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REVIEW OF PARTICLE PROPERTIES

Particle Data Group

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This review of the properties of gauge bosons, leptons, mesons, and baryons is an updating of the Review of Particle Properties, Particle Data Group [Phys. Lett. **170B** (1986)]. Data are evaluated, listed, averaged, and summarized in tables. We continue with the more orderly set of particle names implemented in the 1986 edition. Numerous tables, figures, and formulae of interest to particle physicists are also included. A data booklet is available.

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I. OVERVIEW

This review is an updating through December 1987 of the Review of Particle Properties [Particle Data Group (1986)], a compilation of experimental results on the properties of particles studied in elementary particle physics. These properties include masses, widths or lifetimes, branching ratios, and other experimentally determined properties. Where feasible, we provide a suggested "best" value of each parameter based on our own judgment using the best available data. We also provide an extensive summary of searches for hypothesized particles. These usually take the form of mass limits under specified assumptions. Since such limits are often complex functions of mass and may be model dependent one is often well advised to consult the original papers for detailed information. A discussion of some of the procedures that we apply and a brief review of the historical performance of averages of measurements, may be found below (Section IV Part D).

The results of this compilation are presented in two sections, the "Summary Tables of Particle Properties" and the "Full Listings." The Summary Tables give our estimates of the properties of those states whose existence we consider well established. Our opinion of whether or not a particle is well established can change as new data become available. We attempt to be conservative, so particles awaiting confirmation are not included, even if they may be theoretically well understood. The Summary Tables also give a condensed version of search limits for hypothesized particles, usually the most restrictive limit is given.

All data used for the numerical estimates in the Summary Tables are included in the Full Listings, with references and our comments, if any. Those measurements considered recent enough or important enough to mention but which for some reason were not used in the averaging, appear in a separated section, just underneath the other data. The Full Listings also contain information on unconfirmed particles and unsuccessful particle searches, as well as short "mini-reviews" about subjects of particular interest or data that have particular problems.

In the past, we have attempted to use the Full Listings as an archive of all reported data on particles of interest. This is no longer possible because the growth of information would require a 5 to 10% per year expansion in this Review. Therefore we refer interested readers to previous editions for references to data considered obsolete.

In this edition we continue with our particle naming conventions [Barnett (1985) and Wohl (1984)], which became our standard in 1986. They primarily affect meson names. A few baryon states are renamed as well. In the Summary Tables of Particle Properties and the Full Listings each particle is listed by its new name, with the old name, if different, given below it. It is our hope that these conventions, described in Section III below, if adopted by the community will bring order to the chaos of particle names and facilitate discussion and understanding. A few minor changes are introduced this year to better conform to usage or for increased convenience. Since there will doubtless be a transition period during which the literature may contain a mixture of both old and new names, we will continue to list the old names with the new for several editions.

We categorize the particles into types, intended to correspond roughly to the different types of data and problems encountered.

STABLE PARTICLES — All particles stable under the strong interaction. These include the truly stable particles as well as those which decay weakly or electromagnetically, including the η, D, D_s (formerly called the F), Λ_c, W, Z^0, and so on.

MESONS — All meson resonances that decay strongly including the ψ, χ, and Υ families.

BARYONS — All baryon resonances that decay strongly, including the resonant N and Δ families, dibaryon candidates, and so on.

This classification scheme is used to organize the Summary Tables and the Full Listings.

We include a section of "Miscellaneous Tables, Figures, and Formulae." These provide a quick reference for the practicing elementary particle physicist. They normally presuppose some understanding of the subject matter, and do not attempt to serve as a textbook. We welcome all suggestions and comments regarding topics for inclusion or deletion, any errors or confusing passages, etc.

A pocket-sized Particle Properties Data Booklet is available. This contains the complete Summary Tables of Particle Properties and the most frequently used parts of the Miscellaneous Section but not the Full Listings. For North and South America, Australia and the Far East, write to Technical Information Department, Lawrence Berkeley Laboratory, Berkeley, CA 94720 USA. For all other areas, write to CERN Scientific Information Service CH-1211 Geneva 23, Switzerland.

We have continued our modernization, begun in 1984, of the procedures used to produce the Review. We have introduced a new database management system to store our data internally, and have made many changes in the format of the Full Listings. Some of the details of these changes are given below.

- Use of a modern relational database management system (ORACLE)
  - Data entry is clearly separated from entry of comments and footnotes, making errors less likely,
  - Checking is easier (author-name spelling, standard names for measurement techniques, institutions, etc.),
  - Organization is better for modern typesetting (see following)
- Format of Full Listings
  - Headings for "data blocks" are large and easily visible,
  - Full Greek, math symbols, and upper/lower case English are now used,
  - Our "best" value (from data average, fit, tightest limit, estimate, etc.) for the quantity being tabulated (mass, width, etc.) is now given at the top of the data block,
  - Experimental values which are used in averages, fits etc., are listed in the upper part of the block, values not used (due to various problems) are put in a separate list at the bottom of the block (this means that the old scheme involving parentheses around unused data is no longer in effect),
  - Within each of these two lists, values from later years

are given before those from earlier years (references at the end of the particle are also given in reverse chronological order),

Almost all "best" values appearing in the "Particle Summary Tables" (near the front of the book) will also appear at the top of the appropriate block in the Full Listings, previously, only averages and fits tended to be locatable in the Listings

Value and error are written as "value" ± "error" rather than depending on column position,

Systematic experimental errors are presented separately from statistical errors where possible (they are combined in quadrature for averaging and fitting)

Asymmetric experimental errors are presented in standard format and are used to compute asymmetric final errors,

Some columns in data blocks have been swapped, but all columns are now labeled as to their meaning

Footnote position and numbering have been standardized

ONE CAVEAT Because we have made so many modifications to our files in order to bring about the above changes, there is an excellent chance that we have introduced some errors, despite checking all the substantive information as best as we could Thus we would appreciate your bringing any errors to our attention We would also like to have your comments on the various format changes Please send all comments, corrections, etc to the appropriate author, according to the list of responsibilities below, or to

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for proper routing Rapid access is obtainable via computer mail to LBL PDG on HEPNET or PDG@LBL on BITNET We take comments seriously and will reply to all messages

Thank you

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(4) *Miscellaneous tables, figures and formulae* I Hinchliffe and G P Yost

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The usefulness of this compilation depends in large part on interaction between the users and the authors and consultants We appreciate comments criticisms and suggestions for improvements of all stages of data retrieval evaluation, and presentation

III. THE NAMING SCHEME FOR HADRONS

"Young man, if I could remember the names of these particles, I would have been a botanist "

Enrico Fermi

A. Introduction

We introduced in the 1986 edition a new naming scheme for the hadrons Here we summarize the rules and rationale for the scheme

The virtues sought after were as follows The symbols ought to be as few and as simple as possible, with those already in common use retained where possible, the symbols ought to convey unambiguously the important quantum numbers of the particles they name, and the quark model ought to guide the whole scheme, without limiting it Some compromise between simplicity and long-established usage was unavoidable

Changes from older terminology affect mainly the heavier mesons Otherwise, the only names that change are $F^{\pm}$ becomes $D_s^{\pm}$, A^+ becomes Ξ_c^+, T^0 becomes Ω_c^0 (The last is an unconfirmed baryon) None of the lightest pseudoscalar or vector mesons change names, nor do most of the $c\bar{c}$ or $b\bar{b}$ mesons (we do, however, now use the notation χ_c for the $c\bar{c}$ χ states), nor do any of the established baryons We have this year followed the literature and adopted spectroscopic names as the primary names for most of those ψ, Υ, and χ states for which the spectroscopic identity is known (see below) We continue to use the form of the name with the mass as alternate names in these cases, and as primary names where the spectroscopic identity is not known The Particle Property Summary Tables give both the new and old names whenever a change has occurred

B "Neutral-flavor" mesons ($S = C = B = T = 0$)

Table I shows the naming scheme for mesons having the strangeness and all heavy-flavor quantum numbers equal to zero The naming scheme is designed for all mesons However, we have assigned names only to those states with quantum numbers compatible with being $q\bar{q}$ states The rows of the table give the possible $q\bar{q}$ content The columns give the possible parity/charge-conjugation states, PC = $-+$, $+-$ $--$, and $++$, these combinations correspond one-to-one with the angular-momentum state $^{2S+1}L_J$ of the $q\bar{q}$ system being $^1(L\ \text{even})_J$ $^1(L\ \text{odd})_J$ $^3(L\ \text{even})_J$ or $^3(L\ \text{odd})_J$ * In addition, the spin J is added to the main symbol as a subscript except for pseudoscalar and vector mesons, and the mass is given for any meson that decays strongly (except that for the lowest mass meson resonances, we sometimes shorten names by writing ρ for $\rho(770)$ etc)

Experimental determination of the mass, quark content 9where relevant), and quantum numbers I, J P, and C (or G) of a meson thus fixes its symbol Conversely, these properties may be inferred unambiguously from the symbol

If the main symbol cannot be assigned because the quantum numbers are unknown, the symbol X is used temporarily Sometimes it is not known whether a meson is mainly the isospin-0 mix of $u\bar{u}$ and $d\bar{d}$ or is mainly $s\bar{s}$, a prime (or symbol ϕ) may be used to distinguish two such mixing states

Names have been assigned for the anticipated $t\bar{t}$ mesons No suggestion is made here for names for mesons (should any be found) with the "exotic" quantum numbers that a $q\bar{q}$ system cannot have, namely $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}$, Gluonium states or other mesons that are not $q\bar{q}$ states are (if the quantum numbers are *not* exotic) be named just as the $q\bar{q}$ mesons are named Such non-$q\bar{q}$ states will probably be difficult to distinguish from $q\bar{q}$ states and will likely mix with them — the name makes no attempt to distinguish the "mostly gluonium" or "mostly" $q\bar{q}$ nature of the particles

* The relations between the quantum numbers are

$$P = (-1)^{L+1} \quad C = (-1)^{L+S} \quad G = (-1)^{L+S+I},$$

where of course the C quantum number (charge conjugation) is only relevant to charge-zero mesons

Table I Symbols for mesons with the strangeness and all heavy-flavor quantum numbers equal to zero

$q\bar{q}$ content	$J^{PC}=$ 0^{-+}, 2^{-+} ; $^{2S+1}L_J=$ $^1(L\text{ even})_J$	1^{+-}, 3^{+-} ; $^1(L\text{ odd})_J$	1^{--}, 2^{--} ; $^3(L\text{ even})_J$	0^{++}, 1^{++} ; $^3(L\text{ odd})_J$
$u\bar{d}$, $d\bar{d}-u\bar{u}$, $d\bar{u}$ ($I=1$)	π	b	ρ	a
$d\bar{d}+u\bar{u}$ and/or $s\bar{s}$ ($I=0$)	η,η'	h,h'	ω,ϕ	f,f'
$c\bar{c}$	η_c	h_c	$\psi^{\dagger}$	χ_c
$b\bar{b}$	η_b	h_b	Υ	χ_b
$t\bar{t}$	η_t	h_t	θ	χ_t

†The J/ψ remains the J/ψ

The results of all this were as follows None of the lowest mass pseudoscalar or vector mesons (π, η and η', ρ, ω, and ϕ) changed names, nor did any of the $c\bar{c}$ or $b\bar{b}$ mesons (except for χ becoming χ_c) Established mesons whose names changed slightly are

Old name	New name	Old name	New name
$H(1190)$	$h_1(1170)$	$A_2(1320)$	$a_2(1320)$
$B(1235)$	$b_1(1235)$	$f'(1525)$	$f_2'(1525)$
$f(1270)$	$f_2(1270)$	$\omega(1670)$	$\omega_3(1670)$
$A_1(1270)$	$a_1(1260)$		

Established mesons whose names changed completely are

Old name	New name	Old name	New name
$S(975)$	$f_0(975)$	$A_3(1680)$	$\pi_2(1670)$
$\delta(980)$	$a_0(980)$	$g(1690)$	$\rho_3(1690)$
$D(1285)$	$f_1(1285)$	$\theta(1690)$	$f_2(1720)$
$\epsilon(1300)$	$f_0(1400)$	$\phi(1850)$	$\Upsilon(1850)$
$E(1420)$	$f_1(1420)$	$h(2030)$	$f_4(2050)$
$\iota(1440)$	$\eta(1430)$		

Note that the $S(975)$, $D(1285)$, $\epsilon(1300)$, $E(1420)$, $\theta(1690)$ and $h(2030)$ all became f mesons the new scheme reveals that all have PC=++ and are $^3(L\text{ odd})_J$ states

For ψ Υ, and χ states for which the spectroscopic notation is known, we use that in the primary name and use the mass in alternate names, e g , $\psi(2S) = \psi(3685)$ and $\chi_{b1}(2P) = \chi_{b1}(10255)$

‡Two different conventions exist in the literature for the sign of the flavor of b quarks We have adopted the convention that *the sign of the flavor of a quark is the same sign as its charge* Thus the strangeness of the s quark is negative the charm of the c quark is positive, and the bottom of the b quark is negative In addition, I_3 of the u and d quarks is positive and negative, respectively The effect of this convention is as follows Any *flavor* carried by a *charged* meson has the *same* sign as its *charge* Thus the K^+, D^+, and B^+, have positive strangeness, charm and bottom, respectively, and all have positive I_3 The D_s^+ (formerly the F^+) has positive charm *and* strangeness Furthermore, the Δ(flavor) = ΔQ rule, which is best known for the kaons, applies to every flavor

C. Mesons with nonzero S, C, B, and/or T

Since the strangeness or a heavy flavor is nonzero none of the mesons here are eigenstates of charge conjugation, and in each of them one of the quarks must be heavier than the other The rules are

(1) The main symbol is an upper-case Roman letter indicating the heavier quark as follows ‡
$s \to \bar{K}$ $c \to D$ $b \to \bar{B}$ $t \to T$

(2) If the lighter quark is not a u or a d quark, its identity is given by a subscript

(3) If the spin-parity is in the "normal" series $J^P = 0^+$ 1^- 2^+ , a superscript "*" is added

(4) The spin is added as a subscript unless the meson is a pseudoscalar or a vector

Similarly to the naming for "neutral flavor" mesons, possible non-$q\bar{q}$ (e g , $q\bar{q}g$) states are covered in the same scheme

Thus the pseudoscalar and vector K K^* D, D^*, and B mesons did not change names Established mesons whose names did change were

Old name	New name	Old name	New name
$Q_1(1280)$	$K_1(1270)$	$L(1770)$	$K_2(1770)$
$\kappa(1350)$	$K_0^*(1430)$	$K^*(1780)$	$K_3^*(1780)$
$Q_2(1400)$	$K_1(1400)$	$K^*(2060)$	$K_4^*(2075)$
$K^*(1430)$	$K_2^*(1430)$	F	D_s

Most notably, the F (the $c\bar{s}$ state) changed to a D_s However, with the prospect of B_s B_c, T_s and similar mesons there was no consistent and economical alternative The rules can lead to cumbersome symbols, such as a D_{s2}^* but such particles are unlikely to be often seen

D. Baryons

No change is made to the symbols N, Δ Λ Σ Ξ, and Ω, used for 20 years for the baryons made of light quarks (u, d, and s quarks) They tell the isospin and quark content and the same information is conveyed by the symbols used for the baryons containing one or more heavy quarks (c b and t quarks) The following system was invented earlier and independently by Hendry and Lichtenberg (1978) and by Samios (1980) The rules are (see also Fig 1)

(1) Baryons with *three* u and/or d quarks are N's (isospin 1/2) or Δ's (isospin 3/2)

(2) Baryons with *two* u and/or d quarks are Λ's (isospin 0) or Σ's (isospin 1) If the third quark is a heavy quark (not an s quark) its identity is given by a subscript This nomenclature was already used for the $\Lambda_c(2285)$, $\Sigma_c(2455)$, and $\Lambda_b(5500)$

(3) Baryons with *one* u or d quark are Ξ's (isospin 1/2) One or two subscripts are used if one or both of the remaining quarks are heavy thus Ξ_c, Ξ_{cc}, Ξ_b etc The $A(2460)$ was renamed the $\Xi_c(2460)$

(4) Baryons with *no* u or d quarks are Ω's (isospin 0), and subscripts indicate any heavy-quark content The possible but not established $T(2740)$ was renamed the $\Omega_c(2740)$

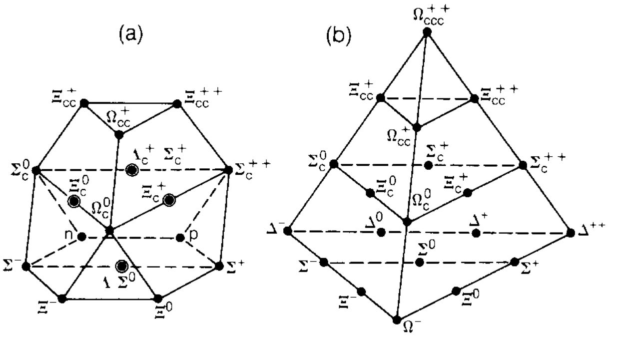

Fig 1 SU(4) multiplets of baryons made of *u* *d*, *s* and *c* quarks (a) The 20-plet with an SU(3) octet (b) The 20-plet with an SU(3) decuplet

In short, the total number of *u* and *d* quarks together with the isospin determine the main symbol, and subscripts indicate any content of heavy quarks A Σ always has isospin 1, an Ω always has isospin 0 etc

Note in Fig 1 that the SU(4) 20-plet that contains the basic SU(3) octet has an Ω_c and an Ω_{cc} although it has no Ω It has *two* Ξ_c's, which would be distinguished by mass (they might also be distinguished by a prime on the heavier of the two)

IV. PROCEDURES

A. Selection and treatment of data

The Full Listings contain a complete record of all *relevant* data known to us As a general rule we do not include results from preprints or conference reports It is our experience that preprinted results often change before publication In some cases, such results may be cited but not used in computing the estimates given in the Summary Tables There are a few exceptions to this exclusion, which we decide on a case-by-case basis after consultation with the experimenters

As mentioned earlier, we no longer attempt to maintain an archival record of data of historical importance only We do, however, quote the references of discoveries, even when the data are no longer useful

If data are included in the Full Listings but not used in calculating or estimating the final value given in the Summary Tables, they are listed in a separate section immediately following the data which *are* used We give explanatory comments in many such cases If no comment is given, the reason the data were excluded is one or more of the following

- The data are superseded or included in later results
- No error was given
- The data were contained in a preprint or conference report
- The result involves some assumptions we do not wish to incorporate
- The measurement has poor signal-to-noise ratio, low statistical significance, or is otherwise of much poorer quality than other data available
- The measurement is clearly inconsistent with other results which appear to be highly reliable (see discussion in Section IV Part D below)
- The measurement is not independent of other results, e g , it is from one of several partial-wave analyses, all of which use the same data, rendering averaging meaningless

In some cases, *none* of the measurements is entirely reliable and no statistically meaningful average is quoted For example, the masses of many of the baryon resonances obtained from partial-wave analyses, are quoted as a range thought to probably include the true value rather than as an average with error This is discussed in more detail in some of the mini-reviews in the Baryon Full Listings

For upper limits, we normally quote in the Summary Tables the strongest limit available from a single experiment We do not average or combine upper limits except in a very few cases where they may be re-expressed as measured numbers with Gaussian errors

For quantum number assignments we indicate in the Summary Tables those which are either well established or probable In the Meson Summary Table, we underline those we consider well established, the others are inferred from whatever experimental evidence is available In the Stable Particle Summary Table nearly all quantum numbers are well established and we do not underline, those which are not well established are indicated by a footnote

As is customary, we assume that antiparticles are the result of operating with *CPT* on particles, so both share the same spins, masses and mean lives There is an entry in the Miscellaneous Section, Tests of Conservation Laws listing tests of *CPT* and other conservation laws

Values which we have extracted from the data include the results of our weighted averages and fits, or of one of the techniques described above We also evaluate quantities which have not been directly measured but which are based on measured quantities For example, ratios of branching fractions can be combined with direct measurements of one part of the ratio to extract an estimate of the other part Whenever we quote a result obtained by us from one of these procedures, we indicate it in the Full Listings by one of the following

OUR AVERAGE —	From a weighted average of selected data
OUR FIT —	From a constrained or overdetermined multiparameter fit of selected data
OUR EVALUATION —	Evaluated by us from measured ratios or other data Not from a direct measurement
OUR ESTIMATE —	Based on the observed range of the data Not from a formal statistical procedure
OUR LIMIT —	For special cases where the limit is evaluated by us from measured ratios or other data Not from a direct measurement

B. Criteria for new states

An experimentalist who sees indications of a new state will of course want to know what has been seen in that region in the past. Hence we include in the Full Listings all reported states which, in our opinion, have sufficient statistical merit and which have not been disproved by better (e.g., more reliable) data.

For the Summary Tables we are much more conservative. We include only those reported states which we feel have a large chance of survival. One's betting odds for survival are of course subjective, therefore no precise criteria can be defined. For more detailed discussions, see the mini-reviews in the Full Listings. In what follows we shall attempt to specify some guidelines.

(a) When energy-independent partial-wave analyses are available (mostly for πN resonances), approximate Breit-Wigner behavior of the amplitude appears to us to be the most satisfactory test for a resonance. We can check that the Argand plot follows roughly a left-hand circle, and that the "speed" of the amplitude also shows a maximum near the resonance energy; further, there should be data well above the resonance, showing that the speed again decreases. Indeed, proper behavior of the partial-wave amplitude often establishes a resonance even if its elasticity is too small to make a noticeable peak in the cross section.

(b) When there are insufficient data to perform energy-independent analyses, one often resorts to energy-dependent partial-wave analyses. In this case Breit-Wigner behavior is an input. We usually require that resonance solutions be found by several different analyses, preferably in different channels ($\bar{K}N \to \bar{K}N$, $\pi\Sigma$, etc.), before putting the claim in the Summary Tables.

(c) Stable particles, most meson resonances, Ξ resonances, and high-mass N, Δ, Λ, and Σ resonances fall into a category for which no partial-wave analyses exist. In general, we accept such states if they are experimentally reliable, of high statistical significance (4.5σ or better), or observed in several different production processes.

(d) Partial-wave analyses of three-body final states ($\pi N \to \pi\pi N$) are also available. While these analyses are based on the isobar model ($\pi N \to \rho N$, $\pi\Delta$, etc.) and are subject to theoretical objections of varying importance, they provide increasingly reliable information on inelastic decay modes of otherwise-established resonances.

C. Averages and Fits

We divide this discussion on obtaining averages and errors into three sections:

1. Treatment of errors,
2. Unconstrained averaging, and
3. Constrained fits.

1. Treatment of errors

In what follows, the term "error", δx, means that the range $x \pm \delta x$ is intended to be a 68.3% confidence interval about the central value x. We treat this error as if it were Gaussian. Thus when the error *is* Gaussian, δx is the usual one standard deviation (1σ). Many experimenters now give statistical and systematic errors separately. In such cases, we usually quote both errors, with the statistical error first. For averages and fits, we then add the the two errors in quadrature and use this combined error for δx.

When experimenters quote asymmetric errors $(\delta x)^+$, $(\delta x)^-$ for a measurement x, the error that we use for that measurement is a continuous function of these three quantities. When the resultant average or fit $\bar{x}$ is less than $x - (\delta x)^-$, we use $(\delta x)^-$; when it is greater than $x + (\delta x)^+$, we use $(\delta x)^+$. In between, the error that is used is a linear function of x. Since the errors that are used are functions of the result, we iterate to find the final answer for both averages and fits. Asymmetric output errors are determined from the input errors assuming a linear relation between the input and output quantities.

In the fitting or averaging process we do not include correlations between different measurements, but we try to select data in such a way as to reduce correlations. When a group improves statistical or systematic errors by further data-taking or analysis, we use only the improved result. The earlier result is either put into the list of measurements that are not used in averages or fits or is omitted entirely.

Correlated errors are treated explicitly when there are a number of results of the form $A_i \pm \sigma_i \pm \Delta$ that have identical systematic errors Δ. In this case one can first average the $A_i \pm \sigma_i$ and then combine the resulting statistical error with Δ. One obtains, however, the same result by a second procedure, averaging $A_i \pm (\sigma_i^2 + \Delta_i^2)^{1/2}$, where $\Delta_i = \sigma_i \Delta \sqrt{\sum(1/\sigma_j^2)}$. The second procedure has the advantage that with the modified systematic errors Δ_i, each measurement may be treated as independent and averaged in the usual way with other data. Therefore, when appropriate, we adopt this procedure, tabulate Δ_i rather than Δ for the systematic error, and include a footnote that this has been done.

2. Unconstrained averaging

To average data, we use a standard weighted least-squares procedure with the addition of a "scale factor" applied to the errors. The Student's t distribution, the basis of an earlier experiment of ours in data averaging, would give more conservative (and perhaps more realistic) errors at the two-standard-deviation (2σ) and higher levels, but we do not choose to quote such errors. It is worth noting, however, that a 2σ error might well be somewhat larger than twice a 1σ error, owing to the non-Gaussian character of some sets of real measurements. This is a persistent problem in averaging mildly discrepant measurements.

We begin by assuming that measurements of a given quantity are uncorrelated, and calculate a weighted average and error as

$$\bar{x} \pm \delta\bar{x} = \left(\sum_i w_i x_i / \sum_i w_i \right) \pm \left(\sum_i w_i \right)^{-1/2},$$

$$w_i = 1/(\delta x_i)^2, \qquad (1)$$

where x_i and δx_i are the value and error reported by the ith experiment, and the sums run over N experiments. We also calculate $\chi^2 = \sum w_i(\bar{x} - x_i)^2$ and compare it with its expectation value, which is $N - 1$ if the measurements obey a Gaussian distribution.

If $\chi^2/(N - 1)$ is less than or equal to 1, and there are no known problems with the data, we accept the above results.

If $\chi^2/(N - 1)$ is very large, we may choose not to average the data at all. Alternatively we may quote the calculated average, but then give an educated guess as to the error, a conservative estimate designed to take into account known problems with the data.

Finally if $\chi^2/(N - 1)$ is greater than 1, but not greatly so, we still average the data, but then also do the following:

(a) We try to take account of $\chi^2/(N - 1)$ being greater than 1 by scaling up our quoted error of $\delta\bar{x}$ in Eq. (1) by a scale factor

$$S = \left[\chi^2/(N - 1)\right]^{1/2} \qquad (2)$$

Our reasoning is as follows. The large value of the χ^2 is likely to be due to underestimation of errors in at least one of the experiments. Since we do not know which of the errors are underestimated, we assume that they are all underestimated by the same factor S. If we scale up all input errors by this factor, the χ^2 becomes $N - 1$, and of course the output error $\delta\bar{x}$ scales up by the same factor.

If we are combining data with widely varying errors, we modify this procedure slightly. We evaluate S by using only the experiments with errors that are not much greater than those of the more precise experiments, i.e., only those experiments with errors less than δ_0, where the ceiling δ_0 is (arbitrarily) chosen to be

$$\delta_0 = 3N^{1/2}\delta\bar{x}$$

Here $\delta\bar{x}$ is the unscaled error of the mean of all the experiments. This is done because although the low-precision experiments have little influence on the value $\bar{x}$ and $\delta\bar{x}$, they can make significant contributions to the χ^2, and the contribution of the high-precision experiments tends to be obscured by them. Note that if each experiment had the same error δx_i, then $\delta\bar{x}$ would be $\delta x_i/N^{1/2}$, so each individual experiment would be well under the ceiling.

This scaling approach has the property that if there are two values with comparable errors separated by much more than their stated errors (with or without a number of other experiments of lower accuracy), the error on the mean value $\delta\bar{x}$ is increased so that it is approximately half the interval between the two discrepant values.

We emphasize that our scaling procedures for *errors* in no way affect central values. In addition, if one wishes to recover the unscaled error $\delta\bar{x}$, one need only divide the quoted error by S.

(b) In cases where $\chi^2/(N - 1)$ is greater than 1.25, we also plot an ideogram to display the pattern of the data. We do not extract numbers from these ideograms; the ideograms are intended simply as visual aids. Sometimes only one or two data points lie apart from the main body; other times the data split into two or more roughly equal groups. The reader may use this information in deciding upon an alternative average. Figure 2 shows such an ideogram.

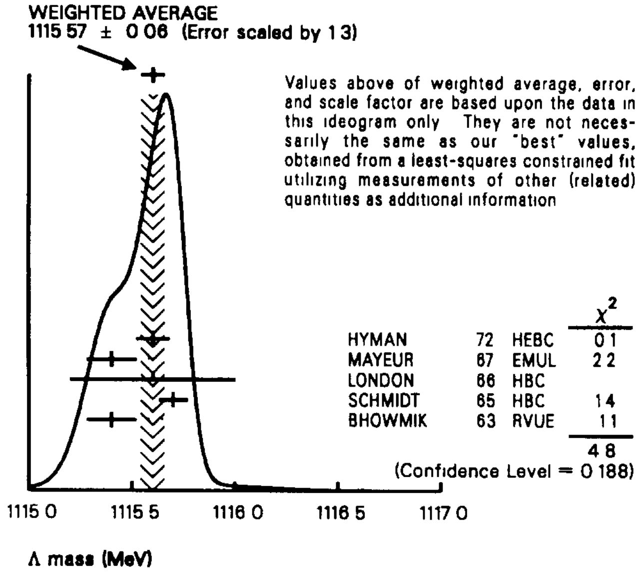

Fig. 2. Ideogram of measurements of the Λ mass. The "data point" at the top shows the position of the weighted average, while the width of the error bar (and the shaded pattern beneath it) shows the error in the average after scaling by the scale factor S. Only those experiments indicated by + error flags were precise enough to be accepted in the calculation of S; the column on the far right gives the χ^2 contribution of each of these experiments. Less precise experiments would be included in the calculation of the weighted average, but not S; they would have ⊥ error flags.

Each experiment appearing in an ideogram is represented by a Gaussian with a central value x_i, error δx_i, and area proportional to $1/\delta x_i$. The choice of $1/\delta x_i$ for the areas is somewhat arbitrary. With this choice, the center of gravity of the ideogram corresponds to an average that uses weights equal to $1/\delta x_i$ rather than the $(1/\delta x_i)^2$ used in the weighted averages. This may be appropriate for the case in which some experiments have seriously underestimated their systematic errors. However, since for this choice of area the height of the Gaussian for each measurement is proportional to $(1/\delta x_i)^2$, the peak position of the ideogram will often favor the high-precision measurements at least as much as does the least-squares average. The 1986 edition contains a detailed discussion of the motivation behind the use of ideograms.

3. Constrained fits

Except for trivial cases, all branching ratios and rate measurements are analyzed by making a simultaneous least-squares fit to all the data and extracting the partial decay fractions P_i, the full width Γ, the partial widths Γ_i, and the associated error matrix.

Assume, for example, that a state has m partial decay fractions P_i, where $\sum P_i = 1$. These have been measured in N_r different ratios R_r, where, e.g. $R_1 = P_1/P_2$, $R_2 = P_1/P_3$, etc.** Further assume that *each* ratio R has been measured by N_k experiments (we designate each experiment with a subscript k, e.g., R_{1k}). We then find the best values of the fractions P_i by minimizing the χ^2 as a function of the $m-1$ independent parameters

$$\chi^2 = \sum_{r=1}^{N_r} \left[\sum_{k=1}^{N_k} \left(\frac{R_{rk} - R_r}{\delta R_{rk}} \right)^2 \right], \quad (3)$$

where the R_{rk} are the measured values and R_r are the fitted values of the branching ratios.

In addition to the fitted values $\overline{P}_i$, we calculate an error matrix $\langle \delta\overline{P}_i \delta\overline{P}_j \rangle$. We tabulate the diagonal elements of $\delta\overline{P}_i = \langle \delta\overline{P}_i \delta\overline{P}_i \rangle^{1/2}$ (except that some errors are scaled as discussed below). In the Full Listings we give the complete correlation matrix, we also calculate the fitted value of each ratio for comparison with the input data, and list it above the relevant input, along with a simple unconstrained average of the same input.

Three comments on the example above:

(1) There was no connection assumed between measurements of the full width and the branching ratios. But often we also have information on partial widths Γ_i as well as the total width Γ. In this case we must introduce Γ as a parameter in the fit, along with the P_i, and we give correlation matrices for the widths in the Full Listings.

(2) We do *not* allow for correlations between input data. We *do* try to pick those ratios and widths that are as independent and as close to the original data as possible. When one experiment measures all the branching fractions and constrains their sum to be one, we leave one of them (usually the least well-determined one) out of the fit to make the set of input data more nearly independent.

(3) We calculate scale factors for both the R_r and P_i when the measurements for any R give a larger-than-expected contribution to the χ^2. According to Eq. (3), the double sum for χ^2 is first summed over experiments $k = 1$ to N_k, leaving a single sum over ratios $\chi^2 = \sum \chi_r^2$. One is tempted to define a scale factor for the ratio r as $S_r^2 = \chi_r^2/\langle \chi_r^2 \rangle$. However since $\langle \chi_r^2 \rangle$ is not a fixed quantity (it is somewhere between N_k and N_{k-1}) we do not know how to evaluate this expression. Instead we define

$$S_r^2 = \frac{1}{N_k} \sum_{k=1}^{N_k} \left[\frac{\left(R_{rk} - \overline{R}_r\right)^2}{(\delta R_{rk})^2 - (\delta \overline{R}_r)^2} \right], \quad (4)$$

where $\delta\overline{R}_r$ is the fitted error for ratio r. With this definition the expected value of S_r^2 is one.

The fit is redone using errors for the branching ratios that are scaled by the maximum of S_r and one, from which new and often larger errors $\delta\overline{P}_i'$ are obtained. The scale factors we finally list in such cases are defined by $S_i = \delta\overline{P}_i'/\delta\overline{P}_i$. However, in line with our policy of not letting S affect the central values, we give the values of $\overline{P}_i$ obtained from the original (unscaled) fit.

There is one special case in which the errors that are obtained by the preceding procedure may be changed. When a fitted branching ratio (or rate) $\overline{P}_i$ turns out to be less than three standard deviations $(\delta\overline{P}_i')$ from zero, a new smaller error $(\delta\overline{P}_i'')^-$ is calculated on the low side by requiring the area under the Gaussian between $\overline{P}_i - (\delta\overline{P}_i'')^-$ and $\overline{P}_i$ to be 68.3% of the area between zero and $\overline{P}_i$. A similar correction is done for branching fractions that are within three standard deviations of one. This keeps the quoted errors from overlapping the boundary of the physical region.

The procedure that we are now using for calculating scale factors in fits is a significant change from what was done in previous editions. Usually the scale factors obtained by the two methods are the same (to two significant figures); the average scale factor is very nearly the same also.

** We can handle any ratio R of the form $\sum \alpha_i P_i / \sum \beta_i P_i$, where α_i and β_i are constants, usually 1 or 0. The forms $R = P_i P_j$ and $R = (P_i P_j)^{1/2}$ are also allowed.

D. Discussion

The entire question of averaging data containing discrepant values is nicely discussed by Taylor (1982). He considers a number of algorithms which attempt to incorporate data which are not completely consistent into a meaningful average. Problems occur because it is very difficult to develop a procedure which handles simultaneously in a reasonable way two basic types of situations: (a) data which seem to lie apart from the main body of the data are incorrect (contain unreported errors), and (b) the opposite (the main body of the data is systematically wrong). Unfortunately, as Taylor shows, case (b) is not infrequent. His conclusion is that the choice of procedure is less significant than the initial choice of data to include or exclude.

We place a great emphasis on the choice of data to include or exclude. Unfortunately, the volume of data precludes spending as much time on the problem as we would like. We address this problem by soliciting the help of as many outside experts (consultants) as possible. In the final analysis, however, it is often impossible to determine which (if either) of two discrepant measurements is correct. Our scale factor technique is an attempt to address this ignorance by increasing the error above that suggested by least-squares analysis. In effect, we are saying that present experiments do not allow a precise determination of this constant because of unresolvable discrepancies and one must await further measurements. The reader is warned of this situation by the size of the scale factor; he or she is then able to go back to the literature (via the Full Listings) and redo the average as desired.

Our situation with regard to discrepant data is easier to handle than most of the cases Taylor considers, such as estimates of the fundamental constants like $\hbar$, etc. Most of the errors in his case are dominated by systematic effects. In particle properties data, statistical effects are often at least as large as systematic effects, and statistical errors are usually easier to estimate. A notable exception occurs in partial-wave analyses, where different techniques applied to the same data yield different results In this case, as stated earlier, we often do not attempt an average, but just quote a range of values

A brief history of Particle Data Group averages is given in Rosenfeld (1975) Updated versions of some of Rosenfeld's figures are shown in Fig 3 The least-squares error is shown by the thick portion of the error bars, the full error bar exhibits the scale factor extension

Some cases of rather wild fluctuation are shown, this usually represents the introduction of significant new data or the discarding of some older data Older data are sometimes discarded in favor of more modern data if it is felt that the newer data had fewer systematic errors, had more checks on their systematic errors, made some corrections unknown at the time of the older experiments, or some such reason Near the time at which a large jump takes place, the scale factor sometimes becomes large, reflecting the uncertainty introduced by the new existence of partly inconsistent data

By and large, a full scan of our history plots shows a rather dull progression toward greater precision at a central value completely consistent with the first data point shown These plots are available on request from the Berkeley Particle Data Group

We conclude that the reliability of the combination of experimental data and Particle Data Group averaging procedures is usually good, but it is important to realize that fluctuations outside of the quoted errors can and do occur, perhaps with more frequency than expected for truly Gaussian errors

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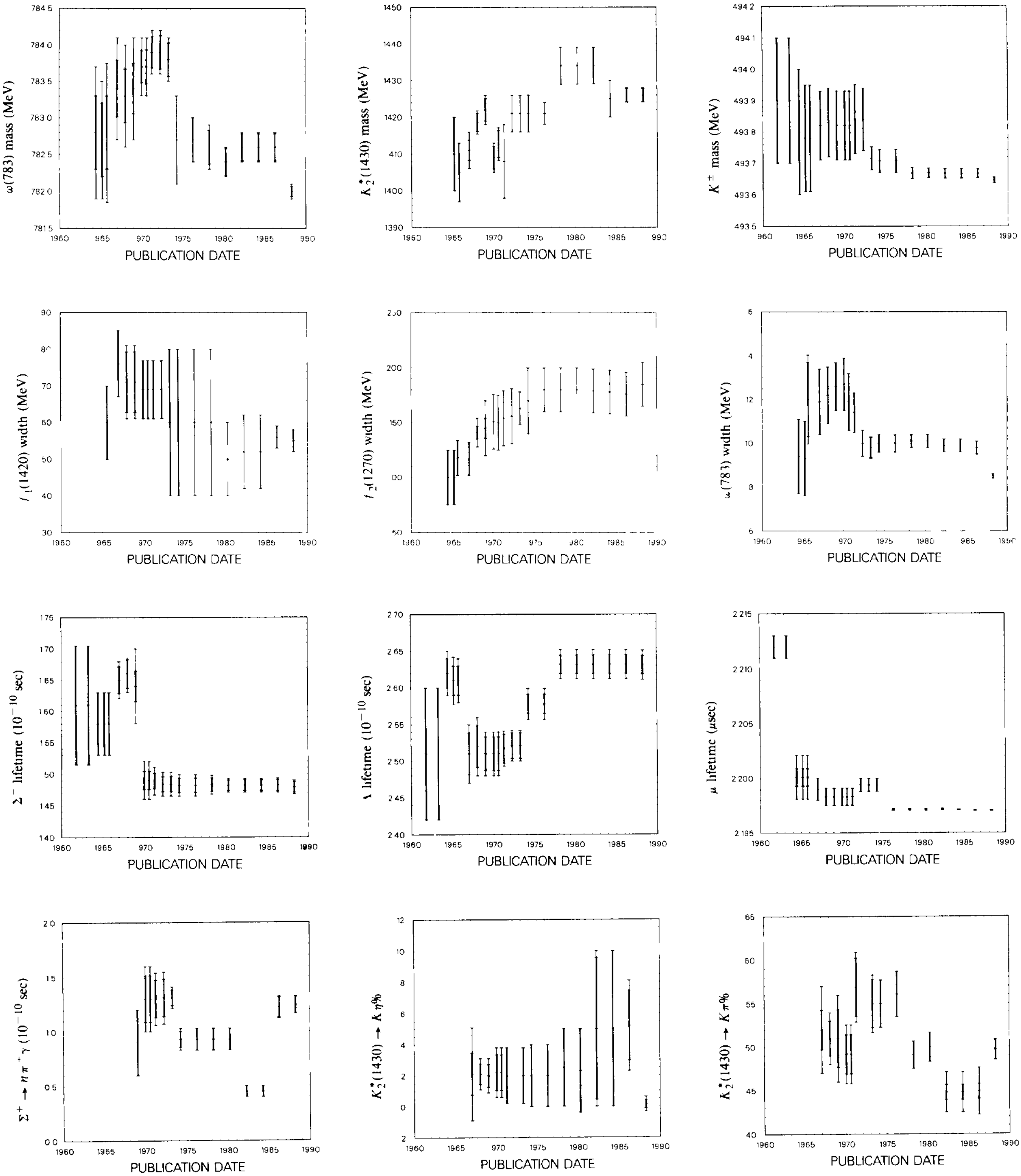

Fig 3 Historical perspective of a few quantities tabulated in the Review of Particle Properties, abcissa specifies date of publication of the Review Data measured by a variety of different techniques are included The general reliability of the averages is good very few are presently more than two standard deviations from their first tabulated values Full error bar indicates quoted error thick-lined portion indicates the same, but without the "scale factor" (see Section IV Part C above) Errors with no thick-lined portion are uncertain and represent a best "educated guess"

SUMMARY TABLES OF PARTICLE PROPERTIES

April 1988

Particle Data Group

M Aguılar-Benıtez, R M Barnett, B Cabrera, G Conforto, R L Crawford, R A Eıchler,
K Hagıwara, K G Hayes, J J Hernandez, I Hınchlıffe, G Hohler, S Kawabata, G R Lynch,
D M Manley, L Montanet, K A Olıve, F C Porter, A Rıttenberg, M Roos, L D Roper, R R Ross,
R H Schındler, K R Schubert, R E Shrock, M Suzukı, N A Tornqvıst, T G Trıppe,
W P Trower, C G Wohl, and G P Yost, and Technıcal Associates B Armstrong and G S Wagman

(Approxımate closıng date for data January 1, 1988)

Stable Particle Summary Table

(stable under strong decay)

For addıtıonal parameters, see the Addendum to thıs Table

Quantıtıes ın ıtalıcs are new or have changed by more than one (old) standard devıatıon sınce our 1986 edıtıon

Particle	$I^G(J^{PC})$ [a]	Mass [b]	Mean life [b] τ (sec) $c\tau$ (cm)	Decay modes: Mode	Decay modes: Fraction [b] [Limits are 90% CL]	Decay modes: p (MeV/c) [c]
			GAUGE BOSONS			
γ	$0,1(1^{--})$	(< 3×10^{-33} MeV)	-------	stable		
W	$J=1$	81 0 ± 1 3 GeV	Γ<6 5 GeV	$e\nu$	(10 0 $^{+2\ 4}_{-3\ 3}$)%	40 5×10^3
				$\mu\nu$	(12 $^{+7}_{-6}$)%	40 5×10^3
				$\tau\nu$	(10 2 $^{+3\ 3}_{-4\ 1}$)%	40 5×10^3
				†[$e\nu\gamma$	[d](< 1 0)%]	40 5×10^3
Z		92 4 ± 1 8 GeV	Γ<5 6 GeV	e^+e^-	(4 6 $^{+1\ 2}_{-1\ 7}$)%	46 2×10^3
				$\mu^+\mu^-$	seen	46 2×10^3
	$m_Z - m_W$ =	11 4 ± 1 4 GeV				
			LEPTONS			
ν_e	$J=\frac{1}{2}$	< *18* eV (CL=95%)	stable [τ> 300 m_{ν_e} sec (m_{ν_e} ın eV) CL=90%]	stable		
ν_μ	$J=\frac{1}{2}$	< 0 25 MeV (CL=90%)	stable [τ> 1 $1\times10^5 m_{\nu_\mu}$ sec (m_{ν_μ} ın MeV) CL=90%]	stable		
ν_τ	$J=\frac{1}{2}$	< *35* MeV (CL=95%)				

Searches	
Searches for massıve neutrınos and lepton mıxıng Lımıts on number of lıght ν types ν bounds from astrophysıcs and cosmology Heavy lepton searches	See the Stable Partıcle Search Lımıts Summary Table and Full Lıstıngs

Stable Particle Summary Table *(cont'd)*

Particle	$I^G(J^{PC})$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) $c\tau$ (cm)	Decay modes: Mode	Fraction [b] [Limits are 90% CL]	p (MeV/c) [c]
e	$J=\frac{1}{2}$	*0 51099906* [e] ± *0 00000015* MeV	stable (> 2×10^{22} years	stable CL=68%)		
μ	$J=\frac{1}{2}$	*105 65839* [e] ± *0 00006* MeV S=1 8*	2 19703×10^{-6} ±0 00004 $c\tau$=6 5865×10^4	μ^- → (or μ^+ →chg conj)		
				$e^-\overline{\nu}\nu$	(100)%	53
				†[$e^-\overline{\nu}\nu\gamma$	[d](1 4 ± 0 4)%]	53
				$e^-\overline{\nu}\nu e^+e^-$	[d](3 4 ± 0 4)×10^{-5}	53
				Forbidden by conservation laws [f]		
				$e^-\nu_e\overline{\nu}_\mu$ LF	(*<5*)%	53
				$e^-\gamma$ LF	(*<5*)×10^{-11}	53
				$e^-e^+e^-$ LF	(*<1 0*)×10^{-13}	53
				$e^-\gamma\gamma$ LF	(*<7*)×10^{-11}	53
τ	$J=\frac{1}{2}$	1784 1$^{+2\,7}_{-3\,6}$	(3 04±0 09)×10^{-13} $c\tau$=0 009	τ^- → (or τ^+ →chg conj)		
				particle$^-$ ≥0neutrals ν	(*85 7* ± *0 4*)%	
				$\mu^-\overline{\nu}\nu$	(17 8 ± 0 4)%	889
				$e^-\overline{\nu}\nu$	(17 5 ± 0 4)%	892
				hadron$^-$ ≥0neutrals ν	(*50 3* ± *0 6*)%	
				hadron$^-$ ν	(11 5 ± 0 6)%	
				$\pi^-\nu$	(10 8 ± 0 6)%	887
				$K^-\nu$	(0 66± 0 19)%	824
				hadron$^-$ ≥1$\pi^0\nu$	(38 8 ± 0 8)%	
				$\rho^-\nu$	(22 3 ±1 1)%	726
				$\pi^-\pi^0$ (non-res) ν	(0 30$^{+0\,30}_{-0\,19}$)%	881
				hadron$^-$ ≥2had^0 ν	(*16 3* ± *1 3*)%	
				$\pi^-\pi^0\pi^0\nu$	(7 5 ± 0 9)%	866
				$\pi^-\pi^0\pi^0\pi^0\nu$	(3 0 ± 2 7)%	840
				K^- ≥1neutral ν	(1 05$^{+0\,27}_{-0\,28}$)%	
				$K^-K^0\nu$	(*<0 26*)%	742
				$K^-K^0\pi^0\nu$	(*<0 26*)%	690
				$\pi^-\pi^-\pi^+$ ≥0$\pi^0\nu$	(13 19± 0 26)%	
				$\pi^-\pi^-\pi^+\gamma$(s)ν	(*6 4* ± *0 6*)%	
				$\pi^-\pi^-\pi^+\pi^0\nu$	(*4 4* ± *1 6*)%	838
				$\pi^-\pi^-\pi^+\nu$	(*6 8* ± *0 6*)%	864
				$\pi^-\rho^0\nu$	(5 4 ± 1 7)%	718
				$\pi^-\pi^-\pi^+$ (non-res) ν	(<1 4)%	865
				$\pi^-\pi^-\pi^+K^0$ ≥0γ ν	(<0 27)%	
				K^- 2charged ≥0neutrals ν	(<0 6)%	
				$K^-\pi^+\pi^-$ ≥0$\pi^0\nu$	(0 22$^{+0\,16}_{-0\,13}$)%	
				$K^+K^-\pi^-\nu$	(0 22$^{+0\,17}_{-0\,11}$)%	689
				$3\pi^-2\pi^+$ ≥0neutrals ν	(0 115±0 027)%	
				$3\pi^-2\pi^+\nu$	(5 6 ± 1 6)×10^{-4}	798
				$3\pi^-2\pi^+\pi^0\nu$	(5 1 ± 2 2)×10^{-4}	750
				7hadron$^\pm$ ≥0$\pi^0\nu$	(*<1 9*)×10^{-4}	
				†[$K^*(892)^-\nu$	(1 43± 0 31)%	669
				$K^*(892)^-$ ≥0neutrals ν	(*1 4* ± *0 9*)%	
				$K_2^*(1430)^-\nu$	(<0 9)%	319
				K^- ≥0neutrals ν	(*1 71*$^{+0\,22}_{-0\,23}$)%	
				$\pi^-\omega\nu$	(*1 6* ± *0 5*)%	712
				$\pi^-\eta\nu$	(*<1 0*)%	801
				$\pi^-\pi^0\eta\nu$	(*<2 1*)%	782
				$\pi^-\eta$ ≥0neutrals ν	(*<2 1*)%	
				$\pi^-\eta\eta$ ≥0neutrals ν	(*<0 5*)%	
				$\pi^-\pi^-\pi^+\eta$ ≥0neutrals ν	(*<0 3*)%]	

τ^- → (or τ^+ →chg conj)

Mode		Fraction	p (MeV/c)
e^- chgd parts + μ^- chgd parts		(<4)%	
Forbidden by conservation laws [f]			
$\mu^-\gamma$	LF	(<6)×10^{-4}	889
$e^-\gamma$	LF	(<6)×10^{-4}	892
$\mu^-\mu^+\mu^-$	LF	(<2 9)×10^{-5}	876
$e^-\mu^+\mu^-$	LF	(<3 3)×10^{-5}	886
$\mu^-e^+e^-$	LF	(<3 3)×10^{-5}	889
$e^-e^+e^-$	LF	(<4)×10^{-5}	892
$\mu^-\pi^0$	LF	(<8)×10^{-4}	884
$e^-\pi^0$	LF	(<2 1)×10^{-3}	887
μ^-K^0	LF	(<1 0)×10^{-3}	819
e^-K^0	LF	(<1 3)×10^{-3}	823
$\mu^-\rho^0$	LF	(<4)×10^{-5}	721
$e^-\rho^0$	LF	(<4)×10^{-5}	726
$e^-\pi^+\pi^-$	LF	(*<4*)×10^{-5}	881
$e^+\pi^-\pi^-$	L	(*<6*)×10^{-5}	881
$\mu^-\pi^+\pi^-$	LF	(*<4*)×10^{-5}	870
$\mu^+\pi^-\pi^-$	L	(*<6*)×10^{-5}	870
$e^-\pi^+K^-$	LF	(*<4*)×10^{-5}	817
$e^+\pi^-K^-$	L	(*<1 2*)×10^{-4}	817
$\mu^-\pi^+K^-$	LF	(*<1 2*)×10^{-4}	804
$\mu^+\pi^-K^-$	L	(*<1 2*)×10^{-4}	804
$e^-K^*(892)^0$	LF	(*<5*)×10^{-5}	669
$\mu^-K^*(892)^0$	LF	(*<6*)×10^{-5}	664
$e^+\mu^-\mu^-$	LF	(*<4*)×10^{-5}	886
$\mu^+e^-e^-$	LF	(*<4*)×10^{-5}	889

Stable Particle Summary Table *(cont'd)*

Particle	$I^G(J^{PC})$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) $c\tau$ (cm)	Decay modes: Mode	Fraction [b] [Limits are 90% CL]	p (MeV/c) [c]
LIGHT MESONS [a]			$[\pi^+ = u\bar{d},\ \pi^0 = (u\bar{u} - d\bar{d})/\sqrt{2},\ \pi^- = \bar{u}d,\ \eta = c_1(u\bar{u} + d\bar{d}) + c_2(s\bar{s})]$			
				$\pi^+ \to$ (or $\pi^- \to$ chg conj)		
$\pi^{\pm}$	$1^-(0^-)$	139 56755 $\pm$0 00033	2 6029$\times 10^{-8}$ $\pm$0 0023	$\mu^+\nu$	100%	30
				$e^+\nu$	(1 228$\pm$0 022)$\times 10^{-4}$ S=1 8*	70
				†[$\mu^+\nu\gamma$	[d](1 24 $\pm$0 25)$\times 10^{-4}$	30
			$c\tau$=780 3	$e^+\nu\gamma$	[d](5 6 $\pm$0 7)$\times 10^{-8}$]	70
		$m_{\pi^\pm} - m_{\mu^\pm}$ = 33 90917 $\pm$0 00033		$e^+\nu\pi^0$	(1 025$^{+0\ 033}_{-0\ 034}$)$\times 10^{-8}$	4
				$e^+\nu e^+e^-$	(<5)$\times 10^{-9}$	70
				Forbidden by conservation laws [f]		
				$\mu^+\bar{\nu}_e$ *L*	(<1 5)$\times 10^{-3}$	30
				$\mu^+\nu_e$ *LF*	(<8)$\times 10^{-3}$	30
				$\mu^-e^+e^+\nu$ *LF*	(<8)$\times 10^{-6}$	30
π^0	$1^-(0^{-+})$	*134 9734* *$\pm$0 0025*	8 4$\times 10^{-17}$ $\pm$0 6 S=3 0*	$\gamma\gamma$	(98 798$\pm$0 032)% S=1 1*	67
				γe^+e^-	(1 198)%	67
				$e^+e^-e^+e^-$	(3 24)$\times 10^{-5}$	67
		$m_{\pi^\pm} - m_{\pi^0}$ = *4 5942* *$\pm$0 0025* S=2 0*	$c\tau$=2 5$\times 10^{-6}$	$\gamma\gamma\gamma\gamma$	(<*1 6*)$\times 10^{-6}$	67
				e^+e^-	(1 8 $^{+0\ 7}_{-0\ 6}$)$\times 10^{-7}$	67
				$\nu\bar{\nu}$	(<2 4)$\times 10^{-5}$	67
				Forbidden by conservation laws [f]		
				$\gamma\gamma\gamma$ *C*	(<4)$\times 10^{-7}$	67
				$\mu^\pm e^\mp$ *LF*	[g](<7)$\times 10^{-8}$	26
η	$0^+(0^{-+})$	548 8 $\pm$0 6 S=1 4*	Γ=(1 08$\pm$0 19) keV S=2 1*	$\gamma\gamma$	(38 9 $\pm$ 0 4)%	274
			Neutral decays (70 9$\pm$0 5)%	$3\pi^0$	(31 90$\pm$ 0 34)%	180
				$\pi^0\gamma\gamma$	(0 071$\pm$0 014)%	258
			Charged decays (29 1$\pm$0 5)%	$\pi^+\pi^-\pi^0$	(23 7 $\pm$ 0 5)%	175
				$\pi^+\pi^-\gamma$	(4 91$\pm$ 0 13)%	236
				$e^+e^-\gamma$	(0 50$\pm$ 0 12)%	274
				$\mu^+\mu^-\gamma$	(3 1 $\pm$ 0 4)$\times 10^{-4}$	253
				e^+e^-	(<3)$\times 10^{-4}$	274
				$\mu^+\mu^-$	(6 5 $\pm$ 2 1)$\times 10^{-6}$	253
				$\pi^+\pi^-e^+e^-$	(0 13$\pm$ 0 13)%	236
				$\pi^+\pi^-\gamma\gamma$	(<0 21)%	236
				$\pi^+\pi^-\pi^0\gamma$	(<6)$\times 10^{-4}$	175
				$\pi^0\mu^+\mu^-\gamma$	(<3)$\times 10^{-6}$	211
				Forbidden by conservation laws [f]		
				$\gamma\gamma\gamma$ *C*	(<5)$\times 10^{-4}$	274
				$\pi^+\pi^-$ *P, CP*	(<1 5)$\times 10^{-3}$	236
				$\pi^0e^+e^-$ *C*	(<5)$\times 10^{-5}$	258
				$\pi^0\mu^+\mu^-$ *C*	(<5)$\times 10^{-6}$	211

Stable Particle Summary Table *(cont'd)*

Particle	$I(J^P)$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) $c\tau$ (cm)	Mode	Fraction [b] |Limits are 90% CL|		p (MeV/c) [c]
STRANGE MESONS [a]				$[K^+ = u\bar{s},\ K^0 = d\bar{s},\ \bar{K}^0 = \bar{d}s,\ K^- = \bar{u}s]$			
				$K^+ \to$ (or $K^- \to$chg conj)			
$K^\pm$	$\frac{1}{2}(0^-)$	*493 646*	$1\ 2371 \times 10^{-8}$	$\mu^+\nu$	(63 51 ± 0 16)%		236
		± 0 009	± 0 0028 S=2 1*	$\pi^+\pi^0$	(21 17 ± 0 15)%		205
				$\pi^+\pi^+\pi^-$	(5 589 ± 0 028)%	S=1 1*	125
			$c\tau$=370 9	$\pi^+\pi^0\pi^0$	(1 73 ± 0 04)%	S=1 2*	133
				$\pi^0\mu^+\nu$	(3 18 ± 0 06)%	S=1 2*	215
	$m_{K^0} - m_{K^\pm}$	= 4 024		$\pi^0 e^+\nu$	(4 82 ± 0 05)%	S=1 1*	228
		± 0 031		$e^+\nu$	(1 54 ± 0 07)$\times 10^{-5}$		247
				$\pi^0\pi^0 e^+\nu$	($1\ 99^{+0\ 48}_{-0\ 34}$)$\times 10^{-5}$		206
				$\pi^+\pi^- e^+\nu$	(3 90 ± 0 14)$\times 10^{-5}$		203
				$\pi^+\pi^-\mu^+\nu$	(1 4 ± 0 9)$\times 10^{-5}$		151
				$\pi^+\gamma\gamma$	[d](< 8)$\times 10^{-6}$		227
				$\pi^+\gamma\gamma\gamma$	[d](< 1 0)$\times 10^{-4}$		227
				$e^+\nu\nu\bar{\nu}$	(< 6)$\times 10^{-5}$		247
				$\mu^+\nu\nu\bar{\nu}$	(< 6)$\times 10^{-6}$		236
				$\mu^+\nu e^+e^-$	(1 05 ± 0 31)$\times 10^{-6}$		236
				$e^+\nu e^+e^-$	($2\ 1\ ^{+2\ 1}_{-1\ 1}$)$\times 10^{-7}$		247
				†[$\mu^+\nu\gamma$	[d](5 40 ± 0 30)$\times 10^{-3}$		236
				$\mu^+\nu\gamma$ (SD+)[h]	(< 3 0)$\times 10^{-5}$		236
				$\mu^+\nu\gamma$ (SD+INT)[h]	(< 2 7)$\times 10^{-5}$		236
				$\mu^+\nu\gamma$ (SD− +SD−INT)[h]	(< 2 6)$\times 10^{-4}$		236
				$e^+\nu\gamma$ (SD+)[h]	(1 52 ± 0 23)$\times 10^{-5}$		247
				$e^+\nu\gamma$ (SD−)[h]	(< 1 6)$\times 10^{-4}$		247
				$\pi^+\pi^0\gamma$	[d](2 75 ± 0 15)$\times 10^{-4}$		205
				$\pi^+\pi^0\gamma$(DE)[j]	[d](*1 8 ± 0 4*)$\times 10^{-5}$		205
				$\pi^+\pi^+\pi^-\gamma$	[d](1 0 ± 0 4)$\times 10^{-4}$		125
				$\pi^+\pi^0\pi^0\gamma$	[d]($7\ 4\ ^{+5\ 5}_{-2\ 9}$)$\times 10^{-6}$		133
				$\pi^0\mu^+\nu\gamma$	[d](< 6)$\times 10^{-5}$		215
				$\pi^0 e^+\nu\gamma$	[d](2 72 ± 0 19)$\times 10^{-4}$		228
				$\pi^0 e^+\nu\gamma$ (SD)[h]	(< 5)$\times 10^{-5}$]		228
				Forbidden by conservation laws [f]			
				$\pi^+\pi^+ e^-\bar{\nu}$ *SQ*	(< 1 2)$\times 10^{-8}$		203
				$\pi^+\pi^+\mu^-\bar{\nu}$ *SQ*	(< 3 0)$\times 10^{-6}$		151
				$\pi^+ e^+ e^-$ *FC*	(2 7 ± 0 5)$\times 10^{-7}$		227
				$\pi^+\mu^+\mu^-$ *FC*	(< 2 4)$\times 10^{-6}$		172
				$\pi^+\nu\bar{\nu}$ *FC*	(< 1 4)$\times 10^{-7}$		227
				$\mu^-\nu e^+e^+$ *LF*	(< 2 0)$\times 10^{-8}$		236
				$\mu^+\nu_e$ *LF*	(< 4)$\times 10^{-3}$		236
				$\pi^+\mu^+e^-$ *LF*	(< 5)$\times 10^{-9}$		214
				$\pi^\mp\mu^\pm e^+$ *LF*, or *L* [g]	(< 7)$\times 10^{-9}$		214
				$\pi^- e^+ e^+$ *L*	(< 1 0)$\times 10^{-8}$		227
				$\mu^+\bar{\nu}_e$ *L*	(< 3 3)$\times 10^{-3}$		236
				$\pi^0 e^+\bar{\nu}_e$ *L*	(< 3 0)$\times 10^{-3}$		228

Stable Particle Summary Table *(cont'd)*

Particle	$I(J^P)$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) $c\tau$ (cm)	Decay modes: Mode	Fraction [b] [Limits are 90% CL]		p (MeV/c) [c]
K^0 $\bar{K}^0$	$\frac{1}{2}(0^-)$	497 671 ±0 030		50 % K_S, 50% K_L			
K_S^0	$\frac{1}{2}(0^-)$		0 8922×10^{-10} ±0 0020	$\pi^+\pi^-$	(68 61 ± 0 26)%	S=1 2*	206
				$\pi^0\pi^0$	(31 39 ± 0 26)%	S=1 2*	209
				$\gamma\gamma$	(2 4 ± 1 2)×10^{-6}		249
			$c\tau$=2 675	$\pi^+\pi^-\pi^0$	(<5)×10^{-5}		133
				$\pi^0\pi^0\pi^0$	(<4)×10^{-5}		139
				†[$\pi^+\pi^-\gamma$	[d](1 85± 0 10)×10^{-3}]		206
				Forbidden by conservation laws [f]			
				$\mu^+\mu^-$ FC	(<3 2)×10^{-7}		225
				e^+e^- FC	(<1 0)×10^{-5}		249
K_L^0	$\frac{1}{2}(0^-)$		5 18×10^{-8} ±0 04	$\pi^0\pi^0\pi^0$	(21 7 ± 0 7)%	S=1 4*	139
				$\pi^+\pi^-\pi^0$	(12 37± 0 18)%	S=1 3*	133
				$\pi^\pm\mu^\mp\nu$	[g](27 01± 0 34)%	S=1 2*	216
			$c\tau$=1554	$\pi^\pm e^\mp\nu$	[g](38 6 ± 0 4)%	S=1 2*	229
				$\pi^+\pi^-$ *CP* [f]	(0 204±0 004)%	S=1 2*	206
	$m_{K_L}-m_{K_S}$ = 0 5349×10^{10} $\hbar$ sec^{-1} ±0 0022			$\pi^0\pi^0$ *CP* [f]	(0 0909±0 0029)%	S=1 6*	209
				$\gamma\gamma$	*(0 0570±0 0023)*%	S=1 7*	249
				$\pi^0\gamma\gamma$	(<2 4)×10^{-4}		231
	= 3 521×10^{-12} MeV ±0 014			$\pi^0\pi^\pm e^\mp\nu$	[g](6 2 ± 2 0)×10^{-5}		207
				($\pi\mu$ atom) ν	(1 05± 0 11)×10^{-7}		216
				†[$\pi e\nu\gamma$	[d](1 3 ± 0 8)%		229
				$\pi^+\pi^-\gamma$	[d](4 41± 0 32)×10^{-5}]		206
				Forbidden by conservation laws [f]			
				$\mu^\pm e^\mp$ LF	[g](<7)×10^{-9}		238
				$\mu^+\mu^-$ FC	($9\,5^{+2\,4}_{-1\,5}$)×10^{-9}		225
				$\mu^+\mu^-\gamma$ FC	(2 8 ± 2 8)×10^{-7}		225
				$\pi^0\mu^+\mu^-$ FC	(<1 2)×10^{-6}		177
				e^+e^- FC	(<5)×10^{-9}		249
				$e^+e^-\gamma$ FC	(1 7 ± 0 9)×10^{-5}		249
				$\pi^0e^+e^-$ FC	(<2 3)×10^{-6}		231
				$\pi^+\pi^-e^+e^-$ FC	(<2 5)×10^{-6}		206
				$\mu^+\mu^-e^+e^-$ FC	(<5)×10^{-6}		225
				$e^+e^-e^+e^-$ FC	(<2 6)×10^{-6}		249

Stable Particle Summary Table *(cont'd)*

Particle	$I(J^P)$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) $c\tau$ (cm)	Decay modes: Mode	Fraction [b] [Limits are 90% CL]		p (MeV/c) [c]
CHARMED MESONS [a]			$[D^+ = c\bar{d}, D^0 = c\bar{u}, \bar{D}^0 = \bar{c}u, D^- = \bar{c}d, D_s^+ = c\bar{s}, D_s^- = \bar{c}s]$				
				$D^+ \to$ (or $D^- \to$ chg conj)			
$D^\pm$	$\frac{1}{2}(0^-)$	1869 3 ±0 6	$(10\ 69^{+0\ 34}_{-0\ 32})\times10^{-13}$ $c\tau$=0 0320	e^+ anything	$(19\ 2\ ^{+2\ 3}_{-1\ 6})\%$	S=1 2*	
				K^- anything	$(16\ 2 \pm 3\ 5)\%$		
		$m_{D^\pm} - m_{D^0}$ = 4 74 ±0 28		K^+ anything	$(6\ 6\ ^{+2\ 9}_{-2\ 8})\%$		
				$\bar{K}^0$ any + K^0 any	$(48 \pm 15)\%$		
				η anything	[k] $(< 13)\%$		
				$e^+\nu$	$(< 2\ 5)\%$		935
				$\mu^+\nu$	$(< 7)\times10^{-4}$		932
				$\pi^+\pi^0$	$(< 0\ 5)\%$		925
				$\pi^+\pi^+\pi^-$	$(0\ 33^{+0\ 15}_{-0\ 14})\%$		908
				†[$K^-\pi^+\pi^+$	$(7\ 8\ ^{+1\ 1}_{-0\ 8})\%$		845
				$K^-\pi^+\pi^+\pi^0$	$(3\ 7\ ^{+1\ 5}_{-0\ 8})\%$		816
				$K^-\pi^+\pi^+\pi^+\pi^-$	$(< 5)\%$		772
				$\bar{K}^0\pi^+$	$(2\ 8 \pm 0\ 4)\%$		862
				$\bar{K}^0\pi^+\pi^0$	$(8\ 3\ ^{+1\ 8}_{-1\ 7})\%$		845
				$\bar{K}^0\pi^+\pi^+\pi^-$	$(7\ 0\ ^{+2\ 3}_{-2\ 1})\%$	S=1 7*	814
				$\bar{K}^0K^+$	$(0\ 84^{+0\ 26}_{-0\ 25})\%$		792
				$K^+K^-\pi^+$	$(0\ 96^{+0\ 18}_{-0\ 13})\%$		744
				$K^+\pi^+\pi^-$	$(< 0\ 4)\%$]		845
				†[$\bar{K}^*(892)^0\pi^+$	$(1\ 7 \pm 0\ 8)\%$		714
				$K^+K^-\pi^+$ (non-res)	$(0\ 39^{+0\ 10}_{-0\ 08})\%$		744
				$\phi\pi^+$	$(0\ 57^{+0\ 11}_{-0\ 09})\%$		647
				$\bar{K}^*(892)^0K^+$	$(0\ 44^{+0\ 10}_{-0\ 09})\%$]		613
				$\bar{K}^0\rho^+$	$(6\ 6\ ^{+1\ 7}_{-1\ 6})\%$		680
				$\bar{K}^0\pi^+\pi^0$ (non-res)	$(1\ 2\ ^{+1\ 0}_{-0\ 7})\%$		845
				$K^-\pi^+\pi^+$ (non-res)	$(6\ 7\ ^{+1\ 1}_{-0\ 9})\%$		845
				$\bar{K}^0\pi^+\pi^+\pi^-\pi^0$	$(4\ 4\ ^{+5\ 2}_{-1\ 5})\%$		772
				$K^-\pi^+\pi^-\pi^0\pi^0$	$(2\ 2\ ^{+5\ 0}_{-0\ 9})\%$		775
				$K^-\pi^+\pi^0e^+\nu$	$(4\ 4\ ^{+5\ 2}_{-1\ 5})\%$		846
				$\bar{K}^0\pi^+\pi^-e^+\nu$	$(2\ 2\ ^{+5\ 0}_{-0\ 7})\%$		844
				$K^-\pi^+e^+\nu$	$(< 6)\%$		863
				$\pi^+\pi^-e^+\nu$	$(< 6)\%$		924
				$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^0$	(seen)		799
				$\phi\pi^+\pi^+\pi^-$	$(< 0\ 2)\%$		565
				$K^+K^-\pi^+\pi^+\pi^-$ (non-res)	$(< 3)\%$		600

Stable Particle Summary Table *(cont'd)*

Particle	$I(J^P)$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) $c\tau$ (cm)	Decay modes: Mode	Fraction [b] [Limits are 90% CL]		p (MeV/c) [c]
				$D^0 \to$ (or $\bar{D}^0 \to$ chg conj)			
D^0 $\bar{D}^0$	$\frac{1}{2}(0^-)$	1864 5 ±0 6	(4 28±0 11)×10^{-13} $c\tau$=0 0128	e^+ anything	(7 7 ± 1 1)%		
				K^- anything	(43 ± 5)%		
				K^+ anything	(6 4 $^{+2\ 6}_{-1\ 7}$)%		
				$\bar{K}^0$ any + K^0 any	(33 ± 10)%		
				η anything	[k] (< 13)%		
				$\pi^+\pi^-$	(0 13± 0 04)%		922
				$\pi^+\pi^+\pi^-\pi^-$	(1 01$^{+0\ 71}_{-0\ 26}$)%		879
				$\pi^+\pi^-\pi^0$	(1 1 ± 0 4)%		907
				†[$K^-\pi^+$	(*3 77*$^{+0\ 37}_{-0\ 32}$)%		861
				$K^-\pi^+\pi^0$	(*12 5* $^{+1\ 5}_{-1\ 3}$)%		844
				$K^-\pi^+\pi^+\pi^-$	(*7 9* $^{+1\ 0}_{-0\ 9}$)%	S=1 1*	812
				$K^-\pi^+\pi^0\pi^0$	(15 ± 5)%		815
				$\bar{K}^0\pi^0$	(2 8 $^{+1\ 3}_{-1\ 2}$)%		860
				$\bar{K}^0\pi^+\pi^-$	(*5 6* $^{+0\ 7}_{-0\ 6}$)%		842
				K^+K^-	(*0 45*± *0 08*)%		791
				$\bar{K}^0K^0$	(<0 4)%		788
				$\bar{K}^0K^+K^-$	(1 16$^{+0\ 25}_{-0\ 22}$)%		544
				$K^0K^-\pi^+$ (non-res) + c c	(<1 2)%		739
				$\bar{K}$*(892)$^0K^0$ + c c	(<0 6)%		607
				K*(892)$^-K^+$ + c c	(0 8 ± 0 4)%]		609
				$K^-\pi^+\pi^+\pi^-\pi^0$	(seen)		771
				$K^+K^-\pi^0\pi^0$	(seen)		681
				$K^0K^-\pi^+\pi^0$	(seen)		677
				$K^-e^+\nu$	(*<5*)%		867
				$\pi^-e^+\nu$	(*<5*)%		927
				$K^+\pi^-$ (doubly Cabibbo suppressed)	(*<1 5*)%		861
				$K^+\pi^-\pi^+\pi^-$ (doubly Cabibbo suppressed)	(*<1 8*)%		812

$|m_{D_1^0} - m_{D_2^0}|$ < 1 3×10^{-10} MeV [f]

$|\tau_{D_1^0} - \tau_{D_2^0}|$ / average < 0 17 [f]

$\Gamma(D^0 \to \bar{D}^0 \to K^+\pi^-) / \Gamma(D^0 \to K^-\pi^+)$ < 0 004

$\Gamma(D^0 \to \bar{D}^0 \to \mu^-$ any$) / \Gamma(D^0 \to \mu^+$ any$)$ < 0 006

$D^0 \to$ (or $\bar{D}^0 \to$ chg conj)		Fraction	p (MeV/c)
†[K*(892)$^-\pi^+$		(4 8 ± 0 7)%	711
$\bar{K}$*(892)$^0\pi^0$		(2 1 ± 0 6)%	711
$K^-\rho^+$		(8 2 $^{+1\ 2}_{-1\ 1}$)%	679
$\bar{K}^0\rho^0$		(0 47$^{+0\ 30}_{-0\ 21}$)%	677
$K^-\pi^+\pi^0$ (non-res)		(1 3 ± 0 5)%	844
$\bar{K}^0\pi^+\pi^-$ (non-res)		(1 9 ± 0 5)%	842
$\bar{K}$*(892)$^0\rho^0$		(*1 2* $^{+1\ 3}_{-1\ 2}$)%	423
$K^-\pi^+\rho^0$		(6 7 $^{+1\ 2}_{-1\ 9}$)%	613
$\bar{K}$*(892)$^0\pi^+\pi^-$		(*<2 1*)%	685
$K^-a_2(1320)^+$		(*<1 3*)%	198
$\bar{K}^0\phi$		(*0 83*$^{+0\ 18}_{-0\ 16}$)%	520
$\bar{K}^0K^+K^-$ (non-res)		(0 74$^{+0\ 23}_{-0\ 18}$)%]	544
Forbidden by conservation laws [f]			
$\mu^+\mu^-$	*FC*	(<1 1)×10^{-5}	926
e^+e^-	*FC*	(*<1 3*)×10^{-4}	932
$\mu^\pm e^\mp$	*LF*	[g] (*<1 2*)×10^{-4}	929

Particle	$I(J^P)$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) $c\tau$ (cm)	Mode	Fraction [b]	p (MeV/c) [c]
				$D_s^+ \to$ (or $D_s^- \to$ chg conj)		
$D_s^\pm$ *was $F^\pm$*	0(0$^-$) [m]	1969 3 ±1 1 S=1 3*	(4 36$^{+0\ 38}_{-0\ 32}$)×10^{-13} $c\tau$=0 0131	$\phi\pi^+$	[n] (*8* ± *5*)%	712
				$\phi\pi^+\pi^+\pi^-$	[n] (*4* ± *3*)%	641
				$\rho^0\pi^+$	[n] (*<2*)%	827
				$\bar{K}$*(892)$^0K^+$	[n] (*8* ± *5*)%	683
				$K^+K^-\pi^+$ (non-res)	[n] (*2* ± *1 4*)%	805
				$K^+K^-\pi^+\pi^-\pi^+$ (non-res)	[n] (*<3*)%	674
				$\mu^+\nu$	[n] (*<3*)%	982
				$\eta\pi^+$	(possibly seen)	902
				$\eta\pi^+\pi^+\pi^-$	(possibly seen)	856
				$\eta'(958)\pi^+\pi^+\pi^-$	(possibly seen)	677
				$\phi\rho^+$	(possibly seen)	408
				$D_s^{*+} \to$ (or $D_s^{*-} \to$ chg conj)		
$D_s^{*\pm}$ *was $F^{*\pm}$*		2112 7 ±2 3 S=1 2*	<22	$D_s^+\gamma$	dominant	137

$m_{D_s^{*\pm}} - m_{D_s^\pm}$ = 141 6 ±1 9 S=1 2*

Stable Particle Summary Table *(cont'd)*

BOTTOM MESONS [a]

$[B^+ = u\bar{b},\ B^0 = d\bar{b},\ \bar{B}^0 = \bar{d}b,\ B^- = \bar{u}b]$

Particle	$I(J^P)$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) cτ (cm)	Mode	Fraction [b] [Limits are 90% CL]	p (MeV/c) [c]
				$B^+ \to$ (or $B^- \to$ chg conj)		
$B^\pm$	$\frac{1}{2}(0^-)$ [p]	5277 6 ± 1 4		$\bar{D}^0\pi^+$	(0 47 $^{+0\ 19}_{-0\ 15}$)%	2307
				$D^*(2010)^-\pi^+\pi^+$	(0 25 $^{+0\ 15}_{-0\ 13}$)%	2247
	$m_{B^0} - m_{B^\pm}$ = 1 9 ± 1 1			$J/\psi(1S)K^+$	(8 0 ± 2 8)×10^{-4}	1683
				$\rho^0\pi^+$	(<2)×10^{-4}	2581
				$D^*(2010)^-\pi^+\pi^+\pi^0$	(4 3 ± 2 9)%	2235
	0 4 < τ_{B^0}/τ_{B^+} < 2 1			$D^-\pi^+\pi^+$	(0 25 $^{+0\ 48}_{-0\ 24}$)%	2299
				$\bar{D}^*(2010)^0\pi^+$	(0 27 ± 0 44)%	2254
				$\pi^+\pi^0$	(<2 3)×10^{-3}	2636
				$\rho^0 a_1(1260)^+$	(<3 2)×10^{-3}	2426
				$\rho^0 a_2(1320)^+$	(<2 3)×10^{-3}	2410
				$J/\psi(1S)K^+\pi^+\pi^-$	(0 11 ± 0 07)%	1611
				$\psi(2S)K^+$	(0 22 ± 0 17)%	1284
				$K^0\pi^+$	(<7)×10^{-4}	2614
				$K^*(892)^0\pi^+$	(<2 6)×10^{-4}	2562
				$K^+\rho^0$	(<2 6)×10^{-4}	2559
				$K^+\phi$	(<2 1)×10^{-4}	2516
				$K^*(892)^+\gamma$	(<1 8)×10^{-3}	2564
				Forbidden by conservation laws [f]		
				$K^+\mu^+\mu^-$ FC	(<3 2)×10^{-4}	2612
				$K^+e^+e^-$ FC	(<2 1)×10^{-4}	2616

Particle	$I(J^P)$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) cτ (cm)	Mode	Fraction [b] [Limits are 90% CL]	p (MeV/c) [c]
				$B^0 \to$ (or $\bar{B}^0 \to$ chg conj)		
B^0 $\bar{B}^0$	$\frac{1}{2}(0^-)$ [p]	5279 4 ± 1 5		$\bar{D}^0\pi^+\pi^-$	(<3 9)%	2301
				$D^*(2010)^-\pi^+$	(0 33 $^{+0\ 12}_{-0\ 10}$)%	2255
				$D^*(2010)^-\rho^+$	(8 $^{+7}_{-4}$)%	2182
	$\lvert m_{B^0_1} - m_{B^0_2} \rvert$ = (3 7 ± 1 0)×10^{-10} MeV [ℓ]			$J/\psi(1S)K^+\pi^-$	(<1 3)×10^{-3}	1653
				$\pi^+\pi^-$	(<3)×10^{-4}	2636
				$K^+\pi^-$	(<3 2)×10^{-4}	2615
	$\frac{\Gamma(B^0 \to \bar{B}^0 \to \mu^- \text{ any})}{\Gamma(B^0 \to \mu^\pm \text{ any})}$ = 0 17 ± 0 05			$K^*(892)^+\pi^-$	(<7)×10^{-4}	2563
				$K^0\rho^0$	(<8)×10^{-4}	2559
				$K^0\phi$	(<1 3)×10^{-3}	2516
				$K^*(892)^0\phi$	(<4 7)×10^{-4}	2460
				$K^*(892)^0\rho^0$	(<1 2)×10^{-3}	2505
				$K^*(892)^0\gamma$	(<2 1)×10^{-3}	2565
				$D^*(2010)^-\pi^+\pi^0$	(1 5 ± 1 1)%	2248
				$D^*(2010)^-\pi^+\pi^+\pi^-$	(3 3 ± 1 8)%	2235
				$D^*(2010)^-e^+\nu$ + $D^*(2010)^-\mu^+\nu$	(14 ± 4)%	
				$J/\psi(1S)K^*(892)^0$	(0 37 ± 0 13)%	1572
				$J/\psi(1S)K^0$	(<5)×10^{-3}	1683
				$\rho^\pm\pi^\mp$	[g](<6)×10^{-3}	2582
				$\rho^0\rho^0$	(<5)×10^{-4}	2525
				$\pi^\pm a_1(1260)^\mp$	[g](<1 2)×10^{-3}	2488
				$\pi^\pm a_2(1320)^\mp$	[g](<1 6)×10^{-3}	2473
				$p\bar{p}$	(<2)×10^{-4}	2468
				$D^-\pi^+$	(5 9 $^{+3\ 6}_{-3\ 2}$)×10^{-3}	2307

$B^0 \to$ (or $\bar{B}^0 \to$ chg conj)

Forbidden by conservation laws [f]

Mode		Fraction	p (MeV/c)
$\mu^+\mu^-$	FC	(<5)×10^{-5}	2638
e^+e^-	FC	(<8)×10^{-5}	2640
$K^0\mu^+\mu^-$	FC	(<4)×10^{-4}	2612
$K^0e^+e^-$	FC	(<6)×10^{-4}	2617
$\mu^\pm e^\mp$	LF	[g](<5)×10^{-5}	2639

Stable Particle Summary Table *(cont'd)*

Particle	$I(J^P)$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) $c\tau$ (cm)	Decay modes: Mode	Decay modes: Fraction [b] [Limits are 90% CL]	p (MeV/c) [c]
				$B \to$		
$B^{\pm}$, B^0, $\overline{B}^0$ (not separated) [q]			$(13\ 1^{+1\ 4}_{-1\ 3}) \times 10^{-13}$	$e^{\pm}\nu$ hadrons	[g](12 3 ± 0 8)%	
				$\mu^{\pm}\nu$ hadrons	[g](11 0 ± 0 9)%	
			$c\tau$=0 039	$D^0/\overline{D}^0$ anything	(*39* ± *6*)%	
				$K^{\pm}$ anything	(85 ± 11)%	
$\dfrac{\Gamma(B \to \ell^{\pm}\nu \text{ noncharm-hadrons})}{\Gamma(B \to \ell^{\pm}\nu \text{ hadrons})}$			< 0 04	$K^0/\overline{K}^0$ anything	(63 ± 8)%	
				p anything	(> 2 1)%	
				Λ anything	(> 1 1)%	
				$J/\psi(1S)$ anything	(1 12 ± 0 18)%	
				$D^*(2010)^{\pm}$ anything	[g](22 $^{+8}_{-6}$)%	
				$D_s^{\pm}$ anything	[g](14 ± 3)%	
				ϕ anything	(2 3 ± 0 8)%	
				charmed baryon anything	(< 11)%	
				$D^{\pm}$ anything	[g](17 ± 6)%	
				$\psi(2S)$ anything	(0 46 ± 0 20)%	
				Forbidden by conservation laws [f]		
				e^+e^- any + $\mu^+\mu^-$ any *FC*	(< 0 24)%	

Particle	
B^*	Not established, see the Stable Particle Full Listings

NUCLEONS [a] $[p = uud,\ n = udd]$

Particle	$I(J^P)$	Mass (MeV)	Mean life
p	$\frac{1}{2}(\frac{1}{2}^+)$	*938 27231* [e] *± 0 00028*	stable (> 1 6 × 10^{25} yr or > 10^{31} – 3 × 10^{32} yr) [r]
	$\lvert q_p + q_e \rvert < 10^{-21}\ e$ [s]		

Partial mean lifetimes of protons (units 10^{30} yr)		Partial mean lifetimes of bound neutrons (units 10^{30} yr)	
e^+ anything	> 0 6	e^+ anything	> 0 6
μ^+ anything	> 12	μ^+ anything	> 12
$e^+\gamma$	> 360	$\nu\gamma$	> 9
$\mu^+\gamma$	> *97*	$e^+\pi^-$	> *31*
$e^+\pi^0$	> 250	$\mu^+\pi^-$	> *23*
$\mu^+\pi^0$	> *76*	e^+K^-	> 1 3
e^+K^0	> 77	μ^+K^-	> 0 4
μ^+K^0	> 41	$\nu\pi^0$	> *40*
$\nu\pi^+$	> 5 1	νK^0	> *32*
νK^+	> *28*	$e^+\rho^-$	> *14*
$e^+\omega$	> 37	$\mu^+\rho^-$	> *7*
$\mu^+\omega$	> 23	$\nu K^*(892)^0$	> *6*
$e^+\rho^0$	> 17	$\nu\nu\nu$	> 0 0005
$\mu^+\rho^0$	> 16	$e^+\pi^0$ any	> 0 6
$e^+e^+e^-$	> 510	$\nu\eta$	> *30*
$\mu^+\mu^+\mu^-$	> 190	$\nu\rho^0$	> *4*
$\nu K^*(892)^+$	> *10*	$\nu\omega$	> *18*
$e^+\pi^0$ any	> 0 6	$e^+e^-\nu$	> *45*
$e^+\eta$	> 200	$\mu^+\mu^-\nu$	> *16*
$\mu^+\eta$	> 46	$e^-\pi^+$	> *16*
$\nu\rho^+$	> *11*	$\mu^-\pi^+$	> *25*
$e^+K^*(892)^0$	> *10*	$e^-\rho^+$	> 12
		$\mu^-\rho^+$	> 9

Particle	$I(J^P)$	Mass (MeV)	Mean life	Mode	Fraction	p (MeV/c)
n	$\frac{1}{2}(\frac{1}{2}^+)$	*939 56563* [e] *± 0 00028*	896 ± 10 S = 1 8*	$pe^-\overline{\nu}$	100%	1 19
				Forbidden by conservation laws [f]		
				$p\nu\overline{\nu}$ *Q*	< 9 × 10^{-24}	1 29
	$m_n - m_p$	= 1 293318 ± 0 000009	$c\tau$=2 69 × 10^{13}			
	$\lvert q_n \rvert$	< $10^{-21}\ e$ [s]				

Stable Particle Summary Table *(cont'd)*

Particle	$I(J^P)$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) $c\tau$ (cm)	Decay modes: Mode	Fraction [b] [Limits are 90% CL]	p (MeV/c) [c]
STRANGENESS −1 BARYONS [a]				[$\Lambda = uds$, $\Sigma^+ = uus$, $\Sigma^0 = uds$, $\Sigma^- = dds$]		
Λ	$0(\frac{1}{2}^+)$	1115 63	$2\,631\times10^{-10}$	$p\pi^-$	(64 1 ± 0 5)%	101
		±0 05	±0 020	$n\pi^0$	(35 7 ± 0 5)%	104
		S=1 4*	S=1 6*	$n\gamma$	(*1 02*± *0 33*)$\times10^{-3}$	162
				$pe^-\nu$	(8 34± 0 14)$\times10^{-4}$	163
			$c\tau$ =7 89	$p\mu^-\nu$	(1 57± 0 35)$\times10^{-4}$	131
				†[$p\pi^-\gamma$	[d](8 5 ± 1 4)$\times10^{-4}$]	101
Σ^+	$1(\frac{1}{2}^+)$	1189 37	$0\,799\times10^{-10}$	$p\pi^0$	(51 57 ± 0 30)%	189
		±0 06	±0 004	$n\pi^+$	(48 30 ± 0 30)%	185
		S=1 9*		$p\gamma$	(1 24± 0 08)$\times10^{-3}$	225
			$c\tau$=2 40	$\Lambda e^+\nu$	(2 0 ± 0 5)$\times10^{-5}$	71
				†[$n\pi^+\gamma$	[d](4 5 ± 0 5)$\times10^{-4}$]	185
	$m_{\Sigma^-} - m_{\Sigma^+}$ = *8 07*		$\frac{\Gamma(\Sigma^+\to n\ell^+\nu)}{\Gamma(\Sigma^-\to n\ell^-\nu)}$ < 0 04	Forbidden by conservation laws [f]		
		±0 08		$ne^+\nu$ SQ	(<5)$\times10^{-6}$	224
		S=1 6*		$n\mu^+\nu$ SQ	(<3)$\times10^{-5}$	202
				pe^+e^- FC	(<7)$\times10^{-6}$	225
Σ^0	$1(\frac{1}{2}^+)^t$	1192 55	*(7 4±0 7)*$\times10^{-20}$	$\Lambda\gamma$	100%	74
		±0 09		Λe^+e^-	[u](5)$\times10^{-3}$	74
		S=1 3*	$c\tau$=2 2$\times10^{-9}$	$\Lambda\gamma\gamma$	(<3)$\times10^{-2}$	74
	$m_{\Sigma^0} - m_\Lambda$ = 76 92					
		±0 10				
		S=1 3*				
Σ^-	$1(\frac{1}{2}^+)$	*1197 43*	$1\,479\times10^{-10}$	$n\pi^-$	(99 848$^{+0\,006}_{-0\,005}$)%	193
		±0 06	±0 011			
		S=1 5*	S=1 3*	$ne^-\nu$	(1 017$^{+0\,032}_{-0\,037}$)$\times10^{-3}$	230
			$c\tau$=4 43	$n\mu^-\nu$	(4 5 ± 0 4)$\times10^{-4}$	210
	$m_{\Sigma^-} - m_{\Sigma^0}$ = 4 89			$\Lambda e^-\nu$	(5 73± 0 27)$\times10^{-5}$	79
		±0 08		†[$n\pi^-\gamma$	[d](4 6 ± 0 6)$\times10^{-4}$]	193
		S=1 2*				
STRANGENESS −2 BARYONS [a]				[$\Xi^0 = uss$, $\Xi^- = dss$]		
Ξ^0	$\frac{1}{2}(\frac{1}{2}^+)^t$	1314 9	$2\,90\times10^{-10}$	$\Lambda\pi^0$	100%	135
		±0 6	±0 10	$\Lambda\gamma$	(0 5 ± 0 5)$\times10^{-2}$	184
				$\Sigma^0\gamma$	(<7)$\times10^{-2}$	117
			$c\tau$=8 69	$\Sigma^+e^-\nu$	(<1 1)$\times10^{-3}$	120
				$\Sigma^+\mu^-\nu$	(<1 1)$\times10^{-3}$	64
	$m_{\Xi^-} - m_{\Xi^0}$ = 6 4			Forbidden by conservation laws [f]		
		±0 6		$\Sigma^-e^+\nu$ SQ	(<9)$\times10^{-4}$	112
				$\Sigma^-\mu^+\nu$ SQ	(<9)$\times10^{-4}$	49
				$p\pi^-$ ΔS	(<4)$\times10^{-5}$	299
				$pe^-\nu$ ΔS	(<1 3)$\times10^{-3}$	323
				$p\mu^-\nu$ ΔS	(<1 3)$\times10^{-3}$	309
Ξ^-	$\frac{1}{2}(\frac{1}{2}^+)^t$	1321 32	$1\,639\times10^{-10}$	$\Lambda\pi^-$	100%	139
		±0 13	±0 015	$\Sigma^-\gamma$	(2 3 ± 1 0)$\times10^{-4}$	118
				$\Lambda e^-\nu$	(5 5 ± 0 3)$\times10^{-4}$	190
			$c\tau$=4 91	$\Lambda\mu^-\nu$	(3 5 ± 3 5)$\times10^{-4}$	163
				$\Sigma^0e^-\nu$	(8 7 ± 1 7)$\times10^{-5}$	122
				$\Sigma^0\mu^-\nu$	(<8)$\times10^{-4}$	70
				$\Xi^0e^-\nu$	(<2 3)$\times10^{-3}$	6
				Forbidden by conservation laws [f]		
				$n\pi^-$ ΔS	(<1 9)$\times10^{-5}$	303
				$ne^-\nu$ ΔS	(<3 2)$\times10^{-3}$	327
				$n\mu^-\nu$ ΔS	(<1 5)$\times10^{-2}$	314
				$p\pi^-\pi^-$ ΔS	(<4)$\times10^{-4}$	223
				$p\pi^-e^-\nu$ ΔS	(<4)$\times10^{-4}$	304
				$p\pi^-\mu^-\nu$ ΔS	(<4)$\times10^{-4}$	250

Stable Particle Summary Table *(cont'd)*

Particle	$I(J^P)$ [a]	Mass [b] (MeV)	Mean life [b] τ (sec) $c\tau$ (cm)	Decay modes: Mode	Fraction [b] [Limits are 90% CL]	p (MeV/c) [c]
			STRANGENESS −3 BARYON [a]	[$\Omega^- = sss$]		
Ω^-	$0(\frac{3}{2}^+)$ [t]	1672 43	$0\,822\times10^{-10}$	ΛK^-	(67 8 ± 0 7)%	211
		±0 32	±0 012	$\Xi^0\pi^-$	(23 6 ± 0 7)%	294
				$\Xi^-\pi^0$	(8 6 ± 0 4)%	290
			$c\tau$=2 46	$\Xi^-\pi^+\pi^-$	(4 3 $^{+3\,4}_{-1\,3}$)$\times10^{-4}$	190
				†[$\Xi(1530)^0\pi^-$	(6 4 $^{+5\,1}_{-2\,0}$)$\times10^{-4}$]	17
				$\Xi^0 e^-\nu$	(5 6 ± 2 8)$\times10^{-3}$	319
				$\Xi^-\gamma$	(<2 2)$\times10^{-3}$	314
				Forbidden by conservation laws [f]		
				$\Lambda\pi^-$ ΔS	(<1 9)$\times10^{-4}$	449
	CHARMED BARYONS [a]			[$\Lambda_c^+ = udc$, $\Sigma_c^{++} = uuc$, $\Sigma_c^+ = udc$, $\Sigma_c^0 = ddc$, $\Xi_c^+ = usc$]		
Λ_c^+	$0(\frac{1}{2}^+)$ [t]	*2284 9*	$(1\,79^{+0\,23}_{-0\,17})\times10^{-13}$	$p\bar{K}^0$	(1 5 ± 0 6)%	872
		±1 5		$pK^-\pi^+$	(2 6 ± 0 9)%	822
		S=1 6*		†[$p\bar{K}^{*0}$	(0 56 $^{+0\,31}_{-0\,28}$)%	684
			$c\tau$=0 0054	$\Delta^{++}K^-$	(0 53 $^{+0\,28}_{-0\,26}$)%]	709
				$p\bar{K}^0\pi^+\pi^-$	(7 4 ± 3 5)%	753
				$pK^-\pi^+\pi^0$	(*seen*)	758
				†[$pK^{*-}\pi^+$	(seen)	579
				$\Delta\bar{K}^*$	(seen)]	417
				Λ anything	(27 ± 9)%	
				†[$\Lambda\pi^+$	(seen, <0 4)%	863
				$\Lambda\pi^+\pi^+\pi^-$	(1 7 ± 0 7)%	806
				$\Sigma^\pm$ anything	[g](*10* ± *5*)%	
				$\Sigma^0\pi^+$	(seen)]	824
				$\Sigma^+\pi^+\pi^-$	(*10* ± *8*)%	803
				†[pe^+ anything	(1 8 ± 0 9)%	
				Λe^+ anything	(1 1 ± 0 8)%]	
				e^+ anything	(4 5 ± 1 7)%	
Σ_c		See the Baryon Summary Table				
Ξ_c^+		2460	$(4\,3^{+1\,7}_{-1\,2})\times10^{-13}$	$\Lambda K^-\pi^+\pi^+$	(seen)	781
		±19		$\Sigma^0 K^-\pi^+\pi^+$	(seen ?)	729
was A^+			$c\tau$=0 013			

Ω_c^0 [*was* T^0], Λ_b^0 — Not established, see the Stable Particle Full Listings

Searches for top hadrons, free quarks, magnetic monopoles, axions, Higgs bosons, heavy bosons, supersymmetric particles, and quark and lepton compositeness — See the Stable Particle Search Limits Summary Table and Full Listings

ADDENDUM 10 Stable Particle Summary Table

	Magnetic moment ($\mu_B = e\hbar/2m_e$)
ν_e	$< 1.5\times10^{-10}$
ν_μ	$< 1.2\times10^{-9}$
e^{x}	1.001 159 652 193 ± 0.000 000 000 010
μ^{x}	1.001 165 923 ± 0.000 000 008 $\frac{e\hbar}{2m_\mu}$
τ	**Michel parameter** $\rho = 0.73\pm0.07$

μ decay parameters [w]

$\rho = 0.7518\pm0.0026$	$\delta = 0.755 \pm0.009$
$\eta = -0.007\pm0.013$	$\bar{\eta} = 0.02\pm0.08$
$\xi' = 1.00\pm0.04$	$\xi'' = 0.65 \pm0.36$
$\xi P_\mu\delta/\rho > 0.99677$ [x]	$\xi P_\mu = 1.0027\pm0.0085$ [x]
$\alpha/A = (0\pm4)\times10^{-3}$	$\alpha'/A = (-0.2\pm4.3)\times10^{-3}$
$\beta/A = (4\pm6)\times10^{-3}$	$\beta'/A = (2\pm6)\times10^{-3}$

π — **$\pi^\pm \to \ell^\pm\nu\gamma$ form factors** [w]

$F_A = 0.0118\pm0.0020$ S=1.6* $F_V = 0.029^{+0.019}_{-0.014}$ $R = 0.063^{+0.026}_{-0.016}$

η

Mode	Left-right asymmetry	Sextant asymmetry	Quadrant asymmetry
$\pi^+\pi^-\pi^0$	(0.12±0.17)%	(0.19±0.16)%	(−0.17±0.17)%
$\pi^+\pi^-\gamma$	(0.9 ±0.4)%		$\beta = 0.05\pm0.06$ S=1.5*

K

Mode	Slope parameter g [y]	
$K^+\to\pi^+\pi^+\pi^-$	−0.215±0.004	S=1.4*
$K^-\to\pi^-\pi^-\pi^+$	−0.217±0.007	S=2.5*
$K^\pm\to\pi^\pm\pi^0\pi^0$	0.594±0.019	S=1.3*
$K^0_L\to\pi^+\pi^-\pi^0$	0.670±0.014	S=1.6*

See Full Listings for quadratic coefficients

$K_{\ell 3}$ form factors [w]

K^+_{e3}: $\lambda_+ = 0.028\pm0.004$; $|f_S/f_+| = 0.12^{+0.04}_{-0.05}$ S=1.3*; $|f_T/f_+| = 0.22^{+0.15}_{-0.13}$

K^0_{e3}: $\lambda_+ = 0.0300\pm0.0016$ S=1.2*; $|f_S/f_+| < 0.04$; $|f_T/f_+| < 0.23$

$K^+_{\mu3}$: $\lambda_+ = 0.033\pm0.008$ S=1.6*; $\lambda_0 = 0.004\pm0.007$ S=1.6*; $|f_T/f_+| = 0.02\pm0.12$

$K^0_{\mu3}$: $\lambda_+ = 0.034\pm0.005$ S=2.3*; $\lambda_0 = 0.025\pm0.006$ S=2.3*; $|f_T/f_+| = 0.12 \pm 0.12$

$\Delta S = -\Delta Q$ in $K^0_{\ell 3}$ decay

Re x = 0.006±0.018 S=1.3*
Im x = −0.003±0.026 S=1.2*

CP-violation parameters [z]

$\lvert\eta_{+-}\rvert = (2.266\pm0.018)\times10^{-3}$	$\lvert\epsilon'/\epsilon\rvert = (3.2\pm1.0)\times10^{-3}$ [aa]
$\lvert\eta_{00}\rvert = (2.245\pm0.019)\times10^{-3}$	$\lvert\epsilon\rvert = (2.259\pm0.018)\times10^{-3}$ [aa]
$\phi_{+-} = (44.6\pm1.2)^\circ$ S=1.1* $\phi_{00} = (54\pm5)^\circ$	Re $\epsilon = (1.621\pm0.088)\times10^{-3}$
$\lvert\eta_{+-0}\rvert^2 < 0.12$ $\lvert\eta_{000}\rvert^2 < 0.1$	$\delta = (0.330\pm0.012)$%

	Magnetic moment ($\mu_N = e\hbar/2m_p$)	Mode	Decay parameters [bb] Measured α	ϕ(degree)	Derived γ	Δ(degree)	Coupling constant ratios
p^{x}	2.792 847 386 ±0.000 000 063						
n^{x}	−1.913 042 75 ±0.000 000 45	$pe^-\bar\nu$					$g_A/g_V = -1.259\pm0.004$; $\phi_{AV} = (180.11\pm0.17)^\circ$
Λ^{x}	−0.613 ±0.004	$p\pi^-$	+0.642±0.013	−6.5±3.5	0.76	8±4	
		$n\pi^0$	+0.65±0.05				
		$pe^-\bar\nu$					$g_A/g_V = -0.696\pm0.025$ S=1.3*
Σ^+	2.42 ±0.05 S=3.1*	$p\pi^0$	$-0.980^{+0.019}_{-0.014}$	36±34	0.16	187±6	
		$n\pi^+$	+0.068±0.013	167±20 S=1.1*	−0.97	-73^{+133}_{-10}	
		$p\gamma$	−0.83 ±0.12				
Σ^0	−1.61 ($\mu_{\Sigma\Lambda}$) ±0.08						
Σ^-	−1.157 ±0.025 S=1.7*	$n\pi^-$	−0.068±0.008	10±15	0.98	249^{+12}_{-120}	
		$ne^-\bar\nu$					$\lvert g_A/g_V\rvert = 0.36\pm0.05$ S=1.9*
		$\Lambda e^-\bar\nu$					$g_V/g_A = 0.01\pm0.10$ S=1.5* $g_{WM}/g_A = 2.4\pm1.7$
Ξ^0	−1.250 ±0.014	$\Lambda\pi^0$	−0.411±0.022 S=2.1*	21±12	0.85	218^{+12}_{-19}	
Ξ^-	−0.69 ±0.04	$\Lambda\pi^-$	−0.456±0.014 S=1.8*	4±4	0.89	188±8	
		$\Lambda e^-\bar\nu$					$g_A/g_V = -0.25\pm0.05$
Ω^-		ΛK^-	−0.026±0.026				
		$\Xi^0\pi^-$	+0.09 ±0.14				
		$\Xi^-\pi^0$	+0.05 ±0.21				

Search Limits Summary Table

Search lımıts usually are crıtically dependent on assumptıons Further detaıls and other lımıts are gıven ın the Full Lıstıngs For complete ınformatıon, the orıgınal lıterature should be consulted All lımıts gıven below are for CL=0 90, except those marked wıth an asterısk (*), whıch are for CL=0 95

Leptons

L^+ — charged lepton	$M > 41$ GeV	$m(\nu) \approx 0$
E^0 — neutral para- or ortho-lepton	$M > 22\ 5$ GeV*	ıf E^0eW vertex ıs $V - A$
	$> 24\ 5$ GeV*	ıf E^0eW vertex ıs $V + A$

No dırect, uncontested evıdence for massıve neutrınos or lepton mıxıng has been obtaıned Sample lımıts are

ν oscıllatıon

$\nu_\mu \rightarrow \nu_e$ (θ = mıxıng angle)	$\sin^2 2\theta < 3\ 4\times10^{-3}$	ıf ΔM^2 ıs large
	$\Delta M^2 < 0\ 09$ eV^2	ıf $\sin^2 2\theta = 1$
$\overline{\nu}_e \not\rightarrow \overline{\nu}_e$	$\sin^2 2\theta < 0\ 14$	ıf ΔM^2 ıs large
	$\Delta M^2 < 0\ 014$ eV^2	ıf $\sin^2 2\theta = 1$

For excıted leptons, see Composıteness Lımıts below

Hadrons with t or b' Quarks

T — hadron wıth t quark	$M > 44$ GeV*	$p\overline{p} \rightarrow T$ +X ($M > 25\ 9$ GeV from e^+e^- coll)
B' — hadron wıth b' quark (4th gen)	$M > 32$ GeV	$p\overline{p} \rightarrow B'$ +X ($M > 23\ 8$ GeV from e^+e^- coll)

Number of Light Neutrino Types (including ν_e, ν_μ, and ν_τ)

	$N < 5\ 9$	from Z wıdth ın Standard Model, assumıng $m(t) > 44$ GeV
	$N < 7\ 5$	from $e^+e^- \rightarrow \gamma\nu\overline{\nu}$

Additional W Bosons

W_R — rıght-handed W	$M > 406$ GeV	assumıng lıght rıght-handed neutrıno
W' — W wıth standard couplıngs decayıng to $e\nu$	$M > 210$ GeV	

Additional Z Bosons

Z_{LR} of $SU(2)_L \times SU(2)_R \times U(1)$	$M > 343$ GeV	ıf magnıtudes of L & R couplıng constants are equal
Z_χ of SO(10) $\rightarrow$ SU(5)×U(1)	$M > 249$ GeV	couplıng constant derıved from G U T
Z_ψ of $E_6 \rightarrow SO(10)\times U(1)_\psi$	$M > 151$ GeV	couplıng constant derıved from G U T
Z_η of $E_6 \rightarrow SU(3)\times SU(2)\times U(1)\times U(1)_\eta$	$M > 112$ GeV	couplıng constant derıved from G U T , charges are $Q_\eta = \sqrt{3/8}Q_\chi - \sqrt{5/8}Q_\psi$
Z_1 wıth standard couplıngs decayıng to e^+e^-	$M > 180$ GeV	

Higgs Bosons (or Technipions)

H^0 $M > 3\ 9$ GeV

The order α_s correctıon reduced the rate for $\Upsilon \rightarrow H^0\gamma$ by a factor of 2 (yıeldıng the above lımıt) The ımpact both of order α_s^2 and of relatıvıstıc correctıons are unknown If they amounted to another factor of 2, the above lımıt would be essentıally elımınated Also the possıbılıty of an allowed wındow for $M(H^0)$ = 100–200 MeV has not been defınıtıvely ruled out, see the Note ın the Full Lıstıngs for Hıggs Bosons

$H^\pm$ $M > 19$ GeV*

Axions

The standard Peccei-Quınn axıon ıs ruled out Varıants wıth reduced couplıngs or much smaller masses are constraıned by varıous data

A reported observatıon of neutrınoless double beta decay wıth Majoron emıssıon ıs contradıcted by later experıments The best lımıt for the half-lıfe ıs $> 1\ 4\times10^{21}$ years

Free Quarks

All searches sınce 1977 have had negatıve results

Monopoles

Isolated candıdate events have not been confırmed Most experıments obtaın negatıve results

cont'd on next page

Search Limits Summary Table (*cont'd*)

Supersymmetric Particles

Assumptions include 1) photino is lightest supersymmetric particle, 2) R-parity is conserved, 3) mass of exchanged particles is less than about 250 GeV (most limits are not sensitive to this requirement), 4) unless otherwise stated, $M(\tilde{f}_L) = M(\tilde{f}_R)$, and u, d, s, c, and b scalar quarks are degenerate in mass

$\tilde{\gamma}$ — photino	$M > 10$ GeV	if $M(\tilde{e}) = 40$ GeV
	$M > 5$ GeV	if $M(\tilde{e}) = 55$ GeV
	$M > 5$ GeV	if $M(\tilde{f}) = 100$ GeV (from cosmology)
$\tilde{\chi}_i^0$ — neutralinos (mixtures of $\tilde{\gamma}$, $\tilde{Z}^0$, and $\tilde{H}_j^0$)	$M > 31$ GeV*	if $M(\tilde{e}) \leq 70$ GeV
$\tilde{\chi}_i^{\pm}$ — charginos (mixtures of $\tilde{W}^{\pm}$ and $\tilde{H}_j^{\pm}$)	$M > 22.5$ GeV*	
$\tilde{\nu}$ — scalar neutrino	$[M(\tilde{\nu}_\tau) + M(\tilde{\nu}_e \text{ or } \tilde{\nu}_\mu)] > m(\tau)$	if $M(\tilde{W}) \approx M(W)$
	$[M(\tilde{\nu}_\mu) + M(\tilde{\nu}_e)] > m(\mu)$	if $M(\tilde{W}) \approx M(W)$
$\tilde{e}$ — scalar electron	$M > 58$ GeV	if $M(\tilde{\gamma}) = 0$
	$M > 39$ GeV	if $M(\tilde{\gamma}) = 10$ GeV
	$M > 23$ GeV*	if $M(\tilde{\gamma}) < 19$ GeV
$\tilde{\mu}$ — scalar muon	$M > 21$ GeV*	if $M(\tilde{\gamma}) < 15$ GeV
$\tilde{\tau}$ — scalar tau	$M > 20.6$ GeV*	if $M(\tilde{\gamma}) = 0$
	$M > 19$ GeV*	if $M(\tilde{\gamma}) = 10$ GeV
$\tilde{q}$ — scalar quark	$M > 58$ GeV	if $M(\tilde{g}) \leq 160$ GeV
	$M > 75$ GeV	if $M(\tilde{g}) = M(\tilde{q})$
$\tilde{g}$ — gluino	$M > 53$ GeV	if $M(\tilde{q}) > M(\tilde{g})$
	$M > 75$ GeV	if $M(\tilde{q}) = M(\tilde{g})$

There is some controversy about a low-mass window ($M(\tilde{g}) < 4$ GeV). Several experiments cast doubt on the existence of this window

Compositeness

Scale Limits Λ for Contact Interactions (the lowest dimensional interactions with four fermions)

If the Lagrangian has the form

$$\pm \frac{g^2}{2\Lambda^2} \bar{\psi}_L \gamma_\mu \psi_L \bar{\psi}_L \gamma^\mu \psi_L$$

(with $g^2/4\pi$ set equal to 1), then we define $\Lambda \equiv \Lambda_{LL}^{\pm}$. For the full definitions and for other forms, see the Note in the Full Listings for Quark and Lepton Compositeness and the original literature

	Λ_{LL}^{+}	Λ_{LL}^{-}
$\Lambda_{LL}(eeee)$	> 1.4 TeV*	> 3.3 TeV*
$\Lambda_{LL}(ee\mu\mu)$	> 4.4 TeV*	> 2.1 TeV*
$\Lambda_{LL}(ee\tau\tau)$	> 2.2 TeV*	> 3.2 TeV*
$\Lambda_{LL}(\mu\nu_\mu e\nu_e)$	> 3.1 TeV	> 3.1 TeV
$\Lambda_{LL}(qqqq)$	> 0.42 TeV*	> 0.42 TeV*

Excited Leptons

The limits from $\ell^{*+}\ell^{*-}$ do not depend on λ (where $\lambda \equiv m(\ell^*)/\Lambda$ is the $\ell\ell^*$ transition coupling). The experiments reporting limits from $e^+e^- \to \mu\mu^*$ and $\tau\tau^*$ assumed transition couplings which violate chirality. As discussed in the note in the Full Listings for Quark and Lepton Compositeness, these may be interpreted as limits for chirality-conserving interactions if the values for λ are multiplied by $\sqrt{2}$

$e^{*\pm}$ — excited electron	$M > 75$ GeV*	if $\lambda = 1$
	$M > 23$ GeV*	from $e^{*+}e^{*-}$
$\mu^{*\pm}$ — excited muon	$M > 43$ GeV*	if $\lambda = 0.6\sqrt{2}$
	$M > 23$ GeV*	from $\mu^{*+}\mu^{*-}$
$\tau^{*\pm}$ — excited tau	$M > 40.8$ GeV*	if $\lambda = 0.7\sqrt{2}$
	$M > 22.7$ GeV*	from $\tau^{*+}\tau^{*-}$

Stable Particle Summary Table *(cont'd)*

- * S = Scale factor = $\sqrt{\chi^2/(N-1)}$, where $N \approx$ number of experiments. S should be ≈ 1. If S > 1, we have enlarged the error of the mean, $\delta\bar{x}$, i.e. $\delta\bar{x} \to S\delta\bar{x}$. This convention is still inadequate, since if S >> 1 the experiments are probably inconsistent and therefore the real uncertainty is probably even greater than $S\delta\bar{x}$. See the Introduction and ideograms in the Full Listings.
- † Square brackets indicate subreactions of some previous unbracketed decay mode(s). Reactions in one set of brackets may overlap with reactions in another set of brackets. A radiative mode such as $\pi \to \mu\nu\gamma$ is a subreaction of its parent mode $\pi \to \mu\nu$.
- *a* The strangeness of the s quark and the bottomness of the b quark are both -1 (so that K^+ has strangeness $+1$ and B^+ has bottomness $+1$). The charm of the c quark is $+1$.
- *b* Masses, mean lives, and decay mode fractions are evaluated assuming equality for particles and antiparticles.
- *c* For a 2-body decay mode this is the momentum of the decay products in the decay rest frame. For a 3-or-more-body mode this is the maximum momentum any of the products can have in this frame.
- *d* See the Full Listings for energy limits used in this measurement.
- *e* The masses of the e, μ, p, and n are most precisely known in u (unified atomic mass units). They are $m_e = 5.48579903(13)\times10^{-4}$ u, $m_\mu = 0.113428913(17)$ u, $m_p = 1.007276470(12)$ u, and $m_n = 1.008664904(14)$ u, where the numbers in parentheses are the 1-standard-deviation uncertainties in the last digits. The conversion to MeV, 1 u = 931.49432(28) MeV, introduces a considerably larger uncertainty in the masses.
- *f* Decays which are forbidden by a conservation law are indicated by the following abbreviations: LF ≡ lepton family number, L ≡ total lepton number, B ≡ baryon number, Q ≡ electric charge, C ≡ charge conjugation, P ≡ parity, CP ≡ charge conjugation times parity, ΔS ≡ ($\Delta S = 2$), SQ ≡ ($\Delta S = \Delta Q$), FC ≡ flavor-changing neutral current. See the Tests of Conservation Laws section for further details.
- *g* Value is for the sum of the charge states indicated.
- *h* Structure-dependent part with positive (SD^+) and negative (SD^-) photon helicity. Interference terms between structure-dependent parts and inner bremsstrahlung (SD^+INT and SD^-INT).
- *j* Direct-emission branching fraction.
- *k* This is a weighted average of $D^\pm$ (44%) and D^0 (56%) branching fractions.
- *ℓ* $D_1^0 - D_2^0$ limits inferred from limit on $D^0 \to \bar{D}^0 \to K^+\pi^-$. $B_1{}^0 - B_2{}^0$ value inferred from $B^0 \to \bar{B}^0 \to \mu^-$ anything.
- *m* Quantum numbers shown are favored but not yet established.
- *n* Values are based on rough estimate of ratio of $D_s^\pm$ to total charm production. Only ratios of each fraction to the $\phi\pi^+$ mode are well known.
- *p* Quantum numbers not measured. Values shown are quark-model predictions.
- *q* Only data from $\Upsilon(4S)$ decays are used for branching fractions. BEBEK 87 (Phys. Rev. **D36**, 1289) estimate the $\Upsilon(4S) \to B^+B^-$ branching fractions to be 43 ± 4 and 57 ± 4%. There is an additional uncertainty due to the assumption of P-wave phase space. ALBRECHT 87D (Phys. Lett. **B199**, 451) assume branching fractions 45 and 55%.
- *r* First limit is geochemical and independent of decay mode. Second limit assumes that the dominant decay modes are among those investigated. For antiprotons the best mean life limit, inferred from observation of cosmic ray $\bar{p}$'s, is $\tau_{\bar{p}} > 10^7$ yrs, the cosmic ray storage time.
- *s* Limit from neutrality-of-matter experiments. It assumes that $q_n = q_p + q_e$.
- *t* P for Ξ, J^P for Ω^- and Σ^0, and J for Λ_c^+ not yet measured. Values shown are quark-model predictions.
- *u* A theoretical value using QED, see the Full Listings.
- *v* For limits on the electric dipole moment (forbidden by P and T invariance), see the Tests of Conservation Laws section.
- *w* For more details and definitions of parameters, see the Full Listings.
- *x* P_μ is muon longitudinal polarization from π decay. In standard V-A theory, $P_\mu = 1$ and $\rho = \delta = 3/4$.
- *y* The definition of the slope parameter g of the $K \to 3\pi$ Dalitz plot is as follows (see also note in the Full Listings):

$$|M|^2 = 1 + g(s_3 - s_0)/m_{\pi^+}^2 + \cdots$$

- *z* The CP-violation parameters are defined as follows (see also note in the Full Listings):

$$\eta_{+-} = |\eta_{+-}|e^{i\phi_{+-}} = \frac{A(K_L^0\to\pi^+\pi^-)}{A(K_S^0\to\pi^+\pi^-)} = \epsilon + \epsilon' \qquad \eta_{00} = |\eta_{00}|e^{i\phi_{00}} = \frac{A(K_L^0\to\pi^0\pi^0)}{A(K_S^0\to\pi^0\pi^0)} = \epsilon - 2\epsilon'$$

$$\delta = \frac{\Gamma(K_L^0\to\ell^+)-\Gamma(K_L^0\to\ell^-)}{\Gamma(K_L^0\to\ell^+)+\Gamma(K_L^0\to\ell^-)}, \quad |\eta_{+-0}|^2 = \frac{\Gamma(K_S^0\to\pi^+\pi^-\pi^0)^{CP\text{ viol}}}{\Gamma(K_L^0\to\pi^+\pi^-\pi^0)}, \quad |\eta_{000}|^2 = \frac{\Gamma(K_S^0\to\pi^0\pi^0\pi^0)^{CP\text{ viol}}}{\Gamma(K_L^0\to\pi^0\pi^0\pi^0)}$$

- *aa* Derived from $|\eta_{00}|$ and $|\eta_{+-}|$ measurements using theoretical input on phases. See note in the Full Listings.
- *bb* The baryon decay parameters α, β, γ, Δ, and ϕ for nonleptonic modes are related as follows (see also the Note on Baryon Decay Parameters in the neutron Full Listings):

$$\alpha = \frac{2|s||p|\cos\Delta}{|s|^2+|p|^2} \qquad \beta = \frac{-2|s||p|\sin\Delta}{|s|^2+|p|^2} = \sqrt{1-\alpha^2}\sin\phi \qquad \gamma = \sqrt{1-\alpha^2}\cos\phi$$

The parameters g_A, g_V, and g_{WM} for semileptonic modes are defined by $\bar{B}_f[\gamma_\lambda(g_V + g_A\gamma_5) + i(g_{WM}/m_{B_i})\sigma_{\lambda\nu}q^\nu]B_i$, and ϕ_{AV} is defined by $g_A/g_V = |g_A/g_V|e^{i\phi_{AV}}$.

Meson Summary Table

April 1988

In addition to the entries in the Meson Summary Table, the Meson Full Listings contain all substantial claims for meson resonances See Contents of the Meson Full Listings at end of this Summary Table

Quantities in italics are new or have changed by more than one (old) standard deviation since our 1986 edition

Particle	$I^G(J^{PC})$ [a] ___ *estab*	Mass M (MeV)	Full width Γ (MeV)	Decay modes: Mode	Fraction(%) [Upper limits (%) are 90% CL]	p [b] (MeV/c)
			NONFLAVORED MESONS			
$\pi^\pm$	$1^-(0^{-+})$	139 57	0 0	See Stable Particle Summary Table		
π^0		134 96	7 57 $\pm$0 32 eV			
η	$0^+(0^{-+})$	548 8 $\pm$0 6	*1 05* $\pm$*0 15* keV	Neutral	70 9	See Stable Particle
				Charged	29 1	Summary Table
ρ(770)	$1^+(1^{--})$	770 $\pm$3§	153 $\pm$2 MeV	$\pi\pi$	$\approx$ 100	359
				$\pi^\pm\gamma$	0 045 $\pm$0 005 S=2 2*	372
Γ from neutral mode				$\mu^+\mu^-$	0 0067 $\pm$0 0014 [d]	370
				e^+e^-	0 0044 $\pm$0 0002 [d]	385
				$\eta\gamma$	seen	189
Γ_{ee} = (6 9$\pm$0 3) keV				$\pi^\pm\eta$	<0 8 (CL=84%)	146
				$2(\pi^+\pi^-)$	<0 15	247
				$\pi^\pm\pi^+\pi^-\pi^0$	<0 2 (CL=84%)	250
ω(783)	$0^-(1^{--})$	*782 0* $\pm$*0 1* S=1 5*	*8 5* $\pm$*0 1*	$\pi^+\pi^-\pi^0$	89 3$\pm$0 6 S=1 1*	327
				$\pi^0\gamma$	*8 0$\pm$0 9*	379
				$\pi^+\pi^-$	1 7$\pm$0 3 S=1 3*	365
				neutrals (excluding $\pi^0\gamma$)	*1 0*$^{+1\ 1}_{-0\ 6}$	
				$\pi^0\mu^+\mu^-$	0 010$\pm$0 002	349
				e^+e^-	0 0071$\pm$0 0003 S=1 2*	391
				$\eta\gamma$	seen	198
				$\pi^+\pi^-\gamma$	<4	365
Γ_{ee} = (*0 60$\pm$0 02*) keV S=1 2*				$\pi^0\pi^0\gamma$	<1	367
				$\mu^+\mu^-$	<0 02	376
η′(958)	$0^+(0^{-+})$	957 50 $\pm$0 24	0 21 $\pm$0 02 S=1 3*	$\eta\pi^+\pi^-$	44 1$\pm$1 6	231
				$\rho^0\gamma$	30 1$\pm$1 4	169
				$\eta\pi^0\pi^0$	20 5$\pm$1 3 S=1 2*	237
				$\omega\gamma$	3 0$\pm$0 3	159
				$\gamma\gamma$	2 16$\pm$0 16 S=1 4*	479
				$3\pi^0$	0 15$\pm$0 03 S=1 1*	430
				$\mu^+\mu^-\gamma$	0 011$\pm$0 003	467
				$\pi^+\pi^-\pi^0$	<5 (CL=84%)	427
				$\pi^0\rho^0$	<4	117
				$\pi^+\pi^-$	<2 (CL=84%)	458
				$\pi^0e^+e^-$	<1 3 (CL=84%)	469
				ηe^+e^-	<1 1	321
				$2(\pi^+\pi^-)$	<1 (CL=95%)	372
				$2(\pi^+\pi^-)\pi^0$	<1 (CL=84%)	298

η′(958) decay modes (cont'd)

Mode	Fraction(%)	p (MeV/c)
6π	<1	189
$\pi^+\pi^-e^+e^-$	<0 6	458
$\pi^0\pi^0$	<0 1	459
$\pi^0\gamma\gamma$	<0 08	469
$4\pi^0$	<0 05	379
3γ	<0 01	479
$\pi^0\mu^+\mu^-$	<6 $\times10^{-3}$	445
$\eta\mu^+\mu^-$	<1 5$\times10^{-3}$	272

Meson Summary Table *(cont'd)*

Particle	$I^G(J^{PC})$ [a] ___ estab	Mass M (MeV)	Full width Γ (MeV)	Decay modes: Mode	Fraction(%) [Upper limits (%) are 90% CL]		p [b] (MeV/c)
f_0(975)	$0^+(0^{++})$	976^c	34^c	$\pi\pi$	78 ± 3		468
was $S(975)$		± 3	± 6	$K\overline{K}$	22 ± 3		
		S=1 2*					
a_0(980)	$1^-(0^{++})$	983^e	57^e	$\eta\pi$	seen		319
was $\delta(980)$		± 3	± 11	$K\overline{K}$	seen		
		S=1 2*					
ϕ(1020)	$0^-(1^{--})$	1019 41	*4 41*	K^+K^-	$49\ 5 \pm 1\ 0$	S=1 3*	127
		$\pm 0\ 01$	*$\pm 0\ 05$*	$K_L K_S$	$34\ 4 \pm 0\ 9$	S=1 3*	110
		S=1 2*		$\rho\pi$	$12\ 9 \pm 0\ 7$		181
				$\pi^+\pi^-\pi^0$	*$1\ 9 \pm 1\ 1$*	S=1 3*	462
				$\eta\gamma$	$1\ 28 \pm 0\ 06$	S=1 1*	362
				$\pi^0\gamma$	$0\ 131 \pm 0\ 013$		501
				e^+e^-	$0\ 031 \pm 0\ 001$		510
				$\mu^+\mu^-$	$0\ 025 \pm 0\ 003$		499
				ηe^+e^-	*$0\ 013^{+0\ 008}_{-0\ 006}$*		362
				$\pi^+\pi^-$	*$0\ 008 \pm 0\ 005$*	S=1 5*	490
				$\pi^+\pi^-\gamma$	$< 0\ 7$		490
				$\omega\gamma$	< 5	(CL=84%)	210
				$\rho\gamma$	< 2	(CL=84%)	219
				$2(\pi^+\pi^-)\pi^0$	< 1	(CL=95%)	341
				$2(\pi^+\pi^-)$	$< 0\ 1$		410
Γ_{ee} = (1 37 ± 0 05) keV				$\pi^0\pi^0\gamma$	*$< 0\ 1$*		492
				$\eta'(958)\gamma$	*$< 0\ 041$*		60
h_1(1170)	$0^-(1^{+-})$	1170	335	$\rho\pi$	seen		310
was $H(1190)$		± 40	± 26				
b_1(1235)	$1^+(1^{+-})$	1233	150	$\omega\pi$	dominant		350
was $B(1235)$		± 10§	± 10§	[D/S amplitude ratio = 0 26 ± 0 04]			
				$\pi^+\pi^+\pi^-\pi^0$	< 50	(CL=84%)	535
				$\eta\pi$	< 25		482
				$\pi\pi$	< 15		600
				$\eta\rho$	< 10		
				$(K\overline{K})^{\pm}\pi^0$	< 8		249
				$K^0_S K^0_L \pi^{\pm}$	< 6		239
				$K\overline{K}$	< 2	(CL=84%)	369
				$K^0_S K^0_S \pi^{\pm}$	< 2		239
				$\phi\pi$	$< 1\ 5$	(CL=84%)	147
a_1(1260)	$1^-(1^{++})$	1260§	300−600	$\rho\pi$	dominant		377
was $A_1(1270)$		± 30§		$\pi^{\pm}\gamma$	*seen*		622
				$\pi(\pi\pi)_{S-\text{wave}}$	$< 0\ 7$§		591
f_2(1270)	$0^+(2^{++})$	1274	185	$\pi\pi$	*86^{+2}_{-1}*		622
was $f(1270)$		± 5§	± 20§	$\pi^+\pi^-2\pi^0$	*$6\ 4^{+1\ 2}_{-2\ 4}$*	S=1 1*	562
				$K\overline{K}$	*$4\ 2^{+1\ 0}_{-0\ 6}$*		398
				$2\pi^+2\pi^-$	$2\ 8 \pm 0\ 4$	S=1 2*	559
				$\eta\eta$	*$0\ 45 \pm 0\ 10$*	S=2 4*	323
				$\gamma\gamma$	$0\ 0015 \pm 0\ 0001$		637
				$4\pi^0$	*$0\ 3 \pm 0\ 1$*	S=1 3*	564
				$\eta\pi\pi$	< 1		473
				$K^0K^-\pi^+$ + c c	$< 0\ 3$		292

Meson Summary Table *(cont'd)*

Particle	$I^G(J^{PC})$ [a] ___ estab	Mass M (MeV)	Full width Γ (MeV)	Decay modes: Mode	Fraction(%) [Upper limits (%) are 90% CL]		p [b] (MeV/c)
$\eta(1280)$	$0^+(0^{-+})$	*1279*	*32*	$\eta\pi\pi$	*seen*		476
		± 5	*± 10*	†[$a_0(980)\pi$	*seen*]		230
$f_1(1285)$	$0^+(1^{++})$	1283	25	$\eta\pi\pi$	49 ± 6		482
was $D(1285)$		± 5§	± 3§	†[$a_0(980)\pi$	36 ± 7]		236
				4π (prob $\rho\pi\pi$)	40 ± 7		564
				$K\bar{K}\pi$	11 ± 3	S=1 1*	302
				$4\pi^0$	*< 0 07*		569
				$\gamma\gamma$	*< 0 006*	(CL=95%)	642
$\pi(1300)$	$1^-(0^{-+})$	1300§	200 – 600	$\rho\pi$	seen		406
		± 100§		$\pi(\pi\pi)_{S-\text{wave}}$	seen		612
Not a well-established resonance							
$a_2(1320)$	$1^-(2^{++})$	1318	110	$\rho\pi$	70 1 ± 2 7	S=1 2*	419
was $A_2(1320)$		± 5§	± 5§	$\eta\pi$	14 5 ± 1 2		534
				$\omega\pi\pi$	10 6 ± 3 2	S=1 3*	361
				$K\bar{K}$	4 9 ± 0 8		434
				$\pi^{\pm}\gamma$	0 27 ± 0 06		652
				$\gamma\gamma$	0 0008 ± 0 0001		659
M and Γ are from $K\bar{K}$ mode				$\eta'(958)\pi$	< 2	(CL=97%)	286
$f_0(1400)$	$0^+(0^{++})$	~1400	150 – 400	$\pi\pi$	*93 ± 2*		686
was $\epsilon(1300)$				$K\bar{K}$	*7 ± 2*		496
				$\eta\eta$	seen		435
$f_1(1420)$‡	$0^+(1^{++})$	1422	55	$K\bar{K}\pi$ (incl $K^*\bar{K}+\bar{K}K^*$)	seen		429
was $E(1420)$		± 10§	± 3	$\eta\pi\pi$	possibly seen		568
				†[$a_0(980)\pi$	possibly seen]		353
$\eta(1430)$‡	$0^+(0^{-+})$	1440§	*60*§	$K\bar{K}\pi$ (incl $K^*\bar{K}+\bar{K}K^*$)	seen		444
was $\iota(1440)$		± 20§	*± 30*§	$\eta\pi\pi$	seen		579
				†[$a_0(980)\pi$	seen]		367
$f_2'(1525)$	$0^+(2^{++})$	1525	76	$K\bar{K}$	dominant		581
was $f'(1525)$		± 5§	± 10§	$\pi\pi$	possibly seen		750
				$\eta\eta$	*seen*		529
				$\gamma\gamma$	0 00014 ± 0 00005		763
$f_1(1530)$	$0^+(1^{++})$	*1527*	*106*	$K^*\bar{K} + \bar{K}^*K$	*seen*		313
		± 5	*± 14*				
$f_0(1590)$	$0^+(0^{++})$	1587	*175*	$\eta'(958)\eta$	dominant		241
		± 11	*± 19*	$\eta\eta$	large		573
Seen by one group only			S=1 3*	$4\pi^0$	*large*		735
$\omega_3(1670)$	$0^-(3^{--})$	1668	166	3π	seen		805
was $\omega(1670)$		± 5	± 15§	†[$\rho\pi$	seen]		647
				5π	seen		740
				†[$\omega\pi\pi$ (prob $b_1(1235)\pi$)	seen]		614
$\pi_2(1670)$	$1^-(2^{-+})$	1665	250	$f_2(1270)\pi$	53 ± 5		322
was $A_3(1680)$		± 20§	± 20§	$\rho\pi$	34 ± 6		645
				$\pi(\pi\pi)_{S-\text{wave}}$	9 ± 5		803
				$K^*\bar{K} + \bar{K}^*K$	4 ± 1 4		448
				$\eta\pi$	< 10		735
				5π	< 10		732

Meson Summary Table *(cont'd)*

Particle	$I^G(J^{PC})$ [a] ___ *estab*	Mass M (MeV)	Full width Γ (MeV)	Decay modes: Mode	Fraction(%) [Upper limits (%) are 90% CL]	p [b] (MeV/c)
$\phi(1680)$	$0^-(1^{--})$	1685§	130§	$K^*\bar{K} + \bar{K}^*K$	seen	466
		+75§	±50§	$\omega\pi\pi$	seen	625
		−15§		$K\bar{K}$	seen	683
				e^+e^-	seen	842
Not a well-established resonance				$\pi^+\pi^-\pi^0$	possibly seen	814
$\rho_3(1690)$	$1^+(3^{--})$	1691	215	4π (incl $\pi\pi\rho$ $\rho\rho$ $a_2\pi$ $\omega\pi$)	71 1 ± 1 9	787
was $g(1690)$		± 5§	± 20§	2π	23 6 ± 1 3	834
				$K\bar{K}\pi$ (incl $K^*\bar{K}+K\bar{K}^*$)	3 8 ± 1 2	628
				$K\bar{K}$	1 6 ± 0 3 S=1 2*	686
J^P M and Γ from the 2π and $K\bar{K}$ modes				$\eta\pi^+\pi^-$	*seen*	728
$\rho(1700)$	$1^+(1^{--})$	*1700*	*235*	4π (incl $\rho\pi^+\pi^-$ $a_1(1260)\pi$)	*seen*	792
		± 20§	*± 50*§	$\pi\pi$	*seen*	838
				$K^*\bar{K} + \bar{K}^*K$	*seen*	479
				$\eta\pi\pi$	*seen*	733
				$K\bar{K}$	*seen*	692
				e^+e^-	*seen*	850
$f_2(1720)$	$0^+(2^{++})$	1721	138	$K\bar{K}$	*38^{+9}_{-19}*	705
was $\theta(1690)$		+ 2	± 11	$\eta\eta$	*18^{+3}_{-13}*	663
		− 4		$\pi\pi$	*$3\ 9^{+0\ 2}_{-2\ 4}$*	849
$f_2(2010)$	$0^+(2^{++})$	*2011*	*202*	$\phi\phi$	*seen*	
was $g_T(2010)$		*± 70*	*± 65*			
Seen by one group only						
$f_4(2050)$	$0^+(4^{++})$	*2047*	204	$\pi\pi$	17 ± 2	1014
was $h(2030)$		*± 11*	± 13	$K\bar{K}$	$0\ 7^{+0\ 3}_{-0\ 2}$	897
		S=1 3*		$\eta\eta$	0 21 ± 0 08	864
				$4\pi^0$	*< 1 2*	979
$f_2(2300)$	$0^+(2^{++})$	*2297*	*149*	$\phi\phi$	*seen*	529
was $g'_T(2300)$		*± 28*	*± 41*			
$f_2(2340)$	$0^+(2^{++})$	*2339*	*319*	$\phi\phi$	*seen*	573
was $g''_T(2340)$		*± 55*	*± 75*			

$c\bar{c}$ MESONS

Particle	$I^G(J^{PC})$	Mass M (MeV)	Full width Γ (MeV)
$\eta_c(1S)$	$0^+(0^{-+})$	2979 6	10 3
or $\eta_c(2980)$		± 1 7	+3 8
			−3 4

Decay modes into stable hadrons

Mode	Fraction(%)	p (MeV/c)
$K\bar{K}\pi$	5 5 ± 0 8	1379
$\eta\pi\pi$	5 0 ± 1 1	1425
$K^+K^-\pi^+\pi^-$	2 0 ± 0 3	1343
$2(\pi^+\pi^-)$	1 2 ± 0 3	1457
$p\bar{p}$	0 10 ± 0 02	1157
$\eta K\bar{K}$	< 3 1	1263
$\pi^+\pi^-p\bar{p}$	< 1 2	1024

Decay modes into hadronic resonances

Mode	Fraction(%)	p (MeV/c)
$\eta'(958)\pi\pi$	4 1 ± 1 7	1320
$K^{*0}K^-\pi^+$ + c c	2 0 ± 0 7	1274
$K^*\bar{K}^*$	0 9 ± 0 5	1193
$\phi\phi$	*0 34 ± 0 12*	1086
$\rho\rho$	*0 26 ± 0 09*	1275
$a_0(980)\pi$	< 2 0	1324
$a_2(1320)\pi$	< 2 0	1193
$f_2(1270)\eta$	< 1 1	1143
$\omega\omega$	< 0 3	1268

Radiative decay modes

Mode	Fraction(%)	p (MeV/c)
$\gamma\gamma$	*$0\ 06^{+0\ 06}_{-0\ 05}$*	1490

Meson Summary Table *(cont'd)*

Particle	$I^G(J^{PC})$ [a] — estab	Mass M (MeV)	Full width Γ (MeV)
$J/\psi(1S)$ or $J/\psi(3097)$	$0^-(1^{--})$	3096.9 ± 0.1	0.068 ± 0.010

$\Gamma_{ee} = (4.72 \pm 0.35)$ keV (assuming $\Gamma_{ee} = \Gamma_{\mu\mu}$)

Decay modes

Mode	Fraction(%) [Upper limits (%) are 90% CL]		p [b] (MeV/c)
e^+e^-	6.9 ± 0.9		1548
$\mu^+\mu^-$	6.9 ± 0.9		1545
hadrons + radiative	86.2 ± 2.0		

Decay modes into stable hadrons

Mode	Fraction(%)		p (MeV/c)
†[$2(\pi^+\pi^-)\pi^0$	3.4 ± 0.3		1496
$3(\pi^+\pi^-)\pi^0$	2.9 ± 0.6		1433
$\pi^+\pi^-\pi^0$	1.50 ± 0.15		1533
$\pi^+\pi^-\pi^0K^+K^-$	1.2 ± 0.3		1368
$4(\pi^+\pi^-)\pi^0$	0.9 ± 0.3		1345
$\pi^+\pi^-K^+K^-$	0.72 ± 0.23		1407
$K\bar{K}\pi$	0.61 ± 0.10		1440
$p\bar{p}\pi^+\pi^-$	0.60 ± 0.05	S=1.3*	1107
$2(\pi^+\pi^-)$	0.4 ± 0.1		1517
$3(\pi^+\pi^-)$	0.4 ± 0.2		1466
$n\bar{n}\pi^+\pi^-$	0.4 ± 0.4		1106
$\Sigma\bar{\Sigma}$	0.38 ± 0.05		988
$2(\pi^+\pi^-)K^+K^-$	0.31 ± 0.13		1320
$p\bar{p}\pi^+\pi^-\pi^0$	0.23 ± 0.09 [f]	S=1.9*	1033
$p\bar{p}$	0.22 ± 0.01		1232
$p\bar{p}\eta$	0.21 ± 0.02		948
$p\bar{n}\pi^-$ or $\bar{p}n\pi^+$	0.20 ± 0.01		1174
$\Xi\bar{\Xi}$	*0.18 ± 0.04*	S=1.8*	818
$n\bar{n}$	0.18 ± 0.09		1231
$\Lambda\bar{\Lambda}$	0.135 ± 0.014	S=1.2*	1074
$p\bar{p}\pi^0$	0.11 ± 0.01		1176
$\Lambda\bar{\Sigma}^{\pm}\pi^{\mp}$	[h] *0.212 ± 0.024*		948
$pK^-\bar{\Lambda}$	0.09 ± 0.02		876
$2(K^+K^-)$	0.07 ± 0.03		1131
$pK^-\bar{\Sigma}^0$	0.03 ± 0.01		820
K^+K^-	0.024 ± 0.003		1468
$\Lambda\bar{\Lambda}\pi^0$	*0.022 ± 0.007*		998
$\pi^+\pi^-$	0.015 ± 0.002		1542
$K_L^0K_S^0$	0.010 ± 0.002		1466
$\Lambda\bar{\Sigma}$ + c.c.	< 0.015		1032
$K_S^0K_S^0$	< *0.0005*]		1466

Radiative decay modes

Mode	Fraction(%)		p (MeV/c)
†[$\gamma\eta_c(1S)$	1.27 ± 0.36		115
$\gamma\pi^+\pi^-2\pi^0$	*0.83 ± 0.31*		1518
$\gamma\eta\pi\pi$	0.61 ± 0.10		1486
$\gamma\eta(1430) \to \gamma K\bar{K}\pi$	0.47 ± 0.06 [g]		1214
$\gamma\rho\rho$	*0.45 ± 0.08*		1343
$\gamma\eta'(958)$	0.42 ± 0.04		1400
$\gamma 2(\pi^+\pi^-)$	*0.33 ± 0.06*	S=1.3*	1517
$\gamma f_4(2050) \to \gamma\pi\pi$	*0.27 ± 0.08*		872
$\gamma\omega\omega$	0.16 ± 0.03		1336
$\gamma f_2(1270)$	0.14 ± 0.02		1286
$\gamma\eta$	0.086 ± 0.008		1500
$\gamma p\bar{p}$	0.038 ± 0.010		1232
$\gamma\phi\phi$	*0.031 ± 0.008*		1166
$\gamma f'_2(1525)$	*0.023 ± 0.005*	S=1.2*	1173
$\gamma\pi^0$	0.004 ± 0.001		1546

Decay modes into hadronic resonances

Mode	Fraction(%)		p (MeV/c)
†[$\rho\pi$	1.28 ± 0.10		1449
$\rho a_2(1320)$	0.86 ± 0.13		1126
$\omega 2(\pi^+\pi^-)$	0.85 ± 0.34		1392
$\omega\pi^+\pi^-$	0.70 ± 0.08		1435
$K^*(892)^0\bar{K}_2^*(1430)^0$ + c.c.	0.67 ± 0.26		1009
$\omega K^*(892)\bar{K}$ + c.c.	*0.53 ± 0.20*		1097
$K^+\bar{K}^*(892)^-$ + c.c.	*0.38 ± 0.07*	S=2.0*	1373
$K^0\bar{K}^*(892)^0$ + c.c.	*0.37 ± 0.08*	S=2.1*	1371
$\omega f_2(1270)$	*0.33 ± 0.07*	S=1.5*	1143
$b_1(1235)^{\pm}\pi^{\mp}$	[h] 0.29 ± 0.07		1299
$\omega K^{\pm}K_S^0\pi^{\mp}$	[h] *0.29 ± 0.07*		1210
$\phi K^*(892)\bar{K}$ + c.c.	*0.20 ± 0.04*		969
$\phi K\bar{K}$	0.18 ± 0.08		1176
$\omega\eta$	0.17 ± 0.02		1394
$\Delta(1232)^{++}\bar{p}\pi^-$	0.16 ± 0.05		1030
$\omega K\bar{K}$	0.16 ± 0.10		1265
$\omega p\bar{p}$	0.13 ± 0.03	S=1.3*	768
$\Delta(1232)^{++}\bar{\Delta}(1232)^{--}$	0.11 ± 0.03		938
$\Sigma(1385)^{\pm}\bar{\Sigma}(1385)^{\mp}$	[h] *0.206 ± 0.026*		692
$\eta'(958)p\bar{p}$	0.09 ± 0.04	S=1.7*	596
$\phi\pi^+\pi^-$	*0.079 ± 0.016*		1365
$\phi\eta$	0.071 ± 0.003		1320
$\phi K^{\pm}K_S^0\pi^{\mp}$	[h] *0.070 ± 0.012*		1114
$\omega f_1(1420)$	*0.068 ± 0.025*		1064
$\Xi(1530)^-\bar{\Xi}^+$	*0.06 ± 0.02*		597
$\omega\pi^0$	*0.048 ± 0.007*		1446
$pK^-\bar{\Sigma}(1385)^0$	0.05 ± 0.03		645
$\phi f'_2(1525)$	0.045 ± 0.005		871
$\phi\eta'(958)$	0.038 ± 0.004	S=1.6*	1192
$\Sigma(1385)^{\pm}\bar{\Sigma}^{\mp}$	[h] *0.062* ± 0.010		856
$\Xi(1530)^0\bar{\Xi}^0$	*0.03 ± 0.01*		608
$\phi f_0(975)$	0.029 ± 0.004		1184
$\rho\eta$	0.019 ± 0.003		1397
$\omega\eta'(958)$	*0.017 ± 0.003*		1279
$\rho\eta'(958)$	0.0096 ± 0.0018	S=1.2*	1283
$\phi f_1(1285)$	*0.008 ± 0.005*	S=2.2*	1032
$\pi^{\pm}a_2^{\mp}(1320)$	[h] < 0.43		1263
$K\bar{K}_2^*(1430)$	< 0.4		1159
$K_2^*(1430)^0\bar{K}_2^*(1430)^0$	< 0.29		604
$\phi 2(\pi^+\pi^-)$	< 0.15		1318
$K^*(892)^0\bar{K}^*(892)^0$	< 0.05		1263
$\phi f_2(1270)$	< 0.037		1037
$\rho p\bar{p}$	< 0.031		779
$\Sigma(1385)^0\bar{\Lambda}$	< *0.02*		911
$\omega f'_2(1525)$	< 0.016		1003
$\Delta(1232)^+\bar{p}$	< *0.01*		1100
$\phi\pi^0$	< *0.0007*]		1377

Radiative decay modes (cont'd)

Mode	Fraction(%)		p (MeV/c)
$\gamma f_2(1720)$	seen		1070
$\gamma f_1(1285)$	< 0.6		1283
$\gamma p\bar{p}\pi^+\pi^-$	< 0.08		1107
2γ	< 0.05		1548
$\gamma\Lambda\bar{\Lambda}$	< *0.013*		1074
3γ	< 0.006]		1548

Meson Summary Table *(cont'd)*

Particle	$I^G(J^{PC})$ [a] estab	Mass M (MeV)	Full width Γ (MeV)	Decay modes: Mode	Fraction(%) [Upper limits (%) are 90% CL]		p [b] (MeV/c)
$\chi_{c0}(1P)$	$0^+(0^{++})$	3415.1	13.5	$2(\pi^+\pi^-)$ (incl $\pi\pi\rho$)	3.7 ± 0.7		1679
or $\chi_{c0}(3415)$		±1.0	±5.3	$\pi^+\pi^-K^+K^-$ (incl $\pi K\bar{K}^*$)	3.0 ± 0.7		1580
was $\chi(3415)$				$3(\pi^+\pi^-)$	1.5 ± 0.5		1633
				$\pi^+\pi^-$	0.8 ± 0.2		1702
				$\gamma J/\psi(1S)$	0.7 ± 0.2		303
				K^+K^-	0.7 ± 0.2		1635
				$p\bar{p}\pi^+\pi^-$	0.5 ± 0.2		1320
				$\gamma\gamma$	<0.15		1708
				$p\bar{p}$	<0.09		1427
$\chi_{c1}(1P)$	$0^+(1^{++})$	3510.6	<1.3	$\gamma J/\psi(1S)$	27.3 ± 1.6		389
or $\chi_{c1}(3510)$		±0.5		$3(\pi^+\pi^-)$	2.2 ± 0.8		1683
was $\chi(3510)$		S=1.3*		$2(\pi^+\pi^-)$ (incl $\pi\pi\rho$)	1.6 ± 0.5		1727
				$\pi^+\pi^-K^+K^-$ (incl $\pi K\bar{K}^*$)	0.9 ± 0.4		1632
				$\pi^+\pi^-p\bar{p}$	0.14 ± 0.09		1381
				$p\bar{p}$	seen		1483
				$\pi^+\pi^-+K^+K^-$	<0.17		
				$\gamma\gamma$	<0.15		1755
$\chi_{c2}(1P)$	$0^+(2^{++})$	3556.3	2.6	$\gamma J/\psi(1S)$	13.5 ± 1.1		430
or $\chi_{c2}(3555)$		±0.4	+1.2	$2(\pi^+\pi^-)$ (incl $\pi\pi\rho$)	2.2 ± 0.5		1751
was $\chi(3555)$			−0.9	$\pi^+\pi^-K^+K^-$ (incl $\pi K\bar{K}^*$)	1.9 ± 0.5		1656
				$3(\pi^+\pi^-)$	1.2 ± 0.8		1707
				$\pi^+\pi^-p\bar{p}$	0.33 ± 0.13		1410
				$\pi^+\pi^-$	0.19 ± 0.10		1773
				K^+K^-	0.15 ± 0.11		1708
				$\gamma\gamma$	*0.11 ± 0.06*		1778
				$p\bar{p}$	*0.009 ± 0.004*		1510
				$J/\psi(1S)\pi^+\pi^-\pi^0$	<1.5		186
$\psi(2S)$	$0^-(1^{--})$	3686.0	0.243	$e^+e^-+\mu^+\mu^-$	1.8 ± 0.3		
or $\psi(3685)$		±0.1	±0.043	hadrons + radiative	98.2 ± 0.3		
$\Gamma_{ee}=(2.15\pm0.21)$ keV				Decay modes into hadrons			
(assuming $\Gamma_{ee}=\Gamma_{\mu\mu}$)				†[$J/\psi(1S)\pi\pi$	50 ± 4		477
				$J/\psi(1S)\eta$	2.7 ± 0.4	S=1.6*	196
				$3(\pi^+\pi^-)\pi^0$	0.35 ± 0.16		1746
				$2(\pi^+\pi^-)\pi^0$	0.31 ± 0.07		1799
				$\pi^+\pi^-K^+K^-$	0.16 ± 0.04		1726
Radiative decay modes				$J/\psi(1S)\pi^0$	0.10 ± 0.02		527
†[$\gamma\chi_{c0}(1P)$	9.3 ± 0.8	261		$p\bar{p}\pi^+\pi^-$	0.08 ± 0.02		1491
$\gamma\chi_{c1}(1P)$	8.7 ± 0.8	171		$K^*(892)^0K^-\pi^+$ + c.c.	0.067 ± 0.025		1673
$\gamma\chi_{c2}(1P)$	7.8 ± 0.8	127		$2(\pi^+\pi^-)$	0.045 ± 0.010		1817
$\gamma\eta_c(1S)$	0.28 ± 0.06	639		$\rho^0\pi^+\pi^-$	0.042 ± 0.015		1751
$\gamma\pi^0$	<0.5 (CL=95%)	1841		$p\bar{p}$	0.019 ± 0.005		1586
$\gamma\eta'(958)$	*<0.11*	1719		$3(\pi^+\pi^-)$	0.015 ± 0.010		1774
$\gamma\eta$	<0.02	1802		$p\bar{p}\pi^0$	0.014 ± 0.005		1543
$\gamma\gamma$	*<0.018*	1843		K^+K^-	0.010 ± 0.007		1776
$\gamma\eta(1430)\to\gamma K\bar{K}\pi$	<0.012[g]]	1562		$\pi^+\pi^-\pi^0$	0.009 ± 0.005		1830
				$\pi^+\pi^-$	0.008 ± 0.005		1838
				$\Lambda\bar{\Lambda}$	<0.04		1467
				$\Xi\bar{\Xi}$	<0.04		1291
				$\rho\pi$	<0.008		1760
				$K^+K^-\pi^0$	<0.003		1754
				$K^\pm K^*(892)^\mp$	<0.002]		1698
$\psi(3770)$	(1^{--})	3769.9	25	e^+e^-	0.0010 ± 0.0002		1885
		±2.5	±3	$D\bar{D}$	dominant		242
		S=1.8*					
$\Gamma_{ee}=(0.26\pm0.05)$ keV S=1.3*							

Meson Summary Table *(cont'd)*

Particle	$I^G(J^{PC})$ [a] — estab	Mass M (MeV)	Full width Γ (MeV)	Decay modes: Mode	Fraction(%) [Upper limits (%) are 90% CL]	p [b] (MeV/c)
ψ(4040)[‡]	(1^{--})	*4040*	52	e^+e^-	0.0014 ± 0.0004	2020
		± *10*	± 10	$D\bar{D}$	seen	766
				$D\bar{D}^*(2010)$ + c.c.	seen	564
Γ_{ee} = (0.75 ± 0.15) keV				$D^*(2010)\bar{D}^*(2010)$	seen	200
ψ(4160)[‡]	(1^{--})	4159	78	e^+e^-	0.0010 ± 0.0004	2079
		± 20	± 20			
Γ_{ee} = (0.77 ± 0.23) keV						
ψ(4415)[‡]	(1^{--})	4415	43	e^+e^-	0.0011 ± 0.0006	2207
		± 6	± 20[§]			
Γ_{ee} = (0.47 ± 0.10) keV						

$b\bar{b}$ MESONS

Particle	$I^G(J^{PC})$	Mass M (MeV)	Full width Γ (MeV)	Mode	Fraction(%)	p (MeV/c)
Υ(1S)	(1^{--})	9460.3	*0.052*	$\tau^+\tau^-$	3.0 ± 0.4	4381
or Υ(9460)		± 0.2	± *0.003*	$\mu^+\mu^-$	2.6 ± 0.2	4729
		S=2.5*		e^+e^-	2.5 ± 0.2	4730
				$\rho\pi$	< 0.21	4698
Γ_{ee} = (*1.34 ± 0.05*) keV				$J/\psi(1S)$ anything	?	
				$f_2(1270)\gamma$	< 0.003	4644
χ_{b0}(1P)	$(^{++})$	9859.8		$\Upsilon(1S)\gamma$	< *6*	391
or χ_{b0}(9860)[j] ± 1.3						
χ_{b1}(1P)	(1^{++})	9891.9		$\Upsilon(1S)\gamma$	35 ± 8	422
or χ_{b1}(9890)[j] ± 0.7						
χ_{b2}(1P)	(2^{++})	9913.2		$\Upsilon(1S)\gamma$	22 ± 4	443
or χ_{b2}(9915)[j] ± 0.6						
Υ(2S)	(1^{--})	10023.3	0.044	$\Upsilon(1S)\pi^+\pi^-$	18.5 ± 0.8	475
or Υ(10023)		± 0.3	± 0.009	$\Upsilon(1S)\pi^0\pi^0$	8.8 ± 1.1	480
				$\chi_{b1}(1P)\gamma$	6.7 ± 0.9	131
				$\chi_{b2}(1P)\gamma$	6.6 ± 0.9	110
				$\chi_{b0}(1P)\gamma$	4.3 ± 1.0	162
				$\tau^+\tau^-$	1.7 ± 1.6	4683
				$\mu^+\mu^-$	1.4 ± 0.3	5011
Γ_{ee} = (*0.60 ± 0.04*) keV				$\Upsilon(1S)\pi^0$	< *0.8*	531
				$\Upsilon(1S)\eta$	< 0.2	122
χ_{b0}(2P)	$(^{++})$	*10235.3*		$\Upsilon(2S)\gamma$	*6.9 ± 4.1*	210
or χ_{b0}(10235)[j]		± *1.1*		$\Upsilon(1S)\gamma$	*1.4 ± 1.0*	746
χ_{b1}(2P)	$(^{++})$	10255.2		$\Upsilon(2S)\gamma$	*25 ± 8*	229
or χ_{b1}(10255)[j]		± 0.4		$\Upsilon(1S)\gamma$	*6.1 ± 1.7*	764
		S=1.2*				
χ_{b2}(2P)	$(^{++})$	10269.0		$\Upsilon(2S)\gamma$	*19 ± 7*	243
or χ_{b2}(10270)[j]		± 0.7		$\Upsilon(1S)\gamma$	*6.3 ± 1.8*	777
		S=2.2*				
Υ(3S)	(1^{--})	10355.3	*0.026*	$\chi_{b2}(2P)\gamma$	13 ± 3	86
or Υ(10355)		± 0.5	± *0.006*	$\chi_{b1}(2P)\gamma$	12 ± 3	100
				$\Upsilon(2S)$ anything	10.1 ± 1.7	
				†[$\Upsilon(2S)\pi^+\pi^-$	2.2 ± 0.5]	177
				$\chi_{b0}(2P)\gamma$	*4.8 ± 1.4*	119
Γ_{ee} = (*0.44 ± 0.03*) keV				$\Upsilon(1S)\pi^+\pi^-$	*3.6 ± 0.3*	814
				$\mu^+\mu^-$	*1.6 ± 0.4* S=1.2*	5177
Υ(4S)	(1^{--})	10580.0	24			
or Υ(10580)		± 3.5	± 2			
Γ_{ee} = (0.24 ± 0.05) keV						

Meson Summary Table *(cont'd)*

Particle	$I(J^P)$ — estab	Mass M (MeV)	Full width Γ (MeV)	Decay modes: Mode	Fraction(%) [Upper limits (%) are 90% CL]		p (MeV/c)
Υ(10860)	(1^{--})	10865 ± 8	110 ± 13				
Γ_{ee} = (0.31 ± 0.07) keV							
Υ(11020)	(1^{--})	11019 ± 8	79 ± 16				
Γ_{ee} = (0.13 ± 0.03) keV							
STRANGE MESONS				$[K^+ = u\bar{s},\ K^0 = d\bar{s},\ \bar{K}^0 = \bar{d}s,\ K^- = \bar{u}s]$			
K^+	$1/2(0^-)$	493.67		See Stable Particle Summary Table			
K^0		497.72					
K*(892)	$1/2(1^-)$	892.1 ± 0.3 S=1.4*	51.3 ± 0.8 S=1.1*	$K\pi$	≈ 100		288
				$K^0\gamma$	0.23 ± 0.02		310
				$K^{\pm}\gamma$	0.10 ± 0.01		309
				$K\pi\pi$	< 0.05		216
M and Γ from charged mode, M^0 = 896.2 ± 0.3 S=1.7*							
K_1(1270) *was Q(1280)*	$1/2(1^+)$	1270§ ± 10§	90§ ± 20§	$K\rho$	42 ± 6		62
				$K_0^*(1430)\pi$	28 ± 4		81
				$K^*(892)\pi$	16 ± 5		298
				$K\omega$	11 ± 2		
				$Kf_0(1400)$	3 ± 2		
K_1(1400) *was Q(1400)*	$1/2(1^+)$	1401 ± 10	184 ± 9	$K^*(892)\pi$	94 ± 6		400
				$K\rho$	3 ± 3		297
				$Kf_0(1400)$	2 ± 2		
				$K\omega$	1 ± 1		283
K*(1415)	$1/2(1^-)$	*1415*§ *± 15*§	*240*§ *± 20*§	$K^*(892)\pi$	*dominant*		410
				$K\pi$	*6.6 ± 1.3*		613
K_0^*(1430) *was κ(1350)*	$1/2(0^+)$	*1429 ± 7*	*287 ± 23*	$K\pi$	*dominant*		621
K_2^*(1430) *was K*(1430)*	$1/2(2^+)$	1426 ± 2 S=1.1*	99 ± 3	$K\pi$	*49.7 ± 1.2*		619
				$K^*(892)\pi$	25.2 ± 1.7		418
				$K^*(892)\pi\pi$	13.0 ± 2.3		367
				$K\rho$	8.8 ± 0.8	S=1.2*	324
				$K\omega$	2.9 ± 0.8		312
				$K^+\gamma$	0.24 ± 0.05	S=1.2*	628
				$K\eta$	*$0.14^{+0.49}_{-0.10}$*	S=1.8*	486
M and Γ from charged mode, M^0 = *1426 ± 2* S=1.6*				$K\omega\pi$	< *0.072*	(CL=95%)	69
K*(1715)	$1/2(1^-)$	*1717 ± 27*	*200–400*	$K\pi$	39 ± 3		781
				$K\rho$	31^{+7}_{-3}	S=1.4*	574
				$K^*(892)\pi$	30^{+3}_{-7}	S=1.4*	617
K_2(1770)‡ *was L(1770)*	$1/2(2^-)$	~1770§	136 ± 18	$K_2^*(1430)\pi$	dominant		284
				$K^*(892)\pi$	seen		651
				$Kf_2(1270)$	seen		41
				$K\phi$	seen		438
K_3^*(1780)‡ *was K*(1780)*	$1/2(3^-)$	1776 ± 4 S=1.3*	160 ± 15 S=1.4*	$K\rho$	*44 ± 4*	S=1.3*	616
				$K^*(892)\pi$	*27 ± 3*	S=1.3*	655
				$K\pi$	19 ± 1		813
				$K\eta$	*11 ± 5*	S=1.3*	719
K_4^*(2075) *was K*(2060)*	$1/2(4^+)$	2074 ± 14	210§ ± 50§	$K\pi$	*10 ± 1*		966
				$K^*(892)\pi\pi$	*9 ± 5*		809
				$K^*(892)\pi\pi\pi$	*7 ± 5*		775
				$\rho K\pi$	*6 ± 3*		751
				$\omega K\pi$	*5 ± 3*		744
				$\phi K\pi$	*3 ± 1*		616
				$\phi K^*(892)$	*1.4 ± 0.7*		402

Meson Summary Table *(cont'd)*

Particle	$I(J^P)$ ___ *estab*	Mass M (MeV)	Full width Γ (MeV)	Decay modes: Mode	Fraction(%) [Upper limits (%) are 90% CL]	p[b] (MeV/c)
CHARMED, NONSTRANGE MESONS				$[D^+ = c\bar{d},\ D^0 = c\bar{u},\ \bar{D}^0 = \bar{c}u,\ D^- = \bar{c}d]$		
D^+	1/2(0^-)	1869.3		See Stable Particle Summary Table		
D^0		1864.6				
$D^*(2010)^+$	1/2(1^-)	2010.1 ±0.6	< 2.0	$D^0\pi^+$	49 ± 8	40
				$D^+\pi^0$	34 ± 7	39
				$D^+\gamma$	17 ± 11	136
	$m_{D^{*+}} - m_{D^0} = (145.45 \pm 0.07)$ MeV					
$D^*(2010)^0$	1/2(1^-)	2007.1 ±1.4	< 5	$D^0\pi^0$	52 ± 7	44
				$D^0\gamma$	48 ± 7	137
$D_J(2420)^0$	1/2( )	*2422 ±4*	*60 ±13*	$D^*(2010)^+\pi^-$	*seen*	354
CHARMED, STRANGE MESONS				$[D_s^+ = c\bar{s},\ D_s^- = \bar{c}s]$		
D_s^+ *was* F^+	0(0^-)	1972		See Stable Particle Summary Table		
D_s^* *was* F^*		*2113*		See Stable Particle Summary Table		
BOTTOM MESON				$[B^+ = u\bar{b},\ B^0 = d\bar{b},\ \bar{B}^0 = \bar{d}b,\ B^- = \bar{u}b]$		
B^+	1/2(0^-)	5271		See Stable Particle Summary Table		
B^0		5275				

‡ See Meson Full Listings

* Quoted error includes scale factor $S = \sqrt{\chi^2/(N-1)}$. See footnote to Stable Particle Summary Table

† Square brackets indicate a subreaction of the previous (unbracketed) decay mode(s)

§ This is only an educated guess; the error given is larger than the error on the average of the published values (See the Meson Full Listings for the latter.)

a Charge conjugation C applies only to neutral states

b For a 2-body decay mode this is the momentum of the decay products in the decay rest frame. For a 3-or-more-body mode this is the maximum momentum any of the products can have in this frame. The momenta have been calculated by using the averaged central mass values without taking into account the widths of the resonances

c From pole position ($M - i\Gamma/2$)

d The e^+e^- branching fraction is from $e^+e^- \to \pi^+\pi^-$ experiments only. The $\omega\rho$ interference is then due to $\omega\rho$ mixing only and is expected to be small. The $\mu^+\mu^-$ branching fraction is compiled from 3 experiments, each possibly with substantial $\omega\rho$ interference. The error reflects this uncertainty; see notes in the Meson Full Listings. If $e\mu$ universality holds $\Gamma(\rho^0 \to \mu^+\mu^-) = \Gamma(\rho^0 \to e^+e^-) \times 0.99785$

e The mass and width are from the $\eta\pi$ mode only. If the $K\bar{K}$ channel is strongly coupled, the width may be larger

f Includes $p\bar{p}\pi^+\pi^-\gamma$ and excludes $p\bar{p}\eta$, $p\bar{p}\omega$, $p\bar{p}\eta'$

g See $f_1(1420)$ mini-review

h Value is for the sum of the charge states indicated

j Spectroscopic labeling for these states is theoretical, pending experimental information

Meson Summary Table *(cont'd)*

Table of Contents of Meson Full Listings

• Indicates particle appears in Meson Summary Table above We do not regard the other entries as established resonances.

† Indicates particle appears in Stable Particle Summary Table and in the Stable Particle Full Listings.

Nonstrange ($S = 0$, $C,B = 0$)						Strange ($\lvert S \rvert = 1$, $C,B = 0$)	
entry	$I^G(J^{PC})$ [a]	entry	$I^G(J^{PC})$ [a]	entry	$I^G(J^{PC})$ [a]	entry	$I\,(J^P)$
† π	$1^-(0^{-+})$	• ω_3 (1670)	$0^-(3^{--})$	e^+e^- (1100—2200)	(1^{--})	† K	$1/2(0^-)$
† η	$0^+(0^{-+})$	• π_2 (1670)	$1^-(2^{-+})$	$\bar{N}N$ (1100—3600)		• K^* (892)	$1/2(1^-)$
• ρ (770)	$1^+(1^{--})$	• ϕ (1680)	$0^-(1^{--})$	X (1900—3600)		• K_1 (1270)	$1/2(1^+)$
• ω (783)	$0^-(1^{--})$	• ρ_3 (1690)	$1^+(3^{--})$	• η_c (1S)	$0^+(0^{-+})$	• K_1 (1400)	$1/2(1^+)$
• η' (958)	$0^+(0^{-+})$	• ρ (1700)	$1^+(1^{--})$	• J/ψ (1S)	$0^-(1^{--})$	• K^* (1415)	$1/2(1^-)$
• f_0 (975)	$0^+(0^{++})$	X (1700)	$^+(\ \ ^+)$	• χ_{c0} (1P)	$0^+(0^{++})$	• K_0^* (1430)	$1/2(0^+)$
• a_0 (980)	$1^-(0^{++})$	• f_2 (1720)	$0^+(2^{++})$	• χ_{c1} (1P)	$0^+(1^{++})$	• K_2^* (1430)	$1/2(2^+)$
• ϕ (1020)	$0^-(1^{--})$	f_0 (1750)	$0^+(0^{++})$	• χ_{c2} (1P)	$0^+(2^{++})$	K (1460)	$1/2(0^-)$
• h_1 (1170)	$0^-(1^{+-})$	π (1770)	$1^-(0^{-+})$	η_c (2S)	$(\ \ ^+)$	K_2 (1580)	$1/2(2^-)$
• b_1 (1235)	$1^+(1^{+-})$	f_2 (1810)	$0^+(2^{++})$	• ψ (2S)	$0^-(1^{--})$	K_1 (1650)	$1/2(1^+)$
f_0 (1240)	$0^+(0^{++})$	X (1850)	0	• ψ (3770)	(1^{--})	• K^* (1715)	$1/2(1^-)$
• a_1 (1260)	$1^-(1^{++})$	X (1935)		• ψ (4040)	(1^{--})	• K_2 (1770)	$1/2(2^-)$
• f_2 (1270)	$0^+(2^{++})$	• f_2 (2010)	$0^+(2^{++})$	• ψ (4160)	(1^{--})	• K_3^* (1780)	$1/2(3^-)$
• η (1280)	$0^+(0^{-+})$	a_4 (2040)	$1^-(4^{++})$	• ψ (4415)	(1^{--})	K (1830)	$1/2(0^-)$
• f_1 (1285)	$0^+(1^{++})$	a_3 (2050)	$1^-(3^{++})$	• Υ (1S)	(1^{--})	K_2^* (1960)	$1/2(2^+)$
• π (1300)	$1^-(0^{-+})$	• f_4 (2050)	$0^+(4^{++})$	• χ_{b0} (1P)	$(\ \ ^{++})$	• K_4^* (2075)	$1/2(4^+)$
• a_2 (1320)	$1^-(2^{++})$	π_2 (2100)	$1^-(2^{-+})$	• χ_{b1} (1P)	(1^{++})	K_2 (2250)	$1/2(2^-)$
h_1 (1380)	$0^-(1^{+-})$	f_2 (2150)	$0^+(2^{++})$	• χ_{b2} (1P)	(2^{++})	K_3 (2320)	$1/2(3^+)$
• f_0 (1400)	$0^+(0^{++})$	ρ (2150)	$1^+(1^{--})$	• Υ (2S)	(1^{--})	K_5^* (2380)	$1/2(5^-)$
• f_1 (1420)	$0^+(1^{++})$	X (2220)	$0\ (\ \ ^{++})$	• χ_{b0} (2P)	$(\ \ ^{++})$	K_4 (2500)	$1/2(4^-)$
• η (1430)	$0^+(0^{-+})$	ρ_3 (2250)	$1^+(3^{--})$	• χ_{b1} (2P)	$(\ \ ^{++})$	**Charmed ($\lvert C \rvert = 1$)**	
f_2 (1430)	$0^+(2^{++})$	• f_2 (2300)	$0^+(2^{++})$	• χ_{b2} (2P)	$(\ \ ^{++})$	† D	$1/2(0^-)$
ρ (1450)	$1^+(1^{--})$	f_4 (2300)	$0^+(4^{++})$	• Υ (3S)	(1^{--})	• D^* (2010)	$1/2(1^-)$
f_0 (1525)	$0^+(0^{++})$	• f_2 (2340)	$0^+(2^{++})$	• Υ (4S)	(1^{--})	• D_J (2420)	$1/2(\ \ )$
• f_2' (1525)	$0^+(2^{++})$	ρ_5 (2350)	$1^+(5^{--})$	• Υ (10860)	(1^{--})	† D_s	$0\ (0^-)$
• f_1 (1530)	$0^+(1^{++})$	a_6 (2450)	$1^-(6^{++})$	• Υ (11020)	(1^{--})	† D_s^*	$0\ (0^-)$
• f_0 (1590)	$0^+(0^{++})$	f_6 (2510)	$0^+(6^{++})$			**Bottom ($\lvert B \rvert = 1$)**	
						† B	$1/2(0^-)$
						† B^*	$1/2(0^-)$
						Non-$q\bar{q}$ Candidates	

Baryon Summary Table

April 1988

The first, short table gives the name, the quantum numbers (where known), and the status of every entry in the Baryon Full Listings Only the baryons with 3- or 4-star status are included in the main Baryon Summary Table Due to insufficient data or uncertain interpretation, the other entries in the short table are not established as baryons See our 1986 edition (Physics Letters **170B**) for listings of evidence for Z baryons (KN resonances)

$N(939)\ P_{11}$	****	$\Delta(1232)\ P_{33}$	****	$\Lambda(1116)\ P_{01}$	****	$\Sigma(1193)\ P_{11}$	****	$\Xi(1318)\ P_{11}$	****
$N(1440)\ P_{11}$	****	$\Delta(1550)\ P_{31}$	*	$\Lambda(1405)\ S_{01}$	****	$\Sigma(1385)\ P_{13}$	****	$\Xi(1530)\ P_{13}$	****
$N(1520)\ D_{13}$	****	$\Delta(1600)\ P_{33}$	**	$\Lambda(1520)\ D_{03}$	****	$\Sigma(1480)$?	*	$\Xi(1620)$	*
$N(1535)\ S_{11}$	****	$\Delta(1620)\ S_{31}$	****	$\Lambda(1600)\ P_{01}$	***	$\Sigma(1560)$?	**	$\Xi(1690)$	***
$N(1540)\ P_{13}$	*	$\Delta(1700)\ D_{33}$	****	$\Lambda(1670)\ S_{01}$	****	$\Sigma(1580)\ D_{13}$	**	$\Xi(1820)$ 13	***
$N(1650)\ S_{11}$	****	$\Delta(1900)\ S_{31}$	***	$\Lambda(1690)\ D_{03}$	****	$\Sigma(1620)\ S_{11}$	**	$\Xi(1950)$	***
$N(1675)\ D_{15}$	****	$\Delta(1905)\ F_{35}$	****	$\Lambda(1800)\ S_{01}$	***	$\Sigma(1660)\ P_{11}$	***	$\Xi(2030)$ 1	***
$N(1680)\ F_{15}$	****	$\Delta(1910)\ P_{31}$	****	$\Lambda(1810)\ P_{01}$	***	$\Sigma(1670)\ D_{13}$	****	$\Xi(2120)$	*
$N(1700)\ D_{13}$	***	$\Delta(1920)\ P_{33}$	***	$\Lambda(1820)\ F_{05}$	****	$\Sigma(1690)$?	**	$\Xi(2250)$	**
$N(1710)\ P_{11}$	***	$\Delta(1930)\ D_{35}$	***	$\Lambda(1830)\ D_{05}$	****	$\Sigma(1750)\ S_{11}$	***	$\Xi(2370)$ 1	**
$N(1720)\ P_{13}$	****	$\Delta(1940)\ D_{33}$	*	$\Lambda(1890)\ P_{03}$	****	$\Sigma(1770)\ P_{11}$	*	$\Xi(2500)$	*
$N(1960)$?	*	$\Delta(1950)\ F_{37}$	****	$\Lambda(2000)$?	*	$\Sigma(1775)\ D_{15}$	****		
$N(1990)\ F_{17}$	**	$\Delta(2000)\ F_{35}$	**	$\Lambda(2020)\ F_{07}$	*	$\Sigma(1840)\ P_{13}$	*	$\Omega(1672)\ P_{03}$	****
$N(2000)\ F_{15}$	**	$\Delta(2150)\ S_{31}$	*	$\Lambda(2100)\ G_{07}$	****	$\Sigma(1880)\ P_{11}$	**	$\Omega(2250)$	***
$N(2080)\ D_{13}$	**	$\Delta(2200)\ G_{37}$	*	$\Lambda(2110)\ F_{05}$	***	$\Sigma(1915)\ F_{15}$	****	$\Omega(2380)$	**
$N(2090)\ S_{11}$	*	$\Delta(2300)\ H_{39}$	**	$\Lambda(2325)\ D_{03}$	*	$\Sigma(1940)\ D_{13}$	***		
$N(2100)\ P_{11}$	*	$\Delta(2350)\ D_{35}$	*	$\Lambda(2350)\ H_{09}$	***	$\Sigma(2000)\ S_{11}$	*	$\Lambda_c(2285)$	****
$N(2190)\ G_{17}$	****	$\Delta(2390)\ F_{37}$	*	$\Lambda(2585)$	**	$\Sigma(2030)\ F_{17}$	****	$\Sigma_c(2455)$	***
$N(2200)\ D_{15}$	**	$\Delta(2400)\ G_{39}$	**			$\Sigma(2070)\ F_{15}$	*	$\Xi_c(2460)$	***
$N(2220)\ H_{19}$	****	$\Delta(2420)\ H_{311}$	****			$\Sigma(2080)\ P_{13}$	**	$\Omega_c(2740)$	*
$N(2250)\ G_{19}$	****	$\Delta(2750)\ I_{313}$	**			$\Sigma(2100)\ G_{17}$	*	$\Lambda_b(5500)$	*
$N(2600)\ I_{111}$	***	$\Delta(2950)\ K_{315}$	**			$\Sigma(2250)$	***		
$N(2700)\ K_{113}$	**	$\Delta(\sim 3000)$				$\Sigma(2455)$	**	Dibaryons	
$N(\sim 3000)$						$\Sigma(2620)$	**		
						$\Sigma(3000)$	*		
						$\Sigma(3170)$	*		

****	Good, clear, and unmistakable
***	Good, but in need of clarification or not absolutely certain
**	Not established, needs confirmation
*	Evidence weak, likely to disappear

Particle [a]	J^P	$L_{2I \cdot 2J}$	P_{beam} [b] (GeV/c) $\hat{\sigma} = 4\pi\lambda\!\!\!^{-2}$ (mb)	Mass [c] M (MeV)	Full [d] width Γ (MeV)	Decay modes: Mode [e]	Fraction [f] (%)	p [g] (MeV/c)
			N BARYONS (S=0, I=1/2)		[$N^+ = uud$, $N^0 = udd$]			
p	$1/2^+$			938 27231		See Stable Particle Table		
n				939 56563				
N(1440)	$1/2^+$	P_{11}	$P = 0\ 61$	1400 to	120 to	$N\pi$	50–70	397
			$\hat{\sigma} = 31\ 0$	1480	350	$N\pi\pi$	30–50	342
					(200)	$\Delta\pi$	10–20	143
						$N\rho$	10–15	†
						$N(\pi\pi)_S$	5–20	342
						$p\gamma$	0 08–0 10	414
						$n\gamma$	0 01–0 06	413
N(1520)	$3/2^-$	D_{13}	$P = 0\ 74$	1510 to	100 to	$N\pi$	50–60	456
			$\hat{\sigma} = 23\ 5$	1530	140	$N\eta$	~0 1	149
					(125)	$N\pi\pi$	40–50	410
						$\Delta\pi$	20–30	228
						$N\rho$	15–25	†
						$N(\pi\pi)_S$	< 5	410
						$p\gamma$	0 43–0 57	470
						$n\gamma$	0 34–0 51	470

Baryon Summary Table *(cont'd)*

Particle [a]	J^P	$L_{2I \cdot 2J}$	P_{beam} [b] (GeV/c) $\hat{\sigma} = 4\pi\lambda\!\!\!^{-2}$ (mb)	Mass [c] M (MeV)	Full [d] width Γ (MeV)	Decay modes: Mode [e]	Fraction [f] (%)	p [g] (MeV/c)
N(1535)	$1/2^-$	S_{11}	$P = 0.76$	1520 to	100 to	$N\pi$	35–50	467
			$\hat{\sigma} = 22.5$	1560	250	$N\eta$	45–55	182
					(150)	$N\pi\pi$	~10	422
						$\Delta\pi$	< 5	242
						$N\rho$	~ 5	†
						$N(\pi\pi)_S$	~ 5	422
						$p\gamma$	0.1–0.2	481
						$n\gamma$	0.15–0.35	480
N(1650)	$1/2^-$	S_{11}	$P = 0.96$	1620 to	100 to	$N\pi$	55–65	547
			$\hat{\sigma} = 16.4$	1680	200	$N\eta$	~1.5	346
					(150)	ΛK	~ 8	161
						$N\pi\pi$	20–35	511
						$\Delta\pi$	<10	344
						$N\rho$	5–30	†
						$N(\pi\pi)_S$	<15	511
						$p\gamma$	0.04–0.16	558
						$n\gamma$	0–0.17	557
N(1675)	$5/2^-$	D_{15}	$P = 1.01$	1660 to	120 to	$N\pi$	35–40	563
			$\hat{\sigma} = 15.4$	1690	180	$N\eta$	~ 1	374
					(155)	ΛK	~0.1	209
						$N\pi\pi$	60–65	529
						$\Delta\pi$	55–60	364
						$N\rho$	<10	†
						$N(\pi\pi)_S$	< 5	529
						$p\gamma$	~0.01	575
						$n\gamma$	0.07–0.12	574
N(1680)	$5/2^+$	F_{15}	$P = 1.01$	1670 to	110 to	$N\pi$	55–65	567
			$\hat{\sigma} = 15.2$	1690	140	$N\eta$	< 1	379
					(125)	ΛK	not seen	218
						$N\pi\pi$	35–45	532
						$\Delta\pi$	10–15	369
						$N\rho$	10–20	†
						$N(\pi\pi)_S$	15–20	532
						$p\gamma$	0.21–0.30	578
						$n\gamma$	0.02–0.05	577
N(1700)	$3/2^-$	D_{13}	$P = 1.05$	1670 to	70 to	$N\pi$	5–15	580
			$\hat{\sigma} = 14.5$	1730	120	$N\eta$	~ 4	400
					(100)	ΛK	~0.2	250
						$N\pi\pi$	80–90	547
						$\Delta\pi$	15–70	385
						$N\rho$	<20	†
						$N(\pi\pi)_S$	<70	547
						$p\gamma$	~0.01	591
N(1710)	$1/2^+$	P_{11}	$P = 1.07$	1680 to	90 to	$N\pi$	10–20	587
			$\hat{\sigma} = 14.2$	1740	130	$N\eta$	~25	410
					(110)	ΛK	~15	264
						ΣK	2–10	138
						$N\pi\pi$	<50	554
						$\Delta\pi$	10–20	393
						$N\rho$	5–35	48
						$N(\pi\pi)_S$	5–35	554
N(1720)	$3/2^+$	P_{13}	$P = 1.09$	1690 to	125 to	$N\pi$	10–20	594
			$\hat{\sigma} = 13.9$	1800	250	$N\eta$	~3.5	420
					(200)	ΛK	~ 5	278
						ΣK	2–5	162
						$N\pi\pi$	<75	561
						$\Delta\pi$	<15	401
						$N\rho$	<75	104
						$N(\pi\pi)_S$	<20	561

Baryon Summary Table *(cont'd)*

Particle [a]	J^P	$L_{2I\,2J}$	P_{beam} [b] (GeV/c) $\hat{\sigma} = 4\pi\lambda\!\!\!^{-2}$ (mb)	Mass [c] M (MeV)	Full [d] width Γ (MeV)	Decay modes: Mode [e]	Fraction [f] (%)	p [g] (MeV/c)
N(2190)	$7/2^-$	G_{17}	$P = 2.07$	2120 to	200 to	$N\pi$	~14	888
			$\hat{\sigma} = 6.21$	2230	500	$N\eta$	~ 3	790
					(350)	ΛK	~0.3	712
N(2220)	$9/2^+$	H_{19}	$P = 2.14$	2150 to	300 to	$N\pi$	~18	905
			$\hat{\sigma} = 5.97$	2300	500	$N\eta$	~0.5	811
					(400)	ΛK	~0.2	732
N(2250)	$9/2^-$	G_{19}	$P = 2.21$	2130 to	200 to	$N\pi$	~10	923
			$\hat{\sigma} = 5.74$	2270	500	$N\eta$	~ 2	831
					(300)	ΛK	~0.3	754
N(2600)	$11/2^-$	I_{111}	$P = 3.12$	2580 to	>300	$N\pi$	~ 5	1126
			$\hat{\sigma} = 3.86$	2700	(400)			
Δ BARYONS (S=0, I=3/2)			$[\Delta^{++} = uuu,\ \Delta^{+} = uud,\ \Delta^{0} = udd,\ \Delta^{-} = ddd]$					
Δ(1232)	$3/2^+$	P_{33}	$P = 0.30$	1230 to	110 to	$N\pi$	99.4	227
			$\hat{\sigma} = 94.8$	1234	120	$N\gamma$	0.56–0.66	259
					(115)			
Δ(1620)	$1/2^-$	S_{31}	$P = 0.91$	1600 to	120 to	$N\pi$	25–35	526
			$\hat{\sigma} = 17.7$	1650	160	$N\pi\pi$	65–75	488
					(140)	$\Delta\pi$	60–70	318
						$N\rho$	10–20	†
						$N\gamma$	~0.03	538
Δ(1700)	$3/2^-$	D_{33}	$P = 1.05$	1630 to	190 to	$N\pi$	10–20	580
			$\hat{\sigma} = 14.5$	1740	300	$N\pi\pi$	80–90	547
					(250)	$\Delta\pi$	50–90	385
						$N\rho$	<35	†
						$N\gamma$	0.14–0.33	591
Δ(1900)	$1/2^-$	S_{31}	$P = 1.44$	1850 to	130 to	$N\pi$	5–15	710
			$\hat{\sigma} = 9.71$	2000	300	ΣK	not seen	410
					(150)			
Δ(1905)	$5/2^+$	F_{35}	$P = 1.45$	1890 to	250 to	$N\pi$	5–15	713
			$\hat{\sigma} = 9.62$	1920	400	ΣK	< 3	415
					(300)	$N\pi\pi$	<75	687
						$\Delta\pi$	~25	542
						$N\rho$	<50	421
						$N\gamma$	0.01–0.05	721
Δ(1910)	$1/2^+$	P_{31}	$P = 1.46$	1850 to	200 to	$N\pi$	15–25	716
			$\hat{\sigma} = 9.54$	1950	330	ΣK	not seen	421
					(220)	$N\pi\pi$	<75	691
						$\Delta\pi$	small	545
						$N\rho$	small	426
						$N(1440)\pi$	large	393
Δ(1920)	$3/2^+$	P_{33}	$P = 1.48$	1860 to	190 to	$N\pi$	15–20	722
			$\hat{\sigma} = 9.38$	2160	300	ΣK	~ 5	431
					(250)			
Δ(1930)	$5/2^-$	D_{35}	$P = 1.50$	1890 to	150 to	$N\pi$	5–15	729
			$\hat{\sigma} = 9.21$	1960	350	ΣK	not seen	441
					(250)	$N\pi\pi$	not seen	704
Δ(1950)	$7/2^+$	F_{37}	$P = 1.54$	1910 to	200 to	$N\pi$	35–45	741
			$\hat{\sigma} = 8.91$	1960	340	ΣK	not seen	460
					(240)	$N\pi\pi$	<40	716
						$\Delta\pi$	~30	574
						$N\rho$	<10	469
						$N\gamma$	0.08–0.17	749
Δ(2420)	$11/2^+$	H_{311}	$P = 2.64$	2380 to	300 to	$N\pi$	5–15	1023
			$\hat{\sigma} = 4.68$	2450	500			
					(300)			

Baryon Summary Table *(cont'd)*

Particle [a]	J^P	$L_{I \cdot 2J}$	P_{beam} [b] (GeV/c) $\hat{\sigma} = 4\pi\lambda\!\!\!^{-2}$ (mb)	Mass [c] M (MeV)	Full [d] width Γ (MeV)	Decay modes Mode	Fraction [f] (%)	p [g] (MeV/c)
			Λ BARYONS ($S=-1$, $I=0$)		[$\Lambda^0 = uds$]			
Λ	$1/2^+$			1115 63		See Stable Particle Table		
Λ(1405)	$1/2^-$	S_{01}	Below $\bar{K}N$ threshold	1405 ± 5 [h]	40 ± 10 [h]	$\Sigma\pi$	100	152
Λ(1520)	$3/2^-$	D_{03}	$P = 0\ 395$	1519 5	15 6	$N\bar{K}$	45 ± 1	244
			$\hat{\sigma} = 82\ 3$	$\pm 1\ 0$ [h]	$\pm 1\ 0$ [h]	$\Sigma\pi$	42 ± 1	267
						$\Lambda\pi\pi$	10 ± 1	252
						$\Sigma\pi\pi$	$0\ 9 \pm 0\ 1$	152
						$\Lambda\gamma$	$0\ 8 \pm 0\ 2$	351
Λ(1600)	$1/2^+$	P_{01}	$P = 0\ 58$	1560 to	50 to	$N\bar{K}$	15–30	343
			$\hat{\sigma} = 41\ 6$	1700	250	$\Sigma\pi$	10–60	336
					(150)			
Λ(1670)	$1/2^-$	S_{01}	$P = 0\ 74$	1660 to	25 to	$N\bar{K}$	15–25	414
			$\hat{\sigma} = 28\ 5$	1680	50	$\Sigma\pi$	20–60	393
					(35)	$\Lambda\eta$	15–35	64
Λ(1690)	$3/2^-$	D_{03}	$P = 0\ 78$	1685 to	50 to	$N\bar{K}$	20–30	433
			$\hat{\sigma} = 26\ 1$	1695	70	$\Sigma\pi$	20–40	409
					(60)	$\Lambda\pi\pi$	~25	415
						$\Sigma\pi\pi$	~20	350
Λ(1800)	$1/2^-$	S_{01}	$P = 1\ 01$	1720 to	200 to	$N\bar{K}$	25–40	528
			$\hat{\sigma} = 17\ 5$	1850	400	$\Sigma\pi$	seen	493
					(300)	$\Sigma(1385)\pi$	seen	345
						$N\bar{K}^*(892)$	seen	†
Λ(1810)	$1/2^+$	P_{01}	$P = 1\ 03$	1750 to	50 to	$N\bar{K}$	20–50	537
			$\hat{\sigma} = 17\ 0$	1850	250	$\Sigma\pi$	10–40	501
					(150)	$\Sigma(1385)\pi$	seen	356
						$N\bar{K}^*(892)$	30–60	†
Λ(1820)	$5/2^+$	F_{05}	$P = 1\ 06$	1815 to	70 to	$N\bar{K}$	55–65	545
			$\hat{\sigma} = 16\ 5$	1825	90	$\Sigma\pi$	8–14	508
					(80)	$\Sigma(1385)\pi$	5–10	362
Λ(1830)	$5/2^-$	D_{05}	$P = 1\ 08$	1810 to	60 to	$N\bar{K}$	3–10	553
			$\hat{\sigma} = 16\ 0$	1830	110	$\Sigma\pi$	35–75	515
					(95)	$\Sigma(1385)\pi$	>15	371
Λ(1890)	$3/2^+$	P_{03}	$P = 1\ 21$	1850 to	60 to	$N\bar{K}$	20–35	599
			$\hat{\sigma} = 13\ 6$	1910	200	$\Sigma\pi$	3–10	559
					(100)	$\Sigma(1385)\pi$	seen	420
						$N\bar{K}^*(892)$	seen	233
Λ(2100)	$7/2^-$	G_{07}	$P = 1\ 68$	2090 to	100 to	$N\bar{K}$	25–35	751
			$\hat{\sigma} = 8\ 68$	2110	250	$\Sigma\pi$	~ 5	704
					(200)	$\Lambda\eta$	< 3	617
						ΞK	< 3	483
						$\Lambda\omega$	< 8	443
						$N\bar{K}^*(892)$	10–20	514
Λ(2110)	$5/2^+$	F_{05}	$P = 1\ 70$	2090 to	150 to	$N\bar{K}$	5–25	757
			$\hat{\sigma} = 8\ 53$	2140	250	$\Sigma\pi$	10–40	711
					(200)	$\Lambda\omega$	seen	455
						$\Sigma(1385)\pi$	seen	589
						$N\bar{K}^*(892)$	10–60	524
Λ(2350)	$9/2^+$	H_{09}	$P = 2\ 29$	2340 to	100 to	$N\bar{K}$	~12	915
			$\hat{\sigma} = 5\ 85$	2370	250	$\Sigma\pi$	~10	867
					(150)			

Baryon Summary Table *(cont'd)*

Particle [a]	J^P	$L_{I\,2J}$	P_{beam} [b] (GeV/c) $\hat{\sigma} = 4\pi\lambda\!\!\!^{-2}$ (mb)	Mass [c] M (MeV)	Full [d] width Γ (MeV)	Decay modes: Mode	Fraction [f] (%)	p [g] (MeV/c)
Σ BARYONS ($S=-1$, $I=1$)				$[\Sigma^+ = uus$ $\Sigma^0 = uds$ $\Sigma^- = dds]$				
Σ^+	$1/2^+$			1189 37		See Stable Particle Table		
Σ^0				1192 55				
Σ^-				1197 43				
$\Sigma(1385)^+$	$3/2^+$	P_{13}	Below	1382 8±0 4	36±1	$\Lambda\pi$	88±2	208
			$\bar{K}N$	S=2 0[i]		$\Sigma\pi$	12±2	127
$\Sigma(1385)^0$			threshold	1383 7±1 0	36±5			
				S=1 4[i]				
$\Sigma(1385)^-$				1387 2±0 6	39±2			
				S=2 2[i]	S=1 7[i]			
$\Sigma(1660)$	$1/2^+$	P_{11}	P = 0 72	1630 to	40 to	$N\bar{K}$	10–30	405
			$\hat{\sigma}$ = 29 9	1690	200	$\Lambda\pi$	seen	439
					(100)	$\Sigma\pi$	seen	385
$\Sigma(1670)$	$3/2^-$	D_{13}	P = 0 74	1665 to	40 to	$N\bar{K}$	7–13	414
			$\hat{\sigma}$ = 28 5	1685	80	$\Lambda\pi$	5–15	447
					(60)	$\Sigma\pi$	30–60	393
$\Sigma(1750)$	$1/2^-$	S_{11}	P = 0 91	1730 to	60 to	$N\bar{K}$	10–40	486
			$\hat{\sigma}$ = 20 7	1800	160	$\Lambda\pi$	seen	507
					(90)	$\Sigma\pi$	< 8	455
						$\Sigma\eta$	15–55	81
$\Sigma(1775)$	$5/2^-$	D_{15}	P = 0 96	1770 to	105 to	$N\bar{K}$	37–43	508
			$\hat{\sigma}$ = 19 0	1780	135	$\Lambda\pi$	14–20	525
					(120)	$\Sigma\pi$	2–5	474
						$\Sigma(1385)\pi$	8–12	324
						$\Lambda(1520)\pi$	17–23	198
$\Sigma(1915)$	$5/2^+$	F_{15}	P = 1 26	1900 to	80 to	$N\bar{K}$	5–15	618
			$\hat{\sigma}$ = 12 8	1935	160	$\Lambda\pi$	seen	622
					(120)	$\Sigma\pi$	seen	577
						$\Sigma(1385)\pi$	< 5	440
$\Sigma(1940)$	$3/2^-$	D_{13}	P = 1 32	1900 to	150 to	$N\bar{K}$	<20	637
			$\hat{\sigma}$ = 12 1	1950	300	$\Lambda\pi$	seen	639
					(220)	$\Sigma\pi$	seen	594
						$\Sigma(1385)\pi$	seen	460
						$\Lambda(1520)\pi$	seen	354
						$\Delta(1232)\bar{K}$	seen	410
						$N\bar{K}^*(892)$	seen	320
$\Sigma(2030)$	$7/2^+$	F_{17}	P = 1 52	2025 to	150 to	$N\bar{K}$	17–23	702
			$\hat{\sigma}$ = 9 93	2040	200	$\Lambda\pi$	17–23	700
					(180)	$\Sigma\pi$	5–10	657
						ΞK	< 2	412
						$\Sigma(1385)\pi$	5–15	529
						$\Lambda(1520)\pi$	10–20	430
						$\Delta(1232)\bar{K}$	10–20	498
						$N\bar{K}^*(892)$	< 5	438
$\Sigma(2250)$	?		P = 2 04	2210 to	60 to	$N\bar{K}$	<10	851
			$\hat{\sigma}$ = 6 76	2280	150	$\Lambda\pi$	seen	842
					(100)	$\Sigma\pi$	seen	803

Baryon Summary Table *(cont'd)*

Particle [a]	J^P	$L_{2I \cdot 2J}$	Mass [c] M (MeV)	Full [d] width Γ (MeV)	Decay modes: Mode	Decay modes: Fraction (%)	Decay modes: p [g] (MeV/c)
Ξ BARYONS ($S=-2$, $I=1/2$)			$[\Xi^0 = uss,\ \Xi^- = dss]$				
Ξ^0	$1/2^+$		1314.9		See Stable Particle Table		
Ξ^-			1321.32				
$\Xi(1530)^0$	$3/2^+$	P_{13}	1531.8 ± 0.3	9.1 ± 0.5	$\Xi\pi$	100	148
			S = 1.3[i]				
$\Xi(1530)^-$			1535.0 ± 0.6	9.9 ± 1.9			
$\Xi(1690)$	?		1690 ±10[h]	<50	$\Lambda\bar{K}$	seen	240
					$\Sigma\bar{K}$	seen	51
$\Xi(1820)$	$3/2^-$	D_{13}	1823 ±5[h]	24^{+15}_{-10}[h]	$\Lambda\bar{K}$	large	400
					$\Sigma\bar{K}$	small	320
					$\Xi\pi$	small	413
					$\Xi(1530)\pi$	large	234
$\Xi(1950)$	?		1950 ±15[h]	60 ± 20[h]	$\Lambda\bar{K}$	seen	522
					$\Xi\pi$	seen	518
$\Xi(2030)$	?		2025 ±5[h]	20^{+15}_{-5}[h]	$\Lambda\bar{K}$	~20	589
					$\Sigma\bar{K}$	~80	533
					$\Xi\pi$	small	573
					$\Xi(1530)\pi$	small	421
					$\Xi\pi\pi$	small	536
					$\Lambda\bar{K}\pi$	small	501
					$\Sigma\bar{K}\pi$	small	430
Ω BARYONS ($S=-3$, $I=0$)			$[\Omega^- = sss]$				
Ω^-	$3/2^+$		1672.43		See Stable Particle Table		
$\Omega(2250)^-$	?		2252 ± 9	55 ± 18	$\Xi^-\pi^+K^-$	seen	531
					$\Xi(1530)^0K^-$	seen	437
CHARMED BARYONS			$[\Lambda_c^+ = udc,\ \Sigma_c^{++} = uuc,\ \Sigma_c^+ = udc,\ \Sigma_c^0 = ddc,\ \Xi_c^+ = usc]$				
Λ_c^+	$1/2^+$[j]		2284.9		See Stable Particle Table		
$\Sigma_c(2455)^{++}$	$1/2^+$[j]		2452.2 ± 1.7		$\Lambda_c^+\pi$	100	89
			S = 1.4[i]				
$\Sigma_c(2455)^+$			2452.9 ± 3.4				97
			S = 1.1[i]				
$\Sigma_c(2455)^0$			(?[k])				
Ξ_c^+	$1/2^+$[j]		2460		See Stable Particle Table		

Baryon Summary Table *(cont'd)*

Only the established baryons are included in this Baryon Summary Table. See the short table at the front of this main Table for a list of *all* the baryons for which there is evidence. *See also the Notes on N and Δ resonances, on Λ and Σ resonances, and on Ξ resonances, introducing those sections of the Baryon Full Listings. In particular there are Argand diagrams of πN and K̄N partial-wave amplitudes, and discussions of the main analyses of elastic and inelastic channels.*

† This mode is energetically forbidden when the nominal mass of the decaying resonance (and of any resonance in the final state) is used, but is in fact allowed due to the nonzero width(s) of the resonance(s).

a The nominal mass here (in MeV) is used for identification; see column 5 for the actual mass.

b The beam momentum and $\hat{\sigma}$ are calculated using the nominal mass of column 1. At resonance the contribution of the resonance to the total cross section is $(J + 1/2)(\Gamma_{e\ell}/\Gamma)\hat{\sigma}$ and the contribution to the elastic cross section is $(J + 1/2)(\Gamma_{e\ell}/\Gamma)^2\hat{\sigma}$. This ignores isospin factors, and assumes that background in the resonating partial wave is negligible.

c Usually a conservatively large range of masses rather than a statistical average of the various determinations of the mass is given. In these cases the mass determinations are nearly entirely from various phase-shift analyses of more or less the same data. It is thus not appropriate to treat the determinations as independent measurements or to average them together. The masses, widths and branching fractions in this Table are Breit-Wigner parameters. The Baryon Full Listings also include pole parameters when they are available, and there is a table of pole parameters for N and Δ resonances in the "Note on N and Δ Resonances" in the Listings.

d Usually a conservatively large range of widths rather than a statistical average of the various determinations of the width is given (see note *c* for the reason). The nominal value in parentheses is then simply a best guess.

e The indented modes are subreactions of the $\Lambda\pi\pi$ mode. The $(\pi\pi)_S$ is the isospin-0 S-wave state of two pions.

f Most of the inelastic branching fractions come from partial-wave analyses, and these determine $(xx')^{1/2}$, where $x = \Gamma_{el}/\Gamma$ and $x' = \Gamma'/\Gamma$ are the elastic and inelastic branching fractions, not x' directly. Thus any uncertainty (and it is often considerable) in x carries over into x'. When x' so determined is really poorly known, we here simply note that the mode is seen. The values of $(xx')^{1/2}$ are given in the Baryon Full Listings.

g For a 2-body decay mode, this is the momentum of the decay products in the rest frame of the decaying particle. For a 3-or-more-body mode, this is the maximum momentum any of the products can have in this frame. The nominal mass of column 1 is used, as is the nominal mass of any resonance in the final state.

h The error given here is only an educated guess. It is larger than the error on the weighted average of the published values.

i The error given here has been scaled up by an "S factor" (see the * footnote to the Stable Particle Summary Table for how S is defined) because the various measurements disagree more seriously than one would expect from statistics.

j For the Λ_c, J is not measured; for the Σ_c and Ξ_c, neither J nor P is measured. The values given are those expected from the quark model.

k FNAL-400 says that the $\Sigma_c^{++} - \Sigma_c^0$ mass difference is -10.8 ± 2.9 MeV. ARGUS says that it is $+1.2 \pm 0.8$ MeV. At least one of them is wrong.

Tests of Conservation Laws*

In response to the current interest in tests of conservation laws, we have made a table of experimental limits on all weak and electromagnetic decays, mass differences, moments, and a few reactions, whose observation would violate conservation laws The table is given only in the full Review of Particle Properties, not in the Data Booklet For the benefit of Booklet readers, we have included the best limits from the table in the following text The table is in two parts "Discrete Space-Time Symmetries," i e, C, P, T, CP, and CPT, and "Number Conservation Laws," i e, lepton, baryon hadronic flavor, and charge conservation The references for these data can be found in the Stable Particle Section of the Full Listings in this Review A discussion of these tests follows

CPT INVARIANCE

General principles of relativistic field theory require invariance under the combined transformation CPT The simplest tests of CPT invariance are the equality of the masses and lifetimes of a particle and its antiparticle The best test comes from a limit on the mass difference between K^0 and $\overline{K}^0$ Any such mass difference contributes to the CP-violating parameter ϵ Assuming CPT invariance, the phase of ϵ should be very close to 44° (See Note on CP Violation in K_L^0 Decay in the Full Listings) In contrast, if the entire source of CP violation in K^0 decays were a $K^0 - \overline{K}^0$ mass difference, the phase would be 44° + 90° From the measured value of ϕ_{+-} it is possible to deduce that $|m(K^0) - m(\overline{K}^0)| < 10^{-4}|m(K_S) - m(K_L)| < 3 \times 10^{-10}$ eV Limits can also be placed on specific CPT-violating decay amplitudes Given the small value of $(1 - |\eta_{00}/\eta_{+-}|)$ the value of $\phi_{00}-\phi_{+-}$ provides a measure of CPT violation in $K_L^0 \to 2\pi$ decay The present listing indicates a two-standard-deviation CPT-violating effect

CP AND *T* INVARIANCE

Given CPT invariance, CP violation and T violation are equivalent So far the only evidence for CP or T violation comes from the measurements of η_{+-} η_{00} and the semileptonic decay charge asymmetry for K_L e g, $|\eta_{+-}| = |A(K_L^0 \to \pi^+\pi^-)/A(K_S^0 \to \pi^+\pi^-)| = (2\,266 \pm 0\,018) \times 10^{-3}$ and $[\Gamma(K_L^0 \to \pi^- e^+ \nu) - \Gamma(K_L^0 \to \pi^+ e^- \overline{\nu})] / [\text{sum}] = (0\,333 \pm 0\,014)\%$ Other searches for CP or T violation should be divided into (a) those that involve weak interactions or parity violation, and (b) those that involve processes allowed by the strong or electromagnetic interactions In class (a) the most sensitive is probably the search for an electric dipole moment of the neutron, which is measured to be $(-1\,1 \pm 0\,8) \times 10^{-25} e$ cm A nonzero value requires both P and T violation Class (b) searches involve looking for C or T violation in strong or electromagnetic processes Examples are the search for C violation in η decay, believed to be an electromagnetic process, e g, as measured by $\Gamma(\eta \to \mu^+\mu^-\pi^0)/\Gamma(\eta \to \text{all}) < 5 \times 10^{-6}$, and the search for T violation in a number of nuclear and electromagnetic reactions

CONSERVATION OF LEPTON NUMBERS

Present experimental evidence and the standard electroweak theory are consistent with the absolute conservation of three separate lepton numbers electron number L_e, muon number L_μ, and τ-number L_τ Searches for violations are of the following types

a) $\Delta L = 2$ for one type of lepton. The best limit comes from the search for neutrinoless double beta decay $(Z,A) \to (Z+2,A) + e^- + e^-$ The best laboratory limit is $t_{1/2} > 5 \times 10^{23}$ yr (CL=68%) for ^{76}Ge

b) Conversion of one lepton type to another. For purely leptonic processes, the best limits are on $\mu \to e\gamma$ and $\mu \to 3e$, measured as $\Gamma(\mu \to e\gamma)/\Gamma(\mu \to \text{all}) < 5 \times 10^{-11}$ and $\Gamma(\mu \to 3e)/\Gamma(\mu \to \text{all}) < 1\,0 \times 10^{-13}$ For semileptonic processes, the best limit comes from the coherent conversion process in a muonic atom, $\mu^- + (Z,A) \to e^- + (Z,A)$, measured as $\Gamma(\mu^- \text{Ti} \to e^- \text{Ti})/\Gamma(\mu^- \text{Ti} \to \text{all}) < 4\,6 \times 10^{-12}$ Of special interest is the case in which the hadronic flavor also changes, as in $K_L \to e\mu$ and $K^+ \to \pi^+ e^- \mu^+$, measured as $\Gamma(K_L \to e\mu)/\Gamma(K_L \to \text{all}) < 7 \times 10^{-9}$ and $\Gamma(K^+ \to \pi^+ e^- \mu^+)/\Gamma(K^+ \to \text{all}) < 5 \times 10^{-9}$ Limits on the conversion of τ into e or μ are found in τ decay and are much less stringent than those for $\mu \to e$ conversion, e g, $\Gamma(\tau \to \mu\gamma)/\Gamma(\tau \to \text{all}) < 6 \times 10^{-4}$ and $\Gamma(\tau \to e\gamma)/\Gamma(\tau \to \text{all}) < 6 \times 10^{-4}$

c) Conversion of one type of lepton into another type of antilepton. The case most studied is $\mu^- + (Z,A) \to e^+ + (Z-2,A)$, the strongest limit being $\Gamma(\mu^- \text{Ti} \to e^+ \text{Ca})/\Gamma(\mu^- \text{Ti} \to \text{all}) < 1\,7 \times 10^{-10}$

d) Relation to neutrino mass. If neutrinos have masses then it is expected even in the standard electroweak theory that separate lepton numbers are not conserved, as a consequence of lepton mixing analogous to the Cabibbo quark mixing However, in this case lepton-number-violating processes such as $\mu \to e\gamma$ are expected to have extremely small probability For small neutrino masses, the lepton-number violation would be observed first in neutrino oscillations, which have been the subject of extensive experimental searches For example searches for $\overline{\nu}_e$ disappearance which we label as $\overline{\nu}_e \not\to \overline{\nu}_e$ give measured limits $\Delta(m^2) < 0\,014$ eV^2 for $\sin^2(2\theta) = 1$, and $\sin^2(2\theta) < 0\,14$ for large $\Delta(m^2)$, where θ is the neutrino mixing angle Searches for $\nu_\mu \to \nu_e$ set limits $\Delta(m^2) < 0\,09$ eV^2 for $\sin^2(2\theta) = 1$, and $\sin^2(2\theta) < 0\,0034$ for large $\Delta(m^2)$ For larger neutrino masses (>> 1 keV), lepton-number violation is searched for by looking for anomalous decays such as $\pi \to e\nu_x$, where ν_x is a massive neutrino If the $\Delta L = 2$ type of violation occurs, it is expected that neutrinos will have a nonzero mass of the Majorana type

CONSERVATION OF HADRONIC FLAVORS

The conversion of a quark of one flavor $(d,u,s\,c,b,t)$, into a quark of another flavor is forbidden in strong and electromagnetic interactions by the conservation of hadron flavors In the Standard Model the weak interactions violate these conservation laws in a manner described by the Cabibbo or Kobayashi-Maskawa mixing (see the section on the Kobayashi-Maskawa Mixing Matrix) The way in which these conservation laws are violated is tested as follows

a) ΔS = ΔQ rule. In the semileptonic decay of strange particles, the strangeness change equals the change in charge of the hadrons Tests come from limits on decay rates such as $\Gamma(\Sigma^+ \to n e^+ \nu)/\Gamma(\Sigma^+ \to \text{all}) < 5 \times 10^{-6}$, and from a detailed analysis of $K_L \to \pi e \nu$, which yields the parameter x, measured to be $(\text{Re}\,x, \text{Im}\,x) = (0\,006 \pm 0\,018, -0\,003 \pm 0\,026)$ Corresponding rules are $\Delta C = \Delta Q$ and $\Delta B = \Delta Q$

b) Change of flavor by two units In the standard model this occurs only in second-order weak interactions The classical example is $\Delta S = 2$ $K^0 - \overline{K}^0$ mixing, which is directly measured by $m(K_S) - m(K_L) = (3\,521 \pm 0\,014) \times 10^{-12}$ MeV There is now evidence for $B^0 - \overline{B}^0$ mixing corresponding to $\Delta B = 2$ with the corresponding mass difference between the eigenstates $|m_{B_1^0} - m_{B_2^0}| = (0\,73 \pm 0\,18)\Gamma_B = (3\,7 \pm 1\,0) \times 10^{-10}$ MeV No evidence exists for $D^0 - \overline{D}^0$ mixing, which is expected to be much smaller in the Standard Model

c) Flavor-changing neutral currents. In the Standard Model the neutral-current interactions do not change flavor The low rate $\Gamma(K_L \to \mu^+\mu^-)/\Gamma(K_L \to \text{all}) = (9\,5^{+2\,4}_{-1\,5}) \times 10^{-9}$ puts limits on such interactions, the nonzero value for this rate is attributed to a combination of the weak and electromagnetic interactions The best test should come from a limit on $K^+ \to \pi^+ \nu\overline{\nu}$, which occurs in the Standard Model only as a second-order weak process with a branching fraction of (1 to 8) $\times 10^{-10}$ The current limit is $\Gamma(K^+ \to \pi^+ \nu\overline{\nu})/\Gamma(K^+ \to \text{all}) < 1\,4 \times 10^{-7}$ Limits for charm-changing or bottom-changing neutral currents are much less stringent $\Gamma(D^0 \to \mu^+\mu^-)/\Gamma(D^0 \to \text{all}) < 1\,1 \times 10^{-5}$ and $\Gamma(B^0 \to \mu^+\mu^-)/\Gamma(B^0 \to \text{all}) < 5 \times 10^{-5}$

* Revised April 1988 by T G Trippe and L Wolfenstein

Tests of Conservation Laws (*cont'd*)

Discrete Space-Time Symmetries

Quantity[a]		Value[b]	Symmetry tested or violated
$\pi^0 \to \gamma\gamma\gamma$ / all		$< 4 \times 10^{-7}$	C
$(e^+e^-)_{J=0} \to 3\gamma/2\gamma$		$< 1 \times 10^{-5}$[c]	C
$(e^+e^-)_{J=1} \to 4\gamma/3\gamma$		$< 1 \times 10^{-5}$[c]	C
$\eta \to \gamma\gamma\gamma$ / all		$< 5 \times 10^{-4}$	C
$\eta \to \pi^0 e^+e^-$ / all		$< 5 \times 10^{-5}$	C (single photon process)
$\eta \to \pi^0\mu^+\mu^-$ / all		$< 5 \times 10^{-6}$	C (single photon process)
$\eta \to \pi^+\pi^-\pi^0$ parameters	left-right asymmetry	$(1.2 \pm 1.7) \times 10^{-3}$	C
	sextant asymmetry	$(1.9 \pm 1.6) \times 10^{-3}$	C
	quadrant asymmetry	$(-1.7 \pm 1.7) \times 10^{-3}$	C
$\eta \to \pi^+\pi^-\gamma$ parameters	left-right asymmetry	$(9 \pm 4) \times 10^{-3}$	C
	β (D-wave)	0.05 ± 0.06	C
$\eta \to \pi^+\pi^-$ / all		$< 1.5 \times 10^{-3}$	P and CP
e electric dipole moment		$< 3 \times 10^{-24}$ e cm	T and P
μ electric dipole moment		$(3.7 \pm 3.4) \times 10^{-19}$ e cm	T and P
p electric dipole moment		$(9 \pm 14) \times 10^{-21}$ e cm	T and P
n electric dipole moment		$(-1.1 \pm 0.8) \times 10^{-25}$ e cm	T and P
Λ electric dipole moment		$< 1.5 \times 10^{-16}$ e cm	T and P
α'/A from $\mu \to e\nu\bar{\nu}$		$(0 \pm 4) \times 10^{-3}$	T
β'/A from $\mu \to e\nu\bar{\nu}$		$(2 \pm 6) \times 10^{-3}$	T
e pol $\perp$ μ spin and e^+ mom from $\mu \to e\nu\bar{\nu}$		0.007 ± 0.023	T
Im ξ in $K^{\pm}_{\mu3}$ decay (from transverse μ pol.)		-0.017 ± 0.025	T
Im ξ in $K^0_{\mu3}$ decay (from transverse μ pol.)		-0.007 ± 0.026	T
ϕ phase of g_A/g_1 for n		$(180.11 \pm 0.17)°$	T (0° or 180°)
n triple correlation coefficient		-0.0007 ± 0.0014	T
$K^{\pm} \to \pi^{\pm}\pi^+\pi^-$ rate difference / average		$(0.07 \pm 0.12)\%$	CP
$K^{\pm} \to \pi^{\pm}2\pi^0$ rate difference / average		$(0.0 \pm 0.6)\%$	CP
$K^{\pm} \to \pi^{\pm}\pi^0\gamma$ rate difference / average		$(0.9 \pm 3.3)\%$	CP
$K \to 3\pi^{\pm}$ slope $(g^+ - g^-)$ / sum		$(-0.7 \pm 0.5)\%$	CP
$\vert\eta_{+-0}\vert^2 = \Gamma(K^0_S \to \pi^+\pi^-\pi^0)/\Gamma(K^0_L \to \pi^+\pi^-\pi^0)$		< 0.12	CP
$\vert\eta_{000}\vert^2 = \Gamma(K^0_S \to 3\pi^0)/\Gamma(K^0_L \to 3\pi^0)$		< 0.1	CP
Charge asymm. j in $K^0_L \to \pi^+\pi^-\pi^0$		0.0011 ± 0.0008	CP
$K^0_L \to (\pi^-\mu^+\nu - \pi^+\mu^-\bar{\nu})$ / sum		$(0.32 \pm 0.04)\%$	CP (violated)
$K^0_L \to (\pi^-e^+\nu - \pi^+e^-\bar{\nu})$ / sum		$(0.333 \pm 0.014)\%$	CP (violated)
$\vert\eta_{00}\vert = \vert A(K^0_L \to \pi^0\pi^0)/A(K^0_S \to \pi^0\pi^0)\vert$		$(2.245 \pm 0.019) \times 10^{-3}$	CP (violated)
$\vert\eta_{+-}\vert = \vert A(K^0_L \to \pi^+\pi^-)/A(K^0_S \to \pi^+\pi^-)\vert$		$(2.266 \pm 0.018) \times 10^{-3}$	CP (violated)
$\vert\epsilon\vert$		$(2.259 \pm 0.018) \times 10^{-3}$	CP (violated)[d]
$\vert\epsilon'/\epsilon\vert = (1 - \vert\eta_{00}/\eta_{+-}\vert)/3$		$(3.2 \pm 1.0) \times 10^{-3}$	CP (violated)[d]
ϕ_{+-} phase of η_{+-}		$(44.6 \pm 1.2)°$	CP (violated)
ϕ_{00} phase of η_{00}		$(54 \pm 5)°$	CP (violated)
Re ϵ in K^0_L decay		$(1.621 \pm 0.088) \times 10^{-3}$	CP (violated)
$[\alpha_-(\Lambda) + \alpha_+(\bar{\Lambda})]/[\alpha_-(\Lambda) - \alpha_+(\bar{\Lambda})]$		-0.06 ± 0.08	CP
$(g_{e^+} - g_{e^-})$ / average		$(-0.5 \pm 2.1) \times 10^{-12}$	CPT
$(g_{\mu^+} - g_{\mu^-})$ / average		$(-2.6 \pm 1.6) \times 10^{-8}$	CPT
$(\mu_p - \vert\mu_{\bar{p}}\vert)$ / average		$(-1 \pm 7) \times 10^{-3}$	CPT
$e^+ - e^-$ mass difference / average		$< 4 \times 10^{-8}$	CPT
$\pi^+ - \pi^-$ mass difference / average		$(2 \pm 5) \times 10^{-4}$	CPT
$K^+ - K^-$ mass difference / average		$(-0.6 \pm 1.8) \times 10^{-4}$	CPT
$\vert K^0 - \bar{K}^0\vert$ mass difference / average		$< 6 \times 10^{-19}$	CPT[e]
$\phi_{00} - \phi_{+-}$		$(10 \pm 5)°$	CPT
$p - \bar{p}$ mass difference / average		$(6 \pm 4) \times 10^{-5}$	CPT
$n - \bar{n}$ mass difference / average		$(9 \pm 5) \times 10^{-5}$	CPT
$\Lambda - \bar{\Lambda}$ mass difference / average		$(0.0 \pm 1.1) \times 10^{-4}$	CPT
$\Xi^- - \bar{\Xi}^+$ mass difference / average		$(1.1 \pm 2.7) \times 10^{-4}$	CPT
$\Omega^- - \bar{\Omega}^+$ mass difference / average		$(-1 \pm 5) \times 10^{-4}$	CPT
$\mu^+ - \mu^-$ mean life difference / average		$(3 \pm 8) \times 10^{-5}$	CPT
$\pi^+ - \pi^-$ mean life difference / average		$(5 \pm 7) \times 10^{-4}$	CPT
$K^+ - K^-$ mean life difference / average		$(1.1 \pm 0.9) \times 10^{-3}$	CPT
$\Lambda - \bar{\Lambda}$ mean life difference / average		$(4 \pm 9) \times 10^{-2}$	CPT
$\Xi^- - \bar{\Xi}^+$ mean life difference / average		(0.02 ± 0.18)	CPT
$K^{\pm} \to \mu^{\pm}\nu$ rate difference / average		$(-0.5 \pm 0.4)\%$	CPT
$K^{\pm} \to \pi^{\pm}\pi^0$ rate difference / average		$(0.8 \pm 1.2)\%$	CPT[f]

Tests of Conservation Laws (*cont'd)*

Number Conservation Laws

Quantity[a]	Value[b]	Conservation law tested
$\mu^- \to e^-\nu_e\bar{\nu}_\mu$ / all	$< 5 \times 10^{-2}$	Lepton family number[g,h]
$\to e^-\gamma$ / all	$< 5 \times 10^{-11}$	Lepton family number[h]
$\to e^-e^+e^-$ / all	$< 1.0 \times 10^{-13}$	″ ″ ″
$\to e^-\gamma\gamma$ / all	$< 7 \times 10^{-11}$	″ ″ ″
$\mu^-\ {}^{32}\mathrm{S} \to e^-\ {}^{32}\mathrm{S}$ / all	$< 7 \times 10^{-11}$	″ ″ ″
$\mu^-\ \mathrm{Ti} \to e^-\ \mathrm{Ti}$ / all	$< 4.6 \times 10^{-12}$	″ ″ ″
coupling for $(\mu^+e^- \to \mu^-e^+)_{\mathrm{bound}}$	$< 7.5\ G_F$	″ ″ ″
$\tau^- \to \mu^-\gamma$ / all	$< 6 \times 10^{-4}$	″ ″ ″
$\to e^-\gamma$ / all	$< 6 \times 10^{-4}$	″ ″ ″
$\to \mu^-\mu^+\mu^-$ / all	$< 2.9 \times 10^{-5}$	″ ″ ″
$\to e^-\mu^+\mu^-$ / all	$< 3.3 \times 10^{-5}$	″ ″ ″
$\to \mu^-e^+e^-$ / all	$< 3.3 \times 10^{-5}$	″ ″ ″
$\to e^-e^+e^-$ / all	$< 4 \times 10^{-5}$	″ ″ ″
$\to \mu^-\pi^0$ / all	$< 8 \times 10^{-4}$	″ ″ ″
$\to e^-\pi^0$ / all	$< 2.1 \times 10^{-3}$	″ ″ ″
$\to \mu^-K^0$ / all	$< 1.0 \times 10^{-3}$	″ ″ ″
$\to e^-K^0$ / all	$< 1.3 \times 10^{-3}$	″ ″ ″
$\to \mu^-\rho^0$ / all	$< 4 \times 10^{-5}$	″ ″ ″
$\to e^-\rho^0$ / all	$< 4 \times 10^{-5}$	″ ″ ″
$\to e^-\pi^+\pi^-$ / all	$< 4 \times 10^{-5}$	″ ″ ″
$\to \mu^-\pi^+\pi^-$ / all	$< 4 \times 10^{-5}$	″ ″ ″
$\to e^-\pi^+K^-$ / all	$< 4 \times 10^{-5}$	″ ″ ″
$\to \mu^-\pi^+K^-$ / all	$< 1.2 \times 10^{-4}$	″ ″ ″
$\to e^-K^*(892)^0$ / all	$< 5 \times 10^{-5}$	″ ″ ″
$\to \mu^-K^*(892)^0$ / all	$< 6 \times 10^{-5}$	″ ″ ″
$\to e^+\mu^-\mu^-$ / all	$< 4 \times 10^{-5}$	″ ″ ″
$\to \mu^+e^-e^-$ / all	$< 4 \times 10^{-5}$	″ ″ ″
$\pi^+ \to \mu^+\nu_e$ / all	$< 8.0 \times 10^{-3}$[j]	″ ″ ″
$\to \mu^-e^+e^+\nu$ / all	$< 8 \times 10^{-6}$	″ ″ ″
$\pi^0 \to e^{\pm}\mu^{\mp}$ / all	$< 7 \times 10^{-8}$	″ ″ ″
$K^+ \to \pi^+e^+\mu^-$ / all	$< 7 \times 10^{-9}$	″ ″ ″
$\to \pi^+e^-\mu^+$ / all	$< 5 \times 10^{-9}$	″ ″ ″
$\to \mu^-\nu e^+e^+$ / all	$< 2 \times 10^{-8}$	″ ″ ″
$\to \mu^+\nu_e$ / all	$< 4 \times 10^{-3}$[j]	″ ″ ″
$K_L^0 \to e^{\pm}\mu^{\mp}$ / all	$< 7 \times 10^{-9}$	″ ″ ″
$D^0 \to e^{\pm}\mu^{\mp}$ / all	$< 1.2 \times 10^{-4}$	″ ″ ″
$B^0 \to e^{\pm}\mu^{\mp}$ / all	$< 5 \times 10^{-5}$	″ ″ ″
ν oscillations		
$\Delta(m^2)$ for $\sin^2(2\theta)=1$		
$\bar{\nu}_e \not\to \bar{\nu}_e$	$< 0.014\ \mathrm{eV}^2$	″ ″ ″
$\nu_\mu \to \nu_e$	$< 0.09\ \mathrm{eV}^2$	″ ″ ″
$\bar{\nu}_\mu \to \bar{\nu}_e$	$< 0.9\ \mathrm{eV}^2$	″ ″ ″
$\nu_\mu \to \nu_\tau$	$< 0.9\ \mathrm{eV}^2$	″ ″ ″
$\bar{\nu}_\mu \to \bar{\nu}_\tau$	$< 2.2\ \mathrm{eV}^2$	″ ″ ″
$\nu_\mu \not\to \nu_\mu$	$< 0.23\ \mathrm{eV}^2$ or $> 1500\ \mathrm{eV}^2$	″ ″ ″
$\nu_e \not\to \nu_e$	$< 2.3\ \mathrm{eV}^2$	″ ″ ″
$\bar{\nu}_\mu \not\to \bar{\nu}_\mu$	$< 7\ \mathrm{eV}^2$ or $> 1200\ \mathrm{eV}^2$	″ ″ ″
$\nu_e \to \nu_\tau$	$< 9\ \mathrm{eV}^2$	″ ″ ″
$\sin^2(2\theta)$ for large $\Delta(m^2)$		
$\bar{\nu}_e \not\to \bar{\nu}_e$	< 0.14	″ ″ ″
$\nu_\mu \to \nu_e$	< 0.0034	″ ″ ″
$\bar{\nu}_\mu \to \bar{\nu}_e$	< 0.004	″ ″ ″
$\nu_\mu \to \nu_\tau$	< 0.004	″ ″ ″
$\bar{\nu}_\mu \to \bar{\nu}_\tau$	< 0.04	″ ″ ″
$\nu_\mu \not\to \nu_\mu$	$< 0.02\ [\Delta(m^2) = 100\ \mathrm{eV}^2]$	″ ″ ″
$\nu_e \not\to \nu_e$	< 0.07	″ ″ ″
$\bar{\nu}_e \to \bar{\nu}_\tau$	< 0.7	″ ″ ″
$\bar{\nu}_\mu \not\to \bar{\nu}_\mu$	$< 0.02\ [190\ \mathrm{eV}^2 < \Delta(m^2) < 320\ \mathrm{eV}^2]$	″ ″ ″
$\nu_e \to \nu_\tau$	< 0.12	″ ″ ″

For other lepton mixing effects in particle decays, see Full Listings

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Tests of Conservation Laws *(cont'd)*

Number Conservation Laws (Cont'd)

Quantity[a]	Value[b]	Conservation law tested
$\mu^- \, {}^{32}S \to e^+ \, {}^{32}Si^*$ / all	$< 9 \times 10^{-10}$	Total lepton number[k]
$\mu^- \, {}^{127}I \to e^+ \, {}^{127}Sb^{stable}$ / all	$< 3 \times 10^{-10}$	″ ″ ″
μ^- Ti $\to e^+$ Ca / all	$< 1.7 \times 10^{-10}$	″ ″ ″
$\tau^- \to e^+\pi^-\pi^-$ / all	$< 6 \times 10^{-5}$	″ ″ ″
$\to \mu^+\pi^-\pi^-$ / all	$< 6 \times 10^{-5}$	″ ″ ″
$\to e^+\pi^-K^-$ / all	$< 1.2 \times 10^{-4}$	″ ″ ″
$\to \mu^+\pi^-K^-$ / all	$< 1.2 \times 10^{-4}$	″ ″ ″
$\pi^+ \to \mu^+\overline{\nu}_e$ / all	$< 1.5 \times 10^{-3}$[j]	″ ″ ″
$K^+ \to \pi^-e^+e^+$ / all	$< 1.0 \times 10^{-8}$	″ ″ ″
$\to \pi^-e^+\mu^+$ / all	$< 7 \times 10^{-9}$	″ ″ ″
$\to \mu^+\overline{\nu}_e$ / all	$< 3.3 \times 10^{-3}$[j]	″ ″ ″
$\to e^+\pi^0\overline{\nu}_e$ / all	$< 3.0 \times 10^{-3}$[j]	″ ″ ″
neutrinoless double beta decay	See Full Listings	″ ″ ″
Eight examples of proton or bound neutron decay follow		
For other nucleon decay channels, see Stable Particle Summary Table		
τ_p / BR$(p \to e^+\pi^0)$	$> 250 \times 10^{30}$ years	Baryon number
τ_n / BR$(n \to e^+\pi^-)$	$> 31 \times 10^{30}$ years	″ ″
τ_p / BR$(p \to \mu^+\pi^0)$	$> 80 \times 10^{30}$ years	″ ″
τ_n / BR$(n \to \mu^+\pi^-)$	$> 23 \times 10^{30}$ years	″ ″
τ_p / BR$(p \to e^+K^0)$	$> 80 \times 10^{30}$ years	″ ″
τ_n / BR$(n \to e^+K^-)$	$> 1.3 \times 10^{30}$ years	″ ″
τ_p / BR$(p \to \mu^+K^0)$	$> 40 \times 10^{30}$ years	″ ″
τ_n / BR$(n \to \mu^+K^-)$	$> 0.4 \times 10^{30}$ years	″ ″
mean time for $n \to \overline{n}$ transition	> 4 years	″ ″
e mean life	$> 2 \times 10^{22}$ years	Charge
$n \to p\nu\overline{\nu} / pe^-\overline{\nu}$	$< 9 \times 10^{-24}$	″
Re x from $K^0 \to \pi e \nu$	0.006 ± 0.018	$\Delta S = \Delta Q$ [l]
Im x from $K^0 \to \pi e \nu$	-0.003 ± 0.026	″
$K^+ \to \pi^+\pi^+e^-\overline{\nu}$ / all	$< 1.2 \times 10^{-8}$	″
$\to \pi^+\pi^+\mu^-\overline{\nu}$ / all	$< 3.0 \times 10^{-6}$	″
$\Sigma^+ \to ne^+\nu$ / all	$< 5 \times 10^{-6}$	″
$\to n\mu^+\nu$ / all	$< 3.0 \times 10^{-5}$	″
$(\Sigma^+ \to n\ell^+\nu)/(\Sigma^- \to n\ell^-\overline{\nu})$	< 0.04	″
$\Xi^0 \to \Sigma^-e^+\nu$ / all	$< 9 \times 10^{-4}$	″
$\to \Sigma^-\mu^+\nu$ / all	$< 9 \times 10^{-4}$	″
$\to pe^-\overline{\nu}$ / all	$< 1.3 \times 10^{-3}$	$\Delta S = 2$ forbidden[l]
$\to p\mu^-\overline{\nu}$ / all	$< 1.3 \times 10^{-3}$	″ ″
$\to p\pi^-$ / all	$< 4 \times 10^{-5}$	″ ″
$\Xi^- \to ne^-\overline{\nu}$ / all	$< 3.2 \times 10^{-3}$	″ ″
$\to n\mu^-\overline{\nu}$ / all	$< 1.5 \times 10^{-2}$	″ ″
$\to p\pi^-e^-\overline{\nu}$ / all	$< 4 \times 10^{-4}$	″ ″
$\to p\pi^-\mu^-\overline{\nu}$ / all	$< 4 \times 10^{-4}$	″ ″
$\to n\pi^-$ / all	$< 1.9 \times 10^{-5}$	″ ″
$\to p\pi^-\pi^-$ / all	$< 4 \times 10^{-4}$	″ ″
$\Omega^- \to \Lambda\pi^-$ / all	$< 1.9 \times 10^{-4}$	″ ″
$m_{K_L} - m_{K_S}$	$(3.521 \pm 0.014) \times 10^{-12}$ MeV	″ ″

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Tests of Conservation Laws (*cont'd*)

Number Conservation Laws (Cont'd)

Quantity[a]	Value[b]	Conservation law tested
$(D^0 \to \bar{D}^0 \to \mu^-$ anything$)/(D^0 \to \mu^+$ anything$)$	$< 0\ 006$	$\Delta C = 2$ forbidden[ℓ]
$(D^0 \to \bar{D}^0 \to K^+\pi^-)/(D^0 \to K\pi)$	$< 0\ 004$	" "
$\lvert m_{D_1^0} - m_{D_2^0} \rvert$ (from previous limit)	$< 1\ 3 \times 10^{-10}$ MeV	" "
$(B^0 \to \bar{B}^0 \to \mu^-$ anything$)/(B^0 \to \mu^\pm$ anything$)$	$(0\ 17 \pm 0\ 05)$	$\Delta B = 2$ forbidden[ℓ]
$\lvert m_{B_1^0} - m_{B_2^0} \rvert$ (from previous limit)	$(3\ 7 \pm 1\ 0) \times 10^{-10}$ MeV	" "
$K_L^0 \to \mu^+\mu^-$ / all	$(9\ 5^{+2\ 4}_{-1\ 5}) \times 10^{-9}$	no flav chng neut curr[m]
$\to e^+e^-$ / all	$< 5 \times 10^{-9}$	" " " " "
$\to \mu^+\mu^-\gamma$ / all	$(2\ 8 \pm 2\ 8) \times 10^{-7}$	" " " " "
$\to e^+e^-\gamma$ / all	$(1\ 7 \pm 0\ 9) \times 10^{-5}$	" " " " "
$\to \pi^0\mu^+\mu^-$ / all	$< 1\ 2 \times 10^{-6}$	" " " " "
$\to \pi^0 e^+e^-$ / all	$< 2\ 3 \times 10^{-6}$	" " " " "
$\to \pi^+\pi^- e^+e^-$ / all	$< 2\ 5 \times 10^{-6}$	" " " " "
$\to \mu^+\mu^- e^+e^-$ / all	$< 5 \times 10^{-6}$	" " " " "
$\to e^+e^- e^+e^-$ / all	$< 2\ 6 \times 10^{-6}$	" " " " "
$K_S^0 \to \mu^+\mu^-$ / all	$< 3\ 2 \times 10^{-7}$	" " " " "
$\to e^+e^-$ / all	$< 1\ 0 \times 10^{-5}$	" " " " "
$K^+ \to \pi^+ e^+e^-$ / all	$(2\ 7 \pm 0\ 5) \times 10^{-7}$	" " " " "
$\to \pi^+\mu^+\mu^-$ / all	$< 2\ 4 \times 10^{-6}$	" " " " "
$\to \pi^+\nu\bar{\nu}$ / all	$< 1\ 4 \times 10^{-7}$	" " " " "
$D^0 \to \mu^+\mu^-$ / all	$< 1\ 1 \times 10^{-5}$	" " " " "
$\to e^+e^-$ / all	$< 1\ 3 \times 10^{-4}$	" " " " "
$B^0 \to \mu^+\mu^-$ / all	$< 5 \times 10^{-5}$	" " " " "
$\to e^+e^-$ / all	$< 8 \times 10^{-5}$	" " " " "
$\to K^0\mu^+\mu^-$ / all	$< 4 \times 10^{-4}$	" " " " "
$\to K^0 e^+e^-$ / all	$< 6 \times 10^{-4}$	" " " " "
$B^+ \to K^+\mu^+\mu^-$ / all	$< 3\ 2 \times 10^{-4}$	" " " " "
$\to K^+e^+e^-$ / all	$< 2\ 1 \times 10^{-4}$	" " " " "
$B \to (e^+e^-$ anything $+ \mu^+\mu^-$ anything$)$ / all	$< 2\ 4 \times 10^{-3}$	" " " " "
$\Sigma^+ \to pe^+e^-$ / all	$< 7 \times 10^{-6}$	" " " " "

a Branching fractions are described by a shorthand notation, e g , "$\mu^+ \to e^+\gamma$/all" means $\Gamma(\mu^+ \to e^+\gamma)/\Gamma(\mu^+ \to \text{all})$

b Limits are given at 90% confidence level while errors are given as ± 1 standard deviation

c Positronium data are from A P Mills and S Berko, Phys Rev Lett **18**, 420 (1967), and K Marko and A Rich, Phys Rev Lett **33**, 980 (1974) Values for 90% confidence limit are from A P Mills, private communication

d Derived from measured values of $\lvert\eta_{00}\rvert$ and $\lvert\eta_{+-}\rvert$, and theoretical input on phases See note on *CP* violation in the K_L^0 Full Listings

e Derived from measured values of ϕ_{+-} and $\lvert m_{K_L^0} - m_{K_S^0}\rvert$

f Neglecting photon channels See, e g , A Pais and S B Treiman, Phys Rev **D12**, 2744 (1975)

g Test of additive vs multiplicative lepton family number conservation

h Lepton family number conservation means separate conservation of e-number, μ-number, and τ-number

j These limits are derived from the analysis of neutrino oscillation experiments

k Violation of total lepton number conservation also implies violation of lepton family number conservation

ℓ Can be violated in second-order weak interactions

m Can be violated in higher-order electroweak interactions

PHYSICAL CONSTANTS*

Quantity	Symbol, equation	Value	Uncert (ppm)
speed of light	c	299 792 458 m s^{-1} (see note**)	(exact)
Planck constant	h	6 626 075 5(40)$\times 10^{-34}$ J s	0 60
Planck constant, reduced	$\hbar \equiv h/2\pi$	1 054 572 66(63)$\times 10^{-34}$ J s	0 60
		= 6 582 122 0(20)$\times 10^{-22}$ MeV s	0 30
electron charge magnitude	e	1 602 177 33(49)$\times 10^{-19}$ C = 4 803 206 8(15)$\times 10^{-10}$ esu	0 30, 0 30
conversion constant	$\hbar c$	197 327 053(59) MeV fm	0 30
conversion constant	$(\hbar c)^2$	0 389 379 66(23) GeV^2 mbarn	0 59
electron mass	m_e	0 510 999 06(15) MeV/c^2 = 9 109 389 7(54)$\times 10^{-31}$ kg	0 30, 0 59
proton mass	m_p	938 272 31(28) MeV/c^2 = 1 672 623 1(10)$\times 10^{-27}$ kg	0 30, 0 59
		= 1 007 276 470(12) u † = 1836 152 701(37) m_e	0 012, 0 020
deuteron mass	m_d	1875 613 39(57) MeV/c^2	0 30
unified atomic mass unit (u†)	(mass C^{12} atom)/12 = (1 g)/N_A	931 494 32(28) MeV/c^2 = 1 660 540 2(10)$\times 10^{-27}$ kg	0 30, 0 59
permittivity of free space	ϵ_0 } $\epsilon_0\mu_0 = 1/c^2$	8 854 187 817 $\times 10^{-12}$ F m^{-1}	(exact)
permeability of free space	μ_0	$4\pi\times 10^{-7}$ N A^{-2} = 12 566 370 614 $\times 10^{-7}$ N A^{-2}	(exact)
fine structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	1/137 035 989 5(61) ‡	0 045
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	2 817 940 92(38)$\times 10^{-15}$ m	0 13
electron Compton wavelength	$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$	3 861 593 23(35)$\times 10^{-13}$ m	0 089
Bohr radius ($m_{\rm nucleus} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	0 529 177 249(24)$\times 10^{-10}$ m	0 045
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$	13 605 698 1(40) eV §	0 30
Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	0 665 246 16(18) barn	0 27
Bohr magneton	$\mu_B = e\hbar/2m_e$	5 788 382 63(52)$\times 10^{-11}$ MeV T^{-1}	0 089
nuclear magneton	$\mu_N = e\hbar/2m_p$	3 152 451 66(28)$\times 10^{-14}$ MeV T^{-1}	0 089
electron cyclotron freq /field	$\omega^e_{\rm cycl}/B = e/m_e$	1 758 819 62(53)$\times 10^{11}$ rad s^{-1} T^{-1}	0 30
proton cyclotron freq /field	$\omega^p_{\rm cycl}/B = e/m_p$	9 578 830 9(29)$\times 10^{7}$ rad s^{-1} T^{-1}	0 30
gravitational constant	G_N	6 672 59(85)$\times 10^{-11}$ m^3 kg^{-1} s^{-2}	128
		= 6 707 11(86)$\times 10^{-39}$ $\hbar c$ (GeV/c^2)$^{-2}$	128
standard grav accel , sea level	g	9 806 65 m s^{-2}	(exact)
Fermi coupling constant	$G_F/(\hbar c)^3$	1 166 37(2)$\times 10^{-5}$ GeV^{-2}	17
Avogadro number	N_A	6 022 136 7(36)$\times 10^{23}$ mol^{-1}	0 59
Boltzmann constant	k	1 380 658(12)$\times 10^{-23}$ J K^{-1}	8 5
		= 8 617 385(73)$\times 10^{-5}$ eV K^{-1}	8 4
Wien displacement law constant	$b = \lambda_{\rm max}T$	2 897 756(24)$\times 10^{-3}$ m K	8 4
molar volume, ideal gas at STP	$N_A k$(273 15 K)/(1 atmosphere)	22 414 10(19)$\times 10^{-3}$ m^3 mol^{-1}	8 4
Stefan-Boltzmann constant	$\sigma = \pi^2 k^4/60\hbar^3c^2$	5 670 51(19)$\times 10^{-8}$ W m^{-2} K^{-4}	34
weak mixing angle	$\sin^2\theta_W$	0 230$\pm$0 005	
$W^\pm$ boson mass	m_W	80 9$\pm$1 4 GeV/c^2	
Z^0 boson mass	m_Z	91 9$\pm$1 8 GeV/c^2	

π = 3 141 592 653 589 793 238 e = 2 718 281 828 459 045 235 γ = 0 577 215 664 901 532 861

1 in ≡ 0 0254 m	1 barn ≡ 10^{-28} m^2	1 eV = 1 602 177 33(49)$\times 10^{-19}$ J	1 gauss (G) ≡ 10^{-4} tesla (T)
1 Å ≡ 10^{-10} m	1 dyne ≡ 10^{-5} newton (N)	1 eV/c^2 = 1 782 662 70(54)$\times 10^{-36}$ kg	0° C ≡ 273 15 K
1 fm ≡ 10^{-15} m	1 erg ≡ 10^{-7} joule (J)	2 997 924 58$\times 10^9$ esu = 1 coulomb (C)	1 atmosphere ≡ 1 013 25 $\times 10^5$ N/m^2

* Revised 1987 by B N Taylor Based mainly on the "1986 Adjustment of the Fundamental Physical Constants" by E Richard Cohen and Barry N Taylor, Rev Mod Phys **59**, 1121 (1987) See also E R Cohen and B N Taylor, "The Fundamental Physical Constants," Physics Today **40**, No 8, Part 2, BG-11 (August 1987) The figures in parentheses after the values give the 1-standard-deviation uncertainties in the last digits, the uncertainties in parts per million (ppm) are given in the last column The uncertainties of the values from a least-squares adjustment are in general correlated, and the laws of error propagation must be used in calculating additional quantities, the full variance matrix is given in the Rev Mod Phys paper The set of constants resulting from the 1986 adjustment has been recommended for international use by CODATA (Committee on Data for Science and Technology), and is the most up-to-date, generally accepted set currently available

** In 1983, the Conf Generale des Poids et Mesures adopted a new definition of the meter it is the distance traveled by light in vacuum in 1/299 792 458 s Thus the speed of light is *defined* to be 299 792 458 m/s For a discussion, see B W Petley, Nature **303**, 373 (1983)

† Formerly known as "amu "

‡ At $Q^2 = m_e^2$ At Q^2 of order m_W^2 the value is approximately 1/128

§ Since the completion of the 1986 adjustment, new experiments have yielded an improved value of the Rydberg constant for infinite mass, R_∞ The new work implies R_∞ = 10 973 731 572(4) m^{-1} rather than the 1986 recommended value of R_∞ = 10 973 731 534(13) m^{-1}

ASTROPHYSICAL CONSTANTS*

Quantity	Symbol, equation	Value
Planck mass	$M_{\rm Planck}$	$1.221\,047(79)\times10^{19}$ GeV/c^2
	$=(\hbar c/G_N)^{1/2}$	$=2.176\,71(14)\times10^{-8}$ kg
Hubble parameter†	H_0	$100h_0$ km s^{-1} Mpc^{-1}
		$=h_0\times(1.0\times10^{10}$ year$)^{-1}$
normalized Hubble parameter†	h_0	$0.4<h_0<1$
density parameter of the universe†	$\Omega_0\equiv\rho_0/\rho_c$	$0.05\lesssim\Omega_0\lesssim4$
critical density of the universe†	$\rho_c=3H_0^2/8\pi G_N$	$1.88\times10^{-26}\,h_0^2$ kg m^{-3}
		$=2.8\times10^{11}\,h_0^2\,M_\odot$ Mpc^{-3}

Quantity	Symbol	Value
cosmological constant	Λ	$\lvert\Lambda\rvert<3\times10^{-52}$ m^{-2}
age of the universe†	t_0	$1.5(5)\times10^{10}$ years
solar mass	$M_\odot$	$1.989(2)\times10^{30}$ kg
solar luminosity	$L_\odot$	$3.826(8)\times10^{26}$ J s^{-1}
solar radius	$R_\odot$	$6.959\,9(7)\times10^{8}$ m

1 tropical year = $3.155\,69\times10^7$ s
1 light year = $9.460\,528\times10^{15}$ m
1 parsec (pc) = 3.261 633 light years
1 astro. unit = $1.495\,979\times10^{11}$ m

* Compiled with the help of K. A. Olive, J. Primack, and S. Rudaz. Some values are taken from C. W. Allen, *Astrophysical Quantities* (Athlone Press, London, 1973).

† Subscript 0 indicates present-day values.

BIG BANG COSMOLOGY*

All observational evidence to date indicates that our universe is very nearly homogeneous and isotropic. The most general space-time interval with these properties is the Friedmann-Robertson-Walker metric (with $c=1$)

$$ds^2=dt^2-R^2(t)\left[\frac{dr^2}{1-\kappa r^2}+r^2(d\theta^2+\sin^2\theta\,d\phi^2)\right],$$

where $\kappa=+1$, -1, or 0 corresponds to closed, open, or spatially flat geometries. $R(t)$ is a scale factor for distances in comoving coordinates. Einstein's equations lead to the Friedmann equation

$$H^2\equiv\left(\frac{\dot R}{R}\right)^2=\frac{8\pi G_N\rho}{3}-\frac{\kappa}{R^2}+\frac{\Lambda}{3}$$

as well as to

$$\frac{\ddot R}{R}=\frac{\Lambda}{3}-\frac{4\pi G_N}{3}(\rho+3p)$$

where $H(t)$ is the Hubble parameter, ρ is the total mass-energy density, p is the isotropic pressure, and Λ is the cosmological constant. (For limits on Λ, see the Table of Astrophysical Constants; we will assume here $\Lambda=0$.) The Friedmann equation serves to define the density parameter Ω_0 (subscript 0 indicates present-day values)

$$\kappa/R_0^2=H_0^2(\Omega_0-1)\,,\qquad\Omega_0=\rho_0/\rho_c$$

and the critical density is defined as

$$\rho_c\equiv\frac{3H_0^2}{8\pi G_N}=1.88\times10^{-26}\,h_0^2\ \text{kg m}^{-3}\,,$$

with

$$H_0=100h_0\ \text{km s}^{-1}\ \text{Mpc}^{-1}\,.$$

Observational bounds give $0.4<h_0<1$. The three possible values of κ, $+1$, -1, and 0, correspond to $\Omega_0>1$, <1, and $=1$, i.e. to closed, open, and flat (critical) universes. The value of Ω_0 is inferred from velocity measurements on scales greater than 100 kpc, which are all consistent with $0.1\lesssim\Omega_0\lesssim0.4$. Conservative bounds are $0.05\lesssim\Omega_0\lesssim4$. The portion of Ω in luminous matter is much smaller, $0.005\lesssim\Omega_{\rm lum}\lesssim0.02$. The excess of Ω_0 over $\Omega_{\rm lum}$ leads to the inference that most of the matter in the universe is nonluminous "dark" matter.

Energy conservation implies that $\dot\rho=-3(\dot R/R)(\rho+p)$, so that for a matter-dominated ($p=0$) universe $\rho\propto R^{-3}$, while for a radiation-dominated ($p=1/3\rho$) universe $\rho\propto R^{-4}$. Thus the less singular curvature term κ/R^2 in the Friedmann equation can be neglected at early times when R is small. Energy conservation also implies that the universe expands adiabatically: R^3s = constant, where the entropy density $s=(\rho+p)/T$ and T is temperature.

The energy density of radiation can be expressed as

$$\rho_r=\frac{\pi^2k^4}{30}\,N(T)\,T^4$$

with $\hbar=1$, where $N(T)$ counts the effectively massless degrees of freedom of bosons and fermions:

$$N(T)=\sum_B g_B+\frac{7}{8}\sum_F g_F\,.$$

For example, for $m_\mu>kT>m_e$, $N(T)=g_\gamma+7/8(g_e+3g_\nu)=2+7/8[4+3(2)]=43/4$. For $m_\pi>kT>m_\mu$, $N(T)=57/4$.

In the early universe when $\rho\approx\rho_r$, then $\dot R\approx1/R$, so that $R\propto t^{1/2}$ and $Ht\to1/2$; the time-temperature relation then follows:

$$t\approx2.4[N(T)]^{-1/2}\left(\frac{1\text{MeV}}{kT}\right)^2\text{s}\,.$$

Today, the energy density in photons is $\rho_\gamma=(\pi^2k^4/15)T_0^4$, where the present temperature of the microwave background is $T_0=2.73\pm0.05$K, and the number density of photons n_γ is $400(T_0/2.7\text{K})^3$ cm^{-3}. For nonrelativistic matter (such as baryons) today, the energy density is $\rho_B=m_Bn_B$ with $n_B\propto R^{-3}$, so that for most of the history of the universe n_B/s is constant. Today, the entropy density is related to the photon density by $s\approx7n_\gamma$. Big Bang nucleosynthesis calculations limit $\eta=n_B/n_\gamma$ to $3\times10^{-10}\lesssim\eta\lesssim10^{-9}$. The parameter η is also related to the portion of Ω in baryons:

$$\Omega_B=3.6\times10^7\eta h_0^{-2}(T_0/2.7\text{K})^3\,,$$

so that $0.01\lesssim\Omega_Bh_0^2\lesssim0.04$ and hence the universe cannot be closed by baryons.

* Written December 1985 by K. A. Olive and S. Rudaz.

INTERNATIONAL SYSTEM (SI) NOMENCLATURE

Complete Set of Units

Physical Quantity	Name of Unit	Symbol for Unit	Physical Quantity	Name of Unit	Symbol for Unit
Base units			*Derived units (cont'd)*		
length	meter	m	electric charge	coulomb	C
mass	kilogram	kg	electric potential	volt	V
time	second	s	electric resistance	ohm	Ω
electric current	ampere	A	electric conductance	siemens	S
thermodynamic temperature	kelvin	K	electric capacitance	farad	F
amount of substance	mole	mol	magnetic flux	weber	Wb
luminous intensity	candela	cd	inductance	henry	H
Supplementary units			magnetic flux density	tesla	T
plane angle	radian	rad	luminous flux	lumen	lm
solid angle	steradian	sr	illuminance	lux	lx
Derived units			*activity (of a radioactive source)	becquerel	Bq
frequency	hertz	Hz	*absorbed dose (of ionizing radiation)	gray	Gy
energy	joule	J			
force	newton	N			
pressure	pascal	Pa			
power	watt	W			

See *Quantities, Units, and Symbols*, report of the Symbols Committee of the Royal Society, 2^{nd} ed (Royal Society, London, 1975)

*See Radioactivity and Radiation Protection Section

COMMONLY-USED METRIC PREFIXES

10^{-1} deci (d)	10^{-2} centi (c)	10^{-3} milli (m)	10^{-6} micro (μ)	10^{-9} nano (n)	10^{-12} pico (p)	10^{-15} femto (f)	10^{-18} atto (a)
10 deca (da)	10^2 hecto (h)	10^3 kilo (k)	10^6 mega (M)	10^9 giga (G)	10^{12} tera (T)	10^{15} peta (P)	10^{18} exa (E)

ATOMIC AND NUCLEAR PROPERTIES OF MATERIALS*

Material	Z	A	Nuclear[a] total cross section σ_T [barn]	Nuclear[b] inelastic cross section σ_I [barn]	Nuclear[c] collision length λ_T [g/cm²]	Nuclear[c] interaction length λ_I [g/cm²]	dE/dx min[d] $\frac{\Delta E}{}$ $\left[\frac{\text{MeV}}{\text{g/cm}^2}\right]$	Radiation length[e] L_{rad} [g/cm²]	Radiation length L_{rad} [cm] () is for gas	Density[f] [g/cm³] () is for gas [g/ℓ]	Refractive index n[f] () is $(n-1)\times10^6$ for gas
H_2	1	1.01	0.0387	0.033	43.3	50.8	4.12	61.28	865	0.0708(0.090)	1.112(140)
D_2	1	2.01	0.073	0.061	45.7	54.7	2.07	122.6	757	0.162(0.177)	1.128
He	2	4.00	0.133	0.102	49.9	65.1	1.94	94.32	755	0.125(0.178)	1.024(35)
Li	3	6.94	0.211	0.157	54.6	73.4	1.58	82.76	155	0.534	
Be	4	9.01	0.268	0.199	55.8	75.2	1.61	65.19	35.3	1.848	
C	6	12.01	0.331	0.231	60.2	86.3	1.78	42.70	18.8	2.265 [g]	
N_2	7	14.01	0.379	0.265	61.4	87.8	1.82	37.99	47.0	0.808(1.25)	1.205(300)
O_2	8	16.00	0.420	0.292	63.2	91.0	1.82	34.24	30.0	1.14(1.43)	1.22(266)
Ne	10	20.18	0.507	0.347	66.1	96.6	1.73	28.94	24.0	1.207(0.90)	1.092(67)
Al	13	26.98	0.634	0.421	70.6	106.4	1.62	24.01	8.9	2.70	
Si	14	28.09	0.660	0.440	70.6	106.0	1.66	21.82	9.36	2.33	
Ar	18	39.95	0.868	0.566	76.4	117.2	1.51	19.55	14.0	1.40(1.78)	1.233(283)
Ti	22	47.88	0.995	0.637	79.9	124.9	1.51	16.17	3.56	4.54	
Fe	26	55.85	1.120	0.703	82.8	131.9	1.48	13.84	1.76	7.87	
Cu	29	63.55	1.232	0.782	85.6	134.9	1.44	12.86	1.43	8.96	
Ge	32	72.59	1.365	0.858	88.3	140.5	1.40	12.25	2.30	5.323	-
Sn	50	118.69	1.967	1.21	100.2	163	1.26	8.82	1.21	7.31	
Xe	54	131.29	2.120	1.29	102.8	169	1.24	8.48	2.77	3.057(5.89)	(705)
W	74	183.85	2.767	1.65	110.3	185	1.16	6.76	0.35	19.3	
Pt	78	195.08	2.861	1.708	113.3	189.7	1.15	6.54	0.305	21.45	
Pb	82	207.19	2.960	1.77	116.2	194	1.13	6.37	0.56	11.35	
U	92	238.03	3.378	1.98	117.0	199	1.09	6.00	≈0.32	≈18.95	-
Air, 20°C, 1 atm (STP in paren.)					62.0	90.0	1.82	36.66	(30420)	0.001205(1.29)	1.000273(293)
H_2O					60.1	84.9	2.03	36.08	36.1	1.00	1.33
Shielding concrete[h]					67.4	99.9	1.70	26.7	10.7	2.5	-
SiO_2 (quartz)					67.0	99.2	1.72	27.05	12.3	2.64	1.458
H_2 (bubble chamber 26°K)					43.3	50.8	4.12	61.28	≈1000	≈0.063[i]	1.100
D_2 (bubble chamber 31°K)					45.7	54.7	2.07	122.6	≈900	≈0.140[i]	1.110
H-Ne mixture (50 mole percent)[j]					65.0	94.5	1.84	29.70	73.0	0.407	1.092
Ilford emulsion G5					82.0	134	1.44	11.0	2.89	3.815	-
NaI					94.8	152	1.32	9.49	2.59	3.67	1.775
BaF_2					92.1	146	1.35	9.91	2.05	4.89	1.56
BGO ($Bi_4Ge_3O_{12}$)					97.4	156	1.27	7.98	1.12	7.1	2.15
Polystyrene, scintillator (CH)[k]					58.4	82.0	1.95	43.8	42.4	1.032	1.581
Lucite, Plexiglas ($C_5H_8O_2$)					59.2	83.6	1.95	40.55	≈34.4	1.16–1.20	≈1.49
Polyethylene (CH_2)					56.9	78.8	2.09	44.8	≈47.9	0.92–0.95	
Mylar ($C_5H_4O_2$)					60.2	85.7	1.86	39.95	28.7	1.39	
Borosilicate glass (Pyrex)[l]					66.2	97.6	1.72	28.3	12.7	2.23	1.474
CO_2					62.4	90.5	1.82	36.2	(18310)	(1.977)	(410)
Ethane C_2H_6					55.73	75.71	2.25	45.66	(34035)	0.509(1.356)[m]	(1.038)[m]
Methane CH_4					54.7	74.0	2.41	46.5	(64850)	0.423(0.717)	(444)
Isobutane C_4H_{10}					56.3	77.4	2.22	45.2	(16930)	(2.67)	(1270)
NaF					66.78	97.57	1.69	29.87	11.68	2.558	1.336
LiF					62.00	88.24	1.66	39.25	14.91	2.632	1.392
Freon 12 (CCl_2F_2) gas, 26°C, 1 atm[n]					70.6	106	1.62	23.7	4810	(4.93)	1.001080
Silica Aerogel[o]					65.5	95.7	1.83	29.85	≈150	0.1–0.3	1.0+0.25ρ
NEMA G10 plate[p]					62.6	90.2	1.87	33.0	19.4	1.7	

ATOMIC AND NUCLEAR PROPERTIES OF MATERIALS (Cont'd)

Material	Dielectric constant () is $(\epsilon-1)\times10^6$ for gas	Young's modulus [10^6 psi]	Coeff of thermal expansion [10^{-6}cm/cm-°C]	Specific heat [cal/g-°C]	Electrical resistivity [$\mu\Omega$cm(@°C)]	Thermal conductivity [cal/cm-°C-sec]
H_2	(253.9)	—				—
D_2		...			—	—
He	(64)	—		...	—	
Li	—		56	0.86	8.55(0°)	0.17
Be	—	37	12.4	0.436	5.885(0°)	0.38
C		0.7	0.6–4.3	0.165	1375(0°)	0.057
N_2	(548.5)	—			—	
O_2	(495)	—			...	
Ne		—			—	
Al	—	10	23.9	0.215	2.65(20°)	0.53
Si		16	2.8–7.3	0.162		0.20
Ar	(517)			—		
Ti		16.8	8.5	0.126	50(0°)	—
Fe		28.5	11.7	0.11	9.71(20°)	0.18
Cu		16	16.5	0.092	1.67(20°)	0.94
Ge		—	5.75	0.073		0.14
Sn	—	6	20	0.052	11.5(20°)	0.16
Xe			—	—		
W		50	4.4	0.032	5.5(20°)	0.48
Pt		21	8.9	0.032	9.83(0°)	0.17
Pb		2.6	29.3	0.038	20.65(20°)	0.083
U			36.1	0.028	29(20°)	0.064

* Table revised April 1988 by R W Kenney. σ_T, σ_I, λ_T, and λ_I are energy dependent. Values quoted apply to high energy range given in footnote *a* or *b* where energy dependence is weak

a σ_{total} at 80–240 GeV for neutrons ($\approx \sigma$ for protons) from Murthy et al., Nucl Phys **B92** 269 (1975). This scales approximately as $A^{0.77}$

b $\sigma_{inelastic}=\sigma_{total}-\sigma_{elastic}-\sigma_{quasielastic}$, for neutrons at 60–375 GeV from Roberts et al., Nucl Phys., **B159** 56 (1979). For protons and other particles, see Carroll et al., Phys Lett **80B**, 319 (1979), note that $\sigma_I(p) \approx \sigma_I(n)$. σ_I scales approximately as $A^{0.71}$

c Mean free path between collisions (λ_T) or inelastic interactions (λ_I), calculated from $\lambda = A/(N \times \sigma)$, where N is the Avogadro number

d For minimum-ionizing protons and pions. ΔE is energy loss per g/cm^2 from Barkas and Berger, *Tables of Energy Losses and Ranges of Heavy Charged Particles*, NASA-SP-3013 (1964). For electrons and positrons see M J Berger and S M Seltzer, *Stopping Powers and Ranges of Electrons and Positrons* (2nd Ed.), U S National Bureau of Standards report NBSIR 82-2550-A (1982)

e From Y S Tsai, Rev Mod Phys **46**, 815 (1974), L_{rad} data for all elements up to uranium may be found here. Corrections for molecular binding applied for H_2, and D_2. Parentheses refer to gaseous form at STP (0°C, 1 atm)

f Values for solids, or the liquid phase at boiling point, except as noted. Values in parentheses for gaseous phase at STP (0°C, 1 atm). Refractive index given for sodium *D* line

g For pure graphite; industrial graphite density may vary 2.1 - 2.3 g/cm^3

h Standard shielding blocks, typical composition O_2 52%, Si 32.5%, Ca 6%, Na 1.5%, Fe 2%, Al 4%, plus reinforcing iron bars. The attenuation length, ℓ = 115 ± 5 g/cm^2, is also valid for earth (typical ρ = 2.15), from CERN-LRL-RHEL Shielding exp., UCRL-17841 (1968)

i Density may vary about ±3%, depending on operating conditions

j Values for typical working conditions with H_2 target 50 mole percent, 29°K, 7 atm

k Typical scintillator, e.g., PILOT B and NE 102A have an atomic ratio H/C = 1.10

ℓ Main components 80% SiO_2 + 12% B_2O_3 + 5% Na_2O

m Solid ethane density at −60°C, gaseous refractive index at 0°C, 546 mm pressure

n Used in Cerenkov counters. Values at 26°C and 1 atm. Indices of refraction from E R Hayes, R A Schluter, and A Tamosaitis, ANL-6916 (1964)

o $n(SiO_2) - 2n(H_2O)$ used in Cerenkov counters, ρ = density in g/cm^3. From M Cantin et al., Nucl Instr Meth **118**, 177 (1974)

p G10-plate, typical 60% SiO_2 and 40% epoxy

PERIODIC TABLE OF THE ELEMENTS

IA	IIA	IIIB	IVB	VB	VIB	VIIB	—	VIII	—	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H Hydrog 1 00794																	2 He Helium 4 002602
3 Li Lithium 6 941	4 Be Beryll 9 012182											5 B Boron 10 811	6 C Carbon 12 011	7 N Nitrog 14 00674	8 O Oxygen 15 9994	9 F Fluorine 18 9984032	10 Ne Neon 20 1797
11 Na Sodium 22 989768	12 Mg Magnes 24 3050											13 Al Alumin 26 981539	14 Si Silicon 28 0855	15 P Phosph 30 973762	16 S Sulfur 32 066	17 Cl Chlorine 35 4527	18 Ar Argon 39 948
19 K Potass 39 0983	20 Ca Calcium 40 078	21 Sc Scand 44 955910	22 Ti Titan 47 88	23 V Vanad 50 9415	24 Cr Chrom 51 9961	25 Mn Mangan 54 93805	26 Fe Iron 55 847	27 Co Cobalt 58 93320	28 Ni Nickel 58 69	29 Cu Copper 63 546	30 Zn Zinc 65 39	31 Ga Gallium 69 723	32 Ge German 72 61	33 As Arsenic 74 92159	34 Se Selen 78 96	35 Br Bromine 79 904	36 Kr Krypton 83 80
37 Rb Rubid 85 4678	38 Sr Stront 87 62	39 Y Yttrium 88 90585	40 Zr Zircon 91 224	41 Nb Niobium 92 90638	42 Mo Molybd 95 94	43 Tc Technet (98)	44 Ru Ruthen 101 07	45 Rh Rhod 102 90550	46 Pd Pallad 106 42	47 Ag Silver 107 8682	48 Cd Cadm 112 411	49 In Indium 114 82	50 Sn Tin 118 710	51 Sb Antimon 121 75	52 Te Tellur 127 60	53 I Iodine 126 90447	54 Xe Xenon 131 29
55 Cs Cesium 132 90543	56 Ba Barium 137 327	57–71 Rare Earths	72 Hf Hafnium 178 49	73 Ta Tantal 180 9479	74 W Tungst 183 85	75 Re Rhen 186 207	76 Os Osmium 190 2	77 Ir Iridium 192 22	78 Pt Platin 195 08	79 Au Gold 196 96654	80 Hg Mercury 200 59	81 Tl Thall 204 3833	82 Pb Lead 207 2	83 Bi Bismuth 208 98037	84 Po Polon (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Franc (223)	88 Ra Radium 226 0254	89–103 Acti- nides	104 (261)	105 (262)	106 (263)	107 (262)	108 (265)	109 (266)									

Rare earths (Lanthanide series)

57 La Lanthan 138 9055	58 Ce Cerium 140 115	59 Pr Prascody 140 90765	60 Nd Neodym 144 24	61 Pm Prometh (145)	62 Sm Samar 150 36	63 Eu Europ 151 965	64 Gd Gadolin 157 25	65 Tb Terb 158 92534	66 Dy Dyspros 162 50	67 Ho Holm 164 93032	68 Er Erbium 167 26	69 Tm Thulium 168 93421	70 Yb Ytterb 173 04	71 Lu Lutet 174 967

Actinide series

89 Ac Actin 227 0278	90 Th Thorium 232 0381	91 Pa Protactin 231 03588	92 U Uranium 238 0289	93 Np Neptun 237 0482	94 Pu Pluton (244)	95 Am Americ (243)	96 Cm Curium (247)	97 Bk Berkel (247)	98 Cf Californ (251)	99 Es Einstein (252)	100 Fm Fermi (257)	101 Md Mendel (258)	102 No Nobel (259)	103 Lr Lawrenc (260)

The atomic number (top left) is the number of protons in the nucleus The atomic mass (bottom) is weighted by isotopic abundance in the earth's surface, relative to the mass of the carbon 12 isotope, which is assigned a mass of exactly 12 unified atomic mass units (u, formerly called amu) Standard errors range from 1 to 9 in the last digit quoted Relative isotopic abundances often vary considerably, both in naturally occurring specimens and in commercially available samples Numbers in parentheses are mass numbers (the whole number nearest the atomic mass, in u) of the most stable isotope of that element Some elements without stable nuclides nevertheless exhibit a range of characteristic terrestrial compositions of long-lived radionuclides such that a meaningful atomic weight can be given Adapted from the Table of Standard Atomic Weights of the Elements, 1985 [*Pure and Applied Chemistry* **58**, 1677 (1986)]

ELECTRONIC STRUCTURE OF THE ELEMENTS

At no	Name	Chem Symbol	K	L		M			N			O	
			s	s	p	s	p	d	s	p	d	s	p
1	Hydrogen	H	1										
2	Helium	He	2										
3	Lithium	Li	2	1									
4	Beryllium	Be	2	2									
5	Boron	B	2	2	1								
6	Carbon	C	2	2	2								
7	Nitrogen	N	2	2	3								
8	Oxygen	O	2	2	4								
9	Fluorine	F	2	2	5								
10	Neon	Ne	2	2	6								
11	Sodium	Na	2	2	6	1							
12	Magnesium	Mg	2	2	6	2							
13	Aluminum	Al	2	2	6	2	1						
14	Silicon	Si	2	2	6	2	2						
15	Phosphorus	P	2	2	6	2	3						
16	Sulfur	S	2	2	6	2	4						
17	Chlorine	Cl	2	2	6	2	5						
18	Argon	Ar	2	2	6	2	6						
19	Potassium	K	2	2	6	2	6		1				
20	Calcium	Ca	2	2	6	2	6		2				
21	Scandium	Sc	2	2	6	2	6	1	2				
22	Titanium	Ti	2	2	6	2	6	2	2				
23	Vanadium	V	2	2	6	2	6	3	2				
24	Chromium	Cr	2	2	6	2	6	5*	1				
25	Manganese	Mn	2	2	6	2	6	5	2				
26	Iron	Fe	2	2	6	2	6	6	2				
27	Cobalt	Co	2	2	6	2	6	7	2				
28	Nickel	Ni	2	2	6	2	6	8	2				
29	Copper	Cu	2	2	6	2	6	10*	1				
30	Zinc	Zn	2	2	6	2	6	10	2				
31	Gallium	Ga	2	2	6	2	6	10	2	1			
32	Germanium	Ge	2	2	6	2	6	10	2	2			
33	Arsenic	As	2	2	6	2	6	10	2	3			
34	Selenium	Se	2	2	6	2	6	10	2	4			
35	Bromine	Br	2	2	6	2	6	10	2	5			
36	Krypton	Kr	2	2	6	2	6	10	2	6			
37	Rubidium	Rb	2	2	6	2	6	10	2	6		1	
38	Strontium	Sr	2	2	6	2	6	10	2	6		2	
39	Yttrium	Y	2	2	6	2	6	10	2	6	1	2	
40	Zirconium	Zr	2	2	6	2	6	10	2	6	2	2	
41	Niobium	Nb	2	2	6	2	6	10	2	6	4*	1	
42	Molybdenum	Mo	2	2	6	2	6	10	2	6	5	1	
43	Technetium	Tc	2	2	6	2	6	10	2	6	6	1	
44	Ruthenium	Ru	2	2	6	2	6	10	2	6	7	1	
45	Rhodium	Rh	2	2	6	2	6	10	2	6	8	1	
46	Palladium	Pd	2	2	6	2	6	10	2	6	10*	0	
47	Silver	Ag	2	2	6	2	6	10	2	6	10	1	
48	Cadmium	Cd	2	2	6	2	6	10	2	6	10	2	
49	Indium	In	2	2	6	2	6	10	2	6	10	2	1
50	Tin	Sn	2	2	6	2	6	10	2	6	10	2	2
51	Antimony	Sb	2	2	6	2	6	10	2	6	10	2	3
52	Tellurium	Te	2	2	6	2	6	10	2	6	10	2	4
53	Iodine	I	2	2	6	2	6	10	2	6	10	2	5
54	Xenon	Xe	2	2	6	2	6	10	2	6	10	2	6

At no	Name	Chem Symbol	K	L		M			N				O				P			Q
			s	s	p	s	p	d	s	p	d	f	s	p	d	f	s	p	d	s
55	Cesium	Cs	2	2	6	2	6	10	2	6	10		2	6			1			
56	Barium	Ba	2	2	6	2	6	10	2	6	10		2	6			2			
57	Lanthanum	La	2	2	6	2	6	10	2	6	10		2	6	1		2			
58	Cerium	Ce	2	2	6	2	6	10	2	6	10	2*	2	6			2			
59	Praseodymium	Pr	2	2	6	2	6	10	2	6	10	3	2	6			2			
60	Neodymium	Nd	2	2	6	2	6	10	2	6	10	4	2	6			2			
61	Promethium	Pm	2	2	6	2	6	10	2	6	10	5	2	6			2			
62	Samarium	Sm	2	2	6	2	6	10	2	6	10	6	2	6			2			
63	Europium	Eu	2	2	6	2	6	10	2	6	10	7	2	6			2			
64	Gadolinium	Gd	2	2	6	2	6	10	2	6	10	7	2	6	1		2			
65	Terbium	Tb	2	2	6	2	6	10	2	6	10	9*	2	6			2			
66	Dysprosium	Dy	2	2	6	2	6	10	2	6	10	10	2	6			2			
67	Holmium	Ho	2	2	6	2	6	10	2	6	10	11	2	6			2			
68	Erbium	Er	2	2	6	2	6	10	2	6	10	12	2	6			2			
69	Thulium	Tm	2	2	6	2	6	10	2	6	10	13	2	6			2			
70	Ytterbium	Yb	2	2	6	2	6	10	2	6	10	14	2	6			2			
71	Lutetium	Lu	2	2	6	2	6	10	2	6	10	14	2	6	1		2			
72	Hafnium	Hf	2	2	6	2	6	10	2	6	10	14	2	6	2		2			
73	Tantalum	Ta	2	2	6	2	6	10	2	6	10	14	2	6	3		2			
74	Tungsten	W	2	2	6	2	6	10	2	6	10	14	2	6	4		2			
75	Rhenium	Re	2	2	6	2	6	10	2	6	10	14	2	6	5		2			
76	Osmium	Os	2	2	6	2	6	10	2	6	10	14	2	6	6		2			
77	Iridium	Ir	2	2	6	2	6	10	2	6	10	14	2	6	7		2			
78	Platinum	Pt	2	2	6	2	6	10	2	6	10	14	2	6	9		1			
79	Gold	Au	2	2	6	2	6	10	2	6	10	14	2	6	10		1			
80	Mercury	Hg	2	2	6	2	6	10	2	6	10	14	2	6	10		2			
81	Thallium	Tl	2	2	6	2	6	10	2	6	10	14	2	6	10		2	1		
82	Lead	Pb	2	2	6	2	6	10	2	6	10	14	2	6	10		2	2		
83	Bismuth	Bi	2	2	6	2	6	10	2	6	10	14	2	6	10		2	3		
84	Polonium	Po	2	2	6	2	6	10	2	6	10	14	2	6	10		2	4		
85	Astatine	At	2	2	6	2	6	10	2	6	10	14	2	6	10		2	5		
86	Radon	Rn	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		
87	Francium	Fr	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		1
88	Radium	Ra	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		2
89	Actinium	Ac	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6	1	2
90	Thorium	Th	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6	2	2
91	Protactinium	Pa	2	2	6	2	6	10	2	6	10	14	2	6	10	2*	2	6	1	2
92	Uranium	U	2	2	6	2	6	10	2	6	10	14	2	6	10	3	2	6	1	2
93	Neptunium	Np	2	2	6	2	6	10	2	6	10	14	2	6	10	4	2	6	1	2
94	Plutonium	Pu	2	2	6	2	6	10	2	6	10	14	2	6	10	6	2	6		2
95	Americium	Am	2	2	6	2	6	10	2	6	10	14	2	6	10	7	2	6		2
96	Curium	Cm	2	2	6	2	6	10	2	6	10	14	2	6	10	7	2	6	1	2
97	Berkelium	Bk	2	2	6	2	6	10	2	6	10	14	2	6	10	9*	2	6		2
98	Californium	Cf	2	2	6	2	6	10	2	6	10	14	2	6	10	10	2	6		2
99	Einsteinium	Es	2	2	6	2	6	10	2	6	10	14	2	6	10	11	2	6		2
100	Fermium	Fm	2	2	6	2	6	10	2	6	10	14	2	6	10	12	2	6		2
101	Mendelevium	Md	2	2	6	2	6	10	2	6	10	14	2	6	10	13	2	6		2
102	Nobelium	No	2	2	6	2	6	10	2	6	10	14	2	6	10	14	2	6		2
103	Lawrencium	Lr	2	2	6	2	6	10	2	6	10	14	2	6	10	14	2	6	1	2
104	---	---	2	2	6	2	6	10	2	6	10	14	2	6	10	14	2	6	2	2

*Note irregularity

HIGH-ENERGY COLLIDER PARAMETERS

e^+e^- Colliders (I)

The numbers here were received from representatives of each collider by late 1987 Numbers for DORIS and for CESR (unless otherwise noted) are achieved SPEAR and PEP numbers are estimates for 1988 (Quantities are, where appropriate, r m s H ≡ horizontal direction, V ≡ vertical)

	SPEAR (SLAC)	DORIS (DESY)	CESR (Cornell)	PEP (SLAC)
Physics start date	1972	1973	1979	1980
Max beam energy (GeV)	4	5 6	6 (8 design)	15
Injection energy (GeV)	2 5	5 6	6 (8 design)	15
Luminosity (10^{30} cm^{-2} s^{-1})	10 at 3 GeV	30 at 5 GeV	90 at 5 3 GeV	50→80
Circumference (km)	0 234	0 288	0 768	2 2
No of interaction regions	2	2	2	1
No of particles per bunch (units 10^{10})	15	27	14	35
No of bunches per ring per species	1	1	7	3
Average beam current per species (mA)	30	30	60	21
Beam-beam tune shift per crossing (units 10^{-4})	300	≤ 260 (space charge limit)	150–250	500
Filling time (min)	15	1–2	20	15
Luminosity lifetime (hr)	≈ 3	0 3–1 5	3–4	≈ 3
Crossing angle (μ rad)	0	0	0	0
Energy spread (units 10^{-3})	1	1 2 at 5 GeV	0 6 at 5 3 GeV	1
Transverse emittance (10^{-9} π rad-m)	H ≈ 430	H 500 | at 5 V 5–50 | GeV	H 50 V 3	H ≈ 120
RF frequency (MHz)	358	500	500	352
Acceleration period (sec)	≤ 100	–	–	≤ 100
Bunch length (cm)	σ_z ≈ 4	σ ~ 2 at 5 GeV	1 7 (1 5 soon)	σ_z = 2
β^*, amplitude function at interaction point (m)	H 1 2 V 0 08	H 0 64 V 0 05	H 1 1 V 0 015	V 0 04
Free space at interaction point (m)	±2 5	±1 2	±2 2 (±0 6 to REC quads)	±3 7
Beam radius (10^{-6} m)	H 700 V 50	H 570 | at 5 V ~30 | GeV	H 500 V 11	H 340 V 14
No of utility insertions	18	1	2	5
Length of standard cell (m)	11 4	13 2	16	14 35
Phase advance per cell (deg)	H 79 V 90	H 140 V 50	45–90 (no standard cell)	H 56 V 33
Magnetic length of dipole (m)	2 35	3 2	1 6–6 6	5 4
No of dipoles in ring	36	H 24 V 8	86	192
No of quadrupoles in ring	46	68	106	248
Peak magnetic field (T)	1 1	1 5	0 3 normal | at 8 0 8 high field | GeV	0 36

HIGH-ENERGY COLLIDER PARAMETERS (Cont'd)

e^+e^- Colliders (II)

The numbers here were received from representatives of each collider by late 1987 (SLC made no updates to the entries in the 1986 edition) Numbers are subject to change, and many are only estimates (Quantities are, where appropriate, r m s H ≡ horizontal direction, V ≡ vertical, s c ≡ superconducting)

	TRISTAN (KEK)	SLC (SLAC)	BEPC (CHINA)	VEPP-4M (Novosibirsk)	LEP (CERN)	VLEPP, INP (Serpukhov)
Physics start date	1987	1988	1988	1989	Mid 1989	1996 (1998) ?
Max beam energy (GeV)	30	50	2 8	6	60	500 (1000)
Injection energy (GeV)	8	50	1 4	2	20	1
Luminosity (10^{30} cm^{-2} s^{-1})	10	6 (0 6 1st yr)	17	50	17	100 (1000)
Circumference or length (km)	3 02	1 45 + 1 47	0 2404	0 37	26 66	2×5 (2×10)
No of interaction regions	4	1	2	1	4	5
No of particles per bunch (units 10^{10})	22	7 2 (5 1st yr)	33	15	41 6	100 (20)
No of bunches per ring per species	2	1	1	2	4	1
Average beam current per species (mA)	7	0 0014	65	40	3	0 0016
Beam-beam tune shift per crossing (units 10^{-4})	300	-	400	500	300	-
Filling time (min)	20	-	40	15	0 25 mA/min	-
Luminosity lifetime (hr)	4–5	-	5	2	5	-
Crossing angle (μ rad)	0	0	0	0	0	0
Energy spread (units 10^{-3})	1 6	2	0 74	1	1 0	10
Transverse emittance (10^{-9} π rad-m)	H 180	0 42	H 610 V 47	H 400 V 20	H 52 V 2 1	H 2 0 | flat V 0 0005 | beam
RF frequency (MHz)	508 5808	-	199 53	180	352 2	0 7×10^4 (1 5×10^4)
Acceleration period (sec)	120	-	120	150	80	-
Bunch length (cm)	1 2	0 1	5 2	5	1 8	0 15
β^*, amplitude function at interaction point (m)	H 1 6 V 0 1	0 01	H 1 3 V 0 1	H 0 80 V 0 05	H 1 75 V 0 07	0 01 (0 005)
Free space at interaction point (m)	±4 5	±2 2	±2 5	±2	±3 5	-
Beam radius (10^{-6} m)	H 520 V 32	1 7 (2 1 1st yr)	H 890 V 69	H 1000 V 50	H 300 V 12	H 4 V 0 07
No of utility insertions	8	-	2	1	2	-
Length of standard cell (m)	16 1	5 2	6 6	7 2	79	1
Phase advance per cell (deg)	60	108	~ 60	65	60	-
Magnetic length of dipole (m)	5 86	2 5	1 6	2	11 66/pair	-
No of dipoles in ring	272	460+440	40 + 4 weak	78	3280+24 inj + 64 weak	-
No of quadrupoles in ring	400	-	68	150	520+288 + 8 s c	-
Peak magnetic field (T)	0 406	0 597	0 9028	0 6	0 135	-

HIGH-ENERGY COLLIDER PARAMETERS (Cont'd)

pp, $\bar{p}p$, and ep Colliders

The numbers here were received from representatives of each collider by late 1987. Numbers are subject to change, and many are only estimates. (Quantities are, where appropriate, r.m.s. H = horizontal direction, V ≡ vertical direction, s.c. = superconducting.)

	$Sp\bar{p}S$ (CERN)	TEVATRON (Fermilab)	HERA (DESY)	UNK (Serpukhov)	LHC (CERN)		SSC (USA)
Physics start date	1981	1987	Spring 1990	1995 ?	1995 ?		1996 ?
Particles collided	$p\bar{p}$	$p\bar{p}$	ep	pp	pp	ep	pp
Max. beam energy (TeV)	0.315 (0.45 in pulsed mode)	0.9–1.0	e 0.026 p 0.82	3	8	e 0.05 p 8	20
Injection energy (TeV)	0.026	0.15	e 0.014 p 0.040	0.4	0.450	e 0.02 p 0.450	1
Luminosity (10^{30} cm^{-2} s^{-1})	0.3 3 (1988)	0.5–1.0	15	400	1400	200	1000, β^* = 0.5 m 56, β^* = 10 m
Circumference (km)	6.911	6.28	6.336	20.772	26.659		83.631
No. of interaction regions	2	2 high β 2 low β	3	4	7	3	4 (initially)
No. of particles per bunch (units 10^{10})	p 15 $\bar{p}$ 2–10	p 6 $\bar{p}$ 2	e 3.48 p 10	3	2.5	e 8 p 30	0.80
No. of bunches per ring per species	3–6	3–6	220	8000	3564	540	15,456
Average beam current per species (mA)	p 6 $\bar{p}$ 0.8–4	p 1.4 $\bar{p}$ 0.5	e 58 p 163	550	164	e 80 p 300	71
Beam-beam tune shift per crossing (units 10^{-4})	40	17	e 250 p 20	6	25	e 400 p 33	8 in crossing plane for β^* = 0.5 m, 9 otherwise
Filling time (min)	0.5	4–7	e 10 p 20	~5	4	40	~40
Luminosity lifetime (hr)	24	6–20	>3	1	18	50	~24
Crossing angle (μ rad)	0	0	0	100	96	0	75
Energy spread (units 10^{-3})	0.35	0.15	e 0.91 p 0.4	0.05	0.1	0.1	0.05
Transverse emittance ($10^{-9}\,\pi$ rad-m)	15	2.6	e 34.5 (H), 6.90 (V) p 9 (H), 9 (V)	2	0.15	e 26 (H), 3.4 (V) p 0.6 (H), 0.6 (V)	0.047
RF frequency (MHz)	200	53	e 499.7 p 208.2	200	400	e 352 p 400	354.2
Acceleration period (sec)	10	44	-	100	1200		1000
Bunch length (cm)	20	50	e 0.83 p 15	10	7.5		6.8
β^*, amplitude function at interaction point (m)	1 (H) 0.5 (V)	0.72	e 2 (H), 0.70 (V) p 10 (H), 1.0 (V)	1	1	e 0.64 (H), 0.20 (V) p 45 (H), 2.8 (V)	0.5 at 2 IR's 10 at 2 IR's
Free space at interaction point (m)	28	±6.5	±5.5	±20	40	20	±20, β^* = 0.5 m ±120, β^* = 10 m
Beam radius (10^{-6} m)	120 (H) 86 (V)	43	e 263 (H), 69 (V) p 293 (H), 95 (V)	50	12	230 (H) 57 (V)	4.8, β^* = 0.5 m 21.7, β^* = 10 m
No. of utility insertions	-	4	4	4	2		4
Length of standard cell (m)	64	59.5	e 23.5 p 47	91.8	100		228.5
Phase advance per cell (deg)	90	67.8	e 60 p 90	82.5	90		90
Magnetic length of dipole (m)	6.26	6.12	e 9.2 p 8.9	5.8	9.54		16.54
No. of dipoles in ring	744	774	e 400 p 416	2176	1760		7664 (H) } 2 160 (V) } rings
No. of quadrupoles in ring	232	216	e 592 p 242	454	560		1576 (2 rings)
Magnet type	H type with bent-up coil ends	s.c. $\cos\theta$ warm iron	e C-shaped p s.c., collared, cold iron	s.c.	s.c. 2 in 1 cold iron		s.c.
Peak magnetic field (T)	1.4 (2 in pulsed mode)	4.4	e 0.274 p 4.65	5	10		6.61
$\bar{p}$ source accum. rate (hr^{-1})	5×10^{9} 5×10^{10} (1988)	4×10^{10}	-	-	-		-
Max. no. $\bar{p}$ in accum. ring	5×10^{11} 1×10^{12} (1988)	4×10^{11}	-	-	-		-

COSMIC RAY FLUXES*

The fluxes of particles of different types depend at the ~10% level on the latitude, their energy, and the conditions of measurement. Some typical sea-level values[1] for charged particles are given below

I_v flux per unit solid angle per unit horizontal area about vertical direction
$\equiv j(\theta=0, \phi)$ $[\theta$ = zenith angle, ϕ = azimuthal angle$]$.

J_1 total flux crossing unit horizontal area from above
$\equiv \int_{\theta \leqslant \pi/2} j(\theta, \phi) \cos\theta \, d\Omega \quad [d\Omega = \sin\theta \, d\theta \, d\phi]$.

J_2 total flux from above (impinging on a sphere of unit cross-sectional area)
$\equiv \int_{\theta \leqslant \pi/2} j(\theta, \phi) \, d\Omega$

	Total Intensity	Hard Component	Soft Component	
I_v	1.1×10^2	0.8×10^2	0.3×10^2	$m^{-2}\,sec^{-1}\,sterad^{-1}$
J_1	1.8×10^2	1.3×10^2	0.5×10^2	$m^{-2}\,sec^{-1}$
J_2	2.4×10^2	1.7×10^2	0.7×10^2	$m^{-2}\,sec^{-1}$

Very approximately, about 75% of all particles at sea level are penetrating, and are muons (the dominant portion of the hard component at sea level). The sea-level vertical flux ratio for protons to muons (both charges together) is about 3½% at 1 GeV/c, decreasing to about ½% at 10 GeV/c.

The muon flux at sea level has a mean energy of 2 GeV and a differential spectrum falling as E^{-2}, steepening smoothly to $E^{-3.6}$ above a few TeV. The angular distribution is $\cos^2\theta$, changing to $\sec\theta$ at energies above a TeV, where θ is the zenith angle at production. The +− charge ratio is 1.25–1.30. The mean energy of muons originating in the atmosphere is roughly 300 GeV at slant depths $\gtrsim$ a few hundred meters. Beyond slant depths of ~10 km water-equivalent, the muons are due primarily to in-the-earth neutrino interactions (roughly 1/8 interaction ton^{-1} year^{-1} for $E_\nu >$ 300 MeV, ~ constant throughout the earth).[2] Muons from this source arrive with a mean energy of 20 GeV, and have a flux of 2×10^{-9} $m^{-2}\,sec^{-1}\,sterad^{-1}$ in the vertical direction and about twice that in the horizontal,[3] down at least as far as the deepest mines.

* Updated April 1986

1. B. Rossi, Rev. Mod. Phys. **20**, 537 (1948). See also C. Grupen, "News from Cosmic Rays at High Energies," Siegen University preprint SI-84-01, and Allkofer and Grieder, *Cosmic Rays on Earth*, Fachinformationszentrum, Karlsruhe (1984); flux ratio for protons at sea level from G. Brook and A. W. Wolfendale, Proc. of the Phys. Soc. of London Vol. 83 (1964), p. 843.
2. J. G. Learned, F. Reines, and A. Soni, Phys. Rev. Lett. **43** 907 (1979).
3. M. F. Crouch et al., Phys. Rev. **D18**, 2239 (1978).

PARTICLE DETECTORS*

In this section we give various parameters for common detectors. The quoted numbers are usually based on some typical apparatus, and obviously should be regarded as rough approximations, valid only for preliminary design when applied to other cases. A more detailed introduction to detectors can be found in *Experimental Techniques in High Energy Physics*, T. Ferbel (ed.) (Addison-Wesley, Menlo Park, CA, 1987).

(1) Scintillators The photon yield in the frequency range of practical photomultiplier tubes is $\cong$ 1γ per 100 eV of charged particle ionization energy loss in plastic scintillator[1] and as below in other materials.

Properties of three scintillators[1,6]

	BaF_2	BGO	NaI(Tl)
Density (g/cm^3)	4.9	7.1	3.7
Radiation length (cm)	2.1	1.1	2.6
dE/dx (avg. for MIP) (MeV/cm)	6.6	9.0	4.8
Peak emission (nm)	220 310	480	410
Decay constant (ns)	0.6 620	300	250
Index of refraction	1.56	2.15	1.85
Light yield (photons/MeV)	2×10^3 6.5×10^3	2.8×10^3	4×10^4
Hygroscopic	slightly	no	very

(2) Cerenkov[7] The half-angle θ_c of the Cerenkov cone aperture in terms of the velocity β and the index of refraction n is

$$\theta_c = \arc\cos\left(\frac{1}{\beta n}\right) \cong \left[2\left(1-\frac{1}{\beta n}\right)\right]^{1/2}$$

The threshold velocity is $\beta_t = 1/n$, $\gamma_t = 1/(1-\beta_t^2)^{1/2}$. Therefore, $\beta_t\gamma_t = 1/(2\delta+\delta^2)^{1/2}$, where $\delta = n - 1$. Values of δ for various commonly used gases are given as a function of pressure and wavelength in Ref. 8; for values at atmospheric pressure, see the Table of Atomic and Nuclear Properties.

The number of photons N per cm of path length is given by

$$N = \frac{\alpha}{c}\int\left(1-\frac{1}{\beta^2 n^2}\right)2\pi d\nu = \frac{\alpha}{c}\beta_t^2\int\left(\frac{1}{\beta_t^2}-\frac{1}{\beta^2}\right)2\pi d\nu$$

$$\cong 500 \sin^2\theta_c \text{ /cm (visible spectrum)}$$

(3) Photon collection In addition to the photon yield, one should take into account the light collection efficiency ($\lesssim$10% for typical 1-cm-thick scintillator), the attenuation length ($\cong$1 to 4 m for typical scintillators[9]), and the quantum efficiency of the photomultiplier cathode ($\lesssim$25%).

(4) Typical detector characteristics

Detector Type	Accuracy (rms)	Resolution Time	Dead Time
Bubble chamber	$\simeq \pm 10$ to $\sim \pm 150\mu m$	$\cong$ 1 ms	$\gtrsim 1/20\ s^a$
Streamer chamber	$\pm 300\mu m$	$\cong$ 2 μs	$\gtrsim$100 ms
Proportional chamber	$\gtrsim \pm 300\mu m^{b,c}$	$\cong$ 50 ns	$\gtrsim$200 ns
Drift chamber	50 to 300μm	$\cong$ 2 ns^d	~100 ns
Scintillator		~150 ps	$\cong$ 10 ns
Emulsion	±1μm		—
Silicon strip	±2.5μm	e	e

^{a} Multiple pulsing time
^{b} 300μm is for 1 mm pitch
^{c} Delay line cathode readout can give ±150μm parallel to anode wire
^{d} For two chambers
^{e} Limited at present by noise and readout time of attached electronics

PARTICLE DETECTORS (Cont'd)

(5a) Electromagnetic shower detectors We give below typical energy resolutions (FWHM) for an incident electron in the 1 GeV range, E is in GeV. For a fixed number of radiation lengths, FWHM in the last three detectors would be expected to be proportional to $\sqrt{t}$ for t (= plate thickness) ≥ 0.2 radiation lengths [10]

For all detectors, operational resolution may be up to 50% worse due to dead areas, non-normally incident tracks, and other effects

NaI (20 rad lengths) [11] $\dfrac{2\%}{E^{1/4}}$

Lead glass (14 rad lengths) [12] $\dfrac{10-12\%}{\sqrt{E}}$

Lead-liquid argon (15.75 rad lengths) [10] $\dfrac{16\%}{\sqrt{E}}$
(42 cells 1.1 mm lead, 2 mm liquid argon, 2.3 mm lead-G10, 2 mm liquid argon)

Lead-scintillator sandwich (12.5 rad lengths) [13] $\dfrac{17\%}{\sqrt{E}}$
(66 cells 1 mm lead, 5 mm scintillator)

Proportional wire shower chamber (17 rad lengths) [14] $\dfrac{40\%}{\sqrt{E}}$
(36 cells 0.474 rad length type-metal + Al, 9.5 mm 80% Ar - 20% CH_4 gas)

(5b) Hadronic shower detectors [15] The performance of hadron calorimeters is crucially influenced by the relative response to the e.m. and non-e.m. shower components (e/h ratio). Ideally, this ratio should be 1 (compensation), thus eliminating the effects of the large non-Gaussian fluctuations in the π^0 content of hadron showers. A noncompensated calorimeter has the following problems

a) A non-Gaussian signal distribution for monoenergetic hadrons,
b) A nonlinear response to hadrons,
c) An energy resolution σ/E that does not scale as $E^{-1/2}$, but rather as $c_1 E^{-1/2} + c_2$ where c_2 is determined by the e/h value ($c_2 \sim 0$ for $e/h = 1$)

These effects may severely deteriorate the performance, particularly at high energies ($E \gtrsim 100$ GeV). a 20% deviation from linearity over one order of magnitude in energy, considerable non-Gaussian tails, and a constant term $c_2 = 5$–7% in the energy resolution were observed for calorimeters with $e/h \sim 1.3$ and 0.8 [16]

Fully sensitive detectors *cannot* be made compensating, unless made out of hydrogen. In all more practical cases $e/h \gtrsim 1.4$, since the undetectable binding energy lost when protons and neutrons are released from their nuclear environment accounts for 30–40% of the energy carried by the non-e.m. shower component

Compensation *can* be achieved in sampling calorimeters with hydrogenous active layers sandwiched between passive layers, making use of the fact that the calorimeter response to the various shower components (π^0's, minimum-ionizing particles, nonrelativistic protons and neutrons) may be very different in that case. The relative contribution of neutrons (through elastic np scattering) to the non-e.m. calorimeter signal, which is ~30% for a compensating calorimeter, can be tuned through the sampling fraction. Efficient neutron detection as provided by hydrogenous active layers also considerably reduces the contribution of fluctuations in nuclear binding-energy losses to the energy resolution

Compensation has been experimentally demonstrated in calorimeters using 2.5 mm plastic scintillator active layers and ^{238}U (3 mm)[17] or Pb (10 mm)[18] passive layers, with a total energy resolution σ/E of $0.34\,E^{-1/2}$ or $0.44\,E^{-1/2}$, respectively (E in GeV). The former has also been shown linear to within 2% over three orders of magnitude in energy with Gaussian signal distributions

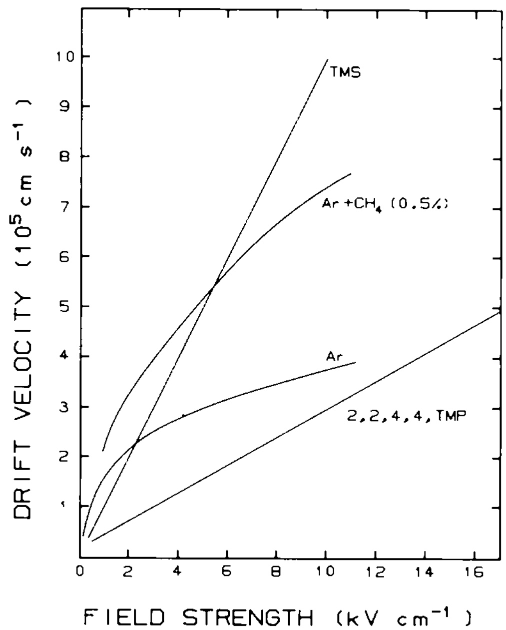
(6) *dE/dx* resolution in argon Particle identification (relativistic, $Q = 1$ incident particles) by dE/dx is dependent on the width of the distribution

Multiple-sample Ar gas counters (no lead) [19]

$$\frac{FWHM\left(\left.\frac{dE}{dx}\right|_{\text{most probable}}\right)}{\left.\frac{dE}{dx}\right|_{\text{most probable}}} = 0.96N^{-0.46}(tp)^{-0.32}, \; bc$$

N = no. samples, t = thickness per sample (cm), p = pressure (atm.), most commonly used chamber gases (except Xe) give approximately the same resolution

(7) Free electron drift velocities in liquid ionization chambers[20–23]



(8) An approximation for the calculation of particle momenta in a uniform magnetic field [24] The path of motion of a charged particle of momentum p, in GeV/c, is a helix of constant radius of curvature and constant pitch angle λ, with the axis of the helix along $\vec{H}$ and

$$p\cos\lambda = 0.29979\,ZH/k\,,$$

where the field strength H is in tesla, the charge Z is in units of the electronic charge, and the curvature k, equal to 1/radius of curvature, is measured in a plane normal to the field, in m^{-1}

The distribution of measurements of curvature about its true value is approximately Gaussian. The curvature error for a large number of uniformly spaced points measured on the trajectory of a charged particle in a uniform magnetic field can be approximated by the following expression

$$(\delta k)^2 = (\delta k_{res})^2 + (\delta k_{ms})^2\,,$$

where δk = curvature error
δk_{res} = curvature error due to finite measurement resolution
δk_{ms} = curvature error due to multiple scattering

For a charged particle measured many times along its path (≥ 10 measurements) in a uniform medium,

$$\delta k_{res} = \frac{\epsilon}{L'^2}\sqrt{\frac{720}{N+5}}\,,$$

PARTICLE DETECTORS (Cont'd)

where N = number of points (uniformly spaced) measured along track
L' = the projected length of the track onto the bending plane
ϵ = measurement error for each point perpendicular to the trajectory

The contribution due to multiple Coulomb scattering is approximately

$$\delta k_{ms} \approx \frac{(0.016)(\text{GeV}/c)Z}{Lp\beta} \sqrt{\frac{L}{L_R}}$$

where p = momentum (GeV/c)
Z = charge of incident particle in units of e
L_R = radiation length of the scattering medium
β = the kinematic variable v/c
L = the total track length

More accurate approximations for multiple scattering may be found in the section on Passage of Particles Through Matter (following). The contribution to the curvature error is given approximately by $\delta k_{ms} \simeq 8 s^{rms}_{plane}/L^2$, where s^{rms}_{plane} is defined there.

(9) Proportional chamber wire instability The limit on the voltage V for a wire tension T, due to mechanical effects when the electrostatic repulsion of adjacent wires exceeds the restoring force of wire tension, is given by (MSKA)[25]

$$V \le \frac{s}{\ell C} \sqrt{4\pi\epsilon_0 T}$$

where s, ℓ, and C are the wire spacing, length, and capacitance per unit length. An approximation to C for chamber half-gap t and wire diameter d (good for $s \lesssim t$) gives[26]

$$V \lesssim 59 T^{1/2} \left[\frac{t}{\ell} \cdot \frac{s}{\pi \ell} \ell n \left(\frac{s}{\pi d} \right) \right],$$

where V is in kV, and T is in grams-weight equivalent.

(10) Proportional and drift chamber potentials The potential distributions and fields in a proportional or drift chamber can usually be calculated with good accuracy from the exact formula for the potential around an array of parallel line charges q (coul/m) along z and located at $y = 0$, $x = 0, \pm s, \pm 2s, \ldots$

$$V(x,y) = -\frac{q}{4\pi\epsilon_0} \ell n \left\{ 4 \left[\sin^2\left(\frac{\pi x}{s}\right) + \sinh^2\left(\frac{\pi y}{s}\right) \right] \right\}$$

Errors from the presence of cathodes, mechanical defects, TPC-type edge effects, etc., are usually small and are beyond the scope of this review.

(11) Silicon strip detectors and photodiodes These are silicon diodes operated with a reverse bias voltage V (typically 30–300 volts) sufficient to deplete the sensitive volume of most mobile charge carriers (electrons and holes). The active (depletion layer) thickness t (cm) is given in a simple model by

$$t \doteq \sqrt{\frac{2\epsilon V}{ne}} - \sqrt{2\rho\mu\epsilon V} \, .$$

where n = number of impurity centers/cm^3
e = electron charge
ϵ = dielectric constant $\cong$ 1 pF/cm $\sim$ 11.9 ϵ_0
ρ = resistivity $\sim$ 1–20 kΩ-cm
μ = majority charge carrier mobility
$\cong$ 1300–1500 cm^2/volt-sec (electrons)
$\cong$ 450–600 cm^2/volt-sec (holes)

The capacitance of the diode is ϵ/t per unit area, but in the case of microstrips this is usually dominated by the interstrip capacitance of ~1 pF per cm of strip length. A minimum-ionizing particle has a Landau energy-loss distribution with average energy loss 39 keV/100 μm, most probable energy loss 26 keV in 100 μm (which scales within ~±10% from ~20 to ~300 μm) and full width at half-maximum of roughly $0.1 t/\beta^2$ keV, where t is the detector thickness in microns and $\beta = v_{inc}/c$. The width is usually increased further by electronic noise ($\sigma \sim$ 1–10 keV) and for thin layers by a Gaussian contribution due to atomic effects [$\sigma \sim (0.3\text{–}0.4)\sqrt{t}$ keV]. The average energy required to produce an electron-hole pair is 3.6 eV, from which one can estimate total charge of either sign released. Silicon detectors can tolerate integrated charged-particle fluxes of up to $\sim 10^{10}$-10^{14}/cm^2 and still operate as efficient detectors.

Typical photodiodes are sensitive (quantum efficiencies greater than ~ 10%) to wavelengths from ~ 200 nm to 1100 nm.

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* Updated April 1988 by D. Anderson, G. Hall, and R. Wigmans.

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PASSAGE OF PARTICLES THROUGH MATTER*

(1) Energy loss rates for heavy charged projectiles A heavy projectile (much more massive than an electron) of charge $Z_{inc}e$ incident at speed βc ($\beta >> 1/137$) through a slowing medium, dissipates energy principally via interactions with the electrons of the medium. The mean rate of such energy loss per unit path length x, called the stopping power, is given by the Bethe-Bloch equation [1]

$$\left(\frac{dE}{dx}\right)_{inc} = \frac{D\,Z_{med}\,\rho_{med}}{A_{med}}\left(\frac{Z_{inc}}{\beta}\right)^2 \times \left[\ln\left(\frac{2m_e\gamma^2\beta^2c^2}{I}\right) - \beta^2 - \frac{\delta}{2} - \frac{C}{Z_{med}}\right]\left\{1 + \nu\right\}$$

where $D = 4\pi N_A r_e^2 m_e c^2 = 0.3071$ MeV cm^2/g (see Physical Constants Table). Mean range and energy loss figures appear at the end of this section.

Here, Z_{med} and A_{med} are the charge and mass numbers of the medium and ρ_{med} is the mass density of the medium. I, δ, C, and ν are phenomenological functions. Frequently, the values of δ, C, and ν are negligibly small, the parameter I characterizes the binding of the electrons of the medium. As a rule of thumb, we may estimate I for an idealized medium as $I \cong 16\ (Z_{med})^{0.9}$ eV when $Z_{med} > 1$. For realistic media the value of I will vary at the 10% level from this estimate. Variations of this order occur due to atomic effects such as completion of a shell, also due to chemical binding, and even due to the phase of the substance. Hydrogen, perhaps the most sensitive, has I of about 15 eV in the atomic mode, rising to about 19.2 eV as H_2 gas and to 21.8 eV as H_2 liquid [2]. For many substances, the transition from gas to solid is accompanied by a 20-30% increase in I [2]. We may *approximately* treat media which are chemical mixtures or compounds by computing

$$\frac{dE}{dx} \simeq \sum_{n=1}^{N}\left(\frac{dE}{dx}\right)_n ,$$

with $(dE/dx)_n$ appropriate to the n^{th} chemical constituent (using $\rho^{(n)}_{med}$ as the partial density in the formula for dE/dx) [3]. For many chemical compounds, small corrections to this additivity rule may be found in Ref. 2.

The function δ represents the density effect upon the energy loss rate, it is non-negligible only for highly relativistic projectiles in denser media [4]. For ultra-relativistic projectiles, δ approaches $2\ln\gamma$ − constant, where the value of the constant depends upon the density of the medium as well as its chemical composition.

The function C represents shell corrections to the energy loss rate [1]. These effects are non-negligible only for projectiles with speeds not much faster than the speeds of the fastest electrons bound in the medium.

The function ν represents corrections due to higher order electrodynamics [5]. These effects become important when $|Z_{inc}/\beta|$ is comparable to 137. For relativistic unit-charge projectiles, $|\nu|$ is of the order of 1%, positively charged projectiles lose energy more rapidly than do their charge conjugates [5,6].

For nonrelativistic projectiles, our formulae above are inapplicable. At the very slowest speeds, total energy loss rates are believed to be proportional to β, rising through a peak at projectile speeds comparable to atomic speeds (β on the order of αc), after having passed through a smaller peak (due to elastic Coulomb collisions with the *nuclei* of the slowing medium[7]) at intermediate speeds. For example, for protons in Si, $dE/dx = 61.23\ \beta$ GeV/(gm cm^{-2}) for $\beta < 0.005$, the peak occurs at $\beta = 0.0126$ where $dE/dx = 522$ MeV/(gm cm^{-2}). In some cases, energy loss rates depend significantly upon the relation of the projectile trajectory to the crystalline structure of the slowing medium [8].

For relativistic projectiles, $(dE/dx)_{inc}$ falls rapidly with increasing β until reaching a minimum around $\beta = 0.96$ (almost independent of medium), followed by a slow rise. Because of the density effect, the quantity in square brackets approaches $\ln\gamma$ + constant for large γ.

The quantity $(dE/dx)_{inc}\delta x$ is the *mean* total energy loss via interactions with electrons of the medium in a layer of thickness δx. For any finite δx, Poisson fluctuations can cause the actual energy loss to deviate from the mean. For thin layers, the distribution is broad and skewed, being peaked below $(dE/dx)\delta x$, and having a long tail toward large energy losses [9]. Only for a very thick layer $[(dE/dx)\delta x >> 2m_e\beta^2\gamma^2c^2]$ will the distribution of energy losses become nearly Gaussian. The large fluctuations of the total energy loss rate from the mean are due to a small number of collisions involving large energy transfers. The fluctuations are greatly reduced for the so-called restricted energy loss rate, described in Section (4).

(2) Ionization yields Physicists frequently relate total energy loss to the number of ion pairs produced near the projectile's track. This relation becomes complicated for relativistic projectiles due to the wandering of energetic knock-on electrons whose ranges exceed the dimensions of the fiducial volume. For a qualitative appraisal of the nonlocality of energy deposition by such modestly energetic knock-on electrons in various media, see Ref. 10. Furthermore, the mean local energy dissipation per local ion pair produced, W, while essentially constant for relativistic projectiles, increases at slow projectile speeds [11]. The numerical value of W for gases can be surprisingly sensitive to trace amounts of various contaminants [11]. Of course, in addition to the preceding effects, practical ionization yields may be greatly influenced by subsequent recombinations and other factors [12].

(3) Energetic knock-on electrons For a relativistic point-charge projectile, the production of high energy (kinetic energy $T >> I$) electrons is given by [13]

$$\frac{d^2N}{dT\,dx} = \frac{1}{2}D\left(\frac{Z_{med}}{A_{med}}\right)\left(\frac{Z_{inc}}{\beta}\right)^2\rho_{med}\frac{1}{T^2}F$$

for $I << T \leq T_{max}$, where

$$T_{max} = \frac{2m_e\beta^2\gamma^2c^2}{1 + 2\gamma\dfrac{m_e}{M_{inc}} + \left(\dfrac{m_e}{M_{inc}}\right)^2} ,$$

M_{inc} is the mass of the incident projectile, and all other quantities except F are as in Sec. (1). F ($\simeq 1$ for $T << T_{max}$) is a factor dependent upon the spin of the projectile.

For spin-0 projectiles,

$$F = 1 - \beta^2\frac{T}{T_{max}} ,$$

for spin-1/2 projectiles,

$$F = 1 - \beta^2\frac{T}{T_{max}} + \frac{1}{2}\left(\frac{T}{T_{inc} + M_{inc}c^2}\right)^2$$

where T_{inc} is the kinetic energy of the projectile,

for electrons incident,

$$F = \beta^2 T^2\left[\frac{T_{inc}}{T(T_{inc} - T)} - \frac{1}{T_{inc}}\right]^2 ,$$

and for positrons incident,

$$F = \beta^2\left[1 - \frac{T}{T_{inc}} + \left(\frac{T}{T_{inc}}\right)^2\right]^2$$

PASSAGE OF PARTICLES THROUGH MATTER (Cont'd)

For incident electrons, the indistinguishability of projectile and target means that the range of T is only up to $T_{inc}/2$. For additional formulas see Ref. 14. Our formula is inaccurate for T close to I: for $2I \lesssim T \lesssim 10I$, the $1/T^2$ dependence above becomes $\simeq T^{-\eta}$ with $3 \lesssim \eta \lesssim 5$.[15]

(4) Rates of restricted energy loss for relativistic charged projectiles. The variability of energy loss for heavy projectiles is due primarily to the variability in the production of energetic knock-on electrons. Bremsstrahlung and pair-production processes make this variability even greater for electrons than for heavy particles as projectiles (see, e.g., the figure Fractional Energy Loss for Electrons and Positrons in Lead). If an instrument such as a bubble chamber, is capable of isolating these high-energy-loss interactions, then it is appropriate to consider the rate of energy loss excluding them, i.e., a restricted energy loss rate. The mean energy loss rate via all collisions which have energy transfer T such that $T \le E_{max} << T_{max}$ is[1]

$$\left(\frac{dE}{dx}\right)_{\le E_{max}} = \frac{1}{2} D \frac{Z_{med}\rho_{med}}{A_{med}} \left(\frac{Z_{inc}}{\beta}\right)^2$$

$$\times \left[\ln\left(\frac{E_{max}T_{max}}{I^2}\right) - \beta^2 - \delta - \frac{2C}{Z_{med}}\right]$$

Notice the overall factor of 1/2. See Sec. (1) above for definitions of the quantities in this equation.

The density effect causes the restricted energy loss rate to approach a constant, the Fermi plateau value, for the fastest projectiles.

(5) Multiple scattering through small angles. As a charged particle traverses a medium it is deflected by many small-angle elastic scatterings. The bulk of this deflection is due to elastic Coulomb scattering from the nuclei within the medium, hence the usual identification as multiple Coulomb scattering (note, however, that strong interactions do contribute to the total multiple scattering for hadronic projectiles). For both Coulomb and strong interactions the Central Limit Theorem provides little useful guidance in establishing the precise nature of the distribution of the total deflections resulting from multiple scattering. The true distribution is roughly Gaussian only for small deflection angles, while it shows much greater probability for large-angle scatterings ($\gtrsim$ a few θ_0, see below, depending on absorber) than the Gaussian would suggest. These tails on the distribution (a few per cent of peak height in the region where the Gaussian part becomes negligible) are more pronounced for hadrons than for muons as projectiles. The large-angle behavior of these distributions is best estimated by computing the exact distribution for the vectorial sum of the largest deflections based upon the true elastic scattering cross section of the projectile against the medium,[16] or, when applicable, by interpolation from tabular data.[17] An easier alternative which may suffice for noncritical applications would be to use a Gaussian approximation with the following width:[18]

$$\theta_0 = \frac{14.1\ \mathrm{MeV}/c}{p\beta} Z_{inc}\sqrt{L/L_R}\left[1 + \frac{1}{9}\log_{10}(L/L_R)\right]\ \text{(radians)},$$

where p, β, and Z_{inc} are the momentum (in MeV/c), velocity, and charge number of the incident particle, and L/L_R is the thickness, in radiation lengths, of the scattering medium. L_R for certain materials is given in the Table of Atomic and Nuclear Properties of Materials. See also Sec. (8) below. The angle, θ_0, is a fit to Molière[16] theory, accurate to about 5% for $10^{-3} < L/L_R < 10$ except for very light elements or low velocity where the error is about 10 to 20%. In this Gaussian approximation, θ_0 has the meaning

$$\theta_0 = \theta_{plane}^{rms} = \frac{1}{\sqrt{2}}\theta_{space}^{rms}.$$

The nonprojected (space) and projected (plane) angular distributions are given approximately[16] by the Gaussian forms

$$\frac{1}{2\pi\theta_0^2}\exp\left(-\frac{\theta_{space}^2}{2\theta_0^2}\right)d\Omega,$$

$$\frac{1}{\sqrt{2\pi}\,\theta_0}\exp\left(-\frac{\theta_{plane}^2}{2\theta_0^2}\right)d\theta_{plane}$$

where θ is the deflection angle. In this approximation, $\theta_{space}^2 \simeq (\theta_{plane,x}^2 + \theta_{plane,y}^2)$, where the x and y axes are orthogonal to the direction of motion, and $d\Omega \simeq d\theta_{plane,x}\,d\theta_{plane,y}$. Deflections into $\theta_{plane,x}$ and $\theta_{plane,y}$ are independent and identically distributed.

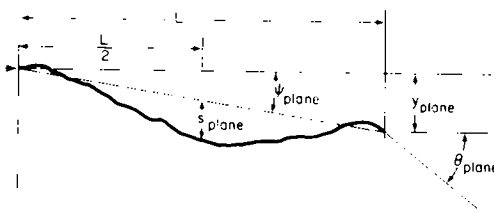
Other quantities are sometimes used to describe the amount of multiple Coulomb scattering: the auxiliary quantities ψ_{plane}, y_{plane}, and s_{plane} (see the figure) obey

$$\psi_{plane}^{rms} = \frac{1}{\sqrt{3}}\theta_{plane}^{rms} = \frac{1}{\sqrt{3}}\theta_0,$$

$$y_{plane}^{rms} = \frac{1}{\sqrt{3}}L\,\theta_{plane}^{rms} = \frac{1}{\sqrt{3}}L\theta_0$$

and

$$s_{plane}^{rms} = \frac{1}{4\sqrt{3}}L\,\theta_{plane}^{rms} = \frac{1}{4\sqrt{3}}L\theta_0$$



All the quantitative estimates in this section apply only in the limit of small θ_{plane}^{rms} and in the absence of large-angle scatters. The random variables s, ψ, y, and θ in a given plane are distributed in a correlated fashion (see the section on Probability, Statistics, and Monte Carlo for the definition of the correlation coefficient). Obviously, $y \simeq L\psi$. In addition, y and θ have correlation coefficient $\rho_{y\theta} = \sqrt{3}/2 \simeq 0.87$. For Monte Carlo generation of a joint $(y_{plane}, \theta_{plane})$ distribution or for other calculations, it may be most convenient to work with independent Gaussian random variables (z_1, z_2) with mean zero and variance one and subsequently set

$$y_{plane} = z_1 L\theta_0(1 - \rho_{y\theta}^2)^{1/2}/\sqrt{3} + z_2\rho_{y\theta}L\theta_0/\sqrt{3}$$

$$= z_1 L\theta_0/\sqrt{12} + z_2 L\theta_0/2,$$

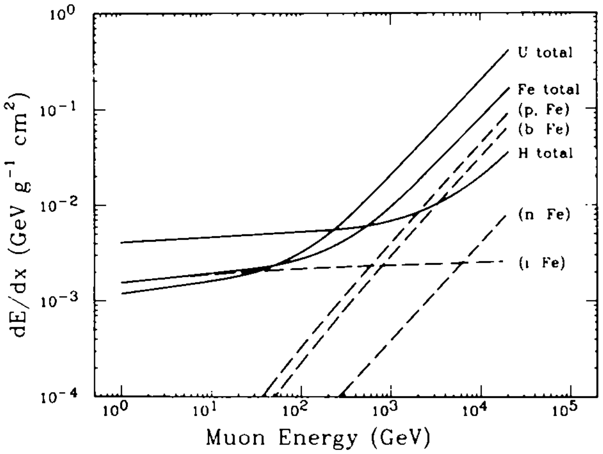
$$\theta_{plane} = z_2\theta_0$$

Note that the second term for y_{plane} equals $L\theta_{plane}/2$ and represents the displacement that would have occurred had the deflection θ_{plane} all occurred at the single point $L/2$.

(6) Muon energy loss at high energy. At muon energies above a few hundred GeV, radiative processes (bremsstrahlung, direct pair production, and photonuclear interactions) dominate over ionization as sources of energy loss. The figure below shows the total average energy loss of a muon per g/cm² in various materials.

PASSAGE OF PARTICLES THROUGH MATTER (Cont'd)

plotted against the muon energy. In the case of iron, the contribution of each process is also shown. Average dE/dx values for many media for muons in the energy range 1–10000 GeV are tabulated in Ref. 19. The radiative processes are characterized by small cross sections, hard spectra, large energy fluctuations, and the associated generation of electromagnetic and (in the case of photonuclear interactions) hadronic showers. As a consequence, the treatment of energy loss as a uniform and continuous process at these energies is inadequate for many purposes. Detailed calculations of the differential cross sections for these processes with respect to the energy loss fraction ν are available.[20–23] In addition, Ref. 24 provides useful parametrizations of the differential cross sections.



The average energy loss of a muon per g/cm^2 of hydrogen, iron, and uranium as a function of muon energy. Contributions of several processes to dE/dx in iron are also shown: (p) direct e^+e^- pair production, (b) bremsstrahlung, (n) photonuclear interactions, and (i) ionization.

The total cross section for muon bremsstrahlung is not large (the probability for a 1 TeV muon to bremsstrahlung in 1 m of iron is 5%), but the probability density $\nu d\sigma/d\nu$ for producing a photon of energy νE_μ is nearly flat across a wide range of values of ν. This means that bremsstrahlung contributes a tail of catastrophic loss to the muon energy loss distribution. Petrukhin and Shestakov[20] provide an expression for the differential cross section for muon bremsstrahlung, taking into account the effects of nuclear and atomic form factors. The form factor Z-dependence is nontrivial; the average dE/dx from bremsstrahlung departs from Z^2/A scaling by 10–15% as one extrapolates from iron to uranium.

At energies above ~500 GeV in iron, and ~150 GeV in uranium, direct e^+e^- pair production becomes the single most important source of of muon energy loss. Unlike the bremsstrahlung case, the pair energy probability peaks at low energies, making high-energy pairs relatively unlikely. Kel'ner and Kotov[22] give an expression for the differential cross section for e^+e^- production by muons which includes screening. See Ref. 21 for an evaluation of various theoretical treatments and approximations. For muon energies above ~100 GeV, $\mu^+\mu^-$ pair production is also possible. Such $\mu^+\mu^-$ production by muons is a potentially important process that can lead to misassignment of the sign of the incident muon, but this mechanism contributes less than 0.01% to the total energy loss.[19]

Photonuclear interactions account for about 5% of the total energy loss of high-energy muons in iron, and about 2% in uranium. The losses are concentrated in rare, relatively hard events. Bezrukov and Bugaev[23] derive an expression for the differential cross section that includes nucleon shadowing effects.

These energy-loss processes will have a significant impact on the design of muon detectors operating in the multihundred-GeV regime. Energy fluctuations can exceed nominal detector resolutions,[25] necessitating the reconstruction of lost energy. Electromagnetic and hadronic showers in detector materials can obscure muon tracks in detector planes and reduce the tracking efficiency.[26] Unresolved shower particles can also degrade position measurements.[26]

(7) Longitudinal distribution of electromagnetic showers. A photon of energy $E > 0.1$ GeV converting in a semi-infinite medium produces an electromagnetic cascade whose intensity initially increases with depth and then falls off. The average number of $e^\pm$ with kinetic energy above 1.5 MeV, crossing a plane at a depth of L radiation lengths from the beginning of the medium, in a material of atomic number Z, calculated using the Monte Carlo program EGS,[27] can be fit by the empirical formula[28]

$$N = N_0 L^a e^{-bL}$$

where $N_0 = 5.51\,E(\text{GeV})/Z\; b^{a+1}/\Gamma(a+1)$ and $b = 0.634 - 0.0021\,Z$. For $Z \geq 26$, $a = 2.0 - Z/340 + (0.664 - Z/340)\ln E$. For $Z = 13$, $a = 1.77 + 0.52\ln E$. The maximum intensity N_{max} occurs at the depth $L = a/b$. The maximum error of the fit occurs in the vicinity of this depth and is less than $0.15\,N_{max}$. The integral of the tail, $\int_{1.5a/b}^{\infty} N\,dL$, is fit to better than 2.5%. The total longitudinally projected $e^\pm$ path length $\int_0^\infty N\,dL = 5.51\,E/Z$ is less than the total $e^\pm$ path length due primarily to multiple Coulomb scattering.

(8) Radiation length. For the passage of electromagnetically interacting particles through a medium it is convenient to measure thickness in terms of radiation length.[29] For most electromagnetic processes (Bremsstrahlung, Coulomb scattering, showering, pair production, etc.), over large energy intervals, some or all of the dependence upon the medium is contained in the radiation length.

The radiation length may be defined as the distance L_R over which a high energy electron ($\gtrsim 1$ GeV for most materials) loses all but a fraction $1/e$ of its energy to Bremsstrahlung, on average. For a homogeneous monoatomic medium, $Z \geq 5$:

$$\frac{1}{L_R} = \frac{4\alpha r_e^2 N_A Z^2}{A}\left\{\ln\left(\frac{184.15}{Z^{1/3}}\right) + \frac{1}{Z}\ln\left(\frac{1194}{Z^{2/3}}\right) - 1.202\alpha^2 Z^2 + 1.0369\alpha^4 Z^4 - \frac{1.008\alpha^6 Z^6}{1+\alpha^2 Z^2}\right\} - \frac{Z^2\{\ \}}{716.405\,A},$$

where α, r_e, and N_A are found in the Physical Constants Table and Z and A are the atomic number and weight of the medium. If r_e is expressed in cm, L_R will have the conventional units of g/cm^2. For $Z < 5$, a more complex numerical calculation is required. Radiation lengths for many substances are tabulated in the Table of Atomic and Nuclear Properties of Materials. For media which are chemical mixtures or compounds,

$$\frac{1}{L_R} = \sum_i \frac{f_i}{L_R^i}$$

where f_i is the fraction by mass of atoms of type i, radiation length L_R^i. Chemical binding can lower L_R from this typically by a few per cent.

For electrons of energy below about one GeV, the average fractional energy loss per unit length decreases as the energy decreases (see Fractional Energy Loss for Electrons and Positrons in Lead figure). With distances measured in units of L_R, dependence of the

PASSAGE OF PARTICLES THROUGH MATTER (Cont'd)

Bremsstrahlung fractional energy loss upon Z of the medium in the low energy region ($\gtrsim$ 10 MeV) is of order a few percent or less.

For photons of infinite energy, the total pair-production cross section is

$$\sigma = \frac{7}{9}(A/L_R N_A)$$

This is accurate to within a few per cent down to ~1 GeV for most materials. For energies below about 1 GeV, the cross section varies in a manner which may be determined from the Photon Attenuation Length figures. See also Contributions to Photon Cross Section in Carbon and Lead figures.

(9) Electron practical range The electron "practical range" a common measure of straight-line penetration distance is shorter than the total path length because of multiple Coulomb scattering, which becomes increasingly important as the electron slows down. E.g., for a fast electron the rms projected angle due to multiple Coulomb scattering reaches 1 radian by the time the electron has slowed to 0.4 MeV in hydrogen, 1.5 MeV in carbon, 9 MeV in copper, and 24 MeV in lead. Electrons which have energy less than 0.2 MeV in Ar, 1.5 MeV in Cu, 3.5 MeV in Sn, and 5 MeV in Pb are likely to deposit 10% of their energy *behind* their starting plane. The practical range, R_p, is defined as that absorber thickness obtained by extrapolating to zero the linearly decreasing part of the curve of penetration probability vs. absorber thickness. Data for Al in the T range up to about 10 MeV are available, and fit (to ~±10%) $R_p = AT[1 - B/(1+CT)]$ mg cm^{-2}, a form suggested in Ref. 30, with A=0.55 mg cm^{-2} keV^{-1}, B = 0.9841, and C = 0.0030 keV^{-1}. At this penetration depth, 90 - 95% of the incident electrons have stopped. Data for other elements are sketchy, but suggest that higher-Z ($\lesssim$50) elements have $1 \lesssim R_p/R_p(\mathrm{Al}) \lesssim 1.4$ below ~10 keV, and $0.6 \lesssim R_p/R_p(\mathrm{Al}) \lesssim 1$ above ~100 keV. The "critical energy" (above which the energy loss due to bremsstrahlung exceeds that due to ionization, and showering becomes important) is 400 MeV for hydrogen, 100 MeV for carbon, 25 MeV for copper and 10 MeV for lead. The mean positron range may differ from the mean electron range by several percent. See Refs. 31 and 32. Electron energy deposition and penetration probability vs. range are discussed in Refs. 10, 33, and 34.

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* Revised April 1988 by J.J. Eastman.

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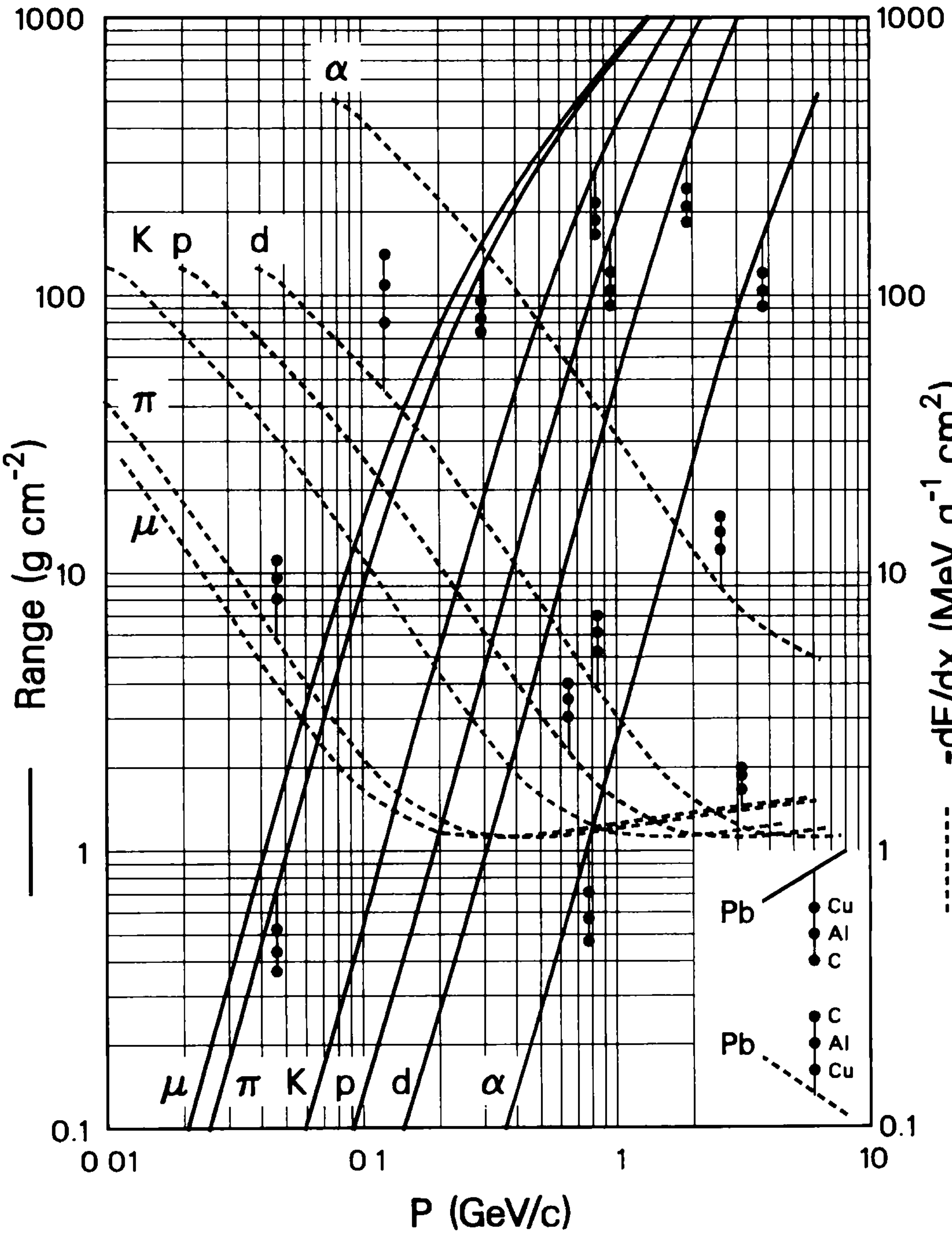
MEAN RANGE AND ENERGY LOSS

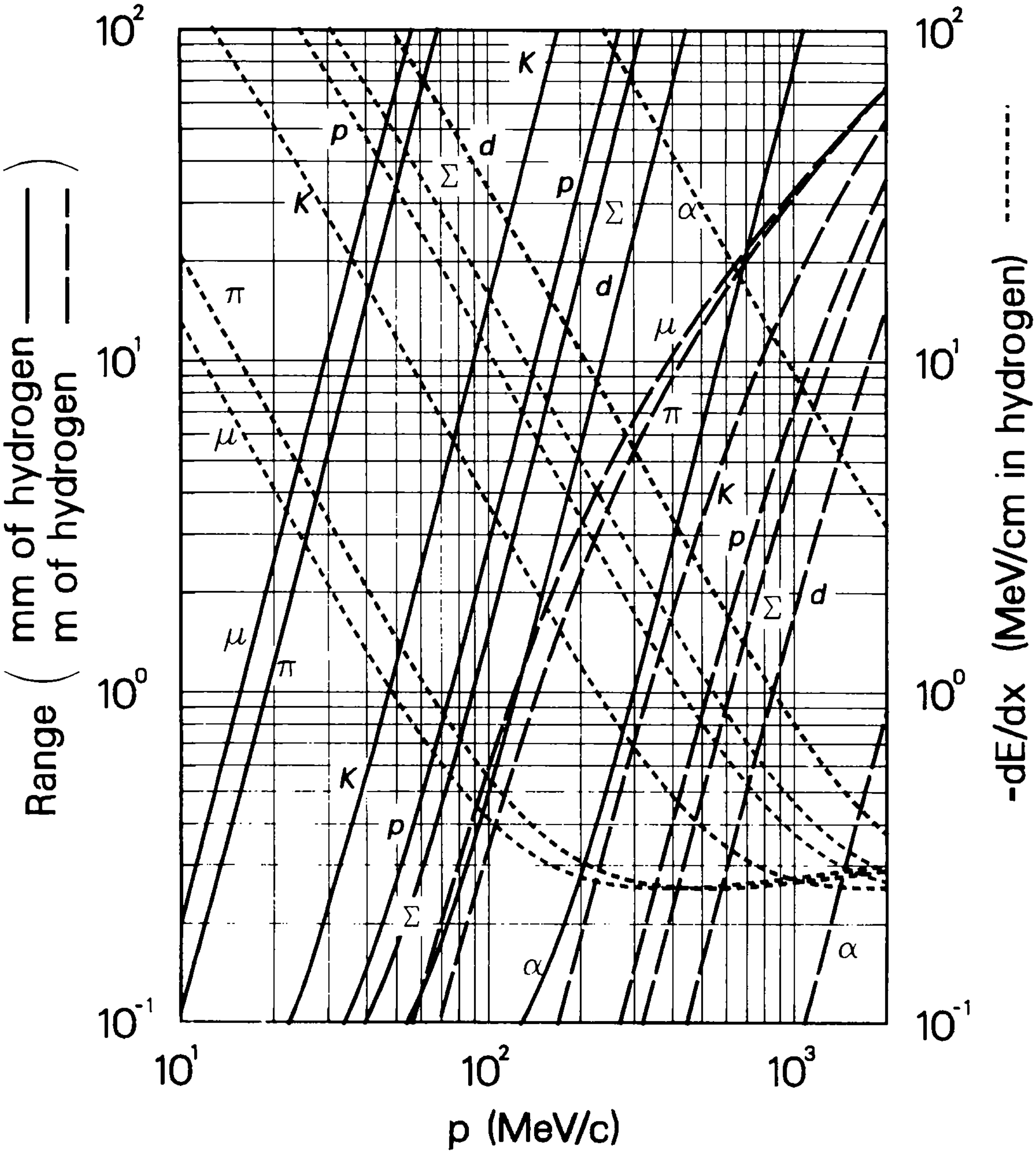
Mean Range and Energy Loss in Lead, Copper, Aluminum, and Carbon



Mean range and energy loss due to ionization for the indicated particles in Pb, with scaling to Cu, Al, and C indicated, using Bethe-Bloch equation [See Sec (1) of Passage of Particles Through Matter] with corrections Calculated by M J Berger, using ionization potentials and density effect corrections as discussed in M J Berger and S M Seltzer, "Stopping Powers and Ranges of Electrons and Positrons," (2nd ed), U S National Bureau of Standards Report NBSIR 82-2550-A (1982) The average ionization potentials (I) assumed were Pb (823 eV), Cu (322 eV), Al (166 eV), and C (78 0 eV) Figure indicates total path length, observed range may be smaller (by ~ 1 % - 2% in heavy elements) due to multiple scattering, primarily from small energy-loss collisions with nuclei The functional forms have not been experimentally verified to better than roughly ± 1% For higher energies refer to discussion by Cobb ["A Study of Some Electromagnetic Interactions of High Velocity Particles with Matter," University of Oxford Report HEP/T/55 (1973)] and by Turner ["Penetration of Charged Particles in Matter A Symposium," National Academy of Sciences, Washington D C (1970), p 48] For lower energies both data and theory are not well understood Scaling to other beam particles is, to a good approximation, described by the formula on the next page

MEAN RANGE AND ENERGY LOSS (Cont'd)

Mean Range and Energy Loss in Liquid Hydrogen

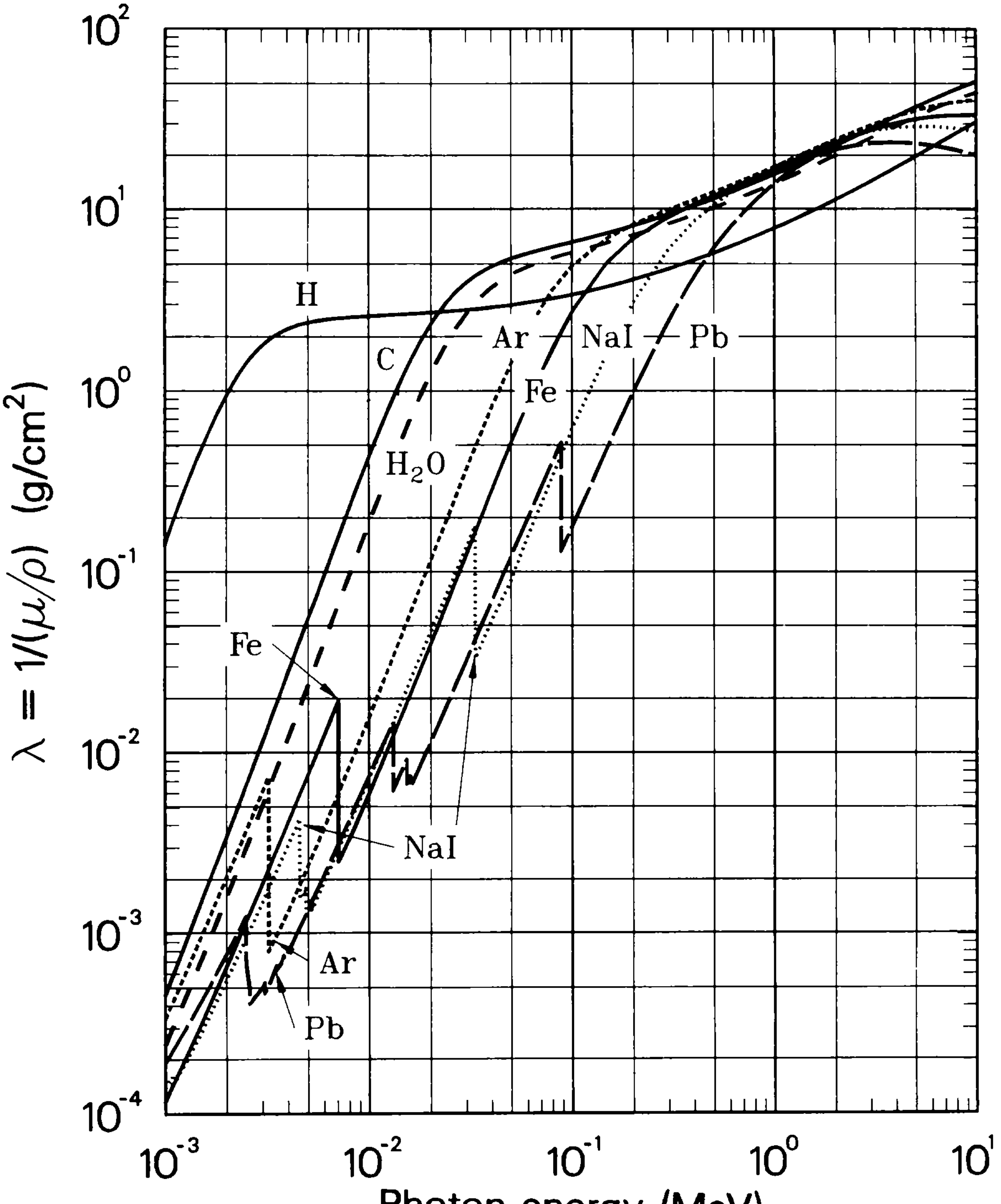


Range and energy loss in liquid hydrogen bubble chamber, based on Bethe-Bloch equation [See Sec. (1) of Passage of Particles Through Matter] using an average ionization potential for H_2 of $I = 20.0$ eV which is an approximate average of the experimental result of Garbincius and Hyman [Phys. Rev. **A2**, 1834 (1970)] and the theoretical result of Ford and Browne [Phys. Rev. **A7**, 418 (1973)]. Bubble chamber conditions are chosen to be those of Garbincius and Hyman: parahydrogen of density = 0.0625 g/cm^3 (note: range $\propto$ 1/density), with vapor-pressure 60.8 lb/in^2 (absolute) and temperature 26.2°K. The functional dependence of the Bethe-Bloch equation is not experimentally verified to better than about ± 1% over large momentum ranges. It should be noted that the number of bubbles per cm of a track in a bubble chamber is nearly proportional to $1/\beta^2$, not dE/dx. For the linear portions of the range curves, $R \propto p^{3.6}$. ***Scaling law for particles of other mass or charge*** *(except electrons)*: for a given medium, the range R_b of any beam particle with mass M_b, charge z_b and momentum p_b is given in terms of the range R_a of any other particle with mass M_a, charge z_a and momentum $p_a = p_b M_a / M_b$ (i.e. having the same velocity) by the expression

$$R_b(M_b, z_b, p_b) = \left[\frac{M_b/M_a}{z_b^2/z_a^2} \right] R_a(M_a, z_a, p_a = p_b M_a/M_b)$$

PHOTON AND ELECTRON ATTENUATION

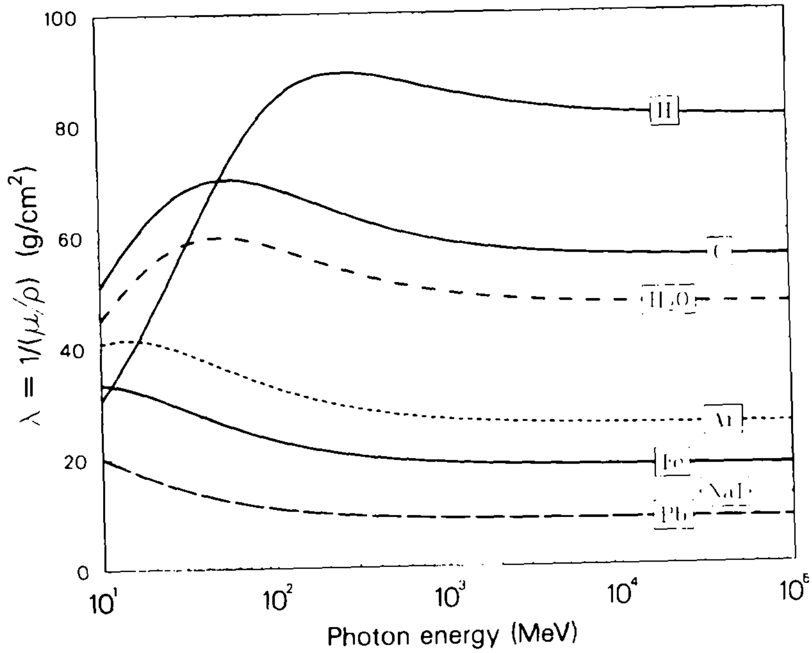
Photon Attenuation Length



The photon mass attenuation length $\lambda = 1/(\mu/\rho)$ (also known as mfp, mean free path) for various absorbers as a function of photon energy, where μ is the mass attenuation coefficient. For a homogeneous medium of density ρ, the intensity I remaining after traversal of thickness t is given by the expression $I = I_0 \exp(-t\rho/\lambda)$. The accuracy is a few percent. Interpolation to other Z should be done in the cross section $\sigma = A/\lambda N_A$ cm²/atom, where A is the atomic weight of the absorber material in grams and N_A is the Avogadro number. For a chemical compound or mixture, use $(1/\lambda)_{\rm eff} \simeq \sum w_i(1/\lambda)_i$, accurate to a few percent, where w_i is the proportion by weight of the $i^{\rm th}$ constituent. See next page for high energy range. The processes responsible for attenuation are given in the bottom figures of the next page. Not all of these processes necessarily result in detectable attenuation. For example, coherent Rayleigh scattering off an atom may occur at such low momentum transfer that the change in energy and momentum of the photon may not be significant. From Hubbell, Gimm, and Øverbø, J Phys Chem Ref Data **9** 1023 (1980). See also J H Hubbell, Int J of Applied Rad and Isotopes **33**, 1269 (1982). Data courtesy J H Hubbell

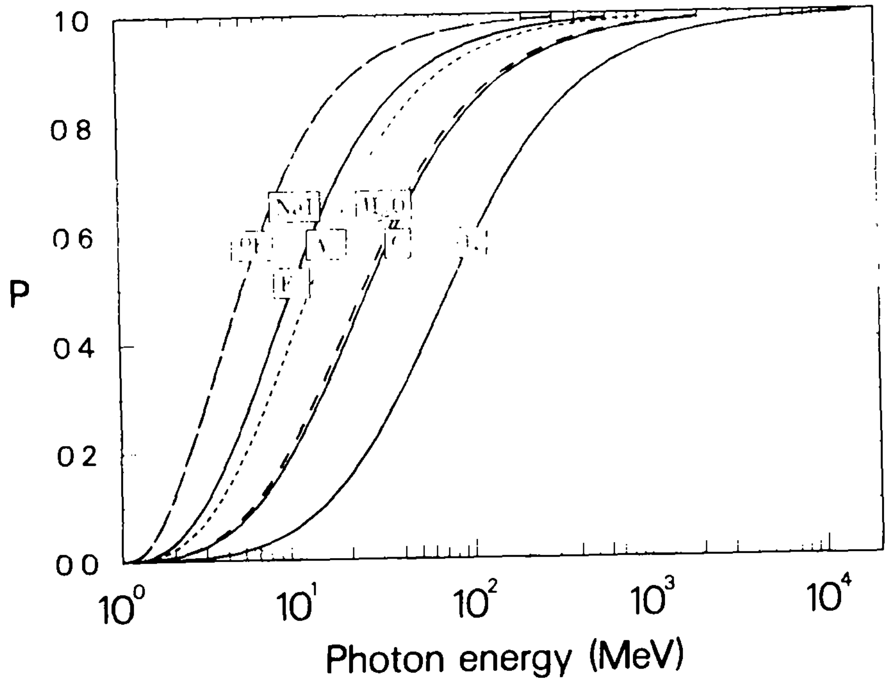
PHOTON AND ELECTRON ATTENUATION (Cont'd)

Photon Attenuation Length (High Energy)



The photon mass attenuation length, high energy range (note that ordinate is linear scale). See caption on previous page for details. The attenuation length is constant beyond the range shown for at least two decades in energy.

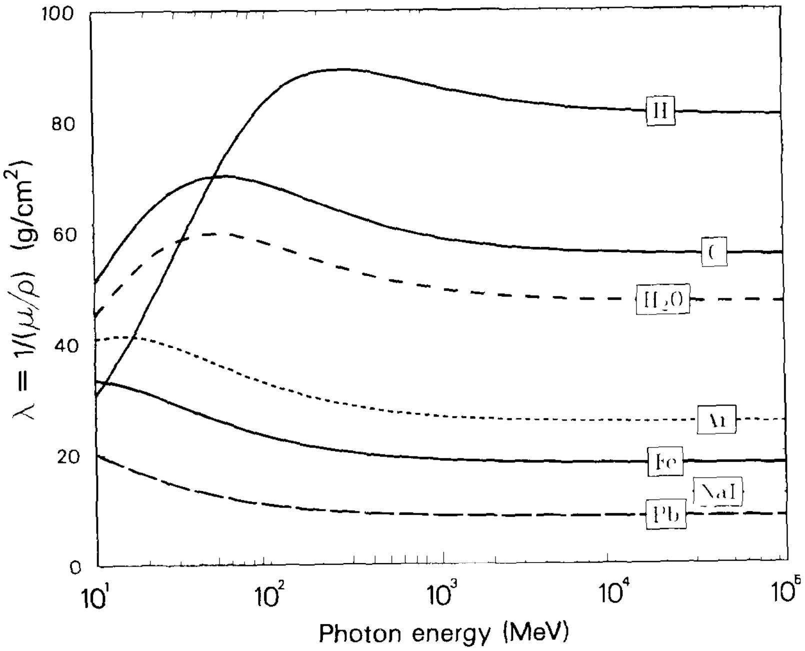
Photon Pair Conversion Probability



Probability P that a photon interaction will result in conversion to an e^+e^- pair. Except for a few-percent contribution from photonuclear absorption around 10 or 20 MeV, essentially all other interactions result in Compton scattering off an atomic electron. For a photon attenuation length λ (g/cm^2) (upper figure), the probability that a given photon will produce an electron pair (without first Compton scattering) in thickness t (cm) of absorber of density ρ (g/cm^3) is $P[1 - \exp(-t\rho/\lambda)]$.

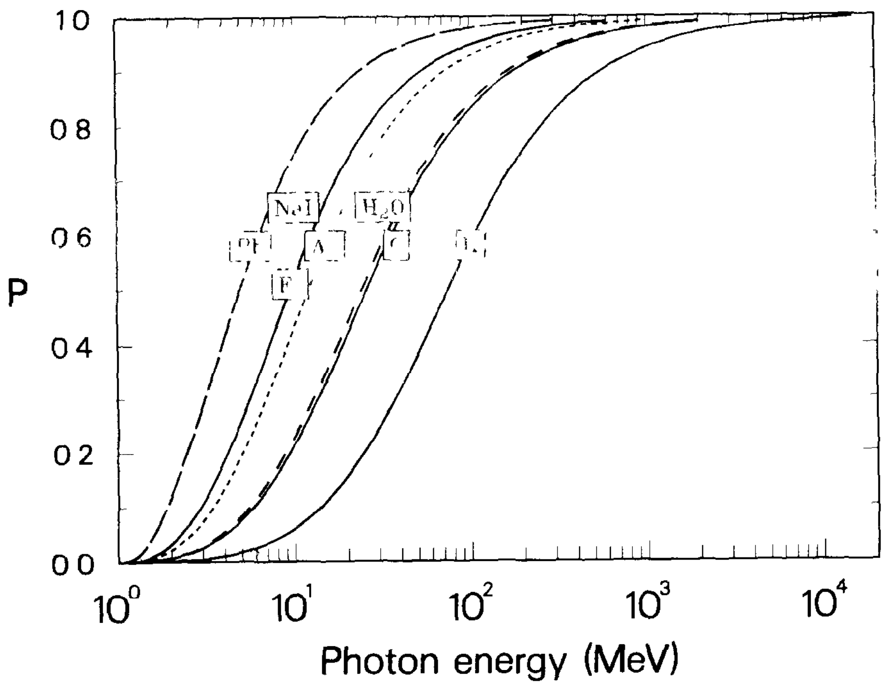
PHOTON AND ELECTRON ATTENUATION (Cont'd)

Photon Attenuation Length (High Energy)



The photon mass attenuation length, high energy range (note that ordinate is linear scale) See caption on previous page for details The attenuation length is constant beyond the range shown for at least two decades in energy

Photon Pair Conversion Probability



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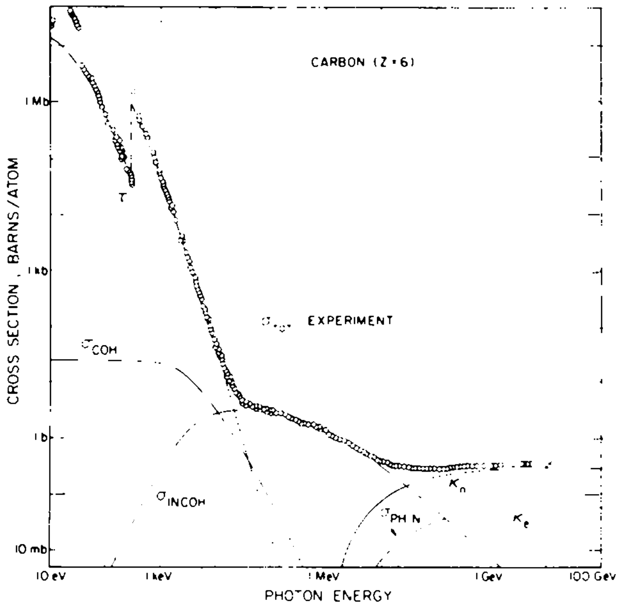
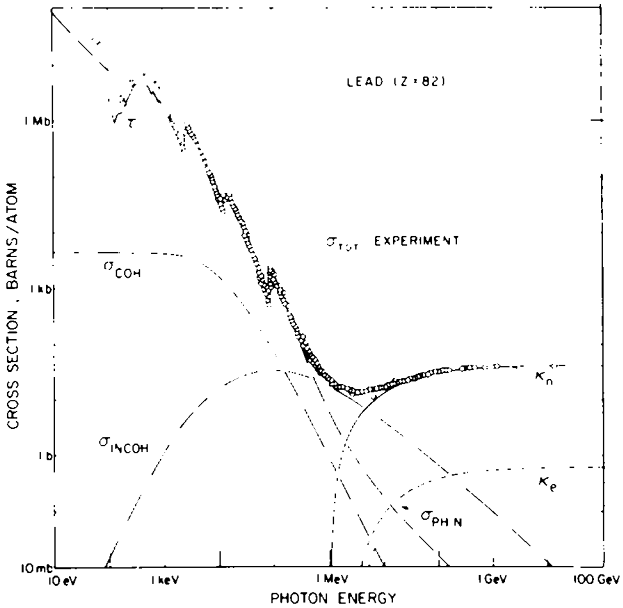
PHOTON AND ELECTRON ATTENUATION (Cont'd)

Contributions to Photon Cross Section in Carbon and Lead





Photon total cross sections as a function of energy in carbon and lead, showing the contributions of different processes

τ	—	Atomic photo-effect (electron ejection, photon absorption)
σ_{COH}	—	Coherent scattering (Rayleigh scattering atom neither ionized nor excited)
σ_{INCOH}	—	Incoherent scattering (Compton scattering off an electron)
κ_n	=	Pair production, nuclear field
κ_e	=	Pair production, electron field
$\sigma_{PH.N}$	—	Photonuclear absorption (nuclear absorption, usually followed by emission of a neutron or other particle)

From Hubbell, Gimm, and Øverbø, J Phys Chem Ref Data 9, 1023 (1980) The photon total cross section is assumed approximately flat for at least two decades beyond the energy range shown Figures courtesy J H Hubbell

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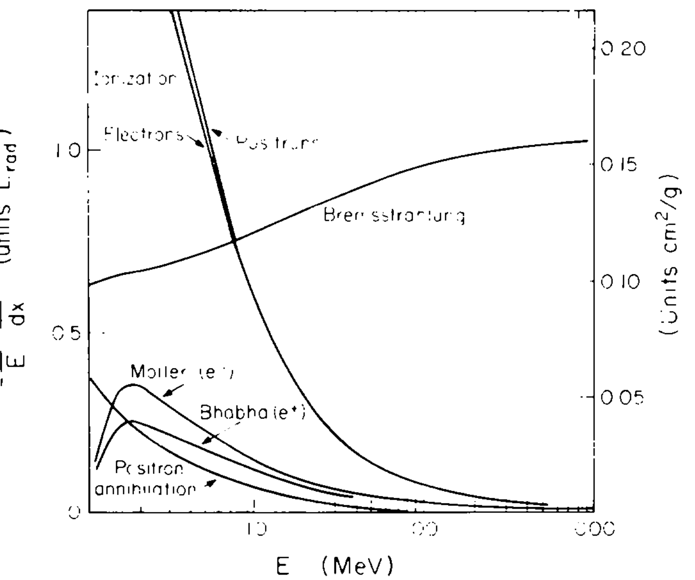
Fractional Energy Loss for Electrons and Positrons in Lead



Fractional energy loss per radiation length in lead as a function of electron or positron energy Electron (positron) scattering is considered as ionization when the energy loss per collision is below 0 255 MeV, and as Moller (Bhabha) scattering when it is above Adapted from Fig 3 2 from Messel and Crawford *Electron-Photon Shower Distribution Function Tables for Lead, Copper and Air Absorbers*, Pergamon Press, 1970 Messel and Crawford use L_r(Pb) = 5 82 g/cm^2, but we have modified the figures to reflect the value given in the Table of Atomic and Nuclear Properties of Materials, namely L_r(Pb) = 6 4 g/cm^2 The development of electron-photon cascades is approximately independent of absorber when the results are expressed in terms of inverse radiation lengths (i e , scale on left of plot)

COMMONLY USED RADIOACTIVE SOURCES*

Nuclide	$t_{1/2}$(y)	Decay mode	Principal emissions E(keV)/Intensity (%) α	β		γ
^{22}Na	2.602	β^+, EC		546/90		(511) 1275/100
^{54}Mn	0.854	EC				5.4/22 X 835/100
^{55}Fe	2.73	EC				5.89/25 X 6.49/3.3 X
^{57}Co	0.744	EC				14.4/10 122/86 136/11
^{60}Co	5.271	β^-		318/100		1173/100 1332/100
^{68}Ge (^{68}Ga)	0.742	EC → β^+		1899/88		(511) 9.4/44 X
^{90}Sr (^{90}Y)	28.5	β^- → β^-		546/100 2284/100		
^{106}Ru (^{106}Rh)	1.020	β^- → β^-		39/100 3541/79		512/21 622/10
^{109}Cd	1.267	EC		62/42 84/44 87/10	e^-	22/83 X 25/17 X 88/3.7
^{113}Sn	0.315	EC		364/28 388/7	e^-	24/79 X 392/65
^{137}Cs	30.17	β^-		512/95 1173/5		662/85
^{133}Ba	10.54	EC		45/48 75/7	e^-	81/34 303/18 356/62
^{207}Bi	32.2	EC		482/2 976/7 1048/2	e^-	570/98 1064/75 1770/7
^{228}Th (^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po)	1.913	6α, 2β	(5341 to 8785)	334/85 1794/18 2246/48		239/45 583/30 2615/36
^{241}Am	432.2	α	5443/13 5486/85			14/13 X 18/20 X 60/36
^{244}Cm	18.10	α	5763/24 5805/76			14/4 X 18/4 X
^{252}Cf	2.638	0.12 fission neutron, 0.6 γ (≲1 MeV)/decay of Cf				
Am/Be	432.2	6×10^{-5} neutron, 4×10^{-5} γ (4.43 MeV)/decay of Am				

* Updated April 1988 by E. Browne.

EC denotes electron capture. X an atomic X-ray. Maximum $\beta^\pm$ energies are listed, unless followed by e^- indicating monoenergetic conversion electrons. (511) indicates annihilation radiation, where intensity depends on the number of stopped positrons. In some cases, the γ-ray values are approximate weighted averages of two or more close-together lines. Daughter isotopes, the actual sources of some lines, are listed in parentheses where appropriate.

E. Browne and R. B. Firestone, *Table of Radioactive Isotopes* (John Wiley & Sons, New York, 1986).

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Neutrons from *Neutron Sources for Basic Physics and Applications* (Pergammon Press, 1983).

RADIOACTIVITY & RADIATION PROTECTION

The International Commission on Radiation Units and Measurements (ICRU) recommends the use of SI units. Therefore we list SI units first, followed by cgs (or other common) units in parentheses, where they differ.

- **Unit of activity** = becquerel (curie):
  1 Bq = 1 disintegration/sec [= $1/(3.7\times10^{10})$ Ci].
- **Unit of exposure**: the quantity of X- or γ- radiation at a point in space integrated over time, in terms of charge of either sign produced by showering electrons in a small volume of air about the point:
  = 1 coul/kg of air (roentgen; 1 R = 2.58×10^{-4} coul/kg
  = 1 esu/cm^3 = 87.8 erg released energy per g of air).
  Implicit in the definition is the assumption that the small test volume is embedded in a sufficiently large uniformly irradiated volume that the number of secondary electrons entering the volume equals the number leaving.
- **Unit of absorbed dose** = gray (rad):
  1 Gy = 1 joule/kg (= 10^4 erg/g = 10^2 rad)
  = 6.24×10^{12} MeV/kg deposited energy.
- **Unit of dose equivalent** (for biological damage) = sievert [= 10^2 rem (roentgen equivalent for man)].
  Dose equivalent in Sv = grays × Q, where Q (quality factor) expresses long-term risk (primarily cancer and leukemia) from low-level chronic exposure. It depends upon the type of radiation and other factors. For γ rays and β particles, $Q \cong 1$; for protons,† $Q \cong 1$ at ~10 MeV, rising gradually to ≈ 2 at ~1 GeV; for thermal neutrons,† $Q \approx 3$; for fast neutrons,† Q ranges up to 10; and for α particles† and heavy ions† (assuming internal deposition — skin and clothing are usually sufficient protection against external sources), $Q \approx 20$.
- **Natural annual background**, all sources: Most world areas, whole-body dose equivalent rate ≈ (0.4-4) mSv (40-400 millirems). Can range up to 50 mSv (5 rems) in certain areas. U.S. average ≅ 3.6 mSv, including ≅ 2 mSv (≅ 200 mrem) from inhaled natural radioactivity, mostly radon and radon daughters. (0.1–0.2 mSv in open areas; average is for typical house and varies by more than an order of magnitude; can be more than two orders of magnitude higher in poorly ventilated mines).
- **Cosmic ray background** in counters (Earth's surface): ~10^4/min/m^2/ster. For more accurate estimates and more details, see Cosmic Rays section.
- **Fluxes** (per m^2) to deposit one Gy in one kg of matter, assuming uniform irradiation:
  ≅ **(charged particles)** $6.24\times10^{12}/(dE/dx)$, where dE/dx (MeV m^2/kg), the energy loss per unit length, may be obtained (after conversion of units) from the Mean Range and Energy Loss figures.
  ≈ 3.5×10^{13} minimum-ionizing singly charged particles in carbon.
  ≅ **(photons)** $6.24\times10^{12}/[E(\mathrm{MeV})/(\lambda f)(\mathrm{m^2/kg})]$, for photons of energy E, attenuation length λ (see Photon Attenuation Length figures) and fraction $f \lesssim 1$ expressing the fraction of the photon's energy deposited in a small volume of thickness << λ but large enough to contain the secondary electrons.
  ≅ 2×10^{15} photons of 1 MeV energy on carbon.
  (Quoted fluxes good to about a factor of 2 for all materials.)
- **U.S. maximum permissible occupational whole-body dose**:
  50 mSv/year (5 rem/year).
- **Lethal dose**: Whole-body dose from penetrating ionizing radiation resulting in 50% mortality in 30 days (assuming no medical treatment): 2.5-3.0 Gy (250-300 rads) as measured internally on body longitudinal center line; surface dose varies due to variable body attenuation and may be a strong function of energy.

For a recent review, see E. Pochin, *Nuclear Radiation: Risks and Benefits* (Clarendon Press, Oxford, 1983).

† The International Commission on Radiological Protection has provisionally recommended that these Q factors for protons, neutrons, and heavy charged particles be doubled.

PROBABILITY, STATISTICS, AND MONTE CARLO*

I. PROBABILITY

I.A General

If x is the outcome of an observation, we define the probability of x as the relative frequency with which x occurs out of a (possibly hypothetical) large set of similar observations. If x may take any value from a *continuous* range, we write $f(x;\theta)dx$ as the probability of observing x between x and $x + dx$. The function $f(x;\theta)$ is the *probability density function* (p.d.f.) for the *random variable* x, which may depend upon a parameter θ. If x can take on only one of a set of *discrete* values (e.g., the non-negative integers), then $f(x;\theta)$ is itself a probability, but we still refer to it as a p.d.f. The p.d.f. is always normalized to unit area (unit sum, if discrete). Both x and θ may have multiple components and are then usually written as column vectors. If θ is unknown and we wish to estimate its value from a given set of data x, we may use statistics (Section II.).

The *cumulative distribution function* $F(a)$ expresses the probability that $x \le a$:

$$F(a) = \int_{-\infty}^{a} f(x)dx \qquad (I.1)$$

Here and in what follows, if x is discrete-valued, the integral is replaced by a sum. The endpoint a is expressly included in the integral or sum. Then $0 \le F(x) \le 1$, $F(x)$ is nondecreasing, and Prob$(a < x \le b) = F(b) - F(a)$. If x is discrete, $F(x)$ is flat except at allowed values of x, where it has a discontinuous jump equal to $f(x)$.

Any function of random variables is itself a random variable, with (in general) a different p.d.f. The *expectation value* of any function $u(x)$ is

$$E\left[u(x)\right] = \int_{-\infty}^{\infty} u(x)f(x)dx \qquad (I.2)$$

The expectation value is said to exist only if it is finite. For x and y any two random variables, $E(x + y) = E(x) + E(y)$. For c and k constants, $E(cx + k) = cE(x) + k$. The most commonly used expectation values are the mean and variance:

$$\mu \equiv E(x) \qquad (I.3a)$$

$$\sigma^2 \equiv \mathrm{Var}(x) = E\left[(x - \mu)^2\right] = E(x^2) - \mu^2 \qquad (I.3b)$$

The mean is the location of the "center of mass" of the distribution of x and the variance is a measure of its width squared. Note that $\mathrm{Var}(cx + k) = c^2\mathrm{Var}(x)$.

In addition to the mean, another useful indicator of the x *location* near which most of the probability is likely to concentrate is the *median* x_{med}. This is that value of x such that $F(x_{med}) = 1/2$, i.e., exactly half of the probability lies above and half lies below x_{med}. For a given *sample* of events, x_{med} is that observed x such that half the events have larger x and half have smaller x (as closely as possible, not counting any that have the same x as the median). If this lies between two observed x values, the sample median is set by convention to be halfway between them. If the p.d.f. for x has the form $f(x - \mu)$ and μ is both mean and median, then for a large number of events N, the variance of the median approaches $1/\left[4Nf^2(0)\right]$, provided $f(0) > 0$.

Let x and y be two random variables with joint p.d.f. $f(x,y)$. The *marginal* p.d.f. of, for example, x, expressing the p.d.f. for x with y unobserved, is

$$f_1(x) = \int_{-\infty}^{\infty} f(x,y)dy \qquad (I.4)$$

and similarly for $f_2(y)$. If y is fixed, the *conditional* p.d.f. for x given the fixed y is given by

$$f(x\,|\,y) = f(x,y)/f_2(y) \qquad (I.5)$$

The x mean is

$$\mu_x = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} xf(x,y)dx\,dy = \int_{-\infty}^{\infty} xf_1(x)dx \qquad (I.6)$$

and similarly for y. The *correlation* between x and y is a measure of the dependence of one on the other:

$$\rho_{xy} = E\left[(x - \mu_x)(y - \mu_y)\right]/\sigma_x\sigma_y = \mathrm{Cov}\left[x,y\right]/\sigma_x\sigma_y \qquad (I.7)$$

where σ_x, σ_y are defined in analogy with Eq. (I.3b). It can be shown that $-1 \le \rho_{xy} \le 1$. The symbol "Cov" represents the covariance of x and y, a 2-variable analogue to the variance Eq. (I.3b). Two random variables are *independent* if and only if

$$f(x,y) = f_1(x)f_2(y) \qquad (I.8)$$

If x and y are independent then $\rho_{xy} = 0$; the converse is not necessarily true except for Gaussian-distributed x and y. If x and y are independent, $E\left[u(x)v(y)\right] = E\left[u(x)\right]E\left[v(y)\right]$ and $\mathrm{Var}(x + y) = \mathrm{Var}(x) + \mathrm{Var}(y)$.

In a *change of continuous random variables* from, e.g., $\vec{x} = (x_1, \ldots, x_n)$, with p.d.f. $f(x_1, \ldots, x_n)$, to $\vec{y} = (y_1, \ldots, y_n)$, a one-to-one function of the x's, the p.d.f. $g(y_1, \ldots, y_n)$ is found by substitution for $(x_1, \ldots, x_n)$ in f followed by multiplication by the absolute value of the Jacobian of the transformation:

$$g(\vec{y}) = f\left[w_1(\vec{y}), \ldots, w_n(\vec{y})\right]|J| \qquad (I.9)$$

The functions w_i express the *reverse* transformation $x_i = w_i(\vec{y})$ for $i = 1, \ldots, n$, and $|J|$ is the absolute value of the determinant of the square matrix $J_{ij} = \partial x_i/\partial y_j$. Such transformations must always preserve the number of random variables, n; to transform to fewer variables, first perform (I.9) and then take the marginal (I.4) to eliminate unwanted variables. To change variables for discrete random variables simply substitute; no Jacobian is necessary because there f is a probability rather than a probability density. If f depends upon a parameter set θ, we can change to a different parameter set $\phi = \phi(\theta)$ by simple substitution; no Jacobian is used.

I.B Specific Probability Density Functions

We describe here a few p.d.f.'s commonly encountered in physics applications. Tables for most of these distributions, relations among them, and further information may be found in Ref.'s 1 and 2.

I.B.1 Uniform distribution (continuous)

This p.d.f. assumes equal probability density for any x in an allowed range $[a,b]$:

$$f(x) = 1/(b - a) \qquad a \le x \le b \qquad (I.10)$$
$$= 0 \qquad \text{otherwise}.$$

$$E(x) = (b + a)/2\,, \quad \mathrm{Var}(x) = (b - a)^2/12 \qquad (I.11)$$

I.B.2 Binomial distribution (discrete)

Any process with exactly two possible outcomes is a *Bernoulli* process. If the process is repeated n times independently, and if the probability of obtaining a certain outcome (a "success") in each trial is p, then the probability of obtaining exactly r successes is given by the binomial distribution

$$f(r;n,p) = \binom{n}{r} p^r q^{n-r} = \frac{n!}{r!(n - r)!}\,p^r q^{n-r}\,, \qquad (I.12)$$

$$r = 0, 1, 2, \ldots, n,$$

where $q = 1 - p$ and the order in which the successes and failures come is assumed irrelevant.

PROBABILITY, STATISTICS, AND MONTE CARLO (Cont'd)

$$E(r) = np\ ,\quad \mathrm{Var}(r) = npq \tag{I 13}$$

If r successes are observed in n_r Bernoulli trials with probability p of success, and if s successes are observed in n_s similar trials, then $t = r + s$ is also binomial with $n_t = n_r + n_s$

I.B.3 Poisson distribution (discrete)

The Poisson distribution with mean μ is

$$f(n;\mu) = \frac{e^{-\mu}\mu^n}{n!}\ ,\quad n = 0,1,2 \tag{I 14}$$

The observed result of a Poisson process is a non-negative integer n, the parameter μ is any non-negative real number The Poisson describes the population of events in any interval of x (e g , space or time) whenever (a) the number of events in any subinterval of x is independent of that in any other subinterval, (b) in any small Δx, the probability of one event is $\lambda\Delta x$ and the probability of two or more vanishes as $\Delta x \to 0$, and (c) λ does not depend on x Then $\mu \equiv \lambda x$,

$$E(n) = \mu\ ,\quad \mathrm{Var}(n) = \mu \tag{I 15}$$

When μ is large ($\gtrsim 7$ or 8), one may often usefully approximate the distribution of n by a Gaussian distribution of mean μ and variance $\sigma^2 = \mu$, as though n were a continuous variable Two or more Poisson processes (e g , *signal* plus *background*, with parameters μ_S and μ_B, respectively) which independently contribute amounts n_S and n_B to a given measurement will produce an observed number $n = n_S + n_B$, which is distributed according to a new Poisson distribution with parameter $\mu = \mu_S + \mu_B$

I.B 4 Normal or Gaussian distribution (continuous)

The Gaussian distribution is

$$f(x;\mu,\sigma^2) = \frac{1}{\sigma\sqrt{2\pi}}e^{-(x-\mu)^2/2\sigma^2}\ ,\quad -\infty < x < \infty \tag{I 16}$$

$$E(x) = \mu\ ,\quad \mathrm{Var}(x) = \sigma^2 \tag{I 17}$$

For x and y independent and normally distributed $z = x + y$ obeys $f(z;\mu_x + \mu_y, \sigma_x^2 + \sigma_y^2)$

The integrated probability for x to fall in the range $\mu - \sigma$ to $\mu + \sigma$ is 0 683 Other measures of width commonly encountered are probable error (central region containing 0 50 of the probability) = $\mu \pm 0\,67\sigma$, mean absolute deviation, $E[\,|x - \mu|\,] = 0\,80\sigma$, RMS deviation = σ, half-width at half-maximum = 1 18σ

The Gaussian gets its importance in large part from the *central limit theorem* if a continuous random variable x is distributed according to *any* p d f with finite mean and variance, then the sample mean $\bar{x}_n$ of n observations of x will have a p d f that approaches a Gaussian as n increases Therefore the end result $\sum^n x_i \equiv n\bar{x}_n$ of a large number of small fluctuations x_i will be distributed as a Gaussian, even if the x_i themselves are not

The cumulative distribution (I 1) for a Gaussian with $\mu = 0$ and $\sigma^2 = 1$ is given by the *error function*, erf(a), through the following ugly relation

$$F(a;0,1) = 0\,5[1 + \mathrm{erf}(a/\sqrt{2})] \tag{I 18}$$

The function erf(a) is tabulated in Ref 1 [caution other definitions of erf(a) are sometimes used], for other mean and variance replace a by $[(a - \mu)/\sigma]$

For $\vec{x}$ a set of n (not necessarily independent) Gaussian random variables x_i arranged into a column vector, their joint p d f is the *multivariate Gaussian*

$$f(\vec{x};\vec{\mu},V) = \frac{1}{(2\pi)^{n/2}}|V|^{-1/2}\ \times \tag{I 19a}$$

$$\exp\left[-\frac{1}{2}(\vec{x} - \vec{\mu})^T V^{-1}(\vec{x} - \vec{\mu})\right],\quad |V| \neq 0\ ,$$

where V is the *covariance matrix* of the x's, $V_{ii} = \mathrm{Var}(x_i)$ and $V_{ij} = E[(x_i - \mu_i)(x_j - \mu_j)] \equiv \rho_{ij}\sigma_i\sigma_j$, and $|V|$ is the determinant of V The quantity ρ_{ij} is the correlation coefficient for x_i and x_j, $|\rho_{ij}|^2 \leq 1$ For $n = 2$ this becomes

$$f(x_1,x_2;\mu_1,\mu_2,\sigma_1,\sigma_2,\rho) = \frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}}\ \times \tag{I 19b}$$

$$\exp\left\{\frac{-1}{2(1-\rho^2)}\left[\frac{(x_1-\mu_1)^2}{\sigma_1^2} - \frac{2\rho(x_1-\mu_1)(x_2-\mu_2)}{\sigma_1\sigma_2} + \frac{(x_2-\mu_2)^2}{\sigma_2^2}\right]\right\}$$

If V is singular, there is a linear relation among some variables, in this case one usually wants to eliminate completely dependent variables and work in a smaller number of dimensions The marginal distribution of any x_i is a Gaussian with mean μ_i and variance V_{ii} V is $n \times n$, symmetric, and positive definite Therefore for any vector $\vec{X}$, the quadratic form $\vec{X}^T V^{-1}\vec{X} = c \geq 0$ traces an n-dimensional ellipsoid, center $\vec{X} = 0$, as $\vec{X}$ varies for any given c If $X_i = (x - \mu)_i/\sigma_i$ in this equation, then c is a random variable obeying the $\chi^2(n)$ distribution Therefore the probability that a random value of $\vec{x}$ will occur *inside* this ellipsoid is CL, reading the ordinate as 1 − CL on the large χ^2 figure below from the curve for $n \equiv n_D$ at $\chi^2 = c$ This assumes that μ_i and σ_i are correct For example, the "one-standard-deviation ellipsoid" occurs at $\chi^2 = 1$, for a two-variable case ($n = 2$) the probability that both x_1 and x_2 will *simultaneously* fall inside that ellipse is 39% The use of these ellipsoids as indicators of probable error is described in II E 1

It is a characteristic of the multivariate Gaussian that $\rho_{ij} = 0$ is necessary and sufficient for x_i and x_j to be independent For a given covariance matrix V, there always exist nonsingular $n \times n$ matrices H such that $HH^T = V$, H is usually upper or lower triangular in the most efficient algorithms Then $\vec{z} = H^{-1}(\vec{x} - \vec{\mu})$ is a vector of n independent Gaussian random variables with zero mean and with covariance matrix equal to the identity

I.B.5 The χ^2 distribution (continuous)

If $x_1, \ldots, x_n$ are independent normally distributed random variables, the sum $z = \sum^n (x_i - \mu_i)^2/\sigma_i^2$ is distributed as a χ^2 with n *degrees of freedom* $[\chi^2(n)]$

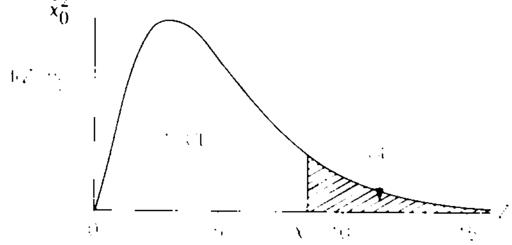
$$f(z;n) = \frac{1}{2^h\Gamma(h)}z^{h-1}e^{-z/2}\ ,\quad h = n/2\ ,\quad z \geq 0\ , \tag{I 20}$$

$$E(z) = n\ ,\quad \mathrm{Var}(z) = 2n \tag{I 21}$$

For a set of z_i, each of which is $\chi^2(n_i)$, $\sum z_i$ is a new random variable which is $\chi^2[\sum n_i]$

The large figure below displays the integral of Eq (I 20) for n_D degrees of freedom,

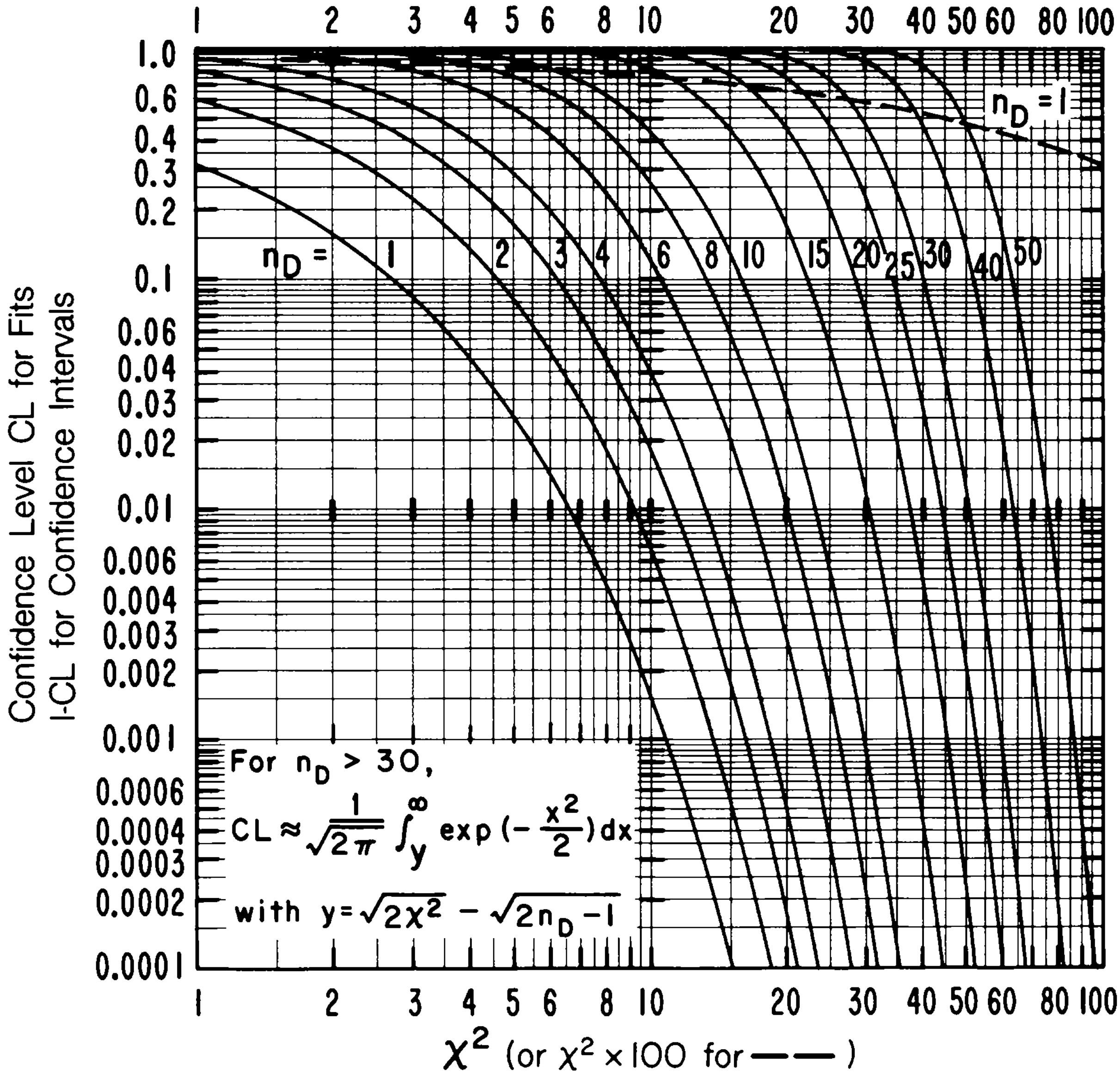
$$\mathrm{CL}(\chi_0^2) = \int_{\chi_0^2}^{\infty} f(z;n_D)\,dz\ , \tag{I 22}$$



which is 1 0 minus the cumulative distribution function $F(z = \chi_0^2;n_D)$ This is useful in evaluating the consistency of data with a model, as will be explained in Section II

PROBABILITY, STATISTICS, AND MONTE CARLO (Cont'd)

χ^2 Confidence Level vs. χ^2 for n_D Degrees of Freedom



I.B.6 Student's t distribution (continuous)

If x is a normally distributed random variable with mean μ and variance σ^2, and z is an independent χ^2 random variable with n degrees of freedom, then

$$t = [(x - \mu)/\sigma]/\sqrt{z/n} \qquad (I.23)$$

is a random variable distributed according to Student's t distribution with n degrees of freedom

$$f(t,n) = \frac{\Gamma(\frac{n+1}{2})}{\Gamma(\frac{n}{2})\sqrt{\pi n}} \left[1 + \frac{t^2}{n}\right]^{-\frac{(n+1)}{2}}, \quad -\infty < t < \infty, \qquad (I.24)$$

$$E(t) = 0, \quad \mathrm{Var}(t) = \frac{n}{n-2} \quad (n > 2) \qquad (I.25)$$

Student's t resembles a Gaussian with wide tails. If $n \to \infty$ Student's t converges to a Gaussian itself; if $n = 1$ the distribution is a *Breit-Wigner*, also called a *Cauchy*. Note that for $n = 1$ or 2 the distribution has infinite variance, therefore such random variables do not obey the central limit theorem.

Student's t describes the distribution of the ratio of the *sample mean* $\bar{x} = \sum x_i/n$ and the *sample variance* $s^2 = \sum(x_i - \bar{x})^2/(n - 1)$ for normally distributed random variables x_i with unknown mean μ and variance σ^2. Then $t = \{(\bar{x} - \mu)/[\sigma\sqrt{n}]\}/\sqrt{s^2/[(n-1)\sigma^2]}$ is of the form Eq. (I.23), with $n - 1$ degrees of freedom, because s^2/σ^2 is a $\chi^2(n - 1)$ and $\bar{x} - \mu$ is an independent Gaussian random variable with variance $n\sigma^2$. Then the unknown true variance σ^2 cancels and t can be used to test the probability that the true mean is some particular value μ.

PROBABILITY, STATISTICS, AND MONTE CARLO (Cont'd)

I.B 7 The gamma distribution (continuous)

If a process generating events as a function of x (e g, space or time) satisfies conditions (a)–(c) of the Poisson distribution, then the x distance from an arbitrary starting point (which may be some particular event) to the k^{th} event is distributed as a *gamma*

$$f(x, \lambda, k) = \frac{x^{k-1}\lambda^k e^{-\lambda x}}{\Gamma(k)}, \quad 0 < x < \infty \qquad \text{(I 26)}$$

$\Gamma(k) = (k-1)!$ is the gamma function, the Poisson parameter μ is λ per unit x

$$E(x) = k/\lambda \quad \mathrm{Var}(x) = k/\lambda^2 \qquad \text{(I 27)}$$

The special case $k = 1$ is called the *exponential* distribution. A sum of k' exponential random variables x_i is distributed as $f(\Sigma x_i, \lambda, k')$. Eq (I 26) is general enough to allow k to be nonintegral. If $\lambda = 1/2$ and $k = n/2$, the gamma is identical to $\chi^2(n)$

II STATISTICS

II.A General

A probability density function with known parameters enables us to predict the frequency with which a random variable will take on a particular value (if discrete) or lie in a given range (if continuous). In *parametric* statistics we have the opposite problem of estimating the parameters of the p d f from a set of actual observations

We refer to the true p d f as the *population*, the data form a *sample* from this population. A *statistic* is any function of the data, plus known constants, which does not depend upon any of the unknown parameters. A statistic is a random variable if the data have random errors. An *estimator* is any statistic whose value is intended as a meaningful guess for the value of an unknown parameter. we denote estimators by a "^", e g, $\hat{\theta}$

Often it is possible to construct more than one reasonable estimator. Let θ represent the true value of a parameter to be estimated, θ is a vector if there is more than one. Then if $\hat{\theta}$ is an estimator for θ, desirable properties for $\hat{\theta}$ are (a) *Unbiased*, bias $b = E(\hat{\theta}) - \theta$, where the expectation value is taken over a hypothetical set of similar experiments in which $\hat{\theta}$ is constructed the same way. The bias may be due to statistical properties of the estimator or to *systematic* errors in the experiment. If we can estimate the average bias we usually subtract it from $\hat{\theta}$ to obtain a new $\hat{\theta}' \equiv \hat{\theta} - b$. However it may depend upon θ or other unknowns in which case we try to choose an estimator which minimizes its average size. (b) *Minimum variance*, the minimum possible variance of $\hat{\theta}$ is given by the Rao-Cramer-Frechet bound

$$\mathrm{Var}_{\min} = \left[1 - \partial b/\partial\theta\right]^2 / I(\theta) \qquad \text{(II 1)}$$

$$I(\theta) = E\left\{\left[\frac{\partial}{\partial\theta}\sum_{i=1}^{n} \ln f(x_i, \theta)\right]^2\right\}$$

The sum is over all data and b is the bias, if any, the x_i are assumed independent and the allowed range of x must not depend upon θ. The ratio $\epsilon = \mathrm{Var}_{\min}/\mathrm{Var}(\hat{\theta})$ is the *efficiency*. An *efficient* estimator (with $\epsilon = 1$) exists only for certain cases. (c) *Minimum mean-squared error* (mse), mse $= E[(\hat{\theta} - \theta)^2] = V(\hat{\theta}) + [E(\hat{\theta}) - \theta]^2$. The mse combines the error due to any bias quadratically with the variance, which expresses only the spread about $E(\hat{\theta})$ as distinct from θ. (d) *Robust*, a robust estimator is not sensitive to errors in our assumptions, e g, to departures from the assumed p d f due to noise or whatever

These criteria (and others) allow us to evaluate any procedure for obtaining $\hat{\theta}$. In many cases these criteria conflict. The bias, variance, and mse may depend on the unknown θ. In this case the optimum prescription for $\hat{\theta}$ may depend on the range in which we assume θ to lie

Following are techniques in common use for obtaining estimators and their standard errors $\sigma(\hat{\theta}) = \sqrt{\mathrm{Var}(\hat{\theta})}$. When the conditions of the central limit theorem are satisfied, the interval $\hat{\theta} \pm \sigma(\hat{\theta})$ forms a 68 3% *confidence interval*. This is a random interval in that its endpoints depend upon the randomly sampled data, its meaning here will be taken to be that in 68 3% of all similar experiments the interval will include the true value θ. One should be aware that in most practical cases the central limit theorem is only approximately satisfied and accordingly confidence intervals which depend on that are only approximate. Confidence intervals are discussed in Section II E below

II.B Data with a Common Mean

(1) Suppose we have a set of N independent measurements y_i assumed to be unbiased measurements of the same unknown quantity μ with a common but unknown, variance σ^2 resulting from measurement error. Then

$$\hat{\mu} = \frac{1}{N}\sum_{i=1}^{N} y_i \qquad \text{(II 2)}$$

$$\hat{\sigma}^2 = \frac{1}{N-1}\sum_{i=1}^{N}(y_i - \hat{\mu})^2 = \frac{N}{N-1}\left[E(y^2) - \hat{\mu}^2\right] \qquad \text{(II 3)}$$

are unbiased estimators of μ and σ^2. The variance of $\hat{\mu}$ is σ^2/N. If the common p d f of the y_i is Gaussian, these statistics are independent. If, also, N is large, the variance of $\hat{\sigma}^2$ is $2\sigma^4/N$. If the y_i are Gaussian or N is large enough that the central limit theorem applies, then $\hat{\mu}$ is an efficient estimator for μ. Otherwise $\hat{\mu}$ is sometimes subject to large fluctuations, e g, if the p d f for y_i has substantial probability in long tails. In this case the median of the y_i may be a more *robust* estimator for μ, provided the median and mean are expected to lie at the same point in the p d f for y. For Gaussian y the median has asymptotic (large-N) efficiency $2/\pi \simeq 0.64$. As an example of cases with large tails, for a Student's t the large-N efficiency of $\hat{\mu}$ = the sample median relative to $\hat{\mu}$ = the sample mean is (∞, ∞, 1 62, 1 12, 0 96, 0 80, 0 64) for (1, 2, 3, 4, 5, 8, ∞) degrees of freedom

If σ^2 is known, $\hat{\mu}$ in Eq (II 2) is still the best estimator for μ, if μ is known, substitute it for $\hat{\mu}$ in Eq (II 3) and replace $N - 1$ by N, for a somewhat better estimator $\hat{\sigma}^2$

(2) If the y_i have different, known, variances σ_i^2, then

$$\hat{\mu} = \frac{1}{w}\sum^{N} w_i y_i \qquad \text{(II 4)}$$

where $w_i = 1/\sigma_i^2$ and $w = \sum w_i$, is an unbiased estimator for μ with smaller variance than (II 2). The variance of $\hat{\mu}$ is $1/w$

II.C Linear Least-Squares Fit

We wish to determine the best fit of unbiased data y_i, measured at N points x_i (assumed known with negligible error), to the form $y(x) = \Sigma a_n f_n(x)$, where the f_n are any known, linearly independent functions (e g, Legendre polynomials) which are single-valued over the allowed range of x, and the sum runs from 1 to k. We require $k \leq N$, and at least k of the x_i must be distinct. We wish to estimate the linear coefficients a_n

The method of least squares assumes that each measured y_i is equal to this sum plus an error ϵ_i. If the distribution of ϵ_i has an expectation value of zero (unbiased) and has a finite, known variance which is fixed (does not depend on the parameters of the fit), then the estimates of a_n obtained by minimizing the sum of squares which physicists call $\chi^2 = \sum_i [y_i - \sum a_n f_n(x_i)]^2/\sigma_i^2$ will be unbiased and have the smallest possible variance of all linear

PROBABILITY, STATISTICS, AND MONTE CARLO (Cont'd)

unbiased estimates (Gauss-Markov Theorem) If the point errors ϵ_i are Gaussian, then $\chi^2 = \sum_i \epsilon_i^2/\sigma_i^2$ will be distributed over a large number of similar experiments, as a χ^2 random variable with $N-k$ degrees of freedom We can then evaluate the goodness-of-fit from the large χ^2 figure The observed χ^2 for $n_D = N - k$ can be used to find the "confidence level" CL This expresses the probability that a *worse* fit would be obtained in a large number of similar experiments under the assumptions that (a) the model ($y = \sum a_n f_n$) is correct and (b) the errors ϵ_i are Gaussian and unbiased with variance σ_i^2 If this probability is larger than an agreed-upon value (0 001, 0 01, or 0 05 are common choices), the data are *consistent* with the assumptions, otherwise we may want to find improved assumptions As for the converse, most people do not regard a model as being truly *inconsistent* unless the probability is as low as four or five standard deviations for a Gaussian (6×10^{-3} or 6×10^{-5}, see Sec II E 1) If the ϵ_i are not Gaussian, the method of least squares still works, but the goodness-of-fit test would have to be done using the correct distribution of the random variable we will continue to call "χ^2"

If, more generally, the measured y_i's are not independent, then the set of σ_i^2's must be replaced by the $N\times N$ covariance matrix V_y Then, in matrix notation, if H is the $N\times k$ matrix with element $H_{in} = f_n(x_i)$, the vector (all vectors are column vectors) of solutions $\hat{a}$, with k elements is given by the solution to the *normal equation*

$$(H^T V_y^{-1} H)\hat{a} = H^T V_y^{-1} \vec{y} \,. \qquad \text{(II 5a)}$$

or, formally,

$$\hat{a} = (H^T V_y^{-1} H)^{-1} H^T V_y^{-1} \vec{y} \equiv D\vec{y} \,, \qquad \text{(II 5b)}$$

where $\vec{y}$ is the N-element vector of measured y_i's The normal equations may be solved by numerical methods much more computationally efficient than Eq (II 5b) In terms of the $k\times N$ matrix D, the standard covariance matrix for the $\hat{a}$ is estimated by

$$V_{\hat{a}} = D V_y D^T \qquad \text{(II 6a)}$$

If the measured y_i's are independent, V_y is diagonal with ii^{th} element σ_i^2, and

$$\left[V_{\hat{a}}^{-1}\right]_{nm} = \sum_i f_n(x_i) f_m(x_i)/\sigma_i^2 \qquad \text{(II 6b)}$$

expresses the covariance of $\hat{a}_n$ and $\hat{a}_m$ [see Eq (I 7)], which are not usually independent even if the y_i's are

The estimated variance of an interpolated or extrapolated value of y at a point x, $\hat{y} = \sum \hat{a}_n f_n(x)$, is

$$\sigma^2(\hat{y}) = \sum_{nm} (V_{\hat{a}})_{nm} f_n(x) f_m(x) \qquad \text{(II 7)}$$

The same results may be obtained by numerical techniques from the sum of squares, χ^2, directly, if we have a reasonable first guess $\vec{a}_0$ for the solution vector

$$\hat{a} = \vec{a}_0 - \left(\frac{\partial^2\chi^2}{\partial a^2}\right)^{-1}_{\vec{a}_0} \left.\frac{\partial\chi^2}{\partial a}\right|_{\vec{a}_0} \qquad \text{(II 8a)}$$

and

$$V_{\hat{a}} = 2\left(\frac{\partial^2\chi^2}{\partial a^2}\right)^{-1}_{\hat{a}} \,, \qquad \text{(II 8b)}$$

where $\partial\chi^2/\partial a$ is a k-element vector whose n^{th} element is $\partial\chi^2/\partial a_n$, $\partial^2\chi^2/\partial a^2$ is a $k\times k$ matrix with mn^{th} element $\partial^2\chi^2/(\partial a_m\, \partial a_n)$, and all derivatives are to be evaluated at the points indicated If "χ^2" is a true χ^2, the second-derivative matrix is independent of $\vec{a}$, and the shape of the χ^2 as a function of $\vec{a}$ is a paraboloid, otherwise one may need to iterate Eq (II 8a) to arrive at a solution (Newton-Raphson method)

Note that the errors on the solution $\hat{a}$ are independent of the value of χ^2 at minimum — they depend only upon the shape about the minimum Eq (II 8b) implies that one-standard-deviation limits on the elements of $\hat{a}$ are given by the set of $\vec{a}'$ such that

$$\chi^2(\vec{a}') = \chi^2_{\min} + 1 \qquad \text{(II 9)}$$

(compare with the corresponding relation for maximum-likelihood estimation, Sec II D 2) This equation, which defines a contour in $\vec{a}$-space, is often convenient for estimating errors in applications of least-squares techniques to *nonlinear* cases, where the second derivative [Eq (II 8b)] may be a rapidly varying function of $\vec{a}$ In general, contours at s standard deviations may be found by replacing the 1 in Eq (II 9) by s^2 If the problem is highly nonlinear, all such contours are at best only approximations to confidence regions with some given probability of covering the true value of $\vec{a}$ It may be that Eq (II 9) will define a set of disjoint regions In addition, iteration of Eq (II 8a) may require sophisticated techniques[3] to reach convergence in a practical amount of computation

Least-squares estimation, unlike maximum likelihood (Sec II D), requires that an error matrix V be known For counting experiments it is therefore necessary to group the data in bins in order to associate a Poisson error with each bin In this case y_i is the bin height and the error depends on the expectation value of the theory in each bin, N_i^{th}, as estimated by the best fit of the model Thus the requirements of the Gauss-Markov theorem are not satisfied Many experimenters arrange the bins to contain enough expected events (say $\gtrsim 7$ or 8) that the Gaussian approximation to the Poisson (Sec I B 3) is accurate, in which case the expected error is the square root of the theoretical height and "χ^2" is approximately a true χ^2 If the error is assumed to be based on the actual observed height N_i^{obs} rather than the theoretical height N_i^{th}, the Gauss-Markov conditions are satisfied but a bias favoring downward fluctuations will occur

For bins with few events, a procedure that converges to the above when N_i^{th} is large and yields correct error estimates for all N_i^{th} is to define $\chi^2 = \sum_i [2(N_i^{th} - N_i^{obs}) + 2N_i^{obs}\ell n(N_i^{obs}/N_i^{th})]$ This assumes that N_i^{obs} is the outcome of a Poisson process, with Poisson parameter $\mu = N_i^{th}$, filling the bin In bins where $N_i^{obs} = 0$, the second term is zero For any N_i^{th}, s-standard-deviation error estimates are constructed as in Eq (II 9) and subsequent discussion

Example — Straight-Line Fit

For the case of a *straight-line fit*, $y(x) = a + bx$, one obtains, for independent measurements y_i the following estimates of a and b,

$$\hat{a} = (S_y S_{xx} - S_x S_{xy})/D \,, \qquad \text{(II 10)}$$

$$\hat{b} = (S_1 S_{xy} - S_x S_y)/D \,,$$

where

$$S_1, S_x, S_y, S_{xx}, S_{xy} = \sum (1, x_i, y_i, x_i^2, x_i y_i)/\sigma_i^2 \,, \qquad \text{(II 11)}$$

respectively, and

$$D = S_1 S_{xx} - S_x^2$$

The covariance matrix of the fitted parameters is

$$\begin{pmatrix} V_{aa} & V_{ab} \\ V_{ab} & V_{bb} \end{pmatrix} = \frac{1}{D}\begin{pmatrix} S_{xx} & -S_x \\ -S_x & S_1 \end{pmatrix} \qquad \text{(II 12)}$$

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The estimated variance of an interpolated or extrapolated value of y at point x is

$$(\hat{y} - y_{\rm true})^2\Big|_{\rm est} = \frac{1}{S_1} + \frac{S_1}{D}\left(x - \frac{S_x}{S_1}\right)^2 \qquad \text{(II 13)}$$

II.D The Method of Maximum Likelihood

II.D.1 General

This is often the simplest method—in many cases the only practical method—for estimating the unknown values of a set of parameters $\vec{\theta}$. We suppose that a set of measured quantities $\vec{x}$ came from a particular p d f f which depends upon $\vec{\theta}$, hence $f(\vec{x},\vec{\theta})$. Now we assume that the probable range of values of $\vec{\theta}$ is restricted by the condition that it must not have been too unlikely that $\vec{x}$ could have come from our f. The principle of maximum likelihood (M L) asserts that the best explanation for a set of data is provided by that value of $\vec{\theta}$ which maximizes the joint probability density for all the data $\vec{x}$. If we have a set of measured $\vec{x}_i$ values which we assume were *independently* sampled from f, then the joint probability density is

$$\mathscr{L}(\vec{\theta}) = \prod_i f(\vec{x}_i,\vec{\theta}) \qquad \text{(II 14)}$$

$\mathscr{L}$ is called the likelihood, it is a function of $\vec{\theta}$ for the fixed set of measured $\vec{x}_i$'s. Although it is computed from a probability density for the data $\vec{x}$, it is not a probability density for $\vec{\theta}$.

In evaluating the $\mathscr{L}$, it is important that any normalization factors in the f's which involve $\vec{\theta}$ be included. However, we will only be interested in the maximum of $\mathscr{L}$ and in ratios of $\mathscr{L}$ at different $\vec{\theta}$'s, hence any multiplicative factors which do not involve the parameters we want to estimate may be dropped, this includes factors which depend on the data but not on $\vec{\theta}$.

It is often more convenient to work with

$$\ell(\vec{\theta}) = \ell n\,\mathscr{L}(\vec{\theta}) \qquad \text{(II 15)}$$

since that converts the product in Eq (II 14) into a sum, also the p d f's f often involve exponentials. The maximum of ℓ is at the same $\vec{\theta}$ as that of $\mathscr{L}$, since, for each component θ_n of $\vec{\theta}$,

$$\frac{\partial\ell}{\partial\theta_n} = \frac{\partial\ell n\mathscr{L}}{\partial\theta_n} = \frac{1}{\mathscr{L}}\frac{\partial\mathscr{L}}{\partial\theta_n} \equiv S = 0 \qquad \text{(II 16)}$$

finds the same extremum for both, S is called the *score* function. Eq (II 16) is called the *likelihood condition* for the optimal solution $\hat{\theta}$. We must be alert to various possibilities for error (a) Eq (II 16) may yield a minimum, therefore one must check the second derivative, (b) there may be more than one maximum—one must try to find the global maximum, (c) the global maximum may lie at a boundary of the physical region, in which case Eq (II 16) will not find it.

If an unbiased, efficient estimator exists, M L will find it. If the estimator is efficient, the score function is linear with a downward slope through zero, in which case the shape of ℓ is a parabola (open at the bottom) and $\mathscr{L}$ has a shape proportional to a Gaussian. This will obtain in certain special cases and in the asymptotic limit of large amounts of data, provided certain conditions (e g , that the solution does not lie on a boundary) are met. However, "large" is not well defined, and in many practical situations the M L estimator may be neither unbiased nor efficient.

The results of two or more experiments may be combined by adding the score functions, adding the ℓ's, or multiplying the $\mathscr{L}$'s.

Under a one-to-one change of parameters from $\vec{\theta}$ to $\vec{\phi} = \vec{\phi}(\vec{\theta})$, the M L estimate is simply $\hat{\phi} = \vec{\phi}(\hat{\theta})$, given the solution for $\hat{\theta}$ for $\vec{\theta}$. That is, the M L solution for $\vec{\phi}$ is found by simple substitution of $\hat{\theta}$ into the transformation equation. It is possible that the new solution $\hat{\phi}$ will be a biased solution for the true value of $\vec{\phi}$ even if $\hat{\theta}$ is not biased, and vice-versa. In the asymptotic limit both $\hat{\theta}$ and $\hat{\phi}$ will converge to unbiased solutions, but at different rates.

Unlike least-squares estimation, the value of the likelihood at the solution does not tell us whether the final fit was a sensible description of the data or not. To evaluate this, one may (a) prepare histograms of the data projected on various axes and make χ^2 (or other) comparisons with the fitted model projected upon the same axes, and/or (b) do numerous Monte Carlo simulations of the experiment under the hypothesis that the fitted parameters are correct, fit each of these, and compare the experimental likelihood (or ℓ) with those obtained from these simulations. If the experimental likelihood is lower than that of some agreed-upon fraction of these results, one should question the appropriateness of the p d f's f. At the same time one can check for bias in the solution.

The likelihood approach has the advantage over least-squares methods that no binning of the data, with its consequent loss of information, is required. For small data samples this may be very important. Additionally, the p d f f may depend on a number of measured quantities. For least-squares fitting it is necessary to project the data onto a histogram in one or more dimensions and fit to this histogram. This loses the information about any variables not in the histogram, in addition to that lost by the binning. M L requires no such projection, it uses the full multidimensional information in the data. However, M L estimation requires that the form of f be known, the results may be sensitive to deviations from this form. That is M L estimators may not be robust. Least-squares fitting only requires that the point errors ϵ_i be unbiased and of finite variance. In the linear least squares problem of Sec II C, if the ϵ_i are Gaussian-distributed both least squares and M L will give the same estimators.

II.D 2 Error estimates

The covariance matrix V may be estimated from

$$V_{nm} = \left\{E\left[-\frac{\partial^2\ell}{\partial\theta_n\partial\theta_m}\bigg|_{\hat{\theta}}\right]\right\}^{-1} \qquad \text{(II 17)}$$

If the estimator is efficient or nearly so the "expectation" operation in Eq (II 17) has no effect because the second derivative of ℓ is constant. Otherwise, it may be approximated by taking the average of the quantity in square brackets over a range of θ_n and θ_m near the solution. For complex cases it may be more practical to evaluate s-standard-deviation errors from the contour

$$\ell(\vec{\theta}) = \ell_{\rm max} - s^2/2\,,$$

where $\ell_{\rm max}$ is the value of ℓ at the solution point (compare with Eq (II 9) for least-squares fitting). The extreme limits of this contour parallel to the θ_n axis give an approximate s-standard-deviation confidence interval in θ_n. These intervals may not be symmetric and they may even consist of two or more disjoint intervals. This procedure gives one-standard-deviation errors in θ_n equal to $\sqrt{V_{nn}}$ of Eq (II 17) if the estimator is efficient. If it is not efficient, the level of confidence implied by the value of s is only approximate.

II E Errors and Confidence Intervals

II.E.1 Gaussian errors

If the data are such that the distribution of the estimator(s) satisfies the central limit theorem (I B 4), the Gaussian distribution is the basis of the error analysis. If there is more than one parameter being estimated, the multivariate Gaussian is used. We define a *confidence interval* as being an interval constructed from the data to have probability *at least* CL (called confidence level) of covering the true value of θ. For the univariate case with known σ,

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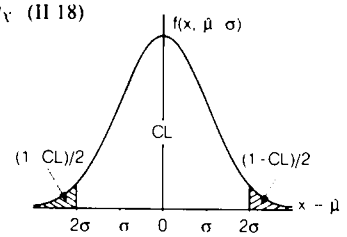
$$CL = \int_{\hat{\mu}-\delta}^{\hat{\mu}+\delta} f(x,\hat{\mu},\sigma^2)dx \quad \text{(II 18)}$$



is the probability that the true value of μ will fall within $\pm\delta$ ($\delta > 0$) of the measured $\hat{\mu}$ This interval will cover μ in a fraction CL of all similar measurements The small figure in Eq (II 18) shows a $\delta = 2\sigma$ confidence interval unshaded The choice $\delta = \sqrt{\mathrm{Var}(\hat{\mu})} \equiv \sigma$ gives an interval called the *standard error* which has CL = 68 33% if σ is known Other frequently used choices for δ, in terms of $1 - $ CL (which is the probability that the stated interval *fails* to cover the unknown μ), are

$1 -$ CL (%)	δ
31 67	1σ
4 55	2σ
0 27	3σ
$6\ 4\times10^{-3}$	4σ
$5\ 8\times10^{-5}$	5σ

$1 -$ CL (%)	δ
10	$1\ 64\sigma$
5	$1\ 96\sigma$
1	$2\ 58\sigma$
0 1	$3\ 29\sigma$
0 01	$3\ 89\sigma$

For other δ, read the ordinate of the χ^2 figure above as $1 - $ CL on the $n_D = 1$ curve at $\chi^2 = (\delta/\sigma)^2$ We can set a one-sided (upper or lower) limit by excluding above $\hat{\mu} + \delta$ (or below $\hat{\mu} - \delta$), $1 - $ CL for such limits are 1/2 the values in the table above

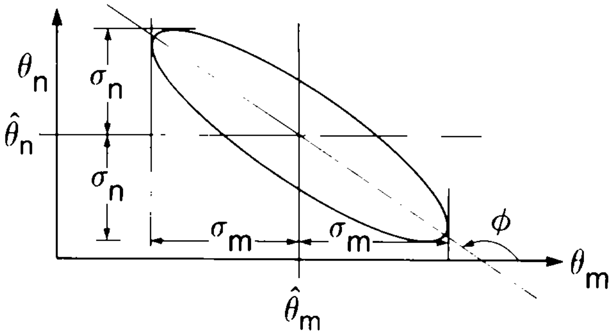
If the variance σ^2 of the estimator is not known, but must be estimated from the data, then we need to incorporate the error in $\hat{\sigma}$ into our confidence interval using Student's t distribution If we have N data points with which we estimate k parameters, the Gaussian approximation is adequate for $N - k >> 1$ Otherwise replace δ by a factor $T\hat{\sigma}$, T being defined by

$$\int_{-T}^{T} f(x, N-k)\,dx = CL\,, \quad \text{(II 19)}$$

where f is defined in Eq (I 24) T is tabulated in Ref 1 and here

	$1 -$ CL (%)					
$N - k$	31 67	10 00	5 00	4 55	1 00	0 27
1	1 84	6 31	12 71	13 97	63 66	235 78
2	1 32	2 92	4 30	4 53	9 92	19 21
3	1 20	2 35	3 18	3 31	5 84	9 22
4	1 14	2 13	2 78	2 87	4 60	6 62
5	1 11	2 01	2 57	2 65	4 03	5 51
10	1 05	1 81	2 23	2 28	3 17	3 96
20	1 03	1 72	2 09	2 13	2 85	3 42
∞	1 00	1 64	1 96	2 00	2 58	3 00

For multivariate θ we must consider pairwise correlations Assuming a multivariate Gaussian, Eq (I 19), the standard error ellipse for the pair $(\hat{\theta}_m, \hat{\theta}_n)$ may be drawn



The minimum χ^2 or maximum likelihood solution is at $(\hat{\theta}_m, \hat{\theta}_n)$ The standard errors σ_m and σ_n are defined as shown, where the ellipse is at a constant value of $\chi^2 = \chi^2_{min} + 1$ or $\ell = \ell_{max} - 1/2$ To construct this contour from these relations, any other parameters θ_ℓ, $\ell \neq m,n$, must be allowed to freely find their optimum values for every trial point The angle of the major axis of the ellipse is given by

$$\tan 2\phi = \frac{2\rho_{mn}\sigma_m\sigma_n}{\sigma_m^2 - \sigma_n^2} \quad \text{(II 20)}$$

For any unbiased procedure (e g , least squares or ML) being used to estimate k parameters θ_i, $i = 1, \ldots, k$, the probability CL that the true values of all k lie within the s-standard deviation ellipsoid may be found from the large χ^2 figure Read the ordinate as $1 - $ CL, the correct value of $1 - $ CL occurs on the $n_D = k$ curve at $\chi^2 = s^2$ For example, for $k = 2$, the probability that the true values of θ_1 and θ_2 simultaneously lie within the one-standard-deviation error ellipse ($s = 1$), centered on $\hat{\theta}_1$ and $\hat{\theta}_2$, is 39% This probability only assumes Gaussian errors, unbiased estimators, and that the model describing the data in terms of the θ_i is correct

II E 2 Gaussian errors — bounded physical region

In certain statistical problems the true value of the parameter to be estimated, μ, is constrained to lie within a bounded *physical region* (e g , the mass of a neutrino is bounded from below by 0) However, due to random measurement error, real measured values may or may not occur inside the physical region For this case no completely satisfactory approach exists, but here we suggest a technique for obtaining approximate limits within the physical region at specified confidence levels

We assume a measurement x, which represents one observation (or the result of combining multiple measurements as in Sec II B) from a Gaussian of true (but unknown) mean μ and known, fixed, variance σ^2 We *estimate* μ by $\hat{\mu} = x$ and attempt to construct a confidence interval for μ from the resultant Gaussian, as above If $\hat{\mu}$ or a significant portion of the probability lies in the unphysical region, the result, while statistically perfectly correct as stated is physically unsatisfactory

If we assume μ is bounded from below by μ_{min} (the argument for μ bounded from above is similar), we may estimate a reasonable upper limit for μ at the CL (e g , 90% or 95%) level by the following procedure (1) *renormalize* the Gaussian probability distribution for x such that the integral of Eq (I 16) with $\mu = \hat{\mu}$ over x from μ_{min} to infinity (i e , over the physical region), unshaded in the figure below, is equal to 1 0, (2) find the value μ_1 such that the integral over x of the renormalized distribution from μ_{min} to μ_1 is equal to the desired value of CL, (3) set μ_1 to be the desired upper limit with confidence CL In fact, it can be shown that this is *conservative*, in the sense that the probability that this interval actually covers the true value of μ is $\geq$ CL

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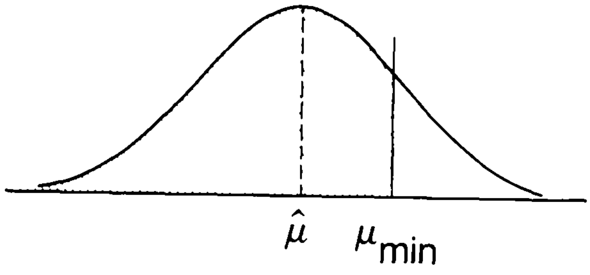


For $\mu - \mu_{min} >> \sigma$, this technique which may be applied for any measured x (physical or unphysical) converges smoothly to that of the previous section since x is then effectively confined to the physical region.

One should exercise caution for values of x which lie many standard deviations outside the physical region. It may be that the particular probability model (Gaussian with variance σ^2) may not be a correct description of the measurement process (e.g. the true variance may have unanticipated components and be $> \sigma^2$, or there may be a bias), in which case confidence levels of this sort will not be correct.

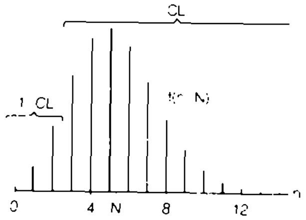
If $\hat{\mu} < \mu_{min}$, some authors prefer to use a fixed upper limit calculated for $\hat{\mu} = \mu_{min}$ or $\hat{\mu} = \mu_{min} + \sigma$ rather than allow the upper limit to decrease as $\hat{\mu}$ decreases. In any case, averaging of experiments requires that $\hat{\mu}$ and its variance be quoted, in addition to any upper limits, even if $\hat{\mu}$ is unphysical.

II E 3 Poisson processes — upper limits

Because the outcome of a Poisson process is an integral number of events, n_0, it is usually not possible to set confidence intervals for the true Poisson parameter μ at a certain exact CL. For large n_0 an approximate interval can be set using the Gaussian approximation, See I B 3 and the techniques of Eq (II E 1).

For small n_0 we can define an upper limit N for μ as being that value of μ such that it would be exactly CL (e.g., CL = 90% or 95%) probable that a random observation of n would then lie above the observed n_0. Thus

$$\mathrm{CL} = \sum_{n=n_0+1}^{\infty} f(n,N) = 1 - \sum_{n=0}^{n_0} f(n,N) \qquad \text{(II 21)}$$



The small figure above illustrates the case with $n_0 = 2$ and CL = 90%, for which it may be shown that $N = 5.3$. For any given n_0 and desired CL we can obtain N from the χ^2 figure because of a relation between the Poisson and the χ^2: read the ordinate as $1 - \mathrm{CL}$, find χ^2 on the curve for $n_D = 2(n_0 + 1)$, then $N = \chi^2/2$. Some useful values are

Poisson upper limits N for n_0 observed events

n_0	CL= 90%	CL= 95%	n_0	CL= 90%	CL= 95%
0	2 30	3 00	6	10 53	11 84
1	3 89	4 74	7	11 77	13 15
2	5 32	6 30	8	13 00	14 44
3	6 68	7 75	9	14 21	15 71
4	7 99	9 15	10	15 41	16 96
5	9 27	10 51			

These choices of N will give *conservative* upper limits. That is the probability that $N \geq \mu$ is at least CL, and it may be more. For example, if $\mu \leq 2.30$ any of the above upper limits will be above the true μ regardless of the outcome of the experiment n_0, i.e. the true CL = 100%.

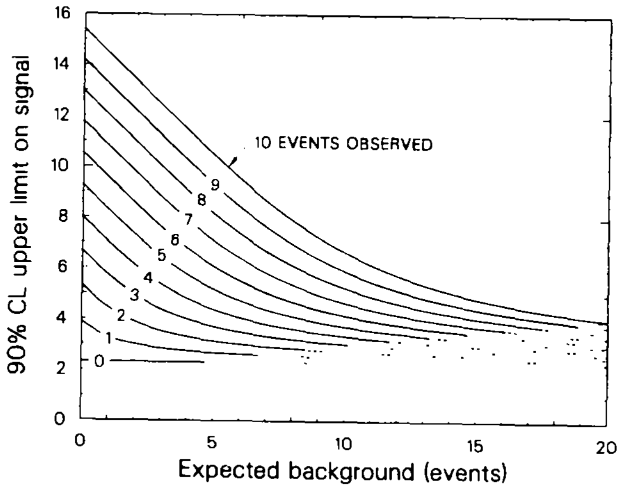
II E 4 Poisson processes with background[4]

If we observe n_0 events in a Poisson process which has two components, signal and background, estimating a limit on the signal is more complicated. Let μ_S be the unknown expectation value for the signal and μ_B be the expectation value (the Poisson parameter) for the sum of all backgrounds. Assume μ_B is known with negligible error, however we don't know n_B, the actual number of events resulting from the background. We do, however, know that $n_B \leq n_0$. If $\mu_B + \mu_S$ is large, the Gaussian approximation to the Poisson (see Sec. I B 3) is usually adequate, and one can define confidence intervals or limits as above, assuming $\hat{n}_B \simeq \mu_B$ and therefore $\hat{\mu}_S = n_0 - \mu_B$ with variance equal to n_0 (larger than $\hat{\mu}_S$ to allow for the error in $\hat{n}_B$).

Otherwise an upper limit can be defined by extension of the argument of the preceding section. Let N be the desired upper limit on μ_S at confidence level CL. Set N to be that value of μ_S such that any random repeat of the current experiment with the same $\mu_S = N$ and μ_B would observe *more* than n_0 events in total *and* would have $n_B \leq n_0$, all with probability CL. For any assumed N and μ_B we can calculate this probability

$$\mathrm{CL} = 1 - \frac{e^{-(\mu_B + N)} \sum_{n=0}^{n_0} (\mu_B + N)^n / n!}{e^{-\mu_B} \sum_{n=0}^{n_0} \mu_B^n / n!} \qquad \text{(II 22)}$$

We adjust N to obtain a desired CL. For $\mu_B = 0$ this converges to (II 21). As in that case this gives a *conservative* upper limit in that for any given true μ_S we get a true probability $\geq$ CL that $N \geq \mu_S$, averaged over a large set of identically performed experiments. For CL = 0 90 the figure below shows N as a function of n_0 and μ_B.



Averaging of experiments and other comparisons require that n_0 and μ_B be quoted and the technique used for upper limit extraction be given.

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If $\mu_B >> n_0$ the experimenter should question the probability of observing n_B as that n_0. If this is very small the background, μ_B, may not have been calculated properly and the upper limit for μ_S obtained under those assumptions may be too low. For example, in the above figure the dashed portions of the curves lie in the region where n_0 is expected to exceed the observed value 99% of the time (or more), even in the complete absence of signal. In these regions one should be cautious about accepting the results of the measurement.

As in the Gaussian case (II.E.2), whenever $n_0 < \mu_B$ some experimenters may prefer to use N calculated as if $n_0 \simeq \mu_B$ rather than the smaller value obtained from the observed n_0.

II.F Propagation of Errors

Suppose we have a set of N random variables y_i which may be direct measurements or derived estimators $\hat{\theta}$, and we have a covariance matrix V for these. We can make a transformation to a different set of variables $f_j \equiv f_j(y)$, $j = 1, \ldots, M$ $(M \leq N)$ and obtain best estimates for the f_j from

$$\hat{f}_j \simeq f_j(\hat{y}) + \frac{1}{2}\sum_{k,n}^{N} V_{kn}\left[\frac{\partial^2 f_j}{\partial y_k \partial y_n}\right]_{\hat{y}} \qquad \text{(II.23)}$$

with covariance matrix

$$V_{ij}(\hat{f}) \simeq D_i^T(\hat{f}) V D_j(\hat{f}), \quad i,j = 1, \ldots, M \qquad \text{(II.24)}$$

The $\hat{y}$ are our best estimates for the y's. The vectors D_i have elements $\partial f_i/\partial y_n$, $n = 1, \ldots, N$, evaluated at $\hat{y}$, arranged in a column vector. For a single-valued function f of a single measurement y with variance σ^2 (i.e., $M = 1, N = 1$), this becomes

$$\hat{f} \simeq f(\hat{y}) + \frac{1}{2}\sigma^2 f''(\hat{y})$$

$$V(\hat{f}) \simeq \sigma^2 f'^2(\hat{y}), \qquad \text{(II.25)}$$

where the primes denote differentiation with respect to y, evaluated at $\hat{y}$.

These approximations are based on a Taylor expansion of f about the true value of y. If f is approximately linear in y over a range of roughly $\hat{y}_i \pm \sigma(y_i)$, the approximation is good and the second-order terms in (II.23) and (II.25) can be neglected. If linearity is badly violated (e.g. $f \propto 1/y$ and $\hat{y}$ is no more than a few σ from zero), it should be recognized that propagation of errors will give very approximate results. In this case $\hat{f} \simeq f(\hat{y})$ may be a biased estimator for f even if $\hat{y}$ is unbiased for y, and the second-order terms in (II.23) and (II.25) will help to reduce that bias.

III. MONTE CARLO TECHNIQUES

Monte Carlo techniques are used to simulate on a computer random behavior which is too complex to be derived analytically. Most calculations are based upon *pseudorandom* numbers, a reproducible sequence of numbers generated on the open interval (0,1) in such a way that they satisfy various statistical tests for a uniform distribution, with independent numbers. No such numbers are truly uniform and independent. Many commercial random number generators sacrifice randomness in favor of speed. It is not rare that unforeseen correlations will introduce non-negligible errors in the results. A useful test for this is to recompute the same results with a different algorithm for the pseudorandom numbers. To improve the performance of an existing generator one may use the *Bays-Durham algorithm* [see Ref. 3 for discussion].
(a) Initialize by generating and storing N (e.g., $N = 97$) random numbers in an array v, using the available generator. Generate a new random number u and save it. (b) On the next call, use this u as an address $j = 1 +$ (integer part of Nu) to select v_j as the random number to be returned. Also save this v_j as u for the next call. Replace v_j in the array with a new random number using the available generator. On the next call, go to (b).

Monte Carlo simulations of complex processes break them down into a sequence of steps. At each step a particular outcome is chosen from a set of possibilities according to a certain p.d.f. To do this we must transform our uniform random numbers into random numbers sampled from a different distribution on a different range.

Two techniques are in wide use to do this. We will discuss only single variable cases; multiple variable cases use straightforward extensions of these techniques. We assume we are in possession of a random number u chosen from a uniform distribution on (0,1).

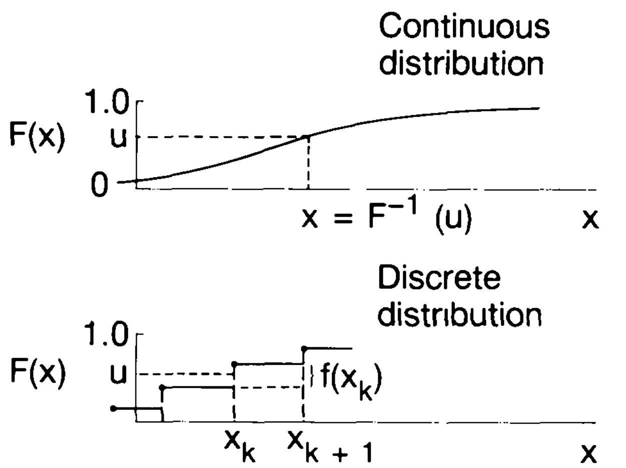
III.A Inverse Transform Method

If the desired probability density function is $f(x)$ on the range $-\infty < x < \infty$, its cumulative distribution function (expressing the probability that $x \leq a$) is given by Eq. (I.1). If a is chosen with probability density $f(a)$, then the integrated probability up to point a, $F(a)$, is itself a random variable which will occur with uniform probability density on [0,1]. Ignoring the endpoints (which occur with zero probability), we can then find a unique x distributed as $f(x)$ for $f(x)$ *continuous*, for a given u if we set

$$u = F(x), \qquad \text{(III.1)}$$

provided we can find an inverse of F, defined by

$$x = F^{-1}(u) \qquad \text{(III.2)}$$



For a *discrete* distribution, $F(x)$ will have a discontinuous jump of size $f(x_k)$ at each allowed x_k, $k = 1, 2, \ldots$. Choose u from a uniform distribution on (0,1) as before. Find x_k such that

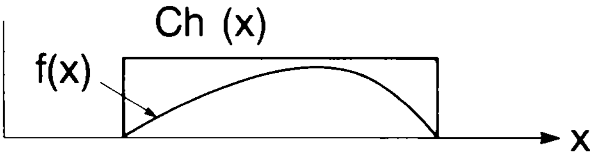
$$F(x_{k-1}) < u \leq F(x_k) \equiv \text{Prob}(x \leq x_k) = \sum_{i=1}^{k} f(x_i), \qquad \text{(III.3)}$$

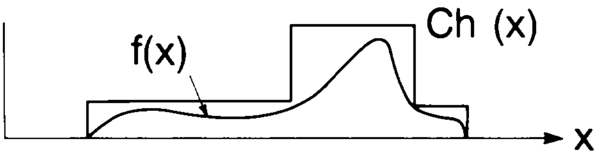
then x_k is the value we seek (note: $F(x_0) \equiv 0$).

III.B Acceptance-Rejection Method (Von Neumann)

Very commonly an analytic form for $F(x)$ is unknown or too complex to work with, so that obtaining an inverse for it as in Eq. (III.2) is impractical. We suppose that for any given value of x the probability density function $f(x)$ can be computed and further that enough is known about $f(x)$ that we can enclose it entirely inside a shape which is strictly proportional to a distribution $h(x)$ which we can generate relatively quickly, for example

PROBABILITY, STATISTICS, AND MONTE CARLO (Cont'd)





Frequently $h(x)$ is uniform or a normalized sum of uniform distributions Note that both $f(x)$ and $h(x)$ must be normalized to unit area and therefore the proportionality constant $C > 1$ To generate $f(x)$, first generate a candidate x according to $h(x)$ Calculate $f(x)$ and the height of the envelope $C\ h(x)$, generate u as above and *test* if $f(x) \leq uC\ h(x)$ If so, accept x, if not reject x and try again If we regard x and $uC\ h(x)$ as the abscissa and ordinate of a point in a two-dimensional plot, these points will populate the entire area $C\ h(x)$ in a smooth manner, then we accept those which fall under $f(x)$ The efficiency is the ratio of areas, which must equal $1/C$, therefore we must keep C as close as possible to 1 0 Therefore we try to choose $C\ h(x)$ to be as close to $f(x)$ as convenience dictates, as in the lower figure above This practice is called *importance sampling*, because this form of $h(x)$ means that we will generate more trial values of x in the region where $f(x)$ is most important

III.C Algorithms

Many algorithms for generating common distributions are given by Rubinstein (1981),[5] Devroye (1986),[6], Press (1986),[3] and Walck (1987),[7] a few of these are reproduced here For many distributions alternative algorithms exist, varying in complexity, speed, and accuracy We have selected compact, accurate, and reasonably fast algorithms Variables named "u" are assumed uniform on (0,1) and independent

III.C.1 Gaussian distribution

Generate u_1 and u_2 Then $v_1 = 2u_1 - 1$ and $v_2 = 2u_1 - 1$ are uniform on $(-1,1)$ Calculate $S = v_1^2 + v_2^2$ If $S > 1$ 0, start over Otherwise,

$$z_1 = v_1[-2\ell n(S)/S]^{1/2} \text{ and } z_2 = v_2[-2\ell n(S)/S]^{1/2}$$

are independent and Gaussian distributed with mean zero and $\sigma^2 = 1$ For other mean μ and variance σ^2 use $z_i' = \sigma z_i + \mu$

For a multivariate Gaussian it often is simplest to find a transformation matrix H as described at the end of Sec I B 4 and generate n independent z_i's with zero means and unit variances, then return $\vec{x} = H\vec{z} + \vec{\mu}$ For $n = 2$ it is convenient to choose H such that $x_1 = z_1\sigma_1 + \mu_1$ and $x_2 =$ $V_{12}x_1/\sigma_1^2 + z_2[(\sigma_1^2\sigma_2^2 - V_{12}^2)/\sigma_1^2]^{1/2} + \mu_2$, where $\sigma_i^2 = V_{ii}$

III C 2 $\chi^2(n_D)$ distribution

For n_D even, generate $n_D/2$ u_i's, then $y = -2\ell n\left[\prod_{i=1}^{n_D/2} u_i\right]$ is $\chi^2(n_D)$ For n_D odd, generate $(n_D - 1)/2$ u_i's and one Gaussian z as in III C 1, then $y = -2\ell n\left[\prod_{i=1}^{(n_D-1)/2} u_i\right] + z^2$ is $\chi^2(n_D)$ For $n_D \gtrsim 30$ the much faster Gaussian approximations for the χ^2 may be preferable generate z as in III C 1 and use $y = \left[z + \sqrt{2n_D - 1}\right]^2/2$

III C.3 Student's t distribution

Use Eq (I 23), first generate one Gaussian z with mean zero and $\sigma^2 = 1$ as in III C 1, and then generate one y obeying $\chi^2(n_D)$ as in III C 2 Then $t = z/\sqrt{y/n_D}$ has a Student's distribution with n_D degrees of freedom

III C 4 Binomial distribution

If $p \leq 1/2$ in Eq (I 12), then iterate until a successful choice is made begin with $k = 1$, compute $P_k = q^n$ [for $k \neq 1$ use $P_k \equiv f(r_k\ n, p)$, Eq (I 12)] and store P_k into B, generate u If $u \leq B$ accept $r_k = k - 1$ and stop, otherwise increment k by 1 and compute next P_k and add to B, generate a new u and repeat If we arrive at $k = n + 1$, stop and accept $r_{n+1} = n$ If $p > 1/2$ it will be more efficient to generate r from $f(r, n, q)$, i e, with p and q interchanged, and then set $r = n - r$

III.C.5 Poisson distribution

Iterate until a successful choice is made Begin with $k = 1$ and set $A = 1$ to start Generate u Replace A with uA, if now $A < \exp(-\mu)$, where μ is the Poisson parameter, accept $n_k = k - 1$ and stop Otherwise increment k by 1, generate a new u and repeat, always starting with the value of A left from the previous try For large μ ($\gtrsim 10$) it may be satisfactory (and much faster) to approximate the Poisson by a Gaussian [Sec I B 4] and generate z from $f(z,0,1)$, then accept $x = \max(0,[\mu + z^{1/2} - 0\ 5])$, where [ ] signifies the greatest integer $\leq$ the expression

III C 6 Gamma distribution

- **If** $k = 1$ in Eq (I 26), accept $x = -(\ell n\ u)/\lambda$
- **If** $0 < k < 1$, initialize with $d = k^{k/(1-k)}(1 - k)$ Ⓐ Generate $v_1 = -(\ell n\ u_1)/\lambda$ and $v_2 = -(\ell n\ u_2)/\lambda$ If $v_1 + v_2 \leq d + v_1^{1/k}$, accept $x = v_1^{1/k}$ and stop, otherwise go back to Ⓐ
- **If** k is a small integer, repeat the $k = 1$ case k times and add the results
- Otherwise, if $k > 1$ initialize with $c = 3k - 0\ 75$ Ⓑ Generate $v_1 = u_1(1 - u_1)$ and $v_2 = (u_1 - 0\ 5)\sqrt{c/v_1}$ If $x = k + v_2 < 0$, go back to Ⓑ, otherwise compute $v_3 = 64 v_1^3 u_2^2$ If $v_3 \leq 1 - 2v_2^2/x$ *or* if $\ell n\ v_3 \leq 2\{[k - 1]\ell n[x/(k - 1)] - v_2\}$, accept x and stop, otherwise go back to Ⓑ

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* Revised April 1988 with the assistance of T L Lavine and R Waldi

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2 W T Eadie, D Drijard, F E James, M Roos, and B Sadoulet, *Statistical Methods in Experimental Physics* (North Holland, Amsterdam and London, 1971), L Lyons, *Statistics for Nuclear and Particle Physicists* (Cambridge University Press, New York, 1986), S L Meyer, *Data Analysis for Scientists and Engineers* (John Wiley and Sons, Inc, New York, 1975), A G Frodesen, O Skjeggestad, and H Tøfte, *Probability and Statistics in Particle Physics* (Universitetsforlaget, Oslo, Norway, 1979)

3 W H Press et al, *Numerical Recipes* (Cambridge University Press, New York, 1986)

4 O Helene, Nucl Instr and Meth **212**, 319 (1983)

5 R Y Rubinstein, *Simulation and the Monte Carlo Method* (John Wiley and Sons, Inc, New York, 1981)

6 L Devroye, *Non-Uniform Random Variate Generation* (Springer-Verlag, New York, 1986)

7 Ch Walck, *Random Number Generation*, University of Stockholm Physics Department Report 1987-10-20 (Vers 3 0)

ELECTROMAGNETIC RELATIONS

Quantity	Gaussian CGS	MKSA
Units and conversions Charge Potential Magnetic field Electron charge	 2.99792×10^{9} esu (1/299.792) statvolt = (1/299.792) erg/esu 10^4 gauss = 10^4 dyne/esu $e = 4.803\,242\times10^{-10}$ esu	 = 1 coul = 1 amp-sec = 1 volt = 1 joule/coul = 1 tesla = 1 nt/amp-m $= 1.602\,189\,2\times10^{-19}$ coul
Lorentz force	$\mathbf{F} = q(\mathbf{E} + \frac{\mathbf{v}}{c}\times\mathbf{B})$	$\mathbf{F} = q(\mathbf{E} + \mathbf{v}\times\mathbf{B})$
Maxwell equations	$\nabla\cdot\mathbf{D} = 4\pi\rho$ $\nabla\times\mathbf{E} = -\frac{1}{c}\frac{\partial\mathbf{B}}{\partial t}$ $\nabla\cdot\mathbf{B} = 0$ $\nabla\times\mathbf{H} = \frac{4\pi\mathbf{J}}{c} + \frac{1}{c}\frac{\partial\mathbf{D}}{\partial t}$	$\nabla\cdot\mathbf{D} = \rho$ $\nabla\times\mathbf{E} = -\frac{\partial\mathbf{B}}{\partial t}$ $\nabla\cdot\mathbf{B} = 0$ $\nabla\times\mathbf{H} = \mathbf{J} + \frac{\partial\mathbf{D}}{\partial t}$
Materials Permittivity of free space Permeability of free space	$\mathbf{D} = \epsilon\mathbf{E},\ \mathbf{B} = \mu\mathbf{H}$ $\epsilon_{vac} = 1$ $\mu_{vac} = 1$	$\mathbf{D} = \epsilon\mathbf{E},\ \mathbf{B} = \mu\mathbf{H}$ $\epsilon_{vac} = \epsilon_0$ $\mu_{vac} = \mu_0$
Fields	$\mathbf{E} = -\nabla V - \frac{1}{c}\frac{\partial\mathbf{A}}{\partial t}$ $\mathbf{B} = \nabla\times\mathbf{A}$	$\mathbf{E} = -\nabla V - \frac{\partial\mathbf{A}}{\partial t}$ $\mathbf{B} = \nabla\times\mathbf{A}$
Static potentials (coulomb gauge)	$V = \sum_{\text{charges}} \frac{q}{r}$ $\mathbf{A} = \frac{1}{c}\sum_{\text{currents}} \frac{\mathbf{I}}{r}$	$V = \frac{1}{4\pi\epsilon_0}\sum_{\text{charges}} \frac{q}{r}$ $\mathbf{A} = \frac{\mu_0}{4\pi}\sum_{\text{currents}} \frac{\mathbf{I}}{r}$
Relativistic transformations (v is the velocity of primed system as seen in unprimed system)	$\mathbf{E}'_\parallel = \mathbf{E}_\parallel$ $\mathbf{E}'_\perp = \gamma(\mathbf{E}_\perp + \frac{1}{c}\mathbf{v}\times\mathbf{B})$ $\mathbf{B}'_\parallel = \mathbf{B}_\parallel$ $\mathbf{B}'_\perp = \gamma(\mathbf{B}_\perp - \frac{1}{c}\mathbf{v}\times\mathbf{E})$	$\mathbf{E}'_\parallel = \mathbf{E}_\parallel$ $\mathbf{E}'_\perp = \gamma(\mathbf{E}_\perp + \mathbf{v}\times\mathbf{B})$ $\mathbf{B}'_\parallel = \mathbf{B}_\parallel$ $\mathbf{B}'_\perp = \gamma(\mathbf{B}_\perp - \frac{1}{c^2}\mathbf{v}\times\mathbf{E})$
	$4\pi\epsilon_0 = \frac{1}{c^2}10^7\frac{\text{coul}^2}{\text{nt sec}^2} = \frac{1}{8.98755}\times10^{-9}\frac{\text{coul}^2}{\text{nt m}^2}$ $\frac{\mu_0}{4\pi} = 10^{-7}\frac{\text{nt sec}^2}{\text{coul}^2}$, $c = 2.997\,924\,58\times10^8$ m sec^{-1}	

ELECTROMAGNETIC RELATIONS (Cont'd)

Impedances (MKSA)

ρ = resistivity in $10^{-8}\ \Omega$m

$\sim$ 1.7 for Cu	$\sim$ 5.5 for W
$\sim$ 2.4 for Au	$\sim$ 73 for SS 304
$\sim$ 2.8 for Al	$\sim$ 100 for Nichrome
(Al alloys may have double this value.)	

For alternating currents, instantaneous current I, voltage V, angular frequency ω

$$V = V_0 e^{i\omega t} = ZI$$

Impedance of self-inductance L: $Z = i\omega L$

Impedance of capacitance C: $Z = 1/i\omega C$

Impedance of free space: $Z = \sqrt{\mu_0/\epsilon_0} = 376.7\ \Omega$

Impedance per unit length of a flat conductor of width w (high frequency, ν)

$$Z = \frac{(1+i)\rho}{w\delta}\ , \text{ where } \delta = \text{effective skin depth}$$

$$\delta = \sqrt{\frac{\rho}{\pi\nu\mu}} \approx \frac{6.6\ \text{cm}}{\sqrt{\nu(\text{sec}^{-1})}} \text{ for Cu}$$

Capacitance $\hat{C}$ and inductance $\hat{L}$ per unit length (MKSA)

Flat rectangular plates of width w, separated by $d \ll w$

$$\hat{C} = \epsilon \frac{w}{d}\ , \quad \hat{L} = \mu \frac{d}{w}\ ,$$

$$\frac{\epsilon}{\epsilon_0} = 2 \text{ to } 6 \text{ for plastics; } 4 \text{ to } 8 \text{ for porcelain, glasses}$$

Coaxial cable of inner radius r_1, outer radius r_2

$$\hat{C} = \frac{2\pi\epsilon}{\ln(r_2/r_1)}\ , \quad \hat{L} = \frac{\mu}{2\pi}\ln(r_2/r_1)$$

Transmission lines (no loss)

Impedance: $Z = \sqrt{\hat{L}/\hat{C}}$

Velocity: $v = 1/\sqrt{\hat{L}\hat{C}} = 1/\sqrt{\mu\epsilon}$

Synchrotron radiation (CGS)

For a relativistic particle of charge e, velocity β, γ, energy E, traveling in a circular orbit of radius R

$$\text{Energy loss/revolution (MeV)} = \frac{4\pi}{3}\frac{e^2}{R}\beta^3\gamma^4$$

$$\simeq 0.0885\ [E(\text{GeV})]^4/R(\text{m}) \text{ for } e^{\pm} \text{ if } \beta \simeq 1$$

Energy spectrum. The energy radiated into the photon energy interval $d(\hbar\omega)$ is

$$dI = \alpha\gamma F(\omega/\omega_c)\,d(\hbar\omega)\ ,$$

where $\alpha = e^2/(\hbar c)$ is the fine-structure constant

$$F(y) = 2\sqrt{3}\,y \int_{2y}^{\infty} dx\ K_{5/3}(x)\ ,$$ with $K_{5/3}(x)$ a modified cylindrical Bessel function of the third kind, and $\omega_c = 3\gamma^3 c/R$ is a critical frequency.

$$\hbar\omega_c\ (\text{keV}) \simeq 4.44\ [E(\text{GeV})]^3/R(\text{m}) \text{ for } e^{\pm} \text{ if } \beta \simeq 1$$

In the limit $\gamma \gg 1$,

for $\omega \ll \omega_c$

$$\frac{dI}{d(\hbar\omega)} \simeq 3.3\alpha\left(\frac{\omega R}{c}\right)^{1/3},$$

for $\dfrac{\omega}{\omega_c} = (0.01,\ 0.1,\ 0.2,\ 1.0,\ 2.0)$

$$\frac{dI}{d(\hbar\omega)} \approx (1.0,\ 1.6,\ 1.6,\ 0.5,\ 0.08)\alpha\gamma \quad \text{respectively}$$

for $\omega \gtrsim 2\omega_c$

$$\frac{dI}{d(\hbar\omega)} \approx \sqrt{3\pi}\,\alpha\gamma\left(\frac{\omega}{\omega_c}\right)^{1/2} e^{-2\omega/\omega_c}$$

The radiation is confined to angles $\lesssim 1/\gamma$ relative to the instantaneous direction of motion.

See J. D. Jackson, *Classical Electrodynamics*, 2nd edition (John Wiley & Sons, New York, 1975) for more formulae and details. (Prepared April 1974; revised April 1984.)

CLEBSCH-GORDAN COEFFICIENTS, SPHERICAL HARMONICS, & *d* FUNCTIONS

Note: A $\sqrt{\ }$ is to be understood over every coefficient, e.g., for −8/15 read $-\sqrt{8/15}$.

Notation:

	J	J	...
	M	M	...
m_1	m_2		
m_1	m_2	Coefficients	

$$Y_1^0 = \sqrt{\frac{3}{4\pi}}\cos\theta$$
$$Y_1^1 = -\sqrt{\frac{3}{8\pi}}\sin\theta\, e^{i\phi}$$
$$Y_2^0 = \sqrt{\frac{5}{4\pi}}\left(\frac{3}{2}\cos^2\theta - \frac{1}{2}\right)$$
$$Y_2^1 = -\sqrt{\frac{15}{8\pi}}\sin\theta\cos\theta\, e^{i\phi}$$
$$Y_2^2 = \frac{1}{4}\sqrt{\frac{15}{2\pi}}\sin^2\theta\, e^{2i\phi}$$

$$Y_\ell^{-m} = (-1)^m Y_\ell^{m*}$$

$$d^\ell_{m,0} = \sqrt{\frac{4\pi}{2\ell+1}}\, Y_\ell^m e^{-im\phi}$$

$$\langle j_1 j_2 m_1 m_2 | j_1 j_2 J M\rangle = (-1)^{J-j_1-j_2}\langle j_2 j_1 m_2 m_1 | j_2 j_1 J M\rangle$$

1/2 × 1/2

m_1 m_2	J=1, M=+1
+1/2 +1/2	1

m_1 m_2	1, 0	0, 0
+1/2 −1/2	1/2	1/2
−1/2 +1/2	1/2	−1/2

m_1 m_2	1, −1
−1/2 −1/2	1

1 × 1/2

m_1 m_2	3/2, +3/2
+1 +1/2	1

m_1 m_2	3/2, +1/2	1/2, +1/2
+1 −1/2	1/3	2/3
0 +1/2	2/3	−1/3

m_1 m_2	3/2, −1/2	1/2, −1/2
0 −1/2	2/3	1/3
−1 +1/2	1/3	−2/3

m_1 m_2	3/2, −3/2
−1 −1/2	1

2 × 1/2

m_1 m_2	5/2, +5/2
+2 +1/2	1

m_1 m_2	5/2, +3/2	3/2, +3/2
+2 −1/2	1/5	4/5
+1 +1/2	4/5	−1/5

m_1 m_2	5/2, +1/2	3/2, +1/2
+1 −1/2	2/5	3/5
0 +1/2	3/5	−2/5

m_1 m_2	5/2, −1/2	3/2, −1/2
0 −1/2	3/5	2/5
−1 +1/2	2/5	−3/5

m_1 m_2	5/2, −3/2	3/2, −3/2
−1 −1/2	4/5	1/5
−2 +1/2	1/5	−4/5

m_1 m_2	5/2, −5/2
−2 −1/2	1

3/2 × 1/2

m_1 m_2	2, +2
+3/2 +1/2	1

m_1 m_2	2, +1	1, +1
+3/2 −1/2	1/4	3/4
+1/2 +1/2	3/4	−1/4

m_1 m_2	2, 0	1, 0
+1/2 −1/2	1/2	1/2
−1/2 +1/2	1/2	−1/2

m_1 m_2	2, −1	1, −1
−1/2 −1/2	3/4	1/4
−3/2 +1/2	1/4	−3/4

m_1 m_2	2, −2
−3/2 −1/2	1

2 × 1

m_1 m_2	3, +3
+2 +1	1

m_1 m_2	3, +2	2, +2
+2 0	1/3	2/3
+1 +1	2/3	−1/3

m_1 m_2	3, +1	2, +1	1, +1
+2 −1	1/15	1/3	3/5
+1 0	8/15	1/6	−3/10
0 +1	6/15	−1/2	1/10

m_1 m_2	3, 0	2, 0	1, 0
+1 −1	1/5	1/2	3/10
0 0	3/5	0	−2/5
−1 +1	1/5	−1/2	3/10

m_1 m_2	3, −1	2, −1	1, −1
0 −1	6/15	1/2	1/10
−1 0	8/15	−1/6	−3/10
−2 +1	1/15	−1/3	3/5

m_1 m_2	3, −2	2, −2
−1 −1	2/3	1/3
−2 0	1/3	−2/3

m_1 m_2	3, −3
−2 −1	1

1 × 1

m_1 m_2	2, +2
+1 +1	1

m_1 m_2	2, +1	1, +1
+1 0	1/2	1/2
0 +1	1/2	−1/2

m_1 m_2	2, 0	1, 0	0, 0
+1 −1	1/6	1/2	1/3
0 0	2/3	0	−1/3
−1 +1	1/6	−1/2	1/3

m_1 m_2	2, −1	1, −1
0 −1	1/2	1/2
−1 0	1/2	−1/2

m_1 m_2	2, −2
−1 −1	1

3/2 × 1

m_1 m_2	5/2, +5/2
+3/2 +1	1

m_1 m_2	5/2, +3/2	3/2, +3/2
+3/2 0	2/5	3/5
+1/2 +1	3/5	−2/5

m_1 m_2	5/2, +1/2	3/2, +1/2	1/2, +1/2
+3/2 −1	1/10	2/5	1/2
+1/2 0	3/5	1/15	−1/3
−1/2 +1	3/10	−8/15	1/6

m_1 m_2	5/2, −1/2	3/2, −1/2	1/2, −1/2
+1/2 −1	3/10	8/15	1/6
−1/2 0	3/5	−1/15	−1/3
−3/2 +1	1/10	−2/5	1/2

m_1 m_2	5/2, −3/2	3/2, −3/2
−1/2 −1	3/5	2/5
−3/2 0	2/5	−3/5

m_1 m_2	5/2, −5/2
−3/2 −1	1

$$d^j_{m',m} = (-1)^{m-m'} d^j_{m,m'} = d^j_{-m,-m'}$$

3/2 × 3/2

m_1 m_2	3, +3
+3/2 +3/2	1

m_1 m_2	3, +2	2, +2
+3/2 +1/2	1/2	1/2
+1/2 +3/2	1/2	−1/2

m_1 m_2	3, +1	2, +1	1, +1
+3/2 −1/2	1/5	1/2	3/10
+1/2 +1/2	3/5	0	−2/5
−1/2 +3/2	1/5	−1/2	3/10

m_1 m_2	3, 0	2, 0	1, 0	0, 0
+3/2 −3/2	1/20	1/4	9/20	1/4
+1/2 −1/2	9/20	1/4	−1/20	−1/4
−1/2 +1/2	9/20	−1/4	−1/20	1/4
−3/2 +3/2	1/20	−1/4	9/20	−1/4

m_1 m_2	3, −1	2, −1	1, −1
+1/2 −3/2	1/5	1/2	3/10
−1/2 −1/2	3/5	0	−2/5
−3/2 +1/2	1/5	−1/2	3/10

m_1 m_2	3, −2	2, −2
−1/2 −3/2	1/2	1/2
−3/2 −1/2	1/2	−1/2

m_1 m_2	3, −3
−3/2 −3/2	1

$$d^{1/2}_{1/2,1/2} = \cos\frac{\theta}{2} \qquad d^{1/2}_{1/2,-1/2} = -\sin\frac{\theta}{2}$$
$$d^1_{1,1} = \frac{1+\cos\theta}{2} \qquad d^1_{1,0} = -\frac{\sin\theta}{\sqrt{2}}$$
$$d^1_{1,-1} = \frac{1-\cos\theta}{2} \qquad d^1_{0,0} = \cos\theta$$

2 × 3/2

m_1 m_2	7/2, +7/2
+2 +3/2	1

m_1 m_2	7/2, +5/2	5/2, +5/2
+2 +1/2	3/7	4/7
+1 +3/2	4/7	−3/7

m_1 m_2	7/2, +3/2	5/2, +3/2	3/2, +3/2
+2 −1/2	1/7	16/35	2/5
+1 +1/2	4/7	1/35	−2/5
0 +3/2	2/7	−18/35	1/5

m_1 m_2	7/2, +1/2	5/2, +1/2	3/2, +1/2	1/2, +1/2
+2 −3/2	1/35	6/35	2/5	2/5
+1 −1/2	12/35	5/14	0	−3/10
0 +1/2	18/35	−3/35	−1/5	1/5
−1 +3/2	4/35	−27/70	2/5	−1/10

m_1 m_2	7/2, −1/2	5/2, −1/2	3/2, −1/2	1/2, −1/2
+1 −3/2	4/35	27/70	2/5	1/10
0 −1/2	18/35	3/35	−1/5	−1/5
−1 +1/2	12/35	−5/14	0	3/10
−2 +3/2	1/35	−6/35	2/5	−2/5

m_1 m_2	7/2, −3/2	5/2, −3/2	3/2, −3/2
0 −3/2	2/7	18/35	1/5
−1 −1/2	4/7	−1/35	−2/5
−2 +1/2	1/7	−16/35	2/5

m_1 m_2	7/2, −5/2	5/2, −5/2
−1 −3/2	4/7	3/7
−2 −1/2	3/7	−4/7

m_1 m_2	7/2, −7/2
−2 −3/2	1

2 × 2

m_1 m_2	4, +4
+2 +2	1

m_1 m_2	4, +3	3, +3
+2 +1	1/2	1/2
+1 +2	1/2	−1/2

m_1 m_2	4, +2	3, +2	2, +2
+2 0	3/14	1/2	2/7
+1 +1	4/7	0	−3/7
0 +2	3/14	−1/2	2/7

m_1 m_2	4, +1	3, +1	2, +1	1, +1
+2 −1	1/14	3/10	3/7	1/5
+1 0	3/7	1/5	−1/14	−3/10
0 +1	3/7	−1/5	−1/14	3/10
−1 +2	1/14	−3/10	3/7	−1/5

m_1 m_2	4, 0	3, 0	2, 0	1, 0	0, 0
+2 −2	1/70	1/10	2/7	2/5	1/5
+1 −1	8/35	2/5	1/14	−1/10	−1/5
0 0	18/35	0	−2/7	0	1/5
−1 +1	8/35	−2/5	1/14	1/10	−1/5
−2 +2	1/70	−1/10	2/7	−2/5	1/5

m_1 m_2	4, −1	3, −1	2, −1	1, −1
+1 −2	1/14	3/10	3/7	1/5
0 −1	3/7	1/5	−1/14	−3/10
−1 0	3/7	−1/5	−1/14	3/10
−2 +1	1/14	−3/10	3/7	−1/5

m_1 m_2	4, −2	3, −2	2, −2
0 −2	3/14	1/2	2/7
−1 −1	4/7	0	−3/7
−2 0	3/14	−1/2	2/7

m_1 m_2	4, −3	3, −3
−1 −2	1/2	1/2
−2 −1	1/2	−1/2

m_1 m_2	4, −4
−2 −2	1

$$d^{3/2}_{3/2,3/2} = \frac{1+\cos\theta}{2}\cos\frac{\theta}{2}$$
$$d^{3/2}_{3/2,1/2} = -\sqrt{3}\,\frac{1+\cos\theta}{2}\sin\frac{\theta}{2}$$
$$d^{3/2}_{3/2,-1/2} = \sqrt{3}\,\frac{1-\cos\theta}{2}\cos\frac{\theta}{2}$$
$$d^{3/2}_{3/2,-3/2} = -\frac{1-\cos\theta}{2}\sin\frac{\theta}{2}$$
$$d^{3/2}_{1/2,1/2} = \frac{3\cos\theta-1}{2}\cos\frac{\theta}{2}$$
$$d^{3/2}_{1/2,-1/2} = -\frac{3\cos\theta+1}{2}\sin\frac{\theta}{2}$$
$$d^2_{2,2} = \left(\frac{1+\cos\theta}{2}\right)^2 \qquad d^2_{2,1} = -\frac{1+\cos\theta}{2}\sin\theta$$
$$d^2_{2,0} = \frac{\sqrt{6}}{4}\sin^2\theta \qquad d^2_{2,-1} = -\frac{1-\cos\theta}{2}\sin\theta$$
$$d^2_{2,-2} = \left(\frac{1-\cos\theta}{2}\right)^2$$
$$d^2_{1,1} = \frac{1+\cos\theta}{2}(2\cos\theta-1) \qquad d^2_{1,0} = -\sqrt{\frac{3}{2}}\sin\theta\cos\theta$$
$$d^2_{1,-1} = \frac{1-\cos\theta}{2}(2\cos\theta+1) \qquad d^2_{0,0} = \left(\frac{3}{2}\cos^2\theta - \frac{1}{2}\right)$$

Sign convention is that of Wigner (*Group Theory*, Academic Press, New York, 1959), also used by Condon and Shortley (*The Theory of Atomic Spectra*, Cambridge Univ Press, New York, 1953), Rose (*Elementary Theory of Angular Momentum*, Wiley, New York, 1957), and Cohen (*Tables of the Clebsch-Gordan Coefficients*, North American Rockwell Science Center, Thousand Oaks, Calif., 1974). The signs and numbers in the current tables have been calculated by computer programs written independently by Cohen and at LBL. (Table extended April 1974.)

SU(3) ISOSCALAR FACTORS AND REPRESENTATION MATRICES

The most commonly used isoscalar factors, corresponding to the singlet, octet, and decuplet content of $8 \otimes 8$ and $10 \otimes 8$, are displayed at the right. The notation uses particle names to identify the coefficients, so that the pattern of relative couplings can be seen at a glance. We illustrate the use of the coefficients by example; see J. J. de Swart, Rev. Mod. Phys. **35**, 916 (1963) for detailed explanation and phase conventions.

A $\sqrt{\ }$ is understood over every integer in the matrices; the exponent ½ is a reminder of this. For example, in de Swart's notation the $\Xi \to \Omega K$ element of our $10 \to 10 \otimes 8$ matrix reads

$$\begin{pmatrix} 10 & 8 & 10 \\ 0\ -2 & \tfrac{1}{2}\ 1 & \tfrac{1}{2}\ -1 \end{pmatrix} = \frac{-\sqrt{6}}{\sqrt{24}}$$

Intramultiplet relative decay strengths can be read directly from our matrices. Thus, the partial widths for $\Delta \to (N\pi)_{I=3/2}$ and $\Omega^* \to (\Xi\bar{K})_{I=0}$ are in the ratio

$$\frac{\Gamma(\Omega^* \to (\Xi\bar{K})_{I=0})}{\Gamma(\Delta \to (N\pi)_{I=3/2})} = \frac{12}{6} \times \text{(phase space factors)}$$

Supplying isospin Clebsch-Gordan coefficients, one obtains, e.g.,

$$\frac{\Gamma(\Omega^{*-} \to \Xi^0 K^-)}{\Gamma(\Delta^+ \to p\pi^0)} = \frac{1/2}{2/3} \times \frac{12}{6} \times p.s.f. = \frac{3}{2} \times p.s.f.$$

Partial widths for $8 \to 8 \otimes 8$ involve a linear superposition of 8_1 (symmetric) and 8_2 (antisymmetric) couplings. For example,

$$\Gamma(\Xi^* \to \Xi\pi) \sim \left(-\sqrt{\frac{9}{20}}g_1 + \sqrt{\frac{3}{12}}g_2 \right)^2$$

The relation between g_1, g_2 (with de Swart's normalization) and the standard D, F couplings appearing in the interaction Lagrangian

$$\mathcal{L} = -\sqrt{2}D\, Tr(\{\bar{B}, B\}M) + \sqrt{2}F\, Tr([\bar{B}, B]M),$$

is

$$D = \frac{\sqrt{30}}{40}g_1, \quad F = \frac{\sqrt{6}}{24}g_2$$

Thus,

$$\Gamma(\Xi^* \to \Xi\pi) \sim (1 - 2\alpha)^2$$

where $\alpha \equiv D/(D+F)$.

When acting upon a representation of dimension d, the generators of SU(3) transformations, λ_a (a=1,8), are $d \times d$ matrices which obey the following commutation and anticommutation relationships

$$[\lambda_a, \lambda_b] = 2if_{abc}\lambda_c$$

$$\{\lambda_a, \lambda_b\} = \frac{4}{3}\delta_{ab}I + 2d_{abc}\lambda_c$$

where I is the $d \times d$ unit matrix. The f_{abc} are odd under the permutation of any pair of indices, while the d_{abc} are even. The nonzero elements are

abc	f_{abc}	abc	d_{abc}	abc	d_{abc}
123	1	118	$1/\sqrt{3}$	355	1/2
147	1/2	146	1/2	366	1/2
156	1/2	157	1/2	377	1/2
246	1/2	228	$1/\sqrt{3}$	448	$-1/(2\sqrt{3})$
257	1/2	247	$-1/2$	558	$-1/(2\sqrt{3})$
345	1/2	256	1/2	668	$-1/(2\sqrt{3})$
367	$-1/2$	338	$1/\sqrt{3}$	778	$-1/(2\sqrt{3})$
458	$\sqrt{3}/2$	344	1/2	888	$1/\sqrt{3}$
678	$\sqrt{3}/2$				

$1 \to 8 \otimes 8$

$$\begin{pmatrix} \Lambda \end{pmatrix}_1 \to \begin{pmatrix} N\bar{K} & \Sigma\pi & \Lambda\eta & \Xi K \end{pmatrix}_{8\otimes 8} = \frac{1}{\sqrt{8}} \begin{pmatrix} 2 & 3 & 1 & -2 \end{pmatrix}^{1/2}$$

$8_1 \to 8 \otimes 8$

$$\begin{pmatrix} N \\ \Sigma \\ \Lambda \\ \Xi \end{pmatrix}_{8_1} \to \begin{pmatrix} N\pi\ \ N\eta\ \ \Sigma K\ \ \Lambda K \\ N\bar{K}\ \ \Sigma\pi\ \ \Lambda\pi\ \ \Sigma\eta\ \ \Xi K \\ N\bar{K}\ \ \Sigma\pi\ \ \Lambda\eta\ \ \Xi K \\ \Sigma\bar{K}\ \ \Lambda\bar{K}\ \ \Xi\pi\ \ \Xi\eta \end{pmatrix}_{8\otimes 8} = \frac{1}{\sqrt{20}} \begin{pmatrix} 9\ \ 1\ \ -9\ \ -1 \\ -6\ \ 0\ \ 4\ \ 4\ \ -6 \\ 2\ \ -12\ \ -4\ \ -2 \\ 9\ \ 1\ \ 9\ \ 1 \end{pmatrix}^{1/2}$$

$8_2 \to 8 \otimes 8$

$$\begin{pmatrix} N \\ \Sigma \\ \Lambda \\ \Xi \end{pmatrix}_{8_2} \to \begin{pmatrix} N\pi\ \ N\eta\ \ \Sigma K\ \ \Lambda K \\ N\bar{K}\ \ \Sigma\pi\ \ \Lambda\pi\ \ \Sigma\eta\ \ \Xi K \\ N\bar{K}\ \ \Sigma\pi\ \ \Lambda\eta\ \ \Xi K \\ \Sigma\bar{K}\ \ \Lambda\bar{K}\ \ \Xi\pi\ \ \Xi\eta \end{pmatrix}_{8\otimes 8} = \frac{1}{\sqrt{12}} \begin{pmatrix} 3\ \ 3\ \ 3\ \ -3 \\ 2\ \ 8\ \ 0\ \ 0\ \ -2 \\ 6\ \ 0\ \ 0\ \ 6 \\ 3\ \ 3\ \ 3\ \ -3 \end{pmatrix}^{1/2}$$

$10 \to 8 \otimes 8$

$$\begin{pmatrix} \Delta \\ \Sigma \\ \Xi \\ \Omega \end{pmatrix}_{10} \to \begin{pmatrix} N\pi\ \ \Sigma K \\ N\bar{K}\ \ \Sigma\pi\ \ \Lambda\pi\ \ \Sigma\eta\ \ \Xi K \\ \Sigma\bar{K}\ \ \Lambda\bar{K}\ \ \Xi\pi\ \ \Xi\eta \\ \Xi\bar{K} \end{pmatrix}_{8\otimes 8} = \frac{1}{\sqrt{12}} \begin{pmatrix} 6\ \ 6 \\ -2\ \ 2\ \ -3\ \ 3\ \ 2 \\ 3\ \ 3\ \ 3\ \ 3 \\ 12 \end{pmatrix}^{1/2}$$

$8 \to 10 \otimes 8$

$$\begin{pmatrix} N \\ \Sigma \\ \Lambda \\ \Xi \end{pmatrix}_{8} \to \begin{pmatrix} \Delta\pi\ \ \Sigma K \\ \Delta\bar{K}\ \ \Sigma\pi\ \ \Sigma\eta\ \ \Xi K \\ \Sigma\pi\ \ \Xi K \\ \Sigma\bar{K}\ \ \Xi\pi\ \ \Xi\eta\ \ \Omega K \end{pmatrix}_{10\otimes 8} = \frac{1}{\sqrt{15}} \begin{pmatrix} -12\ \ 3 \\ 8\ \ -2\ \ -3\ \ 2 \\ -9\ \ 6 \\ 3\ \ 3\ \ 3\ \ 6 \end{pmatrix}^{1/2}$$

$10 \to 10 \otimes 8$

$$\begin{pmatrix} \Delta \\ \Sigma \\ \Xi \\ \Omega \end{pmatrix}_{10} \to \begin{pmatrix} \Delta\pi\ \ \Delta\eta\ \ \Sigma K \\ \Delta\bar{K}\ \ \Sigma\pi\ \ \Sigma\eta\ \ \Xi K \\ \Sigma\bar{K}\ \ \Xi\pi\ \ \Xi\eta\ \ \Omega K \\ \Xi\bar{K}\ \ \Omega\eta \end{pmatrix}_{10\otimes 8} = \frac{1}{\sqrt{24}} \begin{pmatrix} 15\ \ 3\ \ 6 \\ 8\ \ 8\ \ 0\ \ -8 \\ 12\ \ 3\ \ 3\ \ 6 \\ 12\ \ 12 \end{pmatrix}^{1/2}$$

In the fundamental 3-dimensional representation, the λ_a's are given by

$$\lambda_1 = \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad \lambda_2 = \begin{pmatrix} 0 & -i & 0 \\ i & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad \lambda_3 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

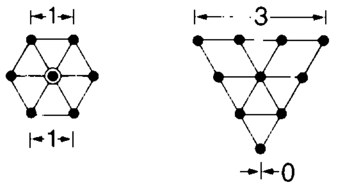
$$\lambda_4 = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \quad \lambda_5 = \begin{pmatrix} 0 & 0 & -i \\ 0 & 0 & 0 \\ i & 0 & 0 \end{pmatrix} \quad \lambda_6 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

$$\lambda_7 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & -i \\ 0 & i & 0 \end{pmatrix} \quad \lambda_8 = \begin{pmatrix} 1/\sqrt{3} & 0 & 0 \\ 0 & 1/\sqrt{3} & 0 \\ 0 & 0 & -2/\sqrt{3} \end{pmatrix}$$

SU(N) MULTIPLETS AND YOUNG DIAGRAMS

This note tells how SU(n) particle multiplets are identified or labeled, how to find the number of particles in a multiplet from its label, how to draw the Young diagram for a multiplet, and how to use Young diagrams to determine the overall multiplet structure of a composite system, such as a 3-quark or a meson-baryon system.

(1) **Multiplet labels** – An SU(n) multiplet is uniquely identified by a string of ($n-1$) nonnegative integers ($\alpha,\beta,\gamma,\ldots$). Any such set of integers specifies a multiplet. For an SU(2) multiplet such as an isospin multiplet, the single integer α is the number of *steps* from one end of the multiplet to the other (i.e., it is one fewer than the number of particles in the multiplet). In SU(3) the two integers α and β are the numbers of steps across the top and bottom levels of the multiplet diagram. Thus the labels for the SU(3) octet and decuplet



are (1,1) and (3,0). For larger n, the interpretation of the integers in terms of the geometry of the multiplets, which exist in an ($n-1$)-dimensional space, is not so readily apparent.

The label for the SU(n) singlet is (0,0,...,0). In a flavor SU(n), the n quarks together form a (1,0,...,0) multiplet, and the n antiquarks belong to a (0,...,0,1) multiplet. These two multiplets are *conjugate* to one another, which means their labels are related by ($\alpha,\beta,\ldots$) ⟷ ($\ldots,\beta,\alpha$).

(2) **Number of particles** – The number of particles in a multiplet, $N = N(\alpha,\beta,\ldots)$, is given as follows (note the pattern of the equations). In SU(2), $N = N(\alpha)$ is

$$N = \frac{(\alpha+1)}{1}$$

In SU(3) $N = N(\alpha,\beta)$ is

$$N = \frac{(\alpha+1)}{1}\frac{(\beta+1)}{1}\frac{(\alpha+\beta+2)}{2}$$

In SU(4), $N = N(\alpha,\beta,\gamma)$ is

$$N = \frac{(\alpha+1)}{1}\frac{(\beta+1)}{1}\frac{(\gamma+1)}{1}\frac{(\alpha+\beta+2)}{2}\frac{(\beta+\gamma+2)}{2}\frac{(\alpha+\beta+\gamma+3)}{3}$$

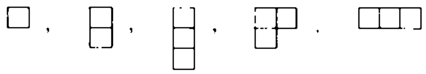
Note that there is no factor with ($\alpha+\gamma+2$): only a *consecutive* sequence of the label integers appears in any factor. One more example should make the pattern clear for any SU(n). In SU(5), $N = N(\alpha,\beta,\gamma,\delta)$ is

$$N = \frac{(\alpha+1)}{1}\frac{(\beta+1)}{1}\frac{(\gamma+1)}{1}\frac{(\delta+1)}{1}\frac{(\alpha+\beta+2)}{2}\frac{(\beta+\gamma+2)}{2}\times$$

$$\frac{(\gamma+\delta+2)}{2}\frac{(\alpha+\beta+\gamma+3)}{3}\frac{(\beta+\gamma+\delta+3)}{3}\frac{(\alpha+\beta+\gamma+\delta+4)}{4}$$

Multiplets that are conjugate to one another obviously have the same number of particles, but so can other multiplets. For example, the SU(4) multiplets (3,0,0) and (1,1,0) each have 20 particles.

(3) **Young diagrams** – A Young diagram consists of an array of boxes (or some other symbol) arranged in one or more *left-justified* rows, with each row being *at least as long* as the row beneath. The correspondence between a diagram and a multiplet label is: The top row juts out α boxes to the right past the end of the second row, the second row juts out β boxes to the right past the end of the third row, etc. A diagram in SU(n) has at most n rows. There can be any number of "completed" columns of n boxes buttressing the left of a diagram; these don't affect the label. Thus in SU(3) the diagrams



represent the multiplets (1,0), (0,1), (0,0), (1,1), and (3,0). In any SU(n), the quark multiplet is represented by a single box, the antiquark multiplet by a column of ($n-1$) boxes, and a singlet by a completed column of n boxes.

(4) **Coupling multiplets together** – The following recipe tells how to find the multiplets that occur in coupling two multiplets together. To couple together more than two multiplets, first couple two, then couple the third with each of the multiplets obtained from the first two, etc.

First a definition: A sequence of the letters $a,b,c,\ldots$ is *admissible* if at any point in the sequence at least as many a's have been reached as b's, at least as many b's have been reached as c's, etc. Thus *abcd* and *aabcb* are admissible sequences and *abb* and *acb* are not. Now the recipe:

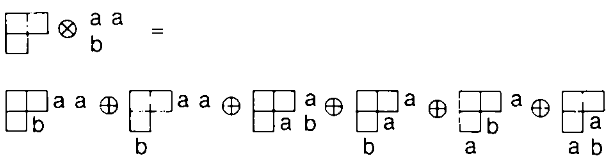
(a) Draw the Young diagrams for the two multiplets, but in one of the diagrams replace the boxes in the first row with a's, the boxes in the second row with b's, etc. The unlettered diagram forms the *upper left-hand corner* of all the enlarged diagrams constructed below.

(b) Add the a's from the lettered diagram to the unlettered diagram to form all possible legitimate Young diagrams that have no more than one a per column. (All the a's appear in each new diagram.)

(c) Use the b's to further enlarge the diagrams already obtained, subject to the same rules. Throw away any diagram in which the sequence of letters formed by reading *right to left* in the first row, then the second row, etc., is not admissible.

(d) Proceed as in (c) with the c's, etc.

Thus, for example, the calculation to find the multiplets that can occur in a system made up of two SU(3) octets (one might be the π-meson octet, the other the N-baryon octet) is as follows:



where only the diagrams with admissible sequences and with fewer than four rows (since $n = 3$) have been kept. In terms of multiplet labels, the above may be written

$$(1,1) \otimes (1,1) = (2,2) \oplus (3,0) \oplus (0,3) \oplus (1,1) \oplus (1,1) \oplus (0,0),$$

or in terms of numbers of particles,

$$\mathbf{8} \otimes \mathbf{8} = \mathbf{27} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{1}$$

The product of the numbers of the left is equal to the sum on the right. (See the section on the Nonrelativistic Quark Model for results for 3-quark systems.)

C.M. ENERGY AND MOMENTUM VS. BEAM MOMENTUM

(for scattering on a fixed proton target)

$$E_{cm} dE_{cm} = m_p dT_{beam} = m_p v_{beam} dP_{beam} \approx m_p dP_{beam}$$

P_{beam} (GeV/c)	E_{cm} (GeV)				Momentum in c m (GeV/c)			
	$\gamma p,\nu p$ $\approx ep$	πp	Kp	pp	$\gamma p,\nu p$ $\approx ep$	πp	Kp	pp
0 00	938	1 078	1 432	1 877	000	000	000	000
0 02	958	1 079	1 432	1 877	020	017	013	010
0 04	977	1 083	1 433	1 877	038	035	026	020
0 06	996	1 089	1 434	1 878	056	052	039	030
0 08	1 015	1 096	1 436	1 878	074	068	052	040
0 10	1 033	1 105	1 439	1 879	091	085	065	050
0 12	1 051	1 116	1 441	1 880	107	101	078	060
0 14	1 069	1 127	1 445	1 882	123	117	091	070
0 16	1 087	1 139	1 448	1 883	138	132	104	080
0 18	1 104	1 152	1 453	1 885	153	147	116	090
0 20	1 121	1 165	1 457	1 887	167	161	129	099
0 22	1 137	1 178	1 462	1 889	182	175	141	109
0 24	1 154	1 192	1 468	1 892	195	189	153	119
0 26	1 170	1 206	1 473	1 894	209	202	166	129
0 28	1 186	1 219	1 480	1 897	222	215	178	138
0 30	1 201	1 233	1 486	1 900	234	228	189	148
0 32	1 217	1 247	1 493	1 903	247	241	201	158
0 34	1 232	1 261	1 500	1 906	259	253	213	167
0 36	1 247	1 275	1 507	1 910	271	265	224	177
0 38	1 262	1 288	1 514	1 913	282	277	235	186
0 40	1 277	1 302	1 522	1 917	294	288	247	196
0 42	1 292	1 315	1 530	1 921	305	300	258	205
0 44	1 306	1 329	1 538	1 925	316	311	268	214
0 46	1 320	1 342	1 546	1 929	327	322	279	224
0 48	1 335	1 356	1 554	1 934	337	332	290	233
0 50	1 349	1 369	1 563	1 938	348	343	300	242
0 52	1 362	1 382	1 571	1 943	358	353	310	251
0 54	1 376	1 395	1 580	1 947	268	363	321	260
0 56	1 390	1 408	1 589	1 952	378	373	331	269
0 58	1 403	1 421	1 598	1 957	388	383	341	278
0 60	1 416	1 434	1 607	1 962	397	393	350	287
0 62	1 430	1 447	1 616	1 968	407	402	360	296
0 64	1 443	1 459	1 625	1 973	416	412	370	304
0 66	1 456	1 472	1 634	1 978	425	421	379	313
0 68	1 468	1 484	1 643	1 984	434	430	388	322
0 70	1 481	1 496	1 653	1 989	443	439	397	330
0 72	1 494	1 509	1 662	1 995	452	448	406	339
0 74	1 506	1 521	1 671	2 001	461	457	415	347
0 76	1 519	1 533	1 681	2 007	470	465	424	355
0 78	1 531	1 545	1 690	2 013	478	474	433	364
0 80	1 543	1 557	1 699	2 019	486	482	442	372
0 82	1 555	1 569	1 709	2 025	495	490	450	380
0 84	1 567	1 580	1 718	2 031	503	499	459	388
0 86	1 579	1 592	1 728	2 037	511	507	467	396
0 88	1 591	1 604	1 737	2 043	519	515	475	404
0 90	1 603	1 615	1 747	2 050	527	523	484	412
0 92	1 615	1 627	1 756	2 056	535	531	492	420
0 94	1 626	1 638	1 765	2 062	542	538	500	428
0 96	1 638	1 649	1 775	2 069	550	546	508	435
0 98	1 649	1 661	1 784	2 075	558	554	515	443
1 00	1 660	1 672	1 794	2 082	565	561	523	451
1 02	1 672	1 683	1 803	2 088	573	569	531	458
1 04	1 683	1 694	1 812	2 095	580	576	538	466
1 06	1 694	1 705	1 822	2 102	587	583	546	473
1 08	1 705	1 716	1 831	2 108	594	591	553	481
1 10	1 716	1 726	1 840	2 115	601	598	561	488
1 12	1 727	1 737	1 850	2 122	609	605	568	495
1 14	1 738	1 748	1 859	2 129	616	612	575	502
1 16	1 748	1 759	1 868	2 136	622	619	583	510
1 18	1 759	1 769	1 877	2 142	629	626	590	517
1 20	1 770	1 780	1 887	2 149	636	633	597	524
1 22	1 780	1 790	1 896	2 156	643	639	604	531
1 24	1 791	1 800	1 905	2 163	650	646	611	538
1 26	1 801	1 811	1 914	2 170	656	653	618	545
1 28	1 812	1 821	1 923	2 177	663	660	624	552
1 30	1 822	1 831	1 932	2 184	669	666	631	559
1 32	1 832	1 841	1 941	2 191	676	673	638	565
1 34	1 843	1 851	1 950	2 198	682	679	645	572
1 36	1 853	1 862	1 959	2 205	689	685	651	579
1 38	1 863	1 872	1 968	2 212	695	692	658	585
1 40	1 873	1 882	1 977	2 219	701	698	664	592
1 42	1 883	1 891	1 986	2 226	708	704	671	599
1 44	1 893	1 901	1 995	2 233	714	711	677	605
1 46	1 903	1 911	2 004	2 240	720	717	684	612
1 48	1 913	1 921	2 013	2 247	726	723	690	618
1 50	1 922	1 931	2 022	2 254	732	729	696	624
1 52	1 932	1 940	2 031	2 261	738	735	702	631
1 54	1 942	1 950	2 039	2 268	744	741	709	637
1 56	1 951	1 959	2 048	2 275	750	747	715	643
1 58	1 961	1 969	2 057	2 282	756	753	721	650
1 60	1 970	1 978	2 065	2 289	762	759	727	656
1 62	1 980	1 988	2 074	2 296	768	765	733	662
1 64	1 989	1 997	2 083	2 304	773	770	739	668
1 66	1 999	2 006	2 091	2 311	779	776	745	674
1 68	2 008	2 016	2 100	2 318	785	782	751	680

P_{beam} (GeV/c)	E_{cm} (GeV)				Momentum in c m (GeV/c)			
	$\gamma p,\nu p$ $\approx ep$	πp	Kp	pp	$\gamma p,\nu p$ $\approx ep$	πp	Kp	pp
1 70	2 018	2 025	2 109	2 325	791	788	756	686
1 72	2 027	2 034	2 117	2 332	796	793	762	692
1 74	2 036	2 043	2 126	2 339	802	799	768	698
1 76	2 045	2 053	2 134	2 346	807	805	774	704
1 78	2 054	2 062	2 143	2 353	813	810	780	710
1 80	2 064	2 071	2 151	2 360	818	816	785	716
1 82	2 073	2 080	2 159	2 367	824	821	791	721
1 84	2 082	2 089	2 168	2 374	829	827	796	727
1 86	2 091	2 098	2 176	2 381	835	832	802	733
1 88	2 100	2 107	2 184	2 388	840	837	808	739
1 90	2 109	2 115	2 193	2 395	845	843	813	744
1 92	2 117	2 124	2 201	2 402	851	848	819	750
1 94	2 126	2 133	2 209	2 409	856	853	824	756
1 96	2 135	2 142	2 217	2 416	861	859	829	761
1 98	2 144	2 151	2 226	2 423	867	864	835	767
2 0	2 153	2 159	2 234	2 430	872	869	840	772
2 1	2 196	2 202	2 274	2 465	897	895	866	799
2 2	2 238	2 244	2 314	2 500	922	920	892	826
2 3	2 280	2 286	2 353	2 534	947	944	917	852
2 4	2 320	2 326	2 392	2 568	970	968	941	877
2 5	2 360	2 366	2 430	2 602	994	991	965	901
2 6	2 400	2 405	2 468	2 636	1 02	1 01	989	926
2 7	2 439	2 444	2 505	2 669	1 04	1 04	1 01	949
2 8	2 477	2 482	2 542	2 702	1 06	1 06	1 03	972
2 9	2 514	2 520	2 578	2 735	1 08	1 08	1 06	995
3 0	2 551	2 556	2 613	2 768	1 10	1 10	1 08	1 02
3 1	2 588	2 593	2 649	2 800	1 12	1 12	1 10	1 04
3 2	2 624	2 629	2 683	2 832	1 14	1 14	1 12	1 06
3 3	2 660	2 664	2 718	2 863	1 16	1 16	1 14	1 08
3 4	2 695	2 699	2 752	2 895	1 18	1 18	1 16	1 10
3 5	2 729	2 734	2 785	2 926	1 20	1 20	1 18	1 12
3 6	2 763	2 768	2 818	2 957	1 22	1 22	1 20	1 14
3 7	2 797	2 801	2 851	2 987	1 24	1 24	1 22	1 16
3 8	2 830	2 835	2 884	3 018	1 26	1 26	1 24	1 18
3 9	2 863	2 868	2 916	3 048	1 28	1 28	1 26	1 20
4 0	2 896	2 900	2 947	3 077	1 30	1 29	1 27	1 22
4 1	2 928	2 932	2 979	3 107	1 31	1 31	1 29	1 24
4 2	2 960	2 964	3 010	3 136	1 33	1 33	1 31	1 26
4 3	2 992	2 996	3 041	3 165	1 35	1 35	1 33	1 27
4 4	3 023	3 027	3 071	3 194	1 37	1 36	1 34	1 29
4 5	3 054	3 058	3 101	3 223	1 38	1 38	1 36	1 31
4 6	3 084	3 088	3 131	3 251	1 40	1 40	1 38	1 33
4 7	3 115	3 118	3 161	3 279	1 42	1 41	1 40	1 34
4 8	3 144	3 148	3 190	3 307	1 43	1 43	1 41	1 36
4 9	3 174	3 178	3 220	3 335	1 45	1 45	1 43	1 38
5 0	3 204	3 207	3 248	3 363	1 46	1 46	1 44	1 40
5 2	3 262	3 265	3 305	3 417	1 50	1 49	1 48	1 43
5 4	3 319	3 322	3 362	3 471	1 53	1 53	1 51	1 46
5 6	3 375	3 378	3 417	3 524	1 56	1 56	1 54	1 49
5 8	3 430	3 433	3 471	3 576	1 59	1 59	1 57	1 52
6 0	3 484	3 487	3 524	3 627	1 62	1 61	1 60	1 55
6 2	3 538	3 541	3 577	3 678	1 64	1 64	1 63	1 58
6 4	3 590	3 593	3 629	3 728	1 67	1 67	1 65	1 61
6 6	3 642	3 645	3 680	3 778	1 70	1 70	1 68	1 64
6 8	3 693	3 696	3 731	3 827	1 73	1 73	1 71	1 67
7 0	3 744	3 747	3 781	3 875	1 75	1 75	1 74	1 70
7 2	3 794	3 797	3 830	3 923	1 78	1 78	1 76	1 72
7 4	3 843	3 846	3 878	3 970	1 81	1 81	1 79	1 75
7 6	3 891	3 894	3 926	4 016	1 83	1 83	1 82	1 78
7 8	3 939	3 942	3 974	4 062	1 86	1 86	1 84	1 80
8 0	3 987	3 989	4 021	4 108	1 88	1 88	1 87	1 83
8 2	4 033	4 036	4 067	4 153	1 91	1 91	1 89	1 85
8 4	4 080	4 082	4 113	4 198	1 93	1 93	1 92	1 88
8 6	4 125	4 128	4 158	4 242	1 96	1 95	1 94	1 90
8 8	4 171	4 173	4 203	4 286	1 98	1 98	1 96	1 93
9 0	4 215	4 218	4 247	4 329	2 00	2 00	1 99	1 95
9 2	4 260	4 262	4 291	4 372	2 03	2 03	2 01	1 97
9 4	4 303	4 306	4 335	4 415	2 05	2 05	2 03	2 00
9 6	4 347	4 349	4 378	4 457	2 07	2 07	2 06	2 02
9 8	4 390	4 392	4 420	4 498	2 09	2 09	2 08	2 04
10 0	4 432	4 435	4 462	4 540	2 12	2 12	2 10	2 07
10 5	4 537	4 539	4 566	4 641	2 17	2 17	2 16	2 12
11 0	4 639	4 642	4 668	4 741	2 22	2 22	2 21	2 18
11 5	4 739	4 742	4 767	4 839	2 28	2 28	2 26	2 23
12 0	4 837	4 839	4 864	4 934	2 33	2 33	2 31	2 28
12 5	4 933	4 935	4 960	5 028	2 38	2 38	2 36	2 33
13 0	5 027	5 030	5 053	5 120	2 43	2 43	2 41	2 38
13 5	5 120	5 122	5 145	5 211	2 47	2 47	2 46	2 43
14 0	5 211	5 213	5 236	5 300	2 52	2 52	2 51	2 48
14 5	5 300	5 302	5 324	5 388	2 57	2 57	2 56	2 53
15 0	5 388	5 390	5 412	5 474	2 61	2 61	2 60	2 57
15 5	5 474	5 476	5 498	5 559	2 66	2 66	2 65	2 62
16 0	5 559	5 561	5 582	5 642	2 70	2 70	2 69	2 66
16 5	5 643	5 645	5 666	5 725	2 74	2 74	2 73	2 70
17 0	5 726	5 727	5 748	5 806	2 79	2 79	2 78	2 75

P_{beam} (GeV/c)	E_{cm} (GeV)				Momentum in c m (GeV/c)			
	$\gamma p,\nu p$ $\approx ep$	πp	Kp	pp	$\gamma p,\nu p$ $\approx ep$	πp	Kp	pp
17 5	5 807	5 809	5 829	5 886	2 83	2 83	2 82	2 79
18 0	5 887	5 889	5 909	5 965	2 87	2 87	2 86	2 83
18 5	5 966	5 968	5 988	6 043	2 91	2 91	2 90	2 87
19 0	6 044	6 046	6 066	6 120	2 95	2 95	2 94	2 91
19 5	6 122	6 123	6 142	6 196	2 99	2 99	2 98	2 95
20	6 198	6 199	6 218	6 272	3 03	3 03	3 02	2 99
21	6 347	6 349	6 367	6 419	3 10	3 10	3 09	3 07
22	6 493	6 495	6 513	6 564	3 18	3 18	3 17	3 14
23	6 636	6 638	6 655	6 705	3 25	3 25	3 24	3 22
24	6 776	6 778	6 795	6 843	3 32	3 32	3 31	3 29
25	6 913	6 915	6 932	6 979	3 39	3 39	3 38	3 36
26	7 048	7 049	7 066	7 112	3 46	3 46	3 45	3 43
27	7 180	7 181	7 197	7 243	3 53	3 53	3 52	3 50
28	7 309	7 311	7 326	7 371	3 59	3 59	3 59	3 56
29	7 436	7 438	7 453	7 497	3 66	3 66	3 65	3 63
30	7 562	7 563	7 578	7 621	3 72	3 72	3 71	3 69
31	7 685	7 686	7 701	7 743	3 79	3 78	3 78	3 76
32	7 806	7 807	7 822	7 864	3 85	3 85	3 84	3 82
33	7 925	7 926	7 941	7 982	3 91	3 91	3 90	3 88
34	8 043	8 044	8 058	8 099	3 97	3 97	3 96	3 94
35	8 158	8 160	8 174	8 214	4 03	4 02	4 02	4 00
36	8 273	8 274	8 288	8 327	4 08	4 08	4 08	4 06
37	8 385	8 386	8 400	8 439	4 14	4 14	4 13	4 11
38	8 496	8 498	8 511	8 549	4 20	4 20	4 19	4 17
39	8 606	8 607	8 621	8 658	4 25	4 25	4 24	4 23
40	8 715	8 716	8 729	8 766	4 31	4 31	4 30	4 28
41	8 822	8 823	8 836	8 872	4 36	4 36	4 35	4 34
42	8 927	8 928	8 941	8 978	4 41	4 41	4 41	4 39
43	9 032	9 033	9 046	9 081	4 47	4 47	4 46	4 44
44	9 135	9 136	9 149	9 184	4 52	4 52	4 51	4 50
45	9 237	9 238	9 251	9 286	4 57	4 57	4 56	4 55
46	9 338	9 339	9 352	9 386	4 62	4 62	4 62	4 60
47	9 438	9 439	9 451	9 486	4 67	4 67	4 67	4 65
48	9 537	9 538	9 550	9 584	4 72	4 72	4 72	4 70
49	9 635	9 636	9 648	9 681	4 77	4 77	4 77	4 75
50	9 732	9 733	9 745	9 778	4 82	4 82	4 81	4 80
52	9 923	9 924	9 935	9 968	4 92	4 92	4 91	4 89
54	10 11	10 11	10 12	10 15	5 01	5 01	5 01	4 99
56	10 29	10 30	10 31	10 34	5 10	5 10	5 10	5 08
58	10 47	10 48	10 49	10 52	5,20	5 19	5 19	5 17
60	10 65	10 65	10 66	10 69	5 28	5 28	5 28	5 26
62	10 83	10 83	10 84	10 87	5 37	5 37	5 37	5 35
64	11 00	11 00	11 01	11 04	5 46	5 46	5 45	5 44
66	11 17	11 17	11 18	11 21	5 54	5 54	5 54	5 53
68	11 34	11 34	11 35	11 37	5 63	5 63	5 62	5 61
70	11 50	11 50	11 51	11 54	5 71	5 71	5 71	5 69
72	11 66	11 66	11 67	11 70	5 79	5 79	5 79	5 77
74	11 82	11 82	11 83	11 86	5 87	5 87	5 87	5 85
76	11 98	11 98	11 99	12 02	5 95	5 95	5 95	5 93
78	12 13	12 14	12 14	12 17	6 03	6 03	6 03	6 01
80	12 29	12 29	12 30	12 32	6 11	6 11	6 10	6 09
82	12 44	12 44	12 45	12 48	6 18	6 18	6 18	6 17
84	12 59	12 59	12 60	12 63	6 26	6 26	6 26	6 24
86	12 74	12 74	12 75	12 77	6 33	6 33	6 33	6 32
88	12 88	12 89	12 89	12 92	6 41	6 41	6 40	6 39
90	13 03	13 03	13 04	13 06	6 48	6 48	6 48	6 46
92	13 17	13 17	13 18	13 21	6 55	6 55	6 55	6 54
94	13 31	13 32	13 32	13 35	6 62	6 62	6 62	6 61
96	13 45	13 46	13 46	13 49	6 69	6 69	6 69	6 68
98	13 59	13 59	13 60	13 63	6 76	6 76	6 76	6 75
100	13 73	13 73	13 74	13 76	6 83	6 83	6 83	6 82
150	16 80	16 80	16 81	16 83	8 38	8 38	8 37	8 36
200	19 40	19 40	19 40	19 42	9 68	9 67	9 67	9 66
250	21 68	21 68	21 69	21 70	10 8	10 8	10 8	10 8
300	23 75	23 75	23 75	23 76	11 9	11 9	11 9	11 8
350	25 65	25 65	25 65	25 66	12 8	12 8	12 8	12 8
400	27 41	27 41	27 42	27 43	13 7	13 7	13 7	13 7
450	29 07	29 07	29 08	29 09	14 5	14 5	14 5	14 5
500	30 65	30 65	30 65	30 66	15 3	15 3	15 3	15 3
550	32 14	32 14	32 14	32 15	16 1	16 1	16 1	16 0
600	33 57	33 57	33 57	33 58	16 8	16 8	16 8	16 8
650	34 94	34 94	34 94	34 95	17 5	17 5	17 5	17 4
700	36 26	36 26	36 26	36 27	18 1	18 1	18 1	18 1
800	38 76	38 76	38 76	38 77	19 4	19 4	19 4	19 4
900	41 11	41 11	41 11	41 12	20 5	20 5	20 5	20 5
1000	43 33	43 33	43 33	43 34	21 7	21 7	21 7	21 6
2000	61 27	61 27	61 27	61 28	30 6	30 6	30 6	30 6
5000	96 87	96 87	96 87	96 87	48 4	48 4	48 4	48 4
10000	137 0	137 0	137 0	137 0	68 5	68 5	68 5	68 5
20000	193 7	193 7	193 7	193 7	96 9	96 9	96 9	96 9
50000	306 3	306 3	306 3	306 3	153	153	153	153
1×10^5	433 2	433 2	433 2	433 2	217	217	217	217
2×10^5	612 6	612 6	612 6	612 6	306	306	306	306
5×10^5	968 6	968 6	968 6	968 6	484	484	484	484
1×10^6	1370	1370	1370	1370	685	685	685	685

KINEMATICS

Throughout we work in units where $\hbar = c = 1$

A. LORENTZ TRANSFORMATIONS

The energy E and 3-momentum $\vec{p}$ of a particle of mass m form a 4-vector $p = (E,\vec{p})$ whose square $p^2 \equiv E^2 - |\vec{p}|^2 = m^2$. The velocity of the particle is $\vec{\beta} = \vec{p}/E$. The energy and momentum $(E^*,\vec{p}^*)$ viewed from a frame moving with velocity $\vec{\beta}_f$ are given by

$$\begin{pmatrix} E^* \\ p_\parallel^* \end{pmatrix} = \begin{pmatrix} \gamma_f & -\gamma_f\beta_f \\ -\gamma_f\beta_f & \gamma_f \end{pmatrix} \begin{pmatrix} E \\ p_\parallel \end{pmatrix}, \quad p_\perp^* = p_\perp \tag{A.1}$$

where $\gamma_f = (1 - \beta_f^2)^{-1/2}$ and $p_\perp$ $(p_\parallel)$ are the components of $\vec{p}$ perpendicular (parallel) to $\vec{\beta}_f$. The scalar product of two 4-vectors $p_1 \cdot p_2 = E_1E_2 - \vec{p}_1 \cdot \vec{p}_2$ is invariant (frame independent).

In the collision of two particles of masses m_1 and m_2 the total center-of-mass energy is

$$E_{cm} = (p_1 + p_2)^{1/2} = \left[(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2\right]^{1/2},$$

$$= \left[m_1^2 + m_2^2 + 2E_1E_2(1 - \beta_1\beta_2\cos\theta)\right]^{1/2}, \tag{A.2}$$

where θ is the angle between the particles. In the frame where one particle (of mass m_2) is at rest (lab frame),

$$E_{cm} = (m_1^2 + m_2^2 + 2E_{1\,lab}m_2)^{1/2} \tag{A.3}$$

The velocity in the lab of the center-of-mass frame is

$$\vec{\beta}_{cm} = \vec{p}_{1\,lab}/(E_{1\,lab} + m_2) \tag{A.4}$$

and

$$\gamma_{cm} = E_{cm}/(E_{1\,lab} + m_2)$$

B. LORENTZ INVARIANT AMPLITUDES

The invariant amplitude $-i\mathcal{M}$ for a scattering or decay process is determined in perturbation theory by a set of Feynman diagrams. The convention of Bjorken and Drell is used except that fermion spinors are normalized so that $\bar{u}u = 2m$. As an example the S-matrix for $2 \rightarrow 2$ scattering is related to $\mathcal{M}$ by

$$\langle p_1'p_2'|S|p_1p_2\rangle = I - i(2\pi)^4\delta^4(p_1 + p_2 - p_1' - p_2')$$

$$\times \frac{\mathcal{M}(p_1,p_2,p_1',p_2')}{(2E_1)^{1/2}(2E_2)^{1/2}(2E_1')^{1/2}(2E_2')^{1/2}} \tag{B.1}$$

The state normalization is such that

$$\langle p'|p\rangle = (2\pi)^3\delta^3(\vec{p} - \vec{p}') \tag{B.2}$$

C. PARTICLE DECAYS

The partial decay rate of a particle of mass M into n bodies in its rest frame is given in terms of the Lorentz invariant matrix element $\mathcal{M}$ by

$$d\Gamma = \frac{(2\pi)^4}{2M}|\mathcal{M}|^2\,d\Phi_n\,(P;p_1,\ldots,p_n), \tag{C.1}$$

where $d\Phi_n$ is an element of n-body phase space given by

$$d\Phi_n(P;p_1,\ldots,p_n) = \delta^4(P - \sum_{i=1}^{n} p_i)\prod_{i=1}^{n}\frac{d^3p_i}{(2\pi)^3 2E_i} \tag{C.2}$$

This phase space can be generated recursively, viz

$$d\Phi_n(P;p_1,\ldots,p_n) = d\Phi_j(q;p_1,\ldots,p_j) \tag{C.3}$$

$$\times d\Phi_{n-j+1}(P;q,p_{j+1},\ldots,p_n)(2\pi)^3dq^2,$$

where $q^2 = (\sum_{i=j+1}^{n} E_i)^2 - \left|\sum_{i=j+1}^{n}\vec{p}_i\right|^2$. This form is particularly useful in the case where a particle decays into another particle which subsequently decays.

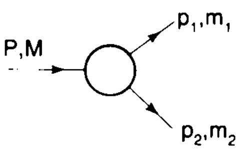
C.1. Survival probability. If a particle of mass M has mean life τ $(= 1/\Gamma)$ (in its rest frame) and has momentum $(E,\vec{p})$, then the probability that it lives for a time t_0 or greater before decaying is given by

$$P(t_0) = e^{-t_0\Gamma/\gamma} = e^{-Mt_0\Gamma/E}, \tag{C.4}$$

and the probability that it travels a distance x_0 or greater is

$$P(x_0) = e^{-Mx_0\Gamma/|\vec{p}|} \tag{C.5}$$

C.2. Two-body decays



In the rest frame of a particle of mass M, decaying into 2 particles labeled 1 and 2,

$$E_1 = \frac{M^2 - m_2^2 + m_1^2}{2M},$$

$$|\vec{p}_1| = |\vec{p}_2| \tag{C.6}$$

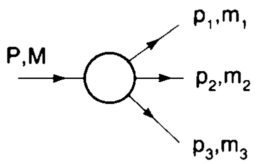
$$= \frac{\left[\left(M^2 - (m_1 + m_2)^2\right)\left(M^2 - (m_1 - m_2)^2\right)\right]^{1/2}}{2M},$$

and

$$d\Gamma = \frac{1}{32\pi^2}|\mathcal{M}|^2\frac{|\vec{p}_1|}{M^2}d\Omega, \tag{C.7}$$

where $d\Omega = d\phi_1 d(\cos\theta_1)$ is the solid angle of particle 1.

C.3.a. Three-body decays



Defining $p_{ij} = p_i + p_j$, $m_{ij}^2 = p_{ij}^2$, then $m_{12}^2 + m_{23}^2 + m_{13}^2 = M^2 + m_1^2 + m_2^2 + m_3^2$ and $m_{12}^2 = (P - p_3)^2 = M^2 + m_3^2 - 2ME_3$. The relative orientation of the three final-state particles is fixed if their energies are known. Their momenta can therefore be specified by giving three Euler angles (α,β,γ) which specify the orientation of the final system relative to the initial particle. Then

KINEMATICS (Cont'd)

$$d\Gamma = \frac{1}{(2\pi)^5}\frac{1}{16M}\,|\mathcal{M}|^2\,dE_1\,dE_2\,d\alpha\,d\cos\beta\,d\gamma \qquad \text{(C.8)}$$

Alternatively

$$d\Gamma = \frac{1}{(2\pi)^5}\frac{1}{16M^2}\,|\mathcal{M}|^2\,|\vec{p}_1^{\,*}|\,|\vec{p}_3|\,dm_{12}\,d\Omega_1^*\,d\Omega_3\,, \qquad \text{(C.9)}$$

where $(|\vec{p}_1^{\,*}|, \Omega_1^*)$ is the momentum of particle 1 in the rest frame of 1 and 2, and Ω_3 is the angle of particle 3 in the rest frame of the decaying particle. $|\vec{p}_1^{\,*}|$ and $|\vec{p}_3|$ are given by

$$|\vec{p}_1^{\,*}| = \frac{\left[\left(m_{12}^2 - (m_1 + m_2)^2\right)\left(m_{12}^2 - (m_1 - m_2)^2\right)\right]^{1/2}}{2m_{12}}\,,$$

and (C.10)

$$|\vec{p}_3| = \frac{\left[\left(M^2 - (m_{12} + m_3)^2\right)\left(M^2 - (m_{12} - m_3)^2\right)\right]^{1/2}}{2M}\,.$$

[Compare with Eq. (C.6).]

Integrating over the angles in Eq. (C.8) (this is only possible if the decaying particle is a scalar or we average over its spin states, otherwise $\mathcal{M}$ depends on α, β, and γ) gives

$$d\Gamma = \frac{1}{(2\pi)^3}\frac{1}{8M}\,|\mathcal{M}|^2\,dE_1\,dE_2$$

$$= \frac{1}{(2\pi)^3}\frac{1}{32M^3}\,|\mathcal{M}|^2\,dm_{12}^2\,dm_{23}^2 \qquad \text{(C.11)}$$

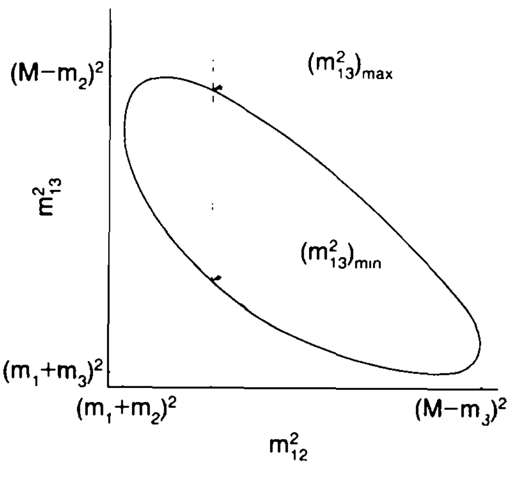
This is the standard form for the Dalitz plot.

C.3.b Dalitz plot. If m_{12}^2 is fixed then the range of m_{13}^2 is determined by its values when $\vec{p}_1$ is parallel or antiparallel to $\vec{p}_3$:

$$(m_{13}^2)_{\max} = (E_1^* + E_3^*)^2 - \left[\sqrt{E_1^{*2} - m_1^2} - \sqrt{E_3^{*2} - m_3^2}\,\right]^2\,,$$

$$(m_{13}^2)_{\min} = (E_1^* + E_3^*)^2 - \left[\sqrt{E_1^{*2} - m_1^2} + \sqrt{E_3^{*2} - m_3^2}\,\right]^2\,,$$

where $E_3^* = (M^2 - m_{12}^2 - m_3^2)/(2m_{12})$ and $E_1^* = (m_{12}^2 - m_1^2 - m_2^2)/(2m_{12})$. The scatter plot in m_{12}^2 and m_{13}^2 has uniform phase space density [see Eq. (C.11)] and is called a Dalitz plot.



A nonuniformity in the plot gives immediate information on $|\mathcal{M}|^2$. For example, in the case of $D \to K\pi\pi$, bands appear when $m_{(K\pi)} = m_{K^*}$, reflecting the appearance of the decay chain $D \to K^*\pi \to K\pi\pi$.

C.4 Kinematic limits. In a three-body decay the maximum of $|\vec{p}_3|$, Eq. (C.10), is achieved when $m_{12} = m_1 + m_2$, i.e., particles 1 and 2 have the same vector velocity in the rest frame of the decaying particle. If, in addition, $m_3 > m_1, m_2$, then $|\vec{p}_3|_{\max} > |\vec{p}_1|_{\max}, |\vec{p}_2|_{\max}$.

C.5 Multibody decays. The above results may be generalized to final states containing any number of particles by combining some of the particles into "effective particles" and treating the final states as 2 or 3 "effective particle" states. Thus, if

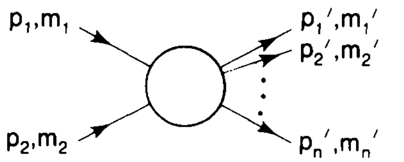
$p_{ijk\ldots} = p_i + p_j + p_k + \ldots$, then

$$m_{ijk\ldots} = \sqrt{p^2_{ijk\ldots}}\,,$$

and $m_{ijk\ldots}$ may be used in place of e.g., m_{12} in the relations in Sec. C.3.a or C.3.b above.

D. CROSS SECTIONS

The following conversions are useful: $\hbar c = 197.3$ MeV fermi, $(\hbar c)^2 = 0.3894\ (\text{GeV})^2$ mb.



The differential cross section is given by

$$d\sigma = \frac{(2\pi)^4\,|\mathcal{M}|^2}{4\sqrt{(p_1\cdot p_2)^2 - m_1^2 m_2^2}} \times d\Phi_n(p_1 + p_2; p_3, \ldots, p_{n+2}) \qquad \text{(D.1)}$$

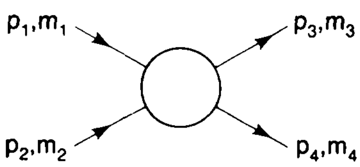
[See Eq. (C.2).] In the rest frame of m_2(lab)

$$\sqrt{(p_1\cdot p_2)^2 - m_1^2 m_2^2} = m_2 p_{1\text{lab}}\,;$$

while in the center-of-mass frame

$$\sqrt{(p_1\cdot p_2)^2 - m_1^2 m_2^2} = p_{1\text{cm}}\sqrt{s}\,.$$

D.1 Two-body reactions



Two particles of momenta p_1 and p_2 and masses m_1 and m_2 scatter to particles of momenta p_3 and p_4 and masses m_3 and m_4; the Lorentz invariant Mandelstam variables are defined by

KINEMATICS (Cont'd)

$$s = (p_1 + p_2)^2 = (p_3 + p_4)^2 \tag{D 2}$$

$$= m_1^2 + 2E_1E_2 - 2\vec{p}_1 \cdot \vec{p}_2 + m_2^2 ,$$

$$t = (p_1 - p_3)^2 = (p_2 - p_4)^2$$

$$= m_1^2 - 2E_1E_3 + 2\vec{p}_1 \cdot \vec{p}_3 + m_3^2 ,$$

$$u = (p_1 - p_4)^2 = (p_2 - p_3)^2$$

$$= m_1^2 - 2E_1E_4 + 2\vec{p}_1 \cdot \vec{p}_4 + m_4^2$$

and they satisfy

$$s + t + u = m_1^2 + m_2^2 + m_3^2 + m_4^2$$

The two-body cross section may be written as

$$\frac{d\sigma}{dt} = \frac{1}{64\pi s} \frac{1}{|\vec{p}_{1\mathrm{cm}}|^2} |\mathcal{M}|^2 \tag{D 3}$$

In the center-of-mass frame

$$t = (E_{1\mathrm{cm}} - E_{3\mathrm{cm}})^2 - (p_{1\mathrm{cm}} - p_{3\mathrm{cm}})^2$$

$$- 4p_{1\mathrm{cm}}p_{3\mathrm{cm}} \sin^2(\theta_{\mathrm{cm}}/2) \tag{D 4}$$

$$= t_0 - 4p_{1\mathrm{cm}}p_{3\mathrm{cm}} \sin^2(\theta_{\mathrm{cm}}/2)$$

where θ_{cm} is the angle between particle 1 and 3

$$t_{\substack{0\\1}} = \left[\frac{m_1^2 - m_3^2 - m_2^2 + m_4^2}{2\sqrt{s}}\right]^2 - \left\{\left[\left(\frac{s + m_1^2 - m_2^2}{2\sqrt{s}}\right)^2 - m_1^2\right]^{1/2} \mp \left[\left(\frac{s + m_3^2 - m_4^2}{2\sqrt{s}}\right)^2 - m_3^2\right]^{1/2}\right\}^2 \tag{D 5}$$

Note that t_0 (t_1) is the largest (smallest) value of t for $2 \to 2$ scattering processes and that t_1 is always negative. In the literature the notation $t_{\min}$ ($t_{\max}$) for t_0 (t_1) is sometimes used. This usage should be discouraged since $t_0 > t_1$. The center-of-mass energies and momenta of the incoming particles are

$$E_{1\mathrm{cm}} = \frac{s + m_1^2 - m_2^2}{2\sqrt{s}} , \tag{D 6}$$

$$p_{1\mathrm{cm}} = \frac{\left[\left(s - (m_1 + m_2)^2\right)\left(s - (m_1 - m_2)^2\right)\right]^{1/2}}{2\sqrt{s}}$$

$$= \frac{p_{1\mathrm{lab}} m_2}{\sqrt{s}} . \tag{D 7}$$

Here the subscript lab refers to the frame where particle 2 is at rest. [For other relations see Eqs. (A2–A4).]

D.2 Inclusive reactions. Choose some direction (usually the beam direction) for the z-axis, then the energy and momentum of a particle can be written as

$$E = m_\perp \cosh y , \quad p_z = m_\perp \sinh y , \quad p_x , \quad p_y$$

where $m_\perp$ is the transverse mass

$$m_\perp^2 = m^2 + p_x^2 + p_y^2$$

and the rapidity y is defined by

$$y = \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z}\right)$$

$$= \ln \left(\frac{E + p_z}{m_\perp}\right) = \tanh^{-1} \left(\frac{p_z}{E}\right) \tag{D 8}$$

Under a boost in the z-direction to a frame with velocity β, $y \to y - \tanh^{-1}\beta$. Hence the rapidity distribution dN/dy is invariant. Also

$$E \frac{d^3\sigma}{d^3p} = \frac{d^3\sigma}{dy\, d^2p_\perp} .$$

If the particle has angle θ to the z-axis, then the pseudorapidity

$$\eta = -\ln\left[\tanh(\theta/2)\right] \tag{D 9}$$

Since $y \simeq \eta$ when $E \gg m$, η can be used as an approximation for y when the momentum or mass of a particle is not well known.

Feynman's x variable is given by

$$x = \frac{p_z}{p_{z\,\max}}$$

in the center-of-mass frame

$$x \approx \frac{2p_{z\,\mathrm{cm}}}{\sqrt{s}} \approx \frac{2m_\perp \sinh y_{\mathrm{cm}}}{\sqrt{s}} \tag{D 10}$$

For y_{cm} such that $e^{-2y_{\mathrm{cm}}} \ll 1$

$$x \approx \frac{m_\perp}{\sqrt{s}} e^{y_{\mathrm{cm}}}$$

and

$$(y_{\mathrm{cm}})_{\max} = \ln\left(\frac{\sqrt{s}}{m}\right)$$

D.3 Partial waves. The amplitude in the center of mass for elastic scattering of spinless particles may be written in a partial-wave expansion in Legendre polynomials

$$f(k,\theta) = \frac{1}{k} \sum_\ell (2\ell + 1)\, a_\ell\, P_\ell(\cos\theta) , \tag{D 11}$$

where k is the c.m. momentum, θ is the c.m. scattering angle, $a_\ell = (\eta_\ell e^{2i\delta_\ell} - 1)/2i$, $0 \le \eta_\ell \le 1$ and δ_ℓ is the phase shift of the ℓ^{th} partial wave. For purely elastic scattering, $\eta_\ell = 1$. The differential cross section is

$$\frac{d\sigma}{d\Omega} = |f(k,\theta)|^2$$

The optical theorem states that

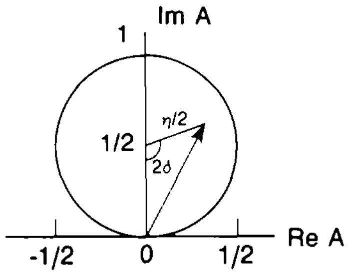
$$\sigma_{\mathrm{tot}} = \frac{4\pi}{k} \operatorname{Im} f(k,0) , \tag{D 12}$$

and the cross section in the ℓ^{th} partial wave is therefore bounded

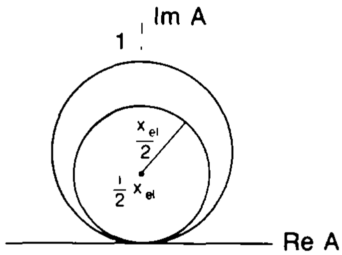
KINEMATICS (Cont'd)

$$\sigma_\ell = \frac{4\pi}{k^2}(2\ell+1)\,|a_\ell|^2 \le \frac{4\pi(2\ell+1)}{k^2} \qquad \text{(D.13)}$$

The partial-wave amplitude a_ℓ can be displayed in an Argand plot



where E is the c.m. energy. This gives a circle in the Argand plot with center $ix_{el}/2$ and radius $x_{el}/2$, where the elasticity $x_{el} = \Gamma_{el}/\Gamma_{tot}$. The amplitude has a pole at $E = E_R - i\Gamma_{tot}/2$.



The usual Lorentz invariant matrix element $\mathcal{M}$ (see Sec. B above) for the elastic process is related to $f(k,\theta)$ by

$$\mathcal{M} = -8\pi\sqrt{s}\, f(k,\theta)\,,$$

so

$$\sigma_{tot} = -\frac{1}{2k\sqrt{s}}\,\mathrm{Im}\,\mathcal{M}(t=0) \qquad \text{(D.14)}$$

where s and t are the center-of-mass energy squared and momentum transfer squared, respectively (see Sec. D.1).

D.3.a Resonances The Breit-Wigner form for a_ℓ with a resonance at c.m. energy E_R, elastic width Γ_{el}, and total width Γ_{tot} is

$$a_\ell = \frac{\frac{1}{2}\Gamma_{el}}{E_R - E - \frac{i}{2}\Gamma_{tot}}\,, \qquad \text{(D.15)}$$

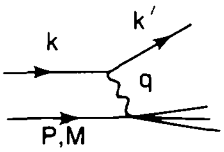
The Breit-Wigner cross section for a spin-J resonance produced in the collision of particles of spin S_1 and S_2 is

$$\sigma_{BW}(E) = \frac{(2J+1)}{(2S_1+1)(2S_2+1)}\,\frac{\pi}{k^2}\,\frac{B_{in}B_{out}\Gamma_{tot}^2}{(E-E_R)^2+\Gamma_{tot}^2/4}\,,$$

where k is the c.m. momentum, E is the c.m. energy, and B_{in} and B_{out} are the branching fractions of the resonance into the entrance and exit channels. The $2S+1$ factors are the multiplicities of the incident spin states, so they are replaced by 2 for photons, etc. This expression is valid only for a particle of narrow width. If the width is not small, Γ_{tot} cannot be treated as a constant independent of E. There are many other forms for σ_{BW}, all of which are equivalent to the one given here in the narrow-width case. Some of these forms may be more appropriate if the resonance is broad.

CROSS-SECTION FORMULAE FOR SPECIFIC PROCESSES

A. LEPTOPRODUCTION



$q = k - k'$ is the four-momentum transferred to the target

Invariant quantities

$\nu = \dfrac{q\cdot P}{M} = E - E'$ is the lepton's energy loss in the lab (in earlier literature sometimes $\nu = q\cdot P$). Here, E and E' are the initial and final lepton energies in the lab.

$Q^2 = -q^2 = 2(EE' - \vec{k}\cdot\vec{k}') - m_\ell^2 - m_{\ell'}^2$ where $m_\ell(m_{\ell'})$ is the initial (final) lepton mass. If $EE'\sin^2(\theta/2) \gg m_\ell^2, m_{\ell'}^2$, then

$\cong 4EE'\sin^2(\theta/2)$, where θ is the lepton's scattering angle in the lab

$x = \dfrac{Q^2}{2M\nu}$ In the parton model, x is the fraction of the target nucleon's momentum carried by the struck quark. See section on QCD

$y = \dfrac{q\cdot P}{k\cdot P} = \dfrac{\nu}{E}$ is the fraction of the lepton's energy lost in the lab

$W^2 = (P+q)^2 = M^2 + 2M\nu - Q^2$ is the mass squared of the system recoiling against the lepton

$s = (k+P)^2 = \dfrac{Q^2}{xy} + M^2$

A.1 Leptoproduction cross sections

$$\frac{d^2\sigma}{dx\,dy} = \nu(s-M^2)\frac{d^2\sigma}{d\nu\,dQ^2} = \frac{2\pi M\nu}{E'}\,\frac{d^2\sigma}{d\Omega_{lab}\,dE'}$$

$$= x(s-M^2)\frac{d^2\sigma}{dx\,dQ^2}$$

CROSS-SECTION FORMULAE FOR SPECIFIC PROCESSES (Cont'd)

A.2 Electroproduction structure functions The neutral-current process, $eN \to eX$, is parity conserving at low Q^2 and can be written in terms of two structure functions $F_1^{NC}(x,Q^2)$ and $F_2^{NC}(x,Q^2)$

$$\frac{d^2\sigma}{dx\,dy} = \frac{4\pi\alpha^2(s-M^2)}{Q^4}\left[(1-y)F_2^{NC} + y^2 x F_1^{NC} - \frac{M^2}{(s-M^2)}xyF_2^{NC}\right]$$

The charged-current processes, $e^-N \to \nu X$, $\nu N \to e^-X$, and $\bar\nu N \to e^+X$, are parity violating and can be written in terms of three structure functions $F_1^{CC}(x,Q^2)$, $F_2^{CC}(x,Q^2)$, and $F_3^{CC}(x,Q^2)$

$$\frac{d^2\sigma}{dx\,dy} = \frac{G_F^2(s-M^2)}{2\pi}\frac{M_W^4}{(Q^2+M_W^2)^2} \qquad \text{(A.2.1)}$$

$$\times\left\{\left[1-y-\frac{M^2}{(s-M^2)}\right]F_2^{CC} + \frac{y^2}{2}2xF_1^{CC} + (y-\frac{y^2}{2})xF_3^{CC}\right\}$$

A.3 The QCD parton model In the QCD parton model, the structure functions defined above can be expressed in terms of parton distribution functions. The quantity $f_i(x,Q^2)dx$ is the probability that a parton of type i (quark, antiquark, or gluon), carries a momentum fraction between x and $x+dx$ of the nucleon's momentum in a frame where the nucleon's momentum is large. For the cross section corresponding to the *neutral-current process* $ep \to eX$, we have for $s >> M^2$ (in the case where the incoming electron is either left- (L) or right- (R) handed)

$$\frac{d^2\sigma}{dx\,dy} = \frac{\pi\alpha^2}{sx^2y^2}\left[\sum_q (xf_q(x,Q^2) + xf_{\bar q}(x,Q^2))\right]$$

$$\times\left[A_q + (1-y)^2B_q\right]$$

Here the index q refers to a quark flavor (i.e., u, d, s, c, b, or t), and

$$A_q = \left[-q_q + g_{Lq}g_{Le}\frac{Q^2}{Q^2+M_Z^2}\right]^2 + \left[-q_q + g_{Rq}g_{Re}\frac{Q^2}{Q^2+M_Z^2}\right]^2$$

$$B_q = \left[-q_q + g_{Rq}g_{Le}\frac{Q^2}{Q^2+M_Z^2}\right]^2 + \left[-q_q + g_{Lq}g_{Re}\frac{Q^2}{Q^2+M_Z^2}\right]^2$$

Here q_q is the charge of flavor q. For a left-handed electron, $g_{Re} = 0$ and $g_{Le} = (-1/2 + \sin^2\theta_W)/(\sin\theta_W\cos\theta_W)$, while for a right-handed one, $g_{Le} = 0$ and $g_{Re} = (\sin^2\theta_W)/(\sin\theta_W\cos\theta_W)$. For the quarks, $g_{Lq} = (T_3 - q_q\sin^2\theta_W)/(\sin\theta_W\cos\theta_W)$, and $g_{Rq} = (-q_q\sin^2\theta_W)/(\sin\theta_W\cos\theta_W)$.

For neutral-current *neutrino (antineutrino) scattering*, the same formula applies with g_{Le} replaced by $g_{L\nu} = 1/(2\sin\theta_W\cos\theta_W)$ ($g_{L\bar\nu} = 0$) and g_{Re} replaced by $g_{R\nu} = 0$ [$g_{R\bar\nu} = -1/(2\sin\theta_W\cos\theta_W)$]

In the case of the *charged-current processes* $e_L^-p \to \nu X$ and $\bar\nu p \to e^+X$, Eq. (A.2.1) applies with

$$F_2 = 2xF_1 = 2x\left[f_u(x,Q^2) + f_c(x,Q^2) + f_t(x,Q^2) + f_{\bar d}(x,Q^2) + f_{\bar s}(x,Q^2) + f_{\bar b}(x,Q^2)\right],$$

$$F_3 = 2x\left[f_u(x,Q^2) + f_c(x,Q^2) + f_t(x,Q^2) - f_{\bar d}(x,Q^2) - f_{\bar s}(x,Q^2) - f_{\bar b}(x,Q^2)\right]$$

For the process $\nu p \to e^-X$

$$F_2 = 2xF_1 = 2x\left[f_d(x,Q^2) + f_s(x,Q^2) + f_b(x,Q^2) + f_{\bar u}(x,Q^2) + f_{\bar c}(x,Q^2) + f_{\bar t}(x,Q^2)\right]$$

$$F_3 = 2x\left[f_d(x,Q^2) + f_s(x,Q^2) + f_b(x,Q^2) - f_{\bar u}(x,Q^2) - f_{\bar c}(x,Q^2) - f_{\bar t}(x,Q^2)\right]$$

B. e^+e^- ANNIHILATION

For pointlike spin-1/2 fermions in the c.m., the differential cross section for $e^+e^- \to f\bar f$ via single photon annihilation is

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4s}\frac{\beta(3-\beta)}{2}\left[1+\cos^2\theta + (1-\beta^2)\sin^2\theta\right]Q_f^2,$$

where β is the velocity of the final state fermion in the center of mass and Q_f is the charge of the fermion in units of the proton charge. For $\beta \to 1$,

$$\sigma = \frac{4\pi\alpha^2}{3s}Q_f^2 = \frac{86.8\,Q_f^2\,nb}{s(GeV^2)}$$

At higher energies the Z^0 (mass M_Z and width Γ_Z) must be included, and the differential cross section for $e^+e^- \to f\bar f$ becomes

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta}{4s}\frac{(3-\beta)}{2}\Big[Q_f^2[1+\cos^2\theta + (1-\beta^2)\sin^2\theta]$$

$$- 2Q_f\chi_1\left\{VV_f[1+\cos^2\theta + (1-\beta^2)\sin^2\theta] - 2a_f\beta\cos\theta\right\}$$

$$+ \chi_2\Big\{V_f^2(1+V^2)[1+\cos^2\theta + (1-\beta^2)\sin^2\theta]$$

$$+ \beta^2a_f^2(1+V^2)[1+\cos^2\theta] - 8\beta VV_fa_f\cos\theta\Big\}\Big]$$

$$\chi_1 = \frac{1}{16\sin^2\theta_W\cos^2\theta_W}\frac{s(s-M_Z^2)}{(s-M_Z^2)^2 + \Gamma_Z^2M_Z^2},$$

$$\chi_2 = \frac{1}{256\sin^4\theta_W\cos^4\theta_W}\frac{s^2}{(s-M_Z^2)^2 + \Gamma_Z^2M_Z^2},$$

$$V = -1 + 4\sin^2\theta_W,$$

$$a_f = 2T_{3f},$$

$$V_f = 2T_{3f} - 4Q_f\sin^2\theta_W,$$

where the subscript f refers to the particular fermion and

$T_3 = +1/2$ for ν_e, ν_μ, ν_τ, u, c, t,

$T_3 = -1/2$ for e^-, μ^-, τ^-, d, s, b

CROSS-SECTION FORMULAE FOR SPECIFIC PROCESSES (Cont'd)

C e^+e^- TWO-PHOTON PROCESS

In the equivalent photon approximation, the cross section for $e^+e^- \to e^+e^- X$ is related to the cross section for $\gamma\gamma \to X$ by

$$d\sigma_{e^+e^- \to e^+e^- X}(s) = \eta^2 \int_0^1 d\omega f(\omega) d\sigma_{\gamma\gamma \to X}(\omega s),$$

where

$$\eta \cong \frac{\alpha}{2\pi} \ell n \left[\frac{s}{4m_e^2} \right]$$

and

$$f(\omega) = \frac{1}{\omega} \left[(2+\omega)^2 \ell n \frac{1}{\omega} - 2(1-\omega)(3+\omega) \right]$$

The factor η arises from integrating over the mass squared of the virtual photon For the production of a resonance, form factors suppress contributions from very virtual photons, so in the standard formula for production of a resonance of mass m_R and spin $J \neq 1$, namely,

$$\sigma(e^+e^- \to e^+e^- R) = \eta^2 \frac{(2J+1) 8\pi^2 \Gamma(R \to \gamma\gamma)}{s m_R} f\left(\frac{m_R^2}{s}\right),$$

it would be better to use

$$\eta \simeq \frac{\alpha}{2\pi} \ell n \left[\frac{m_V^2}{4m_e^2} \right],$$

where m_V is the mass of the vector $(\rho, \phi, \quad)$ that enters into the form factor

D INCLUSIVE HADRONIC REACTIONS

One-particle inclusive cross sections $E(d^3\sigma)/(d^3p_i)$ for the production of a particle of momentum p_i are conveniently expressed in terms of rapidity (see above) and the momentum $p_\perp$ transverse to the beam direction (defined in the center-of-mass frame)

$$\frac{d^3\sigma}{dy d^2 p_\perp} = E \frac{d^3\sigma}{d^3 p}$$

In the case of processes where $p_\perp$ is large or the mass of the produced particle is large (here large means greater than 10 GeV), the parton model can be used to calculate the rate Symbolically

$$\sigma_{\text{hadronic}} = \sum_{ij} \int f_i(x_1, Q^2) f_j(x_2, Q^2) dx_1 dx_2 \hat{\sigma}_{\text{partonic}} \, ,$$

where $f_i(x, Q^2)$ is the parton distribution introduced above and Q is a typical momentum transfer in the partonic process and $\hat{\sigma}$ is the partonic cross section Two examples will help to clarify The production of a W^+ in pp reactions at rapidity y in the center-of-mass frame is given by

$$\frac{d\sigma}{dy} = \frac{G_F \pi \sqrt{2}}{3}$$

$$\times \tau \left[\cos^2\theta_c \left(u(x_1, M_W^2) \bar{d}(x_2, M_W^2) + u(x_2, M_W^2) \bar{d}(x_1, M_W^2) \right) \right.$$

$$\left. + \sin^2\theta_c \left(u(x_1, M_W^2) \bar{s}(x_2, M_W^2) + s(x_2, M_W^2) \bar{u}(x_1, M_W^2) \right) \right],$$

where $x_1 = \sqrt{\tau} e^y$, $x_2 = \sqrt{\tau} e^{-y}$, and $\tau = M_W^2/s$ Similarly the production of a jet in pp (or $p\bar{p}$) collisions is given by

$$\frac{d^3\sigma}{d^2 p_\perp dy} = \sum_{ij} \int f_i(x_1, p_\perp^2) f_j(x_2, p_\perp^2)$$

$$\times \left[\hat{s} \frac{d\hat{\sigma}}{d\hat{t}} \right]_{ij} dx_1 dx_2 \delta(\hat{s} + \hat{t} + \hat{u}), \qquad \text{(D 1)}$$

where the summation is over quarks, gluons, and antiquarks Here

$$s = (p_1 + p_2)^2,$$

$$t = (p_1 - p_{\text{jet}})^2,$$

$$u = (p_2 - p_{\text{jet}})^2,$$

p_1 and p_2 are the momenta of the incoming p and p (or $\bar{p}$) and $\hat{s}$, $\hat{t}$, and $\hat{u}$ are s, t, and u with $p_1 \to x_1 p_1$ and $p_2 \to x_2 p_2$ The partonic cross section $\hat{s}\left[(d\hat{\sigma})/(d\hat{t})\right]$ can be found in Ref 1 Example for the process $gg \to q\bar{q}$,

$$\hat{s} \frac{d\sigma}{dt} = 3\alpha_s^2 \frac{(\hat{t}^2 + \hat{u}^2)}{8\hat{s}} \left[\frac{4}{9\hat{t}\hat{u}} - \frac{1}{\hat{s}^2} \right]$$

The prediction of Eq (D 1) is compared to data from the UA1 and UA2 collaborations in a figure labeled "Jet Production in pp and $\bar{p}p$ Interactions" in the Plots of Cross Sections and Related Quantities section

E. ONE-PARTICLE INCLUSIVE DISTRIBUTIONS

In order to describe one-particle inclusive production in e^+e^- annihilation or deep inelastic scattering, it is convenient to introduce a fragmentation function $D_i^h(z, Q^2)/z$ which is the probability that a parton of type i and momentum p will fragment into a hadron of type h and momentum zp The Q^2 evolution is predicted by QCD and is similar to that of the parton distribution functions (see section on Quantum Chromodynamics) The $D_i^h(z, Q^2)$ are normalized so that

$$\sum_h \int D_i^h(z, Q^2) dz = 1$$

If the contributions of the Z boson and three-jet events are neglected, the cross section for producing a hadron h in e^+e^- annihilation is given by

$$\frac{1}{\sigma_{\text{had}}} \frac{d\sigma}{dz} = \frac{\sum_i e_i^2 D_i^h(z, Q^2)}{\sum_i e_i^2},$$

where e_i is the charge of quark-type i, σ_{had} is the total hadronic cross section, and the momentum of the hadron is $zE_{\text{cm}}/2$

In the case of deep inelastic muon scattering, the cross section for producing a hadron of energy E_h is given by

$$\frac{1}{\sigma_{\text{tot}}} \frac{d\sigma}{dz} = \frac{\sum_i e_i^2 q_i(x, Q^2) D_i^h(z, Q^2)}{\sum_i e_i^2 q_i(x, Q^2)},$$

where $E_h = \nu z$ (For the kinematics of deep inelastic scattering, see section D 2 of the Kinematics section of this Review) The fragmentation functions for light and heavy quarks have a different z dependence, the former peak near $z = 0$ They are illustrated in a figure in the section on Plots of Cross Sections and Related Quantities

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1 G F Owens, F Reya, and M Gluck, Phys Rev **D18**, 1501 (1978)

QUANTUM CHROMODYNAMICS*

A THE QCD LAGRANGIAN

Quantum Chromodynamics (QCD), the gauge field theory which describes the interactions of colored quarks and gluons, is one of the components of the SU(3)×SU(2)×U(1) Standard Model The Lagrangian is (up to gauge-fixing terms)

$$L_{\rm QCD} = -\frac{1}{4}F^{(a)}_{\mu\nu}F^{(a)\mu\nu} + i\sum_q \bar\psi^i_q\gamma^\mu(D_\mu)_{ij}\psi^j_q - \sum_q m_q\bar\psi^i_q\psi_{qi}\ ,$$

$$F^{(a)}_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu - g_s f_{abc}A^b_\mu A^c_\nu$$

$$(D_\mu)_{ij} = \delta_{ij}\partial_\mu - ig_s\sum_a \frac{\lambda^a_{i,j}}{2}A^a_\mu\ . \qquad \text{(A 1)}$$

where g_s is the QCD coupling constant and the f_{abc} are the structure constants of the SU(3) algebra (the λ matrices and values for f_{abc} can be found in "SU(3) Isoscalar Factors and Representation Matrices") The $\psi^i_q(x)$ are the 4-component Dirac spinors associated with each quark field of color i and flavor q and the $A^a(x)$ are the (8) Yang-Mills (gluon) fields A complete list of the Feynman rules which derive from this Lagrangian, together with some useful color-algebra identities can be found in Ref 1

The principle of "asymptotic freedom" (see below) determines that the renormalized QCD coupling is small only at high energies, and it is only in this domain that high-precision tests similar to those in QED can be performed using perturbation theory Nonetheless, there has in recent years been much progress in understanding and quantifying the predictions of QCD in the non-perturbative domain, for example in soft hadronic processes and on the lattice[2] This short review will concentrate on QCD at short distances (large momentum transfers), where perturbation theory is the standard tool

B. THE QCD COUPLING AND RENORMALIZATION SCHEME

The renormalization scale dependence of the effective QCD coupling $\alpha_s = g_s^2/4\pi$ is controled by the β-function

$$\mu\frac{\partial\alpha_s}{\partial\mu} = -\frac{\beta_0}{2\pi}\alpha_s^2 - \frac{\beta_1}{8\pi^2}\alpha_s^3$$

$$\beta_0 = 11 - \frac{2}{3}n_f\ ,$$

$$\beta_1 = 102 - \frac{38}{3}n_f \qquad \text{(B 1)}$$

and n_f is the number of quarks with mass less than the energy scale μ In solving this differential equation for α_s, a constant of integration is introduced This constant is the one fundamental constant of QCD which must be determined from experiment The most sensible choice for this constant is the value of α_s at a fixed reference scale μ_0 but it is more conventional to introduce the dimensional parameter Λ The definition of Λ is arbitrary One way to define it (adopted here) is to write a solution of Eq (B 1) as an expansion in inverse powers of $\ell n(\mu^2)$

$$\alpha_s(\mu) = \frac{12\pi}{(33-2n_f)\ell n(\mu^2/\Lambda^2)}\times\left[1 - \frac{6(153-19n_f)}{(33-2n_f)^2}\frac{\ell n\left(\ell n(\mu^2/\Lambda^2)\right)}{\ell n(\mu^2/\Lambda^2)}\right] + \qquad \text{(B 2)}$$

The next term in this expansion is

$$O\left(\frac{\ell n^2[\ell n(\mu^2/\Lambda^2)]}{\ell n^3(\mu^2/\Lambda^2)}\right)$$

This solution illustrates the *asymptotic freedom* property $\alpha_s\to 0$ as $\mu\to\infty$ Alternative definitions of Λ are possible For example, the solution of Eq (B 1) with the β-function truncated at the second order

$$\frac{1}{\alpha_s} - b_1\ell n\left(\frac{b_1\alpha_s}{1+b_1\alpha_s}\right) = b_0\ell n\frac{\mu}{\Lambda}\ ,$$

$$b_0 = \frac{\beta_0}{2\pi}\ ,\quad b_1 = \frac{\beta_1}{4\pi\beta_0} \qquad \text{(B 3)}$$

can be used[3] For a given value of $\alpha_s(\mu = 5\ \text{GeV})$ one finds that $|\Lambda[\text{Eq}(B\ 2)] - \Lambda[\text{Eq}(B\ 3)]|$ varies by 5 to 22 MeV as Λ goes from 120 to 350 MeV, while for $\alpha_s(\mu = 30\ \text{GeV})$ it varies by 3 to 11 MeV over the same Λ range

In the above discussion we have ignored quark-mass effects i e we have assumed an idealized situation where quarks of mass greater than μ are neglected completely In this picture, the β-function coefficients change by discrete amounts as flavor thresholds are crossed when integrating the differential equation for α_s It follows that, for a relationship such as Eq (B 2) to remain valid for all values of μ Λ must also change discretely through flavor thresholds This leads to the concept of a different Λ for each range of μ corresponding to an effective number of massless quarks $\Lambda\to\Lambda^{(n_f)}$ This is the standard convention It follows that when comparing measured Λ values, account must be taken of the effective number of quark flavors in each experiment In practice it is straightforward to relate the different $\Lambda^{(n_f)}$ using the above expressions For example, one finds[4] (the meaning of $\overline{\rm MS}$ will be explained below)

$$\Lambda^{(4)}_{\overline{\rm MS}} \approx \Lambda^{(5)}_{\overline{\rm MS}}\left(\frac{m_b}{\Lambda^{(5)}_{\overline{\rm MS}}}\right)^{2/25}\left(\ell n\left[\left(\frac{m_b}{\Lambda^{(5)}_{\overline{\rm MS}}}\right)^2\right]\right)^{963/14375}$$

$$\Lambda^{(4)}_{\overline{\rm MS}} \approx \Lambda^{(3)}_{\overline{\rm MS}}\left(\frac{\Lambda^{(3)}_{\overline{\rm MS}}}{m_c}\right)^{2/25}\left(\ell n\left[\left(\frac{m_c}{\Lambda^{(3)}_{\overline{\rm MS}}}\right)^2\right]\right)^{107/1875} \qquad \text{(B 4)}$$

Note that these differences are numerically very significant, for example, if $\Lambda^{(5)}_{\overline{\rm MS}} = 200$ MeV, the corresponding $\Lambda^{(4)}_{\overline{\rm MS}} = 293$ MeV Most data from PEP/PETRA quote a value of $\Lambda^{(5)}_{\overline{\rm MS}}$ We have converted it to $\Lambda^{(4)}_{\overline{\rm MS}}$ as required

All this confusion could be avoided by ignoring Λ altogether, but old habits die hard The confusion can be minimized by adopting $\Lambda^{(4)}_{\overline{\rm MS}}$ defined through Eq (B 2) as the standard This is done for all values of Λ quoted in this summary In a given experiment where 1 5 GeV $<\mu<$ 5 GeV, $\Lambda^{(4)}$ is obtained from Eq (B 2) with $n_f = 4$ For 5 GeV $<\mu< m_t$ GeV (m_t is the top-quark mass), $\Lambda^{(5)}$ is obtained from Eq (B 2) with $n_f = 5$ Eq (B 4) is then used to convert to $\Lambda^{(4)}$

We turn now to a discussion of renormalization-scheme dependence in QCD Although necessarily rather technical, this discussion is vital to understanding how Λ values can be measured and compared See the review by Duke and Roberts[5] for further details

QUANTUM CHROMODYNAMICS (Cont'd)

Consider a "typical" QCD cross section which, when calculated perturbatively, starts at $O(\alpha_s)$

$$\sigma = A_1\alpha_s + A_2\alpha_s^2 + \cdots \tag{B.5}$$

The coefficients A_1, A_2 come from calculating the appropriate Feynman diagrams. In performing such calculations various divergences arise, and these must be regulated in a consistent way. This requires a particular renormalization scheme (RS). The most commonly used one is the modified minimal subtraction ($\overline{\rm MS}$) scheme.[6] This involves continuing momentum integrals from 4 to $4-2\epsilon$ dimensions and then subtracting off the resulting $1/\epsilon$ poles and also $(\ell n 4\pi - \gamma_E)$, which is another artifact of continuing the dimension. (Here γ_E is the Euler-Mascheroni constant.) To preserve the dimensionless nature of the coupling, a mass scale μ must also be introduced: $g \to \mu^\epsilon g$. The finite coefficients A_i thus obtained depend implicitly on the renormalization convention used and explicitly on the scale μ.

The first two coefficients (β_0, β_1) in Eq. (B.1) are independent of the choice of RS's. In contrast, the coefficients of terms proportional to α_s^n for $n \geq 3$ *are* RS-dependent. Although the value of Λ, defined as above, does depend on the convention, it is straightforward to relate the different Λ's corresponding to different RS's. It has become conventional to use the $\overline{\rm MS}$ scheme for calculating QCD cross sections beyond leading order.

The fundamental theorem of RS dependence is straightforward. Physical quantities, in particular the cross section, calculated to all orders in perturbation theory do not depend on the RS. It follows that a truncated series *does* exhibit RS dependence. In practice all QCD cross sections are known either to leading or to next-to-leading order, and it is only the latter, which has reduced RS dependence, that are useful for precision tests. At second order the RS dependence is completely given by one condition which can be taken to be the value of the renormalization scale μ. One therefore has to address the question of what is the "best" choice for μ. There is no definite answer to this question; higher order corrections do not "fix" the scale, rather they render the theoretical predictions less sensitive to its variation.

There has been much discussion as to what constitutes the best choice of scheme. One could imagine that choosing a scale μ characteristic of the typical energy scale in the process would be most appropriate. More sophisticated choices are the scale for which the next-to-leading-order correction vanishes ("Fastest Apparent Convergence"[7]) or the scale for which the next-to-leading-order prediction is stationary.[3]

An important corollary is that if the higher-order corrections are naturally small, then the additional uncertainties introduced by the RS dependence are likely to be less than the experimental measurement errors. There are some processes, however, for which the choice of scheme (i.e., the value of μ) *can* influence the extracted value of $\Lambda_{\overline{\rm MS}}$. There is no resolution to this problem other than to try to calculate even more terms in the perturbation series.[†]

In the cases where the higher-order corrections to a process are known and are large, some caution should be exercised when quoting the value of α_s. In what follows we will, where possible, indicate the size of the correction and will assign a theoretical uncertainty to α_s which corresponds to the size of this higher-order correction. We estimate this error by comparing the value of $\alpha_s(\mu)$ obtained by fitting data using the QCD formula to highest known order in α_s, and then comparing it with the value obtained using the next-to-highest-order formula (μ is chosen as the typical energy scale in the process). The corresponding Λ's are then obtained by evolving $\alpha_s(\mu)$ to μ = 5GeV using Eq. (B.1) to the same order in α_s as the fit, and then converting to $\Lambda^{(4)}$ using Eq. (B.4).

C. QCD IN DEEP INELASTIC SCATTERING

The original and still one of the most powerful quantitative tests of perturbative QCD is the breaking of Bjorken scaling in deep-inelastic lepton-hadron scattering. In the leading-logarithm approximation the measured structure functions $F_i(x,Q^2)$ are related to the quark distribution functions $q_i(x, Q^2)$ according to the naive parton model by the formulae in "Cross-Section Formulae for Specific Processes" (in that section, q_i is denoted by the notation f_q). In describing the way in which scaling is broken in QCD, it is convenient to define nonsinglet and singlet quark distributions

$$F^{NS} = q_i - q_j \qquad F^S = \sum_i (q_i + \overline{q}_i) \tag{C.1}$$

The nonsinglet structure functions have nonzero values of flavor quantum numbers such as isospin or baryon number. The variation with Q^2 of these is described by the so-called Altarelli-Parisi equations[8]

$$Q^2 \frac{\partial F^{NS}}{\partial Q^2} = \frac{\alpha_s(|Q|)}{2\pi} P^{qq} * F^{NS}$$

$$Q^2 \frac{\partial}{\partial Q^2}\begin{pmatrix} F^S \\ G \end{pmatrix} = \frac{\alpha_s(|Q|)}{2\pi}\begin{pmatrix} P^{qq} & 2n_f P^{qg} \\ P^{gq} & P^{gg} \end{pmatrix} * \begin{pmatrix} F^S \\ G \end{pmatrix} \tag{C.2}$$

where $*$ denotes a convolution integral

$$f * g = \int_x^1 \frac{dy}{y} f(y) g\left(\frac{x}{y}\right) \tag{C.3}$$

The leading-order Altarelli-Parisi splitting functions are

$$P^{qq} = \frac{4}{3}\left[\frac{1+x^2}{1-x}\right]_+ + 2\delta(1-x)\,,$$

$$P^{qg} = \frac{1}{2}\left[x^2 + (1-x)^2\right],$$

$$P^{gq} = \frac{4}{3}\left[\frac{1+(1-x)^2}{x}\right],$$

$$P^{gg} = 6\left[\frac{1-x}{x} + x(1-x) + \left[\frac{x}{1-x}\right]_+ + \frac{11}{12}\delta(1-x)\right]$$

$$-\frac{n_f}{3}\delta(1-x) \tag{C.4}$$

Here the gluon distribution $G(x,Q^2)$ has been introduced and $1/(1-x)_+$ means

$$\int_0^1 dx \frac{f(x)}{(1-x)_+} = \int_0^1 dx \frac{f(x) - f(1)}{(1-x)}$$

The precision of contemporary experimental data demands that higher order corrections also be included.[9] The above results are for massless quarks. Algorithms exist for the inclusion of nonzero quark masses.[10] At low Q^2 values there are also important "higher-twist" contributions of the form

$$F_i(x,Q^2) = F_i^{(LT)}(x, Q^2) + \frac{F_i^{(HT)}(x,Q^2)}{Q^2} \,. \tag{C.5}$$

These corrections are numerically important only for $Q^2 < O(10\ {\rm GeV}^2)$ except for x very close to 1.

QUANTUM CHROMODYNAMICS (Cont'd)

A detailed review of the current status of the experimental data can be found, for example, in Ref 11, and only a brief summary will be presented here From Eq (C 2), it is clear that a nonsinglet structure function offers in principle the most precise test of the theory since the Q^2 evolution is independent of the unmeasured gluon distribution In practice, however, such a measurement involves forming differences between cross sections (e g , F_3 in neutrino scattering) Until recently this has meant that the most accurate measurements, involving singlet-dominated structure functions such as F_2, have resulted in strongly correlated measurements of $\Lambda_{\overline{MS}}$ and the gluon distribution The most accurate data currently available are from the BCDMS collaboration By utilizing high-statistics data at large x (> 0 25) and large Q^2, the impact of the gluon distribution on the evolution and hence on the measured value of $\Lambda_{\overline{MS}}$ is much reduced

The result obtained is,[12]

$$\Lambda^{(4)}_{\overline{MS}} = 230 \pm 20(\text{stat}) \pm 60(\text{sys}) \text{ MeV} \qquad (C\ 6)$$

which is consistent with earlier measurements A summary of published $\Lambda_{\overline{MS}}$ values from various experiments is displayed in Fig 1 In Fig 2 we have indicated the average value of $\Lambda^{(4)}_{\overline{MS}}$ (238 ± 43 MeV, statistical and systematic uncertainty added in quadrature) from the deep-inelastic experiments shown in Fig 1

The impact on the measurement of α_s of the higher order corrections can be estimated as follows BCDMS used the evolution Eqs (C 2) to leading order in α_s, and defined Λ_{LO} from $\alpha_s(Q^2) = 12\pi/[(33 - 2n_f)\ln(Q^2/\Lambda^2_{LO})]$ They then obtained Λ_{LO} = 215 MeV This corresponds to α_s(5 GeV) = 0 240, whereas their next-to-leading-order fit corresponds to α_s(5 GeV) = 0 191 We have used this to estimate the theoretical uncertainty shown on Fig 2

Typically, Λ is extracted from the data by parametrizing the parton densities in a simple analytic way at some Q_0^2, evolving to higher Q^2 using the next-to-leading-order evolution equations, and fitting globally to the measured structure functions to obtain $\Lambda_{\overline{MS}}$ Thus an important by-product of such studies is the extraction of parton densities at a fixed reference value of Q_0^2 These can then be evolved in Q^2 and used as input for phenomenological studies in hadron-hadron collisions (see below) To avoid having to evolve from the starting Q_0^2 value each time, a parton density is required, it is useful to have available a simple analytic approximation to the densities valid over a range of x and Q^2 values Such parametrizations are available in the literature [13]

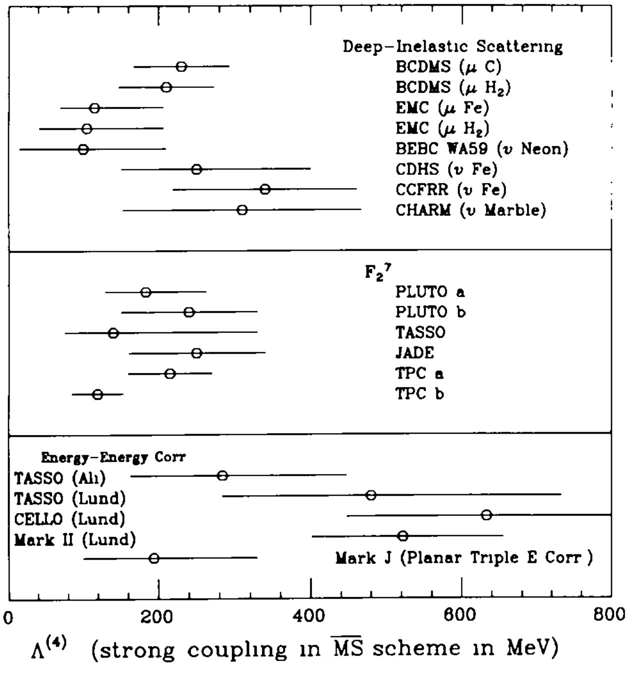

Fig 1 Values of $\Lambda^{(4)}_{\overline{MS}}$ as determined by various experiments The results on deep inelastic scattering are from BCDMS,[12,48] EMC,[49] BEBC,[50] CDHS,[51] CCFRR,[52] and CHARM [53] The photon structure function results are from PLUTO[54] and TPC,[46] who quote two values of Λ arising from different assumptions about the hadronic part of the structure function, and from TASSO[55] and JADE [56] The Energy-Energy correlation results are from TASSO,[37] CELLO,[28] and Mark II [57] The Planar Triple Energy correlation result is due to MARK-J [58]

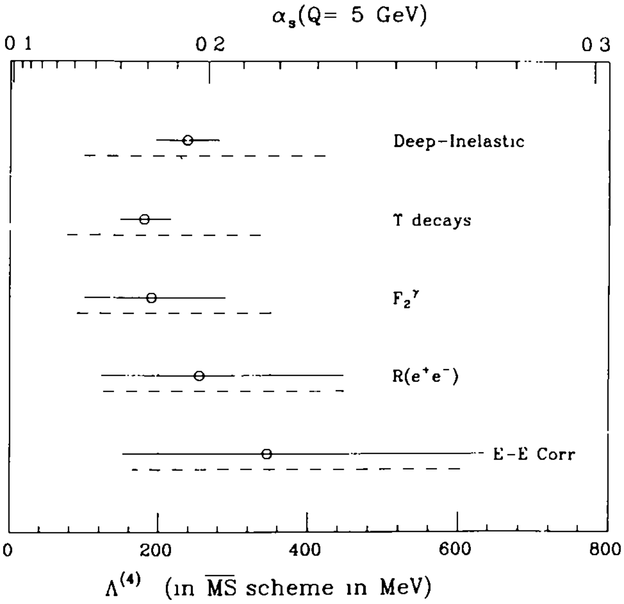

Fig 2 Summary of the values of $\Lambda^{(4)}_{\overline{MS}}$ from various processes The deep inelastic value is an average of those shown in Fig 1 The Υ result is from[22] an average of measurements [23-25] The two-photon value is the allowed range from the results of Fig 1 and takes into account the systematic error from the different models for the nonperturbative component of the structure function The value from R is the average[29] of the compilation of Ref 28 The result for the energy-energy correlations[40] is a range of allowed values and includes the systematic errors due to different fragmentation models The dashed lines give our estimate of the possible uncertainty due to higher order QCD corrections, see text For convenience, the top scale gives the value of α_s(5 GeV) corresponding to the values of $\Lambda^{(4)}_{\overline{MS}}$ The vertical dotted lines indicate our allowed range and central value for Λ

QUANTUM CHROMODYNAMICS (Cont'd)

D. QCD IN HIGH ENERGY HADRON COLLISIONS

There are many ways in which perturbative QCD can be tested in high energy hadron colliders The most precise of these is the production of single large-transverse-momentum photons The leading-order QCD subprocesses are $q\bar{q} \to \gamma g$ and $qg \to \gamma q$ Explicit expressions for the corresponding scattering amplitudes can be found, for example, in Ref 14 If the parton distributions are taken from other processes and a value of $\Lambda_{\overline{MS}}$ assumed, then an absolute prediction is obtained Conversely, the data can be used to extract information on quark and gluon distributions and the value of $\Lambda_{\overline{MS}}$ This is also one of the few hard scattering processes for which the next-to-leading-order corrections are known,[15] and so a precision test is possible in principle In practice, however, the residual uncertainties on the (most accurate) experimental data and in the theoretical prediction are on the order of 20–30%, and this is sufficiently large to limit the accuracy of an α_s measurement Nevertheless a value for $\Lambda_{\overline{MS}}$ in the range 100–300 MeV gives very satisfactory agreement with a wide range of data [16]

The production of hadrons with large transverse momentum in hadron-hadron collisions provides a direct probe of the scattering of quarks and gluons $qq \to qq$, $qg \to qg$, $gg \to gg$, etc The present generation of $p\bar{p}$ colliders provide center-of-mass energies which are sufficiently high that these processes can be unambiguously identified in two-jet production at large transverse momentum Corrected inclusive jet cross sections can be directly compared to the corresponding parton cross sections, and the agreement is impressive As an example the figure on "Jet Production in pp and $p\bar{p}$ Interactions" in "Plots of Cross Sections and Related Quantities" shows the inclusive jet cross section at zero pseudorapidity as a function of the jet transverse momentum for $p\bar{p}$ collisions The QCD prediction combines the parton distributions with the leading-order $2 \to 2$ parton scattering amplitudes Data are also available on the angular distribution of jets, these are also in agreement with QCD expectations [17]

QCD corrections to Drell-Yan type cross sections (i e , the production in hadron collisions by quark-antiquark annihilation of lepton pairs of invariant mass Q from virtual photons, or of real W or Z bosons) are known [18] These $O(\alpha_s)$ QCD corrections are sizable and approximately constant over the lepton-pair mass range probed by experiments Thus

$$\sigma_{DY} \approx \sigma_{DY}^{(0)} \left[1 + \frac{\alpha_s(Q^2)}{2\pi} C + \cdots \right] \tag{D 1}$$

It is interesting to note that the corresponding correction to W and Z production, as measured at $p\bar{p}$ colliders has essentially the same theoretical form and is of order 30% Total W and Z production cross sections soon will be measured accurately enough to be sensitive to such 30% effects and can in principle offer a test of the theory The key ingredient which is missing at present is the complete $O(\alpha_s^2)$ QCD correction which is potentially important in view of the large $O(\alpha_s)$ term QCD effects are also observable in the production of W and Z bosons with large transverse momentum [19] There is good qualitative agreement although the statistics are rather poor at present [20]

E. QCD IN HEAVY QUARKONIUM DECAY

Under the assumption that the hadronic and leptonic decay widths of heavy $Q\bar{Q}$ resonances can be factorized into a nonperturbative part dependent on the confining potential and a calculable perturbative part, the ratios of partial decay widths allow measurements of α_s at the heavy quark mass scale The most precise data come from the decay widths of the 1^{--} J/ψ and Υ resonances Potential model dependences cancel from the ratios of decay widths Important examples of such ratios are

$$\frac{\Gamma(1^{--} \to ggg)}{\Gamma(1^{--} \to \mu^+\mu^-)}, \quad \frac{\Gamma(1^{--} \to \gamma gg)}{\Gamma(1^{--} \to ggg)} \tag{E 1}$$

The perturbative corrections to these ratios are rather large [21] They change the predictions by a factor of 1 64 and 0 77 respectively in the case of Υ decay The corrections in the J/ψ case are much larger Relativistic corrections are unknown and could be substantial for the J/ψ case We will therefore assign a 20% uncertainty to the value of α_s obtained from Υ decays

A recent analysis[22] of bottomonium decay-width ratios from CUSB, CLEO, and ARGUS[23,24,25] finds

$$\alpha_s(m_b) = 0.179 \pm 0.009 \tag{E 2}$$

if the theoretical uncertainties are ignored These uncertainties are indicated in Fig 2

F PERTURBATIVE QCD IN e^+e^- COLLISIONS

The total cross section for $e^+e^- \to$ hadrons is obtained by multiplying the muon-pair cross section by the factor $R = 3\,\Sigma_q e_q^2$ The higher order QCD corrections to this quantity have been calculated, and the results can be expressed in terms of the factor

$$R = R^{(0)}\left[1 + \frac{\alpha_s}{\pi} + C_2\left(\frac{\alpha_s}{\pi}\right)^2 + C_3\left(\frac{\alpha_s}{\pi}\right)^3 + \cdots\right],$$

$$C_2^{\overline{MS}} = \left(\frac{2}{3}\zeta(3) - \frac{11}{12}\right)n_f + \frac{365}{24} - 11\zeta(3) \tag{F 1}$$

$R^{(0)}$ can be obtained from the formula for $d\sigma/d\Omega$ for $e^+e^- \to f\bar{f}$ by integrating over Ω The formula is given in "Cross-Section Formulae for Specific Processes," Section B Numerically $C_2^{\overline{MS}} = 1.41$ Recently C_3 has been computed,[26] numerically (for $n_f = 5$) $C_3^{\overline{MS}} = 64.7$ This result is strictly only correct in the zero-quark-mass limit The $O(\alpha_s)$ corrections are also known for massive quarks [27]

At the highest energies currently accessible (PETRA-PEP-TRISTAN), the corrections from QCD and Z exchange are comparable A comparison of the theoretical prediction of Eq (F 1) (corrected for the b-quark mass) with all the available data (including those from TRISTAN at $\sqrt{s} = 50$ GeV) has been performed by the CELLO collaboration [28] The result is a correlated measurement of α_s and $\sin^2\theta_W$ Fixing $\sin^2\theta_W$ at the world-average value of 0 23 then gives [29]

$$\alpha_s(34\ \text{GeV}) = 0.132 \pm 0.016 \tag{F 2}$$

The corresponding value of $\Lambda_{\overline{MS}}$ is shown in Fig 2 Two comments are in order First, the principal advantage of determining α_s from R in e^+e^- annihilation is that there is no dependence on fragmentation models, jet algorithms, etc Second, the order α_s^3 term in Eq (F 1) is numerically twice as large as the order α_s^2 term The accuracy of the QCD prediction is therefore suspect To take account of this we have given in Fig 2 a theoretical uncertainty which corresponds to the difference of the values of α_s with and without the α_s^3 term (12% of α_s)

The traditional method of determining α_s in e^+e^- annihilation is from measuring quantities which are sensitive to the relative rate of two- and three-jet events There are many possible choices of such "shape variables" thrust,[30] energy-energy correlations,[31] planar triple-energy correlations,[32] average jet mass, etc All of these are infrared safe, which means they can be reliably calculated in perturbation theory The starting point for all these quantities is the simple "three-jet" cross section for $e^+e^- \to q\bar{q}g$

$$\frac{1}{\sigma}\frac{d^2\sigma}{dx_1 dx_2} = \frac{2\alpha_s}{3\pi}\frac{x_1^2 + x_2^2}{(1 - x_1)(1 - x_2)}, \tag{F 3}$$

QUANTUM CHROMODYNAMICS (Cont'd)

where

$$x_i = \frac{2E_i}{\sqrt{s}}$$

are the center-of-mass energy fractions of the final-state (massless) quarks. A distribution in a "three-jet" variable, such as those listed above, is obtained by integrating this differential cross section over an appropriate phase space region for a fixed value of the variable.

See Fig. 1 for a compilation of the more recent data on Λ from the energy-energy correlation. Three comments must be made concerning these determinations of α_s. First, there are theoretical ambiguities in the way that the second-order matrix elements are combined with parton fragmentation. These have been a source of some confusion and have accounted for some of the differences in the results obtained from different analyses. Fortunately, there appears to now be some consensus and the different approaches have converged.[33] A more serious source of uncertainty concerns the effect of using different hadronization models which are used to describe the evolution of a parton jet into a hadron jet.[34,35,36] These dynamics are controlled by QCD effects which we cannot yet calculate. Some experimental groups continue to quote separate α_s values according to the fragmentation model used, while others combine the uncertainty with other systematic errors. For example the TASSO collaboration[37] uses the energy-energy correlation and quotes α_s (44 GeV) = 0.143 ± 0.014 for the Lund fragmentation model[34] and α_s (44 GeV) = 0.129 ± 0.012 for the Ali model,[35] after the fragmentation models have been fitted to the data at $\sqrt{s}$ = 44 GeV.

Third, numerically the order α_s^2 terms produce corrections of order 13%.[38] We will therefore assign a theoretical uncertainty of this size to the value of α_s extracted (see Fig. 2).

A compilation of all the available data and a complete list of references can be found in Ref. 39. A "world-average" is[40]

$$\alpha_s(34\ \text{GeV}) = 0.14 \pm 0.02 \tag{F.4}$$

with the error being the spread between the different experiments including the fragmentation uncertainty, but not that due to the size of the higher order corrections, which from our estimate above is somewhat larger than this error. Notice that this value of α_s is in agreement with the value obtained from the measurement of R described above. Since these results are essentially completely independent, the associated $\Lambda_{\overline{MS}}$ values are displayed separately in Fig. 2.

There are many other ways in which QCD can be tested in electron-positron collisions. Mention should be made in particular of the interesting and important results from "two-photon" processes. For a comprehensive review of the data, see Ref. 41. Paramount among these is the measurement of the photon structure function in collisions involving a highly virtual and an almost real photon.

In contrast to hadronic structure functions, the photon structure function increases linearly with log Q^2,[42] and a measurement of the absolute size at large Q^2 provides information about Λ. However, the exact situation is complicated and somewhat controversial. The difficulty arises when the higher order QCD corrections[43] are included. These appear to introduce a negative singularity in the structure function at $x = 0$.[44] A more complete treatment then reveals that these singularities are in fact compensated by the nonperturbative hadronic component (the solution of the homogeneous part of the Altarelli-Parisi equations). This appears to reduce the usefulness of the photon structure function to that of hadronic structure functions, in that only the evolution can be unambiguously predicted in QCD and the sensitivity to Λ is much reduced. Furthermore, fits to the data involve the determination of parameters which fix the nonperturbative components as well as Λ.[45] The TPC/2-gamma collaboration[46] quotes two values of $\Lambda_{\overline{MS}}$ = 215 ± 55 and 119 ± 34 MeV, depending upon how the nonperturbative component is parametrized. Systematic errors from this parametrization dominate statistical errors and the situation is somewhat similar to that for the energy-energy correlations discussed above. All the data on the photon structure function (see Fig. 1) are consistent with[47]

$$\Lambda_{\overline{MS}} = 180^{+100}_{-90}\ \text{MeV} \tag{F.5}$$

This value is shown in Fig. 2. The higher order QCD corrections correspond approximately to a shift of 20% in the photon structure function and hence in α_s.[43] The corresponding uncertainty is indicated on Fig. 2.

G. CONCLUSIONS

In this short review we have focused on those high energy processes which currently offer the most quantitative tests of perturbative QCD. The precision measurements of $\Lambda_{\overline{MS}}$ come from those processes which involve real or virtual photons and for which the next-to-leading corrections are known. From Fig. 2 we see that all measurements are consistent and point to a value of $\Lambda_{\overline{MS}}$ for n_f = 4 of order 200^{+150}_{-80} MeV. The remarks in Sec. B concerning different Λ's for different effective n_f values should be remembered. It is interesting to note that the measurements are not yet precise enough to reveal the expected differences from different processes. Jet production data from high energy hadron collisions, while not yet in the precision measurement class, demonstrate in a very clear way the scattering of quarks and gluons over many orders of magnitude in cross section.

The need for brevity has meant that many other important topics in QCD phenomenology have had to be omitted from this review. One should mention in particular the study of exclusive processes (form factors, elastic scattering, ...), the behavior of quarks and gluons in nuclei, the spin properties of the theory and the importance of polarized scattering data, the interface of soft and hard QCD as manifest, for example, by minijet production and hard diffractive processes and QCD effects in hadron spectroscopy. While we can be confident that QCD *is* the strong interaction field theory, there are still many important tests to be made.

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* Prepared April 1988 by R.M. Barnett, I. Hinchliffe, and W.J. Stirling.

† Since the perturbation expansion is an asymptotic series, eventually the computation of additional terms is of no value.

‡ This fit includes the C_3 term. If this term is not included, the fit gives α_s (34 GeV) = 0.145 ± 0.019.[28]

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STANDARD MODEL OF ELECTROWEAK INTERACTIONS*

The standard electroweak model is based on the gauge group[1] $SU(2)\times U(1)$, with gauge bosons W_μ^i, $i = 1,2,3$, and B_μ for the SU(2) and U(1) factors respectively, and the corresponding gauge coupling constants g and g'. The left-handed fermion fields

$$\psi_i = \begin{pmatrix} \nu_i \\ \ell_i \end{pmatrix} \text{ and } \begin{pmatrix} u_i \\ d_i' \end{pmatrix}$$

of the i^{th} fermion family transform as doublets under SU(2), where $d_i' \equiv \sum_j V_{ij} d_j$, and V is the Kobayashi-Maskawa mixing matrix.** The right-handed fields are SU(2) singlets. In the minimal model there are three fermion families and a single complex Higgs doublet $\phi \equiv \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$.

After spontaneous symmetry breaking the Lagrangian is

$$\mathscr{L}_F = \sum_i \bar\psi_i \left(i\not\partial - m_i - \frac{g m_i H}{2M_W} \right)\psi_i$$

$$- \frac{g}{2\sqrt{2}} \sum_i \bar\psi_i \gamma^\mu (1-\gamma^5)(T^+ W_\mu^+ + T^- W_\mu^-)\psi_i$$

$$- e\sum_i q_i \bar\psi_i \gamma^\mu \psi_i A_\mu - \frac{g}{2\cos\theta_W} \sum_i \bar\psi_i \gamma_\mu (V^i - A^i\gamma^5)\psi_i Z_\mu \qquad (1)$$

$\theta_W \equiv \tan^{-1}(g'/g)$ is the weak angle, $e = g\sin\theta_W$ is the positron electric charge, and $A \equiv B\cos\theta_W + W^3\sin\theta_W$ is the (massless) photon field. $W^\pm \equiv (W^1 \mp iW^2)/\sqrt{2}$ and $Z \equiv -B\sin\theta_W + W^3\cos\theta_W$ are the massive charged and neutral weak boson fields, respectively. T^+ and T^- are the weak isospin raising and lowering operators. The vector and axial couplings are

$$V^i \equiv t_{3L}(i) - 2q_i \sin^2\theta_W$$

$$A^i \equiv t_{3L}(i) \qquad (2)$$

where $t_{3L}(i)$ is the weak isospin of fermion i ($+1/2$ for u_i and ν_i, $-1/2$ for d_i and e_i) and q_i is the charge of ψ_i in units of e.

The second term in $\mathscr{L}_F$ represents the charged-current weak interaction.[2] For example, the coupling of a W to an electron and a neutrino is

$$\frac{e}{2\sqrt{2}\sin\theta_W}\left[W_\mu^- \bar e \gamma^\mu (1-\gamma^5)\nu + W_\mu^+ \bar\nu\gamma^\mu(1-\gamma^5)e\right] \qquad (3)$$

For momenta small compared to M_W, the second term reduces to the effective four-fermion interaction with the Fermi constant given (at tree level, i.e., lowest order in perturbation theory) by $G_F/\sqrt{2} = g^2/8M_W^2$. CP violation is incorporated in the Standard Model by a single observable phase in V_{ij}. The third term in $\mathscr{L}_F$ describes electromagnetic interactions (QED), and the last is the weak neutral-current interaction.

In Eq. (1), m_i is the mass of the i^{th} fermion ψ_i. For the quarks these are the current masses, which for the light quarks are estimated[3] to be $m_u \sim 5.6 \pm 1.1$ MeV, $m_d \simeq 9.9 \pm 1.1$ MeV, $m_s \simeq 199 \pm 33$ MeV, and $m_c \sim 1.35 \pm 0.05$ GeV (these are running masses evaluated at 1 GeV). For the heavier quarks $m_b \simeq 5$ GeV, and $m_t > O(50)$ GeV.

H is the physical neutral Higgs scalar which is the only remaining part of ϕ after spontaneous symmetry breaking. The Yukawa coupling of H to ψ_i, which is flavor diagonal in the minimal model, is $g m_i/2M_W$. The H mass is not predicted by the model. Experimental limits are given in the Stable Particles section. In nonminimal models there are additional charged and neutral scalar Higgs particles.[4]

Renormalization and radiative corrections. The Standard Model has three parameters (not counting M_H and the fermion masses and mixings). A particularly useful set is: (a) the fine structure constant $\alpha = 1/137.036$,† determined from electron magnetic moment anomaly ($g-2$), (b) the Fermi constant, $G_F = 1.16637\times10^{-5}$ GeV^{-2}, determined from the muon lifetime formula (including lepton mass and $O(\alpha)$ radiative corrections)

$$\tau_\mu^{-1} = \frac{G_F^2 m_\mu^5}{192\pi^3}\left[1 - \frac{\alpha}{2\pi}\left(\frac{25}{4} - \pi^2\right)\left(1 - \frac{2\alpha}{3\pi}\ln\frac{m_\mu}{m_e}\right)\right]$$

$$\times\left[1 - \frac{8m_e^2}{m_\mu^2}\right]\times\left[1 + \frac{3}{5}\frac{m_\mu^2}{M_W^2}\right], \qquad (4)$$

and (c) $\sin^2\theta_W$, determined from neutral-current processes and the W and Z masses. The value of $\sin^2\theta_W$ depends on the renormalization prescription. A very useful scheme[6] is to take the tree-level formula $\sin^2\theta_W = 1 - M_W^2/M_Z^2$ as the definition of the renormalized $\sin^2\theta_W$ to all orders in perturbation theory.‡ Alternatively, one can take M_Z rather than $\sin^2\theta_W$ as the third fundamental parameter. This will be useful when very precise values of M_Z are determined at SLC and LEP.

Experiments are now at such a level of precision that complete $O(\alpha)$ radiative corrections must be applied. These corrections are conveniently divided into two classes:

1. QED diagrams involving the emission of real photons or the exchange of virtual photons in loops, but not including vacuum polarization diagrams. These graphs yield finite and gauge-invariant contributions to observable processes. However, they are dependent on energies, experimental cuts, etc., and must be calculated individually for each experiment.
2. Electroweak corrections, including $\gamma\gamma$, γZ, ZZ, and WW vacuum polarization diagrams, as well as vertex corrections, box graphs, etc., involving virtual W's and Z's. Many of these corrections are absorbed into the renormalized Fermi constant defined in Ref. 4. Others modify the tree-level expressions for neutral-current amplitudes in several ways.[5]

In addition, the tree-level expressions for M_W and M_Z are modified:

$$M_W = \frac{A_0}{\sin\theta_W(1-\Delta r)^{1/2}}$$

$$M_Z = \frac{M_W}{\cos\theta_W} \qquad (5)$$

where $A_0 = (\pi\alpha/\sqrt{2}G_F)^{1/2} = 37.281$ GeV. The radiative correction parameter Δr is predicted to be 0.0713 ± 0.0013 for $m_t = 45$ GeV and $M_H = 100$ GeV, while $\Delta r \to 0$ for $m_t \sim 245$ GeV. If M_Z is regarded as fundamental, then

$$\sin^2\theta_W = \frac{1}{2}\left[1 - \left(1 - \frac{4A_0^2}{M_Z^2(1-\Delta r)}\right)^{1/2}\right] \qquad (6)$$

is a derived parameter, and $M_W = M_Z\cos\theta_W$.

Cross section and asymmetry formulas. It is convenient to write the four-fermion interactions relevant to ν-hadron, νe, and e-hadron processes in a form that is valid in an arbitrary gauge theory (assuming massless left-handed neutrinos). One has

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$$-\mathcal{L}^{\nu\,\mathrm{Hadron}} = -\frac{G_F}{\sqrt{2}}\bar{\nu}\gamma^\mu(1-\gamma^5)\nu$$

$$\times\left\{\sum_i\left[\epsilon_L(i)\bar{q}_i\gamma_\mu(1-\gamma^5)q_i + \epsilon_R(i)\bar{q}_i\gamma_\mu(1+\gamma^5)q_i\right]\right\} \quad (7)$$

$$-\mathcal{L}^{\nu e} = -\frac{G_F}{\sqrt{2}}\bar{\nu}_\mu\gamma^\mu(1-\gamma^5)\nu_\mu\,\bar{e}\gamma_\mu(g_V^e - g_A^e\gamma^5)e \quad (8)$$

(for $\nu_e e$ or $\bar{\nu}_e e$, the charged-current contribution must be included), and

$$-\mathcal{L}^{e\,\mathrm{Hadron}} = -\frac{G_F}{\sqrt{2}}$$

$$\times\sum_i\left[C_{1i}\bar{e}\gamma_\mu\gamma^5 e\bar{q}_i\gamma^\mu q_i + C_{2i}\bar{e}\gamma_\mu e\bar{q}_i\gamma^\mu\gamma^5 q_i\right] \quad (9)$$

The Standard Model expressions for $\epsilon_{L,R}(i)$, $g_{V,A}^e$, and C_{ij} are given in Table I.

Table I. Standard model expressions for the neutral-current parameters for ν-hadron, νe, and e-hadron processes. If radiative corrections are ignored, $\rho = \kappa = 1$, $\lambda = 0$. At $O(\alpha)$, $\rho^{NC}_{\nu N} = 1.00074$, $\kappa_{\nu N} = 0.9902$, $\lambda_{u_L} = -0.0031$, $\lambda_{d_L} = -0.0026$, and $\lambda_{u_R} = 1/2\lambda_{d_R} = 3.5\times10^{-5}$ for $m_t = 45$ GeV, $M_H = 100$ GeV, $\sin^2\theta_W = 0.23$, and $\langle Q^2\rangle = 20$ GeV^2. For νe scattering, $\kappa_{\nu e} = 0.9897$ and $\rho_{\nu e} = 1.0054$ (at $\langle Q^2\rangle = 0$). For atomic parity violation $\rho'_{eq} = 0.9793$ and $\kappa'_{eq} = 0.9948$. For the SLAC polarized electron experiment, $\rho'_{eq} = 0.970$, $\kappa'_{eq} = 0.993$, $\rho_{eq} = 0.993$, and $\kappa_{eq} = 1.03$ after incorporating additional QED corrections.

Quantity	Standard Model Expression
$\epsilon_L(u)$	$\rho^{NC}_{\nu N}\left[\frac{1}{2} - \frac{2}{3}\kappa_{\nu N}\sin^2\theta_W\right] + \lambda_{uL}$
$\epsilon_L(d)$	$\rho^{NC}_{\nu N}\left[-\frac{1}{2} + \frac{1}{3}\kappa_{\nu N}\sin^2\theta_W\right] + \lambda_{dL}$
$\epsilon_R(u)$	$\rho^{NC}_{\nu N}\left[-\frac{2}{3}\kappa_{\nu N}\sin^2\theta_W\right] + \lambda_{uR}$
$\epsilon_R(d)$	$\rho^{NC}_{\nu N}\left[\frac{1}{3}\kappa_{\nu N}\sin^2\theta_W\right] + \lambda_{dR}$
g_V^e	$\rho_{\nu e}\left[-\frac{1}{2} + 2\kappa_{\nu e}\sin^2\theta_W\right]$
g_A^e	$\rho_{\nu e}\left[-\frac{1}{2}\right]$
C_{1u}	$\rho'_{eq}\left[-\frac{1}{2} + \frac{4}{3}\kappa'_{eq}\sin^2\theta_W\right]$
C_{1d}	$\rho'_{eq}\left[\frac{1}{2} - \frac{2}{3}\kappa'_{eq}\sin^2\theta_W\right]$
C_{2u}	$\rho_{eq}\left[-\frac{1}{2} + 2\kappa_{eq}\sin^2\theta_W\right]$
C_{2d}	$-C_{2u}$

At present the most precise determinations of $\sin^2\theta_W$ are from deep inelastic neutrino scattering from (approximately) isoscalar targets. The ratio $R_\nu \equiv \sigma^{NC}_{\nu N}/\sigma^{CC}_{\nu N}$ of neutral- to charged-current cross sections has been measured to 1% accuracy by the CDHS[7] and CHARM[8] collaborations, so it is important to obtain theoretical expressions for R_ν and $R_{\bar{\nu}} \equiv \sigma^{NC}_{\bar{\nu}N}/\sigma^{CC}_{\bar{\nu}N}$ (as functions of $\sin^2\theta_W$) to comparable accuracy. Fortunately, most of the uncertainties from the strong interactions and neutrino spectra cancel in the ratio.

A simple zeroth-order approximation is

$$R_\nu = g_L^2 + g_R^2 r$$

$$R_{\bar{\nu}} = g_L^2 + \frac{g_R^2}{r}, \quad (10)$$

where

$$g_L^2 \equiv \epsilon_L(u)^2 + \epsilon_L(d)^2 \simeq \frac{1}{2} - \sin^2\theta_W + \frac{5}{9}\sin^4\theta_W$$

$$g_R^2 \equiv \epsilon_R(u)^2 + \epsilon_R(d)^2 \simeq \frac{5}{9}\sin^4\theta_W \quad (11)$$

and $r \equiv \sigma^{CC}_{\bar{\nu}N}/\sigma^{CC}_{\nu N}$ is the ratio of $\bar{\nu}$ and ν charged-current cross sections, which can be measured directly. [In the simple parton model, ignoring hadron energy cuts, $r \simeq (\frac{1}{3} + \epsilon)/(1 + \frac{1}{3}\epsilon)$, where $\epsilon \sim 0.125$ is the ratio of the fraction of the nucleon's momentum carried by antiquarks to that carried by quarks.] In practice, Eq. (10) must be corrected for quark mixing, the s and c seas, c-quark threshold effects (which mainly affect σ^{CC} — these turn out to be the largest theoretical uncertainty), nonisoscalar target effects, W-Z propagator differences, and radiative corrections (which lower the extracted value of $\sin^2\theta_W$ by ~ 0.009). Details of the neutrino spectra, experimental cuts, x and Q^2 dependence of structure functions, and longitudinal structure functions enter only at the level of these corrections and therefore lead to very small uncertainties. Altogether, the theoretical uncertainty is $\Delta\sin^2\theta_W \sim \pm0.005$, which would be very hard to improve in the future.

The laboratory cross section for $\nu_\mu e \to \nu_\mu e$ or $\bar{\nu}_\mu e \to \bar{\nu}_\mu e$ elastic scattering is

$$\frac{d\sigma_{\nu_\mu,\bar{\nu}_\mu}}{dy} = \frac{G_F^2 m_e E_\nu}{2\pi}$$

$$\times\left[(g_V^e \pm g_A^e)^2 + (g_V^e \mp g_A^e)^2(1-y)^2 - (g_V^{e2} - g_A^{e2})\frac{y\,m_e}{E_\nu}\right] \quad (12)$$

where the upper (lower) sign refers to $\nu_\mu(\bar{\nu}_\mu)$, and $y \equiv E_e/E_\nu$ [which runs from 0 to $(1 + m_e/2E_\nu)^{-1}$] is the ratio of the kinetic energy of the recoil electron to the incident ν or $\bar{\nu}$ energy. For $E_\nu >> m_e$ this yields a total cross section

$$\sigma \simeq \frac{G_F^2 m_e E_\nu}{2\pi}\left[(g_V^e \pm g_A^e)^2 + \frac{1}{3}(g_V^e \mp g_A^e)^2\right] \quad (13)$$

The most accurate leptonic measurements[9,10] of $\sin^2\theta_W$ are from the ratio $R \equiv \sigma_{\nu_\mu e}/\sigma_{\bar{\nu}_\mu e}$ in which many of the systematic uncertainties cancel. Radiative corrections, which are small compared to the precision of present experiments, increase the extracted $\sin^2\theta_W$ by $\simeq 0.002$. The cross sections for $\nu_e e$ and $\bar{\nu}_e e$ may be obtained from Eq. (12) by replacing $g_{V,A}^e$ by $g_{V,A}^e + 1$, where the 1 is due to the charged-current contribution.

The SLAC polarized-electron experiment[11] measured the parity-violating asymmetry

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}, \quad (14)$$

STANDARD MODEL OF ELECTROWEAK INTERACTIONS (Cont'd)

where $\sigma_{R,L}$ is the cross section for the deep-inelastic scattering of a right- or left-handed electron $e_{R,L}N \to eX$. In the quark parton model

$$\frac{A}{Q^2} = a_1 + a_2 \frac{1-(1-y)^2}{1+(1-y)^2}, \tag{15}$$

where $Q^2>0$ is the momentum transfer and y is the fractional energy transfer from the electron to the hadrons. For the deuteron or other isoscalar target one has, neglecting the s quark and antiquarks,

$$a_1 = \frac{3G_F}{5\sqrt{2}\pi\alpha}\left(C_{1u} - \frac{1}{2}C_{1d}\right) \simeq \frac{3G_F}{5\sqrt{2}\pi\alpha}\left(-\frac{3}{4} + \frac{5}{3}\sin^2\theta_W\right)$$

$$a_2 = \frac{3G_F}{5\sqrt{2}\pi\alpha}\left(C_{2u} - \frac{1}{2}C_{2d}\right) \simeq \frac{9G_F}{5\sqrt{2}\pi\alpha}\left(\sin^2\theta_W - \frac{1}{4}\right) \tag{16}$$

Radiative corrections lower the extracted value of $\sin^2\theta_W$ by ~0.005.

Experiments measuring atomic parity violation[12] are now quite precise, and the uncertainties associated with atomic wave functions are relatively small (especially for cesium). For heavy atoms one determines the "weak charge"

$$Q_W = -2[C_{1u}(2Z+N) + C_{1d}(Z+2N)]$$

$$\simeq Z(1-4\sin^2\theta_W) - N. \tag{17}$$

Radiative corrections increase the extracted $\sin^2\theta_W$ by ~0.008.

The forward-backward asymmetry for $e^+e^- \to \ell\bar{\ell}$, $\ell = \mu$ or τ, is defined as

$$A_{FB} \equiv \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}, \tag{18}$$

where $\sigma_F(\sigma_B)$ is the cross section for ℓ^- to travel forward (backward) with respect to the e^- direction. A_{FB} and R, the total cross section relative to pure QED, are given by

$$R = F_1$$

$$A_{FB} = 3F_2/4F_1, \tag{19}$$

where

$$F_1 = 1 - 2\chi_0 V^e V^\ell \cos\delta_R + \chi_0^2 (V^{e2} + A^{e2})(V^{\ell 2} + A^{\ell 2})$$

$$F_2 = -2\chi_0 A^e A^\ell \cos\delta_R + 4\chi_0^2 A^e A^\ell V^e V^\ell, \tag{20}$$

where

$$\tan\delta_R = \frac{M_Z\Gamma_Z}{M_Z^2 - s}$$

$$\chi_0 = \frac{G_F}{2\sqrt{2}\pi\alpha} \frac{sM_Z^2}{\left[(M_Z^2-s)^2 + M_Z^2\Gamma_Z^2\right]^{1/2}} \tag{21}$$

and $\sqrt{s}$ is the CM energy. Eq. (20) is valid at tree level. If the data are radiatively corrected for QED effects (as described above), then the remaining electroweak corrections can be incorporated[13] (in an approximation adequate for existing PEP and PETRA data) by replacing χ_0 by $\chi(s) \equiv \chi_0(s)\alpha/\hat{\alpha}(s)$, where $\hat{\alpha}(s)$ is the running QED coupling. Numerically, $\alpha/\hat{\alpha}(s) \sim 1 - \Delta_r$ if Δ_r is evaluated for $m_t < 100$ GeV. Formulas for $e^+e^- \to$ hadrons may be found in Ref. 14.

At SLC and LEP, A_{FB} for $e^+e^- \to \ell^+\ell^-$ at the Z pole will be measured to high precision. Similarly, the left-right asymmetry

$$A_{LR} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}, \tag{22}$$

where $\sigma_L(\sigma_R)$ is the cross section for a left- (right)-handed incident electron, will be measured very precisely at SLC and possibly at LEP. At tree level and neglecting terms of order $(\Gamma_Z/M_Z)^2$ one has

$$A_{FB} \simeq 3\eta_\ell \frac{\eta_e + 1/2(P_e)}{1 + 2P_e\eta_e}$$

$$A_{LR} \simeq 2\eta_e, \tag{23}$$

where P_e is the initial e^- polarization and

$$\eta_i = \frac{V^i A^i}{V^{i2} + A^{i2}}, \quad i = e, \mu, \tau. \tag{24}$$

The high-precision measurements will require careful application of both QED and electroweak radiative corrections[13] to Eq. (23).

Neutral-current experimental results. $\sin^2\theta_W$ and, equivalently, M_Z have been determined from the W and Z masses and from a variety of neutral-current processes spanning a very wide Q^2 range. The results,[5] shown in Table 2, are in impressive agreement with each other, indicating the quantitative success of the Standard Model. The best fit to all data yields $\sin^2\theta_W = 0.230 \pm 0.0048$, which corresponds to $M_Z = 92.0 \pm 0.7$ GeV, where the errors (as well as those given below for other neutral-current parameters) include full statistical, systematic, and theoretical uncertainties.

Table 2. Determination of $\sin^2\theta_W$ and M_Z (in GeV) from various reactions. The central values of all fits assume $m_t = 45$ GeV and $M_H = 100$ GeV in the radiative corrections. Where two errors are shown the first is experimental and the second (in square brackets) is theoretical, computed assuming 3 fermion families, $m_t < 100$ GeV and $M_H < 1$ TeV. In the other cases the theoretical and experimental uncertainties are combined. When m_t is allowed to be totally arbitrary, the fits to all data yield $\sin^2\theta_W = 0.229 \pm 0.007$ and $M_Z = 91.8 \pm 0.9$ GeV. The existing e^+e^- data do not yield a useful determination of $\sin^2\theta_W$: at PEP and PETRA energies the asymmetries are nearly an absolute prediction of the model, and all values of $\sin^2\theta_W$ from 0.1 to 0.4 give a good description of the data. (The e^+e^- asymmetries are nearly independent of m_t as well.)

Reaction	$\sin^2\theta_W$	M_Z
Deep inelastic (isoscalar)	0.233 ± 0.003 ± [0.005]	91.6 ± 0.4 ± [0.8]
$\nu_\mu p \to \nu_\mu p$	0.210 ± 0.033	95.0 ± 5.2
$\bar{\nu}_\mu p \to \bar{\nu}_\mu p$	0.210 ± 0.033	95.0 ± 5.2
$\nu_\mu e \to \nu_\mu e$	0.223 ± 0.018 ± [0.002]	93.0 ± 2.7
$\bar{\nu}_\mu e \to \bar{\nu}_\mu e$	0.223 ± 0.018 ± [0.002]	93.0 ± 2.7
W, Z	0.228 ± 0.007 ± [0.002]	92.3 ± 1.1
Atomic parity violation	0.209 ± 0.018 ± [0.014]	95.1 ± 3.9
SLAC eD	0.221 ± 0.015 ± [0.013]	93.3 ± 2.7
μC	0.25 ± 0.08	89.6 ± 9.7
All data	0.230 ± 0.0048	92.0 ± 0.7

STANDARD MODEL OF ELECTROWEAK INTERACTIONS (Cont'd)

The radiative corrections are sensitive to the isospin breaking associated with a large m_t. Consistency of the $\sin^2\theta_W$ values derived from the various reactions requires $m_t < 180$ GeV at 90% CL for $M_H \leq 100$ GeV with a slightly weaker limit for larger M_H. Similar limits hold for the mass splittings between fourth-generation quarks or leptons.

The measured values of M_W and M_Z are given in Table 3. They are in excellent agreement with the predictions of the Standard Model when full radiative corrections (to both the W and Z mass formulas and to deep inelastic scattering) are included, but disagree significantly when the corrections are excluded.

Table 3. The W and Z masses (in GeV). The first uncertainties are mainly statistical and the second are energy calibration uncertainties that are 100% correlated between M_W and M_Z for each group. The last two rows are predictions of the Standard Model, using $\sin^2\theta_W$ determined from deep inelastic scattering, with and without radiative corrections, respectively.

Group	M_W	M_Z
UA2 (Ref. 15)	$80.2 \pm 0.8 \pm 1.3$	$91.5 \pm 1.2 \pm 1.7$
UA1 (Ref. 16)	$83.5^{+1.1}_{-1.0} \pm 2.7$	$93.0 \pm 1.4 \pm 3.0$
UA1 + UA2 combined	80.9 ± 1.4	91.9 ± 1.8
Prediction with radiative corrections	80.2 ± 1.1	91.6 ± 0.9
Prediction without radiative corrections	75.9 ± 1.0	87.1 ± 0.7

W and Z decays. The partial decay width for gauge bosons to decay into massless fermions $f_1 \bar{f}_2$ is

$$\Gamma(W^+ \to e^+\nu_e) = \frac{G_F M_W^3}{6\sqrt{2}\pi} \simeq 230 \text{ MeV}$$

$$\Gamma(W^+ \to u_i \bar{d}_j) = \frac{C G_F M_W^3}{6\sqrt{2}\pi} |V_{ij}|^2 \simeq 717 |V_{ij}|^2 \text{ MeV} \qquad (25)$$

$$\Gamma(Z \to \psi_i \bar{\psi}_i) = \frac{C G_F M_Z^3}{6\sqrt{2}\pi} \left[V_i^2 + A_i^2 \right]$$

$$\simeq \begin{cases} 170 \text{ MeV}(\nu\bar{\nu}) & 85.4 \text{ MeV}(e^+e^-) \\ 305 \text{ MeV}(u\bar{u}) & 394 \text{ MeV}(d\bar{d}) \end{cases}$$

For leptons $C = 1$ while for quarks $C = 3\left[1 + \frac{\alpha_s(M_V)}{\pi}\right]$ where the 3 is due to color and the factor in parentheses is a QCD correction.[17] Corrections to Eq. (25) for massive fermions are given in Ref. 17. Here the numerical values assume $\sin^2\theta_W = 0.230$, $M_W = 80.9$ GeV, and $M_Z = 91.9$ GeV. Expressing the widths in terms of $G_F M_{W,Z}^3$ incorporates the bulk of the electroweak radiative corrections.[17] The remaining corrections introduce negligibly small effects.

For 3-fermion families the total widths are

$$\Gamma_Z \sim (2.58\text{–}2.55) \text{ GeV}$$

$$\Gamma_W \sim (2.52\text{–}2.12) \text{ GeV}, \qquad (26)$$

where the range corresponds to m_t varying from 45 GeV to very large values, and the other fermion masses have been neglected.

Deviations from the Standard Model. The W and Z masses and neutral-current data can be used to search for and set limits on deviations from the Standard Model. For example the relation in Eq. (5) between M_W and M_Z is modified if there are Higgs multiplets with weak isospin $> 1/2$ with significant vacuum expectation values. In order to calculate to higher orders in such theories one must define a set of four fundamental renormalized parameters. It is convenient to take these as α, G_F, M_Z, and M_W, since M_W and M_Z are directly measurable. Then $\sin^2\theta_W$ and ρ can be considered dependent parameters defined by

$$\sin^2\theta_W \equiv A_0^2/M_W^2(1 - \Delta r) \qquad (27)$$

and

$$\rho \equiv M_W^2/(M_Z^2\cos^2\theta_W) \qquad (28)$$

Provided that the new physics which yields $\rho \neq 1$ is a small perturbation which does not significantly affect the radiative corrections, ρ can be regarded as a phenomenological parameter which multiplies G_F in Eqs. (7)–(9) and (21). (Also the expression for M_Z in Eq. (5) is divided by $\sqrt{\rho}$; the M_W formula is unchanged.) The allowed regions in the $\rho - \sin^2\theta_W$ plane are shown in Fig. 1 and a global fit to all data yields[5]

$$\sin^2\theta_W = 0.229 \pm 0.0064$$

$$\rho = 0.998 \pm 0.0086, \qquad (29)$$

remarkably close to unity (justifying the neglect of $\rho - 1$ in the radiative corrections).

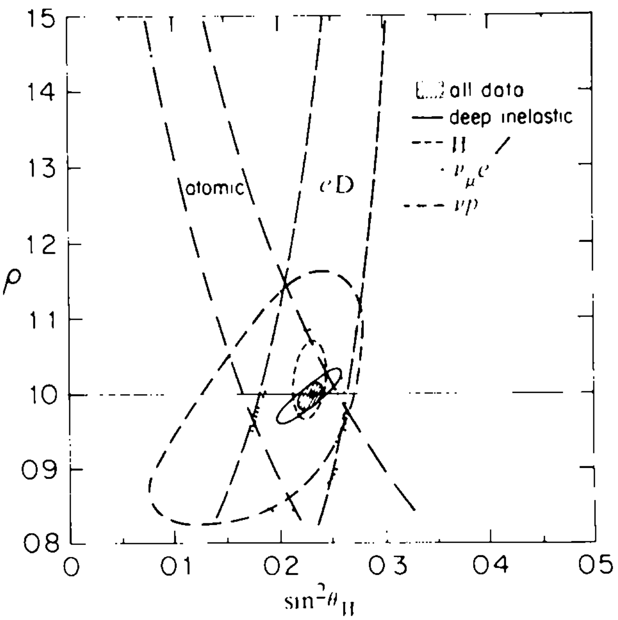

Fig. 1. The allowed regions in $\sin^2\theta_W - \rho$ at 90% CL for various reactions.

STANDARD MODEL OF ELECTROWEAK INTERACTIONS (Cont'd)

Most of the parameters relevant to ν-hadron, νe, e-hadron and e^+e^- processes are now determined uniquely and precisely from the data in "model independent" fits (i e fits which allow for an arbitrary electroweak gauge theory) The values for the parameters defined in Eq (7)--(9) are given in Table 4 along with the predictions of the Standard Model for $\sin^2\theta_W = 0.230$ The agreement is excellent The e^+e^- results are difficult to present in a model-independent way because Z-propagator effects are non-negligible at PETRA and PEP energies However, assuming e-μ-τ universality, the lepton asymmetries imply $g_A^e = -0.511 \pm 0.013$, in good agreement with the Standard Model prediction $-1/2$ The vector coupling is not well determined by existing e^+e^- data values of g_V^e from -0.3 to 0.3 are allowed

Table 4 Values of the model-independent neutral-current parameters, compared with the Standard Model prediction for $\sin^2\theta_W = 0.230$ There is a second $g_{V,A}^e$ solution, given approximately by $g_V^e \leftrightarrow g_A^e$, which is eliminated by e^+e^- data under the assumption that the neutral current is dominated by the exchange of a single Z θ_i, $i = L$ or R is defined as $\tan^{-1}[\epsilon_i(u)/\epsilon_i(d)]$

Quantity	Experimental Value	Standard Model Prediction	Correlation	
$\epsilon_L(u)$	0.339 ± 0.017	0.345		
$\epsilon_L(d)$	-0.429 ± 0.014	-0.427		
$\epsilon_R(u)$	-0.172 ± 0.014	-0.152		
$\epsilon_R(d)$	$-0.011^{+0.081}_{-0.057}$	0.076		
g_L^2	0.2996 ± 0.0044	0.301		
g_R^2	0.0298 ± 0.0038	0.029		
θ_L	2.47 ± 0.04	2.46		
θ_R	$4.65^{+0.48}_{-0.32}$	5.18		
g_A^e	-0.498 ± 0.027	-0.503		0.08
g_V^e	-0.044 ± 0.036	-0.045		
C_{1u}	-0.249 ± 0.071	0.191	0.98	0.88
C_{1d}	0.381 ± 0.064	0.340		0.88
$C_{2u} - \frac{1}{2}C_{2d}$	0.19 ± 0.37	-0.039		

* This section prepared April 1988 by P Langacker For additional discussion see P Langacker, "Standard Model of Electroweak Interactions," DESY 87-153 (1987)

** Constraints on V are discussed in the section on the Kobayashi-Maskawa mixing matrix

† α is dependent upon the energy scale of the process in which it is measured This value is appropriate for low energy At energies of order M_W the value 1/128 is applicable

‡ An alternative is to use the modified minimal subtraction ($\overline{MS}$) quantity $\sin^2\theta_W(\mu)$, where μ is conveniently chosen to be M_W for electroweak processes The two definitions are related by $\sin^2\theta_W(M_W) = C(m_t, M_H)\sin^2\theta_W$, where $C = 0.9907$ for $m_t = 45$ GeV, $M_H = 100$ GeV

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THE KOBAYASHI-MASKAWA MIXING MATRIX*

In the Standard Model with SU(2)×U(1) as the gauge group of electroweak interactions, both the quarks and leptons are assigned to be left-handed doublets and right-handed singlets. The quark mass eigenstates are not the same as the weak eigenstates, and the matrix connecting them has become known as the Kobayashi-Maskawa[1] (K-M) matrix, since an explicit parametrization in the six-quark case was first given by them in 1973. It generalizes the four-quark case, where the matrix is parametrized by a single angle, the Cabibbo angle.[2]

By convention, the three charge 2/3 quarks (u, c and t) are unmixed, and all the mixing is expressed in terms of a 3×3 unitary matrix V operating on the charge $-1/3$ quarks (d, s and b)

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \qquad (1)$$

The values of individual K-M matrix elements can in principle all be determined from weak decays of the relevant quarks, or, in some cases, from deep inelastic neutrino scattering. Using the constraints discussed below, together with unitarity, and assuming only three generations, the 90% confidence limits on the magnitude of the elements of the complete matrix are

$$\begin{pmatrix} 0.9748 \text{ to } 0.9761 & 0.217 \text{ to } 0.223 & 0.003 \text{ to } 0.010 \\ 0.217 \text{ to } 0.223 & 0.9733 \text{ to } 0.9754 & 0.030 \text{ to } 0.062 \\ 0.001 \text{ to } 0.023 & 0.029 \text{ to } 0.062 & 0.9980 \text{ to } 0.9995 \end{pmatrix} \qquad (2)$$

The ranges shown are for the individual matrix elements. The constraints of unitarity connect different elements, so choosing a specific value for one element restricts the range of the others.

There are several parametrizations of the K-M matrix. In view of the need for a "standard" parametrization in the literature, we advocate the form

$$V = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{13}} \\ -s_{12}c_{23}-c_{12}s_{23}s_{13}e^{i\delta_{13}} & c_{12}c_{23}-s_{12}s_{23}s_{13}e^{i\delta_{13}} & s_{23}c_{13} \\ s_{12}s_{23}-c_{12}c_{23}s_{13}e^{i\delta_{13}} & -c_{12}s_{23}-s_{12}c_{23}s_{13}e^{i\delta_{13}} & c_{23}c_{13} \end{pmatrix} \qquad (3)$$

in the notation of Harari and Leurer[3] for a form generalizable to an arbitrary number of "generations" and also proposed by Fritzsch and Plankl.[4] The choice of rotation angles follows that of Maiani[5] and the placement of the phase follows that of Wolfenstein.[6] The three-"generation" form was proposed earlier by Chau and Keung.[7] Here $c_{ij} = \cos\theta_{ij}$ and $s_{ij} = \sin\theta_{ij}$, with i and j being "generation" labels, $i,j = 1,2,3$. In the limit $\theta_{23} = \theta_{13} = 0$ the third generation decouples, and the situation reduces to the usual Cabibbo mixing of the first two generations with θ_{12} identified with the Cabibbo angle.[2] The real angles θ_{12}, θ_{23}, θ_{13} can all be made to lie in the first quadrant by an appropriate redefinition of quark field phases. Then all s_{ij} and c_{ij} are positive, and $|V_{us}| = s_{12}c_{13}$, $|V_{ub}| = s_{13}$ and $|V_{cb}| = s_{23}c_{13}$. As c_{13} deviates from unity only in the fifth decimal place (from experimental measurement of s_{13}), $|V_{us}| = s_{12}$, $|V_{ub}| = s_{13}$, and $|V_{cb}| = s_{23}$ to an excellent approximation. The phase δ_{13} lies in the range $0 \leq \delta_{13} < 2\pi$, with nonzero values generally breaking CP invariance for the weak interactions. This parametrization can be easily generalized to the n-generation case where there are $n(n-1)/2$ angles and $(n-1)(n-2)/2$ phases.[3,4] The range of matrix elements in Eq. (2) corresponds to 90% CL limits on the angles of $s_{12} = 0.217$–0.223, $s_{23} = 0.030$–0.062, and $s_{13} = 0.003$–0.010.

Kobayashi and Maskawa[1] originally chose a parametrization involving the four angles θ_1, θ_2, θ_3, δ:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} c_1 & -s_1c_3 & -s_1s_3 \\ s_1c_2 & c_1c_2c_3 - s_2s_3e^{i\delta} & c_1c_2s_3 + s_2c_3e^{i\delta} \\ s_1s_2 & c_1s_2c_3 + c_2s_3e^{i\delta} & c_1s_2s_3 - c_2c_3e^{i\delta} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}, \qquad (4)$$

where $c_i = \cos\theta_i$ and $s_i = \sin\theta_i$ for $i = 1,2,3$. In the limit $\theta_2 = \theta_3 = 0$, this reduces to the usual Cabibbo mixing with θ_1 identified (up to a sign) with the Cabibbo angle.[2] Slightly different forms of the Kobayashi-Maskawa parametrization are found in the literature. The K-M matrix used in the 1982 Review of Particle Properties is obtained by letting $s_1 \to -s_1$ and $\delta \to \delta + \pi$ in the matrix given above. An alternative[8] is to change Eq. (4) by $s_1 \to -s_1$ but leave δ unchanged. With this change in s_1, the angle θ_1 becomes the usual Cabibbo angle, with the "correct" sign (i.e. $d' = d\cos\theta_1 + s\sin\theta_1$) in the limit $\theta_2 = \theta_3 = 0$. The angles θ_1, θ_2, θ_3 can, as before, all be taken to lie in the first quadrant by adjusting quark field phases. Since all these parametrizations are referred to as "the" Kobayashi-Maskawa form, some care about which one is being used is needed when the quadrant in which δ lies is under discussion.

Other parametrizations, mentioned above, are due to Maiani,[5] to Chau and Keung,[7] and to Wolfenstein.[6] The latter emphasizes the relative sizes of the matrix elements by expressing them in powers of the Cabibbo angle. Still other parametrizations[9] have come into the literature in connection with attempts to define "maximal CP violation." No physics can depend on which of the above parametrizations (or any other) is used as long as a single one is used consistently and care is taken to be sure that no other choice of phases is in conflict.

Our present knowledge of the matrix elements comes from the following sources:

(1) Nuclear beta decay, when compared to muon decay, gives[10,11]

$$|V_{ud}| = 0.9747 \pm 0.0011 \qquad (5)$$

This includes refinements over the past few years in which leading log radiative corrections have been summed using the renormalization group and structure-dependent $O(\alpha)$ terms analyzed and estimated[10] (thereby lowering the value of $|V_{ud}|$) and, more importantly, the order $Z\alpha^2$ Coulomb corrections have been revised[11] to bring the ft-values from low- and high-Z Fermi transitions into better agreement (thereby raising the value of $|V_{ud}|$).

(2) Analysis of K_{e3} decays yields[12]

$$|V_{us}| = 0.2196 \pm 0.0023 \qquad (6)$$

The isospin violation between K^+_{e3} and K^0_{e3} decays has been taken into account, bringing the values of $|V_{us}|$ extracted from these two decays into agreement at the 1% level of accuracy. The analysis of hyperon decay data has larger theoretical uncertainties because of first-order SU(3) symmetry-breaking effects in the axial-vector couplings, but due account of symmetry breaking gives a consistent value[13] of $0.220 \pm 0.001 \pm 0.003$. We average these two results to obtain

$$|V_{us}| = 0.2197 \pm 0.0019 \qquad (7)$$

(3) The magnitude of $|V_{cd}|$ may be deduced from neutrino and antineutrino production of charm off valence d quarks. When the dimuon production cross sections of the CDHS group[14] are supplemented by more recent measurements of the semileptonic branching fractions and the production cross sections in neutrino reactions of various charmed hadron species, the value[15]

$$|V_{cd}| = 0.21 \pm 0.03 \qquad (8)$$

is extracted.

(4) Values of $|V_{cs}|$ from neutrino production of charm are dependent on assumptions about the strange-quark density in the

THE KOBAYASHI-MASKAWA MIXING MATRIX (Cont'd)

parton sea The most conservative assumption that the strange-quark sea does not exceed the value corresponding to an SU(3) symmetric sea leads to a lower bound [14] $|V_{cs}| > 0.59$ It is more advantageous to proceed analogously to the method used for extracting $|V_{us}|$ from K_{e3} decay, namely we compare the experimental value for the width of D_{e3} decay with the expression[16] that follows from the standard weak interaction amplitude

$$\Gamma(D \to \bar{K}e^+\nu_e) = |f_+^D(0)|^2 |V_{cs}|^2 (1.54 \times 10^{11}\ \mathrm{sec}^{-1}) \quad (9)$$

Here $f_+^D((p_D - p_K)^2)$ is the form factor for $D_{\ell 3}$ decay which is the analogue of $f_+((p_K - p_\pi)^2)$ for $K_{\ell 3}$ decay its variation has been taken into account with the parametrization $f_+^D(t)/f_+^D(0) = M^2/(M^2 - t)$ where $M = 2.1$ GeV the mass of the D_s^*, a form and mass consistent with Mark-III measurements[17] Combining data on branching ratios for $D_{\ell 3}$ decays[17,18] with accurate values[19] for τ_{D^+} and τ_{D^0} gives the value $(0.78 \pm 0.11) \times 10^{11}\ \mathrm{sec}^{-1}$ for $\Gamma(D \to Ke^+\nu_e)$ Therefore

$$|f_+^D(0)|^2 |V_{cs}|^2 = 0.51 \pm 0.07 \quad (10)$$

With sufficient confidence in a theoretical calculation of $|f_+^D(0)|$, a value of $|V_{cs}|$ follows[20,21] but even with the very conservative assumption that $|f_+(0)| < 1$ it follows that

$$|V_{cs}| > 0.66 \quad (11)$$

The constraint of unitarity when there are only three generations gives a much tighter bound (see below)

(5) The ratio $|V_{ub}/V_{cb}|$ can be obtained from the semileptonic decay of B mesons by fitting to the lepton energy spectrum as a sum of contributions involving $b \to u$ and $b \to c$ The relative overall phase space factor between the two processes is calculated from the usual four-fermion interaction with one massive fermion (c quark or u quark) in the final state The value of this factor depends on the quark masses but is roughly one-half The lack of observation of the higher momentum leptons characteristic of $b \to u \ell \bar{\nu}_\ell$ as compared to $b \to c \ell \bar{\nu}_\ell$ has resulted thus far only in upper limits which depend on the lepton energy spectrum assumed for each decay[21,22,23] Using the lepton momentum region near the end-point for $b \to c \ell \bar{\nu}_\ell$ and taking the calculation[23] of the lepton spectrum that gives the least restrictive limit results in[24]

$$|V_{ub}/V_{cb}| < 0.20 \quad (12)$$

A lower bound on $|V_{ub}|$ can be established from the observation[25] of exclusive baryonic B decays into $p\bar{p}\pi$ and $p\bar{p}\pi\pi$ which involve $b \to u + d\bar{u}$ at the quark level A chain of assumptions on the relative phase space, the fraction of the quark-level process which hadronizes into baryonic channels and the fraction of those that occur in the observed modes is required No other channels that reflect $b \to u$ at the quark level have been observed[26] Given the branching fractions of the two observed modes a reasonable lower limit is[25]

$$|V_{ub}/V_{cb}| > 0.07 \quad (13)$$

(6) The magnitude of V_{cb} itself can be determined if the measured semileptonic bottom hadron partial width is assumed to be that of a b quark decaying through the usual $V - A$ interaction

$$\Gamma(b \to c \ell \bar{\nu}_\ell) = \frac{\mathrm{BF}(b \to c \ell \bar{\nu}_\ell)}{\tau_b} = \frac{G_F^2 m_b^5}{192\pi^3} F(m_c/m_b) |V_{cb}|^2 \quad (14)$$

where τ_b is the b lifetime and $F(m_c/m_b)$ is the phase space factor chosen as 0.45 Using an average semileptonic branching fraction BF measured in the continuum of[27] 12.1 ± 0.8% (which from Eq (12) is BF($b \to c \ell \bar{\nu}_\ell$) to within 10%), a world-average bottom hadron lifetime[28] of $(1.18 \pm 0.14) \times 10^{-12}$ sec, and m_b between 4.8 and 5.2 GeV, we get

$$|V_{cb}| = 0.046 \pm 0.010 \quad (15)$$

Most of the error quoted in Eq (15) is not from the experimental uncertainty in the value of the b lifetime but in the theoretical uncertainties in choosing a value of m_b and in the use of the quark model to represent inclusively semileptonic decays which at least for the B meson are dominated by a few exclusive channels We have made the error bars larger than they are sometimes stated to reflect these uncertainties They include the central values obtained for $|V_{cb}|$ by using a model for the exclusive final states in semileptonic B decay and extracting $|V_{cb}|$ from the absolute width for one or more of them[21,23,29]

The results for three generations of quarks, from Eqs (5), (7), (8), (11), (12) (13), and (15) plus unitarity are summarized in the matrix in Eq (2) The ranges given there are different from those given in Eqs (5) (15) (because of the inclusion of unitarity) but are consistent with the one-standard-deviation errors on the input matrix elements

The data do not preclude there being more than three generations Moreover, the entries deduced from unitarity might be altered when the K-M matrix is expanded to accommodate more generations Conversely, the known entries restrict the possible values of additional elements if the matrix is expanded to account for additional generations For example unitarity and the known elements of the first row require that any additional element in the first row have a magnitude $|V_{ub'}| < 0.07$ When there are more than three generations, the allowed ranges (at 90% CL) of the matrix elements connecting the first three generations are

$$\begin{pmatrix} 0.9729\ \text{to}\ 0.9760 & 0.217\ \text{to}\ 0.223 & 0.003\ \text{to}\ 0.010 & \cdots \\ 0.162\ \text{to}\ 0.230 & 0.65\ \text{to}\ 0.98 & 0.030\ \text{to}\ 0.062 & \cdots \\ 0\ \text{to}\ 0.15 & 0\ \text{to}\ 0.71 & 0\ \text{to}\ 0.9995 & \cdots \\ \vdots & \vdots & \vdots & \end{pmatrix} \quad (16)$$

where we have used unitarity (for the expanded matrix) and Eqs (5), (7), (8), (11), (12) (13), and (15)

Further information on the angles requires theoretical assumptions For example, $B_d - \bar{B}_d$ mixing, if it originates from short-distance contributions to ΔM_B dominated by box diagrams involving virtual t quarks, gives information on $V_{tb} V_{td}^*$ once hadronic matrix elements and the t quark mass are known[30] A similar comment holds for $V_{tb} V_{ts}^*$ and $B_s - \bar{B}_s$ mixing

CP-violating processes will involve the phase in the K-M matrix, assuming that the observed CP violation is solely related to a nonzero value of this phase This allows additional constraints to be brought to bear More specifically, a necessary and sufficient condition for CP violation with three generations can be formulated in a parametrization-independent manner in terms of the determinant of the commutator of the mass matrices for the charge $2e/3$ and charge $-e/3$ quarks[31] CP-violating rates or differences of rates all are proportional to a single quantity which is the product of factors $s_{12}s_{13}s_{23}c_{12}c_{13}^2c_{23}s_{\delta_{13}}$ in the explicit parametrization of Refs 3 and 4, and is $s_1^2 s_2 s_3 c_1 c_2 c_3 s_\delta$ in that of Ref 1 While hadronic matrix elements whose values are imprecisely known now enter, the constraints from CP violation in the neutral kaon system are tight enough that there may be no solution at all for certain quark masses, values of the phase, etc[30]

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* Prepared April 1988 by F J Gilman, K Kleinknecht, and B Renk

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QUARK MODEL*

A QUANTUM NUMBERS

Each quark has spin 1/2 The additive quantum numbers (other than baryon number = 1/3) of the known (and presumed) quarks are shown in the table

Quantum number	Quark type (flavor)					
	d	u	s	c	b	t
Q — electric charge	$-\frac{1}{3}$	$+\frac{2}{3}$	$-\frac{1}{3}$	$+\frac{2}{3}$	$-\frac{1}{3}$	$+\frac{2}{3}$
I_z isospin z-component	$-\frac{1}{2}$	$+\frac{1}{2}$	0	0	0	0
S strangeness	0	0	−1	0	0	0
C — charm	0	0	0	+1	0	0
B — bottomness	0	0	0	0	−1	0
T — topness	0	0	0	0	0	+1

With these conventions any flavor carried by a charged meson has the same sign as the charge e g, the strangeness S of the K^+ is +1 and the bottomness B of the B^+ is +1

B. MESONS

Nearly all known mesons can be understood as bound states of a quark q and an antiquark $\overline{q}'$ (the flavors of q and q' may be different) If the orbital angular momentum of the $q\overline{q}'$ state is L then the parity $P = (-1)^{L+1}$ A state $q\overline{q}$ of a quark and its own antiquark is also an eigenstate of charge conjugation with $C = (-1)^{L+S}$ where the spin S = 0 or 1 The L = 0 states are the pseudoscalars $J^P = 0^-$, and the vectors, $J^P = 1^-$ See the table on the next page States in the "normal" spin-parity series, $P = (-1)^J$, must, according to the above, have S = 1 and hence CP = +1 Thus mesons with normal spin-parity and CP = −1 are forbidden in the $q\overline{q}'$ quark model The $J^{PC} = 0^{--}$ state is forbidden as well Mesons with such J^{PC} could exist, but would lie outside the $q\overline{q}'$ model

States with the same J^P and additive quantum numbers can mix (if they are eigenstates of charge conjugation, they must also have the same value of C) Thus the physical $J^P = 1^+$, strangeness S = 1 states, $K_1(1270)$ and $K_1(1400)$, are mixtures of the pure quark-model states K_{1A} and K_{1B} The $\psi(3770)$ is a mixture of $^3S_1$ and $^3D_1$ The η and η' are mixtures of the SU(3) octet and singlet states

For the pseudoscalar mesons, the Gell-Mann-Okubo formula is

$$m_\eta^2 = \frac{1}{3}(4m_K^2 - m_\pi^2),$$

QUARK MODEL (Cont'd)

Standard quark-model assignments for some of the known mesons. Some assignments, especially for 0^{++}, are controversial. Note that only the states in the $u\bar{u}$, $d\bar{d}$, $s\bar{s}$, $c\bar{c}$, and $b\bar{b}$ columns and the neutral states in the $I = 1$ column are eigenstates of charge conjugation C.

$^{2S+1}L_J$	J^{PC}	$u\bar{d}$, $u\bar{u}$, $d\bar{d}$ $I = 1$	$u\bar{u}$, $d\bar{d}$, $s\bar{s}$ $I = 0$	$c\bar{c}$ $I = 0$	$b\bar{b}$ $I = 0$	$\bar{s}u$, $\bar{s}d$ $I = 1/2$	$c\bar{u}$, $c\bar{d}$ $I = 1/2$	$c\bar{s}$ $I = 0$	$\bar{b}u$, $\bar{b}d$ $I = 1/2$
$^1S_0$	0^{-+}	π	η, η'	η_c		K	D	D_s	B
$^3S_1$	1	ρ	ϕ, ω	J/ψ	Υ	$K^*(892)$	$D^*(2010)$		
$^1P_1$	1^{+-}	$b_1(1235)$	$h_1(1170)$			K_{1B}			
$^3P_0$	0^{++}	$a_0(980)$	$f_0(975)$ $f_0(1400)$	$\chi_{c0}(1P)$	$\chi_{b0}(1P)$	$K_0^*(1430)$			
$^3P_1$	1^{++}	$a_1(1260)$	$f_1(1285)$ $f_1(1420)$	$\chi_{c1}(1P)$	$\chi_{b1}(1P)$	K_{1A}			
$^3P_2$	2^{++}	$a_2(1320)$	$f_2'(1525)$ $f_2(1270)$	$\chi_{c2}(1P)$	$\chi_{b2}(1P)$	$K_2^*(1430)$			
$^1D_2$	2^{-+}	$\pi_2(1670)$							
$^3D_1$	1^{--}			$\psi(3770)$					
$^3D_2$	2					$K_2(1770)$			
$^3D_3$	3^{--}	$\rho_3(1690)$	$\omega_3(1670)$			$K_3^*(1780)$			

assuming no octet-singlet mixing. However, the octet η_8 and singlet η_1 mix because of SU(3) breaking. The physical states η and η' are given by

$$\eta = \eta_8 \cos\theta_P - \eta_1 \sin\theta_P$$

$$\eta' = \eta_8 \sin\theta_P + \eta_1 \cos\theta_P$$

These combinations diagonalize the mass-squared matrix

$$M^2 = \begin{pmatrix} M_{11}^2 & M_{18}^2 \\ M_{18}^2 & M_{88}^2 \end{pmatrix}$$

where $M_{88}^2 = \frac{1}{3}(4m_K^2 - m_\pi^2)$. It follows that

$$\tan^2\theta_P = \frac{M_{88}^2 - m_\eta^2}{m_{\eta'}^2 - M_{88}^2}$$

The sign of θ_P is meaningful in the quark model. If

$$\eta_1 = (u\bar{u} + d\bar{d} + s\bar{s})/\sqrt{3}$$

$$\eta_8 = (u\bar{u} + d\bar{d} - 2s\bar{s})/\sqrt{6}\,,$$

then the matrix element M_{18}^2, which is due mostly to the strange quark mass, is negative. From the relation

$$\tan\theta_P = \frac{M_{88}^2 - m_\eta^2}{M_{18}^2}\,,$$

we find $\theta_P < 0$. However we note that caution is suggested in the use of the $\eta - \eta'$ mixing angle formulas, as they are extremely sensitive to SU(3) breaking. If we allow $M_{88}^2 = \frac{1}{3}(4m_K^2 - m_\pi^2)(1 - \Delta)$, the mixing angle is determined by

$$\tan^2\theta_P = 0.0319(1 + 17\Delta)$$

$$\theta_P = -10.1°(1 + 8.5\Delta)$$

to first order in Δ. A small breaking of the Gell-Mann-Okubo relation can produce a major modification of θ_P.

For the vector mesons we replace $\pi \to \rho$, $K \to K^*$, $\eta \to \phi$, and $\eta' \to \omega$, so

$$\phi = \omega_8 \cos\theta_V - \omega_1 \sin\theta_V$$

$$\omega = \omega_8 \sin\theta_V + \omega_1 \cos\theta_V$$

For "ideal mixing," $\phi = s\bar{s}$, $\tan\theta_V = 1/\sqrt{2}$, so $\theta_V \approx 35.3°$. Experimentally, θ_V is near 35°, the sign being determined by a formula analogous to that for $\tan\theta_P$. Following this procedure we find the mixing angles below.

Singlet-octet mixing for the pseudoscalar, vector, and tensor mesons. The sign conventions are as above. The value of θ_{quad} is obtained from the equations above, and θ_{lin} is obtained by replacing $m^2 \to m$ throughout. Of the two isosinglets, the mostly octet one is listed first.

J^{PC}	Nonet Members	θ_{quad}	θ_{lin}
0^{-+}	π, K, η, η'	−10°	−23°
1^{--}	ρ, $K^*(892)$, ϕ, ω	39°	36°
2^{++}	$a_2(1320)$, $K_2^*(1430)$, $f_2'(1525)$, $f_2(1270)$	28°	26°
3^{--}	$\rho_3(1690)$, $K_3^*(1780)$, $X(1850)$, $\omega_3(1670)$	29°	28°

QUARK MODEL (Cont'd)

In the quark model, the coupling of neutral mesons to two photons is proportional to $\sum_i Q_i^2$, where Q_i is the charge of the i-th quark. This provides an alternative characterization of mixing. For example, defining

$$\mathrm{Amp}[P \to \gamma(k_1)\gamma(k_2)] = M\epsilon^{\mu\nu\alpha\beta}\epsilon^*_{1\mu}k_{1\nu}\epsilon^*_{2\alpha}k_{2\beta}\,,$$

where $\epsilon_{i\lambda}$ is the λ component of the polarization vector of the i^{th} photon, one finds

$$\frac{M(\eta \to \gamma\gamma)}{M(\pi 0 \to \gamma\gamma)} = \frac{1}{\sqrt{3}}(\cos\theta_P - 2\sqrt{2}\sin\theta_P) = \frac{1.84}{\sqrt{3}} \pm 0.1$$

$$\frac{M(\eta' \to \gamma\gamma)}{M(\pi 0 \to \gamma\gamma)} = 2\sqrt{2/3}\left[\cos\theta_P + \frac{\sin\theta_P}{2\sqrt{2}}\right] = (0.77 \pm 0.03)2\sqrt{2/3}\,.$$

These data favor $\theta_P \approx -20°$, which is compatible with the quadratic mass mixing formula with $\approx 12\%$ SU(3) breaking in M^2_{88}.

C. BARYONS

All the established baryons are apparently 3-quark (qqq) states, and each such state is an SU(3) color singlet, a completely antisymmetric state of the three possible colors. Since the quarks are fermions, the state function for any baryon must be antisymmetric under interchange of any two of its quarks. Thus the state is *symmetric* under interchange of the quantum labels other than color:

$$|qqq\rangle_A = |\mathrm{color}\rangle_A \times |\mathrm{space,\ spin,\ flavor}\rangle_S\,,$$

where the subscripts S and A indicate symmetry or antisymmetry under interchange of any two of the quarks. Note the contrast with the state function for the three nucleons in ^{3}H or ^{3}He:

$$|NNN\rangle_A = |\mathrm{space,\ spin,\ isospin}\rangle_A\,.$$

This difference has major implications for internal structure, magnetic moments, etc. (For a nice discussion, see Ref. 1.)

Few of the baryons containing c or heavier quarks have yet been discovered, so we restrict further attention to baryons made up of just d, u, and s quarks. The three flavors imply a flavor SU(3), which requires that baryons made of these quarks belong to the multiplets on the right side of

$$\mathbf{3} \otimes \mathbf{3} \otimes \mathbf{3} = \mathbf{10}_S \oplus \mathbf{8}_M \oplus \mathbf{8}_M \oplus \mathbf{1}_A$$

(see the section on SU(n) Multiplets and Young Diagrams). Here the subscripts indicate symmetric, mixed-symmetry, or antisymmetric states under interchange of any two quarks. The figure shows particle assignments in these multiplets. States Λ_8 and Λ_1 that have the same spin and parity can mix; an example is the mainly octet D_{03} $\Lambda(1690)$ and mainly singlet D_{03} $\Lambda(1520)$. In the ground state multiplet, the SU(3) flavor singlet Λ is forbidden by Fermi statistics. The mixing formalism is the same as for $\eta - \eta'$ or $\phi - \omega$ (see above), except that for baryons the mass M instead of M^2 is used. The section SU(3) Isoscalar Factors shows how relative decay rates in, say, $\mathbf{10} \to \mathbf{8} \otimes \mathbf{8}$ decays may be calculated. A summary of results of fits to the observed baryon masses and decay rates for the best-known SU(3) multiplets is given in Appendix II of our 1982 edition.[2]

Flavor and spin may be combined in a flavor-spin SU(6) in which the six basic states are $d\uparrow$, $d\downarrow$, $\cdots$, $s\downarrow$ ($\uparrow$, $\downarrow$ = spin up, down). Then the baryons belong to the multiplets on the right side of

$$\mathbf{6} \otimes \mathbf{6} \otimes \mathbf{6} = \mathbf{56}_S \oplus \mathbf{70}_M \oplus \mathbf{70}_M \oplus \mathbf{20}_A\,.$$

These SU(6) multiplets decompose into flavor SU(3) multiplets as follows:

$$\mathbf{56} = {}^4\mathbf{10} \oplus {}^2\mathbf{8}$$

$$\mathbf{70} = {}^2\mathbf{10} \oplus {}^4\mathbf{8} \oplus {}^2\mathbf{8} \oplus {}^2\mathbf{1}$$

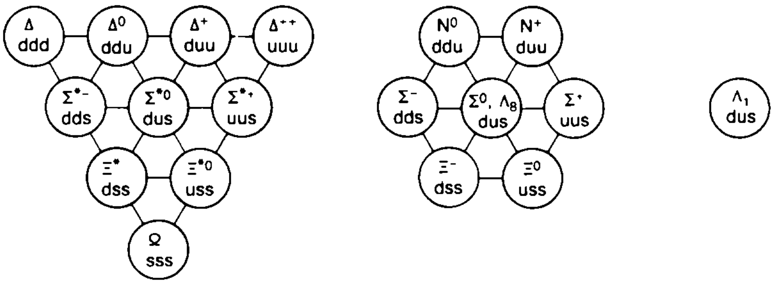
$$\mathbf{20} = {}^2\mathbf{8} \oplus {}^4\mathbf{1}\,,$$

where the superscript $(2S+1)$ gives the net spin S of the quarks for each particle in the SU(3) multiplet. The $J^P = 1/2^+$ octet containing the nucleon and the $J^P = 3/2^+$ decuplet containing the $\Delta(1232)$ together make up the "ground-state" 56-plet in which the orbital angular momenta between the quark pairs are zero (so that the spatial part of the state function is trivially symmetric). The **70** and **20** require some excitation of the spatial part of the state function in order to make the overall state function symmetric. States with nonzero orbital angular momenta are classified in SU(6)⊗O(3) supermultiplets. Physical baryons with the same quantum numbers do not belong to a single supermultiplet, since SU(6) is broken by spin-dependent interactions, differences in quark masses, etc.; nevertheless, the SU(6)⊗O(3) basis provides a suitable framework for describing baryon state functions.

It is convenient to classify the baryons into bands that have the same number N of quanta of excitation. Each band consists of a number of supermultiplets, specified by (D, L_N^P), where D is the dimensionality of the SU(6) representation, L is the total quark orbital angular momentum, and P is the total parity. Supermultiplets contained in bands up to $N = 12$ are given in Ref. 3. The $N = 0$ band, which contains the nucleon and $\Delta(1232)$, consists only of the $(56, 0_0^+)$ supermultiplet. The $N = 1$ band consists only of the $(70, 1_1^-)$ multiplet and contains the negative-parity baryons with masses below about 1.9 GeV. The $N = 2$ band contains five supermultiplets: $(56, 0_2^+)$, $(70, 0_2^+)$, $(56, 2_2^+)$, $(70, 2_2^+)$, and $(20, 1_2^+)$. Baryons belonging to the $(20, 1_2^+)$ supermultiplet are not ever likely to be observed, since a coupling from the ground-state baryons requires a two-quark excitation. Selection rules are similarly responsible for the fact that many other baryon resonances have not been observed.[4]

In the table below, quark-model assignments are given for many of the established baryons whose SU(6)⊗O(3) compositions are relatively unmixed. Note that the unestablished resonances $N(1540)P_{13}$, $\Delta(1550)P_{31}$, $\Sigma(1480)$, $\Sigma(1560)$, $\Sigma(1580)$, $\Sigma(1770)$, and $\Xi(1620)$ in our Baryon Full Listings are too low in mass to be accommodated in most modern quark models.[4,5]

Quark models for baryons are extensively reviewed in Ref. 6.



QUARK MODEL (Cont'd)

D. DYNAMICS

Many specific quark models exist, but most contain basically the same set of dynamical ingredients. These include

i) A confining interaction which is generally spin independent is used.

ii) A spin-dependent interaction is added, modeled after the effects of gluon exchange in QCD. For example, in the S-wave states there is a spin-spin hyperfine interaction of the form

$$H_{HF} = -\alpha_S M \sum_{i>j} (\vec{\sigma}\lambda^A)_i (\vec{\sigma}\lambda^A)_j$$

where M is a constant with units of energy, λ^A ($A = 1, \ldots, 8$) is the set of SU(3) unitary spin matrices defined in the "SU(3) Isoscalar Factors and Representation Matrices" section, and the sum runs over constituent quarks or antiquarks. Spin-orbit interactions, although allowed, seem to be small.

iii) The strange quark mass is taken to be somewhat larger than the up and down quark masses in order to split the SU(3) multiplets.

iv) In the case of isoscalar mesons, an interaction is needed for mixing $q\bar{q}$ configurations of different flavors (e.g., $u\bar{u} \longleftrightarrow d\bar{d}, s\bar{s}$) in a manner which is generally chosen to be flavor independent.

These four ingredients provide the basic mechanisms which determine the hadron spectrum.

* Revised April 1988 by J. Donoghue and D.M. Manley.

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Quark-model assignments for some of the known baryons in terms of a flavor-spin SU(6) basis. Only the dominant representation is listed. Assignments for some states, especially for Λ(1810), Λ(2350), Ξ(1820), and Ξ(2030), are merely educated guesses.

J^P	(D, L_N^P)	S	Octet members				Singlets
$1/2^+$	$(56,0_0^+)$	1/2	N(939)	Λ(1116)	Σ(1193)	Ξ(1318)	
$1/2^+$	$(56,0_2^+)$	1/2	N(1440)	Λ(1600)	Σ(1660)	Ξ(?)	
$1/2^-$	$(70,1_1^-)$	1/2	N(1535)	Λ(1670)	Σ(1620)	Ξ(?)	Λ(1405)
$3/2^-$	$(70,1_1^-)$	1/2	N(1520)	Λ(1690)	Σ(1670)	Ξ(1820)	Λ(1520)
$1/2^-$	$(70,1_1^-)$	3/2	N(1650)	Λ(1800)	Σ(1750)	Ξ(?)	
$3/2^-$	$(70,1_1^-)$	3/2	N(1700)	Λ(?)	Σ(?)	Ξ(?)	
$5/2^-$	$(70,1_1^-)$	3/2	N(1675)	Λ(1830)	Σ(1775)	Ξ(?)	
$1/2^+$	$(70,0_2^+)$	1/2	N(1710)	Λ(1810)	Σ(1880)	Ξ(?)	Λ(?)
$3/2^+$	$(56,2_2^+)$	1/2	N(1720)	Λ(1890)	Σ(?)	Ξ(?)	
$5/2^+$	$(56,2_2^+)$	1/2	N(1680)	Λ(1820)	Σ(1915)	Ξ(2030)	
$7/2^-$	$(70,3_3^-)$	1/2	N(2190)	Λ(?)	Σ(?)	Ξ(?)	Λ(2100)
$9/2^-$	$(70,3_3^-)$	3/2	N(2250)	Λ(?)	Σ(?)	Ξ(?)	
$9/2^+$	$(56,4_4^+)$	1/2	N(2220)	Λ(2350)	Σ(?)	Ξ(?)	
			Decuplet members				
$3/2^+$	$(56,0_0^+)$	3/2	Δ(1232)	Σ(1385)	Ξ(1530)	Ω(1672)	
$1/2^-$	$(70,1_1^-)$	1/2	Δ(1620)	Σ(?)	Ξ(?)	Ω(?)	
$3/2^-$	$(70,1_1^-)$	1/2	Δ(1700)	Σ(?)	Ξ(?)	Ω(?)	
$5/2^+$	$(56,2_2^+)$	3/2	Δ(1905)	Σ(?)	Ξ(?)	Ω(?)	
$7/2^+$	$(56,2_2^+)$	3/2	Δ(1950)	Σ(2030)	Ξ(?)	Ω(?)	
$11/2^+$	$(56,4_4^+)$	3/2	Δ(2420)	Σ(?)	Ξ(?)	Ω(?)	

MONTE CARLO PARTICLE NUMBERING SCHEME*

Most particle physics Monte Carlo and analysis systems use a numbering scheme to represent particles. The lack of standardization of such schemes inhibits interfacing different programs. The following table proposes a standard numbering scheme. Some of the properties of this scheme are:

1. Quarks and leptons are ordered by family, and within the family by isospin. This puts the u and d in the opposite order than is often used in other numbering schemes. In our scheme we call the highest numbered quark the heaviest quark.
2. For multiple quark systems (mesons, baryons, and diquarks), the rightmost digit is generally $L = 2J + 1$. (The K_S^0 and K_L^0 are exceptions.)
3. Mesons are represented by the form NML and baryons by $NMKL$, where N, M, and K are quark numbers.
4. For these systems the heaviest quark is usually on the left and the quarks are in decreasing mass order from left to right. One exception to this convention is the K_L^0-K_S^0 pair. A second exception is for the Λ's for which we invert the up and down quarks to distinguish the Λ from the Σ^0.
5. The other exception to this mass order rule is for some N's and Δ's. For N's the u and d quark are reversed for spins 3/2 and 7/2. For Δ's they are reversed for spins 1/2 and 5/2. The quarks are in the normal decreasing order when $I + J$ is odd.
6. Mesons, and only mesons, have the third digit nonzero and the fourth digit zero. (We designate the rightmost digit as the first digit.)
7. Only baryons and diquarks have the fourth digit nonzero.
8. Only quarks and diquarks have the second digit equal to zero.
9. Particles have positive numbers; each antiparticle has the negative of its counterpart.
10. The particle-antiparticle convention is the one used by the Particle Data Group, so that the K^+ and B^+ are particles.
11. The above rules imply that for mesons (as opposed to antimesons) when the number of the leftmost (heaviest) quark is even, it is a quark, and when the number of the leftmost quark is odd, it is an antiquark.
12. The gluon has two numbers. Its official number is 21 to place it with the other gauge bosons. Its number is also 9 so that a glueball is specified as 99.
13. The fifth digit is used to differentiate different particles with the same quark content and spin.
14. Although isospin is not manifest in this scheme, there is some isospin content. Mesons with $11J$ are isospin 1 and those with $22J$ are isospin 0. For nonstrange baryons, if the quarks are in the normal decreasing order, then $I + J$ is odd; otherwise $I + J$ is even. If a strange baryon does not have the normal decreasing quark order, it has $I = 0$.

More details about the motivation behind, and properties of, this scheme can be found in Ref. 1. Although this scheme has the advantage that a particle's number has considerable physics content, it has the disadvantage that it is not compact. An algorithm that translates this scheme into a more compact scheme is needed for its implementation. Contact the Berkeley Particle Data Group for further information on such an algorithm.

A list of particle numbers follows.

* Written April 1988 by G.R. Lynch and T.G. Trippe.

1. T.G. Trippe and G.R. Lynch, "Particle I.D. Numbers, Decay Tables, and Other Possible Contributions of the Particle Data Group to Monte Carlo Standards," LBL-24287, in *Proceedings of the Workshop on Detector Simulation for the SSC* (August 1987).

ELEMENTARY PARTICLES

Quarks

d	1
u	2
s	3
c	4
b	5
t	6

Leptons

ν_e	12
ν_μ	14
ν_τ	16
e	11
μ	13
τ	15

Gauge and Higgs Bosons

γ	22
W^+	24
Z^0	23
g	21 and 9
H_1^0	25
H_2^0	35
H_3^0	36
H^+	37

DIQUARKS

dd_1	1103
ud_0	2101
ud_1	2103
uu_1	2203
sd_0	3101
sd_1	3103
su_0	3201
su_1	3203

STABLE MESONS

π^+	211
π^0	111
η	221
K^+	321
K^0	311
K_S^0	310
K_L^0	130
D^+	411
D^0	421
D_s^+	431
D_s^{*+}	433
B^+	521
B^0	511

OTHER MESONS

$\rho(770)^+$	213	
$\rho(770)^0$	113	
$\omega(783)$	223	
$\eta'(958)$	331	
$f_0(975)$	10221	
$a_0(980)$	10211	10111
$\phi(1020)$	333	
$h_1(1170)$	10223	
$b_1(1235)$	10213	10113
$a_1(1260)$	20213	20113
$f_2(1270)$	225	
$\eta(1280)$	20221	
$f_1(1285)$	20223	
$\pi(1300)$	20211	20111
$a_2(1320)$	215	115
$f_0(1400)$	30221	
$f_1(1420)$	30223	
$\eta(1430)$	40221	
$f'_2(1525)$	335	
$f_1(1530)$	40223	
$f_0(1590)$	50221	
$\omega_3(1670)$	227	
$\pi_2(1670)$	10215	10115
$\phi(1680)$	10333	
$\rho_3(1690)$	217	117
$\rho(1700)$	30213	30113
$f_2(1720)$	10225	
$f_2(2010)$	20225	
$f_4(2050)$	229	
$f_2(2300)$	30225	
$f_2(2340)$	40225	

MONTE CARLO PARTICLE NUMBERING SCHEME (Cont'd)

OTHER MESONS (Cont'd)

$\eta_c(1S)$	441	
$J/\psi(1S)$	443	
$\chi_{c0}(1P)$	10441	
$\chi_{c1}(1P)$	10443	
$\chi_{c2}(1P)$	445	
$\psi(2S)$	20443	
$\psi(3770)$	30443	
$\psi(4040)$	40443	
$\psi(4160)$	50443	
$\psi(4415)$	60443	
$\Upsilon(1S)$	553	
$\chi_{b0}(1P)$	551	
$\chi_{b1}(1P)$	10553	
$\chi_{b2}(1P)$	555	
$\Upsilon(2S)$	20553	
$\chi_{b0}(2P)$	10551	
$\chi_{b1}(2P)$	70553	
$\chi_{b2}(2P)$	10555	
$\Upsilon(3S)$	30553	
$\Upsilon(4S)$	40553	
$\Upsilon(10860)$	50553	
$\Upsilon(11020)$	60553	
$K^*(892)^+$	323	
$K^*(892)^0$	313	
$K_1(1270)$	10323	10313
$K_1(1400)$	20323	20313
$K^*(1415)$	30323,	30313
$K_0^*(1430)$	10321	10311
$K_2^*(1430)$	325	315
$K^*(1715)$	40323	40313
$K_2(1770)$	10325	10315
$K_3^*(1780)$	327	317
$K_4^*(2075)$	329	319
$D^*(2010)^+$	413	
$D^*(2010)^0$	423	

STABLE BARYONS

p	2212
n	2112
Λ	3122
Σ^+	3222
Σ^0	3212
Σ^-	3112
Ξ^0	3322
Ξ	3312
Ω^-	3332
Λ_c^+	4122
Ξ_c^+	4322
Ω_c^0	4332
Λ_b^0	5122

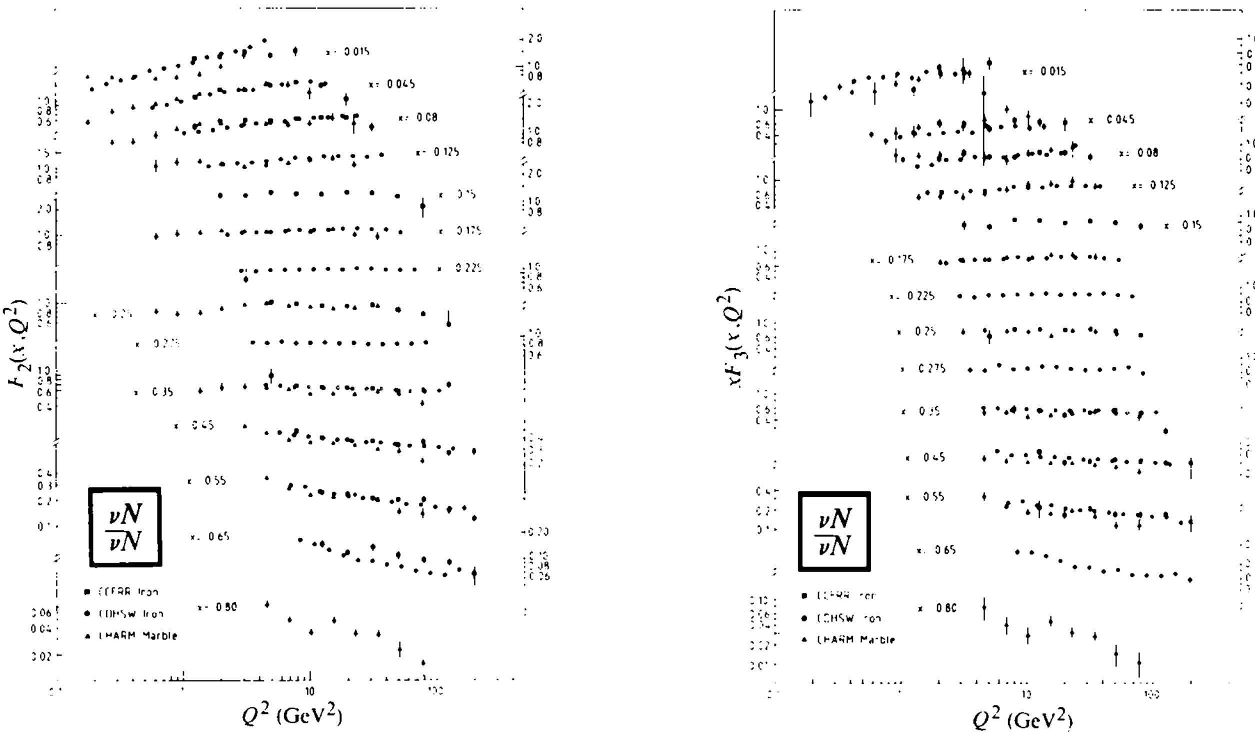
OTHER BARYONS

$N(1440)^+$	P_{11}	12212
$N(1440)^0$	P_{11}	12112
$N(1520)$	D_{13}	2124 1214
$N(1535)$	S_{11}	22212, 22112
$N(1650)$	S_{11}	32212, 32112
$N(1675)$	D_{15}	2216, 2116
$N(1680)$	F_{15}	12216, 12116
$N(1700)$	D_{13}	22124 21214
$N(1710)$	P_{11}	42212, 42112
$N(1720)$	P_{13}	32124, 31214
$N(2190)$	G_{17}	2128 1218
$\Delta(1232)^{++}$	P_{33}	2224
$\Delta(1232)^+$	P_{33}	2214
$\Delta(1232)^0$	P_{33}	2114
$\Delta(1232)^-$	P_{33},	1114
$\Delta(1620)$	S_{31}	2222 2122 1212, 1112
$\Delta(1700)$	D_{33}	12224 12214 12114, 11114
$\Delta(1900)$	S_{31}	12222 12212 12112 11112
$\Delta(1905)$	F_{35}	2226 2126 1216 1116
$\Delta(1910)$	P_{31}	22222 22212 22112 21112
$\Delta(1920)$	P_{33}	22224 22214 22114 21114
$\Delta(1930)$	D_{35}	12226 12216 12116 11116
$\Delta(1950)$	F_{37}	2228 2218 2118 1118
$\Lambda(1405)$	S_{01}	13122
$\Lambda(1520)$	D_{03}	3124
$\Lambda(1600)$	P_{01}	23122
$\Lambda(1670)$	S_{01}	33122
$\Lambda(1690)$	D_{03}	13124
$\Lambda(1800)$	S_{01}	43122
$\Lambda(1810)$	P_{01}	53122
$\Lambda(1820)$	F_{05}	3126
$\Lambda(1830)$	D_{05}	13126
$\Lambda(1890)$	P_{03}	23124
$\Lambda(2100)$	G_{07}	3128
$\Lambda(2110)$	F_{05}	23126
$\Sigma(1385)^+$	P_{13}	3224
$\Sigma(1385)^0$	P_{13}	3214
$\Sigma(1385)$	P_{13}	3114
$\Sigma(1660)$	P_{11}	13222, 13212, 13112
$\Sigma(1670)$	D_{13}	13224 13214, 13114
$\Sigma(1750)$	S_{11}	23222, 23212 23112
$\Sigma(1775)$	D_{15}	3226, 3216 3116
$\Sigma(1915)$	F_{15}	13226, 13216, 13116
$\Sigma(1940)$	D_{13}	23224, 23214, 23114
$\Sigma(2030)$	F_{17}	3228, 3218, 3118
$\Xi(1530)^0$	P_{13}	3324
$\Xi(1530)^-$	P_{13}	3314
$\Xi(1820)$	$_{13}$	13324, 13314

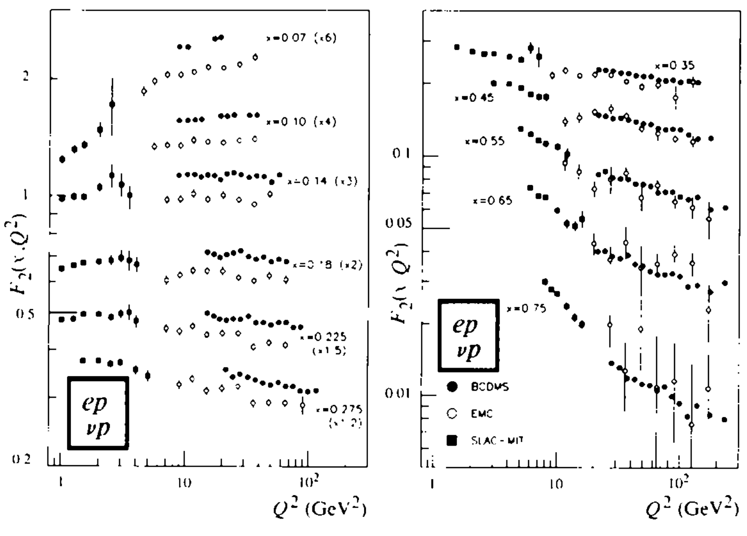
PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES

NOTE: THE FIGURES IN THIS SECTION ARE INTENDED TO SHOW THE "BEST" OR "MOST REPRESENTATIVE" DATA IN THE OPINION OF THE COMPILER. THEY ARE NOT NECESSARILY COMPLETE COMPILATIONS OF ALL THE WORLD'S RELIABLE DATA.

Structure Functions



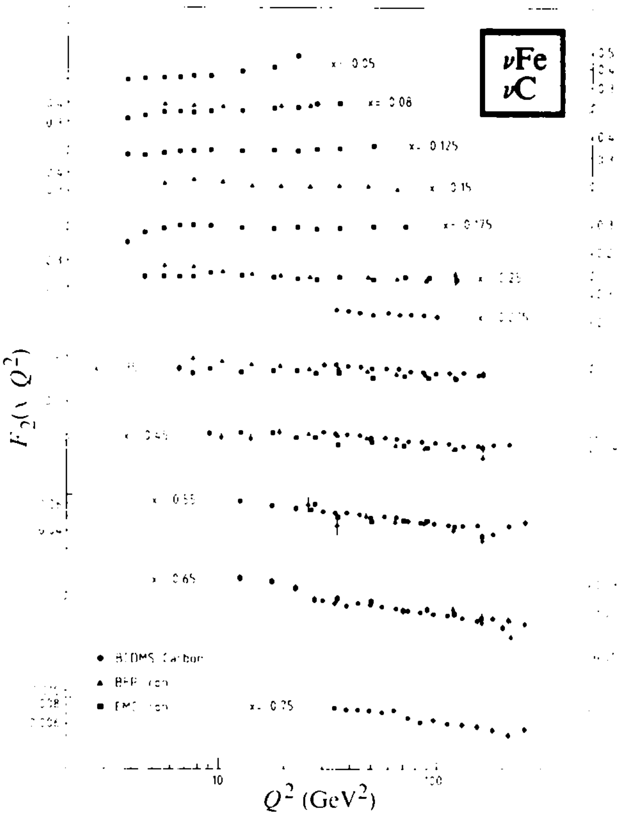
The nucleon structure functions F_2 and xF_3 measured in charged-current neutrino and antineutrino scattering on iron (CCFRR, CDHSW) and marble (CHARM) targets, versus Q^2, for fixed bins of x. Filled symbols are read on the right-hand scale, open symbols (appearing for alternate x values) on the left-hand scale. Only statistical errors are shown. $R = \sigma_L/\sigma_T = 0$ is used in the CHARM data, and a QCD prediction for R is assumed in the CCFRR and CDHSW data. The CHARM measurements have not been corrected for the recalibration of the total neutrino and antineutrino cross sections in the CERN neutrino beam which was completed after the publication of these data. References: **CCFRR** — D B MacFarlane et al., Z Phys **C26**, 1 (1984), **CDHSW** — V Vallage, Thesis, Université de Paris Sud, Orsay (1986) and Chr Geweniger, private communication, **CHARM** — F Bergsma et al., Phys Lett **123B**, 269 (1983) and Phys Lett **141B**, 129 (1984)



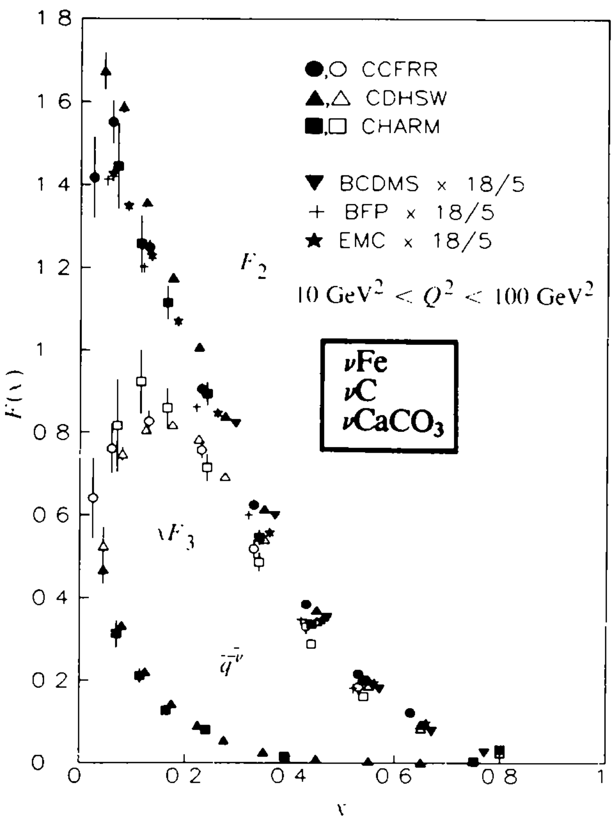
The proton structure function F_2^p measured in electromagnetic scattering of electrons (SLAC-MIT) and muons (BCDMS, EMC) on hydrogen targets, versus Q^2, for fixed bins of x. The data have been multiplied by the factors shown on the left-hand figure for convenience in plotting. Only statistical errors are shown. $R = \sigma_L/\sigma_T = 0.21$ is assumed in the SLAC-MIT data, $R = 0$ in the EMC data, and a QCD prediction for R in the BCDMS data. Where necessary, the SLAC-MIT and EMC data were interpolated to the x bins of the BCDMS data. References: **SLAC-MIT** — A Bodek et al., Phys Rev **D20**, 1471 (1979), **EMC** — J J Aubert et al., Nucl Phys **B259**, 189 (1985), **BCDMS** — A Ouraou, Thesis, Université de Paris Sud, Orsay (1988)

PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)

Structure Functions



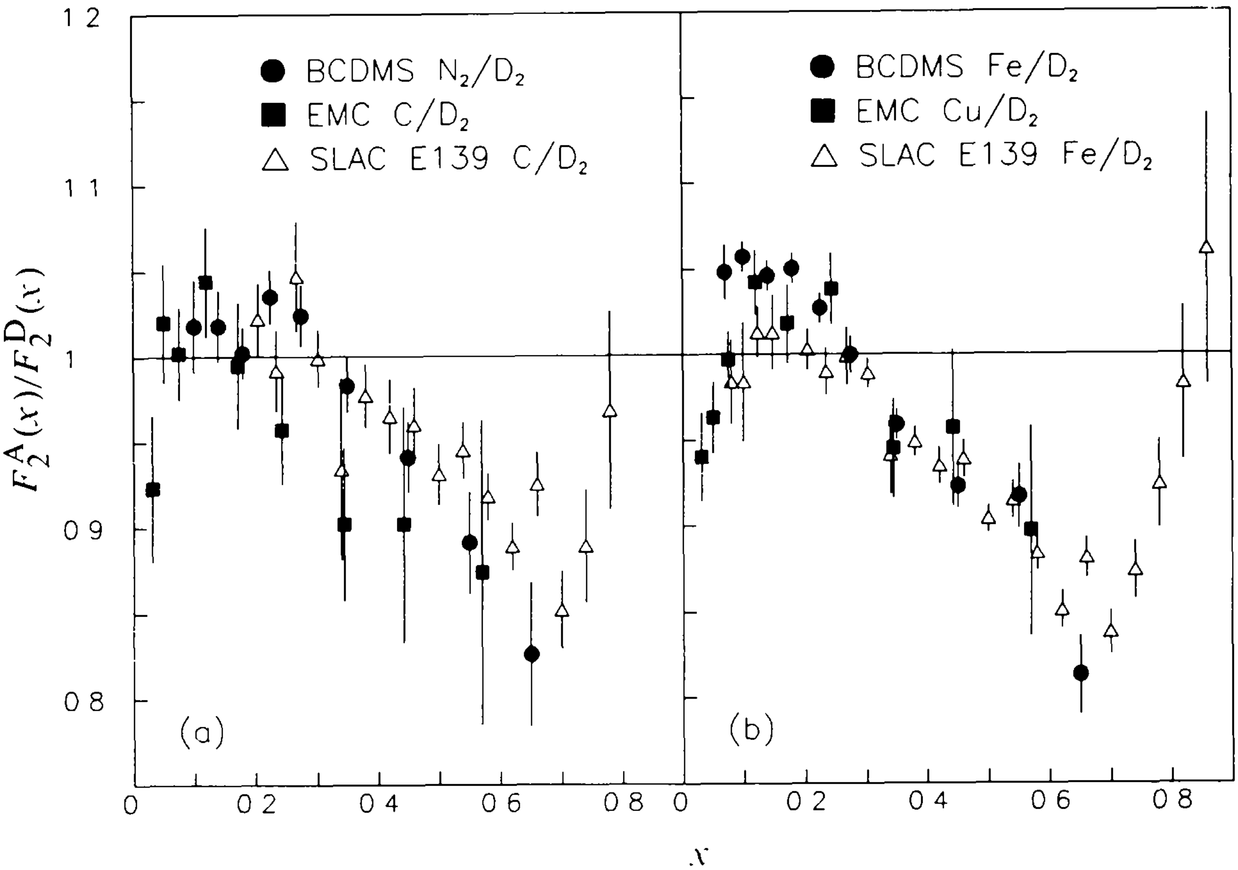
The nucleon structure function F_2 measured in electromagnetic scattering of muons on iron (BFP, EMC) and carbon (BCDMS) targets, versus Q^2, for fixed bins of x. For x of 0 05, 0 125, 0 175, 0 275, 0 45, and 0 65 use the right-hand scale, otherwise use the left-hand scale. Only statistical errors are shown. $R = \sigma_L/\sigma_T = 0$ is used in the BFP data, and a QCD prediction for R is assumed in the BCDMS and EMC data. References: **BCDMS** — A Benvenuti et al., Phys Lett **B195**, 91 (1987), **BFP** — P D Meyers et al., Phys Rev **D34**, 1265 (1986), **EMC** — J J Aubert et al., Nucl Phys **B272**, 158 (1986)



The structure functions F_2, xF_3 and $\bar{q}^{\nu}$ measured in different experiments on isoscalar targets as a function of Bjorken x. The CCFRR, CDHSW, BFP, and EMC data were taken with iron targets, the CHARM data with a marble ($CaCO_3$) target, and the BCDMS data with a carbon target. Only statistical errors are shown. The CHARM and BFP collaborations assume $R = \sigma_L/\sigma_T = 0$, whereas a QCD prediction for R is assumed in the analysis of the CCFRR, CDHSW, BCDMS, and EMC data. The electromagnetic structure function $F_2^{\mu N}$ is compared to the charged-current structure function $F_2^{\nu N}$ correcting for the average squared quark charge 5/18. No corrections have been applied for the difference between the strange and charmed quark sea. References: **CCFRR** — D B MacFarlane et al., Z Phys **C26**, 1 (1984), **CDHSW** — V Vallage, Thesis, Universite de Paris Sud, Orsay (1986) and Chr Geweniger, private communication, **CHARM** — F Bergsma et al., Phys Lett **123B**, 269 (1983) and Phys Lett **141B**, 129 (1984), **BCDMS** — A Benvenuti et al., Phys Lett **B195**, 91 (1987), **BFP** — P D Meyers et al., Phys Rev **D34**, 1265 (1986), **EMC** — J J Aubert et al., Nucl Phys **B272**, 158 (1986)

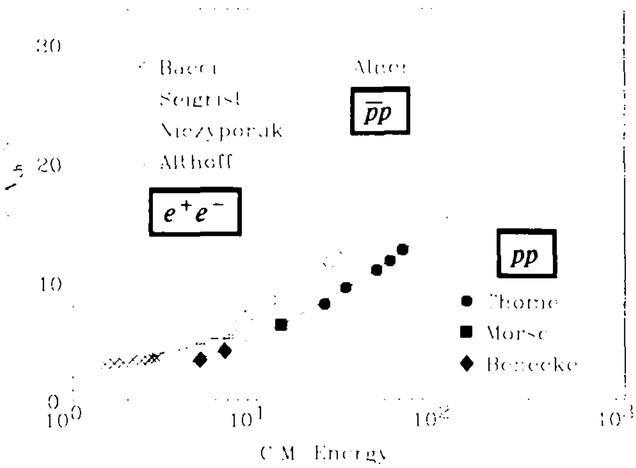
PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)

"EMC" Effect



The ratio of nucleon structure functions $F_2^A(x)/F_2^D(x)$ for nuclear targets A compared to deuterium D, measured in deep inelastic electron (SLAC-E139) and muon (BCDMS, EMC) scattering (a) medium-weight targets (A = N, C), (b) heavy targets (A = Fe, Cu) Only statistical errors are shown The SLAC-E139 data were evaluated as cross section ratios σ^A/σ^D but are equal to structure function ratios if $R = \sigma_L/\sigma_T$ is independent of A References **BCDMS** — G Bari et al, Phys Lett **163B**, 282 (1985), and A C Benvenuti et al, Phys Lett **B189**, 483 (1987), **EMC** — J Ashman et al, CERN-EP/88-06 (1988), **SLAC-E139** — R G Arnold et al, Phys Rev Lett **52**, 727 (1984), and SLAC-PUB-3257 (1983)

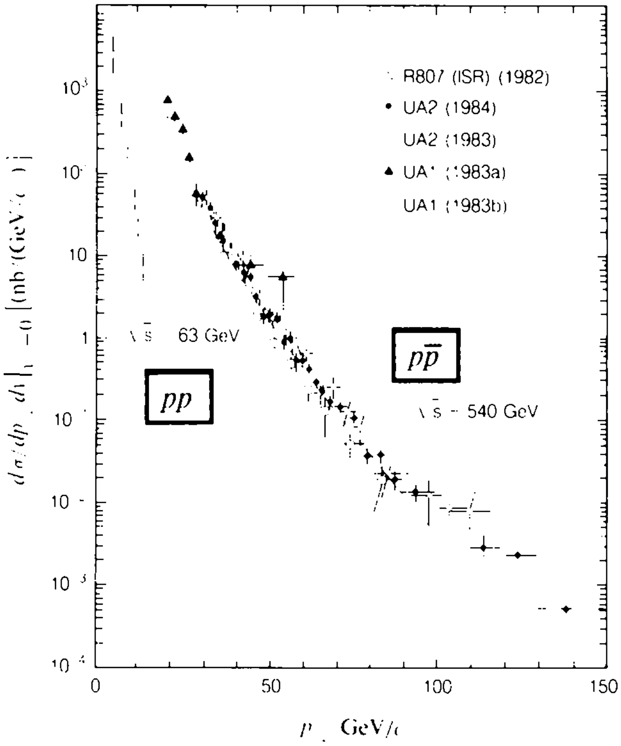
Average e^+e^- pp, and $\bar{p}p$ Multiplicity



Average multiplicity as a function of $\sqrt{s}$ for $p\bar{p}$ at the S$\bar{p}p$S for pp at the ISR, (open circles) and for e^+e^- Solid curve is a fit by Thomé et al to their data (solid circles) with the form $\langle N_{ch}\rangle$ = 0 88 + 0 44 $\ell n\, s$ + 0 118 $(\ell n\, s)^2$ e^+e^- data points have been combined to reduce overlap, errors (not shown) are dominated by 10%–25% systematic effects References $p\bar{p}$ — G J Alner et al, Phys Lett **138B**, 304 (1984), pp - W Thomé et al, Nucl Phys **B129**, 365 (1977), W M Morse et al, Phys Rev **D15**, 66 (1977), and J Benecke et al, Nucl Phys **B76**, 29 (1974), e^+e^- - ADONE C Bacci et al, Phys Lett **86B**, 234 (1979), MARK II J L Siegrist et al, Phys Rev **D26**, 969 (1982), LENA B Niczyporuk et al, Z Phys **C9**, 1 (1981), and TASSO M Althoff et al, Z Phys **C229**, 307 (1984)

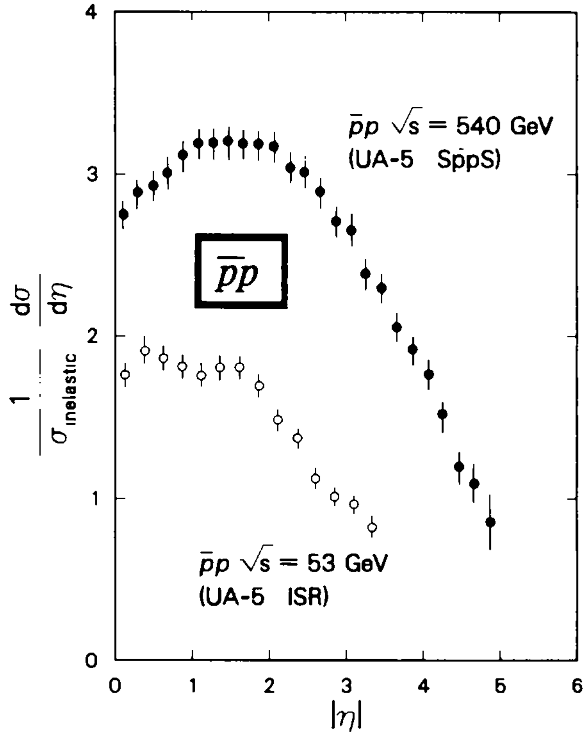
PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)

Jet Production in pp and $\bar{p}p$ Interactions



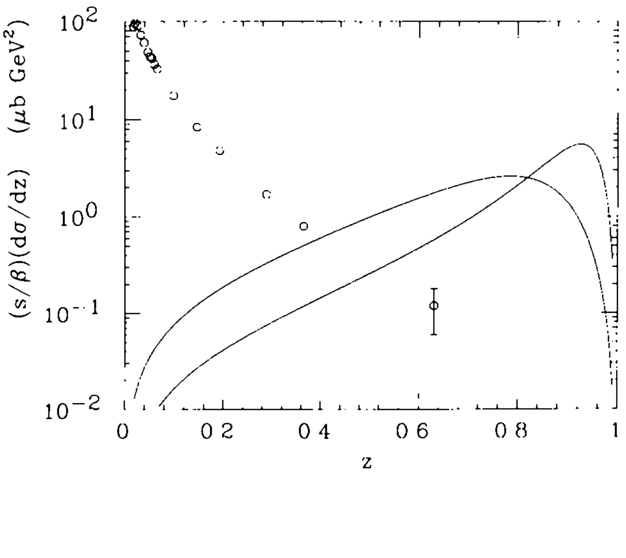
Differential cross sections for observation of a single jet of rapidity $y = 0$ as a function of the jet transverse momentum ISR (pp) and $S\bar{p}pS$ collider ($\bar{p}p$) data compared Error bars include a contribution due to estimated systematic error in defining jet direction and p_T Solid curve QCD prediction, refer to the "Cross-Section Formulae for Specific Processes" section and the "Quantum Chromodynamics" section in the full-sized edition References **ISR** - T Akesson et al, Phys Lett **118B**, 185 (1982), **UA2** - P Bagnaia et al, Phys Lett **138B**, 430 (1984), and P Bagnaia et al, Z Phys **C20**, 117 (1983), **UA1** - G Arnison et al, Phys Lett **123B**, 115 (1983a), and G Arnison et al, Phys Lett **132B**, 144 (1983b)

Pseudorapidity in $\bar{p}p$ Interactions



Comparison of the distribution of the pseudorapidity $\eta = -\ell n(\tan\theta_{cm}/2)$ for charged-particle production in proton-antiproton collisions at $\sqrt{s}$ = 53 GeV (1) and 540 GeV (2) References (1) K Alpgard et al, Phys Lett **112B**, 209 (1982), (2) UA5 Collaboration, presented by J Rushbrooke in the *Proceedings of the XIV International Symposium on Multiparticle Dynamics*, eds J F Gunion and P M Yager (World Scientific Publishing Co, Singapore, 1984)

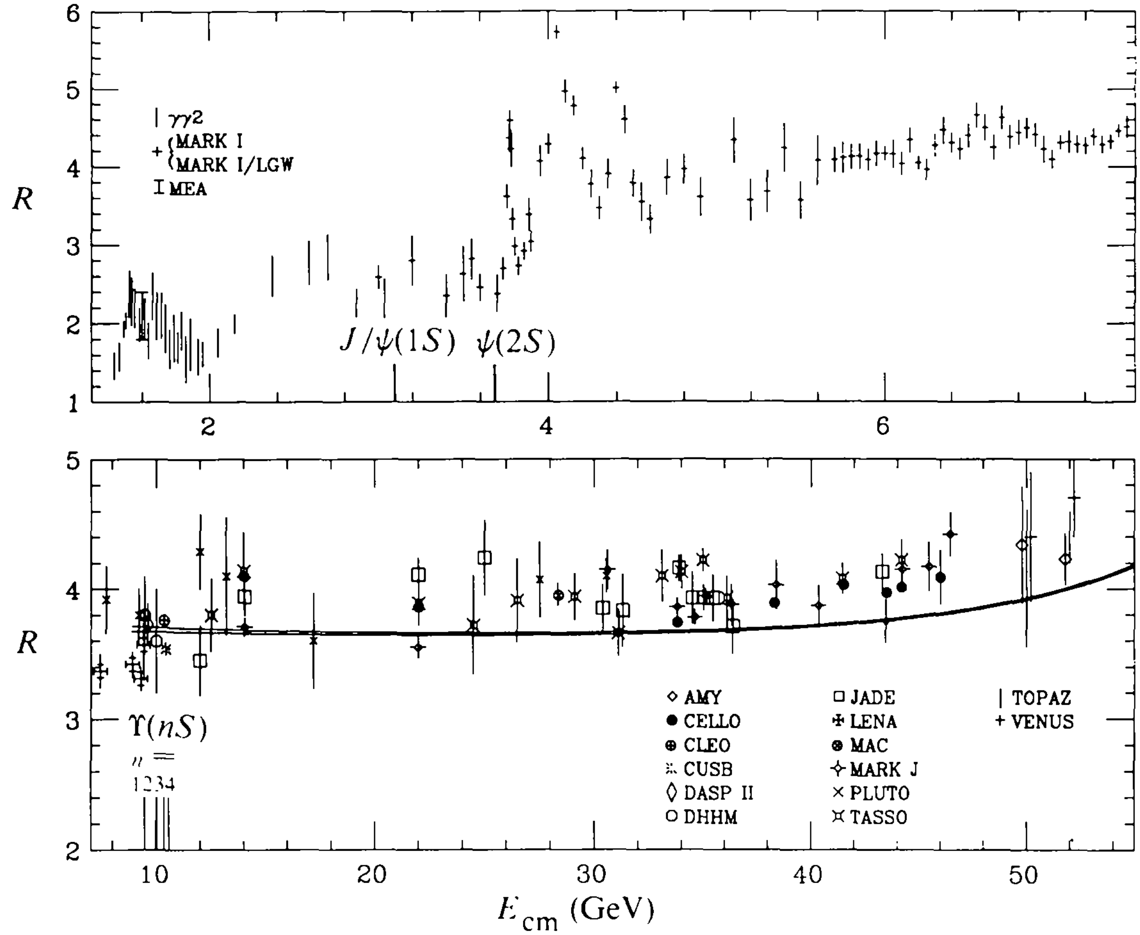
Fragmentation Function



The cross section $(s/\beta)\, d\sigma/dz$ versus z for producing a hadron h in e^+e^- annihilation, measured in different experiments, for fixed energies $Q^2 = s$ This quantity is closely related to the fragmentation function $D_i^h(z, Q^2)$ as discussed in the "Cross-Section Formulae for Specific Processes" section Note that we use $z = (E + p_\parallel)_{\rm hadron}/(E + p_\parallel)_{\rm quark}$, whereas some experiments use $z = E_{\rm hadron}/E_{\rm beam}$ or $z = p_{\rm hadron}/(E^2_{\rm beam} - m^2_{\rm had})^{1/2}$ The data are shown for pions (singlet term) The data for heavy quarks are frequently parametrized by the Peterson et al form, $D(z) = Nz\,(1 - z)^2/[(1 - z)^2 + \epsilon_i z]^2$ The parameter ϵ for quark type i depends on $\sqrt{s}$ and upon the heavy quark mass At $\sqrt{s} \sim 30$ GeV, $\epsilon_b = 0.006 \pm 0.002$, $\epsilon_c = 0.006^{+0.003}_{-0.015}$ Curves coresponding to these values (N is chosen arbitrarily) are shown on the figure References C Peterson et al, Phys Rev **D27**, 105 (1983), **TPC** -- H Aihara et al, Z Phys **C27**, 495 (1985), and J Chrin, Z Phys **C36**, 163 (1987)

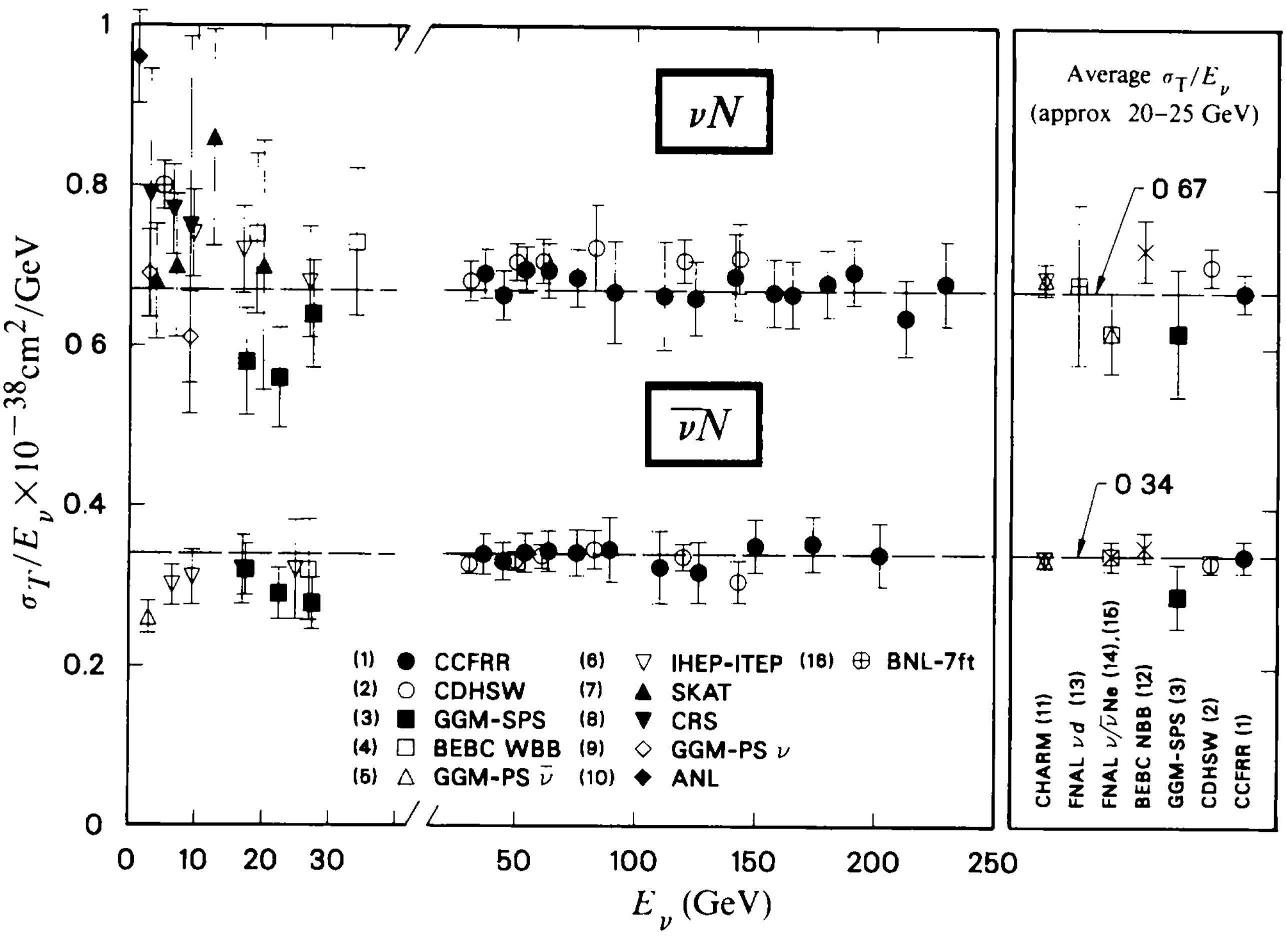
PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)

R in e^-e^- Collisions



Selected measurements of $R \equiv \sigma(e^-e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$, where the annihilation in the numerator proceeds via one photon or via the Z^0. The denominator is the calculated QED single-photon process, see the section on Cross-Section Formulae for Specific Processes. Radiative corrections and, where important, corrections for two-photon processes and τ production have been made. Note that the ADONE data ($\gamma\gamma 2$ and MEA) is for $\geqslant 3$ hadrons. The points in the $\psi(3770)$ region are from the MARK I — Lead Glass Wall experiment. To preserve clarity only a representative subset of the available measurements is shown — references to additional data are included below. Also for clarity some points have been combined or shifted slightly ($<4\%$) in E_{cm} and some points with low statistical significance have been omitted. Systematic normalization errors are not included, they range from ~5 - 20%, depending on experiment. We caution that especially the older experiments tend to have large normalization uncertainties. Note the suppressed zero. The horizontal extent of the plot symbols has no significance. The positions of the $J/\psi(1S)$, $\psi(2S)$ and the four lowest Υ vector-meson resonances are indicated. Two curves are overlaid for $E_{cm} > 11$ GeV, showing the theoretical prediction for R including higher order QCD [M. Dine and J. Sapirstein, Phys. Rev. Lett. **43**, 668 (1979)] and electroweak corrections. The lower curve is with $\Lambda_{QCD} = 100$ MeV and the upper curve is for $\Lambda_{QCD} = 300$ MeV. References (including several references to data not appearing in the figure and some references to preliminary data): **AMY** — H. Sagawa et al., Phys. Rev. Lett. **60**, 93 (1988); **CELLO** — H.-J. Behrend et al., Phys. Lett. **144B**, 297 (1984) and H.-J. Behrend et al., Phys. Lett. **183B**, 400 (1987); **CLEO** — R. Giles et al., Phys. Rev. **D29**, 1285 (1984) and D. Besson et al., Phys. Rev. Lett. **54**, 381 (1985); **CUSB** — E. Rice et al., Phys. Rev. Lett. **48**, 906 (1982); **CRYSTAL BALL** — A. Osterheld et al., SLAC-PUB-4160, submitted to Phys. Rev. **D** (1986); **DASP** — R. Brandelik et al., Phys. Lett. **76B**, 361 (1978); **DASP II** — Phys. Lett. **116B**, 383 (1982); **DCI** — G. Cosme et al., Nucl. Phys. **B152**, 215 (1979); **DHHM** — P. Bock et al. (DESY-Hamburg-Heidelberg-MPI M.), Z. Phys. **C6**, 125 (1980); **γγ2** — C. Bacci et al., Phys. Lett. **86B**, 234 (1979); **HRS** — D. Bender et al., Phys. Rev. **D31**, 1 (1985); **JADE** — W. Bartel et al., Phys. Lett. **129B**, 145 (1983), and W. Bartel et al., Phys. Lett. **160B**, 337 (1985); **LENA** — B. Niczyporuk et al., Phys. Lett. **99B**, 169 (1981) and Phys. Rev. Lett. **46**, 92 (1981); **MAC** — E. Fernandez et al., Phys. Rev. **D31**, 1537 (1985); **MARK J** — B. Adeva et al., Phys. Rev. Lett. **50**, 799 (1983), and B. Adeva et al., Phys. Rev. **D34**, 681 (1986); **MARK I** — J. L. Siegrist et al., Phys. Rev. **D26**, 969 (1982); **MARK I + Lead Glass Wall** — P. A. Rapidis et al., Phys. Rev. Lett. **39**, 526 (1977) and P. A. Rapidis thesis, SLAC-Report-220 (1979); **MARK II** — J. Patrick, Ph.D. thesis LBL-14585 (1982); **MEA** — B. Esposito et al., Lett. Nuovo Cimento **19**, 21 (1977); **PLUTO** — A. B. (1977), C. Gerke, thesis Hamburg Univ. (1979), Ch. Berger et al., Phys. Lett. **81B**, 410 (1979) and W. Lackas thesis RWTH Aachen DESY Pluto-81/11 (1981); **TASSO** — R. Brandelik et al., Phys. Lett. **113B**, 499 (1982), and M. Althoff et al., Phys. Lett. **138B**, 441 (1984); **TOPAZ** — I. Adachi et al., Phys. Rev. Lett. **60**, 97 (1988), and **VENUS** — H. Yoshida et al., Phys. Lett. **198B**, 570 (1987).

PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)



σ_T/E_ν for the muon neutrino and antineutrino charged-current total cross section as a function of neutrino energy The error bars include both statistical and systematic errors The straight lines are averages for the CCFRR measurement Note the change in the energy scale between 30 and 50 GeV The data points on the right give averages for other high energy measurements References (1) D B MacFarlane et al Z Phys **C26**, 1 (1984), (2) P Berge et al Z Phys **C35** 443 (1987), (3) J Morfin et al, Phys Lett **104B** 235 (1981) (4) D C Colley et al Z Phys **C2** 187 (1979) (5) O Erriquez et al Phys Lett **80B**, 309 (1979), (6) A S Vovenko et al Sov J Nucl Phys **30** 527 (1979), (7) D S Baranov et al Phys Lett **81B** 255 (1979), (8) C Baltay et al, Phys Rev Lett **44** 916 (1980), (9) S Ciampolillo et al Phys Lett **84B** 281 (1979), (10) S J Barish et al Phys Rev **D19** 2521 (1979) (11) J V Allaby et al "Total Cross Sections of Charged-Current Neutrino and Anti-Neutrino Interactions on Isoscalar Nuclei," CERN-EP/87-225 (1987), to be publ in Z Phys C E_ν = 10 160 GeV (12) P Bosetti et al Phys Lett **110B**, 167 (1982) E_ν = 20–200 GeV as revised in M Aderholz et al Phys Lett **173B**, 211 (1986) (13) T Kitagaki et al, Phys Rev Lett **49** 98 (1982) E_ν = 10–200 GeV (14) N J Baker et al, Phys Rev Lett **51**, 735 (1983), E_ν = 10–240 GeV (15) G N Taylor et al Phys Rev Lett **51** 739 (1983), E_ν = 5 250 GeV, (16) N J Baker et al, Phys Rev **D25**, 617 (1982) E_ν = 1 6–10 GeV Courtesy M H Shaevitz Columbia University (Nevis Laboratory)

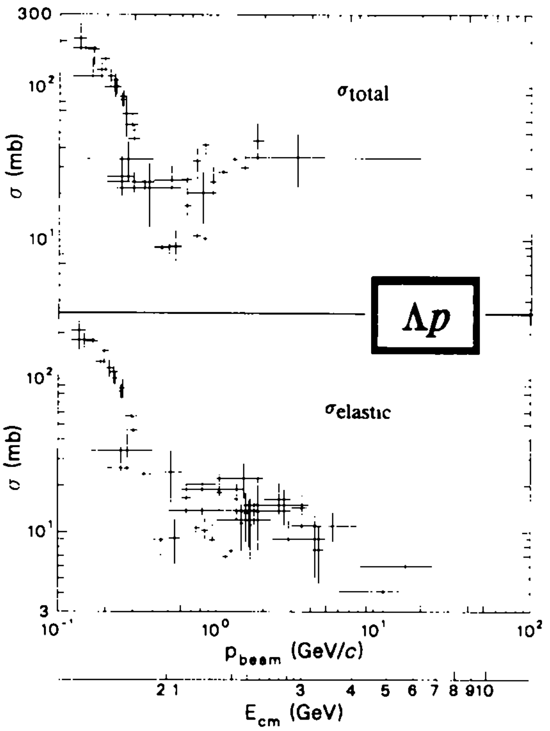
PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)
Hadron Cross Sections

High-energy Parametrizations

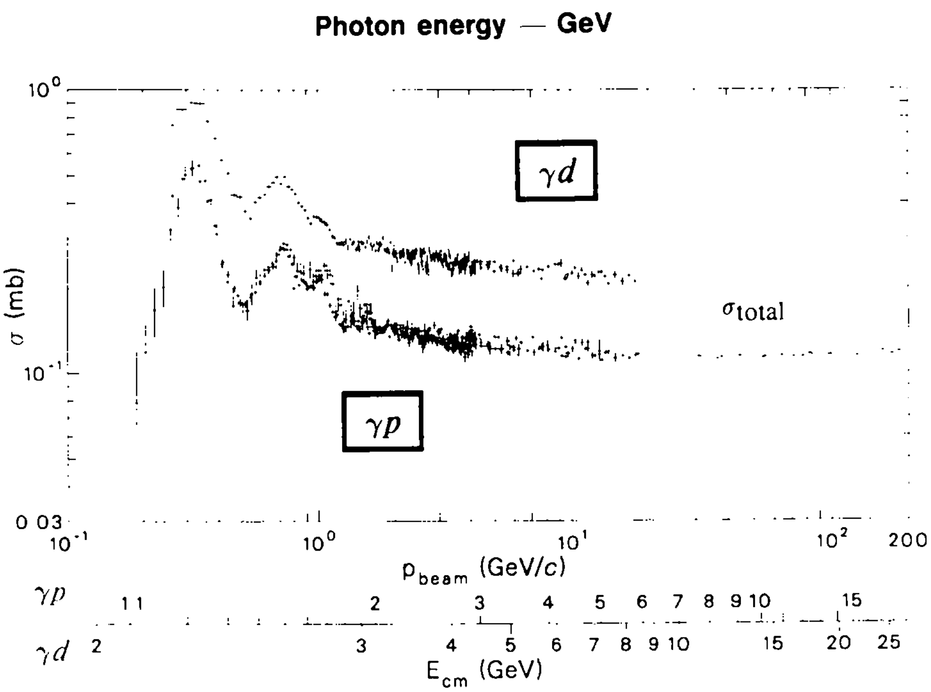
The CERN-HERA Group has done a least-squares fit to the cross section in the high-energy region for each of the hadron reactions plotted below The parametrization they used was $\sigma = A + Bp^n + C\ell n^2(p) + D\ell n(p)$, where σ is in mb and p is in GeV/c The best-fit coefficients A, B, C, and D and the fitted exponent n are tabulated here The errors in these parameters are highly correlated, this should be taken into account before making any changes The applicable momentum range is given in the right-hand column

Reaction	A	B	n	C	D	Momentum range (GeV/c) $p_{min} - p_{max}$
Λp (total)	18 0 ± 1 4	0 121 ± 0 024	−3 92 ± 1 10	6 38 ± 0 54	0	0 120–21 0
Λp (elastic)	3 49 ± 1 45	26 2 ± 7 7	−1 01 ± 2 57	0	0	2 0–24 0
γp (total)	0 152 ± 0 005	−0 0168 ± 0 0200	−1 70 ± 4 71	0 00245 ± 0 00033	−0 0192 ± 0 0026	3 0–183
γd (total)	0 313 ± 0 009	−0 000124 ± 0 000091	1 90 ± 0 25	0 0165 ± 0 0058	−0 0719 ± 0 0141	2 0–17 8
$\pi^+ p$ (total)	32 1 ± 0 2	48700 ± 5910	−7 85 ± 0 25	0 540 ± 0 015	−4 41 ± 0 11	4 00–340
$\pi^+ p$ (elastic)	7 07 ± 0 43	11 3 ± 1 2	−1 60 ± 0 86	0 160 ± 0 032	−1 56 ± 0 24	2 0–250
$\pi^+ d$ (total)	59 2 ± 1 7	363 ± 104	−2 70 ± 2 83	0 775 ± 0 098	−6 54 ± 0 83	6 0–340
$\pi^- p$ (total)	33 1 ± 0 3	15 0 ± 1 0	−1 41 ± 0 50	0 458 ± 0 018	−4 06 ± 0 15	2 5–370
$\pi^- p$ (elastic)	1 73 ± 0 09	11 2 ± 0 3	−0 63 ± 0 15	0 0437 ± 0 0040	0	2 0–360
$\pi^- d$ (total)	41 7 ± 0 3	44 0 ± 1 5	−0 80 ± 0 15	0 150 ± 0 011	0	2 5–370
$K^+ p$ (total)	17 1 ± 0 3	5 54 ± 1 39	−2 67 ± 2 09	0 139 ± 0 039	−0 270 ± 0 229	2 0–310
$K^+ p$ (elastic)	5 84 ± 0 13	17 2 ± 0 5	−3 06 ± 0 40	0 206 ± 0 016	−1 71 ± 0 10	1 5–250
$K^+ d$ (total)	35 3 ± 0 3	23 5 ± 7 0	−4 34 ± 8 18	0 397 ± 0 028	−1 47 ± 0 18	2 0–310
$K^+ n$ (total)	18 4 ± 0 3	175 ± 136	−7 85 ± 0 25	0 198 ± 0 026	−0 753 ± 0 19	2 0–310
$K^- p$ (total)	−21 1 ± 8 7	56 2 ± 9 1	−0 27 ± 0 96	−0 155 ± 0 135	6 24 ± 1 94	3 0–310
$K^- p$ (elastic)	7 24 ± 0 12	46 0 ± 4 2	−4 71 ± 1 42	0 279 ± 0 015	−2 35 ± 0 089	2 0–175
$K^- d$ (total)	46 1 ± 1 6	26 1 ± 3 5	−1 14 ± 1 21	0 569 ± 0 089	−4 17 ± 0 76	3 0–310
$K^- n$ (total)	−1040 ± 100	1060 ± 100	−0 03 ± 0 44	0	27 8 ± 2 7	2 5–310
pp (total)	45 6 ± 0 1	219 ± 9	−4 23 ± 0 92	0 410 ± 0 007	−3 41 ± 0 06	3 0–2100
pp (elastic)	11 2 ± 0 3	25 5 ± 1 0	−1 12 ± 0 28	0 151 ± 0 011	−1 62 ± 0 12	2 0–2100
pd (total)	92 2 ± 0 3	−0 0811 ± 0 0260	0 74 ± 1 42	1 36 ± 0 10	−9 82 ± 0 37	3 0–370
pd (elastic)	−237 ± 426	252 ± 424	0 07 ± 6 00	−0 506 ± 1 39	−20 3 ± 28 5	2 0–384
np (total)	47 7 ± 0 1	−100 ± 2	−4 57 ± 0 40	0 512 ± 0 010	−4 29 ± 0 06	2 0–280
$\bar{p}p$ (total)	41 1 ± 1 2	77 2 ± 2 9	−0 68 ± 0 14	0 293 ± 0 024	−1 82 ± 0 34	5 0–432000
$\bar{p}p$ (elastic)	10 6 ± 0 4	53 1 ± 1 25	−1 19 ± 0 10	0 136 ± 0 012	−1 41 ± 0 14	2 0–159000
$\bar{p}d$ (total)	112 ± 3	125 ± 6	−1 08 ± 0 30	1 15 ± 0 19	−12 6 ± 1 6	2 0–280
$\bar{p}n$ (total)	41 9 ± 0 9	96 2 ± 4 2	−0 99 ± 0 16	−0 154 ± 0 208	0	1 13–280
$\bar{p}n$ (elastic)	37 5 ± 6 2	−2 63 ± 16 1	−2 58 ± 24 16	−12 6 ± 4 3	0	1 13–5 55

PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)



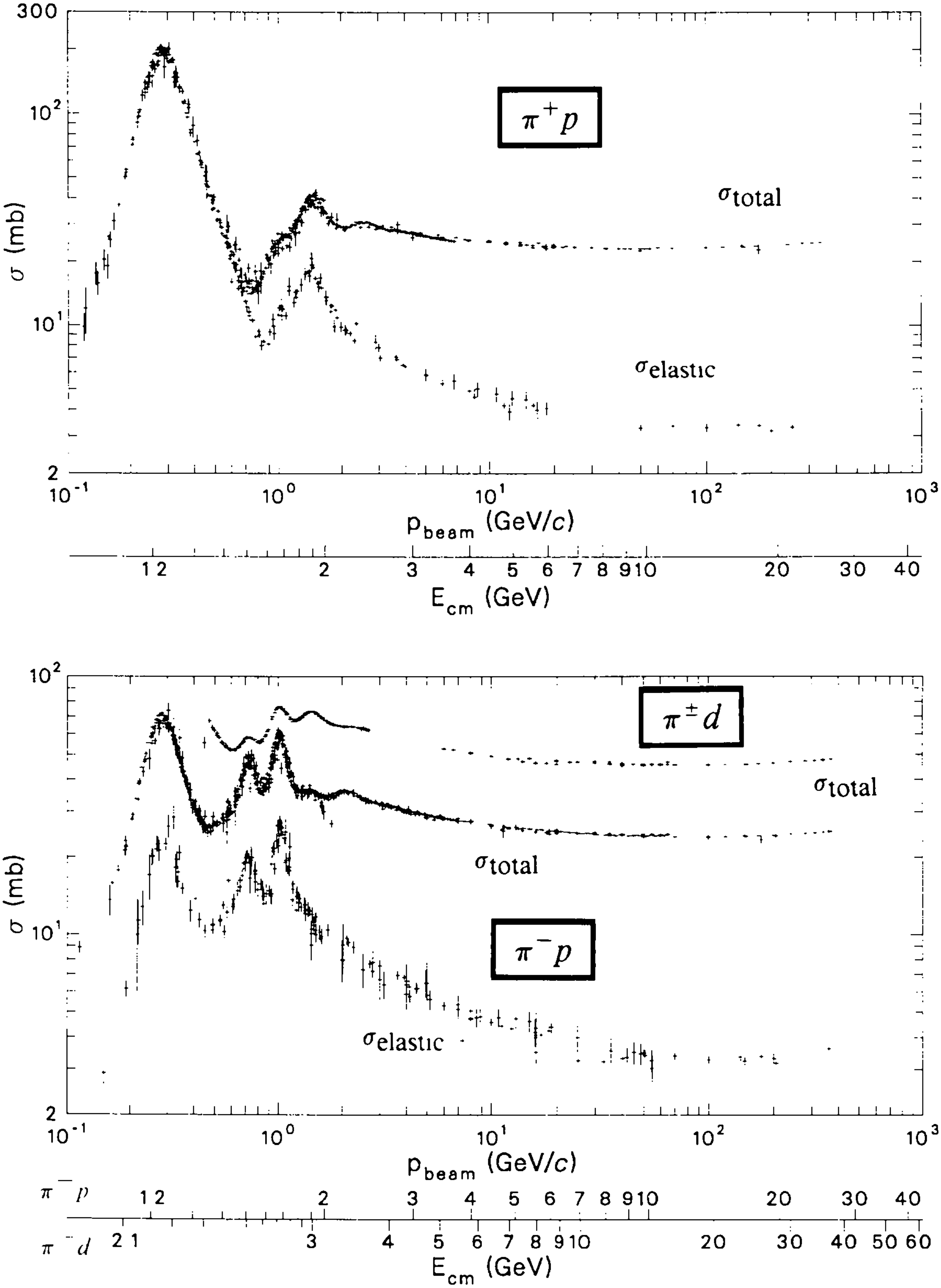
Λp total and elastic cross sections vs laboratory beam momentum p_{beam} and total center-of-mass energy E_{cm} Data courtesy A Baldini V Flaminio, W G Moorhead, and D R O Morrison CERN, and COMPAS Group, IHEP, Serpukhov, USSR See *Total Cross-Sections for Reactions of High Energy Particles*, Landolt-Bornstein, New Series, Vol 12a and 12b, H Schopper, Ed (1987)



Photon cross sections vs laboratory beam momentum p_{beam} and total center-of-mass energy E_{cm} Data courtesy A Baldini, V Flaminio W G Moorhead, and D R O Morrison, CERN COMPAS Group, IHEP, Serpukhov, USSR, and G M Lewis, Glasgow See *Total Cross-Sections for Reactions of High Energy Particles*, Landolt-Bornstein, New Series, Vol 12a and 12b, H Schopper, Ed (1987)

PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)

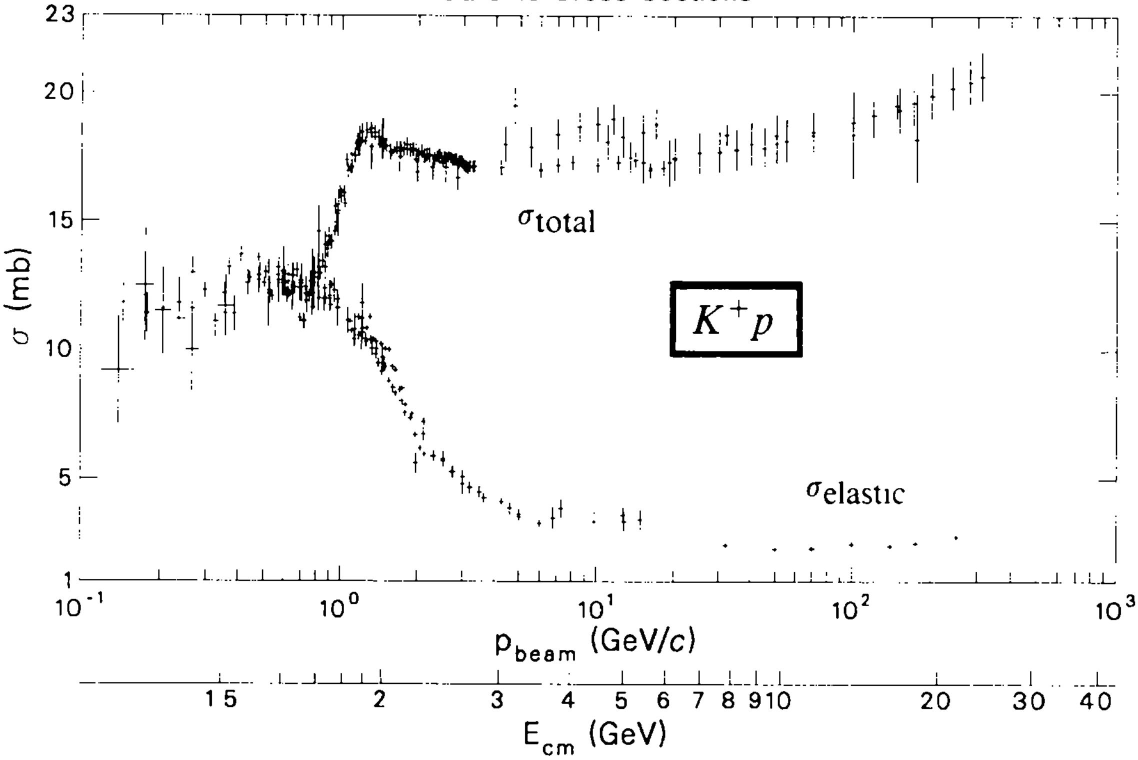
Hadronic Cross Sections

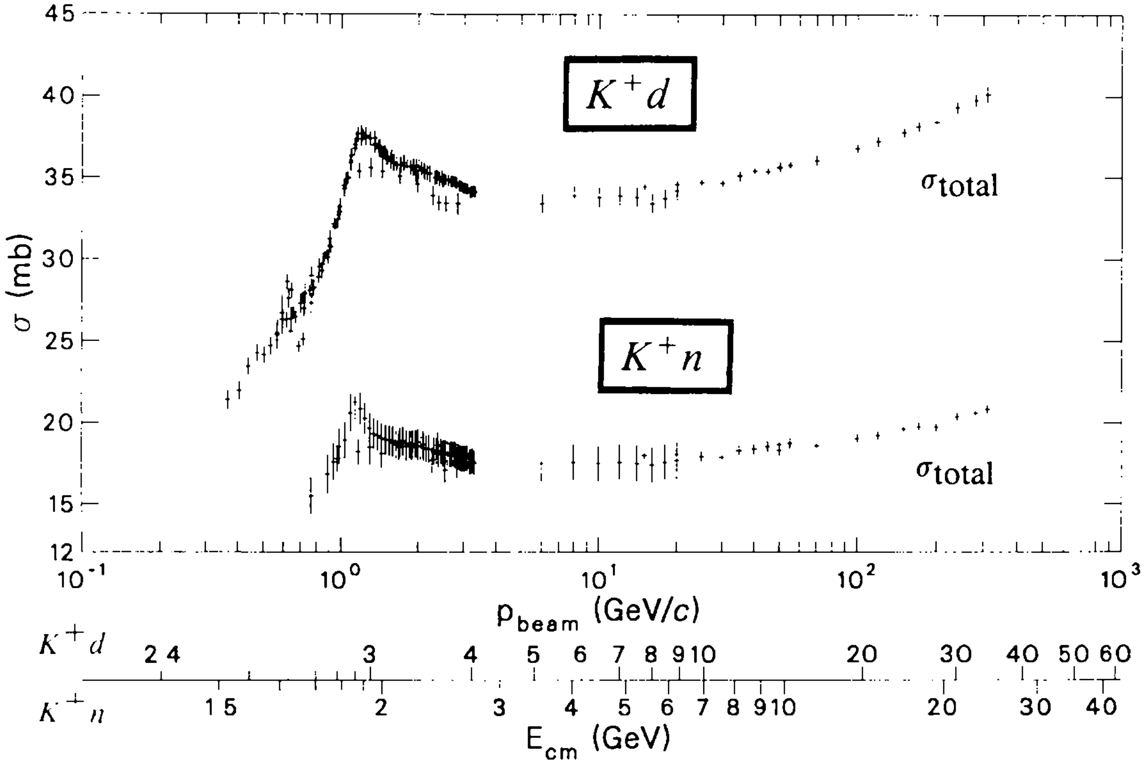


Hadronic total and elastic cross sections vs laboratory beam momentum p_{beam} and total center-of-mass energy E_{cm}. Data courtesy A Baldini, V Flaminio, W G Moorhead and D R O Morrison, CERN and COMPAS Group, IHEP Serpukhov USSR. See *Total Cross-Sections for Reactions of High Energy Particles*, Landolt-Bornstein New Series Vol 12a and 12b H Schopper Ed (1987)

PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)

Hadronic Cross Sections

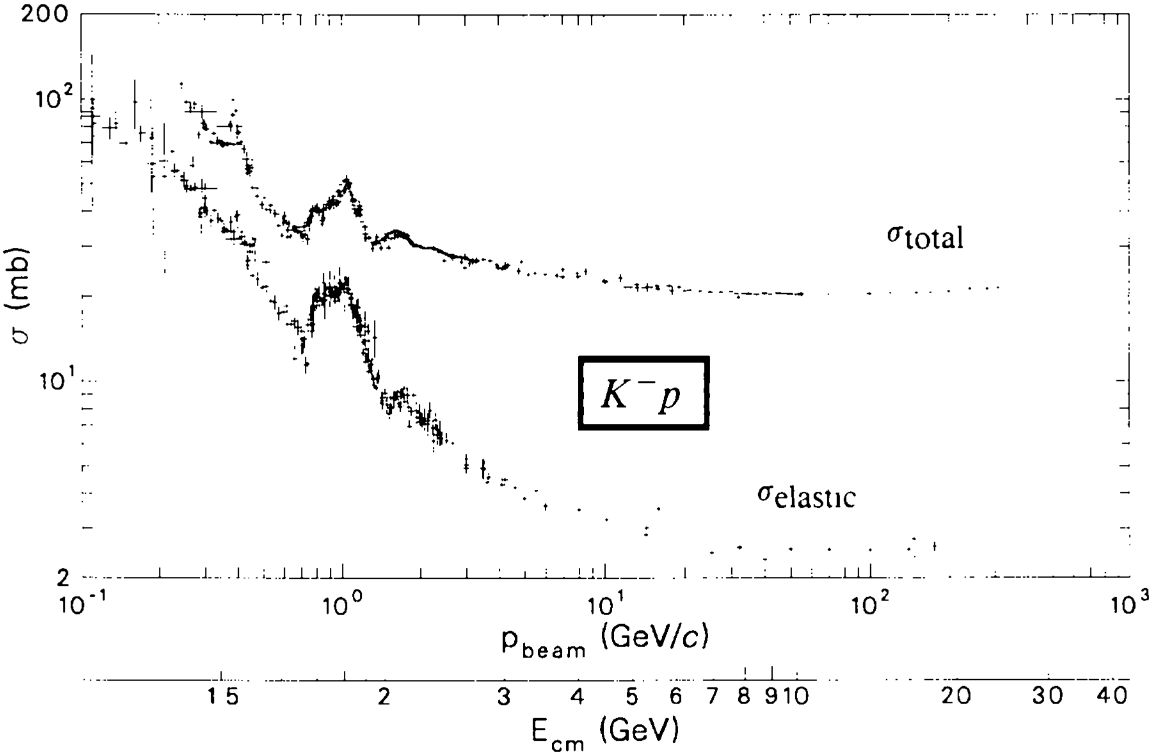


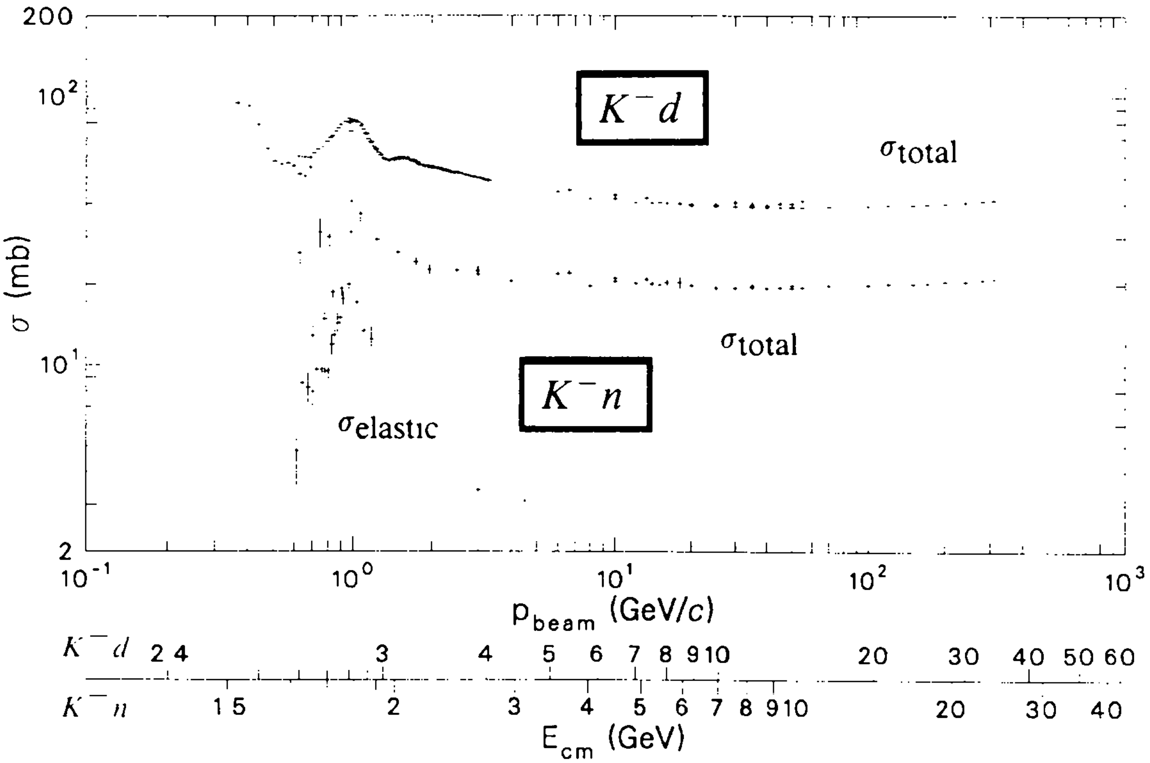


Hadronic total and elastic cross sections vs. laboratory beam momentum p_{beam} and total center-of-mass energy E_{cm}. Data courtesy A. Baldini, V. Flaminio, W.G. Moorhead, and D.R.O. Morrison, CERN, and COMPAS Group, IHEP, Serpukhov, USSR. See *Total Cross-Sections for Reactions of High Energy Particles*, Landolt-Bornstein, New Series Vol. 12a and 12b, H. Schopper, Ed. (1987).

PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)

Hadronic Cross Sections

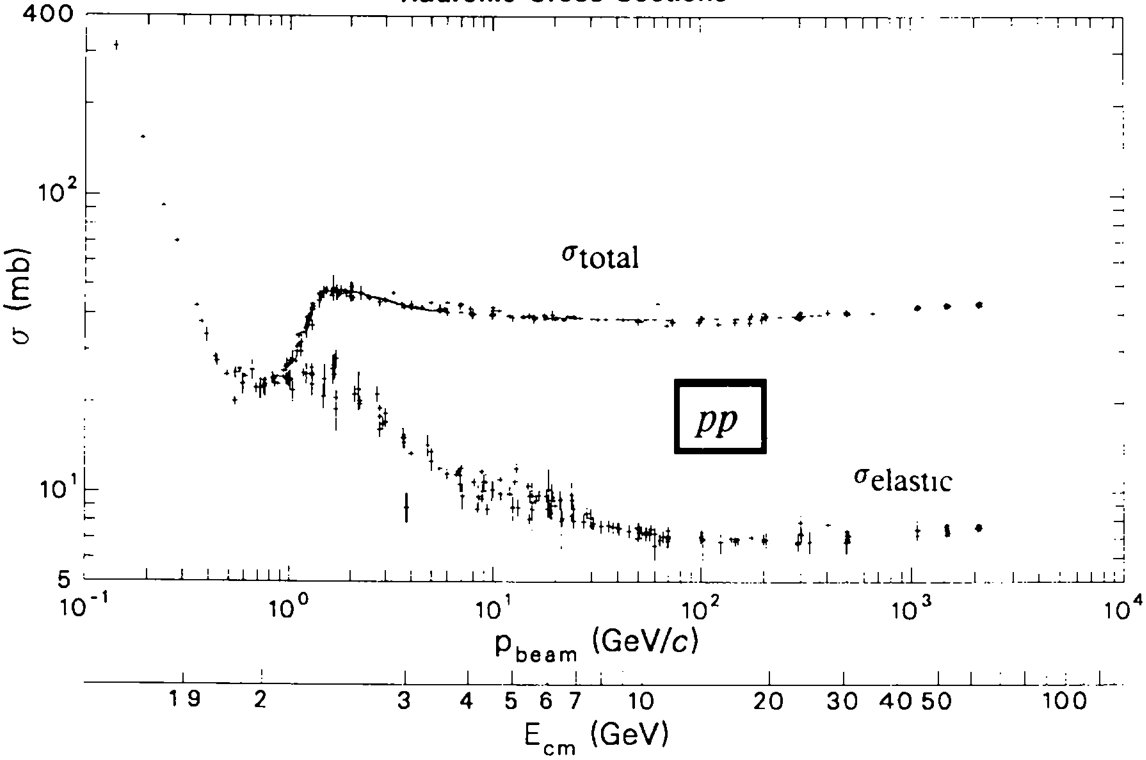


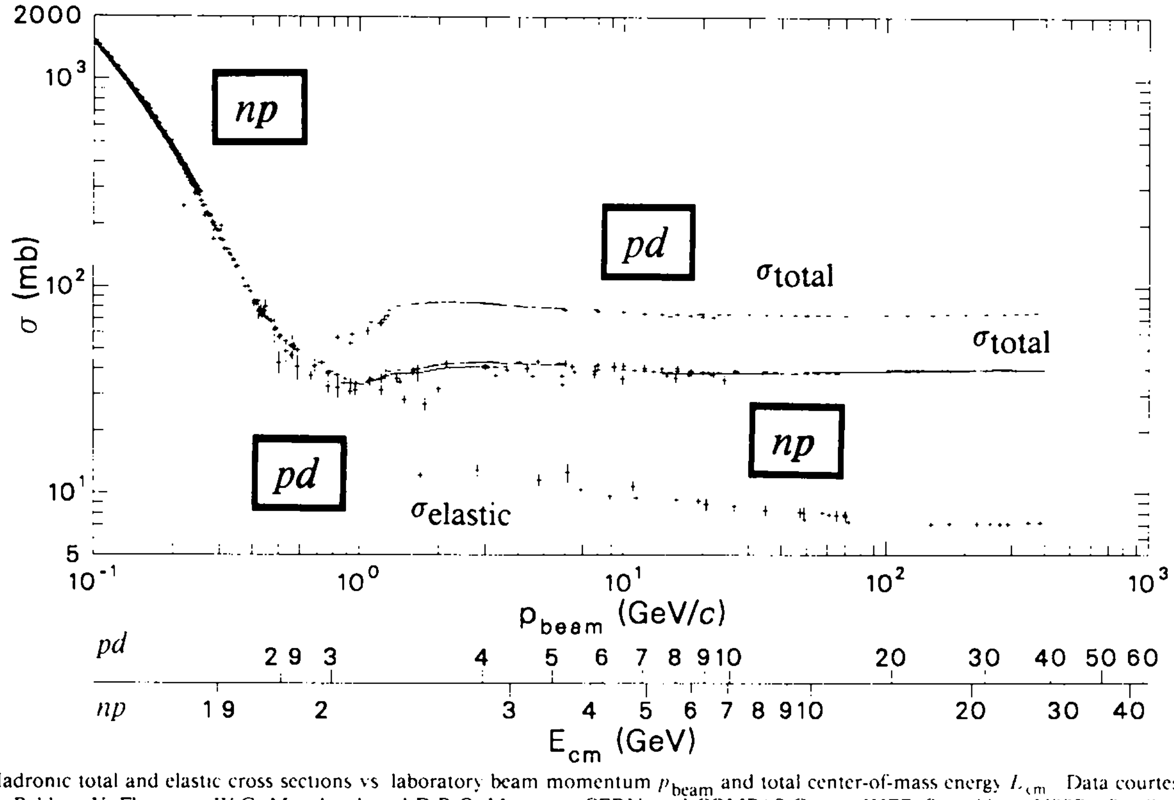


Hadronic total and elastic cross sections vs. laboratory beam momentum p_{beam} and total center-of-mass energy E_{cm}. Data courtesy A. Baldini, V. Flaminio, W.G. Moorhead, and D.R.O. Morrison, CERN; and COMPAS Group, IHEP, Serpukhov, USSR. See *Total Cross-Sections for Reactions of High Energy Particles*, Landolt-Bornstein, New Series, Vol. I2a and I2b, H. Schopper, Ed. (1987).

PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)

Hadronic Cross Sections

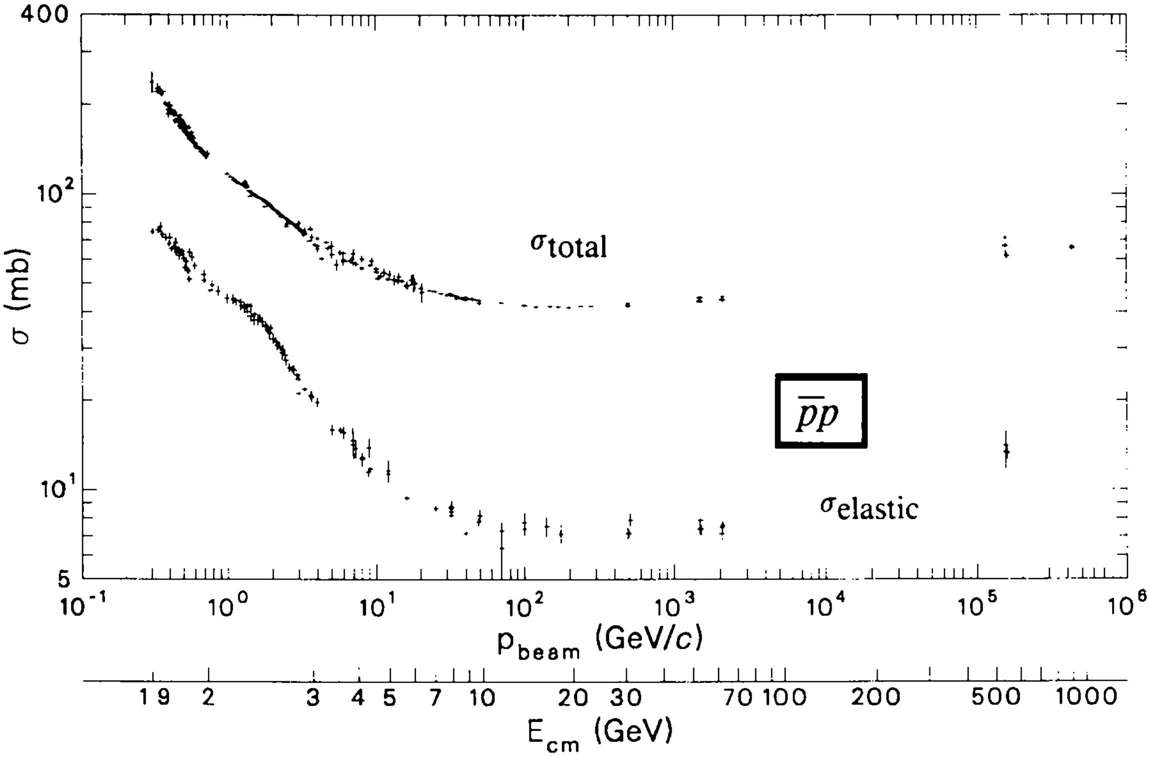


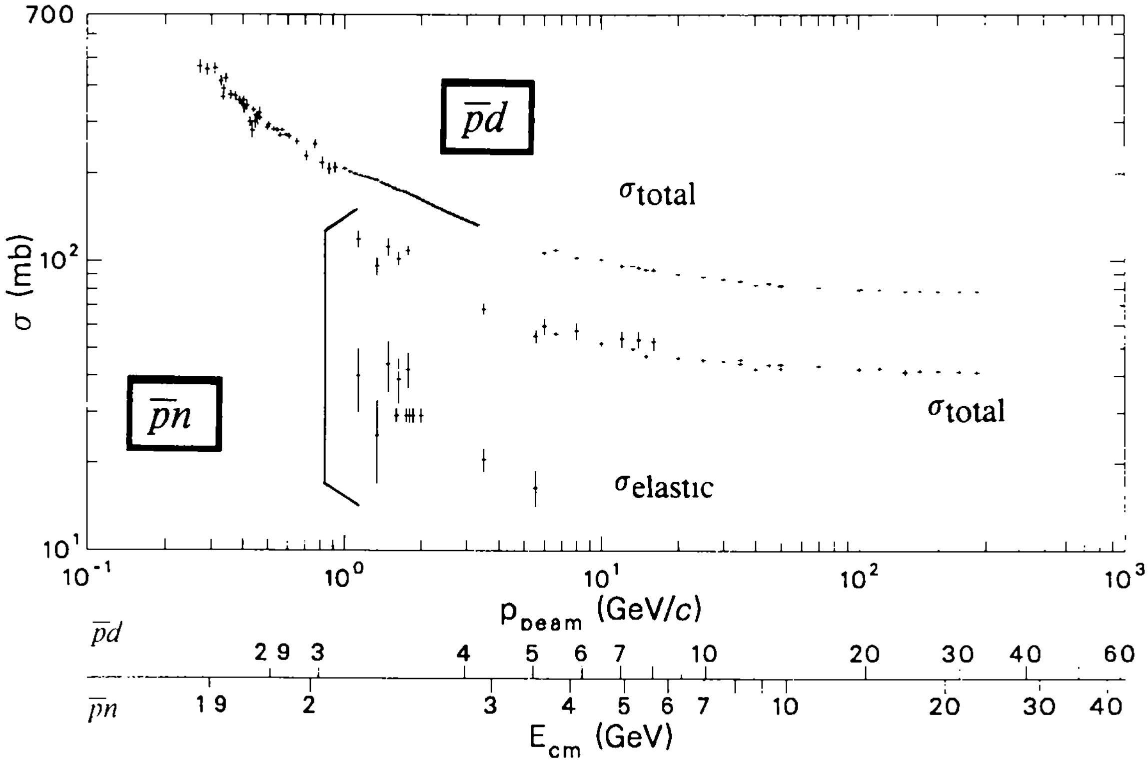


Hadronic total and elastic cross sections vs laboratory beam momentum p_{beam} and total center-of-mass energy E_{cm}. Data courtesy A. Baldini, V. Flaminio, W.G. Moorhead and D.R.O. Morrison, CERN, and COMPAS Group, IHEP, Serpukhov, USSR. See *Total Cross-Sections for Reactions of High Energy Particles*, Landolt-Bornstein, New Series, Vol. 12a and 12b, H. Schopper, Ed. (1987)

PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES (Cont'd)

Hadronic Cross Sections





Hadronic total and elastic cross sections vs laboratory beam momentum p_{beam} and total center-of-mass energy E_{cm}. Data courtesy A Baldini, V Flaminio, W G Moorhead and D R O Morrison, CERN, and COMPAS Group, IHEP, Serpukhov, USSR. See *Total Cross-Sections for Reactions of High Energy Particles*, Landolt-Bornstein, New Series, Vol 12a and 12b, H Schopper Ed (1987)

Illustrative Key to the Full Listings

Name of particle ("old" name used before 1986 renaming scheme also given if different, see Introductory Text for details)

$a_0(1200)$

$I^G(J^{PC}) = 1^-(0^{++})$

Particle quantum numbers (where known)

Indicates particle omitted from Particle Properties Summary Table, implying particle's existence is not confirmed

OMITTED FROM SUMMARY TABLE

Evidence not compelling, may be a kinematic effect

General comments on particle

Quantity tabulated below

$a_0(1200)$ MASS

Top line gives our best value (and error) of quantity tabulated here, based on weighted average of measurements used (could also be from fit, best limit, estimate, or other evaluation) See next page for details

"Document id" for this result, full reference given below

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1207 ± 6 OUR AVERAGE						
1210 ± 8	3000	FENNER	87	MMS	−	3 5 $\pi^- p$
1198 ± 10		PIERCE	83	ASPK	+	2 1 $K^- p$
1216 ± 11 ± 9	1500	[1] MERRILL	81	HBC	0	3 2 $K^- p$
• • • We do not use the following data for averages, fits, limits, etc • • •						
1192 ± 16	200	LYNCH	81	HBC	±	2 7 $\pi^- p$

[1] Systematic error was added quadratically by us in our 1986 edition

Measurement technique (see abbreviations on next page)

Footnote number for this measurement. See footnote(s) below

Number of events *above background*

Charge(s) of particle(s) detected

$a_0(1200)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
41^{+11}_{-10} OUR AVERAGE Error includes scale factor of 1 8 See the ideogram below						
50 ± 8		PIERCE	83	ASPK	+	2 1 $K^- p$
70^{+30}_{-20}	200	LYNCH	81	HBC	±	2 7 $\pi^- p$
25 ± 5 ± 7		MERRILL	81	HBC	0	3 2 $K^- p$
• • • We do not use the following data for averages, fits, limits, etc • • •						
<60		FENNER	87	MMS	−	3 5 $\pi^- p$

Measured value used in averages, fits, limits, etc.

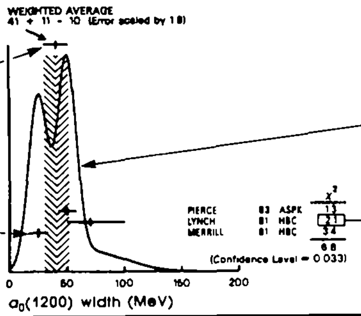
Error in measured value (often statistical only, followed by systematic if separately known, the two are combined in quadrature for averaging and fitting)

Measured value *not used* in averages, fits, limits, etc , see Introductory Text for explanations

Scale factor > 1 indicates possibly inconsistent data

Reaction producing particle, or general comments

"Change bar" indicates result added or changed since previous edition



Top "data point" indicates average, width of error bar (and shaded pattern below) is ± error on average, scaled by "scale factor" S

Value and error for each experiment

Ideogram to display possibly inconsistent data, curve is sum of Gaussians, one for each experiment (area of Gaussian = 1/error, width of Gaussian = ± error) See Introductory Text for discussion

Contribution of experiment to χ^2 (if no entry present, experiment not used in calculating χ^2 or scale factor because of very large error)

$a_0(1200)$ DECAY MODES

Partial decay mode (labeled by Γ_i)

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$a_0(1200) \to 3\pi$	(65 2 ± 1 2)×10^{-2}	S=1 6
Γ_2	$a_0(1200) \to K\bar{K}$	(34.8 ± 1.2)×10^{-2}	S=1 6
Γ_3	$a_0(1200) \to \eta\pi^\pm$	< 4 9 ×10^{-4}	CL=95%

Our best value for branching fraction as determined from data averaging, fitting, evaluating, limit selection etc This list is basically a compact summary of results in the Branching Ratio section below

$a_0(1200)$ BRANCHING RATIOS

Branching ratio

$\Gamma(3\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.652 ± 0.012 OUR FIT Error includes scale factor of 1 6					
0.643 ± 0.010 OUR AVERAGE					
0.64 ± 0.01	PIERCE	83	ASPK	+	2 1 $K^- p$
0 74 ± 0.06	MERRILL	81	HBC	0	3 2 $K^- p$
• • • We do not use the following data for averages, fits, limits, etc • • •					
0 48 ± 0.15	[2] LYNCH	81	HBC	±	2 7 $\pi^- p$

[2] LYNCH 81 data has questionable background subtraction

Our best value (and error) of quantity tabulated, as determined from constrained fit (using *all significant* measured branching ratios for this particle)

Weighted average of measurements of this ratio only

Footnote (referring to LYNCH 81)

$\Gamma(K\bar{K})/\Gamma_{total}$ Γ_2/Γ

Branching ratio in terms of partial decay mode(s) Γ_i above

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.348 ± 0.012 OUR FIT Error includes scale factor of 1 6					
0.35 ± 0.05	PIERCE	83	ASPK	+	2 1 $K^- p$

$\Gamma(K\bar{K})/\Gamma(3\pi)$ Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.535 ± 0.029 OUR FIT Error includes scale factor of 1 6					
0.50 ± 0.03	MERRILL	81	HBC	0	3 2 $K^- p$

Confidence level for measured upper limit

$\Gamma(\eta$ (neutral decay) $\pi^\pm)/\Gamma_{total}$ $.71\Gamma_3/\Gamma$

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<3.5	95	PIERCE	83	ASPK	+	2 1 $K^- p$

References, ordered inversely by year, then author

"Document id" used on data entries above

Partial list of author(s), in addition to first author

Quantum number determinations in this reference

$a_0(1200)$ REFERENCES

FENNER	87	PRL 55 14	+Watson Willis Zorn	(SLAC)
PIERCE	83	PL 123B 230		(FNAL) IJP
LYNCH	81	PR D24 610	+Jones+	(CLEO Collab)
MERRILL	81	PRL 47 143	+Armstrong Rittenberg Wagman	(SACL CERN)

Journal, report, preprint, etc (see abbreviations on next page)

Institution(s) of author(s) (see abbreviations on next page)

Abbreviations Used in the Full Listings

Indicator of Procedure Used to Obtain our Result

OUR AVERAGE	From a weighted average of selected data
OUR FIT	From a constrained or overdetermined multiparameter fit of selected data
OUR EVALUATION	Evaluated by us from measured ratios or other data. Not from a direct measurement
OUR ESTIMATE	Based on the observed range of the data. Not from a formal statistical procedure
OUR LIMIT	For special cases where the limit is evaluated by us from measured ratios or other data. Not from a direct measurement

Measurement Techniques (i.e., Detectors and Methods of Analysis)

AEMS	Argonne effective mass spectrometer
AMY	AMY detector at KEK-TRISTAN
ARG	ARGUS detector at DORIS
ASPK	Automatic spark chambers
ASP	Anomalous single-photon detector
BAKS	Baksan underground scintillation telescope
BC	Bubble chamber
BDMP	Beam dump
BEBC	Big European bubble chamber at CERN
BIS2	BIS-2 spectrometer at Serpukhov
BONA	Bonanza nonmagnetic detector at DORIS
BPWA	Barrelet-zero partial wave analysis
CALO	Calorimeter
CBAL	Crystal Ball detector at SLAC-SPEAR or DORIS
CC	Cloud chamber
CCD	Charge-coupled device
CELL	CELLO detector at DESY
CHRM	CHARM neutrino detector at CERN
CIBS	CERN-IHEP boson spectrometer
CLEO	Cornell magnetic detector at CESR
CNTR	Counters
COSM	Cosmology and astrophysics
CUSB	Columbia U. - Stony Brook segmented NaI detector at CESR
DASP	DESY double-arm spectrometer
DBC	Deuterium bubble chamber
DLCO	DELCO detector at SLAC SPEAR or SLAC-PEP
DM1	Magnetic detector no. 1 at Orsay DCI collider
DM2	Magnetic detector no. 2 at Orsay DCI collider
DPWA	Energy-dependent partial wave analysis
DUD	Deep Underground Detector (IMB)
ELEC	Electronic combination
EMC	European muon collaboration detector at CERN
EMUL	Emulsions
FBC	Freon bubble chamber
FIT	Fit to previously existing data
FMPS	Fermilab Multiparticle Spectrometer
FRAB	ADONE *BB* group detector
FRAG	ADONE γγ group detector
FRAM	ADONE MEA group detector
GAM2	IHEP hodoscope Cerenkov γ calorimeter GAMS-2000
GAM4	CERN hodoscope Cerenkov γ calorimeter GAMS-4000
GGM	CERN Gargamelle bubble chamber
GOLI	CERN Goliath spectrometer
HBC	Hydrogen bubble chamber
HDBC	Hydrogen and deuterium bubble chambers
HEBC	Helium bubble chamber
HEPT	Helium proportional tubes
HLBC	Heavy-liquid bubble chamber
HOME	Homestake underground scintillation detector
HRS	SLAC high-resolution spectrometer
HYBR	Hybrid: bubble chamber + electronics
IMB	Irvine-Michigan-Brookhaven underground Cherenkov detector
INDU	Magnetic induction
IPWA	Energy independent partial-wave analysis
JADE	JADE detector at DESY
KAMI	KAMIOKANDE underground Cherenkov detector
KOLR	Kolar Gold Field underground detector
LASS	Large angle superconducting solenoid spectrometer at SLAC
LENA	Nonmagnetic lead-glass NaI detector at DORIS
MAC	MAC detector at PEP/SLAC
MBR	Molecular beam resonance technique
MDRP	Millikan drop measurement
MICA	Underground mica deposits
MLEV	Magnetic levitation
MMS	Missing mass spectrometer
MPSF	Multiparticle spectrometer at Fermilab
MPS	Multiparticle spectrometer at BNL
MPWA	Model-dependent partial wave analysis
MRK1	SLAC Mark-I detector
MRK2	SLAC Mark-II detector
MRK3	SLAC Mark-III detector
MRKJ	Mark-J detector at DESY
MRS	Magnetic resonance spectrometer
NEUT	Neuland large-angle neutrino spectrometer
NUSX	Mont Blanc NUSEX underground detector
OLYA	Detector at VEPP-4 Novosibirsk
OMEG	CERN OMEGA spectrometer
OSPK	Optical spark chamber
PBC	Propane bubble chamber
PLAS	Plastic detector
PLUT	DESY PLUTO detector
PWA	Partial wave analysis
REDE	Resonance depolarization
RVUE	Review of previous data
SFM	CERN split field magnet
SIGM	Serpukhov CERN-IHEP magnetic spectrometer (SIGMA)
SILI	Silicon detector
SOUD	Soudan underground detector
SPEC	Spectrometer
SPRK	Spark chamber
STRC	Streamer chamber
TASS	DESY TASSO detector
THEO	Theoretical or heavily model-dependent result
TOPZ	TOPAZ detector at KEK-TRISTAN
TPC	TPC detector at PEP/SLAC
TPS	Tagged photon spectrometer at Fermilab
UA1	UA1 detector at CERN
UA2	UA2 detector at CERN
UA5	UA5 detector at CERN
VENS	VENUS detector at KEK TRISTAN
WIRE	Wire chamber
XEBC	Xenon bubble chamber

Journals

AA	Astronomy and Astrophysics
ADVP	Advances in Physics
AFIS	Anales de Fisica
ANP	Annals of Physics
APAH	Acta Phys. Acad. Hungarica
APJ	Astrophysical Journal
APP	Acta Physica Polonica
AP	Atomic Physics
ARNPS	Annual Review of Nuclear & Particle Science
ARNS	Annual Review of Nuclear Science
BAPS	Bulletin of the American Physical Society
BASUP	Bulletin of the Academy of Science USSR (Physics)
CJP	Canadian Journal of Physics
CNPP	Comments on Nuclear and Particle Physics
CZJP	Czechoslovak Journal of Physics
EPL	Europhysics Letters
IJMP	Int. Journal of Modern Physics
JAP	Journal of Applied Physics
JETPL	English Translation of Soviet Physics ZETF Letters
JETP	English Translation of Soviet Physics ZETF
JINR	Joint Inst. for Nucl. Research
JPCRD	Journal of Physical and Chemical Reference Data
JPSJ	Journal of the Physical Society of Japan
JP	Journal of Physics (A, B, G)
LNC	Letters to Nuovo Cimento
MNRA	Monthly Notices of the Royal Astronomical Society
NAT	Nature
NC	Nuovo Cimento
NIM	Nuclear Instruments and Methods
NP	Nuclear Physics
PDAT	Physik Daten
PL	Physics Letters
PN	Particles and Nuclei
PPSL	Proc. of the Physical Society of London
PRAM	Pramana
PRL	Physical Review Letters
PRPL	Physics Reports (Physics Letters C)
PRSE	Proc. of the Royal Society of Edinburgh
PRSL	Proc. of the Royal Society of London
PR	Physical Review
PS	Physica Scripta
PTP	Progress of Theoretical Physics
RA	Radiochimica Acta
RMP	Reviews of Modern Physics
RNC	La Rivista del Nuovo Cimento
RPP	Reports on Progress in Physics
RRP	Revue Romaine de Physique
SCI	Science
SJNP	Soviet Journal of Nuclear Physics
SPU	Soviet Physics - Uspekhi
YAF	Yadernaya Fisika
ZETFP	Zhurnal Eksp. i Teor. Fiziki, Pis'ma v Redakts
ZETF	Zhurnal Eksp. i Teor. Fiziki
ZNAT	Zeitschrift fur Naturforschung
ZPHY	Zeitschrift fur Physik

Conferences

Conferences are generally referred to by the location at which they were held (e.g. HAMBURG, TORONTO, CORNELL, BRIGHTON, etc.)

Abbreviations Used in the Full Listings *(cont'd)*

Institutions

AACH	Technische Univ Aachen	Aachen West Germany
AARH	Univ of Aarhus	Aarhus Denmark
ABO	Abo Akademi	Abo Finland
ADEL	Adelphi Univ	Garden City NY USA
ADLD	Adelaide Univ	Adelaide Australia
AERE	Atomic Energy Res Estab	Harwell Berks England
AFRR	Armed Forces Radiobiology Research Inst	Bethesda MD USA
AICH	Aichi Univ of Education	Kariya Aichi Pref Japan
AIKO	Inst Kernphys Onderzoek	Amsterdam Netherlands
AKIT	Akita Univ	Akita Japan
ALAH	Univ of Alabama at Huntsville	Huntsville AL USA
ALBA	State Univ of New York at Albany	Albany NY USA
ALBE	Alberta Univ	Edmonton AB Canada
AMST	Univ of Amsterdam	Amsterdam Netherlands
ANIK	Amsterdam NIKHEF	Amsterdam Netherlands
ANKA	Middle East Technical Univ	Ankara Turkey
ANL	Argonne National Lab	Argonne IL USA
ARIZ	Univ of Arizona	Tucson AZ USA
ARZS	Arizona State Univ	Tempe AZ USA
ASCI	USSR Academy of Sciences	Moscow USSR
ATEN	Nuclear Res Centre Demokritos	Athens Greece
ATHU	Univ of Athens	Athens Greece
AUCK	Univ of Auckland	Auckland New Zealand
BAKU	Phys Inst Azerbaijanian Acad Sci	Baku USSR
BARC	Univ de Barcelona	Barcelona Spain
BARI	Univ di Bari	Bari Italy
BART	Bartol Research Foundation	Swarthmore PA USA
BASL	Univ of Basel	Basel Switzerland
BAYR	Univ Bayreuth	Bayreuth West Germany
BCEN	CEN Bordeaux Gradignan	Bordeaux France
BELG	Inst Interuniv des Sci Nuc	Bruxelles Belgium
BELL	Bell Labs	Murray Hill NJ USA
BERG	Univ of Bergen	Bergen Norway
BERL	Inst Hochenergiephys DAW	Berlin-Zeuthen East Germany
BERN	Univ Bern	Bern Switzerland
BGNA	Univ di Bologna	Bologna Italy
BHAB	Bhabha Atomic Research Center	Bombay India
BHEP	Inst of High Energy Physics	Beijing China
BIEL	Univ Bielefeld	Bielefeld West Germany
BING	State Univ of New York at Binghamton	Binghamton NY USA
BIRM	Birmingham Univ	Birmingham England
BISU	Bloomsburg State Univ	Bloomsburg PA USA
BNL	Brookhaven National Lab	Upton LI NY USA
BOHR	Niels Bohr Inst	Copenhagen Denmark
BOIS	Boise State Univ	Boise ID USA
BOMB	Univ of Bombay	Bombay India
BONN	Univ Bonn	Bonn West Germany
BORD	Univ de Bordeaux	Bordeaux France
BOST	Boston Univ	Boston MA USA
BRAN	Brandeis Univ	Waltham MA USA
BRAT	Univ of Bratislava	Bratislava Czechoslovakia
BRCO	Univ of British Columbia	Vancouver BC Canada
BRIS	H H Wills Phys Lab U of Bristol	Bristol England
BROW	Brown Univ	Providence RI USA
BRTD	Bartol Research Foundation	Newark DE USA
BRUN	Brunel Univ	Uxbridge Middlesex England
BRUX	Univ Libre de Bruxelles	Bruxelles Belgium
BUCH	Bucharest State Univ	Bucharest Romania
BUDA	Central Research Inst of Physics	Budapest Hungary
BUFF	State Univ of New York at Buffalo	Buffalo NY USA
BURE	Inst des Hautes Etudes Sci	Bures-sur-Yvette France
CAEN	Lab de Phys Corpusculaire	Caen France
CAGL	Cagliari Univ	Cagliari Italy
CAIW	Carnegie Inst of Washington	Washington DC USA
CAMB	Cambridge Univ	Cambridge England
CANB	Australian National Univ	Canberra Australia
CARA	Univ Central de Venezuela	Caracas Venezuela
CARL	Carleton Univ	Ottawa ON Canada
CASE	Case Western Reserve Univ	Cleveland OH USA
CATH	Catholic Univ of America	Washington DC USA
CAVE	Cavendish Lab Cambridge Univ	Cambridge England
CCAC	Community College of Allegheny County	Pittsburgh PA USA
CDEF	College de France	Paris France
CEA	Cambridge Electron Accel	Cambridge MA USA
CENG	CEN Grenoble	Grenoble France
CERN	European Org for Nuclear Research	Geneva Switzerland
CHIC	Univ of Chicago	Chicago IL USA
CINC	Univ of Cincinnati	Cincinnati OH USA
CIT	Calif Inst of Technology	Pasadena CA USA
CLEF	Univ of Clermont-Ferrand	Clermont-Ferrand France
CLER	Univ de Clermont Ferrand	Clermont-Ferrand France
CLEV	Cleveland State Univ	Cleveland OH USA
CMNS	Comenius Univ	Bratislava Czechoslovakia
CMU	Carnegie-Mellon Univ	Pittsburgh PA USA
CNRC	Canadian National Research Council	Ottawa ON Canada
COLO	Univ of Colorado	Boulder CO USA
COLU	Columbia Univ	New York NY USA
CORN	Cornell Univ	Ithaca NY USA
COSU	Colorado State Univ	Fort Collins CO USA
CRAC	Inst for Nuclear Research	Cracow Poland
CUNY	City Univ of New York	New York NY USA
CURI	Laboratoire Joliot-Curie	Paris France
DALH	Dalhousie Univ	Halifax NS Canada
DARE	Daresbury Nuclear Physics Lab	Daresbury England
DELA	Univ of Delaware	Newark DE USA
DELH	Univ of Delhi	Delhi India
DESY	Deutsches Elektronen-Synchrotron	Hamburg West Germany
DOE	US Department of Energy	Washington DC USA
DORT	Univ Dortmund	Dortmund West Germany
DUKE	Duke Univ	Durham NC USA
DURH	Univ of Durham	Durham England
DUUC	University College	Dublin Ireland
EDIN	Univ of Edinburgh	Edinburgh Scotland
EFI	Enrico Fermi Inst for Nucl Studies	Chicago IL USA
ELMT	Elmhurst College	Elmhurst IL USA
ENSP	Ecole Normale Superieure	Paris France
EOTV	Eotvos Univ	Budapest Hungary
EPOL	Ecole Polytechnique	Palaiseau France
ERLA	Univ Erlangen Nurnberg	Erlangen West Germany
ETH	Swiss Federal Inst of Technology	Zurich Switzerland
FERR	Dipartimento di Fisica dell Universita	Ferrara Italy
FIRZ	Univ di Firenze	Firenze Italy
FISK	Fisk Univ	Nashville TN USA
FLOR	Univ of Florida	Gainesville FL USA
FNAL	Fermi National Accelerator Lab	Batavia IL USA
FOM	Found for Fundamental Res on Matter	Utrecht Netherlands
FRAS	Lab Nazionali del CNEN	Frascati Italy
FREI	Univ of Freiburg	Freiburg West Germany
FRIB	Univ of Fribourg	Fribourg Switzerland
FSU	Florida State Univ	Tallahassee FL USA
FUKI	Fukui Univ	Fukui Japan
FUKU	Fukushima Univ	Fukushima Japan
GENO	Univ di Genova	Genova Italy
GEOR	Georgian Academy of Sciences	USSR
GESC	General Electric Res and Dev Center	Schenectady NY USA
GEVA	Univ de Geneve	Geneva Switzerland
GIFU	Gifu Univ	Gifu Japan
GLAS	Univ of Glasgow	Glasgow Scotland
GMAS	George Mason Univ	Fairfax VA USA
GRAZ	Univ Graz	Graz Austria
GREN	Inst des Sci Nuc Univ de Grenoble	Grenoble France
GSCO	Geological Survey of Canada	Ottawa ON Canada
GUEL	Guelph Univ	Guelph ON Canada
GYEO	Gyeongsang Nat'l Univ	Jinju Korea
HAIF	Technion - Israel Inst of Technology	Haifa Israel
HAMB	Univ Hamburg	Hamburg West Germany
HANN	Hannover Tech Univ	Hannover West Germany
HARV	Harvard Univ	Cambridge MA USA
HAWA	Univ of Hawaii	Honolulu HI USA
HEBR	Hebrew Univ	Jerusalem Israel
HEID	Univ Heidelberg	Heidelberg West Germany
HELS	Helsingin Yliopisto	Helsinki Finland
HIRO	Hiroshima Univ	Hiroshima Japan
HOUS	Univ of Houston	Houston TX USA
HPC	Hewlett-Packard Corp	Cupertino CA USA
IASD	Inst of Advanced Studies	Dublin Ireland
IAS	Inst for Advanced Study	Princeton NJ USA
IBAR	Ibaraki Univ Mito	Ibaraki-ken Japan
IBM	International Business Machines	Palo Alto CA USA
ICTP	Int'l Center for Theoretical Physics	Trieste Italy
IFRJ	Inst de Fisica Rio de Janeiro	Rio de Janeiro Brazil
IIT	Illinois Inst of Tech	Chicago IL USA
ILLC	Univ of Illinois at Chicago	Chicago IL USA
ILLG	Inst Laue-Langevin	Grenoble France
ILL	Univ of Illinois	Urbana IL USA
IND	Indiana Univ	Bloomington IN USA
INEL	Idaho National Engineering Lab	Idaho Falls ID USA
INFN	Ist Nazionale di Fisica Nuclear	Roma Italy
INNS	Phys Inst Univ Innsbruck	Innsbruck Austria
INRM	Inst for Nuclear Research	Moscow USSR
INUS	Inst for Nuclear Study at Tokyo Univ	Tokyo Japan
IOFF	Ioffe Inst of Physics and Tech	Leningrad USSR
IOWA	Univ of Iowa	Iowa City IA USA
IPCR	Inst of Physical and Chemical Research	Saitama-ken Japan
IPNP	Inst de Physique Nucleaire	Paris France
IPN	Inst de Phys Nucleaire	Orsay France
IRAD	Inst du Radium	Paris France
ISU	Iowa State Univ	Ames IA USA
ITEP	Inst for Theor and Exp Phys	Moscow USSR
ITHA	Ithaca College	Ithaca NY USA
ITPU	Inst for Theoretical Physics	Utrecht Netherlands
IUPU	Indiana U - Purdue U at Indianapolis	Indianapolis IN USA
JAGL	Jagellonian Univ	Cracow Poland
JHU	Johns Hopkins Univ	Baltimore MD USA

Abbreviations Used in the Full Listings *(cont'd)*

Institutions *(cont'd)*

JINR	Joint Inst for Nucl Research	Dubna USSR
JULI	Kernforschungsanlage Julich	Julich West Germany
KAGO	Kagoshima Univ	Kagoshima Japan
KANS	Univ of Kansas	Lawrence KS USA
KARL	Univ Karlsruhe	Karlsruhe West Germany
KAZA	Kazakh Academy of Science	Alma-Ata USSR
KEK	Nat Lab for High Energy Phys Japan	Tsukuba-gun Japan
KENT	Kent Univ at Canterbury Kent	Canterbury England
KEYN	Open Univ	Milton Keynes England
KHAR	Phys Tech Inst Acad Sci UkrSSR	Kharkov USSR
KIAE	Kurchatov Inst of Atomic Energy	Moscow USSR
KIAM	Keldysk Inst of Applied Math	Moscow USSR
KIEL	Kiel Univ	Kiel West Germany
KIEV	Physical Technical Inst	Kiev USSR
KINK	Kinki Univ	Osaka Japan
KNTY	Univ of Kentucky	Lexington KY USA
KOBE	Kobe Univ	Kobe Japan
KONS	B P Konstantinov Inst of Nucl Phys	USSR
KYOT	Kyoto Univ	Kyoto Japan
LALO	Linear Accelerator Lab Orsay	Orsay France
LANC	Lancaster Univ	Lancaster England
LANL	UC Los Alamos National Lab	Los Alamos NM USA
LAPP	Lab d Annecy de Phys des Particules	Annecy France
LASL	UC Los Alamos Scientific Lab	Los Alamos NM USA
LAUS	Univ of Lausanne	Lausanne Switzerland
LAVA	Univ of Laval	Quebec Canada
LAVL	Laval Univ	Quebec PQ Canada
LBL	UC Lawrence Berkeley Lab	Berkeley CA USA
LCGT	Lab di Cosmo Geofisica del CNR	Torino Italy
LEBD	Lebedev Physics Inst	Moscow USSR
LEED	Univ of Leeds	Leeds England
LEHI	Lehigh Univ	Bethlehem PA USA
LEHM	Herbert H Lehman College	Bronx NY USA
LEID	Inst Lorentz	Leiden Netherlands
LEMO	Le Moyne College	Syracuse NY USA
LENI	Inst of Nucl Phys USSR Acad Sci	Leningrad USSR
LIBH	Lab Interuniv Belge High Eng	Bruxelles Belgium
LINZ	Linz Inst fur Physik Kepler Hoch	Linz Austria
LISB	Univ de Lisboa	Lisboa Codex Portugal
LIVP	Liverpool Univ	Liverpool England
LLL	Lawrence Livermore Lab	Livermore CA USA
LOCK	Lockheed Research Lab	Palo Alto CA USA
LOIC	Imperial College of Science and Technology	London England
LOQM	Queen Mary College	London England
LOUC	University College	London England
LOWC	Westfield College	London England
LPNP	Lab de Phys Nucl et Hautes Energies	Paris France
LPTP	Lab de Phys Theor et Hautes Energies	Paris France
LRL	UC Lawrence Berkeley Lab	Berkeley CA USA
LSU	Louisiana State Univ	Baton Rouge LA USA
LUND	Univ I Lund	Lund Sweden
LVLN	Univ Catholique de Louvain	Louvain-La-Neuve Belgium
LYON	Univ de Lyon	Villeurbanne France
MADR	CIEMAT	Madrid Spain
MADU	Univ Autonome de Madrid	Madrid Spain
MANI	Univ of Manitoba	Winnipeg MB Canada
MANZ	Univ Mainz	Mainz West Germany
MARS	Center National de la Recherche Sci	Marseille France
MASA	Univ of Massachusetts	Amherst MA USA
MASB	Univ of Massachusetts	Boston MA USA
MCGI	McGill Univ	Montreal PQ Canada
MCHS	Univ Manchester	Manchester England
MCMS	McMaster Univ	Hamilton ON Canada
MEIS	Meisei Univ	Hino Tokyo Japan
MELB	Univ of Melbourne	Parkville Australia
MHCO	Mount Holyoke College	South Hadley MA USA
MICH	Univ of Michigan	Ann Arbor MI USA
MILA	Univ di Milano	Milano Italy
MINN	Univ of Minnesota	Minneapolis MN USA
MIT	Massachusetts Inst of Technology	Cambridge MA USA
MIU	Maharishi International Univ	Fairfield IA USA
MIYA	Miyazaki University	Miyazaki Japan
MONP	Univ de Montpellier	Montpellier France
MONS	Univ de l Etat Mons	Mons Belgium
MONT	Univ de Montreal	Montreal PQ Canada
MOSU	Moscow State Univ	Moscow USSR
MPCM	Max Planck Inst fur Chemie	Mainz West Germany
MPEI	Moscow Phys Eng Inst	Moscow USSR
MPIH	Max Planck Inst fur Kernphysik	Heidelberg West Germany
MPIM	Max Planck Inst fur Phys-Astrophys	Munich West Germany
MSU	Michigan State Univ	East Lansing MI USA
MTHO	Mt Holyoke College	South Hadley MA USA
MULH	Centre Univ du Haut-Rhin	Mulhouse France
MUNI	Univ of Munich	Munich West Germany
MURA	Midwestern Univ Research Assoc	Stoughton WI USA
NAAS	North American Aviation Science Center	Thousand Oaks CA USA
NAGO	Nagoya Univ	Nagoya Japan
NAPL	Univ di Napoli	Napoli Italy
NASA	NASA Goddard Space Flight Center	Greenbelt MD USA
NBSB	US National Bureau of Standards	Boulder CO USA
NBS	US National Bureau of Standards	Gaithersburg MD USA
NIJM	R K Univ Nijmegen	Nijmegen Netherlands
NCAR	Nat l Center for Atmospheric Research	Boulder CO USA
NDAM	Univ of Notre Dame	Notre Dame IN USA
NEAS	Northeastern Univ	Boston MA USA
NEUC	Univ de Neuchatel	Neuchatel Switzerland
NIHO	College of Ind Tech Nihon Univ	Chiba Japan
NIIG	Univ of Niigata	Niigata Japan
NIRS	Nat l Inst of Radiological Sciences	Chiba Japan
NMSU	New Mexico State Univ	Las Cruces NM USA
NORD	Nordisk Inst for Teor Atomfys	Copenhagen Denmark
NOTT	Nottingham Univ	Nottingham England
NOVO	Inst of Nucl Phys	Novosibirsk USSR
NPOL	Northern Polytechnic	London England
NRL	Naval Research Laboratory	Washington DC USA
NSF	US National Science Foundation	Washington DC USA
NTUA	National Technical Univ	Athens Greece
NWES	Northwestern Univ	Evanston IL USA
NYU	New York Univ	New York NY USA
OBER	Oberlin College	Oberlin OH USA
OHIO	Ohio Univ	Athens OH USA
OKAY	Okayama Univ	Okayama Japan
OKLA	Univ of Oklahoma	Norman OK USA
OKSU	Oklahoma State Univ	Stillwater OK USA
OREG	Univ of Oregon	Eugene OR USA
ORNL	Oak Ridge National Lab	Oak Ridge TN USA
ORSA	Univ de Paris Fac des Sci	Orsay France
ORST	Oregon State	Corvallis OR USA
OSAK	Osaka Univ	Osaka Japan
OSKC	Osaka City Univ	Osaka Japan
OSLO	Oslo Univ	Oslo Norway
OSU	Ohio State Univ	Columbus OH USA
OTTA	Univ of Ottawa	Ottawa ON Canada
OXF	Oxford Univ	Oxford England
PADO	Univ di Padova	Padova Italy
PARI	Univ Paris (unspecified division)	Paris France
PARM	Univ di Parma	Parma Italy
PATR	Univ of Patras	Patras Greece
PAVI	Univ di Pavia	Pavia Italy
PENN	Univ of Pennsylvania	Philadelphia PA USA
PGIA	Univ di Perugia	Perugia Italy
PHIL	Philipps Univ	Marburg West Germany
PISA	Univ di Pisa	Pisa Italy
PITT	Univ of Pittsburgh	Pittsburgh PA USA
PLAT	State Univ of New York at Plattsburgh	Plattsburgh NY USA
PNL	Pacific Northwest Lab	Richland WA USA
PPA	Princeton-Penn Proton Accel	Princeton NJ USA
PRAG	Inst of Physics CSAV	Prague Czechoslovakia
PRIN	Princeton Univ	Princeton NJ USA
PSLL	Physical Science Lab	Las Cruces NM USA
PSU	Pennsylvania State University	University Park PA USA
PUCB	Pontificia Univ Catolica	Rio de Janeiro Brazil
PURD	Purdue Univ	Lafayette IN USA
QUKI	Queens Univ	Kingston ON Canada
RAL	Rutherford Appleton Lab (formerly RL)	Chilton Did Berks England
REGE	Univ Regensburg	Regensburg West Germany
REHO	Weizmann Inst of Sci	Rehovoth Israel
RHBL	Royal Holloway & Bedford New College	London England
RHEL	Rutherford High Energy Lab	Chilton Did Berks England
RHLC	Royal Holloway College	Englefield Green England
RICE	William Marsh Rice Univ	Houston TX USA
RISC	Rockwell Intl Science Center	Thousand Oaks CA USA
RISO	Research Estab Riso	Roskilde Denmark
RL	Rutherford Lab (formerly RHEL)	Chilton Did Berks England
RMCS	Royal Military College of Science	Shrivenham England
ROCH	Univ of Rochester	Rochester NY USA
ROCK	Rockefeller Univ	New York NY USA
ROMA	Univ di Roma	Roma Italy
ROSE	Rose Polytechnic Inst	Terre Haute IN USA
RPI	Rensselaer Polytechnic Inst	Troy NY USA
RUTG	Rutgers Univ	New Brunswick NJ USA
SACL	Cntr d Etudes Nucl Saclay	Gif-sur-Yvette France
SAGA	Saga Univ	Saga Japan
SANI	Ist Superiore di Sanita	Roma Italy
SBER	San Bernardino State College	San Bernardino CA USA
SCUC	Univ of South Carolina	Columbia SC USA
SEAT	Seattle Pacific College	Seattle WA USA
SEIB	Research Center Seibersdorf	Vienna Austria
SEOU	Korea Univ	Seoul Korea
SERP	Inst of High Energy Physics	Serpukov USSR
SETO	Seton Hall Univ	South Orange NJ USA
SFLA	Univ of South Florida	Tampa FL USA
SFSU	San Francisco State Univ	San Francisco CA USA
SHEF	Univ of Sheffield	Sheffield England
SHMP	Univ of Southampton	Southampton England
SIBE	Inst of Nucl Phys USSR Acad Sci	Siberia USSR
SIEG	Gesamthochschule Siegen	Huttental West Germany
SIN	Swiss Inst of Nuclear Research	Villigen Switzerland

Abbreviations Used in the Full Listings *(cont'd)*

Institutions *(cont'd)*

SLAC	Stanford Linear Accel Center	Stanford CA USA
SLOV	Slovak Academy of Sciences	Bratislava Czechoslovakia
SMAS	Southeastern Massachusetts Univ	North Dartmouth MA USA
SOFI	Bulgarian Acad of Sci	Sofia Bulgaria
STAN	Stanford Univ	Stanford CA USA
STEV	Stevens Inst of Tech	Hoboken NJ USA
STLO	St Louis Univ	St Louis MO USA
STOC	Research Institute of Physics	Stockholm Sweden
STOH	Stockholm Univ	Stockholm Sweden
STON	State Univ of New York at Stony Brook	Stony Brook LI NY USA
STRB	Centre des Res Nucleaires	Strasbourg France
SUGI	Sugiyama Jogaku-en University	Aichi Japan
SURR	Univ of Surrey	Guildford Surrey England
SUSS	Univ of Sussex	Falmer Brighton England
SYDN	Univ of Sydney	Sydney Australia
SYRA	Syracuse Univ	Syracuse NY USA
TAMU	Texas A and M Univ	College Station TX USA
TATA	Tata Inst of Fundamental Research	Bombay India
TBIL	Tbilisi State Univ	Tbilisi USSR
TELA	Univ of Tel Aviv	Tel-Aviv Israel
TEMP	Temple Univ	Philadelphia PA USA
TENN	Univ of Tennessee	Knoxville TN USA
TEXA	Univ of Texas	Austin TX USA
THES	Univ of Thessaloniki	Thessaloniki Greece
TINT	Tokyo Inst of Technology	Tokyo Japan
TMSK	Nucl Phys Inst Tomsk Polytech Inst	Tomsk USSR
TMU	Tokyo Metropolitan Univ	Tokyo Japan
TNTO	Univ of Toronto	Toronto ON Canada
TOHO	Tohoku Univ	Sendai Japan
TOKY	Univ of Tokyo	Tokyo Japan
TORI	Univ di Torino	Torino Italy
TRIK	Rikkyo Univ	Tokyo Japan
TRIN	Trinity College	Dublin Ireland
TRIU	TRIUMF Univ of British Columbia	Vancouver BC Canada
TRST	Univ di Trieste	Trieste Italy
TSUK	Univ of Tsukuba	Tsukuba Japan
TTAM	Tamagawa Univ	Tokyo Japan
TUFT	Tufts Univ	Medford MA USA
TWAS	Waseda Univ	Tokyo Japan
UBEL	Univ of Belgrade	Belgrade Yugoslavia
UCB	Univ of Calif at Berkeley	Berkeley CA USA
UCD	Univ of Calif at Davis	Davis CA USA
UCI	Univ of Calif at Irvine	Irvine CA USA
UCLA	Univ of Calif at Los Angeles	Los Angeles CA USA
UCND	Union Carbide Nuclear Division	Oak Ridge TN USA
UCR	Univ of Calif at Riverside	Riverside CA USA
UCSB	Univ of Calif at Santa Barbara	Santa Barbara CA USA
UCSC	Univ of Calif at Santa Cruz	Santa Cruz CA USA
UCSD	Univ of Calif at San Diego	La Jolla CA USA
UDCF	Univ de Clermont-Ferrand	Aubiere France
UMD	Univ of Maryland	College Park MD USA
UNCS	Union College	Schenectady NY USA
UNC	Univ of North Carolina	Greensboro NC USA
UNM	Univ of New Mexico	Albuquerque NM USA
UOEH	Univ of Occup and Environ Health	Kitakyushu Japan
UPNJ	Upsala College	East Orange NJ USA
UPPS	Gustaf Werner Inst	Uppsala Sweden
URBI	Univ di Urbino	Urbino Italy
USC	Univ of Southern California	Los Angeles CA USA
USF	University of San Francisco	San Francisco CA USA
USIE	University of Siegen	Siegen West Germany
USSR	Unspecified USSR institution	USSR
USTL	Univ Sci et Tech du Languedoc	Montpellier France
UTAH	Univ of Utah	Salt Lake City UT USA
UTRE	Univ of Utrecht	Utrecht Netherlands
UTRO	Univ of Trondheim	Dragvoll Norway
VALE	Univ de Valencia	Valencia Spain
VALP	Valparaiso Univ	Valparaiso IN USA
VAND	Vanderbilt Univ	Nashville TN USA
VICT	Univ of Victoria	Victoria BC Canada
VIEN	Inst for High Energy Physics A A S	Vienna Austria
VIRG	Univ of Virginia	Charlottesville VA USA
VPI	Virginia Polytechnic Inst State Univ	Blacksburg VA USA
VRIJ	Vrije Univ	Amsterdam Netherlands
WARS	Univ of Warsaw	Warsaw Poland
WASE	Sci and Eng Research Lab Waseda Univ	Tokyo Japan
WASH	Univ of Washington	Seattle WA USA
WAYN	Wayne State Univ	Detroit MI USA
WESL	Wesleyan Univ	Middletown CT USA
WIEN	Univ Wien	Wien Austria
WILL	College of William and Mary	Williamsburg VA USA
WINR	Warsaw Inst of Nuclear Research	Warsaw Poland
WISC	Univ of Wisconsin	Madison WI USA
WITW	Univ of the Witwatersrand	Johannesburg S Africa
WMIU	Western Michigan Univ	Kalamazoo MI USA
WOOD	Woodstock College	Woodstock MD USA
WUPG	Gesamthochschule Wuppertal	Wuppertal West Germany
WUPP	Univ Wuppertal	Wuppertal West Germany
WURZ	Univ Wurzburg	Wurzburg West Germany
WUSL	Washington Univ	St Louis MO USA
WYOM	Univ of Wyoming	Laramie WY USA
YALE	Yale Univ	New Haven CT USA
YERE	Yerevan Physics Inst	Yerevan Armenia USSR
YOKO	Yokohama Univ	Yokohama Japan
YORK	York Univ	Toronto ON Canada
ZAGR	Inst Rudjer Boskovic	Zagreb Yugoslavia
ZARA	Univ of Zaragosa	Zaragosa Spain
ZEEM	Zeeman Lab Univ of Amsterdam	Amsterdam Netherlands
ZURI	Univ Zurich	Zurich Switzerland

GAUGE BOSONS

γ

$I(J^{PC}) = 0,1(1^{--})$

γ MASS

For a review of the photon mass see BYRNE 77

VALUE (MeV)	CL%	DOCUMENT ID		TECN	COMMENT
$< 3 \times 10^{-33}$		CHIBISOV	76		Galactic mag field
• • • We do not use the following data for averages fits, limits, etc • • •					
$< 6. \times 10^{-22}$	99 7	DAVIS	75		Jupiter magfield
$< 7\ 3 \times 10^{-22}$		HOLLWEG	74		Alfven waves
$< 6 \times 10^{-23}$		[1] FRANKEN	71		Low freq res cir
$< 1 \times 10^{-20}$		WILLIAMS	71	CNTR	Tests Gauss law
$< 2\ 3 \times 10^{-21}$		GOLDHABER	68		Satellite data
$< 6 \times 10^{-21}$		[1] PATEL	65		Satellite data
$< 6 \times 10^{-21}$		GINTSBURG	64		Satellite data

[1] Validity questionable See criticism in KROLL 71 and GOLDHABER 71

REFERENCES FOR γ

BYRNE	77	Ast Sp Sci 46 115		(LOIC)
CHIBISOV	76	SPU 19 624		(LEBD)
DAVIS	75	PRL 35 1402	+Goldhaber Nieto	(CIT STON LASL)
HOLLWEG	74	PRL 32 961		(NCAR)
FRANKEN	71	PRL 26 115	+Ampulski	(MICH)
GOLDHABER	71	RMP 43 277	+Nieto	(STON BOHR UCSB)
KROLL	71	PRL 26 1395		(SLAC)
WILLIAMS	71	PRL 26 721	+Faller Hill	(WESL)
GOLDHABER	68	PRL 21 567	+Nieto	(STON)
PATEL	65	PL 14 105		(DUKE)
GINTSBURG	64	Sov Astr AJ7 536		(ASCI)

W

$J = 1$

Measurements of charged weak gauge boson parameters are listed here See also section "OTHER STABLE PARTICLE SEARCHES"

W MASS

The fit uses the W and Z mass and mass difference measurements

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	COMMENT
81.0 ± 1.3 OUR FIT					
80.9 ± 1.4 OUR AVERAGE					
80 2 ± 0 6 ± 1 4	251	[1] ANSARI	87	UA2	$p\bar{p}$ E_{cm}=546 630 GeV
$83\ 5^{+1\ 1}_{-1\ 0}$ ± 2 7	86	[2] ARNISON	86	UA1	$p\bar{p}$ E_{cm}=546 630 GeV
• • • We do not use the following data for averages fits limits etc • • •					
81 2 ± 1 0 ± 1 4	119	[1] APPEL	86	UA2	Repl by ANSARI 87
$81^{+6.}_{-7}$	14	[3] ARNISON	84D	UA1	$p\bar{p}$ E_{cm}=546 GeV
83 1 ± 1 9 ± 1 3	37	BAGNAIA	84	UA2	$p\bar{p}$ E_{cm}=546 GeV
81 ± 5	6	ARNISON	83	UA1	Repl by ARNISON 83D
80 9 ± 2 9	27	ARNISON	83D	UA1	$p\bar{p}$ E_{cm}=546 GeV
81 0 ± 2 8		BAGNAIA	83	UA2	Repl by BAGNAIA 84
80^{+10}_{-6}	4	BANNER	83B	UA2	$p\bar{p}$ E_{cm}=546 GeV

[1] There are two contributions to the systematic error (± 1 4) one (± 1 3) which cancels in $m(W)/m(Z)$ and one (± 0 5) which is non cancelling These were added in quadrature

[2] This is enhanced subsample of 172 total events

[3] Using $W^{\pm} \to \mu^{\pm}\nu$

W WIDTH

VALUE (GeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<6 5	90	86	[4] ARNISON	86	UA1	$p\bar{p}$ E_{cm}=546 630 GeV
• • • We do not use the following data for averages fits limits etc • • •						
<7	90	251	ANSARI	87	UA2	$p\bar{p}$ E_{cm}=546.630 GeV
<7	90	119	APPEL	86	UA2	$p\bar{p}$ E_{cm}=546 630 GeV
<7	90	27	ARNISON	83D	UA1	$p\bar{p}$ E_{cm}=546 GeV

[4] If systematic error is neglected result is $2\ 7^{+1\ 4}_{-1\ 5}$ GeV This is enhanced subsample of 172 total events

W ANOMALOUS MAGNETIC MOMENT ($\Delta\kappa$)

The full magnetic moment is given by $\mu(W) = e(2-\Delta\kappa)/2m(W)$ In the Standard Model $\Delta\kappa = 0$ The parameter Λ appearing below is a regularization cutoff and may correspond to the energy scale where the structure of the W boson becomes manifest

VALUE ($e/2m(W)$)	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •			
	[5] GRIFOLS	88	THEO
	[6] GROTCH	87	THEO
	[7] VANDERBIJ	87	THEO
	[8] GRAU	85	THEO
	[9] SUZUKI	85	THEO
	[10] HERZOG	84	THEO

[5] GRIFOLS 88 uses deviation from ρ parameter to set limit $\Delta\kappa \leq 65\ (M_W^2/\Lambda^2)$

[6] GROTCH 87 finds the limit $-37 < \Delta\kappa < 73\ 5$ (90% CL) from the experimental limits on $e^+e^- \to \nu\nu\gamma$ assuming three neutrino generations and $-19\ 5 < \Delta\kappa < 56$ for four generations Note their $\Delta\kappa$ has the opposite sign as our definition

[7] VANDERBIJ 87 uses existing limits to the photon structure to obtain $|\Delta\kappa| < 33\ (m(W)/\Lambda)$ In addition VANDERBIJ 87 discusses problems with using the ρ parameter of the Standard Model to determine $\Delta\kappa$

[8] GRAU 85 uses the muon anomaly to derive a coupled limit on the anomalous magnetic dipole and electric quadrapole (λ) moments $1\ 05 > \Delta\kappa\ \ell n(\Lambda/m(W)) + \lambda/2 > -2\ 77$ In the Standard Model $\lambda = 0$

[9] SUZUKI 85 uses partial wave unitarity at high energies to obtain $|\Delta\kappa| \lesssim 190\ (m(W)/\Lambda)^2$ From the anomalous magnetic moment of the muon SUZUKI 85 obtains $|\Delta\kappa| \lesssim 2\ 2/\ell n(\Lambda/m(W))$ Finally SUZUKI 85 uses deviations from the ρ parameter and obtains a very qualitative order of magnitude limit $|\Delta\kappa| \lesssim 150\ (m(W)/\Lambda)^4$ if $|\Delta\kappa| \ll 1$

[10] HERZOG 84 consider the contribution of W boson to muon magnetic moment including anomalous coupling of $WW\gamma$ Obtain a limit $-1 < \Delta\kappa < 3$ for $\Lambda \gtrsim 1$ TeV

W DECAY MODES

W^- modes are charge conjugates of the modes below

	Mode	Fraction (Γ_i/Γ)
Γ_1	$W^+ \to e^+\nu$	$(10\ 0^{+2\ 4}_{-3\ 3}) \times 10^{-2}$
Γ_2	$W^+ \to \mu^+\nu$	$(12^{+7}_{-6}) \times 10^{-2}$
Γ_3	$W^+ \to \tau^+\nu$	$(10\ 2^{+3\ 3}_{-4\ 1}) \times 10^{-2}$
Γ_4	$W^+ \to e^+\nu\gamma$	$< 1\ 0 \times 10^{-2}$
Γ_5	$W^+ \to \mu^+\nu\gamma$	

W BRANCHING RATIOS

$\Gamma(e^+\nu)/\Gamma_{total}$ Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.10 \pm 0.014^{+0.02}_{-0.03}$	248	[11] ANSARI	87C	UA2	$p\bar{p}$ E_{cm}=546 630 GeV
• • • We do not use the following data for averages fits limits etc • • •					
SEEN	119	APPEL	86	UA2	pp E_{cm}=546 630 GeV
SEEN	172	ARNISON	86	UA1	$p\bar{p}$ E_{cm}=546 630 GeV

[11] The first error was obtained by adding the statistical and systematic experimental uncertainties in quadrature The second error reflects the dependence on theoretical prediction of total W cross section σ(546 GeV) = $4\ 7^{+1\ 4}_{-0\ 7}$ nb and σ(630 GeV) = $5\ 8^{+1\ 8}_{-1\ 0}$ nb See ALTARELLI 85B

$\Gamma(\mu^+\nu)/\Gamma(e^+\nu)$ Γ_2/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$1.24^{+0.6}_{-0.4}$	14	ARNISON	84D	UA1	pp E_{cm}=546 GeV

$\Gamma(\tau^+\nu)/\Gamma(e^+\nu)$ — Γ_3/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
1.02 ± 0.20 ± 0.10	32	ALBAJAR	87	UA1	$p\bar{p}$ E_{cm}=546,630 GeV

$\Gamma(e^+\nu\gamma)/\Gamma_{total}$ — Γ_4/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
none in 119 $W \to e\nu$ evts	0	APPEL	86	UA2	$p\bar{p}$ E_{cm}=546 630 GeV
one in 52 $W \to e\nu$ evts	1	[12] ARNISON	84	UA1	$p\bar{p}$ E_{cm}=546 GeV

[12] ARNISON 84 $W \to e\nu\gamma$ one event is consistent with QED Bremsstrahlung Mass not restricted to W mass

$\Gamma(\mu^-\nu\gamma)/\Gamma_{total}$ — Γ_5/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
none in 18 $W \to \mu\nu$ evts	0	[13] ARNISON	84	UA1	$p\bar{p}$ E_{cm}=546 GeV

[13] Mass not restricted to W mass

$\Gamma(e^+\nu\gamma)/\Gamma(e^+\nu)$ — Γ_4/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0 1	90	[14] ARNISON	84	UA1	$p\bar{p}$ E_{cm}=546 GeV

[14] After accounting for selection efficiency and geometric acceptance and requiring $E_T(\gamma)$ > 10 GeV

REFERENCES FOR *W*

GRIFOLS	88	IJMP A3 225	+Peris Sola	(BARC DESY)
Also	87	PL B197 437	Grifols Peris Sola	(BARC DESY)
ALBAJAR	87	PL B185 233	+Albrow Allkofer Arnison Astbury+	(UA1 Collab)
ANSARI	87	PL B186 440	+Bagnaia Banner Battiston+	(UA2 Collab)
ANSARI	87C	PL B194 158	+Bagnaia Banner Battiston+	(UA2 Collab)
GROTCH	87	PR D36 2153	+Robinett	(PSU)
VANDERBIJ	87	PR D35 1088	van der Bij	(FNAL)
APPEL	86	ZPHY C30 1	+Bagnaia Banner Battiston+	(UA2 Collab)
ARNISON	86	PL 166B 484	+Albrow Allkofer Astbury+	(UA1 Collab) J
ALTARELLI	85B	ZPHY C27 617	+Ellis Martinelli	(CERN FNAL FRAS)
GRAU	85	PL 154B 283	+Grifols	(BARC)
SUZUKI	85	PL 153B 289		(LBL)
ARNISON	84	PL 135B 250	+Astbury Aubert Bacci+	(UA1 Collab)
ARNISON	84D	PL 134B 469	+Astbury Aubert Bacci+	(UA1 Collab)
BAGNAIA	84	ZPHY C24 1	+Banner Battiston Blech+	(UA2 Collab)
HERZOG	84	PL 148B 355		(WISC)
Also Erratum	84B	PL 155B 468	Herzog	(WISC)
ARNISON	83	PL 122B 103	+Astbury Aubert Bacci+	(UA1 Collab)
ARNISON	83D	PL 129B 273	+Astbury Aubert Bacci+	(UA1 Collab)
BAGNAIA	83	PL 129B 130	+Banner Battiston Bloch+	(UA2 Collab)
BANNER	83B	PL 122B 476	+Battiston Bloch Bonaudi+	(UA2 Collab)

Z

J = 1

Measurements of neutral weak gauge boson parameters are listed here See also section "OTHER STABLE PARTICLE SEARCHES" Spin is from Standard Model

Z MASS

The fit uses the *W* and *Z* mass and mass difference measurements

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	COMMENT
92.4 ± 1.8 OUR FIT					
93.0 ± 1.4 ± 3.0	14	ARNISON	86	UA1	$p\bar{p}$ E_{cm}=546 630 GeV
• • • We do not use the following data for averages fits limits etc • • •					
91 5 ± 1 2 ± 1 7	25	[1] ANSARI	87	UA2	$p\bar{p}$ E_{cm}=546 630 GeV
92 5 ± 1 3 ± 1 5	13	APPEL	86	UA2	Repl by ANSARI 87
85 8 +7.0 −5 4		[2] ARNISON	84E	UA1	$p\bar{p}$ E_{cm}=546 GeV
92 7 ± 1 7 ± 1 4	4	[3] BAGNAIA	84	UA2	$p\bar{p}$ E_{cm}=546 GeV
95 2 ± 2 5	5	ARNISON	83C	UA1	Repl by ARNISON 83D
95 6 ± 3 2	5	ARNISON	83D	UA1	$p\bar{p}$ E_{cm}=546 GeV
91 9 ± 1 9	4	BAGNAIA	83	UA2	$p\bar{p}$ E_{cm}=546 GeV

[1] ANSARI 87 enters fit through *Z W* mass difference below
[2] ARNISON 84E is from 4 $\mu^+\mu^-$ $1\mu^+\mu^-\gamma$
[3] BAGNAIA 84 is a reanalysis of BAGNAIA 83 after recalibration of calorimeter

Z − W MASS DIFFERENCE

The fit uses the *W* and *Z* mass and mass difference measurements

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
11.4 ± 1.4 OUR FIT				
11.3 ± 1.3 ± 0.9	ANSARI	87	UA2	$p\bar{p}$ E_{cm}=546 630 GeV

Z WIDTH

VALUE (GeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 5.6	90	25	[4] ANSARI	87	UA2	$p\bar{p}$ E_{cm}=546 630 GeV
• • • We do not use the following data for averages fits limits etc • • •						
2 7 ± 2 0 ± 1 0		25	[4] ANSARI	87	UA2	$p\bar{p}$ E_{cm}=546 630 GeV
< 3 2	90	13	[5] APPEL	86	UA2	Repl by ANSARI 87
2 2 +0 7 −0 5 ± 0 2		13	[5] APPEL	86	UA2	Repl by ANSARI 87
< 4 6	90	13	APPEL	86	UA2	Repl by ANSARI 87
< 8.3	90	14	[6] ARNISON	86	UA1	$p\bar{p}$ E_{cm}=546 630 GeV
< 6 5	90	4	[7] BAGNAIA	84	UA2	Repl by ANSARI 87
< 2 6	90	4	BAGNAIA	84	UA2	Repl by ANSARI 87
<10 2	90	4	ARNISON	83C	UA1	Repl by ARNISON 86
< 8 5	90	4	ARNISON	83D	UA1	Repl by ARNISON 86
<11	90	4	BAGNAIA	83	UA2	Repl by ANSARI 87

[4] Quoted values of ANSARI 87 are from direct fit Ratio of *Z* and *W* production gives either Γ(*Z*) < (1 09 ± 0 07) × Γ(*W*) CL = 90% or Γ(*Z*) = (0 82 +0 19 −0 14 ± 0 06) × Γ(*W*) Assuming Standard Model value Γ(*W*) = 2 65 GeV then gives Γ(*Z*) < 2 89 ± 0 19 or = 2 17 +0 50 −0 37 ± 0 16

[5] Ratio of *Z* and *W* production gives either Γ(*Z*) < Γ(*W*) × (1 2 ± 0 1) CL = 90% or Γ(*Z*) = Γ(*W*) × (0 83 +0 26 −0 22) Assuming Standard-Model value Γ(*W*) = 2 65 GeV then gives Γ(*Z*) < (3 2 ± 0 2) or = 2 2 +0 7 −0 5 ± 0.22

[6] If systematic error is neglected result is 3 9 +2 3 −1 5 GeV

[7] Ratio of *Z* and *W* production gives Γ(*Z*) < Γ(*W*) × (0 93 ± 0 09) Assuming Γ(*W*) = 2 77 GeV gives Γ(*Z*) < 2 6 ± 0 3 GeV

Z DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$Z \to e^+e^-$	$(4\ 6^{+1\ 2}_{-1\ 7}) \cdot 10^{-2}$
Γ_2	$Z \to \mu^+\mu^-$	
Γ_3	$Z \to e^+e^-\gamma$	
Γ_4	$Z \to \mu^+\mu^-\gamma$	

Z BRANCHING RATIOS

$\Gamma(e^+e^-)/\Gamma_{total}$ — Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.046 ± 0.009 +0.008 −0.014	39	[8] ANSARI	87C	UA2	$p\bar{p}$ E_{cm}=546 630 GeV
• • • We do not use the following data for averages fits limits etc • • •					
SEEN	13	APPEL	86	UA2	$p\bar{p}$ E_{cm}=546 630 GeV
SEEN	16	ARNISON	86	UA1	$p\bar{p}$ E_{cm}=546 630 GeV
SEEN	4	ARNISON	83C	UA1	$p\bar{p}$ E_{cm}=546 GeV
SEEN	8	[9] BAGNAIA	83	UA2	$p\bar{p}$ E_{cm}=546 GeV

[8] The first error is obtained by adding the statistical and systematic experimental uncertanties in quadrature The second error reflects the dependence on theoretical prediction of total *Z* cross section σ(546 GeV) = 1 3 +0 4 −0 2 nb and σ(630 GeV) = 1 7 +0 5 −0 3 nb See ALTARELLI 85B

[9] BAGNAIA 83 interpret their events as either ($Z \to e^+e^-$) or ($Z \to e^+e^-\gamma$)

$\Gamma(\mu^+\mu^-)/\Gamma_{total}$ — Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
SEEN	1	ARNISON	83C	UA1	$p\bar{p}$ E_{cm}=546 GeV

$\Gamma(e^+e^-\gamma)/\Gamma_{total}$ — Γ_3/Γ

1983 radiative *Z* decay events ($Z \to e^+e^-\gamma$ $Z \to \mu^+\mu^-\gamma$) are in excess of expected bremsstrahlung rate If $Z \to X\gamma$ with $X \to e^+e^-$ the two $e^+e^-\gamma$ events give $m(X)$ ≈ 40–50 GeV electron width of *X* about 1 MeV See also subsections on $W \to e\nu\gamma$ and on *X* hypothesis in section OTHER STABLE PARTICLE SEARCHES

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
one seen in 13 e^+e^- evts	1	[10] APPEL	86	UA2	$p\bar{p}$ E_{cm}=546 630 GeV

one seen in 4 e^+e^- evts	1	[11] ARNISON	83C UA1	$p\bar{p}$ E_{cm}=546 GeV

[10] Includes event of BAGNAIA 83 Probability of internal Bremsstrahlung = 19%

[11] ARNISON 83C event has negative track of 9 ± 1 GeV with calorimeter deposition of 48 ± 1 GeV Interpreted as hard γ plus e^-

$\Gamma(\mu^+\mu^-\gamma)/\Gamma_{total}$ Γ_4/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
two seen in 5 $\mu^+\mu^-$ evts	2	ARNISON	84E UA1	$p\bar{p}$ E_{cm}=546 GeV

CHARGE ASYMMETRY IN $e^+e^- \to \mu^+\mu^-$ (including radiative corrections)

ASYMMETRY	STD MODEL	$s^{1/2}$ (GeV)	DOCUMENT ID	TECN
• • • We do not use the following data for averages fits limits etc • • •				
− 4.8 ± 6 5 ± 1 0	(− 11.5)	39	BEHREND	87C CELL
− 18 8 ± 4 5 ± 1 0	(− 15 5)	44	BEHREND	87C CELL
+ 2 7 ± 4 9	(− 1 2)	13 9	BARTEL	86C JADE
− 11.1 ± 1 8 ± 1 0	(− 8.6)	34 4	BARTEL	86C JADE
− 17 3 ± 4 8 ± 1 0	(− 13 7)	41 5	BARTEL	86C JADE
− 22 8 ± 5 1 ± 1 0	(− 16 6)	44 8	BARTEL	86C JADE
+ 5 3 ± 5.0	(− 1.5)	14.0	ADEVA	85B MRKJ
− 11.7 ± 1 7	(− 8 5)	34.6	ADEVA	85B MRKJ
− 16 7 ± 4 0	(− 16 0)	44 6	ADEVA	85B MRKJ
− 0 063 ± 0 008 ± 0 002	(− 0 063)	29	[12] ASH	85 MAC
− 0 049 ± 0.015 ± 0 005	(− 0.059)	29	[13] DERRICK	85 HRS
− 0.098 ± 0 023 ± 0 005		34 4	[14] ALTHOFF	84F TASS
− 0 076 $^{+0\ 018}_{-0.003}$	(0.060)	29	[15] FERNANDEZ	83 MAC

[12] ASH 85 have total sample of 16000 events

[13] DERRICK 85 observe A = − 0.049 ± 0.015 ± 0 005 consistent with theory value (with radiation corrections) of 0 059

[14] ALTHOFF 84F obtained A = − 0 098 ± 0.023 ± 0.005 $\sin^2\theta_W$ = 0 27 ± 0.07

[15] FERNANDEZ 83 got A = − 0.076 $^{+0\ 018}_{-0\ 003}$ Standard model (including radiative corrections) gives A = − 0.060

CHARGE ASYMMETRY IN $e^+e^- \to \tau^+\tau^-$ (including radiative corrections)

ASYMMETRY	STD MODEL	$s^{1/2}$ (GeV)	DOCUMENT ID	TECN
• • • We do not use the following data for averages fits limits, etc • • •				
− 6 0 ± 2.5 ± 1 0	(8 8)	34 6	BARTEL	85F JADE
− 11 8 ± 4 6 ± 1 0	(14 8)	43 0	BARTEL	85F JADE

REFERENCES FOR Z

ANSARI	87	PL B186 440	+Bagnala Banner Battiston+	(UA2 Collab)
ANSARI	87C	PL B194 158	+Bagnala Banner Battiston+	(UA2 Collab)
BEHREND	87C	PL B191 209	+Buerger Criegee Dainton+	(CELLO Collab)
APPEL	86	ZPHY C30 1	+Bagnala Banner Battiston+	(UA2 Collab)
ARNISON	86	PL 166B 484	+Albrow Allkofer Astbury+	(UA1 Collab)
BARTEL	86C	ZPHY C30 371	+Becker Cords Felst Haidt+	(JADE Collab)
Also	85B	ZPHY C26 507	Bartel Becker Bowdery Cords+	(JADE Collab)
Also	82	PL 108B 140	Bartel Cords Dittmann Eichler+	(JADE Collab)
ADEVA	85B	PRL 55 665	+Becker Becker Szendy+	(MARK J Collab)
Also	82C	PRL 48 1701	Adeva Barber Becker+	(MARK J Collab)
ALTARELLI	85B	ZPHY C27 617	+Ellis Martinelli	(CERN FNAL FRAS)
ASH	85	PRL 55 1831	+Band Blume Camporesi+	(MAC Collab)
BARTEL	85F	PL 161B 188	+Becker Cords Felst+	(JADE Collab)
DERRICK	85	PR D31 2352	+Fernandez Fries Hyman+	(HRS Collab)
ALTHOFF	84F	ZPHY C22 13	+Braunschweig Kirschfink+	(TASSO Collab)
ARNISON	84E	PL 147B 241	+Allkofer Astbury Aubert+	(UA1 Collab)
BAGNAIA	84	ZPHY C24 1	+Banner Battiston Blech+	(UA2 Collab)
ARNISON	83C	PL 126B 398	+Astbury Aubert Bacci+	(UA1 Collab)
ARNISON	83D	PL 129B 273	+Astbury Aubert Bacci+	(UA1 Collab)
BAGNAIA	83	PL 129B 130	+Banner Battiston Bloch+	(UA2 Collab)
FERNANDEZ	83	PRL 50 1238	+Ford Read Smith+	(MAC Collab)

LEPTONS

NOTE ON NEUTRINOS

(by R E Shrock, State Univ of New York, Stony Brook)

In addition to the ν_e, ν_μ, and ν_τ sections, we include a separate section (Searches for Massive Neutrinos and Lepton Mixing) concerned with correlated bounds on possible neutrino mixing and masses In addition, there are sections on the Number of Light Neutrino Types, on Heavy Lepton Searches, and on Constraints from Cosmological and Astrophysical data

To summarize the current (Spring 1988) situation, many intensive searches for possible nonzero neutrino masses and lepton mixing have yielded progressively better upper limits on these quantities There is no uncontested positive evidence for such masses or mixing A description of the experimental situation may be found in the note at the beginning of the section on Searches for Massive Neutrinos and Lepton Mixing

As an aid to understanding the limits on masses and mixings, we recall that in contrast to the other particles in this Review, the neutrinos ν_e, ν_μ, and ν_τ are defined as weak eigenstates (that is, states which couple weakly with unit strength to e μ, and τ) and are not, in general, states of definite mass In the Standard Model, where all neutrinos are assumed to be massless and hence degenerate, it is possible to define the weak eigenstates to be simultaneously mass eigenstates However, in the general case of possibly massive (nondegenerate) neutrinos, the weak eigenstates have no well-defined masses, but instead are linear combinations of mass eigenstates Let us denote the charged leptons as the set $\{\ell_a\}$, a = 1, , n, where $n \geqslant 3$ is the number of generations, with $\ell_1 \equiv e$, $\ell_2 \equiv \mu$, $\ell_3 \equiv \tau$ In the standard $SU(2)_L \times U(1)$ electroweak theory[1] the mixing of the left-handed components of the mass eigenstates $(\nu_j)_L$ to form the weak gauge-group eigenstates $(\nu_{\ell_a})_L$ is specified by the transformation

$$(\nu_{\ell_a})_L = \sum_{j=1}^{n} U_{aj}(\nu_j)_L ,$$

where $U^+ = U^{-1}$ (In the case of Dirac neutrinos there are right-handed components of the ν_j, but they are singlets under the gauge group, in the case of Majorana neutrinos in the standard theory there are no independent right-handed components) The ordering of the mass eigenbasis is defined such that U is as nearly diagonal as possible, i e , $|U_{jj}|$ (no sum on j) $\geqslant |U_{jk}|$, $k \neq j$ This does not imply that $m(\nu_j) > m(\nu_k)$ if $j > k$, although this ordering might be regarded as natural in view of the similar one that obtains in the quark sector The virtue of this convention is that a mass limit on "$m(\nu_{\ell_a})$" can be used as a definite limit on ν_j $j = a$, the dominantly coupled mass eigenstate in ν_{ℓ_a}

Thus, in this general case of n possibly massive (Dirac or Majorana) neutrinos, decays such as $^3H \to$ $^3He + e^- + \bar{\nu}_e$ and $\pi^+ \to \mu^+ + \nu_\mu$, which have been used to set the best bounds on the respective neutrino masses, really consist of incoherent sums of the separate decay modes $^3H \to {}^3He + e^- + \bar{\nu}_j$ and $\pi^+ \to \mu^+ + \nu_k$, where the ν_j, ν_k are mass eigenstates, and the indices j and k

range over the subset $\{1, \ldots, n\}$ allowed by phase space in these two respective decays[2] The coupling strengths for the j^{th} modes are given for the two decays by the factors $|U_{1j}|^2$ and $|U_{2j}|^2$, respectively There are, in addition, certain kinematic factors depending on the $m(\nu_j)$ which enter in determining the branching ratio for the j^{th} decay mode Assuming that the off-diagonal elements of the lepton mixing matrix U are small relative to the diagonal elements, the dominantly coupled decays are the ones with coupling strength $|U_{aj}|^2$, $a = j$, i e , ${}^3H \rightarrow {}^3He + e^- + \overline{\nu}_1$ and $\pi^+ \rightarrow \mu^+ + \nu_2$

It follows that the old neutrino mass limits quoted in the literature for "$m(\nu_e)$", "$m(\nu_\mu)$" and "$m(\nu_\tau)$" should really be interpreted as limits on the corresponding mass eigenstates Specifically, a bound such as the Bergkvist limit,[3] $m(\nu_e) < 60$ eV (90% CL), really constitutes a weighted limit on each of the mass eigenstates ν_j in the weak eigenstate ν_e which are kinematically allowed to occur in tritium decay and which are coupled with strength $|U_{1j}|^2$ sufficiently large to make a significant contribution to the observed spectrum It is thus certainly a limit on ν_1 If leptonic mixing is hierarchical as quark mixing is known to be (at least for the first three generations), i e , $|U_{jj}|^2 >> |U_{jk}|^2$, $j \neq k$, then ν_1 is the only mass eigenstate significantly constrained by a bound on "$m(\nu_e)$" Furthermore, strictly speaking, a neutrino mass limit cannot be stated in isolation, it always contains some implicit dependence on the relevant lepton mixing angles Fortunately, this dependence is relatively unimportant for the dominantly coupled decay modes, i e , $e\overline{\nu}_1$, $\mu\overline{\nu}_2$, and $\tau\overline{\nu}_3$ Since these modes were the ones responsible for the mass limits given previously, the latter can be reinterpreted without significant complication as proper limits on $m(\nu_j)$, $j = 1, 2$, and 3, respectively

In addition to mass and lifetime limits, we have added data on neutrino magnetic dipole moments These are of interest because a massless, purely chiral (empirically, left-handed) Dirac neutrino cannot have a magnetic (or electric) dipole moment The same is true for a Majorana neutrino, whether massless or massive, because of its defining property of being self-conjugate

If one considers the possibility of nonzero masses for neutrinos, for consistency one must also consider the leptonic mixing which would in general occur concomitantly Accordingly we have devoted one section to correlated bounds on neutrino masses and lepton mixing angles These can be divided into two types First, there are those due to decays involving neutrinos in the final state, which must be recognized to have the possible multimode structure pointed out above In the two most sensitive cases suggested as tests for neutrino masses and mixing,[2] one obtains a limit on $m(\nu_j)$ and $|U_{aj}|^2$ individually for each j Second, there are those due to processes involving the propagation and subsequent interaction of neutrinos The latter are often called neutrino "oscillation"[3] limits, although this term is correct only if the differences in neutrino masses are sufficiently small relative to their momenta that the propagation is effectively coherent in a quantum mechanical sense, otherwise, the individual ν_j from a given decay such as $\pi_{\mu 2}$ or $K_{\mu 2}$ propagate in a measurably incoherent manner and there is no "oscillation" Experimentalists usually present their results in terms of a simplifying model in which mixing is assumed to occur only between two neutrino species Then the transformation equation becomes

$$\begin{pmatrix} \nu_{\ell_a} \\ \nu_{\ell_b} \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \nu_i \\ \nu_j \end{pmatrix}$$

Let the distance between the source of the neutrinos and their point of interaction be labeled as x, and their energy as E Assume furthermore that the $m(\nu_j)$ are such that the coherence assumption is valid Then, the probability of an initial ν_{ℓ_a} being equal to ν_{ℓ_b} at time t, or equivalently (given the above assumption) at distance $x = t$, is

$$|\langle \nu_{\ell_b}(0) | \nu_{\ell_a}(t) \rangle|^2 = \sin^2 2\theta \sin^2 \left(\frac{\Delta m^2 x}{4E} \right) ,$$

where

$$\Delta m^2 = m(\nu_i)^2 - m(\nu_j)^2$$

Thus, neutrino oscillation experiments cannot measure individual neutrino masses, but only differences of masses squared, and indeed these are generally weighted in a more complicated way by mixing-matrix coefficients than in the two-species model Experimental results are presented as allowed regions on a plot, the axes of which are $|\Delta m^2|$ and $\sin^2 2\theta$ These are often summarized in terms of the asymptotic limits $|\Delta m^2|_{max}$ for $\sin^2 2\theta = 1$, and $\sin^2 2\theta$ for "large" $|\Delta m^2|$, i e , sufficiently large $|\Delta m^2|$ that the detector averages over many cycles of oscillation (or there ceases to be any coherence) We refer the reader to the original papers for the two-dimensional plots for the purpose of these Full Listings, we shall give only the asymptotic limits

An important question has to do with whether neutrinos are Dirac or Majorana (self-conjugate) particles In the former case neutrinoless double beta decay, $(Z,A) \rightarrow (Z+2, A) + e^- + e^-$, is forbidden from occurring[4] In the Majorana case it may occur in gauge theories if neutrinos are massive In the light-neutrino case an upper limit on neutrinoless double beta decay yields a correlated upper bound on the quantity

$$\overline{m} = \left| \sum_{j=1}^{n} U_{1j}^{2}\, m(\nu_j) \right|$$

and η, the fractional admixture of right-handed leptonic current

The correlated limits given in the section on Massive Neutrinos and Lepton Mixing are in digital form For recent compendia of limits in convenient graphical form, see e g , Refs 5-6

Further explanatory notes are included in the Full Listings

References

1 S Weinberg, Phys Rev Lett **19**, 1264 (1967), A Salam, in *Elementary Particle Theory Relativistic Groups and Analyticity*, ed N Svartholm (Alqvist and Wiksell, Stockholm, 1968), p 367 See also S Glashow, Nucl Phys **22**, 579 (1961), S Glashow, J Iliopoulos, and L Maiani, Phys Rev **D2**, 1285 (1970), and, for the n=3 case, M Kobayashi and T Maskawa, Prog Theor Phys **49**, 652 (1973)

2 R E Shrock, Phys Lett **96B**, 159 (1980), Phys Rev **D24**, 1232 (1981), Phys Rev **D24**, 1275 (1981), and Phys Lett **112B** 382 (1982)

3 Z Maki, M Nakagawa, and S Sakata, Prog Theor Phys **28**, 870 (1962), B Pontecorvo, Sov Phys JETP **6**, 429 (1957), and **7**, 172 (1958), Zh Ek Theor Fiz **53**, 1717 (1967), Sov Phys JETP **26**, 984 (1968), V Gribov and B Pontecorvo, Phys Lett **28B**, 493 (1969)

4 For studies of neutrinoless double beta decay, see H Primakoff and S P Rosen, Ann Rev Nucl Sci **31**, 145 (1981), S P Rosen, *Proceedings of 1981 International Conference on Neutrino Physics and Astrophysics* (Maui, Hawaii), eds R J Sens et al , v 2, p 76, W C Haxton, G L Stephenson, Jr , and D Strottman, Phys Rev Lett **47**, 153 (1981), M Doi, T Kotani, H Nishiura, K Okuda, and E Takasugi, Phys Lett **103B**, 219 (1981), and Prog Theor Phys **66**, 1739 and 1765 (1981), M Doi, T Kotani, and E Takasugi, Prog Theor Phys Supp **83**, 1 (1985), and W C Haxton, *Proceedings, Intersections between Particle and Nuclear Physics, Steamboat Springs, 1984 (1986), p 980*

5 F Boehm and P Vogel, Ann Rev Nucl Part Sci **34**, 125 (1984)

6 R E Shrock, in *Proceedings of the Third LAMPF II Workshop*, eds J C Allred et al (LASL, 1983), p 316

ν_e

$J = \frac{1}{2}$

Not in general a mass eigenstate

ν_e MASS

Applies to ν_1 the primary mass eigenstate in ν_e Would also apply to any other ν_j which mixes strongly in ν_e and has sufficiently small mass that it can occur in the respective decays The neutrino mass may be of Dirac or Majorana type the former conserves total lepton number while the latter violates it In general either would violate lepton family number since nothing forces the neutrino mass eigenstates to coincide with the neutrino interaction eigenstates For limits on Majorana ν_e mass see the section on SEARCHES FOR MASSIVE NEUTRINOS AND LEPTON MIXING part (C) entitled SEARCHES FOR NEUTRINOLESS DOUBLE β DECAY

VALUE (eV)		CL%	DOCUMENT ID		TECN	COMMENT
< 18		95	FRITSCHI	86	CNTR	ν_e, tritium
• • • We do not use the following data for averages fits limits etc • • •						
17	to 40		[1] BORIS	87	CNTR	$\overline{\nu}_e$ tritium
< 32		95	KAWAKAMI	87	CNTR	ν_e tritium
< 27		95	WILKERSON	87	CNTR	ν_e, tritium
< 550		68	YASUMI	86	CNTR	ν_e ^{163}Ho
20	to 45		[2] BORIS	85	CNTR	ν_e tritium
< 50		90	DERBIN	83	CNTR	ν_e tritium
< 500		90	JONSON	83	CNTR	ν_e ^{193}Pt
> 20		95	[3] LUBIMOV	83	CNTR	ν_e tritium
< 1250			[4] YASUMI	83	CNTR	ν_e ^{163}Ho
< 1300			ANDERSEN	82	CNTR	ν_e ^{163}Ho
< 65		95	SIMPSON	81	CNTR	ν_e tritium
14	to 46	99	[5] LUBIMOV	80	SPEC	ν_e tritium
< 35		90	[5] TRETYAKOV	76	SPEC	ν_e tritium
< 4	5×10^5	90	CLARK	74	ASPK	K_{e3} decay
< 100			PIEL	73	CNTR	ν_e, tritium
< 60		90	BERGKVIST	72	CNTR	ν_e tritium
< 86		90	RODE	72	CNTR	ν_e, tritium
< 500		90	[6] DARIS	69	CNTR	ν_e tritium
< 320		90	SALGO	69	CNTR	ν_e, tritium
< 4100		67	BECK	68	CNTR	ν_e ^{22}Na
550	± 280		FRIEDMAN	58	CNTR	ν_e, tritium
< 500			HAMILTON	53	CNTR	ν_e tritium
< 250			LANGER	52	CNTR	$\overline{\nu}_e$ tritium

[1] See also comment in BORIS 87B

[2] Independent theoretical analysis by BERGKVIST 85B of BORIS 85 data (Lubimov data) disagrees with BORIS 85 claim of nonzero mass

[3] Preliminary result from Brighton Conference See SIMPSON 84 and BERGKVIST 85 whose independent theoretical analyses of LUBIMOV 83 data disagree with LUBIMOV 83 claim of nonzero mass

[4] Limit obtained by YASUMI 83 assumes upper limit on Q-value reported by ANDERSEN 82

[5] TRETYAKOV 76 data included at least in part in LUBIMOV 80 Note that LUBIMOV 83 remarks that the 14 eV lower limit goes to zero if the intrinsic resolution of the conversion lines used for calibration are taken into account A detailed discussion is given by SIMPSON 84 See also the discussion of the LUBIMOV 80 result by BERGKVIST 80 We continue to use upper limit from LUBIMOV 80 in the Stable Particle Summary Table

[6] DARIS 69 value 75 eV (CL = 67%) disagrees with their figure 6 We use figure 6

$\nu_1 - \overline{\nu}_1$ MASS DIFFERENCE

Test of CPT for a Dirac ν (Not a very strong test)

VALUE (eV)		CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits, etc • • •						
< 1250			[7] YASUMI	83	CNTR	ν ^{163}Ho
< 1300			ANDERSEN	82	CNTR	ν ^{163}Ho
< 4	5×10^5	90	CLARK	74	ASPK	K_{e3} decay
< 4100		67	BECK	68	CNTR	ν ^{22}Na

[7] Assumes upper limit on Q-value reported by ANDERSEN 82

ν_1 MEAN LIFE

VALUE (seconds)	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •				
>278	90	[8] LOSECCO	87B	IMB

[8] LOSECCO 87B assumes observed rate of 2 1 SNU (solar neutrino units) comes from sun while 7 0 ± 3 0 is theory

ν_1 (MEAN LIFE) / MASS

VALUE (sec/eV)	CL%	DOCUMENT ID		TECN	COMMENT
>300		[9] REINES	74	CNTR	ν
• • • We do not use the following data for averages, fits, limits, etc. • • •					
> 22	68	[10] OBERAUER	87		ν_R (Dirac)
> 38	68	[10] OBERAUER	87		ν (Majorana)
> 59	68	[10] OBERAUER	87		ν_L (Dirac)
> 30	68	KETOV	86	CNTR	ν (Dirac)
> 20	68	KETOV	86	CNTR	ν (Majorana)

[9] REINES 74 looked for ν_e of nonzero mass decaying to a neutral of lesser mass + γ. Used liquid scintillator detector near fission reactor. Finds lab lifetime $6. \times 10^7$ sec or more. Above value of (mean life)/mass assumes average effective neutrino energy of 0.2 MeV. To obtain the limit 6×10^7 sec REINES 74 assumed that the full $\bar{\nu}_e$ reactor flux could be responsible for yielding decays with photon energies in the interval 0.1 MeV – 0.5 MeV. This represents some overestimate so their lower limit is an over-estimate of the lab lifetime (P. Vogel, private communication 1984).

[10] OBERAUER 87 bounds are from comparison of observed and expected rate of reactor neutrinos.

ν_1 MAGNETIC MOMENT

Must vanish for Majorana neutrino or purely chiral massless Dirac neutrino.

VALUE (μ_B)	CL%	DOCUMENT ID		TECN	COMMENT
$< 1.5 \times 10^{-10}$	90	KYULDJIEV	84	RVUE	$\nu_e e \to \bar{\nu}_e e$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 1 \times 10^{-12}$		[11,12] GOLDMAN	88	ASTR	Supernova SN1987A
$< 1.1 \times 10^{-11}$		[12] FUKUGITA	87	ASTR	Cooling helium stars
$< 8.5 \times 10^{-11}$		BEG	78	ASTR	Stellar plasmons
$< 1.4 \times 10^{-9}$		[13] BERNSTEIN	63	RVUE	Reactor ν_e
$< 1 \times 10^{-10}$		BERNSTEIN	63	ASTR	Cooling white dwarfs
$< 1.4 \times 10^{-9}$		COWAN	57	CNTR	Reactor $\bar{\nu}_e$

[11] A limit of 10^{-13} is obtained with even more model dependence.
[12] Significant dependence on details of stellar models.
[13] BERNSTEIN 63 is a theoretical analysis of reactor $\bar{\nu}_e$ scattering data.

REFERENCES FOR ν_e

GOLDMAN	88	PRL 60 1789	+Aharanov, Alexander, Nussinov	(TELA)
BORIS	87	PRL 58 2019	+Golutvin, Laptin+	(ITEP, ASCI)
BORIS	87B	JETPL 45 333	+Golutvin, Laptin+	(ITEP)
		Translated from ZETFP 45 267		
FUKUGITA	87	PR D36 3817	+Yazaki	(KYOT, TOKY)
KAWAKAMI	87	PL B187 198	+Nisimura+	(TOKY, INUS, TINT, TOHO, KEK+)
LOSECCO	87B	PR D35 2073	+Bionta, Blewitt, Bratton+	(IMB Collab.)
OBERAUER	87	PL B198 113	+von Feilitzsch, Mossbauer	(MUNI)
WILKERSON	87	PRL 58 2023	+Bowles, Browne+	(LANL, PRIN, UCSD)
FRITSCHI	86	PL B173 485	+Holzschuh, Kundig+	(ZURI, SIN)
KETOV	86	JETPL 44 146	+Klimov, Nikolaev, Mikaelyan+	(KIAE)
		Translated from ZETFP 44 114		
YASUMI	86	PL B181 169	+Ando+	(KEK, OSAK, TOHO, TSUK, KYOT, INUS+)
BERGKVIST	85	PL 154B 224		(STOH)
BERGKVIST	85B	PL 159B 408		(STOH)
BORIS	85	PL 159B 217	+Golutvin, Laptin, Lubimov+	(ITEP)
Also	85B	JETPL 42 130	Boris, Golutvin, Laptin, Lubimov+	(ITEP)
		Translated from ZETFP 42 107		
KYULDJIEV	84	NP B243 387		(SOFI)
SIMPSON	84	PR D30 1110		(GUEL)
DERBIN	83	SJNP 38 665	+Popeko	(LENI)
		Translated from YAF 38 1105		
JONSON	83	NP A396 479C	+Andersen, Beyer+	(CERN, AARH, BOHR, LUND)
LUBIMOV	83	Brighton Conf. 386		(ITEP)
YASUMI	83	PL 122B 461	+Rajasekaran+	(KEK, OSAK, TINT, TOHO, TSUK)
ANDERSEN	82	PL 113B 72	+Beyer, Charpak, Derujula+	(AARH, CERN, RISO)
SIMPSON	81	PR D23 649		(GUEL)
BERGKVIST	80	Nu Conf. Erice		(STOH)
LUBIMOV	80	PL 94B 266	+Novikov, Nozik, Tretyakov, Kosik	(ITEP)
Also	80	SJNP 32 154	Kozik, Lubimov, Novikov+	(ITEP)
		Translated from YAF 32 301		
Also	81	JETP 54 616	Lubimov, Novikov, Nozik+	(ITEP)
		Translated from ZETF 81 1158		
BEG	78	PR D17 1395	+Marciano, Ruderman	(ROCK, COLU)
TRETYAKOV	76	BASUP 40 10 1	+	(ITEP)
Also	76B	Nu Conf. Aachen	Tretyakov, Myasoedov, Apalikov+	(ITEP)
CLARK	74	PR D9 533	+Elioff, Frisch, Johnson, Kerth, Shen+	(LBL)
REINES	74	PRL 32 180	+Sobel, Gurr	(UCI)
Also	78	Private Comm.	Barnes	(PURD)
PIEL	73	NP A203 369		(IND)
BERGKVIST	72	NP B39 317		(STOH)
RODE	72	LNC 5 139	+Daniel	(MUNI, MPIH)
DARIS	69	NP A138 545	+St Pierre	(LAVL)
SALGO	69	NP A138 417	+Staub	(ZURI)
BECK	68	ZPHY 216 229	+Daniel	(MPIH)
BERNSTEIN	63	PR 132 1227	+Ruderman, Feinberg	(NYU, COLU)
FRIEDMAN	58	PR 109 2214	+Smith	(BNL)
COWAN	57	PR 107 528	+Reines	(LANL)
HAMILTON	53	PR 92 1521	+Alford, Gross	(PRIN)
LANGER	52	PR 88 689	+Moffat	(IND)

ν_μ

$J = \frac{1}{2}$

Not in general a mass eigenstate. See note on neutrinos in the ν_e section above.

ν_μ MASS

Applies to ν_2, the primary mass eigenstate in ν_μ. Would also apply to any other ν_j which mixes strongly in ν_μ and has sufficiently small mass that it can occur in the respective decays. (This would be nontrivial only for $J \geq 3$, given the ν_e mass limit above.)

VALUE (MeV)	CL%	DOCUMENT ID		TECN	COMMENT
<0.25	90	[1] ABELA	84	SPEC	$m^2 = -0.16 \pm 0.08$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.27	90	[2] JECKELMAN	86	SPEC	$m^2 = -0.097 \pm 0.072$
<0.50	90	ANDERHUB	82	SPEC	$m^2 = -0.14 \pm 0.20$
<0.52	90	[3] LU	80	CNTR	$m^2 = 0.102 \pm 0.119$
<0.57	90	DAUM	79	SPEC	$m^2 = 0.13 \pm 0.14$
<0.65	90	CLARK	74	ASPK	$K_{\mu 3}$ decay

[1] ABELA 84 use PDG84 value for $\pi^\pm$ mass in conjunction with μ momentum measurement in $\pi \to \mu \nu_\mu$ decay.
[2] JECKELMAN 86 uses new π mass value to re-evaluate ABELA 84 limit.
[3] LU 80 combines DAUM 79 $\pi^+ \to \mu^+ \nu_\mu$ measurement with new LU 80 π^- mass and replaces DAUM 79.

$\nu_2 - \bar{\nu}_2$ MASS DIFFERENCE

Test of *CPT* for a Dirac neutrino. (Not a very strong test.)

VALUE (MeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.45	90	CLARK	74	ASPK	$K_{\mu 3}$ decay

ν_2 (MEAN LIFE) / MASS

VALUE (sec/eV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
> 0.11	90	0	[4] FRANK	81	CNTR	$\nu\nu$ LAMPF
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$> 1.0 \times 10^{-2}$	90	0	[4] BLIETSCHAU	78	HLBC	ν_μ CERN GGM
$> 1.7 \times 10^{-2}$	90	0	[4] BLIETSCHAU	78	HLBC	$\bar{\nu}_\mu$ CERN GGM
$> 2.2 \times 10^{-3}$	90	0	[4] BARNES	77	DBC	ν ANL 12 ft
$> 3. \times 10^{-3}$	90	0	[4] BELLOTTI	76	HLBC	ν CERN GGM
$> 1.3 \times 10^{-2}$	90	1	[4] BELLOTTI	76	HLBC	ν CERN GGM

[4] These experiments look for $\nu_\mu \to \nu_e \gamma$ or $\bar{\nu}_\mu \to \bar{\nu}_e \gamma$.

$|(v - c)/c|$ ($v \equiv \nu_2$ VELOCITY)

Expected to be zero for massless neutrino.

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •							
<0.4	95	9800	KALBFLEISCH	79	SPEC		
<2.0	99	77	ALSPECTOR	76	SPEC	0	>5 GeV ν
<4.0	99	26	ALSPECTOR	76	SPEC	0	>5 GeV $\bar{\nu}$

ν_2 MAGNETIC MOMENT

Must vanish for Majorana neutrino or purely Chiral massless Dirac neutrino.

VALUE (μ_B)	CL%	DOCUMENT ID		TECN	COMMENT
$< 1.2 \times 10^{-9}$	90	KYULDJIEV	84	RVUE	$\nu_\mu e \to \nu_\mu e$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 1.1 \times 10^{-11}$		[5,6] FUKUGITA	87	ASTR	Cooling helium stars
$< 8.5 \times 10^{-11}$		[5] BEG	78	ASTR	Stellar plasmons
$< 8.1 \times 10^{-9}$		[7] KIM	74	RVUE	$\nu_\mu e \to \nu_\mu e$
$< 1 \times 10^{-10}$		[8] BERNSTEIN	63	ASTR	Cooling white dwarfs

[5] If $m(\nu_\mu) < 10$ keV.
[6] Significant dependence on details of stellar properties.
[7] KIM 74 is a theoretical analysis of ν_μ reaction data.
[8] If $m(\nu_\mu) < 1$ keV.

REFERENCES FOR ν_μ

FUKUGITA	87	PR D36 3817	+Yazaki	(KYOT TOKY)
JECKELMAN	86	PRL 56 1444	+Nakada Beer+	(ETH FRIB)
ABELA	84	PL 146B 431	+Daum Eaton Frosch Jost Kettle+	(SIN)
KYULDJIEV	84	NP B243 387		(SOFI)
ANDERHUB	82	PL 114B 76	+Boecklin Hofer Kottmann+	(ETH SIN)
FRANK	81	PR D24 2001	+Burman+	(LASL YALE MIT SACL SIN+)
LU	80	PRL 45 1066	+Deiker Dugan Wu Caffrey+	(YALE COLU JHU)
DAUM	79	PR D20 2692	+Eaton Frosch Hirschmann+	(SIN)
Also	76	PL 60B 380	Daum Dubal Eaton Frosch+	(SIN ETH)
Also	78	PL 74B 126	Daum Eaton Frosch Hirschmann+	(SIN)
KALBFLEISCH	79	PRL 43 1361	+Baggett Fowler+	(FNAL PURD BELL)
BEG	78	PR D17 1395	+Marciano Ruderman	(ROCK COLU)
BLIETSCHAU	78	NP B133 205	+Deden Hasert Krenz+	(Gargamelle Collab)
BARNES	77	PRL 38 1049	+Carmony Dauwe Fernandez+	(PURD ANL)
ALSPECTOR	76	PRL 36 837	+	(BNL PURD CIT FNAL ROCK)
BELLOTTI	76	LNC 17 553	+Cavalli Fiorini Rollier	(MILA)
CLARK	74	PR D9 533	+Elioff Frisch Johnson Kerth Shen+	(LBL)
KIM	74	PR D9 3050	+Mather Okubo	(ROCH)
BERNSTEIN	63	PR 132 1227	+Ruderman Feinberg	(NYU COLU)

ν_τ

$J = \frac{1}{2}$

Existence indirectly established from τ decay data combined with ν reaction data See for example FELDMAN 81 KIRKBY 79 rule out $J = 3/2$ using $\tau \to \pi \nu_\tau$ branching ratio

Not in general a mass eigenstate See note on neutrinos in the ν_e section above

ν_τ MASS

Applies to ν_3 the primary mass eigenstate in ν_τ Would also apply to any other ν_j which mixes strongly in ν_τ and has sufficiently small mass that it can occur in the respective decays (This would be nontrivial only for a hypothetical $j \geq 4$ given the ν_e and ν_μ mass limits above)

VALUE (MeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 35	95	12	[1] ALBRECHT	88B	ARG	e^+e^- E_{cm} = 10 GeV
• • • We do not use the following data for averages fits limits etc • • •						
< 76	95	13	[2] ABACHI	87	HRS	e^+e^- E_{cm}=29 GeV
< 85	95		[3] CSORNA	87B	CLEO	e^+e^- E_{cm}=10–11 GeV
< 84	95	10	[4] ABACHI	86	HRS	Repl by ABACHI 87
< 70	95	102	[5] ALBRECHT	85I	ARG	e^+e^- E_{cm}=10 GeV
<125	95	3	[6] BURCHAT	85	MRK2	e^+e^- E_{cm}=29 GeV
<143	95	22	[7] MATTEUZZI	85	MRK2	e^+e^- E_{cm}=29 GeV
<157	95	4	[8] MILLS	85	DLCO	e^+e^- E_{cm}=29 GeV
<250	95		[9] BLOCKER	82D	MRK2	e^+e^- E_{cm}=5 2 GeV
<250	95	594	[10 11] BACINO	79B	DLCO	e^+e^- E_{cm}=3 5–7 4 GeV

[1] ALBRECHT 88 bound comes from analysis of $\tau \to 5\pi^\pm \nu_\tau$ decay mode
[2] Bound comes from analysis of $\tau \to 5\pi^\pm (\pi^0) \nu_\tau$ decay mode in 13 decay events
[3] CSORNA 87B also quote result as $31 \pm 25 \pm 20$ MeV Bound comes from analysis of $\tau \to 3\pi^\pm (\pi^0) \nu_\tau$ decay mode
[4] Bound comes from analysis of $\tau \to 5\pi^\pm \pi^0 \nu_\tau$ decay mode (5 events) and to a lesser extent from $\tau \to 5\pi^\pm \nu_\tau$ mode (5 events)
[5] Bound comes from analysis of $\tau \to 3\pi^\pm \nu_\tau$ decay mode
[6] Bound comes from analysis of $\tau \to 5\pi^\pm (\pi^0) \nu_\tau$ decay
[7] Bound comes from analysis of $\tau \to 3\pi^\pm \pi^0 \nu_\tau$ decay mode
[8] Bound comes from analysis of $\tau \to K^\pm K^\mp \pi^\pm \nu_\tau$ decay mode
[9] Bound comes from analysis of $\tau \to \pi \nu_\tau$ decay mode
[10] Bound comes from analysis of leptonic decay spectrum
[11] BACINO 79B experiment rules out V+A decay, disfavors pure V or A and is in good agreement with V−A

ν_τ MAGNETIC MOMENT

VALUE (μ_B)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
$< 1.1 \times 10^{-11}$	[12 13] FUKUGITA	87	ASTR	Cooling helium stars
$< 8\ 5 \times 10^{-11}$	[12] BEG	78	ASTR	Stellar plasmons

[12] If $m(\nu_\tau) < 10$ keV
[13] Significant dependence on details of stellar properties

LIMIT ON ν_τ PRODUCTION IN BEAM DUMP EXPERIMENT

VALUE	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •			
	[14] FRITZE	80	HYBR

[14] FRITZE 80 is CERN SPS experiment with BEBC Neutral current/charged current ratio corresponds to R = (prompt ν_τ-induced events) / (all prompt-ν events) < 0 1 Mixing probability $P(\nu_e \to \nu_\tau) < 0\ 35$ at CL = 90%

REFERENCES FOR ν_τ

ALBRECHT	88	DESY 87 156	+Binder Boeckmann+	(ARGUS Collab)
ALBRECHT	88B	PL B202 149	+Binder Boeckmann+	(ARGUS Collab)
ABACHI	87	PR D35 2880	+Baringer Bylsma DeBonte+	(HRS Collab)
CSORNA	87B	PR D35 2747	+Mestayer Panvini Word+	(CLEO Collab)
FUKUGITA	87	PR D36 3817	+Yazaki	(KYOT TOKY)
ABACHI	86	PRL 56 1039	+Akerlof Baringer Beltrami+	(HRS Collab)
ALBRECHT	85I	PL 163B 404	+Binder Drescher Schubert+	(ARGUS Collab)
BURCHAT	85	PRL 54 2489	+Schmidke Yelton Abrams+	(MARK II Collab)
MATTEUZZI	85	PR D32 800	+Barklow+	(MARK II Collab)
MILLS	85	PRL 54 624	+Pal Alwood Baillon+	(DELCO Collab)
BLOCKER	82D	PL 109B 119	+Dorfan Abrams Alam+	(MARK II Collab)
FELDMAN	81	SLAC PUB 2839 Santa Cruz APS		(SLAC STAN)
FRITZE	80	PL 96B 427		(AACH BONN CERN LOIC OXF SACL)
BACINO	79B	PRL 42 749	+Ferguson Nodulman Slater+	(DELCO Collab)
KIRKBY	79	SLAC PUB 2419 Batavia Lepton Photon Conference		(SLAC) J
BEG	78	PR D17 1395	+Marciano Ruderman	(ROCK COLU)

SEARCHES FOR MASSIVE NEUTRINOS AND LEPTON MIXING

OMITTED FROM SUMMARY TABLE

See the note on neutrinos by R E Shrock in the ν_e section near the beginning of these data Listings A review can be found in GILMAN 86

Searches for indirect effects of neutrino masses and lepton mixing are listed here Direct searches for masses of dominantly coupled neutrinos are listed in the appropriate section on ν_μ ν_e, or ν_τ Results of indirect searches are correlated upper bounds on mixing matrix coefficients $U_{a\ j}$ versus neutrino mass These results are divided into three sections

(A) bounds from particle and nuclear decays
(B) bounds from neutrino reactions
(C) searches for neutrinoless double β decay

Other limits for lepton mixing are found in the muon and tau sections and include muon-electron and muon positron conversion and various lepton-family number violating decays

The situation can be summarized as follows Current experiments yield no evidence for massive neutrinos or lepton mixing except for the following Of these, only the results of the DAVIS 84 and NAKAHATA 88 solar neutrino experiments are not contested by another experiment And these experiments are not direct evidence for a massive neutrino since their results depend on models of the internal structure and dynamics of the sun

(1) Mass of ν_e (more precisely, ν_1, the primary mass eigenstate in ν_e) Consistent with earlier ITEP reports BORIS 87 still observe a nonzero mass 17 eV < $m(\nu_1)$ < 40 eV FRITSCHI 86 appear to disagree with this result obtaining the upper bound $m(\nu_1)$ < 18 eV (95% CL) See also the criticisms of LUBIMOV 83 and BORIS 85B by BERGKVIST 85 and BERGKVIST 85B Experiments searching directly for masses of the μ and τ neutrinos yield only upper limits

(2) SIMPSON 85 reported observation of a kink in ^{3}H β decay, indicating emission of a heavy neutrino with mass $m(\nu_j)$ = 17 keV and $|U_{1j}|^2$ = 0.03 ± 0.01. This finding was contradicted by four subsequent ^{35}S experiments, ALTZITZOGLOU 85, APALIKOV 85, MARKEY 85, and OHI 85. However, SIMPSON 86 reanalyzes the OHI 85 data and claims to find evidence for emission of a 17 keV neutrino with $|U_{1j}|^2$ from 0.01 to 0.02.

(3) CAVAIGNAC 84 reported indication of neutrino oscillations of the type $\bar\nu_e \not\to \bar\nu_e$, from a reactor neutrino experiment at Bugey. However, ZACEK 85 and others rule out almost all of the allowed region in $\sin^2(2\theta)$ and $\Delta(m^2)$ indicated by CAVAIGNAC 84, and the Bugey collaboration in an unpublished report at the 23rd Moriond Workshop, Jan 23–30, 1988 have withdrawn their result.

(4) BERNARDI 86B reports neutrino oscillations of the type $\nu_\mu \to \nu_e$ with $\sin^2(2\theta)$ = from 0.02 to 0.04 and $\Delta(m^2)$ = from 5 to 10 eV^2. This claim is in conflict with previous limits, as the authors of BERNARDI 86B realize.

(5) The results of the 1970–1983 ^{37}Cl radiochemical solar neutrino experiment of DAVIS 84 indicate a solar neutrino flux (of high energy neutrinos, from ^{8}B source) which is considerably smaller than theoretical calculations of this flux. The Kamiokande detector (NAKAHATA 88) has also set an upper bound on the ^{8}B neutrino flux which is smaller than the expected flux. See section on Solar Neutrino Experiment.

See also Bounds on Masses of Neutrinos above.

(A) BOUNDS FROM PARTICLE AND NUCLEAR DECAYS

LIMITS ON $|U_{1j}|^2$ AS FUNCTION OF $m(\nu_j)$

APPLICATION OF KINK AND PEAK SEARCH TEST TO EXISTING DATA

VALUE	CL%	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$< 1 \times 10^{-4}$	68	[1] SHROCK	81	$m(\nu_j)$=10 MeV
$< 5 \times 10^{-6}$	68	[1] SHROCK	81	$m(\nu_j)$=60 MeV
< 1	95	[2] SIMPSON	81B	$m(\nu_j)$=0.1 keV
$< 4 \times 10^{-3}$	95	[2] SIMPSON	81B	$m(\nu_j)$=10 keV
< 0.1	68	[3] SHROCK	80	$m(\nu_j)$=0.1–3 MeV
$< 1 \times 10^{-5}$	68	[4] SHROCK	80	$m(\nu_j)$=80 MeV
$< 3 \times 10^{-6}$	68	[4] SHROCK	80	$m(\nu_j)$=160 MeV

[1] Analysis of $(\pi^+ \to e^+\nu_e)$ / $(\pi^+ \to \mu^+\nu_\mu)$ and $(K^+ \to e^+\nu_e)$ / $(K^+ \to \mu^+\nu_\mu)$ decay ratios.
[2] Application of kink search test to tritium β decay Kurie plot.
[3] Application of test to search for kinks in β decay Kurie plots.
[4] Analysis of $(K^+ \to e^+\nu_e)$ spectrum.

NEW EXPERIMENTS TO APPLY PEAK AND KINK SEARCH TESTS

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 5 \times 10^{-7}$	90	AZUELOS	86	CNTR	$m(\nu_j)$=60 MeV
$< 2 \times 10^{-7}$	90	AZUELOS	86	CNTR	$m(\nu_j)$=80 MeV
$< 3 \times 10^{-7}$	90	AZUELOS	86	CNTR	$m(\nu_j)$=100 MeV
$< 1 \times 10^{-6}$	90	AZUELOS	86	CNTR	$m(\nu_j)$=120 MeV
$< 2 \times 10^{-7}$	90	AZUELOS	86	CNTR	$m(\nu_j)$=130 MeV
$< 8 \times 10^{-6}$		DELEENER	86	CNTR	$m(\nu_j)$=20 MeV
$< 4 \times 10^{-7}$		DELEENER	86	CNTR	$m(\nu_j)$=60 MeV
$< 2 \times 10^{-6}$		DELEENER	86	CNTR	$m(\nu_j)$=100 MeV
$< 7 \times 10^{-6}$		DELEENER	86	CNTR	$m(\nu_j)$=120 MeV
$< 1 \times 10^{-4}$	90	[5] BRYMAN	83B	CNTR	$m(\nu_j)$=5 MeV
$< 1.5 \times 10^{-6}$	90	BRYMAN	83B	CNTR	$m(\nu_j)$=53 MeV
$< 1 \times 10^{-5}$	90	BRYMAN	83B	CNTR	$m(\nu_j)$=70 MeV
$< 1 \times 10^{-4}$	90	BRYMAN	83B	CNTR	$m(\nu_j)$=130 MeV

[5] BRYMAN 83B obtain upper limits from both direct peak search and analysis of BR($\pi \to e\nu$) / BR($\pi \to \mu\nu$). Latter limits are not listed except for this entry (i.e., we list the most stringent limits for given mass).

SEARCHES FOR DECAYS OF MASSIVE ν

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 2 \times 10^{-2}$	68	[6] OBERAUER	87		$m(\nu_j)$=1.5 MeV
$< 8 \times 10^{-4}$	68	[6] OBERAUER	87		$m(\nu_j)$=4.0 MeV
$< 8 \times 10^{-3}$	90	BADIER	86	CNTR	$m(\nu_j)$=400 MeV
$< 8 \times 10^{-5}$	90	BADIER	86	CNTR	$m(\nu_j)$=1.7 GeV
$< 8 \times 10^{-8}$	90	BERNARDI	86	CNTR	$m(\nu_j)$=100 MeV
$< 4 \times 10^{-8}$	90	BERNARDI	86	CNTR	$m(\nu_j)$=200 MeV
$< 6 \times 10^{-9}$	90	BERNARDI	86	CNTR	$m(\nu_j)$=400 MeV
$< 3 \times 10^{-5}$	90	DORENBOS	86	CNTR	$m(\nu_j)$=150 MeV
$< 1 \times 10^{-6}$	90	DORENBOS	86	CNTR	$m(\nu_j)$=500 MeV
$< 1 \times 10^{-7}$	90	DORENBOS	86	CNTR	$m(\nu_j)$=1.6 GeV
$< 7 \times 10^{-7}$	90	[7] COOPER	85	HLBC	$m(\nu_j)$=0.4 GeV
$< 8 \times 10^{-8}$	90	[7] COOPER	85	HLBC	$m(\nu_j)$=1.5 GeV
$< 1 \times 10^{-2}$	90	[8] BERGSMA	83B	CNTR	$m(\nu_j)$=10 MeV
$< 1 \times 10^{-5}$	90	[8] BERGSMA	83B	CNTR	$m(\nu_j)$=110 MeV
$< 6 \times 10^{-7}$	90	[8] BERGSMA	83B	CNTR	$m(\nu_j)$=410 MeV
$< 1 \times 10^{-5}$	90	GRONAU	83		$m(\nu_j)$=160 MeV
$< 1 \times 10^{-6}$	90	GRONAU	83		$m(\nu_j)$=480 MeV

[6] OBERAUER 87 bounds from search for $\nu \to \nu ee$ decay mode using reactor (anti)neutrinos.
[7] COOPER-SARKAR 85 also give limits based on model-dependent assumptions for ν_τ flux. We do not list these. Note that for this bound to be nontrivial, j is not equal to 3, i.e., ν_j cannot be the dominant mass eigenstate in ν_τ since $m(\nu_3)$ < 70 MeV (ALBRECHT 85I). Also of course j is not equal to 1 or 2, so a fourth generation would be required for this bound to be nontrivial.
[8] BERGSMA 83B also quote limits on $|U_{13}|^2$ where the index 3 refers to the mass eigenstate dominantly coupled to the τ. Those limits were based on assumptions about the D_s mass and $D_s \to \tau\nu_\tau$ branching ratio which are no longer valid. See COOPER-SARKAR 85.

KINK SEARCH IN NUCLEAR β DECAY

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.01 to 0.02		[9] SIMPSON	86	THEO	$m(\nu_j)$=17 keV
$< 4 \times 10^{-3}$	99	[10] ALTZITZOG	85		$m(\nu_j)$=17 keV
$< 7.5 \times 10^{-3}$	99	[10] ALTZITZOG	85		$m(\nu_j)$=5–50 keV
$< 8 \times 10^{-3}$	90	[10,11] APALIKOV	85	SPEC	$m(\nu_j)$=80 keV
$< 1.5 \times 10^{-3}$	90	[10] APALIKOV	85	SPEC	$m(\nu_j)$=60 keV
$< 8 \times 10^{-3}$	90	[10] APALIKOV	85	SPEC	$m(\nu_j)$=30 keV
$< 3 \times 10^{-3}$	90	[10] APALIKOV	85	SPEC	$m(\nu_j)$=17 keV
$< 4.5 \times 10^{-2}$	90	[10] APALIKOV	85	SPEC	$m(\nu_j)$= 4 keV
$< 3.0 \times 10^{-3}$	90	[10] MARKEY	85	SPEC	$m(\nu_j)$=5–50 keV
$< 2.5 \times 10^{-3}$	90	[10] MARKEY	85	SPEC	$m(\nu_j)$=17 keV
$< 0.62 \times 10^{-3}$	90	[10] OHI	85	CNTR	$m(\nu_j)$=48 keV
$< 0.90 \times 10^{-3}$	90	[10] OHI	85	CNTR	$m(\nu_j)$=30 keV
$< 1.30 \times 10^{-3}$	90	[10] OHI	85	CNTR	$m(\nu_j)$=20 keV
$< 1.50 \times 10^{-3}$	90	[10] OHI	85	CNTR	$m(\nu_j)$=17 keV
$< 3.30 \times 10^{-3}$	90	[10] OHI	85	CNTR	$m(\nu_j)$=10 keV
0.03 ± 0.01		[12] SIMPSON	85		$m(\nu_j)$=17.1 ± 0.2 keV
$< 2.5 \times 10^{-2}$	90	SCHRECK	83	CNTR	$m(\nu_j)$=30 keV
$< 0.4 \times 10^{-2}$	90	SCHRECK	83	CNTR	$m(\nu_j)$=140 keV
$< 0.8 \times 10^{-2}$	90	SCHRECK	83	CNTR	$m(\nu_j)$=440 keV

[9] SIMPSON 86 is a reanalysis of the OHI 85 data and claims that these data show evidence of heavy neutrino emission with $m(\nu_j)$ = 17 keV and $|U_{1j}|^2$ = from 0.01 to 0.02 consistent with the earlier reported observation by SIMPSON 85. This conclusion strongly disagrees with the conclusion reached by OHI 85 from their analysis of their own data. SIMPSON 86 also states that a similar threshold effect (due to supposed heavy neutrino emission) is seen in several of the other published ^{35}S experiments as well.
[10] Data from ^{35}S β decay.
[11] This limit was taken from the figure 3 of APALIKOV 85. The text gives a more restrictive limit of 1.7×10^{-3} at CL = 90%.
[12] Data from tritium β decay contradicted by ALTZITZOGLOU 85, APALIKOV 85, MARKEY 85, and by OHI 85. Also comment in LINDHARD 86, DRUKAREV 86, and KALBFLEISCH 85.

LIMITS ON $|U_{2j}|^2$ AS FUNCTION OF $m(\nu_j)$

APPLICATION OF PEAK SEARCH TEST TO EXISTING DATA

VALUE	CL%	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$< 6 \times 10^{-6}$	95	[13] ASANO	81	$m(\nu_j)$=240 MeV
$< 5 \times 10^{-7}$	95	[13] ASANO	81	$m(\nu_j)$=280 MeV
$< 6 \times 10^{-6}$	95	[13] ASANO	81	$m(\nu_j)$=300 MeV
$< 3 \times 10^{-2}$	95	[14] SHROCK	81	$m(\nu_j)$=7 MeV
$< 1 \times 10^{-2}$	95	[14] SHROCK	81	$m(\nu_j)$=13 MeV
$< 1 \times 10^{-4}$	68	[14] SHROCK	81	$m(\nu_j)$=13 MeV
$< 3 \times 10^{-5}$	68	[14] SHROCK	81	$m(\nu_j)$=33 MeV
$< 6 \times 10^{-3}$	68	[15] SHROCK	81	$m(\nu_j)$=80 MeV
$< 5 \times 10^{-3}$	68	[15] SHROCK	81	$m(\nu_j)$=120 MeV
$< 5 \times 10^{-2}$	95	[14] SHROCK	80	$m(\nu_j)$=4–6 MeV

[13] Analysis of experiment on $K^+ \to \mu^+\nu_\mu\nu_x\bar\nu_x$ decay.
[14] Analysis of magnetic spectrometer experiment, bubble chamber experiment, and emulsion experiment on $\pi^+ \to \mu^+\nu_\mu$ decay.
[15] Analysis of magnetic spectrometer experiment on $K \to \mu\nu_\mu$ decay.

APPLICATION OF PEAK SEARCH TEST TO NEW EXPERIMENTS

Limit on $|U_{2j}|^2$ as function of $m(\nu_j)$

VALUE	CL%	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$< 2 \times 10^{-2}$	90	DAUM	87	$m(\nu_j)$=1 MeV
$< 1 \times 10^{-3}$	90	DAUM	87	$m(\nu_j)$=2 MeV
$< 6 \times 10^{-5}$	90	DAUM	87	3 MeV < $m(\nu_j)$ < 19.5 MeV
$< 3 \times 10^{-2}$	90	[16] MINEHART	84	$m(\nu_j)$=2 MeV
$< 1 \times 10^{-3}$	90	[16] MINEHART	84	$m(\nu_j)$=4 MeV
$< 3 \times 10^{-4}$	90	[16] MINEHART	84	$m(\nu_j)$=10 MeV
$< 5 \times 10^{-6}$	90	[17] HAYANO	82	$m(\nu_j)$=330 MeV
$< 1 \times 10^{-4}$	90	[17] HAYANO	82	$m(\nu_j)$=70 MeV
$< 9 \times 10^{-7}$	90	[17] HAYANO	82	$m(\nu_j)$=250 MeV
$< 1 \times 10^{-1}$	90	[16] ABELA	81	$m(\nu_j)$=4 MeV
$< 7 \times 10^{-5}$	90	[16] ABELA	81	$m(\nu_j)$=10.5 MeV
$< 2 \times 10^{-4}$	90	[16] ABELA	81	$m(\nu_j)$=11.5 MeV
$< 2 \times 10^{-5}$	90	[16] ABELA	81	$m(\nu_j)$=16–30 MeV
$< 2 \times 10^{-5}$	95	[17] ASANO	81	$m(\nu_j)$=170 MeV
$< 3 \times 10^{-6}$	95	[17] ASANO	81	$m(\nu_j)$=210 MeV
$< 3 \times 10^{-6}$	95	[17] ASANO	81	$m(\nu_j)$=230 MeV
$< 1 \times 10^{-2}$	95	[16] CALAPRICE	81	$m(\nu_j)$=7 MeV
$< 3 \times 10^{-3}$	95	[16] CALAPRICE	81	$m(\nu_j)$=33 MeV

Stable Particle Full Listings
SEARCHES FOR MASSIVE ν's & LEPTON MIXING

[16] $\pi^+ \to \mu^+ \nu_\mu$ peak search experiment
[17] $K^+ \to \mu^+ \nu_\mu$ peak search experiment

PEAK SEARCH IN MUON-CAPTURE

Limit on $|U_{2j}|^2$ as function of $m(\nu_j)$

VALUE	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$<1 \times 10^{-1}$	DEUTSCH	83	$m(\nu_j)$=45 MeV
$<7 \times 10^{-3}$	DEUTSCH	83	$m(\nu_j)$=70 MeV
$<1 \times 10^{-1}$	DEUTSCH	83	$m(\nu_j)$=85 MeV

SEARCHES FOR DECAYS OF MASSIVE ν

Limit on $|U_{2j}|^2$ as function of $m(\nu_j)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<4 \times 10^{-4}$	90	[18] MISHRA	87	CNTR	$m(\nu_j)$=1.5 GeV
$<4 \times 10^{-3}$	90	[18] MISHRA	87	CNTR	$m(\nu_j)$=2.5 GeV
$<0.9 \times 10^{-2}$	90	[18] MISHRA	87	CNTR	$m(\nu_j)$=5 GeV
<0.1	90	[18] MISHRA	87	CNTR	$m(\nu_j)$=10 GeV
$<8 \times 10^{-4}$	90	BADIER	86	CNTR	$m(\nu_j)$=600 MeV
$<1.2 \times 10^{-5}$	90	BADIER	86	CNTR	$m(\nu_j)$=1.7 GeV
$<9 \times 10^{-5}$	90	BERNARDI	86	CNTR	$m(\nu_j)$= 25 MeV
$<3.6 \times 10^{-7}$	90	BERNARDI	86	CNTR	$m(\nu_j)$=100 MeV
$<3 \times 10^{-8}$	90	BERNARDI	86	CNTR	$m(\nu_j)$=200 MeV
$<6 \times 10^{-9}$	90	BERNARDI	86	CNTR	$m(\nu_j)$=350 MeV
$<1 \times 10^{-6}$	90	DORENBOS	86	CNTR	$m(\nu_j)$=500 MeV
$<1 \times 10^{-7}$	90	DORENBOS	86	CNTR	$m(\nu_j)$=1600 MeV
$<0.8 \times 10^{-5}$	90	[19] COOPER-	85	HLBC	$m(\nu_j)$=0.4 GeV
$<1.0 \times 10^{-7}$	90	[19] COOPER-	85	HLBC	$m(\nu_j)$=1.5 GeV

[18] See also limits on $|U_{3j}|$ from WENDT 87.
[19] COOPER-SARKAR 85 also give limits based on model-dependent assumptions for ν_τ flux. We do not list these. Note that for this bound to be nontrivial, j is not equal to 3, i.e. ν_j cannot be the dominant mass eigenstate in ν_τ since $m(\nu_3) < 70$ MeV (ALBRECHT 85I). Also, of course, j is not equal to 1 or 2, so a fourth generation would be required for this bound to be nontrivial.

LIMITS ON $|U_{a,j}|^2$

where a = 1, 2 from ρ parameter in μ decay

VALUE	CL%	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<1 \times 10^{-2}$	68	SHROCK	81B	$m(\nu_j)$=10 MeV
$<2 \times 10^{-3}$	68	SHROCK	81B	$m(\nu_j)$=40 MeV
$<4 \times 10^{-2}$	68	SHROCK	81B	$m(\nu_j)$=70 MeV

LIMITS ON $U_{1,j} \times U_{2,j}$ AS FUNCTION OF $m(\nu_j)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<9 \times 10^{-5}$	90	BERNARDI	86	CNTR	$m(\nu_j)$=25 MeV
$<3.6 \times 10^{-7}$	90	BERNARDI	86	CNTR	$m(\nu_j)$=100 MeV
$<3 \times 10^{-8}$	90	BERNARDI	86	CNTR	$m(\nu_j)$=200 MeV
$<6 \times 10^{-9}$	90	BERNARDI	86	CNTR	$m(\nu_j)$=350 MeV
$<1 \times 10^{-2}$	90	BERGSMA	83B	CNTR	$m(\nu_j)$=10 MeV
$<1 \times 10^{-5}$	90	BERGSMA	83B	CNTR	$m(\nu_j)$=140 MeV
$<7 \times 10^{-7}$	90	BERGSMA	83B	CNTR	$m(\nu_j)$=370 MeV

(B) BOUNDS FROM ν REACTIONS

—— SOLAR ν EXPERIMENTS ——

SOLAR ν FLUX

Until quite recently, the standard flux unit for solar neutrinos was the Solar neutrino unit, SNU = 1×10^{-36} captures/sec/target atom in the ^{37}Cl radiochemical experiment. The Kamiokande II experiment uses cgs units, cm^{-2}sec^{-1}, instead, for the flux integrated over the energy range accepted by their cuts. See below for an approximate conversion factor.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<3.1 \times 10^{6}$cm^{-2}sec^{-1}	90	[20] NAKAHATA	88		Kamiokande II water Cerenkov detector
2.1±0.3 SNU		[21] DAVIS	84		^{37}Cl radiochem
• • • We do not use the following data for averages, fits, limits, etc. • • •					
7.9±2.6 SNU		[22] BAHCALL	88	THEO	Total theor. range
5.8±2.2 SNU		[22] BAHCALL	84	THEO	Est. 3-σ uncert.
5.6 SNU		[22] FILIPPONE	83	THEO	
7.0±3.0 SNU		[22] FILIPPONE	82	THEO	
6.9±1.0 SNU		[22] FOWLER	82	THEO	
7.3 SNU		[22] BAHCALL	80	THEO	

See also the reviews by BAHCALL 85 and BAHCALL 82, and the analysis by EHRLICH 82.

[20] The flux limit given by NAKAHATA 88 represents an integral over the energy range accepted by their cuts, approximately $E_e > 5$–7 MeV on the scattered electron energy from the (predominantly charged-current) neutrino reactions in the water. NAKAHATA 88 cites a theoretical flux of $(5.8 \pm 2.)\times 10^{6}$ cm^{-2}sec^{-1}, with the central value corresponding to 7.9 SNU. Using this approximate conversion factor, the NAKAHATA 88 upper limit would correspond to <4.2 SNU's in the DAVIS 84 ^{37}CL experiment. The limit is consistent with the DAVIS 84 experiment and independently confirms that the observed 8 Boron neutrino flux is smaller than the theoretically calculated flux.

[21] This is the average from the ^{37}Cl experiment of DAVIS 84 at Homestake mine from 1970–1983.
[22] These are theoretical calculations of the solar neutrino flux and are shown for comparison with the measured flux. The uncertainty shown for BAHCALL 84 is the 3σ error.

—— DEEP UNDERGROUND DETECTOR EXPERIMENTS ——

R= (MEASURED FLUX OF ν_μ) / (EXPECTED FLUX OF ν_μ)

VALUE	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.57±0.07	[23] HIRATA	88	Kamiokande II
0.95±0.22	BOLIEV	81	Baksan
0.62±0.17	CROUCH	78	Case Western/UCI

[23] HIRATA 88 error is statistical.

LIMITS ON $\Delta(m^2)$ FOR $\sin^2(2\theta)$=1

From this data BOLIEV 81 obtain the limit $\Delta(m^2) \leq 6 \times 10^{-3}$ eV^2 for maximal mixing $\nu_\mu \to \nu_\mu$ type oscillation.

VALUE (10^{-5} eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>2.2 OR <11.2	90	[24] LOSECCO	85	IMB	Flux-independent

[24] No limits exist for $\sin^2(2\theta) < 0.22$.

$\sin^2(2\theta)$ FOR GIVEN $\Delta(m^2)$ ($\nu_e \leftrightarrow \nu_\mu$)

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.14	90	LOSECCO	87	IMB	$\Delta(m^2) = 1.1\times 10^{-4}$ eV^2

—— REACTOR $\overline{\nu}$ EXPERIMENTS ——

EVENTS (OBSERVED/EXPECTED) FROM REACTOR $\overline{\nu}_e$ EXPERIMENTS

VALUE	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
1.05 ±0.02 ±0.05	VUILLEUMIER	82	$\overline{\nu}_e p \to e^+ n$
0.955±0.035±0.110	[25] KWON	81	$\overline{\nu}_e p \to e^+ n$
0.89 ±0.15	[25] BOEHM	80	$\overline{\nu}_e p \to e^+ n$
0.38 ±0.21	[26,27] REINES	80	
0.40 ±0.22	[26,27] REINES	80	

[25] KWON 81 represents an analysis of a larger set of data from the same experiment as BOEHM 80.
[26] REINES 80 involves comparison of neutral and charged current reactions $\overline{\nu}_e d \to np\overline{\nu}_e$ and $\overline{\nu}_e d \to nne^+$ respectively. Combined analysis of reactor $\overline{\nu}_e$ experiments was performed by SILVERMAN 81.
[27] The two REINES 80 values correspond to the calculated $\overline{\nu}_e$ fluxes of AVIGNONE 80 and DAVIS 79 respectively.

———— $\overline{\nu}_e \not\to \overline{\nu}_e$ ————

$\Delta(m^2)$ FOR $\sin^2(2\theta)$=1

VALUE (eV^2)	CL%	DOCUMENT ID		COMMENT
<0.014	68	[28] VIDYAKIN	87	$\overline{\nu}_e p \to e^+ n$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.05	68	[29] AFONIN	87	$\overline{\nu}_e p \to e^+ n$
<0.05	68	[29] AFONIN	86	$\overline{\nu}_e p \to e^+ n$
<0.019	90	[30] ZACEK	86	$\overline{\nu}_e p \to e^+ n$
<0.07	90	AFONIN	85	$\overline{\nu}_e p \to e^+ n$
<0.02	90	[31] ZACEK	85	$\overline{\nu}_e p \to e^+ n$
<0.016	90	[32] GABATHULER	84	$\overline{\nu}_e p \to e^+ n$
<0.1	90	AFONIN	83	$\overline{\nu}_e p \to e^+ n$
<0.13		BELENKII	83	$\overline{\nu}_e p \to e^+ n$

[28] VIDYAKIN 87 bound is for L = 32.8 and 92.3 m distance from two reactors.
[29] AFONIN 86 and AFONIN 87 also give limits on $\sin^2(2\theta)$ for intermediate values of $\Delta(m^2)$.
[30] This bound is from data for L=37.9 m, 45.9 m, and 64.7 m distance from Gosgen reactor.
[31] See the comment for ZACEK 85 in the section on $\sin^2(2\theta)$ below.
[32] This bound comes from a combination of the VUILLEUMIER 82 data at distance 37.9m from Gosgen reactor and new data at 45.9m.

$\Delta(m^2)$ FOR GIVEN $\sin^2(2\theta)$

VALUE (eV^2)	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.2±0.1	[33] CAVAIGNAC	84	$\overline{\nu}_e p \to e^+ n$

[33] $\sin^2(2\theta)$ = 0.25±0.1. These are from best fit to data; see CAVAIGNAC 84 for plot of allowed regions in these variables. These data from Bugey reactor.

$\sin^2(2\theta)$ FOR "LARGE" $\Delta(m^2)$ $\quad \overline{\nu}_e \not\to \nu_e$

VALUE	CL%	DOCUMENT ID		COMMENT
<0.14	68	[34] VIDYAKIN	87	$\overline{\nu}_e p \to e^+ n$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.21	68	AFONIN	87	$\overline{\nu}_e p \to e^+ n$
<0.21	90	[35] ZACEK	86	$\overline{\nu}_e p \to e^+ n$
<0.34	90	AFONIN	85	$\overline{\nu}_e p \to e^+ n$
<0.19	90	[36] ZACEK	85	$\overline{\nu}_e p \to e^+ n$
<0.16	90	[37] GABATHULER	84	$\overline{\nu}_e p \to e^+ n$
<0.4		[38] BELENKII	83	$\overline{\nu}_e p \to e^+ n$

[34]VIDYAKIN 87 bound is for L = 32 8 and 92 3 m distance from two reactors
[35]This bound is from data for L=37 9 m, 45 9 m and 64 7 m distance from Gosgen reactor
[36]ZACEK 85 (Gosgen reactor) gives two sets of bounds depending on what assumptions are used in the data analysis The bounds in figure 3(a) of ZACEK 85 are progressively poorer for large $\Delta(m^2)$ whereas those of figure 3(b) approach a constant We list the latter Both sets of bounds use combination of data from 37 9, 45 9 and 64 7m distance from reactor ZACEK 85 states Our experiment excludes this area (the oscillation parameter region allowed by the Bugey data, CAVAIGNAC 84) almost completely, thus disproving the indications of neutrino oscillations of CAVAIGNAC 84 with a high degree of confidence
[37]This bound comes from a combination of the VUILLEUMIER 82 data at distance 37 9m from Gosgen reactor and new data at 45 9m
[38]This bound holds for $\Delta(m^2)$ $\cdot$4 eV^2

ACCELERATOR EXPERIMENTS

Bounds on $\Delta(m^2)$ vs $\sin^2(2\theta)$ where $\Delta(m^2)$ is magnitude of $(m^2(\nu_i) - m^2(\nu_j))$ and θ is the mixing angle for the simplifying assumption of mixing between two neutrino families only For a recent set of bounds assuming three neutrino families see BLUMER 85

Each experimental result is a plot giving allowed and excluded regions as functions of $\Delta(m^2)$ and $\sin^2(2\theta)$ We quote two representative limits from each plot 1) $\Delta(m^2)$ for $\sin^2(2\theta)$=1 2) $\sin^2(2\theta)$ for 'LARGE $\Delta(m^2)$ i e sufficiently large $\Delta(m^2)$ that the detector would measure only an effect averaged over many oscillations Experiments are of two general types (A) those which search for $\nu_a \to \nu_b$ (b not equal a), i e the appearance of ℓ_b from charged current reaction of a ν_a beam (B) those which search for the 'disappearance of part of the initial ν_a beam by comparing the number of observed ℓ_a events with the number expected from flux calculations These experiments do not try to observe the anomalous ℓ_bs We label such experiments as $\nu_a \not\to \nu_a$

$\nu_\mu \to \nu_e$

$\Delta(m^2)$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<0.09	90	ANGELINI	86	BEBC	$\sin^2(2\theta)$=1
• • • We do not use the following data for averages fits limits etc • • •					
<2.4	90	[39] AHRENS	87	CNTR	$\sin^2(2\theta)$=1
<1 8	90	BOFILL	87	CNTR	$\sin^2(2\theta)$=1
5 to 10		[40] BERNARDI	86B	CNTR	$\sin^2(2\theta)$=0 02–0 04
<2 2	90	[41] BRUCKER	86	HLBC	$\sin^2(2\theta)$=1
<0 43	90	[39] AHRENS	85	CNTR	$\sin^2(2\theta)$=1
<3 2	90	[39] AHRENS	85	CNTR	$\sin^2(2\theta)$=0 02
<2.1	90	[39] AHRENS	85	CNTR	$\sin^2(2\theta)$=0 04
<0 20	90	BERGSMA	84	CHRM	$\sin^2(2\theta)$=1
<1 7	90	ARMENISE	81	GGM	$\sin^2(2\theta)$=1
<0 6	90	[41] BAKER	81	HLBC	$\sin^2(2\theta)$=1
<1.7	90	ERRIQUEZ	81	BEBC	$\sin^2(2\theta)$=1
<1 2	95	BLIETSCHAU	78	GGM	$\sin^2(2\theta)$=1
<1.2	95	BELLOTTI	76	GGM	$\sin^2(2\theta)$=1

[39]Liquid-scintillator calorimeter at BNL AGS
[40]This is a typical fit to the data assuming mixing between two species As the authors state this result is in conflict with earlier upper bounds on this type of neutrino oscillations
[41]15ft bubble chamber at FNAL

$\sin^2(2\theta)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 3.4 ×10^{-3}	90	[42] AHRENS	85	CNTR	Large $\Delta(m^2)$
• • • We do not use the following data for averages fits limits, etc • • •					
< 1.0 ×10^{-2}	90	[42] AHRENS	87	CNTR	Large $\Delta(m^2)$
< 1 5 ×10^{-2}	90	BOFILL	87	CNTR	Large $\Delta(m^2)$
< 1 3 ×10^{-2}	90	ANGELINI	86	BEBC	$\Delta(m^2)$=2 2 eV^2
0 02 to 0.04		BERNARDI	86B	CNTR	$\Delta(m^2)$=5–10
< 1 1 ×10^{-2}	90	[43] BRUCKER	86	HLBC	Large $\Delta(m^2)$
< 0.009	90	[42] AHRENS	85	CNTR	$\Delta(m^2)$=5
< 0 003	90	[42] AHRENS	85	CNTR	$\Delta(m^2)$=10
< 0 24	90	BERGSMA	84	CHRM	Large $\Delta(m^2)$
< 1 ×10^{-2}	90	ARMENISE	81	GGM	Large $\Delta(m^2)$
< 6 ×10^{-3}	90	[43] BAKER	81	HLBC	Large $\Delta(m^2)$
< 1 ×10^{-2}	90	ERRIQUEZ	81	BEBC	Large $\Delta(m^2)$
< 4 ×10^{-3}	95	BLIETSCHAU	78	GGM	Large $\Delta(m^2)$
< 1 ×10^{-2}	95	BELLOTTI	76	GGM	Large $\Delta(m^2)$

[42]Liquid scintillator calorimeter at BNL AGS
[43]15ft bubble chamber at FNAL

$\bar{\nu}_\mu \to \bar{\nu}_e$

$\Delta(m^2)$ FOR $\sin^2(2\theta)$=1

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<0.91	90	NEMETHY	81B	CNTR	LAMPF
• • • We do not use the following data for averages fits limits etc • • •					
<3 1	90	BOFILL	87	CNTR	FNAL
<2 4	90	TAYLOR	83	HLBC	15 ft FNAL
<1	95	BLIETSCHAU	78	HLBC	GGM CERN PS

$\sin^2(2\theta)$ FOR "LARGE" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 4 ×10^{-3}	95	BLIETSCHAU	78	HLBC	GGM CERN PS
• • • We do not use the following data for averages fits limits etc • • •					
< 0 04	90	BOFILL	87	CNTR	FNAL
< 1 3 ×10^{-2}	90	TAYLOR	83	HLBC	15 ft FNAL
< 0.2	90	NEMETHY	81B	CNTR	LAMPF

$\nu_\mu \to \nu_\tau$

$\Delta(m^2)$ FOR $\sin^2(2\theta)$=1

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
< 0.9	90	USHIDA	86C	EMUL	FNAL
• • • We do not use the following data for averages, fits limits etc • • •					
<10 2	90	BOFILL	87	CNTR	FNAL
< 6 3	90	BRUCKER	86	HLBC	15 ft FNAL
< 4 6	90	ARMENISE	81	HLBC	GGM CERN SPS
< 3	90	BAKER	81	HLBC	15 ft FNAL
< 6	90	ERRIQUEZ	81	HLBC	BEBC CERN SPS
< 3	90	USHIDA	81	EMUL	FNAL

$\sin^2(2\theta)$ FOR "LARGE" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 4 ×10^{-3}	90	USHIDA	86C	EMUL	FNAL
• • • We do not use the following data for averages fits limits etc • • •					
< 0.34	90	BOFILL	87	CNTR	FNAL
< 8 8 ×10^{-2}	90	BRUCKER	86	HLBC	15-ft FNAL
< 11 ×10^{-2}	90	BALLAGH	84	HLBC	15 ft FNAL
< 1 7 ×10^{-2}	90	ARMENISE	81	HLBC	GGM CERN SPS
< 6 ×10^{-2}	90	BAKER	81	HLBC	15 ft FNAL
< 5 ×10^{-2}	90	ERRIQUEZ	81	HLBC	BEBC CERN SPS
< 1.3 ×10^{-2}	90	USHIDA	81	EMUL	FNAL

$\bar{\nu}_\mu \to \bar{\nu}_\tau$

$\Delta(m^2)$ FOR $\sin^2(2\theta)$=1

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<2.2	90	ASRATYAN	81	HLBC	FNAL
• • • We do not use the following data for averages fits limits etc • • •					
<6 5	90	BOFILL	87	CNTR	FNAL
<7 4	90	TAYLOR	83	HLBC	15 ft FNAL

$\sin^2(2\theta)$ FOR "LARGE" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 4 4 ×10^{-2}	90	ASRATYAN	81	HLBC	FNAL
• • • We do not use the following data for averages, fits limits etc • • •					
< 0 15	90	BOFILL	87	CNTR	FNAL
< 8 8 ×10^{-2}	90	TAYLOR	83	HLBC	15-ft FNAL

$\nu_\mu \not\to \nu_\mu$

$\Delta(m^2)$ FOR $\sin^2(2\theta)$=1

These experiments also allow sufficiently large $\Delta(m^2)$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
$\cdot$ 0 23 OR $\cdot$100	90	DYDAK	84	CNTR	
$\cdot$ 13 OR $\cdot$1500	90	STOCKDALE	84	CNTR	
• • • We do not use the following data for averages fits limits etc • • •					
<7	90	BELIKOV	85	CNTR	Serpukhov
$\cdot$ 8 0 OR $\cdot$1250	90	STOCKDALE	85	CNTR	
$\cdot$ 0 29 OR $\cdot$22	90	BERGSMA	84	CNTR	
<8 0	90	BELIKOV	83	CNTR	

$\sin^2(2\theta)$ AS FUNCTION OF $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	90	[44] STOCKDALE	85	CNTR	FNAL
• • • We do not use the following data for averages fits limits etc • • •					
<0 07	90	[45] BELIKOV	85	CNTR	Serpukhov
<0 27	90	[46] BERGSMA	84	CNTR	CHARM CERN PS
<0 1	90	[47] DYDAK	84	CNTR	CERN PS
<0 02	90	[48] STOCKDALE	84	CNTR	FNAL
<0 1	90	[49] BELIKOV	83	CNTR	Serpukhov

[44]This bound applies for $\Delta(m^2)$ = 100 eV^2 Less stringent bounds apply for other $\Delta(m^2)$ these are nontrivial for 8 $<\Delta(m^2)<$ 1250 eV^2
[45]This bound applies for a wide range of $\Delta(m^2)$ >7 eV^2 For some values of $\Delta(m^2)$, the value is less stringent the least restrictive nontrivial bound occurs approximately at $\Delta(m^2)$ = 300 eV^2 where $\sin^2(2\theta)$ <0 13 at CL = 90%
[46]This bound applies for $\Delta(m^2)$ = 0 7–9 eV^2 Less stringent bounds apply for other $\Delta(m^2)$ these are nontrivial for 0 28 $<\Delta(m^2)<$ 22 eV^2
[47]This bound applies for $\Delta(m^2)$ = 1–10 eV^2 Less stringent bounds apply for other $\Delta(m^2)$, these are nontrivial for 0 23 $<\Delta(m^2)<$ 90 eV^2
[48]This bound applies for $\Delta(m^2)$ = 110 eV^2 Less stringent bounds apply for other $\Delta(m^2)$, these are nontrivial for 13 $<\Delta(m^2)<$ 1500 eV^2
[49]Bound holds for $\Delta(m^2)$ = 20–1000 eV^2

Stable Particle Full Listings
SEARCHES FOR MASSIVE ν's & LEPTON MIXING

---------- $\nu_e \not\to \nu_e$ ----------

$\Delta(m^2)$ FOR $\sin^2(2\theta)=1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
< 8	90	BAKER	81	HLBC	15 ft FNAL
< 2.3 OR > 8	90	NEMETHY	81B	CNTR	LAMPF
• • • We do not use the following data for averages fits limits etc • • •					
< 14.9	90	BRUCKER	86	HLBC	15 ft FNAL
<56	90	DEDEN	81	HLBC	BEBC CERN SPS
< 10	90	ERRIQUEZ	81	HLBC	BEBC CERN SPS

$\sin^2(2\theta)$ FOR "LARGE" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 7 $\times 10^{-2}$	90	ERRIQUEZ	81	HLBC	BEBC CERN SPS
• • • We do not use the following data for averages fits limits etc • • •					
< 0.54	90	BRUCKER	86	HLBC	15-ft FNAL
< 0.6	90	BAKER	81	HLBC	15 ft FNAL
< 0.3	90	DEDEN	81	HLBC	BEBC CERN SPS

---------- $\overline{\nu}_e \to \overline{\nu}_\tau$ ----------

$\sin^2(2\theta)$ FOR "LARGE" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.7	90	[50] FRITZE	80	HYBR	BEBC CERN SPS

[50] Authors give $P(\nu_e \to \nu_\tau) < 0.35$ equivalent to above limit

---------- $\overline{\nu}_\mu \not\to \overline{\nu}_\mu$ ----------

$\Delta(m^2)$ FOR $\sin^2(2\theta)=1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN
< 7 OR > 1200	90	STOCKDALE	85	CNTR

$\sin^2(2\theta)$ AS FUNCTION OF $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	90	[51] STOCKDALE	85	CNTR	FNAL

[51] This bound applies for $\Delta(m^2)$ between 190 and 320 or = 530 eV^2 Less stringent bounds apply for other $\Delta(m^2)$ these are nontrivial for $7 < \Delta(m^2) < 1200$ eV^2

---------- $\nu_e \to \nu_\tau$ ----------

$\Delta(m^2)$ FOR $\sin^2(2\theta)=1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
< 9	90	USHIDA	86C	EMUL	FNAL
• • • We do not use the following data for averages fits, limits etc • • •					
<44	90	TALEBZADEH	87	HLBC	BEBC

$\sin^2(2\theta)$ FOR LARGE $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.12	90	USHIDA	86C	EMUL	FNAL
• • • We do not use the following data for averages fits limits etc • • •					
<0.36	90	TALEBZADEH	87	HLBC	BEBC

---------- $\nu_\mu \to (\overline{\nu}_e)_L$ ----------

This is a limit on lepton family number violation and total lepton number violation $(\overline{\nu}_e)_L$ denotes a hypothetical left handed $\overline{\nu}_e$ The bound is quoted in terms of $\Delta(m^2)$ $\sin(2\theta)$ and α where α denotes the fractional admixture of (V+A) charged current

$\alpha\Delta(m^2)$ FOR $\sin^2(2\theta)=1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits etc • • •				
< 7 $\times 10^{-1}$	90	[52] COOPER	82	HLBC

[52] Existing bounds on V+A currents require α small see COOPER 82

$\alpha^2\sin^2(2\theta)$ FOR "LARGE" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits etc • • •				
< 1 $\times 10^{-3}$	90	[53] COOPER	82	HLBC

[53] Existing bounds on V+A currents require α small see COOPER 82

---------- $\nu_e \to (\overline{\nu}_e)_L$ ----------

See note above for $\nu_\mu \to (\overline{\nu}_e)_L$ limit

$\alpha\Delta(m^2)$ FOR $\sin^2(2\theta)=1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •				
<7	90	[54] COOPER	82	HLBC

[54] Existing bounds on V+A currents require α small see COOPER 82

$\alpha^2\sin^2(2\theta)$ FOR "LARGE" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •				
< 5 $\times 10^{-2}$	90	[55] COOPER	82	HLBC

[55] Existing bounds on V+A currents require α small see COOPER 82

(C) SEARCHES FOR NEUTRINOLESS DOUBLE β DECAY

The nuclear decay $((Z,A) \to (Z+2,A) + e^- + e^-$ i.e. neutrinoless double β decay violates total lepton number by two units It is forbidden if neutrinos are Dirac particles but can occur in gauge theories if neutrinos are Majorana particles and are massive PRIMAKOFF 81 ROSEN 81 and HAXTON 83 discuss correlated bounds on $\langle m(\nu)\rangle$ and right handed couplings Further theoretical discussions include DOI 85 HAXTON 86 and GROTZ 83 The primary information from these experiments is lifetime From lifetime to neutrino mass one needs to invoke nuclear structure The neutrino mass limits below are therefore model dependent Different experiments have used different models Note that regular 2 neutrino double β decay has now been observed directly for ^{82}Se with $t_{1/2} = (1.1^{+0.8}_{-0.3}) \times 10^{20}$ years by ELLIOTT 87B

$\langle m(\nu)\rangle$, THE EFFECTIVE WEIGHTED SUM OF NEUTRINO MASSES CONTRIBUTING TO NEUTRINOLESS DOUBLE β DECAY

$\langle m(\nu)\rangle = |\Sigma\, U_{1j}^2\, m(\nu_j)|$, where the sum goes from 1 to n and where n = number of neutrino generations and ν_j is a Majorana neutrino Note that U_{1j}^2, not $|U_{1j}|^2$ occurs in the sum the possibility of cancellations has been stressed in WOLFENSTEIN 81

VALUE (eV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
< 1.8		[56] CALDWELL	87	CNTR	THY1 ^{76}Ge
< 2.7	68	BELLOTTI	86	CNTR	THY ^{76}Ge
< 2.6	68	[57] CALDWELL	86	CNTR	THY ^{76}Ge
		[58] ELLIOTT	86	CNTR	^{82}Se
< 6	68	[59] CALDWELL	85	CNTR	THY ^{76}Ge
<20	68	[60] HUBERT	85	CNTR	^{76}Ge
< 3.8	68	[61] BELLOTTI	84	CNTR	THY ^{76}Ge
<22		FORSTER	84	CNTR	THY ^{76}Ge
<10	90	AVIGNONE	83	CNTR	THY ^{76}Ge
<22	68	[62] BELLOTTI	83	CNTR	THY1 ^{76}Ge
< 8.3	68	[62] BELLOTTI	83	CNTR	THY2 ^{76}Ge
< 5.6	95	KIRSTEN	83	SPEC	THY ^{128}Te ^{130}Te

[56] CALDWELL 87 gets lower bound on half life for $0^+ \to 0^+$ neutrinoless double β decay of ^{76}Ge $t_{1/2} > 5 \times 10^{23}$ years The derived upper limits on effective neutrino masses are dependent on input for nuclear matrix elements the authors also list two other limits for different input assumptions 1.3 eV and 0.7 eV Used calculations of DOI 83 (=THY1)

[57] CALDWELL 86 gives several limits depending on which calculation of nuclear matrix elements is used we quote the most conservative i e least stringent Other limits are 1.0 eV and 1.9 eV Authors note that the overall uncertainty due to the serious disagreement between nuclear calculations and both lab and geochemical measurements for regular 2 neutrino double β decay is also present in these limits

[58] ELLIOTT 86 gives half-life limits $t_{1/2} > 7 \times 10^{21}$ yr (68% CL) for ^{82}Se neutrinoless double β decay and $t_{1/2} > 1. \times 10^{20}$ yr (68% CL) for regular 2 neutrino double β decay of ^{82}Se Latter limit agrees with the geochemical limit and strongly disagrees with nuclear theory calculations, casting doubt on their application to derive limits on Majorana neutrino masses and η parameters from limits on neutrinoless double β decay

[59] Uses results of HAXTON 81 HAXTON 82 Authors state that bound could be two or three times larger Half life for $0^+ \to 0^+$ transition $> 5 \times 10^{22}$ yr (CL = 68%)

[60] Limit is obtained from analysis of data using theoretical calculations by HAXTON 81 HAXTON 82 Also given are lifetime limits on neutrinoless double β decay of ^{76}Ge to excited states of ^{76}Se

[61] See table 1 of BELLOTTI 84 for their assessment of previous bounds Half life for $0^+ \to 0^+$ transition $> 7 \times 10^{22}$ yr (CL = 90%) $> 1.2 \times 10^{23}$ yr (CL = 68%)

[62] Limits are obtained from analysis of data using theoretical calculations by DOI 83 (= thy1) and ROSEN 81 (= thy2)

LIMITS ON LEPTON-NUMBER VIOLATING (V+A) CURRENT ADMIXTURE

η is defined as the fractional admixture of (V+A) charged current relative to (V−A) in electron type lepton sector

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •						
< 6 $\times 10^{-5}$	68	[63] BELLOTTI	87	CNTR		^{128}Te ^{130}Te (+Theory)
< 6 $\times 10^{-6}$	68	[64] CALDWELL	86	CNTR	+	THY ^{76}Ge
< 1.4 $\times 10^{-5}$	68	[65] CALDWELL	85	CNTR	+	THY ^{76}Ge
< 0.9 $\times 10^{-5}$	68	[65] CALDWELL	85	CNTR	+	THY ^{76}Ge
< 0.8 $\times 10^{-5}$	68	[65] BELLOTTI	84	CNTR	+	THY ^{76}Ge
< 0.6 $\times 10^{-5}$	68	[65] BELLOTTI	84	CNTR	+	THY ^{76}Ge
< 2.4 $\times 10^{-5}$		AVIGNONE	83	CNTR	+	THY ^{76}Ge
< 4 $\times 10^{-5}$	68	[66] BELLOTTI	83	CNTR	+	THY1 ^{76}Ge
< 1.5 $\times 10^{-5}$	68	[66] BELLOTTI	83	CNTR	+	THY2 ^{76}Ge
< 2.4 $\times 10^{-5}$	95	KIRSTEN	83	SPEC	+	THY ^{128}Te/^{130}Te

[63] BELLOTTI 87 gives two limits, depending on the type of chirality mixing These happen to be the same BELLOTTI 87 limit is stated to be independent of neutrino mass

[64] See previous comment for CALDWELL 86 in data block above. Other limits given by CALDWELL 86 for η (left right) are 5.5×10^{-7} and 4.5×10^{-8} as we did for the limit on a Majorana mass we take the most conservative, i.e., least stringent of these model-dependent bounds.
[65] Two bounds given depending on types of chirality mixing. See references.
[66] Limits are obtained from analysis of data using theoretical calculations by DOI 83 (= thy1) and ROSEN 81 (= thy2)

REFERENCES FOR SEARCHES FOR MASSIVE NEUTRINOS AND LEPTON MIXING

BAHCALL 88 RMP 60 297 +Ulrich (IAS UCLA)
HIRATA 88 PL B205 416 +Kajita Koshiba+ (Kamiokande II Collab.)
NAKAHATA 88 Thesis (Kamikande II Collab.)
AFONIN 87 JETPL 45 257 +Bogatov Vershinskii+ (ITEP)
Translated from ZETFP 45 201
AHRENS 87 PR D36 702 +(BNL BROW UCI HIRO KEK OSAK PENN STON)
BELLOTTI 87 EPL 3 889 +Cattadori Cremonesi Fiorini+ (MILA)
BOFILL 87 PR D36 3309 +Busza Eldridge+ (MIT FNAL MSU)
BORIS 87 PRL 58 2019 +Golutvin Laptin+ (ITEP ASCI)
CALDWELL 87 PRL 59 419 +Eisberg Grumm Witherell+ (UCSB LBL)
DAUM 87 PR D36 2624 +Kettle Jost+ (SIN VIRG)
ELLIOTT 87B PRL 59 2020 +Hahn Moe (UCI)
LOSECCO 87 PL B184 305 +Bionta Blewitt Bratton+ (IMB Collab.)
MISHRA 87 PRL 59 1397 +Auchincloss+ (COLU CIT FNAL CHIC ROCH)
OBERAUER 87 PL B198 113 +von Feilitzsch Mossbauer (MUNI)
TALEBZADEH 87 NP B291 503 +Guy Venus+ (BEBC WA66 Collab.)
VIDYAKIN 87 JETP 66 243 +Vyrodov Gurevich Kozlov+ (KIAE)
Translated from ZETF 93 424
WENDT 87 PRL 58 1810 +Abrams Amidei Boden+ (MARK II Collab.)
AFONIN 86 JETPL 44 142 +Bogatov Borovoi Vershinskii+ (KIAE)
Translated from ZETFP 44 111
ANGELINI 86 PL B179 307 +Apostolakis Baldini+ (PISA ATHU PADO WISC)
AZUELOS 86 PRL 56 2241 +Britton Bryman+ (TRIU CNRC)
BADIER 86 ZPHY C31 21 +Bemporad Boucrot Callot+ (NA3 Collab.)
BELLOTTI 86 NC 95A 1 +Cremonesi Fiorini Liguori+ (MILA)
BERNARDI 86 PL 166B 479 +Carugno+ (LPNP INFN CDEF ATEN CERN)
BERNARDI 86B PL B181 173 +Carugno+ (LPNP INFN CDEF ATEN CERN)
BRUCKER 86 PR D34 2183 +Jacques Kalelkar Koller+ (RUTG BNL COLU)
CALDWELL 86 PR D33 2737 +Eisberg Grumm Hale Witherell+ (UCSB LBL)
DELEENER 86 PL B177 228 DeLeener Rosier Deutsch+ (LVLN ZURI LAUS)
DORENBOS 86 PL 166B 473 Dorenbosch Allaby Amaldi+ (CHARM Collab.)
DRUKAREV 86 JETP 64 686 +Strikman (LENI)
Translated from ZETF 91 1160
ELLIOTT 86 PRL 56 2582 +Hahn Moe (UCI)
FRITSCHI 86 PL B173 485 +Holzschuh Kundig+ (ZURI SIN)
GILMAN 86 CNPP 16 231 (SLAC)
HAXTON 86 Proc. Steamboat Springs 84 (WASH)
LINDHARD 86 PRL 57 965 +Hansen (AAHR)
SIMPSON 86 PL B174 113 (GUEL)
USHIDA 86C PRL 57 2897 +Kondo Tasaka Park Song+ (FNAL E531 Collab.)
ZACEK 86 PR D34 2621 +Feilitzsch+ (Cal Tech SIN TUM Collab.)
AFONIN 85 JETPL 41 435 +Borovoi Dobrynin+ (KIAE)
Translated from ZETFP 41 355
Also 85B JETPL 42 285 Afonin Bogatov Borovoi Dobrynin+ (KIAE)
Translated from ZETFP 42 230
AHRENS 85 PR D31 2732 +Aronson+ (BNL BROW KEK OSAK PENN+)
ALBRECHT 85I PL 163B 404 +Binder Drescher Schubert+ (ARGUS Collab.)
ALTZITZOG 85 PRL 55 799 Altzitzoglou Calaprice Dewey+ (PRIN)
APALIKOV 85 JETPL 42 289 +Boris Golutvin Laptin Lubimov+ (ITEP)
Translated from ZETFP 42 233
BAHCALL 85 APJ 292 L79 +Cleveland Davis Rowley (IAS BNL)
BELIKOV 85 SJNP 41 589 +Volkov Kochetkov Mukhin+ (SERP)
Translated from YAF 41 919
BERGKVIST 85 PL 154B 224 (STOH)
BERGKVIST 85B PL 159B 408 (STOH)
BLUMER 85 PL 161B 407 +Kleinknecht (DORT)
BORIS 85B JETPL 42 130 +Golutvin Laptin Lubimov+ (ITEP)
Translated from ZETFP 42 107
CALDWELL 85 PRL 54 281 +Eisberg Grumm Hale Witherell+ (UCSB LBL)
COOPER 85 PL 160B 207 Cooper Sarkar+ (CERN LOIC OXF SACL+)
DOI 85 PTP Supp 83 1 +Kotani Takasugi (OSAK)
HUBERT 85 NC 85A 19 +Leccia Dassie Mennrath+ (BCEN ZARA)
KALBFLEISCH 85 PRL 55 2225 +Milton (OKLA)
LOSECCO 85 PRL 54 2299 +Bionta Blewitt Bratton+ (UCI MICH BNL+)
MARKEY 85 PR C32 2215 +Boehm (CIT)
OHI 85 PL 160B 322 +Nakajima Tamura+ (TOKY INUS KEK)
SIMPSON 85 PRL 54 1891 (GUEL)
STOCKDALE 85 ZPHY C27 53 +Bodek+ (ROCH CHIC COLU FNAL)
ZACEK 85 PL 164B 193 +Zacek Boehm+ (MUNI CIT SIN)
BAHCALL 84 AIP 126 60 (IAS)
Proc. Solar Neutrinos and Neutrino Astronomy (Homestake 1984)
BALLAGH 84 PR D30 2271 +Bingham+ (UCB LBL FNAL HAWA WASH WISC)
BELLOTTI 84 PL 146B 450 +Cremonesi Fiorini Liguori Pullia+ (MILA)
BERGSMA 84 PL 142B 103 +Dorenbosch Allaby Abt+ (CHARM Collab.)
CAVAIGNAC 84 PL 148B 387 +Hoummada Koang+ (GREN LAPP)
DAVIS 84 AIP 123 1037 +Cleveland Rowley (BNL)
Proc. Intersections between Particle and Nuclear Physics (Steamboat Springs 1984)
Also 84B Icoman 1983 Davis Cherry Davidson Lande Lee Marshall+
Also 84 AIP 126 1 Rowley Cleveland Davis (BNL)
DYDAK 84 PL 134B 281 +Feldman+ (CERN DORT HEID SACL WARS)
FORSTER 84 PL 138B 301 +Kwon Markey Boehm Henrikson (CIT)
GABATHULER 84 PL 138B 449 +Boehm+ (CIT SIN MUNI)
MINEHART 84 PRL 52 804 +Ziock Marshall Stephens Daum+ (VIRG SIN)
STOCKDALE 84 PRL 52 1384 +Bodek+ (ROCH CHIC COLU FNAL)
AFONIN 83 JETPL 38 436 +Bogatov Borovoi Vershinskii+ (KIAE)
Translated from ZETFP 38 361
AVIGNONE 83 PRL 50 721 +Brodzinski Brown Evans Hensley+ (SCUC PNL)
BELENKII 83 JETPL 38 493 +Dobrynin Zemlyakov Mikaelyan+ (KIAE)
Translated from ZETFP 38 406
BELIKOV 83 JETPL 38 661 +Volkov Kochetkov Mukhin Sviridov+ (SERP)
Translated from ZETFP 38 547
BELLOTTI 83 PL 121B 72 +Fiorini Liguori Pullia Sarracino+ (MILA)
BERGSMA 83B PL 128B 361 +Dorenbosch+ (CHARM Collab.)
BRYMAN 83B PRL 50 1546 +Dubois Numao Olaniya Olin+ (TRIU CNRC)
Also 83 PRL 50 7 Bryman Dubois Numao Olaniya+ (TRIU CNRC)
DEUTSCH 83 PR D27 1644 +Lebrun Prieels (LVLN)
DOI 83 PTP 69 602 +Kotani Nishiura Takasugi (OSAK KYOT)
FILIPPONE 83 PRL 50 412 +Elwyn Davids+ (ANL CHIC VALP)
GRONAU 83 PR D28 2762 (HAIF)
GROTZ 83 JP G9 L169 +Klapdor Metzinger (MPIH)
HAXTON 83 CNPP 11 41 (LASL PURD)
KIRSTEN 83 PRL 50 474 +Richter Jessberger (MPIH)
Also 83B ZPHY 16 189 Kirsten Richter Jessberger (MPIH)
LUBIMOV 83 Brighton Conf. 386 (ITEP)
SCHRECK 83 PL 129B 265 Schreckenbach Colvin+ (GREN ILLG)
TAYLOR 83 PR D28 2705 +Cence Harris Jones+ (HAWA LBL FNAL)
BAHCALL 82 RMP 54 767 +Huebner Lubow+ (IAS LANL HPC YALE JCLA)
COOPER 82 PL 112B 97 +Guy Michette Tyndel Venus (RL)
EHRLICH 82 PR D25 2282 (GMAS)
FILIPPONE 82 APJ 253 393 +Schramm (ANL EFI)
FOWLER 82 AIP 96 80 (CIT)
HAXTON 82 PR D25 2360 +Stephenson Strottman (LANL PURD)
HAYANO 82 PRL 49 1305 +Taniguchi Yamanaka+ (TOKY KEK TSUK)
VUILLEUMIER 82 PL 114B 298 +Boehm Egger+ (CIT SIN MUNI)
ABELA 81 PL 105B 263 +Daum Eaton Frosch Jost Kettle Steiner (SIN)
ARMENISE 81 PL 100B 182 +Fogli Muciaccia+ (BARI CERN MILA LALO)
ASANO 81 PL 104B 84 +Hayano Kikutani Kurokawa+ (KEK TOKY OSAK)
Also 81 PR D24 1232 Shrock (STON)
ASRATYAN 81 PL 105B 301 +Efremenko Fedotov+ (ITEP FNAL SERP MICH)
BAKER 81 PRL 47 1576 +Connolly Kahn Kirk Murtagh+ (BNL COLU)
Also 78 PRL 40 144 Cnops Connolly Kahn Kirk+ (BNL COLU)
BOLIEV 81 SJNP 34 787 +Butkevich Zakidyshev Makoev+ (INRM)
Translated from YAF 34 1418
CALAPRICE 81 PL 106B 175 +Schreiber Schneider+ (PRIN IND)
DEDEN 81 PL 98B 310 +Grassler Boeckmann Mermikides+ (BEBC Collab.)
ERRIQUEZ 81 PL 102B 73 +Natali+ (BARI BIRM LIBH EPOL RHEL SACL+)
HAXTON 81 PRL 47 153 +Stephenson Strottman (PURD LASL)
KWON 81 PR D24 1097 +Boehm Hahn Henrikson+ (CIT GREN MUNI)
NEMETHY 81B PR D23 262 + (YALE LBL LASL MIT SACL SIN CNRC BERN)
PRIMAKOFF 81 ARNS 31 145 +Rosen (PURD)
ROSEN 81 Nu Conf. Hawaii (PURD)
Also 78 RMP 50 11 Bryman Picciotto (TRIU VICT)
SHROCK 81 PR D24 1232 (STON)
SHROCK 81B PR D24 1275 (STON)
SILVERMAN 81 PRL 46 467 +Soni (UCI UCLA)
SIMPSON 81B PR D24 2971 (GUEL)
USHIDA 81 PRL 47 1694 (AICH FNAL KOBE SEOU MCGI NAGO OSU OKAY+)
WOLFENSTEIN 81 PL 107B 77 (CMU)
AVIGNONE 80 PR C22 594 +Greenwood (SCUC)
BAHCALL 80 PRL 45 945 +Lubow Huebner+ (IAS LASL YALE LLL UCLA)
Also 76 Science 191 264 Bahcall Davis (IAS BNL)
BOEHM 80 PL 97B 310 +Cavaignac Feilitzsch+ (ILLG CIT GREN MUNI)
FRITZE 80 PL 96B 427 (AACH BONN CERN LOIC OXF SACL)
REINES 80 PRL 45 1307 +Sobel Pasierb (UCI)
Also 59 PR 113 273 Reines Cowan (LASL)
Also 66 PR 142 852 Nezrick Reines (CASE)
Also 76 PRL 37 315 Reines Gurr Sobel (UCI)
SHROCK 80 PL 96B 159 (STON)
DAVIS 79 PR C19 2259 +Vogel Mann Schenter (CIT)
BLIETSCHAU 78 NP B133 205 +Deden Hasert Krenz+ (Gargamelle Collab.)
CROUCH 78 PR D18 2239 +Landecker Lathrop Reines+ (CASE UCI WITW)
BELLOTTI 76 LNC 17 553 +Cavalli Fiorini Rollier (MILA)

LIMITS ON NUMBER OF LIGHT NEUTRINO TYPES

NOTE ON LIMITS ON NUMBER OF LIGHT NEUTRINO TYPES FROM $p\bar{p}$ COLLIDERS

The neutrinos referred to in this section are those of the Standard SU(2)×U(1) Electroweak Model. Light neutrinos are those with $M(\nu) << M(Z^0)$. The limits are on the number of neutrino families or species. See also cosmological limits in the "ν Bounds from Astrophysics and Cosmology" section.

In the subsection on "Limits from $p\bar{p}$ Colliders" the results assume that there are only three families of quarks and three families of charged leptons light enough to contribute to W or Z decay. The results were derived from

$$N_\nu = [\Gamma_Z(\text{measured}) - \Gamma_Z(\text{3-family theory})]/C_\nu + 3$$

The term "3" above is for ν_e, ν_μ and ν_τ. C_ν is approximately 0.18 GeV, and the Γ's are measured in GeV. For the results reported here, Γ_Z(measured) is not a directly measured number, but rather an inferred number based on measured cross sections times branching fractions

$$\Gamma_Z = \Gamma_W \frac{\Gamma(Z \to e^+ e^-)}{\Gamma(W \to e\nu)} \frac{\sigma_Z}{\sigma_W} \left[\frac{\sigma_W\, B(W \to e\nu)}{\sigma_Z\, B(Z \to e^+ e^-)} \right]$$

For each result, Γ_W and $\frac{\Gamma(Z \to e^+ e^-)}{\Gamma(W \to e\nu)}$ are calculated from the Standard Model with three families, while σ_Z/σ_W is calculated from QCD (most uncertainties in QCD are thought to cancel in this ratio) Only $\frac{\sigma_W\, B(W \to e\nu)}{\sigma_Z\, B(Z \to e^+ e^-)}$ is a measured quantity The errors quoted include the uncertainties from each theoretical and experimental quantity except Γ_W

LIMITS FROM $p\bar{p}$ COLLIDERS

NUMBER OF ν TYPES INCLUDING ν_e, ν_μ, ν_τ

See above note for method of derivation and crucial assumptions

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 6.1	90	1 ALBAJAR	87E	RVUE	UA1+UA2 any $m(\ell)$
< 5.9	90	1 ALBAJAR	87E	RVUE	UA1+UA2 $m(\ell)$ > 44 GeV
• • • We do not use the following data for averages fits limits etc • • •					
		2 HALZEN	88	THEO	
< 8 3	90	1 ALBAJAR	87E	UA1	any $m(\ell)$
< 8 0	90	1 ALBAJAR	87E	UA1	$m(\ell)$ > 44 GeV
< 8	95	ANSARI	87	UA2	Any $m(\ell)$
< 4	95	ANSARI	87	UA2	$m(\ell)$ > 74 GeV
< 7 3	90	3 APPEL	86	UA2	E_{cm}=546 630 GeV
<10	90	4 ARNISON	86	UA1	E_{cm}=546 630 GeV

[1] ALBAJAR 87E limits are obtained while requiring $N(\nu) \geq 3$ Without this requirement, all limits would be 0 3–0 5 lower The 95% confidence limits are about 1 higher

[2] See theoretical analysis in HALZEN 88 which combines data on W and Z production in $p\bar{p}$ collisions with deep inelastic scattering of leptons on hydrogen and deuterium to conclude that $N_\nu \leq 3$ at 95% CL except that $N_\nu = 4$ is allowed if the fourth neutrino is accompanied by a heavy charged lepton lighter than $m(W)$

[3] Assume $m(t\text{-quark})$ = 40 GeV C_ν = 0 177 GeV $\Gamma(W)$ = 2 65 GeV and $\Gamma(Z$ 3family theory) = 2 72 GeV APPEL 86 reported their limit as 5.6 ± 1 7 or less and we chose the upper value

[4] Assume $m(t\text{-quark})$ = 40 GeV C_ν = 0 182 GeV $\Gamma(W)$ = 2 82 GeV and $\Gamma(Z$ 3family theory) = 2 83 GeV

NOTE ON LIMITS ON NUMBER OF LIGHT NEUTRINO TYPES FROM e^+e^- COLLIDERS

(by C Hearty, LBL)

Experiments at e^+e^- colliders obtain limits on N_ν through the observation of the reaction $e^+e^- \to \gamma\nu\bar{\nu}$, where the neutrinos can be from one of the known generations or any additional generations The neutrinos are not detected, so the signature of this process is a single photon observed in the detector A p_T cut is applied to the photon to eliminate radiative Bhabha scattering and other backgrounds in which particles in the final state remain undetected in the beampipe The ASP, CELLO, and MAC experiments have observed a total of 2 6 events, the Standard Model with three neutrino generations predicts that 4 5 events should be observed The combined 90% CL limit[1] is $N_\nu < 5\,0$, assuming massless neutrinos The bound $N_\nu \geqslant 3$ has not been included in this calculation nor in the calculations of the limits listed below If this bound is imposed, the 90% CL limit[1] is $N_\nu < 7\,3$

Reference

1 C Hearty et al , report no UWSEA-PUB-88-1 (1988)

LIMITS FROM e^+e^- COLLIDERS

NUMBER OF ν TYPES INCLUDING ν_e, ν_μ, ν_τ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 7.5	90	HEARTY	87	ASP	E_{cm}=29 GeV at PEP
• • • We do not use the following data for averages fits limits etc • • •					
<14	90	BARTHA	86	ASP	E_{cm}=29 GeV at PEP
<15	90	BEHREND	86D	CELL	E_{cm} = 38–46 6 GeV PETRA
<17	90	FORD	86	MAC	E_{cm}=29 GeV at PEP

REFERENCES FOR LIMITS ON NUMBER OF LIGHT NEUTRINO TYPES

HALZEN	88	PR D37 229	+Kim Willenbrock	(WISC)
ALBAJAR	87E	PL B198 271	+Albrow Allkofer+	(UA1 Collab)
ANSARI	87	PL B186 440	+Bagnaia Banner Battiston+	(UA2 Collab)
HEARTY	87	PRL 58 1711	+Rothberg Young Johnson+	(ASP Collab)
APPEL	86	ZPHY C30 1	+Bagnaia Banner Battiston+	(UA2 Collab)
ARNISON	86	PL 166B 484	+Albrow Allkofer Astbury+	(UA1 Collab)
Also	87B	PL B185 241	Albajar Albrow Allkofer Arnison+	(UA1 Collab)
BARTHA	86	PRL 56 685	+Burke Extermann+	(ASP Collab)
BEHREND	86D	PL B176 247	+Buerger Criegee Fenner Field+	(CELLO Collab)
FORD	86	PR D33 3472	+Qi Read+	(MAC Collab)

NEUTRINO BOUNDS FROM ASTROPHYSICS AND COSMOLOGY

OMITTED FROM SUMMARY TABLE

See the note on neutrinos by R E Shrock in the ν_e section near the beginning of these Listings For information on neutrinos derived from more conventional (terrestrial) experiments, see the ν_e ν_μ, ν_τ, and heavy-ν sections above

ν MASS

NOTE ON ν MASS LIMITS

The limits on low mass ($m_\nu \lesssim 1$ MeV) neutrinos apply to m_{tot} given by

$$m_{tot} = \sum_\nu \left(\frac{g_\nu}{2} \right) m_\nu ,$$

where g_ν is the number of spin degrees of freedom for ν plus $\bar{\nu}$ $g_\nu = 4$ for neutrinos with Dirac masses, $g_\nu = 2$ for Majorana neutrinos The limits on high mass ($m_\nu > 1$ MeV) neutrinos apply separately to each neutrino type

NEUTRINO BOUNDS FROM ASTROPHYSICS & COSMOLOGY

LIMIT ON TOTAL ν MASS, m(tot)

(Defined in the above note) of effectively stable neutrinos (i.e., those with mean lives greater than or equal to the age of the universe). These papers assumed Dirac neutrinos. When necessary we have generalized the results reported so they apply to m(tot). For other limits see SZALAY 76, VYSOTSKY 77, BERNSTEIN 81, FREESE 84, SCHRAMM 84, and COWSIK 85.

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE (eV)	DOCUMENT ID		TECN
<180	SZALAY	74	COSM
<132	COWSIK	72	COSM
<280	MARX	72	COSM
<400	GERSHTEIN	66	COSM

LIMITS ON NEUTRINO MASS FOR $m(\nu)$ > 1 MeV

For other limits, see SATO 77, DICUS 78, HUT 79, and BERNSTEIN 85.

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
none 20–1000	95	[1] GELMINI	87	COSM	Dirac ν
>15		[1,2] GAISSER	86	COSM	Dirac ν
>27		[1,2] GAISSER	86	COSM	Majorana ν
> 3		KOLB	86	COSM	Dirac ν
> 7		KOLB	86	COSM	Majorana ν
> 3		HUT	77	COSM	
> 2		LEE	77	COSM	Dirac ν
> 2.5		VYSOTSKY	77	COSM	

[1] These results assume that neutrinos make up dark matter in the galactic halo.

[2] Limits based on annihilations in the sun and are due to an absence of high energy neutrinos detected in underground experiments.

ASTROPHYSICAL AND COSMOLOGICAL LIMITS ON ν MASSES

If neutrinos are present as dark matter in galactic halos, limits on neutrino masses have been computed based on neutrino degeneracy and Fermi statistics. The results depend strongly on assumptions. See the references.

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE (eV)	DOCUMENT ID		TECN	COMMENT
	KAWASAKI	86	COSM	
	KAWASAKI	86B	COSM	
	TAKAHARA	86	COSM	supernovae
	MADSEN	85	COSM	Some anisotropy
	MADSEN	84	COSM	Assume isotropy
	SARKAR	84	COSM	Decaying neutrinos
	FREESE	83	COSM	Degenerate ν
	LIN	83	COSM	
	PRIMACK	83	COSM	
	BOND	81	COSM	Adiabatic
	DAVIS	81	COSM	Adiabatic+decaying ν's
	SCHRAMM	81	COSM	Isothermal
	TREMAINE	79	COSM	Isothermal

LIMITS ON MASSES OF LIGHT STABLE RIGHT-HANDED ν (with necessarily suppressed interaction strengths)

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE (eV)	DOCUMENT ID		TECN	COMMENT
<100–200	[3] OLIVE	82	COSM	Dirac ν
<200–2000	[3] OLIVE	82	COSM	Majorana ν

[3] Depending on interaction strength g_R where $g_R < G_F$.

LIMITS ON MASSES OF HEAVY STABLE RIGHT-HANDED ν (with necessarily suppressed interaction strengths)

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
> 10	[4] OLIVE	82	COSM	$g_R/G_F < 0.1$
>100	[4] OLIVE	82	COSM	$g_R/G_F < 0.01$

[4] These results apply to heavy Majorana neutrinos and are summarized by the equation $m(\nu) > 1.2$ GeV (G_F / g_R).

ν RADIATIVE MEAN LIFE VERSUS MASS

In these papers it is assumed that a neutrino can decay to a lighter neutrino plus a photon. The limits obtained are strongly correlated. See references.

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE	DOCUMENT ID		TECN
	KAWASAKI	86	COSM
	LINDLEY	85	COSM
	BINETRUY	84	COSM
	SARKAR	84	COSM
	KRAUSS	83B	COSM
	HENRY	81	COSM
	KIMBLE	81	COSM
	REPHAELI	81	COSM
	TURNER	81	COSM
	DERUJULA	80	COSM
	STECKER	80	COSM
	COWSIK	79	COSM
	GOLDMAN	79	COSM
	LINDLEY	79	COSM
	DICUS	78	COSM
	DICUS	78B	COSM
	FALK	78	COSM
	GUNN	78	COSM
	MIYAMA	78	COSM
	COWSIK	77	COSM
	DICUS	77	COSM
	GOLDMAN	77	COSM

NUMBER OF LIGHT TWO-COMPONENT ν TYPES ("light" means < about 1 MeV)

NUMBER COUPLING WITH FULL WEAK STRENGTH

See also STECKER 80B, OLIVE 81B, STECKER 81, and RANA 82.

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE	DOCUMENT ID		TECN	COMMENT
<5.2	ELLIS	86	COSM	
<4	STEIGMAN	86	COSM	
<4	YANG	84	COSM	
· 10 to 1000	ELLIS	83	COSM	Astrophys model dep
maybe no firm bound	OLIVE	81	COSM	
<4	YANG	79	COSM	
<7	STEIGMAN	77	COSM	
	SHVARTSMAN	69	COSM	

NUMBER COUPLING WITH LESS THAN FULL WEAK STRENGTH

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE	DOCUMENT ID		TECN
<20	[5] OLIVE	81C	COSM
<20	[5] STEIGMAN	79	COSM

[5] Limit varies with strength of coupling.

MAGNETIC MOMENT OF SUFFICIENTLY LIGHT ν

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE (eV/gauss)	DOCUMENT ID		TECN
$< 2 \times 10^{-19}$	LYNN	81	COSM
	SUTHERLAND	76	COSM

REFERENCES FOR NEUTRINO BOUNDS FROM ASTROPHYSICS AND COSMOLOGY

GELMINI	87	Telemark 337	+Ahlen+	(HARV CHIC BOST SCUC PNL+)
ELLIS	86	PL 167B 457	+Enqvist Nanopoulos Sarkar	(CERN OXF)
GAISSER	86	PR D34 2206	+Steigman Tilav	(BRTD DELA)
KAWASAKI	86	PL B176 71	+Terasawa Sato	(TOKY)
KAWASAKI	86B	PL 169B 280	+Sato	(TOKY)
KOLB	86	PR D33 1202	+Olive	(FNAL)
Also Erratum	86B	PR D34 2531	Kolb Olive	(FNAL)
STEIGMAN	86	PL B176 33	+Olive Schramm Turner	(BART MINN+)
TAKAHARA	86	PL B174 373	+Sato	(TOKY)
BERNSTEIN	85	PR D32 3261	+Brown Feinberg	(STEV WASH+)
COWSIK	85	PL 151B 62		(TATA)
LINDLEY	85	APJ 294 1		(FNAL)
MADSEN	85	PRL 54 2720	+Epstein	(AARH LANL)
BINETRUY	84	PL 134B 174	+Girardi Salati	(LAPP)
FREESE	84	NP B233 167	+Schramm	(CHIC FNAL)
MADSEN	84	APJ 282 11	+Epstein	(AARH LANL)
SARKAR	84	PL 148B 347	+Cooper	(OXF CERN)
SCHRAMM	84	PL 141B 337	+Steigman	(FNAL BART)
YANG	84	APJ 281 493	+Turner Steigman Schramm Olive	(CHIC BART)
ELLIS	83	NP B223 256	+Olive	(CERN)
FREESE	83	PR D27 1689	+Kolb Turner	(CHIC LANL)
KRAUSS	83B	PL 128B 37		(HARV)
LIN	83	APJ 266 L21	+Faber	(UCSC)
PRIMACK	83	Phil 4th Workshop on Grand Unification		(UCSC)
Also	82	Nature 299 37	Blumenthal Pagels Primack	(UCSC ROCK)
OLIVE	82	PR D25 213	+Turner	(CHIC UCSB)
RANA	82	PRL 48 209		(TATA)
BERNSTEIN	81	PL 101B 39	+Feinberg	(STEV COLU)
BOND	81	Nu Conf Hawaii	+Szalay	(UCB CHIC)
DAVIS	81	APJ 250 423	+Lecar Pryor Witten	(HARV PRIN)
HENRY	81	PRL 47 618	+Feldman	(JHU)
KIMBLE	81	PRL 46 80	+Bowyer Jakobsen	(UCB)
LYNN	81	PR D23 2151		(COLU)
OLIVE	81	APJ 246 557	+Schramm Steigman Turner Yang+	(CHIC BART)
OLIVE	81B	PRL 46 516	+Turner	(EFI)
OLIVE	81C	NP B180 497	+Schramm Steigman	(EFI BART)
REPHAELI	81	PL 106B 73	+Szalay	(UCSB CHIC)
SCHRAMM	81	APJ 243 1	+Steigman	(CHIC BART)
STECKER	81	PRL 46 517		(NASA)
TURNER	81	Nu Conf Hawaii		(UCSB CHIC)
DERUJULA	80	PRL 45 942	+Glashow	(MIT HARV)
STECKER	80	PRL 45 1460		(NASA)
Also	81B	Hawaii Nu 1 124	Stecker	(NASA)
STECKER	80B	PRL 44 1237		(NASA)
COWSIK	79	PR D19 2219		(TATA)
GOLDMAN	79	PR D19 2215	+Stephenson	(LASL)
HUT	79	PL 87B 144	+Olive	(AMST EFI)
LINDLEY	79	MNRAS 188 15P		(SUSS)
STEIGMAN	79	PRL 43 239	+Olive Schramm	(BART EFI)
TREMAINE	79	PRL 42 407	+Gunn	(CIT CAMB CAIW)

YANG 79 APJ 227 697 +Schramm Steigman Rood (CHIC YALE VIRG)
See footnote 4 in STEIGMAN 79
Also 79 PRL 43 239 Steigman Olive Schramm (BART EFI)
DICUS 78 PR D17 1529 +Kolb Teplitz Wagoner (TEXA VPI STAN)
DICUS 78B APJ 221 327 +Kolb Teplitz (TEXA VPI)
FALK 78 PL 79B 511 +Schramm (CHIC)
GUNN 78 APJ 223 1015 +Lee Lerche+ (CIT CAMB FNAL CHIC YALE)
MIYAMA 78 PTP 60 1703 +Sato (KYOT)
COWSIK 77 PRL 39 784 (MPIM TATA)
DICUS 77 PRL 39 168 +Kolb Teplitz (TEXA VPI)
GOLDMAN 77 PR D16 2256 +Stephenson (LASL)
HUT 77 PL 69B 85 (UTRE)
LEE 77 PRL 39 165 +Weinberg (FNAL STAN)
SATO 77 PTP 58 1775 +Kobayashi (KYOT)
STEIGMAN 77 PL 66B 202 +Schramm Gunn (YALE CHIC CIT)
VYSOTSKY 77 JETPL 26 188 +Dolgov Zeldovich (ITEP)
Translated from ZETFP 26 200
SUTHERLAND 76 PR D13 2700 +Ng Flowers+ (PENN COLU NYU)
SZALAY 76 AA 49 437 +Marx (EOTV)
SZALAY 74 APAH 35 8 +Marx (EOTV)
COWSIK 72 PRL 29 669 +McClelland (UCB)
MARX 72 Nu Conf Budapest +Szalay (EOTV)
SHVARTSMAN 69 JETPL 9 184 (MOSU)
Translated from ZETFP 9 315
GERSHTEIN 66 JETPL 4 120 +Zeldovich (KIAM)
Translated from ZETFP 4 189

HEAVY LEPTON SEARCHES

NOTE ON HEAVY LEPTON SEARCHES

Data on the $\tau^{\mp}$ are listed in a separate section, following the e and μ listings. Data on excited leptons (e^*, μ^*, τ^*) appear in the section "Searches for Quark and Lepton Compositeness." Searches for fractionally charged heavy leptons are included in the section on "Free Quark Searches."

The following section contains information on searches for heavy leptons of other types.

Several types of heavy leptons (that is, non-strongly-interacting fermions other than e and μ) have been proposed. In the Full Listings we distinguish four types.[1,2] Each has a corresponding antiparticle with opposite charge and lepton number. For convenience we omit writing the antiparticles in the following descriptions. The four types are:

Sequential leptons (L^-,ν_L). Such a pair is assumed to have its own separately strictly conserved lepton number $n_L = +1$. This means that the radiative decays

$$\left.\begin{array}{l} L^- \rightarrow e^-\gamma \\ L^- \rightarrow \mu^-\gamma \end{array}\right\} \text{ are forbidden ,}$$

while the weak decays (assuming m_L sufficiently large)

$$\left.\begin{array}{l} L^- \rightarrow \nu_L e^- \bar{\nu}_e \\ L^- \rightarrow \nu_L \mu^- \bar{\nu}_\mu \\ L^- \rightarrow \nu_L \text{ hadrons} \end{array}\right\} \text{ are allowed}$$

There could be an increasing mass sequence of such pairs. It is frequently assumed that the neutrinos are massless.

Decay rates are assumed calculable from conventional weak interaction theory. For an L^- mass between 1 and 3 GeV, the branching fraction to each of the two leptonic modes above should be roughly 10 to 20%. For an L^- mass above 1 GeV, the mean life should be $\lesssim 10^{-12}$ second.

Paraleptons (E^+, E^0) *and* (M^+, M^0). These pairs have the same lepton numbers as the opposite-charge ordinary leptons, i.e., e^- and μ^-, respectively. Radiative decays are again forbidden and decays similar to those allowed for L are allowed here, e.g.,

$$M^+ \rightarrow \nu_\mu e^- \nu_e$$

or

$$M^+ \rightarrow \nu_\mu \mu^+ \nu_\mu$$

However, the lightest member is not stable as is the case for sequential leptons, so that bizarre decay schemes such as (assuming $m_{E^0} < m_{E^+}$)

$$E^+ \rightarrow E^0 \mu^- \nu_\mu, \quad E^0 \rightarrow e^- e^- \nu_e$$

are allowed.

Heavy leptons of this type were proposed (before the discovery of the Z^0 boson) in unified gauge theories of weak and electromagnetic interactions to cancel unphysical high energy behavior in such processes as $e^+e^- \rightarrow W^+W^-$.[3]

Ortholeptons (F^- *and* N^-). These have the same lepton numbers as e^- and μ^-, respectively. They may or may not have associated neutral leptons. Radiative decays are allowed in addition to weak modes similar to those of sequential leptons. The radiative mode can dominate or can be relatively unimportant depending on the model.[4] Decays such as

$$F^- \rightarrow e^- + \text{hadrons}$$

are also allowed.

Long-lived penetrating particles. Heavy leptons could have long mean lives under certain circumstances. For example, if $m_{\nu_L} > m_L$, then L^-, the sequential lepton, is completely stable since its lepton number is conserved.

See PERL 81 for a review.

References

1 M L Perl and P Rapidis, SLAC-PUB-1496 (October 1974)

2 C H Llewellyn Smith, Invited paper presented at the Royal Society Meeting on New Particles and New Quantum Numbers, 11 March 1976, Oxford Ref 33/76

3 J D Bjorken and C H Llewellyn Smith, Phys Rev **D7**, 887 (1973)

4 F Wilczek and A Zee, Nucl Phys **B106**, 461 (1976)

CHARGED HEAVY LEPTON MASS LIMITS

Limits apply only to heavy lepton type given in comment at right of data Listings See review above for description of types L E, M F N stand for sequential lepton para-electron, para-muon ortho electron, ortho-muon respectively Limits for excited leptons (e^*, μ^*, τ^*) are included in the section on SEARCHES FOR QUARK AND LEPTON COMPOSITENESS

SEQUENTIAL CHARGED HEAVY LEPTON MASS LIMITS

VALUE (GeV)	CL%	DOCUMENT ID		TECN	CHG	COMMENT
>41	90	[1] ALBAJAR	87B	UA1	±	Sequential (L)
• • • We do not use the following data for averages, fits limits etc • • •						
>25 0	95	YOSHIDA	87B	VNS	±	Sequential (L)
>22 5	95	[2] ADEVA	85	MRKJ	±	Sequential (L)
>18		[3] ADEVA	83B	MRKJ	±	Sequential (L)
>18 0	95	[4] BARTEL	83	JADE	±	Sequential (L)
>14	95	ADEVA	82	MRKJ	±	Sequential (L)
none 4-14 5 GeV	95	[5] BERGER	81B	PLUT	±	Sequential (L)
>15 5	95	[6] BRANDELIK	81	TASS	±	Sequential (L)
>13		[7] AZIMOV	80		±	Sequential (L)
>16	95	[8] BARBER	80B	CNTR	±	Sequential (L)
> 0 490		[9] ROTHE	69	RVUE	±	Sequential (L)

[1] Assumes associated neutrino is approximately massless

[2] ADEVA 85 analyze one isolated-muon data and sensitive to τ < 10 nanosec Assume BR(lepton) = 0 30 E_{cm} = 40-47 GeV

[3] ADEVA 83B looked for muon opposite against a hadron jet

[4] BARTEL 83 limit is from PETRA e^+e^- experiment with average E_{cm} = 34 2 GeV

[5] BERGER 81B is DESY DORIS and PETRA experiment Looking for $e^+e^- \to L^+L^-$

[6] BRANDELIK 81 is DESY PETRA experiment Looking for $e^+e^- \to L^+L^-$

[7] AZIMOV 80 estimated probabilities for $M + N$ type events in $e^+e^- \to L^+L^-$ deducing semi hadronic decay multiplicities of L from e^+e^- annihilation data at $E_{cm} = (2/3)m(L)$ Obtained above limit comparing these with e^+e^- data (BRANDELIK 80)

[8] BARBER 80B looked for $e^+e^- \to L^+L^-$ $L \to \nu_L^+ X$ with MARK-J at DESY-PETRA

[9] ROTHE 69 examines previous data on μ pair production and π and K decays

CHARGED HEAVY LEPTON MASS LIMITS

VALUE (GeV)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •							
>1 15	95	0	[10] ORITO	74	ASPK	±	Any nonrad type
>1 4	95	0	[11] BERNARDINI	73	ASPK	±	Any nonrad type
>1 0	95	0	[11] BERNARDINI	73	ASPK	±	Any nonrad type

[10] ORITO 74 looked for H^+H^- pairs giving $\mu^- e$ pairs Mass limit refers to any nonradiative type heavy lepton — L, E M, F N Coupling to hadron assumed from theoretical models

[11] BERNARDINI 73 is Frascati e^+e^- experiment First value assumes universal coupling to ordinary leptons Second value also assumes coupling to hadrons

CHARGED ORTHO-ELECTRON MASS LIMITS

See also the section MASS LIMITS FOR EXCITED e in the section on SEARCHES FOR QUARK AND LEPTON COMPOSITENESS

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •						
none 0 25-2 3		[12] BACCI	77B	SPEC	±	Ortho-electron(F)
>0 6	0	[13] BACCI	73	ELEC	±	Ortho-electron(F)
>2 2	0	[13] BACCI	73	ELEC	±	Ortho electron(F)
none 0 263-1 32		[14] LICHTENSTEIN	70	SPEC	−	Ortho-electron(F)
none 0 1-1 3		[15] BOLEY	68	SPEC	−	Ortho electron(F)
none 0 3-0 7		[16] BUDNITZ	66	SPEC	−	Ortho-electron(F)
>1 0	0	[17] BEHREND	65	SPEC	−	Ortho-electron(F)
none 0 12-0 57		[18] BETOURNE	65	SPEC	−	Ortho-electron(F)

[12] BACCI 77B is same type as BACCI 73 Lower mass limit corresponds to λ^2 limit of 4×10^{-5} upper value is for λ^2 limit of 1.5×10^{-3}

[13] BACCI 73 is Frascati e^+e^- experiment Looks for $F \to e\gamma$ Mass limit depends on coupling constant λ for this decay First value above is for $\lambda^2 > 9\times10^{-5}$ second is for λ^2 < 10^{-3}

[14] LICHTENSTEIN 70 is Cornell experiment measuring e Bremsstrahlung Mass limit depends on coupling constant First value above is for λ^2 0 17 second is for λ^2 < 0 42

[15] BOLEY 68 is CEA experiment Looks for $ep \to Fp$ Mass of 0 1 corresponds to coupling constant $\lambda^2 > 3\times10^{-4}$ mass limit of 1 3 to λ^2 > 0 01

[16] BUDNITZ 66 is CEA experiment Looks for $ep \to Fp$

[17] BEHREND 65 is DESY experiment Looks for $ep \to Fp$ $F \to e\gamma$ This mass limit corresponds to a limit on λ^2 of 6.25×10^{-4}

[18] BETOURNE 65 is Orsay experiment Looks for $ep \to Fp$ Mass of 0 12 corresponds to coupling constant λ^2 < 0 0016 mass of 0 57 to λ^2 0 22

CHARGED ORTHO-MUON MASS LIMITS

See also the section MASS LIMITS FOR EXCITED μ in the section on SEARCHES FOR QUARK AND LEPTON COMPOSITENESS

VALUE (GeV)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •							
>10.3	98		[19] ASRATYAN	78		−	Ortho-muon (N)
> 7 5		0	[20] CNOPS	78	HLBC	−	Ortho muon (N)
> 1 8	90		[21] ASRATYAN	74	HLBC	±	Ortho muon (N)
none 0-2 0			[22] GITTLESON	74	SPEC	−	Ortho muon (N)
none 0 2-0 6			[23] LIBERMAN	69	OSPK	−	Ortho muon (N)

[19] ASRATYAN 78 analyzes dependence of (neutral current/charged current) on energy of associated hadrons Uses data of HOLDER 77 ν_μ interactions at CERN SPS

[20] CNOPS 78 is FNAL experiment looking for $\nu_\mu Ne \to L^\pm$ followed by $L^\pm \to e^\pm\nu\nu$

[21] ASRATYAN 74 uses EICHTEN 73 data on $\nu N \to e^-$ hadrons and $\bar{\nu}N \to e^+$ hadrons to set limits on orthomuon production

[22] GITTLESON 74 is $\mu p \to p$ orthomuon search Coupling constant λ^2 is < 0 01 for mass up to 0 7 GeV limit on λ^2 rises to < 0 1 for mass of 2 0 GeV

[23] LIBERMAN 69 is a BNL experiment measuring muon Bremsstrahlung

CHARGED PARA-MUON MASS LIMITS

VALUE (GeV)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •							
> 9 0		0	[24] CNOPS	78	HLBC	+	Para muon (M)
>10 0			[25] ERRIQUEZ	78	BEBC	+	Para muon (M)
>12	90		[26] HOLDER	78	CNTR	+	Para-muon (M)
> 8.4	90		[27] BARISH	74	SPEC	+	Para-muon (M)
> 2.0	90	0	[28] BARISH	73B	ASPK	+	Para-muon (M)
> 2.4	90	0	[29] EICHTEN	73	HLBC	+	Para-muon (M)

[24] CNOPS 78 is FNAL experiment looking for $\nu_\mu Ne \to L^\pm$ followed by $L^\pm \to e^\pm\nu\nu$

[25] ERRIQUEZ 78 is CERN SPS experiment Looks for $\nu_\mu$nucleon $\to \mu^- e^+ X$ Finds cross section for producing heavy lepton $\to e^+$ < $0\ 7\times10^{-3}$ × CC cross section

[26] HOLDER 78 is a CERN ν experiment looking for $\nu_\mu$nucleon $\to \mu^+$ anything Assumes $M^+ \to \mu^+ 2\nu_\mu$ with BR = 0 2

[27] BARISH 74 is FNAL 50 135 GeV ν experiment Looks for (νnucleon $\to M^+$ X) Assumes ($M^+ \to \mu^+\nu\nu$) with BR = 0 3

[28] BARISH 73B is FNAL 50,145 GeV ν experiment Looks for (νnucleon $\to M^+$ X) Assumes ($M^+ \to \mu^+\nu\nu$) with BR = 0 3

[29] EICHTEN 73 is CERN 1-10 GeV ν experiment Looks for M^+ produced in $\nu N \to M^+$ hadrons assuming 15% decay to $e^+\nu\nu$

CHARGED LONG-LIVED HEAVY LEPTON MASS LIMITS

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •						
>0.1	0	[30] ANSORGE	73B	HBC	−	Long-lived
none 0 55-4.5		[31] BUSHNIN	73	CNTR	−	Long-lived
none 0 2-0.92		[32] BARNA	68	CNTR	−	Long lived
none 0 97-1 03		[32] BARNA	68	CNTR	−	Long lived

[30] ANSORGE 73B looks for electron pair production and electron like Bremsstrahlung

[31] BUSHNIN 73 is SERPUKOV 70 GeV p experiment Masses assume mean life above 7×10^{-10} and 3×10^{-8} respectively Calculated from cross section (see ' CHARGED QUASI-STABLE LEPTON PRODUCTION DIFFERENTIAL CROSS SECTION ' below) and 30 GeV muon pair production data

[32] BARNA 68 is SLAC photoproduction experiment

DOUBLY-CHARGED HEAVY LEPTON MASS LIMITS

VALUE (GeV)	CL%	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages, fits limits etc • • •					
none 1-9 GeV	90	[33] CLARK	81	SPEC	++

[33] CLARK 81 is FNAL experiment with 209 GeV muons Bounds apply to M which couples with full weak strength to muon See also section on DOUBLY CHARGED LEPTON PRODUCTION CROSS SECTION

NEUTRAL HEAVY LEPTON MASS LIMITS

Limits apply only to heavy lepton type given in comment at right of data Listings See review above for description of types L E M, F N stand for sequential lepton para electron para-muon ortho electron, ortho-muon respectively

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>24.5	95	[34] BARTEL	83	JADE	Para or ortho- e V+A
>22.5	95	[34] BARTEL	83	JADE	Para or ortho e V−A

Stable Particle Full Listings
HEAVY LEPTON SEARCHES

• • • We do not use the following data for averages fits limits etc • • •

none 0.25–14	90	[35] MISHRA	87	CNTR	$\vert U_{\mu j}\vert^2=1$
none 0.25–10	90	[35] MISHRA	87	CNTR	$\vert U_{\mu j}\vert^2=0.1$
none 0.25–7.7	90	[35] MISHRA	87	CNTR	$\vert U_{\mu j}\vert^2=0.03$
none 1.–2	90	[36] WENDT	87	MRK2	$\vert U_{e\ \mathrm{or}\ \mu j}\vert^2=0.1$
none 2.2–4	90	[36] WENDT	87	MRK2	$\vert U_{e\ \mathrm{or}\ \mu j}\vert^2=0.001$
none 2.3–3	90	[36] WENDT	87	MRK2	$\vert U_{\tau j}\vert^2=0.1$
none 3.2–4.8	90	[36] WENDT	87	MRK2	$\vert U_{\tau j}\vert^2=0.001$
none 0.3–0.9 GeV	90	[37] BADIER	86	CNTR	$\vert U_{e j}\vert^2=0.8$
none 0.33–2.0 GeV	90	[37] BADIER	86	CNTR	$\vert U_{e j}\vert^2=0.03$
none 0.6–0.7 GeV	90	[37] BADIER	86	CNTR	$\vert U_{\mu j}\vert^2=0.8$
none 0.6–2.0 GeV	90	[37] BADIER	86	CNTR	$\vert U_{\mu j}\vert^2=0.01–0.001$
none 1–9 GeV	90	[38] CLARK	81	SPEC	Para-muon($\overline{M}^0$)
> 1.2		MEYER	77	MRK1	Neutral

[34] BARTEL 83 is PETRA e^+e^- experiment with average W_{cm} = 34.2 GeV first (second) limit is for V+A(V−A) type W^-E^0e coupling

[35] MISHRA 87 is Fermilab neutrino experiment looking for either dimuon or double vertex events (hence long-lived)

[36] WENDT 87 is MARK II search at PEP for heavy ν with decay length 1–20 cm (hence long lived)

[37] BADIER 86 is a search for a long lived penetrating sequential lepton produced in π^- – nucleon collisions with lifetimes in the range from 5×10^{-7}–5×10^{-11} sec and decaying into at least two charged particles U_{ej} and U_{mj} are mixing angles to ν_e and ν_μ See also the BADIER 86 entry in the section SEARCHES FOR MASSIVE NEUTRINOS AND LEPTON MIXING

[38] CLARK 81 is FNAL experiment with 209 GeV muons Bounds apply to M^0 which couples with full weak strength to muon See also section on NEUTRAL HEAVY LEPTON PRODUCTION CROSS SECTION (μ NUCLEON) below

DOUBLY-CHARGED LEPTON PRODUCTION CROSS SECTION (μN SCATTERING)

VALUE (cm²)	EVTS	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages fits limits etc • • •					
$<6\times10^{-38}$	0	[39] CLARK	81	SPEC	++

[39] CLARK 81 is FNAL experiment with 209 GeV muon Looked for μ^+ nucleon → $\overline{M}^0$ X $M^0 \rightarrow \mu^+\mu^-\nu_\mu$ and $\mu^+n \rightarrow M^{++}$ X $M^{++} \rightarrow 2\mu^+\nu_\mu$ Above limits are for $\sigma\cdot$ BR taken from their mass dependence plot figure 2

CHARGED QUASI-STABLE LEPTON PRODUCTION DIFFERENTIAL CROSS SECTION (pN SCATTERING)

VALUE (cm²/sr-GeV)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits, etc • • •							
$<4\times10^{-38}$	90	0	[40] BUSHNIN	73	CNTR	−0	7 GeV p Serpukhov
$<1.6\times10^{-37}$	90	0	[41] GOLOVKIN	72	CNTR	−0	7 GeV p, Serpukhov

[40] BUSHNIN 73 heavy lepton path traverses 6800 gm/cm² absorber Differential cross section measured at p = 30 GeV/c θ = 2 mrad Mass range 0.55–4.5 GeV Assume lepton is quasi-stable

[41] Mass range 1–4.5 GeV θ = 0, p = 25 GeV/c Assume lepton is quasi stable

LONG-LIVED CHARGED LEPTON PRODUCTION CROSS SECTION (pN SCATTERING)

VALUE (cm²/GeV²)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •							
$<1.8\times10^{-33}$	90	0	[42] ARMITAGE	79	SPEC	−	m=1.87 GeV
$<6.4\times10^{-35}$	90	0	[43] BINTINGER	75	SPEC	±	m=1–5 GeV
$<5.4\times10^{-39}$	90	0	[44] CRONIN	74	SPEC	−	m=1–6.8 GeV

[42] ARMITAGE 79 is CERN ISR experiment at E_{cm} = 53 GeV Value is for X = 0.1 and p_T = 0.15

[43] BINTINGER 75 is a 30–300 GeV pC experiment Looked for long lived penetrating particles Above limit assumes stable Multiply it by $\exp(3.5\times10^{-8}m/\tau/p)$ for mass m(GeV) lifetime τ(sec) momentum p(GeV) Obtained at θ(lab) = 91 mrad p_T = 1–2.25 GeV/c

[44] CRONIN 74 is an FNAL 300 GeV p Cu experiment Looked for long-lived penetrating particles Above limit assumes stable Multiply it by $\exp(1.22\times10^{-8}m/\tau)$ for mass m(GeV) and lifetime τ(sec) Limit obtained at θ(lab) = 77 mrad p_T = 2.38 GeV/c

CHARGED HEAVY LEPTON PRODUCTION CROSS SECTION (σ(HEAVY LEPTON)/$\sigma(\pi)$)

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits etc • • •						
$<7\times10^{-12}$	95	0	[45] BUSSIERE	80	CNTR	Q= −1 m=4–4.5 GeV
$<2.5\times10^{-12}$	95	0	[45] BUSSIERE	80	CNTR	Q= −2 m=5–7.5 GeV

[45] BUSSIERE 80 is CERN SPS experiment with 200–240 GeV protons on Be and Al target searching for long-lived particles For limits at other mass ranges see their figure 7

NEUTRAL HEAVY LEPTON PRODUCTION CROSS SECTION (μN)

VALUE (cm²)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •						
$<4\times10^{-38}$	0	[46] CLARK	81	SPEC	0	Para muon($\overline{M}^0$)
$<1.22\times10^{-34}$		[47] LEBRITTON	80	SPEC	0	$M^0 \rightarrow \mu^+\mu^-\nu$

[46] CLARK 81 is FNAL experiment with 209 GeV muon Looked for $\mu^+N \rightarrow \overline{M}^0$ X $\overline{M}^0 \rightarrow \mu^+\mu^-\nu_\mu$ and $\mu^+n \rightarrow M^{++}$ X $M^{++} \rightarrow 2\mu^+\nu_\mu$ Above limits are for $\sigma\times$ BR taken from their mass-dependence plot figure 2

[47] LEBRITTON 80 is BNL experiment with 10.5 GeV muons Trimuons are consistent with QED trident and diffractively produced ρ decay

PRODUCTION OF NEUTRAL HEAVY LEPTON IN BEAM DUMP

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
	[48] LOSECCO	81	CALO	28 GeV protons

[48] LOSECCO 81 at BNL AGS set limit for σ(production)σ(interaction) ratio of slow (β < 0.89) heavy leptons to prompt ν's as 2.2×10^{-2} (CL = 90%)

NEUTRAL HEAVY LEPTON PRODUCTION CROSS SECTION (pN SCATTERING)

VALUE (cm²)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •							
$<8.2\times10^{-40}$	90	0	[49] AGAKISHIEV	80	SPRK	0	m=4 GeV $\tau=10^{-7}$ sec
$<2.8\times10^{-35}$	90	0	[50] BECHIS	78	SPEC	0	
$<1\times10^{-29}$		0	[51] FAISSNER	76	HLBC	0	

[49] AGAKISHIEV 80 reanalyzed beam dump data from 70 GeV proton on iron (ASRATYAN 78 Phys Lett 79B 497) Assumed Drell Yan production of charged heavy lepton pair followed by decay into neutral heavy lepton Above value is when limit is most stringent For other mass and life see their table 1 and for limit deduced for π nucleon interaction see their table 2

[50] BECHIS 78 is 400 GeV FNAL experiment Looks for p nucleon → L^+ $L^+ \rightarrow L^0$ X $L^0 \rightarrow \mu\pi$ or $e\pi$ Result is CL = 90% for mass of L^0 < 1 GeV lifetime between 10^{-10} and 10^{-8} sec (Valid only for cases when L^0 unaccompanied by muon of p > 10 GeV)

[51] FAISSNER 76 limit assumes stable neutral weakly interacting lepton Also rules out DERUJULA 75 interpretation of 5 KRISHNASWAMY 75 events as (p nucleon → L^+ X $L^+ \rightarrow L^0$ X) unless L^+ mass is above 3 GeV

NEUTRAL HEAVY LEPTON PRODUCTION CROSS SECTION (e^+e^-)

σ × BR(τ → new neutral lepton) × BR(neutral lepton → $e\pi$ or $\mu\pi$)

VALUE (10^{-5} nb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •					
<450	90	[52] MEYER	77	MRK1	For m(L)=0.5 GeV
<250	90	[52] MEYER	77	MRK1	For m(L)=1.5 GeV

[52] MEYER 77 experiment looks for narrow neutral resonance in $e^-\pi$ and $\mu^-\pi$ channels See HEAVY LEPTON MASS LIMITS section above

$\sigma(L\overline{L})$ × [BR($L \rightarrow e\nu X$) + BR($\overline{L} \rightarrow e\nu X$)]

VALUE (10^{-5} nb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits etc • • •					
< 8	90	[53] ERREDE	84	HRS	For m(L)=1 GeV
<18	90	[53] ERREDE	84	HRS	For m(L)=2 GeV
<20	90	[53] ERREDE	84	HRS	For m(L)=3 GeV
<11	90	[53] ERREDE	84	HRS	For m(L)=4 or 5 GeV
<13	90	[53] ERREDE	84	HRS	For m(L)=6 GeV
<17	90	[53] ERREDE	84	HRS	For m(L)=7 GeV

[53] Assuming X = μ If X = meson limits are 20% higher ERREDE 84 say these limits are comparable to those expected from naive theory e^+e^- E_{cm} = 29 GeV See also GRONAU 84 RIZZO 84

$\sigma(L_1 + L_2)$ × BR(L_1 → only light neutrinos)

VALUE (10^{-5} nb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •					
< 4.7	90	[54] AKERLOF	85	HRS	For m(L)=2 GeV
<18	90	[54] AKERLOF	85	HRS	For m(L)=10 GeV

[54] AKERLOF 85 observe no monojets above background They use standard couplings to Z to find $\sigma(L_1 + L_2)$ = 0.36 pb Above data then imply BR(L_1 → light neutrinos) < 13–50% for m(L) = 2–10 GeV

$\sigma(LL)$ × BR_1 × BR_2 / σ(standard via virtual Z)

where BR_1 and BR_2 are branching ratios leading to events with two or four charged particles and σ(standard) = $0.35(\beta(3+\beta^2)/4)$ pb with β = velocity/c of L

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •						
<0.1–0.2	90	0	[55] PERL	85	MRK2	For m(L) > 1 GeV

[55]PERL 85 examine a variety of models and processes They search up to $m(L)$ = 14 GeV but are most sensitive for $m(L)$ < 1 GeV They require lepton lifetime < $m(L)10^{-11}$ sec [$m(L)$ in GeV] which limits their ability to constrain the mixing of a 4th conventional generation

REFERENCES FOR HEAVY LEPTON SEARCHES

ALBAJAR 87B PL B185 241 +Albrow Allkofer Arnison+ (UA1 Collab)
MISHRA 87 PRL 59 1397 +Auchincloss+ (COLU CIT FNAL CHIC ROCH)
WENDT 87 PRL 58 1810 +Abrams Amidei Baden+ (MARK II Collab)
YOSHIDA 87B PRL 59 2915 +Chiba Endo+ (VENUS Collab)
BADIER 86 ZPHY C31 21 +Bemporad Boucrot Callot+ (NA3 Collab)
ADEVA 85 PL 152B 439 +Becker Becker Szendy+ (MARK J Collab)
Also 84C PRPL 109 131 Adeva Barber Becker+ (MARK J Collab)
AKERLOF 85 PL 156B 271 +Bonvicini Chapman Errede+ (HRS Collab)
PERL 85 PR D32 2859 +Barklow Boyarski+ (MARK II Collab)
ERREDE 84 PL 149B 519 +Akerlof Chapman Harnew+ (HRS Collab)
GRONAU 84 PR D29 2539 +Leung Rosner (SYRA FNAL CHIC)
RIZZO 84 PL 136B 251 (ISU)
ADEVA 83B PRL 51 443 +Barber Becker Berdugo+ (MARK J Collab)
BARTEL 83 PL 123B 353 +Cords Dietrich Eichler+ (JADE Collab)
ADEVA 82 PRL 48 967 +Barber Becker Berdugo+ (MARK J Collab)
BERGER 81B PL 99B 489 +Genzel Grigull Lackas+ (PLUTO Collab)
BRANDELIK 81 PL 99B 163 +Braunschweig Gather+ (TASSO Collab)
CLARK 81 PRL 46 299 +Johnson Kerth Loken+ (UCB LBL FNAL PRIN)
Also 82 PR D25 2762 Smith Clark Johnson Kerth+ (LBL FNAL PRIN)
LOSECCO 81 PL 102B 209 +Sulak Gallk Horstkotte+ (MICH PENN BNL)
AGAKISHIEV 80 SJNP 32 345 +Vovenko Goryachev Mukhin (SERP)
Translated from YAF 32 671
AZIMOV 80 JETPL 32 664 +Khoze (KONS)
Translated from ZETFP 32 677
BARBER 80B PRL 45 1904 +Becker Bei Berghoff+ (MARK J Collab)
BRANDELIK 80 PL 92B 199 +Braunschweig Gather+ (TASSO Collab)
BUSSIERE 80 NP B174 1 +Giacomelli Lesquoy+ (BGNA SACL LAPP)
LEBRITTON 80 PL 89B 271 +McCal Melissinos+ (ROCH BNL NSF)
ARMITAGE 79 NP B150 87 +Benz Bobbink+ (CERN DARE FOM MCHS UTRE)
ASRATYAN 78 PL 76B 237 +Kubantsev (ITEP)
BECHIS 78 PRL 40 602 +Chang Dombeck Ellsworth Glasser Lau+(UMD)
CNOPS 78 PRL 40 144 +Connolly Kahn Kirk+ (BNL COLU)
ERRIQUEZ 78 PL 77B 227 (BARI BIRM BRUX EPOL RHEL SACL LOUC)
HOLDER 78 PL 74B 277 +Knobloch May+ (CDHS Collab)
BACCI 77B PL 71B 227 +Dezorzi Penso Stella+ (ROMA FRAS)
HOLDER 77 PL 70B 393 +Knobloch May+ (CDHS Collab)
MEYER 77 PL 70B 469 +Nguyen Abrams+ (SLAC LBL NWES HAWA)
FAISSNER 76 PL 60B 401 +Hasert Kabe Krenz+ (Gargamelle Collab)
BINTINGER 75 PRL 34 982 +Curry+ (EFI HARV PENN WISC)
DERUJULA 75 PRL 35 628 +Georgi Glashow (HARV)
KRISHNA 75 PL 57B 105 Krishnaswamy Menon+ (BOMB OSAK)
Also 75 PRL 35 628 DeRujula Georgi Glashow (HARV)
Also 75 Pramana 5 78 Rajasekaran Sarma (TATA)
ASRATYAN 74 PL 49B 488 +Gershtein Kaftanov Kubantsev Lapin+ (SERP)
BARISH 74 PRL 32 1387 +Bartlett Buchholz Merritt+ (CIT FNAL)
CRONIN 74 PR D10 3093 +Frisch Shochet Boymond Mermod+ (EFI PRIN)
GITTLESON 74 PR D10 1379 +Kirk+ (HARV ROCH COLU FNAL)
ORITO 74 PL 48B 165 +Visentin Ceradini Conversi+ (FRAS ROMA)
ANSORGE 73B PR D7 26 +Baker Krzesinski Neale Rushbrooke+ (CAVE)
BACCI 73 PL 44B 530 +Parisi Penso Salvini Stella+ (ROMA FRAS)
BARISH 73B PRL 31 410 +Bartlett Buchholz Humphrey+ (CIT FNAL)
BERNARDINI 73 NC 17A 383 +Bollini Brunini+ (CERN BGNA FRAS)
Also 70 LNC 4 1156 Alles Borelli Bernardini Bollini+ (CERN)
BUSHNIN 73 NP B58 476 +Dunaitzev Golovkin Kubarovsky+ (SERP)
Also 72 PL 42B 136 Golovkin Grachev Shodyrev+ (SERP)
EICHTEN 73 PL 46B 281 +Deden Hasert Krenz+ (Gargamelle Collab)
GOLOVKIN 72 PL 42B 136 +Grachev Shodyrev+ (SERP)
LICHTENSTEIN 70 PR D1 825 +Ash Berkelman Hartill+ (CORN)
LIBERMAN 69 PRL 22 663 +Hoffman Engels+ (HARV CASE MCGI SLAC)
ROTHE 69 NP B10 241 +Wolsky (PENN)
BARNA 68 PR 173 1391 +Cox Martin Perl Tan Toner Zipf+ (SLAC STAN)
BOLEY 68 PR 167 1275 +Elias Friedman Hartmann Kendall+ (MIT CEA)
BUDNITZ 66 PR 141 1313 +Dunning Goitein Ramsey Walker+ (HARV)
BEHREND 65 PRL 15 900 +Brasse Engler Ganssauge+ (DESY KARL)
BETOURNE 65 PL 17 70 +Ngoc Perez y Jorba+ (ORSA)

OTHER RELATED PAPERS

PERL 81 SLAC PUB 2752 (SLAC)
Physics in Collision Conference

e

$J = \frac{1}{2}$

e MASS

The mass is known much more precisely in u (atomic mass units) than in MeV (see the footnote) The conversion from u to MeV 1u = 931 49432 ± 0 00028 MeV involves the relatively poorly known electronic charge

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
0.51099906 ± 0.00000015	[1] COHEN	87	RVUE	1986 CODATA value
• • • We do not use the following data for averages fits limits etc • • •				
0 5110034 ± 0 0000014	COHEN	73	RVUE	
0 5110041 ± 0 0000016	TAYLOR	69	RVUE	Using new e/h
0 511006 ± 0 00002	COHEN	65	RVUE	

[1]The mass is known much more precisely in u m = (5 48579903 ± 0 00000013)×10^{-4} u

$e^+ - e^-$ MASS DIFFERENCE/AVERAGE

Test of CPT

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 4 ×10^{-8}	90	CHU	84	CNTR	Positronium spectroscopy

e MEAN LIFE / BRANCHING FRACTION

Test of charge conservation

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
> 2 ×10^{22}	68	[2] BELLOTTI	83B	CNTR	
> 2 ×10^{22}	68	[3] KOVALCHUK	79	CNTR	
• • • We do not use the following data for averages fits limits etc • • •					
> 1 5 ×10^{25}	68	AVIGNONE	86	CNTR	$e^- \to \nu\gamma$
> 1 ×10^{40}		[4] ORITO	85	ASTR	
> 3 ×10^{23}	68	BELLOTTI	83B	CNTR	$e^- \to \nu\gamma$
> 3 5 ×10^{23}	68	KOVALCHUK	79	CNTR	$e^- \to \nu\gamma$
> 5 3 ×10^{21}		[3] STEINBERG	75	CNTR	
> 2 ×10^{24}		[3 5] MOE	65	CNTR	
> 4 ×10^{22}		MOE	65	CNTR	$e^- \to \nu\gamma$

[2]Second limit of BELLOTTI 83B is for disappearance of K-electrons in Ge atoms This would produce a peak in the Ge(Li) counter spectrum
[3]These limits are for all modes in which decay particles escape from the detector without depositing energy
[4]Assuming electromagnetic forces extend out to large enough distances
[5]See MOE 65 for discussion of earlier experiments MOE 65 limit re estimated by STEINBERG 75 to be (1 × 10^{20})

e ANOMALOUS MAGNETIC MOMENT

ELECTRON OR POSITRON $(g-2)/2$ VALUE

This is magnetic moment in units ($e/2m(e^-)$) for e^- ($e/2m(e^+)$) for e^+ For reviews of theory and experiments see KINOSHITA 78 LAUTRUP 72 and RICH 72 For the most accurate theoretical calculation see KINOSHITA 81 The COHEN 87 determination assumes equal $g/2$ values for e^+ and e^- by CPT

VALUE (10^{-6} $e/2m(e)$)	DOCUMENT ID		TECN	CHG	COMMENT
1159.652193 ± 0.000010	COHEN	87	RVUE		1986 CODATA value
• • • We do not use the following data for averages fits limits etc • • •					
1159 6521884 ± 0 0000043	VANDYCK	87	MRS	−	Single electron
1159 6521879 ± 0 0000043	VANDYCK	87	MRS	+	Single positron
1159 652200 ± 0 000040	VANDYCK	86	MRS	−	Single electron
1159.652222 ± 0 000050	SCHWINBERG	81	MRS	+	Single positron
1159 65241 ± 0 00020	VANDYCK	77	MRS	−	Repl by VANDYCK 79
1159 667 ± 0 024	WALLS	73	MRS	−	Bolometric tech
1160 3 ± 1 2	GILLELAND	72	CNTR	+	
1159 6577 ± 0 0035	WESLEY	71	CNTR	−	
1159 644 ± 0 007	WESLEY	70	CNTR		

POSITRON/ELECTRON g-FACTOR RATIO MINUS ONE, $(g_+/g_-)-1$

Test of CPT

VALUE (10^{-12} $e/2m(e)$)	CL%	DOCUMENT ID		TECN	COMMENT
− 0.5 ± 2.1		[6] VANDYCK	87	MRS	Penning trap
• • • We do not use the following data for averages fits limits etc • • •					
< 12	95	[7] VASSERMAN	87	CNTR	$m(e^+) = m(e^-)$ assumed
22 ± 64		SCHWINBERG	81	MRS	Penning trap

[6]VANDYCK 87 measured $(g_- \; g_+)-1$ and we converted it
[7]VASSERMAN 87 measured $(g_+ - g_-)/(g-2)$ We multiplied by $(g-2)/g$ = 1 2 × 10^{-3}

e ELECTRIC DIPOLE MOMENT

Forbidden by both T invariance and P invariance

VALUE (10^{-23} e-cm)	CL%	DOCUMENT ID		TECN	COMMENT
<0.3	90	WEISSKOPF	68	MRS	Cesium
• • • We do not use the following data for averages fits limits etc • • •					
0 4 ± 1 4		FLAMBAUM	85	THEO	Use EDM of ^{129}Xe
8 1 ± 11 6		VASILEV	78		
0 19 ± 0 34	90	SANDARS	75	MRS	Thallium
0 07 ± 0 22	90	PLAYER	70	MRS	Xenon

REFERENCES FOR e

COHEN 87 RMP 59 1121 +Taylor (RISC NBS)
VANDYCK 87 PRL 59 26 Van Dyck Schwinberg Dehmelt (WASH)
VASSERMAN 87 PL B198 302 +Vorobyov Gluskin+ (NOVO)
Also 87B PL B187 172 Vasserman Vorobyov Gluskin+ (NOVO)
AVIGNONE 86 PR D34 97 +Brodzinski Hensley Miley Reeves+ (PNL SCUC)
VANDYCK 86 PR D34 722 +Schwinberg Dehmelt (WASH)
Also 79 BAPS 24 758 VanDyck Schwinberg Dehmelt (WASH)
Also 81 AP 7 337 Dehmelt (WASH)
Editor Kleppner et al Plenum NY

FLAMBAUM	85	JETP 62 872	+Khriplovich	(NOVO)
		Translated from ZETF 89 1505		
ORITO	85	PRL 54 2457	+Yoshimura	(TOKY KEK)
CHU	84	PRL 52 1689	+Mills Hall	(BELL NBS COLO)
BELLOTTI	83B	PL 124B 435	+Corti Fiorini Liguori Pullia+	(MILA)
KINOSHITA	81	PRL 47 1573	+Lindquist	(CORN)
SCHWINBERG	81	PRL 47 1679	+VanDyck Dehmelt	(WASH)
KOVALCHUK	79	JETPL 29 145	+Pomansky Smolnikov	(INRM)
		Translated from ZETFP 29 163		
VANDYCK	79	BAPS 24 758	+Schwinberg Dehmelt	(WASH)
KINOSHITA	78	Tokyo Conf 571		(CORN)
VASILEV	78	JETP 47 243	+Kolycheva	(JINR)
		Translated from ZETF 74 466		
VANDYCK	77	PRL 38 310	+Schwinberg Dehmelt	(WASH)
SANDARS	75	PR A11 473	+Sternheimer	(OXF BNL)
STEINBERG	75	PR D12 2582	+Kwiatkowski Maenhaut+	(UMD)
COHEN	73	JPCRD 2 663	+Taylor	(RISC NBS)
WALLS	73	PRL 31 975	+Stein	(WASH)
GILLELAND	72	PR A5 38	+Rich	(MICH)
LAUTRUP	72	PRPL 3 193	+Peterman DeRafael	(CERN BURE)
RICH	72	RMP 44 250	+Wesley	(MICH)
WESLEY	71	PR A4 1341	+Rich	(MICH)
PLAYER	70	JPB 3 1620	+Sandars	(OXF)
WESLEY	70	PRL 24 1320	+Rich	(MICH)
TAYLOR	69	RMP 41 375	+Parker Langenberg	(PRIN UCI PENN)
WEISSKOPF	68	PRL 21 1645	+Carrico Gould Lipworth+	(BRAN)
COHEN	65	RMP 37 537	+Dumond	(NAAS CIT)
MOE	65	PR 140B 992	+Reines	(CASE)

μ

$J = \frac{1}{2}$

μ MASS

The mass is known more precisely in u (atomic mass units) than in MeV (see the footnote) The conversion from u to MeV, 1u = 931 49432 ± 0 00028 MeV involves the relatively poorly known electronic charge

Where $m(\mu)/m(e)$ was measured we used the 1986 CODATA value for $m(e)$ = 0.51099906 ± 0.00000015 MeV

The fit uses the $\pi^{\pm}$ π^0, and $\mu^{\pm}$ mass and mass difference measurements

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
105.658389 ± 0.000034 OUR FIT					
105.658389 ± 0.000034	[1] COHEN	87	RVUE		1986 CODATA value
• • • We do not use the following data for averages, fits, limits etc • • •					
105.65841 ± 0.00033	[2] BELTRAMI	86	SPEC	−	Muonic atoms
105.658432 ± 0 000064	[3] KLEMPT	82	CNTR	+	Incl in MARIAM 82
105 658386 ± 0.000044	[4] MARIAM	82	CNTR	+	
105.65856 ± 0.00015	[5] CASPERSON	77	CNTR	+	
105 65836 ± 0.00026	[6] CROWE	72	CNTR		
105.65865 ± 0 00044	[7] CRANE	71	CNTR		

[1]The mass is known more precisely in u m = 0 113428913 ± 0.000000017 u COHEN 87 makes use of the other entries below
[2]BELTRAMI 86 gives $m(\mu)/m(e)$ = 206 76830(64)
[3]KLEMPT 82 gives $m(\mu)/m(e)$ = 206 76835(11)
[4]MARIAM 82 gives $m(\mu)/m(e)$ = 206 768259(62)
[5]CASPERSON 77 gives $m(\mu)/m(e)$ = 206 76859(29)
[6]CROWE 72 gives $m(\mu)/m(e)$ = 206 7682(5)
[7]CRANE 71 gives $m(\mu)/m(e)$ = 206 76878(85)

μ MEAN LIFE

VALUE (microsec)	DOCUMENT ID		TECN	CHG	COMMENT
2.19703 ± 0.00004 OUR AVERAGE					
2.197078 ± 0.000073	BARDIN	84	CNTR	+	
2 197025 ± 0 000155	BARDIN	84	CNTR	−	
2 19695 ± 0.00006	GIOVANETTI	84	CNTR	+	
2.1948 ± 0.0010	BAILEY	77B	CNTR	−	Storage rings
2 1966 ± 0 0020	BAILEY	77B	CNTR	+	Storage rings
2.19711 ± 0.00008	BALANDIN	74	CNTR	+	
2.1973 ± 0.0003	DUCLOS	73	CNTR	+	
2.202 ± 0 003	ECKHAUSE	63	CNTR		
2.197 $^{+0\ 005}_{-0\ 002}$	MEYER	63	CNTR	+	
2 198 ± 0 002	MEYER	63	CNTR	−	
2.198 ± 0.001	FARLEY	62	CNTR		
2.203 ± 0.004	LUNDY	62	CNTR		CL=98%
• • • We do not use the following data for averages, fits limits etc • • •					
2 197182 ± 0 000121	BARDIN	81	CNTR		Repl by BARDIN 84
2.20026 ± 0.00081	[8] WILLIAMS	72	CNTR	+	

[8]WILLIAMS 72 mean life measurement was not the primary purpose of their experiment and disagrees strongly with later experiments Not averaged

μ^+/μ^- MEAN LIFE RATIO

Test of *CPT*

VALUE	DOCUMENT ID		TECN	COMMENT
1.00003 ± 0.00008 OUR AVERAGE				
1.000024 ± 0.000078	BARDIN	84	CNTR	
1 0008 ± 0 0010	BAILEY	79	CNTR	Storage ring
1 000 ± 0 001	MEYER	63	CNTR	Mean life μ^+/μ^-

μ ANOMALOUS MAGNETIC MOMENT

For reviews of theory and experiments see HUGHES 85 KINOSHITA 84, COMBLEY 81, FARLEY 79 and CALMET 77

VALUE ($10^{-6}e/2m(\mu)$)	DOCUMENT ID		TECN	CHG	COMMENT
1165.9230 ± 0.0084	COHEN	87	RVUE		1986 CODATA value
• • • We do not use the following data for averages fits limits, etc • • •					
1165.910 ± 0 011	[9] BAILEY	79	CNTR	+	Storage ring
1165 937 ± 0.012	[9] BAILEY	79	CNTR	−	Storage ring
1165.923 ± 0 0085	[9] BAILEY	79	CNTR	±	Storage ring
1165 922 ± 0 009	[9] BAILEY	77	CNTR	±	Storage ring
1166 16 ± 0.31	BAILEY	68	CNTR	±	Storage rings
1162.0 ± 5.0	CHARPAK	62	CNTR	+	

[9]BAILEY 79 is final result Includes BAILEY 77 data We use μ/p magnetic moment ratio = 3 1833452 and recalculate the BAILEY 79 values Third BAILEY 79 result is first two combined

μ^+/μ^- *g*-FACTOR RATIO MINUS ONE, $(g_+/g_-)-1$

Test of *CPT*

VALUE (units 10^{-8})	DOCUMENT ID	
−2.6 ± 1.6	BAILEY	79

μ ELECTRIC DIPOLE MOMENT

Forbidden by both *T* invariance and *P* invariance

VALUE (10^{-19} e−cm)	DOCUMENT ID		TECN	CHG	COMMENT
3.7 ± 3.4	[10] BAILEY	78	CNTR	±	Storage ring
• • • We do not use the following data for averages, fits, limits etc • • •					
8.6 ± 4 5	[10] BAILEY	78	CNTR	+	Storage rings
0.8 ± 4.3	[10] BAILEY	78	CNTR	−	Storage rings

[10]BAILEY 78 yields electric dipole moment < 1.05 × 10^{-18} with CL = 95% Third result is first two combined assuming *CPT*

μ/p MAGNETIC MOMENT RATIO

This ratio is used to obtain a precise value of the muon mass

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
3.18334547 ± 0.00000047	[11] COHEN	87	RVUE		1986 CODATA value
• • • We do not use the following data for averages fits limits, etc • • •					
3 1833441 ± 0.0000017	KLEMPT	82	CNTR	+	Precession strob
3 1833461 ± 0.0000011	MARIAM	82	CNTR	+	HFS splitting
3.1833448 ± 0 0000029	CAMANI	78	CNTR	+	Repl by KLEMPT 82
3 1833403 ± 0.0000044	CASPERSON	77	CNTR	+	HFS splitting
3 1833402 ± 0 0000072	[12] COHEN	73	RVUE		
3 1833467 ± 0 0000082	[13] CROWE	72	CNTR	+	Precession phase
3.183336 ± 0 000013	[14] CRANE	71	CNTR		HFS splitting
3 183349 ± 0.000015	[15] DEVOE	71	CNTR		HFS splitting
3.183326 ± 0 000013	[16] FAVART	71	CNTR		HFS splitting
3 183347 ± 0.000009	[13] HAGUE	70	CNTR	+	Precession phase
3.183330 ± 0.000044	HUTCHINSON	70	CNTR	+	Precession phase
3.183351 ± 0 000016	[15] EHRLICH	69	CNTR		HFS splitting
3.183314 ± 0 000034	[14] THOMPSON	69	CNTR		HFS splitting
3 1808 ± 0.0004	BINGHAM	63	CNTR	−	Precession strob
3.18336 ± 0.00007	BINGHAM	63	CNTR	+	Precession strob
3 18338 ± 0 00004	HUTCHINSON	63	CNTR	+	Precession phase
3.1834 ± 0 0002	GARWIN	60	CNTR	+	Precession phase
3.1865 ± 0 0022	COFFIN	58	CNTR	+	Spin resonance
3 1830 ± 0 0011	LUNDY	58	CNTR	+	Precession strob
3 176 ± 0 013	LUNDY	58	CNTR	−	Precession strob

[11]COHEN 87 (1986 CODATA) value was fitted using their own selection of the following data Because their value is from a multiparameter fit, correlations with other quantities may be important and one cannot arrive at this result by any average of these data alone
[12]The results through 1972 are included in COHEN 73
[13]CROWE 72 supersedes HAGUE 70
[14]CRANE 71 supersedes THOMPSON 69 This is not a direct measurement

[15]DEVOE 71 supersedes EHRLICH 69 This is not a direct measurement We give a new value which contains a theoretical correction of -7.8 ± 2.3 ppm as discussed in footnote 35a of CROWE 72

[16]FAVART 71 assumes a zero value for the proton polarizability

μ DECAY MODES

μ^+ modes are charge conjugates of the modes below

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_1	$\mu^- \to e^- \bar{\nu}_e \nu_\mu$	1.0	
Γ_2	$\mu^- \to e^- \bar{\nu}_e \nu_\mu \gamma$	$(1.4 \pm 0.4) \times 10^{-2}$	
Γ_3	$\mu^- \to e^- \bar{\nu}_e \nu_\mu e^+ e^-$	$(3.4 \pm 0.4) \times 10^{-5}$	
Γ_4	$\mu^- \to e^- \nu_e \bar{\nu}_\mu$	$< 5 \times 10^{-2}$	90%
Γ_5	$\mu^- \to e^- \gamma$	$< 5 \times 10^{-11}$	90%
Γ_6	$\mu^- \to e^- e^+ e^-$	$< 1.0 \times 10^{-13}$	90%
Γ_7	$\mu^- \to e^- 2\gamma$	$< 7 \times 10^{-11}$	90%

μ BRANCHING RATIOS

$\Gamma(e^- \bar{\nu}_e \nu_\mu \gamma)/\Gamma_{total}$ — Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.014 ±0.004		CRITTENDEN	61	CNTR	γ KE > 10 MeV
• • • We do not use the following data for averages fits, limits, etc • • •					
	862	BOGART	67	CNTR	γ KE > 14.5 MeV
0.0033 ± 0.0013		CRITTENDEN	61	CNTR	γ KE > 20 MeV
	27	ASHKIN	59	CNTR	

$\Gamma(e^- \nu_e \bar{\nu}_\mu)/\Gamma_{total}$ — Γ_4/Γ

Forbidden by additive conservation law for lepton family number Multiplicative law predicts this branching ratio to be 1/2 For a review see NEMETHY 81

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
< **0.05**	90	[17] BERGSMA	83	CALO		$\nu_\mu e \to \mu^- \bar{\nu}_e$
• • • We do not use the following data for averages fits, limits etc • • •						
< 0.09	90	JONKER	80	CALO		Repl by BERGSMA 83
−0.001 ± 0.061		WILLIS	80	CNTR	+	
0.13 ± 0.15		BLIETSCHAU	78	HLBC	±	Avg of 4 values
< 0.25	90	EICHTEN	73	HLBC	+	

[17]BERGSMA 83 gives limit on inverse muon decay cross-section ratio $\sigma(\bar{\nu}_\mu e^- \to \mu^- \bar{\nu}_e) / \sigma(\nu_\mu e^- \to \mu^- \nu_e)$ which is essentially equivalent to $\Gamma(e^- \nu_e \bar{\nu}_\mu)/\Gamma_{total}$ for small values like that quoted

$\Gamma(e^- \gamma)/\Gamma_{total}$ — Γ_5/Γ

Forbidden by lepton family number conservation

VALUE (units 10^{-11})	CL%	DOCUMENT ID		TECN	CHG	COMMENT
< **4.9**	90	BOLTON	86	CNTR	+	LAMPF
• • • We do not use the following data for averages, fits limits, etc • • •						
< 100	90	AZUELOS	83	CNTR	+	
< 17	90	KINNISON	82	SPEC	+	LAMPF
< 100	90	SCHAAF	80	ELEC	+	SIN

$\Gamma(e^- e^+ e^-)/\Gamma_{total}$ — Γ_6/Γ

Forbidden by lepton family number conservation

VALUE (units 10^{-11})	CL%	DOCUMENT ID		TECN	CHG	COMMENT
< **0.01**	90	BELLGARDT	88	SPEC	+	SINDRUM
• • • We do not use the following data for averages fits, limits etc • • •						
< 0.24	90	[18] BERTL	85	SPEC	+	SINDRUM
< 16	90	[18] BERTL	84	SPEC	+	SINDRUM
< 13	90	[18] BOLTON	84	CNTR		LANL

[18]These experiments assume a constant matrix element

$\Gamma(e^- 2\gamma)/\Gamma_{total}$ — Γ_7/Γ

Forbidden by lepton family number conservation

VALUE (units 10^{-9})	CL%	DOCUMENT ID		TECN	CHG	COMMENT
< **7.2** $\times 10^{-2}$	90	[19] GROSNICK	86	CNTR	+	LAMPF
• • • We do not use the following data for averages fits, limits etc • • •						
< 8.4	90	[20] AZUELOS	83	CNTR	+	
< 50	90	[21] BOWMAN	78	CNTR		DEPOMMIER 77 data

[19]General local interaction Lagrangian assumed

[20]AZUELOS 83 uses phase space distribution of BOWMAN 78 see above

[21]BOWMAN 78 assumes interaction Lagrangian local on scale of inverse μ mass

$\Gamma(e^- \bar{\nu}_e \nu_\mu e^+ e^-)/\Gamma_{total}$ — Γ_3/Γ

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
3.4 ± 0.2 ± 0.3	7443	[22] BERTL	85	SPEC	+	SINDRUM
• • • We do not use the following data for averages fits, limits, etc • • •						
2.2 ± 1.5	7	[23] CRITTENDEN	61	HLBC	+	$E(e^+e^-) > 10$ MeV
2	1	[24] GUREVICH	60	EMUL	+	
1.5 ± 1.0	3	[25] LEE	59	HBC	+	

[22]BERTL 85 has transverse momentum cut p_T > 17 MeV/c Systematic error was increased by us

[23]CRITTENDEN 61 count only those decays where total energy of either (e^+ e^-) combination is > 10 MeV)

[24]GUREVICH 60 interpret their event as either virtual or real photon conversion e^+ and e^- energies not measured

[25]In the three LEE 59 events, the sum of energies $\Sigma S = E(e^+) + (e^-) + (e^+)$ was Σ = 51 MeV 55 MeV and 33 MeV

LIMIT ON $\mu^- \to e^-$ CONVERSION

Forbidden by lepton family number conservation

$\sigma(\mu^- {}^{32}S \to e^- {}^{32}S)$ / $\sigma(\mu^- {}^{32}S \to \nu_\mu {}^{32}P^*)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< **7** $\times 10^{-11}$	90	BADERT	80	STRC	SIN
• • • We do not use the following data for averages, fits limits etc • • •					
< 4. $\times 10^{-10}$	90	BADERT	77	STRC	SIN

$\sigma(\mu^- Cu \to e^- Cu)$ / $\sigma(\mu^- Cu \to$ capture$)$

VALUE	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •				
< 1.6 $\times 10^{-8}$	90	BRYMAN	72	SPEC

$\sigma(\mu^- Ti \to e^- Ti)$ / $\sigma(\mu^- Ti \to$ capture$)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< **4.6** $\times 10^{-12}$	90	AHMAD	87	SPEC	TRIUMF
• • • We do not use the following data for averages fits limits etc • • •					
< 1.6 $\times 10^{-11}$	90	BRYMAN	85	SPEC	TRIUMF

LIMIT ON $\mu^- \to e^+$ CONVERSION

Forbidden by total lepton number conservation

$\sigma(\mu^- {}^{32}S \to e^+ {}^{32}Si^*)$ / $\sigma(\mu^- {}^{32}S \to \nu_\mu {}^{32}P^*)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< **9** $\times 10^{-10}$	90	BADERT	80	STRC	SIN
• • • We do not use the following data for averages, fits limits etc • • •					
< 1.5 $\times 10^{-9}$	90	BADERT	78	STRC	SIN

$\sigma(\mu^- {}^{127}I \to e^+ {}^{127}Sb^*)$ / $\sigma(\mu^- {}^{127}I \to$ anything$)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< **3** $\times 10^{-10}$	90	[26] ABELA	80	CNTR	Radiochemical tech

[26]ABELA 80 is upper limit for $\mu^- e^+$ conversion leading to particle-stable states of ^{127}Sb Limit for total conversion rate is higher by a factor less than 4 (G Backenstoss private communication)

$\sigma(\mu^- Cu \to e^+ Co)$ / $\sigma(\mu^- Cu \to \nu_\mu Ni)$

VALUE	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •				
< 2.6 $\times 10^{-8}$	90	BRYMAN	72	SPEC
< 2.2 $\times 10^{-7}$	90	CONFORTO	62	OSPK

$\sigma(\mu^- Ti \to e^+ Ca)$ / $\sigma(\mu^- Ti \to$ capture$)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< **1.7** $\times 10^{-10}$	90	[27] AHMAD	87	SPEC	TRIUMF

[27]Assuming a giant-resonance excitation model

LIMIT ON (μ^+, e^-) BOUND STATE CONVERSION TO (μ^-, e^+)

Forbidden by lepton family number conservation

$R_g = g_C / G_F$

Where $G_F = 1.16637 \times 10^{-5}$ GeV^{-2} is the Fermi constant and g_C is an effective coupling (dimensions GeV^{-2}) for a four fermion interaction assumed to be responsible for the conversion of the (μ^+ e^-) bound state to (μ^- e^+)

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< **7.5**	90	NI	87	CNTR	LAMPF
• • • We do not use the following data for averages fits limits etc • • •					
< 20	95	BEER	86	CNTR	TRIUMF
< 42	95	MARSHALL	82	CNTR	

NOTE ON MUON DECAY PARAMETERS

(by F Scheck University of Mainz, West Germany and K Mursula, Nordita Copenhagen, Denmark)

The muon decay parameters describe the momentum spectrum (ρ and η), the asymmetry (ξ and δ), and the polarization of the electron (ξ', ξ'', α, β, α', β') in the process $\mu \to e^- + \nu_\mu + \overline{\nu}_e$ Assuming a local, lepton-number-conserving, derivative-free, four-fermion interaction, the matrix element in charge-*changing* form may be written as[1]

$$\frac{G_F}{\sqrt{2}} \Big\{ \sum_{1}^{2} h_{ik} \langle \bar{e} | 1 [1 + (-)^{i-1}\gamma_5] | \nu_e \rangle$$

$$\times \langle \overline{\nu}_\mu | 1 [1 + (-)^{k-1}\gamma_5] | \mu \rangle$$

$$+ \sum_{1}^{2} g_{ik} \langle \bar{e} | \gamma^\alpha [1 + (-)^{i-1}\gamma_5] | \nu_e \rangle$$

$$\times \langle \overline{\nu}_\mu | \gamma_\alpha [1 + (-)^{k-1}\gamma_5] | \mu \rangle$$

$$+ \sum_{1}^{2} f_{ii} \frac{1}{2} \langle \bar{e} | \sigma^{\alpha\beta} [1 + (-)^{i-1}\gamma_5] | \nu_e \rangle$$

$$\times \langle \overline{\nu}_\mu | \sigma_{\alpha\beta} [1 + (-)^{i-1}\gamma_5] | \mu \rangle \Big\} \qquad (1)$$

The definitions of covariants and the sign conventions are the ones of Sachs and Sirlin (1975)[2] and Scheck (1978)[3] The connection to other charge-changing and charge-retention forms is worked out in Mursula and Scheck (1985)[4] Note that for massless particles the covariants chosen above project onto states of definite helicity In the Standard Model, $g_{22} = 1$ and all other coupling constants vanish

All electron observables can be expressed, in a model-independent way, as functions of the ten standard real constants (see references above) a, b, c, a', b', c', α, β, α', and β' The rate is proportional to $A = a + 4b + 6c$ The above decay parameters depend on nine of these constants only

$$\rho - \frac{3}{4} = \frac{3}{4}[-a + 2c]/A ,$$

$$\eta = [\alpha - 2\beta]/A ,$$

$$\delta - \frac{3}{4} = \frac{9}{4}\frac{[a' - 2c']/A}{1 - [a + 3a' + 4(b + b') + 6c - 14c']/A} ,$$

$$1 - \xi\frac{\delta}{\rho} = 4\frac{[(b + b') + 2(c - c')]/A}{1 - [a - 2c]/A} , \qquad (2)$$

$$1 - \xi' = [a + a' + 4(b + b') + 6(c + c')]/A ,$$

$$1 - \xi'' = [-2a + 20c]/A ,$$

$$\alpha/A,\ \beta/A,\ \alpha'/A,\ \beta'/A$$

the last four of which are obtained from the transverse components of the electron polarization These real constants are easily related to bilinear combinations of coupling constants in any form of the interaction For the case of the form (1), they are given by [note the scale factor $G_F/\sqrt{2}$ in Eq (1)]

$$\left.\begin{matrix} a \\ a' \end{matrix}\right\} = 16(|g_{12}|^2 \pm |g_{21}|^2) \pm |h_{11} + 6f_{11}|^2$$

$$+ |h_{22} + 6f_{22}|^2 , \qquad (3)$$

$$\left.\begin{matrix} b \\ b' \end{matrix}\right\} = 4(|g_{11}|^2 \pm |g_{22}|^2) \pm |h_{12}|^2 + |h_{21}|^2 , \qquad (4)$$

$$\left.\begin{matrix} c \\ c' \end{matrix}\right\} = \frac{1}{2}\Big[\pm|h_{11} - 2f_{11}|^2 + |h_{22} - 2f_{22}|^2\Big] , \qquad (5)$$

$$\left.\begin{matrix} \alpha \\ \alpha' \end{matrix}\right\} = \left.\begin{matrix} \mathrm{Re} \\ \mathrm{Im} \end{matrix}\right\} 8[g_{21}(h^*_{22} + 6f^*_{22}) \pm g_{12}(h^*_{11} + 6f^*_{11})] , \qquad (6)$$

$$\left.\begin{matrix} \beta \\ \beta' \end{matrix}\right\} = \left.\begin{matrix} \mathrm{Re} \\ \mathrm{Im} \end{matrix}\right\} (-4)[g_{22}h^*_{21} \pm g_{11}h^*_{12}] \qquad (7)$$

As the decay parameters (2) depend on $(b + b')$ but not on $(b - b')$, the constant h_{12} appears only in β and β', Eq (7) However, g_{11} is found to be compatible with zero, so the decay parameters do not determine h_{12} (The coupling constant h_{12} does occur in the rate parameter A and may, in principle, be obtained by comparing μ decay to other data) By using Eqs (2) and the experimental determinations of ρ, η, $\xi\delta/\rho$, δ, ξ' ξ'', α, β, α', and β', limits can be placed on the nine parameters a/A, a'/A, $(b + b')/A$, c/A, c'/A, α/A, α'/A, β/A, and β'/A These are given in the Listings These limits are easily translated into limits on specific coupling constants in Eq (1), depending on what kind of extension of the Standard Model one wishes to test Examples such as tests for right-handed interactions or for scalar/pseudoscalar effective couplings are given in Mursula and Scheck (1985)[4]

The limits on a, a', , can be recast into limits on the effective charge-retention coordinates g_S/g_V, g_P/g_V, g_A/g_V, g_T/g_V, ϕ_{VA}, and ψ_{VA}, which were used in the earlier literature (cf , e g , DERENZO 69) The most recent values are found in BURKARD2 85

Note that the radiative corrections are unambiguous only if h_{11}, h_{22}, g_{12}, g_{21}, f_{11}, and f_{22} vanish

References

1 F Scheck, in *Leptons, Hadrons, and Nuclei* (North Holland, Amsterdam, 1983)

2 A M Sachs and A Sirlin, in *Muon Physics II*, eds C S Wu and V Hughes (Academic Press, New York, 1975), p 49

3 F Scheck, Phys Rep **44**, 187 (1978)

4 K Mursala and F Scheck, Nucl Phys **B253**, 189 (1985), and K Mursala et al, Nucl Phys **B219**, 321 (1983)

μ DECAY PARAMETERS

ρ PARAMETER

(V−A) theory predicts ρ = 0 75

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.7518 ± 0.0026		DERENZO	69	RVUE		
••• We do not use the following data for averages fits limits etc •••						
0 762 ± 0 008	170k	[28] FRYBERGER	68	ASPK	+	25–53 MeV e^+
0 760 ± 0 009	280k	[28] SHERWOOD	67	ASPK	+	25–53 MeV e^+
0.7503 ± 0 0026	800k	[28] PEOPLES	66	ASPK	+	20–53 MeV e^+

[28] η constrained = 0 These values incorporated into a two parameter fit to ρ and η by DERENZO 69

η PARAMETER

(V−A) theory predicts η = 0

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
−0.007 ± 0.013 OUR AVERAGE						
−0 007 ± 0 013	5 3M	[29] BURKARD	85B	FIT	+	9–53 MeV e^+
−0.12 ± 0 21	6346	DERENZO	69	HBC	+	1 6–6 8 MeV e^+
••• We do not use the following data for averages fits limits etc •••						
−0 012 ± 0 015 ± 0 003	5 3M	[30] BURKARD	85B	CNTR	+	9–53 MeV e^+
0 011 ± 0.081 ± 0 026	5 3M	BURKARD	85B	CNTR	+	9–53 MeV e^+
−0 7 ± 0 5	170k	[31] FRYBERGER	68	ASPK	+	25–53 MeV e^+
−0 7 ± 0 6	280k	[31] SHERWOOD	67	ASPK	+	25–53 MeV e^+
0 05 ± 0 5	800k	[31] PEOPLES	66	ASPK	+	20–53 MeV e^+
−2 0 ± 0 9	9213	[32] PLANO	60	HBC	+	Whole spectrum

[29] Global fit to all measured parameters Correlation coefficients are given in BURKARD 85B

[30] α = α = 0 assumed

[31] ρ constrained = 0 75

[32] Two parameter fit to ρ and η − PLANO 60 discounts value for η

ξ'' PARAMETER

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.65 ± 0.36	326k	[33] BURKARD	85	CNTR	+	Bhabha + annihil

[33] BURKARD 85 measure (ξ ξξ) / ξ and ξ' and set ξ = 1

(ξ PARAMETER) × (μ LONGITUDINAL POLARIZATION)

(V−A) theory predicts ξ = 1 longitudinal polarization = 1

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1.0027 ± 0.0079 ± 0.0030		BELTRAMI	87	CNTR		SIN π decay in flight
••• We do not use the following data for averages fits limits etc •••						
0 975 ± 0 015		AKHMANOV	68	EMUL		140 kG
0 975 ± 0 030	66k	GUREVICH	64	EMUL		Repl by AKHMANOV 68
0 903 ± 0 027		[34] ALI-ZADE	61	EMUL	+	27 kG
0 93 ± 0 06	8354	PLANO	60	HBC	+	8 8 kG
0 97 ± 0 05	9k	BARDON	59	CNTR		Bromoform target

[34] Depolarization by medium not known sufficiently well

ξ × (μ LONGITUDINAL POLARIZATION) × δ / ρ

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
>0.99677	90	[35,36] JODIDIO	86	SPEC	+	TRIUMF
••• We do not use the following data for averages fits limits, etc •••						
>0.9966	90	[37] STOKER	85	SPEC	+	μ spin rotation
>0.9959	90	CARR	83	SPEC	+	11 kG

[35] JODIDIO 86 includes data from CARR 83 and STOKER 85

[36] The above value is the result given in the erratum JODIDIO 88

[37] STOKER 85 find ($\xi P_\mu \delta/\rho$) ·0 9955 and ·0 9966 where first limit is from new μ spin rotation data and second is from combination with CARR 83 data (δ/ρ) = 1 0 in V−A theory

δ PARAMETER

(V−A) theory predicts δ = 0 75

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.755 ± 0 009 OUR AVERAGE						
0 752 ± 0.009	490k	FRYBERGER	68	ASPK	+	25–53 MeV e^+
0 782 ± 0 031		KRUGER	61			
0 78 ± 0 05	8354	PLANO	60	HBC	+	Whole spectrum
••• We do not use the following data for averages fits limits etc •••						
		[38] VOSSLER	69			

[38] VOSSLER 69 has measured the asymmetry below 10 MeV See comments about radiative corrections in VOSSLER 69

ξ' = LONGITUDINAL POLARIZATION OF $e^{\mp}$

(V−A) theory predicts the longitudinal polarization = ±1 for $e^{\pm}$ respectively We have flipped the sign for e^- so our programs can average

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1.00 ± 0 04 OUR AVERAGE						
0 998 ± 0 045	1M	BURKARD	85	CNTR	+	Bhabha + annihil
0 89 ± 0 28	29k	SCHWARTZ	67	OSPK	-	Moller scattering
0 94 ± 0 38		BLOOM	64	CNTR	+	Brems transmiss
1 04 ± 0 18		DUCLOS	64	CNTR	+	Bhabha scattering
1 05 ± 0 30		BUHLER	63	CNTR	+	Annihilation

TRANSVERSE e^+ POLARIZATION IN PLANE OF μ SPIN, e^+ MOMENTUM

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
••• We do not use the following data for averages fits limits etc •••						
0 016 ± 0.021 ± 0 015	3M	BURKARD	85B	CNTR	+	Annihil 9–53 MeV

TRANSVERSE e^+ POLARIZATION NORMAL TO PLANE OF μ SPIN, e^+ MOMENTUM

Zero if T invariance holds

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.007 ± 0.022 ± 0.007	5 3M	BURKARD	85B	CNTR	+	Annihil 9–53 MeV

α/A

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.4 ± 4.3		[39] BURKARD	85B	FIT		
••• We do not use the following data for averages fits limits etc •••						
15 ± 50 ± 14	5 3M	BURKARD	85B	CNTR	+	9–53 MeV e^+

[39] Global fit to all measured parameters Correlation coefficients are given in BURKARD 85B

α'/A

Zero if T invariance holds

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
− 0.2 ± 4.3		[40] BURKARD	85B	FIT		
••• We do not use the following data for averages fits limits etc •••						
−47 ± 50 ± 14	5 3M	[41] BURKARD	85B	CNTR	+	9–53 MeV e^+

[40] Global fit to all measured parameters Correlation coefficients are given in BURKARD 85B

[41] BURKARD 85B measure e^+ polarizations P_{T_1} and P_{T_2} versus e^+ energy

β/A

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
3.9 ± 6.2		[42] BURKARD	85B	FIT		
••• We do not use the following data for averages fits limits etc •••						
2 ± 17 ± 6	5 3M	BURKARD	85B	CNTR	+	9–53 MeV e^+

[42] Global fit to all measured parameters Correlation coefficients are given in BURKARD 85B

β'/A

Zero if T invariance holds

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1.5 ± 6.3		[43] BURKARD	85B	FIT		
••• We do not use the following data for averages fits limits etc •••						
17 ± 17 ± 6	5 3M	[44] BURKARD	85B	CNTR	+	9–53 MeV e^+

[43] Global fit to all measured parameters Correlation coefficients are given in BURKARD 85B

[44] BURKARD 85B measure e^+ polarizations P_{T_1} and P_{T_2} versus e^+ energy

a/A

This comes from an alternative parameterization to that used in the Summary Table (see Note on Muon Decay Parameters above)

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN
••• We do not use the following data for averages fits limits etc •••				
<15.9	90	[45] BURKARD	85B	FIT

[45] Global fit to all measured parameters Correlation coefficients are given in BURKARD 85B

a'/A

This comes from an alternative parameterization to that used in the Summary Table (see Note on Muon Decay Parameters above)

VALUE (units 10^{-3})	DOCUMENT ID		TECN
••• We do not use the following data for averages fits limits etc •••			
5 3 ± 4 1	[46] BURKARD	85B	FIT

[46] Global fit to all measured parameters Correlation coefficients are given in BURKARD 85B

$(b'+b)/A$

This comes from an alternative parameterization to that used in the Summary Table (see Note on Muon Decay Parameters above)

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits, etc • • •				
<1.04	90	[47] BURKARD	85B	FIT

[47] Global fit to all measured parameters Correlation coefficients are given in BURKARD 85B

c/A

This comes from an alternative parameterization to that used in the Summary Table (see Note on Muon Decay Parameters above)

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits, etc • • •				
<6.4	90	[48] BURKARD	85B	FIT

[48] Global fit to all measured parameters Correlation coefficients are given in BURKARD 85B

c'/A

This comes from an alternative parameterization to that used in the Summary Table (see Note on Muon Decay Parameters above)

VALUE (units 10^{-3})	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits limits etc • • •			
3 5 ± 2.0	[49] BURKARD	85B	FIT

[49] Global fit to all measured parameters Correlation coefficients are given in BURKARD 85B

$\bar{\eta}$ PARAMETER

(V−A) theory predicts $\bar{\eta} = 0$ $\bar{\eta}$ affects spectrum of radiative muon decay

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.02 ± 0.08 OUR AVERAGE					
−0 014 ± 0 090	EICHENBER	84	ELEC	+	ρ free
+0.09 ± 0.14	BOGART	67	CNTR	+	
• • • We do not use the following data for averages, fits limits, etc • • •					
−0 035 ± 0 098	EICHENBER	84	ELEC	+	ρ=0 75 assumed

REFERENCES FOR μ

BELLGARDT 88 NP B299 1 +Otter Eichler+ (SINDRUM Collab)
JODIDIO 88 PR D37 237 +Balke Carr+ (LBL NWES TRIU)
Erratum
AHMAD 87 PRL 59 970 +Azuelos+ (TRIU VPI VICT BRCO MONT CNRC)
BELTRAMI 87 PL B194 326 +Burkard Von Dincklage+ (ETH SIN MANZ)
COHEN 87 RMP 59 1121 +Taylor (RISC NBS)
NI 87 PRL 59 2716 +Arnold Chmely+ (YALE LANL WILL MISS HEID)
BEER 86 PRL 57 671 +Marshall Mason+ (VICT TRIU WYOM)
BELTRAMI 86 NP A451 679 +Aas Beer Dechambrier Goudsmit+ (ETH FRIB)
BOLTON 86 PRL 56 2461 +Bowman Cooper+ (LANL STAN CHIC TEMP)
GROSNICK 86 PRL 57 3241 +Wright Bolton+ (CHIC LANL STAN TEMP)
JODIDIO 86 PR D34 1967 +Balke Carr Gidal Shinsky+ (LBL NWES TRIU)
Also 88 PR D37 237 Jodidio Balke Carr+ (LBL NWES TRIU)
Erratum
BERTL 85 NP B260 1 +Egli Eichler+ (SINDRUM Collab)
BRYMAN 85 PRL 55 465 + (TRIU CNRC BRCO LANL CHIC CARL+)
BURKARD 85 PL 150B 242 +Corriveau Egger+ (ETH SIN MANZ)
BURKARD 85B PL 160B 343 +Corriveau Egger+ (ETH SIN MANZ)
Also 81B PR D24 2004 Corriveau Egger Fetscher+ (ETH SIN MANZ)
Also 83B PL 129B 260 Corriveau Egger Fetscher+ (ETH SIN MANZ)
HUGHES 85 CNPP 14 341 +Kinoshita (YALE CORN)
STOKER 85 PRL 54 1887 +Balke Carr Gidal+ (LBL NWES TRIU)
BARDIN 84 PL 137B 135 +Duclos Magnon+ (SACL CERN BGNA FIRZ)
BERTL 84 PL 140B 299 +Eichler Felawka+ (SINDRUM Collab)
BOLTON 84 PRL 53 1415 +Bowman Carlini+ (LANL CHIC STAN TEMP)
EICHENBER 84 NP A412 523 Eichenberger Engfer VanderSchaff (ZURI)
GIOVANETTI 84 PR D29 343 +Dey Eckhause Hart+ (WILL)
KINOSHITA 84 PRL 52 717 +Nizic Okamoto (CORN)
AZUELOS 83 PRL 51 164 +Depommier Leroy Martin+ (MONT TRIU BRCO)
Also 77 PRL 39 1113 Depommier+ (MONT BRCO TRIU VICT MELB)
BERGSMA 83 PL 122B 465 +Dorenbosch Jonker+ (CHARM Collab)
CARR 83 PRL 51 627 +Gidal Gobbi Jodidio Oram+ (LBL NWES TRIU)
KINNISON 82 PR D25 2846 +Anderson Matis Wright+ (EFI STAN LANL)
Also 79 PRL 42 556 Bowman Cooper Hamm+ (LASL EFI STAN)
KLEMPT 82 PR D25 652 +Schulze Wolf Camani Gygax+ (MANZ ETH)
MARIAM 82 PRL 49 993 +Beer Bolton Egan Gardner+ (YALE HEID BERN)
MARSHALL 82 PR D25 1174 +Warren Oram Kiefl (BRCO)
BARDIN 81 NP A352 365 +Duclos Magnon+ (SACL CERN BGNA TRIU)
COMBLEY 81 PRPL 68 93 +Farley Picasso (SHEF RMCS CERN)
NEMETHY 81 CNPP 10 147 +Hughes (LBL YALE)
ABELA 80 PL 95B 318 +Backenstoss Simons Wuest+ (BASL KARL)
BADERT 80 LNC 28 401 Badertscher Borer Czapek Flueckiger+ (BERN)
Also 82 NP A377 406 Badertscher Borer Czapek Flueckiger+ (BERN)
JONKER 80 PL 93B 203 +Panman Udo Allaby+ (CHARM Collab)
SCHAAF 80 NP A340 249 +Engfer Povel Dey+ (ZURI ETH SIN)
Also 77 PL 72B 183 Povel Dey Walter Pfeiffer+ (ZURI ETH SIN)
WILLIS 80 PRL 44 522 +Hughes+ (YALE LBL LASL SACL SIN CNRC+)
Also 80B PRL 45 1370 Willis+ (YALE LBL LASL SACL SIN CNRC+)
BAILEY 79 NP B150 1 (CERN DARE MANZ)
FARLEY 79 ARNPS 29 243 +Picasso (RMCS CERN)
BADERT 78 PL 79B 371 Badertscher Borer Czapek Flueckiger+ (BERN)
BAILEY 78 JP G4 345 (DARE BERN SHEF MANZ RMCS CERN BIRM)
Also 79 NP B150 1 Bailey (CERN DARE MANZ)
BLIETSCHAU 78 NP B133 205 +Deden Hasert Krenz+ (Gargamelle Collab)
BOWMAN 78 PRL 41 442 +Cheng Li Matis (LASL IAS CMU EFI)
CAMANI 78 PL 77B 326 +Gygax Klempt Schenck Schulze+ (ETH MANZ)
BADERT 77 PRL 39 1385 Badertscher Borer Czapek Flueckiger+ (BERN)
BAILEY 77 PL 67B 225 + (CERN Muon Storage Ring Collab)
Also 77C PL 68B 191 Bailey+ (CERN DARE BERN SHEF MANZ+)
Also 75 PL 55B 420 Bailey+(CERN MUON Storage Ring Collab BIRM)
BAILEY 77B Nature 268 301 + (DARE BERN SHEF CERN MANZ RMCS+)
Also 79 NP B150 1 Bailey (CERN DARE MANZ)
CALMET 77 RMP 49 21 +Narison Perrottet+ (MARS)
CASPERSON 77 PRL 38 956 +Crane+ (BERN HEID LASL WYOM YALE)
DEPOMMIER 77 PRL 39 1113 + (MONT BRCO TRIU VICT MELB)
BALANDIN 74 JETP 40 811 +Grebenyuk Zinov Konin Ponomarev (JINR)
Translated from ZETF 67 1631
COHEN 73 JPCRD 2 663 +Taylor (RISC NBS)
DUCLOS 73 PL 47B 491 +Magnon, Picard (SACL)
EICHTEN 73 PL 46B 281 +Deden Hasert Krenz+ (Gargamelle Collab)
BRYMAN 72 PRL 28 1469 +Blecher Gotow Powers (VPI)
CROWE 72 PR D5 2145 +Hague Rothberg Schenck+ (LBL WASH)
WILLIAMS 72 PR D6 737 +Williams (WASH)
CRANE 71 PRL 27 474 +Casperson Crane Egan Hughes+ (YALE)
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τ $J = \frac{1}{2}$

τ discovery paper was PERL 75 $e^+e^- \to \tau^+\tau^-$ cross-section threshold behavior and magnitude are consistent with pointlike spin-1/2 Dirac particle BRANDELIK 78 ruled out pointlike spin-0 or spin-1 particle FELDMAN 78 ruled out $J = 3/2$ KIRKBY 79 also ruled out J=integer, $J = 3/2$

NOTE ON THE τ DECAY PROBLEM

There exists a problem in understanding the 1-charged-particle decay modes of the τ The problem, first discussed by Truong[1] and Gilman and Rhie,[2] is that the measured inclusive branching fraction to 1-charged prong is larger than the sum of exclusive 1-charged-particle modes [3] Since the measurement of exclusive modes with 2 or more neutral hadrons is difficult given the limitations of present detectors, the inequality between the sum of exclusive modes and the inclusive measurements is significant only if theoretical predictions are used to put limits on unmeasured or poorly measured modes

The current status of the 1-prong modes is summarized in the table below For the theoretical estimates, we use the results of Ref 2, updated to include new experimental data

1-Prong Branching Fractions of the τ (%)

Decay Mode	Experiment	Theory[a]
$e^-\nu\nu$	17.7 ± 0.4	18.0
$\mu^-\nu\nu$	17.7 ± 0.4	17.5
$\rho^-\nu$	22.5 ± 0.9	22.1
$\pi^-\nu$	10.8 ± 0.6	10.9
$K^-(\geq 0\text{ neutrals})\,\nu$	1.71 ± 0.29	
$K^{*-}\nu,\ K^{*-}\to\pi^-(2\pi^0\text{ or }K_L)$	0.5 ± 0.1	
$\pi^-(2\pi^0)\nu$	7.4 ± 1.4[b]	$\leq 6.7\pm0.4$
$\pi^-(\geq 3\pi^0)\nu$		< 1.4[d]
$\pi^-(\geq 1\eta)(\geq 0\pi^0)\nu$[c]	< 1.7	< 0.8
Sum of measured modes		78.3 ± 1.9
Theoretical limits on unmeasured modes		< 2.2
Sum of exclusive modes		$< 80.5\pm1.9$
Measured 1-prong branching fraction		86.6 ± 0.3
Difference		$> 6.1\pm1.9$

[a] Normalized to constrained fit to $e\nu\nu$ and $\mu\nu\nu$ measurements assuming $BF_\mu = 0.973\ BF_e$

[b] Crystal Ball Collaboration, S Lowe SLAC-PUB-4449 (1987)

[c] Contribution to 1-prong mode only

[d] Assumes 15% systematic error on the measured cross section for $e^+e^-\to 2\pi^+2\pi^-$

The discrepancy is due to errors in the experimental measurements or theoretical limits or to the existence of one or more modes not included in the table Early measurements of the inclusive one-prong branching fraction reported significantly lower values but suffered from large backgrounds not present in more recent experiments

Systematic errors dominate most measurements particularly for the $\tau^-\to\pi^-\nu_\tau$ and $\tau^-\to\rho^-\nu_\tau$ modes The technique used to obtain the experimental averages ignores correlated errors which can be especially important when systematic errors are dominant There is a tendency for multiple experimental measurements of a given mode to be more consistent than expected from their quoted errors [4] This indicates either the existence of systematic errors accounted for by the experimenters which are correlated and should not be averaged, or inflation of experimental errors, or a bias in the experimental measurements The $\tau^-\to\rho^-\nu_\tau$ measurements show this tendency even if the systematic errors are ignored and only the statistical errors are used

Resolution of the missing one-prong puzzle will require either new measurements with much reduced systematic and statistical errors or an explicit measurement of a mode which is presently unmeasured or very poorly measured

References

1 T N Truong, Phys Rev **D30** 1509 (1984)

2 F J Gilman and S H Rhie Phys Rev **D31**, 1066 (1985), and F J Gilman, Phys Rev **D35** 3541 (1987)

3 Many authors have examined the discrepancy Some recent references are M G D Gilchriese *Proceedings of the 1986 International Conference on High Energy Physics* ed S Loken (Berkeley, 1986), B C Barish and R Stroynowski, Phys Rep **157**, 1 (1988), K K Gan and M L Perl, SLAC-PUB-4331 (1987), to be published in Journal of Mod Phys A and M L Perl SLAC-PUB-4481 (1987) in *Annals of the New York Academy of Sciences*

4 K G Hayes and M L Perl, SLAC-PUB-4471 (1987)

τ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
$1784.1^{+2.7}_{-3.6}$ OUR AVERAGE					
1787 ± 10		BLOCKER	80	MRK2	e^+e^- E_{cm}=3.5–6.7 GeV
1783^{+3}_{-4}	692	[1] BACINO	78B	DLCO	e^+e^- E_{cm}=3.1–7.4 GeV
1787^{+10}_{-18}	299	[2] BARTEL	78	SPEC	e^+e^- E_{cm}=3.6–4.4 GeV
1807 ± 20		BRANDELIK	78	DASP	e^+e^- E_{cm}=3.1–5.2 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1803 ± 16	1138	BLOCKER	82D	MRK2	Incl. in BLOCKER 80

[1] BACINO 78B value comes from $e^\pm X^\mp$ threshold. Published mass 1782 MeV increased by 1 MeV using the high precision $\psi(2S)$ mass measurement of ZHOLENTZ 80 to eliminate the absolute SPEAR energy calibration uncertainty.

[2] BARTEL 78 fits energy dependence of cross section for $e^\pm$ and $\mu^\pm$ events. Mass value not dependent on whether V−A or V+A decay assumed.

τ MEAN LIFE

VALUE (10^{-13} sec)	EVTS	DOCUMENT ID		TECN	COMMENT
3.04 ± 0.09 OUR AVERAGE					
$2.88 \pm 0.16 \pm 0.17$	807	AMIDEI	88	MRK2	e^+e^- E_{cm}=29 GeV
$2.99 \pm 0.15 \pm 0.10$	1311	ABACHI	87C	HRS	e^+e^- E_{cm}=29 GeV
$2.95 \pm 0.14 \pm 0.11$	5696	ALBRECHT	87P	ARG	e^+e^- E_{cm}=9.3–10.6 GeV
$3.09 \pm 0.17 \pm 0.07$	3788	BAND	87B	MAC	e^+e^- E_{cm}=29 GeV
$3.25 \pm 0.14 \pm 0.18$	8470	BEBEK	87C	CLEO	e^+e^- E_{cm}=10.5 GeV
$3.15 \pm 0.36 \pm 0.40$	10k	FERNANDEZ	85	MAC	e^+e^- E_{cm}=29 GeV
$3.18^{+0.81}_{-0.94}$	50	ALTHOFF	84D	TASS	e^+e^- E_{cm}=43 GeV
$4.7^{+3.9}_{-2.9}$	143	BEHREND	83D	CELL	e^+e^- E_{cm}=22.34 GeV
4.6 ± 1.9	102	FELDMAN	82	MRK2	e^+e^- E_{cm}=29 GeV
4.9 ± 2.0	121	FORD	82	MAC	e^+e^- E_{cm}=28.29 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3.20 ± 0.54	156	JAROS	83	MRK2	Repl. by AMIDEI 88

τ DECAY MODES

τ^+ modes are charge conjugates of the modes below.

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau$	$(17.8 \pm 0.4) \times 10^{-2}$	
Γ_2	$\tau^- \to e^- \overline{\nu}_e \nu_\tau$	$(17.5 \pm 0.4) \times 10^{-2}$	
Γ_3	$\tau^- \to 2\pi^+ 3\pi^- \nu_\tau$	$(5.6 \pm 1.6) \times 10^{-4}$	
Γ_4	$\tau^- \to 2\pi^+ 3\pi^- \pi^0 \nu_\tau$	$(5.1 \pm 2.2) \times 10^{-4}$	
Γ_5	$\tau^- \to K^+ K^- \pi^- \nu_\tau$	$(2.2^{+1.7}_{-1.1}) \times 10^{-3}$	
Γ_6	$\tau^- \to K^- \pi^+ \pi^- (\geq 0\ \pi^0)\ \nu_\tau$	$(2.2^{+1.6}_{-1.3}) \times 10^{-3}$	
Γ_7	$\tau^- \to K^- \nu_\tau$	$(6.6 \pm 1.9) \times 10^{-3}$	S=1.1
Γ_8	$\tau^- \to \pi^- \omega \nu_\tau$	$(1.6 \pm 0.5) \times 10^{-2}$	
Γ_9	$\tau^- \to \pi^- \rho^0 \nu_\tau$	$(5.4 \pm 1.7) \times 10^{-2}$	
Γ_{10}	$\tau^- \to a_1(1260)^- \nu_\tau$		
Γ_{11}	$\tau^- \to K^- (\geq 1$ neutral$)\ \nu_\tau$	$(1.05^{+0.27}_{-0.28}) \times 10^{-2}$	
Γ_{12}	$\tau^- \to \pi^- \nu_\tau$	$(10.8 \pm 0.6) \times 10^{-2}$	
Γ_{13}	$\tau^- \to \pi^+ 2\pi^- \nu_\tau$ (non-resonant)	$< 1.4 \times 10^{-2}$	CL=95%
Γ_{14}	$\tau^- \to \pi^- \eta \nu_\tau$	$< 1.0 \times 10^{-2}$	CL=95%
Γ_{15}	$\tau^- \to \rho^- \nu_\tau$	$(22.3 \pm 1.1) \times 10^{-2}$	
Γ_{16}	$\tau^- \to \pi^+ 2\pi^- \nu_\tau$	$(6.8 \pm 0.6) \times 10^{-2}$	S=1.5
Γ_{17}	$\tau^- \to \pi^+ 2\pi^- \gamma(s)\ \nu_\tau$	$(6.4 \pm 0.6) \times 10^{-2}$	S=1.4
Γ_{18}	$\tau^- \to$ hadron$^-$ (≥ 2 hadron^0) ν_τ	$(16.3 \pm 1.3) \times 10^{-2}$	
Γ_{19}	$\tau^- \to 2\pi^+ 3\pi^- (\geq 0$ neutrals$)\ \nu_\tau$	$(1.15 \pm 0.27) \times 10^{-3}$	
Γ_{20}	$\tau^- \to K^*(892)^- \nu_\tau$	$(1.43 \pm 0.31) \times 10^{-2}$	
Γ_{21}	$\tau^- \to K_2^*(1430)^- \nu_\tau$	$< 9 \times 10^{-3}$	CL=95%
Γ_{22}	$\tau^- \to K^*(892)^- (\geq 0$ neutrals$)\ \nu_\tau$	$(1.4 \pm 0.9) \times 10^{-2}$	
Γ_{23}	$\tau^- \to \pi^- \pi^0$ (non-resonant) ν_τ	$(3.0^{+3.0}_{-1.9}) \times 10^{-3}$	
Γ_{24}	$\tau^- \to \pi^+ 2\pi^- \pi^0 \nu_\tau$	$(4.4 \pm 1.6) \times 10^{-2}$	
Γ_{25}	$\tau^- \to \pi^- 3\pi^0 \nu_\tau$	$(3.0 \pm 2.7) \times 10^{-2}$	
Γ_{26}	$\tau^- \to \pi^- 2\pi^0 \nu_\tau$	$(7.5 \pm 0.9) \times 10^{-2}$	
Γ_{27}	$\tau^- \to K^-$ (2 charged) (≥ 0 neutrals) ν_τ	$< 6 \times 10^{-3}$	CL=90%
Γ_{28}	$\tau^- \to \pi^+ 2\pi^- K^0 (\geq 0\ \gamma)\ \nu_\tau$	$< 2.7 \times 10^{-3}$	CL=90%
Γ_{29}	$\tau^- \to \pi^- \pi^0 \eta \nu_\tau$	$< 2.1 \times 10^{-2}$	CL=95%
Γ_{30}	$\tau^- \to$ 7hadrons$^\pm$ ($\geq 0\pi^0$) ν_τ	$< 1.9 \times 10^{-4}$	CL=90%
Γ_{31}	$\tau^- \to K^- K^0 \nu_\tau$	$< 2.6 \times 10^{-3}$	CL=95%
Γ_{32}	$\tau^- \to K^- K^0 \pi^0 \nu_\tau$	$< 2.6 \times 10^{-3}$	CL=95%
Γ_{33}	$\tau^- \to \pi^- \eta\ (\geq 0$ neutrals$)\ \nu_\tau$	$< 2.1 \times 10^{-2}$	CL=95%
Γ_{34}	$\tau^- \to \pi^- \eta\eta\ (\geq 0$ neutrals$)\ \nu_\tau$	$< 5 \times 10^{-3}$	CL=90%
Γ_{35}	$\tau^- \to \pi^+ \pi^- \pi^- \eta\ (\geq 0$ neutrals$)\ \nu_\tau$	$< 3.0 \times 10^{-3}$	CL=90%
Γ_{36}	$\tau^- \to$ (1 charged) (≥ 0 neutrals) ν_τ		
Γ_{37}	$\tau^- \to$ hadron$^-$ ($\geq 1\ \pi^0$) ν_τ		
Γ_{38}	$\tau^- \to$ hadron$^-$ (≥ 0 neutrals) ν_τ		
Γ_{39}	$\tau^- \to \pi^+ 2\pi^- (\geq 0\ \pi^0)\ \nu_\tau$		
Γ_{40}	$\tau^- \to K^- (\geq 0$ neutrals$)\ \nu_\tau$		

LEPTON NUMBER OR LEPTON FAMILY NUMBER VIOLATING MODES

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_{41}	$\tau^- \to \mu^- \gamma$	$< 5 \times 10^{-4}$	CL=90%
Γ_{42}	$\tau^- \to e^- \gamma$	$< 6 \times 10^{-4}$	CL=90%
Γ_{43}	$\tau^- \to \mu^-$ charged particles		
Γ_{44}	$\tau^- \to e^-$ charged particles		
Γ_{45}	$\tau^- \to \mu^- \mu^+ \mu^-$	$< 2.9 \times 10^{-5}$	CL=90%
Γ_{46}	$\tau^- \to e^- \mu^+ \mu^-$	$< 3.3 \times 10^{-5}$	CL=90%
Γ_{47}	$\tau^- \to \mu^- e^+ e^-$	$< 3.3 \times 10^{-5}$	CL=90%
Γ_{48}	$\tau^- \to e^- e^+ e^-$	$< 4 \times 10^{-5}$	CL=90%
Γ_{49}	$\tau^- \to \mu^- \pi^0$	$< 8 \times 10^{-4}$	CL=90%
Γ_{50}	$\tau^- \to e^- \pi^0$	$< 2.1 \times 10^{-3}$	CL=90%
Γ_{51}	$\tau^- \to \mu^- K^0$	$< 1.0 \times 10^{-3}$	CL=90%
Γ_{52}	$\tau^- \to e^- K^0$	$< 1.3 \times 10^{-3}$	CL=90%
Γ_{53}	$\tau^- \to \mu^- \rho^0$	$< 4 \times 10^{-5}$	CL=90%
Γ_{54}	$\tau^- \to e^- \rho^0$	$< 4 \times 10^{-5}$	CL=90%
Γ_{55}	$\tau^- \to e^- \pi^+ \pi^-$	$< 4 \times 10^{-5}$	CL=90%
Γ_{56}	$\tau^- \to e^+ \pi^- \pi^-$	$< 6 \times 10^{-5}$	CL=90%
Γ_{57}	$\tau^- \to \mu^- \pi^+ \pi^-$	$< 4 \times 10^{-5}$	CL=90%
Γ_{58}	$\tau^- \to \mu^+ \pi^- \pi^-$	$< 6 \times 10^{-5}$	CL=90%
Γ_{59}	$\tau^- \to e^- \pi^+ K^-$	$< 4 \times 10^{-5}$	CL=90%
Γ_{60}	$\tau^- \to e^+ \pi^- K^-$	$< 1.2 \times 10^{-4}$	CL=90%
Γ_{61}	$\tau^- \to \mu^- \pi^+ K^-$	$< 1.2 \times 10^{-4}$	CL=90%
Γ_{62}	$\tau^- \to \mu^+ \pi^- K^-$	$< 1.2 \times 10^{-4}$	CL=90%
Γ_{63}	$\tau^- \to e^- K^*(892)^0$	$< 5 \times 10^{-5}$	CL=90%
Γ_{64}	$\tau^- \to \mu^- K^*(892)^0$	$< 6 \times 10^{-5}$	CL=90%
Γ_{65}	$\tau^- \to e^+ \mu^- \mu^-$	$< 4 \times 10^{-5}$	CL=90%
Γ_{66}	$\tau^- \to \mu^+ e^- e^-$	$< 4 \times 10^{-5}$	CL=90%

CONSTRAINED FIT INFORMATION

An overall fit to 21 branching ratios uses 83 measurements and one constraint to determine 11 parameters. The overall fit has a χ^2 = 64.3 for 73 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle \delta x_i\, \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

x_2	−16									
x_7	0	0								
x_{11}	−3	−3	−58							
x_{12}	8	11	−1	−3						
x_{15}	−2	−2	0	0	0					
x_{16}	0	0	0	0	0	0				
x_{17}	−1	−2	0	−1	−2	0	91			
x_{18}	18	18	−2	−9	−35	−79	0	−6		
x_{19}	0	0	0	0	−1	0	0	0	−1	
x_{23}	0	0	0	0	0	0	0	0	23	0
	x_1	x_2	x_7	x_{11}	x_{12}	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}

τ BRANCHING RATIOS

$\Gamma(\mu^-\bar{\nu}_\mu\nu_\tau)/\Gamma_{total}$ — Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.178 ± 0.004 OUR FIT					
0.178 ± 0.004 OUR AVERAGE					
0.177 ± 0.012 ± 0.007		AIHARA	87B	TPC	e^+e^- E_{cm}= 29 GeV
0.183 ± 0.009 ± 0.008		BURCHAT	87	MRK2	e^+e^- E_{cm}= 29 GeV
0.174 ± 0.006 ± 0.008	1201	ADEVA	86B	MRKJ	e^+e^- E_{cm}= 14–47 GeV
0.188 ± 0.008 ± 0.007	558	BARTEL	86D	JADE	e^+e^- E_{cm}= 34.6 GeV
0.129 ± 0.017 $^{+0.007}_{-0.005}$		ALTHOFF	85	TASS	e^+e^- E_{cm}= 34.5 GeV
0.183 ± 0.009 ± 0.005	473	[3] ASH	85B	MAC	e^+e^- E_{cm}= 29 GeV
0.180 ± 0.010 ± 0.006		[4] BALTRUSAITIS	85	MRK3	e^+e^- E_{cm}= 3.77 GeV
0.194 ± 0.016 ± 0.017	153	BERGER	85	PLUT	e^+e^- E_{cm}= 34.6 GeV
0.176 ± 0.026 ± 0.021	47	BEHREND	83C	CELL	e^+e^- E_{cm}= 34 GeV
0.178 ± 0.027		BERGER	81B	PLUT	e^+e^- E_{cm}= 9–32 GeV
0.35 ± 0.14		BRANDELIK	80	TASS	e^+e^- E_{cm}= 30 GeV
0.22 $^{+0.07}_{-0.08}$	11	SMITH	78B	SPEC	$e^+e^- \to \mu^+\mu^- X^0$
0.15 ± 0.03	220	BURMESTER	77B	PLUT	Assumes V−A decay
0.22 $^{+0.10}_{-0.07}$		CAVALLI	77	SPEC	$e^+e^- \to \mu^\pm X^\mp$
0.175 ± 0.040		PERL	77	MRK1	$e^+e^- \to \mu^\pm X^\mp$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.178 ± 0.007 ± 0.005		[5] AIHARA	87B	TPC	e^+e^- E_{cm}= 29 GeV
0.177 ± 0.007		[6] BARTEL	86D	JADE	e^+e^- E_{cm}= 34.6 GeV
0.173 ± 0.005		[7] ASH	85B	MAC	e^+e^- E_{cm}= 29 GeV

[3] Error correlated with FERNANDEZ 85 1-prong value
[4] Error correlated with BALTRUSAITIS 85 $e\nu\bar{\nu}$ value
[5] Combined result of AIHARA 87B $e\nu\bar{\nu}$ and $\mu\nu\nu$ measurements assuming $BR(\mu\nu\bar{\nu})/BR(e\nu\bar{\nu})$ = 0.973
[6] Combined result of BARTEL 86D $e\nu\nu$ and $\mu\nu\bar{\nu}$ measurements assuming $BR(\mu\nu\nu)/BR(e\nu\nu)$ = 0.973
[7] Combined result of ASH 85B $\Gamma(\mu^-\nu_\mu\nu_\tau)/\Gamma_{total}$, $\Gamma(e^-\bar{\nu}_e\nu_\tau)/\Gamma_{total}$, and $\Gamma(\mu^-\bar{\nu}_\mu\nu_\tau)\Gamma(e^-\nu_e\nu_\tau)/\Gamma^2_{total}$ measurements assuming $BR(\mu\nu\nu)$ / $BR(e\nu\nu)$ = 0.97

$\Gamma(e^-\bar{\nu}_e\nu_\tau)/\Gamma_{total}$ — Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.175 ± 0.004 OUR FIT					
0.178 ± 0.005 OUR AVERAGE					
0.184 ± 0.012 ± 0.010		AIHARA	87B	TPC	e^+e^- E_{cm}= 29 GeV
0.191 ± 0.008 ± 0.011		BURCHAT	87	MRK2	e^+e^- E_{cm}= 29 GeV
0.170 ± 0.007 ± 0.009	515	BARTEL	86D	JADE	e^+e^- E_{cm}= 34.6 GeV
0.204 ± 0.030 $^{+0.014}_{-0.009}$		ALTHOFF	85	TASS	e^+e^- E_{cm}= 34.5 GeV
0.180 ± 0.009 ± 0.006	390	[8] ASH	85B	MAC	e^+e^- E_{cm}= 29 GeV
0.182 ± 0.007 ± 0.005		[9] BALTRUSAITIS	85	MRK3	e^+e^- E_{cm}= 3.77 GeV
0.130 ± 0.019 ± 0.029		BERGER	85	PLUT	e^+e^- E_{cm}= 34.6 GeV
0.183 ± 0.024 ± 0.019	60	BEHREND	83C	CELL	e^+e^- E_{cm}= 34 GeV
0.19 ± 0.09		BRANDELIK	80	TASS	e^+e^- E_{cm}= 30 GeV
0.160 ± 0.013	459	[10] BACINO	78B	DLCO	e^+e^- E_{cm}= 3.1–7.4 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.183 ± 0.007 ± 0.005		[11] AIHARA	87B	TPC	e^+e^- E_{cm}= 29 GeV
0.182 ± 0.008		[12] BARTEL	86D	JADE	e^+e^- E_{cm}= 34.6 GeV
0.178 ± 0.005		[13] ASH	85B	MAC	e^+e^- E_{cm}= 29 GeV

[8] Error correlated with FERNANDEZ 85 1-prong value
[9] Error correlated with BALTRUSAITIS 85 $\Gamma(\mu^-\nu_\mu\nu_\tau)/\Gamma_{total}$
[10] BACINO 78B value comes from fit to events with $e^\pm$ and one other nonelectron charged prong
[11] Combined result of AIHARA 87B $e\nu\nu$ and $\mu\nu\nu$ measurements assuming $BR(\mu\nu\nu)/BR(e\nu\bar{\nu})$ = 0.973
[12] Combined result of BARTEL 86D $e\nu\nu$ and $\mu\nu\nu$ measurements assuming $BR(\mu\nu\nu)/BR(e\nu\bar{\nu})$ = 0.973
[13] Combined result of ASH 85B $\Gamma(\mu^-\nu_\mu\nu_\tau)/\Gamma_{total}$, $\Gamma(e^-\nu_e\nu_\tau)/\Gamma_{total}$, and $\Gamma(\mu^-\nu_\mu\nu_\tau)\Gamma(e^-\bar{\nu}_e\nu_\tau)/\Gamma^2_{total}$ measurements assuming $BR(\mu\nu\nu)$ / $BR(e\nu\nu)$ = 0.97

$(\Gamma(\mu^-\bar{\nu}_\mu\nu_\tau)\Gamma(e^-\bar{\nu}_e\nu_\tau))^{1/2}/\Gamma_{total}$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.1766 ± 0.0026 OUR FIT					
0.189 ± 0.020 OUR AVERAGE					
0.182 ± 0.028 ± 0.014	13	[14] BRANDELIK	78	DASP	Assumes V−A decay
0.224 ± 0.032 ± 0.045	21	[14] BARBARO-	77	MRK1	
0.186 ± 0.010 ± 0.028	144	[14] PERL	77	MRK1	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.17 $^{+0.06}_{-0.03}$	105	[15] PERL	76	MRK1	Repl. by PERL 77

[14] Assumes V−A coupling, τ mass = 1.9 GeV, ν_τ mass = 0
[15] Assumes V−A coupling, τ mass = 1.8 GeV, ν_τ mass = 0

$\Gamma(\mu^-\bar{\nu}_\mu\nu_\tau)\Gamma(e^-\bar{\nu}_e\nu_\tau)/\Gamma^2_{total}$ — $\Gamma_1\Gamma_2/\Gamma^2$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0312 ± 0.0009 OUR FIT					
0.0293 ± 0.0022 OUR AVERAGE					
0.0288 ± 0.0017 ± 0.0019		ASH	85B	MAC	e^+e^- E_{cm}= 29 GeV
0.030 ± 0.005	257	BLOCKER	82D	MRK2	e^+e^- E_{cm}= 3.5–6.7 GeV
0.034 ± 0.008 ± 0.005	20	[16] BACINO	79C	DLCO	e^+e^- E_{cm}= 3.6–7.4 GeV

[16] BACINO 79C quotes $BR(\mu)$ = 0.21 ± 0.05 ± 0.03 assuming $BR(e)$ = 0.16. We multiply by 0.16 to get above value

$\Gamma(e^-\bar{\nu}_e\nu_\tau)/\Gamma(\mu^-\bar{\nu}_\mu\nu_\tau)$ — Γ_2/Γ_1

Predicted to be 1 for sequential lepton, 2 for para-electron, and 1/2 for para-muon. Para-electron also ruled out by HEILE 78.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.986 ± 0.034 OUR FIT					
0.86 ± 0.17 OUR AVERAGE					
0.75 ± 0.23	154	[17] BLOCKER	82D	MRK2	e^+e^- E_{cm}= 3.5–6.7 GeV
1.09 ± 0.38	18	[18] BRANDELIK	78	DASP	e^+e^- E_{cm}= 3.1–5.2 GeV
0.92 ± 0.37	21	BURMESTER	77C	PLUT	Assumes V−A decay
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.91 ± 0.06 ± 0.05		[19] BARTEL	86D	JADE	e^+e^- E_{cm}= 34.6 GeV
0.98 ± 0.07 ± 0.04	390	[20] ASH	85B	MAC	e^+e^- E_{cm}= 29 GeV

[17] BLOCKER 82D gives the inverse of this ratio as 1.33 ± 0.18 ± 0.36
[18] BRANDELIK 78 quotes the inverse of this ratio as 0.92 ± 0.32
[19] BARTEL 86D gives inverse of this ratio as 1.10 ± 0.07 ± 0.06. Not independent of BARTEL 86D $e\nu\bar{\nu}$ and $\mu\nu\nu$ values
[20] Not independent of ASH 85B $\Gamma(\mu^-\bar{\nu}_\mu\nu_\tau)/\Gamma_{total}$ and $\Gamma(e^-\bar{\nu}_e\nu_\tau)/\Gamma_{total}$ values

$\Gamma(\pi^-\nu_\tau)/\Gamma_{total}$ — Γ_{12}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.108 ± 0.006 OUR FIT					
0.109 ± 0.006 OUR AVERAGE					
0.100 ± 0.011 ± 0.014		BURCHAT	87	MRK2	e^+e^- E_{cm}= 29 GeV
0.107 ± 0.005 ± 0.008	798	FORD	87	MAC	e^+e^- E_{cm}= 29 GeV
0.118 ± 0.006 ± 0.011	328	[21] BARTEL	86D	JADE	e^+e^- E_{cm}= 34.6 GeV
0.099 ± 0.017 ± 0.013	34	BEHREND	83C	CELL	e^+e^- E_{cm}= 34 GeV
0.117 ± 0.019	1138	BLOCKER	82D	MRK2	e^+e^- E_{cm}= 3.5–6.7 GeV

[21] BARTEL 86D have corrected their result with $\Gamma(K^-\nu_\tau)/\Gamma_{total}$ = 0.0059 ± 0.0018

$\Gamma(K^-\nu_\tau)/\Gamma_{total}$ — Γ_7/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.0066 ± 0.0019 OUR FIT Error includes scale factor of 1.1				
0.0067 ± 0.0023 OUR AVERAGE Error includes scale factor of 1.3				
0.0059 ± 0.0018	16	MILLS 84	DLCO	e^+e^- E_{cm}= 29 GeV
0.013 ± 0.005	15	BLOCKER 82B	MRK2	e^+e^- E_{cm}= 3.9–6.7 GeV

$\Gamma(\rho^-\nu_\tau)/\Gamma_{total}$ — Γ_{15}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.223 ± 0.011 OUR FIT				
0.224 ± 0.011 OUR AVERAGE				
0.230 ± 0.013 ± 0.017	582	ADLER 87B	MRK3	e^+e^- E_{cm}= 3.77 GeV
0.223 ± 0.006 ± 0.014	629	YELTON 86	MRK2	e^+e^- E_{cm}= 29 GeV
0.221 ± 0.025		BEHREND 84	CELL	e^+e^- E_{cm}= 14.22 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.258 ± 0.017 ± 0.025		[22] BURCHAT 87	MRK2	e^+e^- E_{cm}= 29 GeV

[22] BURCHAT 87 value is not independent of YELTON 86 value. Nonresonant decays included.

$\Gamma(K^*(892)^-\nu_\tau)/\Gamma_{total}$ — Γ_{20}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.0143 ± 0.0031 OUR AVERAGE				
0.015 ± 0.004 ± 0.004	15	AIHARA 87C	TPC	e^+e^- E_{cm}= 29 GeV
0.013 ± 0.003 ± 0.003	31	YELTON 86	MRK2	e^+e^- E_{cm}= 29 GeV
0.017 ± 0.007	11	DORFAN 81	MRK2	e^+e^- E_{cm}= 4.2–6.7 GeV

$\Gamma(K_2^*(1430)^-\nu_\tau)/\Gamma_{total}$ — Γ_{21}/Γ

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
<0.009	95	0	DORFAN 81	MRK2	e^+e^- E_{cm}= 4.2–6.7 GeV

$\Gamma(a_1(1260)^-\nu_\tau)/\Gamma_{total}$ — Γ_{10}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.108 ± 0.034	27	[23] WAGNER 80	PLUT	e^+e^- E_{cm}= 4–5 GeV

[23] Not independent of WAGNER 80 $\Gamma(\pi^-\rho^0\nu_\tau)/\Gamma_{total}$ value below. Assumes that all $(\nu\rho^0\pi^\pm)$ events are $(\nu a_1^\mp)$ and BR($\ell^\pm\nu\nu$) = 0.173 ± 0.013.

$\Gamma(\pi^-\nu_\tau)/\Gamma(e^-\bar{\nu}_e\nu_\tau)$ — Γ_{12}/Γ_2

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.647 ± 0.039 ± 0.061	[24] BARTEL 86D	JADE	e^+e^- E_{cm}= 34.6 GeV

[24] Combined result of BARTEL 86D $e\nu\bar{\nu}$, $\mu\nu\bar{\nu}$ and $\pi^-\nu$ assuming BR($\mu\nu\bar{\nu}$)/BR($e\nu\bar{\nu}$) = 0.973.

$\Gamma(\pi^-\eta\nu_\tau)/\Gamma_{total}$ — Γ_{14}/Γ

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
<0.010	95		GAN 87B	MRK2	e^+e^- E_{cm}= 29 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.014	90		BEHREND 88	CELL	e^+e^- E_{cm}= 14–46.8 GeV
<0.013	95		ALBRECHT 87N	ARG	e^+e^- E_{cm}= 9.4–10.6 GeV
<0.018	95		BARINGER 87	CLEO	e^+e^- E_{cm}= 10.5 GeV
<0.025	90	0	COFFMAN 87	MRK3	e^+e^- E_{cm}= 3.77 GeV
0.051 ± 0.010 ± 0.012		65	DERRICK 87	HRS	e^+e^- E_{cm}= 29 GeV

$\Gamma(\pi^-\omega\nu_\tau)/\Gamma(\pi^+2\pi^-\pi^0\nu_\tau)$ — Γ_8/Γ_{24}

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.36 ± 0.06	146	[25] ALBRECHT 87L	ARG	e^+e^- E_{cm}= 10 GeV

[25] ALBRECHT 87L quotes this ratio times BR($\omega \rightarrow \pi^+\pi^-\pi^0$) = 0.32 ± 0.05. We divide by 0.896 to get above value.

$\Gamma(\rho^-\nu_\tau)\Gamma(\mu^-\bar{\nu}_\mu\nu_\tau)/\Gamma^2_{total}$ — $\Gamma_{15}\Gamma_1/\Gamma^2$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.0397 ± 0.0021 OUR FIT				
0.041 ± 0.009	103	BLOCKER 80	MRK2	e^+e^- E_{cm}= 3.5–6.7 GeV

$\Gamma(\rho^-\nu_\tau)\Gamma(e^-\bar{\nu}_e\nu_\tau)/\Gamma^2_{total}$ — $\Gamma_{15}\Gamma_2/\Gamma^2$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.0391 ± 0.0020 OUR FIT				
0.034 ± 0.008	139	BLOCKER 80	MRK2	e^+e^- E_{cm}= 3.5–6.7 GeV

$\Gamma(\pi^-\nu_\tau)\Gamma(e^-\bar{\nu}_e\nu_\tau)/\Gamma^2_{total}$ — $\Gamma_{12}\Gamma_2/\Gamma^2$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.0189 ± 0.0010 OUR FIT				
0.014 ± 0.004 OUR AVERAGE				
0.013 ± 0.005 ± 0.002	10	[26] BACINO 79C	DLCO	e^+e^- E_{cm}= 3.6–7.4 GeV
0.015 ± 0.005 ± 0.005	23	[27] ALEXANDER 78B	PLUT	e^+e^- E_{cm}= 3.6–5 GeV

[26] BACINO 79C quote BR(π) = 0.080 ± 0.032 ± 0.013 assuming BR(e) = 0.16. We multiply by 0.16 to get above value.
[27] ALEXANDER 78B quote BR(π) = 0.090 ± 0.029 ± 0.029 using BR(e) = 0.167 ± 0.010. We multiply by 0.167 to get above value.

$\Gamma(\pi^-\pi^0\text{ (non-resonant) }\nu_\tau)/\Gamma_{total}$ — Γ_{23}/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.0030 ± 0.0030 OUR FIT			
0.003 ± 0.003	BEHREND 84	CELL	e^+e^- E_{cm}= 14.22 GeV

$\Gamma(\pi^-2\pi^0\nu_\tau)/\Gamma_{total}$ — Γ_{26}/Γ

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
0.075 ± 0.009 OUR AVERAGE					
0.087 ± 0.004 ± 0.011		815	[28] BAND 87	MAC	e^+e^- E_{cm}= 29 GeV
0.062 ± 0.006 ± 0.012			[29] GAN 87	MRK2	e^+e^- E_{cm}= 29 GeV
0.060 ± 0.035			BEHREND 84	CELL	e^+e^- E_{cm}= 14.22 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>0.083	95		[30] AIHARA 86E	TPC	e^+e^- E_{cm}= 29 GeV

[28] BAND 87 assume BR($\pi^-3\pi^0\nu_\tau$) = 0.01 and BR($\pi^-\pi^0\eta\nu_\tau$) = 0.005.
[29] GAN 87 analysis use photon multiplicity distribution. See comments for Γ(hadron$^-$ (≥2 hadron^0) ν_τ)/Γ_{total}.
[30] AIHARA 86E analysis is sensitive to the sum of several multiple neutral meson decay modes. See comments for Γ(hadron$^-$ (≥2 hadron^0) ν_τ)/Γ_{total}.

$\Gamma(\pi^-3\pi^0\nu_\tau)/\Gamma_{total}$ — Γ_{25}/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.030 ± 0.027	BEHREND 84	CELL	e^+e^- E_{cm}= 14.22 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$0.000^{+0.014}_{-0.001}{}^{+0.011}_{-0.001}$	[31] GAN 87	MRK2	e^+e^- E_{cm}= 29 GeV

[31] Highly correlated with GAN 87 $\Gamma(\pi^-\pi^0\eta\nu_\tau)/\Gamma_{total}$ value. Authors quote BR($\pi^\pm 3\pi^0\nu_\tau$) + 0.67BR($\pi^\pm\eta\pi^0\nu_\tau$) = 0.047 ± 0.010 ± 0.011.

$\Gamma(\pi^-\rho^0\nu_\tau)/\Gamma_{total}$ — Γ_9/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.054 ± 0.017	27	WAGNER 80	PLUT	e^+e^- E_{cm}= 4–5 GeV

$\Gamma(\pi^-\omega\nu_\tau)/\Gamma_{total}$ — Γ_8/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN	COMMENT
16.0 ± 2.7 ± 4.1	139	BARINGER 87	CLEO	e^+e^- E_{cm}= 10.5 GeV

$\Gamma((1\text{ charged})(\geq 0\text{ neutrals})\ \nu_\tau)/\Gamma_{total}$ — $(\Gamma_1+\Gamma_2+\Gamma_7+\Gamma_{12}+\Gamma_{15}+\Gamma_{18}+\Gamma_{23})/\Gamma$

Charged particle can be e, μ, or hadron. Since 5 prong branching fraction is very small this branching fraction is not independent of 3 prong value ($\Gamma(\pi^+2\pi^-\ (\geq 0\ \pi^0)\ \nu_\tau)/\Gamma_{total}$).

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.857 ± 0.004 OUR FIT				
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.847 ± 0.008 ± 0.006		[32] AIHARA 87B	TPC	e^+e^- E_{cm}= 29 GeV
0.871 ± 0.010 ± 0.007		[33] BURCHAT 87	MRK2	e^+e^- E_{cm}= 29 GeV
0.879 ± 0.005 ± 0.012		RUCKSTUHL 86	DLCO	e^+e^- E_{cm}= 29 GeV
0.872 ± 0.005 ± 0.008		SCHMIDKE 86	MRK2	e^+e^- E_{cm}= 29 GeV
0.869 ± 0.002 ± 0.003	4098	AKERLOF 85B	HRS	e^+e^- E_{cm}= 29 GeV
$0.847 \pm 0.011^{+0.016}_{-0.013}$	169	[34] ALTHOFF 85	TASS	e^+e^- E_{cm}= 34.5 GeV
0.861 ± 0.005 ± 0.009		BARTEL 85F	JADE	e^+e^- E_{cm}= 34.6 GeV
0.878 ± 0.013 ± 0.039		[35] BERGER 85	PLUT	e^+e^- E_{cm}= 34.6 GeV

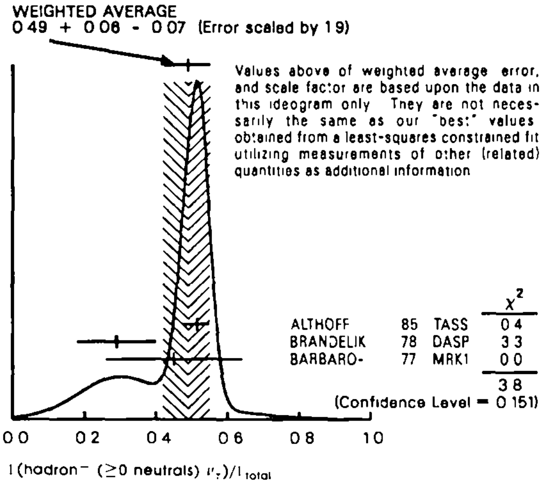
0 867 ± 0.003 ± 0 006		FERNANDEZ	85	MAC	e^+e^- E_{cm}= 29 GeV
0 852 ± 0 009 ± 0 015	660	AIHARA	84C	TPC	e^+e^- E_{cm}= 29 GeV
0 852 ± 0 026 ± 0 013	178	BEHREND	84	CELL	e^+e^- E_{cm}= 14 GeV
0 851 ± 0 028 ± 0 013	182	BEHREND	84	CELL	e^+e^- E_{cm}= 22 GeV
0 840 ± 0 020	672	BEHREND	82	CELL	e^+e^- E_{cm}= 32–36 8 GeV
0 86 ± 0 02 ± 0 01	764	BLOCKER	82C	MRK2	e^+e^- E_{cm}= 29 GeV

[32]Not independent of AIHARA 87B $\Gamma(\mu^-\bar{\nu}_\mu\nu_\tau)/\Gamma_{total}$, $\Gamma(e^-\bar{\nu}_e\nu_\tau)/\Gamma_{total}$, and Γ(hadron$^-$ (≥0 neutrals) ν_τ)/Γ_{total} values
[33]Not independent of SCHMIDKE 86 value (also not independent of BURCHAT 87 value for $\Gamma(\pi^+2\pi^-$ (≥0 π^0) $\nu_\tau)/\Gamma_{total}$
[34]Not independent of ALTHOFF 85 $\Gamma(\mu^-\bar{\nu}_\mu\nu_\tau)/\Gamma_{total}$, $\Gamma(e^-\bar{\nu}_e\nu_\tau)/\Gamma_{total}$, Γ(hadron$^-$ (≥0 neutrals) ν_τ)/Γ_{total} and $\Gamma(\pi^+2\pi^-$ (≥0 π^0) $\nu_\tau)/\Gamma_{total}$ values
[35]Not independent of (1-prong + 0π^0) and (1 prong + ≥1π^0) values

Γ(hadron$^-$ (≥0 neutrals) ν_τ)/Γ_{total} — (Γ_7+Γ_{12}+Γ_{15}+Γ_{18}+Γ_{23})/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.503 ± 0.006 OUR FIT					
0.49 $^{+0.06}_{-0.07}$ OUR AVERAGE Error includes scale factor of 1 9 See the ideogram below					
0 515 ± 0 029 $^{+0\ 016}_{-0\ 026}$		ALTHOFF	85	TASS	e^+e^- E_{cm}= 34 5 GeV
0 29 ± 0 11		BRANDELIK	78	DASP	Assumes V−A decay
0 45 ± 0 19	19	BARBARO	77	MRK1	
• • • We do not use the following data for averages fits limits etc • • •					
0.486 ± 0 012 ± 0 009		[36] AIHARA	87B	TPC	e^+e^- E_{cm}= 29 GeV
0.22 ± 0 14		[37] BRANDELIK	80	TASS	e^+e^- E_{cm}= 30 GeV

[36]Not independent of AIHARA 87B $e\nu\nu$, $\mu\nu\nu$ and $\pi^+2\pi^-$(≥0π^0)ν values
[37]Not independent of BRANDELIK 80 $\Gamma(\mu^-\nu_\mu\nu_\tau)/\Gamma_{total}$, $\Gamma(e^-\nu_e\nu_\tau)/\Gamma_{total}$ and Γ((1 charged) (≥0 neutrals) ν_τ)/Γ_{total} values



$\Gamma(K^-$ (≥0 neutrals) ν_τ)/Γ_{total} — (Γ_7+Γ_{11})/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0171 $^{+0.0022}_{-0.0023}$ OUR FIT					
0.0168 ± 0.0024 OUR AVERAGE					
0 016 ± 0 004 ± 0 002	35	AIHARA	87B	TPC	e^+e^- E_{cm}= 29 GeV
0 0171 ± 0 0029	53	MILLS	84	DLCO	e^+e^- E_{cm}= 29 GeV

$\Gamma(K^-$ (≥1 neutral) ν_τ)/Γ_{total} — Γ_{11}/Γ

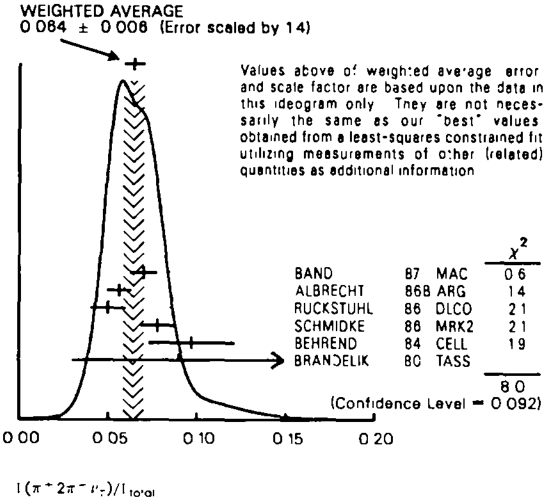
VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0105 $^{+0.0027}_{-0.0028}$ OUR FIT					
0.012 ± 0.005 $^{+0.002}_{-0.004}$	9	AIHARA	87B	TPC	e^+e^- E_{cm}= 29 GeV

$\Gamma(\pi^+2\pi^-\nu_\tau)/\Gamma_{total}$ — Γ_{16}/Γ

Decay modes with kaons are measured to be small so all hadrons are assumed to be pions BEHREND 84 and RUCKSTUHL 86 subtract kaons by hand

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.068 ± 0.006 OUR FIT Error includes scale factor of 1 5					
0.064 ± 0.006 OUR AVERAGE Error includes scale factor of 1 4 See the ideogram below					
0 070 ± 0 003 ± 0 007	1566	BAND	87	MAC	e^+e^- E_{cm}= 29 GeV
0.056 ± 0.007	593	[38] ALBRECHT	86B	ARG	e^+e^- E_{cm}= 10 GeV
0 050 ± 0 010		[39] RUCKSTUHL	86	DLCO	e^+e^- E_{cm}= 29 GeV
0 078 ± 0 005 ± 0 008	890	SCHMIDKE	86	MRK2	e^+e^- E_{cm}= 29 GeV
0.097 ± 0.024		BEHREND	84	CELL	e^+e^- E_{cm}= 14 22 GeV
0 09 ± 0 06		BRANDELIK	80	TASS	e^+e^- E_{cm}= 30 GeV
• • • We do not use the following data for averages fits limits etc • • •					
0 067 ± 0 008 ± 0 009		[40] BURCHAT	87	MRK2	e^+e^- E_{cm}= 29 GeV
0 081 ± 0 008	1255	FERNANDEZ	85	MAC	Repl by BAND 87
0.07 ± 0.05	13	[41] JAROS	78	MRK1	e^+e^- E_{cm}> 6 GeV

[38]ALBRECHT 86B does not include kaon modes Statistical and systematic errors are added in quadrature by authors
[39]Contributions from kaons are subtracted
[40]BURCHAT 87 value is not independent of SCHMIDKE 86 value
[41]JAROS 78 events consistent with being $\rho\pi$ or a.



$\Gamma(\pi^+2\pi^-\nu_\tau$ (non-resonant))/Γ_{total} — Γ_{13}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.014	95	WAGNER	80	PLUT	e^+e^- E_{cm}= 4–5 GeV

$\Gamma(\pi^+2\pi^-\pi^0\nu_\tau)/\Gamma_{total}$ — Γ_{17}/Γ

This measurement of $\tau^- \to \pi^+2\pi^-\pi^0\nu_\tau$ is put into the fit as $\tau^- \to \pi^+2\pi^-\gamma(s)\ \nu_\tau$ we assume that the multi π^0 fraction is small

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.064 ± 0.006 OUR FIT Error includes scale factor of 1 4					
0.046 ± 0.010 OUR AVERAGE					
0 042 ± 0 005 ± 0 009	203	[42] ALBRECHT	87L	ARG	e^+e^- E_{cm}= 10 GeV
0 062 ± 0.029		BEHREND	84	CELL	e^+e^- E_{cm}= 14 22 GeV
0 15 ± 0 07		BRANDELIK	80	TASS	e^+e^- E_{cm}= 30 GeV
• • • We do not use the following data for averages fits limits etc • • •					
0 061 ± 0 008 ± 0 009		[43] BURCHAT	87	MRK2	e^+e^- E_{cm}= 29 GeV
0 060 ± 0 012		[44] RUCKSTUHL	86	DLCO	e^+e^- E_{cm}= 29 GeV
0 047 ± 0 005 ± 0 008	530	[45] SCHMIDKE	86	MRK2	e^+e^- E_{cm}= 29 GeV
0.11 ± 0 07		JAROS	78	MRK1	e^+e^- E_{cm}> 6 GeV

[42]ALBRECHT 87L measure the product of branching ratios BR($3\pi^\pm\pi^0\nu_\tau$) BR(($e\nu$ or $\mu\nu$ or π or K or ρ) ν_τ) = 0 029 and use the PDG 86 values for the second branching ratio which sum to 0 69 ± 0 03 to get the quoted value
[43]BURCHAT 87 value is not independent of SCHMIDKE 86 value
[44]Contributions from kaons and from >1π^0 are subtracted Not independent of (3 prong + 0π^0) and (3 prong + ≥0π^0) values
[45]Not independent of SCHMIDKE 86 $\pi^+2\pi^-\nu$ and $\pi^+2\pi^-$(≥0π^0)ν values

$\Gamma(\pi^+2\pi^-\ (\geq 0\ \pi^0)\ \nu_\tau)/\Gamma_{total}$ $(\Gamma_{16}+\Gamma_{17})/\Gamma$

Decay modes with kaons are measured to be small so all hadrons are assumed to be pions

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.1319 ± 0.0026 OUR FIT					
0.1331 ± 0.0026 OUR AVERAGE					
0 151 ± 0 008 ± 0.006		AIHARA	87B	TPC	e^+e^- E_{cm}= 29 GeV
0 121 ± 0 005 ± 0 012		RUCKSTUHL	86	DLCO	e^+e^- E_{cm}= 29 GeV
0 128 ± 0 005 ± 0 008	1420	SCHMIDKE	86	MRK2	e^+e^- E_{cm}= 29 GeV
0.130 ± 0 002 ± 0 003	4098	AKERLOF	85B	HRS	e^+e^- E_{cm}= 29 GeV
0 153 ± 0 011 $^{+0\ 013}_{-0\ 016}$	367	ALTHOFF	85	TASS	e^+e^- E_{cm}= 34 5 GeV
0.136 ± 0 005 ± 0 008		BARTEL	85F	JADE	e^+e^- E_{cm}= 34 6 GeV
0.122 ± 0 013 ± 0 039		[46] BERGER	85	PLUT	e^+e^- E_{cm}= 34 6 GeV
0 133 ± 0 003 ± 0.006		FERNANDEZ	85	MAC	e^+e^- E_{cm}= 29 GeV
0 148 ± 0 020 ± 0 013	178	BEHREND	84	CELL	e^+e^- E_{cm}= 14 GeV
0 145 ± 0 022 ± 0 013	182	BEHREND	84	CELL	e^+e^- E_{cm}= 22 GeV
0 150 ± 0 020	186	BEHREND	82	CELL	e^+e^- E_{cm}= 32-36 8 GeV
0 24 ± 0 06	35	BRANDELIK	80	TASS	e^+e^- E_{cm}= 30 GeV
• • • We do not use the following data for averages fits limits etc • • •					
0.128 ± 0 010 ± 0 007		[47] BURCHAT	87	MRK2	e^+e^- E_{cm}= 29 GeV
0 148 ± 0 009 ± 0.015	660	AIHARA	84C	TPC	Repl by AIHARA 87B
0 14 ± 0 02	152	BLOCKER	82C	MRK2	Repl by SCHMIDKE 86
0.32 ± 0 05	692	[48] BACINO	78B	DLCO	e^+e^- E_{cm}= 3 1-7 4 GeV
0.35 ± 0 11		[48] BRANDELIK	78	DASP	Assumes V−A decay
0 18 ± 0.065	33	[48] JAROS	78	MRK1	e^+e^- E_{cm}> 6 GeV

[46] Not independent of BERGER 85 $\Gamma(\mu^-\bar{\nu}_\mu\nu_\tau)/\Gamma_{total}$, $\Gamma(e^-\bar{\nu}_e\nu_\tau)/\Gamma_{total}$, $\Gamma(\text{hadron}^-\ (\geq 1\ \pi^0)\ \nu_\tau)/\Gamma_{total}$, and $[\Gamma(K^-\nu_\tau)+\Gamma(\pi^-\nu_\tau)]/\Gamma_{total}$

[47] BURCHAT 87 value is not independent of SCHMIDKE 86 value

[48] Low energy experiments are not in average or fit because the systematic errors in background subtraction are judged to be large

$\Gamma(\pi^-\pi^0\eta\nu_\tau)/\Gamma_{total}$ Γ_{29}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.021	95	BARINGER	87	CLEO	e^+e^- E_{cm}= 10 5 GeV
• • • We do not use the following data for averages, fits, limits, etc • • •					
0 042 $^{+0\ 007}_{-0\ 012}$ ± 0 016		[49] GAN	87	MRK2	e^+e^- E_{cm}= 29 GeV

[49] Highly correlated with GAN 87 $\Gamma(\pi^-3\pi^0\nu_\tau)/\Gamma(\text{total})$ value

$\Gamma(2\pi^+3\pi^-\ (\geq 0\ \text{neutrals})\ \nu_\tau)/\Gamma_{total}$ Γ_{19}/Γ

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
1.15 ± 0.27 OUR FIT						
1.15 ± 0.27 OUR AVERAGE						
1 02 ± 0 29		13	BYLSMA	87	HRS	e^+e^- E_{cm}= 29 GeV
3 ± 1 ± 2			BARTEL	85F	JADE	e^+e^- E_{cm}= 34 6 GeV
1.6 ± 0.8 ± 0 4		4	BURCHAT	85	MRK2	e^+e^- E_{cm}= 29 GeV
10 ± 4		10	BEHREND	82	CELL	e^+e^- E_{cm}= 32-36 8 GeV
• • • We do not use the following data for averages fits limits etc • • •						
< 7	95	0	ALTHOFF	85	TASS	e^+e^- E_{cm}= 34 5 GeV
1 3 ± 0 4		10	BELTRAMI	85	HRS	Repl by BYLSMA 87
< 1.7	95	2	FERNANDEZ	85	MAC	e^+e^- E_{cm}= 29 GeV
< 3	90	4	AIHARA	84C	TPC	e^+e^- E_{cm}= 29 GeV
< 9	95	1	BEHREND	84	CELL	e^+e^- E_{cm}= 14,22 GeV
< 5	95	2	BLOCKER	82C	MRK2	e^+e^- E_{cm}= 29 GeV
<60	95		BRANDELIK	80	TASS	e^+e^- E_{cm}= 30 GeV

$\Gamma(K^-\ (2\ \text{charged})\ (\geq 0\ \text{neutrals})\ \nu_\tau)/\Gamma_{total}$ Γ_{27}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.006	90	AIHARA	84C	TPC	e^+e^- E_{cm}= 29 GeV

$\Gamma(\pi^+2\pi^-\nu_\tau)/[\Gamma(\pi^+2\pi^-\nu_\tau)+\Gamma(\pi^+2\pi^-\gamma(s)\ \nu_\tau)]$ $\Gamma_{16}/(\Gamma_{16}+\Gamma_{17})$

Not independent of values for $\Gamma(\pi^+2\pi^-\nu_\tau)/\Gamma_{total}$ and $\Gamma(\pi^+2\pi^-\ (\geq 0\ \pi^0)\ \nu_\tau)/\Gamma_{total}$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits, etc • • •					
0 37 $^{+0.35}_{-0\ 20}$	103	ALTHOFF	85	TASS	e^+e^- E_{cm}= 34 5 GeV
0 61 ± 0 03 ± 0 05		FERNANDEZ	85	MAC	e^+e^- E_{cm}= 29 GeV

$\Gamma(7\text{hadrons}^\pm\ (\geq 0\pi^0)\ \nu_\tau)/\Gamma_{total}$ Γ_{30}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 1.9 × 10⁻⁴	90	BYLSMA	87	HRS	e^+e^- E_{cm}= 29 GeV

$\Gamma(\pi^+2\pi^-K^0\ (\geq 0\ \gamma)\ \nu_\tau)/\Gamma_{total}$ Γ_{28}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0027	90	BELTRAMI	85	HRS	e^+e^- E_{cm}= 29 GeV

$\Gamma(2\pi^+3\pi^-\nu_\tau)/\Gamma_{total}$ Γ_3/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
5.6 ± 1.6 OUR AVERAGE					
6 4 ± 2.3 ± 1	12	ALBRECHT	88B	ARG	e^+e^- E_{cm}= 10 GeV
5 1 ± 2.0	7	BYLSMA	87	HRS	e^+e^- E_{cm}= 29 GeV
• • • We do not use the following data for averages fits limits, etc • • •					
6 7 ± 3.0	5	[50] BELTRAMI	85	HRS	Repl by BYLSMA 87

[50] The error quoted is statistical only

$\Gamma(2\pi^+3\pi^-\pi^0\nu_\tau)/\Gamma_{total}$ Γ_4/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
5.1 ± 2.2	6	BYLSMA	87	HRS	e^+e^- E_{cm}= 29 GeV
• • • We do not use the following data for averages, fits, limits, etc • • •					
6 7 ± 3.0	5	[51] BELTRAMI	85	HRS	Repl by BYLSMA 87

[51] The error quoted is statistical only

$\Gamma(K^+K^-\pi^-\nu_\tau)/\Gamma_{total}$ Γ_5/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0022 $^{+0.0017}_{-0.0011}$	9	[52] MILLS	85	DLCO	e^+e^- E_{cm}= 29 GeV

[52] Error correlated with MILLS 85 $(K\pi\pi\pi^0\nu)$ value Excludes 23% systematic error

$\Gamma(K^-\pi^+\pi^-\ (\geq 0\ \pi^0)\ \nu_\tau)/\Gamma_{total}$ Γ_6/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0022 $^{+0.0016}_{-0.0013}$	9	[53] MILLS	85	DLCO	e^+e^- E_{cm}= 29 GeV

[53] Error correlated with MILLS 85 $(KK\pi\nu)$ value Excludes 23% systematic error

$\Gamma(\text{hadron}^-\ (\geq 1\ \pi^0)\ \nu_\tau)/\Gamma_{total}$ $(\Gamma_{15}+\Gamma_{18}+\Gamma_{23})/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.389 ± 0.007 OUR FIT				
0.389 ± 0.017 OUR AVERAGE Error includes scale factor of 1 2				
0 382 ± 0.012 ± 0.010	[54] BURCHAT	87	MRK2	e^+e^- E_{cm}= 29 GeV
0 427 ± 0 020 ± 0 029	BERGER	85	PLUT	e^+e^- E_{cm}= 34 6 GeV

[54] BURCHAT 87 quote for BR($\pi^\pm$ ≥1 neutral ν_τ) = 0 378 ± 0.012 ± 0.010 We add 0.004 to account for contribution from $(K^{*-}\nu_\tau)$ which they fixed at BR = 0 013

$[\Gamma(K^-\nu_\tau)+\Gamma(\pi^-\nu_\tau)]/\Gamma_{total}$ $(\Gamma_7+\Gamma_{12})/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.114 ± 0.006 OUR FIT				
0.130 ± 0.020 ± 0.040	BERGER	85	PLUT	e^+e^- E_{cm}= 34 6 GeV

$\Gamma(\text{hadron}^- (\geq 2\ \text{hadron}^0)\ \nu_\tau)/\Gamma_{total}$ — Γ_{18}/Γ

Experimental situation is confused. The data below are not added into the overall fit at this time. Acceptances for individual modes contributing to this category vary greatly. For modes ($\tau^- \to \pi^- X \nu_\tau$), AIHARA 86E (TPC) quote $BR(2\pi^0\pi^-\nu_\tau) + 1.6BR(3\pi^0\pi^-\nu_\tau) + 1.1BR(\pi^0\eta\pi^-\nu_\tau) = 0.139 \pm 0.020 \pm 0.019$ and GAN 87 (Mark II) quote $BR(2\pi^0\pi^-\nu_\tau) + 0.95BR(3\pi^0\pi^-\nu_\tau) + 0.43BR(\pi^0\eta\pi^-\nu_\tau) = 0.090 \pm 0.010 \pm 0.012$

VALUE	DOCUMENT ID		TECN	COMMENT
$0.129^{+0.020}_{-0.021}$ OUR AVERAGE				
$0.120 \pm 0.014 \pm 0.025$	[55] BURCHAT	87	MRK2	e^+e^- E_{cm}= 29 GeV
$0.139 \pm 0.020^{+0.019}_{-0.022}$	AIHARA	86E	TPC	e^+e^- E_{cm}= 29 GeV

[55] Error correlated with BURCHAT 87 $\Gamma(\rho^-\nu_e)/\Gamma$(total) value

$\Gamma(K^*(892)^- (\geq 0\ \text{neutrals})\ \nu_\tau)/\Gamma_{total}$ — Γ_{22}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.014 \pm 0.009 \pm 0.003$	5	AIHARA	87B	TPC	e^+e^- E_{cm}= 29 GeV

$\Gamma(K^- K^0 \nu_\tau)/\Gamma_{total}$ — Γ_{31}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0026	95	AIHARA	87C	TPC	e^+e^- E_{cm}= 29 GeV

$\Gamma(K^- K^0 \pi^0 \nu_\tau)/\Gamma_{total}$ — Γ_{32}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0026	95	AIHARA	87C	TPC	e^+e^- E_{cm}= 29 GeV

$\Gamma(\pi^- \eta\ (\geq 0\ \text{neutrals})\ \nu_\tau)/\Gamma_{total}$ — Γ_{33}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.021	90	ABACHI	87B	HRS	e^+e^- E_{cm}= 29 GeV
<0.021	95	BARINGER	87	CLEO	e^+e^- E_{cm}= 10.5 GeV

$\Gamma(\pi^- \eta\eta\ (\geq 0\ \text{neutrals})\ \nu_\tau)/\Gamma_{total}$ — Γ_{34}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.005	90	ABACHI	87B	HRS	e^+e^- E_{cm}= 29 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.015	95	BARINGER	87	CLEO	e^+e^- E_{cm}= 10.5 GeV

$\Gamma(\pi^+\pi^-\pi^-\eta\ (\geq 0\ \text{neutrals})\ \nu_\tau)/\Gamma_{total}$ — Γ_{35}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.003	90	ABACHI	87B	HRS	e^+e^- E_{cm}= 29 GeV

$[\Gamma(\mu^-\ \text{charged particles}) + \Gamma(e^-\ \text{charged particles})]/\Gamma_{total}$ — $(\Gamma_{43}+\Gamma_{44})/\Gamma$

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.04	90	[56] BURMESTER	77C	PLUT	e^+e^- E_{cm}= 4–5 GeV

[56] Assumes same μ, e momentum spectrum as (μe + nothing detected)

$\Gamma(\mu^-\gamma)/\Gamma_{total}$ — Γ_{41}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 5.5 \times 10^{-4}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(e^-\gamma)/\Gamma_{total}$ — Γ_{42}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 6.4 \times 10^{-4}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(\mu^-\mu^+\mu^-)/\Gamma_{total}$ — Γ_{45}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 2.9 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 4.9 \times 10^{-4}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(e^-\mu^+\mu^-)/\Gamma_{total}$ — Γ_{46}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 3.3 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 3.3 \times 10^{-4}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(\mu^- e^+ e^-)/\Gamma_{total}$ — Γ_{47}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 3.3 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 4.4 \times 10^{-4}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(e^- e^+ e^-)/\Gamma_{total}$ — Γ_{48}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 3.8 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 4.0 \times 10^{-4}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(\mu^-\pi^0)/\Gamma_{total}$ — Γ_{49}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 8.2 \times 10^{-4}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(e^-\pi^0)/\Gamma_{total}$ — Γ_{50}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 2.1 \times 10^{-3}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(\mu^- K^0)/\Gamma_{total}$ — Γ_{51}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 1.0 \times 10^{-3}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(e^- K^0)/\Gamma_{total}$ — Γ_{52}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 1.3 \times 10^{-3}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(\mu^-\rho^0)/\Gamma_{total}$ — Γ_{53}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 3.8 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 4.4 \times 10^{-4}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(e^-\rho^0)/\Gamma_{total}$ — Γ_{54}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 3.9 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^-e^- E_{cm}= 10 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 3.7 \times 10^{-4}$	90	HAYES	82	MRK2	e^+e^- E_{cm}= 3.8–6.8 GeV

$\Gamma(e^-\pi^+\pi^-)/\Gamma_{total}$ — Γ_{55}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 4.2 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(e^+\pi^-\pi^-)/\Gamma_{total}$ — Γ_{56}/Γ

Test of lepton number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 6.3 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^-e^- E_{cm}= 10 GeV

$\Gamma(\mu^-\pi^+\pi^-)/\Gamma_{total}$ — Γ_{57}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 4.0 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(\mu^+\pi^-\pi^-)/\Gamma_{total}$ — Γ_{58}/Γ

Test of lepton number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 6.3 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV

Stable Particle Full Listings

$\Gamma(e^-\pi^+K^-)/\Gamma_{total}$ — Γ_{59}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 4.2 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(e^+\pi^-K^-)/\Gamma_{total}$ — Γ_{60}/Γ

Test of lepton number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 1.2 \times 10^{-4}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(\mu^-\pi^+K^-)/\Gamma_{total}$ — Γ_{61}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 1.2 \times 10^{-4}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(\mu^+\pi^-K^-)/\Gamma_{total}$ — Γ_{62}/Γ

Test of lepton number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 1.2 \times 10^{-4}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(e^-K^*(892)^0)/\Gamma_{total}$ — Γ_{63}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 5.4 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(\mu^-K^*(892)^0)/\Gamma_{total}$ — Γ_{64}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 5.9 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(e^+\mu^-\mu^-)/\Gamma_{total}$ — Γ_{65}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 3.8 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(\mu^+e^-e^-)/\Gamma_{total}$ — Γ_{66}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 3.8 \times 10^{-5}$	90	ALBRECHT	87M	ARG	e^+e^- E_{cm}= 10 GeV

τ DECAY PARAMETERS

ρ (MICHEL) PARAMETER

(V−A) theory predicts ρ = 0.75

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.73 ± 0.07 OUR AVERAGE					
0.79 ± 0.10 ± 0.10	3732	FORD	87B	MAC	e^+e^- E_{cm}= 29 GeV
0.71 ± 0.09 ± 0.03	1426	BEHRENDS	85	CLEO	e^+e^- near $\Upsilon(4S)$
0.72 ± 0.15	594	BACINO	79B	DLCO	e^+e^- E_{cm}= 3.5–7.4 GeV

τ/μ CHARGED COUPLING-CONSTANT RATIO

VALUE	DOCUMENT ID		TECN	COMMENT
$0.94^{+0.12}_{-0.09} \pm 0.09$	ALTHOFF	84D	TASS	e^+e^- E_{cm}= 43 GeV

REFERENCES FOR τ

ALBRECHT	88B	PL B202 149	+Binder Boeckmann+	(ARGUS Collab.)	
AMIDEI	88	PR D37 1750	+Trilling Abrams Baden+	(MARK II Collab.)	
BEHREND	88	PL B200 226	+Criegee Dainton Field+	(CELLO Collab.)	
ABACHI	87B	PL B197 291	+Baringer Bylsma De Bonte+	(HRS Collab.)	
ABACHI	87C	PRL 59 2519	+Akerlof Baringer Blockus+	(HRS Collab.)	
ADLER	87B	PRL 59 1527	+Becker Blaylock Bolton+	(MARK III Collab.)	
AIHARA	87B	PR D35 1553	+Alston Garnjost Avery+	(TPC Collab.)	
AIHARA	87C	PRL 59 751	+Alston Garnjost Avery+	(TPC Collab.)	
ALBRECHT	87L	PL B185 223	+Binder Boeckmann Glaser+	(ARGUS Collab.)	
ALBRECHT	87M	PL B185 228	+Binder Boeckmann Glaser+	(ARGUS Collab.)	
ALBRECHT	87N	PL B195 307	+Andam Andam Binder+	(ARGUS Collab.)	
ALBRECHT	87P	PL B199 580	+Andam Binder Boeckmann+	(ARGUS Collab.)	
BAND	87	PL B198 297	+Camporesi Chadwick Delfino+	(MAC Collab.)	
BAND	87B	PRL 59 415	+Bosman Camporesi Chadwick+	(MAC Collab.)	
BARINGER	87	PRL 59 1993	+McIlwain Miller Shibata+	(CLEO Collab.)	
BEBEK	87C	PR D36 690	+Berkelman Blucher Cassel+	(CLEO Collab.)	
BURCHAT	87	PR D35 27	+Feldman Barklow Boyarski+	(MARK II Collab.)	
BYLSMA	87	PR D35 2269	+Abachi Baringer DeBonte+	(HRS Collab.)	
COFFMAN	87	PR D36 2185	+Dubois Eigen Hauser+	(MARK III Collab.)	
DERRICK	87	PL B189 260	+Kooijman Loos Musgrave+	(HRS Collab.)	
FORD	87	PR D35 408	+Qi Read Smith+	(MAC Collab.)	
FORD	87B	PR D36 1971	+Qi Read Smith+	(MAC Collab.)	
GAN	87	PRL 59 411	+Abrams Amidei Baden+	(MARK II Collab.)	
GAN	87B	PL B197 561	+Abrams Amidei Baden+	(MARK II Collab.)	
ADEVA	86B	PL B179 177	+Ansari Becker Becker Szendy+	(MARK J Collab.)	
AIHARA	86E	PRL 57 1836	+Alston Garnjost Avery+	(TPC Collab.)	
ALBRECHT	86B	ZPHY C33 7	+Donker Gabriel Edwards+	(ARGUS Collab.)	
BARTEL	86D	PL B182 216	+Becker Felst Haidt Knies+	(JADE Collab.)	
PDG	86	PL 170B	Aguilar Benitez Porter+	(Particle Data Group)	
RUCKSTUHL	86	PRL 56 2132	+Stroynowski Atwood Barish+	(DELCO Collab.)	
SCHMIDKE	86	PRL 57 527	+Abrams Matteuzzi Amidei+	(MARK II Collab.)	
YELTON	86	PRL 56 812	+Dorfan Abrams Amidei+	(MARK II Collab.)	
AKERLOF	85B	PRL 55 570	+Baranko Baringer Beltrami+	(HRS Collab.)	
ALTHOFF	85	ZPHY C26 521	+Braunschweig Kirschfink+	(TASSO Collab.)	
ASH	85B	PRL 55 2118	+Band Blume Camporesi+	(MAC Collab.)	
BALTRUSAITIS	85	PRL 55 1842	+Becker Blaylock Brown+	(MARK III Collab.)	
BARTEL	85F	PL 161B 188	+Becker Cords Felst+	(JADE Collab.)	
BEHRENDS	85	PR D32 2468	+Gentile Guida Guida Morrow+	(CLEO Collab.)	
BELTRAMI	85	PRL 54 1775	+Bylsma DeBonte Gan+	(HRS Collab.)	
BERGER	85	ZPHY C28 1	+Genzel Lackas Pielorz+	(PLUTO Collab.)	
BURCHAT	85	PRL 54 2489	+Schmidke Yelton Abrams+	(MARK II Collab.)	
FERNANDEZ	85	PRL 54 1624	+Ford Qi Read+	(MAC Collab.)	
MILLS	85	PRL 54 624	+Pal Atwood Baillon+	(DELCO Collab.)	
AIHARA	84C	PR D30 2436	+Alston Garnjost Badtke Bakken+	(TPC Collab.)	
ALTHOFF	84D	PL 141B 264	+Braunschweig Kirschfink+	(TASSO Collab.)	
BEHREND	84	ZPHY C23 103	+Fenner Schachter Schroder+	(CELLO Collab.)	
MILLS	84	PRL 52 1944	+Ruckstuhl Atwood Baillon+	(DELCO Collab.)	
BEHREND	83C	PL 127B 270	+Chen Fenner Gumpel+	(CELLO Collab.)	
BEHREND	83D	NP B211 369	+Chen Field Fenner+	(CELLO Collab.)	
JAROS	83	PRL 51 955	+Amidei Trilling Abrams+	(MARK II Collab.)	
BEHREND	82	PL 114B 282	+Chen Fenner Field+	(CELLO Collab.)	
BLOCKER	82B	PRL 48 1586	+Abrams Alam Blondel+	(MARK II Collab.)	
BLOCKER	82C	PRL 49 1369	+Levi Abrams Amidei+	(MARK II Collab.)	
BLOCKER	82D	PL 109B 119	+Dorfan Abrams Alam+	(MARK II Collab.)	J
FELDMAN	82	PRL 48 66	+Trilling Abrams Amidei+	(MARK II Collab.)	
FORD	82	PRL 49 106	+Smith Allaby Ash	(MAC Collab.)	
HAYES	82	PR D25 2869	+Perl Alam Boyarski+	(MARK II Collab.)	
BERGER	81B	PL 99B 489	+Genzel Grigull Lackas+	(PLUTO Collab.)	
DORFAN	81	PRL 46 215	+Blocker Abrams Alam+	(MARK II Collab.)	
BLOCKER	80	LBL 10801 Thesis		(LBL)	
BRANDELIK	80	PL 92B 199	+Braunschweig Gather+	(TASSO Collab.)	
WAGNER	80	ZPHY C3 193	+Alexander Criegee Dehne+	(PLUTO Collab.)	
ZHOLENTZ	80	PL 96B 214	+Kurdadze Lelchuk Mishnev+	(NOVO)	
Also	81	SJNP 34 814	Zholentz Kurdadze Lelchuk+	(NOVO)	
		Translated from YAF 34 1471			
BACINO	79B	PRL 42 749	+Ferguson Nodulman Slater+	(DELCO Collab.)	
BACINO	79C	PRL 42 6	+Ferguson Nodulman Slater+	(DELCO Collab.)	
KIRKBY	79	SLAC PUB 2419		(SLAC)	J
Batavia Lepton Photon Conference					
ALEXANDER	78B	PL 78B 162	+Criegee Dehne Derikum+	(PLUTO Collab.)	
BACINO	78B	PRL 41 13	+Ferguson Nodulman Slater+	(DELCO Collab.)	J
Also	78	Tokyo Conf. 249	Kirz	(STON)	
Also	80	PL 96B 214	Zholentz Kurdadze Lelchuk Mishnev+	(NOVO)	
BARTEL	78	PL 77B 331	+Dittmann Duinker Olsson Oneill+	(DESY HEID)	
BRANDELIK	78	PL 73B 109	+Braunschweig Martyn Sander+	(DASP Collab.)	J
FELDMAN	78	Tokyo Conf. 777		(SLAC)	J
HEILE	78	NP B138 189	+Perl Abrams Alam Boyarski+	(SLAC LBL)	
JAROS	78	PRL 40 1120	+Abrams Alam+	(SLAC LBL NWES HAWA)	
SMITH	78B	PR D18 1	+Ford Morse Mann+	(COLO PENN WISC)	
BARBARO	77	PRL 39 1058	Barbaro Galtieri Kwan+	(LBL NWES SLAC HAWA)	
BURMESTER	77B	PL 68B 297	+Criegee Dehne Derikum+	(PLUTO Collab.)	
BURMESTER	77C	PL 68B 301	+Criegee Dehne Derikum+	(PLUTO Collab.)	
CAVALLI	77	LNC 20 337	Cavalli Sforza Goggi+	(PAVI PRIN UMD)	
PERL	77	PL 70B 487	+Feldman Abrams Alam Boyarski+	(SLAC LBL)	
PERL	76	PL 63B 466	+Feldman Abrams Alam Boyarski+	(SLAC LBL)	
PERL	75	PRL 35 1489	+Abrams Boyarski Breidenbach+	(LBL SLAC)	

OTHER RELATED PAPERS

BARISH	88	PRPL 157 1	+Stroynowski	(CIT)	
PERL	80	ARNPS 30 299		(SLAC)	
ALLES	79	LNC 25 404	Alles Borelli	(BGNA)	J
FLUGGE	79	ZPHY C1 121		(DESY)	
AZIMOV	78	SPU 21 225	+Frankfurt Khoze	(LENI)	
PERL	78	SLAC PUB 2219		(SLAC)	
Karlsruhe Summer Institute					
FLUGGE	77	Boston Conf.		(DESY)	
Also issued as DESY 77/35					
PERL	77B	Hamburg Symp.		(SLAC)	
Also issued as SLAC PUB 2022					

LIGHT MESONS

NOTE ON DECAY CONSTANTS OF PSEUDOSCALAR MESONS

The decay constant f_P of pseudoscalar meson P is defined by

$$\langle 0 | A_\mu(0) | P(\vec{q}) \rangle = i f_P q_\mu$$

where A_μ is the axial-vector part of the charged weak current after a Kobayashi-Maskawa mixing-matrix element $V_{qq'}$ is removed. The state vector is normalized as $\langle P(\vec{q}) | P(\vec{q}') \rangle = (2\pi)^3 2E_q \delta(\vec{q} - \vec{q}')$ and its phase is chosen such that f_P is real and positive. Note however that in many theoretical papers $f_P/\sqrt{2}$ is denoted by f_P and called the pseudoscalar decay constant.

For experimental determination of f_P, radiative correction must be taken into account in principle. Since the photon-loop correction introduces an infrared divergence which is canceled by soft-photon emission $P \to \ell\nu\gamma$, we can determine f_P only from a combined rate of $P \to \ell\nu$ and $P \to \ell\nu\gamma$. The combined rate is given by

$$\Gamma[P \to \ell\nu(+\ell\nu\gamma)] =$$

$$\frac{G_F^2 |V_{qq'}|^2}{8\pi} f_P^2 m_\ell^2 m_P \left(1 - \frac{m_\ell^2}{m_P^2}\right)^2 \left[1 + \frac{\alpha}{2\pi}(B + B_{SD})\right]$$

The term of $O(\alpha)$ consists of the inner bremsstrahlung part B which does not depend on the structure of meson P[1,2] and the structure-dependent part B_{SD}[3]. Although the latter involves a substantial theoretical ambiguity and grows with m_P, it is much smaller than the unambiguous inner bremsstrahlung part in the case of muonic decays. Since we determine f_π, f_K, and f_D from muonic decays, we keep only the inner bremsstrahlung part given by[4]

$$B = 4\left[\frac{x^2+1}{x^2-1}\ell n x - 1\right]\left[\ell n(x^2-1) - 2\ell n x - \frac{3}{4}\right]$$

$$+ 4\frac{x^2+1}{x^2-1} L\left(1 - \frac{1}{x^2}\right) - \ell n x - \frac{3}{4}$$

$$+ \frac{10x^2-7}{(x^2-1)^2}\ell n x + \frac{15x^2-21}{4(x^2-1)} ,$$

where

$$L(z) = \int_0^z \ell n(1-t)\frac{dt}{t} , \text{ and } x = m_P/m_\ell$$

B takes the value -1.35 for $\pi \to \mu\nu$ and -6.44 for $K \to \mu\nu$.

We use the experimental values of $|V_{qq'}|$ given in Eqs. (5), (7), and (8) of the "Kobayashi-Maskawa Mixing Matrix" section and our current best values of branching ratios, lifetimes, and masses to obtain the following values:

$$f_\pi = (131.69 \pm 0.15) \text{ MeV}$$

$$f_K = (161.2 \pm 1.4) \text{ MeV} ,$$

$$f_D < 300 \text{ MeV (CL} = 90\%)$$

References

1. S. Berman, Phys. Rev. Lett. **1**, 468 (1958)
2. T. Kinoshita, Phys. Rev. Lett. **2**, 477 (1959)
3. T. Goldman and W. J. Wilson, Phys. Rev. **D15**, 709 (1977)
4. A. Sirlin, Phys. Rev. **D5**, 436 (1972)

$\pi^{\pm}$

$I^G(J^P) = 1^-(0^-)$

$\pi^{\pm}$ MASS

The fit uses the $\pi^{\pm}$, π^0 and $\mu^{\pm}$ mass and mass difference measurements.

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
139.56755 ± 0.00033 OUR FIT					
139.56737 ± 0.00033 OUR AVERAGE					
139.56752 ± 0.00037	[1] JECKELMAN	86	CNTR	−	Mesonic atoms
139.5664 ± 0.0009	[2] LU	80	CNTR	−	Mesonic atoms
139.5686 ± 0.0020	CARTER	76	CNTR	−	Mesonic atoms
139.571 ± 0.010	D OLIVERA	76	CNTR	−	Mesonic atoms
139.5660 ± 0.0024	[2,3] MARUSHEN	76	CNTR	−	Mesonic atoms
139.569 ± 0.008	[4] BACKENSTO	73B	CNTR	−	Mesonic atoms
139.566 ± 0.013	[5] SHAFER	72	CNTR	−	Mesonic atoms
• • • We do not use the following data for averages, fits, limits, etc. • • •					
139.5704 ± 0.0011	[6] ABELA	84	SPEC	+	$\pi^+ \to \mu^+\nu$
139.549 ± 0.008	[4] BACKENSTO	71	CNTR	−	Mesonic atoms
139.577 ± 0.013	[5] SHAFER	67	CNTR	−	Mesonic atoms
139.68 ± 0.15	BARKAS	56	EMUL	+	
139.37 ± 0.20	CROWE	54	CNTR	−	

[1] JECKELMAN 86 gives $m(\pi)/m(e) = 273.12677(71)$. We use $m(e) = 0.51099906(15)$ MeV.

[2] Value scaled with new wavelength-energy conversion factor $V\lambda = 1.23984244(37) \times 10^{-6}$ eV m from COHEN 87.

[3] This MARUSHENKO 76 value used at authors request because it uses accepted set of calibration γ energies. Error increased from 0.0017 to include QED calculation error of 0.0017 (12 ppm).

[4] BACKENSTOSS 73B corrects BACKENSTOSS 71 with new vacuum polarization calculation.

[5] SHAFER 72 updates SHAFER 67 with new α and new calibration line energy.

[6] ABELA 84 value depends on assumed μ^+ mass $m(\mu) = 105.65932 \pm 0.00029$ enters our fit via $\pi - \mu$ mass difference below which is independent of $m(\mu)$.

$\pi^+ - \mu^+$ MASS DIFFERENCE

The fit uses the $\pi^{\pm}$, π^0 and $\mu^{\pm}$ mass and mass difference measurements.

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
33.90916 ± 0.00033 OUR FIT						
33.9111 ± 0.0011 OUR AVERAGE						
33.9111 ± 0.0011		ABELA	84	SPEC		
33.925 ± 0.025		BOOTH	70	CNTR	+	Magnetic spect
33.881 ± 0.035	145	HYMAN	67	HEBC	+	K^- He
34.00 ± 0.076		BARKAS	56	EMUL		
33.89 ± 0.076		BARKAS	56	EMUL		

$(m(\pi^+) - m(\pi^-))$ / AVERAGE

Test of CPT

VALUE (units 10^{-4})	DOCUMENT ID		TECN
2 ± 5	AYRES	71	CNTR

$\pi^{\pm}$ MEAN LIFE

VALUE (10^{-9} sec)	EVTS	DOCUMENT ID		TECN	CHG
26.029 ± 0.023 OUR AVERAGE					
26 09 ± 0 08		DUNAITSEV	73	CNTR	+
26 02 ± 0 04		AYRES	71	CNTR	±
26 04 ± 0.05		NORDBERG	67	CNTR	+
25 6 ± 0 3		BARDON	66	CNTR	
25 9 ± 0 3		DUNAITSEV	66	CNTR	
26.67 ± 0 24		LOBKOWICZ	66	CNTR	
26.02 ± 0 04		ECKHAUSE	65	CNTR	+
25.6 $^{+0.8}_{-0\ 8}$		ANDERSON	60	CNTR	
25 46 ± 0 32	8000	ASHKIN	60	CNTR	+
25 6 ± 0 5		CROWE	57	RVUE	
• • • We do not use the following data for averages fits limits, etc • • •					
26 40 ± 0 08		[7] KINSEY	66	CNTR	+

[7] Systematic errors in calibration in this experiment discussed by NORDBERG 67

$(\pi^+ - \pi^-)$ / AVERAGE, MEAN LIFE DIFFERENCE

This quantity is a measure of CPT invariance in weak interactions

VALUE (units 10^{-4})	DOCUMENT ID		TECN
5 ± 7 OUR AVERAGE			
5 5 ± 7 1	AYRES	71	CNTR
−14 ± 29	PETRUKHIN	68	CNTR
40 ± 70	BARDON	66	CNTR
23 ± 40	[8] LOBKOWICZ	66	CNTR

[8] Above is the most conservative value quoted by authors

π^+ DECAY MODES

π^- modes are charge conjugates of the modes below

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$\pi^+ \to \mu^+ \nu_\mu$	1 0	
Γ_2	$\pi^+ \to e^+ \nu_e$	$(1.228 \pm 0.022) \times 10^{-4}$	S=1 8
Γ_3	$\pi^+ \to \mu^+ \nu_\mu \gamma$	$(1\ 24 \pm 0\ 25) \times 10^{-4}$	
Γ_4	$\pi^+ \to e^+ \nu_e \pi^0$	$(1\ 025 ^{+0.033}_{-0\ 034}) \times 10^{-8}$	
Γ_5	$\pi^+ \to e^+ \nu \gamma$	$(5.6 \pm 0.7) \times 10^{-8}$	
Γ_6	$\pi^+ \to e^+ \nu e^+ e^-$	$< 5 \times 10^{-9}$	CL=90%
Γ_7	$\pi^+ \to \mu^+ \bar{\nu}_e$	$< 1\ 5 \times 10^{-3}$	CL=90%
Γ_8	$\pi^+ \to \mu^+ \nu_e$	$< 8 \times 10^{-3}$	CL=90%
Γ_9	$\pi^- \to \mu^- e^+ e^+ \nu$	$< 8 \times 10^{-6}$	CL=90%

π^+ BRANCHING RATIOS

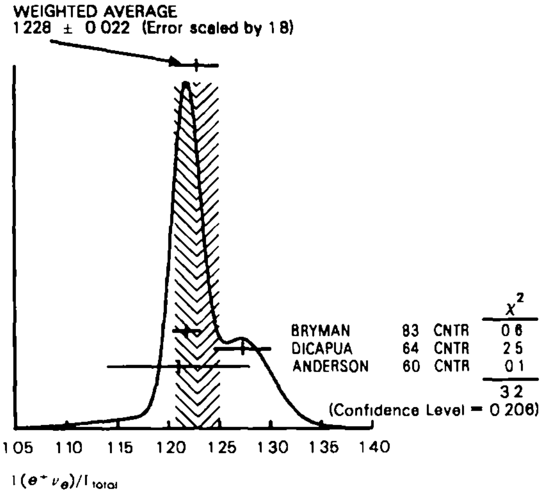
$\Gamma(\mu^+ \nu_\mu \gamma)/\Gamma_{total}$ Γ_3/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
1.24 ± 0.25	26	CASTAGNOLI	58	EMUL	$e_\mu < 3\ 38$ MeV

$\Gamma(e^+ \nu_e)/\Gamma_{total}$ Γ_2/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	CHG
1.228 ± 0.022 OUR AVERAGE		Error includes scale factor of 1 8 See the ideogram below			
1.218 ± 0 014	32k	BRYMAN	83	CNTR	+
1 273 ± 0.028	11k	[9] DICAPUA	64	CNTR	
1 21 ± 0 07		ANDERSON	60	CNTR	

[9] DICAPUA 64 updated using current mean life



$\Gamma(e^+ \nu_e \pi^0)/\Gamma_{total}$ Γ_4/Γ

VALUE (units 10^{-8})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1.025 $^{+0.033}_{-0.034}$ OUR AVERAGE						
1 026 ± 0.039	1224	[10] MCFARLANE	85	CNTR	+	Decay in flight
1 00 $^{+0\ 08}_{-0\ 10}$	332	DEPOMMIER	68	CNTR	+	
1 07 ± 0 21	38	[11] BACASTOW	65	OSPK	+	
1 10 ± 0.26		[11] BERTRAM	65	OSPK	+	
1 1 ± 0 2	43	[11] DUNAITSEV	65	CNTR	+	
0 97 ± 0 20	36	[11] BARTLETT	64	OSPK	+	
• • • We do not use the following data for averages, fits limits etc • • •						
1 15 ± 0 22	52	[11] DEPOMMIER	63	CNTR	+	

[10] Combines measured rate (0.394 ± 0 015)/sec with 1982 PDG mean life
[11] DEPOMMIER 68 states that the result of DEPOMMIER 63 is at least 10% too large because of a systematic error in the π^0 detection efficiency This may be true of all the previous measurements according to DEPOMMIER 68 and V Soergel, private communication, 1972

$\Gamma(e^+ \nu \gamma)/\Gamma_{total}$ Γ_5/Γ

VALUE (units 10^{-8})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
5.6 ± 0.7	226	[12] STETZ	78	SPEC	+	e mom >56 MeV/c
• • • We do not use the following data for averages fits limits etc • • •						
3.0	143	DEPOMMIER	63B	CNTR	+	$e^+\gamma$ KE >48 MeV

[12] STETZ 78 is for $e^-\gamma$ opening angle >132° Obtains 3 7 when using same cutoffs as DEPOMMIER 63B

$\Gamma(e^+ \nu e^+ e^-)/\Gamma_{total}$ Γ_6/Γ

VALUE (units 10^{-8})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
<0.48	90		KORENCHE	76B	SPEC	+	
• • • We do not use the following data for averages, fits, limits etc • • •							
SEEN		79	EGLI	86	SPEC	+	SINDRUM
<3 4	90		KORENCHE	71	OSPK	+	

$\Gamma(\mu^+ \bar{\nu}_e)/\Gamma_{total}$ Γ_7/Γ

Forbidden by total lepton number conservation

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<1.5	90	COOPER	82	HLBC	Wideband ν beam

$\Gamma(\mu^+ \nu_e)/\Gamma_{total}$ Γ_8/Γ

Forbidden by lepton family number conservation

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<8 0	90	COOPER	82	HLBC	Wideband ν beam

$\Gamma(\mu^- e^+ e^+ \nu)/\Gamma_{total}$ Γ_9/Γ

Forbidden by lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	CHG
< 7.7 $\times 10^{-6}$	90	KORENCHE	87	SPEC	+

π^+ — POLARIZATION OF EMITTED μ^+

$\pi^+ \to \mu^+ \nu$

Tests Lorentz structure of leptonic charged weak interactions

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
(-0.9959)	90	[13] FETSCHER	84	RVUE	+	
-0.99 ± 0.16		[14] ABELA	83	SPEC	−	μ X-rays

[13] FETSCHER 84 uses only measurement of CARR 83.

[14] Sign of measurement reversed in ABELA 83 to compare with μ^+ measurements.

NOTE ON $\pi^{\pm} \to \ell^{\pm}\nu\gamma$ AND $K^{\pm} \to \ell^{\pm}\nu\gamma$ FORM FACTORS

(by H. S. Pruys, Zurich University)

In the radiative decay $P^{\pm} \to \ell^{\pm}\nu\gamma$, where P stands for π or K, ℓ for e or μ, and γ is a real or virtual photon (e^+e^- pair), both the vector and the axial-vector weak hadronic currents contribute to the decay amplitude. The axial-vector current gives two contributions, one describing inner bremsstrahlung from the lepton and the meson (IB) and one describing structure-dependent radiation (SD_A) from virtual hadronic states. The vector current only leads to a structure-dependent term (SD_V). The IB amplitudes are determined by the meson decay constants f_π and f_K.[1] The amplitudes for SD_V and SD_A are parametrized by the vector form factor F_V and the axial-vector form factors F_A and R.[1-4]

$$M(SD_V) = \frac{-eG_F V_{qq'}}{\sqrt{2}\, m_P}\, \epsilon^{\mu} \ell^{\nu} F_V \epsilon_{\mu\nu\sigma\tau} k^{\sigma} q^{\tau} ,$$

$$M(SD_A) = \frac{-ieG_F V_{qq'}}{\sqrt{2}\, m_P}\, \epsilon^{\mu} \ell^{\nu} F_A \left[(s-t) g_{\mu\nu} - q_{\mu} k_{\nu}\right] + R t g_{\mu\nu}$$

where $V_{qq'}$ is the Kobayashi-Maskawa mixing-matrix element. The quantity ϵ^{μ} is the polarization vector of the real photon or the electron-positron current, $\epsilon^{\mu} = (e/t)\overline{u}(p_-)\gamma^{\mu} v(p_+)$, and ℓ^{ν} is the lepton-neutrino current $\ell^{\nu} = \overline{u}(p_\nu)\gamma^{\nu}(1-\gamma_5)v(p_\ell)$; q and k are the four-momenta of the meson and the photon, respectively, $s = q \cdot k$, and $t = k^2$. The s and t dependence of the form factors is neglected, which is a good approximation for pions[2] but not for kaons.[4] In the case of pions, the vector form factor F_V^{π} is related via CVC to the π^0 lifetime, $|F_V^{\pi}| = (1/\alpha)\sqrt{(2\Gamma_{\pi^0})/(\pi m_{\pi^0})}$.[1] PCAC relates R to the electromagnetic radius of the meson,[2,4] $R^P = \frac{1}{3} m_P f_P \langle r_P^2 \rangle$. The calculation of the other form factors F_A^{π}, F_V^K, and F_A^K is model dependent.[1,4]

For the decay $P \to \ell\nu\gamma$ with a real photon, the partial decay rate can be given analytically:[1,5]

$$\frac{d^2\Gamma_{P\to\ell\nu\gamma}}{dx\,dy} = \frac{d^2\Gamma_{IB}}{dx\,dy} + \frac{d^2\Gamma_{SD}}{dx\,dy} + \frac{d^2\Gamma_{INT}}{dx\,dy}$$

$$\frac{d^2\Gamma_{SD}}{dx\,dy} = \frac{\alpha}{8\pi}\Gamma_{P\to\ell\nu}\frac{1}{r(1-r)^2}\left(\frac{m_P}{f_P}\right)^2$$

$$\times\left[(F_V + F_A)^2 SD^+ + (F_V - F_A)^2 SD^-\right]$$

$$SD^+ = (x + y - 1 - r)\left[(x + y - 1)(1 - x) - r\right]$$

$$SD^- = (1 - y + r)\left[(1 - x)(1 - y) + r\right]$$

where $x = 2E_\gamma/m_P$, $y = 2E_\ell/m_P$, and $r = (m_\ell/m_P)^2$. Γ_{IB}, Γ_{SD}, and Γ_{INT} are the contributions from inner bremsstrahlung, structure-dependent radiation, and their interference, respectively.

In the decays $\pi \to e\nu\gamma$ and $K \to e\nu\gamma$ the interference terms are small, and thus only the absolute values $|F_V + F_A|$ and $|F_V - F_A|$ can be obtained. In the decay $K \to \mu\nu\gamma$ the interference term is important and thus also the signs of F_V and F_A can be obtained. The decay $\pi \to \mu\nu\gamma$ is completely dominated by bremsstrahlung. The decays $\pi \to e\nu e^+e^-$ and $K \to \mu(e)\nu e^+e^-$ allow the determination of all three form factors F_V, F_A, and R.

We list the π^- form factors F_A, F_V, and R below. In the K^+ branching ratio section of the Full Data Listings we list measurements of Γ_{SD^-} and combinations of the interference terms and Γ_{SD} for $K \to \mu\nu\gamma$ and Γ_{SD^+} and Γ_{SD} for $K \to e\nu\gamma$.

References

1. D. A. Bryman et al., Phys. Rep. **88**, 151 (1982). See also the "Note on Decay Constants of Pseudoscalar Mesons" above.
2. A. Kersch and F. Scheck, Nucl. Phys. **B263**, 475 (1986).
3. W. T. Chu et al., Phys. Rev. **166**, 1577 (1968).
4. D. Yu. Bardin and E. A. Ivanov, Sov. J. Part. Nucl. **7**, 286 (1976).
5. S. G. Brown and S. A. Bludman, Phys. Rev. **136**, B1160 (1964).

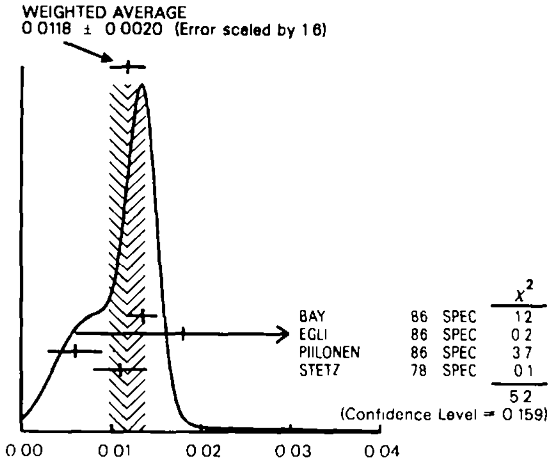
$\pi^{\pm}$ FORM FACTORS

F_A, AXIAL-VECTOR FORM FACTOR

VALUE		DOCUMENT ID		TECN	CHG	COMMENT
0.0118 ± 0.0020	**OUR AVERAGE**	Error includes scale factor of 1.6. See the ideogram below.				
0.0135 ± 0.0016		[15] BAY	86	SPEC	+	$\pi \to e\nu\gamma$
$0.018^{+0.015}_{-0.012}$		EGLI	86	SPEC	+	$\pi \to e^+e^-e^+\nu$
0.006 ± 0.003		[15] PIILONEN	86	SPEC	+	$\pi \to e\nu\gamma$
0.011 ± 0.003		[15,16] STETZ	78	SPEC	+	$\pi \to e\nu\gamma$

[15] Using the vector form factor from CVC prediction $f_V = 0.0259 \pm 0.0005$. Only the absolute value of f_A is determined.

[16] Result of STETZ 78 is two-fold ambiguous. Solution compatible with later determinations is taken.



$\pi^{\pm}$ axial vector form factor

F_V, VECTOR FORM FACTOR

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$0.029^{+0.019}_{-0.014}$	EGLI	86	SPEC	+	$\pi \rightarrow e^+ e^- e^+ \nu$

R, SECOND AXIAL-VECTOR FORM FACTOR

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$0.063^{+0.026}_{-0.016}$	EGLI	86	SPEC	+	$\pi \rightarrow e^+ e^- e^+ \nu$

REFERENCES FOR $\pi^{\pm}$

COHEN 87 RMP 59 1121 +Taylor (RISC NBS)
KORENCHE 87 SJNP 46 192 Korenchenko Kostir Mzhaviya+ (JINR)
Translated from YAF 46 313
BAY 86 PL B174 445 +Ruegger Gabioud Joseph Loude+ (LAUS ZURI)
EGLI 86 PL B175 97 +Engfer Grab Hermes+ (AACH ETH SIN ZURI)
JECKELMAN 86 PRL 56 1444 +Nakada Beer+ (ETH FRIB)
PIILONEN 86 PRL 57 1402 +Bolton Cooper Frank+ (LANL TEMP CHIC)
MCFARLANE 85 PR D32 547 +Auerbach Gaille+ (TEMP LANL)
ABELA 84 PL 146B 431 +Daum Eaton Frosch Jost Kettle+ (SIN)
Also 78 PL 74B 126 Daum Eaton Frosch Hirschmann+ (SIN)
Also 79 PR D20 2692 Daum Eaton Frosch Hirschmann+ (SIN)
FETSCHER 84 PL 140B 117 (ETH)
ABELA 83 NP A395 413 +Backenstoss Kunold Simons+ (BASL KARL)
BRYMAN 83 PRL 50 7 +Dubois Numao Olaniya+ (TRIU CNRC)
CARR 83 PRL 51 627 +Gidal Gobbi Jodidio Oram+ (LBL NWES TRIU)
COOPER 82 PL 112B 97 +Guy Michette Tyndel Venus (RL)
LU 80 PRL 45 1066 +Delker Dugan Wu Caffrey+ (YALE COLU JHU)
STETZ 78 NP B138 285 +Carroll Ortendahl Perez Mendez+ (LBL UCLA)
CARTER 76 PRL 37 1380 +Dixit Sundaresan+ (CARL CNRC CHIC CIT)
D OLIVERA 76 ZNAT 31A 1150 +Daniel VonEgidy+ (MUNI)
KORENCHE 76B JETP 44 35 Korenchenko Kostin Micelmacher+ (JINR)
Translated from ZETF 71 69
MARUSHEN 76 JETPL 23 72 Marushenko Mezentsev Petrunin+ (LENI)
Translated from ZETFP 23 80
Also 76 Private Comm Shafer (FNAL)
Also 78 Private Comm Smirnov (LENI)
BACKENSTO 73B PL 43B 539 Backenstoss Daniel Koch+ (CERN KARL MUNI)
Also 73 NP to be pub Tauscher
DUNAITSEV 73 SJNP 16 292 +Prokoshkin Razuvaev+ (SERP)
Translated from YAF 16 524
SHAFER 72 Private Comm (FNAL)
AYRES 71 PR D3 1051 +Cormack Greenberg Kenney+ (LRL UCSB)
Also 67 PR 157 1288 Ayres Caldwell Greenberg Kenney Kurz+(LRL)
Also 68 PRL 21 261 Ayres Cormack Greenberg+ (LRL UCSB)
Also 69 UCRL 18369 Thesis Ayres (LRL)
Also 69 PRL 23 1267 Greenberg Ayres Cormack+ (LRL UCSB)
BACKENSTO 71 PL 36B 403 Backenstoss Daniel Koch+ (CERN KARL HEID)
Also 70 Thesis VonDerMalsburg (HEID)
KORENCHE 71 SJNP 13 189 Korenchenko Kostin Micelmacher+ (JINR)
Translated from YAF 13 339
BOOTH 70 PL 32B 723 +Johnson Williams Wormald (LIVP)
DEPOMMIER 68 NP B4 189 +Duclos Heintze Kleinknecht+ (CERN)
PETRUKHIN 68 JINR P1 3862 +Rykalin Khazins Cisek (JINR)
HYMAN 67 PL 25B 376 +Loken Pewitt McKenzie+ (ANL CMU NWES)
NORDBERG 67 PL 24B 594 +Lobkowicz Burman (ROCH)
SHAFER 67 PR 163 1451 (LRL)
Also 65 PRL 14 923 Shafer Crowe Jenkins (LRL)
BARDON 66 PRL 16 775 +Dore Dorfan Krieger+ (COLU)
DUNAITSEV 66 PL 23 283 +Kutyin Prokoshkin Rasuvaev Simonov (JINR)
KINSEY 66 PR 144 1132 +Lobkowicz Nordberg (ROCH)
LOBKOWICZ 66 PRL 17 548 +Melissinos Nagashima+ (ROCH BNL)
BACASTOW 65 PR 139B 407 +Ghesquiere Wiegand Larsen (LRL SLAC)
BERTRAM 65 PR 139B 617 +Meyer Carrigan+ (MICH CMU)
DUNAITSEV 65 JETP 20 58 +Petrukhin Prokoshkin+ (JINR)
Translated from ZETF 47 84
ECKHAUSE 65 PL 19 348 +Harris Shuler+ (WILL)
BARTLETT 64 PR 136B 1452 +Devons Meyer Rosen (COLU)
DICAPUA 64 PR 133B 1333 +Garland Pondrom Strelzoff (COLU)
Also 86 Private Comm Pondrom (WISC)
DEPOMMIER 63 PL 5 61 +Heintze Rubbia Soergel (CERN)
DEPOMMIER 63B PL 7 285 +Heintze Rubbia Soergel (CERN)
ANDERSON 60 PR 119 2050 +Fujii Miller+ (EFI)
ASHKIN 60 NC 16 490 +Fazzini Fidecaro Lipman+ (CERN)
CASTAGNOLI 58 PR 112 1779 +Muchnik (ROMA)
CROWE 57 NC 5 541 (STAN)
BARKAS 56 PR 101 778 +Birnbaum Smith (LRL)
CROWE 54 PR 96 470 +Phillips (LRL)

OTHER RELATED PAPERS

BRYMAN 86 PR D33 1211 +Dubois Macdonald Numao+ (TRIU CNRC)
BRYMAN 82B PRPL 88 151 +Depommier Leroy (TRIU MONT LVLN)
DEPOMMIER 80 NP A335 97 (MONT)
WILKIN 80 JP G6 L5 (LOUC) P
BRYMAN 75 PR D11 1337 +Picciotto (VICT)
CARRIGAN 68 NP B6 662 (CMU) J
CZIRR 63 PR 130 341 (LRL)
MERRISON 62 ADVP 11 1 (LIVP)
SHAPIRO 62 PR 125 1022 +Lederman (COLU)
CARTWRIGHT 53 PR 91 677 +Richman Whitehead Wilcox (LRL) J

π^0

$I^G(J^{PC}) = 1^-(0^{-+})$

π^0 MASS

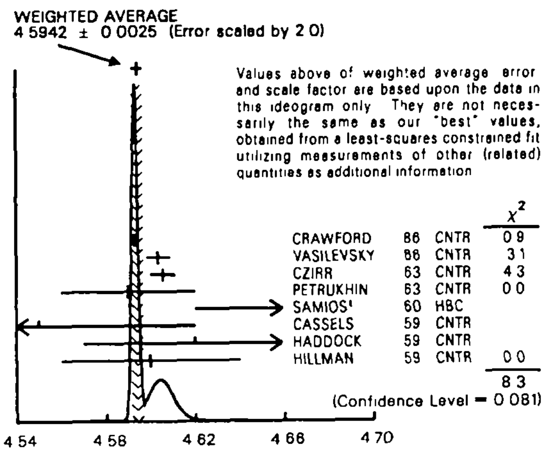
The fit uses the $\pi^{\pm}$, π^0, and $\mu^{\pm}$ mass and mass difference measurements

VALUE (MeV)	DOCUMENT ID
134.9733 ± 0 0029 OUR FIT Error includes scale factor of 2 3	

$\pi^{\pm} - \pi^0$ MASS DIFFERENCE

The fit uses the $\pi^{\pm}$, π^0, and $\mu^{\pm}$ mass and mass difference measurements

VALUE (MeV)	DOCUMENT ID		TECN	CHG
4.5942 ± 0.0028 OUR FIT Error includes scale factor of 2 3				
4.5942 ± 0.0025 OUR AVERAGE Error includes scale factor of 2 0 See the ideogram below				
4 5930 ± 0 0013	CRAWFORD	86	CNTR	−
4 6034 ± 0 0052	VASILEVSKY	66	CNTR	−
4 6056 ± 0 0055	CZIRR	63	CNTR	
4.59 ± 0 03	PETRUKHIN	63	CNTR	−
4 69 ± 0 07	SAMIOS	60	HBC	
4 55 ± 0 07	CASSELS	59	CNTR	
4 62 ± 0 05	HADDOCK	59	CNTR	−
4 60 ± 0 04	HILLMAN	59	CNTR	



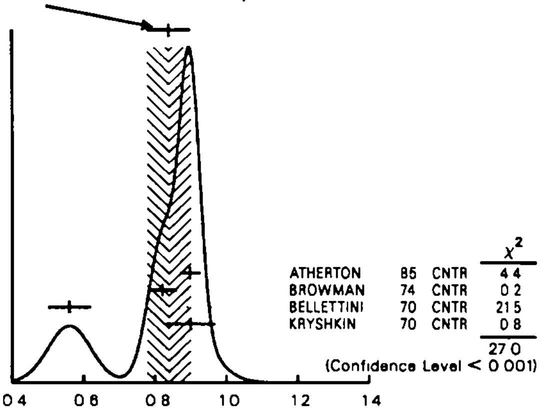
$\pi^{\pm} - \pi^0$ mass difference (MeV)

π^0 MEAN LIFE

VALUE (10^{-16} sec)	EVTS	DOCUMENT ID		TECN	COMMENT
0.84 ±0.06		**OUR AVERAGE** Error includes scale factor of 3.0. See the ideogram below.			
0.897±0.022±0.017		ATHERTON	85	CNTR	
0.82 ±0.04		[1] BROWMAN	74	CNTR	Primakoff effect
0.56 ±0.06		BELLETTINI	70	CNTR	Primakoff effect on nucl.
0.9 ±0.068		KRYSHKIN	70	CNTR	Primakoff effect
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1.0 ±0.5	232	[2] STAMER	66	EMUL	
0.730±0.105		BELLETTINI	65B	CNTR	
$1.05\,^{+0.18}_{-0.18}$		VONDARDEL	63	CNTR	

[1] BROWMAN 74 gives π^0 width = 8.02 ± 0.42 eV. Mean life is $\hbar$/width.
[2] Includes events of KOLLER 63.

WEIGHTED AVERAGE
0.84 ± 0.06 (Error scaled by 3.0)



π^0 mean life (10^{-16} sec)

π^0 DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$\pi^0 \to 2\gamma$	$(98.798\pm0.032)\times10^{-2}$	S=1.1
Γ_2	$\pi^0 \to e^+e^-\gamma$	$(1.198\pm0.032)\times10^{-2}$	S=1.1
Γ_3	$\pi^0 \to e^+e^+e^-e^-$	$(3.14\pm0.30)\times10^{-5}$	
Γ_4	$\pi^0 \to 3\gamma$	$< 4 \times10^{-7}$	CL=90%
Γ_5	$\pi^0 \to 4\gamma$	$< 1.6 \times10^{-6}$	CL=90%
Γ_6	$\pi^0 \to e^+e^-$	$(1.8\,^{+0.7}_{-0.6})\times10^{-7}$	
Γ_7	$\pi^0 \to 2\nu$	$< 2.4 \times10^{-5}$	CL=90%
Γ_8	$\pi^0 \to \mu^+e^- + \mu^-e^+$	$< 7 \times10^{-8}$	

CONSTRAINED FIT INFORMATION

An overall fit to 2 branching ratios uses 4 measurements and one constraint to determine 3 parameters. The overall fit has a χ^2 = 1.9 for 2 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i\,\delta x_j\rangle/(\delta x_i\cdot\delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

x_2	100	
x_3	−1	0
	x_1	x_2

π^0 BRANCHING RATIOS

$\Gamma(e^+e^-\gamma)/\Gamma(2\gamma)$ — Γ_2/Γ_1

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
1.213 ±0.033		**OUR FIT** Error includes scale factor of 1.1.			
1.213 ±0.030		**OUR AVERAGE**			
1.25 ±0.04		SCHARDT	81	SPEC	$\pi^-p \to n\pi^0$
1.166±0.047	3071	[3] SAMIOS	61	HBC	$\pi^-p \to n\pi^0$
1.17 ±0.15	27	BUDAGOV	60	HBC	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1.196		[4] JOSEPH	60		Quantum elect.

[3] SAMIOS 61 value uses Panofsky ratio = 1.62.
[4] Theoretical calculation.

$\Gamma(3\gamma)/\Gamma_{total}$ — Γ_4/Γ

Forbidden by C invariance.

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN
<0.38	90	0	HIGHLAND	80	CNTR
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<1.5	90	0	AUERBACH	78	CNTR
<4.9	90	0	[5] DUCLOS	65	CNTR
<4.9	90		[5] KUTIN	65	CNTR

[5] These experiments give BR(3γ/2γ) < 5.0 × 10^{-6}.

$\Gamma(e^+e^+e^-e^-)/\Gamma(2\gamma)$ — Γ_3/Γ_1

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	COMMENT
3.18 ±0.30		**OUR FIT**			
3.18 ±0.30	146	[6] SAMIOS	62B	HBC	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3.28		[7] MIYAZAKI	73	THEO	Quantum elect.

[6] SAMIOS 62B value uses Panofsky ratio = 1.62.
[7] MIYAZAKI 73 value is a theoretical calculation.

$\Gamma(4\gamma)/\Gamma_{total}$ — Γ_5/Γ

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN
< 1.6	90		BOLOTOV	86C	CALO
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 4.4	90	0	AUERBACH	80	CNTR
<38	90	0	AUERBACH	78B	CNTR
<60	90	0	[8] ABRAMS	73	ASPK

[8] ABRAMS 73 gives BR(4γ/2γ) < 6.1 × 10^{-5}.

$\Gamma(e^+e^-)/\Gamma(2\gamma)$ — Γ_6/Γ_1

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
$0.18\,^{+0.07}_{-0.06}$			**OUR AVERAGE**			
0.17 ±0.07		59	FRANK	83	SPEC	$\pi^-p \to n\pi^0$
$0.223\,^{+0.240}_{-0.110}$	90	8	FISCHER	78B	SPRK	K^+ expt.
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.18 ±0.06		58	MISCHKE	82	SPEC	Repl. by FRANK 83
<4.0	90		SCHACHER	77	STRC	$\pi^-p \to n\pi^0$
<2.0	90		[9] DAVIES	74	RVUE	

[9] DAVIES 74 extracts this information from BLOCH 75 K^+ experiment.

$\Gamma(2\nu)/\Gamma_{total}$ — Γ_7/Γ

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN
<2.4	90	0	HERCZEG	81	RVUE

$\Gamma(\mu^+e^-) + \Gamma(\mu^-e^+)/\Gamma_{total}$ — Γ_8/Γ

Forbidden by lepton family number conservation.

VALUE	DOCUMENT ID		TECN	COMMENT
< 7 × 10^{-8}	BRYMAN	82	RVUE	$K^+ \to \pi^+\mu e$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
< 14 × 10^{-8}	HERCZEG	84	RVUE	$K^+ \to \pi^+\mu e$
< 2 × 10^{-15}	HERCZEG	84	THEO	$\mu^- \to e^-$ conv.

π^0 ELECTROMAGNETIC FORM FACTOR

The amplitude for the process $\pi^0 \to e^+e^-\gamma$ contains a form factor $F(x^2)$ at the $\pi^0\gamma\gamma$ vertex where $x = m(e^+e^-)/m(\pi^0)$. The parameter a in the linear expansion $F(x^2) = 1 + ax^2$ is listed below.

LINEAR COEFFICIENT OF π^0 ELECTROMAGNETIC FORM FACTOR

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
+0.10 ±0.03	30k	[10] FISCHER	78	SPEC	Rad. corr.
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[11] TUPPER	83	THEO	FISCHER 78 data
+0.01 ±0.11	2200	DEVONS	69	OSPK	No rad. corr.
−0.15 ±0.10		KOBRAK	61	HBC	No rad. corr.
−0.24 ±0.16	3071	SAMIOS	61	HBC	No rad. corr.

[10] Error statistical only. Result without radiation corrections = +0.05 ± 0.03.
[11] TUPPER 83 is theoretical analysis of FISCHER 78 including two-photon exchange. Their estimate of the impact of these corrections is that the modified number would be $0.12\,^{+0.05}_{-0.04}$.

REFERENCES FOR π^0

BOLOTOV 86C JETPL 43 520 +Gninenko, Dzhilkibaev, Isakov (INRM)
Translated from ZETFP 43 405.
CRAWFORD 86 PRL 56 1043 +Daum, Frosch, Jost, Kettle+ (SIN, VIRG)
ATHERTON 85 PL 158B 81 +Bovet, Coet+ (CERN, ISU, LUND, LPTP, EFI)
HERCZEG 84 PR D29 1954 +Hoffman (LANL)
FRANK 83 PR D28 423 +Hoffman, Mischke, Moir+ (LANL, ARZS)

Stable Particle Full Listings
π^0, η

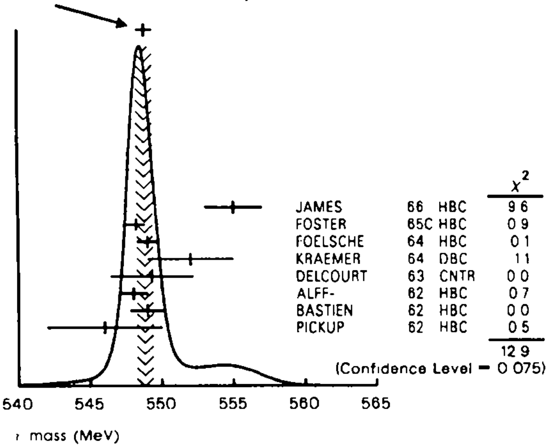
TUPPER	83	PR D28 2905	+Grose Samuel	(OKSU)
BRYMAN	82	PR D26 2538		(TRIU)
MISCHKE	82	PRL 48 1153	+Frank Hoffman Moir Sarracino+	(LANL ARZS)
HERCZEG	81	PL 100B 347	+Hoffman	(LANL)
SCHARDT	81	PR D23 639	+Frank Hoffmann Mischke Moir+	(ARZS LANL)
AUERBACH	80	PL 90B 317	+Haik Highland McFarlane Macek+	(TEMP LASL)
HIGHLAND	80	PRL 44 628	+Auerbach Haik McFarlane Macek+	(TEMP LASL)
AUERBACH	78	PRL 41 275	+Highland Johnson+	(TEMP LASL)
AUERBACH	78B	PL 78B 353	+Highland Johnson+	(TEMP LASL)
FISCHER	78	PL 73B 359	+Extermann Guisan Mermod+	(GEVA SACL)
FISCHER	78B	PL 73B 364	+Extermann Guisan Mermod+	(GEVA SACL)
SCHACHER	77	LNC 20 177	+Czapek Hahn Marti	(BERN)
BLOCH	75	PL 56B 201	+Brehin Bunce Devaux+	(SACL GEVA)
BROWMAN	74	PRL 33 1400	+Dewire Gittelman Hanson+	(CORN BING)
DAVIES	74	NC 24A 324	+Guy Zia	(BIRM RHEL SHMP)
ABRAMS	73	PL 45B 66	+Carroll Kycia Li Michael Mockett+	(BNL)
MIYAZAKI	73	PR D8 2051	+Takasugi	(TOKY)
BELLETTINI	70	NC 66A 243	+Bemporad Lubelsmey+	(PISA BONN)
KRYSHKIN	70	JETP 30 1037	+Sterligov Usov	(TMSK)
		Translated from ZETF 57 1917		
DEVONS	69	PR 184 1356	+Nemethy Nissim Sabat Capua+	(COLU ROMA)
STAMER	66	PR 151 1108	+Taylor Koller Huetter+	(STEV)
VASILEVSKY	66	PL 23 281	+Vishnyakov Dunaitsev+	(JINR)
BELLETTINI	65B	NC 40A 1139	+Bemporad Braccini+	(PISA FIRZ)
DUCLOS	65	PL 19 253	+Freytag Heintze+	(CERN HEID)
KUTIN	65	JETPL 2 243	+Petrukhin Prokoshkin	(JINR)
		Translated from unknown journal		
CZIRR	63	PR 130 341		(LRL)
KOLLER	63	NC 27 1405	+Taylor Huetter	(STEV)
Also	66	PR 151 1108	Stamer Taylor Koller Huetter+	(STEV)
PETRUKHIN	63	Siena Conf 208	+Prokoshkin	(JINR)
VONDARDEL	63	PL 4 51	+Dekkers Mermod VanPutten+	(CERN)
SAMIOS	62B	PR 126 1844	+Plano Prodell+	(COLU BNL)
KOBRAK	61	NC 20 1115		(EFI)
SAMIOS	61	PR 121 275		(COLU BNL)
BUDAGOV	60	JETP 11 755	+Viktor Dzhelepov Ermolov+	(JINR)
		Translated from ZETF 38 1047		
JOSEPH	60	NC 16 997		(EFI)
SAMIOS	60	NC 18 154		(COLU)
CASSELS	59	PPSL 74 92	+Jones Murphy Neill	(LIVP)
HADDOCK	59	PRL 3 478	+Abashian Crowe Czirr	(LRL)
HILLMAN	59	NC 14 887	+Middelkoop Yamagata Zavattini	(CERN)

η

$I^G(J^{PC}) = 0^+(0^{-+})$

η MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN
548.8 ± 0.6	**OUR AVERAGE**	Error includes scale factor of 1.4. See the ideogram below.		
555.0 ± 2.0	250	JAMES	66	HBC
548.2 ± 0.65		FOSTER	65C	HBC
549.0 ± 0.7	148	FOELSCHE	64	HBC
552.0 ± 3.0	325	KRAEMER	64	DBC
549.3 ± 2.9		DELCOURT	63	CNTR
548.0 ± 1.0	91	ALFF	62	HBC
549.0 ± 1.2	53	BASTIEN	62	HBC
546.0 ± 4.0	35	PICKUP	62	HBC



η WIDTH

η WIDTH DETERMINED FROM MASS SPECTRUM

VALUE (keV)	CL%	EVTS	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 4000			BALTAY	66C	DBC
< 12000		31	JAMES	66	HBC
< 900	95		JONES	66	CNTR
< 10000		148	FOELSCHE	64	HBC
< 10000		91	ALFF	62	HBC

η WIDTH DETERMINED FROM DECAY RATE

This is the partial decay rate $\Gamma(2\gamma)$ for the mode $\eta \to 2\gamma$ divided by the fitted branching fraction for that mode.

VALUE (keV)	DOCUMENT ID
1.08 ± 0.19 **OUR FIT**	Error includes scale factor of 2.1

η DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_1	$\eta \to 2\gamma$	$(38.9 \pm 0.4) \cdot 10^{-2}$	
Γ_2	$\eta \to 3\pi^0$	$(31.90 \pm 0.34) \cdot 10^{-2}$	
Γ_3	$\eta \to \pi^+\pi^-\pi^0$	$(23.7 \pm 0.5) \cdot 10^{-2}$	
Γ_4	$\eta \to \pi^+\pi^-\gamma$	$(4.91 \pm 0.13) \cdot 10^{-2}$	
Γ_5	$\eta \to e^+e^-\pi^0$	$< 5 \cdot 10^{-5}$	
Γ_6	$\eta \to e^+e^-\pi^+\pi^-$	$(1.3 \pm 1.3) \cdot 10^{-3}$	
Γ_7	$\eta \to \pi^0 2\gamma$	$(7.1 \pm 1.4) \cdot 10^{-4}$	
Γ_8	$\eta \to e^+e^-\gamma$	$(5.0 \pm 1.2) \cdot 10^{-3}$	
Γ_9	$\eta \to \pi^+\pi^-\pi^0\gamma$	$< 6 \cdot 10^{-4}$	
Γ_{10}	$\eta \to \pi^+\pi^- 2\gamma$	$< 2.1 \cdot 10^{-3}$	
Γ_{11}	$\eta \to \mu^+\mu^-$	$(6.5 \pm 2.1) \cdot 10^{-6}$	
Γ_{12}	$\eta \to \mu^+\mu^-\gamma$	$(3.1 \pm 0.4) \cdot 10^{-4}$	
Γ_{13}	$\eta \to \mu^+\mu^-\pi^0$	$< 5 \cdot 10^{-6}$	90%
Γ_{14}	$\eta \to \pi^+\pi^-$	$< 1.5 \cdot 10^{-3}$	
Γ_{15}	$\eta \to e^+e^-$	$< 3.0 \cdot 10^{-4}$	90%
Γ_{16}	$\eta \to \mu^+\mu^-\pi^0\gamma$	$< 3.0 \cdot 10^{-6}$	90%
Γ_{17}	$\eta \to 3\gamma$	$< 5 \cdot 10^{-4}$	

CONSTRAINED FIT INFORMATION

An overall fit to a partial width and 12 branching ratios uses 46 measurements and one constraint to determine 7 parameters. The overall fit has a χ^2 = 38.9 for 40 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i \delta x_j\rangle/(\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions $x_i \equiv \Gamma_i/\Gamma_{total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

x_2	45					
x_3	85	81				
x_4	74	70	79			
x_7	2	2	4	4		
x_8	11	10	6	6	1	
Γ	6	3	5	4	0	1
	x_1	x_2	x_3	x_4	x_7	x_8

	Mode	Rate (keV)	Scale
Γ_1	$\eta \to 2\gamma$	0.42 ± 0.07	2.1
Γ_2	$\eta \to 3\pi^0$	0.34 ± 0.06	2.1
Γ_3	$\eta \to \pi^+\pi^-\pi^0$	0.26 ± 0.04	2.0
Γ_4	$\eta \to \pi^+\pi^-\gamma$	0.053 ± 0.009	2.0
Γ_7	$\eta \to \pi^0 2\gamma$	0.00077 ± 0.00020	1.2
Γ_8	$\eta \to e^+e^-\gamma$	0.0054 ± 0.0016	1.2

NOTE ON THE RADIATIVE WIDTH OF THE η

(by N.A. Roe, SLAC)

The measurements of $\Gamma(\eta \to \gamma\gamma)$ listed below display a discrepancy: the results from two-photon production do not agree with the results from Primakoff production.

Since the last edition, the only change has been a final result from Crystal Ball,[1] $\Gamma(\eta \to \gamma\gamma) = 0.514 \pm 0.017 \pm 0.035$ keV. This measurement, with its high statistics and small systematic error, is consistent with previous two-photon results and strengthens the case for this technique. Yet the origin of the disagreement with the Primakoff results remains obscure.

In the two-photon measurements, η's were produced in the QED process $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-\eta$. The calculation of the rate is well understood, and the uncertainty due to the virtual photon form factor is small. Williams[1] quotes an uncertainty of 0.2% from this source. Backgrounds to the η signal from beam-gas interactions and other two-photon interactions with missing particles are also small. The weighted average from the four experiments is 0.52 ± 0.03 keV, and agreement among them is excellent within errors.

In the Primakoff experiments, η's were produced by the interaction of a real photon with a virtual photon in the Coulomb field of the nucleus. There is coherent background from strong production of η's in the nuclear hadronic field, and interference between the strong and Primakoff production amplitudes. The angular dependence of the background differs from that of the Primakoff signal, allowing $\Gamma(\eta \to \gamma\gamma)$ to be extracted from the data by a fit to the angular distribution. In the best fit to their data, BEMPORAD 67 found the coherent hadronic background to be consistent with zero. BROWMAN 74 had a wider range of photon energies, a higher maximum energy, better angular resolution, and higher statistics. They found a significant contribution from the hadronic background, especially at lower energies. BROWMAN 74 also analyzed the data of BEMPORAD 67 and found that it was compatible with their fit including background terms.[2] This suggests that the background was underestimated by BEMPORAD 67, and their result is superseded by that of BROWMAN 74.

We are still left with a serious disagreement, at the 3σ level, between the average two-photon value and the result of BROWMAN 74. The errors assigned by BROWMAN 74 include a 5.3% statistical error, a 12.2% systematic error for uncertainty in the accepted photon spectrum, and a systematic error of 2.5% for uncertainty in the nuclear parameters used in the calculation of the Primakoff and nuclear form factors. The Primakoff form factor F_C is a function of the momentum transfer q and the production angle θ. As $q^2 \to 0$, the uncertainty in F_C due to the q^2 dependence vanishes. The minimum q^2 in this experiment ranged from -680 MeV^2 at the lowest energy to -174 MeV^2 at the highest. In this range the result is sensitive to details in the calculation of F_C but it is difficult to estimate the systematic error of this dependence. Another possible source of systematic error is in the phase of the interference term ϕ. This was a free parameter in the fit, but it was not well determined by the data. This is because the interference contribution peaks in the same angular region as the Primakoff signal and so cannot be unambiguously separated by an angular fit. A reanalysis of the data would be necessary to determine whether any of these factors may have been overlooked in the determination of the systematic error.

Using the same apparatus, the authors of BROWMAN 74 measured $\Gamma(\pi^0 \to \gamma\gamma) = 7.93 \pm 0.39$ eV in good agreement with the world average value of 7.3 ± 0.2 eV which is dominated by the decay-length measurement of Atherton et al.[3] However the uncertainty due to F_C is reduced at lower momentum transfers, and q^2 was ~ 100 times smaller in the π^0 measurement. The signal-to-background ratio is also larger making the fit less sensitive to nuclear production. The radiative width of the π^0 has been measured using the two-photon technique by Crystal Ball,[1] whose value of $7.7 \pm 0.5 \pm 0.5$ eV is also consistent with the world average.

References

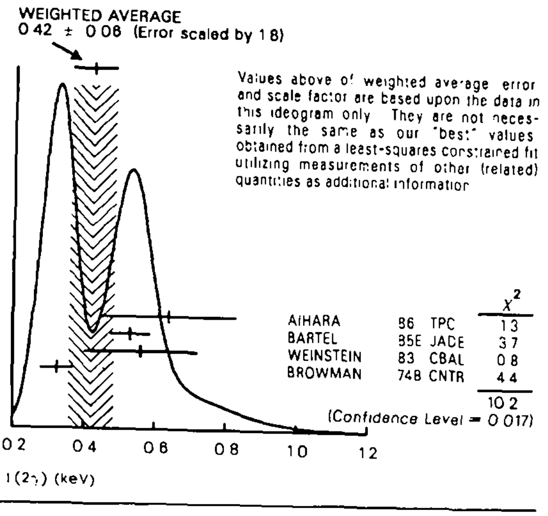
1. D Williams, Ph D thesis Harvard University, 1987 (unpublished)
2. A Browman et al, Phys Rev Lett **33** 1400 (1974)
3. H W Atherton et al, Phys Lett **158B** 81 (1985)

η DECAY RATES

$\Gamma(2\gamma)$ Γ_1

VALUE (keV)		EVTS	DOCUMENT ID		TECN	COMMENT
0.42 ±0.07	**OUR FIT** Error includes scale factor of 2.1					
0.42 ±0.06	**OUR AVERAGE** Error includes scale factor of 1.8. See the ideogram below					
0.64 ±0.14	±0.13		AIHARA	86	TPC	$e^+e^- \to e^+e^-\eta$
0.53 ±0.04	±0.04		BARTEL	85E	JADE	$e^+e^- \to e^+e^-\eta$
0.56 ±0.16		56	WEINSTEIN	83	CBAL	$e^+e^- \to e^+e^-\eta$
0.324±0.046			BROWMAN	74B	CNTR	Primakoff effect
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1.00 ±0.22			[1] BEMPORAD	67	CNTR	Primakoff effect

[1] BEMPORAD 67 gives $\Gamma(\eta \to 2\gamma) = 1.21 \pm 0.26$ keV assuming that $\Gamma(\eta \to 2\gamma)$ / total = 0.314. Bemporad private communication gives more general result as $\Gamma(\eta \to 2\gamma)\Gamma(\eta \to 2\gamma)$ / total = 0.380 ± 0.083. We evaluate this using $\Gamma(\eta \to 2\gamma)$ / total = 0.38 ± 0.01. Not included in average because the uncertainty resulting from the separation of the coulomb and nuclear amplitudes has apparently been underestimated.



η BRANCHING RATIOS

$[\Gamma(2\gamma) + \Gamma(3\pi^0) + \Gamma(\pi^0 2\gamma)]/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi^+\pi^-\gamma) + \Gamma(e^+e^-\gamma)]$ — $(\Gamma_1+\Gamma_2+\Gamma_7)/(\Gamma_3+\Gamma_4+\Gamma_8)$

VALUE	EVTS	DOCUMENT ID		TECN
2.44±0.08 OUR FIT				
2.64±0.23		BALTAY	67B	DBC
• • • We do not use the following data for averages, fits, limits, etc. • • •				
4.5 ±1.0	280	[2] JAMES	66	HBC
3.20±1.26	53	[2] BASTIEN	62	HBC
2.5 ±1.0	10	[2] PICKUP	62	HBC

[2] These experiments have not been used in computing the averages as they were unable to separate clearly partial modes $\eta \to \pi^+\pi^-\pi^0$ and $\eta \to \pi^+\pi^-\gamma$ from each other. The reported values thus probably contain some (unknown) fraction of mode $\eta \to \pi^+\pi^-\gamma$.

$\Gamma(2\gamma)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi^+\pi^-\gamma) + \Gamma(e^+e^-\gamma)]$ — $\Gamma_1/(\Gamma_3+\Gamma_4+\Gamma_8)$

VALUE	EVTS	DOCUMENT ID		TECN
1.34±0.04 OUR FIT				
1.1 ±0.4 OUR AVERAGE				
1.51±0.93	75	KENDALL	74	OSPK
0.99±0.48		CRAWFORD	63	HBC

$\Gamma(\pi^0 2\gamma)/[\Gamma(2\gamma) + \Gamma(3\pi^0) + \Gamma(\pi^0 2\gamma)]$ — $\Gamma_7/(\Gamma_1+\Gamma_2+\Gamma_7)$

For other results, see $\Gamma(\pi^0 2\gamma)/\Gamma_{total}$.

VALUE	CL%	DOCUMENT ID		TECN
0.00100±0.00020 OUR FIT				
0.0010 ±0.0002		ALDE	84	GAM2
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.04	90	ABROSIMOV	80	HLBC

$\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_4/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN
0.2074±0.0034 OUR FIT				
0.207±0.004 OUR AVERAGE Error includes scale factor of 1.1.				
0.209±0.004	18k	THALER	73	ASPK
0.201±0.006	7250	GORMLEY	70	ASPK
0.28 ±0.04		BALTAY	67B	DBC
0.25 ±0.035		LITCHFIELD	67	DBC
0.30 ±0.06		CRAWFORD	66	HBC
0.196±0.041		FOSTER	65C	HBC
0.14 ±0.08		FOELSCHE	64	HBC
0.10 ±0.10		KRAEMER	64	DBC
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.73 ±0.25	24	PAULI	64	DBC

$\Gamma(3\pi^0)/\Gamma(2\gamma)$ — Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0.819±0.009 OUR FIT				
0.84±0.06 OUR AVERAGE				
0.91±0.14	COX	70B	HBC	
0.75±0.09	DEVONS	70	OSPK	
0.88±0.16	BALTAY	67D	DBC	
1.1 ±0.2	CENCE	67	OSPK	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.25±0.39	BACCI	63	CNTR	Inverse BR reported
>0.90	CHRETIEN	62	PBC	

$\Gamma(2\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_1/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN
1.64±0.05 OUR FIT				
1.69±0.21 OUR AVERAGE				
1.72±0.25	401	BAGLIN	69	HLBC
1.61±0.39		FOSTER	65	HBC

$[\Gamma(2\gamma) + \Gamma(3\pi^0) + \Gamma(\pi^0 2\gamma)]/\Gamma(\pi^+\pi^-\pi^0)$ — $(\Gamma_1+\Gamma_2+\Gamma_7)/\Gamma_3$

VALUE	EVTS	DOCUMENT ID		TECN
2.99±0.09 OUR FIT				
3.26±0.30 OUR AVERAGE				
2.54±1.89	74	KENDALL	74	OSPK
3.4 ±1.1	29	AGUILAR	72B	HBC
2.83±0.80	70	[3] BLOODWO	72B	HBC
3.6 ±0.6	244	FLATTE	67B	HBC
2.89±0.56		ALFF-	66	HBC
3.6 ±0.8	50	KRAEMER	64	DBC
3.8 ±1.1		PAULI	64	DBC

[3] Error increased from published value 0.5 by Bloodworth (private communication).

$\Gamma(e^+e^-\pi^0)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_5/Γ_3

Single photon process forbidden by C parity.

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN
< 1.9	90		JANE	75	OSPK
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 42	90		BAGLIN	67	HLBC
< 16	90	0	BILLING	67	HLBC
< 77		0	FOSTER	65B	HBC
<110.			PRICE	65	HBC

$\Gamma(e^+e^-\pi^+\pi^-)/\Gamma_{total}$ — Γ_6/Γ

VALUE (units 10^{-2})	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
<0.7	RITTENBERG	65	HBC

$\Gamma(e^+e^-\pi^+\pi^-)/\Gamma(\pi^+\pi^-\gamma)$ — Γ_6/Γ_4

VALUE	EVTS	DOCUMENT ID		TECN
0.026±0.026	1	GROSSMAN	66	HBC

$\Gamma(2\gamma)/[\Gamma(2\gamma) + \Gamma(3\pi^0) + \Gamma(\pi^0 2\gamma)]$ — $\Gamma_1/(\Gamma_1+\Gamma_2+\Gamma_7)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.5491±0.0027 OUR FIT					
0.549±0.004 OUR AVERAGE					
0.549±0.004		ALDE	84	GAM2	
0.52 ±0.09	88	ABROSIMOV	80	HLBC	
0.60 ±0.14	113	KENDALL	74	OSPK	
0.535±0.018		BUTTRAM	70	OSPK	
0.59 ±0.033		BUNIATOV	67	OSPK	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.57 ±0.09		STRUGALSKI	71	HLBC	
0.579±0.052		FELDMAN	67	OSPK	
0.416±0.044		DIGIUGNO	66	CNTR	Error doubled
0.44 ±0.07		GRUNHAUS	66	OSPK	
0.39 ±0.06		[4] JONES	66	CNTR	

[4] This result from combining cross sections from two different experiments.

$\Gamma(3\pi^0)/[\Gamma(2\gamma) + \Gamma(3\pi^0) + \Gamma(\pi^0 2\gamma)]$ — $\Gamma_2/(\Gamma_1+\Gamma_2+\Gamma_7)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.4499±0.0027 OUR FIT					
0.450±0.004 OUR AVERAGE					
0.450±0.004		ALDE	84	GAM2	
0.44 ±0.08	75	ABROSIMOV	80	HLBC	
0.439±0.024		BUTTRAM	70	OSPK	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.32 ±0.09		STRUGALSKI	71	HLBC	
0.41 ±0.033		BUNIATOV	67	OSPK	Not indep. of $\Gamma(2\gamma)/[\Gamma(2\gamma)+\Gamma(3\pi^0)+\Gamma(\pi^0 2\gamma)]$
0.177±0.035		FELDMAN	67	OSPK	
0.209±0.054		DIGIUGNO	66	CNTR	Error doubled
0.29 ±0.10		GRUNHAUS	66	OSPK	

$\Gamma(e^+e^-\pi^0)/\Gamma_{total}$ — Γ_5/Γ

Single photon process forbidden by C parity.

VALUE (units 10^{-2})	CL%	EVTS	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.016	90	0	MARTYNOV	76	HLBC
<0.084	90		BAZIN	68	DBC
<0.7			RITTENBERG	65	HBC

$\Gamma(\pi^+\pi^-\pi^0\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_9/Γ_3

VALUE (units 10^{-2})	CL%	EVTS	DOCUMENT ID		TECN
<0.24	90	0	THALER	73	ASPK
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<1.7	90		ARNOLD	68	HLBC
<1.6	95		BALTAY	67B	DBC
<7.0			FLATTE	67	HBC
<0.9			PRICE	67	HBC

$\Gamma(\pi^+\pi^- 2\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_{10}/Γ_3

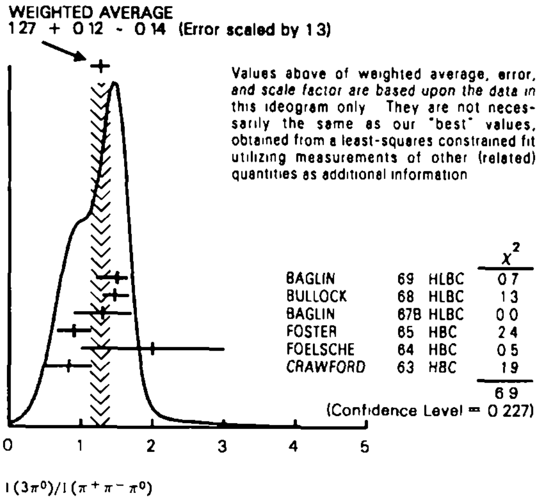
VALUE	CL%	DOCUMENT ID		TECN
<0.009		PRICE	67	HBC
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.016	95	BALTAY	67B	DBC

$\Gamma(3\pi^0)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_2/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN
1.35±0.04 OUR FIT				
$1.27^{+0.12}_{-0.14}$ OUR AVERAGE Error includes scale factor of 1.3. See the ideogram below.				
$1.50^{+0.15}_{-0.29}$	199	BAGLIN	69	HLBC
$1.47^{+0.20}_{-0.17}$		BULLOCK	68	HLBC
1.3 ±0.4		BAGLIN	67B	HLBC
0.90±0.24		FOSTER	65	HBC
2.0 ±1.0		FOELSCHE	64	HBC
0.83±0.32		CRAWFORD	63	HBC

$[\Gamma(2\gamma) + \Gamma(3\pi^0) + \Gamma(\pi^0 2\gamma)]/\Gamma_{total}$ — $(\Gamma_1+\Gamma_2+\Gamma_7)/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.709±0.006 OUR FIT					
0.706±0.008 OUR AVERAGE					
0.705±0.008	16k	BASILE	71D	CNTR	MM spectrometer
0.79 ±0.08		BUNIATOV	67	OSPK	



$\Gamma(\pi^0 2\gamma)/\Gamma_{total}$ — Γ_7/Γ

See also the review by LANDSBERG 85

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
7.1 ± 1.4 OUR FIT						
• • • We do not use the following data for averages, fits, limits, etc. • • •						
7.1 ± 1.7			[5] ALDE	84	GAM2	$\pi^- p \to \eta n$
9.5 ± 2.3		70	BINON	82	GAM2	Repl. by ALDE 84
<30	90	0	DAVYDOV	81	GAM2	$\pi^- p \to \eta n$

[5] Not independent of ALDE 84 result $\Gamma(\pi^0 2\gamma)/[\Gamma(2\gamma) + \Gamma(3\pi^0) + \Gamma(\pi^0 2\gamma)]$

$\Gamma(\mu^+\mu^-)/\Gamma_{total}$ — Γ_{11}/Γ

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.65 ± 0.21		27	DZHELYADIN	80B	SPEC	$\pi^- p \to \eta n$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<2	95	0	WEHMANN	68	OSPK	

$\Gamma(\mu^+\mu^-\pi^0)/\Gamma_{total}$ — Γ_{13}/Γ

Single photon process forbidden by C-parity

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<0.05	90	DZHELYADIN	81	SPEC	$\pi^- p \to \eta n$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<5		WEHMANN	68	OSPK	

$\Gamma(\mu^+\mu^-)/\Gamma(2\gamma)$ — Γ_{11}/Γ_1

VALUE (units 10^{-5})	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
5.9 ± 2.2	HYAMS	69	OSPK

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ — Γ_{14}/Γ

Violates P and CP invariance

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
<0.15	0	THALER	73	ASPK	CL not given

$\Gamma(e^+e^-\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_8/Γ_3

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN
2.1 ± 0.5 OUR FIT				
2.1 ± 0.5	80	[6] JANE	75B	OSPK

[6] Value changed by erratum

$\Gamma(e^+e^-)/\Gamma_{total}$ — Γ_{15}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN
<3.	90	[7] DAVIES	74	RVUE

[7] DAVIES 74 extracts this information from ESTEN 67

$\Gamma(\mu^+\mu^-\gamma)/\Gamma_{total}$ — Γ_{12}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
3.1 ± 0.4	600	DZHELYADIN	80	SPEC	$\pi^- p \to \eta n$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1.5 ± 0.75	100	BUSHNIN	78	SPEC	Repl. by DZHELYADIN 80

$\Gamma(\mu^+\mu^-\pi^0\gamma)/\Gamma_{total}$ — Γ_{16}/Γ

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN	COMMENT
<3.	90	DZHELYADIN	81	SPEC	$\pi^- p \to \eta n$

$\Gamma(3\gamma)/[\Gamma(2\gamma) + \Gamma(3\pi^0) + \Gamma(\pi^0 2\gamma)]$ — $\Gamma_{17}/(\Gamma_1+\Gamma_2+\Gamma_7)$

Forbidden by C invariance

VALUE		CL%	DOCUMENT ID		TECN
<7.	$\times 10^{-4}$	95	ALDE	84	GAM2

NOTE ON η DECAY PARAMETERS

C violation in η decays

As a test of possible C violation in electromagnetic interactions, a number of experiments have looked for possible charge asymmetries in the decays $\eta \to \pi^+\pi^-\pi^0$ and $\eta \to \pi^+\pi^-\gamma$. We list the following parameters

(a) The left-right asymmetry

$$A = (N^+ - N^-)/(N^+ + N^-),$$

where $N^{\pm}$ means the number of events with the $\pi^{\pm}$ energy greater than the $\pi^{\mp}$ energy in the η rest frame.

(b) The sextant asymmetry

$$A_s = \frac{N_1 + N_3 + N_5 - N_2 - N_4 - N_6}{N_1 + N_2 + N_3 + N_4 + N_5 + N_6}$$

for the decay $\eta \to \pi^+\pi^-\pi^0$. The numbers refer to sextants of the Dalitz plot (see, for example, Layter et al.[1]). A_s is sensitive to an $I = 0$ C-violating asymmetry.

(c) The quadrant asymmetry A_q, defined in a similar way as A_s, but with each sector of the Dalitz plot now containing $\pi/2$ rather than $\pi/3$ radians. A_q is sensitive to an $I = 2$ C-violating final state.

(d) The D-wave contribution to the C-violating amplitude in the decay $\eta \to \pi^+\pi^-\gamma$. The upper limit for this contribution is measured by the parameter β, defined by

$$dN/d|\cos\theta| \propto \sin^2\theta(1 + \beta\cos^2\theta),$$

where θ is the angle between the π^+ and the γ in the dipion center of mass. A term proportional to $\cos^2\theta$ could also be due to P- and F-wave interference.

We list A for the decay modes $\eta \to \pi^+\pi^-\pi^0$ and $\eta \to \pi^+\pi^-\gamma$, A_s and A_q for the decay $\eta \to \pi^+\pi^-\pi^0$, and β for the decay $\eta \to \pi^+\pi^-\gamma$ in the Full Listings below.

Dalitz plot for $\eta \to \pi^+\pi^-\pi^0$

The Dalitz plot for the decay $\eta \to \pi^+\pi^-\pi^0$ may be fit by the distribution

$$|M(x,y)|^2 \propto 1 + ay + by^2 + cx + dx^2 + exy$$

Here,

$$x = \sqrt{3}(T_+ - T_-)/Q, \quad y = (3T_0/Q) - 1,$$

T_+, T_-, and T_0 are the kinetic energies of the π^+, π^-, and π^0 in the η rest system and $Q = m_\eta - m_{\pi^+} - m_{\pi^-} - m_{\pi^0}$. The coefficient of the term linear in x is sensitive to C violation due to an $I = 0$ or $I = 2$ final state. We list papers presenting determinations of the parameters a, b, c, and d in the section DP below. However, we do not tabulate values of these parameters because the assumptions made by different authors are not compatible and do not allow comparison of the numerical values

Dalitz plot for $\eta \to \pi^0\pi^0\pi^0$

The Dalitz plot for the decay $\eta \to \pi^0\pi^0\pi^0$ may be fit to the expression

$$|M|^2 \propto 1 + 2\alpha z$$

where

$$z = \frac{2}{3}\sum_{i=1}^{3}\left[3(m_\eta - 3m_\pi)^{-1}(E_i - \tfrac{1}{3}m_\eta)\right]^2 = \rho^2/\rho^2_{max}$$

Here E_i is the energy of the i^{th} pion in the η rest frame and ρ is the distance to the center of the Dalitz plot We list the parameter α in section A0 below

Reference

1 J G Layter et al Phys Rev Lett **29**, 316 (1972)

η C-NONCONSERVING DECAY PARAMETERS

$\pi^+\pi^-\pi^0$ LEFT-RIGHT ASYMMETRY PARAMETER

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
0.12 ± 0.17 OUR AVERAGE					
0 28 ± 0 26	165k	JANE	74	OSPK	
−0 05 ± 0 22	220k	LAYTER	72	ASPK	
−1 4 ± 3	1138	CARPENTER	70	HBC	
3 2 ± 5 4	349	DANBURG	70	DBC	
0 3 ± 1 1	10709	MULLER	69	OSPK	
7 2 ± 2 8	1351	BALTAY	66C	DBC	
5 8 ± 3 4	1300	CLPWY	66	HBC	
−6 1 ± 4 0	705	LARRIBE	66	HBC	
• • • We do not use the following data for averages fits limits etc • • •					
1 5 ± 0 5	36800	8 GORMLEY	68C	ASPK	
0 3 ± 1 0	10665	CNOPS	66	OSPK	Repl by MULLER 69

8GORMLEY 68C asymmetry probably due to unmeasured (E × B) spark chamber effects New experiments with (E × B) controls don t observe asymmetry

$\pi^+\pi^-\gamma$ LEFT-RIGHT ASYMMETRY PARAMETER

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN
0 9 ± 0.4 OUR AVERAGE				
1 2 ± 0 6	35k	JANE	74B	OSPK
0 5 ± 0 6	36k	THALER	72	ASPK
1 22 ± 1 56	7257	GORMLEY	70	ASPK
1 5 ± 2 5	1620	9 MULLER	69	OSPK
−4 ± 8		LITCHFIELD	67	DBC
−2 ± 17	33	CRAWFORD	66	HBC

9MULLER 69 is sensitive only to upper 0 4 of γ-ray spectrum

$\pi^+\pi^-\pi^0$ SEXTANT ASYMMETRY PARAMETER

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN
0.49 ± 0.16 OUR AVERAGE				
0 20 ± 0 25	165k	JANE	74	OSPK
0 10 ± 0 22	220k	LAYTER	72	ASPK
0 5 ± 0 5	37k	GORMLEY	68C	WIRE
6 8 ± 3 3	1300	CLPWY	66	HBC
−2.4 ± 4.0	705	LARRIBE	66	HBC

$\pi^+\pi^-\pi^0$ QUADRANT ASYMMETRY PARAMETER

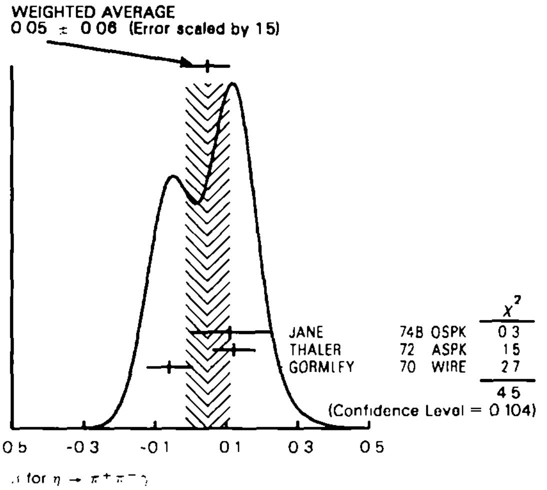
VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN
−0.17 ± 0.17 OUR AVERAGE				
−0 30 ± 0 25	165k	JANE	74	OSPK
−0 07 ± 0 22	220k	LAYTER	72	ASPK

β FOR $\eta \to \pi^+\pi^-\gamma$

Sensitive to D-wave contribution $dN/d\cos\theta = \sin^2\theta\,(1 + \beta\cos^2\theta)$

VALUE	EVTS	DOCUMENT ID		TECN
0.05 ± 0.06 OUR AVERAGE Error includes scale factor of 1 5 See the ideogram below				
0.11 ± 0 11	35k	JANE	74B	OSPK
0 12 ± 0 06		10 THALER	72	ASPK
−0 060 ± 0 065	7250	GORMLEY	70	WIRE

10Authors don t believe this to indicate D-wave because dependence of β on γ energy inconsistent with theoretical prediction Cos² dependence may also come from P wave and F-wave interference



ENERGY DEPENDENCE OF η DALITZ PLOT

See note on η decay parameters above The following experiments fit to one or more of the coefficients a b c d or e for $\eta \to \pi^+\pi^-\pi^0$ $|\text{matrix element}|^2 = 1 + ay + by^2 + cx + dx^2 + exy$

VALUE	EVTS	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •				
	81k	11 LAYTER	73	ASPK
	220k	11 LAYTER	72	ASPK
	1138	11 CARPENTER	70	HBC
	349	11 DANBURG	70	DBC
	7250	11 GORMLEY	70	WIRE
	526	11 BAGLIN	69	HLBC
	7170	11 CNOPS	68	OSPK
	37k	11 GORMLEY	68C	WIRE
	1300	11 CLPWY	66	HBC
	705	11 LARRIBE	66	HBC

11See note on η DECAY PARAMETERS above

α PARAMETER FOR $\eta \to 3\pi^0$

$|\text{matrix element}|^2 = 1 + 2\alpha z$ (See note above)

VALUE	EVTS	DOCUMENT ID		TECN
0.023 ± 0.023 OUR AVERAGE				
−0 022 ± 0 023	50k	ALDE	84	GAM2
−0 32 ± 0 37	192	BAGLIN	70	HLBC

REFERENCES FOR η

AIHARA	86	PR D33 844	+Alston Garnjost+	(TPC Two Gamma Collab)
BARTEL	85E	PL 160B 421	+Becker Cords Felst+	(JADE Collab)
LANDSBERG	85	PRPL 128 310		(SERP)
ALDE	84	ZPHY C25 225	+Binon Bricman Donskov+	(SERP BELG LAPP)
Also	84B	SJNP 40 918	Alde Binon Bricman+	(SERP BELG LAPP)
		Translated from YAF 40 1447		
WEINSTEIN	83	PR D28 2896	+Antreasyan Gu Kollman+	(Crystal Ball Collab)
BINON	82	SJNP 36 391	+Bricman Gouanere+	(SERP BELG LAPP CERN)
		Translated from YAF 36 670		
Also	82B	NC 71A 497	Binon Bricman+	(SERP BELG LAPP CERN)
DAVYDOV	81	LNC 32 45	+Donskov Inyakin+	(SERP BELG LAPP CERN)
Also	81B	SJNP 33 825	Davydov Binon+	(SERP BELG LAPP CERN)
		Translated from YAF 33 1534		
DZHELYADIN	81	PL 105B 239	+Golovkin Konstantinov Kubarovski+	(SERP)
Also	81C	SJNP 33 822	Dzhelyadin Viktorov Golovkin+	(SERP)
		Translated from YAF 33 1529		
ABROSIMOV	80	SJNP 31 195	+Ilina Niszcz Okhrimenko+	(JINR)
		Translated from YAF 31 371		
DZHELYADIN	80	PL 94B 548	+Viktorov Golovkin+	(SERP)
Also	80C	SJNP 32 516	Dzhelyadin Golovkin Kachanov+	(SERP)
		Translated from YAF 32 998		
DZHELYADIN	80B	PL 97B 471	+Viktorov Golovkin+	(SERP)
Also	80D	SJNP 32 518	Dzhelyadin Golovkin Kachanov+	(SERP)
		Translated from YAF 32 1002		
BUSHNIN	78	PL 79B 147	+Dzhelyadin Golovkin Gritsuk+	(SERP)
Also	78B	SJNP 28 775	Bushnin Golovkin Gritsuk Dzhelyadin+	(SERP)
		Translated from YAF 28 1507		
MARTYNOV	76	SJNP 23 48	+Saltykov Tarasov Uzhinskii	(JINR)
		Translated from YAF 23 93		
JANE	75	PL 59B 99	+Grannis Jones Lipman Owen+	(RHEL LOWC)
JANE	75B	PL 59B 103	+Grannis Jones Lipman Owen+	(RHEL LOWC)
Also	78B	PL 73B 503	Jane	
Erratum in private communication				
BROWMAN	74B	PRL 32 1067	+Dewire Gittelman Hanson Loh+	(CORN BING)
DAVIES	74	NC 24A 324	+Guy Zia	(BIRM RHEL SHMP)
JANE	74	PL 48B 260	+Jones Lipman Owen+	(RHEL LOWC SUSS)
JANE	74B	PL 48B 265	+Jones Lipman Owen+	(RHEL LOWC SUSS)
KENDALL	74	NC 21A 387	+Lanou Massimo Shapiro+	(BROW BARI MIT)
LAYTER	73	PR D7 2565	+Appel Kotlewski Lee Stein Thaler	(COLU)
THALER	73	PR D7 2569	+Appel Kotlewski Layter Lee Stein	(COLU)
AGUILAR	72B	PR D6 29	Aguilar Benitez Chung Elsner Samios	(BNL)

BLOODWO	72B	NP B39 525	Bloodworth Jackson Prentice Yoon	(TNTO)
LAYTER	72	PRL 29 316	+Appel Kotlewski Lee Stein Thaler	(COLU)
THALER	72	PRL 29 313	+Appel Kotlewski Layter Lee Stein	(COLU)
BASILE	71D	NC 3A 796	+Bollini Dalpiaz Frabetti+	(CERN BGNA STRB)
STRUGALSKI	71	NP B27 429	+Chuvilo Gemesy Ivanovskaya+	(JINR)
BAGLIN	70	NP B22 66	+Bezaguet Degrange+	(EPOL MADR STRB)
BUTTRAM	70	PRL 25 1358	+Kreisler Mischke	(PRIN)
CARPENTER	70	PR D1 1303	+Binkley Chapman Cox Dagan+	(DUKE)
COX	70B	PRL 24 534	+Fortney Golson	(DUKE)
DANBURG	70	PR D2 2564	+Abolins Dahl Davies Hoch Kirz+	(LRL)
DEVONS	70	PR D1 1936	+Grunhaus Kozlowski Nemethy+	(COLU SYRA)
GORMLEY	70	PR D2 501	+Hyman Lee Nash Peoples+	(COLU BNL)
Also	70B	Nevis 181 Thesis	Gormley	(COLU)
BAGLIN	69	PL 29B 445	+Bezaguet+	(EPOL UCB MADR STRB)
Also	70	NP B22 66	Baglin Bezaguet Degrange+	(EPOL MADR STRB)
HYAMS	69	PL 29B 128	+Koch Potter VonLindern+	(CERN MPIM)
MULLER	69	Thesis		(STRB)
ARNOLD	68	PL 27B 466	+Paty Baglin Bingham+	(STRB MADR EPOL UCB)
BAZIN	68	PRL 20 895	+Goshaw Zacher+	(PRIN QUKI)
BULLOCK	68	PL 27B 402	+Esten Fleming Govan Henderson+	(LOUC)
CNOPS	68	PRL 21 1609	+Hough Cohn+	(BNL ORNL UCND TENN PENN)
GORMLEY	68C	PRL 21 402	+Hyman Lee Nash Peoples+	(COLU BNL)
WEHMANN	68	PRL 20 748	+Engels+	(HARV CASE SLAC CORN MCGI)
BAGLIN	67	PL 24B 637	+Bezaguet Degrange+	(EPOL UCB)
BAGLIN	67B	BAPS 12 567	+Bezaguet Degrange+	(EPOL UCB)
BALTAY	67B	PRL 19 1498	+Franzini Kim Newman+	(COLU STON)
BALTAY	67D	PRL 19 1495	+Franzini Kim Newman+	(COLU BRAN)
BEMPORAD	67	PL 25B 380	+Braccini Foa Lubelsmey+	(PISA BONN)
Also	67	Private Comm	Ion	
BILLING	67	PL 25B 435	+Bullock Esten Govan+	(LOUC OXF)
BUNIATOV	67	PL 25B 560	+Zavattini Deinet+	(CERN KARL)
CENCE	67	PRL 19 1393	+Peterson Stenger Chiu+	(HAWA LRL)
ESTEN	67	PL 24B 115	+Govan Knight Miller Tovey+	(LOUC OXF)
FELDMAN	67	PRL 18 868	+Frati Gleeson Halpern+	(PENN)
FLATTE	67	PRL 18 976		(LRL)
FLATTE	67B	PR 163 1441	+Wohl	(LRL)
LITCHFIELD	67	PL 24B 486	+Rangan Segar Smith+	(RHEL SACL)
PRICE	67	PRL 18 1207	+Crawford	(LRL)
ALFF	66	PR 145 1072	Alff Steinberger Berley+	(COLU RUTG)
BALTAY	66C	PRL 16 1224	+Franzini Kim Kirsch+	(COLU STON)
CLPWY	66	PR 149 1044		(SCUC LRL PURD WISC YALE)
CNOPS	66	PL 22 546	+Finocchiaro Lassalle+	(CERN ETH SACL)
CRAWFORD	66	PRL 16 333	+Price	(LRL)
DIGIUGNO	66	PRL 16 767	+Giorgi Silvestri+	(NAPL TRST FRAS)
GROSSMAN	66	PR 146 993	+Price Crawford	(LRL)
GRUNHAUS	66	Thesis		(COLU)
JAMES	66	PR 142 896	+Kraybill	(YALE BNL)
JONES	66	PL 23 597	+Binnie Duane Horsey Mason+	(LOIC RHEL)
LARRIBE	66	PL 23 600	+Leveque Muller Pauli+	(SACL RHEL)
FOSTER	65	PR 138B 652	+Peters Meer Loeffler+	(WISC PURD)
FOSTER	65B	Athens Conf	+Good Meer	(WISC)
FOSTER	65C	Thesis		(WISC)
PRICE	65	PRL 15 123	+Crawford	(LRL)
RITTENBERG	65	PRL 15 556	+Kalbfleisch	(LRL BNL)
FOELSCHE	64	PR 134B 1138	+Kraybill	(YALE)
KRAEMER	64	PR 136B 496	+Madansky Fields+	(JHU NWES WOOD)
PAULI	64	PL 13 351	+Muller	(SACL)
BACCI	63	PRL 11 37	+Penso Salvini+	(ROMA FRAS)
CRAWFORD	63	PRL 10 546	+Lloyd Fowler	(LRL DUKE)
Also	66B	PRL 16 907	Crawford Lloyd Fowler	(LRL DUKE)
DELCOURT	63	PL 7 215	+Lefrancois Perez y Jorba+	(ORSA)
ALFF	62	PRL 9 322	Alff Steinberger Berley Colley+	(COLU RUTG)
BASTIEN	62	PRL 8 114	+Berge Dahl Ferro Luzzi+	(LRL)
CHRETIEN	62	PRL 9 127	+Bulos+	(BRAN BROW HARV MIT PADO)
PICKUP	62	PRL 8 329	+Robinson Salant	(CNRC BNL)

— OTHER RELATED PAPERS —

BOWEN	67	PL 24B 206	+Cnops Finocchiaro+	(CERN ETH SACL)
CARMONY	62	PRL 8 117	+Rosenfeld VanDeWalle	(LRL)
ROSENFELD	62	PRL 8 293	+Carmony VanDeWalle	(LRL)
PEVSNER	61	PRL 7 421	+Kraemer Nussbaum Richardson+	(JHU)

STRANGE MESONS

$K^{\pm}$ $\quad I(J^P) = \frac{1}{2}(0^-)$

$K^{\pm}$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
493.646 ± 0.009 OUR FIT					
493.646 ± 0.009 OUR AVERAGE					
493.636 ± 0.011	GALL	88	CNTR	−	Kaonic atoms
493.640 ± 0.054	LUM	81	CNTR	−	Kaonic atoms
493.670 ± 0.029	BARKOV	79	EMUL	±	$e^+e^- \to K^+K^-$
493.657 ± 0.020	CHENG	75	CNTR	−	Kaonic atoms
493.691 ± 0.040	BACKENSTO	73	CNTR	−	Kaonic atoms
• • • We do not use the following data for averages, fits, limits, etc. • • •					
493.662 ± 0.19	KUNSELMAN	74	CNTR	−	Kaonic atoms
493.78 ± 0.17	GREINER	65	EMUL	+	
493.7 ± 0.3	BARKAS	63	EMUL	−	
493.9 ± 0.2	COHEN	57	RVUE	+	

$K^+ - K^-$ MASS DIFFERENCE

Test of *CPT*

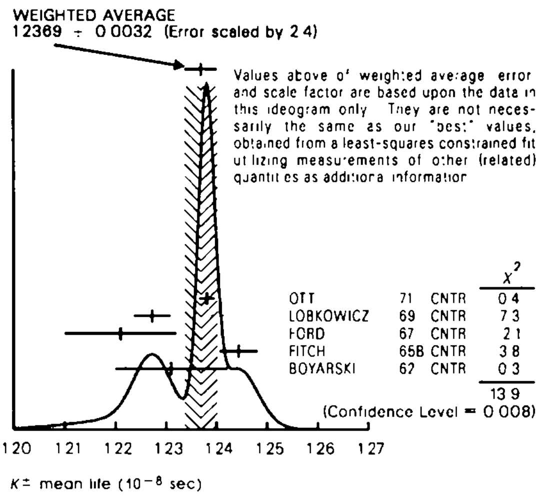
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG
−0.032 ± 0.090	1.5M	[1] FORD	72	ASPK	±

[1] FORD 72 uses $m(\pi^+) - m(\pi^-) = +28 \pm 70$ keV

$K^{\pm}$ MEAN LIFE

VALUE (10^{-8} sec)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1.2371 ± 0.0028 OUR FIT Error includes scale factor of 2.1						
1.2369 ± 0.0032 OUR AVERAGE Error includes scale factor of 2.4. See the ideogram below						
1.2380 ± 0.0016	3M	OTT	71	CNTR	+	Stopping K
1.2272 ± 0.0036		LOBKOWICZ	69	CNTR	+	K in flight
1.221 ± 0.011		FORD	67	CNTR	±	
1.2443 ± 0.0038		FITCH	65B	CNTR	+	K at rest
1.231 ± 0.011		BOYARSKI	62	CNTR	+	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1.25 $^{+0.22}_{-0.17}$		[2] BARKAS	61	EMUL		
1.27 $^{+0.36}_{-0.23}$	51	[2] BHOWMIK	61	EMUL		
1.31 ± 0.08	293	NORDIN	61	HBC	−	
1.24 ± 0.07		NORDIN	61	RVUE	−	
1.38 ± 0.24	33	[2] FREDEN	60B	EMUL		
1.21 ± 0.06		BURROWES	59	CNTR		
1.60 ± 0.3	52	[2] EISENBERG	58	EMUL		
0.95 $^{+0.36}_{-0.25}$		[2] ILOFF	56	EMUL		

[2] Old experiments with large errors excluded from averaging



$K^{\pm}$ mean life (10^{-8} sec)

$(K^+ - K^-)$ / AVERAGE, MEAN LIFE DIFFERENCE

This quantity is a measure of *CPT* invariance in weak interactions.

VALUE (%)	DOCUMENT ID		TECN
0.11 ± 0.09 OUR AVERAGE Error includes scale factor of 1.2			
0.090 ± 0.078	LOBKOWICZ	69	CNTR
0.47 ± 0.30	FORD	67	CNTR

K^+ DECAY MODES

K^- modes are charge conjugates of the modes below

	Mode	Fraction (Γ_i/Γ)	Scale / Conf Lev
Γ_1	$K^+ \to \mu^+\nu$	$(63.51 \pm 0.16) \times 10^{-2}$	
Γ_2	$K^+ \to \pi^+\pi^0$	$(21.17 \pm 0.15) \times 10^{-2}$	
Γ_3	$K^+ \to \pi^+\pi^+\pi^-$	$(5.589 \pm 0.028) \times 10^{-2}$	S=1.1
Γ_4	$K^+ \to \pi^+\pi^0\pi^0$	$(1.73 \pm 0.04) \times 10^{-2}$	S=1.2
Γ_5	$K^+ \to \pi^0\mu^+\nu$ Called $K_{\mu 3}$	$(3.18 \pm 0.06) \times 10^{-2}$	S=1.2
Γ_6	$K^+ \to \pi^0 e^+\nu$ Called K_{e3}	$(4.82 \pm 0.05) \times 10^{-2}$	S=1.1
Γ_7	$K^+ \to e^+\nu$	$(1.54 \pm 0.07) \times 10^{-5}$	

Stable Particle Full Listings
$K^{\pm}$

Γ_8	$K^+ \to \pi^0\pi^0 e^+\nu$	$(1.99\ ^{+0.47}_{-0.35})\times10^{-5}$	
Γ_9	$K^+ \to \pi^+\pi^- e^+\nu$ Called K_{e4}	$(3.90\ \pm0.14)\times10^{-5}$	
Γ_{10}	$K^+ \to \pi^+\pi^-\mu^+\nu$ Called $K_{\mu4}$	$(1.4\ \pm0.9)\times10^{-5}$	
Γ_{11}	$K^+ \to \pi^+\gamma\gamma$	< 8	$\times10^{-6}$ CL=90%
Γ_{12}	$K^+ \to \pi^+3\gamma$	< 1.0	$\times10^{-4}$ CL=90%
Γ_{13}	$K^+ \to e^+\nu\nu\bar\nu$	< 6	$\times10^{-5}$
Γ_{14}	$K^+ \to \mu^+\nu\nu\bar\nu$	< 6	$\times10^{-6}$ CL=90%
Γ_{15}	$K^+ \to \mu^+\nu e^+e^-$	$(1.05\ \pm0.31)\times10^{-6}$	
Γ_{16}	$K^+ \to e^+\nu e^+e^-$	$(2.1\ ^{+2.1}_{-1.1})\times10^{-7}$	
Γ_{17}	$K^+ \to \mu^+\nu\gamma$	$(5.40\ \pm0.30)\times10^{-3}$	
Γ_{18}	$K^+ \to \mu^+\nu\gamma$ (SD$^+$)	< 3.0	$\times10^{-5}$ CL=90%
Γ_{19}	$K^+ \to \mu^+\nu\gamma$ (SD$^+$INT)	< 2.7	$\times10^{-5}$ CL=90%
Γ_{20}	$K^+ \to \mu^+\nu\gamma$ (SD$^-$ + SD$^-$INT)	< 2.6	$\times10^{-4}$ CL=90%
Γ_{21}	$K^+ \to e^+\nu\gamma$ (SD$^+$)	$(1.52\ \pm0.23)\times10^{-5}$	
Γ_{22}	$K^+ \to e^+\nu\gamma$ (SD$^-$)	< 1.6	$\times10^{-4}$ CL=90%
Γ_{23}	$K^+ \to \pi^+\pi^0\gamma$	$(2.75\ \pm0.15)\times10^{-4}$	
Γ_{24}	$K^+ \to \pi^+\pi^0\gamma$ (DE)	$(1.8\ \pm0.4)\times10^{-5}$	
Γ_{25}	$K^+ \to \pi^+\pi^+\pi^-\gamma$	$(1.0\ \pm0.4)\times10^{-4}$	
Γ_{26}	$K^+ \to \pi^+2\pi^0\gamma$	$(7.4\ ^{+5.5}_{-2.9})\times10^{-6}$	
Γ_{27}	$K^+ \to \pi^0\mu^+\nu\gamma$	< 6	$\times10^{-5}$ CL=90%
Γ_{28}	$K^+ \to \pi^0 e^+\nu\gamma$	$(2.72\ \pm0.19)\times10^{-4}$	
Γ_{29}	$K^+ \to \pi^0 e^+\nu\gamma$ (SD)	< 5	$\times10^{-5}$ CL=90%

FORBIDDEN BY CONSERVATION LAWS

Γ_{30}	$K^+ \to \pi^+\pi^+e^-\bar\nu$	< 1.2	$\times10^{-8}$
Γ_{31}	$K^+ \to \pi^+\pi^+\mu^-\bar\nu$	< 3.0	$\times10^{-6}$ CL=95%
Γ_{32}	$K^+ \to \pi^+e^+e^-$	$(2.7\ \pm0.5)\times10^{-7}$	
Γ_{33}	$K^+ \to \pi^+\mu^+\mu^-$	< 2.4	$\times10^{-6}$ CL=90%
Γ_{34}	$K^+ \to \pi^+\nu\bar\nu$	< 1.4	$\times10^{-7}$ CL=90%
Γ_{35}	$K^+ \to \mu^-\nu e^+e^+$	< 2.0	$\times10^{-8}$
Γ_{36}	$K^+ \to \mu^+\nu_e$	< 4	$\times10^{-3}$ CL=90%
Γ_{37}	$K^+ \to \pi^+\mu^+e^-$	< 5	$\times10^{-9}$
Γ_{38}	$K^+ \to \pi^\pm\mu^\mp e^+$	< 7	$\times10^{-9}$
Γ_{39}	$K^+ \to \pi^+e^+\mu^-$		
Γ_{40}	$K^+ \to \pi^-e^+e^+$	< 1.0	$\times10^{-8}$
Γ_{41}	$K^+ \to \mu^+\bar\nu_e$	< 3.3	$\times10^{-3}$ CL=90%
Γ_{42}	$K^+ \to \pi^0e^+\bar\nu_e$	< 3.0	$\times10^{-3}$ CL=90%
Γ_{43}	$K^+ \to \pi^+\gamma$		

CONSTRAINED FIT INFORMATION

An overall fit to the mean life, 2 partial widths and 18 branching ratios uses 58 measurements and one constraint to determine 7 parameters. The overall fit has a $\chi^2 = 74.6$ for 52 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta p_i\,\delta p_j\rangle/(\delta p_i\cdot\delta p_j)$, in percent, from the fit to parameters p_i, including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

x_2	−77					
x_3	−21	−7				
x_4	22	3	11			
x_5	−33	18	6	2		
x_6	34	15	17	−1	37	
Γ	5	4	35	3	1	5
	x_1	x_2	x_3	x_4	x_5	x_6

		Rate (10^8 sec^{-1})	Scale
Γ_1	$K^+ \to \mu^+\nu$	0.5134 ±0.0018	1.3
Γ_2	$K^+ \to \pi^+\pi^0$	0.1711 ±0.0013	1.1
Γ_3	$K^+ \to \pi^+\pi^+\pi^-$	0.04518 ±0.00021	
Γ_4	$K^+ \to \pi^+\pi^0\pi^0$	0.01400 ±0.00032	1.2
Γ_5	$K^+ \to \pi^0\mu^+\nu$ Called $K_{\mu3}$	0.0257 ±0.0005	1.2
Γ_6	$K^+ \to \pi^0e^+\nu$ Called K_{e3}	0.0390 ±0.0004	1.1

$K^{\pm}$ DECAY RATES

$\Gamma(\mu^+\nu)$ Γ_1

VALUE (10^6 sec^{-1})	DOCUMENT ID		TECN	CHG
51.34 ± 0.18 OUR FIT Error includes scale factor of 1.3				
51.2 ± 0.8	FORD	67	CNTR	±

$\Gamma(\pi^+\pi^+\pi^-)$ Γ_3

VALUE (10^6 sec^{-1})	EVTS	DOCUMENT ID		TECN	CHG
4.518 ± 0.021 OUR FIT					
4.511 ± 0.024		FORD [3]	70	ASPK	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
4.529 ± 0.032	3.2M	FORD [3]	70	ASPK	
4.496 ± 0.030		FORD [3]	67	CNTR	±

[3] First FORD 70 value is second FORD 70 combined with FORD 67.

$(\Gamma(K^+) - \Gamma(K^-)) / \Gamma(K)$

$K^+ \to \mu^+\nu$ RATE DIFFERENCE
Test of *CPT* conservation

VALUE (%)	DOCUMENT ID		TECN
−0.54 ± 0.41	FORD	67	CNTR

$K^+ \to \pi^+\pi^+\pi^-$ RATE DIFFERENCE
Test of *CP* conservation

VALUE (%)	EVTS	DOCUMENT ID		TECN	CHG
0.07 ± 0.12 OUR AVERAGE					
0.08 ± 0.12		FORD [4]	70	ASPK	
−0.50 ± 0.90		FLETCHER	67	OSPK	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−0.02 ± 0.16		SMITH [5]	73	ASPK	±
0.10 ± 0.14	3.2M	FORD [4]	70	ASPK	
−0.04 ± 0.21		FORD [4]	67	CNTR	

[4] First FORD 70 value is second FORD 70 combined with FORD 67.
[5] SMITH 73 value of $K^\pm \to \pi^\pm\pi^+\pi^-$ rate difference is derived from SMITH 73 value of $K^\pm \to \pi^\pm 2\pi^0$ rate difference.

$K^+ \to \pi^+\pi^0\pi^0$ RATE DIFFERENCE
Test of *CP* conservation

VALUE (%)	EVTS	DOCUMENT ID		TECN	CHG
0.0 ± 0.6 OUR AVERAGE					
0.08 ± 0.58		SMITH	73	ASPK	±
−1.1 ± 1.8	1802	HERZO	69	OSPK	

$K^+ \to \pi^+\pi^0$ RATE DIFFERENCE
Test of *CPT* conservation

VALUE (%)	DOCUMENT ID		TECN
0.8 ± 1.2	HERZO	69	OSPK

$K^+ \to \pi^+\pi^0\gamma$ RATE DIFFERENCE
Test of *CP* conservation

VALUE (%)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.9 ± 3.3 OUR AVERAGE						
0.8 ± 5.8	2461	SMITH	76	WIRE	±	$\pi^\pm$ KE 55–90 MeV
1.0 ± 4.0	4000	ABRAMS	73B	ASPK	±	π KE 51–100 MeV
0.0 ± 24.0	24	EDWARDS	72	OSPK		π KE 58–90 MeV

K^+ BRANCHING RATIOS

$\Gamma(\mu^+\nu)/\Gamma_{total}$ Γ_1/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
63.51 ± 0.16 OUR FIT						
63.24 ± 0.44	62k	CHIANG	72	OSPK	+	1.84 GeV/c K^+
• • • We do not use the following data for averages, fits, limits, etc. • • •						
56.9 ± 2.6		ALEXANDER [6]	57	EMUL	+	
58.5 ± 3.0		BIRGE [6]	56	EMUL	+	

[6] Old experiments not included in averaging.

$\Gamma(\mu^+\nu)/\Gamma(\pi^+\pi^+\pi^-)$ Γ_1/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	CHG
11.36 ± 0.07 OUR FIT Error includes scale factor of 1.1					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
10.38 ± 0.82	427	YOUNG [7]	65	EMUL	+

[7] Deleted from overall fit because YOUNG 65 constrains his results to add up to 1. Only YOUNG 65 measured $(\mu\nu)$ directly.

$\Gamma(\pi^+\pi^0)/\Gamma_{total}$ Γ_2/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
21.17 ± 0.15 OUR FIT						
21.18 ± 0.28	16k	CHIANG	72	OSPK	+	1.84 GeV/c K^+

See key on page 129

• • • We do not use the following data for averages fits limits etc • • •

21 0 ±0 6		CALLAHAN	65	HLBC	See $\Gamma(\pi^+\pi^0)/\Gamma(\pi^+\pi^+\pi^-)$
21 6 ±0 6		TRILLING	65B	RVUE	
23 2 ±2 2		[8] ALEXANDER	57	EMUL	+
27 7 ±2 7		[8] BIRGE	56	EMUL	+

[8] Earlier experiments not averaged

$\Gamma(\pi^+\pi^0)/\Gamma(\mu^+\nu)$ — Γ_2/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	CHG
0.3333 ± 0.0030 OUR FIT					
0.331 ± 0.005 OUR AVERAGE Error includes scale factor of 1 2					
0 3355 ± 0.0057		[9] WEISSENBERG	76	SPEC	+
0 305 ± 0 018	1600	ZELLER	69	ASPK	+
0 3277 ± 0.0065	4517	[10] AUERBACH	67	OSPK	+
• • • We do not use the following data for averages fits limits etc • • •					
0 328 ± 0 005	25k	[9] WEISSENBERG	74	STRC	+

[9] WEISSENBERG 76 revises WEISSENBERG 74
[10] AUERBACH 67 changed from 0 3253 ± 0 0065 See comment with ratio $\Gamma(\pi^0\mu^+\nu)/\Gamma(\mu^+\nu)$

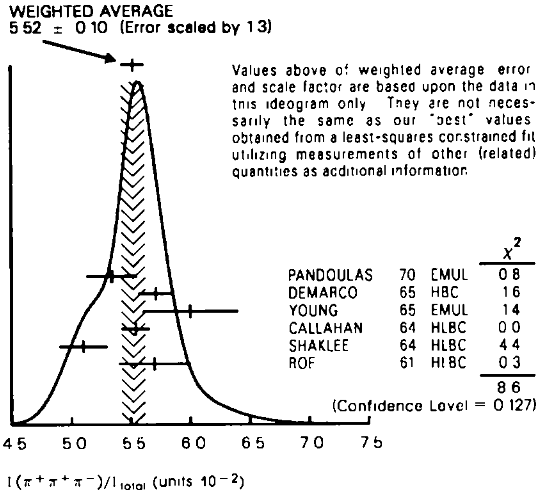
$\Gamma(\pi^+\pi^0)/\Gamma(\pi^-\pi^+\pi^-)$ — Γ_2/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	CHG
3.787 ± 0.034 OUR FIT					
3.84 ± 0 27 OUR AVERAGE Error includes scale factor of 1 9					
3 96 ± 0 15	1045	CALLAHAN	66	FBC	+
3 24 ± 0 34	134	YOUNG	65	EMUL	+

$\Gamma(\pi^+\pi^+\pi^-)/\Gamma_{total}$ — Γ_3/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
5.589 ± 0.028 OUR FIT Error includes scale factor of 1 1						
5.52 ± 0.10 OUR AVERAGE Error includes scale factor of 1 3 See the ideogram below						
5 34 ± 0 21	693	[11] PANDOULAS	70	EMUL	+	
5 71 ± 0 15		DEMARCO	65	HBC		
6 0 ± 0 4	44	YOUNG	65	EMUL	+	
5.54 ± 0 12	2332	CALLAHAN	64	HLBC	+	
5 1 ± 0 2	540	SHAKLEE	64	HLBC	+	
5 7 ± 0 3		ROE	61	HLBC	+	
• • • We do not use the following data for averages fits limits etc • • •						
5 56 ± 0 20	2330	[12] CHIANG	72	OSPK	+	1 84 GeV/c K^+
5 2 ± 0 3		[13] TAYLOR	59	EMUL	+	
6.8 ± 0 4		[13] ALEXANDER	57	EMUL	+	
5 6 ± 0 4		[13] BIRGE	56	EMUL	+	

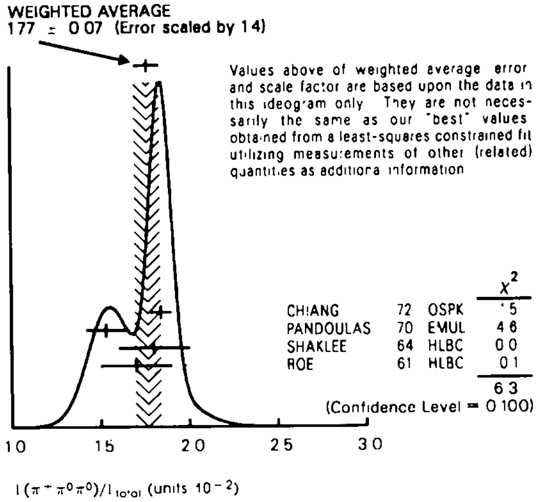
[11] Includes events of TAYLOR 59
[12] Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu)/\Gamma_{total}$ $\Gamma(\pi^+\pi^0)/\Gamma_{total}$ $\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{total}$ $\Gamma(\pi^0\mu^+\nu)/\Gamma_{total}$ and $\Gamma(\pi^0 e^+\nu)/\Gamma_{total}$
[13] Earlier experiments not averaged



$\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{total}$ — Γ_4/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1.73 ± 0.04 OUR FIT Error includes scale factor of 1 2						
1.77 ± 0.07 OUR AVERAGE Error includes scale factor of 1 4 See the ideogram below						
1 84 ± 0 06	1307	CHIANG	72	OSPK	+	1 84 GeV/c K^+
1.53 ± 0 11	198	[14] PANDOULAS	70	EMUL	+	
1 8 ± 0 2	108	SHAKLEE	64	HLBC	+	
1 7 ± 0 2		ROE	61	HLBC	+	
• • • We do not use the following data for averages fits limits etc • • •						
1 5 ± 0 2		[15] TAYLOR	59	EMUL	+	
2 2 ± 0 4		[15] ALEXANDER	57	EMUL	+	
2 1 ± 0 5		[15] BIRGE	56	EMUL	+	

[14] Includes events of TAYLOR 59
[15] Earlier experiments not averaged



$\Gamma(\pi^+\pi^0\pi^0)/\Gamma(\pi^+\pi^0)$ — Γ_4/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.0819 ± 0.0020 OUR FIT Error includes scale factor of 1 2						
0.081 ± 0 005	574	[16] LUCAS	73B	HBC	−	Dalitz pairs only

[16] LUCAS 73B gives $N(\pi 2\pi^0)$ = 574 ± 5 9% $N(2\pi)$ = 3564 ± 3 1% We quote 0 5N($\pi 2\pi^0$) / N(2π) where 0 5 is because only Dalitz pair π^0 s were used

$\Gamma(\pi^+\pi^0\pi^0)/\Gamma(\pi^+\pi^+\pi^-)$ — Γ_4/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.310 ± 0 007 OUR FIT Error includes scale factor of 1 2						
0.304 ± 0.009 OUR AVERAGE						
0 303 ± 0 009	2027	BISI	65	BC	+	HBC+HLBC
0 393 ± 0 099	17	YOUNG	65	EMUL	+	

$\Gamma(\pi^0\mu^+\nu)/\Gamma_{total}$ — Γ_5/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
3.18 ± 0.06 OUR FIT Error includes scale factor of 1 2						
3.33 ± 0.16	2345	CHIANG	72	OSPK	+	1 84 GeV/c K^+
• • • We do not use the following data for averages fits limits etc • • •						
2 8 ± 0 4		[17] TAYLOR	59	EMUL	+	
5 9 ± 1 3		[17] ALEXANDER	57	EMUL	+	
2 8 ± 1 0		[17] BIRGE	56	EMUL	+	

[17] Earlier experiments not averaged

$\Gamma(\pi^0\mu^+\nu)/\Gamma(\mu^+\nu)$ — Γ_5/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	CHG
0.0501 ± 0.0010 OUR FIT Error includes scale factor of 1 2					
0.0488 ± 0.0026 OUR AVERAGE					
0 054 ± 0 009	240	ZELLER	69	ASPK	+
0 0480 ± 0 0037	424	[18] GARLAND	68	OSPK	+
0 0486 ± 0 0040	307	[19] AUERBACH	67	OSPK	+

[18] GARLAND 68 changed from 0 055 ± 0 004 in agreement with μ spectrum calculation of GAILLARD 70 appendix B L G Pondrom (private communication 73)
[19] AUERBACH 67 changed from 0 0602 ± 0 0046 by erratum which brings the μ spectrum calculation into agreement with GAILLARD 70 appendix B

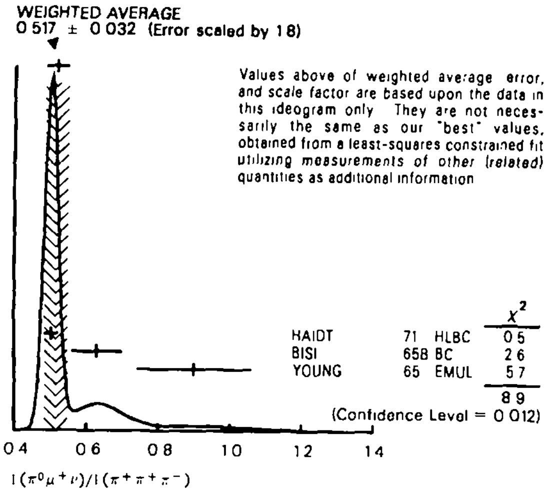
$\Gamma(\pi^0\mu^+\nu)/\Gamma(\pi^+\pi^+\pi^-)$ — Γ_5/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.569 ± 0.011 OUR FIT Error includes scale factor of 1 2						
0.517 ± 0.032 OUR AVERAGE Error includes scale factor of 1 8 See the ideogram below						
0 503 ± 0 019	1505	[20] HAIDT	71	HLBC	+	
0 63 ± 0 07	2845	[21] BISI	65B	BC	+	HBC+HLBC
0 90 ± 0 16	38	YOUNG	65	EMUL	+	
• • • We do not use the following data for averages fits limits etc • • •						
0 510 ± 0 017	1505	[20] EICHTEN	68	HLBC	+	

[20] HAIDT 71 is a reanalysis of EICHTEN 68
[21] Error enlarged for background problems See GAILLARD 70

Stable Particle Full Listings

$K^{\pm}$



$\Gamma(\pi^0\mu^+\nu)/\Gamma(\pi^0e^+\nu)$ — Γ_5/Γ_6

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.660 ± 0.012 OUR FIT Error includes scale factor of 1 1						
0.679 ± 0.013 OUR AVERAGE						
0 67 ± 0.12		WEISSENBERG	76	SPEC	+	
0 705 ± 0.063	554	[22] LUCAS	73B	HBC	−	Dalitz pairs only
0 698 ± 0 025	3480	[23] CHIANG	72	OSPK	+	1 84 GeV/c K^+
0.667 ± 0 017	5601	BOTTERILL	68B	ASPK	+	
0.703 ± 0 056	1509	[24] CALLAHAN	66B	HLBC		
• • • We do not use the following data for averages fits limits etc • • •						
0 670 ± 0 014		[25] HEINTZE	77	SPEC	+	
0 608 ± 0 014	1585	[26] BRAUN	75	HLBC	+	
0 596 ± 0.025		[27] HAIDT	71	HLBC	+	
0 604 ± 0 022	1398	[27] EICHTEN	68	HLBC		

[22] LUCAS 73B gives $N(K_{\mu3})$ = 554 ± 7 6% $N(K_{e3})$ = 786 ± 3 1% We divide

[23] CHIANG 72 $\Gamma(\pi^0\mu^+\nu)/\Gamma(\pi^0e^+\nu)$ is statistically independent of CHIANG 72 $\Gamma(\pi^0\mu^+\nu)/\Gamma_{total}$ and $\Gamma(\pi^0e^+\nu)/\Gamma_{total}$

[24] From CALLAHAN 66B we use only the $K_{\mu3}/K_{e3}$ ratio and do not include in the fit the ratios $K_{\mu3}$ / $(\pi\pi^+\pi^0)$ and K_{e3} / $(\pi\pi^+\pi^0)$ since they show large disagreements with the rest of the data

[25] HEINTZE 77 value from fit to λ_0 Assumes μ-e universality

[26] BRAUN 75 value is from form factor fit Assumes μ e universality

[27] HAIDT 71 is a reanalysis of EICHTEN 68 Only individual ratios included in fit (see $\Gamma(\pi^0\mu^+\nu)/\Gamma(\pi^+\pi^+\pi^-)$ and $\Gamma(\pi^0e^+\nu)/\Gamma(\pi^+\pi^+\pi^-)$)

$[\Gamma(\pi^+\pi^0) + \Gamma(\pi^0\mu^+\nu)]/\Gamma_{total}$ — $(\Gamma_2+\Gamma_5)/\Gamma$

We combine these two modes for experiments measuring them in xenon bubble chamber because of difficulties of separating them there

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG
24.35 ± 0.15 OUR FIT					
24.6 ± 1.0 OUR AVERAGE Error includes scale factor of 1 4					
25 4 ± 0 9	886	SHAKLEE	64	HLBC	+
23 4 ± 1 1		ROE	61	HLBC	+

$\Gamma(\pi^0e^+\nu)/\Gamma_{total}$ — Γ_6/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
4.82 ± 0.05 OUR FIT Error includes scale factor of 1 1						
4.85 ± 0.09 OUR AVERAGE						
4 86 ± 0 10	3516	CHIANG	72	OSPK	+	1 84 GeV/c K^+
4 7 ± 0 3	429	SHAKLEE	64	HLBC	+	
5 0 ± 0.5		ROE	61	HLBC	+	
• • • We do not use the following data for averages fits limits etc • • •						
5 1 ± 1 3		[28] ALEXANDER	57	EMUL	+	
3 2 ± 1 3		[28] BIRGE	56	EMUL	+	

[28] Earlier experiments not averaged

$\Gamma(\pi^0e^+\nu)/\Gamma(\mu^+\nu)$ — Γ_6/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	CHG
0.0759 ± 0.0009 OUR FIT Error includes scale factor of 1 1					
0.0752 ± 0.0024 OUR AVERAGE					
0.069 ± 0 006	350	ZELLER	69	ASPK	+
0.0775 ± 0 0033	960	BOTTERILL	68C	ASPK	+
0 069 ± 0 006	561	GARLAND	68	OSPK	+
0 0791 ± 0 0054	295	[29] AUERBACH	67	OSPK	+

[29] AUERBACH 67 changed from 0 0797 ± 0.0054 See comment with ratio $\Gamma(\pi^0\mu^+\nu)/\Gamma(\mu^+\nu)$ The value 0 0785 ± 0.0025 given in AUERBACH 67 is an average of AUERBACH 67 $\Gamma(\pi^0e^+\nu)/\Gamma(\mu^+\nu)$ and CESTER 66 $\Gamma(\pi^0e^+\nu)/[\Gamma(\mu^+\nu) + \Gamma(\pi^+\pi^0)]$

$\Gamma(\pi^0e^+\nu)/\Gamma(\pi^+\pi^0)$ — Γ_6/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.2278 ± 0.0030 OUR FIT Error includes scale factor of 1 1						
0.221 ± 0.012	786	[30] LUCAS	73B	HBC	−	Dalitz pairs only

[30] LUCAS 73B gives $N(K_{e3})$ = 786 ± 3 1% $N(2\pi)$ = 3564 ± 3 1% We divide

$\Gamma(\pi^0e^+\nu)/\Gamma(\pi^+\pi^+\pi^-)$ — Γ_6/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	CHG
0.863 ± 0.009 OUR FIT Error includes scale factor of 1 1					
0 860 ± 0.014 OUR AVERAGE					
0 867 ± 0 027	2768	BARMIN	87	XEBC	+
0 856 ± 0 040	2827	BRAUN	75	HLBC	+
0.850 ± 0 019	4385	[31] HAIDT	71	HLBC	+
0 94 ± 0 09	854	BELLOTTI	67B	HLBC	
0 90 ± 0 16	37	YOUNG	65	EMUL	+
0 90 ± 0 06	230	BORREANI	64	HBC	+
• • • We do not use the following data for averages fits limits etc • • •					
0 846 ± 0 021	4385	[31] EICHTEN	68	HLBC	+

[31] HAIDT 71 is a reanalysis of EICHTEN 68

$\Gamma(\pi^0e^+\nu)/[\Gamma(\mu^+\nu) + \Gamma(\pi^+\pi^0)]$ — $\Gamma_6/(\Gamma_1+\Gamma_2)$

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG
5.69 ± 0.06 OUR FIT Error includes scale factor of 1 1					
6.01 ± 0.15 OUR AVERAGE					
5 92 ± 0 65		[32] WEISSENBERG	76	SPEC	+
6 16 ± 0.22	5110	ESCHSTRUTH	68	OSPK	+
5 89 ± 0 21	1679	CESTER	66	OSPK	+

[32] Value calculated from WEISSENBERG 76 ($\pi^0e\nu$) ($\mu\nu$) and ($\pi\pi^0$) values to eliminate dependence on our 1974 ($\pi 2\pi^0$) and ($\pi\pi^+\pi^-$) fractions

$\Gamma(e^+\nu)/\Gamma_{total}$ — Γ_7/Γ

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages fits limits, etc • • •						
$2\ 1^{+1\ 8}_{-1\ 3}$		4	BOWEN	67B	OSPK	+
<160 0	95		BORREANI	64	HBC	+

$\Gamma(e^+\nu)/\Gamma(\mu^+\nu)$ — Γ_7/Γ_1

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	CHG
$2.42^{+0.11}_{-0.10}$ OUR AVERAGE					
2 51 ± 0 15	404	HEINTZE	76	SPEC	+
2 37 ± 0 17	534	HEARD	75B	SPEC	+
2 42 ± 0 42	112	CLARK	72	OSPK	+
$1\ 8^{+0\ 8}_{-0\ 6}$	8	MACEK	69	ASPK	+
$1\ 9^{+0\ 7}_{-0\ 5}$	10	BOTTERILL	67	ASPK	+

$\Gamma(\pi^0\pi^0e^+\nu)/\Gamma(\pi^0e^+\nu)$ — Γ_8/Γ_6

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	CHG
$4.1^{+1.0}_{-0.7}$ OUR AVERAGE						
$4\ 2^{+1\ 0}_{-0\ 9}$		25	BOLOTOV	86B	CALO	−
$3\ 8^{+5\ 0}_{-1\ 2}$		2	LJUNG	73	HLBC	+
• • • We do not use the following data for averages fits limits etc • • •						
<37 0	90	0	ROMANO	71	HLBC	+

$\Gamma(\pi^+\pi^-e^+\nu)/\Gamma(\pi^+\pi^+\pi^-)$ — Γ_9/Γ_3

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	CHG
6.98 ± 0.26 OUR AVERAGE					
7.21 ± 0 32	30k	ROSSELET	77	SPEC	+
7 36 ± 0.68	500	BOURQUIN	71	ASPK	
7 0 ± 0 9	106	SCHWEINB	71	HLBC	+
5 83 ± 0 63	269	ELY	69	HLBC	+
6.7 ± 1 5	69	BIRGE	65	FBC	+

$\Gamma(\pi^+\pi^-\mu^+\nu)/\Gamma_{total}$ — Γ_{10}/Γ

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages fits, limits etc • • •					
$0\ 77^{+0\ 54}_{-0\ 50}$	1	CLINE	65	FBC	+

$\Gamma(\pi^+\pi^-\mu^+\nu)/\Gamma(\pi^+\pi^+\pi^-)$ — Γ_{10}/Γ_3

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	CHG
2.57 ± 1.55	7	BISI	67	DBC	+
• • • We do not use the following data for averages, fits, limits etc • • •					
~2 5	1	GREINER	64	EMUL	+

$\Gamma(\pi^+\gamma\gamma)/\Gamma_{total}$ — Γ_{11}/Γ

All values given here assume a phase space pion energy spectrum

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
< 0.084	90	0	ASANO	82	CNTR	+	$T\pi$ 117-127 MeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

−0.42 ±0.52		0	ABRAMS	77	SPEC	+	$T\pi$ · 92 MeV
< 0.35	90	0	LJUNG	73	HLBC	+	6–102,114–127 MeV
< 0.5	90	0	KLEMS	71	OSPK	+	$T\pi$ · 117 MeV
−0.1 ±0.6			CHEN	68	OSPK	+	$T\pi$ 60–90 MeV

$\Gamma(\pi^+ 3\gamma)/\Gamma_{total}$ Γ_{12}/Γ

Values given here assume a phase space pion energy spectrum

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<1.0	90	ASANO	82	CNTR	+	$T(\pi)$ 117–127 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<3.0	90	KLEMS	71	OSPK	+	$T(\pi)$ >117 MeV

$\Gamma(e^+ \nu\nu\bar{\nu})/\Gamma(e^+ \nu)$ Γ_{13}/Γ_7

VALUE	CL%	EVTS	DOCUMENT ID		TECN	CHG
<3.8	90	0	HEINTZE	79	SPEC	+

$\Gamma(\mu^+ \nu\nu\bar{\nu})/\Gamma_{total}$ Γ_{14}/Γ

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN	CHG
<6.0	90	0	[33] PANG	73	CNTR	+

[33] PANG 73 assumes μ spectrum from $\nu\nu$ interaction of BARDIN 70.

$\Gamma(\mu^+ \nu e^+ e^-)/\Gamma(\pi^+\pi^- e^+ \nu)$ Γ_{15}/Γ_9

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
27. ±8.	14	[34] DIAMANT	76	SPEC	+	Extrapolated BR
• • • We do not use the following data for averages, fits, limits, etc. • • •						
3.3±0.9	14	[34] DIAMANT	76	SPEC	+	$m(ee)$ >140

[34] DIAMANT-BERGER 76 quotes this result times our 1975 $\pi^+\pi^- e\nu$ BR ratio. The first DIAMANT-BERGER 76 value is the second value extrapolated to 0 to include low mass e pairs.

$\Gamma(e^+ \nu e^+ e^-)/\Gamma(\pi^+\pi^- e^+ \nu)$ Γ_{16}/Γ_9

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG
$0.54^{+0.54}_{-0.27}$	4	DIAMANT	76	SPEC	+

$\Gamma(\mu^+ \nu\gamma)/\Gamma_{total}$ Γ_{17}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
5.4±0.3		[35] AKIBA	85	SPEC		$P(\mu)$ < 231.5 MeV/c
• • • We do not use the following data for averages, fits, limits, etc. • • •						
5.8±3.5	12	WEISSENBERG	74	STRC	+	$E(\gamma)$ >9 MeV

[35] Assumes μ-e universality and uses constraints from $K \to e\nu\gamma$.

$\Gamma(\mu^+ \nu\gamma\ (SD^+))/\Gamma_{total}$ Γ_{18}/Γ

Structure-dependent part with $+\gamma$ helicity (SD^+ term). See the "Note on $\pi^\pm \to \ell^\pm \nu\gamma$ and $K^\pm \to \ell^\pm \nu\gamma$ Form Factors" in the $\pi^\pm$ section of the Full Data Listings above.

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN
<3.0	90	AKIBA	85	SPEC

$\Gamma(\mu^+ \nu\gamma\ (SD^+INT))/\Gamma_{total}$ Γ_{19}/Γ

Interference term between internal bremsstrahlung and SD^+ term. See the "Note on $\pi^\pm \to \ell^\pm \nu\gamma$ and $K^\pm \to \ell^\pm \nu\gamma$ Form Factors" in the $\pi^\pm$ section of the Full Data Listings above.

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN
<2.7	90	AKIBA	85	SPEC

$\Gamma(\mu^+ \nu\gamma\ (SD^- + SD^-INT))/\Gamma_{total}$ Γ_{20}/Γ

Sum of structure-dependent part with $-\gamma$ helicity (SD^- term) and interference term between internal bremsstrahlung and SD^- term. See the "Note on $\pi^\pm \to \ell^\pm \nu\gamma$ and $K^\pm \to \ell^\pm \nu\gamma$ Form Factors" in the $\pi^\pm$ section of the Full Data Listings above.

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN
<2.6	90	[36] AKIBA	85	SPEC

[36] Assumes μ-e universality and uses constraints from $K \to e\nu\gamma$.

$\Gamma(e^+ \nu\gamma\ (SD^+))/\Gamma_{total}$ Γ_{21}/Γ

Structure-dependent part with $+\gamma$ helicity (SD^+ term). See the "Note on $\pi^\pm \to \ell^\pm \nu\gamma$ and $K^\pm \to \ell^\pm \nu\gamma$ Form Factors" in the $\pi^\pm$ section of the Full Data Listings above.

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<7.1	90	MACEK	70	OSPK	+	$P(e)$ 234–247

$\Gamma(e^+ \nu\gamma\ (SD^+))/\Gamma(\mu^+ \nu)$ Γ_{21}/Γ_1

Structure-dependent part with $+\gamma$ helicity (SD^+ term). See the "Note on $\pi^\pm \to \ell^\pm \nu\gamma$ and $K^\pm \to \ell^\pm \nu\gamma$ Form Factors" in the $\pi^\pm$ section of the Full Data Listings above.

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	CHG
2.40±0.36	107	[37] HEINTZE	79	SPEC	+
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.33±0.42	51	[37] HEINTZE	79	SPEC	+

[37] First HEINTZE 79 result is second combined with HEARD 75 result from section $\Gamma(e^+\nu\gamma\ (SD^+))/\Gamma(e^+\nu)$ below.

$\Gamma(e^+ \nu\gamma\ (SD^+))/\Gamma(e^+ \nu)$ Γ_{21}/Γ_7

Structure-dependent part with $+\gamma$ helicity (SD^+ term). See the "Note on $\pi^\pm \to \ell^\pm \nu\gamma$ and $K^\pm \to \ell^\pm \nu\gamma$ Form Factors" in the $\pi^\pm$ section of the Full Data Listings above.

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$1.05^{+0.25}_{-0.30}$	56	[38] HEARD	75	SPEC	+	$P(e)$ 236–247

[38] This value is included in the first HEINTZE 79 value in the section on $\Gamma(e^+\nu\gamma\ (SD^+))/\Gamma(\mu^+\nu)$ above.

$\Gamma(e^+ \nu\gamma\ (SD^-))/\Gamma_{total}$ Γ_{22}/Γ

Structure-dependent part with $-\gamma$ helicity (SD^- term). See the "Note on $\pi^\pm \to \ell^\pm \nu\gamma$ and $K^\pm \to \ell^\pm \nu\gamma$ Form Factors" in the $\pi^\pm$ section of the Full Data Listings above.

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	CHG
<1.6	90	[39] HEINTZE	79	SPEC	+

[39] Implies (axial-vector/vector) amplitude ratio outside range from −1.8 to −0.54.

$\Gamma(\pi^+ \pi^0 \gamma)/\Gamma_{total}$ Γ_{23}/Γ

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
2.75±0.15 OUR AVERAGE							
2.71±0.45		140	BOLOTOV	87	WIRE	−	$T\pi^-$ 55–90 MeV
2.87±0.32		2461	SMITH	76	WIRE	±	$T\pi^\pm$ 55–90 MeV
2.71±0.19		2100	ABRAMS	72	ASPK	±	$T\pi^+$ 55–90 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •							
$1.5^{+1.1}_{-0.6}$			[40] LJUNG	73	HLBC	+	$T\pi^+$ 55–80 MeV
$2.6^{+1.5}_{-1.1}$			[40] LJUNG	73	HLBC	+	$T\pi^+$ 55–90 MeV
$6.8^{+3.7}_{-2.1}$		17	[40] LJUNG	73	HLBC	+	$T\pi^+$ 55–102 MeV
2.4 ±0.8		24	EDWARDS	72	OSPK		$T\pi^+$ 58–90 MeV
<1.0		0	[41] MALTSEV	70	HLBC	+	$T\pi^+$ <55 MeV
<1.9	90	0	EMMERSON	69	OSPK		$T\pi^+$ 55–80 MeV
2.2 ±0.7		18	CLINE	64	FBC	+	$T\pi^+$ 55–80 MeV

[40] The LJUNG 73 values are not independent.
[41] MALTSEV 70 selects low π^+ energy to enhance direct emission contribution.

$\Gamma(\pi^+ \pi^0 \gamma\ (DE))/\Gamma_{total}$ Γ_{24}/Γ

Direct emission part of $\Gamma(\pi^+\pi^0\gamma)/\Gamma_{total}$.

VALUE (units 10^{-5})	DOCUMENT ID		TECN	CHG	COMMENT
1.8 ±0.4 OUR AVERAGE					
$2.05\pm0.46^{+0.39}_{-0.23}$	BOLOTOV	87	WIRE	−	$T\pi^-$ 55–90 MeV
2.3 ±3.2	SMITH	76	WIRE	±	$T\pi^\pm$ 55–90 MeV
1.56±0.35±0.5	ABRAMS	72	ASPK	±	$T\pi^\pm$ 55–90 MeV

$\Gamma(\pi^+ \pi^+ \pi^- \gamma)/\Gamma_{total}$ Γ_{25}/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	CHG	COMMENT
1.0±0.4	STAMER	65	EMUL	+	$E(\gamma)$ > 11 MeV

$\Gamma(\pi^+ 2\pi^0 \gamma)/\Gamma(\pi^+ \pi^0 \pi^0)$ Γ_{26}/Γ_4

VALUE (units 10^{-4})	DOCUMENT ID		TECN	CHG	COMMENT
$4.3^{+3.2}_{-1.7}$	BOLOTOV	85	SPEC		$E(\gamma)$ > 10 MeV

$\Gamma(\pi^0 \mu^+ \nu\gamma)/\Gamma_{total}$ Γ_{27}/Γ

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
<6.1	90	0	LJUNG	73	HLBC	+	$E(\gamma)$ > 30 MeV

$\Gamma(\pi^0 e^+ \nu\gamma)/\Gamma(\pi^0 e^+ \nu)$ Γ_{28}/Γ_6

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.56±0.04 OUR AVERAGE						
0.56±0.04	192	[42] BOLOTOV	86B	CALO	−	$E(\gamma)$ > 10 MeV
0.76±0.28	13	[43] ROMANO	71	HLBC		$E(\gamma)$ > 10 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.48±0.20	16	[44] LJUNG	73	HLBC	+	$E(\gamma)$ > 30 MeV
$0.22^{+0.15}_{-0.10}$		[44] LJUNG	73	HLBC	+	$E(\gamma)$ > 30 MeV
0.53±0.22		[43] ROMANO	71	HLBC	+	$E(\gamma)$ > 30 MeV
1.2 ±0.8		BELLOTTI	67	HLBC	+	$E(\gamma)$ > 30 MeV

[42] $\cos\theta(e\gamma)$ between 0.6 and 0.9.
[43] Both ROMANO 71 values are for $\cos\theta(e\gamma)$ between 0.6 and 0.9. Second value is for comparison with second LJUNG 73 value. We use lowest $E(\gamma)$ cut for Summary Table value. See ROMANO 71 for E_γ dependence.
[44] First LJUNG 73 value is for $\cos\theta(e\gamma)$ < 0.9, second value is for $\cos\theta(e\gamma)$ between 0.6 and 0.9 for comparison with ROMANO 71.

$\Gamma(\pi^0 e^+ \nu\gamma\ (SD))/\Gamma_{total}$ Γ_{29}/Γ

Structure dependent part

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN	CHG
<5 3	90	BOLOTOV	86B	CALO	−

$\Gamma(\pi^+\pi^+ e^- \nu)/\Gamma_{total}$ Γ_{30}/Γ

Test of $\Delta S = \Delta Q$ rule

VALUE (units 10^{-7})	CL%	EVTS	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages fits limits etc • • •						
< 9 0	95	0	SCHWEINB	71	HLBC	+
< 6 9	95	0	ELY	69	HLBC	+
<20	95		BIRGE	65	FBC	+

$\Gamma(\pi^+\pi^+ e^- \overline{\nu})/\Gamma(\pi^+\pi^- e^+ \nu)$ Γ_{30}/Γ_9

Test of $\Delta S = \Delta Q$ rule

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN
< 3	90	3	[45] BLOCH	76	SPEC
• • • We do not use the following data for averages fits, limits, etc • • •					
<130	95	0	BOURQUIN	71	ASPK

[45] BLOCH 76 quotes 3 6×10^{-4} at CL = 95% we convert

$\Gamma(\pi^+\pi^+ \mu^- \overline{\nu})/\Gamma_{total}$ Γ_{31}/Γ

Test of $\Delta S = \Delta Q$ rule

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN	CHG
<3.0	95	0	BIRGE	65	FBC	+

$\Gamma(\pi^+ e^+ e^-)/\Gamma_{total}$ Γ_{32}/Γ

Test for $\Delta S = 1$ weak neutral current Allowed by combined first order weak and electromagnetic interactions

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •							
< 1 7	90		CENCE	74	ASPK	+	Three track evts
< 0 27	90		CENCE	74	ASPK	+	Two track events
<32 0	90		BEIER	72	OSPK	±	
< 4 4	90		BISI	67	DBC	+	
< 0 88	90		CLINE	67B	FBC	+	
< 2 45	90	1	CAMERINI	64	FBC	+	

$\Gamma(\pi^+ e^+ e^-)/\Gamma(\pi^+\pi^- e^+ \nu)$ Γ_{32}/Γ_9

Test for $\Delta S = 1$ weak neutral current Allowed by higher order electroweak interactions

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG
7.0 ± 1.3	41	[46] BLOCH	75	SPEC	+

[46] BLOCH 75 quotes this result multiplied by our 1974 $\pi^+\pi^- e\nu$ BR fraction

$\Gamma(\pi^+ \mu^+ \mu^-)/\Gamma_{total}$ Γ_{33}/Γ

Test for $\Delta S = 1$ weak neutral current Allowed by higher order electroweak interactions

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN	CHG
<2 4	90	BISI	67	DBC	+
• • • We do not use the following data for averages fits, limits etc • • •					
<3 0	90	CAMERINI	65	FBC	+

$\Gamma(\pi^+ \nu\overline{\nu})/\Gamma_{total}$ Γ_{34}/Γ

Test for $\Delta S = 1$ weak neutral current Allowed by higher order electroweak interactions

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
< 0.14	90		ASANO	81B	CNTR	+	$T(\pi)$ 116–127 MeV
• • • We do not use the following data for averages fits limits etc • • •							
< 0 94	90		[47] CABLE	73	CNTR	+	$T(\pi)$ 60–105 MeV
< 0 56	90		[47] CABLE	73	CNTR	+	$T(\pi)$ 60–127 MeV
<57 0	90	0	[48] LJUNG	73	HLBC	+	
< 1 4	90		[47] KLEMS	71	OSPK	+	$T(\pi)$ 117–127 MeV

[47] KLEMS 71 and CABLE 73 assume π spectrum same as K_{e3} decay Second CABLE 73 limit combines CABLE 73 and KLEMS 71 data for vector interaction

[48] LJUNG 73 assumes vector interaction

$\Gamma(\mu^- \nu e^+ e^+)/\Gamma(\pi^+\pi^- e^+ \nu)$ Γ_{35}/Γ_9

Test of lepton family number conservation

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	CHG
<0.5	90	0	[49] DIAMANT	76	SPEC	+

[49] DIAMANT-BERGER 76 quotes this result times our 1975 $\pi^+\pi^- e\nu$ BR ratio

$\Gamma(\mu^+ \nu_e)/\Gamma_{total}$ Γ_{36}/Γ

Forbidden by lepton family number conservation

VALUE	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
<0.004	90	0	LYONS	81	HLBC	0	200 GeV K^+ narrow band ν beam
• • • We do not use the following data for averages fits limits etc • • •							
<0 012	90		COOPER	82	HLBC		Wideband ν beam

$\Gamma(\pi^+ \mu^+ e^-)/\Gamma(\pi^+\pi^- e^+ \nu)$ Γ_{37}/Γ_9

Test of lepton family number conservation

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	CHG
<1.3	90	0	[50] DIAMANT	76	SPEC	+

[50] DIAMANT BERGER 76 quotes this result times our 1975 $\pi^+\pi^- e\nu$ BR ratio

$\Gamma(\pi^{\pm} \mu^{\mp} e^+)/\Gamma_{total}$ Γ_{38}/Γ

VALUE (units 10^{-8})	CL%	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages fits limits etc • • •					
<2 8	90	BEIER	72	OSPK	±

$\Gamma(\pi^{\pm} \mu^{\mp} e^+)/\Gamma(\pi^+\pi^- e^+ \nu)$ Γ_{38}/Γ_9

Test of lepton family number or total lepton number conservation
Sum of $\pi^+\mu^- e^+$ and $\pi^-\mu^+ e^+$ modes

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	CHG
<1.9	90	0	[51] DIAMANT	76	SPEC	+

[51] DIAMANT-BERGER 76 quotes this result times our 1975 $\pi^+\pi^- e\nu$ BR ratio

$\Gamma(\pi^+ e^+ \mu^-)/\Gamma_{total}$ Γ_{39}/Γ

VALUE (units 10^{-8})	CL%	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages fits limits etc • • •					
<1 4	90	BEIER	72	OSPK	±

$\Gamma(\pi^- e^+ e^+)/\Gamma_{total}$ Γ_{40}/Γ

Test of total lepton number conservation

VALUE (units 10^{-5})	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages fits limits, etc • • •				
<1 5	CHANG	68	HBC	−

$\Gamma(\pi^- e^+ e^+)/\Gamma(\pi^+\pi^- e^+ \nu)$ Γ_{40}/Γ_9

Test of total lepton number conservation

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	CHG
<2.5	90	0	[52] DIAMANT	76	SPEC	+

[52] DIAMANT-BERGER 76 quotes this result times our 1975 BR ratio

$\Gamma(\mu^+ \overline{\nu}_e)/\Gamma_{total}$ Γ_{41}/Γ

Forbidden by total lepton number conservation

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<3.3	90	COOPER	82	HLBC	Wideband ν beam

$\Gamma(\pi^0 e^+ \overline{\nu}_e)/\Gamma_{total}$ Γ_{42}/Γ

Forbidden by total lepton number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.003	90	COOPER	82	HLBC	Wideband ν beam

$\Gamma(\pi^+ \gamma)/\Gamma_{total}$ Γ_{43}/Γ

Violates angular momentum conservation Not listed in Summary Table

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages, fits, limits etc • • •					
<1 4	90	ASANO	82	CNTR	+
<4 0	90	[53] KLEMS	71	OSPK	+

[53] Test of model of Selleri NC 60A 291(1969)

K^+ LONGITUDINAL POLARIZATION OF EMITTED μ^+

$K^+ \to \mu^+ \nu$

Tests for right handed currents in strangeness changing decay

VALUE	DOCUMENT ID		TECN	CHG
−0.97 ±0.04 OUR AVERAGE				
−0 970 ± 0.047	YAMANAKA	86	SPEC	+
−1.0 ±0 1	CUTTS	69	SPRK	+
−0 96 ±0 12	COOMBES	57	CNTR	+

NOTE ON DALITZ PLOT PARAMETERS FOR $K \rightarrow 3\pi$ DECAYS

The Dalitz plot distribution for $K^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}\pi^{\mp}$, $K^{\pm} \rightarrow \pi^0\pi^0\pi^{\pm}$ and $K_L^0 \rightarrow \pi^+\pi^-\pi^0$ can be parametrized by a series expansion such as that introduced by Weinberg [1] We use the form

$$|M|^2 \propto 1 + g\frac{(s_3 - s_0)}{m_{\pi^+}^2} + h\left[\frac{s_3 - s_0}{m_{\pi^+}^2}\right]^2$$

$$+ j\frac{(s_2 - s_1)}{m_{\pi^+}^2} + k\left[\frac{s_2 - s_1}{m_{\pi^+}^2}\right]^2 + \qquad , \qquad (1)$$

where $m_{\pi^+}^2$ has been introduced to make the coefficients g, h, j, and k dimensionless and

$$s_i = (P_K - P_i)^2 = (m_K - m_i)^2 - 2m_K T_i, \quad i = 1,2,3$$

$$s_0 = \frac{1}{3}\sum_i s_i = \frac{1}{3}(m_K^2 + m_1^2 + m_2^2 + m_3^2)$$

Here the P_i are four-vectors, m_i and T_i are the mass and kinetic energy of the i^{th} pion, and the index 3 is used for the odd pion

The coefficient g is a measure of the slope in the variable s_3 (or T_3) of the Dalitz plot, while h and k measure the quadratic dependence on s_3 and $(s_2 - s_1)$ respectively The coefficient j is related to the asymmetry of the plot and must be zero if CP invariance holds Note also that if CP is good, g, h, and k must be the same for $K^- \rightarrow \pi^+\pi^+\pi^-$ as for $K^- \rightarrow \pi^-\pi^-\pi^+$

Since different experiments use different forms for $|M|^2$, in order to compare the experiments we have converted to g, h, j, and k whatever coefficients have been measured Where such conversions have been done, the measured coefficient a_y, a_t, a_u or a_v is given in the comment at the right For definitions of these coefficients, details of this conversion, and discussion of the data, see the April 1982 version of this note [2]

See also the review of Devlin and Dickey [3] which contains an analysis of $K \rightarrow 2\pi$ and $K \rightarrow 3\pi$ data in terms of transition amplitudes with appropriate energy dependence

References

1 S Weinberg, Phys Rev Lett **4** 87 (1960)

2 Particle Data Group, Phys Lett **111B**, 69 (1982)

3 T J Devlin and J O Dickey, Rev Mod Phys **51**, 237 (1979)

$K^{\pm}$ ENERGY DEPENDENCE OF DALITZ PLOT

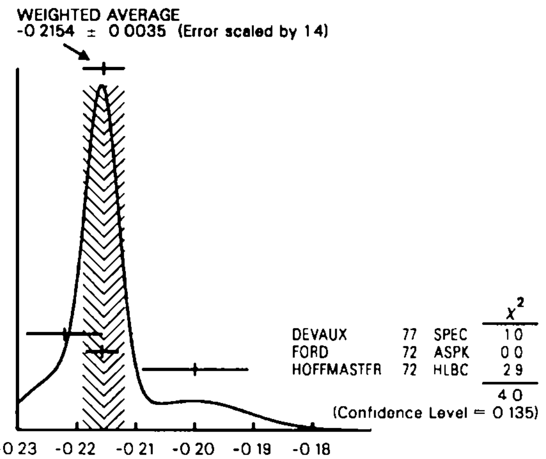
matrix element $|M|^2 = 1 + gu + hu^2 + kv^2$
where $u = (s_3 - s_0) / m^2(\pi)$ and $v = (s_1 - s_2) / m^2(\pi)$

LINEAR COEFFICIENT g_{τ^+} FOR $K^+ \rightarrow \pi^+\pi^+\pi^-$

Some experiments use Dalitz variables x and y In the comments we give a_y = coefficient of y term See note above on Dalitz Plot Parameters for $K \rightarrow 3\pi$ Decays For discussion of the conversion of a_y to g see the earlier version of the same note in the 1982 edition of this Review published in Physics Letters **111B** 70 (April 1982)

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
−0 2154 ±0 0035	**OUR AVERAGE**	Error includes scale factor of 1 4 See the ideogram below				
−0 2221 ±0 0065	225k	DEVAUX	77	SPEC	+	a_y = 2814 ± 0082
−0 2157 ±0 0028	750k	FORD	72	ASPK	+	a_y = 2734 ± 0035
−0 200 ±0 009	39819	[54] HOFFMASTER	72	HLBC	+	
• • • We do not use the following data for averages fits limits etc • • •						
−0 196 ±0 012	17898	[55] GRAUMAN	70	HLBC	+	a_y = 0 228 ± 0 030
−0 218 ±0 016	9994	[56] BUTLER	68	HBC	+	a_y = 0 277 ± 0 020
−0 22 ±0 024	5428	[56,57] ZINCHENKO	67	HBC	+	a_y = 0 28 ± 0 03

[54] HOFFMASTER 72 includes GRAUMAN 70 data
[55] Emulsion data added all events included by HOFFMASTER 72
[56] Experiments with large errors not included in average
[57] Also includes DBC events



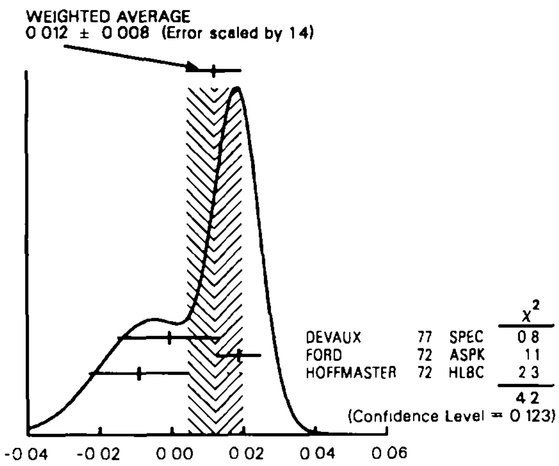
Linear energy dependence for $K^+ \rightarrow \pi^+\pi^+\pi^-$

QUADRATIC COEFFICIENT h FOR $K^+ \rightarrow \pi^+\pi^+\pi^-$

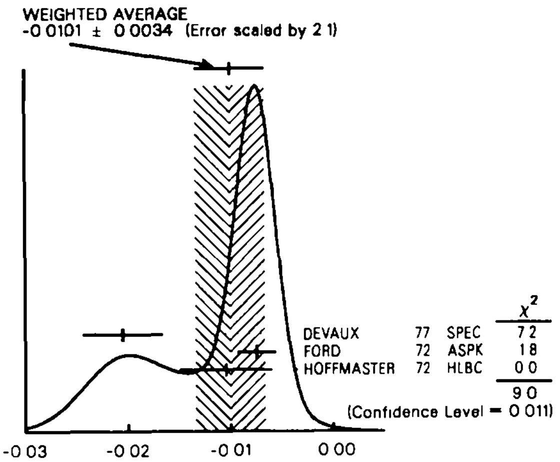
VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
0.012 ±0 008	**OUR AVERAGE**	Error includes scale factor of 1 4 See the ideogram below			
−0 0006 ±0 0143	225k	DEVAUX	77	SPEC	+
0 0187 ±0 0062	750k	FORD	72	ASPK	+
−0 009 ±0 014	39819	HOFFMASTER	72	HLBC	+

QUADRATIC COEFFICIENT k FOR $K^+ \rightarrow \pi^+\pi^+\pi^-$

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
−0.0101 ±0.0034	**OUR AVERAGE**	Error includes scale factor of 2 1 See the ideogram below			
−0 0205 ±0 0039	225k	DEVAUX	77	SPEC	+
−0 0075 ±0 0019	750k	FORD	72	ASPK	+
−0 0105 ±0 0045	39819	HOFFMASTER	72	HLBC	+



Quadratic coefficient h for $K^+ \to \pi^+\pi^+\pi^-$



Quadratic coefficient k for $K^+ \to \pi^+\pi^+\pi^-$

LINEAR COEFFICIENT g_{T^-} FOR $K^- \to \pi^-\pi^-\pi^+$

Some experiments use Dalitz variables x and y. In the comments we give a_y = coefficient of y term. See note above on "Dalitz Plot Parameters for $K \to 3\pi$ Decays." For discussion of the conversion of a_y to g see the earlier version of the same note in the 1982 edition of this Review published in Physics Letters **111B** 70 (April 1982).

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
−0 217 ± 0.007	**OUR AVERAGE**	Error includes scale factor of 2 5				
−0 2186 ± 0 0028	750k	FORD	72	ASPK	−	a_y = .2770 ± .0035
−0 193 ± 0 010	50919	MAST	69	HBC	−	a_y = 0 244 ± 0.013
• • • We do not use the following data for averages, fits, limits, etc • • •						
−0 199 ± 0 008	81k	[58] LUCAS	73	HBC	−	a_y = 0 252 ± 0 011
−0 190 ± 0 023	5778	[59,60] MOSCOSO	68	HBC	−	a_y = 0 242 ± 0 029
−0 220 ± 0 035	1347	[61] FERRO-LUZZI	61	HBC	−	a_y = 0 28 ± 0.045

[58] Quadratic dependence is required by K^0_L experiments. For comparison we average only those $K^{\pm}$ experiments which quote quadratic fit values.
[59] Experiments with large errors not included in average.
[60] Also includes DBC events.
[61] No radiative corrections included.

QUADRATIC COEFFICIENT h FOR $K^- \to \pi^-\pi^-\pi^+$

VALUE	EVTS	DOCUMENT ID		TECN	CHG
0.010 ± 0.006	**OUR AVERAGE**				
0 0125 ± 0 0062	750k	FORD	72	ASPK	−
−0 001 ± 0 012	50919	MAST	69	HBC	−

QUADRATIC COEFFICIENT k FOR $K^- \to \pi^-\pi^-\pi^+$

VALUE	EVTS	DOCUMENT ID		TECN	CHG
−0.0084 ± 0.0019	**OUR AVERAGE**				
−0 0083 ± 0 0019	750k	FORD	72	ASPK	−
−0 014 ± 0 012	50919	MAST	69	HBC	−

$(g_{T^+} - g_{T^-}) / (g_{T^+} + g_{T^-})$

A nonzero value for this quantity indicates CP violation.

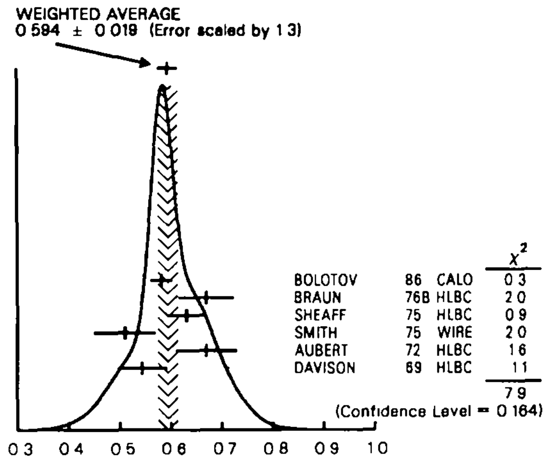
VALUE (%)	EVTS	DOCUMENT ID		TECN
−0.70 ± 0.53	3 2M	FORD	70	ASPK

LINEAR COEFFICIENT g FOR $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$

Unless otherwise stated all experiments include terms quadratic in $(s_3 - s_0) / m^2(\pi^+)$. See mini review above.

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.594 ± 0.019	**OUR AVERAGE**	Error includes scale factor of 1 3. See the ideogram below				
0 582 ± 0.021	43k	BOLOTOV	86	CALO	−	
0 670 ± 0 054	3263	BRAUN	76B	HLBC	+	
0 630 ± 0 038	5635	SHEAFF	75	HLBC	+	
0 510 ± 0 060	27k	SMITH	75	WIRE	+	
0 67 ± 0 06	1365	AUBERT	72	HLBC	+	
0 544 ± 0 048	4048	DAVISON	69	HLBC	+	Also emulsion
• • • We do not use the following data for averages, fits, limits, etc • • •						
0 806 ± 0 220	4639	[62] BERTRAND	76	EMUL	+	
0 484 ± 0 084	574	[63] LUCAS	73B	HBC	−	Dalitz pairs only
0 527 ± 0 102	198	[62] PANDOULAS	70	EMUL	+	
0 586 ± 0 098	1874	[63] BISI	65	HLBC	+	Also HBC
0 48 ± 0 04	1792	[63] KALMUS	64	HLBC	+	

[62] Experiments with large errors not included in average.
[63] Authors give linear fit only.



Linear energy dependence for $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$

QUADRATIC COEFFICIENT h FOR $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$

See mini review above.

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.035 ± 0.015	**OUR AVERAGE**					
0.037 ± 0 024	43k	BOLOTOV	86	CALO	−	
0 152 ± 0 082	3263	BRAUN	76B	HLBC	+	
0 041 ± 0 030	5635	SHEAFF	75	HLBC	+	
0 009 ± 0 040	27k	SMITH	75	WIRE	+	
−0 01 ± 0 08	1365	AUBERT	72	HLBC	+	
0 026 ± 0.050	4048	DAVISON	69	HLBC	+	Also emulsion
• • • We do not use the following data for averages, fits, limits, etc • • •						
0 164 ± 0 121	4639	[64] BERTRAND	76	EMUL	+	
0 018 ± 0 124	198	[64] PANDOULAS	70	EMUL	+	

[64] Experiments with large errors not included in average.

NOTE ON $K^{\pm}_{\ell 3}$ AND $K^0_{\ell 3}$ FORM FACTORS

Assuming that only the vector current contributes to $K \to \pi \ell \nu$ decays, we write the matrix element as

$$M \propto f_+(t)\left[(P_K + P_\pi)_\mu \bar{\ell}\gamma_\mu(1+\gamma_5)\nu\right]$$

$$+ f_-(t)\left[m_\ell \bar{\ell}(1+\gamma_5)\nu\right] . \qquad (1)$$

where P_K and P_π are the four-momenta of the K and π mesons, m_ℓ is the lepton mass, and f_+ and f_- are dimensionless form factors which can depend only on $t = (P_K - P_\pi)^2$, the square of the four-momentum transfer to the leptons. If time-reversal invariance holds, f_+ and f_- are relatively real. $K_{\mu3}$ experiments measure f_+ and f_-, while K_{e3} experiments are sensitive only to f_+ because the small electron mass makes the f_- term negligible.

(a) $K_{\mu3}$ experiments. Analyses of $K_{\mu3}$ data frequently assume a linear dependence of f_+ and f_- on t, i.e.,

$$f_\pm(t) = f_\pm(0)\left[1 + \lambda_\pm(t/m_\pi^2)\right] \qquad (2)$$

Most $K_{\mu3}$ data are adequately described by Eq. (2) for f_+ and a constant f_- (i.e., $\lambda_- = 0$). There are two equivalent parametrizations commonly used in these analyses.

(1) λ_+, $\xi(0)$ parametrization. Analyses of $K_{\mu3}$ data often introduce the ratio of the two form factors

$$\xi(t) = f_-(t)/f_+(t)$$

The $K_{\mu3}$ decay distribution is then described by the two parameters λ_+ and $\xi(0)$ (assuming time reversal invariance and $\lambda_- = 0$). These parameters can be determined by three different methods.

Method A. By studying the Dalitz plot or the pion spectrum of $K_{\mu3}$ decay. The Dalitz plot density is (see, e.g., Chounet et al.[1])

$$\rho(E_\pi,E_\mu) \propto f_+^2(t)\left[A + B\xi(t) + C\xi(t)^2\right],$$

where

$$A = m_K(2E_\mu E_\nu - m_K E'_\pi) + m_\mu^2\left(\tfrac{1}{4}E'_\pi - E_\nu\right),$$

$$B = m_\mu^2\left(E_\nu - \tfrac{1}{2}E'_\pi\right),$$

$$C = \tfrac{1}{4}m_\mu^2 E'_\pi,$$

$$E'_\pi = E_\pi^{\max} - E_\pi = (m_K^2 + m_\pi^2 - m_\mu^2)/2m_K - E_\pi.$$

Here E_π, E_μ, and E_ν are, respectively, the pion, muon, and neutrino energies in the kaon center of mass. The density ρ is fit to the data to determine the values of λ_+, $\xi(0)$, and their correlation.

Method B. By measuring the $K_{\mu3}/K_{e3}$ branching ratio and comparing it with the theoretical ratio (see, e.g., Fearing et al.[2]) as given in terms of λ_+ and $\xi(0)$, assuming μ-e universality:

$$\Gamma(K_{\mu3}^{\pm})/\Gamma(K_{e3}^{\pm}) = 0.6457 + 1.4115\lambda_+ + 0.1264\xi(0) + 0.0192\xi(0)^2 + 0.0080\lambda_+\xi(0),$$

$$\Gamma(K_{\mu3}^{0})/\Gamma(K_{e3}^{0}) = 0.6452 + 1.3162\lambda_+ + 0.1264\xi(0) + 0.0186\xi(0)^2 + 0.0064\lambda_+\xi(0).$$

This cannot determine λ_+ and $\xi(0)$ simultaneously but simply fixes a relationship between them.

Method C. By measuring the muon polarization in $K_{\mu3}$ decay. In the rest frame of the K, the μ is expected to be polarized in the direction $\mathbf{A}$ with $\mathbf{P} = \mathbf{A}/|\mathbf{A}|$, where $\mathbf{A}$ is given (Cabibbo and Maksymowicz[3]) by

$$\mathbf{A} = a_1(\xi)\mathbf{p}_\mu - a_2(\xi)\left[\frac{\mathbf{p}_\mu}{m_\mu}\left(m_K - E_\pi + \frac{\mathbf{p}_\pi\cdot\mathbf{p}_\mu}{|\mathbf{p}_\mu|^2}(E_\mu - m_\mu)\right) + \mathbf{p}_\pi\right] + m_K\,\mathrm{Im}\xi(t)(\mathbf{p}_\pi\times\mathbf{p}_\mu).$$

If time-reversal invariance holds, ξ is real, and thus there is no polarization perpendicular to the K-decay plane. Polarization experiments measure the weighted average of $\xi(t)$ over the t range of the experiment, where the weighting accounts for the variation with t of the sensitivity to $\xi(t)$.

(2) λ_+, λ_0 parametrization. Most of the more recent $K_{\mu3}$ analyses have parametrized in terms of the form factors f_+ and f_0, which are associated with vector and scalar exchange, respectively, to the lepton pair. f_0 is related to f_+ and f_- by

$$f_0(t) = f_+(t) + \left[t/(m_K^2 - m_\pi^2)\right]f_-(t).$$

Here $f_0(0)$ must equal $f_+(0)$ unless $f_-(t)$ diverges at $t = 0$. The earlier assumption that f_+ is linear in t and f_- is constant leads to f_0 linear in t:

$$f_0(t) = f_0(0)\left[1 + \lambda_0(t/m_\pi^2)\right]$$

With the assumption that $f_0(0) = f_+(0)$, the two parametrizations (λ_+, $\xi(0)$) and (λ_+, λ_0) are equivalent as long as correlation information is retained. (λ_+, λ_0) correlations tend to be less strong than (λ_+, $\xi(0)$) correlations.

The experimental results for $\xi(0)$ and its correlation with λ_+ are listed in the $K^{\pm}$ and K_L^0 sections of the Stable Particle Full Listings in section ξ_A, ξ_B, or ξ_C, depending on whether method A, B, or C discussed above was used. The corresponding values of λ_+ are also listed.

Because recent experiments tend to use the (λ_+, λ_0) parametrization, we include a subsection for λ_0 results. Wherever possible we have converted $\xi(0)$ results into λ_0 results and vice versa.

See the 1982 version of this note[4] for additional discussion of the $K^0_{\mu 3}$ parameters, correlations, and conversion between parametrizations, and also for a comparison of the experimental results

(b) K_{e3} experiments Analysis of K_{e3} data is simpler than that of $K_{\mu 3}$ because the second term of the matrix element assuming a pure vector current [Eq (1) above] can be neglected Here f_- is usually assumed to be linear in t and the linear coefficient λ_- of Eq (2) is determined

If we remove the assumption of a pure vector current, then the matrix element for the decay, in addition to the terms in Eq (2) would contain

$$+ 2m_K f_S \bar{\ell}(1 - \gamma_5)\nu$$

$$+ (2f_T / m_K)(P_K)_\lambda (P_\pi)_\mu \bar{\ell}\sigma_{\lambda\mu}(1 - \gamma_5)\nu$$

where f_S is the scalar form factor, and f_T is the tensor form factor In the case of the K_{e3} decays where the f_- term can be neglected, experiments have yielded limits on $|f_S/f_+|$ and $|f_T/f_+|$

References

1 L M Chounet, J M Gaillard, and M K Gaillard Phys Rep **4C**, 199 (1972)

2 H W Fearing, E Fischbach, and J Smith, Phys Rev **D2**, 542 (1970)

3 N Cabibbo and A Maksymowicz, Phys Lett **9**, 352 (1964)

4 Particle Data Group, Phys Lett **111B**, 73 (1982)

$K^{\pm}$ FORM FACTORS

In the form factor comments the following symbols are used
f_+ and f_- are form factors for the vector matrix element
f_S and f_T refer to the scalar and tensor term
$f_0 = f_+ + f_- t/(m^2(K) - m^2(\pi))$
λ_+ λ_- and λ_0 are the linear expansion coefficients of f_+ f_- and f_0
λ_+ refers to the $K_{\mu 3}$ value except in the K_{e3} sections
$d\xi(0)/d\lambda_+$ is the correlation between $\xi(0)$ and λ_+ in $K_{\mu 3}$
$d\lambda_0/d\lambda_+$ is the correlation between λ_0 and λ_+ in $K_{\mu 3}$
t = momentum transfer to the π in units of $m^2(\pi)$
DP = Dalitz plot analysis
PI = π spectrum analysis
MU = μ spectrum analysis
POL= μ polarization analysis
BR = $K_{\mu 3}/K_{e3}$ branching ratio analysis
E = positron or electron spectrum analysis
RC = radiative corrections

$\xi_A = f_-/f_+$ (determined from spectra)

The parameter ξ is redundant with λ_0 below and is not put into the Stable Particle Summary Table

VALUE	$d\xi(0)/d\lambda_+$	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
−0.35 ± 0 15	**OUR EVALUATION**		Error includes scale factor of 1 6 From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition, PL **111B** (April 1982)				
−0 27 ± 0 25	− 17	3973	WHITMAN	80	SPEC	+	DP
−0 8 ± 0 8	− 20	490	65 ARNOLD	74	HLBC	+	DP
−0 57 ± 0 24	− 9	6527	66 MERLAN	74	ASPK	+	DP
−0 36 ± 0 40	− 19	1897	67 BRAUN	73C	HLBC	+	DP
−0 62 ± 0 28	− 12	4025	68 ANKENBRA	72	ASPK	+	PI
+0 45 ± 0 28	− 15	3480	69 CHIANG	72	OSPK	+	DP
−1 1 ± 0 56	− 29	3240	70 HAIDT	71	HLBC	+	DP
−0 5 ± 0 8	− 26	2041	71 KIJEWSKI	69	OSPK	+	PI
+0.72 ± 0 93	− 17	444	CALLAHAN	66B	FBC	+	PI
• • • We do not use the following data for averages fits limits etc • • •							
−0 5 ± 0 9	none	78	EISLER	68	HLBC	+	PI λ_+=0
0 0 $^{+1\ 1}_{-0\ 9}$		2648	72 CALLAHAN	66B	FBC	+	μ λ_+=0 t unknown
+0 7 ± 0 5		87	GIACOMELLI	64	EMUL	+	MU+BR λ_+=0
−0 08 ± 0 7			73 JENSEN	64	XEBC	+	DP+BR($K_{\mu 3}$ K_{e3})
+1 8 ± 0 6		76	BROWN	62B	XEBC	+	DP+BR λ_+=0

65 ARNOLD 74 figure 4 was used to obtain ξ_A and $d\xi(0)/d\lambda_+$
66 MERLAN 74 figure 5 was used to obtain $d\xi(0)/d\lambda_+$
67 BRAUN 73C gives $\xi(t)$ = −0 34 ± 0 20 $d\xi(t)/d\lambda_+$ = − 14 for λ_+ = 0 027 t = 6 6 We calculate above $\xi(0)$ and $d\xi(0)/d\lambda_+$ for their λ_+ = 0 025 ± 0 017
68 ANKENBRANDT 72 figure 3 was used to obtain $d\xi(0)/d\lambda_+$
69 CHIANG 72 figure 10 was used to obtain $d\xi(0)/d\lambda_+$ Fit had $\lambda_- = \lambda_+$ but would not change for λ_- = 0 L Pondrom (private communication 74)
70 HAIDT 71 table 8 (Dalitz plot analysis) gives $d\xi(0)/d\lambda_+$ = (− 1 1+0 5)/(0 050 − 0 029) = − 29 error raised from 0 50 to agree with $d\xi(0)$ = 0 20 for fixed λ_+
71 KIJEWSKI 69 figure 17 was used to obtain $d\xi(0)/d\lambda_+$ and errors
72 CALLAHAN 66 table 1 (π analysis) gives $d\xi(0)/d\lambda_+$ = (0 72−0 05)/(0−0 04) = − 17, error raised from 0 80 to agree with $d\xi(0)$ = 0 37 for fixed λ_+
73 JENSEN 64 gives $\lambda^{\mu}_+ = \lambda^{e}_+$ = −0 020 ± 0 027 $d\xi(0)/d\lambda_+$ unknown Includes SHAKLEE 64 $\xi_B(K_{\mu 3}/K_{e3})$

$\xi_B = f_-/f_+$ (determined from $K_{\mu 3}/K_{e3}$)

The $K_{\mu 3}/K_{e3}$ branching ratio fixes a relationship between $\xi(0)$ and λ_+ We quote the author s $\xi(0)$ and associated λ_+ but do not average because the λ_+ values differ The fit result and scale factor given below are not obtained from these ξ_B values Instead they are obtained directly from the fitted $K_{\mu 3}/K_{e3}$ ratio $\Gamma(\pi^0\mu^+\nu)/\Gamma(\pi^0 e^+\nu)$, with the exception of HEINTZE 77 The parameter ξ is redundant with λ_0 below and is not put into the Stable Particle Summary Table

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
−0.35 ± 0 15	**OUR EVALUATION**	Error includes scale factor of 1 6 From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition PL **111B** (April 1982)				
−0 12 ± 0 12	55k	74 HEINTZE	77	CNTR	+	BR λ_+=0 029
• • • We do not use the following data for averages fits limits etc • • •						
0 0 ± 0 15	5825	CHIANG	72	OSPK	+	BR λ_+=0 03 fig 10
−0 81 ± 0 27	1505	75 HAIDT	71	HLBC	+	BR λ_+=0 028 fig 8
−0 35 ± 0 22		76 BOTTERILL	70	OSPK	+	BR λ_+=0 045 ± 0 015
+0 91 ± 0 82		ZELLER	69	ASPK	+	BR λ_+=0 023
−0 08 ± 0 15	5601	76 BOTTERILL	68B	ASPK	+	BR λ_+=0 023 ± 0 008
−0 60 ± 0 20	1398	75 EICHTEN	68	HLBC	+	BR see note
+1 0 ± 0 6	986	GARLAND	68	OSPK	+	BR λ_+=0
+0 75 ± 0 50	306	AUERBACH	67	OSPK	+	BR λ_+=0
+0 4 ± 0 4	636	CALLAHAN	66B	FBC	+	BR λ_+=0
+0 6 ± 0 5		BISI	65B	HBC	+	BR λ_+=0
+0 8 ± 0 6	500	CUTTS	65	OSPK	+	BR λ_+=0
−0 17 $^{+0\ 75}_{-0\ 99}$		SHAKLEE	64	XEBC	+	BR λ_+=0

74 Calculated by us from λ_0 and λ_+ given below
75 EICHTEN 68 has λ_+ = 0 023 ± 0 008 t = 4 independent of λ_- Replaced by HAIDT 71
76 BOTTERILL 70 is re evaluation of BOTTERILL 68B with different λ_+

$\xi_C = f_-/f_+$ (determined from μ polarization in $K_{\mu 3}$)

The μ polarization is a measure of $\xi(t)$ No assumptions on λ_{+-} necessary t (weighted by sensitivity to $\xi(t)$) should be specified In λ_+ $\xi(0)$ parametrization this is $\xi(0)$ for λ_+=0 $d\xi/d\lambda = \xi t$ For radiative correction to muon polarization in $K_{\mu 3}$ see GINSBERG 71 The parameter ξ is redundant with λ_0 below and is not put into the Stable Particle Summary Table

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
−0.35 ± 0.15	**OUR EVALUATION**	Error includes scale factor of 1 6 From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition PL **111B** (April 1982)				
−0 25 ± 1 20	1585	77 BRAUN	75	HLBC	+	POL t=4 2
−0 95 ± 0 3	3133	78 CUTTS	69	OSPK	+	Total pol t=4 0
−1 0 ± 0 3	6000	79 BETTELS	68	HLBC	+	Total pol t=4 9
• • • We do not use the following data for averages fits limits etc • • •						
−0 64 ± 0 27	40k	80 MERLAN	74	ASPK	+	POL $d\xi(0)/d\lambda_+$ = +1 7
−1 4 ± 1 8	397	81 CALLAHAN	66B	FBC	+	Total pol
−0 7 $^{+0\ 9}_{-3\ 3}$	2950	81 CALLAHAN	66B	FBC	+	Long pol
+1 2 $^{+2.4}_{-1\ 8}$	2100	81 BORREANI	65	HLBC	+	Polarization
−4 0 to +1 7	500	81 CUTTS	65	OSPK	+	Long pol

77 BRAUN 75 $d\xi(0)/d\lambda_+ = \xi t$ = −0 25 × 4 2 = −1 0
78 CUTTS 69 t = 4 0 was calculated from figure 8 $d\xi(0)/d\lambda_+ = \xi t$ = −0 95 × 4 = −3 8
79 BETTELS 68 $d\xi(0)/d\lambda_+ = \xi t$ = −1 0 × 4 9 = −4 9
80 MERLAN 74 polarization result (figure 5) not possible See discussion of polarization experiments in note on $K_{\ell 3}$ Form Factors in the 1982 edition of this Review [Physics Letters **111B** (April 1982)]
81 t value not given

IMAGINARY PART OF ξ

Test of T reversal invariance

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
−0.017 ± 0.025 OUR AVERAGE						
−0.016 ± 0.025	20M	CAMPBELL	81	CNTR	+	Pol
$-0.3\ ^{+0.3}_{-0.4}$	3133	CUTTS	69	OSPK	+	Total pol fig 7
−0.1 ± 0.3	6000	BETTELS	68	HLBC	+	Total pol
0.0 ± 1.0	2648	CALLAHAN	66B	FBC	+	MU
+1.6 ± 1.3	397	CALLAHAN	66B	FBC	+	Total pol
$0.5\ ^{+1.4}_{-0.5}$	2950	CALLAHAN	66B	FBC	+	Long pol
• • • We do not use the following data for averages fits limits etc • • •						
−0.010 ± 0.019	32M	[82] BLATT	83	CNTR		Polarization

[82] Combined result of MORSE 80 ($K^0_{\mu 3}$) and CAMPBELL 81 ($K^+_{\mu 3}$)

λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN $K_{\mu 3}$ DECAY)

See also the corresponding entries and footnotes in sections ξ_A ξ_C and λ_0. For radiative correction of $K_{\mu 3}$ Dalitz plot see GINSBERG 70 and BECHERRAWY 70

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.033 ± 0.008 OUR EVALUATION		Error includes scale factor of 1.6. From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition PL **111B** (April 1982)				
+0.050 ± 0.013	3973	WHITMAN	80	SPEC	+	DP
0.025 ± 0.030	490	ARNOLD	74	HLBC	+	DP
0.027 ± 0.019	6527	MERLAN	74	ASPK	+	DP
0.025 ± 0.017	1897	BRAUN	73C	HLBC	+	DP
0.024 ± 0.019	4025	[83] ANKENBRA	72	ASPK	+	PI
−0.006 ± 0.015	3480	CHIANG	72	OSPK	+	DP
0.050 ± 0.018	3240	HAIDT	71	HLBC	+	DP
0.009 ± 0.026	2041	KIJEWSKI	69	OSPK	+	PI
0.0 ± 0.05	444	CALLAHAN	66B	FBC	+	PI

[83] ANKENBRANDT 72 λ_+ from figure 3 to match $d\xi(0)/d\lambda_+$. Text gives 0.024 ± 0.022

λ_0 (LINEAR ENERGY DEPENDENCE OF f_0 IN $K_{\mu 3}$ DECAY)

Wherever possible we have converted the above values of $\xi(0)$ into values of λ_0 using the associated λ^{μ}_{+} and $d\xi/d\lambda$

VALUE	$d\lambda_0/d\lambda_+$	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
−0.004 ± 0.007 OUR EVALUATION			Error includes scale factor of 1.6. From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition, PL **111B** (April 1982)				
+0.029 ± 0.011	−0.37	3973	WHITMAN	80	SPEC	+	DP
+0.019 ± 0.010	+0.03	55k	[84] HEINTZE	77	SPEC	+	BR
+0.008 ± 0.097	+0.92	1585	[85] BRAUN	75	HLBC	+	POL
−0.040 ± 0.040	−0.62	490	ARNOLD	74	HLBC	+	DP
−0.019 ± 0.015	+0.27	6527	[86] MERLAN	74	ASPK	+	DP
−0.008 ± 0.020	−0.53	1897	[87] BRAUN	73C	HLBC	+	DP
−0.026 ± 0.013	+0.03	4025	[88] ANKENBRA	72	ASPK	+	PI
+0.030 ± 0.014	−0.21	3480	[88] CHIANG	72	OSPK	+	DP
−0.039 ± 0.029	−1.34	3240	[88] HAIDT	71	HLBC	+	DP
−0.056 ± 0.024	+0.69	3133	[85] CUTTS	69	OSPK	+	POL
−0.031 ± 0.045	−1.10	2041	[88] KIJEWSKI	69	OSPK	+	PI
−0.063 ± 0.024	+0.60	6000	[85] BETTELS	68	HLBC	+	POL
+0.058 ± 0.036	−0.37	444	[88] CALLAHAN	66B	FBC	+	PI
• • • We do not use the following data for averages fits limits etc • • •							
−0.017 ± 0.011			[89] BRAUN	74	HLBC	+	$K_{\mu 3}/K_{e3}$ vs t

[84] HEINTZE 77 uses $\lambda_+ = 0.029 \pm 0.003$. $d\lambda_0/d\lambda_+$ estimated by us

[85] λ_0 value is for $\lambda_+ = 0.03$ calculated by us from $\xi(0)$ and $d\xi(0)/d\lambda_+$

[86] MERLAN 74 λ_0 and $d\lambda_0/d\lambda_+$ were calculated by us from ξ_A λ^{μ}_{+} and $d\xi(0)/d\lambda_+$. Their figure 6 gives $\lambda_0 = -0.025 \pm 0.012$ and no $d\lambda_0/d\lambda_+$

[87] This value and error are taken from BRAUN 75 but correspond to the BRAUN 73C λ^{μ}_{+} result. $d\lambda_0/d\lambda_+$ is from BRAUN 73C $d\xi(0)/d\lambda_+$ in ξ_A above

[88] λ_0 calculated by us from $\xi(0)$ λ^{μ}_{+} and $d\xi(0)/d\lambda_+$

[89] BRAUN 74 is a combined $K_{\mu 3}^{+}K_{e3}$ result. It is not independent of BRAUN 73C ($K_{\mu 3}$) and BRAUN 73B (K_{e3}) form factor results

λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN K_{e3} DECAY)

For radiative correction of K_{e3} Dalitz plot see GINSBERG 67 and BECHERRAWY 70

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.028 ± 0.004 OUR AVERAGE						
0.027 ± 0.008		[90] BRAUN	73B	HLBC	+	DP no RC
0.029 ± 0.011	4017	CHIANG	72	OSPK	+	DP RC negligible
0.027 ± 0.010	2707	STEINER	71	HLBC	+	DP uses RC
0.045 ± 0.015	1458	BOTTERILL	70	OSPK		PI uses RC
0.08 ± 0.04	960	BOTTERILL	68C	ASPK	+	e^+ uses RC
$-0.02\ ^{+0.08}_{-0.12}$	90	EISLER	68	HLBC	+	PI uses RC
$0.045\ ^{+0.017}_{-0.018}$	854	BELLOTTI	67B	FBC	+	DP uses RC
+0.016 ± 0.016	1393	IMLAY	67	OSPK	+	DP no RC
$+0.028\ ^{+0.013}_{-0.014}$	515	KALMUS	67	FBC	+	e^+ PI no RC
−0.04 ± 0.05	230	BORREANI	64	HBC	+	e^+ no RC
−0.010 ± 0.029	407	JENSEN	64	XEBC	+	PI no RC
+0.036 ± 0.045	217	BROWN	62B	XEBC	+	PI no RC
• • • We do not use the following data for averages fits limits etc • • •						
0.025 ± 0.007		[91] BRAUN	74	HLBC	+	$K_{\mu 3}$ K_{e3} vs t

[90] BRAUN 73B states that radiative corrections of GINSBERG 67 would lower λ^{e}_{+} by 0.002 but that radiative corrections of BECHERRAWY 70 disagrees and would raise λ^{e}_{+} by 0.005

[91] BRAUN 74 is a combined $K_{\mu 3}$ K_{e3} result. It is not independent of BRAUN 73C ($K_{\mu 3}$) and BRAUN 73B (K_{e3}) form factor results

$|f_S/f_+|$ FOR K_{e3} DECAY

Ratio of scalar to f_+ couplings

VALUE	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
$\mathbf{0.12\ ^{+0.04}_{-0.05}}$ **OUR AVERAGE**			Error includes scale factor of 1.3				
0.00 ± 0.10		2827	BRAUN	75	HLBC	+	
$0.14\ ^{+0.03}_{-0.04}$		2707	STEINER	71	HLBC	+	λ_+ f_S f_T φ fit
• • • We do not use the following data for averages fits limits etc • • •							
<0.13	90	4017	CHIANG	72	OSPK	+	
<0.23	90		BOTTERILL	68C	ASPK		
<0.18	90		BELLOTTI	67B	HLBC		
<0.30	95		KALMUS	67	HLBC	+	

$|f_T/f_+|$ FOR K_{e3} DECAY

Ratio of tensor to f_+ couplings

VALUE	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
$\mathbf{0.22\ ^{+0.15}_{-0.13}}$ **OUR AVERAGE**							
0.07 ± 0.37		2827	BRAUN	75	HLBC	+	
$0.24\ ^{+0.16}_{-0.14}$		2707	STEINER	71	HLBC	+	λ_+ f_S f_T φ fit
• • • We do not use the following data for averages fits limits etc • • •							
<0.75	90	4017	CHIANG	72	OSPK	+	
<0.58	90		BOTTERILL	68C	ASPK		
<0.58	90		BELLOTTI	67B	HLBC		
<1.1	95		KALMUS	67	HLBC	+	

f_T/f_+ FOR $K_{\mu 3}$ DECAY

Ratio of tensor to f_+ couplings

VALUE	EVTS	DOCUMENT ID		TECN
0.02 ± 0.12	1585	BRAUN	75	HLBC

DECAY FORM FACTORS FOR $K^{\pm} \to \pi^{+}\pi^{-}e^{\pm}\nu$

Given in ROSSELET 77 BEIER 73 and BASILE 71C

DECAY FORM FACTOR FOR $K^{\pm} \to \pi^{0}\pi^{0}e^{\pm}\nu$

Given in BOLOTOV 86B

REFERENCES FOR $K^{\pm}$

GALL 88 PRL 60 186 +Austin+ (BOST MIT WILL CIT CMU WYOM)
BARMIN 87 SJNP 45 62 +Barylov Davidenko Demidov+ (ITEP)
Translated from YAF 45 97
BOLOTOV 87 SJNP 45 1023 +Gninenko Dzhilkibaev Isakov Klubakov+(INRM)
Translated from YAF 45 1652
BOLOTOV 86 SJNP 44 73 +Gninenko Dzhilkibaev Isakov+ (INRM)
Translated from YAF 44 117
BOLOTOV 86B SJNP 44 68 +Gninenko Dzhilkibaev Isakov+ (INRM)
Translated from YAF 44 108
YAMANAKA 86 PR D34 85 +Hayano Taniguchi Ishikawa+ (KEK TOKY)
Also 84 PRL 52 329 Hayano Yamanaka Taniguchi+ (TOKY KEK)
AKIBA 85 PR D32 2911 +Ishikawa Iwasaki+ (TOKY TINT TSUK KEK)
BOLOTOV 85 JETPL 42 481 +Gninenko Dzhilkibaev Isakov+ (INRM)
Translated from ZETFP 42 390
BLATT 83 PR D27 1056 +Adair Black Campbell+ (YALE BNL)
ASANO 82 PL 113B 195 +Kikutani Kurokawa Miyachi+(KEK TOKY OSAK)
COOPER 82 PL 112B 97 +Guy Michette Tyndel Venus (RL)
ASANO 81B PL 107B 159 +Kikutani Kurokawa Miyachi+(KEK TOKY OSAK)
CAMPBELL 81 PRL 47 1032 +Black Blatt Kasha Schmidt+ (YALE BNL)
Also 83 PR D27 1056 Blatt Adair Black Campbell+ (YALE BNL)
LUM 81 PR D23 2522 +Wiegand Kessler Deslattes Seki+ (LBL NBS+)
LYONS 81 ZPHY C10 215 +Albajar Myatt (OXF)
MORSE 80 PR D21 1750 +Leipuner Larsen Schmidt Blatt+ (BNL YALE)
WHITMAN 80 PR D21 652 +Abrams Carroll Kycia Li+ (ILLC BNL ILL)
BARKOV 79 NP B148 53 +Vasserman Zolotorev Krupin+ (NOVO KIAE)
HEINTZE 79 NP B149 365 +Heinzelmann Igo Kemenes+ (HEID CERN)
ABRAMS 77 PR D15 22 +Carroll Kycia Li Michael Mockett+ (BNL)
DEVAUX 77 NP B126 11 +Bloch Diamant Berger Maillard+ (SACL GEVA)
HEINTZE 77 PL 70B 482 +Heinzelmann Igo Kemenes+ (HEID CERN)
ROSSELET 77 PR D15 574 +Extermann Fischer Guisan+ (GEVA SACL)
BERTRAND 76 NP B114 387 +Sacton+ (BRUX UBEL DUUC LOUC WARS)
BLOCH 76 PL 60B 393 +Bunce Devaux Diamant Berger+ (GEVA SACL)
BRAUN 76B LNC 17 521 +Martyn Erriquez+ (AACH BARI BELG CERN)
DIAMANT 76 PL 62B 485 Diamant Berger Bloch Devaux+ (SACL GEVA)
HEINTZE 76 PL 60B 302 +Heinzelmann Igo Kemenes Mundhenke+ (HEID)
SMITH 76 NP B109 173 +Booth Renshall Jones+ (GLAS LIVP OXF RHEL)
WEISSENBERG 76 NP B115 55 +Egorov Minervina+ (ITEP LEBD)
BLOCH 75 PL 56B 201 +Brehin Bunce Devaux+ (SACL GEVA)
BRAUN 75 NP B89 210 +Cornelssen+ (AACH BARI BRUX CERN)
CHENG 75 NP A254 381 +Asano Chen Dugan Hu Wu+ (COLU YALE)
HEARD 75 PL 55B 324 +Heintze Heinzelmann+ (CERN HEID)
HEARD 75B PL 55B 327 +Heintze Heinzelmann+ (CERN HEID)
SHEAFF 75 PR D12 2570 (WISC)
SMITH 75 NP B91 45 +Booth Renshall Jones+ (GLAS LIVP OXF RHEL)
ARNOLD 74 PR D9 1221 +Roe Sinclair (MICH)
BRAUN 74 PL 51B 393 +Cornelssen Martyn+ (AACH BARI BRUX CERN)

CENCE 74 PR D10 776 +Harris Jones Morgado+ (HAWA LBL WISC)
Also 73 Thesis unpub Clarke (WISC)
KUNSELMAN 74 PR C9 2469 (WYOM)
MERLAN 74 PR D9 107 +Kasha Wanderer Adair+ (YALE BNL LASL)
WEISSENBERG 74 PL 48B 474 +Egorov Minervina+ (ITEP LEBD)
ABRAMS 73B PRL 30 500 +Carroll Kycia Li Menes Michael+ (BNL)
BACKENSTO 73 PL 43B 431 Backenstoss+ (CERN KARL HEID STOH)
BEIER 73 PRL 30 399 +Buchholz Mann Parker Roberts (PENN)
BRAUN 73B PL 47B 185 +Cornelssen (AACH BARI BRUX CERN)
Also 75 NP B89 210 Braun Cornelssen+ (AACH BARI BRUX CERN)
BRAUN 73C PL 47B 182 +Cornelssen (AACH BARI BRUX CERN)
Also 75 NP B89 210 Braun Cornelssen+ (AACH BARI BRUX CERN)
CABLE 73 PR D8 3807 +Hildebrand Pang Stiening (EFI LBL)
LJUNG 73 PR D8 1307 +Cline (WISC)
Also 72 PRL 28 523 Ljung (WISC)
Also 72 PRL 28 1287 Cline Ljung (WISC)
Also 69 PRL 23 326 Camerini Ljung Sheaff Cline (WISC)
LUCAS 73 PR D8 719 +Taft Willis (YALE)
LUCAS 73B PR D8 727 +Taft Willis (YALE)
PANG 73 PR D8 1989 +Hildebrand Cable Stiening (EFI ARIZ LBL)
Also 72 PL 40B 699 Cable Hildebrand Pang Stiening (EFI LBL)
SMITH 73 NP B60 411 +Booth Renshall Jones+ (GLAS LIVP OXF RHEL)
ABRAMS 72 PRL 29 1118 +Carroll Kycia Li Menes Michael+ (BNL)
ANKENBRA 72 PRL 28 1472 Ankenbrandt Larsen+ (BNL LASL FNAL YALE)
AUBERT 72 NC 12A 509 +Heusse Pascaud Vialle+ (ORSA BRUX EPOL)
BEIER 72 PRL 29 678 +Buchholz Mann Parker (PENN)
CHIANG 72 PR D6 1254 +Rosen Shapiro Handler Olsen+ (ROCH WISC)
CLARK 72 PRL 29 1274 +Cork Elioff Kerth McReynolds Newton+ (LBL)
EDWARDS 72 PR D5 2720 +Beier Bertram Herzo Koester+ (ILL)
FORD 72 PL 38B 335 +Piroue Remmel Smith Souder (PRIN)
HOFFMASTER 72 NP B36 1 +Koller Taylor+ (STEV SETO LEHI)
BASILE 71C PL 36B 619 +Brehin Diamant Berger Kunz+ (SACL GEVA)
BOURQUIN 71 PL 36B 615 +Boymond Extermann Marasco+ (GEVA SACL)
GINSBERG 71 PR D4 2893 (MIT)
HAIDT 71 PR D3 10 (AACH BARI CERN EPOL NIJM+)
Also 69 PL 29B 691 Haidt+ (AACH BARI CERN EPOL NIJM ORSA+)
KLEMS 71 PR D4 66 +Hildebrand Stiening (CHIC LRL)
Also 70 PRL 24 1086 Klems Hildebrand Stiening (LRL CHIC)
Also 70B PRL 25 473 Klems Hildebrand Stiening (LRL CHIC)
OTT 71 PR D3 52 +Pritchard (LOQM)
ROMANO 71 PL 36B 525 +Renton Aubert Burban Lutz (BARI CERN ORSA)
SCHWEINB 71 PL 36B 246 Schweinberger (AACH BELG CERN NIJM+)
STEINER 71 PL 36B 521 (AACH BARI CERN EPOL ORSA NIJM PADO+)
BARDIN 70 PL 32B 121 +Bilenky Pontecorvo (JINR)
BECHERRAWY 70 PR D1 1452 (ROCH)
BOTTERILL 70 PL 31B 325 +Brown Clegg Corbett Culligan+ (OXF)
FORD 70 PRL 25 1370 +Piroue Remmel Smith Souder (PRIN)
GAILLARD 70 CERN 70 14 +Chounet (CERN ORSA)
GINSBERG 70 PR D1 229 (HAIF)
GRAUMAN 70 PR D1 1277 +Koller Taylor Pandoulas+ (STEV SETO LEHI)
Also 69 PRL 23 737 Grauman Koller Taylor+ (STEV SETO LEHI)
MACEK 70 PR D1 1249 +Mann McFarlane Roberts (PENN)
MALTSEV 70 SJNP 10 678 +Pestova Solodovnikova Fadeev+ (JINR)
Translated from YAF 10 1195
PANDOULAS 70 PR D2 1205 +Taylor Koller Grauman+ (STEV SETO)
CUTTS 69 PR 184 1380 +Stiening Wiegand Deutsch (LRL MIT)
Also 68 PRL 20 955 Cutts Stiening Wiegand Deutsch (LRL MIT)
DAVISON 69 PR 180 1333 +Bacastow Barkas Evans Fung Porter+ (UCR)
ELY 69 PR 180 1319 +Gidal Hagopian Kalmus+ (LOUC WISC LRL)
EMMERSON 69 PRL 23 393 +Quirk (OXF)
HERZO 69 PR 186 1403 +Banner Beier Bertram Edwards+ (ILL)
KIJEWSKI 69 UCRL 18433 Thesis (LBL)
LOBKOWICZ 69 PR 185 1676 +Melissinos Nagashima Tewksbury+ (ROCH BNL)
Also 66 PRL 17 548 Lobkowicz Melissinos Nagashima+ (ROCH BNL)
MACEK 69 PRL 22 32 +Mann McFarlane Roberts+ (PENN TEMP)
MAST 69 PR 183 1200 +Gershwin Alston Garnjost Bangerter+ (LRL)
ZELLER 69 PR 182 1420 +Haddock Helland Pahl+ (UCLA LRL)
BETTELS 68 NC 56A 1106 (AACH BARI BERG CERN EPOL NIJM ORSA+)
Also 71 PR D3 10 Haidt (AACH BARI CERN EPOL NIJM+)
BOTTERILL 68B PRL 21 766 +Brown Clegg Corbett+ (OXF)
BOTTERILL 68C PR 174 1661 +Brown Clegg Corbett+ (OXF)
BUTLER 68 UCRL 18420 +Bland Goldhaber Goldhaber Hirata+ (LRL)
CHANG 68 PRL 20 510 +Yodh Ehrlich Plano+ (UMD RUTG)
CHEN 68 PRL 20 73 +Cutts Kijewski Stiening+ (LRL MIT)
EICHTEN 68 PL 27B 586 (AACH BARI CERN EPOL ORSA PADO VALE)
EISLER 68 PR 169 1090 +Fung Marateck Meyer Plano (RUTG)
ESCHSTRUTH 68 PR 165 1487 +Franklin Hughes+ (PRIN PENN)
GARLAND 68 PR 167 1225 +Tsipis Devons Rosen+ (COLU RUTG WISC)
MOSCOSO 68 Thesis (ORSA)
AUERBACH 67 PR 155 1505 +Dobbs Mann+ (PENN PRIN)
Also 74 PR D9 3216 Auerbach
Erratum
BELLOTTI 67 Heidelberg Conf +Pullia (MILA)
BELLOTTI 67B NC 52A 1287 +Fiorini Pullia (MILA)
Also 66B PL 20 690 Bellotti Fiorini Pullia+ (MILA)
BISI 67 PL 25B 572 +Cester Chiesa Vigone (TORI)
BOTTERILL 67 PRL 19 982 +Brown Corbett Culligan+ (OXF)
Also 68 PR 171 1402 Botterill Brown Clegg Corbett+ (OXF)
BOWEN 67B PR 154 1314 +Mann McFarlane Hughes+ (PPA)
CLINE 67B Herceg Novi Tbl 4
Proc International School on Elementary Particle Physics
FLETCHER 67 PRL 19 98 +Beier Edwards+ (ILL)
FORD 67 PRL 18 1214 +Lemonick Nauenberg Piroue (PRIN)
GINSBERG 67 PR 162 1570 (MASB)
IMLAY 67 PR 160 1203 +Eschstruth Franklin+ (PRIN)
KALMUS 67 PR 159 1187 +Kernan (LRL)
ZINCHENKO 67 Rutgers Thesis (RUTG)
CALLAHAN 66 NC 44A 90 (WISC)
CALLAHAN 66B PR 150 1153 +Camerini+ (WISC LRL UCR BARI)
CESTER 66 PL 21 343 +Eschstruth Onelli+ (PPA)
See footnote 1 in AUERBACH 67
Also 67 PR 155 1505 Auerbach Dobbs Mann+ (PENN PRIN)
BIRGE 65 PR 139B 1600 +Ely Gidal Camerini Cline+ (LRL WISC)
BISI 65 NC 35 768 +Borreani Cester Ferraro+ (TORI)
BISI 65B PR 139B 1068 +Borreani Marzari Chiesa Rinaudo+ (TORI)
BORREANI 65 PR 140B 1686 +Gidal Rinaudo Caforio+ (BARI TORI)
CALLAHAN 65 PRL 15 129 +Cline (WISC)
CAMERINI 65 NC 37 1795 +Cline Gidal Kalmus Kernan (WISC LRL)
CLINE 65 PL 15 293 +Fry (WISC)
CUTTS 65 PR 138B 969 +Elioff Stiening (LRL)
DEMARCO 65 PR 140B 1430 +Grosso Rinaudo (TORI CERN)
FITCH 65B PR 140B 1088 +Quarles Wilkins (PRIN MTHO)
GREINER 65 ARNS 15 67 (LRL)
STAMER 65 PR 138B 440 +Huetter Koller Taylor Grauman (STEV)
TRILLING 65B UCRL 16473 (LRL)
Updated from 1965 Argonne Conference page 5
YOUNG 65 UCRL 16362 Thesis (LRL)
Also 67 PR 156 1464 Young Osborne Barkas (LRL)
BORREANI 64 PL 12 123 +Rinaudo Werbrouck (TORI)
CALLAHAN 64 PR 136B 1463 +March Stark (WISC)
CAMERINI 64 PRL 13 318 +Cline Fry Powell (WISC LRL)
CLINE 64 PRL 13 101 +Fry (WISC)
GIACOMELLI 64 NC 34 1134 +Monti Quareni+ (BGNA MUNI)
GREINER 64 PRL 13 284 +Osborne Barkas (LRL)
JENSEN 64 PR 136B 1431 +Shaklee Roe Sinclair (MICH)
KALMUS 64 PRL 13 99 +Kernan Pu Powell Dowd (LRL WISC)
SHAKLEE 64 PR 136B 1423 +Jensen Roe Sinclair (MICH)
BARKAS 63 PRL 11 26 +Dyer Heckman (LRL)
BOYARSKI 62 PR 128 2398 +Loh Niemela Rilson (MIT)
BROWN 62B PRL 8 450 +Kadyk Trilling Roe+ (LRL MICH)
BARKAS 61 PR 124 1209 +Dyer Mason Norris Nickols Smil (LRL)
BHOWMIK 61 NC 20 857 +Jain Mathur (DELH)
FERRO LUZZI 61 NC 22 1087 +Miller Murray Rosenfeld+ (LRL)
NORDIN 61 PR 123 2166 (LRL)
ROE 61 PRL 7 346 +Sinclair Brown Glaser+ (MICH LRL)
FREDEN 60B PR 118 564 +Gilbert White (LRL)
BURROWES 59 PRL 2 117 +Caldwell Frisch Hill+ (MIT)
TAYLOR 59 PR 114 359 +Harris Orear Lee Baumel (COLU)
EISENBERG 58 NC 8 663 +Koch Lohrmann Nikolic+ (BERN)
ALEXANDER 57 NC 6 478 +Johnston Oceallaigh (DUUC)
COHEN 57 Fund Cons Phys +Crowe Dumond (NAAS LRL CIT)
COOMBES 57 PR 108 1348 +Cork Galbraith Lambertson Wenzel (LBL)
BIRGE 56 NC 4 834 +Perkins Peterson Stork Whitehead (LRL)
ILOFF 56 PR 102 927 +Goldhaber Lannutti Gilbert+ (LRL)

OTHER RELATED PAPERS ———

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FEARING 70 PR D2 542 +Fischbach Smith (STON BOHR)
HAIDT 69B PL 29B 696 + (AACH BARI CERN EPOL NIJM ORSA+)
CRONIN 68B Vienna Conf 241 (PRIN)
Rapporteur talk
WILLIS 67 Heidelberg Conf 273 (YALE)
Rapporteur talk
CABIBBO 66 Berkeley Conf 33 (CERN)
ADAIR 64 PL 12 67 +Leipuner (YALE BNL)
CABIBBO 64 PL 9 352 +Maksymowicz (CERN)
Also 64B PL 11 360 Cabibbo Maksymowicz (CERN)
Also 65 PL 14 72 Cabibbo Maksymowicz (CERN)
BIRGE 63 PRL 11 35 +Ely Gidal Camerini+ (LRL WISC BARI)
BLOCK 62B CERN Conf 371 +Lendinara Monari (NWES BGNA)
BRENE 61 NP 22 553 +Egardt Qvist (NORD)

K^0

$I(J^P) = \frac{1}{2}(0^-)$

K^0 MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
497.671 ± 0.030 OUR FIT					
497.676 ± 0.030 OUR AVERAGE					
497 661 ± 0 033	3713	BARKOV	87B	OSPK	$e^+e^- \to K_L^0 K_S^0$
497 742 ± 0 085	780	BARKOV	85B	OSPK	$e^+e^- \to K_L^0 K_S^0$
497.44 ± 0 50		FITCH	67	OSPK	
498 9 ± 0 5	4500	BALTAY	66	HBC	K^0 from $\bar{p}p$
497 44 ± 0.33	2223	KIM	65B	HBC	K^0 from $\bar{p}p$
498 1 ± 0 4		CHRISTENSON	64	OSPK	

$K^0 - K^{\pm}$ MASS DIFFERENCE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
4.024 ± 0.031 OUR FIT						
3.92 ± 0.14 OUR AVERAGE						
3 95 ± 0 21	417	HILL	68B	DBC	+	$K^+d \to K^0pp$
3 90 ± 0 25	9	BURNSTEIN	65	HBC	−	
3 71 ± 0 35	7	KIM	65B	HBC	−	$K^-p \to nK^0$
5.4 ± 1.1		CRAWFORD	59	HBC	+	
3 9 ± 0 6		ROSENFELD	59	HBC	−	

REFERENCES FOR K^0

BARKOV 87B SJNP 46 630 +Vasserman Vorobev Ivanov+ (NOVO)
Translated from YAF 46 1088
BARKOV 85B JETPL 42 138 +Blinov Vasserman+ (NOVO)
Translated from ZETFP 42 113
HILL 68B PR 168 1534 +Robinson Sakitt Canter (BNL CMU)
FITCH 67 PR 164 1711 +Roth Russ Vernon (PRIN)
BALTAY 66 PR 142 932 +Sandweiss Stonehill+ (YALE BNL)
BURNSTEIN 65 PR 138B 895 +Rubin (UMD)
KIM 65B PR 140B 1334 +Kirsch Miller (COLU)
CHRISTENSON 64 PRL 13 138 +Cronin Fitch Turlay (PRIN)
CRAWFORD 59 PRL 2 112 +Cresti Good Stevenson Ticho (LRL)
ROSENFELD 59 PRL 2 110 +Solmitz Tripp (LRL)

K^0_S $I(J^P) = \frac{1}{2}(0^-)$

K^0_S MEAN LIFE

For earlier measurements beginning with BOLDT 58B see our our 1986 edition Physics Letters 170B 130 (1986)

VALUE (10^{-10} sec)	EVTS	DOCUMENT ID	TECN	COMMENT
0.8922 ± 0.0020 OUR AVERAGE				
0 8920 ± 0 0044	214k	GROSSMAN 87	SPEC	E=100-350 GeV
0 881 ± 0 009	26k	ARONSON 76	SPEC	
0.8913 ± 0 0032		[1] CARITHERS 75	SPEC	
0 8937 ± 0 0048	6M	GEWENIGER 74B	ASPK	
0 8958 ± 0 0045	50k	[2] SKJEGGEST 72	HBC	
• • • We do not use the following data for averages fits limits etc • • •				
0 905 ± 0 007		[3] ARONSON 82B	SPEC	E=30-110 GeV
0 867 ± 0 024	2173	[4] FACKLER 73	OSPK	
0 856 ± 0 008	19994	[5] DONALD 68B	HBC	
0 872 ± 0 009	20000	[5,6] HILL 68	DBC	
0 866 ± 0 016		[5] ALFF 66B	OSPK	
0 843 ± 0 013	5000	[5] KIRSCH 66	HBC	

[1] CARITHERS 75 value is for $K^0_L - K^0_S$ mass difference $\Delta(m)$ = 0 5348 ± 0 0021 The $\Delta(m)$ dependence of the total decay rate (inverse mean life) is $\Gamma(K^0_S)$ = [(1 122 ± 0 004)+0 16($\Delta(m)$ − 0 5348) / $\Delta(m)$] 10^{10}/sec Value would not change with our current $\Delta(m)$ = 0 5349 ± 0 0022

[2] HILL 68 has been changed by the authors from the published value (0 865 ± 0 009) because of a correction in the shift due to η_{+-} SKJEGGESTAD 72 and HILL 68 give detailed discussions of systematics encountered in this type of experiment

[3] ARONSON 82 find that K^0_S mean life may depend on the kaon energy

[4] FACKLER 73 does not include systematic errors

[5] Pre-1971 experiments are excluded from the average because of disagreement with later more precise experiments

[6] HILL 68 has been changed by the authors from the published value (0.865 ± 0 009) because of a correction in the shift due to η_{+-} SKJEGGESTAD 72 and HILL 68 give detailed discussions of systematics encountered in this type of experiment

K^0_S DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$K^0_S \to \pi^+\pi^-$	$(68.61 \pm 0.26)\times 10^{-2}$	S=1 2
Γ_2	$K^0_S \to \pi^0\pi^0$	$(31\ 39 \pm 0\ 26)\times 10^{-2}$	S=1 2
Γ_3	$K^0_S \to \gamma\gamma$	$(2\ 4 \pm 1\ 2)\times 10^{-6}$	
Γ_4	$K^0_S \to \pi^+\pi^-\pi^0$	$< 5 \times 10^{-5}$	CL=90%
Γ_5	$K^0_S \to 3\pi^0$	$< 4 \times 10^{-5}$	CL=90%
Γ_6	$K^0_S \to \pi^+\pi^-\gamma$	$(1\ 85 \pm 0\ 10)\times 10^{-3}$	

FORBIDDEN BY CONSERVATION LAWS

	Mode	Fraction	
Γ_7	$K^0_S \to \mu^+\mu^-$	$< 3\ 2 \times 10^{-7}$	
Γ_8	$K^0_S \to e^+e^-$	$< 1\ 0 \times 10^{-5}$	

CONSTRAINED FIT INFORMATION

An overall fit to 3 branching ratios uses 17 measurements and one constraint to determine 2 parameters The overall fit has a χ^2 = 16 5 for 16 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i \delta x_j\rangle/(\delta x_i\ \delta x_j)$, in percent from the fit to the branching fractions $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

x_2	100
	x_1

K^0_S BRANCHING RATIOS

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ — Γ_1/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.6861 ± 0.0026 OUR FIT Error includes scale factor of 1 2				
0.671 ± 0.010 OUR AVERAGE				
0.670 ± 0 010	3447	[7] DOYLE 69	HBC	$\pi^- p \to \Lambda K^0$
0 70 ± 0.08		COLUMBIA 60B	HBC	
0 68 ± 0.04		CRAWFORD 59B	HBC	
• • • We do not use the following data for averages fits limits etc • • •				
0.740 ± 0.024		[7] ANDERSON 62B	HBC	

[7] Anderson result not published events added to Doyle sample

$\Gamma(\pi^+\pi^-)/\Gamma(\pi^0\pi^0)$ — Γ_1/Γ_2

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
2.186 ± 0.027 OUR FIT Error includes scale factor of 1 2				
2.197 ± 0.026 OUR AVERAGE				
2 11 ± 0 09	1315	EVERHART 76	WIRE	$\pi^- p \to \Lambda K^0$
2 169 ± 0 094	16k	COWELL 74	OSPK	$\pi^- p \to \Lambda K^0$
2 16 ± 0 08	4799	HILL 73	DBC	$K^+ d \to K^0 pp$
2 22 ± 0 10	3068	[8] ALITTI 72	HBC	$K^+ p \to \pi^+ p K^0$
2 22 ± 0.08	6380	MORSE 72B	DBC	$K^+ n \to K^0 p$
2 10 ± 0 11	701	[9] NAGY 72	HLBC	$K^+ n \to K^0 p$
2 22 ± 0 095	6150	[10] BALTAY 71	HBC	$Kp \to K^0$ neutrals
2 282 ± 0 043	7944	[11] MOFFETT 70	OSPK	$K^+ n \to K^0 p$
2 10 ± 0 06	3700	MORFIN 69	HLBC	$K^+ n \to K^0 p$
• • • We do not use the following data for averages fits limits etc • • •				
2 12 ± 0 17	267	[9] BOZOKI 69	HLBC	
2 285 ± 0 055	3016	[11] GOBBI 69	OSPK	$K^+ n \to K^0 p$

[8] The directly measured quantity is $K^0_S \to \pi^+\pi^-$ / all K^0 = 0 345 ± 0 005

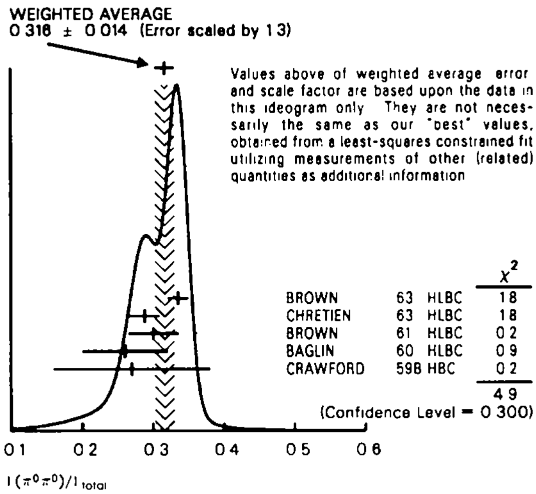
[9] NAGY 72 is a final result which includes BOZOKI 69

[10] The directly measured quantity is $K^0_S \to \pi^+\pi^-$ / all K^0 = 0 345 ± 0 005

[11] MOFFETT 70 is a final result which includes GOBBI 69

$\Gamma(\pi^0\pi^0)/\Gamma_{total}$ — Γ_2/Γ

VALUE	EVTS	DOCUMENT ID	TECN
0.3139 ± 0.0026 OUR FIT Error includes scale factor of 1 2			
0.316 ± 0.014 OUR AVERAGE Error includes scale factor of 1 3 See the ideogram below			
0 335 ± 0 014	1066	BROWN 63	HLBC
0 288 ± 0 021	198	CHRETIEN 63	HLBC
0 30 ± 0 035		BROWN 61	HLBC
0 26 ± 0 06		BAGLIN 60	HLBC
0 27 ± 0 11		CRAWFORD 59B	HBC



$\Gamma(\gamma\gamma)/\Gamma_{total}$ — Γ_3/Γ

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
0.0024 ± 0.0012		19	BURKHARDT 87	CALO	
• • • We do not use the following data for averages fits limits etc • • •					
< 0 133	90		BARMIN 86B	XEBC	
< 0 2	90		VASSERMAN 86	CALO	$\phi \to K^0_S K^0_L$
< 0 4	90	0	BARMIN 73B	HLBC	
< 0 71	90	0	[12] BANNER 72B	OSPK	
< 2 0	90	0	MORSE 72B	DBC	
< 2 2	90	0	[12] REPELLIN 71	OSPK	
<21 0	90	0	[12] BANNER 69	OSPK	

[12] These limits are for maximum interference in K^0_S-K^0_L to 2γ s

$\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{total}$ — Γ_4/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN	COMMENT
<0.49	90	BARMIN 85	HLBC	K^+ 850 MeV
• • • We do not use the following data for averages fits limits etc • • •				
<0 85	90	METCALF 72	ASPK	

$\Gamma(3\pi^0)/\Gamma_{total}$ — Γ_5/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN
<0.37	90	BARMIN 83	HLBC
• • • We do not use the following data for averages fits limits etc • • •			
<4 3	90	BARMIN 73	HLBC

$\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-)$ — Γ_6/Γ_1

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2 70 ± 0.14 OUR AVERAGE					
2 68 ± 0 15		[13] TAUREG	76	SPEC	p_γ 50 MeV/c
2 8 ± 0 6		[14] BURGUN	73	HBC	p_γ >50 MeV/c
3 3 ± 1 2	10	WEBBER	70	HBC	p_γ >50 MeV/c
no ratio given	27	BELLOTTI	66	HBC	p_γ >50 MeV/c
• • • We do not use the following data for averages fits limits etc • • •					
3 0 ± 0 6	29	[15] BOBISUT	74	HLBC	p_γ >40 MeV/c

[13]TAUREG 76 find direct emission contribution < 0 06 CL = 90%

[14]BURGUN 73 estimates that direct emission contribution is 0 3 ± 0 6

[15]BOBISUT 74 not included in average because p_γ cut differs Estimates direct emission contribution to be 0 5 or less CL = 95%

$\Gamma(\mu^+\mu^-)/\Gamma(\pi^+\pi^-)$ — Γ_7/Γ_1

Test for ΔS = 1 weak neutral current Allowed by first-order weak interaction combined with electromagnetic interaction

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN
< 0.047	90	GJESDAL	73	ASPK
• • • We do not use the following data for averages fits limits etc • • •				
<20 0	90	BOHM	69	OSPK
< 1 07	90	HYAMS	69B	OSPK
<32 6	90	[16] STUTZKE	69	OSPK
<10 0	90	BOTT	67	OSPK

[16]Value calculated by us using 2 3 instead of 1 event 90% CL

$\Gamma(e^+e^-)/\Gamma(\pi^+\pi^-)$ — Γ_8/Γ_1

Test for ΔS = 1 weak neutral current Allowed by first order weak interaction combined with electromagnetic interaction

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN
< 1.5	90	BARMIN	86	XEBC
• • • We do not use the following data for averages fits limits etc • • •				
<16 0	90	[17] BITSADZE	86	CALO
<50 0	90	BOHM	69	OSPK

[17]Use BR($\pi^+\pi^-$) = 0 6861

NOTE ON CP VIOLATION IN $K^0_S \to 3\pi$

For $K^0_S \to 3\pi$ the quantities which measure CP violation are the ratios of amplitudes

$$\eta_{+-0} = \frac{A_S(K_S \to \pi^+\pi^-\pi^0)}{A_L(K_L \to \pi^+\pi^-\pi^0)},$$

$$\eta_{000} = \frac{A_S(K_S \to \pi^0\pi^0\pi^0)}{A_L(K_L \to \pi^0\pi^0\pi^0)}$$

If one assumes that CPT invariance holds and that there are no transitions to I = 3 states then $\mathrm{Re}(\eta_{+-0})$ and $\mathrm{Re}(\eta_{000})$ can be neglected, and CP violation would be observed as nonzero values of $\mathrm{Im}(\eta_{+-0})$ and $\mathrm{Im}(\eta_{000})$ We list the relative rates

$$(\mathrm{Im}\eta_{+-0})^2 = \frac{\Gamma(K_S \to \pi^+\pi^-\pi^0)}{\Gamma(K_L \to \pi^+\pi^-\pi^0)}$$

$$(\mathrm{Im}\eta_{000})^2 = \frac{\Gamma(K_S \to \pi^0\pi^0\pi^0)}{\Gamma(K_L \to \pi^0\pi^0\pi^0)}$$

obtained under the above assumptions

In the above expressions the three pions are restricted to the dominant symmetric I = 1 state, a CP = −1 state which couples to K_S only if CP is violated The decay $K_S \to \pi^+\pi^-\pi^0$ also has CP-allowed amplitudes to I = 0 and I = 2 states of the three pions The angular momenta in these states cannot be S wave so they are strongly suppressed by centrifugal barrier effects, and, for the I = 2 state, by the ΔI = 1/2 rule as well

CP-VIOLATION PARAMETERS IN K^0_S DECAY

$\mathrm{Im}(\eta_{+-0})^2$

where η_{+-0} = A($K^0_S \to \pi^+\pi^-\pi^0$ CP violating) / A($K^0_L \to \pi^+\pi^-\pi^0$) CPT assumed valid (i e $\mathrm{Re}(\eta_{+-0})$ = 0)

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.12	90	384	METCALF	72	ASPK	
• • • We do not use the following data for averages fits limits etc • • •						
<0 23	90	601	[18] BARMIN	85	HLBC	K^+ 850 MeV
<1 2	90	192	BALDO-	75	HLBC	
<0 71	90	148	MALLARY	73	OSPK	Re(A)= − 0 05 ± 0 17
<0 66	90	180	JAMES	72	HBC	
<1 2	90	99	JONES	72	OSPK	
<1 2	90	99	CHO	71	DBC	
<1 0	90	98	JAMES	71	HBC	Incl in JAMES 72
<1 2	95	50	[19] MEISNER	71	HBC	CL=90% not avail
<0 8	90	71	WEBBER	70	HBC	
<0 45	90		BEHR	66	HLBC	
<3 8	90	18	ANDERSON	65	HBC	Incl in WEBBER 70

[18]BARMIN 85 find $\mathrm{Re}(\eta_{+-0})$ = (0 05 ± 0.17) and $\mathrm{Im}(\eta_{+-0})$ = (0 15 ± 0 33) Includes events of BALDO-CEOLIN 75

[19]These authors find Re(A) = 2 75 ± 0 65, above value at Re(A) = 0

$\mathrm{Im}(\eta_{000})^2$

where η_{000} = A($K^0_S \to 3\pi^0$ CP violating) / A($K^0_L \to 3\pi^0$) See text header for section $\mathrm{Im}(\eta_{+-0})^2$ above This limit determines branching ratio $\Gamma(3\pi^0)/\Gamma_{total}$ above

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.1	90	632	[20] BARMIN	83	HLBC	
• • • We do not use the following data for averages fits limits etc • • •						
<0 28	90		[21] GJESDAL	74B	SPEC	Indirect meas
<1 2	90	22	BARMIN	73	HLBC	

[20]BARMIN 83 find $\mathrm{Re}(\eta_{000})$ = (− 0 08 ± 0 18) and $\mathrm{Im}(\eta_{000})$ = (− 0 05 ± 0 27) Assuming CPT invariance they obtain the limit quoted above

[21]GJESDAL 74B uses $K2\pi$, $K_{\mu3}$ and K_{e3} decay results unitarity and CPT Calculates $|\eta_{000}|$ = 0 26 ± 0 20 We convert to upper limit

REFERENCES FOR K^0_S

BURKHARDT	87	PL B199 139	+	(CERN DORT EDIN MANZ ORSA PISA SIEG)
GROSSMAN	87	PRL 59 18	+Heller James Shupe+	(MINN MICH RUTG)
BARMIN	86	SJNP 44 622	+Barylov Davidenko Demidov+	(ITEP)
		Translated from YAF 44 965		
BARMIN	86B	NC 96A 159	+Barylov Chistyakova Chuvilo+	(ITEP PADO)
BITSADZE	86	PL 167B 138	+Budagov (BRAT SOFI SERP TBLI	JINR BAKU+)
VASSERMAN	86	JETPL 43 588	+Golubev Gluskin Druzhinin+	(SIBE)
		Translated from ZETFP 43 457		
BARMIN	85	NC 85A 67	+Barylov Chistyakova Chuvilo+	(ITEP PADO)
Also	85B	SJNP 41 759	Barmin Barylov Volkov+	(ITEP)
		Translated from YAF 41 1187		
BARMIN	83	PL 128B 129	+Barylov Chistyakova Chuvilo+	(ITEP PADO)
Also	84	SJNP 39 269	Barmin Barylov Golubchikov+	(ITEP PADO)
		Translated from YAF 39 428		
ARONSON	82	PRL 48 1078	+Bernstein+	(BNL CHIC STAN WISC)
ARONSON	82B	PRL 48 1306	+Bock Cheng Fischbach	(BNL CHIC PURD)
Also	82B	PL 116B 73	Fischbach Cheng+	(PURD BNL CHIC)
Also	83	PR D28 476	Aronson Bock Cheng+	(BNL CHIC PURD)
Also	83B	PR D28 495	Aronson Bock Cheng+	(BNL CHIC PURD)
ARONSON	76	NC 32A 236	+McIntyre Roehrig+	(WISC EFI UCSD ILLC)
EVERHART	76	PR D14 661	+Kraus Lande Long Lowenstein+	(PENN)
TAUREG	76	PL 65B 92	+Zech Dydak Navarria+	(HEID CERN DORT)
BALDO	75	NC 25A 688	Baldo Ceolin Bobisut Calimani+	(PADO WISC)
CARITHERS	75	PRL 34 1244	+Modis Nygren Pun+	(COLU NYU)
BOBISUT	74	LNC 11 646	+Huzita Mattioli Puglierin	(PADO)
COWELL	74	PR D10 2083	+Lee Franzini Orcutt Franzini+	(STON COLU)
GEWENIGER	74B	PL 48B 487	+Gjesdal Presser+	(CERN HEID)
GJESDAL	74B	PL 52B 119	+Presser Steffen+	(CERN HEID)
BARMIN	73	PL 46B 465	+Barylov Davidenko Demidov+	(ITEP)
BARMIN	73B	PL 47B 463	+Barylov Davidenko Demidov+	(ITEP)
BURGUN	73	PL 46B 481	+Bertranet Lesquoy Muller Pauli+	(SACL CERN)
FACKLER	73	PRL 31 847	+Frisch Martin Smoot Sompayrac	(MIT)
GJESDAL	73	PL 44B 217	+Presser Steffen Steinberger+	(CERN HEID)
HILL	73	PR D8 1290	+Sakitt Samios Burris Engler+	(BNL CMU)
MALLARY	73	PR D7 1953	+Binnie Gallivan Gomez Peck Sciulli+	(CIT)
ALITTI	72	PL 39B 568	+Lesquoy Muller	(SACL)
BANNER	72B	PRL 29 237	+Cronin Hoffman Knapp Shochet	(PRIN)
JAMES	72	NP B49 1	+Montanet Paul Saetre+	(CERN SACL OSLO)
JONES	72	NC 9A 151	+Abashian Graham Mantsch Orr Smith+	(ILL)
METCALF	72	PL 40B 703	+Neuhofer Niebergall+	(CERN IPN WIEN)
MORSE	72B	PRL 28 388	+Nauenberg Bierman Sager+(COLO	PRIN UMD)
NAGY	72	NP B47 94	+Telbisz Vestergombi	(BUDA)
Also	69	PL 30B 498	Bozoki Fenyves Gombosi Nagy+	(BUDA)
SKJEGGEST	72	NP B48 343	Skjeggestad James+	(OSLO CERN SACL)
BALTAY	71	PRL 27 1678	+Bridgewater Cooper Gershwin Habibi+	(COLU)
Also	71	Nevis 187 Thesis	Cooper	(COLU)
CHO	71	PR D3 1557	+Dralle Canter Engler Fisk+	(CMU BNL CASE)
JAMES	71	PL 35B 265	+Montanet Paul Pauli+	(CERN SACL OSLO)
MEISNER	71	PR D3 59	+Mann Hertzbach Kofler+	(MASA BNL YALE)
REPELLIN	71	PL 36B 603	+Wolff Chollet Gaillard Jane+	(ORSA CERN)
MOFFETT	70	BAPS 15 512	+Gobbi Green Hakel Rosen	(ROCH)
WEBBER	70	PR D1 1967	+Solmitz Crawford Alston Garnjost	(LRL)
Also	69	UCRL 19226 Thesis	Webber	(LRL)
BANNER	69	PR 188 2033	+Cronin Liu Pilcher	(PRIN)
BOHM	69	Thesis		(AACH)
BOZOKI	69	PL 30B 498	+Fenyves Gombosi Nagy+	(BUDA)
DOYLE	69	UCRL 18139 Thesis		(LRL)
GOBBI	69	PRL 22 682	+Green Hakel Moffett Rosen+	(ROCH)
HYAMS	69B	PL 29B 521	+Koch Potter VonLindern Lorenz+	(CERN MPIM)
MORFIN	69	PRL 23 660	+Sinclair	(MICH)

STUTZKE	69	PR 177 2009	+Abashian Jones Mantsch Orr Smith	(ILL)
DONALD	68B	PL 27B 58	+Edwards Nisar+	(LIVP CERN IPNP CDEF)
HILL	68	PR 171 1418	+Robinson Sakitt+	(BNL CMU)
BOTT	67	PL 24B 194	Bott Bodenhausen DeBouard Cassel+	(CERN)
ALFF	66B	PL 21 595	Alff Steinberger Heuer Kleinknecht+	(CERN)
BEHR	66	PL 22 540	+Brisson Petiau+	(EPOL MILA PADO ORSA)
BELLOTTI	66	NC 45A 737	+Pullia Baldo Ceolin+	(MILA PADO)
KIRSCH	66	PR 147 939	+Schmidt	(COLU)
ANDERSON	65	PRL 14 475	+Crawford Golden Stern Binford+	(LRL WISC)
BROWN	63	PR 130 769	+Kadyk Trilling Roe+	(LRL MICH)
CHRETIEN	63	PR 131 2208	+	(BRAN BROW HARV MIT)
ANDERSON	62B	CERN Conf 836	+Crawford+	(LRL)
BROWN	61	NC 19 1155	+Bryant Burnstein Glaser Kadyk+	(MICH)
BAGLIN	60	NC 18 1043	+Bloch Brisson Hennessy+	(EPOL)
COLUMBIA	60B	Rochester Conf 727	Schwartz+	(COLU)
CRAWFORD	59B	PRL 2 266	+Cresti Douglass Good Ticho+	(LRL)
BOLDT	58B	PRL 1 150	+Caldwell Pal	(MIT)

OTHER RELATED PAPERS

TRILLING	65B	UCRL 16473		(LRL)
		Updated from 1965 Argonne Conference page 115		
CRAWFORD	62	CERN Conf 827		(LRL)
FITCH	61	NC 22 1160	+Piroue Perkins	(PRIN LASL)
GOOD	61	PR 124 1223	+Matsen Muller Piccioni+	(LRL)
BIRGE	60	Rochester Conf 601	+Ely+	(LRL WISC)
MULLER	60	PRL 4 418	+Birge Fowler Good Piccioni+	(LRL BNL)

K_L^0

$I(J^P) = \frac{1}{2}(0^-)$

$(m(K_L^0) - m(K_S^0)) / \hbar$

For earlier measurements, beginning with GOOD 61 and FITCH 61 see our our 1986 edition Physics Letters 170B 132 (1986)

VALUE (10^{10} sec^{-1})	DOCUMENT ID		TECN	COMMENT
0.5349 ± 0.0022 OUR AVERAGE				
0.5340 ± 0.0030	GEWENIGER	74C	SPEC	Gap method
0.5334 ± 0.0040	GJESDAL	74	SPEC	Charge asymmetry
0.542 ± 0.006	CULLEN	70	CNTR	
• • • We do not use the following data for averages fits, limits etc • • •				
0.482 ± 0.014	[1] ARONSON	82B	SPEC	E=30–110 GeV
0.534 ± 0.007	[2] CARNEGIE	71	ASPK	Gap method
0.542 ± 0.006	[2] ARONSON	70	ASPK	Gap method

[1] ARONSON 82 find that $\Delta(m)$ may depend on the kaon energy

[2] ARONSON 70 and CARNEGIE 71 use K_S^0 mean life = $(0.862 \pm 0.006) \times 10^{-10}$ sec We have not attempted to adjust these values for the subsequent change in the K_S^0 mean life or in η_{+-}

K_L^0 MEAN LIFE

VALUE (10^{-8} sec)	EVTS	DOCUMENT ID		TECN
5.18 ± 0.04 OUR FIT				
5.16 ± 0.04 OUR AVERAGE				
5.154 ± 0.044	0.4M	VOSBURGH	72	CNTR
5.15 ± 0.14		DEVLIN	67	CNTR
$6.1^{+1.5}_{-1.2}$	1700	ASTBURY	65C	CNTR
5.3 ± 0.6		FUJII	64	OSPK
$5.1^{+2.4}_{-1.3}$	15	DARMON	62	FBC
$8.1^{+3.2}_{-2.4}$	34	BARDON	58	CNTR
• • • We do not use the following data for averages fits, limits, etc • • •				
5.0 ± 0.5		[3] LOWYS	67	HLBC

[3] Sum of partial decay rates

K_L^0 DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$K_L^0 \to 3\pi^0$	$(21.7 \pm 0.7) \times 10^{-2}$	S=1.4
Γ_2	$K_L^0 \to \pi^+\pi^-\pi^0$	$(12.37 \pm 0.18) \times 10^{-2}$	S=1.3
Γ_3	$K_L^0 \to \pi\mu\nu$	$(27.01 \pm 0.34) \times 10^{-2}$	S=1.2
	Called $K_{\mu3}$		
Γ_4	$K_L^0 \to \pi^-\mu^+\nu$		
Γ_5	$K_L^0 \to \pi^+\mu^-\nu$		
Γ_6	$K_L^0 \to \pi e\nu$	$(38.6 \pm 0.4) \times 10^{-2}$	S=1.2
	Called K_{e3}		
Γ_7	$K_L^0 \to \pi^-e^+\nu$		
Γ_8	$K_L^0 \to \pi^+e^-\nu$		
Γ_9	$K_L^0 \to \pi^+\pi^-$	$(2.04 \pm 0.04) \times 10^{-3}$	S=1.2
Γ_{10}	$K_L^0 \to \pi^0\pi^0$	$(9.09 \pm 0.29) \times 10^{-4}$	S=1.6
Γ_{11}	$K_L^0 \to 2\gamma$	$(5.70 \pm 0.23) \times 10^{-4}$	S=1.7
Γ_{12}	$K_L^0 \to \pi^0 2\gamma$	$< 2.4 \times 10^{-4}$	
Γ_{13}	$K_L^0 \to \pi^0\pi^\pm e^\mp\nu$	$(6.2 \pm 2.0) \times 10^{-5}$	
Γ_{14}	$K_L^0 \to (\pi\mu$ atom$)\nu$	$(1.05 \pm 0.11) \times 10^{-7}$	
Γ_{15}	$K_L^0 \to \pi e\nu\gamma$	$(1.3 \pm 0.8) \times 10^{-2}$	
Γ_{16}	$K_L^0 \to \pi^+\pi^-\gamma$	$(4.41 \pm 0.32) \times 10^{-5}$	

FORBIDDEN BY CONSERVATION LAWS

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_{17}	$K_L^0 \to e\mu$	$< 7 \times 10^{-9}$	CL=90%
Γ_{18}	$K_L^0 \to \mu^+\mu^-$	$(9.5^{+2.4}_{-1.5}) \times 10^{-9}$	
Γ_{19}	$K_L^0 \to \mu^+\mu^-\gamma$	$(2.8 \pm 2.8) \times 10^{-7}$	
Γ_{20}	$K_L^0 \to \pi^0\mu^+\mu^-$	$< 1.2 \times 10^{-6}$	CL=90%
Γ_{21}	$K_L^0 \to e^+e^-$	$< 5 \times 10^{-9}$	CL=90%
Γ_{22}	$K_L^0 \to e^+e^-\gamma$	$(1.7 \pm 0.9) \times 10^{-5}$	
Γ_{23}	$K_L^0 \to \pi^0e^+e^-$	$< 2.3 \times 10^{-6}$	CL=90%
Γ_{24}	$K_L^0 \to \pi^+\pi^-e^+e^-$	$< 2.5 \times 10^{-6}$	CL=90%
Γ_{25}	$K_L^0 \to \mu^+\mu^-e^+e^-$	$< 5 \times 10^{-6}$	CL=90%
Γ_{26}	$K_L^0 \to e^+e^-e^+e^-$	$< 2.6 \times 10^{-6}$	CL=90%

CONSTRAINED FIT INFORMATION

An overall fit to the mean life, 6 partial widths, and 14 branching ratios uses 76 measurements and one constraint to determine 8 parameters The overall fit has a χ^2 = 78.3 for 69 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta p_i \delta p_j\rangle/(\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

x_2	45						
x_3	77	17					
x_6	−85	20	40				
x_9	28	39	15	17			
x_{10}	5	15	0	0	46		
x_{11}	3	6	5	5	27	61	
Γ	11	−10	−7	−9	−5	−1	0
	x_1	x_2	x_3	x_6	x_9	x_{10}	x_{11}

	Mode	Rate (10^8 sec^{-1})	Scale
Γ_1	$K_L^0 \to 3\pi^0$	0.0419 ± 0.0014	1.3
Γ_2	$K_L^0 \to \pi^+\pi^-\pi^0$	0.0239 ± 0.0004	1.2
Γ_3	$K_L^0 \to \pi\mu\nu$	0.0521 ± 0.0007	1.1
	Called $K_{\mu3}$		
Γ_6	$K_L^0 \to \pi e\nu$	0.0745 ± 0.0010	1.1
	Called K_{e3}		
Γ_9	$K_L^0 \to \pi^+\pi^-$	0.000393 ± 0.000008	1.1
Γ_{10}	$K_L^0 \to \pi^0\pi^0$	0.000175 ± 0.000006	1.5
Γ_{11}	$K_L^0 \to 2\gamma$	0.000110 ± 0.000005	1.7

K_L^0 DECAY RATES

$\Gamma(3\pi^0)$ — Γ_1

VALUE (10^6 sec^{-1})	EVTS	DOCUMENT ID		TECN	COMMENT
4.19 ± 0.14 OUR FIT Error includes scale factor of 1.3					
$5.22^{+1.03}_{-0.84}$	54	BEHR	66	HLBC	Assumes *CP*

$\Gamma(\pi^+\pi^-\pi^0)$ — Γ_2

VALUE (10^6 sec^{-1})	EVTS	DOCUMENT ID		TECN	COMMENT
2.39 ± 0.04 OUR FIT Error includes scale factor of 1.2					
2.34 ± 0.11 OUR AVERAGE Error includes scale factor of 1.2					
$2.32^{+0.13}_{-0.15}$	192	BALDO	75	HLBC	Assumes *CP*
2.35 ± 0.20	180	[4] JAMES	72	HBC	Assumes *CP*
2.71 ± 0.28	99	CHO	71	DBC	Assumes *CP*
2.12 ± 0.33	50	MEISNER	71	HBC	Assumes *CP*
2.20 ± 0.35	53	WEBBER	70	HBC	Assumes *CP*
$2.62^{+0.28}_{-0.27}$	136	BEHR	66	HLBC	Assumes *CP*
3.26 ± 0.77	18	ANDERSON	65	HBC	
1.4 ± 0.4	14	FRANZINI	65	HBC	

• • • We do not use the following data for averages fits limits etc • • •

2 5 ±0 3	98	[4] JAMES	71	HBC	Assumes *CP*

In the fit this rate is well determined by the mean life and the branching ratio $\Gamma(\pi^+\pi^-\pi^0)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ For this reason the discrepancy between the $\Gamma(\pi^+\pi^-\pi^0)$ measurements does not affect the scale factor of the overall fit

[4] JAMES 72 is a final measurement and includes JAMES 71

$\Gamma(\pi\mu\nu)$ — Γ_3

VALUE (10^6 sec^{-1})	EVTS	DOCUMENT ID		TECN
5.21 ± 0 07 OUR FIT Error includes scale factor of 1 1				
$4\ 54^{+1\ 24}_{-1\ 08}$	19	LOWYS	67	HLBC

$\Gamma(\pi e\nu)$ — Γ_6

VALUE (10^6 sec^{-1})	EVTS	DOCUMENT ID		TECN	COMMENT
7.45 ± 0.10 OUR FIT Error includes scale factor of 1 1					
$7.7\ ^{+0.5}_{-0.4}$ **OUR AVERAGE**					
7 81 ± 0 56	620	CHAN	71	HBC	
$7\ 52^{+0\ 85}_{-0\ 72}$		AUBERT	65	HLBC	$\Delta S=\Delta Q$ *CP* assumed

$\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)$ — $(\Gamma_2+\Gamma_3+\Gamma_6)$

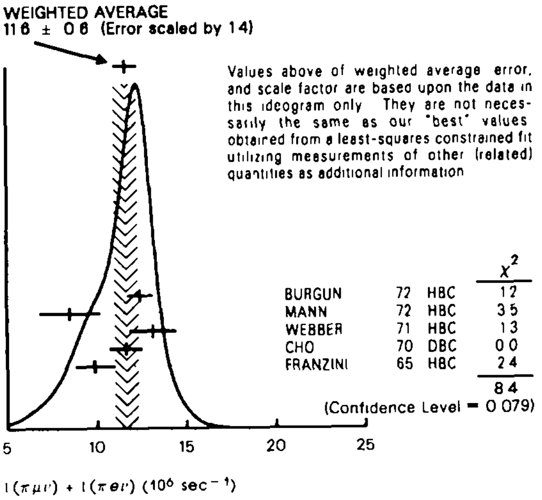
$K_L^0 \to$ charged

VALUE (10^6 sec^{-1})	EVTS	DOCUMENT ID		TECN
15.05 ± 0.17 OUR FIT Error includes scale factor of 1 1				
15.1 ± 1.9	98	AUERBACH	66B	OSPK

$\Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)$ — $(\Gamma_3+\Gamma_6)$

VALUE (10^6 sec^{-1})	EVTS	DOCUMENT ID		TECN	COMMENT
12 66 ± 0.15 OUR FIT Error includes scale factor of 1 2					
11.6 ± 0 6 OUR AVERAGE Error includes scale factor of 1 4 See the ideogram below					
12 4 ± 0 7	410	[5] BURGUN	72	HBC	$K^+p \to K^0p\pi^+$
8 47 ± 1 69	126	[5] MANN	72	HBC	$K^-p \to nK^0$
13.1 ± 1 3	252	[5] WEBBER	71	HBC	$K^-p \to nK^0$
11 6 ± 0 9	393	[5,6] CHO	70	DBC	$K^+n \to K^0p$
$9.85^{+1\ 15}_{-1\ 05}$	109	[5] FRANZINI	65	HBC	
• • • We do not use the following data for averages fits limits etc • • •					
10 3 ± 0 8	335	[6] HILL	67	DBC	$K^+n \to K^0p$

[5] Assumes $\Delta S = \Delta Q$ rule
[6] CHO 70 includes events of HILL 67



K_L^0 BRANCHING RATIOS

$\Gamma(3\pi^0)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_1/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
1.75 ± 0.07 OUR FIT Error includes scale factor of 1 3					
1.81 ± 0 13 OUR AVERAGE					
1 80 ± 0 13	1010	BUDAGOV	68	HLBC	
2 0 ± 0 6	188	ALEKSANYAN	64B	FBC	
• • • We do not use the following data for averages fits limits etc • • •					
1 65 ± 0 07	883	BARMIN	72B	HLBC	Error statistical only

$\Gamma(3\pi^0)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ — $\Gamma_1/(\Gamma_2+\Gamma_3+\Gamma_6)$

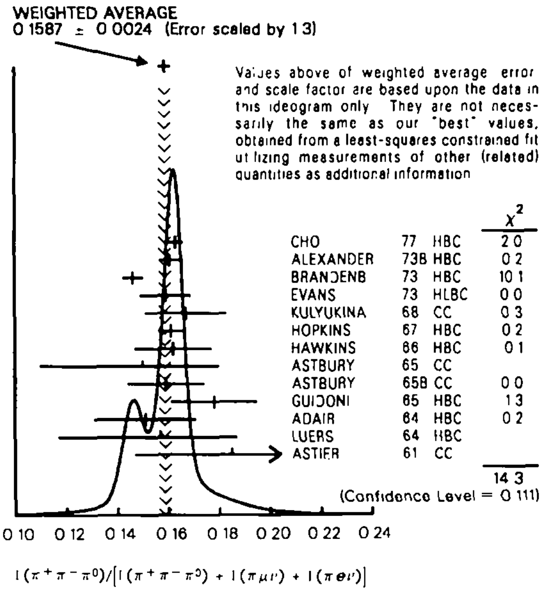
VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.278 ± 0.012 OUR FIT Error includes scale factor of 1 4					
0.260 ± 0.011 OUR AVERAGE					
0.251 ± 0 014	549	BUDAGOV	68	HLBC	ORSAY measur
0 277 ± 0 021	444	BUDAGOV	68	HLBC	Ecole polytec meas
$0\ 31\ ^{+0\ 07}_{-0\ 06}$	29	KULYUKINA	68	CC	
0 24 ± 0 08	24	ANIKINA	64	CC	

$\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{total}$ — Γ_2/Γ

VALUE	DOCUMENT ID
0.1237 ± 0.0018 OUR FIT Error includes scale factor of 1 3	

$\Gamma(\pi^+\pi^-\pi^0)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ — $\Gamma_2/(\Gamma_2+\Gamma_3+\Gamma_6)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.1586 ± 0.0021 OUR FIT Error includes scale factor of 1 3					
0.1587 ± 0.0024 OUR AVERAGE Error includes scale factor of 1 3 See the ideogram below					
0 163 ± 0.003	6499	CHO	77	HBC	
0 1605 ± 0 0038	1590	ALEXANDER	73B	HBC	
0 146 ± 0 004	3200	BRANDENB	73	HBC	
0 159 ± 0 010	558	EVANS	73	HLBC	
0 167 ± 0 016	1402	KULYUKINA	68	CC	
0 161 ± 0 005		HOPKINS	67	HBC	
0 162 ± 0 015	126	HAWKINS	66	HBC	
$0\ 15\ ^{+0\ 03}_{-0\ 04}$	66	ASTBURY	65	CC	
0 159 ± 0 015	326	ASTBURY	65B	CC	
0 178 ± 0 017	566	GUIDONI	65	HBC	
0 151 ± 0 020	79	ADAIR	64	HBC	
$0\ 157\ ^{+0\ 03}_{-0\ 04}$	75	LUERS	64	HBC	
0 185 ± 0.038	59	ASTIER	61	CC	
• • • We do not use the following data for averages fits limits etc • • •					
0 144 ± 0 004	1729	HOPKINS	65	HBC	See HOPKINS 67



$\Gamma(\pi\mu\nu)/\Gamma(\pi e\nu)$ — Γ_3/Γ_6

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.700 ± 0.009 OUR FIT					
0.700 ± 0.009 OUR AVERAGE					
0 702 ± 0 011	33k	CHO	80	HBC	
0 662 ± 0 037	10k	WILLIAMS	74	ASPK	
0 741 ± 0.044	6700	BRANDENB	73	HBC	
0 662 ± 0 030	1309	EVANS	73	HLBC	
0 68 ± 0 08	3548	BASILE	70	OSPK	
0 71 ± 0 05	770	BUDAGOV	68	HLBC	
0 82 ± 0 10		DEBOUARD	67	OSPK	
0 7 ± 0 2	273	HAWKINS	67	HBC	
0 81 ± 0 08		HOPKINS	67	HBC	
0 81 ± 0 19		ADAIR	64	HBC	
• • • We do not use the following data for averages fits limits etc • • •					
0 71 ± 0 04	569	[7] BEILLIERE	69	HLBC	
0 648 ± 0 030	1309	EVANS	69	HLBC	Repl by EVANS 73
0 67 ± 0 13		[8] KULYUKINA	68	CC	

[7] BEILLIERE 69 is a scanning experiment using same exposure as BUDAGOV 68

[8] KULYUKINA 68 $\Gamma(\pi\mu\nu)/\Gamma(\pi e\nu)$ is not measured independently from $\Gamma(\pi^+\pi^-\pi^0)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ and $\Gamma(\pi e\nu)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$

$\Gamma(\pi\mu\nu)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ — $\Gamma_3/(\Gamma_2+\Gamma_3+\Gamma_6)$

VALUE	EVTS	DOCUMENT ID		TECN
0.3464 ± 0.0028 OUR FIT				
• • • We do not use the following data for averages fits limits etc • • •				
0 335 ± 0 055	330	[9] KULYUKINA	68	CC
0 39 $^{+0\ 08}_{-0\ 10}$	172	[9] ASTBURY	65	CC
0 356 ± 0 07	251	[9] LUERS	64	HBC

[9]This mode not measured independently from $\Gamma(\pi^+\pi^-\pi^0)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ and $\Gamma(\pi e\nu)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$

$\Gamma(\pi e\nu)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ — $\Gamma_6/(\Gamma_2+\Gamma_3+\Gamma_6)$

VALUE	EVTS	DOCUMENT ID		TECN
0.4949 ± 0.0029 OUR FIT				
0.485 $^{+0.031}_{-0.032}$ OUR AVERAGE				
0 498 ± 0 052	500	KULYUKINA	68	CC
0 46 $^{+0\ 08}_{-0\ 10}$	202	ASTBURY	65	CC
0 487 ± 0 05	153	LUERS	64	HBC
0 46 ± 0 11	24	NYAGU	61	CC

$\Gamma(\pi e\nu)/[\Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ — $\Gamma_6/(\Gamma_3+\Gamma_6)$

VALUE	EVTS	DOCUMENT ID		TECN
0.5882 ± 0.0032 OUR FIT				
0.415 ± 0 120	320	ASTIER	61	CC

$[\Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]/\Gamma_{total}$ — $(\Gamma_3+\Gamma_6)/\Gamma$

VALUE	DOCUMENT ID
0.656 ± 0.006 OUR FIT Error includes scale factor of 1 4	

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ — Γ_9/Γ

Violates *CP* conservation

VALUE (units 10^{-3})	DOCUMENT ID	
2.04 ± 0.04 OUR FIT Error includes scale factor of 1 2		
2.105 ± 0.056	[10] ETAFIT	88

[10]This ETAFIT value is computed from fitted values of η_{+-}, the K^0_L and K^0_S lifetimes and the $K^0_S \to \pi^+\pi^-$ branching fraction See the discussion in the Note on *CP* violation in K^0_L decay

$\Gamma(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_9/Γ_2

Violates *CP* conservation

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
1.645 ± 0.031 OUR FIT Error includes scale factor of 1 1					
1.64 ± 0.04	4200	MESSNER	73	ASPK	η_{+-} = 2 23

$\Gamma(\pi^+\pi^-)/[\Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ — $\Gamma_9/(\Gamma_3+\Gamma_6)$

Violates *CP* conservation

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
3.10 ± 0 06 OUR FIT Error includes scale factor of 1 2					
3.09 ± 0.10 OUR AVERAGE					
3.13 ± 0 14	1687	COUPAL	85	SPEC	η_{+-}=2.28 ± 0 06
3 04 ± 0 14	2703	DEVOE	77	SPEC	η_{+-}=2 25 ± 0 05
• • • We do not use the following data for averages fits limits etc • • •					
2 51 ± 0 23	309	[11] DEBOUARD	67	OSPK	η_{+-}=2 00 ± 0 09
2.35 ± 0 19	525	[11] FITCH	67	OSPK	η_{+-}=1.94 ± 0 08

[11]Old experiments excluded from fit See subsection on η_{+-} in section on "PARAMETERS FOR $K^0_L \to 2\pi$ DECAY below for average η_{+-} of these experiments and for note on discrepancy

$\Gamma(\pi^+\pi^-)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ — $\Gamma_9/(\Gamma_2+\Gamma_3+\Gamma_6)$

Violates *CP* conservation

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.61 ± 0.05 OUR FIT Error includes scale factor of 1 1					
• • • We do not use the following data for averages fits limits etc • • •					
2 60 ± 0 07	4200	[12] MESSNER	73	ASPK	η_{+-} = 2 23 ± 0 05
1 93 ± 0 26		[13] BASILE	66	OSPK	η_{+-} = 1 92 ± 0 13
1 993 ± 0 080		[13] BOTT	66	OSPK	η_{+-} = 1 95 ± 0 04
2 08 ± 0 35	54	[13] GALBRAITH	65	OSPK	η_{+-} = 1 99 ± 0 16
2 0 ± 0 4	45	[13] CHRISTENSON	64	OSPK	η_{+-} = 1 95 ± 0 20

[12]From same data as $\Gamma(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ MESSNER 73 but with different normalization

[13]Old experiments excluded from fit See subsection on η_{+-} in section on PARAMETERS FOR $K^0_L \to 2\pi$ DECAY below for average η_{+-} of these experiments and for note on discrepancy

$\Gamma(\pi^0\pi^0)/\Gamma_{total}$ — Γ_{10}/Γ

Violates *CP* conservation

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.909 ± 0.029 OUR FIT Error includes scale factor of 1 6					
• • • We do not use the following data for averages fits limits etc • • •					
2 5 ± 0 8	189	[14] GAILLARD	69	OSPK	η_{00}=3 6 ± 0 6
1 2 $^{+1\ 5}_{-1\ 2}$	7	[15] CRIEGEE	66	OSPK	

[14]Latest result of this experiment given by FAISSNER 70 $\Gamma(\pi^0\pi^0)/\Gamma(3\pi^0)$

[15]CRIEGEE 66 experiment not designed to measure $2\pi^0$ decay mode

$\Gamma(\pi^0\pi^0)/\Gamma(3\pi^0)$ — Γ_{10}/Γ_1

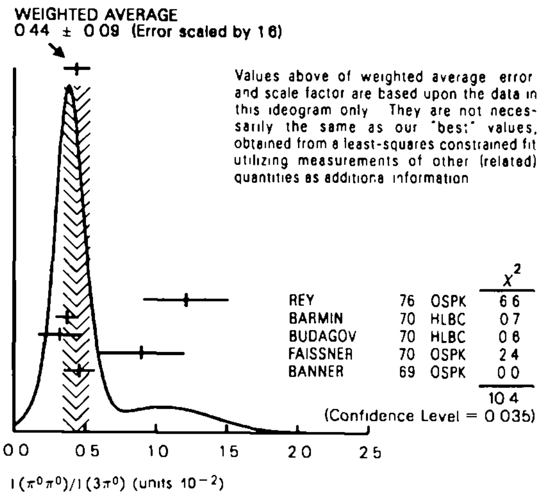
Violates *CP* conservation

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
0.419 ± 0 019 OUR FIT Error includes scale factor of 1 4					
0.44 ± 0 09 OUR AVERAGE Error includes scale factor of 1 6 See the ideogram below					
1 21 ± 0 30	150	[16] REY	76	OSPK	η_{00}=3 8 ± 0 5
0 37 ± 0 08	29	BARMIN	70	HLBC	η_{00}=2 02 ± 0 23
0 32 ± 0 15	30	BUDAGOV	70	HLBC	η_{00}=1 9 ± 0 5
0 90 ± 0 30	172	[17] FAISSNER	70	OSPK	η_{00}=3 2 ± 0 5
0 46 ± 0 11	57	BANNER	69	OSPK	η_{00}=2 2 ± 0 3
no events seen		BARTLETT	68	OSPK	See η_{00} below
• • • We do not use the following data for averages fits limits etc • • •					
1 31 ± 0 31	133	[16] CENCE	69	OSPK	η_{00}=3 7 ± 0 5
1 89 ± 0 31	109	[18] CRONIN	67	OSPK	η_{00}=4 9 ± 0 5
1 36 ± 0 18		[18] CRONIN	67B	OSPK	η_{00}=3 92 − 0 3

[16]CENCE 69 events are included in REY 76

[17]FAISSNER 70 contains same $2\pi^0$ events as GAILLARD 69 $\Gamma(\pi^0\pi^0)/\Gamma_{total}$

[18]CRONIN 67B is further analysis of CRONIN 67 now both withdrawn



$\Gamma(\pi^0\pi^0)/\Gamma(\pi^+\pi^-)$ — Γ_{10}/Γ_9

Violates *CP* conservation

VALUE	DOCUMENT ID	
0 446 ± 0.013 OUR FIT Error includes scale factor of 2 1		
0.4494 ± 0.0062	[19] ETAFIT	88

[19]This ETAFIT value is computed from fitted values of η_{00}, η_{+-}, and the $\Gamma(K^0_S \to \pi^+\pi^-)$, $\Gamma(K^0_S \to \pi^0\pi^0)$ branching fraction See the discussion in the Note on *CP* violation in K^0_L decay

$\Gamma(2\gamma)/\Gamma_{total}$ — Γ_{11}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
5.70 ± 0.23 OUR FIT Error includes scale factor of 1 7					
4.9 ± 0.5 OUR AVERAGE					
4 54 ± 0 84		[20] BANNER	72B	OSPK	
4.5 ± 1 0	23	ENSTROM	71	OSPK	K^0_L 1 5–9 GeV/c
5 5 ± 1 1	90	KUNZ	68	OSPK	Norm to 3 π(C+N)
6 7 ± 2 2	32	TODOROFF	67	OSPK	Repl CRIEGEE 66
• • • We do not use the following data for averages fits limits etc • • •					
6 04 ± 0 04 ± 0 22	110k	[21] BURKHARDT	87	CALO	
5 0 ± 1 0		[22] REPELLIN	71	OSPK	
7 4 ± 1 6	33	[23] CRONIN	67	OSPK	
1 3 ± 0 6		[24] CRIEGEE	66	OSPK	

$\Gamma(2\gamma)/\Gamma(3\pi^0)$ below gives (4 82 ± 52) × 10^{-4} Combined average (4 85 ± 37) × 10^{-4}

[20]This value uses $(\eta_{00}/\eta_{+-})^2$ = 1 05 ± 0 14 In general $\Gamma(2\gamma)/\Gamma_{total}$ = (4 32 ± 0 55) × $10^{-4}[\eta_{00}/\eta_{+-}]^2$

[21]BURKHARDT 87 measured $K^0_L \to (2\gamma)/K^0_L \to (2\pi^0)$ The systematic error is ± 0 08 combined in quadrature with an external systematic error from η_{00} of ± 0 20 Enters fit via $\Gamma(2\gamma)/\Gamma(\pi^0\pi^0)$ below

[22]Assumes regeneration amplitude in copper at 2 GeV is 22 mb To evaluate for a given regeneration amplitude and error multiply by (regeneration amplitude/22mb)^2

[23]CRONIN 67 replaced by KUNZ 68

[24]CRIEGEE 66 replaced by TODOROFF 67

$\Gamma(2\gamma)/\Gamma(3\pi^0)$ — Γ_{11}/Γ_1

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.63 ± 0.13 OUR FIT Error includes scale factor of 1 4					
2.24 ± 0.22 OUR AVERAGE					
2 13 ± 0 43	28	BARMIN	71	HLBC	
2 24 ± 0 28	115	BANNER	69	OSPK	
2 5 ± 0 7	16	ARNOLD	68B	HLBC	Vacuum decay

$\Gamma(2\gamma)/\Gamma(\pi^0\pi^0)$ — Γ_{11}/Γ_{10}

VALUE	EVTS	DOCUMENT ID		TECN
0.627 ± 0.021 OUR FIT Error includes scale factor of 2 4				
0.632 ± 0 004 ± 0 008	110k	BURKHARDT	87	CALO

$\Gamma(\pi^0 2\gamma)/\Gamma(3\pi^0)$ — Γ_{12}/Γ_1

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN
<1 1	90	0	BANNER	69	OSPK

$\Gamma(\pi^0\pi^\pm e^\mp\nu)/\Gamma_{total}$ — Γ_{13}/Γ

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN
0.062 ± 0.020		16	CARROLL	80C	SPEC
• • • We do not use the following data for averages fits limits, etc • • •					
<2 2	90		[25] DONALDSON	74	SPEC

[25] DONALDSON 74 uses $K_L^0 \to \pi^+\pi^-\pi^0$ / (all K_L^0) decays = 0 126

$\Gamma((\pi\mu \text{ atom})\ \nu)/\Gamma(\pi\mu\nu)$ — Γ_{14}/Γ_3

VALUE (units 10^{-7})	EVTS	DOCUMENT ID		TECN
3.90 ± 0.39	155	[26] ARONSON	86	SPEC
• • • We do not use the following data for averages fits limits etc • • •				
SEEN	18	COOMBES	76	WIRE

[26] ARONSON 86 quote theoretical value of (4 31 ± 0 08) × 10^{-7}

$\Gamma(\pi e\nu\gamma)/\Gamma(\pi e\nu)$ — Γ_{15}/Γ_6

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
3.3 ± 2.0	10	PEACH	71	HLBC	γ KE > 15 MeV

$\Gamma(\pi^+\pi^-\gamma)/\Gamma_{total}$ — Γ_{16}/Γ

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.0441 ± 0.0032		1062	[27] CARROLL	80B	SPEC	±0	γ KE > 20 MeV
• • • We do not use the following data for averages fits limits etc • • •							
0.0152 ± 0 0016		516	[28] CARROLL	80B	SPEC	±0	γ KE > 20 MeV
0 0289 ± 0 0028		546	[29] CARROLL	80B	SPEC	±0	
< 3 2	90		BOBISUT	74	HLBC		γ KE > 40 MeV
0 062 ± 0 021		24	[30] DONALDSON	74C	SPEC		
< 0 46	90		WOO	74	SPEC		
< 0 4	90		THATCHER	68	OSPK		γ KE 20–170 MeV
< 5 0		0	BELLOTTI	66	HLBC		γ KE 40–130 MeV
< 3 0		1	NEFKENS	66	OSPK		γ KE 120 MeV
<15 0			ANIKINA	65	CC		

[27] Both components Uses $K_L^0 \to \pi^+\pi^-\pi^0$ / (all K_L^0) decays = 0 1239
[28] Internal Bremsstrahlung component only
[29] Direct γ emission component only
[30] Uses $K_L^0 \to \pi^+\pi^-\pi^0$ / (all K_L^0) decays = 0 126

$\Gamma(e\mu)/\Gamma_{total}$ — Γ_{17}/Γ

VALUE (units 10^{-9})	CL%	DOCUMENT ID		TECN
<6.7	90	GREENLEE	88	SPEC
• • • We do not use the following data for averages fits limits etc • • •				
<1 57	90	[31] CLARK	71	ASPK

[31] Possible (but unknown) systematic errors See note on CLARK 71 $\Gamma(\mu^+\mu^-)/\Gamma(\pi^+\pi^-)$ entry

$\Gamma(e\mu)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ — $\Gamma_{17}/(\Gamma_2+\Gamma_3+\Gamma_6)$

Test of lepton family number conservation

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN
< 0 08	90	FITCH	67	OSPK
• • • We do not use the following data for averages fits limits etc • • •				
< 0 1	90	BOTT	67	OSPK
< 1 0	90	CARPENTER	66	OSPK
<10 0		ANIKINA	65	CC

$\Gamma(\mu^+\mu^-)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ — $\Gamma_{18}/(\Gamma_2+\Gamma_3+\Gamma_6)$

Test for ΔS = 1 weak neutral current Allowed by higher order electroweak interaction

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •				
< 2 0	90	BOTT	67	OSPK
< 35 0	90	FITCH	67	OSPK
<250 0	90	ALFF	66B	OSPK
<100 0		ANIKINA	65	CC

$\Gamma(\mu^+\mu^-)/\Gamma(\pi^+\pi^-)$ — Γ_{18}/Γ_9

Test for ΔS = 1 weak neutral current Allowed by higher order electroweak interaction

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN
$4.7^{+1.2}_{-0.7}$ OUR AVERAGE					
$4\ 0^{+1\ 4}_{-0\ 9}$		15	SHOCHET	79	SPEC
$4\ 2^{+5\ 1}_{-2\ 6}$		3	[32] FUKUSHIMA	76	SPEC
$5\ 8^{+2\ 3}_{-1\ 5}$		9	[33] CARITHERS	73	SPEC
• • • We do not use the following data for averages, fits limits etc • • •					
< 1 53	90	0	[34] CLARK	71	SPEC
< 18	90	0	DARRIULAT	70	SPEC
<140	90	0	FOETH	69	SPEC

[32] FUKUSHIMA 76 errors are at CL = 90%
[33] CARITHERS 73 errors are at CL = 68% W Carithers, (private communication 79)
[34] CLARK 71 limit raised from 1 2 × 10^{-6} by FIELD 74 reanalysis Not in agreement with subsequent experiments So not averaged

$\Gamma(\mu^+\mu^-\gamma)/\Gamma_{total}$ — Γ_{19}/Γ

Test for ΔS = 1 weak neutral current Allowed by higher order electroweak interaction

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN	CHG
0 28 ± 0.28		1	[35] CARROLL	80D	SPEC	±0
• • • We do not use the following data for averages fits limits etc • • •						
<7 81	90		[36] DONALDSON	74	SPEC	

[35] Uses $K_L^0 \to \pi^+\pi^-\pi^0$ / (all K_L^0) decays = 0 1239
[36] Uses $K_L^0 \to \pi^+\pi^-\pi^0$ / (all K_L^0) decays = 0 126

$\Gamma(\pi^0\mu^+\mu^-)/\Gamma_{total}$ — Γ_{20}/Γ

Test for ΔS = 1 weak neutral current Allowed by higher order electroweak interaction

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN
<0.12	90	0	[37] CARROLL	80D	SPEC
• • • We do not use the following data for averages fits limits etc • • •					
<5 66	90		[38] DONALDSON	74	SPEC

[37] Uses $K_L^0 \to \pi^+\pi^-\pi^0$ / (all K_L^0) decays = 0 1239
[38] Uses $K_L^0 \to \pi^+\pi^-\pi^0$ / (all K_L^0) decays = 0 126

$\Gamma(e^+e^-)/\Gamma_{total}$ — Γ_{21}/Γ

Test for ΔS = 1 weak neutral current Allowed by higher order electroweak interaction

VALUE (units 10^{-9})	CL%	EVTS	DOCUMENT ID		TECN
< 4.5	90		GREENLEE	88	SPEC
• • • We do not use the following data for averages fits limits etc • • •					
< 1 57	90		[39] CLARK	71	ASPK
<150 0	90	0	FOETH	69	ASPK

[39] Possible (but unknown) systematic errors See note on CLARK 71 $\Gamma(\mu^+\mu^-)/\Gamma(\pi^+\pi^-)$ entry

$\Gamma(e^+e^-)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi\mu\nu) + \Gamma(\pi e\nu)]$ — $\Gamma_{21}/(\Gamma_2+\Gamma_3+\Gamma_6)$

Test for ΔS = 1 weak neutral current Allowed by higher order electroweak interaction

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •				
< 23 0	90	BOTT	67	OSPK
< 200 0	90	ALFF-	66B	OSPK
<1000 0		ANIKINA	65	CC

$\Gamma(e^+e^-\gamma)/\Gamma_{total}$ — Γ_{22}/Γ

Test for ΔS = 1 weak neutral current Allowed by higher-order electroweak interaction

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN	CHG
1.74 ± 0.87		4	[40] CARROLL	80D	SPEC	±0
• • • We do not use the following data for averages fits limits etc • • •						
<2 7	90	0	[41] BARMIN	72	HLBC	

[40] Uses $K_L^0 \to \pi^+\pi^-\pi^0$ / (all K_L^0) decays = 0 1239
[41] Uses $K_L^0 \to 3\pi^0$ / total = 0 214

$\Gamma(\pi^0 e^+e^-)/\Gamma_{total}$ — Γ_{23}/Γ

Test for ΔS = 1 weak neutral current Allowed by higher order electroweak interaction

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN
<2.3	90	0	[42] CARROLL	80D	SPEC

[42] Uses $K_L^0 \to \pi^+\pi^-\pi^0$ / (all K_L^0) decays = 0 1239

$\Gamma(\pi^+\pi^-e^+e^-)/\Gamma_{total}$ — Γ_{24}/Γ

Test for ΔS = 1 weak neutral current Allowed by higher order electroweak interaction

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN
< 2.5	90	0	BALATS	83	SPEC
• • • We do not use the following data for averages fits limits etc • • •					
< 8 81	90		[43] DONALDSON	76	SPEC
<30			ANIKINA	73	STRC

[43] Uses $K_L^0 \to \pi^+\pi^-\pi^0$ / (all K_L^0) decays = 0 126

$\Gamma(\mu^+\mu^-e^+e^-)/\Gamma_{total}$ — Γ_{25}/Γ

Test for ΔS = 1 weak neutral current Allowed by higher order electroweak interaction

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN
<4.9	90	BALATS	83	SPEC

$\Gamma(e^+e^-e^+e^-)/\Gamma_{total}$ — Γ_{26}/Γ

Test for ΔS = 1 weak neutral current Allowed by higher order electroweak interaction

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN
<2.6	90	BALATS	83	SPEC

K^0_L ENERGY DEPENDENCE OF DALITZ PLOT

For discussion see note on Dalitz plot parameters in the $K^\pm$ section of the Full Listings above For definitions of a_v a_t a_u and a_y, see the earlier version of the same note in the 1982 edition of this Review published in Physics Letters **111B** 70 (April 1982)

$|\text{matrix element}|^2 = 1 + gu + hu^2 + jv + kv^2$
where $u = (s_3 - s_0) / m^2(\pi)$ and $v = (s_1 - s_2) / m^2(\pi)$

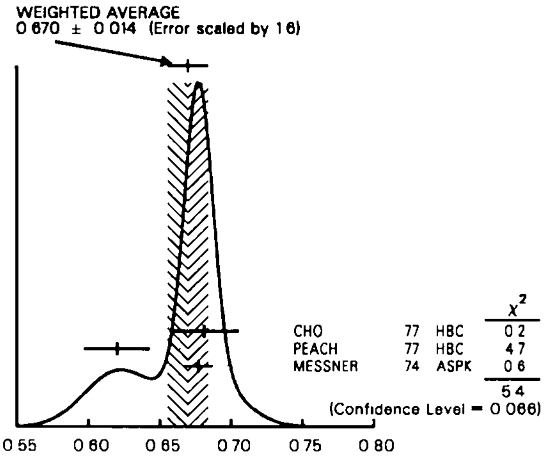
LINEAR COEFFICIENT g FOR $K^0_L \to \pi^+\pi^-\pi^0$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.670 ± 0 014	**OUR AVERAGE**	Error includes scale factor of 1 6 See the ideogram below			
0 681 ± 0 024	6499	CHO	77	HBC	
0 620 ± 0 023	4709	PEACH	77	HBC	
0 677 ± 0 010	509k	MESSNER	74	ASPK	a_y= − 0 917 ± 0.013
• • • We do not use the following data for averages fits limits etc • • •					
0 69 ± 0 07	192	44 BALDO	75	HLBC	
0.590 ± 0 022	56k	44 BUCHANAN	75	SPEC	a_u= − 0 277 ± 0 010
0 619 ± 0 027	20k	44 45 BISI	74	ASPK	a_t= − 0 282 ± 0 011
0 612 ± 0.032		44 ALEXANDER	73B	HBC	
0.73 ± 0 04	3200	44 BRANDENB	73	HBC	
0 50 ± 0 11	180	44 JAMES	72	HBC	
0 608 ± 0 043	1486	44 KRENZ	72	HLBC	a_t= − 0 277 ± 0.018
0 688 ± 0 074	384	44 METCALF	72	ASPK	a_t= − 0 31 ± 0 03
0 650 ± 0 012	29k	44 ALBROW	70	ASPK	a_y= − 0 858 ± 0 015
0 593 ± 0 022	36k	44 46 BUCHANAN	70	SPEC	a_u= − 0 278 ± 0 010
0 664 ± 0 056	4400	44 SMITH	70	OSPK	a_t= − 0 306 ± 0 024
0 400 ± 0 045	2446	44 BASILE	68B	OSPK	a_t= − 0 188 ± 0.020
0 649 ± 0 044	1350	44 HOPKINS	67	HBC	a_t= − 0.294 ± 0 018
0 428 ± 0 055	1198	44 NEFKENS	67	OSPK	a_u= − 0 204 ± 0 025
0.64 ± 0 17	280	44 ANIKINA	66	CC	a_v=(− 8 2 $^{+0\ 9}_{-1\ 3}$)
0 70 ± 0 12	126	44 HAWKINS	66	HBC	a_v= − 8 6 ± 0 7
0 32 ± 0 13	66	44 ASTBURY	65	CC	a_v= − 5 5 ± 1 5
0 51 ± 0 09	310	44 ASTBURY	65B	CC	a_v=(− 7 3 $^{+0\ 6}_{-0\ 8}$)
0 55 ± 0 23	79	44 ADAIR	64	HBC	a_v= − 7 6 ± 1 7
0 51 ± 0 20	77	44 LUERS	64	HBC	a_v= − 7 3 ± 1 6

[44] Quadratic dependence required by some experiments (See sections on QUADRATIC COEFFICIENT h and 'QUADRATIC COEFFICIENT k below) Correlations prevent us from averaging results of fits not including g h and k terms

[45] BISI 74 value comes from quadratic fit with quad term consistent with zero g error is thus larger than if linear fit were used

[46] BUCHANAN 70 result revised by BUCHANAN 75 to include radiative corrections and to use more reliable K^0_L momentum spectrum of second experiment (had same beam)



Linear coeff g for $K^0_L \to \pi^+\pi^-\pi^0$ matrix element squared

QUADRATIC COEFFICIENT h FOR $K^0_L \to \pi^+\pi^-\pi^0$

VALUE	EVTS	DOCUMENT ID		TECN
0 079 ± 0 007	**OUR AVERAGE**			
0 095 ± 0 032	6499	CHO	77	HBC
0 048 ± 0 036	4709	PEACH	77	HBC
0 079 ± 0 007	509k	MESSNER	74	ASPK
• • • We do not use the following data for averages, fits, limits etc • • •				
− 0 011 ± 0 018	29k	47 ALBROW	70	ASPK
0 043 ± 0 052	4400	47 SMITH	70	OSPK

See notes in section LINEAR COEFFICIENT g FOR $K^0_L \to \pi^+\pi^-\pi^0$,MATRIX ELEMENT$|^2$ above

[47] Quadratic coefficients h and k required by some experiments (See section on 'QUADRATIC COEFFICIENT k' below) Correlations prevent us from averaging results of fits not including g h and k terms

QUADRATIC COEFFICIENT k FOR $K^0_L \to \pi^+\pi^-\pi^0$

VALUE	EVTS	DOCUMENT ID		TECN
0.0098 ± 0.0018	**OUR AVERAGE**			
0 024 ± 0 010	6499	CHO	77	HBC
− 0 008 ± 0 012	4709	PEACH	77	HBC
0 0097 ± 0 0018	509k	MESSNER	74	ASPK

LINEAR COEFFICIENT j FOR $K^0_L \to \pi^+\pi^-\pi^0$ (CP-VIOLATING TERM)

Listed in CP violation section below

K^0_L FORM FACTORS

For discussion see note on form factors in the $K^\pm$ section of the Full Listings above

In the form factor comments, the following symbols are used
f_+ and f_- are form factors for the vector matrix element
f_S and f_T refer to the scalar and tensor term
$f_0 = f_+ + f_- t / (m^2(K) - m^2(\pi))$
λ_+ λ_- and λ_0 are the linear expansion coefficients of f_+ f_- and f_0
λ_+ refers to the $K_{\mu 3}$ value except in the K_{e3} sections
$d\xi(0)/d\lambda_+$ is the correlation between $\xi(0)$ and λ_+ in $K_{\mu 3}$
$d\lambda_0/d\lambda_+$ is the correlation between λ_0 and λ_+ in $K_{\mu 3}$
t = momentum transfer to the π in units of $m^2(\pi)$
DP = Dalitz plot analysis
PI = π spectrum analysis
MU = μ spectrum analysis
POL= μ polarization analysis
BR = $K_{\mu 3}/K_{e3}$ branching ratio analysis
E = positron or electron spectrum analysis
RC = radiative corrections

$\xi_a = f_-/f_+$ (determinded from spectra)

The parameter ξ is redundant with λ_0 below and is not put into the Stable Particle Summary Table

VALUE	$d\xi(0)/d\lambda_+$	EVTS	DOCUMENT ID		TECN	COMMENT
− 0 11 ± 0.09	**OUR EVALUATION**		Error includes scale factor of 2 3 From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition PL **111B** (April 1982)			
− 0.10 ± 0 09	− 12	150k	48 BIRULEV	81	SPEC	DP
+ 0 26 ± 0 16	− 13	14k	49 CHO	80	HBC	DP
+ 0 13 ± 0 23	− 20	16k	49 HILL	79	STRC	DP
− 0 25 ± 0.22	− 5 9	32k	50 BUCHANAN	75	SPEC	DP
− 0 11 ± 0 07	− 17	1 6M	51 DONALDSON	74B	SPEC	DP
− 1 00 ± 0.45	− 20	1385	52 PEACH	73	HLBC	DP
− 1 5 ± 0 7	− 28	9086	53 ALBROW	72	ASPK	DP
+ 1 2 ± 0 8	− 18	1341	54 CARPENTER	66	OSPK	DP
• • • We do not use the following data for averages fits limits etc • • •						
+ 0 50 ± 0 61	unknown	16k	55 DALLY	72	ASPK	DP
− 3 9 ± 0 4		3140	56 BASILE	70	OSPK	DP indep of λ_+
− 0 68 $^{+0\ 12}_{-0\ 20}$	− 26	16k	55 CHIEN	70	ASPK	DP

[48] BIRULEV 81 error $d\xi(0)/d\lambda_+$ calculated by us from λ_0 λ_+ $d\lambda_0/d\lambda_+ = 0$ used

[49] HILL 79 and CHO 80 calculated by us from λ_0 λ_+ and $d\lambda_0/d\lambda_+$

[50] BUCHANAN 75 is calculated by us from λ_0 λ_+ and $d\lambda_0/d\lambda_+$ because their appendix A value − 0.20 ± 22 assumes $\xi(t)$ constant i e $\lambda_- = \lambda_+$

[51] DONALDSON 74B gives ξ = − 0 11 ± 0 02 not including systematics Above error and $d\xi(0)/d\lambda_+$ were calculated by us from λ_0 and λ_+ errors (which include systematics) and $d\lambda_0/d\lambda_+$

[52] PEACH 73 gives $\xi(0)$ = − 0 95 ± 0 45 for $\lambda_+ = \lambda_-$ = 0 025 The above value is for $\lambda_- = 0$ K Peach private communication (1974)

[53] ALBROW 72 fit has λ_- free gets λ_- = − 0 030 ± 0 060 or λ = + 0 15 $^{+0\ 17}_{-0\ 11}$

[54] CARPENTER 66 $\xi(0)$ is for $\lambda_+ = 0$ $d\xi(0)/d\lambda_+$ is from figure 9

[55] CHIEN 70 errors are statistical only $d\xi(0)$ $d\lambda_+$ from figure 4 DALLY 72 is a reanalysis of CHIEN 70 The DALLY 72 result is not compatible with assumption $\lambda_- = 0$ so not included in our fit The nonzero λ_- value and the relatively large λ_+ value found by DALLY 72 come mainly from a single low t bin (figures 1 2) The $(f_+ \xi)$ correlation was ignored We estimate from figure 2 that fixing λ_- = 0 would give $\xi(0)$ = − 1 4 ± 0 3 and would add 10 to χ^2 $d\xi(0)/d\lambda_+$ is not given

[56] BASILE 70 is incompatible with all other results Authors suggest that efficiency estimates might be responsible

$\xi_b = f_-/f_+$ (determined from $K_{\mu 3}/K_{e3}$)

The $K_{\mu 3}/K_{e3}$ branching ratio fixes a relationship between $\xi(0)$ and λ_+ We quote the author s $\xi(0)$ and associated λ_+ but do not average because the λ_+ values differ The fit result and scale factor given below are not obtained from these ξ_b values Instead they are obtained directly from the authors $K_{\mu 3}/K_{e3}$ branching ratio via the fitted $K_{\mu 3}/K_{e3}$ ratio ($\Gamma(\pi\mu\nu)/\Gamma(\pi e\nu)$) The parameter ξ is redundant with λ_0 below and is not put into the Stable Particle Summary Table

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
− 0 11 ± 0.09	**OUR EVALUATION**	Error includes scale factor of 2 3 From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition PL **111B** (April 1982)		

Stable Particle Full Listings

K_L^0

• • • We do not use the following data for averages, fits, limits, etc. • • •

0.5 ±0.4	6700	BRANDENB	73	HBC	BR λ_+=0.019 ± 0.013
−0.08 ±0.25	1309	[57] EVANS	73	HLBC	BR λ_+=0.02
−0.5 ±0.5	3548	BASILE	70	OSPK	BR λ_+=0.02
+0.45 ±0.28	569	BEILLIERE	69	HLBC	BR λ_+=0
−0.22 ±0.30	1309	[57] EVANS	69	HLBC	
+0.2 $^{+0.8}_{-1.2}$		KULYUKINA	68	CC	BR λ_+=0
+1.1 ±1.1	389	ADAIR	64	HBC	BR λ_+=0
+0.66 $^{+0.9}_{-1.3}$		LUERS	64	HBC	BR λ_+=0

[57]EVANS 73 replaces EVANS 69

$\xi_C = f_-/f_+$ (determined from μ polarization in $K_{\mu 3}$)

The μ polarization is a measure of $\xi(t)$. No assumptions on λ_{+-} necessary; t (weighted by sensitivity to $\xi(t)$) should be specified. In λ_- $\xi(0)$ parametrization this is $\xi(0)$ for $\lambda_+ = 0$, $d\xi/d\lambda = \xi t$. For radiative correction to μ polarization in $K_{\mu 3}$, see GINSBERG 73. The parameter ξ is redundant with λ_0 below and is not put into the Stable Particle Summary Table.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.11 ±0.09	**OUR EVALUATION**				Error includes scale factor of 2.3. From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition PL **111B** (April 1982)
+0.178 ±0.105	207k	[58] CLARK	77	SPEC	POL $d\xi(0)/d\lambda_+$=+0.68
−0.385 ±0.105	2.2M	[59] SANDWEISS	73	CNTR	POL $d\xi(0)/d\lambda_+$=−6
−1.81 $^{+0.50}_{-0.26}$		[60] LONGO	69	CNTR	POL t=3.3

• • • We do not use the following data for averages, fits, limits, etc. • • •

−1.6 ±0.5	638	[61] ABRAMS	68B	OSPK	Polarization
−1.2 ±0.5	2608	[61] AUERBACH	66B	OSPK	Polarization

[58]CLARK 77 t = +3.80, $d\xi(0)/d\lambda_+ = \xi(t)t$ = 0.178 × 3.80 = +0.68.
[59]SANDWEISS 73 is for λ_- = 0 and t = 0.
[60]LONGO 69 t = 3.3 calculated from $d\xi(0)/d\lambda_+$ = −6.0 (table 1) divided by ξ = −1.81.
[61]t value not given.

IMAGINARY PART OF ξ

Test of T reversal invariance.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.007 ±0.026	**OUR AVERAGE**				
0.009 ±0.030	12M	MORSE	80	CNTR	Polarization
0.35 ±0.30	207k	[62] CLARK	77	SPEC	POL t=0
−0.085 ±0.064	2.2M	[63] SANDWEISS	73	CNTR	POL t=0
−0.02 ±0.08		LONGO	69	CNTR	POL t=3.3
−0.2 ±0.6		ABRAMS	68B	OSPK	Polarization

• • • We do not use the following data for averages, fits, limits, etc. • • •

0.012 ±0.026		SCHMIDT	79	CNTR	Repl. by MORSE 80

[62]CLARK 77 value has additional $\xi(0)$ dependence +0.21Re[$\xi(0)$].
[63]SANDWEISS 73 value corrected from value quoted in their paper due to new value of Re(ξ). See footnote 4 of SCHMIDT 79.

λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN $K_{\mu 3}$ DECAY)

See also the corresponding entries and notes in section '$\xi_A = f_-/f_+$' above and section 'λ_0 (LINEAR ENERGY DEPENDENCE OF f_0 IN $K_{\mu 3}$ DECAY)' below. For radiative correction of $K_{\mu 3}$ Dalitz plot see GINSBERG 70 and BECHERRAWY 70.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.034 ±0.005	**OUR EVALUATION**				Error includes scale factor of 2.3. From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition PL **111B** (April 1982)
0.0427 ±0.0044	150k	BIRULEV	81	SPEC	DP
0.028 ±0.010	14k	CHO	80	HBC	DP
0.028 ±0.011	16k	HILL	79	STRC	DP
0.046 ±0.030	32k	BUCHANAN	75	SPEC	DP
0.030 ±0.003	1.6M	DONALDSON	74B	SPEC	DP
0.085 ±0.015	9086	ALBROW	72	ASPK	DP

• • • We do not use the following data for averages, fits, limits, etc. • • •

0.0337 ±0.0033	129k	DZHORD	77	SPEC	Repl. by BIRULEV 81
0.046 ±0.008	82k	ALBRECHT	74	WIRE	Repl. by BIRULEV 81
0.11 ±0.04	16k	DALLY	72	ASPK	DP
0.07 ±0.02	16k	CHIEN	70	ASPK	Repl. by DALLY 72

λ_0 (LINEAR ENERGY DEPENDENCE OF f_0 IN $K_{\mu 3}$ DECAY)

Wherever possible, we have converted the above values of $\xi(0)$ into values of λ_0 using the associated λ_+^μ and $d\xi(0)/d\lambda_+$.

VALUE	$d\lambda_0/d\lambda_+$	EVTS	DOCUMENT ID		TECN	COMMENT
0.025 ±0.006	**OUR EVALUATION**					Error includes scale factor of 2.3. From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition PL **111B** (April 1982)
0.0341 ±0.0067	unknown	150k	[64] BIRULEV	81	SPEC	DP
+0.050 ±0.008	−0.11	14k	CHO	80	HBC	DP
+0.039 ±0.010	−0.67	16k	HILL	79	STRC	DP
+0.047 ±0.009	1.06	207k	[65] CLARK	77	SPEC	POL
+0.025 ±0.019	+0.5	32k	[66] BUCHANAN	75	SPEC	DP
+0.019 ±0.004	−0.47	1.6M	[67] DONALDSON	74B	SPEC	DP
−0.060 ±0.038	−0.71	1385	[68] PEACH	73	HLBC	DP
−0.018 ±0.009	+0.49	2.2M	[65] SANDWEISS	73	CNTR	POL
−0.043 ±0.052	−1.39	9086	[69] ALBROW	72	ASPK	DP
−0.140 $^{+0.043}_{-0.022}$	+0.49		[65] LONGO	69	CNTR	POL
+0.08 ±0.07	−0.54	1371	[65] CARPENTER	66	OSPK	DP

• • • We do not use the following data for averages, fits, limits, etc. • • •

0.041 ±0.008		14k	[70] CHO	80	HBC	BR λ_+=0.028
−0.0485 ±0.0076		47k	DZHORD	77	SPEC	Repl. by BIRULEV 81
−0.024 ±0.011		82k	ALBRECHT	74	WIRE	Repl. by BIRULEV 81
+0.06 ±0.03		6700	[71] BRANDENB	73	HBC	BR λ_+=0.019 ± 0.01
−0.067 ±0.227	unknown	16k	[72] DALLY	72	ASPK	DP
−0.333 ±0.034	+1	3140	[73] BASILE	70	OSPK	DP

[64]BIRULEV 81 gives $d\lambda_0/d\lambda_+$ = −1.5, giving an unreasonably narrow error ellipse which dominates all other results. We use $d\lambda_0/d\lambda_+$ = 0.
[65]λ_0 value is for λ_+ = 0.03, calculated by us from $\xi(0)$ and $d\xi(0)/d\lambda_+$.
[66]BUCHANAN 75 value is from their appendix A and uses only $K_{\mu 3}$ data. $d\lambda_0/d\lambda_+$ was obtained by private communication, C. Buchanan 1976.
[67]DONALDSON 74B $d\lambda_0/d\lambda_+$ obtained from figure 18.
[68]PEACH 73 assumes λ_+ = 0.025. Calculated by us from $\xi(0)$ and $d\xi(0)/d\lambda_+$.
[69]ALBROW 72 λ_0 is calculated by us from ξ_A, λ_+, and $d\xi(0)/d\lambda_+$. They give λ_0 = −0.043 ± 0.039 for λ_- = 0. We use our larger calculated error.
[70]CHO 80 BR result not independent of their Dalitz plot result.
[71]Fit for λ_0 does not include this value but instead includes the $K_{\mu 3}/K_{e3}$ result from this experiment.
[72]DALLY 72 gives f_0 = 1.20 ± 0.35, λ_0 = −0.080 ± 0.272, λ_0 = −0.006 ± 0.045 but with a different definition of λ_0. Our quoted λ_0 is his λ_0/f_0. We cannot calculate true λ_0 error without his (λ_0, f_0) correlations. See also note on DALLY 72 in section ξ_A.
[73]BASILE 70 λ_0 is for λ_+ = 0. Calculated by us from ξ_A with $d\xi(0)/d\lambda_+$ = 0. BASILE 70 is incompatible with all other results. Authors suggest that efficiency estimates might be responsible.

λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN K_{e3} DECAY)

For radiative correction of K_{e3} DP, see GINSBERG 67 and BECHERRAWY 70.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0300 ±0.0016	**OUR AVERAGE**				Error includes scale factor of 1.2
0.0306 ±0.0034	74k	BIRULEV	81	SPEC	DP
0.025 ±0.005	12k	[74] ENGLER	78B	HBC	DP
0.0348 ±0.0044	18k	HILL	78	STRC	DP
0.0312 ±0.0025	500k	GJESDAL	76	SPEC	DP
0.0270 ±0.0028	25k	BLUMENTHAL	75	SPEC	DP
0.044 ±0.006	24k	BUCHANAN	75	SPEC	DP
0.040 ±0.012	2171	WANG	74	OSPK	DP
0.045 ±0.014	5600	ALBROW	73	ASPK	DP
0.019 ±0.013	1871	BRANDENB	73	HBC	PI transv
0.022 ±0.014	1910	NEUHOFER	72	ASPK	PI
0.023 ±0.005	42k	BISI	71	ASPK	DP
0.05 ±0.01	16k	CHIEN	71	ASPK	DP no RC
0.02 ±0.013	1000	ARONSON	68	OSPK	PI
+0.023 ±0.012	4800	BASILE	68	OSPK	DP no RC
−0.01 ±0.02	762	FIRESTONE	67	HBC	DP no RC
+0.01 ±0.015	531	KADYK	67	HBC	e PI no RC
+0.08 $^{+0.10}_{-0.08}$	240	LOWYS	67	FBC	PI
+0.15 ±0.08	577	FISHER	65	OSPK	DP no RC
+0.07 ±0.06	153	LUERS	64	HBC	DP no RC

• • • We do not use the following data for averages, fits, limits, etc. • • •

0.029 ±0.005	19k	[74] CHO	80	HBC	DP
0.0286 ±0.0049	26k	BIRULEV	79	SPEC	Repl. by BIRULEV 81
0.032 ±0.0042	48k	BIRULEV	76	SPEC	Repl. by BIRULEV 81

[74]ENGLER 78B uses an unique K_{e3} subset of CHO 80 events and is less subject to systematic effects.

$|f_S/f_+|$ FOR K_{e3} DECAY

Ratio of scalar to f_+ couplings.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.04	68	25k	BLUMENTHAL	75	SPEC	

• • • We do not use the following data for averages, fits, limits, etc. • • •

<0.095	95	18k	HILL	78	STRC	
<0.07	68	48k	BIRULEV	76	SPEC	See also BIRULEV 81
<0.19	95	5600	ALBROW	73	ASPK	
<0.15	68		KULYUKINA	67	CC	

$|f_T/f_+|$ FOR K_{e3} DECAY

Ratio of tensor to f_+ couplings.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.23	68	25k	BLUMENTHAL	75	SPEC	

• • • We do not use the following data for averages, fits, limits, etc. • • •

<0.40	95	18k	HILL	78	STRC	
<0.34	68	48k	BIRULEV	76	SPEC	See also BIRULEV 81
<1.0	95	5600	ALBROW	73	ASPK	
<1.0	68		KULYUKINA	67	CC	

$|f_T/f_+|$ FOR $K_{\mu 3}$ DECAY

Ratio of tensor to f_+ couplings.

VALUE	DOCUMENT ID		TECN
0.12 ±0.12	BIRULEV	81	SPEC

See key on page 129

NOTE ON CP VIOLATION IN K_L^0 DECAY

We list the parameters which measure CP violation in K_L^0 decays and compare them with superweak model predictions.

Parameters

There are two different K_L^0 decays in which CP violation has been observed (for details, see Kleinknecht[1]).

(a) Asymmetry in the $K_L \to \pi^{\mp} \ell^{\pm} \nu$ decays. The quantity measured and compiled here is

$$\delta = \frac{\Gamma(K_L \to \pi^- \ell^+ \nu) - \Gamma(K_L \to \pi^+ \ell^- \bar{\nu})}{\Gamma(K_L \to \pi^- \ell^+ \nu) + \Gamma(K_L \to \pi^+ \ell^- \bar{\nu})}$$

This asymmetry violates CP invariance. If CPT is good for a pure K_L^0 beam, δ can be written as

$$\delta = 2[(1 - |x|^2)/(|1 - x|^2)]\ \mathrm{Re}\ \epsilon$$

where x is defined below in the "Note on the $\Delta S = \Delta Q$ Rule in K^0 Decay," and ϵ is the parameter of the expansion

$$|K_L\rangle = [(1 + \epsilon)|K\rangle - (1 - \epsilon)|\bar{K}\rangle]/[2(1 + |\epsilon|^2)]^{1/2} \qquad (1a)$$

$$|K_S\rangle = [(1 + \epsilon)|K\rangle + (1 - \epsilon)|\bar{K}\rangle]/[2(1 + |\epsilon|^2)]^{1/2} \qquad (1b)$$

We list $\delta(\mu)$ for $K_L^0 \to \pi\mu\nu$ and $\delta(e)$ for $K_L^0 \to \pi e \nu$ separately and list δ for $K_L^0 \to \pi\mu\nu$ and $K_L^0 \to \pi e \nu$ experiments combined.

(b) $K_L \to 2\pi$ decay. The relevant parameters are

$$\eta_{+-} = A(K_L \to \pi^+\pi^-)/A(K_S \to \pi^+\pi^-)$$

$$= |\eta_{+-}| \exp(i\phi_{+-})$$

$$\eta_{00} = A(K_L \to \pi^0\pi^0)/A(K_S \to \pi^0\pi^0)$$

$$= |\eta_{00}| \exp(i\phi_{00})$$

ϵ defined in Eqs. (1) above, and

$$\epsilon' = \frac{1}{2} i \sqrt{2} \exp[i(\delta_2 - \delta_0)]\ \mathrm{Im}(A_2/A_0)$$

Here the decay amplitudes to $\pi\pi$ states with definite isospin I are given by

$$\langle I=0|T|K\rangle = \exp(i\delta_0) A_0$$

$$\langle I=2|T|K\rangle = \exp(i\delta_2) A_2$$

where the δ_I are the $\pi\pi$ scattering phase shifts at the K mass. Wu and Yang[2] derived the relationships

$$\eta_{+-} = \epsilon + \epsilon' \qquad \eta_{00} = \epsilon - 2\epsilon'$$

assuming CPT invariance, using a phase convention in which A_0 is real, and neglecting small corrections of order $\mathrm{Re}\ A_2/\mathrm{Re}\ A_0$.

Fitting procedures

We list measurements of $|\eta_{+-}|$, $|\eta_{00}|$, and $|\eta_{00}/\eta_{+-}|$. Independent information on $|\eta_{+-}|$ and $|\eta_{00}|$ can be obtained from measurements of the K_L^0 and K_S^0 lifetimes (τ) and branching ratios (BR) to $\pi\pi$, using the relations

$$|\eta_{+-}| = \left[\frac{\mathrm{BR}(K_L^0 \to \pi^+\pi^-)}{\tau(K_L^0)} \frac{\tau(K_S^0)}{\mathrm{BR}(K_S^0 \to \pi^+\pi^-)}\right]^{1/2}$$

$$|\eta_{00}| = \left[\frac{\mathrm{BR}(K_L^0 \to \pi^0\pi^0)}{\tau(K_L^0)} \frac{\tau(K_S^0)}{\mathrm{BR}(K_S^0 \to \pi^0\pi^0)}\right]^{1/2}$$

We approximate a global fit to these independent sources by first performing two independent fits: 1) BRFIT, a fit to the K_L^0 branching ratios, rates, and mean life, and 2) ETAFIT, a fit to the $|\eta_{+-}|$, $|\eta_{00}|$, and $|\eta_{+-}/\eta_{00}|$ measurements. The results from fit 1,

$$\tau(K_L^0) = (5.18 \pm 0.04)\times 10^{-8}\ \mathrm{s}$$

$$\mathrm{BR}(K_L^0 \to \pi^+\pi^-) = (2.03 \pm 0.04)\times 10^{-3}$$

$$\mathrm{BR}(K_L^0 \to \pi^0\pi^0) = (8.0 \pm 0.6)\times 10^{-4}$$

along with the K_S^0 values from this edition are used to compute the values

$$|\eta_{+-}|_{\mathrm{BRFIT}} = (2.257 \pm 0.024)\times 10^{-3}$$

$$|\eta_{00}|_{\mathrm{BRFIT}} = (2.095 \pm 0.079)\times 10^{-3}$$

These values are included as measurements in the $|\eta_{00}|$ and $|\eta_{+-}|$ sections with a document ID of BRFIT 88. The fit to $|\eta_{+-}|$, $|\eta_{00}|$, and $|\eta_{+-}/\eta_{00}|$ is then redone to include the BRFIT 88 information. Thus the fit values given in this edition,

$$|\eta_{+-}| = (2.266 \pm 0.018)\times 10^{-3}$$

$$|\eta_{00}| = (2.245 \pm 0.019)\times 10^{-3}$$

include both the direct measurements and the results from the branching ratio fit.

The process is reversed in order to include the direct $|\eta|$ measurements in the branching ratio fit. The results from fit 2 above (before including BRFIT 88 values),

$$|\eta_{+-}| = (2.299 \pm 0.029)\times 10^{-3}$$

$$|\eta_{00}/\eta_{+-}| = 0.9912 \pm 0.0031$$

are used along with the K_L^0 and K_S^0 mean lives and the $K_S^0 \to \pi\pi$ branching fractions to compute the K_L^0 branching ratios.

$$\mathrm{BR}(K_L^0 \to \pi^+\pi^-)_{\mathrm{ETAFIT}} = (2.105 \pm 0.056)\times 10^{-3}$$

$$\left[\frac{\mathrm{BR}(K_L^0 \to \pi^0\pi^0)}{\mathrm{BR}(K_L^0 \to \pi^+\pi^-)}\right]_{\mathrm{ETAFIT}} = 0.4494 \pm 0.0062$$

$|\eta_{00}/\eta_{+-}|$ is used because it is precisely determined and almost uncorrelated with $|\eta_{+-}|$ whereas $|\eta_{00}|$ is highly correlated with $|\eta_{+-}|$ because of the precise measurements of $|\eta_{00}/\eta_{+-}|$.

These branching ratio values are included as measurements in the branching ratio sections $\Gamma(K_L^0 \to \pi^+\pi^-)/\Gamma(\mathrm{total})$ and $\Gamma(K_L^0 \to \pi^0\pi^0)/\Gamma(K_L^0 \to \pi^+\pi^-)$ with a document ID of ETAFIT 88. Thus the K_L^0 branching ratio fit results in this edition include the results of direct measurements of $|\eta_{+-}|$, $|\eta_{00}|$ and $|\eta_{00}/\eta_{+-}|$.

A separate constrained fit is done to combine measurements of the phases ϕ_{+-} and ϕ_{00} and their difference $\phi_{00} - \phi_{+-}$.

Superweak model predictions for ϵ', $|\eta_{00}/\eta_{+-}|$, ϕ_{+-}, and Re ϵ

The superweak model[3] predicts that[4] $\epsilon' = 0$ so that

$$|\eta_{00}/\eta_{+-}| = 1 .$$

It also predicts that

$$\phi_{+-} = \phi_{00} = \tan^{-1}\left(\frac{2\Delta m\,\tau_S}{\hbar}\right) ,$$

and

$$\mathrm{Re}\,\epsilon = |\eta_{+-}|\left[1 + \left(\frac{2\Delta m\,\tau_S}{\hbar}\right)^2\right]^{-1/2}$$

The latter two expressions and the values of the K_L^0–K_S^0 mass difference $\Delta m = (0.5349 \pm 0.0022)\times 10^{10}\,\hbar\ \mathrm{sec}^{-1}$, the K_S^0 mean life $\tau_S = (0.8922 \pm 0.0020)\times 10^{-10}$ sec, and the magnitude of the $(K_L^0 \to \pi^+\pi^-)/(K_S^0 \to \pi^+\pi^-)$ amplitude ratio $|\eta_{+-}| = (2.266 \pm 0.018)\times 10^{-3}$, all from the current edition, result in the predictions that

$$\phi_{+-} = \phi_{00} = (43.67 \pm 0.13)^\circ ,$$

and

$$\mathrm{Re}\,\epsilon = (1.639 \pm 0.014)\times 10^{-3}$$

The above predictions can be compared with the experimental values

$$|\eta_{00}/\eta_{+-}| = 0.9905 \pm 0.0029$$

$$\phi_{+-} = (44.6 \pm 1.2)^\circ ,$$

$$\phi_{00} = (54 \pm 5)^\circ ,$$

$$\mathrm{Re}\,\epsilon = (1.630 \pm 0.083)\times 10^{-3} ,$$

where Re ϵ has been computed using the relation

$$\mathrm{Re}\,\epsilon = \frac{\delta}{2}\left(\frac{|1-x|^2}{1-|x|^2}\right) ,$$

and our current values of the charge asymmetry parameter for leptonic K_L^0 decay $\delta = (0.330 \pm 0.012)\%$ and the $\Delta S = -\Delta Q$ amplitude (Re x, Im x) = (0.006 ± 0.018, −0.003 ± 0.026).

The superweak prediction for $|\eta_{00}/\eta_{+-}|$ is violated by three standard deviations as a result of the BURKHARDT 88 high-precision CERN measurement. This is the first clear evidence for direct CP violation in the transition of the CP-odd K_2 into two pions.

In the Standard Model, direct CP violation, as well as that induced by state mixing, are accomodated in the Kobayashi-Maskawa model[5] by transitions via heavy-quark intermediate states. The value of ϵ'/ϵ is a measure of the amount of direct CP violation. Recent evaluations of ϵ'/ϵ in the Standard Model are in agreement with the observed value of ϵ'/ϵ (see below) for plausible values of the t mass. For example, Buras and Gerard[6] find fairly good agreement for 55 GeV $< m_t <$ 130 GeV.

The measured value of ϕ_{00} is two standard deviations above the superweak prediction. This results primarily from the CHRISTENSON 79 measurement $\phi_{00} = (55.7 \pm 5.8)$.

Values of $|\epsilon|$ and $|\epsilon'|$

One can determine the values of $|\epsilon|$ and $|\epsilon'|$ using theoretical input on their phases. The phase of ϵ is determined from unitarity and CPT invariance to be within a few degrees of the "superweak value" of 44° (e.g., see V. Barmin et al.[7]). The phase of ϵ' is given by $\delta_2 - \delta_0 + \pi/2$, which equals $48 \pm 8°$ from an analysis of $\pi\pi$ phase shifts.[8] Thus ϵ and ϵ' have the same phase within 10 to 15°. Therefore to a good approximation

$$\left|\frac{\epsilon'}{\epsilon}\right| = \mathrm{Re}\left(\frac{\epsilon'}{\epsilon}\right) = \frac{1}{3}\left[1 - |\eta_{00}/\eta_{+-}|\right] = (3.2 \pm 1.0)\times 10^{-3}$$

$$|\epsilon| = |\eta_{+-}|\left[1 - \mathrm{Re}\left(\frac{\epsilon'}{\epsilon}\right)\right] = (2.259 \pm 0.018)\times 10^{-3}$$

The value of $\phi_{00} - \phi_{+-}$ is not used in this analysis since taken literally it represents a violation of CPT invariance.[7]

Searches for CP violation in $K_L \to \pi^+\pi^-\pi^0$

As was discussed in the "Note on Dalitz Plot Parameters for $K \to 3\pi$ Decay" in the $K^\pm$ section of the Full Listings, the Dalitz plot distribution for $K_L^0 \to \pi^+\pi^-\pi^0$ contains a charge asymmetry term with coefficient j, the presence of which would indicate CP violation. Experimenters have used several forms for this CP-violation term. As described in the "Note on Slope Parameters for $K \to 3\pi$ Decays" in the 1982 edition of this Review[9] we have converted all results to coefficient j for this compilation. The coefficient j is consistent with zero, i.e., absence of CP violation.

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CP-VIOLATION PARAMETERS IN K^0_L DECAYS

CHARGE ASYMMETRY IN LEPTONIC DECAYS

Such asymmetry violates CP. It is related to Re(ϵ)

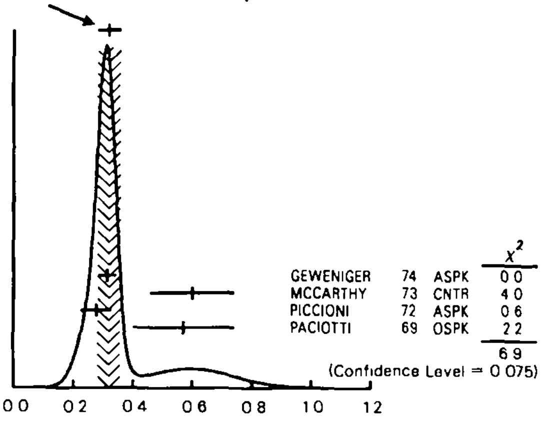
$$\delta(\mu) = [\Gamma(\pi^-\mu^+\nu) - \Gamma(\pi^+\mu^-\nu)]/[\Gamma(\pi^-\mu^+\nu) + \Gamma(\pi^+\mu^-\nu)] \qquad (\Gamma_4-\Gamma_5)/(\Gamma_4+\Gamma_5)$$

Only the combined value below is put into the Stable Particle Summary Table

VALUE (%)	EVTS	DOCUMENT ID		TECN
0.32 ± 0.04 OUR AVERAGE		Error includes scale factor of 1.5. See the ideogram below		
0.313 ± 0.029	15M	GEWENIGER	74	ASPK
0.60 ± 0.14	4.1M	MCCARTHY	73	CNTR
0.278 ± 0.051	7.7M	PICCIONI	72	ASPK
0.57 ± 0.17	1M	[75] PACIOTTI	69	OSPK
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.403 ± 0.134	1M	[75] DORFAN	67	OSPK

[75] PACIOTTI 69 is a reanalysis of DORFAN 67 and is corrected for $\mu^+\mu^-$ range difference in MCCARTHY 72

WEIGHTED AVERAGE
0.32 ± 0.04 (Error scaled by 1.5)



Charge asymmetry for $K^0_L \to \mu\pi\nu$

$$\delta(e) = [\Gamma(\pi^-e^+\nu) - \Gamma(\pi^+e^-\nu)]/[\Gamma(\pi^-e^+\nu) + \Gamma(\pi^+e^-\nu)] \qquad (\Gamma_7-\Gamma_8)/(\Gamma_7+\Gamma_8)$$

Only the combined value below is put into the Stable Particle Summary Table

VALUE (%)	EVTS	DOCUMENT ID		TECN
0.333 ± 0.014 OUR AVERAGE				
0.341 ± 0.018	34M	GEWENIGER	74	ASPK
0.318 ± 0.038	40M	FITCH	73	ASPK
0.36 ± 0.18	600k	ASHFORD	72	ASPK
0.346 ± 0.033	10M	MARX	70	CNTR
0.246 ± 0.059	10M	[76] SAAL	69	CNTR
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.224 ± 0.036	10M	[76] BENNETT	67	CNTR

[76] SAAL 69 is a reanalysis of BENNETT 67

δ = weighted average of $\delta(\mu)$ and $\delta(e)$
(Combination of the above two sections.)

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
0.330 ± 0.012 OUR AVERAGE					
0.313 ± 0.029	15M	GEWENIGER	74	ASPK	$K_{\mu 3}$
0.341 ± 0.018	34M	GEWENIGER	74	ASPK	K_{e3}
0.318 ± 0.038	40M	FITCH	73	ASPK	K_{e3}
0.60 ± 0.14	4.1M	MCCARTHY	73	CNTR	$K_{\mu 3}$
0.333 ± 0.050	33M	WILLIAMS	73	ASPK	$K_{\mu 3} + K_{e3}$
0.36 ± 0.18	600k	ASHFORD	72	ASPK	K_{e3}
0.278 ± 0.051	7.7M	PICCIONI	72	ASPK	$K_{\mu 3}$
0.346 ± 0.033	10M	MARX	70	CNTR	K_{e3}
0.57 ± 0.17	1M	PACIOTTI	69	OSPK	$K_{\mu 3}$
0.246 ± 0.059	10M	SAAL	69	CNTR	K_{e3}

PARAMETERS FOR $K^0_L \to 2\pi$ DECAY

$\eta_{+-} = A(K^0_L \to \pi^+\pi^-) / A(K^0_S \to \pi^+\pi^-)$
$\eta_{00} = A(K^0_L \to \pi^0\pi^0) / A(K^0_S \to \pi^0\pi^0)$

The fitted values of η_{+-} and η_{00} given below are the results of a fit to $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{00}/\eta_{+-}|$, and Re(ϵ'/ϵ). Independent information on $|\eta_{+-}|$ and $|\eta_{00}|$ can be obtained from the fitted values of the $K^0_L \to \pi\pi$ and $K^0_S \to \pi\pi$ branching ratios and the K^0_L and K^0_S lifetimes. This information is included as data in the $|\eta_{+-}|$ and $|\eta_{00}|$ sections with a Document ID BRFIT. See the Note on CP Violation in K^0_L Decay above for details.

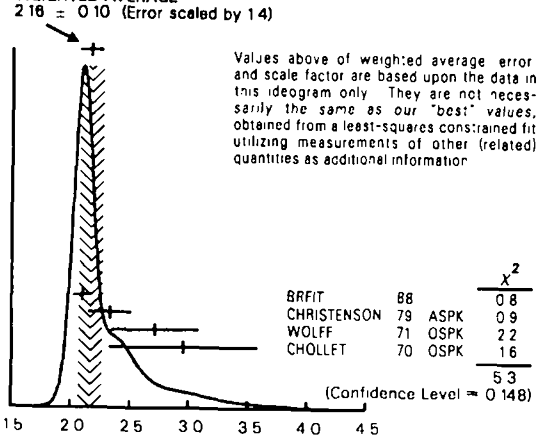
$$|\eta_{00}| = |A(K^0_L \to 2\pi^0) / A(K^0_S \to 2\pi^0)|$$

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.245 ± 0.019 OUR FIT					
2.16 ± 0.10 OUR AVERAGE		Error includes scale factor of 1.4. See the ideogram below			
2.095 ± 0.079		[77] BRFIT	88		
2.33 ± 0.18		CHRISTENSON	79	ASPK	
2.71 ± 0.37	56	[78] WOLFF	71	OSPK	Cu reg 4.5 s
2.95 ± 0.63		[78] CHOLLET	70	OSPK	Cu reg 4.5 s

[77] This BRFIT value is computed from fitted values of the K^0_L and K^0_S lifetimes and branching fractions to $\pi\pi$. See the discussion in the Note on CP violation in K^0_L decay.

[78] CHOLLET 70 gives η_{00} = (1.23 ± 0.24) × (regeneration amplitude 2 GeV/c Cu)/10000mb. WOLFF 71 gives η_{00} = (1.13 ± 0.12) × (regeneration amplitude 2 GeV/c Cu)/10000mb. We compute both η_{00} values for (regeneration amplitude 2 GeV/c Cu) = 24 ± 2mb. This regeneration amplitude results from averaging over FAISSNER 69 extrapolated using optical model calculations of Bohm et al, Phys Lett **27B** 594 (1968) and the data of BALATS 71. (From H Faissner, private communication)

WEIGHTED AVERAGE
2.16 ± 0.10 (Error scaled by 1.4)



η_{00} = $|A(K^0_L \to 2\pi^0) / A(K^0_S \to 2\pi^0)|$

Stable Particle Full Listings

K_L^0

$|\eta_{+-}| = |A(K_L^0 \to \pi^+\pi^-) / A(K_S^0 \to \pi^+\pi^-)|$

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN	COMMENT
2.266 ± 0.018 OUR FIT				
2.272 ± 0.019 OUR AVERAGE				
2.257 ± 0.024		[79] BRFIT 88		
2.28 ± 0.06	1687	[80] COUPAL 85	SPEC	$P(K)$=70 GeV/c
2.27 ± 0.12		CHRISTENSON 79B	ASPK	
2.30 ± 0.035		GEWENIGER 74B	ASPK	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2.09 ± 0.02		[81] ARONSON 82B	SPEC	E=30–110 GeV

[79] This BRFIT value is computed from fitted values of the K_L^0 and K_S^0 lifetimes and branching fractions to $\pi\pi$. See the discussion in the "Note on CP violation in K_L^0 decay."
[80] COUPAL 85 concludes no energy dependence of $|\eta_{+-}|$, because their value is consistent with above values which occur at lower energies.
[81] ARONSON 82B find that $|\eta_{+-}|$ may depend on the kaon energy.

$|\eta_{00}/\eta_{+-}|$

VALUE		EVTS	DOCUMENT ID	TECN
0.9905 ± 0.0029 OUR FIT				
0.9908 ± 0.0030 OUR AVERAGE				
0.9899 ± 0.0020 ± 0.0025			[82] BURKHARDT 88	CALO
0.9904 ± 0.0084 ± 0.0036			[83] WOODS 88	SPEC
1.014 ± 0.016 ± 0.007		3152	BERNSTEIN 85B	SPEC
0.995 ± 0.025		1122	BLACK 85	SPEC
1.03 ± 0.07		124	BANNER 72	OSPK
1.00 ± 0.06		167	HOLDER 72	ASPK
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.00 ± 0.09			[84] CHRISTENSON 79	ASPK

[82] This is the square root of the ratio R given by BURKHARDT 88.
[83] We calculate $|\eta_{00}/\eta_{+-}| = 1-3|\epsilon'/\epsilon|$ from WOODS 88 $|\epsilon'/\epsilon|$ value.
[84] Not independent of $|\eta_{+-}|$ and $|\eta_{00}|$ values which are included in fit.

$\mathrm{Re}(\epsilon'/\epsilon) = (1-|\eta_{00}/\eta_{+-}|)/3$

Approximately equal to ϵ'/ϵ. See "Note on CP violation in K_L^0 decay."

VALUE (units 10^{-3})	DOCUMENT ID	TECN
3.2 ± 1.0 OUR FIT		
• • • We do not use the following data for averages, fits, limits, etc. • • •		
3.3 ± 1.1	[85] BURKHARDT 88	CALO
3.2 ± 2.8 ± 1.2	[85] WOODS 88	SPEC

[85] These values are derived from $|\eta_{00}/\eta_{+-}|$ measurements and enter the fit via the $|\eta_{00}/\eta_{+-}|$ section.

ϕ_{+-}, PHASE of η_{+-}

The dependence of the phase on the $K_L^0 - K_S^0$ mass difference is given for each experiment in the comments below, where DM is (mass difference/$\hbar$) in units 10^{10} sec^{-1}. We have evaluated these mass dependences using our April 1982 value DM = 0.5349 ± 0.0022 to obtain the values and average quoted below. We also give the regeneration phase ϕ_f in the comments below.

VALUE (degrees)	DOCUMENT ID	TECN	COMMENT
44.6 ± 1.2 OUR FIT Error includes scale factor of 1.1.			
44.6 ± 1.2 OUR AVERAGE			
41.7 ± 3.5	CHRISTENSON 79B	ASPK	
45.5 ± 2.8	[86] CARITHERS 75	SPEC	C regenerator
46.5 ± 1.6	[87] GEWENIGER 74B	ASPK	Vacuum regen
36.2 ± 6.1	[88] CARNEGIE 72	ASPK	Cu regenerator
37.2 ± 12.0	[89] BALATS 71	OSPK	Cu regenerator
40.6 ± 4.2	[90] JENSEN 70	ASPK	Vacuum regen
34.2 ± 10.0	[91] BENNETT 69	CNTR	Cu regenerator
45.3 ± 12.0	[92] BOHM 69B	OSPK	Vacuum regen
45.2 ± 7.4	[93] FAISSNER 69	ASPK	Cu regenerator
• • • We do not use the following data for averages, fits, limits, etc. • • •			
35.3 ± 3.9	[94] ARONSON 82B	SPEC	E=30–110 GeV
51.0 ± 11.0	[95] BENNETT 68B	CNTR	Cu reg. uses
70.0 ± 21.0	[96] BOTT 67B	OSPK	C regenerator
25.0 ± 35.0	[96] MISCHKE 67	OSPK	Cu regenerator
30.0 ± 45.0	[96] FIRESTONE 66	HBC	
45.0 ± 50.0	[96] FITCH 65	OSPK	Be regenerator

[86] CARITHERS 75 $\phi_{+-} = (45.5 \pm 2.8) + 224[\Delta(m) - 0.5348]^\circ$. $\phi_f = -40.9 \pm 2.6^\circ$.
[87] GEWENIGER 74B $\phi_{+-} = (49.4 \pm 1.0) + 565[\Delta(m) - 0.540]^\circ$.
[88] CARNEGIE 72 ϕ_{+-} is insensitive to $\Delta(m)$. $\phi_f = -56.2 \pm 5.2^\circ$.
[89] BALATS 71 $\phi_{+-} = (39.0 \pm 12.0) + 198[\Delta(m) - 0.544]^\circ$. $\phi_f = -43.0 \pm 4.0^\circ$.
[90] JENSEN 70 $\phi_{+-} = (42.4 \pm 4.0) + 576[\Delta(m) - 0.538]^\circ$.
[91] BENNETT 69 uses measurement of $(\phi_{+-})-(\phi_f)$ of ALFF-STEINBERGER 66B. BENNETT 69 $\phi_{+-} = (34.9 \pm 10.0) + 69[\Delta(m) - 0.545]^\circ$. $\phi_f = -49.9 \pm 5.4^\circ$.
[92] BOHM 69B $\phi_{+-} = (41.0 \pm 12.0) + 479(\Delta(m) - 0.526)^\circ$.
[93] FAISSNER 69 error enlarged to include error in regenerator phase. FAISSNER 69 $\phi_{+-} = (49.3 \pm 7.4) + 205[\Delta(m) - 0.555]^\circ$. $\phi_f = -42.7 \pm 5.0^\circ$.
[94] ARONSON 82 find that ϕ_{+-} may depend on the kaon energy.
[95] BENNETT 69 is a re-evaluation of BENNETT 68B.
[96] Old experiments with large errors not included in average.

ϕ_{00}, PHASE OF η_{00}

VALUE (degrees)	EVTS	DOCUMENT ID	TECN	COMMENT
54 ± 5 OUR FIT				
55 ± 6 OUR AVERAGE				
55.7 ± 5.8		CHRISTENSON 79	ASPK	
38.0 ± 25.0	56	[97] WOLFF 71	OSPK	Cu reg., 4γ's
51.0 ± 30.0		[98] CHOLLET 70	OSPK	Cu reg., 4γ's
first quadrant preferred		GOBBI 69B	OSPK	

[97] WOLFF 71 uses regenerator phase $\phi_f = -48.2 \pm 3.5^\circ$.
[98] CHOLLET 70 uses regenerator phase $\phi_f = -46.5 \pm 4.4^\circ$.

PHASE DIFFERENCE $\phi_{00} - \phi_{+-}$

Test of CPT.

VALUE (degrees)	DOCUMENT ID	TECN
10 ± 5 OUR FIT		
7.6 ± 18.0	[99] BARBIELLINI 73	ASPK
• • • We do not use the following data for averages, fits, limits, etc. • • •		
12.6 ± 6.2	[100] CHRISTENSON 79	ASPK

[99] Independent of regenerator mechanism, $\Delta(m)$ and lifetimes.
[100] Not independent of ϕ_{+-} and ϕ_{00} values which are included in fit.

— CHARGE ASYMMETRY IN $\pi^+\pi^-\pi^0$ DECAYS —

CP-VIOLATION COEFFICIENT j FOR $K_L^0 \to \pi^+\pi^-\pi^0$

Defined at beginning of section "LINEAR COEFFICIENT g FOR $K_L^0 \to \pi^+\pi^-\pi^0$" above. See also note on Dalitz plot parameters in $K^\pm$ section and note on CP violation in K_L^0 decay above.

VALUE	EVTS	DOCUMENT ID	TECN
0.0011 ± 0.0008 OUR AVERAGE			
0.001 ± 0.011	6499	CHO 77	
−0.001 ± 0.003	4709	PEACH 77	
0.0013 ± 0.0009	3M	SCRIBANO 70	
0.0 ± 0.017	4400	SMITH 70	OSPK
0.001 ± 0.004	238k	BLANPIED 68	

NOTE ON $\Delta S = \Delta Q$ RULE IN K^0 DECAYS

The relative amount of $\Delta S \neq \Delta Q$ component present is measured by the parameter x, defined as

$$x = A(\bar{K}^0 \to \pi^- \ell^+ \nu)/A(K^0 \to \pi^- \ell^+ \nu)$$

We list $\mathrm{Re}\{x\}$ and $\mathrm{Im}\{x\}$ for K_{e3} and $K_{\mu3}$ combined.

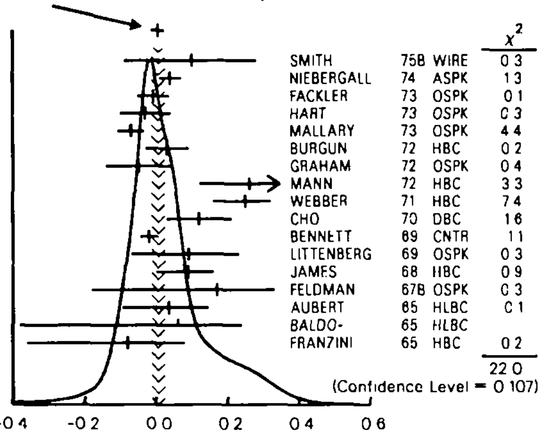
x = ($\Delta S = -\Delta Q$ AMPLITUDE) / ($\Delta S = +\Delta Q$ AMPLITUDE)

REAL PART OF x

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.006 ± 0.018 OUR AVERAGE Error includes scale factor of 1.3. See the ideogram below.				
0.10 $^{+0.18}_{-0.19}$	79	SMITH 75B	WIRE	$\pi^- p \to K^0 X$
0.04 ± 0.03	4724	NIEBERGALL 74	ASPK	$K^+ p \to K^0 p \pi^+$
−0.008 ± 0.044	1757	FACKLER 73	OSPK	K_{e3} from K^0
−0.03 ± 0.07	1367	HART 73	OSPK	K_{e3} from $K^0 X$
−0.070 ± 0.036	1079	MALLARY 73	OSPK	K_{e3} from $K^0 X$ +
0.03 ± 0.06	410	[101] BURGUN 72	HBC	$K^+ p \to K^0 p \pi^+$
−0.05 ± 0.09	442	[102] GRAHAM 72	OSPK	$\pi^- p \to K^0 X$
0.26 $^{+0.10}_{-0.14}$	126	MANN 72	HBC	$K^- p \to n K^0$
0.25 $^{+0.07}_{-0.09}$	252	WEBBER 71	HBC	$K^- p \to n K^0$
0.12 ± 0.09	215	[103] CHO 70	DBC	$K^+ d \to K^0 p p$
−0.020 ± 0.025		[104] BENNETT 69	CNTR	Charge asym+ Cu regen
0.09 $^{+0.14}_{-0.16}$	686	LITTENBERG 69	OSPK	$K^+ n \to K^0 p$
0.09 $^{+0.07}_{-0.09}$	121	JAMES 68	HBC	$\bar{p} p$
0.17 $^{+0.16}_{-0.35}$	116	FELDMAN 67B	OSPK	$\pi^- p \to K^0 X$
0.035 $^{+0.11}_{-0.13}$	196	AUBERT 65	HLBC	K^+ charge exchange
0.06 $^{+0.18}_{-0.44}$	152	[105] BALDO 65	HLBC	K^+ charge exchange
−0.08 $^{+0.16}_{-0.28}$	109	[106] FRANZINI 65	HBC	$p p$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.04 $^{+0.10}_{-0.13}$	100	[102] GRAHAM 72	OSPK	$K_{\mu3}$ from $K^0 X$
−0.13 ± 0.11	342	[102] MANTSCH 72	OSPK	K_{e3} from $K^0 X$
0.04 $^{+0.07}_{-0.08}$	222	[101] BURGUN 71	HBC	$K^+ p \to K^0 p \pi^+$
0.03 ± 0.03		[104] BENNETT 68	CNTR	
0.17 ± 0.10	335	[103] HILL 67	DBC	$K^+ d \to K^0 p p$

[101] BURGUN 72 is a final result which includes BURGUN 71.
[102] First GRAHAM 72 value is second GRAHAM 72 value combined with MANTSCH 72.
[103] CHO 70 is analysis of unambiguous events in new data and HILL 67.
[104] BENNETT 69 is a reanalysis of BENNETT 68.
[105] BALDO-CEOLIN 65 gives x and θ converted by us to Re(x) and Im(x).
[106] FRANZINI 65 gives x and θ for Re(x) and Im(x). See SCHMIDT 67.

WEIGHTED AVERAGE
0.006 ± 0.018 (Error scaled by 1.3)



Re(x) ($\Delta S = -\Delta Q$ amplitude)

IMAGINARY PART OF x

Assumes $m(K^0_L) - m(K^0_S)$ positive See Listings above

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.003 ± 0.026	**OUR AVERAGE**	Error includes scale factor of 1.2			
$-0.10^{+0.16}_{-0.19}$	79	SMITH	75B	WIRE	$\pi^- p \to K^0 \Lambda$
−0.06 ± 0.05	4724	NIEBERGALL	74	ASPK	$K^+ p \to K^0 p \pi^+$
−0.017 ± 0.060	1757	FACKLER	73	OSPK	K_{e3} from K^0
0.09 ± 0.07	1367	HART	73	OSPK	K_{e3} from $K^0 \Lambda$
$0.107^{+0.092}_{-0.074}$	1079	MALLARY	73	OSPK	K_{e3} from $K^0 \Lambda$ +
$0.07^{+0.06}_{-0.07}$	410	[107] BURGUN	72	HBC	$K^+ p \to K^0 p \pi^+$
0.05 ± 0.13	442	[108] GRAHAM	72	OSPK	$\pi^- p \to K^0 \Lambda$
$0.21^{+0.15}_{-0.12}$	126	MANN	72	HBC	$K^- p \to n K^0$
0.0 ± 0.08	252	WEBBER	71	HBC	$K^- p \to n K^0$
−0.08 ± 0.07	215	[109] CHO	70	DBC	$K^+ d \to K^0 p p$
$-0.11^{+0.10}_{-0.11}$	686	LITTENBERG	69	OSPK	$K^+ n \to K^0 p$
$+0.22^{+0.37}_{-0.29}$	121	JAMES	68	HBC	$\bar{p} p$
0.0 ± 0.25	116	FELDMAN	67B	OSPK	$\pi^- p \to K^0 \Lambda$
$-0.21^{+0.11}_{-0.15}$	196	AUBERT	65	HLBC	K^+ charge exchange
$-0.44^{+0.32}_{-0.19}$	152	[110] BALDO	65	HLBC	K^+ charge exchange
$+0.24^{+0.40}_{-0.30}$	109	[111] FRANZINI	65	HBC	$\bar{p} p$
• • • We do not use the following data for averages fits limits etc • • •					
$0.12^{+0.17}_{-0.16}$	100	[108] GRAHAM	72	OSPK	$K_{\mu 3}$ from $K^0 \Lambda$
−0.04 ± 0.16	342	[108] MANTSCH	72	OSPK	K_{e3} from $K^0 \Lambda$
$0.12^{+0.08}_{-0.09}$	222	[107] BURGUN	71	HBC	$K^+ p \to K^0 p \pi^+$
−0.20 ± 0.10	335	[109] HILL	67	DBC	$K^+ d \to K^0 p p$

[107] BURGUN 72 is a final result which includes BURGUN 71

[108] First GRAHAM 72 value is second GRAHAM 72 value combined with MANTSCH 72

[109] Footnote 10 of HILL 67 should read +0.58 not −0.58 (private communication) CHO 70 is analysis of unambiguous events in new data and HILL 67

[110] BALDO CEOLIN 65 gives x and θ converted by us to Re(x) and Im(x)

[111] FRANZINI 65 gives x and θ for Re(x) and Im(x) See SCHMIDT 67

REFERENCES FOR K^0_L

BRFIT 88 RPP
See Note on CP Violation above
BURKHARDT 88 PL B206 169 + (CERN DORT EDIN MANZ ORSA PISA SIEG)
ETAFIT 88 RPP
See Note on CP Violation above
GREENLEE 88 PRL 60 893 +Kasha Mannelli Mannelli+ (YALE BNL)
WOODS 88 PRL 60 1695 +Nishikawa+ (EFI CHIC FNAL PRIN SACL)
BURKHARDT 87 PL B199 139 + (CERN DORT EDIN MANZ ORSA PISA SIEG)
ARONSON 86 PR D33 3180 +Bernstein Bock+ (BNL CHIC STAN WISC)
Also 82 PRL 48 1078 Aronson Bernstein+ (BNL CHIC STAN WISC)
BERNSTEIN 85B PRL 54 1631 +Bock Carlsmith Coupal+ (CHIC SACL)
BLACK 85 PRL 54 1628 +Blatt Campbell Kasha Mannelli+ (BNL YALE)
COUPAL 85 PRL 55 566 +Bernstein Bock Carlsmith+ (CHIC SACL)
BALATS 83 SJNP 38 556 +Berezin Bogdanov Vishnevsky+ (ITEP)
Translated from YAF 38 927
ARONSON 82 PRL 48 1078 +Bernstein+ (BNL CHIC STAN WISC)
ARONSON 82B PRL 48 1306 +Bock Cheng Fischbach (BNL CHIC PURD)
Also 82B PL 116B 73 Fischbach Cheng+ (PURD BNL CHIC)
Also 83 PR D28 476 Aronson Bock Cheng+ (BNL CHIC PURD)
Also 83B PR D28 495 Aronson Bock Cheng+ (BNL CHIC PURD)
BIRULEV 81 NP B182 1 +Dzhordzhadze Genchev Grigalashvili+ (JINR)
Also 80 SJNP 31 622 Birulev Vestergombi Genchev+ (JINR)
Translated from YAF 31 1204
CARROLL 80B PRL 44 529 +Chiang Kycia Li Littenberg Marx+(BNL ROCH)
CARROLL 80C PL 96B 407 +Chiang Kycia Li Littenberg Marx+(BNL ROCH)
CARROLL 80D PRL 44 525 +Chiang Kycia Li Littenberg Marx+(BNL ROCH)
CHO 80 PR D22 2688 +Derrick Miller Schlereth Engler+ (ANL CMU)
MORSE 80 PR D21 1750 +Leipuner Larsen Schmidt Blatt+ (BNL YALE)
BIRULEV 79 SJNP 29 778 +Vestergombi Gvakhariya Genchev+ (JINR)
Translated from YAF 29 1516
CHRISTENSON 79 PRL 43 1209 +Goldman Hummel Roth+ (NYU)
CHRISTENSON 79B PRL 43 1212 +Goldman Hummel Roth+ (NYU)
HILL 79 NP B153 39 +Sakitt Snape Stevens+ (BNL SLAC SBER)
SCHMIDT 79 PRL 43 556 +Blatt Campbell Grannan+ (YALE BNL)
SHOCHET 79 PR D19 1965 +Linsay Grosso Pilcher Frisch+ (EFI ANL)
Also 77 PRL 39 59 Shochet Linsay Grosso Pilcher+ (EFI ANL)
ENGLER 78B PR D18 623 +Keyes Kraemer Tanaka Cho+ (CMU ANL)
HILL 78 PL 73B 483 +Sakitt Snape Stevens+ (BNL SLAC SBER)
CHO 77 PR D15 587 +Derrick Lissauer Miller Engler+ (ANL CMU)
CLARK 77 PR D15 553 +Field Holley Johnson Kerth San Shen (LBL)
Also 75 LBL 4275 Thesis Shen (LBL)
DEVOE 77 PR D16 565 +Cronin Frisch Grosso Pilcher+ (EFI ANL)
DZHORD 77 SJNP 26 478 Dzhordzhadze Kekelidze Krivokhizhin+ (JINR)
Translated from YAF 26 910
PEACH 77 NP B127 399 +Cameron+ (BGNA EDIN GLAS PISA RHEL)
BIRULEV 76 SJNP 24 178 +Vestergombi Vovenko Votruba+ (JINR)
Translated from YAF 24 340
COOMBES 76 PRL 37 249 +Flexer Hall Kennelly Kirkby+ (STAN NYU)
DONALDSON 76 PR D14 2839 +Hitlin Kennelly Kirkby Liu+ (SLAC)
Also 74 SLAC 184 Thesis Donaldson (SLAC)
FUKUSHIMA 76 PRL 36 348 +Jensen Surko Thaler+ (PRIN MASA)
GJESDAL 76 NP B109 118 +Kamae Presser Steffen+ (CERN HEID)
REY 76 PR D13 1161 +Cence Jones Parker+ (NDAM HAWA LBL)
Also 69 PRL 22 1210 Cence Jones Peterson Stenger+ (HAWA LRL)
BALDO 75 NC 25A 688 Baldo Ceolin Bobisut Calimani+ (PADO WISC)
BLUMENTHAL 75 PRL 34 164 +Frankel Nagy+ (PENN CHIC TEMP)
BUCHANAN 75 PR D11 457 +Drickey Pepper Rudnick+ (UCLA SLAC JHU)
CARITHERS 75 PRL 34 1244 +Modis Nygren Pun+ (COLU NYU)
SMITH 75B UCSD Thesis unpub (UCSD)
ALBRECHT 74 PL 48B 393 (JINR BERL BUDA PRAG SERP SOFI)
BISI 74 PL 50B 504 +Ferrero (TORI)
BOBISUT 74 LNC 11 646 +Huzita Mattioli Puglierin (PADO)
DONALDSON 74 SLAC 184 Thesis (SLAC)
Also 76 PR D14 2839 Donaldson Hitlin Kennelly Kirkby Liu+ (SLAC)
DONALDSON 74B PR D9 2960 +Fryberger Hitlin Liu+ (SLAC UCSC)
Also 73B PRL 31 337 Donaldson Fryberger Hitlin Liu+ (SLAC UCSC)
DONALDSON 74C PRL 33 554 +Hitlin Kennelly Kirkby+ (SLAC)
Also 74 SLAC 184 Thesis Donaldson (SLAC)
Also 76 PR D14 2839 Donaldson Hitlin Kennelly Kirkby Liu+ (SLAC)
FIELD 74 SLAC PUB 1498 unpub (SLAC)
GEWENIGER 74 PL 48B 483 +Gjesdal Kamae Presser+ (CERN HEID)
Also 74 CERN Int 74 4 Thesis Luth (HEID)
GEWENIGER 74B PL 48B 487 +Gjesdal Presser+ (CERN HEID)
Also 74B PL 52B 119 Gjesdal Presser Steffen+ (CERN HEID)
GEWENIGER 74C PL 52B 108 +Gjesdal Presser+ (CERN HEID)
GJESDAL 74 PL 52B 113 +Presser Kamae Steffen+ (CERN HEID)
MESSNER 74 PRL 33 1458 +Franklin Morse+ (COLO SLAC UCSC)
NIEBERGALL 74 PL 49B 103 +Regler Stier+ (CERN ORSA VIEN)
WANG 74 PR D9 540 +Smith Whatley Zorn Hornbostel (UMD BNL)
WILLIAMS 74 PRL 33 240 +Larsen Leipuner Sapp Sessoms+ (BNL YALE)
WOO 74 LNC 10 38 +Buchanan Pepper (UCLA)
ALBROW 73 NP B58 22 +Aston Barber Bird Ellison+ (MCHS DARE)
ALEXANDER 73B NP B65 301 +Benary Borowitz Lande+ (TELA HEID)
ANIKINA 73 JINR P1 7539 +Balashov Bannik+ (JINR)
BARBIELLINI 73 PL 43B 529 +Darriulat Fainberg+ (CERN)
BRANDENB 73 PR D8 1978 Brandenburg Johnson Leith Loos+ (SLAC)
CARITHERS 73 PRL 31 1025 +Nygren Gordon+ (COLU BNL CERN)
Also 73B PRL 30 1336 Carithers Modis Nygren+ (COLU CERN NYU)
EVANS 73 PR D7 36 +Muir Peach Budagov+ (EDIN CERN)
Also 69 PRL 23 427 Evans Golden Muir Peach+ (EDIN CERN)
FACKLER 73 PRL 31 847 +Frisch Martin Smoot Sompayrac (MIT)
FITCH 73 PRL 31 1524 +Hepp Jensen Strovink Webb (PRIN)
Also 72 COO 3072 13 Thesis Webb (PRIN)
GINSBERG 73 PR D8 3887 +Smith (MIT STON)
HART 73 NP B66 317 +Hutton Field Sharp Blackmore+ (CAVE RHEL)
MALLARY 73 PR D7 1953 +Binnie Gallivan Gomez Peck Sciulli+ (CIT)
Also 70 PRL 25 1214 Sciulli Gallivan Binnie Gomez+ (CIT)
MCCARTHY 73 PR D7 687 +Brewer Budnitz Entis Graven Miller+ (LBL)
Also 72 PL 42B 291 McCarthy Brewer Budnitz Entis Graven+ (LBL)
Also 71 LBL 550 Thesis McCarthy (LBL)
MESSNER 73 PRL 30 876 +Morse Nauenberg Hitlin+ (COLO SLAC UCSC)
PEACH 73 PL 43B 441 +Evans Muir Hopkins Krenz (EDIN CERN AACH)
SANDWEISS 73 PRL 30 1002 +Sunderland Turner Willis Keller (YALE ANL)
WILLIAMS 73 PRL 31 1521 +Larsen Leipuner Sapp Sessoms+ (BNL YALE)
ALBROW 72 NP B44 1 +Aston Barber Bird Ellison+ (MCHS DARE)
ASHFORD 72 PL 38B 47 +Brown Masek Maung Miller Ruderman+(UCSD)
BANNER 72 PRL 28 1597 +Cronin Hoffman Knapp Shochet (PRIN)
BANNER 72B PRL 29 237 +Cronin Hoffman Knapp Shochet (PRIN)
BARMIN 72 SJNP 15 636 +Davidenko Demidov Dolgolenko+ (ITEP)
Translated from YAF 15 1149
BARMIN 72B SJNP 15 638 +Barylov Davidenko Demidov+ (ITEP)
Translated from YAF 15 1152
BURGUN 72 NP B50 194 +Lesquoy Muller Pauli+ (SACL CERN OSLO)
CARNEGIE 72 PR D6 2335 +Cester Fitch Strovink Sulak (PRIN)
DALLY 72 PL 41B 647 +Innocenti Seppi+ (SLAC JHU UCLA)
Also 70 PL 33B 627 Chien Cox Ettinger+ (JHU SLAC UCLA)
Also 71 PL 35B 261 Chien Cox Ettinger+ (JHU SLAC UCLA)
GRAHAM 72 NC 9A 166 +Abashian Jones Mantsch Orr+ (ILL NEAS)
HOLDER 72 PL 40B 141 +Radermacher Staude+ (AACH CERN TORI)
JAMES 72 NP B49 1 +Montanet Paul Saetre+ (CERN SACL OSLO)
KRENZ 72 LNC 4 213 +Hopkins Evans Muir Peach (AACH CERN EDIN)
MANN 72 PR D6 137 +Kofler Meisner Hertzbach+ (MASA BNL YALE)
MANTSCH 72 NC 9A 160 +Abashian Graham Jones Orr+ (ILL NEAS)
MCCARTHY 72 PL 42B 291 +Brewer Budnitz Entis Graven+ (LBL)
METCALF 72 PL 40B 703 +Neuhofer Niebergall+ (CERN IPN WIEN)
NEUHOFER 72 PL 41B 642 +Niebergall Regler Stier+ (CERN ORSA VIEN)
PICCIONI 72 PRL 29 1412 +Coombes Donaldson Dorfan Fryberger+(SLAC)
Also 74 PR D9 2939 Piccioni Donaldson+ (SLAC UCSC COLO)
VOSBURGH 72 PR D6 1834 +Devlin Esterling Goz Bryman+ (RUTG MASA)
Also 71 PRL 26 866 Vosburgh Devlin Esterling Goz+ (RUTG MASA)
BALATS 71 SJNP 13 53 +Berezin Vishnevsky Galanina+ (ITEP)
Translated from YAF 13 93

Stable Particle Full Listings

K_L^0

BARMIN	71	PL 35B 604	+Barylov Veselovsky Davidenko+	(ITEP)
BISI	71	PL 36B 533	+Darriulat Ferrero Rubbia+	(AACH CERN TORI)
BURGUN	71	LNC 2 1169	+Lesquoy Muller Pauli+	(SACL CERN OSLO)
CARNEGIE	71	PR D4 1	+Cester Fitch Strovink Sulak	(PRIN)
CHAN	71	LBL 350 Thesis		(LBL)
CHIEN	71	PL 35B 261	+Cox Ettlinger+	(JHU SLAC UCLA)
Also	72	PL 41B 647	Dally Innocenti Seppi+	(SLAC JHU UCLA)
CHO	71	PR D3 1557	+Dralle Canter Engler Fisk+	(CMU BNL CASE)
CLARK	71	PRL 26 1667	+Eliott Field Frisch Johnson Kerth+	(LRL)
Also	70	UCRL 19709 Thesis	Johnson	(LRL)
Also	71	UCRL 20264 Thesis	Frisch	(LRL)
Also	74	SLAC PUB 1498 unpub	Field	(SLAC)
ENSTROM	71	PR D4 2629	+Akavia Coombes Dorfan+	(SLAC STAN)
Also	70	SLAC 125 Thesis	Enstrom	(STAN)
JAMES	71	PL 35B 265	+Montanet Paul Pauli+	(CERN SACL OSLO)
MEISNER	71	PR D3 59	+Mann Hertzbach Kofler+	(MASA BNL YALE)
PEACH	71	PL 35B 351	+Evans Muir Budagov Hopkins+	(EDIN CERN)
REPELLIN	71	PL 36B 603	+Wolff Chollet Gaillard Jane+	(ORSA CERN)
WEBBER	71	PR D3 64	+Solmitz Crawford Alston Garnjost	(LRL)
Also	68	PRL 21 498	Webber Solmitz Crawford Alston Garnjost	(LRL)
Also	69	UCRL 19226 Thesis	Webber	(LRL)
WOLFF	71	PL 36B 517	+Chollet Repellin Gaillard+	(ORSA CERN)
ALBROW	70	PL 33B 516	+Aston Barber Bird Ellison+	(MCHS DARE)
ARONSON	70	PRL 25 1057	+Ehrlich Hofer Jensen+	(EFI ILLC SLAC)
BARMIN	70	PL 33B 377	+Barylov Borisov Bysheva+	(ITEP JINR)
BASILE	70	PR D2 78	+Cronin Thevent Turlay Zylberajch+	(SACL)
BECHERRAWY	70	PR D1 1452		(ROCH)
BUCHANAN	70	PL 33B 623	+Drickey Rudnick Shepard+	(SLAC JHU UCLA)
Also	71	Private Comm	Cox	
BUDAGOV	70	PR D2 815	+Cundy Myatt Nezrick+	(CERN ORSA EPOL)
Also	68B	PL 28B 215	Budagov Cundy Myatt+	(CERN ORSA EPOL)
CHIEN	70	PL 33B 627	+Cox Ettlinger+	(JHU SLAC UCLA)
Also	71	Private Comm	Cox	
CHO	70	PR D1 3031	+Dralle Canter Engler Fisk+	(CMU BNL CASE)
Also	67	PRL 19 668	Hill Luers Robinson Sakitt+	(BNL CMU)
CHOLLET	70	PL 31B 658	+Gaillard Jane Ratcliffe Repellin+	(CERN)
CULLEN	70	PL 32B 523	+Darriulat Deutsch Foeth+	(AACH CERN TORI)
DARRIULAT	70	PL 33B 249	+Ferrero Grosso Holder+	(AACH CERN TORI)
FAISSNER	70	NC 70A 57	+Reithler Thome Gaillard+	(AACH CERN RHEL)
GINSBERG	70	PR D1 229		(HAIF)
JENSEN	70	Thesis		(EFI)
Also	69	PRL 23 615	Jensen Aronson Ehrlich Fryberger+	(EFI ILL)
MARX	70	PL 32B 219	+Nygren Peoples+	(COLU HARV CERN)
Also	70B	Nevis 179 Thesis	Marx	(COLU)
SCRIBANO	70	PL 32B 224	+Mannelli Pierazzini Marx+	(PISA COLU HARV)
SMITH	70	PL 32B 133	+Wang Whatley Zorn Hornbostel	(UMD BNL)
WEBBER	70	PR D1 1967	+Solmitz Crawford Alston Garnjost	(LRL)
Also	69	UCRL 19226 Thesis	Webber	(LRL)
BANNER	69	PR 188 2033	+Cronin Liu Pilcher	(PRIN)
Also	68	PRL 21 1103	Banner Cronin Liu Pilcher	(PRIN)
Also	68	PRL 21 1107	Cronin Liu Pilcher	(PRIN)
BEILLIERE	69	PL 30B 202	+Boutang Limon	(EPOL)
BENNETT	69	PL 29B 317	+Nygren Saal Steinberger+	(COLU BNL)
BOHM	69B	NP B9 605	+Darriulat Grosso Kaftanov+	(CERN)
Also	68	PL 27B 321	Bohm Darriulat Grosso Kaftanov	(CERN)
CENCE	69	PRL 22 1210	+Jones Peterson Stenger+	(HAWA LRL)
EVANS	69	PRL 23 427	+Golden Muir Peach+	(EDIN CERN)
FAISSNER	69	PL 30B 204	+Foeth Staude Tittel+	(AACH CERN TORI)
FOETH	69	PL 30B 282	+Holder Radermacher+	(AACH CERN TORI)
GAILLARD	69	NC 59A 453	+Galbraith Hussri Jane+	(CERN RHEL AACH)
Also	67	PRL 18 20	Gaillard Krienen Galbraith+	(CERN RHEL AACH)
GOBBI	69B	PRL 22 685	+Green Hakel Moffett Rosen Goz+	(ROCH RUTG)
LITTENBERG	69	PRL 22 654	+Field Piccioni Mehlhop+	(UCSD)
LONGO	69	PR 181 1808	+Young Helland	(MICH UCLA)
PACIOTTI	69	UCRL 19446 Thesis		(LRL)
SAAL	69	Thesis		(COLU)
ABRAMS	68B	PR 176 1603	+Abashian Mischke Nefkens Smith+	(ILL)
ARNOLD	68B	PL 28B 56	+Budagov Cundy Aubert+	(CERN ORSA)
ARONSON	68	PRL 20 287	+Chen	(PRIN)
Also	69	PR 175 1708	Aronson Chen	(PRIN)
BARTLETT	68	PRL 21 558	+Carnegie Fitch+	(PRIN)
BASILE	68	PL 26B 542	+Cronin Thevenet Turlay+	(SACL)
BASILE	68B	PL 28B 58	+Cronin Thevenet Turlay Zylberajch+	(SACL)
BENNETT	68	PL 27B 244	+Nygren Steinberger+	(COLU CERN)
BENNETT	68B	PL 27B 248	+Nygren Steinberger+	(COLU CERN)
BLANPIED	68	PRL 21 1650	+Levit Engels+	(CASE HARV MCGI)
BUDAGOV	68	NC 57A 182	+Burmeister Cundy+	(CERN ORSA IPNP)
Also	68B	PL 28B 215	Budagov Cundy Myatt+	(CERN ORSA EPOL)
JAMES	68	NP B8 365	+Briand	(IPNP CERN)
Also	68	PRL 21 257	Helland Longo Young	(UCLA MICH)
KULYUKINA	68	JETP 26 20	+Mestvirishvili Nyagu+	(JINR)
		Translated from ZETF 53 29		
KUNZ	68	PU 46 Thesis		(PRIN)
THATCHER	68	PR 174 1674	+Abashian Abrams Carpenter+	(ILL)
BENNETT	67	PRL 19 993	+Nygren Saal Steinberger+	(COLU)
BOTT	67	PL 24B 194	Bott Bodenhausen DeBouard Cassel+	(CERN)
BOTT	67B	PL 24B 438	Bott Bodenhausen Debouard Dekkers+	(CERN)
Also	66B	PL 20 212	Bott Bodenhausen Debouard Cassel+	(CERN)
Also	66	PL 23 277	Bott Bodenhausen DeBouard Cassel+	(CERN)
CRONIN	67	PRL 18 25	+Kunz Risk Wheeler	(PRIN)
CRONIN	67B	Princeton 11-67	+Kunz Risk Wheeler	(PRIN)
DEBOUARD	67	NC 52A 662	+Dekkers Jordan Mermod+	(CERN)
Also	65	PL 15 58	DeBouard Dekkers Scharff+	(CERN ORSA MPIM)
DEVLIN	67	PRL 18 54	+Solomon Shepard Beall+	(PRIN UMD)
Also	68	PR 169 1045	Sayer Beall Devlin Shephard+	(UMD PPA PRIN)
DORFAN	67	PRL 19 987	+Enstrom Raymond Schwartz+	(SLAC LRL)
FELDMAN	67B	PR 155 1611	+Frankel Highland Sloan	(PENN)
FIRESTONE	67	PRL 18 176	+Kim Lach Sandweiss+	(YALE BNL)
FITCH	67	PR 164 1711	+Roth Russ Vernon	(PRIN)
GINSBERG	67	PR 162 1570		(MASB)
HAWKINS	67	PR 156 1444		(YALE)
HILL	67	PRL 19 668	+Luers Robinson Sakitt+	(BNL CMU)
HOPKINS	67	PRL 19 185	+Bacon Eisler	(BNL)
KADYK	67	PRL 19 597	+Chan Drijard Oren Sheldon	(LRL)
KULYUKINA	67	Preprint	+Mestvirishvili Nyagu+	(JINR)
LOWYS	67	PL 24B 75	+Aubert Chounet Pascaud+	(EPOL ORSA)
MISCHKE	67	PRL 18 138	+Abashian Abrams+	(ILL)
NEFKENS	67	PR 157 1233	+Abashian Abrams Carpenter Fisher+	(ILL)
SCHMIDT	67	Nevis 160 Thesis		(COLU)
TODOROFF	67	Thesis		(ILL)
ALFF	66B	PL 21 595	Alff Steinberger Heuer Kleinknecht+	(CERN)
ANIKINA	66	SJNP 2 339	+Vardenga Zhuravleva+	(JINR)
		Translated from YAF 2 471		
AUERBACH	66B	PRL 17 980	+Mann McFarlane Sciulli	(PENN)
BASILE	66	Balaton Conf	+Cronin Thevenet+	(SACL)
BEHR	66	PL 22 540	+Brisson Petiau+	(EPOL MILA PADO ORSA)
BELLOTTI	66	NC 45A 737	+Pullia Baldo Ceolin+	(MILA PADO)
BOTT	66	PL 23 277	Bott Bodenhausen DeBouard Cassel+	(CERN)
CARPENTER	66	PR 142 871	+Abashian Abrams Fisher	(ILL)
CRIEGEE	66	PRL 17 150	+Fox Frauenfelder Hanson Moscati+	(ILL)
FIRESTONE	66	PRL 16 556	+Kim Lach Sandweiss+	(YALE BNL)
HAWKINS	66	PL 21 238		(YALE)
Also	67	PR 156 1444	Hawkins	(YALE)
NEFKENS	66	PL 19 706	+Abashian Abrams Carpenter+	(ILL)
ANDERSON	65	PRL 14 475	+Crawford Golden Stern Binford+	(LRL WISC)
ANIKINA	65	JINR P 2488	+Vardenga Zhuravleva Kotlya+	(JINR)
ASTBURY	65	PL 16 80	+Finocchiaro Beusch+	(CERN ZURI)
Also	65	HPA 39 523	Pepin	
ASTBURY	65B	PL 18 175	+Michelini Beusch+	(CERN ZURI)
ASTBURY	65C	PL 18 178	+Michelini Beusch+	(CERN ZURI)
AUBERT	65	PL 17 59	+Behr Canavan Chounet+	(EPOL ORSA)
Also	67	PL 24B 75	Lowys Aubert Chounet Pascaud+	(EPOL ORSA)
BALDO	65	NC 38 684	Baldo Ceolin Callmani Ciampolillo+	(PADO)
FISHER	65	ANL 7130 83	+Abashian Abrams Carpenter+	(ILL)
FITCH	65	PRL 15 73	+Roth Russ Vernon	(PRIN)
FRANZINI	65	PR 140B 127	+Kirsch Plano+	(COLU RUTG)
GALBRAITH	65	PRL 14 383	+Manning Jones+	(AERE BRIS RHEL)
GUIDONI	65	Argonne Conf 49	+Barnes Foelsche Ferbel Firestone+	(BNL YALE)
HOPKINS	65	Argonne Conf 67	+Bacon Eisler	(VAND RUTG)
ADAIR	64	PL 12 67	+Leipuner	(YALE BNL)
ALEKSANYAN	64B	Dubna Conf 2 102	+Alikhanyan Vartazaryan+	(YERE)
Also	64	JETP 19 1019	Aleksanyan+	(LEBD MPEI YERE)
		Translated from ZETF 46 1504		
ANIKINA	64	JETP 19 42	+Zhuravleva+	(GEOR JINR)
		Translated from ZETF 46 59		
CHRISTENSON	64	PRL 13 138	+Cronin Fitch Turlay	(PRIN)
FUJII	64	Dubna Conf 2 146	+Jovanovich Turkot+	(BNL UMD MIT)
LUERS	64	PR 133B 1276	+Mittra Willis Yamamoto	(BNL)
DARMON	62	PL 3 57	+Rousset Six	(EPOL)
ASTIER	61	Aix Conf 1 227	+Blaskovic Rivet Siaud+	(EPOL)
FITCH	61	NC 22 1160	+Piroue Perkins	(PRIN LASL)
GOOD	61	PR 124 1223	+Matsen Muller Piccioni+	(LRL)
NYAGU	61	PRL 6 552	+Okonov Petrov Rosanova Rusakov	(JINR)
Also	61B	JETP 13 1138	Nyagu Okonov Petrov Rozanova+	(JINR)
		Translated from ZETF 40 1618		
BARDON	58	ANP 5 156	+Lande Lederman	(COLU BNL)

OTHER RELATED PAPERS

KLEINKNECHT	76	ARNS 26 1		(DORT)
GINSBERG	73	PR D8 3887	+Smith	(MIT STON)
GINSBERG	70	PR D1 229		(HAIF)
HEUSSE	70	LNC 3 449	+Aubert Pascaud Vialle	(ORSA)
CRONIN	68C	Vienna Conf 281		(PRIN)
RUBBIA	67	PL 24B 531	+Steinberger	(CERN COLU)
Also	66C	PL 23 167	Rubbia Steinberger	(CERN COLU)
Also	66C	PL 20 207	Alff-Steinberger Heuer Kleinknecht+	(CERN)
Also	66B	PL 21 595	Alff Steinberger Heuer Kleinknecht+	(CERN)
AUERBACH	66	PR 149 1052	+Dobbs Lande Mann Sciulli+	(PENN)
Also	65	PRL 14 192	Auerbach Lande Mann Sciulli Uto+	(PENN)
FIRESTONE	66B	PRL 17 116	+Kim Lach Sandweiss+	(YALE BNL)
BEHR	65	Argonne Conf 59	+Brisson Bellotti+	(EPOL MILA PADO)
MESTVIRISH	65	JINR P 2449	Mestvirishvili Nyagu Petrov Rusakov+	(JINR)
TRILLING	65B	UCRL 16473		(LRL)
Updated from 1965 Argonne Conference page 115				
JOVANOV	63	BNL Conf 42	Jovanovich Fischer Burris+	(BNL UMD)

CHARMED MESONS

$D^{\pm}$

$I(J^P) = \frac{1}{2}(0^-)$

$D^{\pm}$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
1869.3 ± 0.6 OUR AVERAGE					
1875 ± 10	9	ADAMOVICH 87	EMUL		Photo production
1863 ± 4		DERRICK 84	HRS		e^+e^- E_{cm}= 29 GeV
1869.4 ± 0.6		[1] TRILLING 81	RVUE	±	e^+e^- E_{cm}= 3.77 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1860 ± 16	6	ADAMOVICH 84	EMUL		Photo production
1868.4 ± 0.5		[1] SCHINDLER 81	MRK2	±	e^+e^- E_{cm}= 3.77 GeV
1874 ± 5		GOLDHABER 77	MRK1	±	D^0 D^+ recoil spectra
1868.3 ± 0.9		[1] PERUZZI 77	MRK1	±	e^+e^- E_{cm}= 3.77 GeV
1874 ± 11		PICCOLO 77	MRK1	±	e^+e^- E_{cm}= 4.03, 4.41 GeV
1876 ± 15	50	PERUZZI 76	MRK1	±	$K^{\mp}\pi^{\pm}\pi^{\pm}$

[1] PERUZZI 77 and SCHINDLER 81 errors do not include the 0.13% uncertainty in the absolute SPEAR energy calibration. TRILLING 81 uses the high precision $J/\psi(1S)$ and $\psi(2S)$ measurements of ZHOLENTZ 80 to determine this uncertainty and combines the PERUZZI 77 and SCHINDLER 81 results to obtain the value quoted.

$D^{\pm}$ MEAN LIFE

VALUE (10^{-13} sec)	CL%	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
$10.69^{+0.34}_{-0.32}$ OUR AVERAGE						
10.90 ± 0.30 ± 0.25		3000	RAAB 88	SILI		Photo-production
$5.0^{+1.5}_{-1.0}$ ± 1.9		27	ADAMOVICH 87	EMUL		Photo production
$11.2^{+1.4}_{-1.1}$		149	AGUILAR 87D	HYBR		π^-p and pp
$10.9^{+1.9}_{-1.5}$		59	BARLAG 87B	SILI		K^- and π^- 200 GeV
11.4 ± 1.6 ± 0.7		526	CSORNA 87	CLEO		e^+e^- E_{cm}=10 GeV
10.9 ± 1.4		74	[2] PALKA 87B	SILI		πBe 200 GeV
8.6 ± 1.3 $^{+0.7}_{-0.3}$		48	ABE 86	HYBR		SLAC γp 20 GeV
$8.9^{+3.8}_{-2.7}$ ± 1.3		23	GLADNEY 86	MRK2		e^+e^- E_{cm}=29 GeV
$11.1^{+4.4}_{-2.9}$		28	USHIDA 86	EMUL		ν wideband
$10.6^{+3.6}_{-2.4}$		28	BAILEY 85	SILI	+	π^-Be 200 GeV
$9.5^{+3.1}_{-1.9}$		70	[3] ALBINI 82	SILI		CERN γSi
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$10.7^{+2.8}_{-1.8}$		40	AGUILAR 87C	HYBR		Repl. by AGUILAR 87D
10.6 ± 0.5 ± 0.3		969	ANJOS 87	SILI		Repl. by RAAB 88
$7.2^{+2.3}_{-2.0}$		21	[4] ABE 84	HYBR		Repl. by ABE 86
$3.91^{+2.35}_{-1.25}$		12	[5] ADAMOVICH 84	EMUL		Repl. by ADAMOVICH 87
$8.4^{+3.5}_{-2.2}$		15	AGUILAR 83	HYBR	−	Repl. by Aguilar 87D
$6.3^{+5.0}_{-2.7}$		7	BADERT 83	HYBR		CERN π^-N
$11.5^{+7.5}_{-3.5}$		11	USHIDA 83	EMUL		Repl. by USHIDA 86
$2.2^{+2.3}_{-1.1}$		1	[6] BALLAGH 81	HYBR		FNAL 15 ft ν He ^{2}H
$2.5^{+2.2}_{-1.1}$		4	ALLASIA 80	EMUL		ν wideband
$10.4^{+3.9}_{-2.9}$			[7] BACINO 80	DLCO	+	e^+e^- E_{cm}=3.77 GeV
< 8	90		ARMENISE 79	HYBR		$\nu p \to$ dimuons +

[2] PALKA 87B observed this in $D^+ \to K^*(892)e\nu$.
[3] ALBINI 82 assumes D momentum is 1/2 beam momentum.
[4] Some events may be D_s^+ and 5 events could be Λ_c^+.
[5] Estimate systematic error less than $^{+1.2}_{-1.3}$.
[6] BALLAGH 81 value quoted here assumes that all dilepton events contain D^0 or D^+, each with equal numbers of semileptonic decays.
[7] Uses theoretical rate $D \to (Ke\nu) = 1.4 \times 10^{11}$ sec^{-1}.

D^+ DECAY MODES

D^- modes are charge conjugates of the modes below.

	Mode	Fraction (Γ_i/Γ)	Scale/Conf Lev
Γ_1	$D^+ \to K^0\pi^+$	$(2.8 \pm 0.4) \cdot 10^{-2}$	
Γ_2	$D^+ \to K^0K^+$	$(8.4^{+2.6}_{-2.5}) \cdot 10^{-3}$	
Γ_3	$D^+ \to \bar{K}^0\rho^+$	$(6.6^{+1.7}_{-1.6}) \cdot 10^{-2}$	
Γ_4	$D^+ \to K^*(892)^0\pi^+$	$(1.7 \pm 0.8) \cdot 10^{-2}$	
Γ_5	$D^+ \to K^0\pi^+\pi^0$ (non-resonant)	$(1.2^{+1.0}_{-0.7}) \cdot 10^{-2}$	
Γ_6	$D^+ \to K^-\pi^+\pi^+$ (non-resonant)	$(6.7^{+1.1}_{-0.9}) \cdot 10^{-2}$	
Γ_7	$D^+ \to \phi\pi^+$	$(5.7^{+1.1}_{-0.9}) \cdot 10^{-3}$	
Γ_8	$D^+ \to \bar{K}^*(892)^0K^+$	$(4.4^{+1.0}_{-0.9}) \cdot 10^{-3}$	
Γ_9	$D^+ \to \pi^+K^+K^-$ (non-resonant)	$(3.9^{+1.0}_{-0.8}) \cdot 10^{-3}$	
Γ_{10}	$D^+ \to \pi^+\pi^+\pi^-$	$(3.3^{+1.5}_{-1.4}) \cdot 10^{-3}$	
Γ_{11}	$D^+ \to \bar{K}^0\pi^+\pi^+\pi^-$	$(7.0^{+2.3}_{-2.1}) \cdot 10^{-2}$	S=1.7
Γ_{12}	$D^+ \to K^-\pi^+\pi^+\pi^0$	$(3.7^{+1.5}_{-0.8}) \cdot 10^{-2}$	
Γ_{13}	$D^+ \to K^0\pi^+\pi^+\pi^-\pi^0$	$(4.4^{+5.2}_{-1.5}) \cdot 10^{-2}$	
Γ_{14}	$D^+ \to K^-\pi^+\pi^+\pi^0\pi^0$	$(2.2^{+5.0}_{-0.9}) \cdot 10^{-2}$	
Γ_{15}	$D^+ \to e^+$ anything	$(19.2^{+2.3}_{-1.6}) \cdot 10^{-2}$	S=1.2
Γ_{16}	$D^+ \to$ all except the above modes	$(42^{+4}_{-9}) \cdot 10^{-2}$	S=1.1
Γ_{17}	$D^+ \to K^-\pi^+\pi^+$	$(7.8^{+1.0}_{-0.8}) \cdot 10^{-2}$	
	In the fit as $2/3\Gamma_4 + \Gamma_6$		
Γ_{18}	$D^+ \to K^0\pi^+\pi^0$	$(8.3^{+1.8}_{-1.7}) \cdot 10^{-2}$	
	In the fit as $1/3\Gamma_4 + \Gamma_3 + \Gamma_5$		
Γ_{19}	$D^+ \to \pi^+K^+K^-$	$(9.9^{+4.0}_{-2.2}) \cdot 10^{-3}$	
	In the fit as $1/2\Gamma_7 + 2/3\Gamma_8 + \Gamma_9$		
Γ_{20}	$D^+ \to K^-$ anything	$(16.2 \pm 3.5) \cdot 10^{-2}$	
Γ_{21}	$D^+ \to \bar{K}^0$ anything + K^0 anything	$(48 \pm 15) \cdot 10^{-2}$	
Γ_{22}	$D^+ \to K^+$ anything	$(6.6^{+2.9}_{-2.8}) \cdot 10^{-2}$	
Γ_{23}	$D^+ \to K^-\pi^+\pi^0e^+\nu$	$(4.4^{+5.2}_{-1.5}) \cdot 10^{-2}$	
Γ_{24}	$D^+ \to \bar{K}^0\pi^+\pi^-e^+\nu$	$(2.2^{+5.0}_{-0.7}) \cdot 10^{-2}$	
Γ_{25}	$D^+ \to \pi^+\pi^0$	$< 5 \cdot 10^{-3}$	CL=90%
Γ_{26}	$D^+ \to \mu^+\nu_\mu$	$< 7 \cdot 10^{-4}$	CL=90%
Γ_{27}	$D^+ \to K^+\pi^+\pi^-$	$< 4 \cdot 10^{-3}$	CL=90%
Γ_{28}	$D^+ \to K^-\pi^+e^+\nu$	$< 6 \cdot 10^{-2}$	CL=90%
Γ_{29}	$D^+ \to \pi^+\pi^-e^+\nu$	$< 6 \cdot 10^{-2}$	CL=90%
Γ_{30}	$D^+ \to K^-\pi^+\pi^+\pi^+\pi^-$	$< 5 \cdot 10^{-2}$	CL=90%
Γ_{31}	$D^+ \to \pi^+\pi^+\pi^+\pi^-\pi^-\pi^0$		
Γ_{32}	$D^+ \to e^+\nu_e$		
Γ_{33}	$D^+ \to \eta$ anything		
Γ_{34}	$D^+ \to \mu^+$ anything		
Γ_{35}	$D^+ \to \mu^+\mu^-$ anything		
Γ_{36}	$D^+ \to \phi\pi^+\pi^-\pi^+$	$< 2.0 \cdot 10^{-3}$	CL=90%
Γ_{37}	$D^+ \to K^+K^-\pi^+\pi^-\pi^+$ (non-resonant)	$< 3.0 \cdot 10^{-2}$	CL=90%

CONSTRAINED FIT INFORMATION

An overall fit to 9 products of a cross section and a partial width, a cross section, and 13 branching ratios uses 38 measurements and one constraint to determine 17 parameters. The overall fit has a χ^2 = 18.4 for 22 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta p_i \delta p_j\rangle/(\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i, including the branching fractions $x_i \equiv \Gamma_i/\Gamma_{total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

x_2	45									
x_3	28	13								
x_4	14	6	2							
x_5	9	4	20	1						
x_6	47	21	29	41	10					
x_7	38	17	21	13	6	52				
x_8	32	14	17	10	5	43	34			
x_9	30	13	16	10	5	41	31	25		
x_{10}	15	7	8	5	2	20	16	13	12	
x_{11}	21	10	12	6	4	20	16	13	12	6
x_{12}	24	11	13	7	4	25	20	17	16	8
x_{13}	0	0	0	0	0	0	0	0	0	0
x_{14}	0	0	0	0	0	0	0	0	0	0
x_{15}	0	0	0	0	0	0	0	0	0	0
x_{16}	45	24	44	15	17	42	36	30	28	16
σ	71	32	39	20	12	66	54	45	42	20
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}

x_{12}	10					
x_{13}	0	0				
x_{14}	0	0	0			
x_{15}	0	0	0	0		
x_{16}	55	35	44	29	32	
σ	30	33	0	0	0	57
	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}

NOTE ON CHARMED MESON BRANCHING FRACTIONS AND NEW RESULTS ON CHARMED MESON DECAYS

In the previous edition of the Review of Particle Properties, D^0 and D^+ branching fractions were modified to reflect a consistent average of the results from BALTRUSAITIS 86, PERUZZI 77, SCHARRE 78, and SCHINDLER 81. The cross section for D production (σ_D) from BALTRUSAITIS 86 was chosen as the common value with which to normalize all measured production rates ($\sigma_D \cdot B$) in these e^+e^- experiments; here, B represents the branching fraction of the D into a particular mode. As noted at that time, while production rates were in good agreement, a large discrepancy existed among the cross-section (σ_D) measurements. The possibility that the $\psi(3770)$ decayed significantly to noncharmed final states was ruled out by the measurement of Feller[1] suggesting that the fraction of $\psi(3770)$ decays to charm is 1.09 ± 0.23.

About one-half of the discrepancy was resolved in ADLER 88C. In ADLER 88C, the results of BALTRUSAITIS 86 on the magnitude of the charm cross section were revised upward about 20% for $D^{\pm}$ and 23% for D^0. This change reflected an underestimate in the original analysis of feed-down from Cabibbo-suppressed decays and the contamination of hitherto unmeasured Cabibbo-allowed D meson decay channels that contained two or more π^0's. As an example of the latter, ADLER 88C finds $B(D^0 \to K^-\pi^+\pi^0\pi^0) = 14.9 \pm 3.7 \pm 3.0\%$, the first direct measurement of this decay mode. The D meson production rates ($\sigma_D \cdot B$) in ADLER 88C remained unchanged from those measured in BALTRUSAITIS 86, the original work. Further discussion of the implications for other heavy-meson decays is available in SCHINDLER 87.

In this edition of the Review of Particle Properties, we have restructured the Listings to minimize the influence of any future shifts in normalization and to correctly propagate errors in the fits for branching ratios. Wherever possible, we have entered only the information actually measured by an experiment and have not used *derived* quantities. Topological normalizations (e.g., AGUILAR-BENITEZ 84) have been retained, but where experiments have measured only relative branching fractions, only those ratios have been included in the fits. Experiments that measure production cross sections times branching fractions in e^+e^- at the $\psi(3770)$ have been separated off. They are now listed as $\sigma_D \cdot B$ at the $\psi(3770)$. They are normalized by averaging the cross section at the $\psi(3770)$, derived either by resonance scans or by the direct method of BALTRUSAITIS 86 updated in ADLER 88C. A new compilation of the $\psi(3770)$ cross section is now included (for this purpose only).

A new technique introduced in SNYDER 87 (see OTHER RELATED PAPERS) measures the $K^-\pi^+$ branching ratio by tagging D^0 in the cascade from $D^*(2010)^+$ in e^+e^- at 29 GeV. While these results are preliminary in nature, the $B(D^0 \to K^-\pi^+) = 4.5 \pm 0.8 - 0.6\%$ reported is in excellent agreement with that of ADLER 88C, where a value of $4.2 \pm 0.4 \pm 0.4\%$ is obtained. We note that the RPP 88 fitted value is now $3.77 - 0.37 \pm 0.32\%$.

In 1987, a strict limit on the pure leptonic decay of the D^+ was obtained (see ADLER 88B). The experiment obtained $B(D^+ \to \mu^+\nu_\mu) < 7.2 \times 10^{-4}$ at CL=0.90. This limit measures the strength of the weak axial-vector current, which is proportional to f_D, the D meson decay constant. The branching-fraction limit translates into the limit $f_D \leqslant 290$ MeV/c; it is the first measurement of the weak decay constant for a heavy meson. Under simple theoretical assumptions (see references of ADLER 88B), the pseudoscalar decay constants for mesons containing different species of heavy quarks are ordered in magnitude $f_D \gtrsim f_B \gtrsim f_T$. The limit on f_D can thus be interpreted also as a phenomenological bound on f_B.

In 1987, the first series of measurements on rare D meson decays were made These provide tests of the Standard Model and its possible extensions (technicolor, leptoquarks, supersymmetry etc) Weak flavor-changing neutral currents (FCNC) are forbidden only in lowest order by the Standard Model, they may appear to occur through a combination of electromagnetic and higher order weak processes Tests of FCNC include measurements of $D^0 \to e^+ e^-$ and $\mu^+ \mu^-$ Lepton-family-number-violating (LFNV) decays, a subset of all FCNC, are forbidden to all orders in the Standard Model and are tested by measurements of $D^0 \to \mu^{\pm} e^{\mp}$ These two-body decays now have measured constraints on their branching fractions as low as $\sim 10^{-4}$ In the absence of knowledge of the mass or couplings associated with a particular extension to the Standard Model, these measurements provide either a measure of the coupling assuming a mass or a measure of the mass assuming a coupling On the assumption that couplings are unity, the results typically give limits on masses of nonstandard objects of a few TeV The most recent experimental results are summarized in GRAB 87 and SCHUBERT 87

Reference

1 J M Feller et al , Ph D thesis, LBL-9017 (1979)

D^+ BRANCHING RATIOS

$\Gamma(K^-$ anything$)/\Gamma_{total}$ Γ_{20}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.162 ± 0.035 OUR AVERAGE					
0 17 ± 0 07		AGUILAR	87E	HYBR	πp pp 360 400 GeV
0 19 ± 0 05	26	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV
0.10 ± 0 07	3	VUILLEMIN	78	MRK1	e^+e^- E_{cm}= 3 772 GeV
• • • We do not use the following data for averages fits limits etc • • •					
0 16 $^{+0\ 08}_{-0\ 07}$		AGUILAR	86B	HYBR	Repl by AGUILAR BENITEZ 87E

$\Gamma(K^+$ anything$)/\Gamma_{total}$ Γ_{22}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.066 $^{+0.029}_{-0.028}$ OUR AVERAGE					
0 08 $^{+0\ 06}_{-0\ 05}$		AGUILAR	87E	HYBR	πp pp 360 400 GeV
0 06 ± 0 04	12	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV
0 06 ± 0 06	2	VUILLEMIN	78	MRK1	e^+e^- E_{cm}= 3 772 GeV

$\Gamma(\overline{K}^0$ anything$)$ + $\Gamma(K^0$ anything$)/\Gamma_{total}$ Γ_{21}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.48 ± 0.15 OUR AVERAGE					
0 52 ± 0 18	15	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV
0 39 ± 0 29	3	VUILLEMIN	78	MRK1	e^+e^- E_{cm}= 3 772 GeV

D^+ and $D^0 \to$ (η anything) / (total D^+ and D^0)

If measured at the $\psi(3770)$ this quantity is a weighted average of D^+ (44 percent) and D^0 (56 percent) branching fractions Only the experiment at E_{cm} = 3 77 GeV is used

VALUE	DOCUMENT ID		TECN	COMMENT
<0.13	PARTRIDGE	81	CBAL	e^+e^- E_{cm}= 3 77 GeV
• • • We do not use the following data for averages fits limits etc • • •				
<0 02	[8] BRANDELIK	79	DASP	e^+e^- E_{cm}= 4 03 GeV

[8] BRANDELIK 79 result based on absence of η signal at E_{cm} = 4 03 GeV PARTRIDGE 81 observe substantially higher η cross section at E_{cm} = 4 03 GeV

$\Gamma(e^+$ anything$)/\Gamma_{total}$ Γ_{15}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.192 $^{+0.023}_{-0.016}$ OUR FIT Error includes scale factor of 1 2					
0.192 $^{+0.017}_{-0.014}$ OUR AVERAGE					
0 20 $^{+0\ 09}_{-0\ 07}$		AGUILAR	87E	HYBR	πp pp 360 400 GeV
0 170 ± 0 019 ± 0 007	158	BALTRUSAITIS	85B	MRK3	e^+e^- E_{cm}= 3 77 GeV
0 168 ± 0 064	23	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV
0 220 $^{+0\ 044}_{-0\ 022}$		BACINO	80	DLCO	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(c/\overline{c} \to \mu^+$ anything$)/\Gamma(c/\overline{c} \to$ anything$)$

VALUE	DOCUMENT ID		TECN	COMMENT
0.081 $^{+0.017}_{-0.013}$ OUR AVERAGE				
0 078 ± 0 015 ± 0 02	[9] BARTEL	87	JADE	e^+e^- E_{cm} 34 6 GeV
0 082 $^{+0\ 023}_{-0\ 016}$	[9] ALTHOFF	84G	TASS	e^+e^- E_{cm}= 34 5 GeV
• • • We do not use the following data for averages fits limits etc • • •				
0 089 ± 0 018 ± 0 025	[9] BARTEL	85J	JADE	Repl by BARTEL 87

[9] Average BR for charm $\to \mu^+$ X The mixture of charmed particles is unknown and may actually contain states other than D mesons

$\Gamma(c/c \to \mu^+\mu^-$ anything$)/\Gamma(c/c \to$ anything$)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
<0 007	95	[10] ALTHOFF	84G	TASS	e^+e^- E_{cm}= 34 5 GeV

[10] Average BR for charm $\to \mu^+\mu^-$ X The mixture of charmed particles is unknown and may actually contain states other than D mesons

D^+ and $D^0 \to$ (e^+ anything) / (total D^+ and D^0)

If measured at the $\psi(3770)$ this quantity is a weighted average of D^+ (44 percent) and D^0 (56 percent) branching fractions Only experiments at E_{cm} = 3 77 GeV are included in the average

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.110 ± 0.011 OUR AVERAGE Error includes scale factor of 1 1					
0 117 ± 0 011	295	BALTRUSAITIS	85B	MRK3	e^+e^- E_{cm}= 3 77 GeV
0 10 ± 0 032		[11] SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV
0 072 ± 0 028		FELLER	78	MRK1	e^+e^- E_{cm}= 3 772 GeV
• • • We do not use the following data for averages fits limits etc • • •					
0 116 $^{+0\ 011}_{-0\ 009}$		PAL	86	DLCO	e^+e^- E_{cm}= 29 GeV
0 091 ± 0 009 ± 0 013		[12] AIHARA	85	TPC	e^+e^- E_{cm}= 29 GeV
0 092 ± 0 046		[12] ALTHOFF	84J	TASS	e^+e^- E_{cm}= 34 6 GeV
0 091 ± 0 013		[12] KOOP	84	DLCO	Repl by PAL 86
0 08 ± 0 015		[13] BACINO	79	DLCO	e^+e^- E_{cm}= 3 772 GeV

[11] Isolates D^+ and $D^0 \to e^+$ X and weights for relative production (44%-56%)

[12] Average BR for charm $\to e^+$ X Unlike E_{cm} = 3 77 GeV the admixture of charmed mesons is unknown

[13] Not independent of BACINO 80 $\Gamma(e^+$ anything$)/\Gamma_{total}$ (D^+) and $\Gamma(e^+$ anything$)/\Gamma_{total}$ (D^0)

$\sigma(e^+e^- \to \psi(3770))$ × $\Gamma(\overline{K}^0\pi^-)/\Gamma_{total}$ $\sigma\Gamma_1/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
0.136 ± 0 013 OUR FIT					
0.136 ± 0.013 OUR AVERAGE					
0 135 ± 0 012 ± 0 010	161	BALTRUSAITIS	86E	MRK3	e^+e^- E_{cm}= 3 77 GeV
0 14 ± 0 03	36	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV
0 14 ± 0 05	17	PERUZZI	77	MRK1	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(\overline{K}^0\pi^+)/\Gamma(K^-\pi^+\pi^+)$ $\Gamma_1/(\frac{2}{3}\Gamma_4+\Gamma_6)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
<0 45	90	[14] PICCOLO	77	MRK1	e^+e^- E_{cm}= 4 03 GeV

[14] Obtained from σ · BR values of table I

$\Gamma(K^0K^+)/\Gamma(K^0\pi^+)$ Γ_2/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0 30 ± 0 08 OUR FIT					
0.30 ± 0.08 OUR AVERAGE					
0 317 ± 0 086 ± 0 048	31	BALTRUSAITIS	85E	MRK3	e^+e^- E_{cm}= 3 77 GeV
0 25 ± 0 15	6	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(\overline{K}^0\rho^-)/\Gamma_{total}$ — $\sigma\Gamma_3/\Gamma$

VALUE (nanobarns)	DOCUMENT ID		TECN	COMMENT
0.32 ± 0.07 OUR FIT				
0 29 ± 0.03 ± 0.09	ADLER	87	MRK3	e^+e^- E_{cm}= 3 77 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(\overline{K}^*(892)^0\pi^+)/\Gamma_{total}$ — $\sigma\Gamma_4/\Gamma$

VALUE (nanobarns)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.08 ± 0 04 OUR FIT							
0.08 ± 0.01 ± 0.04			ADLER	87	MRK3		e^+e^- E_{cm}= 3 77 GeV
• • • We do not use the following data for averages fits limits etc • • •							
<0 27	90		SCHINDLER	81	MRK2		e^+e^- E_{cm}= 3 771 GeV
		92	DRIJARD	79	SFM	+	pp E_{cm}= 53 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(\overline{K}^0\pi^+\pi^0$ (non-resonant)$)/\Gamma_{total}$ — $\sigma\Gamma_5/\Gamma$

VALUE (nanobarns)	DOCUMENT ID		TECN	COMMENT
0.06 ± 0.05 OUR FIT				
0 05 ± 0.03 ± 0.04	ADLER	87	MRK3	e^+e^- E_{cm}= 3 77 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^-\pi^+\pi^+$ (non-resonant)$)/\Gamma_{total}$ — $\sigma\Gamma_6/\Gamma$

VALUE (nanobarns)	DOCUMENT ID		TECN	COMMENT
$0.320^{+0.035}_{-0.034}$ OUR FIT				
0.31 ± 0.03 ± 0.10	ADLER	87	MRK3	e^+e^- E_{cm}= 3 77 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^-\pi^+\pi^+)/\Gamma_{total}$ — $\sigma(\frac{2}{3}\Gamma_4+\Gamma_6)/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
0.376 ± 0.024 OUR FIT					
0.381 ± 0.024 OUR AVERAGE					
0 388 ± 0 013 ± 0 029	1164	BALTRUSAITIS	86E	MRK3	e^+e^- E_{cm}= 3 77 GeV
0 38 ± 0 05	239	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV
0.36 ± 0 06	85	PERUZZI	77	MRK1	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(K^-\pi^+\pi^+)/\Gamma_{total}$ — $(\frac{2}{3}\Gamma_4+\Gamma_6)/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.078^{+0.011}_{-0.008}$ OUR FIT					
$0.063^{+0.028}_{-0.014}$ ± 0.011	8	[15] AGUILAR	87F	HYBR	πp, pp 360 400 GeV

[15] AGUILAR BENITEZ 87F computed the branching ratio by topological normalization

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(\overline{K}^0\pi^+\pi^0)/\Gamma_{total}$ — $\sigma(\frac{1}{3}\Gamma_4+\Gamma_3+\Gamma_5)/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
0.40 ± 0.08 OUR FIT					
0.44 ± 0.11 OUR AVERAGE					
0 417 ± 0 081 ± 0 075	159	BALTRUSAITIS	86E	MRK3	e^+e^- E_{cm}= 3 77 GeV
0 78 ± 0 48	10	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV

$\Gamma(\overline{K}^0\pi^+\pi^0)/\Gamma_{total}$ — $(\frac{1}{3}\Gamma_4+\Gamma_3+\Gamma_5)/\Gamma$

VALUE	DOCUMENT ID
$0.083^{+0.018}_{-0.017}$ OUR FIT	

$\Gamma(\phi\pi^+)/\Gamma_{total}$ — Γ_7/Γ

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
$0.0057^{+0.0011}_{-0.0009}$ OUR FIT						
• • • We do not use the following data for averages fits limits etc • • •						
SEEN	234	GEORGIO	85	SPEC	+	pN 400 GeV

$\Gamma(\pi^+K^+K^-$ (non-resonant)$)/\Gamma_{total}$ — Γ_9/Γ

VALUE	DOCUMENT ID
$0.0039^{+0.0010}_{-0.0008}$ OUR FIT	

$\Gamma(\phi\pi^+)/\Gamma(K^-\pi^+\pi^+)$ — $\Gamma_7/(\frac{2}{3}\Gamma_4+\Gamma_6)$

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.073 ± 0.010 OUR FIT						
0.073 ± 0.010 OUR AVERAGE						
0 071 ± 0 008 ± 0 007	84	ANJOS	88	SILI		Photo-production
0 084 ± 0 021 ± 0 011	21	BALTRUSAITIS	85E	MRK3	+	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(\overline{K}^*(892)^0K^+)/\Gamma(K^-\pi^+\pi^+)$ — $\Gamma_8/(\frac{2}{3}\Gamma_4+\Gamma_6)$

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0 056 ± 0.010 OUR FIT						
0.056 ± 0.010 OUR AVERAGE						
0 058 ± 0 009 ± 0 006	73	ANJOS	88	SILI		Photo production
0 048 ± 0 021 ± 0 011	14	BALTRUSAITIS	85E	MRK3	+	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(\pi^+K^+K^-$ (non-resonant)$)/\Gamma(K^-\pi^+\pi^+)$ — $\Gamma_9/(\frac{2}{3}\Gamma_4+\Gamma_6)$

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
$0.050^{+0.010}_{-0.009}$ OUR FIT						
0 050 ± 0 009 OUR AVERAGE						
0 049 ± 0 008 ± 0 006	95	ANJOS	88	SILI		Photo production
0 059 ± 0 026 ± 0 009	37	[16] BALTRUSAITIS	85E	MRK3	+	e^+e^- E_{cm}= 3 77 GeV

[16] This measurement excludes contributions to $K^+K^-\pi^+$ from $\phi\pi^+$ and $\overline{K}^*(892)^0K^+$

$\Gamma(\pi^+K^+K^-)/\Gamma_{total}$ — $(\frac{1}{2}\Gamma_7+\frac{2}{3}\Gamma_8+\Gamma_9)/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.0096^{+0.0018}_{-0.0013}$ OUR FIT					
$0.008^{+0.017}_{-0.002}$ ± 0.001	1	[17] AGUILAR	87F	HYBR	πp, pp 360 400 GeV

[17] AGUILAR BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(\pi^+K^+K^-)/\Gamma(K^-\pi^+\pi^+)$ — $(\frac{1}{2}\Gamma_7+\frac{2}{3}\Gamma_8+\Gamma_9)/(\frac{2}{3}\Gamma_4+\Gamma_6)$

These measurement do not distinguish possible resonant substructure

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
$0.124^{+0.014}_{-0.012}$ OUR FIT						
• • • We do not use the following data for averages fits limits etc • • •						
0 25 ± 0 20		5	[18] BAILEY	84	SILI	Hadroproduction
<0 14	90		SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV
<0 15	90		[19] PICCOLO	77	MRK1	e^+e^- E_{cm}= 4 03 GeV

[18] One event consistent with $D^{\pm} \to \phi\pi^+$

[19] Obtained from $\sigma \times$ BR values of table I

$\Gamma(\pi^+\pi^+\pi^-)/\Gamma(K^-\pi^+\pi^+)$ — $\Gamma_{10}/(\frac{2}{3}\Gamma_4+\Gamma_6)$

VALUE	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.042 ± 0.019 OUR FIT							
0.042 ± 0.016 ± 0.010		57	BALTRUSAITIS	85E	MRK3	+	e^+e^- E_{cm}= 3 77 GeV
• • • We do not use the following data for averages fits limits etc • • •							
<0 084	90		SCHINDLER	81	MRK2		e^+e^- E_{cm}= 3 771 GeV
<0 08	90		[20] PICCOLO	77	MRK1	±	e^+e^- E_{cm}= 4 03 GeV

[20] Obtained from $\sigma \times$ BR values of table I

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(\overline{K}^0\pi^+\pi^+\pi^-)/\Gamma_{total}$ — $\sigma\Gamma_{11}/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.34 ± 0.10 OUR FIT Error includes scale factor of 2 0					
0 31 ± 0.06 OUR AVERAGE Error includes scale factor of 1 2					
0 291 ± 0 047 ± 0 029	168	ADLER	88C	MRK3	e^+e^- E_{cm}= 3 77 GeV
0 51 ± 0 18	21	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV

$\Gamma(\overline{K}^0\pi^+\pi^+\pi^-)/\Gamma_{total}$ — Γ_{11}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.070^{+0.023}_{-0.021}$ OUR FIT Error includes scale factor of 1 7					
$0.243^{+0.064}_{-0.041}$ ± 0.041	11	[21] AGUILAR	87F	HYBR	πp, pp 360 400 GeV

[21] AGUILAR BENITEZ 87F computed the branching ratio by topological normalization

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^-\pi^+\pi^+\pi^0)/\Gamma_{total}$ — $\sigma\Gamma_{12}/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
$0.18^{+0.07}_{-0.04}$ OUR FIT					
0.18 ± 0.04 ± 0.04	175	BALTRUSAITIS	86E	MRK3	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(K^-\pi^+\pi^+\pi^0)/\Gamma_{total}$ — Γ_{12}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.037^{+0.015}_{-0.008}$ OUR FIT					
$0.022^{+0.047}_{-0.006}$ ± 0.004	1	[22] AGUILAR	87F	HYBR	πp, pp 360 400 GeV
• • • We do not use the following data for averages fits, limits etc • • •					
SEEN	7	AGUILAR	86B	HYBR	π^-p 360 GeV

[22] AGUILAR BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(K^-\pi^+\pi^+\pi^0)/\Gamma(K^-\pi^+\pi^+)$ — $\Gamma_{12}/(\frac{2}{3}\Gamma_4+\Gamma_6)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.48^{+0.20}_{-0.10}$ OUR FIT					
$0.57^{+0.65}_{-0.17}$	1	AGUILAR-	83B	HYBR	$\pi^- p$ 360 GeV

$\Gamma(\bar{K}^0\pi^+\pi^+\pi^-\pi^0)/\Gamma_{total}$ — Γ_{13}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.044^{+0.052}_{-0.015}$ OUR FIT					
$0.044^{+0.052}_{-0.013}\pm0.007$	2	[23] AGUILAR	87F	HYBR	πp, pp 360 400 GeV
• • • We do not use the following data for averages fits, limits etc • • •					
SEEN	3	AGUILAR	86B	HYBR	$\pi^- p$ 360 GeV

[23] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(K^-\pi^+\pi^+\pi^0\pi^0)/\Gamma_{total}$ — Γ_{14}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.022^{+0.050}_{-0.009}$ OUR FIT					
$0.022^{+0.047}_{-0.008}\pm0.004$	1	[24] AGUILAR-	87F	HYBR	πp pp 360 400 GeV
• • • We do not use the following data for averages, fits limits etc • • •					
SEEN	1	AGUILAR-	86B	HYBR	$\pi^- p$ 360 GeV

[24] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(K^-\pi^+\pi^0 e^+\nu)/\Gamma_{total}$ — Γ_{23}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.044^{+0.052}_{-0.013}\pm0.007$	2	[25] AGUILAR	87F	HYBR	πp pp 360,400 GeV

[25] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(\bar{K}^0\pi^+\pi^- e^+\nu)/\Gamma_{total}$ — Γ_{24}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.022^{+0.047}_{-0.006}\pm0.004$	1	[26] AGUILAR	87F	HYBR	πp pp 360 400 GeV

[26] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(\pi^+\pi^0)/\Gamma_{total}$ — Γ_{25}/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.0053	90	1	BALTRUSAITIS	85E	MRK3	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(\pi^+\pi^0)/\Gamma(\bar{K}^0\pi^+)$ — Γ_{25}/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •					
<0 30	90	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV

$\Gamma(\mu^+\nu_\mu)/\Gamma_{total}$ — Γ_{26}/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.00072	90		[27] ADLER	88B	MRK3	e^+e^- E_{cm}= 3 77 GeV
• • • We do not use the following data for averages fits limits etc • • •						
<0 02	90	0	[28] AUBERT	83	SPEC	μ^+Fe, 250 GeV

[27] Using 10 9 ps for the D^+ lifetime and $|V_{cd}|^2$ = 0 0493 ADLER 88B find the weak hadronic axial vector decay constant of the D^+ to be f_D < 290 MeV/c at 90% CL

[28] AUBERT 83 obtain upper limit 0 014 assuming that final state contains equal mixture of (D^+D^-), ($D^+\bar{D}^0$) (D^-,D^0) and ($D^0\bar{D}^0$) We quote the limit which they get under more general assumptions

$\Gamma(K^+\pi^+\pi^-)/\Gamma(K^-\pi^+\pi^+)$ — $\Gamma_{27}/(\frac{2}{3}\Gamma_4+\Gamma_6)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.05	90	[29] PICCOLO	77	MRK1	e^+e^- E_{cm}= 4 03 GeV

[29] Obtained from $\sigma\times$ BR values of table I

$\Gamma(K^-\pi^+e^+\nu)/\Gamma_{total}$ — Γ_{28}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.057	90	[30] AGUILAR-	87F	HYBR	πp pp 360 400 GeV

[30] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(\pi^+\pi^- e^+\nu)/\Gamma_{total}$ — Γ_{29}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.057	90	[31] AGUILAR	87F	HYBR	πp, pp 360,400 GeV

[31] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\sigma(e^+e^-\to\psi(3770))\times\Gamma(K^-\pi^+\pi^+\pi^+\pi^-)/\Gamma_{total}$ — $\sigma\Gamma_{30}/\Gamma$

VALUE (nanobarns)	CL%	DOCUMENT ID		TECN	COMMENT
<0.23	90	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV

$\Gamma(K^-\pi^+\pi^+\pi^+\pi^-)/\Gamma_{total}$ — Γ_{30}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
SEEN	2	AGUILAR	86B	HYBR	$\pi^- p$ 360 GeV

$\Gamma(\pi^+\pi^+\pi^+\pi^-\pi^-\pi^0)/\Gamma_{total}$ — Γ_{31}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
SEEN	2	AGUILAR	86B	HYBR	$\pi^- p$ 360 GeV

$\Gamma(\phi\pi^+\pi^-\pi^+)/\Gamma_{total}$ — Γ_{36}/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0 002	90	0	ANJOS	88	SILI	Photoproduction

$\Gamma(K^+K^-\pi^+\pi^-\pi^+$ (non-resonant)$)/\Gamma_{total}$ — Γ_{37}/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.03	90	12	ANJOS	88	SILI	Photoproduction

$D^{\pm}$ PRODUCTION CROSS SECTION AT $\psi(3770)$

A compilation of the cross sections for the direct production of $D^{\pm}$ mesons at or near the $\psi(3770)$ peak in e^+e^- production These cross sections are used for normalization of product branching fractions

VALUE (nanobarns)	DOCUMENT ID		TECN	COMMENT
$4.8\ ^{+0.5}_{-0.6}$ OUR FIT Error includes scale factor of 1 1				
4.8 ±0.5 OUR AVERAGE Error includes scale factor of 1 1				
4 2 ±0 6 ±0 3	[32] ADLER	88C	MRK3	e^+e^- E_{cm}= 3 768 GeV
5 5 ±1.0	[33] PARTRIDGE	84	CBAL	e^+e^- E_{cm}= 3 771 GeV
6 00±0.72±1 02	[34] SCHINDLER	80	MRK2	e^+e^- E_{cm}= 3 771 GeV
• • • We do not use the following data for averages fits, limits etc • • •				
9 1 ±2 0	[35] PERUZZI	77	MRK1	e^+e^- E_{cm}= 3 774 GeV

[32] This measurement compares events with one detected D to those with two detected D mesons, to determine the the absolute cross section ADLER 88C measure the ratio of cross sections (neutral to charged) to be 1 36±0 23±0 14 This measurement does not include the decays of the $\psi(3770)$ not associated with charmed particle production

[33] This measurement comes from a scan of the $\psi(3770)$ resonance and a fit to the cross section PARTRIDGE 84 measures 6 4±1 15 nb for the cross section We take the phase space division of neutral and charged D mesons in $\psi(3770)$ decay to be 1 33 and we assume that the $\psi(3770)$ is an isosinglet to evaluated the cross sections The noncharm decays (e g radiative) of the $\psi(3770)$ are included in this measurement and may amount to a few percent correction

[34] This measurement comes from a scan of the $\psi(3770)$ resonance and a fit to the cross section SCHINDLER 80 assume the phase space division of neutral and charged D mesons in $\psi(3770)$ decay to be 1 33, and that the $\psi(3770)$ is an isosinglet The noncharm decays (e g radiative) of the $\psi(3770)$ are included in this measurement and may amount to a few per cent correction

[35] This measurement comes from a scan of the $\psi(3770)$ resonance and a fit to the cross section The phase space division of neutral and charged D mesons in $\psi(3770)$ decay is taken to be 1 33, and $\psi(3770)$ is assumed to be an isosinglet The noncharm decays (e g radiative) of the $\psi(3770)$ are included in this measurement and may amount to a few percent correction We exclude this measurement from the average because of uncertainties in the contamination from τ lepton pairs Also see RAPIDIS 77

REFERENCES FOR $D^{\pm}$

ADLER	88B	PRL 60 1375	+Becker Blaylock+	(MARK III Collab)
ADLER	88C	PRL 60 89	+Becker Blaylock+	(MARK III Collab)
ANJOS	88	PRL 60 897	+Appel+ (Tagged Photon Spectrometer Collab)	
RAAB	88	PR D37 2391	+Anjos Appel Bracker+	(FNAL TPS Collab)
ADAMOVICH	87	EPL 4 887	+Alexandrov Bolta+	(Photon Emulsion Collab)
ADLER	87	PL B196 107	+Becker Blaylock Bolton+	(MARK III Collab)
AGUILAR	87C	ZPHY C34 143	Aguilar Benitez Allison+	(LEBC EHS Collab)
AGUILAR	87D	PL B193 140	Aguilar Benitez Allison+	(LEBC EHS Collab)
AGUILAR	87E	ZPHY C36 551	Aguilar Benitez Allison+	(LEBC EHS Collab)
AGUILAR	87F	ZPHY C36 559	Aguilar Benitez Allison+	(LEBC EHS Collab)
ANJOS	87	PRL 58 311	+Appel Bracker Browder+	(FNAL TPS Collab)
BARLAG	87B	ZPHY C37 17	+Becker Bohringer Bosman+	(ACCMOR Collab)
BARTEL	87	ZPHY C33 339	+Becker Felst Haidt+	(JADE Collab)
CSORNA	87	PL B191 318	+Mestayer Panvini Word+	(CLEO Collab)
PALKA	87B	ZPHY C35 151	+Bailey Becker+	(ACCMOR Collab)
ABE	86	PR D33 1	+ (SLAC Hybrid Facility Photon Collab)	
AGUILAR	86B	ZPHY C31 491	Aguilar Benitez Allison+	(LEBC EHS Collab)
BALTRUSAITIS	86E	PRL 56 2140	+Becker Blaylock Brown+	(MARK III Collab)
GLADNEY	86	PR D34 2601	+Jaros Ong Barklow+	(MARK II Collab)
PAL	86	PR D33 2708	+Atwood Barish Bonneaud+	(DELCO Collab)
USHIDA	86	PRL 56 1767	+Kondo+ (AICH FNAL GIFU GYEO KOBE SEOU+)	
AIHARA	85	ZPHY C27 39	+Alston Garnjost Badtke Bakken+ (TPC Collab)	
BAILEY	85	ZPHY C28 357	+Belau Boehringer Bosman+ (ABCCMR Collab)	

BALTRUSAITIS 85B PRL 54 1976 +Becker Blaylock Brown+ (MARK III Collab)
BALTRUSAITIS 85F PRL 55 150 +Becker Blaylock Brown+ (MARK III Collab)
BARTEL 85J PL 163B 277 +Becker Cords Felst+ (JADE Collab)
GEORGIO 85 PL 152B 428 Georgiopoulos+ (TUFT ARIZ FNAL FSU NDAM+)
ABE 84 PR D30 1 + (SLAC Hybrid Facility Photon Collab)
ADAMOVICH 84 PL 140B 119 +Alexandrov Bolta Bravo+ (WA58 Collab)
ALTHOFF 84G ZPHY C22 219 +Braunschweig Kirschfink+ (TASSO Collab)
ALTHOFF 84J PL 146B 443 +Branschweig Kirschfink+ (TASSO Collab)
BAILEY 84 PL 139B 320 +Belau Bohringer Bosman+ (ACCMOR Collab)
DERRICK 84 PRL 53 1971 +Fernandez Fries Hyman+ (HRS Collab)
KOOP 84 PRL 52 970 +Sakuda Atwood Barlon+ (DELCO Collab)
PARTRIDGE 84 Cal Tech 1984 Thesis (Crystal Ball Collab)
AGUILAR 83 PL 122B 312 Aguilar Benitez Allison+ (LEBC EHS Collab)
AGUILAR 83B PL 123B 98 Aguilar Benitez Allison+ (LEBC EHS Collab)
AUBERT 83 NP B213 31 +Bassompierre Becks Best+ (EMC Collab)
BADERT 83 PL 123B 471 Badertscher Hahn Hugentobler+ (BERN MPIM)
USHIDA 83 PRL 51 2362 + (AICH FNAL KOBE SEOU MCGI NAGO+)
ALBINI 82 PL 110B 339 + (FRAS MILA PISA ROMA TORI TRST)
BALLAGH 81 PR D24 7 +Bingham+ (LBL UCB FNAL HAWA WASH WISC)
Also 80 PL 89B 423 Ballagh+ (LBL UCB FNAL HAWA WASH WISC)
PARTRIDGE 81 PRL 47 760 +Peck Porter Gu+ (Crystal Ball Collab)
SCHINDLER 81 PR D24 78 +Alam Boyarski Breidenbach+ (MARK II Collab)
TRILLING 81 PRPL 75 57 (LBL UCB) J
ALLASIA 80 NP B176 13 + (ANKA LIBH CERN DUUC LOUC KEYN+)
BACINO 80 PRL 45 329 +Ferguson+ (UCLA SLAC STAN UCI STON)
SCHINDLER 80 PR D21 2716 +Siegrist Alam Boyarski+ (MARK II Collab)
ZHOLENTZ 80 PL 96B 214 +Kurdadze Lelchuk Mishnev+ (NOVO)
Also 81 SJNP 34 814 Zholentz Kurdadze Lelchuk+ (NOVO)
Translated from YAF 34 1471
ARMENISE 79 PL 86B 115 +Erriquez+ (BARI CERN EPOL MILA ORSA)
BACINO 79 PRL 43 1073 +Ferguson Nodulman+ (DELCO Collab)
BRANDELIK 79 PL 80B 412 +Braunschweig Martyn Sander+ (DASP Collab)
DRIJARD 79 PL 81B 250 +Fischer Geist+ (CERN CDEF HEID KARL)
FELLER 78 PRL 40 274 +Litke Madaras Ronan+(LBL SLAC NWES HAWA)
VUILLEMIN 78 PRL 41 1149 +Feldman Feller+ (LBL SLAC NWES HAWA)
GOLDHABER 77 PL 69B 503 +Wiss Abrams Alam+ (LBL SLAC)
PERUZZI 77 PRL 39 1301 +Piccolo Feldman+ (SLAC LBL NWES HAWA)
PICCOLO 77 PL 70B 260 +Peruzzi Luth Nguyen Wiss Abrams+(SLAC LBL)
RAPIDIS 77 PRL 39 526 +Gobbi Luke Barbaro Galtieri+ (MARK I Collab)
PERUZZI 76 PRL 37 569 +Piccolo Feldman Nguyen Wiss+ (SLAC LBL)

OTHER RELATED PAPERS

GRAB 87 SLAC PUB 4372 (SLAC)
EPS Conference Uppsala
SCHINDLER 87 SLAC PUB 4417 (SLAC)
EPS Conference Uppsala Proc Vol 1 p 341
SCHUBERT 87 IHEP HD 87 7 (HEID)
EPS Conference Uppsala Proc Vol 2 p 791
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Symp on Prod and Decay of Heavy Flavors Stanford
SCHINDLER 86 SLAC PUB 4136 (SLAC)
World Press International
SCHINDLER 86B SLAC PUB 4248 (SLAC)
SLAC Summer Institute
KIRKBY 79 SLAC PUB 2419 (SLAC)
Batavia Lepton Photon Conference
BARBARO 78 LBL 8537 Erice 1978 Barbaro Galtieri (LBL)
WOJCICKI 78 SLAC PUB 2232 (SLAC)
SLAC Summer Institute
GOLDHABER 76 PRL 37 255 +Pierre Abrams Alam+ (LBL SLAC)
WISS 76 PRL 37 1531 +Goldhaber Abrams Alam Boyarski+(LBL SLAC)

D^0

$I(J^P) = \frac{1}{2}(0^-)$

D^0 MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1864.5 ± 0 6 OUR AVERAGE					
1852 ± 7	16	ADAMOVICH	87	EMUL	Photoproduction
1861 ± 4 0		DERRICK	84	HRS	e^+e^- E_{cm}= 29 GeV
1864 7 ± 0 6		[1] TRILLING	81	RVUE	e^+e^- E_{cm}= 3 77 GeV
• • • We do not use the following data for averages fits limits etc • • •					
1856 ± 36	22	ADAMOVICH	84B	EMUL	Photoproduction
1847 ± 7	1	FIORINO	81	EMUL	$\gamma N \rightarrow \bar{D}^0$ +
1863 8 ± 0 5		[1] SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 77 GeV
1863 0 ± 2 5	238	ASTON	80E	OMEG	$\gamma p \rightarrow \bar{D}^0$
1860 ± 2	143	[2] AVERY	80	SPEC	$\gamma N \rightarrow D^{*+}$
1869 ± 4	35	[2] AVERY	80	SPEC	$\gamma N \rightarrow D^{*+}$
1854 ± 6	94	[2] ATIYA	79	SPEC	$\gamma N \rightarrow D^0\bar{D}^0$
1850 ± 15	64	BALTAY	78C	HBC	$\nu N \rightarrow K^0\pi\pi$
1863 ± 3		GOLDHABER	77	MRK1	D^0 D^+ recoil spectra
1863 3 ± 0 9		[1] PERUZZI	77	MRK1	e^+e^- E_{cm}= 3 77 GeV
1868 ± 11		PICCOLO	77	MRK1	e^+e^- E_{cm}= 4 03 4 41 GeV
1865 ± 15	234	GOLDHABER	76	MRK1	$K\pi$ and $K3\pi$

[1] PERUZZI 77 and SCHINDLER 81 errors do not include the 0 13% uncertainty in the absolute SPEAR energy calibration TRILLING 81 uses the high precision $J/\psi(1S)$ and $\psi(2S)$ measurements of ZHOLENTZ 80 to determine this uncertainty and combines the PERUZZI 77 and SCHINDLER 81 results to obtain the value quoted

[2] Error does not include possible systematic mass scale shift estimated to be less than 5 MeV

$|m_{D_1^0} - m_{D_2^0}|$. MASS DIFFERENCE

D_1^0 and D_2^0 are the mass eigenstates of the D^0 meson

VALUE (10^{-4} eV)	CL%	DOCUMENT ID		TECN	COMMENT
< 1.3	90	[3,4] ANJOS	88C	SILI	Photoproduction
• • • We do not use the following data for averages fits limits etc • • •					
< 2.6	90	[3] ALBRECHT	87K	ARG	e^+e^- E_{cm}= 10 GeV
< 1 6	90	[5] LOUIS	86	SPEC	π^- W 225 GeV
< 7	90	[3,6] YAMAMOTO	85	DLCO	e^+e^- E_{cm}= 29 GeV
< 6 5	90	[5] BODEK	82	SPEC	π^- pFe $\rightarrow D^0$

[3] Limit inferred from D^0-$\bar{D}^0$ mixing ratio $\Gamma(K^+\pi^-$ (via $\bar{D}^0$))/$\Gamma(K^-\pi^+)$ below

[4] Calculated by us using Δm = $(2r/(1-r))^{1/2}\hbar/4.3 \times 10^{-13}$s where r is the D^0-$\bar{D}^0$ mixing ratio

[5] Limit inferred from D^0 $\bar{D}^0$ mixing ratio $\Gamma(\mu^-$ anything (via $\bar{D}^0$))/$\Gamma(\mu^+$ anything) below

[6] YAMAMOTO 85 gives $\Delta m \Gamma$ < 0 44 We use $\Gamma = \hbar/4.3 \times 10^{-13}$s

$D^{\pm}$ – D^0 MASS DIFFERENCE

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
4.74 ± 0.28 OUR AVERAGE				
4 7 ± 0 3	[7] SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 77 GeV
5 0 ± 0 8	[7] PERUZZI	77	MRK1	e^+e^- E_{cm}= 3 77 GeV

[7] Not independent of $D^{\pm}$ and D^0 mass measurements

D^0 MEAN LIFE

VALUE (10^{-13} sec)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
4 28 ± 0.11 OUR AVERAGE						
4 22 ± 0 08 ± 0 10		4200	RAAB	88	SILI	Photoproduction
3 6 $^{+1\ 2}_{-0\ 8}$ ± 0 7		44	ADAMOVICH	87	EMUL	Photoproduction
4 6 $^{+0\ 6}_{-0\ 5}$		145	AGUILAR	87D	HYBR	π^-p and pp
4 3 $^{+2\ 0}_{-1\ 4}$ ± 0 8		15	ALTHOFF	87	TASS	e^+e^- 42 2 GeV
4 2 ± 0 5		90	BARLAG	87B	SILI	K^- and π 200 GeV
5 0 ± 0 7 ± 0 4		345	CSORNA	87	CLEO	e^+e^- E_{cm}= 10 GeV
4 4 $^{+1\ 2}_{-1\ 1}$ ± 0 6		53	WAGNER	87	MRK2	e^+e^- E_{cm}= 29 GeV
6 1 ± 0 9 ± 0 3		50	ABE	86	HYBR	SLAC γp 20 GeV
4 7 $^{+0\ 9}_{-0\ 8}$ ± 0 5		74	GLADNEY	86	MRK2	e^+e^- E_{cm}= 29 GeV
4 3 $^{+0\ 7}_{-0\ 5}$ $^{+0\ 1}_{-0\ 2}$		58	USHIDA	86B	EMUL	ν wideband
3 7 $^{+1\ 0}_{-0\ 7}$		26	BAILEY	85	SILI	π^- Be 200 GeV
4 6 ± 1 5 $^{+0\ 6}_{-0\ 5}$		269	[8] YAMAMOTO	85B	DLCO	e^+e^- E_{cm}= 29 GeV
• • • We do not use the following data for averages fits limits etc • • •						
4 1 $^{+0\ 7}_{-0\ 6}$		60	AGUILAR	87C	HYBR	Repl by AGUILAR BENITEZ 87D
4 35 ± 0 15 ± 0 10		1360	ANJOS	87	SILI	Repl by RAAB 88
6 8 $^{+2\ 3}_{-1\ 8}$		22	ABE	84	HYBR	Repl by ABE 86
2 11 $^{+1\ 21}_{-0\ 63}$ $^{+0\ 8}_{-0\ 7}$		22	ADAMOVICH	84B	EMUL	Repl by ADAMOVICH 87
3 5 $^{+1\ 4}_{-0\ 9}$		11	AGUILAR	84B	HYBR	Repl by AGUILAR BENITEZ 87D
4 2 $^{+1\ 6}_{-1\ 4}$		27	YELTON	84	MRK2	e^+e^- E_{cm}= 29 GeV
4 1 $^{+1\ 3}_{-0\ 9}$		16	AGUILAR	83	HYBR	Repl by AGUILAR BENITEZ 87D
4 1 $^{+2\ 6}_{-1\ 4}$		9	BADERT	83	HYBR	CERN π^-N
2 3 $^{+0\ 8}_{-0\ 5}$		16	[9] USHIDA	82	EMUL	Repl by USHIDA 86B
2 1		1	[10] ADEVA	81	HYBR	LEBC CERN SPS π^-p
5.9		1	[10] ADEVA	81	HYBR	LEBC CERN-SPS π^-p
2 8 $^{+2\ 2}_{-1\ 3}$		2	[11] BALLAGH	81	HYBR	FNAL 15 ft ν Ne ^{2}H
3 1 $^{+2\ 0}_{-1\ 6}$		5	FUCHI	81	EMUL	CERN SPS π^-N
0 53 $^{+0\ 57}_{-0\ 25}$		3	[12] ALLASIA	80	EMUL	ν wideband
< 2 1	95		[13] BACINO	80	DLCO	e^+e^- E_{cm}= 3 77 GeV
< 8 0	90		ARMENISE	79	HYBR	νp → dimuons +

[8] Uses impact parameter technique

[9] USHIDA 82 have 3 semi-leptonic decays not included in this number but believed to have much longer lifetimes

[10] ADEVA 81 first and second values are proper lifetimes of D^0 and $\bar{D}^0$ from single event Detection efficiency low for lifetimes 10^{-13} sec or less

[11] BALLAGH 81 value quoted here assumes that all dilepton events contain D^0 or D^+ each with equal numbers of semileptonic decays

[12] ALLASIA 80 assumes no long-length losses Visibility problems in the emulsion

[13] Uses theoretical rate $D \rightarrow (Ke\nu)$ = 1.4×10^{11} sec^{-1}

$\left|\tau_{D_1^0} - \tau_{D_2^0}\right|/\tau_{D^0}$, MEAN LIFE DIFFERENCE/AVERAGE

D_1^0 and D_2^0 are the mass eigenstates of the D^0 meson

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.17	90	[14,15] ANJOS	88C	SILI	Photoproduction
• • • We do not use the following data for averages fits limits etc • • •					
<0.21	90	[16] LOUIS	86	SPEC	π^-W 225 GeV
<0.8	90	[14] YAMAMOTO	85	DLCO	e^+e^- E_{cm}= 29 GeV
<0.55	90	[16] BODEK	82	SPEC	π^- pFe $\rightarrow D^0$

[14] Limit inferred from $D^0\overline{D}^0$ mixing ratio $\Gamma(K^+\pi^-$ (via $\overline{D}^0))/\Gamma(K^-\pi^+)$ below

[15] Calculated by us using $\Delta\Gamma = (8r/(1+r))^{1/2}\hbar/4.3\times10^{-13}$s where r is the D^0–$\overline{D}^0$ mixing ratio

[16] Limit inferred from $D^0\overline{D}^0$ mixing ratio $\Gamma(\mu^-$ anything (via $\overline{D}^0))/\Gamma(\mu^+$ anything) below

D^0 DECAY MODES

$\overline{D}^0$ modes are charge conjugates of above modes

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$D^0 \rightarrow K^-\pi^+$	$(3.77^{+0.37}_{-0.32})\times10^{-2}$	
Γ_2	$D^0 \rightarrow \overline{K}^0\pi^0$	$(2.8^{+1.3}_{-1.2})\times10^{-2}$	
Γ_3	$D^0 \rightarrow \pi^+\pi^-$	$(1.3 \pm 0.4)\times10^{-3}$	
Γ_4	$D^0 \rightarrow K^+K^-$	$(4.5 \pm 0.8)\times10^{-3}$	
Γ_5	$D^0 \rightarrow K^*(892)^-\pi^+$	$(4.8 \pm 0.7)\times10^{-2}$	
Γ_6	$D^0 \rightarrow \overline{K}^*(892)^0\pi^0$	$(2.1 \pm 0.6)\times10^{-2}$	
Γ_7	$D^0 \rightarrow K^-\rho^+$	$(8.2^{+1.2}_{-1.1})\times10^{-2}$	
Γ_8	$D^0 \rightarrow \overline{K}^0\rho^0$	$(4.7^{+3.0}_{-2.1})\times10^{-3}$	
Γ_9	$D^0 \rightarrow K^-\pi^+\pi^0$ (non-resonant)	$(1.3 \pm 0.5)\times10^{-2}$	
Γ_{10}	$D^0 \rightarrow \overline{K}^0\pi^+\pi^-$ (non-resonant)	$(1.9 \pm 0.5)\times10^{-2}$	
Γ_{11}	$D^0 \rightarrow K^*(892)^-K^+ + K^*(892)^+K^-$	$(8 \pm 4)\times10^{-3}$	
Γ_{12}	$D^0 \rightarrow \overline{K}^0\phi$	$(8.3^{+1.8}_{-1.6})\times10^{-3}$	
Γ_{13}	$D^0 \rightarrow \overline{K}^0K^+K^-$ (non-resonant)	$(7.4^{+2.3}_{-1.8})\times10^{-3}$	
Γ_{14}	$D^0 \rightarrow \pi^-\pi^+\pi^0$	$(1.1 \pm 0.4)\times10^{-2}$	
Γ_{15}	$D^0 \rightarrow K^-\pi^+\pi^+\pi^-$	$(7.9^{+1.0}_{-0.9})\times10^{-2}$	S=1.1
Γ_{16}	$D^0 \rightarrow K^-\pi^+\pi^0\pi^0$	$(15 \pm 5)\times10^{-2}$	
Γ_{17}	$D^0 \rightarrow \pi^-\pi^-\pi^-\pi^+$	$(1.01^{+0.71}_{-0.26})\times10^{-2}$	
Γ_{18}	$D^0 \rightarrow e^+$ anything	$(7.7 \pm 1.1)\times10^{-2}$	
Γ_{19}	$D^0 \rightarrow$ all except the above modes	$(39 \pm 6)\times10^{-2}$	
Γ_{20}	$D^0 \rightarrow \overline{K}^0\pi^+\pi^-$	$(5.6^{+0.7}_{-0.6})\times10^{-2}$	
	In the fit as $2/3\Gamma_5 + \Gamma_8 + \Gamma_{10}$		
Γ_{21}	$D^0 \rightarrow K^-\pi^+\pi^0$	$(12.5^{+1.5}_{-1.3})\times10^{-2}$	
	In the fit as $1/3\Gamma_5 + 2/3\Gamma_6 + \Gamma_7 + \Gamma_9$		
Γ_{22}	$D^0 \rightarrow \overline{K}^0K^+K^-$	$(1.16^{+0.25}_{-0.22})\times10^{-2}$	
	In the fit as $1/2\Gamma_{12} + \Gamma_{13}$		
Γ_{23}	$D^0 \rightarrow K^-$ anything	$(43 \pm 5)\times10^{-2}$	
Γ_{24}	$D^0 \rightarrow K^+$ anything	$(6.4^{+2.6}_{-1.7})\times10^{-2}$	
Γ_{25}	$D^0 \rightarrow \overline{K}^0$ anything + K^0 anything	$(33 \pm 10)\times10^{-2}$	
Γ_{26}	$D^0 \rightarrow \overline{K}^*(892)^0\rho^0$	$(1.2^{+1.3}_{-1.2})\times10^{-2}$	
Γ_{27}	$D^0 \rightarrow K^-\pi^+\rho^0$	$(6.7^{+1.2}_{-1.9})\times10^{-2}$	
Γ_{28}	$D^0 \rightarrow \overline{K}^0\pi^+\pi^-\pi^0$		
Γ_{29}	$D^0 \rightarrow K^-e^+\nu\pi^0(\pi^0)$		
Γ_{30}	$D^0 \rightarrow \overline{K}^0\pi^-e^+\nu(\pi^0)$		
Γ_{31}	$D^0 \rightarrow \overline{K}^*(892)^0\pi^+\pi^-$	< 2.1 $\times10^{-2}$	
Γ_{32}	$D^0 \rightarrow K^-a_2(1320)^+$	< 1.3 $\times10^{-2}$	
Γ_{33}	$D^0 \rightarrow \overline{K}^0K^0$	< 4 $\times10^{-3}$	CL=90%
Γ_{34}	$D^0 \rightarrow K^0K^-\pi^+$ (non-res.) + c.c.	< 1.2 $\times10^{-2}$	CL=90%
Γ_{35}	$D^0 \rightarrow \overline{K}^*(892)^0K^0 + K^*(892)^0\overline{K}^0$	< 6 $\times10^{-3}$	CL=90%
Γ_{36}	$D^0 \rightarrow K^-e^+\nu$	< 5 $\times10^{-2}$	CL=90%
Γ_{37}	$D^0 \rightarrow \pi^-e^+\nu$	< 5 $\times10^{-2}$	CL=90%
Γ_{38}	$D^0 \rightarrow \eta$ anything		
	See section $D^\pm$ for $D^\pm$ and $D^0 \rightarrow \eta$		
Γ_{39}	$D^0 \rightarrow K^-\pi^+\pi^+\pi^-\pi^0$		
Γ_{40}	$D^0 \rightarrow K^+K^-\pi^0\pi^0$		
Γ_{41}	$D^0 \rightarrow K^0K^-\pi^+\pi^0$		
Γ_{42}	$D^0 \rightarrow \mu^+$ anything		
Γ_{43}	$D^0 \rightarrow K^+\pi^-$ (doubly Cabibbo suppressed)	< 1.5 $\times10^{-2}$	CL=90%
Γ_{44}	$D^0 \rightarrow K^+\pi^-\pi^+\pi^-$ (doubly Cabibbo suppressed)	< 1.8 $\times10^{-2}$	CL=90%

FORBIDDEN BY CONSERVATION LAWS

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_{45}	$D^0 \rightarrow K^+\pi^-$ (via $\overline{D}^0$)	< 1.4 $\times10^{-4}$	
Γ_{46}	$D^0 \rightarrow \mu^-$ anything (via $\overline{D}^0$)		
Γ_{47}	$D^0 \rightarrow \mu^+\mu^-$	< 1.1 $\times10^{-5}$	CL=90%
Γ_{48}	$D^0 \rightarrow e^+e^-$	< 1.3 $\times10^{-4}$	CL=90%
Γ_{49}	$D^0 \rightarrow \mu^\pm e^\mp$	< 1.2 $\times10^{-4}$	CL=90%

CONSTRAINED FIT INFORMATION

An overall fit to 14 products of a cross section and a partial width, a cross section, and 20 branching ratios uses 62 measurements and one constraint to determine 20 parameters. The overall fit has a χ^2 = 26.5 for 43 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta p_i\,\delta p_j\rangle/(\delta p_i\cdot\delta p_j)$, in percent, from the fit to parameters p_i, including the branching fractions, $x_i = \Gamma_i/\Gamma_{total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
x_2	15									
x_3	31	5								
x_4	52	8	16							
x_5	47	10	14	24						
x_6	22	4	7	11	12					
x_7	49	10	15	25	26	1				
x_8	12	2	4	6	6	4	9			
x_9	13	3	4	7	6	2	14	2		
x_{10}	27	6	8	14	−17	8	20	20	6	
x_{11}	13	3	4	7	9	4	9	2	2	5
x_{12}	33	7	10	17	32	10	21	13	5	31
x_{13}	26	5	8	13	21	7	17	7	4	17
x_{14}	0	0	0	0	0	0	0	0	0	0
x_{15}	61	11	19	32	34	16	35	9	9	19
x_{16}	0	0	0	0	0	0	0	0	0	0
x_{17}	0	0	0	0	0	0	0	0	0	0
x_{18}	0	0	0	0	0	0	0	0	0	0
x_{19}	43	29	−14	23	−29	18	−36	8	−10	18
σ	85	18	26	44	55	25	−57	14	−15	31

	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}
x_{12}	6								
x_{13}	5	1							
x_{14}	0	0	0						
x_{15}	10	24	19	0					
x_{16}	0	0	0	0	0				
x_{17}	0	0	0	0	0	0			
x_{18}	0	0	0	0	0	0	0		
x_{19}	−14	23	18	7	39	−80	−8	18	
σ	−16	39	−30	0	−62	0	0	0	46

D^0 BRANCHING RATIOS

See note in $D^\pm$ section concerning revisions to hadronic branching fractions and new measurements of D^+ and D^0 decays

$\Gamma(K^-\ \text{anything})/\Gamma_{total}$ — Γ_{23}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.43±0.05 OUR AVERAGE					
0.42±0.08		AGUILAR	87E	HYBR	πp, pp 360, 400 GeV
0.55±0.11	121	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3.771 GeV
0.35±0.10	19	VUILLEMIN	78	MRK1	e^+e^- E_{cm}= 3.772 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.44^{+0.11}_{-0.10}$		AGUILAR [17]	86	HYBR	π^-p 360 GeV

[17] Includes K^+ anything

$\Gamma(K^+\ \text{anything})/\Gamma_{total}$ — Γ_{24}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.064^{+0.026}_{-0.017}$ OUR AVERAGE					
$0.03^{+0.05}_{-0.02}$		AGUILAR	87E	HYBR	πp, pp 360, 400 GeV
0.08±0.03	25	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3.771 GeV

$\Gamma(\bar{K}^0\ \text{anything}) + \Gamma(K^0\ \text{anything})/\Gamma_{total}$ — Γ_{25}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.33±0.10 OUR AVERAGE					
0.29±0.11	13	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3.771 GeV
0.57±0.26	6	VUILLEMIN	78	MRK1	e^+e^- E_{cm}= 3.772 GeV

$\Gamma(e^+\ \text{anything})/\Gamma_{total}$ — Γ_{18}/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.077±0.011 OUR FIT						
0.077±0.012 OUR AVERAGE Error includes scale factor of 1.1						
0.15 ±0.05			AGUILAR	87E	HYBR	πp, pp 360, 400 GeV
0.075±0.011±0.004		137	BALTRUSAITIS	85B	MRK3	e^+e^- E_{cm}= 3.77 GeV
0.055±0.037		12	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3.771 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$0.17^{+0.08}_{-0.06}$		7	AGUILAR [18]	86	HYBR	π^-p 360 GeV
$0.051^{+0.048}_{-0.014}$		3	AGUILAR	83	HYBR	πp, pp
<0.04	95	0	BACINO	80	DLCO	e^+e^- E_{cm}= 3.77 GeV

[18] Includes (e^- anything) which is expected to be small

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^-\pi^+)/\Gamma_{total}$ — $\sigma\Gamma_1/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
0.244±0.012 OUR FIT					
0.245±0.012 OUR AVERAGE					
0.248±0.009±0.014	930	BALTRUSAITIS	86E	MRK3	e^+e^- E_{cm}= 3.77 GeV
0.24 ±0.02	263	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3.771 GeV
0.25 ±0.05	130	PERUZZI	77	MRK1	e^+e^- E_{cm}= 3.77 GeV

$\Gamma(K^-\pi^+)/\Gamma_{total}$ — Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.0377^{+0.0037}_{-0.0032}$ OUR FIT					
$0.044^{+0.009}_{-0.007}$ OUR AVERAGE					
0.045 ±0.008 ±0.005	56	ABACHI [19]	88	HRS	e^+e^- E_{cm}= 29 GeV
$0.040^{+0.021}_{-0.010}$ ±0.002	7	AGUILAR- [20]	87F	HYBR	πp, pp 360, 400 GeV

[19] ABACHI 88 branching ratio computed by tagging $D^*(2010)^+ \to D^0\pi^+$ through excess low momentum π^+ over background.
[20] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization.

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^0\pi^0)/\Gamma_{total}$ — $\sigma\Gamma_2/\Gamma$

VALUE (nanobarns)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.18±0.08 OUR FIT						
0.18±0.08		8	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3.771 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.11±0.02±0.01		70	SCHINDLER [21]	86B	MRK3	e^+e^- E_{cm}= 3.77 GeV
<0.7	90		SCHARRE	78	MRK1	e^+e^- E_{cm}= 3.77 GeV

[21] The value has not been published as of this printing

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ — Γ_3/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0013±0.0004 OUR FIT					
$0.005^{+0.012}_{-0.002}$±0.004	1	AGUILAR [22]	87F	HYBR	πp, pp 360, 400 GeV

[22] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(\pi^+\pi^-)/\Gamma(K^-\pi^+)$ — Γ_3/Γ_1

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.034±0.009 OUR FIT						
0.033±0.009 OUR AVERAGE						
0.033±0.010±0.006		39	BALTRUSAITIS	85E	MRK3	e^+e^- E_{cm}= 3.77 GeV
0.033±0.015			ABRAMS	79D	MRK2	e^+e^- E_{cm}= 3.77 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.07	90		PICCOLO	77	MRK1	e^+e^- E_{cm}= 4.03 GeV

$\Gamma(K^+K^-)/\Gamma(K^-\pi^+)$ — Γ_4/Γ_1

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.119 ±0.018 OUR FIT						
0.119 ±0.018 OUR AVERAGE						
0.122±0.018±0.012		118	BALTRUSAITIS	85E	MRK3	e^+e^- E_{cm}= 3.77 GeV
0.113±0.030			ABRAMS	79D	MRK2	e^+e^- E_{cm}= 3.77 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.07	90		PICCOLO	77	MRK1	e^+e^- E_{cm}= 4.03 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^*(892)^-\pi^+)/\Gamma_{total}$ — $\sigma\Gamma_5/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
0.31±0.04 OUR FIT					
0.30±0.04 OUR AVERAGE					
0.28±0.04±0.08		ADLER	87	MRK3	Using $K^{*-} \to K^-\pi^0$
0.31±0.02±0.05		ADLER	87	MRK3	Using $K^{*-} \to K^0\pi^-$
$0.31^{+0.11}_{-0.12}$	25	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3.771 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(\bar{K}^*(892)^0\pi^0)/\Gamma_{total}$ — $\sigma\Gamma_6/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
0.14±0.04 OUR FIT					
0.15±0.04 OUR AVERAGE					
0.15±0.02±0.04		ADLER	87	MRK3	e^+e^- E_{cm}= 3.77 GeV
$0.11^{+0.18}_{-0.14}$	4	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3.771 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^-\rho^+)/\Gamma_{total}$ — $\sigma\Gamma_7/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
0.53±0.06 OUR FIT					
0.61±0.09 OUR AVERAGE					
0.62±0.02±0.09		ADLER	87	MRK3	e^+e^- E_{cm}= 3.77 GeV
$0.58^{+0.22}_{-0.23}$	31	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3.771 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(\bar{K}^0\rho^0)/\Gamma_{total}$ — $\sigma\Gamma_8/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
$0.030^{+0.019}_{-0.014}$ OUR FIT					
$0.027^{+0.020}_{-0.008}$ OUR AVERAGE					
0.04 ±0.01 ±0.02		ADLER	87	MRK3	e^+e^- E_{cm}= 3.77 GeV
$0.006^{+0.040}_{-0.009}$	1	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3.771 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^-\pi^+\pi^0\ \text{(non-resonant)})/\Gamma_{total}$ — $\sigma\Gamma_9/\Gamma$

VALUE (nanobarns)	CL%	DOCUMENT ID		TECN	COMMENT
0.083±0.034 OUR FIT					
0.07 ±0.02 ±0.03		ADLER	87	MRK3	e^+e^- E_{cm}= 3.77 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.19	90	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3.771 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(\overline{K}^0\pi^+\pi^- \text{ (non-resonant)})/\Gamma_{total}$ — $\sigma\Gamma_{10}/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
0.123 ± 0.030 OUR FIT					
0.11 ± 0.04 OUR AVERAGE					
0 12 ± 0 02 ± 0.04		ADLER	87	MRK3	e^+e^- E_{cm}= 3 77 GeV
$0\ 090^{+0\ 075}_{-0.069}$	10	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^-\pi^+\pi^0)/\Gamma_{total}$ — $\sigma(\frac{1}{3}\Gamma_5+\frac{2}{3}\Gamma_6+\Gamma_7+\Gamma_9)/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
0.81 ± 0.06 OUR FIT					
0.75 ± 0.09 OUR AVERAGE					
0 759 ± 0.044 ± 0 083	931	BALTRUSAITIS	86E	MRK3	e^+e^- E_{cm}= 3 77 GeV
0 68 ± 0 23	37	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV
• • • We do not use the following data for averages fits, limits etc • • •					
1 4 ± 0.6	7	SCHARRE	78	MRK1	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(K^-\pi^+\pi^0)/\Gamma_{total}$ — $(\frac{1}{3}\Gamma_5+\frac{2}{3}\Gamma_6+\Gamma_7+\Gamma_9)/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.125^{+0.015}_{-0.013}}$ **OUR FIT**					
$0.106^{+0.061}_{-0.028} \pm 0.006$	5	[23] AGUILAR-	87F	HYBR	πp pp 360 400 GeV

[23] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(\overline{K}^0\pi^+\pi^-)/\Gamma_{total}$ — $\sigma(\frac{2}{3}\Gamma_5+\Gamma_8+\Gamma_{10})/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.361^{+0.029}_{-0.027}}$ **OUR FIT**					
0.36 ± 0.04 OUR AVERAGE					
0.37 ± 0.03 ± 0.03		ADLER	87	MRK3	e^+e^- E_{cm}= 3 77 GeV
0.30 ± 0 08	32	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV
0 46 ± 0.12	28	PERUZZI	77	MRK1	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(\overline{K}^0\pi^+\pi^-)/\Gamma_{total}$ — $(\frac{2}{3}\Gamma_5+\Gamma_8+\Gamma_{10})/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.056^{+0.007}_{-0.006}}$ **OUR FIT**					
$0.045^{+0.059}_{-0.014} \pm 0.003$	2	[24] AGUILAR-	87F	HYBR	πp pp 360 400 GeV

[24] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(\overline{K}^0\pi^+\pi^-)/\Gamma(K^-\pi^+)$ — $(\frac{2}{3}\Gamma_5+\Gamma_8+\Gamma_{10})/\Gamma_1$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{1.48^{+0.14}_{-0.13}}$ **OUR FIT**					
2.1 ± 0.6 OUR AVERAGE					
1.7 ± 0 8	35	AVERY	80	SPEC	$\gamma N \to D^{*+}$
2 8 ± 1.0	116	PICCOLO	77	MRK1	e^+e^- E_{cm}= 4 03 4 41 GeV

$\Gamma(K^-\pi^+\pi^0)/\Gamma(K^-\pi^+)$ — $(\frac{1}{3}\Gamma_5+\frac{2}{3}\Gamma_6+\Gamma_7+\Gamma_9)/\Gamma_1$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{3.31^{+0.30}_{-0.29}}$ **OUR FIT**					
4.2 ± 1.4	41	SUMMERS	84	TPS	Photoproduction

$\Gamma(K^-\rho^+)/\Gamma(K^-\pi^+\pi^0)$ — $\Gamma_7/(\frac{1}{3}\Gamma_5+\frac{2}{3}\Gamma_6+\Gamma_7+\Gamma_9)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.66 ± 0.05 OUR FIT					
$0.31^{+0.20}_{-0.14}$	13	SUMMERS	84	TPS	Photoproduction

$\Gamma(\overline{K}^*(892)^0\pi^0)/\Gamma(K^-\pi^+\pi^0)$ — $\Gamma_6/(\frac{1}{3}\Gamma_5+\frac{2}{3}\Gamma_6+\Gamma_7+\Gamma_9)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.17 ± 0.05 OUR FIT					
$0.09^{+0.14}_{-0.09}$	2	SUMMERS	84	TPS	Photoproduction

$\Gamma(K^*(892)^-\pi^+)/\Gamma(K^-\pi^+\pi^0)$ — $\Gamma_5/(\frac{1}{3}\Gamma_5+\frac{2}{3}\Gamma_6+\Gamma_7+\Gamma_9)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.38 ± 0.05 OUR FIT					
$0.33^{+0.36}_{-0.24}$	5	SUMMERS	84	TPS	Photoproduction

$\Gamma(K^-\pi^+\pi^0 \text{ (non-resonant)})/\Gamma(K^-\pi^+\pi^0)$ — $\Gamma_9/(\frac{1}{3}\Gamma_5+\frac{2}{3}\Gamma_6+\Gamma_7+\Gamma_9)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.40 ± 0.04 OUR FIT					
0.51 ± 0.22	21	SUMMERS	84	TPS	Photoproduction

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^*(892)^-K^+) + \Gamma(K^*(892)^+K^-)/\Gamma_{total}$ — $\sigma\Gamma_{11}/\Gamma$

VALUE (nanobarns)	DOCUMENT ID		TECN	COMMENT
0.050 ± 0.025 OUR FIT				
0.050 ± 0.023 ± 0.010	BALTRUSAITIS	86C	MRK3	e^+e^- E_{cm}= 3 77 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(\overline{K}^0\phi)/\Gamma_{total}$ — $\sigma\Gamma_{12}/\Gamma$

VALUE (nanobarns)	DOCUMENT ID		TECN	COMMENT
0.054 ± 0.010 OUR FIT				
$0.05\ ^{+0.03}_{-0.02}\ ^{+0.02}_{-0.01}$	BALTRUSAITIS	86C	MRK3	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(\overline{K}^0\phi)/\Gamma(\overline{K}^0\pi^+\pi^-)$ — $\Gamma_{12}/(\frac{2}{3}\Gamma_5+\Gamma_8+\Gamma_{10})$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.148^{+0.026}_{-0.025}}$ **OUR FIT**					
0.150 ± 0.028 OUR AVERAGE					
0 155 ± 0 033		[25] ALBRECHT	87E	ARG	e^+e^- E_{cm}= 10 GeV
0 14 ± 0.05	29	BEBEK	86	CLEO	e^+e^- near $\Upsilon(4S)$
• • • We do not use the following data for averages fits limits etc • • •					
0.186 ± 0 052	26	ALBRECHT	85B	ARG	Repl by ALBRECHT 87E

[25] ALBRECHT 87E also report $\Gamma(K^0K^+K^-$ non-$\phi)$ = 0 0064 ± 0 0015 ± 0 0009 where they used BR($D^0 \to K^0\pi^+\pi^-$) = 0.076 ± 0 007 ± 0 008

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^0K^+K^- \text{ (non-resonant)})/\Gamma_{total}$ — $\sigma\Gamma_{13}/\Gamma$

VALUE (nanobarns)	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.048^{+0.014}_{-0.011}}$ **OUR FIT**				
$0.05\ ^{+0.02}_{-0.01} \pm 0.01$	[26] BALTRUSAITIS	86C	MRK3	e^+e^- E_{cm}= 3 77 GeV

[26] Excludes contributions from $D^0 \to \overline{K}^0\phi$

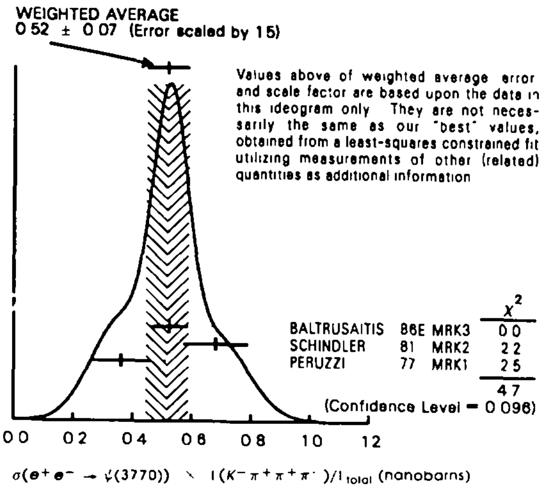
$\Gamma(\pi^-\pi^+\pi^0)/\Gamma_{total}$ — Γ_{14}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.011 ± 0.004 OUR FIT					
0.011 ± 0.004 ± 0.002	10	[27] BALTRUSAITIS	85E	MRK3	e^+e^- E_{cm}= 3 77 GeV

[27] All events consistent with $\rho^0\pi^0$

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^-\pi^+\pi^+\pi^-)/\Gamma_{total}$ — $\sigma\Gamma_{15}/\Gamma$

VALUE (nanobarns)	EVTS	DOCUMENT ID		TECN	COMMENT
0.51 ± 0.05 OUR FIT Error includes scale factor of 1 2					
0.52 ± 0.07 OUR AVERAGE Error includes scale factor of 1 5 See the ideogram below					
0 525 ± 0 026 ± 0 054	992	BALTRUSAITIS	86E	MRK3	e^+e^- E_{cm}= 3 77 GeV
0 68 ± 0 11	185	SCHINDLER	81	MRK2	e^+e^- E_{cm}= 3 771 GeV
0 36 ± 0 10	44	PERUZZI	77	MRK1	e^+e^- E_{cm}= 3 77 GeV



$\Gamma(K^-\pi^+\pi^+\pi^-)/\Gamma_{total}$ — Γ_{15}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$0\ 079^{+0.010}_{-0.009}$ OUR FIT Error includes scale factor of 1 1				
$0.065^{+0.017}_{-0.011}\pm0\ 019$	13	28 AGUILAR 87F	HYBR	πp pp 360 400 GeV
• • • We do not use the following data for averages fits limits etc • • •				
0 10 ±0 04	6	AGUILAR 84	HYBR	$\pi^- p$ pp 360 GeV
0 071 ± 0 025	8	AGUILAR 84B	HYBR	$\pi^- p$ 360 GeV

[28] AGUILAR BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(K^-\pi^+\pi^+\pi^-)/\Gamma(K^-\pi^+)$ — Γ_{15}/Γ_1

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
2.10 ± 0.20 OUR FIT Error includes scale factor of 1 1				
2.14 ± 0.30 OUR AVERAGE				
2 0 ±0 9		BAILEY 86	SPEC	π^- Be fixed target
2 17 ± 0 28 ± 0 23		29 ALBRECHT 85F	ARG	e^+e^- E_{cm}= 10 GeV
2 0 ±1 0	10	BAILEY 83B	SPEC	π^- Be $\rightarrow D^0$
2 2 ±0 8	214	30 PICCOLO 77	MRK1	e^+e^- E_{cm}= 4 03 4 41 GeV

[29] Not independent of $(K^-3\pi)$ / total

[30] This channel dominated by $K^-\pi^+\rho^0$ (85 ± 15%) $K^{*}\pi^+\pi^-$ and $K^-a_2(1320)^+$ consistent with zero $K^*\rho^0$ fraction is 0 1 ± 0 1

$\Gamma(K^-\pi^+\pi^0\pi^0)/\Gamma_{total}$ — Γ_{16}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.15 ±0.05 OUR FIT				
$0.149\pm0.037\pm0\ 030$	24	31 ADLER 88C	MRK3	e^+e^- E_{cm}= 3 77 GeV
• • • We do not use the following data for averages fits limits etc • • •				
$0\ 209^{+0\ 074}_{-0\ 043}\pm0\ 012$	9	32 AGUILAR 87F	HYBR	πp pp 360 400 GeV
SEEN	6	AGUILAR 86B	HYBR	$\pi^- p$ 360 GeV
SEEN	1	ADEVA 81	HYBR	$\pi^- p \rightarrow D^0\overline{D}^0$

[31] ADLER 88C uses an absolute normalization method finding this decay channel opposite a detected $D^0 \rightarrow K^-\pi^+$ in pure $D\overline{D}$ events

[32] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization Does not distinguish presence of a third π^0 and thus is not included in the average

$\Gamma(\pi^-\pi^-\pi^+\pi^+)/\Gamma_{total}$ — Γ_{17}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$0.0101^{+0.0071}_{-0.0026}$ **OUR FIT**				
$0.0101^{+0.0061}_{-0.0015}$ **OUR AVERAGE** Error includes scale factor of 1 1				
$0\ 005\ ^{+0\ 011}_{-0.001}\pm0\ 001$	1	33 AGUILAR 87F	HYBR	πp pp 360 400 GeV
0 015 ±0 006 ±0 002	9	BALTRUSAITIS 85E	MRK3	e^+e^- E_{cm}= 3 77 GeV

[33] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(\pi^-\pi^-\pi^+\pi^+)/\Gamma(K^-\pi^+\pi^+\pi^-)$ — Γ_{17}/Γ_{15}

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
<0 21	90	SCHINDLER 81	MRK2	e^+e^- E_{cm}= 3 771 GeV

$\Gamma(\overline{K}^0K^+K^-)/\Gamma(K^0\pi^+\pi^-)$ — $(\frac{1}{2}\Gamma_{12}+\Gamma_{13})/(\frac{2}{3}\Gamma_5+\Gamma_8+\Gamma_{10})$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$0\ 208^{+0.037}_{-0.032}$ **OUR FIT**				
0.20 ±0.05 OUR AVERAGE				
0 24 ±0.08		34 BEBEK 86	CLEO	e^+e^- near $\Upsilon(4S)$
0 185 ± 0 055	52	34 ALBRECHT 85B	ARG	e^+e^- E_{cm}= 10 GeV

[34] Resonant contributions to $K^0K^+K^-$ are not distinguished ($K^0\phi$ is included)

$\Gamma(K^*(892)^0\rho^0)/\Gamma(K^-\pi^+\pi^+\pi^-)$ — Γ_{26}/Γ_{15}

Followed by decay $K^*(892)^0 \rightarrow K^-\pi^+$ (BR = 0 67)

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
$0.15^{+0.16}_{-0.15}$		20	35 PICCOLO 77	MRK1	e^+e^- E_{cm}= 4 03 4 41 GeV
• • • We do not use the following data for averages fits limits etc • • •					
0 75 ± 0 3	90	5	36 BAILEY 83B	SPEC	πBe $\rightarrow D^0$

[35] We have corrected the reported number $(0\ 10^{+0\ 11}_{-0\ 10})$ to account for BR($K^*(892)^0 \rightarrow K^-\pi^+$) = 0 67

[36] We have corrected the reported number (0 5 ± 0 2) to account for BR($K^*(892)^0 \rightarrow K^-\pi^+$) = 0 67

$\Gamma(K^-\pi^+\rho^0)/\Gamma(K^-\pi^+\pi^+\pi^-)$ — Γ_{27}/Γ_{15}

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
$0\ 85^{+0.11}_{-0.22}$		180	PICCOLO 77	MRK1	e^+e^- E_{cm}= 4 03 4 41 GeV
• • • We do not use the following data for averages fits limits etc • • •					
0 2 ±0.2	90	2	BAILEY 83B	SPEC	πBe $\rightarrow D^0$

$\Gamma(K^0\pi^+\pi^-\pi^0)/\Gamma_{total}$ — Γ_{28}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
$0\ 106^{+0\ 073}_{-0\ 029}\pm0\ 006$	4	37 AGUILAR 87F	HYBR	πp pp 360 400 GeV
SEEN	7	AGUILAR 86B	HYBR	$\pi^- p$ 360 GeV

[37] AGUILAR BENITEZ 87F computed the branching ratio by topological normalization Does not distinguish presence of a second π^0 and thus is not included in the average

$\Gamma(K^-e^+\nu\pi^0(\pi^0))/\Gamma_{total}$ — Γ_{29}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
$0\ 023^{+0\ 050}_{-0\ 006}\pm0\ 001$	1	38 AGUILAR 87F	HYBR	πp pp 360 400 GeV

[38] AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization Does not distinguish presence of a second π^0 and thus is not included in the average

$\Gamma(K^0\pi^-e^+\nu(\pi^0))/\Gamma_{total}$ — Γ_{30}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
$0\ 079^{+0\ 069}_{-0\ 023}\pm0\ 005$	3	39 AGUILAR 87F	HYBR	πp pp 360 400 GeV

[39] AGUILAR BENITEZ 87F computed the branching ratio by topological normalization Does not distinguish presence of a possible π^0 and thus is not included in the average

$\Gamma(K^+\pi^-$ (via $\overline{D}^0$))$/\Gamma(K^-\pi^+)$ — Γ_{45}/Γ_1

This is a D^0-$\overline{D}^0$ mixing limit

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
<0.0037	90	1	40 ANJOS 88C	SILI	Photoproduction
• • • We do not use the following data for averages fits limits etc • • •					
<0 014	90		ALBRECHT 87K	ARG	e^+e^- E_{cm}= 10 GeV
<0 04	90		ABACHI 86D	HRS	e^+e^- E_{cm}= 29 GeV
<0 07	90	0	40 BAILEY 86	SPEC	π^- Be fixed target
<0 11	90	2	ALBRECHT 85F	ARG	e^+e^- E_{cm}= 10 GeV
<0 081	90		41 YAMAMOTO 85	DLCO	e^+e^- E_{cm}= 29 GeV
<0 23	90		41 ALTHOFF 84B	TASS	e^+e^- E_{cm}= 34 4 GeV
<0 11	90		41 AVERY 80	SPEC	$\gamma N \rightarrow D^{*+}$
<0 16	90		41 FELDMAN 77B	MRK1	$D^{*+} \rightarrow D^0\pi^+$
<0 18	90		41 GOLDHABER 77	MRK1	

[40] This measurement also uses $K^-\pi^+\pi^+\pi^-$ as well as $K^-\pi^+$

[41] Results given as $\Gamma(K^+\pi^-)/[\Gamma(K^-\pi^+)+\Gamma(K^+\pi^-)]$ but do not change significantly for our denominator

$\Gamma(K^*(892)^0\pi^+\pi^-)/\Gamma(K^-\pi^+\pi^+\pi^-)$ — Γ_{31}/Γ_{15}

Followed by decay $K^*(892)^0 \rightarrow K^-\pi^+$ (BR = 0 67)

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
<0.27	90	0	42 BAILEY 83B	SPEC	πBe $\rightarrow D^0$
• • • We do not use the following data for averages fits limits etc • • •					
$0\ 0\ ^{+0\ 3}_{-0\ 0}$		0	43 PICCOLO 77	MRK1	e^+e^- E_{cm}= 4 03 4 41 GeV

[42] We have corrected the reported number <0 18 to account for BR($K^*(892)^0 \rightarrow K^-\pi^+$) = 0 67

[43] Corresponds to <0 5 at 90% CL We have corrected the reported numbers to account for BR($K^*(892)^0 \rightarrow K^-\pi^+$) = 0 67

$\Gamma(K^-a_2(1320)^+)/\Gamma(K^-\pi^+\pi^+\pi^-)$ — Γ_{32}/Γ_{15}

Followed by decay $a_2(1320)^+ \rightarrow \pi^+\pi^+\pi^-$ (BR = 0 35)

VALUE	DOCUMENT ID	TECN	COMMENT
<0 17	44 PICCOLO 77	MRK1	e^+e^- E_{cm}= 4 03 4 41 GeV

[44] We have corrected the reported number <0 06 to account for BR($a_2(1320)^+ \rightarrow \pi^+\pi^+\pi^-$) = 0 35

$\Gamma(\mu^-$ anything (via $\overline{D}^0$))$/\Gamma(\mu^-$ anything) — Γ_{46}/Γ_{42}

This is a D^0 $\overline{D}^0$ mixing limit See the somewhat better limit in the section above on $D^0 \rightarrow K^+\pi^-$ (via $\overline{D}^0$)

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$< 5.6 \times 10^{-3}$	90	LOUIS 86	SPEC	π^-W 225 GeV
• • • We do not use the following data for averages fits limits etc • • •				
< 0 012	90	BENVENUTI 85	CNTR	μC 200 GeV
< 0 044	90	BODEK 82	SPEC	π^- pFe $\rightarrow D^0$

$\Gamma(\mu^+\mu^-)/\Gamma_{total}$ — Γ_{47}/Γ

Test for ΔC = 1 weak neutral current Allowed by first order weak interaction combined with electromagnetic interaction

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$< 1\ 1 \times 10^{-5}$	90	LOUIS 86	SPEC	π^-W 225 GeV
• • • We do not use the following data for averages fits limits etc • • •				
$< 3\ 4 \times 10^{-4}$	90	AUBERT 85	EMC	Deep inelast μ^-N

$\sigma(e^+e^- \rightarrow \psi(3770)) \times \Gamma(K^0K^0)/\Gamma_{total}$ — $\sigma\Gamma_{33}/\Gamma$

VALUE (nanobarns)	CL%	DOCUMENT ID	TECN	COMMENT
<0.025	90	BALTRUSAITIS 86C	MRK3	e^+e^- E_{cm}= 3 77 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(K^0K^-\pi^+ \text{ (non-res)})/\Gamma_{total}$ — $\sigma\Gamma_{34}/\Gamma$

VALUE (nanobarns)	CL%	DOCUMENT ID		TECN	COMMENT
<0.079	90	[45] BALTRUSAITIS	86C	MRK3	e^+e^- E_{cm}= 3 77 GeV

[45]Excludes contributions from $D^0 \to K^*(892)K$

$\Gamma(K^0K^-\pi^+ \text{ (non-res)})/\Gamma_{total}$ — Γ_{34}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
SEEN	1	AGUILAR	86B	HYBR	π^-p 360 GeV

$\sigma(e^+e^- \to \psi(3770)) \times \Gamma(\overline{K}^*(892)^0K^0) + \Gamma(K^*(892)^0\overline{K}^0)/\Gamma_{total}$ — $\sigma\Gamma_{35}/\Gamma$

VALUE (nanobarns)	CL%	DOCUMENT ID		TECN	COMMENT
<0.036	90	BALTRUSAITIS	86C	MRK3	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(e^+e^-)/\Gamma_{total}$ — Γ_{48}/Γ

Test for ΔC = 1 weak neutral current Allowed by first-order weak interaction combined with electromagnetic interaction

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.00013	90	ADLER	88	MRK3	e^+e^- E_{cm}= 3 77 GeV

$\Gamma(\mu^\pm e^\mp)/\Gamma_{total}$ — Γ_{49}/Γ

Test of lepton family number conservation

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.00012	90		BECKER	87C	MRK3	e^+e^- E_{cm}= 3 77 GeV
• • • We do not use the following data for averages fits limits etc • • •						
<0.0009	90		PALKA	87	SILI	200 GeV πp
<0 0021	90	0	[46] RILES	87	MRK2	e^+e^- E_{cm}= 29 GeV

[46]RILES 87 assumes BR($D \to K\pi$) = 3 0% and has production model dependency

$\Gamma(K^-e^+\nu)/\Gamma_{total}$ — Γ_{36}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.05	90	[47] AGUILAR	87F	HYBR	πp pp 360 400 GeV

[47]AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(\pi^-e^+\nu)/\Gamma_{total}$ — Γ_{37}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.054	90	[48] AGUILAR	87F	HYBR	πp pp 360 400 GeV

[48]AGUILAR-BENITEZ 87F computed the branching ratio by topological normalization

$\Gamma(K^-\pi^+\pi^+\pi^-\pi^0)/\Gamma_{total}$ — Γ_{39}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
SEEN	6	AGUILAR	86B	HYBR	π^-p 360 GeV

$\Gamma(K^+K^-\pi^0\pi^0)/\Gamma_{total}$ — Γ_{40}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
SEEN	1	AGUILAR-	86B	HYBR	π^-p 360 GeV

$\Gamma(K^0K^-\pi^+\pi^0)/\Gamma_{total}$ — Γ_{41}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
SEEN	1	AGUILAR	86B	HYBR	π^-p 360 GeV

$\Gamma(K^+\pi^-$ (doubly Cabibbo suppressed)$)/\Gamma_{total}$ — Γ_{43}/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.015	90	2	ANJOS	88C	SILI	Photoproduction

$\Gamma(K^+\pi^-\pi^+\pi^-$ (doubly Cabibbo suppressed)$)/\Gamma_{total}$ — Γ_{44}/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.018	90	5	ANJOS	88C	SILI	Photoproduction

D^0 PRODUCTION CROSS SECTION AT $\psi(3770)$

A compilation of the cross sections for the direct production of D^0 mesons at or near the $\psi(3770)$ peak in e^+e^- production These cross sections are used for normalization of product branching fractions

VALUE (nanobarns)		DOCUMENT ID		TECN	COMMENT
$6.5^{+0.5}_{-0.6}$	OUR FIT				
6.5 ±0.6	OUR AVERAGE				
5 8 ±0 5 ±0 6		[49] ADLER	88C	MRK3	e^+e^- E_{cm}= 3 768 GeV
7 3 ±1 3		[50] PARTRIDGE	84	CBAL	e^+e^- E_{cm}= 3 771 GeV
8 00 ±0 95 ±1 21		[51] SCHINDLER	80	MRK2	e^+e^- E_{cm}= 3 771 GeV
• • • We do not use the following data for averages fits limits etc • • •					
11 5 ±2 5		[52] PERUZZI	77	MRK1	e^+e^- E_{cm}= 3 774 GeV

[49]This measurement compares events with one detected D to those with two detected D mesons to determine the the absolute cross section ADLER 88C find the ratio of cross sections (neutral to charged) to be 1 36 ± 0 23 ± 0 14

[50]This measurement comes from a scan of the $\psi(3770)$ resonance and a fit to the cross section PARTRIDGE 84 measures 6 4 ± 1 15 nb for the cross section We take the phase space division of neutral and charged D mesons in $\psi(3770)$ decay to be 1 33 and we assume that the $\psi(3770)$ is an isosinglet to evaluated the cross sections The noncharm decays (e g radiative) of the $\psi(3770)$ are included in this measurement and may amount to a few percent correction

[51]This measurement comes from a scan of the $\psi(3770)$ resonance and a fit to the cross section SCHINDLER 80 assume the phase space division of neutral and charged D mesons in $\psi(3770)$ decay to be 1 33 and that the $\psi(3770)$ is an isosinglet The noncharm decays (e g radiative) of the $\psi(3770)$ are included in this measurement and may amount to a few per cent correction

[52]This measurement comes from a scan of the $\psi(3770)$ resonance and a fit to the cross section The phase space division of neutral and charged D mesons in $\psi(3770)$ decay is taken to be 1 33 and $\psi(3770)$ is assumed to be an isosinglet The noncharm decays (e g radiative) of the $\psi(3770)$ are included in this measurement and may amount to a few percent correction We exclude this measurement from the average because of uncertainties in the contamination from τ lepton pairs Also see RAPIDIS 77

REFERENCES FOR D^0

ABACHI 88 PL B205 411 +Akerlof Baringer+ (HRS Collab)
ADLER 88 PR D37 2023 +Becker Blaylock+ (MARK III Collab)
ADLER 88C PRL 60 89 +Becker Blaylock+ (MARK III Collab)
ANJOS 88C PRL 60 1239 +Appel+ (Tagged Photon Spectrometer Collab)
RAAB 88 PR D37 2391 +Anjos Appel Bracker+ (FNAL TPS Collab)
ADAMOVICH 87 EPL 4 887 +Alexandrov Bolla+ (Photon Emulsion Collab)
ADLER 87 PL B196 107 +Becker Blaylock Bolton+ (MARK III Collab)
AGUILAR 87C ZPHY C34 143 Aguilar Benitez Allison+ (LEBC EHS Collab)
AGUILAR 87D PL B193 140 Aguilar Benitez Allison+ (LEBC EHS Collab)
AGUILAR 87E ZPHY C36 551 Aguilar Benitez Allison+ (LEBC EHS Collab)
AGUILAR 87F ZPHY C36 559 Aguilar Benitez Allison+ (LEBC EHS Collab)
ALBRECHT 87E ZPHY C33 359 +Binder Boeckmann Glaser+ (ARGUS Collab)
ALBRECHT 87K PL B199 447 +Andam Binder Boeckmann+ (ARGUS Collab)
ALTHOFF 87 ZPHY C32 343 +Braunschweig Gerhards+ (TASSO Collab)
ANJOS 87 PRL 58 311 +Appel Bracker Browder+ (FNAL TPS Collab)
BARLAG 87B ZPHY C37 17 +Becker Bohringer Bosman+ (ACCMOR Collab)
BECKER 87C PL B193 147 +Blaylock Bolton Brown+ (MARK III Collab)
Also 87D PL B198 590 Becker Blaylock Bolton+ (MARK III Collab)
Erratum
CSORNA 87 PL B191 318 +Mestayer Panvini Word+ (CLEO Collab)
PALKA 87 PL B189 238 +Bailey Becker Belau+ (ACCMOR Collab)
RILES 87 PR D35 2914 +Dorfan Abrams Amidei+ (MARK II Collab)
WAGNER 87 PR D36 2850 +Hinshaw Ong Abrams+ (MARK II Collab)
ABACHI 86D PL B182 101 +Akerlof Baringer Ballam+ (HRS Collab)
ABE 86 PR D33 1 + (SLAC Hybrid Facility Photon Collab)
AGUILAR 86 PL 168B 170 Aguilar Benitez Allison+ (LEBC EHS Collab)
AGUILAR 86B ZPHY C31 491 Aguilar Benitez Allison+ (LEBC EHS Collab)
BAILEY 86 ZPHY C30 51 +Belau Boehringer Bosman+ (ACCMOR Collab)
BALTRUSAITIS 86C PRL 56 2136 +Becker Blaylock Brown+ (MARK III Collab)
BALTRUSAITIS 86E PRL 56 2140 +Becker Blaylock Brown+ (MARK III Collab)
BEBEK 86 PRL 56 1893 +Berkelman Bucher Cassel+ (CLEO Collab)
GLADNEY 86 PR D34 2601 +Jaros Ong Barklow+ (MARK II Collab)
LOUIS 86 PRL 56 1027 +Adolphsen Alexander+ (PRIN CHIC ISU)
SCHINDLER 86B SLAC PUB 4248 (SLAC)
SLAC Summer Institute
USHIDA 86B PRL 56 1771 +Kondo+ (AICH FNAL KOBE SEOU MCGI+)
ALBRECHT 85B PL 158B 525 +Binder Harder Philipp+ (ARGUS Collab)
ALBRECHT 85F PL 150B 235 +Binder Harder Philipp+ (ARGUS Collab)
AUBERT 85 PL 155B 461 +Bassompierre Becks Benchouk+ (EMC Collab)
BAILEY 85 ZPHY C28 357 +Belau Boehringer Bosman+ (ABCCMR Collab)
BALTRUSAITIS 85B PRL 54 1976 +Becker Blaylock Brown+ (MARK III Collab)
BALTRUSAITIS 85E PRL 55 150 +Becker Blaylock Brown+ (MARK III Collab)
BENVENUTI 85 PL 158B 531 +Bollini Bruni Camporesi+ (BCDMS Collab)
YAMAMOTO 85 PRL 54 522 +Yamamoto Atwood Baillon+ (DELCO Collab)
YAMAMOTO 85B PR D32 2901 +Yamamoto Atwood Baillon+ (DELCO Collab)
ABE 84 PR D30 1 + (SLAC Hybrid Facility Photon Collab)
ADAMOVICH 84B PL 140B 123 +Alexandrov Bravo Cartacci+ (WA58 Collab)
AGUILAR 84 PL 135B 237 Aguilar Benitez Allison+ (LEBC EHS Collab)
AGUILAR 84B PL 146B 266 Aguilar Benitez Allison+ (LEBC EHS Collab)
ALTHOFF 84B PL 138B 317 +Braunschweig Kirschfink+ (TASSO Collab)
DERRICK 84 PRL 53 1971 +Fernandez Fries Hyman+ (HRS Collab)
PARTRIDGE 84 Cal Tech 1984 Thesis (Crystal Ball Collab)
SUMMERS 84 PRL 52 410 + (UCSB CARL COLO FNAL TNTO OKLA CNRC)
YELTON 84 PRL 52 2019 +Gladney Goldhaber Abrams+(MARK II Collab)
AGUILAR 83 PL 122B 312 Aguilar Benitez Allison+ (LEBC EHS Collab)
BADERT 83 PL 123B 471 Badertscher Hahn Hugentobler+ (BERN MPIM)
BAILEY 83B PL 132B 237 +Bardsley Becker Blanar+ (ACCMOR Collab)
BODEK 82 PL 113B 82 +Breedon+ (ROCH CIT CHIC FNAL STAN)
USHIDA 82 PRL 48 844 + (AICH FNAL KOBE SEOU MCGI NAGO OSJ+)
ADEVA 81 PL 102B 285 +Aguilar Benitez Allison+ (LEBC EHS Collab)
BALLAGH 81 PR D24 7 +Bingham+ (LBL UCB FNAL HAWA WASH WISC)
Also 80 PL 89B 423 Ballagh+ (LBL UCB FNAL HAWA WASH WISC)
FIORINO 81 LNC 30 166 + (Photon Emulsion and Omega Photon C)
FUCHI 81 LNC 31 199 +Hoshino Miyanishi+ (NAGO AICH TOKY YOKO)
SCHINDLER 81 PR D24 78 +Alam Boyarski Breidenbach+ (MARK I Collab)
TRILLING 81 PRPL 75 57 (LBL UCB)
ALLASIA 80 NP B176 13 + (ANKA LIBH CERN DUUC LOJC KEYN+)
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BACINO 80 PRL 45 329 +Ferguson+ (UCLA SLAC STAN UCI STON)
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ZHOLENTZ 80 PL 96B 214 +Kurdadze Lelchuk Mishnev+ (NOVO)
Also 81 SJNP 34 814 Zholentz Kurdadze Lelchuk+ (NOVO)
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ABRAMS 79D PRL 43 481 +Alam Blocker Boyarski+ (SLAC LBL)
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BALTAY 78C PRL 41 73 +Caroumbalis French Hibbs Hylton+(COLU BNL)
SCHARRE 78 PRL 40 74 +Barbaro Galtieri+ (SLAC LBL NWES HAWA)
VUILLEMIN 78 PRL 41 1149 +Feldman Feller+ (LBL SLAC NWES HAWA)
FELDMAN 77B PRL 38 1313 +Peruzzi Piccolo Abrams Alam+ (SLAC LBL)
GOLDHABER 77 PL 69B 503 +Wiss Abrams Alam+ (LBL SLAC)
PERUZZI 77 PRL 39 1301 +Piccolo Feldman+ (SLAC LBL NWES HAWA)
PICCOLO 77 PL 70B 260 +Peruzzi Luth Nguyen Wiss Abrams+ (SLAC LBL)
RAPIDIS 77 PRL 39 526 +Gobbi Luke Barbaro Galtieri+ (MARK I Collab)
GOLDHABER 76 PRL 37 255 +Pierre Abrams Alam+ (LBL SLAC)

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NGUYEN 77 PRL 39 262 +Wiss Abrams Alam Boyarski+ (LBL SLAC) J

CHARMED STRANGE MESONS

$D_s^{\pm}$ was $F^{\pm}$

$I(J^P) = 0(0^-)$

Quantum numbers not measured Values are assigned here assuming charmed-strange ground state D_s meson CHEN 83B observations are consistent with $J = 0$ BLAYLOCK 87 observations are consistent with $J^P = 0^-$

NOTE ON THE D_s MESON

(by W Toki, SLAC)

Results on the D_s ($c\bar{s}$) meson (formerly called the F) have substantially improved since the last Review of Particle Properties New results since that Review are summarized in this note Previously only the $D_s \rightarrow \phi\pi$ and $\phi 3\pi$ decays were reported in the 1970 MeV mass region Now D_s decays are well established in the $\phi\pi$, $\phi 3\pi$, and $K^*(892)K$ modes The reports of observations and searches of new modes are summarized in the following table

The $K^*(892)^0K$ modes are in agreement and provide evidence for decays via the nonspectator (exchange and annihilation) diagrams [9] The new observations of the $\phi 3\pi$ mode are about a factor of two smaller than the previous measurement [10] The $\eta\pi$ and $\eta'\pi$ modes are preliminary and they have a much larger rate than $\phi\pi$ If the $\eta'\pi$ and $\eta\pi$ have the conventional mixing angle ($\theta \approx 10°$) and the D_s decays via the spectator diagram, the $\eta\pi$ and $\eta'\pi$ branching ratios are predicted to be roughly the same [11] The observation of multipion modes would indicate possible evidence for weak-annihilation diagrams [12] The mode $\rho\pi$ appears to be suppressed, whereas there is evidence for nonresonant 3-pion decay It is unexpected to see three-body decays and not the quasi-two-body mode

Mode	$\Gamma(\text{Mode})/\Gamma(D_s^{\pm} \rightarrow \phi\pi^{\pm})$	Group
$K^*(892)^0K^{\pm}$	1.44 ± 0.37	ARGUS[1]
$K^*(892)^0K^{\pm}$	1.0 ± 0.6	MARK-III[2]*
$K^*(892)^0K^{\pm}$	$0.87 \pm 0.13 \pm 0.05$	TPS[3]
$K_S^0K^+$	1.1 ± 0.6	MARK-III[2]*
$K^+K^-\pi^{\pm}$ (n r)	$0.25 \pm 0.07 \pm 0.05$	TPS[3]
$\phi\pi^+\pi^-\pi^{\pm}$	$0.42 \pm 0.13 \pm 0.07$	TPS[3]
$\phi\pi^+\pi^-\pi^{\pm}$	$0.41 \pm 0.13 \pm 0.11$	ARGUS[4]*
$\eta\pi^{\pm}$	$2.5 \pm 0.8 \pm 0.8$	MARK-III[5]*
$\eta\pi^{\pm}$	3 ± 1.3	MARK-II[6]*
$\eta'\pi^+$	seen	MARK-II[6]*
$\pi^+\pi^-\pi^{\pm}$ (n r)	$0.29 \pm 0.07 \pm 0.05$	TPS[7]*
$\rho^0\pi^{\pm}$	< 0.08 (90% CL)	TPS[7]*
$\rho^0\pi^{\pm}$	< 0.22 (90% CL)	ARGUS[8]

* Asterisked references are not yet published or submitted for publication

Recent lifetime measurements are shown in the following table The results are in agreement, and the D_s appears to have a slightly longer lifetime than that of the D^+

Mode	Lifetime (10^{-12} s)	Group
$\phi\pi^{\pm}$, $K^*(892)^0K^+$	$0.47 \pm 0.04 \pm 0.02$	TPS[13]
$K^+K^-\pi^+$	$0.33^{+0.10}_{-0.06}$	ACCMOR[14]
$\phi\pi^{\pm}$	$0.57^{+0.36}_{-0.26} \pm 0.09$	TASSO[15]

The recent mass measurements have become very precise and are listed in the following table

Mode	Mass (MeV)	Group
$K^+K^-\pi^+$	$1968.1 \pm 0.8 \pm 0.6$	TPS[3]
$K^+K^-\pi^+$	$1972.1 \pm 1.5 \pm 1.0$	ACCMOR[14]
$\phi\pi^+$	$1968.8 \pm 1.4 \pm 3.0$	ARGUS[16]
$\phi\pi^+$	$1972.4 \pm 3.7 \pm 3.7$	MARK-III[17]

Usually the groups compare their measurements with, and calibrate against, the mass of the D^+ meson The recent TPS and ARGUS measurements have a lower trend (approximately 5 MeV lower) than previous measurements with the exception of the HRS measurement

New measurements of the $D_s^*(2110) - D_s$ mass difference are summarized in the following table

Mode	Mass Difference (MeV)	Group
$D_s^*(2110) \rightarrow \gamma D_s$ $D_s \rightarrow \phi\pi$	$142.5 \pm 0.8 \pm 1.4$	ARGUS[16]
$D_s^*(2110) \rightarrow \gamma D_s$ $D_s \rightarrow \phi\pi$	$137.9 \pm 2.1 \pm 4.3$	MARK-III[17]

The results are in agreement They follow the empirical rule that the vector mass squared minus the pseudoscalar mass squared, $M^2(1^{--}) - M^2(0^{-+})$, is approximately constant [18]

References

1 H Albrecht et al, Phys Lett **167B**, 360 (1986)
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3 J Anjos et al, Phys Rev Lett **60**, 897 (1988)
4 J McKenna, Ph D thesis, University of Toronto (October 1987), unpublished
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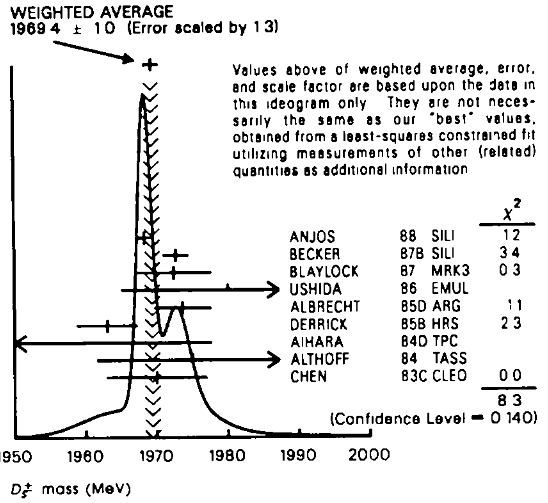
14 H Becker et al, Phys Lett **B184**, 277 (1987)
15 W Braunschweig et al, Z Phys **C35**, 317 (1987)
16 H Albrecht et al, DESY-87-156, submitted to Phys Lett (1987)
17 G Blaylock et al, Phys Rev Lett **58**, 2171 (1987)
18 See the references in G Blaylock et al, Phys Rev Lett **58**, 2171 (1987)

$D_s^{\pm}$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
1969.3 ± 1.1 OUR FIT Error includes scale factor of 1 3					
1969.4 ± 1.0 OUR AVERAGE Error includes scale factor of 1 3 See the ideogram below					
1968 3 ± 0.7 ± 0 7	290	ANJOS 88	SILI		Photo production
1972 7 ± 1 5 ± 1 0	21	BECKER 87B	SILI		200 GeV π Kp
1972 4 ± 3 7 ± 3 7	27	BLAYLOCK 87	MRK3		e^+e^- E_{cm}= 4 14 GeV
1980 0 ± 15 0	6	USHIDA 86	EMUL		ν wideband
1973 6 ± 2 6 ± 3 0	163	ALBRECHT 85D	ARG		e^+e^- E_{cm}= 10 GeV
1963 ± 3 ± 3	30	DERRICK 85B	HRS	+	e^+e^- E_{cm}= 29 GeV
1948 ± 28 ± 10	65	AIHARA 84D	TPC	+	e^+e^- E_{cm}= 29 GeV
1975 ± 9 ± 10	49	ALTHOFF 84	TASS	±	e^+e^- E_{cm} 14–25 GeV
1970 ± 5 ± 5	104	CHEN 83C	CLEO	±	e^+e^- E_{cm}= 10 5 GeV
• • • We do not use the following data for averages fits limits etc • • •					
1975 0 ± 4 0	3	BAILEY 84	SILI		hadron$^+$ Be → $\phi\pi^+X$
1970 ± 10		ARGUS 83	ARG		Preliminary
2017 ± 13	17	[1] ATKINSON 83	OMEG	±	γp
2020 ± 10 ± 20	460	[2] ASTON 81	OMEG	±	γp
2049 ± 15	30	ASTON 81B	OMEG	±	γp
2017 ± 25	1	AMMAR 80	HYBR	+	ν wideband
2026 ± 56	1	USHIDA 80B	EMUL	−	FNAL ν wideband
2089 ± 121	1	USHIDA 80B	EMUL	+	FNAL ν wideband
2030 ± 60	6	BRANDELIK 79	DASP	±	e^+e^- E_{cm}= 4 42 GeV
2030 ± 60	4	BRANDELIK 77B	DASP	±	In BRANDELIK 79

[1] ATKINSON 83 mass error includes systematic uncertainties
[2] Error quoted by ASTON 81 is 10 MeV statistical and · 20 MeV systematic average of three modes listed in sections $\Gamma(\eta\pi^+)/\Gamma_{total}$ $\Gamma(\eta\pi^+\pi^+\pi^-)/\Gamma_{total}$ and $\Gamma(\eta'(958)\pi^+\pi^+\pi^-)/\Gamma_{total}$ below



$D_s^{\pm}$ MEAN LIFE

VALUE (10^{-13} sec)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
$\mathbf{4.36^{+0.38}_{-0.32}}$ **OUR AVERAGE**					
4 7 ± 0 4 ± 0 2	230	RAAB 88	SILI		Photo-production
$3\ 3^{+1\ 0}_{-0\ 6}$	21	[3] BECKER 87B	SILI		200 GeV π,Kp
$5\ 7^{+3\ 6}_{-2\ 6}$ ± 0 9		BRAUNSCH 87	TASS		e^+e^- E_{cm}= 35–44 GeV
4 7 ± 2 2 ± 0 5	141	CSORNA 87	CLEO		e^+e^- E_{cm}= 10 GeV
$3\ 5^{+2\ 4}_{-1.8}$ ± 0 9	17	JUNG 86	HRS	+	$e^+e^- \to \phi\pi^+X$
$2\ 6^{+1\ 6}_{-0\ 9}$	6	USHIDA 86	EMUL		ν wideband
• • • We do not use the following data for averages fits limits etc • • •					
$4.8^{+0\ 6}_{-0\ 5}$ ± 0 2	99	ANJOS 87B	SILI		Repl by RAAB 88
$3\ 2^{+3\ 0}_{-1\ 3}$	3	BAILEY 84	SILI		hadron$^+$ Be → $\phi\pi^+X$
$1\ 9^{+1\ 3}_{-0\ 7}$	4	USHIDA 83	EMUL		Repl by USHIDA 86
1 4	1	AMMAR 80	HYBR	+	ν wideband
$2\ 24^{+2\ 78}_{-1\ 05}$	2	USHIDA 80B	EMUL		ν wideband

[3] BECKER 87B say systematic error was negligible

D_s^{+} DECAY MODES

D_s^- modes are charge conjugates of the modes below

	Mode	Fraction (Γ_i/Γ)
Γ_1	$D_s^+ \to \phi\pi^+$	$(8 \pm 5) \times 10^{-2}$
Γ_2	$D_s^+ \to \phi\pi^+\pi^+\pi^-$	$(3\ 9 \pm 2\ 9) \times 10^{-2}$
Γ_3	$D_s^+ \to \rho^0\pi^+$	$< 1\ 8 \times 10^{-2}$
Γ_4	$D_s^+ \to \bar{K}^*(892)^0 K^+$	$(8 \pm 5) \times 10^{-2}$
Γ_5	$D_s^+ \to K^-K^+\pi^+$ (non-resonant)	$(2\ 0 \pm 1\ 4) \times 10^{-2}$
Γ_6	$D_s^+ \to K^+K^-\pi^+\pi^-\pi^+$ (non-resonant)	$< 2\ 6 \times 10^{-2}$
Γ_7	$D_s^+ \to \mu^+\nu$	$< 3\ 0 \times 10^{-2}$
Γ_8	$D_s^+ \to \eta\pi^+$	
Γ_9	$D_s^+ \to \eta$ anything	
Γ_{10}	$D_s^+ \to \eta\pi^+\pi^+\pi^-$	
Γ_{11}	$D_s^+ \to \eta'(958)\pi^+\pi^+\pi^-$	
Γ_{12}	$D_s^+ \to \phi\rho^+$	

D_s^+ BRANCHING RATIOS

$\Gamma(\phi\pi^+)/\Gamma_{total}$ — Γ_1/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.08 ± 0.05		[4] PDG 88	RVUE	Our estimate
• • • We do not use the following data for averages fits limits etc • • •				
	100	ALBRECHT 85D	ARG	e^+e^- E_{cm}= 10 GeV
0.033 ± 0 011	30	[5] DERRICK 85B	HRS	e^+e^- E_{cm}= 29 GeV
0 13 ± 0 03 $^{+0\ 04}_{-0\ 07}$	49	[5] ALTHOFF 84	TASS	e^+e^- E_{cm} 14–25 GeV
SEEN		ARGUS 83	ARG	Preliminary
0 044	104	[5] CHEN 83C	CLEO	e^+e^- E_{cm}= 10 5 GeV

[4] This value is our estimate based on the measurements of DERRICK 85B and ALTHOFF 84

[5] Values based on same crude estimate of $D_s^\pm$ production level ALTHOFF 84 errors have additional negative error for $D_s^\pm$ from primary B-meson For DERRICK 85B the errors are statistical only

$\Gamma(\phi\pi^+\pi^+\pi^-)/\Gamma_{total}$ — Γ_2/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
Seen OUR EVALUATION				
• • • We do not use the following data for averages fits limits etc • • •				
	62	ALBRECHT 85D	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(\phi\pi^+\pi^+\pi^-)/\Gamma(\phi\pi^+)$ — Γ_2/Γ_1

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.48 ± 0.20 OUR AVERAGE Error includes scale factor of 1 4				
0 42 ± 0 13 ± 0 07	19	ANJOS 88	SILI	Photoproduction
1 11 ± 0 37 ± 0 28		ALBRECHT 85D	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(\rho^0\pi^+)/\Gamma(\phi\pi^+)$ — Γ_3/Γ_1

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0 22	90	ALBRECHT 87G	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(\bar{K}^*(892)^0K^+)/\Gamma(\phi\pi^+)$ — Γ_4/Γ_1

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0 94 ± 0.19 OUR AVERAGE Error includes scale factor of 1 4				
0 87 ± 0 13 ± 0 05	117	ANJOS 88	SILI	Photoproduction
1 44 ± 0 37	87	ALBRECHT 87F	ARG	e^+e^- E_{cm}= 10 GeV

$\Gamma(K^-K^+\pi^+$ (non-resonant)$)/\Gamma(\phi\pi^+)$ — Γ_5/Γ_1

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0 25 ± 0.07 ± 0.05	48	ANJOS 88	SILI	Photoproduction

$\Gamma(K^+K^-\pi^+\pi^-\pi^+$ (non-resonant)$)/\Gamma(\phi\pi^+)$ — Γ_6/Γ_1

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
<0 32	90	0	ANJOS 88	SILI	Photoproduction

$\Gamma(\mu^+\nu)/\Gamma_{total}$ — Γ_7/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
<0.03	0	[6] AUBERT 83	SPEC	μ^+Fe 250 GeV

[6] AUBERT 83 obtain this limit assuming that $D_s^\pm$ production rate is 20% of total charm production rate

$\Gamma(\eta\pi^+)/\Gamma(\eta$ anything$)$ — Γ_8/Γ_9

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
Possibly seen OUR EVALUATION				
• • • We do not use the following data for averages, fits, limits etc • • •				
0 09 ± 0 06	6	[7] BRANDELIK 79	DASP	e^+e^- E_{cm}= 4 42 GeV

[7] Denominator is inconsistent with PARTRIDGE 81 (Crystal Ball)

$\Gamma(\eta\pi^+)/\Gamma_{total}$ — Γ_8/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
Possibly seen OUR EVALUATION				
• • • We do not use the following data for averages fits limits etc • • •				
	17	ATKINSON 83	OMEG	γp
	40	ASTON 81	OMEG	γp

$\Gamma(\eta\pi^+\pi^+\pi^-)/\Gamma_{total}$ — Γ_{10}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
Possibly seen OUR EVALUATION				
• • • We do not use the following data for averages fits limits etc • • •				
	360	ASTON 81	OMEG	γp

$\Gamma(\eta'(958)\pi^+\pi^+\pi^-)/\Gamma_{total}$ — Γ_{11}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
Possibly seen OUR EVALUATION				
• • • We do not use the following data for averages fits limits etc • • •				
	60	ASTON 81	OMEG	γp

$\Gamma(\phi\rho^+)/\Gamma_{total}$ — Γ_{12}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
Possibly seen OUR EVALUATION				
• • • We do not use the following data for averages fits limits etc • • •				
	83	ASTON 81B	OMEG	γp

REFERENCES FOR $D_s^\pm$

ANJOS	88	PRL 60 897	+Appel+ (Tagged Photon Spectrometer Collab)
PDG	88	RPP	Yost Barnett+ (Particle Data Group)
RAAB	88	PR D37 2391	+Anjos Appel Bracker+ (FNAL TPS Collab)
ALBRECHT	87F	PL B179 398	+Binder Boeckmann Glaeser+ (ARGUS Collab)
ALBRECHT	87G	PL B195 102	+Andam Binder Boeckmann+ (ARGUS Collab)
ANJOS	87B	PRL 58 1818	+Appel Bracker Browder+ (FNAL TPS Collab)
BECKER	87B	PL B184 277	+Bohringer Bosman+ (NA11 & NA32 Collab)
BLAYLOCK	87	PRL 58 2171	+Bolton Brown Bunnell+ (MARK III Collab)
BRAUNSCH	87	ZPHY C35 317	Braunschweig Gerhards+ (TASSO Collab)
CSORNA	87	PL B191 318	+Mestayer Panvini Word+ (CLEO Collab)
JUNG	86	PRL 56 1775	+Abachi+ (HRS Collab)
USHIDA	86	PRL 56 1767	+Kondo+ (AICH FNAL GIFU GYEO KOBE SEOU+)
ALBRECHT	85D	PL 153B 343	+Drescher Binder Drews+ (ARGUS Collab)
DERRICK	85B	PRL 54 2568	+Fernandez Fries Hyman+ (HRS Collab)
AIHARA	84D	PRL 53 2465	+Alston Garnjost Badtke Bakken+ (TPC Collab)
ALTHOFF	84	PL 136B 130	+Braunschweig Kirschfink+ (TASSO Collab)
BAILEY	84	PL 139B 320	+Belau Bohringer Bosman+ (ACCMOR Collab)
ARGUS	83	CERN Cour 23 423	(ARGUS Collab)
Preliminary			
ATKINSON	83	ZPHY C17 1	+ (BONN CERN GLAS LANC MCHS LPNP RL+)
AUBERT	83	NP B213 31	+Bassompierre Becks Best+ (EMC Collab)
CHEN	83B	PR D28 2304	+Fenker+ (ARIZ FNAL FLOR NDAM TUFT+)
CHEN	83C	PRL 51 634	+Alam Giles Kagan+ (CLEO Collab)
USHIDA	83	PRL 51 2362	+ (AICH FNAL KOBE SEOU MCGI NAGO+)
ASTON	81	PL 100B 91	+ (BONN CERN EPOL GLAS LANC MCHS+)
ASTON	81B	NP B189 205	+ (BONN CERN EPOL GLAS LANC MCHS+)
PARTRIDGE	81	PRL 47 760	+Peck Porter Gu+ (Crystal Ball Collab)
AMMAR	80	PL 94B 118	+ (KANS FNAL SERP ITEP CRAC JINR WASH+)
USHIDA	80B	PRL 45 1053	+ (AICH FNAL KOBE SEOU MCGI NAGO OSU+)
BRANDELIK	79	PL 80B 412	+Braunschweig Martyn Sander+ (DASP Collab)
BRANDELIK	77B	PL 70B 132	+Braunschweig Martyn Sander+ (DASP Collab)

OTHER RELATED PAPERS

GRAB	87	SLAC PUB 4372 EPS Conference Uppsala	(SLAC)
SCHINDLER	87	SLAC PUB 4417 EPS Conference Uppsala Proc Vol 1 p 341	(SLAC)
SCHUBERT	87	IHEP HD/87 7 EPS Conference Uppsala Proc Vol 2 p 791	(HEID)
SNYDER	87	IUHEE 87 11 Symp on Prod and Decay of Heavy Flavors Stanford	(IND)
SCHINDLER	86	SLAC PUB 4136 World Press International	(SLAC)
SCHINDLER	86B	SLAC PUB 4248 SLAC Summer Institute	(SLAC)
TRILLING	81	PRPL 75 57	(LBL UCB)

D_s^* was F^*

$I(J^P) = ?(?^?)$

D_s^* MASS

VALUE (MeV)	DOCUMENT ID	TECN	CHG	COMMENT
2111.2 ± 1.8 OUR FIT Error includes scale factor of 1 1				
2108.9 ± 2.1 ± 3.0	[1] BLAYLOCK 87	MRK3	−	$e^+e^- \to D_s X$

[1] Assuming D_s mass = 1971 8 ± 1 5 MeV

D_s^* WIDTH

VALUE (MeV)	CL%	DOCUMENT ID	TECN	CHG	COMMENT
<22	90	BLAYLOCK 87	MRK3	−	$e^+e^- \to D_s X$

$D_s^{*+} - D_s^+$ MASS DIFFERENCE

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
141.9 ± 1.5 OUR FIT					
142.4 ± 1.7 OUR AVERAGE					
142 5 ± 0 8 ± 1 5		[2] ALBRECHT 88	ARG		$e^+e^- \to D_s\gamma$
143.0 ± 18.0	8	ASRATYAN 85	HLBC		FNAL 15-ft ν ^{2}H
139 5 ± 8 3 ± 9 7	60	AIHARA 84D	TPC	±	$e^+e^- \to$ hadrons
110 ± 46		BRANDELIK 79	DASP	±	$e^+e^- \to D_s\gamma$

[2] Result includes data of ALBRECHT 84B

D_s^* DECAY MODES

Γ_1 $D_s^* \to D_s\gamma$

D_s^* BRANCHING RATIOS

$\Gamma(D_s\gamma)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
Dominant	OUR EVALUATION			
• • • We do not use the following data for averages, fits, limits, etc. • • •				
SEEN	ALBRECHT	88	ARG	$e^+e^- \to D_s\gamma$
SEEN	ASRATYAN	85		
SEEN	AIHARA	84D		
SEEN	ALBRECHT	84B		
SEEN	BRANDELIK	79		

D_s^* REFERENCES

ALBRECHT	88	DESY 87 156	+Binder, Boeckmann+	(ARGUS Collab.)
BLAYLOCK	87	PRL 58 2171	+Bolton, Brown, Bunnell+	(MARK III Collab.)
ASRATYAN	85	PL 156B 441	+Fedotov, Ammosov, Burtovoy+	(ITEP, SERP)
AIHARA	84D	PRL 53 2465	+Alston-Garnjost, Badtke, Bakken+	(TPC Collab.)
ALBRECHT	84B	PL 146B 111	+Drescher, Heller+	(ARGUS Collab.)
BRANDELIK	79	PL 80B 412	+Braunschweig, Martyn, Sander+	(DASP Collab.)

——— OTHER RELATED PAPERS ———

BRANDELIK	78C	PL 76B 361	+Cords+	(AACH, DESY, HAMB, MPIM, TOKY)
BRANDELIK	77B	PL 70B 132	+Braunschweig, Martyn, Sander+	(DASP Collab.)

BOTTOM MESONS

NOTE ON HIGHLIGHTS OF B MESON DECAYS

(by R. H. Schindler, SLAC)

The past two years have seen a large improvement in our knowledge of B meson decays. The hadronic decays appear to proceed primarily through the $b \to c$ transition, yielding final states containing D^*, D, D_s and ψ mesons. Experiments generally measure only product branching fractions, (e.g., BF($B \to D$X) BF($D \to f$), where f is a hadronic or semileptonic final state). B meson branching ratios are thus normalized by D^*, D, D_s and ψ branching ratios, thus requiring one or more independently determined quantities. In this issue we have attempted to bring the oldest measurements up to date wherever possible, and to explicitly state the input assumptions that the author(s) have made. Our own best fits to the D branching fractions now differ somewhat from the ones that have been used to calculate the B branching fractions. Whenever possible, the product branching fractions (the measured quantities) have been given.

The measurements of hadronic branching fractions of B mesons ($B \to D$ or $D^* + n\pi$) have improved significantly through higher statistics and a better understanding of backgrounds. The original CLEO measurements (GILES 84 and CHEN 85), which provided the first evidence for these channels, are systematically higher than recent ARGUS and CLEO measurements (see for example SCHUBERT 87) even when the recent correction (20–25%) of D meson branching ratios (ADLER 88) is taken into account. With the exception of $B^0 \to D^{*-}\rho^+$ (CHEN 85) the two-body decays appear to have branching fractions less than ~1% while the multibody decays are a few percent (see SCHUBERT 87). The decays to bound charmonium states ($B \to \psi + X$, $\psi' + X$) are now well established, with branching fractions of about 1.1% and 0.5%, respectively.

While inclusive semileptonic branching fractions around 11% have been well established, an exclusive semileptonic B decay channel has now been observed by ARGUS. They measured BF($B^0 \to D^{*-}\ell^+\nu$) = 7.0 ± 1.2 ± 1.9% (SCHUBERT 87). This is not unlike D decay, where a significant part of the semileptonic width appears in one or two exclusive channels.

The inclusive measurements of B decay provide a coarse measure of the relative magnitude of the CKM matrix elements V_{ub} and V_{cb}. At present, however, the various inclusive measurements of B decay appear somewhat inconsistent when examined in detail. The published product branching fractions to charmed mesons [BF($B \to D^0$ or $D^+ + X$)×BF($D \to f$)] from ARGUS and CLEO may be systematically shifted from each other (see SCHINDLER 87). New and higher statistics data available from CLEO later this year will probably resolve this discrepancy. While the D_s is observed in B decays, the absolute branching fraction is indeterminable at present. Charmed baryons appear to account for ~7.5% of the B branching fractions. When open and closed charm are summed, about 1.11 ± 0.13 charmed particles per B decay are observed (SCHUBERT 87) by ARGUS and 1.00 + 0.10 − 0.11 are observed by CLEO[1]. One expects about 1.15 charmed particles per B decay based on the simple assumptions of the Spectator picture.

Many attempts have been made to measure V_{ub} directly. Limits on exclusive channels (e.g., $B \to \pi\pi$, $\rho\pi$, $\rho\rho$, etc.) are in the range of (2–5)×10^{-4} at 90% CL corresponding to $|V_{ub}/V_{cb}| \lesssim 0.40$. This interpretation requires a model-dependent calculation of a hadronic two-body decay. The lepton spectrum can also only provide a model-dependent limit as well. Published results from CUSB and CLEO yield limits of $|V_{ub}/V_{cb}| \lesssim 0.13$, however these use an optimistic Spectator model to interpret the lepton spectrum. A more rigorous and conservative upper limit using the Grinstein, Isgur, and Wise model would lie closer to 0.20–0.25 for the ratio.

One of the most intriguing results of the past year was the observation by ARGUS of the exclusive charmless B decays into $p\bar{p}\pi^\pm$ and $p\bar{p}\pi^+\pi^-$. The branching fractions of (3.7 ± 1.9)×10^{-4} and (6.0 ± 3.0)×10^{-4}, respectively, are close in magnitude to the upper limits observed for $B \to \pi\pi$, $\rho\pi$, $\rho\rho$, etc.

Naive estimates (see for example Bigi[2]) from these decays place $|V_{ub}/V_{cb}| \sim (0.1–0.4)$; however the limits from the semileptonic spectra probably rule out the upper end of this range for the CKM parameters.

Finally, evidence for nonzero $B_d^0\bar{B}_d^0$ and $B_s^0\bar{B}_s^0$ mixing has been presented this year ARGUS (ALBRECHT 87E) looks for like-sign dilepton pairs in B_d^0 decay at the $\Upsilon(4S)$, while UA1 (ALBAJAR 87) looks for like-sign dimuon events from admixtures of B_d and B_s in jets in $p\bar{p}$ collisions The ARGUS result is $\chi_0 = 0.18 \pm 0.06$, where χ_0 = fraction of all B^0 mixing into $\bar{B}^0$ integrated over time The UA1 result is on $\chi = 0.12 \pm 0.05$, where $\chi = f_{B_d}\chi_0 + f_{B_s}\chi_s$, (a weighted admixture of B_s and B_d) These values may be used to infer a lower limit on the top-quark mass of about 50 GeV These estimates depend strongly on the knowledge of hadronic quantities such as B (bag parameter) and f_B (decay constants), and assume box-diagram contributions exclusively

References

1 S Stone, report CLNS 87/103 (1987)

2 I Bigi, SLAC-PUB-4455, in *Proceedings of the International Symposium on the Production and Decay of Heavy Flavors, Stanford, CA (1987)*

$B^{\pm}$

$I(J^P) = \frac{1}{2}(0^-)$

Quantum numbers not measured Values shown are quark-model predictions See also the Listings for the B (following the entry for the B^0) for measurements which do not identify the charge state

$B^{\pm}$ MASS

The fit uses the $B^{\pm}$ and B^0 mass and mass difference measurements These experiments actually measure the difference between half of E_{cm} and the B mass

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
5277.6 ± 1.4 OUR FIT				
5277.8 ± 1.6 OUR AVERAGE				
5275.8 ± 1.3 ± 3.0	32	ALBRECHT	87C ARG	$e^+e^- \to \Upsilon(4S)$
5278.2 ± 1.8 ± 3.0	12	[1] ALBRECHT	87D ARG	$e^+e^- \to \Upsilon(4S)$
5278.6 ± 0.8 ± 2.0		[2] BEBEK	87 CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits limits etc • • •				
5280.1 ± 1.6 ± 3.0	3	[3] ALAM	86 CLEO	$e^+e^- \to \Upsilon(4S)$
5271.2 ± 2.2 ± 2.0		[2,3] GILES	84 CLEO	$e^+e^- \to \Upsilon(4S)$
5270.8 ± 2.3 ± 2.0	6	BEHRENDS	83 CLEO	$D^{*-}\pi^+\pi^+$ + c c

[1] Found using fully reconstructed decays with J/ψ ALBRECHT 87D assume $m(\Upsilon(4S))$ = 10577 MeV

[2] Previous mass values in GILES 84 retracted in BEBEK 87 due to shifts in mass from feeddown of other B-meson channels and an error in the CESR energy scale BEBEK 87 assume $m(\Upsilon(4S))$ = 10580 MeV

[3] ALAM 86 supercedes GILES 84 which is about 3 standard deviations lower These data are independent from those reported in BEBEK 87, but the authors feel that the BEBEK 87 data reflect a greatly improved detector, and suggested that we do not use ALAM 86 for averaging

B^+ DECAY MODES

B^- modes are charge conjugates of the modes below

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_1	$B^+ \to \bar{D}^0\pi^+$	$(4.7^{+1.9}_{-1.5}) \times 10^{-3}$	
Γ_2	$B^+ \to D^*(2010)^-\pi^+\pi^+$	$(2.5^{+1.5}_{-1.3}) \times 10^{-3}$	
Γ_3	$B^+ \to J/\psi(1S)K^+$	$(8.0 \pm 2.8) \times 10^{-4}$	
Γ_4	$B^+ \to \rho^0\pi^+$	$< 2.0 \times 10^{-4}$	90%
Γ_5	$B^+ \to K^0\pi^+$	$< 7 \times 10^{-4}$	90%
Γ_6	$B^+ \to K^*(892)^0\pi^+$	$< 2.6 \times 10^{-4}$	90%
Γ_7	$B^+ \to K^+\rho^0$	$< 2.6 \times 10^{-4}$	90%
Γ_8	$B^+ \to K^+\phi$	$< 2.1 \times 10^{-4}$	90%
Γ_9	$B^+ \to K^*(892)^+\gamma$	$< 1.8 \times 10^{-3}$	90%
Γ_{10}	$B^+ \to D^*(2010)^-\pi^+\pi^+\pi^0$	$(4.3 \pm 2.9) \times 10^{-2}$	
Γ_{11}	$B^+ \to D^-\pi^+\pi^+$	$(2.5^{+4.8}_{-2.4}) \times 10^{-3}$	
Γ_{12}	$B^+ \to \bar{D}^*(2010)^0\pi^+$	$(3 \pm 4) \times 10^{-3}$	
Γ_{13}	$B^+ \to \pi^+\pi^0$	$< 2.3 \times 10^{-3}$	90%
Γ_{14}	$B^+ \to \rho^0 a_1(1260)^+$	$< 3.2 \times 10^{-3}$	90%
Γ_{15}	$B^+ \to \rho^0 a_2(1320)^+$	$< 2.3 \times 10^{-3}$	90%
Γ_{16}	$B^+ \to J/\psi(1S)K^+\pi^-\pi^+$	$(1.1 \pm 0.7) \times 10^{-3}$	
Γ_{17}	$B^+ \to \psi(2S)K^+$	$(2.2 \pm 1.7) \times 10^{-3}$	

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	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_{18}	$B^+ \to K^+\mu^+\mu^-$	$< 3.2 \times 10^{-4}$	90%
Γ_{19}	$B^+ \to K^+e^+e^-$	$< 2.1 \times 10^{-4}$	90%

B^+ BRANCHING RATIOS

$\Gamma(\bar{D}^0\pi^+)/\Gamma_{total}$ — Γ_1/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$0.0047^{+0.0016}_{-0.0013}{}^{+0.0011}_{-0.0008}$	14	[4] BEBEK	87 CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits etc • • •				
0.014 ± 0.006 ± 0.004		[5,6] GILES	84 CLEO	Repl by BEBEK 87
0.030 ± 0.029	2	[5,7] BEHRENDS	83 CLEO	$e^+e^- \to \Upsilon(4S)$

[4] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$ BR($D^0 \to K^-\pi^+$) = (4.2 ± 0.4 ± 0.4)% and BR($D^0 \to K^-\pi^+\pi^+\pi^-$) = (9.1 ± 0.8 ± 0.8)% were used

[5] Corrected by us using assumptions BR($D^0 \to K^-\pi^+$) = (4.2 ± 0.6)% and BR($\Upsilon(4S) \to B^+B^-$) = 60 ± 2% May be contaminated by $D^{*-}\pi^+$ and $D^{*0}\pi^+\pi^-$

[6] The BR($\bar{D}^0\pi^+$)BR($\bar{D}^0 \to K^+\pi^-$) = (6.0 ± 2.4 ± 1.3) × 10^{-4}

[7] The BR($\bar{D}^0\pi^+$)BR($\bar{D}^0 \to K^+\pi^-$) = (12.6 ± 12.3) × 10^{-4}

$\Gamma(D^*(2010)^-\pi^+\pi^+)/\Gamma_{total}$ — Γ_2/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$0.0025^{+0.0015}_{-0.0013}$ OUR AVERAGE				
0.005 ± 0.002 ± 0.003	7	[8] ALBRECHT	87C ARG	$e^+e^- \to \Upsilon(4S)$
$0.0020^{+0.0014}_{-0.0013}{}^{+0.0008}_{-0.0005}$	3	[9] BEBEK	87 CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages fits limits, etc • • •				
$0.034^{+0.021}_{-0.020}$	6	[10] BEHRENDS	83 CLEO	Repl by BEBEK 87

[8] ALBRECHT 87C use PDG 86 branching ratios for D and $D^*(2010)$ and assume BR($\Upsilon(4S) \to B^+B^-$) = 55% and BR($\Upsilon(4S) \to B^0\bar{B}^0$) = 45%

[9] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$ BR($D^*(2010)^+ \to \pi^+D^0$) = (60^{+8}_{-15})% BR($D^0 \to K^-\pi^+$) = (4.2 ± 0.4 ± 0.4)% and BR($D^0 \to K^-\pi^+\pi^+\pi^-$) = (9.1 ± 0.8 ± 0.8)% were used

[10] Corrected by us using assumptions BR($D^0 \to K^-\pi^+$) = (0.042 ± 0.006), BR($D^* \to D^0\pi^-$) = $0.6^{+0.08}_{-0.15}$ and BR($\Upsilon(4S) \to B^+B^-$) = 0.60 ± 0.02 The product branching ratio measured is BR($B \to D^{*-}\pi^+\pi^+$)BR($D^{*-} \to \bar{D}^0\pi^-$)BR($\bar{D}^0 \to K^+\pi^-$) = (8.6 ± 4.6) × 10^{-4}

$\Gamma(J/\psi(1S)K^+)/\Gamma_{total}$ — Γ_3/Γ

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
8.0 ± 2.8 OUR AVERAGE					
7 ± 4		3	[11] ALBRECHT	87D ARG	$e^+e^- \to \Upsilon(4S)$
9 ± 6 ± 2		3	[12] BEBEK	87 CLEO	$e^+e^- \to \Upsilon(4S)$
9 ± 5		3	[13] ALAM	86 CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages fits limits, etc • • •					
<26	90	1	GILES	84 CLEO	Repl by BEBEK 87

[11] ALBRECHT 87D assume $B^+B^-/B^0\bar{B}^0$ ratio is 55/45

[12] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$

[13] ALAM 86 assumes $B^{\pm}/B^0$ ratio is 60/40

$\Gamma(\rho^0\pi^+)/\Gamma_{total}$ Γ_4/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.0002	90		[14] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.0006	90	0	GILES	84	CLEO	Repl. by BEBEK 87

[14] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$.

$\Gamma(K^0\pi^+)/\Gamma_{total}$ Γ_5/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 6.8 \times 10^{-4}$	90	AVERY	87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^*(892)^0\pi^+)/\Gamma_{total}$ Γ_6/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 2.6 \times 10^{-4}$	90	AVERY	87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^+\rho^0)/\Gamma_{total}$ Γ_7/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 2.6 \times 10^{-4}$	90	AVERY	87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^+\phi)/\Gamma_{total}$ Γ_8/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 2.1 \times 10^{-4}$	90	AVERY	87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^*(892)^+\gamma)/\Gamma_{total}$ Γ_9/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 1.8 \times 10^{-3}$	90	AVERY	87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^+\mu^+\mu^-)/\Gamma_{total}$ Γ_{18}/Γ

Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 3.2 \times 10^{-4}$	90	AVERY	87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^+e^+e^-)/\Gamma_{total}$ Γ_{19}/Γ

Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 2.1 \times 10^{-4}$	90	AVERY	87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(D^*(2010)^-\pi^+\pi^+\pi^0)/\Gamma_{total}$ Γ_{10}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.043 \pm 0.013 \pm 0.026$	24	[15] ALBRECHT	87C	ARG	$e^+e^- \to \Upsilon(4S)$

[15] ALBRECHT 87C use PDG 86 branching ratios for D and $D^*(2010)$ and assume $BR(\Upsilon(4S) \to B^+B^-) = 55\%$ and $BR(\Upsilon(4S) \to B^0\bar{B}^0) = 45\%$.

$\Gamma(D^-\pi^+\pi^+)/\Gamma_{total}$ Γ_{11}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.0025^{+0.0041}_{-0.0023}{}^{+0.0024}_{-0.0008}$	1	[16] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$

[16] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$. $BR(D^- \to K^+\pi^-\pi^-) = (9.1 \pm 1.3 \pm 0.4)\%$ is assumed.

$\Gamma(\bar{D}^*(2010)^0\pi^-)/\Gamma_{total}$ Γ_{12}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.0027 ± 0.0044	[17] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$

[17] This is a derived branching ratio, using the inclusive pion spectrum and other two-body B decays. BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$.

$\Gamma(\pi^+\pi^0)/\Gamma_{total}$ Γ_{13}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0023	90	[18] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$

[18] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$.

$\Gamma(\rho^0a_1(1260)^+)/\Gamma_{total}$ Γ_{14}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0032	90	[19] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$

[19] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$.

$\Gamma(\rho^0a_2(1320)^+)/\Gamma_{total}$ Γ_{15}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0023	90	[20] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$

[20] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$.

$\Gamma(J/\psi(1S)K^+\pi^-\pi^-)/\Gamma_{total}$ Γ_{16}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0011 ± 0.0007	6	[21] ALBRECHT	87D	ARG	$e^+e^- \to \Upsilon(4S)$

[21] ALBRECHT 87D assume $B^+B^-/B^0\bar{B}^0$ ratio is 55/45. Analysis explicitly removes $B^+ \to \Upsilon(2S)K^+$.

$\Gamma(\psi(2S)K^+)/\Gamma_{total}$ Γ_{17}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0022 ± 0.0017	3	[22] ALBRECHT	87D	ARG	$e^+e^- \to \Upsilon(4S)$

[22] ALBRECHT 87D assume $B^+B^-/B^0\bar{B}^0$ ratio is 55/45.

REFERENCES FOR $B^{\pm}$

ALBRECHT	87C	PL B185 218	+Binder, Boeckmann, Glaser+ (ARGUS Collab.)
ALBRECHT	87D	PL B199 451	+Andam, Binder, Boeckmann+ (ARGUS Collab.)
AVERY	87	PL B183 429	+Besson, Bowcock, Giles+ (CLEO Collab.)
BEBEK	87	PR D36 1289	+Berkelman, Blucher, Cassel+ (CLEO Collab.)
ALAM	86	PR D34 3279	+Katayama, Kim, Sun+ (CLEO Collab.)
PDG	86	PL 170B	Aguilar-Benitez, Porter+ (Particle Data Group)
GILES	84	PR D30 2279	+Hassard, Hempstead, Kinoshita+ (CLEO Collab.)
BEHRENDS	83	PRL 50 881	+Chadwick, Chauveau, Ganci+ (CLEO Collab.)

OTHER RELATED PAPERS

SCHINDLER 87 SLAC PUB 4417 (SLAC)
EPS Conference, Uppsala Proc., Vol. 1, p. 341
SCHUBERT 87 IHEP HD 87 7 (HEID)
EPS Conference, Uppsala Proc., Vol. 2, p. 791

B^0

$I(J^P) = \frac{1}{2}(0^-)$

Quantum numbers not measured. Values shown are quark-model predictions. See also the Listings for the B (following this entry) for measurements which do not identify the charge state.

In this issue we have attempted to bring the oldest measurements of branching ratios up to date wherever possible, and to explicitly state the input assumptions that the author(s) have made. Our own best fits to the D branching fractions now differ somewhat from the ones that have been used to calculate the B branching fractions. Whenever possible, the product branching fractions (the measured quantities) have been given.

See the Note at the beginning of the $B^{\pm}$ section.

B^0 MASS

The fit uses the $B^{\pm}$ and B^0 mass and mass difference measurements. These experiments actually measure the difference between half of E_{cm} and the B mass.

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
5279.4 ± 1.5 OUR FIT					
5278.8 ± 2.3 OUR AVERAGE					
$5278.2 \pm 1.0 \pm 3.0$	40	ALBRECHT	87C	ARG	$e^+e^- \to \Upsilon(4S)$
$5279.5 \pm 1.6 \pm 3.0$	7	[1] ALBRECHT	87D	ARG	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$5280.6 \pm 0.8 \pm 2.0$		[2,3] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$
$5281.2 \pm 1.3 \pm 3.0$	5	[2,4] ALAM	86	CLEO	$e^+e^- \to \Upsilon(4S)$
$5275.2 \pm 1.9 \pm 2.0$		[3,4] GILES	84	CLEO	$e^+e^- \to \Upsilon(4S)$
$5274.2 \pm 1.9 \pm 2.0$	5	BEHRENDS	83	CLEO	$D^{*-}\pi^+$ + c.c.

[1] Found using fully reconstructed decays with J/ψ. ALBRECHT 87D assume $m(\Upsilon(4S)) = 10577$ MeV.
[2] Redundant with data in the mass difference listing below. Enters fit via the mass difference.
[3] Previous mass values in GILES 84 retracted in BEBEK 87 due to shifts in mass from feeddown of other B meson channels and an error in the CESR energy scale. BEBEK 87 assume $m(\Upsilon(4S)) = 10580$ MeV.
[4] ALAM 86 supercedes GILES 84 which is about 3 standard deviations lower.

$|m_{B^0_1} - m_{B^0_2}|$, MASS DIFFERENCE

VALUE (10^{-10} MeV)	DOCUMENT ID		TECN	COMMENT
3.7 ± 1.0	[5] ALBRECHT	87I	ARG	$e^+e^- \to \Upsilon(4S)$

[5] Calculated by us using $\Delta m = (2r/(1-r))^{1/2}\hbar/\tau_{B^0}$ where $\tau_{B^0} = (13.1 \pm 1.4) \times 10^{-13}$s and r is the B^0–$\bar{B}^0$ mixing ratio $\Gamma(B^0 \to \bar{B}^0 \to \mu^-$ anything$)/\Gamma(B^0 \to \mu^+$ anything$)$.

Stable Particle Full Listings
B^0

$B^0 - B^+$ MASS DIFFERENCE

The fit uses the $B^\pm$ and B^0 mass and mass difference measurements

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1.9 ± 1.1 OUR FIT				
2.0 ± 1.1 ± 0.3	[6] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc • • •				
1.1 ± 2 1	[7] ALAM	86	CLEO	$e^+e^- \to \Upsilon(4S)$
4.0 ± 2 7 ± 2.0	GILES	84	CLEO	$e^+e^- \to \Upsilon(4S)$
3.4 ± 3 0 ± 2 0	BEHRENDS	83	CLEO	$e^+e^- \to \Upsilon(4S)$

[6] BEBEK 87 actually measure the difference between half of E_{cm} and the $B^\pm$ or B^0 mass, so the $B^0 - B^\pm$ mass difference is more accurate
[7] ALAM 86 say the systematic error cancels in the mass difference These data are independent from those reported in BEBEK 87, but the authors feel that the BEBEK 87 data reflect a greatly improved detector and suggested that we do not use ALAM 86 for averaging

MEAN LIFE RATIO $\tau(B^0)/\tau(B^+)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
0.44 to 2.05	90	[8] BEAN	87B	CLEO	$e^+e^- \to \Upsilon(4S)$

[8] BEAN 87B assume the fraction of $B^0\bar{B}^0$ events at the $\Upsilon(4S)$ is 0 41

B^0 DECAY MODES

B^0 modes are charge conjugates of the modes below

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_1	$B^0 \to \bar{D}^0\pi^+\pi^-$	$< 4 \times 10^{-2}$	90%
Γ_2	$B^0 \to D^*(2010)^-\pi^+$	$(3.3^{+1.2}_{-1.0}) \times 10^{-3}$	
Γ_3	$B^0 \to D^*(2010)^-\rho^+$	$(8\ ^{+7}_{-4}) \times 10^{-2}$	
Γ_4	$B^0 \to J/\psi(1S)K^+\pi^-$	$< 1\ 3 \times 10^{-3}$	90%
Γ_5	$B^0 \to \pi^+\pi^-$	$< 3\ 0 \times 10^{-4}$	90%
Γ_6	$B^0 \to \mu^+$ anything		
Γ_7	$B^0 \to K^+\pi^-$	$< 3\ 2 \times 10^{-4}$	90%
Γ_8	$B^0 \to K^*(892)^+\pi^-$	$< 7 \times 10^{-4}$	90%
Γ_9	$B^0 \to K^0\rho^0$	$< 8 \times 10^{-4}$	90%
Γ_{10}	$B^0 \to K^0\phi$	$< 1\ 3 \times 10^{-3}$	90%
Γ_{11}	$B^0 \to K^*(892)^0\phi$	$< 5 \times 10^{-4}$	90%
Γ_{12}	$B^0 \to K^*(892)^0\rho^0$	$< 1\ 2 \times 10^{-3}$	90%
Γ_{13}	$B^0 \to K^*(892)^0\gamma$	$< 2\ 1 \times 10^{-3}$	90%
Γ_{14}	$B^0 \to D^*(2010)^-\pi^+\pi^0$	$(1\ 5 \pm 1\ 1) \times 10^{-2}$	
Γ_{15}	$B^0 \to D^*(2010)^-\pi^+\pi^+\pi^-$	$(3\ 3 \pm 1\ 8) \times 10^{-2}$	
Γ_{16}	$B^0 \to D^*(2010)^-e^+\nu$		
Γ_{17}	$B^0 \to J/\psi(1S)K^*(892)^0$	$(3.7 \pm 1\ 3) \times 10^{-3}$	
Γ_{18}	$B^0 \to J/\psi(1S)K^0$	$< 5 \times 10^{-3}$	90%
Γ_{19}	$B^0 \to \rho^\pm\pi^\mp$	$< 6 \times 10^{-3}$	90%
Γ_{20}	$B^0 \to \rho^0\rho^0$	$< 5 \times 10^{-4}$	90%
Γ_{21}	$B^0 \to \pi^\pm a_1(1260)^\mp$	$< 1\ 2 \times 10^{-3}$	90%
Γ_{22}	$B^0 \to \pi^\pm a_2(1320)^\mp$	$< 1\ 6 \times 10^{-3}$	90%
Γ_{23}	$B^0 \to p\bar{p}$	$< 2\ 0 \times 10^{-4}$	90%
Γ_{24}	$B^0 \to D^-\pi^+$	$(5\ 9^{+3\ 6}_{-3\ 2}) \times 10^{-3}$	
Γ_{25}	$B^0 \to D^*(2010)^-\mu^+\nu$		

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	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_{26}	$B^0 \to e^+e^-$	$< 8 \times 10^{-5}$	90%
Γ_{27}	$B^0 \to \mu^+\mu^-$	$< 5 \times 10^{-5}$	90%
Γ_{28}	$B^0 \to e^+\mu^- + e^-\mu^+$	$< 5 \times 10^{-5}$	90%
Γ_{29}	$B^0 \to K^0\mu^+\mu^-$	$< 5 \times 10^{-4}$	90%
Γ_{30}	$B^0 \to K^0e^+e^-$	$< 7 \times 10^{-4}$	90%
Γ_{31}	$B^0 \to \mu^-$ anything (via $\bar{B}^0$)		

B^0 BRANCHING RATIOS

$\Gamma(\bar{D}^0\pi^+\pi^-)/\Gamma_{total}$ Γ_1/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.039	90		[9] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages fits limits, etc • • •						
0 09 ±0.06		5	[10] BEHRENDS	83	CLEO	$e^+e^- \to \Upsilon(4S)$

[9] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$ $BR(D^0 \to K^-\pi^+)$ = (4 2 ± 0 4 ± 0 4)% and $BR(D^0 \to K^-\pi^+\pi^+\pi^-)$ = (9 1 ± 0 8 ± 0 8)% were used
[10] Corrected by us using assumptions $BR(D^0 \to K^-\pi^+)$ = (0 042 ± 0 006) and $BR(\Upsilon(4S) \to B^0\bar{B}^0)$ = 0 40 ± 0 02 The product branching ratio is $BR(B^0 \to \bar{D}^0\pi^+\pi^-)BR(\bar{D}^0 \to K^+\pi^-)$ = (0 39 ± 0 26) × 10^{-2}

$\Gamma(D^*(2010)^-\pi^+)/\Gamma_{total}$ Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.0033^{+0.0012}_{-0.0010}$ OUR AVERAGE					
0 0027 ± 0 0014 ± 0 0010	5	[11] ALBRECHT	87C	ARG	$e^+e^- \to \Upsilon(4S)$
$0\ 0031^{+0\ 0017\ +0\ 0011}_{-0\ 0013\ -0\ 0007}$	5	[12] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$
0 0035 ± 0.002 ± 0 002		[13] ALBRECHT	86F	ARG	$e^+e^- \to \Upsilon(4S)$
0 017 ± 0 005 ± 0 005	41	[14] GILES	84	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages fits limits etc • • •					
0 019 ± 0.013	5	[15] BEHRENDS	83	CLEO	$e^+e^- \to \Upsilon(4S)$

[11] ALBRECHT 87C use PDG 86 branching ratios for D and $D^*(2010)$ and assume $BR(\Upsilon(4S) \to B^+B^-)$ = 55% and $BR(\Upsilon(4S) \to B^0\bar{B}^0)$ = 45%
[12] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$ $BR(D^*(2010)^+ \to \pi^+D^0)$ = (60^{+8}_{-15})% $BR(D^0 \to K^-\pi^+)$ = (4 2 ± 0 4 ± 0 4)% and $BR(D^0 \to K^-\pi^+\pi^+\pi^-)$ = (9 1 ± 0 8 ± 0 8)% were used
[13] ALBRECHT 86F uses pseudomass that is independent of D^0 and D^+ branching ratios
[14] Assumes $BR(D^*(2010)^+ \to D^0\pi^+)$ = $0\ 60^{+0\ 08}_{-0\ 15}$ Assumes $BR(\Upsilon(4S) \to B^0\bar{B}^0)$ = 0 40 ± 0 02 Does not depend on D branching ratios
[15] Corrected by us using assumptions $BR(D^0 \to K^-\pi^+)$ = (0 042 ± 0 006) $BR(D^{*+} \to D^0\pi^+)$ = $0\ 6^{+0\ 08}_{-0\ 15}$ and $BR(\Upsilon(4S) \to B^0\bar{B}^0)$ = 0 40 ± 0 02 The product branching ratio measured is $BR(B^0 \to D^{*-}\pi^+)BR(D^{*-} \to \bar{D}^0\pi^-)BR(\bar{D}^0 \to K^+\pi^-)$ = (4 7 ± 3 1) × 10^{-4}

$\Gamma(D^*(2010)^-\rho^+)/\Gamma_{total}$ Γ_3/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.081 \pm 0\ 029^{+0.059}_{-0.024}$	19	[16] CHEN	85	CLEO	$e^+e^- \to \Upsilon(4S)$

[16] Uses $BR(D^* \to D^0\pi^+)$ = 0 6 ± 0 15 and $BR(\Upsilon(4S) \to B^0\bar{B}^0)$ = 0 4 Does not depend on D branching ratios

$\Gamma(J/\psi(1S)K^+\pi^-)/\Gamma_{total}$ Γ_4/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.0013	90		[17] ALBRECHT	87D	ARG	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages fits limits etc • • •						
<0 0063	90	2	GILES	84	CLEO	$e^+e^- \to \Upsilon(4S)$

[17] ALBRECHT 87D assume $B^+B^-/B^0\bar{B}^0$ ratio is 55/45 $K\pi$ system is specifically selected as nonresonant

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ Γ_5/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.0003	90		[18] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits limits etc • • •						
<0 0005	90	4	GILES	84	CLEO	$e^+e^- \to \Upsilon(4S)$

[18] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$

$\Gamma(e^+e^-)/\Gamma_{total}$ Γ_{26}/Γ

Test for ΔB = 1 weak neutral current Allowed by higher order electroweak interactions

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 8 × 10^{-5}	90	AVERY	87	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages fits limits, etc • • •					
< 8 5 × 10^{-5}	90	ALBRECHT	87D	ARG	$e^+e^- \to \Upsilon(4S)$
< 3 × 10^{-4}	90	GILES	84	CLEO	Repl by AVERY 87

$\Gamma(\mu^+\mu^-)/\Gamma_{total}$ Γ_{27}/Γ

Test for ΔB = 1 weak neutral current Allowed by higher order electroweak interactions

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 5.0 × 10^{-5}	90	ALBRECHT	87D	ARG	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages fits limits etc • • •					
< 9 × 10^{-5}	90	AVERY	87	CLEO	$e^+e^- \to \Upsilon(4S)$
< 2 × 10^{-4}	90	GILES	84	CLEO	Repl by AVERY 87

$\Gamma(e^+\mu^-) + \Gamma(e^-\mu^+)/\Gamma_{total}$ Γ_{28}/Γ

Test of lepton family number conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 5.0 × 10^{-5}	90	ALBRECHT	87D	ARG	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages fits limits etc • • •					
< 9 × 10^{-5}	90	AVERY	87	CLEO	$e^+e^- \to \Upsilon(4S)$
< 3 × 10^{-4}	90	GILES	84	CLEO	Repl by AVERY 87

$\Gamma(\mu^-$ anything (via B^0))/$\Gamma(\mu^\pm$ anything) $\Gamma_{31}/(\Gamma_{31}+\Gamma_6)$

This is a B^0 B^0 mixing measurement Violates $\Delta B \neq 2$ rule Two different variables χ and r are used We have converted all results to χ

$$\chi = \Gamma(B \to \mu^- X)/\Gamma(B \to \mu^\pm X)$$
$$= \Gamma(B \to \mu^+ X)/\Gamma(\bar{B} \to \mu^\pm X)$$
$$\text{or} \quad r = \chi/(1-\chi)$$

Note that the experiments other than those at the $\Upsilon(4S)$ have not separated χ_d from χ_s where the subscripts indicate $B^0(b\bar{d})$ or $B^0_s(b\bar{s})$ so they are not included in the average

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
0.17 ±0.05		[19] ALBRECHT 87I	ARG	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages fits limits etc • • •				
0 21 $^{+0\ 29}_{-0.15}$		[20] BAND 88	MAC	e^+e^- E_{cm} = 29 GeV
>0 02	90	[20] BAND 88	MAC	e^+e^- E_{cm} = 29 GeV
0 121 ± 0 047		[20,21] ALBAJAR 87C	UA1	$p\bar{p}$ 546–630 GeV
<0 19	90	[22] BEAN 87B	CLEO	$e^+e^- \to \Upsilon(4S)$
<0 12	90	[20,23] SCHAAD 85	MRK2	e^+e^- E_{cm}=29 GeV
<0 27	90	[24] AVERY 84	CLEO	$e^+e^- \to \Upsilon(4S)$

[19] Measured inclusively with like-sign dileptons with tagged B decays plus leptons, and one fully reconstructed event ALBRECHT 87I measured r=0 21 ± 0 08 We converted to χ for comparison
[20] These experiments see a combination of B_s and B_d mesons
[21] ALBAJAR 87C measured χ = ($B^0 \to B^0 \to \mu^+$ X) divided by the average production weighted semileptonic branching fraction for B hadrons at 546 and 630 GeV
[22] BEAN 87B measured r < 0 24 we converted to χ
[23] Limit is average probability for hadron containing B quark to produce a positive lepton
[24] *Same sign dilepton events Limit assumes semileptonic BR for B^+ and B^0 equal If $B^0/B^\pm$ ratio · 0 58 no limit exists* The limit was corrected in BEAN 87B from r < 0 30 to r < 0 37 We converted this limit to χ

$\Gamma(K^+\pi^-)/\Gamma_{total}$ Γ_7/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.00032	90	AVERY 87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^*(892)^+\pi^-)/\Gamma_{total}$ Γ_8/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.0007	90	AVERY 87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^0\rho^0)/\Gamma_{total}$ Γ_9/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.0008	90	AVERY 87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^0\phi)/\Gamma_{total}$ Γ_{10}/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.0013	90	AVERY 87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^*(892)^0\phi)/\Gamma_{total}$ Γ_{11}/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.00047	90	AVERY 87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^*(892)^0\rho^0)/\Gamma_{total}$ Γ_{12}/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0 0012	90	AVERY 87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^*(892)^0\gamma)/\Gamma_{total}$ Γ_{13}/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.0021	90	AVERY 87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^0\mu^+\mu^-)/\Gamma_{total}$ Γ_{29}/Γ

Test for ΔB = 1 weak neutral current Allowed by higher order electroweak interactions

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.00045	90	AVERY 87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(K^0e^+e^-)/\Gamma_{total}$ Γ_{30}/Γ

Test for ΔB = 1 weak neutral current Allowed by higher-order electroweak interactions

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.00065	90	AVERY 87	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(D^*(2010)^-\pi^+\pi^0)/\Gamma_{total}$ Γ_{14}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.015 ± 0.008 ± 0.008	8	[25] ALBRECHT 87C	ARG	$e^+e^- \to \Upsilon(4S)$

[25] ALBRECHT 87C use PDG 86 branching ratios for D and $D^*(2010)$ and assume BR($\Upsilon(4S) \to B^+B^-$) = 55% and BR($\Upsilon(4S) \to B^0\bar{B}^0$) = 45%

$\Gamma(D^*(2010)^-\pi^+\pi^+\pi^-)/\Gamma_{total}$ Γ_{15}/Γ

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
0.033 ± 0.009 ± 0 016		27	[26] ALBRECHT 87C	ARG	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages fits limits etc • • •					
<0 046	90		[27] BEBEK 87	CLEO	$e^+e^- \to \Upsilon(4S)$

[26] ALBRECHT 87C use PDG 86 branching ratios for D and $D^*(2010)$ and assume BR($\Upsilon(4S) \to B^+B^-$) = 55% and BR($\Upsilon(4S) \to B^0\bar{B}^0$) = 45%
[27] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$ BR($D^*(2010)^+ \to \pi^+D^0$) = (60^{+8}_{-15})% BR($D^0 \to K^-\pi^+$) = (4 2 ± 0 4 ± 0 4)% and BR($D^0 \to K^-\pi^+\pi^+\pi^-$) = (9 1 ± 0 8 ± 0 8)% were used

$[\Gamma(D^*(2010)^-e^+\nu) + \Gamma(D^*(2010)^-\mu^+\nu)]/\Gamma_{total}$ $(\Gamma_{16}+\Gamma_{25})/\Gamma$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.140 ± 0 024 ± 0.038	47	[28] ALBRECHT 87J	ARG	$e^+e^- \to \Upsilon(4S)$

[28] ALBRECHT 87J assume μ e universality the BR($\Upsilon(4S) \to B^0\bar{B}^0$) = 0 45 the BR($D^0 \to K^-\pi^+$) = (0 042 ± 0 004 ± 0 004) and the BR($D^*(2010)^- \to D^0\pi^-$) = 0 49 ± 0 08

$\Gamma(J/\psi(1S)K^*(892)^0)/\Gamma_{total}$ Γ_{17}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.0037 ± 0.0013 OUR AVERAGE				
0 0033 ± 0 0018	5	[29] ALBRECHT 87D	ARG	$e^+e^- \to \Upsilon(4S)$
0 0041 ± 0 0019 ± 0 0003	5	[30] BEBEK 87	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages fits limits etc • • •				
0 0041 ± 0 0018	5	[31] ALAM 86	CLEO	Repl by BEBEK 87

[29] ALBRECHT 87D assume B^+B^- : $B^0\bar{B}^0$ ratio is 55 45
[30] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$
[31] ALAM 86 assumes $B^\pm$ B^0 ratio is 60 40 The observation of the decay $B^+ \to J/\psi K^*(892)^+$ (HAAS 85) has been retracted in this paper

$\Gamma(J/\psi(1S)K^0)/\Gamma_{total}$ Γ_{18}/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.005	90	ALAM 86	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(\rho^\pm\pi^\mp)/\Gamma_{total}$ Γ_{19}/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.0061	90	[32] BEBEK 87	CLEO	$e^+e^- \to \Upsilon(4S)$

[32] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$

$\Gamma(\rho^0\rho^0)/\Gamma_{total}$ Γ_{20}/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.0005	90	[33] BEBEK 87	CLEO	$e^+e^- \to \Upsilon(4S)$

[33] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$

$\Gamma(\pi^\pm a_1(1260)^\mp)/\Gamma_{total}$ Γ_{21}/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.0012	90	[34] BEBEK 87	CLEO	$e^+e^- \to \Upsilon(4S)$

[34] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$

$\Gamma(\pi^\pm a_2(1320)^\mp)/\Gamma_{total}$ Γ_{22}/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.0016	90	[35] BEBEK 87	CLEO	$e^+e^- \to \Upsilon(4S)$

[35] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$

$\Gamma(p\bar{p})/\Gamma_{total}$ Γ_{23}/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.0002	90	[36] BEBEK 87	CLEO	$e^+e^- \to \Upsilon(4S)$

[36] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$

$\Gamma(D^-\pi^+)/\Gamma_{total}$ Γ_{24}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.0059 $^{+0.0033}_{-0.0029}$ $^{+0.0015}_{-0.0014}$	4	[37] BEBEK 87	CLEO	$e^+e^- \to \Upsilon(4S)$

[37] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$ and BR($D^- \to K^+\pi^-\pi^-$) = (9 1 ± 1 3 ± 0 4)%

REFERENCES FOR B^0

BAND	88	PL B200 221	+Camporesi Chadwick+	(MAC Collab)
ALBAJAR	87C	PL B186 247	+Albrow Allkofer Arnison+	(UA1 Collab)
ALBRECHT	87C	PL B185 218	+Binder Boeckmann+	(ARGUS Collab)
ALBRECHT	87D	PL B199 451	+Andam Binder Boeckmann+	(ARGUS Collab)
ALBRECHT	87I	PL B192 245	+Andam Binder Boeckmann+	(ARGUS Collab)
ALBRECHT	87J	PL B197 452	+Andam Binder Boeckmann+	(ARGUS Collab)
AVERY	87	PL B183 429	+Besson Bowcock Giles+	(CLEO Collab)
BEAN	87B	PRL 58 183	+Bobbink Brock Engler+	(CLEO Collab)
BEBEK	87	PR D36 1289	+Berkelman Blucher Cassel+	(CLEO Collab)
ALAM	86	PR D34 3279	+Katayama Kim Sun+	(CLEO Collab)
ALBRECHT	86F	PL B182 95	+Binder Boeckmann Glaser+	(ARGUS Collab)
PDG	86	PL 170B	Aguilar Benitez Porter+	(Particle Data Group)
CHEN	85	PR D31 2386	+Goldberg Horwitz Jawahery+	(CLEO Collab)
HAAS	85	PRL 55 1248	+Hempstead Jensen Kagan+	(CLEO Collab)
SCHAAD	85	PL 160B 188	+Nelson Abrams Amidei+	(MARK II Collab)
AVERY	84	PRL 53 1309	+Bebek Berkelman Cassel+	(CLEO Collab)
GILES	84	PR D30 2279	+Hassard Hempstead Kinoshita+	(CLEO Collab)
BEHRENDS	83	PRL 50 881	+Chadwick Chauveau Ganc +	(CLEO Collab)

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EPS Conference Uppsala Proc Vol 1 p 341
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EPS Conference Uppsala Proc Vol 2 p 791

B

$I(J^P) = \frac{1}{2}(0^-)$

Quantum numbers not measured. Values shown are quark-model predictions. This entry lists measurements of B meson parameters for which the charge states are not separated. Measurements in which the charge state is clearly identified are listed in the preceding $B^\pm$ and B^0 entries.

In this issue we have attempted to bring the oldest measurements of branching ratios up to date wherever possible, and to explicitly state the input assumptions that the author(s) have made. Our own best fits to the D branching fractions now differ somewhat from the ones that have been used to calculate the B branching fractions. Whenever possible the product branching fractions (the measured quantities) have been given.

See the Note at the beginning of the $B^\pm$ section.

B MEAN LIFE

VALUE (10^{-13} sec)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
$13.1^{+1.4}_{-1.3}$ OUR AVERAGE						
$11.7^{+2.7+1.7}_{-2.2-1.6}$			KLEM	88	DELC	e^+e^- E_{cm}=29 GeV
$12.9\pm2.0\pm2.6$			[1] ASH	87	MAC	e^+e^- E_{cm}=29 GeV
$10.2^{+4.2}_{-3.9}$		301	[2] BROM	87	HRS	e^+e^- E_{cm}=29 GeV
$13.9\pm1.0\pm2.5$			WU	87	RVUE	TASSO result
$14.6\pm1.9\pm3.5$			[3] WU	87	RVUE	JADE result
$18^{+5}_{-4}\pm4$		25	BARTEL	86B	JADE	e^+e^- E_{cm}=35 GeV
$12.0^{+4.5}_{-3.6}\pm3.0$			[4] LOCKYER	83	MRK2	e^+e^- E_{cm}=29 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
		2	[5] ALBANESE	85	HYBR	350 GeV $\pi^- p$ emulsion
$18.3^{+3.8+3.7}_{-3.7-3.4}$			ALTHOFF	84H	TASS	e^+e^- E_{cm}=30–46.8 GeV
$11.6^{+3.7}_{-3.4}\pm2.3$		46	KLEM	84	DLCO	Repl. by KLEM 88
$18\pm6\pm4$			FERNANDEZ	83B	MAC	e^+e^- E_{cm}=29 GeV
<14	95		BARTEL	82C	JADE	e^+e^- average E_{cm}=34 GeV

[1] We have added an overall scale error of 15% linearly to the systematic error of ±0.7 to obtain ±2.6 systematic error.
[2] Statistical and systematic errors were combined by BROM 87.
[3] The systematic error quoted here came from a private communication from the authors.
[4] The lifetime is an average over bottom particles produced.
[5] The mean flight time for the one B^0 was 5×10^{-13} sec while the one B^- was 0.8×10^{-13} sec. Possible evidence for difference in B^0 and $B^\pm$ lifetime.

B DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_1	$B \to e\nu$ hadrons	$(12.3\pm0.8)\times10^{-2}$	
Γ_2	$B \to \mu\nu$ hadrons	$(11.0\pm0.9)\times10^{-2}$	
Γ_3	$B \to K^\pm$ anything	$(85\pm11)\times10^{-2}$	
Γ_4	$B \to J/\psi(1S)$ anything	$(1.12\pm0.18)\times10^{-2}$	
Γ_5	$B \to D^0/\overline{D}^0$ anything	$(39\pm6)\times10^{-2}$	
Γ_6	$B \to p$ anything	$>2.1\times10^{-2}$	
Γ_7	$B \to \Lambda$ anything	$>1.1\times10^{-2}$	
Γ_8	$B \to \ell\nu$ hadrons (noncharm)		
Γ_9	$B \to D^*(2010)^\pm$ anything	$(22^{+8}_{-6})\times10^{-2}$	
Γ_{10}	$B \to \overline{D}^0\pi^+$, $D^-\pi^+$, $\overline{D}^*(2010)^0\pi^+$, or $D^*(2010)^-\pi^+$		
Γ_{11}	$B \to D_s^\pm$ anything	$(14.0\pm3.0)\times10^{-2}$	
Γ_{12}	$B \to \phi$ anything	$(2.3\pm0.8)\times10^{-2}$	
Γ_{13}	$B \to$ Charmed baryon anything	$<11\times10^{-2}$	90%
Γ_{14}	$B \to D^\pm$ anything	$(17\pm6)\times10^{-2}$	
Γ_{15}	$B \to K^+\ell^+$ anything		
Γ_{16}	$B \to K^-\ell^+$ anything		
Γ_{17}	$B \to K^0/\overline{K}^0\ell^+$ anything		
Γ_{18}	$B \to K^+$ anything		
Γ_{19}	$B \to K^-$ anything		
Γ_{20}	$B \to K^0/\overline{K}^0$ anything	$(63\pm8)\times10^{-2}$	
Γ_{21}	$B \to \ell^+$ anything		
Γ_{22}	$B \to \psi(2S)$ anything	$(4.6\pm2.0)\times10^{-3}$	
Γ_{23}	$B \to \ell\nu$ hadrons		

FORBIDDEN BY CONSERVATION LAWS

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_{24}	$B \to e^+e^-$ anything	$<2.4\times10^{-3}$	90%
Γ_{25}	$B \to \mu^+\mu^-$ anything	$<2.4\times10^{-3}$	90%

B BRANCHING RATIOS

$\Gamma(e\nu\ \text{hadrons})/\Gamma_{total}$ — Γ_1/Γ

Only the experiments at the $\Upsilon(4S)$ are used in the average.

VALUE	DOCUMENT ID		TECN	COMMENT
0.123 ± 0.008 OUR AVERAGE				
$0.120\pm0.007\pm0.005$	CHEN	84	CLEO	Direct e at $\Upsilon(4S)$
$0.132\pm0.008\pm0.014$	[6] KLOPFEN	83B	CUSB	Direct e at $\Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.149^{+0.022}_{-0.019}$	PAL	86	DLCO	e^+e^- E_{cm}=29 GeV
$0.110\pm0.018\pm0.010$	AIHARA	85	TPC	e^+e^- E_{cm}=29 GeV
$0.111\pm0.034\pm0.040$	ALTHOFF	84J	TASS	e^+e^- E_{cm}=34.6 GeV
0.146 ± 0.028	KOOP	84	DLCO	Repl. by PAL 86
$0.116\pm0.021\pm0.017$	NELSON	83	MRK2	e^+e^- E_{cm}=29 GeV

[6] Ratio $\sigma(b \to e\nu\ up)$ / $\sigma(b \to e\nu\ charm)$ < 0.055 at CL = 90%.

$\Gamma(\mu\nu\ \text{hadrons})/\Gamma_{total}$ — Γ_2/Γ

The average of the four high-energy results is 0.117 ± 0.013. These experiments produce other bottom particles in addition to the B meson.

VALUE	DOCUMENT ID		TECN	COMMENT
0.110 ± 0.009 OUR AVERAGE				
$0.108\pm0.006\pm0.01$	CHEN	84	CLEO	Direct μ at $\Upsilon(4S)$
$0.112\pm0.009\pm0.01$	LEVMAN	84	CUSB	Direct μ at $\Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.117\pm0.016\pm0.015$	BARTEL	87	JADE	e^+e^- E_{cm}=34.6 GeV
$0.114\pm0.018\pm0.025$	BARTEL	85J	JADE	Repl. by BARTEL 87
$0.117\pm0.028\pm0.010$	ALTHOFF	84G	TASS	e^+e^- E_{cm}=34.5 GeV
$0.105\pm0.015\pm0.013$	ADEVA	83B	MRKJ	e^+e^- E_{cm}=33–38.5 GeV
$0.155^{+0.054}_{-0.029}$	FERNANDEZ	83D	MAC	e^+e^- E_{cm}=29 GeV

$\Gamma(e^+e^-\ \text{anything})/\Gamma_{total}$ — Γ_{24}/Γ

Test for $\Delta B = 1$ weak neutral current.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0024 OUR LIMIT	Our 90% CL limit, using $[\Gamma(e^+e^-\ \text{anything}) + \Gamma(\mu^+\mu^-\ \text{anything})]/\Gamma_{total}$ below				
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.05	90	BEBEK	81	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(\mu^+\mu^-\ \text{anything})/\Gamma_{total}$ — Γ_{25}/Γ

Test for $\Delta B = 1$ weak neutral current.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0024 OUR LIMIT	Our 90% CL limit, using $[\Gamma(e^+e^-\ \text{anything}) + \Gamma(\mu^+\mu^-\ \text{anything})]/\Gamma_{total}$ below				
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.02	95	ALTHOFF	84G	TASS	e^+e^- E_{cm}=34.5 GeV
<0.007	95	ADEVA	83	MRKJ	e^+e^- E_{cm} = 30–38 GeV
<0.007	95	BARTEL	83B	JADE	e^+e^- E_{cm} = 33–37 GeV
<0.017	90	CHADWICK	81	CLEO	$e^+e^- \to \Upsilon(4S)$

$[\Gamma(e^+e^-\ \text{anything}) + \Gamma(\mu^+\mu^-\ \text{anything})]/\Gamma_{total}$ — $(\Gamma_{24}+\Gamma_{25})/\Gamma$

Test for $\Delta B = 1$ weak neutral current.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0024	90	[7] BEAN	87	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.0062	90	[8] AVERY	84	CLEO	Repl. by BEAN 87
<0.008	90	MATTEUZZI	83	MRK2	e^+e^- E_{cm}=29 GeV

[7] BEAN 87 reports $[(\mu^+\mu^-)+(e^+e^-)]/2$ and we converted it.
[8] Determine ratio of B^+ to B^0 semileptonic decays to be in the range 0.25–2.9.

$\Gamma(K^{\pm}$ anything$)/\Gamma_{total}$ — Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.85±0.07±0.09	ALAM	87B	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
SEEN	[9] BRODY	82	CLEO	$e^+e^- \to \Upsilon(4S)$
SEEN	[10] GIANNINI	82	CUSB	$e^+e^- \to \Upsilon(4S)$

[9] Assuming $\Upsilon(4S) \to B\bar{B}$, a total of 3.38±0.34±0.68 kaons per $\Upsilon(4S)$ decay is found (the second error is systematic). In the context of the standard B-decay model this leads to a value for (b-quark $\to$ c-quark) / (b-quark $\to$ all) of 1.09±0.33±0.13.
[10] GIANNINI 82 at CESR-CUSB observed 1.58±0.35 K^0 per hadronic event much higher than 0.82±0.10 below threshold. Consistent with predominant $b \to c$ X decay.

$\Gamma(J/\psi(1S)$ anything$)/\Gamma_{total}$ — Γ_4/Γ

VALUE (units 10^{-2})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
1.12±0.18 OUR AVERAGE						
1.07±0.16±0.22		120	[11] ALBRECHT	87D	ARG	$e^+e^- \to \Upsilon(4S)$
1.09±0.16±0.21		52	ALAM	86	CLEO	$e^+e^- \to \Upsilon(4S)$
$1.4\,^{+0.6}_{-0.5}$		7	[12] ALBRECHT	85H	ARG	e^+e^- near $\Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1.1 ±0.21±0.23		46	[13] HAAS	85	CLEO	Repl. by ALAM 86
<4.9	90		MATTEUZZI	83	MRK2	e^+e^- E_{cm}=29 GeV

[11] ALBRECHT 87D find the branching ratio for J/ψ not from $\psi(2S)$ to be 0.0081±0.0023.
[12] Statistical and systematic errors were added in quadrature. ALBRECHT 85H also report a CL = 90% limit of 0.007 for $B \to J/\psi(1S)$ + X where m(X) < 1 GeV.
[13] Dimuon and dielectron events used.

$\Gamma(D^0/\bar{D}^0$ anything$)/\Gamma_{total}$ — Γ_5/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.39±0.05±0.04	21k	[14] BORTOLETTO	87	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.57±0.14±0.12		[15] GREEN	83	CLEO	Repl. by BORTOLETTO 87

[14] BORTOLETTO 87 uses old MARK III (BALTRUSAITIS 86E) branching ratio for $K^-\pi^+$ = 0.056±0.004±0.003. The product branching ratio for BR($B \to D^0$ X) BR($D^0 \to K^-\pi^+$) is 0.0210±0.0015±0.0021.
[15] Corrected by us using assumptions BR($D^0 \to K^-\pi^+$) = (0.042±0.006). The product branching ratio is BR($B^0 \to D^0$ X)BR($D^0 \to K^-\pi^+$) = 0.024±0.006±0.004.

$\Gamma(p$ anything$)/\Gamma_{total}$ — Γ_6/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
>0.021	[16] ALAM	83B	CLEO	$e^+e^- \to \Upsilon(4S)$

[16] ALAM 83B reported their result as >0.036±0.006±0.009. Values are for (BR($B \to p$ X)+BR($B \to \bar{p}$ X))/2. Data are consistent with equal yields of p and $\bar{p}$. Using assumed yields below cut BR($B \to p$ + X) = 0.03 not including protons from Λ decays.

$\Gamma(\Lambda$ anything$)/\Gamma_{total}$ — Γ_7/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
>0.011	[17] ALAM	83B	CLEO	$e^+e^- \to \Upsilon(4S)$

[17] ALAM 83B reported their result as >0.022±0.007±0.004. Values are for (BR(Λ X)+BR($\bar{\Lambda}$ X))/2. Data are consistent with equal yields of p and $\bar{p}$. Using assumed yields below cut BR($B \to \Lambda$ X) = 0.03.

$\Gamma(\ell\nu$ hadrons (noncharm)$)/\Gamma(\ell\nu$ hadrons$)$ — Γ_8/Γ_{23}

ℓ denotes e or μ but not the sum.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.04	90	[18] BEHRENDS	87	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.04	90	CHEN	84	CLEO	Direct e at $\Upsilon(4S)$
<0.055	90	KLOPFEN	83B	CUSB	Direct e at $\Upsilon(4S)$

[18] The quoted possible limits range from 0.018 to 0.04 for the ratio depending on which model or momentum range is chosen. We select the most conservative limit they have calculated. This corresponds to a limit on $V_{bu}/|V_{bc}|$ < 0.20. While the endpoint technique employed is more robust than their previous results in CHEN 84, these results do not provide a numerical improvement in the limit.

$\Gamma(D^*(2010)^{\pm}$ anything$)/\Gamma_{total}$ — Γ_9/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.22\pm0.04\,^{+0.07}_{-0.04}$	5200	[19] BORTOLETTO	87	CLEO	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.27\pm0.06\,^{+0.08}_{-0.06}$	510	[20] CSORNA	85	CLEO	Repl. by BORTOLETTO 87

[19] BORTOLETTO 87 uses old MARK III (BALTRUSAITIS 86E) branching ratios BR($D^0 \to K^-\pi^+$) = 0.056±0.004±0.003 and also assumes BR($D^*(2010)^+ \to D^0\pi^+$) = $0.60\,^{+0.08}_{-0.15}$. The product branching ratio for BR($B \to D^*(2010)^+$) BR($D^*(2010)^+ \to D^0\pi^+$) is 0.13±0.02±0.012.
[20] $V-A$ momentum spectrum used to extrapolate below p = 1 GeV. We correct the value assuming BR($D^0 \to K^-\pi^+$) = 0.042±0.006 and BR($D^{*+} \to D^0\pi^+$) = $0.6\,^{+0.08}_{-0.15}$. The product branching fraction is BR($B \to D^{*+}$ X)BR($D^{*+} \to \pi^+D^0$)BR($D^0 \to K^-\pi^+$) = (68±15±9) × 10^{-4}.

$\Gamma(\bar{D}^0\pi^+, D^-\pi^+, \bar{D}^*(2010)^0\pi^+$, or $D^*(2010)^-\pi^+)/\Gamma_{total}$ — Γ_{10}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.0162±0.0032	[21] BEBEK	87	CLEO	$e^+e^- \to \Upsilon(4S)$
0.020 ±0.006 ±0.005	[22] GILES	84	CLEO	Repl. by BEBEK 87

[21] BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\bar{B}^0$. This measurement is independent of D and $D^*(2010)$ meson branching fractions.
[22] No dependence on D used fast π momentum.

$\Gamma(D_s^{\pm}$ anything$)/\Gamma_{total}$ — Γ_{11}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.14±0.03	[23] ALBRECHT	87H	ARG	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.11	[24] HAAS	86	CLEO	$e^+e^- \to \Upsilon(4S)$

[23] ALBRECHT 87H obtained this result by measuring BR($B \to D_s^{\pm}$ X) BR($D_s^{\pm} \to \phi\pi^+$) = 0.0042±0.0009±0.006 and calculating BR($D_s^{\pm} \to \phi\pi^+$) = 0.030±0.008. 46±16% of $B \to D_s$ X decays are 2 body.
[24] HAAS 86 obtained this result by measuring BR($B \to D_s^{\pm}$ X)BR($D_s^{\pm} \to \phi\pi^+$) = 0.0038±0.001 and assume BR($D_s^{\pm} \to \phi\pi^+$) = 0.035. 64±22% decays are 2 body.

$\Gamma(\phi$ anything$)/\Gamma_{total}$ — Γ_{12}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.023±0.006±0.005	BORTOLETTO	86	CLEO	$e^+e^- \to \Upsilon(4S)$

Γ(Charmed baryon anything)$/\Gamma_{total}$ — Γ_{13}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.112	90	[25] ALAM	87	CLEO	$e^+e^- \to \Upsilon(4S)$

[25] Assuming all baryons result from charmed baryons. ALAM 86 conclude the branching fraction is 7.4±2.9%. The limit given above is model independent.

$\Gamma(D^{\pm}$ anything$)/\Gamma_{total}$ — Γ_{14}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.17±0.04±0.04	20k	[26] BORTOLETTO	87	CLEO	$e^+e^- \to \Upsilon(4S)$

[26] BORTOLETTO 87 uses old MARK III (BALTRUSAITIS 86E) branching ratio for $K^-\pi^+\pi^+$ = 0.116±0.014±0.007. The product branching ratio for BR($B \to D^+$ X) BR($D^+ \to K^-\pi^+\pi^+$) is 0.019±0.004±0.002.

$\Gamma(K^+\ell^+$ anything$)/\Gamma(\ell^+$ anything$)$ — Γ_{15}/Γ_{21}

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.54±0.07±0.06	[27] ALAM	87B	CLEO	$e^+e^- \to \Upsilon(4S)$

[27] ALAM 87B measurement relies on lepton-kaon correlations. It does not consider the possibility of $B\bar{B}$ mixing. We have thus removed it from the average.

$\Gamma(K^-\ell^+$ anything$)/\Gamma(\ell^+$ anything$)$ — Γ_{16}/Γ_{21}

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.10±0.05±0.02	[28] ALAM	87B	CLEO	$e^+e^- \to \Upsilon(4S)$

[28] ALAM 87B measurement relies on lepton-kaon correlations. It does not consider the possibility of $B\bar{B}$ mixing. We have thus removed it from the average.

$\Gamma(K^0/\bar{K}^0\ell^+$ anything$)/\Gamma(\ell^+$ anything$)$ — Γ_{17}/Γ_{21}

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.39±0.06±0.04	[29] ALAM	87B	CLEO	$e^+e^- \to \Upsilon(4S)$

[29] ALAM 87B measurement relies on lepton-kaon correlations. It does not consider the possibility of $B\bar{B}$ mixing. We have thus removed it from the average.

$\Gamma(K^+$ anything$)/\Gamma_{total}$ — Γ_{18}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.66±0.05±0.07	[30] ALAM	87B	CLEO	$e^+e^- \to \Upsilon(4S)$

[30] ALAM 87B measurement relies on lepton-kaon correlations. It does not consider the possibility of $B\bar{B}$ mixing. We have thus removed it from the average.

$\Gamma(K^-$ anything$)/\Gamma_{total}$ — Γ_{19}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.19±0.05±0.02	[31] ALAM	87B	CLEO	$e^+e^- \to \Upsilon(4S)$

[31] ALAM 87B measurement relies on lepton-kaon correlations. It does not consider the possibility of $B\bar{B}$ mixing. We have thus removed it from the average.

$\Gamma(K^0/\bar{K}^0$ anything$)/\Gamma_{total}$ — Γ_{20}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.63±0.06±0.06	ALAM	87B	CLEO	$e^+e^- \to \Upsilon(4S)$

$\Gamma(c\bar{c})/\Gamma_{total}$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
0 98 ± 0 16 ± 0 12	[32] ALAM	87B	CLEO	$e^+e^- \to \Upsilon(4S)$

[32] From the difference between K^- and K^+ widths ALAM 87B measurement relies on lepton kaon correlations It does not consider the possibility of $B\bar{B}$ mixing We have thus removed it from the average

$\Gamma(\psi(2S)$ anything$)/\Gamma_{total}$ — Γ_{22}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0046 ± 0 0017 ± 0.0011	8	ALBRECHT	87D	ARG	$e^+e^- \to \Upsilon(4S)$

REFERENCES FOR B

KLEM	88	PR D37 41	+Atwood Barish+	(DELCO Collab)
ALAM	87	PRL 59 22	+Kitukama Kim Li+	(CLEO Collab)
ALAM	87B	PRL 58 1814	+Katayama Kim Sun+	(CLEO Collab)
ALBRECHT	87D	PL B199 451	+Andam Binder Boeckmann+	(ARGUS Collab)
ALBRECHT	87H	PL B187 425	+Binder Boeckmann Glaser+	(ARGUS Collab)
ASH	87	PRL 58 640	+Band Bloom Bosman+	(MAC Collab)
BARTEL	87	ZPHY C33 339	+Becker Felst Haidt+	(JADE Collab)
BEAN	87	PR D35 3533	+Bobbink Brock Engler+	(CLEO Collab)
BEBEK	87	PR D36 1289	+Berkelman Blucher Cassel+	(CLEO Collab)
BEHRENDS	87	PRL 59 407	+Morrow Guida Guida+	(CLEO Collab)
BORTOLETTO	87	PR D35 19	+Chen Garren Goldberg+	(CLEO Collab)
BROM	87	PL B195 301	+Abachi Akerlof Baringer+	(HRS Collab)
WU	87	Lepton Photon Conf DESY 87 164 and CERN EP 87 235		(WISC DESY)
ALAM	86	PR D34 3279	+Katayama Kim Sun+	(CLEO Collab)
BALTRUSAITIS	86E	PRL 56 2140	+Becker Blaylock Brown+	(MARK III Collab)
BARTEL	86B	ZPHY C31 349	+Becker Cords Felst Haidt+	(JADE Collab)
BORTOLETTO	86	PRL 56 800	+Chen Garren Goldberg+	(CLEO Collab)
HAAS	86	PRL 56 2781	+Hempstead Jensen Kagan+	(CLEO Collab)
PAL	86	PR D33 2708	+Atwood Barish Bonneaud+	(DELCO Collab)
AIHARA	85	ZPHY C27 39	+Alston Garnjost Badtke Bakken+	(TPC Collab)
ALBANESE	85	PL 158B 186 WA75 experiment	+Alpe Aoki+	(BARI CERN DUUC LOUC NAGO+)
ALBRECHT	85H	PL 162B 395	+Binder Harder+	(ARGUS Collab)
BARTEL	85J	PL 163B 277	+Becker Cords Felst+	(JADE Collab)
CSORNA	85	PRL 54 1894	+Garren Mestayer Panvini+	(CLEO Collab)
HAAS	85	PRL 55 1248	+Hempstead Jensen Kagan+	(CLEO Collab)
ALTHOFF	84G	ZPHY C22 219	+Braunschweig Kirschfink+	(TASSO Collab)
ALTHOFF	84H	PL 149B 524	+Braunschweig Kirschfink+	(TASSO Collab)
ALTHOFF	84J	PL 146B 443	+Branschweig Kirschfink+	(TASSO Collab)
AVERY	84	PRL 53 1309	+Bebek Berkelman Cassel+	(CLEO Collab)
CHEN	84	PRL 52 1084	+Goldberg Horwitz Jawahery+	(CLEO Collab)
GILES	84	PR D30 2279	+Hassard Hempstead Kinoshita+	(CLEO Collab)
KLEM	84	PRL 53 1873	+Dubois Young Atwood+	(DELCO Collab)
KOOP	84	PRL 52 970	+Sakuda Atwood Baillon+	(DELCO Collab)
LEVMAN	84	PL 141B 271	+Sreedhar Han Imlay+	(CUSB Collab)
ADEVA	83	PRL 50 799	+Barber Becker Berdugo+	(MARK J Collab)
ADEVA	83B	PRL 51 443	+Barber Becker Berdugo+	(MARK J Collab)
ALAM	83B	PRL 51 1143	+Csorna Garren Mestayer+	(CLEO Collab)
BARTEL	83B	PL 132B 241	+Becker Bowdery Cords+	(JADE Collab)
FERNANDEZ	83B	PRL 51 1022	+Ford Read Smith+	(MAC Collab)
FERNANDEZ	83D	PRL 50 2054	+Ford Read Smith+	(MAC Collab)
GREEN	83	PRL 51 347	+Hicks Sannes Skubic+	(CLEO Collab)
KLOPFEN	83B	PL 130B 444	Klopfenstein Horstkotte+	(CUSB Collab)
LOCKYER	83	PRL 51 1316	+Jaros Nelson Abrams+	(MARK II Collab)
MATTEUZZI	83	PL 129B 141	+Abrams Amidei Blocker+	(MARK II Collab)
NELSON	83	PRL 50 1542	+Blondel Trilling Abrams+	(MARK II Collab)
BARTEL	82C	PL 114B 71	+Cords Dittmann Eichler+	(JADE Collab)
BRODY	82	PRL 48 1070	+Chen Goldberg Horwitz+	(CLEO Collab)
GIANNINI	82	NP B206 1	+Finocchiaro Franzini+	(CUSB Collab)
BEBEK	81	PRL 46 84	+Haggerty Izen Longuemare+	(CLEO Collab)
CHADWICK	81	PRL 46 88	+Ganci Kagan Kass+	(CLEO Collab)

OTHER RELATED PAPERS

SCHINDLER 87 SLAC PUB 4417 (SLAC)
EPS Conference Uppsala Proc Vol 1 p 341
SCHUBERT 87 IHEP HD/87 7 (HEID)
EPS Conference Uppsala Proc Vol 2 p 791

B^*

$I(J^P) = ?(?^?)$

OMITTED FROM SUMMARY TABLE

B^* MASS

VALUE (MeV)		DOCUMENT ID
5331.3 ± 4.7	**OUR EVALUATION**	From mass difference below and $B^\pm$ and B^0 masses 5279 3 ± 1 4 MeV
5330 ± 5	**OUR FIT**	

$B^* - B$ MASS DIFFERENCE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
52 ± 4 OUR FIT					
52.0 ± 2 ± 4.	1400	HAN	85	CUSB	$e^+e^- \to \gamma e X$

B^* REFERENCES

HAN 85 PRL 55 36 +Klopfenstein Mageras+ (COLU LSU MPIM STON)

NUCLEONS

p

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

p MASS

The mass is known much more precisely in u (atomic mass units) than in MeV (see the footnote) The conversion from u to MeV, 1 u = 931 49432±0 00028 MeV involves the relatively poorly known electronic charge

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
938.27231 ± 0.00028	[1] COHEN	87	RVUE	1986 CODATA value
• • • We do not use the following data for averages fits limits etc • • •				
938 2796 ± 0 0027	COHEN	73	RVUE	1973 CODATA value

[1] The mass is known much more precisely in u m = 1 007276470 ± 0 000000012 u

$\bar{p}$ MASS

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
938.22 ± 0 04	**OUR AVERAGE**				
938 30 ± 0 13		ROBERTS	78	CNTR	
938 229 ± 0 049		ROBERSON	77	CNTR	
938 179 ± 0 058		HU	75	CNTR	Exotic atoms
938 3 ± 0 5		BAMBERGER	70	CNTR	

NOTE ON PROTON MEAN LIFE LIMITS

(by M Goldhaber, Brookhaven National Laboratory, and F Reines, University of California, Irvine)

Current ideas on the unification of the weak, electromagnetic, and strong forces suggest that baryon number might not be strictly conserved, so that the proton could decay In the Particle Properties Summary Tables there are nearly thirty particles listed with a mass smaller than that of the proton (if we count both particles and antiparticles and different members of multiplets separately) Ten of these particles are fermions and the remainder bosons There are then a great many possible two-body decay modes of the proton and an even larger number of three-body, etc , decay modes which satisfy charge, energy, momentum, and angular momentum conservation Each decay mode has to contain at least one fermion to satisfy angular momentum conservation Fig 1 shows masses of possible decay products of the proton

The "decay signature" distributions as well as the backgrounds depend on detector characteristics (the material

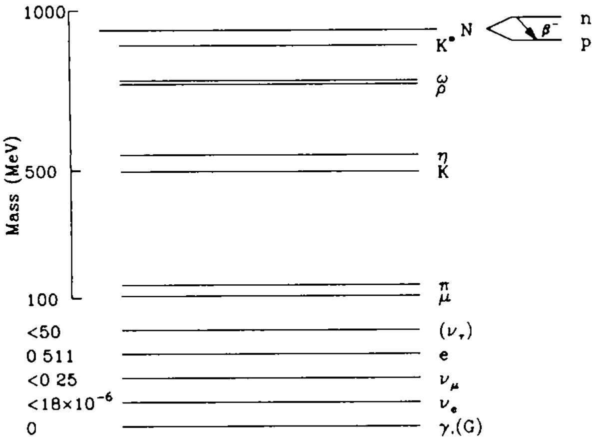


Fig 1 Masses of particles (in MeV) into which a proton might decay The hypothetical graviton (G) is included

from which the detector is made, the method of detection, timing information, time resolution, etc) The background, due chiefly to atmospheric neutrinos, depends also on the geomagnetic latitude and on the phase of the solar cycle with which the magnetic field of the sun is associated The depth-dependent cosmic ray background is due to cosmic ray muons and their progeny For each possible proton decay signature there is a finite probability of a background event with a similar signature, where the probability depends on the detector characteristics

The simplest grand unified theory, minimal SU(5), predicts $e^+\pi^0$ to be the predominant proton decay mode, see Table I The IMB lower limit on the partial mean life for this mode, $3\ 1\times10^{32}$ years, is a factor of 40 higher than predicted by minimal SU(5) theory

See also the reviews in Refs 1–5

See also the neutron-antineutron oscillations section in the neutron Full Listings below for another test of baryon conservation

References

1 M Goldhaber, P Langacker, and R Slansky, Science **210** 851 (1980)

2 D H Perkins, Ann Rev Nucl Part Sci **34**, 1 (1984)

3 J M LoSecco, Comments Nucl Part Phys **15**, 23 (1985)

4 W Lucha, Comments Nucl Part Phys **16**, 155 (1986)

5 M Goldhaber et al , in *Proceedings XXIII International Conference on High Energy Physics*, Berkeley, 1986, ed S C Loken (World Scientific, Singapore, 1986), p 248

Table I Approximate ranges of the branching ratios

$$BR(X \to \ell + M) = \frac{\Gamma(X \to \ell + M)}{\Gamma(X \to 2\text{-body})}$$

for the two-body proton decay $p \to \ell + M$ in the minimal conventional SU(5) model This table was taken from Ref 4

Decay Mode	Branching Ratio [%]
$p \to e^+\pi^0$	31–46
$p \to e^+\eta$	0–8
$p \to e^+\rho^0$	2 18
$p \to e^+\omega$	15 29
$p \to \bar\nu_e\pi^+$	11–17
$p \to \bar\nu_e\rho^+$	1–7
$p \to \mu^+K^0$	1–20
$p \to \bar\nu_\mu K^+$	0–1

p MEAN LIFE

Test of baryon conservation See proton partial mean lives section for limits which depend on decay modes *p* = proton *n* = bound neutron

LIMIT (years)	PARTICLE	DOCUMENT ID		TECN
$>1.6\times10^{25}$	*p n*	[2 3] EVANS	77	
• • • We do not use the following data for averages fits limits etc • • •				
$>3\times10^{23}$	*p*	[3] DIX	70	CNTR
$>3\times10^{23}$	*p n*	[3 4] FLEROV	58	

[2]Mean lifetime of nucleons in ^{130}Te nuclei
[3]Converted to mean life by dividing half life by ln(2) = 0 693
[4]Mean lifetime of nucleons in ^{232}Th nuclei

$\bar p$ MEAN LIFE

LIMIT (years)	PARTICLE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
$>1.1\times10^{7}$				[5] GOLDEN	79	SPEC	$\bar p \to X$
• • • We do not use the following data for averages fits limits etc • • •							
$>0\ 08$		90	1	[6] BELL	79	CNTR	$\bar p \to e^-\pi^0$
$>3\ 7\times10^{-3}$				[7] BREGMAN	78	CNTR	$\bar p \to X$

[5]GOLDEN 79 value inferred from $\bar p/p$ ratio in cosmic rays
[6]BELL 79 stored antiprotons in ICE storage ring for 10 days
[7]BREGMAN 78 stored antiprotons in ICE storage ring at CERN 85 hours

p DECAY MODES

		Partial Mean Life (10^{30} years)	Conf Lev
τ_1	$N \to e^+$ anything	>0 6 (*n p*)	90%
τ_2	$N \to \mu^+$ anything	>12 (*n p*)	90%
τ_3	$p \to e^+\gamma$	>400	90%
τ_4	$p \to \mu^+\gamma$	>100	90%
τ_5	$n \to \nu\gamma$	>9	90%
τ_6	$N \to e^+\pi$	>31 (*n*) >250 (*p*)	90%
τ_7	$N \to \mu^+\pi$	>23 (*n*) >76 (*p*)	90%
τ_8	$N \to e^+K$	>1 3 (*n*) >80 (*p*)	90%
τ_9	$N \to \mu^+K$	>0 4 (*n*) >40 (*p*)	90%
τ_{10}	$N \to \nu\pi$	>40 (*n*) >5 8 (*p*)	90%
τ_{11}	$N \to \nu K$	>32 (*n*) >28 (*p*)	90%
τ_{12}	$p \to e^+\omega$	>40	90%
τ_{13}	$p \to \mu^+\omega$	>23	90%
τ_{14}	$N \to e^+\rho$	>14 (*n*) >17 (*p*)	90%
τ_{15}	$N \to \mu^+\rho$	>7 (*n*) >16 (*p*)	90%
τ_{16}	$p \to e^+e^+e^-$	>500	90%
τ_{17}	$p \to \mu^+\mu^+\mu^-$	>190	90%
τ_{18}	$N \to \nu K^*(892)$	>6 (*n*) >10 (*p*)	90%
τ_{19}	$N \to e^+\pi^0$ anything	>0 6 (*n p*)	90%
τ_{20}	$N \to \nu$ anything		

τ_{21}	$n \to 3\nu$	>0 0005	90%
τ_{22}	$p \to e^+\eta$	>200	90%
τ_{23}	$p \to \mu^+\eta$	>50	90%
τ_{24}	$n \to \nu\eta$	>30	90%
τ_{25}	$N \to \nu\rho$	>4 (n) >11 (p)	90%
τ_{26}	$n \to \nu\omega$	>18	90%
τ_{27}	$n \to e^+e^-\nu$	>50	90%
τ_{28}	$n \to \mu^+\mu^-\nu$	>16	90%
τ_{29}	$n \to e^-\pi^+$	>16	90%
τ_{30}	$n \to \mu^-\pi^+$	>25	90%
τ_{31}	$n \to e^-\rho^+$	>12	90%
τ_{32}	$n \to \mu^-\rho^+$	>9	90%
τ_{33}	$p \to e^+K^*(892)$	>10	90%

p PARTIAL MEAN LIVES

Mean life divided by branching fraction

Decaying particle p = proton or n = bound neutron Same event may appear under more than one partial decay mode Background estimates may be accurate to a factor of 2 Quoted limits are without background subtraction

$\tau(N \to e^+$ anything) τ_1

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	DOCUMENT ID		TECN
>0.6	p n		90	[8] LEARNED	79	RVUE

[8] The electron may be primary or secondary

$\tau(N \to \mu^+$ anything) τ_2

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>12	p n		90	2	[9,10] CHERRY	81	HOME
••• We do not use the following data for averages fits, limits etc •••							
> 1 8	p n		90		[10] COWSIK	80	CNTR
> 6	p n		90		[10] LEARNED	79	RVUE

[9] We have converted 2 possible events to 90% CL limit
[10] The muon may be primary or secondary

$\tau(p \to e^+\gamma)$ τ_3

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>360	p	0.3	90	0	HAINES	86	IMB
••• We do not use the following data for averages fits limits etc •••							
> 87	p (free)	0 2	90	0	BLEWITT	85	IMB
>360	p	0 2	90	0	BLEWITT	85	IMB
> 0 1	p		90		[11] GURR	67	CNTR

[11] We have converted half-life to 90% CL mean life

$\tau(p \to \mu^+\gamma)$ τ_4

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
> 97	p	2	90	3	HAINES	86	IMB
••• We do not use the following data for averages fits limits etc •••							
> 61	p (free)	0 2	90	0	BLEWITT	85	IMB
>280	p	0 6	90	0	BLEWITT	85	IMB
> 0 3	p		90		[12] GURR	67	CNTR

[12] We have converted half-life to 90% CL mean life

$\tau(n \to \nu\gamma)$ τ_5

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
> 9	n	60	90	73	HAINES	86	IMB
••• We do not use the following data for averages fits limits etc •••							
>11	n	19	90	28	PARK	85	IMB

$\tau(N \to e^+\pi)$ τ_6

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>250	p	0.3	90	0	HAINES	86	IMB
> 31	n	9	90	8	HAINES	86	IMB
••• We do not use the following data for averages fits, limits etc •••							
> 64	p	<0 4	90	0	ARISAKA	85	KAMI
> 26	n	<0 7	90	0	ARISAKA	85	KAMI
> 82	p (free)	0 2	90	0	BLEWITT	85	IMB
>250	p	0 2	90	0	BLEWITT	85	IMB
> 25	n	4	90	4	PARK	85	IMB
> 15	p, n		90	0	BATTISTONI	84	NUSX
> 0 5	p	0 3	90	1	[13] BARTELT	83	SOUD
> 0 5	n	0 3	90	1	[13] BARTELT	83	SOUD
> 5 8	p		90	2	[14] KRISHNA	82	KOLR
> 5 8	n		90	2	[14] KRISHNA	82	KOLR
> 0 1	n		90		[15] GURR	67	CNTR

[13] Limit based on zero events
[14] We have calculated 90% CL limit from 1 confined event
[15] We have converted half life to 90% CL mean life

$\tau(N \to \mu^+\pi)$ τ_7

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
> 76	p	1	90	2	HAINES	86	IMB
> 23	n	7	90	8	HAINES	86	IMB
••• We do not use the following data for averages fits limits etc •••							
> 46	p	<0 7	90	0	ARISAKA	85	KAMI
> 20	n	<0 4	90	0	ARISAKA	85	KAMI
> 59	p (free)	0 2	90	0	BLEWITT	85	IMB
>100	p	0 4	90	1	BLEWITT	85	IMB
> 38	n	4	90	1	PARK	85	IMB
> 10	p n		90	0	BATTISTONI	84	NUSX
> 1 3	p n		90	0	ALEKSEEV	81	BAKS

$\tau(N \to e^+K)$ τ_8

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>77	p	4.5	90	5	HAINES	86	IMB
> 1.3	n		90	0	ALEKSEEV	81	BAKS
••• We do not use the following data for averages, fits limits etc •••							
>38	p	<0 8	90	0	ARISAKA	85	KAMI
>24	p (free)	8 5	90	7	BLEWITT	85	IMB
>77	p	4	90	5	BLEWITT	85	IMB
> 1 3	p		90	0	ALEKSEEV	81	BAKS

$\tau(N \to \mu^+K)$ τ_9

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>40	p	6	90	7	HAINES	86	IMB
> 0.4	n		90	0	[16] BARTELT	83	SOUD
••• We do not use the following data for averages fits limits etc •••							
>19	p	<1 1	90	1	ARISAKA	85	KAMI
> 6 7	p (free)	13	90	11	BLEWITT	85	IMB
>40	p	8	90	7	BLEWITT	85	IMB
> 6	p		90	1	BATTISTONI	84	NUSX
> 0 6	p		90	0	[16] BARTELT	83	SOUD
> 5 8	p		90	2	[17] KRISHNA	82	KOLR
> 2 0	p		90	0	CHERRY	81	HOME
> 0.2	n		90		[18] GURR	67	CNTR

[16] Limit based on zero events
[17] We have calculated 90% CL limit from 1 confined event
[18] We have converted half-life to 90% CL mean life

$\tau(N \to \nu\pi)$ τ_{10}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>40	n	1	90	0	KAJITA	86	KAMI
> 5.8	p		90	1	[19] KRISHNA	82	KOLR
••• We do not use the following data for averages fits limits etc •••							
> 6	n	60	90	73	HAINES	86	IMB
> 2	p	13	90	16	KAJITA	86	KAMI
> 7	n	19	90	28	PARK	85	IMB
> 7	n		90	0	BATTISTONI	84	NUSX
> 2	p		90	≤3	BATTISTONI	84	NUSX
> 0 3	p		90	2	[20] CHERRY	81	HOME
> 0 1	p		90		[21] GURR	67	CNTR

[19] We have calculated 90% CL limit from 1 confined event
[20] We have converted 2 possible events to 90% CL limit
[21] We have converted half-life to 90% CL mean life

$\tau(N \to \nu K)$ τ_{11}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>28	p	3	90	3	KAJITA	86	KAMI
>32	n	1.4	90	0	KAJITA	86	KAMI
••• We do not use the following data for averages fits limits etc •••							
>10	p	5	90	6	HAINES	86	IMB
>15	n	5	90	3	HAINES	86	IMB
> 1 8	p (free)	11	90	6	BLEWITT	85	IMB
> 9 6	p	5	90	6	BLEWITT	85	IMB
>10	n	2	90	2	PARK	85	IMB
> 5	n		90	0	BATTISTONI	84	NUSX
> 2	p		90	0	BATTISTONI	84	NUSX
> 0 3	n		90	0	[22] BARTELT	83	SOUD
> 0 1	p		90	0	[22] BARTELT	83	SOUD
> 5 8	p		90	1	[23] KRISHNA	82	KOLR
> 0 3	p		90	2	[24] CHERRY	81	HOME

[22] Limit based on zero events
[23] We have calculated 90% CL limit from 1 confined event
[24] We have converted 2 possible events to 90% CL limit

$\tau(p \to e^+\omega)$ τ_{12}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>37	p	5 3	90	6	HAINES	86	IMB
••• We do not use the following data for averages fits limits etc •••							
>25	p	<1 4	90	1	ARISAKA	85	KAMI
>12	p (free)	7 5	90	6	BLEWITT	85	IMB
>37	p	5 7	90	6	BLEWITT	85	IMB
> 0 6	p	0 3	90	1	[25] BARTELT	83	SOUD
> 9 8	p		90	1	[26] KRISHNA	82	KOLR
> 2 8	p		90	2	[27] CHERRY	81	HOME

[25] Limit based on zero events
[26] We have calculated 90% CL limit from 0 confined events
[27] We have converted 2 possible events to 90% CL limit

$\tau(p \to \mu^+\omega)$ — τ_{13}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>23	p	1	90	2	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
> 6 5	p (free)	8 7	90	9	BLEWITT	85	IMB
>23	p	7	90	8	BLEWITT	85	IMB

$\tau(N \to e^+\rho)$ — τ_{14}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>17	p	7	90	7	HAINES	86	IMB
>14	n	4	90	9	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
>12	p	<1 2	90	0	ARISAKA	85	KAMI
> 6	n	<1	90	2	ARISAKA	85	KAMI
> 6 7	p (free)	6	90	6	BLEWITT	85	IMB
>17	p	7	90	7	BLEWITT	85	IMB
>12	n	2	90	4	PARK	85	IMB
> 0 6	n	0 3	90	1	[28] BARTELT	83	SOUD
> 0 5	p	0 3	90	1	[28] BARTELT	83	SOUD
> 9 8	p		90	1	[29] KRISHNA	82	KOLR
> 0 8	p		90	2	[30] CHERRY	81	HOME

[28] Limit based on zero events

[29] We have calculated 90% CL limit from 0 confined events

[30] We have converted 2 possible events to 90% CL limit

$\tau(N \to \mu^+\rho)$ — τ_{15}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>16	p	4.5	90	4	HAINES	86	IMB
> 7	n	5	90	6	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
>12	p	<0.7	90	0	ARISAKA	85	KAMI
> 5	n	<1 2	90	1	ARISAKA	85	KAMI
> 5 5	p (free)	5	90	4	BLEWITT	85	IMB
>16	p	5	90	4	BLEWITT	85	IMB
> 9	n	2	90	1	PARK	85	IMB

$\tau(p \to e^+e^+e^-)$ — τ_{16}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>510	p	0.3	90	0	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
> 89	p (free)	0 5	90	0	BLEWITT	85	IMB
>510	p	0 7	90	0	BLEWITT	85	IMB

$\tau(p \to \mu^+\mu^+\mu^-)$ — τ_{17}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>190	p	0.1	90	1	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
> 44	p (free)	0 7	90	1	BLEWITT	85	IMB
>190	p	0 9	90	1	BLEWITT	85	IMB
> 2 1	p		90	1	[31] BATTISTONI	82	NUSX

[31] We have converted 1 possible event to 90% CL limit

$\tau(N \to \nu K^*(892))$ — τ_{18}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>10	p	6	90	7	HAINES	86	IMB
> 6	n	1.6	90	2	KAJITA	86	KAMI
• • • We do not use the following data for averages fits limits etc • • •							
> 5	n	7	90	8	HAINES	86	IMB
> 8	p	2	90	3	KAJITA	86	KAMI
> 5 8	p (free)	16	90	10	BLEWITT	85	IMB
> 9 6	p	6	90	7	BLEWITT	85	IMB
> 7	n	4	90	1	PARK	85	IMB
> 2 1	p		90	1	[32] BATTISTONI	82	NUSX

[32] We have converted 1 possible event to 90% CL limit

$\tau(N \to e^+\pi^0$ anything) — τ_{19}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>0 6	p n		90	0	LEARNED	79	RVUE

$\tau(N \to \nu$ anything) — τ_{20}

Anything = π, ρ, K etc

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits etc • • •							
>0 0002	p n		90	0	LEARNED	79	RVUE

$\tau(n \to 3\nu)$ — τ_{21}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>0.0005	n		90	0	LEARNED	79	RVUE

$\tau(p \to e^+\eta)$ — τ_{22}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>200	p	3.3	90	5	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
> 64	p	<0 8	90	0	ARISAKA	85	KAMI
> 64	p (free)	6 5	90	5	BLEWITT	85	IMB
>200	p	4 7	90	5	BLEWITT	85	IMB
> 1 2	p		90	2	[33] CHERRY	81	HOME

[33] We have converted 2 possible events to 90% CL limit

$\tau(p \to \mu^+\eta)$ — τ_{23}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>46	p	6	90	7	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
>26	p	<0 8	90	1	ARISAKA	85	KAMI
>17	p (free)	6	90	6	BLEWITT	85	IMB
>46	p	8	90	7	BLEWITT	85	IMB

$\tau(n \to \nu\eta)$ — τ_{24}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>30	n	0.4	90	0	KAJITA	86	KAMI
• • • We do not use the following data for averages fits limits etc • • •							
>25	n	6	90	7	HAINES	86	IMB
>18	n	3	90	4	PARK	85	IMB
> 0 6	n		90	2	[34] CHERRY	81	HOME

[34] We have converted 2 possible events to 90% CL limit

$\tau(N \to \nu\rho)$ — τ_{25}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>11	p	1	90	2	KAJITA	86	KAMI
> 4	n	2	90	2	KAJITA	86	KAMI
• • • We do not use the following data for averages fits limits etc • • •							
> 8	p	5	90	6	HAINES	86	IMB
> 2	n	10	90	15	HAINES	86	IMB
> 4 1	p (free)	7	90	6	BLEWITT	85	IMB
> 8 4	p	5	90	6	BLEWITT	85	IMB
> 2	n	3	90	7	PARK	85	IMB
> 0 9	p		90	2	[35] CHERRY	81	HOME
> 0 6	n		90	2	[35] CHERRY	81	HOME

[35] We have converted 2 possible events to 90% CL limit

$\tau(n \to \nu\omega)$ — τ_{26}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>18	n	2	90	2	KAJITA	86	KAMI
• • • We do not use the following data for averages fits limits etc • • •							
>12	n	6	90	6	HAINES	86	IMB
>16	n	2	90	1	PARK	85	IMB
> 2 0	n		90	2	[36] CHERRY	81	HOME

[36] We have converted 2 possible events to 90% CL limit

$\tau(n \to e^+e^-\nu)$ — τ_{27}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>45	n	5	90	5	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
>26	n	3	90	4	PARK	85	IMB

$\tau(n \to \mu^+\mu^-\nu)$ — τ_{28}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>16	n	7	90	14	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
>19	n	7	90	4	PARK	85	IMB

$\tau(n \to e^-\pi^+)$ — τ_{29}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>16	n	7	90	9	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
>25	n	4	90	2	PARK	85	IMB

$\tau(n \to \mu^-\pi^+)$ — τ_{30}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>25	n	6	90	7	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
>27	n	3	90	2	PARK	85	IMB

$\tau(n \to e^-\rho^+)$ — τ_{31}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>12	n	6	90	13	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
>12	n	3	90	5	PARK	85	IMB

$\tau(n \to \mu^- \rho^+)$ — τ_{32}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>9	n	5	90	7	HAINES	86	IMB
• • • We do not use the following data for averages fits limits etc • • •							
>9	n	2	90	2	PARK	85	IMB

$\tau(N \to 2$ bodies, ν-free) — $(\tau_6+\tau_7+\tau_8+\tau_9)$

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •							
>1 3	p n		90	0	ALEKSEEV	81	BAKS

$\tau(p \to e^+ K^*(892))$ — τ_{33}

LIMIT (10^{30} years)	PARTICLE	BACKGROUND ESTIMATE	CL%	EVTS	DOCUMENT ID		TECN
>10	p	<1	90	1	ARISAKA	85	KAMI

p MAGNETIC MOMENT

See the Note on Baryon Magnetic Moments in the Λ Listings

VALUE (μ_N)	DOCUMENT ID		TECN	COMMENT
2.792847386 ± 0.000000063	COHEN	87	RVUE	1986 CODATA value
• • • We do not use the following data for averages fits limits etc • • •				
2 7928456 ± 0 0000011	COHEN	73	RVUE	1973 CODATA value

$\bar{p}$ MAGNETIC MOMENT

A few early results have been omitted

VALUE (μ_N)	DOCUMENT ID		TECN	COMMENT
−2.795 ± 0.019 OUR AVERAGE				
−2 817 ± 0 048	ROBERTS	78	CNTR	
−2 791 ± 0 021	HU	75	CNTR	Exotic atoms

p ELECTRIC DIPOLE MOMENT

A nonzero value is forbidden by both T invariance and P invariance

VALUE (10^{-21} e-cm)	EVTS	DOCUMENT ID		TECN	COMMENT
9 ± 14		[37] WILKENING	84		
• • • We do not use the following data for averages fits limits etc • • •					
< 4		DZUBA	85	THEO	Uses ^{129}Xe moment
1 3 ± 2 0		[38] WILKENING	84		
<550		KHRIPLOVICH	76		
7 ± 9	1G	HARRISON	69	MBR	Molecular beam

[37] This WILKENING 84 value is more cautious than the other and excludes the finite-size effect which relies on uncertain nuclear integrals

[38] This WILKENING 84 value includes a finite size effect and a magnetic effect

$|q_p+q_e|$ CHARGE MAGNITUDE DIFFERENCE

See DYLLA 73 for a summary of experiments on the neutrality of matter See also n CHARGE in the neutron Listings

VALUE (10^{-21}e)	DOCUMENT ID		COMMENT
<1.0	[39] DYLLA	73	Neutrality of SF_6
• • • We do not use the following data for averages fits limits etc • • •			
<0 8	MARINELLI	84	Magnetic levitation

[39] Assumes that $q_n = q_p+q_e$

REFERENCES FOR p

COHEN	87	RMP 59 1121	+Taylor	(RISC NBS)
HAINES	86	PRL 57 1986	+Bionta Blewitt Bratton Casper Claus+	(IMB C)
KAJITA	86	JPSJ 55 711	+Arisaka Koshiba Nakahata+	(Kamiokande C)
ARISAKA	85	JPSJ 54 3213	+Kajita Koshiba Nakahata+	(Kamiokande C)
BLEWITT	85	PRL 55 2114	+LoSecco Bionta Bratton+	(IMB Collab)
DZUBA	85	PL 154B 93	+Flambaum Silvestrov	(NOVO)
PARK	85	PRL 54 22	+Blewitt Cortez Foster+	(IMB Collab)
BATTISTONI	84	PL 133B 454	+Bellotti Bologna Campana+	(NUSEX Collab)
MARINELLI	84	PL 137B 439	+Morpurgo	(GENO)
WILKENING	84	PR A29 425	+Ramsey Larson	(HARV VIRG)
BARTELT	83	PRL 50 651	+Courant Heller Joyce Marshak+	(MINN ANL)
BATTISTONI	82	PL 118B 461	+Bellotti Bologna Campana+	(NUSEX Collab)
KRISHNA	82	PL 115B 349	Krishnaswamy Menon+	(TATA OSKC TOKY)
ALEKSEEV	81	JETPL 33 651	+Bakatanov Butkevich Voevodskii+	(LENI)
		Translated from ZETFP 33 664		
CHERRY	81	PRL 47 1507	+Deakyne Lande Lee Steinberg+	(PENN BNL)
COWSIK	80	PR D22 2204	+Narasimhan	(TATA)
BELL	79	PL 86B 215	+Calvetti Carron Chaney Cittolin+	(CERN)
GOLDEN	79	PRL 43 1196	+Horan Mauger Badhwar Lacy+	(NASA PSLL)
LEARNED	79	PRL 43 907	+Reines Soni	(UCI)
BREGMAN	78	PL 78B 174	+Calvetti Carron Cittolin Hauer Herr+	(CERN)
ROBERTS	78	PR D17 358		(WILL RHEL)
EVANS	77	Science 197 989	+Steinberg	(BNL PENN)
ROBERSON	77	PR C16 1945	+King Kunselman+	(WYOM CIT CMU VPI WILL)
KHRIPLOVICH	76	JETP 44 25		(SIBE)
		Translated from ZETF 71 51		
HU	75	NP A254 403	+Asano Chen Cheng Dugan+	(COLU YALE)
COHEN	73	JPCRD 2 663	+Taylor	(RISC NBS)
DYLLA	73	PR A7 1224	+King	(MIT)
BAMBERGER	70	PL 33B 233	+Lynen Piekarz+	(MPIH CERN KARL)
DIX	70	Case Thesis		(CASE)
HARRISON	69	PRL 22 1263	+Sandars Wright	(OXF)
GURR	67	PR 158 1321	+Kropp Reines Meyer	(CASE WITW)
FLEROV	58	DOKL 3 79	+Klochkov Skobkin Terentiev	(USSR)

OTHER RELATED PAPERS

MAMYRIN	83	JETP 57 1152	+Aruev Alekseenko	(IOFF)
		Translated from ZETF 84 1980		
FRANKLIN	77	PR D16 910		(HAIF) P
KALOGERO	76	PRL 37 1037	Kalogeropoulos Chiu Sudarshan	(SYRA TEXA) P

n

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

We have omitted some results that have been superseded by later experiments The omitted results may be found in our 1986 edition (Physics Letters **170B**) or in earlier editions

n MASS

The mass is known much more precisely in u (atomic mass units) than in MeV (see the footnotes) The conversion from u to MeV 1 u = 931 49432 ± 0 00028 MeV involves the relatively poorly known electronic charge

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
939.56563 ± 0.00028	[1] COHEN	87	RVUE	1986 CODATA value
• • • We do not use the following data for averages fits limits etc • • •				
939 56564 ± 0 00028	[2,3] GREENE	86	SPEC	$np \to d\gamma$
939 5731 ± 0 0027	[3] COHEN	73	RVUE	1973 CODATA value

[1] The mass is known much more precisely in u m = 1 008664904 ± 0 000000014 u

[2] The mass is known much more precisely in u m = 1 008664919 ± 0 000000014 u

[3] These determinations are not independent of the $n-p$ mass difference measurements below

$\bar{n}$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
939.485 ± 0.051	59	[4] CRESTI	86	HBC	$\bar{p}p \to \bar{n}n$

[4] This is a corrected result (see the erratum) The error is statistical The maximum systematic error is 0 029 MeV

n − p MASS DIFFERENCE

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1 293318 ± 0.000009	[5] COHEN	87	RVUE	1986 CODATA value
• • • We do not use the following data for averages fits limits etc • • •				
1 2933328 ± 0 0000072	GREENE	86	SPEC	$np \to d\gamma$
1 293429 ± 0 000036	COHEN	73	RVUE	1973 CODATA value

[5] Calculated by us from the COHEN 87 ratio $m(n)/m(p)$ = 1 001378404 ± 0 000000009

n MEAN LIFE

Limits on lifetimes for bound neutrons are given in the proton partial mean-lives section

VALUE (sec)	DOCUMENT ID		TECN	COMMENT
896 ± 10 OUR AVERAGE	Error includes scale factor of 1 8 See the ideogram below			
876 ± 10 ± 19	LAST	88	SPEC	Pulsed beam
903 ± 13	KOSVINTSEV	86	CNTR	Ultracold neutrons
937 ± 18	BYRNE	80	CNTR	
881 ± 8	[6] BONDAREN	78	CNTR	
918 ± 14	CHRISTENSEN	72	CNTR	

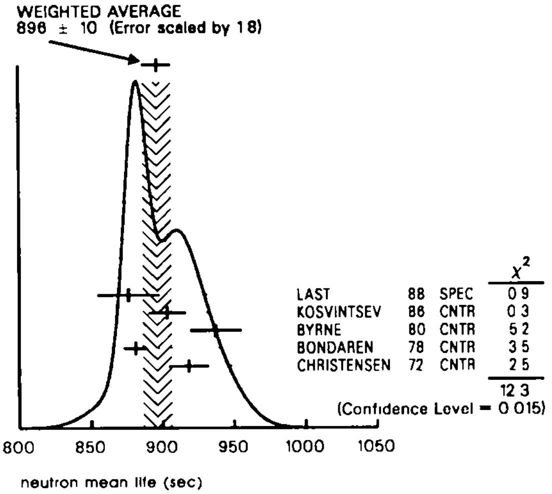
• • • We do not use the following data for averages fits limits etc • • •

898 ± 6	[7] BOPP	86	SPEC	Inferred value
902 ± 10	[8] WILKINSON	82	RVUE	Inferred value
875 ± 95	KOSVINTSEV	80	CNTR	

[6] Includes correction for recoil proton scattering see BONDARENKO 82

[7] The BOPP 86 value is inferred from their g_A/g_V measurement and independent measurement of g_V

[8] The WILKINSON 82 value is inferred from n decay correlations



n MAGNETIC MOMENT

VALUE (μ_N)	DOCUMENT ID		TECN	COMMENT
−1.91304275 ± 0.00000045	COHEN	87	RVUE	1986 CODATA value
• • • We do not use the following data for averages fits limits etc • • •				
−1 91304308 ± 0 00000054	[9] GREENE	82	MRS	

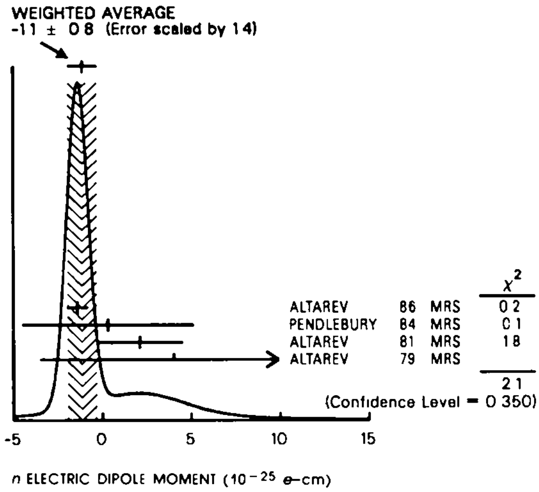
[9] GREENE 82 measures the moment in Bohr magnetons to be (1 04187564 ± 0 00000026) × 10^{-3} The value above is obtained by multiplying by $m(p)/m(e)$ = 1836 153000 (which is not the most recent result)

n ELECTRIC DIPOLE MOMENT

A nonzero value is forbidden by both T invariance and P invariance See RAMSEY 82B for a review A number of early results have been omitted

VALUE (10^{-25} e-cm)	DOCUMENT ID		TECN	COMMENT
−1.1 ± 0.8 OUR AVERAGE	Error includes scale factor of 1 4 See the ideogram below			
−1.4 ± 0.6	[10] ALTAREV	86	MRS	< 2 6 × 10^{-25} 95% CL
0 3 ± 4 8	PENDLEBURY	84	MRS	Ultracold neutrons
2 1 ± 2 4	[10] ALTAREV	81	MRS	< 6 × 10^{-25} 90% CL
4 0 ± 7 5	[10] ALTAREV	79	MRS	< 1 6 × 10^{-24} 90% CL

[10] ALTAREV 79, ALTAREV 81 and ALTAREV 86 use ultracold neutrons



n CHARGE

See also "$|q_p + q_e|$ CHARGE MAGNITUDE DIFFERENCE" in the proton Listings

VALUE (units 10^{-20} e)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc • • •				
−1 5 ± 2 2	[11] GAHLER	82	CNTR	Reactor neutrons

[11] The error ± 2 2 gives the 90% CL limits about the the value − 1 5

LIMIT ON $n\bar{n}$ OSCILLATIONS

MEAN TIME FOR $n\bar{n}$ TRANSITION IN VACUUM

Test of baryon conservation Limits are derived from experimental limits on ΔB = 2 nuclear decay processes using theoretical assumptions for nuclear physics effects See also the theoretical analysis in DOVER 83 See the reviews in ANDERSON 81 on nuclear particle physics at energies up to 31 GeV

VALUE (sec)	CL%	DOCUMENT ID		TECN	COMMENT
> 1.2 × 10^8	90	TAKITA	86	CNTR	Kamiokande
• • • We do not use the following data for averages, fits limits, etc • • •					
> 1 × 10^6	90	FIDECARO	85	CNTR	Reactor neutrons
> 8 8 × 10^7	90	PARK	85B	CNTR	
> 3 × 10^7		BATTISTONI	84	NUSX	
> 2.7 × 10^7 − 1.1 × 10^8		JONES	84	CNTR	
> 2 × 10^7		CHERRY	83	CNTR	
> 3 × 10^7		ALBERICO	82	THEO	
> 1 × 10^8		CHETYRKIN	81	THEO	
> 5 × 10^7	90	COWSIK	81	THEO	

n DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$n \rightarrow p e^- \bar{\nu}_e$	1
Γ_2	$n \rightarrow p \nu_e \bar{\nu}_e$	0

n BRANCHING RATIOS

$\Gamma(p\nu_e\bar{\nu}_e)/\Gamma(pe^-\bar{\nu}_e)$ Γ_2/Γ_1

Forbidden by charge conservation

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 9 × 10^{-24}	90	BARABANOV	80	CNTR	$^{71}Ga \rightarrow {}^{71}Ge$ X
• • • We do not use the following data for averages fits limits etc • • •					
< 9 7 × 10^{-18}	90	ROY	83	CNTR	$^{113}Cd \rightarrow {}^{113m}In$ neut
< 7 9 × 10^{-21}		VAIDYA	83	CNTR	$^{87}Rb \rightarrow {}^{87m}Sr$ neut
< 3 × 10^{-19}		NORMAN	79	CNTR	$^{87}Rb \rightarrow {}^{87m}Sr$ neut

NOTE ON BARYON DECAY PARAMETERS

(by E D Commins, University of California Berkeley)

Baryon semileptonic decays

The typical baryon semileptonic decay is described by a matrix element the hadronic part of which may be written as

$$\bar{B}_f \left[f_1(q^2)\gamma_\lambda + i f_2(q^2)\sigma_{\lambda\mu}q^\mu + g_1(q^2)\gamma_\lambda\gamma_5 + g_3(q^2)\gamma_5 q_\lambda \right] B_i$$

Here B_i and B_f are spinors describing the initial and final baryons while the terms in f_1, f_2, g_1 and g_3 account for vector, induced tensor ("weak magnetism"), axial vector, and induced pseudoscalar contributions respectively.[1] Second-class current contributions are ignored here. In the limit of zero momentum transfer, f_1 reduces to the vector coupling constant g_V and g_1 reduces to the axial-vector coupling constant g_A. The latter coefficients are related by Cabibbo's theory[2] generalized to six quarks (and three mixing angles) by Kobayashi and Maskawa.[3] The g_3 term is negligible for transitions in which an $e^{\pm}$ is emitted, and gives a very small correction, which can be estimated by PCAC,[4] for $\mu^{\pm}$ modes. Recoil effects include weak magnetism, and are taken into account adequately by considering terms of first order in

$$\delta = (m_i - m_f)/(m_i + m_f)\,,$$

where m_i and m_f are the masses of the initial and final baryons.

The experimental quantities of interest are the total decay rate, the lepton-neutrino angular correlation, the asymmetry coefficients in the decay of a polarized initial baryon, and the polarization of the decay baryon in its own rest frame for an unpolarized initial baryon. Formulae for these quantities are derived by standard means[5] and are analogous to similar formulae for beta decay.[6] For comparison with high-precision experiments, it is necessary to modify the form factors at $q^2 = 0$ by a "dipole" q^2 dependence, and also to apply appropriate radiative corrections.[7]

The ratio g_A/g_V may be written as

$$g_A/g_V = |g_A/g_V|\, e^{i\phi_{AV}}\,.$$

The presence of a "triple correlation" term in the transition probability proportional to $\mathrm{Im}(g_A/g_V)$ and of the form

$$\boldsymbol{\sigma}_i\cdot(\mathbf{p}_\ell\times\mathbf{p}_\nu)$$

for initial baryon polarization or

$$\boldsymbol{\sigma}_f\cdot(\mathbf{p}_\ell\times\mathbf{p}_\nu)$$

for final baryon polarization would indicate failure of time-reversal invariance. The phase angle ϕ has been measured precisely only in neutron decay (and in ^{19}Ne nuclear beta decay), and the results are consistent with T invariance.

The amplitude for the decay

$$\Sigma^- \to \Lambda e^- \overline{\nu}_e$$

is of special interest because it is predicted by the strong form of CVC, and is not sensitive to the assumptions concerning SU(3) that enter into Cabibbo's predictions for the other hyperon semileptonic decays. The decay

$$\Sigma^0 \to \Lambda\gamma$$

(the isospin-rotation analogue of $\Sigma^- \to \Lambda e^- \overline{\nu}$) is mediated by the electromagnetic interaction and is an M1 transition, assuming that there are no inhomogeneities in the charge distributions of the Σ^0 and Λ.

Hyperon nonleptonic decays

The most general decay amplitude for $J^P = 1/2^+$ hyperons may be written in the form

$$M = G_F m_\pi^2\, \overline{B}_f (A - B\gamma_5) B_i\,,$$

where A and B are constants.[1] Then the transition rate is proportional to

$$R = 1 + \gamma\hat{\omega}_f\cdot\hat{\omega}_i + (1-\gamma)(\hat{\omega}_f\cdot\hat{\mathbf{n}})(\hat{\omega}_i\cdot\hat{\mathbf{n}}) + \alpha(\hat{\omega}_f\cdot\hat{\mathbf{n}} + \hat{\omega}_i\cdot\hat{\mathbf{n}}) + \beta\hat{\mathbf{n}}\cdot(\hat{\omega}_f\times\hat{\omega}_i)\,,$$

where $\hat{\mathbf{n}}$ is a unit vector in the direction of the final baryon momentum, and $\hat{\omega}_i$ and $\hat{\omega}_f$ are unit vectors in the directions of the initial and final baryon spins. Also,

$$\alpha = 2\,\mathrm{Re}(s^*p)/(|s|^2 + |p|^2)\,,$$

$$\beta = 2\,\mathrm{Im}(s^*p)/(|s|^2 + |p|^2)\,,$$

and

$$\gamma = (|s|^2 - |p|^2)/(|s|^2 + |p|^2)\,,$$

where $s = A$, and $p = |\mathbf{p}_f|B/(E_f + m_f)$; here E_f and $\mathbf{p}_f$ are the energy and momentum of the final baryon. The parameters α, β and γ satisfy

$$\alpha^2 + \beta^2 + \gamma^2 = 1\,.$$

An additional parameter ϕ is defined by

$$\beta = (1-\alpha^2)^{1/2}\sin\phi\,.$$

In the Listings, we compile α and ϕ for each decay, since these quantities are most closely related to experiment and are essentially uncorrelated. When necessary, we have changed the signs of reported values to agree with our sign conventions. In the Stable Particle Summary Table, we give α, ϕ, and Δ (defined below) with errors, and also give the value of γ without error.

Time-reversal invariance requires, in the absence of final-state interaction, that s and p be relatively real, and therefore that $\beta = 0$. However, for the decays discussed here, the final-state interaction is strong. Thus

$$s = |s|\,e^{i\delta_s} \text{ and } p = |p|\,e^{i\delta_p}\,,$$

where δ_s and δ_p are the pion-baryon s- and p-wave strong interaction phase shifts. We then have

$$\beta = \frac{-2|s||p|}{|s|^2 + |p|^2}\sin(\delta_s - \delta_p)\,.$$

One also defines $\Delta = -\tan^{-1}(\beta/\alpha)$. If T invariance holds, $\Delta = \delta_s - \delta_p$. For $\Lambda \to p\pi^-$ decay, the value of Δ may be compared with the s- and p-wave phase shifts in low-energy $\pi^- p$ scattering, and the results are consistent with T invariance

References

1 E D Commins and P H Bucksbaum, *Weak Interactions of Leptons and Quarks* (Cambridge University Press, Cambridge England, 1983)

2. N Cabibbo, Phys Rev Lett **10**, 531 (1963)

3 M Kobayashi and T Maskawa Progr Theor Phys **49** 652 (1973)

4 M L Goldberger and S B Treiman, Phys Rev **111** 354 (1958)

5 P H Frampton and W K Tung, Phys Rev **D3**, 1114 (1971)

6 J D Jackson S B Treiman, and H W Wyld Jr, Phys Rev **106** 517 (1957), and Nucl Phys **4** 206 (1957)

7 Y Yokoo, S Suzuki, and M Morita, Progr Theor Phys **50** 1894 (1973)

$n \to p e^- \nu$ DECAY PARAMETERS

See the above Note on Baryon Decay Parameters

g_A/g_V

VALUE	DOCUMENT ID		TECN	COMMENT
−1.259 ± 0.004 OUR AVERAGE				
−1.262 ± 0.005	BOPP	86	SPEC	e mom n spin corr
−1 226 ± 0 042	MOSTOVOY	83	RVUE	
−1 261 ± 0 012	[12] EROZOLIM	79	CNTR	e mom n spin corr
−1 259 ± 0 017	[12] STRATOWA	78	CNTR	proton recoil spectrum
−1 253 ± 0 021	[13] KROHN	75	CNTR	e mom n spin corr
−1.250 ± 0.009	[14] KROPF	74	RVUE	n decay + ft value
• • • We do not use the following data for averages fits limits etc • • •				
−1.263 ± 0.015	EROZOLIM	77	CNTR	See EROZOLIMSKII 79
−1 250 ± 0.036	[12] DOBROZE	75	CNTR	See STRATOWA 78
−1.263 ± 0.016	[14] KROPF	74	RVUE	n decay alone

[12] These experiments measure the absolute value of g_A/g_V only

[13] KROHN 75 gives −1 258 ± 0.015 including events of CHRISTENSEN 70 The value here is derived from the asymmetry coefficient A based on the new experiment only

[14] KROPF 74 reviews all data through 1972

ϕ, PHASE ANGLE OF g_A RELATIVE TO g_V

Time reversal invariance requires this to be 0 or 180 °

VALUE (degrees)	DOCUMENT ID		TECN	COMMENT
180.11 ± 0.17 OUR AVERAGE				
179.71 ± 0.39	EROZOLIM	78	CNTR	Polarized neutrons
180 35 ± 0.43	EROZOLIM	74	CNTR	Polarized neutrons
181 1 ± 1 3	[15] KROPF	74	RVUE	n decay
180 14 ± 0 22	STEINBERG	74	CNTR	Polarized neutrons

[15] KROPF 74 reviews all data through 1972

TRIPLE CORRELATION COEFFICIENT

These are measurements of the component of n spin perpendicular to the decay plane in β decay Should be zero if T invariance is not violated

VALUE	DOCUMENT ID		TECN	COMMENT
−0.0007 ± 0.0014 OUR AVERAGE				
+0 0022 ± 0.0030	EROZOLIM	78	CNTR	Polarized neutrons
−0.0027 ± 0.0050	[16] EROZOLIM	74	CNTR	Polarized neutrons
−0.0011 ± 0.0017	STEINBERG	74	CNTR	Polarized neutrons
−0.01 ± 0 01	EROZOLIM	70B	CNTR	Polarized neutrons

[16] EROZOLIMSKII 78 says asymmetric proton losses and nonuniform beam polarization may give a systematic error up to 0 003, thus increasing the EROZOLIMSKII 74 error to 0 005 STEINBERG 74 and STEINBERG 76 estimate these systematic errors to be insignificant in their experiment

REFERENCES FOR n

We have omitted some papers that have been superseded by later experiments The omitted papers may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

LAST 88 PRL 60 995 +Arnold Doehner Dubbers+ (HEID ILLG ANL)
COHEN 87 RMP 59 1121 +Taylor (RISC NBS)
ALTAREV 86 JETPL 44 460 +Borisov Borovikova Brandin Egorov+ (LENI)
Translated from ZETFP 44 357
BOPP 86 PRL 56 919 +Dubbers Hornig Klemt Last+ (HEID ANL ILLG)
Also 88 ZPHY C37 179 Klemt Bopp Hornig Last+ (HEID ANL ILLG)
CRESTI 86 PL B177 206 +Pasquali Peruzzo Pinori Sartori (PADO)
Also 88 PL B200 587 Cresti Pasquali Peruzzo Pinori Sartori (PADO)
Erratum
GREENE 86 PRL 56 819 +Kessler Deslattes Boerner (NBS ILLG)
KOSVINTSEV 86 JETPL 44 571 +Morozov Terekhov (KIAE)
Translated from ZETFP 44 444
TAKITA 86 PR D34 902 +Arisaka Kajita Kifune Koshiba+ (KEK TOKY)
FIDECARO 85 PL 156B 122 +Lanceri+ (CERN ILLG PADO RAL SUSS)
PARK 85B NP B252 261 +Blewitt Cortez Foster+ (IMB Collab)
BATTISTONI 84 PL 133B 454 +Bellotti Bologna Campana+ (NUSEX Collab)
JONES 84 PRL 52 720 +Bionta Blewitt Bratton+ (IMB Collab)
PENDLEBURY 84 PL 136B 327 +Smith Golub Byrne+ (SUSS HARV RAL ILLG)
CHERRY 83 PRL 50 1354 +Lande Lee Steinberg Cleveland (PENN BNL)
DOVER 83 PR D27 1090 +Gal Richards (BNL)
MOSTOVOY 83 JETPL 37 196 (KIAE)
Translated from ZETFP 37 162
ROY 83 PR D28 1770 +Vaidya Ephraim Datar Bhatki+ (TATA)
VAIDYA 83 PR D27 486 +Roy Ephraim Datar Bhattacherjee (TATA)
ALBERICO 82 PL 114B 266 +Bottino Molinari (CERN TORI)
BONDAREN 82 Smolenice Conf Bondarenko (KIAE)
GAHLER 82 PR D25 2887 +Kalus Mampe (BAYR ILLG)
GREENE 82 Metrologia 18 93 + (YALE HARV ILLG SUSS ORNL CENG)
RAMSEY 82B RPP 45 95 (HARV)
WILKINSON 82 NP A377 474 (SUSS BNL)
ALTAREV 81 PL 102B 13 +Borisov Borovikova Brandin Egorov+ (LENI)
ANDERSON 81 LASL Conf 507
CHETYRKIN 81 PL 99B 358 +Kazarnovsky Kuzmin+ (INRM)
COWSIK 81 PL 101B 237 +Nussinov (UMD)
BARABANOV 80 JETPL 32 359 +Veretenkin Gavrin+ (LENI)
Translated from ZETFP 32 384
BYRNE 80 PL 92B 274 +Morse Smith Shaikh Green Greene (SUSS RL)
KOSVINTSEV 80 JETPL 31 236 +Kushnir Morozov Terekhov (JINR)
Translated from ZETFP 31 257
ALTAREV 79 JETPL 29 730 +Borisov Brandin Egorov Ezhov Ivanov+ (LENI)
Translated from ZETFP 29 794
EROZOLIM 79 SJNP 30 356 Erozolimskii Frank Mostovoy+ (KIAE)
Translated from YAF 30 692
NORMAN 79 PRL 43 1226 +Seamster (WASH)
BONDAREN 78 JETPL 28 303 Bondarenko Kurguzov Prokofev+ (KIAE)
Translated from ZETFP 28 328
EROZOLIM 78 SJNP 28 48 Erozolimskii Mostovoy Fedunin Frank+ (KIAE)
Translated from YAF 28 98
STRATOWA 78 PR D18 3970 +Dobrozemsky Weinzierl (SEIB)
EROZOLIM 77 JETPL 23 663 Erozolimskii Frank Mostovoy+ (KIAE)
Translated from ZETFP 23 720
STEINBERG 76 PR D13 2469 +Liaud Vignon Hughes (YALE GREN)
DOBROZE 75 PR D11 510 Dobrozemsky Kerschbaum Moraw Paul+ (SEIB)
KROHN 75 PL 55B 175 +Ringo (ANL)
EROZOLIM 74 JETPL 20 345 Erozolimskii Mostovoy Fedunin Frank+
Translated from ZETFP 20 745
KROPF 74 ZPHY 267 129 +Paul (LINZ)
Also 70 NP A154 160 Paul (VIEN)
STEINBERG 74 PRL 33 41 +Liaud Vignon Hughes (YALE GREN)
COHEN 73 JPCRD 2 663 +Taylor (RISC NBS)
CHRISTENSEN 72 PR D5 1628 +Nielson Bahnsen Brown+ (RISO)
CHRISTENSEN 70 PR C1 1693 +Krohn Ringo (ANL)
EROZOLIM 70B SJNP 11 583 Erozolimskii Bondarenko+ (KIAE)
Translated from YAF 11 1049
Also 70 PL 27B 557 Erozolimskii Bondarenko+ (KIAE)

OTHER RELATED PAPERS

BYRNE 82 RPP 45 115 (SUSS)
FRANK 82 SPU 25 280 (KIAE)

STRANGENESS −1 BARYONS

Λ

$I(J^P) = 0(\frac{1}{2}^+)$

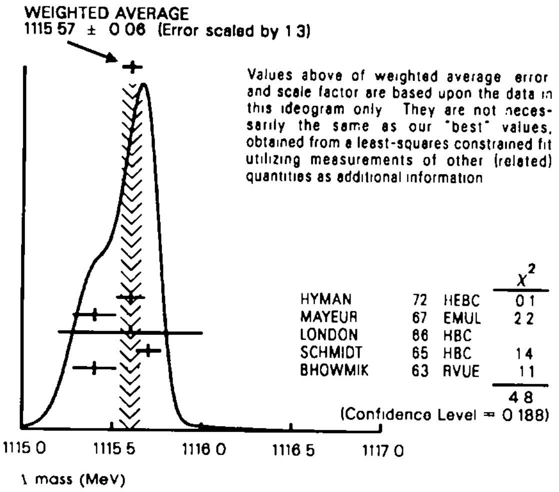
We have omitted some results that have been superseded by later experiments The omitted results may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

Λ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN
1115.63 ± 0.05	**OUR FIT**	Error includes scale factor of 1.4		
1115.57 ± 0.06	**OUR AVERAGE**	Error includes scale factor of 1.3. See the ideogram below.		
1115.59 ± 0.08	935	HYMAN	72	HEBC
1115.39 ± 0.12	195	MAYEUR	67	EMUL
1115.6 ± 0.4		LONDON	66	HBC
1115.65 ± 0.07	488	[1] SCHMIDT	65	HBC
1115.44 ± 0.12		[2] BHOWMIK	63	RVUE

[1] Since our final values for the Σ and Λ masses come from doin an overall fit to all measured masses and mass differences we have used the uncorrelated measurements from SCHMIDT 65 rather than the ones coming from the ovrall fit reported in that paper. Since there seems to be no convincing argument as to why one should ignore data using range measurements, we have included here values depending on proton and pion ranges. The SCHMIDT 65 masses have been reevaluated using our April 1973 proton and $K^{\pm}$ and $\pi^{\pm}$ masses. P. Schmidt, private communication (1974).

[2] The mass has been raised 35 keV to take into account a 46 keV increase in the proton mass and an 11 keV decrease in the $\pi^{\pm}$ mass.



Λ − $\bar{\Lambda}$ MASS DIFFERENCE

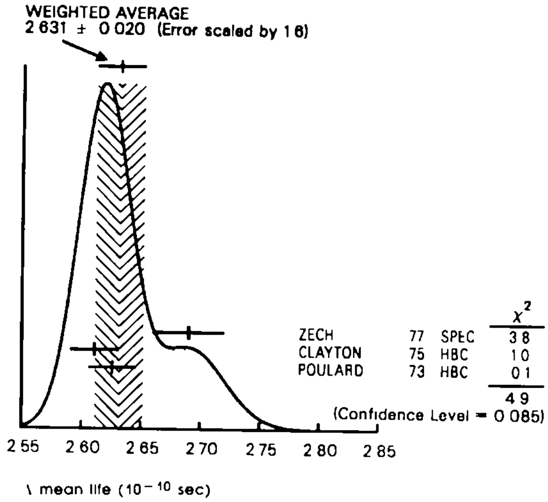
A test of *CPT*

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
0.00 ± 0.12 OUR AVERAGE	Error includes scale factor of 2.1			
−0.29 ± 0.15	BADIER	67	HBC	2.4 GeV/c $\bar{p}p$
0.05 ± 0.06	CHIEN	66	HBC	6.9 GeV/c $\bar{p}p$

Λ MEAN LIFE

Measurements with an error ≥ 0.1×10⁻¹⁰ s have been omitted and only the latest high statistics measurements are used for the average.

VALUE (10^{-10} sec)	EVTS	DOCUMENT ID		TECN	COMMENT
2.631 ± 0.020	**OUR AVERAGE**	Error includes scale factor of 1.6. See the ideogram below.			
2.69 ± 0.03	53k	ZECH	77	SPEC	Neutral hyperon beam
2.611 ± 0.020	34k	CLAYTON	75	HBC	0.96–1.4 GeV/c K^-p
2.626 ± 0.020	36k	POULARD	73	HBC	0.4–2.3 GeV/c K^-p
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.69 ± 0.05	6582	ALTHOFF	73B	OSPK	$\pi^+ n \to \Lambda K^+$
2.54 ± 0.04	4572	BALTAY	71B	HBC	K^-p at rest
2.535 ± 0.035	8342	GRIMM	68	HBC	
2.47 ± 0.08	2600	HEPP	68	HBC	
2.35 ± 0.09	916	BURAN	66	HLBC	
$2.452^{+0.056}_{-0.054}$	2213	ENGELMANN	66	HBC	
2.59 ± 0.09	794	HUBBARD	64	HBC	
2.59 ± 0.07	1378	SCHWARTZ	64	HBC	
2.36 ± 0.06	2239	BLOCK	63	HEBC	



(Λ − $\bar{\Lambda}$) / AVERAGE, MEAN LIFE DIFFERENCE

A test of *CPT*

VALUE	DOCUMENT ID		TECN	COMMENT
0.044 ± 0.085	BADIER	67	HBC	2.4 GeV/c $\bar{p}p$

NOTE ON BARYON MAGNETIC MOMENTS

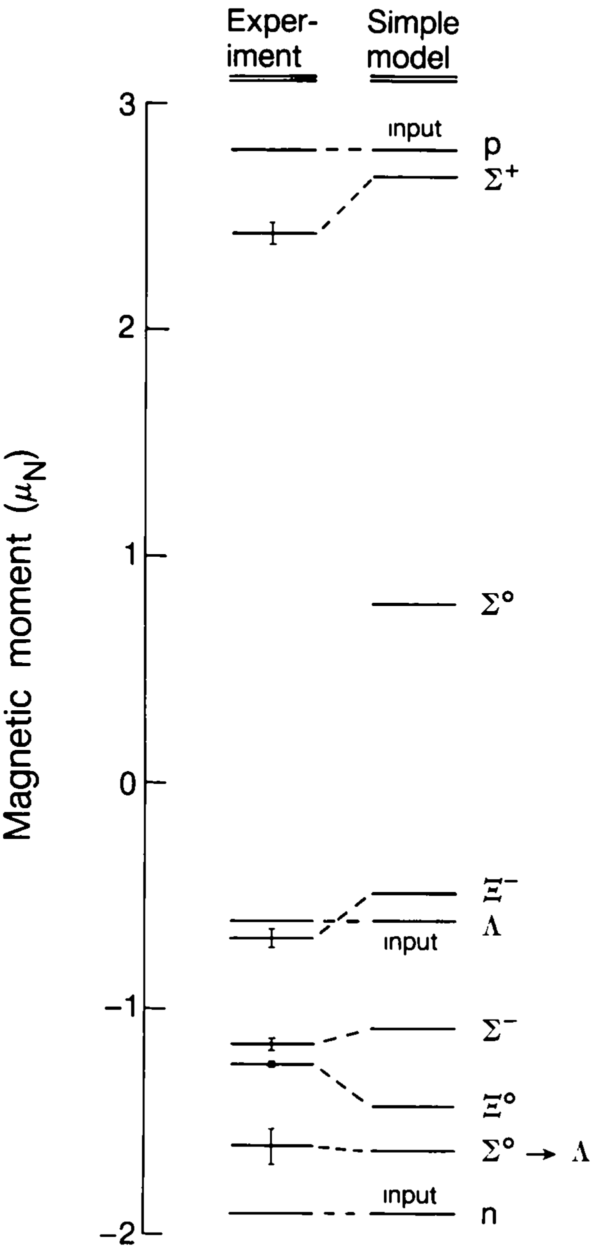
The figure shows the measured magnetic moments of the stable baryons. It also shows the predictions of the simplest quark model, using the measured p, n, and Λ moments as input. In this model, the moments are[1]

$$\mu_p = (4\mu_u - \mu_d)/3 \qquad \mu_n = (4\mu_d - \mu_u)/3$$
$$\mu_{\Sigma^+} = (4\mu_u - \mu_s)/3 \qquad \mu_{\Sigma^-} = (4\mu_d - \mu_s)/3$$
$$\mu_{\Xi^0} = (4\mu_s - \mu_u)/3 \qquad \mu_{\Xi^-} = (4\mu_s - \mu_d)/3$$
$$\mu_\Lambda = \mu_s \qquad \mu_{\Sigma^0} = (2\mu_u + 2\mu_d - \mu_s)/3$$

and the $\Sigma^0 \to \Lambda$ transition moment is

$$\mu_{\Sigma^0\Lambda} = (\mu_d - \mu_u)/\sqrt{3}$$

The quark moments that result from this simple model are $\mu_u = +1.852\mu_N$, $\mu_d = -0.972\mu_N$ and $\mu_s = -0.613\mu_N$ (the corresponding effective quark masses, taking the quarks to be Dirac point particles, where $\mu = q\hbar/2m$, are 338, 322, and 510 MeV). As the figure shows, the model gives a good first approximation to the experimental moments. For efforts to make a better model, we refer to the literature.[2]



References

1 See, for example, D H Perkins, *Introduction to High Energy Physics* (Addison-Wesley, Reading, MA, 1987), or D Griffiths, *Introduction to Elementary Particles* (Harper & Row, New York, 1987)

2 See, for example, J Franklin, Phys Rev **D29**, 2648 (1984), H J Lipkin, Nucl Phys **B241**, 477 (1984), K Suzuki, H Kumagai, and Y Tanaka, Europhys Lett **2**, 109 (1986), S K Gupta and S B Khadkikar Phys Rev **D36**, 307 (1987), M I Krivoruchenko, Sov Jour Nucl Phys **45**, 109 (1987) L Brekke and J L Rosner Comments Nucl Part Phys **18**, 83 (1988), and references cited therein

Λ MAGNETIC MOMENT

See the Note on Baryon Magnetic Moments above Measurements with an error ≥ 0.15 μ_N have been omitted

VALUE (μ_N)	EVTS	DOCUMENT ID		TECN	COMMENT
−0.613 ±0.004 OUR AVERAGE					
−0 606 ±0 015	200k	COX	81	SPEC	
−0 6138 ±0.0047	3M	SCHACHIN	78	SPEC	
−0 59 ±0 07	350k	HELLER	77	SPEC	
−0 57 ±0.05	1 2M	BUNCE	76	SPEC	
−0.66 ±0 07	1300	DAHL JENSEN	71	EMUL	200 kG field

Λ ELECTRIC DIPOLE MOMENT

A nonzero value is forbidden by both T invariance and P invariance

VALUE (10^{-16} e-cm)	CL%	DOCUMENT ID		TECN
< 1.5	95	[3] PONDROM	81	SPEC
• • • We do not use the following data for averages fits limits etc • • •				
<100	95	[4] BARONI	71	EMUL
<500	95	GIBSON	66	EMUL

[3] PONDROM 81 measures $(-3.0 \pm 7.4) \times 10^{-17}$ e-cm
[4] BARONI 71 measures $(-5.9 \pm 2.9) \times 10^{-15}$ e-cm

Λ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\Lambda \to p\pi^-$	$(64\ 1 \pm 0.5) \times 10^{-2}$
Γ_2	$\Lambda \to n\pi^0$	$(35\ 7 \pm 0\ 5) \times 10^{-2}$
Γ_3	$\Lambda \to n\gamma$	$(1\ 02 \pm 0\ 33) \times 10^{-3}$
Γ_4	$\Lambda \to p\pi^-\gamma$	$(8\ 5 \pm 1\ 4) \times 10^{-4}$
Γ_5	$\Lambda \to pe^-\nu$	$(8\ 34 \pm 0\ 14) \times 10^{-4}$
Γ_6	$\Lambda \to p\mu^-\nu$	$(1.57 \pm 0\ 35) \times 10^{-4}$

CONSTRAINED FIT INFORMATION

An overall fit to 5 branching ratios uses 24 measurements and one constraint to determine 5 parameters The overall fit has a χ^2 = 13 6 for 20 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

x_2	100			
x_3	−9	2		
x_5	46	46	4	
x_6	0	0	0	0
	x_1	x_2	x_3	x_5

Λ BRANCHING RATIOS

$\Gamma(p\pi^-)/\Gamma(N\pi)$ $\Gamma_1/(\Gamma_1+\Gamma_2)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.642 ± 0.005 OUR FIT					
0.640 ± 0.005 OUR AVERAGE					
0.646 ± 0.008	4572	BALTAY	71B	HBC	$K^- p$ at rest
0 635 ± 0 007	6736	DOYLE	69	HBC	$\pi^- p \to \Lambda K^0$
0.643 ± 0 016	903	HUMPHREY	62	HBC	
0 65 ± 0.05		COLUMBIA	60	HBC	
0 627 ± 0 031		CRAWFORD	59B	HBC	

$\Gamma(n\pi^0)/\Gamma(N\pi)$ $\Gamma_2/(\Gamma_1+\Gamma_2)$

VALUE	EVTS	DOCUMENT ID		TECN
0.358 ± 0.005 OUR FIT				
0.304 ± 0.025 OUR AVERAGE				
0.35 ± 0 05		BROWN	63	HLBC
0 291 ± 0 034	75	CHRETIEN	63	HLBC
0 28 ± 0 08		BAGLIN	60	HLBC
0.43 ± 0.14		CRAWFORD	59B	HBC
0.23 ± 0.09		EISLER	57	HLBC

$\Gamma(n\gamma)/\Gamma(n\pi^0)$ Γ_3/Γ_2

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.9 ± 0.9 OUR FIT					
2.86 ± 0.74 ± 0.57	24	BIAGI	86	SPEC	SPS hyperon beam

$\Gamma(p\pi^-\gamma)/\Gamma(p\pi^-)$ — Γ_4/Γ_1

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.32 ± 0.22	72	BAGGETT	72C	HBC	$\pi^- < 95$ MeV/c

$\Gamma(pe^-\nu)/\Gamma(p\pi^-)$ — Γ_5/Γ_1

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.301 ± 0.019 OUR FIT					
1.301 ± 0.019 OUR AVERAGE					
1 335 ± 0 056	7111	BOURQUIN	83	SPEC	SPS hyperon beam
1 313 ± 0.024	10k	WISE	80	SPEC	
1 23 ± 0 11	544	LINDQUIST	77	SPEC	$\pi^- p \to K^0 \Lambda$
1.27 ± 0 07	1089	KATZ	73	HBC	
1.31 ± 0 06	1078	ALTHOFF	71	OSPK	
1 17 ± 0 13	86	[5] CANTER	71	HBC	$K^- p$ at rest
1 20 ± 0 12	143	[6] MALONEY	69	HBC	
1 17 ± 0 18	120	[6] BAGLIN	64	FBC	K^- freon 1 45 GeV/c
1 23 ± 0 20	150	[6] ELY	63	FBC	
• • • We do not use the following data for averages, fits limits, etc • • •					
1 32 ± 0 15	218	[5] LINDQUIST	71	OSPK	See LINDQUIST 77

[5] Changed by us from $\Gamma(pe^-\nu)/\Gamma(N\pi)$ assuming the authors used $\Gamma(p\pi^-)/\Gamma_{total} = 2/3$

[6] Changed by us from $\Gamma(pe^-\nu)/\Gamma(N\pi)$ because $\Gamma(pe^-\nu)/\Gamma(p\pi^-)$ is the directly measured quantity

$\Gamma(p\mu^-\nu)/\Gamma(N\pi)$ — $\Gamma_6/(\Gamma_1+\Gamma_2)$

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
1.57 ± 0.35 OUR FIT					
1.57 ± 0.35 OUR AVERAGE					
1 4 ± 0 5	14	BAGGETT	72B	HBC	K^- at rest
2 4 ± 0.8	9	CANTER	71B	HBC	$K^- p$ at rest
1 3 ± 0 7	3	LIND	64	RVUE	
1.5 ± 1 2	2	RONNE	64	FBC	

Λ DECAY PARAMETERS

See the Note on Baryon Decay Parameters in the neutron Listings Some early results have been omitted

α_- FOR $\Lambda \to p\pi^-$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.642 ± 0.013 OUR AVERAGE					
0.584 ± 0 046	8500	ASTBURY	75	SPEC	
0 649 ± 0.023	10325	CLELAND	72	OSPK	
0.67 ± 0.06	3520	DAUBER	69	HBC	From Ξ decay
0.645 ± 0 017	10130	OVERSETH	67	OSPK	Λ from $\pi^- p$
0 62 ± 0 07	1156	CRONIN	63	CNTR	Λ from $\pi^- p$

α_0 / α_- — $\alpha(\Lambda \to n\pi^0) / \alpha(\Lambda \to p\pi^-)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
1.01 ± 0.07 OUR AVERAGE					
1 000 ± 0.068	4760	[7] OLSEN	70	OSPK	$\pi^+ n \to \Lambda K^+$
1.10 ± 0 27		CORK	60	CNTR	

[7] OLSEN 70 compares proton and neutron distributions from Λ decay

$[\alpha_-(\Lambda) + \alpha_+(\overline{\Lambda})] / [\alpha_-(\Lambda) - \alpha_+(\overline{\Lambda})]$

Zero if CP is conserved

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.06 ± 0.08 OUR AVERAGE					
−0 07 ± 0 09	4063	BARNES	87	CNTR	$\overline{p}p \to \overline{\Lambda}\Lambda$ LEAR
−0 02 ± 0 14	10k	[8] CHAUVAT	85	CNTR	pp, $\overline{p}p$ ISR

[8] CHAUVAT 85 actually gives $\alpha_+(\overline{\Lambda})/\alpha_-(\Lambda) = -1.04 \pm 0.29$ Assumes polarization is same in $pp \to \Lambda X$ and $\overline{p}p \to \overline{\Lambda} X$ Tests of this assumption, based on C invariance and fragmentation are satisfied by the data

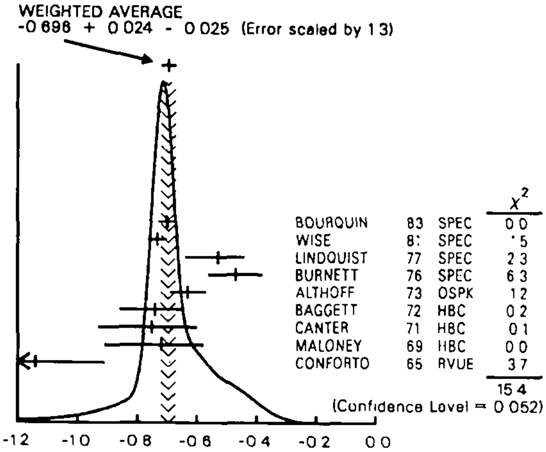
ϕ ANGLE FOR $\Lambda \to p\pi^-$ — ($\tan\phi = \beta / \gamma$)

VALUE (degrees)	EVTS	DOCUMENT ID		TECN	COMMENT
− 6.5 ± 3.5 OUR AVERAGE					
− 7.0 ± 4.5	10325	CLELAND	72	OSPK	Λ from $\pi^- p$
− 8 0 ± 6 0	10130	OVERSETH	67	OSPK	Λ from $\pi^- p$
13 0 ± 17 0	1156	CRONIN	63	OSPK	Λ from $\pi^- p$

g_A / g_V FOR $\Lambda \to pe^-\nu$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-0.696^{+0.024}_{-0.025}$ OUR AVERAGE		Error includes scale factor of 1 3 See the ideogram below			
−0 70 ± 0 03	7111	BOURQUIN	83	SPEC	$\Xi^- \to \Lambda\pi^-$
−0 734 ± 0.031	10k	[9] WISE	81	SPEC	$e\nu$ angular correl
$-0\ 53\ ^{+0\ 09}_{-0.11}$	441	LINDQUIST	77	SPEC	Pol Λ 3 asymm
−0 47 ± 0 09	405	BURNETT	76	SPEC	$e^-\nu$ and spin
−0 63 ± 0 06	817	ALTHOFF	73	OSPK	Polarized Λ
$-0\ 74\ ^{+0\ 09}_{-0\ 12}$	352	[9] BAGGETT	72	HBC	K^- at rest
$-0.75\ ^{+0\ 15}_{-0\ 18}$	141	[9] CANTER	71	HBC	
$-0\ 72\ ^{+0\ 14}_{-0\ 19}$	148	[9] MALONEY	69	HBC	
$-1\ 14\ ^{+0\ 23}_{-0\ 33}$		CONFORTO	65	RVUE	

[9] These experiments measure only the absolute value of g_A/g_V



g_A/g_V for $\Lambda \to pe^-\nu$

REFERENCES FOR Λ

We have omitted some papers that have been superseded by later experiments The omitted papers may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

BARNES	87	PL B199 147	+	(CARN SACL LANL VIEN FREI ILL UPPS+)
BIAGI	86	ZPHY C30 201	+	(BRIS CERN GEVA HEID LAUS LOQM RAL)
CHAUVAT	85	PL 163B 273	+Erhan Hayes+	(CERN UDCF UCLA SACL)
BOURQUIN	83	ZPHY C21 1	+Brown+	(BRIS GEVA HEID LALO RL STRB)
COX	81	PRL 46 877	+Dworkin+	(MICH WISC RUTG MINN BNL)
PONDROM	81	PR D23 814	+Handler Sheaff Cox+	(WISC MICH RUTG MINN)
WISE	81	PL 98B 123	+Jensen Kreisler Lomanno Poster+	(MASA BNL)
WISE	80	PL 91B 165	+Jensen Kreisler Lomanno Poster+	(MASA BNL)
SCHACHIN	78	PRL 41 1348	Schachinger Bunce Cox+	(MICH RUTG WISC)
HELLER	77	PL 68B 480	+Overseth Bunce Dydak+	(MICH WISC HEID)
LINDQUIST	77	PR D16 2104	+Swallow Sumner+	(EFI OSU ANL)
Also	76	JP G2 L211	Lindquist Swallow+	(EFI WUSL OSU ANL)
ZECH	77	NP B124 413	+Dydak Navarria+	(SIEG CERN DORT HEID)
BUNCE	76	PRL 36 1113	+Handler March Martin+	(WISC MICH RUTG)
BURNETT	76	NC 34A 14	+Innes Masek Maung Miller Ruderman+	(UCSC)
ASTBURY	75	NP B99 30	+Gallivan Jafar+	(LOIC CERN ETH SACL)
CLAYTON	75	NP B95 130	+Bacon Butterworth Waters+	(LOIC RHEL)
ALTHOFF	73	PL 43B 237	+Brown Freytag Heard Heintze+	(CERN HEID)
ALTHOFF	73B	NP B66 29	+Brown Freytag Heard Heintze+	(CERN HEID)
KATZ	73	Maryland Thesis		(UMD)
POULARD	73	PL 46B 135	+Givernaud Borg	(SACL)
BAGGETT	72	ZPHY 249 279	+Baggett Eisele Filthuth Frehse+	(HEID)
BAGGETT	72B	ZPHY 252 362	+Baggett Eisele Filthuth Frense+	(HEID)
BAGGETT	72C	PL 42B 379	+Baggett Eisele Filthuth Frehse Hepp+	(HEID)
CLELAND	72	NP B40 221	+Conforto Eaton Gerber+	(CERN GEVA LUND)
HYMAN	72	PR D5 1063	+Bunnell Derrick Fields Katz+	(ANL CMU)
ALTHOFF	71	PL 37B 531	+Brown Freytag Heard Heintze+	(CERN HEID)
BALTAY	71B	PR D4 670	+Bridgewater Cooper Habibi+	(COLU BING)
BARONI	71	LNC 2 1256	+Petrera Romano	(ROMA)
CANTER	71	PRL 26 868	+Cole Lee Franzini Loveless+	(STON COLU)
CANTER	71B	PRL 27 59	+Cole Lee Franzini Loveless+	(STON COLU)
DAHL JENSEN	71	NC 3A 1	+	(CERN ANKA LAUS MPIM ROMA)
LINDQUIST	71	PRL 27 612	+Sumner+	(EFI WUSL OSU ANL)
OLSEN	70	PRL 24 843	+Pondrom Handler Limon Smith+	(WISC MICH)
DAUBER	69	PR 179 1262	+Berge Hubbard Merrill Miller	(LRL)
DOYLE	69	UCRL 18139 Thesis		(LRL)
MALONEY	69	PRL 23 425	+Sechi Zorn	(UMD)
GRIMM	68	NC 54A 187		(HEID)
HEPP	68	ZPHY 214 71	+Schleich	(HEID)
BADIER	67	PL 25B 152	+Bonnet Briandet Sadoulet	(EPOL)
MAYEUR	67	U Libr Brux Bul 32	+Tompa Wickens	(BELG LOUC)
OVERSETH	67	PRL 19 391	+Roth	(MICH PRIN)
BURAN	66	PL 20 318	+Eivindson Skjeggestad Tofte+	(OSLO)
CHIEN	66	PR 152 1171	+Lach Sandweiss Taft Yeh Oren+	(YALE BNL)
ENGELMANN	66	NC 45A 1038	+Filthuth Alexander+	(HEID REHO)
GIBSON	66	NC 45A 882	+Green	(BRIS)
LONDON	66	PR 143 1034	+Rau Goldberg Lichtman+	(BNL SYRA)
CONFORTO	65	EC Int Herzegnovi		(CERN)
SCHMIDT	65	PR 140B 1328		(COLU)
BAGLIN	64	NC 35 977	+Bingham+	(EPOL CERN LOUC RHEL BERG)
HUBBARD	64	PR 135B 183	+Berge Kalbfleisch Shafer+	(LRL)
LIND	64	PR 135B 1483	+Binford Good Stern	(WISC)
RONNE	64	PL 11 357	+	(CERN EPOL LOUC BERG+)
SCHWARTZ	64	UCRL 11360 Thesis		(LRL)
BHOWMIK	63	NC 28 1494	+Goyal	(DELH)
BLOCK	63	PR 130 766	+Gessaroli Ratti+	(NWES BGNA SYRA ORNL)
BROWN	63	PR 130 769	+Kadyk Trilling Roe+	(LRL MICH)
CHRETIEN	63	PR 131 2208	+	(BRAN BROW HARV MIT)
CRONIN	63	PR 129 1795	+Overseth	(PRIN)
ELY	63	PR 131 868	+Gidal Kalmus Oswald Powell+	(LRL)
HUMPHREY	62	PR 127 1305	+Ross	(LRL)
BAGLIN	60	NC 18 1043	+Bloch Brisson Hennessy+	(EPOL)
COLUMBIA	60	Rochester Conf 726	Schwartz+	(COLU)
CORK	60	PR 120 1000	+Keith Wenzel Cronin+	(LRL PRIN BNL)
CRAWFORD	59B	PRL 2 266	+Cresti Douglass Good Ticho+	(LRL)
EISLER	57	NC 5 1700	+Plano Samios Schwartz+	(COLU BNL)

Σ^+

$I(J^P) = 1(\frac{1}{2}^+)$

We have omitted some results that have been superseded by later experiments The omitted results may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

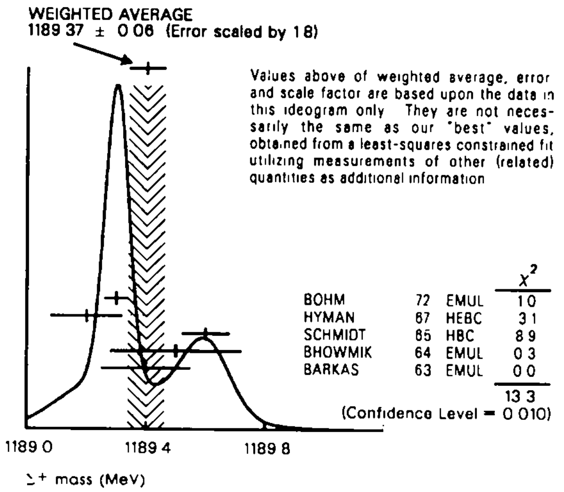
Σ^+ MASS

The fit uses Σ^+, Σ^0 Σ^- and Λ mass and mass difference measurements

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1189.37 ± 0.06	**OUR FIT**	Error includes scale factor of 1 9			
1189.37 ± 0.06	**OUR AVERAGE**	Error includes scale factor of 1 8 See the ideogram below			
1189 33 ± 0 04	607	[1] BOHM	72	EMUL	
1189 16 ± 0 12		HYMAN	67	HEBC	
1189 61 ± 0 08	4205	SCHMIDT	65	HBC	See note with Λ mass
1189 48 ± 0 22	58	[2] BHOWMIK	64	EMUL	
1189.38 ± 0 15	144	[2] BARKAS	63	EMUL	

[1] BOHM 72 is updated with our 1973 K^-, π^- and π^0 masses (RMP 45 No 2, Pt II)

[2] These masses have been raised 30 keV to take into account a 46 keV increase in the proton mass and a 21 keV decrease in the pion mass (added 1967 edition RMP 39 1)



Σ^+ MEAN LIFE

Measurements with an error $\geq$ 0 1 × 10^{-10} s have been omitted

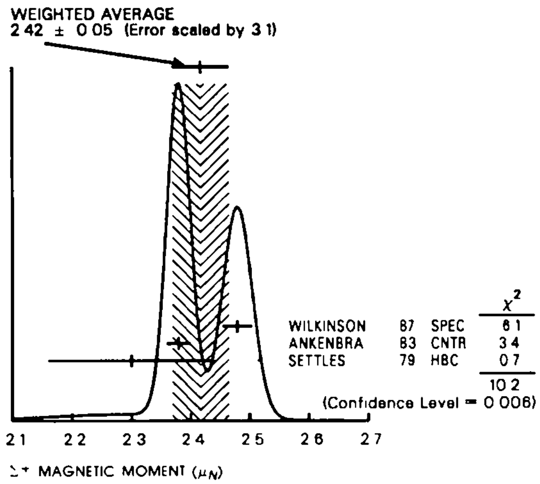
VALUE (10^{-10} sec)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.799 ± 0.004	**OUR AVERAGE**				
0 798 ± 0 005	30k	MARRAFFINO	80	HBC	$K^- p$ 0 42–0 5 GeV/c
0 807 ± 0 013	5719	CONFORTO	76	HBC	$K^- p$ 1–1 4 GeV/c
0 83 ± 0 04	526	BAKKER	71	DBC	$K^- n \to \Sigma^+ \pi^- \pi^-$
0.795 ± 0 010	20k	EISELE	70	HBC	$K^- p$ at rest
0 803 ± 0 008	10664	BARLOUTAUD	69	HBC	$K^- p$ 0 4–1 2 GeV/c
0 83 ± 0 032	1300	[3] CHANG	66	HBC	
0 80 ± 0.07	381	COOK	66	OSPK	
0.84 ± 0 09	181	BALTAY	65	HBC	
0 76 ± 0.03	900	CARAYAN	65	HBC	
0 749 $^{+0\ 056}_{-0\ 052}$	192	GRARD	62	HBC	
0 765 ± 0 04	456	HUMPHREY	62	HBC	

[3] We have increased the CHANG 66 error of 0 018 see our 1970 edition RMP 42 123

Σ^+ MAGNETIC MOMENT

See the Note on Baryon Magnetic Moments in the Λ Listings Measurements with an error $\geq$ 0 3 μ_N have been omitted

VALUE (μ_N)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.42 ± 0.05	**OUR AVERAGE**	Error includes scale factor of 3 1 See the ideogram below			
2.479 ± 0 012 ± 0 022	137k	WILKINSON	87	SPEC	400 GeV pBe
2 38 ± 0 02	44k	ANKENBRA	83	CNTR	210 GeV hyperon beam
2 30 ± 0 14	14k	SETTLES	79	HBC	$K^- p$ 0 42–0 50 GeV/c



Σ^+ DECAY MODES

		Fraction (Γ_i/Γ)
Γ_1	$\Sigma^+ \to p\pi^0$	(51 57 ± 0 30) × 10^{-2}
Γ_2	$\Sigma^+ \to n\pi^+$	(48 30 ± 0 30) × 10^{-2}
Γ_3	$\Sigma^+ \to p\gamma$	(1 24 ± 0 08) × 10^{-3}
Γ_4	$\Sigma^+ \to pe^+e^-$	< 7 0 × 10^{-6}
Γ_5	$\Sigma^+ \to n\pi^+\gamma$	(4.5 ± 0 5) × 10^{-4}
Γ_6	$\Sigma^+ \to \Lambda e^+\nu$	(2 0 ± 0 5) × 10^{-5}
Γ_7	$\Sigma^+ \to ne^+\nu$	< 5 × 10^{-6}
Γ_8	$\Sigma^+ \to n\mu^+\nu$	< 3 0 × 10^{-5}

CONSTRAINED FIT INFORMATION

An overall fit to 2 branching ratios uses 12 measurements and one constraint to determine 3 parameters The overall fit has a χ^2 = 6 9 for 10 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i \delta x_j\rangle/(\delta x_i \cdot \delta x_j)$ in percent from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

x_2	−100	
x_3	8	11
	x_1	x_2

Σ^+ BRANCHING RATIOS

$\Gamma(n\pi^+)/\Gamma(N\pi)$ $\Gamma_2/(\Gamma_1+\Gamma_2)$

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.4836 ± 0.0030	**OUR FIT**				
0.4836 ± 0.0030	**OUR AVERAGE**				
0 4828 ± 0 0036	10k	[4] MARRAFFINO	80	HBC	$K^- p$ 0 42–0 5 GeV/c
0.488 ± 0.008	1861	NOWAK	78	HBC	
0 484 ± 0 015	537	TOVEE	71	EMUL	
0.488 ± 0 010	1331	BARLOUTAUD	69	HBC	$K^- p$ 0 4–1 2 GeV/c
0 46 ± 0 02	534	CHANG	66	HBC	
0 490 ± 0 024	308	HUMPHREY	62	HBC	

[4] MARRAFFINO 80 actually gives $\Gamma(p\pi^0)$ / Γ(total) = 0 5172 ± 0 0036

$\Gamma(p\gamma)/\Gamma(p\pi^0)$ — Γ_3/Γ_4

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.40 ± 0.15 OUR FIT					
2.40 ± 0.15 OUR AVERAGE					
2 52 ± 0 28	190	[5] KOBAYASHI	87	CNTR	$\pi^+ p \to \Sigma^+ K^+$
$2\ 46^{+0\ 30}_{-0\ 35}$	155	BIAGI	85	CNTR	CERN hyperon beam
2 11 ± 0 38	46	MANZ	80	HBC	$K^- p \to \Sigma^+ \pi^-$
2 1 ± 0.3	45	ANG	69B	HBC	K^- at rest
2 76 ± 0.51	31	GERSHWIN	69B	HBC	
3 7 ± 0 8	24	BAZIN	65	HBC	

[5] KOBAYASHI 87 actually gives $\Gamma(p\gamma)$ / Γ(total) = (1 30 ± 0.15) × 10^{-3}

$\Gamma(pe^+e^-)/\Gamma_{total}$ — Γ_4/Γ

VALUE (units 10^{-6})	DOCUMENT ID		TECN	COMMENT
<7.0	[6] ANG	69B	HBC	K^- at rest

[6] ANG 69B found three pe^+e^- events in agreement with $\gamma \to e^+e^-$ conversion from $\Sigma^+ \to p\gamma$ The limit here is for neutral currents

$\Gamma(n\pi^+\gamma)/\Gamma(n\pi^+)$ — Γ_5/Γ_2

The π^+ momentum cuts differ, so we do not average the results, but simply use the latest value in the Summary Table

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0 93 ± 0 10	180	EBENHOH	73	HBC	π^+ · 150 MeV/c
• • • We do not use the following data for averages, fits limits etc • • •					
0 27 ± 0.05	29	ANG	69B	HBC	π^+ · 110 MeV/c
~1 8		BAZIN	65B	HBC	π^+ · 116 MeV/c

$\Gamma(\Lambda e^+\nu)/\Gamma_{total}$ — Γ_6/Γ

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	COMMENT
2.0 ± 0.5 OUR AVERAGE					
1 6 ± 0 7	5	BALTAY	69	HBC	K^- at rest
2 9 ± 1 0	10	EISELE	69	HBC	K^- at rest
2 0 ± 0.8	6	BARASH	67	HBC	K^- at rest

$\Gamma(ne^+\nu)/\Gamma(n\pi^+)$ — Γ_7/Γ_2

Test of $\Delta S = \Delta Q$ rule Experiments with an effective denominator less than 100,000 have been omitted

EFFECTIVE DENOM	EVTS	DOCUMENT ID		TECN	COMMENT
<1.1×10⁻⁵ OUR LIMIT Our 90% CL limit = (2 3 events)/(effective denominator sum) Number of events increased to 2 3 for a 90% confidence level					
111000	0	[7] EBENHOH	74	HBC	K^- at rest
105000	0	[7] SECHI-ZORN	73	HBC	K^- at rest

[7] Effective denominator calculated by us

$\Gamma(n\mu^+\nu)/\Gamma(n\pi^+)$ — Γ_8/Γ_2

Test of $\Delta S = \Delta Q$ rule

EFFECTIVE DENOM	EVTS	DOCUMENT ID		TECN
<6.2×10⁻⁵ OUR LIMIT Our 90% CL limit = (6 7 events)/(effective denominator sum) Number of events increased to 6 7 for a 90% confidence level				
33800	0	BAGGETT	69B	HBC
62000	2	[8] EISELE	69B	HBC
10150	0	[9] COURANT	64	HBC
1710	0	[9] NAUENBERG	64	HBC
120	1	GALTIERI	62	EMUL

[8] Effective denominator calculated by us
[9] Effective denominator taken from EISELE 67

$\Gamma(\Sigma^+ \to ne^+\nu)/\Gamma(\Sigma^- \to ne^-\nu)$

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.009 OUR LIMIT Our 90% CL limit, using $\Gamma(ne^+\nu)/\Gamma(n\pi^+)$ above						
• • • We do not use the following data for averages, fits, limits, etc • • •						
<0 019	90	0	EBENHOH	74	HBC	K^- at rest
<0 018	90	0	SECHI-ZORN	73	HBC	K^- at rest
<0 12	95	0	COLE	71	HBC	K^- at rest
<0.03	90	0	EISELE	69B	HBC	See EBENHOH 74

$\Gamma(\Sigma^+ \to n\mu^+\nu)/\Gamma(\Sigma^- \to n\mu^-\nu)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
<0.12 OUR LIMIT Our 90% CL limit using $\Gamma(n\mu^+\nu)/\Gamma(n\pi^+)$ above					
• • • We do not use the following data for averages, fits, limits etc • • •					
$0\ 06^{+0\ 045}_{-0.03}$	2	EISELE	69B	HBC	K^- at rest

$\Gamma(\Sigma^+ \to n\ell^+\nu)/\Gamma(\Sigma^- \to n\ell^-\nu)$

Test of $\Delta S = \Delta Q$ rule

VALUE	EVTS	DOCUMENT ID		TECN
<0.043 OUR LIMIT Our 90% CL limit, using $[\Gamma(n\mu^+\nu) + \Gamma(ne^+\nu)]/\Gamma(n\pi^+)$				
• • • We do not use the following data for averages, fits, limits, etc • • •				
<0.08	1	NORTON	69	HBC
<0 034	0	BAGGETT	67	HBC

Σ^+ DECAY PARAMETERS

See the Note on Baryon Decay Parameters in the neutron Listings A few early results have been omitted

α_+ FOR $\Sigma^+ \to n\pi^+$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.068 ± 0.013 OUR FIT					
0.066 ± 0.016 OUR AVERAGE					
0.037 ± 0 049	4101	BERLEY	70B	HBC	
0 069 ± 0 017	35k	BANGERTER	69	HBC	$K^- p$ 0 4 GeV/c

α_0 FOR $\Sigma^+ \to p\pi^0$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-0.980^{+0.019}_{-0.014}$ OUR FIT					
$-0.980^{+0.017}_{-0.013}$ OUR AVERAGE					
$-0\ 945^{+0\ 055}_{-0\ 042}$	1259	[10] LIPMAN	73	OSPK	$\pi^+ p \to \Sigma^+$
−0 940 ± 0 045	16k	BELLAMY	72	ASPK	$\pi^+ p \to \Sigma^+ K^+$
$-0\ 98\ ^{+0\ 05}_{-0.02}$	1335	[11] HARRIS	70	OSPK	$\pi^+ p \to \Sigma^+ K^+$
−0.999 ± 0 022	32k	BANGERTER	69	HBC	$K^- p$ 0 4 GeV/c

[10] Decay protons scattered off aluminum
[11] Decay protons scattered off carbon

α_+ / α_0

Older results have been omitted

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.069 ± 0.013 OUR FIT					
−0.073 ± 0.021	23k	MARRAFFINO	80	HBC	$K^- p$ 0 42–0 5 GeV/c

α_γ FOR $\Sigma^+ \to p\gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.83 ± 0.12 OUR AVERAGE					
−0 86 ± 0.13 ± 0.04	190	KOBAYASHI	87	CNTR	$\pi^+ p \to \Sigma^+ K^+$
$-0\ 53^{+0\ 38}_{-0.36}$	46	MANZ	80	HBC	$K^- p \to \Sigma^+ \pi^-$
$-1\ 03^{+0\ 52}_{-0.42}$	61	GERSHWIN	69B	HBC	$K^- p \to \Sigma^+ \pi^-$

ϕ_+ ANGLE FOR $\Sigma^+ \to n\pi^+$ — $(\tan\phi_+ = \beta / \gamma)$

VALUE (degrees)	EVTS	DOCUMENT ID		TECN	COMMENT
167 ± 20 OUR AVERAGE Error includes scale factor of 1 1					
184 ± 24	1054	[12] BERLEY	70B	HBC	
143 ± 29	560	BANGERTER	69B	HBC	$K^- p$ 0 4 GeV/c

[12] Changed from 176 to 184° to agree with our sign convention

ϕ_0 ANGLE FOR $\Sigma^+ \to p\pi^0$ — $(\tan\phi_0 = \beta / \gamma)$

VALUE (degrees)	EVTS	DOCUMENT ID		TECN	COMMENT
$36\ ^{+33}_{-34}$ OUR AVERAGE					
$38\ 1^{+35\ 7}_{-37\ 1}$	1259	[13] LIPMAN	73	OSPK	$\pi^+ p \to \Sigma^+ K^+$
22 ± 90		[14] HARRIS	70	OSPK	$\pi^+ p \to \Sigma^+ K^+$

[13] Decay proton scattered off aluminum
[14] Decay protons scattered off carbon

REFERENCES FOR Σ^+

We have omitted some papers that have been superseded by later experiments The omitted papers may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

KOBAYASHI	87	PRL 59 868	+Haba Homma Kawai, Miyake+	(KYOT)
WILKINSON	87	PRL 58 855	+Handler+	(WISC MICH RUTG MINN)
BIAGI	85	ZPHY C28 495	+Bourquin+	(BRIS CERN GEVA HEID+)
ANKENBRA	83	PRL 51 863	Ankenbrandt Berge+	(FNAL IOWA ISU YALE)
MANZ	80	PL 96B 217	+Reucroft Settles Wolf+	(MPIM VAND)
MARRAFFINO	80	PR D21 2501	+Reucroft Roos Waters+	(VAND MPIM)
SETTLES	79	PR D20 2154	+Manz Matt Hansl Herynek+	(MPIM VAND)
NOWAK	78	NP B139 61	+Armstrong Davis+	(LOUC BELG DURH WARS)
CONFORTO	76	NP B105 189	+Gopal Kalmus Litchfield Ross+	(RHEL LOIC)
EBENHOH	74	ZPHY 266 367	+Eisele Engelmann Filthuth Hepp+	(HEID)
EBENHOH	73	ZPHY 264 413	+Eisele Filthuth Hepp Leitner Thouw+	(HEID)
LIPMAN	73	PL 43B 89	+Uto Walker Montgomery+	(RHEL SUSS LOWC)
SECHI-ZORN	73	PR D8 12	+Snow	(UMD)
BELLAMY	72	PL 39B 299	+Anderson Crawford+	(LOWC RHEL. SUSS)
BOHM	72	NP B48 1	+	(BERL UBEL BRUX IASD DUUC LOUC+)
Also	73	IIHE 73 2 Nov	Bohm	(BERL UBEL BRUX IASD DUUC LOUC+)
BAKKER	71	LNC 1 37	+Hoogland Kluyver Massard+	(SABRE Collab)
COLE	71	PR D4 631	+Lee-Franzini Loveless Baltay+	(STON COLU)
TOVEE	71	NP B33 493	+	(LOUC UBEL BERL BRUX DUUC WARS)
BERLEY	70B	PR D1 2015	+Yamin Hertzbach Kofler+	(BNL MASA YALE)
EISELE	70	ZPHY 238 372	+Filthuth Hepp Presser Zech	(HEID)
HARRIS	70	PRL 24 165	+Overseth Pondrom Dettmann	(MICH WISC)
ANG	69B	ZPHY 228 151	+Ebenhoh Eisele Engelmann Filthuth+	(HEID)
BAGGETT	69B	MDDP TR 973 Thesis		(UMD)
BALTAY	69	PRL 22 615	+Franzini Newman Norton+	(COLU STON)
BANGERTER	69	UCRL 19244 Thesis		(LRL)
BANGERTER	69B	PR 187 1821	+Garnjost Galtieri Gershwin+	(LRL)
BARLOUTAUD	69	NP B14 153	+DeBellefon Granet+	(SACL CERN HEID)

EISELE	69	ZPHY 221 1	+Engelmann Filthuth Fohlisch Hepp+	(HEID)
Also	64	PRL 13 291	Willis, Courant+	(BNL CERN HEID UMD)
EISELE	69B	ZPHY 221 401	+Engelmann Filthuth Fohlisch Hepp+	(HEID)
GERSHWIN	69B	PR 188 2077	+Alston Garnjost Bangerter+	(LRL)
Also	69	UCRL 19246 Thesis	Gershwin	(LRL)
NORTON	69	Nevis 175 Thesis		(COLU)
BAGGETT	67	PRL 19 1458	+Day Glasser Kehoe Knop+	(UMD)
Also	68	Vienna Abs 374	Baggett Kehoe	(UMD)
Also	68B	Private Comm	Baggett	(UMD)
BARASH	67	PRL 19 181	+Day Glasser Kehoe Knop+	(UMD)
EISELE	67	ZPHY 205 409	+Engelmann Filthuth Folish Hepp+	(HEID)
HYMAN	67	PL 25B 376	+Loken Pewitt McKenzie+	(ANL CMU NWES)
CHANG	66	PR 151 1081		(COLU)
Also	65	Nevis 145 Thesis	Chang	(COLU)
COOK	66	PRL 17 223	+Ewart Masek Orr Platner	(WASH)
BALTAY	65	PR 140B 1027	+Sandweiss Culwick Kopp+	(YALE BNL)
BAZIN	65	PRL 14 154	+Blumenfeld Nauenberg+	(PRIN COLU)
BAZIN	65B	PR 140B 1358	+Piano Schmidt+	(PRIN RUTG COLU)
CARAYAN	65	PR 138B 433	Carayannopoulos Tautfest Willmann	(PURD)
SCHMIDT	65	PR 140B 1328		(COLU)
BHOWMIK	64	NP 53 22	+Jain Mathur Lakshmi	(DELH)
COURANT	64	PR 136B 1791	+Filthuth+	(CERN HEID UMD NRL BNL)
NAUENBERG	64	PRL 12 679	+Marateck+	(COLU RUTG PRIN)
BARKAS	63	PRL 11 26	+Dyer Heckman	(LRL)
Also	61	UCRL 9450 Thesis	Dyer	(LRL)
GALTIERI	62	PRL 9 26	+Barkas Heckman Patrick Smith	(LRL)
GRARD	62	PR 127 607	+Smith	(LRL)
HUMPHREY	62	PR 127 1305	+Ross	(LRL)

Σ^0

$I(J^P) = 1(\frac{1}{2}^+)$

The spin and parity have not been measured directly. They are of course assumed to be the same as for the Σ^+ and Σ^-.

Σ^0 MASS

The fit uses Σ^+, Σ^0, Σ^-, and Λ mass and mass difference measurements.

VALUE (MeV)	*DOCUMENT ID*
1192.55 ± 0.09 OUR FIT	Error includes scale factor of 1.3

$\Sigma^- - \Sigma^0$ MASS DIFFERENCE

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
4.89 ± 0.08 OUR FIT	Error includes scale factor of 1.2				
4.86 ± 0.08 OUR AVERAGE	Error includes scale factor of 1.2				
4.87 ± 0.12	37	DOSCH	65	HBC	
5.01 ± 0.12	12	SCHMIDT	65	HBC	See note with Λ mass
4.75 ± 0.1	18	BURNSTEIN	64	HBC	

$\Sigma^0 - \Lambda$ MASS DIFFERENCE

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
76.92 ± 0.10 OUR FIT	Error includes scale factor of 1.3				
76.55 ± 0.25 OUR AVERAGE					
76.23 ± 0.55	109	COLAS	75	HLBC	$\Sigma^0 \to \Lambda\gamma$
76.63 ± 0.28	208	SCHMIDT	65	HBC	See note with Λ mass

Σ^0 MEAN LIFE

These lifetimes are deduced from measurements of the cross sections for the Primakoff process $\Lambda \to \Sigma^0$ in nucleon Coulomb fields. An alternative expression of the same information is the Σ^0 Λ transition magnetic moment given in the following section. The relation is $(\mu_{\Sigma\Lambda}/\mu_N)^2\ \tau$ = 1.92951×10^{-19} s (see DEVLIN 86).

VALUE (10^{-20} sec)	*DOCUMENT ID*		*TECN*	*COMMENT*
7.4 ± 0.7 OUR EVALUATION	Using $\mu_{\Sigma\Lambda}$ (see the above note)			
$6.5^{+1.7}_{-1.1}$	DEVLIN [1]	86	SPEC	Primakoff effect
7.6 ± 0.5 ± 0.7	PETERSEN [2]	86	SPEC	Primakoff effect
• • • We do not use the following data for averages, fits, limits, etc. • • •				
5.8 ± 1.3	DYDAK [1]	77	SPEC	See DEVLIN 86

[1] DEVLIN 86 is a recalculation of the results of DYDAK 77 removing a numerical approximation made in that work.

[2] An additional uncertainty of the Primakoff formalism is estimated to be < 5%.

$|\mu(\Sigma^0 \to \Lambda)|$ TRANSITION MAGNETIC MOMENT

See the note in the Σ^0 mean-life section above. Also see the Note on Baryon Magnetic Moments in the Λ Listings.

VALUE (μ_N)	*DOCUMENT ID*		*TECN*	*COMMENT*
1.61 ± 0.08 OUR AVERAGE				
$1.72^{+0.17}_{-0.19}$	DEVLIN [3]	86	SPEC	Primakoff effect
1.59 ± 0.05 ± 0.07	PETERSEN [4]	86	SPEC	Primakoff effect
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$1.82^{+0.25}_{-0.18}$	DYDAK [3]	77	SPEC	See DEVLIN 86

[3] DEVLIN 86 is a recalculation of the results of DYDAK 77 removing a numerical approximation made in that work.

[4] An additional uncertainty of the Primakoff formalism is estimated to be < 2.5%.

Σ^0 DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_1	$\Sigma^0 \to \Lambda\gamma$	1	
Γ_2	$\Sigma^0 \to \Lambda e^+ e^-$	5×10^{-3}	
Γ_3	$\Sigma^0 \to \Lambda\gamma\gamma$	$< 3 \times 10^{-2}$	90%

Σ^0 BRANCHING RATIOS

$\Gamma(\Lambda e^+ e^-)/\Gamma_{total}$ — Γ_2/Γ

VALUE	*DOCUMENT ID*		*COMMENT*
0.00545	FEINBERG	58	Theoretical QED calculation

$\Gamma(\Lambda\gamma\gamma)/\Gamma_{total}$ — Γ_3/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*
<0.03	90	COLAS	75	HLBC

REFERENCES FOR Σ^0

DEVLIN	86	PR D34 1626	+Petersen Beretvas	(RUTG)
PETERSEN	86	PRL 57 949	+Beretvas Devlin Luk+	(RUTG WISC MICH MINN)
DYDAK	77	NP B118 1	+Navarria Overseth Steffen+	(CERN DORT HEID)
COLAS	75	NP B91 253	+Farwell Ferrer Six	(ORSA)
DOSCH	65	PL 14 239	+Engelmann Filthuth Hepp Kluge+	(HEID)
SCHMIDT	65	PR 140B 1328		(COLU)
BURNSTEIN	64	PRL 13 66	+Day Kehoe Zorn Snow	(UMD)
FEINBERG	58	PR 109 1019		(BNL)

Σ^-

$I(J^P) = 1(\frac{1}{2}^+)$

We have omitted some results that have been superseded by later experiments. The omitted results may be found in our 1986 edition (Physics Letters **170B**) or in earlier editions.

Σ^- MASS

The fit uses Σ^+, Σ^0, Σ^-, and Λ mass and mass difference measurements.

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1197.43 ± 0.06 OUR FIT	Error includes scale factor of 1.5				
1197.50 ± 0.05 OUR AVERAGE					
1197.532 ± 0.057		GALL	88	CNTR	Σ^-Pb, Σ^-W atoms
1197.43 ± 0.08	3000	SCHMIDT	65	HBC	See note with Λ mass
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1197.24 ± 0.15		DUGAN [1]	75	CNTR	Exotic atoms

[1] GALL 88 concludes that the DUGAN 75 mass needs to be reevaluated.

$\Sigma^- - \Sigma^+$ MASS DIFFERENCE

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*
8.07 ± 0.08 OUR FIT	Error includes scale factor of 1.6			
8.09 ± 0.16 OUR AVERAGE				
7.91 ± 0.23	86	BOHM	72	EMUL
8.25 ± 0.25	2500	DOSCH	65	HBC
8.25 ± 0.40	87	BARKAS	63	EMUL

Σ^- − Λ MASS DIFFERENCE

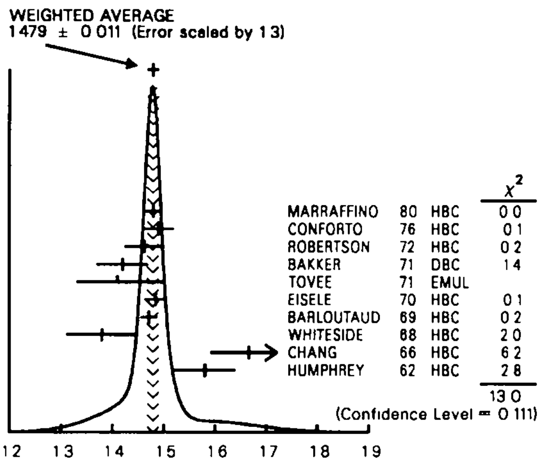
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
81.81 ± 0.06 OUR FIT	Error includes scale factor of 1 4				
81 69 ± 0.07 OUR AVERAGE					
81 64 ± 0.09	2279	HEPP	68	HBC	
81 80 ± 0 13	85	SCHMIDT	65	HBC	See note with Λ mass
81 70 ± 0 19		BURNSTEIN	64	HBC	

Σ^- MEAN LIFE

Measurements with an error ≥ 0 2 × 10^{-10} s have been omitted

VALUE (10^{-10} sec)	EVTS	DOCUMENT ID		TECN	COMMENT
1.479 ± 0.011 OUR AVERAGE	Error includes scale factor of 1 3 See the ideogram below				
1 480 ± 0 014	16k	MARRAFFINO	80	HBC	$K^- p$ 0 42–0 5 GeV/c
1 49 ± 0 03	8437	CONFORTO	76	HBC	$K^- p$ 1–1 4 GeV/c
1.463 ± 0 039	2400	ROBERTSON	72	HBC	$K^- p$ 0 25 GeV/c
1 42 ± 0.05	1383	BAKKER	71	DBC	$K^- N \to \Sigma^- \pi\pi$
1 41 $^{+0\ 09}_{-0\ 08}$		TOVEE	71	EMUL	
1 485 ± 0 022	100k	EISELE	70	HBC	$K^- p$ at rest
1 472 ± 0 016	10k	BARLOUTAUD	69	HBC	$K^- p$ 0 4–1 2 GeV/c
1.38 ± 0 07	506	WHITESIDE	68	HBC	K^- at rest
1 666 ± 0 075	3267	[2] CHANG	66	HBC	K^- at rest
1 58 ± 0 06	1208	HUMPHREY	62	HBC	K^- at rest

[2]We have increased the CHANG 66 error of 0 018 see our 1970 edition, RMP 42, 123



Σ^- mean life (10^{-10} sec)

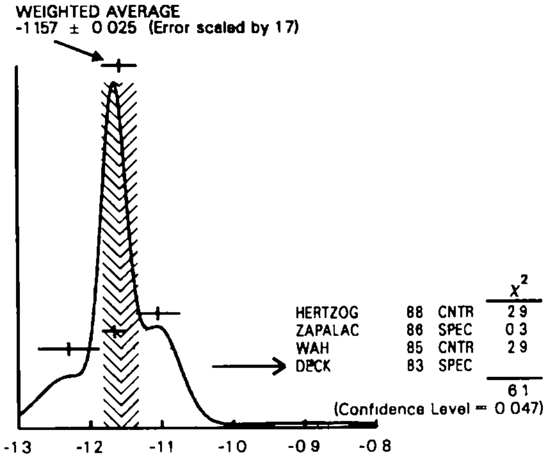
Σ^- MAGNETIC MOMENT

See the Note on Baryon Magnetic Moments in the Λ Listings
Measurements with an error ≥ 0.3 μ_N have been omitted

VALUE (μ_N)	EVTS	DOCUMENT ID		TECN	COMMENT
− 1.157 ± 0.025 OUR AVERAGE	Error includes scale factor of 1 7 See the ideogram below				
− 1.105 ± 0.029 ± 0.010		HERTZOG	88	CNTR	Σ^-Pb Σ^-W atoms
− 1 166 ± 0 014 ± 0 010	671k	ZAPALAC	86	SPEC	$ne^-\nu$, $n\pi^-$ decays
− 1 23 ± 0.03 ± 0 03		WAH	85	CNTR	pCu → Σ^- X
− 0 89 ± 0 14	516k	DECK	83	SPEC	pBe → Σ^- X

Σ^- DECAY MODES

		Fraction (Γ_i/Γ)
Γ_1	$\Sigma^- \to n\pi^-$	(99 848 $^{+0\ 006}_{-0\ 005}$) × 10^{-2}
Γ_2	$\Sigma^- \to ne^-\nu$	(1 017 $^{+0\ 032}_{-0.037}$) × 10^{-3}
Γ_3	$\Sigma^- \to n\mu^-\nu$	(4.5 ± 0.4) × 10^{-4}
Γ_4	$\Sigma^- \to \Lambda e^-\nu$	(5 73 ± 0 27) × 10^{-5}
Γ_5	$\Sigma^- \to n\pi^-\gamma$	(4 6 ± 0 6) × 10^{-4}



Σ^- magnetic moment

CONSTRAINED FIT INFORMATION

An overall fit to 3 branching ratios uses 16 measurements and one constraint to determine 4 parameters The overall fit has a χ^2 = 8 7 for 13 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i\,\delta x_j\rangle/(\delta x_i\cdot\delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

x_2	64		
x_3	− 77	0	
x_4	5	0	0
	x_1	x_2	x_3

Σ^- BRANCHING RATIOS

$\Gamma(ne^-\nu)/\Gamma(n\pi^-)$ — Γ_2/Γ_1

Measurements with an error ≥ 0 2 × 10^{-3} have been omitted

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.019 $^{+0.032}_{-0.037}$ OUR FIT					
1.019 $^{+0.031}_{-0.036}$ OUR AVERAGE					
0 96 ± 0 05	2847	BOURQUIN	83C	SPEC	SPS hyperon beam
1 09 $^{+0.06}_{-0.08}$	601	[3] EBENHOH	74	HBC	K^- at rest
1 05 $^{+0\ 07}_{-0\ 13}$	455	[3] SECHI ZORN	73	HBC	K^- at rest
0.97 ± 0 15	57	COLE	71	HBC	K^- at rest
1.11 ± 0.09	180	BIERMAN	68	HBC	

[3]An additional negative systematic error is included for internal radiative corrections and latest form factors see BOURQUIN 83C

$\Gamma(n\mu^-\nu)/\Gamma(n\pi^-)$ — Γ_3/Γ_1

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.45 ± 0.04 OUR FIT					
0.45 ± 0.04 OUR AVERAGE					
0.38 ± 0 11	13	COLE	71	HBC	K^- at rest
0 43 ± 0.06	72	ANG	69	HBC	K^- at rest
0 43 ± 0 09	56	BAGGETT	69	HBC	K^- at rest
0 56 ± 0 20	11	BAZIN	65B	HBC	K^- at rest
0 66 ± 0 15	22	COURANT	64	HBC	

$\Gamma(\Lambda e^-\nu)/\Gamma(n\pi^-)$ — Γ_4/Γ_1

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
0.574 ± 0.027 OUR FIT					
0.574 ± 0.027 OUR AVERAGE					
0 561 ± 0 031	1620	[4] BOURQUIN	82	SPEC	SPS hyperon beam
0 63 ± 0 11	114	THOMPSON	80	ASPK	Hyperon beam
0 52 ± 0 09	31	BALTAY	69	HBC	K^- at rest
0.69 ± 0.12	31	EISELE	69	HBC	K^- at rest
0 64 ± 0.12	35	BARASH	67	HBC	K^- at rest
0 75 ± 0 28	11	COURANT	64	HBC	K^- at rest

[4]The value is from BOURQUIN 83B, and includes radiation corrections and new acceptance

$\Gamma(n\pi^-\gamma)/\Gamma(n\pi^-)$ Γ_5/Γ_4

The π^+ momentum cuts differ, so we do not average the results, but simply use the latest value in the Summary Table

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.46 ± 0.06	292	EBENHOH	73	HBC	π^+ < 150 MeV/c
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.10 ± 0.02	23	ANG	69B	HBC	π^- < 110 MeV/c
~1.1		BAZIN	65B	HBC	π^- < 166 MeV/c

Σ^- DECAY PARAMETERS

See the Note on Baryon Decay Parameters in the neutron Listings. Older outdated results have been omitted.

α_- FOR $\Sigma^- \to n\pi^-$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.068 ± 0.008 OUR AVERAGE					
−0.062 ± 0.024	28k	HANSL	78	HBC	$K^-p \to \Sigma^-\pi^+$
−0.067 ± 0.011	60k	BOGERT	70	HBC	K^-p 0.4 GeV/c
−0.071 ± 0.012	51k	BANGERTER	69	HBC	K^-p 0.4 GeV/c

ϕ ANGLE FOR $\Sigma^- \to n\pi^-$ ($\tan\phi = \beta/\gamma$)

VALUE (degrees)	EVTS	DOCUMENT ID		TECN	COMMENT
10 ± 15 OUR AVERAGE					
+ 5 ± 23	1092	BERLEY [5]	70B	HBC	n rescattering
14 ± 19	1385	BANGERTER	69B	HBC	K^-p 0.4 GeV/c

[5] BERLEY 70B changed from −5 to +5° to agree with our sign convention.

g_A/g_V FOR $\Sigma^- \to ne^-\nu$

See also the next data block. For the sign convention, see the Note on Baryon Decay Parameters in the neutron Listings.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
+0.29 ± 0.07		25k	HSUEH [6,7]	85	SPEC	250 GeV/c Σ^-
$-0.4^{+0.52}_{-1.5}$		43	ELLIS	72	ASPK	Polarized Σ's
$-0.33^{+0.30}_{-0.85}$		63	BOGERT	70	HBC	K^-p 0.4 GeV/c
$+0.19^{+0.20}_{-0.17}$		61	GERSHWIN	69	HBC	Polarized Σ's
• • • We do not use the following data for averages, fits, limits, etc. • • •						
+0.33		4456	BOURQUIN [7,8]	83C	SPEC	SPS hyperon beam
< +0.15	95	193	KELLER [7]	82	SPEC	

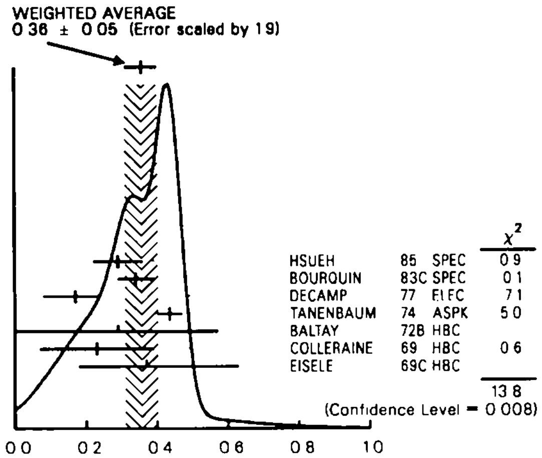
[6] From measurement of the electron asymmetry = −0.53 ± 0.14.
[7] The sign has been changed to agree with our convention.
[8] The value +0.33 is preferred over −0.33 by at least 2.6 standard deviations including systematic errors.

$|g_A/g_V|$ FOR $\Sigma^- \to ne^-\nu$

See also the previous data block.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.36 ± 0.05 OUR AVERAGE		Error includes scale factor of 1.9. See the ideogram below.			
0.29 ± 0.07	25k	HSUEH [9]	85	SPEC	250 GeV/c Σ^-
0.34 ± 0.05	4456	BOURQUIN [10]	83C	SPEC	SPS hyperon beam
$0.17^{+0.07}_{-0.09}$	519	DECAMP	77	ELEC	Hyperon beam
0.435 ± 0.035	3507	TANENBAUM	74	ASPK	
$0.29^{+0.28}_{-0.29}$	36	BALTAY	72B	HBC	n scattering
0.23 ± 0.16	49	COLLERAINE	69	HBC	n scattering
$0.37^{+0.26}_{-0.19}$	33	EISELE	69C	HBC	n scattering

[9] From measurement of the electron asymmetry = −0.53 ± 0.14.
[10] The positive sign is favored by at least 2.6 standard deviations.



$|g_A/g_V|$ for $\Sigma^- \to ne^-\nu$

NOTE ON $\Sigma^- \to \Lambda e^-\nu$ DECAY

(by J.A. Thompson, University of Pittsburgh)

The decay $\Sigma^- \to \Lambda e^-\nu$ is of special interest because the matrix element of the vector current is predicted by the strong form of CVC and is not sensitive to the current octet assumptions or SU(3) structure constants which enter into Cabibbo's predictions for the other hyperon decays. For $\Delta S = 0$ transitions, the weak interaction vector current is related to the electromagnetic current through a multiplicative constant, set by neutron beta decay, and an isospin rotation.

The decay $\Sigma^0 \to \Lambda\gamma$ (the isospin-rotation analogue of $\Sigma^- \to \Lambda e^-\nu$) is mediated predominantly through the magnetic interaction, assuming there are no inhomogeneities in the Σ^0, Λ charge distributions. Thus we expect the g_{WM} term

$$g_{WM} \approx \mu_{\Sigma^0\Lambda} \approx \frac{\sqrt{3}}{2}\mu_n \text{ [by SU(3)]}$$

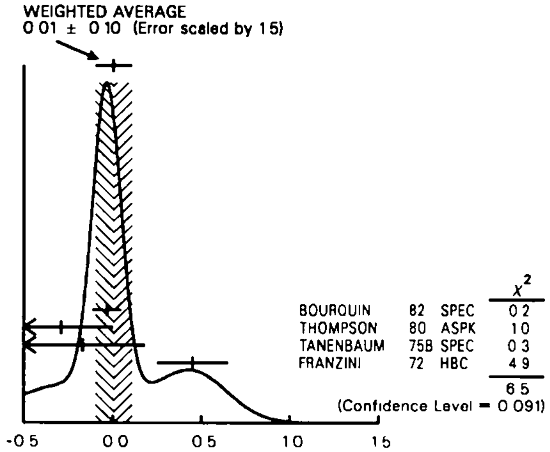
to dominate the vector part of the weak current. The strong CVC predictions are thus $f_1/g_1 = 0$ and $g_{WM} \approx 1.6$.

g_V/g_A FOR $\Sigma^- \to \Lambda e^-\nu$

For the sign convention, see the Note on Baryon Decay Parameters in the neutron Listings. The value is predicted to be zero by conserved vector current theory. The values averaged assume CVC-SU(3) weak magnetism term.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.01 ± 0.10 OUR AVERAGE		Error includes scale factor of 1.5. See the ideogram below.			
−0.034 ± 0.080	1620	BOURQUIN [11]	82	SPEC	SPS hyperon beam
−0.29 ± 0.29	114	THOMPSON	80	ASPK	BNL hyperon beam
−0.17 ± 0.35	55	TANENBAUM	75B	SPEC	BNL hyperon beam
+0.45 ± 0.20	186	FRANZINI [11,12]	72	HBC	

[11] The sign has been changed to agree with our convention.
[12] The FRANZINI 72 value includes the events of earlier papers.



g_V/g_A for $\Sigma^- \to \Lambda e^-\nu$

g_{WM} / g_A FOR $\Sigma^- \to \Lambda e^- \nu$

The values quoted assume the CVC prediction $g_V = 0$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
2.4 ± 1 7 OUR AVERAGE					
1 75 ± 3 5	114	THOMPSON	80	ASPK	BNL hyperon beam
3 5 ± 4 5	55	TANENBAUM	75B	SPEC	BNL hyperon beam
2 4 ± 2.1	186	FRANZINI	72	HBC	

REFERENCES FOR Σ^-

We have omitted some papers that have been superseded by later experiments The omitted papers may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

GALL	88	PRL 60 186	+Austin+	(BOST MIT WILL CIT CMU WYOM)
HERTZOG	88	PR D37 1142	+Eckhouse+	(WILL BOST MIT CIT CMU WYOM)
ZAPALAC	86	PRL 57 1526	+	(EFI ELMT FNAL IOWA ISU LENI YALE)
HSUEH	85	PRL 54 2399	+Muller+	(CHIC ELMT FNAL ISU LENI YALE)
WAH	85	PRL 55 2551	+Cardello Cooper Teig+	(FNAL IOWA ISU)
BOURQUIN	83B	ZPHY C21 27	+	(BRIS GEVA HEID LALO RL STRB)
BOURQUIN	83C	ZPHY C21 17	+	(BRIS GEVA HEID LALO RL STRB)
DECK	83	PR D28 1	+Beretvas Devlin Luk+	(RUTG WISC MICH MINN)
BOURQUIN	82	ZPHY C12 307	+Brown+	(BRIS GEVA HEID LALO RL STRB)
KELLER	82	PRL 48 971	+Lesnik Romanowski Keig+	(OSU CHIC ANL)
MARRAFFINO	80	PR D21 2501	+Reucroft Roos Waters+	(VAND MPIM)
THOMPSON	80	PR D21 25	+Cleland Cooper Dris Engels+	(PITT BNL)
HANSL	78	NP B132 45	+Manz Matt Reucroft Settles+	(MPIM VAND)
DECAMP	77	PL 66B 295	+Badier Bland Chollet Gaillard+	(LALO EPOL)
CONFORTO	76	NP B105 189	+Gopal Kalmus Litchfield Ross+	(RHEL LOIC)
DUGAN	75	NP A254 396	+Asano Chen Cheng Hu Lidofsky+	(COLU YALE)
TANENBAUM	75B	PR D12 1871	+Hungerbuhler+	(YALE FNAL BNL)
EBENHOH	74	ZPHY 266 367	+Eisele Engelmann Filthuth Hepp+	(HEID)
TANENBAUM	74	PRL 33 175	+Hungerbuhler+	(YALE FNAL BNL)
EBENHOH	73	ZPHY 264 413	+Eisele Filthuth Hepp Leitner Thouw+	(HEID)
SECHI ZORN	73	PR D8 12	+Snow	(UMD)
BALTAY	72B	PR D5 1569	+Feinman Franzini Newman Yeh+	(COLU STON)
BOHM	72	NP B48 1	+	(BERL UBEL BRUX IASD DUUC LOUC+)
ELLIS	72	NP B39 77	+	(OXF AERE RHEL LOQM LYON NWES ITEP)
FRANZINI	72	PR D6 2417	+	(COLU HEID UMD STON)
ROBERTSON	72	Thesis		(IIT)
BAKKER	71	LNC 1 37	+Hoogland Kluyver Massard+	(SABRE Collab)
COLE	71	PR D4 631	+Lee Franzini Loveless Baltay+	(STON COLU)
Also	69	Nevis 175 Thesis	Norton	(COLU)
TOVEE	71	NP B33 493	+	(LOUC UBEL BERL BRUX DUUC WARS)
BERLEY	70B	PR D1 2015	+Yamin Hertzbach Kofler+	(BNL MASA YALE)
BOGERT	70	PR D2 6	+Lucas Taft Willis Berley+	(BNL MASA YALE)
EISELE	70	ZPHY 238 372	+Filthuth Hepp Presser Zech	(HEID)
ANG	69	ZPHY 223 103	+Eisele Engelmann Filthuth+	(HEID)
ANG	69B	ZPHY 228 151	+Ebenhoh Eisele Engelmann Filthuth+	(HEID)
BAGGETT	69	PRL 23 249	+Kehoe Snow	(UMD)
BALTAY	69	PRL 22 615	+Franzini Newman Norton+	(COLU STON)
BANGERTER	69	UCRL 19244 Thesis		(LRL)
BANGERTER	69B	PR 187 1821	+Garnjost Gottleri Gershwin+	(LRL)
BARLOUTAUD	69	NP B14 153	+DeBellefon Granet+	(SACL CERN HEID)
COLLERAINE	69	PRL 23 198	+Day Glasser Knop+	(UMD)
EISELE	69	ZPHY 221 1	+Engelmann Filthuth Fohlisch Hepp+	(HEID)
EISELE	69C	ZPHY 223 487	+Engelmann Filthuth Fohlisch+	(HEID)
GERSHWIN	69	UCRL 19246 Thesis		(LRL)
BIERMAN	68	PRL 20 1459	+Kounosu Nauenberg+	(PRIN)
HEPP	68	ZPHY 214 71	+Schleich	(HEID)
WHITESIDE	68	NC 54A 537	+Gollub	(OBER)
BARASH	67	PRL 19 181	+Day Glasser Kehoe Knop+	(UMD)
CHANG	66	PR 151 1081		(COLU)
BAZIN	65B	PR 140B 1358	+Piano Schmidt+	(PRIN RUTG COLU)
DOSCH	65	PL 14 239	+Engelmann Filthuth Hepp Kluge+	(HEID)
Also	66	PR 151 1081	Chang	(COLU)
SCHMIDT	65	PR 140B 1328		(COLU)
BURNSTEIN	64	PRL 13 66	+Day Kehoe Zorn Snow	(UMD)
COURANT	64	PR 136B 1791	+Filthuth+	(CERN HEID UMD NRL BNL)
BARKAS	63	PRL 11 26	+Dyer Heckman	(LRL)
HUMPHREY	62	PR 127 1305	+Ross	(LRL)

STRANGENESS −2 BARYONS

Ξ^0

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

The parity has not actually been measured, but + is of course expected

Ξ^0 MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN
1314.9 ± 0.6 OUR FIT				
1314.8 ± 0.8 OUR AVERAGE				
1315 2 ± 0 92	49	WILQUET	72	HLBC
1313 4 ± 1.8	1	PALMER	68	HBC

$\Xi^- - \Xi^0$ MASS DIFFERENCE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
6.4 ± 0.6 OUR FIT					
6.3 ± 0 7 OUR AVERAGE					
6 9 ± 2 2	29	LONDON	66	HBC	
6 1 ± 0 9	88	PJERROU	65B	HBC	
6 8 ± 1.6	23	JAUNEAU	63	FBC	
• • • We do not use the following data for averages fits limits etc • • •					
6 1 ± 1 6	45	CARMONY	64B	HBC	See PJERROU 65B

Ξ^0 MEAN LIFE

VALUE (10^{-10} sec)	EVTS	DOCUMENT ID		TECN	COMMENT
$2.90^{+0.10}_{-0.09}$ OUR AVERAGE					
2 83 ± 0 16	6300	ZECH [1]	77	SPEC	Neutral hyperon beam
$2\ 88^{+0\ 21}_{-0\ 19}$	652	BALTAY	74	HBC	1 75 GeV/c $K^- p$
$2\ 90^{+0\ 32}_{-0\ 27}$	157	MAYEUR [2]	72	HLBC	2 1 GeV/c K^-
$3\ 07^{+0\ 22}_{-0\ 20}$	340	DAUBER	69	HBC	
3 0 ± 0 5	80	PJERROU	65B	HBC	
$2\ 5^{+0\ 4}_{-0\ 3}$	101	HUBBARD	64	HBC	
$3\ 9^{+1\ 4}_{-0.80}$	24	JAUNEAU	63	FBC	
• • • We do not use the following data for averages fits limits, etc • • •					
$3\ 5^{+1\ 0}_{-0\ 8}$	45	CARMONY	64B	HBC	See PJERROU 65B

[1] The ZECH 77 result is $\tau_{\Xi^0} = [2\ 77 - (\tau_\Lambda - 2\ 69)] \times 10^{-10}$ s in which we use $\tau_\Lambda = 2\ 63 \times 10^{-10}$ s

[2] The MAYEUR 72 value is modified by the erratum

Ξ^0 MAGNETIC MOMENT

See the Note on Baryon Magnetic Moments in the Λ Listings

VALUE (μ_N)	EVTS	DOCUMENT ID		TECN
−1.250 ± 0.014 OUR AVERAGE				
−1 253 ± 0.014	270k	COX	81	SPEC
−1.20 ± 0 06	42k	BUNCE	79	SPEC

Ξ^0 DECAY MODES

		Fraction (Γ_i/Γ)	Conf Lev
Γ_1	$\Xi^0 \to \Lambda\pi^0$	1 0	
Γ_2	$\Xi^0 \to \Lambda\gamma$	$(0\ 5 \pm 0\ 5) \times 10^{-2}$	
Γ_3	$\Xi^0 \to \Sigma^0\gamma$	$< 7 \times 10^{-2}$	90%
Γ_4	$\Xi^0 \to \Sigma^+ e^- \nu$	$< 1\ 1 \times 10^{-3}$	90%
Γ_5	$\Xi^0 \to \Sigma^- e^+ \nu$	$< 0\ 9 \times 10^{-3}$	90%
Γ_6	$\Xi^0 \to \Sigma^+ \mu^- \nu$	$< 1\ 1 \times 10^{-3}$	90%
Γ_7	$\Xi^0 \to \Sigma^- \mu^+ \nu$	$< 0\ 9 \times 10^{-3}$	90%
Γ_8	$\Xi^0 \to p\pi^-$	$< 3\ 6 \times 10^{-5}$	90%
Γ_9	$\Xi^0 \to p e^- \nu$	$< 1\ 3 \times 10^{-3}$	90%
Γ_{10}	$\Xi^0 \to p\mu^- \nu$	$< 1\ 3 \times 10^{-3}$	90%

Ξ^0 BRANCHING RATIOS

$\Gamma(\Lambda\gamma)/\Gamma(\Lambda\pi^0)$ Γ_2/Γ_1

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
5 ± 5	1	YEH	74	HBC	Effective denom =200

$\Gamma(\Sigma^0\gamma)/\Gamma(\Lambda\pi^0)$ Γ_3/Γ_1

VALUE (units 10^{-2})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<6.5	90	0-1	YEH	74	HBC	Effective denom =60

$\Gamma(\Sigma^+ e^- \nu)/\Gamma(\Lambda\pi^0)$ Γ_4/Γ_1

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 1.1	90	0	YEH	74	HBC	Effective denom =2100
• • • We do not use the following data for averages fits limits etc • • •						
< 1 5			DAUBER	69	HBC	
< 7			HUBBARD	66	HBC	
<13			TICHO	63	HBC	

$\Gamma(\Sigma^- e^+ \nu)/\Gamma(\Lambda \pi^0)$ Γ_5/Γ_1

Test of $\Delta S = \Delta Q$ rule

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.9	90	0	YEH	74	HBC	Effective denom =2500
• • • We do not use the following data for averages, fits limits etc • • •						
<1 5			DAUBER	69	HBC	
<6			HUBBARD	66	HBC	

$\Gamma(\Sigma^+ \mu^- \nu)/\Gamma(\Lambda \pi^0)$ Γ_6/Γ_1

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<1 1	90	0	YEH	74	HBC	Effective denom =2100
• • • We do not use the following data for averages fits limits etc • • •						
<1 5			DAUBER	69	HBC	
<7			HUBBARD	66	HBC	

$\Gamma(\Sigma^- \mu^+ \nu)/\Gamma(\Lambda \pi^0)$ Γ_7/Γ_1

Test of $\Delta S = \Delta Q$ rule

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.9	90	0	YEH	74	HBC	Effective denom =2500
• • • We do not use the following data for averages fits limits etc • • •						
<1 5			DAUBER	69	HBC	
<6			HUBBARD	66	HBC	

$\Gamma(p\pi^-)/\Gamma(\Lambda \pi^0)$ Γ_8/Γ_1

$\Delta S=2$ Forbidden in first order weak interaction

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 3.6	90		GEWENIGER	75	SPEC	
• • • We do not use the following data for averages fits limits etc • • •						
< 180	90	0	YEH	74	HBC	Effective denom =1300
< 90			DAUBER	69	HBC	
< 500			HUBBARD	66	HBC	
<2700			TICHO	63	HBC	

$\Gamma(pe^- \nu)/\Gamma(\Lambda \pi^0)$ Γ_9/Γ_1

$\Delta S=2$ Forbidden in first order weak interaction

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 1.3			DAUBER	69	HBC	
• • • We do not use the following data for averages fits limits etc • • •						
< 3 4	90	0	YEH	74	HBC	Effective denom =670
< 6			HUBBARD	66	HBC	
<27			TICHO	63	HBC	

$\Gamma(p\mu^- \nu)/\Gamma(\Lambda \pi^0)$ Γ_{10}/Γ_1

$\Delta S=2$ Forbidden in first-order weak interaction

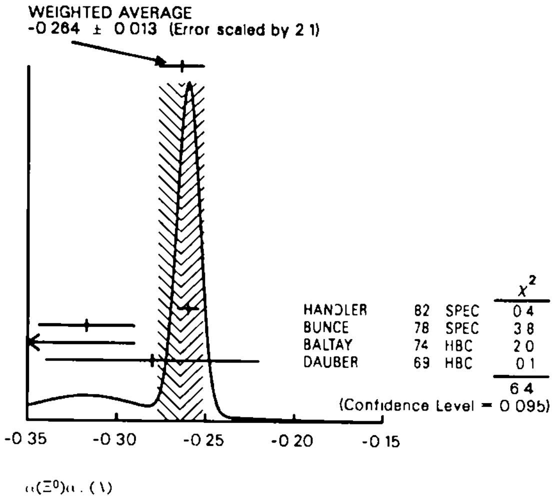
VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<1.3			DAUBER	69	HBC	
• • • We do not use the following data for averages fits limits etc • • •						
<3 5	90	0	YEH	74	HBC	Effective denom =664
<6			HUBBARD	66	HBC	

Ξ^0 DECAY PARAMETERS

See the Note on Baryon Decay Parameters in the neutron Listings

$\alpha(\Xi^0)\,\alpha_-(\Lambda)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.264 ± 0.013 OUR AVERAGE Error includes scale factor of 2 1 See the ideogram below					
−0 260 ± 0 004 ± 0 005	300k	HANDLER	82	SPEC	FNAL hyperon beam
−0 317 ± 0 027	6075	BUNCE	78	SPEC	FNAL hyperon beam
−0 35 ± 0 06	505	BALTAY	74	HBC	$K^- p$ 1 75 GeV/c
−0 28 ± 0 06	739	DAUBER	69	HBC	$K^- p$ 1 7–2 6 GeV/c



α FOR $\Xi^0 \to \Lambda\pi^0$

The above average $\alpha(\Xi^0)\alpha_-(\Lambda) = -0\ 264 \pm 0\ 013$ including a scale factor of 2 1 divided by our current average $\alpha_-(\Lambda) = 0\ 642 \pm 0\ 013$ give the following average for $\alpha(\Xi^0)$

VALUE	DOCUMENT ID
−0.411 ± 0.022 OUR EVALUATION Error includes scale factor of 2 1	

ϕ ANGLE FOR $\Xi^0 \to \Lambda\pi^0$ $(\tan\phi = \beta/\gamma)$

VALUE (degrees)	EVTS	DOCUMENT ID		TECN	COMMENT
21 ± 12 OUR AVERAGE					
16 ± 17	652	BALTAY	74	HBC	1 75 GeV/c $K^- p$
38 ± 19	739	[3] DAUBER	69	HBC	
− 8 ± 30	146	[4] BERGE	66	HBC	

[3]DAUBER 69 uses $\alpha_\Lambda = 0\ 647 \pm 0\ 020$

[4]The errors have been multiplied by 1 2 due to approximations used for the Ξ polarization see DAUBER 69 for a discussion

REFERENCES FOR Ξ^0

HANDLER	82	PR D25 639	+Grobel Pondrom+	(WISC MICH MINN RUTG)
COX	81	PRL 46 877	+Dworkin+	(MICH WISC RUTG MINN BNL)
BUNCE	79	PL 86B 386	+Overseth Cox+	(BNL MICH RUTG WISC)
BUNCE	78	PR D18 633	+Handler March Martin+	(WISC MICH RUTG)
ZECH	77	NP B124 413	+Dydak Navarria+	(SIEG CERN DORT HEID)
GEWENIGER	75	PL 57B 193	+Gjesdal Presser+	(CERN HEID)
BALTAY	74	PR D9 49	+Bridgewater Cooper Gershwin+	(COLU BING) J
YEH	74	PR D10 3545	+Gaigalas Smith Zendle Baltay+	(BING COLU)
MAYEUR	72	NP B47 333	+VanBinst Wilquet+	(BRUX CERN TUFT LOUC)
Also	73	NP B53 268 erratum	Mayeur	
WILQUET	72	PL 42B 372	+Fragine Guy+	(BRUX CERN TUFT LOUC)
DAUBER	69	PR 179 1262	+Berge Hubbard Merrill Miller	(LRL)
PALMER	68	PL 26B 323	+Radojicic Rau Richardson+	(BNL SYRA)
BERGE	66	PR 147 945	+Eberhard Hubbard Merrill+	(LRL)
HUBBARD	66	UCRL 11510 Thesis		(LRL)
LONDON	66	PR 143 1034	+Rau Goldberg Lichtman+	(BNL SYRA)
PJERROU	65B	PRL 14 275	+Schlein Slater Smith Stork Ticho	(UCLA)
Also	65	Thesis	Pjerrou	(UCLA)
CARMONY	64B	PRL 12 482	+Pjerrou Schlein Slater Stork+	(UCLA)
HUBBARD	64	PR 135B 183	+Berge Kalbfleisch Shafer+	(LRL)
JAUNEAU	63	PL 4 49	+	(EPOL CERN LOUC RHEL BERG)
Also	63C	Siena Conf 1 1	Jauneau+	(EPOL CERN LOUC RHEL BERG)
TICHO	63	BNL Conf 410		(UCLA)

Ξ^-

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

The parity has not actually been measured but + is of course expected

We have omitted some results that have been superseded by later experiments The omitted results may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

Ξ^- MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1321.32 ± 0.13 OUR FIT					
1321.34 ± 0.14 OUR AVERAGE					
1321.46 ± 0 34	632	DIBIANCA	75	DBC	4 9 GeV/c $K^- d$
1321 12 ± 0 41	268	WILQUET	72	HLBC	
1321 87 ± 0 51	195	[1] GOLDWASSER	70	HBC	5 5 GeV/c $K^- p$
1321 67 ± 0.52	6	CHIEN	66	HBC	6 9 GeV/c $\bar{p}p$
1321 4 ± 1 1	299	LONDON	66	HBC	
1321 3 ± 0.4	149	PJERROU	65B	HBC	
1321 1 ± 0 3	241	[2] BADIER	64	HBC	
1321 4 ± 0 4	517	[2] JAUNEAU	63D	FBC	
1321 1 ± 0 65	62	[2] SCHNEIDER	63	HBC	

[1] GOLDWASSER 70 uses $m(\Lambda)$ = 1115 58 MeV
[2] These masses have been increased 0 09 MeV because the Λ mass increased

Ξ^+ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1321.32 ± 0.13 OUR FIT					
1321.20 ± 0.33 OUR AVERAGE					
1321.6 ± 0.8	35	VOTRUBA	72	HBC	10 GeV/c $K^+ p$
1321 2 ± 0 4	34	STONE	70	HBC	
1320.69 ± 0 93	5	CHIEN	66	HBC	6 9 GeV/c $\bar{p}p$

Ξ^- MEAN LIFE

Measurements with an error > 0 2×10^{-10} s or with systematic errors not included have been omitted

VALUE (10^{-10} sec)	EVTS	DOCUMENT ID		TECN	COMMENT
1.639 ± 0.015 OUR AVERAGE					
1.652 ± 0 051	32k	BOURQUIN	84	SPEC	Hyperon beam
1 665 ± 0 065	41k	BOURQUIN	79	SPEC	Hyperon beam
1.609 ± 0.028	4286	HEMINGWAY	78	HBC	4 2 GeV/c $K^- p$
1.67 ± 0.08		DIBIANCA	75	DBC	4 9 GeV/c $K^- d$
1 63 ± 0.03	4303	BALTAY	74	HBC	1 75 GeV/c $K^- p$
1.73 $^{+0\ 08}_{-0\ 07}$	680	MAYEUR	72	HLBC	2 1 GeV/c K^-
1 61 ± 0 04	2610	DAUBER	69	HBC	
1.80 ± 0 16	299	LONDON	66	HBC	
1 70 ± 0 12	246	PJERROU	65B	HBC	
1 69 ± 0 07	794	HUBBARD	64	HBC	
1 86 $^{+0\ 15}_{-0\ 14}$	517	JAUNEAU	63D	FBC	

Ξ^+ MEAN LIFE

VALUE (10^{-10} sec)	EVTS	DOCUMENT ID		TECN	COMMENT
1.6 ± 0.3	34	STONE	70	HBC	
• • • We do not use the following data for averages fits limits etc • • •					
1.55 $^{+0\ 35}_{-0.20}$	35	[3] VOTRUBA	72	HBC	10 GeV/c $K^+ p$
1 9 $^{+0\ 7}_{-0.5}$	12	[3] SHEN	67	HBC	
1 51 ± 0 55	5	[3] CHIEN	66	HBC	6 9 GeV/c $\bar{p}p$

[3] The error is statistical only

Ξ^- MAGNETIC MOMENT

See the Note on Baryon Magnetic Moments in the Λ Listings

VALUE (μ_N)	EVTS	DOCUMENT ID		TECN	COMMENT
−0.69 ± 0.04	218k	RAMEIKA	84	SPEC	400 GeV pBe
• • • We do not use the following data for averages, fits, limits etc • • •					
−2 1 ± 0 8	2436	COOL	74	OSPK	1 8 GeV/c $K^- p$
−0 1 ± 2 1	2724	BINGHAM	70B	OSPK	1 8 GeV/c $K^- p$

Ξ^- DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_1	$\Xi^- \to \Lambda\pi^-$	1.00	
Γ_2	$\Xi^- \to \Sigma^-\gamma$	(2 3 ± 1 0)×10^{-4}	
Γ_3	$\Xi^- \to \Lambda e^-\nu$	(5 5 ± 0 3)×10^{-4}	
Γ_4	$\Xi^- \to \Lambda\mu^-\nu$	(3.5 ± 3 5)×10^{-4}	
Γ_5	$\Xi^- \to \Sigma^0 e^-\nu$	(8 7 ± 1 7)×10^{-5}	
Γ_6	$\Xi^- \to \Sigma^0\mu^-\nu$	< 8 ×10^{-4}	90%
Γ_7	$\Xi^- \to n\pi^-$	< 1 9 ×10^{-5}	90%
Γ_8	$\Xi^- \to ne^-\nu$	< 3 2 ×10^{-3}	90%
Γ_9	$\Xi^- \to n\mu^-\nu$	< 1 5 ×10^{-2}	90%
Γ_{10}	$\Xi^- \to p\pi^-\pi^-$	< 4 ×10^{-4}	90%
Γ_{11}	$\Xi^- \to p\pi^-e^-\nu$	< 4 ×10^{-4}	90%
Γ_{12}	$\Xi^- \to p\pi^-\mu^-\nu$	< 4 ×10^{-4}	90%
Γ_{13}	$\Xi^- \to \Xi^0 e^-\nu$	< 2 3 ×10^{-3}	90%

Ξ^- BRANCHING RATIOS

A number of early results have been omitted

$\Gamma(\Sigma^-\gamma)/\Gamma(\Lambda\pi^-)$ — Γ_2/Γ_1

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
2.27 ± 1.02	9	BIAGI	87B	SPEC	SPS hyperon beam

$\Gamma(\Lambda e^-\nu)/\Gamma(\Lambda\pi^-)$ — Γ_3/Γ_1

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.550 ± 0.030 OUR AVERAGE					
0.564 ± 0 031	2857	BOURQUIN	83	SPEC	SPS hyperon beam
0.30 ± 0.13	11	THOMPSON	80	ASPK	Hyperon beam

$\Gamma(\Lambda\mu^-\nu)/\Gamma(\Lambda\pi^-)$ — Γ_4/Γ_1

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.35 ± 0.35		1	YEH	74	HBC	Effective denom =2859
• • • We do not use the following data for averages fits limits etc • • •						
< 2 3	90	0	THOMPSON	80	ASPK	Effective denom =1017
< 1 3			DAUBER	69	HBC	
<12			BERGE	66	HBC	

$\Gamma(\Sigma^0 e^-\nu)/\Gamma(\Lambda\pi^-)$ — Γ_5/Γ_1

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.087 ± 0.017	154	BOURQUIN	83	SPEC	SPS hyperon beam

$\Gamma(\Sigma^0\mu^-\nu)/\Gamma(\Lambda\pi^-)$ — Γ_6/Γ_1

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.76	90	0	YEH	74	HBC	Effective denom =3026
• • • We do not use the following data for averages fits limits, etc • • •						
<5			BERGE	66	HBC	

$[\Gamma(\Lambda e^-\nu) + \Gamma(\Sigma^0 e^-\nu)]/\Gamma(\Lambda\pi^-)$ — $(\Gamma_3+\Gamma_5)/\Gamma_1$

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
0 651 ± 0 031	3011	[4] BOURQUIN	83	SPEC	SPS hyperon beam
0 68 ± 0.22	17	[5] DUCLOS	71	OSPK	

[4] See the separate BOURQUIN 83 values for $\Gamma(\Lambda e^-\nu)/\Gamma(\Lambda\pi^-)$ and $\Gamma(\Sigma^0 e^-\nu)/\Gamma(\Lambda\pi^-)$ above
[5] DUCLOS 71 cannot distinguish Σ^0 s from Λ s The Cabibbo theory predicts the Σ^0 rate is about a factor 6 smaller than the Λ rate

$\Gamma(n\pi^-)/\Gamma(\Lambda\pi^-)$ — Γ_7/Γ_1

ΔS=2 Forbidden in first order weak interaction

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.019	90		BIAGI	82B	SPEC	SPS hyperon beam
• • • We do not use the following data for averages, fits, limits, etc • • •						
<3 0	90	0	YEH	74	HBC	Effective denom =760
<1 1			DAUBER	69	HBC	
<5 0			FERRO-LUZZI	63	HBC	

$\Gamma(ne^-\nu)/\Gamma(\Lambda\pi^-)$ — Γ_8/Γ_1

ΔS=2 Forbidden in first order weak interaction

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 3.2	90	0	YEH	74	HBC	Effective denom =715
• • • We do not use the following data for averages fits limits etc • • •						
<10	90		BINGHAM	65	RVUE	

$\Gamma(n\mu^-\nu)/\Gamma(\Lambda\pi^-)$ — Γ_9/Γ_1

ΔS=2 Forbidden in first order weak interaction

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<15.3	90	0	YEH	74	HBC	Effective denom =150

$\Gamma(p\pi^-\pi^-)/\Gamma(\Lambda\pi^-)$ — Γ_{10}/Γ_1

ΔS=2 Forbidden in first order weak interaction

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<3.7	90	0	YEH	74	HBC	Effective denom =6200

$\Gamma(p\pi^-e^-\nu)/\Gamma(\Lambda\pi^-)$ — Γ_{11}/Γ_1

ΔS=2 Forbidden in first order weak interaction

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<3.7	90	0	YEH	74	HBC	Effective denom =6200

$\Gamma(p\pi^-\mu^-\nu)/\Gamma(\Lambda\pi^-)$ — Γ_{12}/Γ_1

$\Delta S = 2$ Forbidden in first-order weak interaction

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<3.7	90	0	YEH	74	HBC	Effective denom =6200

$\Gamma(\Xi^0 e^-\nu)/\Gamma(\Lambda\pi^-)$ — Γ_{13}/Γ_1

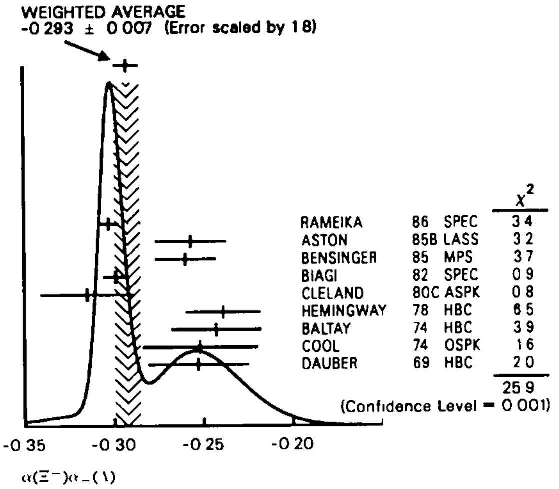
VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<2.3	90	0	YEH	74	HBC	Effective denom =1000

Ξ^- DECAY PARAMETERS

See the Note on Baryon Decay Parameters in the neutron Listings

$\alpha(\Xi^-)\alpha_-(\Lambda)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.293 ± 0.007 OUR AVERAGE		Error includes scale factor of 1 8 See the ideogram below			
−0.303 ± 0 004 ± 0 004	192k	RAMEIKA	86	SPEC	400 GeV pBe
−0 257 ± 0.020	11k	ASTON	85B	LASS	11 GeV/c K^-p
−0 260 ± 0 017	21k	BENSINGER	85	MPS	5 GeV/c K^-p
−0.299 ± 0 007	150k	BIAGI	82	SPEC	SPS hyperon beam
−0 315 ± 0 026	9046	CLELAND	80C	ASPK	BNL hyperon beam
−0 239 ± 0.021	6599	HEMINGWAY	78	HBC	4 2 GeV/c K^-p
−0 243 ± 0 025	4303	BALTAY	74	HBC	1 75 GeV/c K^-p
−0 252 ± 0.032	2436	COOL	74	OSPK	1 8 GeV/c K^-p
−0 253 ± 0.028	2781	DAUBER	69	HBC	



$\alpha(\Xi^-)\alpha_-(\Lambda)$

α FOR $\Xi^- \rightarrow \Lambda\pi^-$

The above average $\alpha(\Xi^-)\ \alpha_-(\Lambda) = -0\ 293 \pm 0.007$, including a scale factor of 1 8 divided by our current average $\alpha_-(\Lambda) = 0\ 642 \pm 0\ 013$ gives the following average value for $\alpha(\Xi^-)$

VALUE	DOCUMENT ID
−0.456 ± 0.014 OUR EVALUATION	Error includes scale factor of 1 8

ϕ ANGLE FOR $\Xi^- \rightarrow \Lambda\pi^-$ $(\tan\phi = \beta/\gamma)$

VALUE (degrees)	EVTS	DOCUMENT ID		TECN	COMMENT
4 ± 4 OUR AVERAGE					
5 ± 10	11k	ASTON	85B	LASS	K^-p
14.7 ± 16.0	21k	[6] BENSINGER	85	MPS	5 GeV/c K^-p
11 ± 9	4303	BALTAY	74	HBC	1 75 GeV/c K^-p
5 ± 16	2436	COOL	74	OSPK	1 8 GeV/c K^-p
−26 ± 30	2724	BINGHAM	70B	OSPK	
−14 ± 11	2781	DAUBER	69	HBC	Uses α_Λ = 0 647 ± 0 020
0 ± 12	1004	[7] BERGE	66	HBC	
0 ± 20 4	364	[7] LONDON	66	HBC	Using α_Λ = 0 62
54 ± 30	356	[7] CARMONY	64B	HBC	

[6] BENSINGER 85 used $\alpha_\Lambda = 0.642 \pm 0.013$

[7] The errors have been multiplied by 1 2 due to approximations used for the Ξ polarization see DAUBER 69 for a discussion

g_A/g_V FOR $\Xi^- \rightarrow \Lambda e^-\nu$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.25 ± 0.05	1992	BOURQUIN	83	SPEC	SPS hyperon beam

REFERENCES FOR Ξ^-

We have omitted some papers that have been superseded by later experiments The omitted papers may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

BIAGI 87B ZPHY C35 143 + (BRIS CERN GEVA HEID LAUS LOQM RAL)
RAMEIKA 86 PR D33 3172 +Beretvas Deck+ (RUTG MICH WISC MINN)
ASTON 85B PR D32 2270 +Carnegie+ (SLAC CARL CNRC CINC)
BENSINGER 85 NP B252 561 + (CHIC ELMT FNAL ISU LENI SMAS)
BOURQUIN 84 NP B241 1 + (BRIS GEVA HEID LALO RAL STRB)
RAMEIKA 84 PRL 52 581 +Beretvas Deck+ (RUTG MICH WISC MINN)
BOURQUIN 83 ZPHY C21 1 +Brown+ (BRIS GEVA HEID LALO RL STRB)
BIAGI 82 PL 112B 265 + (BRIS CAMB GEVA HEID LAUS LOQM RL)
BIAGI 82B PL 112B 277 + (LOQM GEVA RL HEID CAMB LAUS BRIS)
CLELAND 80C PR D21 12 +Cooper Dris Engels Herbert+ (PITT BNL)
THOMPSON 80 PR D21 25 +Cleland Cooper Dris Engels+ (PITT BNL)
BOURQUIN 79 PL 87B 297 + (BRIS GEVA HEID ORSA RHEL STRB)
HEMINGWAY 78 NP B142 205 +Armenteros+ (CERN ZEEM NIJM OXF)
DIBIANCA 75 NP B98 137 +Endorf (CMU)
BALTAY 74 PR D9 49 +Bridgewater Cooper Gershwin+ (COLU BING) J
COOL 74 PR D10 792 +Giacomelli Jenkins Kycia Leontic Li+ (BNL)
Also 72 PRL 29 1630 Cool Giacomelli Jenkins Kycia Leontic+(BNL)
YEH 74 PR D10 3545 +Gaigalas Smith Zendle Baltay+ (BING COLU)
MAYEUR 72 NP B47 333 +VanBinst Wilquet+ (BRUX CERN TUFT LOUC)
VOTRUBA 72 NP B45 77 +Safder Ratcliffe (BIRM EDIN)
WILQUET 72 PL 42B 372 +Filagine Guy+ (BRUX CERN TUFT LOUC)
DUCLOS 71 NP B32 493 +Freytag Heintze Heinzelmann Jones+ (CERN)
BINGHAM 70B PR D1 3010 +Cook Humphrey Sander+ (UCSD WASH)
GOLDWASSER 70 PR D1 1960 +Schultz (ILL)
STONE 70 PL 32B 515 +Berlinghieri Bromberg Cohen Ferbel+ (ROCH)
DAUBER 69 PR 179 1262 +Berge Hubbard Merrill Miller (LRL) J
SHEN 67 PL 25B 443 +Firestone Goldhaber (UCB LRL)
BERGE 66 PR 147 945 +Eberhard Hubbard Merrill+ (LRL)
CHIEN 66 PR 152 1171 +Lach Sandweiss Taft Yeh Oren+ (YALE BNL)
LONDON 66 PR 143 1034 +Rau Goldberg Lichtman+ (BNL SYRA)
BINGHAM 65 PRSL 285 202 (CERN)
PJERROU 65B PRL 14 275 +Schlein Slater Smith Stork Ticho (UCLA)
Also 65 Thesis Pjerrou (UCLA)
BADIER 64 Dubna Conf 1 593 +Demoulin Barloutaud+ (EPOL SACL ZEEM)
CARMONY 64B PRL 12 482 +Pjerrou Schlein Slater Stork+ (UCLA) J
HUBBARD 64 PR 135B 183 +Berge Kalbfleisch Shafer+ (LRL)
FERRO LUZZI 63 PR 130 1568 +Alston Rosenfeld Wojcicki (LRL)
JAUNEAU 63D Siena Conf 4 + (EPOL CERN LOUC RHEL BERG)
Also 63B PL 5 261 Jauneau+ (EPOL CERN LOUC RHEL BERG)
SCHNEIDER 63 PL 4 360 (CERN)

OTHER RELATED PAPERS

PONDROM 85 PRPL 122 57 (WISC)
Review of FNAL hyperon experiments

STRANGENESS −3 BARYON

Ω^-

$I(J^P) = 0(\frac{3}{2}^+)$

The quantum numbers have not actually been measured, but follow from the assignment of the particle to the baryon decuplet The unambiguous discovery in both production and decay was by BARNES 64

We have omitted some results that have been superseded by later experiments The omitted results may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

Ω^- MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1672.43 ± 0.32 OUR AVERAGE					
1673 ± 1	100	HARTOUNI	85	SPEC	80–280 GeV $K^0_L C$
1673 0 ± 0 8	41	BAUBILLIER	78	HBC	8 25 GeV/c K^-p
1671 7 ± 0.6	27	HEMINGWAY	78	HBC	4 2 GeV/c K^-p
1673 4 ± 1 7	4	[1] DIBIANCA	75	DBC	4 9 GeV/c K^-d
1673.3 ± 1 0	3	PALMER	68	HBC	K^-p 4 6 5 GeV/c
1671.8 ± 0 8	3	SCHULTZ	68	HBC	K^-p 5 5 GeV/c
1674 2 ± 1.6	5	SCOTTER	68	HBC	K^-p 6 GeV/c
1672 1 ± 1 0	1	[2] FRY	55	EMUL	
• • • We do not use the following data for averages fits limits etc • • •					
1671.43 ± 0 78	13	[3] ABCLV	73	HBC	K^-p 10 GeV/c
1671 9 ± 1 2	6	[3] SPETH	69	HBC	See ABCLV 73
1673 0 ± 8 0	1	ABRAMS	64	HBC	$\rightarrow \Xi^-\pi^0$
1670 6 ± 1 0	1	[2] FRY	55B	EMUL	
1615	1	[4] EISENBERG	54	EMUL	

[1]DIBIANCA 75 gives a mass for each event We quote the average
[2]The FRY 55 and FRY 55B events were identified as Ω^- by ALVAREZ 73 The masses assume decay to ΛK^- at rest For FRY 55B decay from an atomic orbit could Doppler shift the K^- energy and the resulting Ω^- mass by several MeV This shift is negligible for FRY 55 because the Ω decay is approximately perpendicular to its orbital velocity as is known because the Λ strikes the nucleus (L Alvarez private communication 1973) We have calculated the error assuming that the orbital n is 4 or larger
[3]Excluded from the average the Ω^- lifetimes measured by the experiments differ significantly from other measurements
[4]The EISENBERG 54 mass was calculated for decay in flight ALVAREZ 73 has shown that the Ω interacted with an Ag nucleus to give $K^- \Xi$Ag

$\bar{\Omega}^+$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1672.6 ± 0 7 OUR AVERAGE					
1672 ± 1	72	HARTOUNI	85	SPEC	80-280 GeV $K^0_L C$
1673 1 ± 1 0	1	FIRESTONE	71B	HBC	12 GeV c $K^- d$

Ω^- MEAN LIFE

Measurements with an error > 0 1 · 10^{-10} s have been omitted

VALUE (10^{-10} sec)	EVTS	DOCUMENT ID		TECN	COMMENT
0.822 ± 0.012 OUR AVERAGE					
0 811 ± 0 037	1096	LUK	88	SPEC	pBe 400 GeV
0 823 ± 0 013	12k	BOURQUIN	84	SPEC	SPS hyperon beam
• • • We do not use the following data for averages fits limits etc • • •					
0 822 ± 0 028	2437	BOURQUIN	79B	SPEC	See BOURQUIN 84

Ω^- DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_1	$\Omega^- \to \Lambda K^-$	$(67\ 8 \pm 0\ 7) \cdot 10^{-2}$	
Γ_2	$\Omega^- \to \Xi^0 \pi^-$	$(23\ 6 \pm 0\ 7) \cdot 10^{-2}$	
Γ_3	$\Omega^- \to \Xi^- \pi^0$	$(8.6 \pm 0\ 4) \cdot 10^{-2}$	
Γ_4	$\Omega^- \to \Xi^- \pi^+ \pi^-$	$(4\ 3^{+3\ 4}_{-1\ 3}) \cdot 10^{-4}$	
Γ_5	$\Omega^- \to \Xi(1530)^0 \pi^-$	$(6\ 4^{+5\ 1}_{-2\ 0}) \cdot 10^{-4}$	
Γ_6	$\Omega^- \to \Xi^0 e^- \nu$	$(5\ 6 \pm 2\ 8) \cdot 10^{-3}$	
Γ_7	$\Omega^- \to \Xi^- \gamma$	$< 2\ 2 \cdot 10^{-3}$	90%
Γ_8	$\Omega^- \to \Lambda \pi^-$	$< 1\ 9 \cdot 10^{-4}$	90%

Ω^- BRANCHING RATIOS

The BOURQUIN 84 values (which include results of BOURQUIN 79B a separate experiment) are much more accurate than any other results and so the latter have been omitted

$\Gamma(\Lambda K^-)/\Gamma_{total}$ — Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.678 ± 0.007	14k	BOURQUIN	84	SPEC	SPS hyperon beam
• • • We do not use the following data for averages fits limits, etc • • •					
0 686 ± 0 013	1920	BOURQUIN	79B	SPEC	See BOURQUIN 84

$\Gamma(\Xi^0 \pi^-)/\Gamma_{total}$ — Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.236 ± 0.007	1947	BOURQUIN	84	SPEC	SPS hyperon beam
• • • We do not use the following data for averages fits limits etc • • •					
0 234 ± 0 013	317	BOURQUIN	79B	SPEC	See BOURQUIN 84

$\Gamma(\Xi^- \pi^0)/\Gamma_{total}$ — Γ_3/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.086 ± 0.004	759	BOURQUIN	84	SPEC	SPS hyperon beam
• • • We do not use the following data for averages fits limits etc • • •					
0 080 ± 0 008	145	BOURQUIN	79B	SPEC	See BOURQUIN 84

$\Gamma(\Xi^- \pi^+ \pi^-)/\Gamma_{total}$ — Γ_4/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
$4\ 3^{+3.4}_{-1.3}$	4	BOURQUIN	84	SPEC	SPS hyperon beam

$\Gamma(\Xi(1530)^0 \pi^-)/\Gamma_{total}$ — Γ_5/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
$6.4^{+5.1}_{-2.0}$	4	[5] BOURQUIN	84	SPEC	SPS hyperon beam
• • • We do not use the following data for averages fits limits etc • • •					
~20	1	BOURQUIN	79B	SPEC	See BOURQUIN 84

[5]The same 4 events as in the previous mode with the isospin factor to take into account $\Xi(1530)^0 \to \Xi^0 \pi^0$ decays included

$\Gamma(\Xi^0 e^- \nu)/\Gamma_{total}$ — Γ_6/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
5.6 ± 2.8	14	BOURQUIN	84	SPEC	SPS hyperon beam
• • • We do not use the following data for averages fits, limits etc • • •					
~10	3	BOURQUIN	79B	SPEC	See BOURQUIN 84

$\Gamma(\Xi^- \gamma)/\Gamma_{total}$ — Γ_7/Γ

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<2.2	90	9	BOURQUIN	84	SPEC	SPS hyperon beam
• • • We do not use the following data for averages fits limits etc • • •						
<3 1	90	0	BOURQUIN	79B	SPEC	See BOURQUIN 84

$\Gamma(\Lambda \pi^-)/\Gamma_{total}$ — Γ_8/Γ

ΔS=2 Forbidden in first order weak interaction

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<1 9	90	0	BOURQUIN	84	SPEC	SPS hyperon beam
• • • We do not use the following data for averages fits limits etc • • •						
<13	90	0	BOURQUIN	79B	SPEC	See BOURQUIN 84

Ω^- DECAY PARAMETERS

α FOR $\Omega^- \to \Lambda K^-$

Some early results have been omitted

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0 026 ± 0.026 OUR AVERAGE					
−0 034 ± 0 079	1743	LUK	88	SPEC	pBe 400 GeV
−0 025 ± 0 028	12k	BOURQUIN	84	SPEC	SPS hyperon beam

α FOR $\Omega^- \to \Xi^0 \pi^-$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.09 ± 0.14	1630	BOURQUIN	84	SPEC	SPS hyperon beam

α FOR $\Omega^- \to \Xi^- \pi^0$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.05 ± 0 21	614	BOURQUIN	84	SPEC	SPS hyperon beam

REFERENCES FOR Ω^-

We have omitted some papers that have been superseded by later experiments The omitted papers may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

LUK	88	PR D38 19	+Beretvas Deck+	(RUTG WISC MICH MINN)
HARTOUNI	85	PRL 54 628	+Atiya Holmes Knapp Lee+	(COLU ILL FNAL)
BOURQUIN	84	NP B241 1	+	(BRIS GEVA HEID LALO RAL STRB)
Also	79	PL 87B 297	Bourquin+	(BRIS GEVA HEID ORSA RHEL STRB)
BOURQUIN	79B	PL 88B 192	+	(BRIS GEVA HEID LALO RAL)
BAUBILLIER	78	PL 78B 342	+	(BIRM CERN GLAS MSU LPNP)
HEMINGWAY	78	NP B142 205	+Armenteros+	(CERN ZEEM NIJM OXF)
DIBIANCA	75	NP B98 137	+Endorf	(CMU)
ABCLV	73	NP B61 102	Deutschmann Kaufmann+	(ABCLV Collab)
ALVAREZ	73	PR D8 702	+	(LBL)
FIRESTONE	71B	PRL 26 410	+Goldhaber Lissauer Sheldon Trilling	(LRL)
SPETH	69	PL 29B 252	+	(AACH BERL CERN LOIC VIEN)
PALMER	68	PL 26B 323	+Radojicic Rau Richardson+	(BNL SYRA)
SCHULTZ	68	PR 168 1509	+	(ILL ANL NWES WISC)
SCOTTER	68	PL 26B 474	+	(BIRM GLAS LOIC MUNI OXF)
ABRAMS	64	PRL 13 670	+Burnstein Glasser+	(UMD NRL)
BARNES	64	PRL 12 204	+Connolly Crennell Culwick+	(BNL)
FRY	55	PR 97 1189	+Schneps Swami	(WISC)
FRY	55B	NC 2 346	+Schneps Swami	(WISC)
EISENBERG	54	PR 96 541		(CORN)

CHARMED BARYONS

Λ_c^+

$I(J^P) = 0(\frac{1}{2}^+)$

J has not actually been measured yet $J = 1/2$ is of course expected The quark content is udc

We have omitted some results that have been superseded by later experiments The omitted results may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

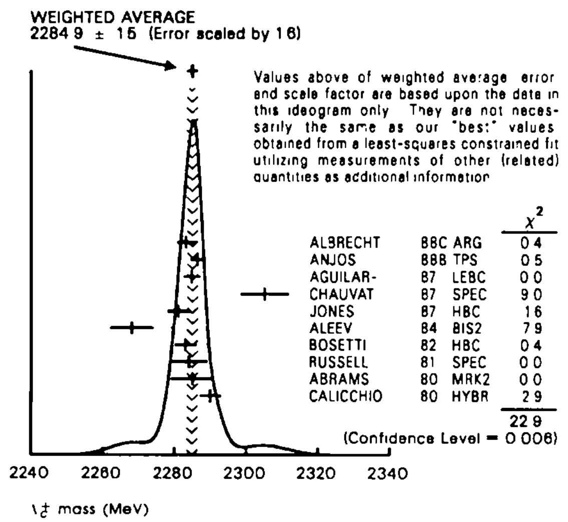
Λ_c^+ MASS

We only average the measurements with an error less than 10 MeV It seems clear that the early values around 2260 MeV were too low

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
2284.9 ± 1.5	**OUR FIT** Error includes scale factor of 1 6				
2284.9 ± 1.5	**OUR AVERAGE** Error includes scale factor of 1 6 See the ideogram below				
2283 1 ± 1 7 ± 2 0	628	ALBRECHT	88C	ARG	$pK^-\pi^+$ pK^0 $\Lambda 3\pi$
2286 2 ± 1.7 ± 0 7	97	ANJOS	88B	TPS	$pK^-\pi^+$ + c c
2284 7 ± 2 3 ± 0 5	5	AGUILAR-	87	LEBC	$pK^-\pi^+$ + c c
2305 ± 3 ± 6	621	CHAUVAT	87	SPEC	pp 63 GeV ISR
2281 ± 3	2	JONES	87	HBC	$pK^-\pi^+$
2268 ± 6	187	ALEEV	84	BIS2	$\Lambda\pi^+\pi^+\pi^-$ $pK_S^0\pi^+\pi^-$
2283 ± 3	3	BOSETTI	82	HBC	$pK^-\pi^+$
2284 ± 5	55	RUSSELL	81	SPEC	pK^0 + c c
2285 ± 6	39	ABRAMS	80	MRK2	$pK^-\pi^+$ + c c
2290 ± 3	1	CALICCHIO	80	HYBR	$pK^-\pi^+$
• • • We do not use the following data for averages, fits limits etc • • •					
2301 ± 17	4	ADAMOVICH	87	EMUL	γ A 20–70 GeV/c
2285 6 ± 1 1	14	[1] BARLAG	87	CCD	$pK^-\pi^+$
2293 ± 6 ± 30	78	DIESBURG	87	SPEC	nA ~600 GeV
2300 ± 25	1	AMMAR	86	EMUL	$\Sigma^+\pi^+\pi^-$
2266 ± 13	8	USHIDA	86	EMUL	Wideband ν
2270 ± 15	3	KITAGAKI	82	DBC	$\Sigma^0\pi^+$
2260 ± 20	1	ALLASIA	80	EMUL	$pK^-\pi^+$
2275 ± 10	19	KITAGAKI	80	DBC	$\Lambda\pi^+$, pK^0
2257 ± 10	6	BALTAY	79	HLBC	$\Lambda\pi^+$
2254 ± 12	1	CNOPS	79	DBC	$pK^*(892)^-\pi^+$
2262 ± 10	30	[2] GIBONI	79	SPEC	$pK^-\pi^+$
2260 ± 10	60	KNAPP	76	SPEC	$\Lambda 2\pi^-\pi^+$
2260 ± 20	1	CAZZOLI	75	HBC	$\Lambda 2\pi^+\pi^-$

[1] The BARLAG 87 error is statistical The systematic error is still under investigation

[2] GIBONI 79 has been changed from 2255 ± 4 MeV by the authors see KERNAN 79



Λ_c^+ MEAN LIFE

Measurements with an error $\geq$ 1 0 · 10 ^{13} s have been omitted

VALUE (10^{-13} sec)	EVTS	DOCUMENT ID		TECN	COMMENT
$1.79^{+0.23}_{-0.17}$ OUR AVERAGE					
2 2 ± 0 3 ± 0 2	97	ANJOS	88B	TPS	$pK^-\pi^+$ + c c
$2\ 3^{+0\ 9}_{-0\ 6}$ ± 0 4	11	ADAMOVICH	87	EMUL	γ A 20–70 GeV c
$1\ 2^{+0\ 5}_{-0\ 3}$	9	AGUILAR	87	LEBC	
$1\ 1^{+0\ 8}_{-0\ 4}$	9	AMENDOLIA	87	SPEC	γ Ge Si $pK^-\pi^+\pi^0$
$1\ 4^{+0\ 5}_{-0\ 3}$ ± 0 3	14	BARLAG	87	CCD	$pK^-\pi^+$ + c c
$2\ 0^{+0\ 7}_{-0\ 5}$	13	USHIDA	86	EMUL	

Λ_c^+ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	$\Lambda_c^+ \to pK^0$	(1 5 ± 0 6) × 10^{-2}	
Γ_2	$\Lambda_c^+ \to pK^-\pi^+$	(2 6 ± 0 9) × 10^{-2}	
Γ_3	$\Lambda_c^+ \to pK^*(892)^0$	($5\ 6^{+3\ 1}_{-2\ 8}$) × 10^{-3}	
Γ_4	$\Lambda_c^+ \to \Delta(1232)^{++}K^-$	($5\ 3^{+2\ 8}_{-2\ 6}$) × 10^{-3}	1 1
Γ_5	$\Lambda_c^+ \to p\bar{K}^0\pi^+\pi^-$	($7\ 4^{+3\ 6}_{-3\ 4}$) × 10^{-2}	
Γ_6	$\Lambda_c^+ \to pK^-\pi^+\pi^0$		
Γ_7	$\Lambda_c^+ \to pK^*(892)^-\pi^+$		
Γ_8	$\Lambda_c^+ \to \Delta(1232)K^*(892)$		
Γ_9	$\Lambda_c^+ \to p$ hadrons		
Γ_{10}	$\Lambda_c^+ \to p\bar{K}^0\pi^-\pi^0e^+\nu$		
Γ_{11}	$\Lambda_c^+ \to pe^+$ anything	(1 8 ± 0 9) × 10^{-2}	
Γ_{12}	$\Lambda_c^+ \to \Lambda\pi^+$	< 4 × 10^{-3}	
Γ_{13}	$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	(1 7 ± 0 7) × 10^{-2}	
Γ_{14}	$\Lambda_c^+ \to \Lambda e^+$ anything	(1 1 ± 0 8) × 10^{-2}	
Γ_{15}	$\Lambda_c^+ \to \Lambda$ anything	(27 ± 9) × 10^{-2}	
Γ_{16}	$\Lambda_c^+ \to \Sigma^+\pi^0$		
Γ_{17}	$\Lambda_c^+ \to \Sigma^0\pi^+$		
Γ_{18}	$\Lambda_c^+ \to \Sigma^+\eta$		
Γ_{19}	$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	(10 ± 8) × 10^{-2}	
Γ_{20}	$\Lambda_c^+ \to \Sigma^\pm$ anything	(10 ± 5) × 10^{-2}	
Γ_{21}	$\Lambda_c^+ \to e^+$ anything	(4 5 ± 1 7) × 10^{-2}	

CONSTRAINED FIT INFORMATION

An overall fit to 7 branching ratios uses 10 measurements and one constraint to determine 7 parameters The overall fit has a χ^2 = 3 5 for 4 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i\delta x_j\rangle/(\delta x_i\cdot\delta x_j)$ in percent from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

x_2	84				
x_3	53	63			
x_4	55	65	41		
x_5	54	65	40	42	
x_{13}	67	79	50	52	81
	x_1	x_2	x_3	x_4	x_5

Λ_c^+ BRANCHING RATIOS

$\Gamma(pK^-\pi^+)/\Gamma_{total}$ Γ_2/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.026 ± 0 009 OUR FIT						
0.022 ± 0.010		39	ABRAMS	80	MRK2	e^+e^- 5 2 GeV
• • • We do not use the following data for averages fits limits etc • • •						
>0 044	90	6	[3] AGUILAR	87B	LEBC	pp 27 4 GeV

[3] The AGUILAR BENITEZ 87B lower limit is on the face of it in disagreement with the ABRAMS 80 measurement However the limit assumes that $\tau(\Lambda_c)$ = 1 2 × 10^{-13} s and it decreases by 20% [to > 0 035] assuming a life time of 1 7 × 10^{-13} s instead Our average for $\tau(\Lambda_c)$ is still higher

$(1\ 79^{+0\ 23}_{-0\ 17})\times 10^{-13}$ s (see the mean-life section) which if correct would further reduce the limit The two experiments then do not disagree so badly Given the very limited statistics and the uncertainties all around we stick with the ABRAMS 80 result which claims to be a measurement rather than a limit and wait for a good measurement

$\Gamma(p\bar{K}^0)/\Gamma(pK^-\pi^+)$ — Γ_1/Γ_2

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
0.59 ± 0.13 OUR FIT					
0.59 ± 0.13 OUR AVERAGE					
0 62 ± 0 15 ± 0 03		73	ALBRECHT 88C	ARG	e^+e^- 10 GeV
0 5 ± 0.25		12	WEISS 80	MRK2	e^+e^- 5 2 GeV
• • • We do not use the following data for averages, fits, limits, etc • • •					
>0 67	90	50	RUSSELL 81	SPEC	Photoproduction

$\Gamma(p\bar{K}^*(892)^0)/\Gamma(pK^-\pi^+)$ — Γ_3/Γ_2

Corrected for the $K^{*0} \to \bar{K}^0\pi^0$ mode

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.22 ± 0.09 OUR FIT				
0.22 ± 0.09 OUR AVERAGE				
0 42 ± 0 24	12	BASILE 81B	CNTR	$pp \to \Lambda_c^+ e^- X$
0.18 ± 0 10		WEISS 80	MRK2	e^+e^- 5 2 GeV

$\Gamma(\Delta(1232)^{++}K^-)/\Gamma(pK^-\pi^+)$ — Γ_4/Γ_2

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.20 ± 0.08 OUR FIT Error includes scale factor of 1 3				
0.20 ± 0.08 OUR AVERAGE Error includes scale factor of 1 3				
0.40 ± 0 17	17	BASILE 81B	CNTR	$pp \to \Lambda_c^+ e^- X$
0 17 ± 0.07		WEISS 80	MRK2	e^+e^- 5 2 GeV

$\Gamma(p\bar{K}^0\pi^+\pi^-)/\Gamma(p\bar{K}^0)$ — Γ_5/Γ_1

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •					
<3 3	90	45	RUSSELL 81	SPEC	Photoproduction

$\Gamma(pK^-\pi^+\pi^0)/\Gamma_{total}$ — Γ_6/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
SEEN	44	AMENDOLIA 87	SPEC	γ Ge Si

$\Gamma(pK^*(892)^-\pi^+)/\Gamma_{total}$ — Γ_7/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
SEEN	1	CNOPS 79	DBC	νN in BNL 7-ft

$\Gamma(\Delta(1232)\bar{K}^*(892))/\Gamma_{total}$ — Γ_8/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
SEEN	35	AMENDOLIA 87	SPEC	γGe-Si

$\Gamma(p\text{ hadrons})/\Gamma_{total}$ — Γ_9/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits, etc • • •			
0.41 ± 0.24	ADAMOVICH 87	EMUL	γA 20-70 GeV/c

$\Gamma(pe^+\text{ anything})/\Gamma_{total}$ — Γ_{11}/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.018 ± 0.009	[4] VELLA 82	MRK2	e^+e^- 4 5-6 8 GeV

[4]VELLA 82 includes protons from Λ decay

$\Gamma(\Lambda\pi^+)/\Gamma(p\bar{K}^0)$ — Γ_{12}/Γ_1

We regard this mode as seen, but with a limit given by the ALBRECHT 88C result

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
<0.26	90		[5] ALBRECHT 88C	ARG	e^+e^- 10 GeV
• • • We do not use the following data for averages, fits, limits, etc • • •					
<0 4	90	40	RUSSELL 81	SPEC	Photoproduction
$0\ 51^{+0\ 62}_{-0\ 27}$		9	KITAGAKI 80	DBC	ν d in FNAL 15 ft
$0\ 67^{+0.78}_{-0\ 35}$		5	[6] BALTAY 79	HLBC	ν Ne-H in 15 ft

[5]This ALBRECHT 88C result is redundant with their limit on $\Gamma(\Lambda\pi^+)/\Gamma(pK^-\pi^+)$ below

[6]Calculated by KITAGAKI 80 from BALTAY 79 results

$\Gamma(\Lambda\pi^+)/\Gamma(pK^-\pi^+)$ — Γ_{12}/Γ_2

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.16	90	ALBRECHT 88C	ARG	e^+e^- 10 GeV
• • • We do not use the following data for averages fits limits etc • • •				
<0 8	90	WEISS 80	MRK2	e^+e^- 5 2 GeV

$\Gamma(\Lambda\pi^+\pi^+\pi^-)/\Gamma_{total}$ — Γ_{13}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.017 ± 0.007 OUR FIT				
0.028 ± 0.007 ± 0.011	70	[7] BOWCOCK 85	CLEO	e^+e^- 10 5 GeV

[7]See BOWCOCK 85 for assumptions made on charm production and Λ_c production from charm to get this result

$\Gamma(\Lambda\pi^+\pi^+\pi^-)/\Gamma(p\bar{K}^0)$ — Γ_{13}/Γ_1

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits etc • • •					
<3 1	90	220	RUSSELL 81	SPEC	Photoproduction

$\Gamma(\Lambda\pi^+\pi^+\pi^-)/\Gamma(pK^-\pi^+)$ — Γ_{13}/Γ_2

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
0.66 ± 0.16 OUR FIT					
0.61 ± 0.16 ± 0.04		105	ALBRECHT 88C	ARG	e^+e^- 10 GeV
• • • We do not use the following data for averages fits limits etc • • •					
<1 4	90		WEISS 80	MRK2	e^+e^- 5 2 GeV

$\Gamma(p\bar{K}^0\pi^+\pi^-)/\Gamma(\Lambda\pi^-\pi^+\pi^-)$ — Γ_5/Γ_{13}

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
4.3 ± 1.2 OUR FIT				
4.3 ± 1.2	130	ALEEV 84	BIS2	nC 40-70 GeV

$\Gamma(\Lambda e^+\text{ anything})/\Gamma_{total}$ — Γ_{14}/Γ

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
0.011 ± 0.008			[8] VELLA 82	MRK2	e^+e^- 4 5-6 8 GeV
• • • We do not use the following data for averages, fits limits etc • • •					
<0 022	90	1	BALLAGH 81	HYBR	ν Ne-H in 15-ft

[8]VELLA 82 includes Λ s from Σ^0 decay

$\Gamma(\Lambda\text{ anything})/\Gamma_{total}$ — Γ_{15}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.27 ± 0.09 OUR AVERAGE				
0 49 ± 0.24		ADAMOVICH 87	EMUL	γA 20-70 GeV/c
0.23 ± 0 10	8	[9] ABE 86	HYBR	20 GeV γp

[9]ABE 86 includes Λ s from Σ^0 decay

$\Gamma(\Lambda e^+\text{ anything})/\Gamma(\Lambda\text{ anything})$ — Γ_{14}/Γ_{15}

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits etc • • •			
0.027 ± 0 017	[10] SON 82	DBC	ν d in FNAL 15 ft

[10]SON 82 uses own data and $\Lambda\mu^-e^+$ events of MURTAGH 79

$\Gamma(\Sigma^0\pi^-)/\Gamma_{total}$ — Γ_{17}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
SEEN	3	KITAGAKI 82	DBC	ν d in FNAL 15-ft

$\Gamma(\Sigma^+\pi^+\pi^-)/\Gamma_{total}$ — Γ_{19}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.10 ± 0.08		ADAMOVICH 87	EMUL	γA 20-70 GeV/c
• • • We do not use the following data for averages fits limits, etc • • •				
SEEN	1	AMMAR 86	EMUL	νA

$\Gamma(\Sigma^\pm\text{ anything})/\Gamma_{total}$ — Γ_{20}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.1 ± 0.05	5	ABE 86	HYBR	20 GeV γp

$\Gamma(e^+\text{ anything})/\Gamma_{total}$ — Γ_{21}/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.045 ± 0.017	VELLA 82	MRK2	e^+e^- 4 5-6 8 GeV

REFERENCES FOR Λ_c^+

We have omitted some papers that have been superseded by later experiments The omitted papers may be found in our 1986 edition (Physics Letters 170B) or in earlier editions

ALBRECHT 88C PL B207 109 + (ARGUS Collab)
ANJOS 88B PRL 60 1379 +Appel+ (Tagged Photon Spectrometer Collab)
ADAMOVICH 87 EPL 4 887 +Alexandrov Bolta+ (Photon Emulsion Collab)
AGUILAR 87 PL B189 254 Aguilar-Benitez Allison Bailly+(LEBC EHS Collab)
AGUILAR 87B PL B199 462 Aguilar Benitez Allison Bailly+(LEBC EHS Collab)
AMENDOLIA 87 ZPHY C36 513 +Bagliesi Batignani Beck+ (CERN NA1 Collab)
BARLAG 87 PL B184 283 + (MPIM CERN RAL ANIK BRIS CRAC+)
CHAUVAT 87 PL B199 304 +Cousins Hayes+ (CERN UCLA SACL UDCF)
DIESBURG 87 PRL 59 2711 +Ladbury+ (COLO ILL FNAL BGNA MILA INFN)
JONES 87 ZPHY C36 593 +Jones+ (BIRM CERN LOIC MPIM OXF LOUC)
ABE 86 PR D33 1 + (SLAC Hybrid Facility Photon Collab)
AMMAR 86 JETPL 43 515 +Ammosov Bakic Baranov Burnett+ (ITEP)
Translated from ZETFP 43 401
USHIDA 86 PRL 56 1767 +Kondo+ (AICH FNAL GIFU GYEO KOBE SEOU+)
BOWCOCK 85 PRL 55 923 +Giles Hassard Kinoshita+ (CLEO Collab)
ALEEV 84 ZPHY C23 333 +Arefiev Balandin Berdyshev+ (BIS 2 Collab)
BOSETTI 82 PL 109B 234 +Graessler+ (AACH BONN CERN MPIM OXF)
KITAGAKI 82 PRL 48 299 +Tanaka Yuta+ (TOHO IIT UMD STON TUFT)
SON 82 PRL 49 1128 +Snow Chang+ (UMD IIT STON TOHO TUFT)
VELLA 82 PRL 48 1515 +Trilling Abrams Alam+ (SLAC LBL UCB)
BALLAGH 81 PR D24 7 +Bingham+ (LBL UCB FNAL HAWA WASH WISC)
BASILE 81B NC 62A 14 +Romeo+ (CERN BGNA PGIA FRAS)
RUSSELL 81 PRL 46 799 +Avery Butler Gladding+ (ILL FNAL COLU)
ABRAMS 80 PRL 44 10 +Alam Blocker Boyarski+ (SLAC LBL)
ALLASIA 80 NP B176 13 + (ANKA LIBH CERN DUUC LOUC KEYN+)
CALICCHIO 80 PL 93B 521 + (BARI BIRM BRUX CERN EPOL RHEL+)
KITAGAKI 80 PRL 45 955 +Tanaka Yuta+ (TOHO IIT UMD STON TUFT)
WEISS 80 Toronto Conf 319 (SLAC)

BALTAY	79	PRL 42 1721	*+Caroumbalis French Hibbs+*	(COLU BNL)
CNOPS	79	PRL 42 197	+Connolly Kahn Kirk Murtagh Palmer+	(BNL)
GIBONI	79	PL 85B 437	+	(AACH CERN HARV MUNI NWES UCR)
KERNAN	79	Lepton Conf FNAL		(UCR)
MURTAGH	79	Fermilab Symp 277		(FNAL)
KNAPP	76	PRL 37 882	*+Lee Leung Smith+*	(COLU HAWA ILL FNAL)
CAZZOLI	75	PRL 34 1125	+Cnops Connolly Louttit Murtagh+	(BNL)

——— OTHER RELATED PAPERS ———

GRAB	87	SLAC PUB 4372		(SLAC)
EPS Conference Uppsala				
SCHINDLER	87	SLAC PUB 4417		(SLAC)
EPS Conference Uppsala, Proc Vol 1 p 341				
SCHUBERT	87	IHEP HD/87 7		(HEID)
EPS Conference Uppsala Proc Vol 2 p 791				
SNYDER	87	IUHEEE 87 11		(IND)
Symp on Prod and Decay of Heavy Flavors Stanford				
AMMAR	86	JETPL 43 515	+Ammosov Bakic Baranov Burnett+	(ITEP)
		Translated from ZETFP 43 401		
SCHINDLER	86	SLAC PUB 4136		(SLAC)
World Press International				
SCHINDLER	86B	SLAC PUB-4248		(SLAC)
SLAC Summer Institute				

$\Sigma_c(2455)$

$I(J^P) = 1(?^?)$

SEE BARYON RESONANCES

Ξ_c^+ was A^+

$I(J^P) = ?(?^?)$

Narrow signals (widths compatible with resolutions) interpreted as a stable charmed strange baryon (quark content *usc*) Although COTEUS 87 claims to agree well with BIAGI 83 on the mass and width, there appears to be a discrepancy between the two experiments BIAGI 83 sees a single peak (stated significance about 6 standard deviations) in the $\Lambda K^- \pi^+ \pi^+$ mass spectrum COTEUS 87 sees *two* peaks in the same spectrum, one at the Ξ_c^+ mass, the other 75 MeV lower The latter is attributed to $\Xi_c^+ \to \Sigma^0 K^- \pi^+ \pi^+ \to (\Lambda\gamma) K^- \pi^+ \pi^+$, with the γ unseen The *combined* significance of the double peak is stated to be 5 5 standard deviations But the absence of any *trace of a lower peak in BIAGI 83 seems to us to throw* into question the interpretation of the lower peak of COTEUS 87, and to lessen the significance of COTEUS 87 as confirmation of the Ξ_c^+

With some hesitation, we elevate the Ξ_c^+ to the Stable Particle Table

BIAGI 85B looked for the isospin partner Ξ_c^0 in $\Lambda K^- \pi^+$ and other channels without success

Ξ_c^+ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2460 ± 19 OUR AVERAGE					
2459 ± 5 ± 30	56	COTEUS	87	SPEC	nA ~ 600 GeV
2460 ± 25	82	BIAGI	83	SPEC	Σ^-Be 135 GeV

Ξ_c^+ MEAN LIFE

VALUE (10^{-13} sec)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{4.3^{+1.7}_{-1.2}}$ **OUR AVERAGE**					
$4.0^{+1.8+1.0}_{-1.2-1.0}$		COTEUS	87	SPEC	nA ~ 600 GeV
$4.8^{+2.9}_{-1.8}$	53	BIAGI	85C	SPEC	Σ^-Be 135 GeV

Ξ_c^+ DECAY MODES

Γ_1 $\Xi_c^+ \to \Lambda K^- \pi^+ \pi^+$

Γ_2 $\Xi_c^+ \to \Sigma^0 K^- \pi^+ \pi^+$

Ξ_c^+ BRANCHING RATIOS

$\Gamma(\Lambda K^- \pi^+ \pi^+)$ Γ_1

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
SEEN	82	[1] BIAGI	83	SPEC	Σ^-Be 135 GeV

[1] *BIAGI 85B look for but do not see the Ξ_c^+ in $pK^-K^0\pi^+$* (branching fraction < 0 08 with 90% CL) $p2K^-2\pi^+$ (< 0 03 90% CL) $\Omega^- K^+ \pi^+$ $\Lambda K^{*0} \pi^+$ and $\Sigma(1385)^+ K^- \pi^+$

$\Gamma(\Sigma^0 K^- \pi^+ \pi^+)/\Gamma(\Lambda K^- \pi^+ \pi^+)$ Γ_2/Γ_1

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.84 ± 0.36	102	COTEUS	87	SPEC	nA ~ 600 GeV

REFERENCES FOR Ξ_c^+

COTEUS	87	PRL 59 1530	+Binkley+	(COLO ILL FNAL BGNA MILA INFN)
BIAGI	85B	ZPHY C28 175	+	(BRIS CERN GEVA HEID LAUS LOQM+)
BIAGI	85C	PL 150B 230	+	(BRIS CERN GEVA HEID LAUS LOQM+)
BIAGI	83	PL 122B 455	+	(BRIS CERN GEVA HEID LAUS LOQM+)

Ω_c^0 was T^0

$I(J^P) = ?(?^?)$

OMITTED FROM SUMMARY TABLE

A cluster of three $\Xi^- K^- \pi^+ \pi^+$ events The $\Omega_c^0 - \Xi_c^+$ mass difference is 280 ± 10 MeV The existence of the effect and its interpretation as being the Ω_c^0 (quark content *ssc*) need confirmation

Ω_c^0 MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2740 ± 20	3	BIAGI	85B	SPEC	Σ^-Be →

REFERENCES FOR Ω_c^0

BIAGI	85B	ZPHY C28 175	+	(BRIS CERN GEVA HEID LAUS LOQM+)

BOTTOM BARYON

Λ_b^0

$I(J^P) = ?(?^?)$

OMITTED FROM SUMMARY TABLE

The claim by BASILE 81 to have discovered the Λ_b^0 (quark content *udb*) is hotly disputed by DRIJARD 82 BASILE 82 is the reply, and DRIJARD 82B is the reply to that

The decay of the Λ_b^0 to the final state observed by ARENTON 86 is Cabibbo suppressed, whereas the decay of a Ξ_b^0 to this final state is allowed ARENTON 86 thus only claims to have observed a baryon which probably has a *b* quark and which has a D^0 among the decay products, not necessarily the Λ_b^0

Stable Particle Full Listings

Λ_b^0, TOP AND FOURTH GENERATION HADRON SEARCHES

Λ_b^0 MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
~5750	4	ARENTON	86	FMPS	$\Lambda K_S^0 2\pi^+ 2\pi^-$
5425^{+175}_{-75}		BASILE	81	SFM	62 GeV pp

Λ_b^0 DECAY MODES

Γ_1 $\Lambda_b^0 \to p D^0 \pi$

Γ_2 $\Lambda_b^0 \to \Lambda K^0 2\pi^+ 2\pi^-$

Λ_b^0 BRANCHING RATIOS

$\Gamma(pD^0\pi^-)$ Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
SEEN	BASILE	81	SFM	$D^0 \to K^-\pi^+$

$\Gamma(\Lambda K^0 2\pi^+ 2\pi^-)$ Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
SEEN	4	ARENTON	86	FMPS	$\Lambda K_S^0 2\pi^+ 2\pi^-$

REFERENCES FOR Λ_b^0

ARENTON	86	NP B274 707	+Chen Cormell Dieterle+	(ARIZ NDAM VAND)
BASILE	82	NC 68A 289	+Bonvicini Romeo+	(CERN BGNA FRAS)
DRIJARD	82	PL 108B 361	+	(CERN CDEF DORT HEID LAPP WARS)
DRIJARD	82B	CERN EP 82 31	+	(CERN CDEF DORT HEID LAPP WARS)
BASILE	81	LNC 31 97	+Bonvicini Romeo+	(CERN BGNA FRAS PGIA)

SEARCHES

SEARCHES FOR TOP AND FOURTH GENERATION HADRONS

Experiments at e^+e^- colliders search for both top-flavored hadrons and vector toponium states, whereas experiments at $p\bar{p}$ colliders search only for top-flavored hadrons Theoretical uncertainties are relatively small in e^+e^- collisions although details of the production cross section at threshold are not known but uncertainties in pp collisions are large due to our present ignorance of the details of the parton distributions in a proton and (to a lesser extent) of higher-order QCD corrections

MASS LIMITS FOR TOP AND FOURTH GENERATION HADRONS IN e^+e^- COLLISIONS

The last column specifies measured quantities S = Sphericity T = Thrust

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>25.9	**95**	[1] SAGAWA	88	AMY	R T
• • • We do not use the following data for averages fits limits etc • • •					
>25 8	95	[2] ADACHI	88	TOPZ	R T Acoplanarity
none E_{cm}=50	95	[3] ABE	87	VENS	R T Acoplanarity
>25 5	95	[4] YOSHIDA	87	VENS	R T Acoplanarity
none E_{cm} = 39 79–46 78	95	[5] ADEVA	86	MRKJ	R T μ
none E_{cm} = 40–46 78	95	[6] ADEVA	85	MRKJ	μ
none E_{cm} = 39 8–45 2		[7] ALTHOFF	84C	TASS	R event shape
none E_{cm} = 12 –43		[8] ALTHOFF	84I	TASS	Aplanarity
none E_{cm} = 33–36 72	95	[9] BEHREND	84D	CELL	Aplanarity
none E_{cm} = 38 66–46 78	95	[9] BEHREND	84D	CELL	Aplanarity
none E_{cm} < 38 54	99	[10] ADEVA	83	MRKJ	R T ($\mu^+\mu^-X$)
none E_{cm} < 38		ADEVA	83B	MRKJ	$p_T(\mu)$ T
none E_{cm} = 14–36 7		[11] BRANDELIK	82	TASS	R
none E_{cm} = 33–35 8		[12] BARTEL	81	JADE	μ
none E_{cm} = 30–36		[13] BARBER	80	MRKJ	R T μ
none E_{cm} = 12–31 6		[14] BERGER	80	PLUT	μ
none E_{cm} = 31 6		[15] BARBER	79	MRKJ	R S T
none E_{cm} = 22–31 6		[16] BARTEL	79	JADE	R
none E_{cm} = 22–31 6		[17] BARTEL	79B	JADE	S
none E_{cm} = 22–31 6		[18] BERGER	79B	PLUT	R S T μ

[1] SAGAWA 88 set limit σ(top) < 6 1 pb at CL=95% for top flavored hadron production from event shape analyses at E_{cm} = 52 GeV By using the quark parton model cross section formula near threshold the above limit leads to lower mass bounds of 25 9 GeV (23 8 GeV) for charge 2/3 (−1/3) quarks

[2] ADACHI 88 set limit σ(top) < 8 2 pb at CL=95% for top-flavored-hadron production from event shape analyses at E_{cm} = 52 GeV By using the quark parton model cross section formula with first order QCD corrections near the threshold the above limit leads to a lower mass limit of 25 8 GeV at 95% confidence level for top quarks

[3] ABE 87 set limit σ(top) < 16 pb at CL=95% for top-flavored hadron production which should be compared with the full top quark production cross section of 45 9 pb

[4] YOSHIDA 87 set limit σ(top) < 17 pb at CL=95% for top flavored hadron production from event shape analyses at E_{cm} = 52 GeV This limit should be compared with the full top quark production cross section of 34 pb which takes into account the effect of weak neutral current but neglects its axial-vector coupling contribution expected to be suppressed near threshold After considering the radiative effects top quarks of mass below 25 5 GeV can be excluded by the above limit

[5] ADEVA 86 give 95%CL upper bound on an excess of the normalized cross section ΔR as a function of the minimum c m energy (see their figure 3) An increase of the hadronic cross section predicted for full top quark production (ΔR_{top} ~ 1 5) is then excluded up to E_{cm} = 46 6 GeV Production of a pair of 1 3 charge quarks is excluded up to E_{cm} = 45 4 GeV Toponium search sets limit $\Gamma(e^+e^-)$BR(hadrons) < 3 keV at CL=95% at E_{cm} = 44–46 GeV Also reported is an observation of eight low thrust hadron events containing muons which remains unexplained

[6] ADEVA 85 exclude toponium below 46 6 GeV and open top continuum below 23 3 GeV at CL = 95% Toponium search sets limit $\Gamma(e^+e^-)$BR(hadrons) 3 keV

[7] ALTHOFF 84C narrow state search sets limit $\Gamma(e^+e^-)$BR(hadrons) 2 4 keV CL = 95% and heavy charge 1/3 (2/3) quark pair production m 21 GeV (22 GeV) CL = 95%

[8] ALTHOFF 84I exclude heavy quark pair production for masses in GeV 5 m 20 3 (2/3 charge) and 7 m 19 (1/3 charge) using aplanarity Distributions (CL = 95%)

[9] BEHREND 84D exclude toponium below 46 7 GeV and continuum production below 23 3 GeV (2/3 charge) and 22 7 GeV (1/3 charge) at CL = 90% Toponium search sets limit $\Gamma(e^+e^-)$BR(hadrons) 2 9 keV where toponium is expected to have $\Gamma(e^+e^-)$ = 4–5 keV

[10] ADEVA 83 energy scan excludes open top continuum below 38 54 GeV and toponium between 29 90 and 38 63 GeV $\Gamma(e^+e^-)$BR(hadrons) 2 0 keV at CL = 95%) Also set limit BR($B \to \mu^+\mu^- X$) 0 007 (CL = 95%) which excludes flavor-changing neutral current in topless models

[11] BRANDELIK 82 got R = 4 01 ± 0 03 ± 0 2 with no step for W 14 GeV Narrow state search for W = 33–36 7 GeV sets $\Gamma(e^+e^-)$BR(hadrons) 1 5 keV (CL = 95%)

[12] BARTEL 81 measures inclusive muons with momentum 1 4 GeV/c Agree with expected semileptonic decays from charmed and bottom mesons

[13] BARBER 80 find no evidence for an open top antitop threshold in R thrust distributions and inclusive muons Energy scan in the range 29 9 E_{cm} 31 6 GeV reveals no hadron resonance corresponding to a (top-quark antitop quark) bound state

[14] BERGER 80 measures inclusive muons with momentum 2 GeV/c Agree with expected semileptonic decays from charmed and bottom mesons

[15] BARBER 79 R thrust sphericity indicate top production unlikely

[16] BARTEL 79 saw no evidence of new Q = 2/3 quark production in R-ratio

[17] BARTEL 79B observe no significant accumulation of spherical events

[18] BERGER 79B find R = 3 88 + 0 22 which along with sphericity and thrust behaviors is against open top antitop channel below 30 GeV Final muons are also consistent with expectation without top quark state

MASS LIMITS FOR TOP AND FOURTH GENERATION HADRONS IN $p\bar{p}$ COLLISIONS

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>44	95	[19] ALBAJAR	88	UA1	for top hadrons
>32	90	[19] ALBAJAR	88	UA1	for b' hadrons

[19] ALBAJAR 88 study events at E_{cm} = 546 and 630 GeV with a muon or isolated electron accompanied by one or more jets and find agreement with Monte Carlo predictions for the production of charm and bottom, without the need for a new quark The top quark mass bound $m(t)$ > 44 GeV (CL=95%) is obtained by using the $W \to tb$ cross section normalized to their own $W \to \ell\nu$ rate and by adding to it the $t\bar{t}$ contribution with a conservative value of the cross section with the lowest order calculation The analysis is not sensitive to the $W \to tb$ process alone For a fourth generation, charge −1/3 quark (b') a lower mass limit $m(b')$ > 32 GeV (CL=90%) is obtained by using the same conservative estimate for the $b'\bar{b}'$ production cross section and by assuming that it cannot be produced in W decays

REFERENCES FOR SEARCHES FOR TOP AND FOURTH GENERATION HADRONS

ADACHI	88	PRL 60 97	+Aihara Dijkstra+	(TOPAZ Collab)
ALBAJAR	88	ZPHY C37 505	+Albrow Allkofer+	(UA1 Collab)
SAGAWA	88	PRL 60 93	+Mori Abe+	(AMY Collab)
ABE	87	JPSJ 56 3763	+Amako Arai+	(VENUS Collab)
YOSHIDA	87	PL B198 570	+Chiba Endo+	(VENUS Collab)
ADEVA	86	PR D34 681	+Ansari Becker Becker Szendy+	(MARK J Collab)
ADEVA	85	PL 152B 439	+Becker Becker Szendy+	(MARK J Collab)
ALTHOFF	84C	PL 138B 441	+Braunschweig kirschfink+	(TASSO Collab)
ALTHOFF	84I	ZPHY C22 307	+Braunschweig Kirschfink+	(TASSO Collab)
BEHREND	84D	PL 144B 297	+Buerger Criegee Fenner+	(CELLO Collab)
ADEVA	83	PRL 50 799	+Barber Becker Berdugo+	(MARK J Collab)
ADEVA	83B	PRL 51 443	+Barber Becker Berdugo+	(MARK J Collab)
BRANDELIK	82	PL 113B 499	+Braunschweig Gather+	(TASSO Collab)
BARTEL	81	PL 99B 277	+Cords Dittmann Eichler+	(Jade Collab)
BARBER	80	PRL 44 1722	+Becker Benda Boehm+	(MARK J Collab)
BERGER	80	PRL 45 1533	+Gnezel Grigull Lockas+	(PLUTO Collab)
BARBER	79	PL 85B 463	+Becker Benda+	(MARK J Collab)
BARTEL	79	PL 88B 171	+Canzler Cords Dittmann+	(JADE Collab)
BARTEL	79B	PL 89B 136	+Canzler Cords Dittmann+	(JADE Collab)
BERGER	79B	PL 86B 413	+Genzel Grigull Lockas+	(PLUTO Collab)

FREE QUARK SEARCHES

NOTE ON QUARK SEARCHES

(by W P Trower, Virginia Polytechnic Institute and State University)

The basis for much of the theory of particle scattering and hadron spectroscopy is the construction of the hadrons from a set of fractionally charged constituents (quarks) Central to this theory, QuantumChromoDynamics, is the as yet unproven prohibition that quarks must forever be confined to the mesons and baryons they make up

Experiments show that it is at best difficult to "unglue" quarks Accelerator searches at increasing energies have produced no evidence for free quarks, while only a few cosmic-ray and matter searches have produced uncorroborated events

This compilation is only a guide to the literature, since the quoted experimental limits are often only indicative

QUARK PRODUCTION CROSS SECTION — ACCELERATOR SEARCHES

X SECT (cm^2)	CHG (e/3)	MASS (GeV)	ENERGY (GeV)	BEAM	EVTS	DOCUMENT ID		TECN
<1 E−4	±1 2 4	·4	10	e^+e^-	0	[1] ALBRECHT	85G	ARG
<6 E−5	±1 2	1	540	$p\bar{p}$	0	[2] BANNER	85	UA2
<5 E−3	−4	1−8	29	e^+e^-	0	[1] AIHARA	84	TPC
<1 E−2	±1,2	1−13	29	e^+e^-	0	[1] AIHARA	84B	TPC
<2 E−4	±1		72	^{40}Ar	0	[2 3] BARWICK	84	CNTR
<1 E−40	±1 2	<10		$p\nu\bar{\nu}$	0	BERGSMA	84B	CHRM
<1 E−4	±2	<0 4	1 4	e^+e^-	0	[1] BONDAR	84	CNTR
<5 E−1	±1 2	<13	29	e^+e^-	0	[1] GURYN	84	CNTR
<1 E−36	±1,2	<9	200	μ	0	AUBERT	83C	SPEC
<3 E−3	±1,2	<2	540	$p\bar{p}$	0	[2] BANNER	83	CNTR
<1 E−4	±1,2		106	^{56}Fe	0	[2] LINDGREN	83	CNTR
<3 E−3	> ±1/6		74	^{40}Ar	0	[2 3] PRICE	83	PLAS
<1 E−2	±1 2	<14	29	e^+e^-	0	[1] MARINI	82B	CNTR
<8 E−2	±1,2	<12	29	e^+e^-	0	[1] ROSS	82	CNTR
<2 E−10	±2 4	1−3	200	p	0	[4] BUSSIERE	80	CNTR
<5 E−38	+1,2	>5	300	p	0	[5 6] STEVENSON	79	CNTR
<1 E−33	±1	<20	52	pp	0	BASILE	78	SPEC
<9 E−39	±1,2	<6	400	p	0	[5] ANTREASYAN	77	SPEC
<8 E−35	+1 2	<20	52	pp	0	[7] FABJAN	75	CNTR
<5 E−38	−1 2	4−9	200	p	0	NASH	74	CNTR
<1 E−32	+2 4	4−24	52	pp	0	ALPER	73	SPEC
<5 E−31	+1 2 4	<12	300	p	0	LEIPUNER	73	CNTR
<6 E−34	±1 2	<13	52	pp	0	BOTT	72	CNTR
<1 E−36	−4	4	70	p	0	ANTIPOV	71	CNTR
<1 E−35	±1 2	2	28	p	0	[8] ALLABY	69B	CNTR
<4 E−37	−2	<5	70	p	0	[4] ANTIPOV	69	CNTR
<3 E−37	−1 2	2−5	70	p	0	[8] ANTIPOV	69B	CNTR
<1 E−35	+1,2	<7	30	p	0	DORFAN	65	CNTR
<2 E−35	−2	<2 5−5	30	p	0	[9] FRANZINI	65B	CNTR
<5 E−35	+1 2	<2 2	21	p	0	BINGHAM	64	HLBC
<1 E−32	+1 2	<4 0	28	p	0	BLUM	64	HBC
<1 E−35	+1,2	<2 5	31	p	0	[9] HAGOPIAN	64	HBC
<1 E−34	+1	<2	28	p	0	LEIPUNER	64	CNTR
<1 E−33	+1 2	<2 4	24	p	0	MORRISON	64	HBC

[1] For cross section read cross section (q-q X) / cross section (μ μ)
[2] For cross section read fraction of fragments
[3] Bound to nuclei
[4] Hadronic or leptonic quarks
[5] Cross section cm^2/GeV^2
[6] 3×10^{-5} · lifetime · 1×10^{-3} s
[7] Includes BOTT 72 results
[8] Assumes isotropic cm production
[9] Cross section inferred from flux

QUARK DIFFERENTIAL PRODUCTION CROSS SECTION ACCELERATOR SEARCHES

X SECT (cm^2/sr/GeV)	CHG e/3	MASS (GeV)	ENERGY (GeV)	BEAM	EVTS	DOCUMENT ID		TECN
<4 E−36	−2 4	1 5−6	70	p	0	BALDIN	76	CNTR
<2 E−33	±4	5−20	52	pp	0	ALBROW	75	SPEC
<5 E−34	<7	7−15	44	pp	0	JOVANOV	75	CNTR
<5 E−35			20	γ	0	[10] GALIK	74	CNTR
<9 E−35	−1 2		200	p	0	NASH	74	CNTR
<4 E−36	−4	2 3−2 7	70	p	0	ANTIPOV	71	CNTR
<3 E−35	±1 2	<2 7	27	p	0	ALLABY	69B	CNTR
<7 E−38	−1 2	<2 5	70	p	0	ANTIPOV	69B	CNTR

[10] Cross section in cm^2/sr/equivalent quanta

QUARK FLUX ACCELERATOR SEARCHES

The definition of FLUX depends on the experiment
(a) is the ratio of measured free quarks to predicted free quarks if there is no confinement
(b) is the probability of fractional charge on nuclear fragments
(c) is the 90% upper limit on fractional charge produced per incident ^{16}O
(d) is quarks per collision
(e) is quark production cross section ratio to $\sigma(e^+e^- \to \mu^+\mu^-)$
(f) is quark flux per charged particle
(g) is the flux per ν event

FLUX		CHG (e/3)	MASS (GeV)	ENRGY (GeV)	BEAM	EVTS	DOCUMENT ID		TECN
<5 E−5	g	1 2	<0.5		$\nu\nu d$	0	ALLASIA	88	BEBC
<3 E−4	b	See note		14 5	^{16}OPb	0	[11] HOFFMANN	88	PLAS
<2 E−4	b	See note		200	^{16}OPb	0	[12] HOFFMANN	88	PLAS
<2 E−4	a	±1 2	· 300	320	$\bar{p}p$	0	LYONS	87	MLEV
<2 E−9	c	±1 2		14.5	^{16}OHg	0	SHAW	87	MDRP
<3 E−3	d	−1,2,3,4 6	<5	2	SiSi	0	[13] ABACHI	86C	CNTR
<3 E−4	e	±2	1 8−2	7	e^+e^-	0	WEISS	81	MRK2
<5 E−2	e	+1 2 4 5	2−12	27	e^+e^-	0	BARTEL	80	JADE
<2 E−5	g	+1 2			ν	0	[14 15] BASILE	80	CNTR
<3 E−10	f	±2 4	1−3	200	p	0	[16] BOZZOLI	79	CNTR
<6 E−11	f	±1	<21	52	pp	0	BASILE	78	SPEC
<5 E−3	g				ν_μ	0	BASILE	78B	CNTR
<2 E−9	f	±1	<26	62	pp	0	BASILE	77	SPEC
<7 E−10	f	+1 2	<20	52	p	0	[17] FABJAN	75	CNTR
		+1 2	>4 5		γ	0	[14 15] GALIK	74	CNTR
		+1 2	>1 5	12	e^-	0	[14 15] BELLAMY	68	CNTR
		+1 2	>0 9		γ	0	[14] BATHOW	67	CNTR
		+1 2	>0 9	6	γ	0	[14] FOSS	67	CNTR

[11] The limits apply to projectile fragment charges of 17 19 20 22 23 in units of $e/3$
[12] The limits apply to projectile fragment charges of 16 17 19 20, 22 23 in units of $e/3$
[13] Flux limits and mass range depend on charge
[14] Leptonic quark
[15] Hadronic quark
[16] Quark lifetimes ·1×10^{-8} s
[17] One candidate m · 0 17 GeV

QUARK FLUX COSMIC RAY SEARCHES

Shielding values followed with an asterisk indicate altitude in km
Shielding values not followed with an asterisk indicate sea level in kg/cm^2

FLUX (/cm^2/s/sr)	CHG (e/3)	MASS (GeV)	SHIELDING	EVTS	DOCUMENT ID		TECN
<1 E−12	±2,3/2		−70	0	[18] KAWAGOE	84B	PLAS
<9 E−10	±1 2		0 3	0	WADA	84B	PLAS
4 E−9	±4		0 3	7	WADA	84B	PLAS
<2 E−12	±1 2,3		−0 3*	0	MASHIMO	83	CNTR
<3 E−10	±1 2		0 3	0	MARINI	82	CNTR

Stable Particle Full Listings
FREE QUARK SEARCHES

<2 E−11	±1 2			0	MASHIMO 82	CNTR
<8 E−10	±1 2		0 3	0	[18] NAPOLITANO 82	CNTR
				3	[19] YOCK 78	CNTR
<1 E−9				0	[20] BRIATORE 76	ELEC
<2 E−11	+1			0	[21] HAZEN 75	CC
<2 E−10	+1 2			0	KRISOR 75	CNTR
<1 E−7	+1 2			0	[21,22] CLARK 74B	CC
<3 E−10	+1	>20		0	KIFUNE 74	CNTR
<8 E−11	+1			0	[21] ASHTON 73	CNTR
<2 E−8	+1 2			0	HICKS 73B	CNTR
<5 E−10	+4		2 8•	0	BEAUCHAMP 72	CNTR
<1 E−10	+1 2			0	[21] BOHM 72B	CNTR
<1 E−10	+1 2		2 8•	0	COX 72	ELEC
<3 E−10	+2			0	CROUCH 72	CNTR
<3 E−8			7	0	[20] DARDO 72	CNTR
<4 E−9	+1			0	[21] EVANS 72	CC
<2 E−9		>10		0	[20] TONWAR 72	CNTR
<2 E−10	+1		2 8•	0	CHIN 71	CNTR
<3 E−10	+1 2			0	[21] CLARK 71B	CC
<1 E−10	+1 2			0	[21] HAZEN 71	CC
<5 E−10	+1 2		3 5•	0	BOSIA 70	CNTR
	+1 2	<6 5		1	[21] CHU 70	HLBC
<2 E−9	+1			0	FAISSNER 70B	CNTR
<2 E−10	+1 2		0 8•	0	KRIDER 70	CNTR
<5 E−11	+2			4	CAIRNS 69	CC
<8 E−10	+1 2	<10		0	FUKUSHIMA 69	CNTR
	+2			1	[21,23] MCCUSKER 69	CC
<1 E−10		>5	1 7 3 6	0	[20] BJORNBOE 68	CNTR
<1 E−8	±1 2 4		6 3 2•	0	[18] BRIATORE 68	CNTR
<3 E−8		>2		0	FRANZINI 68	CNTR
<9 E−11	±1 2			0	GARMIRE 68	CNTR
<4 E−10	±1			0	HANAYAMA 68	CNTR
<3 E−8		>15		0	KASHA 68	OSPK
<2 E−10	+2			0	KASHA 68B	CNTR
<2 E−10	−4			0	KASHA 68C	CNTR
<2 E−10	−2		6	0	BARTON 67	CNTR
<2 E−7	−4		0 008,0 5•	0	BUHLER 67	CNTR
<5 E−10	1 2		0 008,0 5•	0	BUHLER 67B	CNTR
<4 E−10	+1,2			0	GOMEZ 67	CNTR
<2 E−9	+2			0	KASHA 67	CNTR
<2 E−10	+2		220	0	BARTON 66	CNTR
<2 E−9	+1 2		0 5•	0	BUHLER 66	CNTR
<3 E−9	+1 2			0	KASHA 66	CNTR
<2 E−9	+1 2			0	LAMB 66	CNTR
<2 E−8	+1 2	>7	2.8•	0	DELISE 65	CNTR
<5 E−8	+2	>2 5	0 5•	0	MASSAM 65	CNTR
<2 E−8	+1		2.5•	0	BOWEN 64	CNTR
<2 E−7	+1		0 8	0	SUNYAR 64	CNTR

[18] Leptonic quarks
[19] Lifetime $\cdot 10^{-8}$ s charge ±0 70 0 68 0 42 and mass ·4 4 4 8 and 20 GeV respectively
[20] Time delayed air shower search
[21] Prompt air shower search
[22] Also 1/4 and 1/6e charges
[23] No events in subsequent experiments

QUARK DENSITY MATTER SEARCHES

QUARKS/ NUCLEON	CHG (e/3)	MASS (GeV)	MATERIAL, METHOD	EVTS	DOCUMENT ID
<1 E−19	±1 2		various/spectrometer	0	MILNER 87
<5 E−22	±1 2		W/levitation	0	SMITH 87
<3 E−20	+1 2		org liq/droplet tower	0	VANPOLEN 87
<6 E−20	−1 2		org liq/droplet tower	0	VANPOLEN 87
<3 E−21	±1		Hg drops untreated	0	SAVAGE 86
<3 E−22	±1 2		levitated niobium	0	SMITH 86
<2 E−26	±1 2		^{4}He/levitation	0	SMITH 86B
<2 E−20	>±1	0 2–250	niobium+tungs/ion	0	MILNER 85
<1 E−21	±1		levitated niobium	0	SMITH 85
	+1 2	<100	niobium/mass spec	0	KUTSCHERA 84
<5 E−22			levitated steel	0	MARINELLI 84
<9 E−20	±<13		water/oil drop	0	JOYCE 83
<2 E−21	±>1/2		levitated steel	0	LIEBOWITZ 83
<1 E−19	±1 2		photo ion spec	0	VANDESTEEG 83
<2 E−20			mercury/oil drop	0	[24] HODGES 81
<2 E−20	+1		levitated niobium	4	LARUE 81
<2 E−20	−1		levitated niobium	4	LARUE 81
<1 E−21			levitated steel	0	MARINELLI 80B
<6 E−16			helium/mass spec	0	BOYD 79
<5 E−21	+1		levitated niobium	3	LARUE 79
<4 E−28			earth+/ion beam	0	OGOROD 79
<5 E−15	+1		tungs /mass spec	0	BOYD 78
<5 E−16	+3	<1 7	hydrogen/mass spec	0	BOYD 78B
<1 E−21	±2 4		water/ion beam	0	LUND 78
<6 E−15	>1/2		levitated tungsten	0	PUTT 78
<1 E−22			metals/mass spec	0	SCHIFFER 78
<5 E−15			levitated tungsten ox	0	BLAND 77
<3 E−21			levitated iron	0	GALLINARO 77
1 E−23	−1		levitated niobium	1	LARUE 77
1 E−23	+1		levitated niobium	2	LARUE 77
<1 E−13	+3	<7 7	hydrogen/mass spec	0	MULLER 77
<5 E−27			water+/ion beam	0	OGOROD 77
<1 E−21			lunar+/ion spec	0	STEVENS 76
<1 E−15	+1	<60	oxygen+/ion spec	0	ELBERT 70
<5 E−19			levitated graphite	0	MORPURGO 70
<5 E−23			water+/atom beam	0	COOK 69
<1 E−17	±1 2		levitated graphite	0	BRAGINSK 68
<1 E−17			water+/uv spec	0	RANK 68
<3 E−19	±1		levitated iron	0	STOVER 67
<1 E−10			sun/uv spec	0	[25] BENNETT 66
<1 E−17	+1 2		meteorites+/ion beam	0	CHUPKA 66
<1 E−16	±1		levitated graphite	0	GALLINARO 66
<1 E−22			argon/electrometer	0	HILLAS 59
	−2		levitated oil	0	MILLIKAN 10

[24] Also set limits for $Q = \pm 1/6e$
[25] Limit inferred by JONES 77B

REFERENCES FOR FREE QUARK SEARCHES

ALLASIA	88	PR D37 219	+Angelini Baldini+	(WA25 Collab)
HOFFMANN	88	PL B200 583	+Brechtmann Heinrich Benton	(USIE USF)
LYONS	87	ZPHY C36 363	+Smith Homer Lewin Walford+	(OXF RAL LOIC)
MILNER	87	PR D36 37	+Cooper Chang Wilson Labrenz, McKeown	(CIT)
SHAW	87	PR D36 3533	+Matis Pugh Slansky+	(UCI LBL LANL SFSU)
SMITH	87	PL B197 447	+Homer Lewin Walford Jones	(RAL LOIC)
VANPOLEN	87	PR D36 1983	+Hagstrom Hirsch	(ANL LBL)
ABACHI	86C	PR D33 2733	+Shor Barasch Carroll+	(UCLA LBL UCD)
SAVAGE	86	PL 167B 481	+Bland Hodges Huntington Joyce+	(SFSU)
SMITH	86	PL B171 129	+Homer Lewin Walford Jones	(RAL LOIC)
SMITH	86B	PL B181 407	+Homer Lewin Walford Jones	(RAL LOIC)
ALBRECHT	85G	PL 156B 134	+Binder Harder Hasemann+	(ARGUS Collab)
BANNER	85	PL 156B 129	+Bloch Borer Borghini+	(UA2 Collab)
MILNER	85	PRL 54 1472	+Cooper Chang Wilson Labrenz McKeown	(CIT)
SMITH	85	PL 153B 188	+Homer Lewin Walford Jones	(RAL LOIC)
AIHARA	84	PRL 52 168	+Alston Garnjost Badtke Bakker+	(TPC Collab)
AIHARA	84B	PRL 52 2332	+Alston Garnjost Badtke Bakker+	(TPC Collab)
BARWICK	84	PR D30 691	+Musser Stevenson	(UCB)
BERGSMA	84B	ZPHY C24 217	+Allaby Abt Gemanov+	(CHARM Collab)
BONDAR	84	JETPL 40 1265	+Kurdadze Lelchuk Panin Sidorov+	(SIBE)
		Translated from ZETFP 40 440		
GURYN	84	PL 139B 313	+Parker Fries+	(FRAS LBL NWES STAN HAWA)
KAWAGOE	84B	LNC 41 604	+Mashimo Nakamura Nozaki Orito	(TOKY)
KUTSCHERA	84	PR D29 791	+Schiffer Frekers+	(ANL FNAL)
MARINELLI	84	PL 137B 439	+Morpurgo	(GENO)
WADA	84B	LNC 40 329	+Yamashita Yamamoto	(OKAY)
AUBERT	83C	PL 133B 461	+Bassompierre Becks Best+	(EMC Collab)
BANNER	83	PL 121B 187	+Bloch Bonaudi Borer+	(UA2 Collab)
JOYCE	83	PRL 51 731	+Abrams Bland Johnson Lindgren+	(SFSU)
LIEBOWITZ	83	PRL 50 1640	+Binder Ziock	(VIRG)
LINDGREN	83	PRL 51 1621	+Joyce+	(SFSU UCR UCI SLAC LBL LANL)
MASHIMO	83	PL 128B 327	+Orito Kawagoe Nakamura Nozaki	(TOKY)
PRICE	83	PRL 50 566	+Tincknell Tarle Ahlen Frankel+	(UCB)
VANDESTEEG	83	PRL 50 1234	+Jongbloets Wyder	(NIJM)
MARINI	82	PR D26 1777	+Peruzzi Piccolo+	(FRAS LBL NWES STAN HAWA)
MARINI	82B	PRL 48 1649	+Peruzzi Piccolo+	(FRAS LBL NWES STAN HAWA)
MASHIMO	82	JPSJ 51 3067	+Kawagoe Koshiba	(TOKY)
NAPOLITANO	82	PR D25 2837	+Besset+	(STAN FRAS LBL NWES HAWA)
ROSS	82	PL 118B 199	+Ronga Besset+	(FRAS LBL NWES STAN HAWA)
HODGES	81	PRL 47 1651	+Abrams Baden Bland Joyce+	(UCR SFSU)
LARUE	81	PRL 46 967	+Phillips Fairbank	(STAN)
WEISS	81	PL 101B 439	+Abrams Alam Blocker+	(SLAC LBL UCB)
BARTEL	80	ZPHY C6 295	+Canzler Lords Drumm+	(JADE Collab)
BASILE	80	LNC 29 251	+Berbiers+	(BGNA CERN FRAS ROMA BARI)
BUSSIERE	80	NP B174 1	+Giacomelli Lesquoy+	(BGNA SACL LAPP)
MARINELLI	80B	PL 94B 433	+Morpurgo	(GENO)
Also	80	PL 94B 427	Marinelli Morpurgo	(GENO)
BOYD	79	PRL 43 1288	+Blatt Donoghue Dries Hausman Sulter	(OSU)
BOZZOLI	79	NP B159 363	+Bussiere Giacomelli+	(BGNA LAPP SACL CERN)
LARUE	79	PRL 42 142	+Fairbank Phillips	(STAN)
Also	79B	PRL 42 1019	Larue Fairbank Phillips	
OGOROD	79	JETP 49 953	Ogorodnikov Samoilov Solntsev	(KIAE)
		Translated from ZETF 76 1881		
STEVENSON	79	PR D20 82		(LBL)
BASILE	78	NC 45A 171	+Cara Romeo Cifarelli Contin+	(CERN BGNA)
BASILE	78B	NC 45A 281	+Cara Romeo Cifarelli Contin+	(CERN BGNA)
BOYD	78	PRL 40 216	+Elmore Melissinos Sugarbaker	(ROCH)
BOYD	78B	PL 72B 484	+Elmore Nitz Olsen Sugarbaker Warren+	(ROCH)
LUND	78	RA 25 75	+Brandt Fares	(PHIL)
PUTT	78	PR D17 1466	+Yock	(AUCK)
SCHIFFER	78	PR D17 2241	+Renner Gemmell Mooring	(CHIC ANL)
YOCK	78	PR D18 641		(AUCK)
ANTREASYAN	77	PRL 39 513	+Cocconi Cronin Frisch+	(EFI PRIN)
BASILE	77	NC 40A 41	+Romeo Cifarelli Giusti+	(CERN BGNA)
BLAND	77	PRL 39 369	+Bocobo Eubank Royer	(SFSU)
GALLINARO	77	PRL 38 1255	+Marinelli Morpurgo	(GENO)
JONES	77B	RMP 69 717		
LARUE	77	PRL 38 1011	+Fairbank Hebard	(STAN)
MULLER	77	Science 521	+Alvarez Holley Stephenson	(LBL)
OGOROD	77	JETP 45 857	Ogorodnikov Samoilov Solntsev	(KIAE)
		Translated from ZETF 72 1633		
BALDIN	76	SJNP 22 264	+Vertogradov Vishnevsky Grishkevich+	(JINR)
		Translated from YAF 22 512		
BRIATORE	76	NC 31A 553	+Dardo Piazzoli Mannocchi+	(LCGT FRAS FREI)
STEVENS	76	PR D14 716	+Schiffer Chupka	(ANL)
ALBROW	75	NP B97 189	+Barber+	(CERN DARE FOM LANC MCHS UTRE)
FABJAN	75	NP B101 349	+Gruhn Peak Sauli Caldwell+	(CERN MPIM)
HAZEN	75	NP B95 189	+Hodson Winterstein Green Kass+	(MICH LEED)
JOVANOV	75	PL 56B 105	Jovanovich+	(MANI AACH CERN GENO HARV+)
KRISOR	75	NC 27A 132		(AACH)
CLARK	74B	PR D10 2721	+Finn Hansen Smith	(LLL)
GALIK	74	PR D9 1856	+Jordan Richter Seppi Siemann+	(SLAC FNAL)
KIFUNE	74	JPSJ 36 629	+Hieda Kurokawa Tsunemoto+	(TOKY KEK)
NASH	74	PRL 32 858	+Yamanouchi Nease Sculli	(FNAL CORN NYU)
ALPER	73	PL 46B 265	+	(CERN LIVP LUND BOHR RHEL STOH BERG+)
ASHTON	73	JPA 6 577	+Cooper Parvaresh Saleh	(DURH)
HICKS	73B	NC 14A 65	+Flint Standil	(MANI)

LEIPUNER	73	PRL 31 1226	+Larsen Sessoms Smith Williams+	(BNL YALE)
BEAUCHAMP	72	PR D6 1211	+Bowen Cox Kalbach	(ARIZ)
BOHM	72B	PRL 28 326	+Diemont Faissner Fasold Krisor+	(AACH)
BOTT	72	PL 40B 693	+Caldwell Fabjan Gruhn Peak+	(CERN MPIM)
COX	72	PR D6 1203	+Beauchamp Bowen Kalbach	(ARIZ)
CROUCH	72	PR D5 2667	+Mori Smith	(CASE)
DARDO	72	NC 9A 319	+Navarra Penengo Sitte	(TORI)
EVANS	72	PRSE A70 143	+Fancey Muir Watson	(EDIN LEED)
TONWAR	72	JPA 5 569	+Naranan Sreekantan	(TATA)
ANTIPOV	71	NP B27 374	+Kachanov Kutjin Landsberg Lebedev+	(SERP)
CHIN	71	NC 2A 419	+Hanayama Hara Higashi Tsuji	(OSAK)
CLARK	71B	PRL 27 51	+Ernst Finn Griffin Hansen Smith+	(LLL LBL)
HAZEN	71	PRL 26 582		(MICH)
BOSIA	70	NC 66A 167	+Briatore	(TORI)
CHU	70	PRL 24 917	+Kim Beam Kwak	(OSU ROSE KANS)
Also	70B	PRL 25 550	Allison Derrick Hunt Simpson Voyvodic	(ANL)
ELBERT	70	NP B20 217	+Erwin Herb Nielsen Petrilak Weinberg	(WISC)
FAISSNER	70B	PRL 24 1357	+Holder Krisor Mason Sawat Umbach	(AACH)
KRIDER	70	PR D1 835	+Bowen Kalbach	(ARIZ)
MORPURGO	70	NIM 79 95	+Gallinaro Palmieri	(GENO)
ALLABY	69B	NC 64A 75	+Bianchini Diddens Dobinson Hartung+	(CERN)
ANTIPOV	69	PL 29B 245	+Karpov Khromov Landsberg Lapshin+	(SERP)
ANTIPOV	69B	PL 30B 576	+Bolotov Devishev Devisheva Isakov+	(SERP)
CAIRNS	69	PR 186 1394	+McCkusker Peak Woolcott	(SYDN)
COOK	69	PR 188 2092	+Depasquali Frauenfelder Peacock+	(ILL)
FUKUSHIMA	69	PR 178 2058	+Kifune Kondo Koshiba+	(TOKY)
MCCUSKER	69	PRL 23 658	+Cairns	(SYDN)
BELLAMY	68	PR 166 1391	+Hofstadter Lakin Perl Toner	(STAN SLAC)
BJORNBOE	68	NC B53 241	+Damgard Hansen+	(BOHR TATA BERN BERG)
BRAGINSK	68	JETP 27 51	+Zeldovich Martynov Migulin	(MOSU)
		Translated from ZETF 54 91		
BRIATORE	68	NC 57A 850	+Castagnoli Bollini Massam+	(TORI CERN BGNA)
FRANZINI	68	PRL 21 1013	+Shulman	(COLU)
GARMIRE	68	PR 166 166	+Leong Sreekantan	(MIT)
HANAYAMA	68	CJP 46 S734	+Hara Higashi Kitamura Miono+	(OSAK)
KASHA	68	PR 172 1297	+Stefanski	(BNL YALE)
KASHA	68B	PRL 20 217	+Larsen Leipuner Adair	(BNL YALE)
KASHA	68C	CJP 46 S730	+Larsen Leipuner Adair	(BNL YALE)
RANK	68	PR 176 1635		(MICH)
BARTON	67	PRSL 90 87		(NPOL)
BATHOW	67	PL 25B 163	+Freytag Schulz Tesch	(DESY)
BUHLER	67	NC 49A 209	+Fortunato Massam Zichichi	(CERN BGNA)
BUHLER	67B	NC 51A 837	+Dalpiaz Massam Zichichi	(CERN BGNA STRB)
FOSS	67	PL 25B 166	+Garelick Homma Lobar Osborne Uglum	(MIT)
GOMEZ	67	PRL 18 1022	+Kobrak Moline Mullins Orth VanPutten+	(CIT)
KASHA	67	PR 154 1263	+Leipuner Wangler Alspector Adair	(BNL YALE)
STOVER	67	PR 164 1599	+Moran Trischka	(SYRA)
BARTON	66	PL 21 360	+Stockel	(NPOL)
BENNETT	66	PRL 17 1196		(YALE)
BUHLER	66	NC 45A 520	+Fortunato Massam Muller+	(CERN BGNA STRB)
CHUPKA	66	PRL 17 60	+Schiffer Stevens	(ANL)
GALLINARO	66	PL 23 609	+Morpurgo	(GENO)
KASHA	66	PR 150 1140	+Leipuner Adair	(BNL YALE)
LAMB	66	PRL 17 1068	+Lundy Novey Yovanovitch	(ANL)
DELISE	65	PR 140B 458	+Bowen	(ARIZ)
DORFAN	65	PRL 14 999	+Eades Lederman Lee Ting	(COLU)
FRANZINI	65B	PRL 14 196	+Leontic Rahm Samios Schwartz	(BNL COLU)
MASSAM	65	NC 40A 589	+Muller Zichichi	(CERN)
BINGHAM	64	PL 9 201	+Dickinson Diebold Koch Leith+	(CERN EPOL)
BLUM	64	PRL 13 353A	+Brandt Cocconi Czyzewski Danysz+	(CERN)
BOWEN	64	PRL 13 728	+Delise Kalbach Mortara	(ARIZ)
HAGOPIAN	64	PRL 13 280	+Selove Ehrlich Leboy Lanza+	(PENN BNL)
LEIPUNER	64	PRL 12 423	+Chu Larsen Adair	(BNL YALE)
MORRISON	64	PL 9 199		(CERN)
SUNYAR	64	PR 136B 1157	+Schwarzschild Connors	(BNL)
HILLAS	59	Nature 184 892	+Cranshaw	(AERE)
MILLIKAN	10	Phil Mag 19 209		(CHIC)

OTHER RELATED PAPERS

LYONS Review	85	PRPL C129 225		(OXF)
MARINELLI Review	82	PRPL 85 161	+Morpurgo	(GENO)

MAGNETIC MONOPOLE SEARCHES

NOTE ON MAGNETIC MONOPOLE SEARCHES

(by W P Trower, Virginia Polytechnic Institute and State University)

Although the usual formulation of Maxwell's equations suggests magnetic monopoles, no observed phenomenon requires them for explanation [1] A monopole anywhere in the universe results in electric charge quantization everywhere, and leads to the prediction of a least magnetic charge $G = e/2\alpha$, the Dirac charge [2] Recently monopoles have become indispensable in many gauge theories, which endow them with a variety of extraordinarily large masses

Monopole detectors have predominantly used either induction or ionization Induction experiments measure the monopole magnetic charge and are independent of monopole electric charge, mass, and velocity A solitary monopole candidate event (CABRERA 82) has been detected by this method Ionization experiments rely on a magnetic charge producing more ionization than an electrical charge with the same velocity However the ability to distinguish a monopole by ionization diminishes with velocity

Cosmic rays are the most likely source of massive monopoles, since accelerator energies are insufficient to produce them Evidence for such monopoles may also be obtained from astrophysical observations

This compilation is only a guide to the literature, since the quoted experimental limits are often only indicative

References

1 J D Jackson, CERN-77-17 (1977)

2 P A M Dirac, Proc Royal Soc London **A133**, 60 (1931)

MONOPOLE PRODUCTION CROSS SECTION ACCELERATOR SEARCHES

X SECT (cm^2)	MASS (GeV)	CHG (G)	ENERGY (GeV)	BEAM	EVTS	DOCUMENT ID		TECN
<9 E−34	<4	<0 15	10 6	e^+e^-	0	GENTILE	87	CLEO
<3 E−32	<800	≥1	1800	$p\bar{p}$	0	PRICE	87	PLAS
<3 E−38		<3	29	e^+e^-	0	FRYBERGER	84	PLAS
<1 E−31		1 3	540	$p\bar{p}$	0	AUBERT	83B	PLAS
<4 E−38	<10	<6	34	e^+e^-	0	MUSSET	83	PLAS
<8 E−36	<20		52	pp	0	[1] DELL	82	CNTR
<9 E−37	<30	<3	29	e^+e^-	0	KINOSHITA	82	PLAS
<1 E−37	<20	<24	63	pp	0	CARRIGAN	78	CNTR
<1 E−37	<30	<3	56	pp	0	HOFFMANN	78	PLAS
			62	pp	0	[1] DELL	76	SPRK
<4 E−33			300	p	0	[1] STEVENS	76B	SPRK
<1 E−40	<5	<2	70	p	0	[2] ZRELOV	76	CNTR
<2 E−30			300	n	0	[1] BURKE	75	OSPK
<1 E−38			8	ν	0	[3] CARRIGAN	75	HLBC
<5 E−43	<12	<10	400	p	0	EBERHARD	75B	INDU
<2 E−36	<30	<3	60	pp	0	GIACOMELLI	75	PLAS
<5 E−42	<13	<24	400	p	0	CARRIGAN	74	CNTR
<6 E−42	<12	<24	300	p	0	CARRIGAN	73	CNTR
<2 E−36		1	001	γ	0	[2] BARTLETT	72	CNTR
<1 E−41	<5		70	p	0	GUREVICH	72	EMUL
<1 E−40	<3	<2	28	p	0	AMALDI	63	EMUL
<2 E−40	<3	<2	30	p	0	PURCELL	63	CNTR
<1 E−35	<3	<4	28	p	0	FIDECARO	61	CNTR
<2 E−35	<1	1	6	p	0	BRADNER	59	EMUL

[1] Multiphoton events
[2] Cherenkov radiation polarization
[3] Re-examines CERN neutrino experiments

MONOPOLE FLUX COSMIC RAY SEARCHES

FLUX (/cm^2/s/sr)	MASS (GeV)	CHG (G)	COMMENTS ($\beta = v/c$)	EVTS	DOCUMENT ID		TECN
<5 E−12	>E7	1	3 E−4<β<5 E−3	0	BARISH	87	CNTR
<1 E−13			1 E−5<β<1	0	[4] BARTELT	87	SOUD
<1 E−10		1	all β	0	EBISU	87	INDU
<2 E−13			1 E−4<β<6 E−4	0	MASEK	87	HEPT
<2 E−14			4 E−5<β<2 E−4	0	NAKAMURA	87	PLAS
<5 E−14			9 E−4<β<1 E−2	0	SHEPKO	87	CNTR
<2 E−13			4 E−4<β<1	0	TSUKAMOTO	87	CNTR
<5 E−14		1	all β	1	[5] CAPLIN	86	INDU
<5 E−12		1		0	CROMAR	86	INDU
<1 E−13		1	7 E−4<β	0	HARA	86	CNTR
<7 E−11		1	all β	0	INCANDELA	86	INDU
<1 E−18			4 E−4<β<1 E−3	0	[6] PRICE	86	MICA

Stable Particle Full Listings
MAGNETIC MONOPOLE SEARCHES

<1 E−23			Jovian planets		[4] ARAFUNE	85	COSM
<5 E−12		1		0	BERMON	85	INDU
<1 E−16	E15		solar trapping	0	BRACCI	85B	COSM
<6 E−12		1		0	CAPLIN	85	INDU
<6 E−10		1		0	EBISU	85	INDU
<3 E−15			5 E−5≤β≤1 E−3	0	[4] KAJITA	85	CNTR
			β<1 E−3	0	[7] KAJITA	85	CNTR
<3 E−15			1 E−3<β<1 E−1	0	[4] PARK	85B	CNTR
<5 E−12		1	1 E−4<β<1	0	BATTISTONI	84	NUSX
<1 E−18		1		0	[4] HARVEY	84	COSM
<7 E−12		1		0	INCANDELA	84	INDU
<7 E−13		1	3 E−4<β	0	[8] KAJINO	84	CNTR
<2 E−12		1	3 E−4<β<1 E−1	0	KAJINO	84B	CNTR
<6 E−13		1	5 E−4<β<1	0	KAWAGOE	84	CNTR
<3 E−23			neutron stars		KOLB	84	COSM
<2 E−14			1 E−3<β	0	[4] KRISHNA	84	CNTR
<4 E−13		1	6 E−4<β<2 E−3	0	LISS	84	CNTR
<1 E−16			3 E−4<β<1 E−3	0	[6] PRICE	84	MICA
<1 E−13		1	1 E−4<β	0	PRICE	84B	PLAS
<4 E−13		1	6 E−4<β<2 E−3	0	TARLE	84	CNTR
				7	[9] ANDERSON	83	EMUL
<4 E−13		1	1 E−2<β<1 E−3	0	BARTELT	83B	CNTR
<1 E−12		1	7 E−3<β<1	0	BARWICK	83	PLAS
<3 E−13		1	1 E−3<β<4 E−1	0	BONARELLI	83	CNTR
<3 E−12			5 E−4<β<5 E−2	0	[4] BOSETTI	83	CNTR
<4 E−11		1		0	CABRERA	83	INDU
<5 E−15		1	1 E−2<β<1	0	DOKE	83	PLAS
<8 E−15			1 E−4<β<1 E−1	0	[4] ERREDE	83	CNTR
<7 E−22			pulsars	0	[4] FREESE	83B	COSM
<5 E−12		1	1 E−4<β<3 E−2	0	GROOM	83	CNTR
<2 E−12			6 E−4<β<1	0	MASHIMO	83	CNTR
<1 E−18	<E18	1	intergalactic field	0	[4] REPHAELI	83	COSM
<1 E−13		1	β=3 E−3	0	ALEXEYEV	82	CNTR
<2 E−12		1	7 E−3<β<6 E−1	0	BONARELLI	82	CNTR
6 E−10		1	DG= ± 0 06	1	CABRERA	82	INDU
<1 E−23			neutron stars	0	[4] DIMOPOUL	82	COSM
<5 E−22			neutron stars	0	[4] KOLB	82	COSM
<2 E−11			1 E−2<β<1 E−1	0	MASHIMO	82	CNTR
<5 E−15	>E21		galactic halo		SALPETER	82	COSM
<1 E−12	E19	1	β=3 E−3	0	[10] TURNER	82	COSM
<2 E−15			concentrator	0	BARTLETT	81	PLAS
<1 E−13	>1		1 E−3<β	0	KINOSHITA	81B	PLAS
<5 E−11	<E17		3 E−4<β<1 E−3	0	ULLMAN	81	CNTR
<2 E−11			concentrator	0	BARTLETT	78	PLAS
1 E−1	>200	2		1	[11] PRICE	75	PLAS
<2 E−13		>2		0	FLEISCHER	71	PLAS
<1 E−16		1	galactic field	0	PARKER	70	COSM
<1 E−19		>2	obsidian mica	0	FLEISCHER	69C	PLAS
<5 E−15	<15	<3	concentrator	0	CARITHERS	66	ELEC
<2 E−11		<1−3	concentrator	0	MALKUS	51	EMUL

[4] Catalysis of nucleon decay

[5] Limit from combining data of CAPLIN 86 BERMON 85 INCANDELA 84 and CABRERA 83 For a discussion of controversy about CAPLIN 86 observed event see GUY 87 Also see SCHOUTEN 87

[6] Assumes monopole attaches fermion nucleus

[7] The flux limit is $<2\times10^{-21}(\beta/10^{-3})^2$

[8] Used DKMPR mechanism and Penning effect

[9] Anomalous long-range α (^4He) tracks

[10] Re-evaluates PARKER 70 limit for GUT monopoles

[11] ALVAREZ 75 FLEISCHER 75, and FRIEDLANDER 75 explain as fragmenting nucleus EBERHARD 75 and ROSS 76 discuss conflict with other experiments HAGSTROM 77 reinterprets as antinucleus PRICE 78 reassesses

MONOPOLE DENSITY MATTER SEARCHES

DENSITY	*CHG (G)*	*MATERIAL*	*EVTS*	*DOCUMENT ID*		*TECN*
<2 E−7/gram	>0 6	Fe ore	0	[12] EBISU	87	INDU
<1 E−9/gram	1	sun, catalysis	0	[13] ARAFUNE	83	COSM
>1 E−14/gram	>1/3	iron aerosols	>1	MIKHAILOV	83	SPEC
<6 E−33/nucl	1	moon wake	0	SCHATTEN	83	ELEC
<2 E−28/nucl		earth heat	0	CARRIGAN	80	COSM
<2 E−4/prot		42cm absorption	0	BRODERICK	79	COSM
<6 E−4/gram		air, seawater	0	CARRIGAN	76	CNTR
<5 E−1/gram	>0 04	11 materials	0	CABRERA	75	INDU
<2 E−4/gram	>0 05	moon rock	0	ROSS	73	INDU
<6 E−7/gram	<140	seawater	0	KOLM	71	CNTR
<2 E−13/m^3		moon wake	0	SCHATTEN	70	ELEC
<1 E−2/gram	<120	manganese nodules	0	FLEISCHER	69	PLAS
<1 E−4/gram	>0	manganese	0	FLEISCHER	69B	PLAS
<2 E−3/gram	<1−3	magnetite meteor	0	GOTO	63	EMUL
<2 E−2/gram		meteorite	0	PETUKHOV	63	CNTR

[12] Mass 1×10^{14}–1×10^{17} GeV

[13] Catalysis of nucleon decay

REFERENCES FOR MAGNETIC MONOPOLE SEARCHES

BARISH 87 PR D36 2641 +Liu Lane (CIT)
BARTELT 87 PR D36 1990 +Courant Heller+ (Soudan Collab)
EBISU 87 PR D36 3359 +Watanabe (KOBE)
Also 85 JP G11 883 Ebisu Watanabe (KOBE)
GENTILE 87 PR D35 1081 +Haas Hempstead+ (CLEO Collab)
GUY 87 Nature 325 463 (LOIC)
MASEK 87 PR D35 2758 +Knapp Miller Stronski Vernon White (UCSD)
NAKAMURA 87 PL B183 395 +Kawagoe Yamamoto+ (TOKY WASE NIHO)
PRICE 87 PRL 59 2523 +Guoxiao Kinoshita (UCB HARV)
SCHOUTEN 87 JP E20 850 +Caplin Guy Hardiman+ (LOIC)
SHEPKO 87 PR D35 2917 +Gagliardi Green McIntyre+ (TAMU)
TSUKAMOTO 87 EPL 3 39 +Nagano Anraku+ (TOKY)
CAPLIN 86 Nature 321 402 +Hardiman Koratzinos Schouten (LOIC)
Also 87 JP E20 850 Schouten Caplin Guy Hardiman+ (LOIC)
Also 87 Nature 325 463 Guy (LOIC)
CROMAR 86 PRL 56 2561 +Clark Fickett (NBSB)
HARA 86 PRL 56 553 +Honda Ohno+ (TOKY KYOT KEK KOBE)
INCANDELA 86 PR D34 2637 +Frisch Somalwar Kuchnir+ (CHIC FNAL MICH)
PRICE 86 PRL 56 1226 +Salamon (UCB)
ARAFUNE 85 PR D32 2586 +Fukugita Yanagita (TOKY KYOT IBAR)
BERMON 85 PRL 55 1850 +Choudhari Chi Tesche Tsuei (IBM)
BRACCI 85B NP B258 726 +Fiorentini Mezzorani (PISA CAGL)
Also 85 LNC 42 123 Bracci Fiorentini (PISA)
CAPLIN 85 Nature 317 234 +Guy Hardiman Park Schouten (LOIC)
EBISU 85 JP G11 883 +Watanabe (KOBE)
KAJITA 85 JPSJ 54 4065 +Arisaka Koshiba Nakahata+ (TOKY KEK NIIG)
PARK 85B NP B252 261 +Blewitt Cortez Foster+ (IMB Collab)
BATTISTONI 84 PL 133B 454 +Bellotti Bologna Campana+ (NUSEX Collab)
FRYBERGER 84 PR D29 1524 +Coan Kinoshita Price (SLAC UCB)
HARVEY 84 NP B236 255 (PRIN)
INCANDELA 84 PRL 53 2067 +Campbell Frisch+ (CHIC FNAL MICH)
KAJINO 84 PRL 52 1373 +Matsuno Yuan Kitamura (TOKY)
KAJINO 84B JP G10 447 +Matsuno Kitamura Aoki Yuan Mitsui+ (TOKY)
KAWAGOE 84 LNC 41 315 +Mashimo Nakamura Nozaki Orito (TOKY)
KOLB 84 APJ 286 702 +Turner (FNAL CHIC)
KRISHNA 84 PL 142B 99 Krishnaswamy Menon+ (TATA OSKC TOKY)
LISS 84 PR D30 884 +Ahlen Tarle (UCB IND MICH)
PRICE 84 PRL 52 1265 +Guo Ahlen Fleischer (ROMA UCB IND GESC)
PRICE 84B PL 140B 112 (CERN)
TARLE 84 PRL 52 90 +Ahlen Liss (UCB MICH IND)
ANDERSON 83 PR D28 2308 +Lord Strausz Wilkes (WASH)
ARAFUNE 83 PL 133B 380 +Fukugita (TOKY KYOT)
AUBERT 83B PL 120B 465 +Musset Price Vialle (CERN LAPP)
BARTELT 83B PRL 50 655 +Courant Heller Joyce Marshak+ (MINN ANL)
BARWICK 83 PR D28 2338 +Kinoshita Price (UCB)
BONARELLI 83 PL 126B 137 +Capiluppi Dantone (BGNA)
BOSETTI 83 PL 133B 265 +Gorham Harris Learned+ (AACH HAWA TOKY)
CABRERA 83 PRL 51 1933 +Taber Gardner Bourg (STAN)
DOKE 83 PL 129B 370 +Hayahsi Hamasaki+ (TWAS TRIK TTAM IPCR)
ERREDE 83 PRL 51 245 +Stone Vander Velde Bionta+ (IMB Collab)
FREESE 83B PRL 51 1625 +Turner Schramm (CHIC)
GROOM 83 PRL 50 573 +Loh Nelson Ritson (UTAH STAN)
MASHIMO 83 PL 128B 327 +Orito Kawagoe Nakamura Nozaki (TOKY)
MIKHAILOV 83 PL 130B 331 (KAZA)
MUSSET 83 PL 128B 333 +Price Lohrmann (CERN HAMB)
REPHAELI 83 PL 121B 115 +Turner (CHIC)
SCHATTEN 83 PR D27 1525 (NASA)
ALEXEYEV 82 LNC 35 413 +Boliev Chudakov Makoev Mikheyev+ (INRM)
BONARELLI 82 PL 112B 100 +Capiluppi Dantone+ (BGNA)
CABRERA 82 PRL 48 1378 (STAN)
DELL 82 NP B209 45 +Yuan Roberts Dooher+ (BNL ADEL ROMA)
DIMOPOUL 82 PL 119B 320 Dimopoulos Preskill Wilczek (HARV UCSB)
KINOSHITA 82 PRL 48 77 +Price Fryberger (UCB SLAC)
KOLB 82 PRL 49 1373 +Colgate Harvey (LASL PRIN)
MASHIMO 82 JPSJ 51 3067 +Kawagoe Koshiba (TOKY)
SALPETER 82 PRL 49 1114 +Shapiro Wasserman (CORN)
TURNER 82 PR D26 1296 +Parker Bogdan (CHIC)
BARTLETT 81 PR D24 612 +Soo Fleischer Hart+ (COLO GESC)
KINOSHITA 81B PR D24 1707 +Price (UCB)
ULLMAN 81 PRL 47 289 (LEHM BNL)
CARRIGAN 80 Nature 288 348 (FNAL)
BRODERICK 79 PR D19 1046 +Ficenec Teplitz Teplitz (VPI)
BARTLETT 78 PR D18 2253 +Soo White (COLO PRIN)
CARRIGAN 78 PR D17 1754 +Strauss Giacomelli (FNAL BGNA)
HOFFMANN 78 LNC 23 357 +Kantardjian Dilliberto Meddi+ (CERN ROMA)
PRICE 78 PR D18 1382 +Shirk Osborne Pinsky (UCB HOUS)
HAGSTROM 77 PRL 38 729 (LBL)
CARRIGAN 76 PR D13 1823 +Nezrick Strauss (FNAL)
DELL 76 LNC 15 269 +Uto Yuan Amaldi+ (CERN BNL ROMA ADEL)
ROSS 76 LBL 4665 (LBL)
STEVENS 76B PR D14 2207 +Collins Ficenec Trower Fischer+ (VPI BNL)
ZRELOV 76 CZJP B26 1306 +Kollarova Kollar Lupiltsev Pavlovic+ (JINR)
ALVAREZ 75 LBL 4260 (LBL)
BURKE 75 PL 60B 113 +Gustafson Jones Longo (MICH)
CABRERA 75 Thesis (STAN)
CARRIGAN 75 NP B91 279 +Nezrick (FNAL)
Also 71 PR D3 56 Carrigan Nezrick (FNAL)
EBERHARD 75 PR D11 3099 +Ross Taylor Alvarez Oberlack (LBL MPIM)
EBERHARD 75B LBL 4289 (LBL)
FLEISCHER 75 PRL 35 1412 +Walker (GESC WUSL)
FRIEDLANDER 75 PRL 35 1167 (WUSL)
GIACOMELLI 75 NC 28A 21 +Rossi+ (BGNA CERN SACL ROMA)
PRICE 75 PRL 35 487 +Shirk Osborne Pinsky (UCB HOUS)
CARRIGAN 74 PR D10 3867 +Nezrick Strauss (FNAL)
CARRIGAN 73 PR D8 3717 +Nezrick Strauss (FNAL)
ROSS 73 PR D8 698 +Eberhard Alvarez Watt (LBL SLAC)
Also 71 PR D4 3260 Eberhard Ross Alvarez Watt (LBL SLAC)
Also 70 Science 167 701 Alvarez Eberhard Ross Watt (LBL SLAC)
BARTLETT 72 PR D6 1817 +Lahana (COLO)
GUREVICH 72 PL 38B 549 +Khakimov Martemyanov+ (KIAE NOVO SERP)
Also 72B JETP 34 917 Barkov Gurevich Zolotorev (KIAE NOVO SERP)
Translated from ZETF 61 1721
Also 70 PL 31B 394 Gurevich Khakimov+ (KIAE NOVO SERP)
FLEISCHER 71 PR D4 24 +Hart Nichols Price (GESC)
KOLM 71 PR D4 1285 +Villa Odian (MIT SLAC)
PARKER 70 APJ 160 383 (CHIC)
SCHATTEN 70 PR D1 2245 (NASA)
FLEISCHER 69 PR 177 2029 +Jacobs Schwartz Price (GESC FSU)
FLEISCHER 69B PR 184 1393 +Hart Jacobs+ (GESC UNCS GSCO)

FLEISCHER	69C	PR 184 1398	+Price Woods	(GESC)
Also	70C	JAP 41 958	Fleischer Hart Jacobs Price+	(GESC)
CARITHERS	66	PR 149 1070	+Stefanski Adair	(YALE BNL)
AMALDI	63	NC 28 773	+Baroni Manfredini+	(ROMA UCSD CERN)
GOTO	63	PR 132 387	+Kolm Ford	(TOKY MIT BRAN)
PETUKHOV	63	NP 49 87	+Yakimenko	(LEBD)
PURCELL	63	PR 129 2326	+Collins Fujii Hornbostel Turkot	(HARV BNL)
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Review				
RUZICKA	80	JINR 2 80 850	+Zrelov	(JINR)
Bibliography				

SEARCHES FOR AXIONS (A^0) AND OTHER VERY LIGHT BOSONS

NOTE ON AXIONS

In this section we list limits for very light neutral (pseudo) scalar bosons that couple weakly to stable matter. Typical examples are pseudo-Goldstone bosons like axions (A^0),[1] familons,[2] and Majorons,[3] associated, respectively with spontaneously broken Peccei-Quinn,[4] family, and lepton-number symmetries.

Peccei-Quinn symmetry gives a natural solution to the strong CP-violation problem. Axion mass and its coupling to stable particles are inversely proportional to the scale of the Peccei-Quinn symmetry breaking Λ_{PQ}. The original axion model[4,1] assumes $\Lambda_{PQ} = \Lambda_{EW}$, where $\Lambda_{EW} = (\sqrt{2}G_F)^{-1/2}$ is the scale of the electroweak symmetry breaking, and has two Higgs doublets as minimal ingredients. By requiring tree-level flavor conservation the axion mass and its couplings are completely fixed in terms of one parameter, the ratio of the vacuum expectation values of two Higgs particles. The result of extensive experimental searches for such an axion have been negative.[5]

Observation of a narrow-peak structure in positron spectra from heavy ion collisions[6] suggested a particle of mass 1.8 MeV that decays into e^+e^-. Variants of the original axion model, which keep $\Lambda_{PQ} = \Lambda_{EW}$ but drop the constraints of tree-level flavor conservation, were proposed.[7] Extensive searches for this particle $A^0(1.8\ \text{MeV})$, ended up with another negative result.[8]

One way to avoid these experimental constraints is to make A^0 sufficiently massive. One way to achieve this is to introduce a new strong interaction (QC'D) with $\Lambda_{QC'D} >> \Lambda_{QCD}$, whose anomaly couples to the axion.[9] A^0 can receive significant mass from the QC'D sector if QC'D colored quarks are massive.

Another way to save the Peccei-Quinn idea is to discard the proposition $\Lambda_{PQ} = \Lambda_{EW}$ and introduce a new scale. With $\Lambda_{PQ} >> \Lambda_{EW}$, the A^0 mass becomes smaller and its coupling weaker, thus one can easily avoid all the existing experimental limits, hence such models are called invisible axion models.[10] Various invisible axion models can be constructed by identifying Λ_{PQ} with other large mass scales such as the Planck mass, the GUT scale, the SUSY-breaking scale, and so on. It has been found, however, that invisible axions are not completely elusive. Cosmological considerations on the matter density of our universe suggest[11] $\Lambda_{PQ} < O(10^{12})$ GeV as a possible upper bound of the scale. Lower bounds of $\Lambda_{PQ} > O(10^7)$ GeV are obtained from astrophysics,[12] where axion emission from the center of stellar objects can speed up their evolutionary timescales. Various terrestrial experiments to detect 'invisible' axions by making use of their coupling to photons have been proposed,[13] and the first result of such experiments appeared recently.

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A^0 (AXION) MASS LIMITS FROM ASTROPHYSICS AND COSMOLOGY

These bounds depend on model dependent assumptions (i.e. on a combination of axion parameters).

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>0.2	[1] BARROSO	82	ASTR	Standard Axion
>0.25	[2] RAFFELT	82	ASTR	Standard Axion
>0.2	[3] DICUS	78C	ASTR	Standard Axion
>0.2	VYSOTSKII	78	ASTR	Standard Axion

[1] BARROSO 82 derive in DFS model [Phys. Lett. 104B 199 (1981)] A^0 mass limits from nuclear decays and red giants energy-loss bound. Allowed mass regions are $m(A^0)$ < 10 eV (axion invisible due to very small coupling) and $m(A^0)$ around 200 keV (corresponding DFS A^0 parameter is hardly compatible with ZEHNDER 81 reactor data).

[2] Lower bound from 5.5 MeV γ-ray line from the sun.

[3] Lower bound from requiring the red giants stellar evolution not be disrupted by axion emission.

A^0 (AXION) SEARCHES IN STABLE PARTICLE DECAYS

Limits are for branching ratios.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<8 \times 10^{-7}$	90		[4] BAKER	87	CALO	$K^\pm \to \pi^\pm A^0$ ($A^0 \to e^+e^-$)
$<1.3 \times 10^{-8}$	90		[5] KORENCHE	87	SPEC	$\pi^+ \to e^+\nu A^0$ ($A^0 \to e^+e^-$)
$<1 \times 10^{-10}$	90	0	[6] EICHLER	86	SPEC	Stopped $\mu^+ \to e^+A^0$
$<1 \times 10^{-9}$	90	0	[6] EICHLER	86	SPEC	Stopped $\pi^+ \to e^+\nu A^0$
$<2 \times 10^{-5}$	90		[7] YAMAZAKI	84	SPEC	For 160 < m < 260 MeV
$<(1.5\text{–}4) \times 10^{-6}$	90		[7] YAMAZAKI	84	SPEC	K decay, $m(A^0)$ < 100 MeV
		0	[8] ASANO	82	CNTR	Stopped $K^+ \to \pi^+A^0$
		0	[9] ASANO	81B	CNTR	Stopped $K^+ \to \pi^+A^0$
			[10] ZHITNITSKII	79		Heavy axion

[4] BAKER 87 limit assumes that the A^0 travels much less than 1.4 cm in the lab before decaying.

[5] KORENCHENKO 87 limit assumes $m(A^0)$ = 1.7 MeV, $\tau(A^0) \lesssim 10^{-12}$ sec, and BR($A^0 \to e^+e^-$) = 1.

[6] EICHLER 86 looked for $\mu^+ \to e^+A^0$ and $\pi^+ \to e^+\nu A^0$ followed by $A^0 \to e^+e^-$. Limits on the branching fraction depend on the mass and and lifetime of A^0. The quoted limits are valid when $\tau(A^0) \gtrsim 3 \times 10^{-10}$s if the decays are kinematically allowed.

[7] YAMAZAKI 84 looked for a discrete line in $K^+ \to \pi^+ X$. Sensitive to wide mass range (5–300 MeV), independent of whether X decays promptly or not.

[8] ASANO 82 at KEK set limits for BR($K^+ \to \pi^+A^0$) for $m(A^0)$ < 100 MeV as BR < 4 $\times 10^{-8}$ for $\tau(A^0 \to n\gamma\text{'s})$ > 1 $\times 10^{-9}$ s, BR < 1.4 $\times 10^{-6}$ for τ < 1 $\times 10^{-9}$s.

[9] ASANO 81B is KEK experiment. Set BR($K^+ \to \pi^+A^0$) < 3.8 $\times 10^{-8}$ at CL = 90%.

[10] ZHITNITSKII 79 argue that a heavy axion predicted by YANG 78 (3 < m < 40 MeV) contradicts experimental muon anomalous magnetic moments.

A^0 (AXION) SEARCHES IN QUARKONIUM AND POSITRONIUM DECAYS

Decay or transition of positronium, quarkonium, kaon, nucleon, and radioactive nucleus. Limits are for branching ratio.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<5 \times 10^{-5}$			[11] DRUZHININ	87	CALO	$\phi \to \gamma A^0$ ($A^0 \to e^+e^-$)
$<2 \times 10^{-3}$			[12] DRUZHININ	87	CALO	$\phi \to \gamma A^0$ ($A^0 \to \gamma\gamma$)
$<7 \times 10^{-6}$			[13] DRUZHININ	87	CALO	$\phi \to \gamma A^0$ ($A^0 \to$ missing)
$<3.1 \times 10^{-4}$	90	0	[14] ALBRECHT	86D	ARG	$\Upsilon(1S) \to \gamma A^0$ ($A^0 \to e^+e^-$)
$<4 \times 10^{-4}$	90	0	[14] ALBRECHT	86D	ARG	$\Upsilon(1S) \to \gamma A^0$ ($A^0 \to \mu^+\mu^-, \pi^+\pi^-, K^+K^-$)
$<8 \times 10^{-4}$	90	1	[15] ALBRECHT	86D	ARG	$\Upsilon(1S) \to \gamma A^0$
$<1.3 \times 10^{-3}$	90	0	[16] ALBRECHT	86D	ARG	$\Upsilon(1S) \to \gamma A^0$ ($A^0 \to e^+e^-, \gamma\gamma$)
$<2 \times 10^{-3}$	90		[17] BOWCOCK	86	CLEO	$\Upsilon(2S) \to \Upsilon(1S) \to A^0$
$<5 \times 10^{-3}$	90		[18] MAGERAS	86	CUSB	$\Upsilon(1S) \to A^0\gamma$
$<3 \times 10^{-4}$	90		[19] ALAM	83	CLEO	$\Upsilon(1S) \to A^0\gamma$
			[20] CARBONI	83	CNTR	Ortho positronium
$<9.1 \times 10^{-4}$	90		[21] NICZYPORUK	83	LENA	$\Upsilon(1S) \to A^0\gamma$
$<1.4 \times 10^{-5}$	90		[22] EDWARDS	82	CBAL	$J/\psi \to A^0\gamma$
$<3.5 \times 10^{-4}$	90		[23] SIVERTZ	82	CUSB	$\Upsilon(1S) \to A^0\gamma$
$<1.2 \times 10^{-4}$	90		[23] SIVERTZ	82	CUSB	$\Upsilon(3S) \to A^0\gamma$

[11] The first DRUZHININ 87 limit is valid when $\tau(A^0)/m(A^0)$ < 3 $\times 10^{-13}$ s/MeV and $m(A^0)$ < 20 MeV.

[12] The second DRUZHININ 87 limit is valid when $\tau(A^0)/m(A^0)$ < 5 $\times 10^{-13}$ s/MeV and $m(A^0)$ < 20 MeV.

[13] The third DRUZHININ 87 limit is valid when $\tau(A^0)/m(A^0)$ > 7 $\times 10^{-12}$ s/MeV and $m(A^0)$ < 200 MeV.

[14] $\tau(A^0)$ < 1 $\times 10^{-13}$s and $m(A^0)$ < 1.5 GeV. Applies for $A^0 \to \gamma\gamma$ when $m(A^0)$ < 100 MeV.

[15] $\tau(A^0)$ > 1 $\times 10^{-7}$s.

[16] Independent of $\tau(A^0)$.

[17] BOWCOCK 86 looked for A^0 that decays into e^+e^- in the cascade decay $\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$ followed by $\Upsilon(1S) \to A^0\gamma$. The limit for BR($\Upsilon(1S) \to A^0\gamma$)BR($A^0 \to e^+e^-$) depends on $m(A^0)$ and $\tau(A^0)$. The quoted limit for $m(A^0)$=1.8 MeV is at $\tau(A^0)$~2 $\times 10^{-12}$s where the limit is the worst. The same limit (2 $\times 10^{-3}$) applies for all lifetimes for masses $2m(e)$ < $m(A^0)$ < $2m(\mu)$ when the results of this experiment are combined with the results of ALAM 83.

[18] MAGERAS 86 looked for $\Upsilon(1S) \to \gamma A^0$ ($A^0 \to e^+e^-$). The quoted branching fraction limit is for $m(A^0)$ = 1.7 MeV at τ(A0)~4 $\times 10^{-13}$s where the limit is the worst.

[19] ALAM 83 is at CESR. This limit combined with limit for BR($J/\psi \to A^0\gamma$) (EDWARDS 82) excludes standard axion.

[20] CARBONI 83 looked for orthopositronium $\to A^0\gamma$. Set limit for A^0 electron coupling squared, $g(eeA^0)^2/(4\pi)$ < 6. $\times 10^{-10}$–7 $\times 10^{-9}$ for $m(A^0)$ from 150–900 keV (CL = 99.7%). This is about 1/10 of g-2 bound.

[21] NICZYPORUK 83 is DESY-DORIS experiment. This limit together with lower limit 9.2 $\times 10^{-4}$ of BR($\Upsilon \to A^0\gamma$) derived from BR($J/\psi(1S) \to A^0\gamma$) limit (EDWARDS 82) excludes standard axion.

[22] EDWARDS 82 looked for $J/\psi \to \gamma A^0$ decays by looking for events with a single γ [of energy ~1/2 the $J/\psi(1S)$ mass], plus nothing else in the detector. The limit is inconsistent with the axion interpretation of the FAISSNER 81B result.

[23] SIVERTZ 82 is CESR experiment. Looked for $\Upsilon \to \gamma A^0$, A^0 undetected. Limit for 1S (3S) is valid for $m(A^0)$ < 7 GeV (4 GeV).

A^0 (AXION) PRODUCTION IN HADRON COLLISIONS

Limits are for $\sigma(A^0)$ / $\sigma(\pi^0)$.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
			[24] BADIER	86	BDMP	$A^0 \to e^+e^-$
$<2 \times 10^{-11}$	90	0	[25] BERGSMA	85	CHRM	CERN beam dump
$<1 \times 10^{-13}$	90	0	[25] BERGSMA	85	CHRM	CERN beam dump
		24	[26] FAISSNER	83	OSPK	Beam dump $A^0 \to 2\gamma$
			[27] FAISSNER	83B	RVUE	LAMPF beam dump
			[28] FRANK	83B	RVUE	LAMPF beam dump
			[29] HOFFMAN	83	CNTR	$\pi p \to nA^0$ ($A^0 \to e^+e^-$)
			[30] FETSCHER	82	RVUE	See FAISSNER 81B
		12	[31] FAISSNER	81	OSPK	CERN PS ν wideband
		15	[32] FAISSNER	81B	OSPK	Beam dump $A^0 \to 2\gamma$
		8	[33] KIM	81	OSPK	26 GeV $pN \to A^0$ X
		0	[34] FAISSNER	80	OSPK	Beam dump $A^0 \to e^+e^-$
$<1 \times 10^{-8}$	90		[35] JACQUES	80	HLBC	28 GeV protons
$<1 \times 10^{-14}$	90		[35] JACQUES	80	HLBC	Beam dump
			[36] SOUKAS	80	CALO	28 GeV p beam dump
			[37] BECHIS	79	CNTR	
$<1 \times 10^{-8}$	90		[38] COTEUS	79	OSPK	Beam dump
$<1 \times 10^{-3}$	95		[39] DISHAW	79	CALO	400 GeV pp
$<1 \times 10^{-8}$	90		ALIBRAN	78	HYBR	Beam dump
$<6 \times 10^{-9}$	95		ASRATYAN	78B	CALO	Beam dump
$<1.5 \times 10^{-8}$	90		[40] BELLOTTI	78	HLBC	Beam dump
$<5.4 \times 10^{-14}$	90		[40] BELLOTTI	78	HLBC	$m(A^0)$=1.5 MeV
$<4.1 \times 10^{-9}$	90		[40] BELLOTTI	78	HLBC	$m(A^0)$=1 MeV
$<1 \times 10^{-8}$	90		[41] BOSETTI	78B	HYBR	Beam dump
			[42] DONNELLY	78		
$<0.5 \times 10^{-8}$	90		HANSL	78D	WIRE	Beam dump
			[43] MICELMAC	78		
			[44] VYSOTSKII	78		

[24] BADIER 86 did not find long-lived A^0 in 300 GeV π^- Beam Dump Experiment that decays into e^+e^- in the mass range $m(A^0)$ = (20-200) MeV which excludes the A^0 decay constant $f(A^0)$ in the interval (60-600) GeV. See their figure 6 for excluded region on $f(A^0)$–$m(A^0)$ plane.

[25] BERGSMA 85 look for $A^0 \to 2\gamma$, e^+e^-, $\mu^+\mu^-$. First limit above is for $m(A^0)$ = 1 MeV; second is for 200 MeV. See their figure 4 for excluded region on $F_{A^0}-m(A^0)$ plane, where F_{A^0} is A^0 decay constant. For Peccei-Quinn PECCEI 77 A^0, $m(A^0)$ < 180 keV and τ < 0.037 sec (CL = 90%). For the axion of FAISSNER 81B at 250 keV, BERGSMA 85 expect 15 events but observe zero.

[26] FAISSNER 83 observed 19 1-γ and 12 2-γ events where a background of 4.8 and 2.3 respectively is expected. A small-angle peak is observed even if iron wall is set in front of the decay region.

[27] FAISSNER 83B extrapolate SIN γ signal to LAMPF ν experimental condition. Resulting 370 γ's are not at variance with LAMPF upper limit of 450 γ's. Derived from LAMPF limit that $[d\sigma(A^0)/d\omega$ at $90°]m(A^0)/\tau(A^0)$ < 14×10^{-35} $cm^2\,sr^{-1}$ MeV $msec^{-1}$. See comment on FRANK 83B.

[28] FRANK 83B stress the importance of LAMPF data bins with negative net signal. By statistical analysis say that LAMPF and SIN A0 are at variance when extrapolation by phase-space model is done. They find LAMPF upper limit is 248 not 450 γ's. See comment on FAISSNER 83B.

[29] HOFFMAN 83 set CL = 90% limit $d\sigma/dt$ BR(e^+e^-) < 3.5×10^{-32} cm^2/GeV^2 for 140 < $m(A^0)$ < 160 MeV. Limit assumes $\tau(A^0)$ < 10^{-9} sec.

[30] FETSCHER 82 reanalyzes SIN beam-dump data of FAISSNER 81. Claims no evidence for axion since 2-γ peak rate remarkably decreases if iron wall is set in front of the decay region.

[31] FAISSNER 81 see excess μe events. Suggest axion interactions.

[32] FAISSNER 81B is SIN 590 MeV proton beam dump. Observed 14.5 ± 5.0 events of 2γ decay of long lived neutral penetrating particle with $m(2\gamma)$ $\lesssim$ 1 MeV. Axion interpretation with η-A^0 mixing gives $m(A^0)$ = (250 ± 25) keV, $\tau_{(2\gamma)}$ = (7.3 ± 3.7)$\times10^{-3}$ sec from above rate. See critical remarks below in comments of FETSCHER 82, FAISSNER 83, FAISSNER 83B, FRANK 83B, and BERGSMA 85. Also see in the next subsection ALEKSEEV 82, CAVAIGNAC 83, and ANANEV 85.

[33] KIM 81 analyzed 8 candidates for $A^0 \to 2\gamma$ obtained by Aachen-Padova experiment at CERN with 26 GeV protons on Be. Estimated axion mass is about 300 keV and lifetime is (0.86~5.6) $\times$ 10^{-3} sec depending on models. Faissner (private communication) says axion production underestimated and mass overestimated. Correct value around 200 keV.

[34] FAISSNER 80 is SIN beam dump experiment with 590 MeV protons looking for $A^0 \to e^+e^-$ decay. Assuming A^0/π^0 = 5.5×10^{-7}, obtained decay rate limit 20/(A^0 mass) MeV/sec (CL = 90%) which is about 10^{-7} below theory and interpreted as upper limit to $m(A^0)$ < $2m(e^-)$.

[35] JACQUES 80 is a BNL beam dump experiment. First limit above comes from nonobservation of excess neutral-current-type events [σ(production)σ(interaction) < 7×10^{-68} cm^4, CL = 90%]. Second limit is from nonobservation of axion decays into 2γ's or e^+e^- and for axion mass a few MeV.

[36] SOUKAS 80 at BNL observed no excess of neutral-current-type events in beam dump.

[37] BECHIS 79 looked for the axion production in low energy electron Bremsstrahlung and the subsequent decay into either 2γ or e^+e^-. No signal found. CL = 90% limits for model parameter(s) are given.

[38] COTEUS 79 is a beam dump experiment at BNL.

[39] DISHAW 79 is a calorimetric experiment and looks for low energy tail of energy distributions due to energy lost to weakly interacting particles.

[40] BELLOTTI 78 first value comes from search for $A^0 \to e^+e^-$. Second value comes from search for $A^0 \to 2\gamma$, assuming mass < $2m(e^-)$. For any mass satisfying this limit is above value $\times$ (mass^{-4}). Third value uses data of PL 60B 401 and quotes σ(production)σ(interaction) < 10^{-67} cm^4.

[41] BOSETTI 78B quotes σ(production)σ(interaction) < 2×10^{-67} cm^4.

[42] DONNELLY 78 examines data from reactor neutrino experiments of REINES 76 and GURR 74 as well as SLAC beam dump experiment. Evidence is negative.

[43] MICELMACHER 78 finds no evidence of axion existence in reactor experiments of REINES 76 and GURR 74. (See reference under DONNELLY 78 below.)

[44] VYSOTSKII 78 derived lower limit for the axion mass 25 keV from luminosity of the sun and 200 keV from red supergiants.

A^0 (AXION) SEARCHES IN REACTOR EXPERIMENTS

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[45] KETOV	86	SPEC	Reactor $A^0 \to \gamma\gamma$
	[46] KOCH	86	SPEC	Reactor $A^0 \to \gamma\gamma$
	[47] DATAR	82	CNTR	Light water reactor
	[48] VUILLEUMIER	81	CNTR	Reactor, $A^0 \to 2\gamma$

[45] KETOV 86 searched for A^0 at the Rovno nuclear power plant. They found an upper limit on the A^0 production probability of 0.8 [100 keV/$m(A^0)$]^6 $\times$ 10^{-6} per fission. In the standard axion model, this corresponds to $m(A^0)$ > 150 keV. Not valid for $m(A^0)$ $\gtrsim$ 1 MeV.

[46] KOCH 86 searched for $A^0 \to \gamma\gamma$ at nuclear power reactor Biblis A. They found an upper limit on the A^0 production rate of $\omega(A^0)/\omega(\gamma(M1))$ < 1.5×10^{-10} (CL=95%). Standard axion with $m(A^0)$ = 250 keV gives 10^{-5} for the ratio. Not valid for $m(A^0)$ > 1022 keV.

[47] DATAR 82 looked for $A^0 \to 2\gamma$ in neutron capture ($np \to dA^0$) at Tarapur 500 MW reactor. Sensitive to sum of I = 0 and I = 1 amplitudes. With ZEHNDER 81 [(I = 0)−(I = 1)] result assert nonexistence of standard A^0.

[48] VUILLEUMIER 81 is at Grenoble reactor. Set limit $m(A^0)$ < 280 keV.

A^0 (AXION) SEARCHES IN NUCLEAR TRANSITIONS

Limits are for branching ratio.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 4 $\times10^{-4}$	95		[49] SAVAGE	88	CNTR	Nuclear decay (isovector)
< 3 $\times10^{-3}$	95		[49] SAVAGE	88	CNTR	Nuclear decay (isoscalar)
< 4 $\times10^{-4}$	90	0	[50] SAVAGE	86B	CNTR	$^{14}N^*$
			[51] ANANEV	85	CNTR	Li^*, deut* $A^0 \to 2\gamma$
			[52] CAVAIGNAC	83	CNTR	$^{97}Nb^*$, deut* transition $A^0 \to 2\gamma$
			[53] ALEKSEEV	82B	CNTR	Li^*, deut* transition $A^0 \to 2\gamma$
			[54] LEHMANN	82	CNTR	$Cu^* \to CuA^0$ ($A^0 \to 2\gamma$)
		0	[55] ZEHNDER	82	CNTR	Li^*, Nb^* decay, n capt
		0	[56] ZEHNDER	81	CNTR	$Ba^* \to BaA^0$ ($A^0 \to 2\gamma$)
			[57] CALAPRICE	79		Carbon

[49] SAVAGE 88 looked for A^0 that decays into e^+e^- in the decay of the 9.17 MeV $J^P = 2^+$ state in ^{14}N, 17.64 MeV state $J^P = 1^+$ in ^8Be, and the 18.15 MeV state $J^P = 1^+$ in ^8Be. This experiment constrains the isovector coupling of A^0 to hadrons, if $m(A^0)$ = (1.1 → 2.2) MeV and the isoscalar coupling of A^0 to hadrons, if $m(A^0)$ = (1.1 → 2.6) MeV. Both limits are valid only if $\tau(A^0)$ $\lesssim$ 1×10^{-11} s.

[50] SAVAGE 86B looked for A^0 that decays into e^+e^- in the decay of the 9.17 MeV $J^P = 2^+$ state in ^{14}N. Limit on the branching fraction is valid if $\tau(A^0) \lesssim 1\times10^{-11}$s for $m(A^0)$ = (1.1–1.7) MeV. This experiment constrains the iso-vector coupling of A^0 to hadrons.

[51] ANANEV 85 with IBR-2 pulsed reactor exclude standard A^0 at CL = 95% masses below 470 keV (Li^* decay) and below $2m(e)$ for deuteron* decay.

[52] CAVAIGNAC 83 at Bugey reactor exclude axion at any m($^{97}Nb^*$decay) and axion with $m(A^0)$ between 275 and 288 keV (deuteron* decay).

[53] ALEKSEEV 82 with IBR-2 pulsed reactor exclude standard A^0 at CL = 95% mass ranges $m(A^0)$ < 400 keV (Li^* decay) and 330 keV < $m(A^0)$ < 2.2 MeV (deuteron* decay).

[54] LEHMANN 82 obtained $A^0 \to 2\gamma$ rate < 6.2×10^{-5}/sec (CL = 95%) excluding $m(A^0)$ between 100 and 1000 keV.

[55] ZEHNDER 82 used Goesgen 2.8GW light-water reactor to check A^0 production. No 2γ peak in Li^*, Nb^* decay (both single p transition) nor in n capture (combined with previous Ba^* negative result) rules out standard A^0. Set limit $m(A^0)$ < 60 keV for any A^0.

[56] ZEHNDER 81 looked for $Ba^* \to A^0Ba$ transition with $A^0 \to 2\gamma$. Obtained 2γ coincidence rate < 2.2×10^{-5}/sec (CL = 95%) excluding $m(A^0)$ > 160 keV (or 200 keV depending on Higgs mixing). However see BARROSO 81.

[57] CALAPRICE 79 saw no axion emission from excited states of carbon. Sensitive to axion mass between 1 and 15 MeV.

A^0 (1.8 MeV) SEARCHES IN NUCLEAR TRANSITIONS

Limits are for $\Gamma(A(1.8\ MeV))/\Gamma(\pi M1)$, i.e., for 1.8 MeV axion emission normalized to the rate for internal emission of e^+e^- pairs.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 0.106	90	[58] HALLIN	86	SPEC	^6Li isovector decay
< 10.8	90	[58] HALLIN	86	SPEC	^{10}B isoscalar decays
< 2.2	90	[58] HALLIN	86	SPEC	^{14}N isoscalar decays

[58] Valid for $\tau(A^0)$ < 2×10^{-11}s. ^6Li isovector decay data strongly disfavor PECCEI 86 model I, whereas the ^{10}B and ^{14}N isoscalar decay data strongly reject PECCEI 86 model II and III.

A^0 (1.8 MeV) LIMITS FROM ITS ELECTRON COUPLING

Limits are for $\tau(A^0 \to e^+e^-)$ at $m(A^0)$ = 1.8 MeV.

VALUE (sec)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[59] MILLS	87	SPEC	$e^+e^- \to A^0 \to e^+e^-$
none 1×10^{-14}–1×10^{-10}	90	[60] RIORDAN	87	BDMP	$eN \to eA^0N$ ($A^0 \to e^+e^-$)
none 1×10^{-14}–1×10^{-11}	90	[61] BROWN	86	BDMP	$eN \to eA^0N$ ($A^0 \to e^+e^-$)

Stable Particle Full Listings
SEARCHES FOR AXIONS AND OTHER VERY LIGHT BOSONS

none	6×10^{-14}–9×10^{-11}	95	[62] DAVIER	86	BDMP	$eN \to eA^0N$ ($A^0 \to e^+e^-$)
none	3×10^{-13}–1×10^{-7}	90	[63] KONAKA	86	BDMP	$eN \to eA^0N$ ($A^0 \to e^+e^-$)

[59] MILLS 87 searched for a Bhabha scattering resonance near 1 8 MeV
[60] Assumes $A^0\gamma\gamma$ coupling is small and hence Primakoff production is small Their figure 2 shows limits on axions for $m(A^0) < 15$ MeV
[61] Uses electrons in hadronic showers from an incident 800 GeV proton beam Limits for $m(A^0) < 15$ MeV are shown in their figure 3
[62] $m(A^0)$ = 1 8 MeV assumed The excluded domain in the $\tau(A^0)-m(A^0)$ plane extends up to $m(A^0)$ 14 MeV see their figure 4
[63] The limits are obtained from their figure 3 Also given is the limit on the $A^0\gamma\gamma - A^0e^+e^-$ coupling plane by assuming Primakoff production

SEARCHES FOR GOLDSTONE BOSONS (X^0)

(Including Horizontal Bosons and Majorons) Limits are for branching ratios

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •					
$< 1\ 3 \times10^{-9}$	90	[64] GOLDMAN	87	CNTR	$\mu \to e\gamma X^0$ Familon
$< 3 \times10^{-4}$	90	[65] BRYMAN	86B	RVUE	$\mu \to eX^0$ Familon
$< 2\ 6 \times10^{-6}$	90	[66] JODIDIO	86	SPEC	$\mu^+ \to e^+X^0$ Familon
		[67] BALTRUSAITIS	85	MRK3	$\tau \to \ell X^0$ Familon
		[68] DICUS	83	COSM	ν (hvy) $\to \nu$ (light) X^0

[64] GOLDMAN 87 limit corresponds to $F > 2\ 9\times10^9$ GeV for the family symmetry breaking scale from the Lagrangian $L_{int} = (1/F)\bar{\psi}_\mu\gamma^\mu\ (a+b\gamma_5)\ \psi_e\partial_\mu\phi X^0$ with $a^2+b^2 = 1$ This is not as sensitive as the limit $F > 9\ 9\times10^9$ GeV derived from the search for $\mu^+ \to e^+X^0$ by JODIDIO 86 but does not depend on the chirality property of the coupling
[65] Limits are for $\Gamma(\mu \to eX^0)/\Gamma(\mu \to e\nu\nu)$ Valid when $m(X^0)$ = 0–93 4 98 1–103 5 MeV
[66] JODIDIO 86 corresponds to $F > 9\ 9\times10^9$ GeV for the family symmetry breaking scale with the parity conserving effective Lagrangian $L_{int} = (1/F)\ \bar{\psi}_\mu\gamma^\mu\psi_e\partial_\mu\phi X^0$
[67] BALTRUSAITIS 85 search for light Goldstone boson(X^0) of broken U(1) CL = 95% limits are BR($\tau \to \mu^+X^0$) / BR($\tau \to \mu^+\nu\nu$) < 0 125 and BR($\tau \to e^+X^0$) / BR($\tau \to e^+\nu\nu$) < 0 04 Inferred limit for the symmetry breaking scale is m > 3000 TeV
[68] The primordial heavy neutrino must decay into ν and familon f_A early so that the red-shifted decay products are below critical density see their table In addition $K \to \pi$ and $\mu \to e$ are unseen Combining these excludes m(heavy ν) between 5×10^{-5} and 5×10^{-4} MeV (μ decay) and m(heavy ν) between 5×10^{-5} and 0 1 MeV (K decay)

MAJORON SEARCHES IN NEUTRINOLESS DOUBLE β DECAY

Limits are for the half life of neutrinoless $\beta\beta$ decay with a Majoron emission

AVIGNONE 87 reported observation of neutrinoless double beta decay with emission of a scalar (e g , majoron) This claim is strongly refuted by CALDWELL 87 and FISHER 87 See however AVIGNONE 87B which claims that if FISHER 87 data are analyzed in a different way they are not in conflict with AVIGNONE 87

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
$> 1\ 4 \times10^{21}$	90	CALDWELL	87	CNTR	^{76}Ge
• • • We do not use the following data for averages fits limits etc • • •					
$> 3\ 3 \times10^{20}$	90	ALSTON	88	CNTR	^{100}Mo
$(6 \pm 1)\times10^{20}$		AVIGNONE	87	CNTR	^{76}Ge
$> 4\ 4 \times10^{20}$	90	ELLIOTT	87	CNTR	^{82}Se
$> 1\ 2 \times10^{21}$	90	FISHER	87	SPEC	^{76}Ge
		[69] VERGADOS	82	CNTR	

[69] VERGADOS 82 sets limit $g_H < 4\times10^{-3}$ for (dimensionless) lepton-number violating coupling g_H of scalar boson (Majoron) to neutrinos from analysis of data on double β decay of ^{48}Ca

REFERENCES FOR SEARCHES FOR AXIONS (A^0) AND OTHER VERY LIGHT BOSONS

ALSTON	88	PRL 60 1928	Alston Garnjost Dougherty+	(LBL MTHO UNM)
SAVAGE	88	PR D37 1134	+Filippone Mitchell	(CIT)
AVIGNONE	87	AIP Conf 1987	+Brodzinski Miley Reeves	(SCUC PNL)
AIP Conf Proc Salt Lake City UT				
AVIGNONE	87B	PL B198 253	+Brodzinski Miley Reeves	(SCUC PNL)
BAKER	87	PRL 59 2832	+Gordon Lazarus+	(BNL SIN WASH YALE)
CALDWELL	87	PRL 59 419	+Elsberg Grumm Witherell+	(UCSB LBL)
DRUZHININ	87	ZPHY C37 1	+Dubrovin Eidelman Golubev+	(NOVO)
ELLIOTT	87	PRL 59 1649	+Hahn Moe	(UCI)
FISHER	87	PL B192 460	+Boehm Bovet Egger+	(CIT NEUC SIN)
GOLDMAN	87	PR D36 1543	+Hallin Hoffman+	(LANL CHIC STAN TEMP)
KORENCHE	87	SJNP 46 192	Korenchenko Kostin Mzhavlya+	(JINR)
		Translated from YAF 46 313		
MILLS	87	PR D36 707	+Levy	(BELL)
RIORDAN	87	PRL 59 755	+Krasny Lang Barbaro Bodek+	(ROCH CIT+)
ALBRECHT	86D	PL B179 403	+Binder Boeckmann+	(ARGUS Collab)
BADIER	86	ZPHY C31 21	+Bemporad Boucrot Callot+	(NA3 Collab)
BOWCOCK	86	PRL 56 2676	+Giles Hassard Kinoshita+	(CLEO Collab)
BROWN	86	PRL 57 2101	+	(FNAL WASH KYOT KEK COLU STON SACL)
BRYMAN	86B	PRL 57 2787	+Clifford	(TRIU)
DAVIER	86	PL B180 295	+Jeanjean Nguyen Ngoc	(LALO)
EICHLER	86	PL B175 101	+Felawka Kraus Niebuhr+	(SINDRUM Collab)
HALLIN	86	PRL 57 2105	+Calparice Dunford McDonald	(PRIN)
JODIDIO	86	PR D34 1967	+Balke Carr Gidal Shinsky+	(LBL NWES TRIU)
Also	88	PR D37 237	Jodidio Balke Carr+	(LBL NWES TRIU)
Erratum				
KETOV	86	JETPL 44 146	+Klimov Nikolaev Mikaelyan+	(KIAE)
		Translated from ZETFP 44 114		
KOCH	86	NC 96A 182	+Schult	(JULI)
KONAKA	86	PRL 57 659	+Imai Kobayashi Masaike Miyake+	(KYOT KEK)
MAGERAS	86	PRL 56 2672	+Franzini Tuts Youssef+	(MPIM COLU STON)
PECCEI	86	PL B172 435	+Wu Yanagida	(DESY)
SAVAGE	86B	PRL 57 178	+Mckeon Filippone Mitchell	(CIT)
ANANEV	85	SJNP 41 585	+Kalinina Lushchikov Olshevskii+	(JINR)
		Translated from YAF 41 912		
BALTRUSAITIS	85	PRL 55 1842	+Becker Blaylock Brown+	(MARK III Collab)
BERGSMA	85	PL 157B 458	+Dorenbosch Allaby Amaldi+	(CHARM Collab)
YAMAZAKI	84	PRL 52 1089	+Ishikawa Taniguchi Yamanaka+	(TOKY KEK)
ALAM	83	PR D27 1665	+	(VAND CORN ITHA HARV OHIO ROCH+)
CARBONI	83	PL 123B 349	+Dahme	(CERN MUNI)
CAVAIGNAC	83	PL 121B 193	+Hoummada Koang Ost+	(GREN LAPP)
DICUS	83	PR D28 1778	+Teplitz	(TEXA UMD)
FAISSNER	83	PR D28 1198	+Heinrigs Preussger Samm	(AACH)
FAISSNER	83B	PR D28 1787	+Frenzel Heinrigs Preussger+	(AACH)
FRANK	83B	PR D28 1790	+	(LANL YALE LBL MIT SACL SIN CNRC BERN)
HOFFMAN	83	PR D28 660	+Frank Mischke Moir Schardt	(LANL ARZS)
NICZYPORUK	83	ZPHY C17 197	+Jakubowski Zeludziewicz+	(LENA Collab)
ALEKSEEV	82	JETP 55 591	+Kartamyshev Makarin+	(KIAE)
		Translated from ZETF 82 1007		
ALEKSEEV	82B	JETPL 36 116	+Kalinina Kruglov Kulikov+	(MOSU JINR)
		Translated from ZETFP 36 94		
ASANO	82	PL 113B 195	+Kikutani Kurokawa Miyachi+	(KEK TOKY OSAK)
BARROSO	82	PL 116B 247	+Branco	(LISB)
DATAR	82	PL 114B 63	+Baba Beligeri Singh	(BHAB)
EDWARDS	82	PRL 48 903	+Partridge Peck Porter+	(Crystal Ball Collab)
FETSCHER	82	JP G8 L147		(ETH)
LEHMANN	82	PL 115B 270	+Lesquoy Muller Zylberajch	(SACL)
RAFFELT	82	PL 119B 323	+Stodolsky	(MPIM)
SIVERTZ	82	PR D26 717	+Lee Franzini Horstkotte+	(CUSB Collab)
VERGADOS	82	PL 109B 96		(CERN)
ZEHNDER	82	PL 110B 419	+Gabathuler Vuilleumier	(ETH SIN CIT)
ASANO	81B	PL 107B 159	+Kikutani Kurokawa Miyachi+	(KEK TOKY OSAK)
BARROSO	81	PL 106B 91	+Mukhopadhyay	(SIN)
FAISSNER	81	ZPHY C10 95	+Frenzel Grimm Hansl Hoffman+	(AACH)
FAISSNER	81B	PL 103B 234	+Frenzel Heinrigs Preussger+	(AACH)
KIM	81	PL 105B 55	+Stamm	(AACH)
VUILLEUMIER	81	PL 101B 341	+Boehm Hahn Kwon+	(CIT MUNI)
ZEHNDER	81	PL 104B 494		(ETH)
FAISSNER	80	PL 96B 201	+Frenzel Heinrigs Preussger Samm+	(AACH)
JACQUES	80	PR D21 1206	+Kalelkar Miller Plano+	(RUTG STEV COLU)
SOUKAS	80	PRL 44 564	+Wanderer Weng+	(BNL HARV ORNL PENN)
BECHIS	79	PRL 42 1511	+Dombeck+	(UMD COLU AFRR)
CALAPRICE	79	PR D20 2708	+Dunford Kouzes Miller+	(PRIN)
COTEUS	79	PRL 42 1438	+Diesburg Fine Lee Sokolsky+	(COLU ILL BNL)
DISHAW	79	PL 85B 142	+Diamant Berger Faessler Liu+	(SLAC CIT)
ZHITNITSKII	79	SJNP 29 517	+Skovpen	(NOVO)
		Translated from YAF 29 1001		
ALIBRAN	78	PL 74B 134	+Armenise Arnold Bartley	(Gargamelle Collab)
ASRATYAN	78B	PL 79B 497	+Epstein Fakhrutdinov+	(ITEP SERP)
BELLOTTI	78	PL 76B 223	+Fiorini Zanotti	(MILA)
BOSETTI	78B	PL 74B 143	+Deden Deutschmann Fritze+	(BEBC Collab)
DICUS	78C	PR D18 1829	+Kolb Teplitz Wagoner	(TEXA VPI STAN)
DONNELLY	78	PR D18 1607	+Freedman Lytel Peccei Schwartz	(STAN)
Also	76	PRL 37 315	Reines Gurr Sobel	(UCI)
Also	74	PRL 33 179	Gurr Reines Sobel	(UCI)
HANSL	78D	PL 74B 139	+Holder Knobloch May Paar+	(CDHS Collab)
MICELMAC	78	LNC 21 441	Micelmacher Pontecorvo	(JINR)
VYSOTSKII	78	JETPL 27 502	+Zeldovich Khlopov Chechetkin	(ASCI)
		Translated from ZETFP 27 533		
YANG	78	PRL 41 523		(MASA)
PECCEI	77	PR D16 1791	+Quinn	(STAN SLAC)
Also	77B	PRL 38 1440	Peccei Quinn	(STAN SLAC)
REINES	76	PRL 37 315	+Gurr Sobel	(UCI)
GURR	74	PRL 33 179	+Reines Sobel	(UCI)

SEARCHES FOR NEUTRAL AND CHARGED HIGGS BOSONS

NOTE ON THE HIGGS BOSON

The Standard Model[1] contains one neutral scalar Higgs boson which is a remnant of the mechanism which breaks the SU(2)×U(1) symmetry and generates the W and Z boson masses. The Higgs couples to quarks and leptons of mass m_f, with a strength of $gm_f/2M_W$ (g is the coupling constant of the SU(2) gauge theory). Consequently its coupling to stable matter is very small, and production and detection are very difficult.

If the Higgs mass were small then the vacuum state with $M_H = 0$ would become the true ground state of the theory. A theoretical constraint can then be obtained from the requirement that the stable state ground state of the theory be that with $M_H \neq 0$. This implies[2] $M_{H^0} \gtrsim 7$ GeV. The slightly stronger bound[3] $M_{H^0} \gtrsim 10$ GeV depends upon a detailed analysis of the thermal history of the universe, in particular, the assumption that its baryon number density is produced at temperatures larger than $T_H = M_H c^2/k$ and that this density is not then diluted by the electroweak phase transition which takes place at $T \sim T_H$. All these constraints weaken as the top-quark mass increases; they disappear when $m_{top} \gtrsim M_W$.

A very light Higgs boson would produce an additional long-range component to the nuclear force. No such component has been seen and the constraint[4,5] $M_{H^0} > 13$ MeV can be obtained. Direct searches[6] for Higgs bosons emitted in nuclear decay also exclude the mass range from 3 to 14 MeV. A light Higgs could be emitted in K meson decay via the process $K \to \pi H^0$. If the Higgs is lighter than $2m_\mu$ the final state will be $\pi e^+ e^-$, or $\pi\gamma\gamma$ (the former has at least twice the width of the latter provided it is kinematically accessible).[5,7] At larger masses, $\pi\mu^+\mu^-$ or 3π will dominate.[8] Attempts to calculate the branching ratio $K \to \pi H^0$ are fraught with uncertainties. It is convenient to distinguish two contributions to the process. Firstly the strange quark can decay while the u or d antiquark in the K meson acts a spectator. This quark decay process $s \to dH^0$ is straightforward to compute[9,10] but its value depends on the unknown top-quark mass and the elements of the Kobayashi-Maskawa matrix. The hadronic matrix element of this quark decay operator must then be evaluated; this gives rise to an additional uncertainty. Recent evaluation[11] of this for $M_{H^0} < 2m_\mu$ gives a branching fraction BF($K \to \pi H^0$) $\gtrsim 5\times10^{-6}$. Since a value of 2.7×10^{-7} for BF($K^+ \to \pi^+ e^+ e^-$) for $m_{e^+e^-} > 50$ MeV has been measured,[12] a Higgs of mass between 50 MeV and 211 MeV would seem to be ruled out. The experimental limit[13] on BF($K^+ \to \pi^+\mu\mu$) is too weak to constrain the Higgs mass from this process. However, there is the possibility of a second contribution to $K \to \pi H^0$ arising from the process where the u or d quark in the K meson participates directly in the Higgs production. This contribution is more difficult to evaluate,[14] and it is possible that it could partially cancel[15] that from the first process. Early results[14,16] indicating that this latter contribution may be dominant have been shown to be incorrect; recently it has been claimed[11] that it has the same sign as the spectator contribution. In view of these uncertainties, some caution should be exercised, however a strong cancellation would be required to void the limit from K decay. One needs either less uncertain theoretical calculations, which are unlikely to appear until all the problems associated with K decay such as the $\Delta I = 1/2$ rule are understood, or an improvement by at least a factor of 20 in the experimental limits before one can have absolute confidence in the limits.

Predicted[14,16] branching fractions for $\eta' \to \eta H^0$ are close to the experimental limit,[17] however again predictions are rather uncertain and no definite conclusion can be reached.

The process $B \to KH^0$ can proceed similarly to $K \to \pi H^0$ but with a larger branching fraction. The uncertainties in the calculated branching fraction are no worse than in the K meson case; again the result[19] depends on the top-quark mass and on Kobayashi-Maskawa angles (V_{ij}): BF($B \to KH^0$)$\sim 4\times10^{-3}\,(V_{ts}V_{tb}/0.05)^2\,(m_t/M_W)^4$. Here m_t and M_W are the top-quark and W masses. The final states Ke^+e^- or $K\mu\mu$ should provide a probe of Higgs masses below $(m_B - m_K)$. The latter has an upper limit[18] on its branching fraction of 4.5×10^{-4}. The current limit[20] of $m_t > 44$ GeV implies that this branching fractions is comparable to or less than the experimental limit. (Recall also that according to the theoretical argument above, the top quark mass must be similar to or larger than the W mass if $M_{H^0} \lesssim 7$ GeV is to be allowed.) The CLEO collaboration[21] claims to exclude the ranges 0.3 GeV $< M_{H^0} < 3.0$ and $3.2 < M_{H^0} < 3.6$ GeV assuming $M_{top} > 43$ GeV. However some caution should be exercised in view of the theoretical uncertainties.

The process $\Upsilon \to H^0\gamma$ can be more reliably calculated in principle.[22] The CUSB group[23] has used this process to exclude the range 600 MeV $< M_H <$ 3.2 GeV at 95% confidence. However the order α_s correction[24] reduced the predicted branching fraction by a factor of 2 and since the order α_s^2 correction is not known some uncertainty remains concerning the predicted value. There is also the possibility of relativistic corrections in the Υ bound states. Corrections at the 10% level should be expected. Recent calculations[25] showing a large reduction in the predicted branching fraction are valid only for $M_H \gtrsim 7.5$ GeV.

Stable Particle Full Listings
SEARCHES FOR NEUTRAL AND CHARGED HIGGS BOSONS

These additional theoretical uncertainties are important since the current experimental limit on this branching ratio lies at most a factor of two below the prediction over the relevant range of Higgs mass. Until the experimental limit improves by another factor of 2, caution should be exercised in extracting a Higgs bound from it.

In summary, the only cast-iron constraint on the Higgs mass is $M_{H^0} > 14$ MeV. A combination of theoretical arguments and bounds from B, Υ and K decays probably excludes the range below 4 GeV. More meaningful constraints both from the above processes (better limits on the branching fractions and the top-quark mass) and from searches for $Z \to H^0 \mu\mu$ at LEP should appear in the next few years.

Extensions of the Standard Model, such as those based on supersymmetry,[26] can have two Higgs doublets whose neutral components have vacuum expectation values v_1 and v_2, both of which contribute to the W and Z masses. The physical particle spectrum contains one charged Higgs boson ($H^\mp$), two neutral scalars (H_1^0, H_2^0) and one pseudoscalar (P^0) if CP is conserved in the scalar sector.[27] In models where all fermions of the same electric charge receive their masses from only one of the two doublets there are, as in the Standard Model, no flavor-changing neutral currents at tree level[28] (lowest order in perturbation theory). The H_i^0/P^0 couplings to fermions depend on v_2/v_1 and are either enhanced or supressed relative to the couplings in the Standard Model. If the couplings to b quarks are enhanced, then there are significant limits from Υ and B meson decays.[18,19,23]

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H^0 (HIGGS BOSON) MASS LIMIT

For early higgs search papers see J Ellis M K Gaillard, D V Nanopoulos, Nucl Phys B106, 292 (1976)

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>0.100	90	[1] BAKER	87	CALO	$K^\pm \to \pi^\pm H^0$ ($H^0 \to e^+e^-$)
none 0 6–3 9	90	[2] LEE FRANZINI	87	RVUE	$\Upsilon(1S\,3S) \to \gamma H^0$
none 0 003–0 014	95	[3] FREEDMAN	84	CNTR	$He^* \to He H^0$ ($H^0 \to e^+e^-$)
none 0 00103–0 00584		[4] MUKHOPAD	84	RVUE	$O^* \to O H^0$ ($H^0 \to e^+e^-$)
>0.013		[5] BARBIERI	75	RVUE	$nN \to nN$
• • • We do not use the following data for averages fits limits etc • • •					
		[6] DRUZHININ	87	CALO	$\phi \to \gamma H^0$ ($H^0 \to \pi^0\pi^0$)
>0 010		BELTRAMI	86	SPEC	Muonic atoms
none 0 05–0 211		[7] WILLEY	86	RVUE	$K^\pm \to \pi^\pm H^0$ ($H^0 \to e^+e^-$)
		[8] HOFFMAN	83	CNTR	$\pi p \to n H^0$ ($H^0 \to e^+e^-$)
none 0 25–0 409		[9] DZHELYADIN	81		$\eta' \to \eta H^0$ ($H^0 \to \mu^+\mu^-$)
		[10] WITTEN	81	COSM	
>9		[10] GUTH	80	COSM	
>9		[10] SHER	80	COSM	

[1]BAKER 87 sets limit BR($K^{\pm} \rightarrow \pi^{\pm} H^0$)BR($H^0 \rightarrow e^+e^-$) < 8×10^{-7} at CL=90% for $m(H^0)$ < 100 MeV if H^0 travels much less than 1 4 cm in the lab frame This limit is inconsistent with the Standard Model estimate (WILLEY 86) BR($K^{\pm} \rightarrow \pi^{\pm} H^0$) > 4 5$\times 10^{-6}$ and BR($H^0 \rightarrow e^+e^-$) $\gtrsim$ 1/2 for $m(H^0) < 2m(\mu)$

[2]LEE-FRANZINI 87 presents the latest results from the CUSB experiment (see FRANZINI 87 for more details) First order QCD correction included with $\alpha_s \sim$ 0 2 (Λ = 0 2 GeV and $n(f)$ = 4) The 95% CL excluded mass region is 0 6–3 2 GeV

[3]FREEDMAN 84 is ANL experiment with dynamitron proton bombarding tritium to form He* They also reanalyze KOHLER 74 He* data to find no mass region is excluded by that data See also comment cards on MUKHOPADHYAY 84 below

[4]MUKHOPADHYAY 84 examine KOHLER 74 He* and C* data Claim that no mass region can be excluded by 74 He* data since He* decay width to proton is large [BR(He* $\rightarrow H^0$He) = 3.4$\times 10^{-11}$ is very small] Above limit is from KOHLER 74 O* decay data

[5]BARBIERI 75 studied Higgs boson exchange effect in neutron-nucleon scattering and found limit ($g^2_{H^0 nn}/4\pi$) ($m(H^0)$/Mev)$^{-4}$ $\leq$ 3 4$\times 10^{-11}$ By assuming (cf ELLIS 76) $g_{H^0 nn} \simeq m(n)/v$ with $v^2 = 1/(2^{1/2} G_F)$ the above limit becomes $m(H^0) \gtrsim$ 13 MeV

[6]DRUZHININ 87 sets limit BR($\phi \rightarrow \gamma H^0$)BR($H^0 \rightarrow \pi^0\pi^0$) < 8×10^{-5} at CL=90% for $m(h)$ = 0 6–1 GeV which is still far from the standard Higgs model prediction and does not exclude the existence of light Higgs bosons

[7]WILLEY 86 re examined the theoretical estimate of the decay $K^{\pm} \rightarrow \pi^{\pm} H^0$ rate via the one loop sdH^0 coupling The bound applies to H^0 whose couplings to up quarks are comparable or larger than those of the standard one-doublet model H^0 couplings The experimental bound BR($K \rightarrow \pi\mu\mu$) < 2 4$\times 10^{-6}$ is not strong enough to rule out $2m(\mu) < m(H^0) < 2m(\pi^0)$

[8]HOFFMAN 83 looked for e^+e^- peak from Higgs produced in $\pi^- p \rightarrow H^0 n$ at 300 MeV/c Set CL = 90% limit $d\sigma/dt$ BR(e^+e^-) < 3 5$\times 10^{-32}$ cm^2/GeV^2 for 140 < $m(H^0)$ < 160 MeV which does not exclude H^0 with the standard one-doublet model couplings

[9]DZHELYADIN 81 obtained BR($\eta' \rightarrow \eta\mu^+\mu^-$) < 1 5$\times 10^{-5}$ (CL = 90%) and argued that it excludes H^0 with the standard one doublet model couplings in $\mu^+\mu^-$ channel

[10]Limits from cosmological considerations of SU(2) $\times$ U(1) symmetry breaking phase transition occurring only after extreme supercooling resulting in too high a ratio of entropy to baryon number Limits apply to the standard one doublet model H^0 with zero bare mass whose physical mass is determined by the Coleman Weinberg mechanism of dynamical symmetry breakdown These limits depend on the mass of the top quark approximately according to $m(H^0)$ > 10 4−($m(t)$/15 GeV)^4 0 006 GeV So for large $m(t)$, there is no limit

H^0 (HIGGS BOSON) MASS LIMIT IN EXTENDED HIGGS MODELS

The parameter x denotes the Hbb coupling relative to the value in the standard one-Higgs-doublet model

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages fits limits etc • • •					
none 0 6–6 2	90	[11] FRANZINI	87	CUSB	$\Upsilon(1S) \rightarrow \gamma H^0$ x=2
none 0 6–7.9	90	[11] FRANZINI	87	CUSB	$\Upsilon(1S) \rightarrow \gamma H^0$ x=4
none 3 7–5 6	90	[12] ALBRECHT	85J	ARG	$\Upsilon(1S) \rightarrow \gamma H^0$ x=2
none 3 7–8.2	90	[12] ALBRECHT	85J	ARG	$\Upsilon(1S) \rightarrow \gamma H^0$ x=4

[11]First order QCD correction included with $\alpha_s \simeq$ 0 2 Their figure 4 shows the limits vs x

[12]ALBRECHT 85J found no mono-energetic photons in both $\Upsilon(1S)$ and $\Upsilon(2S)$ radiative decays in the range 0 5 GeV <$E(\gamma)$<4 0 GeV with typically BR<0 01 for $\Upsilon(1S)$ and BR<0 02 for $\Upsilon(2S)$ at 90% CL These upper limits are 5–10 times the prediction of the standard Higgs-doublet model The quoted 90% limit BR($\Upsilon(1S) \rightarrow H^0\gamma$) < 1 5$\times 10^{-3}$ at $E(\gamma)$ = 1 07 GeV contradicts previous Crystal Ball observation of (4 7 ± 1 1)$\times 10^{-3}$ see their reference 3 Their figure 8a shows the upper limits of x^2 as a function of $E(\gamma)$ by assuming no QCD corrections We used $m(H^0) = m(\Upsilon)$ $(1-2E(\gamma)/m(\Upsilon))^{1/2}$

$H^{\pm}$ (CHARGED HIGGS OR TECHNI-PION) MASS LIMIT

Most of the following limits assume BR($H^+ \rightarrow \tau^+\nu$) + BR($H^+ \rightarrow cs$) = 1 BEHREND 87 and BARTEL 86 assume BR($H^+ \rightarrow \tau^+\nu$) + BR($H^+ \rightarrow cs$) + BR($H^+ \rightarrow cb$) = 1 For a discussion of techni-particles, see EICHTEN 86

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>19	95	[13] BEHREND	87	CELL	BR($\tau\nu$) = 0–1
• • • We do not use the following data for averages fits limits, etc • • •					
>18	95	[14] BARTEL	86	JADE	BR($\tau\nu$)=0 1–1 0
>17	95	[14] ADEVA	85	MRKJ	BR($\tau\nu$)=0 25–1 0
none 5–13	95	[15] ALTHOFF	83B	TASS	BR($\tau\nu$)=0 –0 26
< $m(B)$		[16] CHEN	83	RVUE	B decay at $\Upsilon(4S)$
none 5–13	95	[14] ADEVA	82B	MRKJ	BR($\tau\nu$)=0 25
none 3–13	95	[14] BARTEL	82D	JADE	BR($\tau\nu$)=0 2–1 0
none 7–14 9	95	[17] BEHREND	82B	CELL	BR($\tau\nu$)=0 80
none 4–9	90	[14] BLOCKER	82	MRK2	BR($\tau\nu$)=0 10–0 90

[13]Studied $H^+H^- \rightarrow (\tau\nu) + (\tau\nu)$ $H^+H^- \rightarrow (\tau\nu)$ + hadrons $H^+H^- \rightarrow$ hadrons

[14]Studied $H^+H^- \rightarrow (\tau\nu) + (\tau\nu)$ $H^+H^- \rightarrow (\tau\nu)$ + hadrons Search for muon opposite hadronic shower

[15]ALTHOFF 83 analyzed $H^+H^- \rightarrow$ 4 jets The same limit is obtained for BR($\nu\tau$) = 0–1 0 if BR($H^+ \rightarrow cb$)/BR($H^+ \rightarrow cs$) = 1 See their figure 3

[16]CHEN 83 excluded a model where $b \rightarrow H^-$ light quark at BR = 1 Observed BR($b \rightarrow e$ X) would require BR($H^+ \rightarrow \tau$ X) = 1 but then charged energy fraction would be smaller than experiment value (0 60 ± 0 03) (CLEO data)

[17]BEHREND 82B studied $H^+H^- \rightarrow (\tau\nu) + (\tau\nu)$ See their figure 3

SEARCHES FOR X(2200) (A NEUTRAL HIGGS CANDIDATE)

Limits are for branching ratios or products of branching ratios The notation ξ below refers to X(2200)

VALUE (units 10^{-4})	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages fits limits etc • • •					
< 0 31	90	[18] BEAN	86	CLEO	$\Upsilon(1S) \rightarrow K^+K^-$ mode
< 2	90	[19] BEHRENDS	84	CLEO	$\Upsilon(1S) \rightarrow K^+K^-$ mode
< 0 9	90	[19] BEHRENDS	84	CLEO	$\Upsilon(2S) \rightarrow K^+K^-$ mode
<30	90	[19] BEHRENDS	84	CLEO	B meson K^+K^- mode
<4–12	90	[20] YOUSSEF	84	CUSB	Υ(1 2S) 2 charged
<5–15	90	[20] YOUSSEF	84	CUSB	$\Upsilon(1S) \rightarrow \gamma$ X

[18]BEAN 86 looked for cascade decays $\Upsilon(1S) \rightarrow \gamma H^0$ ($H^0 \rightarrow h^+h^-$) for the 3 modes, $\pi^+\pi^-$ K^+K^- and $p\bar{p}$ See their figure 4 for limits on branching fractions as function of $m(H^0)$ in the range $2m(h) < m(H^0) < 8$ GeV

[19]BEHRENDS 84 first and second limits are for BR($\Upsilon \rightarrow \gamma\xi$)BR($\xi \rightarrow K^+K^-$) the third is for BR($B \rightarrow \xi$ X)BR($\xi \rightarrow K^+K^-$) All for $m(\xi)$ = 2 2 GeV but are similar for 1 5–4 GeV(first second) and for 2–3 GeV(third)

[20]YOUSSEF 84 first limit is for inclusive radiative decay the second is for BR($\Upsilon \rightarrow \xi\gamma$)BR($\xi \rightarrow$ 2 charged) For $m(\xi)$ = 1–7 GeV

REFERENCES FOR NEUTRAL AND CHARGED HIGGS BOSONS

BAKER	87	PRL 59 2832	+Gordon Lazarus+	(BNL SIN WASH YALE)
BEHREND	87	PL B193 376	+Buerger Criegee Dainton+	(CELLO Collab)
DRUZHININ	87	ZPHY C37 1	+Dubrovin Eidelman Golubev+	(NOVO)
FRANZINI	87	PR D35 2883	+Son Tuts Youssef Zhao+	(CUSB Collab)
LEE FRANZINI	87	Hamburg Conf		(CUSB Collab)
BARTEL	86	ZPHY C31 359	+Becker Felst Haidt+	(JADE Collab)
BEAN	86	PR D34 905	+Bobbink Brock Engler+	(CLEO Collab)
BELTRAMI	86	NP A451 679	+Aas Beer Dechambrier Goudsmit+	(ETH FRIB)
EICHTEN	86	PR D34 1547	+Hinchliffe Lane Quigg+	(FNAL LBL OSU)
WILLEY	86	PL B173 480		(PITT)
ADEVA	85	PL 152B 439	+Becker Becker Szendy+	(MARK J Collab)
ALBRECHT	85J	ZPHY C29 167	+Binder Harder+	(ARGUS Collab)
BEHRENDS	84	PL 137B 277	+Chadwich Chauveau Gentile+	(CLEO Collab)
FREEDMAN	84	PRL 52 240	+Napolitano Camp Kroupa	(ANL CHIC)
MUKHOPAD	84	PR D29 565	Mukhopadhyay Goudsmit+	(RPI SIN LISB)
YOUSSEF	84	PL 139B 332	+Franzini Son Tuts+	(CUSB Collab)
ALTHOFF	83	PL 121B 216	+Brandelik Boerner Burkhardt+	(TASSO Collab)
ALTHOFF	83B	PL 122B 95	+Brandelik Boerner Burkhardt+	(TASSO Collab)
CHEN	83	PL 122B 317	+Goldberg Alam Andrews+	(CLEO Collab)
HOFFMAN	83	PR D28 660	+Frank Mischke Moir Schardt	(LANL ARZS)
ADEVA	82B	PL 115B 345	+Barber Becker Berdugo+	(MARK J Collab)
BARTEL	82D	PL 114B 211	+Cords Elsen Bethke+	(JADE Collab)
BEHREND	82B	PL 114B 287	+Chen Fenner Field+	(CELLO Collab)
BLOCKER	82	PRL 49 517	+Matteuzzi Abrams Amidei+	(MARK II Collab)
DZHELYADIN	81	PL 105B 239	+Golovkin Konstantinov Kubarovski+	(SERP)
WITTEN	81	NP B177 477		(HARV)
GUTH	80	PRL 45 1131	+Weinberg	(SLAC)
SHER	80	PR D22 2989		(UCSC)
Also	83	ANP 148 95	Flores Sher	(UCSC UCI)
ELLIS	76	NP B106 292	+Gaillard Nanopoulos	(CERN)
BARBIERI	75	PL 57B 270	+Ericson	(CERN)
KOHLER	74	PRL 33 1628	+Watson Becker	(LOCK)

SEARCHES FOR HEAVY BOSONS OTHER THAN HIGGS BOSONS

We list here various limits on charged and neutral heavy vector bosons (other than Ws and Zs) heavy scalar bosons (other than Higgs bosons), and vector or scalar leptoquarks

Stable Particle Full Listings
SEARCHES FOR HEAVY BOSONS OTHER THAN HIGGS BOSONS

W_R (RIGHT-HANDED W BOSON) MASS LIMITS

Assuming a light right handed neutrino

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>406	90	[1] JODIDIO	86	ELEC	Any L-R mixing angle
• • • We do not use the following data for averages fits limits etc • • •					
>482	90	[1] JODIDIO	86	ELEC	L R mix angle =0
>800		MOHAPATRA	86	RVUE	$SU(2)_L \times SU(2)_R \times U(1)$
>400	95	[2] STOKER	85	ELEC	Any L-R mix ang
>475	95	[2] STOKER	85	ELEC	L R mix ang· 0 041
		[3] BERGSMA	83	CHRM	$\nu_\mu e \to \mu \nu_e$
>380	90	[4] CARR	83	ELEC	μ^+ decay

[1] JODIDIO 86 is the same TRIUMF experiment as STOKER 85 (and CARR 83) however it uses a different technique The results given here are combined results of the two techniques The technique here involves precise measurement of the end-point e^+ spectrum in the decay of the highly polarized μ^+ Alternative results can be obtained by fixing $m(W_R)$ and obtaining limits on the L R mixing angle ζ If $m(W_R) = \infty$ then $|\zeta| <$ 0 040 whereas for unconstrained $m(W_R)$ $-0\ 056 < \zeta < 0\ 040$

[2] STOKER 85 is same TRIUMF experiment as CARR 83 Here they measure the decay e^+ spectrum asymmetry above 46 MeV/c using a muon-spin-rotation technique Assumed a light right handed neutrino Quoted limits are from combining with CARR 83

[3] BERGSMA 83 set limit $m(W_2)/m(W_1)$ · 1 9 at CL = 90%

[4] CARR 83 is TRIUMF experiment with a highly polarized μ^+ beam Looked for deviation from V−A at the high momentum end of the decay e^+ energy spectrum Limit from previous world-average muon polarization parameter is $m(W_R)$ ·240 GeV Assumes a light right handed neutrino

MASS LIMITS FOR W' (A HEAVY CHARGED VECTOR BOSON OTHER THAN W) IN HADRON COLLIDER EXPERIMENTS

Limits are obtained when the W' couplings to quarks $g_{W'q}$ and the leptonic branching ratio $BR(W' \to e\nu)$ are the same as those of the standard W where the leptonic cross section is proportional to $(g_{W'q})^2\ BR(W' \to e\bar{\nu})$

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>210	90	[5] ARNISON	86B	UA1	$p\bar{p} \to W'\ X\ (W' \to e\nu)$
• • • We do not use the following data for averages fits limits etc • • •					
>209	90	[6] ANSARI	87D	UA2	$p\bar{p} \to W'\ X\ (W' \to e\nu)$
>170	90	[7] ARNISON	83D	UA1	$p\bar{p} \to W'\ X\ (W' \to e\nu)$

[5] ARNISON 86B find no excess at large p_T in 148 $W \to e\nu$ events Set limit $\sigma \times BR(e\nu)$ · 10 pb at CL = 90% at E_{cm} = 546 and 630 GeV

[6] See Fig 5 of ANSARI 87D for the excluded region in the $m(W')$-$[(g_{W'q})^2$ $BR(W' \to e\nu)]$ plane Note that the quantity $(g_{W'q})^2$ $BR(W' \to e\nu)$ is normalized to unity for the standard W couplings

[7] ARNISON 83B find among 47 $W \to e\nu$ candidates no event with excess p_T Also set $\sigma \times BR(e\nu)$ · 30 pb with CL = 90% at E_{cm} = 540 GeV

MASS LIMITS FOR Z' (HEAVY NEUTRAL VECTOR BOSON OTHER THAN Z)

The mass bounds depend on the quantum number and the coupling strength of Z' and neutral currents In particular we use the following notation for Z' associated with specific U(1) currents

Z_1 SM $\times$ $U(1)_{Z_1}$
Z_{LR} $SU(2)_L \times SU(2)_R \times U(1) \to SM \times U(1)_{LR}$
Z_χ $SO(10) \to SU(5) \times U(1)_\chi$
Z_ψ. $E_6 \to SO(10) \times U(1)_\psi$
Z_η. $E_6 \to SM \times U(1)_\eta$

Here SM denotes either $SU(2)_L \times U(1)_Y$ or $SU(3)_C \times SU(2)_L \times U(1)_Y$ whichever is appropriate Typical reference coupling strengths are g_Y = $e/\cos\theta_W$ and g_Z = $g_Y/\sin\theta_W$ In particular g_{Z_1} = g_Z is always assumed

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>343	90	[8] AMALDI	87	RVUE	Z_{LR}, $g_L = g_R$
>112	90	[9] AMALDI	87	RVUE	Z_η $g_\eta = g_Y$
>249	90	[10] AMALDI	87	RVUE	Z_χ $g_\chi = g_Y$
>151	90	[11] AMALDI	87	RVUE	Z_ψ $g_\psi = g_Y$
>180	90	[12] ANSARI	87D	UA2	$p\bar{p} \to Z_1\ X\ (Z_1 \to e^+e^-)$
• • • We do not use the following data for averages fits limits, etc • • •					
>160	90	[13] ARNISON	86B	UA1	$p\bar{p} \to Z_1\ X\ (Z_1 \to e^+e^-)$
>143	90	[14] BARGER	86B	RVUE	Z_η $g_\eta = g_Y$
>275	90	[8] DURKIN	86	RVUE	Z_{LR} $g_L = g_R$
>126	90	[9 14] DURKIN	86	RVUE	Z_η $g_\eta = g_Y$
>222	90	[10] DURKIN	86	RVUE	Z_χ $g_\chi = g_Y$
>114	90	[11] DURKIN	86	RVUE	Z_ψ $g_\psi = g_Y$
>150	95	[15] ADEVA	85	MRKJ	Z_1 Bhabha

[8] Left right symmetry ($g_L = g_R$) assumed

[9] $g_\psi = g_Y$ assumed which implies that $E_6 \to SM \times U(1) \times U(1)_\psi$ in one step

[10] $g_\chi = g_Y$ assumed which implies that $SO(10) \to SM \times U(1)_\chi$ in one step

[11] $g_\eta = g_Y$ assumed which implies that $E_6 \to SM \times U(1)_\eta$ in one step $U(1)_\eta$ is defined by $Q_\eta = (3/8)^{1/2} Q_\chi - (5/8)^{1/2} Q_\psi$

[12] See Fig 5 of ANSARI 87D for the excluded region in the $m(Z_1)$-$[(g_{Z_1q})^2$ $BR(Z_1 \to e^+e^-)]$ plane Note that the quantity $(g_{Z_1q})^2 BR(Z_1 \to e^+e^-)$ is normalized to unity for the standard Z couplings

[13] ARNISON 86B find no excess e^+e^- pairs among 13 pairs from Z Set limit $\sigma \times BR(e^+e^-)$ · 13 pb at CL = 90% at E_{cm} = 546 and 630 GeV

[14] BARGER 86B assume $g_\eta = g_Y$ and it can only decay into ordinary 3 generations of fermions of the Standard Model The mass bound weakens if other particles such as exotic particles of E_6 and supersymmetry contribute to Z_η width The bound by DURKIN 86 is independent of Z_η width

[15] ADEVA 85 measure asymmetry of μ-pair production following formalism of RIZZO 81

CONSTRAINT ON COEFFICIENT (c) OF ADDITIONAL NEUTRAL CURRENT

Term in $SU(2) \times U(1)_Y \times U(1)_G$ theory The coefficent c depends on the group G

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
<0.04	95	[16] BARTEL	86C	JADE	$e^+e^- \to \mu^+\mu^-\ \tau^+\tau^-$
<0 03	95	[16] BARTEL	86C	JADE	$e^+e^- \to e^+e^-$
<0 05	95	[17] DERRICK	86	HRS	$e^+e^- \to e^+e^-$
<0 035	95	[18] ADEVA	85	MRKJ	$e^+e^- \to \mu^+\mu^-$
<0.05	95	[19] BERGER	85B	PLUT	$e^+e^- \to e^+e^-\ \mu^+\mu^-$

[16] E_{cm}=12–46 78 GeV $m(Z)$ = 93 GeV and $\sin^2\theta_W$ = 0 217 assumed

[17] E_{cm}=29 GeV $m(Z)$ = 93 GeV and $\sin^2\theta_W$ = 0 217 assumed

[18] ADEVA 85 measure asymmetry of μ pair production at E_{cm} = 14–46 8 GeV See also Adeva et al in Phys Rep 109 133 (1984) for more details

[19] E_{cm}=34 7 GeV $m(Z)$ = 93 GeV and $\sin^2\theta_W$ = 0 217 assumed

MASS LIMITS FOR A HEAVY NEUTRAL BOSON COUPLING TO e^+e^-

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
>45	95	[20] DERRICK	86	HRS	$\Gamma(X^0 \to e^+e^-)$ = 6 MeV
>46.6	95	[21] ADEVA	85	MRKJ	$\Gamma(X^0 \to e^+e^-)$ = 10 keV
>48	95	[21] ADEVA	85	MRKJ	$\Gamma(X^0 \to e^+e^-)$ = 4 MeV
none 39 8–45.5		[22] ADEVA	84	MRKJ	$\Gamma(X^0 \to e^+e^-)$ = 10 keV
>47 8	95	[22] ADEVA	84	MRKJ	$\Gamma(X^0 \to e^+e^-)$ = 4 MeV
none 39 8–45 2		[22] BEHREND	84C	CELL	
>47	95	[22] BEHREND	84C	CELL	$\Gamma(X^0 \to e^+e^-)$ = 4 MeV

[20] DERRICK 86 found no deviation from the Standard Model Bhabha scattering at E_{cm}= 29 GeV and set limits on the possible scalar boson e^+e^- coupling See their figure 4 for excluded region in the $\Gamma(X^0 \to e^+e^-)$-$m(X^0)$ plane Electronic chiral invariance requires a parity doublet of X^0, in which case the limit applies for $\Gamma(X^0 \to e^+e^-)$ = 3 MeV

[21] ADEVA 85 first limit is from 2γ $\mu^+\mu^-$ hadrons assuming X^0 is a scalar Second limit is from e^+e^- channel E_{cm} = 40–47 GeV Supercedes ADEVA 84

[22] ADEVA 84 and BEHREND 84C have E_{cm} = 39 8–45 5 GeV MARK J searched X^0 in $e^+e^- \to$ hadrons, 2γ $\mu^+\mu^-$ e^+e^- and CELLO in the same channels plus τ pair No narrow or broad X^0 is found in the energy range They also searched for the effect of X^0 with $m(X)$ > E_{cm} The second limits are from Bhabha data and for spin-0 singlet The same limits apply for $\Gamma(X^0 \to e^+e^-)$ = 2 MeV if X^0 is a spin-0 doublet The second limit of BEHREND 84C was read off from their figure 2 The original papers also list limits in other channels

SEARCH FOR LEPTOQUARKS

Mass bounds derived

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits, etc • • •						
none 5–20 8 GeV	95		23 BARTEL	87B	JADE	Spinless leptoquark
none 7–20.5 GeV	95	2	24 BEHREND	86B	CELL	Spinless leptoquark
>350 TeV			25 DESHPANDE	83	RVUE	Pati Salam X boson
>1 TeV			26 SHANKER	82	RVUE	PS leptoquark
>125 TeV			26 SHANKER	82	RVUE	Vector-leptoquark

[23] BARTEL 87B limit is valid when a pair of charge 2/3 spinless leptoquarks X is produced with point coupling and when they decay under the constraint $BR(X \to c\nu_\mu) + BR(X \to s\mu^+) = 1$

[24] BEHREND 86B assumed that a charge 2/3 spinless leptoquark χ decays either into $s\mu^+$ or $c\nu$ $BR(\chi \to s\mu^+) + BR(\chi \to c\nu) = 1$

[25] DESHPANDE 83 used upper limit on $K^0_L \to \mu e$ decay with renormalization group equations to estimate coupling at the heavy boson mass See also Dimopoulos et al, NP B182 77 (1981)

[26] From $(\pi \to e\nu) / (\pi \to \mu\nu)$ ratio

REFERENCES FOR SEARCHES FOR HEAVY BOSONS OTHER THAN HIGGS BOSONS

AMALDI	87	PR D36 1385	+Bohm Durkin Langacker+	(CERN AACH OSU+)
ANSARI	87D	PL B195 613	+Bagnaia Banner+	(UA2 Collab)
BARTEL	87B	ZPHY C36 15	+Becker Felst+	(JADE Collab)
ARNISON	86B	EPL 1 327	+Albrow Allkofer+	(UA1 Collab)
BARGER	86B	PRL 56 30	+Deshpande Whisnant	(WISC OREG FSU)
BARTEL	86C	ZPHY C30 371	+Becker Cords Felst Haidt+	(JADE Collab)
BEHREND	86B	PL B178 452	+Buerger Criegee Fenner Field+	(CELLO Collab)
DERRICK	86	PL 166B 463	+Gan Kooijman Loos+	(HRS Collab)
DURKIN	86	PL 166B 436	+Langacker	(PENN)
JODIDIO	86	PR D34 1967	+Balke Carr Gidal Shinsky+	(LBL NWES TRIU)
Also	88	PR D37 237	Jodidio Balke Carr+	(LBL NWES TRIU)
Erratum				
MOHAPATRA	86	PR D34 909		(UMD)
ADEVA	85	PL 152B 439	+Becker Becker Szendy+	(MARK J Collab)
BERGER	85B	ZPHY C27 341	+Deuter Genzel+	(PLUTO Collab)
STOKER	85	PRL 54 1887	+Balke Carr Gidal+	(LBL NWES TRIU)
ADEVA	84	PRL 53 134	+Barber Becker Berdugo+	(MARK J Collab)
BEHREND	84C	PL 140B 130	+Burger Criegee Fenner+	(CELLO Collab)
ARNISON	83B	PL 122B 189	+Astbury Aubert Bacci+	(UA1 Collab)
ARNISON	83D	PL 129B 273	+Astbury Aubert Bacci+	(UA1 Collab)
BERGSMA	83	PL 122B 465	+Dorenbosch Jonker+	(CHARM Collab)
CARR	83	PRL 51 627	+Gidal Gobbi Jodidio Oram+	(LBL NWES TRIU)
DESHPANDE	83	PR D27 1193	+Johnson	(OREG)
SHANKER	82	NP B204 375		(TRIU)
RIZZO	81	PR D24 704	+Senjanovic	(BNL)

SUPERSYMMETRIC PARTICLE SEARCHES

All results shown below (except where stated otherwise) involve the following "minimal" assumptions

1) The $\tilde\gamma$ is the lightest supersymmetric particle (LSP) When needed, specific assumptions of the eigenstate content of other neutralinos and charginos are indicated (use of the notation $\tilde\gamma$ (photino), $\tilde H$ (Higgsino), $\tilde W$ (w-ino), and $\tilde Z$ (z-ino) indicates the approximation of a pure state was made)
2) R-parity is conserved
3) the mass of exchanged particles is less than about 250 GeV (most limits are not sensitive to this requirement)
4) $m(\tilde f_L) = m(\tilde f_R)$ where $\tilde f_L$ and $\tilde f_R$ refer to the scalar partners of left-and right-handed fermions, f_L and f_R

Limits involving nonminimal assumptions either are identified with comments or are in the miscellaneous section

$\tilde\gamma$ (PHOTINO) MASS LIMIT

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
>10 GeV	90	1 HEARTY	87	ASP	For $m(\tilde e)$=40 GeV
>5 GeV	90	1 HEARTY	87	ASP	For $m(\tilde e)$=55 GeV
none 100 eV–5 GeV		2 ELLIS	84	COSM	For $m(\tilde f)$=100 GeV
• • • We do not use the following data for averages fits limits etc • • •					
none 100 eV–2 GeV		2 ELLIS	84	COSM	For $m(\tilde f)$=40 GeV
		2 GOLDBERG	83	COSM	
		3 KRAUSS	83	COSM	
		2 VYSOTSKII	83	COSM	

[1] HEARTY 87 assumed pure $\tilde\gamma$ eigenstate and $m(\tilde e_L) = m(\tilde e_R)$ There is no limit for $m(\tilde e) > 58$ GeV Uses $e^+e^- \to \gamma\tilde\gamma\tilde\gamma$

[2] These authors require that relic $\tilde\gamma$s from the big bang do not generate too large a contribution to the energy density of the universe

[3] KRAUSS 83 finds $m(\tilde\gamma)$ not 30 eV to 2 5 GeV KRAUSS 83 takes into account the gravitino decay Find that limits depend strongly on reheated temperature For example a new allowed region $m(\tilde\gamma)$ = 4–20 MeV exists if m(gravitino) 40 TeV See figure 2

$\tilde\chi^0_1$, $\tilde\chi^0_2$, $\tilde\chi^0_3$, $\tilde\chi^0_4$ (NEUTRALINOS) MASS LIMITS

Neutralinos are unknown mixtures of photinos z inos and neutral higgsinos (the supersymmetric partners of photons and of Z and Higgs bosons) The limits here apply only to $\tilde\chi^0_1$ $\tilde\chi^0_2$ and $\tilde\chi^0_3$ $\tilde\chi^0_1$ is the lightest supersymmetric particle (LSP) for $\tilde\chi^0_1$ which are dominantly $\tilde\gamma$ then see Photino Mass Limits It is not possible to quote rigorous mass limits because they are extremely model dependent i e they depend on branching ratios of various $\tilde\chi$ decay modes on the masses of decay products ($\tilde e$ $\tilde\gamma$ $\tilde q$ $\tilde g$) and on the $\tilde e$ mass exchanged at $\tilde\chi$ production Often limits are given as contour plots in the $m(\tilde\chi^0) - m(\tilde e)$ plane vs other parameters When specific assumptions are made e g the neutralino is a pure photino ($\tilde\gamma$) pure z ino ($\tilde Z$) or pure neutral higgsino ($\tilde H^0$) the neutralinos will be labelled as such We quote values only as examples Our choice of best limit is more conservative than some limits but still requires $m(\tilde e) < 70$ GeV and $m(\tilde\gamma) < 10$ GeV It is not as reliable as limits for other supersymmetric particles If this limit is discarded the mass is limited only by $m(\tilde\chi^0_2) > m(\tilde\chi^0_1)$ where $\tilde\chi^0_1$ is defined as the LSP

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>31	95	4 BEHREND	87B	CELL	$e^+e^- \to \tilde\gamma\tilde Z$ ($\tilde Z \to q\bar q\tilde\gamma$) $m(\tilde e) <$ 70 GeV
• • • We do not use the following data for averages fits limits etc • • •					
>30	95	5 BEHREND	87B	CELL	$e^+e^- \to \tilde\gamma\tilde Z$ ($\tilde Z \to q\bar q\tilde g$)
>31 3	95	6 BEHREND	87B	CELL	$e^+e^- \to \tilde H^0_1\tilde H^0_2$ ($\tilde H^0_2 \to f\bar f\tilde H^0_1$)
>22	95	7 BEHREND	87B	CELL	$e^+e^- \to \tilde\gamma\tilde Z$ ($\tilde Z \to \nu\bar\nu$)
		8 AKERLOF	85	HRS	e^+e E_{cm}=29 GeV
		9 BEHREND	85	CELL	$e^+e^- \to$ monojet + X
>35	95	10 ADEVA	84B	MRKJ	$e^+e^- \to \tilde\gamma\tilde Z$ ($\tilde Z \to \ell\bar\ell\tilde\gamma$)
>28	95	11 BARTEL	84C	JADE	$e^+e^- \to \tilde\gamma\tilde Z$ ($\tilde Z \to f\bar f\tilde\gamma$)
		12 ELLIS	84	COSM	

[4] Pure $\tilde\gamma$ and pure $\tilde Z$ eigenstates $BR(\tilde Z \to q\bar q\tilde\gamma) = 0\,60$ and $BR(\tilde Z \to e^+e^-\tilde\gamma) = 0\,13$ $m(\tilde e_L) = m(\tilde e_R) < 70$ GeV $m(\tilde\gamma) < 10$ GeV

[5] Pure $\tilde\gamma$ and pure $\tilde Z$ eigenstates $BR(\tilde Z \to q\bar q\tilde g) = 1$ $m(\tilde e_L) = m(\tilde e_R) < 70$ GeV $m(\tilde\gamma) = 0$

[6] Pure higgsino The LSP is the other higgsino and is taken massless Limit degraded if $\tilde\chi^0$ not pure higgsino or if LSP not massless

[7] Pure $\tilde\gamma$ and pure $\tilde Z$ eigenstates $BR(\tilde Z \to \nu\bar\nu) = 1$ $m(\tilde e_L) = m(\tilde e_R) = 26$ GeV $m(\tilde\gamma) = 10$ GeV No excluded region remains for $m(\tilde e) > 30$ GeV

[8] AKERLOF 85 is e^+e^- monojet search motivated by UA1 monojet events Observed only one event consistent with $e^+e^- \to \tilde\gamma + \tilde\chi^0$ where $\tilde\chi^0 \to$ monojet Assuming that missing p_T is due to $\tilde\gamma$ and monojet due to $\tilde\chi^0$ limits dependent on the mixing and $m(\tilde e)$ are given see their figure 4

[9] BEHREND 85 find no monojet at E_{cm} = 40–46 GeV Consider $\tilde\chi^0$ pair production via Z^0 One is assumed as massless and escapes detector Limit is for the heavier one decaying into a jet and massless $\tilde\chi^0$ Both $\tilde\chi^0$s are assumed to be pure higgsino For these very model dependent results BEHREND 85 excludes m = 1 5–19 5 GeV

[10] ADEVA 84B observed no events with signature of acoplanar lepton pair with missing energy Above example limit is for $m(\tilde\gamma)$ 2 GeV and $m(\tilde e)$ 40 GeV and assumes $BR(\tilde Z \to \mu^+\mu^-\tilde\gamma) = BR(\tilde Z \to e^+e^-\tilde\gamma) = 0\,10$ BR = 0 05 gives 33 5 GeV limit

[11] BARTEL 84C search for $e^+e^- \to \tilde Z + \tilde\gamma$ with $\tilde Z \to \tilde\gamma + e^+e^-$ $\mu^+\mu^-$ $q\bar q$ etc They see no acoplanar events with missing p_T due to two $\tilde\gamma$s Above example limit is for $m(\tilde e)$ = 40 GeV and for light stable $\tilde\gamma$ with $BR(\tilde Z \to e^+e^-\tilde\gamma) = 0\,1$

[12] ELLIS 84 find if lightest neutralino is stable then $m(\tilde\chi^0)$ not 100 eV – 2 GeV (for $m(\tilde q)$ = 40 GeV) The upper limit depends on $m(\tilde q)$ (similar to the $\tilde\gamma$ limit) and on nature of $\tilde\chi^0$ For pure higgsino the higher limit is 5 GeV

$\widetilde{\chi}_1^{\pm}$, $\widetilde{\chi}_2^{\pm}$ (CHARGINOS) MASS LIMITS

Charginos ($\widetilde{\chi}^{\pm}$ s) are unknown mixtures of w inos and charged higgsinos (the supersymmetric partners of W and Higgs bosons). Mass limits are relatively model dependent so assumptions concerning branching ratios need to be specified. When specific assumptions are made, e g the chargino is a pure w ino ($\widetilde{W}$) or pure charged higgsino ($\widetilde{H}^{\pm}$), the charginos will be labelled as such. The limits from $e^+e^- \to \gamma\widetilde{\gamma}\widetilde{\gamma}$ or $\gamma\widetilde{\nu}\widetilde{\nu}$ assume three neutrino generations. We quote values only as examples. To choose our best limit we disregard limits requiring light $\widetilde{\nu}$. Our choice of best limit is fairly general and conservative.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
> 22.5	95	[13] BARTEL	85H	JADE	$e^+e^- \to \widetilde{W}^+\widetilde{W}^-$
• • • We do not use the following data for averages, fits, limits, etc • • •					
> 39	95	[14] ADEVA	87	MRKJ	$e^+e^- \to \gamma\widetilde{\nu}\widetilde{\nu}$
> 45	90	[15] ANSARI	87D	UA2	$p\bar{p} \to Z X$ ($Z \to \widetilde{W}^+\widetilde{W}^-$, $\widetilde{W}^{\pm} \to e^{\pm}\widetilde{\nu}$)
> 40		[16] BAER	87B	RVUE	$p\bar{p} \to W/Z X$ ($W/Z \to \widetilde{W}\widetilde{Z}\widetilde{\gamma}$)
none 7.5–22 4	95	[17] BEHREND	87B	CELL	$e^+e^- \to \widetilde{W}^+\widetilde{W}^-$
> 22.4	95	[18] BEHREND	87B	CELL	$e^+e^- \to \widetilde{W}^+\widetilde{W}^-$ ($\widetilde{W} \to q\bar{q}\widetilde{g}$)
> 37 3	95	[14] BEHREND	87B	CELL	$e^+e^- \to \gamma\widetilde{\nu}\widetilde{\nu}$
none 3 9–21 5	95	[19] BEHREND	87B	CELL	$e^+e^- \to \widetilde{H}^+\widetilde{H}^-$ ($\widetilde{H}^{\pm} \to \tau^{\pm}\widetilde{\nu}$)
>270	90	[20] BELTRAMI	87	CNTR	$\mu \to e\widetilde{\nu}\widetilde{\nu}$
> 22 0	90	[21] FERNANDEZ	87	MAC	$e^+e^- \to e^{\pm}\widetilde{W}^{\mp}\widetilde{\nu}$ ($\widetilde{W} \to \ell\widetilde{\nu}$)
> 61	90	[22] HEARTY	87	ASP	$e^+e^- \to \gamma\widetilde{\nu}\widetilde{\nu}$
> 48	90	[23] BARTHA	86	ASP	$e^+e^- \to \gamma\widetilde{\nu}\widetilde{\nu}$
> 40 2	90	[24] BEHREND	86D	CELL	$e^+e^- \to \gamma\widetilde{\nu}\widetilde{\nu}$
> 25	95	[25] ADEVA	84B	MRKJ	$e^+e^- \to \widetilde{W}^+\widetilde{W}^-$ ($\widetilde{W} \to \ell\widetilde{\nu}$)

[13] BARTEL 85H search $\widetilde{\chi}^{\pm}$ decay modes $\ell\widetilde{\nu}$, $\ell\nu\widetilde{\gamma}$, $q\bar{q}\widetilde{\gamma}$ and $q\bar{q}\widetilde{g}$ with $\widetilde{g} \to q\bar{q}\widetilde{\gamma}$. They use acoplanar jets, acoplanar leptons, spherical hadronic events, R-measurement, etc to search. The above limit is typical of most of their results, details with various branching ratios and $\widetilde{\gamma}$ masses appear in fig's in BARTEL 85C. E_{cm} = 27–46 GeV

[14] Pure $\widetilde{W}$ eigenstate exchange and $m(\widetilde{\nu}_{\ell})$ = 0 assumed for $\ell = e, \mu, \tau$. The limit drops to 25 GeV if $m(\widetilde{\nu}) \geq$ 12 GeV

[15] ANSARI 87D looks for high p_T e^+e^- pair with large missing p_T at the CERN $p\bar{p}$ collider at E_{cm} = 546–630 GeV. The limit is valid when $m(\widetilde{\nu}) \lesssim$ 20 GeV, BR($\widetilde{W} \to e\widetilde{\nu}_e$) = 1/3 and BR($Z \to \widetilde{W}^+\widetilde{W}^-$) is calculated by assuming pure gaugino eigenstate. See their Fig 3(b) for excluded region in the $m(\widetilde{W})-m(\widetilde{\nu})$ plane

[16] BAER 87B argue that the charged heavy lepton mass limit of 41 GeV obtained by UA1 collaboration (ALBAJAR 87B) corresponds to the mass limit of 40 GeV under the assumptions that the LSP (photino) has a mass smaller than 8 GeV and that the gaugino-higgsino mixing is parametrized by the three minimal supergravity model parameters. In grand unified theories $m(\widetilde{\gamma})$ < 8 implies $m(\widetilde{g})$ < 50 GeV

[17] Only $e^+e^- \to \gamma^* \to \widetilde{W}^+\widetilde{W}^-$ considered. BR($\widetilde{W} \to q\bar{q}\widetilde{\gamma}$) + BR($\widetilde{W} \to \ell\nu\widetilde{\gamma}$) = 1. The lower limit does not change for $m(\widetilde{\gamma})$ < 10 GeV although the upper limit must increase

[18] Only $e^+e^- \to \gamma^* \to \widetilde{W}^+\widetilde{W}^-$ considered. BR($\widetilde{W} \to q\bar{q}\widetilde{g}$) = 1. Not sensitive to $m(\widetilde{g})$

[19] Pure Higgsino eigenstates. Only $e^+e^- \to \gamma^* \to \widetilde{H}^+\widetilde{H}^-$. BR($\widetilde{H}^{\pm} \to \tau^{\pm}\widetilde{\nu}$) = 1. $m(\widetilde{\nu}_{\tau})$ = 0

[20] BELTRAMI 87 measure the integral asymmetry parameter of $\mu^+ \to e^+ X$ decay. Note that the limit is only valid when $m(\widetilde{\nu}) \ll m(\mu)$ and $\widetilde{W}$ is the pure gaugino eigenstate

[21] Assumes BR($\widetilde{W} \to \ell\widetilde{\nu}$) = 1/3. The limit drops to 20 GeV if $m(\widetilde{\nu}) \geq$ 5 GeV

[22] The 95% CL limit is 57 GeV. Exchange of pure $\widetilde{W}$ eigenstate and $m(\widetilde{\nu}_{\ell})$ = 0 for $\ell = e, \mu, \tau$ assumed

[23] Uses the model of HAGELIN 84 with $m(\widetilde{\nu})$ = 0, O^+ ($\widetilde{W}$) = 1 and $M(1) \ll M(2)$

[24] Pure $\widetilde{W}$ exchange and $m(\widetilde{\nu})$ = 0. The limit drops to 25 GeV if $m(\widetilde{\nu}) \geq$ 15 GeV

[25] ADEVA 84B observed no events with signature of acoplanar lepton pair with missing energy. Limit is for $m(\widetilde{W}) \gg m(\widetilde{\gamma})$ and $m(\widetilde{\nu})$. Assumes $\widetilde{W} \to \widetilde{\nu} + \ell$ dominates. E_{cm} = 30–47 GeV

$\widetilde{\nu}$ (SNEUTRINO) MASS LIMIT

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
		[26] KANE	84	RVUE	$\tau \to \ell\widetilde{\nu}\widetilde{\nu}$, $\mu \to e\widetilde{\nu}\widetilde{\nu}$
• • • We do not use the following data for averages, fits, limits, etc • • •					
> 4		[27] NG	87	COSM	
>10 8	90	[28] FORD	86	MAC	$e^+e^- \to \gamma\widetilde{\nu}\widetilde{\nu}$
< 2 8		[27] GAISSER	86	COSM	
		[29] FERNANDEZ	85B	MAC	$e^+e^- \to \gamma\widetilde{\nu}\widetilde{\nu}$
		[30] HAGELIN	84	COSM	
		[30] IBANEZ	84	COSM	
		[29] WARE	84	RVUE	$e^+e^- \to \gamma\widetilde{\nu}\widetilde{\nu}$

[26] KANE 84 finds $|m(\widetilde{\nu}_{\tau}) + m(\widetilde{\nu}_e$ or $\widetilde{\nu}_{\mu})| > m(\tau)$ or $|m(\widetilde{\nu}_{\mu}) + m(\widetilde{\nu}_e)| > m(\mu)$. This limit is for $m(\widetilde{W}) = m(W)$. For other cases see their figure 2. Derived from $\tau \to e\bar{\nu}_e\nu_{\tau}$ or $\mu\bar{\nu}_{\mu}\nu_{\tau}$, or from $\mu \to e\bar{\nu}_e\nu_{\mu}$

[27] Limits based on annihilations in the sun and are due to an absence of high energy neutrinos detected in underground experiments. GAISSER 86 limit applies only if $\widetilde{\nu}$ is LSP and if it is a major component of dark matter

[28] FORD 86 looked for single γ event $e^+e^- \to \gamma\widetilde{\nu}\widetilde{\nu}$ assuming $\widetilde{\nu}$'s escape dectection. The limit is for $m(\widetilde{W})$ = 25 GeV. It disappears at $m(\widetilde{W})$ = 50 GeV

[29] WARE 84 and FERNANDEZ 85B assume $\widetilde{\nu}$ is lightest stable supersymetric particle or decays invisibly. Also assume $m(\widetilde{W})$ is 20–29 GeV. Looked for single γ event ($e^+e^- \to \widetilde{\nu}\widetilde{\nu}\gamma$). Limit from 1 observed event consistent with $\nu\nu\gamma$ background is $m(\widetilde{\nu})$ ~10 GeV at CL = 90%. E_{cm} = 29 GeV

[30] IBANEZ 84 and HAGELIN 84 find no cosmological limits on mass of $\widetilde{\nu}$ from cosmological density $\Omega(\widetilde{\nu}) = \rho(\widetilde{\nu})/\rho_c$ or elsewhere

$\widetilde{e}$ (SELECTRON) MASS LIMIT

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>23	95	BEHREND	87B	CELL	$m(\widetilde{\gamma})$<19 $\widetilde{e}^+\widetilde{e}^-$
>58	90	[31] HEARTY	87	ASP	$m(\widetilde{\gamma})$= 0 GeV, $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>55	90	[31] HEARTY	87	ASP	$m(\widetilde{\gamma})$= 5 GeV $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>39	90	[31] HEARTY	87	ASP	$m(\widetilde{\gamma})$= 10 GeV $\gamma\widetilde{\gamma}\widetilde{\gamma}$
• • • We do not use the following data for averages, fits, limits, etc • • •					
>36	95	[32] ADEVA	87	MRKJ	$e^+e^- \to \gamma\widetilde{\gamma}\widetilde{\gamma}$, $\widetilde{e}^+\widetilde{e}^-\widetilde{\gamma}$
~30	90	[33] ANSARI	87D	UA2	$p\bar{p} \to Z X$ ($Z \to \widetilde{e}^+\widetilde{e}^-$, $\widetilde{e}^{\pm} \to e^{\pm}\widetilde{\gamma}$)
>34 2	95	[34] BEHREND	87B	CELL	$e^+e^- \to \gamma\widetilde{\gamma}\widetilde{\gamma}$
>26 8	95	[35] BEHREND	87B	CELL	$e^+e^- \to e^{\pm}\widetilde{e}^{\mp}\widetilde{\gamma}$
>24 5	90	[36] FERNANDEZ	87	MAC	$e^+e^- \to e^{\pm}\widetilde{e}^{\mp}\widetilde{\gamma}$
>23 3	90	[37] FERNANDEZ	87	MAC	$e^+e^- \to e^{\pm}\widetilde{e}^{\mp}\widetilde{\gamma}$
>26	90	[38] ARNISON	86C	UA1	$p\bar{p} \to W' X$ ($W' \to \widetilde{e}\widetilde{\nu}$) ($\widetilde{e} \to e\widetilde{\gamma}$)
>33	90	[39] BARTHA	86	ASP	$m(\widetilde{\gamma})$=10 GeV $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>51	90	[39] BARTHA	86	ASP	$m(\widetilde{\gamma})$=0 GeV $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>48	90	[39] BARTHA	86	ASP	$m(\widetilde{\gamma})$=5 GeV $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>33 7	90	[40] BEHREND	86D	CELL	$m(\widetilde{\gamma})$=0 $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>48	90	[41] FORD	86	MAC	$m(\widetilde{\gamma})$=0 $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>22	95	ADEVA	85	MRKJ	$e^+e^- \to \widetilde{e}^+\widetilde{e}^-$
>25 2	95	[42] BARTEL	85C	JADE	$m(\widetilde{\gamma})$ = 0 GeV
>22	95	[42] BARTEL	85C	JADE	$m(\widetilde{\gamma})$ = 15 GeV
>37	90	[43] FERNANDEZ	85B	MAC	$e^+e^- \to \gamma\widetilde{\gamma}\widetilde{\gamma}$
	95	[44] BARTEL	84B	JADE	e^+e^-
		[45] BARTEL	84C	JADE	e^+e^- $m(\widetilde{Z})$~30 GeV
>22 4	95	[46] FERNANDEZ	84	MAC	$e^+e^- \to e^{\pm}\widetilde{e}^{\mp}\widetilde{\gamma}$
>22 2	95	[47] GLADNEY	83	MRK2	$e^+e^- \to e^{\pm}\widetilde{e}^{\mp}\widetilde{\gamma}$
none 2–16 8	95	BEHREND	82B	CELL	$e^+e^- \to \widetilde{e}^+\widetilde{e}^-$
>16 6	95	[48] BRANDELIK	82B	TASS	$e^+e^- \to \widetilde{e}^+\widetilde{e}^-$
> 3 5		FARRAR	80	RVUE	$e^+e^- \to \widetilde{e}^+\widetilde{e}^-$

[31] HEARTY 87 assumed pure $\widetilde{\gamma}$ eigenstate and $m(\widetilde{e}_L) = m(\widetilde{e}_R)$. There is no limit for $m(\widetilde{\gamma})$> 13 GeV. The 95% CL limit is 55 GeV for $m(\widetilde{\gamma})$=0

[32] Pure $\widetilde{\gamma}$ eigenstate with $m(\widetilde{\gamma})$ = 0 and $m(\widetilde{e}_L) = m(\widetilde{e}_R)$ assumed. The limit drops to about 21 GeV if $m(\widetilde{\gamma})$ = 10 GeV

[33] ANSARI 87D limit is valid when $m(\widetilde{\gamma}) \lesssim$ 10 GeV and $m(\widetilde{e}_L) \simeq m(\widetilde{e}_R)$

[34] Pure $\widetilde{\gamma}$ eigenstate with $m(\widetilde{\gamma})$ = 0 and $m(\widetilde{e}_L) = m(\widetilde{e}_R)$ assumed. This limit drops to 26 1 GeV if $m(\widetilde{\gamma})$ = 10 GeV

[35] Pure $\widetilde{\gamma}$ eigenstate with $m(\widetilde{\gamma})$ = 0 and $m(\widetilde{e}_L) \gg m(\widetilde{e}_R)$. This limit drops to 23 2 GeV if $m(\widetilde{\gamma})$ = 10 GeV

[36] There is no limit for $m(\widetilde{\gamma})$> 12 GeV. At 95% CL limit is 24 1 GeV

[37] Pure $\widetilde{\gamma}$ eigenstate with $m(\widetilde{\gamma})$ = 0 and $m(\widetilde{e}_L) \gg m(\widetilde{e}_R)$ or $m(\widetilde{e}_L) \ll m(\widetilde{e}_R)$ assumed

[38] ARNISON 86C limit applies for $\widetilde{e}_L$ when $m(\widetilde{e}_L) = m(\widetilde{\nu}_L)$ and $m(\widetilde{\gamma})$ = 0. See their Fig 7 for the 90% CL excluded region in the $m(\widetilde{e}_L) - m(\widetilde{\nu}_L)$ plane. $m(\widetilde{e}_L)$ > 32 GeV at CL=90% if $m(\widetilde{\nu}_L) = m(\widetilde{\gamma})$ = 0

[39] BARTHA 86 search for anomalous photons from $e^+e^- \to (\widetilde{\gamma}\widetilde{\gamma}\gamma)$ where $\widetilde{\gamma}$ s are assumed to leave apparatus undetected. For $m(\widetilde{e}_R) \gg m(\widetilde{e}_L)$ and $m(\widetilde{\gamma})$ = 0, limit is 42 GeV at CL = 90%

[40] For $m(\widetilde{e}_L) \gg m(\widetilde{e}_R)$ limit is 28 GeV. There is no limit for $m(\widetilde{\gamma})$> 15 GeV

[41] One observed event is consistent with $e^+e^- \to \gamma\nu\bar{\nu}$ for 3 neutrinos. The limit comes from the process $e^+e^- \to \gamma\widetilde{\gamma}$ with $\widetilde{e}$ exchange. The limit assumes $m(\widetilde{e}_L)=m(\widetilde{e}_R)$ and becomes 40 GeV if $m(\widetilde{e}_L) \gg m(\widetilde{e}_R)$. There is no limit for $m(\widetilde{\gamma})$>12 GeV

[42] BARTEL 85C consider single and pair $\widetilde{e}$ production as well as $\widetilde{\gamma}$ pair + γ. First limit is for massless $\widetilde{\gamma}$ and second is for $m(\widetilde{\gamma})$ ~ 15 GeV. Both assume equal mass for $\widetilde{e}_L$ and $\widetilde{e}_R$. For $m(\widetilde{e}_R) \gg m(\widetilde{e}_L)$ and massless $\widetilde{\gamma}$ limit is 21 8 GeV (see also their figure 2)

[43] FERNANDEZ 85B analyze single γ event expected from $e^+e^- \to 2\widetilde{\gamma} + \gamma$. Above limit is for $m(\widetilde{\gamma})$ = 0 and equal mass $\widetilde{e}_L$ and $\widetilde{e}_R$. (See also figure 2). For $m(\widetilde{e}_R) \gg m(\widetilde{e}_L)$ limit is 30 GeV

[44]BARTEL 84B make nonstandard assumption that $\tilde{\gamma}$ decays to goldstino + γ. They look for 2γ events from $\tilde{\gamma}$ pair production. For supersymmetric breaking parameter d = (100 GeV)^2 they find at CL = 95% $m(\tilde{e}) > 80$ GeV. Limit is also applicable if the $\tilde{\gamma}$ decays radiatively within the detector.

[45]BARTEL 84C limit is from $\tilde{Z}$ search assuming that $m(\tilde{Z}) < 30$ GeV. Using acoplanar events with missing p_T. Under these conditions, $m(\tilde{e}) > 50$ GeV at CL = 90%.

[46]FERNANDEZ 84 analyzed single electron events from singly produced $\tilde{e}$. Energy distribution is consistent with $e^+e^-\gamma$ background.

[47]GLADNEY 83 looked for large p_T e from singly produced $\tilde{e}$'s.

[48]BRANDELIK 82B limit is from no enhancement in events with θ near 90°(light scalar) and with large acoplanarity (heavy scalar).

$\tilde{\mu}$ (SMUON) MASS LIMIT

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>21	95	[49] BARTEL	85D	JADE	$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\gamma}\tilde{\gamma}$
••• We do not use the following data for averages, fits, limits, etc. •••					
none 2.8–20.5	95	[50] BEHREND	87B	CELL	$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\gamma}\tilde{\gamma}$
none 3.4–19.4	95	[51] BEHREND	87B	CELL	$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\gamma}\tilde{\gamma}$
>20	95	[52] ADEVA	85	MRKJ	$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\gamma}\tilde{\gamma}$
>20.9	95	[49] BARTEL	85D	JADE	e^+e^- stable $\tilde{\mu}$
>13.8	95	[52] FERNANDEZ	83C	MAC	e^+e^-
none 3.3–16	95	BEHREND	82B	CELL	e^+e^-
>16.4	95	[53] BRANDELIK	82B	TASS	e^+e^-
none 3–15	95	BARBER	80B	MRKJ	e^+e^-
> 3.5		FARRAR	80	RVUE	$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$
>15		FAYET	79	RVUE	$g_\mu - 2$

[49]BARTEL 85B second limit is for stable $\tilde{\mu}$ from nonobservation of $\tilde{\mu}$-pair production. First limit is for $\tilde{\mu} \to \mu$ + stable-$\tilde{\gamma}$ from nonobservation of acoplanar μ pair with large missing p_T and applies if $m(\tilde{\gamma}) < 15$ GeV. First limit assumes $m(\tilde{e}_L) = m(\tilde{e}_R)$; if $m(\tilde{e}_L) \gg m(\tilde{e}_R)$ the limit is 20.3 GeV.

[50]$m(\tilde{\mu}_L) = m(\tilde{\mu}_R)$ with $m(\tilde{\gamma}) = 10$ GeV.

[51]$m(\tilde{\mu}_L) \gg m(\tilde{\mu}_R)$ or $m(\tilde{\mu}_L) \ll m(\tilde{\mu}_R)$ with $m(\tilde{\gamma}) = 0$.

[52]FERNANDEZ 83C and ADEVA 85 observed no excess acoplanar $\mu^+\mu^-$ events.

[53]BRANDELIK 82B limit is from no enhancement in events with θ near 90°(light scalar) and with large acoplanarity (heavy scalar).

$\tilde{\tau}$ (STAU) MASS LIMIT

$\tilde{\tau} \to \tau\tilde{\gamma}$ looks identical to $H^\pm \to \tau\nu$ as in Stable Particle Search Section. Where taken from results quoted for $H^\pm$, the limits below correspond to BR($\tau\nu$) = 1.0 line in mass limit graphs for pair of $H^+H^- \to \tau^+\nu + \tau^-\nu$.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
none 5.3–20.6	95	[54] BEHREND	87B	CELL	$e^+e^- \to \tilde{\tau}^+\tilde{\tau}^- \to \tau^+\tau^-\tilde{\gamma}\tilde{\gamma}$
>19	95	BEHREND	87B	CELL	$m(\tilde{\gamma})$=10 GeV
••• We do not use the following data for averages, fits, limits, etc. •••					
none 5.6–19.5	95	[55] BEHREND	87B	CELL	$e^+e^- \to \tilde{\tau}^+\tilde{\tau}^- \to \tau^+\tau^-\tilde{\gamma}\tilde{\gamma}$
>18.7	95	[55] BARTEL	86	JADE	BR($\tilde{\tau} \to \tau\tilde{\gamma}$) = 1, $m(\tilde{\gamma})$=0
>17	95	[56] ADEVA	85	MRKJ	e^+e^- E_{cm}=40–47 GeV
>14	95	ADEVA	82B	MRKJ	
none 4–14	95	BARTEL	82D	JADE	
none 6–15.3	95	[57] BEHREND	82B	CELL	
none $m(\tau)$ to 3.8	95	[57] BEHREND	82B	CELL	
none $m(\tau)$ to 9.9	90	BLOCKER	82	MRK2	

[54]$m(\tilde{\tau}_L) = m(\tilde{\tau}_R)$ with $m(\tilde{\gamma}) = 0$.

[55]$m(\tilde{\tau}_L) \gg m(\tilde{\tau}_R)$ or $m(\tilde{\tau}_L) \ll m(\tilde{\tau}_R)$.

[56]No excess acoplanar μ and hadronic jet.

[57]BEHREND 82B first limit for $\tilde{\tau}$ is from p_T-cut τ pair analysis, second limit from no excess τ pair events.

$\tilde{q}$ (SQUARK) MASS LIMIT

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>45	90	[58] ALBAJAR	87D	UA1	any $m(\tilde{g}) > m(\tilde{q})$
>58	90	[58] ALBAJAR	87D	UA1	$m(\tilde{g}) \leq 160$ GeV
>75	90	[58] ALBAJAR	87D	UA1	$m(\tilde{g}) = m(\tilde{q})$
••• We do not use the following data for averages, fits, limits, etc. •••					
none 2.1–21.5	95	[59] BEHREND	87B	CELL	$e^+e^- \to \tilde{q}\bar{\tilde{q}} \to q\bar{q}\tilde{\gamma}\tilde{\gamma}$
none 2.2–21.2	95	[60] BEHREND	87B	CELL	$e^+e^- \to \tilde{q}\bar{\tilde{q}} \to q\bar{q}\tilde{\gamma}\tilde{\gamma}$
>20.3	95	[61] BEHREND	87B	CELL	$e^+e^- \to \tilde{q}\bar{\tilde{q}} \to$ aplanar evts
>19.2	95	[62] BEHREND	87B	CELL	$e^+e^- \to \tilde{q}\bar{\tilde{q}} \to q\bar{q}\tilde{\gamma}\tilde{\gamma}$
>50		[63] BERTOLINI	87	RVUE	$m(\tilde{q}) \simeq m(\tilde{g})$, $m(t)$=45 GeV
		[64] BAER	85	RVUE	$p\bar{p}$
> 3		[65] NAPPI	82	RVUE	Q=2/3 $\tilde{q}$ only

[58]The limits of ALBAJAR 87D are from $p\bar{p} \to \tilde{q}\bar{\tilde{q}}$ X ($\tilde{q} \to q\tilde{\gamma}$) and assume 5 flavors of degenerate mass squarks each with $m(\tilde{q}_L) = m(\tilde{q}_R)$. They also assume $m(\tilde{g}) > m(\tilde{q})$. These limits apply for $m(\tilde{\gamma}) \lesssim 20$ GeV.

[59]$e(\tilde{q})$ = 2/3. BR($\tilde{q} \to q\tilde{\gamma}$) = 1. $m(\tilde{q}_L) = m(\tilde{q}_R)$. If $m(\tilde{\gamma})$ = 10 GeV the limits become 12.5 < m < 21.3 GeV.

[60]$e(\tilde{q})$ = 2/3. BR($\tilde{q} \to q\tilde{\gamma}$) = 1. $m(\tilde{q}_L) \ll m(\tilde{q}_R)$ or $m(\tilde{q}_L) \gg m(\tilde{q}_R)$. If $m(\tilde{\gamma})$ = 10 GeV the limits become 13.3 < m < 20.8 GeV.

[61]$e(\tilde{q})$ = 2/3. BR($\tilde{q} \to q\tilde{g}$) = 1. $m(\tilde{q}_L) = m(\tilde{q}_R)$.

[62]$e(\tilde{q})$ = 2/3. BR($\tilde{q} \to q\tilde{g}$) = 1. $m(\tilde{q}_L) \gg m(\tilde{q}_R)$ or $m(\tilde{q}_L) \ll m(\tilde{q}_R)$.

[63]Uses BR($b \to s\gamma$) < 2×10^{-3} and the supersymetric model estimate $m^2(\tilde{d}) - m^2(\tilde{b}) \sim 0.5\,m^2(t)$. The bound strengthens as $m(t)$ increases and $m(\tilde{g})$ decreases.

[64]BAER 85 evaluate the contribution of $\tilde{q} \to$ quark + zino, wino. No change is needed for limits for $m(\tilde{g})$, $m(\tilde{q})$ derived assuming the dominance of $\tilde{q} \to$ quark + $\tilde{\gamma}$.

[65]NAPPI 82 limit applies to charge 2/3 $\tilde{q}$. No limit found for charge 1/3. Limit from P wave $\tilde{q}$-$\bar{\tilde{q}}$ bound state nonobservation in e^+e^- annihilation.

$\tilde{g}$ (GLUINO) MASS LIMIT

There is an ongoing controversy (reflected in these Listings) about whether very light $\tilde{g}$'s are ruled out. These papers sometimes make different assumptions and use different calculational techniques.

VALUE (GeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
none 4–53	90		[66] ALBAJAR	87D	UA1	any $m(\tilde{q}) > m(\tilde{g})$
none 4–75	90		[66] ALBAJAR	87D	UA1	$m(\tilde{q}) = m(\tilde{g})$
••• We do not use the following data for averages, fits, limits, etc. •••						
none 16–58	90		[67] ANSARI	87D	UA2	$m(\tilde{q}) \lesssim 100$ GeV
> 3.8	90		[68] ARNOLD	87	EMUL	π^- (350 GeV) $\sigma \sim A^1$
> 3.2	90		[68] ARNOLD	87	EMUL	π^- (350 GeV) $\sigma \sim A^{0.72}$
>50			[69] BERTOLINI	87	RVUE	$m(\tilde{q}) \simeq m(\tilde{g})$, $m(t)$=45 GeV
none 0.6–2.2	90		[70] TUTS	87	CUSB	$\Upsilon(1S) \to \gamma$ + gluinonium
none 1.–4.5	90	0	[71] ALBRECHT	86C	ARG	$1\times10^{-11} \lesssim \tau \lesssim 1\times10^{-9}$s
none 1–4	90	0	[72] BADIER	86	BDMP	$1\times10^{-10} < \tau < 1\times10^{-7}$s
none			[73] VOLOSHIN	86	RVUE	If (quasi) stable $\tilde{g}uud$
			[74] BAER	85	RVUE	$p\bar{p}$
none 0.5–2			[75] COOPER	85B	BDMP	For $m(\tilde{q})$=300 GeV
none 0.5–4			[75] COOPER	85B	BDMP	For $m(\tilde{q})$ 65 GeV
none 0.5–3			[75] COOPER	85B	BDMP	For $m(\tilde{q})$=150 GeV
none 2–4			[76] DAWSON	85	RVUE	τ 10^{-7} sec
none 1–2.5			[76] DAWSON	85	RVUE	For $m(\tilde{q})$=100 GeV
none 0.5–4.1	90		[77] FARRAR	85	RVUE	FNAL beam dump
> 1			[78] GOLDMAN	85	RVUE	Gluinonium
1–2			[79] HABER	85	RVUE	
			[80] BALL	84	CALO	
			[81] BRICK	84	RVUE	
			[82] FARRAR	84	RVUE	
> 2			[83] BERGSMA	83C	RVUE	For $m(\tilde{q})$ 100 GeV
			[84] CHANOWITZ	83	RVUE	$\tilde{g}u\bar{d}$, $\tilde{g}uud$
2–3			[85] KANE	82	RVUE	Beam dump
1.5–2			FARRAR	78	RVUE	R-hadron

[66]The limits of ALBAJAR 87D are from $p\bar{p} \to \tilde{g}\tilde{g}$ X ($\tilde{g} \to q\bar{q}\tilde{\gamma}$) and assume $m(\tilde{q}) > m(\tilde{g})$. These limits apply for $m(\tilde{\gamma}) \lesssim 20$ GeV.

[67]The limit of ANSARI 87D assumes $m(\tilde{q}) > m(\tilde{g})$ and $m(\tilde{\gamma}) \simeq 0$.

[68]The limits assmue $m(\tilde{q})$ = 100 GeV. See their figure 3 for limits vs. $m(\tilde{q})$.

[69]Uses BR($b \to s\gamma$) < 2×10^{-3} and the supersymetric model estimate $m^2(\tilde{d}) - m^2(\tilde{b}) \sim 0.5\,m^2(t)$. The bound strengthens as $m(t)$ increases and $m(\tilde{q})$ decreases.

[70]The gluino mass is defined by half the bound $\tilde{g}\tilde{g}$ mass. If zero gluino mass gives a $\tilde{g}\tilde{g}$ of mass about 1 GeV as suggested by various glueball mass estimates, then the low-mass bound can be replaced by zero. The high mass bound is obtained by comparing the data with nonrelativistic potential model estimates.

[71]ALBRECHT 86C search for secondary decay vertices from $\chi_{b1}(1P) \to \tilde{g}\tilde{g}g$ where $\tilde{g}$s make long lived hadrons See their figure 4 for excluded region in the $m(\tilde{g})$ · $\tau(\tilde{g})$ and $m(\tilde{g})-m(\tilde{q})$ plane The lower $m(\tilde{g})$ region below ~2 GeV may be sensitive to fragmentation effects Remark that the $\tilde{g}$ hadron mass is expected to be ~1 GeV (glueball mass) in the zero $\tilde{g}$ mass limit

[72]BADIER 86 looked for secondary decay looked for secondary decay vertices from long lived $\tilde{g}$-hadrons produced at 300 GeV π^- beam dump The quoted bound assumes $\tilde{g}$-hadron nucleon total cross section of 10μb See their figure 7 for excluded region in the $m(\tilde{g})-m(\tilde{q})$ plane for several assumed total cross section values

[73]VOLOSHIN 86 rules out stable gluino based on the cosmological argument that predicts too much hydrogen consisting of the charged stable hadron $\tilde{g}uud$ Quasi stable ($\tau > 1 \times 10^{-7}$s) light gluino of $m(\tilde{g})<3$ GeV is also ruled out by nonobservation of the stable charged particles $\tilde{g}uud$ in high energy hadrond collisions

[74]BAER 85 evaluate the contribution of $\tilde{q} \to q\tilde{Z}W$ No change is needed of limit on $m(\tilde{g})$ $m(\tilde{q})$ derived assuming the dominance of $\tilde{q} \to q\tilde{\gamma}$

[75]COOPER SARKAR 85B is BEBC beam dump Gluinos decaying in dump would yield $\tilde{\gamma}$s in the detector giving neutral current like interactions For $m(\tilde{q})$ 330 GeV no limit is set

[76]DAWSON 85 first limit from neutral particle search Second limit based on FNAL beam dump experiment

[77]FARRAR 85 points out that BALL 84 analysis applies only if the $\tilde{g}$s decay before interacting i e $m(\tilde{q})$ 80$m(\tilde{g})^{1\ 5}$ FARRAR 85 finds $m(\tilde{g})$ · 0 5 not excluded for $m(\tilde{q})$ = 30–1000 GeV and $m(\tilde{g})$ 1 0 not excluded for $m(\tilde{q})$ = 100–500 GeV by BALL 84 experiment

[78]GOLDMAN 85 use nonobservation of a pseudoscalar $\tilde{g}$-$\tilde{g}$ bound state in radiative ψ decay

[79]HABER 85 is based on survey of all previous searches sensitive to low mass $\tilde{g}$s Limit makes assumptions regarding the lifetime and electric charge of the lightest supersymmetric particle

[80]BALL 84 is FNAL beam dump experiment Observed no interactions of $\tilde{\gamma}$ in the calorimeter where $\tilde{\gamma}$s are expected to come from pair-produced $\tilde{g}$s Search for long lived $\tilde{\gamma}$ interacting in calorimeter 56m from target Limit is for $m(\tilde{q})$ = 40 GeV and production cross section proportional to $A^{0\ 72}$ BALL 84 find no $\tilde{g}$ allowed below 4 1 GeV at CL = 90% Their figure 1 shows dependence on $m(\tilde{q})$ and A See also KANE 82

[81]BRICK 84 reanalyzed FNAL 147 GeV HBC data for R-Δ(1232)$^{++}$ with τ · 10^{-9} sec and p_{lab} 2GeV Set CL = 90% upper limits 6 1 4 4 and 29 microbarns in pp π^+p K^+p collisions respectively R Δ^{++} is defined as being $\tilde{g}$ and 3 up quarks If mass = 1 2–1 5 GeV then limits may be lower than theory predictions

[82]FARRAR 84 argues that $m(\tilde{g})$ 100 MeV is not ruled out if the lightest R hadrons are long lived A long lifetime would occur if R hadrons are lighter than $\tilde{\gamma}$s or if $m(\tilde{q})$ 100 GeV

[83]BERGSMA 83C is reanalysis of CERN SPS beam dump data See their figure 1

[84]CHANOWITZ 83 find in bag model that charged s hadron exists which is stable against strong decay if $m(\tilde{g}) <$ 1 GeV This is important since tracks from decay of neutral s hadron cannot be reconstructed to primary vertex because of missed $\tilde{\gamma}$ Charged s hadron leaves track from vertex

[85]KANE 82 inferred above $\tilde{g}$ mass limit from retroactive analysis of hadronic collision and beam dump experiments Limits valid if $\tilde{g}$ decays inside detector

UNSTABLE $\tilde{\gamma}$ (PHOTINO) MASS LIMIT

The limits below assume that the $\tilde{\gamma}$ decays either into $\gamma\tilde{G}$ (goldstino) or into $\gamma\tilde{H}^0$ (Higgsino)

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
>15	95	[86] BEHREND	87B	CELL	$e^+e^- \to \tilde{\gamma}\tilde{\gamma}$ ($\tilde{\gamma} \to \gamma\tilde{G}$ or $\gamma\tilde{H}^0$)
		[87] ADEVA	85	MRKJ	
		[88] BALL	84	CALO	Beam dump
		[89] BARTEL	84B	JADE	
		[89] BEHREND	83	CELL	
		[90] CABIBBO	81	COSM	

[86]BEHREND 87B limit is for unstable photinos only Assumes BR($\tilde{\gamma} \to \gamma(\tilde{G}$ or $\tilde{H}^0$)) =1 $m(\tilde{G}$ or $\tilde{H}^0) \ll m(\tilde{\gamma})$ and pure $\tilde{\gamma}$ eigenstate $m(\tilde{e}_L) = m(\tilde{e}_R) <$ 100 GeV

[87]ADEVA 85 is sensitive to $\tilde{\gamma}$ decay path · 5 cm With $m(\tilde{e})$ = 50 GeV limit (CL = 90%) is $m(\tilde{\gamma})$ ·20 5 GeV Assume $\tilde{\gamma}$ decays to photon + goldstino and search for acoplanar photons with large missing p_T

[88]BALL 84 is FNAL beam dump experiment Observed no $\tilde{\gamma}$ decay where $\tilde{\gamma}$s are expected to come from $\tilde{g}$'s produced at the target Three possible $\tilde{\gamma}$ lifetimes are considered Gluino decay to goldstino + gluon is also considered

[89]BEHREND 83 and BARTEL 84B look for 2γ events from $\tilde{\gamma}$ pair production With supersymmetric breaking parameter d = (100 GeV)^2 and $m(\tilde{e})$ = 40 GeV the excluded regions at CL = 95% would be $m(\tilde{\gamma})$ = 100 MeV – 13 GeV for BEHREND 83 $m(\tilde{\gamma})$ = 80 MeV – 18 GeV for BARTEL 84B Limit is also applicable if the $\tilde{\gamma}$ decays radiatively within the detector

[90]CABIBBO 81 consider $\tilde{\gamma} \to \gamma$ + goldstino Photino must be either light enough (· 30 eV) to satisfy cosmology bound or heavy enough (0 3 MeV) to have disappeared at early universe

LIMITS ON SUPERSYMMETRY BREAKING SCALE, $\Lambda_{ss} = d^{1/2}$

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
> 80	95	[91] BEHREND	87B	CELL	$m(\tilde{\gamma})<35$ GeV
>225	95	[91] BEHREND	87B	CELL	$m(\tilde{\gamma})$= 0 2–10 GeV
> 69	90	[92] BEHREND	86D	CELL	$e^+e^- \to \gamma\tilde{\gamma}\tilde{G}$
>117		[93] FAYET	86	RVUE	$m(\tilde{\gamma})<20$ GeV
>240		[93] FAYET	86	RVUE	0 3$<m(\tilde{\gamma})<$10 GeV
> 9		FAYET	79B	RVUE	$\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \tilde{\gamma}\tilde{G}$

[91]$e^+e^- \to \tilde{\gamma}\tilde{G}$ $\tilde{\gamma} \to \gamma\tilde{G}$ if $m(\tilde{\gamma}) >$ 0 2 GeV $e^+e^- \to \gamma\tilde{\gamma}\tilde{G}$ with $\tilde{\gamma}$ decay outside the detector if $m(\tilde{\gamma}) <$ 0 1 GeV

[92]The $\tilde{\gamma}$ is assumed to be light and decay outside the detector The quoted gravitino mass limit m(gravitino)> 0 8 · 10^{-6} eV is converted to the lower limit of the supersymmetry breaking scale $d^{1/2}$ = Λ(ss) via the formula m(gravitino) = $(4\pi/3)^{1/2}$ (Λ(ss)^2/m(planck)) with m(planck) = 1 22 × 10^{19} GeV

[93]FAYET 86 uses $e^+e^- \to$ single photon data to rule out small supersymmetry breaking scale based on the process $e^+e^- \to \tilde{\gamma}\tilde{G}$ ($\tilde{\gamma} \to \gamma\tilde{G}$) or $e^+e^- \to \gamma\tilde{\gamma}\tilde{G}$ where $\tilde{G}$ denotes a goldstino or a gravitino respectively in global or local supersymmetric theories The limits vanish above $m(\tilde{\gamma})$ = 20 GeV In local supersymmetry theories the above bounds can be reinterpreted as the gravitino mass bounds i e m(gravitino) > 2 3 · 10^{-6} eV and m(gravitino) > 1 · 10^{-5} eV respectively These limits are independent of $m(\tilde{f}_L)$ and $m(\tilde{f}_R)$

SUPERSYMMETRY MISCELLANEOUS RESULTS

Results that do not appear under other headings or that make nonminimal assumptions

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
	[94] BARBER	84B	RVUE	
	[95] HOFFMAN	83	CNTR	$\pi p \to n(e^+e^-)$

[94]BARBER 84B consider that $\tilde{\mu}$ and $\tilde{e}$ may mix leading to $\mu \to e\tilde{\gamma}\tilde{\gamma}$ They discuss mass mixing limits from decay dist asym in LBL TRIUMF data and e^+ polarization in SIN data

[95]HOFFMAN 83 set CL = 90% limit $d\sigma/dt$ BR(e^+e^-) 3 5 × 10^{-32} cm^2/GeV^2 for spin 1 partner of Goldstone fermions with 140 m <160 MeV decaying → e^+e^- pair

REFERENCES FOR SUPERSYMMETRIC PARTICLE SEARCHES

ADEVA	87	PL B194 167	+Anderhub Ansari Becker+	(MARK J Collab)
ALBAJAR	87B	PL B185 241	+Albrow Allkofer Arnison+	(UA1 Collab)
ALBAJAR	87D	PL B198 261	+Albrow Allkofer+	(UA1 Collab)
ANSARI	87D	PL B195 613	+Bagnaia Banner+	(UA2 Collab)
ARNOLD	87	PL B186 435	+Barth+ (LIBH DUUC LOUC BARI AICH CERN+)	
BAER	87B	PR D35 1598	+Hagiwara Tata	(KEK ANL WISC)
Also	86	PRL 57 294	Baer Hagiwara Tata	(ANL DESY WISC)
BEHREND	87B	ZPHY C35 181	+Buerger Criegee Dainton+	(CELLO Collab)
BELTRAMI	87	PL B194 326	+Burkard Von Dincklage+	(ETH SIN MANZ)
BERTOLINI	87	PL B192 437	+Borzumati Masiero	(CMU NYU)
FERNANDEZ	87	PR D35 374	+Ford Qi Read Smith+	(MAC Collab)
HEARTY	87	PRL 58 1711	+Rothberg Young Johnson+	(ASP Collab)
NG	87	PL B188 138	+Olive Srednicki	(MINN UCSB)
TUTS	87	PL B186 233	+Franzini Youssef Zhao+	(CUSB Collab)
ALBRECHT	86C	PL 167B 360	+Binder Harder+	(ARGUS Collab)
ARNISON	86C	EPL 1 327	+Albrow Allkofer+	(UA1 Collab)
BADIER	86	ZPHY C31 21	+Bemporad Boucrot Callot+	(NA3 Collab)
BARTEL	86	ZPHY C31 359	+Becker Felst Haidt+	(JADE Collab)
BARTHA	86	PRL 56 685	+Burke Extermann+	(ASP Collab)
BEHREND	86D	PL B176 247	+Buerger Criegee Fenner Field+	(CELLO Collab)
FAYET	86	PL B175 471		(ENSP)
FORD	86	PR D33 3472	+Qi Read+	(MAC Collab)
GAISSER	86	PR D34 2206	+Steigman Tilav	(BRTD DELA)
VOLOSHIN	86	SJNP 43 495	+Okun	(ITEP)
		Translated from YAF 43 779		
ADEVA	85	PL 152B 439	+Becker Becker Szendy+	(MARK J Collab)
Also	84C	PRPL 109 131	Adeva Barber Becker+	(MARK J Collab)
AKERLOF	85	PL 156B 271	+Bonvicini Chapman Errede+	(HRS Collab)
BAER	85	PL 161B 175	+Ellis Gelmini Nanopoulos Tata	(CERN)
BARTEL	85B	ZPHY C26 507	+Becker Bowdery Cords+	(JADE Collab)
BARTEL	85C	PL 152B 385	+Becker Bowdery Cords+	(JADE Collab)
BARTEL	85D	PL 152B 392	+Becker Bowdery Cords+	(JADE Collab)
BARTEL	85H	ZPHY 29 505	+Becker Cords Felst+	(JADE Collab)
BEHREND	85	PL 161B 182	+Burger Criegee Fenner+	(CELLO Collab)
COOPER	85B	PL 160B 212	Cooper Sarkar Parker Sarkar+	(WA66 Collab)
DAWSON	85	PR D31 1581	+Eichten Quigg	(LBL FNAL)
FARRAR	85	PRL 55 895		(RUTG)
FERNANDEZ	85B	PRL 54 1118	+Ford Qi Read+	(MAC Collab)
GOLDMAN	85	Physica 15D 181	+Haber	(LANL UCSC)

HABER	85	PRPL 117 75	+Kane	(UCSC MICH)
ADEVA	84B	PRL 53 1806	+Barber Becker Berdugo+	(MARK J Collab.)
BALL	84	PRL 53 1314	+Coffin Gustafson+	(MICH FIRZ OSU FNAL WISC)
BARBER	84B	PL 139B 427	+Shrock	(STON)
BARTEL	84B	PL 139B 327	+Becker Bowdery Cords+	(JADE Collab.)
BARTEL	84C	PL 146B 126	+Becker Bowdery Cords+	(JADE Collab.)
BRICK	84	PR D30 1134	+	(BROW CAMB IIT IND MIT MONS NIJM+)
ELLIS	84	NP B238 453	+Hagelin Nanopoulos Olive Srednicki	(CERN)
FARRAR	84	PRL 53 1029		(RUTG)
FERNANDEZ	84	PRL 52 22	+Ford Read Smith+	(MAC Collab.)
HAGELIN	84	NP B241 638	+Kane Raby	(MIU MICH)
IBANEZ	84	PL 137B 160		(MADU)
KANE	84	NP B232 21	+Rolnick	(MICH WAYN)
WARE	84	PL 147B 415	+Machacek	(NEAS)
BEHREND	83	PL 123B 127	+Chen Fenner Gumpel+	(CELLO Collab.)
BERGSMA	83C	PL 121B 429	+Dorenbosch Jonker+	(CHARM Collab.)
CHANOWITZ	83	PL 126B 225	+Sharpe	(UCB LBL)
FERNANDEZ	83C	PR D28 2721	+Ford Read Smith+	(MAC Collab.)
GLADNEY	83	PRL 51 2253	+Hollebeek Leclaire Abrams+	(SLAC LBL HARV)
GOLDBERG	83	PRL 50 1419		(NEAS)
HOFFMAN	83	PR D28 660	+Frank Mischke Moir Schardt	(LANL ARZS)
KRAUSS	83	NP B227 556		(HARV)
VYSOTSKII	83	SJNP 37 948		(ITEP)
		Translated from YAF 37 1597		
ADEVA	82B	PL 115B 345	+Barber Becker Berdugo+	(MARK J Collab.)
BARTEL	82D	PL 114B 211	+Cords Elsen Bethke+	(JADE Collab.)
BEHREND	82B	PL 114B 287	+Chen Fenner Field+	(CELLO Collab.)
BLOCKER	82	PRL 49 517	+Matteuzzi Abrams Amidei+	(MARK II Collab.)
BRANDELIK	82B	PL 117B 365	+Braunschweig Gather+	(TASSO Collab.)
KANE	82	PL 112B 227	+Leveille	(MICH)
NAPPI	82	PR D25 84		(PRIN)
CABIBBO	81	PL 105B 155	+Farrar Maiani	(ROMA RUTG)
BARBER	80B	PRL 45 1904	+Becker Bei Berghoff+	(MARK J Collab.)
FARRAR	80	PL 89B 191	+Fayet	(RUTG ENSP)
FAYET	79	PL 84B 416		(CIT)
FAYET	79B	PL 84B 421		(CIT)
FARRAR	78	PL 76B 575	+Fayet	(CIT)
Also	78B	PL 79B 442	Farrar Fayet	(CIT)

SEARCHES FOR QUARK AND LEPTON COMPOSITENESS

NOTE ON SEARCHES FOR QUARK AND LEPTON COMPOSITENESS

If quarks and leptons are made of constituents, then at the scale of constituent binding energies, there should appear new interactions among quarks and leptons. At energies much below the compositeness scale (Λ), these interactions are suppressed by inverse powers of Λ. The dominant effect should come from the lowest dimensional interactions with four fermions (contact terms), whose most general chirally invariant form reads[1]

$$\mathscr{L} = \frac{g^2}{2\Lambda^2}\Big[\eta_{LL}\overline{\psi}_L\gamma_\mu\psi_L\overline{\psi}_L\gamma^\mu\psi_L + \eta_{RR}\overline{\psi}_R\gamma_\mu\psi_R\overline{\psi}_R\gamma^\mu\psi_R$$

$$- 2\eta_{LR}\overline{\psi}_L\gamma_\mu\psi_L\overline{\psi}_R\gamma^\mu\psi_R\Big] \qquad (1)$$

Chiral invariance is needed to understand why quark and lepton masses are much smaller than their inverse size Λ. We may determine the scale Λ unambiguously by using the above form of the effective interactions, the conventional method[1] is to fix its scale by setting $g^2/4\pi = g^2(\Lambda)/4\pi = 1$ for the new strong interaction coupling and by setting the largest magnitude of the coefficients $\eta_{\alpha\beta}$ to be unity. In the following, we denote

$$\Lambda = \Lambda^{\pm}_{LL} \quad \text{for } (\eta_{LL}\ \eta_{RR}\ \eta_{LR}) = (\pm 1\ 0\ 0)$$

$$\Lambda = \Lambda^{\pm}_{RR} \quad \text{for } (\eta_{LL}\ \eta_{RR}\ \eta_{LR}) = (0\ \pm 1\ 0)$$

$$\Lambda = \Lambda^{\pm}_{VV} \quad \text{for } (\eta_{LL}\ \eta_{RR}\ \eta_{LR}) = (\pm 1\ \pm 1\ \pm 1)$$

$$\Lambda = \Lambda^{\pm}_{AA} \quad \text{for } (\eta_{LL}\ \eta_{RR}\ \eta_{LR}) = (\pm 1\ \pm 1,\ \mp 1)\,, \qquad (2)$$

as typical examples. Such interactions are expected independent of models when all the four fermions entering the vertex are identical, e.g., in $eeee$ and $qqqq$ processes. In other processes like $ee\mu\mu$, $ee\tau\tau$, $eeqq$, and $qqq'q'$ the contact interactions should appear in models where two fermions have a common constituent.

Another typical consequence of compositeness is the appearance of excited leptons and quarks (ℓ^* and q^*). They can be pair-produced via their gauge couplings just like ordinary heavy leptons and quarks, although they may have different electroweak quantum numbers and may have form factors.[2] In addition, we expect a f-f^* transition (f^* = excited fermion) via dimension-five interactions with a gauge boson. The photon coupling for spin-1/2 excited fermions can be expressed as

$$\mathscr{L} = \frac{1}{2\Lambda}\sum_f\left\{\overline{f}^*\, eF_{\mu\nu}\sigma^{\mu\nu}\left(\eta_L f_L + \eta_R f_R\right) + h.c.\right\}, \qquad (3)$$

where $e = \sqrt{4\pi\alpha}$, $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$, $\sigma^{\mu\nu} = (i/2)(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)$, and we fix the scale Λ by choosing $\mathrm{Max}(|\eta_L|, |\eta_R|) = 1$ as before. The gluon coupling for quarks is obtained from the above by replacing the factor $eF_{\mu\nu}$ by $g_S T^\alpha F^\alpha_{\mu\nu}$, where $F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + O(g_S)$ and T^α is half the Gell-Mann matrix for color-triplet excited quarks. Chiral invariance implies

$$\eta_L \eta_R = 0 \qquad (4)$$

in the massless fermion limit for both photon and gluon couplings. The ratio

$$\lambda = m_{f^*}/\Lambda \qquad (5)$$

can be chosen as a free parameter.

In the analysis of some experimental results the relation $\eta_L = \eta_R = 1$, which violates the condition in Eq. (4), has been assumed. We encode the results of such analyses when the sensitive part of the cross section is proportional to the factor $\eta_L^2 + \eta_R^2$ and the limits can be reinterpreted as those for the cases $(\eta_L\ \eta_R) = (1\ 0)$ or $(0\ 1)$ after dividing the scale Λ by $\sqrt{2}$ (or, equivalently, multiplying the factor λ by $\sqrt{2}$).

At energies above the weak boson mass scale, transitions via weak boson couplings can be studied. If weak bosons are the gauge bosons of the electroweak symmetry as in the Standard Model, the transition couplings are constrained by

$SU(2)_L \times U(1)_Y$ invariance For example, if we consider a class of models in which both the right- and left-handed states of the excited fermions are weak-isospin doublets then the interaction Lagrangian is[3]

$$\mathscr{L} = \frac{1}{2\Lambda} \times \tag{6}$$

$$\sum_f \left\{ \bar{f}^* \left[\eta g T^i W^i_{\mu\nu} + \eta' g' B_{\mu\nu} - \eta_S g_S T^\alpha F^\alpha_{\mu\nu} \right] \sigma^{\mu\nu} f_L + h\,c \right\}.$$

where f_L denotes either lepton or quark doublets, g and g' are $SU(2)_L$ and $U(1)_Y$ couplings,

$$W^i_{\mu\nu} = \partial_\mu W^i_\nu - \partial_\nu W^i_\mu + O(g)\,,$$

$$B_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu$$

in terms of the $SU(2)_L$ and $U(1)_Y$ gauge bosons, and T^i is half the Pauli matrix If, instead, the excited fermions are singlets in both chiralities, then their transition couplings are obtained from Eq (6) by replacing f_L by f_R and by deleting the W couplings ($\eta = 0$) We do not pursue the option where excited fermions have $SU(2)_L \times U(1)_Y$ noninvariant masses We may again fix the scale Λ by the condition $\text{Max}(|\eta|, |\eta'|, |\eta_S|) = 1$ The photon couplings of Eq (3) are obtained after the mixing of $SU(3)_c$ and $U(1)_{EM}$ neutral vector bosons, W^3_μ and B_μ For example, $(\eta, \eta') = (1, -1/2)$ in Eq (6) gives $(\eta_L, \eta_R) = (-1, 0)$ for charged leptons, and $(\eta, \eta') = (1, 1/2)$ gives $(\eta_L, \eta_R) = (1, 0)$ for neutrinos in Eq (3) The chirality condition, Eq (4), is automatically satisfied in $SU(2)_L$ and $U(1)_Y$ invariant models

If leptons are made of color triplet and antitriplet constituents, we may expect their color-octet partners Transitions between the octet leptons (ℓ_8) and the ordinary lepton (ℓ) may take place via the dimension-five interactions

$$\mathscr{L} = \frac{1}{2\Lambda} \sum_\ell \left\{ \bar{\ell}^\alpha_8 g_S F^\alpha_{\mu\nu} \sigma^{\mu\nu} \left[\eta_L \ell_L + \eta_R \ell_R \right] + h\,c \right\}, \tag{7}$$

where the summation is over charged leptons and neutrinos The leptonic chiral invariance implies $\eta_L \eta_R = 0$ as before

References

1 E J Eichten, K D Lane, and M E Peskin, Phys Rev Lett **50**, 811 (1983)

2 K Hagiwara, S Komamiya, and D Zeppenfeld, Z Phys **C29**, 115 (1985)

3 F M Renard, Phys Lett **126B**, 59 (1983), Phys Lett **139B**, 449 (1984), and N Cabibbo, L Maiani, and Y Srivastava, Phys Lett **139B**, 459 (1984)

SCALE LIMITS FOR CONTACT INTERACTIONS $\Lambda(eeee)$

Limits are for $\Lambda^\pm_{LL}$ only For other cases, see each reference

VALUE (TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>1.4	95	[1] BRAUNSCH	88	TASS	Λ^+_{LL}
>3.3	95	[1] BRAUNSCH	88	TASS	Λ^-_{LL}
• • • We do not use the following data for averages fits limits etc • • •					
>1 1	95	[2] BARTEL	86	JADE	Λ^+_{LL}
>1 4	95	[2] BARTEL	86	JADE	Λ^-_{LL}
>1.17	95	[3] DERRICK	86	HRS	Λ^+_{LL}
>0.87	95	[3] DERRICK	86	HRS	Λ^-_{LL}
>1.1	95	[4] BERGER	85	PLUT	Λ^+_{LL}
>0 76	95	[4] BERGER	85	PLUT	Λ^-_{LL}

[1] BRAUNSCHWEIG 88 is at E_{cm} = 12–46 8 GeV $m(Z)$ = 92 GeV and $\sin^2\theta_W$ = 0.23 assumed
[2] BARTEL 86 is at E_{cm} = 12–46 8 GeV $m(Z)$ = 93 GeV and $\sin^2\theta_W$ = 0 217 assumed
[3] DERRICK 86 is at E_{cm} = 29 GeV $m(Z)$ = 93 GeV and g^2_V = $(-1/2+2\sin^2\theta_W)^2$ = 0 004 assumed
[4] BERGER 85 is at E_{cm} = 34 7 GeV $m(Z)$ = 93 GeV and $\sin^2\theta_W$ = 0 217 assumed

SCALE LIMITS FOR CONTACT INTERACTIONS $\Lambda(ee\mu\mu)$

Limits are for $\Lambda^\pm_{LL}$ only For other cases see each reference

VALUE (TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>4.4	95	[5] BARTEL	86	JADE	Λ^+_{LL}
>2.1	95	[5] BARTEL	86	JADE	Λ^-_{LL}
• • • We do not use the following data for averages fits, limits, etc • • •					
>2 9	95	[6] BERGER	85	PLUT	Λ^+_{LL}
>0.86	95	[6] BERGER	85	PLUT	Λ^-_{LL}

[5] BARTEL 86 is at E_{cm} = 12–46 8 GeV $m(Z)$ = 93 GeV and $\sin^2\theta_W$ = 0 217 assumed
[6] BERGER 85 is at E_{cm} = 34 7 GeV $m(Z)$ = 93 GeV and $\sin^2\theta_W$ = 0 217 assumed

SCALE LIMITS FOR CONTACT INTERACTIONS $\Lambda(ee\tau\tau)$

Limits are for $\Lambda^\pm_{LL}$ only For other cases see each reference

VALUE (TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>2.2	95	[7] BARTEL	86	JADE	Λ^+_{LL}
>3.2	95	[7] BARTEL	86	JADE	Λ^-_{LL}

[7] BARTEL 86 is at E_{cm} = 12–46 8 GeV $m(Z)$ = 93 GeV and $\sin^2\theta_W$ = 0 217 assumed

SCALE LIMITS FOR CONTACT INTERACTIONS $\Lambda(\mu\nu_\mu e\nu_e)$

Limits are for $\Lambda^\pm_{LL}$ only For other cases see each reference

VALUE (TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>3.10	90	[8] JODIDIO	86	SPEC	$\Lambda^\pm_{LR}$ from $\mu^+ \to \bar{\nu}_\mu e^+ \nu_e$

[8] In JODIDIO 86 chirality invariant interactions $L = (g^2/\Lambda^2)\,[\eta_{LL}\,(\bar{\nu}_{\mu L}\gamma^\alpha \mu_L)(\bar{e}_L\gamma_\alpha \nu_{eL}) + \eta_{LR}\,(\bar{\nu}_{\mu L}\gamma^\alpha \nu_{eL})(\bar{e}_R\gamma_\alpha \mu_R)]$ with $g^2/4\pi = 1$ and (η_{LL}, η_{LR}) = $(0, \pm1)$ are taken No limits are given for $\Lambda^\pm_{LL}$ with $(\eta_{LL}, \eta_{LR}) = (\pm1\ 0)$ For more general constraints with right handed neutrinos and chirality non conserving contact interactions see their text

SCALE LIMITS FOR CONTACT INTERACTIONS $\Lambda(qqqq)$

Limits are for $\Lambda^\pm_{LL}$ with color-singlet isoscalar exchanges among u_L's and d_L's only See EICHTEN 84 for details

VALUE (TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>0.415	95	[9] ARNISON	86D	UA1	$p\bar{p} \to$ dijets
• • • We do not use the following data for averages fits limits etc • • •					
>0 400	95	[10] ARNISON	86E	UA1	$p\bar{p} \to$ jets inclusive
>0 370	95	[11] APPEL	85	UA2	$p\bar{p} \to$ jets inclusive
>0 275	95	[12] BAGNAIA	84C	UA2	$p\bar{p} \to$ jet dijet

[9] ARNISON 86D limit is from the study of dijet angular distribution in the range 240 < m(dijet) < 300 GeV at the CERN $\bar{p}p$ collider (E_{cm} = 630 GeV) QCD prediction using EHLQ structure function (EICHTEN 84) with Λ_{QCD} = 0.2 GeV for the choice of $Q^2 = p_T^2$ gives the best fit to the data
[10] ARNISON 86E limit is from the study of inclusive high-p_T jet distributions at the CERN $\bar{p}p$ collider (E_{cm} = 546 and 630 GeV) The QCD prediction renormalized to the low p_T region gives a good fit to the data

SEARCHES FOR QUARK AND LEPTON COMPOSITENESS

[11]APPEL 85 limit is from the study of inclusive high-p_T jet distributions at the CERN $\bar{p}p$ collider (E_{cm} = 630 GeV) The QCD prediction renormalized to the low-p_T region gives a good description of the data

[12]BAGNAIA 84C limit is from the study of jet p_T and dijet mass distributions at the CERN $\bar{p}p$ collider (E_{cm} = 540 GeV) The limit suffers from the uncertainties in comparing the data with the QCD prediction

MASS LIMITS FOR EXCITED e (e^*)

$\lambda = m(e^*)/\Lambda$

The limits from e^+e^- experiments which depend on λ have assumed transition couplings which are chirality violating However they can be interpreted as limits for chirality conserving interactions after multiplying the coupling value λ by $2^{1/2}$ see Note

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>75	95	[13] ANSARI	87D	UA2	$W \to e^*\nu$ λ=1
>23	95	[14] BEHREND	86	CELL	$e^+e^- \to e^*e^*$
• • • We do not use the following data for averages, fits limits etc • • •					
>63	95	[13] ANSARI	87D	UA2	$W \to e^*\nu$ λ=0 3
>40	95	[13] ANSARI	87D	UA2	$W \to e^*\nu$ λ=0 13
>84	95	[14] BEHREND	86	CELL	$e^+e^- \to \gamma\gamma$, λ=1
>68	95	[14] BEHREND	86	CELL	$e^+e^- \to \gamma\gamma$ λ=0 7
none 15-27	95	[15] BONNEAUD	86	DLCO	$e^+e^- \to ee^*$ λ > 0 01
		[16] GRIFOLS	86	THEO	$\nu_\mu e \to \nu_\mu e$
>72	95	[17] ADEVA	85	MRKJ	$e^+e^- \to \gamma\gamma$ λ=1
>20		[17] ADEVA	84C	MRKJ	$e^+e^- \to \gamma\gamma$ λ=0.2
>70		[17] ADEVA	84C	MRKJ	$e^+e^- \to \gamma\gamma$ λ=1
>58	95	[18] ADEVA	82	MRKJ	$e^+e^- \to \gamma\gamma$, λ=1
		[19] BUKIN	82	CNTR	$e^+e^- \to ee^*$
none 0 5-3 3		[20] HAYES	82	MRK2	$e^+e^- \to e^*e^*$
		[21] RENARD	82	THEO	g-2 of electron
> 3 9	95	[22] HANSON	73	WIRE	$e^+e^- \to \gamma\gamma$ λ=1

[13]ANSARI 87 is at E_{cm} = 546-630 GeV $W \to e^*\nu$ ($e^* \to e\gamma$) See their Fig 1 for excluded region in the $\lambda - m(e^*)$ plane The limits depend only on the assumption η = 1 and nonvanishing $e^*e\gamma$ coupling to ensure rapid $e^* \to e\gamma$ decay (η and $\eta' \neq 0$)

[14]BEHREND 86 limits are from reactions $e^+e^- \to e^+e^-$ $e^+e^-\gamma$, $e^+e^-\gamma\gamma$, and $\gamma\gamma$ at E_{cm} = 33-46 8 GeV See their Fig 5 for excluded region in the $(\lambda/m(e^*))^2 - m(e^*)$ plane The second and third limits are for $\eta_L = \eta_R$ = 1

[15]BONNEAUD 86 mass limit is from the DELCO collaboration at PEP Their limit is actually quoted as a correlated upper bound on λ as a function of $m(e^*)$ $\eta_L = \eta_R$ = 1 assumed

[16]GRIFOLS 86 uses $\nu_\mu e \to \nu_\mu e$ and $\bar{\nu}_\mu e \to \nu_\mu e$ data from CHARM Collaboration to derive mass limits which depend on the scale of compositeness

[17]ADEVA 84 and ADEVA 85 limits are from $e^-e^+ \to 2\gamma$ with e^* exchange $\eta_L = \eta_R$ = 1 assumed

[18]ADEVA 82 study $e^+e^- \to e^+e^-\gamma$ $e^+e^-\gamma\gamma$, and $\gamma\gamma$ See their figure 2 for dependence on the coupling $\eta_L = \eta_R$ = 1 assumed

[19]BUKIN 82 is VEPP-2m ring experiment for $e^+e^- \to e^+e^-\gamma$ with E_{cm} = 0 64-1 4 GeV Observed no peak in $m(e\ \gamma)$ spectrum Set CL = 95% limit $\sigma(e^{*+}e^-)$ / $\sigma(e^+e^-)$ · (0 2-6)10^{-4} for $m(e^*)$ = 0 2-1 0 GeV $\eta_L = \eta_R$ = 1 assumed

[20]HAYES 82 is SLAC SPEAR experiment Their tables 5,6 give cross-section limits for orthomuon and orthoelectron for masses in above range

[21]RENARD 82 derived from g-2 data limits on mass and couplings of e^* and μ^* See figures 2 and 3 of the paper

[22]HANSON 73 look for deviations from QED in $e^+e^- \to 2\gamma$ The limit is for $\eta_L = \eta_R$ = 1

MASS LIMITS FOR EXCITED μ (μ^*)

$\lambda = m(\mu^*)/\Lambda$

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>23	95	[23] BEHREND	86	CELL	$e^+e^- \to \mu^*\mu^*$
>43	95	[23] BEHREND	86	CELL	$e^+e^- \to \mu\mu^*$ λ=0 6
• • • We do not use the following data for averages, fits, limits etc • • •					
>25	95	[24] ADEVA	85	MRKJ	$e^+e^- \to \mu\mu^*$ λ=1
>34	95	[25] BARTEL	84	JADE	$e^+e^- \to \mu\mu^*$ λ = 0.2
>22	95	[25] BARTEL	84	JADE	$e^+e^- \to \mu^*\mu^*$
		[26] FORD	83	MAC	$e^+e^- \to \mu\mu^*$ $\mu^*\mu^*$
>10	95	[27] ADEVA	82	MRKJ	$e^+e^- \to \mu^*\mu^*$
none 0 6-3 3		[28] HAYES	82	MRK2	$e^+e^- \to \mu^*\mu^*$
		[29] RENARD	82	THEO	g-2 of muon

[23]BEHREND 86 limit is from analysis of data on $e^+e^- \to \mu^+\mu^-$ $\mu^+\mu^-\gamma$ $\mu^+\mu^-\gamma\gamma$ at E_{cm} = 33-46 8 GeV See their Fig 6 for excluded region in the $(\lambda/m(\mu^*))^2 - m(\mu^*)$ plane The second limit is for $\eta_L = \eta_R$ = 1

[24]ADEVA 85 studies $e^+e^- \to \mu^+\mu^-\gamma$ and $\mu^+\mu^-\gamma\gamma$ The limit is for $\eta_L = \eta_R$ = 1

[25]BARTEL 84 observed 270 $\mu^+\mu^-\gamma$ events and 16 $\mu^+\mu^-2\gamma$ events Distributions are consistent with QED Second limit is from 2γ events and assumes μ^* is pointlike The first limit is from 1γ events and depends on λ $\eta_L = \eta_R$ = 1 assumed

[26]FORD 83 at PEP MAC (E_{cm} = 29 GeV) set CL = 90% limits $\sigma(\mu^*\mu^*)$ / $\sigma(\mu^+\mu^-)$ · (1-2)10^{-3} for $m(\mu^*)$ = 2-14 GeV and $\sigma(\mu^*\mu)$ / $\sigma(\mu^+\mu^-)$ · (1-2)10^{-3} for $m(\mu^*)$ = 2 5-27 GeV

[27]ADEVA 82 limit assumes pointline μ^* coupling They also set limit $\sigma(\mu^*\mu)/\sigma(\mu^+\mu^-)$ < 1% (CL=95%) from $\mu^+\mu^-\gamma$ events See their figure 2 for dependence on the coupling

[28]HAYES 82 is SLAC SPEAR experiment Their tables 5 6 give cross section limits for orthomuon and orthoelectron for masses in above range

[29]RENARD 82 derived from g-2 data limits on mass and couplings of e^* and μ^* See figures 2 and 3 of the paper

MASS LIMITS FOR EXCITED τ (τ^*)

$\lambda = m(\tau^*)/\Lambda$

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>22.7	95	[30] BEHREND	86	CELL	$e^+e^- \to \tau^*\tau^*$
>40.8	95	[30] BEHREND	86	CELL	$e^+e^- \to \tau^*\tau^*$ λ=0 7
• • • We do not use the following data for averages fits limits etc • • •					
>22	95	[31] BARTEL	86	JADE	$e^+e^- \to \tau^*\tau^*$
>40	95	[31] BARTEL	86	JADE	$e^+e^- \to \tau\tau^*$ λ=1
>41.4	95	[30] BEHREND	86	CELL	$e^+e^- \to \tau\tau^*$ λ=1

[30]BEHREND 86 limit is from study of reactions $e^+e^- \to \tau^+\tau^-\gamma$ and $\tau^+\tau^-\gamma\gamma$ at E_{cm} = 33-46 8 GeV The first limit is from $\tau^*\tau^*$ analysis for point like photon coupling The second and third limits are from $\tau\tau^*$ analysis with $\eta_L = \eta_R$ = 1 See their Fig 6 for the excluded region in $m(\tau^*) - (\lambda/m(\tau^*))^2$ plane

[31]BARTEL 86 gives lower bounds on mass of an excited τ lepton First bound is from search for $e^+e^- \to \tau^{*+}\tau^{*-}$ with decay $\tau^* \to \tau\gamma$ Second bound is from search for $e^+e^- \to \tau^+\tau^{*-}$ or $\tau^-\tau^{*+}$ with decay $\tau^* \to \tau\gamma$ E_{cm} = 30-46.78 GeV See their Fig 6 for excluded region in the $m(\tau^*) - (\lambda/m(\tau^*))^2$ plane The first limit is for point like photon coupling and the latter one assumes $\eta_L = \eta_R$ = 1 and λ = 1

MASS LIMITS FOR EXCITED q (q^*)

$\lambda = m(q^*)/\Lambda$

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
>21 1	95	[32] BEHREND	86C	CELL	$e(q^*)$ = − 1/3 $q^* \to qg$
>22 3	95	[32] BEHREND	86C	CELL	$e(q^*)$ = 2/3, $q^* \to qg$
>22.5	95	[32] BEHREND	86C	CELL	$e(q^*)$ = − 1/3 $q^* \to q\gamma$
>23 2	95	[32] BEHREND	86C	CELL	$e(q^*)$ = 2/3 $q^* \to q\gamma$
>39	95	[33] BEHREND	86C	CELL	$e^+e^- \to q^*q$ ($q^* \to gq\ g\gamma$) λ=1

[32]BEHREND 86C search for $e^+e^- \to q^*\bar{q}^*$ for $m(q^*)$ > 5 GeV But m < 5 GeV excluded by total hadronic cross section The limits are for point like photon couplings of excited quarks

[33]BEHREND 86C has E_{cm} = 42 5-46 8 GeV See their Fig 3 for excluded region in the $m(q^*) - (\lambda/m(q^*))^2$ plane The limit is for λ = 1 with $\eta_L = \eta_R$ = 1

MASS LIMITS FOR COLOR OCTET LEPTONS (ℓ_8)

$\lambda = m(\ell_8)/\Lambda$

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
>19 8	95	[34] BARTEL	87B	JADE	e_8 μ_8 τ_8 e^+e^- R
none 5-23 2	95	[34] BARTEL	87B	JADE	μ_8 $e^+e^- \to \mu\mu$ + jets
none 9-21 9	95	[34] BARTEL	87B	JADE	ν_8 $e^+e^- \to$ acoplanar jets
		[35] BARTEL	85K	JADE	e_8 $e^+e^- \to gg$ R

[34]BARTEL 87B is at E_{cm} = 46 3-46 78 GeV The limits assume ℓ_8 pair production cross sections to be eight times larger than those of the corresponding heavy lepton pair production This assumption is not valid in general for the weak couplings and the limit on ν_8 can be sensitive to its $SU(2)_L \times U(1)_Y$ quantum numbers

[35]In BARTEL 85K R can be affected by $e^+e^- \to gg$ via e_q exchange Their limit $m(e_8) > 173$ GeV (CL=95%) at $\Lambda = m(e_8)$ $\Lambda_M = 1$ ($\eta_L = \eta_R = 1$) is not listed above because the cross section is sensitive to the product $\eta_L\eta_R$ which should be absent in ordinary theory with electronic chiral invariance

REFERENCES FOR SEARCHES FOR QUARK AND LEPTON COMPOSITENESS

BRAUNSCH	88	ZPHY C37 171	Braunschweig Gerhards+	(TASSO Collab)
ANSARI	87	PL B186 440	+Bagnaia Banner Battiston+	(UA2 Collab)
ANSARI	87D	PL B195 613	+Bagnaia Banner+	(UA2 Collab)
BARTEL	87B	ZPHY C36 15	+Becker Felst+	(JADE Collab)
ARNISON	86D	PL B177 244	+Albajar Albrow+	(UA1 Collab)
ARNISON	86F	PL B172 461	+Albrow Allkofer+	(UA1 Collab)
BARTEL	86	ZPHY C31 359	+Becker Felst Haidt+	(JADE Collab)
BEHREND	86	PL 168B 420	+Burger Criegee Fenner+	(CELLO Collab)
BEHREND	86C	PL B181 178	+Buerger Criegee Dainton+	(CELLO Collab)
BONNEAUD	86	PL B177 109	+Courau Johnson Yamamoto+	(DELCO Collab)
DERRICK	86	PL 166B 463	+Gan Kooijman Loos+	(HRS Collab)
GRIFOLS	86	PL 168B 264	+Peris	(BARC)
JODIDIO	86	PR D34 1967	+Balke Carr Gidal Shinsky+	(LBL NWES TRIU)
Also Erratum	88	PR D37 237	Jodidio Balke Carr+	(LBL NWES TRIU)
ADEVA	85	PL 152B 439	+Becker Becker Szendy+	(MARK J Collab)
APPEL	85	PL 160B 349	+Bagnaia Banner+	(UA2 Collab)
BARTEL	85K	PL 160B 337	+Becker Cords Eichler+	(JADE Collab)
BERGER	85	ZPHY C28 1	+Genzel Lackas Pielorz+	(PLUTO Collab)
ADEVA	84	PRL 53 134	+Barber Becker Berdugo+	(MARK J Collab)
ADEVA	84C	PRPL 109 131	+Barber Becker+	(MARK J Collab)
BAGNAIA	84C	PL 138B 430	+Banner Battiston+	(UA2 Collab)
BARTEL	84	ZPHY C24 223	+Becker Bowdery Cords+	(JADE Collab)
EICHTEN	84	RMP 56 579	+Hinchliffe Lane Quigg	(FNAL LBL OSU)
FORD	83	PRL 51 257	+Read Smith Marini+	(MAC Collab)
ADEVA	82	PRL 48 967	+Barber Becker Berdugo+	(MARK J Collab)
BUKIN	82	SJNP 35 844	+Kurdadze Lelchuk Panin Sidorov+	(SIBE)
		Translated from YAF 35 1444		
HAYES	82	PR D25 2869	+Perl Alam Boyarski+	(MARK II Collab)
RENARD	82	PL 116B 264		(CERN)
HANSON	73	LNC 7 587	+Leong Newman Low+	(MIT HARV CEA HAIF)

OTHER STABLE PARTICLE SEARCHES

OMITTED FROM SUMMARY TABLE

NOTE ON OTHER STABLE PARTICLE SEARCHES

We collect here those searches which do not appear in any of the above search categories These include searches for centauros Also shown are heavy particle searches in accelerator experiments, in cosmic rays and in matter Searches are also listed for light particles, highly ionizing particles penetrating non-neutrino-like particles and tachyons Note that axion, supersymmetry Higgs bosons (and technipions), other heavy bosons, leptoquarks familons compositeness, heavy neutrino, and heavy lepton searches appear in separate sections above

CENTAURO PRODUCTION CROSS SECTION IN ACCELERATOR EXPERIMENTS

VALUE (cm^2)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •						
<0 005σ (nondiff)	95	0	[1] ALNER	86	UA5	pp collider
< 1 × 10^{-30}		0	[2] ARNISON	83B	UA1	$p\bar{p}$ collider
		0	[3] ALPGARD	82	UA5	$p\bar{p}$ collider

[1]ALNER 86 is CERN collider experiment at W_{cm} = 900 GeV Looked for high multiplicity low EM content in measured high p_T events from an unbiased sample of 5500 events No candidates observed
[2]ARNISON 83B is CERN collider experiment with W_{cm} = 540 GeV Looked for events with large hadronic and low electromagnetic content None in 48000 low bias events
[3]ALPGARD 82 is CERN collider experiment with W_{cm} = 540 GeV (155 TeV lab equivalent) Observed no large charged multiplicity events with photon multiplicity consistent with zero in 3600 inelastic events

OBSERVATION OF CENTAURO-LIKE EVENTS

A Centauro event is characterized by a hadronic event with high multiplicity high mean p_T and unusually small photon energy

VALUE	EVTS	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •				
	1	BORISOV	87	EMUL

LIGHT (BETWEEN μ AND e MASSES) PARTICLE MASS

VALUE ($m(e)$)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits, limits etc • • •					
none 110–180	0	[4] VIERTEL	78	CNTR	τ 2 × 10^{-5} sec
none 2–13	0	[5] BLAGOV	75	CNTR	Spinor τ < 2 × 10^{-10} sec
none 2–10 6	0	[5] BLAGOV	75	CNTR	Scalar τ 2 × 10^{-10} sec
none 5–175	0	COWARD	63	CNTR	Spinor τ < 22 × 10^{-10}
none 5–175	0	COWARD	63	CNTR	Scalar τ < 68 × 10^{-10}
none 6–25	0	BELOUSOV	60	CNTR	Spinor τ < 1 × 10^{-8}
none 2–25	0	GORBUNOV	60	CC	Spinor τ 1 × 10^{-9}

[4]VIERTEL 78 searches for $\mu^+ \to X^+\nu$ Finds BR < 8 5 × 10^{-6} in mass range given above (CL = 90%) Best limit BR < 5 × 10^{-7} (CL = 90%) is found at mass = 80 MeV
[5]BLAGOV 75 bounds on lifetime depend on mass and improve as mass decreases At 2 GeV the experiment is sensitive to τ 3 × 10^{-11} sec for spinor τ < 5 × 10^{-11} sec for scalar

HIGHLY IONIZING PARTICLE FLUX

VALUE (number/m^2 yr)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •						
<0 4	95	0	KINOSHITA	81B	PLAS	Z/β 30–100

TACHYON FLUX IN COSMIC RAYS

See SMITH 77 for a review of earlier cosmic ray and accelerator experiments

VALUE (number/cm^2 sec sr)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •						
< 2 4 × 10^{-9}	90	0	[6] MARINI	82	CNTR	v/c 1 2
< 2 3 × 10^{-10}	95	0	[7] BHAT	79	CNTR	
			[8] SMITH	77	CNTR	
			[9] PRESCOTT	76	CNTR	

[6]MARINI 82 is TOF measurement using PEP-counter at sea level
[7]BHAT 79 is at Ootacamund (2200m above sea) No signal in 3621 hours
[8]SMITH 77 analyzed more than 200000 showers(223 days) with E >10^{14} eV scanning 290 × 10^{-6} sec period before each shower Observed excess 46 ± 40 events does not constitute statistically significant evidence
[9]PRESCOTT 76 reanalyzed Clay and Crouch(C C) 74 data (Nature 248 28) Found apparatus effect correction for which much reduces the statistical significance of positive C C result Also performed two new experiments one using C C apparatus another with new apparatus Set upper limit at CL = 95% of about 30 tachyons per shower with average size N = 6 × 10^5

TACHYON SEARCHES IN e^+e^- ANNIHILATION

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •						
< 1 × 10^{-6}	90	0	[10] PEREPELITSA	77	CNTR	uv_{eq} < 1
< 1 × 10^{-5}	90	0	[10] PEREPELITSA	77	CNTR	1 < uv_{eq} < 15

[10]PEREPELITSA 77 is Michelson type experiment for pair produced tachyons in e^+e^- annihilation (e^+ from Cu isotope) Above limits are for $\sigma(e^+e^- \to \text{tachyon pair}) / \sigma(e^+e^- \to 2\gamma)$ and uv_{eq} is tachyon velocities times earth equator component of velocity of preferred reference frame

SEARCHES FOR TACHYONIC DECAY (lower limit for mean life)

See LJUBICIC 75 figure 1 for review of earlier experiments

VALUE (years)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •				
> 4 6 × 10^{13}	[11] LJUBICIC	75	ELEC	m(tachyon) < 1 1 keV

[11]LJUBICIC 75 used lead oxide cathode and electron multiplier looking for ionization due to tachyonic decay (spontaneous acquisition of energy) of bound-state e^-. Sensitive to proper tachyon mass < 1.1 keV. Above limit is obtained from observed e^- emission rate 3/hour.

PRODUCTION OF NEW PENETRATING NON-ν LIKE STATES IN BEAM DUMP

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[12] LOSECCO	81	CALO	28 GeV protons

[12]No excess neutral-current events leads to σ(production)$\times\sigma$(interaction)$\times$acceptance < 2.26$\times10^{-71}$ cm^4/nucleon^2 (CL = 90%) for light neutrals. Acceptance depends on models (0.1 to 4 $\times10^{-4}$).

HEAVY PARTICLE PRODUCTION CROSS SECTION IN e^+e^-

Ratio to $\sigma(e^+e^- \to \mu^+\mu^-)$. See also entries in quark search and magnetic monopole searches.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<1.6 $\times10^{-2}$	95	0	[13] KINOSHITA	82	PLAS	Q=3–180 m< 14.5 GeV
<5.0 $\times10^{-2}$	90	0	[14] BARTEL	80	JADE	Q=(3.4.5)/3 2–12 GeV

[13]KINOSHITA 82 is SLAC PEP experiment at W_{cm} = 29 GeV using lexan and ^{39}Cr plastic sheets sensitive to highly ionizing particles.
[14]BARTEL 80 is DESY-PETRA experiment with W_{cm} = 27–35 GeV. Above limit is for inclusive pair production and ranges between 1.$\times10^{-1}$ and 1 $\times10^{-2}$ depending on mass and production momentum distributions. (See their figures 9, 10, 11).

HEAVY PARTICLE PRODUCTION CROSS SECTION

VALUE (cm^2)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<(0.3∼1.3) $\times$ 10^{-31}		[15] CARROLL	78	SPEC		m=2–2.5 GeV
<1. $\times10^{-31}$	0	[16] LEIPUNER	73	CNTR	±	m=3–11 GeV

[15]CARROLL 78 look for neutral S = −2 dihyperon resonance in $pp \to 2K^+ X$. Cross section varies within above limits over mass range and p_{lab} = 5.1–5.9 GeV/c.
[16]LEIPUNER 73 is an NAL 300 GeV p experiment. Would have detected particles with lifetime greater than 200 nsec.

HEAVY PARTICLE PRODUCTION CROSS SECTION

VALUE (cm^2/N)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<2.5 $\times10^{-35}$	0	[17] GUSTAFSON	76	CNTR	0	τ > 10^{-7} sec

[17]GUSTAFSON 76 is a 300 GeV FNAL experiment looking for heavy (m > 2 GeV) long-lived neutral hadrons in the M4 neutral beam. The above typical value is for m = 3 GeV and assumes an interaction cross section of 1 mb. Values as a function of mass and interaction cross section are given in figure 2.

HEAVY PARTICLE PRODUCTION DIFFERENTIAL CROSS SECTION

VALUE (cm^2/sr-GeV)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •							
<2.6 $\times10^{-36}$	90	0	[18] BALDIN	76	CNTR	−	Q= 1 m=2.1–9.4 GeV
<2.2 $\times10^{-33}$	90	0	[19] ALBROW	75	SPEC	±	Q= ±1 m=4–15 GeV
<1.1 $\times10^{-33}$	90	0	[19] ALBROW	75	SPEC	±	Q= ±2 m=6–27 GeV
<8 $\times10^{-35}$	90	0	[20] JOVANOV	75	CNTR	±	m=15–26 GeV
<1.5 $\times10^{-34}$	90	0	[20] JOVANOV	75	CNTR	±	Q= ±2 m=3–10 GeV
<6 $\times10^{-35}$	90	0	[20] JOVANOV	75	CNTR	±	Q= ±2, m=10–26 GeV
<1 $\times10^{-31}$	90	0	[21] APPEL	74	CNTR	±	m=3.2–7.2 GeV
<5.8 $\times10^{-34}$	90	0	[22] ALPER	73	SPEC	±	m=1.5–24 GeV
<1.2 $\times10^{-35}$	90	0	[23] ANTIPOV	71B	CNTR	−	Q=− m=2.2–2.8
<2.4 $\times10^{-35}$	90	0	[24] ANTIPOV	71C	CNTR	−	Q=− m=1.2–1.7 2.1–4
<2.4 $\times10^{-35}$	90	0	BINON	69	CNTR	−	Q=− m=1–1.8 GeV
<1.5 $\times10^{-36}$		0	[25] DORFAN	65	CNTR		Be target m=3–7 GeV
<3.0 $\times10^{-36}$		0	[25] DORFAN	65	CNTR		Fe target m=3–7 GeV

[18]BALDIN 76 is a 70 GeV Serpukhov experiment. Value is per Al nucleus at θ = 0. For other charges in range −0.5 to −3.0, CL = 90% limit is (2.6 $\times10^{-36}$) / (charge)! for mass range (2.1–9.4 GeV) $\times$ (charge). Assumes stable particle interacting with matter as do antiprotons.
[19]ALBROW 75 is a CERN ISR experiment with E_{cm} = 53 GeV. θ = 40 mr. See figure 5 for mass ranges up to 35 GeV.
[20]JOVANOVICH 75 is a CERN ISR 26+26 and 15+15 GeV pp experiment. Figure 4 covers ranges Q = 1/3 to 2 and m = 3 to 26 GeV. Value is per GeV momentum.
[21]APPEL 74 is NAL 300 GeV pW experiment. Studies forward production of heavy (up to 24 GeV) charged particles with momenta 24–200 GeV (−charge) and 40–150 GeV (+charge). Above typical value is for 75 GeV and is per GeV momentum per nucleon.
[22]ALPER 73 is CERN ISR 26+26 GeV pp experiment. p > 0.9 GeV, 0.2 < β < 0.65.
[23]ANTIPOV 71B is from same 70 GeV p experiment as ANTIPOV 71C and BINON 69.
[24]ANTIPOV 71C limit inferred from flux ratio. 70 GeV p experiment.
[25]DORFAN 65 is a 30 GeV/c p experiment at BNL. Units are per GeV momentum per nucleus.

LONGLIVED HEAVY PARTICLE INVARIANT CROSS SECTION

VALUE (cm^2/GeV^2/N)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •							
<2.5 $\times10^{-36}$	90	0	[26] THRON	85	CNTR	−	Q= 1 m=4–12 GeV
<1 $\times10^{-35}$	90	1	[26] THRON	85	CNTR	+	Q= 1 m=4–12 GeV
<6 $\times10^{-33}$	90	0	[27] ARMITAGE	79	SPEC		m=1.87 GeV
<1.5 $\times10^{-33}$	90	0	[27] ARMITAGE	79	SPEC		m=1.5–3.0 GeV
		0	[28] BOZZOLI	79	CNTR	±	Q= (2/3.1.4/3.2)
<1.1 $\times10^{-37}$	90	0	[29] CUTTS	78	CNTR		m=4–10 GeV
<3.0 $\times10^{-37}$	90	0	[30] VIDAL	78	CNTR		m=4.5–6 GeV

[26]THRON 85 is FNAL 400 GeV proton experiment. Mass determined from measured velocity and momentum. Limits are for τ > 3 $\times$ 10^{-9} sec.
[27]ARMITAGE 79 is CERN ISR experiment at E_{cm} = 53 GeV. Value is for x = 0.1 and p_T = 0.15. Observed particles at m = 1.87 GeV are found all consistent with being antideuterons.
[28]BOZZOLI 79 is CERN SPS 200 GeV pN experiment. Looks for particle with τ larger than 10^{-8} sec. See their figure 11–18 for production cross section upper limits vs mass.
[29]CUTTS 78 is pBe experiment at FNAL sensitive to particles of τ > 5 $\times10^{-8}$ sec. Value is for −0.3 < x < 0 and p_T = 0.175.
[30]VIDAL 78 is FNAL 400 GeV proton experiment. Value is for x = 0 and p_T = 0. Puts lifetime limit of > 5 $\times$ 10^{-8} sec on particle in this mass range.

LONGLIVED HEAVY PARTICLE PRODUCTION (σ(HEAVY PARTICLE) / $\sigma(\pi)$)

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
	0	[31] BUSSIERE	80	CNTR	±	Q= (2/3.1.4/3.2)

[31]BUSSIERE 80 is CERN SPS experiment with 200–240 GeV protons on Be and Al target. See their figures 6 and 7 for cross section ratio vs mass.

PRODUCTION AND CAPTURE OF LONG-LIVED MASSIVE PARTICLES

VALUE (10^{-36}cm^2)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<20 TO 800	0	[32] ALEKSEEV	76	ELEC	τ=5 ms to 1 day
<200 TO 2000	0	[32] ALEKSEEV	76B	ELEC	τ=100 ms to 1 day
<1.4 TO 9	0	[33] FRANKEL	75	CNTR	τ=50 ms to 10 hours
<0.1 TO 9	0	[34] FRANKEL	74	CNTR	τ=1 to 1000 hours

[32]ALEKSEEV 76 and ALEKSEEV 76B are 61–70 GeV p Serpukhov experiment. Cross section is per Pb nucleus.
[33]FRANKEL 75 is extension of FRANKEL 74.
[34]FRANKEL 74 looks for particles produced in thick Al targets by 300–400 GeV/c protons.

Stable Particle Full Listings
OTHER STABLE PARTICLE SEARCHES

HEAVY PARTICLE FLUX IN COSMIC RAYS

VALUE (number/cm²-sec-sr)		CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •								
< 1.4	$\times 10^{-12}$	90	0	35 MINCER	85	CALO		$m \geq 1$ TeV
< 3.2	$\times 10^{-11}$	90	0	36 NAKAMURA	85	CNTR		m ·1.5×10^{-13} gram
				37 SAKUYAMA	83B	PLAS		$m \sim 1$ TeV
< 1.7	$\times 10^{-11}$	99	0	38 BHAT	82	CC		
< 1.	$\times 10^{-9}$	90	0	39 MARINI	82	CNTR	±	Q= 1, m ~4.5$m(p)$
< 3.5	$\times 10^{-11}$	90	0	40 ULLMAN	81	CNTR		Planck-mass 10^{19}GeV
< 7.	$\times 10^{-11}$	90	0	40 ULLMAN	81	CNTR		m=1.$\times 10^{-16}$ GeV or less
2.	$\times 10^{-9}$		3	41 YOCK	81	SPRK	±	Q= 1, m ~4.5$m(p)$
			3	41 YOCK	81	SPRK		Fractionally charged
3.0	$\times 10^{-9}$		3	42 YOCK	80	SPRK		m ~4.5 $m(p)$
(4 ± 1)	$\times 10^{-11}$		3	GOODMAN	79	ELEC		$m \geq 5$ GeV
< 1.3	$\times 10^{-9}$	90		43 BHAT	78	CNTR	±	m ·1 GeV
< 1.0	$\times 10^{-9}$		0	BRIATORE	76	ELEC		
< 7.	$\times 10^{-10}$	90	0	YOCK	75	ELEC	±	Q ·7e or · −7e
> 6.	$\times 10^{-9}$		5	44 YOCK	74	CNTR		m ·6 GeV
< 3.0	$\times 10^{-8}$		0	DARDO	72	CNTR		
< 1.5	$\times 10^{-9}$		0	TONWAR	72	CNTR		m ·10 GeV
< 3.0	$\times 10^{-10}$		0	BJORNBOE	68	CNTR		m · 5 GeV
< 5.0	$\times 10^{-11}$	90	0	JONES	67	ELEC		m=5–15 GeV

[35] MINCER 85 is high statistics study of calorimeter signals delayed by 20–200 nsec. Calibration with AGS beam shows they can be accounted for by rare fluctuations in signals from low-energy hadrons in the shower. Claim that previous delayed signals including BJORNBOE 68, DARDO 72, BHAT 82, SAKUYAMA 83B below may be due to this fake effect.

[36] NAKAMURA 85 at KEK searched for quark-matter. These might be lumps of strange quark matter with roughly equal numbers of u, d, s quarks. These lumps or nuclearites were assumed to have m ·1.5×10^{-13} G and velocity/c of 10^{-4}–10^{-3}.

[37] SAKUYAMA 83B analyzed 6000 extended air shower events. Increase of delayed particles and change of lateral distribution above 10^{17} eV may indicate production of very heavy parent at top of atmosphere.

[38] BHAT 82 observed 12 events with delay ·$2.\times 10^{-8}$ sec and with more than 40 particles. 1 eV has good hadron shower. However all events are delayed in only one of two detectors in cloud chamber, and could not be due to strongly interacting massive particle.

[39] MARINI 82 applied PEP-counter for TOF. Above limit is for velocity = 0.54 of light. Limit is inconsistent with YOCK 80 YOCK 81 events if isotropic dependence on zenith angle is assumed.

[40] ULLMAN 81 is sensitive for heavy slow singly charge particle reaching earth with vertical velocity 100–350 km/s.

[41] YOCK 81 saw another 3 events with Q = ±1 and m about 4.5$m(p)$ as well as 2 events with m ·5.3$m(p)$. Q = ±0.75±0.05 and m ·2.8$m(p)$, Q = ±0.70±0.05 and 1 event with m = (9.3±3.)$m(p)$, Q = ±0.89±0.06 as possible heavy candidates.

[42] YOCK 80 events are with charge exactly or approximately equal to unity.

[43] BHAT 78 is at Kolar gold fields. Limit is for τ ·10^{-6} sec.

[44] YOCK 74 events could be tritons.

CONCENTRATION OF HEAVY (CHARGE+1) STABLE PARTICLES IN MATTER

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
< 1. $\times 10^{-29}$	SMITH	82B	SPEC	Water, m=30–400$m(p)$
< 2. $\times 10^{-28}$	SMITH	82B	SPEC	Water, m=12–1000$m(p)$
< 1. $\times 10^{-14}$	SMITH	82B	SPEC	Water, m ·1000 $m(p)$
<(0.2–1) $\times 10^{-21}$	SMITH	79	SPEC	Water, m=6–350 $m(p)$

CONCENTRATION OF HEAVY (CHARGE −1) STABLE PARTICLES

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<1.2×10^{-12} per nucleon	68	45 NORMAN	87	SPEC	^{56,58}FeX^-

[45] Bound valid up to $m(X^-) \sim 100$ TeV.

LONG-LIVED PARTICLE SEARCH AT HADRON COLLISIONS

Limits are for cross section times branching ratio.

VALUE (pb/nucleon)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<2	90	0	46 BADIER	86	BDMP	τ = (0.05–1) $\times 10^{-8}$s

[46] BADIER 86 looked for long-lived particles at 300 GeV π^- beam dump. The limit applies for nonstrongly interaction neutral or charged particles with mass > 2 GeV. The limit applies for particle modes, $\mu^+\pi^-$, $\mu^+\mu^-$, $\pi^+\pi^-$ X, $\pi^+\pi^-\pi^\pm$ etc. See their figure 5 for the contours of limits in the mass-τ plane for each mode.

REFERENCES FOR OTHER STABLE PARTICLE SEARCHES

BORISOV	87	PL B190 226	+Cherdyntseva+	(Pamir-Chacaltaya Collab.)
NORMAN	87	PRL 58 1403	+Gazes, Bennett	(LBL)
ALNER	86	PL B180 415	+Ansorge, Asman, Booth, Burow+	(UA5 Collab.)
BADIER	86	ZPHY C31 21	+Bemporad, Boucrot, Callot+	(NA3 Collab.)
MINCER	85	PR D32 541	+Freudenreich, Goodman+	(UMD, GMAS, NSF)
NAKAMURA	85	PL 161B 417	+Horie, Takahashi, Tanimori	(KEK, TOKY)
THRON	85	PR D31 451	+Cardello, Cooper, Teig+	(YALE, FNAL, IOWA)
ARNISON	83B	PL 122B 189	+Astbury, Aubert, Bacci+	(UA1 Collab.)
SAKUYAMA	83B	LNC 37 17	+Nuzuki	(MEIS)
Also	83	LNC 36 389	Sakuyama, Watanabe	(MEIS)
Also	83D	NC 78A 147	Sakuyama, Watanabe	(MEIS)
Also	83C	NC 6C 371	Sakuyama, Watanabe	(MEIS)
ALPGARD	82	PL 115B 71	+Ansorge, Asman, Berglund+	(UA5 Collab.)
BHAT	82	PR D25 2820	+Gupta, Murthy, Sreekantan+	(TATA)
KINOSHITA	82	PRL 48 77	+Price, Fryberger	(UCB, SLAC)
MARINI	82	PR D26 1777	+Peruzzi, Piccolo+	(FRAS, LBL, NWES, STAN, HAWA)
SMITH	82B	NP B206 333	+Bennett, Homer, Lewin, Walford, Smith	(RAL)
KINOSHITA	81B	PR D24 1707	+Price	(UCB)
LOSECCO	81	PL 102B 209	+Sulak, Gallk, Horstkotte+	(MICH, PENN, BNL)
ULLMAN	81	PRL 47 289		(LEHM, BNL)
YOCK	81	PR D23 1207		(AUCK)
BARTEL	80	ZPHY C6 295	+Canzler, Lords, Drumm+	(JADE Collab.)
BUSSIERE	80	NP B174 1	+Giacomelli, Lesquoy+	(BGNA, SACL, LAPP)
YOCK	80	PR D22 61		(AUCK)
ARMITAGE	79	NP B150 87	+Benz, Bobbink+	(CERN, DARE, FOM, MCHS, UTRE)
BHAT	79	JP G5 L13	+Gopalakrishnan, Gupta Tonwar	(TATA)
BOZZOLI	79	NP B159 363	+Bussiere, Giacomelli+	(BGNA, LAPP, SACL CERN)
GOODMAN	79	PR D19 2572	+Ellsworth, Ito, Macfall, Siohan+	(UMD)
SMITH	79	NP B149 525	+Bennett	(RHEL)
BHAT	78	Pramana 10 115	+Murthy	(TATA)
CARROLL	78	PRL 41 777	+Chiang, Johnson, Kycia, Ki+	(BNL, PRIN)
CUTTS	78	PRL 41 363	+Dulude+	(BROW, FNAL, ILL, BARI, MIT, WARS)
VIDAL	78	PL 77B 344	+Herb, Lederman+	(COLU, FNAL, STON, UCB)
VIERTEL	78	LNC 22 235	+Hahn, Schacher	(BERN)
PEREPELITSA	77	PL 67B 471		(ITEP)
SMITH	77	CJP 55 1280	+Standil	(MANI)
ALEKSEEV	76	SJNP 22 531 Translated from YAF 22 1021.	+Zaitsev, Kalinina, Kruglov+	(JINR)
ALEKSEEV	76B	SJNP 23 633 Translated from YAF 23 1190.	+Zaitsev, Kalinina, Kruglov+	(JINR)
BALDIN	76	SJNP 22 264 Translated from YAF 22 512.	+Vertogradov, Vishnevsky, Grishkevich+	(JINR)
BRIATORE	76	NC 31A 553	+Dardo, Piazzoli, Mannocchi+	(LCGT, FRAS, FREI)
GUSTAFSON	76	PRL 37 474	+Ayre, Jones, Longo, Murthy	(MICH)
PRESCOTT	76	JP G2 261		(ADLD)
ALBROW	75	NP B97 189	+Barber+	(CERN, DARE, FOM, LANC, MCHS, UTRE)
BLAGOV	75	SJNP 21 158 Translated from YAF 21 300.	+Komar, Murashova, Syreishchikova+	(LEBD)
FRANKEL	75	PR D12 2561	+Frati, Resvanis, Yang, Nezrick	(PENN, FNAL)
JOVANOV...	75	PL 56B 105	Jovanovich+	(MANI, AACH, CERN, GENO, HARV+)
LJUBICIC	75	PR D11 696	+Pavlovic, Pisk, Logan	(ZAGR, OTTA)
YOCK	75	NP B86 216		(AUCK, SLAC)
APPEL	74	PRL 32 428	+Bourquin, Gaines, Lederman+	(COLU, FNAL)
FRANKEL	74	PR D9 1932	+Frati, Resvanis, Yang, Nezrick	(PENN, FNAL)
YOCK	74	NP B76 175		(AUCK)
ALPER	73	PL 46B 265	+	(CERN, LIVP, LUND, BOHR, RHEL, STOH, BERG+)
LEIPUNER	73	PRL 31 1226	+Larsen, Sessoms, Smith, Williams+	(BNL, YALE)
DARDO	72	NC 9A 319	+Navarra, Penengo, Sitte	(TORI)
TONWAR	72	JPA 5 569	+Naranan, Sreekantan	(TATA)
ANTIPOV	71B	NP B31 235	+Denisov, Donskov, Gorin, Kachanov+	(SERP)
ANTIPOV	71C	PL 34B 164	+Denisov, Donskov, Gorin, Kachanov+	(SERP)
BINON	69	PL 30B 510	+Duteil, Kachanov, Khromov, Kutyin+	(SERP)
BJORNBOE	68	NC B53 241	+Damgard, Hansen+	(BOHR, TATA, BERN, BERG)
JONES	67	PR 164 1584		(MICH, WISC, LBL, UCLA, MINN, COSU, COLO+)
DORFAN	65	PRL 14 999	+Eades, Lederman, Lee, Ting	(COLU)
COWARD	63	PR 131 1782	+Gittelman, Lynch, Ritson	(STAN)
BELOUSOV	60	JETP 11 1143 Translated from ZETF 38 1589	+Rusakov, Tamm, Cerenkov	(LEBD)
GORBUNOV	60	JETP 11 51 Translated from ZETF 38 69.	+Spiridonov, Cerenkov	(LEBD)

UNFLAVORED MESONS
($S = C = B = 0$)

$\pi^{\pm}$

$I^G(J^P) = 1^-(0^-)$

SEE STABLE PARTICLES

π^0

$I^G(J^{PC}) = 1^-(0^{-+})$

SEE STABLE PARTICLES

η

$I^G(J^{PC}) = 0^+(0^{-+})$

SEE STABLE PARTICLES

$\rho(770)$

$I^G(J^{PC}) = 1^+(1^{--})$

Our latest mini-review on this particle can be found in the 1984 edition

$\rho(770)$ MASS

We no longer list S-wave Breit-Wigner fits, or data with high combinatorial background

CHARGED ONLY

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
766.9 ± 1.2 OUR AVERAGE						
767 ± 3	2935	[1] CAPRARO	87	SPEC	−	200 $\pi^- Cu \to \pi^- \pi^0 Cu$
761 ± 5	967	[1] CAPRARO	87	SPEC	−	200 $\pi^- Pb \to \pi^- \pi^0 Pb$
771 ± 4		HUSTON	86	SPEC	+	202 $\pi^+ A \to \pi^+ \pi^0 A$
766. ± 7	6500	[2] BYERLY	73	OSPK	−	5 $\pi^- p$
766 8 ± 1.5	9650	[3] PISUT	68	RVUE	−	1 7–3 2 $\pi^- p$ t <10
767. ± 6	900	[1] EISNER	67	HBC	−	4 2 $\pi^- p$, t <10

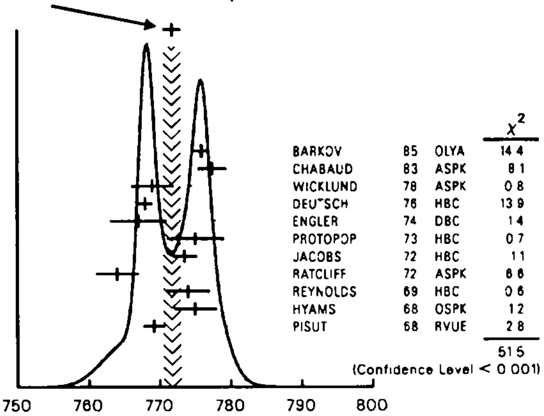
NEUTRAL ONLY, PHOTOPRODUCED

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
768.1 ± 1.3 OUR AVERAGE						
767 6 ± 2.7		BARTALUCCI	78	CNTR	0	$\gamma p \to e^+ e^- p$
775 ± 5		GLADDING	73	CNTR	0	2 9–4 7 γp
767.0 ± 4 0	1930	BALLAM	72	HBC	0	2 8 γp
770 0 ± 4.0	2430	BALLAM	72	HBC	0	4 7 γp
765.0 ± 10 0		ALVENSLEBEN	70	CNTR	0	γA t <0 01
767.7 ± 1.9	140k	BIGGS	70	CNTR	0	<4 1 $\gamma C \to \pi^+ \pi^- C$
765. ± 5 0	4000	ASBURY	67B	CNTR	0	γ + Pb

NEUTRAL ONLY, OTHER REACTIONS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
771.7 ± 1.2 OUR AVERAGE		Error includes scale factor of 2 3				See the ideogram below
775 9 ± 1 1		[4] BARKOV	85	OLYA	0	π form factor
777 4 ± 2.0		[5] CHABAUD	83	ASPK	0	17 $\pi^- p$ polarized
769 0 ± 3.0		[2] WICKLUND	78	ASPK	0	3 4 6 $\pi^{\pm} N$
768 0 ± 1 0	76000	DEUTSCH	76	HBC	0	16 $\pi^+ p$
767 ± 4	4100	ENGLER	74	DBC	0	6 $\pi^+ n \to \pi^+ \pi^- p$
775.0 ± 4 0	32000	[6] PROTOPOP	73	HBC	0	7 1 $\pi^+ p$ t <0 4
773.5 ± 1 7	11200	[1] JACOBS	72	HBC	0	2 8 $\pi^- p$
764 0 ± 3 0	6800	RATCLIFF	72	ASPK	0	15 $\pi^- p$ t <0 3
774 0 ± 3 0	1700	REYNOLDS	69	HBC	0	2 26 $\pi^- p$
775 0 ± 3 0	2250	HYAMS	68	OSPK	0	11 2 $\pi^- p$
769 2 ± 1 5	13300	[7] PISUT	68	RVUE	0	1 7–3 2 $\pi^- p$ t <10
• • • We do not use the following data for averages, fits limits etc • • •						
768 0 ± 4 0		[6,8] BOHACIK	80	RVUE	0	
770 ± 2		[9] HEYN	80	RVUE		Pion form factor
769 5 ± 0.7		[6,8] LANG	79	RVUE	0	
770. ± 9		[8] ESTABROOKS	74	RVUE	0	17 $\pi^- p \to \pi^+ \pi^- n$

WEIGHTED AVERAGE
7717 ± 12 (Error scaled by 2 3)



ρ^0 mass (MeV)

[1] Mass errors enlarged by us to $\Gamma/N^{1/2}$ see the note with the $K^*(892)$ mass

[2] Phase shift analysis Systematic errors added corresponding to spread of different fits

[3] From fit of 3-parameter relativistic P-wave Breit-Wigner to total mass distribution Includes BATON 68 MILLER 67B ALFF-STEINBERGER 66 HAGOPIAN 66 HAGOPIAN 66B JACOBS 66B JAMES 66 WEST 66 BLIEDEN 65 and CARMONY 64

[4] From the Gounaris Sakurai parametrization of the pion form factor

[5] From fit of 3 parameter relativistic Breit Wigner to helicity zero part of P wave intensity CHABAUD 83 and BECKER 79 include data of GRAYER 74

[6] From pole extrapolation

[7] Includes MALAMUD 69 ARMENISE 68 BACON 67 HUWE 67 MILLER 67B ALFF STEINBERGER 66 HAGOPIAN 66 HAGOPIAN 66B JACOBS 66B JAMES 66 WEST 66 GOLDHABER 64 ABOLINS 63

[8] From phase shift analysis of GRAYER 74 data

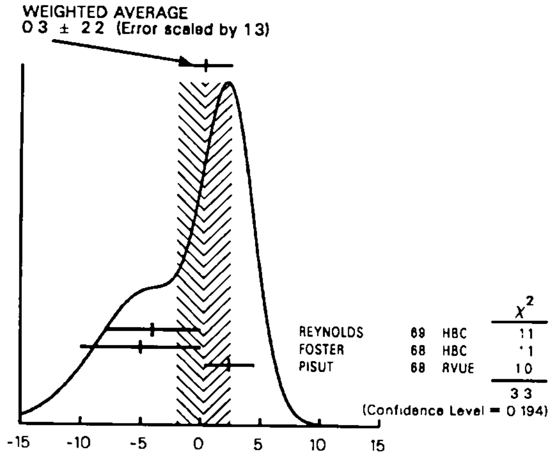
[9] HEYN 80 includes all spacelike and timelike F_{π} values until 1978

$\rho^0 - \rho^{\pm}$ MASS DIFFERENCE

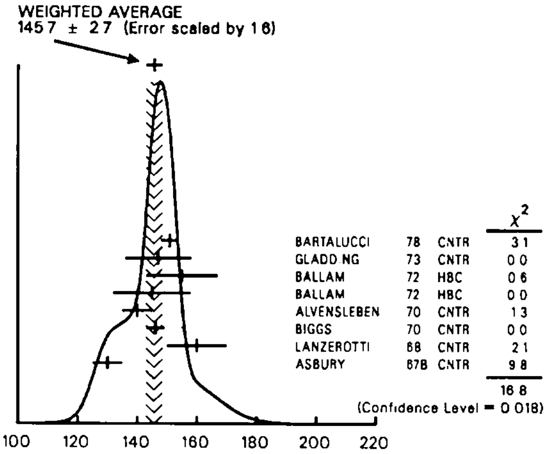
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.3 ± 2.2 OUR AVERAGE		Error includes scale factor of 1 3				See the ideogram below
−4 0 ± 4 0	3000	[10] REYNOLDS	69	HBC	−0	2 26 $\pi^- p$
−5 ± 5	3600	[10] FOSTER	68	HBC	±0	0 0 $\bar{p}p$
2 4 ± 2 1	22950	[11] PISUT	68	RVUE		$\pi N \to \rho N$

[10] From quoted masses of charged and neutral modes

[11] Includes MALAMUD 69 ARMENISE 68 BATON 68 BACON 67 HUWE 67 MILLER 67B ALFF STEINBERGER 66 HAGOPIAN 66 HAGOPIAN 66B JACOBS 66B JAMES 66 WEST 66 BLIEDEN 65 CARMONY 64 GOLDHABER 64 ABOLINS 63



$\rho^0 - \rho^{\pm}$ mass difference (MeV)



$\rho(770)$ width neutral only photoproduced (MeV)

$\rho(770)$ RANGE PARAMETER

The range parameter R enters an energy dependent correction to the width of the form $(1 + q_r^2 R^2) / (1 + q^2 R^2)$ where q is the momentum of one of the pions in the $\pi\pi$ rest system. At resonance, $q = q_r$

VALUE (GeV^{-1})	DOCUMENT ID		TECN	CHG	COMMENT
$5.3^{+0.9}_{-0.7}$	CHABAUD	83	ASPK	0	17 $\pi^- p$ polarized

$\rho(770)$ WIDTH

We no longer list S-wave Breit-Wigner fits or data with high combinatorial background

CHARGED ONLY

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
149.1 ± 2.9 OUR FIT						
149.1 ± 2.9 OUR AVERAGE						
155 ± 11	2935	[12] CAPRARO	87	SPEC	−	200 $\pi^- Cu \to \pi^- \pi^0 Cu$
154 ± 20	967	[12] CAPRARO	87	SPEC	−	200 $\pi^- Pb \to \pi^- \pi^0 Pb$
150. ± 5		HUSTON	86	SPEC	+	202 $\pi^+ A \to \pi^+ \pi^0 A$
146 ± 12	6500	[13] BYERLY	73	OSPK	−	5 $\pi^- p$
148.2 ± 4 1	9650	[14] PISUT	68	RVUE	−	1 7-3 2 $\pi^- p$ t <1 0
146 ± 13	900	EISNER	67	HBC	−	4 2 $\pi^- p$, t <1 0

NEUTRAL ONLY, PHOTOPRODUCED

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
145.7 ± 2.7 OUR AVERAGE	Error includes scale factor of 1 6 See the ideogram below					
150 9 ± 3 0		BARTALUCCI	78	CNTR	0	$\gamma p \to e^+ e^- p$
147 ± 11		GLADDING	73	CNTR	0	2 9-4 7 γp
155.0 ± 12 0	2430	BALLAM	72	HBC	0	4 7 γp
145 0 ± 13.0	1930	BALLAM	72	HBC	0	2 8 γp
140.0 ± 5 0		ALVENSLEBEN	70	CNTR	0	γ A, t <0 01
146 1 ± 2 9	140k	BIGGS	70	CNTR	0	<4 1 $\gamma C \to \pi^+ \pi^- C$
160 0 ± 10 0		LANZEROTTI	68	CNTR	0	γp
130 ± 5	4000	ASBURY	67B	CNTR	0	γ + Pb

NEUTRAL ONLY, OTHER REACTIONS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
153.3 ± 1.5 OUR FIT						
153.3 ± 1.5 OUR AVERAGE						
150 5 ± 3 0		[15] BARKOV	85	OLYA	0	π form factor
$160\ 0^{+4\ 1}_{-4\ 0}$		[16] CHABAUD	83	ASPK	0	17 $\pi^- p$ polarized
148 0 ± 6 0		[17,18] BOHACIK	80	RVUE	0	
152 0 ± 9.0		[13] WICKLUND	78	ASPK	0	3 4 6 $\pi^{\pm} pN$
154.0 ± 2 0	76000	DEUTSCH	76	HBC	0	16 $\pi^+ p$
157 0 ± 8 0	6800	RATCLIFF	72	ASPK	0	15 $\pi^- p$, t <0 3
143.0 ± 8 0	1700	REYNOLDS	69	HBC	0	2 26 $\pi^- p$
• • • We do not use the following data for averages fits limits etc • • •						
155 ± 1		[19] HEYN	80	RVUE	0	π form factor
148 0 ± 1 3		[17,18] LANG	79	RVUE	0	
146 ± 14	4100	ENGLER	74	DBC	0	6 $\pi^+ n \to \pi^+ \pi^- p$
143 ± 13		[18] ESTABROOKS	74	RVUE	0	17 $\pi^- p \to \pi^+ \pi^- n$
160 0 ± 10 0	32000	[17] PROTOPOP	73	HBC	0	7 1 $\pi^+ p$ t <0 4
145 0 ± 12 0	2250	[12] HYAMS	68	OSPK	0	11 2 $\pi^- p$
163 0 ± 15 0	13300	[20] PISUT	68	RVUE	0	1 7-3 2 $\pi^- p$ t <1 0

[12] Width errors enlarged by us to $4\Gamma/N^{1/2}$, see the note with the $K^*(892)$ mass

[13] Phase shift analysis Systematic errors added corresponding to spread of different fits

[14] From fit of 3 parameter relativistic P-wave Breit Wigner to total mass distribution Includes BATON 68, MILLER 67B, ALFF-STEINBERGER 66 HAGOPIAN 66 HAGOPIAN 66B, JACOBS 66B JAMES 66, WEST 66 BLIEDEN 65 and CARMONY 64

[15] From the Gounaris-Sakurai parametrization of the pion form factor

[16] From fit of 3-parameter relativistic Breit-Wigner to helicity-zero part of P wave intensity CHABAUD 83 and BECKER 79 include data of GRAYER 74

[17] From pole extrapolation

[18] From phase shift analysis of GRAYER 74 data

[19] HEYN 80 includes all spacelike and timelike F_π values until 1978

[20] Includes MALAMUD 69 ARMENISE 68 BACON 67, HUWE 67 MILLER 67B, ALFF-STEINBERGER 66 HAGOPIAN 66, HAGOPIAN 66B JACOBS 66B JAMES 66 WEST 66 GOLDHABER 64 ABOLINS 63

$\rho(770)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	$\rho(770) \to 2\pi$	$\simeq 100 \times 10^{-2}$	
Γ_2	$\rho(770)^{\pm} \to \pi^{\pm}\pi^0$	$\simeq 100 \times 10^{-2}$	
Γ_3	$\rho(770)^0 \to \pi^+\pi^-$	$\simeq 100 \times 10^{-2}$	
Γ_4	$\rho(770)^0 \to \pi^+\pi^-\pi^+\pi^-$		
Γ_5	$\rho(770)^{\pm} \to \pi^{\pm}\gamma$	$(4\ 5\ \pm 0\ 5\ ) \times 10^{-4}$	2 2
Γ_6	$\rho(770)^0 \to e^+e^-$	$(4\ 42 \pm 0\ 21) \times 10^{-5}$	
Γ_7	$\rho(770)^{\pm} \to \pi^{\pm}\eta$		
Γ_8	$\rho(770)^0 \to \mu^+\mu^-$	$(6\ 7\ ^{+1\ 1}_{-1\ 4}) \times 10^{-5}$	
Γ_9	$\rho(770)^0 \to \pi^+\pi^-\pi^0$		
Γ_{10}	$\rho(770)^0 \to \eta\gamma$		
Γ_{11}	$\rho(770)^{\pm} \to \pi^{\pm}\pi^+\pi^-\pi^0$		
Γ_{12}	$\rho(770)^0 \to \pi^+\pi^-\pi^0\pi^0$		

CONSTRAINED FIT INFORMATION

An overall fit to the total width and a partial width uses 9 measurements and one constraint to determine 3 parameters. The overall fit has a $\chi^2 = 10.2$ for 7 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle \delta p_i \delta p_j \rangle / (\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i, including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$. The fit constrains the x_i in this array to sum to one.

x_5	100	
Γ	18	−18
	x_2	x_5

		Rate (MeV)	Scale
Γ_2	$\rho(770)^{\pm} \to \pi^{\pm}\pi^0$	149.1 ± 2.9	
Γ_5	$\rho(770)^{\pm} \to \pi^{\pm}\gamma$	0.068 ± 0.007	2.3

CONSTRAINED FIT INFORMATION

An overall fit to the total width, a partial width, and a branching ratio uses 11 measurements and one constraint to determine 4 parameters. The overall fit has a $\chi^2 = 8.1$ for 8 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle \delta p_i \delta p_j \rangle / (\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i, including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$. The fit constrains the x_i in this array to sum to one.

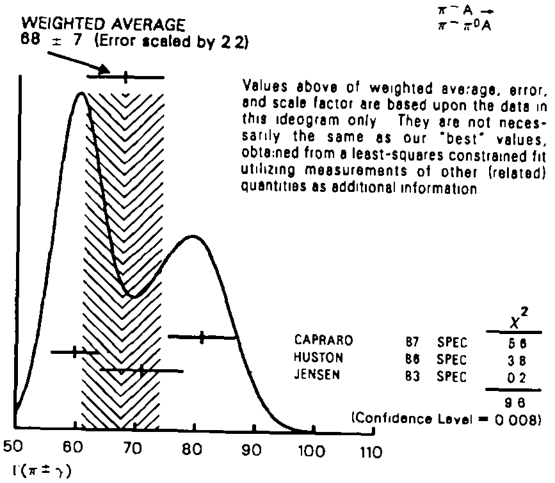
x_6	−17		
x_8	−99	0	
Γ	3	−20	0
	x_3	x_6	x_8

		Rate (MeV)
Γ_3	$\rho(770)^0 \to \pi^+\pi^-$	153.3 ± 1.5
Γ_6	$\rho(770)^0 \to e^+e^-$	0.00677 ± 0.00032
Γ_8	$\rho(770)^0 \to \mu^+\mu^-$	$0.0102^{+0.0017}_{-0.0021}$

$\rho(770)$ PARTIAL WIDTHS

$\Gamma(\pi^{\pm}\gamma)$ Γ_5

VALUE (keV)		DOCUMENT ID		TECN	CHG	COMMENT
68 ± 7	**OUR FIT** Error includes scale factor of 2.3					
68 ± 7	**OUR AVERAGE** Error includes scale factor of 2.2. See the ideogram below.					
81.0 ± 4.0 ± 4.0		CAPRARO	87	SPEC	−	200 $\pi^- A \to \pi^-\pi^0 A$
59.8 ± 4.0		HUSTON	86	SPEC	+	202 $\pi^+ A \to \pi^+\pi^0 A$
71.0 ± 7.0		JENSEN	83	SPEC	−	156–260 $\pi^- A \to \pi^-\pi^0 A$



$\Gamma(e^+e^-)$ Γ_6

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
6.77 ± 0.32 OUR FIT				
6.77 ± 0.10 ± 0.30	BARKOV	85	OLYA	e^+e^-

$\rho(770)$ BRANCHING RATIOS

$\Gamma(\rho(770)^{\pm} \to \pi^{\pm}\pi^+\pi^-\pi^0)/\Gamma(\rho(770) \to 2\pi)$ Γ_{11}/Γ_1

VALUE (units 10^{-4})	DOCUMENT ID		TECN	CHG	COMMENT
<20	FERBEL	66	HBC	±	$\pi^{\pm} p$ above 2.5
••• We do not use the following data for averages, fits, limits, etc. •••					
35 ± 40	JAMES	66	HBC	+	2.1 $\pi^+ p$

$\Gamma(\rho(770)^0 \to \pi^+\pi^-\pi^+\pi^-)/\Gamma(\rho(770) \to 2\pi)$ Γ_4/Γ_1

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<15	90	ERBE	69	HBC	0	2.5–5.8 γp
••• We do not use the following data for averages, fits, limits, etc. •••						
<20		CHUNG	68	HBC	0	3.2,4.2 $\pi^- p$
<20	90	HUSON	68	HLBC	0	16.0 $\pi^- p$
<80		JAMES	66	HBC	0	2.1 $\pi^+ p$

$\Gamma(\rho(770)^0 \to e^+e^-)/\Gamma(\rho(770) \to 2\pi)$ Γ_6/Γ_1

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
••• We do not use the following data for averages, fits, limits, etc. •••				
0.41 ± 0.05	BENAKSAS	72	OSPK	e^+e^-

$\Gamma(\rho(770)^{\pm} \to \pi^{\pm}\eta)/\Gamma(\rho(770) \to 2\pi)$ Γ_7/Γ_1

VALUE (units 10^{-4})	DOCUMENT ID		TECN	CHG	COMMENT
<80	FERBEL	66	HBC	±	$\pi^{\pm} p$ above 2.5

$\Gamma(\mu^+\mu^-)/\Gamma(\pi^+\pi^-)$ Γ_8/Γ_3

VALUE (units 10^{-4})		DOCUMENT ID		TECN	COMMENT
$0.67^{+0.11}_{-0.14}$	**OUR FIT**				
$0.67^{+0.10}_{-0.13}$	**OUR AVERAGE**				
$0.82^{+0.16}_{-0.36}$		[21] ROTHWELL	69	CNTR	Photoproduction
0.56 ± 0.15		[22] WEHMANN	69	OSPK	12 π^-C, Fe
$0.97^{+0.31}_{-0.33}$		[23] HYAMS	67	OSPK	11 π^-Li, H

[21] Possibly large ρ-ω interference leads us to increase the minus error.
[22] Result contains 11 ± 11% correction using SU(3) for central value. The error on the correction takes account of possible ρ-ω interference and the upper limit agrees with the upper limit of $\omega \to \mu^+\mu^-$ from this experiment.
[23] HYAMS 67's mass resolution is 20 MeV. The ω region was excluded.

$\Gamma(\rho(770)^0 \to \pi^+\pi^-\pi^0)/\Gamma(\rho(770) \to 2\pi)$ Γ_9/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
••• We do not use the following data for averages, fits, limits, etc. •••						
~0.01		BRAMON	86	RVUE	0	$J/\psi \to \omega\pi^0$
<0.01	84	[24] ABRAMS	71	HBC	0	3.7 $\pi^+ p$

[24] Model dependent, assumes $I = 1, 2$, or 3 for the 3π system.

$\Gamma(\eta\gamma)/\Gamma_{total}$ Γ_{10}/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	CHG	COMMENT
••• We do not use the following data for averages, fits, limits, etc. •••					
3.6 ± 0.9	[25] ANDREWS	77	CNTR	0	6.7–10 γ Cu
5.4 ± 1.1	[26] ANDREWS	77	CNTR	0	6.7–10 γ Cu

[25] Solution corresponding to constructive ω-ρ interference. The quark model predicts a relative decay phase of zero.
[26] Solution corresponding to destructive ω-ρ interference.

$\Gamma(\pi^+\pi^-\pi^0\pi^0)/\Gamma_{total}$ Γ_{12}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	CHG	COMMENT
••• We do not use the following data for averages, fits, limits, etc. •••						
<2	90	KURDADZE	83D	OLYA	0	$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$

$\rho(770)$ REFERENCES

CAPRARO	87	NP B288 659	+Levy+	(CLER, FRAS, MILA, PISA, LCGT, TRST+)
BRAMON	86	PL 8173 97	+Casulleras	(BARC)
HUSTON	86	PR 33 3199	+Berg, Collick, Jonckheere+	(ROCH, FNAL, MINN)
BARKOV	85	NP B256 365	+Chilingarov, Eidelman, Khazin, Lelchuk+	(NOVO)
CHABAUD	83	NP B223 1	+Gorlich, Cerrada+	(CERN, CRAC, MPIM)
JENSEN	83	PR D27 26	+Berg, Biel, Collick+	(ROCH, FNAL, MINN)
KURDADZE	83D	JETPL 43 643	+Lelchuk, Pakhtusova, Sidorov, Skrinskii+	(NOVO)
		Translated from ZETFP 43 497		
BOHACIK	80	PR D21 1342	+Kuhnelt	(SLOV, WIEN)
HEYN	80	ZPHY C7 169	+Lang	(GRAZ)
BECKER	79	NP B151 46	+Blanar, Blum+	(MPIM, CERN, ZEEM, CRAC)
LANG	79	PR D19 956	+Mas-Parareda	(GRAZ)
BARTALUCCI	78	NC 44A 587	+Basini, Bertolucci+	(DESY, FRAS)

WICKLUND 78 PR D17 1197 +Ayres Diebold Greene Kramer Pawlicki (ANL)
ANDREWS 77 PRL 38 198 +Fukushima Harvey Lobkowicz May+ (ROCH)
DEUTSCH 76 NP B103 426 Deutschmann+ (AACH BERL BONN CERN+)
ENGLER 74 PR D10 2070 +Kraemer Toaff Weisser Diaz+ (CMU CASE)
ESTABROOKS 74 NP B79 301 +Martin (DURH)
GRAYER 74 NP B75 189 +Hyams Blum Dietl+ (CERN MPIM)
BYERLY 73 PR D7 637 +Anthony Coffin Meanley Meyer Rice+ (MICH)
GLADDING 73 PR D8 3721 +Russell Tannenbaum Weiss Thomson (HARV)
PROTOPOP 73 PR D7 1280 Protopopescu Garnjost Galtieri Flatte+ (LBL)
BALLAM 72 PR D5 545 +Chadwick Bingham Milburn+ (SLAC LBL TUFT)
BENAKSAS 72 PL 39B 289 +Cosme Jean-Marie Jullian Laplanche+ (ORSA)
JACOBS 72 PR D6 1291 (SACL)
RATCLIFF 72 PL 38B 345 +Bulos Carnegie Kluge Leith Lynch+ (SLAC)
ABRAMS 71 PR D4 653 +Barnham Butler Coyne Goldhaber Hall+ (LBL)
ALVENSLEBEN 70 PRL 24 786 +Becker Bertram Chen Cohen (DESY)
BIGGS 70 PRL 24 1197 +Braben Clifft Gabathuler Kitching+ (DARE)
ERBE 69 PR 188 2060 (German Bubble Chamber Collab.)
MALAMUD 69 Argonne Conf 93 +Schlein (UCLA)
REYNOLDS 69 PR 184 1424 +Albright Bradley Brucker Harms+ (FSU)
ROTHWELL 69 PRL 23 1521 +Chase Earles Gettner Glass Weinstein+(NEAS)
WEHMANN 69 PR 178 2095 + (HARV CASE SLAC CORN MCGI)
ARMENISE 68 NC 54A 999 +Ghidini Forino+ (BARI BGNA FIRZ ORSA)
BATON 68 PR 176 1574 +Laurens (SACL)
CHUNG 68 PR 165 1491 +Dahl Kirz Miller (LRL)
FOSTER 68 NP B6 107 +Gavillet Labrosse Montanet+ (CERN CDEF)
HUSON 68 PL 28B 208 +Lubatti Six Veillet+ (ORSA MILA UCLA)
HYAMS 68 NP B7 1 +Koch Potter Wilson VonLindern+ (CERN MPIM)
LANZEROTTI 68 PR 166 1365 +Blumenthal Ehn Faissler+ (HARV)
PISUT 68 NP B6 325 +Roos (CERN)
ASBURY 67B PRL 19 865 +Becker Bertram Joos Jordan+ (DESY COLU)
BACON 67 PR 157 1263 +Fickinger Hill Hopkins Robinson+ (BNL)
EISNER 67 PR 164 1699 +Johnson Klein Peters Sahni Yen+ (PURD)
HUWE 67 PL 24B 252 +Marquit Oppenheimer Schultz Wilson (COLU)
HYAMS 67 PL 24B 634 +Koch Pellett Potter VonLindern+ (CERN MPIM)
MILLER 67B PR 153 1423 +Gutay Johnson Loeffler+ (PURD)
ALFF 66 PR 145 1072 Alff Steinberger Berley+ (COLU RUTG)
FERBEL 66 PL 21 111 (ROCH)
HAGOPIAN 66 PR 145 1128 +Selove Alitti Baton+ (PENN SACL)
HAGOPIAN 66B PR 152 1183 +Pan (PENN LRL)
JACOBS 66B UCRL 16877 (LRL)
JAMES 66 PR 142 896 +Kraybill (YALE BNL)
WEST 66 PR 149 1089 +Boyd Erwin Walker (WISC)
BLIEDEN 65 PL 19 444 (CERN Missing Mass Spectrometer Collab.)
CARMONY 64 PRL 12 254 +Lander Rindfleisch Xuong Yager (UCB)
GOLDHABER 64 PRL 12 336 +Brown Kadyk Shen+ (LRL UCB)
ABOLINS 63 PRL 11 381 +Lander Mehlhop Nguyen Yager (UCSD)

OTHER RELATED PAPERS

ERKAL 85 ZPHY C29 485 +Olsson (WISC)
RYBICKI 85 ZPHY C28 65 +Sakrejda (CRAC)
KURDADZE 83 JETPL 37 733 +Leichuk Pakhtusova+ (NOVO)
Translated from ZETFP 37 613
ALEKSEEV 82 JETP 55 591 +Kartamyshev Makarin+ (KIAE)
Translated from ZETF 82 1007
BERG 80 PRL 44 706 +Chandlee Biel+ (ROCH FNAL MINN)
BALTAY 78B PR D17 62 +Cautis Cohen Csorna+ (COLU BING)
QUENZER 78 PL 76B 512 +Ribes Rumpf Bertrand Bizot Chase+ (LALO)
MONTONEN 75 LNC 12 627 +Roos Tornqvist (HELS)
CARROLL 74B PR D10 1430 +Matthews Walker+ (SLAC DUKE WISC TNTO)
HABER 74 PR D10 1387 +Hodous Hulsizer Kistiakowsky Levy+ (MIT)
NORDBERG 74 PL 51B 106 +Abramson Andrews Harvey+ (CORN ROCH)
SPITAL 74 PR D9 126 +Yennie (CORN)
CHARLESW 73 NP B65 253 Charlesworth Emms Bell+ (RHEL BIRM DURH)
BAILLON 72 PL 38B 555 +Carnegie Kluge Leith Lynch Ratcliff+ (SLAC)
BASDEVANT 72 PL 41B 178 +Froggatt Petersen (CERN)
DRIVER 72 NP B38 1 +Heinloth Hohne Hofmann Ratnje+(DESY HAMB)
EISENBERG 72 PR D5 15 +Ballam Dagan+ (REHO SLAC TELA)
GRAYER 72 NP B50 29 +Hyams Jones Wellhammer Blum+(CERN MPIM)
GRAYER 72B Phil Conf 5 +Hyams Jones Schlein+ (CERN MPIM)
TAKAHASHI 72 PR D6 1266 +Barish+ (TOHO PENN NDAM ANL)
BLOODWO 71 NP B35 133 Bloodworth Jackson Prentice Yoon (TNTO)
DEERY 71 PR D3 635 +Biswas Cason Groves Johnson+ (NDAM)
BINGHAM 70 PRL 24 955 +Fretter Moffeit Ballam+ (LRL SLAC TUFT)
GALLOWAY 70 PR D1 3077 +Mott Alyea Lee Martin Prickett (IND)
AUGUSTIN 69B LNC 2 214 +Lefrancois Lehmann Marin+ (ORSA)
AUGUSTIN 69C PL 28B 508 +Bizot Buon Haissinski Lalanne+ (ORSA)
HAISSINSKI 69 Argonne Conf 373 (ORSA)
JUHALA 69 PR 184 1461 +Leacock Rhode Kopelman Libby+(ISU COLO)
MILLER 69 PR 178 2061 +Lichtman Willmann (PURD)
MOTT 69 PR 177 1966 +Ammar Davis Kropac Slate+ (NWES ANL)
ROOS 69 NP B10 563 +Pisut (CERN CMNS)
SCHARENG 69 Argonne Conf 306 Scharenguivel (PURD)
BLECHSCH 68 NC 53A 1045 Blechschmidt Dowd Elsner+ (DESY MCHS)
Also 67 NC 52A 1348 Blechschmidt
BOESEBECK 68 NP B4 501 +Deutschmann+ (AACH BERL CERN)
DONALD 68C NP B6 174 +Edwards Frodesen Bettini+ (LIVP OSLO PADO)
JOHNSON 68 PR 176 1651 +Poirier Biswas Gutay+ (NDAM PURD SLAC)
JONES 68 PR 166 1405 +Bleuler Caldwell Elsner Harting+ (CERN)
KEY 68 PR 166 1430 +Prentice Cooper Manner+ (TNTO ANL WISC)
LAMSA 68 PR 166 1395 +Cason Biswas Derado Groves+ (NDAM)
MARATECK 68 PRL 21 1613 +Hagopian+ (PENN LRL COLO PURD TNTO+)
ALLES 67B NC 50A 776 Alles Borelli French Frisk+ (CERN BONN)
BANNER 67 PL 25B 300 +Fayoux Hamel Zsembery Cheze+(SACL CAEN)
BARLOW 67 NC 50A 701 +Lillestol Montanet+ (CERN CDEF IRAD LIVP)
BATON 67 PL 25B 419 +Laurens Reignier (SACL)
Also 67B NP B3 349 Baton Laurens Reignier (SACL)
CLEAR 67 NC 49A 399 +Johnston Cooper Manner+ (TNTO ANL WISC)
DANYSZ 67B NC 51A 801 +French Simak (CERN)
FRENCH 67 NC 52A 438 +Kinson McDonald Riddiford+ (CERN BIRM)
POIRIER 67 PR 163 1462 +Biswas Cason Derado Kenney+ (NDAM PENN)
ACCENSI 66 PL 20 557 +Alles Borelli French Frisk+ (CERN)
BALTAY 66B PR 145 1103 +Franzini Lutjens Severiens Tycko+ (COLU)
CAMBRIDGE 66 PR 146 994 (Cambridge Bubble Chamber Collab.)
CASON 66 PR 148 1282 (WISC)
DEUTSCH 66 PL 20 82 Deutschmann Steinberg+ (AACH BERL CERN)
ALYEA 65 PL 15 82 +Crittenden Martin Rhode+ (IND)
ARMENISE 65 NC 37 361 (SACL ORSA BARI BGNA)
CLARK 65 PR 139B 1556 +Christenson Cronin Turlay (PRIN)
GUTAY 65 NC 39 381 +Lannutti Tull (FSU)
ZDANIS 65 PRL 14 721 +Madansky Kraemer+ (JHU BNL)
BONDAR 64 NC 31 729 + (AACH BIRM BONN DESY LOIC MPIM)
GUIRAGOS 63 PRL 11 85 Guiragossian (LRL)
SACLAY 63 Siena Conf 1 239 (SACL ORSA BARI BGNA)
KENNEY 62 PR 126 736 +Shephard Gall (KNTY)
SAMIOS 62 PRL 9 139 +Bachman Lea+ (BNL CUNY COLU KNTY)
XUONG 62 PR 128 1849 +Lynch (LRL)
ANDERSON 61 PRL 6 365 +Bang Burke Carmony Schmitz (LRL)
ERWIN 61 PRL 6 628 +March Walker West (WISC)

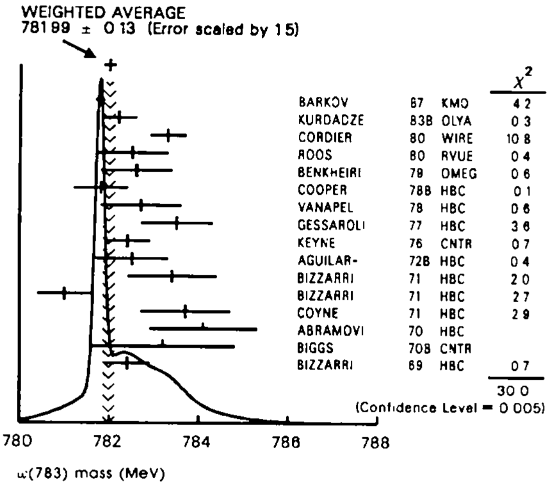
$\omega(783)$

$I^G(J^{PC}) = 0^-(1^{--})$

$\omega(783)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
781.99 ± 0.13 OUR AVERAGE		Error includes scale factor of 1.5. See the ideogram below.		
781.78 ± 0.10		BARKOV 87	KMD	$e^+e^- \to \pi^+\pi^-\pi^0$
782.2 ± 0.4		KURDADZE 83B	OLYA	e^+e^-
783.3 ± 0.4		CORDIER 80	WIRE	$e^+e^- \to \pi^+\pi^-\pi^0$
782.5 ± 0.8	33260	ROOS 80	RVUE	0.0–3.6 $\bar{p}p$
782.6 ± 0.8	3000	BENKHEIRI 79	OMEG	9–12 $\pi^\pm p$
781.8 ± 0.6	1430	COOPER 78B	HBC	0.7–0.8 $\bar{p}p \to 5\pi$
782.7 ± 0.9	535	VANAPEL 78	HBC	7.2 $\bar{p}p \to \bar{p}p\omega$
783.5 ± 0.8	2100	GESSAROLI 77	HBC	11 $\pi^-p \to \omega\pi$
782.4 ± 0.5	7000	[1] KEYNE 76	CNTR	$\pi^-p \to \omega n$
782.5 ± 0.8	418	AGUILAR- 72B	HBC	3.9,4.6 K^-p
783.4 ± 1.0	248	BIZZARRI 71	HBC	0.0 $\bar{p}p \to K^+K^-\omega$
781.0 ± 0.6	510	BIZZARRI 71	HBC	0.0 $\bar{p}p \to K_1K_1\omega$
783.7 ± 1.0		[2] COYNE 71	HBC	3.7 π^+p
784.1 ± 1.2	750	ABRAMOVI 70	HBC	3.9 π^-p
783.2 ± 1.6		[3] BIGGS 70B	CNTR	<4.1 $\gamma C \to \pi^+\pi^-C$
782.4 ± 0.5	2400	BIZZARRI 69	HBC	0.0 $\bar{p}p$

[1] Observed by threshold crossing technique. Mass resolution = 4.8 MeV FWHM.
[2] From best-resolution sample of COYNE 71.
[3] From $\omega\rho$ interference in the $\pi^+\pi^-$ mass spectrum assuming ω width 12.6 MeV.



$\omega(783)$ WIDTH

VALUE (MeV)		EVTS	DOCUMENT ID	TECN	COMMENT
8.45 ± 0.09 OUR AVERAGE					
8.4 ± 0.1			[4] AULCHENKO 87	SPEC	$e^+e^- \to \pi^+\pi^-\pi^0$
8.30 ± 0.40			BARKOV 87	KMD	$e^+e^- \to \pi^+\pi^-\pi^0$
9.8 ± 0.9			KURDADZE 83B	OLYA	e^+e^-
9.0 ± 0.8			CORDIER 80	WIRE	$e^+e^- \to \pi^+\pi^-\pi^0$
9.1 ± 0.8			BENAKSAS 72B	OSPK	e^+e^-
10.5 ± 1.5			BORENSTEIN 72	HBC	2.18 K^-p
7.70 ± 0.9	± 1.15	940	BROWN 72	MMS	2.5 $\pi^-p \to n$ MM
10.3 ± 1.4		510	BIZZARRI 71	HBC	0.0 $\bar{p}p \to K_1K_1\omega$
9.5 ± 1.0		4270	COYNE 71	HBC	3.7 π^+p
• • • We do not use the following data for averages, fits, limits, etc. • • •					
12.0 ± 2.0		1430	COOPER 78B	HBC	0.7–0.8 $\bar{p}p \to 5\pi$
9.4 ± 2.5		2100	GESSAROLI 77	HBC	11 $\pi^-p \to \omega\pi$
10.22 ± 0.43		20000	[5] KEYNE 76	CNTR	$\pi^-p \to \omega n$
13.3 ± 2		418	AGUILAR- 72B	HBC	3.9,4.6 K^-p
12.8 ± 3.0		248	BIZZARRI 71	HBC	0.0 $\bar{p}p \to K^+K^-\omega$

[4] Relativistic Breit Wigner includes radiative corrections.
[5] Observed by threshold crossing technique. Mass resolution = 4.8 MeV FWHM.

ω(783) DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	$\omega(783) \to \pi^+\pi^-\pi^0$	$(89.3 \pm 0.6) \times 10^{-2}$	1.1
Γ_2	$\omega(783) \to \pi^+\pi^-$	$(1.70^{+0.28}_{-0.26}) \times 10^{-2}$	1.3
Γ_3	$\omega(783) \to \pi^0\gamma$	$(8.0 \pm 0.9) \times 10^{-2}$	
Γ_4	$\omega(783) \to$ neutrals (excluding $\pi^0\gamma$)	$(10 \ ^{+11}_{-6}) \times 10^{-3}$	
Γ_5	$\omega(783) \to \pi^+\pi^-\gamma$	$< 4 \times 10^{-2}$	
Γ_6	$\omega(783) \to \pi^0\pi^0\gamma$	$< 8 \times 10^{-3}$	
Γ_7	$\omega(783) \to \eta\gamma$	$(8 \pm 40) \times 10^{-4}$	
Γ_8	$\omega(783) \to e^+e^-$	$(7.05 \pm 0.25) \times 10^{-5}$	1.2
Γ_9	$\omega(783) \to \mu^+\mu^-$	$< 2 \times 10^{-4}$	
Γ_{10}	$\omega(783) \to \eta\pi^0$		
Γ_{11}	$\omega(783) \to 3\gamma$		
Γ_{12}	$\omega(783) \to \pi^0\mu^+\mu^-$	$(9.6 \pm 2.3) \times 10^{-5}$	
Γ_{13}	$\omega(783) \to \pi^+\pi^-\pi^0\pi^0$		

CONSTRAINED FIT INFORMATION

An overall fit to 6 branching ratios uses 23 measurements and one constraint to determine 4 parameters. The overall fit has a $\chi^2 = 16.4$ for 20 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i \delta x_j\rangle/(\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

x_2	−39		
x_3	6	−3	
x_4	−54	0	−85
	x_1	x_2	x_3

ω(783) BRANCHING RATIOS

$\Gamma(\text{neutrals})/\Gamma(\pi^+\pi^-\pi^0)$ — $(\Gamma_3+\Gamma_4)/\Gamma_1$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.101 ± 0.007 OUR FIT					
0.105 ± 0.009 OUR AVERAGE					
0.15 ± 0.04	46	AGUILAR	72B	HBC	3.9,4.6 K^-p
0.10 ± 0.03	19	BARASH	67B	HBC	0.0 $\bar{p}p$
0.134 ± 0.026	850	DIGIUGNO	66B	CNTR	1.4 π^-p
0.097 ± 0.016	348	FLATTE	66	HBC	1.8 K^-p
0.06 $^{+0.05}_{-0.02}$		JAMES	66	HBC	2.1 π^+p
0.08 ± 0.03	35	KRAEMER	64	DBC	1.2 π^+d
0.11 ± 0.02	20	BUSCHBECK	63	HBC	1.5 K^-p

$\Gamma(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_2/Γ_1

See also $\Gamma(\pi^+\pi^-)/\Gamma_{total}$.

VALUE	DOCUMENT ID		TECN	COMMENT
0.0190 $^{+0.0032}_{-0.0029}$ OUR FIT Error includes scale factor of 1.3.				
0.026 $^{+0.005}_{-0.004}$ OUR AVERAGE				
0.021 $^{+0.028}_{-0.009}$	[6] RATCLIFF	72	ASPK	15 $\pi^-p \to n2\pi$
0.028 ± 0.006	BEHREND	71	ASPK	Photoproduction
0.022 $^{+0.009}_{-0.01}$	[7] ROOS	70	RVUE	

[6] Significant interference effect observed. NB of $\omega \to 3\pi$ comes from an extrapolation.
[7] ROOS 70 combines ABRAMOVICH 70 and BIZZARRI 70.

$\Gamma(\pi^0\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_3/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0.090 ± 0.010 OUR FIT				
0.090 ± 0.010 OUR AVERAGE				
0.084 ± 0.013	KEYNE	76	CNTR	$\pi^-p \to \omega n$
0.109 ± 0.025	BENAKSAS	72C	OSPK	e^+e^-
0.081 ± 0.020	BALDIN	71	HLBC	2.9 π^+p
0.13 ± 0.04	JACQUET	69B	HLBC	

$\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_5/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.05	90	FLATTE	66	HBC	1.8 K^-p
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.066	90	KALBFLEISCH	75	HBC	2.2 K^-p

$\Gamma(\pi^+\pi^-\pi^0\pi^0)/\Gamma_{total}$ — Γ_{13}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<2	90	KURDADZE	83D	OLYA	0	$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$

$\Gamma(\mu^+\mu^-)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_9/Γ_1

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<0.2		WILSON	69	OSPK	12 $\pi^-C \to$ Fe
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<1.7	74	FLATTE	66	HBC	1.8 K^-p
<1.2		BARBARO	65	HBC	2.7 K^-p

$\Gamma(\pi^0\pi^0\gamma)/\Gamma(\pi^0\gamma)$ — Γ_6/Γ_3

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.1		BARMIN	64	HLBC	1.3–2.8 π^-p
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.18	95	KEYNE	76	CNTR	$\pi^-p \to \omega n$
<0.15	90	BENAKSAS	72C	OSPK	e^+e^-
<0.14		BALDIN	71	HLBC	2.9 π^+p

$[\Gamma(\eta\gamma) + \Gamma(\eta\pi^0)]/\Gamma(\pi^+\pi^-\pi^0)$ — $(\Gamma_7+\Gamma_{10})/\Gamma_1$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.017	90	FLATTE	66	HBC	1.8 K^-p
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.045	95	JACQUET	69B	HLBC	

$\Gamma(\text{neutrals})/\Gamma(\text{charged})$ — $(\Gamma_3+\Gamma_4)/(\Gamma_1+\Gamma_2+\Gamma_5)$

VALUE	DOCUMENT ID		TECN	COMMENT
0.099 ± 0.007 OUR FIT				
0.124 ± 0.021	FELDMAN	67C	OSPK	1.2 π^-p

$\Gamma(\pi^0\pi^0\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_6/Γ_1

VALUE	CL%	DOCUMENT ID		TECN
<0.08	95	JACQUET	69B	HLBC

$\Gamma(\eta\gamma)/\Gamma(\pi^0\gamma)$ — Γ_7/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
0.010 ± 0.045	APEL	72B	OSPK	4–8 $\pi^-p \to n3\gamma$

$\Gamma(\pi^0\mu^+\mu^-)/\Gamma_{total}$ — Γ_{12}/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
0.96 ± 0.23	DZHELYADIN	81B	CNTR	25–33 $\pi^-p \to \omega n$

$\Gamma(e^+e^-)/\Gamma_{total}$ — Γ_8/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
0.705 ± 0.025 OUR AVERAGE Error includes scale factor of 1.2.					
0.72 ± 0.03		BARKOV	87	KMD	$e^+e^- \to \pi^+\pi^-\pi^0$
0.64 ± 0.04		KURDADZE	83B	OLYA	e^+e^-
0.675 ± 0.069		CORDIER	80	WIRE	$e^+e^- \to 3\pi$
0.83 ± 0.10		BENAKSAS	72B	OSPK	$e^+e^- \to 3\pi$
0.77 ± 0.06		[8] AUGUSTIN	69D	OSPK	$e^+e^- \to 2\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.65 ± 0.13	33	[9] ASTVACAT...	68	OSPK	Assume SU(3)+mixing

[8] Rescaled by us to correspond to ω width 8.4 MeV.
[9] Not resolved from ρ decay. Error statistical only.

$\Gamma(\text{neutrals})/\Gamma_{total}$ — $(\Gamma_3+\Gamma_4)/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.090 ± 0.006 OUR FIT					
0.079 ± 0.009 OUR AVERAGE					
0.073 ± 0.018	42	BASILE	72B	CNTR	1.67 π^-p
0.075 ± 0.025		BIZZARRI	71	HBC	0.0 $\bar{p}p$
0.079 ± 0.019		DEINET	69B	OSPK	1.5 π^-p
0.084 ± 0.015		BOLLINI	68C	CNTR	2.1 π^-p

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ — Γ_2/Γ

See also $\Gamma(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$.

VALUE	DOCUMENT ID		TECN	COMMENT
0.0170 $^{+0.0028}_{-0.0026}$ OUR FIT Error includes scale factor of 1.3.				
0.0150 $^{+0.0026}_{-0.0025}$ OUR AVERAGE Error includes scale factor of 1.1.				
0.023 ± 0.005	BARKOV	85	OLYA	e^+e^-
0.016 $^{+0.009}_{-0.007}$	QUENZER	78	CNTR	e^+e^-
0.0122 ± 0.0030	ALVENSLEBEN	71C	CNTR	Photoproduction
0.013 $^{+0.012}_{-0.009}$	MOFFEIT	71	HBC	2.8,4.7 γp
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.010 ± 0.001	[10] WICKLUND	78	ASPK	3,4,6 $\pi^\pm N$
0.0080 $^{+0.0028}_{-0.002}$	[11] BIGGS	70B	CNTR	4.2 $\gamma C \to \pi^+\pi^-C$

[10] From a model-dependent analysis assuming complete coherence.
[11] Re-evaluated under $\Gamma(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ by BEHREND 71 using more accurate ω → ρ photoproduction cross section ratio.

$\Gamma(\pi^0\pi^0\gamma)/\Gamma(\text{neutrals})$ — $\Gamma_6/(\Gamma_3+\Gamma_4)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
0 22 ± 0 07		[12] DAKIN	72	OSPK	1 4 $\pi^- p \to n$ MM
<0 19	90	DEINET	69B	OSPK	

[12] See $\Gamma(\pi^0\gamma)/\Gamma(\text{neutrals})$ See $\Gamma(\pi^0\gamma)/\Gamma(\text{neutrals})$

$\Gamma(\pi^0\gamma)/\Gamma(\text{neutrals})$ — $\Gamma_3/(\Gamma_3+\Gamma_4)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
0 78 ± 0 07		[13] DAKIN	72	OSPK	1 4 $\pi^- p \to n$ MM
>0 81	90	DEINET	69B	OSPK	

[13] Error statistical only Authors obtain good fit also assuming $\pi^0\gamma$ as the only neutral decay

$\Gamma(\eta\gamma)/\Gamma_{total}$ — Γ_7/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits, etc • • •				
$3\,0^{+2\,5}_{-1\,8}$	[14] ANDREWS	77	CNTR	6 7–10 γ Cu
29 0 ± 7 0	[15] ANDREWS	77	CNTR	6 7–10 γ Cu

[14] Solution corresponding to constructive ω-ρ interference The quark model predicts a relative decay phase of zero

[15] Solution corresponding to destructive ω ρ interference

$\Gamma(\pi^0\mu^+\mu^-)/\Gamma(\mu^+\mu^-)$ — Γ_{12}/Γ_9

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits, etc • • •					
1 2 ± 0 6	30	[16] DZHELYADIN	79	CNTR	25–33 $\pi^- p$

[16] Superseded by DZHELYADIN 81B result above

$\omega(783)$ REFERENCES

AULCHENKO 87 PL B186 432 +Dolinsky Druzhinin Dubrovin+ (NOVO)
BARKOV 87 JETPL 46 164 +Vasserman Vorobev Ivanov (NOVO)
Translated from ZETFP 46 132
BARKOV 85 NP B256 365 +Chilingarov Eidelman Khazin Leichuk+ (NOVO)
KURDADZE 83B JETPL 36 274 +Pakhtusova Sidorov+ (NOVO)
Translated from ZETFP 36 221
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Translated from ZETPF 43 497
DZHELYADIN 81B PL 102B 296 +Golovkin Konstantinov+ (SERP)
CORDIER 80 NP B172 13 +Delcourt Eschstruth Fulda+ (LALO)
ROOS 80 LNC 27 321 +Pellinen (HELS)
BENKHEIRI 79 NP B150 268 +Eisenstein+ (EPOL CERN CDEF LALO)
DZHELYADIN 79 PL 84B 143 +Golovkin Gritsuk+ (SERP)
COOPER 78B NP B146 1 +Gurtu+ (TATA CERN CDEF MADR)
QUENZER 78 PL 76B 512 +Ribes Rumpf Bertrand Bizot Chase+ (LALO)
VANAPEL 78 NP B133 245 VanApeldoorn Grundeman Harting+ (ZEEM)
WICKLUND 78 PR D17 1197 +Ayres Diebold Greene Kramer Pawlicki (ANL)
ANDREWS 77 PRL 38 198 +Fukushima Harvey Lobkowicz May+ (ROCH)
GESSAROLI 77 NP B126 382 + (BGNA FIRZ GENO MILA OXF PAVI)
KEYNE 76 PR D14 28 +Binnie Carr Debenham Garbutt+ (LOIC SHMP)
Also 73B PR D8 2789 Binnie Carr Debenham Duane+ (LOIC SHMP)
KALBFLEISCH 75 PR D11 987 +Strand Chapman (BNL MICH)
AGUILAR 72B PR D6 29 Aguilar Benitez Chung Eisner Samios (BNL)
APEL 72B PL 41B 234 +Auslander Muller Bertolucci+ (KARL PISA)
BASILE 72B Phil Conf 153 +Bollini Broglin Dalpiaz Frabetti+ (CERN)
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DAKIN 72 PR D6 2321 +Hauser Kreisler Mischke (PRIN)
RATCLIFF 72 PL 38B 345 +Bulos Carnegie Kluge Leith Lynch+ (SLAC)
ALVENSLEBEN 71C PRL 27 888 +Becker Busza Chen Cohen+ (DESY)
BALDIN 71 SJNP 13 758 +Yergakov Trebukhovsky Shishov (ITEP)
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BEHREND 71 PRL 27 61 +Lee Nordberg Wehmann+ (ROCH CORN FNAL)
BIZZARRI 71 NP B27 140 +Montanet Nilsson D Andlau+ (CERN CDEF)
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ABRAMOVI 70 NP B20 209 Abramovich Blumenfeld Bruyant+ (CERN)
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BIZZARRI 69 NP B14 169 +Foster Gavillet Montanet+ (CERN CDEF)
DEINET 69B PL 30B 426 +Menzione Muller Buniatov+ (KARL CERN)
JACQUET 69B NC 63A 743 +Nguyen Khac Haatuft Halsteinslid (EPOL BERG)
WILSON 69 Private Comm (HARV)
Also 69 PR 178 2095 Wehmann+ (HARV CASE SLAC CORN MCGI)
ASTVACAT 68 PL 27B 45 Astvacaturov Azimov Baldin+ (JINR MOSU)
BOLLINI 68C NC 56A 531 +Buhler Dalpiaz Massam+ (CERN BGNA STRB)
BARASH 67B PR 156 1399 +Kirsch Miller Tan (COLU)
FELDMAN 67C PR 159 1219 +Frati Gleeson Halpern Nussbaum+ (PENN)
DIGIUGNO 66B NC 44A 1272 +Peruzzi Troise+ (NAPL FRAS TRST)
FLATTE 66 PR 145 1050 +Huwe Murray Button Shafer Solmitz+ (LRL)
JAMES 66 PR 142 896 +Kraybill (YALE BNL)
BARBARO 65 PRL 14 279 Barbaro Galtieri Tripp (LRL)
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EMMS 75E NP B98 1 +Kinson Stacey Bell Dale+ (BIRM DURH RHEL)
ROOS 75 NP B97 165 (HELS)
ESTABROOKS 74B NP B81 70 +Hyams Jones Blum+ (CERN MPIM)
GREGORIO 74 NC 20A 437 (ICTP)
KRAMER 74 PRL 33 505 +Ayres Diebold Greene Pawlicki+ (ANL)
EISENBERG 72 PR D5 15 +Ballam Dagan+ (REHO SLAC TELA)
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BARDADIN 71 PR D4 2711 Bardadin Otwinowska Hofmokl+ (WARS)
BLOODWO 71 NP B35 133 Bloodworth Jackson Prentice Yoon (TNTO)
CHAPMAN 71 PR D3 38 +Fortney Fowler (DUKE)
FIELDS 71 PRL 27 1749 +Cooper Rhines Allison (ANL OXF)
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CASON 70 PR D1 851 +Andrews Biswas Groves Harrington+ (NDAM)
DANBURG 70 PR D2 2564 +Abolins Dahl Davies Hoch Kirz+ (LRL)
FLATTE 70 PR D1 1 (LRL)
GOLDHABER 70B Phil Conf 59 (LRL)
HAGOPIAN 70 PRL 25 1050 +Hagopian Bogart Selove (FSU PENN)
DANBURG 69 UCRL 19275 Thesis (LRL)
ERWIN 69 NP B9 364 +Walker Goshaw Weinberg (WISC PRIN VAND)
MILLER 69 PR 178 2061 +Lichtman Willmann (PURD)
STRUGALSKI 69B PL 29B 532 +Chuvilo Fenyves+ (WARS JINR BUDA)
KEY 68 PR 166 1430 +Prentice Cooper Manner+ (TNTO ANL WISC)
PISUT 68 NP B6 325 +Roos (CERN)
WEHMANN 68 PRL 20 748 +Engels+ (HARV CASE SLAC CORN MCGI)
HERTZBACH 67 PR 155 1461 +Kraemer Madanski Zdanis+ (JHU BNL)
BINNIE 65 PL 18 348 +Duane Jane Jones+ (LOIC MCHS)
MILLER 65B CU 237/Nevis 131 Thesis (COLU)
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ARMENTEROS 63 Siena Conf 1 296 +Edwards Jacobsen+ (CERN CDEF)
BARMIN 63 Siena Conf 1 207 +Dolgolenko Krestnikov+ (ITEP)
GELFAND 63 PRL 11 436 +Miller Nussbaum Ratau+ (COLU RUTG)
MURRAY 63 PL 7 358 +Ferro Luzzi Huwe Shafer Solmitz+ (LRL)
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ARMENTEROS 62 CERN Conf 90 +Budde+ (CERN CDEF EPOL)
STEVENSON 62 PR 125 687 +Alvarez Maglich Rosenfeld (LRL)
MAGLICH 61 PRL 7 178 +Alvarez Rosenfeld Stevenson (LRL)
PEVSNER 61 PRL 7 421 +Kraemer Nussbaum Richardson+ (JHU)
XUONG 61 PRL 7 327 +Lynch (LRL)

$\eta'(958)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Our latest mini-review on this particle can be found in the 1984 edition See also the mini-review under non-$q\bar{q}$ candidates

$\eta'(958)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
957.50 ± 0.24	**OUR AVERAGE**				
956 3 ± 1.0	143 ± 12	GIDAL	87	MRK2	$e^+e^- \to e^+e^-\eta\pi^+\pi^-$
957 46 ± 0.33		DUANE	74	MMS	$\pi^- p \to n$ MM
958.2 ± 0 5	1414	DANBURG	73	HBC	2 2 $K^- p \to \Lambda X^0$
958 ± 1	400	JACOBS	73	HBC	2 9 $K^- p \to \Lambda X^0$
956.1 ± 1 1	3415	BASILE	71	CNTR	1 6 $\pi^- p \to n X^0$
957 4 ± 1 4	535	BASILE	71	CNTR	1 6 $\pi^- p \to n X^0$
957 ± 1		RITTENBERG	69	HBC	1 7–2 7 $K^- p$

$\eta'(958)$ WIDTH

We include direct measurements of the $\eta'(958)$ total width and $\gamma\gamma$ partial width together with the measured branching ratios in the fit for the partial decay rates

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.207 ± 0.020	**OUR FIT**	Error includes scale factor of 1 3				
0.28 ± 0.10	1000	BINNIE	79	MMS	0	$\pi^- p \to n$ MM

$\eta'(958)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$\eta'(958) \to \pi^+\pi^-\eta$	(44 1 ± 1 6) $\times 10^{-2}$	
Γ_2	$\eta'(958) \to \pi^0\pi^0\eta$	(20 5 ± 1 3) $\times 10^{-2}$	S=1 2
Γ_3	$\eta'(958) \to \pi^+\pi^-\gamma$ (including $\rho^0\gamma$)		
Γ_4	$\eta'(958) \to \gamma\gamma$	(2.16 ± 0.16) $\times 10^{-2}$	S=1 4
Γ_5	$\eta'(958) \to \omega\gamma$	(2 99 ± 0 30) $\times 10^{-2}$	

Γ_6	$\eta'(958) \to 3\pi^0$	$(1\ 53 \pm 0\ 26) \times 10^{-3}$		S=1 1
Γ_7	$\eta'(958) \to \rho^0\gamma$	$(30.1\ \pm 1\ 4\ ) \times 10^{-2}$		
Γ_8	$\eta'(958) \to \pi^+\pi^- e^+ e^-$	< 6	$\times 10^{-3}$	
Γ_9	$\eta'(958) \to \pi^+\pi^-$	< 2	$\times 10^{-2}$	
Γ_{10}	$\eta'(958) \to \pi^+\pi^-\pi^0$	< 5	$\times 10^{-2}$	
Γ_{11}	$\eta'(958) \to \pi^+\pi^+\pi^-\pi^-$	< 1	$\times 10^{-2}$	
Γ_{12}	$\eta'(958) \to \pi^+\pi^+\pi^-\pi^-$ neutrals	< 1	$\times 10^{-2}$	CL=95%
Γ_{13}	$\eta'(958) \to \pi^+\pi^+\pi^-\pi^-\pi^0$	< 1	$\times 10^{-2}$	
Γ_{14}	$\eta'(958) \to 6\pi$	< 1	$\times 10^{-2}$	
Γ_{15}	$\eta'(958) \to \pi^0 e^+ e^-$	$< 1\ 3$	$\times 10^{-2}$	
Γ_{16}	$\eta'(958) \to \eta e^+ e^-$	$< 1\ 1$	$\times 10^{-2}$	
Γ_{17}	$\eta'(958) \to \pi^0\rho^0$	< 4	$\times 10^{-2}$	
Γ_{18}	$\eta'(958) \to \mu^+\mu^-\gamma$	$(1\ 06 \pm 0\ 27) \times 10^{-4}$		
Γ_{19}	$\eta'(958) \to \eta\mu^+\mu^-$	< 1.5	$\times 10^{-5}$	CL=90%
Γ_{20}	$\eta'(958) \to \pi^0\mu^+\mu^-$	< 6.0	$\times 10^{-5}$	CL=90%
Γ_{21}	$\eta'(958) \to 3\gamma$	$< 9\ 4$	$\times 10^{-5}$	
Γ_{22}	$\eta'(958) \to \pi^0\gamma\gamma$	$< 7\ 6$	$\times 10^{-4}$	
Γ_{23}	$\eta'(958) \to \pi^0\pi^0$	< 9.2	$\times 10^{-4}$	
Γ_{24}	$\eta'(958) \to 4\pi^0$	$< 4\ 7$	$\times 10^{-4}$	

CONSTRAINED FIT INFORMATION

An overall fit to the total width, a partial width, 2 combinations of partial widths obtained from integrated cross section, and 16 branching ratios uses 37 measurements and one constraint to determine 7 parameters The overall fit has a $\chi^2 = 27\ 5$ for 31 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta p_i\, \delta p_j\rangle/(\delta p_i\ \delta p_j)$, in percent, from the fit to parameters p_i, including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

x_2	57					
x_4	−18	23				
x_5	−22	32	7			
x_6	21	35	8	11		
x_7	53	−36	−14	27	−14	
Γ	39	−13	73	2	−4	24
	x_1	x_2	x_4	x_5	x_6	x_7

		Rate (MeV)	Scale
Γ_1	$\eta'(958) \to \pi^+\pi^-\eta$	0.091 ± 0 010	1 1
Γ_2	$\eta'(958) \to \pi^0\pi^0\eta$	0.042 ± 0 005	1 4
Γ_4	$\eta'(958) \to \gamma\gamma$	0 00447 ± 0.00029	1 1
Γ_5	$\eta'(958) \to \omega\gamma$	0 0062 ± 0.0009	1 2
Γ_6	$\eta'(958) \to 3\pi^0$	0 00032 ± 0.00006	1 1
Γ_7	$\eta'(958) \to \rho^0\gamma$	0 062 ± 0 006	1 3

$\eta'(958)$ PARTIAL WIDTHS

$\Gamma(\gamma\gamma)$ — Γ_4

VALUE (keV)	EVTS	DOCUMENT ID		TECN	COMMENT
4.47 ± 0.29 OUR FIT Error includes scale factor of 1 1					
4.7 ± 0.6 ± 0.9	143 ± 12	GIDAL	87	MRK2	$e^+e^- \to e^+e^-\eta\pi^+\pi^-$
• • • We do not use the following data for averages, fits, limits, etc • • •					
4 0 ± 0 9		BARTEL [1]	85E	JADE	$e^+e^- \to e^+e^- 2\gamma$

[1] Systematic error not evaluated

$\eta'(958)$ $\Gamma(\mathrm{i})\Gamma(\gamma\gamma)/\Gamma(\mathrm{total})$

This combination of a partial width with the partial width into $\gamma\gamma$ and with the total width is obtained from the integrated cross section into channel$_i$ in the $\gamma\gamma$ annihilation

$\Gamma(\gamma\gamma) \times \Gamma(\rho^0\gamma)/\Gamma_{total}$ — $\Gamma_4\Gamma_7/\Gamma$

VALUE (keV)	EVTS	DOCUMENT ID		TECN	COMMENT
1.35 ± 0.08 OUR FIT Error includes scale factor of 1 2					
1.32 ± 0.08 OUR AVERAGE Error includes scale factor of 1 2					
1 35 ± 0.09 ± 0.21		AIHARA	87	TPC	$e^+e^- \to e^+e^-\rho\gamma$
1 13 ± 0.04 ± 0.13	867 ± 30	ALBRECHT	87B	ARG	$e^+e^- \to e^+e^-\rho\gamma$
1.53 ± 0.09 ± 0.21		ALTHOFF	84E	TASS	$e^+e^- \to e^+e^-\rho\gamma$
1 14 ± 0.08 ± 0 11		BERGER	84B	PLUT	$e^+e^- \to e^+e^-\rho\gamma$
1 85 ± 0 31 ± 0 24	43	BEHREND	83B	CELL	$e^+e^- \to e^+e^-\rho\gamma$
1 73 ± 0 34 ± 0 35	95	JENNI	83	MRK2	$e^+e^- \to e^+e^-\rho\gamma$
1 49 ± 0.13 ± 0 027	213	BARTEL	82B	JADE	$e^+e^- \to e^+e^-\rho\gamma$

$\Gamma(\gamma\gamma) \times \Gamma(\pi^0\pi^0\eta)/\Gamma_{total}$ — $\Gamma_4\Gamma_2/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.91 ± 0.09 OUR FIT Error includes scale factor of 1 1				
1.03 ± 0.08 ± 0.11	ANTREASYAN	87	CBAL	$e^+e^- \to e^+e^-\eta\pi^0\pi^0$

$\eta'(958)$ α PARAMETER

$|\text{MATRIX ELEMENT}|^2 = (1 + \alpha y)^2 + cx^2$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.061 ± 0.012 OUR AVERAGE				
−0 058 ± 0.013	ALDE	86	GAM4	38 $\pi^- p \to n\eta\pi^0\pi^0$
−0.08 ± 0 03	KALBFLEISCH	74	RVUE	$\eta' \to \eta\pi^+\pi^-$

$\eta'(958)$ BRANCHING RATIOS

$\Gamma(\pi^+\pi^-\eta(\text{neutral decay}))/\Gamma_{total}$ — $709\Gamma_1/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.313 ± 0.011 OUR FIT					
0.314 ± 0.026	281	RITTENBERG	69	HBC	1 7-2 7 $K^- p$

$\Gamma(\pi^+\pi^-\ \text{neutrals})/\Gamma_{total}$ — $(709\Gamma_1 + 291\Gamma_2 + 9\Gamma_5)/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.399 ± 0.009 OUR FIT					
0.36 ± 0.05 OUR AVERAGE					
0.4 ± 0 1	39	LONDON	66	HBC	2 2 $K^- p$
0 35 ± 0.06	33	BADIER	65B	HBC	3 $K^- p$

$\Gamma(\pi^+\pi^-\eta(\text{charged decay}))/\Gamma_{total}$ — $291\Gamma_1/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.128 ± 0.005 OUR FIT					
0.116 ± 0.013 OUR AVERAGE					
0.123 ± 0.014	107	RITTENBERG	69	HBC	1 7-2 7 $K^- p$
0 1 ± 0 04	10	LONDON	66	HBC	2 2 $K^- p$
0 07 ± 0.04	7	BADIER	65B	HBC	3 $K^- p$

$[\Gamma(\pi^0\pi^0\eta\ (\text{charged decay})) + \Gamma(\omega\ (\text{charged decay})\ \gamma)]/\Gamma_{total}$ — $(291\Gamma_2 + 9\Gamma_5)/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.087 ± 0.005 OUR FIT Error includes scale factor of 1 1					
0.045 ± 0.029	42	RITTENBERG	69	HBC	1 7-2 7 $K^- p$

$\Gamma(\text{neutrals})/\Gamma_{total}$ — $(709\Gamma_2 + \Gamma_4 + 09\Gamma_5)/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.170 ± 0.009 OUR FIT Error includes scale factor of 1 1					
0.187 ± 0.017 OUR AVERAGE					
0 185 ± 0.022	535	BASILE	71	CNTR	1 6 $\pi^- p \to n X^0$
0.189 ± 0 026	123	RITTENBERG	69	HBC	1 7-2 7 $K^- p$

$\Gamma(\rho^0\gamma)/\Gamma_{total}$ — Γ_7/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.301 ± 0.014 OUR FIT					
0.319 ± 0.030 OUR AVERAGE					
0.329 ± 0 033	298	RITTENBERG	69	HBC	1 7-2 7 $K^- p$
0 2 ± 0.1	20	LONDON	66	HBC	2 2 $K^- p$
0 34 ± 0 09	35	BADIER	65B	HBC	3 $K^- p$

$\Gamma(\rho^0\gamma)/\Gamma(\pi\pi\eta)$ — $\Gamma_7/(\Gamma_1+\Gamma_2)$

VALUE	DOCUMENT ID		TECN	COMMENT
0.467 ± 0.031 OUR FIT				
0.31 ± 0.15	DAVIS	68	HBC	5 5 $K^- p$

$\Gamma(\pi^0 e^+ e^-)/\Gamma_{total}$ — Γ_{15}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.013	RITTENBERG	65	HBC	2 7 $K^- p$

$\Gamma(\eta e^+ e^-)/\Gamma_{total}$ — Γ_{16}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.011	RITTENBERG	65	HBC	2 7 $K^- p$

$\Gamma(\pi^0\rho^0)/\Gamma_{total}$ — Γ_{17}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.04	RITTENBERG	65	HBC	2 7 $K^- p$

Meson Full Listings

$\eta'(958)$

$\Gamma(\pi^+\pi^- e^+ e^-)/\Gamma_{total}$ — Γ_8/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.006	RITTENBERG	65	HBC	2 7 $K^- p$

$\Gamma(6\pi)/\Gamma_{total}$ — Γ_{14}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.01	LONDON	66	HBC	Compilation

$\Gamma(\omega\gamma)/\Gamma(\pi^+\pi^-\eta)$ — Γ_5/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.068 ± 0.008 OUR FIT Error includes scale factor of 1 1					
0.068 ± 0.013	68	ZANFINO	77	ASPK	8 4 $\pi^- p$

$\Gamma(\rho^0\gamma)/[\Gamma(\pi^+\pi^-\eta) + \Gamma(\pi^0\pi^0\eta) + \Gamma(\omega\gamma)]$ — $\Gamma_7/(\Gamma_1+\Gamma_2+\Gamma_5)$

VALUE	DOCUMENT ID		TECN	COMMENT
0.446 ± 0.029 OUR FIT				
0.25 ± 0.14	DAUBER	64	HBC	1 95 $K^- p$

$\Gamma(\gamma\gamma)/\Gamma_{total}$ — Γ_4/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0216 ± 0.0016 OUR FIT Error includes scale factor of 1 4					
0.0196 ± 0.0015 OUR AVERAGE					
0.0200 ± 0 0018		STANTON [2]	80	SPEC	8 45 $\pi^- p \to n\pi^+\pi^- 2\gamma$
0.025 ± 0.007		DUANE	74	MMS	$\pi^- p \to n$ MM
0.0171 ± 0 0033	68	DALPIAZ	72	CNTR	1 6 $\pi^- p \to nX^0$
0 020 $^{+0\ 008}_{-0.006}$	31	HARVEY	71	OSPK	3 65 $\pi^- p \to nX^0$
• • • We do not use the following data for averages fits limits, etc • • •					
0 018 ± 0 002	6000	APEL [3]	79	CNTR	15–40 $\pi^- p$

[2] Includes APEL 79 result
[3] Data is included in STANTON 80 evaluation

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ — Γ_9/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02		RITTENBERG	69	HBC	1 7–2 7 $K^- p$
• • • We do not use the following data for averages, fits, limits etc • • •					
<0 08	95	DANBURG	73	HBC	2 2 $K^- p \to \Lambda X^0$

$\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{total}$ — Γ_{10}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.05		RITTENBERG	69	HBC	1 7–2 7 $K^- p$
• • • We do not use the following data for averages, fits limits, etc • • •					
<0 09	95	DANBURG	73	HBC	2 2 $K^- p \to \Lambda X^0$

$\Gamma(\pi^+\pi^+\pi^-\pi^-$ neutrals$)/\Gamma_{total}$ — Γ_{12}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.01	95	DANBURG	73	HBC	2 2 $K^- p \to \Lambda X^0$
<0.01		RITTENBERG	69	HBC	1 7–2 7 $K^- p$

$\Gamma(\pi^+\pi^+\pi^-\pi^-\pi^0)/\Gamma_{total}$ — Γ_{13}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.01	RITTENBERG	69	HBC	1 7–2 7 $K^- p$

$\Gamma(\pi^+\pi^+\pi^-\pi^-)/\Gamma_{total}$ — Γ_{11}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.01	RITTENBERG	69	HBC	1 7–2 7 $K^- p$

$\Gamma(\rho^0\gamma)/\Gamma(\pi^+\pi^-\gamma$ (including $\rho^0\gamma$)) — Γ_7/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
1.08 ± 0.08 OUR AVERAGE					
1.15 ± 0 10	473	DANBURG	73	HBC	2 2 $K^- p \to \Lambda X^0$
1 01 ± 0.15	137	JACOBS	73	HBC	2 9 $K^- p \to \Lambda X^0$
0.94 ± 0 20		AGUILAR	70D	HBC	3 9–4 6 $K^- p$

$\Gamma(\pi^0\pi^0\eta$ ($3\pi^0$ decay))$/\Gamma_{total}$ — $319\Gamma_2/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.065 ± 0.004 OUR FIT Error includes scale factor of 1 2					
0.11 ± 0.06	4	BENSINGER	70	DBC	2 2 $\pi^+ d$

$\Gamma(\rho^0\gamma)/\Gamma(\pi^+\pi^-\eta$(neutral decay)) — $\Gamma_7/\ 709\Gamma_1$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.96 ± 0.07 OUR FIT					
0.99 ± 0.11 OUR AVERAGE					
0 92 ± 0.14	473	DANBURG	73	HBC	2 2 $K^- p \to \Lambda X^0$
1.11 ± 0 18	192	JACOBS	73	HBC	2 9 $K^- p \to \Lambda X^0$

$\Gamma(\gamma\gamma)/\Gamma(\pi^0\pi^0\eta$(neutral decay)) — $\Gamma_4/\ 709\Gamma_2$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.149 ± 0.012 OUR FIT Error includes scale factor of 1 5					
0.188 ± 0.058	16	APEL	72	OSPK	3 8 $\pi^- p \to nX^0$

$\Gamma(\mu^+\mu^-\gamma)/\Gamma(\gamma\gamma)$ — Γ_{18}/Γ_4

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
4.9 ± 1.2	33	VIKTOROV	80	CNTR	25 33 $\pi^- p \to 2\mu\gamma$

$\Gamma(\eta\mu^+\mu^-)/\Gamma_{total}$ — Γ_{19}/Γ

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN	COMMENT
<1.5	90	DZHELYADIN	81	CNTR	30 $\pi^- p \to \eta' n$

$\Gamma(\pi^0\mu^+\mu^-)/\Gamma_{total}$ — Γ_{20}/Γ

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN	COMMENT
<6.0	90	DZHELYADIN	81	CNTR	30 $\pi^- p \to \eta' n$

$\Gamma(3\pi^0)/\Gamma(\pi^0\pi^0\eta)$ — Γ_6/Γ_2

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
74 ± 12 OUR FIT				
74 ± 12 OUR AVERAGE				
74 ± 15	ALDE	87C	GAM2	38 $\pi^- p \to n + \gamma$'s
75 ± 18	BINON	84	SPEC	30–40 $\pi^- p \to 6\gamma$

$\Gamma(\gamma\gamma)/\Gamma(\pi^0\pi^0\eta)$ — Γ_4/Γ_2

VALUE	DOCUMENT ID		TECN	COMMENT
0.106 ± 0.008 OUR FIT Error includes scale factor of 1 5				
0.112 ± 0.002 ± 0.006	ALDE	87C	GAM2	38 $\pi^- p \to n + \gamma$'s

$\Gamma(\omega\gamma)/\Gamma(\pi^0\pi^0\eta)$ — Γ_5/Γ_2

VALUE	DOCUMENT ID		TECN	COMMENT
0.146 ± 0.014 OUR FIT				
0.147 ± 0.016	ALDE	87C	GAM2	38 $\pi^- p \to n + \gamma$ s

$\Gamma(3\gamma)/\Gamma(\pi^0\pi^0\eta)$ — Γ_{21}/Γ_2

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<4.6	90	ALDE	87C	GAM2	38 $\pi^- p \to n + \gamma$ s

$\Gamma(\pi^0\gamma\gamma)/\Gamma(\pi^0\pi^0\eta)$ — Γ_{22}/Γ_2

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<37	90	ALDE	87C	GAM2	38 $\pi^- p \to n + \gamma$'s

$\Gamma(\pi^0\pi^0)/\Gamma(\pi^0\pi^0\eta)$ — Γ_{23}/Γ_2

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<45	90	ALDE	87C	GAM2	38 $\pi^- p \to n + \gamma$'s

$\Gamma(4\pi^0)/\Gamma(\pi^0\pi^0\eta)$ — Γ_{24}/Γ_2

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<23	90	ALDE	87C	GAM2	38 $\pi^- p \to n + \gamma$ s

$\eta'(958)$ C-NONCONSERVING DECAY PARAMETER

See the note on η decay parameters in the Stable Particle Full Listings for definition of this parameter

DECAY ASYMMETRY PARAMETER FOR $\pi^+\pi^-\gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.01 ± 0.04 OUR AVERAGE					
−0.019 ± 0 056		AIHARA	87	TPC	$2\gamma \to \pi^+\pi^-\gamma$
−0 069 ± 0.078	295	GRIGORIAN	75	STRC	2 1 $\pi^- p$
0.00 ± 0 10	103	KALBFLEISCH	75	HBC	2 2 $K^- p$
0 07 ± 0.08	152	RITTENBERG	65	HBC	2 1–2 7 $K^- p$

$\eta'(958)$ REFERENCES

AIHARA 87 PR D35 2650 + (TPC Two-Gamma Collab) JP
ALBRECHT 87B PL B199 457 +Andam Binder+ (ARGUS Collab)
ALDE 87C ZPHY C36 603 +Binon Brickman+ (LANL BELG SERP LAPP)
ANTREASYAN 87 PR D36 2633 +Bartels Bessel+ (Crystal Ball Collab)
GIDAL 87 PRL 59 2012 +Boyer Butler Cords Abrams+ (LBL SLAC HARV)
ALDE 86 PL B177 115 +Binon Bricman+ (SERP BELG LANL LAPP)
BARTEL 85E PL 160B 421 + (JADE Collab)
ALTHOFF 84E PL 147B 487 (TASSO Collab)
BERGER 84B PL 142B 125 (AACH BERG DESY GLAS HAMB UMD SIEG+)
BINON 84 PL 140B 264 +Donskov Dufeil+ (SERP BELG LAPP CERN)
BEHREND 83B PL 125B 518 +D Agostini+ (DESY KARL MPIM LALO LPNP+)
Also 82C PL 114B 378 Behrend+ (DESY KARL MPIM LALO LPNP+)
JENNI 83 PR D27 1031 +Burke Telnov Abrams Blocker+ (SLAC LBL)
BARTEL 82B PL 113B 190 +Cords+ (DESY HAMB HEID LANC MCHS+)
DZHELYADIN 81 PL 105B 239 +Golovkin Konstantinov+ (SERP)
STANTON 80 PL 92 B 353 +Edwards Legacey+ (OSU CARL MCGI TNTO)
VIKTOROV 80 SJNP 32 520 +Golovkin Dzhelyadin Zaitsev Mukhin+ (NOVO)
Translated from YAF 32 1005
APEL 79 PL 83B 131 +Augenstein Bertolucci (KARL PISA SERP WIEN)
BINNIE 79 PL 83B 141 +Carr Debenham Jones Karami Keyne+ (LOIC)
ZANFINO 77 PRL 38 930 +Brockman+ (CARL MCGI OHIO TNTO)
GRIGORIAN 75 NP B91 232 +Ladage Mellema Rudnick+ (UCLA)
KALBFLEISCH 75 PR D11 987 +Strand Chapman (BNL MICH)
DUANE 74 PRL 32 425 +Binnie Camilleri Carr+ (LOIC SHMP)
KALBFLEISCH 74 PR D10 916 (BNL)
DANBURG 73 PR D8 3744 +Kalbfleisch Borenstein Chapman+ (BNL MICH) JP
JACOBS 73 PR D8 18 +Chang Gauthier+ (BRAN UMD SYRA TUFT) JP
APEL 72 PL 40B 680 +Auslander Muller Bertolucci+ (KARL PISA)
DALPIAZ 72 PL 42B 377 +Frabetti Massam Navarria Zichichi (CERN)
BASILE 71 NC 3A 371 +Bollini Dalpiaz Frabetti+ (CERN BGNA, STRB)
HARVEY 71 PRL 27 885 +Marquit Peterson Rhoades+ (MINN MICH)

AGUILAR 70D PRL 25 1635 Aguilar Benitez Bassano Samios Barnes+ (BNL)
BENSINGER 70 PL 33B 505 +Erwin Thompson Walker (WISC)
RITTENBERG 69 UCRL 18863 Thesis (LRL) I
DAVIS 68 PL 27B 532 +Ammar Mott Dagan Derrick+ (NWES ANL)
LONDON 66 PR 143 1034 +Rau Goldberg Lichtman+ (BNL SYRA) IJP
BADIER 65B PL 17 337 +Demoulin Barloutaud+ (EPOL SACL AMST)
RITTENBERG 65 PRL 15 556 +Kalbfleisch (LRL BNL)
DAUBER 64 PRL 13 449 +Slater Smith Stork Ticho (UCLA) JP
Also 64B Dubna Conf 1 418 Dauber Slater Smith Stork Ticho (UCLA)

OTHER RELATED PAPERS

BICKERSTAFF 82 ZPHY C16 171 +McKellar (MELB)
ABRAMS 79B PRL 43 477 +Alam Blocker Boyarski+ (SLAC LBL)
DZHELYADIN 79B PL 88B 379 +Golovkin Gritsuk Kachanov+ (SERP)
CERRADA 77 NP B126 189 +Wagner Blockzijl+ (CERN AMST NIJM OXF) JP
DELAGUILA 77 PR D16 2833 +Doncel (BARC) JP
GESSAROLI 77 NP B126 382 + (BGNA FIRZ GENO MILA OXF PAVI)
LEDNICKY 77 E2 10521 22 23 (JINR) JP
BALTAY 74B PR D9 2999 +Cohen Csorna Habibi Kalelkar+ (COLU BING) JP
GAULT 74 NC 24A 259 +Jones Scadron Thews (DURH LOIC ARIZ)
KALBFLEISCH 73 PRL 31 333 +Chapman+ (BNL MICH LBL) JP
AGUILAR 72B PR D6 29 Aguilar Benitez Chung Elsner Samios (BNL)
BINNIE 72 PL 39B 275 +Camilleri Duane Garbutt Burton+ (LOIC SHMP)
BLOODWO 72B NP B39 525 Bloodworth Jackson Prentice Yoon (TNTO)
RADER 72 PR D6 3059 +Abolins Dahl Danburg Davies Hoch+ (LBL)
BARDADIN 71 PR D4 2711 Bardadin Otwinowska Hofmokl+ (WARS)
BASILE 71B NP B33 29 +Bollini Dalpiaz Frabetti+ (CERN BGNA STRB)
OGIEVETSKY 71 PL 35B 69 +Tybor Zaslavsky (JINR)
DUFEY 69 PL 29B 605 +Gobbi Pouchon Cnops+ (ETH CERN SACL) IJP
MOTT 69 PR 177 1966 +Ammar Davis Kropac Slate+ (NWES ANL)
BARBARO 68 PRL 20 349 Barbaro Galtieri Matison Rittenberg+ (LRL) I
BARLOUTAUD 68 PL 26B 674 + (SACL AMST BGNA REHO EPOL) I
BOLLINI 68D NC 58A 289 +Buhler Dalpiaz Massam+ (CERN BGNA STRB)
COHN 66 PL 21 347 +McCulloch Bugg Condo (ORNL TENN UCND)
MARTIN 66 PL 22 352 +Crittenden Schroeder (IND) I
KIENZLE 65 PL 19 438 +Maglich Levrat Lefebvres+ (CERN)
TRILLING 65 PL 19 427 +Brown Goldhaber Kadyk Scanio (LRL)
GOLDBERG 64 PRL 12 546 +Gundzik Lichtman Connolly Hart+ (SYRA BNL)
GOLDBERG 64B PRL 13 249 +Gundzik Leitner Connolly Hart+ (SYRA BNL)
KALBFLEISCH 64 PRL 12 527 +Alvarez Barbaro Galtieri+ (LRL) JP
KALBFLEISCH 64B PRL 13 349 +Dahl Rittenberg (LRL) JP

$f_0(975)$ was $S(975)$

$I^G(J^{PC}) = 0^+(0^{++})$

For early work using Breit-Wigner or scattering length parametrization in fits to the $K\overline{K}$ mass spectrum, see reference section and our 1972 edition

See also the mini-review under non-$q\overline{q}$ candidates

$f_0(975)$ MASS OR REAL PART OF POLE POSITION

POLE POSITION DETERMINATIONS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
975.6 ± 3.1 OUR AVERAGE	Error includes scale factor of 1 2			
978 ± 9	ABACHI	86B	HRS	$e^+e^- \rightarrow \pi^+\pi^-$
974 0 ± 4.0	GIDAL	81	MRK2	J/ψ decay
986. ± 10	AGUILAR	78	HBC	0 7 $\overline{p}p \rightarrow K^0_S K^0_S$
969 0 ± 5 0	LEEPER	77	ASPK	2-2 4 $\pi^- p$
987 ± 7	BINNIE	73	CNTR	$\pi^- p \rightarrow n$ MM
• • • We do not use the following data for averages fits limits etc • • •				
985 0 ± 39 0	[1] ETKIN	82B	MPS	23 $\pi^- p \rightarrow n 2K^0_S$
1012 ± 6	[2] GRAYER	73	ASPK	17 $\pi^- p \rightarrow \pi^+\pi^- n$
1007 ± 20	[2] HYAMS	73	ASPK	17 $\pi^- p \rightarrow \pi^+\pi^- n$
997 ± 6	[2] PROTOPOP	73	HBC	7 $\pi^+ p \rightarrow \pi^+ p \pi^+ \pi^-$

[1] ETKIN 82B quotes errors $^{+9}_{-39}$ MeV We use ± 39 MeV in the average
[2] Included in AGUILAR BENITEZ 78 fit

MASS DETERMINATIONS
(Real part of mass matrix eigenvalue)

VALUE (MeV)	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits, etc • • •			
985	[3] TORNQVIST	82	RVUE
975	[3] ACHASOV	80	RVUE

[3] Coupled channel analysis with finite width corrections

$f_0(975)$ WIDTH OR IMAGINARY PART OF POLE POSITION

POLE POSITION DETERMINATIONS
(Corresponds to half width not full width)

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
16.8 ± 2.8 OUR AVERAGE				
29 ± 13	ABACHI	86B	HRS	$e^+e^- \rightarrow \pi^+\pi^-$
14 0 ± 5 0	GIDAL	81	MRK2	J/ψ decay
15 0 ± 4 0	LEEPER	77	ASPK	2-2 4 $\pi^- p$
24 ± 7	BINNIE	73	CNTR	$\pi^- p \rightarrow n$ MM
• • • We do not use the following data for averages fits limits etc • • •				
60 0 $^{+141\ 0}_{-\ 10.0}$	ETKIN	82B	MPS	23 $\pi^- p \rightarrow n 2K^0_S$
50 ± 40	[4] AGUILAR-	78	HBC	0 7 $pp \rightarrow K^0_S K^0_S$
16 ± 5	[5] GRAYER	73	ASPK	17 $\pi^- p \rightarrow \pi^+\pi^- n$
15 ± 5	[5] HYAMS	73	ASPK	17 $\pi^- p \rightarrow \pi^+\pi^- n$
27 ± 8	[5] PROTOPOP	73	HBC	7 $\pi^+ p \rightarrow \pi^+ p \pi^+ \pi^-$

[4] From coupled channel fit to the HYAMS 73 and PROTOPOPESCU 73 data With a simultaneous fit to the $\pi\pi$ phase shifts inelasticity and to the $K^0_S K^0_S$ invariant mass
[5] Included in AGUILAR-BENITEZ 78 fit

FULL WIDTH DETERMINATIONS
(From imaginary part of mass matrix eigenvalue)

VALUE (MeV)	DOCUMENT ID		TECN
• • • We do not use the following data for averages fits limits etc • • •			
~400	[6] TORNQVIST	82	RVUE
70 to 300	[6] ACHASOV	80	RVUE

[6] Coupled channel analysis with finite width corrections

$f_0(975)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$f_0(975) \rightarrow K\overline{K}$	
Γ_2	$f_0(975) \rightarrow \pi\pi$	(78 1 $^{+2\ 7}_{-2\ 3}$) $\times 10^{-2}$
Γ_3	$f_0(975) \rightarrow \eta\eta$	

$f_0(975)$ BRANCHING RATIOS

$\Gamma(\pi\pi)/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.781 $^{+0.027}_{-0.023}$ OUR AVERAGE				
0 67 ± 0 09	LOVERRE	80	HBC	4 $\pi^- p \rightarrow K\overline{K}N$
0 81 $^{+0\ 09}_{-0\ 04}$	CASON	78	STRC	7 $\pi^- p \rightarrow n 2K^0_S$
0 78 ± 0 03	WETZEL	76	OSPK	8 9 $\pi^- p \rightarrow n 2K^0_S$

$f_0(975)$ REFERENCES

ABACHI 86B PRL 57 1990 +Derrick Blockus+ (PURD ANL IND MICH LBL)
ETKIN 82B PR D25 1786 +Foley Lai+ (BNL CUNY TUFT VAND)
TORNQVIST 82 PRL 49 624 (HELS)
GIDAL 81 PL 107B 153 +Goldhaber Guy Millikan Abrams+ (SLAC LBL)
ACHASOV 80 SJNP 32 566 +Devyanin Shestakov (NOVO)
Translated from YAF 32 1098
LOVERRE 80 ZPHY C6 187 +Armenteros Dionisi+ (CERN CDEF MADR STOH) IJP
AGUILAR 78 NP B140 73 Aguilar Benitez Cerrada+(MADR BOMB CERN+)
CASON 78 PRL 41 271 +Baumbaugh Bishop Biswas+ (NDAM ANL)
LEEPER 77 PR D16 2054 +Buttram Crowley Duke Lamb Peterson (ISU)
WETZEL 76 NP B115 208 +Freudenreich Beusch+ (ETH CERN LOIC)
BINNIE 73 PRL 31 1534 +Carr Debenham Duane Garbutt+(LOIC SHMP)
GRAYER 73 Tallahassee +Hyams Jones Blum Dietl Koch+ (CERN MPIM)
HYAMS 73 NP B64 134 +Jones Weilhammer Blum Dietl+ (CERN MPIM)
PROTOPOP 73 PR D7 1280 Protopopescu Garnjost Galtieri Flatte+ (LBL)

OTHER RELATED PAPERS

AU 87 PR D35 1633 +Morgan Pennington (DURH RAL)
AKESSON 86 NP B264 154 +Albrow Almehed+ (Axial Field Spec Collab)
MENNESSIER 83 ZPHY C16 241 (MONP)
BARBER 82 ZPHY C12 1 +Dainton Brodbeck Brookes+(DARE LANC SHEF)
ETKIN 82C PR D25 2446 +Foley Lai+ (BNL CUNY TUFT VAND)
ACHASOV 81 PL 102B 196 +Devyanin Shestakov (NOVO)
AGUILAR 81 ZPHY C10 299 Aguilar Benitez Done Martin (MADR DURH)
ROUSSARIE 81 PL 105B 304 +Burke Abrams Alam+ (SLAC LBL)
WICKLUND 80 PRL 45 1469 +Ayres Cohen Diebold Pawlicki (ANL)
ACHASOV 79 PL 88B 367 +Devyanin Shestakov (NOVO)
APEL 79B NP B160 42 +Auslander Muller Rehak+ (KARL PISA)
BECKER 79 NP B151 46 +Blanar Blum+ (MPIM CERN ZEEM CRAC)
CORDEN 79 NP B157 250 +Dowell Garvey+ (BIRM RHEL TELA LOWC) JP
ESTABROOKS 79 PR D19 2678 (CARL)
GREENHUT 79 PR D20 2326 +Intemann (SETO)
POLYCHRO 79 PR D19 1317 Polychronakos Cason Bishop+ (NDAM ANL)
BALAND 78 NP B140 220 +Grard+ (MONS BELG CERN LOIC LALO)
FROGGATT 77 NP B129 89 +Petersen (GLAS NORD)
MARTIN 77D NP B121 514 +Ozmutlu Squires (DUKE)
PAWLICKI 77 PR D15 3196 +Ayres Cohen Diebold Kramer Wicklund (ANL) IJ
BRANDENB 76C NP B104 413 Brandenburg Carnegie Cashmore+ (SLAC)
BUTTRAM 76 PR D13 1153 +Crawley Duke Lamb Leeper Peterson (ISU)

Meson Full Listings
$f_0(975)$, $a_0(980)$

CERRADA 76 PL 62B 353 +Gonzalez Arroyo Rubio Yndurain (CERN MADR)
FLATTE 76B PL 63B 228 (CERN)
WILKINS 76 PR D13 1831 +Albright Hagopian Hagopian Lannutti (FSU)
MORGAN 75 Argonne Conf 45 (RHEL)
PAWLICKI 75 PR D12 631 +Ayres Diebold Greene Kramer Wicklund (ANL)
BALLAM 74 NP B76 375 +Chadwick Bingham Fretter+ (SLAC LBL MPIM)
GRAYER 74 NP B75 189 +Hyams Blum Dietl+ (CERN MPIM)
MORGAN 74 PL 51B 71 (RHEL)
DIAMOND 73 PR D7 1977 +Binkley+ (WISC DUKE COLO TNTO OHIO)
FUJII 73 NC 13A 311 +Kato (TOKY)
OCHS 73 Thesis (MPIM)
BASDEVANT 72 PL 41B 178 +Froggatt Petersen (CERN)
DAMERI 72 NC 9A 1 +Borzatto Goussu+ (GENO MILA SACL)
DUBOC 72 NP B46 429 +Goldberg Makowski Donald+ (LPNP LIVP)
FLATTE 72 PL 38B 232 +Alston Garnjost Barbaro Galtieri+ (LBL)
GRAYER 72B Phil Conf 5 +Hyams Jones Schlein+ (CERN MPIM)
WILLIAMS 72B PR D6 3178 (FSU)
ALSTON 71B PL 36B 152 Alston Garnjost Barbaro Galtieri+ (LBL)
BADIER 70 NP B22 512 +Bonnet Drevillon Baubillier+ (EPOL IPNP)
BATON 70 PL 33B 528 +Laurens Reignier (SACL)
BEUSCH 70 Phil Conf 185 (ETH CERN)
HYAMS 70B Phil Conf 41 +Koch Beusch+ (CERN MPIM ETH LOIC HAWA)
Also 70 NP B22 189 Hyams Koch Potter VonLindern+ (CERN MPIM)
OH 70 PR D1 2494 +Garfinkel Morse Walker Prentice (WISC TNTO)
AGUILAR 69C PL 29B 241 Aguilar Benitez Barlow+ (CERN CDEF)
Also 69 NP B14 195 Aguilar Benitez Barlow+ (CERN CDEF)
HOANG 69 NC 61A 325 (ANL)
HOANG 69B PR 184 1363 +Eartly Phelan Roberts+ (ANL ILLC)
ALITTI 68B PRL 21 1705 +Barnes Crennell Flaminio Goldberg+ (BNL)
LAI 68 Phil Conf 303 (BNL)
PHELAN 68 Thesis (ANL STLO)
Also 68 PRL 21 316 Hoang Eartly Phelan+ (ANL CHIC NDAM)
BARLOW 67 NC 50A 701 +Lillestol Montanet+ (CERN CDEF IRAD LIVP)
BEUSCH 67 PL 25B 357 +Fischer Gobbi Astbury+ (ETH CERN)
DAHL 67 PR 163 1377 +Hardy Hess Kirz Miller (LRL)
CRENNELL 66 PRL 16 1025 +Kalbfleisch Lai Scarr Schumann+ (BNL)
HESS 66 PRL 17 1109 +Dahl Hardy Kirz Miller (LRL)
BALTAY 64 Dubna Conf 1 409 +Lach Crennell Oren Stump+ (YALE BNL)
BARMIN 64B Dubna Conf 1 433 +Dolgolenko Yerofeev Krestni+ (ITEP)
BIGI 62 CERN Conf 247 +Brandt Carrara+ (CERN)
BINGHAM 62 CERN Conf 240 +Bloch+ (EPOL CERN)
ERWIN 62 PRL 9 34 +Hoyer March Walker Wangler (WISC BNL)
WANG 61 JETP 13 323 +Veksler Vrana+ (JINR)
Translated from ZETF 40 464

$a_0(980)$ was $\delta(980)$

$I^G(J^{PC}) = 1^-(0^{++})$

Our latest mini-review on this particle can be found in the 1984 edition

$a_0(980)$ MASS

$\eta\pi$ FINAL STATE ONLY

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
983.3 ± 2.6 OUR AVERAGE Error includes scale factor of 1 2						
976 ± 6		ATKINSON	84E	OMEG	±	25–55 $\gamma p \to \eta\pi n$
986 ± 3	500	[1] EVANGELISTA	81	OMEG		12 $\pi^- p \to \eta\pi p$
990 0 ± 7 0	145	[1] GURTU	79	HBC	±	4 2 $K^- p \to \Lambda\eta 2\pi$
977.0 ± 7 0		GRASSLER	77	HBC	−	16 $\pi^\mp p \to p\eta 3\pi$
972 ± 10	150	DEFOIX	72	HBC	±	0 7 $\bar{p}p \to 7\pi$
• • • We do not use the following data for averages fits limits etc • • •						
980 ± 11	47	CONFORTO	78	OSPK	−	4 5 $\pi^- p \to pX^-$
978 0 ± 16 0	50	CORDEN	78	OMEG	±	12–15 $\pi^- p \to n\eta 2\pi$
989 0 ± 4 0	70	WELLS	75	HBC	−	3 1–6 $K^- p \to \Lambda\eta 2\pi$
970 0 ± 15 0	20	BARNES	69C	HBC	−	4–5 $K^- p \to \Lambda\eta 2\pi$
980 ± 10.		CAMPBELL	69	DBC	±	2 7 $\pi^+ d$
980 0 ± 10 0	15	MILLER	69B	HBC	−	4 5 $K^- N \to \eta\pi\Lambda$
980 0 ± 10 0	30	AMMAR	68	HBC	±	5 5 $K^- p \to \Lambda\eta 2\pi$

[1] From $f_1(1285)$ decay

$K\bar{K}$ ONLY

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
976. ± 6.	316	DEBILLY	80	HBC	±	1 2–2 $\bar{p}p \to f_1(1285)\omega$
• • • We do not use the following data for averages, fits limits etc • • •						
1016. ± 10.	100	[2] ASTIER	67	HBC	±	0 0 $\bar{p}p$
1003.3 ± 7 0	143	[3] ROSENFELD	65	RVUE	±	

[2] ASTIER 67 includes data of BARLOW 67 CONFORTO 67 ARMENTEROS 65
[3] Plus systematic errors

$a_0(980)$ WIDTH

$\eta\pi$ FINAL STATE ONLY

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
57 ± 11 OUR AVERAGE						
62. ± 15	500	[4] EVANGELISTA	81	OMEG		12 $\pi^- p \to \eta\pi p$
60 0 ± 20 0	145	[4] GURTU	79	HBC	±	4 2 $K^- p \to \Lambda\eta 2\pi$
44 0 ± 22 0		GRASSLER	77	HBC	−	16 $\pi^\mp p \to p\eta 3\pi$
• • • We do not use the following data for averages fits limits etc • • •						
60^{+50}_{-30}	47	CONFORTO	78	OSPK	−	4 5 $\pi^- p \to pX^-$
$86\ 0^{+60\ 0}_{-50\ 0}$	50	CORDEN	78	OMEG	±	12–15 $\pi^- p \to n\eta 2\pi$
80 to 300		[5] FLATTE	76	RVUE	−	4 2 $K^- p \to \Lambda\eta 2\pi$
$16\ 0^{+25\ 0}_{-16\ 0}$	70	WELLS	75	HBC	−	3 1–6 $K^- p \to \Lambda\eta 2\pi$
30 ± 5	150	DEFOIX	72	HBC	±	0 7 $\bar{p}p \to 7\pi$
40 ± 15		CAMPBELL	69	DBC	±	2 7 $\pi^+ d$
60 0 ± 30 0	15	MILLER	69B	HBC	−	4 5 $K^- N \to \eta\pi\Lambda$
80 0 ± 30 0	30	AMMAR	68	HBC	±	5 5 $K^- p \to \Lambda\eta 2\pi$

[4] From $f_1(1285)$ decay
[5] Using a two-channel resonance parametrization of GAY 76B data

$K\bar{K}$ ONLY

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages fits limits etc • • •					
~25	100	[6] ASTIER	67	HBC	±
57 0 ± 13 0	143	[7] ROSENFELD	65	RVUE	±

[6] ASTIER 67 includes data of BARLOW 67 CONFORTO 67 ARMENTEROS 65
[7] Plus systematic errors

$a_0(980)$ DECAY MODES

Γ_1 $a_0(980) \to \eta\pi$
Γ_2 $a_0(980) \to \rho\pi$
Γ_3 $a_0(980) \to KK$
Γ_4 $a_0(980) \to \pi\eta'(958)$
Γ_5 $a_0(980) \to \gamma\gamma$

$a_0(980)$ $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(\text{total})$

$\Gamma(\eta\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ $\Gamma_1\Gamma_5/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
$0.19 \pm 0.07^{+0.10}_{-0.07}$	ANTREASYAN	86	CBAL	$e^+e^- \to e^+e^-\pi^0\eta$

$a_0(980)$ BRANCHING RATIOS

$\Gamma(\rho\pi)/\Gamma(\eta\pi)$ Γ_2/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •						
<0.25	70	AMMAR	70	HBC	±	4 1,5 5 $K^- p \to \Lambda\eta 2\pi$

$\Gamma(K\bar{K})/\Gamma(\eta\pi)$ Γ_3/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •					
0 7 ± 0 3	[8] CORDEN	78	OMEG		12–15 $\pi^- p \to n\eta 2\pi$
0 25 ± 0 08	[8] DEFOIX	72	HBC	±	0 7 $\bar{p} \to 7\pi$

[8] From the decay of $f_1(1285)$

$a_0(980)$ REFERENCES

ANTREASYAN 86 PR D33 1847 +Aschman Besset Bienlein+ (Crystal Ball Collab)
ATKINSON 84E PL 138B 459 + (BONN CERN GLAS LANC MCHS LPNP+)
EVANGELISTA 81 NP B178 197 + (BARI BONN CERN DARE LIVP+)
DEBILLY 80 NP B176 1 +Briand Duboc Levy+ (CURI LAUS NEUC GLAS)
GURTU 79 NP B151 181 +Gavillet Blokzijl+ (CERN ZEEM NIJM OXF)
CONFORTO 78 LNC 23 419 +Conforto Key+ (RHEL TNTO CHIC FNAL+)
CORDEN 78 NP B144 253 +Corbett Alexander+ (BIRM RHEL TELA LOWC)
GRASSLER 77 NP B121 189 + (AACH BERL BONN CERN CRAC HEID+)
FLATTE 76 PL 63B 224 (CERN)
GAY 76B PL 63B 220 +Chaloupka Blokzijl Heinen+ (CERN AMST NIJM) JP
WELLS 75 NP B101 333 +Radojicic Roscoe Lyons (OXF)
DEFOIX 72 NP B44 125 +Nascimento Bizzarri+ (CDEF CERN)
AMMAR 70 PR D2 430 +Kropac Davis+ (KANS NWES ANL WISC)
BARNES 69C PRL 23 610 +Chung Eisner Bassano Goldberg+ (BNL SYRA)

CAMPBELL	69	PRL 22 1204	+Lichtman Loeffler+	(PURD)
MILLER	69B	PL 29B 255	+Kramer Carmony+	(PURD)
Also	69	PR 188 2011	Yen Ammann Carmony Eisner+	(PURD)
AMMAR	68	PRL 21 1832	+Davis Kropac Derrick Fields+	(NWES ANL)
ASTIER	67	PL 25B 294	+Montanet Baubillier Duboc+(CDEF CERN IRAD)	
Includes data of BARLOW 67 CONFORTO 67 and ARMENTEROS 65				
BARLOW	67	NC 50A 701	+Lillestol Montanet+	(CERN CDEF IRAD LIVP)
CONFORTO	67	NP B3 469	+Marechal+	(CERN CDEF IPNP LIVP)
ARMENTEROS	65	PL 17 344	+Edwards Jacobsen+	(CERN CDEF)
ROSENFELD	65	Oxford Conf 58		(LRL)

$\phi(1020)$

$I^G(J^{PC}) = 0^-(1^{--})$

$\phi(1020)$ MASS

We average mass and width values only when the systematic errors have been evaluated

VALUE (MeV)		EVTS	DOCUMENT ID		TECN	COMMENT
1019.414 ± 0.010 OUR AVERAGE			Error includes scale factor of 1.2			
1019.8 ± 0.7			ARMSTRONG	86	OMEG	85 $\pi^+ p p \to \pi^+ p 4K p$
1019.7 ± 1.0			BEBEK	86	CLEO	$e^+e^- \to \Upsilon(4S)$
1019.7 ± 0.3		2012	DAVENPORT	86	MPSF	400 $pA \to 4K X$
1019.411 ± 0.008		642k	[1] DIJKSTRA	86	SPEC	100–200 $\pi^\pm$ $\bar{p}$ p $K^\pm$, on Be
1019.7 ± 0.1	± 0.1	5079	ALBRECHT	85D	ARG	$e^+e^- \to$ hadrons
1019.3 ± 0.1		1500	ARENTON	82	AEMS	11.8 polar $pp \to KK$
1019.67 ± 0.17		25080	[2] PELLINEN	82	RVUE	
1019.8 ± 0.2	± 0.5	766	IVANOV	81	OLYA	1–1.4 $e^+e^- \to K^+K^-$
1019.54 ± 0.12		1100	BARKOV	79B	EMUL	e^+e^-
1019.52 ± 0.13			BUKIN	78C	OLYA	e^+e^-
1019.4 ± 0.5		337	COOPER	78B	HBC	0.7–0.8 $\bar{p}p \to K^0_S K^0_L$
1018.9 ± 0.6		800	COHEN	77	ASPK	6 $\pi^\pm N \to K^+K^- N$
1019.7 ± 0.5		454	KALBFLEISCH	76	HBC	2.18 $K^-p \to KKn$
1019.4 ± 0.8		984	BESCH	74	CNTR	2 $\gamma p \to pK^+K^-$
1020.3 ± 0.4		100	BALLAM	73	HBC	2.8–9.3 γp
1019.4 ± 0.7			BINNIE	73B	CNTR	$\pi^- p \to \phi n$
1019.6 ± 0.5		120	[3] AGUILAR	72B	HBC	3.9,4.6 $K^-p \to \Lambda K^+K^-$
1019.9 ± 0.5		100	[3] AGUILAR-	72B	HBC	3.9,4.6 $K^-p \to K^-pK^+K^-$
1020.4 ± 0.5		131	COLLEY	72	HBC	10 $K^+p \to K^+p\phi$
1019.9 ± 0.3		410	STOTTLEMYER	71	HBC	2.9 $K^-p \to \Sigma/\Lambda KK$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1020.1 ± 0.11		5526	[4] ATKINSON	86	OMEG	20–70 γp
1020.9 ± 0.2			[4] FRAME	86	OMEG	13 $K^+p \to \phi K^+ p$
1021.0 ± 0.2			[4] ARMSTRONG	83B	OMEG	18.5 $K^-p \to K^-K^+\Lambda$
1020.0 ± 0.5			[4] ARMSTRONG	83B	OMEG	18.5 $K^-p \to K^-K^+\Lambda$
1019.7 ± 0.3			[4] BARATE	83	GOLI	190 π^-Be $\to 2\mu X$
1020.0 ± 1.0		383	[4] BALDI	77	CNTR	10 $\pi^-p \to \pi^-\phi p$

[1] Weighted and scaled average of 12 measurements of DIJKSTRA 86

[2] PELLINEN 82 review includes AKERLOF 77, DAUM 81, BALDI 77, AYRES 74, DEGROOT 74

[3] Mass errors enlarged by us to $\Gamma/N^{1/2}$; see the note with the $K^*(892)$ mass

[4] Systematic errors not evaluated

$\phi(1020)$ WIDTH

We average mass and width values only when the systematic errors have been evaluated

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
4.41 ± 0.05 OUR FIT					
4.41 ± 0.05 OUR AVERAGE					
4.45 ± 0.06	271k	DIJKSTRA	86	SPEC	100 π^-Be
4.5 ± 0.7	1500	ARENTON	82	AEMS	11.8 polar $pp \to KK$
4.2 ± 0.6	766	[5] IVANOV	81	OLYA	1–1.4 $e^+e^- \to K^+K^-$
4.3 ± 0.6		[5] CORDIER	80	WIRE	$e^+e^- \to \pi^+\pi^-\pi^0$
4.58 ± 0.55	1100	[5] BARKOV	79B	EMUL	e^+e^-
4.36 ± 0.29	3681	[5,6] BUKIN	78C	OLYA	e^+e^-
3.6 ± 0.8	337	[5] COOPER	78B	HBC	0.7–0.8 $\bar{p}p \to K^0_S K^0_L$
4.5 ± 0.50	1300	[5,7] AKERLOF	77	SPEC	400 $pA \to K^+K^- X$
4.4 ± 0.6	984	[5] BESCH	74	CNTR	2 $\gamma p \to pK^+K^-$
3.81 ± 0.37		COSME	74B	OSPK	e^+e^-
3.8 ± 1.5	100	[5] BALLAM	73	HBC	2.8–9.3 γp
4.5 ± 1.1		BINNIE	73B	CNTR	$\pi^-p \to \phi n$
4.6 ± 1.7	120	[5] AGUILAR	72B	HBC	3.9,4.6 $K^-p \to \Lambda K^+K^-$
4.7 ± 1.9	100	[5] AGUILAR	72B	HBC	3.9,4.6 $K^-p \to K^-pK^+K^-$
3.8 ± 0.7	454	[5] BORENSTEIN	72	HBC	2.18 $K^-p \to KKn$
5.0 ± 1.8	131	[5] COLLEY	72	HBC	10 $K^+p \to K^+p\phi$
4.67 ± 0.72	681	[5] BALAKIN	71	OSPK	e^+e^-
4.09 ± 0.29		BIZOT	70	OSPK	e^+e^-
4.2 ± 1.4	150	[5] AUGUSTIN	69	OSPK	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •					
8.9 ± 0.3		[7] FRAME	86	OMEG	13 $K^+p \to \phi K^+p$
4.5 ± 0.8	500	[5,7] AYRES	74	ASPK	3–6 $\pi^-p \to K^+K^-n$, $K^-p \to K^+K^-\Lambda/\Sigma^0$
4.2 ± 1.3	170	[5,7] DEGROOT	74	HBC	4.2 $K^-p \to \Lambda K^+K^-$

[5] Width errors enlarged by us to $4\Gamma/N^{1/2}$; see the note with the $K^*(892)$ mass

[6] Number of events includes a small background contribution

[7] Systematic errors not evaluated

$\phi(1020)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$\phi(1020) \to K^+K^-$	$(49.5 \pm 1.0) \times 10^{-2}$	S=1.3
Γ_2	$\phi(1020) \to K^0_L K^0_S$	$(34.4 \pm 0.9) \times 10^{-2}$	S=1.3
Γ_3	$\phi(1020) \to \pi^+\pi^-\pi^0$	$(1.9 {}^{+1.2}_{-1.0}) \times 10^{-2}$	S=1.3
Γ_4	$\phi(1020) \to \eta\gamma$	$(1.28 \pm 0.06) \times 10^{-2}$	S=1.1
Γ_5	$\phi(1020) \to e^+e^-$	$(3.11 \pm 0.10) \times 10^{-4}$	
Γ_6	$\phi(1020) \to \mu^+\mu^-$	$(2.48 \pm 0.34) \times 10^{-4}$	
Γ_7	$\phi(1020) \to \pi^0\gamma$	$(1.31 \pm 0.13) \times 10^{-3}$	
Γ_8	$\phi(1020) \to \pi^+\pi^-$	$(8 {}^{+5}_{-4}) \times 10^{-5}$	S=1.5
Γ_9	$\phi(1020) \to \pi^+\pi^-\gamma$	$< 7 \times 10^{-3}$	CL=90%
Γ_{10}	$\phi(1020) \to \omega\gamma$	$< 5 \times 10^{-2}$	
Γ_{11}	$\phi(1020) \to \eta\pi^0$		
Γ_{12}	$\phi(1020) \to \rho\gamma$	$< 2 \times 10^{-2}$	
Γ_{13}	$\phi(1020) \to \pi^+\pi^+\pi^-\pi^-\pi^0$	$< 10 \times 10^{-3}$	
Γ_{14}	$\phi(1020) \to \pi^+\pi^-\pi^+\pi^-$	$< 8.7 \times 10^{-4}$	CL=90%
Γ_{15}	$\phi(1020) \to \rho\pi$	$(12.9 \pm 0.7) \times 10^{-2}$	
Γ_{16}	$\phi(1020) \to \eta e^+e^-$	$(1.3 {}^{+0.8}_{-0.6}) \times 10^{-4}$	
Γ_{17}	$\phi(1020) \to \eta'(958)\gamma$	$< 4.1 \times 10^{-4}$	CL=90%
Γ_{18}	$\phi(1020) \to \pi^0\pi^0\gamma$	$< 1 \times 10^{-3}$	CL=90%

CONSTRAINED FIT INFORMATION

An overall fit to the total width, a partial width, and 9 branching ratios uses 48 measurements and one constraint to determine 6 parameters. The overall fit has a $\chi^2 = 43.6$ for 43 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta p_i \delta p_j\rangle/(\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i, including the branching fractions $x_i \equiv \Gamma_i/\Gamma_{total}$. The fit constrains the x_i in this array to sum to one.

x_2	43				
x_3	49	37			
x_4	3	3	1		
x_{15}	0	0	57	0	
Γ	0	0	13	0	23
	x_1	x_2	x_3	x_4	x_{15}

	Mode	Rate (MeV)	Scale
Γ_1	$\phi(1020) \to K^+K^-$	2.18 ± 0.05	1.2
Γ_2	$\phi(1020) \to K^0_L K^0_S$	1.52 ± 0.04	1.2
Γ_3	$\phi(1020) \to \pi^+\pi^-\pi^0$	0.08 ± 0.05	1.3
Γ_4	$\phi(1020) \to \eta\gamma$	0.0567 ± 0.0028	1.1
Γ_{15}	$\phi(1020) \to \rho\pi$	0.570 ± 0.030	

$\phi(1020)$ PARTIAL WIDTH

$\Gamma(\rho\pi)$ Γ_{15}

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
0.570 ± 0.030 OUR FIT				
0.57 ± 0.03	JULLIAN	76	OSPK	e^+e^-

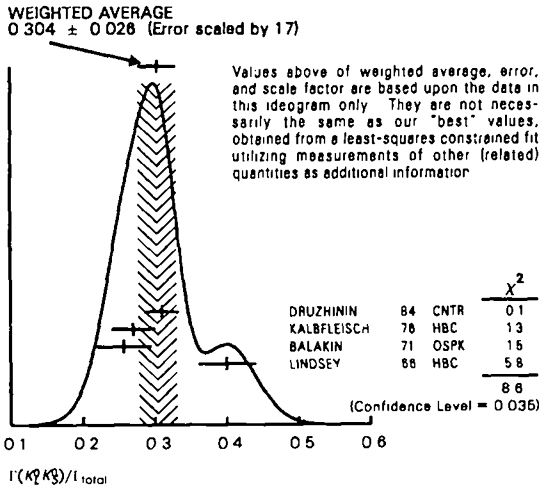
$\phi(1020)$ BRANCHING RATIOS

$\Gamma(K^+K^-)/\Gamma_{total}$ Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.495 ± 0.010 OUR FIT Error includes scale factor of 1.3					
0.497 ± 0.019 OUR AVERAGE					
0.45 ± 0.05	321	KALBFLEISCH	76	HBC	2.18 K^-p
0.49 ± 0.06	270	DEGROOT	74	HBC	4.2 $K^-p \to \Lambda\phi$
0.540 ± 0.034		BALAKIN	71	OSPK	e^+e^-
0.486 ± 0.044		CHATELUS	71	OSPK	e^+e^-
0.48 ± 0.04	252	LINDSEY	66	HBC	2.7 K^-p

$\Gamma(K_L^0K_S^0)/\Gamma_{total}$ Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.344 ± 0.009 OUR FIT Error includes scale factor of 1.3					
0.304 ± 0.026 OUR AVERAGE Error includes scale factor of 1.7. See the ideogram below.					
0.310 ± 0.024		DRUZHININ	84	CNTR	$e^+e^- \to K_L^0K_S^0$
0.27 ± 0.03	133	KALBFLEISCH	76	HBC	2.18 K^-p
0.257 ± 0.038		BALAKIN	71	OSPK	e^+e^-
0.40 ± 0.04	167	LINDSEY	66	HBC	2.7 K^-p



$[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\rho\pi)]/\Gamma_{total}$ $(\Gamma_3+\Gamma_{15})/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.148 ± 0.010 OUR FIT Error includes scale factor of 1.7				
0.139 ± 0.007	[8] PARROUR	76B	OSPK	e^+e^-

[8] Using total width 4.1 MeV. The 3π mode is more than 80% $\rho\pi$ at the 90% confidence level.

$\Gamma(K_L^0K_S^0)/\Gamma(K\overline{K})$ $\Gamma_2/(\Gamma_1+\Gamma_2)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.410^{+0.010}_{-0.009}$ OUR FIT Error includes scale factor of 1.2					
0.45 ± 0.04 OUR AVERAGE					
0.44 ± 0.07		LONDON	66	HBC	2.2 K^-p
0.48 ± 0.07	52	BADIER	65B	HBC	3 K^-p
0.40 ± 0.10	10	SCHLEIN	63	HBC	2.0 K^-p

$[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\rho\pi)]/\Gamma(K\overline{K})$ $(\Gamma_3+\Gamma_{15})/(\Gamma_1+\Gamma_2)$

VALUE	DOCUMENT ID		TECN	COMMENT
0.177 ± 0.014 OUR FIT Error includes scale factor of 1.7				
0.24 ± 0.04 OUR AVERAGE				
0.237 ± 0.039	CERRADA	77B	HBC	4.2 $K^-p \to \Lambda 3\pi$
0.30 ± 0.15	LONDON	66	HBC	2.2 K^-p

$[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\rho\pi)]/\Gamma(K_L^0K_S^0)$ $(\Gamma_3+\Gamma_{15})/\Gamma_2$

VALUE	DOCUMENT ID		TECN	COMMENT
0.43 ± 0.04 OUR FIT Error includes scale factor of 1.7				
0.49 ± 0.05 OUR AVERAGE				
0.56 ± 0.13	BUKIN	78C	OLYA	e^+e^-
0.47 ± 0.06	COSME	74	OSPK	e^+e^-

$\Gamma(\mu^+\mu^-)/\Gamma_{total}$ Γ_6/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
2.48 ± 0.34 OUR AVERAGE				
2.69 ± 0.46	HAYES	71	CNTR	Photoproduction
2.17 ± 0.60	EARLES	70	CNTR	6.0 Bremsstr.
2.34 ± 1.01	MOY	69	CNTR	Photoproduction

$\Gamma(\eta\gamma)/\Gamma_{total}$ Γ_4/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0128 ± 0.0006 OUR FIT Error includes scale factor of 1.1					
0.0128 ± 0.0007 OUR AVERAGE Error includes scale factor of 1.2					
0.0130 ± 0.0006		[9] DRUZHININ	84	CNTR	$e^+e^- \to 3\gamma$
0.014 ± 0.002		[10] DRUZHININ	84	CNTR	$e^+e^- \to 6\gamma$
0.0088 ± 0.0020	290	KURDADZE	83C	OLYA	$e^+e^- \to 3\gamma$
0.0135 ± 0.0029		ANDREWS	77	CNTR	6.7–10 γCu
0.015 ± 0.004	54	[9] COSME	76	OSPK	e^+e^-

[9] From 2γ decay mode of η.
[10] From $3\pi^0$ decay mode of η.

$\Gamma(\pi^+\pi^-\gamma)/\Gamma_{total}$ Γ_9/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.007	90	COSME	74	OSPK	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.06	90	KALBFLEISCH	75	HBC	2.2 K^-p
<0.04		LINDSEY	65	HBC	2.7 K^-p

$\Gamma(\omega\gamma)/\Gamma_{total}$ Γ_{10}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.05	LINDSEY	66	HBC	2.7 K^-p

$\Gamma(\rho\gamma)/\Gamma_{total}$ Γ_{12}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.02	LINDSEY	66	HBC	2.7 K^-p

$\Gamma(e^+e^-)/\Gamma_{total}$ Γ_5/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
3.11 ± 0.10 OUR AVERAGE				
3.00 ± 0.21	BUKIN	78C	OLYA	e^+e^-
3.10 ± 0.14	[11] PARROUR	76	OSPK	e^+e^-
3.3 ± 0.3	COSME	74	OSPK	e^+e^-
2.81 ± 0.25	BALAKIN	71	OSPK	e^+e^-
3.50 ± 0.27	CHATELUS	71	OSPK	e^+e^-

[11] Using total width 4.2 MeV. They detect 3π mode and observe significant interference with ω tail. This is accounted for in the result quoted above.

$\Gamma(\pi^0\gamma)/\Gamma_{total}$ Γ_7/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.31 ± 0.13 OUR AVERAGE					
1.30 ± 0.13		DRUZHININ	84	CNTR	$e^+e^- \to 3\gamma$
1.4 ± 0.5	32	COSME	76	OSPK	e^+e^-

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ Γ_8/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
$0.8^{+0.5}_{-0.4}$ OUR AVERAGE Error includes scale factor of 1.5					
$0.63^{+0.37}_{-0.28}$		[12] GOLUBEV	86	CNTR	e^+e^-
$1.94^{+1.03}_{-0.81}$		[12] VASSERMAN	81	OLYA	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<6.6	95	BUKIN	78B	OLYA	e^+e^-
<4.0	95	JULLIAN	76	OSPK	e^+e^-
<2.7	95	ALVENSLEBEN	72	OSPK	γC

[12] Using $\Gamma(e^+e^-)/\Gamma_{total} = 3.1 \times 10^{-4}$.

$\Gamma(K_L^0K_S^0)/\Gamma(K^+K^-)$ Γ_2/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.694 ± 0.028 OUR FIT Error includes scale factor of 1.2					
0.736 ± 0.030 OUR AVERAGE					
0.70 ± 0.05		BUKIN	78C	OLYA	e^+e^-
0.82 ± 0.08		LOSTY	78	HBC	4.2 $K^-p \to \phi$ hyperon
0.71 ± 0.05		LAVEN	77	HBC	10 $K^-p \to K^+K^-\Lambda$
0.71 ± 0.08		LYONS	77	HBC	3–4 $K^-p \to \Lambda\phi$
0.89 ± 0.10	144	AGUILAR-...	72B	HBC	3.9,4.6 K^-p

$[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\rho\pi)]/\Gamma(K^+K^-)$ $(\Gamma_3+\Gamma_{15})/\Gamma_1$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.299 ± 0.025 OUR FIT Error includes scale factor of 1.7					
0.28 ± 0.09	34	AGUILAR-...	72B	HBC	3.9,4.6 K^-p

$\Gamma(\eta e^+e^-)/\Gamma_{total}$ Γ_{16}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
$1.3^{+0.8}_{-0.6}$	7	GOLUBEV	85	CNTR	$e^+e^- \to \gamma\gamma e^+e^-$

$\Gamma(\eta'(958)\gamma)/\Gamma_{total}$ — Γ_{17}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<4.1	90	DRUZHININ	87	CNTR	e^+e^-

$\Gamma(\pi^0\pi^0\gamma)/\Gamma_{total}$ — Γ_{18}/Γ

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<1	90	DRUZHININ	87	CNTR	$e^+e^- \to 5\gamma$

$\Gamma(\pi^+\pi^+\pi^-\pi^-\pi^0)/\Gamma(K^+K^-)$ — Γ_{13}/Γ_1

0.04 CL for 1σ with $\phi \to K^+K^-$ = 0.47 0.09 CL for 1σ for num/total

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	95	AGUILAR	72B	HBC	3.9 4.6 K^-p

$\Gamma(\pi^+\pi^-\pi^+\pi^-)/\Gamma_{total}$ — Γ_{14}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<8.7	90	CORDIER	79	WIRE	$e^+e^- \to 4\pi$

$\Gamma(\rho\pi)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\eta\gamma) + \Gamma(\rho\pi)]$ — $\Gamma_{15}/(\Gamma_3+\Gamma_4+\Gamma_{15})$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>0.8	90	JULLIAN	76	OSPK	e^+e^-

$\phi(1020)$ REFERENCES

DRUZHINININ 87 ZPHY C37 1 +Dubrovin, Eidelman, Golubev+ (NOVO)
ARMSTRONG 86 PL 166B 245 +Bloodworth, Carney+ (ATHU, BARI, BIRM, CERN)
ATKINSON 86 ZPHY C30 521 + (BONN, CERN, GLAS, LANC, MCHS, LPNP+)
BEBEK 86 PRL 56 1893 + (CLEO Collab.)
DAVENPORT 86 PR 33 2519 (TUFT, ARIZ, FNAL, FSU, NDAM, VAND)
DIJKSTRA 86 ZPHY C31 375 +Bailey+ (ANIK, BRIS, CERN, CRAC, MPIM, RAL)
FRAME 86 NP B276 667 +Hughes, Lynch, Minto, McFadzean+ (GLAS)
GOLUBEV 86 SJNP 44 409 +Druzhinin, Ivanchenko, Perevedentsev+ (NOVO)
Translated from YAF 44 633.
ALBRECHT 85D PL 153B 343 +Drescher+ (ARGUS Collab.)
GOLUBEV 85 SJNP 41 756 +Druzhinin, Ivanchenko, Peryshkin+ (NOVO)
Translated from YAF 41 1183.
DRUZHININ 84 PL 144B 136 +Golubev, Ivanchenko, Peryshkin+ (NOVO)
ARMSTRONG 83B NP B224 193 + (BARI, BIRM, CERN, MILA, LPNP, PAVI)
BARATE 83 PL 121B 449 +Bareyre, Bonamy+ (SACL, LOIC, SHMP, IND)
KURDADZE 83C JETPL 38 366 +Lelchuk, Root+ (NOVO)
Translated from ZETFP 38 306.
ARENTON 82 PR D25 2241 +Ayres, Diebold, May, Swallow+ (ANL, ILL)
PELLINEN 82 PS 25 599 +Roos (HELS)
DAUM 81 PL 100B 439 +Bardsley+ (AMST, BRIS, CERN, CRAC, MPIM+)
IVANOV 81 PL 107B 297 +Kurdadze, Lelchuk, Sidorov, Skrinsky+ (NOVO)
Also 82 Private Comm. Eidelman (NOVO)
VASSERMAN 81 PL 99B 62 +Kurdadze, Sidorov, Skrinsky+ (NOVO)
CORDIER 80 NP B172 13 +Delcourt, Eschstruth, Fulda+ (LALO)
BARKOV 79B IYAF 79 93 +Zolotorev, Makarina, Mishakova+ (NOVO)
CORDIER 79 PL 81B 389 +Delcourt, Eschstruth, Fulda+ (LALO)
BUKIN 78B SJNP 27 521 +Kurdadze, Sidorov, Skrinsky+ (NOVO)
Translated from YAF 27 985.
BUKIN 78C SJNP 27 516 +Kurdadze, Serednyakov, Sidorov+ (NOVO)
Translated from YAF 27 976.
COOPER 78B NP B146 1 +Gurtu+ (TATA, CERN, CDEF, MADR)
LOSTY 78 NP B133 38 +Holmgren, Blokzijl+ (CERN, AMST, NIJM, OXF)
AKERLOF 77 PRL 39 861 +Alley, Bintinger, Ditzler+ (FNAL, MICH, PURD)
ANDREWS 77 PRL 38 198 +Fukushima, Harvey, Lobkowicz, May+ (ROCH)
BALDI 77 PL 68B 381 +Bohringer, Dorsaz, Hungerbuhler+ (GEVA)
CERRADA 77B NP B126 241 +Blockzijl, Heinen+ (AMST, CERN, NIJM, OXF)
COHEN 77 PRL 38 269 +Ayres, Diebold, Kramer, Pawlicki, Wicklund (ANL)
LAVEN 77 NP B127 43 +Otter, Klein+ (AACH, BERL, CERN, LOIC, WIEN)
LYONS 77 NP B125 207 +Cooper, Clark (OXF)
COSME 76 PL 63B 352 +Courau, Dudelzak, Grelaud, Jean-Marie+ (ORSA)
JULLIAN 76 Tbilisi 2 B19 (ORSA)
KALBFLEISCH 76 PR D13 22 +Strand, Chapman (BNL, MICH)
PARROUR 76 PL 63B 357 +Grelaud, Cosme, Courau, Dudelzak+ (ORSA)
PARROUR 76B PL 63B 362 +Grelaud, Cosme, Courau, Dudelzak+ (ORSA)
KALBFLEISCH 75 PR D11 987 +Strand, Chapman (BNL, MICH)
AYRES 74 PRL 32 1463 +Diebold, Greene, Kramer, Levine+ (ANL)
BESCH 74 NP B70 257 +Hartmann, Kose, Krautschneider, Paul+ (BONN)
COSME 74 PL 48B 155 +Jean-Marie, Jullian, Laplanche+ (ORSA)
COSME 74B PL 48B 159 +Jean-Marie, Jullian, Laplanche+ (ORSA)
DEGROOT 74 NP B74 77 +Hoogland, Jongejans, Metzger+ (AMST, NIJM)
BALLAM 73 PR D7 3150 +Chadwick, Eisenberg, Bingham+ (SLAC, LBL)
BINNIE 73B PR D8 2789 +Carr, Debenham, Duane+ (LOIC, SHMP)
AGUILAR 72B PR D6 29 Aguilar-Benitez, Chung, Eisner, Samios (BNL)
ALVENSLEBEN 72 PRL 28 66 +Becker, Biggs, Binkley+ (MIT, DESY)
BORENSTEIN 72 PR D5 1559 +Danburg, Kalbfleisch+ (BNL, MICH)
COLLEY 72 NP B50 1 +Jobes, Riddiford, Griffiths+ (BIRM, GLAS)
BALAKIN 71 PL 34B 328 +Budker, Pakhtusova, Sidorov, Skrinsky+ (NOVO)
CHATELUS 71 LAL 1247 Thesis (STRB)
Also 70 PL 32 416 Bizot, Buon, Chatelus, Jeanjean+ (ORSA)
HAYES 71 PR D4 899 +Imlay, Joseph, Keizer, Stein (CORN)
STOTTLEMYER 71 ORO 2504 170 Thesis (UMD)
BIZOT 70 PL 32 416 +Buon, Chatelus, Jeanjean+ (ORSA)
Also 69 Liverpool Sym. 69 Perez y Jorba
EARLES 70 PRL 25 1312 +Faissler, Gettner, Lutz, Moy, Tang+ (NEAS)
AUGUSTIN 69 PL 28B 517 +Bizot, Buon, Delcourt, Haissinski+ (ORSA)
MOY 69 Thesis (NEAS)
LINDSEY 66 PR 147 913 +Smith (LRL)
LONDON 66 PR 143 1034 +Rau, Goldberg, Lichtman+ (BNL, SYRA)
BADIER 65B PL 17 337 +Demoulin, Barloutaud+ (EPOL, SACL, AMST)
LINDSEY 65 PRL 15 221 +Smith (LRL)
LINDSEY 65 data included in LINDSEY 66.
SCHLEIN 63 PRL 10 368 +Slater, Smith, Stork, Ticho (UCLA)

OTHER RELATED PAPERS

GEORGIO 85 PL 152B 428 Georgiopoulos+ (TUFT, ARIZ, FNAL, FSU, NDAM+)
ROOS 80 LNC 27 321 +Pellinen (HELS)
BARTALUCCI 78 NC 44A 587 +Basini, Bertolucci+ (DESY, FRAS)
COURANT 77 PR D16 1 +Makdisi, Marshak, Peterson, Ruddick+ (MINN)
EVANGELISTA 77 NP B127 384 + (BARI, BONN, CERN, DARE, GLAS+)
BIZZARRI 74 NC 20A 393 +Ciapetti, Dionisi, Dore, Gaspero+ (ROMA)
BALAKIN 72 PL 40B 431 +Bokin, Pakhtusova, Sidorov+ (NOVO)
BASILE 72 NP B44 605 +Dalpiaz, Frabetti, Zichichi+ (CERN, BGNA, STRB)
BENAKSAS 72C PL 42B 511 +Cosme, Jean-Marie, Jullian, Laplanche+ (ORSA)
ALVENSLEBEN 71B PRL 27 441 +Becker, Busza, Chen+ (MIT, DESY)
DIBIANCA 71 NP B35 13 +Einschlag, Endorf, Engler, Fisk+ (CORN)
BIZOT 70B LNC 4 1273 +Delcourt, Jeanjean, Lalanne+ (ORSA)
HYAMS 70 NP B22 189 +Koch, Potter, VonLindern+ (CERN, MPIM)
SCOTTER 69 NC 62A 1057 +Erskine, Paler+ (BIRM, GLAS, LOIC, MPIM, OXF)
ABRAMS 68 PR 175 1697 +Glasser, Kehoe, Sechi-Zorn, Wolsky (UMD)
ASTVACAT 68 PL 27B 45 Astvacaturov, Azimov, Baldin+ (JINR, MOSU)
Also 67 PRL 19 869 Asbury, Becker, Bertram, Ting+ (DESY, COLU)
BINNIE 68 PL 27B 106 +Duane, Faruqi, Horsey+ (LOIC, RHEL)
BOLLINI 68B NC 56A 1171 +Buhler, Dalpiaz, Massam+ (CERN, BGNA, STRB)
MOSTEK 68 PRL 20 1057 +Eisenhandler, McClellan, Mistry+ (CORN)
WEHMANN 68 PRL 20 748 +Engels+ (HARV, CASE, SLAC, CORN, MCGI)
ABRAMS 67 MD Tech Rep 720 Thesis (UMD)
BARLOW 67 NC 50A 701 +Lillestol, Montanet+ (CERN, CDEF, IRAD, LIVP)
CHASE 67 PRL 18 710 +Rothwell, Weinstein (CEA, NEAS)
DAHL 67 PR 163 1377 +Hardy, Hess, Kirz, Miller (LRL)
HERTZBACH 67 PR 155 1461 +Kraemer, Madanski, Zdanis+ (JHU, BNL)
KHACHAT 67 PL 24B 349 Khachaturyan, Azimov, Baldin, Belousov+ (JINR)
GRAY 66 PRL 17 501 +Hagerty, Bizzarri, Ciapetti+ (SYRA, ROMA) GJP
LINDSEY 66B PL 20 93 +Smith (LRL)
BARBARO 65 PRL 14 279 Barbaro-Galtieri, Tripp (LRL)
BERLEY 65B PR 139B 1097 +Gelfand (BNL, COLU)
MILLER 65B CU 237; Nevis 131 Thesis (COLU)
ARMENTEROS 63B Siena Conf. 2 70 +Edwards, Astier+ (CERN, CDEF)
GELFAND 63B PRL 11 438 +Miller, Nussbaum, Kirsch+ (COLU, RUTG)
BERTANZA 62 PRL 9 180 +Brisson, Connolly, Hart+ (BNL, SYRA)

$h_1(1170)$ was $H(1190)$

$I^G(J^{PC}) = 0^-(1^{+-})$

$h_1(1170)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1172 ± 40 OUR AVERAGE					
1160 ± 50	ANDO	87	SPEC	0	$8\ \pi p \to 3\pi n$
1190 ± 60	[1] DANKOWY	81	SPEC	0	$8\ \pi p \to 3\pi n$

[1] Uses the model of BOWLER 75.

$h_1(1170)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
335 ± 26 OUR AVERAGE					
340 ± 30	ANDO	87	SPEC	0	$8\ \pi p \to 3\pi n$
320 ± 50	[2] DANKOWY	81	SPEC	0	$8\ \pi p \to 3\pi n$

[2] Uses the model of BOWLER 75.

$h_1(1170)$ DECAY MODES

Γ_1 $h_1(1170) \to \rho\pi$

$h_1(1170)$ BRANCHING RATIOS

$\Gamma(\rho\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
SEEN	ANDO	87	SPEC	0	$8\ \pi p \to 3\pi n$
SEEN	ATKINSON	84	OMEG		20-70 $\gamma p \to \pi^+\pi^-\pi^0 p$
SEEN	DANKOWY	81	SPEC		$8\ \pi p \to 3\pi n$

$h_1(1170)$ REFERENCES

ANDO 87 Hadron Conf. +Imai, Inaba (KEK)
ATKINSON 84 NP B231 15 + (BONN, CERN, GLAS, LANC, MCHS, LPNP+)
DANKOWY 81 PRL 46 580 Dankowych+ (TNTO, BNL, CARL, MCGI, OHIO)
BOWLER 75 NP B97 227 +Game, Aitchison, Dainton (OXF, DARE)

$b_1(1235)$ was $B(1235)$

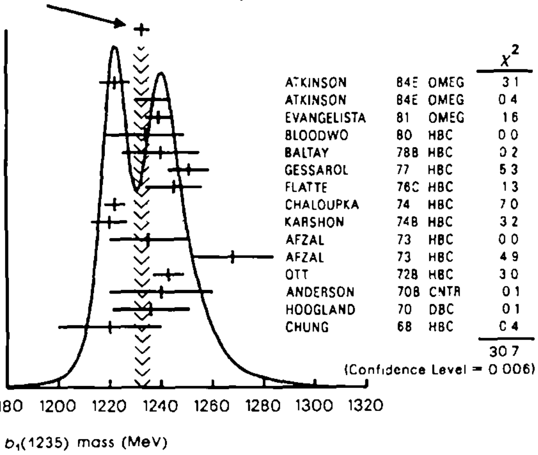
$I^G(J^{PC}) = 1^+(1^{+-})$

$b_1(1235)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1232.6 ± 3 0	**OUR AVERAGE**	Error includes scale factor of 1 5 See the ideogram below				
1222 ± 6		ATKINSON	84E	OMEG	±	25–55 $\gamma p \to \omega \pi X$
1237 ± 7		ATKINSON	84E	OMEG	0	25–55 $\gamma p \to \omega \pi X$
1239 ± 5		EVANGELISTA	81	OMEG	−	12 $\pi^- p \to \omega \pi p$
1234 0 ± 15 0	105	BLOODWO	80	HBC	−	8 2 $K^- p$
1240 0 ± 15 0	225	BALTAY	78B	HBC	+	15 $\pi^+ p \to p 4\pi$
1251 0 ± 8 0	450	GESSAROLI	77	HBC	−	11 $\pi^- p \to \pi^- \omega p$
1245 0 ± 11 0	890	FLATTE	76C	HBC	−	4 2 $K^- p \to \pi^- \omega \Sigma^+$
1222 ± 4	1400	CHALOUPKA	74	HBC	−	3 9 $\pi^- p$
1220 ± 7	600	KARSHON	74B	HBC	+	4 9 $\pi^+ p$
1235 ± 15		AFZAL	73	HBC	+	11 7 $\pi^+ p$
1268 ± 16		AFZAL	73	HBC	−	11 2 $\pi^- p$
1243 ± 6	1163	[1] OTT	72B	HBC	+	7 1 $\pi^+ p$
1240 0 ± 20 0		ANDERSON	70B	CNTR	0	5–18 γp
1236 0 ± 15 0		HOOGLAND	70	DBC	−	3 0 $K^- d$
1220 ± 20		CHUNG	68	HBC	−	3 2 4 2 $\pi^- p$
• • • We do not use the following data for averages, fits limits etc • • •						
1213 ± 5		ATKINSON	84C	OMEG	0	20–70 γp
1271 ± 11		COLLICK	84	SPEC	+	200 $\pi^+ Z \to Z \pi \omega$
1208 0 ± 18 0	360	GAVILLET	78B	HBC	+	4 2 $K^- p$ backward
1228 ± 5		[2] FRENKIEL	72	HBC	±	0 0 $\bar{p}p$ 5π

[1] From fit of the mass spectrum
[2] Fit requires an additional $J^P = 1^-$ resonance at 1256 MeV width 129 MeV

WEIGHTED AVERAGE
1232 6 ± 3 0 (Error scaled by 1 5)



$b_1(1235)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
150 ± 7	**OUR AVERAGE**					
170 ± 15		EVANGELISTA	81	OMEG	−	12 $\pi^- p \to \omega \pi p$
150 0 ± 50 0	105	BLOODWO	80	HBC	−	8 2 $K^- p$
170 0 ± 50 0	225	BALTAY	78B	HBC	+	15 $\pi^+ p \to p 4\pi$
155 0 ± 32 0	450	GESSAROLI	77	HBC	−	11 $\pi^- p \to \pi^- \omega p$
182 0 ± 45 0	890	FLATTE	76C	HBC	−	4 2 $K^- p \to \pi^- \omega \Sigma^+$
135 ± 20	1400	CHALOUPKA	74	HBC	−	3 9 $\pi^- p$
156 ± 22	600	KARSHON	74B	HBC	+	4 9 $\pi^+ p$
120 ± 50		AFZAL	73	HBC	+	11 7 $\pi^+ p$
130 ± 50		AFZAL	73	HBC	−	11 2 $\pi^- p$
134 $^{+23}_{-26}$	1163	[3] OTT	72B	HBC	+	7 1 $\pi^+ p$
132 0 ± 20 0		HOOGLAND	70	DBC	−	3 0 $K^- d$
150 ± 20		CHUNG	68	HBC	−	3 2,4 2 $\pi^- p$
• • • We do not use the following data for averages fits limits etc • • •						
231. ± 14		ATKINSON	84C	OMEG	0	20–70 γp
232 ± 29		COLLICK	84	SPEC	+	200 $\pi^+ Z \to Z \pi \omega$
163 0 ± 50 8	360	GAVILLET	78B	HBC	+	4 2 $K^- p$ backward
126 ± 10		[4] FRENKIEL	72	HBC	±	0 0 $\bar{p}p$ 5π

[3] From fit of the mass spectrum
[4] See note under the FRENKIEL 72 mass above

$b_1(1235)$ DECAY MODES

Γ_1	$b_1(1235) \to \omega \pi$
Γ_2	$b_1(1235) \to \pi^+ \pi^+ \pi^- \pi^0$
Γ_3	$b_1(1235) \to K \bar{K}$
Γ_4	$b_1(1235) \to \pi \pi$
Γ_5	$b_1(1235) \to \pi \phi$
Γ_6	$b_1(1235) \to \eta \pi$
Γ_7	$b_1(1235) \to (K \bar{K})^{\pm} \pi^0$
Γ_8	$b_1(1235) \to K_S^0 K_S^0 \pi^{\pm}$
Γ_9	$b_1(1235) \to K_S^0 K_L^0 \pi^{\pm}$
Γ_{10}	$b_1(1235) \to \eta \rho$
Γ_{11}	$b_1(1235) \to \pi^{\pm} \gamma$

$b_1(1235)$ PARTIAL WIDTHS

$\Gamma(\pi^{\pm}\gamma)$ — Γ_{11}

VALUE (keV)	DOCUMENT ID		TECN	CHG	COMMENT
230 0 ± 60 0	COLLICK	84	SPEC	+	200 $\pi^+ Z \to Z \pi \omega$

$b_1(1235)$ D-wave/S-wave RATIO IN DECAY OF $b_1(1235) \to \omega \pi$

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.260 ± 0.035	**OUR AVERAGE**					
0 235 ± 0 047		ATKINSON	84C	OMEG		20–70 γp
0 4 $^{+0\ 1}_{-0\ 1}$		GESSAROLI	77	HBC	−	11 $\pi^- p \to \pi^- \omega p$
0 21 ± 0 08		CHUNG	75B	HBC	+	7 1 $\pi^+ p$
0 3 ± 0 1		CHALOUPKA	74	HBC	−	3 9–7 5 $\pi^- p$
0 35 ± 0 25	600	KARSHON	74B	HBC	+	4 9 $\pi^+ p$

$b_1(1235)$ BRANCHING RATIOS

$\Gamma(\pi^+ \pi^+ \pi^- \pi^0)/\Gamma(\omega \pi)$ — Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
<0 5	ABOLINS	63	HBC	+	3 5 $\pi^+ p$

$\Gamma(K\bar{K})/\Gamma(\omega\pi)$ — Γ_3/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.02		DAHL	67	HBC	−	1 6–4 2 $\pi^- p$
• • • We do not use the following data for averages fits limits etc • • •						
<0 08	95	BIZZARRI	69	HBC	±	0 0 $\bar{p}p$
<0 10	90	BALTAY	67	HBC	±	0 0 $\bar{p}p$

$\Gamma(\pi\pi)/\Gamma(\omega\pi)$ — Γ_4/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.15	90	OTT	72B	HBC	+	7 1 $\pi^+ p$
• • • We do not use the following data for averages fits limits etc • • •						
<0 3		ADERHOLZ	64B	HBC		4 0 $\pi^+ p$

$\Gamma(\pi\phi)/\Gamma(\omega\pi)$ — Γ_5/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.015		DAHL	67	HBC		1 6–4 2 $\pi^- p$
• • • We do not use the following data for averages fits limits etc • • •						
<0 04	95	BIZZARRI	69	HBC	±	0 0 $\bar{p}p$

$\Gamma(\eta\pi)/\Gamma(\omega\pi)$ — Γ_6/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.25	90	BALTAY	67	HBC	±	0 0 $\bar{p}p$

$\Gamma((K\bar{K})^{\pm}\pi^0)/\Gamma(\omega\pi)$ — Γ_7/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.08	90	BALTAY	67	HBC	±	0 0 $\bar{p}p$

$\Gamma(K_S^0 K_S^0 \pi^{\pm})/\Gamma(\omega\pi)$ — Γ_8/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.02	90	BALTAY	67	HBC	±	0 0 $\bar{p}p$

$\Gamma(K^0_S K^0_S \pi^\pm)/\Gamma(\omega\pi)$ Γ_9/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.06	90	BALTAY	67	HBC	±	0.0 $\bar{p}p$

$\Gamma(\eta\rho)/\Gamma(\omega\pi)$ Γ_{10}/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
<0.10	ATKINSON	84D	OMEG	20–70 γp

$b_1(1235)$ REFERENCES

ATKINSON 84C NP B243 1 + (BONN CERN GLAS LANC MCHS LPNP+)
ATKINSON 84D NP B242 269 + (BONN CERN GLAS LANC MCHS LPNP+)
ATKINSON 84E PL 138B 459 + (BONN CERN GLAS LANC MCHS LPNP+)
COLLICK 84 PRL 53 2374 +Heppelmann Berg+ (MINN ROCH FNAL)
EVANGELISTA 81 NP B178 197 + (BARI BONN CERN DARE LIVP+)
BLOODWO 80 LNC 27 555 Bloodworth+ (BIRM CERN GLAS MSU LPNP)
BALTAY 78B PR D17 62 +Cautis Cohen Csorna+ (COLU BING)
GAVILLET 78B PL 78B 158 +Dionisi Gurtu+ (CERN AMST NIJM OXF) JP
GESSAROLI 77 NP B126 382 + (BGNA FIRZ GENO MILA OXF PAVI) JP
FLATTE 76C PL 64B 225 +Gay Blokzijl Metzger+ (CERN AMST NIJM OXF) JP
CHUNG 75B PR D11 2426 +Protopopescu Lynch Flatte+ (BNL LBL UCSC) JP
CHALOUPKA 74 PL 51B 407 +Ferrando Losty Montanet (CERN) JP
KARSHON 74B PR D10 3608 +Mikenberg Eisenberg Pitluck Ronat+ (REHO) JP
AFZAL 73 LNC 15A 61 +Bassler+ (DURH GENO DESY MILA SACL) JP
FRENKIEL 72 NP B47 61 +Ghesquiere Lillestol Chung+ (CDEF CERN) JP
OTT 72B LBL 1547 Thesis (LBL) JP
ANDERSON 70B PR D1 27 +Gustavson Johnson+ (SLAC CIT UCSB NEAS)
HOOGLAND 70 PL 33B 631 (SABRE Collab.)
BIZZARRI 69 NP B14 169 +Foster Gavillet Montanet+ (CERN CDEF)
CHUNG 68 PR 165 1491 +Dahl Kirz Miller (LRL)
BALTAY 67 PRL 18 93 +Franzini Severiens Yeh Zanello (COLU)
DAHL 67 PR 163 1377 +Hardy Hess Kirz Miller (LRL)
ADERHOLZ 64B PL 10 240 + (AACH BERL BIRM BONN HAMB LOIC+)
ABOLINS 63 PRL 11 381 +Lander Mehlhop Nguyen Yager (UCSD)

OTHER RELATED PAPERS

WONG 81 PRL 46 974 +Key Frisken Cline+ (TNTO YORK PURD)
DUBOVIKOV 75 SJNP 20 229 +Erofeev (ITEP) JP
Translated from YAF 20 428
BALLAM 74 NP B76 375 +Chadwick Bingham Fretter+ (SLAC LBL MPIM)
ARMENISE 73 NC 17A 707 +Forino Cartacci+ (BARI BGNA FIRZ)
ARMENISE 73B LNC 8 425 +Forino Cartacci+ (BARI BGNA FIRZ)
ARNOLD 73 LNC 6 707 +Engel Escoubes Kurtz Lloret Paty+ (STRB)
CASON 73 PR D7 1971 +Biswas Kenney Madden+ (NDAM)
CASON 73B NP B64 14 +Madden Bishop Biswas Kenney+ (NDAM)
CHUNG 73 PL 47B 526 +Protopopescu Lynch Flatte+ (BNL LBL UCSC) JP
COHEN 73C PR D8 23 +Ferbel Slattery (ROCH)
SISTERSON 72 NP B48 493 +Harrison Heyda Johnson+ (HARV)
DEVONS 71 PRL 27 1614 +Kozlowski Horwitz+ (COLU SYRA)
CASO 70 LNC 3 707 +Conte Tomasini+ (GENO HAMB MILA SACL)
CASON 70 PR D1 851 +Andrews Biswas Groves Harrington+ (NDAM)
EROFEEV 70 SJNP 11 450 +Vetlitsky Wladimirsky Grigorev+ (ITEP)
Translated from YAF 11 805
HONES 70 PR D2 827 +Cason Biswas Helland Kenney+ (NDAM)
MIYASHITA 70 PR D1 771 +VonKrogh Kopelman Libby (COLO)
POLS 70 NP B25 109 +Boeckmann Cirba+ (BONN DURH EPOL TORI)
WERBROUCK 70 LNC 4 1267 +Rinaudo+ (TORI NIJM BONN LBL) JP
ASCOLI 68B PRL 20 1411 +Crawley Mortara Shapiro (ILL) JP
BOESEBECK 68 NP B4 501 +Deutschmann+ (AACH BERL CERN)
CASO 68 NC 54A 983 +Conte Cords Diaz+ (GENO HAMB MILA SACL)
LEE 67 PR 159 1156 +Moebs Roe Sinclair VanderVelde (MICH)
SLATTERY 67 NC 50A 377 +Kraybill Forman Ferbel (YALE ROCH)
GOLDHABER 65 PRL 15 118 +Goldhaber Kadyk Shen (LRL)
CARMONY 64 PRL 12 254 +Lander Rindfleisch Xuong Yager (UCB) JP
BONDAR 63B PL 5 209 +Dodd+ (AACH BIRM HAMB LOIC MPIM)

$f_0(1240)$
was $g_S(1240)$

$I^G(J^{PC}) = 0^+(0^{++})$

OMITTED FROM SUMMARY TABLE

Seen in phase shift analysis of $K^0_S K^0_S$ system. Named g_S by ETKIN 82C. Needs confirmation.

$f_0(1240)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1240.0 ± 10 ± 20	ETKIN	82C	MPS	0	23 $\pi^- p \to n 2K^0_S$

$f_0(1240)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
140.0 ± 10 ± 20	ETKIN	82C	MPS	0	23 $\pi^- p \to n 2K^0_S$

$f_0(1240)$ DECAY MODES

Γ_1 $f_0(1240) \to K\bar{K}$

$f_0(1240)$ REFERENCES

ETKIN 82C PR D25 2446 +Foley Lai+ (BNL CUNY TUFT VAND) JP

$a_1(1260)$
was $A_1(1270)$

$I^G(J^{PC}) = 1^-(1^{++})$

See also the mini-review under non-$q\bar{q}$ candidates.

NOTE ON $a_1(1260)$

The long-standing question concerning the resonance parameters of the $a_1(1260)$ has been clarified by four new experiments on $\tau \to a_1(1260)\nu \to \rho\pi\nu$ (ALBRECHT 86B, BAND 87, RUCKSTUHL 86, SCHMIDKE 86). These τ decay data have been reanalyzed by BOWLER 86 and TORNQVIST 87, who resolve the apparent inconsistencies quoted for the mass and width by using the same parametrization for all experiments [not including the very recent data of BAND 87, whose data are consistent with the others (BARISH 88)]. BOWLER 86 and TORNQVIST 87 use different analytic forms; this explains their slightly different mass values.

The analyses of the hadronically produced $a_1(1260)$ are similar to the BOWLER 86 analyses. In order to have comparable data, we use the BOWLER 86 value in the averaging, together with the data from hadronic production, although inclusion of further unitarity effects (TORNQVIST 87) presumably would increase the mass extracted from both data sets.

In all these analyses the mass is defined as the energy where the $\pi\rho$ phase shift passes 90°, not as the S-matrix pole position. Although the latter has the theoretical advantage of simple factorization, it is much more sensitive to the analytic continuation defined by the expression used. For a broad resonance like the $a_1(1260)$, the pole position and the 90° mass value differ considerably for the same analytic form.

Although the τ data are expected to be less affected by background than the hadronic data, they do include systematic uncertainties of two kinds. (i) There may be a contamination due to $\tau \to \pi(1300)\nu \to \rho\pi\nu$, which, although forbidden by PCAC, could be present at the 10% level. Also the decay mode $a_1(1260) \to (\pi\pi)_{S\text{-wave}}\pi$ leads to the same 3π final state and may slightly modify the extracted $a_1(1260)$ parameters, although the effect presumably is negligible since the branching fraction is only 0.003 ± 0.003 (LONGACRE 82). (ii) There is an ≈30 MeV uncertainty

Meson Full Listings
$a_1(1260)$, $f_2(1270)$

due to the weak-interaction form factor at the W-$a_1(1260)$ transition (usually parametrized by the parameter x as x [illegible])

It should also be noted that although a consistent mass value can be obtained from both τ decay and hadronic production data the width extracted from τ decay data is considerably larger than that from hadronic production This inconsistency cannot be resolved by the uncertainty due to the weak-interaction form factor discussed above

The hadronically produced $a_1(1260)$ data are dominated by the results of two high-statistics experiments dealing with diffractive (DAUM 80, 81B) and charge-exchange (DANKOWYCH 81) production of the 3π system in πp interactions The behavior of the 1^+S0^+ $(\rho\pi)$ amplitude requires the presence of both a Deck background and a resonance [in agreement with earlier studies of diffractive production on nuclei (PERNEGR 78)] The resonance parameters are obtained by fitting the intensity and relative phases of the partial-wave analysis to a phenomenological amplitude containing the resonance and the Deck background rescattered through a resonance (BOWLER 75 BASDEVANT 77) In the context of this analysis the Deck background is responsible for making the peak in the 1^+S0^- intensity appear some 110 MeV below the most likely resonance mass In our previous editions we obtained an average for the $a_1(1260)$ mass of 1275 ± 28 MeV using the hadronically produced data alone Note, however that in a backwardly produced 3π system in $K^- p \to \Sigma^- \pi^+ \pi^- \pi$ a very low mass, 1041 ± 13 MeV (GAVILLET 77) has been reported

$a_1(1260)$ MASS

VALUE (MeV)			DOCUMENT ID		TECN	CHG	COMMENT
1262	± 23	OUR AVERAGE					
1235	± 40		[1] BOWLER	86	RVUE		
1240 0	± 80.0		[2] DANKOWY	81	SPEC	0	8 45 $\pi^- p \to n 3\pi$
1280 0	± 30.0		[2] DAUM	81B	CNTR		63,94 $\pi^- p \to p 3\pi$
• • • We do not use the following data for averages fits limits etc • • •							
1166	± 18	± 11	[3] BAND	87	MAC		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
1164	± 41	± 23	[3] BAND	87	MAC		$\tau^+ \to \pi^+\pi^0\pi^0\nu$
1250	± 40		[1] TORNQVIST	87	RVUE		
1046	± 11		[3,4] ALBRECHT	86B	ARG		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
1056	± 20	± 15	[3,4] RUCKSTUHL	86	DLCO		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
1194	± 14	± 10	[3,4] SCHMIDKE	86	MRK2		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
1041 0	± 13 0		[5] GAVILLET	77	HBC	+	4 2 $K^- p \to \Sigma 3\pi$

[1] See mini review
[2] Uses the model of BOWLER 75
[3] From $\tau \to a_1 + \nu$ decays
[4] Included in BOWLER 86 and TORNQVIST 87 reviews
[5] Produced in K^- backward scattering

$a_1(1260)$ WIDTH

VALUE (MeV)			DOCUMENT ID		TECN	CHG	COMMENT
330	± 40	OUR AVERAGE					
400	± 100		[6] BOWLER	86	RVUE		
380 0	± 100 0		[7] DANKOWY	81	SPEC	0	8 45 $\pi^- p \to n 3\pi$
300 0	± 50 0		[7] DAUM	81B	CNTR		63 94 $\pi^- p \to p 3\pi$
• • • We do not use the following data for averages. fits limits etc • • •							
405	± 75	± 25	BAND	87	MAC		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
419	± 108	± 57	BAND	87	MAC		$\tau^+ \to \pi^+\pi^0\pi^0\nu$
600	± 100		[6] TORNQVIST	87	RVUE		
521	± 27		[8,9] ALBRECHT	86B	ARG		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
476.	$^{+132}_{-120}$	± 54	[8,9] RUCKSTUHL	86	DLCO		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
462	± 56	± 30	[8,9] SCHMIDKE	86	MRK2		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
230.0	± 50 0		[10] GAVILLET	77	HBC	+	4 2 $K^- p \to \Sigma 3\pi$

[6] See mini review
[7] Uses the model of BOWLER 75
[8] From $\tau \to a_1 + \nu$ decays
[9] Included in BOWLER 86 and TORNQVIST 87 reviews
[10] Produced in K^- backward scattering

$a_1(1260)$ DECAY MODES

Γ_1 $a_1(1260) \to \rho\pi$
Γ_2 $a_1(1260) \to K\bar{K}$
Γ_3 $a_1(1260) \to \pi(\pi\pi)_{S\text{-wave}}$
Γ_4 $a_1(1260) \to \pi\gamma$

$a_1(1260)$ PARTIAL WIDTHS

$\Gamma(\pi\gamma)$ Γ_4

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
640.0 ± 246.0	ZIELINSKI	84C	SPEC	200 $\pi^+ Z \to Z 3\pi$

$a_1(1260)$ BRANCHING RATIOS

$\Gamma(\pi(\pi\pi)_{S\text{-wave}})/\Gamma(\rho\pi)$ Γ_3/Γ_1

VALUE	DOCUMENT ID		TECN
0.003 ± 0.003	[11] LONGACRE	82	RVUE

[11] Uses multichannel Aitchison-Bowler model (BOWLER 75) Uses data from GAVILLET 77, DAUM 80 and DANKOWYCH 81

$a_1(1260)$ REFERENCES

BAND	87	PL B198 297	+Camporesi+	(MAC Collab)
TORNQVIST	87	ZPHY C36 695		(HELS)
ALBRECHT	86B	ZPHY C33 7	+Donker Gabriel+	(ARGUS Collab)
BOWLER	86	PL B182 400		(OXF)
RUCKSTUHL	86	PRL 56 2132	+Stroynowski+	(DELCO Collab)
SCHMIDKE	86	PRL 57 527	+Abrams Matteuzzi Amidei+	(MARK II Collab)
ZIELINSKI	84C	PRL 52 1195	+Berg Chandlee Cihangir+	(ROCH MINN FNAL)
LONGACRE	82	PR D26 83		(BNL)
DANKOWY	81	PRL 46 580	Dankowych+	(INTO BNL CARL MCGI OHIO)
DAUM	81B	NP B182 269	+Hertzberger+	(AMST CERN CRAC MPIM OXF+)
DAUM	80	PL 89B 281	+Hertzberger+	(AMST CERN CRAC MPIM OXF+) JP
GAVILLET	77	PL 69B 119	+Blockzijl Engelen+	(AMST CERN NIJM OXF) JP
BOWLER	75	NP B97 227	+Game Aitchison Dainton	(OXF DARE)

OTHER RELATED PAPERS

BARISH	88	PRPL 157 1	+Stroynowski	(CIT)
PERNEGR	78	NP B134 436	+Aebischer+	(ETH CERN LOIC MILA) JP
BASDEVANT	77	PR D16 657	+Berger	(FNAL ANL) JP
ADERHOLZ	64	PL 10 226	+	(AACH BERL BIRM BONN DESY HAMB+)
GOLDHABER	64	PRL 12 336	+Brown Kadyk Shen+	(LRL UCB)
LANDER	64	PRL 13 346A	+Abolins Carmony Hendricks Xuong+	(UCSD) JP
BELLINI	63	NC 29 896	+Fiorini Herz Negri Ratti	(MILA)

$f_2(1270)$

$I^G(J^{PC}) = 0^+(2^{++})$

Named f by SELOVE 62

$f_2(1270)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1274.2 ± 1.3	OUR AVERAGE	Error includes scale factor of 1 2			
1283 ± 6	400 ± 50	ALDE	87	GAM4	100 $\pi^- p \to 4\pi^0 n$
1274 ± 4		AUGUSTIN	87	DM2	$J/\psi \to \gamma\pi^+\pi^-$
1288 0 ± 12 0		ABACHI	86B	HRS	$e^+e^- \to \pi^+\pi^-$
1270 0 ± 10 0	1665	BREAKSTONE	86	SFM	$pp \to pp\pi^+\pi^-$
1283 0 ± 6 0		[1] LONGACRE	86	MPS	22 $\pi^- p \to n 2K^0_S$

1276 0 ± 7 0		COURAU	84	DLCO	$e^+e^- \to e^+e^-\pi^+\pi^-$
1273.3 ± 2.3		CHABAUD	83	ASPK	17 $\pi^- p$ polarized
1280 0 ± 4 0		CASON	82	STRC	8 $\pi^+ p \to p\pi^+ 2\pi^0$
1281 0 ± 7 0		GIDAL	81	MRK2	J/ψ decay
1282 0 ± 5.0		CORDEN	79	OMEG	12–15 $\pi^- p \to n2\pi$
1284 0 ± 10 0	16000	DEUTSCH	76	HBC	16 $\pi^+ p$
1269 ± 4	10k	APEL	75	CNTR	40 $\pi^- p \to n2\pi^0$
1272. ± 4	4600	ENGLER	74	DBC	6 $\pi^+ n \to \pi^+\pi^- p$
1258 0 ± 10 0	600	TAKAHASHI	72	HBC	8 $\pi^- p \to n2\pi$
1277.0 ± 4 0	5300	FLATTE	71	HBC	7 0 $\pi^+ p$
1275 0 ± 13 0		ARMENISE	70	HBC	9 $\pi^+ n \to p\pi^+\pi^-$
1261. ± 5	1960	[2] ARMENISE	68	DBC	5 1 $\pi^+ n \to p\pi^+ MM^-$
1270 ± 10	360	[2] ARMENISE	68	DBC	5 1 $\pi^+ n \to p\pi^0$ MM
1265 ± 8		BOESEBECK	68	HBC	8 $\pi^+ p$
1268 0 ± 6.0		[3] JOHNSON	68	HBC	3 7–4 2 $\pi^- p$
1276. ± 11		RABIN	67	HBC	8 5 $\pi^+ p$
• • • We do not use the following data for averages fits limits, etc • • •					
1284 0 ± 30.0	3k	BINON	83	GAM2	38 $\pi^- p \to n2\eta$
1280.0 ± 20 0	3k	APEL	82	CNTR	25 $\pi^- p \to n2\pi^0$

[1]From a partial-wave analysis of data using a K-matrix formalism with 5 poles

[2]Mass errors enlarged by us to $\Gamma/N^{1/2}$, see the note with the $K^*(892)$ mass

[3]JOHNSON 68 includes BONDAR 63, LEE 64 DERADO 65, EISNER 67

$f_2(1270)$ WIDTH

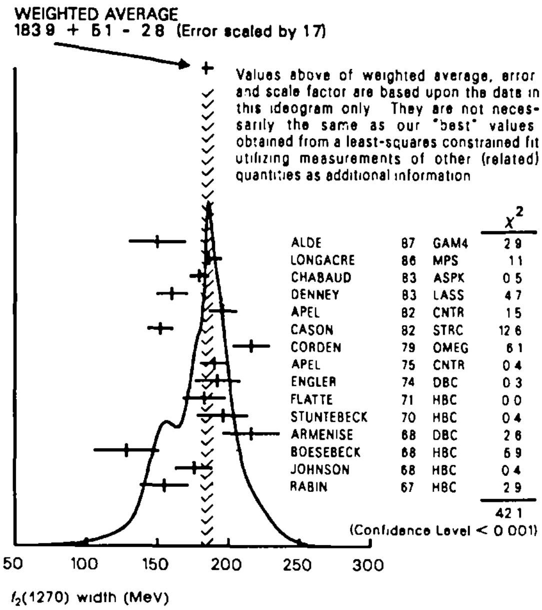
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
184.9 $^{+5.4}_{-2.4}$		**OUR FIT** Error includes scale factor of 1 5			
183.9 $^{+5.1}_{-2.8}$		**OUR AVERAGE** Error includes scale factor of 1 7 See the ideogram below			
150 ± 20	400 ± 50	ALDE	87	GAM4	100 $\pi^- p \to 4\pi^0 n$
186.0 $^{+9.0}_{-2.0}$		[4] LONGACRE	86	MPS	22 $\pi^- p \to n2K^0_S$
179.2 $^{+6\ 9}_{-6\ 6}$		[5] CHABAUD	83	ASPK	17 $\pi^- p$ polarized
160 0 ± 11 0		DENNEY	83	LASS	10 $\pi^+ N$
196 0 ± 10 0	3k	APEL	82	CNTR	25 $\pi^- p \to n2\pi^0$
152 0 ± 9.0		CASON	82	STRC	8 $\pi^+ p \to p\pi^+ 2\pi^0$
216.0 ± 13.0		CORDEN	79	OMEG	12–15 $\pi^- p \to n2\pi$
190 ± 10	10k	APEL	75	CNTR	40 $\pi^- p \to n2\pi^0$
192 ± 16.	4600	ENGLER	74	DBC	6 $\pi^+ n \to \pi^+\pi^- p$
183.0 ± 15 0	5300	FLATTE	71	HBC	7 $\pi^+ p \to \Delta^{++} f_2$
196 0 ± 18.0		STUNTEBECK	70	HBC	8 $\pi^- p$ 5 4 $\pi^+ d$
216. ± 20	1960	[6] ARMENISE	68	DBC	5 1 $\pi^+ n \to p\pi^+ MM^-$
128 ± 23.		BOESEBECK	68	HBC	8 $\pi^+ p$
176.0 ± 13 0		[7] JOHNSON	68	HBC	3 7–4 2 $\pi^- p$
155. ± 17		RABIN	67	HBC	8 5 $\pi^+ p$
• • • We do not use the following data for averages, fits limits, etc • • •					
196.0 ± 34 0	1665	BREAKSTONE	86	SFM	$pp \to pp\pi^+\pi^-$
240 0 ± 40.0	3k	BINON	83	GAM2	38 $\pi^- p \to n2\eta$
186.0 ± 27 0		GIDAL	81	MRK2	J/ψ decay
187 0 ± 30.0	650	[6] ANTIPOV	77	CIBS	25 $\pi^- p \to p3\pi$
225 0 ± 38 0	16000	DEUTSCH	76	HBC	16 $\pi^+ p$
166 0 ± 28 0	600	[6] TAKAHASHI	72	HBC	8 $\pi^- p \to n2\pi$
173.0 ± 25 0		ARMENISE	70	HBC	9 $\pi^+ n \to p\pi^+\pi^-$

[4]From a partial wave analysis of data using a K matrix formalism with 5 poles

[5]CHABAUD 83 analysis includes HYAMS 75

[6]Width errors enlarged by us to $4\Gamma/N^{1/2}$ see the note with the $K^*(892)$ mass

[7]JOHNSON 68 includes BONDAR 63, LEE 64 DERADO 65 EISNER 67



$f_2(1270)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	$f_2(1270) \to \pi\pi$	(85.8 $^{+2.0}_{-1.0}$)×10^{-2}	
Γ_2	$f_2(1270) \to 2\pi^+ 2\pi^-$	(2.8 ±0 4)×10^{-2}	1 2
Γ_3	$f_2(1270) \to \pi^+\pi^- 2\pi^0$	(6.4 $^{+1.2}_{-2\ 4}$)×10^{-2}	1 1
Γ_4	$f_2(1270) \to K\bar{K}$	(4.2 $^{+1\ 0}_{-0\ 6}$)×10^{-2}	3 7
Γ_5	$f_2(1270) \to K^0 K^- \pi^+$ + c c	< 3 ×10^{-3}	
Γ_6	$f_2(1270) \to \eta\pi\pi$	< 8 6 ×10^{-3}	
Γ_7	$f_2(1270) \to \eta\eta$	(4.5 ±1 0)×10^{-3}	2 4
Γ_8	$f_2(1270) \to \gamma\gamma$	(1 49 ± 0.08)×10^{-5}	
Γ_9	$f_2(1270) \to 4\pi^0$	(3 0 ±1 3)×10^{-3}	1 3

CONSTRAINED FIT INFORMATION

An overall fit to the total width, 4 partial widths, and 6 branching ratios uses 46 measurements and one constraint to determine 8 parameters The overall fit has a χ^2 = 113 8 for 39 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta p_i \delta p_j\rangle/(\delta p_i\ \delta p_j)$ in percent, from the fit to parameters p_i, including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i in this array to sum to one

x_2	9						
x_3	90	34					
x_4	8	0	40				
x_7	2	0	8	0			
x_8	24	2	−22	2	1		
x_9	0	0	8	0	0	0	
Γ	83	8	74	−7	−3	29	0
	x_1	x_2	x_3	x_4	x_7	x_8	x_9

	Mode	Rate (MeV)	Scale
Γ_1	$f_2(1270) \to \pi\pi$	158.6 $^{+2\ 9}_{-0\ 5}$	
Γ_2	$f_2(1270) \to 2\pi^+ 2\pi^-$	5 3 ±0 7	1 2
Γ_3	$f_2(1270) \to \pi^+\pi^- 2\pi^0$	11 9 $^{+2\ 5}_{-4\ 6}$	1 1
Γ_4	$f_2(1270) \to K\bar{K}$	7 8 $^{+2\ 0}_{-1\ 0}$	3 8
Γ_7	$f_2(1270) \to \eta\eta$	0 83 ±0 19	2 4
Γ_8	$f_2(1270) \to \gamma\gamma$	0 00276 ± 0.00014	
Γ_9	$f_2(1270) \to 4\pi^0$	0 55 $^{+0\ 24}_{-0\ 23}$	1 3

$f_2(1270)$ PARTIAL WIDTHS

$\Gamma(\pi\pi)$ — Γ_1

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
158.6 $^{+2.9}_{-0.5}$ OUR FIT			
157.0 $^{+6.0}_{-1.0}$	[8] LONGACRE 86	MPS	22 $\pi^- p \to n2K^0_S$

$\Gamma(K\bar{K})$ — Γ_4

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
7.8 $^{+2.0}_{-1.0}$ OUR FIT Error includes scale factor of 3 8			
9.0 $^{+0.7}_{-0.3}$	[8] LONGACRE 86	MPS	22 $\pi^- p \to n2K^0_S$

$\Gamma(\eta\eta)$ — Γ_7

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
0.83 ± 0.19	**OUR FIT** Error includes scale factor of 2.4			
1.0 ± 0.1	[8] LONGACRE	86	MPS	$22\ \pi^- p \to n 2K_S^0$

$\Gamma(\gamma\gamma)$ — Γ_8

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
2.76 ± 0.14	**OUR FIT**			
2.76 ± 0.14	**OUR AVERAGE**			
3.2 ± 0.1 ± 0.4	[9] AIHARA	86B	TPC	$e^+e^- \to e^+e^-\pi^+\pi^-$
2.5 ± 0.1 ± 0.5	BEHREND	84B	CELL	$e^+e^- \to e^+e^-\pi^+\pi^-$
2.85 ± 0.25 ± 0.5	BERGER	84	PLUT	$e^+e^- \to e^+e^-2\pi$
2.70 ± 0.21	COURAU	84	DLCO	$e^+e^- \to e^+e^-\pi^+\pi^-$
2.52 ± 0.13 ± 0.38	SMITH	84C	MRK2	$e^+e^- \to e^+e^-K^+K^-$
2.3 ± 0.2 ± 0.5	FRAZER	83	JADE	$e^+e^- \to e^+e^-\pi^+\pi^-$
2.7 ± 0.2 ± 0.6	EDWARDS	82F	CBAL	$e^+e^- \to e^+e^-2\pi^0$
3.2 ± 0.2 ± 0.6	BRANDELIK	81B	TASS	$e^+e^- \to e^+e^-2\pi^0$
3.6 ± 0.3 ± 0.5	ROUSSARIE	81	MRK2	$e^+e^- \to e^+e^-2\pi^0$
2.3 ± 0.8	[10] BERGER	80B	PLUT	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$2.9^{+0.6}_{-0.4}$ ± 0.6	[11] EDWARDS	82F	CBAL	$e^+e^- \to e^+e^-2\pi^0$

[8] From a partial wave analysis of data using a K matrix formalism with 5 poles.
[9] Radiative corrections modify the partial widths, for instance the COURAU 84 value becomes 2.66 ± 0.21 in the calculation of LANDRO 86.
[10] Using mass, width and BR($f_2(1270) \to 2\pi$) from PDG 78.
[11] If helicity = 2 assumption is not made.

$f_2(1270)$ BRANCHING RATIOS

$\Gamma(2\pi^+2\pi^-)/\Gamma(\pi\pi)$ — Γ_2/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.033^{+0.004}_{-0.005}$	**OUR FIT** Error includes scale factor of 1.2				
0.033 ± 0.004	**OUR AVERAGE** Error includes scale factor of 1.1				
0.024 ± 0.006	160	EMMS	75D	DBC	$4\ \pi^+ n \to p f_2$
0.051 ± 0.025	70	EISENBERG	74	HBC	$4.9\ \pi^+ p \to \Delta^{++} f_2$
$0.043^{+0.007}_{-0.011}$	285	LOUIE	74	HBC	$3.9\ \pi^- p \to n f_2$
0.037 ± 0.007	154	ANDERSON	73	DBC	$6\ \pi^+ n \to p f_2$
0.047 ± 0.013		OH	70	HBC	$1.26\ \pi^- p \to \pi^+\pi^- n$

$\Gamma(\pi^+\pi^-2\pi^0)/\Gamma(\pi\pi)$ — Γ_3/Γ_1

Should be twice $\Gamma(2\pi^+2\pi^-)/\Gamma(\pi\pi)$ if decay is $\rho\rho$. (See ASCOLI 68D.)

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.075^{+0.015}_{-0.030}$	**OUR FIT** Error includes scale factor of 1.1				
0.15 ± 0.06	600	EISENBERG	74	HBC	$4.9\ \pi^+ p \to \Delta^{++} f_2$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.07		EMMS	75D	DBC	$4\ \pi^+ n \to p f_2$

$\Gamma(K\overline{K})/\Gamma(\pi\pi)$ — Γ_4/Γ_1

We average only experiments which either take into account $f_2(1270)$–$a_2(1320)$ interference explicitly or demonstrate that $a_2(1320)$ production is negligible.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.049^{+0.011}_{-0.007}$	**OUR FIT** Error includes scale factor of 3.7				
$0.0345^{+0.0027}_{-0.0029}$	**OUR AVERAGE**				
$0.037^{+0.008}_{-0.021}$		ETKIN	82B	MPS	$23\ \pi^- p \to n 2K_S^0$
0.045 ± 0.009		CHABAUD	81	ASPK	$17\ \pi^- p$ polarized
0.036 ± 0.005		[12] COSTA	80	OMEG	$1\text{–}2.2\ \pi^- p \to K^+K^- n$
0.039 ± 0.008		LOVERRE	80	HBC	$4\ \pi^- p \to K\overline{K}N$
0.030 ± 0.005		[13] MARTIN	79	RVUE	
0.027 ± 0.009		[14] POLYCHRO	79	STRC	$7\ \pi^- p \to n 2K_S^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.025 ± 0.015		EMMS	75D	DBC	$4\ \pi^+ n \to p f_2$
0.031 ± 0.012	20	ADERHOLZ	69	HBC	$8\ \pi^+ p \to K^+K^-\pi^+ p$

[12] Re-evaluated by CHABAUD 83.
[13] Includes PAWLICKI 77 data.
[14] Takes into account the $f_2(1270)$ – $f_2'(1525)$ interference.

$\Gamma(K^0K^-\pi^+ + \text{c.c.})/\Gamma(\pi\pi)$ — Γ_5/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.004	95	EMMS	75D	DBC	$4\ \pi^+ n \to p f_2$

$\Gamma(\eta\pi\pi)/\Gamma(\pi\pi)$ — Γ_6/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.010	95	EMMS	75D	DBC	$4\ \pi^+ n \to p f_2$

$\Gamma(\eta\eta)/\Gamma(\pi\pi)$ — Γ_7/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.05	95	EDWARDS	82F	CBAL	$e^+e^- \to e^+e^-2\eta$
<0.016	95	EMMS	75D	DBC	$4\ \pi^+ n \to p f_2$
<0.09	95	EISENBERG	74	HBC	$4.9\ \pi^+ p \to \Delta^{++} f_2$

$\Gamma(\eta\eta)/\Gamma_{total}$ — Γ_7/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
4.5 ± 1.0	**OUR FIT** Error includes scale factor of 2.4			
3.1 ± 0.8	**OUR AVERAGE** Error includes scale factor of 1.3			
2.8 ± 0.7	ALDE	86D	GAM4	$100\ \pi^- p \to 4\gamma$
5.2 ± 1.7	BINON	83	GAM2	$38\ \pi^- p \to 4\gamma$

$\Gamma(\pi\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.858^{+0.020}_{-0.010}$	**OUR FIT**				
0.837 ± 0.020	**OUR AVERAGE**				
0.849 ± 0.025		CHABAUD	83	ASPK	$17\ \pi^- p$ polarized
0.85 ± 0.05	250	BEAUPRE	71	HBC	$8\ \pi^+ p \to \Delta^{++} f_2$
0.8 ± 0.04	600	OH	70	HBC	$1.26\ \pi^- p \to \pi^+\pi^- n$

$\Gamma(4\pi^0)/\Gamma_{total}$ — Γ_9/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0030 ± 0.0013	**OUR FIT** Error includes scale factor of 1.3				
0.003 ± 0.001	400 ± 50	ALDE	87	GAM4	$100\ \pi^- p \to 4\pi^0 n$

$f_2(1270)$ REFERENCES

ALDE	87	PL B198 286	+Binon, Bricman+	(LANL, BRUX, SERP, LAPP)
AUGUSTIN	87	ZPHY C36 369	+Cosme+	(LALO, CLER, FRAS, PADO)
ABACHI	86B	PRL 57 1990	+Derrick, Blockus+	(PURD, ANL, IND, MICH, LBL)
AIHARA	86B	PRL 57 404	+Alston-Garnjost+	(TPC-Two-Gamma Collab.)
ALDE	86D	NP B269 485	+Binon, Bricman+	(BELG, LAPP, SERP, CERN)
BREAKSTONE	86	ZPHY C31 185	+	(ISU, BGNA, CERN, DORT, HEID, WARS)
LANDRO	86	PL B172 445	+Mork, Olsen	(UTRO)
LONGACRE	86	PL B177 223	+Etkin+	(BNL, BRAN, CUNY, DUKE, NDAM)
BEHREND	84B	ZPHY C23 223		(CELLO Collab.)
BERGER	84	ZPHY C26 199	+Klovning, Burger+	(PLUTO Collab.)
COURAU	84	PL 147B 227	+Johnson, Sherman, Atwood, Baillon+	(CIT, SLAC)
SMITH	84C	PR D30 851	+Burke, Abrams, Blocker, Levi+	(SLAC, LBL, HARV)
BINON	83	NC 78A 313	+Donskov, Duteil+	(BELG, LAPP, SERP, CERN)
Also	83B	SJNP 38 561	Binon, Gouanere+	(BELG, LAPP, SERP, CERN)
		Translated from YAF 38 934		
CHABAUD	83	NP B223 1	+Gorlich, Cerrada+	(CERN, CRAC, MPIM)
DENNEY	83	PR D28 2726	+Cranley, Firestone, Chapman+	(IOWA, MICH)
FRAZER	83	Aachen Conf.		(UCSD)
APEL	82	NP B201 197	+Augenstein+	(KARL, PISA, SERP, WIEN, CERN)
CASON	82	PRL 48 1316	+Biswas, Baumbaugh, Bishop+	(NDAM, ANL)
EDWARDS	82F	PL 110B 82	+Partridge, Peck+	(CIT, HARV, PRIN, STAN, SLAC)
ETKIN	82B	PR D25 1786	+Foley, Lai+	(BNL, CUNY, TUFT, VAND)
BRANDELIK	81B	ZPHY C10 117	+Boerner+	(TASSO Collab.)
CHABAUD	81	APP B12 575	+Niczyporuk, Becker+	(CERN, CRAC, MPIM)
GIDAL	81	PL 107B 153	+Goldhaber, Guy, Millikan, Abrams+	(SLAC, LBL)
ROUSSARIE	81	PL 105B 304	+Burke, Abrams, Alam+	(SLAC, LBL)
BERGER	80B	DESY 80-34	+Genzel+	(AACH, BERG, DESY, HAMB, UMD+)
COSTA	80	NP B175 402	Costa De Beauregard+	(BARI, BONN, CERN+)
LOVERRE	80	ZPHY C6 187	+Armenteros, Dionisi+	(CERN, CDEF, MADR, STOH)
CORDEN	79	NP B157 250	+Dowell, Garvey+	(BIRM, RHEL, TELA, LOWC)
MARTIN	79	NP B158 520	+Ozmutlu	(DURH)
POLYCHRO	79	PR D19 1317	Polychronakos, Cason, Bishop+	(NDAM, ANL)
PDG	78	PL 75B	Bricman+	(Particle Data Group)
ANTIPOV	77	NP B119 45	+Busnello, Damgaard, Kienzle+	(SERP, GEVA)
PAWLICKI	77	PR D15 3196	+Ayres, Cohen, Diebold, Kramer, Wicklund	(ANL)
DEUTSCH	76	NP B103 426	Deutschmann+	(AACH, BERL, BONN, CERN+)
APEL	75	PL 57B 398	+Augenstein+	(KARL, PISA, SERP, WIEN, CERN)
EMMS	75D	NP B96 155	+Kinson, Stacey, Votruba+	(BIRM, DURH, RHEL)
HYAMS	75	NP B100 205	+Jones, Weilhammer, Blum, Dietl+	(CERN, MPIM)
EISENBERG	74	PL 52B 239	+Engler, Haber, Karshon+	(REHO)
ENGLER	74	PR D10 2070	+Kraemer, Toaff, Weisser, Diaz+	(CMU, CASE)
LOUIE	74	PL 48B 385	+Alitti, Gandois, Chaloupka+	(SACL, CERN)
ANDERSON	73	PRL 31 562	+Engler, Kraemer, Toaff, Diaz+	(CMU, CASE)
TAKAHASHI	72	PR D6 1266	+Barish+	(TOHO, PENN, NDAM, ANL)
BEAUPRE	71	NP B28 77	+Deutschmann, Graessler+	(AACH, BERL, CERN)
FLATTE	71	PL 34B 551	+Alston-Garnjost, Barbaro-Galtieri+	(LBL)
ARMENISE	70	LNC 4 199	+Ghidini, Foring, Cartacci+	(BARI, BGNA, FIRZ)
OH	70	PR D1 2494	+Garfinkel, Morse, Walker, Prentice	(WISC, TNTO) JP
STUNTEBECK	70	PL 32B 391	+Kenney, Deery, Biswas, Cason+	(NDAM)
ADERHOLZ	69	NP B11 259	+Bartsch+	(AACH, BERL, CERN, JAGL, WARS)
ARMENISE	68	NC 54A 999	+Ghidini, Forino+	(BARI, BGNA, FIRZ, ORSA)
ASCOLI	68D	PRL 21 1712	+Crawley, Mortara+	(ILL)
BOESEBECK	68	NP B4 501	+Deutschmann+	(AACH, BERL, CERN)
JOHNSON	68	PR 176 1651	+Poirier, Biswas, Gutay+	(NDAM, PURD, SLAC)
EISNER	67	PR 164 1699	+Johnson, Klein, Peters, Sahni, Yen+	(PURD)
RABIN	67	Thesis		(RUTG)
DERADO	65	PRL 14 872	+Kenney, Poirier, Shephard	(NDAM)
LEE	64	PRL 12 342	+Roe, Sinclair, VanderVelde	(MICH)
BONDAR	63	PL 5 153	+	(AACH, BIRM, BONN, DESY, LOIC, MPIM)
SELOVE	62	PRL 9 272	+Hagopian, Brody, Baker, Leboy	(PENN)

$\eta(1280)$ was $\eta(1275)$

$I^G(J^{PC}) = 0^+(0^{-+})$

See also the mini-review under non-$q\bar{q}$ candidates

$\eta(1280)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1279 ± 5	ANDO	86	SPEC	8 $\pi^- p \to n\eta\pi^+\pi^-$
• • • We do not use the following data for averages fits, limits etc • • •				
~1275	STANTON	79	CNTR	8 4 $\pi^- p \to n\eta 2\pi$

$\eta(1280)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
32 ± 10	ANDO	86	SPEC	8 $\pi^- p \to n\eta\pi^+\pi^-$
• • • We do not use the following data for averages fits, limits etc • • •				
~70.	STANTON	79	CNTR	8 4 $\pi^- p \to n\eta 2\pi$

$\eta(1280)$ DECAY MODES

Γ_1 $\eta(1280) \to a_0(980)\pi$

Γ_2 $\eta(1280) \to \eta\pi^+\pi^-$

Γ_3 $\eta(1280) \to \gamma\gamma$

$\eta(1280)$ BRANCHING RATIOS

$\Gamma(a_0(980)\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
LARGE	ANDO	86	SPEC	8 $\pi^- p \to n\eta\pi^+\pi^-$
LARGE	STANTON	79	CNTR	8 4 $\pi^- p \to n\eta 2\pi$

$\eta(1280)$ $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

$\Gamma(\eta\pi^+\pi^-) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ $\Gamma_2\Gamma_3/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits, etc • • •				
<0 3	ANTREASYAN	87	CBAL	$e^+e^- \to e^+e^-\eta\pi\pi$

$\eta(1280)$ REFERENCES

ANTREASYAN 87 PR D36 2633 +Bartels Bessel+ (Crystal Ball Collab)
ANDO 86 PRL 57 1296 +Imai+ (KEK KYOT NIRS SAGA TOKY TSUK+) IJP
STANTON 79 PRL 42 346 +Brockman+ (OSU CARL MCGI TNTO) JP

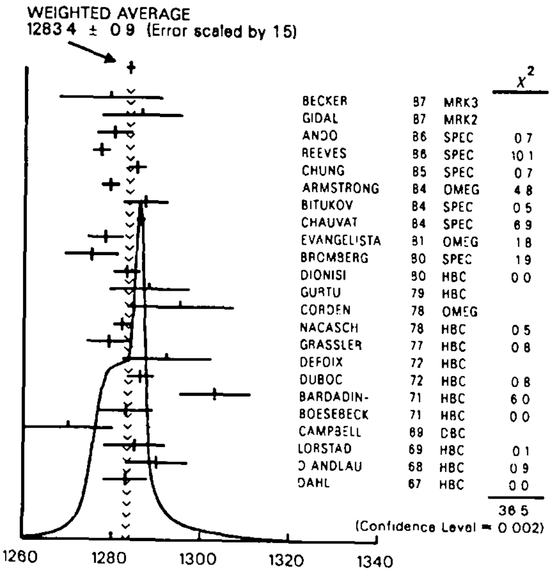
$f_1(1285)$ was $D(1285)$

$I^G(J^{PC}) = 0^+(1^{++})$

$f_1(1285)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1283.4 ± 0.9	**OUR AVERAGE**	Error includes scale factor of 1 5 See the ideogram below			
1279 ± 6 ± 10	16 ± 6	BECKER	87	MRK3	$e^+e^- \to \phi K K\pi$
1286 ± 9		GIDAL	87	MRK2	$e^+e^- \to e^+e^-\eta\pi^+\pi^-$
1280 ± 4		ANDO	86	SPEC	8 $\pi^- p \to n\eta\pi^+\pi^-$
1277 0 ± 2 0	420	REEVES	86	SPEC	6 6 $p\bar{p} \to KK\pi$ X
1285 0 ± 2 0		CHUNG	85	SPEC	8 $\pi^- p \to NKK\pi$
1279 0 ± 2 0	604	ARMSTRONG	84	OMEG	85 $\pi^+ p \to KK\pi\pi p$ $pp \to K\bar{K}\pi pp$
1287 0 ± 5 0	353	BITUKOV	84	SPEC	32 $\pi^- p \to K^+K^-\pi^0 n$
1286 0 ± 1.0		CHAUVAT	84	SPEC	ISR 31 5 pp
1278 ± 4		EVANGELISTA	81	OMEG	12 $\pi^- p \to \eta\pi p$
1275 0 ± 6 0	31	BROMBERG	80	SPEC	100 $\pi^- p \to KK\pi X$
1283 0 ± 3 0	103	DIONISI	80	HBC	4 $\pi^- p \to KK\pi n$
1288 0 ± 9 0	200	GURTU	79	HBC	4 2 $K^- p \to n\eta 2\pi$
1295 0 ± 12 0	85	CORDEN	78	OMEG	12-15 $\pi^- p \to n5\pi$
1282 0 ± 2 0	320	NACASCH	78	HBC	0 7 0 76 $pp \to KK3\pi$
1279 0 ± 5 0	210	GRASSLER	77	HBC	16 $\pi^{\mp} p$
1292 ± 10	150	DEFOIX	72	HBC	0 7 $pp \to 7\pi$
1286 ± 3	180	DUBOC	72	HBC	1 2 $\bar{p}p \to 2K4\pi$
1303 0 ± 8 0		BARDADIN	71	HBC	8 $\pi^+ p \to p6\pi$
1283.0 ± 6 0		BOESEBECK	71	HBC	16 0 $\pi p \to p5\pi$
1270 0 ± 10.0		CAMPBELL	69	DBC	2 7 $\pi^+ d$
1285 ± 7		LORSTAD	69	HBC	0 7 $\bar{p}p$ 4 5 body
1290 ± 7		D ANDLAU	68	HBC	1 2 $\bar{p}p$ 5-6 body
1283 0 ± 5 0		DAHL	67	HBC	1 6-4 2 π p
• • • We do not use the following data for averages fits limits etc • • •					
~1279		[1] TORNQVIST	82B	RVUE	
~1275 0	46	[2] STANTON	79	CNTR	8 5 $\pi^- p \to n2\gamma 2\pi$
1271 0 ± 10 0	34	CORDEN	78	OMEG	12-15 $\pi^- p \to K^+K^-\pi n$
1280 ± 3	500	[3] THUN	72	MMS	13 4 $\pi^- p$

[1] From a unitarized quark model calculation
[2] From phase shift analysis of $\eta\pi^+\pi^-$ system
[3] Seen in the missing mass spectrum



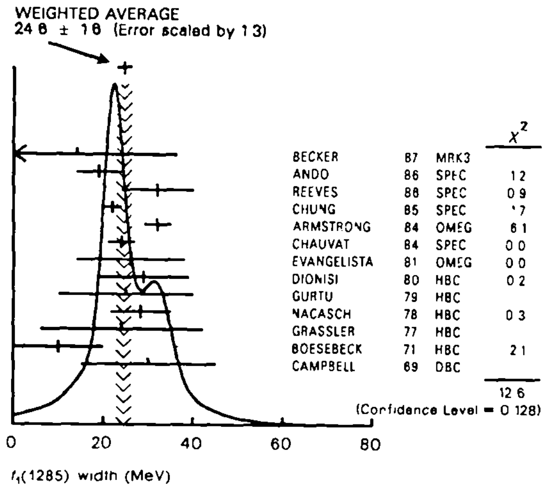
$f_1(1285)$ mass (MeV)

$f_1(1285)$ WIDTH

Only experiments giving width error less than 20 MeV are kept for averaging

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
24.6 ± 1 6	**OUR AVERAGE**	Error includes scale factor of 1 3 See the ideogram below			
14 $^{+20}_{-14}$ ± 10	16 ± 6	BECKER	87	MRK3	$e^+e^- \to \phi KK\pi$
19 ± 5		ANDO	86	SPEC	8 $\pi^- p \to n\eta\pi^+\pi^-$
32 0 ± 8 0	420	REEVES	86	SPEC	6 6 $p\bar{p} \to KK\pi$ X
22.0 ± 2 0		CHUNG	85	SPEC	8 $\pi^- p \to NKK\pi$
32 0 ± 3 0	604	ARMSTRONG	84	OMEG	85 $\pi^+ p \to KK\pi\pi p$ $pp \to KK\pi pp$
24 0 ± 3 0		CHAUVAT	84	SPEC	ISR 31 5 pp
26 ± 12		EVANGELISTA	81	OMEG	12 $\pi^- p \to \eta\pi p$
29 0 ± 10 0	103	DIONISI	80	HBC	4 π $p \to KK\pi n$
25 0 ± 15 0	200	GURTU	79	HBC	4 2 $K^- p \to n\eta 2\pi$
28 3 ± 6 7	320	NACASCH	78	HBC	0 7 0 76 $pp \to KK3\pi$
24 0 ± 18 0	210	GRASSLER	77	HBC	16 $\pi^{\mp} p$
10 0 ± 10 0		BOESEBECK	71	HBC	16 0 $\pi p \to p5\pi$
30 0 ± 15 0		CAMPBELL	69	DBC	2 7 $\pi^+ d$
• • • We do not use the following data for averages fits limits etc • • •					
~10.0		[4] STANTON	79	CNTR	8 5 $\pi^- p \to n2\gamma 2\pi$
28 ± 5	150	[5] DEFOIX	72	HBC	0 7 $\bar{p}p \to 7\pi$
46 ± 9	180	[5] DUBOC	72	HBC	1 2 $\bar{p}p \to 2K4\pi$
37 ± 5	500	[6] THUN	72	MMS	13 4 $\pi^- p$
60 ± 15		[5] LORSTAD	69	HBC	0 7 $\bar{p}p$ 4 5 body
35 0 ± 10 0		[5] DAHL	67	HBC	1 6-4 2 $\pi^- p$

[4] From phase shift analysis of $\eta\pi^+\pi$ system
[5] Resolution is not unfolded
[6] Seen in the missing mass spectrum



$f_1(1285)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$f_1(1285) \to K\bar{K}\pi$	$(11.2 \pm 2.9) \times 10^{-2}$	S=1.1
Γ_2	$f_1(1285) \to \rho\pi\pi$	$(40 \pm 7) \times 10^{-2}$	
Γ_3	$f_1(1285) \to \eta\pi\pi$	$(49 \pm 6) \times 10^{-2}$	
Γ_4	$f_1(1285) \to a_0(980)\pi$	$(36 \pm 7) \times 10^{-2}$	
Γ_5	$f_1(1285) \to 2\pi^+2\pi^-$ (including $\rho^0\pi^+\pi^-$)		
Γ_6	$f_1(1285) \to K\bar{K}^*(892)$		
Γ_7	$f_1(1285) \to 4\pi^0$	$< 7 \times 10^{-4}$	
Γ_8	$f_1(1285) \to \gamma\gamma$	$< 6 \times 10^{-5}$	CL=95%
Γ_9	$f_1(1285) \to \gamma\gamma^*$		

CONSTRAINED FIT INFORMATION

An overall fit to 2 branching ratios uses 6 measurements and one constraint to determine 3 parameters. The overall fit has a $\chi^2 = 4.6$ for 4 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

x_2	59	
x_3	23	-92
	x_1	x_2

$f_1(1285)$ $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(\text{total})$

$\Gamma(\eta\pi\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ — $\Gamma_3\Gamma_8/\Gamma$

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
<0.62	95	GIDAL	87	MRK2	$e^+e^- \to e^+e^-\eta\pi^+\pi^-$

$\Gamma(\eta\pi\pi) \times \Gamma(\gamma\gamma^*)/\Gamma_{total}$ — $\Gamma_3\Gamma_9/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
4.6 ± 0.12 ± 0.83	GIDAL	87	MRK2	$e^+e^- \to e^+e^-\eta\pi^+\pi^-$

$f_1(1285)$ BRANCHING RATIOS

The $f_1(1285)$ branching ratios fit is made with the assumptions that the $f_1(1285) \to 4\pi$ decay is all $\rho\pi\pi$ and that the $\pi\pi$ pair has $I = 1$.

$\Gamma(\rho\pi\pi)/\Gamma(K\bar{K}\pi)$ — Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<4.0	[7] DONALD	69	HBC	1.2 $\bar{p}p \to 5\pi^+$
<2.0	DAHL	67	HBC	$\pi^\pm p \to (K\bar{K})^\pm \pi^+ X$

[7] This is for $\Gamma(\rho^0\pi^+\pi^-)/\Gamma(K\bar{K}\pi^0)$.

$\Gamma(K\bar{K}\pi)/\Gamma(\eta\pi\pi)$ — Γ_1/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
0.23 ± 0.06 OUR FIT Error includes scale factor of 1.1.				
0.23 ± 0.06 OUR AVERAGE Error includes scale factor of 1.2.				
0.42 ± 0.15	GURTU	79	HBC	4.2 K^-p
0.5 ± 0.2	CORDEN	78	OMEG	12–15 π^-p
0.20 ± 0.08	[8] DEFOIX	72	HBC	0.7 $\bar{p}p \to 7\pi$
0.16 ± 0.08	CAMPBELL	69	DBC	2.7 π^+d

[8] $K\bar{K}$ system characterized by the $I = 1$ threshold enhancement. (See under $a_0(980)$.)

$\Gamma(a_0(980)\pi)/\Gamma(\eta\pi\pi)$ — Γ_4/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
$0.74^{+0.12}_{-0.11}$ OUR AVERAGE				
0.72 ± 0.15	GURTU	79	HBC	4.2 K^-p
$0.6^{+0.3}_{-0.2}$	CORDEN	78	OMEG	12–15 π^-p
1.0 ± 0.3	GRASSLER	77	HBC	16 $\pi^\mp p$

$\Gamma(\rho\pi\pi)/\Gamma(\eta\pi^+\pi^-)$ — $\frac{1}{3}\Gamma_2/\frac{2}{3}\Gamma_3$

VALUE	DOCUMENT ID		TECN	COMMENT
0.41 ± 0.12 OUR FIT				
0.41 ± 0.12 OUR AVERAGE				
0.32 ± 0.20	GURTU	79	HBC	4.2 K^-p
0.46 ± 0.15	GRASSLER	77	HBC	16 $\pi^\mp p$

$\Gamma(K\bar{K}^*(892))/\Gamma_{total}$ — Γ_6/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
NOT SEEN	NACASCH	78	HBC	0.7–0.76 $\bar{p}p \to K\bar{K}3\pi$

$\Gamma(\rho^0\pi^+\pi^-)/\Gamma(2\pi^+2\pi^-$ (including $\rho^0\pi^+\pi^-))$ — $\frac{1}{3}\Gamma_2/\Gamma_5$

VALUE	DOCUMENT ID		TECN	COMMENT
1.0 ± 0.4	GRASSLER	77	HBC	16 GeV $\pi^\pm p$

$\Gamma(\rho\pi\pi)/\Gamma(\eta\pi\pi)$ — Γ_2/Γ_3

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.4	95	[9] CORDEN	78	OMEG	12–15 π^-p

[9] Note that CORDEN 78 and GRASSLER 77 are in disagreement.

$\Gamma(4\pi^0)/\Gamma_{total}$ — Γ_7/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
<7	ALDE	87	GAM4	100 $\pi^-p \to 4\pi^0 n$

$f_1(1285)$ REFERENCES

ALDE	87	PL B198 286	+Binon, Bricman+	(LANL, BRUX, SERP, LAPP)
BECKER	87	PRL 59 186	+	(MARK III Collab.)
GIDAL	87	PRL 59 2012	+Boyer, Butler, Cords, Abrams+	(LBL, SLAC, HARV)
ANDO	86	PRL 57 1296	+Imai+	(KEK, KYOT, NIRS, SAGA, TOKY, TSUK+) IJP
REEVES	86	PR 34 1960	+Chung, Crittenden+	(FLOR, BNL, IND, SMAS) JP
CHUNG	85	PRL 55 779	+Fernow, Boehnlein+	(BNL, FLOR, IND, SMAS) JP
ARMSTRONG	84	PL 146B 273	+Bloodworth, Burns+	(ATHU, BARI, BIRM, CERN) JP
BITUKOV	84	PL 144B 133	+Dorofeev, Dzhelyadin, Golovkin, Kulik+	(SERP)
CHAUVAT	84	PL 148B 382	+Meritet, Bonino+	(CERN, UDCF, UCLA, SACL)
TORNQVIST	82B	NP B203 268		(HELS)
EVANGELISTA	81	NP B178 197	+	(BARI, BONN, CERN, DARE, LIVP+)
BROMBERG	80	PR D22 1513	+Haggerty, Abrams, Dzierba	(CIT, FNAL, ILLC, IND)
DIONISI	80	NP B169 1	+Gavillet+	(CERN, MADR, CDEF, STOH)
GURTU	79	NP B151 181	+Gavillet, Blokzijl+	(CERN, ZEEM, NIJM, OXF)
STANTON	79	PRL 42 346	+Brockman+	(OSU, CARL, MCGI, TNTO) JP
CORDEN	78	NP B144 253	+Corbett, Alexander+	(BIRM, RHEL, TELA, LOWC) JP
NACASCH	78	NP B135 203	+Defoix, Dobrzynski+	(PARI, MADR, CERN)
GRASSLER	77	NP B121 189	+	(AACH, BERL, BONN, CERN, CRAC, HEID+)
DEFOIX	72	NP B44 125	+Nascimento, Bizzarri+	(CDEF, CERN)
DUBOC	72	NP B46 429	+Goldberg, Makowski, Donald+	(LPNP, LIVP)
THUN	72	PRL 28 1733	+Blieden, Finocchiaro, Bowen+	(STON, NEAS)
BARDADIN	71	PR D4 2711	Bardadin, Otwinowska, Hofmokl+	(WARS)
BOESEBECK	71	PL 34B 659		(AACH, BERL, BONN, CERN, CRAC, HEID, WARS)
CAMPBELL	69	PRL 22 1204	+Lichtman, Loeffler+	(PURD)
DONALD	69	NP B11 551	+Edwards, Buran, Bettini+	(LIVP, OSLO, PADO)
LORSTAD	69	NP B14 63	+D'Andlau, Astier+	(CDEF, CERN) JP
D'ANDLAU	68	NP B5 693	+Astier, Barlow+	(CDEF, CERN, IRAD, LIVP) IJP
DAHL	67	PR 163 1377	+Hardy, Hess, Kirz, Miller	(LRL) IJP

OTHER RELATED PAPERS

ASTON	85	PR D32 2255	+Carnegie Dunwoodie+	(SLAC CARL CNRC)
ATKINSON	84E	PL 138B 459	+	(BONN CERN GLAS LANC MCHS LPNP+)
GAVILLET	82	ZPHY C16 119	+Armenteros+	(CERN CDEF PADO ROMA)
DEBILLY	80	NP B176 1	+Briand Duboc Levy+	(CURI LAUS NEUC GLAS) JP
IRVING	78	NP B139 327	+Sepangi	(LIVP)
HANDLER	76	NP B110 173	+Plano Brucker Koller+	(RUTG STEV SETO)
VUILLEMIN	76	NC 33A 133	+	(LAUS NEUC LPNP LIVP GLAS)
VUILLEMIN	75	LNC 14 165	+	(LAUS NEUC LPNP LIVP GLAS) JP
WELLS	75	NP B101 333	+Radojicic Roscoe Lyons	(OXF)
BERENYI	72	NP B37 621	+Prentice Steenberg Yoon Walker	(TNTO WISC)
CHAPMAN	72	NP B42 1	+Church Lys Murphy Ring VanderVelde	(MICH)
GOLDBERG	71	LNC 1 627	+Makowski Touchard Donald+	(IPN LIVP) JP
AMMAR	70	PR D2 430	+Kropac Davis+	(KANS NWES ANL WISC)
OTWINOWSKI	69	PL 29B 529		(WARS)
DEFOIX	68B	PL 28B 353	+Rivet Siaud Conforto+	(CDEF IPNP CERN)
BARLOW	67	NC 50A 701	+Lillestol Montanet+	(CERN CDEF IRAD LIVP)
D ANDLAU	65	PL 17 347	+Barlow Adamson+	(CDEF CERN IRAD LIVP)
MILLER	65	PRL 14 1074	+Chung Dahl Hess Hardy Kirz+	(LRL UCB)

$\pi(1300)$

$I^G(J^{PC}) = 1^-(0^{-+})$

$\pi(1300)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
••• We do not use the following data for averages fits limits etc •••				
1190 ± 30	ZIELINSKI	84	SPEC	200 $\pi^+ Z \to Z 3\pi$
1240 ± 30	BELLINI	82	SPEC	40 $\pi^- A \to A 3\pi$
1273 0 ± 50 0	[1] AARON	81	RVUE	
1342 ± 20	BONESINI	81	OMEG	12 $\pi^- p \to p 3\pi$
~1400	DAUM	81B	SPEC	63 94 $\pi^- p$

[1] Uses multichannel Aitchison Bowler model (BOWLER 75) Uses data from DAUM 80 and DANKOWYCH 81

$\pi(1300)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
••• We do not use the following data for averages fits limits etc •••				
440 ± 80	ZIELINSKI	84	SPEC	200 $\pi^+ Z \to Z 3\pi$
360. ± 120	BELLINI	82	SPEC	40 $\pi^- A \to A 3\pi$
580 0 ± 100 0	[2] AARON	81	RVUE	
220 ± 70	BONESINI	81	OMEG	12 $\pi^- p \to p 3\pi$
~600	DAUM	81B	SPEC	63 94 $\pi^- p$

[2] Uses multichannel Aitchison-Bowler model (BOWLER 75) Uses data from DAUM 80 and DANKOWYCH 81

$\pi(1300)$ DECAY MODES

Γ_1 $\pi(1300) \to \rho\pi$

Γ_2 $\pi(1300) \to f_0(1400)\pi$

Γ_3 $\pi(1300) \to \pi(\pi\pi)_{S\text{-wave}}$

$\pi(1300)$ BRANCHING RATIOS

$\Gamma(\pi(\pi\pi)_{S\text{-wave}})/\Gamma(\rho\pi)$ — Γ_3/Γ_1

VALUE	DOCUMENT ID		TECN
••• We do not use the following data for averages, fits limits etc •••			
2 12	[3] AARON	81	RVUE

[3] Uses multichannel Aitchison Bowler model (BOWLER 75) Uses data from DAUM 80 and DANKOWYCH 81

$\pi(1300)$ REFERENCES

ZIELINSKI	84	PR D30 1855	+Berg Chandlee Cihangir+	(ROCH MINN FNAL)
BELLINI	82	PRL 48 1697	+Frabetti Ivanshin Litkin+	(MILA BGNA JINR)
AARON	81	PR D24 1207	+Longacre	(NEAS BNL)
BONESINI	81	PL 103B 75	+Donald+	(MILA LIVP DARE CERN BARI BONN)
DANKOWY	81	PRL 46 580	Dankowych+	(TNTO BNL CARL MCGI OHIO)
DAUM	81B	NP B182 269	+Hertzberger+	(AMST CERN CRAC MPIM OXF+)
DAUM	80	PL 89B 281	+Hertzberger+	(AMST CERN CRAC MPIM OXF+)
BOWLER	75	NP B97 227	+Game Aitchison Dainton	(OXF DARE)

$a_2(1320)$ was $A_2(1320)$

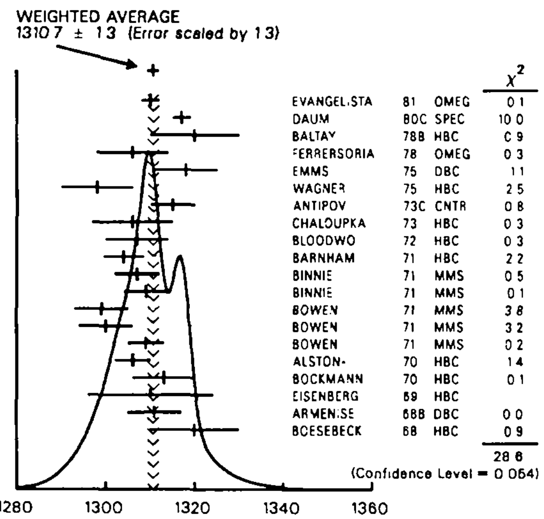
$I^G(J^{PC}) = 1^-(2^{++})$

$a_2(1320)$ MASS

3π MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1310.7 ± 1.3	**OUR AVERAGE**	Error includes scale factor of 1 3 See the ideogram below				
1310 ± 2		[1] EVANGELISTA	81	OMEG	−	12 $\pi^- p \to 3\pi p$
1317 0 ± 2 0	25000	[1] DAUM	80C	SPEC	−	63 94 $\pi^- p \to 3\pi p$
1320 0 ± 10 0	1097	[1] BALTAY	78B	HBC	+0	15 $\pi^+ p \to p 4\pi$
1306 0 ± 8 0		FERRERSORIA	78	OMEG	−	9 $\pi^- p \to p 3\pi$
1318 ± 7	1600	[1] EMMS	75	DBC	0	4 $\pi^+ n \to p(3\pi)^0$
1298 ± 8	1200	[1] WAGNER	75	HBC	0	7 $\pi^+ p \to \Delta^{++}(3\pi)^0$
1315 ± 5		[1] ANTIPOV	73C	CNTR	−	25 40 $\pi^- p \to p\eta\pi^-$
1306 ± 9	1580	CHALOUPKA	73	HBC	−	3 9 $\pi^- p$
1307 ± 7	160	BLOODWO	72	HBC	+	5 45 $\pi^+ p \to p 3\pi$
1304 0 ± 4 5	360	BARNHAM	71	HBC	+	3 7 $\pi^+ p \to (3\pi)^+ p$
1307 ± 5	10000	BINNIE	71	MMS	−	$\pi^- p$ near a_2 threshold
1309 ± 5	5000	BINNIE	71	MMS	−	$\pi^- p$ near a_2 threshold
1299 0 ± 6 0	28000	BOWEN	71	MMS	−	5 $\pi^- p$
1300 ± 6 0	24000	BOWEN	71	MMS	+	5 $\pi^+ p$
1309 0 ± 4 0	17000	BOWEN	71	MMS	−	7 $\pi^- p$
1306.0 ± 4 0	941	ALSTON	70	HBC	+	7 0 $\pi^+ p \to 3\pi p$
1313 0 ± 7 0	280	BOCKMANN	70	HBC	0	5 $\pi^+ p$
1310 0 ± 14 0		EISENBERG	69	HBC	+	4 3 5 3 γp
1311 0 ± 6 0	260	ARMENISE	68B	DBC	0	5 1 $\pi^+ d$
1320 ± 10	120	BOESEBECK	68	HBC	0	8 $\pi^+ p$
••• We do not use the following data for averages fits limits etc •••						
1343 0 ± 11 0	490	BALTAY	78B	HBC	0	15 $\pi^+ p \to \Delta 3\pi$
1285 0 ± 9 0		CORDEN	78B	OMEG	−	12 15 $\pi^- p \to 3\pi n$

[1] From a fit to $J^P = 2^+$ $\rho\pi$ partial wave



$a_2(1320)$ mass (MeV) 3π mode

Meson Full Listings
$a_2(1320)$

$K^\pm K^0_S$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1318.2 ± 0.7	**OUR AVERAGE**					
1330.0 ± 11.0	1000	[2,3] CLELAND	82B	SPEC	+	30 $\pi^+ p \to K^0_S K^+ p$
1319.0 ± 5.0	4700	[2,3] CLELAND	82B	SPEC	+	50 $\pi^+ p \to K^0_S K^+ p$
1324.0 ± 6.0	5200	[2,3] CLELAND	82B	SPEC	−	50 $\pi^- p \to K^0_S K^- p$
1320.0 ± 2.0	4000	CHABAUD	80	SPEC	−	17 $\pi^- A \to K^0_S K^- A$
1312.0 ± 4.0	11000	CHABAUD	78	SPEC	−	9.8 $\pi^- p \to K^- K^0_S p$
1316.0 ± 2.0	4730	CHABAUD	78	SPEC	−	18.8 $\pi^- p \to K^- K^0_S p$
1324.0 ± 5.0	350	HYAMS	78	ASPK	+	12.7 $\pi^+ p \to K^+ K^0_S p$
1318 ± 1		[2,4] MARTIN	78D	SPEC	−	10 $\pi^- p \to K^0_S K^- p$
1320.0 ± 2.0	2724	MARGULIE	76	SPEC	−	23 $\pi^- p \to K^- K^0_S p$
1313.0 ± 4.0	730	FOLEY	72	CNTR	−	20.3 $\pi^- p \to K^- K^0_S p$
1319.0 ± 3.0	1500	[4] GRAYER	71	ASPK	−	17.2 $\pi^- p \to K^- K^0_S p$

[2] From a fit to $J^P = 2^+$ partial wave
[3] Number of events evaluated by us
[4] Systematic error in mass scale subtracted

$\eta\pi$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1334.0 ± 2.6	**OUR AVERAGE**	Error includes scale factor of 1.9				
1336.2 ± 1.7	2561	DELFOSSE	81	SPEC	+	$\pi^\pm p \to p\pi^\pm\eta$
1330.7 ± 2.4	1653	DELFOSSE	81	SPEC	−	$\pi^\pm p \to p\pi^\pm\eta$
1323 ± 8	1000	[5] KEY	73	OSPK	−	6 $\pi^- p \to p\pi^-\eta$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1324 ± 8	6200	[5,6] CONFORTO	73	OSPK	−	6 $\pi^- p \to p$ MM$^-$

[5] Error includes 5 MeV systematic mass scale error
[6] Missing mass with enriched MMS = $\eta\pi^-$, $\eta = 2\gamma$

$a_2(1320)$ WIDTH

3π MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
100.6 ± 2.2	**OUR AVERAGE**					
97 ± 5		[7] EVANGELISTA	81	OMEG	−	12 $\pi^- p \to 3\pi p$
96.0 ± 9.0	25000	[7] DAUM	80C	SPEC		63,94 $\pi^- p \to 3\pi p$
110.0 ± 15.0	1097	[7] BALTAY	78B	HBC	+0	15 $\pi^+ p \to p 4\pi$
112 ± 18	1600	[7] EMMS	75	DBC	0	4 $\pi^+ n \to p(3\pi)^0$
122 ± 14	1200	[7,8] WAGNER	75	HBC	0	7 $\pi^+ p \to \Delta^{++}(3\pi)^0$
115 ± 15		[7] ANTIPOV	73C	CNTR	−	25,40 $\pi^- p \to p\eta\pi^-$
99 ± 15	1580	CHALOUPKA	73	HBC	−	3.9 $\pi^- p$
111.4 ± 18.0	360	BARNHAM	71	HBC	+	3.7 $\pi^+ p \to (3\pi)^+ p$
72 ± 16	5000	BINNIE	71	MMS	−	$\pi^- p$ near a_2 threshold
105.0 ± 5.0	28000	BOWEN	71	MMS	−	5 $\pi^- p$
99.0 ± 5.0	24000	BOWEN	71	MMS	+	5 $\pi^+ p$
103.0 ± 5.0	17000	BOWEN	71	MMS	−	7 $\pi^- p$
79.0 ± 12.0	941	ALSTON	70	HBC	+	7.0 $\pi^+ p \to 3\pi p$
96.0 ± 16.0	260	ARMENISE	68B	DBC	0	5.1 $\pi^+ d$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
115.0 ± 14.0	490	BALTAY	78B	HBC	0	15 $\pi^+ p \to \Delta 3\pi$
150.0 ± 20.0		CORDEN	78B	OMEG	−	12,15 $\pi^- p \to 3\pi n$
100	10000	BINNIE	71	MMS	−	$\pi^- p$ near a_2 threshold

[7] From a fit to $J^P = 2^+$ $\rho\pi$ partial wave
[8] Width errors enlarged by us to $4\Gamma/N^{1/2}$; see the note with the $K^*(892)$ mass

$K^\pm K^0_S$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
109.8 ± 2.4	**OUR AVERAGE**					
121.0 ± 51.0	1000	[9,10] CLELAND	82B	SPEC	+	30 $\pi^+ p \to K^0_S K^+ p$
112.0 ± 20.0	4700	[9,10] CLELAND	82B	SPEC	+	50 $\pi^+ p \to K^0_S K^+ p$
120.0 ± 25.0	5200	[9,10] CLELAND	82B	SPEC	−	50 $\pi^- p \to K^0_S K^- p$
106.0 ± 4.0	4000	CHABAUD	80	SPEC	−	17 $\pi^- A \to K^0_S K^- A$
126.0 ± 11.0	11000	CHABAUD	78	SPEC	−	9.8 $\pi^- p \to K^- K^0_S p$
101.0 ± 8.0	4730	CHABAUD	78	SPEC	−	18.8 $\pi^- p \to K^- K^0_S p$
110.0 ± 18.0	350	HYAMS	78	ASPK	+	12.7 $\pi^+ p \to K^+ K^0_S p$
113 ± 4		[9,11] MARTIN	78D	SPEC	−	10 $\pi^- p \to K^0_S K^- p$
105.0 ± 8.0	2724	[11] MARGULIE	76	SPEC	−	23 $\pi^- p \to K^- K^0_S p$
113.0 ± 19.0	730	FOLEY	72	CNTR	−	20.3 $\pi^- p \to K^- K^0_S p$
123.0 ± 13.0	1500	[11] GRAYER	71	ASPK	−	17.2 $\pi^- p \to K^- K^0_S p$

[9] From a fit to $J^P = 2^+$ partial wave
[10] Number of events evaluated by us
[11] Width errors enlarged by us to $4\Gamma/N^{1/2}$; see the note with the $K^*(892)$ mass

$\eta\pi$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
113 ± 4	**OUR AVERAGE**					
112.2 ± 5.7	2561	DELFOSSE	81	SPEC	+	$\pi^\pm p \to p\pi^\pm\eta$
116.6 ± 7.7	1653	DELFOSSE	81	SPEC	−	$\pi^\pm p \to p\pi^\pm\eta$
108 ± 9	1000	KEY	73	OSPK	−	6 $\pi^- p \to p\pi^-\eta$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
104 ± 9	6200	[12] CONFORTO	73	OSPK	−	6 $\pi^- p \to p$ MM$^-$

[12] Model dependent

$a_2(1320)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale/Conf Lev
Γ_1	$a_2(1320) \to \rho\pi$	$(70.1 \pm 2.7) \cdot 10^{-2}$	S=1.2
Γ_2	$a_2(1320) \to K\bar{K}$	$(4.9 \pm 0.8) \cdot 10^{-2}$	
Γ_3	$a_2(1320) \to \eta\pi$	$(14.5 \pm 1.2) \cdot 10^{-2}$	
Γ_4	$a_2(1320) \to \omega\pi\pi$	$(10.6 \pm 3.2) \cdot 10^{-2}$	S=1.3
Γ_5	$a_2(1320) \to \pi^+\pi^-\pi^0$		
Γ_6	$a_2(1320) \to \pi^+\pi^-\pi^-$	$< 8.4 \cdot 10^{-2}$	
Γ_7	$a_2(1320) \to \pi^\pm\gamma$	$(2.7 \pm 0.6) \cdot 10^{-3}$	
Γ_8	$a_2(1320) \to \eta'(958)\pi$	$< 2 \cdot 10^{-2}$	CL=97%
Γ_9	$a_2(1320) \to \gamma\gamma$	$(8.2 \pm 1.0) \cdot 10^{-6}$	

CONSTRAINED FIT INFORMATION

An overall fit to 5 branching ratios uses 18 measurements and one constraint to determine 4 parameters. The overall fit has a $\chi^2 = 9.3$ for 15 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i\,\delta x_j\rangle/(\delta x_i\cdot\delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$. The fit constrains the x_i in this array to sum to one.

x_2	1		
x_3	10	2	
x_4	89	24	46
	x_1	x_2	x_3

$a_2(1320)$ PARTIAL WIDTHS

$\Gamma(\pi^\pm\gamma)$ — Γ_7

VALUE (keV)	DOCUMENT ID		TECN	CHG	COMMENT
295.± 60.	CIHANGIR	82	SPEC	+	200 $\pi^+ A$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
461 ± 110	[12] MAY	77	SPEC	±	9.7 γA

$\Gamma(\gamma\gamma)$ — Γ_9

VALUE (keV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
$0.90^{+0.11}_{-0.10}$	**OUR AVERAGE**					
0.90 ± 0.27 ± 0.15	56	[13] ALTHOFF	86	TASS	0	$e^+e^- \to e^+e^- 3\pi$
1.14 ± 0.20 ± 0.26		[14] ANTREASYAN	86	CBAL	0	$e^+e^- \to e^+e^-\pi^0\eta$
1.06 ± 0.18 ± 0.19		BERGER	84C	PLUT	0	$e^+e^- \to e^+e^- 3\pi$
$0.81 \pm 0.19^{+0.42}_{-0.11}$	35	[13] BEHREND	83B	CELL	0	$e^+e^- \to e^+e^- 3\pi$
0.84 ± 0.07 ± 0.15		[13] FRAZER	83	JADE	0	$e^+e^- \to e^+e^- 3\pi$
0.77 ± 0.18 ± 0.27	22	[14] EDWARDS	82F	CBAL	0	$e^+e^- \to e^+e^-\pi^0\eta$

[13] From $\rho\pi$ decay mode
[14] From $\eta\pi^0$ decay mode

$a_2(1320)$ BRANCHING RATIOS

$\Gamma(K\bar{K})/\Gamma(\rho\pi)$ Γ_2/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.070±0.012 OUR FIT						
0.078±0.017		CHABAUD	78	RVUE		
• • • We do not use the following data for averages fits limits etc • • •						
0.056±0.014	50	[15] CHALOUPKA	73	HBC	−	3.9 $\pi^- p$
0.097±0.018	113	[15] ALSTON-	71	HBC	+	7.0 $\pi^+ p$
0.06 ±0.03		[15] ABRAMOVI	70B	HBC	−	3.93 $\pi^- p$
0.054±0.022		[15] CHUNG	68	HBC	−	3.2 $\pi^- p$

[15] Included in CHABAUD 78 review

$\Gamma(\eta\pi)/[\Gamma(\rho\pi) + \Gamma(K\bar{K}) + \Gamma(\eta\pi)]$ $\Gamma_3/(\Gamma_1+\Gamma_2+\Gamma_3)$

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.162±0.012 OUR FIT						
0.140±0.028 OUR AVERAGE						
0.13 ±0.04		ESPIGAT	72	HBC	±	0.0 $\bar{p}p$
0.15 ±0.04	34	BARNHAM	71	HBC	+	3.7 $\pi^+ p$

$\Gamma(\eta\pi)/\Gamma(\rho\pi)$ Γ_3/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.207±0.018 OUR FIT						
0.213±0.020 OUR AVERAGE						
0.18 ±0.05		FORINO	76	HBC		11 $\pi^- p$
0.22 ±0.05	52	ANTIPOV	73	CNTR	−	40 $\pi^- p$
0.211±0.044	149	CHALOUPKA	73	HBC	−	3.9 $\pi^- p$
0.246±0.042	167	ALSTON	71	HBC	+	7.0 $\pi^+ p$
0.25 ±0.09	15	BOCKMANN	70	HBC	+	5.0 $\pi^+ p$
0.23 ±0.08	22	ASCOLI	68	HBC	−	5 $\pi^- p$
0.12 ±0.08		CHUNG	68	HBC	−	3.2 $\pi^- p$
0.22 ±0.09		CONTE	67	HBC	−	11.0 $\pi^- p$

$\Gamma(\eta'(958)\pi)/\Gamma_{total}$ Γ_8/Γ

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.02	97	BARNHAM	71	HBC	+	3.7 $\pi^+ p$

$\Gamma(\eta'(958)\pi)/\Gamma(\rho\pi)$ Γ_8/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
$0.04^{+0.03}_{-0.04}$		BOCKMANN	70	HBC	0	5.0 $\pi^+ p$
• • • We do not use the following data for averages fits limits, etc • • •						
<0.011	90	EISENSTEIN	73	HBC	−	5 $\pi^- p$
<0.04		ALSTON	71	HBC	+	7.0 $\pi^+ p$

$\Gamma(K\bar{K})/[\Gamma(\rho\pi) + \Gamma(K\bar{K}) + \Gamma(\eta\pi)]$ $\Gamma_2/(\Gamma_1+\Gamma_2+\Gamma_3)$

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.054±0.009 OUR FIT						
0.048±0.012 OUR AVERAGE						
0.05 ±0.02		TOET	73	HBC	+	5 $\pi^+ p$
0.09 ±0.04		TOET	73	HBC	0	5 $\pi^+ p$
0.03 ±0.02	8	DAMERI	72	HBC	−	11 $\pi^- p$
0.06 ±0.03	17	BARNHAM	71	HBC	+	3.7 $\pi^+ p$
• • • We do not use the following data for averages fits limits etc • • •						
0.020±0.004		[16] ESPIGAT	72	HBC	±	0.0 $\bar{p}p$

[16] Not averaged because of discrepancy between masses from KK and $\rho\pi$ modes

$\Gamma(\pi^+\pi^-\pi^-)/\Gamma(\rho\pi)$ Γ_6/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.12	90	ABRAMOVI	70B	HBC	−	3.93 $\pi^- p$

$\Gamma(\pi^\pm\gamma)/\Gamma_{total}$ Γ_7/Γ

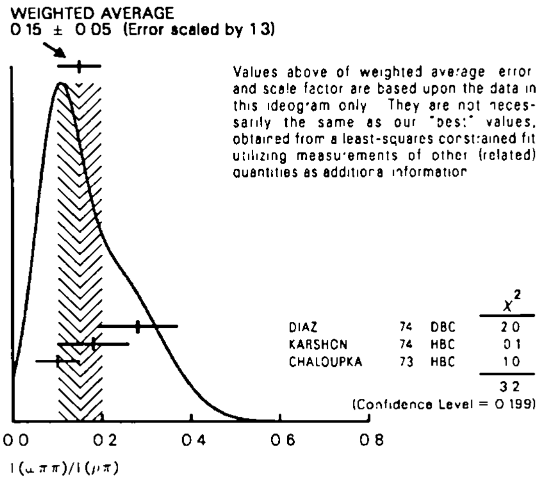
VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
$0.005^{+0.005}_{-0.003}$	[17] EISENBERG	72	HBC	4.3,5.25,7.5 γp

[17] Pion-exchange model used in this estimation

$\Gamma(\omega\pi\pi)/\Gamma(\rho\pi)$ Γ_4/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.15±0.05 OUR FIT Error includes scale factor of 1.3						
0.15±0.05 OUR AVERAGE Error includes scale factor of 1.3 See the ideogram below						
0.28±0.09	60	DIAZ	74	DBC	0	6 $\pi^+ n$
0.18±0.08		[18] KARSHON	74	HBC		Avg of above two
0.10±0.05	279	CHALOUPKA	73	HBC	−	3.9 $\pi^- p$
• • • We do not use the following data for averages fits limits etc • • •						
0.29±0.08	140	[18] KARSHON	74	HBC	0	4.9 $\pi^+ p$
0.10±0.04	60	[18] KARSHON	74	HBC	+	4.9 $\pi^+ p$
0.19±0.08		DEFOIX	73	HBC	0	0.7 $\bar{p}p$

[18] KARSHON 74 suggest an additional $I = 0$ state strongly coupled to $\omega\pi\pi$ which could explain discrepancies in branching ratios and masses We use a central value and a systematic spread



$a_2(1320)$ REFERENCES

ALTHOFF	86	ZPHY C31 537	+Bach Foster Bernardi+	(TASSO Collab)
ANTREASYAN	86	PR D33 1847	+Aschman Besset Bienlein+	(Crystal Ball Collab)
BERGER	84C	PL 149B 427	+Klovning Burger+	(PLUTO Collab)
BEHREND	83B	PL 125B 518	+D Agostini+	(DESY KARL MPIM LALO LPNP+)
FRAZER	83	Aachen Conf		(UCSD)
CIHANGIR	82	PL 117B 123	+Berg Biel Chandlee+	(FNAL MINN ROCH)
CLELAND	82B	NP B208 228	+Delfosse Dorsaz Gloor	(DURH GEVA LAUS PITT)
EDWARDS	82F	PL 110B 82	+Partridge Peck+	(CIT HARV PRIN STAN SLAC)
DELFOSSE	81	NP B183 349	+Guisan Martin Muhlemann Weill+	(GEVA LAUS)
EVANGELISTA	81	NP B178 197	+	(BARI BONN CERN DARE LIVP+)
CHABAUD	80	NP B175 189	+Hyams Papadopoulou+	(CERN MPIM AMST)
DAUM	80C	PL 89B 276	+Hertzberger+	(AMST CERN CRAC MPIM OXF+) JP
BALTAY	78B	PR D17 62	+Cautis Cohen Csorna+	(COLU BING)
CHABAUD	78	NP B145 349	+Hyams Jones Weilhammer Blum+	(CERN MPIM)
CORDEN	78B	NP B138 235	+Corbett Alexander+	(BIRM RHEL TELA LOWC)
FERRERSORIA	78	PL 74B 287	+Treille+	(ORSA CERN CDEF LPNP)
HYAMS	78	NP B146 303	+Jones Weilhammer Blum+	(CERN MPIM ATEN)
MARTIN	78D	PL 74B 417	+Ozmutlu Baldi Bohringer Dorsaz+	(DURH GEVA) JP
MAY	77	PR D16 1983	+Abramson Andrews Busnello+	(ROCH CORN)
FORINO	76	NC 35A 465	+Gessaroli+	(BGNA FIRZ GENO MILA OXF PAVI)
MARGULIE	76	PR D14 667	+Kramer Foley Love Lindenbaum+	(BNL CUNY)
EMMS	75	PL 58B 117	+Jones Kinson Stacey Bell+	(BIRM DURH RHEL) JP
WAGNER	75	PL 58B 201	+Tabak Chew	(LBL) JP
DIAZ	74	PRL 32 260	+Diblanca Fickinger Anderson+	(CASE, CMU)
KARSHON	74	PRL 32 852	+Mikenberg Pitluck Eisenberg Ronat+	(REHO)
ANTIPOV	73	NP B63 175	+Ascoli Busnello Focacci+	(CERN SERP) JP
ANTIPOV	73C	NP B63 153	+Ascoli Busnello Focacci+	(CERN SERP) JP
CHALOUPKA	73	PL 44B 211	+Dobrzynski Ferrando Losty+	(CERN)
CONFORTO	73	PL 45B 154	+Mobley Key+	(EFI FNAL INTO WISC)
DEFOIX	73	PL 43B 141	+Dobrzynski Espigat Nascimento+	(CDEF)
EISENSTEIN	73	PR D7 278	+Schultz Ascoli Ioffredo+	(ILL)
KEY	73	PRL 30 503	+Conforto Mobley+	(INTO EFI FNAL WISC)
TOET	73	NP B63 248	+Thuan Major+	(NIJM BONN DURH TORI)
BLOODWO	72	NP B37 203	Bloodworth Jackson Prentice Yoon	(INTO)
DAMERI	72	NC 9A 1	+Borzatta Goussu+	(GENO MILA SACL)
EISENBERG	72	PR D5 15	+Ballam Dagan+	(REHO SLAC TELA)
ESPIGAT	72	NP B36 93	+Ghesquiere Lillestol Montanet	(CERN CDEF)
FOLEY	72	PR D6 747	+Love Ozaki Platner Lindenbaum+	(BNL CUNY)
ALSTON	71	PL 34B 156	Alston Garnjost Barbaro Buhl Derenzo+	(LRL)
BARNHAM	71	PRL 26 1494	+Abrams Butler Coyne Goldhaber Hall+	(LBL)
BINNIE	71	PL 36B 257	+Camilleri Duane Faruqi Burton+	(LOIC SHMP)
BOWEN	71	PRL 26 1663	+Earles Faissler Blieden+	(NEAS STON)
GRAYER	71	PL 34B 333	+Hyams Jones Schlein Blum+	(CERN MPIM)
ABRAMOVI	70B	NP B23 466	Abramovich Blumenfeld Bruyant+	(CERN) JP
ALSTON	70	PL 33B 607	Alston Garnjost Barbaro Buhl Derenzo+	(LRL)
BOECKMANN	70	NP B16 221	+Major+	(BONN DURH NIJM EPOL TORI)
EISENBERG	69	PRL 23 1322	+Haber Ballam Chadwick+	(REHO SLAC)
ARMENISE	68B	PL 26B 336	+Forino Cartacci+	(BARI BGNA FIRZ ORSA)
ASCOLI	68	PRL 20 1321	+Crawley Mortara Shapiro Bridges+	(ILL) JP
BOESEBECK	68	NP B4 501	+Deutschmann+	(AACH BERL CERN)
CHUNG	68	PR 165 1491	+Dahl Kirz Miller	(LRL)
CONTE	67	NC 51A 175	+Tomasini Cords+	(GENO HAMB MILA SACL)

—— OTHER RELATED PAPERS ——

JENNI	83	PR D27 1031	+Burke Telnov Abrams Blocker+	(SLAC LBL)
BEHREND	82C	PL 114B 378	+	(DESY KARL MPIM LALO LPNP+)
DAUM	81B	NP B182 269	+Hertzberger+	(AMST CERN CRAC MPIM OXF+)
BALTAY	78E	PRL 40 87	+Cautis Kalelkar	(COLU) JP
CORDEN	78C	NP B136 77	+Dowell Garvey+	(BIRM RHEL TELA LOWC) JP
MARTIN	78B	NP B140 158	+Ozmutlu Baldi Bohringer Dorsaz+	(DURH GEVA)
CERRADA	77B	NP B126 241	+Blockzijl Heinen+	(AMST CERN NIJM OXF)
PAWLICKI	77	PR D15 3196	+Ayres Cohen Diebold Kramer Wicklund	(ANL) IJ
HANDLER	76	NP B110 173	+Piano Brucker Koller+	(RUTG STEV SETO)
ABASHIAN	75	PRL 34 691	+Beamer Bross Eisenstein+	(ILL ANL ISU)
LOSTY	75	PL 56B 96	+Chaloupka Montanet Gandois+	(CERN SACL) JP
UNDERWOOD	75	PR D11 2345	+Conforto Key+	(EFI FNAL INTO WISC)
Also	73	PL 45B 154	Conforto Mobley Key+	(EFI FNAL INTO WISC)
Also	73	PRL 30 503	Key Conforto Mobley+	(INTO EFI FNAL WISC)
OTTER	74	NP B80 1	+Rudolph+	(AACH BERL BONN CERN HEID) JP
THOMPSON	74B	NP B69 381	+Badewitz Gaidos McIlwain+	(PURD) JP
THOMPSON	74D	PR D9 560	+Gaidos McIlwain Willmann	(PURD) JP
AMMANN	73	PR D7 1345	+Carmony Garfinkel Gutay Miller+	(PURD IUPU)

ANKENBRA	73	PR D8 2785	Ankenbrandt Brabson Crittenden Heinz+	(IND)
ANTIPOV	73B	NP B63 141	+Ascoli Busnello Focacci+	(CERN SERP) JP
CASON	73B	NP B64 14	+Madden Bishop Biswas Kenney+	(NDAM)
ANKENBRA	72B	PRL 29 1688	Ankenbrandt Brabson Crittenden Heinz+	(IND)
BERENYI	72	NP B37 621	+Prentice Steenberg Yoon Walker	(TNTO WISC)
DIEBOLD	72	Batavia Conf 3 1		(ANL)
LASSILA	72	PRL 28 1491	+Young	(IOWA)
MORSE	72	NP B43 77	+Oh Walker Johnston Yoon	(WISC TNTO)
AGUILAR	71B	PR D4 2583	Aguilar Benitez Eisner Kinson	(BNL)
BEKETOV	71	SJNP 4 765	+Sombkowsky Konovalov Krutschinin+	(ITEP) JP
		Translated from unknown journal		
BINNIE	71B	PL 36B 537	+Camilleri Duane Faruqi Burton+	(LOIC SHMP)
CRENNELL	71	PL 35B 185	+Gordon Lai Scarr	(BNL)
FARBER	71	NP B29 237	+DePinto Biswas Cason Deery Kenney+	(NDAM)
FOLEY	71	PRL 26 413	+Love Ozaki Platner Lindenbaum+	(BNL CUNY)
LYNCH	71	UCRL 20022		(LBL)
Also 1971 Amsterdam Conference				
RINAUDO	71	NC 5A 239	+	(TORI BONN DURH NIJM EPOL) JP
ASCOLI	70	PRL 25 962	+Brockway Crawley Eisenstein Hanft+	(ILL) JP
BASILE	70B	LNC 4 838	+Dalpiaz Frabetti Massam+	(CERN BGNA STRB)
BAUD	70B	Phil Conf 311		(CERN Boson Spectrometer Collab)
BAUD	70C	PL 31B 401		(CERN Boson Spectrometer Collab)
BAUD	70D	PL 31B 397		(CERN Boson Spectrometer Collab)
BUTLER	70	UCRL 19845 Thesis		(LRL)
CAROLL	70	PRL 25 1393	+Firebaugh Garfinkel Morse Oh+	(WISC TNTO)
CASO	70	LNC 3 707	+Conte Tomasini+	(GENO HAMB MILA SACL)
DIAZ	70	NP B16 239	+Gavillet Labrosse Montanet+	(CERN CDEF) JP
DZIERBA	70	PR D2 2544	+Shephard Biswas Cason Johnson+	(NDAM)
GARFINKEL	70	PL 33B 536	+Ammann Carmony Yen	(PURD) JPC
JOHNSTON	70	NP B24 253	+Key Prentice Yoon Garfinkel+	(TNTO WISC)
KRUSE	70	Phil Conf 359		(ILL) JP
SUTHERLAND	70	Phil Conf 369		(GLAS)
ADERHOLZ	69	NP B11 259	+Bartsch+	(AACH BERL CERN JAGL WARS)
AGUILAR	69B	PL 29B 62	Aguilar Benitez Barlow+	(CERN CDEF LIVP)
AGUILAR	69C	PL 29B 241	Aguilar Benitez Barlow+	(CERN CDEF)
ANDERSON	69	PRL 22 1390	+Collins+	(BNL CMU)
ARMENISE	69	LNC 2 501	+Ghidini Forino Cartacci+	(BARI BGNA FIRZ)
CHIKOVAN	69	PL 28B 526		(CERN Missing Mass Spectrometer Collab) JP
CRENNELL	69	PRL 22 1327	+Karshon Lai+	(BNL) IJP
DONALD	69B	NP B12 325	+Edwards Foster Moore	(LIVP)
VETLITSKY	69B	SJNP 9 596	+Grigorev Grishin+	(ITEP)
		Translated from YAF 9 1018		
BALLAM	68	PRL 21 934	+Brody Chadwick Fries Guiragossian+	(SLAC)
BENZ	68	PL 28B 233		(CERN Missing Mass Spectrometer Collab)
CASO	68	NC 54A 983	+Conte Cords Diaz+	(GENO HAMB MILA SACL)
CRENNELL	68C	PRL 20 1318	+Karshon Lai Scarr Skillicorn	(BNL)
DONALD	68	PL 26B 327	+Frodesen Bettini+	(LIVP OSLO PADO)
FRIDMAN	68	PR 167 1268	+Maurer Michalon Oudet+	(HEID STRB)
JUNKMANN	68	NP B8 471	+Cocconi+	(AACH BERL BONN CERN WARS)
KEY	68	PR 166 1430	+Prentice Cooper Manner+	(TNTO ANL WISC)
LAMSA	68	PR 166 1395	+Cason Biswas Derado Groves+	(NDAM)
VONKROGH	68	PL 27B 253	+Miyashita Kopelman Libby	(COLO)
ARMENISE	67	PL 25B 53	+Forino+	(BARI BGNA FIRZ ORSA)
BALTAY	67C	PL 25B 160	+Kirsch Kung Yeh Rabin	(COLU BNL RUTG)
BARLOW	67	NC 50A 701	+Lillestol Montanet+	(CERN CDEF IRAD LIVP)
BARTSCH	67	PL 25B 48	+Deutschmann Grote+	(AACH BERL CERN)
BEUSCH	67	PL 25B 357	+Fischer Gobbi Astbury+	(ETH CERN)
CASON	67	PRL 18 880	+Lamsa Biswas Derado Groves+	(NDAM)
CHIKOVAN	67	PL 25B 44		(CERN Missing Mass Spectrometer Collab)
CHUNG	67	PRL 18 100	+Dahl Hardy Hess Kirz Miller	(LRL)
Also	66B	UCRL 16832 Thesis	Hess	(LRL)
COHN	67	NP B1 57	+McCulloch Bugg Condo	(ORNL TENN)
CONFORTO	67	NP B3 469	+Marechal+	(CERN CDEF IPNP LIVP)
DAHL	67	PR 163 1377	+Hardy Hess Kirz Miller	(LRL)
DANYSZ	67B	NC 51A 801	+French Simak	(CERN)
SLATTERY	67	NC 50A 377	+Kraybill Forman Ferbel	(YALE ROCH) JP
BARNES	66	PRL 16 41	+Fowler Lai Orenstein+	(BNL CUNY)
EHRLICH	66	PR 152 1194	+Selove Yuta	(PENN)
FERBEL	66	PL 21 111		(ROCH)
LEVRAT	66	PL 22 714		(CERN Missing Mass Spectrometer Collab)
ABOLINS	65	Athens Conf	+Carmony Lander Xuong Yager	(UCSD) I
ADERHOLZ	65	PR 138B 897		(AACH BERL BIRM BONN HAMB LOIC MPIM)
ALITTI	65	PL 15 69	+Baton Deler Crussard+	(SACL BGNA) JP
CHUNG	65	PRL 15 325	+Dahl Hardy Hess Jacobs Kirz	(LRL)
FORINO	65B	PL 19 68	+Gessaroli+	(BGNA BARI FIRZ ORSA SACL)
LEFEBVRE	65	PL 19 434		(CERN Missing Mass Spectrometer Collab)
SEIDLITZ	65	PRL 15 217	+Dahl Miller	(LRL)
ADERHOLZ	64	PL 10 226	+	(AACH BERL BIRM BONN DESY HAMB+)
CHUNG	64	PRL 12 621	+Dahl Hardy Hess Kalbfleisch Kirz	(LRL)
GOLDHABER	64B	Dubna Conf 1 480	+Goldhaber O Halloran Shen	(LRL)
Also	64	PRL 12 336	Goldhaber Brown Kadyk Shen+	(LRL UCB)
LANDER	64	PRL 13 346A	+Abolins Carmony Hendricks Xuong+	(UCSD)

$h_1(1380)$

$I^G(J^{PC}) = 0^-(1^{+-})$

OMITTED FROM SUMMARY TABLE

Seen in partial-wave analysis of the $K^0_S K^\pm \pi^\mp$ system. Evidence for $K^- K + \bar{K}^+ K$ decays (ASTON 88C). Needs confirmation.

$h_1(1380)$ MASS

VALUE	DOCUMENT ID		TECN	COMMENT
1380 ± 20	ASTON	88C	LASS	11 $K^- p \to K^0 K^\pm \pi^\mp \Lambda$

$h_1(1380)$ WIDTH

VALUE	DOCUMENT ID		TECN	COMMENT
80 ± 30	ASTON	88C	LASS	11 $K^- p \to K^0 K^\pm \pi^\mp \Lambda$

$h_1(1380)$ DECAY MODES

Γ_1 $h_1(1380) \to K\bar{K}^*(892)$ + c c

$h_1(1380)$ REFERENCES

ASTON 88C PL B201 573 +Awaji Bienz+ (SLAC NAGO CINC TOKY)

$f_0(1400)$ was $\epsilon(1300)$

$I^G(J^{PC}) = 0^+(0^{++})$

Our latest mini-review on this particle can be found in the 1984 edition

See also the mini-review under non-$q\bar{q}$ candidates

$f_0(1400)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •				
1420 0 ± 20.0	AKESSON	86	SPEC	$pp \to pp\pi^+\pi^-$
1220.0 ± 40 0	ALDE	86D	GAM4	100 $\pi^- p \to n2\eta$
1463 0 ± 9 0	ETKIN	82B	MPS	23 $\pi^- p \to n2K^0_S$
1470 0 ± 10 ± 20	[1] ETKIN	82C	MPS	23 $\pi^- p \to n2K^0_S$
1425 ± 15	WICKLUND	80	SPEC	6 $\pi N \to K^+K^-N$
~1300	POLYCHRO	79	STRC	7 $\pi^- p \to n2K^0_S$

[1] Fit includes interference with the $f_0(1240)$ resonance

$f_0(1400)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
460 0 ± 50 0	AKESSON	86	SPEC	$pp \to pp\pi^+\pi^-$
320 0 ± 40 0	ALDE	86D	GAM4	100 $\pi^- p \to n2\eta$
$118\ 0^{+138\ 0}_{-16\ 0}$	ETKIN	82B	MPS	23 $\pi^- p \to n2K^0_S$
140 0 ± 10 ± 20	[2] ETKIN	82C	MPS	23 $\pi^- p \to n2K^0_S$
160 ± 30	WICKLUND	80	SPEC	6 $\pi N \to K^+K^-N$
~150.	POLYCHRO	79	STRC	7 $\pi^- p \to n2K^0_S$

[2] Fit includes interference with the $f_0(1240)$ resonance

$f_0(1400)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$f_0(1400) \to \pi\pi$	$(93.6^{+1\ 9}_{-1\ 5}) \times 10^{-2}$
Γ_2	$f_0(1400) \to K\bar{K}$	$(7\ 5 \pm 0\ 9) \times 10^{-2}$
Γ_3	$f_0(1400) \to \eta\eta$	

$f_0(1400)$ BRANCHING RATIOS

$\Gamma(\pi\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
$0.936^{+0.019}_{-0.015}$	GORLICH	80	ASPK	17 18 $\pi^- p$ polarized
• • • We do not use the following data for averages fits limits etc • • •				
0 93	LOVERRE	80	HBC	4 $\pi^- p \to KKN$
0 73	HYAMS	75	ASPK	17 2 $\pi^- p \to n\pi^+\pi^-$

$\Gamma(K\bar{K})/\Gamma(\pi\pi)$ Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0.08 ± 0.01	COSTA	80	OMEG	10 $\pi^- p \to K^+K^-n$

f_0(1400) REFERENCES

AKESSON	86	NP B264 154	+Albrow Almehed+	(Axial Field Spec Collab)
ALDE	86D	NP B269 485	+Binon Bricman+	(BELG LAPP SERP CERN)
ETKIN	82B	PR D25 1786	+Foley Lai+	(BNL CUNY TUFT VAND)
ETKIN	82C	PR D25 2446	+Foley Lai+	(BNL CUNY TUFT VAND)
COSTA	80	NP B175 402	Costa De Beauregard+	(BARI BONN CERN+)
GORLICH	80	NP B174 16	+Niczyporuk+	(CRAC MPIM CERN ZEEM)
LOVERRE	80	ZPHY C6 187	+Armenteros Dionisi+ (CERN CDEF MADR STOH)	IJP
WICKLUND	80	PRL 45 1469	+Ayres Cohen Diebold Pawlicki	(ANL)
POLYCHRO	79	PR D19 1317	Polychronakos Cason Bishop+ (NDAM ANL)	IJP
HYAMS	75	NP B100 205	+Jones Wellhammer Blum Dietl+	(CERN MPIM)

—— OTHER RELATED PAPERS ——

AU	87	PR D35 1633	+Morgan Pennington	(DURH RAL)

f_1(1420) was E(1420)

$I^G(J^{PC}) = 0^+(1^{++})$

The $J^{PC} = 1^{++}$ state (DIONISI 80 ARMSTRONG 84, GIDAL 87B) appears to have a dominant quasi-two-body S-wave decay mode into $K^*(892)\bar{K}$. The spin-parity determination is based on the analysis of the $K\bar{K}\pi$ Dalitz plot (DIONISI 80 ARMSTRONG 84), or on the observation of the $f_1(1420)$ in $\gamma\gamma^*$ reactions where one photon is off the mass shell (GIDAL 87B)

Partial-wave analyses of the $K\bar{K}\pi$ system in this mass region (PROTOPOPESCU 87) find a phase variation for the $J^{PC} = 0^{-+}$, rather than for the 1^{++}, wave with a substantial coupling to $a_0(980)\pi$ [see the η(1430) mini-review]

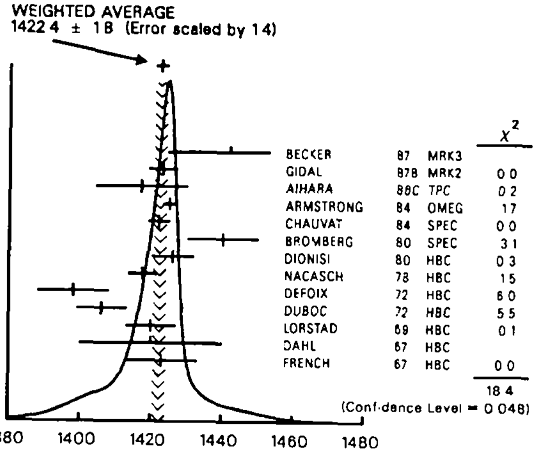
f_1(1420) MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1422.4 ± 1.8 OUR AVERAGE Error includes scale factor of 1 4 See the ideogram below					
$1442 \pm 5.0^{+10.0}_{-17.0}$	111^{+31}_{-26}	BECKER	87	MRK3	e^+e^-, $\omega K\bar{K}\pi$
1423 ± 4		GIDAL	87B	MRK2	$e^+e^- \to e^+e^- KK\pi$
1417 0 ± 13 0	13	AIHARA	86C	TPC	$e^+e^- \to e^+e^- KK\pi$
1425 0 ± 2 0	1520	ARMSTRONG	84	OMEG	85 $\pi^+ p$ $pp \to (\pi^+ p)(KK\pi)$
1422.0 ± 3 0		CHAUVAT	84	SPEC	ISR 31 5 pp
1440 0 ± 10.0		[1] BROMBERG	80	SPEC	100 $\pi^- p \to K\bar{K}\pi X$
1426 0 ± 6 0	221	DIONISI	80	HBC	4 $\pi^- p \to K\bar{K}\pi n$
1417 5 ± 4		NACASCH	78	HBC	0 7,0 76 $\bar{p}p$
1398 ± 10	170	DEFOIX	72	HBC	0 7 $\bar{p}p \to 7\pi$
1406 ± 7	280	DUBOC	72	HBC	1 2 $\bar{p}p \to 2K4\pi$
1420 ± 7	310	LORSTAD	69	HBC	0 7 $\bar{p}p$
1420 ± 20		DAHL	67	HBC	1 6–4 2 $\pi^- p$
1423 0 ± 10 0		FRENCH	67	HBC	3–4 $\bar{p}p$

[1] Mass error increased to account for $a_0(980)$ mass cut uncertainties

f_1(1420) WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
55.2 ± 3.3 OUR AVERAGE					
$40^{+17}_{-13} \pm 5$	111^{+31}_{-26}	BECKER	87	MRK3	e^+e^- $\omega KK\pi$
$35.0^{+47.0}_{-20.0}$	13	AIHARA	86C	TPC	$e^+e^- \to e^+e^- KK\pi$
62 0 ± 5 0	1520	ARMSTRONG	84	OMEG	85 $\pi^+ p$, $pp \to (\pi^+, p)(KK\pi)$
47 0 ± 10 0		CHAUVAT	84	SPEC	ISR 31 5 pp
62.0 ± 14 0		BROMBERG	80	SPEC	100 $\pi^- p \to KK\pi X$
40.0 ± 15 0	221	DIONISI	80	HBC	4 $\pi^- p \to KK\pi n$
53 ± 20 0		NACASCH	78	HBC	0 7 0 76 $\bar{p}p$
50 ± 10	170	DEFOIX	72	HBC	0 7 $\bar{p}p \to 7\pi$
50 ± 12	280	DUBOC	72	HBC	1 2 $\bar{p}p \to 2K4\pi$
60 ± 20	310	LORSTAD	69	HBC	0 7 $\bar{p}p$
60 0 ± 20 0		DAHL	67	HBC	1 6–4 2 $\pi^- p$
45. ± 20		FRENCH	67	HBC	3–4 $\bar{p}p$



f_1(1420) mass (MeV)

f_1(1420) DECAY MODES

Γ_1	$f_1(1420) \to K\bar{K}^*(892)$ + c c
Γ_2	$f_1(1420) \to K\bar{K}\pi$
Γ_3	$f_1(1420) \to \pi\pi\rho$
Γ_4	$f_1(1420) \to a_0(980)\pi$
Γ_5	$f_1(1420) \to \eta\pi\pi$
Γ_6	$f_1(1420) \to 4\pi$
Γ_7	$f_1(1420) \to \gamma\gamma$

f_1(1420) $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(\text{total})$

$\Gamma(K\bar{K}\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ — $\Gamma_2\Gamma_7/\Gamma$

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
3.2 ± 1.4 ± 0 6		[2] GIDAL	87B	MRK2	$e^+e^- \to e^+e^- KK\pi$
• • • We do not use the following data for averages fits limits etc • • •					
<8 0	95	JENNI	83	MRK2	$e^+e^- \to e^+e^- KK\pi$

[2] Assuming a ρ pole form factor

f_1(1420) BRANCHING RATIOS

$\Gamma(K\bar{K}^*(892)$ + c c $)/\Gamma(KK\pi)$ — Γ_1/Γ_2

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
0 76 ± 0 06	BROMBERG	80	SPEC	100 $\pi^- p \to KK\pi X$
0 86 ± 0 12	DIONISI	80	HBC	4 $\pi^- p \to KK\pi n$

$\Gamma(\pi\pi\rho)/\Gamma(K\bar{K}\pi)$ — Γ_3/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
<0 3	95	CORDEN	78	OMEG	12–15 $\pi^- p$
<2.0		DAHL	67	HBC	1 6–4 2 $\pi^- p$

$\Gamma(\eta\pi\pi)/\Gamma(K\bar{K}\pi)$ — Γ_5/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
<0 6	90	GIDAL	87	MRK2	$e^+e^- \to e^+e^-\eta\pi^+\pi^-$
<0 5	95	CORDEN	78	OMEG	12–15 $\pi^- p$
1 5 ± 0 8		DEFOIX	72	HBC	0 7 $\bar{p}p$
<1 5	95	FOSTER	68B	HBC	0 0 $\bar{p}p$

$\Gamma(a_0(980)\pi)/\Gamma(\eta\pi\pi)$ — Γ_4/Γ_5

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
Not seen in either mode	ANDO	86	SPEC	8 $\pi^- p$
Not seen in either mode	CORDEN	78	OMEG	12–15 $\pi^- p$
0 4 ± 0 2	DEFOIX	72	HBC	0 7 $pp \to 7\pi$

$\Gamma(4\pi)/\Gamma(KK^*(892)$ + c c $)$ — Γ_6/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
<0 90	95	DIONISI	80	HBC	4 $\pi^- p$

$\Gamma(K\bar{K}\pi)/[\Gamma(K\bar{K}^*(892) + c.c.) + \Gamma(a_0(980)\pi)]$ $\Gamma_2/(\Gamma_1+\Gamma_4)$

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
0 65 ± 0 27	[3] DIONISI 80	HBC	4 $\pi^- p$

[3]Calculated using $\Gamma(K\bar{K})/\Gamma(\eta\pi)$ = 0 24 ± 0 07 for $a_0(980)$ fractions

$\Gamma(a_0(980)\pi)/\Gamma(K\bar{K}^*(892) + c.c.)$ Γ_4/Γ_1

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
<0 04	68	ARMSTRONG 84	OMEG	85 $\pi^+ p$

$f_1(1420)$ REFERENCES

BECKER	87	PRL 59 186	+ (MARK III Collab)	JP
GIDAL	87	PRL 59 2012	+Boyer Butler Cords Abrams+ (LBL SLAC HARV)	
GIDAL	87B	PRL 59 2016	+Boyer Butler Cords Abrams+ (LBL SLAC HARV)	
AIHARA	86C	PRL 57 2500	+Alston Garnjost+ (TPC Two Gamma Collab)	JP
ANDO	86	PRL 57 1296	+Imai+ (KEK KYOT NIRS SAGA TOKY TSUK+)	
ARMSTRONG	84	PL 146B 273	+Bloodworth Burns+ (ATHU BARI BIRM CERN)	JP
CHAUVAT	84	PL 148B 382	+Meritet Bonino+ (CERN UDCF UCLA SACL)	
JENNI	83	PR D27 1031	+Burke Telnov Abrams Blocker+ (SLAC LBL)	
BROMBERG	80	PR D22 1513	+Haggerty Abrams Dzierba (CIT FNAL ILLC IND)	
DIONISI	80	NP B169 1	+Gavillet+ (CERN MADR CDEF STOH)	IJP
CORDEN	78	NP B144 253	+Corbett Alexander+ (BIRM RHEL TELA LOWC)	
NACASCH	78	NP B135 203	+Defoix Dobrzynski+ (PARI MADR CERN)	
DEFOIX	72	NP B44 125	+Nascimento Bizzarri+ (CDEF CERN)	
DUBOC	72	NP B46 429	+Goldberg Makowski Donald+ (LPNP LIVP)	
LORSTAD	69	NP B14 63	+D Andlau Astier+ (CDEF CERN)	JP
FOSTER	68B	NP B8 174	+Gavillet Labrosse Montanet+ (CERN CDEF)	
DAHL	67	PR 163 1377	+Hardy Hess Kirz Miller (LRL)	IJP
Also	65	PRL 14 1074	Miller Chung Dahl Hess Hardy Kirz+ (LRL UCB)	
FRENCH	67	NC 52A 438	+Kinson McDonald Riddiford+ (CERN BIRM)	

— OTHER RELATED PAPERS —

PROTOPOP 87B Hadron Conf Protopopescu Chung (BNL)

$\eta(1430)$ was $\iota(1440)$

$I^G(J^{PC}) = 0^+(0^{-+})$

See also the mini-review under non-$q\bar{q}$ candidates

The first observation of a meson with $I^G J^{PC} = 0^+0^{-+}$ in the 1400 MeV mass region was made with $p\bar{p}$ annihilations at rest (BAILLON 67) in the channel $\eta(1430) \to K\bar{K}\pi$. It was seen to decay equally into $a_0(980)\pi$ and $K^*(892)\bar{K}$.

The $\eta(1430)$ is now observed in other hadronic reactions: in a partial-wave analysis of the $\eta\pi^-\pi$ system, confirming the decay $\eta(1430) \to a_0(980)\pi$ (ANDO 86) and in a partial-wave analysis of the $K\bar{K}\pi$ system (PROTOPOPESCU 87). It is also observed in 6 GeV $p\bar{p}$ annihilation (REEVES 86). It is, however, not observed in the $s\bar{s}$-enriched reaction $K^- p \to K\bar{K}\pi\Lambda$ at 11 GeV/c (ASTON 87). Note that all these results (except BAILLON 67) are obtained in peripheral interactions. In contrast to these conditions, ARMSTRONG 87, studying $K\bar{K}\pi$ central production in $\pi^+ p \to \pi^+(K\bar{K}\pi)p$ and $pp \to p(K\bar{K}\pi)p$ at 85 GeV/c, do not see the $\eta(1430)$ but the $f_1(1420)$ which is found to be mainly coupled to $K^*(892)\bar{K}$. This is in line with earlier results (DIONISI 80, DEFOIX 72, DUBOC 72, LORSTAD 69, etc.). Note that these earlier data were dominated by central processes.

The $\eta(1430)$ is also present as a broad enhancement in the J/ψ radiative decay (RICHMAN 85). In the $K\bar{K}\pi$ channel, however, its mass is higher than observed in hadronic interactions and its width is larger. It has been shown (TOKI 87) that a two-Breit-Wigner fit (with M = 1420 MeV and M = 1500 MeV) would give a better description of the data. Moreover, the $\eta\pi^+\pi^-$ channel peaks at 1390 MeV as well as the $\rho^0\gamma$ channel (TOKI 87).

In the present situation we list under $\eta(1430)$ all the results obtained on the 0^{-+} system in the 1380–1460 MeV mass region.

$\eta(1430)$ MASS

PRODUCED BY HADRON BEAM

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1421 9 ± 1.5 OUR AVERAGE					
1420 ± 5		ANDO	86	SPEC	8 $\pi^- p \to n\eta\pi^+\pi^-$
1424 0 ± 3 0	620	REEVES	86	SPEC	6 6 $p\bar{p} \to K\bar{K}\pi X$
1421 0 ± 2 0		CHUNG	85	SPEC	8 $\pi^- p \to K\bar{K}\pi n$
1425 ± 7		BAILLON	67	HBC	0 0 $p\bar{p} \to K\bar{K}\pi\pi\pi$

PRODUCED IN $J/\psi(1S)$ DECAY

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1451 9 ± 2.5 OUR AVERAGE Error includes scale factor of 1 1					
1454 ± 3		WISNIEWSKI	87	MRK3	$J/\psi \to K\bar{K}\pi\gamma$
1444 0 ± 7 0		AUGUSTIN	85	DM2	$J/\psi \to K^+K^-\pi^0\gamma$
1454 0 ± 5 0		AUGUSTIN	85	DM2	$J/\psi \to K^0_S K^\pm \pi^\mp\gamma$
1440 0 $^{+20\ 0}_{-15\ 0}$	174	EDWARDS	82E	CBAL	$J/\psi \to K^+K^-\pi^0\gamma$
1440 0 $^{+10\ 0}_{-15\ 0}$		SCHARRE	80	MRK2	$J/\psi \to K^0_S K^\pm \pi^\mp\gamma$
• • • We do not use the following data for averages fits, limits etc • • •					
1420 0 ± 15 0 ± 20 0		[1] RICHMAN	85	MRK3	$J/\psi \to \pi^+\pi^- 2\gamma$

[1]This peak in the $\gamma\rho$ channel may not be related to the $\eta(1430)$

$\eta(1430)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
160 ± 11		WISNIEWSKI	87	MRK3	$J/\psi \to K\bar{K}\pi\gamma$
31 ± 7		ANDO	86	SPEC	8 $\pi^- p \to n\eta\pi^+\pi^-$
60 0 ± 10 0	620	REEVES	86	SPEC	6 6 $p\bar{p} \to K\bar{K}\pi X$
95 0 ± 10 0		AUGUSTIN	85	DM2	$J/\psi \to K^+K^-\pi^0\gamma$
92 0 ± 16 0		AUGUSTIN	85	DM2	$J/\psi \to K^0_S K^\pm \pi^\mp\gamma$
60 0 ± 10 0		CHUNG	85	SPEC	8 $\pi^- p \to K\bar{K}\pi n$
133 0 ± 55 ± 30		[2] RICHMAN	85	MRK3	$J/\psi \to \pi^+\pi^- 2\gamma$
55 0 $^{+30\ 0}_{-30\ 0}$	174	EDWARDS	82E	CBAL	$J/\psi \to K^+K^-\pi^0\gamma$
50 0 $^{+30\ 0}_{-20\ 0}$		SCHARRE	80	MRK2	$J/\psi \to K^0_S K^\pm \pi^\mp\gamma$
80 ± 10		BAILLON	67	HBC	0 0 $p\bar{p}$

[2]This peak in the $\gamma\rho$ channel may not be related to the $\eta(1430)$

$\eta(1430)$ DECAY MODES

Γ_1	$\eta(1430) \to K\bar{K}^*(892)$ + c.c.
Γ_2	$\eta(1430) \to K\bar{K}\pi$
Γ_3	$\eta(1430) \to \pi\pi\rho$
Γ_4	$\eta(1430) \to a_0(980)\pi$
Γ_5	$\eta(1430) \to \eta\pi\pi$
Γ_6	$\eta(1430) \to 4\pi$
Γ_7	$\eta(1430) \to \gamma\gamma$
Γ_8	$\eta(1430) \to \rho^0\gamma$

$\eta(1430)$ $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(\text{total})$

$\Gamma(K\bar{K}\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ $\Gamma_2\Gamma_7/\Gamma$

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
<1 6	95	AIHARA	86D	TPC	$e^+e^- \to e^+e^- K^0_S K^\pm \pi^\mp$
<2 2	95	ALTHOFF	85B	TASS	$e^+e^- \to e^+e^- K\bar{K}\pi$
<8 0	95	JENNI	83	MRK2	$e^+e^- \to e^+e^- K\bar{K}\pi$

$\Gamma(\eta\pi\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ — $\Gamma_5\Gamma_7/\Gamma$

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits, etc • • •			
<0 3	ANTREASYAN 87	CBAL	$e^+e^- \to e^+e^-\eta\pi\pi$

$\Gamma(\rho^0\gamma) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ — $\Gamma_8\Gamma_7/\Gamma$

VALUE (keV)	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
<1 5	95	ALTHOFF 84E	TASS	$e^+e^- \to e^+e^-\pi^+\pi^-\gamma$

$\eta(1430)$ BRANCHING RATIOS

$\Gamma(K\overline{K}^*(892) + c\,c)/\Gamma(KK\pi)$ — Γ_1/Γ_2

VALUE	DOCUMENT ID	TECN	COMMENT
0.50±0.10	BAILLON 67	HBC	0 0 $\bar{p}p$

$\Gamma(\eta\pi\pi)/\Gamma(KK\pi)$ — Γ_5/Γ_2

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
<0 5	90	EDWARDS 83B	CBAL	$J/\psi \to \eta\pi\pi\gamma$
<1 1	90	SCHARRE 80	MRK2	$J/\psi \to \eta\pi\pi\gamma$

$\Gamma(a_0(980)\pi)/\Gamma(KK\pi)$ — Γ_4/Γ_2

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
~0 75	[3] REEVES 86	SPEC	6 6 $pp \to KK\pi X$

[3]Assuming that the $a_0(980)$ decays only into KK

$\Gamma(K\overline{K}^*(892) + c\,c)/[\Gamma(K\overline{K}^*(892) + c\,c) + \Gamma(a_0(980)\pi)]$ — $\Gamma_1/(\Gamma_1+\Gamma_4)$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
<0 25	90	EDWARDS 82E	CBAL	$J/\psi \to K^+K^-\pi^0\gamma$

$\eta(1430)$ REFERENCES

ANTREASYAN	87	PR D36 2633	+Bartels Besset+	(Crystal Ball Collab)
WISNIEWSKI	87	CALT 68 1446		(MARK III Collab)
AIHARA	86D	PRL 57 51	+Alston Garnjost+	(TPC Two Gamma Collab)
ANDO	86	PRL 57 1296	+Imai+	(KEK KYOT NIRS SAGA TOKY TSUK+) IJP
REEVES	86	PR 34 1960	+Chung Crittenden+	(FLOR BNL IND SMAS) JP
ALTHOFF	85B	ZPHY C29 189	+Braunschweig Kirschfink+	(TASSO Collab)
AUGUSTIN	85	Moriond XX 1 479	+Calcaterra Cosme+	(ORSA CLER PADO FRAS)
CHUNG	85	PRL 55 779	+Fernow Boehnlein+	(BNL FLOR IND SMAS) JP
RICHMAN	85	Moriond XX Conf		(CIT)
ALTHOFF	84E	PL 147B 487		(TASSO Collab)
EDWARDS	83B	PRL 51 859	+Partridge Peck+	(CIT HARV PRIN STAN SLAC)
JENNI	83	PR D27 1031	+Burke Telnov Abrams Blocker+	(SLAC LBL)
EDWARDS	82E	PRL 49 259	+Partridge Peck+	(CIT HARV PRIN STAN SLAC)
Also	83	PRL 50 219	Edwards Partridge+	(CIT HARV PRIN STAN+)
SCHARRE	80	PL 97B 329	+Trilling Abrams Alam Blocker+	(SLAC LBL)
BAILLON	67	NC 50A 393	+Edwards D Andlau Astier+	(CERN CDEF IRAD)

OTHER RELATED PAPERS

ARMSTRONG	87	ZPHY C34 23	+Bloodworth+	(CERN BIRM BARI ATHU LPNP)
PROTOPOP	87B	Hadron Conf	Protopopescu Chung	(BNL)
TOKI	87	Hadron Conf		(TOKY)
DIONISI	80	NP B169 1	+Gavillet+	(CERN MADR CDEF STOH)
DEFOIX	72	NP B44 125	+Nascimento Bizzarri+	(CDEF CERN)
DUBOC	72	NP B46 429	+Goldberg Makowski Donald+	(LPNP LIVP)
LORSTAD	69	NP B14 63	+D Andlau Astier+	(CDEF CERN)

$f_2(1430)$

$I^G(J^{PC}) = 0^+(2^{++})$

OMITTED FROM SUMMARY TABLE

This entry lists nearby peaks observed in the D-wave of the KK and $\pi^+\pi^-$ systems

$f_2(1430)$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
1421 ± 5	AUGUSTIN 87	DM2	$J/\psi \to \gamma\pi^+\pi^-$
1480 0 ± 50 0	AKESSON 86	SPEC	$pp \to pp\pi^+\pi^-$
1436 $0^{+26\ 0}_{-16\ 0}$	DAUM 84	CNTR	17–18 $\pi^-p \to K^+K^-n$
1412 0 ± 3 0	DAUM 84	CNTR	63 $\pi^-p \to K^0_SK^0_Sn$ K^+K^-n
1439 $0^{+5\ 0}_{-6\ 0}$	[1] BEUSCH 67	OSPK	5 7 12 $\pi^-p \to K^0_SK^0_Sn$

[1]Not seen by WETZEL 76

$f_2(1430)$ WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
30 ± 9	AUGUSTIN 87	DM2	$J/\psi \to \gamma\pi^+\pi^-$
150 0 ± 40 0	AKESSON 86	SPEC	$pp \to pp\pi^+\pi^-$
81 $0^{+56\ 0}_{-29\ 0}$	DAUM 84	CNTR	17–18 $\pi^-p \to K^-K^-n$
14 0 ± 6 0	DAUM 84	CNTR	63 $\pi^-p \to K^0_SK^0_Sn$ K^+K^-n
43 $0^{+17\ 0}_{-18\ 0}$	[2] BEUSCH 67	OSPK	5 7 12 $\pi\ p \to K^0_SK^0_Sn$

[2]Not seen by WETZEL 76

$f_2(1430)$ DECAY MODES

Γ_1 $f_2(1430) \to KK$

Γ_2 $f_2(1430) \to \pi\pi$

$f_2(1430)$ REFERENCES

AUGUSTIN	87	ZPHY C36 369	+Cosme+	(LALO CLER FRAS PADO)
AKESSON	86	NP B264 154	+Albrow Almehed+	(Axial Field Spec Collab)
DAUM	84	ZPHY C23 339	+Hertzberger+	(AMST CERN CRAC MPIM OXF+) JP
WETZEL	76	NP B115 208	+Freudenreich Beusch+	(ETH CERN LOIC)
BEUSCH	67	PL 25B 357	+Fischer Gobbi Astbury+	(ETH CERN)

$\rho(1450)$

$I^G(J^{PC}) = 1^+(1^{--})$

OMITTED FROM SUMMARY TABLE

This entry contains claims for vector mesons in the 1250–1500 MeV range Needs confirmation See the mini-review under the $\rho(1700)$

$\rho(1450)$ MASS

$\eta\pi^+\pi^-$ MODE

VALUE	DOCUMENT ID	TECN	COMMENT
1449 ± 9 OUR AVERAGE Includes data from the datablock that follows this one			
1446 ± 10	FUKUI 88	SPEC	8 95 $\pi^-p \to \eta\pi^+\pi^-n$

MIXED MODES

VALUE	DOCUMENT ID	TECN
The data in this block is included in the average printed for a previous datablock		
1465 ± 25	DONNACHIE 87	RVUE

$\omega\pi$ MODE

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
1250	[1] ASTON 80C	OMEG	20–70 $\gamma p \to \omega\pi^0p$
1290 ± 40	[1] BARBER 80C	SPEC	3–5 $\gamma p \to \omega\pi^0p$

[1]Not separated from $b_1(1235)$ not pure $J^P = 1^-$ effect

$\phi\pi$ MODE

VALUE	DOCUMENT ID	TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
1480 ± 40	BITYUKOV 87	SPEC	0	32 5 $\pi^-p \to \phi\pi^0n$

$\rho(1450)$ WIDTH

$\eta\pi^+\pi^-$ MODE

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
60 ± 15	FUKUI	88	SPEC	8 95 $\pi^- p \to \eta\pi^+\pi^- n$

MIXED MODES

VALUE	DOCUMENT ID		TECN
The data in this block is included in the average printed for a previous datablock			
• • • We do not use the following data for averages fits limits etc • • •			
220 ± 25	DONNACHIE	87	RVUE

$\omega\pi$ MODE

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •				
300	[2] ASTON	80C	OMEG	20–70 $\gamma p \to \omega\pi^0 p$
320 ± 100	[2] BARBER	80C	SPEC	3–5 $\gamma p \to \omega\pi^0 p$

[2]Not separated from $b_1(1235)$ not pure $J^P = 1^-$ effect

$\phi\pi$ MODE

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
130 ± 60	BITYUKOV	87	SPEC	0	32 5 $\pi^- p \to \phi\pi^0 n$

$\rho(1450)$ DECAY MODES

Γ_1	$\rho(1450) \to \pi^+\pi^-$
Γ_2	$\rho(1450) \to 4\pi$
Γ_3	$\rho(1450) \to \eta\pi^+\pi^-$
Γ_4	$\rho(1450) \to e^+e^-$
Γ_5	$\rho(1450) \to \phi\pi$
Γ_6	$\rho(1450) \to \omega\pi$

$\rho(1450)$ PARTIAL WIDTHS

$\Gamma(\pi^+\pi^-) \times \Gamma(e^+e^-)/\Gamma_{total}$ $\Gamma_1\Gamma_4/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits, limits etc • • •				
0 12	[3] DIEKMAN	87	RVUE	$e^+e^- \to \pi^+\pi^-$

[3]Using total width = 235 MeV

$\rho(1450)$ BRANCHING RATIOS

$\Gamma(\phi\pi)/\Gamma(\omega\pi)$ Γ_5/Γ_6

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
>0.5	95	BITYUKOV	87	SPEC	0	32 5 $\pi^- p \to \phi\pi^0 n$

$\rho(1450)$ REFERENCES

FUKUI 88 PL B202 441 +Horikawa+ (SUGI NAGO KEK KYOT MIYA)
BITYUKOV 87 PL B188 383 +Dzhelyadin Dorofeev Golovkin+ (SERP)
DIEKMAN 87 Tsukuba Conf 7 (BONN)
DONNACHIE 87 ZPHY C33 407 +Mirzaie (MCHS)
ASTON 80C PL 92B 211 (BONN CERN EPOL GLAS LANC MCHS+)
BARBER 80C ZPHY C4 169 +Dainton Brodbeck Brookes+(DARE LANC SHEF)

— OTHER RELATED PAPERS —

ASTON 87 NP B292 693 +Awaji D Amore+ (SLAC NAGO CINC TOKY)
BARKOV 85 NP B256 365 +Chilingarov Eidelman Khazin Lelchuk+(NOVO)
BISELLO 85 LAL 85 15 +Augustin Ajaltouni+ (PADO LALO CLER FRAS)
ABE 84B PRL 53 751 + (SLAC Hybrid Facility Photon Collab)
KURDADZE 83D JETPL 43 643 +Lelchuk Pakhtusova Sidorov Skrinskii+ (NOVO)
Translated from ZETPF 43 497
CORDIER 82 PL 109B 129 +Bisello Bizot Buon Delcourt (LALO)
DIBIANCA 81 PR D23 595 +Fickinger Malko Dado Engler+ (CASE CMU)
ASTON 80 PL 92B 215 (BONN CERN EPOL GLAS LANC MCHS+)
COSME 79 NP B152 215 +Dudelzak Grelaud Jean Marie Jullian+ (IPN)
SIDOROV 79 Batavia Conf 79 490 (NOVO)
QUENZER 78 PL 76B 512 +Ribes Rumpf Bertrand Bizot Chase+ (LALO)
COSME 76 PL 63B 352 +Courau Dudelzak Grelaud Jean Marie+(ORSA)
SCHACHT 74 NP B81 205 +Derado Fries Park Yount (MPIM)
BINGHAM 72B PL 41B 635 +Rabin Rosenfeld Smadja+ (LBL UCB SLAC)
FRENKIEL 72 NP B47 61 +Ghesquiere Lillestol Chung+ (CDEF CERN)
LAYSSAC 71 NC 6A 134 +Renard (MONP)

$f_0(1525)$

$I^G(J^{PC}) = 0^+(0^{++})$

OMITTED FROM SUMMARY TABLE

This entry contains evidence for $K\bar{K}$ S-wave intensity peaking at the mass of the $f_2'(1525)$ and with a comparable width Needs confirmation

$f_0(1525)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits, etc • • •				
~1525	ASTON	88D	LASS	11 $K^- p \to K_S^0 K_S^0 \Lambda$
~1525	BAUBILLIER	83		8 $K^- p \to K^+ K^- \Lambda$

$f_0(1525)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~90	ASTON	88D	LASS	11 $K^- p \to K_S^0 K_S^0 \Lambda$
~90	BAUBILLIER	83		8 $K^- p \to K^+ K^- \Lambda$

$f_0(1525)$ REFERENCES

ASTON 88D NP to be pub +Awaji Bienz+ (SLAC NAGO CINC TOKY)
BAUBILLIER 83 ZPHY C17 309 + (BIRM CERN GLAS MSU LPNP)

$f_2'(1525)$ was $f'(1525)$

$I^G(J^{PC}) = 0^+(2^{++})$

See also the mini-review under non-$q\bar{q}$ candidates

$f_2'(1525)$ MASS

PRODUCED BY PION BEAM

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
$1547\,0^{+10\,0}_{-2\,0}$		[1] LONGACRE	86	MPS	22 $\pi^- p \to K_S^0 K_S^0 n$
$1496\,0^{+9}_{-8}$		[2] CHABAUD	81	ASPK	6 $\pi^- p \to K^+ K^- n$
1497.0^{+8}_{-9}		CHABAUD	81	ASPK	18 4 $\pi^- p \to K^+ K^- n$
1492 0 ± 29 0		GORLICH	80	ASPK	17 $\pi^- p$ polarized $\to K^+ K^- n$
1502 0 ± 25 0		[3] CORDEN	79	OMEG	12–15 $\pi^- p \to \pi^+\pi^- n$
1480 0	14	CRENNELL	66	HBC	6 0 $\pi^- p \to K_S^0 K_S^0 n$

PRODUCED BY $K^\pm$ BEAM

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1525.0 ± 1 4 OUR AVERAGE Includes data from the datablock that follows this one					
1526 8 ± 4 3		ASTON	88D	LASS	11 $K^- p \to K_S^0 K_S^0 \Lambda$
1529 0 ± 3 0		ARMSTRONG	83B	OMEG	18 5 $K^- p \to K^- K^+ \Lambda$
1521 0 ± 6 0	650	AGUILAR-	81B	HBC	4 2 $K^- p \to \Lambda K^+ K^-$
1521 0 ± 3 0	572	ALHARRAN	81	HBC	8 25 $K^- p \to \Lambda K\bar{K}$
1522 0 ± 6 0	123	BARREIRO	77	HBC	4 15 $K^- p \to \Lambda K_S^0 K_S^0$
1528 ± 7	166	EVANGELISTA	77	OMEG	10 $K^- p \to K^+ K^- (\Lambda \Sigma)$
1527 0 ± 3 0	120	BRANDENB	76C	ASPK	13 $K^- p \to K^+ K^- (\Lambda \Sigma)$
1519 ± 7	100	AGUILAR	72B	HBC	3 9,4 6 $K^- p \to K\bar{K}(\Lambda,\Sigma)$
• • • We do not use the following data for averages fits limits etc • • •					
1514 ± 4	46	COLLEY	72	HBC	10 $K^+ p \to K^+ K^- K^+ p$
1521 ± 7.	47	VIDEAU	72	HBC	4 $K^- p \to K\bar{K}(\Lambda \Sigma)$
1515 0 ± 7 0		AMMAR	67	HBC	5 5 $K^- p \to K K \Lambda$

PRODUCED IN e^+e^- ANNIHILATION

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
The data in this block is included in the average printed for a previous datablock			
1524 ± 5 OUR AVERAGE			
1525 ± 10 ± 10	BALTRUSAITIS 87	MRK3	$J/\psi \to \gamma K^+K^-$
1527.0 ± 8.0	AUGUSTIN 85	DM2	$J/\psi \to K^+K^-\gamma$
1522 0 ± 6 0	AUGUSTIN 85	DM2	$J/\psi \to K_S^0K_S^0\gamma$

[1]From a partial wave analysis of data using a K matrix formalism with 5 poles
[2]CHABAUD 81 is a reanalysis of PAWLICKI 77 data
[3]From an amplitude analysis where the $f_2'(1525)$ width and elasticity are in complete disagreement with the values obtained from $K\bar{K}$ channel making the solution dubious

$f_2'(1525)$ WIDTH

PRODUCED BY PION BEAM

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
$108\ 0^{+5\ 0}_{-2\ 0}$	[4] LONGACRE 86	MPS	22 $\pi^-p \to K_S^0K_S^0n$
$69\ 0^{+22.}_{-16}$	[5] CHABAUD 81	ASPK	6 $\pi^-p \to K^+K^-n$
$137\ 0^{+23}_{-21}$	CHABAUD 81	ASPK	18 4 $\pi^-p \to K^+K^-n$
$150\ 0^{+83\ 0}_{-50\ 0}$	GORLICH 80	ASPK	17 π^-p polarized $\to K^+K^-n$
165 0 ± 42 0	[6] CORDEN 79	OMEG	12–15 $\pi^-p \to \pi^+\pi^-n$
$92\ 0^{+39\ 0}_{-22\ 0}$	[7] POLYCHRO 79	STRC	7 $\pi^-p \to nK_S^0K_S^0$

PRODUCED BY $K^\pm$ BEAM

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
76^{+5}_{-4} **OUR AVERAGE** Includes data from the datablock that follows this one				
90.2 ± 11.8		ASTON 88D	LASS	11 $K^-p \to K_S^0K_S^0\Lambda$
83 0 ± 15 0		ARMSTRONG 83B	OMEG	18 5 $K^-p \to K^-K^+\Lambda$
85 0 ± 16 0	650	AGUILAR- 81B	HBC	4 2 $K^-p \to \Lambda K^+K^-$
$80\ 0^{+14\ 0}_{-11\ 0}$	572	ALHARRAN 81	HBC	8 25 $K^-p \to \Lambda KK$
$62\ 0^{+19\ 0}_{-14\ 0}$	123	BARREIRO 77	HBC	4 15 $K^-p \to \Lambda K_S^0K_S^0$
72 0 ± 25 0	166	EVANGELISTA 77	OMEG	10 $K^-p \to K^+K^-(\Lambda\Sigma)$
61 0 ± 8 0	120	BRANDENB 76C	ASPK	13 $K^-p \to K^+K^-(\Lambda\Sigma)$
69 ± 22	100	AGUILAR 72B	HBC	3 9,4 6 $K^-p \to KK(\Lambda\Sigma)$
• • • We do not use the following data for averages fits limits etc • • •				
28 ± 15	46	COLLEY 72	HBC	10 $K^+p \to K^+K^-K^+p$
40 ± 10	47	VIDEAU 72	HBC	4 $K^-p \to KK(\Lambda\Sigma)$
35.0 ± 25 0		AMMAR 67	HBC	5 5 $K^-p \to KK\Lambda$

PRODUCED IN e^+e^- ANNIHILATION

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
The data in this block is included in the average printed for a previous datablock			
93 ± 15 OUR AVERAGE			
85 ± 35	BALTRUSAITIS 87	MRK3	$J/\psi \to \gamma K^+K^-$
85 0 ± 27 0	AUGUSTIN 85	DM2	$J/\psi \to K^+K^-\gamma$
100 0 ± 20 0	AUGUSTIN 85	DM2	$J/\psi \to K_S^0K_S^0\gamma$

[4]From a partial wave analysis of data using a K matrix formalism with 5 poles
[5]CHABAUD 81 is a reanalysis of PAWLICKI 77 data
[6]From an amplitude analysis where the $f_2'(1525)$ width and elasticity are in complete disagreement with the values obtained from $K\bar{K}$ channel making the solution dubious
[7]From a fit to the D with $f_2(1270)$-$f_2'(1525)$ interference Mass fixed at 1516 MeV

$f_2'(1525)$ DECAY MODES

- Γ_1 $f_2'(1525) \to \pi\pi$
- Γ_2 $f_2'(1525) \to KK$
- Γ_3 $f_2'(1525) \to K\bar{K}^*(892)$ + c c
- Γ_4 $f_2'(1525) \to \eta\eta$
- Γ_5 $f_2'(1525) \to \pi\pi\eta$
- Γ_6 $f_2'(1525) \to \pi K\bar{K}$
- Γ_7 $f_2'(1525) \to \pi^+\pi^+\pi^-\pi^-$
- Γ_8 $f_2'(1525) \to \gamma\gamma$

$f_2'(1525)$ PARTIAL WIDTHS

$\Gamma(\pi\pi)$ — Γ_1

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
$1.4^{+1.0}_{-0.5}$	[8] LONGACRE 86	MPS	22 $\pi^-p \to K_S^0K_S^0n$

$\Gamma(K\bar{K})$ — Γ_2

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
$63.0^{+6.0}_{-5.0}$	[8] LONGACRE 86	MPS	22 $\pi^-p \to K_S^0K_S^0n$

$\Gamma(\eta\eta)$ — Γ_4

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
$24.0^{+3.0}_{-1\ 0}$	[8] LONGACRE 86	MPS	22 $\pi^-p \to K_S^0K_S^0n$

$\Gamma(\gamma\gamma)$ — Γ_8

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
0.11 ± 0.04 OUR AVERAGE			
0 12 ± 0 07 ± 0 04	[9] AIHARA 86B	TPC	$e^+e^- \to e^+e^-K^+K^-$
0 11 ± 0 02 ± 0 04	[9] ALTHOFF 83	TASS	$e^+e^- \to e^+e^-KK$

[8]From a partial wave analysis of data using a K matrix formalism with 5 poles
[9]Using BR($f_2'(1525) \to KK$) = 1

$f_2'(1525)$ BRANCHING RATIOS

$\Gamma(\pi\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
<0 06	95	AGUILAR 81B	HBC	4 2 $K^-p \to \Lambda K^+K^-$
0.007 ± 0.002		COSTA 80	OMEG	10 $\pi^-p \to K^+K^-n$
$0\ 027^{+0\ 071}_{-0\ 013}$		[10] GORLICH 80	ASPK	17 18 π^-p
0 19 ± 0 03		CORDEN 79	OMEG	12–15 $\pi^-p \to \pi^+\pi^-n$
0 0075 ± 0 0025		[10,11] MARTIN 79	RVUE	
<0.045	95	BARREIRO 77	HBC	4 15 $K^-p \to \Lambda K_S^0K_S^0$
0 012 ± 0 004		[10] PAWLICKI 77	SPEC	6 $\pi N \to K^+K^-N$
<0 063	90	BRANDENB 76C	ASPK	13 $K^-p \to K^+K^-(\Lambda\Sigma)$
<0 0086		[10] BEUSCH 75B	OSPK	8 9 $\pi^-p \to K^0K^0n$

[10]Assuming that the $f_2'(1525)$ is produced by an one pion exchange production mechanism
[11]MARTIN 79 uses the PAWLICKI 77 data with different input value of the $f_2'(1525) \to KK$ branching ratio

$\Gamma(\eta\eta)/\Gamma(K\bar{K})$ — Γ_4/Γ_2

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
<0 50	BARNES 67	HBC	4 6 5 0 K^-p

$\Gamma(\pi\pi\eta)/\Gamma(KK)$ — Γ_5/Γ_2

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
<0 41	95	AGUILAR 72B	HBC	3 9 4 6 K^-p
<0 3	67	AMMAR 67	HBC	

$[\Gamma(K\bar{K}^*(892) + c\,c) + \Gamma(\pi K\bar{K})]/\Gamma(K\bar{K})$ — $(\Gamma_3+\Gamma_6)/\Gamma_2$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
<0 35	95	AGUILAR 72B	HBC	3 9 4 6 K^-p
<0 4	67	AMMAR 67	HBC	

$\Gamma(\pi^+\pi^+\pi^-\pi^-)/\Gamma(K\bar{K})$ — Γ_7/Γ_2

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
<0.32	95	AGUILAR 72B	HBC	3 9 4 6 K^-p

$\Gamma(\pi\pi)/\Gamma(KK)$ — Γ_1/Γ_2

VALUE	DOCUMENT ID	TECN	COMMENT
0.075 ± 0.035	AUGUSTIN 87	DM2	$J/\psi \to \gamma\pi^+\pi^-$

$f_2'(1525)$ REFERENCES

ASTON	88D	NP to be pub	+Awaji Bienz+	(SLAC NAGO CINC TOKY)
AUGUSTIN	87	ZPHY C36 369	+Cosme+	(LALO CLER FRAS PADO)
BALTRUSAITIS	87	PR D35 2077	+Coffman Dubois+	(MARK III Collab)
AIHARA	86B	PRL 57 404	+Alston Garnjost+	(TPC Two Gamma Collab)
LONGACRE	86	PL 8177 223	+Etkin+	(BNL BRAN CUNY DUKE NDAM)
AUGUSTIN	85	Moriond XX 1 479	+Calcaterra Cosme+	(ORSA CLER PADO FRAS)
ALTHOFF	83	PL 121B 216	+Brandelik Boerner+	(TASSO Collab)
ARMSTRONG	83B	NP 8224 193	+	(BARI BIRM CERN MILA LPNP PAVI)
AGUILAR	81B	ZPHY C8 313	Aguilar Benitez Albajar+	(CERN CDEF MADR+)
ALHARRAN	81	NP B191 26	+Boubillier+	(BIRM CERN GLAS MICH LPNP)
CHABAUD	81	APP B12 575	+Niczyporuk Becker+	(CERN CRAC MPIM)

COSTA	80	NP B175 402	Costa De Beauregard+	(BARI BONN CERN+)
GORLICH	80	NP B174 16	+Niczyporuk+	(CRAC MPIM CERN ZEEM)
CORDEN	79	NP B157 250	+Dowell Garvey+	(BIRM RHEL TELA LOWC) JP
MARTIN	79	NP B158 520	+Ozmutlu	(DURH)
POLYCHRO	79	PR D19 1317	Polychronakos Cason Bishop+	(NDAM ANL)
BARREIRO	77	NP B121 237	+Diaz Gay Hemingway+	(CERN AMST NIJM OXF)
EVANGELISTA	77	NP B127 384	+	(BARI BONN CERN DARE GLAS+)
PAWLICKI	77	PR D15 3196	+Ayres Cohen Diebold Kramer Wicklund	(ANL) IJP
BRANDENB	76C	NP B104 413	Brandenburg Carnegie Cashmore+	(SLAC)
BEUSCH	75B	PL 60B 101	+Birman Websdale Wetzel	(CERN ETH)
AGUILAR	72B	PR D6 29	Aguilar Benitez Chung Eisner Samios	(BNL)
COLLEY	72	NP B50 1	+Jobes Riddiford Griffiths+	(BIRM GLAS)
VIDEAU	72	PL 41B 213	+Videau Rouge Barrelet Debrion+	(EPOL SACL)
AMMAR	67	PRL 19 1071	+Davis Hwang Dagan Derrick+	(NWES ANL) JP
BARNES	67	PRL 19 964	+Dornan Goldberg Leitner+	(BNL SYRA) IJPC
CRENNELL	66	PRL 16 1025	+Kalbfleisch Lai Scarr Schumann+	(BNL) I

— OTHER RELATED PAPERS —

JENNI	83	PR D27 1031	+Burke Telnov Abrams Blocker+	(SLAC LBL)
ARMSTRONG	82	PL 110B 77	+Baubillier+	(BARI BIRM CERN MILA LPNP+)
ETKIN	82B	PR D25 1786	+Foley Lai+	(BNL CUNY TUFT VAND)
LUKE	82	DESY 82-73		(DESY)
BECKER	79	NP B151 46	+Blanar Blum+	(MPIM CERN ZEEM CRAC)
LAVEN	77	NP B127 43	+Otter Klein+	(AACH BERL CERN LOIC WIEN)
LORSTAD	69	NP B14 63	+D Andlau Astier+	(CDEF CERN)
SCOTTER	69	NC 62A 1057	+Erskine Paler+	(BIRM GLAS LOIC MPIM OXF)
ALITTI	68B	PRL 21 1705	+Barnes Crennell Flaminio Goldberg+	(BNL)
ABRAMS	67B	PRL 18 620	+Kehoe Glasser Sechi Zorn Wolsky	(UMD)
BARNES	65	PRL 15 322	+Culwick Guidoni Kalbfleisch Goz+	(BNL SYRA)

$f_1(1530)$ was $D(1530)$

$I^G(J^{PC}) = 0^+(1^{++})$

$f_1(1530)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1527 ± 5	**OUR AVERAGE**				
1530 ± 10		ASTON	88C	LASS	11 $K^- p \to K^0 K^\pm \pi^\mp \Lambda$
1526.0 ± 6.0	271	GAVILLET	82	HBC	4.2 $K^- p \to \Lambda K \bar{K} \pi$

$f_1(1530)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
106 ± 14	**OUR AVERAGE**				
100 ± 40		ASTON	88C	LASS	11 $K^- p \to K^0 K^\pm \pi^\mp \Lambda$
107.0 ± 15.0	271	GAVILLET	82	HBC	4.2 $K^- p \to \Lambda K \bar{K} \pi$

$f_1(1530)$ DECAY MODES

Γ_1 $f_1(1530) \to K\bar{K}^*(892) + c.c.$

$f_1(1530)$ REFERENCES

ASTON	88C	PL B201 573	+Awaji Bienz+	(SLAC NAGO CINC TOKY) JP
GAVILLET	82	ZPHY C16 119	+Armenteros+	(CERN CDEF PADO ROMA)

$f_0(1590)$

$I^G(J^{PC}) = 0^+(0^{++})$

See also the mini-review under non-$q\bar{q}$ candidates

$f_0(1590)$ MASS

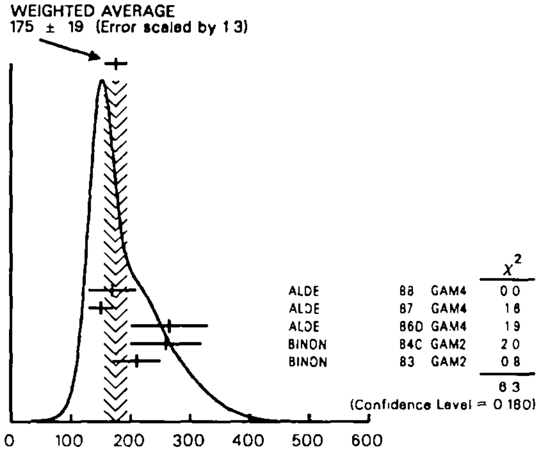
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1587 ± 11	**OUR AVERAGE**				
1610 ± 20		ALDE	88	GAM4	300 $\pi^- N \to \eta\eta\pi^- N$
1570 ± 20	600 ± 70	ALDE	87	GAM4	100 $\pi^- p \to 4\pi^0 n$
1575.0 ± 45.0		[1] ALDE	86D	GAM4	100 $\pi^- p \to 4\gamma n$
1568.0 ± 33.0		BINON	84C	GAM2	38 $\pi^- p \to 4\gamma n$
1592.0 ± 25.0		BINON	83	GAM2	38 $\pi^- p \to 4\gamma n$

[1] From central value and spread of two solutions

$f_0(1590)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
175 ± 19	**OUR AVERAGE**	Error includes scale factor of 1.3. See the ideogram below			
170 ± 40		ALDE	88	GAM4	300 $\pi^- N \to \eta\eta\pi^- N$
150 ± 20	600 ± 70	ALDE	87	GAM4	100 $\pi^- p \to 4\pi^0 n$
265.0 ± 65.0		[2] ALDE	86D	GAM4	100 $\pi^- p \to 4\gamma n$
260.0 ± 60.0		BINON	84C	GAM2	38 $\pi^- p \to 4\gamma n$
210.0 ± 40.0		BINON	83	GAM2	38 $\pi^- p \to 4\gamma n$

[2] From central value and spread of two solutions



$f_0(1590)$ width (MeV)

$f_0(1590)$ DECAY MODES

Γ_1 $f_0(1590) \to \eta\eta$
Γ_2 $f_0(1590) \to \eta\eta'(958)$
Γ_3 $f_0(1590) \to \pi^0\pi^0$
Γ_4 $f_0(1590) \to K\bar{K}$
Γ_5 $f_0(1590) \to 4\pi^0$

$f_0(1590)$ BRANCHING RATIOS

$\Gamma(\eta\eta)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
LARGE	ALDE	88	GAM4	300 $\pi^- N \to \eta\eta\pi^- N$
LARGE	BINON	83	GAM2	38 $\pi^- p \to 4\gamma n$

$\Gamma(\eta\eta'(958))/\Gamma(\eta\eta)$ Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
2.7 ± 0.8	BINON	84C	GAM2	38 $\pi^- p \to 4\gamma n$

$\Gamma(\pi^0\pi^0)/\Gamma(\eta\eta)$ Γ_3/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.3	BINON	83	GAM2	38 $\pi^- p \to 4\gamma n$

$\Gamma(K\bar{K})/\Gamma(\eta\eta)$ Γ_4/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.6	BINON	83	GAM2	38 $\pi^- p \to 4\gamma n$

$\Gamma(4\pi^0)/\Gamma(\eta\eta)$ Γ_5/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0.8 ± 0.3	ALDE	87	GAM4	100 $\pi^- p \to 4\pi^0 n$

$f_0(1590)$ REFERENCES

ALDE	88	PL B201 160	+Bellazzini Binon+	(SERP BELG LANL LAPP PISA) JP
ALDE	87	PL B198 286	+Binon Bricman+	(LANL BRUX SERP, LAPP)
ALDE	86D	NP B269 485	+Binon Bricman+	(BELG LAPP SERP CERN) IGJP
BINON	84C	NC 80A 363	+Bricman Donskov+	(BELG LAPP SERP CERN)
BINON	83	NC 78A 313	+Donskov Dutell+	(BELG LAPP SERP CERN) IGJP
Also	83B	SJNP 38 561	Binon Gouanere+	(BELG LAPP SERP CERN)
		Translated from YAF 38 934		

$\omega_3(1670)$

$I^G(J^{PC}) = 0^-(3^{--})$

$\omega_3(1670)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1668 ± 5	**OUR AVERAGE**				
1685.0 ± 20.0	60	BAUBILLIER	79	HBC	8.2 $K^- p$ backward
1673.0 ± 12.0	430	[1,2] BALTAY	78E	HBC	15 $\pi^+ p \to \Delta 3\pi$
1650.0 ± 12.0		CORDEN	78B	OMEG	8–12 $\pi^- p \to N 3\pi$
1669 ± 11	600	[2] WAGNER	75	HBC	7 $\pi^+ p \to \Delta^{++} 3\pi$
1678 ± 14	500	DIAZ	74	DBC	6 $\pi^+ n \to p 3\pi^0$
1660 ± 13	200	DIAZ	74	DBC	6 $\pi^+ n \to p \omega \pi^0 \pi^0$
1679 ± 17	200	MATTHEWS	71D	DBC	7.0 $\pi^+ n \to p 3\pi^0$
1695.0 ± 20.0		BARNES	69B	HBC	4.6 $K^- p \to \omega 2\pi X$
1670 ± 20		KENYON	69	DBC	8 $\pi^+ n \to p 3\pi^0$
1636 ± 20		ARMENISE	68B	DBC	5.1 $\pi^+ n \to p 3\pi^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~1700.0	110	[1] CERRADA	77B	HBC	4.2 $K^- p \to \Lambda 3\pi$

[1] Phase rotation seen for $J^P = 3^-$ $\rho\pi$ wave.
[2] From a fit to $I(J^P) = 0(3^-)$ $\rho\pi$ partial wave.

$\omega_3(1670)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
166 ± 12	**OUR AVERAGE**	Error includes scale factor of 1.1.			
160.0 ± 80.0	60	[3] BAUBILLIER	79	HBC	8.2 $K^- p$ backward
173.0 ± 16.0	430	[4,5] BALTAY	78E	HBC	15 $\pi^+ p \to \Delta 3\pi$
253.0 ± 39.0		CORDEN	78B	OMEG	8–12 $\pi^- p \to N 3\pi$
173 ± 28	600	[3,5] WAGNER	75	HBC	7 $\pi^+ p \to \Delta^{++} 3\pi$
167 ± 40	500	DIAZ	74	DBC	6 $\pi^+ n \to p 3\pi^0$
122 ± 39	200	DIAZ	74	DBC	6 $\pi^+ n \to p \omega \pi^0 \pi^0$
155 ± 40	200	[3] MATTHEWS	71D	DBC	7.0 $\pi^+ n \to p 3\pi^0$
100 ± 40		KENYON	69	DBC	8 $\pi^+ n \to p 3\pi^0$
112 ± 60		ARMENISE	68B	DBC	5.1 $\pi^+ n \to p 3\pi^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
90. ± 20		BARNES	69B	HBC	4.6 $K^- p \to \omega 2\pi$

[3] Width errors enlarged by us to $4\Gamma/N^{1/2}$; see the note with the $K^*(892)$ mass.
[4] Phase rotation seen for $J^P = 3^-$ $\rho\pi$ wave.
[5] From a fit to $I(J^P) = 0(3^-)$ $\rho\pi$ partial wave.

$\omega_3(1670)$ DECAY MODES

Γ_1 $\omega_3(1670) \to 3\pi$
Excluding $\rho\pi$
Γ_2 $\omega_3(1670) \to 5\pi$
Excluding $\omega\pi\pi$
Γ_3 $\omega_3(1670) \to \rho\pi$
Γ_4 $\omega_3(1670) \to \omega\pi\pi$
Γ_5 $\omega_3(1670) \to b_1(1235)\pi$

$\omega_3(1670)$ BRANCHING RATIOS

$[\Gamma(5\pi) + \Gamma(\omega\pi\pi)]/[\Gamma(3\pi) + \Gamma(\rho\pi)]$ $(\Gamma_2+\Gamma_4)/(\Gamma_1+\Gamma_3)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.97 ± 0.28	200	DIAZ	74	DBC	6 $\pi^+ n \to p 5\pi^0$

$\Gamma(\rho\pi)/[\Gamma(3\pi) + \Gamma(\rho\pi)]$ $\Gamma_3/(\Gamma_1+\Gamma_3)$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>0.70	200	MATTHEWS	71D	DBC	7.0 $\pi^+ n \to p 3\pi^0$

$\Gamma(\omega\pi\pi)/\Gamma(\rho\pi)$ Γ_4/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.71 ± 0.27	100	DIAZ	74	DBC	6 $\pi^+ n \to p 5\pi^0$

$\Gamma(b_1(1235)\pi)/\Gamma(\rho\pi)$ Γ_5/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
POSSIBLY SEEN	DIAZ	74	DBC	6 $\pi^+ n \to p 5\pi^0$

$\Gamma(b_1(1235)\pi)/\Gamma(\omega\pi\pi)$ Γ_5/Γ_4

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>0.75	68	BAUBILLIER	79	HBC	8.2 $K^- p$ backward

$\omega_3(1670)$ REFERENCES

BAUBILLIER	79	PL 89B 131	+	(BIRM, CERN, GLAS, MSU, LPNP)
BALTAY	78E	PRL 40 87	+Cautis, Kalelkar	(COLU) JP
CORDEN	78B	NP B138 235	+Corbett, Alexander+	(BIRM, RHEL, TELA, LOWC)
CERRADA	77B	NP B126 241	+Blockzijl, Heinen+	(AMST, CERN, NIJM, OXF) JP
WAGNER	75	PL 58B 201	+Tabak, Chew	(LBL) JP
DIAZ	74	PRL 32 260	+Dibianca, Fickinger, Anderson+	(CASE, CMU)
MATTHEWS	71D	PR D3 2561	+Prentice, Yoon, Carroll+	(TNTO, WISC)
BARNES	69B	PRL 23 142	+Chung, Eisner, Flaminio+	(BNL)
KENYON	69	PRL 23 146	+Kinson, Scarr+	(BNL, UCND, ORNL)
ARMENISE	68B	PL 26B 336	+Forino, Cartacci+	(BARI, BGNA, FIRZ, ORSA)

OTHER RELATED PAPERS

MATTHEWS	71	LNC 1 361	+Prentice, Yoon, Carroll+	(TNTO, WISC)
ARMENISE	70	LNC 4 199	+Ghidini, Forino, Cartacci+	(BARI, BGNA, FIRZ)

$\pi_2(1670)$ was $A_3(1680)$

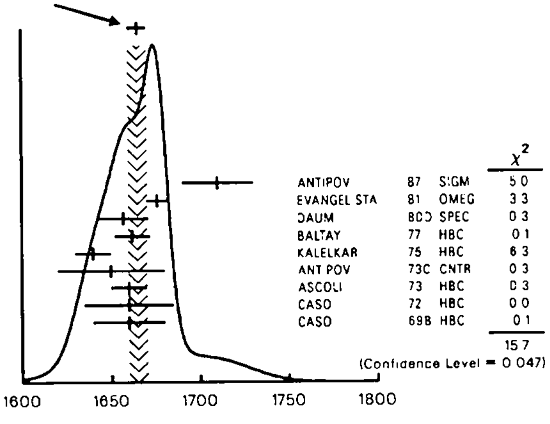
$I^G(J^{PC}) = 1^-(2^{-+})$

Our latest mini-review on this particle can be found in the 1984 edition.

$\pi_2(1670)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1665 ± 5	**OUR AVERAGE**	Error includes scale factor of 1.4. See the ideogram below.				
1710 ± 20	700 ± 150	ANTIPOV	87	SIGM	−	50 π^- Cu → $\mu^+\mu^-\pi^-$ Cu
1676 ± 6		[1] EVANGELISTA	81	OMEG	−	12 $\pi^- p \to 3\pi p$
1657.0 ± 14.0		[1,2] DAUM	80D	SPEC	−	63–94 $\pi p \to 3\pi X$
1662.0 ± 10.0	2000	[1] BALTAY	77	HBC	+	15 $\pi^+ p \to p 3\pi$
1640 ± 10	575	KALELKAR	75	HBC	+	15 $\pi^+ p \to p\pi^+ f_2$
1650 ± 30		[1] ANTIPOV	73C	CNTR	−	25, 40 $\pi^- p$
1660 ± 10		[1] ASCOLI	73	HBC	−	5–25 $\pi^- p \to p\pi_2$
1660 ± 25	260	CASO	72	HBC	+	11.7 $\pi^+ p$
1660.0 ± 20.0		CASO	69B	HBC	−	11 $\pi^- p \to f_2\pi^- p$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1710.0 ± 20.0		[3] DAUM	81B	SPEC	−	63, 94 $\pi^- p$
1650.0		[4] PERNEGR	78	CNTR	−	9+13+15 $\pi^- N$
1600 ± 10		THOMPSON	74C	HBC	+	13 $\pi^+ p \to p\pi f_2$

[1] From a fit to $J^P = 2^-$ S-wave $f_2(1270)\pi$ partial wave.
[2] Clear phase rotation seen in 2^-S, 2^-P, 2^-D waves. We quote central value and spread of single resonance fits to three channels.
[3] From a two resonance fit to four 2^-0^+ waves. This should not be averaged with all the single resonance fits.
[4] Clear phase rotation seen in 2^-S and 2^-P waves.



$\pi_2(1670)$ mass (MeV)

$\pi_2(1670)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
247 ± 11	**OUR AVERAGE**					
170 ± 80	700 ± 150	ANTIPOV	87	SIGM	−	50 π^- Cu → $\mu^+\mu^-\pi^-$ Cu
312.0 ± 50.0		[5] DAUM	81B	SPEC	−	63,94 $\pi^- p$
260 ± 20		[6] EVANGELISTA	81	OMEG	−	12 $\pi^- p \to 3\pi p$
219.0 ± 20.0		[6,7] DAUM	80D	SPEC	−	63–94 $\pi p \to 3\pi X$
285.0 ± 60.0	2000	[6] BALTAY	77	HBC	+	15 $\pi^+ p \to p 3\pi$
240 ± 30	575	KALELKAR	75	HBC	+	15 $\pi^+ p \to p\pi^+ f_2$
300 ± 50		[6] ANTIPOV	73C	CNTR	−	25,40 $\pi^- p$
270 ± 60		[6] ASCOLI	73	HBC	−	5–25 $\pi^- p \to p\pi_2$
190 ± 100	260	CASO	72	HBC	+	11.7 $\pi^+ p$
240.0 ± 50.0	297	ARMENISE	69	DBC	+	5.1 $\pi^+ d \to d 3\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
400.0		[8] PERNEGR	78	CNTR	−	9+13+15 $\pi^- N$
310 ± 40		THOMPSON	74C	HBC	+	13 $\pi^+ p \to p\pi_2^+$
200 to 400		[6] CASO	72	HBC	+	11.7 $\pi^+ p$
130		CASO	69B	HBC	−	11 $\pi^- p$
150.0		CASO	69B	HBC	−	11 $\pi^- p \to f_2\pi^- p$

[5] From a two resonance fit to four 2^-0^+ waves. This should not be averaged with all the single resonance fits.
[6] From a fit to $J^P = 2^-$ $f_2(1270)\pi$ partial wave.
[7] Clear phase rotation seen in 2^-S, 2^-P, 2^-D waves. We quote central value and spread of single-resonance fits to three channels.
[8] Clear phase rotation seen in 2^-S and 2^-P waves.

$\pi_2(1670)$ DECAY MODES

Γ_1	$\pi_2(1670) \to \rho^0\pi^\pm$
Γ_2	$\pi_2(1670) \to \eta\pi^\pm$
Γ_3	$\pi_2(1670) \to \pi^\pm 2\pi^+ 2\pi^-$
Γ_4	$\pi_2(1670) \to K\bar{K}^*(892)$ + c.c.
Γ_5	$\pi_2(1670) \to K\bar{K}\pi$
Γ_6	$\pi_2(1670) \to K\bar{K}$
Γ_7	$\pi_2(1670) \to f_2(1270)\pi^\pm$
Γ_8	$\pi_2(1670) \to \omega\pi\pi$
Γ_9	$\pi_2(1670) \to \pi^\pm\pi^+\pi^-$
Γ_{10}	$\pi_2(1670) \to f_0(1400)\pi$

$\pi_2(1670)$ BRANCHING RATIOS

$\Gamma(\rho^0\pi^\pm)/\Gamma(\pi^\pm\pi^+\pi^-)$ — Γ_1/Γ_9

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.29 ± 0.05	[9] DAUM	81B	SPEC		63,94 $\pi^- p$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.3	BARTSCH	68	HBC	+	8 $\pi^+ p \to 3\pi p$
<0.4	FERBEL	68	RVUE	±	

[9] From a two-resonance fit to four 2^-0^+ waves.

$\Gamma(f_2(1270)\pi^\pm)/\Gamma(\pi^\pm\pi^+\pi^-)$ — Γ_7/Γ_9

(With $f_2(1270) \to \pi^+\pi^-$.)

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.60 ± 0.05	**OUR AVERAGE**	Error includes scale factor of 1.3.			
0.61 ± 0.04	[10] DAUM	81B	SPEC		63,94 $\pi^- p$
$0.76^{+0.24}_{-0.34}$	ARMENISE	69	DBC	+	5.1 $\pi^+ d \to d 3\pi$
0.35 ± 0.20	BALTAY	68	HBC	+	7–8.5 $\pi^+ p$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.59	BARTSCH	68	HBC	+	8 $\pi^+ p \to 3\pi p$

[10] From a two resonance fit to four 2^-0^+ waves.

$\Gamma(\eta\pi^\pm)/\Gamma(\pi^\pm\pi^+\pi^-)$ — Γ_2/Γ_9

(All η decays.)

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
<0.09	BALTAY	68	HBC	+	7–8.5 $\pi^+ p$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.10	CRENNELL	70	HBC	−	6 $\pi^- p \to f_2\pi^- N$

$\Gamma(\pi^\pm 2\pi^+ 2\pi^-)/\Gamma(\pi^\pm\pi^+\pi^-)$ — Γ_3/Γ_9

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
<0.10	CRENNELL	70	HBC	−	6 $\pi^- p \to f_2\pi^- N$
<0.1	BALTAY	68	HBC	+	7.85 $\pi^+ p$

$\Gamma(f_0(1400)\pi)/\Gamma(\pi^\pm\pi^+\pi^-)$ — Γ_{10}/Γ_9

(With $f_0(1400) \to \pi^+\pi^-$.)

VALUE	DOCUMENT ID		TECN	COMMENT
0.10 ± 0.05	[11] DAUM	81B	SPEC	63,94 $\pi^- p$

[11] From a two resonance fit to four 2^-0^+ waves.

$\Gamma(K\bar{K}^*(892)$ + c.c.$)/\Gamma(f_2(1270)\pi^\pm)$ — Γ_4/Γ_7

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.075 ± 0.025	[12] ARMSTRONG	82B	OMEG	−	16 $\pi^- p \to K^+K^-\pi^- p$

[12] From a partial wave analysis of $K^+K^-\pi^-$ system.

D-wave/S-wave RATIO FOR $\pi_2(1670) \to f_2(1270)\pi$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.22 ± 0.10	[13] DAUM	81B	SPEC	63,94 $\pi^- p$

[13] From a two resonance fit to four 2^-0^+ waves.

$\pi_2(1670)$ REFERENCES

ANTIPOV	87	EPL 4 403	+Batarin+	(SERP JINR INRM TBLI BGNA MILA)
ARMSTRONG	82B	NP B202 1	+Baccari	(AACH BARI BONN CERN GLAS+)
DAUM	81B	NP B182 269	+Hertzberger+	(AMST CERN CRAC MPIM OXF+)
EVANGELISTA	81	NP B178 197	+	(BARI BONN CERN DARE LIVP+)
Also	81B	NP B186 594	Evangelista	
DAUM	80D	PL 89B 285	+Hertzberger+	(AMST CERN CRAC MPIM OXF+) JP
PERNEGR	78	NP B134 436	+Aebischer+	(ETH CERN LOIC MILA)
BALTAY	77	PRL 39 591	+Cautis Kalelkar	(COLU) JP
KALELKAR	75	Nevis 207 Thesis		(COLU)
THOMPSON	74C	PRL 32 331	+Badewitz Goldos Mcllwain Paler+	(PURD) JP
Also	74B	NP B69 381	Thompson Badewitz Goldos Mcllwain+	(PURD) JP
ANTIPOV	73C	NP B63 153	+Ascoli Busnello Focacci+	(CERN SERP) JP
ASCOLI	73	PR D7 669		(ILL TNTO GENO HAMB MILA SACL) JP
CASO	72	NP B36 349	+Maddock Bassler+	(DURH GENO DESY MILA+)
CRENNELL	70	PRL 24 781	+Karshon Lai Scarr Sims	(BNL)
ARMENISE	69	LNC 2 501	+Ghidini Forino Cartacci+	(BARI BGNA FIRZ)
CASO	69B	LNC 2 437	+Conte Tomasini Cantore+	(GENO MILA SACL)
BALTAY	68	PRL 20 887	+Kung Yeh Ferbel+	(COLU ROCH RUTG YALE) I
BARTSCH	68	NP B7 345	+Keppel Kraus+	(AACH BERL CERN) JP
FERBEL	68	Phil Conf 335		(ROCH)

OTHER RELATED PAPERS

CHEN	83B	PR D28 2304	+Fenker+	(ARIZ FNAL FLOR NDAM TUFT+)
LEEDOM	83	PR D27 1426	+DeBonte Goldos Key Wong+	(PURD TNTO)
BELLINI	82B	NP B199 1	+	(CERN MILA JINR BGNA HELS PAVI WARS+)
BALTAY	78	PR D17 52	+Cautis Cohen Csorna Kalelkar+	(COLU BING)
CORDEN	78C	NP B136 77	+Dowell Garvey+	(BIRM RHEL TELA LOWC) JP
ROBERTS	78B	PR D18 59	+Kruse Edelstein+	(ILL CMU NWES ROCH)
CAUTIS	77	Nevis 221 Thesis		(COLU) JP
CERRADA	77B	NP B126 241	+Blockzijl Heinen+	(AMST CERN NIJM OXF) JP
BEKETOV	75	SJNP 20 379	+Zombkovskii Kaidalov Konovalov+	(ITEP)
		Translated from YAF 20 709		
EMMS	75B	PL 60B 109	+Jones Kinson Bell Dale+	(BIRM DURH RHEL) JP
HORNE	75	PR D11 996	+Hagopian Hagopian Bensinger+	(FSU BRAN)
WAGNER	75	PL 58B 201	+Tabak Chew	(LBL) JP
ASCOLI	74	PR D9 1963	+Cutler Jones Kruse Roberts Weinstein+	(ILL)
LICHTMAN	74	NP B81 31	+Biswas Cason Kenney McGahan+	(NDAM)
OTTER	74	NP B80 1	+Rudolph+	(AACH BERL BONN CERN HEID) JP
TABAK	74	Boston Conf	+Ronat Rosenfeld Lasinski+	(LBL SLAC) JP
ANTIPOV	73B	NP B63 141	+Ascoli Busnello Focacci+	(CERN SERP) JP
ASCOLI	73B	PR D8 3894	+Jones Weinstein Wyld	(ILL) JP
ALEXANDER	72	NP B45 29	+Bar Nir Benary Dagan+	(TELA)
ARMENISE	72	LNC 4 201	+Forino Cartacci+	(BARI BGNA FIRZ)
SALZBERG	72	NP B41 397	+Harrison Heyda Johnson Kim Law+	(HARV)
BEKETOV	71	SJNP 4 765	+Sombkowsky Konovalov Krutschinin+	(ITEP) JP
		Translated from unknown journal		
PALER	71	PRL 26 1675	+Badewitz Barton Miller Palfrey Tebes	(PURD)
BRANDENB	70	NP B16 369	Brandenburg Brenner Ioffredo+	(HARV)
CHIEN	70B	Phil Conf 275		(JHU)
MIYASHITA	70	PR D1 771	+VonKrogh Kopelman Libby	(COLO)
BARNES	69B	PRL 23 142	+Chung Eisner Flaminio+	(BNL)
CASO	68	NC 54A 983	+Conte Cords Diaz+	(GENO HAMB MILA SACL)
IOFFREDO	68	PRL 21 1212	+Brandenburg Brenner Eisenstein+	(HARV)
LAMSA	68	PR 166 1395	+Cason Biswas Derado Groves+	(NDAM)
DANYSZ	67B	NC 51A 801	+French Simak	(CERN)
DUBAL	67	NP B3 435		(CERN Missing Mass Spectrometer Collab.)
Also	68	Thesis 1456	Dubal	(GEVA)
FOCACCI	66	PRL 17 890	+Kienzle Levrat Maglich Martin	(CERN)
LEVRAT	66	PL 22 714		(CERN Missing Mass Spectrometer Collab.)
LUBATTI	66	Berkeley Thesis		(LRL)
VETLITSKY	66	PL 21 579	+Guszavin Kliger Zolganov+	(ITEP)
FORINO	65B	PL 19 68	+Gessaroli+	(BGNA BARI FIRZ ORSA SACL)

$\phi(1680)$

$I^G(J^{PC}) = 0^-(1^{--})$

First identified using Dalitz plot analysis of $e^+e^- \to K\bar{K}^*(892)$ (BIZOT 80, DELCOURT 81). We list below candidates for the ω and ϕ radial excitations until they are well established.

$\phi(1680)$ MASS

$K\bar{K}$ MODE

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1760 ±20	ATKINSON	85C	OMEG	20–70 $\gamma p \to K\bar{K}X$
1680. ±10	[1] BUON	82	DM1	$e^+e^- \to$ hadrons
1677 ±12	[2] MANE	82	DM1	$e^+e^- \to K^0_S K\pi$
1690 ±10	[3] ASTON	81F	OMEG	25–70 $\gamma p \to K^+K^-X$

PIONS MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1670 ±20		[4] ATKINSON	83B	OMEG		20–70 $\gamma p \to 3\pi X$
1657 ±13		[2] CORDIER	81	DM1		$e^+e^- \to \omega 2\pi$
1679 ±34	21	ESPOSITO	80	FRAM		$e^+e^- \to 3\pi$
1652.0±17.0		COSME	79	OSPK	0	$e^+e^- \to 3\pi$

[1] From global fit of ρ, ω, ϕ and their radial excitations to channels $\omega\pi^+\pi^-$, K^+K^-, $K^0_S K^0_L$, $K^0_S K^\pm\pi^\mp$. Assume mass 1570 MeV and width 510 MeV for ρ radial excitations, mass 1570 and width 500 MeV for ω radial excitation.
[2] Fit to one channel only, neglecting interference with ω, $\rho(1700)$.
[3] J^P not unambiguously 1^-.
[4] May be ϕ or ω radial excitation. Interpretation complicated.

$\phi(1680)$ WIDTH

$K\bar{K}$ MODE

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
80 ±40	ATKINSON	85C	OMEG	20–70 $\gamma p \to K\bar{K}X$
185 ±22	[5] BUON	82	DM1	$e^+e^- \to$ hadrons
102 ±36	[6] MANE	82	DM1	$e^+e^- \to K^0_S K\pi$
100 ±40	[7] ASTON	81F	OMEG	25–70 $\gamma p \to K^+K^-X$

PIONS MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
160 ±20		[8] ATKINSON	83B	OMEG		20–70 $\gamma p \to 3\pi X$
136 ±46		[6] CORDIER	81	DM1		$e^+e^- \to \omega 2\pi$
99. ±49	21	ESPOSITO	80	FRAM		$e^+e^- \to 3\pi$
42.0±17.0		COSME	79	OSPK	0	$e^+e^- \to 3\pi$

[5] From global fit of ρ, ω, ϕ and their radial excitations to channels $\omega\pi^+\pi^-$, K^+K^-, $K^0_S K^0_L$, $K^0_S K^\pm\pi^\mp$. Assume mass 1570 MeV and width 510 MeV for ρ radial excitations, mass 1570 and width 500 MeV for ω radial excitation.
[6] Fit to one channel only, neglecting interference with ω, $\rho(1700)$.
[7] J^P not unambiguously 1^-.
[8] May be ϕ or ω radial excitation. Interpretation complicated.

$\phi(1680)$ DECAY MODES

- Γ_1 $\phi(1680) \to \omega\pi\pi$
- Γ_2 $\phi(1680) \to 3\pi$
- Γ_3 $\phi(1680) \to K\bar{K}$
- Γ_4 $\phi(1680) \to K\bar{K}^*(892)$ + c.c.
- Γ_5 $\phi(1680) \to K^0_S K\pi$
- Γ_6 $\phi(1680) \to e^+e^-$

$\phi(1680)$ $\Gamma(i)\Gamma(e^+e^-)/\Gamma(\text{total})$

This combination of a partial width with the partial width into e^+e^- and with the total width is obtained from the integrated cross section into channel (i) in e^+e^- annihilation. We list only data that have not been used to determine the partial width $\Gamma(i)$ or the branching ratio $\Gamma(i)$/total.

$\Gamma(\omega\pi\pi) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_1\Gamma_6/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
~0.017	[9] BIZOT	80	DM1	e^+e^-

$\Gamma(K\bar{K}) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_3\Gamma_6/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.053±0.035	[9] BIZOT	80	DM1	e^+e^-

$\Gamma(K\bar{K}^*(892)$ + c.c.$) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_4\Gamma_6/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.413±0.033	[9] BIZOT	80	DM1	e^+e^-

[9] Model dependent.

$\phi(1680)$ BRANCHING RATIOS

$\Gamma(\omega\pi\pi)/\Gamma(K\bar{K}^*(892)$ + c.c.$)$ — Γ_1/Γ_4

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.10	BUON	82	DM1	e^+e^-

$\Gamma(K\bar{K})/\Gamma(K\bar{K}^*(892)$ + c.c.$)$ — Γ_3/Γ_4

VALUE	DOCUMENT ID		TECN	COMMENT
0.07 ±0.01	BUON	82	DM1	e^+e^-

$\Gamma(K\bar{K}^*(892)$ + c.c.$)/\Gamma(K^0_S K\pi)$ — Γ_4/Γ_5

VALUE	DOCUMENT ID		TECN	COMMENT
DOMINANT	MANE	82	DM1	$e^+e^- \to K^0_S K^\pm\pi^\mp$

$\Gamma(3\pi)/\Gamma_{total}$ — Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
SEEN	ATKINSON	83B	OMEG	20–70 $\gamma p \to 3\pi X$

$\phi(1680)$ REFERENCES

ATKINSON	85C	ZPHY C27 233	+ (BONN, CERN, GLAS, LANC, MCHS, LPNP+)
ATKINSON	83B	PL 127B 132	+ (BONN, CERN, GLAS, LANC, MCHS, LPNP+)
BUON	82	PL 118B 221	+Bisello, Bizot, Cordier, Delcourt+ (LALO, MONP)
MANE	82	PL 112B 178	+Bisello, Bizot, Buon, Delcourt, Fayard+ (LALO)
ASTON	81F	PL 104B 231	(BONN, CERN, EPOL, GLAS, LANC, MCHS+)
CORDIER	81	PL 106B 155	+Bisello, Bizot, Buon, Delcourt, Mane (ORSA)
DELCOURT	81	PL 99B 257	+Bisello, Bizot, Buon, Cordier, Mane (ORSA)
BIZOT	80	Madison Conf. 546	+Bisello, Buon, Cordier, Delcourt+ (LALO, USTL)
ESPOSITO	80	LNC 28 195	+Marini, Patteri+ (FRAS, NAPL, PADO, ROMA)
COSME	79	NP B152 215	+Dudelzak, Grelaud, Jean-Marie, Jullian+ (IPN)

OTHER RELATED PAPERS

ATKINSON	86C	ZPHY C30 541	+ (BONN, CERN, GLAS, LANC, MCHS, LPNP+)
ATKINSON	84	NP B231 15	+ (BONN, CERN, GLAS, LANC, MCHS, LPNP+)
ATKINSON	84B	NP B231 1	+ (BONN, CERN, GLAS, LANC, MCHS, LPNP+)
ATKINSON	83C	NP B229 269	+ (BONN, CERN, GLAS, LANC, MCHS, LPNP+)
MANE	81	PL 99B 261	+Bisello, Bizot, Buon, Cordier, Delcourt (ORSA)
ASTON	80F	NP B174 269	(BONN, CERN, EPOL, GLAS, LANC, MCHS+)

$\rho_3(1690)$ was $g(1690)$

$I^G(J^{PC}) = 1^+(3^{--})$

$\rho_3(1690)$ MASS

We include only high statistics experiments in the average for the 2π and $K\bar{K}$ modes.

2π MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1691.4 ± 2.7 OUR AVERAGE		Includes data from the datablock that follows this one.				
1677 ±14.		EVANGELISTA	81	OMEG	−	12 $\pi^-p \to 2\pi p$
1679.0±11.0	476	BALTAY	78B	HBC	0	15 $\pi^+p \to \pi^+\pi^-n$
1678.0±12.0	175	[1] ANTIPOV	77	CIBS	0	25 $\pi^-p \to p3\pi$
1690 ± 7	600	[1] ENGLER	74	DBC	0	6 $\pi^+n \to \pi^+\pi^-p$

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1693 ± 8		[2] GRAYER	74	ASPK	0	17 $\pi^- p \to \pi^+\pi^- n$
1678 ± 12		MATTHEWS	71C	DBC	0	7 $\pi^+ N$
• • • We do not use the following data for averages fits limits, etc • • •						
1734.0 ± 10.0		[3] CORDEN	79	OMEG		12–15 $\pi^- p \to n 2\pi$
1692 ± 12		[2,4] ESTABROOKS	75	RVUE		17 $\pi^- p \to \pi^+\pi^- n$
1737.0 ± 23.0		ARMENISE	70	DBC	0	9 $\pi^+ N$
1650.0 ± 35.0	122	BARTSCH	70B	HBC	+	8 $\pi^+ p \to N 2\pi$
1687 ± 21		STUNTEBECK	70	HDBC	0	8 $\pi^- p$, 5.4 $\pi^+ d$
1683 ± 13		ARMENISE	68	DBC	0	5.1 $\pi^+ d$
1670.0 ± 30.0		GOLDBERG	65	HBC	0	6 $\pi^+ d$ 8 $\pi^- p$

[1] Mass errors enlarged by us to $\Gamma/N^{1/2}$, see the note with the $K^*(892)$ mass

[2] Uses same data as HYAMS 75

[3] From a phase shift solution containing a $f_2'(1525)$ width two times larger than the $K\bar{K}$ result

[4] From phase shift analysis Error takes account of spread of different phase shift solutions

$K\bar{K} + K\bar{K}\pi$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
The data in this block is included in the average printed for a previous datablock						
1699.0 ± 5.0		ALPER	80	CNTR	0	62 $\pi^- p \to K^+ K^- n$
1698 ± 12	6k	[5,6] MARTIN	78D	SPEC		10 $\pi p \to K_S^0 K^- p$
1692 ± 6		BLUM	75	ASPK	0	18.4 $\pi^- p \to n K^+ K^-$
1690.0 ± 16.0		ADERHOLZ	69	HBC	+	8 $\pi^+ p \to K\bar{K}\pi$
• • • We do not use the following data for averages fits limits etc • • •						
1694.0 ± 8.0		[7] COSTA	80	OMEG		10 $\pi^- p \to K^+ K^- n$

[5] From a fit to $J^P = 3^-$ partial wave

[6] Systematic error on mass scale subtracted

[7] They cannot distinguish between $\rho_3(1690)$ and $\omega_3(1670)$

$(4\pi)^\pm$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1675 ± 11	**OUR AVERAGE**	Error includes scale factor of 1.9 See the ideogram below				
1665.0 ± 15.0	177	BALTAY	78B	HBC	+	15 $\pi^+ p \to p 4\pi$
1670 ± 10		THOMPSON	74	HBC	+	13 $\pi^+ p$
1687 ± 20		CASON	73	HBC	−	8.18.5 $\pi^- p$
1630 ± 15.		HOLMES	72	HBC	+	10–12 $K^+ p$
1680.0 ± 40.0	144	BARTSCH	70B	HBC	+	8 $\pi^+ p \to N 4\pi$
1705.0 ± 21.0		CASO	70	HBC	−	11.2 $\pi^- p \to n \rho 2\pi$
1720 ± 15.		BALTAY	68	HBC	+	7, 8.5 $\pi^+ p$
• • • We do not use the following data for averages fits limits etc • • •						
1694 ± 6.		[8] EVANGELISTA	81	OMEG	−	12 $\pi^- p \to p 4\pi$
1718 ± 10		[10] EVANGELISTA	81	OMEG	−	12 $\pi^- p \to p 4\pi$
1673 ± 9.		[9] EVANGELISTA	81	OMEG	−	12 $\pi^- p \to p 4\pi$
1733 ± 9	66	[11] KLIGER	74	HBC	−	4.5 $\pi^- p \to p 4\pi$
1685. ± 14.		[11] CASON	73	HBC	−	8.18.5 $\pi^- p$
1689.0 ± 20.0	102	[11] BARTSCH	70B	HBC	+	8 $\pi^+ p \to N 2\rho$

[8] From $\rho^-\rho^0$ mode not independent of the other two EVANGELISTA 81 entries

[9] From $a_2(1320)^0\pi^-$ mode not independent of the other two EVANGELISTA 81 entries

[10] From $a_2(1320)^-\pi^0$ mode not independent of the other two EVANGELISTA 81 entries

[11] From $\rho^\pm\rho^0$ mode

$\omega\pi$ MODE

VALUE (MeV)		DOCUMENT ID		TECN	CHG	COMMENT
1680 ± 7	**OUR AVERAGE**					
1690 ± 15		EVANGELISTA	81	OMEG	−	12 $\pi^- p \to \omega\pi p$
1666.0 ± 14.0		GESSAROLI	77	HBC		11 $\pi^- p \to \omega\pi p$
1686 ± 9		THOMPSON	74	HBC	+	13 $\pi^+ p$
1654 ± 24		BARNHAM	70	HBC	+	10 $K^+ p \to \omega\pi X$

$\eta\pi^+\pi^-$ MODE

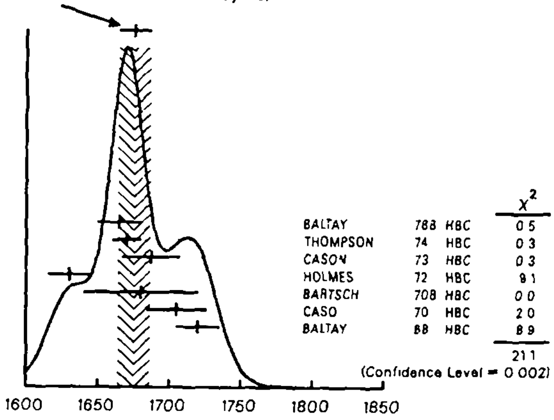
(For difficulties with MMS experiments see the $a_2(1320)$ mini review in the 1973 edition)

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1680 ± 15	FUKUI	88	SPEC	0	8.95 $\pi^- p \to \eta\pi^+\pi^- n$
• • • We do not use the following data for averages fits limits, etc • • •					
1700.0 ± 47.0	[12] ANDERSON	69	MMS	−	16 $\pi^- p$ backward
1632 ± 15	[12,13] FOCACCI	66	MMS	−	7–12 $\pi^- p \to p$ MM
1700 ± 15	[12,13] FOCACCI	66	MMS	−	7–12 $\pi^- p \to p$ MM
1748 ± 15	[12,13] FOCACCI	66	MMS	−	7–12 $\pi^- p \to p$ MM

[12] Seen in 2.5–3 GeV/c $\bar{p}p$ $2\pi^+2\pi^-$ with 0, 1, 2 $\pi^+\pi^-$ pairs in ρ band not seen by OREN 74 (2.3 GeV/c $\bar{p}p$) with more statistics (Jan 1976)

[13] Not seen by BOWEN 72

WEIGHTED AVERAGE
1675 ± 11 (Error scaled by 1.9)



$\rho_3(1690)$ mass (MeV) $(4\pi)^\pm$ mode

$\rho_3(1690)$ WIDTH

We include only high statistics experiments in the average for the 2π and $K\bar{K}$ modes

2π MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
215 ± 6	**OUR AVERAGE**	Includes data from the datablock that follows this one Error includes scale factor of 1.8 See the ideogram below				
220 ± 29		DENNEY	83	LASS		10 $\pi^+ N$
246 ± 37		EVANGELISTA	81	OMEG	−	12 $\pi^- p \to 2\pi p$
116.0 ± 30.0	476	BALTAY	78B	HBC	0	15 $\pi^+ p \to \pi^+\pi^- n$
162.0 ± 50.0	175	[14] ANTIPOV	77	CIBS	0	25 $\pi^- p \to p 3\pi$
167 ± 40	600	ENGLER	74	DBC	0	6 $\pi^+ n \to \pi^+\pi^- p$
200 ± 18		[15] GRAYER	74	ASPK	0	17 $\pi^- p \to \pi^+\pi^- n$
156 ± 36		MATTHEWS	71C	DBC	0	7 $\pi^+ N$
171.0 ± 65.0		ARMENISE	70	DBC	0	9 $\pi^+ d$
• • • We do not use the following data for averages fits limits etc • • •						
322.0 ± 35.0		[16] CORDEN	79	OMEG		12–15 $\pi^- p \to n 2\pi$
240 ± 30		[15,17] ESTABROOKS	75	RVUE		17 $\pi^- p \to \pi^+\pi^- n$
180.0 ± 30.0	122	BARTSCH	70B	HBC	+	8 $\pi^+ p \to N 2\pi$
267^{+72}_{-46}		STUNTEBECK	70	HDBC	0	8 $\pi^- p$ 5.4 $\pi^+ d$
188 ± 49.		ARMENISE	68	DBC	0	5.1 $\pi^+ d$
180.0 ± 40.0		GOLDBERG	65	HBC	0	6 $\pi^+ d$, 8 $\pi^- p$

[14] Width errors enlarged by us to $4\Gamma/N^{1/2}$ see the note with the $K^*(892)$ mass

[15] Uses same data as HYAMS 75 and BECKER 79

[16] From a phase shift solution containing a $f_2'(1525)$ width two times larger than the $K\bar{K}$ result

[17] From phase shift analysis Error takes account of spread of different phase shift solutions

$K\bar{K} + K\bar{K}\pi$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
The data in this block is included in the average printed for a previous datablock						
219.0 ± 4.0		ALPER	80	CNTR	0	62 $\pi^- p \to K^+ K^- n$
199 ± 40	6000	[18] MARTIN	78D	SPEC		10 $\pi p \to K_S^0 K^- p$
205 ± 20		BLUM	75	ASPK	0	18.4 $\pi^- p \to n K^+ K^-$

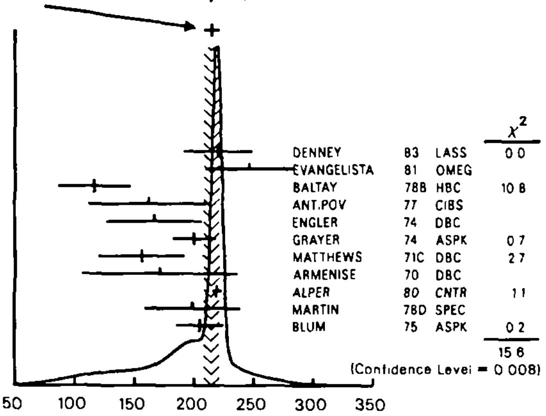
• • • We do not use the following data for averages fits, limits etc • • •

186 0 ± 11 0	[19] COSTA	80	OMEG		10 $\pi^- p \to K^+K^- n$
112 0 ± 60 0	ADERHOLZ	69	HBC	+	8 $\pi^+ p \to K\bar{K}\pi$

[18] From a fit to $J^P = 3^-$ partial wave

[19] They cannot distinguish between $\rho_3(1690)$ and $\omega_3(1670)$

WEIGHTED AVERAGE
215 ± 6 (Error scaled by 1 8)



$\rho_3(1690)$ width (MeV) $\pi\pi + KK + KK\pi$ modes

$(4\pi)^{\pm}$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
119 ± 13 OUR AVERAGE						
105 0 ± 30 0	177	BALTAY	78B	HBC	+	15 $\pi^+ p \to p4\pi$
106 ± 25		THOMPSON	74	HBC	+	13 $\pi^+ p$
169 $^{+70}_{-48}$		CASON	73	HBC	−	8 18 5 $\pi^- p$
130 ± 30		HOLMES	72	HBC	+	10–12 $K^+ p$
135 0 ± 30 0	144	BARTSCH	70B	HBC	+	8 $\pi^+ p \to N4\pi$
100 ± 35		BALTAY	68	HBC	+	7 8 5 $\pi^+ p$
• • • We do not use the following data for averages fits, limits etc • • •						
123 ± 13		[20] EVANGELISTA	81	OMEG	−	12 $\pi^- p \to p4\pi$
230 ± 28		[22] EVANGELISTA	81	OMEG	−	12 $\pi^- p \to p4\pi$
184 ± 33		[21] EVANGELISTA	81	OMEG	−	12 $\pi^- p \to p4\pi$
150	66	[23] KLIGER	74	HBC	−	4 5 $\pi^- p \to p4\pi$
125 $^{+83}_{-35}$		[23] CASON	73	HBC	−	8 18 5 $\pi^- p$
180.0 ± 30 0	90	[23] BARTSCH	70B	HBC	+	8 $\pi^+ p \to Na_2\pi$
160 0 ± 30 0	102	BARTSCH	70B	HBC	+	8 $\pi^+ p \to N2\rho$

[20] From $\rho^-\rho^0$ mode not independent of the other two EVANGELISTA 81 entries

[21] From $a_2(1320)^0\pi^-$ mode not independent of the other two EVANGELISTA 81 entries

[22] From $a_2(1320)^-\pi^0$ mode not independent of the other two EVANGELISTA 81 entries

[23] From $\rho^{\pm}\rho^0$ mode

$\omega\pi$ MODE

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
114 $^{+21}_{-20}$ OUR AVERAGE					
190 ± 65	EVANGELISTA	81	OMEG	−	12 $\pi^- p \to \omega\pi p$
160.0 ± 56 0	GESSAROLI	77	HBC		11 $\pi^- p \to \omega\pi p$
89 ± 25	THOMPSON	74	HBC	+	13 $\pi^+ p$
130 $^{+73}_{-43}$	BARNHAM	70	HBC	+	10 $K^+ p \to \omega\pi X$

$\eta\pi^+\pi^-$ MODE

(For difficulties with MMS experiments see the $a_2(1320)$ mini-review in the 1973 edition)

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
106 ± 27	FUKUI	88	SPEC	0	8 95 $\pi^- p \to \eta\pi^+\pi^- n$

• • • We do not use the following data for averages fits limits etc • • •

195 0	[24] ANDERSON	69	MMS	−	16 $\pi^- p$ backward
< 21	[24,25] FOCACCI	66	MMS	−	7–12 $\pi^- p \to p$ MM
< 30	[24,25] FOCACCI	66	MMS	−	7–12 $\pi^- p \to p$ MM
< 38	[24,25] FOCACCI	66	MMS	−	7–12 $\pi^- p \to p$ MM

[24] Seen in 2 5–3 GeV/c $\bar{p}p$ $2\pi^+2\pi^-$ with 0 1 2 $\pi^+\pi^-$ pairs in ρ^0 band not seen by OREN 74 (2 3 GeV/c $\bar{p}p$) with more statistics (Jan 1979)

[25] Not seen by BOWEN 72

$\rho_3(1690)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	$\rho_3(1690) \to \pi\pi$	$(23\ 6\ ^{+1\ 2}_{-1\ 3}) \times 10^{-2}$	
Γ_2	$\rho_3(1690) \to 4\pi$ Including π^0's	$(71\ 1\ \pm 1\ 9) \times 10^{-2}$	
Γ_3	$\rho_3(1690) \to KK\pi$	$(3\ 8\ \pm 1\ 2) \times 10^{-2}$	
Γ_4	$\rho_3(1690) \to KK$	$(1\ 58\ ^{+0\ 28}_{-0\ 25}) \times 10^{-2}$	1 2
Γ_5	$\rho_3(1690) \to \pi\pi\rho$ Excluding 2ρ and $a_2(1320)\pi$		
Γ_6	$\rho_3(1690) \to a_2(1320)\pi$		
Γ_7	$\rho_3(1690) \to \omega\pi$		
Γ_8	$\rho_3(1690) \to \rho\rho$		
Γ_9	$\rho_3(1690) \to \phi\pi$		
Γ_{10}	$\rho_3(1690) \to \eta\pi$		
Γ_{11}	$\rho_3(1690) \to \pi^{\pm}\pi^+\pi^-\pi^0$		
Γ_{12}	$\rho_3(1690) \to \pi^{\pm}2\pi^+2\pi^-\pi^0$		
Γ_{13}	$\rho_3(1690) \to \eta\pi^+\pi^-$	seen	

CONSTRAINED FIT INFORMATION

An overall fit to 5 branching ratios uses 10 measurements and one constraint to determine 4 parameters The overall fit has a $\chi^2 = 14\ 7$ for 7 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i \delta x_j\rangle/(\delta x_i \cdot \delta x_j)$ in percent from the fit to the branching fractions $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i in this array to sum to one

x_2	76		
x_3	15	74	
x_4	2	15	0
	x_1	x_2	x_3

$\rho_3(1690)$ BRANCHING RATIOS

$\Gamma(\pi\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.236 $^{+0\ 012}_{-0.013}$ OUR FIT					
0.243 ± 0.013 OUR AVERAGE					
0 259 $^{+0\ 018}_{-0\ 019}$	BECKER	79	ASPK	0	17 $\pi^- p$ polarized
0.23 ± 0 02	CORDEN	79	OMEG		12–15 $\pi^- p \to n2\pi$
0 22 ± 0 04	[26] MATTHEWS	71C	HDBC	0	7 $\pi^+ n \to \pi^- p$
• • • We do not use the following data for averages fits limits etc • • •					
0.245 ± 0 006	[27] ESTABROOKS	75	RVUE		17 $\pi^- p \to \pi^+\pi^- n$

[26] One-pion exchange model used in this estimation

[27] From phase shift analysis of HYAMS 75 data

$\Gamma(\pi\pi)/\Gamma(\pi^{\pm}\pi^+\pi^-\pi^0)$ — Γ_1/Γ_{11}

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.35 ± 0.11	CASON	73	HBC	−	8 18 5 $\pi^- p$
• • • We do not use the following data for averages fits limits etc • • •					
<0 2	HOLMES	72	HBC	+	10–12 $K^+ p$
<0 12	BALLAM	71B	HBC	−	16 $\pi^- p$

Meson Full Listings

$\rho_3(1690)$

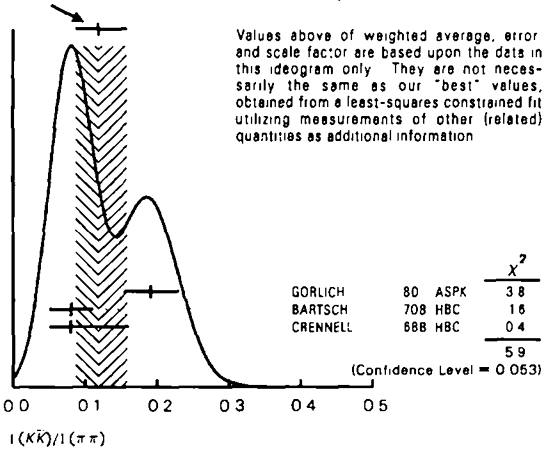
$\Gamma(\pi\pi)/\Gamma(4\pi)$ — Γ_1/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$0.332^{+0.025}_{-0.026}$ **OUR FIT**					
0.30 ± 0.10	BALTAY	78B	HBC	0	15 $\pi^+ p \to p 4\pi$

$\Gamma(K\bar{K})/\Gamma(\pi\pi)$ — Γ_4/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$0.067^{+0.012}_{-0.011}$ **OUR FIT** Error includes scale factor of 1.2					
$0.118^{+0.039}_{-0.032}$ **OUR AVERAGE** Error includes scale factor of 1.7. See the ideogram below					
$0.191^{+0.040}_{-0.037}$	GORLICH	80	ASPK	0	17.18 $\pi^- p$ polarized
0.08 ± 0.03	BARTSCH	70B	HBC	+	8 $\pi^+ p$
$0.08^{+0.08}_{-0.03}$	CRENNELL	68B	HBC		6.0 $\pi^- p$

WEIGHTED AVERAGE
0.118 + 0.039 - 0.032 (Error scaled by 1.7)



$\Gamma(K\bar{K}\pi)/\Gamma(\pi\pi)$ — Γ_3/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.16 ± 0.05 **OUR FIT**					
0.16 ± 0.05	[28] BARTSCH	70B	HBC	+	8 $\pi^+ p$

[28] Increased by us to correspond to $B(\rho_3(1690) \to \pi\pi) = 0.24$

$[\Gamma(\pi\pi\rho) + \Gamma(a_2(1320)\pi) + \Gamma(\rho\rho)]/\Gamma(\pi^\pm\pi^+\pi^-\pi^0)$ — $(\Gamma_5+\Gamma_6+\Gamma_8)/\Gamma_{11}$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.94 ± 0.09 **OUR AVERAGE**					
0.96 ± 0.21	BALTAY	78B	HBC	+	15 $\pi^+ p \to p 4\pi$
0.88 ± 0.15	BALLAM	71B	HBC	−	16 $\pi^- p$
1 ± 0.15	BARTSCH	70B	HBC	+	8 $\pi^+ p$
CONSISTENT WITH 1	CASO	68	HBC	−	11 $\pi^- p$

$\Gamma(\rho\rho)/\Gamma(\pi^\pm\pi^+\pi^-\pi^0)$ — Γ_8/Γ_{11}

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.12 ± 0.11		BALTAY	78B	HBC	+	15 $\pi^+ p \to p 4\pi$
0.56	66	KLIGER	74	HBC	−	4.5 $\pi^- p \to p 4\pi$
0.13 ± 0.09		[29] THOMPSON	74	HBC	+	13 $\pi^+ p$
0.7 ± 0.15		BARTSCH	70B	HBC	+	8 $\pi^+ p$

[29] $\rho\rho$ and $a_2(1320)\pi$ modes are indistinguishable

$\Gamma(\rho\rho)/[\Gamma(\pi\pi\rho) + \Gamma(a_2(1320)\pi) + \Gamma(\rho\rho)]$ — $\Gamma_8/(\Gamma_5+\Gamma_6+\Gamma_8)$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.48 ± 0.16	CASO	68	HBC	−	11 $\pi^- p$

$\Gamma(a_2(1320)\pi)/\Gamma(\pi^\pm\pi^+\pi^-\pi^0)$ — Γ_6/Γ_{11}

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.66 ± 0.08	BALTAY	78B	HBC	+	15 $\pi^+ p \to p 4\pi$
0.36 ± 0.14	[30] THOMPSON	74	HBC	+	13 $\pi^+ p$
NOT SEEN	CASON	73	HBC	−	8.18.5 $\pi^- p$
0.6 ± 0.15	BARTSCH	70B	HBC	+	8 $\pi^+ p$
0.6	BALTAY	68	HBC	+	7.8.5 $\pi^+ p$

[30] $\rho\rho$ and $a_2(1320)\pi$ modes are indistinguishable

$\Gamma(\omega\pi)/\Gamma(\pi^\pm\pi^+\pi^-\pi^0)$ — Γ_7/Γ_{11}

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
0.23 ± 0.05 **OUR AVERAGE** Error includes scale factor of 1.2						
0.33 ± 0.07		THOMPSON	74	HBC	+	13 $\pi^+ p$
0.12 ± 0.07		BALLAM	71B	HBC	−	16 $\pi^- p$
0.25 ± 0.10		BALTAY	68	HBC	+	7.8.5 $\pi^+ p$
0.25 ± 0.10		JOHNSTON	68	HBC	−	7.0 $\pi^- p$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.11	95	BALTAY	78B	HBC	+	15 $\pi^+ p \to p 4\pi$
<0.09		KLIGER	74	HBC	−	4.5 $\pi^- p \to p 4\pi$

$\Gamma(\phi\pi)/\Gamma(\pi^\pm\pi^+\pi^-\pi^0)$ — Γ_9/Γ_{11}

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.11	BALTAY	68	HBC	+	7.8.5 $\pi^+ p$

$\Gamma(\pi^\pm 2\pi^+ 2\pi^- \pi^0)/\Gamma(\pi^\pm\pi^+\pi^-\pi^0)$ — Γ_{12}/Γ_{11}

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.15	BALTAY	68	HBC	+	7.8.5 $\pi^+ p$

$\Gamma(\eta\pi)/\Gamma(\pi^\pm\pi^+\pi^-\pi^0)$ — Γ_{10}/Γ_{11}

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.02	THOMPSON	74	HBC	+	13 $\pi^+ p$

$\Gamma(K\bar{K})/\Gamma_{total}$ — Γ_4/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$0.0158^{+0.0028}_{-0.0025}$ **OUR FIT** Error includes scale factor of 1.2					
0.0130 ± 0.0024 **OUR AVERAGE**					
0.013 ± 0.003	COSTA	80	OMEG	0	10 $\pi^- p \to K^+ K^- n$
0.013 ± 0.004	[31] MARTIN	78B	SPEC	−	10 $\pi p \to K^0_S K^- p$

[31] From $(\Gamma_1 \Gamma_4)^{1/2} = 0.056 \pm 0.034$ assuming $B(\rho_3(1690) \to \pi\pi) = 0.24$

$\Gamma(\omega\pi)/[\Gamma(\omega\pi) + \Gamma(\rho\rho)]$ — $\Gamma_7/(\Gamma_7+\Gamma_8)$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.22 ± 0.08	CASON	73	HBC	−	8.18.5 $\pi^- p$

$\Gamma(\eta\pi^+\pi^-)/\Gamma_{total}$ — Γ_{13}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
SEEN	FUKUI	88	SPEC	8.95 $\pi^- p \to \eta\pi^+\pi^- n$

$\rho_3(1690)$ REFERENCES

FUKUI	88	PL B202 441	+Horikawa+	(SUGI NAGO KEK KYOT MIYA)	
DENNEY	83	PR D28 2726	+Cranley Firestone Chapman+	(IOWA MICH)	
EVANGELISTA	81	NP B178 197	+	(BARI BONN CERN DARE LIVP+)	
ALPER	80	PL 94B 422	+Becker+	(AMST CERN CRAC MPIM OXF+)	
COSTA	80	NP B175 402	Costa De Beauregard+	(BARI BONN CERN+)	
GORLICH	80	NP B174 16	+Niczyporuk+	(CRAC MPIM CERN ZEEM)	
BECKER	79	NP B151 46	+Blanar, Blum+	(MPIM CERN ZEEM CRAC)	
CORDEN	79	NP B157 250	+Dowell Garvey+	(BIRM RHEL TELA LOWC)	JP
BALTAY	78B	PR D17 62	+Cautis Cohen Csorna+	(COLU BING)	
MARTIN	78B	NP B140 158	+Ozmutlu Baldi Bohringer Dorsaz+	(DURH GEVA)	
MARTIN	78D	PL 74B 417	+Ozmutlu Baldi Bohringer Dorsaz+	(DURH GEVA)	
ANTIPOV	77	NP B119 45	+Busnello Damgaard Kienzle+	(SERP GEVA)	
GESSAROLI	77	NP B126 382	+	(BGNA FIRZ GENO MILA OXF PAVI)	
BLUM	75	PL 57B 403	+Chabaud Dietl Garelick Grayer+	(CERN MPIM)	JP
ESTABROOKS	75	NP B95 322	+Martin	(DURH)	
HYAMS	75	NP B100 205	+Jones Weilhammer Blum Dietl+	(CERN MPIM)	
ENGLER	74	PR D10 2070	+Kraemer Toaff Weisser Diaz+	(CMU CASE)	
GRAYER	74	NP B75 189	+Hyams Blum Dietl+	(CERN MPIM)	
KLIGER	74	SJNP 19 428	+Beketov Grechko Guzhavin Dubovikov+	(ITEP)	
		Translated from YAF 19 839			
OREN	74	NP B71 189	+Cooper Fields Rhines Allison+	(ANL OXF)	
THOMPSON	74	NP B69 220	+Gaidos McIlwain Miller Mulera+	(PURD)	
CASON	73	PR D7 1971	+Biswas Kenney Madden+	(NDAM)	
BOWEN	72	PRL 29 890	+Earles Faissler Blieden+	(NEAS STON)	
HOLMES	72	PR D6 3336	+Ferbel Slattery Werner	(ROCH)	
BALLAM	71B	PR D3 2606	+Chadwick Guiragossian Johnson+	(SLAC)	
MATTHEWS	71C	NP B33 1	+Prentice Yoon Carroll+	(TNTO WISC)	JP
ARMENISE	70	LNC 4 199	+Ghidini Foring Cartacci+	(BARI BGNA FIRZ)	
BARNHAM	70	PRL 24 1083	+Colley Jobes Kenyon Pathak Riddiford	(BIRM)	
BARTSCH	70B	NP B22 109	+Kraus Tsanos Grote+	(AACH BERL CERN)	
CASO	70	LNC 3 707	+Conte Tomasini+	(GENO HAMB MILA SACL)	
STUNTEBECK	70	PL 32B 391	+Kenney Deery Biswas Cason+	(NDAM)	
ADERHOLZ	69	NP B11 259	+Bartsch+	(AACH BERL CERN JAGL WARS)	
ANDERSON	69	PRL 22 1390	+Collins+	(BNL CMU)	
ARMENISE	68	NC 54A 999	+Ghidini Forino+	(BARI BGNA FIRZ ORSA)	I
BALTAY	68	PRL 20 887	+Kung Yeh Ferbel+	(COLU ROCH RUTG YALE)	I
CASO	68	NC 54A 983	+Conte Cords Diaz+	(GENO HAMB MILA SACL)	
CRENNELL	68B	PL 28B 136	+Karshon Lai Scarr Skillicorn	(BNL)	
JOHNSTON	68	PRL 20 1414	+Prentice Steenberg Yoon	(TNTO WISC)	IJP
FOCACCI	66	PRL 17 890	+Kienzle Levrat Maglich Martin	(CERN)	
GOLDBERG	65	PL 17 354	+	(CERN EPOL ORSA MILA CEA SACL)	

OTHER RELATED PAPERS

BARNETT	83B	PL 120B 455	+Blockus Burka Chien Christian+	(JHU)
EVANGELISTA	79B	NP B154 381	+	(BARI BONN CERN DARE GLAS LIVP+)
FORINO	78	NP B139 413	+Cartacci+	(BGNA FIRZ GENO MILA OXF PAVI) JP
MARTIN	78C	ANP 114 1	+Pennington	(CERN)
KALELKAR	75	Nevis 207 Thesis		(COLU) I
DUBOVIKOV	74	SJNP 19 568	+Matsyuk Nilov Sokolov	(ITEP)
		Translated from YAF 19 1109		
OREN	74	NP B71 189	+Cooper Fields Rhines Allison+	(ANL OXF)
ARNOLD	73	LNC 6 707	+Engel Escoubes Kurtz Lloret Paty+	(STRB)
CASON	73B	NP B64 14	+Madden Bishop Biswas Kenney+	(NDAM)
HYAMS	73	NP B64 134	+Jones Weilhammer Blum Dietl+	(CERN MPIM)
ROBERTSON	73	PR D7 2554	+Walker Davis	(DUKE WISC)
ARMENISE	72B	LNC 4 205	+Forino Cartacci+	(BARI BGNA FIRZ)
Also	75	LNC 14 177	Armenise Fogli Muciaccia+	(BARI BGNA FIRZ) JP
BOWEN	72	PRL 29 890	+Earles Faissler Blieden+	(NEAS STON)
CLAYTON	72	NP B47 81	+Mason Muirhead Rigopoulos+	(LIVP PATR)
GRAYER	72B	Phil Conf 5	+Hyams Jones Schlein+	(CERN MPIM)
GRAYER	71B	PL 35B 610	+Hyams Jones Schlein Blum+	(CERN MPIM) JP
KRAMER	70	PRL 25 396	+Barton Gutay Lichtman Miller+	(PURD)
BARISH	69	PR 184 1375	+Selove Biswas Cason+	(PENN NDAM ROCH)
CASO	69	NC 62A 755	+Conte Benz+	(GENO DESY HAMB MILA SACL)
VETLITSKY	69	SJNP 9 461	+Guzhavin Kliger Kolganov Lebedev+	(ITEP)
		Translated from YAF 9 789		
BOESEBECK	68	NP B4 501	+Deutschmann+	(AACH BERL CERN)
CRENNELL	68B	PL 28B 136	+Karshon Lai Scarr Skillicorn	(BNL)
ABRAMS	67B	PRL 18 620	+Kehoe Glasser Sechi Zorn Wolsky	(UMD)
DUBAL	67	NP B3 435		(CERN Missing Mass Spectrometer Collab)
Also	68	Thesis 1456	Dubal	(GEVA)
FRENCH	67	NC 52A 438	+Kinson McDonald Riddiford+	(CERN BIRM)
EHRLICH	66	PR 152 1194	+Selove Yuta	(PENN)
LEVRAT	66	PL 22 714		(CERN Missing Mass Spectrometer Collab)
SEGUINOT	66	PL 19 712		(CERN Missing Mass Spectrometer Collab)
BELLINI	65	NC 40A 948	+DiCorato Duimio Fiorini	(MILA)
DEUTSCH	65	PL 18 351	Deutschmann+	(AACH BERL CERN)
FORINO	65	PL 19 65	+Gessaroli+	(BGNA ORSA SACL)

$\rho(1700)$

$I^G(J^{PC}) = 1^+(1^{--})$

NOTE ON $\rho(1450)$ AND $\rho(1700)$

Early indications that the 1600 MeV mass region may contain two 1^- resonances were given by COSME 79 BARBER 80 DIBIANCA 81

It has been shown by DONNACHIE 87 that a good interpretation of all e^+e^- and photoproduction data on $\pi^+\pi^-$, $4\pi^\pm$, and $\pi^+\pi^-\pi^0\pi^0$ is obtained with the introduction of two resonances whose mass and width are determined using the recent $e^+e^- \rightarrow \pi^+\pi^-$ data (QUENZER 78, BARKOV 85 BISELLO 85) DIEKMANN 87 has shown that this two-ρ scenario also gives an acceptable interpretation of photoproduction data of $\eta\pi^+\pi^-$ (ATKINSON 86)

An independent confirmation comes from the analysis of hadroproduction of the $\eta\pi^+\pi^-$ system (FUKUI 88)

The two-ρ scenario is also suggested by data on electroproduction of $4\pi^\pm$ (KILIAN 80) Note also that ERKAL 85 point out that the understanding of the 2π and 4π electromagnetic form factors suggests that two vector resonances are present in the 1600 MeV mass region

We therefore replace the old $\rho(1600)$ entry by two new ones the $\rho(1450)$ and the $\rho(1700)$ For the $\rho(1700)$ we define the mass and width as the average of DONNACHIE 87 and FUKUI 88 and we list there all the results previously listed under the $\rho(1600)$ For the $\rho(1450)$ we do not give an average width, since DONNACHIE 87 and FUKUI 88 do not agree on the width We list under $\rho(1450)$ all the results with a low mass value

Several observations made on the $J^P = 1^-$ $\omega\pi$ in the 1200 MeV mass region (FRENKIEL 72 COSME 76 BARBER 80 ATKINSON 84) may be interpreted in terms of $\rho(770) \rightarrow \pi\omega$ coupling (LAYSSAC 71) It seems therefore not justified to keep a special entry for $\rho(1250)$ For completeness the relevant observations are listed under $\rho(1450)$

$\rho(1700)$ MASS

MIXED MODES

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1701 ± 13 OUR AVERAGE Includes data from the datablock that follows this one			
1700 ± 25	DONNACHIE 87	RVUE	
• • • We do not use the following data for averages fits limits etc • • •			
1580 ± 20	[1] BUON 82	DM1	$e^+e^- \rightarrow$ hadrons

$\eta\pi^+\pi^-$ MODE

VALUE	DOCUMENT ID	TECN	COMMENT
The data in this block is included in the average printed for a previous datablock			
1701 ± 15	FUKUI 88	SPEC	8 95 $\pi^-p \rightarrow \eta\pi^+\pi^-n$

$\pi^+\pi^-$ MODE

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
1650	[2] ERKAL 85	RVUE	20–70 $\gamma p \rightarrow \gamma\pi$
1550 ± 70	ABE 84B	HYBR	20 $\gamma p \rightarrow \pi^+\pi^-p$
1590 ± 20	[3] ASTON 80	OMEG	20–70 $\gamma p \rightarrow p2\pi$
1600 0 ± 10.0	[4] ATIYA 79B	SPEC	50 $\gamma C \rightarrow C2\pi$
1598 0 $^{+24.0}_{-22\ 0}$	BECKER 79	ASPK	17 π^-p polarized
1659 ± 25	[2] LANG 79	RVUE	
1575	[2] MARTIN 78C	RVUE	17 $\pi^-p \rightarrow \pi^+\pi^-n$
1610 ± 30.	[2] FROGGATT 77	RVUE	17 $\pi^-p \rightarrow \pi^+\pi^-n$
1590 ± 20	[5] HYAMS 73	ASPK	17 $\pi^-p \rightarrow \pi^+\pi^-n$

$K\bar{K}$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
1582 ± 36	1600	CLELAND 82B	SPEC	±	50 $\pi p \rightarrow K^0_S K^\pm p$

$2(\pi^+\pi^-)$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
1570 ± 20		[6] CORDIER 82	DM1	$e^+e^- \rightarrow 2(\pi^+\pi^-)$
1520 ± 30		[3] ASTON 81E	OMEG	20–70 $\gamma p \rightarrow p4\pi$
1654 ± 25		[7] DIBIANCA 81	DBC	$\pi^+d \rightarrow pp2(\pi^+\pi^-)$
1666 ± 39		[6] BACCI 80	FRAG	$e^+e^- \rightarrow 2(\pi^+\pi^-)$
1780.	34	KILLIAN 80	SPEC	11 $e^-p \rightarrow 2(\pi^+\pi^-)$
1500		[8] ATIYA 79B	SPEC	50 $\gamma C \rightarrow C4\pi^\pm$
1570 ± 60	65	[9] ALEXANDER 75	HBC	7 5 $\gamma p \rightarrow p4\pi$
1550 ± 60		[3] CONVERSI 74	OSPK	$e^+e^- \rightarrow 2(\pi^+\pi^-)$
1550 ± 50	160	SCHACHT 74	STRC	5 5–9 $\gamma p \rightarrow p4\pi$
1450 ± 100	340	SCHACHT 74	STRC	9–18 $\gamma p \rightarrow p4\pi$
1430 ± 50	400	BINGHAM 72B	HBC	9 3 $\gamma p \rightarrow p4\pi$

$\pi^+\pi^-\pi^0\pi^0$ MODE

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
1660. ± 30	ATKINSON 85B	OMEG	20–70 γp

[1] From global fit of ρ, ω, ϕ and their radial excitations to channels $\omega\pi^+\pi^-$, K^+K^-, $K^0_S K^0_L$, $K^0_S K^\pm\pi^\mp$

[2] From phase shift analysis of HYAMS 73 data

[3] Simple relativistic Breit Wigner fit with constant width

[4] An additional 40 MeV uncertainty in both the mass and width is present due to the choice of the background shape

[5] Included in BECKER 79 analysis

[6] Simple relativistic Breit Wigner fit with model dependent width

[7] One peak fit result

[8] Parameters roughly estimated not from a fit

[9] Skew mass distribution compensated by Ross Stodolsky factor

Meson Full Listings
$\rho(1700)$

$\rho(1700)$ WIDTH

MIXED MODES

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
235 ± 27 OUR AVERAGE Includes data from the datablock that follows this one Error includes scale factor of 1 2			
220 ± 25	DONNACHIE 87	RVUE	
• • • We do not use the following data for averages fits limits, etc • • •			
340 ± 80	[10] BUON 82	DM1	$e^+e^- \rightarrow$ hadrons

$\eta\pi^+\pi^-$ MODE

VALUE	DOCUMENT ID	TECN	COMMENT
The data in this block is included in the average printed for a previous datablock			
282 ± 44	FUKUI 88	SPEC	8 95 $\pi^- p \rightarrow \eta\pi^+\pi^- n$

$\pi^+\pi^-$ MODE

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits, etc • • •			
<315	[11] ERKAL 85	RVUE	20-70 $\gamma p \rightarrow \gamma\pi$
280 $^{+30}_{-80}$	ABE 84B	HYBR	20 $\gamma p \rightarrow \pi^+\pi^- p$
230 0 ± 80 0	[12] ASTON 80	OMEG	20-70 $\gamma p \rightarrow p 2\pi$
283 0 ± 14 0	[13] ATIYA 79B	SPEC	50 $\gamma C \rightarrow C 2\pi$
175 0 $^{+98\ 0}_{-53\ 0}$	BECKER 79	ASPK	17 $\pi^- p$ polarized
232 ± 34	[11] LANG 79	RVUE	
340	[11] MARTIN 78C	RVUE	17 $\pi^- p \rightarrow \pi^+\pi^- n$
300 ± 100	[11] FROGGATT 77	RVUE	17 $\pi^- p \rightarrow \pi^+\pi^- n$
180 + 50	[14] HYAMS 73	ASPK	17 $\pi^- p \rightarrow \pi^+\pi^- n$

KK MODE

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
265 ± 120	1600	CLELAND 82B	SPEC	±	50 $\pi p \rightarrow K^0_S K^\pm p$

$2(\pi^+\pi^-)$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
510 ± 40		[15] CORDIER 82	DM1	$e^+e^- \rightarrow 2(\pi^+\pi^-)$
400 ± 50		[12] ASTON 81E	OMEG	20-70 $\gamma p \rightarrow p 4\pi$
400 ± 146		[16] DIBIANCA 81	DBC	$\pi^+ d \rightarrow pp2(\pi^+\pi^-)$
700 ± 160		[15] BACCI 80	FRAG	$e^+e^- \rightarrow 2(\pi^+\pi^-)$
100	34	KILLIAN 80	SPEC	11 $e^- p \rightarrow 2(\pi^+\pi^-)$
600		[17] ATIYA 79B	SPEC	50 $\gamma C \rightarrow C 4\pi^\pm$
340 ± 160	65	[18] ALEXANDER 75	HBC	7 5 $\gamma p \rightarrow p 4\pi$
360 ± 100		[12] CONVERSI 74	OSPK	$e^+e^- \rightarrow 2(\pi^+\pi^-)$
400 ± 120	160	[19] SCHACHT 74	STRC	5 5-9 $\gamma p \rightarrow p 4\pi$
850 ± 200	340	[19] SCHACHT 74	STRC	9-18 $\gamma p \rightarrow p 4\pi$
650 ± 100	400	BINGHAM 72B	HBC	9 3 $\gamma p \rightarrow p 4\pi$

$\pi^+\pi^-\pi^0\pi^0$ MODE

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
300 ± 50	ATKINSON 85B	OMEG	20-70 γp

[10] From global fit of ρ ω ϕ and their radial excitations to channels $\omega\pi^+\pi^-$ K^+K^- $K^0_S K^0_L$ $K^0_S K^\pm\pi^\mp$

[11] From phase shift analysis of HYAMS 73 data

[12] Simple relativistic Breit-Wigner fit with constant width

[13] An additional 40 MeV uncertainty in both the mass and width is present due to the choice of the background shape

[14] Included in BECKER 79 analysis

[15] Simple relativistic Breit-Wigner fit with model-dependent width

[16] One peak fit result

[17] Parameters roughly estimated, not from a fit

[18] Skew mass distribution compensated by Ross Stodolsky factor

[19] Width errors enlarged by us to $4\Gamma/N^{1/2}$ see the note with the $K^*(892)$ mass

$\rho(1700)$ DECAY MODES

Γ_1	$\rho(1700) \rightarrow \rho^0\pi^+\pi^-$
Γ_2	$\rho(1700) \rightarrow 4\pi^\pm$
Γ_3	$\rho(1700) \rightarrow \rho^0\rho^0$
Γ_4	$\rho(1700) \rightarrow \pi^+\pi^-$
Γ_5	$\rho(1700) \rightarrow \bar{K}K$
Γ_6	$\rho(1700) \rightarrow \pi\omega$
Γ_7	$\rho(1700) \rightarrow \rho^0\pi^0\pi^0$
Γ_8	$\rho(1700) \rightarrow e^+e^-$
Γ_9	$\rho(1700) \rightarrow \rho^\pm\pi^\mp\pi^0$
Γ_{10}	$\rho(1700) \rightarrow K\bar{K}^*(892)$ + c c
Γ_{11}	$\rho(1700) \rightarrow \pi\pi\eta$
Γ_{12}	$\rho(1700) \rightarrow \rho\pi\pi$

$\rho(1700)$ $\Gamma(i)\Gamma(e^+e^-)/\Gamma(\text{total})$

This combination of a partial width with the partial width into e^+e^- and with the total width is obtained from the cross section into channel$_i$ in e^+e^- annihilation

$\Gamma(4\pi^\pm) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_2\Gamma_8/\Gamma$

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
2.64 ± 0.18 OUR AVERAGE			
2 6 ± 0 2	DELCOURT 81B	DM1	$e^+e^- \rightarrow 2(\pi^+\pi^-)$
2 83 ± 0 42	BACCI 80	FRAG	$e^+e^- \rightarrow 2(\pi^+\pi^-)$

$\Gamma(\pi^+\pi^-) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_4\Gamma_8/\Gamma$

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
0 13	[20] DIEKMAN 87	RVUE	$e^+e^- \rightarrow \pi^+\pi^-$

[20] Using total width = 220 MeV

$\Gamma(\bar{K}K) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_5\Gamma_8/\Gamma$

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •			
0 035 ± 0 029	[21] BIZOT 80	DM1	e^+e^-

$\Gamma(K\bar{K}^*(892)$ + c c $) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_{10}\Gamma_8/\Gamma$

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •			
0 305 ± 0 071	[21] BIZOT 80	DM1	e^+e^-

$\Gamma(\rho\pi\pi) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_{12}\Gamma_8/\Gamma$

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
3 510 ± 0 090	[21] BIZOT 80	DM1	e^+e^-

[21] Model dependent

$\rho(1700)$ BRANCHING RATIOS

$\Gamma(\rho^0\pi^+\pi^-)/\Gamma(4\pi^\pm)$ — Γ_1/Γ_2

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~1 0		DELCOURT 81B	DM1	$e^+e^- \rightarrow 2(\pi^+\pi^-)$
0 7 ± 0 1	500	SCHACHT 74	STRC	5 5-18 $\gamma p \rightarrow p 4\pi$
0 80		[22] BINGHAM 72B	HBC	9 3 $\gamma p \rightarrow p 4\pi$

[22] The $\pi\pi$ system is in S-wave

$\Gamma(\pi^+\pi^-)/\Gamma(4\pi^\pm)$ — Γ_4/Γ_2

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
0 13 ± 0 05	ASTON 80	OMEG	20-70 $\gamma p \rightarrow p 2\pi$
<0 14	[23] DAVIER 73	STRC	6-18 $\gamma p \rightarrow p 4\pi$
<0 2	[24] BINGHAM 72B	HBC	9 3 $\gamma p \rightarrow p 2\pi$

[23] Upper limit is estimate

[24] 2σ upper limit

$\Gamma(K\bar{K})/\Gamma(4\pi^\pm)$ — Γ_5/Γ_2

VALUE	CL%	DOCUMENT ID	TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits, etc • • •					
0 015 ± 0 010		[25] DELCOURT 81B	DM1		$e^+e^- \rightarrow \bar{K}K$
<0 04	95	BINGHAM 72B	HBC	0	9 3 γp

[25] Assuming $\rho(1700)$ and ω radial excitations to be degenerate in mass

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ — Γ_4/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
0 287 $^{+0\ 043}_{-0\ 042}$	BECKER 79	ASPK	17 $\pi^- p$ polarized
0 15 to 0 30	[26] MARTIN 78C	RVUE	17 $\pi^- p \rightarrow \pi^+\pi^- n$
<0 20	[27] COSTA 77B	RVUE	$e^+e^- \rightarrow 2\pi$ 4π
0 30 ± 0 05	[26] FROGGATT 77	RVUE	17 $\pi^- p \rightarrow \pi^+\pi^- n$
<0 15	[28] EISENBERG 73	HBC	5 $\pi^+ p \rightarrow \Delta^{++} 2\pi$
0 25 ± 0 05	[29] HYAMS 73	ASPK	17 $\pi^- p \rightarrow \pi^+\pi^- n$
0 20 ± 0 05	MONTANET 73	HBC	0 0 $\bar{p}p$

[26] From phase shift analysis of HYAMS 73 data

[27] Estimate using unitarity time reversal invariance Breit-Wigner

[28] Estimated using one-pion exchange model

[29] Included in BECKER 79 analysis

$\Gamma(\rho^0\pi^0\pi^0)/\Gamma(\rho^\pm\pi^\mp\pi^0)$ — Γ_7/Γ_9

VALUE	DOCUMENT ID	TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
<0 10	ATKINSON 85B	OMEG		20-70 γp
<0 15	ATKINSON 82	OMEG	0	20-70 $\gamma p \rightarrow p 4\pi$

$\Gamma(\pi^+\pi^-$ neutrals$)/\Gamma(4\pi^\pm)$ $(\Gamma_7+\Gamma_9+709\Gamma_{11})/\Gamma_2$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
2 6±0 4	[30] BALLAM	74	HBC	9 3 γp

[30] Upper limit Background not subtracted

$\Gamma(\pi\pi\eta)/\Gamma(4\pi^\pm)$ Γ_{11}/Γ_2

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •				
0 123 ± 0 027	DELCOURT	82	DM1	$e^+e^- \to \pi^+\pi^-$ MM
~0 1	ASTON	80	OMEG	20-70 γp

$\Gamma(K\bar{K}^*(892)$ + c c $)/\Gamma(4\pi^\pm)$ Γ_{10}/Γ_2

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
0 15 ± 0.03	[31] DELCOURT	81B	DM1	$e^+e^- \to KK\pi$

[31] Assuming ρ(1700) and ω radial excitations to be degenerate in mass

$\Gamma(K\bar{K})/\Gamma(K\bar{K}^*(892)$ + c c $)$ Γ_5/Γ_{10}

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits, limits etc • • •				
0 052 ± 0 026	BUON	82	DM1	$e^+e^- \to$ hadrons

$\Gamma(\pi\pi\eta)/\Gamma_{total}$ Γ_{11}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •					
<0 02	58	ATKINSON	86B	OMEG	20-70 γp

ρ(1700) REFERENCES

FUKUI 88 PL B202 441 +Horikawa+ (SUGI NAGO KEK KYOT MIYA)
DIEKMAN 87 Tsukuba Conf 7 (BONN)
DONNACHIE 87 ZPHY C33 407 +Mirzaie (MCHS)
ATKINSON 86B ZPHY C30 531 + (BONN CERN GLAS LANC MCHS LPNP+)
ATKINSON 85B ZPHY C26 499 + (BONN CERN GLAS LANC MCHS LPNP+)
ERKAL 85 ZPHY C29 485 +Olsson (WISC)
ABE 84B PRL 53 751 + (SLAC Hybrid Facility Photon Collab)
ATKINSON 82 PL 108B 55 + (BONN CERN GLAS LANC MCHS CURI+)
BUON 82 PL 118B 221 +Bisello Bizot Cordier Delcourt+ (LALO MONP)
CLELAND 82B NP B208 228 +Delfosse Dorsaz Gloor (DURH GEVA LAUS PITT)
CORDIER 82 PL 109B 129 +Bisello Bizot Buon Delcourt (LALO)
DELCOURT 82 PL 113B 93 +Bisello Bizot Buon Cordier Mane (LALO)
ASTON 81E NP B189 15 (BONN CERN EPOL GLAS LANC MCHS+)
DELCOURT 81B Bonn Conf 205 (ORSA)
Also 82 PL 109B 129 Cordier Bisello Bizot Buon Delcourt (LALO)
DIBIANCA 81 PR D23 595 +Fickinger Malko Dado Engler+ (CASE CMU)
ASTON 80 PL 92B 215 (BONN CERN EPOL GLAS LANC MCHS+)
BACCI 80 PL 95B 139 +DeZorzi Penso Baldini Celio+ (ROMA FRAS)
BIZOT 80 Madison Conf 546 +Bisello Buon Cordier Delcourt+ (LALO USTL)
KILLIAN 80 PR D21 3005 +Treadwell Ahrens Berkelman Cassel+ (CORN)
ATIYA 79B PRL 43 1691 +Holmes Knapp Lee Seto+ (COLU ILL FNAL)
BECKER 79 NP B151 46 +Blanar Blum+ (MPIM CERN ZEEM CRAC)
LANG 79 PR D19 956 +Mas Parareda (GRAZ)
MARTIN 78C ANP 114 1 +Pennington (CERN)
COSTA 77B PL 71B 345 Costa De Beauregard Pire Truong (EPOL)
FROGGATT 77 NP B129 89 +Petersen (GLAS NORD)
ALEXANDER 75 PL 57B 487 +Benary Gandsman Lissauer+ (TELA)
BALLAM 74 NP B76 375 +Chadwick Bingham Fretter+ (SLAC LBL MPIM)
CONVERSI 74 PL 52B 493 +Paoluzi Ceradini Grilli+ (ROMA FRAS)
SCHACHT 74 NP B81 205 +Derado Fries Park Yount (MPIM)
DAVIER 73 NP B58 31 +Derado Fries Liu Mozley Odian Park+ (SLAC)
EISENBERG 73 PL 43B 149 +Karshon Mikenberg Pitluck+ (REHO)
HYAMS 73 NP B64 134 +Jones Weilhammer Blum Dietl+ (CERN MPIM)
MONTANET 73 Erice School 518 (CERN)
BINGHAM 72B PL 41B 635 +Rabin Rosenfeld Smadja+ (LBL UCB SLAC) IGJP

OTHER RELATED PAPERS

ASTON 87 NP B292 693 +Awaji D Amore+ (SLAC NAGO CINC TOKY)
BARKOV 85 NP B256 365 +Chilingarov Eidelman Khazin Lelchuk+(NOVO)
BISELLO 85 LAL 85 15 +Augustin Ajaltouni+ (PADO LALO CLER FRAS)
ATKINSON 83B PL 127B 132 + (BONN CERN GLAS LANC MCHS LPNP+)
ATKINSON 83C NP B229 269 + (BONN CERN GLAS LANC MCHS LPNP+)
AUGUSTIN 83 LAL 83 21 +Ayach Bisello Baldini+ (LALO PADO FRAS)
SHAMBROO 82 PR D26 1 +Wilson Anderson Francis+ (HARV EFI ILL OXF)
ASTON 81F PL 104B 231 (BONN CERN EPOL GLAS LANC MCHS+)
DELCOURT 81 PL 99B 257 +Bisello Bizot Buon Cordier Mane (ORSA)
ASTON 80F NP B174 269 (BONN CERN EPOL GLAS LANC MCHS+)
BARBER 80C ZPHY C4 169 +Dainton Brodbeck Brookes+(DARE LANC SHEF)
HEYN 80 ZPHY C7 169 +Lang (GRAZ)
O DONNELL 80 PR D22 711 (TNTO)
BACCI 79 PL 86B 234 +DeZorzi Penso Stella+ (ROMA BGNA FRAS)
CORDEN 79 NP B157 250 +Dowell Garvey+ (BIRM RHEL TELA LOWC) JP
CORDIER 79 PL 81B 389 +Delcourt Eschstruth Fulda+ (LALO)
COSME 79 NP B152 215 +Dudelzak Grelaud Jean Marie Jullian+ (IPN)
RICHARD 79 Fermilab Symp 469 (LALO)
SIDOROV 79 Batavia Conf 79 490 (NOVO)
GENSINI 78 PR D17 1368 (SLAC)
QUENZER 78 PL 76B 512 +Ribes Rumpf Bertrand Bizot Chase+ (LALO)
BUDNEV 77 PL 70B 365 +Budnev Serebryakov (NOVO)
COSTA 77 PL 67B 213 Costa De Beauregard Pham Pire+ (EPOL)
GESSAROLI 77 NP B126 382 + (BGNA FIRZ GENO MILA OXF PAVI)
BASSOMPIE 76 PL 65B 397 Bassompierre Binder+ (MULH STRB TORI)
COMMON 76 NP B103 109 (KENT) JP
JOHNSON 76 PL 63B 95 +Martin Pennington (DURH CERN) JP
ALLES 75 NC 30A 136 Alles Borelli Bernardini+ (CERN BGNA FRAS)
CHUNG 75C PR D11 2436 +Protopopescu Lynch Flatte+ (BNL LBL USC)
ESTABROOKS 75 NP B95 322 +Martin (DURH)
FROGGATT 75 NP B91 454 +Petersen (GLAS NORD)
HYAMS 75 NP B100 205 +Jones Weilhammer Blum Dietl+ (CERN MPIM)
LANG 75 PL 58B 450 +Stefanescu (KARL)
LANGACKER 75 PR D13 697 +Segre (PENN)
LEE 75 Stanford Conf 213 (COLU)
ROOS 75 NP B97 165 (HELS)
BERNABEI 74 LNC 11 261 +Angelo Spillantini Valente (ROMA FRAS)
CHALOUPKA 74 PL 51B 407 +Ferrando Losty Montanet (CERN)
ESTABROOKS 74 NP B79 301 +Martin (DURH)
FERBEL 74 PR D9 824 +Slattery (ROCH)
GRAYER 74 NP B75 189 +Hyams Blum Dietl+ (CERN MPIM)
HIRSHFELD 74 NP B74 211 +Kramer (HAMB)
CERADINI 73 PL 43B 341 +Conversi Ekstrand Grilli+ (ROMA FRAS PADO) IGJP
CHUNG 73 PL 47B 526 +Protopopescu Lynch Flatte+ (BNL LBL UCSC)
KREUZER 73 PR D8 1431 +Kamal (ALBE)
OCHS 73 Thesis (MPIM)
PARK 73 NP B58 45 (MPIM) JP
BACCI 72 PL 38B 551 +Penso Salvini Stella Baldini Celio(ROMA FRAS) JPC
BARBARINO 72 LNC 3 689 +Ceradini+ (FRAS ROMA PADO UMD) IGJP
BARTOLI 72 PR D6 2374 +Felicetti Ogren+ (FRAS ROMA NAPL) IG.P
BRAMON 72 LNC 3 693 +Greco (FRAS)
DIEBOLD 72 Batavia Conf 3 1 (ANL)
EISENBERG 72 PR D5 15 +Ballam Dagan+ (REHO SLAC TELA)
LAYSSAC 72 NC 10A 407 +Renard (MONP)
SMADJA 72 Phil Conf 349 +Bingham Fretter Ballam Chadwick+(LBL SLAC)
ALVENSLEBEN 71 PRL 26 273 +Becker Bertram Chen+ (DESY MIT) G
BRAUN 71 NP B30 213 +Fridman Gerber Givernaud+ (STRB) G
BULOS 71 PRL 26 149 +Busza Kehoe Beniston+ (SLAC UMD IBM LBL) G

X(1700) was η(1700)

$I^G(J^{PC})$ = EVEN$^+(?^{?+})$

OMITTED FROM SUMMARY TABLE

Enhancement seen in the $\eta\pi\pi$ system produced in the radiative decay of the $J/\psi(1S)$ May contain significant substructure Relation to other enhancements seen in radiative $J/\psi(1S)$ decay unclear (see HITLIN 83) Tentatively called X(1700) by us

X(1700) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1700.0 ± 45.	EDWARDS	83B	CBAL	$J/\psi \to \eta\gamma 2\pi$

X(1700) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
520 ± 110.	EDWARDS	83B	CBAL	$J/\psi \to \eta\gamma 2\pi$

X(1700) REFERENCES

EDWARDS 83B PRL 51 859 +Partridge Peck+ (CIT HARV PRIN STAN SLAC)
HITLIN 83 Cornell Conf 746 (CIT)

f_2(1720) was θ(1690)

$I^G(J^{PC}) = 0^+(2^{++})$

Named θ by EDWARDS 82D Seen in $J/\psi(1S) \to \gamma f_2(1720)$ therefore $C = +$ f_2(1720) decays into 2η therefore $I^G = 0^+$ $J^P = 2^+$ is preferred over $J^P = 0^+$ higher spins not studied

Mass and width determination complicated by overlap with f_2'(1525) in mass spectra Possible connection of this state with structure seen in $J/\psi(1S) \to \gamma\rho\rho$ and in $J/\psi(1S) \to \gamma\eta\pi\pi$ is unclear (see BURKE 82, HITLIN 83) Recent results (BALTRUSAITIS 85G) indicate that the $\rho\rho$ enhancement is $J^P = 0^-$ hence unrelated to the f_2(1720) The f_2(1720) is not seen in $K^-p \to K^0_S K^0_S \Lambda$ by ASTON 88D

See also the mini-review under non $q\bar{q}$ candidates

$f_2(1720)$ MASS

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
$1720\ 9^{+1.8}_{-4.2}$	OUR AVERAGE				
1698 ± 15		AUGUSTIN	87	DM2	$J/\psi \to \gamma \pi^+\pi^-$
1720 ± 10	± 10	BALTRUSAITIS	87	MRK3	$J/\psi \to \gamma K^+K^-$
1730^{+2}_{-10}		[1,2] LONGACRE	86	MPS	$22\ \pi^- p \to n 2K^0_S$
1718 ± 7		AUGUSTIN	85	DM2	$J/\psi \to K^+K^-\gamma$
1725 ± 8		AUGUSTIN	85	DM2	$J/\psi \to K^0_S K^0_S \gamma$
• • • We do not use the following data for averages fits limits etc • • •					
1670 + 50		BLOOM	83	CBAL	$J/\psi \to \gamma 2\eta$
1650 ± 50		BURKE	82	MRK2	$J/\psi \to \gamma 2\rho$
1708 0 ± 30 0		FRANKLIN	82	MRK2	$e^+e^- \to \gamma K^+K^-$

[1]From a partial-wave analysis of data using a K matrix formalism with 5 poles
[2]Fit with constrained inelasticity

$f_2(1720)$ WIDTH

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
138^{+11}_{-9}	OUR AVERAGE				
136 ± 28		AUGUSTIN	87	DM2	$J/\psi \to \gamma \pi^+\pi^-$
130 ± 20		BALTRUSAITIS	87	MRK3	$J/\psi \to \gamma K^+K^-$
122^{+74}_{-15}		[3,4] LONGACRE	86	MPS	$22\ \pi^- p \to n 2K^0_S$
148 ± 22		AUGUSTIN	85	DM2	$J/\psi \to K^+K^-\gamma$
146 ± 24		AUGUSTIN	85	DM2	$J/\psi \to K^0_S K^0_S \gamma$
• • • We do not use the following data for averages, fits limits etc • • •					
160 ± 80		BLOOM	83	CBAL	$J/\psi \to \gamma 2\eta$
200 ± 100		BURKE	82	MRK2	$J/\psi \to \gamma 2\rho$
156 0 ± 60 0		FRANKLIN	82	MRK2	$e^+e^- \to \gamma K^+K^-$

[3]From a partial-wave analysis of data using a K matrix formalism with 5 poles
[4]Fit with constrained inelasticity

$f_2(1720)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$f_2(1720) \to \eta\eta$	$(18\ 0\ {}^{+3.0}_{-13\ 0}) \times 10^{-2}$
Γ_2	$f_2(1720) \to K\bar{K}$	$(38\ {}^{+9}_{-19}) \times 10^{-2}$
Γ_3	$f_2(1720) \to \rho\rho$	
Γ_4	$f_2(1720) \to \omega\omega$	
Γ_5	$f_2(1720) \to \pi\pi$	$(3\ 90^{+0\ 20}_{-2\ 40}) \times 10^{-2}$
Γ_6	$f_2(1720) \to \gamma\gamma$	

$f_2(1720)$ $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(\text{total})$

$\Gamma(K\bar{K}) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ $\Gamma_2\Gamma_6/\Gamma$

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
<0 28	95	ALTHOFF	85B	TASS	$\gamma\gamma \to K\bar{K}\pi$

$f_2(1720)$ BRANCHING RATIOS

$\Gamma(\eta\eta)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
$0.18^{+0.03}_{-0.13}$	[5,6] LONGACRE	86	MPS	$22\ \pi^- p \to n 2K^0_S$

$\Gamma(K\bar{K})/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
$0\ 38^{+0.09}_{-0.19}$	[5,6] LONGACRE	86	MPS	$22\ \pi^- p \to n 2K^0_S$

$\Gamma(\pi\pi)/\Gamma_{total}$ Γ_5/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
$0.039^{+0.002}_{-0.024}$	[5,6] LONGACRE	86	MPS	$22\ \pi^- p \to n 2K^0_S$

[5]From a partial wave analysis of data using a K-matrix formalism with 5 poles
[6]Fit with constrained inelasticity

$f_2(1720)$ REFERENCES

ASTON	88D	NP to be pub	+Awaji Bienz+	(SLAC NAGO CINC TOKY)
AUGUSTIN	87	ZPHY C36 369	+Cosme+	(LALO CLER FRAS PADO)
BALTRUSAITIS	87	PR D35 2077	+Coffman Dubois+	(MARK III Collab)
LONGACRE	86	PL B177 223	+Etkin+	(BNL BRAN CUNY DUKE NDAM)
ALTHOFF	85B	ZPHY C29 189	+Braunschweig Kirschfink+	(TASSO Collab)
AUGUSTIN	85	Moriond XX 1 479	+Calcaterra Cosme+	(ORSA CLER PADO FRAS)
BALTRUSAITIS	85G	PR D33 1222	+	(CIT UCSC ILL SLAC WASH)
BLOOM	83	ARNS 33 143	+Peck	(SLAC CIT)
HITLIN	83	Cornell Conf 746		(CIT)
BURKE	82	PRL 49 632	+Trilling Abrams Alam Blocker+	(LBL SLAC)
EDWARDS	82D	PRL 48 458	+Partridge Peck+	(CIT HARV PRIN STAN SLAC)
FRANKLIN	82	SLAC 254		(SLAC)

OTHER RELATED PAPERS

AKESSON	86	NP B264 154	+Albrow Almehed+	(Axial Field Spec Collab)
ARMSTRONG	86B	PL 167B 133	+Bloodworth Carney+	(ATHU BARI BIRM CERN)
ALTHOFF	83	PL 121B 216	+Brandelik Boerner+	(TASSO Collab)
BARNETT	83B	PL 120B 455	+Blockus Burka Chien Christian+	(JHU)
ALTHOFF	82	ZPHY C16 13	+Boerner Burkhardt+	(TASSO Collab)
BARNES	82	PL 116B 365	+Close	(RHEL)
BARNES	82B	NP B198 360	+Close Monaghan	(RHEL OXF)
TANIMOTO	82	PL 116B 198		(BIEL)

$f_0(1750)$ was $S(1730)$

$I^G(J^{PC}) = 0^+(0^{++})$

OMITTED FROM SUMMARY TABLE

Seen in phase-shift analysis of $K^0_S K^0_S$ system and in $\eta\eta$ mass distribution We also include ALDE 86C here although the quantum numbers are not certain Needs confirmation

$f_0(1750)$ MASS

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits, limits etc • • •					
1755 0 ± 8 0		ALDE	86C	GAM2	$38\ \pi^- p \to n 2\eta$
1742 0 ± 15 0		WILLIAMS	84	MPSF	$200\ \pi^- N \to 2K^0_S X$
1730 0 ± 10	± 20	[1] ETKIN	82C	MPS	$23\ \pi^- p \to n 2K^0_S$

[1]From an amplitude analysis of the $K^0_S K^0_S$ system

$f_0(1750)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •				
50 0 ± 8.0	ALDE	86C	GAM2	$38\ \pi^- p \to n 2\eta$
57.0 ± 38 0	WILLIAMS	84	MPSF	$200\ \pi^- N \to 2K^0_S X$
$200\ 0^{+156\ 0}_{-9\ 0}$	[2] ETKIN	82B	MPS	$23\ \pi^- p \to n 2K^0_S$

[2]From an amplitude analysis of the $K^0_S K^0_S$ system

$f_0(1750)$ DECAY MODES

Γ_1	$f_0(1750) \to K\bar{K}$
Γ_2	$f_0(1750) \to \eta\eta$

$f_0(1750)$ REFERENCES

ALDE	86C	PL B182 105	+Binon Bricman+	(SERP BELG LANL LAPP)
WILLIAMS	84	PR D30 877	+Diamond+	(VAND NDAM TUFT ARIZ FNAL+)
ETKIN	82B	PR D25 1786	+Foley Lai+	(BNL CUNY TUFT VAND) JP
ETKIN	82C	PR D25 2446	+Foley Lai+	(BNL CUNY TUFT VAND)

$\pi(1770)$

$I^G(J^{PC}) = 1^-(0^{-+})$

OMITTED FROM SUMMARY TABLE

Seen in partial-wave analysis of the diffractively produced 3π system. Needs confirmation.

$\pi(1770)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1770. ± 30.	1100	BELLINI	82	SPEC	−	40 $\pi^- A \to 3\pi A$

$\pi(1770)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
310. ± 50.	1100	BELLINI	82	SPEC	−	40 $\pi^- A \to 3\pi A$

$\pi(1770)$ DECAY MODES

Γ_1 $\pi(1770) \to f_0(1400)\pi$

Γ_2 $\pi(1770) \to \rho\pi$

$\pi(1770)$ BRANCHING RATIOS

$\Gamma(f_0(1400)\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
DOMINANT	BELLINI	82	SPEC	−	40 $\pi^- A \to 3\pi A$

$\Gamma(\rho\pi)/\Gamma_{total}$ — Γ_2/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
NOT SEEN	BELLINI	82	SPEC	−	40 $\pi^- A \to 3\pi A$

$\pi(1770)$ REFERENCES

BELLINI 82 PRL 48 1697 +Frabetti, Ivanshin, Litkin+ (MILA, BGNA, JINR)

$f_2(1810)$

$I^G(J^{PC}) = 0^+(2^{++})$

OMITTED FROM SUMMARY TABLE

From an amplitude analysis of the K^+K^- system seen in $\pi^- p \to K^+K^-n$ at 10 GeV/c. Confirmed by LONGACRE 86. Seen also in $\pi^+\pi^- \to 2\pi^0$ amplitude analysis (CASON 82), in the partial-wave analysis of the $\eta\eta$ system (ALDE 86D) and in the $4\pi^0$ mass spectrum (ALDE 87C).

$f_2(1810)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1806 ± 10	1600 ± 100	ALDE	87	GAM4	100 $\pi^- p \to 4\pi^0 n$
1870 ± 40		[1] ALDE	86D	GAM4	100 $\pi^- p \to 4\gamma n$
$1858.0^{+18.0}_{-71.0}$		[2] LONGACRE	86	MPS	Compilation
1799.0 ± 15.0		CASON	82	STRC	8 $\pi^+ p \to p\pi^+ 2\pi^0$
$1857.0^{+35.0}_{-24.0}$		[3] COSTA	80	OMEG	10 $\pi^- p \to K^+K^- n$

[1] Seen in only one solution.
[2] From a partial wave analysis of data using a K-matrix formalism with 5 poles. Includes compilation of several other experiments.
[3] Error increased by spread of two solutions. Included in LONGACRE 86 global analysis.

$f_2(1810)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
190 ± 20	1600 ± 100	ALDE	87	GAM4	100 $\pi^- p \to 4\pi^0 n$
250 ± 30		[4] ALDE	86D	GAM4	100 $\pi^- p \to 4\gamma n$
$388.0^{+15.0}_{-21.0}$		[5] LONGACRE	86	MPS	Compilation
$280.0^{+42.0}_{-35.0}$		CASON	82	STRC	8 $\pi^+ p \to p\pi^+ 2\pi^0$
$185.0^{+102.0}_{-139.0}$		[6] COSTA	80	OMEG	10 $\pi^- p \to K^+K^- n$

[4] Seen in only one solution.
[5] From a partial wave analysis of data using a K matrix formalism with 5 poles. Includes compilation of several other experiments.
[6] Error increased by spread of two solutions. Included in LONGACRE 86 global analysis.

$f_2(1810)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$f_2(1810) \to K^+K^-$	$(3.0^{+19.0}_{-2.0}) \times 10^{-3}$
Γ_2	$f_2(1810) \to \pi\pi$	$(21.0^{+2.0}_{-3.0}) \times 10^{-2}$
Γ_3	$f_2(1810) \to \eta\eta$	$(8.0^{+28.0}_{-3.0}) \times 10^{-3}$
Γ_4	$f_2(1810) \to 4\pi^0$	$(6.4^{+23.0}_{-3.4}) \times 10^{-3}$

$f_2(1810)$ BRANCHING RATIOS

$\Gamma(K^+K^-)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.003^{+0.019}_{-0.002}}$	[7] LONGACRE	86	MPS	Compilation
• • • We do not use the following data for averages, fits, limits, etc. • • •				
SEEN	COSTA	80	OMEG	10 $\pi^- p \to K^+K^- n$

$\Gamma(\pi\pi)/\Gamma_{total}$ — Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.21^{+0.02}_{-0.03}}$	[7] LONGACRE	86	MPS	Compilation
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.44 ± 0.03	[8] CASON	82	STRC	8 $\pi^+ p \to p\pi^+ 2\pi^0$

$\Gamma(\eta\eta)/\Gamma_{total}$ — Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.008^{+0.028}_{-0.003}}$	[7] LONGACRE	86	MPS	Compilation

$\Gamma(\pi\pi)/\Gamma(4\pi^0)$ — Γ_2/Γ_4

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.75	ALDE	87	GAM4	100 $\pi^- p \to 4\pi^0 n$

$\Gamma(4\pi^0)/\Gamma(\eta\eta)$ — Γ_4/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
0.8 ± 0.3	ALDE	87	GAM4	100 $\pi^- p \to 4\pi^0 n$

[7] From a partial-wave analysis of data using a K matrix formalism with 5 poles. Includes compilation of several other experiments.
[8] Included in LONGACRE 86 global analysis.

$f_2(1810)$ REFERENCES

ALDE 87 PL B198 286 +Binon, Bricman+ (LANL, BRUX, SERP, LAPP)
ALDE 87C ZPHY C36 603 +Binon, Brickman+ (LANL, BELG, SERP, LAPP)
ALDE 86D NP B269 485 +Binon, Bricman+ (BELG, LAPP, SERP, CERN)
LONGACRE 86 PL B177 223 +Etkin+ (BNL, BRAN, CUNY, DUKE, NDAM)
CASON 82 PRL 48 1316 +Biswas, Baumbaugh, Bishop+ (NDAM, ANL)
COSTA 80 NP B175 402 Costa De Beauregard+ (BARI, BONN, CERN+)

——— OTHER RELATED PAPERS ———

CASON 83 PR D28 1586 +Cannata, Baumbaugh, Bishop+ (NDAM, ANL)
ETKIN 82B PR D25 1786 +Foley, Lai+ (BNL, CUNY, TUFT, VAND)

$X(1850)$ was $\phi_J(1850)$

$I^G(J^{PC}) = 0^?(?^{??})$

OMITTED FROM SUMMARY TABLE

Seen in the $K\bar{K}$ and $K\bar{K}\pi$ mass distributions

$X(1850)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1854 ± 9	**OUR AVERAGE**				
1870 0 $^{+30\ 0}_{-20\ 0}$	430	ARMSTRONG	82	OMEG	18 5 $K^-p \to K^-K^+\Lambda$
1850 0 ± 10 0	123	ALHARRAN	81B	HBC	8 25 $K^-p \to K\bar{K}\Lambda$

$X(1850)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
110 $^{+46}_{-33}$	**OUR AVERAGE**	Error includes scale factor of 1 3			
160 0 $^{+90\ 0}_{-50\ 0}$	430	ARMSTRONG	82	OMEG	18 5 $K^-p \to K^-K^+\Lambda$
80 0 $^{+40\ 0}_{-30\ 0}$	123	ALHARRAN	81B	HBC	8 25 $K^-p \to K\bar{K}\Lambda$

$X(1850)$ DECAY MODES

Γ_1 $X(1850) \to K\bar{K}$

Γ_2 $X(1850) \to K\bar{K}^*(892)$ + c c

$X(1850)$ BRANCHING RATIOS

$\Gamma(K\bar{K}^*(892)$ + c c $)/\Gamma(K\bar{K})$ Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0.8 ± 0 4	ALHARRAN	81B	OMEG	8 25 $K^-p \to K\bar{K}\Lambda$

$X(1850)$ REFERENCES

ARMSTRONG	82	PL 110B 77	+Baubillier+	(BARI BIRM CERN MILA LPNP+) JP
ALHARRAN	81B	PL 101B 357	+Amirzadeh+	(BIRM CERN GLAS MICH LPNP)

OTHER RELATED PAPERS

CORDIER	82B	PL 110B 335	+Bisello B-zol Buon Delcourt Fayard+	(LALO)
ASTON	80B	PL 92B 219		(BONN CERN EPOL GLAS LANC MCHS+)

$X(1935)$ was $S(1935)$

$I^G(J^{PC}) = ?^?(?^{??})$

OMITTED FROM SUMMARY TABLE

Early results on a narrow peak observed in $\bar{p}p$ interactions (CARROLL 74 CHALOUPKA 76, BRUCKNER 77 SAKAMOTO 79 HAMILTON 80B) have now been disclaimed by a series of high-statistics high-resolution experiments (CLOUGH 84 ARMSTRONG 86, FICKINGER 86, BRUCKNER 87, BUGG 87) We therefore close the $X(1935)$ entry and list the relevant information under $N\bar{N}(1100-3600)$

$X(1935)$ REFERENCES

BRUCKNER	87	PL B197 463	+Cujec+	(MPIH LAVL HEID)
BUGG	87	PL B194 563	+Clough Heer+	(LOQM+)
ARMSTRONG	86	PL 166B 245	+Bloodworth Carney+	(ATHU BARI BIRM CERN)
FICKINGER	86	PR 34 3332	+Marino Robinson Ashford Sakitt+	(CASE BNL)
CLOUGH	84	PL 146B 299	+Beard Bugg+	(SURR LOQM ANIK TRST GEVA)
HAMILTON	80B	PRL 44 1182	+Pun Tripp Lazarus+	(LBL BNL MTHO)
SAKAMOTO	79	NP B158 410	+Hashimoto Sai Yamamoto+	(TOKY)
BRUCKNER	77	PL 67B 222	+Granz Ingham Killian+	(MPIH HEID CERN)
CHALOUPKA	76	PL 61B 487	+	(CERN LIVP MONS PADO ROMA TRST)
CARROLL	74	PRL 32 247	+Chiang Kycia Li Mazur Michael+	(BNL)

$f_2(2010)$ was $g_T(2010)$

$I^G(J^{PC}) = 0^+(2^{++})$

See also the mini-review under non $q\bar{q}$ candidates

$f_2(2010)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2011 $^{+62}_{-76}$	[1] ETKIN	88	MPS	22 $\pi^-p \to \phi\phi n$
• • • We do not use the following data for averages fits limits etc • • •				
2050 0 $^{+90\ 0}_{-50\ 0}$	ETKIN	85	MPS	22 $\pi^-p \to 2\phi n$
2120 0 $^{+20\ 0}_{-120\ 0}$	LINDENBAUM	84	RVUE	
2160 0 ± 50 0	ETKIN	82	MPS	16 $\pi^-p \to 2\phi n$

[1] Includes data of ETKIN 85 The percentage of the resonance going into $\phi\phi$ 2^{++} S_2 D_2 and D_0 is 98 $^{+1}_{-3}$ 0 $^{+1}_{-0}$ and 2 $^{+2}_{-1}$ respectively

$f_2(2010)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
202 $^{+67}_{-62}$	[2] ETKIN	88	MPS	22 $\pi^-p \to \phi\phi n$
• • • We do not use the following data for averages fits limits etc • • •				
200 0 $^{+160\ 0}_{-50\ 0}$	ETKIN	85	MPS	22 $\pi^-p \to 2\phi n$
300 0 $^{+150\ 0}_{-50\ 0}$	LINDENBAUM	84	RVUE	
310 0 ± 70 0	ETKIN	82	MPS	16 $\pi^-p \to 2\phi n$

[2] Includes data of ETKIN 85

$f_2(2010)$ DECAY MODES

Γ_1 $f_2(2010) \to \phi\phi$

$f_2(2010)$ REFERENCES

ETKIN	88	PL B201 568	+Foley Lindenbaum+	(BNL CUNY)
ETKIN	85	PL 165B 217	+Foley Longacre Lindenbaum+	(BNL CUNY)
LINDENBAUM	84	CNPP 13 285		(CUNY)
ETKIN	82	PRL 49 1620	+Foley Longacre Lindenbaum+	(BNL CUNY)
Also	83	Brighton Conf 351	Lindenbaum	(BNL CUNY)

OTHER RELATED PAPERS

GREEN	86	PRL 56 1639	+Lai+	(FNAL ARIZ FSU NDAM TUFT VAND+)
BOOTH	84	NP B242 51	+Ballance Carroll Donald+	(LIVP GLAS CERN)

$a_4(2040)$

$I^G(J^{PC}) = 1^-(4^{++})$

OMITTED FROM SUMMARY TABLE

Seen in partial-wave analysis of the $K\bar{K}$ and $\pi^+\pi^-\pi^0$ systems Needs confirmation

$a_4(2040)$ MASS

VALUE (MeV)		DOCUMENT ID		TECN	CHG	COMMENT
2037 ± 26	**OUR AVERAGE**					
2040 0 ± 30 0		[1] CLELAND	82B	SPEC	±	50 $\pi p \to K^0_S K^{\pm} p$
2030 0 ± 50 0		[2] CORDEN	78C	OMEG	0	15 $\pi^-p \to 3\pi n$
• • • We do not use the following data for averages, fits limits etc • • •						
1903 0 ± 10 0		[3] BALDI	78	SPEC	−	10 $\pi^-p \to pK^0_S K^-$

[1] From an amplitude analysis

[2] $J^P = 4^+$ is favored though $J^P = 2^+$ cannot be excluded

[3] From a fit to the Y^0_8 moment Limited by phase space

$a_4(2040)$ WIDTH

VALUE (MeV)		DOCUMENT ID		TECN	CHG	COMMENT
427 ± 120	**OUR AVERAGE**					
380 0 ± 150.0		[4] CLELAND	82B	SPEC	±	50 $\pi p \rightarrow K_S^0 K^{\pm} p$
510.0 ± 200 0		[5] CORDEN	78C	OMEG	0	15 $\pi^- p \rightarrow 3\pi n$
• • • We do not use the following data for averages fits limits, etc • • •						
166.0 ± 43 0		[6] BALDI	78	SPEC	−	10 $\pi^- p \rightarrow p K_S^0 K^-$

[4] From an amplitude analysis
[5] $J^P = 4^+$ is favored though $J^P = 2^+$ cannot be excluded
[6] From a fit to the Y_8^0 moment Limited by phase space

$a_4(2040)$ DECAY MODES

Γ_1 $a_4(2040) \rightarrow K\overline{K}$
Γ_2 $a_4(2040) \rightarrow \pi^+ \pi^- \pi^0$

$a_4(2040)$ BRANCHING RATIOS

$\Gamma(K\overline{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
SEEN	BALDI	78	SPEC	±	10 $\pi^- p \rightarrow K_S^0 K^- p$

$\Gamma(\pi^+ \pi^- \pi^0)/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
SEEN	CORDEN	78C	OMEG	0	15 $\pi^- p \rightarrow 3\pi n$

$a_4(2040)$ REFERENCES

CLELAND 82B NP B208 228 +Dellosse Dorsaz Gloor (DURH GEVA LAUS PITT)
BALDI 78 PL 74B 413 +Bohringer Dorsaz Hungerbuhler+ (GEVA) JP
CORDEN 78C NP B136 77 +Dowell Garvey+ (BIRM RHEL TELA LOWC) JP

— — OTHER RELATED PAPERS —

DELFOSSE 81 NP B183 349 +Gulsan Martin Muhlemann Weill+(GEVA LAUS)

$a_3(2050)$ was $A(2050)$

$I^G(J^{PC}) = 1^-(3^{++})$

OMITTED FROM SUMMARY TABLE

Formerly called A_4 or π Needs confirmation

$a_3(2050)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
2080. ± 40.	208	KALELKAR	75	HBC	+	15 $\pi^+ p \rightarrow p \pi^+ \rho_3$
• • • We do not use the following data for averages fits limits etc • • •						
~2100		ANTIPOV	77	CIBS	−	25 $\pi^- p \rightarrow p \pi^- \rho_3$
2214 ± 15		BALTAY	77	HBC	0	15 $\pi^- p \rightarrow \Delta^{++} 3\pi$

$a_3(2050)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
340. ± 80.	208	KALELKAR	75	HBC	+	15 $\pi^+ p \rightarrow p \pi^+ \rho_3$
• • • We do not use the following data for averages fits limits etc • • •						
~500		ANTIPOV	77	CIBS	−	25 $\pi^- p \rightarrow p \pi^- \rho_3$
355 ± 21		BALTAY	77	HBC	0	15 $\pi^- p \rightarrow \Delta^{++} 3\pi$

$a_3(2050)$ DECAY MODES

Γ_1 $a_3(2050) \rightarrow 3\pi$
Γ_2 $a_3(2050) \rightarrow \rho_3(1690)\pi$

$a_3(2050)$ BRANCHING RATIOS

$\Gamma(\rho_3(1690)\pi)/\Gamma(3\pi)$ Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
DOMINANT	KALELKAR	75	HBC	+	15 $\pi^+ p \rightarrow p 3\pi$

$a_3(2050)$ REFERENCES

ANTIPOV 77 NP B119 45 +Busnello Damgaard Kienzle+ (SERP GEVA)
BALTAY 77 PRL 39 591 +Cautis Kalelkar (COLU) JP
KALELKAR 75 Nevis 207 Thesis (COLU)

— — OTHER RELATED PAPERS —

HARRIS 81 ZPHY C9 275 +Dunn Lubatti Moriyasu Podolsky+ (SEAT JCB)
BALTAY 78 PR D17 52 +Cautis Cohen Csorna Kalelkar+ (COLU BING)
CAUTIS 77 Nevis 221 Thesis (COLU) JP
DEUTSCH 75 NP B99 397 Deutschmann+ (ABBCCHW Collab)
OREN 74 NP B71 189 +Cooper Fields Rhines Allison+ (ANL OXF)
BASTIEN 73 Uppsala Conf 73 +Dunn Harris Lubatti Bingham+ (SEAT UCB)
CLAYTON 72 NP B47 81 +Mason Muirhead Rigopoulos+ (LIVP PATR)
HARRISON 72 PRL 28 775 +Heyda Johnson Kim Law Mueller+ (HARV)
SALZBERG 72 NP B41 397 +Harrison Heyda Johnson Kim Law+ (HARV)
BEMPORAD 71 NP B33 397 +Beusch Melissinos+ (CERN ETH LOIC MILA)
HUSON 68 PL 28B 208 +Lubatti Six Veillet+ (ORSA MILA UCLA)
DANYSZ 67B NC 51A 801 +French Simak (CERN)

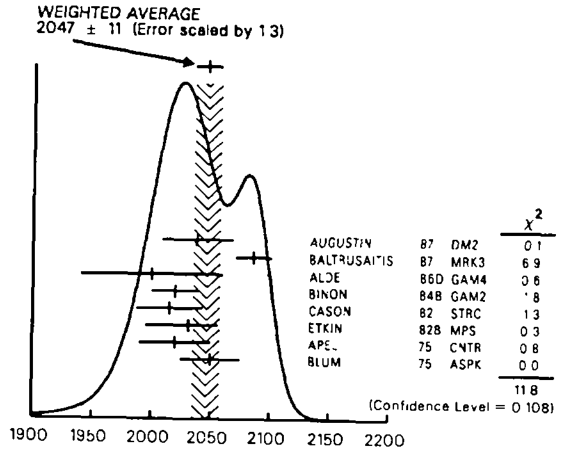
$f_4(2050)$ was $h(2030)$

$I^G(J^{PC}) = 0^+(4^{++})$

$f_4(2050)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
2047 ± 11	**OUR AVERAGE**	Error includes scale factor of 1 3 See the ideogram below			
2038 ± 30		AUGUSTIN	87	DM2	$J/\psi \rightarrow \gamma \pi^+ \pi^-$
2086 ± 15		BALTRUSAITIS	87	MRK3	$J/\psi \rightarrow \gamma \pi^+ \pi^-$
2000 0 ± 60 0		ALDE	86D	GAM4	100 $\pi^- p \rightarrow n 2\eta$
2020 0 ± 20 0	40k	[1] BINON	84B	GAM2	38 $\pi^- p \rightarrow n 2\pi^0$
2015 0 ± 28 0		[1] CASON	82	STRC	8 $\pi^+ p \rightarrow p \pi^+ 2\pi^0$
2031 0 $^{+25}_{-36}$		ETKIN	82B	MPS	23 $\pi^- p \rightarrow n 2K_S^0$
2020 ± 30	700	APEL	75	CNTR	40 $\pi^- p \rightarrow n 2\pi^0$
2050 ± 25		BLUM	75	ASPK	18 4 $\pi^- p \rightarrow n K^+ K^-$
• • • We do not use the following data for averages fits limits etc • • •					
1978 0 ± 5 0		[2] ALPER	80	CNTR	62 $\pi^- p \rightarrow K^+ K^- n$
2040 0 ± 10 0		[2] ROZANSKA	80	SPRK	18 $\pi^- p \rightarrow p \bar{p} n$
1935 0 ± 13 0		[2] CORDEN	79	OMEG	12–15 $\pi^- p \rightarrow n 2\pi$
1988 0 ± 7 0		EVANGELISTA	79B	OMEG	10 $\pi^- p \rightarrow K^+ K^- n$
1922 0 ± 14 0		[3] ANTIPOV	77	CIBS	25 $\pi^- p \rightarrow p 3\pi$

[1] From amplitude analysis of reaction $\pi^+ \pi^- \rightarrow 2\pi^0$
[2] $I(J^P) = 0(4^+)$ from amplitude analysis assuming one pion exchange
[3] Width errors enlarged by us to 4Γ $N^{1/2}$ see the note with the $K^*(892)$ mass



$f_4(2050)$ mass (MeV)

$f_4(2050)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
204 ± 13	**OUR AVERAGE**	Error includes scale factor of 1.1			
304 ± 60		AUGUSTIN	87	DM2	$J/\psi \to \gamma\pi^+\pi^-$
210 ± 63		BALTRUSAITIS	87	MRK3	$J/\psi \to \gamma\pi^+\pi^-$
400.0 ± 100.0		ALDE	86D	GAM4	100 $\pi^- p \to n2\eta$
240.0 ± 40.0	40k	[4] BINON	84B	GAM2	38 $\pi^- p \to n2\pi^0$
190.0 ± 14.0		DENNEY	83	LASS	10 $\pi^+ n / \pi^+ p$
$186.0^{+103.0}_{-58.0}$		[4] CASON	82	STRC	8 $\pi^+ p \to p\pi^+ 2\pi^0$
305.0^{+36}_{-119}		ETKIN	82B	MPS	23 $\pi^- p \to n2K^0_S$
180. ± 60	700	APEL	75	CNTR	40 $\pi^- p \to n2\pi^0$
225^{+120}_{-70}		BLUM	75	ASPK	18.4 $\pi^- p \to nK^+K^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
243.0 ± 16.0		[5] ALPER	80	CNTR	62 $\pi^- p \to K^+K^- n$
140.0 ± 15.0		[5] ROZANSKA	80	SPRK	18 $\pi^- p \to p\bar{p}n$
263.0 ± 57.0		[5] CORDEN	79	OMEG	12–15 $\pi^- p \to n2\pi$
100.0 ± 28.0		EVANGELISTA	79B	OMEG	10 $\pi^- p \to K^+K^- n$
107.0 ± 56.0		[6] ANTIPOV	77	CIBS	25 $\pi^- p \to p3\pi$

[4] From amplitude analysis of reaction $\pi^+\pi^- \to 2\pi^0$.
[5] $I(J^P) = 0(4^+)$ from amplitude analysis assuming one-pion exchange.
[6] Width errors enlarged by us to $4\Gamma/N^{1/2}$; see the note with the $K^*(892)$ mass.

$f_4(2050)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$f_4(2050) \to \pi\pi$	$(17.0 \pm 1.5) \times 10^{-2}$
Γ_2	$f_4(2050) \to K\bar{K}$	$(6.8^{+3.4}_{-1.8}) \times 10^{-3}$
Γ_3	$f_4(2050) \to \eta\eta$	$(2.1 \pm 0.8) \times 10^{-3}$
Γ_4	$f_4(2050) \to \gamma\gamma$	
Γ_5	$f_4(2050) \to 4\pi^0$	$< 1.2 \times 10^{-2}$

$f_4(2050)$ $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(\text{total})$

$\Gamma(K\bar{K}) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ $\Gamma_2\Gamma_4/\Gamma$

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.29	95	ALTHOFF	85B	TASS	$\gamma\gamma \to K\bar{K}\pi$

$f_4(2050)$ BRANCHING RATIOS

$\Gamma(\pi\pi)/\Gamma_{\text{total}}$ Γ_1/Γ

VALUE		DOCUMENT ID		TECN	COMMENT
0.170 ± 0.015	**OUR AVERAGE**				
0.18 ± 0.03		[7] BINON	83C	GAM2	38 $\pi^- p \to n4\gamma$
0.16 ± 0.03		[7] CASON	82	STRC	8 $\pi^+ p \to p\pi^+ 2\pi^0$
0.17 ± 0.02		[7] CORDEN	79	OMEG	12–15 $\pi^- p \to n2\pi$

[7] Assuming one pion exchange.

$\Gamma(K\bar{K})/\Gamma(\pi\pi)$ Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
$0.04^{+0.02}_{-0.01}$	ETKIN	82B	MPS	23 $\pi^- p \to n2K^0_S$

$\Gamma(\eta\eta)/\Gamma_{\text{total}}$ Γ_3/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
2.1 ± 0.8	ALDE	86D	GAM4	100 $\pi^- p \to n4\gamma$

$\Gamma(4\pi^0)/\Gamma_{\text{total}}$ Γ_5/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.012	ALDE	87	GAM4	100 $\pi^- p \to 4\pi^0 n$

$f_4(2050)$ REFERENCES

ALDE	87	PL B198 286	+Binon, Bricman+	(LANL, BRUX, SERP, LAPP)
AUGUSTIN	87	ZPHY C36 369	+Cosme+	(LALO, CLER, FRAS, PADO)
BALTRUSAITIS	87	PR D35 2077	+Coffman, Dubois+	(MARK III Collab.)
ALDE	86D	NP B269 485	+Binon, Bricman+	(BELG, LAPP, SERP, CERN)
ALTHOFF	85B	ZPHY C29 189	+Braunschweig, Kirschfink+	(TASSO Collab.)
BINON	84B	LNC 39 41	+Donskov, Dutell, Gouanere+	(SERP, BELG, LAPP)
BINON	83C	SJNP 38 723	+Gouanere, Donskov, Duteil+	(SERP, BRUX+)
		Translated from YAF 38 1199		
DENNEY	83	PR D28 2726	+Cranley, Firestone, Chapman+	(IOWA, MICH)
CASON	82	PRL 48 1316	+Biswas, Baumbaugh, Bishop+	(NDAM, ANL)
ETKIN	82B	PR D25 1786	+Foley, Lai+	(BNL, CUNY, TUFT, VAND)
ALPER	80	PL 94B 422	+Becker+	(AMST, CERN, CRAC, MPIM, OXF+)
ROZANSKA	80	NP B162 505	+Blum, Dietl, Grayer, Lorenz+	(MPIM, CERN)
CORDEN	79	NP B157 250	+Dowell, Garvey+	(BIRM, RHEL, TELA, LOWC) JP
EVANGELISTA	79B	NP B154 381	+	(BARI, BONN, CERN, DARE, GLAS, LIVP+)
ANTIPOV	77	NP B119 45	+Busnello, Damgaard, Kienzle+	(SERP, GEVA)
APEL	75	PL 57B 398	+Augenstein+	(KARL, PISA, SERP, WIEN, CERN) JP
BLUM	75	PL 57B 403	+Chabaud, Dietl, Garelick, Grayer+	(CERN, MPIM) JP

— — OTHER RELATED PAPERS — —

CASON	83	PR D28 1586	+Cannata, Baumbaugh, Bishop+	(NDAM, ANL)
GOTTESMAN	80	PR D22 1503	+Jacobs+	(SYRA, BRAN, BNL, CINC)
WAGNER	74	London Conf. 2 27		(MPIM)

$\pi_2(2100)$ was $A(2100)$

$I^G(J^{PC}) = 1^-(2^{-+})$

OMITTED FROM SUMMARY TABLE

Seen in the $\rho\pi$, $f_0(1400)\pi$, and $f_2(1270)\pi$ $J^P = 2^-$ waves of the diffractively produced 3π system. Needs confirmation.

$\pi_2(2100)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2100. ± 150.	[1] DAUM	81B	CNTR	63.94 $\pi^- p \to 3\pi X$

[1] From a two resonance fit to four 2^-0^+ waves.

$\pi_2(2100)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
651. ± 50.	[2] DAUM	81B	CNTR	63.94 $\pi^- p \to 3\pi X$

[2] From a two resonance fit to four 2^-0^+ waves.

$\pi_2(2100)$ DECAY MODES

	Mode
Γ_1	$\pi_2(2100) \to 3\pi$
Γ_2	$\pi_2(2100) \to \rho\pi$
Γ_3	$\pi_2(2100) \to f_2(1270)\pi$
Γ_4	$\pi_2(2100) \to f_0(1400)\pi$

$\pi_2(2100)$ BRANCHING RATIOS

$\Gamma(\rho\pi)/\Gamma(3\pi)$ Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0.19 ± 0.05	[3] DAUM	81B	CNTR	63.94 $\pi^- p$

$\Gamma(f_2(1270)\pi)/\Gamma(3\pi)$ Γ_3/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0.36 ± 0.09	[3] DAUM	81B	CNTR	63.94 $\pi^- p$

$\Gamma(f_0(1400)\pi)/\Gamma(3\pi)$ Γ_4/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0.45 ± 0.07	[3] DAUM	81B	CNTR	63.94 $\pi^- p$

D-wave/S-wave RATIO FOR $\pi_2(2100) \to f_2(1270)\pi$

VALUE	DOCUMENT ID		TECN	COMMENT
0.39 ± 0.23	[3] DAUM	81B	CNTR	63.94 $\pi^- p$

[3] From a two-resonance fit to four 2^-0^+ waves.

$\pi_2(2100)$ REFERENCES

DAUM 81B NP B182 269 +Hertzberger+ (AMST, CERN, CRAC, MPIM, OXF+)

$f_2(2150)$

$I^G(J^{PC}) = 0^+(2^{++})$

OMITTED FROM SUMMARY TABLE

This entry was previously called T_0. Contains results only from formation experiments. For production experiments see the $\overline{N}N(1100-3600)$ entry. See also $\rho(2150)$, $\rho_3(2250)$, $f_4(2300)$, $\rho_5(2350)$.

$f_2(2150)$ MASS

$\overline{p}p \to \pi\pi$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
~2170.0	[1] MARTIN	80B	RVUE	
~2150.0	[1] MARTIN	80C	RVUE	
~2150.0	[2] DULUDE	78B	OSPK	1–2 $\overline{p}p \to \pi^0\pi^0$

[1] $I(J^P) = 0(2^+)$ from simultaneous analysis of $p\overline{p} \to \pi^-\pi^+$ and $\pi^0\pi^0$.
[2] $I^G(J^P) = 0^+(2^+)$ from partial wave amplitude analysis.

S-CHANNEL $\overline{p}p$ or $\overline{N}N$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~2190.0	[3] CUTTS	78B	CNTR		0.97–3 $\overline{p}p \to \overline{N}N$
2155.0 ± 15.0	[3,4] COUPLAND	77	CNTR	0	0.7–2.4 $\overline{p}p \to \overline{p}p$
2193 ± 2	[3,5] ALSPECTOR	73	CNTR		$\overline{p}p$ S channel

[3] Isospins 0 and 1 not separated.
[4] From a fit to the total elastic cross section.
[5] Referred to as T or T region by ALSPECTOR 73.

$f_2(2150)$ WIDTH

$\overline{p}p \to \pi\pi$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
~250.0	[6] MARTIN	80B	RVUE	
~250.0	[6] MARTIN	80C	RVUE	
~250.0	[7] DULUDE	78B	OSPK	1–2 $\overline{p}p \to \pi^0\pi^0$

[6] $I(J^P) = 0(2^+)$ from simultaneous analysis of $p\overline{p} \to \pi^-\pi^+$ and $\pi^0\pi^0$.
[7] $I^G(J^P) = 0^+(2^+)$ from partial-wave amplitude analysis.

S-CHANNEL $\overline{p}p$ or $\overline{N}N$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
135.0 ± 75.0	[8,9] COUPLAND	77	CNTR	0	0.7–2.4 $\overline{p}p \to \overline{p}p$
98 ± 8	[9] ALSPECTOR	73	CNTR		$\overline{p}p$ S channel

[8] From a fit to the total elastic cross section.
[9] Isospins 0 and 1 not separated.

$f_2(2150)$ DECAY MODES

Γ_1 $f_2(2150) \to \pi\pi$

$f_2(2150)$ REFERENCES

MARTIN 80B NP B176 355 +Morgan (LOUC RHEL) JP
MARTIN 80C NP B169 216 +Pennington (DURH) JP
CUTTS 78B PR D17 16 +Good Grannis Green Lee+ (STON WISC)
DULUDE 78B PL 79B 335 +Lanou Massimo Peaslee+ (BROW MIT BARI) JP
COUPLAND 77 PL 71B 460 +Eisenhandler Gibson Astbury+ (LOQM RHEL)
ALSPECTOR 73 PRL 30 511 +Cohen Cvijanovich+ (RUTG UPNJ)

OTHER RELATED PAPERS

BOWCOCK 80 LNC 28 21 +Hodgson (BIRM)
MARTIN 79B PL 86B 93 +Pennington (DURH)
DULUDE 78 PL 79B 329 +Lanou Massimo Peaslee+ (BROW MIT BARI) JP
GAY 76 NC 31A 593 +Jeanneret Bogdanski+ (NEUC LAUS LIVP LPNP)
BACON 73 PR D7 577 +Butterworth+ (RHEL LIVP)
DONALD 73 NP B61 333 +Edwards Gibbins Briand Duboc+ (LIVP LPNP)
NICHOLSON 73 PR D7 2572 +Delorme Carroll+ (CIT ROCH BNL)
DONALD 72 PL 40B 586 +Galletly Edwards DeBilly+ (LIVP LPNP)
FIELDS 71 PRL 27 1749 +Cooper Rhines Allison (ANL OXF)
YOH 71 PRL 26 922 +Barish Caroll Lobkowicz+ (CIT BNL ROCH)

$\rho(2150)$

$I^G(J^{PC}) = 1^+(1^{--})$

OMITTED FROM SUMMARY TABLE

This entry was previously called $T_1(2190)$. Contains results only from formation experiments. For production experiments see the $\overline{N}N(1100-3600)$ entry. See also $f_2(2150)$, $\rho_3(2250)$, $f_4(2300)$, $\rho_5(2350)$.

Our latest mini-review on this particle can be found in the 1984 edition.

$\rho(2150)$ MASS

$\overline{p}p \to \pi\pi$

VALUE (MeV)	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
~2170.0	[1] MARTIN	80B	RVUE
~2100.0	[1] MARTIN	80C	RVUE

S-CHANNEL $\overline{N}N$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~2190.0	[2] CUTTS	78B	CNTR		0.97–3 $\overline{p}p \to NN$
2155.0 ± 15.0	[2,3] COUPLAND	77	CNTR	0	0.7–2.4 $pp \to \overline{p}p$
2193 ± 2	[2,4] ALSPECTOR	73	CNTR		$\overline{p}p$ S channel
2190 ± 10	[5] ABRAMS	70	CNTR		S channel $\overline{p}N$

[1] $I(J^P) = 1(1^-)$ from simultaneous analysis of $p\overline{p} \to \pi^-\pi^+$ and $\pi^0\pi^0$.
[2] Isospins 0 and 1 not separated.
[3] From a fit to the total elastic cross section.
[4] Referred to as T or T region by ALSPECTOR 73.
[5] Seen as bump in $I = 1$ state. See also COOPER 68. PEASLEE 75 confirm $\overline{p}p$ results of ABRAMS 70, no narrow structure.

$\rho(2150)$ WIDTH

$\overline{p}p \to \pi\pi$

VALUE (MeV)	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
~250.0	[6] MARTIN	80B	RVUE
~200.0	[6] MARTIN	80C	RVUE

S-CHANNEL $\overline{N}N$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
135.0 ± 75.0	[7,8] COUPLAND	77	CNTR	0	0.7–2.4 $pp \to \overline{p}p$
98 ± 8	[8] ALSPECTOR	73	CNTR		$\overline{p}p$ S channel
~ 85	[9] ABRAMS	70	CNTR		S channel $\overline{p}N$

[6] $I(J^P) = 1(1^-)$ from simultaneous analysis of $p\overline{p} \to \pi^-\pi^+$ and $\pi^0\pi^0$.
[7] From a fit to the total elastic cross section.
[8] Isospins 0 and 1 not separated.
[9] Seen as bump in $I = 1$ state. See also COOPER 68. PEASLEE 75 confirm $\overline{p}p$ results of ABRAMS 70, no narrow structure.

$\rho(2150)$ REFERENCES

MARTIN 80B NP B176 355 +Morgan (LOUC RHEL) JP
MARTIN 80C NP B169 216 +Pennington (DURH) JP
CUTTS 78B PR D17 16 +Good Grannis Green Lee+ (STON WISC)
COUPLAND 77 PL 71B 460 +Eisenhandler Gibson Astbury+ (LOQM RHEL)
PEASLEE 75 PL 57B 189 +Demarzo Guerriero+ (CANB BARI BROW MIT)
ALSPECTOR 73 PRL 30 511 +Cohen Cvijanovich+ (RUTG UPNJ)
ABRAMS 70 PR D1 1917 +Cool Giacomelli Kycia Leontic Li+ (BNL)
COOPER 68 PRL 20 1059 +Hyman Manner Musgrove+ (ANL)

OTHER RELATED PAPERS

MARTIN 79B PL 86B 93 +Pennington (DURH)
CARTER 78 NP B132 176 (LOQM) JP
CARTER 78B NP B141 467 (LOQM)
CARTER 77 PL 67B 117 +Coupland Eisenhandler Astbury+ (LOQM RHEL) JP
CARTER 77B PL 67B 122 (LOQM) JP
CARTER 77C NP B127 202 +Coupland Atkinson+ (LOQM DARE RHEL)
JONES 77 NP B119 476 +Piano (RUTG)
MONTANET 77 Boston Conf. 260 (CERN)
GAY 76 NC 31A 593 +Jeanneret Bogdanski+ (NEUC LAUS LIVP LPNP)
ZEMANY 76 NP B103 537 +MingMa Mountz Smith (MSU)
DONNACHIE 75 NC 26A 317 +Thomas (MCHS)
EISENHAND 75 NP B96 109 Eisenhandler Gibson+ (LOQM LIVP DARE RHEL)
HANDLER 75 NP B101 35 +Jacques Jones Pandoulas+ (RUTG STEV ALBA)
HUESMAN 75 NC 25A 91 +Garnjost Ross+ (LBL PADO PISA TORI)
BERTANZA 74 NC 23A 209 +Biai Casali Lariccia+ (PISA PADO TORI)

HYAMS	74	NP B73 202	+Jones Weilhammer Blum+	(CERN MPIM)
BACON	73	PR D7 577	+Butterworth+	(RHEL LIVP)
BETTINI	73	NC 15A 563	+Garnjost Bigi+	(PADO LBL PISA TORI)
DONALD	73	NP B6* 333	+Edwards Gibbins Briand Duboc+	(LIVP LPNP)
NICHOLSON	73	PR D7 2572	+Delorme Carroll+	(CIT ROCH BNL)
ALEXANDER	72	NP B45 29	+Bar Nir Benary Dagan+	(TELA)
DONALD	72	PL 40B 586	+Gallelly Edwards DeBilly+	(LIVP LPNP)
BACON	71	NP B32 66	+Butterworth Miller Phelan+	(RHEL LIVP)
FIELDS	71	PRL 27 1749	+Cooper Rhines Allison	(ANL OXF)
YOH	71	PRL 26 922	+Barish Caroll Lobkowicz+	(CIT BNL ROCH)
BRICMAN	69	PL 29B 451	+Ferro Luzzi Bizard+	(CERN CAEN SACL)
ABRAMS	67C	PRL 18 1209	+Cool Giocomelli Kycio Leontic Li+	(BNL)

X(2220) was ξ(2220)

$I^G(J^{PC}) = 0^?(\mathrm{EVEN}^{++})$

OMITTED FROM SUMMARY TABLE

This state has been seen at SPEAR in the $K\bar{K}$ systems (K^+K^- and $K^0_S K^0_S$) produced in the radiative decay of $J/\psi(1S)$. Seen in $\eta\eta'$ (ALDE 86B) and in $K^0_S K^0_S$ (ASTON 88D). Needs confirmation. Not seen in Υ radiative decays nor in B inclusive decay (BEHRENDS 84). Not seen in $\bar{p}p \to K^+K^-$ formation experiment (SCULLI 87).

X(2220) MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
2227 ± 6 OUR AVERAGE					
2220 ± 10	41	ALDE	86B	GAM4	38–100 $\pi p \to n\eta\eta'$
2230 ± 6 ± 14	93	BALTRUSAITIS	86D	MRK3	$e^+e^- \to K^+K^-\gamma$
2232 ± 7 ± 7	23	BALTRUSAITIS	86D	MRK3	$e^+e^- \to K^0_S K^0_S\gamma$

X(2220) WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
21^{+18}_{-14} OUR AVERAGE					
$26^{+20}_{-16} \pm 17$	93	BALTRUSAITIS	86D	MRK3	$e^+e^- \to K^+K^-\gamma$
$18^{+23}_{-15} \pm 10$	23	BALTRUSAITIS	86D	MRK3	$e^+e^- \to K^0_S K^0_S\gamma$

X(2220) DECAY MODES

Γ_1 $X(2220) \to K\bar{K}$
Γ_2 $X(2220) \to \gamma\gamma$
Γ_3 $X(2220) \to \eta\eta'(958)$

X(2220) $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(\text{total})$

$\Gamma(K\bar{K}) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ $\Gamma_1\Gamma_2/\Gamma$

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<1.0	95	[1] ALTHOFF	85B	TASS	$\gamma\gamma \to K\bar{K}\pi$

[1] True for $J^P = 0^+$ and $J^P = 2^+$

X(2220) REFERENCES

ASTON	88D	NP to be pub	+Awaji Bienz+	(SLAC NAGO CINC TOKY)
SCULLI	87	PRL 58 1715	+Christenson Kreiter Nemethy Yamin	(NYU BNL)
ALDE	86B	PL B177 120	+Binon Bricman+	(SERP BELG LANL LAPP)
BALTRUSAITIS	86D	PRL 56 107		(CIT UCSC ILL SLAC WASH)
ALTHOFF	85B	ZPHY C29 189	+Braunschweig Kirschfink+	(TASSO Collab.)
BEHRENDS	84	PL 137B 277	+	(CLEO Collab.)

OTHER RELATED PAPERS

BARDIN	87	PL B195 292	+Burgun+	(SACL FERR CERN PADO TORI)
JEAN MARIE	85	LAL 85 34		(LALO)
YAOUANC	85	ZPHY C28 309	+Oliver Pene Raynal Ono	(ORSA TOKY)
GODFREY	84	PL 141B 439	+Kokoski Isgur	(TNTO)
SHATZ	84	PL 138B 209		(CIT)
WILLEY	84	PRL 52 585		(PITT)
EINSWEILER	83	Brighton Conf. 348		(MARK III Collab.)
HITLIN	83	Cornell Conf. 746		(CIT)

$\rho_3(2250)$

$I^G(J^{PC}) = 1^+(3^{--})$

OMITTED FROM SUMMARY TABLE

Contains results only from formation experiments. For production experiments see the $N\bar{N}(1100\text{–}3600)$ entry. See also $\rho(2150)$, $f_2(2150)$, $f_4(2300)$, $\rho_5(2350)$.

$\rho_3(2250)$ MASS

$\bar{p}p \to \pi\pi$ or $K\bar{K}$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~2250.0	[1] MARTIN	80B	RVUE		
~2300.0	[1] MARTIN	80C	RVUE		
~2140.0	[2] CARTER	78B	CNTR	0	0.7–2.4 $\bar{p}p \to K^-K^+$
~2150.0	[3] CARTER	77	CNTR	0	0.7–2.4 $\bar{p}p \to \pi\pi$

[1] $I(J^P) = 1(3^-)$ from simultaneous analysis of $p\bar{p} \to \pi^-\pi^+$ and $\pi^0\pi^0$.
[2] $I = 1$. $J^P = 3^-$ from Barrelet-zero analysis.
[3] $I(J^P) = 1(3^-)$ from amplitude analysis.

S-CHANNEL $\bar{N}N$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~2190.0	[4] CUTTS	78B	CNTR		0.97–3 $\bar{p}p \to \bar{N}N$
2155.0 ± 15.0	[4,5] COUPLAND	77	CNTR	0	0.7–2.4 $\bar{p}p \to \bar{p}p$
2193 ± 2.	[4,6] ALSPECTOR	73	CNTR		$\bar{p}p$ S channel
2190. ± 10	[7] ABRAMS	70	CNTR		S channel $\bar{p}N$

[4] Isospins 0 and 1 not separated.
[5] From a fit to the total elastic cross section.
[6] Referred to as T or T region by ALSPECTOR 73.
[7] Seen as bump in $I = 1$ state. See also COOPER 68. PEASLEE 75 confirm $\bar{p}p$ results of ABRAMS 70, no narrow structure.

$\rho_3(2250)$ WIDTH

$\bar{p}p \to \pi\pi$ or $K\bar{K}$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~250.0	[8] MARTIN	80B	RVUE		
~200.0	[8] MARTIN	80C	RVUE		
~150.0	[9] CARTER	78B	CNTR	0	0.7–2.4 $\bar{p}p \to K^-K^+$
~200.0	[10] CARTER	77	CNTR	0	0.7–2.4 $\bar{p}p \to \pi\pi$

[8] $I(J^P) = 1(3^-)$ from simultaneous analysis of $p\bar{p} \to \pi^-\pi^+$ and $\pi^0\pi^0$.
[9] $I = 1$. $J^P = 3^-$ from Barrelet-zero analysis.
[10] $I(J^P) = 1(3^-)$ from amplitude analysis.

S-CHANNEL $\bar{N}N$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
135.0 ± 75.0	[11,12] COUPLAND	77	CNTR	0	0.7–2.4 $\bar{p}p \to \bar{p}p$
98 ± 8	[12] ALSPECTOR	73	CNTR		$\bar{p}p$ S channel
~85	[13] ABRAMS	70	CNTR		S channel $\bar{p}N$

[11] From a fit to the total elastic cross section.
[12] Isospins 0 and 1 not separated.
[13] Seen as bump in $I = 1$ state. See also COOPER 68. PEASLEE 75 confirm $\bar{p}p$ results of ABRAMS 70, no narrow structure.

$\rho_3(2250)$ REFERENCES

MARTIN	80B	NP B176 355	+Morgan	(LOUC RHEL) JP
MARTIN	80C	NP B169 216	+Pennington	(DURH) JP
CARTER	78B	NP B141 467		(LOQM)
CUTTS	78B	PR D17 16	+Good Grannis Green Lee+	(STON WISC)
CARTER	77	PL 67B 117	+Coupland Eisenhandler Astbury+	(LOQM RHEL) JP
COUPLAND	77	PL 71B 460	+Eisenhandler Gibson Astbury+	(LOQM RHEL)
PEASLEE	75	PL 57B 189	+Demarzo Guerriero+	(CANB BARI BROW MIT)
ALSPECTOR	73	PRL 30 511	+Cohen Cvijanovich+	(RUTG UPNJ)
ABRAMS	70	PR D1 1917	+Cool Giacomelli Kycia Leontic Li+	(BNL)
COOPER	68	PRL 20 1059	+Hyman Manner Musgrave+	(ANL)

OTHER RELATED PAPERS

MARTIN	79B	PL 86B 93	+Pennington	(DURH)
CARTER	78	NP B132 176		(LOQM) JP
CARTER	77B	PL 67B 122		(LOQM) JP
CARTER	77C	NP B127 202	+Coupland Atkinson+	(LOQM DARE RHEL)
MONTANET	77	Boston Conf. 260		(CERN)
ZEMANY	76	NP B103 537	+MingMa Mountz Smith	(MSU)
BERTANZA	74	NC 23A 209	+Bial Casali Lariccia+	(PISA PADO TORI)

BETTINI 73 NC 15A 563 +Garnjost Bigi+ (PADO LBL PISA TORI)
DONNACHIE 73 LNC 7 285 +Thomas (MCHS)
NICHOLSON 73 PR D7 2572 +Delorme Carroll+ (CIT ROCH BNL)
FIELDS 71 PRL 27 1749 +Cooper Rhines Allison (ANL OXF)
YOH 71 PRL 26 922 +Barish Caroll Lobkowicz+ (CIT BNL ROCH)
ABRAMS 67C PRL 18 1209 +Cool Giacomelli Kycia Leontic Li+ (BNL)

$f_2(2300)$ was $g_T(2300)$

$I^G(J^{PC}) = 0^+(2^{++})$

See also the mini-review under non-$q\bar{q}$ candidates

$f_2(2300)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2297 ± 28	[1] ETKIN	88	MPS	22 $\pi^- p \to \phi\phi n$
• • • We do not use the following data for averages fits limits etc • • •				
2220 ± 15 ± 20	WISNIEWSKI	87	MRK3	$J/\psi \to 2K^+ 2K^- \gamma$
2206 ± 20 ± 25	WISNIEWSKI	87	MRK3	$J/\psi \to 2K^0 K^+ K^- \gamma$
2231 0 ± 10 0	BOOTH	86	OMEG	85 π^- Be $\to 2\phi$Be
2220 0 $^{+90\ 0}_{-20\ 0}$	LINDENBAUM	84	RVUE	
2320 0 ± 40 0	ETKIN	82	MPS	16 $\pi^- p \to 2\phi n$

[1] Includes data of ETKIN 85 The percentage of the resonance going into $\phi\phi$ 2^{++} S_2 D_2 and D_0 is 6^{+15}_{-5} 25^{+18}_{-14} and 69^{+16}_{-27} respectively

$f_2(2300)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
149 ± 41	[2] ETKIN	88	MPS	22 $\pi^- p \to \phi\phi n$
• • • We do not use the following data for averages, fits limits etc • • •				
114 ± 45 ± 35	WISNIEWSKI	87	MRK3	$J/\psi \to 2K^+ 2K^- \gamma$
150 ± 46 ± 35	WISNIEWSKI	87	MRK3	$J/\psi \to 2K^0 K^+ K^- \gamma$
133 0 ± 50 0	BOOTH	86	OMEG	85 π^- Be $\to 2\phi$Be
200 0 ± 50 0	LINDENBAUM	84	RVUE	
220.0 ± 70 0	ETKIN	82	MPS	16 $\pi^- p \to 2\phi n$

[2] Includes data of ETKIN 85

$f_2(2300)$ DECAY MODES

Γ_1 $f_2(2300) \to \phi\phi$

$f_2(2300)$ REFERENCES

ETKIN 88 PL B201 568 +Foley Lindenbaum+ (BNL CUNY)
WISNIEWSKI 87 CALT 68 1446 (MARK III Collab)
BOOTH 86 NP B273 677 +Carroll Donald Edwards+ (LIVP GLAS CERN)
ETKIN 85 PL 165B 217 +Foley Longacre Lindenbaum+ (BNL CUNY)
LINDENBAUM 84 CNPP 13 285 (CUNY)
ETKIN 82 PRL 49 1620 +Foley Longacre Lindenbaum+ (BNL CUNY)
Also 83 Brighton Conf 351 Lindenbaum (BNL CUNY)

OTHER RELATED PAPERS

GREEN 86 PRL 56 1639 +Lai+ (FNAL ARIZ FSU NDAM TUFT VAND+)
BOOTH 84 NP B242 51 +Ballance Carroll Donald+ (LIVP GLAS CERN)

$f_4(2300)$

$I^G(J^{PC}) = 0^+(4^{++})$

OMITTED FROM SUMMARY TABLE

This entry was previously called $U_0(2350)$ Contains results only from formation experiments For production experiments see the $N\bar{N}(1100\text{-}3600)$ entry See also $\rho(2150)$ $f_2(2150)$, $\rho_3(2250)$ $\rho_5(2350)$

$f_4(2300)$ MASS

$\bar{p}p \to \pi\pi$ or KK

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~2300	[1] MARTIN	80B	RVUE	
~2300	[1] MARTIN	80C	RVUE	
~2340	[2] CARTER	78B	CNTR	0 7-2 4 $pp \to K^- K^+$
~2330	DULUDE	78B	OSPK	1-2 $\bar{p}p \to \pi^0\pi^0$
~2310	[3] CARTER	77	CNTR	0 7-2 4 $\bar{p}p \to \pi\pi$

[1] $I(J^P) = 0(4^+)$ from simultaneous analysis of $p\bar{p} \to \pi^-\pi^+$ and $\pi^0\pi^0$
[2] $I(J^P) = 0(4^+)$ from Barrelet zero analysis
[3] $I(J^P) = 0(4^+)$ from amplitude analysis

S-CHANNEL $\bar{p}p$ or $\bar{N}N$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~2380 0	[4] CUTTS	78B	CNTR	0 97-3 $pp \to \bar{N}N$
2345 ± 15 0	[4,5] COUPLAND	77	CNTR	0 7-2 4 $\bar{p}p \to \bar{p}p$
2359. ± 2	[4,6] ALSPECTOR	73	CNTR	$\bar{p}p$ S channel
2375 ± 10	ABRAMS	70	CNTR	S channel $\bar{N}N$

[4] Isospins 0 and 1 not separated
[5] From a fit to the total elastic cross section
[6] Referred to as U or U region by ALSPECTOR 73

$f_4(2300)$ WIDTH

$\bar{p}p \to \pi\pi$ or $\bar{K}K$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~200	[7] MARTIN	80C	RVUE	
~150	[8] CARTER	78B	CNTR	0 7-2 4 $\bar{p}p \to K^- K^+$
~210	[9] CARTER	77	CNTR	0 7-2 4 $\bar{p}p \to \pi\pi$

[7] $I(J^P) = 0(4^+)$ from simultaneous analysis of $p\bar{p} \to \pi^-\pi^+$ and $\pi^0\pi^0$
[8] $I(J^P) = 0(4^+)$ from Barrelet zero analysis
[9] $I(J^P) = 0(4^+)$ from amplitude analysis

S-CHANNEL $\bar{p}p$ or $\bar{N}N$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
135 0 $^{+150\ 0}_{-65.0}$	[10,11] COUPLAND	77	CNTR	0 7-2 4 $\bar{p}p \to pp$
165 $^{+18}_{-8}$	[11] ALSPECTOR	73	CNTR	pp S channel
~190	ABRAMS	70	CNTR	S channel $\bar{N}N$

[10] From a fit to the total elastic cross section
[11] Isospins 0 and 1 not separated

$f_4(2300)$ REFERENCES

MARTIN 80B NP B176 355 +Morgan (LOUC RHEL) JP
MARTIN 80C NP B169 216 +Pennington (DURH) JP
CARTER 78B NP B141 467 (LOQM)
CUTTS 78B PR D17 16 +Good Grannis Green Lee+ (STON WISC)
DULUDE 78B PL 79B 335 +Lanou Massimo Peaslee+ (BROW MIT BARI) JP
CARTER 77 PL 67B 117 +Coupland Eisenhandler Astbury+ (LOQM RHEL) JP
COUPLAND 77 PL 71B 460 +Eisenhandler Gibson Astbury+ (LOQM RHEL)
ALSPECTOR 73 PRL 30 511 +Cohen Cvijanovich+ (RUTG UPNJ)
ABRAMS 70 PR D1 1917 +Cool Giacomelli Kycia Leontic Li+ (BNL)

OTHER RELATED PAPERS

BOWCOCK 80 LNC 28 21 +Hodgson (BIRM)
MARTIN 79B PL 86B 93 +Pennington (DURH)
CARTER 78 NP B132 176 (LOQM) JP
DULUDE 78 PL 79B 329 +Lanou Massimo Peaslee+ (BROW MIT BARI) JP
CARTER 77B PL 67B 122 (LOQM) JP
CARTER 77C NP B127 202 +Coupland Atkinson+ (LOQM DARE RHEL)
MONTANET 77 Boston Conf 260 (CERN)
DONNACHIE 75 NC 26A 317 +Thomas (MCHS)
EISENHAND 75 NP B96 109 Eisenhandler Gibson+ (LOQM LIVP DARE RHEL)
HYAMS 74 NP B73 202 +Jones Weilhammer Blum+ (CERN MPIM)
MINGMA 74 NP B68 214 +Mountz Zemany Smith (MICH)
DONNACHIE 73 LNC 7 285 +Thomas (MCHS)
EASTMAN 73 NP B51 29 +MingMa Oh Parker Smith Sprafka (MSU)
NICHOLSON 73 PR D7 2572 +Delorme Carroll+ (CIT ROCH BNL)
FIELDS 71 PRL 27 1749 +Cooper Rhines Allison (ANL OXF)
YOH 71 PRL 26 922 +Barish Caroll Lobkowicz+ (CIT BNL ROCH)
BRICMAN 69 PL 29B 451 +Ferro Luzzi Bizard+ (CERN CAEN SACL)

$f_2(2340)$ was $g_T''(2340)$

$I^G(J^{PC}) = 0^+(2^{++})$

See also the mini-review under non-$q\bar{q}$ candidates

$f_2(2340)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2339 ± 55	[1] ETKIN	88	MPS	22 $\pi^- p \to \phi\phi n$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2392 0 ± 10.0	BOOTH	86	OMEG	85 π^-Be $\to 2\phi$Be
2360 0 ± 20.0	LINDENBAUM	84	RVUE	

[1] Includes data of ETKIN 85. The percentage of the resonance going into $\phi\phi$ 2^{++} S_2, D_2, and D_0 is 37 ± 19, 4^{+12}_{-4}, and 59^{+21}_{-19} respectively

$f_2(2340)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
319^{+81}_{-69}	[2] ETKIN	88	MPS	22 $\pi^- p \to \phi\phi n$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
198.0 ± 50 0	BOOTH	86	OMEG	85 π^-Be $\to 2\phi$Be
$150\ 0^{+150\ 0}_{-50.0}$	LINDENBAUM	84	RVUE	

[2] Includes data of ETKIN 85

$f_2(2340)$ DECAY MODES

Γ_1 $f_2(2340) \to \phi\phi$

$f_2(2340)$ REFERENCES

ETKIN	88	PL B201 568	+Foley Lindenbaum+	(BNL CUNY)
BOOTH	86	NP B273 677	+Carroll Donald Edwards+	(LIVP GLAS CERN)
ETKIN	85	PL 165B 217	+Foley Longacre Lindenbaum+	(BNL CUNY)
LINDENBAUM	84	CNPP 13 285		(CUNY)

OTHER RELATED PAPERS

GREEN	86	PRL 56 1639	+Lai+	(FNAL ARIZ FSU NDAM TUFT VAND+)
BOOTH	84	NP B242 51	+Ballance Carroll Donald+	(LIVP GLAS CERN)

$\rho_5(2350)$

$I^G(J^{PC}) = 1^+(5^{--})$

OMITTED FROM SUMMARY TABLE

This entry was previously called $U_1(2400)$. Contains results only from formation experiments. For production experiments see the $\bar{N}N(1100-3600)$ entry. See also $\rho(2150)$, $f_2(2150)$, $\rho_3(2250)$, $f_4(2300)$

$\rho_5(2350)$ MASS

$\bar{p}p \to \pi\pi$ or $\bar{K}K$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~2300	[1] MARTIN	80B	RVUE		
~2250	[1] MARTIN	80C	RVUE		
~2500	[2] CARTER	78B	CNTR	0	0 7–2 4 $\bar{p}p \to K^-K^+$
~2480	[3] CARTER	77	CNTR	0	0 7–2 4 $\bar{p}p \to \pi\pi$

[1] $I(J^P) = 1(5^-)$ from simultaneous analysis of $p\bar{p} \to \pi^-\pi^+$ and $\pi^0\pi^0$
[2] $I = \rho(1)$ $J^P = 5^-$ from Barrelet-zero analysis
[3] $I(J^P) = 1(5^-)$ from amplitude analysis

S-CHANNEL $\bar{N}N$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~2380	[4] CUTTS	78B	CNTR		0 97–3 $\bar{p}p \to \bar{N}N$
2345 0 ± 15 0	[4,5] COUPLAND	77	CNTR	0	0 7–2 4 $\bar{p}p \to \bar{p}p$
2359 ± 2	[4,6] ALSPECTOR	73	CNTR		$\bar{p}p$ S channel
2350 ± 10.	[7] ABRAMS	70	CNTR		S channel $\bar{N}N$
2360.0 ± 25 0	[8] OH	70B	HDBC	−0	$\bar{p}(pn)$ $K^*K2\pi$

[4] Isospins 0 and 1 not separated
[5] From a fit to the total elastic cross section
[6] Referred to as U or U region by ALSPECTOR 73
[7] For $I = 1$ $\bar{N}N$
[8] No evidence for this bump seen in the $\bar{p}p$ data of CHAPMAN 71B. Narrow state not confirmed by OH 73 with more data

$\rho_5(2350)$ WIDTH

$\bar{p}p \to \pi\pi$ or $\bar{K}K$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~250	[9] MARTIN	80B	RVUE		
~300	[9] MARTIN	80C	RVUE		
~150	[10] CARTER	78B	CNTR	0	0 7–2 4 $\bar{p}p \to K^-K^+$
~210	[11] CARTER	77	CNTR	0	0 7–2 4 $\bar{p}p \to \pi\pi$

[9] $I(J^P) = 1(5^-)$ from simultaneous analysis of $p\bar{p} \to \pi^-\pi^+$ and $\pi^0\pi^0$
[10] $I = \rho(1)$ $J^P = 5^-$ from Barrelet zero analysis
[11] $I(J^P) = 1(5^-)$ from amplitude analysis

S-CHANNEL $\bar{N}N$

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$135\ 0^{+150\ 0}_{-65\ 0}$	[12,13] COUPLAND	77	CNTR	0	0 7–2 4 $\bar{p}p \to \bar{p}p$
165^{+18}_{-8}	[13] ALSPECTOR	73	CNTR		$\bar{p}p$ S channel
< 60 0	[14] OH	70B	HDBC	−0	$\bar{p}(pn)$, $K^*K2\pi$
~140	ABRAMS	67C	CNTR		S channel $\bar{p}N$

[12] From a fit to the total elastic cross section
[13] Isospins 0 and 1 not separated
[14] No evidence for this bump seen in the $\bar{p}p$ data of CHAPMAN 71B. Narrow state not confirmed by OH 73 with more data

$\rho_5(2350)$ REFERENCES

MARTIN	80B	NP B176 355	+Morgan	(LOUC RHEL) JP
MARTIN	80C	NP B169 216	+Pennington	(DURH) JP
CARTER	78B	NP B141 467		(LOQM)
CUTTS	78B	PR D17 16	+Good Grannis Green Lee+	(STON WISC)
CARTER	77	PL 67B 117	+Coupland Eisenhandler Astbury+	(LOQM RHEL) JP
COUPLAND	77	PL 71B 460	+Eisenhandler Gibson Astbury+	(LOQM RHEL)
ALSPECTOR	73	PRL 30 511	+Cohen Cvijanovich+	(RUTG UPNJ)
OH	73	NP B51 57	+Eastman MingMa Parker Smith+	(MSU)
CHAPMAN	71B	PR D4 1275	+Green Lys Murphy Ring+	(MICH)
ABRAMS	70	PR D1 1917	+Cool Giacomelli Kycia Leontic Li+	(BNL)
OH	70B	PRL 24 1257	+Parker Eastman Smith Sprafka Ma	(MSU)
ABRAMS	67C	PRL 18 1209	+Cool Giacomelli Kycia Leontic Li+	(BNL)

OTHER RELATED PAPERS

BOWCOCK	80	LNC 28 21	+Hodgson	(BIRM)
MARTIN	79B	PL 86B 93	+Pennington	(DURH)
CARTER	78	NP B132 176		(LOQM) JP
CARTER	77B	PL 67B 122		(LOQM) JP
CARTER	77C	NP B127 202	+Coupland Atkinson+	(LOQM DARE RHEL)
MONTANET	77	Boston Conf 260		(CERN)
DONNACHIE	75	NC 26A 317	+Thomas	(MCHS)
EISENHAND	75	NP B96 109	Eisenhandler Gibson+	(LOQM LIVP DARE RHEL)
HYAMS	74	NP B73 202	+Jones Weilhammer Blum+	(CERN MPIM)
MINGMA	74	NP B68 214	+Mountz Zemany Smith	(MICH)
EASTMAN	73	NP B51 29	+MingMa Oh Parker Smith Sprafka	(MSU)
MINGMA	73	NP B51 77	+Eastman Oh Parker Smith Sprafka	(MSU)
NICHOLSON	73	PR D7 2572	+Delorme Carroll+	(CIT ROCH BNL)
OH	73	NP B51 57	+Eastman MingMa Parker Smith+	(MSU)
FIELDS	71	PRL 27 1749	+Cooper Rhines Allison	(ANL OXF)
YOH	71	PRL 26 922	+Barish Caroll Lobkowicz+	(CIT BNL ROCH)
CASO	70	LNC 3 707	+Conte Tomasini+	(GENO HAMB MILA SACL)
BRICMAN	69	PL 29B 451	+Ferro Luzzi Bizard+	(CERN CAEN SACL)

$a_6(2450)$

$I^G(J^{PC}) = 1^-(6^{++})$

OMITTED FROM SUMMARY TABLE

Seen in partial-wave analysis of the $K\overline{K}$ system. Needs confirmation.

$a_6(2450)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
$2450 \pm 130.$	[1] CLELAND	82B	SPEC	$\pm$	$50\ \pi p \to K^0_S K^\pm p$

[1] From an amplitude analysis.

$a_6(2450)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
$400. \pm 250.$	[2] CLELAND	82B	SPEC	$\pm$	$50\ \pi p \to K^0_S K^\pm p$

[2] From an amplitude analysis.

$a_6(2450)$ DECAY MODES

Γ_1 $a_6(2450) \to K\overline{K}$

$a_6(2450)$ REFERENCES

CLELAND 82B NP B208 228 +Delfosse, Dorsaz, Gloor (DURH, GEVA, LAUS, PITT)

$f_6(2510)$ was $r(2510)$

$I^G(J^{PC}) = 0^+(6^{++})$

OMITTED FROM SUMMARY TABLE

Seen in $\pi^0\pi^0$. Needs confirmation.

$f_6(2510)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2510.0 ± 30.0	BINON	84B	GAM2	$38\ \pi^- p \to n 2\pi^0$

$f_6(2510)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
240.0 ± 60.0	BINON	84B	GAM2	$23\ \pi^- p \to n 2\pi^0$

$f_6(2510)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$f_6(2510) \to \pi\pi$	$(6.0 \pm 1.0) \times 10^{-2}$

$f_6(2510)$ BRANCHING RATIOS

$\Gamma(\pi\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.06 ± 0.01	[1] BINON	83C	GAM2	$38\ \pi^- p \to n 4\gamma$

[1] Assuming one pion exchange.

$f_6(2510)$ REFERENCES

BINON 84B LNC 39 41 +Donskov, Dutell, Gouanere+ (SERP, BELG, LAPP) JP

BINON 83C SJNP 38 723 +Gouanere, Donskov, Dutell+ (SERP, BRUX+)
Translated from YAF 38 1199.

$e^+e^-(1100-2200)$

$I^G(J^{PC}) = ?^?(1^{--})$

OMITTED FROM SUMMARY TABLE

This entry contains nonstrange vector mesons coupled to e^+e^- (photon) between ϕ and $J/\psi(1S)$ mass regions. See also $\rho(1250)$, $\rho(1700)$ and $\omega(1680)$.

We do not use these data for averages, fits, limits, etc.

$e^+e^-(1100-2200)$ MASSES AND WIDTHS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
$1097.0^{+16.0}_{-19.0}$	BARTALUCCI	79	OSPK	$7\ \gamma p \to e^+e^- p$
$31.0^{+24.0}_{-20.0}$	BARTALUCCI	79	OSPK	$7\ \gamma p \to e^+e^- p$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
~ 1830.0	PETERSON	78	SPEC	$\gamma p \to K^+K^- p$
~ 120.0	PETERSON	78	SPEC	$\gamma p \to K^+K^- p$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
~ 1820	[1] SPINETTI	79	RVUE	$e^+e^- \to 4\pi \pm 2\gamma$
~ 30	[1] SPINETTI	79	RVUE	$e^+e^- \to 4\pi \pm 2\gamma$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
~ 2130	[2] ESPOSITO	78	FRAM	$e^+e^- \to K^*(892)^+$
~ 30	[2] ESPOSITO	78	FRAM	$e^+e^- \to K^*(892)^+$

[1] Integrated cross section of BACCI 77, BARBIELLINI 77, ESPOSITO 77.
[2] Not seen by DELCOURT 79.

$e^+e^-(1100-2200)$ REFERENCES

BARTALUCCI 79 NC 49A 207 +Basini, Bertolucci+ (DESY, FRAS)
DELCOURT 79 PL 86B 395 +Derado, Bertrand, Bisello, Bizot, Buon+ (LALO)
SPINETTI 79 Batavia Conf. 506 (FRAS)
ESPOSITO 78 LNC 22 305 +Felicetti (FRAS, NAPL, PADO, ROMA)
PETERSON 78 PR D18 3955 +Dixon, Ehrlich, Galik, Larson (CORN, HARV)
BACCI 77 PL 68B 393 +DeZorzi, Penso, Stella, Baldini+ (ROMA, FRAS)
BARBIELLINI 77 PL 68B 397 +Barletta+ (FRAS, NAPL, PISA, SANI)
ESPOSITO 77 PL 68B 389 +Felicetti, Marini+ (FRAS, NAPL, PADO, ROMA)

— OTHER RELATED PAPERS —

BALDINI 81 LNC 30 337 +Battistoni, Capon, Bacci, Dezorzi+ (FRAS, ROMA)
DELCOURT 79B Batavia Conf. 499 +Bertrand, Bisello, Bizot, Buon, Cordier+ (LALO)
ESPOSITO 79 LNC 25 5 +Marini, Pallotta+ (FRAS, JMD, PADO, ROMA)
AMBROSIO 78 PL 80B 141 +Cerrito, Bemporad, Brosco+ (NAPL, PISA, ROMA)
BALDINI 78 PL 78B 167 +Battistoni, Capon, Bacci, Dezorzi+ (FRAS, ROMA)
ESPOSITO 78B LNC 23 604 +Felicetti (FRAS, NAPL, PADO, ROMA)
BARTALUCCI 77 NC 39A 374 +Bertolucci, Bradaschia (DESY, FRAS)
BACCI 76 PL 64B 356 +Bidoli, Penso, Stella, Baldini+ (ROMA, FRAS)
BACCI 75 PL 58B 481 +Bidoli, Penso, Stella+ (ROMA, FRAS)

$\overline{N}N(1100-3600)$

OMITTED FROM SUMMARY TABLE

This entry contains various high mass nonstrange structures coupled to the baryon antibaryon system as well as quasi-nuclear bound states below threshold.

See also $X(1935)$, $\rho(2150)$, $f_2(2150)$, $\rho_3(2250)$, $f_4(2300)$, $\rho_5(2350)$. Evidence for structures coupled to the antihyperon nucleon (or $c\overline{c}$) system is listed under $K_2(2250)$, $K_3(2320)$, $K_4(2500)$.

We do not use these data for averages, fits, limits, etc.

$\overline{N}N(1100-3600)$ MASSES AND WIDTHS

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1107 ± 4	DAFTARI	87	DBC	0	$0\ \overline{p}n\ \rho^-\pi^+\pi^-$
$111 \pm 8 \pm 15$	DAFTARI	87	DBC	0	$0\ \overline{p}n\ \rho^-\pi^+\pi^-$

Meson Full Listings
$\overline{N}N(1100-3600)$

MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1210 ±5 0	[1,2,3] RICHTER	83	CNTR	0	Stopped $\bar{p}$

MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1395	[2,3,4] PAVLOPO	78	CNTR	Stopped $\bar{p}$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
~1410	BETTINI	66	DBC	0	0 $\bar{p}N$ 5π
~ 100	BETTINI	66	DBC	0	0 $\bar{p}N$ 5π

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1468 ± 6	[5] BRIDGES	86B	DBC	0	0 $\bar{p}N$ $2\pi^-\pi^+\pi^0$
88 ± 18	[5] BRIDGES	86B	DBC	0	0 $\bar{p}N$ $2\pi^-\pi^+\pi^0$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1477 ± 5	[5] BRIDGES	86B	DBC	−	0 $\bar{p}N$ $3\pi^-2\pi^+$
116 ± 9	[5] BRIDGES	86B	DBC	−	0 $\bar{p}N$ $3\pi^-2\pi^+$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1522 ± 7	[5] BRIDGES	86B	DBC	0	0 $\bar{p}N$ $2\pi^-\pi^+$
59 ± 12	[5] BRIDGES	86B	DBC	0	0 $\bar{p}N$ $2\pi^-\pi^+$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1527 ± 5	GRAY	83	DBC	0	0 0 $\bar{p}N$ 3π
101 ± 13	GRAY	83	DBC	0	0 0 $\bar{p}N$ 3π

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1594 ± 9	[5] BRIDGES	86B	DBC	−	0 $\bar{p}N$ $2\pi^-\pi^+\pi^0$
81 ± 12	[5] BRIDGES	86B	DBC	−	0 $\bar{p}N$ $2\pi^-\pi^+\pi^0$

MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1637 1 $^{+5\ 6}_{-7\ 3}$	ADIELS	84	CNTR	pHe

MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1638 ±3 0	[1,2,3] RICHTER	83	CNTR	0	Stopped $\bar{p}$

MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1644 0 $^{+5\ 6}_{-7\ 3}$	ADIELS	84	CNTR	$\bar{p}$He

MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1646	[2,3,4] PAVLOPO	78	CNTR	Stopped $\bar{p}$

MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1687 1 $^{+5\ 0}_{-4\ 3}$	ADIELS	84	CNTR	$\bar{p}$He
1684	[2,3,4] PAVLOPO	78	CNTR	Stopped $\bar{p}$

MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1694 ±2.0	[1,2,3] RICHTER	83	CNTR	0	Stopped $\bar{p}$

MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1771 ±1 0	[2,3,6] RICHTER	83	CNTR	0	Stopped $\bar{p}$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1856 6 ± 5	BRIDGES	86D	SPEC	0	0 $\bar{p}d \to \pi\pi N$
20 ± 5	BRIDGES	86D	SPEC	0	0 $\bar{p}d \to \pi\pi N$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1873 ± 2 5	BRIDGES	86D	SPEC	0	0 $\bar{p}d \to \pi\pi N$
< 5	BRIDGES	86D	SPEC	0	0 $\bar{p}d \to \pi\pi N$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1897 0 ± 17 0	[7] ABASHIAN	76	STRC	8 $\pi^-p \to p3\pi$
110 0 ± 82 0	[7] ABASHIAN	76	STRC	8 $\pi^-p \to p3\pi$
1897 ± 1	KALOGERO	75	DBC	$\bar{p}n$ annihilation near threshold
25 ± 6	KALOGERO	75	DBC	$\bar{p}n$ annihilation near threshold

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
~1920 0	[8] EVANGELISTA	79	OMEG	10 16 $\pi^-p \to \bar{p}p$
~ 190 0	EVANGELISTA	79	OMEG	10 16 $\pi^-p \to \bar{p}p$

MASS AND WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1937 3 $^{+1\ 3}_{-0\ 7}$		[9] FRANKLIN	87	SPEC		0 586 $\bar{p}p$
< 3 0		[9] FRANKLIN	87	SPEC		0 586 $\bar{p}p$
1940 ± 20		TANIMORI	85	CNTR		0 4–0 8 $\bar{p}p$ M^+M^-
< 40		TANIMORI	85	CNTR		0 4–0 8 $\bar{p}p$ M^+M^-
1930 0 ± 2 0		ASTON	80D	OMEG		$\gamma p \to p\bar{p}$ X
12 0 ± 7 0		ASTON	80D	OMEG		$\gamma p \to p\bar{p}$ X
1940 0 ± 1 0	36	DAUM	80E	CNTR	0	93 $\bar{p}p \to \bar{p}p$ + X
~ 6 0		DAUM	80E	CNTR		93 $\bar{p}p \to \bar{p}p$ + X
1949 ± 10		[10] DEFOIX	80	HBC	0	$\bar{p}p \to 5\pi$
80 ± 20		[10] DEFOIX	80	HBC	0	$\bar{p}p \to 5\pi$
1939 0 ± 2 0		[11] HAMILTON	80B	CNTR	0	S channel $\bar{p}p$
22 0 ± 6 0		[11] HAMILTON	80B	CNTR	0	S channel $\bar{p}p$
1935.5 ± 1 0		SAKAMOTO	79	HBC	0	0 37–0 73 $\bar{p}p$
2 8 ± 1 4		SAKAMOTO	79	HBC	0	0 37–0 73 $\bar{p}p$
1939 0 ± 3 0		BRUCKNER	77	SPEC	0	0 4–0 85 $\bar{p}p$
< 4.0		BRUCKNER	77	SPEC	0	0 4–0 85 $\bar{p}p$
1935 9 ± 1 0		[12] CHALOUPKA	76	HBC	0	$\bar{p}p$ total elastic
8 8 $^{+4\ 3}_{-3\ 2}$		[13] CHALOUPKA	76	HBC	0	$\bar{p}p$ total elastic
1942 ± 5		[14] D ANDLAU	75	HBC	0	0 175–0 750 $\bar{p}p$
57 5 ± 5		[15] D ANDLAU	75	HBC	0	0 175–0 750 $\bar{p}p$
1934 4 $^{+2\ 6}_{-1\ 4}$		[16] KALOGERO	75	DBC	−	$\bar{p}N$ annihilation
11 $^{+11}_{-4}$		[17] KALOGERO	75	DBC	−	$\bar{p}N$ annihilation
1932 ± 2		[12] CARROLL	74	CNTR		S channel $\bar{p}p$ d
9 $^{+4}_{-3}$		[13] CARROLL	74	CNTR		S channel $\bar{p}p$ d
1968		[18] BENVENUTI	71	HBC	0	0 1–0 8 $\bar{p}p$
35		[18] BENVENUTI	71	HBC	0	0 1–0 8 $\bar{p}p$
1940 ± 8		CLINE	70	HBC	0	0 25–0 74 $\bar{p}p$
49 ± 9		CLINE	70	HBC	0	0 25–0 74 $\bar{p}p$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1949 ± 10	[19] DEFOIX	80	HBC	0	0 0–1 2 $\bar{p}p \to 5\pi$
80 ± 20	[19] DEFOIX	80	HBC	0	0 0–1 2 $\bar{p}p \to 5\pi$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2022 0 ± 6.0	[20] AZOOZ	83	HYBR	+	6 $\bar{p}p \to pn3\pi$
14 0 ± 13 0	[20] AZOOZ	83	HYBR	+	6 $\bar{p}p \to pn3\pi$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2023 0 ± 5 0	BODENKAMP	83	SPEC	0	$\gamma p \to \bar{p}pp$
27 0 ± 12 0	BODENKAMP	83	SPEC	0	$\gamma p \to \bar{p}pp$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2026 0 ± 5.0	[20] AZOOZ	83	HYBR	−	4 $\bar{p}p \to \bar{p}n3\pi$
20 0 ± 11 0	[20] AZOOZ	83	HYBR	−	4 $\bar{p}p \to \bar{p}n3\pi$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2080 ± 10	[21] KREYMER	80	STRC	0	13 $\pi^-d \to p\bar{p}n(n)$
110 ± 20	[21] KREYMER	80	STRC	0	13 $\pi^-d \to p\bar{p}n(n)$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2090 0 ± 20 0	[22] KREYMER	80	STRC	13 $\pi^-d \to np\bar{p}\pi^-p$
170 0 ± 50 0	[22] KREYMER	80	STRC	13 $\pi^-d \to np\bar{p}\pi^-p$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
~2110 0	[23] EVANGELISTA	79	OMEG	10 16 $\pi^-p \to \bar{p}p$
~ 330 0	[23] EVANGELISTA	79	OMEG	10 16 $\pi^-p \to \bar{p}p$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2110 0 ± 10 0	[24] ROZANSKA	80	SPRK	18 $\pi^- p \to p\bar{p}n$
190 0 ± 10 0	[24] ROZANSKA	80	SPRK	18 $\pi^- p \to p\bar{p}n$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2141	[25] DONALD	73	HBC	0	$\bar{p}p$ S channel
14	[25] DONALD	73	HBC	0	$\bar{p}p$ S channel

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2180 0 ± 10 0	[26] ROZANSKA	80	SPRK	18 $\pi^- p \to p\bar{p}n$
270 0 ± 10 0	[26] ROZANSKA	80	SPRK	18 $\pi^- p \to p\bar{p}n$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2207 ± 13	[27] ALLES	67B	HBC	0	5 7 $\bar{p}p$
62 ± 52	[27] ALLES	67B	HBC	0	5 7 $\bar{p}p$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2210 $0^{+79\ 0}_{-21\ 0}$	EVANGELISTA	79B	OMEG	10 $\pi^- p \to K^+K^- n$
~ 203 0	EVANGELISTA	79B	OMEG	10 $\pi^- p \to K^+K^- n$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
~2260 0	[28] EVANGELISTA	79	OMEG	10 16 $\pi^- p \to \bar{p}p$
~ 440 0	[28] EVANGELISTA	79	OMEG	10 16 $\pi^- p \to \bar{p}p$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2307 0 ± 6 0	ALPER	80	CNTR	0	62 $\pi^- p \to K^+K^- n$
245 0 ± 20 0	ALPER	80	CNTR	0	62 $\pi^- p \to K^+K^- n$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2380.0 ± 10 0	[29] ROZANSKA	80	SPRK	18 $\pi^- p \to p\bar{p}n$
380 0 ± 20 0	[29] ROZANSKA	80	SPRK	18 $\pi^- p \to p\bar{p}n$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2450 0 ± 10 0	[30] ROZANSKA	80	SPRK	18 $\pi^- p \to p\bar{p}n$
280 0 ± 20 0	[30] ROZANSKA	80	SPRK	18 $\pi^- p \to p\bar{p}n$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2480 0 ± 30 0	[31] CARTER	77	CNTR	0	0 7–2 4 $\bar{p}p \to \pi\pi$
210 0 ± 25 0	[31] CARTER	77	CNTR	0	0 7–2 4 $\bar{p}p \to \pi\pi$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
~2500 0	[32] CARTER	78B	CNTR	0	0 7–2 4 $\bar{p}p \to K^-K^+$
~ 150 0	[32] CARTER	78B	CNTR	0	0 7–2 4 $\bar{p}p \to K^-K^+$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2710 0 ± 20.0	ROZANSKA	80	SPRK	18 $\pi^- p \to p\bar{p}n$
170 0 ± 40.0	ROZANSKA	80	SPRK	18 $\pi^- p \to p\bar{p}n$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2850 0 ± 5 0	[33] BRAUN	76	DBC	–	5 5 $\bar{p}d \to \overline{N}N\pi$
< 39	[33] BRAUN	76	DBC		5 5 $\bar{p}d \to \overline{N}N\pi$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
3370 ± 10	[34] ALEXANDER	72	HBC	0	6 94 $\bar{p}p$
150 ± 40	[34] ALEXANDER	72	HBC	0	6 94 $\bar{p}p$

MASS AND WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
3600 ± 20	[34] ALEXANDER	72	HBC	0	6 94 $\bar{p}p$
140 ± 20	[34] ALEXANDER	72	HBC	0	6 94 $\bar{p}p$

[1] Not seen by CHIBA 86 CHIBA 88 ANGELOPOULOS 86 ADIELS 86
[2] They looked for radiative transitions to bound $p\bar{p}$ states mono energetic γ rays detected
[3] Observed widths consistent with experimental resolution
[4] Not seen by ADIELS 86
[5] From analysis of difference of π^- and π^+ spectra
[6] Not seen by CHIBA 86 CHIBA 88 ANGELOPOULOS 86
[7] Produced backwards
[8] $I(J^P)$ = 1(1$^-$) from a mass dependent partial wave analysis taking solution A
[9] From reanalysis of data from JASTRZEMBSKI 81
[10] From energy dependence of 5π cross section I^G = 1$^-$ from observation of $\omega\rho$ decay P = + and J 1 $a_2(1320)\pi\pi$ also seen
[11] I = 0 favored J = 0 or 1 seen in total $\bar{p}p$ total cross section Primarily from annihilation reactions Not seen in $\bar{p}d$ total and annihilation cross sections
[12] Narrow bump seen in total $\bar{p}p$ $\bar{p}d$ cross sections Isospin uncertain Not seen in $\bar{p}p$ charge exchange by GARNJOST 75 CHALOUPKA 76 Integrated cross section three times larger than BRUCKNER 77
[13] Narrow bump seen in total $\bar{p}p$ $\bar{p}d$ cross sections Isospin uncertain Not seen in $\bar{p}p$ charge exchange by GARNJOST 75 CHALOUPKA 76 Integrated cross section three times larger than BRUCKNER 77 Not seen by CLOUGH 84
[14] From energy dependence of far backward elastic scattering Some indication of additional structure
[15] From energy dependence of far backward elastic scattering Some indication of additional structure
[16] Not seen by ALBERI 79 with comparable statistics
[17] Not seen by ALBERI 79 with comparable statistics
[18] Seen as a bump in the $\bar{p}p \to K^0_S K^0_L$ cross section with J^{PC} = 1^{--}
[19] Isospin 1 favored
[20] Not seen by BIONTA 80 CARROLL 80 HAMILTON 80 BANKS 81 CHUNG 81 BARNETT 83
[21] Neutron spectator See also $np\bar{p}\pi^-(p)$ channel following
[22] Proton spectator See also $p\bar{p}n(n)$ channel above
[23] $I(J^P)$ = 1(3$^-$) from a mass dependent partial wave analysis taking solution A
[24] $I(J^P)$ = 1(3$^-$) from amplitude analysis assuming one pion exchange
[25] Seen in final state $\omega\pi^+\pi^-$
[26] $I(J^P)$ = 0(2$^+$) from amplitude analysis assuming one pion exchange
[27] ALLES BORELLI 67B see neutral mode only $\pi^+\pi^-\pi^0$
[28] $I(J^P)$ = 0(4$^+$) from a mass dependent partial wave analysis taking solution A
[29] $I(J^P)$ = 0(4$^+$) from amplitude analysis assuming one pion exchange
[30] $I(J^P)$ = 1(5$^-$) from amplitude analysis assuming one pion exchange
[31] $I(J^P)$ = 1(5$^-$) from amplitude analysis of $\bar{p}p \to \pi\pi$
[32] I=0 1 J^P = 5$^-$ from Barrelet zero analysis
[33] Decays to $\overline{N}N$ and $\overline{N}N\pi$ Not seen by BARNETT 83
[34] Decays to $4\pi^+4\pi^-$

$\overline{N}N$(1100–3600) REFERENCES

CHIBA	88	PL B202 447	+Di	(FJKI 'NLS KEK KYOT OSAK TOKY)
DAFTARI	87	PRL 58 859	+Gray Kalogeropoulos Roy	(SYRA)
FRANKLIN	87	PL B184 81		
ADIELS	86	PL B182 405	+Backenstoss+	(STOH BASL LASL THES CERN)
ANGELOPO	86	PL B178 441	Angelopoulos+	(ATHU UCI KARL NMSU PENN)
BRIDGES	86B	PRL 56 215	+Daftari Kalogeropoulos Debbe+	(SYRA CASE)
BRIDGES	86C	PL B180 313	+Brown Daftari+	(SYRA BNL CASE UMD COLU)
CHIBA	86	PL B177 217	+Doi Fujitani+	(FUKU KEK KYOT OSAK TOKY)
TANIMORI	85	PRL 55 1835	+Fujii Kageyama Nakamura Sai+	(TOKY TSUK)
ADIELS	84	PL 138B 235	+Backenstoss+	(BASL KARL STOH STRB THES)
CLOUGH	84	PL 146B 299	+Beard Bugg+	(SURR LOQM ANIK TRST GEVA)
AZOOZ	83	PL 122B 471	+Butterworth	(LOIC RHEL SACL SLAC TOHO+)
BARNETT	83	PR D27 493	+Blockus Burka Chien Christian+	(JHU)
BODENKAMP	83	PL 133B 275	+Fries Behrend Fenner+	(KARL DESY)
GRAY	83	PR D27 307	+Kalogeropoulos Nandy Roy Zenone	(SYRA)
RICHTER	83	PL 126B 284	+Adiels	(BASL KARL STOH STRB THES)
BANKS	81	PL 100B 191	+Booth Campbell Armstrong+	(LIVP CERN)
CHUNG	81	PRL 46 395	+Bensinger+	(BNL BRAN CINC FSU SMAS)
JASTRZEM	81	PR D23 2784	Jastrzembski Mandelkern+	(TEMP UCI UNM)
ALPER	80	PL 94B 422	+Becker+	(AMST CERN CRAC MPIM OXF+)
ASTON	80D	PL 93B 517		(BONN CERN EPOL GLAS LANC MCHS ORSA+)
BIONTA	80	PRL 44 909	+Carroll Edelstein+	(BNL CMU FNAL SMAS)
CARROLL	80	PRL 44 1572	+Chiang Johnson Cester Webb+	(BNL PRIN)
DAUM	80E	PL 90B 475	+Hertzberger+	(AMST CERN CRAC MPIM OXF+)
DEFOIX	80	NP B162 12	+Dobrzynski Angelini Bigi+	(CDEF PISA)
HAMILTON	80	PRL 44 1179	+Pun Tripp Lazarus+	(LBL BNL MTHO)
HAMILTON	80B	PRL 44 1182	+Pun Tripp Lazarus+	(LBL BNL MTHO)
KREYMER	80	PR D22 36	+Baggett Fieguth+	(IND PURD SLAC VAND)
ROZANSKA	80	NP B162 505	+Blum Dietl Grayer Lorenz+	(MPIM CERN)
ALBERI	79	PL 83B 247	+Alvear Castelli Poropat+	(TRST CERN IFRJ)
EVANGELISTA	79	NP B153 253	+	(BARI BONN CERN DARE GLAS LIVP+)
EVANGELISTA	79B	NP B154 381	+	(BARI BONN CERN DARE GLAS LIVP+)
SAKAMOTO	79	NP B158 410	+Hashimoto Sai Yamamoto+	(TOKY)
CARTER	78B	NP B141 467		(LOQM)
PAVLOPO	78	PL 72B 415	Pavlopoulos+	(KARL BASL CERN STOH STRB)
BRUCKNER	77	PL 67B 222	+Granz Ingram Kilian+	(MPIH HEID CERN)
CARTER	77	PL 67B 117	+Coupland Eisenhandler Astbury+	(LOQM RHEL) JP
ABASHIAN	76	PR D13 5	+Watson Gelfand Buttram+	(ILL ANL CHIC ISU)
BRAUN	76	PL 60B 481	+Brick Fridman Gerber Juillot Maurer+	(STRB)
CHALOUPKA	76	PL 61B 487	+	(CERN LIVP MONS PADO ROMA TRST)
D ANDLAU	75	PL 58B 223	+Cohen Ganouna Laloum Lutz Petri	(CDEF PISA)
GARNJOST	75	PRL 35 1685	+Kenney Pollard Ross Tripp+	(LBL MHCO)
KALOGERO	75	PRL 34 1047	Kalogeropoulos Tzanakos	(SYRA)
CARROLL	74	PRL 32 247	+Chiang Kycia Li Mazur Michael+	(BNL)
DONALD	73	NP B61 333	+Edwards Gibbins Briand Duboc+	(LIVP LPNP)
ALEXANDER	72	NP B45 29	+Bar Nir Benary Dagan+	(TELA)
BENVENUTI	71	PRL 27 283	+Cline Rutz Reeder Scherer	(WISC)
CLINE	70	Preprint	+English Reeder	(WISC)
ALLES	67B	NC 50A 776	Alles Borelli French Frisk+	(CERN BONN) G
BETTINI	66	NC 42A 695	+Cresti Limentani Bertanza Bigi+	(PADO PISA)

— — OTHER RELATED PAPERS — —

LIU 87 PRL 58 2288 +Kiu Li (STON)
ARMSTRONG 86C PL B175 383 +Chu Clement Ellnon+ (BNL HOUS PENN RICE)
BRIDGES 86 PRL 56 211 +Brown+ (BLSU BNL CASE COLU UMD SYRA)
BRIDGES 86C PRL 57 1534 +Daftari Kalogeropoulos+ (SYRA) JP
DOVER 86 PRL 57 1207 + (BNL) JP
ANGELOPO 85 PL 159B 210 Angelopoulos+ (ATHU UCI UNM PENN TEMP)
BODENKAMP 85 NP B255 717 +Fries Behrend Hesse+ (KARL DESY)
AZOOZ 84 NP B244 277 +Butterworth (LOIC RHEL SACL SLAC TOHO+)

X(1900–3600)

OMITTED FROM SUMMARY TABLE

NOTE ON THE X(1900-3600) REGION

The high-mass region is covered nearly continuously with evidence for peaks of various widths having various decay modes. As a satisfactory grouping into particles is not yet possible, we list all the $Y = 0$ bumps coupled neither to $N\overline{N}$ nor to e^+e^-, and having $M > 1900$ MeV together, ordered by increasing mass.

The narrow peaks observed in a missing-mass-spectrometer experiment at 1929, 2195, and 2382 MeV, called respectively S, T, and U by the authors (CHIKOVANI 66, FOCACCI 66), were not seen by ANTIPOV 72 who performed a similar experiment at 25 and 40 GeV/c.

We do not use the following data for averages, fits, limits, etc.

X(1900–3600) MASSES AND WIDTHS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1870.0 ± 40.0		[1] ALDE	86D	GAM4	0	100 $\pi^- p \to 2\eta X$
250.0 ± 30.0		[1] ALDE	86D	GAM4	0	100 $\pi^- p \to 2\eta X$
1898 ± 18	100	THOMPSON	74	HBC	+	13 $\pi^+ p \to 2\rho X$
108^{+41}_{-27}	100	THOMPSON	74	HBC	+	13 $\pi^+ p \to 2\rho X$
1900 ± 40	100	BOESEBECK	68	HBC	+	8 $\pi^+ p \to \pi^+ \pi^0 X$
216 ± 105	100	BOESEBECK	68	HBC	+	8 $\pi^+ p \to \pi^+ \pi^0 X$
1929 ± 14		FOCACCI	66	MMS	−	3–12 $\pi^- p$
22 ± 2		FOCACCI	66	MMS	−	3–12 $\pi^- p$
1970 ± 10		CHLIAPNIK	80	HBC	0	32 $K^+ p \to 2K_S^0 2\pi X$
40 ± 20		CHLIAPNIK	80	HBC	0	32 $K^+ p \to 2K_S^0 2\pi X$
1973.0 ± 15.0	30	CASO	70	HBC	−	11.2 $\pi^- p \to \rho 2\pi$
80.0	30	CASO	70	HBC	−	11.2 $\pi^- p \to \rho 2\pi$
2070	50	TAKAHASHI	72	HBC		8 $\pi^- p \to N 2\pi$
160	50	TAKAHASHI	72	HBC		8 $\pi^- p \to N 2\pi$
2100.0 ± 40.0		[2] ALDE	86D	GAM4	0	100 $\pi^- p \to 2\eta X$
250.0 ± 40.0		[2] ALDE	86D	GAM4	0	100 $\pi^- p \to 2\eta X$
2141.0 ± 12.0	389	GREEN	86	MPSF		400 $pA \to 4K X$
49.0 ± 28.0	389	GREEN	86	MPSF		400 $pA \to 4K X$
2190.0 ± 10.0		CLAYTON	67	HBC	±	2.5 $\bar{p}p \to a_2 \omega$
2195 ± 15		FOCACCI	66	MMS	−	3–12 $\pi^- p$
39 ± 14		FOCACCI	66	MMS	−	3–12 $\pi^- p$
2207.0 ± 22.0		[3] CASO	70	HBC	−	11.2 $\pi^- p$
130.0		[3] CASO	70	HBC	−	11.2 $\pi^- p$
2280.0 ± 50.0		ATKINSON	85	OMEG	0	20–70 $\gamma p \to (p)\omega\pi^+\pi^-\pi^0$
440.0 ± 110.0		ATKINSON	85	OMEG	0	20–70 $\gamma p \to (p)\omega\pi^+\pi^-\pi^0$
2300.0 ± 100.0		ATKINSON	84F	OMEG	±0	20–70 $\gamma p \to \rho f$
~ 250.0		ATKINSON	84F	OMEG	±0	20–70 $\gamma p \to \rho f$
2340 ± 20	126	[4] BALTAY	75	HBC	+	15 $\pi^+ p \to p 5\pi$
180 ± 60	126	[4] BALTAY	75	HBC	+	15 $\pi^+ p \to p 5\pi$
2382 ± 24		FOCACCI	66	MMS	−	3–12 $\pi^- p$
62 ± 6		FOCACCI	66	MMS	−	3–12 $\pi^- p$
2500.0 ± 32.0		ANDERSON	69	MMS	−	16 $\pi^- p$ backward
87.0		ANDERSON	69	MMS	-	16 $\pi^- p$ backward
2620 ± 20	550	BAUD	69	MMS	−	8–10 $\pi^- p$
85 ± 30	550	BAUD	69	MMS	−	8–10 $\pi^- p$
2676.0 ± 27.0		[3] CASO	70	HBC	−	11.2 $\pi^- p$
150.0		[3] CASO	70	HBC	−	11.2 $\pi^- p$
2747 ± 32		DENNEY	83	LASS		10 $\pi^+ N$
195 ± 75		DENNEY	83	LASS		10 $\pi^+ N$
2800 ± 20	640	BAUD	69	MMS	−	8–10 $\pi^- p$
46 ± 10	640	BAUD	69	MMS	−	8–10 $\pi^- p$
2820 ± 10	15	[5] SABAU	71	HBC	+	8 $\pi^+ p$
50 ± 10	15	[5] SABAU	71	HBC	+	8 $\pi^+ p$
2880 ± 20	230	BAUD	69	MMS	−	8–10 $\pi^- p$
< 15	230	BAUD	69	MMS	−	8–10 $\pi^- p$
3025.0 ± 20.0		BAUD	70	MMS	−	10.5–13 $\pi^- p$
~ 25.0		BAUD	70	MMS	−	10.5–13 $\pi^- p$
3075.0 ± 20.0		BAUD	70	MMS	−	10.5–13 $\pi^- p$
~ 25.0		BAUD	70	MMS	−	10.5–13 $\pi^- p$
3145.0 ± 20.0		BAUD	70	MMS	−	10.5–15 $\pi^- p$
< 10.0		BAUD	70	MMS	−	10.5–15 $\pi^- p$
3475.0 ± 20.0		BAUD	70	MMS	−	14–15.5 $\pi^- p$
~ 30.0		BAUD	70	MMS	-	14–15.5 $\pi^- p$
3535.0 ± 20.0		BAUD	70	MMS	−	14–15.5 $\pi^- p$
~ 30.0		BAUD	70	MMS	−	14–15.5 $\pi^- p$

[1] Seen in $J = 2$ wave in one of the two ambiguous solutions.
[2] Seen in $J = 0$ wave in one of the two ambiguous solutions.
[3] Seen in $\rho^-\pi^+\pi^-$ (ω and η antiselected in 4π system).
[4] Dominant decay into $\rho^0\rho^0\pi^+$. BALTAY 78 finds confirmation in $2\pi^+\pi^-2\pi^0$ events which contain $\rho^+\rho^0\pi^0$ and $2\rho^+\pi^-$.
[5] Seen in $(KK\pi\pi)$ mass distribution.

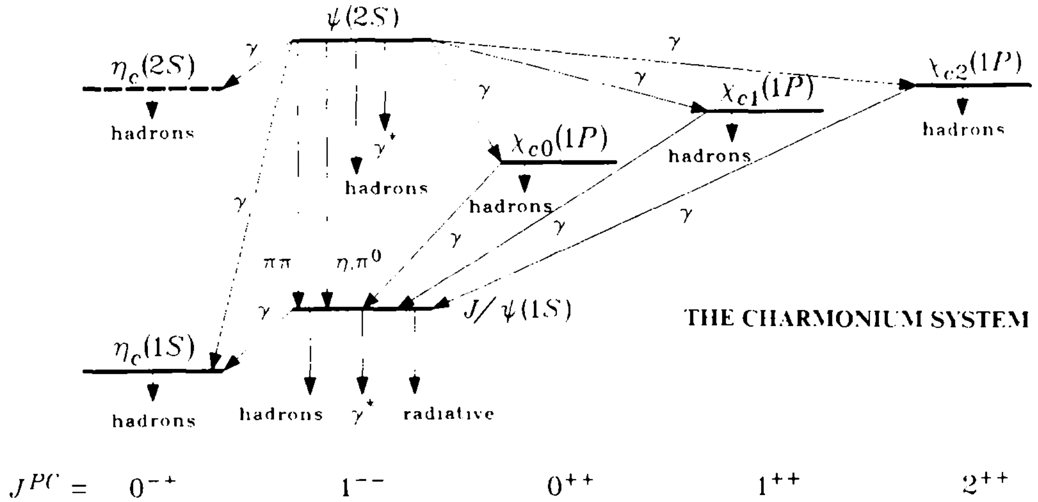
$X(1900-3600)$ REFERENCES

ALDE	86D	NP B269 485	+Binon Bricman+	(BELG LAPP SERP CERN)
GREEN	86	PRL 56 1639	+Lai+	(FNAL ARIZ FSU NDAM TUFT VAND+)
ATKINSON	85	ZPHY C29 333	+	(BONN CERN GLAS LANC MCHS IPNP+)
ATKINSON	84F	NP B239 1	+	(BONN CERN GLAS LANC MCHS IPNP+)
DENNEY	83	PR D28 2726	+Cranley Firestone Chapman+	(IOWA MICH) J
CHLIAPNIK	80	ZPHY C3 285	Chliapnikov Gerdyukov+	(SERP BRUX MONS)
BALTAY	78	PR D17 52	+Cautis Cohen Csorna Kalelkar+	(COLU BING)
BALTAY	75	PRL 35 891	+Cautis Cohen Kalelkar Pisello+	(COLU BING)
THOMPSON	74	NP B69 220	+Galdos Mcllwain Miller Mulera+	(PURD)
TAKAHASHI	72	PR D6 1266	+Barish+	(TOHO PENN NDAM ANL)
SABAU	71	LNC 1 514	+Uretsky	(BUCH ANL)
BAUD	70	PL 31B 549		(CERN CERN Boson Spectrometer Collab.)
CASO	70	LNC 3 707	+Conte Tomasini+	(GENO HAMB MILA SACL)
ANDERSON	69	PRL 22 1390	+Collins+	(BNL CMU)
BAUD	69	PL 30B 129		(CERN Boson Spectrometer Collab.)
BOESEBECK	68	NP B4 501	+Deutschmann+	(AACH BERL CERN)
CLAYTON	67	Heidelberg Conf. 57	+Mason Muirhead Filippas+	(LIVP ATHU)
FOCACCI	66	PRL 17 890	+Kienzle Levrat Maglich Martin	(CERN)

— OTHER RELATED PAPERS —

BALTAY	78	PR D17 52	+Cautis Cohen Csorna Kalelkar+	(COLU BING)
ANTIPOV	72	PL 40 147	+Kienzle Landsberg+	(SERP)
CHIKOVANI	66	PL 22 233	+Kienzle Maglich+	(SERP)

$c\bar{c}$ MESONS



THE CHARMONIUM SYSTEM

The current state of knowledge of the charmonium system and transitions, as interpreted by the charmonium model. Uncertain states and transitions are indicated by dashed lines. The notation γ^* refers to decay processes involving intermediate virtual photons, including decays to e^+e^- and $\mu^+\mu^-$.

$\eta_c(1S)$ or $\eta_c(2980)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Observed in the inclusive γ spectrum generated from $\psi(2S)$ decay, therefore $C = +$. From the 4π decay $G = +$, therefore $I = 0$. From angular distribution in $J/\psi(1S) \rightarrow \eta_c\gamma$, $\eta_c \rightarrow \phi\phi$, $J^P = 0^-$ (BALTRUSAITIS 84).

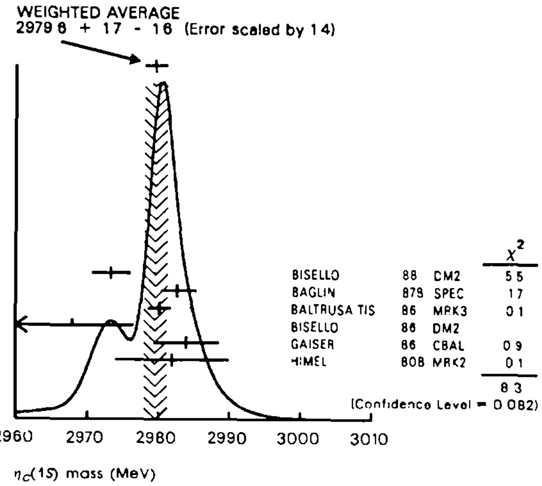
$\eta_c(1S)$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$2979.6^{+1.7}_{-1.6}$	**OUR AVERAGE**	Error includes scale factor of 1 4. See the ideogram below			
2973 3 ± 2 7	137 ± 23	BISELLO	88	DM2	$J/\psi \rightarrow \gamma 2\pi^+ 2\pi^-$
$2982\ 6^{+2.7}_{-2\ 3}$	12	BAGLIN	87B	SPEC	$\bar{p}p \rightarrow \gamma\gamma$
2980 2 ± 1 6		[1] BALTRUSAITIS	86	MRK3	$J/\psi \rightarrow \eta_c\gamma$
2968 0 ± 5 ± 7	19	BISELLO	86	DM2	$J/\psi \rightarrow \gamma\phi\phi$
2984 ± 2 3 ± 4 0		GAISER	86	CBAL	$J/\psi \rightarrow \gamma X$, $\psi(2S) \rightarrow \gamma X$
2982 ± 8	18	[2] HIMEL	80B	MRK2	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2976 ± 8		[3] BALTRUSAITIS	84	MRK3	$J/\psi \rightarrow 2\phi\gamma$
2980 ± 9		[2] PARTRIDGE	80B	CBAL	e^+e^-

[1] Average of several decay modes

[2] Mass adjusted by us to correspond to $J/\psi(1S)$ mass = 3097 MeV

[3] $\eta_c \rightarrow \phi\phi$



$\eta_c(1S)$ WIDTH

VALUE (MeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
$10.3^{+3.8}_{-3.4}$ OUR AVERAGE						
$7.0^{+7.5}_{-7.0}$		12	BAGLIN	87B	SPEC	$\bar{p}p \to \gamma\gamma$
$10.1^{+33.0}_{-8.2}$		23 ± 11	[4] BALTRUSAITIS	86	MRK3	$J/\psi \to \gamma p\bar{p}$
11.5 ± 4.5			GAISER	86	CBAL	$J/\psi \to \gamma X$, $\psi(2S) \to \gamma X$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<40	90	18	HIMEL	80B	MRK2	e^+e^-
<20	90		PARTRIDGE	80B	CBAL	e^+e^-

[4] Positive and negative errors correspond to 90% confidence level.

$\eta_c(1S)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
	HADRONIC DECAYS		
Γ_1	$\eta_c(1S) \to 2(\pi^+\pi^-)$	$(1.17^{+0.29}_{-0.27}) \times 10^{-2}$	
Γ_2	$\eta_c(1S) \to p\bar{p}$	$(1.04 \pm 0.19) \times 10^{-3}$	
Γ_3	$\eta_c(1S) \to \pi^+\pi^- p\bar{p}$	$< 1.2 \times 10^{-2}$	CL=90%
Γ_4	$\eta_c(1S) \to K\bar{K}\pi$	$(5.5 \pm 0.8) \times 10^{-2}$	
Γ_5	$\eta_c(1S) \to \pi^+\pi^- K^+K^-$	$(2.04^{+0.29}_{-0.27}) \times 10^{-2}$	
Γ_6	$\eta_c(1S) \to \eta\pi\pi$	$(5.0 \pm 1.1) \times 10^{-2}$	
Γ_7	$\eta_c(1S) \to \phi\phi$	$(3.4 \pm 1.2) \times 10^{-3}$	S=1.5
Γ_8	$\eta_c(1S) \to K^*(892)\bar{K}^*(892)$	$(9 \pm 5) \times 10^{-3}$	
Γ_9	$\eta_c(1S) \to \rho\rho$	$(2.6 \pm 0.9) \times 10^{-3}$	
Γ_{10}	$\eta_c(1S) \to \omega\omega$	$< 3.1 \times 10^{-3}$	CL=90%
Γ_{11}	$\eta_c(1S) \to a_0(980)\pi$	$< 2 \times 10^{-2}$	CL=90%
Γ_{12}	$\eta_c(1S) \to a_2(1320)\pi$	$< 2 \times 10^{-2}$	CL=90%
Γ_{13}	$\eta_c(1S) \to f_2(1270)\eta$	$< 1.1 \times 10^{-2}$	CL=90%
Γ_{14}	$\eta_c(1S) \to \eta'(958)\pi\pi$	$(4.1 \pm 1.7) \times 10^{-2}$	
Γ_{15}	$\eta_c(1S) \to K\bar{K}\eta$	$< 3.1 \times 10^{-2}$	CL=90%
Γ_{16}	$\eta_c(1S) \to K^*(892)^0 K^-\pi^+$ + c.c.	$(2.0 \pm 0.7) \times 10^{-2}$	
	RADIATIVE DECAYS		
Γ_{17}	$\eta_c(1S) \to \gamma\gamma$	$(6^{+6}_{-5}) \times 10^{-4}$	

$\eta_c(1S)$ PARTIAL WIDTHS

$\Gamma(\gamma\gamma)$ Γ_{17}

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
<11	90	BLINOV	86	MD1	$e^+e^- \to e^+e^- X$

$\eta_c(1S)$ $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(\text{total})$

$\Gamma(K\bar{K}\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ $\Gamma_4\Gamma_{17}/\Gamma$

VALUE (keV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
$1.5^{+0.60}_{-0.45} \pm 0.3$		7	[5] BERGER	86	PLUT	$\gamma\gamma \to K\bar{K}\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<4.4	95		ALTHOFF	85B	TASS	$\gamma\gamma \to KK\pi$

[5] $K^\pm K^0_S \pi^\mp$ corrected to $K\bar{K}\pi$ by factor 3.

$\eta_c(1S)$ BRANCHING RATIOS

— HADRONIC DECAYS —

$\Gamma(2(\pi^+\pi^-))/\Gamma_{total}$ Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.0117^{+0.0029}_{-0.0027}$ OUR AVERAGE					
0.0105 ± 0.0038	7	BISELLO	88	DM2	$J/\psi \to \eta_c\gamma$
0.013 ± 0.005	25 ± 9	[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$
$0.013^{+0.009}_{-0.006}$		[7] HIMEL	80B	MRK2	$\psi(2S) \to \eta_c\gamma$

$\Gamma(p\bar{p})/\Gamma_{total}$ Γ_2/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
10.4 ± 1.9 OUR AVERAGE					
10 ± 2		[6] AUGUSTIN	86	DM2	$J/\psi \to \eta_c\gamma$
11 ± 6	23 ± 11	[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$
20^{+20}_{-10}		[7] HIMEL	80B	MRK2	$\psi(2S) \to \eta_c\gamma$

$\Gamma(\pi^+\pi^- p\bar{p})/\Gamma_{total}$ Γ_3/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.012	90	HIMEL	80B	MRK2	$\psi(2S) \to \eta_c\gamma$

$\Gamma(K\bar{K}\pi)/\Gamma_{total}$ Γ_4/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.055 ± 0.008 OUR AVERAGE						
0.0613 ± 0.0122			[6] AUGUSTIN	86	DM2	$J/\psi \to \eta_c\gamma$
0.048 ± 0.011		96 ± 18	[6,8] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$
$0.079^{+0.042}_{-0.032}$			[7,9] HIMEL	80B	MRK2	$\psi(2S) \to \eta_c\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.107	90		[6] PARTRIDGE	80B	CBAL	$J/\psi \to \eta_c\gamma$

$\Gamma(\pi^+\pi^- K^+K^-)/\Gamma_{total}$ Γ_5/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.0204^{+0.0029}_{-0.0027}$ OUR AVERAGE					
0.021 ± 0.003	110 ± 17	[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$
$0.009^{+0.014}_{-0.006}$		[7] HIMEL	80B	MRK2	$\psi(2S) \to \eta_c\gamma$

$\Gamma(\eta\pi\pi)/\Gamma_{total}$ Γ_6/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.050 ± 0.011 OUR AVERAGE					
0.054 ± 0.013	75 ± 11	[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$
0.036 ± 0.024	18	[6] PARTRIDGE	80B	CBAL	$J/\psi \to \eta\pi^+\pi^-\gamma$

$\Gamma(\phi\phi)/\Gamma_{total}$ Γ_7/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
34 ± 12 OUR AVERAGE Error includes scale factor of 1.5.					
31 ± 7 ± 4	19	[6] BISELLO	86	DM2	$J/\psi \to 2\phi\gamma$
80 ± 20 ± 25	16 ± 4	[6] BALTRUSAITIS	84	MRK3	$J/\psi \to 2\phi\gamma$

$\Gamma(K^*(892)\bar{K}^*(892))/\Gamma_{total}$ Γ_8/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
90 ± 50	9 ± 4	[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(\rho\rho)/\Gamma_{total}$ Γ_9/Γ

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
26 ± 8 ± 5		113	BISELLO	88	DM2	$J/\psi \to \eta_c\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<140	90		[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(\omega\omega)/\Gamma_{total}$ Γ_{10}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0031	90	[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(a_0(980)\pi)/\Gamma_{total}$ Γ_{11}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	90	[6,10] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(a_2(1320)\pi)/\Gamma_{total}$ Γ_{12}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	90	[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(f_2(1270)\eta)/\Gamma_{total}$ Γ_{13}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.011	90	[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(\eta'(958)\pi\pi)/\Gamma_{total}$ Γ_{14}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.041 ± 0.017	14 ± 4	[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(K\bar{K}\eta)/\Gamma_{total}$ Γ_{15}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.031	90	[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(K^*(892)^0 K^-\pi^+$ + c.c.$)/\Gamma_{total}$ Γ_{16}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.02 ± 0.007	63 ± 10	[6] BALTRUSAITIS	86	MRK3	$J/\psi \to \eta_c\gamma$

[6] The quoted branching ratios use $BR(J/\psi(1S) \to \eta_c(1S)\gamma)$ = 0.0127 ± 0.0036.
[7] Estimated using $BR(\psi(2S) \to \eta_c(1S)\gamma)$ = 0.0043. The errors do not contain the uncertainty in the $\psi(2S)$ decay.
[8] Average from $K^+K^-\pi^0$ and $K^\pm K^0_S\pi^\mp$ decay channels.
[9] Not seen by Partridge in $K^+K^-\pi^0$.
[10] We are assuming $BR(a_0(980) \to \eta\pi)$ = 0.5.

RADIATIVE DECAYS

$\Gamma(\gamma\gamma)/\Gamma_{total}$ Γ_{17}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
$6^{+4}_{-3} \pm 4$		BAGLIN	87B	SPEC	$p\bar{p} \to \gamma\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<18	90	[11] BLOOM	83	CBAL	$J/\psi \to \eta_c \gamma$

[11] Using $BR(J/\psi(1S) \to \eta_c(1S)\gamma) = 0.0127 \pm 0.0036$

$\Gamma_i\Gamma_j/\Gamma^2_{total}$ in $p\bar{p} \to \eta_c(1S) \to \gamma\gamma$ $\Gamma_2\Gamma_{17}/\Gamma^2$

VALUE (units 10^{-6})	EVTS	DOCUMENT ID		TECN	COMMENT
$0.68^{+0.42}_{-0.31}$	12	BAGLIN	87B	SPEC	$\bar{p}p \to \gamma\gamma$

$\eta_c(1S)$ REFERENCES

BISELLO	88	PL B200 215	+Busetto+	(PADO, CLER, FRAS, LALO)
BAGLIN	87B	PL B187 191	+Baird, Bassompierre, Borreani+	(R704 Collab.)
AUGUSTIN	86	Moriond XXI 421	+Ajaltouni, Bisello+	(LALO, CLER, PADO, FRAS)
BALTRUSAITIS	86	PR D33 629	+Coffman, Hauser+	(MARK III Collab.)
BERGER	86	PL 167B 120	+Genzel, Lackas, Pielorz+	(TASSO Collab.)
BISELLO	86	PL B179 289	+Busetto, Castro, Limentani+	(DM2 Collab.)
BLINOV	86	NOVO 86 107	+Blinov, Bondar, Bukin+	(NOVO)
GAISER	86	PR D34 711	+Bloom, Bulos, Godfrey+	(Crystal Ball Collab.)
ALTHOFF	85B	ZPHY C29 189	+Braunschweig, Kirschfink+	(TASSO Collab.)
BALTRUSAITIS	84	PRL 52 2126	+	(CIT, UCSC, ILL, SLAC, WASH) JP
BLOOM	83	ARNS 33 143	+Peck	(SLAC, CIT)
HIMEL	80B	PRL 45 1146	+Trilling, Abrams, Alam+	(SLAC, LBL, UCB)
PARTRIDGE	80B	PRL 45 1150	+Peck+	(CIT, HARV, PRIN, STAN, SLAC)

OTHER RELATED PAPERS

BLOOM 79 Fermilab Symp. 92 (CIT, HARV, PRIN, SLAC, STAN)

$J/\psi(1S)$ or $J/\psi(3097)$

$I^G(J^{PC}) = 0^-(1^{--})$

$J/\psi(1S)$ MASS

We use independent measurements of the $J/\psi(1S)$ mass, the $\psi(2S)$ mass, and the mass difference to perform a constrained fit.

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3096.93 ± 0.09 OUR AVERAGE					
3096.95 ± 0.1 ± 0.3	193	BAGLIN	87	SPEC	$p\bar{p} \to e^+e^- X$
3098.4 ± 2.0	38k	LEMOIGNE	82	GOLI	190 GeV π^- Be $\to 2\mu$
3096.93 ± 0.09	502	ZHOLENTZ	80	REDE	e^+e^-
3097.0 ± 1		[1] BRANDELIK	79C	DASP	e^+e^-

[1] From a simultaneous fit to e^+e^-, $\mu^+\mu^-$, and hadronic channels assuming $\Gamma(e^+e^-) = \Gamma(\mu^+\mu^-)$.

$J/\psi(1S)$ WIDTH

VALUE (keV)	DOCUMENT ID
68 ± 10 OUR EVALUATION	Uses $\Gamma(ee)$ from ALEXANDER 88 and $BR(ee) = BR(\mu\mu)$ from BOYARSKI 75

$J/\psi(1S)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale/Conf Lev
Γ_1	$J/\psi(1S) \to e^+e^-$	$(6.9 \pm 0.9) \times 10^{-2}$	
Γ_2	$J/\psi(1S) \to \mu^+\mu^-$	$(6.9 \pm 0.9) \times 10^{-2}$	
Γ_3	$J/\psi(1S) \to$ hadrons	$(86.0 \pm 2.0) \times 10^{-2}$	
Γ_4	$J/\psi(1S) \to$ virtual $\gamma \to$ hadrons	$(17.0 \pm 2.0) \times 10^{-2}$	

HADRONIC DECAYS

	Mode	Fraction (Γ_i/Γ)	Scale/Conf Lev
Γ_5	$J/\psi(1S) \to \pi^+\pi^-$	$(1.47 \pm 0.23) \times 10^{-4}$	
Γ_6	$J/\psi(1S) \to \pi^+\pi^-\pi^0$	$(1.50 \pm 0.15) \times 10^{-2}$	
Γ_7	$J/\psi(1S) \to 2(\pi^+\pi^-)$	$(4.0 \pm 1.0) \times 10^{-3}$	
Γ_8	$J/\psi(1S) \to 2(\pi^+\pi^-)\pi^0$	$(3.42 \pm 0.31) \times 10^{-2}$	
Γ_9	$J/\psi(1S) \to 3(\pi^+\pi^-)$	$(4.0 \pm 2.0) \times 10^{-3}$	
Γ_{10}	$J/\psi(1S) \to 3(\pi^+\pi^-)\pi^0$	$(2.9 \pm 0.6) \times 10^{-2}$	
Γ_{11}	$J/\psi(1S) \to 4(\pi^+\pi^-)\pi^0$	$(9.0 \pm 3.0) \times 10^{-3}$	
Γ_{12}	$J/\psi(1S) \to K^+K^-$	$(2.36 \pm 0.30) \times 10^{-4}$	
Γ_{13}	$J/\psi(1S) \to K^0_S K^0_S$	$< 5.2 \times 10^{-6}$	CL=90%
Γ_{14}	$J/\psi(1S) \to K^0_S K^0_L$	$(1.01 \pm 0.18) \times 10^{-4}$	
Γ_{15}	$J/\psi(1S) \to K\bar{K}\pi$	$(6.1 \pm 1.0) \times 10^{-3}$	
Γ_{16}	$J/\psi(1S) \to \pi^+\pi^-K^+K^-$	$(7.2 \pm 2.3) \times 10^{-3}$	
Γ_{17}	$J/\psi(1S) \to 2(\pi^+\pi^-)K^+K^-$	$(3.1 \pm 1.3) \times 10^{-3}$	
Γ_{18}	$J/\psi(1S) \to \pi^+\pi^-\pi^0K^+K^-$	$(1.20 \pm 0.30) \times 10^{-2}$	
Γ_{19}	$J/\psi(1S) \to 2(K^+K^-)$	$(7.0 \pm 3.0) \times 10^{-4}$	
Γ_{20}	$J/\psi(1S) \to \rho\pi$	$(1.28 \pm 0.10) \times 10^{-2}$	
Γ_{21}	$J/\psi(1S) \to \rho^0\pi^0$	$(4.2 \pm 0.5) \times 10^{-3}$	
Γ_{22}	$J/\psi(1S) \to \rho\eta$	$(1.93 \pm 0.32) \times 10^{-4}$	
Γ_{23}	$J/\psi(1S) \to \rho\eta'(958)$	$(9.6 \pm 1.8) \times 10^{-5}$	S=1.2
Γ_{24}	$J/\psi(1S) \to \omega\pi^+\pi^-$	$(7.0 \pm 0.8) \times 10^{-3}$	
Γ_{25}	$J/\psi(1S) \to \omega\pi^+\pi^+\pi^-\pi^-$	$(8.5 \pm 3.4) \times 10^{-3}$	
Γ_{26}	$J/\psi(1S) \to \omega K\bar{K}$	$(1.6 \pm 1.0) \times 10^{-3}$	
Γ_{27}	$J/\psi(1S) \to \omega f_2(1270)$	$(3.3 \pm 0.7) \times 10^{-3}$	S=1.5
Γ_{28}	$J/\psi(1S) \to \omega f'_2(1525)$	$< 1.6 \times 10^{-4}$	CL=90%
Γ_{29}	$J/\psi(1S) \to \omega\eta$	$(1.71 \pm 0.22) \times 10^{-3}$	
Γ_{30}	$J/\psi(1S) \to \omega\eta'(958)$	$(1.66 \pm 0.25) \times 10^{-4}$	
Γ_{31}	$J/\psi(1S) \to \omega\pi^0$	$(4.8 \pm 0.7) \times 10^{-4}$	
Γ_{32}	$J/\psi(1S) \to \phi\pi^0$	$< 6.8 \times 10^{-6}$	
Γ_{33}	$J/\psi(1S) \to \phi\pi^+\pi^-$	$(7.9 \pm 1.6) \times 10^{-4}$	
Γ_{34}	$J/\psi(1S) \to \phi 2(\pi^+\pi^-)$	$< 1.5 \times 10^{-3}$	CL=90%
Γ_{35}	$J/\psi(1S) \to \phi KK$	$(1.8 \pm 0.8) \times 10^{-3}$	
Γ_{36}	$J/\psi(1S) \to \phi\eta$	$(7.14 \pm 0.30) \times 10^{-4}$	
Γ_{37}	$J/\psi(1S) \to \phi\eta'(958)$	$(3.8 \pm 0.4) \times 10^{-4}$	S=1.6
Γ_{38}	$J/\psi(1S) \to \phi f_2(1270)$	$< 3.7 \times 10^{-4}$	CL=90%
Γ_{39}	$J/\psi(1S) \to \phi f'_2(1525)$	$(4.5 \pm 0.5) \times 10^{-4}$	
Γ_{40}	$J/\psi(1S) \to \phi f_0(975)$	$(2.9 \pm 0.4) \times 10^{-4}$	
Γ_{41}	$J/\psi(1S) \to a_2(1320)^\pm\pi^\mp$	$< 4.3 \times 10^{-3}$	CL=90%
Γ_{42}	$J/\psi(1S) \to a_2(1320)\rho$	$(8.6 \pm 1.3) \times 10^{-3}$	
Γ_{43}	$J/\psi(1S) \to K^+K^*(892)^- +$ c.c.	$(3.8 \pm 0.7) \times 10^{-3}$	S=2.0
Γ_{44}	$J/\psi(1S) \to K^0\bar{K}^*(892)^0 +$ c.c.	$(3.7 \pm 0.8) \times 10^{-3}$	S=2.1
Γ_{45}	$J/\psi(1S) \to K\bar{K}^*_2(1430) +$ c.c.	$< 4.0 \times 10^{-3}$	CL=90%
Γ_{46}	$J/\psi(1S) \to K^*(892)^0 K^*(892)^0$	$< 5 \times 10^{-4}$	CL=90%
Γ_{47}	$J/\psi(1S) \to K^*_2(1430)^0 K^*_2(1430)^0$	$< 2.9 \times 10^{-3}$	CL=90%
Γ_{48}	$J/\psi(1S) \to K^*(892)^0 K^*_2(1430)^0 +$ c.c.	$(6.7 \pm 2.6) \times 10^{-3}$	
Γ_{49}	$J/\psi(1S) \to b_1(1235)^\pm\pi^\mp$	$(2.9 \pm 0.7) \times 10^{-3}$	
Γ_{50}	$J/\psi(1S) \to p\bar{p}$	$(2.16 \pm 0.11) \times 10^{-3}$	
Γ_{51}	$J/\psi(1S) \to p\bar{p}\pi^0$	$(1.09 \pm 0.09) \times 10^{-3}$	
Γ_{52}	$J/\psi(1S) \to pn\pi^-$	$(2.00 \pm 0.10) \times 10^{-3}$	
Γ_{53}	$J/\psi(1S) \to p\bar{p}\pi^+\pi^-$	$(6.0 \pm 0.5) \times 10^{-3}$	S=1.3
Γ_{54}	$J/\psi(1S) \to p\bar{p}\pi^+\pi^-\pi^0$	$(2.3 \pm 0.9) \times 10^{-3}$	S=1.9
Γ_{55}	$J/\psi(1S) \to p\bar{p}\eta$	$(2.09 \pm 0.18) \times 10^{-3}$	
Γ_{56}	$J/\psi(1S) \to p\bar{p}\rho$	$< 3.1 \times 10^{-4}$	CL=90%
Γ_{57}	$J/\psi(1S) \to p\bar{p}\omega$	$(1.30 \pm 0.25) \times 10^{-3}$	S=1.3
Γ_{58}	$J/\psi(1S) \to p\bar{p}\eta'(958)$	$(9 \pm 4) \times 10^{-4}$	S=1.7
Γ_{59}	$J/\psi(1S) \to \Lambda\bar{\Lambda}$	$(1.35 \pm 0.14) \times 10^{-3}$	S=1.2
Γ_{60}	$J/\psi(1S) \to \Lambda\bar{\Sigma} +$ c.c.	$< 1.5 \times 10^{-4}$	CL=90%
Γ_{61}	$J/\psi(1S) \to \Xi\bar{\Xi}$	$(1.8 \pm 0.4) \times 10^{-3}$	S=1.8
Γ_{62}	$J/\psi(1S) \to \Sigma\bar{\Sigma}$	$(3.8 \pm 0.5) \times 10^{-3}$	
Γ_{63}	$J/\psi(1S) \to n\bar{n}$	$(1.8 \pm 0.9) \times 10^{-3}$	
Γ_{64}	$J/\psi(1S) \to n\bar{n}\pi^+\pi^-$	$(4 \pm 4) \times 10^{-3}$	
Γ_{65}	$J/\psi(1S) \to \Delta(1232)^{++}\bar{\Delta}(1232)^{--}$	$(1.10 \pm 0.29) \times 10^{-3}$	
Γ_{66}	$J/\psi(1S) \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$ (or c.c.)	$(1.03 \pm 0.13) \times 10^{-3}$	
Γ_{67}	$J/\psi(1S) \to \Sigma(1385)^-\bar{\Sigma}^+$ (or c.c.)	$(3.1 \pm 0.5) \times 10^{-4}$	
Γ_{68}	$J/\psi(1S) \to \Delta(1232)^{++}\bar{p}\pi^-$	$(1.6 \pm 0.5) \times 10^{-3}$	
Γ_{69}	$J/\psi(1S) \to \Lambda\bar{\Sigma}^-\pi^+$ (or c.c.)	$(1.06 \pm 0.12) \times 10^{-3}$	
Γ_{70}	$J/\psi(1S) \to pK^-\bar{\Lambda}$	$(8.9 \pm 1.6) \times 10^{-4}$	
Γ_{71}	$J/\psi(1S) \to pK^-\bar{\Sigma}^0$	$(2.9 \pm 0.8) \times 10^{-4}$	
Γ_{72}	$J/\psi(1S) \to pK^-\Sigma(1385)^0$	$(5.1 \pm 3.2) \times 10^{-4}$	
Γ_{73}	$J/\psi(1S) \to \omega K^\pm K^0_S\pi^\mp$	$(2.9 \pm 0.7) \times 10^{-3}$	
Γ_{74}	$J/\psi(1S) \to \omega K^*(892)\bar{K} +$ c.c.	$(5.3 \pm 2.0) \times 10^{-3}$	

Γ_{75}	$J/\psi(1S) \to \phi K^{\pm} K^0_S \pi^{\mp}$	$(7.0 \pm 1.2) \times 10^{-4}$	
Γ_{76}	$J/\psi(1S) \to \phi K^*(892)\overline{K}$ + c.c.	$(2.0 \pm 0.4) \times 10^{-3}$	
Γ_{77}	$J/\psi(1S) \to \omega f_1(1420)$	$(6.8 {}^{+2.5}_{-2.3}) \times 10^{-4}$	
Γ_{78}	$J/\psi(1S) \to \phi f_1(1285)$	$(8 \pm 5) \times 10^{-5}$	S=2.2
Γ_{79}	$J/\psi(1S) \to \Xi(1530)^{-}\overline{\Xi}^{+}$	$(5.9 \pm 1.5) \times 10^{-4}$	
Γ_{80}	$J/\psi(1S) \to \Xi(1530)^{0}\overline{\Xi}^{0}$	$(3.2 \pm 1.4) \times 10^{-4}$	
Γ_{81}	$J/\psi(1S) \to \Lambda\overline{\Lambda}\pi^0$	$(2.2 \pm 0.7) \times 10^{-4}$	
Γ_{82}	$J/\psi(1S) \to \Sigma^0\overline{\Lambda}$	$< 9 \times 10^{-5}$	CL=90%
Γ_{83}	$J/\psi(1S) \to \Sigma(1385)^0\overline{\Lambda}$	$< 2 \times 10^{-4}$	CL=90%
Γ_{84}	$J/\psi(1S) \to \Delta(1232)^+\overline{p}$	$< 1 \times 10^{-4}$	CL=90%

RADIATIVE DECAYS

Γ_{85}	$J/\psi(1S) \to \gamma\gamma$	$< 5 \times 10^{-4}$	CL=90%
Γ_{86}	$J/\psi(1S) \to 3\gamma$	$< 5.5 \times 10^{-5}$	CL=90%
Γ_{87}	$J/\psi(1S) \to \pi^0\gamma$	$(3.9 \pm 1.3) \times 10^{-5}$	
Γ_{88}	$J/\psi(1S) \to \eta\gamma$	$(8.6 \pm 0.8) \times 10^{-4}$	
Γ_{89}	$J/\psi(1S) \to \eta'(958)\gamma$	$(4.2 \pm 0.4) \times 10^{-3}$	
Γ_{90}	$J/\psi(1S) \to \eta_c(1S)\gamma$	$(1.3 \pm 0.4) \times 10^{-2}$	
Γ_{91}	$J/\psi(1S) \to f_2(1270)\gamma$	$(1.38 \pm 0.14) \times 10^{-3}$	
Γ_{92}	$J/\psi(1S) \to f_2'(1525)\gamma$	$(2.3 \pm 0.5) \times 10^{-4}$	S=1.2
Γ_{93}	$J/\psi(1S) \to f_1(1285)\gamma$	$< 6 \times 10^{-3}$	CL=90%
Γ_{94}	$J/\psi(1S) \to \eta(1430)\gamma$	$(4.7 \pm 0.6) \times 10^{-3}$	
Γ_{95}	$J/\psi(1S) \to p\overline{p}\gamma$	$(3.8 \pm 1.0) \times 10^{-4}$	
Γ_{96}	$J/\psi(1S) \to f_2(1720)\gamma$		
Γ_{97}	$J/\psi(1S) \to X(2220)\gamma$		
Γ_{98}	$J/\psi(1S) \to p\overline{p}\pi^+\pi^-\gamma$	$< 7.9 \times 10^{-4}$	CL=90%
Γ_{99}	$J/\psi(1S) \to \rho\rho\gamma$	$(4.5 \pm 0.8) \times 10^{-3}$	
Γ_{100}	$J/\psi(1S) \to 2\pi^+2\pi^-\gamma$	$(3.3 \pm 0.6) \times 10^{-3}$	S=1.3
Γ_{101}	$J/\psi(1S) \to \eta\pi\pi\gamma$	$(6.1 \pm 1.0) \times 10^{-3}$	
Γ_{102}	$J/\psi(1S) \to \omega\omega\gamma$	$(1.59 \pm 0.33) \times 10^{-3}$	
Γ_{103}	$J/\psi(1S) \to \phi\phi\gamma$	$(3.1 \pm 0.8) \times 10^{-4}$	
Γ_{104}	$J/\psi(1S) \to \pi^+\pi^-2\pi^0\gamma$	$(8.3 \pm 3.1) \times 10^{-3}$	
Γ_{105}	$J/\psi(1S) \to f_4(2050)\gamma$	$(2.7 \pm 0.8) \times 10^{-3}$	
Γ_{106}	$J/\psi(1S) \to \Lambda\overline{\Lambda}\gamma$	$< 1.3 \times 10^{-4}$	CL=90%

$J/\psi(1S)$ PARTIAL WIDTHS

$\Gamma(e^+e^-)$ — Γ_1

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
4.72 ± 0.35	ALEXANDER	88	RVUE	See Υ mini-review
• • • We do not use the following data for averages, fits, limits, etc. • • •				
4.4 ± 0.6	[2] BRANDELIK	79C	DASP	e^+e^-
4.6 ± 0.8	[3] BALDINI	75	FRAG	e^+e^-
4.8 ± 0.6	BOYARSKI	75	MRK1	e^+e^-
4.6 ± 1.0	ESPOSITO	75B	FRAM	e^+e^-

[2] From a simultaneous fit to e^+e^-, $\mu^+\mu^-$, and hadronic channels assuming $\Gamma(e^+e^-) = \Gamma(\mu^+\mu^-)$.
[3] Assuming equal partial widths for e^+e^- and $\mu^+\mu^-$.

$\Gamma(\mu^+\mu^-)$ — Γ_2

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
4.8 ± 0.6	BOYARSKI	75	MRK1	e^+e^-
5.0 ± 1.0	ESPOSITO	75B	FRAM	e^+e^-

Γ(hadrons) — Γ_3

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
59 ± 24	BALDINI	75	FRAG	e^+e^-
59 ± 14	BOYARSKI	75	MRK1	e^+e^-
50 ± 25	ESPOSITO	75B	FRAM	e^+e^-

Γ(virtual $\gamma \to$ hadrons) — Γ_4

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
12. ± 2.	[4] BOYARSKI	75	MRK1	e^+e^-

[4] Included in Γ(hadrons).

$\Gamma(\gamma\gamma)$ — Γ_{85}

VALUE (eV)	CL%	DOCUMENT ID		TECN	COMMENT
<5.4	90	BRANDELIK	79C	DASP	e^+e^-

$J/\psi(1S)$ $\Gamma(i)\Gamma(e^+e^-)/\Gamma$(total)

This combination of a partial width with the partial width into e^+e^- and with the total width is obtained from the integrated cross section into channel$_i$ in the e^+e^- annihilation.

$\Gamma(e^+e^-) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_1\Gamma_1/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.35 ± 0.02	BRANDELIK	79C	DASP	e^+e^-
0.32 ± 0.07	[5] BALDINI	75	FRAG	e^+e^-
0.34 ± 0.14	BEMPORAD	75	FRAB	e^+e^-
0.34 ± 0.09	[5] ESPOSITO	75B	FRAM	e^+e^-
0.36 ± 0.10	[5] FORD	75	SPEC	e^+e^-

$\Gamma(\mu^+\mu^-) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_2\Gamma_1/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.31 ± 0.09	BEMPORAD	75	FRAB	e^+e^-
0.51 ± 0.09	DASP	75	DASP	e^+e^-
0.38 ± 0.05	[5] ESPOSITO	75B	FRAM	e^+e^-
0.46 ± 0.10	[5] LIBERMAN	75	SPEC	e^+e^-

Γ(hadrons) $\times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_3\Gamma_1/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
4 ± 0.8	[5] BALDINI	75	FRAG	e^+e^-
3.9 ± 0.8	[5] ESPOSITO	75B	FRAM	e^+e^-

[5] Data redundant with branching ratios or partial widths above.

$J/\psi(1S)$ BRANCHING RATIOS

For the first four branching ratios, see also the partial widths, and (partial widths) × $\Gamma(e^+e^-)/\Gamma_{total}$ above.

$\Gamma(e^+e^-)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.069 ± 0.009	BOYARSKI	75	MRK1	e^+e^-

$\Gamma(\mu^+\mu^-)/\Gamma_{total}$ — Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.069 ± 0.009	BOYARSKI	75	MRK1	e^+e^-

Γ(hadrons)$/\Gamma_{total}$ — Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.86 ± 0.02	BOYARSKI	75	MRK1	e^+e^-

Γ(virtual $\gamma \to$ hadrons)$/\Gamma_{total}$ — Γ_4/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.17 ± 0.02	[6] BOYARSKI	75	MRK1	e^+e^-

[6] Included in Γ(hadrons)/Γ$_{total}$.

$\Gamma(e^+e^-)/\Gamma(\mu^+\mu^-)$ — Γ_1/Γ_2

VALUE	DOCUMENT ID		TECN	COMMENT
0.98 ± 0.04 OUR AVERAGE				
1.00 ± 0.05	BOYARSKI	75	MRK1	e^+e^-
0.91 ± 0.15	ESPOSITO	75B	FRAM	e^+e^-
0.93 ± 0.10	FORD	75	SPEC	e^+e^-

HADRONIC DECAYS

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ — Γ_5/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
1.47 ± 0.23 OUR AVERAGE					
1.58 ± 0.20 ± 0.15	84	BALTRUSAITIS	85D	MRK3	e^+e^-
1.0 ± 0.5	5	BRANDELIK	78B	DASP	e^+e^-
1.6 ± 1.6	1	VANNUCCI	77	MRK1	e^+e^-

$\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{total}$ — Γ_6/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0150 ± 0.0015 OUR AVERAGE					
0.0149 ± 0.0022		EINSWEILER	83	MRK3	e^+e^-
0.015 ± 0.002	168	FRANKLIN	83C	MRK2	e^+e^-

$\Gamma(2(\pi^+\pi^-))/\Gamma_{total}$ — Γ_7/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.004 ± 0.001	76	JEAN-MARIE	76	MRK1	e^+e^-

$\Gamma(2(\pi^+\pi^-)\pi^0)/\Gamma_{total}$ — Γ_8/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0342 ± 0.0031 OUR AVERAGE					
0.0317 ± 0.0042	147	FRANKLIN	83C	MRK2	$e^+e^- \to$ hadrons
0.0364 ± 0.0052	1500	BURMESTER	77D	PLUT	e^+e^-
0.04 ± 0.01	675	JEAN-MARIE	76	MRK1	e^+e^-

$\Gamma(3(\pi^+\pi^-))/\Gamma_{total}$ — Γ_9/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
40 ± 20	32	JEAN-MARIE 76	MRK1	e^+e^-

$\Gamma(3(\pi^+\pi^-)\pi^0)/\Gamma_{total}$ — Γ_{10}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.029 ± 0.006 OUR AVERAGE				
0.028 ± 0.009	11	FRANKLIN 83C	MRK2	$e^+e^- \to$ hadrons
0.029 ± 0.007	181	JEAN-MARIE 76	MRK1	e^+e^-

$\Gamma(4(\pi^+\pi^-)\pi^0)/\Gamma_{total}$ — Γ_{11}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
90 ± 30	13	JEAN-MARIE 76	MRK1	e^+e^-

$\Gamma(K^+K^-)/\Gamma_{total}$ — Γ_{12}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
2.36 ± 0.30 OUR AVERAGE				
2.39 ± 0.24 ± 0.22	107	BALTRUSAITIS 85D	MRK3	e^+e^-
2.2 ± 0.9	6	BRANDELIK 79C	DASP	e^+e^-
2.0 ± 1.6	2	VANNUCCI 77	MRK1	e^+e^-

$\Gamma(K^0_S K^0_S)/\Gamma_{total}$ — Γ_{13}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN	COMMENT
<0.052	90	[7] BALTRUSAITIS 85C	MRK3	e^+e^-

[7] Forbidden by CP

$\Gamma(K\bar{K}\pi)/\Gamma_{total}$ — Γ_{15}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
61 ± 10 OUR AVERAGE				
55.2 ± 12.0	25	FRANKLIN 83C	MRK2	$e^+e^- \to K^+K^-\pi^0$
78.0 ± 21.0	126	VANNUCCI 77	MRK1	$e^+e^- \to K^0_S K^\pm \pi^\mp$

$\Gamma(\pi^+\pi^-K^+K^-)/\Gamma_{total}$ — Γ_{16}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
72 ± 23	205	VANNUCCI 77	MRK1	e^+e^-

$\Gamma(2(\pi^+\pi^-)K^+K^-)/\Gamma_{total}$ — Γ_{17}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
31 ± 13	30	VANNUCCI 77	MRK1	e^+e^-

$\Gamma(\pi^+\pi^-\pi^0K^+K^-)/\Gamma_{total}$ — Γ_{18}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.012 ± 0.003	309	VANNUCCI 77	MRK1	e^+e^-

$\Gamma(2(K^+K^-))/\Gamma_{total}$ — Γ_{19}/Γ

VALUE (units 10^{-4})	DOCUMENT ID	TECN	COMMENT
7 ± 3	VANNUCCI 77	MRK1	e^+e^-

$\Gamma(\rho\pi)/\Gamma_{total}$ — Γ_{20}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.0128 ± 0.0010 OUR AVERAGE				
0.0142 ± 0.0001 ± 0.0019		COFFMAN 88	MRK3	e^+e^-
0.013 ± 0.003	150	FRANKLIN 83C	MRK2	e^+e^-
0.016 ± 0.004	183	ALEXANDER 78	PLUT	e^+e^-
0.0133 ± 0.0021		BRANDELIK 78B	DASP	e^+e^-
0.010 ± 0.002	543	BARTEL 76	CNTR	e^+e^-
0.013 ± 0.003	153	JEAN-MARIE 76	MRK1	e^+e^-

$\Gamma(\rho^0\pi^0)/\Gamma(\rho\pi)$ — Γ_{21}/Γ_{20}

VALUE	DOCUMENT ID	TECN	COMMENT
0.328 ± 0.005 ± 0.027	COFFMAN 88	MRK3	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.36 ± 0.03	SCHARRE 79B	MRK1	e^+e^-
0.35 ± 0.08	ALEXANDER 78	PLUT	e^+e^-
0.32 ± 0.08	BRANDELIK 78B	DASP	e^+e^-
0.39 ± 0.11	BARTEL 76	CNTR	e^+e^-
0.37 ± 0.09	JEAN-MARIE 76	MRK1	e^+e^-

$\Gamma(\rho\eta)/\Gamma_{total}$ — Γ_{22}/Γ

VALUE (units 10^{-3})	DOCUMENT ID	TECN	COMMENT
0.193 ± 0.013 ± 0.029	COFFMAN 88	MRK3	$e^+e^- \to \pi^+\pi^-\eta$

$\Gamma(\rho\eta'(958))/\Gamma_{total}$ — Γ_{23}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN	COMMENT
0.096 ± 0.018 OUR AVERAGE Error includes scale factor of 1.2				
0.114 ± 0.014 ± 0.016		COFFMAN 88	MRK3	$J/\psi \to \pi^+\pi^-\eta'$
0.078 ± 0.017 ± 0.012	18	AUGUSTIN 86	DM2	$J/\psi \to$ hadrons

$\Gamma(\omega\pi^+\pi^-)/\Gamma_{total}$ — Γ_{24}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN	COMMENT
7.0 ± 0.8 OUR AVERAGE				
6.6 ± 1.0 ± 0.6		AUGUSTIN 86	DM2	$J/\psi \to$ hadrons
7.8 ± 1.6	215	BURMESTER 77D	PLUT	e^+e^-
6.8 ± 1.9	348	VANNUCCI 77	MRK1	$e^+e^- \to 2(\pi^+\pi^-)\pi^0$

$\Gamma(\omega\pi^+\pi^-)/\Gamma(2(\pi^+\pi^-)\pi^0)$ — Γ_{24}/Γ_8

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.3	[8] JEAN-MARIE 76	MRK1	e^+e^-

[8] Final state $(\pi^+\pi^-)\pi^0$ under the assumption that $\pi\pi$ is isospin 0.

$\Gamma(\omega\pi^+\pi^+\pi^-\pi^-)/\Gamma_{total}$ — Γ_{25}/Γ

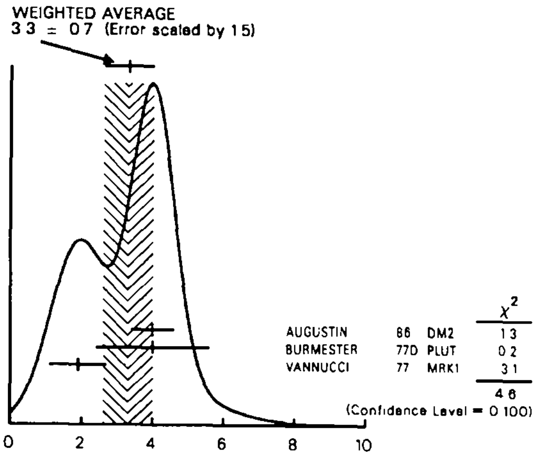
VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
85 ± 34	140	VANNUCCI 77	MRK1	$e^+e^- \to 3(\pi^+\pi^-)\pi^0$

$\Gamma(\omega K\bar{K})/\Gamma_{total}$ — Γ_{26}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
16 ± 10	22	FELDMAN 77	MRK1	e^+e^-

$\Gamma(\omega f_2(1270))/\Gamma_{total}$ — Γ_{27}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN	COMMENT
3.3 ± 0.7 OUR AVERAGE Error includes scale factor of 1.5. See the ideogram below.				
4.0 ± 0.6		AUGUSTIN 86	DM2	$J/\psi \to$ hadrons
4.0 ± 1.6	70	BURMESTER 77D	PLUT	e^+e^-
1.9 ± 0.8	81	VANNUCCI 77	MRK1	$e^+e^- \to 2(\pi^+\pi^-)\pi^0$



$\Gamma(\omega f_2(1270))/\Gamma_{total}$

$\Gamma(\omega f_2'(1525))/\Gamma_{total}$ — Γ_{28}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN	COMMENT
<1.6	90	VANNUCCI 77	MRK1	$e^+e^- \to \pi^+\pi^-\pi^0K^+K^-$

$\Gamma(\omega\eta)/\Gamma_{total}$ — Γ_{29}/Γ

VALUE (units 10^{-3})	DOCUMENT ID	TECN	COMMENT
1.71 ± 0.08 ± 0.20	COFFMAN 88	MRK3	$e^+e^- \to 3\pi\eta$

$\Gamma(\omega\eta'(958))/\Gamma_{total}$ — Γ_{30}/Γ

VALUE (units 10^{-3})	DOCUMENT ID	TECN	COMMENT
0.166 ± 0.017 ± 0.019	COFFMAN 88	MRK3	$e^+e^- \to 3\pi\eta'$

$\Gamma(\omega\pi^0)/\Gamma_{total}$ — Γ_{31}/Γ

VALUE (units 10^{-3})	DOCUMENT ID	TECN	COMMENT
0.482 ± 0.019 ± 0.064	COFFMAN 88	MRK3	$e^+e^- \to \pi^0\pi^+\pi^-\pi^0$

$\Gamma(\phi\pi^0)/\Gamma_{total}$ — Γ_{32}/Γ

VALUE (units 10^{-4})	DOCUMENT ID	TECN	COMMENT
<0.068	COFFMAN 88	MRK3	$e^+e^- \to K^+K^-\pi^0$

$\Gamma(\phi\pi^+\pi^-)/\Gamma_{total}$ — Γ_{33}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN	COMMENT
0.79 ± 0.16 OUR AVERAGE				
0.75 ± 0.16		AUGUSTIN 86	DM2	$J/\psi \to$ hadrons
2.1 ± 0.9	23	FELDMAN 77	MRK1	e^+e^-

$\Gamma(\phi 2(\pi^+\pi^-))/\Gamma_{total}$ — Γ_{34}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN	COMMENT
<15	90	VANNUCCI 77	MRK1	$e^+e^- \to 2(\pi^+\pi^-)K^+K^-$

$\Gamma(\phi K\bar{K})/\Gamma_{total}$ — Γ_{35}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
18 ± 8	14	FELDMAN	77	MRK1	e^+e^-

$\Gamma(\phi\eta)/\Gamma_{total}$ — Γ_{36}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0 714 ± 0 030 OUR AVERAGE					
0 661 ± 0 045 ± 0 078		COFFMAN	88	MRK3	$e^+e^- \to K^+K^-\eta$
0 72 ± 0 03 ± 0 01	330	AUGUSTIN	86	DM2	$J/\psi \to$ hadrons
1 0 ± 0 6	5	VANNUCCI	77	MRK1	$e^+e^- \to \pi^+\pi^-\pi^0K^+K^-$

$\Gamma(\phi\eta'(958))/\Gamma_{total}$ — Γ_{37}/Γ

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0 38 ± 0.04 OUR AVERAGE Error includes scale factor of 1 6						
0 308 ± 0 034 ± 0 036			COFFMAN	88	MRK3	$e^+e^- \to K^+K^-\eta'$
0 40 ± 0 025 ± 0 01		177	AUGUSTIN	86	DM2	$J/\psi \to$ hadrons
• • • We do not use the following data for averages fits limits etc • • •						
<1 3	90		VANNUCCI	77	MRK1	e^+e^-

$\Gamma(\phi f_2(1270))/\Gamma_{total}$ — Γ_{38}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<3.7	90	VANNUCCI	77	MRK1	$e^+e^- \to \pi^+\pi^-K^+K^-$

$\Gamma(\phi f_2'(1525))/\Gamma_{total}$ — Γ_{39}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
4.5 ± 0.5 OUR AVERAGE					
4 6 ± 0 5		AUGUSTIN	86	DM2	$J/\psi \to$ hadrons
3 4 ± 1 3	46	[9] GIDAL	81	MRK2	e^+e^-
8 0 ± 5 0	6	[9] VANNUCCI	77	MRK1	$e^+e^- \to 2(K^+K^-)$

[9] Assumes $f_2(1525) \to K\bar{K}$ is 100%

$\Gamma(\phi f_0(975))/\Gamma_{total}$ — Γ_{40}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
2.9 ± 0.4 OUR AVERAGE					
3 1 ± 0 6		[10] AUGUSTIN	86	DM2	$J/\psi \to$ hadrons
2.6 ± 0 6	50	[10] GIDAL	81	MRK2	e^+e^-

[10] Assuming $BR(f_0(975) \to \pi\pi) = 0\ 78$

$\Gamma(a_2(1320)^{\pm}\pi^{\mp})/\Gamma_{total}$ — Γ_{41}/Γ

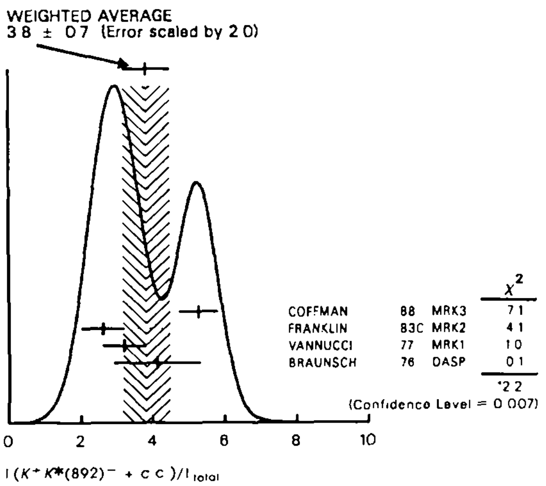
VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<43	90	BRAUNSCH	76	DASP	e^+e^-

$\Gamma(a_2(1320)\rho)/\Gamma_{total}$ — Γ_{42}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
8 6 ± 1.3 OUR AVERAGE					
8 6 ± 0 3 ± 1 3		AUGUSTIN	86	DM2	$J/\psi \to$ hadrons
8 4 ± 4 5	36	VANNUCCI	77	MRK1	$e^+e^- \to 2(\pi^+\pi^-)\pi^0$

$\Gamma(K^+\bar{K}^*(892)^- + c.c.)/\Gamma_{total}$ — Γ_{43}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
3.8 ± 0.7 OUR AVERAGE Error includes scale factor of 2 0 See the ideogram below					
5 26 ± 0 13 ± 0 53		COFFMAN	88	MRK3	$J/\psi \to K^{\pm}K^0_S\pi^{\mp}$, $K^+K^-\pi^0$
2 6 ± 0 6	24	FRANKLIN	83C	MRK2	$J/\psi \to K^+K^-\pi^0$
3 2 ± 0 6	48	VANNUCCI	77	MRK1	$J/\psi \to K^{\pm}K^0_S\pi^{\mp}$
4 1 ± 1 2	39	BRAUNSCH	76	DASP	$J/\psi \to K^{\pm}X$



$\Gamma(K^0\bar{K}^*(892)^0 + c.c.)/\Gamma_{total}$ — Γ_{44}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
3.7 ± 0.8 OUR AVERAGE Error includes scale factor of 2 1					
4 33 ± 0 12 ± 0 45		COFFMAN	88	MRK3	$J/\psi \to K^{\pm}K^0_S\pi^{\mp}$
2 7 ± 0 6	45	VANNUCCI	77	MRK1	$J/\psi \to K^{\pm}K^0_S\pi^{\mp}$

$\Gamma(K^0\bar{K}^*(892)^0 + c.c.)/\Gamma(K^+\bar{K}^*(892)^- + c.c.)$ — Γ_{44}/Γ_{43}

VALUE	DOCUMENT ID		TECN	COMMENT
0.82 ± 0.05 ± 0.09	COFFMAN	88	MRK3	$J/\psi \to K\bar{K}^*(892)$ +c.c.

$\Gamma(K\bar{K}_2^*(1430) + c.c.)/\Gamma_{total}$ — Γ_{45}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<40	90	VANNUCCI	77	MRK1	$e^+e^- \to K^0\bar{K}_2^{*0}$
• • • We do not use the following data for averages fits limits etc • • •					
<66	90	BRAUNSCH	76	DASP	$e^+e^- \to K^{\pm}K_2^{*\mp}$

$\Gamma(K^*(892)^0\bar{K}^*(892)^0)/\Gamma_{total}$ — Γ_{46}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<5	90	VANNUCCI	77	MRK1	$e^+e^- \to \pi^+\pi^-K^+K^-$

$\Gamma(K_2^*(1430)^0\bar{K}_2^*(1430)^0)/\Gamma_{total}$ — Γ_{47}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<29	90	VANNUCCI	77	MRK1	$e^+e^- \to \pi^+\pi^-K^+K^-$

$\Gamma(K^*(892)^0\bar{K}_2^*(1430)^0 + c.c.)/\Gamma_{total}$ — Γ_{48}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
67 ± 26	40	VANNUCCI	77	MRK1	$e^+e^- \to \pi^+\pi^-K^+K^-$

$\Gamma(b_1(1235)^{\pm}\pi^{\mp})/\Gamma_{total}$ — Γ_{49}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
29 ± 7	87	BURMESTER	77D	PLUT	e^+e^-

$\Gamma(p\bar{p})/\Gamma_{total}$ — Γ_{50}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.16 ± 0.11 OUR AVERAGE					
1 91 ± 0 04 ± 0 30		PALLIN	87	DM2	e^+e^-
2 16 ± 0 07 ± 0 15	1420	EATON	84	MRK2	e^+e^-
2 5 ± 0 4	133	BRANDELIK	79C	DASP	e^+e^-
2 0 ± 0 5		BESCH	78	BONA	e^+e^-
2 2 ± 0 2	331	[11] PERUZZI	78	MRK1	e^+e^-

[11] Assuming angular distribution $(1+\cos^2\theta)$

$\Gamma(p\bar{p})/\Gamma(\mu^+\mu^-)$ — Γ_{50}/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.051 ± 0.02	20	[12] WIIK	75	PLUT	e^+e^-

[12] Assuming angular distribution $(1+\cos^2\theta)$

$\Gamma(p\bar{p}\pi^0)/\Gamma_{total}$ — Γ_{51}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.09 ± 0.09 OUR AVERAGE					
1 13 ± 0 09 ± 0 09	685	EATON	84	MRK2	e^+e^-
1 4 ± 0 4		BRANDELIK	79C	DASP	e^+e^-
1 00 ± 0 15	109	PERUZZI	78	MRK1	e^+e^-

$\Gamma(pn\pi^-)/\Gamma_{total}$ — Γ_{52}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.00 ± 0.10 OUR AVERAGE					
2 02 ± 0 07 ± 0 16	1288	EATON	84	MRK2	$e^+e^- \to p\pi^-$
1 93 ± 0 07 ± 0 16	1191	EATON	84	MRK2	$e^+e^- \to \bar{p}\pi^+$
1 7 ± 0 7	32	BESCH	81	BONA	$e^+e^- \to p\pi^-$
1 6 ± 1 2	5	BESCH	81	BONA	$e^+e^- \to \bar{p}\pi^+$
2 16 ± 0 29	194	PERUZZI	78	MRK1	$e^+e^- \to p\pi^-$
2 04 ± 0 27	204	PERUZZI	78	MRK1	$e^+e^- \to \bar{p}\pi^+$

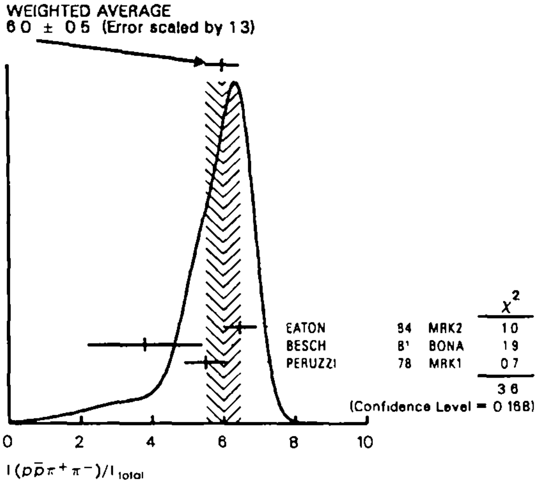
$\Gamma(p\bar{p}\pi^+\pi^-)/\Gamma_{total}$ — Γ_{53}/Γ

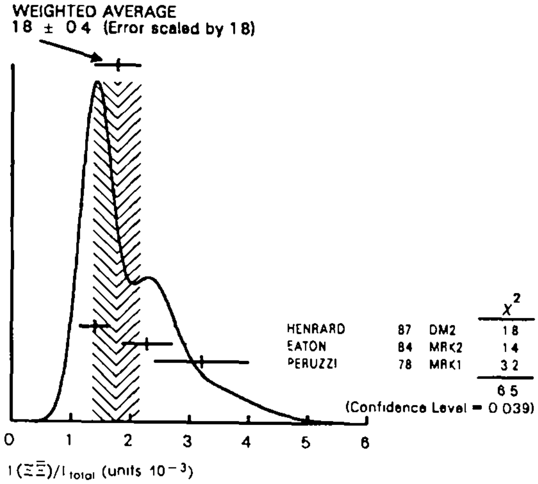
VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
6.0 ± 0 5 OUR AVERAGE Error includes scale factor of 1 3 See the ideogram below					
6 46 ± 0 17 ± 0 43	1435	EATON	84	MRK2	e^+e^-
3 8 ± 1 6	48	BESCH	81	BONA	e^+e^-
5 5 ± 0 6	533	PERUZZI	78	MRK1	e^+e^-

$\Gamma(p\bar{p}\pi^+\pi^-\pi^0)/\Gamma_{total}$ — Γ_{54}/Γ

Including $p\bar{p}\pi^+\pi^-\gamma$ and excluding ω, η, η'

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.3 ± 0.9 OUR AVERAGE Error includes scale factor of 1 9					
3 36 ± 0 65 ± 0 28	364	EATON	84	MRK2	e^+e^-
1 6 ± 0 6	39	PERUZZI	78	MRK1	e^+e^-





$\Gamma(p\bar{p}\eta)/\Gamma_{total}$ Γ_{55}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.09 ± 0.18 OUR AVERAGE					
2.03 ± 0.13 ± 0.15	826	EATON	84	MRK2	e^+e^-
2.5 ± 1.2		BRANDELIK	79C	DASP	e^+e^-
2.3 ± 0.4	197	PERUZZI	78	MRK1	e^+e^-

$\Gamma(p\bar{p}\rho)/\Gamma_{total}$ Γ_{56}/Γ

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<0.31	90	EATON	84	MRK2	$e^+e^- \to$ hadrons γ

$\Gamma(p\bar{p}\omega)/\Gamma_{total}$ Γ_{57}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.30 ± 0.25 OUR AVERAGE	Error includes scale factor of 1.3				
1.10 ± 0.17 ± 0.18	486	EATON	84	MRK2	e^+e^-
1.6 ± 0.3	77	PERUZZI	78	MRK1	e^+e^-

$\Gamma(p\bar{p}\eta'(958))/\Gamma_{total}$ Γ_{58}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.9 ± 0.4 OUR AVERAGE	Error includes scale factor of 1.7				
0.68 ± 0.23 ± 0.17	19	EATON	84	MRK2	e^+e^-
1.8 ± 0.6	19	PERUZZI	78	MRK1	e^+e^-

$\Gamma(\Lambda\bar{\Lambda})/\Gamma_{total}$ Γ_{59}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.35 ± 0.14 OUR AVERAGE	Error includes scale factor of 1.2				
1.38 ± 0.05 ± 0.20	1847	PALLIN	87	DM2	e^+e^-
1.58 ± 0.08 ± 0.19	365	EATON	84	MRK2	e^+e^-
2.6 ± 1.6	5	BESCH	81	BONA	e^+e^-
1.1 ± 0.2	196	PERUZZI	78	MRK1	e^+e^-

$\Gamma(\Lambda\bar{\Sigma}$ + c.c.$)/\Gamma_{total}$ Γ_{60}/Γ

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<0.15	90	PERUZZI	78	MRK1	$e^+e^- \to \Lambda X$

$\Gamma(\Xi\bar{\Xi})/\Gamma_{total}$ Γ_{61}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.8 ± 0.4 OUR AVERAGE	Error includes scale factor of 1.8. See the ideogram below.				
1.40 ± 0.12 ± 0.24	132 ± 11	HENRARD	87	DM2	e^+e^-
2.28 ± 0.16 ± 0.40	194	EATON	84	MRK2	e^+e^-
3.2 ± 0.8	71	PERUZZI	78	MRK1	e^+e^-

$\Gamma(\Sigma\bar{\Sigma})/\Gamma_{total}$ Γ_{62}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
3.8 ± 0.5 OUR AVERAGE					
3.18 ± 0.12 ± 0.69	884 ± 30	PALLIN	87	DM2	e^+e^-
4.74 ± 0.48 ± 0.75	90	EATON	84	MRK2	$e^+e^- \to \Sigma^0\bar{\Sigma}^0$
7.2 ± 7.8	3	BESCH	81	BONA	$e^+e^- \to \Sigma^+\bar{\Sigma}^-$
3.9 ± 1.2	52	PERUZZI	78	MRK1	$e^+e^- \to \Sigma^0\bar{\Sigma}^0$

$\Gamma(n\bar{n})/\Gamma_{total}$ Γ_{63}/Γ

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
0.18 ± 0.09	BESCH	78	BONA	e^+e^-

$\Gamma(n\bar{n}\pi^+\pi^-)/\Gamma_{total}$ Γ_{64}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
3.8 ± 3.6	5	BESCH	81	BONA	e^+e^-

$\Gamma(\Delta(1232)^{++}\bar{\Delta}(1232)^{--})/\Gamma_{total}$ Γ_{65}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.10 ± 0.09 ± 0.28	233	EATON	84	MRK2	e^+e^-

$\Gamma(\Sigma(1385)^-\bar{\Sigma}(1385)^+$ (or c.c.)$)/\Gamma_{total}$ Γ_{66}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.03 ± 0.13 OUR AVERAGE					
1.00 ± 0.04 ± 0.21	631 ± 25	HENRARD	87	DM2	$e^+e^- \to \Sigma^{*-}$
1.19 ± 0.04 ± 0.25	754 ± 27	HENRARD	87	DM2	$e^+e^- \to \Sigma^{*+}$
0.86 ± 0.18 ± 0.22	56	EATON	84	MRK2	$e^+e^- \to \Sigma^{*-}$
1.03 ± 0.24 ± 0.25	68	EATON	84	MRK2	$e^+e^- \to \Sigma^{*+}$

$\Gamma(\Sigma(1385)^-\bar{\Sigma}^+$ (or c.c.)$)/\Gamma_{total}$ Γ_{67}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.31 ± 0.05 OUR AVERAGE					
0.30 ± 0.03 ± 0.07	74 ± 8	HENRARD	87	DM2	$e^+e^- \to \Sigma^{*-}$
0.34 ± 0.04 ± 0.07	77 ± 9	HENRARD	87	DM2	$e^+e^- \to \Sigma^{*+}$
0.29 ± 0.11 ± 0.10	26	EATON	84	MRK2	$e^+e^- \to \Sigma^{*-}$
0.31 ± 0.11 ± 0.11	28	EATON	84	MRK2	$e^+e^- \to \Sigma^{*+}$

$\Gamma(\Delta(1232)^{++}\bar{p}\pi^-)/\Gamma_{total}$ Γ_{68}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.58 ± 0.23 ± 0.40	332	EATON	84	MRK2	e^+e^-

$\Gamma(\Lambda\bar{\Sigma}^-\pi^+$ (or c.c.)$)/\Gamma_{total}$ Γ_{69}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.06 ± 0.12 OUR AVERAGE					
0.90 ± 0.06 ± 0.16	225 ± 15	HENRARD	87	DM2	$e^+e^- \to \Lambda\bar{\Sigma}^+\pi^-$
1.11 ± 0.06 ± 0.20	342 ± 18	HENRARD	87	DM2	$e^+e^- \to \Lambda\bar{\Sigma}^-\pi^+$
1.53 ± 0.17 ± 0.38	135	EATON	84	MRK2	$e^+e^- \to \Lambda\bar{\Sigma}^+\pi^-$
1.38 ± 0.21 ± 0.35	118	EATON	84	MRK2	$e^+e^- \to \Lambda\bar{\Sigma}^-\pi^+$

$\Gamma(pK^-\bar{\Lambda})/\Gamma_{total}$ Γ_{70}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.89 ± 0.07 ± 0.14	307	EATON	84	MRK2	e^+e^-

$\Gamma(pK^-\bar{\Sigma}^0)/\Gamma_{total}$ Γ_{71}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.29 ± 0.06 ± 0.05	90	EATON	84	MRK2	e^+e^-

$\Gamma(pK^-\bar{\Sigma}(1385)^0)/\Gamma_{total}$ Γ_{72}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.51 ± 0.26 ± 0.18	89	EATON	84	MRK2	e^+e^-

$\Gamma(K^0_S K^0_L)/\Gamma_{total}$ Γ_{14}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
1.01 ± 0.16 ± 0.09	74	BALTRUSAITIS	85D	MRK3	e^+e^-

$\Gamma(\omega K^{\pm}K^0_S\pi^{\mp})/\Gamma_{total}$ Γ_{73}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
29.5 ± 1.4 ± 7.0	879 ± 41	BECKER	87	MRK3	$e^+e^- \to$ hadrons

$\Gamma(\omega K^*(892)\bar{K})$ + Γ(c.c.)$/\Gamma_{total}$ Γ_{74}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
53 ± 14 ± 14	530 ± 140	BECKER	87	MRK3	$e^+e^- \to$ hadrons

Meson Full Listings

$J/\psi(1S) = J/\psi(3097)$

$\Gamma(\phi K^{\pm} K_S^0 \pi^{\mp})/\Gamma_{total}$ — Γ_{75}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
7 ±0.6±1.0	163 ± 15	BECKER	87	MRK3	$e^+e^- \to$ hadrons

$\Gamma(\phi K^*(892)\bar{K}) + \Gamma(c.c.)/\Gamma_{total}$ — Γ_{76}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
20±3±3	155 ± 20	BECKER	87	MRK3	$e^+e^- \to$ hadrons

$\Gamma(\omega f_1(1420))/\Gamma_{total}$ — Γ_{77}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
$6.8^{+1.9}_{-1.6}\pm1.7$	111^{+31}_{-26}	BECKER	87	MRK3	$e^+e^- \to$ hadrons

$\Gamma(\phi f_1(1285))/\Gamma_{total}$ — Γ_{78}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
0.8 ±0.5 OUR AVERAGE Error includes scale factor of 2.2					
0.6 ±0.2±0.1	16 ± 6	BECKER	87	MRK3	$e^+e^- \to$ hadrons
1.77±0.4±0.25	10	AUGUSTIN	86	DM2	$J/\psi \to$ hadrons

$\Gamma(\Xi(1530)^- \bar{\Xi}^+)/\Gamma_{total}$ — Γ_{79}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.59±0.09±0.12	75 ± 11	HENRARD	87	DM2	e^+e^-

$\Gamma(\Xi(1530)^0 \bar{\Xi}^0)/\Gamma_{total}$ — Γ_{80}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.32±0.12±0.07	24 ± 9	HENRARD	87	DM2	e^+e^-

$\Gamma(\Lambda\bar{\Lambda}\pi^0)/\Gamma_{total}$ — Γ_{81}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.22±0.05±0.05	19 ± 4	HENRARD	87	DM2	e^+e^-

$\Gamma(\Sigma^0\bar{\Lambda})/\Gamma_{total}$ — Γ_{82}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<0.9	90	HENRARD	87	DM2	e^+e^-

$\Gamma(\Sigma(1385)^0\bar{\Lambda})/\Gamma_{total}$ — Γ_{83}/Γ

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<0.2	90	HENRARD	87	DM2	e^+e^-

$\Gamma(\Delta(1232)^+\bar{p})/\Gamma_{total}$ — Γ_{84}/Γ

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<0.1	90	HENRARD	87	DM2	e^+e^-

RADIATIVE DECAYS

$\Gamma(\gamma\gamma)/\Gamma_{total}$ — Γ_{85}/Γ

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<0.5	90	BARTEL	77	CNTR	e^+e^-

$\Gamma(3\gamma)/\Gamma_{total}$ — Γ_{86}/Γ

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<0.055	90	PARTRIDGE	80	CBAL	e^+e^-

$\Gamma(\pi^0\gamma)/\Gamma_{total}$ — Γ_{87}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.039±0.013 OUR AVERAGE					
0.036±0.011±0.007		BLOOM	83	CBAL	e^+e^-
0.073±0.047	10	BRANDELIK	79C	DASP	e^+e^-

$\Gamma(\eta\gamma)/\Gamma_{total}$ — Γ_{88}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
0.86±0.08 OUR AVERAGE					
0.88±0.08±0.11		BLOOM	83	CBAL	e^+e^-
0.82±0.10		BRANDELIK	79C	DASP	e^+e^-
1.3 ±0.4	21	BARTEL	77	CNTR	e^+e^-

$\Gamma(\eta'(958)\gamma)/\Gamma_{total}$ — Γ_{89}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
4.2±0.4 OUR AVERAGE					
4.1±0.3±0.6		BLOOM	83	CBAL	$e^+e^- \to 3\gamma$ + hadrons γ
4.6±0.4±0.65		EINSWEILER	83	MRK3	$e^+e^- \to \gamma\eta\pi^+\pi^-$
4.7±0.3±0.9		EINSWEILER	83	MRK3	$e^+e^- \to \gamma\rho^0\gamma$
2.9±1.1	6	BRANDELIK	79C	DASP	$e^+e^- \to 3\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3.8±1.3		[13] SCHARRE	79B	MRK1	$e^+e^- \to \gamma X$
3.4±0.7		SCHARRE	79B	MRK1	$e^+e^- \to 2\pi 2\gamma$
2.4±0.7	57	BARTEL	76	CNTR	$e^+e^- \to 2\gamma\rho$

[13] From the inclusive γ decay spectrum

$\Gamma(\eta_c(1S)\gamma)/\Gamma_{total}$ — Γ_{90}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0127±0.0036		GAISER	86	CBAL	$J/\psi \to \gamma X$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
SEEN	16	BALTRUSAITIS	84	MRK3	$J/\psi \to 2\phi\gamma$

$\Gamma(f_2(1270)\gamma)/\Gamma_{total}$ — Γ_{91}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1.38±0.14 OUR AVERAGE						
1.33±0.05±0.20		[14] AUGUSTIN	87	DM2		$J/\psi \to \gamma\pi^+\pi^-$
1.36±0.09±0.23		[14] BALTRUSAITIS	87	MRK3		$J/\psi \to \gamma\pi^+\pi^-$
1.48±0.25±0.30	178	EDWARDS	82B	CBAL		$e^+e^- \to 2\pi^0\gamma$
2.0 ±0.7	35	ALEXANDER	78	PLUT	0	e^+e^-
1.2 ±0.6	30	[15] BRANDELIK	78B	DASP		$e^+e^- \to \pi^+\pi^-\gamma$

[14] Estimated using BR($f_2(1270) \to \pi\pi$)=0.843±0.012. The errors do not contain the uncertainty in the $f_2(1270)$ decay.
[15] Restated by us to take account of spread of E1, M2, E3 transitions.

$\Gamma(f_2'(1525)\gamma)/\Gamma_{total}$ — Γ_{92}/Γ

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.23±0.05 OUR AVERAGE Error includes scale factor of 1.2						
0.6 ±0.14±0.12			[16] BALTRUSAITIS	87	MRK3	$J/\psi \to \gamma K^+K^-$
0.22±0.07±0.04			[16] AUGUSTIN	85	DM2	$e^+e^- \to K^+K^-\gamma$
0.21±0.03±0.05			[16] AUGUSTIN	85	DM2	$e^+e^- \to K_S^0K_S^0\gamma$
0.18±0.10			[16] FRANKLIN	83B	MRK2	$J/\psi \to K\bar{K}\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.34	90	4	[17] BRANDELIK	79C	DASP	$e^+e^- \to \pi^+\pi^-\gamma$
<0.23	90	3	ALEXANDER	78	PLUT	$e^+e^- \to K^+K^-\gamma$

[16] Using BR($f_2'(1525) \to K\bar{K}$) = 1.0.
[17] Assuming isotropic production and decay of the $f_2'(1525)$ and isospin.

$\Gamma(f_1(1285)\gamma)/\Gamma_{total}$ — Γ_{93}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.006	90	[18] SCHARRE	80	MRK2	e^+e^-

[18] Using BR($f_1(1285) \to K\bar{K}\pi$) = 0.12.

$\Gamma(\eta(1430)\gamma)/\Gamma_{total}$ — Γ_{94}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.0047±0.0006 OUR AVERAGE				
0.0063±0.0014	[19] WISNIEWSKI	87	MRK3	$J/\psi \to K\bar{K}\pi\gamma$
0.0045±0.0004±0.0008	[19] AUGUSTIN	85	DM2	$J/\psi \to K^+K^-\pi^0\gamma$
0.0040±0.0007±0.001	[19] EDWARDS	82E	CBAL	$J/\psi \to K^+K^-\pi^0\gamma$
0.0043±0.0017	[19,20] SCHARRE	80	MRK2	e^+e^-

[19] Includes unknown branching fraction $\eta(1430) \to K\bar{K}\pi$.
[20] Corrected for spin zero hypothesis for $\eta(1430)$.

$\Gamma(p\bar{p}\gamma)/\Gamma_{total}$ — Γ_{95}/Γ

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.38±0.07±0.07		49	EATON	84	MRK2	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.11	90		PERUZZI	78	MRK1	e^+e^-

$\Gamma(f_2(1720)\gamma)/\Gamma_{total}$ — Γ_{96}/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
4.8±0.6±0.9	[21] BALTRUSAITIS	87	MRK3	$J/\psi \to \gamma K^+K^-$
1.6±0.4±0.3	[22] BALTRUSAITIS	87	MRK3	$J/\psi \to \gamma\pi^+\pi^-$
4.3±0.7±0.9	[23] AUGUSTIN	85	DM2	$e^+e^- \to K^+K^-\gamma$
3.1±0.5±0.7	[23] AUGUSTIN	85	DM2	$e^+e^- \to K_S^0K_S^0\gamma$
6.0±3.4	[23] FRANKLIN	83B	MRK2	$e^+e^- \to K^+K^-\gamma$
3.8±1.6	[24] EDWARDS	82D	CBAL	$e^+e^- \to \eta\eta\gamma$

[21] Includes unknown branching fraction to K^+K^-.
[22] Includes unknown branching fraction to $\pi^+\pi^-$.
[23] Includes unknown branching fraction to K^+K^- or $K_S^0K_S^0$.
[24] Includes unknown branching fraction to $\eta\eta$.

$\Gamma(X(2220)\gamma)/\Gamma_{total}$ — Γ_{97}/Γ

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$12.4^{+6.4}_{-5.2}\pm2.8$		23	[25] BALTRUSAITIS	86D	MRK3	$J/\psi \to K_S^0K_S^0\gamma$
$8.4^{+3.4}_{-2.8}\pm1.6$		93	[25] BALTRUSAITIS	86D	MRK3	$J/\psi \to K^+K^-\gamma$
< 1.5	95		[26] AUGUSTIN	85	DM2	$e^+e^- \to K^+K^-\gamma$
< 3.0	95		[26] AUGUSTIN	85	DM2	$e^+e^- \to K_S^0K_S^0\gamma$

[25] Includes unknown branching fraction to $K\bar{K}$.
[26] Includes unknown branching fraction into K^+K^- or $K_S^0K_S^0$.

$\Gamma(p\bar{p}\pi^+\pi^-\gamma)/\Gamma_{total}$ — Γ_{98}/Γ

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<0.79	90	EATON	84	MRK2	e^+e^-

$\Gamma(\rho\rho\gamma)/\Gamma_{total}$ — Γ_{99}/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
4.5 ±0.8 OUR AVERAGE				
4 7 ±0 3 ±0.9	[27] BALTRUSAITIS	86B	MRK3	$J/\psi \to 4\pi\gamma$
3.75 ± 1.05 ± 1.20	[28] BURKE	82	MRK2	$J/\psi \to 4\pi\gamma$

[27] 4π mass less than 2 0 GeV
[28] 4π mass less than 2 0 GeV $2\rho^0$ corrected to 2ρ by factor of 3

$\Gamma(2\pi^+2\pi^-\gamma)/\Gamma_{total}$ — Γ_{100}/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
3.3 ±0.6 OUR AVERAGE Error includes scale factor of 1 3				
3.05 ± 0.08 ± 0.45	[29] BALTRUSAITIS	86B	MRK3	$J/\psi \to 4\pi\gamma$
4.85 ± 0.45 ± 1.20	[30] BURKE	82	MRK2	e^+e^-

[29] 4π mass less than 2 0 GeV
[30] 4π mass less than 2 5 GeV

$\Gamma(\eta\pi\pi\gamma)/\Gamma_{total}$ — Γ_{101}/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
6.1 ±1.0 OUR AVERAGE				
5 85 ± 0.3 ± 1 05	[31] EDWARDS	83B	CBAL	$J/\psi \to \eta\pi^+\pi^-$
7.8 ±1.2 ± 2 4	[31] EDWARDS	83B	CBAL	$J/\psi \to \eta 2\pi^0$

[31] Broad enhancement at 1700 MeV

$\Gamma(\omega\omega\gamma)/\Gamma_{total}$ — Γ_{102}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.59 ± 0.33 OUR AVERAGE					
1.41 ± 0.2 ±0.42	120 ± 17	BISELLO	87	SPEC	e^+e^- hadrons γ
1 76 ± 0.09 ± 0 45		BALTRUSAITIS	85C	MRK3	$e^+e^- \to$ hadrons γ

$\Gamma(\phi\phi\gamma)/\Gamma_{total}$ — Γ_{103}/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
3.1 ± 0.7 ± 0.4	[32] BISELLO	86B	DM2	$J/\psi \to \gamma\phi\phi$

[32] $\phi\phi$ mass less than 2 9 GeV η_c excluded

$\Gamma(\pi^+\pi^-2\pi^0\gamma)/\Gamma_{total}$ — Γ_{104}/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
8.3 ± 0.2 ± 3.1	[33] BALTRUSAITIS	86B	MRK3	$J/\psi \to 4\pi\gamma$

[33] 4π mass less than 2 0 GeV

$\Gamma(f_4(2050)\gamma)/\Gamma_{total}$ — Γ_{105}/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
2.7 ± 0.5 ± 0.6	[34] BALTRUSAITIS	87	MRK3	$J/\psi \to \gamma\pi^+\pi^-$

[34] Assuming branching fraction $f_4(2050) \to \pi\pi$/ total = 0 167

$\Gamma(\Lambda\bar{\Lambda}\gamma)/\Gamma_{total}$ — Γ_{106}/Γ

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<0.13	90	HENRARD	87	DM2	e^+e^-

$J/\psi(1S)$ REFERENCES

ALEXANDER	88	SLAC PUB 4501	+Bonvicini Drell Frey Luth	(LBL MICH SLAC)
COFFMAN	88	SLAC PUB 4424	+	(MARK III Collab)
AUGUSTIN	87	ZPHY C36 369	+Cosme+	(LALO CLER FRAS PADO)
BAGLIN	87	NP B286 592	+	(LAPP CERN GENO LYON OSLO ROMA+)
BALTRUSAITIS	87	PR D35 2077	+Coffman Dubois+	(MARK III Collab)
BECKER	87	PRL 59 186	+	(MARK III Collab)
BISELLO	87	PL B192 239	+Ajaltouni Baldini+	(PADO CLER FRAS LALO)
HENRARD	87	NP B292 670	+Ajaltouni et al	(CLER FRAS LALO PADO)
PALLIN	87	NP B292 653	+Ajaltouni+	(CLER FRAS LALO PADO)
WISNIEWSKI	87	CALT 68 1446		(MARK III Collab)
AUGUSTIN	86	Moriond XXI 421	+Ajaltouni Bisello+	(LALO CLER PADO FRAS)
BALTRUSAITIS	86B	PR D33 1222	+Coffman Hauser+	(MARK III Collab)
BALTRUSAITIS	86D	PRL 56 107		(CIT UCSC ILL SLAC WASH)
BISELLO	86B	PL B179 294	+Busetto Castro Limentani+	(DM2 Collab)
GAISER	86	PR D34 711	+Bloom Bulos Godfrey+	(Crystal Ball Collab)
AUGUSTIN	85	Moriond XX 1 479	+Calcaterra Cosme+	(ORSA CLER PADO FRAS)
BALTRUSAITIS	85C	PRL 55 1723	+	(CIT UCSC ILL SLAC WASH)
BALTRUSAITIS	85D	PR D32 566	+Coffman Hauser+	(CIT UCSC ILL SLAC WASH)
BALTRUSAITIS	84	PRL 52 2126	+	(CIT UCSC ILL SLAC WASH)
EATON	84	PR D29 804	+Goldhaber Abrams Alam Boyarski+	(LBL SLAC)
BLOOM	83	ARNS 33 143	+Peck	(SLAC CIT)
EDWARDS	83B	PRL 51 859	+Partridge Peck+	(CIT HARV PRIN STAN SLAC)
EINSWEILER	83	Brighton Conf 348		(MARK III Collab)
FRANKLIN	83B	SLAC 254 Thesis		(STAN)
FRANKLIN	83C	PRL 51 963	+Franklin Feldman Abrams Alam+	(LBL SLAC)
BURKE	82	PRL 49 632	+Trilling Abrams Alam Blocker+	(LBL SLAC)
EDWARDS	82B	PR D25 3065	+Partridge Peck+	(CIT HARV PRIN STAN SLAC)
EDWARDS	82D	PRL 48 458	+Partridge Peck+	(CIT HARV PRIN STAN SLAC)
Also	83	ARNS 33 143	Bloom Peck	(SLAC CIT)
EDWARDS	82E	PRL 49 259	+Partridge Peck+	(CIT HARV PRIN STAN SLAC)
LEMOIGNE	82	PL 113B 509	+Barate Astbury+	(SACL LOIC SHMP IND)
BESCH	81	ZPHY C8 1	+Eisermann Lohr Kowalski+	(BONN DESY MANZ)
GIDAL	81	PL 107B 153	+Goldhaber Guy Millikan Abrams+	(SLAC LBL)
PARTRIDGE	80	PRL 44 712	+Peck+	(CIT HARV PRIN SLAC STAN)
SCHARRE	80	PL 97B 329	+Trilling Abrams Alam Blocker+	(SLAC LBL)
ZHOLENTZ	80	PL 96B 214	+Kurdadze Lelchuk Mishnev+	(NOVO)
Also	81	SJNP 34 814	Zholentz+	(NOVO)
		Translated from YAF 34 1471		
BRANDELIK	79C	ZPHY C1 233	+	(AACH DESY HAMB MPIM TOKY)
SCHARRE	79B	SLAC PUB 2321		(SLAC LBL)
Also	79	LBL 9502	Abrams Alam Blocker Boyarski+	(SLAC LBL)
ALEXANDER	78	PL 72B 493	+Criegee+	(DESY HAMB SIEG WUPP)
BESCH	78	PL 78B 347	+Eisermann Kowalski Eyss+	(BONN DESY MANZ)
BRANDELIK	78B	PL 74B 292	+Cords+	(AACH DESY HAMB MPIM TOKY)
PERUZZI	78	PR D17 2901	+Piccolo Alam Boyarski Goldhaber+	(SLAC LBL)
BARTEL	77	PL 66B 489	+Duinker Olsson Heintze+	(DESY HEID)
BURMESTER	77C	PL 72B 135	+Criegee+	(DESY HAMB SIEG WUPP)
FELDMAN	77	PL 33C 285	+Perl	(LBL SLAC)
VANNUCCI	77	PR D15 1814	+Abrams Alam Boyarski+	(SLAC LBL)
BARTEL	76	PL 64B 483	+Duinker Olsson Steffen Heintze+	(DESY HEID)
BRAUNSCH	76	PL 63B 487	Braunschweig+	(AACH DESY HAMB MPIM+)
JEAN MARIE	76	PRL 36 291	+Abrams Boyarski Breidenbach+	(SLAC LBL) IG
BALDINI	75	PL 58B 471	Baldini Celio Bozzo Capon+	(FRAS ROMA)
BEMPORAD	75	Stanford Symp 113		(PISA FRAS)
BOYARSKI	75	PRL 34 1357	+Breidenbach Bulos Feldman+	(SLAC LBL) JPC
DASP	75	PL 56B 491	Braunschweig+	(AACH DESY MPIM TOKY)
ESPOSITO	75B	LNC 14 73	+Bartoli Bisello+	(FRAS NAPL PADO ROMA)
FORD	75	PRL 34 604	+Beron Hilger Hofstadter+	(SLAC PENN)
LIBERMAN	75	Stanford Symp 55		(STAN)
WIIK	75	Stanford Symp 69		(DESY)

— — OTHER RELATED PAPERS — —

BAGLIN	85	CERN PRE 85		(LAPP CERN GENO LYON OSLO ROMA+)
BARATE	83	PL 121B 449	+Bareyre Bonamy+	(SACL LOIC SHMP IND)
KIRK	79	PRL 42 619	+Goodman+	(FNAL HARV ILL OXF TUFT)
BIDDICK	77	PRL 38 1324	+Burnett+	(UCSD UMD PAVI PRIN SLAC STAN)
CORDEN	77	PL 68B 96	+Dowell+	(BIRM CERN MPIM NEUC EPOL+)
YAMADA	77	Hamburg Conf 69		(DESY TOKY)
ANTIPOV	76	Tbilisi Conf N8	+Bessubov Budanov Bushnin Denisov+	(SERP)
BUSSER	76	NP B113 189	+Blumenfeld Banner+	(CERN COLU ROCK SACL)
ANDREWS	75	PRL 34 231	+Harvey Lobkowicz May+	(ROCH CORN)
AUBERT	75	NP B89 1	+Becker Biggs Burger Glenn+	(MIT BNL)
BACCI	75B	LNC 12 269	+Penso Stella Baldini Celio+	(ROMA FRAS)
BALDINI	75B	PL 58B 475	Baldini Celio Capon DelFabbro+	(FRAS ROMA)
BLANAR	75	PRL 35 346	+Boyer Faissler Garelick Gettner+	(NEAS)
BRAUNSCH	75	PL 53B 491	Braunschweig+	(AACH HAMB MUNI TOKY)
BUSSER	75	PL 56B 482	+Blumenfeld Banner+	(CERN COLU ROCK SACL)
CAMERINI	75	PRL 35 483	+Learned Prepost Ash Anderson+	(WISC SLAC)
DAKIN	75	PL 56B 405	+Kreisler Bolon Helle+	(MASA MIT SLAC)
DASP	75B	PL 57B 297	Braunschweig+	(AACH DESY MPIM TOKY)
GITTELMAN	75	PRL 35 1616	+Hanson Larson Loh+	(CORN)
GRECO	75	PL 56B 367	+Pancheri Srivastava Srivastava	(FRAS)
HEINTZE	75	Stanford Symp 97		(HEID)
JACKSON	75	NIM 128 13	+Scharre	(LBL)
KNAPP	75	PRL 34 1040	+Lee Bronstein+	(COLU HAWA CORN ILL FNAL)
KNAPP	75B	PRL 34 1044	+Lee Bronstein+	(COLU HAWA CORN ILL FNAL)
MARTIN	75B	PRL 34 288	+Bolon Dakin Feldman+	(MIT MASA SLAC)
SIMPSON	75	PRL 35 699	+Beron Ford Hilger Hofstadter+	(STAN PENN)
YENNIE	75	PRL 34 239		(CORN)
ABRAMS	74	PRL 33 1453	+Briggs Augustin Boyarski+	(LBL SLAC)
ASH	74	LNC 11 705	+Zorn Bartoli+	(FRAS UMD NAPL PADO ROMA)
BACCI	74	PRL 33 1408	+Bartoli Barbarino Barbiellini+	(FRAS)
Also	74B	PRL 33 1649	Bacci	
BALDINI	74	LNC 11 711	Baldini Celio Bacci+	(FRAS ROMA)
BARBIELLINI	74	LNC 11 718	+Bemporad+	(FRAS NAPL PISA ROMA)
BRAUNSCH	74	PL 53B 393	Braunschweig+	(AACH HAMB MUNI TOKY)
CHRISTENSON	70	PRL 25 1523	+Hicks Lederman+	(COLU BNL CERN)

$\chi_{c0}(1P)$ or $\chi_{c0}(3415)$ was $\chi(3415)$

$I^G(J^{PC}) = 0^+(0^{++})$

Observed in the radiative decay $\psi(2S) \to \gamma\chi_{c0}(1P)\gamma$. Therefore C = + The observed decay into $\pi^+\pi^-$ or K^+K^- implies G = + $J^P = 0^+$ 2^+ The angular distribution is consistent with J = 0 J^P abnormal excluded by $\pi^+\pi^-$ and K^+K^- decays $J^P = 0^+$ preferred (FELDMAN 77)

$\chi_{c0}(1P)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3415.1 ± 1.0 OUR AVERAGE					
3417 8 ± 0 4 ± 4		[1] GAISER	86	CBAL	$\psi(2S) \to \gamma X$
3414 8 ± 1 1		[2,3] HIMEL	79	MRK2	$e^+e^- \to$ hadrons
3422 0 ± 10 0		[2] BARTEL	78B	CNTR	$e^+e^- \to J/\psi 2\gamma$
3416 0 ± 3 ± 4		[2] TANENBAUM	78	MRK1	e^+e^-
3415 0 ± 9 0		[2] BIDDICK	77	CNTR	$e^+e^- \to \gamma X$
• • • We do not use the following data for averages fits limits etc • • •					
3407 0 ± 8 0	2	[4] WIIK	75	DASP	$e^+e^- \to J/\psi 2\gamma$

[1] Using mass of $\psi(2S)$ = 3686 0 MeV
[2] Mass value shifted by us by amount appropriate for $\psi(2S)$ mass = 3686 MeV and $J/\psi(1S)$ mass = 3097 MeV
[3] Systematic error added linearly by us
[4] Only two events this mass apparently never published

$\chi_{c0}(1P)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
13.5 ± 3.3 ± 4.2	GAISER	86	CBAL	$\psi(2S) \to \gamma X$ $\gamma\pi^0\pi^0$

$\chi_{c0}(1P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Conf Lev
	HADRONIC DECAYS		
Γ_1	$\chi_{c0}(1P) \to \pi^+\pi^-$	$(7.5\pm2.1)\times10^{-3}$	
Γ_2	$\chi_{c0}(1P) \to K^+K^-$	$(7.1\pm2.4)\times10^{-3}$	
Γ_3	$\chi_{c0}(1P) \to 2(\pi^+\pi^-)$	$(3.7\pm0.7)\times10^{-2}$	
Γ_4	$\chi_{c0}(1P) \to 3(\pi^+\pi^-)$	$(1.5\pm0.5)\times10^{-2}$	
Γ_5	$\chi_{c0}(1P) \to \pi^+\pi^-K^+K^-$	$(3.0\pm0.7)\times10^{-2}$	
Γ_6	$\chi_{c0}(1P) \to \pi^+\pi^-p\bar{p}$	$(5.0\pm2.0)\times10^{-3}$	
Γ_7	$\chi_{c0}(1P) \to \rho^0\pi^+\pi^-$	$(1.6\pm0.5)\times10^{-2}$	
Γ_8	$\chi_{c0}(1P) \to K^+\bar{K}^*(892)^0\pi^-$ + c.c.	$(1.2\pm0.4)\times10^{-2}$	
Γ_9	$\chi_{c0}(1P) \to p\bar{p}$	$<9.0\times10^{-4}$	90%
	RADIATIVE DECAYS		
Γ_{10}	$\chi_{c0}(1P) \to \gamma\gamma$	$<1.5\times10^{-3}$	90%
Γ_{11}	$\chi_{c0}(1P) \to J/\psi(1S)\gamma$	$(6.6\pm1.8)\times10^{-3}$	

$\chi_{c0}(1P)$ BRANCHING RATIOS

HADRONIC DECAYS

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ — Γ_1/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
75 ± 21 OUR AVERAGE				
70 ± 30	[5] BRANDELIK	79B	DASP	$\psi(2S) \to \gamma\chi_{c0}$
80 ± 30	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c0}$

$\Gamma(K^+K^-)/\Gamma_{total}$ — Γ_2/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
71 ± 24 OUR AVERAGE				
60 ± 30	[5] BRANDELIK	79B	DASP	$\psi(2S) \to \gamma\chi_{c0}$
90 ± 40	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c0}$

$\Gamma(2(\pi^+\pi^-))/\Gamma_{total}$ — Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.037 ± 0.007	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c0}$

$\Gamma(3(\pi^+\pi^-))/\Gamma_{total}$ — Γ_4/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.015 ± 0.005	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c0}$

$\Gamma(\pi^+\pi^-K^+K^-)/\Gamma_{total}$ — Γ_5/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.030 ± 0.007	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c0}$

$\Gamma(\pi^+\pi^-p\bar{p})/\Gamma_{total}$ — Γ_6/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.005 ± 0.002	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c0}$

$\Gamma(\rho^0\pi^+\pi^-)/\Gamma_{total}$ — Γ_7/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.016 ± 0.005	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c0}$

$\Gamma(K^+\bar{K}^*(892)^0\pi^- + \text{c.c.})/\Gamma_{total}$ — Γ_8/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.012 ± 0.004	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c0}$

$\Gamma(p\bar{p})/\Gamma_{total}$ — Γ_9/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<9.0	90	[5] BRANDELIK	79B	DASP	$\psi(2S) \to \gamma\chi_{c0}$

[5] Calculated using $BR(\psi(2S) \to \chi_{c0}(1P)\gamma) = 0.094$. The errors do not contain the uncertainty in the $\psi(2S)$ decay.

RADIATIVE DECAYS

$\Gamma(\gamma\gamma)/\Gamma_{total}$ — Γ_{10}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<15	90	[6] YAMADA	77	DASP	$e^+e^- \to 3\gamma$

$\Gamma(J/\psi(1S)\gamma)/\Gamma_{total}$ — Γ_{11}/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
66 ± 18 OUR AVERAGE				
60 ± 18	GAISER	86	CBAL	$\psi(2S) \to \gamma\chi_{c0}$
320 ± 210	[6] BRANDELIK	79B	DASP	$\psi(2S) \to \gamma\chi_{c0}$
150 ± 100	[6] BARTEL	78B	CNTR	$\psi(2S) \to \gamma\chi_{c0}$
210 ± 210	[6] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c0}$

[6] Calculated using $BR(\psi(2S) \to \chi_{c0}(1P)\gamma) = 0.094$. The errors do not contain the uncertainty in the $\psi(2S)$ decay.

$\chi_{c0}(1P)$ REFERENCES

GAISER	86	PR D34 711	+Bloom, Bulos, Godfrey+	(Crystal Ball Collab.)
BRANDELIK	79B	NP B160 426	+Cords+	(AACH, DESY, HAMB, MPIM, TOKY)
HIMEL	79	SLAC 223 Thesis		(SLAC)
Also	82	Private Comm.	Trilling	(LBL, UCB)
BARTEL	78B	PL 79B 492	+Dittmann, Duinker, Olsson, O'Neill+	(DESY, HEID)
TANENBAUM	78	PR D17 1731	+Alam, Boyarski+	(SLAC, LBL)
Also	82	Private Comm.	Trilling	(LBL, UCB)
BIDDICK	77	PRL 38 1324	+Burnett+	(UCSD, UMD, PAVI, PRIN, SLAC, STAN)
FELDMAN	77	PL 33C 285	+Perl	(LBL, SLAC)
YAMADA	77	Hamburg Conf. 69		(DESY, TOKY)
WIIK	75	Stanford Symp. 69		(DESY)

— OTHER RELATED PAPERS —

OREGLIA	82	PR D25 2259	+Partridge+	(SLAC, CIT, HARV, PRIN, STAN)
BRANDELIK	79C	ZPHY C1 233	+	(AACH, DESY, HAMB, MPIM, TOKY)
KIRK	79	PRL 42 619	+Goodman+	(FNAL, HARV, ILL, OXF, TUFT)
FELDMAN	77	PL 33C 285	+Perl	(LBL, SLAC)
FELDMAN	75B	PRL 35 821	+Jean-Marie, Sadoulet, Vannucci+	(LBL, SLAC)
Also Erratum	75C	PRL 35 1189	Feldman	
TANENBAUM	75	PRL 35 1323	+Whitaker, Abrams+	(LBL, SLAC)

$\chi_{c1}(1P)$ or $\chi_{c1}(3510)$ was $\chi(3510)$

$I^G(J^{PC}) = 0^+(1^{++})$

Observed in the radiative sequential decay $\psi(2S) \to \chi_{c1}(1P)\gamma$, $\chi_{c1}(1P) \to J/\psi(1S)\gamma$. Therefore, $C = +$. The lack of decays into $\pi^+\pi^-$ or K^+K^- is suggestive of J^P=abnormal. The decays into 4π and 6π imply $G = +$, thus $I = 0$. J=0,2 excluded by angular distribution in the $J/\psi(1S)\gamma$ decay. $J^P = 1^+$ preferred (FELDMAN 77, OREGLIA 82).

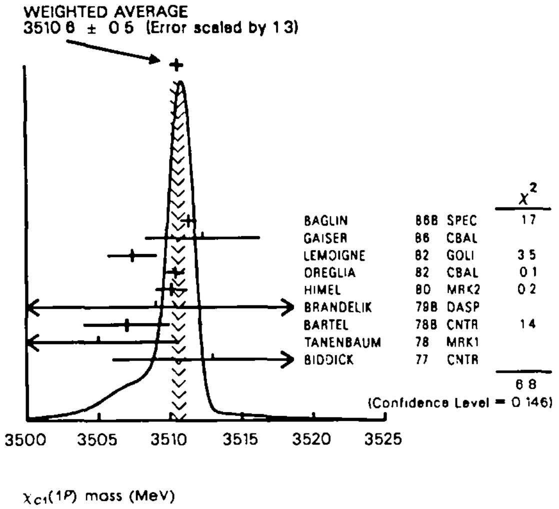
$\chi_{c1}(1P)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3510.6 ± 0.5 OUR AVERAGE		Error includes scale factor of 1.3. See the ideogram below.			
3511.3 ± 0.4 ± 0.4	30	BAGLIN	86B	SPEC	$p\bar{p} \to e^+e^-$
3512.3 ± 0.3 ± 4.0		[1] GAISER	86	CBAL	$\psi(2S) \to \gamma X$
3507.4 ± 1.7	91	[2] LEMOIGNE	82	GOLI	190 GeV π^- Be $\to \gamma 2\mu$
3510.4 ± 0.6		OREGLIA	82	CBAL	$e^+e^- \to J/\psi 2\gamma$
3510.1 ± 1.1	254	[3] HIMEL	80	MRK2	$e^+e^- \to J/\psi 2\gamma$
3509.0 ± 11.0	21	BRANDELIK	79B	DASP	$e^+e^- \to J/\psi 2\gamma$
3507.0 ± 3.0		[3] BARTEL	78B	CNTR	$e^+e^- \to J/\psi 2\gamma$
3505.0 ± 4 ± 4		[3,4] TANENBAUM	78	MRK1	e^+e^-
3513.0 ± 7.0	367	[3] BIDDICK	77	CNTR	$\psi(2S) \to \gamma X$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3510.0 ± 20.0		BARTEL	76B	CNTR	$e^+e^- \to J/\psi 2\gamma$
3500. ± 10	40	TANENBAUM	75	MRK1	Hadrons γ
3507.0 ± 7.0	7	WIIK	75	DASP	$e^+e^- \to J/\psi 2\gamma$

[1] Using mass of $\psi(2S)$ = 3686.0 MeV.
[2] $J/\psi(1S)$ mass constrained to 3097 MeV.
[3] Mass value shifted by us by amount appropriate for $\psi(2S)$ mass = 3686 MeV and $J/\psi(1S)$ mass = 3097 MeV.
[4] From a simultaneous fit to radiative and hadronic decay channels.

$\chi_{c1}(1P)$ WIDTH

VALUE (MeV)	CL%	DOCUMENT ID		TECN	COMMENT
<1.3	95	BAGLIN	86B	SPEC	$\bar{p}p \to e^+e^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<3.8	90	GAISER	86	CBAL	$\psi(2S) \to \gamma X$



$\chi_{c1}(1P)$ DECAY MODES

		Fraction (Γ_i/Γ)	Conf Lev
	HADRONIC DECAYS		
Γ_1	$\chi_{c1}(1P) \to \pi^+\pi^-$	< 1 7 $\times 10^{-3}$	
Γ_2	$\chi_{c1}(1P) \to K^+K^-$	< 1 7 $\times 10^{-3}$	
Γ_3	$\chi_{c1}(1P) \to 2(\pi^+\pi^-)$	(1 6 ± 0.5) $\times 10^{-2}$	
Γ_4	$\chi_{c1}(1P) \to 3(\pi^+\pi^-)$	(2 2 ± 0 8) $\times 10^{-2}$	
Γ_5	$\chi_{c1}(1P) \to \pi^+\pi^-K^+K^-$	(9 ± 4) $\times 10^{-3}$	
Γ_6	$\chi_{c1}(1P) \to \pi^+\pi^-p\bar{p}$	(1 4 ± 0 9) $\times 10^{-3}$	
Γ_7	$\chi_{c1}(1P) \to \rho^0\pi^+\pi^-$	(3 9 ± 3 5) $\times 10^{-3}$	
Γ_8	$\chi_{c1}(1P) \to K^+\bar{K}^*(892)^0\pi^-$ + c c	(3 2 ± 2 1) $\times 10^{-3}$	
Γ_9	$\chi_{c1}(1P) \to p\bar{p}$		
	RADIATIVE DECAYS		
Γ_{10}	$\chi_{c1}(1P) \to \gamma\gamma$	< 1 5 $\times 10^{-3}$	90%
Γ_{11}	$\chi_{c1}(1P) \to J/\psi(1S)\gamma$	(27 3 ± 1 6) $\times 10^{-2}$	

$\chi_{c1}(1P)$ PARTIAL WIDTHS

$\Gamma(p\bar{p})$ Γ_9

VALUE (eV)	DOCUMENT ID		TECN	COMMENT
$57.^{+13.}_{-11.} \pm 11$	BAGLIN	86B	SPEC	$\bar{p}p \to e^+e^-$

$\chi_{c1}(1P)$ BRANCHING RATIOS

HADRONIC DECAYS

$[\Gamma(\pi^+\pi^-) + \Gamma(K^+K^-)]/\Gamma_{total}$ $(\Gamma_1+\Gamma_2)/\Gamma$

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<17		[5] FELDMAN	77	MRK1	$\psi(2S) \to \gamma\chi_{c1}$
• • • We do not use the following data for averages fits limits etc • • •					
<38	90	[5] BRANDELIK	79B	DASP	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(2(\pi^+\pi^-))/\Gamma_{total}$ Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.016 ± 0.005	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(3(\pi^+\pi^-))/\Gamma_{total}$ Γ_4/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.022 ± 0.008	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(\pi^+\pi^-K^+K^-)/\Gamma_{total}$ Γ_5/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
90 ± 40	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(\pi^+\pi^-p\bar{p})/\Gamma_{total}$ Γ_6/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
14 ± 9	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(\rho^0\pi^+\pi^-)/\Gamma_{total}$ Γ_7/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
39 ± 35	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(K^+K^*(892)^0\pi^-$ + c c $)/\Gamma_{total}$ Γ_8/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
32 ± 21	[5] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(p\bar{p})/\Gamma_{total}$ Γ_9/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
> 0 54	95	BAGLIN	86B	SPEC	$\bar{p}p \to \gamma e^+e^-$
<12 0	90	[5] BRANDELIK	79B	DASP	$\psi(2S) \to \gamma\chi_{c1}$

RADIATIVE DECAYS

$\Gamma(\gamma\gamma)/\Gamma_{total}$ Γ_{10}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0 0015	90	[6] YAMADA	77	DASP	$e^+e^- \to 3\gamma$

$\Gamma(J/\psi(1S)\gamma)/\Gamma_{total}$ Γ_{11}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.273 ± 0 016 OUR AVERAGE					
0 284 ± 0 021		GAISER	86	CBAL	$\psi(2S) \to \gamma X$
0 274 ± 0 046	943	[6] OREGLIA	82	CBAL	$\psi(2S) \to \gamma\chi_{c1}$
0 28 ± 0 07		[6] HIMEL	80	MRK2	$\psi(2S) \to \gamma\chi_{c1}$
0 19 ± 0 05		[6] BRANDELIK	79B	DASP	$\psi(2S) \to \gamma\chi_{c1}$
0 29 ± 0 05		[6] BARTEL	78B	CNTR	$\psi(2S) \to \gamma\chi_{c1}$
0 28 ± 0 09		[6] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$
• • • We do not use the following data for averages fits limits etc • • •					
0 57 ± 0 17		[6] BIDDICK	77	CNTR	$\psi(2S) \to \gamma X$

[6] Estimated using BR($\psi(2S) \to \gamma\chi_{c1}(1P)$) = 0 087 The errors do not contain the uncertainty in the $\psi(2S)$ decay

$\chi_{c1}(1P)$ REFERENCES

BAGLIN	86B	PL B172 455		(LAPP CERN GENO LYON OSLO ROMA+)
GAISER	86	PR D34 711	+Bloom Bulos Godfrey+	(Crystal Ball Collab)
LEMOIGNE	82	PL 113B 509	+Barate Astbury+	(SACL LOIC SHMP IND)
OREGLIA	82	PR D25 2259	+Partridge+	(SLAC CIT HARV PRIN STAN)
Also	82B	Private Comm	Oreglia	(EFI)
HIMEL	80	PRL 44 920	+Abrams Alam Blocker+	(LBL SLAC)
Also	82	Private Comm	Trilling	(LBL UCB)
BRANDELIK	79B	NP B160 426	+Cords+	(AACH DESY HAMB MPIM TOKY)
BARTEL	78B	PL 79B 492	+Dittmann Duinker Olsson O Neill+	(DESY HEID)
TANENBAUM	78	PR D17 1731	+Alam Boyarski+	(SLAC LBL)
Also	82	Private Comm	Trilling	(LBL UCB)
BIDDICK	77	PRL 38 1324	+Burnett+	(UCSD UMD PAVI PRIN SLAC STAN)
FELDMAN	77	PL 33C 285	+Perl	(LBL SLAC)
YAMADA	77	Hamburg Conf 69		(DESY TOKY)
BARTEL	76B	Tbilisi Conf N75	+Duinker Olsson Heintze+	(DESY HEID)
TANENBAUM	75	PRL 35 1323	+Whitaker Abrams+	(LBL SLAC)
WIIK	75	Stanford Symp 69		(DESY)

OTHER RELATED PAPERS

BARATE	83	PL 121B 449	+Bareyre Bonamy+	(SACL LOIC SHMP IND)
BRANDELIK	79C	ZPHY C1 233	+	(AACH DESY HAMB MPIM TOKY)
KIRK	79	PRL 42 619	+Goodman+	(FNAL HARV ILL OXF TUFT)
BRAUNSCH	75B	PL 57B 407	Braunschweig+	(AACH DESY MPIM TOKY)
FELDMAN	75	Stanford Symp 39		(SLAC)
HEINTZE	75	Stanford Symp 97		(HEID)
SIMPSON	75	PRL 35 699	+Beron Ford Hilger Hofstadter+	(STAN PENN)

$\chi_{c2}(1P)$ or $\chi_{c2}(3555)$ was $\chi(3555)$

$I^G(J^{PC}) = 0^+(2^{++})$

Observed in the radiative decay $\psi(2S) \to \chi_{c2}(1P)\gamma$ Therefore $C = +$ The observed decay into 4π and 6π imply $G = +$ thus $I = 0$ $J = 0$ is excluded by the angular distribution in the hadronic decays J^P abnormal excluded by $\pi^+\pi^-$ and K^+K^- decays $J^P = 2^+$ preferred (FELDMAN 77 OREGLIA 82)

$\chi_{c2}(1P)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3556.3 ± 0.4 OUR AVERAGE					
3556.9 ± 0.4 ± 0.5	50	BAGLIN	86B	SPEC	$\bar{p}p \to e^+e^-$
3557.8 ± 0.2 ± 4		[1] GAISER	86	CBAL	$\psi(2S) \to \gamma X$
3553.4 ± 2.2	66	[2] LEMOIGNE	82	GOLI	190 GeV π^-Be $\to \gamma 2\mu$
3555.9 ± 0.7		[3] OREGLIA	82	CBAL	$e^+e^- \to J/\psi 2\gamma$
3557 ± 1.5	69	[4] HIMEL	80	MRK2	$e^+e^- \to J/\psi 2\gamma$
3551.0 ± 11.0	15	BRANDELIK	79B	DASP	$e^+e^- \to J/\psi 2\gamma$
3553.0 ± 4.0		[4] BARTEL	78B	CNTR	$e^+e^- \to J/\psi 2\gamma$
3553.0 ± 4 ± 4		[4,5] TANENBAUM	78	MRK1	e^+e^-
3563.0 ± 7.0	360	[4] BIDDICK	77	CNTR	$e^+e^- \to \gamma X$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3550.0 ± 10.0		TRILLING	76	MRK1	$e^+e^- \to$ hadrons γ
3543.0 ± 10.0	4	WHITAKER	76	MRK1	$e^+e^- \to J/\psi 2\gamma$

[1] Using mass of $\psi(2S)$ = 3686.0 MeV.
[2] $J/\psi(1S)$ mass constrained to 3097 MeV.
[3] Assuming $\psi(2S)$ mass = 3686 MeV and $J/\psi(1S)$ mass = 3097 MeV.
[4] Mass value shifted by us by amount appropriate for $\psi(2S)$ mass = 3686 MeV and $J/\psi(1S)$ mass = 3097 MeV.
[5] From a simultaneous fit to radiative and hadronic decay channels.

$\chi_{c2}(1P)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
$2.6^{+1.2}_{-0.9}$ OUR AVERAGE					
$2.6^{+1.4}_{-1.0}$	50	BAGLIN	86B	SPEC	$\bar{p}p \to e^+e^-$
$2.8^{+2.1}_{-2.0}$		[6] GAISER	86	CBAL	$\psi(2S) \to \gamma X$

[6] Errors correspond to 90% confidence level; authors give only width range.

$\chi_{c2}(1P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Conf. Lev.
	HADRONIC DECAYS		
Γ_1	$\chi_{c2}(1P) \to \pi^+\pi^-$	$(1.9 \pm 1.0) \times 10^{-3}$	
Γ_2	$\chi_{c2}(1P) \to K^+K^-$	$(1.5 \pm 1.1) \times 10^{-3}$	
Γ_3	$\chi_{c2}(1P) \to 2(\pi^+\pi^-)$	$(2.2 \pm 0.5) \times 10^{-2}$	
Γ_4	$\chi_{c2}(1P) \to 3(\pi^+\pi^-)$	$(1.2 \pm 0.8) \times 10^{-2}$	
Γ_5	$\chi_{c2}(1P) \to \pi^+\pi^-K^+K^-$	$(1.9 \pm 0.5) \times 10^{-2}$	
Γ_6	$\chi_{c2}(1P) \to \pi^+\pi^-p\bar{p}$	$(3.3 \pm 1.3) \times 10^{-3}$	
Γ_7	$\chi_{c2}(1P) \to \rho^0\pi^+\pi^-$	$(7 \pm 4) \times 10^{-3}$	
Γ_8	$\chi_{c2}(1P) \to K^+\bar{K}^*(892)^0\pi^-$ + c.c.	$(4.8 \pm 2.8) \times 10^{-3}$	
Γ_9	$\chi_{c2}(1P) \to p\bar{p}$	$(9.0^{+4.5}_{-3.2}) \times 10^{-5}$	
Γ_{10}	$\chi_{c2}(1P) \to J/\psi(1S)\pi^+\pi^-\pi^0$	$< 1.5 \times 10^{-2}$	90%
	RADIATIVE DECAYS		
Γ_{11}	$\chi_{c2}(1P) \to \gamma\gamma$	$(1.1 \pm 0.6) \times 10^{-3}$	
Γ_{12}	$\chi_{c2}(1P) \to J/\psi(1S)\gamma$	$(13.5 \pm 1.1) \times 10^{-2}$	

$\chi_{c2}(1P)$ PARTIAL WIDTHS

$\Gamma(p\bar{p})$ — Γ_9

VALUE (eV)	DOCUMENT ID		TECN	COMMENT
$233.^{+51.}_{-45.} \pm 48$	BAGLIN	86B	SPEC	$\bar{p}p \to e^+e^-$

$\chi_{c2}(1P)$ BRANCHING RATIOS

HADRONIC DECAYS

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ — Γ_1/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.9 ± 1.0	4	[7] BRANDELIK	79C	DASP	$\psi(2S) \to \gamma\chi_{c2}$

$\Gamma(K^+K^-)/\Gamma_{total}$ — Γ_2/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.5 ± 1.1	2	[7] BRANDELIK	79C	DASP	$\psi(2S) \to \gamma\chi_{c2}$

$[\Gamma(\pi^+\pi^-) + \Gamma(K^+K^-)]/\Gamma_{total}$ — $(\Gamma_1+\Gamma_2)/\Gamma$

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
24 ± 10	[7] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c2}$

$\Gamma(2(\pi^+\pi^-))/\Gamma_{total}$ — Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.022 ± 0.005	[7] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c2}$

$\Gamma(3(\pi^+\pi^-))/\Gamma_{total}$ — Γ_4/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.012 ± 0.008	[7] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c2}$

$\Gamma(\pi^+\pi^-K^+K^-)/\Gamma_{total}$ — Γ_5/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.019 ± 0.005	[7] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c2}$

$\Gamma(\pi^+\pi^-p\bar{p})/\Gamma_{total}$ — Γ_6/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
33 ± 13	[7] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c2}$

$\Gamma(\rho^0\pi^+\pi^-)/\Gamma_{total}$ — Γ_7/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
68 ± 40	[7] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c2}$

$\Gamma(K^+\bar{K}^*(892)^0\pi^-$ + c.c.$)/\Gamma_{total}$ — Γ_8/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
48 ± 28	[7] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c2}$

$\Gamma(p\bar{p})/\Gamma_{total}$ — Γ_9/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
$0.90^{+0.41}_{-0.26} \pm 0.19$		BAGLIN	86B	SPEC	$\bar{p}p \to e^+e^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<9.5	90	[7] BRANDELIK	79B	DASP	$\psi(2S) \to \gamma\chi_{c2}$

$\Gamma(J/\psi(1S)\pi^+\pi^-\pi^0)/\Gamma_{total}$ — Γ_{10}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.015	90	BARATE	81	SPEC	190 GeV π^-Be $\to 2\pi 2\mu$

$\Gamma_i\Gamma_f/\Gamma^2_{total}$ in $\gamma\gamma \to \chi_{c2}(1P) \to p\bar{p}$ — $\Gamma_{11}\Gamma_9/\Gamma^2$

VALUE (units 10^{-7})	EVTS	DOCUMENT ID		TECN	COMMENT
$0.99^{+0.46}_{-0.35}$	6	BAGLIN	87B	SPEC	$\bar{p}p \to \gamma\gamma$

[7] Estimated using BR($\psi(2S) \to \chi_{c2}(1P)\gamma$) = 0.078; the errors do not contain the uncertainty in the $\psi(2S)$ decay.

RADIATIVE DECAYS

$\Gamma(\gamma\gamma)/\Gamma_{total}$ — Γ_{11}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
$11^{+5}_{-4} \pm 4$		BAGLIN	87B	SPEC	$\bar{p}p \to \gamma\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<6	90	[7] YAMADA	77	DASP	$e^+e^- \to 3\gamma$

$\Gamma(J/\psi(1S)\gamma)/\Gamma_{total}$ — Γ_{12}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.135 ± 0.011 OUR AVERAGE					
0.124 ± 0.015		GAISER	86	CBAL	$\psi(2S) \to \gamma X$
0.162 ± 0.028	479	[8] OREGLIA	82	CBAL	$\psi(2S) \to \gamma\chi_{c2}$
0.14 ± 0.04		[8] HIMEL	80	MRK2	$\psi(2S) \to \gamma\chi_{c2}$
0.18 ± 0.05		[8] BRANDELIK	79B	DASP	$\psi(2S) \to \gamma\chi_{c2}$
0.13 ± 0.03		[8] BARTEL	78B	CNTR	$\psi(2S) \to \gamma\chi_{c2}$
$0.11^{+0.13}_{-0.07}$		[8] SPITZER	78	PLUT	$\psi(2S) \to \gamma\chi_{c2}$
0.13 ± 0.08		[8] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c2}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.28 ± 0.13		[8] BIDDICK	77	CNTR	$\psi(2S) \to \gamma X$

[8] Estimated using BR($\psi(2S) \to \chi_{c2}(1P)\gamma$) = 0.078; the errors do not contain the uncertainty in the $\psi(2S)$ decay.

$\chi_{c2}(1P)$ REFERENCES

BAGLIN	87B	PL B187 191	+Baird, Bassompierre, Borreani+	(R704 Collab.)
BAGLIN	86B	PL B172 455		(LAPP, CERN, GENO, LYON, OSLO, ROMA+)
GAISER	86	PR D34 711	+Bloom, Bulos, Godfrey+	(Crystal Ball Collab.)
LEMOIGNE	82	PL 113B 509	+Barate, Astbury+	(SACL, LOIC, SHMP, IND)
OREGLIA	82	PR D25 2259	+Partridge+	(SLAC, CIT, HARV, PRIN, STAN)
Also	82B	Private Comm.	Oreglia	(EFI)
BARATE	81	PR D24 2994	+Astbury+	(SACL, LOIC, SHMP, CERN, IND)
HIMEL	80	PRL 44 920	+Abrams, Alam, Blocker+	(LBL, SLAC)
Also	82	Private Comm.	Trilling	(LBL, UCB)
BRANDELIK	79B	NP B160 426	+Cords+	(AACH, DESY, HAMB, MPIM, TOKY)
BRANDELIK	79C	ZPHY C1 233	+	(AACH, DESY, HAMB, MPIM, TOKY)
BARTEL	78B	PL 79B 492	+Dittmann, Duinker, Olsson, O'Neill+	(DESY, HEID)
SPITZER	78	Kyoto Sum. Inst. 47		(HAMB)

TANENBAUM	78	PR D17 1731	+Alam, Boyarski+	(SLAC, LBL)
Also	82	Private Comm	Trilling	(LBL, UCB)
BIDDICK	77	PRL 38 1324	+Burnett+ (UCSD, UMD, PAVI, PRIN, SLAC, STAN)	
FELDMAN	77	PL 33C 285	+Perl	(LBL, SLAC)
YAMADA	77	Hamburg Conf 69		(DESY, TOKY)
TRILLING	76	Stanford Symp 437		(LBL)
WHITAKER	76	PRL 37 1596	+Tanenbaum, Abrams, Alam+	(SLAC, LBL)

— OTHER RELATED PAPERS —

BARATE	83	PL 121B 449	+Bareyre, Bonamy+	(SACL, LOIC, SHMP, IND)
KIRK	79	PRL 42 619	+Goodman+ (FNAL, HARV, ILL, OXF, TUFT)	
FELDMAN	77	PL 33C 285	+Perl	(LBL, SLAC)
FELDMAN	75B	PRL 35 821	+Jean-Marie, Sadoulet, Vannucci+	(LBL, SLAC)
Also	75C	PRL 35 1189	Feldman	
Erratum				
TANENBAUM	75	PRL 35 1323	+Whitaker, Abrams+	(LBL, SLAC)

$\eta_c(2S)$ or $\eta_c(3590)$

$I^G(J^{PC}) = ?^?(?^{?+})$

OMITTED FROM SUMMARY TABLE

Our latest mini-review on this particle can be found in the 1984 edition. Needs confirmation.

$\eta_c(2S)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
3594.0 ± 5.0	[1] EDWARDS	82C	CBAL	$e^+e^- \to \gamma X$

[1] Assuming mass of $\psi(2S)$ = 3686 MeV

$\eta_c(2S)$ WIDTH

VALUE (MeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<8.0	95	EDWARDS	82C	CBAL	$e^+e^- \to \gamma X$

$\eta_c(2S)$ DECAY MODES

Γ_1 $\eta_c(2S) \to$ hadrons

$\eta_c(2S)$ BRANCHING RATIOS

$\Gamma(\text{hadrons})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
SEEN	EDWARDS	82C	CBAL	$e^+e^- \to \gamma X$

$\eta_c(2S)$ REFERENCES

EDWARDS	82C	PRL 48 70	+Partridge, Peck+	(CIT, HARV, PRIN, STAN, SLAC)

— OTHER RELATED PAPERS —

OREGLIA	82	PR D25 2259	+Partridge+	(SLAC, CIT, HARV, PRIN, STAN)
PORTER	81	SLAC Sum Conf 355	+Edwards+	(CIT, HARV, PRIN, STAN, SLAC)
BARTEL	78B	PL 79B 492	+Dittmann, Duinker, Olsson, O'Neill+	(DESY, HEID)

$\psi(2S)$ or $\psi(3685)$

$I^G(J^{PC}) = 0^-(1^{--})$

$\psi(2S)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3686.00 ± 0.10	413	ZHOLENTZ	80	OLYA	e^+e^-

$\psi(2S) - J/\psi(1S)$ MASS DIFFERENCE

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
589.07 ± 0.13 OUR AVERAGE				
589.7 ± 1.2	LEMOIGNE	82	GOLI	190 GeV π^-Be $\to 2\mu$
589.07 ± 0.13	[1] ZHOLENTZ	80	OLYA	e^+e^-
588.7 ± 0.8	LUTH	75	MRK1	

[1] Redundant with data in mass above.

$\psi(2S)$ WIDTH

VALUE (keV)	DOCUMENT ID
243 ± 43 OUR EVALUATION	Uses $\Gamma(ee)$ from ALEXANDER 88 and BR(ee) = (88 ± 13) · 10^{-4} from FELDMAN 75

$\psi(2S)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$\psi(2S) \to e^+e^-$	$(8.8 \pm 1.3) \times 10^{-3}$	
Γ_2	$\psi(2S) \to \mu^+\mu^-$	$(7.7 \pm 1.7) \times 10^{-3}$	
Γ_3	$\psi(2S) \to$ hadrons	$(98.10 \pm 0.30) \times 10^{-2}$	
Γ_4	$\psi(2S) \to$ virtual $\gamma \to$ hadrons	$(2.9 \pm 0.4) \times 10^{-2}$	
	DECAYS INTO $J/\psi(1S)$ AND ANYTHING		
Γ_5	$\psi(2S) \to J/\psi(1S)$ anything	$(55 \pm 7) \times 10^{-2}$	
Γ_6	$\psi(2S) \to J/\psi(1S)$ neutrals	$(22.6 \pm 2.9) \times 10^{-2}$	
Γ_7	$\psi(2S) \to J/\psi(1S)\pi^+\pi^-$		
Γ_8	$\psi(2S) \to J/\psi(1S)\pi^0\pi^0$		
Γ_9	$\psi(2S) \to J/\psi(1S)\eta$	$(2.7 \pm 0.4) \times 10^{-2}$	S=1.6
Γ_{10}	$\psi(2S) \to J/\psi(1S)\pi^0$	$(9.7 \pm 2.1) \times 10^{-4}$	
	HADRONIC DECAYS		
Γ_{11}	$\psi(2S) \to \pi^+\pi^-$	$(8 \pm 5) \times 10^{-5}$	
Γ_{12}	$\psi(2S) \to \rho\pi$	$< 8.3 \times 10^{-5}$	CL=90%
Γ_{13}	$\psi(2S) \to K^+K^-$	$(1.0 \pm 0.7) \times 10^{-4}$	
Γ_{14}	$\psi(2S) \to 2(\pi^+\pi^-)$	$(4.5 \pm 1.0) \times 10^{-4}$	
Γ_{15}	$\psi(2S) \to 2(\pi^+\pi^-)\pi^0$	$(3.1 \pm 0.7) \times 10^{-3}$	
Γ_{16}	$\psi(2S) \to \pi^+\pi^-K^+K^-$	$(1.6 \pm 0.4) \times 10^{-3}$	
Γ_{17}	$\psi(2S) \to \bar{p}p$	$(1.9 \pm 0.5) \times 10^{-4}$	
Γ_{18}	$\psi(2S) \to \Lambda\bar{\Lambda}$	$< 4 \times 10^{-4}$	CL=90%
Γ_{19}	$\psi(2S) \to \Xi^-\bar{\Xi}^+$	$< 2 \times 10^{-4}$	CL=90%
Γ_{20}	$\psi(2S) \to \pi^+\pi^-p\bar{p}$	$(8.0 \pm 2.0) \times 10^{-4}$	
Γ_{21}	$\psi(2S) \to 3(\pi^+\pi^-)$	$(1.5 \pm 1.0) \times 10^{-4}$	
Γ_{22}	$\psi(2S) \to \rho^0\pi^+\pi^-$	$(4.2 \pm 1.5) \times 10^{-4}$	
Γ_{23}	$\psi(2S) \to K^+\bar{K}^*(892)^0\pi^-$ + c.c.	$(6.7 \pm 2.5) \times 10^{-4}$	
Γ_{24}	$\psi(2S) \to \bar{p}p\pi^0$	$(1.4 \pm 0.5) \times 10^{-4}$	
Γ_{25}	$\psi(2S) \to \pi^+\pi^-\pi^0$	$(9 \pm 5) \times 10^{-5}$	
Γ_{26}	$\psi(2S) \to 3(\pi^+\pi^-)\pi^0$	$(3.5 \pm 1.6) \times 10^{-3}$	
Γ_{27}	$\psi(2S) \to K^+K^-\pi^0$	$< 2.96 \times 10^{-5}$	CL=90%
Γ_{28}	$\psi(2S) \to K^+K^*(892)^-$ + c.c.	$< 1.79 \times 10^{-5}$	CL=90%
	RADIATIVE DECAYS		
Γ_{29}	$\psi(2S) \to \gamma\gamma$	$< 1.8 \times 10^{-4}$	CL=90%
Γ_{30}	$\psi(2S) \to \pi^0\gamma$	$< 5.4 \times 10^{-3}$	CL=95%
Γ_{31}	$\psi(2S) \to \eta\gamma$	$< 2 \times 10^{-4}$	CL=90%
Γ_{32}	$\psi(2S) \to \eta'(958)\gamma$	$< 1.1 \times 10^{-3}$	CL=90%
Γ_{33}	$\psi(2S) \to \chi_{c0}(1P)\gamma$	$(9.3 \pm 0.8) \times 10^{-2}$	
Γ_{34}	$\psi(2S) \to \chi_{c1}(1P)\gamma$	$(8.7 \pm 0.8) \times 10^{-2}$	
Γ_{35}	$\psi(2S) \to \chi_{c2}(1P)\gamma$	$(7.8 \pm 0.8) \times 10^{-2}$	
Γ_{36}	$\psi(2S) \to \eta_c(1S)\gamma$	$(2.8 \pm 0.6) \times 10^{-3}$	
Γ_{37}	$\psi(2S) \to \eta(1430)\gamma$	$< 1.2 \times 10^{-4}$	CL=90%
Γ_{38}	$\psi(2S) \to \eta_c(2S)\gamma$		

Meson Full Listings
$\psi(2S) = \psi(3685)$

$\psi(2S)$ PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_1

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
2.14 ± 0.21	ALEXANDER 88	RVUE	See Υ mini-review
• • • We do not use the following data for averages, fits, limits, etc. • • •			
2.0 ± 0.3	BRANDELIK 79C	DASP	e^+e^-
2.1 ± 0.3	[2] LUTH 75	MRK1	e^+e^-

[2]From a simultaneous fit to e^+e^-, $\mu^+\mu^-$, and hadronic channels assuming $\Gamma(e^+e^-) = \Gamma(\mu^+\mu^-)$.

$\Gamma(\text{hadrons})$ Γ_3

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
224 ± 56	LUTH 75	MRK1	e^+e^-

$\Gamma(\gamma\gamma)$ Γ_{29}

VALUE (eV)	CL%	DOCUMENT ID	TECN	COMMENT
<43.	90	BRANDELIK 79C	DASP	e^+e^-

$\psi(2S)$ $\Gamma(i)\Gamma(e^+e^-)/\Gamma(\text{total})$

This combination of a partial width with the partial width into e^+e^- and with the total width is obtained from the integrated cross section into channel$_i$ in the e^+e^- annihilation. We list only data that have not been used to determine the partial width $\Gamma(i)$ or the branching ratio $\Gamma(i)$/total.

$\Gamma(\text{hadrons}) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_3\Gamma_1/\Gamma$

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
2.2 ± 0.4	ABRAMS 75	MRK1	e^+e^-

$\psi(2S)$ BRANCHING RATIOS

$\Gamma(e^+e^-)/\Gamma_{\text{total}}$ Γ_1/Γ

VALUE (units 10^{-4})	DOCUMENT ID	TECN	COMMENT
88 ± 13	[3] FELDMAN 77	RVUE	e^+e^-

$\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ Γ_2/Γ

VALUE (units 10^{-4})	DOCUMENT ID	TECN	COMMENT
77 ± 17	[4] HILGER 75	SPEC	e^+e^-

$\Gamma(\text{hadrons})/\Gamma_{\text{total}}$ Γ_3/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.981 ± 0.003	[5] LUTH 75	MRK1	e^+e^-

$\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-)$ Γ_2/Γ_1

VALUE	DOCUMENT ID	TECN	COMMENT
0.89 ± 0.16	BOYARSKI 75C	MRK1	e^+e^-

$\Gamma(\text{virtual } \gamma \to \text{hadrons})/\Gamma_{\text{total}}$ Γ_4/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.029 ± 0.004	[6] LUTH 75	MRK1	e^+e^-

[3]From an overall fit assuming equal partial widths for e^+e^- and $\mu^+\mu^-$. For a measurement of the ratio see the entry $\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-)$ below. Includes LUTH 75, HILGER 75, BURMESTER 77.
[4]Restated by us using BR($\psi(2S) \to J/\psi(1S)$ anything) = 0.55.
[5]Includes cascade decay into $J/\psi(1S)$.
[6]Included in $\Gamma(\text{hadrons})/\Gamma_{\text{total}}$.

—— DECAYS INTO $J/\psi(1S)$ AND ANYTHING ——

$\Gamma(J/\psi(1S)\text{ anything})/\Gamma_{\text{total}}$ Γ_5/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.55 ± 0.07 OUR AVERAGE			
0.51 ± 0.12	BRANDELIK 79C	DASP	e^+e^-
0.57 ± 0.08	ABRAMS 75	MRK1	e^+e^-

$\Gamma(J/\psi(1S)\text{ neutrals})/\Gamma(J/\psi(1S)\text{ anything})$ Γ_6/Γ_5

VALUE	DOCUMENT ID	TECN	COMMENT
0.41 ± 0.02	TANENBAUM 76	MRK1	e^+e^-

$\Gamma(J/\psi(1S)\pi\pi)/\Gamma_{\text{total}}$ $(1.5\Gamma_7+3\Gamma_8)/\Gamma$

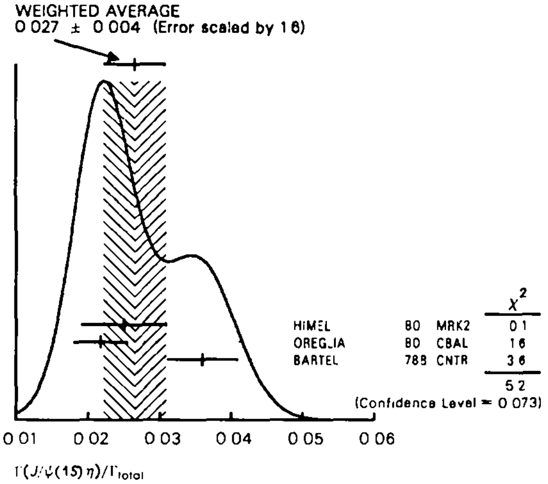
VALUE	DOCUMENT ID	TECN	COMMENT
0.50 ± 0.04 OUR AVERAGE			
0.48 ± 0.06	ABRAMS 75B	MRK1	$e^+e^- \to J/\psi\pi^+\pi^-$
0.51 ± 0.087	ABRAMS 75B	MRK1	$e^+e^- \to J/\psi 2\pi^0$
0.54 ± 0.09	WIIK 75	DASP	$e^+e^- \to J/\psi\pi^+\pi^-$
0.54 ± 0.18	WIIK 75	DASP	$e^+e^- \to J/\psi 2\pi^0$

$\Gamma(J/\psi(1S)\pi^0\pi^0)/\Gamma(J/\psi(1S)\pi^+\pi^-)$ Γ_8/Γ_7

VALUE	DOCUMENT ID	TECN	COMMENT
0.53 ± 0.06	TANENBAUM 76	MRK1	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.64 ± 0.15	[7] HILGER 75	SPEC	e^+e^-

$\Gamma(J/\psi(1S)\eta)/\Gamma_{\text{total}}$ Γ_9/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.027 ± 0.004 OUR AVERAGE	Error includes scale factor of 1.6. See the ideogram below.			
0.025 ± 0.006	166	HIMEL 80	MRK2	e^+e^-
0.0218 ± 0.0014 ± 0.0035	386	OREGLIA 80	CBAL	$e^+e^- \to J/\psi 2\gamma$
0.036 ± 0.005	164	BARTEL 78B	CNTR	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.035 ± 0.009	17	[8] BRANDELIK 79B	DASP	$e^+e^- \to J/\psi 2\gamma$
0.043 ± 0.008	44	[8] TANENBAUM 76	MRK1	e^+e^-



$\Gamma(J/\psi(1S)\pi^0)/\Gamma_{\text{total}}$ Γ_{10}/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.00097 ± 0.00021 OUR AVERAGE				
0.0015 ± 0.0006	7	HIMEL 80	MRK2	e^+e^-
0.0009 ± 0.0002 ± 0.0001	23	OREGLIA 80	CBAL	$\psi(2S) \to J/\psi 2\gamma$

[7]Ignoring the $J/\psi(1S)\eta$ and $J/\psi(1S)\gamma\gamma$ decays.
[8]Low statistics data removed from average.

—— HADRONIC DECAYS ——

$\Gamma(\pi^+\pi^-)/\Gamma_{\text{total}}$ Γ_{11}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN	COMMENT
0.8 ± 0.5		BRANDELIK 79C	DASP	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.5	90	FELDMAN 77	MRK1	e^+e^-

$\Gamma(2(\pi^+\pi^-)\pi^0)/\Gamma_{\text{total}}$ Γ_{15}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
31 ± 7 OUR AVERAGE				
30 ± 8	42	FRANKLIN 83	MRK2	e^+e^-
35 ± 15		ABRAMS 75	MRK1	e^+e^-

$\Gamma(K^+K^-)/\Gamma_{\text{total}}$ Γ_{13}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN	COMMENT
1.0 ± 0.7		BRANDELIK 79C	DASP	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.5	90	FELDMAN 77	MRK1	e^+e^-

$\Gamma(\pi^+\pi^-K^+K^-)/\Gamma_{\text{total}}$ Γ_{16}/Γ

VALUE (units 10^{-4})	DOCUMENT ID	TECN	COMMENT
16 ± 4	[9] TANENBAUM 78	MRK1	e^+e^-

$\Gamma(p\bar{p})/\Gamma_{\text{total}}$ Γ_{17}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
1.9 ± 0.5 OUR AVERAGE				
1.4 ± 0.8	4	BRANDELIK 79C	DASP	e^+e^-
2.3 ± 0.7		FELDMAN 77	MRK1	e^+e^-

$\Gamma(\rho\pi)/\Gamma_{total}$ — Γ_{12}/Γ

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 0.83	90	1	FRANKLIN	83	MRK2	e^+e^-
••• We do not use the following data for averages fits limits etc •••						
<10	90		BARTEL	76	CNTR	e^+e^-
<10	90		[10] ABRAMS	75	MRK1	e^+e^-

$\Gamma(2(\pi^+\pi^-))/\Gamma_{total}$ — Γ_{14}/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
4.5 ± 1 0	TANENBAUM	78	MRK1	e^+e^-

$\Gamma(\Lambda\bar{\Lambda})/\Gamma_{total}$ — Γ_{18}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<4	90	FELDMAN	77	MRK1	e^+e^-

$\Gamma(\Xi^-\bar{\Xi}^+)/\Gamma_{total}$ — Γ_{19}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<2	90	FELDMAN	77	MRK1	e^+e^-

$\Gamma(\pi^+\pi^- p\bar{p})/\Gamma_{total}$ — Γ_{20}/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
8 ± 2	[9] TANENBAUM	78	MRK1	e^+e^-

$\Gamma(3(\pi^+\pi^-))/\Gamma_{total}$ — Γ_{21}/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
1 5 ± 1 0	[9] TANENBAUM	78	MRK1	e^+e^-

$\Gamma(\rho^0\pi^+\pi^-)/\Gamma_{total}$ — Γ_{22}/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
4 2 ± 1.5	TANENBAUM	78	MRK1	e^+e^-

$\Gamma(K^+K^*(892)^0\pi^- + \text{c.c.})/\Gamma_{total}$ — Γ_{23}/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
6.7 ± 2.5	TANENBAUM	78	MRK1	e^+e^-

$\Gamma(\bar{p}p\pi^0)/\Gamma_{total}$ — Γ_{24}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
1.4 ± 0.5	9	FRANKLIN	83	MRK2	e^+e^-

$\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{total}$ — Γ_{25}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
0.85 ± 0 46	4	FRANKLIN	83	MRK2	$e^+e^- \to$ hadrons

$\Gamma(3(\pi^+\pi^-)\pi^0)/\Gamma_{total}$ — Γ_{26}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
35 ± 16	6	FRANKLIN	83	MRK2	$e^+e^- \to$ hadrons

$\Gamma(K^+K^-\pi^0)/\Gamma_{total}$ — Γ_{27}/Γ

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<2.96	90	1	FRANKLIN	83	MRK2	$e^+e^- \to$ hadrons

$\Gamma(K^+\bar{K}^*(892)^- + \text{c.c.})/\Gamma_{total}$ — Γ_{28}/Γ

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<1.79	90	0	FRANKLIN	83	MRK2	$e^+e^- \to$ hadrons

[9] Assuming entirely strong decay
[10] Final state $\rho^0\pi^0$

RADIATIVE DECAYS

$\Gamma(\pi^0\gamma)/\Gamma_{total}$ — Γ_{30}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
< 54	95	[11] LIBERMAN	75	SPEC	e^+e^-
••• We do not use the following data for averages fits limits etc •••					
<100	90	WIIK	75	DASP	e^+e^-

$\Gamma(\eta\gamma)/\Gamma_{total}$ — Γ_{31}/Γ

VALUE (units 10^{-2})	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	90	YAMADA	77	DASP	$e^+e^- \to 3\gamma$

$\Gamma(\eta'(958)\gamma)/\Gamma_{total}$ — Γ_{32}/Γ

VALUE (units 10^{-2})	CL%	DOCUMENT ID		TECN	COMMENT
<0.11	90	[13] BARTEL	76	CNTR	e^+e^-
••• We do not use the following data for averages fits limits, etc •••					
<0 6	90	[12] BRAUNSCH	77	DASP	e^+e^-

$\Gamma(\chi_{c0}(1P)\gamma)/\Gamma_{total}$ — Γ_{33}/Γ

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
9.3 ± 0.8 OUR AVERAGE				
9 9 ± 0.5 ± 0 8	[14] GAISER	86	CBAL	$e^+e^- \to \gamma X$
7.2 ± 2 3	[14] BIDDICK	77	CNTR	$e^+e^- \to \gamma X$
7 5 ± 2 6	[14] WHITAKER	76	MRK1	e^+e^-

$\Gamma(\chi_{c1}(1P)\gamma)/\Gamma_{total}$ — Γ_{34}/Γ

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
8.7 ± 0.8 OUR AVERAGE				
9 0 ± 0 5 ± 0 7	[15] GAISER	86	CBAL	$e^+e^- \to \gamma X$
7 1 ± 1 9	[16] BIDDICK	77	CNTR	$e^+e^- \to \gamma X$

$\Gamma(\chi_{c2}(1P)\gamma)/\Gamma_{total}$ — Γ_{35}/Γ

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
7.8 ± 0.8 OUR AVERAGE				
8 0 ± 0 5 ± 0 7	[17] GAISER	86	CBAL	$e^+e^- \to \gamma X$
7 0 ± 2 0	[16] BIDDICK	77	CNTR	$e^+e^- \to \gamma X$

$\Gamma(\eta_c(1S)\gamma)/\Gamma_{total}$ — Γ_{36}/Γ

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
0.28 ± 0.06	GAISER	86	CBAL	$e^+e^- \to \gamma X$

$\Gamma(\eta(1430)\gamma)/\Gamma_{total}$ — Γ_{37}/Γ

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<0.12	90	[18] SCHARRE	80	MRK1	e^+e^-

$\Gamma(\eta_c(2S)\gamma)/\Gamma_{total}$ — Γ_{38}/Γ

VALUE (units 10^{-2})	CL%	DOCUMENT ID		TECN	COMMENT
••• We do not use the following data for averages, fits, limits etc •••					
0 2 to 1 3	95	EDWARDS	82C	CBAL	$e^+e^- \to \gamma X$

[11] Restated by us using $BR(\psi(2S) \to \mu^+\mu^-) = 0\ 0077$
[12] Restated by us using total decay width 228 keV
[13] The value is normalized to the branching ratio for $\Gamma(J/\psi(1S)\eta)/\Gamma_{total}$
[14] Angular distribution $(1+\cos^2\theta)$ assumed
[15] Angular distribution $(1-0\ 189\ \cos^2\theta)$ assumed
[16] Valid for isotropic distribution of the photon
[17] Angular distribution $(1-0\ 052\ \cos^2\theta)$ assumed
[18] Includes unknown branching fraction $\eta(1430) \to K K \pi$

$\psi(2S)$ REFERENCES

ALEXANDER	88	SLAC PUB 4501	+Bonvicini Drell Frey Luth	(LBL MICH SLAC)
GAISER	86	PR D34 711	+Bloom Bulos Godfrey+	(Crystal Ball Collab)
FRANKLIN	83	PRL 51 963	+Franklin Feldman Abrams Alam+	(LBL SLAC)
EDWARDS	82C	PRL 48 70	+Partridge Peck+	(CIT HARV PRIN STAN SLAC)
LEMOIGNE	82	PL 113B 509	+Barate Astbury+	(SACL LOIC SHMP IND)
HIMEL	80	PRL 44 920	+Abrams Alam Blocker+	(LBL SLAC)
OREGLIA	80	PRL 45 959	+Partridge+	(SLAC CIT HARV PRIN STAN)
SCHARRE	80	PL 97B 329	+Trilling Abrams Alam Blocker+	(SLAC LBL)
ZHOLENTZ	80	PL 96B 214	+Kurdadze Lelchuk Mishnev+	(NOVO)
Also	81	SJNP 34 814	Zholentz+	(NOVO)
		Translated from YAF 34 1471		
BRANDELIK	79B	NP B160 426	+Cords+	(AACH DESY HAMB MPIM TOKY)
BRANDELIK	79C	ZPHY C1 233	+	(AACH DESY HAMB MPIM TOKY)
BARTEL	78B	PL 79B 492	+Dittmann Duinker Olsson O Neill+	(DESY HEID)
TANENBAUM	78	PR D17 1731	+Alam Boyarski+	(SLAC LBL)
BIDDICK	77	PRL 38 1324	+Burnett+	(UCSD UMD PAVI PRIN SLAC STAN)
BRAUNSCH	77	PL 67B 249	Braunschweig+	(AACH DESY HAMB MPIM+)
BURMESTER	77	PL 66B 395	+Criegee+	(DESY HAMB SIEG WUPP)
FELDMAN	77	PL 33C 285	+Perl	(LBL SLAC)
YAMADA	77	Hamburg Conf 69		(DESY TOKY)
BARTEL	76	PL 64B 483	+Duinker Olsson Steffen Heintze+	(DESY HEID)
TANENBAUM	76	PRL 36 402	+Abrams Boyarski Bulos+	(SLAC LBL) IG
WHITAKER	76	PRL 37 1596	+Tanenbaum Abrams Alam+	(SLAC LBL)
ABRAMS	75	Stanford Symp 25		(LBL)
ABRAMS	75B	PRL 34 1181	+Briggs Chinowsky Friedberg+	(LBL SLAC)
BOYARSKI	75C	Palermo Conf 54	+Breidenbach Bulos Abrams Briggs+	(SLAC LBL)
FELDMAN	75	Stanford Symp 39		(SLAC)
HILGER	75	PRL 35 625	+Beron Ford Hofstadter Howell+	(STAN PENN)
LIBERMAN	75	Stanford Symp 55		(STAN)
LUTH	75	PRL 35 1124	+Boyarski Lynch Breidenbach+	(SLAC LBL) JPC
WIIK	75	Stanford Symp 69		(DESY)

OTHER RELATED PAPERS

BARATE	83	PL 121B 449	+Bareyre Bonamy+	(SACL LOIC SHMP IND)
FRANKLIN	83B	SLAC 254 Thesis		(STAN)
BARATE	81	PR D24 2994	+Astbury+	(SACL LOIC SHMP CERN IND)
PARTRIDGE	80B	PRL 45 1150	+Peck+	(CIT HARV PRIN STAN SLAC)
BURMESTER	77	PL 66B 395	+Criegee+	(DESY HAMB SIEG WUPP)
SNYDER	76	PRL 36 1415	+Hom Lederman Appel+	(COLU FNAL STON)
AUBERT	75B	PRL 33 1624	+Becker Biggs Burger Glenn+	(MIT BNL)
BRAUNSCH	75B	PL 57B 407	Braunschweig+	(AACH DESY MPIM TOKY)
CAMERINI	75	PRL 35 483	+Learned Prepost Ash Anderson+	(WISC SLAC)
FELDMAN	75B	PRL 35 821	+Jean Marie Sadoulet Vannucci+	(LBL SLAC)
GRECO	75	PL 56B 367	+Pancheri Srivastava Srivastava	(FRAS)
JACKSON	75	NIM 128 13	+Scharre	(LBL)
SIMPSON	75	PRL 35 699	+Beron Ford Hilger Hofstadter+	(STAN PENN)
ABRAMS	74	PRL 33 1453	+Briggs Augustin Boyarski+	(LBL SLAC)

ψ(3770)

$I^G(J^{PC}) = ?^?(1^{--})$

ψ(3770) MASS

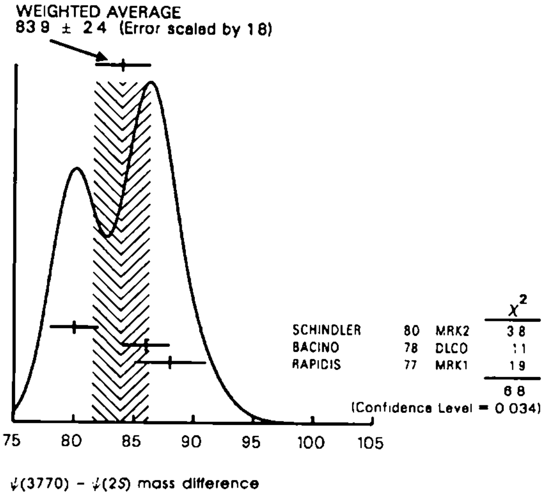
VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
3769.9 ± 2.5 OUR EVALUATION	From ψ(3685) mass and mass difference below			
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3764.0 ± 5.0	[1] SCHINDLER	80	MRK2	e^+e^-
3770 ± 6.0	[1] BACINO	78	DLCO	e^+e^-
3772.0 ± 6.0	[1] RAPIDIS	77	MRK1	e^+e^-

[1] Errors include systematic common to all experiments

ψ(3770) − ψ(2S) MASS DIFFERENCE

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
83.9 ± 2.4 OUR AVERAGE	Error includes scale factor of 1.8. See the ideogram below.			
80.0 ± 2.0	SCHINDLER	80	MRK2	e^+e^-
86.0 ± 2.0	[2] BACINO	78	DLCO	e^+e^-
88.0 ± 3.0	RAPIDIS	77	MRK1	e^+e^-

[2] SPEAR ψ(2S) mass subtracted (see SCHINDLER 80)



ψ(3770) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
25.3 ± 2.9 OUR AVERAGE				
24.0 ± 5.0	SCHINDLER	80	MRK2	e^+e^-
24.0 ± 5.0	BACINO	78	DLCO	e^+e^-
28.0 ± 5.0	RAPIDIS	77	MRK1	e^+e^-

ψ(3770) DECAY MODES

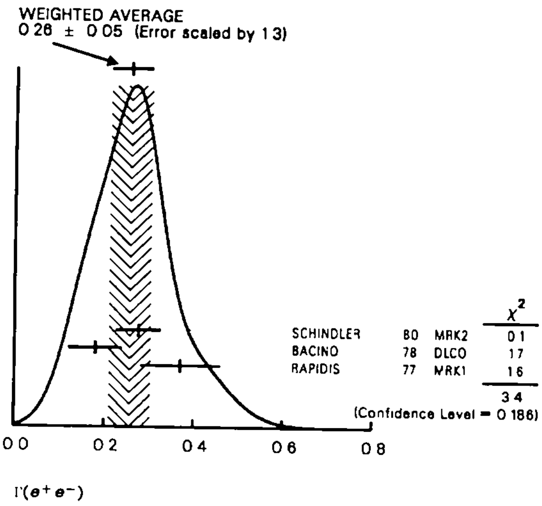
	Mode	Fraction (Γ_i/Γ)
Γ_1	ψ(3770) → e^+e^-	$(1.30 \pm 0.20)\times 10^{-5}$
Γ_2	ψ(3770) → $D\bar{D}$	

ψ(3770) PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_1

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.26 ± 0.05 OUR AVERAGE	Error includes scale factor of 1.3. See the ideogram below.			
0.276 ± 0.050	SCHINDLER	80	MRK2	e^+e^-
0.18 ± 0.06	BACINO	78	DLCO	e^+e^-
0.37 ± 0.09	[3] RAPIDIS	77	MRK1	e^+e^-

[3] See also $\Gamma(e^+e^-)/\Gamma_{total}$ below



ψ(3770) BRANCHING RATIOS

$\Gamma(D\bar{D})/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
DOMINANT	PERUZZI	77	MRK1	$e^+e^- \to D\bar{D}$

$\Gamma(e^+e^-)/\Gamma_{total}$ Γ_1/Γ

VALUE (units 10^{-5})	DOCUMENT ID		TECN	COMMENT
1.3 ± 0.2	RAPIDIS	77	MRK1	e^+e^-

ψ(3770) REFERENCES

SCHINDLER	80	PR D21 2716	+Siegrist, Alam, Boyarski+	(MARK II Collab.)
BACINO	78	PRL 40 671	+Baumgarten, Birkwood+	(SLAC, UCLA, UCI)
PERUZZI	77	PRL 39 1301	+Piccolo, Feldman+	(SLAC, LBL, NWES, HAWA)
RAPIDIS	77	PRL 39 526	+Gobbi, Luke+	(MARK I Collab.)

ψ(4040)

$I^G(J^{PC}) = ?^?(1^{--})$

J^{PC} for the ψ(4040) is known by its production in e^+e^- collisions via single-photon annihilation. I^G is not known, and the interpretation of this state as a single resonance is unclear because of the expectation of substantial threshold effects in this energy region.

ψ(4040) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
4040.0 ± 10.0	BRANDELIK	78C	DASP	e^+e^-

ψ(4040) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
52.0 ± 10.0	BRANDELIK	78C	DASP	e^+e^-

ψ(4040) DECAY MODES

	Mode
Γ_1	ψ(4040) → $D^0\bar{D}^0$
Γ_2	ψ(4040) → $D^*(2010)^0\bar{D}^0$ + c.c.
Γ_3	ψ(4040) → $D^*(2010)^0\bar{D}^*(2010)^0$
Γ_4	ψ(4040) → $J/\psi(1S)$ hadrons
Γ_5	ψ(4040) → e^+e^-
Γ_6	ψ(4040) → $\mu^+\mu^-$

ψ(4040) PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_5

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.75 ± 0.15	BRANDELIK	78C	DASP	e^+e^-

ψ(4040) BRANCHING RATIOS

$\Gamma(D^0\bar{D}^0)/\Gamma(D^*(2010)^0\bar{D}^0$ + c.c.) Γ_1/Γ_2

VALUE	DOCUMENT ID		TECN	COMMENT
0.05 ± 0.03	[1] GOLDHABER	77	MRK1	e^+e^-

[1] Phase-space factor (p^3) explicitly removed

$\Gamma(D^*(2010)^0\bar{D}^*(2010)^0)/\Gamma(D^*(2010)^0\bar{D}^0$ + c.c.) Γ_3/Γ_2

VALUE	DOCUMENT ID		TECN	COMMENT
32.0 ± 12.0	[2] GOLDHABER	77	MRK1	e^+e^-

[2] Phase-space factor (p^3) explicitly removed

$\Gamma(e^+e^-)/\Gamma_{total}$ Γ_5/Γ

VALUE (units 10^{-5})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
~1.0	FELDMAN	77	MRK1	e^+e^-

ψ(4040) REFERENCES

BRANDELIK	78C	PL 76B 361	+Cords+	(AACH, DESY, HAMB, MPIM, TOKY)
Also	79C	ZPHY C1 233	Brandelik+	(AACH, DESY, HAMB, MPIM, TOKY)
FELDMAN	77	PL 33C 285	+Perl	(LBL, SLAC)
GOLDHABER	77	PL 69B 503	+Wiss, Abrams, Alam+	(LBL, SLAC)

OTHER RELATED PAPERS

HEIKKILA	84	PR D29 110	+Tornqvist, Ono	(HELS, TOKY)
ONO	84	ZPHY C26 307		(ORSA)
SIEGRIST	82	PR D26 969	+Schwitters, Alam, Chinowsky+	(SLAC, LBL)
KIRKBY	79B	Fermilab Symp. 107		(SLAC)
RICHARDSON	79	PL 82B 272		(SLAC)
LUTH	77	PL 70B 120	+Pierre, Abrams, Alam, Boyarski+	(LBL, SLAC)
PERUZZI	76	PRL 37 569	+Piccolo, Feldman, Nguyen, Wiss+	(SLAC, LBL)
AUGUSTIN	75	PRL 34 764	+Boyarski, Abrams, Briggs+	(SLAC, LBL)
BACCI	75	PL 58B 481	+Bidoli, Penso, Stella+	(ROMA, FRAS)
BOYARSKI	75B	PRL 34 762	+Breidenbach, Abrams, Briggs+	(SLAC, LBL)
ESPOSITO	75	PL 58B 478	+Felicetti, Peruzzi+	(FRAS, NAPL, PADO, ROMA)

ψ(4160)

$I^G(J^{PC}) = ?^?(1^{--})$

J^{PC} for the ψ(4160) is known by its production in e^+e^- collisions via single-photon annihilation. I^G is not known, and the interpretation of this state as a single resonance is unclear because of the expectation of substantial threshold effects in this energy region.

ψ(4160) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
4159.0 ± 20.0	BRANDELIK	78C	DASP	e^+e^-

ψ(4160) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
78.0 ± 20.0	BRANDELIK	78C	DASP	e^+e^-

ψ(4160) DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	ψ(4160) → e^+e^-	$(1.0 \pm 0.4) \times 10^{-5}$

ψ(4160) PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_1

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.77 ± 0.23	BRANDELIK	78C	DASP	e^+e^-

ψ(4160) REFERENCES

BRANDELIK	78C	PL 76B 361	+Cords+	(AACH, DESY, HAMB, MPIM, TOKY)

OTHER RELATED PAPERS

ONO	84	ZPHY C26 307		(ORSA)
KIRKBY	79B	Fermilab Symp. 107		(SLAC)
BURMESTER	77	PL 66B 395	+Criegee+	(DESY, HAMB, SIEG, WUPP)

ψ(4415)

$I^G(J^{PC}) = ?^?(1^{--})$

J^{PC} for the ψ(4415) is known by its production in e^+e^- collisions via single-photon annihilation. I^G is not known, and the interpretation of this state as a single resonance is unclear because of the expectation of substantial threshold effects in this energy region.

ψ(4415) MASS

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
4415 ± 6	OUR AVERAGE				
4417.0 ± 10.0		BRANDELIK	78C	DASP	e^+e^-
4414. ± 7		SIEGRIST	76	MRK1	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~4400		KNIES	77	PLUT	$e^+e^- \to \mu^+\mu^-$

ψ(4415) WIDTH

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
43 ± 15	OUR AVERAGE	Error includes scale factor of 1.8.			
66.0 ± 15.0		BRANDELIK	78C	DASP	e^+e^-
33. ± 10		SIEGRIST	76	MRK1	e^+e^-

ψ(4415) DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	ψ(4415) → e^+e^-	$(1.1 \pm 0.4) \times 10^{-5}$
Γ_2	ψ(4415) → hadrons	

ψ(4415) PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_1

VALUE (keV)		DOCUMENT ID		TECN	COMMENT
0.47 ± 0.10	OUR AVERAGE				
0.49 ± 0.13		BRANDELIK	78C	DASP	e^+e^-
0.44 ± 0.14		SIEGRIST	76	MRK1	e^+e^-

ψ(4415) BRANCHING RATIOS

$\Gamma(\text{hadrons})/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
DOMINANT	SIEGRIST	76	MRK1	e^+e^-

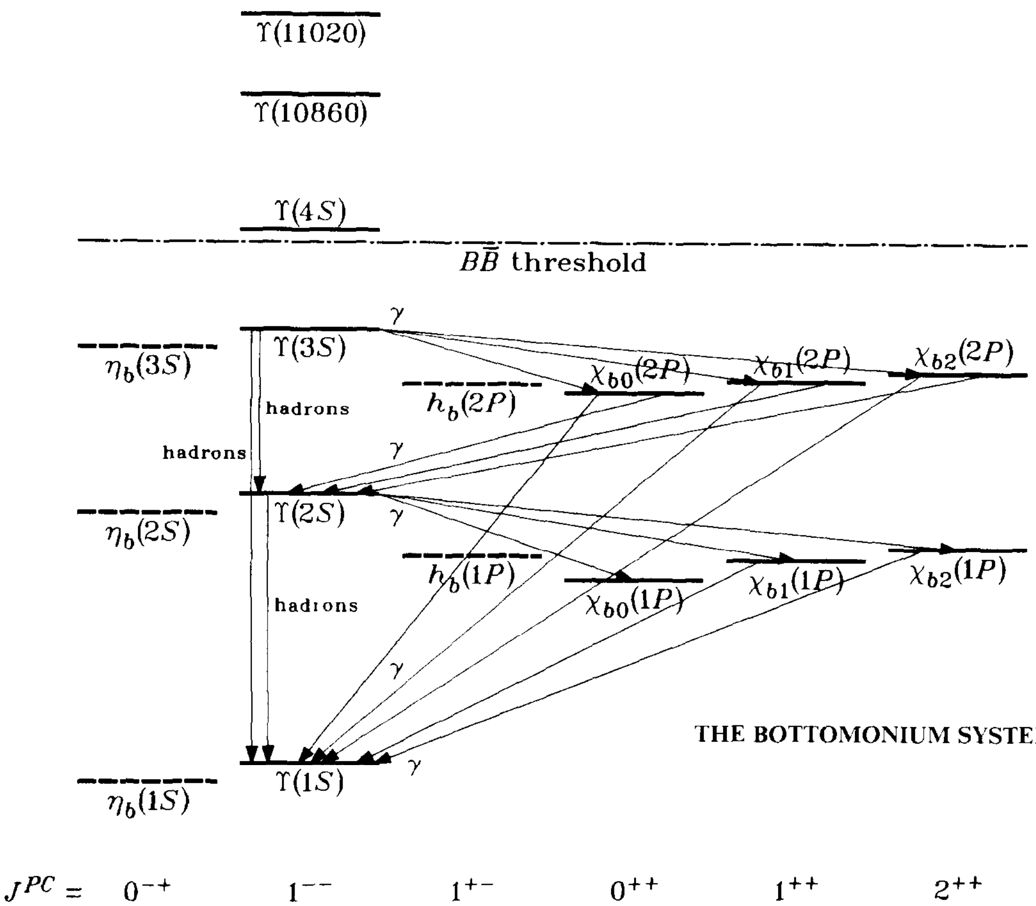
ψ(4415) REFERENCES

BRANDELIK	78C	PL 76B 361	+Cords+	(AACH, DESY, HAMB, MPIM, TOKY)
KNIES	77	Hamburg Symp. 93		(PLUTO Collab.)
SIEGRIST	76	PRL 36 700	+Abrams, Boyarski, Breidenbach+	(LBL, SLAC)

OTHER RELATED PAPERS

BURMESTER	77	PL 66B 395	+Criegee+	(DESY, HAMB, SIEG, WUPP)
LUTH	77	PL 70B 120	+Pierre, Abrams, Alam, Boyarski+	(LBL, SLAC)

$b\bar{b}$ MESONS



THE BOTTOMONIUM SYSTEM

The level scheme of the $b\bar{b}$ states showing experimentally established states with solid lines Singlet states are called η_b and h_b, triplet states Υ and χ_{bJ} In parentheses it is sufficient to give the radial quantum number and the orbital angular momentum to specify the states with all their quantum numbers E g, $h_b(2P)$ means 2^1P_1 with $n = 2$, $L = 1$, $S = 0$, $J = 1$, $PC = +-$ If found, D-wave states would be called $\eta_b(nD)$ and $\Upsilon_J(nD)$, with $J =$ 1,2,3 and $n =$ 1,2,3,4, For the χ_b states the spins of only the $\chi_{b2}(1P)$ and $\chi_{b1}(1P)$ have been experimentally established The spins of the other χ_b are given as the preferred values, based on the quarkonium models The figure also shows the observed hadronic and radiative transitions

NOTE ON WIDTH DETERMINATIONS OF THE Υ STATES

As is the case for $J/\psi(1S)$ and $\psi(2S)$, the full widths of the bound $b\bar{b}$ states $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ are not directly measurable since they are much smaller than the energy resolution of the e^+e^- storage rings where these states are produced. The common indirect method to determine Γ starts from

$$\Gamma = \Gamma_{\ell\ell}/B_{\ell\ell} \qquad (1)$$

where $\Gamma_{\ell\ell}$ is one leptonic partial width and $B_{\ell\ell}$ is the corresponding branching fraction ($\ell = e$, μ, or τ). One then assumes e-μ-τ universality and uses

$$\Gamma_{\ell\ell} = \Gamma_{ee}$$

$$B_{\ell\ell} = \text{average of } B_{ee},\ B_{\mu\mu}, \text{ and } B_{\tau\tau} \qquad (2)$$

The electronic partial width Γ_{ee} is also not directly measurable at e^+e^- storage rings, only the combination $\Gamma_{ee}\Gamma_{had}/\Gamma$, where Γ_{had} is the hadronic partial width and

$$\Gamma_{had} + 3\Gamma_{ee} = \Gamma \qquad (3)$$

This combination is obtained experimentally from the energy-integrated hadronic cross section

$$\int_{\text{resonance}} \sigma(e^+e^- \rightarrow \Upsilon \rightarrow \text{hadrons})dE$$

$$= \frac{6\pi}{M^2}\frac{\Gamma_{ee}\Gamma_{had}}{\Gamma}C_r = \frac{6\pi}{M^2}\frac{\Gamma_{ee}^{(0)}\Gamma_{had}}{\Gamma}C_r^{(0)} \qquad (4)$$

where M is the Υ mass, and C_r and $C_r^{(0)}$ are radiative correction factors. C_r is used for obtaining Γ_{ee} as defined in Eq. (1) and contains corrections from all orders of QED for describing $(b\bar{b}) \rightarrow e^+e^-$. The lowest order QED value $\Gamma_{ee}^{(0)}$, relevant for the comparison with potential-model calculations, is defined by the lowest order QED graph (Born term) alone and is about 7% lower than Γ_{ee}. In the past this distinction had been overlooked by some authors as pointed out by ALEXANDER 88, BARU 86, COOPER 86, KOENIGSMANN 86, and others.

The Listings give experimental results on B_{ee}, $B_{\mu\mu}$, $B_{\tau\tau}$, and $\Gamma_{ee}\Gamma_{had}/\Gamma$. The entries of the latter quantity have been re-evaluated using consistently the correction procedure of KURAEV 85. The partial width Γ_{ee} is obtained from the average values for $\Gamma_{ee}\Gamma_{had}/\Gamma$ and $B_{\ell\ell}$ using

$$\Gamma_{ee} = \frac{\Gamma_{ee}\Gamma_{had}}{\Gamma(1 - 3B_{\ell\ell})} \qquad (5)$$

The total width Γ is then obtained from Eq. (1). We do not list Γ_{ee} and Γ values of individual experiments. The Γ_{ee} values in the Meson Summary Table are also those defined in Eq. (1) and no longer the lowest order quantities $\Gamma_{ee}^{(0)}$.

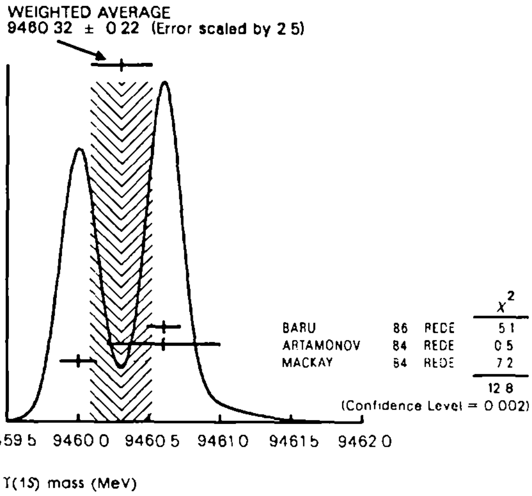
Υ(1S) or Υ(9460)

$I^G(J^{PC}) = ?^?(1^{--})$

Υ(1S) MASS

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
9460.32±0.22	**OUR AVERAGE**	Error includes scale factor of 2.5. See the ideogram below.			
9460.59±0.12		BARU	86	REDE	$e^+e^- \rightarrow$ hadrons
9460.6 ±0.4		[1] ARTAMONOV	84	REDE	$e^+e^- \rightarrow$ hadrons
9459.97±0.11±0.07		MACKAY	84	REDE	$e^+e^- \rightarrow$ hadrons

[1] Value includes data of ARTAMONOV 82.



Υ(1S) WIDTH

VALUE (keV)		DOCUMENT ID
51.6 ±3.1	**OUR EVALUATION**	See Υ mini-review

Υ(1S) DECAY MODES

	Mode	Fraction (Γ_i/Γ)		Conf. Lev.
Γ_1	$\Upsilon(1S) \rightarrow \mu^+\mu^-$	$(2.62\pm0.16)\times10^{-2}$		
Γ_2	$\Upsilon(1S) \rightarrow e^+e^-$	$(2.52\pm0.17)\times10^{-2}$		
Γ_3	$\Upsilon(1S) \rightarrow \tau^+\tau^-$	$(2.97\pm0.35)\times10^{-2}$		
	HADRONIC DECAYS			
Γ_4	$\Upsilon(1S) \rightarrow \rho\pi$	< 2.1	$\times10^{-3}$	90%
Γ_5	$\Upsilon(1S) \rightarrow J/\psi(1S)$ anything	< 2	$\times10^{-2}$	90%
	RADIATIVE DECAYS			
Γ_6	$\Upsilon(1S) \rightarrow f_2(1270)\gamma$	< 3.2	$\times10^{-5}$	90%
Γ_7	$\Upsilon(1S) \rightarrow f_2'(1525)\gamma$	< 2.4	$\times10^{-5}$	90%
Γ_8	$\Upsilon(1S) \rightarrow f_2(1720)\gamma$			

Meson Full Listings

$\Upsilon(1S) = \Upsilon(9460)$, $\chi_{b0}(1P) = \chi_{b0}(9860)$

$\Upsilon(1S)$ $\Gamma(i)\Gamma(e^+e^-)/\Gamma(\text{total})$

$\Gamma(\text{hadrons}) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_0\Gamma_2/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
1.24 ± 0.05 OUR AVERAGE				
1 37 ± 0 06 ± 0.09	[2] GILES	84B	CLEO	$e^+e^- \to$ hadrons
1 17 ± 0 06 ± 0.10	[2] TUTS	83	CUSB	$e^+e^- \to$ hadrons
1 23 ± 0 08 ± 0.04	[2] ALBRECHT	82	DASP	$e^+e^- \to$ hadrons
1 13 ± 0.07 ± 0.11	[2] NICZYPORUK	82	LENA	$e^+e^- \to$ hadrons
1 09 ± 0.25	[2] BOCK	80	CNTR	$e^+e^- \to$ hadrons
1 35 ± 0 14	[3] BERGER	79	PLUT	$e^+e^- \to$ hadrons

[2]Radiative corrections reevaluated by BUCHMUELLER 87 following KURAEV 85
[3]Radiative corrections reevaluated by ALEXANDER 88 using BR($\mu\mu$) = 0 026

$\Upsilon(1S)$ PARTIAL WIDTHS

$\Gamma(e^-e^-)$ — Γ_2

VALUE (keV)	DOCUMENT ID
1.34 ± 0.05 OUR EVALUATION	See Υ mini-review

$\Upsilon(1S)$ BRANCHING RATIOS

$\Gamma(\mu^+\mu^-)/\Gamma_{total}$ — Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0262 ± 0.0016 OUR AVERAGE					
0.0230 ± 0 0025 ± 0.0013	86	ALBRECHT	87	ARG	$\Upsilon(2S) \to \pi^+\pi^-\mu^+\mu^-$
0.029 ± 0 003 ± 0.002		BESSON	84	CLEO	$\Upsilon(2S) \to \pi^+\pi^-\mu^+\mu^-$
0 027 ± 0.003 ± 0 003		ANDREWS	83	CLEO	$e^+e^- \to \mu^+\mu^-$
0 0270 ± 0 0028 ± 0 0014		TUTS	83	CUSB	$e^-e^- \to \mu^+\mu^-$
0.032 ± 0 013 ± 0.003		ALBRECHT	82	DASP	$e^+e^- \to \mu^+\mu^-$
0 038 ± 0 015 ± 0 002		NICZYPORUK	82	LENA	$e^+e^- \to \mu^+\mu^-$
0 014 $^{+0\ 034}_{-0\ 014}$		BOCK	80	CNTR	$e^+e^- \to \mu^+\mu^-$
0 022 ± 0 020		BERGER	79	PLUT	$e^+e^- \to \mu^+\mu^-$

$\Gamma(e^+e^-)/\Gamma_{total}$ — Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0252 ± 0.0017 OUR AVERAGE					
0 0242 ± 0.0014 ± 0 0014	307	ALBRECHT	87	ARG	$\Upsilon(2S) \to \pi^+\pi^-e^+e^-$
0 028 ± 0 003 ± 0 002		BESSON	84	CLEO	$\Upsilon(2S) \to \pi^+\pi^-e^+e^-$
0 051 ± 0.030		BERGEP	80C	PLUT	$e^+e^- \to e^+e^-$

$\Gamma(\tau^+\tau^-)/\Gamma_{total}$ — Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.0297 ± 0.0035 OUR AVERAGE				
0.027 ± 0 004 ± 0 002	[4] ALBRECHT	85C	ARG	$\Upsilon(2S) \to \pi^+\pi^-\tau^+\tau^-$
0 034 ± 0.004 ± 0 004	GILES	83	CLEO	$e^+e^- \to \tau^+\tau^-$

[4]Using BR($\Upsilon(1S) \to ee$) = BR($\Upsilon(1S) \to \mu\mu$) = 0 0256 not used for width evaluations

$\Gamma(\rho\pi)/\Gamma_{total}$ — Γ_4/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN
<21	90	NICZYPORUK 83	LENA

$\Gamma(J/\psi(1S)\text{ anything})/\Gamma_{total}$ — Γ_5/Γ

VALUE	CL%	DOCUMENT ID	TECN
<0.02	90	NICZYPORUK 83	LENA

$\Gamma(f_2(1270)\gamma)/\Gamma_{total}$ — Γ_6/Γ

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN	COMMENT
<3.2	90	[5] BEAN	86	CLEO	$e^+e^- \to \gamma\pi\pi$

[5]Using BR($f_2(1270) \to \pi\pi$) = 0 84

$\Gamma(f_2'(1525)\gamma)/\Gamma_{total}$ — Γ_7/Γ

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN	COMMENT
<2.4	90	[6] BEAN	86	CLEO	$e^+e^- \to \gamma K^+K^-$

[6]Assuming BR($f_2'(1525) \to K\bar{K}$) = 1 0

$\Gamma(f_2(1720)\gamma)/\Gamma_{total}$ — Γ_8/Γ

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •					
<3 2	90	[7] BEAN	86	CLEO	$e^+e^- \to \gamma K^+K^-$
<2 6	90	[8] BEAN	86	CLEO	$e^+e^- \to \gamma\pi^+\pi^-$

[7]Includes unknown branching ratio of $f_2(1720) \to K^+K^-$
[8]Includes unknown branching ratio of $f_2(1720) \to \pi^+\pi^-$

$\Upsilon(1S)$ REFERENCES

ALEXANDER	88	SLAC PUB 4501	+Bonvicini Drell Frey Luth	(LBL MICH SLAC)
ALBRECHT	87	ZPHY C35 283	+Binder Boeckmann Glaeser+	(ARGUS Collab)
BUCHMUEL	87	MIT LNS 159	Buchmueller Cooper	(HANN MIT)
BARU	86	ZPHY C30 551	+Blinov Bondar Bukin+	(NOVO)
BEAN	86	PR D34 905	+Bobbink Brock Engler+	(CLEO Collab)
ALBRECHT	85C	PL 154B 452	+Drescher Heller+	(ARGUS Collab)
KURAEV	85	SJNP 41 466	+Fadin	(ASCI)
		Translated from YAF 41 733		
ARTAMONOV	84	PL 137B 272	+Baru Blinov Bondar+	(NOVO)
BESSON	84	PR D30 1433	+Green Hicks Namjoshi Sannes+	(CLEO Collab)
GILES	84B	PR D29 1285	+Hassard Hempstead Kinoshita+	(CLEO Collab)
MACKAY	84	PR D29 2483	+	(CUSB Collab)
ANDREWS	83	PRL 50 807	+	(CLEO Collab)
GILES	83	PRL 50 877	+	(HARV OSU ROCH RUTG SYRA VAND+)
NICZYPORUK	83	ZPHY C17 197	+	(LENA Collab)
TUTS	83	Cornell Conf 284		(CUSB Collab)
ALBRECHT	82	PL 116B 383	+Hofmann+	(DESY DORT HEID LUND ITEP)
ARTAMONOV	82	PL 118B 225	+Baru Blinov Bondar Bukin Groshev+	(NOVO)
NICZYPORUK	82	ZPHY C15 299	+Folger Bienlein+	(LENA Collab)
BERGER	80C	PL 93B 497	+Lackas+	(AACH DESY HAMB SIEG, WUPP)
BOCK	80	ZPHY C6 125	+Blanar Blum+	(HEID MPIM DESY HAMB)
BERGER	79	ZPHY C1 343	+Alexander+	(AACH DESY HAMB SIEG WUPG)

OTHER RELATED PAPERS

ALEXANDER	88	SLAC PUB 4501	+Bonvicini Drell Frey Luth	(LBL MICH SLAC)
COOPER	86	Berkeley Conf 67		(MIT)
KOENIGS	86	DESY 86/136	Koenigsmann	(DESY)
ALBRECHT	84	PL 134B 137	+Drescher Heller+	(ARGUS Collab)
ARTAMONOV	84	PL 137B 272	+Baru Blinov Bondar+	(NOVO)
ARTAMONOV	82	PL 118B 225	+Baru Blinov Bondar Bukin Groshev+	(NOVO)
MAGERAS	81	PRL 46 1115	+Bohringer Finocchiaro+	(COLU STON LSU MPIM)
MUELLER	81	PRL 46 1181	+	(RUTG SYRA LEMO VAND CORN ITHA+)
NICZYPORUK	81	PL 46 92	+Chen Vogel Wegener+	(LENA Collab)
ALBRECHT	80	PL 93B 500	+Hofmann+	(DESY DORT HEID LUND)
ANDREWS	80	PRL 44 1108	+	(CLEO Collab)
BOHRINGER	80	PRL 44 1111	+Costantini Finocchiaro	(COLU STON)
KOURKOU	80	PL 91B 481	Kourkoumelis+	(ATHU NTUA, BNL CERN+)
ANGELIS	79	PL 87B 398	+Besch Blumenfeld+	(CERN COLU OXF ROCK)
BADIER	79	PL 86B 98	+Boucrot+	(SACL CERN CDEF EPOL LALO)
DARDEN	79	PL 80B 419	+Hofmann Schubert+	(DESY DORT HEID LUND)
BERGER	78	PL 76B 243	+Alexander+	(AACH DESY HAMB SIEG WUPG)
BIENLEIN	78	PL 78B 360	+Glawe Bock Blanar+	(DESY HAMB HEID MPIM)
DARDEN	78	PL 76B 246	+Hofmann Schubert+	(DESY DORT HEID LUND)
GARELICK	78	PR D18 945	+Gauthier Hicks Oliver+	(NEAS WASH TUFT)
KAPLAN	78	PRL 40 435	+Appel Herb Hom+	(STON FNAL COLU)
YOH	78	PRL 41 684	+Herb Hom Lederman+	(COLU, FNAL STON)
COBB	77	PL 72B 273	+Iwata Fabjan+	(BNL CERN SYRA YALE)
HERB	77	PRL 39 252	+Hom Lederman Appel Ito+	(COLU FNAL STON)
INNES	77	PRL 39 1240	+Appel Brown Herb Hom+	(COLU FNAL STON)

$\chi_{b0}(1P)$ or $\chi_{b0}(9860)$

$I^G(J^{PC}) = ?^?(0\text{ preferred}^{++})$

Observed in radiative decay of the $\Upsilon(2S)$, therefore $C = +$ Branching ratio requires E1 transition, M1 is strongly disfavored, therefore $P = +$

$\chi_{b0}(1P)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
9859.8 ± 1.3 OUR AVERAGE				
9860 0 ± 0 5 ± 1 4	[1] ALBRECHT	85E	ARG	$\Upsilon(2S) \to$ conv γX
9858.3 ± 1.6 ± 2.7	[1] NERNST	85	CBAL	$\Upsilon(2S) \to \gamma X$
9864.1 ± 7 ± 1	[1] HAAS	84	CLEO	$\Upsilon(2S) \to$ conv γX
• • • We do not use the following data for averages, fits limits etc • • •				
9872.8 ± 0.7 ± 5 0	[1] KLOPFEN	83	CUSB	$\Upsilon(2S) \to \gamma X$

[1]From γ energy below, assuming $\Upsilon(2S)$ mass = 10023 4 MeV

γ ENERGY IN $\Upsilon(2S)$ DECAY

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
162.3 ± 1.3 OUR AVERAGE				
162.1 ± 0.5 ± 1 4	ALBRECHT	85E	ARG	$\Upsilon(2S) \to$ conv γX
163 8 ± 1 6 ± 2 7	NERNST	85	CBAL	$\Upsilon(2S) \to \gamma X$
158 0 ± 7 ± 1	HAAS	84	CLEO	$\Upsilon(2S) \to$ conv γX
• • • We do not use the following data for averages, fits limits etc • • •				
149 4 ± 0 7 ± 5 0	KLOPFEN	83	CUSB	$\Upsilon(2S) \to \gamma X$

$\chi_{b0}(1P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_1	$\chi_{b0}(1P) \to \Upsilon(1S)\gamma$	< 6 × 10^{-2}	90%

$\chi_{b0}(1P)$ BRANCHING RATIOS

$\Gamma(\Upsilon(1S)\gamma)/\Gamma_{total}$ Γ_1/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.06	90	WALK	86	CBAL	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$
• • • We do not use the following data for averages, fits, limits, etc • • •					
<0 11	90	PAUSS	83	CUSB	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$

$\chi_{b0}(1P)$ REFERENCES

WALK	86	PR D34 2611	+Zschorsch+ (Crystal Ball Collab)
ALBRECHT	85E	PL 160B 331	+Drescher Heller+ (ARGUS Collab)
NERNST	85	PRL 54 2195	+Antreasyan Aschman+ (Crystal Ball Collab)
HAAS	84	PRL 52 799	+Jensen Kagan Kass Behrends+ (CLEO Collab)
KLOPFEN	83	PRL 51 160	Klopfenstein Horstkotte+ (CUSB Collab)
PAUSS	83	PL 130B 439	+Dietl Eigen+ (MPIM COLU CORN LSU STON)

$\chi_{b1}(1P)$ or $\chi_{b1}(9890)$

$I^G(J^{PC}) = ?^?(1^{++})$

Observed in radiative decay of the $\Upsilon(2S)$, therefore C = + Branching ratio requires E1 transition, M1 is strongly disfavored, therefore P = + J = 1 from SKWARNICKI 87

$\chi_{b1}(1P)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
9891.9 ± 0.7 OUR AVERAGE				
9890 8 ± 0.9 ± 1 3	[1] WALK	86	CBAL	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$
9890 8 ± 0 3 ± 1.1	[1] ALBRECHT	85E	ARG	$\Upsilon(2S) \to$ conv γ X
9892.0 ± 0 8 ± 2.4	[1] NERNST	85	CBAL	$\Upsilon(2S) \to \gamma$ X
9893.6 ± 0.8 ± 1.0	[1] HAAS	84	CLEO	$\Upsilon(2S) \to$ conv γ X
9894.4 ± 0.4 ± 3 0	[1] KLOPFEN	83	CUSB	$\Upsilon(2S) \to \gamma$ X
9892 0 ± 3.0	[1] PAUSS	83	CUSB	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$

[1] From γ energy below, assuming $\Upsilon(2S)$ mass = 10023 4 MeV

γ ENERGY IN $\Upsilon(2S)$ DECAY

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
130.6 ± 0.7 OUR AVERAGE				
131.7 ± 0.9 ± 1.3	WALK	86	CBAL	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$
131 7 ± 0.3 ± 1.1	ALBRECHT	85E	ARG	$\Upsilon(2S) \to$ conv γ X
130.6 ± 0 8 ± 2 4	NERNST	85	CBAL	$\Upsilon(2S) \to \gamma$ X
129.0 ± 0.8 ± 1.0	HAAS	84	CLEO	$\Upsilon(2S) \to$ conv γ X
128.1 ± 0 4 ± 3 0	KLOPFEN	83	CUSB	$\Upsilon(2S) \to \gamma$ X
130 6 ± 3.0	PAUSS	83	CUSB	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$

$\chi_{b1}(1P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\chi_{b1}(1P) \to \Upsilon(1S)\gamma$	$(35 \pm 8) \times 10^{-2}$

$\chi_{b1}(1P)$ BRANCHING RATIOS

$\Gamma(\Upsilon(1S)\gamma)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.35 ± 0.08 OUR AVERAGE				
0 32 ± 0 06 ± 0.07	WALK	86	CBAL	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$
0 47 ± 0 18	KLOPFEN	83	CUSB	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$

$\chi_{b1}(1P)$ REFERENCES

SKWARNICKI	87	PRL 58 972	+Antreasyan Bessel+ (Crystal Ball Collab) J
WALK	86	PR D34 2611	+Zschorsch+ (Crystal Ball Collab)
ALBRECHT	85E	PL 160B 331	+Drescher Heller+ (ARGUS Collab)
NERNST	85	PRL 54 2195	+Antreasyan Aschman+ (Crystal Ball Collab)
HAAS	84	PRL 52 799	+Jensen Kagan, Kass Behrends+ (CLEO Collab)
KLOPFEN	83	PRL 51 160	Klopfenstein Horstkotte+ (CUSB Collab)
PAUSS	83	PL 130B 439	+Dietl Eigen+ (MPIM COLU CORN LSU STON)

$\chi_{b2}(1P)$ or $\chi_{b2}(9915)$

$I^G(J^{PC}) = ?^?(2^{++})$

Observed in radiative decay of the $\Upsilon(2S)$, therefore C = + Branching ratio requires E1 transition, M1 is strongly disfavored, therefore P = + J = 2 from SKWARNICKI 87

$\chi_{b2}(1P)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
9913.2 ± 0.6 OUR AVERAGE				
9915 8 ± 1.1 ± 1.3	[1] WALK	86	CBAL	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$
9912.2 ± 0.3 ± 0.9	[1] ALBRECHT	85E	ARG	$\Upsilon(2S) \to$ conv γ X
9912.4 ± 0 8 ± 2 2	[1] NERNST	85	CBAL	$\Upsilon(2S) \to \gamma$ X
9913 3 ± 0.7 ± 1.0	[1] HAAS	84	CLEO	$\Upsilon(2S) \to$ conv γ X
9914 6 ± 0.3 ± 2.0	[1] KLOPFEN	83	CUSB	$\Upsilon(2S) \to \gamma$ X
9914 0 ± 4 0	[1] PAUSS	83	CUSB	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$

[1] From γ energy below, assuming $\Upsilon(2S)$ mass = 10023 4 MeV

γ ENERGY IN $\Upsilon(2S)$ DECAY

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
109.6 ± 0.6 OUR AVERAGE				
107.0 ± 1 1 ± 1 3	WALK	86	CBAL	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$
110.6 ± 0 3 ± 0 9	ALBRECHT	85E	ARG	$\Upsilon(2S) \to$ conv γ X
110.4 ± 0.8 ± 2.2	NERNST	85	CBAL	$\Upsilon(2S) \to \gamma$ X
109 5 ± 0 7 ± 1.0	HAAS	84	CLEO	$\Upsilon(2S) \to$ conv γ X
108.2 ± 0 3 ± 2.0	KLOPFEN	83	CUSB	$\Upsilon(2S) \to \gamma$ X
108.8 ± 4 0	PAUSS	83	CUSB	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$

$\chi_{b2}(1P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\chi_{b2}(1P) \to \Upsilon(1S)\gamma$	$(22 \pm 4) \times 10^{-2}$

$\chi_{b2}(1P)$ BRANCHING RATIOS

$\Gamma(\Upsilon(1S)\gamma)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.22 ± 0.04 OUR AVERAGE				
0.27 ± 0.06 ± 0.06	WALK	86	CBAL	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$
0.20 ± 0.05	KLOPFEN	83	CUSB	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$

$\chi_{b2}(1P)$ REFERENCES

SKWARNICKI	87	PRL 58 972	+Antreasyan Bessel+ (Crystal Ball Collab) J
WALK	86	PR D34 2611	+Zschorsch+ (Crystal Ball Collab)
ALBRECHT	85E	PL 160B 331	+Drescher Heller+ (ARGUS Collab)
NERNST	85	PRL 54 2195	+Antreasyan, Aschman+ (Crystal Ball Collab)
HAAS	84	PRL 52 799	+Jensen Kagan Kass Behrends+ (CLEO Collab)
KLOPFEN	83	PRL 51 160	Klopfenstein Horstkotte+ (CUSB Collab)
PAUSS	83	PL 130B 439	+Dietl Eigen+ (MPIM COLU CORN LSU STON)

$\Upsilon(2S)$ or $\Upsilon(10023)$

$I^G(J^{PC}) = ?^?(1^{--})$

$\Upsilon(2S)$ MASS

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
10.02329 ± 0.00031 OUR AVERAGE				
10 0236 ± 0.0005	[1] BARU	86B	REDE	$e^+e^- \to$ hadrons
10.0231 ± 0 0004	BARBER	84	REDE	$e^+e^- \to$ hadrons

[1] Reanalysis of ARTAMONOV 84

Meson Full Listings
$\Upsilon(2S) = \Upsilon(10023)$

$\Upsilon(2S)$ WIDTH

VALUE (keV)	DOCUMENT ID
44 ± 9	OUR EVALUATION See Υ mini review

$\Upsilon(2S)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Conf Lev
Γ_1	$\Upsilon(2S) \to \mu^+\mu^-$	$(1.36 \pm 0.28) \times 10^{-2}$	
Γ_2	$\Upsilon(2S) \to e^+e^-$		
Γ_3	$\Upsilon(2S) \to \tau^+\tau^-$	$(1.7 \pm 1.6) \times 10^{-2}$	
Γ_4	$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	$(18.5 \pm 0.8) \times 10^{-2}$	
Γ_5	$\Upsilon(2S) \to \Upsilon(1S)\pi^0\pi^0$	$(8.8 \pm 1.1) \times 10^{-2}$	
Γ_6	$\Upsilon(2S) \to \Upsilon(1S)\eta$	$< 2 \times 10^{-3}$	90%
Γ_7	$\Upsilon(2S) \to \chi_{b2}(1P)\gamma$	$(6.6 \pm 0.9) \times 10^{-2}$	
Γ_8	$\Upsilon(2S) \to \chi_{b1}(1P)\gamma$	$(6.7 \pm 0.9) \times 10^{-2}$	
Γ_9	$\Upsilon(2S) \to \chi_{b0}(1P)\gamma$	$(4.3 \pm 1.0) \times 10^{-2}$	
Γ_{10}	$\Upsilon(2S) \to \Upsilon(1S)\pi^0$	$< 8 \times 10^{-3}$	90%

$\Upsilon(2S)$ $\Gamma(i)\Gamma(e^+e^-)/\Gamma(\text{total})$

$\Gamma(\text{hadrons}) \times \Gamma(e^+e^-)/\Gamma_{total}$ $\Gamma_0\Gamma_2/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
$0.574^{+0.034}_{-0.033}$ **OUR AVERAGE**				
$0.58 \pm 0.03 \pm 0.04$	[2] GILES	84B	CLEO	$e^+e^- \to$ hadrons
$0.59 \pm 0.03 \pm 0.05$	[2] TUTS	83	CUSB	$e^+e^- \to$ hadrons
$0.60 \pm 0.12 \pm 0.07$	[2] ALBRECHT	82	DASP	$e^+e^- \to$ hadrons
$0.54 \pm 0.07^{+0.09}_{-0.05}$	[2] NICZYPORUK	81C	LENA	$e^+e^- \to$ hadrons
0.41 ± 0.18	[2] BOCK	80	CNTR	$e^+e^- \to$ hadrons

[2] Radiative corrections reevaluated by BUCHMUELLER 87 following KURAEV 85.

$\Upsilon(2S)$ PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_2

VALUE (keV)	DOCUMENT ID
0.600 ± 0.036	OUR EVALUATION $e^+e^- \to$ hadrons See Υ mini-review

$\Upsilon(2S)$ BRANCHING RATIOS

$\Gamma(\mu^+\mu^-)/\Gamma_{total}$ Γ_1/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
0.0136 ± 0.0028 **OUR AVERAGE**					
$0.0138 \pm 0.0026 \pm 0.0018$		LEE FRANZINI	87	CUSB	$e^+e^- \to \mu^+\mu^-$
$0.009 \pm 0.006 \pm 0.006$		[3] ALBRECHT	85	ARG	$e^+e^- \to \mu^+\mu^-$
$0.018 \pm 0.008 \pm 0.005$		HAAS	84B	CLEO	$e^+e^- \to \mu^+\mu^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.038	90	NICZYPORUK	81C	LENA	$e^+e^- \to \mu^+\mu^-$

[3] Re evaluated using $BR(\Upsilon(1S) \to \mu^+\mu^-)=0.026$

$\Gamma(\tau^+\tau^-)/\Gamma_{total}$ Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
$0.017 \pm 0.015 \pm 0.006$	HAAS	84B	CLEO	$e^+e^- \to \tau^+\tau^-$

$\Gamma(\Upsilon(1S)\pi^+\pi^-)/\Gamma_{total}$ Γ_4/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.185 ± 0.008 **OUR AVERAGE**					
$0.181 \pm 0.005 \pm 0.010$	11.6k	ALBRECHT	87	ARG	$e^+e^- \to \pi^+\pi^-$ MM
0.169 ± 0.040		GELPHMAN	85	CBAL	$e^+e^- \to e^+e^-\pi^+\pi^-$
$0.191 \pm 0.012 \pm 0.006$		BESSON	84	CLEO	$\pi^+\pi^-$ MM
0.189 ± 0.026		FONSECA	84	CUSB	$e^+e^- \to \ell^+\ell^-\pi^+\pi^-$
0.21 ± 0.07	7	NICZYPORUK	81B	LENA	$e^+e^- \to \ell^+\ell^-\pi^+\pi^-$

$\Gamma(\Upsilon(1S)\pi^0\pi^0)/\Gamma_{total}$ Γ_5/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.088 ± 0.011 **OUR AVERAGE**					
$0.095 \pm 0.019 \pm 0.019$	25	ALBRECHT	87	ARG	$e^+e^- \to \pi^0\pi^0\ell^+\ell^-$
0.080 ± 0.015		GELPHMAN	85	CBAL	$e^+e^- \to \ell^+\ell^-\pi^0\pi^0$
0.103 ± 0.023		FONSECA	84	CUSB	$e^+e^- \to \ell^+\ell^-\pi^0\pi^0$

$\Gamma(\Upsilon(1S)\eta)/\Gamma_{total}$ Γ_6/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.002	90	FONSECA	84	CUSB	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.005	90	ALBRECHT	87	ARG	$e^+e^- \to \pi^+\pi^-\ell^+\ell^-$ MM
<0.007	90	LURZ	87	CBAL	$e^+e^- \to \ell^+\ell^-(\gamma\gamma, 3\pi^0)$
<0.010	90	BESSON	84	CLEO	

$\Gamma(\chi_{b2}(1P)\gamma)/\Gamma_{total}$ Γ_7/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.066 ± 0.009 **OUR AVERAGE**				
$0.098 \pm 0.021 \pm 0.024$	ALBRECHT	85E	ARG	$e^+e^- \to \gamma$ conv X
$0.058 \pm 0.007 \pm 0.010$	NERNST	85	CBAL	$e^+e^- \to \gamma X$
$0.102 \pm 0.018 \pm 0.021$	HAAS	84	CLEO	$e^+e^- \to \gamma$ conv X
0.061 ± 0.014	KLOPFEN	83	CUSB	$e^+e^- \to \gamma X$

$\Gamma(\chi_{b1}(1P)\gamma)/\Gamma_{total}$ Γ_8/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.067 ± 0.009 **OUR AVERAGE**				
$0.091 \pm 0.018 \pm 0.022$	ALBRECHT	85E	ARG	$e^+e^- \to \gamma$ conv X
$0.065 \pm 0.007 \pm 0.012$	NERNST	85	CBAL	$e^+e^- \to \gamma X$
$0.080 \pm 0.017 \pm 0.016$	HAAS	84	CLEO	$e^+e^- \to \gamma$ conv X
0.059 ± 0.014	KLOPFEN	83	CUSB	$e^+e^- \to \gamma X$

$\Gamma(\chi_{b0}(1P)\gamma)/\Gamma_{total}$ Γ_9/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.043 ± 0.010 **OUR AVERAGE**				
$0.064 \pm 0.014 \pm 0.016$	ALBRECHT	85E	ARG	$e^+e^- \to \gamma$ conv X
$0.036 \pm 0.008 \pm 0.009$	NERNST	85	CBAL	$e^+e^- \to \gamma X$
$0.044 \pm 0.023 \pm 0.009$	HAAS	84	CLEO	$e^+e^- \to \gamma$ conv X
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.035 ± 0.014	KLOPFEN	83	CUSB	$e^+e^- \to \gamma X$

$\Gamma(\Upsilon(1S)\pi^0)/\Gamma_{total}$ Γ_{10}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.008	90	LURZ	87	CBAL	$e^+e^- \to \ell^+\ell^-\gamma\gamma$

$\Upsilon(2S)$ REFERENCES

ALBRECHT	87	ZPHY C35 283	+Binder, Boeckmann, Glaeser+	(ARGUS Collab.)
BUCHMUEL	87	MIT LNS 159	Buchmueller, Cooper	(HANN, MIT)
LEE FRANZINI	87	Hamburg Conf.		(CUSB Collab.)
LURZ	87	ZPHY C36 383	+Antreasyan, Besset+	(Crystal Ball Collab.)
BARU	86B	ZPHY C32 622	+Blinov, Bondar, Bukin+	(NOVO)
ALBRECHT	85	ZPHY C28 45	+Drescher, Heller+	(ARGUS Collab.)
ALBRECHT	85E	PL 160B 331	+Drescher, Heller+	(ARGUS Collab.)
GELPHMAN	85	PR D11 2893	+Lurz, Antreasyan+	(Crystal Ball Collab.)
KURAEV	85	SJNP 41 466	+Fadin	(ASCI)
		Translated from YAF 41 733		
NERNST	85	PRL 54 2195	+Antreasyan, Aschman+	(Crystal Ball Collab.)
ARTAMONOV	84	PL 137B 272	+Baru, Blinov, Bondar+	(NOVO)
BARBER	84	PL 135B 498	+ (DESY ARGUS Collab. Crystal Ball Collab.)	
BESSON	84	PR D30 1433	+Green, Hicks, Namjoshi, Sannes+	(CLEO Collab.)
FONSECA	84	NP B242 31	+Mageras, Son, Dietl, Eigen+	(CUSB Collab.)
GILES	84B	PR D29 1285	+Hassard, Hempstead, Kinoshita+	(CLEO Collab.)
HAAS	84	PRL 52 799	+Jensen, Kagan, Kass, Behrends+	(CLEO Collab.)
HAAS	84B	PR D30 1996	+Jensen, Kagan, Kass, Behrends+	(CLEO Collab.)
KLOPFEN	83	PRL 51 160	Klopfenstein, Horstkotte+	(CUSB Collab.)
TUTS	83	Cornell Conf. 284		(CUSB Collab.)
ALBRECHT	82	PL 116B 383	+Hofmann+	(DESY, DORT, HEID, LUND, ITEP)
NICZYPORUK	81B	PL 100B 95	+Chen, Folger, Lurz+	(LENA Collab.)
NICZYPORUK	81C	PL 99B 169	+Chen, Vogel, Wegener+	(LENA Collab.)
BOCK	80	ZPHY C6 125	+Blanar, Blum+	(HEID, MPIM, DESY, HAMB)

OTHER RELATED PAPERS

ALEXANDER	88	SLAC PUB 4501	+Bonvicini, Drell, Frey, Luth	(LBL, MICH, SLAC)
COOPER	86	Berkeley Conf. 67		(MIT)
WALK	86	PR D34 2611	+Zschorsch+	(Crystal Ball Collab.)
ALBRECHT	84	PL 134B 137	+Drescher, Heller+	(ARGUS Collab.)
ARTAMONOV	84	PL 137B 272	+Baru, Blinov, Bondar+	(NOVO)
ANDREWS	83	PRL 50 807	+	(CLEO Collab.)
GREEN	82	PRL 49 617	+	(CLEO Collab.)
MAGERAS	81	PRL 46 1115	+Bohringer, Finocchiaro+	(COLU, STON, LSU, MPIM)
MUELLER	81	PRL 46 1181	+ (RUTG, SYRA, LEMO, VAND, CORN, ITHA+)	
ANDREWS	80	PRL 44 1108	+	(CLEO Collab.)
ARESTOV	80	IHEP 80 165	+Bogoljubski+	(SERP)
BOHRINGER	80	PRL 44 1111	+Costantini, Finocchiaro	(COLU, STON)
KOURKOU	80	PL 91B 481	Kourkoumelis+	(ATHU, NTUA, BNL, CERN+)
UENO	79	PRL 42 486	+Brown, Herb, Hom, Fisk+	(FNAL, COLU, STON)
BIENLEIN	78	PL 78B 360	+Glawe, Bock, Blanar+	(DESY, HAMB, HEID, MPIM)
DARDEN	78	PL 76B 246	+Hofmann, Schubert+	(DESY, DORT, HEID, LUND)
KAPLAN	78	PRL 40 435	+Appel, Herb, Hom+	(STON, FNAL, COLU)
YOH	78	PRL 41 684	+Herb, Hom, Lederman+	(COLU, FNAL, STON)
COBB	77	PL 72B 273	+Iwata, Fabjan+	(BNL, CERN, SYRA, YALE)
HERB	77	PRL 39 252	+Hom, Lederman, Appel, Ito+	(COLU, FNAL, STON)
INNES	77	PRL 39 1240	+Appel, Brown, Herb, Hom+	(COLU, FNAL, STON)

$\chi_{b0}(2P) = \chi_{b0}(10235)$, $\chi_{b1}(2P) = \chi_{b1}(10255)$, $\chi_{b2}(2P) = \chi_{b2}(10270)$

$\chi_{b0}(2P)$ or $\chi_{b0}(10235)$

$I^G(J^{PC}) = ?^?(0 \text{ preferred}^{++})$

Observed in radiative decay of the $\Upsilon(3S)$, therefore $C = +$. Branching ratio requires E1 transition. M1 is strongly disfavored, therefore $P = +$.

$\chi_{b0}(2P)$ MASS

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
10.2353 ± 0.0011 OUR AVERAGE			
10.2353 ± 0.0016	[1] LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma X$
10.2352 ± 0.0016	[1] LEE FRANZINI 87	CUSB	$e^+e^- \to \ell^+\ell^-\gamma\gamma$

[1] From γ energy below assuming $\Upsilon(3S)$ mass = 10355.3 MeV.

γ ENERGY IN $\Upsilon(3S)$ DECAY

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
119.3 ± 1.1 OUR AVERAGE			
119.3 ± 1.6	LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma X$
119.4 ± 1.6	LEE FRANZINI 87	CUSB	$e^+e^- \to \ell^+\ell^-\gamma\gamma$

$\chi_{b0}(2P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\chi_{b0}(2P) \to \Upsilon(1S)\gamma$	$(1.4 \pm 1.0) \times 10^{-2}$
Γ_2	$\chi_{b0}(2P) \to \Upsilon(2S)\gamma$	$(7 \pm 4) \times 10^{-2}$

$\chi_{b0}(2P)$ BRANCHING RATIOS

$\Gamma(\Upsilon(1S)\gamma)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.014 ± 0.010	[2] LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma\gamma\ell^+\ell^-$

$\Gamma(\Upsilon(2S)\gamma)/\Gamma_{total}$ — Γ_2/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.069 ± 0.041	[2] LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma\gamma\ell^+\ell^-$

[2] Using $BR(\Upsilon(3S) \to \chi_{b0}(2P)\gamma) = 0.048 \pm 0.014$.

$\chi_{b0}(2P)$ REFERENCES

LEE FRANZINI 87 Hamburg Conf (CUSB Collab.)

OTHER RELATED PAPERS

TUTS 83 Cornell Conf 284 (CUSB Collab.)
EIGEN 82 PRL 49 1616 +Bohringer, Herb+ (CUSB Collab.)
HAN 82 PRL 49 1612 +Horstkotte, Imlay+ (CUSB Collab.)

$\chi_{b1}(2P)$ or $\chi_{b1}(10255)$

$I^G(J^{PC}) = ?^?(1 \text{ preferred}^{++})$

Observed in radiative decay of the $\Upsilon(3S)$, therefore $C = +$. Branching ratio requires E1 transition. M1 is strongly disfavored, therefore $P = +$.

$\chi_{b1}(2P)$ MASS

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
10.2552 ± 0.0004 OUR AVERAGE Error includes scale factor of 1.2.			
10.2556 ± 0.0005	[1] LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma X$
10.2548 ± 0.00045	[1] LEE FRANZINI 87	CUSB	$e^+e^- \to \ell^+\ell^-\gamma\gamma$

[1] From γ energy below assuming $\Upsilon(3S)$ mass = 10355.3 MeV.

γ ENERGY IN $\Upsilon(3S)$ DECAY

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
99.6 ± 0.4 OUR AVERAGE Error includes scale factor of 1.2.			
99.2 ± 0.5	LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma X$
100.0 ± 0.45	LEE FRANZINI 87	CUSB	$e^+e^- \to \ell^+\ell^-\gamma\gamma$

$\chi_{b1}(2P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\chi_{b1}(2P) \to \Upsilon(1S)\gamma$	$(6.1 \pm 1.7) \times 10^{-2}$
Γ_2	$\chi_{b1}(2P) \to \Upsilon(2S)\gamma$	$(25 \pm 8) \times 10^{-2}$

$\chi_{b1}(2P)$ BRANCHING RATIOS

$\Gamma(\Upsilon(1S)\gamma)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.061 ± 0.017	[2] LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma\gamma\ell^+\ell^-$

$\Gamma(\Upsilon(2S)\gamma)/\Gamma_{total}$ — Γ_2/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.247 ± 0.083	[2] LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma\gamma\ell^+\ell^-$

[2] Using $BR(\Upsilon(3S) \to \chi_{b1}(2P)\gamma) = 0.120 \pm 0.026$.

$\chi_{b1}(2P)$ REFERENCES

LEE FRANZINI 87 Hamburg Conf (CUSB Collab.)

OTHER RELATED PAPERS

TUTS 83 Cornell Conf 284 (CUSB Collab.)
EIGEN 82 PRL 49 1616 +Bohringer, Herb+ (CUSB Collab.)
HAN 82 PRL 49 1612 +Horstkotte, Imlay+ (CUSB Collab.)

$\chi_{b2}(2P)$ or $\chi_{b2}(10270)$

$I^G(J^{PC}) = ?^?(2 \text{ preferred}^{++})$

Observed in radiative decay of the $\Upsilon(3S)$, therefore $C = +$. Branching ratio requires E1 transition. M1 is strongly disfavored, therefore $P = +$.

$\chi_{b2}(2P)$ MASS

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
10.2690 ± 0.0007 OUR AVERAGE Error includes scale factor of 2.2.			
10.2682 ± 0.0005	[1] LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma X$
10.2697 ± 0.00045	[1] LEE FRANZINI 87	CUSB	$e^+e^- \to \ell^+\ell^-\gamma\gamma$

[1] From γ energy below assuming $\Upsilon(3S)$ mass = 10355.5 MeV.

γ ENERGY IN $\Upsilon(3S)$ DECAY

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
85.9 ± 0.7 OUR AVERAGE Error includes scale factor of 2.1.			
86.7 ± 0.5	LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma X$
85.3 ± 0.45	LEE FRANZINI 87	CUSB	$e^+e^- \to \ell^+\ell^-\gamma\gamma$

$\chi_{b2}(2P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\chi_{b2}(2P) \to \Upsilon(1S)\gamma$	$(6.3 \pm 1.8) \times 10^{-2}$
Γ_2	$\chi_{b2}(2P) \to \Upsilon(2S)\gamma$	$(19 \pm 7) \times 10^{-2}$

$\chi_{b2}(2P)$ BRANCHING RATIOS

$\Gamma(\Upsilon(1S)\gamma)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.063 ± 0.018	[2] LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma\gamma\ell^+\ell^-$

Meson Full Listings
$\chi_{b2}(2P)$ = $\chi_{b2}(10270)$, $\Upsilon(3S)$ = $\Upsilon(10355)$, $\Upsilon(4S)$ = $\Upsilon(10580)$

$\Gamma(\Upsilon(2S)\gamma)/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.189 ± 0.065	[2] LEE-FRANZINI 87	CUSB	$e^+e^- \to \gamma\gamma\ell^+\ell^-$

[2]Using BR($\Upsilon(3S) \to \chi_{b2}(2P)\gamma$)=0 128 ± 0 029

$\chi_{b2}(2P)$ REFERENCES

LEE FRANZINI 87 Hamburg Conf (CUSB Collab)

— OTHER RELATED PAPERS —

TUTS 83 Cornell Conf 284 (CUSB Collab)
EIGEN 82 PRL 49 1616 +Bohringer Herb+ (CUSB Collab)
HAN 82 PRL 49 1612 +Horstkotte Imlay+ (CUSB Collab)

$\Upsilon(3S)$ or $\Upsilon(10355)$

$I^G(J^{PC}) = ?^?(1^{--})$

$\Upsilon(3S)$ MASS

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
10.3553 ± 0.0005	[1] BARU	86B	REDE	$e^+e^- \to$ hadrons

[1]Reanalysis of ARTAMONOV 84

$\Upsilon(3S)$ WIDTH

VALUE (keV)	DOCUMENT ID
26 ± 6 OUR EVALUATION	See Υ mini review

$\Upsilon(3S)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	$\Upsilon(3S) \to \mu^+\mu^-$	(1 6 ± 0 4) × 10^{-2}	1 2
Γ_2	$\Upsilon(3S) \to e^+e^-$		
Γ_3	$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	(3 63 ± 0 31) × 10^{-2}	
Γ_4	$\Upsilon(3S) \to \Upsilon(2S)\pi^+\pi^-$	(2 2 ± 0 5) × 10^{-2}	
Γ_5	$\Upsilon(3S) \to \chi_{b2}(2P)\gamma$	(12 8 ± 2 9) × 10^{-2}	
Γ_6	$\Upsilon(3S) \to \chi_{b1}(2P)\gamma$	(12 0 ± 2 6) × 10^{-2}	
Γ_7	$\Upsilon(3S) \to \chi_{b0}(2P)\gamma$	(4 8 ± 1 4) × 10^{-2}	
Γ_8	$\Upsilon(3S) \to \Upsilon(2S)$anything	(10 1 ± 1 7) × 10^{-2}	

$\Upsilon(3S)$ $\Gamma(i)\Gamma(e^+e^-)/\Gamma(total)$

$\Gamma(\text{hadrons}) \times \Gamma(e^+e^-)/\Gamma_{total}$ $\Gamma_0\Gamma_2/\Gamma$

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.415 ± 0.030 OUR AVERAGE	Error includes scale factor of 1 1			
0.45 ± 0 03 ± 0.03	[2] GILES	84B	CLEO	$e^+e^- \to$ hadrons
0 39 ± 0.02 ± 0 03	[2] TUTS	83	CUSB	$e^+e^- \to$ hadrons

[2]Radiative corrections reevaluated by BUCHMUELLER 87 following KURAEV 85

$\Upsilon(3S)$ PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_2

VALUE (keV)	DOCUMENT ID
0.44 ± 0.03 OUR EVALUATION	$e^+e^- \to$ hadrons See Υ mini review

$\Upsilon(3S)$ BRANCHING RATIOS

$\Gamma(\mu^+\mu^-)/\Gamma_{total}$ Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.016 ± 0.004 OUR AVERAGE	Error includes scale factor of 1 2				
0 0153 ± 0.0033 ± 0.0021	697	KAARSBERG	87	CUSB	$e^+e^- \to \mu^+\mu^-$
0 033 ± 0 013 ± 0.007	1096	ANDREWS	83	CLEO	$e^+e^- \to \mu^+\mu^-$

$\Gamma(\Upsilon(1S)\pi^+\pi^-)/\Gamma_{total}$ Γ_3/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0363 ± 0.0031 OUR AVERAGE					
0 0347 ± 0 0034	3 9k	BOWCOCK	87	CLEO	$e^+e^- \to \pi^+\pi^- X$ $\pi^+\pi^-\ell^+\ell^-$
0 049 ± 0 010	22	GREEN	82	CLEO	$\Upsilon(3S) \to \pi^+\pi^-\ell^+\ell^-$
0 039 ± 0 013	26	MAGERAS	82	CUSB	$\Upsilon(3S) \to \pi^+\pi^-\ell^+\ell^-$

$\Gamma(\Upsilon(2S)\pi^+\pi^-)/\Gamma_{total}$ Γ_4/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.022 ± 0.005 OUR AVERAGE					
0 021 ± 0 005	314	BOWCOCK	87	CLEO	$e^+e^- \to \pi^+\pi^- X$ $\pi^+\pi^-\ell^+\ell^-$
0 031 ± 0 020	5	MAGERAS	82	CUSB	$\Upsilon(3S) \to \pi^+\pi^-\ell^+\ell^-$

$\Gamma(\chi_{b2}(2P)\gamma)/\Gamma_{total}$ Γ_5/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.128 ± 0.012 ± 0.026	LEE-FRANZINI 87	CUSB	$e^+e^- \to \gamma X$

$\Gamma(\chi_{b1}(2P)\gamma)/\Gamma_{total}$ Γ_6/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.120 ± 0 011 ± 0.024	LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma X$

$\Gamma(\chi_{b0}(2P)\gamma)/\Gamma_{total}$ Γ_7/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.048 ± 0.010 ± 0.010	LEE FRANZINI 87	CUSB	$e^+e^- \to \gamma X$

$\Gamma(\Upsilon(2S)\text{anything})/\Gamma_{total}$ Γ_8/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.101 ± 0.017	1 6k	BOWCOCK	87	CLEO	$e^+e^- \to \pi^+\pi^- X$ $\pi^+\pi^-\ell^+\ell^-$

$\Upsilon(3S)$ REFERENCES

BOWCOCK 87 PRL 58 307 +Giles Hassard Kinoshita+ (CLEO Collab)
BUCHMUEL 87 MIT LNS 159 Buchmueller Cooper (HANN MIT)
KAARSBERG 87 PR D35 2265 +Lee Franzini Lovelock Narain+ (CUSB II Collab)
LEE FRANZINI 87 Hamburg Conf (CUSB Collab)
BARU 86B ZPHY C32 662 +Blinov Bondar Bukin+ (NOVO)
KURAEV 85 SJNP 41 466 +Fadin (ASCI)
Translated from YAF 41 733
ARTAMONOV 84 PL 137B 272 +Baru Blinov Bondar+ (NOVO)
GILES 84B PR D29 1285 +Hassard Hempstead Kinoshita+ (CLEO Collab)
ANDREWS 83 PRL 50 807 + (CLEO Collab)
TUTS 83 Cornell Conf 284 (CUSB Collab)
GREEN 82 PRL 49 617 + (CLEO Collab)
MAGERAS 82 PL 118B 453 +Herb Imlay+ (COLU CORN LSU MPIM STON)

— OTHER RELATED PAPERS —

ALEXANDER 88 SLAC PUB 4501 +Bonvicini Drell Frey Luth (LBL MICH SLAC)
ARTAMONOV 84 PL 137B 272 +Baru Blinov Bondar+ (NOVO)
GILES 84B PR D29 1285 +Hassard Hempstead Kinoshita+ (CLEO Collab)
HAN 82 PRL 49 1612 +Horstkotte Imlay+ (CUSB Collab)
PETERSON 82 PL 114B 277 +Giannini Lee Franzini+ (CUSB Collab)
ANDREWS 80 PRL 44 1108 + (CLEO Collab)
BOHRINGER 80 PRL 44 1111 +Costantini Finocchiaro (COLU STON)
UENO 79 PRL 42 486 +Brown Herb Hom Fisk+ (FNAL COLU STON)
KAPLAN 78 PRL 40 435 +Appel Herb Hom+ (STON FNAL COLU)
YOH 78 PRL 41 684 +Herb Hom Lederman+ (COLU FNAL STON)
COBB 77 PL 72B 273 +Iwata Fabjan+ (BNL CERN SYRA YALE)
HERB 77 PRL 39 252 +Hom Lederman Appel Ito+(COLU FNAL STON)
INNES 77 PRL 39 1240 +Appel Brown Herb Hom+ (COLU FNAL STON)

$\Upsilon(4S)$ or $\Upsilon(10580)$

$I^G(J^{PC}) = ?^?(1^{--})$

$\Upsilon(4S)$ MASS

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
10 5800 ± 0.0035	[1] BEBEK	87	CLEO	$e^+e^- \to$ hadrons
• • • We do not use the following data for averages fits limits etc • • •				
10 5774 ± 0 0010	[2] LOVELOCK	85	CUSB	$e^+e^- \to$ hadrons

[1]Reanalysis of BESSON 85

[2]No systematic error given

Υ(4S) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
23.8 ± 2.2 OUR AVERAGE				
20 0 ± 2 ± 4	BESSON	85	CLEO	$e^+e^- \to$ hadrons
25. ± 2 5	LOVELOCK	85	CUSB	$e^+e^- \to$ hadrons

Υ(4S) DECAY MODES

		Fraction (Γ_i/Γ)
Γ_1	$\Upsilon(4S) \to e^+e^-$	$(1\ 00 \pm 0\ 21)\times 10^{-5}$

Υ(4S) PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_1

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.24 ± 0.05 OUR AVERAGE	Error includes scale factor of 1 7			
0 192 ± 0 007 ± 0 038	BESSON	85	CLEO	$e^+e^- \to$ hadrons
0 283 ± 0 037	LOVELOCK	85	CUSB	$e^+e^- \to$ hadrons

Υ(4S) REFERENCES

BEBEK	87	PR D36 1289	+Berkelman Blucher Cassel+	(CLEO Collab)
BESSON	85	PRL 54 381	+Green Namjoshi Sannes+	(CLEO Collab)
LOVELOCK	85	PRL 54 377	+Horstkotte Klopfenstein+	(CUSB Collab)

——- OTHER RELATED PAPERS ——

ANDREWS	80B	PRL 45 219	+	(CORN HARV ITHA SYRA ROCH RUTG+)
FINOCCHI	80	PRL 45 222	Finocchiaro Giannini+	(STON COLU LSU)

Υ(10860)

$I^G(J^{PC}) = ?^?(1^{--})$

Υ(10860) MASS

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
10.865 ± 0.008 OUR AVERAGE	Error includes scale factor of 1 1			
10 868 ± 0.006 ± 0 005	BESSON	85	CLEO	$e^+e^- \to$ hadrons
10 845 ± 0 020	LOVELOCK	85	CUSB	$e^+e^- \to$ hadrons

Υ(10860) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
110 ± 13 OUR AVERAGE				
112 0 ± 17 ± 23	BESSON	85	CLEO	$e^+e^- \to$ hadrons
110 0 ± 15 0	LOVELOCK	85	CUSB	$e^+e^- \to$ hadrons

Υ(10860) DECAY MODES

		Fraction (Γ_i/Γ)
Γ_1	$\Upsilon(10860) \to e^+e^-$	$(2\ 8 \pm 0\ 7)\times 10^{-6}$

Υ(10860) PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_1

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.31 ± 0.07 OUR AVERAGE	Error includes scale factor of 1 3			
0 22 ± 0 05 ± 0 07	BESSON	85	CLEO	$e^+e^- \to$ hadrons
0 365 ± 0 070	LOVELOCK	85	CUSB	$e^+e^- \to$ hadrons

Υ(10860) REFERENCES

BESSON	85	PRL 54 381	+Green Namjoshi Sannes+	(CLEO Collab)
LOVELOCK	85	PRL 54 377	+Horstkotte Klopfenstein+	(CUSB Collab)

Υ(11020)

$I^G(J^{PC}) = ?^?(1^{--})$

Υ(11020) MASS

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
11.019 ± 0.008 OUR AVERAGE				
11 019 ± 0 005 ± 0 007	BESSON	85	CLEO	$e^+e^- \to$ hadrons
11 020 ± 0 030	LOVELOCK	85	CUSB	$e^+e^- \to$ hadrons

Υ(11020) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
79 ± 16 OUR AVERAGE				
61 0 ± 13 ± 22	BESSON	85	CLEO	$e^+e^- \to$ hadrons
90.0 ± 20 0	LOVELOCK	85	CUSB	$e^+e^- \to$ hadrons

Υ(11020) DECAY MODES

		Fraction (Γ_i/Γ)
Γ_1	$\Upsilon(11020) \to e^+e^-$	$(1\ 6 \pm 0\ 5)\times 10^{-6}$

Υ(11020) PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_1

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.130 ± 0 030 OUR AVERAGE				
0 095 ± 0 03 ± 0 035	BESSON	85	CLEO	$e^+e^- \to$ hadrons
0 156 ± 0 040	LOVELOCK	85	CUSB	$e^+e^- \to$ hadrons

Υ(11020) REFERENCES

BESSON	85	PRL 54 381	+Green Namjoshi Sannes+	(CLEO Collab)
LOVELOCK	85	PRL 54 377	+Horstkotte Klopfenstein+	(CUSB Collab)

STRANGE MESONS
($S = \pm 1$, $C = B = 0$)

$K^{\pm}$

$I(J^P) = \frac{1}{2}(0^-)$

SEE STABLE PARTICLES

K^0

$I(J^P) = \frac{1}{2}(0^-)$

SEE STABLE PARTICLES

$K^*(892)$

$I(J^P) = \frac{1}{2}(1^-)$

NOTE ON $K^*(892)$ MASSES AND MASS DIFFERENCES

Unrealistically small errors are reported by some experiments. We use simple "realistic" tests for the minimum errors on the determination of mass and width from a sample of N events:

$$\delta_{min}(m) = \frac{\Gamma}{\sqrt{N}}, \quad \delta_{min}(\Gamma) = 4\frac{\Gamma}{\sqrt{N}}.$$

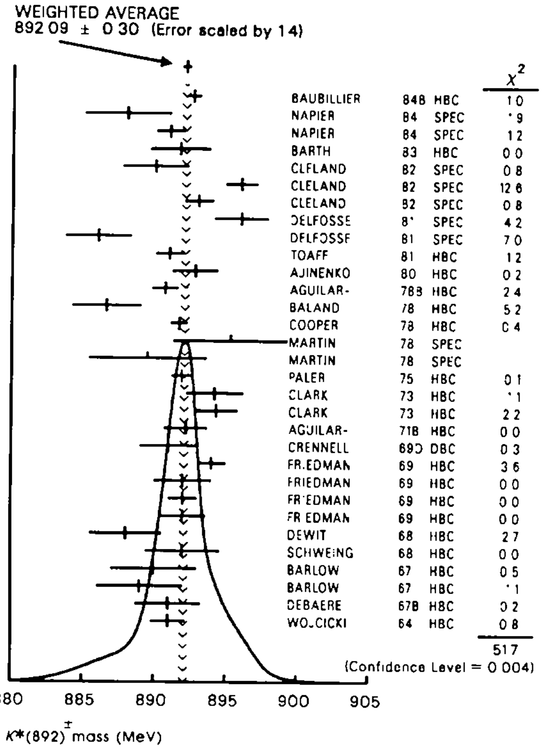
(For a detailed discussion, see the 1971 edition of this note.) We consistently increase unrealistic errors before averaging.

$K^*(892)$ MASS

CHARGED ONLY

This is what appears in the Meson Summary Table

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
892.09±0.30	**OUR AVERAGE**	Error includes scale factor of 1.4. See the ideogram below.				
892.6±0.5	5840	BAUBILLIER	84B	HBC	−	8.25 $K^-p \to \bar{K}^0\pi^-p$
888.0±3.0		NAPIER	84	SPEC	+	200 $\pi^-p \to 2K^0_S X$
891.0±1.0		NAPIER	84	SPEC	−	200 $\pi^-p \to 2K^0_S X$
891.7±2.1	3700	BARTH	83	HBC	+	70 $K^+p \to K^0\pi^+X$
890.0±2.3	800	[1,2] CLELAND	82	SPEC	+	30 $K^+p \to K^0_S\pi^+p$
896.0±1.1	3200	[1,2] CLELAND	82	SPEC	+	50 $K^+p \to K^0_S\pi^+p$
893.0±1.0	3600	[1,2] CLELAND	82	SPEC	−	50 $K^+p \to K^0_S\pi^-p$
896.0±1.9	380	DELFOSSE	81	SPEC	+	50 $K^\pm p \to K^\pm\pi^0p$
886.0±2.3	187	DELFOSSE	81	SPEC	−	50 $K^\pm p \to K^\pm\pi^0p$
891.0±1.0	4100	TOAFF	81	HBC	−	6.5 $K^-p \to \bar{K}^0\pi^-p$
892.8±1.6		AJINENKO	80	HBC	+	32 $K^+p \to K^0\pi^+X$
890.7±0.9	1800	AGUILAR	78B	HBC	±	0.76 $\bar{p}p \to K^\mp K^0_S\pi^\pm$
886.6±2.4	1225	BALAND	78	HBC	±	12 $\bar{p}p \to (K\pi)^\pm X$
891.7±0.6	6706	COOPER	78	HBC	±	0.76 $\bar{p}p \to (K\pi)^\pm X$
895.3±4.0		[3] MARTIN	78	SPEC	+	10 $K^\pm p \to K^0_S\pi p$
889.5±4.1		[3] MARTIN	78	SPEC	−	10 $K^\pm p \to K^0_S\pi p$
891.9±0.7	9000	[4] PALER	75	HBC	−	14.3 $K^-p \to (K\pi)^-X$
894.2±2.0	765	[1] CLARK	73	HBC	−	3.13 $K^-p \to \bar{K}^0\pi^-p$
894.3±1.5	1150	[1,2] CLARK	73	HBC	−	3.3 $K^-p \to \bar{K}^0\pi^-p$
892.2±1.5	4404	AGUILAR	71B	HBC	−	3.9,4.6 $K^-p \to (K\pi)^-p$
891.0±2.0	1000	CRENNELL	69D	DBC	−	3.9 $K^-N \to K^0\pi^-X$
894 ±1.0	2886	[1] FRIEDMAN	69	HBC	−	2.1 $K^-p \to \bar{K}^0\pi^-p$
892 ±2	728	FRIEDMAN	69	HBC	−	2.45 $K^-p \to \bar{K}^0\pi^-p$
892 ±1.0	3229	FRIEDMAN	69	HBC	−	2.6 $K^-p \to \bar{K}^0\pi^-p$
892 ±1.6	1027	FRIEDMAN	69	HBC	−	2.7 $K^-p \to \bar{K}^0\pi^-p$
888 ±2.5	540	[1] DEWIT	68	HBC	−	3 $K^-n \to \bar{K}^0\pi^-n$
892.0±2.6	341	[1] SCHWEING	68	HBC	−	5.5 $K^-p \to \bar{K}^0\pi^-p$
890 ±3.0	720	BARLOW	67	HBC	±	1.2 $\bar{p}p \to (K^0\pi)^\pm K^\mp$
889 ±3.0	600	BARLOW	67	HBC	±	1.2 $\bar{p}p \to (K^0\pi)^\pm K\pi$
891 ±2.3	620	[1] DEBAERE	67B	HBC	+	3.5 $K^+p \to K^0\pi^+p$
891.0±1.2	1700	[2] WOJCICKI	64	HBC	−	1.7 $K^-p \to \bar{K}^0\pi^-p$

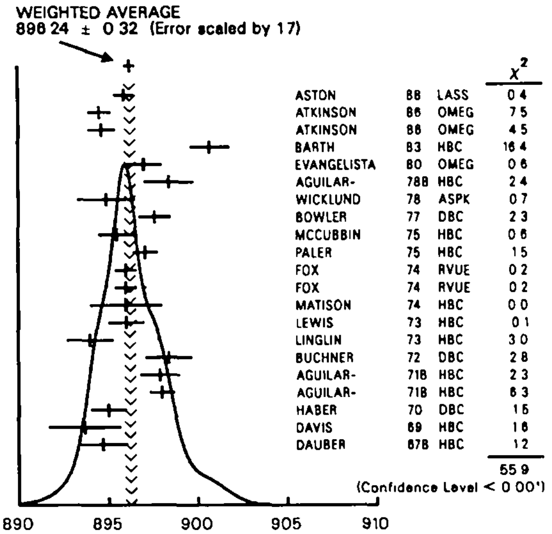


NEUTRAL ONLY

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
896.24±0.32	**OUR AVERAGE**	Error includes scale factor of 1.7. See the ideogram below.				
895.9 ±0.5 ±0.2		ASTON	88	LASS	0	11 $K^-p \to K^-\pi^+n$
894.52±0.63	25k	[4] ATKINSON	86	OMEG		20–70 γp
894.63±0.76	20k	[4] ATKINSON	86	OMEG		20–70 γp
900.7 ±1.1	5900	BARTH	83	HBC	0	70 $K^+p \to K^+\pi^-X$
897 ±1	28k	EVANGELISTA	80	OMEG	0	10 $\pi^-p \to K^+\pi^-(\Lambda\Sigma)$
898.4 ±1.4	1180	AGUILAR	78B	HBC	0	0.76 $\bar{p}p \to K^\mp K^0_S\pi^\pm$
894.9 ±1.6		WICKLUND	78	ASPK	0	3,4,6 $K^\pm N \to (K\pi)^0 N$
897.6 ±0.9		BOWLER	77	DBC	0	5.4 $K^+d \to K^+\pi^-pp$
895.5 ±1.0	3600	MCCUBBIN	75	HBC	0	3.6 $K^-p \to K^-\pi^+n$
897.1 ±0.7	22k	[4] PALER	75	HBC	0	14.3 $K^-p \to (K\pi)^0 X$
896.0 ±0.6	10k	FOX	74	RVUE	0	2 $K^-p \to K^-\pi^+n$
896.0 ±0.6		FOX	74	RVUE	0	2 $K^+n \to K^+\pi^-p$
896 ±2		[5] MATISON	74	HBC	0	12 $K^+p \to K^+\pi^-\Delta$
896.0 ±1.0	3186	LEWIS	73	HBC	0	2.1–2.7 $K^+p \to K\pi\pi p$
894.0 ±1.3		[5] LINGLIN	73	HBC	0	2–13 $K^+p \to K^+\pi^-\pi^+p$
898.4 ±1.3	1700	[1] BUCHNER	72	DBC	0	4.6 $K^+n \to K^+\pi^-p$
897.9 ±1.1	2934	[1] AGUILAR-	71B	HBC	0	3.9,4.6 $K^-p \to K^-\pi^+n$
898.0 ±0.7	5362	[1] AGUILAR	71B	HBC	0	3.9,4.6 $K^-p \to K^-\pi^+\pi^-p$
895.0 ±1.0	4300	[2] HABER	70	DBC	0	3 $K^-N \to K^-\pi^+X$
893.7 ±2.0	10k	DAVIS	69	HBC	0	12 $K^+p \to K^+\pi^-\pi^+p$
894.7 ±1.4	1040	[1] DAUBER	67B	HBC	0	2.0 $K^-p \to K^-\pi^+\pi^-p$

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
892.8 ±1.3		[5] LANG	79	RVUE	0	
895.7 ±0.3		[6] ESTABROOKS	78	ASPK	0	13 $K^\pm p \to K^\pm\pi^\pm(n\Delta)$



$K^*(892)^0$ mass (MeV)

[1] Mass errors enlarged by us to $\Gamma/N^{1/2}$ See note
[2] Number of events in peak re-evaluated by us
[3] Systematic error added
[4] Inclusive reaction Complicated background and phase-space effects
[5] From pole extrapolation
[6] From phase shift analysis of 155 000 events

$K^*(892)^0$ − $K^*(892)^\pm$ MASS DIFFERENCE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
6.7 ± 1.2 OUR AVERAGE						
7 7 ± 1.7	2980	AGUILAR	78B	HBC	±0	0 76 $\bar{p}p \to K^\mp K^0_S \pi^\pm$
5 7 ± 1.7	7338	AGUILAR-	71B	HBC	−0	3.9,4.6 $K^- p$
6 3 ± 4 1	283	[7] BARASH	67B	HBC		0 0 $\bar{p}p$
• • • We do not use the following data for averages fits limits etc • • •						
6.5 ± 5 0	1400	[8,9] FICENEC	68	HBC		1 3 $K^- p$
9 5 ± 5 0	1600	[8,9] FICENEC	68B	HBC		2 7 $K^- p$

[7] Number of events in peak re-evaluated by us
[8] Mass errors enlarged by us to $\Gamma/N^{1/2}$ See note
[9] Data with mass error of 3 MeV or more not averaged

$K^*(892)$ RANGE PARAMETER

VALUE (GeV^{-1})	DOCUMENT ID		TECN	CHG	COMMENT
3.4 ± 0.7	ASTON	88	LASS	0	11 $K^- p \to K^- \pi^+ n$

$K^*(892)$ WIDTH

CHARGED ONLY

This is what appears in the Meson Summary Table

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
51.3 ± 0.8 OUR FIT Error includes scale factor of 1 1						
51.3 ± 0.8 OUR AVERAGE Error includes scale factor of 1 1						
49.0 ± 2.0	5840	BAUBILLIER	84B	HBC	−	8 25 $K^- p \to K^0 \pi^- p$
54 0 ± 9.0		NAPIER	84	SPEC	+	200 $\pi^- p \to 2K^0_S X$
56.0 ± 4 0		NAPIER	84	SPEC	−	200 $\pi^- p \to 2K^0_S X$
42.8 ± 7.1	3700	BARTH	83	HBC	+	70 $K^+ p \to K^0 \pi^+ X$
64 0 ± 9 2	800	[10,11] CLELAND	82	SPEC	+	30 $K^+ p \to K^0_S \pi^+ p$
62 0 ± 4 4	3200	[10,11] CLELAND	82	SPEC	+	50 $K^+ p \to K^0_S \pi^+ p$
55 0 ± 4 0	3600	[10,11] CLELAND	82	SPEC	−	50 $K^+ p \to K^0_S \pi^- p$
62 6 ± 3 8	380	DELFOSSE	81	SPEC	+	50 $K^\pm p \to K^\pm \pi^0 p$
50.5 ± 3.9	187	DELFOSSE	81	SPEC	−	50 $K^\pm p \to K^\pm \pi^0 p$
51 0 ± 2 0	4100	TOAFF	81	HBC	−	6 5 $K^- p \to K^0 \pi^- p$
50 5 ± 5 6		AJINENKO	80	HBC	+	32 $K^+ p \to K^0 \pi^+ X$
45 8 ± 3.6	1800	AGUILAR	78B	HBC	±	0 76 $\bar{p}p \to K^\mp K^0_S \pi^\pm$
43 0 ± 8.4	1225	BALAND	78	HBC	±	12 $\bar{p}p \to (K\pi)^\pm X$
52 0 ± 2 5	6706	[10] COOPER	78	HBC	±	76 $\bar{p}p \to (K\pi)^\pm X$
50 9 ± 2 3		MARTIN	78	SPEC	+	10 $K^\pm p \to K^0_S \pi p$
52 1 ± 2 2	9000	[12] PALER	75	HBC	−	14 3 $K^- p \to (K\pi)^- X$
46 3 ± 6 7	765	[10] CLARK	73	HBC	−	3 13 $K^- p \to K^0 \pi^- p$
48 2 ± 5 7	1150	[10,11] CLARK	73	HBC	−	3 3 $K^- p \to K^0 \pi^- p$
54.3 ± 3 3	4404	[10] AGUILAR	71B	HBC	−	3.9,4.6 $K^- p \to (K\pi)^- p$
53 ± 4 0	2886	[10] FRIEDMAN	69	HBC	−	2 1 $K^- p \to K^0 \pi^- p$
49 ± 7 3	728	[10] FRIEDMAN	69	HBC	−	2 45 $K^- p \to K^0 \pi^- p$
46 ± 3 2	3229	[10] FRIEDMAN	69	HBC	−	2 6 $K^- p \to K^0 \pi^- p$
49 ± 6 1	1027	[10] FRIEDMAN	69	HBC	−	2 7 $K^- p \to K^0 \pi^- p$
44 0 ± 8 0	540	[10] DEWIT	68	DBC	−	3 $K^- n \to K^0 \pi^- n$
43 ± 9 0	720	[10] BARLOW	67	HBC	±	1 2 $\bar{p}p \to (K^0\pi)^\pm K^\mp$
53. ± 9 0	600	BARLOW	67	HBC	±	1 2 $\bar{p}p \to (K^0\pi)^\pm K\pi$
56 0 ± 9 0	620	[10] DEBAERE	67B	HBC	+	3 5 $K^+ p \to K^0 \pi^+ p$
46 0 ± 5 0	1700	[10,11] WOJCICKI	64	HBC	−	1 7 $K^- p \to K^0 \pi^- p$

NEUTRAL ONLY

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
50.5 ± 0.6 OUR FIT Error includes scale factor of 1 1						
50.5 ± 0.6 OUR AVERAGE Error includes scale factor of 1 1						
50 8 ± 0 8 ± 0 9		ASTON	88	LASS	0	11 $K^- p \to K^- \pi^+ n$
46.5 ± 4 3	5900	BARTH	83	HBC	0	70 $K^+ p \to K^+ \pi^- X$
54. ± 2	28k	EVANGELISTA	80	OMEG	0	10 $\pi^- p \to K^+ \pi^- (\Lambda,\Sigma)$
45.9 ± 4 8	1180	AGUILAR	78B	HBC	0	0 76 $\bar{p}p \to K^\mp K^0_S \pi^\pm$
51.2 ± 1 7		WICKLUND	78	ASPK	0	3 4 6 $K^\pm N \to (K\pi)^0 N$
48 9 ± 2.5		BOWLER	77	DBC	0	5 4 $K^+ d \to K^+ \pi^- pp$
48. $^{+3.}_{-2.}$	3600	MCCUBBIN	75	HBC	0	3 6 $K^- p \to K^- \pi^+ n$
50 6 ± 2 5	22k	[12] PALER	75	HBC	0	14 3 $K^- p \to (K\pi)^0 X$
47 ± 2	10k	FOX	74	RVUE	0	2 $K^- p \to K^- \pi^+ n$
51 ± 2		FOX	74	RVUE	0	2 $K^+ n \to K^+ \pi^- p$
46 0 ± 3 3	3186	[10] LEWIS	73	HBC	0	2 1–2 7 $K^+ p \to K\pi\pi p$
51.4 ± 5 0	1700	[10] BUCHNER	72	DBC	0	4 6 $K^+ n \to K^+ \pi^- p$
55.8 $^{+4\ 2}_{-3\ 4}$	2934	[10] AGUILAR	71B	HBC	0	3 9 4 6 $K^- p \to K^- \pi^+ n$
48 5 ± 2 7	5362	AGUILAR-	71B	HBC	0	3 9 4 6 $K^- p \to K^- \pi^+ \pi^- p$
54.0 ± 3.3	4300	[10,11] HABER	70	DBC	0	3 $K^- N \to K^- \pi^+ X$
53 2 ± 2 1	10k	[10] DAVIS	69	HBC	0	12 $K^+ p \to K^+ \pi^- \pi^+ p$
44 ± 5.5	1040	[10] DAUBER	67B	HBC	0	2 0 $K^- p \to K^- \pi^+ \pi^- p$
• • • We do not use the following data for averages fits limits etc • • •						
40 1 ± 6 0		[13] LANG	79	RVUE	0	
52 9 ± 0 4		[14] ESTABROOKS	78	ASPK	0	13 $K^\pm p \to K^\pm \pi^\pm (n \Delta)$
47 ± 3		[13] MATISON	74	HBC	0	12 $K^+ p \to K^+ \pi^- \Delta$
46 5 ± 1.5		[13] LINGLIN	73	HBC	0	2–13 $K^+ p \to K^+ \pi^- \pi^+ p$

[10] Width errors enlarged by us to $4 \times \Gamma/N^{1/2}$ see note
[11] Number of events in peak re-evaluated by us
[12] Inclusive reaction Complicated background and phase space effects
[13] From pole extrapolation
[14] From phase shift analysis of 155 000 events

$K^*(892)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$K^*(892)^\pm \to K\pi$	(99 902 ± 0 009) × 10^{-2}
Γ_2	$K^*(892)^0 \to K\pi$	(99 770 ± 0 020) × 10^{-2}
Γ_3	$K^*(892) \to K\pi\pi$	< 7 × 10^{-4}
Γ_4	$K^*(892)^\pm \to K^\pm\gamma$	(9.8 ± 0 9) × 10^{-4}
Γ_5	$K^*(892)^0 \to K^0\gamma$	(2 30 ± 0 20) × 10^{-3}

Meson Full Listings
$K^*(892)$

CONSTRAINED FIT INFORMATION

An overall fit to the total width and a partial width uses 30 measurements and one constraint to determine 3 parameters The overall fit has a $\chi^2 = 33.4$ for 28 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta p_i \delta p_j\rangle/(\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i, including the branching fractions $x_i = \Gamma_i/\Gamma_{total}$ The fit constrains the x_i in this array to sum to one

x_4	100	
Γ	17	17
	x_1	x_4

		Rate (MeV)	Scale
Γ_1	$K^*(892)^\pm \to K\pi$	51 3 ± 0 8	1 1
Γ_4	$K^*(892)^\pm \to K^\pm\gamma$	0 050 ± 0 005	

CONSTRAINED FIT INFORMATION

An overall fit to the total width and a partial width uses 18 measurements and one constraint to determine 3 parameters The overall fit has a $\chi^2 = 18.4$ for 16 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta p_i \delta p_j\rangle/(\delta p_i \cdot \delta p_j)$ in percent, from the fit to parameters p_i, including the branching fractions, $x_i = \Gamma_i/\Gamma_{total}$ The fit constrains the x_i in this array to sum to one

x_5	100	
Γ	14	14
	x_2	x_5

		Rate (MeV)	Scale
Γ_2	$K^*(892)^0 \to K\pi$	50 4 ± 0.6	1 1
Γ_5	$K^*(892)^0 \to K^0\gamma$	0 117 ± 0.010	

$K^*(892)$ PARTIAL WIDTHS

$\Gamma(K^\pm\gamma)$ Γ_4

VALUE (keV)		DOCUMENT ID		TECN	CHG	COMMENT
50 ± 5	OUR FIT					
50 ± 5	OUR AVERAGE					
48 0 ± 11.0		BERG	83	SPEC	−	156 $K^- A \to \bar{K}\pi A$
51 0 ± 5 0		CHANDLEE	83	SPEC	+	200 $K^+ A \to K\pi A$

$\Gamma(K^0\gamma)$ Γ_5

VALUE (keV)		EVTS	DOCUMENT ID		TECN	CHG	COMMENT
117 ± 10	OUR FIT						
116 5 ± 9.9		584	CARLSMITH	86	SPEC	0	$K^0_L A \to K^0_S \pi^0 A$

$K^*(892)$ BRANCHING RATIOS

$\Gamma(K^*(892) \to K\pi\pi)/\Gamma(K^*(892)^\pm \to K\pi)$ Γ_3/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.0007	95	JONGEJANS	78	HBC		4 $K^- p \to p\bar{K}^0 2\pi$
• • • We do not use the following data for averages fits limits etc • • •						
<0 002		WOJCICKI	64	HBC	−	1.7 $K^- p \to \bar{K}^0\pi^- p$

$\Gamma(K^\pm\gamma)/\Gamma_{total}$ Γ_4/Γ

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	CHG	COMMENT
0 98 ± 0.09 OUR FIT						
• • • We do not use the following data for averages fits limits etc • • •						
<1 6	95	BEMPORAD	73	CNTR	+	10–16 $K^+ A$

$\Gamma(K^0\gamma)/\Gamma_{total}$ Γ_5/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	CHG	COMMENT
2.30 ± 0.20 OUR FIT					
• • • We do not use the following data for averages fits limits etc • • •					
1 5 ± 0 7	CARITHERS	75B	CNTR	0	8–16 $\bar{K}^0 A$

$K^*(892)$ REFERENCES

ASTON 88 NP B296 493 +Awaji Bienz Bird+ (SLAC NAGO CINC TOKY)
ATKINSON 86 ZPHY C30 521 + (BONN CERN GLAS LANC MCHS LPNP+)
CARLSMITH 86 PRL 56 18 +Bernstein Peyaud Turlay (EFI SACL)
BAUBILLIER 84B ZPHY C26 37 + (BIRM CERN GLAS MICH LPNP)
NAPIER 84 PL 149B 514 +Chen+ (TUFT ARIZ FNAL FLOR NDAM+)
BARTH 83 NP B223 296 +Drevermann+ (BRUX CERN GENO MONS+)
BERG 83 Thesis (ROCH)
CHANDLEE 83 COO 3065 354 +Berg Cihangir Collick+ (ROCH FNAL MINN)
CLELAND 82 NP B208 189 +Delfosse Dorsaz Gloor (DURH GEVA LAUS PITT)
DELFOSSE 81 NP B183 349 +Gulsan Martin Muhlemann Weill+(GEVA LAUS)
TOAFF 81 PR D23 1500 +Musgrave Ammar Davis Ecklund+ (ANL KANS)
AJINENKO 80 ZPHY 5 177 +Barth Dujardin+ (SERP LIBH MONS SACL)
EVANGELISTA 80 NP B165 383 + (BARI BONN CERN DARE GLAS LIVP+)
LANG 79 PR D19 956 +Mas Parareda (GRAZ)
AGUILAR 78B NP B141 101 Aguilar Benitez+ (MADR TATA CERN+)
BALAND 78 NP B140 220 +Grard+ (MONS BELG CERN LOIC LALO)
COOPER 78 NP B136 365 +Gurtu+ (TATA CERN CDEF+)
ESTABROOKS 78 NP B133 490 +Carnegie+ (MONT CARL DURH SLAC)
Also 78B PR D17 658 Estabrooks Carnegie+ (MONT CARL DURH+)
JONGEJANS 78 NP B139 383 +Cerrada+ (ZEEM CERN NIJM OXF)
MARTIN 78 NP B134 392 +Shimada Baldi Bohringer+ (DURH GEVA)
WICKLUND 78 PR D17 1197 +Ayres Diebold Greene Kramer Pawlicki (ANL)
BOWLER 77 NP B126 31 +Dainton Drake Williams (OXF)
CARITHERS 75B PRL 35 349 +Muhlemann Underwood+ (ROCH MCGI)
MCCUBBIN 75 NP B86 13 +Lyons (OXF)
PALER 75 NP B96 1 +Tovey Shah Spiro+ (RHEL SACL EPOL)
FOX 74 NP B80 403 +Griss (CIT)
MATISON 74 PR D9 1872 +Galtieri Garnjost Flatte Friedman+ (LBL)
BEMPORAD 73 NP B51 1 +Beusch Freudenreich+ (CERN ETH LOIC)
CLARK 73 NP B54 432 +Lyons Radojicic (OXF)
LEWIS 73 NP B60 283 +Allen Jacobs+ (LOWC LOIC CDEF)
LINGLIN 73 NP B55 408 (CERN)
BUCHNER 72 NP B45 333 +Dehm Charriere Cornet+ (MPIM CERN BRUX)
AGUILAR 71B PR D4 2583 Aguilar Benitez Eisner Kinson (BNL)
HABER 70 NP B17 289 +Shapira Alexander+ (REHO SACL BGNA EPOL)
CRENNELL 69D PRL 22 487 +Karshon Lai O Neall Scarr (BNL)
DAVIS 69 PRL 23 1071 +Derenzo Flatte Alston Lynch Solmitz (LRL)
FRIEDMAN 69 UCRL 18860 Thesis (LRL)
DEWIT 68 Thesis (ANIK)
FICENEC 68 PR 169 1034 +Hulsizer Swanson Trower (ILL)
FICENEC 68B PR 175 1725 +Gordon Trower (ILL)
SCHWEING 68 PR 166 1317 Schweingruber Derrick Fields+ (ANL NWES)
BARASH 67B PR 156 1399 +Kirsch Miller Tan (COLU)
BARLOW 67 NC 50A 701 +Lillestol Montanet+ (CERN CDEF IRAD LIVP)
DAUBER 67B PR 153 1403 +Schlein Slater Ticho (UCLA)
DEBAERE 67B NC 51A 401 +Goldschmidt Clermont Henri+ (BRUX CERN)
WOJCICKI 64 PR 135B 484 (LRL)

OTHER RELATED PAPERS

BERG 81 PL 98B 119 +Chandlee Biel+ (ROCH FNAL MINN)
BALDI 78B NP B134 365 +Bohringer Dorsaz Hungerbuhler+ (GEVA)
ENGELEN 78 NP B134 14 +Jongejans+ (NIJM ZEEM CERN OXF)
KIRK 76 NP B116 99 +Klein+ (AACH BERL CERN LOIC WIEN)
BRANDENB 75 PL 59B 405 Brandenburg Carnegie Cashmore+ (SLAC)
BERTHON 73 NP B63 54 +Montanet Paul Bertranet+ (CERN SACL)
CHARRIERE 73 NP B51 317 +Drijard DeBaere+ (CERN BELG)
WALUCH 73 PR D8 2837 +Flatte Friedman (LBL)
ABRAMOVI 72 NP B39 189 Abramovich Chaloupka Chung Hilpert+(CERN)
BINGHAM 72 NP B41 1 + (International K+ Collab)
BRUNET 72 NP B37 114 +Danysz Goldsack+ (CDEF SACL LOIC LOWC)
CRENNELL 72 PR D6 1220 +Gordon Lai Scarr (BNL)
DEUTSCH 72 NP B36 373 Deutschmann+ (ABCLV Collab)
ENGELMANN 72 PR D5 2162 +Musgrave Forman+ (ANL EFI)
ROUGE 72 NP B46 29 +Videau Volte DeBrion+ (EPOL SACL)
TIECKE 72 NP B39 596 +Grijns Heinen DeGroot+ (NIJM AMST)
AGUILAR 71 PRL 26 466 Aguilar Benitez Barnes Bassano Eisner+ (BNL)
BARNHAM 71C NP B28 171 +Colley Jobes Griffiths Hughes+ (BIRM GLAS)
BUCHNER 71 NP B29 381 +Dehm Goebel+ (MPIM CERN BELG)
CORDS 71 PR D4 1974 +Carmony Erwin Meiere+ (PURD UCD IUPU)
MERCER 71 NP B32 381 +Antich Callahan Chien Cox+ (JHU)
YUTA 71 PRL 26 1502 +Derrick Engelmann Musgrave (ANL EFI)
ATHERTON 70 NP B16 416 +Franek French Frisk Bednar+ (CERN PRAG)
DEBAERE 69 NC 61A 397 +Goldschmidt Clermont Henri+ (BELG CERN)
JUHALA 69 PR 184 1461 +Leacock Rhode Kopelman Libby+ (ISU COLO)
LIND 69 NP B14 1 +Alexander Firestone Fu Goldhaber (LRL) JP
KANG 68 PR 176 1587 (IOWA)
BOMSE 67 PR 158 1298 +Borenstein Cole Gillespie+ (JHU)
CONFORTO 67 NP B3 469 +Marechal+ (CERN CDEF IPNP LIVP)
FRENCH 67 NC 52A 438 +Kinson McDonald Riddiford+ (CERN BIRM)
GEORGE 67 NC 49A 9 +Goldschmidt Clermont Henri+ (CERN BRUX)
SALLSTROM 67 NC 49A 348 +Otter Ekspong (STOH)
ADELMAN 65B Athens Conf 527 (CAVE)
FERRO LUZZI 65B NC 39 417 +George Goldschmidt Clermont+ (CERN)
GELSEMA 65 Thesis (ANIK)
Also 64 PL 10 341 Gelsema Kluyver Tenner Wolters (ZEEM)
WANGLER 65 PR 137B 414 +Erwin Walker (WISC)
CHADWICK 63B PL 6 309 +Crennell Davies Bettini+ (OXF PADO)
GOLDHABER 63 Athens Conf 92 (LRL)
ALEXANDER 62 PRL 8 447 +Kalbfleisch Miller Smith (LRL)
COLLEY 62B CERN Conf 315 +Gelfand+ (COLU RUTG)
ALSTON 61 PRL 6 300 Alston Garnjost Alvarez Eberhard Good+ (LRL)

$K_1(1270)$ was $Q(1280)$

$I(J^P) = \frac{1}{2}(1^+)$

Our latest mini-review on this particle can be found in the 1984 edition

$K_1(1270)$ MASS

PRODUCED BY BEAMS OTHER THAN K MESONS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
$1242.0^{+9.0}_{-10.0}$		[1] ASTIER	69	HBC	0	$\bar{p}p$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1294 ± 10.	310	RODEBACK	81	HBC		4 $\pi^- p \to \Lambda K 2\pi$
1300	40	CRENNELL	72	HBC	0	4.5 $\pi^- p \to \Lambda K 2\pi$
1300	45	CRENNELL	67	HBC	0	6 $\pi^- p \to \Lambda K 2\pi$

[1]This was called the C meson

PRODUCED BY K^-, BACKWARD SCATTERING, HYPERON EXCHANGE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1275.0 ± 10.0	700	GAVILLET	78	HBC	+	4.2 $K^- p \to \Xi^- (K\pi\pi)^+$

PRODUCED BY K BEAMS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1270. ± 10.	DAUM	81C	CNTR	−	63 $K^- p \to \bar{K} 2\pi p$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~1276.0	[2] TORNQVIST	82B	RVUE		
~1300.0	VERGEEST	79	HBC	−	4.2 $K^- p \to (K\pi\pi)^- p$
1289.0 ± 25.0	[3] CARNEGIE	77	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$
~1300.	BRANDENB	76	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$
~1270.0	OTTER	76	HBC	−	10,14,16 $K^- p \to (\bar{K}\pi\pi)^- p$
1260	DAVIS	72	HBC	+	12 $K^+ p$
1234 ± 12.	FIRESTONE	72B	DBC	+	12 $K^+ d$

[2]From a unitarized quark-model calculation

[3]From a model-dependent fit with Gaussian background to BRANDENBURG 76 data

$K_1(1270)$ WIDTH

PRODUCED BY BEAMS OTHER THAN K MESONS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
$127.0^{+7.0}_{-25.0}$		ASTIER	69	HBC	0	$\bar{p}p$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
66 ± 15	310	RODEBACK	81	HBC		4 $\pi^- p \to \Lambda K 2\pi$
60	40	CRENNELL	72	HBC	0	4.5 $\pi^- p \to \Lambda K 2\pi$
60	45	CRENNELL	67	HBC	0	6 $\pi^- p \to \Lambda K 2\pi$

PRODUCED BY K^-, BACKWARD SCATTERING, HYPERON EXCHANGE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
75.0 ± 15.0	700	GAVILLET	78	HBC	+	4.2 $K^- p \to \Xi^- K\pi\pi$

PRODUCED BY K BEAMS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
90. ± 8.	DAUM	81C	CNTR	−	63 $K^- p \to \bar{K} 2\pi p$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~150.0	VERGEEST	79	HBC	−	4.2 $K^- p \to (K\pi\pi)^- p$
150.00 ± 71.0	[4] CARNEGIE	77	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$
~200.	BRANDENB	76	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$
120.	DAVIS	72	HBC	+	12 $K^+ p$
188. ± 21	FIRESTONE	72B	DBC	+	12 $K^+ d$

[4]From a model-dependent fit with Gaussian background to BRANDENBURG 76 data

$K_1(1270)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$K_1(1270) \to K^*(892)\pi$	(16 ± 5) × 10^{-2}
Γ_2	$K_1(1270) \to K\rho$	(42 ± 6) × 10^{-2}
Γ_3	$K_1(1270) \to K\omega$	(11.0 ± 2.0) × 10^{-2}
Γ_4	$K_1(1270) \to K_0^*(1430)\pi$	(28 ± 4) × 10^{-2}
Γ_5	$K_1(1270) \to Kf_0(1400)$	(3.0 ± 2.0) × 10^{-2}

$K_1(1270)$ PARTIAL WIDTHS

$\Gamma(K^*(892)\pi)$ — Γ_1

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
14.0 ± 11.0	MAZZUCATO	79	HBC	+	4.2 $K^- p \to \Xi^- (K\pi\pi)^+$
2.0 ± 2.0	CARNEGIE	77B	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$

$\Gamma(K\rho)$ — Γ_2

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
57.0 ± 5.0	MAZZUCATO	79	HBC	+	4.2 $K^- p \to \Xi^- (K\pi\pi)^+$
75.0 ± 6.0	CARNEGIE	77B	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$

$\Gamma(K\omega)$ — Γ_3

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
4.0 ± 4.00	MAZZUCATO	79	HBC	+	4.2 $K^- p \to \Xi^- (K\pi\pi)^+$
24.0 ± 3.0	CARNEGIE	77B	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$

$\Gamma(K_0^*(1430)\pi)$ — Γ_4

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
26.0 ± 6.0	CARNEGIE	77B	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$

$\Gamma(Kf_0(1400))$ — Γ_5

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
22.0 ± 5.0	CARNEGIE	77B	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$

$K_1(1270)$ BRANCHING RATIOS

$\Gamma(K^*(892)\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.16 ± 0.05	[5] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

$\Gamma(K\rho)/\Gamma_{total}$ — Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.42 ± 0.06	[5] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
DOMINANT	RODEBACK	81	HBC	4 $\pi^- p \to \Lambda K 2\pi$

$\Gamma(K\omega)/\Gamma_{total}$ — Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.11 ± 0.02	[5] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

$\Gamma(K_0^*(1430)\pi)/\Gamma_{total}$ — Γ_4/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.28 ± 0.04	[5] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

$\Gamma(Kf_0(1400))/\Gamma_{total}$ — Γ_5/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.03 ± 0.02	[5] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

$\Gamma(K\omega)/\Gamma(K\rho)$ — Γ_3/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.30	95	RODEBACK	81	HBC	4 $\pi^- p \to \Lambda K 2\pi$

D-wave/S-wave RATIO FOR $K_1(1270) \to K^*(892)\pi$

VALUE	DOCUMENT ID		TECN	COMMENT
1.0 ± 0.7	[5] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

[5]Average from low and high t data

$K_1(1270)$ REFERENCES

TORNQVIST 82B NP B203 268 (HELS)
DAUM 81C NP B187 1 +Hertzberger+ (AMST CERN CRAC MPIM OXF+)
RODEBACK 81 ZPHY C9 9 +Sjogren+ (CERN CDEF MADR STOH)
MAZZUCATO 79 NP B156 532 +Pennington+ (CERN ZEEM NIJM OXF)
VERGEEST 79 NP B158 265 +Jongejans Dionisi+ (NIJM AMST CERN OXF)
GAVILLET 78 PL 76B 517 +Diaz Dionisi+ (AMST CERN. NIJM OXF) JP
CARNEGIE 77 NP B127 509 +Cashmore Davier Dunwoodie Lasinski+ (SLAC)
CARNEGIE 77B PL 68B 287 +Cashmore Dunwoodie Lasinski+ (SLAC)
BRANDENB 76 PRL 26 703 Brandenburg Carnegie Cashmore+ (SLAC) JP
OTTER 76 NP B106 77 + (AACH BERL CERN LOIC VIEN LPNP+) JP
CRENNELL 72 PR D6 1220 +Gordon Lai Scarr (BNL)
DAVIS 72 PR D5 2688 +Alston Barbaro Flatte Friedman Lynch+ (LBL)
FIRESTONE 72B PR D5 505 +Goldhaber Lissauer Trilling (LBL)
ASTIER 69 NP B10 65 +Morechal Montanet+ (CDEF CERN IPNP LIVP) IJP
CRENNELL 67 PRL 19 44 +Kalbfleisch Lai Scarr Schumann (BNL) I

— OTHER RELATED PAPERS — —

BAUBILLIER 82B NP B202 21 + (BIRM CERN GLAS MSU LPNP)
FERNANDEZ 82 ZPHY C16 95 +Aguilar Benitez+ (MADR CERN CDEF STOH) JP
GAVILLET 82 ZPHY C16 119 +Armenteros+ (CERN CDEF PADO ROMA)
OTTER 81 NP B181 1 (AACH BERL LOIC VIEN BIRM BELG CERN+)
BACON 80 NP B162 189 +Barrey Butterworth Ansorge+ (LOIC CAVE)
DIONISI 80 NP B169 1 +Gavillet+ (CERN MADR CDEF STOH)
ETKIN 80 PR D22 42 +Foley Lindenbaum Kramer+ (BNL CUNY) JP
IRVING 80 JP G6 153 (LIVP)
RADFORD 80 NP B167 181 +Brandenburg (MIT)
BASDEVANT 79 PR D19 246 +Berger (ANL)
BEUSCH 78 PL 74B 282 +Birman Konigs Otter+ (CERN AACH ETH) JP
WOHL 78 NP B132 401 +Paler Chaurand+ (LPNP RHEL SACL)
BASDEVANT 76 PRL 37 977 +Berger (FNAL ANL)
BOAL 76 PR D14 2998 +Edwards Kamal Torgeson (ALBE)
BOWLER 76 JP G3 775 (OXF)
VERGEEST 76 PL 62B 471 +Engelen Jongejans+ (AMST CERN NIJM OXF) JP
ANTIPOV 75 NP B86 381 +Ascoli Busnello Kienzle+ (SERP CERN ILL) JP
BOWLER 75 NP B97 227 +Game Aitchison Dainton (OXF DARE)
DORE 75 LNC 13 265 +Guidoni Laakso Marini Conforto+(ROMA RHEL)
DREVILLON 75 PL 55B 245 +Borenstein+ (EPOL BOHR CDEF) JP
DUNWOODIE 75 NP B91 189 +Grant+ (CERN BELG MONS MPIM) JP
OTTER 75 NP B84 333 + (AACH BERL CERN LOIC VIEN ATHU+) JP
OTTER 75B NP B93 365 +Rudolph+ (AACH BERL CERN LOIC VIEN) JP
OTTER 75C NP B96 29 +Rudolph+ (AACH BERL CERN LOIC VIEN) IJP
TOVEY 75 NP B95 109 +Hansen Borenstein Borg+ (RHEL EPOL SACL) IJP
ANGELOPO 74 NC 20A 49 Angelopoulos+ (ATHU ATEN LIVP VIEN) JP
BOWLER 74 NP B74 493 +Dainton Kaddoura Aitchison (OXF)
DAVIDSON 74B PR D9 77 +Chapman Green Lys Roe (MICH)
DEUTSCH 74 PL 49B 388 Deutschmann+ (AACH BERL CERN LOIC VIEN) JP
BARLOUTAUD 73 NP B59 374 +Drevillon Shah+ (SACL EPOL RHEL) JP
BINGHAM 73 NP B52 31 +Farwell+ (LBL ORSA BNL SACL MILA) JP
DEJONGH 73 NP B58 110 +Cornet Charriere+ (BRUX MONS CERN MPIM)
JONES 73 NP B52 383 (CERN) JP
LEWIS 73 NP B60 283 +Allen Jacobs+ (LOWC LOIC CDEF)
WERNER 73 PR D7 1275 +Slattery Ferbel (ROCH)
ANDERSON 72 PR D6 1823 +Franklin Godden Kopelman Libby Tan(COLO)
BINGHAM 72C NP B48 589 +Eisenstein Grard Herquet+ (CERN BRUX)
BRANDENB 72 PRL 28 932 Brandenburg Johnson Leith Loos+ (SLAC)
BRANDENB 72B NP B45 397 Brandenburg Brody Johnson Leith+ (SLAC)
FIRESTONE 72 NP B47 348 (CIT)
FRATI 72 PR D6 2361 +Halpern Hargis Snape+ (PENN CINC)
HAATUFT 72 NP B48 78 +Arnold Haguenauer+ (BERG STRB EPOL MADR)
BARNHAM 71B NP B25 49 +Colley Griffiths Alper+ (BIRM GLAS OXF)
DENEGRI 71 NP B28 13 +Antich Callahan Carson Chien Cox+ (JHU)
FORMAN 71 PR D3 2610 +Gelfand Leary Moser Seidl Wolfson (EFI)
GARFINKEL 71 PRL 26 1505 +Holland Carmony Lander+ (PURD UCD)
ABRAMS 70B PR D1 2433 +Eisenstein Kim Marshall O Halloran+ (ILL)
ANTICH 70 NP B20 201 +Carson Chien Cox Denegri Ettlinger+ (JHU)
BOWLER 70 PL 31B 318 (OXF)
FARBER 70 PR D1 78 +Ferbel Slattery Yuta (ROCH)
ALEXANDER 69B NP B13 503 +Firestone Goldhaber+ (LRL)
ANDREWS 69 PRL 22 731 +Lach Ludlam Sandweiss Berger+ (YALE LRL)
BARBARO 69 PRL 22 1207 Barbaro Galtieri Davis Flatte+ (LRL)
BETTINI 69 NC 62A 1038 +Cresti Limentani Bertanza Bigi+ (PADO PISA) I
BISHOP 69 NP B9 403 +Goshaw Erwin Walker (WISC)
CHIEN 69 PL 29B 433 +Malamud Mellema Rudnick Schlein+ (UCLA)
CHUNG 69 PR 182 1443 +Eisner Ball Luers (BNL)
COLLEY 69 NC 59A 519 +Eastwood+ (BIRM GLAS LOIC MPIM OXF+)
ERWIN 69 NP B9 364 +Walker Goshaw Weinberg (WISC PRIN VAND)
FRIEDMAN 69 UCRL 18860 Thesis (LRL)
WERNER 69 PR 188 2023 +Ammar Davis Kropac Yarger+ (NWES ANL)
BARTSCH 68B NP B8 9 +Cocconi+ (AACH BERL CERN LOIC VIEN)
BOMSE 68 PRL 20 1519 +Borenstein Callahan Cole Cox+ (JHU)
DENEGRI 68 PRL 20 1194 +Callahan Ettlinger Gillespie+ (JHU)
BASSOMPIE 67B PL 26B 30 Bassompierre Goldschmidt+ (CERN BRUX BIRM) IJP
BERLINGHIERI 67 PRL 18 1087 +Farber Ferbel Forman (ROCH) IJP
DEBAERE 67 NC 49A 374 +Debaisieux Fast Filippas+ (CERN BRUX)
Also 67 Private Comm Jongejans
GOLDHABER 67B PRL 19 976 (LBL)
SHEN 66 PRL 17 726 +Butterworth Fu Goldhaber Trilling (LRL)
Also 66 Private Comm Goldhaber (LRL)
ALMEIDA 65 PL 16 184 +Atherton Byer Dornan Forson+ (CAVE)
ARMENTEROS 64 PL 9 207 +Edwards D Andlau+ (CERN CDEF)
Also 66 PR 145 1095 Barash Kirsch Miller Tan (COLU)
ARMENTEROS 64B Dubna Conf 1 577 +Edwards D Andlau+ (CERN CDEF)
Also 64C Dubna Conf 1 617 Armenteros

$K_1(1400)$ was $Q(1400)$

$I(J^P) = \frac{1}{2}(1^+)$

$K_1(1400)$ MASS

VALUE (MeV)			DOCUMENT ID		TECN	CHG	COMMENT
1401	**± 10**	**OUR AVERAGE**					
1373	± 14	± 18	[1] ASTON	87	LASS	0	11 $K^- p \to K^0 \pi^+ \pi^- n$
1392	± 18		BAUBILLIER	82B	HBC	0	8 25 $K^- p \to K^0_S \pi^+ \pi^- n$
1410	± 25		DAUM	81C	CNTR	-	63 $K^- p \to K 2\pi p$
1415	± 15		ETKIN	80	MPS	0	6 $K^- p \to K^0 \pi^+ \pi^- n$
• • • We do not use the following data for averages fits limits etc • • •							
~1350			[2] TORNQVIST	82B	RVUE		
~1400 0			VERGEEST	79	HBC	−	4 2 $K^- p \to (K\pi\pi)^- p$
1404 0 ± 10 0			[3] CARNEGIE	77	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$
~1400			BRANDENB	76	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$
1420			DAVIS	72	HBC	+	12 $K^+ p$
1368	± 18		FIRESTONE	72B	DBC	+	12 $K^+ d$

[1] From partial wave analysis of $K^0 \pi^+ \pi^-$ system

[2] From a unitarized quark-model calculation

[3] From a model-dependent fit with Gaussian background to BRANDENBURG 76 data

$K_1(1400)$ WIDTH

VALUE (MeV)			DOCUMENT ID		TECN	CHG	COMMENT
184	**± 9**	**OUR AVERAGE**					
188	± 54	± 60	[4] ASTON	87	LASS	0	11 $K^- p \to K^0 \pi^+ \pi^- n$
276	± 65.		BAUBILLIER	82B	HBC	0	8 25 $K^- p \to K^0_S \pi^+ \pi^- n$
195	± 25.		DAUM	81C	CNTR	−	63 $K^- p \to K 2\pi p$
180	± 10		ETKIN	80	MPS	0	6 $K^- p \to K^0 \pi^+ \pi^- n$
• • • We do not use the following data for averages fits limits etc • • •							
~200 0			VERGEEST	79	HBC	−	4 2 $K^- p \to (K\pi\pi)^- p$
142 0 ± 16 0			[5] CARNEGIE	77	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$
~160			BRANDENB	76	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$
80			DAVIS	72	HBC	+	12 $K^+ p$
241	± 30		FIRESTONE	72B	DBC	+	12 $K^+ d$

[4] From partial wave analysis of $K^0 \pi^+ \pi^-$ system

[5] From a model dependent fit with Gaussian background to BRANDENBURG 76 data

$K_1(1400)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$K_1(1400) \to K^*(892)\pi$	$(94 \pm 6) \times 10^{-2}$
Γ_2	$K_1(1400) \to K\rho$	$(3\ 0 \pm 3\ 0) \times 10^{-2}$
Γ_3	$K_1(1400) \to K\omega$	$(1\ 0 \pm 1\ 0) \times 10^{-2}$
Γ_4	$K_1(1400) \to K_0^*(1430)\pi$	
Γ_5	$K_1(1400) \to K f_0(1400)$	$(2\ 0 \pm 2\ 0) \times 10^{-2}$

$K_1(1400)$ PARTIAL WIDTHS

$\Gamma(K^*(892)\pi)$ — Γ_1

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
117.0 ± 10.0	CARNEGIE	77	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$

$\Gamma(K\rho)$ — Γ_2

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2.0 ± 1.0	CARNEGIE	77	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$

$\Gamma(K\omega)$ — Γ_3

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
23.0 ± 12.0	CARNEGIE	77	ASPK	±	13 $K^\pm p \to (K\pi\pi)^\pm p$

$K_1(1400)$ BRANCHING RATIOS

$\Gamma(K^*(892)\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.94 ± 0.06	[6] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

$\Gamma(K\rho)/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.03 ± 0.03	[6] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

$\Gamma(K\omega)/\Gamma_{total}$ Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.01 ± 0.01	[6] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

$\Gamma(K_0^*(1430)\pi)/\Gamma_{total}$ Γ_4/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
~0.00	[6] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

$\Gamma(Kf_0(1400))/\Gamma_{total}$ Γ_5/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.02 ± 0.02	[6] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

D-wave/S-wave RATIO FOR $K_1(1400) \to K^*(892)\pi$

VALUE	DOCUMENT ID		TECN	COMMENT
0.04 ± 0.01	[6] DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

[6] Average from low and high t data.

$K_1(1400)$ REFERENCES

ASTON	87	NP B292 693	+Awaji, D'Amore+	(SLAC, NAGO, CINC, TOKY)
BAUBILLIER	82B	NP B202 21	+	(BIRM, CERN, GLAS, MSU, LPNP)
TORNQVIST	82B	NP B203 268		(HELS)
DAUM	81C	NP B187 1	+Hertzberger+	(AMST, CERN, CRAC, MPIM, OXF+)
ETKIN	80	PR D22 42	+Foley, Lindenbaum, Kramer+	(BNL, CUNY) JP
VERGEEST	79	NP B158 265	+Jongejans, Dionisi+	(NIJM, AMST, CERN, OXF)
CARNEGIE	77	NP B127 509	+Cashmore, Davier, Dunwoodie, Lasinski+	(SLAC)
BRANDENB	76	PRL 26 703	Brandenburg, Carnegie, Cashmore+	(SLAC) JP
DAVIS	72	PR D5 2688	+Alston, Barbaro, Flatte, Friedman, Lynch+	(LBL)
FIRESTONE	72B	PR D5 505	+Goldhaber, Lissauer, Trilling	(LBL)

OTHER RELATED PAPERS

FERNANDEZ	82	ZPHY C16 95	+Aguilar Benitez+	(MADR, CERN, CDEF, STOH)
OTTER	81	NP B181 1		(AACH, BERL, LOIC, VIEN, BIRM, BELG, CERN+)
RODEBACK	81	ZPHY C9 9	+Sjogren+	(CERN, CDEF, MADR, STOH)
BACON	80	NP B162 189	+Barrey, Butterworth, Ansorge+	(LOIC, CAVE)
DIONISI	80	NP B169 1	+Gavillet+	(CERN, MADR, CDEF, STOH)
IRVING	80	JP G6 153		(LIVP)
RADFORD	80	NP B167 181	+Brandenburg	(MIT)
BASDEVANT	79	PR D19 246	+Berger	(ANL)
MAZZUCATO	79	NP B156 532	+Pennington+	(CERN, ZEEM, NIJM, OXF)
BEUSCH	78	PL 74B 282	+Birman, Konigs, Otter+	(CERN, AACH, ETH) JP
GAVILLET	78	PL 76B 517	+Diaz, Dionisi+	(AMST, CERN, NIJM, OXF) JP
WOHL	78	NP B132 401	+Poler, Chaurand+	(LPNP, RHEL, SACL)
CARNEGIE	77B	PL 68B 287	+Cashmore, Dunwoodie, Lasinski+	(SLAC)
BASDEVANT	76	PRL 37 977	+Berger	(FNAL, ANL)
BOAL	76	PR D14 2998	+Edwards, Kamal, Torgeson	(ALBE)
BOWLER	76	JP G3 775		(OXF)
OTTER	76	NP B106 77	+	(AACH, BERL, CERN, LOIC, VIEN, LPNP+) JP
VERGEEST	76	PL 62B 471	+Engelen, Jongejans+	(AMST, CERN, NIJM, OXF) JP
ANTIPOV	75	NP B86 381	+Ascoli, Busnello, Kienzle+	(SERP, CERN, ILL) JP
BOWLER	75	NP B97 227	+Game, Aitchison, Dainton	(OXF, DARE)
DORE	75	LNC 13 265	+Guidoni, Laakso, Marini, Conforto+	(ROMA, RHEL)
DREVILLON	75	PL 55B 245	+Borenstein+	(EPOL, BOHR, CDEF) JP
DUNWOODIE	75	NP B91 189	+Grant+	(CERN, BELG, MONS, MPIM) JP
OTTER	75	NP B84 333	+	(AACH, BERL, CERN, LOIC, VIEN, ATHU+) JP
OTTER	75B	NP B93 365	+Rudolph+	(AACH, BERL, CERN, LOIC, VIEN) JP
OTTER	75C	NP B96 29	+Rudolph+	(AACH, BERL, CERN, LOIC, VIEN) IJP
TOVEY	75	NP B95 109	+Hansen, Borenstein, Borg+	(RHEL, EPOL, SACL) IJP
ANGELOPO	74	NC 20A 49	Angelopoulos+	(ATHU, ATEN, LIVP, VIEN) JP
BOWLER	74	NP B74 493	+Dainton, Kaddoura, Aitchison	(OXF)
DAVIDSON	74B	PR D9 77	+Chapman, Green, Lys, Roe	(MICH)
DEUTSCH	74	PL 49B 388	Deutschmann+	(AACH, BERL, CERN, LOIC, VIEN) JP
BARLOUTAUD	73	NP B59 374	+Drevillon, Shah+	(SACL, EPOL, RHEL) JP
BINGHAM	73	NP B52 31	+Farwell+	(LBL, ORSA, BNL, SACL, MILA) JP
DEJONGH	73	NP B58 110	+Cornet, Charriere+	(BRUX, MONS, CERN, MPIM)
JONES	73	NP B52 383		(CERN) JP
LEWIS	73	NP B60 283	+Allen, Jacobs+	(LOWC, LOIC, CDEF)
WERNER	73	PR D7 1275	+Slattery, Ferbel	(ROCH)
ANDERSON	72	PR D6 1823	+Franklin, Godden, Kopelman, Libby, Tan	(COLO)
BINGHAM	72C	NP B48 589	+Eisenstein, Grard, Herquet+	(CERN, BRUX)
BRANDENB	72	PRL 28 932	Brandenburg, Johnson, Leith, Loos+	(SLAC)
BRANDENB	72B	NP B45 397	Brandenburg, Brody, Johnson, Leith+	(SLAC)
CRENNELL	72	PR D6 1220	+Gordon, Lai, Scarr	(BNL)
FIRESTONE	72	NP B47 348		(CIT)
FRATI	72	PR D6 2361	+Halpern, Hargis, Snape+	(PENN, CINC)
HAATUFT	72	NP B48 78	+Arnold, Haguenauer+	(BERG, STRB, EPOL, MADR)
BARNHAM	71B	NP B25 49	+Colley, Griffiths, Alper+	(BIRM, GLAS, OXF)
DENEGRI	71	NP B28 13	+Antich, Callahan, Carson, Chien, Cox+	(JHU)
FORMAN	71	PR D3 2610	+Gelfand, Leary, Moser, Seidl, Wolfson	(EFI)
GARFINKEL	71	PRL 26 1505	+Holland, Carmony, Lander+	(PURD, UCD)
ABRAMS	70B	PR D1 2433	+Eisenstein, Kim, Marshall, O'Halloran+	(ILL)
ANTICH	70	NP B20 201	+Carson, Chien, Cox, Denegri, Ettlinger+	(JHU)
BOWLER	70	PL 31B 318		(OXF)
FARBER	70	PR D1 78	+Ferbel, Slattery, Yuta	(ROCH)
ALEXANDER	69B	NP B13 503	+Firestone, Goldhaber+	(LRL)
ANDREWS	69	PRL 22 731	+Lach, Ludlam, Sandweiss, Berger+	(YALE, LRL)
ASTIER	69	NP B10 65	+Marechal, Montanet+	(CDEF, CERN, IPNP, LIVP) IJP
BARBARO	69	PRL 22 1207	Barbaro-Galtieri, Davis, Flatte+	(LRL)
BETTINI	69	NC 62A 1038	+Cresti, Limentani, Bertanza, Bigi+	(PADO, PISA) I
BISHOP	69	NP B9 403	+Goshaw, Erwin, Walker	(WISC)
CHIEN	69	PL 29B 433	+Malamud, Mellema, Rudnick, Schlein+	(UCLA)
CHUNG	69	PR 182 1443	+Eisner, Bali, Luers	(BNL)
COLLEY	69	NC 59A 519	+Eastwood+	(BIRM, GLAS, LOIC, MPIM, OXF+)
ERWIN	69	NP B9 364	+Walker, Goshaw, Weinberg	(WISC, PRIN, VAND)
FRIEDMAN	69	UCRL 18860 Thesis		(LRL)
WERNER	69	PR 188 2023	+Ammar, Davis, Kropac, Yarger+	(NWES, ANL)
BARTSCH	68B	NP B8 9	+Cocconi+	(AACH, BERL, CERN, LOIC, VIEN)
BOMSE	68	PRL 20 1519	+Borenstein, Callahan, Cole, Cox+	(JHU)
DENEGRI	68	PRL 20 1194	+Callahan, Ettlinger, Gillespie+	(JHU)
BASSOMPIE	67B	PL 26B 30	Bassompierre, Goldschmidt+	(CERN, BRUX, BIRM) IJP
BERLINGHIERI	67	PRL 18 1087	+Farber, Ferbel, Forman	(ROCH) IJP
CRENNELL	67	PRL 19 44	+Kalbfleisch, Lai, Scarr, Schumann	(BNL)
DEBAERE	67	NC 49A 374	+Debaisieux, Fast, Filippas+	(CERN, BRUX)
Also	67	Private Comm.	Jongejans	
GOLDHABER	67B	PRL 19 976		(LBL)
SHEN	66	PRL 17 726	+Butterworth, Fu, Goldhaber, Trilling	(LRL)
Also	66	Private Comm.	Goldhaber	(LRL)
ALMEIDA	65	PL 16 184	+Atherton, Byer, Dornan, Forson+	(CAVE)
ARMENTEROS	64	PL 9 207	+Edwards, D'Andlau+	(CERN, CDEF)
Also	66	PR 145 1095	Barash, Kirsch, Miller, Tan	(COLU)
ARMENTEROS	64B	Dubna Conf. 1 577	+Edwards, D'Andlau+	(CERN, CDEF)
Also	64C	Dubna Conf. 1 617	Armenteros	

$K^*(1415)$
was $K^*(1410)$

$I(J^P) = \frac{1}{2}(1^-)$

$K^*(1415)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1414 ± 15 OUR AVERAGE Error includes scale factor of 1.3.					
1380 ± 21 ± 19	ASTON	88	LASS	0	11 $K^- p \to K^- \pi^+ n$
1420 ± 7 ± 10	ASTON	87	LASS	0	11 $K^- p \to K^0 \pi^+ \pi^- n$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1474 ± 25	BAUBILLIER	82B	HBC	0	8.25 $K^- p \to K^0 2\pi n$
1500 ± 30	ETKIN	80	MPS	0	6 $K^- p \to K^0 \pi^+ \pi^- n$

$K^*(1415)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
232 ± 21 OUR AVERAGE Error includes scale factor of 1.1.					
176 ± 52 ± 22	ASTON	88	LASS	0	11 $K^- p \to K^- \pi^+ n$
240 ± 18 ± 12	ASTON	87	LASS	0	11 $K^- p \to K^0 \pi^+ \pi^- n$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
275 ± 65	BAUBILLIER	82B	HBC	0	8.25 $K^- p \to K^0 2\pi n$
500 ± 100	ETKIN	80	MPS	0	6 $K^- p \to K^0 \pi^+ \pi^- n$

$K^*(1415)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$K^*(1415) \to K\pi$	$(6.6 \pm 1.3) \cdot 10^{-2}$
Γ_2	$K^*(1415) \to K^*(892)\pi$	
Γ_3	$K^*(1415) \to K\rho$	

$K^*(1415)$ BRANCHING RATIOS

$\Gamma(K\rho)/\Gamma(K^*(892)\pi)$ Γ_3/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.17	95	ASTON	84	LASS	0	11 $K^- p \to K^0 2\pi n$

$\Gamma(K\pi)/\Gamma(K^*(892)\pi)$ Γ_1/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.16	95	ASTON	84	LASS	0	11 $K^- p \to K^0 2\pi n$

$\Gamma(K\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.066 ± 0.010 ± 0.008	ASTON	88	LASS	0	11 $K^-p \to K^-\pi^+n$

$K^*(1415)$ REFERENCES

ASTON	88	NP B296 493	+Awaji Bienz Bird+	(SLAC NAGO CINC TOKY)
ASTON	87	NP B292 693	+Awaji D Amore+	(SLAC NAGO CINC TOKY)
ASTON	84	PL 149B 258	+Carnegie Dunwoodie+	(SLAC CARL OTTA) JP
BAUBILLIER	82B	NP B202 21	+	(BIRM CERN GLAS MSU LPNP)
ETKIN	80	PR D22 42	+Foley Lindenbaum Kramer+	(BNL CUNY) JP

$K_0^*(1430)$ was $K_0^*(1350)$ was $\kappa(1350)$

$I(J^P) = \frac{1}{2}(0^+)$

Our latest mini-review on this particle can be found in the 1984 edition

$K_0^*(1430)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1429 ± 4 ± 5	ASTON	88	LASS	0	11 $K^-p \to K^-\pi^+n$
• • • We do not use the following data for averages fits limits etc • • •					
~1430	BAUBILLIER	84B	HBC	−	8 25 $K^-p \to \overline{K}^0\pi^-p$
1350.	[1,2] TORNQVIST	82	RVUE		13 $K^\pm p$
1278 ± 50	[3,4] LANG	79	RVUE	0	
~1425	[3,5] ESTABROOKS	78	ASPK		13 $K^\pm p \to K^\pm\pi^\pm(n,\Delta)$
~1450 0	MARTIN	78	SPEC		10 $K^\pm p \to K_S^0\pi p$

[1] Mass defined as the energy where the phase shift passes 90° (for a discussion see mini-review on $a_1(1260)$)
[2] From a unitarized quark model calculation
[3] Mass defined by pole position
[4] Pole extrapolation using FIRESTONE 72C and MATISON 74 data
[5] From elastic $K\pi$ partial-wave analysis

$K_0^*(1430)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
287 ± 10 ± 21	ASTON	88	LASS	0	11 $K^-p \to K^-\pi^+n$
• • • We do not use the following data for averages fits limits, etc • • •					
~200	BAUBILLIER	84B	HBC	−	8 25 $K^-p \to \overline{K}^0\pi^-p$
>430	[6] TORNQVIST	82	RVUE		13 $K^\pm p$
540 ± 106	[7] LANG	79	RVUE	0	
200 to 300	[8] ESTABROOKS	78	ASPK		13 $K^\pm p \to K^\pm\pi^\pm(n,\Delta)$

[6] From a unitarized quark model calculation
[7] Pole extrapolation using FIRESTONE 72C and MATISON 74 data
[8] From elastic $K\pi$ partial-wave analysis

$K_0^*(1430)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$K_0^*(1430) \to K\pi$	$(93 \pm 10) \times 10^{-2}$

$K_0^*(1430)$ BRANCHING RATIOS

$\Gamma(K\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.93 ± 0.04 ± 0.09	ASTON	88	LASS	0	11 $K^-p \to K^-\pi^+n$
• • • We do not use the following data for averages, fits limits etc • • •					
~0.93	[9] TORNQVIST	82	RVUE		13 $K^\pm p$

[9] From a unitarized quark model calculation

$K_0^*(1430)$ REFERENCES

ASTON	88	NP B296 493	+Awaji Bienz Bird+	(SLAC NAGO CINC TOKY)
BAUBILLIER	84B	ZPHY C26 37	+	(BIRM CERN GLAS MICH LPNP)
TORNQVIST	82	PRL 49 624		(HELS)
LANG	79	PR D19 956	+Mas Parareda	(GRAZ)
ESTABROOKS	78	NP B133 490	+Carnegie+	(MONT CARL DURH SLAC)
MARTIN	78	NP B134 392	+Shimada Baldi Bohringer+	(DURH GEVA)
MATISON	74	PR D9 1872	+Galtieri Garnjost Flatte Friedman+	(LBL)
FIRESTONE	72C	PR D5 2188	+Goldhaber Lissauer Trilling	(LBL) P

— OTHER RELATED PAPERS —

TOAFF	81	PR D23 1500	+Musgrave Ammar Davis Ecklund+	(ANL KANS)
ESTABROOKS	79	PR D19 2678		(CARL)
BALDI	78B	NP B134 365	+Bohringer Dorsaz Hungerbuhler+	(GEVA)
ENGELEN	78	NP B134 14	+Jongejans+	(NIJM ZEEM CERN OXF)
BOWLER	77	NP B126 31	+Dainton Drake Williams	(OXF)
SPIRO	77	NP B125 162	+Barloutaud Comber Paler+	(SACL RHEL EPOL)
CHIEN	76	NP B106 355	+Felock Lucas Pevsner Zoanis	(JHU)
BAKER	75	NP B99 211	+Banerjee Campbell Allen+	(LOIC LOWC)
LAUSCHER	75	NP B86 189	+Otter Wieczorek+	(ABCLV Collab)
MORGAN	75	Argonne Conf 45		(RHEL)
FOX	74	NP B80 403	+Griss	(CIT)
MORGAN	74	PL 51B 71		(RHEL)
CORDS	73	NP B54 109	+Carmony Lander Meiere+	(PURD UCD IUPU)
GALTIERI	73	LBL 1772	+Matison Garnjost Flatte Friedman+	(LBL)
LINGLIN	73	NP B55 408		(CERN)
YUTA	73	NP B52 70	+Engelmann Musgrave Forman+	(ANL EFI)
AGUILAR	72	PR D6 11	Aguilar Benitez Chung Eisner	(BNL)
BINGHAM	72	NP B41 1	+	(International K+ Collab)
BUCHNER	72	NP B45 333	+Dehm Charriere Cornet+	(MPIM CERN BRUX)
CHUNG	72	PRL 29 1570	+Eisner Aguilar Benitez	(BNL)
CRENNELL	72	PR D6 1220	+Gordon Lai Scarr	(BNL)
DIEBOLD	72B	Batavia Conf 3 17		(ANL)
ENGELMANN	72	PR D5 2162	+Musgrave Forman+	(ANL EFI)
FRATI	72	PR D6 2361	+Halpern Hargis Snape+	(PENN CINC)
MATISON	72	LBL 1537 Thesis		(LBL)
ROUGE	72	NP B46 29	+Videau Volte DeBrion+	(EPOL SACL)
FIRESTONE	71C	PRL 26 1460	+Goldhaber Lissauer	(LRL)
MERCER	71	NP B32 381	+Antich Callahan Chien Cox+	(JHU)
YUTA	71	PRL 26 1502	+Derrick Engelmann Musgrave	(ANL EFI)
CRENNELL	69D	PRL 22 487	+Karshon Lai O Neall Scarr	(BNL)
DODD	69B	PR 177 1994	+Joldersma Palmer Samios	(BNL)
GOLDBERG	69	PL 30B 434		(SABRE Collab)
SCHLEIN	69	Argonne Conf 446		(UCLA)
TRIPPE	68	PL 28B 203	+Chien Malamud Mellema Schlein+	(UCLA)

$K_2^*(1430)$ was $K^*(1430)$

$I(J^P) = \frac{1}{2}(2^+)$

We consider that phase-shift analyses provide more reliable determinations of the mass and width

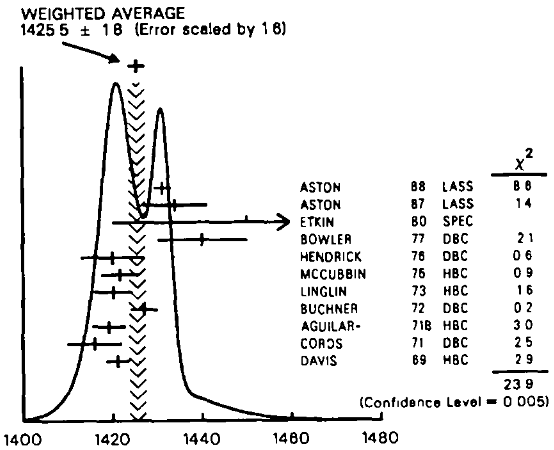
$K_2^*(1430)$ MASS

CHARGED ONLY, WITH FINAL STATE $K\pi$

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1425.6 ± 1.5 OUR AVERAGE Error includes scale factor of 1 1						
1420 ± 4	1587	BAUBILLIER	84B	HBC	−	8 25 $K^-p \to K^0\pi^-p$
1436 ± 5 5	400	[1,2] CLELAND	82	SPEC	+	30 $K^+p \to K_S^0\pi^+p$
1430 ± 3 2	1500	[1,2] CLELAND	82	SPEC	+	50 $K^+p \to K_S^0\pi^+p$
1430 ± 3 2	1200	[1,2] CLELAND	82	SPEC	−	50 $K^+p \to K_S^0\pi^-p$
1423 0 ± 5 0	935	TOAFF	81	HBC	−	6 5 $K^-p \to \overline{K}^0\pi^-p$
1428 0 ± 4 6		[3] MARTIN	78	SPEC	+	10 $K^\pm p \to K_S^0\pi p$
1423 8 ± 4 6		[3] MARTIN	78	SPEC	−	10 $K^\pm p \to K_S^0\pi p$
1420.0 ± 3 1	1400	AGUILAR-	71B	HBC	−	3 9 4 6 K^-p
1425 ± 8 0	225	[1,2] BARNHAM	71C	HBC	+	$K^+p \to K^0\pi^+p$
1416 0 ± 10 0	220	CRENNELL	69D	DBC	−	3 9 $K^-N \to \overline{K}^0\pi^-N$
1414 ± 13.0	60	[1] LIND	69	HBC	+	9 $K^+p \to K^0\pi^+p$
1427 0 ± 12 0	63	[1] SCHWEING	68	HBC	−	5 5 $K^-p \to K\pi N$
1423 ± 11 0	39	[1] BASSANO	67	HBC	−	4 6–5 0 $K^-p \to \overline{K}^0\pi^-p$
• • • We do not use the following data for averages fits limits etc • • •						
1448 5 ± 5 0	579	[1] DELFOSSE	81	SPEC	+	50 $K^\pm p \to K^\pm\pi^0p$
1431 8 ± 5 6	292	[1] DELFOSSE	81	SPEC	−	50 $K^\pm p \to K^\pm\pi^0p$

NEUTRAL ONLY

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
1425.5 ± 1.8	**OUR AVERAGE**	Error includes scale factor of 1 6 See the ideogram below			
1431 2 ± 1.8 ± 0.7		[4] ASTON	88 LASS	0	11 $K^- p \to K^- \pi^+ n$
1434 ± 4 ± 6		[4] ASTON	87 LASS	0	11 $K^- p \to K^0 \pi^+ \pi^- n$
1450. ± 30.		ETKIN	80 SPEC	0	6 $K^- p \to \overline{K}^0 \pi^+ \pi^- n$
1440 0 ± 10 0		[4] BOWLER	77 DBC	0	5 5 $K^+ d \to K \pi p p$
1420.0 ± 7 0	300	HENDRICK	76 DBC		8 25 $K^+ N \to K^+ \pi N$
1421 6 ± 4 2	800	MCCUBBIN	75 HBC	0	3 6 $K^- p \to K^- \pi^+ n$
1420.1 ± 4 3		[5] LINGLIN	73 HBC	0	2–13 $K^+ p \to K^+ \pi^- X$
1427. ± 3	1100	BUCHNER	72 DBC	0	4 6 $K^+ n \to K^+ \pi^- p$
1419.1 ± 3 7	1800	AGUILAR-	71B HBC	0	3 9,4 6 $K^- p$
1416. ± 6	600	CORDS	71 DBC	0	9 $K^+ n \to K^+ \pi^- p$
1421.1 ± 2 6	2200	DAVIS	69 HBC	0	12 $K^+ p \to K^+ \pi^- X$
• • • We do not use the following data for averages, fits limits etc • • •					
1408 45 ± 6 22	1402	[6] ATKINSON	86 OMEG		20–70 γp
1435 39 ± 6 49	1582	[6] ATKINSON	86 OMEG		20–70 γp
1471. ± 12		[4] BAUBILLIER	82B HBC	0	8 25 $K^- p \to N K_S^0 \pi \pi$
1434 0 ± 2 0		[4] ESTABROOKS	78 ASPK	0	13 $K^\pm p \to p K \pi$
1423 0 ± 3 0		[7] ETKIN	76 SPEC	0	6 $K^- p \to K^0 \pi^+ \pi^- n$



$K_2^*(1430)$ mass neutral only (MeV)

[1] Errors enlarged by us to $\Gamma/N^{1/2}$ see the note with the $K^*(892)$ mass
[2] Number of events in peak re-evaluated by us
[3] Systematic error added by us
[4] From phase shift or partial wave analysis
[5] From pole extrapolation using world $K^+ p$ data summary tape
[6] Inclusive reaction Complicated background and phase space effects
[7] See more recent partial wave analysis (ETKIN 80)

$K_2^*(1430)$ WIDTH

CHARGED ONLY, WITH FINAL STATE $K\pi$

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
99.0 ± 2.4	**OUR FIT**				
99.0 ± 2.4	**OUR AVERAGE**				
102. ± 10	1587	BAUBILLIER	84B HBC	−	8 25 $K^- p \to \overline{K}^0 \pi^- p$
109. ± 22	400	[8,9] CLELAND	82 SPEC	+	30 $K^+ p \to K_S^0 \pi^+ p$
124. ± 12 8	1500	[8,9] CLELAND	82 SPEC	+	50 $K^+ p \to K_S^0 \pi^+ p$
113. ± 12 8	1200	[8,9] CLELAND	82 SPEC	−	50 $K^+ p \to K_S^0 \pi^- p$
118.9 ± 20 0	579	[8] DELFOSSE	81 SPEC	+	50 $K^\pm p \to K^\pm \pi^0 p$
96 0 ± 22 5	292	[8] DELFOSSE	81 SPEC	−	50 $K^\pm p \to K^\pm \pi^0 p$
85.0 ± 16 0	935	TOAFF	81 HBC	−	6 5 $K^- p \to \overline{K}^0 \pi^- p$
96 5 ± 3.8		MARTIN	78 SPEC	+	10 $K^\pm p \to K_S^0 \pi p$
97 7 ± 4.0		MARTIN	78 SPEC	−	10 $K^\pm p \to K_S^0 \pi p$
94 7 $^{+15\ 1}_{-12\ 5}$	1400	AGUILAR-	71B HBC	−	3 9 4 6 $K^- p$

NEUTRAL ONLY

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
115.0 $^{+3.3}_{-3.4}$	**OUR AVERAGE**				
116 5 ± 3 6 ± 1 7		[10] ASTON	88 LASS	0	11 $K^- p \to K^- \pi^+ n$
129 ± 15 ± 15		[10] ASTON	87 LASS	0	11 $K^- p \to K^0 \pi^+ \pi^- n$
140 ± 30.		[10] ETKIN	80 SPEC	0	6 $K^- p \to K^0 \pi^+ \pi^- n$
116 ± 18	800	MCCUBBIN	75 HBC	0	3 6 $K^- p \to K^- \pi^+ n$
109 ± 14 0	1100	[8] BUCHNER	72 DBC	0	4 6 $K^+ n \to K^+ \pi^- p$
116 6 $^{+10.3}_{-15\ 5}$	1800	AGUILAR	71B HBC	0	3 9 4 6 $K^- p$
101 ± 10.	2200	DAVIS	69 HBC	0	12 $K^+ p \to K^+ \pi^- \pi^+ p$
• • • We do not use the following data for averages fits limits etc • • •					
143 ± 34		[10] BAUBILLIER	82B HBC	0	8 25 $K^- p \to N K_S^0 \pi \pi$
98 0 ± 5 0		[10] ESTABROOKS	78 ASPK	0	13 $K^\pm p \to p K \pi$
170 0 ± 20 0		[10] BOWLER	77 DBC	0	5 5 $K^+ d \to K \pi p p$
61.0 ± 14 0		[11] LINGLIN	73 HBC	0	2–13 $K^+ p \to K^+ \pi^- X$

[8] Errors enlarged by us to $4\Gamma/N^{1/2}$ see the note with the $K^*(892)$ mass
[9] Number of events in peak re-evaluated by us
[10] From phase shift or partial-wave analysis
[11] From pole extrapolation using world $K^+ p$ data summary tape

$K_2^*(1430)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale/ Conf Lev
Γ_1	$K_2^*(1430) \to K\pi$	(49 7 ± 1.2) × 10^{-2}	
Γ_2	$K_2^*(1430) \to K^*(892)\pi$	(25 2 ± 1.7) × 10^{-2}	
Γ_3	$K_2^*(1430) \to K\rho$	(8 8 ± 0 8) × 10^{-2}	S=1 2
Γ_4	$K_2^*(1430) \to K\omega$	(2 9 ± 0 8) × 10^{-2}	
Γ_5	$K_2^*(1430) \to K\eta$	(1 4 $^{+4\ 9}_{-1\ 0}$) × 10^{-3}	S=1 8
Γ_6	$K_2^*(1430) \to K^*(892)\pi\pi$	(13 0 ± 2 3) × 10^{-2}	
Γ_7	$K_2^*(1430) \to K\omega\pi$	< 7 2 × 10^{-4}	CL=95%
Γ_8	$K_2^*(1430)^+ \to K^+\gamma$	(2.4 ± 0 5) × 10^{-3}	S=1 2

CONSTRAINED FIT INFORMATION

An overall fit to the total width, a partial width, and 10 branching ratios uses 30 measurements and one constraint to determine 8 parameters The overall fit has a χ^2 = 20 7 for 23 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle \delta p_i \delta p_j \rangle / (\delta p_i\ \delta p_j)$ in percent, from the fit to parameters p_i, including the branching fractions, $x_i = \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

x_2	−16						
x_3	−11	38					
x_4	11	2	−7				
x_5	5	−11	−8	4			
x_6	−33	74	52	−25	7		
x_8	1	−1	−1	0	0	1	
Γ	0	0	0	0	0	0	−11
	x_1	x_2	x_3	x_4	x_5	x_6	x_8

	Mode	Rate (MeV)	Scale
Γ_1	$K_2^*(1430) \to K\pi$	49 2 ± 1.7	
Γ_2	$K_2^*(1430) \to K^*(892)\pi$	24 9 ± 1 8	
Γ_3	$K_2^*(1430) \to K\rho$	8 8 ± 0 8	1 2
Γ_4	$K_2^*(1430) \to K\omega$	2 9 ± 0 8	
Γ_5	$K_2^*(1430) \to K\eta$	0 14 $^{+0\ 50}_{-0\ 09}$	1 8
Γ_6	$K_2^*(1430) \to K^*(892)\pi\pi$	12 9 ± 2 3	
Γ_8	$K_2^*(1430)^+ \to K^+\gamma$	0 24 ± 0 05	1 2

Meson Full Listings
$K_2^*(1430)$

$K_2^*(1430)$ PARTIAL WIDTHS

$\Gamma(K^+\gamma)$ — Γ_8

VALUE (keV)	DOCUMENT ID		TECN	CHG	COMMENT
240 ± 50 OUR FIT Error includes scale factor of 1 2					
240 ± 45	CIHANGIR	82	SPEC	+	200 $K^+Z \to ZK^+\pi^0$ $ZK_S^0\pi^+$

$K_2^*(1430)$ BRANCHING RATIOS

$\Gamma(K\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.497 ± 0.012 OUR FIT					
0.488 ± 0.014 OUR AVERAGE					
0.485 ± 0 006 ± 0 020	[12] ASTON	88	LASS	0	11 $K^-p \to K^-\pi^+n$
0 49 ± 0 02	[12] ESTABROOKS	78	ASPK	±	13 $K^\pm p \to pK\pi$

[12] From phase shift analysis

$\Gamma(K^*(892)\pi)/\Gamma(K\pi)$ — $\Gamma_2/(\Gamma_1+\Gamma_2+\Gamma_3)$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •					
0 47 ± 0 10	BASSANO	67	HBC	−0	4 6 5 0 K^-p
0 45 ± 0.13	[14] BADIER	65C	HBC	−	3 K^-p

$\Gamma(K\rho)/\Gamma(K\pi)$ — $\Gamma_3/(\Gamma_1+\Gamma_2+\Gamma_3)$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
0 14 ± 0 10	BASSANO	67	HBC	−0	4 6 5 0 K^-p
0 14 ± 0.07	[14] BADIER	65C	HBC	−	3 K^-p

$\Gamma(K^*(892)\pi)/\Gamma(K\pi)$ — Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.51 ± 0.04 OUR FIT					
0.48 ± 0.05 OUR AVERAGE					
0 44 ± 0 09	ASTON	84B	LASS	0	11 $K^-p \to K^0 2\pi n$
0 62 ± 0 19	LAUSCHER	75	HBC	0	10,16 $K^-p \to K^-\pi^+n$
0 54 ± 0 16	DEHM	74	DBC	0	4 6 K^+N
0 47 ± 0 08	AGUILAR-	71B	HBC		3 9 4 6 K^-p
• • • We do not use the following data for averages, fits, limits etc • • •					
0 52 ± 0 12	SCHWEING	68	HBC	0	4 1,5 5 K^-p
0 65 ± 0 20	SHEN	66	HBC	0	N^* produced

$\Gamma(K\omega)/\Gamma(K\pi)$ — Γ_4/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.059 ± 0.017 OUR FIT					
0.070 ± 0.035 OUR AVERAGE					
0 05 ± 0 04	AGUILAR-	71B	HBC		3 9,4 6 K^-p
0 13 ± 0 07	BASSOMPIE	69	HBC	0	5 K^+p

$\Gamma(K\rho)/\Gamma(K\pi)$ — Γ_3/Γ_1

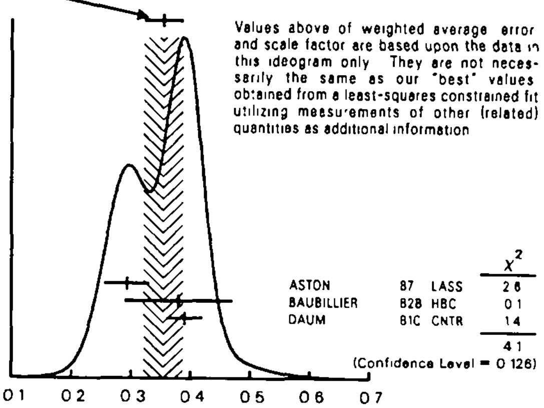
VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$0.178^{+0.018}_{-0.017}$ **OUR FIT** Error includes scale factor of 1 2					
$0.153^{+0.034}_{-0.018}$ **OUR AVERAGE**					
0 18 ± 0 05	ASTON	84B	LASS	0	11 $K^-p \to K^0 2\pi n$
$0\ 02^{+0\ 10}_{-0\ 02}$	DEHM	74	DBC	0	4 6 K^+N
0 16 ± 0 05	AGUILAR	71B	HBC		3 9 4 6 K^-p
• • • We do not use the following data for averages fits limits etc • • •					
0 26 ± 0 16	SCHWEING	68	HBC	0	4 1 5 5 K^-p
<0 09	CHUNG	65	HBC	+0	3 9,4 2 π^-p

$\Gamma(K\rho)/\Gamma(K^*(892)\pi)$ — Γ_3/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.351 ± 0.032 OUR FIT Error includes scale factor of 1 5						
0.354 ± 0 033 OUR AVERAGE Error includes scale factor of 1 4 See the ideogram below						
0 293 ± 0 032 ± 0.020		ASTON	87	LASS	0	11 $K^-p \to K^0\pi^+\pi^-n$
0 38 ± 0 09		BAUBILLIER	82B	HBC	0	8 25 $K^-p \to NK_S^0\pi\pi$
0 39 ± 0 03		DAUM	81C	CNTR		63 $K^-p \to K2\pi p$
• • • We do not use the following data for averages fits limits etc • • •						
0 36 ± 0 10		[13] VERGEEST	76	HBC	0	4 2 $K^-p \to pK^0\pi\pi$
0 13 ± 0 09	130	[13] OTTER	75	HBC	0	8 10 16 $K^-p \to K^*N$

[13] From partial-wave analysis of $K^0\pi^+\pi^-$ system

WEIGHTED AVERAGE
0 354 ± 0 033 (Error scaled by 1 4)



$\Gamma(K\rho)/\Gamma(K^*(892)\pi)$

$\Gamma(K\omega)/\Gamma(K^*(892)\pi)$ — Γ_4/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.116 ± 0.034 OUR FIT					
0.10 ± 0.04	FIELD	67	HBC	−	3 8 K^-p

$\Gamma(K\eta)/\Gamma(K^*(892)\pi)$ — Γ_5/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.006 ± 0.020 OUR FIT Error includes scale factor of 1 8					
0.07 ± 0.04	FIELD	67	HBC	−	3 8 K^-p

$\Gamma(K\eta)/\Gamma(K\pi)$ — Γ_5/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
0.003 ± 0.010 OUR FIT Error includes scale factor of 1 8						
0 ± 0 0056		ASTON	88B	LASS	−	11 $K^-p \to K^-\eta p$
• • • We do not use the following data for averages, fits limits, etc • • •						
<0 04	95	AGUILAR	71B	HBC		3 9,4 6 K^-p
<0.065		[14] BASSOMPIE	69	HBC		5 0 K^+p
<0 02		BISHOP	69	HBC		3 5 K^+p

$\Gamma(K^*(892)\pi\pi)/\Gamma_{total}$ — Γ_6/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.130 ± 0.023 OUR FIT					
0.12 ± 0.04	[15] GOLDBERG	76	HBC	−	3 $K^-p \to pK^0\pi\pi\pi$

$\Gamma(K^*(892)\pi\pi)/\Gamma(K\pi)$ — Γ_6/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.26 ± 0.05 OUR FIT					
0.21 ± 0 08	[14 15] JONGEJANS	78	HBC	−	4 $K^-p \to pK^0\pi\pi\pi$

$\Gamma(K\omega\pi)/\Gamma_{total}$ — Γ_7/Γ

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.72	95	0	JONGEJANS	78	HBC	4 $K^-p \to pK^0 4\pi$

[14] Restated by us
[15] Assuming $\pi\pi$ system has isospin 1 which is supported by the data

$K_2^*(1430)$ REFERENCES

ASTON	88	NP B296 493	+Awaji Bienz Bird+ (SLAC NAGO CINC TOKY)
ASTON	88B	PL B201 169	+Awaji Bienz+ (SLAC NAGO CINC TOKY)
ASTON	87	NP B292 693	+Awaji D Amore+ (SLAC NAGO CINC TOKY)
ATKINSON	86	ZPHY C30 521	+ (BONN CERN GLAS LANC MCHS LPNP+)
ASTON	84B	NP B247 261	+Carnegie Dunwoodie+ (SLAC CARL OTTA)
BAUBILLIER	84B	ZPHY C26 37	+ (BIRM CERN GLAS MICH LPNP)
BAUBILLIER	82B	NP B202 21	+ (BIRM CERN GLAS MSU LPNP)
CIHANGIR	82	PL 117B 123	+Berg Biel Chandlee+ (FNAL MINN ROCH)
CLELAND	82	NP B208 189	+Delfosse Dorsaz Gloor (DURH GEVA LAUS PITT)
DAUM	81C	NP B187 1	+Hertzberger+ (AMST CERN CRAC MPIM OXF+)
DELFOSSE	81	NP B183 349	+Guisan Martin Muhlemann Weill+(GEVA LAUS)
TOAFF	81	PR D23 1500	+Musgrave Ammar Davis Ecklund+ (ANL KANS)
ETKIN	80	PR D22 42	+Foley Lindenbaum Kramer+ (BNL CUNY) JP
ESTABROOKS	78	NP B133 490	+Carnegie+ (MONT CARL DURH SLAC)
Also	78B	PR D17 658	Estabrooks Carnegie+ (MONT CARL DURH+)
JONGEJANS	78	NP B139 383	+Cerrada+ (ZEEM CERN NIJM OXF)
MARTIN	78	NP B134 392	+Shimada Baldi Bohringer+ (DURH GEVA)
BOWLER	77	NP B126 31	+Dainton Drake Williams (OXF)
ETKIN	76	PRL 36 1482	+Foley Goldman Lindenbaum Kim+(BNL CUNY)
GOLDBERG	76	LNC 17 253	(HAIF)
HENDRICK	76	NP B112 189	+Vignaud Burlaud+ (MONS SACL LPNP BELG)
VERGEEST	76	PL 62B 471	+Engelen Jongejans+ (AMST CERN NIJM OXF) JP
LAUSCHER	75	NP B86 189	+Otter Wieczorek+ (ABCLV Collab) JP
MCCUBBIN	75	NP B86 13	+Lyons (OXF)

OTTER	75	NP B84 333	+	(AACH BERL CERN LOIC VIEN ATHU+)
DEHM	74	NP B75 47	+Goebel Wittek+	(MPIM BRUX MONS CERN)
LINGLIN	73	NP B55 408		(CERN)
BUCHNER	72	NP B45 333	+Dehm Charriere Cornet+	(MPIM CERN BRUX)
AGUILAR	71B	PR D4 2583	Aguilar Benitez Eisner Kinson	(BNL)
BARNHAM	71C	NP B28 171	+Colley Jobes Griffiths Hughes+	(BIRM GLAS)
CORDS	71	PR D4 1974	+Carmony Erwin Meiere+	(PURD UCD IUPU)
BASSOMPIE	69	NP B13 189	Bassompierre+	(CERN BRUX) JP
BISHOP	69	NP B9 403	+Goshaw Erwin Walker	(WISC)
CRENNELL	69D	PRL 22 487	+Karshon Lai O Neall Scarr	(BNL)
DAVIS	69	PRL 23 1071	+Derenzo Flatte Alston Lynch Solmitz	(LRL)
LIND	69	NP B14 1	+Alexander Firestone Fu Goldhaber	(LRL) JP
SCHWEING	68	PR 166 1317	Schweingruber Derrick Fields+	(ANL NWES)
Also	67	Thesis	Schweingruber	(NWES NWES)
BASSANO	67	PRL 19 968	+Goldberg Goz Barnes Leitner+	(BNL SYRA)
FIELD	67	PL 24B 638	+Hendricks Piccioni Yager	(UCSD)
SHEN	66	PRL 17 726	+Butterworth Fu Goldhaber Trilling	(LRL)
Also	66	Private Comm	Goldhaber	(LRL)
BADIER	65C	PL 19 612	+Demoulin Goldberg+	(EPOL SACL AMST)
CHUNG	65	PRL 15 325	+Dahl Hardy Hess Jacobs Kirz	(LRL)

— OTHER RELATED PAPERS —

BALDI	78B	NP B134 365	+Bohringer Dorsaz Hungerbuhler+	(GEVA)
BOHM	78	PRL 41 1761	+VanDalen+	(AACH UCR CERN HARV MUNI+)
ENGELEN	78	NP B134 14	+Jongejans+	(NIJM ZEEM CERN OXF)
KIRK	76	NP B116 99	+Klein+	(AACH BERL CERN LOIC WIEN)
CHARRIERE	73	NP B51 317	+Drijard DeBaere+	(CERN BELG)
Also	75	Private Comm	Goldschmidt Clermont	(CERN)
CLARK	73	NP B54 432	+Lyons Radojicic	(OXF)
DEJONGH	73	NP B58 110	+Cornet Charriere+	(BRUX MONS CERN MPIM)
WALUCH	73	PR D8 2837	+Flatte Friedman	(LBL)
CRENNELL	72	PR D6 1220	+Gordon Lai Scarr	(BNL)
DEUTSCH	72	NP B36 373	Deutschmann Honecker+	(ABCLV Collab)
ENGELMANN	72	PR D5 2162	+Musgrave Forman+	(ANL EFI)
FRATI	72	PR D6 2361	+Halpern Hargis Snape+	(PENN CINC)
ROUGE	72	NP B46 29	+Videau Volte DeBrion+	(EPOL SACL)
TIECKE	72	NP B39 596	+Grijns Heinen DeGroot+	(NIJM AMST)
ABRAMS	70B	PR D1 2433	+Eisenstein Kim Marshall O Halloran+	(ILL)
DEBAERE	69	NC 61A 397	+Goldschmidt Clermont Henri+	(BELG CERN)
ANTICH	68	PRL 21 1842	+Callahan Carson Cox Denegri+	(JHU)
KANG	68	PR 176 1587		(IOWA)
CRENNELL	67	PRL 19 44	+Kalbfleisch Lai Scarr Schumann	(BNL)
DAHL	67	PR 163 1377	+Hardy Hess Kirz Miller	(LRL)
Also	65	PRL 14 401	Hardy Chung Dahl Hess Kirz Miller	(LRL)
DEBAERE	67B	NC 51A 401	+Goldschmidt Clermont Henri+	(BRUX CERN)
GOLDHABER	67	PRL 19 972	+Firestone Shen	(LRL)
SHEN	66	PRL 17 726	+Butterworth Fu Goldhaber Trilling	(LRL)
Also	66	Private Comm	Goldhaber	(LRL)

K(1460) was K(1400)

$I(J^P) = \frac{1}{2}(0^-)$

OMITTED FROM SUMMARY TABLE

Observed in $K\pi\pi$ partial-wave analysis Not seen by VERGEEST 79 Wait confirmation

K(1460) MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
~1460	DAUM	81C	CNTR	−	63 $K^- p \to K 2\pi p$
~1400	[1] BRANDENB	76B	ASPK	±	13 $K^\pm p \to K\pi\pi N$

[1] Coupled mainly to $Kf_0(1400)$ Decay into $K^*(892)\pi$ seen

K(1460) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •					
~260	DAUM	81C	CNTR	−	63 $K^- p \to K 2\pi p$
~250	[2] BRANDENB	76B	ASPK	±	13 $K^\pm p \to K\pi\pi N$

[2] Coupled mainly to $Kf_0(1400)$ Decay into $K^*(892)\pi$ seen

K(1460) DECAY MODES

Γ_1 $K(1460) \to K^*(892)\pi$

Γ_2 $K(1460) \to K\rho$

Γ_3 $K(1460) \to K_0^*(1430)\pi$

K(1460) PARTIAL WIDTHS

$\Gamma(K^*(892)\pi)$ Γ_1

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~109	DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

$\Gamma(K\rho)$ Γ_2

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~34	DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

$\Gamma(K_0^*(1430)\pi)$ Γ_3

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~117	DAUM	81C	CNTR	63 $K^- p \to K 2\pi p$

K(1460) REFERENCES

DAUM	81C	NP B187 1	+Hertzberger+	(AMST CERN CRAC MPIM OXF+)
VERGEEST	79	NP B158 265	+Jongejans Dionisi+	(NIJM AMST CERN OXF)
BRANDENB	76B	PRL 36 1239	Brandenburg Carnegie Cashmore+	(SLAC) JP

— OTHER RELATED PAPERS —

BARNES	82	PL 116B 365	+Close	(RHEL)
TANIMOTO	82	PL 116B 198		(BIEL)
VERGEEST	79	NP B158 265	+Jongejans Dionisi+	(NIJM AMST CERN OXF)

$K_2(1580)$ was $L(1580)$

$I(J^P) = \frac{1}{2}(2^-)$

OMITTED FROM SUMMARY TABLE

Seen in partial-wave analysis of the $K^-\pi^+\pi^-$ system Needs confirmation

$K_2(1580)$ MASS

VALUE (MeV)	DOCUMENT ID		CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~1580	OTTER	79	−	10 14 16 $K^- p$

$K_2(1580)$ WIDTH

VALUE (MeV)	DOCUMENT ID		CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~110	OTTER	79	−	10 14 16 $K^- p$

$K_2(1580)$ DECAY MODES

Γ_1 $K_2(1580) \to K^*(892)\pi$

Γ_2 $K_2(1580) \to K_2^*(1430)\pi$

$K_2(1580)$ BRANCHING RATIOS

$\Gamma(K^*(892)\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
SEEN	OTTER	79	HBC	−	10 14 16 $K^- p$

$\Gamma(K_2^*(1430)\pi)/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
POSSIBLY SEEN	OTTER	79	HBC	−	10 14 16 $K^- p$

$K_2(1580)$ REFERENCES

OTTER	79	NP B147 1	+Rudolph+	(AACH BERL CERN LOIC WIEN) JP

Meson Full Listings
$K_1(1650)$, $K^*(1715)$

$K_1(1650)$

$I(J^P) = \frac{1}{2}(1^+)$

OMITTED FROM SUMMARY TABLE

This entry contains various peaks in strange meson systems ($K^+\phi$, $K\pi\pi$) reported in partial-wave analysis in the 1600–1900 mass region

$K_1(1650)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1650. ± 50.	FRAME	86	OMEG	+	13 $K^+p \to \phi K^+p$
• • • We do not use the following data for averages, fits limits etc • • •					
~1840	ARMSTRONG	83	OMEG	−	18.5 $K^-p \to 3Kp$
~1800	DAUM	81C	CNTR	−	63 $K^-p \to \bar{K}2\pi p$

$K_1(1650)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
150. ± 50.	FRAME	86	OMEG	+	13 $K^+p \to \phi K^+p$
• • • We do not use the following data for averages, fits limits etc • • •					
~250	DAUM	81C	CNTR	−	63 $K^-p \to K2\pi p$

$K_1(1650)$ DECAY MODES

Γ_1 $K_1(1650) \to K\pi\pi$

Γ_2 $K_1(1650) \to K\phi$

$K_1(1650)$ REFERENCES

FRAME 86 NP B276 667 +Hughes Lynch Minto McFadzean+ (GLAS)
ARMSTRONG 83 NP B221 1 + (BARI BIRM CERN MILA LPNP PAVI)
DAUM 81C NP B187 1 +Hertzberger+ (AMST CERN CRAC MPIM OXF+)

$K^*(1715)$ was $K^*(1790)$

$I(J^P) = \frac{1}{2}(1^-)$

$K^*(1715)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
1717 ± 27 OUR AVERAGE Error includes scale factor of 1.4					
1677 ± 10 ± 32	ASTON	88	LASS	0	11 $K^-p \to K^-\pi^+n$
1735 ± 10 ± 20	ASTON	87	LASS	0	11 $K^-p \to \bar{K}^0\pi^+\pi^-n$
• • • We do not use the following data for averages, fits limits etc • • •					
1800 ± 70	ETKIN	80	MPS	0	6 $K^-p \to K^0\pi^+\pi^-n$
~1650	ESTABROOKS	78	ASPK	0	13 $K^\pm p \to K^\pm\pi^\pm n$

$K^*(1715)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
322 ± 110 OUR AVERAGE Error includes scale factor of 4.2					
205 ± 16 ± 34	ASTON	88	LASS	0	11 $K^-p \to K^-\pi^+n$
423 ± 18 ± 30	ASTON	87	LASS	0	11 $K^-p \to \bar{K}^0\pi^+\pi^-n$
• • • We do not use the following data for averages, fits limits etc • • •					
170. ± 30	ETKIN	80	MPS	0	6 $K^-p \to K^0\pi^+\pi^-n$
250 to 300	ESTABROOKS	78	ASPK	0	13 $K^\pm p \to K^\pm\pi^\pm n$

$K^*(1715)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	$K^*(1715) \to K\pi$	$(38.7 \pm 2.5) \times 10^{-2}$	
Γ_2	$K^*(1715) \to K^*(892)\pi$	$(29.9^{+2.9}_{-6.9}) \times 10^{-2}$	1.4
Γ_3	$K^*(1715) \to K\rho$	$(31.4^{+6.7}_{-2.9}) \times 10^{-2}$	1.4

CONSTRAINED FIT INFORMATION

An overall fit to 4 branching ratios uses 4 measurements and one constraint to determine 3 parameters The overall fit has a $\chi^2 = 3.0$ for 2 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i\,\delta x_j\rangle/(\delta x_i\cdot\delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i in this array to sum to one

x_2	30	
x_3	23	86
	x_1	x_2

$K^*(1715)$ BRANCHING RATIOS

$\Gamma(K\rho)/\Gamma(K^*(892)\pi)$ — Γ_3/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$1.05^{+0.48}_{-0.21}$ OUR FIT Error includes scale factor of 1.6					
$0.97 \pm 0.09^{+0.30}_{-0.10}$	ASTON	87	LASS	0	11 $K^-p \to K^0\pi^+\pi^-n$

$\Gamma(K\pi)/\Gamma(K^*(892)\pi)$ — Γ_1/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$1.30^{+0.35}_{-0.19}$ OUR FIT Error includes scale factor of 1.3					
2.8 ± 1.1	ASTON	84	LASS	0	11 $K^-p \to K^0 2\pi n$

$\Gamma(K\rho)/\Gamma(K\pi)$ — Γ_3/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$0.81^{+0.18}_{-0.12}$ OUR FIT Error includes scale factor of 1.3					
1.2 ± 0.4	ASTON	84	LASS	0	11 $K^-p \to K^0 2\pi n$

$\Gamma(K\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.387 ± 0.025 OUR FIT					
0.388 ± 0.014 ± 0.022	ASTON	88	LASS	0	11 $K^-p \to K^-\pi^+n$

$K^*(1715)$ REFERENCES

ASTON 88 NP B296 493 +Awaji Bienz Bird+ (SLAC NAGO CINC TOKY)
ASTON 87 NP B292 693 +Awaji D Amore+ (SLAC NAGO CINC TOKY)
ASTON 84 PL 149B 258 +Carnegie Dunwoodie+ (SLAC CARL OTTA) JP
ETKIN 80 PR D22 42 +Foley Lindenbaum Kramer+ (BNL CUNY) JP
ESTABROOKS 78 NP B133 490 +Carnegie+ (MONT CARL DURH SLAC) JP

$K_2(1770)$ was $L(1770)$

$I(J^P) = \frac{1}{2}(2^-)$

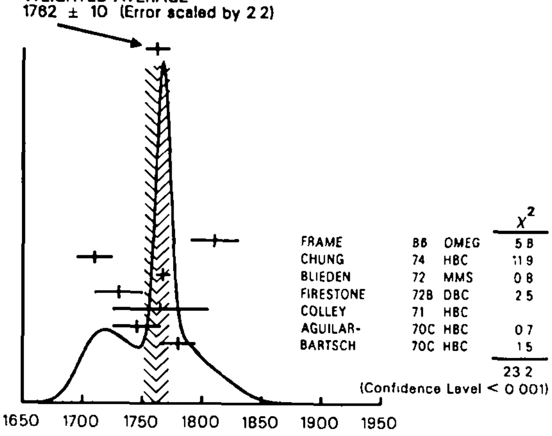
Our latest mini-review on this particle can be found in the 1984 edition

$K_2(1770)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1762 ± 10	**OUR AVERAGE**	Error includes scale factor of 2 2 See the ideogram below				
1810 ± 20		FRAME	86	OMEG	+	13 $K^+p \to \phi K^+p$
1710 ± 15	60	CHUNG	74	HBC	−	7 3 $K^-p \to K^-\omega p$
1767 ± 6		BLIEDEN	72	MMS	−	11–16 K^-p
1730 ± 20	306	[1] FIRESTONE	72B	DBC	+	12 K^+d
1765 0 ± 40 0		[2] COLLEY	71	HBC	+	10 $K^+p \to K2\pi N$
1745 0 ± 20 0		AGUILAR-	70C	HBC	−	4 6 K^-p
1780.0 ± 15 0		BARTSCH	70C	HBC	−	10 1 K^-p
• • • We do not use the following data for averages fits, limits etc • • •						
~1730		ARMSTRONG	83	OMEG	−	18 5 $K^-p \to 3Kp$
~1820		DAUM	81C	CNTR	−	63 $K^-p \to K2\pi p$
1740 0		DENEGRI	71	DBC	−	12 6 $K^-d \to K2\pi d$
1760 0 ± 15 0		LUDLAM	70	HBC	−	12 6 K^-p

[1]Produced in conjunction with excited deuteron
[2]Systematic errors added correspond to spread of different fits

WEIGHTED AVERAGE
1762 ± 10 (Error scaled by 2 2)



$K_2(1770)$ mass (MeV)

$K_2(1770)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
136 ± 18	**OUR AVERAGE**	Error includes scale factor of 1 2				
140 ± 40.		FRAME	86	OMEG	+	13 $K^+p \to \phi K^+p$
110 ± 50	60	CHUNG	74	HBC	−	7 3 $K^-p \to K^-\omega p$
100 ± 26		BLIEDEN	72	MMS	−	11–16 K^-p
210 ± 30	306	[3] FIRESTONE	72B	DBC	+	12 K^+d
90 ± 70		[4] COLLEY	71	HBC	+	10 $K^+p \to K2\pi N$
100 0 ± 50 0		AGUILAR-	70C	HBC	−	4 6 K^-p
138.0 ± 40 0		BARTSCH	70C	HBC	−	10 1 K^-p
• • • We do not use the following data for averages fits limits etc • • •						
~220		ARMSTRONG	83	OMEG	−	18 5 $K^-p \to 3Kp$
~200		DAUM	81C	CNTR	−	63 $K^-p \to K2\pi p$
130 0		DENEGRI	71	DBC	−	12 6 $K^-d \to K2\pi d$
$50\,0^{+40\,0}_{-20.0}$		LUDLAM	70	HBC	−	12 6 K^-p

[3]Produced in conjunction with excited deuteron
[4]Systematic errors added correspond to spread of different fits

$K_2(1770)$ DECAY MODES

Γ_1 $K_2(1770) \to K\pi\pi$
Γ_2 $K_2(1770) \to K_2^*(1430)\pi$
Γ_3 $K_2(1770) \to K^*(892)\pi$
Γ_4 $K_2(1770) \to K\omega$
Γ_5 $K_2(1770) \to Kf_2(1270)$
Γ_6 $K_2(1770) \to K\phi$

$K_2(1770)$ BRANCHING RATIOS

For discussion of the experimental evidence on other decay modes see HUGHES 71 SLATTERY 71 EISNER 74

$\Gamma(K_2^*(1430)\pi)/\Gamma(K\pi\pi)$ Γ_2/Γ_1
$(K_2^*(1430) \to K\pi)$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.2 ± 0.2	AGUILAR-	70C	HBC	−	4 6 K^-p
• • • We do not use the following data for averages fits limits etc • • •					
~0 6	DAUM	81C	CNTR		63 $K^-p \to K2\pi p$
~1 0	[5] FIRESTONE	72B	DBC	+	12 K^+d
<1 0	COLLEY	71	HBC		10 K^+p
<1 0	BARTSCH	70C	HBC	−	10 1 K^-p
1 0	BARBARO-	69	HBC	+	12 0 K^+p

[5]Produced in conjunction with excited deuteron

$\Gamma(K\omega)/\Gamma_{total}$ Γ_4/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
SEEN	OTTER	81	HBC	±	8 25 10 16 $K^\pm p$
SEEN	CHUNG	74	HBC	−	7 3 $K^-p \to K^-\omega p$

$\Gamma(K^*(892)\pi)/\Gamma(K\pi\pi)$ Γ_3/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~0 24	DAUM	81C	CNTR	63 $K^-p \to K2\pi p$

$\Gamma(Kf_2(1270))/\Gamma(K\pi\pi)$ Γ_5/Γ_1
$(f_2(1270) \to \pi\pi)$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
~0 16	DAUM	81C	CNTR	63 $K^-p \to K2\pi p$

$\Gamma(K\phi)/\Gamma_{total}$ Γ_6/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
SEEN	ARMSTRONG	83	OMEG	−	18 5 $K^-p \to K^-\phi N$

$K_2(1770)$ REFERENCES

FRAME	86	NP B276 667	+Hughes Lynch Minto McFadzean+	(GLAS)
ARMSTRONG	83	NP B221 1	+	(BARI BIRM CERN MILA LPNP PAVI)
DAUM	81C	NP B187 1	+Hertzberger+	(AMST CERN CRAC MPIM OXF+)
OTTER	81	NP B181 1		(AACH BERL LOIC VIEN BIRM BELG CERN+)
CHUNG	74	PL 51B 413	+Eisner Protopopescu Samios Strand	(BNL)
EISNER	74	Boston Conf 140		(BNL)
BLIEDEN	72	PL 39B 668	+Finocchiaro Bowen Earles+	(STON NEAS)
FIRESTONE	72B	PR D5 505	+Goldhaber Lissauer Trilling	(LBL)
COLLEY	71	NP B26 71	+Jobes Kenyon Pathak Hughes+	(BIRM GLAS)
DENEGRI	71	NP B28 13	+Antich Callahan Carson Chien Cox+	(JHU) JP
HUGHES	71	Bologna Conf 293		(GLAS)
SLATTERY	71	UR 875 332		(ROCH)
AGUILAR	70C	PRL 25 54	Aguilar Benitez Barnes Bassano Chung+	(BNL)
BARTSCH	70C	PL 33B 186	+Deutschmann+	(AACH BERL CERN LOIC VIEN)
LUDLAM	70	PR D2 1234	+Sandweiss Slaughter	(YALE)
BARBARO	69	PRL 22 1207	Barbaro Galtieri Davis Flatte+	(LRL)

OTHER RELATED PAPERS

OTTER	79	NP B147 1	+Rudolph+	(AACH BERL CERN LOIC WIEN) JP
ANTIPOV	75	NP B86 381	+Ascoli Busnello Kienzle+	(SERP CERN ILL) JP
OTTER	75B	NP B93 365	+Rudolph+	(AACH BERL CERN LOIC VIEN) JP
DEUTSCH	74	PL 49B 388	Deutschmann+	(AACH BERL CERN LOIC VIEN) JP
BARLOUTAUD	73	NP B59 374	+Drevillon Shah+	(SACL EPOL RHEL)
BINGHAM	73	NP B52 31	+Farwell+	(LBL ORSA BNL SACL MILA)
CHARRIERE	73	NP B51 317	+Drijard DeBaere+	(CERN BELG)
ANDERSON	72	PR D6 1823	+Franklin Godden Kopelman Libby Tan	(COLO)
ANDREWS	69	PRL 22 731	+Lach Ludlam Sandweiss Berger+	(YALE LRL)
COLLEY	69	NC 59A 519	+Eastwood+	(BIRM GLAS LOIC MPIM OXF+)
BARTSCH	68B	NP B8 9	+Cocconi+	(AACH BERL CERN LOIC VIEN)
DENEGRI	68	PRL 20 1194	+Callahan Ettlinger Gillespie+	(JHU)
BERLINGHIERI	67	PRL 18 1087	+Farber Ferbel Forman	(ROCH)
CARMONY	67	PRL 18 615	+Hendricks Lander	(UCSD)
JOBES	67	PL 26B 49	+Bassompierre DeBaere+	(BIRM CERN BRUX)
BARTSCH	66	PL 22 357	+Deutschmann+	(AACH BERL CERN+)

$K_3^*(1780)$ was $K^*(1780)$ $I(J^P) = \frac{1}{2}(3^-)$

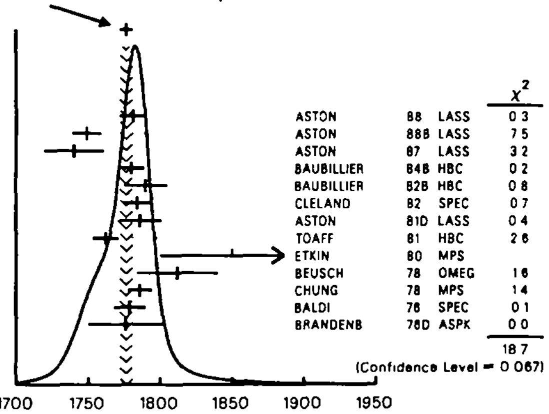
Our latest mini-review on this particle can be found in the 1984 edition

$K_3^*(1780)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
1776 ± 4	OUR AVERAGE	Error includes scale factor of 1 3 See the ideogram below			
1781 ± 8 ± 4		[1] ASTON	88 LASS	0	11 $K^- p \to K^- \pi^+ n$
1749 ± 10		ASTON	88B LASS	−	11 $K^- p \to K^- \eta p$
1740 ± 14 ± 15		[1] ASTON	87 LASS	0	11 $K^- p \to \overline{K}^0 \pi^+ \pi^- n$
1780 0 ± 9 0	300	BAUBILLIER	84B HBC	−	8 25 $K^- p \to \overline{K}^0 \pi^- p$
1790 0 ± 15.0		BAUBILLIER	82B HBC	0	8 25 $K^- p \to \overline{K}{}^0_S 2\pi N$
1784 0 ± 9.0	2060	CLELAND	82 SPEC	±	50 $K^+ p \to K^0_S \pi^\pm p$
1786 ± 15		[2] ASTON	81D LASS	0	11 $K^- p \to K^- \pi^+ n$
1762 0 ± 9 0	190	TOAFF	81 HBC	−	6 5 $K^- p \to \overline{K}^0 \pi^- p$
1850 ± 50		ETKIN	80 MPS	0	6 $K^- p \to \overline{K}^0 \pi^+ \pi^-$
1812 0 ± 28 0		BEUSCH	78 OMEG		10 $K^- p \to K^0 \pi^+ \pi^- n$
1786 0 ± 8 0		CHUNG	78 MPS	0	6 $K^- p \to K^- \pi^+ n$
1779 0 ± 11 0		[3] BALDI	76 SPEC	+	10 $K^+ p \to K^0 \pi^+ p$
1776 ± 26		[4] BRANDENB	76D ASPK	0	13 $K^\pm p \to K^\pm \pi^\mp N$

[1] From energy independent partial-wave analysis
[2] From a fit to the Y_6^0 moment
[3] From a fit to Y_6^2 moment $J^P = 3^-$ found
[4] Confirmed by phase shift analysis of ESTABROOKS 78 yields $J^P = 3^-$

WEIGHTED AVERAGE
1776 ± 4 (Error scaled by 1 3)



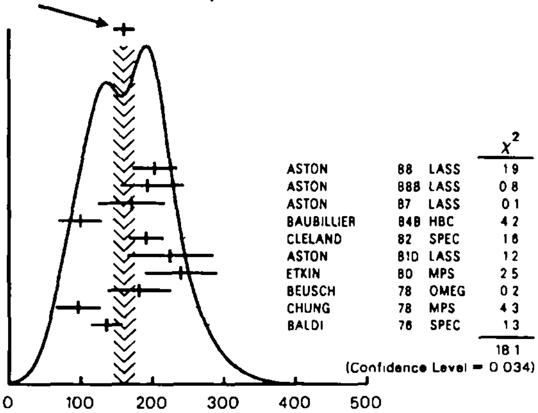
$K_3^*(1780)$ mass (MeV)

$K_3^*(1780)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
160 ± 15	OUR AVERAGE	Error includes scale factor of 1 4 See the ideogram below			
203 ± 30 ± 8		[5] ASTON	88 LASS	0	11 $K^- p \to K^- \pi^+ n$
193 $^{+51}_{-37}$		ASTON	88B LASS	−	11 $K^- p \to K^- \eta p$
171 ± 42 ± 20		[5] ASTON	87 LASS	0	11 $K^- p \to \overline{K}^0 \pi^+ \pi^- n$
99 0 ± 30 0	300	BAUBILLIER	84B HBC	−	8 25 $K^- p \to \overline{K}^0 \pi^- p$
191.0 ± 24.0	2060	CLELAND	82 SPEC	±	50 $K^+ p \to K^0_S \pi^\pm p$
225 ± 60		[6] ASTON	81D LASS	0	11 $K^- p \to K^- \pi^+ n$
240 ± 50		ETKIN	80 MPS	0	6 $K^- p \to \overline{K}^0 \pi^+ \pi^-$
181.0 ± 44 0		[7] BEUSCH	78 OMEG		10 $K^- p \to K^0 \pi^+ \pi^- n$
96.0 ± 31 0		CHUNG	78 MPS	0	6 $K^- p \to K^- \pi^+ n$
135.0 ± 22 0		[8] BALDI	76 SPEC	+	10 $K^+ p \to K^0 \pi^+ p$
• • • We do not use the following data for averages, fits limits, etc • • •					
~130.0		BAUBILLIER	82B HBC	0	8 25 $K^- p \to \overline{K}{}^0_S 2\pi N$
~ 80.	190	TOAFF	81 HBC	−	6 5 $K^- p \to \overline{K}^0 \pi^- p$
270. ± 70.		[9] BRANDENB	76D ASPK	0	13 $K^\pm p \to K^\pm \pi^\mp N$

[5] From energy independent partial-wave analysis
[6] From a fit to Y_6^0 moment
[7] Errors enlarged by us to $4\Gamma/N^{1/2}$ see the note with the $K^*(892)$ mass
[8] From a fit to Y_6^2 moment $J^P = 3^-$ found
[9] ESTABROOKS 78 find that BRANDENBURG 76D data are consistent with 175 MeV width Not averaged

WEIGHTED AVERAGE
160 ± 15 (Error scaled by 1 4)



$K_3^*(1780)$ width (MeV)

$K_3^*(1780)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	$K_3^*(1780) \to K\pi$	$(19.2 {}^{+1\ 0}_{-0\ 9}) \times 10^{-2}$	
Γ_2	$K_3^*(1780) \to K^*(892)\pi$	$(26.6 \pm 3.2) \times 10^{-2}$	1 3
Γ_3	$K_3^*(1780) \to K\rho$	$(44 \pm 4) \times 10^{-2}$	1 3
Γ_4	$K_3^*(1780) \to K_2^*(1430)\pi$		
Γ_5	$K_3^*(1780) \to K\eta$	$(11 {}^{+5}_{-4}) \times 10^{-2}$	1 3

CONSTRAINED FIT INFORMATION

An overall fit to 4 branching ratios uses 5 measurements and one constraint to determine 4 parameters The overall fit has a χ^2 = 1 8 for 2 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i\,\delta x_j\rangle/(\delta x_i\ \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i in this array to sum to one

x_2	−4		
x_3	25	−26	
x_5	6	44	73
	x_1	x_2	x_3

$K_3^*(1780)$ BRANCHING RATIOS

$\Gamma(K\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID	TECN	CHG	COMMENT
$0.192 {}^{+0.010}_{-0.009}$ OUR FIT				
0.188 ± 0.010 OUR AVERAGE				
0.187 ± 0 008 ± 0.008	ASTON	88 LASS	0	11 $K^- p \to K^- \pi^+ n$
0 19 ± 0 02	ESTABROOKS 78	ASPK	0	13 $K^\pm p \to K\pi N$

$\Gamma(K\rho)/\Gamma(K^*(892)\pi)$ Γ_3/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
1.64 ± 0.29 OUR FIT Error includes scale factor of 1 3					
1.52 ± 0.21 ± 0.10	ASTON	87	LASS	0	11 $K^- p \to K^0 \pi^+ \pi^- n$

$\Gamma(K_2^*(1430)\pi)/\Gamma(K^*(892)\pi)$ Γ_4/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.78	95	ASTON	87	LASS	0	11 $K^- p \to K^0 \pi^+ \pi^- n$

$\Gamma(K^*(892)\pi)/\Gamma(K\pi)$ Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
1.38 ± 0.18 OUR FIT Error includes scale factor of 1 3					
1.09 ± 0 26	ASTON	84B	LASS	0	11 $K^- p \to K^0 2\pi n$

$\Gamma(K\eta)/\Gamma(K\pi)$ Γ_5/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.55 ± 0.24 OUR FIT Error includes scale factor of 1 3					
0.50 ± 0.18	ASTON	88B	LASS	−	11 $K^- p \to K^- \eta p$

$K_3^*(1780)$ REFERENCES

ASTON	88	NP B296 493	+Awaji Bienz Bird+	(SLAC NAGO CINC TOKY)
ASTON	88B	PL B201 169	+Awaji Bienz+	(SLAC NAGO CINC TOKY) JP
ASTON	87	NP B292 693	+Awaji D Amore+	(SLAC NAGO CINC TOKY)
ASTON	84B	NP B247 261	+Carnegie Dunwoodie+	(SLAC CARL OTTA)
BAUBILLIER	84B	ZPHY C26 37	+	(BIRM CERN GLAS MICH LPNP)
BAUBILLIER	82B	NP B202 21	+	(BIRM CERN GLAS MSU LPNP)
CLELAND	82	NP B208 189	+Delfosse Dorsaz Gloor	(DURH GEVA LAUS PITT)
ASTON	81D	PL 99B 502	+Dunwoodie Durkin Fieguth+	(SLAC CARL OTTA) JP
TOAFF	81	PR D23 1500	+Musgrave Ammar Davis Ecklund+	(ANL KANS)
ETKIN	80	PR D22 42	+Foley Lindenbaum Kramer+	(BNL CUNY) JP
BEUSCH	78	PL 74B 282	+Birman Konigs Otter+	(CERN AACH ETH) JP
CHUNG	78	PRL 40 355	+Etkin+	(BNL BRAN CUNY MASA PENN) JP
ESTABROOKS	78	NP B133 490	+Carnegie+	(MONT CARL DURH SLAC) JP
Also	78B	PR D17 658	Estabrooks Carnegie+	(MONT CARL DURH+)
BALDI	76	PL 63B 344	+Boehringer Dorsaz Hungerbuhler+	(GEVA) JP
BRANDENB	76D	PL 60B 478	Brandenburg Carnegie Cashmore+	(SLAC) JP

OTHER RELATED PAPERS

CLELAND	80	PL 97B 465	+Dorsaz Martin Nef+	(PITT GEVA LAUS DURH) JP
ENGELEN	80	NP B167 61	+Jongejans Dionisi+	(NIJM AMST CERN OXF) JP
BOWLER	77	NP B126 31	+Dainton Drake Williams	(OXF) JP
GRASSLER	77B	NP B125 189	+Klugow+	(AACH BERL CERN LOIC VIEN)
WALUCH	73	PR D8 2837	+Flatte Friedman	(LBL)
CARMONY	71	PRL 27 1160	+Cords Clopp Erwin Meiere+	(PURD UCD IUPU)
FIRESTONE	71	PL 36B 513	+Goldhaber Lissauer Trilling	(LBL)

$K(1830)$

$I(J^P) = \frac{1}{2}(0^-)$

OMITTED FROM SUMMARY TABLE

Seen in partial-wave analysis of $K^- \phi$ system Needs confirmation

$K(1830)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits etc • • •					
~1830 0	ARMSTRONG	83	OMEG	−	18 5 $K^- p \to 3Kp$

$K(1830)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •					
~250 0	ARMSTRONG	83	OMEG	−	18 5 $K^- p \to 3Kp$

$K(1830)$ DECAY MODES

Γ_1 $K(1830) \to K\phi$

$K(1830)$ REFERENCES

ARMSTRONG	83	NP B221 1	+	(BARI BIRM CERN MILA LPNP PAVI) JP

$K_2^*(1960)$

$I(J^P) = \frac{1}{2}(2^+)$

OMITTED FROM SUMMARY TABLE

$K_2^*(1960)$ MASS

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
1957 ± 17 OUR AVERAGE					
1945 ± 10 ± 20	[1] ASTON	88	LASS	0	11 $K^- p \to K^- \pi^+ n$
1973 ± 8 ± 25	ASTON	87	LASS	0	11 $K^- p \to K^0 \pi^+ \pi^- n$

[1]We take the central value of the two solutions and the larger error given

$K_2^*(1960)$ WIDTH

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
306 ± 80 OUR AVERAGE Error includes scale factor of 1 6					
200 ± 34 ± 79	[2] ASTON	88	LASS	0	11 $K^- p \to K^- \pi^+ n$
373 ± 33 ± 60	ASTON	87	LASS	0	11 $K^- p \to K^0 \pi^+ \pi^- n$

[2]We take the central value of the two solutions and the larger error given

$K_2^*(1960)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$K_2^*(1960) \to K\pi$	$(51 \pm 14) \times 10^{-2}$
Γ_2	$K_2^*(1960) \to K^*(892)\pi$	
Γ_3	$K_2^*(1960) \to K\rho$	

$K_2^*(1960)$ BRANCHING RATIOS

$\Gamma(K\rho)/\Gamma(K^*(892)\pi)$ Γ_3/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
1.49 ± 0.24 ± 0 09	ASTON	87	LASS	0	11 $K^- p \to K^0 \pi^+ \pi^- n$

$\Gamma(K\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.51 ± 0.08 ± 0.12	[3] ASTON	88	LASS	0	11 $K^- p \to K^- \pi^+ n$

[3]We take the central value of the two solutions and the larger error given

$K_2^*(1960)$ REFERENCES

ASTON	88	NP B296 493	+Awaji Bienz Bird+	(SLAC NAGO CINC TOKY)
ASTON	87	NP B292 693	+Awaji D Amore+	(SLAC NAGO CINC TOKY)

$K_4^*(2075)$ was $K^*(2060)$

$I(J^P) = \frac{1}{2}(4^+)$

$K_4^*(2075)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
2074 ± 14 OUR AVERAGE						
2062 ± 14 ± 13		[1] ASTON	86	LASS	0	11 $K^- p \to K^- \pi^+ n$
2088. ± 20	650	BAUBILLIER	82	HBC	−	8 25 $K^- p \to K_S^0 \pi^- p$
• • • We do not use the following data for averages fits limits etc • • •						
2079 ± 7	431	TORRES	86	MPSF		400 $pA \to 4K X$
2039 ± 10	400	[2,3] CLELAND	82	SPEC	±	50 $K^+ p \to K_S^0 \pi^\pm p$
2115 ± 46	488	CARMONY	77	HBC	0	9 $K^+ d \to K^+ \pi s X$

[1]From a fit to all moments
[2]From a fit to 8 moments
[3]Number of events evaluated by us

Meson Full Listings
$K_4^*(2075)$, $K_2(2250)$, $K_3(2320)$

$K_4^*(2075)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
204^{+50}_{-40} OUR AVERAGE						
221 ± 48 ± 27		[4] ASTON	86	LASS	0	11 $K^- p \to K^- \pi^+ n$
170^{+100}_{-50}	650	BAUBILLIER	82	HBC	−	8.25 $K^- p \to \overline{K}{}^0 \pi^- p$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
61 ± 58	431	TORRES	86	MPSF		400 $pA \to 4K X$
189 ± 35	400	[5,6] CLELAND	82	SPEC	±	50 $K^+ p \to K^0_S \pi^\pm p$
300 ± 200		CARMONY	77	HBC	0	9 $K^+ d \to K^+ \pi$'s X

[4]From a fit to all moments
[5]From a fit to 8 moments
[6]Number of events evaluated by us

$K_4^*(2075)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$K_4^*(2075) \to K\pi$	$(9.9 \pm 1.2) \times 10^{-2}$
Γ_2	$K_4^*(2075) \to K^*(892)\pi\pi$	$(9 \pm 5) \times 10^{-2}$
Γ_3	$K_4^*(2075) \to \rho K\pi$	$(5.7 \pm 3.2) \times 10^{-2}$
Γ_4	$K_4^*(2075) \to \omega K\pi$	$(4.9 \pm 3.0) \times 10^{-2}$
Γ_5	$K_4^*(2075) \to K^*(892)\pi\pi\pi$	$(7 \pm 5) \times 10^{-2}$
Γ_6	$K_4^*(2075) \to \phi K\pi$	$(2.8 \pm 1.4) \times 10^{-2}$
Γ_7	$K_4^*(2075) \to \phi K^*(892)$	$(1.4 \pm 0.7) \times 10^{-2}$

$K_4^*(2075)$ BRANCHING RATIOS

$\Gamma(K\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.099 ± 0.012	ASTON	88	LASS	0	11 $K^- p \to K^- \pi^+ n$

$\Gamma(K^*(892)\pi\pi)/\Gamma(K\pi)$ — Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.89 ± 0.53	BAUBILLIER	82	HBC	−	8.25 $K^- p \to p K^0_S 3\pi$

$\Gamma(\rho K\pi)/\Gamma(K\pi)$ — Γ_3/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.58 ± 0.32	BAUBILLIER	82	HBC	−	8.25 $K^- p \to p K^0_S 3\pi$

$\Gamma(\omega K\pi)/\Gamma(K\pi)$ — Γ_4/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.50 ± 0.30	BAUBILLIER	82	HBC	−	8.25 $K^- p \to p K^0_S 3\pi$

$\Gamma(K^*(892)\pi\pi\pi)/\Gamma(K\pi)$ — Γ_5/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.75 ± 0.49	BAUBILLIER	82	HBC	−	8.25 $K^- p \to p K^0_S 3\pi$

$\Gamma(\phi K\pi)/\Gamma_{total}$ — Γ_6/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.028 ± 0.014	[7] TORRES	86	MPSF	400 $pA \to 4K X$

[7]Error determination is model dependent

$\Gamma(\phi K^*(892))/\Gamma_{total}$ — Γ_7/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.014 ± 0.007	[8] TORRES	86	MPSF	400 $pA \to 4K X$

[8]Error determination is model dependent

$K_4^*(2075)$ REFERENCES

ASTON 88 NP B296 493 +Awaji, Bienz, Bird+ (SLAC, NAGO, CINC, TOKY)
ASTON 86 PL B180 308 +Awaji, D'Amore+ (SLAC, NAGO, CINC, TOKY)
TORRES 86 PR 34 707 +Lai+ (VPI, ARIZ, FNAL, FSU, NDAM, TUFT+)
BAUBILLIER 82 PL 118B 447 +Burns+ (BIRM, CERN, GLAS, MSU, LPNP)
CLELAND 82 NP B208 189 +Delfosse, Dorsaz, Gloor (DURH, GEVA, LAUS, PITT)
CARMONY 77 PR D16 1251 +Clopp, Lander, Meiere, Yen+ (PURD, UCD, IUPU)

— OTHER RELATED PAPERS —

ASTON 87 NP B292 693 +Awaji, D'Amore+ (SLAC, NAGO, CINC, TOKY)
BROMBERG 80 PR D22 1513 +Haggerty, Abrams, Dzierba (CIT, FNAL, ILLC, IND)
CLELAND 80 PL 97B 465 +Dorsaz, Martin, Nef+ (PITT, GEVA, LAUS, DURH) JP
CARMONY 71 PRL 27 1160 +Cords, Clopp, Erwin, Meiere+ (PURD, UCD, IUPU)

$K_2(2250)$ was $K(2250)$

$I(J^P) = \frac{1}{2}(2^-)$

OMITTED FROM SUMMARY TABLE

This entry contains various peaks in strange meson systems reported in the 2100–2300 MeV region, as well as enhancements seen in the antihyperon-nucleon system, either in the mass spectra or in the $J^P = 2^-$ wave.

$K_2(2250)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
2247 ± 17 OUR AVERAGE						
2200.0 ± 40.0		[1] ARMSTRONG	83C	OMEG	−	18 $K^- p \to \Lambda\overline{p} X$
2235. ± 50		[1] BAUBILLIER	81	HBC	−	8 $K^- p \to \Lambda\overline{p} X$
2260 ± 20		[1] CLELAND	81	SPEC	±	50 $K^+ p \to \Lambda\overline{p} X$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
2147 ± 4	37	CHLIAPNIK	79	HBC	+	32 $K^+ p \to \Lambda\overline{p} X$
2240 ± 20	20	LISSAUER	70	HBC		9 $K^+ p$

[1]$J^P = 2^-$ from moments analysis

$K_2(2250)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
180 ± 30 OUR AVERAGE Error includes scale factor of 1.4						
150.0 ± 30.0		[2] ARMSTRONG	83C	OMEG	−	18 $K^- p \to \Lambda\overline{p} X$
210 ± 30		[2] CLELAND	81	SPEC	±	50 $K^+ p \to \Lambda\overline{p} X$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
~200		[2] BAUBILLIER	81	HBC	−	8 $K^- p \to \Lambda\overline{p} X$
~ 40	37	CHLIAPNIK	79	HBC	+	32 $K^+ p \to \Lambda\overline{p} X$
80 ± 20	20	LISSAUER	70	HBC		9 $K^+ p$

[2]$J^P = 2^-$ from moments analysis

$K_2(2250)$ DECAY MODES

	Mode
Γ_1	$K_2(2250) \to K\pi\pi$
Γ_2	$K_2(2250) \to \Lambda\overline{p}$

$K_2(2250)$ REFERENCES

ARMSTRONG 83C NP B227 365 + (BARI, BIRM, CERN, MILA, LPNP, PAVI)
BAUBILLIER 81 NP B183 1 + (BIRM, CERN, GLAS, MSU, LPNP) JP
CLELAND 81 NP B184 1 +Nef, Martin+ (PITT, GEVA, LAUS, DURH) JP
CHLIAPNIK 79 NP B158 253 Chliapnikov, Gerdyukov+ (CERN, BELG, MONS)
LISSAUER 70 NP B18 491 +Alexander, Firestone, Goldhaber (LBL)

— OTHER RELATED PAPERS —

ALEXANDER 68B PRL 20 755 +Firestone, Goldhaber, Shen (LRL)

$K_3(2320)$ was $K(2320)$

$I(J^P) = \frac{1}{2}(3^+)$

OMITTED FROM SUMMARY TABLE

This entry contains enhancements seen in the $J^P = 3^+$ wave of the antihyperon-nucleon system.

$K_3(2320)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2324 ± 24 OUR AVERAGE					
2330.0 ± 40.0	[1] ARMSTRONG	83C	OMEG	−	18 $K^- p \to \Lambda\overline{p} X$
2320.0 ± 30.0	[1] CLELAND	81	SPEC	±	50 $K^+ p \to \Lambda\overline{p} X$

[1]$J^P = 3^+$ from moments analysis

$K_3(2320)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
150.0 ± 30.0	[2] ARMSTRONG	83C	OMEG	−	18 $K^- p \to \Lambda \bar{p} X$
• • • We do not use the following data for averages fits limits etc • • •					
~250 0	[2] CLELAND	81	SPEC	±	50 $K^+ p \to \Lambda \bar{p} X$

[2] $J^P = 3^+$ from moments analysis

$K_3(2320)$ DECAY MODES

Γ_1 $K_3(2320) \to \Lambda \bar{p}$

$K_3(2320)$ REFERENCES

ARMSTRONG 83C NP B227 365 + (BARI BIRM CERN MILA LPNP PAVI)
CLELAND 81 NP B184 1 +Nef Martin+ (PITT GEVA LAUS DURH)

$K_5^*(2380)$

$I(J^P) = \frac{1}{2}(5^-)$

OMITTED FROM SUMMARY TABLE

Seen in moment analysis of the $K^- \pi^+$ system Needs confirmation

$K_5^*(2380)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2382. ± 14 ± 19	[1] ASTON	86	LASS	0	11 $K^- p \to K^- \pi^+ n$

[1] From a fit to all the moments

$K_5^*(2380)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
178. ± 37 ± 32	[2] ASTON	86	LASS	0	11 $K^- p \to K^- \pi^+ n$

[2] From a fit to all the moments

$K_5^*(2380)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$K_5^*(2380) \to K\pi$	$(6\ 1 \pm 1\ 2) \times 10^{-2}$

$K_5^*(2380)$ BRANCHING RATIOS

$\Gamma(K\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.061 ± 0.012	ASTON	88	LASS	0	11 $K^- p \to K^- \pi^+ n$

$K_5^*(2380)$ REFERENCES

ASTON 88 NP B296 493 +Awaji Bienz Bird+ (SLAC NAGO CINC TOKY)
ASTON 86 PL B180 308 +Awaji D Amore+ (SLAC NAGO CINC TOKY)

$K_4(2500)$ was $K(2500)$

$I(J^P) = \frac{1}{2}(4^-)$

OMITTED FROM SUMMARY TABLE

This entry contains enhancements seen in the $J^P = 4^-$ wave of the antihyperon-nucleon system

$K_4(2500)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2490.0 ± 20.0	[1] CLELAND	81	SPEC	±	50 $K^+ p \to \Lambda p$

[1] $J^P = 4^-$ from moments analysis

$K_4(2500)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •					
~250 0	[2] CLELAND	81	SPEC	±	50 $K^+ p \to \Lambda \bar{p}$

[2] $J^P = 4^-$ from moments analysis

$K_4(2500)$ DECAY MODES

Γ_1 $K_4(2500) \to \Lambda \bar{p}$

$K_4(2500)$ REFERENCES

CLELAND 81 NP B184 1 +Nef Martin+ (PITT GEVA LAUS DURH)

CHARMED MESONS ($C = \pm 1$, $B = 0$)

$D^\pm$

$I(J^P) = \frac{1}{2}(0^-)$

SEE STABLE PARTICLES

D^0

$I(J^P) = \frac{1}{2}(0^-)$

SEE STABLE PARTICLES

$D^*(2010)^\pm$

$I(J^P) = \frac{1}{2}(1^-)$

$D^*(2010)^\pm$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2010.1 ± 0.6 OUR EVALUATION	From D^0 mass and mass difference below				
• • • We do not use the following data for averages fits limits etc • • •					
2008 ± 3	[1] GOLDHABER	77	MRK1	±	$e^+ e^-$
2008 6 ± 1 0	[2] PERUZZI	77	MRK1	±	$e^+ e^-$

[1] From simultaneous fit to $D^*(2010)^+$ $D^*(2010)^0$ D^+ and D^0 not independent of FELDMAN 77B mass difference below

[2] PERUZZI 77 mass not independent of FELDMAN 77B mass difference below and PERUZZI 77 D^0 mass value

$D^*(2010)^+ - D^0$ MASS DIFFERENCE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
145.45 ± 0.07 OUR AVERAGE					
145 46 ± 0 07 ± 0 03		ALBRECHT	85F	ARG	$D^{*\pm} \to D^0 \pi^+$
145 8 ± 1 5	16	AHLEN	83	HRS	$D^{*+} \to D^0 \pi^+$
145 1 ± 1 8	12	BAILEY	83	SPEC	$D^{*\pm} \to D^0 \pi^\pm$
145 5 ± 0 3	28	BAILEY	83	SPEC	$D^{*\pm} \to D^0 \pi^\pm$
145 1 ± 0 5	14	BAILEY	83	SPEC	$D^{*\pm} \to D^0 \pi^\pm$
145 5 ± 0.5	14	YELTON	82	MRK2	29 $e^+ e^- \to K^- \pi^+$
145 5 ± 0 3	60	FITCH	81	SPEC	π^- A
145 2 ± 0 6	2	BLIETSCHAU	79	BEBC	νp
145 3 ± 0 5	30	FELDMAN	77B	MRK1	$D^{*+} \to D^0 \pi^+$
• • • We do not use the following data for averages fits limits etc • • •					
~145 5		AVERY	80	SPEC	γ A

$D^*(2010)^+ - D^*(2010)^0$ MASS DIFFERENCE

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
2.9 ± 1.3 OUR EVALUATION	From D^{*+} D^0 and D^{*0} D^0 mass differences				
• • • We do not use the following data for averages, fits, limits, etc • • •					
2 6 ± 1 8	[3] PERUZZI	77	MRK1	±	e^+e^-

[3] Not independent of FELDMAN 77B mass difference above PERUZZI 77 D^0 mass and GOLDHABER 77 $D^*(2010)^0$ mass

$D^*(2010)^{\pm}$ WIDTH

VALUE (MeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<2.0	90	30	FELDMAN	77B	MRK1	$D^{*+} \to D^0\pi^+$
• • • We do not use the following data for averages, fits, limits, etc • • •						
<2 2			YELTON	82	MRK2	$e^+e^- \to K^-\pi^+\pi^-$

$D^*(2010)^{\pm}$ DECAY MODES

$D^*(2010)^-$ modes are charge conjugates of the modes below

	Mode	Fraction (Γ_i/Γ)
Γ_1	$D^*(2010)^+ \to D^0\pi^+$	$(49 \pm 8) \times 10^{-2}$
Γ_2	$D^*(2010)^+ \to D^+\gamma$	$(17 {}^{+11}_{-9}) \times 10^{-2}$
Γ_3	$D^*(2010)^+ \to D^+\pi^0$	$(34 \pm 7) \times 10^{-2}$

CONSTRAINED FIT INFORMATION

An overall fit to 2 branching ratios uses 3 measurements and one constraint to determine 3 parameters The overall fit has a $\chi^2 = 0\,8$ for 1 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i\,\delta x_j\rangle/(\delta x_i\cdot\delta x_j)$, in percent, from the fit to the branching fractions, $x_i = \Gamma_i/\Gamma_{total}$ The fit constrains the x_i in this array to sum to one

x_2	−77	
x_3	0	−64
	x_1	x_2

$D^*(2010)^{\pm}$ BRANCHING RATIOS

$\Gamma(D^0\pi^+)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.49 ± 0.08 OUR FIT					
0.49 ± 0.08 OUR AVERAGE					
0 44 ± 0 10	COLES	82	MRK2		e^+e^-
0 6 ± 0 15	[4] GOLDHABER	77	MRK1	+	e^+e^-

[4] Assuming that isospin is conserved in the decay

$\Gamma(D^+\gamma)/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.17 ± 0.11 OUR FIT				
• • • We do not use the following data for averages, fits, limits, etc • • •				
0 22 ± 0 12	[5] COLES	82	MRK2	e^+e^-

[5] Not independent of $\Gamma(D^0\pi^+)/\Gamma_{total}$ and $\Gamma(D^+\pi^0)/\Gamma_{total}$ measurement

$\Gamma(D^+\pi^0)/\Gamma_{total}$ Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.34 ± 0.07 OUR FIT				
0.34 ± 0.07	COLES	82	MRK2	e^+e^-

$D^*(2010)^{\pm}$ REFERENCES

ALBRECHT	85F	PL 150B 235	+	(ARGUS Collab)
AHLEN	83	PRL 51 1147	+Akerlof+	(ANL IND LBL MICH PURD SLAC)
BAILEY	83	PL 132B 230	+Bardsley+	(AMST BRIS CERN CRAC MPIM+)
COLES	82	PR D26 2190	+Abrams Blocker Blondel+	(LBL SLAC)
YELTON	82	PRL 49 430	+Feldman Goldhaber+	(SLAC LBL UCB HARV)
FITCH	81	PRL 46 761	+Devaux Cavaglia May+	(PRIN SACL TORI BNL)
AVERY	80	PRL 44 1309	+Wiss Butler Gladding+	(ILL FNAL COLU)
BLIETSCHAU	79	PL 86B 108	+	(AACH BONN CERN MPIM OXF)
FELDMAN	77B	PRL 38 1313	+Peruzzi Piccolo Abrams Alam+	(SLAC LBL)
GOLDHABER	77	PL 69B 503	+Wiss Abrams Alam+	(LBL SLAC)
PERUZZI	77	PRL 39 1301	+Piccolo Feldman+	(SLAC LBL NWES HAWA)

— OTHER RELATED PAPERS —

ALTHOFF	83C	PL 126B 493	+Fischer Burkhardt+	(TASSO Collab)
BEBEK	82	PRL 49 610	+	(HARV OSU ROCH RUTG SYRA VAND+)
TRILLING	81	PRPL 75 57		(LBL UCB)
PERUZZI	76	PRL 37 569	+Piccolo Feldman Nguyen Wiss+	(SLAC LBL)

$D^*(2010)^0$

$I(J^P) = \frac{1}{2}(1^-)$

J consistent with 1, value 0 ruled out (NGUYEN 77)

$D^*(2010)^0$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2007.1 ± 1.4 OUR EVALUATION	From D^0 mass and mass difference below			
• • • We do not use the following data for averages, fits, limits, etc • • •				
2006 ± 1 5	[1] GOLDHABER	77	MRK1	e^+e^-

[1] From simultaneous fit to $D^*(2010)^+$ $D^*(2010)^0$ D^+ and D^0

$D^*(2010)^0 - D^0$ MASS DIFFERENCE

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
142.5 ± 1.3 OUR AVERAGE					
142 2 ± 2.0	SADROZINSKI	80	CBAL	0	$D^{*0} \to D^0\pi^0$
142 7 ± 1 7	[2] GOLDHABER	77	MRK1	0	e^+e^-

[2] From simultaneous fit to $D^*(2010)^+$ $D^*(2010)^0$ D^+ and D^0

$D^*(2010)^0$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
<5.	GOLDHABER	76B	MRK1	$e^+e^- \to D^*D^*$

$D^*(2010)^0$ DECAY MODES

$\bar{D}^*(2010)^0$ modes are charge conjugates of modes below

	Mode
Γ_1	$D^*(2010)^0 \to D^0\pi^0$
Γ_2	$D^*(2010)^0 \to D^0\gamma$

$D^*(2010)^0$ BRANCHING RATIOS

$\Gamma(D^0\gamma)/[\Gamma(D^0\pi^0) + \Gamma(D^0\gamma)]$ $\Gamma_2/(\Gamma_1+\Gamma_2)$

VALUE	DOCUMENT ID		TECN	COMMENT
0.48 ± 0.07 OUR AVERAGE				
0 47 ± 0 23	LOW	87	HRS	29 GeV e^+e^-
0 53 ± 0 13	BARTEL	85G	JADE	e^+e^- hadrons
0 47 ± 0 12	COLES	82	MRK2	e^+e^-
0 45 ± 0 15	[3] GOLDHABER	77	MRK1	e^+e^-

[3] We quote the normal fit value from table 1 The isospin-constrained fit is now known to give a $D^0\gamma$ fraction which is too large See details in footnote 21 of FELDMAN 77C review

$D^*(2010)^0$ REFERENCES

LOW	87	PL B183 232	+Abachi Akerlof Baringer+	(HRS Collab)
BARTEL	85G	PL 161B 197	+Dietrich Ambrus+	(JADE Collab)
COLES	82	PR D26 2190	+Abrams Blocker Blondel+	(LBL SLAC)
SADROZINSKI	80	Madison Conf 681	+	(PRIN CIT HARV SLAC STAN)
FELDMAN	77C	Banff Sum Inst 75		(SLAC)
GOLDHABER	77	PL 69B 503	+Wiss Abrams Alam+	(LBL SLAC)
NGUYEN	77	PRL 39 262	+Wiss Abrams Alam Boyarski+	(LBL SLAC) J
GOLDHABER	76B	SLAC Conf 379		(LBL SLAC)
		Available as LBL 5534		

— OTHER RELATED PAPERS —

TRILLING	81	PRPL 75 57		(LBL UCB)
FELDMAN	77C	Banff Sum Inst 75		(SLAC)
GOLDHABER	76	PRL 37 255	+Pierre Abrams Alam+	(LBL SLAC)

$D_J(2420)^0$

$I(J^P) = \frac{1}{2}(?^?)$

Seen in $D^*(2010)^+\pi^-$. $J^P = 0^+$ ruled out

$D_J(2420)^0$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2422 ± 4 OUR AVERAGE				
2424 ± 6	BEBEK	87B	CLEO	$e^+e^- \rightarrow D^{*+}\pi^- X$
2421 ± 5	[1] PRENTICE	87	ARG	$e^+e^- \rightarrow D^{*+}\pi^- X$

[1] Includes data of ALBRECHT 86E

$D_J(2420)^0$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
60^{+13}_{-11} **OUR AVERAGE**				
53^{+30}_{-20}	BEBEK	87B	CLEO	$e^+e^- \rightarrow D^{*+}\pi^- X$
62 ± 14	[2] PRENTICE	87	ARG	$e^+e^- \rightarrow D^{*+}\pi^- X$

[2] Includes data of ALBRECHT 86E

$D_J(2420)^0$ DECAY MODES

Γ_1 $D_J(2420)^0 \rightarrow D^*(2010)^+\pi^-$

$D_J(2420)^0$ BRANCHING RATIOS

$\Gamma(D^*(2010)^+\pi^-)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
SEEN	BEBEK	87B	CLEO	$e^+e^- \rightarrow D^{*+}\pi^- X$
SEEN	ALBRECHT	86E	ARG	$e^+e^- \rightarrow D^{*+}\pi^- X$

$D_J(2420)^0$ REFERENCES

BEBEK 87B Uppsala Conf prep + (CLEO Collab)
Quoted in PRENTICE 87
PRENTICE 87 Uppsala Conf p 910 + (ARGUS Collab)
ALBRECHT 86E PRL 56 549 +Binder Harder+ (ARGUS Collab)

$D_s^{\pm}$ was $F^{\pm}$

$I(J^P) = 0(0^-)$

SEE STABLE PARTICLES

D_s^* was F^*

$I(J^P) = ?(?^?)$

SEE STABLE PARTICLES

BOTTOM MESONS ($B = \pm 1$)

$B^{\pm}$

$I(J^P) = \frac{1}{2}(0^-)$

SEE STABLE PARTICLES

B^0

$I(J^P) = \frac{1}{2}(0^-)$

SEE STABLE PARTICLES

B^*

$I(J^P) = ?(?^?)$

SEE STABLE PARTICLES
OMITTED FROM SUMMARY TABLE

NON-$q\bar{q}$ CANDIDATES

We include here mini-reviews and reference lists on non-$q\bar{q}$ candidates. These are divided into two subsections:
1) Gluonium candidates, and
2) Other non-$q\bar{q}$ candidates: $q\bar{q}q\bar{q}$ and $q\bar{q}g$ hybrids.
See also $N\bar{N}(1100-3600)$ for possible bound states.

NOTE ON NON-$q\bar{q}$ MESONS

The existence of a gluon self coupling in QCD suggests that in addition to the conventional $q\bar{q}$ meson states, there may be bound states including gluons: gluonia or glueballs and hybrids ($q\bar{q}g$). Another example of non-$q\bar{q}$ mesons could be multiquark states. For detailed reviews see, e.g., CLOSE 87, COOPER 86, MESHKOV 86, HEUSCH 86.

The theoretical guidance on the properties of unusual states is often contradictory, and models which agree in the $q\bar{q}$ sector often differ in their predictions about new states. Among the naively expected signatures for gluonium are:

(i) no place in $q\bar{q}$ nonets
(ii) flavor-singlet couplings
(iii) enhanced production in gluon-rich channels such as J/ψ decay
(iv) reduced $\gamma\gamma$ coupling
(v) exotic quantum numbers not allowed for $q\bar{q}$ (in some cases)

Meson Full Listings
NON $-q\bar{q}$ CANDIDATES

However, it must be pointed out that mixing effects and other dynamical effects will obscure these simple signatures. If the mixing is large, only counting the number of observed states remains a clear signal for non-exotic non-$q\bar{q}$ states. Exotic quantum number states $(0^{--}, 0^{+-}, 1^{-+}, 2^{+-})$ would be the best signatures for non-$q\bar{q}$ states.

Points (iii) and (iv) can be summarized by the Chanowitz S parameter (CHANOWITZ 85)

$$S = \frac{\Gamma(J/\psi \to \gamma X)}{PS(J/\psi \to \gamma X)} \times \frac{PS(\gamma\gamma \to X)}{\Gamma(\gamma\gamma \to X)}$$

where PS stands for phase space. S is expected to be larger for gluonium than for $q\bar{q}$ states.

It should be emphasized that no state has unambiguously been identified as gluonium or as a hybrid. The candidates which we discuss below are chosen because their interpretation as conventional quark-model $q\bar{q}$ states may have difficulties. Higher radial excitations of $q\bar{q}$ or multiquark states, or mixtures of these, cannot be excluded since in general there is enough freedom to fit the data.

The scalar meson sector. The established isoscalars with $J^{PC} = 0^{++}$ are the $f_0(975)$, the $f_0(1400)$, and the $f_0(1590)$. In the quark model one expects two 1^3P_0 states and two 2^3P_0 states in the 1–2 GeV region. Thus, by simple state counting, all well-established scalars can easily find a place in the quark model, and one must invoke dynamical arguments or believe in nonestablished states to claim the existence of non-$q\bar{q}$ resonances.

In an analysis using a K-matrix coupled-channel formalism including the $\pi\pi$ and $K\bar{K}$ channels (AU 84, 87), three resonance poles are claimed in the 1 GeV mass region $[f_0(975)]$. In this analysis the ISR data (AKESSON 86) on pion production in the central region are very important. The analysis lacks, however, the $\eta\eta$, $\eta\eta'$, and $\eta'\eta'$ thresholds. In particular, since the ISR data show a dip just before the $\eta\eta$ threshold, the analysis leaves room for doubt. More data are needed on $K\bar{K}$ and $\eta\eta$ in the 1 GeV region to reach a firmer conclusion.

The $f_0(1400)$ is seen in $\pi\pi$ phase-shift analyses and is conventionally interpreted as a quark-model $(u\bar{u}+d\bar{d})$ state. However, a large gluonium mixing is not excluded because the $\eta\eta/\pi\pi$ branching ratio is only half of the flavor-symmetry prediction (ALDE 86D).

The $f_0(1590)$ seen in $\pi^- p$ reactions at 38 GeV/c (BINON 83, BINON 84C, ALDE 87, ALDE 87B) has a peculiar decay pattern for a $q\bar{q}$ state:

$$\pi^0\pi^0 : K\bar{K} : \eta\eta : \eta\eta' : 4\pi^0 = <0.3 : <1 : 1 : 3 : 0.8$$

GERSHTEIN 84 claim that this could favor the gluonium interpretation. It could possibly be a 4-quark state $(u\bar{u} + d\bar{d})s\bar{s}$, although this interpretation is slightly disfavored by the branching ratio $K\bar{K}/\eta\eta$, which should be 2.

The pseudoscalar meson sector. The established isoscalars with $J^{PC} = 0^{-+}$ are the η, $\eta'(958)$, $\eta(1280)$, and $\eta(1430)$ (see, however, the $\eta(1430)$ minireview). In the $q\bar{q}$ model we expect two 1^1S_0 and two 2^1S_0 pseudoscalars in the 0.5–1.5 GeV mass range.

Whereas the assignment of the $\eta(1280)$ to the 2^1S_0 $(u\bar{u}+d\bar{d})$ state is natural, it is more problematic to assign the $\eta(1430)$ to the 2^1S_0 $s\bar{s}$ state. The $\eta(1430)$ is observed in $s\bar{s}$-depleted reactions like $\pi^- p \to \eta\pi\pi n$ (ANDO 86) and $\pi^- p \to a_0(980)\pi p$ (CHUNG 85) and is not seen in the $s\bar{s}$-enriched channels like $K^- p \to K^*(892)K\Lambda$ (ASTON 87). Moreover, its S parameter is large compared to related $q\bar{q}$ states:

$$S[\eta] : S[\eta'] : S[\eta(1430)] = 1 : 4 : >45$$

One may understand the small $\gamma\gamma$ coupling and therefore the large S parameter within a $q\bar{q}$ model if the quark structure is $(u\bar{u} + d\bar{d} - 5s\bar{s})$, which also decouples from $\gamma\gamma$. The fact that ANDO 86 see the $\eta(1430)$ and the $\eta(1280)$ with similar intensities speaks in favor of these states being of similar nature, i.e., radial excitations of η and η'. There may even be several resonances in the $\eta(1430)$ structure. The experimental situation thus remains confused and the possible gluonium nature of $\eta(1430)$ is far from well established.

The tensor meson sector. The two 1^3P_2 $q\bar{q}$ states are very likely the two well-known states $f_2(1270)$ and $f_2'(1525)$. Four more $J^{PC} = 2^{++}$ states have to be considered: the $f_2(1720)$, $f_2(2010)$, $f_2(2300)$, and $f_2(2340)$. The $q\bar{q}$ quark model predicts indeed four states in the 1.5–2.5 GeV mass range (two 2^3P_2 and two 1^3F_2). However, this numerical agreement may be fortuitous since all four resonances have very peculiar properties.

The $f_2(1720)$ has been seen mainly in the "gluon-rich" J/ψ radiative decays, where it is copiously produced.

It has not been seen in hadronic production ($K^- p \to K\bar{K}\Lambda$) (LONGACRE 86, ASTON 88C) or in $\gamma\gamma \to f_2(1720)$. It is produced in J/ψ radiative decays with very different helicity couplings than the $q\bar{q}$ tensor mesons $f_2(1270)$ and $f_2'(1525)$. The ratio of the branching fractions indicate a sizeable $s\bar{s}$ component. However, its mass is too close to the $s\bar{s}$ $f_2'(1525)$ to be the radially excited $s\bar{s}$ state, nor is it compatible with an SU(3) singlet, although its S parameter favors a large gluonium component:

$$S[f_2(1270)] : S[f_2'(1525)] : S[f_2(1720)] = 1 : 3 : >20$$

For recent reviews on the $f_2(1720)$, see COOPER 86, MALLIK 87.

The three f_2 resonances between 2 and 2.4 GeV have been observed in an OZI-rule-forbidden process $\pi p \to \phi\phi n$ (ETKIN 88). The OZI suppression has been used as a strong argument for favoring a gluonium interpretation of these states. The argument is, however, not fully compelling since broad resonances, by unitarity, are expected to mix substantially and therefore the OZI rule may not apply. Moreover, one of these resonances, the one closest to the $\phi\phi$ threshold, could possibly be interpreted as a $\phi\phi$ molecule (mesonium) candidate. The DM2 and MARK-III collaborations see threshold $\phi\phi$ production but preliminary indications are that it occurs in the $J^P = 0$ partial wave.

Other exotic candidates. A $\phi\pi^0$ resonance has been reported in $\pi^- p \rightarrow \phi\pi^0 n$ [see $\rho(1450)$]. Preliminary indications favor $J^{PC} = 1^{--}$, i.e., non-exotic, but the branching ratio $\phi\pi/\omega\pi$ seems peculiar for a $(u\bar{u} - d\bar{d})$ $I = 1$ $q\bar{q}$ object. A $qq\bar{q}\bar{q}$ interpretation comes to mind.

A narrow resonance at 3100 MeV has been reported in $\Lambda p\pi^+\pi^+$, $\Lambda p\pi^+\pi^+\pi^-$, and $\Lambda p\pi^-\pi^-$ (BOURQUIN 86). The three different charge states would require a $I = 3/2$ classification, clearly outside the $q\bar{q}$ system; however these observations need confirmation.

GLUONIUM CANDIDATES

OMITTED FROM SUMMARY TABLE

GLUONIUM CANDIDATES REFERENCES

OTHER RELATED PAPERS

ALDE 87 PL B198 286 +Binon Bricman+ (LANL BRUX SERP LAPP)
ALDE 87B CERN EP/87 197 +Bellazzini Binon+ (LANL BRUX SERP LAPP)
AU 87 PR D35 1633 +Morgan Pennington (DURH RAL)
CLOSE 87 RAL 87 072 (RHEL)
GIDAL 87 PRL 59 2012 +Boyer Butler Cords Abrams+ (LBL SLAC HARV)
GIDAL 87B PRL 59 2016 +Boyer Butler Cords Abrams+ (LBL SLAC HARV)
MALLIK 87 SLAC PUB 4238 (MARK III Collab.)
PARTRIDGE 87 Moriond XXII Conf Patridge (SLAC)
SINHA 87 PR D35 952 +Okubo Tuan (ROCH HAWA)
AIHARA 86B PRL 57 404 +Alston Garnjost+ (TPC Two Gamma Collab.)
AIHARA 86C PRL 57 2500 +Alston Garnjost+ (TPC Two Gamma Collab.)
AIHARA 86D PRL 57 51 +Alston Garnjost+ (TPC Two Gamma Collab.)
AKESSON 86 NP B264 154 +Albrow Almehed+ (Axial Field Spec Collab.)
ALDE 86B PL B177 120 +Binon Bricman+ (SERP BELG LANL LAPP)
ALDE 86C PL B182 105 +Binon Bricman+ (SERP BELG LANL LAPP)
ALDE 86D NP B269 485 +Binon Bricman+ (BELG LAPP SERP CERN)
ANDO 86 PRL 57 1296 +Imai+ (KEK KYOT NIRS SAGA TOKY TSUK+)
ARMSTRONG 86D Berkeley Conf 7870 (CERN)
BISELLO 86B PL B179 294 +Busetto Castro Limentani+ (DM2 Collab.)
BRAMON 86B ZPHY C32 467 +Casulleras (BARC)
CHUNG 86 Berkeley Conf 725 (BNL)
COOPER 86 Berkeley Conf 67 (MIT)
EISNER 86 Berkeley Conf 1211 (SLAC)
HEUSCH 86 Seewinkel Symposium on Multiparticle Dynamics (SLAC)
LINDENBAUM 86 BNL 37412 preprint (BNL)
LONGACRE 86 PL B177 223 +Etkin+ (BNL BRAN CUNY DUKE NDAM)
MESHKOV 86 Aspen Winter Conf (NBS)
AUGUSTIN 85 Moriond XX 1 479 +Calcaterra Cosme+ (ORSA CLER PADO FRAS)
BALTRUSAITIS 85D PR D32 566 +Coffman Hauser+ (CIT UCSC ILL SLAC WASH)
CHUNG 85 PRL 55 779 +Fernow Boehnlein+ (BNL FLOR IND SMAS)
COOPER 85 Bari Conf 947 (SLAC)
ETKIN 85 PL 165B 217 +Foley Longacre Lindenbaum+ (BNL CUNY)
LINDENBAUM 85 PL 165B 202 +Longacre (BNL)
LINDENBAUM 85B BNL 36610 preprint +Longacre (BNL)
RYBICKI 85 ZPHY C28 65 +Sakrejda (CRAC)
ARMSTRONG 84 PL 146B 273 +Bloodworth Burns+ (ATHU BARI BIRM CERN)
AU 84 PL 167B 229 +Morgan Pennington (RL)
BINON 84C NC 80A 363 +Bricman Donskov+ (BELG LAPP SERP CERN)
DAUM 84 ZPHY C23 339 +Hertzberger+ (AMST CERN CRAC MPIM OXF+)
GERSHTEIN 84 ZPHY C24 305 +Likhoded Prokoshkin (SERP)
LINDENBAUM 84B PL 149B 407 +Lipkin (BNL FNAL)
MORGAN 84 PL 137B 411 +Pennington (RHEL DURH)
ARMSTRONG 83B NP B224 193 + (BARI BIRM CERN MILA LPNP PAVI)
BAUBILLIER 83 ZPHY C17 309 + (BIRM CERN GLAS MSU LPNP)
BINON 83 NC 78A 313 +Donskov Duteil+ (BELG LAPP SERP CERN)
CASON 83 PR D28 1586 +Cannata Baumbaugh Bishop+ (NDAM ANL)
ONO 83 ZPHY C21 109 +Pene (AACH ORSA)
TEPER 83 Brighton Conf 4 (LAPP)
EDWARDS 82E PRL 49 259 +Partridge Peck+ (CIT HARV PRIN STAN SLAC)
ETKIN 82 PRL 49 1620 +Foley Longacre Lindenbaum+ (BNL CUNY)
ETKIN 82B PR D25 1786 +Foley Lai+ (BNL CUNY TUFT VAND)
ETKIN 82C PR D25 2446 +Foley Lai+ (BNL CUNY TUFT VAND)
LIPKIN 82 PL 109B 326 (ANL)
CHABAUD 81 APP B12 575 +Niczyporuk Becker+ (CERN CRAC MPIM)
DAUM 81D PL 104B 246 +Bardsley+ (ACCMOR Collab.)
DONOGHUE 81 PL 99B 416 +Johnson Li (MIT)
LINDENBAUM 81 NC 65A 222 (BNL)
SCHARRE 81 Bonn Conf 163 (SLAC)
DIONISI 80 NP B169 1 +Gavillet+ (CERN MADR CDEF STOH)
JAFFE 80 PRL 34 1645 +Johnson (MIT)
STANTON 79 PRL 42 346 +Brockman+ (OSU CARL MCGI TNTO)
ROBSON 77 NP B130 328 (LIVP)
JAFFE 76 PL 60B 201 +Johnson (MIT)
BAILLON 67 NC 50A 393 +Edwards D'Andlau Astier+ (CERN CDEF IRAD)

OTHER NON-$q\bar{q}$ CANDIDATES

OMITTED FROM SUMMARY TABLE

OTHER NON-$q\bar{q}$ CANDIDATES REFERENCES

OTHER RELATED PAPERS

BITYUKOV 87 PL B188 383 +Dzhelyadin Dorofeev Golovkin+ (SERP)
CHANOWITZ 87 PL B187 409 (LBL)
LIU 87 PRL 58 2288 +Kiu Li (STON)
BALTRUSAITIS 86B PR D33 1222 +Coffman Hauser+ (MARK III Collab.)
BISELLO 86 PL B179 289 +Busetto Castro Limentani+ (DM2 Collab.)
BOURQUIN 86 PL B172 113 +Brown+ (GEVA RAL HEID LAUS BRIS CERN)
BRIDGES 86 PRL 56 211 +Brown+ (BLSU BNL CASE COLU UMD SYRA)
BRIDGES 86B PRL 56 215 +Daftari Kalogeropoulos Debbe+ (SYRA CASE)
BRIDGES 86C PRL 57 1534 +Daftari Kalogeropoulos+ (SYRA)
ACHASOV 85 ZPHY C27 99 +Devyanin Shestakov (NOVO)
DOVER 84 PL 146B 103 (ORSA)
JENKINS 84 PR D30 1409 +Diamond Kirsch+ (FSU BRAN BNL CINC SMAS)
KITAZOE 84 ZPHY C24 143 +Wada Kaburagi Kawaguchi Mori+ (KOBE MIT)
ONO 84 ZPHY C26 307 (ORSA)
AGUILAR 81C ZPHY C6 109 Aguilar Benitez+ (CERN CDEF MADR STOH)
APEL 81 NP B193 269 +Augenstein Bertolucci Donskov+ (SERP CERN)
BIONTA 81 PRL 46 970 +Carroll Edelstein+ (BNL CMU FNAL SMAS)
EVANGELISTA 81 NP B178 197 + (BARI BONN CERN DARE LIVP+)
FRAME 81 PL 107B 301 +Hughes Colley Armstrong+ (GLAS BIRM CERN)
IRVING 81B NP B193 1 +Loverre+ (CERN CDEF MADR STOH)
KOOIJMAN 80 PRL 45 316 +Arenton Ayres Diebold May+ (ANL EFI)
SCHARRE 80 PL 97B 329 +Trilling Abrams Alam Blocker+ (SLAC LBL)
ALAM 78 PRL 40 1685 +Baggett Baglin+ (IND PURD SLAC VAND)
ARMSTRONG 78 PL 77B 447 +Frame Hughes Bienlein+ (GLAS DESY)
HOLMGREN 78 PL 77B 304 +Pennington (STOH CERN)
BOUCROT 77 NP B121 251 +Navach Rivet+ (LALO CERN CDEF EPOL)
HOOGLAND 77 NP B126 109 +Grayer Hyams Blum Dietl+ (AMST CERN MPIM)
MOSER 77 NP B129 28 (EFI)
BRUNDIERS 76 PL 64B 107 +Brun Fluri+ (FREI SACL ETH)
BALTAY 75B PL 57B 293 +Cautis Cohen Kaielkar Pisello+ (COLU BING)
DAVIS 75B NP B96 426 +Ammar Kropac Yarger+ (KANS CCAC ANL)
ALAM 74 PL 53B 207 +Brabson Galloway+ (IND PURD SLAC VAND)
COHEN 74 Boston Conf 79 (COLU)
OREN 74 NP B71 189 +Cooper Fields Rhines Allison+ (ANL OXF)
COHEN 73B NP B53 1 +Ferbel Slattery Werner (ROCH)
DURUSOY 73 PL 45B 517 +Baubillier George Armenise+ (LPNP BARI)
FAIMAN 73 PL 43B 307 +Goldhaber Zarmi (CERN)
LIPKIN 73 PR D7 2262 (ANL FNAL)
BUHL 72 NP B37 421 +Cline Terrell (WISC)
CHO 70B PL 32B 409 +Derrick Johnson Musgrave+ (ANL NWES KANS)
GIACOMELLI 70 PL 33B 373 + (BGNA SACL AMST REHO EPOL)
LYS 70 PR D2 2525 + (MICH)
ROSNER 70 Exp Meson Spectroscopy 499
DODD 69 PR 177 1991 +Joldersma Palmer Samios (BNL)
ROSENFELD 68 Phil Conf 455 (LRL)
ROSNER 68 PRL 21 950 1468 (TELA)

Baryon Full Listings
N's and Δ's

NOTE ON *N* AND Δ RESONANCES

I Introduction

(by G Hohler University of Karlsruhe)

The excited states of the nucleon have been studied in a large number of formation and production experiments Production experiments are not suitable for accurate determination of resonance parameters but will be essential in searching for the many predicted nucleon resonances that decouple from the πN channel [1]

The masses widths, and elasticities of the N and Δ resonances in the Baryon Summary Table come almost entirely from partial-wave analyses of πN total elastic and charge-exchange scattering data (see Sec II below) Similar methods have been used to get the $N\eta$ ΛK and ΣK branching fractions Other branching fractions come from isobar-model analyses of $\pi N \rightarrow N\pi\pi$ data (Sec III) Finally some $N\gamma$ branching fractions have been determined from photoproduction experiments (Sec IV)

Table 1 lists all the N and Δ entries in the Baryon Listings and gives our evaluation of the status of each, both overall and channel by channel Only the established resonances (overall status 3 or 4 stars) appear in the Baryon Summary Table A resonance is considered to be well established only if it has been seen in at least two independent analyses and its partial wave does not behave erratically or have large errors Some recent data[2,3] differ appreciably from earlier data and from predictions of the existing analyses so a cautious attitude is called for

The Baryon Listings give, in addition to the usual Breit-Wigner parameters, the positions and residues of the poles of the resonant partial waves on the second sheet of the complex energy plane as obtained from $\pi N \rightarrow \pi N$ partial-wave analyses and from $\pi N \rightarrow N\pi\pi$ isobar-model analyses

The Listings are much shortened by the omission of many now-obsolete results, nearly all of which were published before 1975 There also used to be separate entries for bumps seen in production experiments bumps with masses in the 1440 MeV region, the 1520 MeV region etc -- but these have been removed All the omitted material may be found in our 1982 edition [4]

There are two extensive reviews of nucleon resonances [5] See also the proceedings of the recent Workshop on πN Physics[6] for further comments on N and Δ resonances by this author and others

Further progress in understanding the N and Δ resonances depends on investigations of three different types

(1) ***New accurate data*** Much new data is coming from groups working at LAMPF,[3,7] and there is also some new data from Leningrad [8] The results include some preliminary spin-rotation data, the first such in the resonance region Unfortunately, however, none of this work extends above a mass of about 1500 MeV and we know of no plans anywhere for new measurements at higher masses Recently published results[2] of an older high-statistics measurement of $\pi^+ p$ backward differential cross sections from 1 3 to 2 5 GeV/c disagree with earlier high-statistics experiments and thus also with predictions from existing partial-

Table 1 The status of the N and Δ resonances Only those with an overall status of *** or **** are included in the main Baryon Summary Table

Particle	$L_{2I\,2J}$	Overall status	Status as seen in -- $N\pi$	$N\eta$	ΛK	ΣK	$\Delta\pi$	$N\rho$	$N\gamma$
N(939)	P_{11}	****							
N(1440)	P_{11}	****	****	*			***	*	***
N(1520)	D_{13}	****	****	*			****	****	****
N(1535)	S_{11}	****	****	****			*	**	***
N(1540)	P_{13}	*					*	*	
N(1650)	S_{11}	****	****	*	***	**	***	*	***
N(1675)	D_{15}	****	****	*	*		****	*	***
N(1680)	F_{15}	****	****				****	****	****
N(1700)	D_{13}	***	***	*	**	*	**	*	**
N(1710)	P_{11}	***	***	**	**	*	**	*	***
N(1720)	P_{13}	****	****	*	**	*	*	*	*
N(1960)	?	*				*			
N(1990)	F_{17}	**	**	*	*	*			*
N(2000)	F_{15}	**	**	*	*	*			
N(2080)	D_{13}	**	**	*	*				*
N(2090)	S_{11}	*	*						
N(2100)	P_{11}	*	*						
N(2190)	G_{17}	****	****	*	*	*			*
N(2200)	D_{15}	**	**	*	*				
N(2220)	H_{19}	****	****	*					
N(2250)	G_{19}	****	****	*					
N(2600)	$I_{1\,11}$	***	***						
N(2700)	$K_{1\,13}$	**	**						
N(~3000)									
Δ(1232)	P_{33}	****	****	F					****
Δ(1550)	P_{31}	*		o			*	*	*
Δ(1600)	P_{33}	**	**	r			**	*	**
Δ(1620)	S_{31}	****	****	b			****	****	***
Δ(1700)	D_{33}	****	****	i		*	***	**	***
Δ(1900)	S_{31}	***	***	d		*		*	*
Δ(1905)	F_{35}	****	****	d		*	**	*	***
Δ(1910)	P_{31}	****	****	e		*	*	*	*
Δ(1920)	P_{33}	***	***	n		*	*		*
Δ(1930)	D_{35}	***	***	F		*			*
Δ(1940)	D_{33}	*	*	o					
Δ(1950)	F_{37}	****	****	r		*	***	*	***
Δ(2000)	F_{35}	**		b				**	
Δ(2150)	S_{31}	*	*	i					
Δ(2200)	G_{37}	*	*	d					
Δ(2300)	H_{39}	**	**	d					
Δ(2350)	D_{35}	*	*	e					
Δ(2390)	F_{37}	*	*	n					
Δ(2400)	G_{39}	**	**						
Δ(2420)	$H_{3\,11}$	****	****						*
Δ(2750)	$I_{3\,13}$	**	**						
Δ(2950)	$K_{3\,15}$	**	**						
Δ(~3000)									

**** Good, clear and unmistakable
*** Good, but in need of clarification or not absolutely certain
** Not established, needs confirmation
* Evidence weak, could disappear

wave analyses.[5] (Most of the other just-published results[9] were available long ago and were included in the principal analyses.)

(2) ***New partial-wave analyses.*** Existing solutions will need to be adjusted to get a good fit to the new data. The first step should be to perform single-energy analyses combined with calculations of the zeros of the transversity amplitudes, as was done by Abaev et al.,[10] but adding existing information on the tail of high partial waves (see Sec. II). The zeros must lie on trajectories that fulfill conditions derived from two-variable analyticity (see Sec. 2.4.3 in Ref. 5). Finally, a new analysis of the type carried out by the Karlsruhe and CMU-LBL groups is necessary, but these groups lack the manpower to do it. The Karlsruhe group and R.A. Arndt (VPI and State U.) have begun a collaboration, the aim being to improve the method of Ref. 11 by imposing part of the constraints following from the Mandelstam hypothesis.

(3) ***New theoretical investigations.*** Many authors have disregarded the fact that the resonance parameters listed in our table are different from the quantities calculated from their models. This is no problem for Skyrmion models, which predict scattering amplitudes, but in quark shell models or lattice calculations the authors determine stable excited states, ignoring the mass shifts expected from the strong coupling to the decay channels. It is essential to estimate these mass shifts before making detailed comparisons.

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II. Two-body partial-wave analyses and determination of resonance parameters

(by G. Hohler, University of Karlsruhe)

πN partial-wave analysis. Even if $\pi N \to \pi N$ scattering data were measured with infinite accuracy, it would not be possible in the inelastic region to determine a unique set of partial waves from the data alone. It is essential to add theoretical constraints, and unitarity, analyticity, and isospin invariance are chosen in order to avoid the biases that a specific model or parametrization might introduce.

Atkinson et al.,[1] continuing earlier work, assumed $d\sigma/d\Omega$ and P angular distributions for $\pi^{\pm} p$ elastic scattering to be given at one energy with very high precision and investigated how well the partial-wave amplitudes could be determined if unitarity but not analyticity was also used. They found that the same distributions could be fit by a variety of solutions differing from one another substantially in some of the lower partial waves and strongly in the tail of high partial waves. They concluded that cutting off the partial-wave expansion sharply (which has been done even in some recent analyses[2,3]) is not justified, but it can, of course, happen that a nearly correct solution is obtained anyway.

In QCD, isospin is not exactly conserved in strong interactions because the masses of the up and down quarks are different. The only well-established experimental evidence in πN scattering for a violation is in the Δ(1232) region, where it manifests itself in the slightly different masses and widths of the Δ^{++} and Δ^{0}. (See Ref. 4 for a test of isospin invariance at higher momenta.)

The problem of getting a unique solution remains even if one includes data from all three reactions ($\pi^{\pm} p \to \pi^{\pm} p$, $\pi^{-} p \to \pi^{0} n$) plus unitarity and isospin invariance; it is still necessary to add analyticity constraints, and much stronger ones than just the forward dispersion relations. Constraints based on Mandelstam's 2-variable analyticity have been used successfully only in the CMU-LBL[5] and Karlsruhe-Helsinki[6,7] analyses. In these, long tails of high partial waves were admitted, but only global results for these waves, not those about a particular high wave, should be taken seriously.[8]

The resonance masses, widths, and elasticities in the Baryon Summary Table are mainly determined by these two analyses. The amplitudes are shown in Fig. 1, and more detailed figures and speed plots may be found in Ref. 9. Results from other analyses should be considered preliminary as long as the compatibility with analyticity constraints and the effect of the neglect of higher partial waves have not been investigated (see Sec. 2.1 in Ref. 7).

For a few of the low-mass resonances, substantial progress may be expected when results of recent experiments at

Baryon Full Listings
N's and Δ's

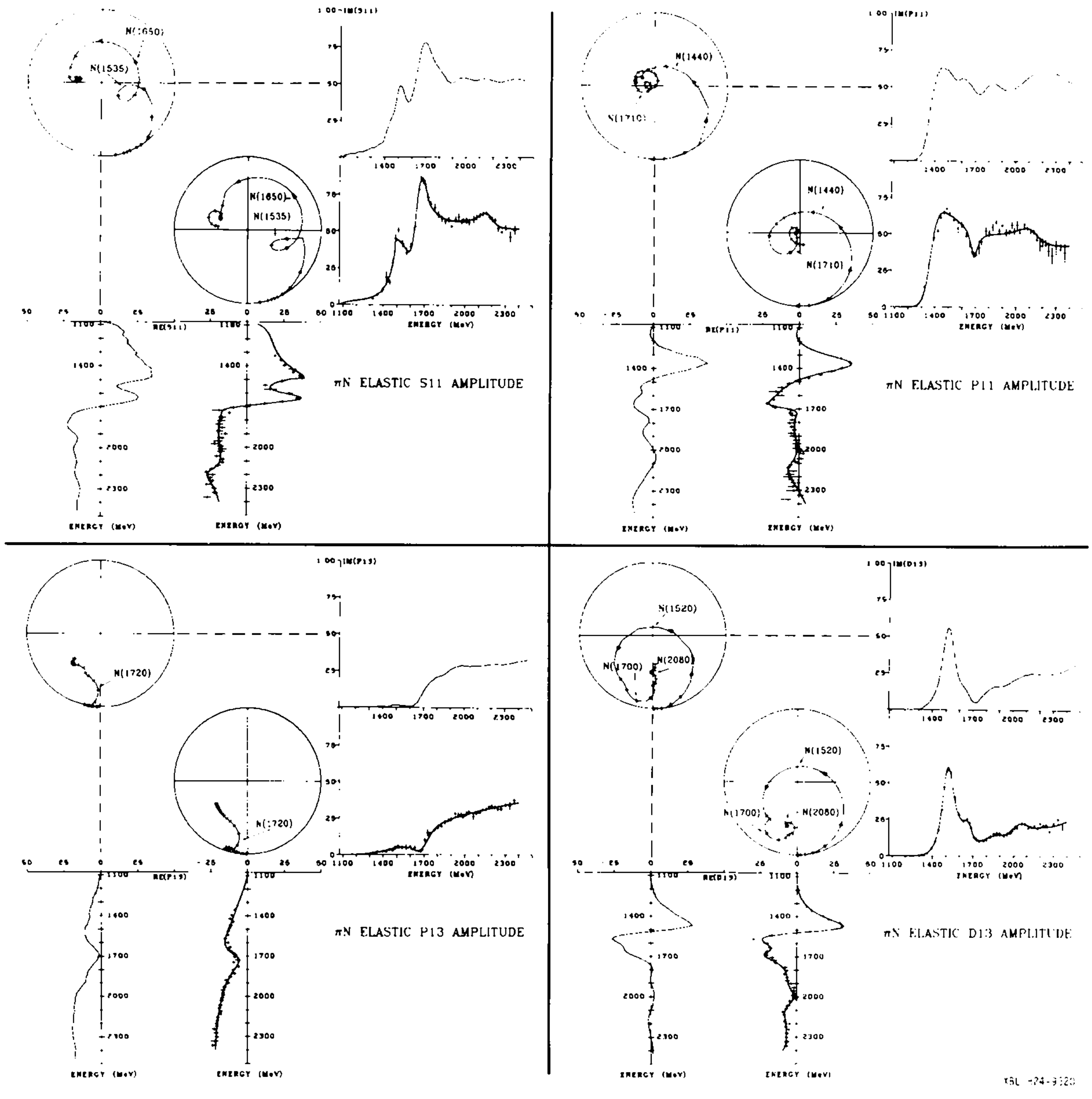

Fig 1(a) The $L_{2I\,2J}$ = S_{11}, P_{11}, P_{13}, and D_{13} partial-wave amplitudes for πN elastic scattering The upper plot for each amplitude is from HOEHLER 79 and the lower one is from CUTKOSKY 80 In the Argand plots, the ticks are at integral multiples of 50 MeV, and the established resonances are shown at their nominal positions The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots (in the projections of the CUTKOSKY 80 amplitudes, the "data points" are results of energy-independent fits, and the curves are from an energy-dependent fit to join them)

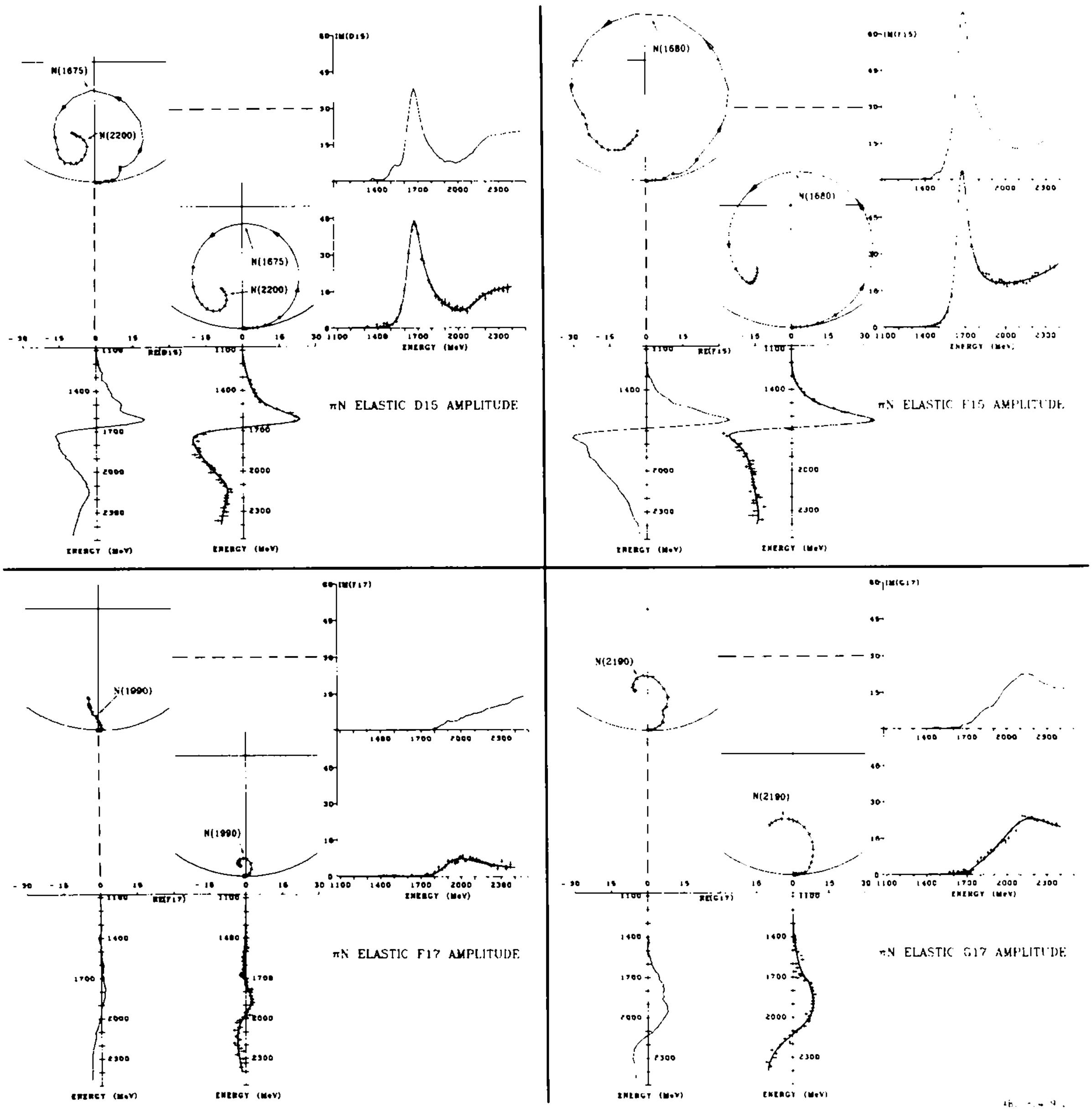

Fig 1(b) The $L_{2I\,2J} = D_{15}, F_{15}, F_{17}$ and G_{17} partial-wave amplitudes for πN elastic scattering. The upper plot for each amplitude is from HOEHLER 79 and the lower one is from CUTKOSKY 80. In the Argand plots the ticks are at integral multiples of 50 MeV, and the established resonances are shown at their nominal positions. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots (in the projections of the CUTKOSKY 80 amplitudes, the "data points" are results of energy-independent fits and the curves are from an energy-dependent fit to join them).

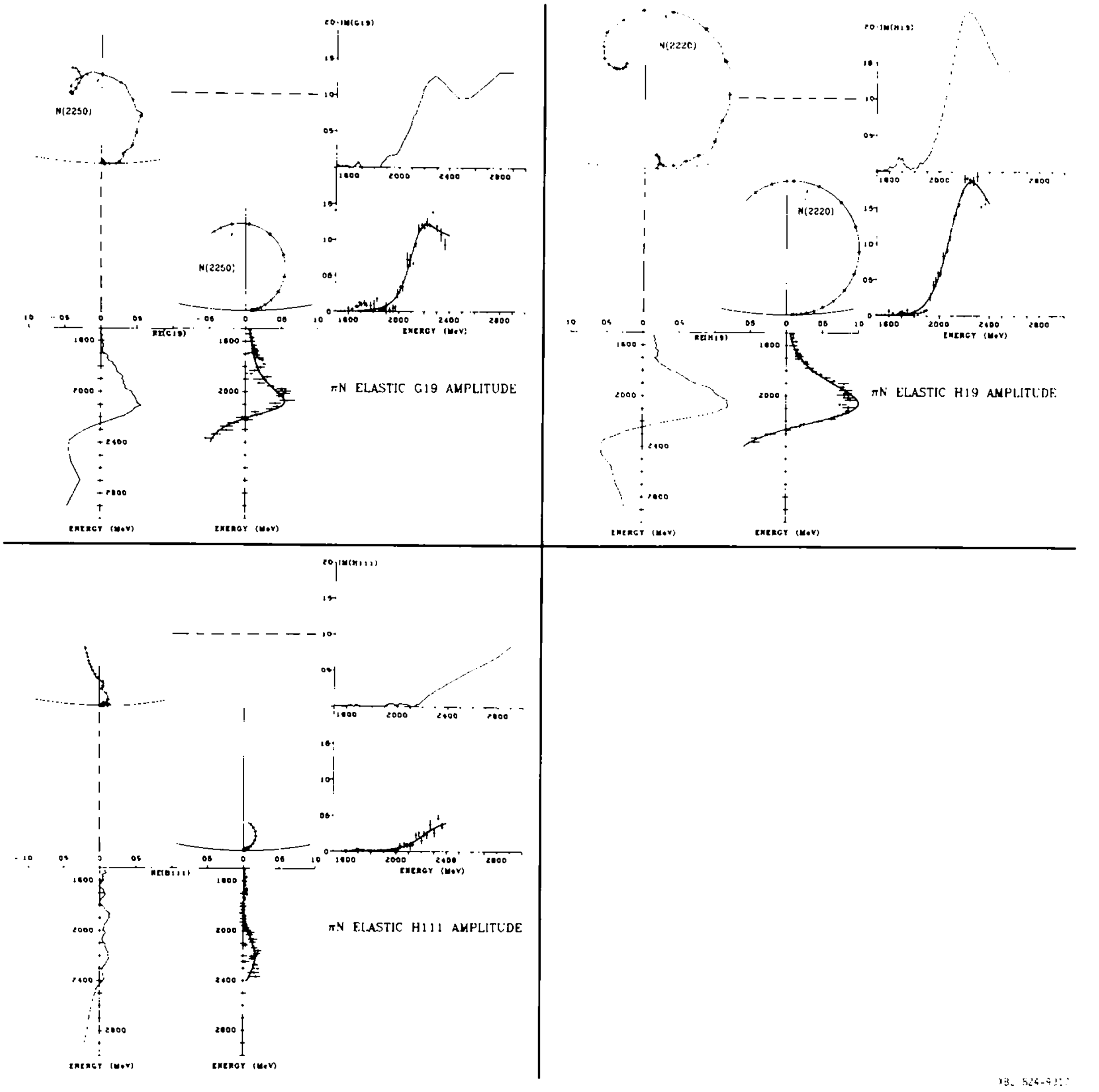

Fig 1(c) The $L_{2I\,2J} = G_{19}$, H_{19} and $H_{1\,11}$ partial-wave amplitudes for πN elastic scattering The upper plot for each amplitude is from HOEHLER 79 and the lower one is from CUTKOSKY 80 In the Argand plots, the ticks are at integral multiples of 50 MeV, and the established resonances are shown at their nominal positions The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots (in the projections of the CUTKOSKY 80 amplitudes, the "data points" are results of energy-independent fits and the curves are from an energy-dependent fit to join them)

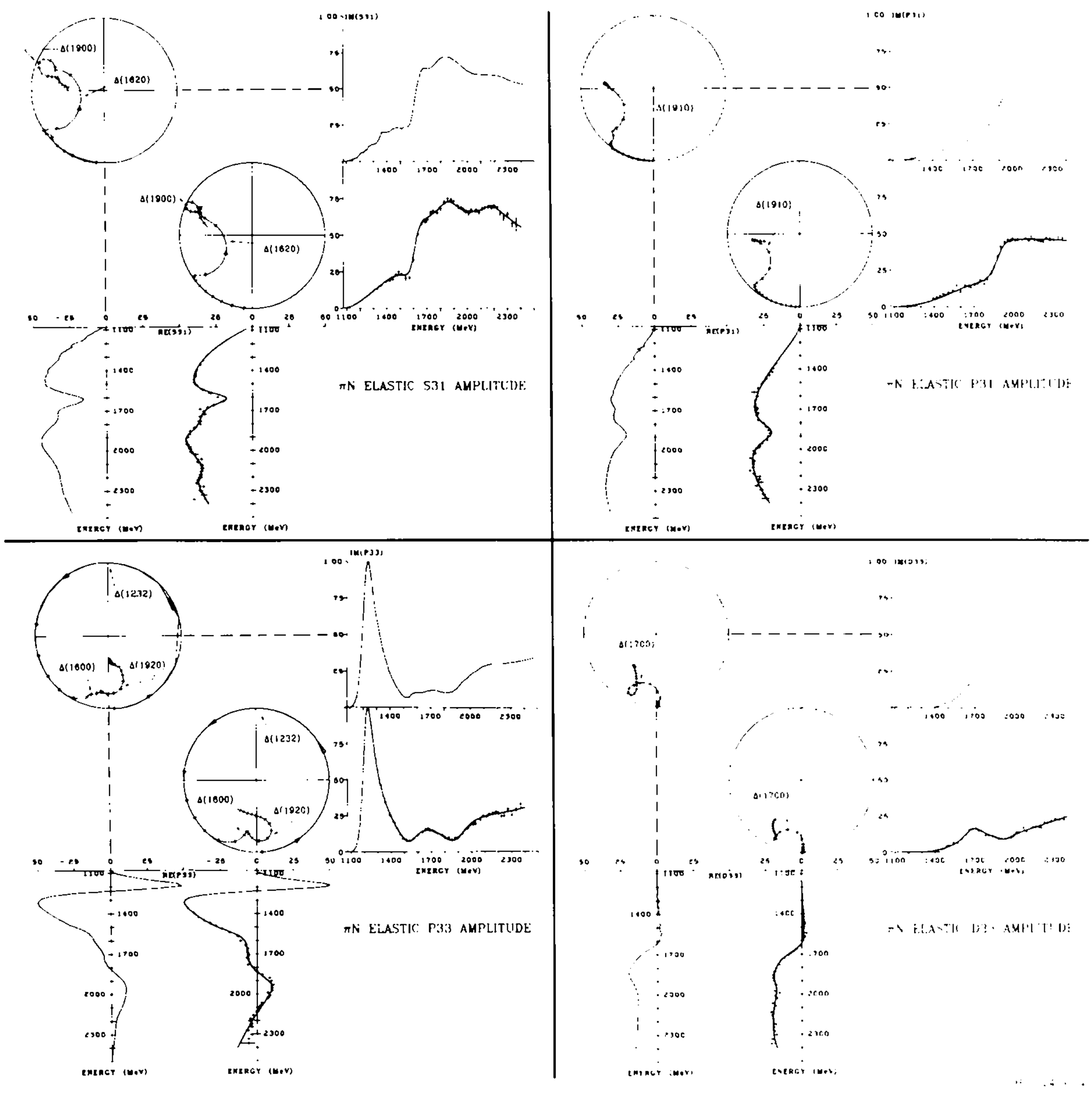

Fig. 1(d) The $L_{2I,2J}$ = S_{31}, P_{31}, P_{33} and D_{33} partial-wave amplitudes for πN elastic scattering. The upper plot for each amplitude is from HÖEHLER 79 and the lower one is from CUTKOSKY 80. In the Argand plots, the ticks are at integral multiples of 50 MeV, and the established resonances are shown at their nominal positions. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots (in the projections of the CUTKOSKY 80 amplitudes, the "data points" are results of energy-independent fits, and the curves are from an energy-dependent fit to join them).

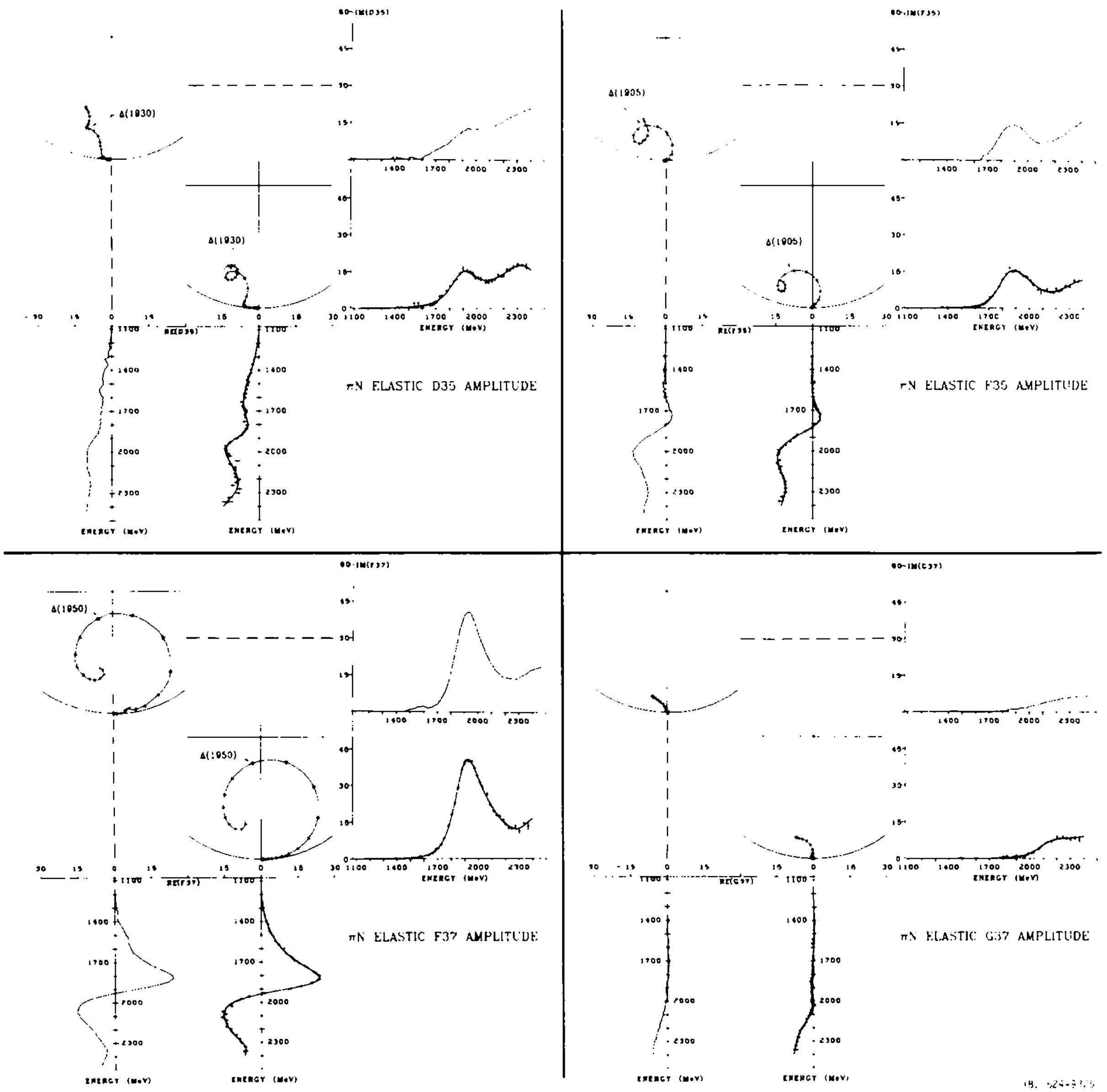

Fig 1(c) The $L_{2I\,2J}$ = D_{35}, F_{35}, F_{37}, and G_{37} partial-wave amplitudes for πN elastic scattering The upper plot for each amplitude is from HOEHLER 79 and the lower one is from CUTKOSKY 80 In the Argand plots, the ticks are at integral multiples of 50 MeV and the established resonances are shown at their nominal positions The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots (in the projections of the CUTKOSKY 80 amplitudes, the "data points" are results of energy-independent fits, and the curves are from an energy-dependent fit to join them)

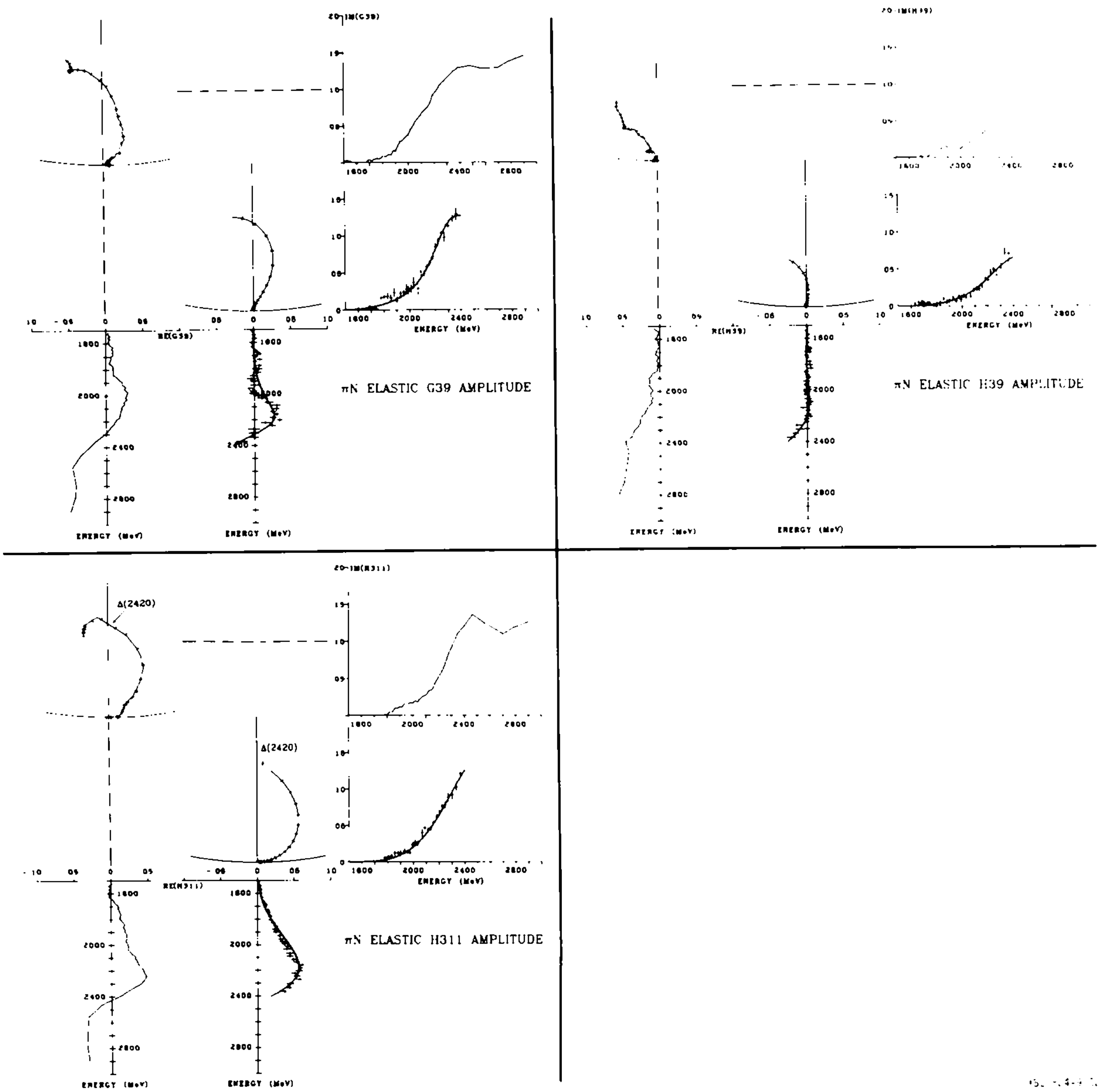

Fig 1(f) The $L_{2I\,2J} = G_{39}$, H_{39} and H_{311} partial-wave amplitudes for πN elastic scattering The upper plot for each amplitude is from HOEHLER 79 and the lower one is from CUTKOSKY 80 In the Argand plots the ticks are at integral multiples of 50 MeV, and the established resonances are shown at their nominal positions The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots (in the projections of the CUTKOSKY 80 amplitudes, the "data points" are results of energy-independent fits and the curves are from an energy-dependent fit to join them)

Los Alamos and Leningrad are analyzed. New analyses should use predictions for the tail of high partial waves based on a new evaluation of the nearby parts of the Mandelstam double spectral function.[10] R. Koch[8] included these predictions in getting a smooth interpolation of the earlier Karlsruhe solution for D and higher partial waves constrained by the condition that the partial-wave dispersion relations be satisfied. Koch's solution improves knowledge about the shapes of the resonances and has been used for a determination of the pole parameters.[11]

In a second paper,[12] Koch gave real parts of partial waves up to 500 MeV/c from a projection of fixed-t dispersion relations (an exact version of the approach of Ref. 13). Agreement with the results of the quite different application of analyticity constraints in the first paper is in general good. Together with the demonstration of the compatibility of the Karlsruhe solution with various other single-variable dispersion relations,[7] this justifies the use of Mandelstam analyticity in partial-wave analyses.

A smooth starting solution for a new analysis has been prepared from the results of Refs. 8 and 12, but a study of the zero trajectories of transversity amplitudes shows that around 600 MeV/c, i.e., around the $N(1440)$, the solution is not yet satisfactory near the backward direction.

Data are still too poor and have too many gaps for a good determination of resonances with masses above about 2.2 GeV. Evidence for resonances in this range has been reported by Hendry[14] and also by Koch,[6] who used additional large data sets from Argonne and from KEK.[15]

Determination of resonance parameters. Since a dynamical theory of πN scattering does not yet exist, the resonance parameters are not uniquely defined. One can fit a partial-wave amplitude with a phenomenological ansatz consisting of a generalized Breit-Wigner form plus a background term, and most of the earlier analyses, including the first CMU-LBL analysis and the KH 78 analysis,[6] used a prescription of this type. A more sophisticated multichannel coupled resonance scheme was used in the more recent work of the CMU-LBL group.[5] The parameters listed in the Baryon Summary Table were obtained using these methods.

A difficulty that becomes more and more important as the energy increases is that "background terms," namely diffraction and ρ exchange, make contributions to the partial waves that resemble those of highly inelastic resonances (see Sec. 2.4.1.1 in Ref. 7). The energy dependences are different, but at high energies data are insufficient to determine accurately the speed with which a partial-wave amplitude traverses the complex plane. Furthermore, it is a dynamical question whether this background is part of the resonance mechanism.

If the resonances are ordered according to the shapes of their Argand plots, there is a continuous transition from clean textbook-type resonances to tiny wiggles on large backgrounds. The Baryon Summary Table lists all objects that have a "resonance-like" shape on the Argand diagram and a maximum of the speed. The reader must decide which of these are "resonances" in the framework of his or her model.

This discussion shows that a comparison of the resonance masses listed in the Baryon Summary Table with predictions from lattice calculations or from quark-shell, bag, Skyrmion, or other models is rather uncertain, especially if small mass differences are considered, since most of the models cannot yet describe the scattering process and take into account the background.

Resonance poles. The Baryon Listings give a second set of resonance parameters, the positions and residues of the resonance poles of the partial-wave amplitudes on the second sheet of the s plane. These may be determined in a more or less model-independent way. Table 2 summarizes some of the recent results.[2,5,11] Note, however, that Fonda et al.[16] were able to fit even the P_{33} amplitude in the vicinity of 1230 MeV *without a pole*. A theoretical assumption or argument that excludes such parametrizations is needed.

A special situation arises when a resonance is located near the threshold of an inelastic channel that is strongly coupled to the πN system. For instance, the $\Delta\pi$ threshold is near the $N(1440)P_{11}$ and the $N\eta$ threshold is near the $N(1535)S_{11}$. In these cases, a single resonance usually has poles in different sheets of the Riemannian surface. Cutkosky[17] has called attention to this, and in fact it was already noticed in the early 1960's.

The CMU-LBL group has listed only the poles nearest to the real s axis.[5] Using a coupled-channel K-matrix formalism, Arndt et al.[2] found two poles on different sheets for the $N(1440)P_{11}$ but only one pole for the $N(1535)S_{11}$. Obviously, this should not be interpreted as a "splitting of the $N(1440)$." Similar effects in nuclear physics have recently been discussed in the literature.[17]

A more satisfactory treatment of the multichannel problem was developed by Cutkosky et al.,[5] who used coupled-channel Dyson equations. But unfortunately, these authors have not continued their work for many years.

Another aspect is that poles lying near thresholds of strongly coupled inelastic channels could be an essential part of the resonance mechanism.[18] Of course, this is at variance with the treatment of these resonances in the quark shell model or in lattice calculations. Furthermore, the rapid increase of the inelastic cross section leads via analyticity to a positive real part and thereby contributes to a resonance-like wiggle in the Argand diagram.[19]

Remarkably, there exist families of resonances in which

Table 2. Recent determinations of pole parameters of 3- and 4-star N and Δ resonances. Cutkosky et al.[5] and Arndt et al.[2] take into account inelastic channels in the isobar approximation. Sararu[11] uses Koch's smoothed version[8] of the Karlsruhe solution without taking into account inelastic scattering. In general, a resonance has poles in several sheets of the energy plane. The parameters here are of the pole reached most directly from the physical region. This condition can be ambiguous when a strong inelastic channel ($\Delta\pi$, $N\eta$, $N\rho$, etc.) opens within the width of the resonance. Theoreticians working on quark or bag models who use the parameters should keep in mind that their models do not include the effects caused by the opening of inelastic channels.[19] In particular, they should not try to describe the two poles given by Arndt et al.[2] for the $N(1440)\,P_{11}$. A splitting of this resonance was claimed earlier from an analysis of the elastic data alone, but this was not tenable (see the remark in Sec. 2.1.8 of Ref. 7).

Resonance	Pole position (MeV)		Residue		
	Re W	$-2\times$Im W	$\lvert r\rvert$ (MeV)	θ (°)	Ref†
$N(1440)\,P_{11}$	1375 ± 30	180 ± 40	52 ± 5	−100 ± 35	C
	1355	200	62	−108	A
	1416	156	118	4	
$N(1520)\,D_{13}$	1510 ± 5	114 ± 10	35 ± 2	12 ± 5	C
	1508	124	40	−9	A
$N(1535)\,S_{11}$	1510 ± 50	260 ± 80	120 ± 40	+15 ± 45	C
	1464	150	40	−44	A
$N(1650)\,S_{11}$	1640 ± 20	150 ± 30	60 ± 10	75 ± 25	C
	1656	108	34	−54	A
$N(1675)\,D_{15}$	1660 ± 10	140 ± 10	31 ± 5	30 ± 10	C
	1658	136	32	−20	A
$N(1680)\,F_{15}$	1667 ± 5	110 ± 10	34 ± 2	25 ± 5	C
	1668	110	33	−18	A
	1671	122	25	20	S
$N(1700)\,D_{13}$	1660 ± 30	90 ± 40	6 ± 3	0 ± 50	C
	1676	48	2	+43	A
$N(1710)\,P_{11}$	1690 ± 20	80 ± 20	8 ± 2	+175 ± 35	C
	(not seen)				A
$N(1720)\,P_{13}$	1680 ± 30	120 ± 40	8 ± 2	−160 ± 30	C
	1690	66	3.7	138	A
	1670	188	8	−127	S
$N(2190)\,G_{17}$	2100 ± 50	400 ± 160	25 ± 10	30 ± 50	C
	2056	580	40	−18	S
$N(2220)\,H_{19}$	2160 ± 80	480 ± 100	45 ± 20	−45 ± 25	C
	2130	340	19	−47	S
$N(2250)\,G_{19}$	2150 ± 50	360 ± 100	20 ± 6	50 ± 20	C
$N(2600)\,I_{1\,11}$	2589	460			S
$\Delta(1232)\,P_{33}$	1210 ± 1	100 ± 2	53 ± 2	−47 ± 1	C
	1211	102	56	30	A
	1209	100			S
$\Delta(1620)\,S_{31}$	1600 ± 15	120 ± 20	15 ± 2	−110 ± 20	C
	1592	108	13	117	A
$\Delta(1700)\,D_{33}$	1675 ± 25	220 ± 40	13 ± 3	−20 ± 25	C
	1674	336	32	−24	A
	1680	226	14	+34	S
$\Delta(1900)\,S_{31}$	1870 ± 40	180 ± 50	10 ± 3	+20 ± 40	C
$\Delta(1905)\,F_{35}$	1830 ± 40	280 ± 60	25 ± 8	−50 ± 20	C
	1872	228	23	−13	A
	1850	220	10	−11	S
$\Delta(1910)\,P_{31}$	1880 ± 30	200 ± 40	20 ± 4	90 ± 30	C
	1883	392	27	89	S
$\Delta(1920)\,P_{33}$	1900 ± 80	300 ± 100	24 ± 4	−150 ± 30	C
	(not seen)				A
$\Delta(1930)\,D_{35}$	1890 ± 50	260 ± 60	18 ± 6	20 ± 40	C
$\Delta(1950)\,F_{37}$	1890 ± 15	260 ± 40	50 ± 7	33 ± 8	C
	1864	216	50	20	A
	1890	242	32	22	S
$\Delta(2420)\,H_{3\,11}$	2360 ± 100	420 ± 100	18 ± 6	30 ± 40	C

†C = Cutkosky et al.[5], A = Arndt et al.[2], and S = Sararu.[11]

the pole positions are the same within errors, i.e., degeneracy is not excluded.[7] For example, all six isospin-1/2 partial waves from S_{11} to F_{15} have a well-established resonance with a pole near W = (1665-60i) MeV, and at least six of the seven possible isospin-3/2 resonances from S_{31} to F_{37} have a pole near (1880-120i) MeV.

We have not included in the Listings the zeros of the partial-wave amplitudes given in Ref. 2, because a zero in the neighborhood of a resonance pole only gives information on the background. However, zero trajectories of the invariant and transversity amplitudes may be of fundamental importance (see Sec. 2.4.3 in Ref. 7).

Inelastic 2-body reactions. Analyses of the reactions $\pi N \to N\eta$, $\pi N \to \Lambda K$, and $\pi N \to \Sigma K$ are similar to $\pi N \to \pi N$ analyses. However, the data are far less complete and accurate, and energy-dependent parametrizations must be used.

The best results, giving resonance masses and widths as well as couplings, follow from the $\pi^- p \to \Lambda K^0$ data of the Rutherford group.[20] One analysis used a reggeized K^*-exchange term to represent the nonresonant and high waves. Another used a Lagrangian model for the long-range forces.[21] In general, agreement with the $\pi N \to \pi N$ analyses is good, but there are discrepancies about the $N(1675)\,D_{15}$ and $N(1710)\,P_{11}$ widths and the $N(2200)\,D_{15}$ mass.

In an analysis of the less accurate $\pi^- p \to n\eta$ data,[22] partial waves were parametrized as Breit-Wigner resonances without background. The resonance spectrum was assumed and the data were used to determine the $n\eta$ couplings. For resonances with relatively large couplings, the masses and widths were varied in a second step.

The results derived from the bubble-chamber data for $\pi^+ p \to \Sigma^+ K^+$[23] have large uncertainties. Values of the resonance masses were assumed, and Breit-Wigner forms and an empirical ansatz for the background were used for partial waves up to F waves (the G waves are probably not negligible at 1.7 GeV/c). The recent addition of precise data from 1820 to 2350 MeV[24] has allowed an improved analysis.[25] The solution found is unique. Above 2 GeV, all the resonances with two or more stars are seen, but none of the 1-star states is supported.

Isgur[26] has pointed out that distortions of resonance couplings can occur in cases such as $\pi N \to \Delta \to \Sigma K$ if the threshold is just below the resonance mass.

Baryon Full Listings
N's and Δ's

A possible new resonance, an N(1960), has been detected in the final state $\Sigma(1385)$ K^+ in the scattering of neutrons from carbon, aluminum and copper targets.[27] If confirmed, the small width 27 ± 15 MeV indicates an exotic nature.

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III. The $\pi N \rightarrow N\pi\pi$ reaction

(by D M Manley, Kent State University)

The $\pi N \rightarrow N\pi\pi$ reaction has been studied up to c m energies of about 2000 MeV using isobar models which are validated by the observation that almost all $\pi N \rightarrow N\pi\pi$ events lie in quasi-2-body bands in the Dalitz plots Isobar models parametrize partial-wave amplitudes with a coherent sum of terms that describe quasi-2-body scattering processes, e g , $\pi N \rightarrow \Delta(1232)\pi$, $\pi N \rightarrow N\rho$ and $\pi N \rightarrow N(1440)\pi$ The couplings obtained from these analyses provide stringent constraints on quark models of baryon structure Details of the isobar-model formalism are given in our 1982 edition [1]

The Listings give the results from five analyses, none of which are new to this edition

LONGACRE 75[2] and LONGACRE 78 (LBL-SLAC)[3] estimated resonance parameters based, in part, on $\pi N \rightarrow N\pi\pi$ partial-wave amplitudes obtained from an analysis of 170,000 $\pi^- p \rightarrow n\pi^-\pi^+$, $\pi^- p \rightarrow p\pi^-\pi^0$, and $\pi^+ p \rightarrow p\pi^+\pi^0$ events with c m energies between 1300 and 1990 MeV [4] The analysis included the $\Delta(1232)\pi$, $N\rho$, and $N(\pi\pi)_S$ intermediate states where $(\pi\pi)_S$ is the strong isospin-0 S-wave $\pi\pi$ interaction The Listings give masses, widths, and couplings for nine N and five Δ resonances from LONGACRE 75 and pole positions from ten N and seven Δ resonances from LONGACRE 78 Resonance parameters included in this edition were estimated from a T matrix that satisfies unitarity and which was derived from a K-matrix parametrization of $\pi N \rightarrow N\pi$ and $\pi N \rightarrow$

$N\pi\pi$ partial-wave amplitudes Parameters we give from LONGACRE 75 were estimated by drawing Breit-Wigner circles through Argand plots (Method II of that paper) Parameters from LONGACRE 78 were estimated by searching for poles in the T matrix (following Method III of LONGACRE 75) We do not include in this edition parameters from Method I of LONGACRE 75, since the masses and widths were taken from an elastic partial-wave analysis and the couplings violate unitarity These parameters may be found in our 1986 edition [5]

LONGACRE 77 (Saclay)[6] is a similar but independent analysis of 91,000 $\pi^- p \rightarrow n\pi^-\pi^+$, $\pi^- p \rightarrow p\pi^-\pi^0$ and $\pi^+ p \rightarrow p\pi^+\pi^0$ events with c m energies between 1360 and 1760 MeV [7] The Listings give masses, widths, pole positions and couplings for ten N and five Δ resonances, including an $N(1540)P_{13}$ and a $\Delta(1550)P_{31}$ which this analysis suggested for the first time

NOVOSELLER 78 (Cal Tech)[8] estimated resonance couplings to the inelastic channels by fitting partial-wave amplitudes with a resonant parametrization of the T matrix Masses and widths of resonances were fixed to the results of elastic phase-shift analyses Two solutions are given one is based on the $\pi N \rightarrow N\pi\pi$ amplitudes of the LBL-SLAC analysis (referred to in the Listings as a Breit-Wigner fit to HERNDON 75[4]), the other is based on a similar analysis that included the effects of one-pion exchange (referred to in the Listings as a Breit-Wigner fit to NOVOSELLER 78B[9]) The Listings give couplings for two N and three Δ resonances between 1650 and 1970 MeV

BARNHAM 80 (Imperial College)[10] estimated resonance parameters by a procedure similar to Method I of LONGACRE 75 [2] The $\pi N \rightarrow N\pi\pi$ amplitudes were obtained from an analysis of 44,000 $\pi^+ p \rightarrow p\pi^+\pi^0$ and $\pi^+ p \rightarrow n\pi^+\pi^+$ events with c m energies between 1400 and 1700 MeV hence this analysis is concerned only with Δ resonances It included the $\Delta(1232)\pi$, $N(1440)\pi$, and $N\rho$ intermediate states The Listings give masses, widths and couplings for four Δ resonances

MANLEY 84 (VPI&SU)[11] is an analysis of 241,000 $\pi^- p \rightarrow n\pi^-\pi^+$, $\pi^- p \rightarrow p\pi^-\pi^0$, $\pi^+ p \rightarrow p\pi^+\pi^0$ and $\pi^+ p \rightarrow n\pi^+\pi^+$ events with c m energies between 1320 and 1930 MeV It included the $\Delta(1232)\pi$, $N(1440)\pi$, $N(\pi\pi)_S$, and $N\rho$ intermediate states Partial-wave amplitudes were fitted to a resonant parametrization of the T matrix to obtain smoothed Argand plots, however, resonance parameters were not published The Listings give signs of couplings for eight N and eight Δ resonances including a $\Delta(2000)F_{35}$ which this analysis suggested for the first time

A compilation of the signs of various $\pi N \rightarrow N\pi\pi$ couplings determined from these analyses is given in our 1986 edition [5] For further details of the analyses, refer to both our 1982 and 1986 editions [1,5]

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IV. Photoproduction and Compton scattering

(by R L Crawford, University of Glasgow)

Pion photoproduction The $N\gamma$ couplings of the N and Δ resonances have been obtained in a large number of partial-wave analyses of single-pion photoproduction on protons and neutrons The couplings, $A_{1/2}$ and $A_{3/2}$, are related to the helicity amplitudes of the process, $A_{\ell+}$ and $B_{\ell+}$, by

$$A_{\ell+} = \mp\alpha C_{N\pi} A_{1/2}$$

$$B_{\ell+} = \pm\alpha\left[\frac{16}{(2J-1)(2J+3)}\right]^{1/2} C_{N\pi} A_{3/2}$$

where

$$\alpha = \left[\frac{1}{\pi}\,\frac{k}{q}\,\frac{1}{(2J-1)}\,\frac{M_N}{M_R}\,\frac{\Gamma_\pi}{\Gamma^2}\right]^{1/2}$$

Here k and q are the photon and pion c m momenta, J is the angular momentum, M_R is the mass, Γ is the full width, and Γ_π is the $N\pi$ partial width of the resonance M_N is the nucleon mass, and $C_{N\pi}$ is the Clebsch-Gordan coefficient for the resonance decay into a specific πN charge state

The large amount of pion photoproduction data including many measurements from single and double polarization experiments has permitted an accurate evaluation of the couplings for many of the resonances with masses below 2 GeV and has given at least qualitative information about most of the others Most photoproduction analyses rely heavily upon $\pi N \rightarrow \pi N$ analyses for information on the existence masses, and widths of the resonances The only photoproduction analyses that quote resonance masses and widths as well as couplings are BERENDS 75 BERENDS 77, BARBOUR 78, and CRAWFORD 80 These results are of interest since they are about the charge +1 states of the resonances. In particular the mass of the $\Delta(1232)^+$ seems to be as well determined as those of the Δ^{++} and Δ^0 seen in elastic π^+p and π^-p scattering.

There are three main methods of analysis.

(a) The simple isobar model. The simple isobar model is an energy-dependent partial-wave analysis (DPWA) in which the partial waves are parametrized as Breit-Wigner resonances plus smooth background. The model is relatively simple but is flexible enough to give good fits. However there are possible problems about the uniqueness of the solutions obtained.

The Listings give the results of the isobar analyses of FELLER 76, TAKEDA 80, and BRATASHEVSKIJ 80. A much quoted isobar analysis of Metcalf and Walker[2] is now obsolete and has been omitted from the Listings.

(b) Fixed-t dispersion relations (FTDR). Here only the imaginary parts of the photoproduction amplitudes are parametrized, and the real parts are calculated from them using fixed-t dispersion relations. The dominance by resonances of the imaginary parts permits a relatively simple parametrization scheme, and there are fewer ambiguity problems than in the isobar model. However, it is less flexible than the isobar model and gives poorer fits, and it can only be used properly in a large-scale analysis over a wide energy range.

The Listings give the results from the FTDR analyses of BARBOUR 78, ARAI 80, CRAWFORD 80, FUJII 81, and AWAJI 81.

(c) Energy-independent analyses (IPWA). These energy-*in*dependent partial-wave analyses fit the data at essentially single energies. Watson's theorem is used at low energies to fix the complex phases of many of the partial waves. This allows a unique solution but becomes difficult above the first resonance region due to the onset of inelasticity. BERENDS 77 is the only true IPWA that has been carried out in the second resonance region. BERENDS 75 is an earlier analysis in the first resonance region. CRAWFORD 83 is an IPWA that depends on the CRAWFORD 80 FTDR analysis as a constraint to give a stable solution and is thus not independent of the energy-dependent analysis. It does, however, obtain a useful improvement in the quality of the fits, and shows that this can be achieved without making important changes to the couplings from FTDR analyses.

(d) Other analyses. NOELLE 78 is a hybrid analysis using FTDR in a coupled-channel isobar calculation.

Compton scattering. Two analyses, ISHII 80 and WADA 84, contribute measurements of the couplings obtained from Compton scattering on protons. Both are isobar analyses. In general, there is good agreement with results from photoproduction. The differences should not be taken seriously since the quality and quantity of the photoproduction data are much higher and constrain the values of the couplings more strongly than do the Compton scattering data.

$N\gamma$ branching fractions. The Baryon Summary Table gives the $N\gamma$ branching fractions for the resonances whose couplings are considered to have an unambiguous sign. The $N\gamma$ partial width Γ_γ is given by

$$\Gamma_\gamma = \frac{k^2}{\pi}\,\frac{2M_N}{M_R(2J+1)}\left[\,|A_{1/2}|^2 + |A_{3/2}|^2\,\right]$$

where M_N and M_R are the masses of the nucleon and resonance, J is the resonance spin, and k is the photon c.m. decay momentum. The couplings $A_{1/2}$ and $A_{3/2}$ are taken from Table 3 below.

Resonance couplings in the Listings. The Listings omit a number of analyses that are now considered to be obsolete. Most of them may be found in our 1982 edition.[1]

The errors quoted for the couplings in the Listings are calculated in different ways in different analyses and therefore should be used with care. In general, it is likely that the systematic differences between the analyses caused by using different parametrization schemes are more indicative of true uncertainties than are the errors quoted in the separate analyses.

Probably the most reliable analyses are those from Glasgow (BARBOUR 78, CRAWFORD 80, and CRAWFORD 83) and those from Tokyo or based on the Tokyo analyses (ARAI 80, FUJII 81, and AWAJI 81). Table 3 gives a compilation of the couplings from these analyses (unchanged since our 1986 edition). The errors given are a combination of the statistical errors quoted in the analyses and the systematic differences between them. Two values are quoted for $A_{1/2}$ of the $\Delta(1620)\,S_{31}$ to take account of the surprisingly large spread in values obtained for it. This seems to be caused by the different methods of treating the imaginary background in this partial wave. The second value given uses only the Glasgow analyses. These have always succeeded in getting stable and acceptable values for the mass and width of this resonance, and it seems reasonable to infer that the coupling obtained is accurate.

References for section IV

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Table 3. A compilation of measured γN decay couplings. Sources are given in the text.

(a) Proton-target couplings

Resonance	Helicity	Couplings ($GeV^{-1/2} \times 10^{-3}$)	Status
$N(1440)\ P_{11}$	1/2	69 ± 7	good
$N(1520)\ D_{13}$	1/2	22 ± 10	good
	3/2	+167 ± 10	good
$N(1535)\ S_{11}$	1/2	+73 ± 14	good
$N(1650)\ S_{11}$	1/2	+48 ± 16	good
$N(1675)\ D_{15}$	1/2	−19 ± 12	good, nonzero
	3/2	+19 ± 12	good, nonzero
$N(1680)\ F_{15}$	1/2	17 ± 10	good, nonzero
	3/2	+127 ± 12	good
$N(1700)\ D_{13}$	1/2	22 ± 13	good, small
	3/2	0 ± 19	fair, small
$N(1710)\ P_{11}$	1/2	−5 ± 16	fair, small
$N(1720)\ P_{13}$	1/2	+52 ± 39	poor
	3/2	35 ± 24	fair
$N(1990)\ F_{17}$	1/2	+24 ± 30	poor
	3/2	+31 ± 55	bad
$\Delta(1232)\ P_{33}$	1/2	−141 ± 5	very good
	3/2	258 ± 11	very good
$\Delta(1550)\ P_{31}$	1/2	+16 ± 16	doubtful
$\Delta(1600)\ P_{33}$	1/2	20 ± 29	poor, small
	3/2	+1 ± 22	fair, small
$\Delta(1620)\ S_{31}$	1/2	+19 ± 16	fair
	(1/2	−30 ± 10	good -- see text)
$\Delta(1700)\ D_{33}$	1/2	−116 ± 17	good
	3/2	+77 ± 28	fair
$\Delta(1900)\ S_{31}$	1/2	+10 ± ?	?
$\Delta(1905)\ F_{35}$	1/2	+27 ± 13	good
	3/2	47 ± 19	fair
$\Delta(1910)\ P_{31}$	1/2	12 ± 30	poor
$\Delta(1920)\ P_{33}$	1/2	+40 ± ?	?
	3/2	+23 ± ?	?
$\Delta(1930)\ D_{35}$	1/2	30 ± 40	poor
	3/2	−10 ± 35	poor
$\Delta(1950)\ F_{37}$	1/2	73 ± 14	good
	3/2	−90 ± 13	good

(b) Neutron-target couplings

Resonance	Helicity	Couplings ($GeV^{-1/2} \times 10^{-3}$)	Status
$N(1440)\ P_{11}$	1/2	+37 ± 19	fair
$N(1520)\ D_{13}$	1/2	65 ± 13	good
	3/2	144 ± 14	good
$N(1535)\ S_{11}$	1/2	76 ± 32	fair
$N(1650)\ S_{11}$	1/2	17 ± 37	poor
$N(1675)\ D_{15}$	1/2	47 ± 23	fair
	3/2	69 ± 19	fair
$N(1680)\ F_{15}$	1/2	+31 ± 13	good
	3/2	30 ± 14	good
$N(1700)\ D_{13}$	1/2	0 ± 56	bad
	3/2	2 ± 44	bad
$N(1710)\ P_{11}$	1/2	5 ± 23	fair, small
$N(1720)\ P_{13}$	1/2	2 ± 26	fair, small
	3/2	43 ± 94	very bad
$N(1990)\ F_{17}$	1/2	49 ± 45	poor
	3/2	122 ± 55	poor

V. Electroproduction

The excitation of N and Δ resonances by virtual photons has been studied by means of the electroproduction of π and η mesons. The resulting information is expressed in terms of form factors, and it is not practical to give these in tabular form; therefore there are no entries in the Listings. The interested reader is referred to our 1982 edition[1] and to the extensive review by Foster and Hughes.[2]

There is presently little activity in the field, and there is no new information since our last edition. Since 1982, a small amount of information has been obtained from π electroproduction about the behavior of the helicity-1/2 and -3/2 form factors of the $N(1520)\ D_{13}$ and $N(1680)\ F_{15}$.[3] And in η electroproduction[4] the Q^2 dependence of the $N(1535)\ S_{11}$ has been examined for Q^2 up to 3 GeV^2. In both cases, the main features found were already well known and are described in the reviews mentioned above.

References for section V

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4. F.W. Brasse et al., Z. Phys. **C22**, 33 (1984).

VI. Production experiments

Partial-wave analyses, of course, separate partial waves, whereas a peak in a cross section or an invariant mass distribution usually cannot be disentangled from background and analyzed for its quantum numbers, and more than one resonance may be contributing to the peak. We used to have separate entries in the Baryon Listings for bumps seen in production experiments in the 1440 MeV region, the 1520 MeV region, etc., but these have been removed. They last appeared in our 1982 edition.[1]

Reference for section VI

1. Particle Data Group, Phys. Lett. **111B** (1982).

N BARYONS
(S = 0, I = 1/2)

p

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

SEE STABLE PARTICLES

n

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

SEE STABLE PARTICLES

$N(1440)$ P_{11}

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**) In addition, results in this region from production experiments, which used to be listed separately as the next entry, have been entirely omitted They too may be found in our 1982 edition

N(1440) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1400 to 1480 OUR ESTIMATE				
1440 ± 30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1410 ± 12	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1411	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1472	[1] BAKER	79	DPWA	$\pi^- p \to n\eta$
1417	BARBOUR	78	DPWA	$\gamma N \to \pi N$
1460	BERENDS	77	IPWA	$\gamma N \to \pi N$
1380	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1390	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N(1440) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
120 to 350 OUR ESTIMATE				
340 ± 70	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
135 ± 10	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
334	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
113	[1] BAKER	79	DPWA	$\pi^- p \to n\eta$
331	BARBOUR	78	DPWA	$\gamma N \to \pi N$
279	BERENDS	77	IPWA	$\gamma N \to \pi N$
200	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
200	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N(1440) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1375 ± 30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits, etc • • •				
1359	[4] ARNDT	85	DPWA	$\pi N \to \pi N$
1381 or 1379	[5] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
1360 or 1333	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
180 ± 40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits etc • • •				
200	[4] ARNDT	85	DPWA	$\pi N \to \pi N$
209 or 210	[5] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
167 or 234	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

N(1440) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−9 ± 31	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−51 ± 7	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

N(1440) DECAY MODES

Γ_1 $N(1440) \to N\pi$
Γ_2 $N(1440) \to N\eta$
Γ_3 $N(1440) \to N\pi\pi$
Γ_4 $N(1440) \to \Delta(1232)\pi$, P-wave
Γ_5 $N(1440) \to N\rho$, S=1/2, P-wave
Γ_6 $N(1440) \to N\rho$, S=3/2, P-wave
Γ_7 $N(1440) \to N(\pi\pi)_{S\text{-wave}}$
Γ_8 $N(1440) \to p\gamma$, helicity=1/2
Γ_9 $N(1440) \to n\gamma$, helicity=1/2

N(1440) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.5 to 0.7 OUR ESTIMATE				
0.68 ± 0.04	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 51 ± 0 05	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1440) \to N\eta$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
SEEN	[1] BAKER	79	DPWA	$\pi^- p \to n\eta$
+0 328	[6] FELTESSE	75	DPWA	1488–1745 MeV

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1440) \to \Delta(1232)\pi$, P-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (LARGE)	[7] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0 41	[2,8] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0 37	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1440) \to N\rho$, S=1/2, P-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 0	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0.11	[2,8] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0 23	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1440) \to N\rho$, S=3/2, P-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.0	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0 18	[2,8] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1440) \to N(\pi\pi)_{S\text{-wave}}$ $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (LARGE)	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0.18	[2,8] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0 23	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N(1440) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$N(1440) \to p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.069 ±0 018	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
−0 063 ±0.008	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.069 ±0 004	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0 066 ±0 004	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0 079 ±0 009	BRATASHEV	80	DPWA	$\gamma N \to \pi N$
−0 068 ±0.015	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0 0584 ±0 0148	ISHII	80	DPWA	Compton scattering
−0 075 ±0.015	BARBOUR	78	DPWA	$\gamma N \to \pi N$
−0.087 ±0 006	FELLER	76	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages fits limits, etc • • •				
−0.129	[9] WADA	84	DPWA	Compton scattering
−0 125	[10] NOELLE	78		$\gamma N \to \pi N$
−0.076	BERENDS	77	IPWA	$\gamma N \to \pi N$

$N(1440) \to n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0.037 ±0 010	AWAJI	81	DPWA	$\gamma N \to \pi N$
0 030 ±0 003	FUJII	81	DPWA	$\gamma N \to \pi N$
0.023 ±0.009	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0.019 ±0 012	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0 056 ±0 015	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0.029 ±0 035	TAKEDA	80	DPWA	$\gamma N \to \pi N$
+0 059 ±0 016	BARBOUR	78	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages fits limits, etc • • •				
0 062	[10] NOELLE	78		$\gamma N \to \pi N$

N(1440) FOOTNOTES

[1] BAKER 79 finds a coupling of the N(1440) to the $N\eta$ channel near (but slightly below) threshold

[2] LONGACRE 77 pole positions are from a search for poles in the unitarized T matrix the first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes

[3] From method II of LONGACRE 75 eyeball fits with Breit-Wigner circles to the T matrix amplitudes

[4] ARNDT 85 finds a second P_{11} pole at (1410, −80) MeV

[5] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis

[6] An alternative which cannot be distinguished from this is to have a P_{13} resonance with M = 1530 MeV Γ = 79 MeV, and elasticity = +0 271

[7] MANLEY 84 considers this coupling sign to be well determined

[8] LONGACRE 77 considers this coupling to be well determined

[9] WADA 84 is inconsistent with other analyses see the Note on N and Δ Resonances

[10] Converted to our conventions using M = 1486 MeV Γ = 613 MeV from NOELLE 78

N(1440) REFERENCES

For early references see Physics Letters 111B (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
WADA	84	NP B247 313	+Egawa Imanishi Ishii Kato Ukai+	(INUS)
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
FUJII	81	NP B187 53	+Hayashii Iwata Kajikawa+	(TOKY)
ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
BRATASHEV	80	NP B166 525	Bratashevskij Gorbenko Derebchinskij+	(KHAR)
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
ISHII	80	NP B165 189	+Egawa Kato Miyachi+	(KYOT TOKY)
TAKEDA	80	NP B168 17	+Arai Fujii Ikeda Iwasaki+	(TOKY)
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
NOELLE	78	PTP 60 778		(NAGO)
BERENDS	77	NP B136 317	+Donnachie	(LEID MCHS) IJP
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+	(NAGO OSAK) IJP
FELTESSE	75	NP B93 242	+Ayed Bareyre Borgeaud David+	(SACL) IJP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP

N(1520) D_{13}

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters 111B) In addition results in this region from production experiments which used to be listed separately as the next entry have been entirely omitted They too may be found in our 1982 edition

N(1520) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1510 to 1530 OUR ESTIMATE				
1525 ± 10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1519 ± 4	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1504	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1503	BARBOUR	78	DPWA	$\gamma N \to \pi N$
1510	BERENDS	77	IPWA	$\gamma N \to \pi N$
1510	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1520	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N(1520) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
100 to 140 OUR ESTIMATE				
120 ± 15	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
114 ± 7	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc • • •				
124	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
183	BAKER	79	DPWA	$\pi^- p \to n\eta$
135	BARBOUR	78	DPWA	$\gamma N \to \pi N$
105	BERENDS	77	IPWA	$\gamma N \to \pi N$
110	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
150	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N(1520) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1510 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits limits etc • • •				
1510	ARNDT	85	DPWA	$\pi N \to \pi N$
1514 or 1511	[3] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
1508 or 1505	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
114 ± 10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
122	ARNDT	85	DPWA	$\pi N \to \pi N$
146 or 137	[3] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
109 or 107	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

N(1520) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
34 ± 2	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−7 ± 3	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

N(1520) DECAY MODES

Γ_1 $N(1520) \to N\pi$

Γ_2 $N(1520) \to N\eta$

Γ_3 $N(1520) \to N\pi\pi$

Γ_4 $N(1520) \to \Delta(1232)\pi$, S-wave

Γ_5 $N(1520) \to \Delta(1232)\pi$, D-wave

Γ_6 $N(1520) \to N\rho$, S=1/2, D-wave

Γ_7 $N(1520) \to N\rho$, S=3/2, S-wave

Γ_8 $N(1520) \to N\rho$, S=3/2, D-wave

Γ_9 $N(1520) \to N(\pi\pi)_{S\text{-wave}}$
Γ_{10} $N(1520) \to p\gamma$, helicity=1/2
Γ_{11} $N(1520) \to p\gamma$, helicity=3/2
Γ_{12} $N(1520) \to n\gamma$, helicity=1/2
Γ_{13} $N(1520) \to n\gamma$, helicity=3/2

N(1520) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.5 to 0.6 OUR ESTIMATE				
0.58 ± 0.03	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.54 ± 0.03	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1520) \to N\eta$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.02	BAKER	79	DPWA	$\pi^- p \to n\eta$
+0.011 or +0.058	FELTESSE	75	DPWA	1488–1745 MeV

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1520) \to \Delta(1232)\pi$, S-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− (LARGE)	[4] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0.26	[1,5] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0.24	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1520) \to \Delta(1232)\pi$, D-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− (LARGE)	[4] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0.21	[1,5] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0.30	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1520) \to N\rho$, S=3/2, S-wave $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− (LARGE)	[4] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0.35	[1,5] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0.24	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1520) \to N(\pi\pi)_{S\text{-wave}}$ $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.13	[1,5] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0.17	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N(1520) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$N(1520) \to p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.028 ± 0.014	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
−0.007 ± 0.004	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.032 ± 0.005	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0.032 ± 0.004	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0.031 ± 0.009	BRATASHEV	80	DPWA	$\gamma N \to \pi N$
−0.019 ± 0.007	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0.0430 ± 0.0063	ISHII	80	DPWA	Compton scattering
−0.016 ± 0.008	BARBOUR	78	DPWA	$\gamma N \to \pi N$
−0.005 ± 0.005	FELLER	76	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
−0.012	WADA	84	DPWA	Compton scattering
−0.008	[6] NOELLE	78		$\gamma N \to \pi N$
−0.021	BERENDS	77	IPWA	$\gamma N \to \pi N$

$N(1520) \to p\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0.156 ± 0.022	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0.168 ± 0.013	AWAJI	81	DPWA	$\gamma N \to \pi N$
0.178 ± 0.003	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0.162 ± 0.003	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0.166 ± 0.005	BRATASHEV	80	DPWA	$\gamma N \to \pi N$
0.167 ± 0.010	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
0.1695 ± 0.0014	ISHII	80	DPWA	Compton scattering
+0.157 ± 0.007	BARBOUR	78	DPWA	$\gamma N \to \pi N$
+0.164 ± 0.008	FELLER	76	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages, fits, limits etc • • •				
0.168	WADA	84	DPWA	Compton scattering
0.206	[6] NOELLE	78		$\gamma N \to \pi N$
+0.075	BERENDS	77	IPWA	$\gamma N \to \pi N$

$N(1520) \to n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.066 ± 0.013	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.067 ± 0.004	FUJII	81	DPWA	$\gamma N \to \pi N$
−0.076 ± 0.006	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0.071 ± 0.011	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0.056 ± 0.011	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0.050 ± 0.014	TAKEDA	80	DPWA	$\gamma N \to \pi N$
−0.055 ± 0.014	BARBOUR	78	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
−0.060	[6] NOELLE	78		$\gamma N \to \pi N$

$N(1520) \to n\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.124 ± 0.009	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.158 ± 0.003	FUJII	81	DPWA	$\gamma N \to \pi N$
−0.147 ± 0.008	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0.148 ± 0.009	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0.144 ± 0.015	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0.118 ± 0.011	TAKEDA	80	DPWA	$\gamma N \to \pi N$
−0.141 ± 0.015	BARBOUR	78	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc • • •				
−0.127	[6] NOELLE	78		$\gamma N \to \pi N$

N(1520) FOOTNOTES

[1] LONGACRE 77 pole positions are from a search for poles in the unitarized T matrix the first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis The other LONGACRE 77 values are from eyeball fits with Breit Wigner circles to the T-matrix amplitudes
[2] From method II of LONGACRE 75 eyeball fits with Breit-Wigner circles to the T-matrix amplitudes
[3] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial-wave analysis
[4] MANLEY 84 considers this coupling sign to be well determined
[5] LONGACRE 77 considers this coupling to be well determined
[6] Converted to our conventions using M = 1528 MeV, Γ = 187 MeV from NOELLE 78

N(1520) REFERENCES

For early references see Physics Letters 111B (1982) For very early references see Rev Mod Phys 37 633 (1965)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
WADA	84	NP B247 313	+Egawa Imanishi Ishii Kato Ukai+	(INUS)
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
FUJII	81	NP B187 53	+Hayashii Iwata Kajikawa+	(TOKY)
ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
BRATASHEV	80	NP B166 525	Bratashevskij Gorbenko Derebchinskij+	(KHAR)
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
ISHII	80	NP B165 189	+Egawa Kato Miyachi+	(KYOT TOKY)
TAKEDA	80	NP B168 17	+Arai Fujii Ikeda Iwasaki+	(TOKY)
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
NOELLE	78	PTP 60 778		(NAGO)
BERENDS	77	NP B136 317	+Donnachie	(LEID MCHS) IJP
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+	(NAGO OSAK) IJP
FELTESSE	75	NP B93 242	+Ayed Bareyre Borgeaud David+	(SACL) IJP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP

N(1535) S_{11}

$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters 111B)

N(1535) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1520 to 1560 OUR ESTIMATE				
1550 ± 40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1526 ± 7	HOEHLER	79	IPWA	$\pi N \to \pi N$

• • • We do not use the following data for averages fits limits, etc • • •

1513	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1511	BARBOUR	78	DPWA	$\gamma N \to \pi N$
1500	BERENDS	77	IPWA	$\gamma N \to \pi N$
1547 ± 6	BHANDARI	77	DPWA	Uses $N\eta$ cusp
1520	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1510	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$N(1535)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
100 to 250 OUR ESTIMATE				
240 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
120 ± 20	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
136	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
180	BAKER	79	DPWA	$\pi^- p \to n\eta$
132	BARBOUR	78	DPWA	$\gamma N \to \pi N$
57	BERENDS	77	IPWA	$\gamma N \to \pi N$
139 ± 33	BHANDARI	77	DPWA	Uses $N\eta$ cusp
135	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
100	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$N(1535)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1510 ± 50	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1461	ARNDT	85	DPWA	$\pi N \to \pi N$
1496 or 1499	[3] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
1519 ± 4	BHANDARI	77	DPWA	Uses $N\eta$ cusp
1525 or 1527	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$-2 \times$ IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
260 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits etc • • •				
140	ARNDT	85	DPWA	$\pi N \to \pi N$
103 or 105	[3] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
140 ± 32	BHANDARI	77	DPWA	Uses $N\eta$ cusp
135 or 123	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$N(1535)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
116 ± 46	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits, limits etc • • •				
20 ± 21	BHANDARI	77	DPWA	Uses $N\eta$ cusp

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
31 ± 92	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
13 ± 8	BHANDARI	77	DPWA	Uses $N\eta$ cusp

$N(1535)$ DECAY MODES

Γ_1	$N(1535) \to N\pi$
Γ_2	$N(1535) \to N\eta$
Γ_3	$N(1535) \to N\pi\pi$
Γ_4	$N(1535) \to \Delta(1232)\pi$, D-wave
Γ_5	$N(1535) \to N\rho$, S=1/2, S-wave
Γ_6	$N(1535) \to N\rho$, S=3/2, D-wave
Γ_7	$N(1535) \to N(\pi\pi)_{S\text{-wave}}$
Γ_8	$N(1535) \to p\gamma$, helicity=1/2
Γ_9	$N(1535) \to n\gamma$, helicity=1/2

$N(1535)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.35 to 0.50 OUR ESTIMATE				
0 50 ± 0 10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 38 ± 0 04	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
0.297 ± 0.026	BHANDARI	77	DPWA	Uses $N\eta$ cusp

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1535) \to N\eta$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0 33	BAKER	79	DPWA	$\pi^- p \to n\eta$
+0.48	FELTESSE	75	DPWA	1488–1745 MeV

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon first convention the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1535) \to \Delta(1232)\pi$, D-wave — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.00	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0 06	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1535) \to N\rho$, S=1/2, S-wave — $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− (SMALL)	[4] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0 10	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0 09	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1535) \to N(\pi\pi)_{S\text{-wave}}$ — $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (SMALL)	[4] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0 08	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0 09	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$N(1535)$ PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes, see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$N(1535) \to p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 053 ± 0 015	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0 077 ± 0 021	AWAJI	81	DPWA	$\gamma N \to \pi N$
0 083 ± 0 007	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0.080 ± 0.007	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0 029 ± 0 007	BRATASHEV	80	DPWA	$\gamma N \to \pi N$
0 065 ± 0 016	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
0.0704 ± 0 0091	ISHII	80	DPWA	Compton scattering
+0 082 ± 0 019	BARBOUR	78	DPWA	$\gamma N \to \pi N$
+0 070 ± 0 004	FELLER	76	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
0 055	WADA	84	DPWA	Compton scattering
0 046	[5] NOELLE	78		$\gamma N \to \pi N$
+0 034	BERENDS	77	IPWA	$\gamma N \to \pi N$

$N(1535) \to n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 035 ± 0 014	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0 062 ± 0 003	FUJII	81	DPWA	$\gamma N \to \pi N$
−0 075 ± 0 019	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0 075 ± 0.018	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0 098 ± 0 026	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0 011 ± 0 017	TAKEDA	80	DPWA	$\gamma N \to \pi N$
−0 112 ± 0 034	BARBOUR	78	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
−0 048	[5] NOELLE	78		$\gamma N \to \pi N$

$N(1535)$ FOOTNOTES

[1] LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix the first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis The other LONGACRE 77 values are from eyeball fits with Breit Wigner circles to the T matrix amplitudes

[2] From method II of LONGACRE 75 eyeball fits with Breit Wigner circles to the T matrix amplitudes

[3] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis

[4] MANLEY 84 considers this coupling sign to be well determined

[5] Converted to our conventions using M = 1548 MeV Γ = 73 MeV from NOELLE 78

$N(1535)$ REFERENCES

For early references see Physics Letters 111B (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
WADA	84	NP B247 313	+Egawa Imanishi Ishii Kato Ukai+	(INUS)
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
FUJII	81	NP B187 53	+Hayashii Iwata Kajikawa+	(TOKY)

Baryon Full Listings
$N(1535)$, $N(1540)$, $N(1650)$

ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
BRATASHEV	80	NP B166 525	Bratashevskij Gorbenko Derebchinskij+	(KHAR)
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
ISHII	80	NP B165 189	+Egawa Kato Miyachi+	(KYOT TOKY)
TAKEDA	80	NP B168 17	+Arai Fujii Ikeda Iwasaki+	(TOKY)
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
NOELLE	78	PTP 60 778		(NAGO)
BERENDS	77	NP B136 317	+Donnachie	(LEID MCHS) IJP
BHANDARI	77	PR D15 192	+Chao	(CMU) IJP
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+	(NAGO OSAK) IJP
FELTESSE	75	NP B93 242	+Ayed Bareyre Borgeaud David+	(SACL) IJP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP

OTHER RELATED PAPERS

DAVIES	67B	NC 52A 1112	+Moorhouse	(GLAS RHEL)

$N(1540)$ P_{13}

$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$ Status *

OMITTED FROM SUMMARY TABLE

Not seen in $\pi N \to \pi N$ analyses and its existence is thus doubtful

$N(1540)$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1540	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

$N(1540)$ WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
200	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

$N(1540)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1535 or 1482	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

$-2 \times$ IMAGINARY PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
207 or 314	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

$N(1540)$ DECAY MODES

Γ_1 $N(1540) \to N\pi$
Γ_2 $N(1540) \to \Delta(1232)\pi$, P-wave
Γ_3 $N(1540) \to N\rho$, S=1/2, P-wave
Γ_4 $N(1540) \to N\rho$, S=3/2, P-wave
Γ_5 $N(1540) \to N(\pi\pi)_{S\text{-wave}}$
Γ_6 $N(1540) \to p\gamma$, helicity=1/2
Γ_7 $N(1540) \to p\gamma$, helicity=3/2

$N(1540)$ BRANCHING RATIOS

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\pi \to N(1540) \to \Delta(1232)\pi$, P-wave $(\Gamma_1\Gamma_2)^{½}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
−0 11	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\pi \to N(1540) \to N\rho$, S=1/2, P-wave $(\Gamma_1\Gamma_3)^{½}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
+0 08	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\pi \to N(1540) \to N\rho$, S=3/2, P-wave $(\Gamma_1\Gamma_4)^{½}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
0.00	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\pi \to N(1540) \to N(\pi\pi)_{S\text{-wave}}$ $(\Gamma_1\Gamma_5)^{½}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
0.00	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

$N(1540)$ PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$N(1540) \to p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID	TECN	COMMENT
−0 014 ± 0 028	CRAWFORD 83	IPWA	$\gamma N \to \pi N$

$N(1540) \to p\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID	TECN	COMMENT
0 009 ± 0 027	CRAWFORD 83	IPWA	$\gamma N \to \pi N$

$N(1540)$ FOOTNOTES

[1] LONGACRE 77 pole positions are from a search for poles in the unitarized T matrix the first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T matrix amplitudes

$N(1540)$ REFERENCES

CRAWFORD	83	NP B211 1	+Morton	(GLAS)
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP

$N(1650)$ S_{11}

$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**)

$N(1650)$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1620 to 1680 OUR ESTIMATE			
1650 ± 30	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
1670 ± 8	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits, etc • • •			
1688	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
1672	MUSETTE 80	IPWA	$\pi^- p \to \Lambda K^0$
1680	SAXON 80	DPWA	$\pi^- p \to \Lambda K^0$
1680	BAKER 78	DPWA	$\pi^- p \to \Lambda K^0$
1694	BARBOUR 78	DPWA	$\gamma N \to \pi N$
1700 ± 5	[1] BAKER 77	IPWA	$\pi^- p \to \Lambda K^0$
1680	[1] BAKER 77	DPWA	$\pi^- p \to \Lambda K^0$
1700	[2] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$
1675	KNASEL 75	DPWA	$\pi^- p \to \Lambda K^0$
1660	[3] LONGACRE 75	IPWA	$\pi N \to N\pi\pi$

$N(1650)$ WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
100 to 200 OUR ESTIMATE			
150 ± 40	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
180 ± 20	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits, limits etc • • •			
183	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
179	MUSETTE 80	IPWA	$\pi^- p \to \Lambda K^0$
120	SAXON 80	DPWA	$\pi^- p \to \Lambda K^0$
90	BAKER 78	DPWA	$\pi^- p \to \Lambda K^0$
193	BARBOUR 78	DPWA	$\gamma N \to \pi N$
130 ± 10	[1] BAKER 77	IPWA	$\pi^- p \to \Lambda K^0$
90	[1] BAKER 77	DPWA	$\pi^- p \to \Lambda K^0$
170	[2] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$
170	KNASEL 75	DPWA	$\pi^- p \to \Lambda K^0$
130	[3] LONGACRE 75	IPWA	$\pi N \to N\pi\pi$

$N(1650)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1640 ± 20	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1660	ARNDT	85	DPWA	$\pi N \to \pi N$
1648 or 1651	[4] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
1699 or 1698	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
150 ± 30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
122	ARNDT	85	DPWA	$\pi N \to \pi N$
117 or 119	[4] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
174 or 173	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$N(1650)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
16 ± 25	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
− 58 ± 12	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$N(1650)$ DECAY MODES

Γ_1	$N(1650) \to N\pi$
Γ_2	$N(1650) \to N\eta$
Γ_3	$N(1650) \to \Lambda K$
Γ_4	$N(1650) \to \Sigma K$
Γ_5	$N(1650) \to N\pi\pi$
Γ_6	$N(1650) \to \Delta(1232)\pi$, D-wave
Γ_7	$N(1650) \to N\rho$, S=1/2, S-wave
Γ_8	$N(1650) \to N\rho$, S=3/2, D-wave
Γ_9	$N(1650) \to N(\pi\pi)_{S\text{-wave}}$
Γ_{10}	$N(1650) \to N(1440)\pi$, S-wave
Γ_{11}	$N(1650) \to p\gamma$, helicity=1/2
Γ_{12}	$N(1650) \to n\gamma$, helicity=1/2

$N(1650)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.55 to 0.65 OUR ESTIMATE				
0.65 ± 0 10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 61 ± 0.04	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to N\eta$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.09	[5] BAKER	79	DPWA	$\pi^- p \to n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to \Lambda K$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 22	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
−0 22	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
• • • We do not use the following data for averages, fits, limits, etc • • •				
−0 25	[6] BAKER	78	DPWA	See SAXON 80
−0 23 ± 0 01	[1] BAKER	77	IPWA	$\pi^- p \to \Lambda K^0$
−0 25	[1] BAKER	77	DPWA	$\pi^- p \to \Lambda K^0$
0 12	KNASEL	75	DPWA	$\pi^- p \to \Lambda K^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to \Sigma K$ — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
−0 254	LIVANOS	80	DPWA	$\pi p \to \Sigma K$
0 066 to 0 137	[7] DEANS	75	DPWA	$\pi N \to \Sigma K$
0 20	KNASEL	75	DPWA	

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon first convention the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to \Delta(1232)\pi$, D-wave — $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (LARGE)	[8] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0.29	[2,9] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0.15	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to N\rho$, S=1/2, S-wave — $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0 17	[2,9] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0.16	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to N\rho$, S=3/2, D-wave — $(\Gamma_1\Gamma_8)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
LARGE	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0.29	[2,9] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to N(\pi\pi)_{S\text{-wave}}$ — $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
0 00	[2,9] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0 25	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to N(1440)\pi$, S-wave — $(\Gamma_1\Gamma_{10})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+	MANLEY	84	IPWA	$\pi N \to N\pi\pi$

$N(1650)$ PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$N(1650) \to p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 033 ± 0 015	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0 050 ± 0 010	AWAJI	81	DPWA	$\gamma N \to \pi N$
0.065 ± 0.005	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0 061 ± 0 005	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0.031 ± 0 017	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
+0 048 ± 0 017	BARBOUR	78	DPWA	$\gamma N \to \pi N$
+0 068 ± 0 009	FELLER	76	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
0 091	WADA	84	DPWA	Compton scattering

$N(1650) \to n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0 008 ± 0 004	AWAJI	81	DPWA	$\gamma N \to \pi N$
0 004 ± 0 004	FUJII	81	DPWA	$\gamma N \to \pi N$
0.010 ± 0 020	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0 008 ± 0 019	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0.068 ± 0.040	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0 011 ± 0 011	TAKEDA	80	DPWA	$\gamma N \to \pi N$
−0 045 ± 0 024	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(1650)$ FOOTNOTES

[1] The two BAKER 77 entries are from an IPWA using the Barrelet-zero method and from a conventional energy dependent analysis

[2] LONGACRE 77 pole positions are from a search for poles in the unitarized T matrix, the first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis The other LONGACRE 77 values are from eyeball fits with Breit Wigner circles to the T matrix amplitudes

[3] From method II of LONGACRE 75 eyeball fits with Breit Wigner circles to the T matrix amplitudes

[4] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis

[5] BAKER 79 fixed this coupling during fitting but the negative sign relative to the $N(1535)$ is well determined

[6] The overall phase of BAKER 78 couplings has been changed to agree with previous conventions Superseded by SAXON 80

[7] The range given for DEANS 75 is from the four best solutions

[8] MANLEY 84 considers this coupling sign to be well determined

[9] LONGACRE 77 considers this coupling to be well determined

$N(1650)$ REFERENCES

For early references see Physics Letters **111B** (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
WADA	84	NP B247 313	+Egawa Imanishi Ishii Kato Ukai+	(INUS)
BELL	83	NP B222 389	+Blissett Broome Daley Hart Lintern+	(RL) IJP
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
FUJII	81	NP B187 53	+Hayashii Iwata Kajikawa+	(TOKY)

ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
LIVANOS	80	Toronto Conf 35	+Baton Coutures Kochowski Neveu	(SACL) IJP
MUSETTE	80	NC 57A 37		(BRUX) IJP
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS) IJP
TAKEDA	80	NP B168 17	+Arai Fujii Ikeda Iwasaki+	(TOKY)
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BAKER	78	NP B141 29	+Blissett Bloodworth Broome+	(RL CAMB) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
BAKER	77	NP B126 365	+Blissett Bloodworth Broome Hart+	(RHEL) IJP
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+	(NAGO OSAK) IJP
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP
KNASEL	75	PR D11 1	+Lindquist Nelson+	(CHIC WUSL OSU ANL) IJP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP

$N(1675)$ D_{15}

$I(J^P) = \frac{1}{2}(\frac{5}{2}^-)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition (Physics Letters **111B**). In addition, results in this region from production experiments, which used to be listed separately in an entry following the $N(1700)$, have been entirely omitted. They too may be found in our 1982 edition.

$N(1675)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1660 to 1690 OUR ESTIMATE				
1675 ± 10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1679 ± 8	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1685	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1670	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
1680	BARBOUR	78	DPWA	$\gamma N \to \pi N$
1650	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1660	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$N(1675)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
120 to 180 OUR ESTIMATE				
160 ± 20	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
120 ± 15	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
191	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
40	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
88	BAKER	79	DPWA	$\pi^- p \to n\eta$
192	BARBOUR	78	DPWA	$\gamma N \to \pi N$
130	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
150	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$N(1675)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1660 ± 10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1661	ARNDT	85	DPWA	$\pi N \to \pi N$
1663 or 1668	[3] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
1649 or 1650	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
140 ± 10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
142	ARNDT	85	DPWA	$\pi N \to \pi N$
146 or 171	[3] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
127 or 127	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$N(1675)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
27 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
− 16 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$N(1675)$ DECAY MODES

Γ_1	$N(1675) \to N\pi$
Γ_2	$N(1675) \to N\eta$
Γ_3	$N(1675) \to \Lambda K$
Γ_4	$N(1675) \to \Sigma K$
Γ_5	$N(1675) \to N\pi\pi$
Γ_6	$N(1675) \to \Delta(1232)\pi$, D-wave
Γ_7	$N(1675) \to \Delta(1232)\pi$, G-wave
Γ_8	$N(1675) \to N\rho$, S=1/2, D-wave
Γ_9	$N(1675) \to N\rho$, S=3/2, D-wave
Γ_{10}	$N(1675) \to N\rho$, S=3/2, G-wave
Γ_{11}	$N(1675) \to N(\pi\pi)_{S\text{-wave}}$
Γ_{12}	$N(1675) \to N(1520)\pi$, P-wave
Γ_{13}	$N(1675) \to p\gamma$, helicity=1/2
Γ_{14}	$N(1675) \to p\gamma$, helicity=3/2
Γ_{15}	$N(1675) \to n\gamma$, helicity=1/2
Γ_{16}	$N(1675) \to n\gamma$, helicity=3/2

$N(1675)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.35 to 0.40 OUR ESTIMATE				
0.38 ± 0.05	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.38 ± 0.03	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1675) \to N\eta$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.07	BAKER	79	DPWA	$\pi^- p \to n\eta$
0.0 or +0.009	FELTESSE	75	DPWA	1488–1745 MeV

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1675) \to \Lambda K$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.01	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
+0.036	[4] SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
−0.034 ± 0.006	DEVENISH	74B		Fixed t dispersion rel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1675) \to \Sigma K$ — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.003	[5] DEANS	75	DPWA	$\pi N \to \Sigma K$

Note: Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon first convention: the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$.

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1675) \to \Delta(1232)\pi$, D-wave — $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (LARGE)	[6] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0.46	[1,7] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0.50	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
+0.5	[8] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1675) \to N\rho$, S=3/2, D-wave — $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− (SMALL)	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0.15	[1,7] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1675) \to N(\pi\pi)_{S\text{-wave}}$ — $(\Gamma_1\Gamma_{11})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.03	[1,7] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1675) \to N(1520)\pi$, P-wave — $(\Gamma_1\Gamma_{12})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.15	MANLEY	84	IPWA	$\pi N \to N\pi\pi$

$N(1675)$ PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes, see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$N(1675) \to p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID	TECN	COMMENT
0.021 ± 0.011	CRAWFORD 83	IPWA	$\gamma N \to \pi N$
0.034 ± 0.005	AWAJI 81	DPWA	$\gamma N \to \pi N$
0.006 ± 0.005	ARAI 80	DPWA	$\gamma N \to \pi N$ (fit 1)
0.006 ± 0.004	ARAI 80	DPWA	$\gamma N \to \pi N$ (fit 2)
0.023 ± 0.015	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
+0.022 ± 0.010	BARBOUR 78	DPWA	$\gamma N \to \pi N$
+0.034 ± 0.004	FELLER 76	DPWA	$\gamma N \to \pi N$

$N(1675) \to p\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID	TECN	COMMENT
0.015 ± 0.009	CRAWFORD 83	IPWA	$\gamma N \to \pi N$
0.024 ± 0.008	AWAJI 81	DPWA	$\gamma N \to \pi N$
0.030 ± 0.004	ARAI 80	DPWA	$\gamma N \to \pi N$ (fit 1)
0.029 ± 0.004	ARAI 80	DPWA	$\gamma N \to \pi N$ (fit 2)
0.003 ± 0.012	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
+0.015 ± 0.006	BARBOUR 78	DPWA	$\gamma N \to \pi N$
+0.019 ± 0.009	FELLER 76	DPWA	$\gamma N \to \pi N$

$N(1675) \to n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID	TECN	COMMENT
−0.057 ± 0.024	AWAJI 81	DPWA	$\gamma N \to \pi N$
−0.033 ± 0.004	FUJII 81	DPWA	$\gamma N \to \pi N$
−0.039 ± 0.017	ARAI 80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0.025 ± 0.027	ARAI 80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0.059 ± 0.015	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
−0.021 ± 0.011	TAKEDA 80	DPWA	$\gamma N \to \pi N$
−0.066 ± 0.020	BARBOUR 78	DPWA	$\gamma N \to \pi N$

$N(1675) \to n\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID	TECN	COMMENT
−0.077 ± 0.018	AWAJI 81	DPWA	$\gamma N \to \pi N$
−0.069 ± 0.004	FUJII 81	DPWA	$\gamma N \to \pi N$
−0.066 ± 0.026	ARAI 80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0.071 ± 0.022	ARAI 80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0.059 ± 0.020	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
−0.030 ± 0.012	TAKEDA 80	DPWA	$\gamma N \to \pi N$
−0.073 ± 0.014	BARBOUR 78	DPWA	$\gamma N \to \pi N$

$N(1675)$ FOOTNOTES

[1] LONGACRE 77 pole positions are from a search for poles in the unitarized T matrix the first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis The other LONGACRE 77 values are from eyeball fits with Breit Wigner circles to the T-matrix amplitudes

[2] From method II of LONGACRE 75 eyeball fits with Breit-Wigner circles to the T-matrix amplitudes

[3] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial-wave analysis

[4] SAXON 80 finds the coupling phase is near 90°

[5] The range given is from the four best solutions DEANS 75 disagrees with $\pi^+ p \to \Sigma^+ K^+$ data of WINNIK 77 around 1920 MeV

[6] MANLEY 84 considers this coupling sign to be well determined

[7] LONGACRE 77 considers this coupling to be well determined

[8] A Breit Wigner fit to the HERNDON 75 IPWA

$N(1675)$ REFERENCES

For early references see Physics Letters 111B (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)	
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)	
BELL	83	NP B222 389	+Blissett Broome Daley Hart Lintern+	(RL)	IJP
CRAWFORD	83	NP B211 1	+Morton	(GLAS)	
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)	
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)	
FUJII	81	NP B187 53	+Hayashii Iwata Kajikawa+	(TOKY)	
ARAI	80	Toronto Conf 93		(TOKY)	
Also	82	NP B194 251	Arai Fujii	(TOKY)	
CRAWFORD	80	Toronto Conf 107		(GLAS)	
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL)	IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)	IJP
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS)	IJP
TAKEDA	80	NP B168 17	+Arai Fujii Ikeda Iwasaki+	(TOKY)	
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL)	IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL)	IJP
Also	80	Toronto Conf 3	Koch	(KARL)	IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)	
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)	
NOVOSELLER	78	NP B137 509		(CIT)	IJP
Also	78B	NP B137 445	Novoseller	(CIT)	IJP
LONGACRE	77	NP B122 493	+Dolbeau	(SACL)	IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL)	IJP
WINNIK	77	NP B128 66	+Toaff Revel Goldberg Berny	(HAIF)	I
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+	(NAGO OSAK)	IJP
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH)	IJP
FELTESSE	75	NP B93 242	+Ayed Bareyre Borgeaud David+	(SACL)	IJP
HERNDON	75	PR D11 3183	+Longacre Miller Rosenfeld+	(LBL SLAC)	
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC)	IJP
DEVENISH	74B	NP B81 330	+Froggatt Martin	(DESY NORD LOUC)	

$N(1680)$ F_{15}

$I(J^P) = \frac{1}{2}(\frac{5}{2}^+)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters 111B) In addition results in this region from production experiments which used to be listed separately in an entry following the $N(1700)$ have been entirely omitted They too may be found in our 1982 edition

$N(1680)$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1670 to 1690 OUR ESTIMATE			
1680 ± 10	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
1684 ± 3	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •			
1682	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
1680	BARBOUR 78	DPWA	$\gamma N \to \pi N$
1660	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$
1685	KNASEL 75	DPWA	$\pi^- p \to \Lambda K^0$
1670	[2] LONGACRE 75	IPWA	$\pi N \to N\pi\pi$

$N(1680)$ WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
110 to 140 OUR ESTIMATE			
120 ± 10	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
128 ± 8	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •			
121	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
119	BARBOUR 78	DPWA	$\gamma N \to \pi N$
150	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$
155	KNASEL 75	DPWA	$\pi^- p \to \Lambda K^0$
130	[2] LONGACRE 75	IPWA	$\pi N \to N\pi\pi$

$N(1680)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1667 ± 5	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •			
1680	ARNDT 85	DPWA	$\pi N \to \pi N$
1668 or 1674	[3] LONGACRE 78	IPWA	$\pi N \to N\pi\pi$
1656 or 1653	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
110 ± 10	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •			
120	ARNDT 85	DPWA	$\pi N \to \pi N$
132 or 137	[3] LONGACRE 78	IPWA	$\pi N \to N\pi\pi$
145 or 143	[1] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

$N(1680)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
31 ± 2	CUTKOSKY 80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
−14 ± 3	CUTKOSKY 80	IPWA	$\pi N \to \pi N$

$N(1680)$ DECAY MODES

Γ_1 $N(1680) \to N\pi$
Γ_2 $N(1680) \to N\eta$
Γ_3 $N(1680) \to \Lambda K$
Γ_4 $N(1680) \to \Sigma K$
Γ_5 $N(1680) \to N\pi\pi$
Γ_6 $N(1680) \to \Delta(1232)\pi$, P-wave
Γ_7 $N(1680) \to \Delta(1232)\pi$, F-wave
Γ_8 $N(1680) \to N\rho$, $S=1/2$, F-wave
Γ_9 $N(1680) \to N\rho$, $S=3/2$, P-wave
Γ_{10} $N(1680) \to N\rho$, $S=3/2$, F-wave

Γ_{11} $N(1680) \to N(\pi\pi)_{S\text{-wave}}$
Γ_{12} $N(1680) \to p\gamma$, helicity=1/2
Γ_{13} $N(1680) \to p\gamma$, helicity=3/2
Γ_{14} $N(1680) \to n\gamma$, helicity=1/2
Γ_{15} $N(1680) \to n\gamma$, helicity=3/2

$N(1680)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.55 to 0.65 OUR ESTIMATE				
0 62 ± 0 05	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 65 ± 0 02	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1680) \to N\eta$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
NOT SEEN	BAKER	79	DPWA	$\pi^- p \to n\eta$

$\Gamma(N\eta)/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
0 0005 or 0 001	[4] CARRERAS	70	MPWA	t pole + resonance
0 0004	[4] BOTKE	69	MPWA	t pole + resonance
0 003 ± 0 002	[4] DEANS	69	MPWA	t pole + resonance

$\Gamma(N\eta)/\Gamma(N\pi)$ Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits limits, etc • • •				
<0 027	HEUSCH	66	RVUE	π^0 η photoproduction

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1680) \to \Lambda K$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

Coupling to ΛK not required in the analyses of BAKER 77 SAXON 80 or BELL 83

VALUE	DOCUMENT ID		TECN	COMMENT
0 01	KNASEL	75	DPWA	$\pi^- p \to \Lambda K^0$
−0 009 ± 0 009	DEVENISH	74B		Fixed-t dispersion rel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1680) \to \Sigma K$ $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
<0 001	[5] DEANS	75	DPWA	$\pi N \to \Sigma K$

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon first convention the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1680) \to \Delta(1232)\pi$, P-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− (LARGE)	[6] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0 27	[1,7] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0 25	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$
• • • We do not use the following data for averages fits limits, etc • • •				
−0 38	[8] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1680) \to \Delta(1232)\pi$, F-wave $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (SMALL)	[6] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0 07	[1,7] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0 08	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$
• • • We do not use the following data for averages fits, limits etc • • •				
+0 05	[8] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1680) \to N\rho$, S=3/2, P-wave $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− (LARGE)	[6] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0 23	[1,7] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0 30	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$
• • • We do not use the following data for averages fits limits etc • • •				
−0 34	[8] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1680) \to N\rho$, S=3/2, F-wave $(\Gamma_1\Gamma_{10})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− (SMALL)	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0 15	[1,7] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1680) \to N(\pi\pi)_{S\text{-wave}}$ $(\Gamma_1\Gamma_{11})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (LARGE)	[6] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0 31	[1,7] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0 30	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$
• • • We do not use the following data for averages fits limits etc • • •				
+0 42	[8] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$

$N(1680)$ PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$N(1680) \to p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0 017 ± 0 018	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
−0 009 ± 0 006	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0 028 ± 0 003	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0 026 ± 0.003	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0 018 ± 0 014	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0 005 ± 0 015	BARBOUR	78	DPWA	$\gamma N \to \pi N$
−0 009 ± 0 002	FELLER	76	DPWA	$\gamma N \to \pi N$

$N(1680) \to p\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 132 ± 0 010	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0 115 ± 0 008	AWAJI	81	DPWA	$\gamma N \to \pi N$
0 115 ± 0.003	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0 122 ± 0 003	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0 141 ± 0 014	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
+0 138 ± 0 021	BARBOUR	78	DPWA	$\gamma N \to \pi N$
+0 121 ± 0 010	FELLER	76	DPWA	$\gamma N \to \pi N$

$N(1680) \to n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 017 ± 0 014	AWAJI	81	DPWA	$\gamma N \to \pi N$
0 032 ± 0 003	FUJII	81	DPWA	$\gamma N \to \pi N$
0 026 ± 0.005	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0 028 ± 0 014	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0 044 ± 0 012	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
0 025 ± 0 010	TAKEDA	80	DPWA	$\gamma N \to \pi N$
+0 037 ± 0 010	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(1680) \to n\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.033 ± 0 013	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0 023 ± 0 005	FUJII	81	DPWA	$\gamma N \to \pi N$
−0 024 ± 0 009	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0 029 ± 0 017	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0 033 ± 0 015	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0 035 ± 0 012	TAKEDA	80	DPWA	$\gamma N \to \pi N$
−0 038 ± 0 018	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(1680)$ FOOTNOTES

[1] LONGACRE 77 pole positions are from a search for poles in the unitarized T matrix, the first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial-wave analysis The other LONGACRE 77 values are from eyeball fits with Breit Wigner circles to the T-matrix amplitudes
[2] From method II of LONGACRE 75 eyeball fits with Breit-Wigner circles to the T matrix amplitudes
[3] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial-wave analysis
[4] The parametrization used may be double counting
[5] The range given is from 3 of 4 best solutions not present in solution 1 DEANS 75 disagrees with $\pi^+ p \to \Sigma^+ K^+$ data of WINNIK 77 around 1920 MeV
[6] MANLEY 84 considers this coupling sign to be well determined
[7] LONGACRE 77 considers this coupling to be well determined
[8] A Breit Wigner fit to the HERNDON 75 IPWA

$N(1680)$ REFERENCES

For early references, see Physics Letters **111B** (1982) For very early references see Rev Mod Phys **37** 633 (1965)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
BELL	83	NP B222 389	+Blissett Broome Daley Hart Lintern+	(RL) IJP
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
FUJII	81	NP B187 53	+Hayashii Iwata Kajikawa+	(TOKY)
ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS) IJP
TAKEDA	80	NP B168 17	+Arai Fujii Ikeda Iwasaki+	(TOKY)

BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
NOVOSELLER	78	NP B137 509		(CIT) IJP
Also	78B	NP B137 445	Novoseller	(CIT) IJP
BAKER	77	NP B126 365	+Blissett Bloodworth Broome Hart+	(RHEL) IJP
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP
WINNIK	77	NP B128 66	+Toaff Revel Goldberg Berny	(HAIF) I
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+	(NAGO OSAK) IJP
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP
HERNDON	75	PR D11 3183	+Longacre Miller Rosenfeld+	(LBL SLAC)
KNASEL	75	PR D11 1	+Lindquist Nelson+	(CHIC WUSL OSU ANL) IJP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP
DEVENISH	74B	NP B81 330	+Froggatt Martin	(DESY NORD LOUC)
CARRERAS	70	NP B16 35	+Donnachie	(DARE MCHS)
BOTKE	69	PR 180 1417		(UCSB)
DEANS	69	PR 185 1797	+Wooten	(SFLA)
HEUSCH	66	PRL 17 1019	+Prescott Dashen	(CIT)

$N(1700)$ D_{13}

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ Status * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**) In addition, results in this region from production experiments, which used to be listed separately as the next entry, have been entirely omitted They too may be found in our 1982 edition

The various partial-wave analyses do not agree very well

$N(1700)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1670 to 1730 OUR ESTIMATE				
1675 ± 25	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1731 ± 15	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1709	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1650	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
1880	[1] BAKER	79	DPWA	$\pi^- p \to n\eta$
1690 to 1710	BAKER	78	DPWA	$\pi^- p \to \Lambda K^0$
1719	BARBOUR	78	DPWA	$\gamma N \to \pi N$
1670 ± 10	[2] BAKER	77	IPWA	$\pi^- p \to \Lambda K^0$
1690	[2] BAKER	77	DPWA	$\pi^- p \to \Lambda K^0$
1660	[3] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1710	[4] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$N(1700)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
70 to 120 OUR ESTIMATE				
90 ± 40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
110 ± 30	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits, etc • • •				
166	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
70	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
87	[1] BAKER	79	DPWA	$\pi^- p \to n\eta$
70 to 100	BAKER	78	DPWA	$\pi^- p \to \Lambda K^0$
126	BARBOUR	78	DPWA	$\gamma N \to \pi N$
90 ± 25	[2] BAKER	77	IPWA	$\pi^- p \to \Lambda K^0$
100	[2] BAKER	77	DPWA	$\pi^- p \to \Lambda K^0$
600	[3] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
300	[4] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$N(1700)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1660 ± 30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1670	ARNDT	85	DPWA	$\pi N \to \pi N$
1710 or 1678	[5] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
1616 or 1613	[3] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
90 ± 40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
80	ARNDT	85	DPWA	$\pi N \to \pi N$
607 or 567	[5] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
577 or 575	[3] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$N(1700)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
6 ± 3	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
0 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$N(1700)$ DECAY MODES

Γ_1 $N(1700) \to N\pi$
Γ_2 $N(1700) \to N\eta$
Γ_3 $N(1700) \to \Lambda K$
Γ_4 $N(1700) \to \Sigma K$
Γ_5 $N(1700) \to \Delta(1232)\pi$, S-wave
Γ_6 $N(1700) \to \Delta(1232)\pi$, D-wave
Γ_7 $N(1700) \to N\rho$, S=1/2, D-wave
Γ_8 $N(1700) \to N\rho$, S=3/2, S-wave
Γ_9 $N(1700) \to N\rho$, S=3/2, D-wave
Γ_{10} $N(1700) \to N(\pi\pi)_{S\text{-wave}}$
Γ_{11} $N(1700) \to p\gamma$, helicity=1/2
Γ_{12} $N(1700) \to p\gamma$, helicity=3/2
Γ_{13} $N(1700) \to n\gamma$, helicity=1/2
Γ_{14} $N(1700) \to n\gamma$, helicity=3/2

$N(1700)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0 05 to 0.15 OUR ESTIMATE				
0 11 ± 0.05	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 08 ± 0 03	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1700) \to N\eta$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 065	BAKER	79	DPWA	$\pi^- p \to n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1700) \to \Lambda K$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 012	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
−0.012	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
+0 026 ± 0 019	DEVENISH	74B		Fixed t dispersion rel
• • • We do not use the following data for averages fits limits etc • • •				
−0 04	[6] BAKER	78	DPWA	See SAXON 80
−0 03 ± 0 004	[2] BAKER	77	IPWA	$\pi^- p \to \Lambda K^0$
−0 03	[2] BAKER	77	DPWA	$\pi^- p \to \Lambda K^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1700) \to \Sigma K$ $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
NOT SEEN	LIVANOS	80	DPWA	$\pi p \to \Sigma K$
<0 017	[7] DEANS	75	DPWA	$\pi N \to \Sigma K$

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon first convention the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1700) \to \Delta(1232)\pi$, S-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
SMALL	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
0.00	[3] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0 16	[4] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1700) \to \Delta(1232)\pi$, D-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (SMALL)	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0 12	[3] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0 14	[4] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

Baryon Full Listings
$N(1700)$, $N(1710)$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(1700) \rightarrow N\rho$, S=3/2, S-wave $(\Gamma_1\Gamma_8)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.07	[3] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
+0.07	[4] LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(1700) \rightarrow N(\pi\pi)_{S\text{-wave}}$ $(\Gamma_1\Gamma_{10})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (SMALL)	MANLEY	84	IPWA	$\pi N \rightarrow N\pi\pi$
0.00	[3] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
+0.2	[4] LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$N(1700)$ PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$N(1700) \rightarrow p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.016 ± 0.014	CRAWFORD	83	IPWA	$\gamma N \rightarrow \pi N$
−0.002 ± 0.013	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
−0.028 ± 0.007	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 1)
−0.029 ± 0.006	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 2)
−0.024 ± 0.019	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
−0.033 ± 0.021	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
−0.014 ± 0.025	FELLER	76	DPWA	$\gamma N \rightarrow \pi N$

$N(1700) \rightarrow p\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.009 ± 0.012	CRAWFORD	83	IPWA	$\gamma N \rightarrow \pi N$
0.029 ± 0.014	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
−0.002 ± 0.005	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 1)
0.014 ± 0.005	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 2)
−0.017 ± 0.014	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
−0.014 ± 0.025	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
0.0 ± 0.014	FELLER	76	DPWA	$\gamma N \rightarrow \pi N$

$N(1700) \rightarrow n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0.006 ± 0.024	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
−0.002 ± 0.013	FUJII	81	DPWA	$\gamma N \rightarrow \pi N$
−0.052 ± 0.030	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 1)
−0.055 ± 0.030	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 2)
0.052 ± 0.035	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
+0.050 ± 0.042	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$

$N(1700) \rightarrow n\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.033 ± 0.017	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
0.018 ± 0.018	FUJII	81	DPWA	$\gamma N \rightarrow \pi N$
−0.037 ± 0.036	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 1)
−0.035 ± 0.024	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 2)
0.041 ± 0.030	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
+0.035 ± 0.030	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$

$N(1700)$ FOOTNOTES

[1] The high mass found by BAKER 79 may be influenced by the $N(2080)$

[2] The two BAKER 77 entries are from an IPWA using the Barrelet zero method and from a conventional energy dependent analysis

[3] LONGACRE 77 pole positions are from a search for poles in the unitarized T matrix the first (second) value uses, in addition to $\pi N \rightarrow N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial wave analysis The other LONGACRE 77 values are from eyeball fits with Breit Wigner circles to the T-matrix amplitudes

[4] From method II of LONGACRE 75 eyeball fits with Breit Wigner circles to the T-matrix amplitudes

[5] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \rightarrow N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis

[6] The overall phase of BAKER 78 couplings has been changed to agree with previous conventions

[7] The range given is from the four best solutions

$N(1700)$ REFERENCES

For early references see Physics Letters **111B** (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
BELL	83	NP B222 389	+Blissett Broome Daley Hart Lintern+	(RL) IJP
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
FUJII	81	NP B187 53	+Hayashii Iwata Kajikawa+	(TOKY)
ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
LIVANOS	80	Toronto Conf 35	+Baton Coutures Kochowski Neveu	(SACL) IJP
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS) IJP
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BAKER	78	NP B141 29	+Blissett Bloodworth Broome+	(RL CAMB) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
BAKER	77	NP B126 365	+Blissett Bloodworth Broome Hart+	(RHEL) IJP
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+	(NAGO OSAK) IJP
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP
DEVENISH	74B	NP B81 330	+Froggatt Martin	(DESY NORD LOUC)

$N(1710)$ P_{11}

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**)

The various partial wave analyses do not agree very well

$N(1710)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1680 to 1740 OUR ESTIMATE				
1700 ± 50	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
1723 ± 9	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1692	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
1730	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$
1690	BAKER	79	DPWA	$\pi^- p \rightarrow n\eta$
1650 to 1680	BAKER	78	DPWA	$\pi^- p \rightarrow \Lambda K^0$
1721	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
1625 ± 10	[1] BAKER	77	IPWA	$\pi^- p \rightarrow \Lambda K^0$
1650	[1] BAKER	77	DPWA	$\pi^- p \rightarrow \Lambda K^0$
1720	[2] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
1670	KNASEL	75	DPWA	$\pi^- p \rightarrow \Lambda K^0$
1710	[3] LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$N(1710)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
90 to 130 OUR ESTIMATE				
90 ± 30	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
120 ± 15	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
540	BELL	83	DPWA	$\pi^- p \rightarrow \Lambda K^0$
200	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
550	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$
97	BAKER	79	DPWA	$\pi^- p \rightarrow n\eta$
90 to 150	BAKER	78	DPWA	$\pi^- p \rightarrow \Lambda K^0$
167	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
160 ± 6	[1] BAKER	77	IPWA	$\pi^- p \rightarrow \Lambda K^0$
95	[1] BAKER	77	DPWA	$\pi^- p \rightarrow \Lambda K^0$
120	[2] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
174	KNASEL	75	DPWA	$\pi^- p \rightarrow \Lambda K^0$
75	[3] LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$N(1710)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1690 ± 20	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages fits, limits etc • • •				
1708 or 1712	[4] LONGACRE	78	IPWA	$\pi N \rightarrow N\pi\pi$
1720 or 1711	[2] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$

$-2 \times$ IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
80 ± 20	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc • • •				
17 or 22	[4] LONGACRE	78	IPWA	$\pi N \rightarrow N\pi\pi$
123 or 115	[2] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$

$N(1710)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−8 ± 2	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$N(1710)$ DECAY MODES

Γ_1	$N(1710) \to N\pi$
Γ_2	$N(1710) \to N\eta$
Γ_3	$N(1710) \to \Lambda K$
Γ_4	$N(1710) \to \Sigma K$
Γ_5	$N(1710) \to N\pi\pi$
Γ_6	$N(1710) \to \Delta(1232)\pi$, P-wave
Γ_7	$N(1710) \to N\rho$, S=1/2, P-wave
Γ_8	$N(1710) \to N\rho$, S=3/2, P-wave
Γ_9	$N(1710) \to N(\pi\pi)_{S\text{-wave}}$
Γ_{10}	$N(1710) \to p\gamma$, helicity=1/2
Γ_{11}	$N(1710) \to n\gamma$, helicity=1/2

$N(1710)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.10 to 0.20 OUR ESTIMATE				
0.20 ± 0.04	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.12 ± 0.04	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1710) \to N\eta$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits etc • • •				
0.22	BAKER	79	DPWA	$\pi^- p \to n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1710) \to \Lambda K$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.16	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
+0.14	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
• • • We do not use the following data for averages, fits, limits etc • • •				
−0.12	[5] BAKER	78	DPWA	See SAXON 80
−0.05 ± 0.03	[1] BAKER	77	IPWA	$\pi^- p \to \Lambda K^0$
−0.10	[1] BAKER	77	DPWA	$\pi^- p \to \Lambda K^0$
0.10	KNASEL	75	DPWA	$\pi^- p \to \Lambda K^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1710) \to \Sigma K$ $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.034	LIVANOS	80	DPWA	$\pi p \to \Sigma K$
0.075 to 0.203	[6] DEANS	75	DPWA	$\pi N \to \Sigma K$

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon first convention the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1710) \to \Delta(1232)\pi$, P-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0.17	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0.20	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1710) \to N\rho$, S=1/2, P-wave $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0.19	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0.20	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1710) \to N\rho$, S=3/2, P-wave $(\Gamma_1\Gamma_8)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.31	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1710) \to N(\pi\pi)_{S\text{-wave}}$ $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.26	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0.28	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$N(1710)$ PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$N(1710) \to p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0.006 ± 0.018	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0.028 ± 0.009	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.009 ± 0.006	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0.012 ± 0.005	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0.015 ± 0.025	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
+0.001 ± 0.039	BARBOUR	78	DPWA	$\gamma N \to \pi N$
+0.053 ± 0.019	FELLER	76	DPWA	$\gamma N \to \pi N$

$N(1710) \to n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0.000 ± 0.018	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.001 ± 0.003	FUJII	81	DPWA	$\gamma N \to \pi N$
0.005 ± 0.013	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0.011 ± 0.021	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0.017 ± 0.020	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0.028 ± 0.045	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(1710)$ FOOTNOTES

[1] The two BAKER 77 entries are from an IPWA using the Barrelet zero method and from a conventional energy dependent analysis

[2] LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix the first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis The other LONGACRE 77 values are from eyeball fits with Breit Wigner circles to the T matrix amplitudes

[3] From method II of LONGACRE 75 eyeball fits with Breit Wigner circles to the T matrix amplitudes

[4] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis

[5] The overall phase of BAKER 78 couplings has been changed to agree with previous conventions

[6] The range given for DEANS 75 is from the four best solutions

$N(1710)$ REFERENCES

For early references see Physics Letters 111B (1982)

MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
BELL	83	NP B222 389	+Blissett Broome Daley Hart Lintern+	(RL) IJP
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
FUJII	81	NP B187 53	+Hayashii Iwata Kajikawa+	(TOKY)
ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
LIVANOS	80	Toronto Conf 35	+Baton Coutures Kochowski Neveu	(SACL) IJP
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS) IJP
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BAKER	78	NP B141 29	+Blissett Bloodworth Broome+	(RL CAMB) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
BAKER	77	NP B126 365	+Blissett Bloodworth Broome Hart+	(RHEL) IJP
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+	(NAGO OSAK) JP
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP
KNASEL	75	PR D11 1	+Lindquist Nelson+	(CHIC WUSL OSU ANL) JP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) JP

$N(1720)$ P_{13}

$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters 111B)

$N(1720)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1690 to 1800 OUR ESTIMATE				
1700 ± 50	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1710 ± 20	HOEHLER	79	IPWA	$\pi N \to \pi N$

• • • We do not use the following data for averages, fits, limits, etc. • • •

1785	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1690	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
1710 to 1790	BAKER	78	DPWA	$\pi^- p \to \Lambda K^0$
1809	BARBOUR	78	DPWA	$\gamma N \to \pi N$
1640 ± 10	[1] BAKER	77	IPWA	$\pi^- p \to \Lambda K^0$
1710	[1] BAKER	77	DPWA	$\pi^- p \to \Lambda K^0$
1750	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1850	KNASEL	75	DPWA	$\pi^- p \to \Lambda K^0$
1720	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N(1720) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
125 to 250 OUR ESTIMATE				
125 ± 70	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
190 ± 30	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
308	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
120	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
447	BAKER	79	DPWA	$\pi^- p \to n\eta$
300 to 400	BAKER	78	DPWA	$\pi^- p \to \Lambda K^0$
285	BARBOUR	78	DPWA	$\gamma N \to \pi N$
200 ± 50	[1] BAKER	77	IPWA	$\pi^- p \to \Lambda K^0$
500	[1] BAKER	77	DPWA	$\pi^- p \to \Lambda K^0$
130	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
327	KNASEL	75	DPWA	$\pi^- p \to \Lambda K^0$
150	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N(1720) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1680 ± 30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1705	ARNDT	85	DPWA	$\pi N \to \pi N$
1716 or 1716	[4] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
1745 or 1748	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
120 ± 40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
80	ARNDT	85	DPWA	$\pi N \to \pi N$
124 or 126	[4] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
135 or 123	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

N(1720) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−8 ± 2	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−3 ± 4	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

N(1720) DECAY MODES

- Γ_1 $N(1720) \to N\pi$
- Γ_2 $N(1720) \to N\eta$
- Γ_3 $N(1720) \to \Lambda K$
- Γ_4 $N(1720) \to \Sigma K$
- Γ_5 $N(1720) \to N\pi\pi$
- Γ_6 $N(1720) \to \Delta(1232)\pi$, P-wave
- Γ_7 $N(1720) \to N\rho$, S=1/2, P-wave
- Γ_8 $N(1720) \to N\rho$, S=3/2, P-wave
- Γ_9 $N(1720) \to N(\pi\pi)_{S\text{-wave}}$
- Γ_{10} $N(1720) \to p\gamma$, helicity=1/2
- Γ_{11} $N(1720) \to p\gamma$, helicity=3/2
- Γ_{12} $N(1720) \to n\gamma$, helicity=1/2
- Γ_{13} $N(1720) \to n\gamma$, helicity=3/2

N(1720) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.10 to 0.20 OUR ESTIMATE				
0.10 ± 0.04	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.14 ± 0.03	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1720) \to N\eta$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.08	BAKER	79	DPWA	$\pi^- p \to n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1720) \to \Lambda K$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.09	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
−0.11	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.09	[5] BAKER	78	DPWA	See SAXON 80
−0.06 ± 0.02	[1] BAKER	77	IPWA	$\pi^- p \to \Lambda K^0$
−0.09	[1] BAKER	77	DPWA	$\pi^- p \to \Lambda K^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1720) \to \Sigma K$ $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.051 to 0.087	[6] DEANS	75	DPWA	$\pi N \to \Sigma K$

Note: Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$.

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1720) \to \Delta(1232)\pi$, P-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.17	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1720) \to N\rho$, S=1/2, P-wave $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.26	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0.40	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1720) \to N\rho$, S=3/2, P-wave $(\Gamma_1\Gamma_8)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.15	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1720) \to N(\pi\pi)_{S\text{-wave}}$ $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.19	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

N(1720) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes, see Sec. IV of the Note on N and Δ Resonances preceding the Baryon Listings.

$N(1720) \to p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0.044 ± 0.066	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
−0.004 ± 0.007	AWAJI	81	DPWA	$\gamma N \to \pi N$
0.051 ± 0.009	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0.071 ± 0.010	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0.038 ± 0.050	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
+0.111 ± 0.047	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(1720) \to p\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.024 ± 0.006	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
−0.040 ± 0.016	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.058 ± 0.010	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0.011 ± 0.011	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0.014 ± 0.040	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0.063 ± 0.032	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(1720) \to n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0.002 ± 0.005	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.019 ± 0.033	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0.001 ± 0.038	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0.003 ± 0.034	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
+0.007 ± 0.020	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(1720) \to n\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.015 ± 0.019	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.139 ± 0.039	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0.134 ± 0.044	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0.018 ± 0.028	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
+0.051 ± 0.051	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(1720)$ FOOTNOTES

[1] The two BAKER 77 entries are from an IPWA using the Barrelet-zero method and from a conventional energy dependent analysis

[2] LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix, the first (second) value uses in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T matrix amplitudes

[3] From method II of LONGACRE 75 eyeball fits with Breit Wigner circles to the T matrix amplitudes

[4] LONGACRE 78 values are from a search for poles in the unitarized T-matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial-wave analysis

[5] The overall phase of BAKER 78 copulings has been changed to agree with previous conventions

[6] The range given is from the four best solutions DEANS 75 disagrees with $\pi^+ p \to \Sigma^+ K^+$ data of WINNIK 77 around 1920 MeV

$N(1720)$ REFERENCES

For early references see Physics Letters 111B (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)	
BELL	83	NP B222 389	+Blissett Broome Daley Hart Lintern+	(RL)	IJP
CRAWFORD	83	NP B211 1	+Morton	(GLAS)	
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)	
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)	
ARAI	80	Toronto Conf 93		(TOKY)	
Also	82	NP B194 251	Arai Fujii	(TOKY)	
CRAWFORD	80	Toronto Conf 107		(GLAS)	
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL)	IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)	IJP
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS)	IJP
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL)	IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL)	IJP
Also	80	Toronto Conf 3	Koch	(KARL)	IJP
BAKER	78	NP B141 29	+Blissett Bloodworth Broome+	(RL CAMB)	IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)	
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)	
BAKER	77	NP B126 365	+Blissett Bloodworth Broome Hart+	(RHEL)	IJP
LONGACRE	77	NP B122 493	+Dolbeau	(SACL)	IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL)	IJP
WINNIK	77	NP B128 66	+Toaff Revel Goldberg Berny	(HAIF)	I
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH)	IJP
KNASEL	75	PR D11 1	+Lindquist Nelson+	(CHIC WUSL OSU ANL)	IJP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC)	IJP

$N(1960)$

$I(J^P) = \frac{1}{2}(?^?)$ Status *

OMITTED FROM SUMMARY TABLE

A narrow peak in $\Sigma(1385)^- K^+$ diffractively produced by neutrons on quasi-free nucleons of carbon, aluminum, and copper The spin-parity is one of $5/2^+$ $7/2^-$, etc

$N(1960)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1956^{+8}_{-6}	ALEEV	84B	BIS2	$\Sigma(1385)^- K^+$

$N(1960)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
27 ± 15	ALEEV	84B	BIS2	$\Sigma(1385)^- K^+$

$N(1960)$ REFERENCES

ALEEV	84B	ZPHY C25 205	+	(JINR BERL LEBD MOSU PRAG SOFI TBLI)

OTHER RELATED PAPERS

AMAGLOBELI	87	SJNP 45 632	+Dzhordzhadze Kekelidze+	(JINR)
		Translated from YAF 45 1020		
ALEEV	86	SJNP 44 652	+	(BERL JINR MOSU PRAG SOFI TBLI)
		Translated from YAF 44 1010		

$N(1990)$ F_{17}

$I(J^P) = \frac{1}{2}(\frac{7}{2}^+)$ Status * *

OMITTED FROM SUMMARY TABLE

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters 111B)

The various analyses do not agree very well with one another

$N(1990)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2018	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1970 ± 50	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2005 ± 150	HOEHLER	79	IPWA	$\pi N \to \pi N$
1999	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(1990)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
295	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
350 ± 120	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
350 ± 100	HOEHLER	79	IPWA	$\pi N \to \pi N$
216	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(1990)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1900 ± 30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
260 ± 60	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$N(1990)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
5 ± 4	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−8 ± 4	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$N(1990)$ DECAY MODES

Γ_1	$N(1990) \to N\pi$
Γ_2	$N(1990) \to N\eta$
Γ_3	$N(1990) \to \Lambda K$
Γ_4	$N(1990) \to \Sigma K$
Γ_5	$N(1990) \to N\pi\pi$
Γ_6	$N(1990) \to p\gamma$, helicity=1/2
Γ_7	$N(1990) \to p\gamma$, helicity=3/2
Γ_8	$N(1990) \to n\gamma$, helicity=1/2
Γ_9	$N(1990) \to n\gamma$, helicity=3/2

$N(1990)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.06 ± 0.02	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.04 ± 0.02	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1990) \to N\eta$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.043	BAKER	79	DPWA	$\pi^- p \to n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(1990) \rightarrow \Lambda K$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.01	BELL	83	DPWA	$\pi^- p \rightarrow \Lambda K^0$
NOT SEEN	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$
−0.021 ± 0.033	DEVENISH	74B		Fixed t dispersion rel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(1990) \rightarrow \Sigma K$ — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.010 to 0.023	[1] DEANS	75	DPWA	$\pi N \rightarrow \Sigma K$
0.06	LANGBEIN	73	IPWA	$\pi N \rightarrow \Sigma K$ (sol 1)

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(1990) \rightarrow N\pi\pi$ — $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
NOT SEEN	MANLEY	84	IPWA	$\pi N \rightarrow N\pi\pi$
NOT SEEN	LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

N(1990) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec. IV of the Note on N and Δ Resonances preceding the Baryon Listings.

$N(1990) \rightarrow p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0.030 ± 0.029	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
0.001 ± 0.040	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
0.040	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$

$N(1990) \rightarrow p\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0.086 ± 0.060	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
0.004 ± 0.025	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
+0.004	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$

$N(1990) \rightarrow n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.001	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
−0.078 ± 0.030	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
−0.069	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$

$N(1990) \rightarrow n\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.178	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
−0.116 ± 0.045	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
−0.072	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$

N(1990) FOOTNOTES

[1] The range given for DEANS 75 is from the four best solutions.

N(1990) REFERENCES

For early references see Physics Letters **111B** (1982).

MANLEY 84 PR D30 904 +Arndt, Goradia, Teplitz (VPI)
BELL 83 NP B222 389 +Blissett, Broome, Daley, Hart, Lintern+ (RL) IJP
AWAJI 81 Bonn Conf. 352 +Kajikawa (NAGO)
Also 82 NP B197 365 Fujii, Hayashii, Iwata, Kajikawa+ (NAGO)
CRAWFORD 80 Toronto Conf. 107 (GLAS)
CUTKOSKY 80 Toronto Conf. 19 +Forsyth, Babcock, Kelly, Hendrick (CMU, LBL) IJP
Also 79 PR D20 2839 Cutkosky, Forsyth, Hendrick, Kelly (CMU, LBL) IJP
SAXON 80 NP B162 522 +Baker, Bell, Blissett, Bloodworth+ (RHEL, BRIS) IJP
BAKER 79 NP B156 93 +Brown, Clark, Davies, Depagter, Evans+ (RHEL) IJP
HOEHLER 79 PDAT 12-1 +Kaiser, Koch, Pietarinen (KARL) IJP
Also 80 Toronto Conf. 3 Koch (KARL) IJP
BARBOUR 78 NP B141 253 +Crawford, Parsons (GLAS)
DEANS 75 NP B96 90 +Mitchell, Montgomery+ (SFLA, ALAH) IJP
LONGACRE 75 PL 55B 415 +Rosenfeld, Lasinski, Smadja+ (LBL, SLAC) IJP
DEVENISH 74B NP B81 330 +Froggatt, Martin (DESY, NORD, LOUC)
LANGBEIN 73 NP B53 251 +Wagner (MUNI) IJP

N(2000) F_{15}

$I(J^P) = \frac{1}{2}(\frac{5}{2}^+)$ Status: * *

OMITTED FROM SUMMARY TABLE

Older results have been retained simply because there is little information at all about this possible state.

N(2000) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1882 ± 10	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
2025	AYED	76	IPWA	$\pi N \rightarrow \pi N$
1970	[1] LANGBEIN	73	IPWA	$\pi N \rightarrow \Sigma K$ (sol 2)
2175	ALMEHED	72	IPWA	$\pi N \rightarrow \pi N$
1930	DEANS	72	MPWA	$\gamma p \rightarrow \Lambda K$ (sol D)

N(2000) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
95 ± 20	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
157	AYED	76	IPWA	$\pi N \rightarrow \pi N$
170	[1] LANGBEIN	73	IPWA	$\pi N \rightarrow \Sigma K$ (sol 2)
150	ALMEHED	72	IPWA	$\pi N \rightarrow \pi N$
112	DEANS	72	MPWA	$\gamma p \rightarrow \Lambda K$ (sol D)

N(2000) DECAY MODES

Γ_1 $N(2000) \rightarrow N\pi$
Γ_2 $N(2000) \rightarrow N\eta$
Γ_3 $N(2000) \rightarrow \Lambda K$
Γ_4 $N(2000) \rightarrow \Sigma K$
Γ_5 $N(2000) \rightarrow p\gamma$

N(2000) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.04 ± 0.02	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
0.08	AYED	76	IPWA	$\pi N \rightarrow \pi N$
0.25	ALMEHED	72	IPWA	$\pi N \rightarrow \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(2000) \rightarrow N\eta$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.03	BAKER	79	DPWA	$\pi^- p \rightarrow n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(2000) \rightarrow \Lambda K$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
NOT SEEN	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(2000) \rightarrow \Sigma K$ — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.022	[2] DEANS	75	DPWA	$\pi N \rightarrow \Sigma K$
0.05	[1] LANGBEIN	73	IPWA	$\pi N \rightarrow \Sigma K$ (sol 2)

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $p\gamma \rightarrow N(2000) \rightarrow \Lambda K$ — $(\Gamma_5\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.0022	DEANS	72	MPWA	$\gamma p \rightarrow \Lambda K$ (sol D)

N(2000) FOOTNOTES

[1] Not seen in solution 1 of LANGBEIN 73.
[2] Value given is from solution 1 of DEANS 75; not present in solutions 2, 3, or 4.

N(2000) REFERENCES

SAXON 80 NP B162 522 +Baker, Bell, Blissett, Bloodworth+ (RHEL, BRIS) IJP
BAKER 79 NP B156 93 +Brown, Clark, Davies, Depagter, Evans+ (RHEL) IJP
HOEHLER 79 PDAT 12-1 +Kaiser, Koch, Pietarinen (KARL) IJP
Also 80 Toronto Conf. 3 Koch (KARL) IJP
AYED 76 CEA-N-1921 Thesis (SACL) IJP
DEANS 75 NP B96 90 +Mitchell, Montgomery+ (SFLA, ALAH) IJP
LANGBEIN 73 NP B53 251 +Wagner (MUNI) IJP
ALMEHED 72 NP B40 157 +Lovelace (LUND, RUTG) IJP
DEANS 72 PR D6 1906 +Jacobs, Lyons, Montgomery (SFLA) IJP

N(2080) D_{13}

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ Status: * *

OMITTED FROM SUMMARY TABLE

There is some evidence for two resonances in this wave between 1800 and 2200 MeV (see CUTKOSKY 80). However, the solution of HOEHLER 79 is quite different.

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**)

$N(2080)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1920	BELL	83	DPWA	$\pi^- p \rightarrow \Lambda K^0$
1880 ± 100	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
2060 ± 80	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
1900	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$
2081 ± 20	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$

$N(2080)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
320	BELL	83	DPWA	$\pi^- p \rightarrow \Lambda K^0$
180 ± 60	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (lower mass)
300 ± 100	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (higher mass)
240	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$
265 ± 40	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$

$N(2080)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1880 ± 100	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (lower mass)
2050 ± 70	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (higher mass)

$-2 \times$ IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
160 ± 80	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (lower mass)
200 ± 80	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (higher mass)

$N(2080)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
− 2 ± 14	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (lower mass)
30 ± 20	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (higher mass)

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
10 ± 5	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (lower mass)
0 ± 52	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (higher mass)

$N(2080)$ DECAY MODES

Γ_1	$N(2080) \rightarrow N\pi$
Γ_2	$N(2080) \rightarrow N\eta$
Γ_3	$N(2080) \rightarrow \Lambda K$
Γ_4	$N(2080) \rightarrow \Sigma K$
Γ_5	$N(2080) \rightarrow N\pi\pi$
Γ_6	$N(2080) \rightarrow p\gamma$, helicity=1/2
Γ_7	$N(2080) \rightarrow p\gamma$, helicity=3/2
Γ_8	$N(2080) \rightarrow n\gamma$, helicity=1/2
Γ_9	$N(2080) \rightarrow n\gamma$, helicity=3/2
Γ_{10}	$N(2080) \rightarrow p\gamma$

$N(2080)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0 10 ± 0 04	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (lower mass)
0 14 ± 0 07	[1] CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$ (higher mass)
0 06 ± 0 02	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(2080) \rightarrow N\eta$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
NOT SEEN	BAKER	79	DPWA	$\pi^- p \rightarrow n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(2080) \rightarrow \Lambda K$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0 04	BELL	83	DPWA	$\pi^- p \rightarrow \Lambda K^0$
+0 03	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(2080) \rightarrow \Sigma K$ — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 014 to 0 037	[2] DEANS	75	DPWA	$\pi N \rightarrow \Sigma K$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $p\gamma \rightarrow N(2080) \rightarrow N\eta$ — $(\Gamma_{10}\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 0037	HICKS	73	MPWA	$\gamma p \rightarrow p\eta$

$N(2080)$ PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$N(2080) \rightarrow p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0 020 ± 0 008	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
0 026 ± 0 052	DEVENISH	74	DPWA	$\gamma N \rightarrow \pi N$

$N(2080) \rightarrow p\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 017 ± 0 011	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
0 128 ± 0 057	DEVENISH	74	DPWA	$\gamma N \rightarrow \pi N$

$N(2080) \rightarrow n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 007 ± 0 013	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
0 053 ± 0 083	DEVENISH	74	DPWA	$\gamma N \rightarrow \pi N$

$N(2080) \rightarrow n\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0 053 ± 0 034	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
0 100 ± 0 141	DEVENISH	74	DPWA	$\gamma N \rightarrow \pi N$

$N(2080)$ FOOTNOTES

[1] CUTKOSKY 80 finds a lower mass D_{13} resonance as well as one in this region Both are listed here
[2] The range given for DEANS 75 is from the four best solutions Disagrees with $\pi^+ p \rightarrow \Sigma^+ K^+$ data of WINNIK 77 around 1920 MeV

$N(2080)$ REFERENCES

For early references see Physics Letters **111B** (1982)

BELL	83	NP B222 389	+Blissett Broome Daley Hart Lintern+	(RL) IJP
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS) IJP
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
WINNIK	77	NP B128 66	+Toaff Revel Goldberg Berny	(HAIF) I
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP
DEVENISH	74	PL 52B 227	+Lyth Rankin	(DESY LANC BONN) IJP
HICKS	73	PR D7 2614	+Deans Jacobs Lyons+	(CMU ORNL SFLA) IJP

$N(2090)$ S_{11}

$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$ Status *

OMITTED FROM SUMMARY TABLE

Any structure in the S_{11} wave above 1800 MeV is listed here A few early results that are now obsolete have been omitted

$N(2090)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2180 ± 80	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
1880 ± 20	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$

Baryon Full Listings
$N(2090)$, $N(2100)$, $N(2190)$

$N(2090)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
350 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
95 ± 30	HOEHLER	79	IPWA	$\pi N \to \pi N$

$N(2090)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2150 ± 70	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1937 or 1949	[1] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$

$-2 \times$ IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
350 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
139 or 131	[1] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$

$N(2090)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
40 ± 20	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
0 ± 60	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$N(2090)$ DECAY MODES

Γ_1 $N(2090) \to N\pi$
Γ_2 $N(2090) \to \Lambda K$
Γ_3 $N(2090) \to N\pi\pi$

$N(2090)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.18 ± 0.08	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.09 ± 0.05	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(2090) \to \Lambda K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
NOT SEEN	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$

$N(2090)$ FOOTNOTES

[1] LONGACRE 78 values are from a search for poles in the unitarized T matrix. The first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.

$N(2090)$ REFERENCES

CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)

$N(2100)$ P_{11}

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status *

OMITTED FROM SUMMARY TABLE

$N(2100)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2125 ± 75	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2050 ± 20	HOEHLER	79	IPWA	$\pi N \to \pi N$

$N(2100)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
260 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
200 ± 30	HOEHLER	79	IPWA	$\pi N \to \pi N$

$N(2100)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2120 ± 40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$-2 \times$ IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
240 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$N(2100)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
11 ± 7	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
8 ± 6	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$N(2100)$ DECAY MODES

Γ_1 $N(2100) \to N\pi$

$N(2100)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.12 ± 0.03	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.10 ± 0.04	HOEHLER	79	IPWA	$\pi N \to \pi N$

$N(2100)$ REFERENCES

CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP

$N(2190)$ G_{17}

$I(J^P) = \frac{1}{2}(\frac{7}{2}^-)$ Status ****

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition (Physics Letters **111B**).

$N(2190)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2120 to 2230 OUR ESTIMATE				
2200 ± 70	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2140 ± 12	HOEHLER	79	IPWA	$\pi N \to \pi N$
2140 ± 40	HENDRY	78	MPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2098	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
2180	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
2140	BAKER	79	DPWA	$\pi^- p \to n\eta$
2117	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(2190)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
200 to 500 OUR ESTIMATE				
500 ± 150	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
390 ± 30	HOEHLER	79	IPWA	$\pi N \to \pi N$
270 ± 50	HENDRY	78	MPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
238	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
80	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
319	BAKER	79	DPWA	$\pi^- p \to n\eta$
220	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$N(2190)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2100 ± 50	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$

$-2 \times$ IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
400 ± 160	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$

$N(2190)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
22 ± 14	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
-13 ± 20	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$

$N(2190)$ DECAY MODES

Γ_1	$N(2190) \rightarrow N\pi$
Γ_2	$N(2190) \rightarrow N\eta$
Γ_3	$N(2190) \rightarrow \Lambda K$
Γ_4	$N(2190) \rightarrow \Sigma K$
Γ_5	$N(2190) \rightarrow N\pi\pi$
Γ_6	$N(2190) \rightarrow N\rho$, S=3/2, D-wave
Γ_7	$N(2190) \rightarrow p\gamma$, helicity=1/2
Γ_8	$N(2190) \rightarrow p\gamma$, helicity=3/2
Γ_9	$N(2190) \rightarrow n\gamma$, helicity=1/2
Γ_{10}	$N(2190) \rightarrow n\gamma$, helicity=3/2

$N(2190)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ $\qquad \Gamma_1/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
~0.14 OUR ESTIMATE				
0.12 ± 0.06	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
0.14 ± 0.02	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
0.16 ± 0.04	HENDRY	78	MPWA	$\pi N \rightarrow \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(2190) \rightarrow N\eta$ $\qquad (\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
$+0.052$	BAKER	79	DPWA	$\pi^- p \rightarrow n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(2190) \rightarrow \Lambda K$ $\qquad (\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
-0.02	BELL	83	DPWA	$\pi^- p \rightarrow \Lambda K^0$
-0.02	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(2190) \rightarrow \Sigma K$ $\qquad (\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
0.014 to 0.019	[1] DEANS	75	DPWA	$\pi N \rightarrow \Sigma K$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(2190) \rightarrow N\rho$, S=3/2, D-wave $\qquad (\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− (LARGE)	MANLEY	84	IPWA	$\pi N \rightarrow N\pi\pi$

$N(2190)$ PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$N(2190) \rightarrow p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
-0.055	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
-0.030	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$

$N(2190) \rightarrow p\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
0.081	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
$+0.180$	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$

$N(2190) \rightarrow n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
-0.042	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
-0.085	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$

$N(2190) \rightarrow n\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
-0.126	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
$+0.007$	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$

$N(2190)$ FOOTNOTES

[1] The range given for DEANS 75 is from the four best solutions Disagrees with $\pi^+ p \rightarrow \Sigma^+ K^+$ data of WINNIK 77 around 1920 MeV

$N(2190)$ REFERENCES

For early references see Physics Letters **111B** (1982)

MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
Also	84B	PRL 52 2122	Manley	(VPI)
BELL	83	NP B222 389	+Blissett Broome Daley Hart Lintern+	(RL) IJP
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS) IJP
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)
WINNIK	77	NP B128 66	+Toaff Revel Goldberg Berny	(HAIF) I
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP

$N(2200)$ D_{15}

$I(J^P) = \frac{1}{2}(\frac{5}{2}^-)$ Status * *

OMITTED FROM SUMMARY TABLE

The mass is not well determined A few early results have been omitted

$N(2200)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1900	BELL	83	DPWA	$\pi^- p \rightarrow \Lambda K^0$
2180 ± 80	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
1920	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$
2228 ± 30	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$

$N(2200)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
130	BELL	83	DPWA	$\pi^- p \rightarrow \Lambda K^0$
400 ± 100	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
220	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$
310 ± 50	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$

$N(2200)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2100 ± 60	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$

$-2 \times$ IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
360 ± 80	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$

$N(2200)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
0 ± 17	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
-20 ± 10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

N(2200) DECAY MODES

Γ_1 $N(2200) \to N\pi$
Γ_2 $N(2200) \to N\eta$
Γ_3 $N(2200) \to \Lambda K$

N(2200) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.10 ± 0.03	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.07 ± 0.02	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(2200) \to N\eta$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.066	BAKER	79	DPWA	$\pi^- p \to n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(2200) \to \Lambda K$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
-0.03	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
-0.05	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$

N(2200) REFERENCES

BELL	83	NP B222 389	+Blissett Broome Daley Hart Lintern+	(RL) IJP
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS) IJP
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP

N(2220) H_{19}

$I(J^P) = \frac{1}{2}(\frac{9}{2}^-)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition (Physics Letters **111B**).

N(2220) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2150 to 2300 OUR ESTIMATE				
2230 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2205 ± 10	HOEHLER	79	IPWA	$\pi N \to \pi N$
2300 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2050	BAKER	79	DPWA	$\pi^- p \to n\eta$

N(2220) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
300 to 500 OUR ESTIMATE				
500 ± 150	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
365 ± 30	HOEHLER	79	IPWA	$\pi N \to \pi N$
450 ± 150	HENDRY	78	MPWA	$\pi N \to \pi N$

N(2220) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2160 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$-2 \times$ IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
480 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

N(2220) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
32 ± 20	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
-32 ± 20	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

N(2220) DECAY MODES

Γ_1 $N(2220) \to N\pi$
Γ_2 $N(2220) \to N\eta$
Γ_3 $N(2220) \to \Lambda K$

N(2220) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
~0.18 OUR ESTIMATE				
0.15 ± 0.03	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.18 ± 0.015	HOEHLER	79	IPWA	$\pi N \to \pi N$
0.12 ± 0.04	HENDRY	78	MPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(2220) \to N\eta$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.034	BAKER	79	DPWA	$\pi^- p \to n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(2220) \to \Lambda K$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
NOT REQUIRED	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
NOT SEEN	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$

N(2220) REFERENCES

For early references, see Physics Letters **111B** (1982).

BELL	83	NP B222 389	+Blissett Broome Daley Hart Lintern+	(RL) IJP
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS) IJP
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)

N(2250) G_{19}

$I(J^P) = \frac{1}{2}(\frac{9}{2}^-)$ Status * * * *

N(2250) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2130 to 2270 OUR ESTIMATE				
2250 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2268 ± 15	HOEHLER	79	IPWA	$\pi N \to \pi N$
2200 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$

N(2250) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
200 to 500 OUR ESTIMATE				
480 ± 120	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
300 ± 40	HOEHLER	79	IPWA	$\pi N \to \pi N$
350 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$

N(2250) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2150 ± 50	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$-2 \times$ IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
360 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$N(2250)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
13 ± 7	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
-15 ± 6	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$N(2250)$ DECAY MODES

Γ_1 $N(2250) \to N\pi$
Γ_2 $N(2250) \to N\eta$
Γ_3 $N(2250) \to \Lambda K$

$N(2250)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
~0.10 OUR ESTIMATE				
0.10 ± 0.02	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.10 ± 0.02	HOEHLER	79	IPWA	$\pi N \to \pi N$
0.09 ± 0.02	HENDRY	78	MPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(2250) \to N\eta$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
-0.043	BAKER	79	DPWA	$\pi^- p \to n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(2250) \to \Lambda K$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
-0.02	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
NOT SEEN	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$

$N(2250)$ REFERENCES

BELL	83	NP B222 389	+Blissett Broome Daley Hart Lintern+	(RL) IJP
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
SAXON	80	NP B162 522	+Baker Bell Blissett Bloodworth+	(RHEL BRIS) IJP
BAKER	79	NP B156 93	+Brown Clark Davies Depagter Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)

$N(2600)$ $I_{1,11}$

$I(J^P) = \frac{1}{2}(\frac{11}{2}^-)$ Status ***

$N(2600)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2580 to 2700 OUR ESTIMATE				
2577 ± 50	HOEHLER	79	IPWA	$\pi N \to \pi N$
2700 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$

$N(2600)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
>300 OUR ESTIMATE				
400 ± 100	HOEHLER	79	IPWA	$\pi N \to \pi N$
900 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$

$N(2600)$ DECAY MODES

Γ_1 $N(2600) \to N\pi$

$N(2600)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
~0.05 OUR ESTIMATE				
0.05 ± 0.01	HOEHLER	79	IPWA	$\pi N \to \pi N$
0.08 ± 0.02	HENDRY	78	MPWA	$\pi N \to \pi N$

$N(2600)$ REFERENCES

HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)

$N(2700)$ $K_{1,13}$

$I(J^P) = \frac{1}{2}(\frac{13}{2}^+)$ Status **

OMITTED FROM SUMMARY TABLE

$N(2700)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2612 ± 45	HOEHLER	79	IPWA	$\pi N \to \pi N$
3000 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$

$N(2700)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
350 ± 50	HOEHLER	79	IPWA	$\pi N \to \pi N$
900 ± 150	HENDRY	78	MPWA	$\pi N \to \pi N$

$N(2700)$ DECAY MODES

Γ_1 $N(2700) \to N\pi$

$N(2700)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.04 ± 0.01	HOEHLER	79	IPWA	$\pi N \to \pi N$
0.07 ± 0.02	HENDRY	78	MPWA	$\pi N \to \pi N$

$N(2700)$ REFERENCES

HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)

$N(\sim 3000$ REGION) PARTIAL-WAVE ANALYSES

We list here miscellaneous high mass candidates for isospin 1 2 resonances found in partial wave analyses

Our 1982 edition had an $N(3245)$ an $N(3690)$ and an $N(3755)$ each a narrow peak seen in a production experiment Since nothing has been heard from them since the 1960 s we declare them to be dead There was also an $N(3030)$ deduced from total cross section and 180 elastic cross-section measurements it is the KOCH 80 $L_{1,15}$ state below

$N(\sim 3000)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2600	KOCH	80	IPWA	$\pi N \to \pi N$ D_{13}
3100	KOCH	80	IPWA	$\pi N \to \pi N$ $L_{1,15}$ wave
3500	KOCH	80	IPWA	$\pi N \to \pi N$ $M_{1,17}$ wave
3500 to 4000	KOCH	80	IPWA	$\pi N \to \pi N$ $N_{1,19}$ wave
3500 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$ $L_{1,15}$ wave
3800 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$ $M_{1,17}$ wave
4100 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$ $N_{1,19}$ wave

Baryon Full Listings
$N(\sim 3000)$, $\Delta(1232)$

$N(\sim 3000)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1300 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$ $L_{1\,15}$ wave
1600 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$ $M_{1\,17}$ wave
1900 ± 300	HENDRY	78	MPWA	$\pi N \to \pi N$ $N_{1\,19}$ wave

$N(\sim 3000)$ DECAY MODES

Γ_1 $N(\sim 3000) \to N\pi$

$N(\sim 3000)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0 055 ± 0 02	HENDRY	78	MPWA	$\pi N \to \pi N$ $L_{1\,15}$ wave
0 040 ± 0 015	HENDRY	78	MPWA	$\pi N \to \pi N$ $M_{1\,17}$ wave
0 030 ± 0 015	HENDRY	78	MPWA	$\pi N \to \pi N$ $N_{1\,19}$ wave

$N(\sim 3000)$ REFERENCES

KOCH	80	Toronto Conf 3		(KARL) IJP
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND) IJP

Δ BARYONS
(S = 0, I = 3/2)

$\Delta(1232)$ P_{33}

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$ Status ****

Most of the results published before 1977 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**) In addition results in this region from production experiments, which used to be listed separately as the next entry have been entirely omitted They too may be found in our 1982 edition

$\Delta(1232)$ MASSES

MIXED CHARGES

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1230 to 1234 OUR ESTIMATE				
1232 ± 3	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1233 ± 2	HOEHLER	79	IPWA	$\pi N \to \pi N$

$\Delta(1232)^{++}$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1230 9 ± 0 3	KOCH	80B	IPWA	$\pi N \to \pi N$
1230 6 ± 0 2	ZIDELL	80	DPWA	$\pi N \to \pi N$ 0-350 MeV
1231 1 ± 0 2	PEDRONI	78		$\pi N \to \pi N$ 70-370 MeV

$\Delta(1232)^{+}$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1234 9 ± 1 4	MIROSHNIC	79		Fit photoproduction
• • • We do not use the following data for averages fits limits etc • • •				
1231 6	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1231 2	BARBOUR	78	DPWA	$\gamma N \to \pi N$
1231 8	BERENDS	75	IPWA	$\gamma p \to \pi N$

$\Delta(1232)^{0}$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1233 6 ± 0.5	KOCH	80B	IPWA	$\pi N \to \pi N$
1232 5 ± 0 3	ZIDELL	80	DPWA	$\pi N \to \pi N$ 0-350 MeV
1233 8 ± 0 2	PEDRONI	78		$\pi N \to \pi N$ 70-370 MeV

$\Delta^0 - \Delta^{++}$ MASS DIFFERENCE

VALUE (MeV)	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
2 7 ± 0 3	[1] PEDRONI	78	See the masses

$\Delta(1232)$ WIDTHS

MIXED CHARGES

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
110 to 120 OUR ESTIMATE				
120 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
116 ± 5	HOEHLER	79	IPWA	$\pi N \to \pi N$

$\Delta(1232)^{++}$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
111 0 ± 1 0	KOCH	80B	IPWA	$\pi N \to \pi N$
113.2 ± 0 3	ZIDELL	80	DPWA	$\pi N \to \pi N$ 0-350 MeV
111 3 ± 0 5	PEDRONI	78		$\pi N \to \pi N$ 70-370 MeV

$\Delta(1232)^{+}$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
131 1 ± 2 4	MIROSHNIC	79		Fit photoproduction
• • • We do not use the following data for averages fits limits etc • • •				
111 2	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
111 0	BARBOUR	78	DPWA	$\gamma N \to \pi N$

$\Delta(1232)^{0}$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
113 0 ± 1 5	KOCH	80B	IPWA	$\pi N \to \pi N$
121 3 ± 0 4	ZIDELL	80	DPWA	$\pi N \to \pi N$ 0-350 MeV
117 9 ± 0 9	PEDRONI	78		$\pi N \to \pi N$ 70-370 MeV

$\Delta^0 - \Delta^{++}$ WIDTH DIFFERENCE

VALUE (MeV)	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
6 6 ± 1 0	PEDRONI	78	See the widths

$\Delta(1232)$ POLE POSITIONS

REAL PART, MIXED CHARGES

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1210 ± 1	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1210	ARNDT	85	DPWA	$\pi N \to \pi N$

−IMAGINARY PART, MIXED CHARGES

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
50 ± 1	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
50	ARNDT	85	DPWA	$\pi N \to \pi N$

REAL PART, $\Delta(1232)^{++}$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1210 70 ± 0 16	[2] ZIDELL	80	DPWA	$\pi N \to \pi N$ 0-350 MeV
1209 6 ± 0 5	[3] VASAN	76B		Fit to CARTER 73
• • • We do not use the following data for averages fits limits etc • • •				
1210 4 ± 0 17	[4] ZIDELL	78		
1210 5 to 1210 8	[5] VASAN	76B		Fit to CARTER 73

−IMAGINARY PART, $\Delta(1232)^{++}$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
49 61 ± 0 12	[2] ZIDELL	80	DPWA	$\pi N \to \pi N$ 0-350 MeV
50 4 ± 0 5	[3] VASAN	76B		Fit to CARTER 73
• • • We do not use the following data for averages fits limits etc • • •				
49 745 ± 0 14	[4] ZIDELL	78		
49 9 to 50 0	[5] VASAN	76B		Fit to CARTER 73

REAL PART, $\Delta(1232)^{+}$

VALUE (MeV)	DOCUMENT ID		COMMENT
1206 9 ± 0 9 to 1210 5 ± 1 8	MIROSHNIC	79	Fit photoproduction
1208 0 ± 2 0	CAMPBELL	76	Fit photoproduction

−IMAGINARY PART, $\Delta(1232)^+$

VALUE (MeV)	DOCUMENT ID		COMMENT
55 6 ± 1 0 to 58 3 ± 1 1	MIROSHNIC	79	Fit photoproduction
53 0 ± 2 0	CAMPBELL	76	Fit photoproduction

REAL PART, $\Delta(1232)^0$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1210 30 ± 0 36	[2] ZIDELL	80	DPWA	$\pi N \rightarrow \pi N$ 0–350 MeV
1210 75 ± 0 6	[3] VASAN	76B		Fit to CARTER 73
• • • We do not use the following data for averages fits limits etc • • •				
1209 5 ± 0 41	[4] ZIDELL	78		
1210 2	[5] VASAN	76B		Fit to CARTER 73

−IMAGINARY PART, $\Delta(1232)^0$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
54 0 ± 0 26	[2] ZIDELL	80	DPWA	$\pi N \rightarrow \pi N$ 0–350 MeV
52 8 ± 0 6	[3] VASAN	76B		Fit to CARTER 73
• • • We do not use the following data for averages fits limits etc • • •				
52 45 ± 0 2	[4] ZIDELL	78		
52.9 to 53 1	[5] VASAN	76B		Fit to CARTER 73

$\Delta(1232)$ ELASTIC POLE RESIDUES

ABSOLUTE VALUE, MIXED CHARGES

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
53 ± 2	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$

PHASE, MIXED CHARGES

VALUE	DOCUMENT ID		TECN	COMMENT
−0 82 ± 0 02	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$

ABSOLUTE VALUE, $\Delta(1232)^{++}$

VALUE (MeV)	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages fits, limits etc • • •			
52 4 to 53 2	[3] VASAN	76B	Fit to CARTER 73
52 1 to 52 4	[5] VASAN	76B	Fit to CARTER 73

PHASE, $\Delta(1232)^{++}$

VALUE	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
−0 822 to −0 833	[3] VASAN	76B	Fit to CARTER 73
−0 823 to −0 830	[5] VASAN	76B	Fit to CARTER 73

ABSOLUTE VALUE, $\Delta(1232)^0$

VALUE (MeV)	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
54 8 to 55 0	[3] VASAN	76B	Fit to CARTER 73
55 2 to 55 3	[5] VASAN	76B	Fit to CARTER 73

PHASE, $\Delta(1232)^0$

VALUE	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
−0 840 to −0 847	[3] VASAN	76B	Fit to CARTER 73
−0 848 to −0 856	[5] VASAN	76B	Fit to CARTER 73

$\Delta(1232)$ PHASE OF M1+(3/2) PHOTOPRODUCTION MULTIPOLE AMPLITUDE POLE RESIDUE

Information on the phase (and magnitude) of the M1+(3/2) multipole amplitude pole residue is contained implicitly in the paper of MIROSHNICHENKO 79 They find that the phase is consistent with being equal to that of the elastic pole residue

$\Delta(1232)$ MAGNETIC MOMENT

VALUE (n m)	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
+4 7 to +6 7	NEFKENS	78	$\pi p \rightarrow \pi p \gamma$

$\Delta(1232)$ DECAY MODES

Γ_1	$\Delta(1232) \rightarrow N\pi$
Γ_2	$\Delta(1232) \rightarrow N\pi\pi$
Γ_3	$\Delta(1232) \rightarrow N\gamma$
Γ_4	$\Delta(1232) \rightarrow N\gamma$, helicity=1/2
Γ_5	$\Delta(1232) \rightarrow N\gamma$, helicity=3/2

$\Delta(1232)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.994 OUR ESTIMATE				
1 0	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
1 0	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$

$\Delta(1232)$ PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$\Delta(1232) \rightarrow N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0 145 ± 0 015	CRAWFORD	83	IPWA	$\gamma N \rightarrow \pi N$
−0 138 ± 0 004	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
−0 147 ± 0 001	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 1)
−0 145 ± 0 001	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 2)
−0 136 ± 0 006	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
−0 142 ± 0 007	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
−0 141 ± 0 004	FELLER	76	DPWA	$\gamma N \rightarrow \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
−0 140	[6] NOELLE	78		$\gamma N \rightarrow \pi N$

$\Delta(1232) \rightarrow N\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0 263 ± 0 026	CRAWFORD	83	IPWA	$\gamma N \rightarrow \pi N$
−0 259 ± 0 006	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
−0 264 ± 0 002	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 1)
−0 261 ± 0 002	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 2)
−0 247 ± 0 010	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
−0 271 ± 0 010	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
−0 256 ± 0 003	FELLER	76	DPWA	$\gamma N \rightarrow \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
−0 247	[6] NOELLE	78		$\gamma N \rightarrow \pi N$

$\Delta(1232)$ FOOTNOTES

[1] Using $\pi^\pm d$ as well PEDRONI 78 determine $(M^- - M^{++}) + (M^0 - M^+)$ / 3 = 4 6 ± 0 2 MeV

[2] The accuracy claimed by ZIDELL 80 on the real part is considerably better than is allowed by uncertainties in the beam momentum

[3] This VASAN 76B value is from fits to the coulomb barrier corrected CARTER 73 phase shift

[4] ZIDELL 78 fits the nuclear phase shift without coulomb barrier corrections

[5] This VASAN 76B value is from fits to the CARTER 73 nuclear phase shift without coulomb barrier corrections

[6] Converted to our conventions using M = 1232 MeV Γ = 110 MeV from NOELLE 78

$\Delta(1232)$ REFERENCES

For early references see Physics Letters 111B (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)
KOCH	80B	NP A336 331	+Pietarinen	(KARL) IJP
ZIDELL	80	PR D21 1255	+Arndt Roper	(VPI) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
MIROSHNIC	79	SJNP 29 94	Miroshnichenko Nikiforov Sanin+	(KHAR) IJP
		Translated from YAF 29 188		
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
NEFKENS	78	PR D18 3911	+Arman Balagh Glodis Haddock+	(UCLA CATH) IJP
NOELLE	78	PTP 60 778		(NAGO)
PEDRONI	78	NP A300 321	+Gabathuler Domingo Hirt+	(SIN GREN KARL+) IJP
ZIDELL	78	LNC 21 140	+Arndt Roper	(VPI) IJP
CAMPBELL	76	PR D14 2431	+Shaw Ball	(BOIS UCI UTAH) IJP
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+	(NAGO OSAK) IJP
VASAN	76B	NP B106 535		(CMU) IJP
Also	76	NP B106 526	Vasan	(CMU) IJP
BERENDS	75	NP B84 342	+Donnachie	(LEID MCHS)
CARTER	73	NP B58 378	+Bugg Carter	(CAVE LOQM) IJP

Δ(1550) P_{31}

$I(J^P) = \frac{3}{2}(\frac{1}{2}^+)$ Status *

OMITTED FROM SUMMARY TABLE

Not seen in $\pi N \to \pi N$ analyses and its existence is thus doubtful

Δ(1550) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1525	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
1506	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1550	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

Δ(1550) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
40	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
137	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
110	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

Δ(1550) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1554 or 1553	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
105 or 104	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

Δ(1550) DECAY MODES

Γ_1 Δ(1550) → $N\pi$
Γ_2 Δ(1550) → Δ(1232)π, P-wave
Γ_3 Δ(1550) → $N\rho$, S=3/2, P-wave
Γ_4 Δ(1550) → $N\gamma$, helicity=1/2

Δ(1550) BRANCHING RATIOS

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon first convention the overall phase ambiguity is resolved by choosing a negative sign for the Δ(1620) S_{31} coupling to Δ(1232)π

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1550) → Δ(1232)π, P-wave $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 13 ± 0 05	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
−0 11	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1550) → $N\rho$, S=3/2, P-wave $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 17 ± 0 05	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
−0 08	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

Δ(1550) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

Δ(1550) → $N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 016 ± 0 016	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0 013	CRAWFORD	80	DPWA	$\gamma N \to \pi N$

Δ(1550) FOOTNOTES

[1] LONGACRE 77 pole positions are from a search for poles in the unitarized T matrix the first (second) value uses, in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial-wave analysis The other LONGACRE 77 values are from eyeball fits with Breit Wigner circles to the T matrix amplitudes

Δ(1550) REFERENCES

CRAWFORD	83	NP B211 1	+Morton	(GLAS)
BARNHAM	80	NP B168 243	+Glickman Mier Jedrzejowicz+	(LOIC)
CRAWFORD	80	Toronto Conf 107		(GLAS)
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP

Δ(1600) P_{33}

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$ Status * *

OMITTED FROM SUMMARY TABLE

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**)

The various analyses are not in good agreement

Δ(1600) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1690	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
1600 ± 50	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1522 ± 13	HOEHLER	79	IPWA	$\pi N \to \pi N$
1560	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1640	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

Δ(1600) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
250	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
300 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
220 ± 40	HOEHLER	79	IPWA	$\pi N \to \pi N$
180	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
300	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

Δ(1600) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1581	ARNDT	85	DPWA	$\pi N \to \pi N$
1550 ± 40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1609 or 1610	[3] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
1541 or 1542	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
300	ARNDT	85	DPWA	$\pi N \to \pi N$
200 ± 60	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
323 or 325	[3] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
178 or 178	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

Δ(1600) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
− 15 ± 6	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
8 ± 8	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(1600) DECAY MODES

Γ_1 Δ(1600) → $N\pi$
Γ_2 Δ(1600) → ΣK
Γ_3 Δ(1600) → Δ(1232)π, P-wave
Γ_4 Δ(1600) → Δ(1232)π, F-wave
Γ_5 Δ(1600) → $N\rho$, S=1/2, P-wave
Γ_6 Δ(1600) → $N\rho$, S=3/2, P-wave
Γ_7 Δ(1600) → $N\rho$, S=3/2, F-wave
Γ_8 Δ(1600) → N(1440)π, P-wave
Γ_9 Δ(1600) → $N\gamma$, helicity=1/2
Γ_{10} Δ(1600) → $N\gamma$, helicity=3/2

Δ(1600) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.18 ± 0.04	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.21 ± 0.06	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to \Sigma K$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.006 to 0.042	[4] DEANS	75	DPWA	$\pi N \to \Sigma K$

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention the overall phase ambiguity is resolved by choosing a negative sign for the Δ(1620) S_{31} coupling to $\Delta(1232)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to \Delta(1232)\pi$, P-wave — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (LARGE)	[5] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0.24 ± 0.05	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
+0.34	[1,6] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0.30	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to \Delta(1232)\pi$, F-wave — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.07	[1,6] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to N\rho$, $S=1/2$, P-wave — $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.10	[1,6] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to N\rho$, $S=3/2$, P-wave — $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.10	[1,6] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to N(1440)\pi$, P-wave — $(\Gamma_1\Gamma_8)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (LARGE)	[5] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0.23 ± 0.04	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$

Δ(1600) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes, see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

Δ(1600) → Nγ, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.039 ± 0.030	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
−0.046 ± 0.013	AWAJI	81	DPWA	$\gamma N \to \pi N$
0.005 ± 0.020	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
0.000 ± 0.030	BARBOUR	78	DPWA	$\gamma N \to \pi N$
0.0 ± 0.020	FELLER	76	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
−0.200	[7] WADA	84	DPWA	Compton scattering

Δ(1600) → Nγ, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.013 ± 0.014	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0.025 ± 0.031	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.009 ± 0.020	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
0.000 ± 0.045	BARBOUR	78	DPWA	$\gamma N \to \pi N$
0.0 ± 0.015	FELLER	76	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages, fits, limits etc • • •				
0.023	WADA	84	DPWA	Compton scattering

Δ(1600) FOOTNOTES

[1] LONGACRE 77 pole positions are from a search for poles in the unitarized T matrix, the first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis The other LONGACRE 77 values are from eyeball fits with Breit Wigner circles to the T-matrix amplitudes

[2] From method II of LONGACRE 75 eyeball fits with Breit-Wigner circles to the T-matrix amplitudes

[3] LONGACRE 78 values are from a search for poles in the unitarized T-matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis

[4] The range given is from the four best solutions DEANS 75 disagrees with $\pi^+ p \to \Sigma^+ K^+$ data of WINNIK 77 around 1920 MeV

[5] MANLEY 84 considers this coupling sign to be well determined

[6] LONGACRE 77 considers this coupling to be well determined

[7] WADA 84 is inconsistent with other analyses see the Note on N and Δ Resonances

Δ(1600) REFERENCES

For early references see Physics Letters 111B (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
WADA	84	NP B247 313	+Egawa Imanishi Ishii Kato Ukai+	(NUS)
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
BARNHAM	80	NP B168 243	+Glickman Mier Jedrzejowicz+	(LOIC)
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) JP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) JP
WINNIK	77	NP B128 66	+Zoll Revel Goldberg Berny	(HAIF)
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+ (NAGO OSAK)	JP
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP

Δ(1620) S_{31}

$I(J^P) = \frac{3}{2}(\frac{1}{2}^-)$ Status ********

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters 111B)

Δ(1620) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1600 to 1650 OUR ESTIMATE				
1620 ± 20	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1610 ± 7	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1620	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
1712.8 ± 6.0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
1786.7 ± 2.0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
1657	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1662	BARBOUR	78	DPWA	$\gamma N \to \pi N$
1580	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1600	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

Δ(1620) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
120 to 160 OUR ESTIMATE				
140 ± 20	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
139 ± 18	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
120	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
228.3 ± 18.0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$ (lower mass)
30.0 ± 6.4	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$ (higher mass)
161	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
180	BARBOUR	78	DPWA	$\gamma N \to \pi N$
120	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
150	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

Δ(1620) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1600 ± 15	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1599	ARNDT	85	DPWA	$\pi N \to \pi N$
1583 or 1583	[4] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
1575 or 1572	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
120 ± 20	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
120	ARNDT	85	DPWA	$\pi N \to \pi N$
143 or 149	[4] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
119 or 128	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

Baryon Full Listings
Δ(1620), Δ(1700)

Δ(1620) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−5 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−14 ± 3	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(1620) DECAY MODES

Γ_1 Δ(1620) → $N\pi$
Γ_2 Δ(1620) → $N\pi\pi$
Γ_3 Δ(1620) → Δ(1232)π, D-wave
Γ_4 Δ(1620) → $N\rho$, S=1/2, S-wave
Γ_5 Δ(1620) → $N\rho$, S=3/2, D-wave
Γ_6 Δ(1620) → N(1440)π, S-wave
Γ_7 Δ(1620) → $N\gamma$, helicity=1/2

Δ(1620) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.25 to 0.35 OUR ESTIMATE				
0 25 ± 0 03	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 35 ± 0 06	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
0 60	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$ (lower mass)
0 36	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$ (higher mass)

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon first convention the overall phase ambiguity is resolved by choosing a negative sign for the Δ(1620) S_{31} coupling to Δ(1232)π

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1620) → Δ(1232)π, D-wave $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− (LARGE)	[5] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0 33 ± 0.06	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
−0 39	[2,6] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0 40	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1620) → $N\rho$, S=1/2, S-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (LARGE)	[5] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0 40 ± 0 10	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
+0 08	[2,6] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0 28	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1620) → $N\rho$, S=3/2, D-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− (SMALL)	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
−0 13	[2,6] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1620) → N(1440)π, S-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.11 ± 0.05	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$

Δ(1620) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

Δ(1620) → $N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 035 ± 0 010	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0 010 ± 0 015	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0 022 ± 0 007	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0 026 ± 0 008	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0 021 ± 0 020	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
0 126 ± 0 021	TAKEDA	80	DPWA	$\gamma N \to \pi N$
−0 034 ± 0 028	BARBOUR	78	DPWA	$\gamma N \to \pi N$
−0 005 ± 0 016	FELLER	76	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
0 066	WADA	84	DPWA	Compton scattering

Δ(1620) FOOTNOTES

[1] CHEW 80 reports two S_{31} resonances at somewhat higher masses than other analyses Problems with this analysis are discussed in section 2 1 11 of HOEHLER 83
[2] LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix the first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T matrix amplitudes
[3] From method II of LONGACRE 75 eyeball fits with Breit Wigner circles to the T matrix amplitudes
[4] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis
[5] MANLEY 84 considers this coupling sign to be well determined
[6] LONGACRE 77 considers this coupling to be well determined

Δ(1620) REFERENCES

For early references see Physics Letters **111B** (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
WADA	84	NP B247 313	+Egawa Imanishi Ishii Kato Ukai+	(INUS)
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
HOEHLER	83	Landolt Boernstein 1 9B2		(KARL)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
BARNHAM	80	NP B168 243	+Glickman Mier Jedrzejowicz+	(LOIC)
CHEW	80	Toronto Conf 123		(LBL) IJP
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
TAKEDA	80	NP B168 17	+Arai Fujii Ikeda Iwasaki+	(TOKY)
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+	(NAGO OSAK) IJP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP

Δ(1700) D_{33}

$I(J^P) = \frac{3}{2}(\frac{3}{2}^-)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**)

Δ(1700) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1630 to 1740 OUR ESTIMATE				
1710 ± 30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1680 ± 70	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1650	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
1718 4 $^{+13\ 1}_{-13\ 0}$	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
1622	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1629	BARBOUR	78	DPWA	$\gamma N \to \pi N$
1600	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1680	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

Δ(1700) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
190 to 300 OUR ESTIMATE				
280 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
230 ± 80	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
160	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
193 3 ± 26 0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
209	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
216	BARBOUR	78	DPWA	$\gamma N \to \pi N$
200	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
240	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$\Delta(1700)$ POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1675 ± 25	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1668	ARNDT	85	DPWA	$\pi N \to \pi N$
1681 or 1672	[4] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
1600 or 1594	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

− 2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
220 ± 40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
320	ARNDT	85	DPWA	$\pi N \to \pi N$
245 or 241	[4] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$
208 or 201	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

$\Delta(1700)$ ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
12 ± 3	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
− 4 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$\Delta(1700)$ DECAY MODES

Γ_1	$\Delta(1700) \to N\pi$
Γ_2	$\Delta(1700) \to \Sigma K$
Γ_3	$\Delta(1700) \to N\pi\pi$
Γ_4	$\Delta(1700) \to \Delta(1232)\pi$, *S*-wave
Γ_5	$\Delta(1700) \to \Delta(1232)\pi$, *D*-wave
Γ_6	$\Delta(1700) \to N\rho$, S=1/2, *D*-wave
Γ_7	$\Delta(1700) \to N\rho$, S=3/2, *S*-wave
Γ_8	$\Delta(1700) \to N\rho$, S=3/2, *D*-wave
Γ_9	$\Delta(1700) \to N\gamma$, helicity=1/2
Γ_{10}	$\Delta(1700) \to N\gamma$, helicity=3/2

$\Delta(1700)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.10 to 0.20 OUR ESTIMATE				
0 12 ± 0 03	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 20 ± 0 03	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
0 16	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1700) \to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
0 002	LIVANOS	80	DPWA	$\pi p \to \Sigma K$
0 001 to 0 011	[5] DEANS	75	DPWA	$\pi N \to \Sigma K$

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon first convention the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1700) \to \Delta(1232)\pi$, *S*-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+	[6] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0 18 ± 0.04	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
+0 30	[2,7] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0 24	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1700) \to \Delta(1232)\pi$, *D*-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+	[6] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
0.14 ± 0 04	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$
+0 05	[2,7] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0 10	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1700) \to N\rho$, S=1/2, *D*-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0 17 ± 0 05	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1700) \to N\rho$, S=3/2, *S*-wave $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0 04	[2,7] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0 30	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1700) \to N\rho$, S=3/2, *D*-wave $(\Gamma_1\Gamma_8)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 18 ± 0 07	BARNHAM	80	IPWA	$\pi N \to N\pi\pi$

$\Delta(1700)$ PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

$\Delta(1700) \to N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 111 ± 0 017	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0 089 ± 0 033	AWAJI	81	DPWA	$\gamma N \to \pi N$
0 112 ± 0 006	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0 130 ± 0 006	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0 123 ± 0 022	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
+0 130 ± 0 037	BARBOUR	78	DPWA	$\gamma N \to \pi N$
+0 072 ± 0 033	FELLER	76	DPWA	$\gamma N \to \pi N$

$\Delta(1700) \to N\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 107 ± 0 015	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0 060 ± 0 015	AWAJI	81	DPWA	$\gamma N \to \pi N$
0 047 ± 0 007	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0 050 ± 0 007	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0 102 ± 0.015	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
+0 098 ± 0 036	BARBOUR	78	DPWA	$\gamma N \to \pi N$
+0 087 ± 0 023	FELLER	76	DPWA	$\gamma N \to \pi N$

$\Delta(1700)$ FOOTNOTES

[1] Problems with CHEW 80 are discussed in section 2 1 11 of HOEHLER 83

[2] LONGACRE 77 pole positions are from a search for poles in the unitarized T matrix the first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis The other LONGACRE 77 values are from eyeball fits with Breit Wigner circles to the T matrix amplitudes

[3] From method II of LONGACRE 75 eyeball fits with Breit Wigner circles to the T matrix amplitudes

[4] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis

[5] The range given is from the four best solutions DEANS 75 disagrees with $\pi^+ p \to \Sigma^+ K^+$ data of WINNIK 77 around 1920 MeV

[6] MANLEY 84 considers this coupling sign to be well determined

[7] LONGACRE 77 considers this coupling to be well determined

$\Delta(1700)$ REFERENCES

For early references see Physics Letters **111B** (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
HOEHLER	83	Landolt Boernstein 1 9B2		(KARL)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
BARNHAM	80	NP B168 243	+Glickman Mier Jedrzejowicz+	(LOIC)
CHEW	80	Toronto Conf 123		(LBL) IJP
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
LIVANOS	80	Toronto Conf 35	+Baton Coutures Kochowski Neveu	(SACL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP
WINNIK	77	NP B128 66	+Toaff Revel Goldberg Berny	(HAIF) I
FELLER	76	NP B104 219	+Fukushima Horikawa Kajikawa+	(NAGO OSAK) IJP
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP

Δ(1900) S_{31}

$I(J^P) = \frac{3}{2}(\frac{1}{2}^-)$ Status * * *

Δ(1900) MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1850 to 2000 OUR ESTIMATE			
1890 ± 50	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
1908 ± 30	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •			
1918 5 ± 23 0	CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
1803	CRAWFORD 80	DPWA	$\gamma N \to \pi N$

Δ(1900) WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
130 to 300 OUR ESTIMATE			
170 ± 50	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
140 ± 40	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits, limits etc • • •			
93 5 ± 54 0	CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
137	CRAWFORD 80	DPWA	$\gamma N \to \pi N$

Δ(1900) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1870 ± 40	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •			
2029 or 2025	[1] LONGACRE 78	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
180 ± 50	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits limits etc • • •			
164 or 163	[1] LONGACRE 78	IPWA	$\pi N \to N\pi\pi$

Δ(1900) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
9 ± 4	CUTKOSKY 80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
3 ± 7	CUTKOSKY 80	IPWA	$\pi N \to \pi N$

Δ(1900) DECAY MODES

Γ_1 Δ(1900) → $N\pi$
Γ_2 Δ(1900) → ΣK
Γ_3 Δ(1900) → $N\rho$, S=3/2, D-wave
Γ_4 Δ(1900) → $N(1440)\pi$, S-wave
Γ_5 Δ(1900) → $N\gamma$, helicity=1/2

Δ(1900) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.05 to 0.15 OUR ESTIMATE			
0 10 ± 0 03	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
0 08 ± 0 04	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •			
0 28	CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1900) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
<0 03	CANDLIN 84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
• • • We do not use the following data for averages, fits limits etc • • •			
0 076	[2] DEANS 75	DPWA	$\pi N \to \Sigma K$
0 11	LANGBEIN 73	IPWA	$\pi N \to \Sigma K$ (sol 1)
0 12	LANGBEIN 73	IPWA	$\pi N \to \Sigma K$ (sol 2)

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1900) $\to N\rho$, S=3/2, D-wave $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
LARGE	MANLEY 84	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1900) $\to N(1440)\pi$, S-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
+ (LARGE)	MANLEY 84	IPWA	$\pi N \to N\pi\pi$

Δ(1900) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

Δ(1900) → $N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID	TECN	COMMENT
−0 004 ± 0 016	CRAWFORD 83	IPWA	$\gamma N \to \pi N$
0 029 ± 0 008	AWAJI 81	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •			
−0 006 to −0 025	CRAWFORD 80	DPWA	$\gamma N \to \pi N$

Δ(1900) FOOTNOTES

[1] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial-wave analysis
[2] The value given is from solution 1 the resonance is not present in solutions 2 3 or 4

Δ(1900) REFERENCES

For early references see Physics Letters 111B (1982)

CANDLIN	84	NP B238 477	+Lowe Peach Scotland+	(EDIN RAL LOWC)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
CHEW	80	Toronto Conf 123		(LBL) IJP
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP
LANGBEIN	73	NP B53 251	+Wagner	(MUNI) IJP

Δ(1905) F_{35}

$I(J^P) = \frac{3}{2}(\frac{5}{2}^+)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters 111B)

Δ(1905) MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1890 to 1920 OUR ESTIMATE			
1910 ± 30	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
1905 ± 20	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits etc • • •			
1960 ± 40	CANDLIN 84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
1787 0 $^{+6\ 0}_{-5\ 7}$	CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
1880	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
1892	BARBOUR 78	DPWA	$\gamma N \to \pi N$
1830	[1] LONGACRE 75	IPWA	$\pi N \to N\pi\pi$

Δ(1905) WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
250 to 400 OUR ESTIMATE			
400 ± 100	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
260 ± 20	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •			
270 ± 40	CANDLIN 84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
66 0 $^{+24\ 0}_{-16\ 0}$	CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
193	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
159	BARBOUR 78	DPWA	$\gamma N \to \pi N$
220	[1] LONGACRE 75	IPWA	$\pi N \to N\pi\pi$

Δ(1905) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1830 ± 40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits etc • • •				
1830	ARNDT	85	DPWA	$\pi N \to \pi N$
1813 or 1808	[2] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$

− 2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
280 ± 60	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
180	ARNDT	85	DPWA	$\pi N \to \pi N$
193 or 187	[2] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$

Δ(1905) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
16 ± 8	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
− 19 ± 8	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(1905) DECAY MODES

Γ_1 Δ(1905) → $N\pi$
Γ_2 Δ(1905) → ΣK
Γ_3 Δ(1905) → $N\pi\pi$
Γ_4 Δ(1905) → Δ(1232)π, *P*-wave
Γ_5 Δ(1905) → Δ(1232)π, *F*-wave
Γ_6 Δ(1905) → $N\rho$, S=1/2, *F*-wave
Γ_7 Δ(1905) → $N\rho$, S=3/2, *P*-wave
Γ_8 Δ(1905) → $N\rho$, S=3/2, *F*-wave
Γ_9 Δ(1905) → $N\gamma$, helicity=1/2
Γ_{10} Δ(1905) → $N\gamma$, helicity=3/2

Δ(1905) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.05 to 0.15 OUR ESTIMATE				
0 08 ± 0 03	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 15 ± 0 02	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
0.11	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1905) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 015 ± 0 003	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
• • • We do not use the following data for averages fits limits etc • • •				
−0 013	LIVANOS	80	DPWA	$\pi p \to \Sigma K$
0.021 to 0.054	[3] DEANS	75	DPWA	$\pi N \to \Sigma K$

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention the overall phase ambiguity is resolved by choosing a negative sign for the Δ(1620) S_{31} coupling to Δ(1232)π

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1905) $\to$ Δ(1232)π, *P*-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (SMALL)	MANLEY	84	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1905) $\to$ Δ(1232)π, *F*-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+	[4] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
+0 17	[5] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$
+0.06	[6] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$
+0 20	[1] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1905) $\to N\rho$, S=3/2, *P*-wave $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0 26	[5] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$
+0.11 to +0 33	[7] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$
+0.33	[1] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

Δ(1905) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

Δ(1905) → $N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 021 ± 0 010	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0 043 ± 0 020	AWAJI	81	DPWA	$\gamma N \to \pi N$
0 022 ± 0 010	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
0 031 ± 0 009	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
0 024 ± 0 014	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
+0 033 ± 0 018	BARBOUR	78	DPWA	$\gamma N \to \pi N$

Δ(1905) → $N\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.056 ± 0.028	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
−0 025 ± 0 023	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0 029 ± 0 007	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0 045 ± 0 006	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0 072 ± 0 035	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0.055 ± 0 019	BARBOUR	78	DPWA	$\gamma N \to \pi N$

Δ(1905) FOOTNOTES

[1] From method II of LONGACRE 75 eyeball fits with Breit Wigner circles to the T matrix amplitudes
[2] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis
[3] The range given for DEANS 75 is from the four best solutions
[4] MANLEY 84 considers this coupling sign to be well determined and suggests that the large $N\rho$ decay seen in previous analyses is predominantly from a higher mass F_{35} resonance See the Listings for the Δ(2000) F_{35}
[5] A Breit Wigner fit to the HERNDON 75 IPWA
[6] A Breit Wigner fit to the NOVOSELLER 78B IPWA
[7] A Breit Wigner fit to the NOVOSELLER 78B IPWA the phase is near 90°

Δ(1905) REFERENCES

For early references see Physics Letters 111B (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
CANDLIN	84	NP B238 477	+Lowe Peach Scotland+	(EDIN RAL LOWC)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
Also	84B	PRL 52 2122	Manley	(VPI)
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
CHEW	80	Toronto Conf 123		(LBL) IJP
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
LIVANOS	80	Toronto Conf 35	+Baton Coutures Kochowski Neveu	(SACL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
NOVOSELLER	78	NP B137 509		(CIT) IJP
NOVOSELLER	78B	NP B137 445		(CIT) IJP
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP
HERNDON	75	PR D11 3183	+Longacre Miller Rosenfeld+	(LBL SLAC)
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP

Δ(1910) P_{31}

$I(J^P) = \frac{3}{2}(\frac{1}{2}^+)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters 111B)

Δ(1910) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1850 to 1950 OUR ESTIMATE				
1910 ± 40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1888 ± 20	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1715 2 ± 21 0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
1778.4 ± 9 0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
1960 1 ± 21 0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
2121 4 $^{+13\ 0}_{-14\ 3}$	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$

1921	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
1899	BARBOUR 78	DPWA	$\gamma N \to \pi N$
1790	[2] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

Δ(1910) WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
200 to 330 OUR ESTIMATE			
225 ± 50	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
280 ± 50	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits, etc • • •			
93 3 ± 55 0	[1] CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
23 0 ± 29 0	[1] CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
152 9 ± 60 0	[1] CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
172 2 ± 37 0	[1] CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
351	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
230	BARBOUR 78	DPWA	$\gamma N \to \pi N$
170	[2] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

Δ(1910) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1880 ± 30	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits etc • • •			
1792 or 1801	[2] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
200 ± 40	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits etc • • •			
172 or 165	[2] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

Δ(1910) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
0 ± 10	CUTKOSKY 80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
− 20 ± 4	CUTKOSKY 80	IPWA	$\pi N \to \pi N$

Δ(1910) DECAY MODES

Γ_1 Δ(1910) → $N\pi$
Γ_2 Δ(1910) → ΣK
Γ_3 Δ(1910) → $N\pi\pi$
Γ_4 Δ(1910) → Δ(1232)π, *P*-wave
Γ_5 Δ(1910) → $N\rho$, *S*=3/2, *P*-wave
Γ_6 Δ(1910) → $N(1440)\pi$, *P*-wave
Γ_7 Δ(1910) → $N\gamma$, helicity=1/2

Δ(1910) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.15 to 0.25 OUR ESTIMATE			
0 19 ± 0 03	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
0.24 ± 0.06	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits, limits etc • • •			
0.18	[1] CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
0 20	[1] CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
0.17	[1] CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
0 40	[1] CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1910) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
< 0 03	CANDLIN 84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
• • • We do not use the following data for averages fits limits etc • • •			
−0 019	LIVANOS 80	DPWA	$\pi p \to \Sigma K$
0 082 to 0 184	[3] DEANS 75	DPWA	$\pi N \to \Sigma K$

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention the overall phase ambiguity is resolved by choosing a negative sign for the Δ(1620) S_{31} coupling to Δ(1232)π

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1910) $\to$ Δ(1232)π, *P*-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
+0 06	[2] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1910) $\to N\rho$, *S*=3/2, *P*-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
+0 29	[2] LONGACRE 77	IPWA	$\pi N \to N\pi\pi$
• • • We do not use the following data for averages fits limits etc • • •			
+0 17	[4] NOVOSELLER 78	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1910) $\to N(1440)\pi$, *P*-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
+ (LARGE)	[5] MANLEY 84	IPWA	$\pi N \to N\pi\pi$

Δ(1910) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on *N* and Δ Resonances preceding the Baryon Listings

Δ(1910) → $N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID	TECN	COMMENT
0 014 ± 0 030	CRAWFORD 83	IPWA	$\gamma N \to \pi N$
0 025 ± 0 011	AWAJI 81	DPWA	$\gamma N \to \pi N$
−0 012 ± 0.005	ARAI 80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0 031 ± 0 004	ARAI 80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0.005 ± 0 030	CRAWFORD 80	DPWA	$\gamma N \to \pi N$
−0 035 ± 0.021	BARBOUR 78	DPWA	$\gamma N \to \pi N$

Δ(1910) FOOTNOTES

[1] CHEW 80 reports four resonances in the P_{31} wave Problems with this analysis are discussed in section 2 1 11 of HOEHLER 83
[2] LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix the first (second) value uses in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis The other LONGACRE 77 values are from eyeball fits with Breit Wigner circles to the T-matrix amplitudes
[3] The range given for DEANS 75 is from the four best solutions
[4] Evidence for this coupling is weak see NOVOSELLER 78 This coupling assumes the mass is near 1820 MeV
[5] MANLEY 84 finds this decay mode accounts for all the inelasticity

Δ(1910) REFERENCES

For early references, see Physics Letters **111B** (1982)

CANDLIN	84	NP B238 477	+Lowe Peach Scotland+	(EDIN RAL LOWC)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
HOEHLER	83	Landolt Boernstein 1/9B2		(KARL)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
CHEW	80	Toronto Conf 123		(LBL) IJP
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
LIVANOS	80	Toronto Conf 35	+Baton Coutures Kochowski Neveu	(SACL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
NOVOSELLER	78	NP B137 509		(CIT) IJP
Also	78B	NP B137 445	Novoseller	(CIT) IJP
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau Triantis Neveu Cadiet	(SACL) IJP
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP

Δ(1920) P_{33}

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$ Status * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**)

Δ(1920) MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1860 to 2160 OUR ESTIMATE			
1920 ± 80	CUTKOSKY 80	IPWA	$\pi N \to \pi N$
1868 ± 10	HOEHLER 79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits, etc • • •			
1840 ± 40	CANDLIN 84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
1955 0 ± 13 0	[1] CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$
2065 $0^{+13\ 6}_{-12\ 9}$	[1] CHEW 80	BPWA	$\pi^+ p \to \pi^+ p$

Δ(1920) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
190 to 300 OUR ESTIMATE				
300 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
220 ± 80	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
200 ± 40	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
88.3 ± 35.0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
62.0 ± 44.0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$

Δ(1920) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1900 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
300 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(1920) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−21 ± 7	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−12 ± 11	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(1920) DECAY MODES

- Γ_1 Δ(1920) → $N\pi$
- Γ_2 Δ(1920) → ΣK
- Γ_3 Δ(1920) → Δ(1232)π, *P*-wave
- Γ_4 Δ(1920) → $N(1440)\pi$, *P*-wave
- Γ_5 Δ(1920) → $N\gamma$, helicity=1/2
- Γ_6 Δ(1920) → $N\gamma$, helicity=3/2

Δ(1920) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.15 to 0.20 OUR ESTIMATE				
0.20 ± 0.05	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.14 ± 0.04	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.24	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
0.18	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1920) $\to \Sigma K$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.052 ± 0.015	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.049	LIVANOS	80	DPWA	$\pi p \to \Sigma K$
0.048 to 0.120	[2] DEANS	75	DPWA	$\pi N \to \Sigma K$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1920) $\to$ Δ(1232)π, *P*-wave — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
0.3	[3] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$
0.27	[4] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1920) $\to N(1440)\pi$, *P*-wave — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+	MANLEY	84	IPWA	$\pi N \to N\pi\pi$

Δ(1920) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes, see Sec. IV of the Note on *N* and Δ Resonances preceding the Baryon Listings.

Δ(1920) → $N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0.040 ± 0.014	AWAJI	81	DPWA	$\gamma N \to \pi N$

Δ(1920) → $N\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0.023 ± 0.017	AWAJI	81	DPWA	$\gamma N \to \pi N$

Δ(1920) FOOTNOTES

[1] CHEW 80 reports two P_{33} resonances in this mass region. Problems with this analysis are discussed in section 2.1.11 of HOEHLER 83.
[2] The range given for DEANS 75 is from the four best solutions.
[3] A Breit-Wigner fit to the HERNDON 75 IPWA; the phase is near −90°.
[4] A Breit-Wigner fit to the NOVOSELLER 78B IPWA; the phase is near −90°.

Δ(1920) REFERENCES

For early references, see Physics Letters 111B (1982).

CANDLIN	84	NP B238 477	+Lowe, Peach, Scotland+	(EDIN, RAL, LOWC)
MANLEY	84	PR D30 904	+Arndt, Goradia, Teplitz	(VPI)
HOEHLER	83	Landolt-Boernstein 1/9B2		(KARL)
AWAJI	81	Bonn Conf. 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii, Hayashii, Iwata, Kajikawa+	(NAGO)
CHEW	80	Toronto Conf. 123		(LBL) IJP
CUTKOSKY	80	Toronto Conf. 19	+Forsyth, Babcock, Kelly, Hendrick	(CMU, LBL) IJP
Also	79	PR D20 2839	Cutkosky, Forsyth, Hendrick, Kelly	(CMU, LBL) IJP
LIVANOS	80	Toronto Conf. 35	+Baton, Coutures, Kochowski, Neveu	(SACL) IJP
HOEHLER	79	PDAT 12-1	+Kaiser, Koch, Pietarinen	(KARL) IJP
Also	80	Toronto Conf. 3	Koch	(KARL) IJP
NOVOSELLER	78	NP B137 509		(CIT)
NOVOSELLER	78B	NP B137 445		(CIT)
DEANS	75	NP B96 90	+Mitchell, Montgomery+	(SFLA, ALAH) IJP
HERNDON	75	PR D11 3183	+Longacre, Miller, Rosenfeld+	(LBL, SLAC)

Δ(1930) D_{35}

$I(J^P) = \frac{3}{2}(\frac{5}{2}^-)$ Status: * * *

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition (Physics Letters 111B).

The various analyses are not in good agreement.

Δ(1930) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1890 to 1960 OUR ESTIMATE				
1940 ± 30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1901 ± 15	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$1910.0^{+15.0}_{-17.2}$	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
2000	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
2024	BARBOUR	78	DPWA	$\gamma N \to \pi N$

Δ(1930) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
150 to 350 OUR ESTIMATE				
320 ± 60	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
195 ± 60	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$74.8^{+17.0}_{-16.0}$	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
442	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
462	BARBOUR	78	DPWA	$\gamma N \to \pi N$

Δ(1930) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1890 ± 50	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
260 ± 60	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(1930) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
17 ± 7	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Baryon Full Listings
Δ(1930), Δ(1940)

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−6 ± 12	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(1930) DECAY MODES

Γ_1 Δ(1930) → $N\pi$
Γ_2 Δ(1930) → ΣK
Γ_3 Δ(1930) → $N\pi\pi$
Γ_4 Δ(1930) → $N\gamma$, helicity=1/2
Γ_5 Δ(1930) → $N\gamma$, helicity=3/2

Δ(1930) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.05 to 0.15 OUR ESTIMATE				
0.14 ± 0 04	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 04 ± 0.03	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits etc • • •				
0 11	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1930) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
< 0 015	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
• • • We do not use the following data for averages fits limits etc • • •				
−0 031	LIVANOS	80	DPWA	$\pi p \to \Sigma K$
0 018 to 0 035	[1] DEANS	75	DPWA	$\pi N \to \Sigma K$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1930) $\to N\pi\pi$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
NOT SEEN	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
NOT SEEN	LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

Δ(1930) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

Δ(1930) → $N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
0 009 ± 0 009	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.030 ± 0.047	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0 062 ± 0 064	BARBOUR	78	DPWA	$\gamma N \to \pi N$

Δ(1930) → $N\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.025 ± 0 011	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0 033 ± 0 060	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
+0 019 ± 0 054	BARBOUR	78	DPWA	$\gamma N \to \pi N$

Δ(1930) FOOTNOTES

[1] The range given for DEANS 75 is from the four best solutions

Δ(1930) REFERENCES

For early references, see Physics Letters **111B** (1982)

CANDLIN	84	NP B238 477	+Lowe Peach Scotland+	(EDIN RAL LOWC)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
CHEW	80	Toronto Conf 123		(LBL) IJP
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
LIVANOS	80	Toronto Conf 35	+Baton Coutures Kochowski Neveu	(SACL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP

Δ(1940) D_{33}

$I(J^P) = \frac{3}{2}(\frac{3}{2}^-)$ Status *

OMITTED FROM SUMMARY TABLE

Δ(1940) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2058 1 ± 34 5	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
1940 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(1940) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
198 4 ± 45.5	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
200 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(1940) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1900 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1915 or 1926	[1] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
200 ± 60	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
190 or 186	[1] LONGACRE	78	IPWA	$\pi N \to N\pi\pi$

Δ(1940) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−6 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
6 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(1940) DECAY MODES

Γ_1 Δ(1940) → $N\pi$
Γ_2 Δ(1940) → ΣK
Γ_3 Δ(1940) → $N\gamma$, helicity=1/2
Γ_4 Δ(1940) → $N\gamma$, helicity=3/2

Δ(1940) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0 18	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
0 05 ± 0 02	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(1940) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
<0 015	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(1940) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes, see Sec IV of the Note on N and Δ Resonances preceding the Baryon Listings

Δ(1940) → $N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0 036 ± 0 058	AWAJI	81	DPWA	$\gamma N \to \pi N$

Δ(1940) → $N\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.031 ± 0 012	AWAJI	81	DPWA	$\gamma N \to \pi N$

Δ(1940) FOOTNOTES

[1] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial-wave analysis

Δ(1940) REFERENCES

CANDLIN	84	NP B238 477	+Lowe Peach Scotland+	(EDIN RAL LOWC)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
CHEW	80	Toronto Conf 123		(LBL) IJP
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)

Δ(1950) F_{37}

$I(J^P) = \frac{3}{2}(\frac{7}{2}^+)$ Status * * * *

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**) In addition, results in this region from production experiments, which used to be listed separately as the next entry, have been entirely omitted They too may be found in our 1982 edition

Δ(1950) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1910 to 1960 OUR ESTIMATE				
1950 ± 15	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1913 ± 8	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits limits etc • • •				
1925 ± 20	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
$1855\ 0^{+11\ 0}_{-10\ 0}$	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
1902	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1912	BARBOUR	78	DPWA	$\gamma N \to \pi N$
1925	[1] LONGACRE	75	IPWA	$\pi N \to N \pi\pi$

Δ(1950) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
200 to 340 OUR ESTIMATE				
340 ± 50	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
224 ± 10	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits etc • • •				
330 ± 40	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
$157\ 2^{+22\ 0}_{-19\ 0}$	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
225	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
198	BARBOUR	78	DPWA	$\gamma N \to \pi N$
240	[1] LONGACRE	75	IPWA	$\pi N \to N \pi\pi$

Δ(1950) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1890 ± 15	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
1858	ARNDT	85	DPWA	$\pi N \to \pi N$
1924 or 1924	[2] LONGACRE	78	IPWA	$\pi N \to N \pi\pi$

− 2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
260 ± 40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits etc • • •				
238	ARNDT	85	DPWA	$\pi N \to \pi N$
258 or 258	[2] LONGACRE	78	IPWA	$\pi N \to N \pi\pi$

Δ(1950) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
42 ± 7	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−27 ± 7	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(1950) DECAY MODES

Γ_1 Δ(1950) → $N\pi$
Γ_2 Δ(1950) → ΣK
Γ_3 Δ(1950) → Δ(1232)π, *F*-wave
Γ_4 Δ(1950) → Δ(1232)π, *H*-wave
Γ_5 Δ(1950) → $N\rho$, *S*=1/2, *F*-wave
Γ_6 Δ(1950) → $N\rho$, *S*=3/2, *F*-wave
Γ_7 Δ(1950) → *N*(1680)π, *P*-wave
Γ_8 Δ(1950) → $N\gamma$, helicity=1/2
Γ_9 Δ(1950) → $N\gamma$, helicity=3/2

Δ(1950) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.35 to 0.45 OUR ESTIMATE				
0 39 ± 0 04	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 38 ± 0.02	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
0 44	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\pi \to$ Δ(1950) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{½}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 053 ± 0 005	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
• • • We do not use the following data for averages fits limits etc • • •				
0 022 to 0.040	[3] DEANS	75	DPWA	$\pi N \to \Sigma K$

Note Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention the overall phase ambiguity is resolved by choosing a negative sign for the Δ(1620) S_{31} coupling to Δ(1232)π

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\pi \to$ Δ(1950) $\to$ Δ(1232)π, *F*-wave $(\Gamma_1\Gamma_3)^{½}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (LARGE)	[4] MANLEY	84	IPWA	$\pi N \to N\pi\pi$
0 21	[5] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$
0 38	[6] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$
+0 32	[1] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\pi \to$ Δ(1950) $\to N\rho$, *S*=3/2, *F*-wave $(\Gamma_1\Gamma_6)^{½}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 24	[7] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$
0 43	[8] NOVOSELLER	78	IPWA	$\pi N \to N\pi\pi$
+0.24	[1] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\pi \to$ Δ(1950) $\to$ *N*(1680)π, *P*-wave $(\Gamma_1\Gamma_7)^{½}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0 20	MANLEY	84	IPWA	$\pi N \to N\pi\pi$

Δ(1950) PHOTON DECAY AMPLITUDES

For definition of the γN decay amplitudes see Sec IV of the Note on *N* and Δ Resonances preceding the Baryon Listings

Δ(1950) → $N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0 068 ± 0.007	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.091 ± 0 005	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0 083 ± 0 005	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0 067 ± 0 014	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0 058 ± 0 013	BARBOUR	78	DPWA	$\gamma N \to \pi N$

Δ(1950) → $N\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0 094 ± 0 016	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0 101 ± 0 005	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 1)
−0 100 ± 0 005	ARAI	80	DPWA	$\gamma N \to \pi N$ (fit 2)
−0 082 ± 0 017	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
−0 075 ± 0 020	BARBOUR	78	DPWA	$\gamma N \to \pi N$

Δ(1950) FOOTNOTES

[1] From method II of LONGACRE 75 eyeball fits with Breit Wigner circles to the T-matrix amplitudes
[2] LONGACRE 78 values are from a search for poles in the unitarized T matrix The first (second) value uses in addition to $\pi N \to N\pi\pi$ data elastic amplitudes from a Saclay (CERN) partial wave analysis
[3] The range given is from the four best solutions DEANS 75 disagrees with $\pi^+ p \to \Sigma^+ K^+$ data of WINNIK 77 around 1920 MeV
[4] MANLEY 84 considers this coupling sign to be well determined
[5] A Breit Wigner fit to the HERNDON 75 IPWA the phase is near −60°

Baryon Full Listings
Δ(1950), Δ(2000), Δ(2150)

[6]A Breit Wigner fit to the NOVOSELLER 78B IPWA the phase is near −60°
[7]A Breit Wigner fit to the HERNDON 75 IPWA the phase is near 120°
[8]A Breit Wigner fit to the NOVOSELLER 78B IPWA the phase is near 120°

Δ(1950) REFERENCES

For early references see Physics Letters 111B (1982)

ARNDT	85	PR D32 1085	+Ford Roper	(VPI)
CANDLIN	84	NP B238 477	+Lowe Peach Scotland+	(EDIN RAL LOWC)
MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
Also	84B	PRL 52 2122	Manley	(VPI)
AWAJI	81	Bonn Conf 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii Hayashii Iwata Kajikawa+	(NAGO)
ARAI	80	Toronto Conf 93		(TOKY)
Also	82	NP B194 251	Arai Fujii	(TOKY)
CHEW	80	Toronto Conf 123		(LBL) IJP
CRAWFORD	80	Toronto Conf 107		(GLAS)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL) IJP
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
BARBOUR	78	NP B141 253	+Crawford Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski Rosenfeld Smadja+	(LBL SLAC)
NOVOSELLER	78	NP B137 509		(CIT) IJP
NOVOSELLER	78B	NP B137 445		(CIT) IJP
WINNIK	77	NP B128 66	+Toaff Revel Goldberg Berny	(HAIF) I
DEANS	75	NP B96 90	+Mitchell Montgomery+	(SFLA ALAH) IJP
HERNDON	75	PR D11 3183	+Longacre Miller Rosenfeld+	(LBL SLAC)
LONGACRE	75	PL 55B 415	+Rosenfeld Lasinski Smadja+	(LBL SLAC) IJP

Δ(2000) F_{35}

$I(J^P) = \frac{3}{2}(\frac{5}{2}^+)$ Status ＊＊

OMITTED FROM SUMMARY TABLE

Δ(2000) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
~2000	MANLEY	84	IPWA	$\pi N \to N\pi\pi$
2200 ± 125	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2000) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
400 ± 125	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2000) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2150 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
350 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2000) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−14 ± 13	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
8 ± 22	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2000) DECAY MODES

Γ_1 Δ(2000) → $N\pi$
Γ_2 Δ(2000) → $N\rho$, S=3/2, P-wave

Δ(2000) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.07 ± 0.04	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(2000) $\to N\rho$, S=3/2, P-wave $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ (LARGE)	[1] MANLEY	84	IPWA	$\pi N \to N\pi\pi$

Δ(2000) FOOTNOTES

[1]MANLEY 84 considers this coupling sign to be well determined This resonance has not been seen in $\pi N \to \pi N$ analyses Thus its coupling to the $N\pi$ channel is expected to be weak

Δ(2000) REFERENCES

MANLEY	84	PR D30 904	+Arndt Goradia Teplitz	(VPI)
Also	84B	PRL 52 2122	Manley	(VPI)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL)
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)

Δ(2150) S_{31}

$I(J^P) = \frac{3}{2}(\frac{1}{2}^-)$ Status ＊

OMITTED FROM SUMMARY TABLE

Δ(2150) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2047.4 ± 27.0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
2203.2 ± 8.4	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
2150 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2150) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
121.6 ± 62.0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
120.5 ± 45.0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
200 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2150) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2140 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
200 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2150) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
4 ± 10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−6 ± 6	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2150) DECAY MODES

Γ_1 Δ(2150) → $N\pi$
Γ_2 Δ(2150) → ΣK

Δ(2150) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.41	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
0.37	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
0.08 ± 0.02	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(2150) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
<0.03	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(2150) FOOTNOTES

[1] CHEW 80 reports two S_{31} resonances in this mass region. Problems with this analysis are discussed in section 2.1.11 of HOEHLER 83.

Δ(2150) REFERENCES

CANDLIN	84	NP B238 477	+Lowe, Peach, Scotland+	(EDIN, RAL, LOWC)
HOEHLER	83	Landolt-Boernstein 1/9B2		(KARL)
CHEW	80	Toronto Conf. 123		(LBL) IJP
CUTKOSKY	80	Toronto Conf. 19	+Forsyth, Babcock, Kelly, Hendrick	(CMU, LBL) IJP
Also	79	PR D20 2839	Cutkosky, Forsyth, Hendrick, Kelly	(CMU, LBL)

Δ(2200) G_{37}

$I(J^P) = \frac{3}{2}(\frac{7}{2}^-)$ Status: *

OMITTED FROM SUMMARY TABLE

The various analyses are not in good agreement.

Δ(2200) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2200 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2215 ± 60	HOEHLER	79	IPWA	$\pi N \to \pi N$
2280 ± 80	HENDRY	78	MPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2280 ± 40	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(2200) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
450 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
400 ± 100	HOEHLER	79	IPWA	$\pi N \to \pi N$
400 ± 150	HENDRY	78	MPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
400 ± 50	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(2200) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2100 ± 50	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
340 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2200) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
3 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−8 ± 3	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2200) DECAY MODES

Γ_1 Δ(2200) → $N\pi$
Γ_2 Δ(2200) → ΣK

Δ(2200) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.06 ± 0.02	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.05 ± 0.02	HOEHLER	79	IPWA	$\pi N \to \pi N$
0.09 ± 0.02	HENDRY	78	MPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(2200) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.014 ± 0.005	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(2200) REFERENCES

CANDLIN	84	NP B238 477	+Lowe, Peach, Scotland+	(EDIN, RAL, LOWC)
CUTKOSKY	80	Toronto Conf. 19	+Forsyth, Babcock, Kelly, Hendrick	(CMU, LBL) IJP
Also	79	PR D20 2839	Cutkosky, Forsyth, Hendrick, Kelly	(CMU, LBL) IJP
HOEHLER	79	PDAT 12-1	+Kaiser, Koch, Pietarinen	(KARL) IJP
Also	80	Toronto Conf. 3	Koch	(KARL) IJP
HENDRY	78	PRL 41 222		(IND, LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)

Δ(2300) H_{39}

$I(J^P) = \frac{3}{2}(\frac{9}{2}^+)$ Status: **

OMITTED FROM SUMMARY TABLE

Δ(2300) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2204.5 ± 3.4	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
2400 ± 125	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2217 ± 80	HOEHLER	79	IPWA	$\pi N \to \pi N$
2450 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2400	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(2300) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
32.3 ± 1.0	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
425 ± 150	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
300 ± 100	HOEHLER	79	IPWA	$\pi N \to \pi N$
500 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
200	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(2300) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2370 ± 80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
420 ± 160	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2300) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
9 ± 4	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−3 ± 5	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2300) DECAY MODES

Γ_1 Δ(2300) → $N\pi$
Γ_2 Δ(2300) → ΣK

Δ(2300) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.05	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
0.06 ± 0.02	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.03 ± 0.02	HOEHLER	79	IPWA	$\pi N \to \pi N$
0.08 ± 0.02	HENDRY	78	MPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(2300) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.017	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(2300) REFERENCES

CANDLIN	84	NP B238 477	+Lowe Peach Scotland+	(EDIN RAL LOWC)
CHEW	80	Toronto Conf 123		(LBL) IJP
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)

Δ(2350) D_{35}

$I(J^P) = \frac{3}{2}(\frac{5}{2}^-)$ Status *

OMITTED FROM SUMMARY TABLE

Δ(2350) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2400 ± 125	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2305 ± 26	HOEHLER	79	IPWA	$\pi N \to \pi N$

Δ(2350) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
400 ± 150	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
300 ± 70	HOEHLER	79	IPWA	$\pi N \to \pi N$

Δ(2350) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2400 ± 125	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
400 ± 150	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2350) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
5 ± 17	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−14 ± 10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2350) DECAY MODES

Γ_1 Δ(2350) → $N\pi$
Γ_2 Δ(2350) → ΣK

Δ(2350) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.20 ± 0.10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.04 ± 0.02	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(2350) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
<0.015	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(2350) REFERENCES

CANDLIN	84	NP B238 477	+Lowe Peach Scotland+	(EDIN RAL LOWC)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP

Δ(2390) F_{37}

$I(J^P) = \frac{3}{2}(\frac{7}{2}^+)$ Status *

OMITTED FROM SUMMARY TABLE

Δ(2390) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2350 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2425 ± 60	HOEHLER	79	IPWA	$\pi N \to \pi N$

Δ(2390) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
300 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
300 ± 80	HOEHLER	79	IPWA	$\pi N \to \pi N$

Δ(2390) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2350 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
260 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2390) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
0 ± 13	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−12 ± 6	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2390) DECAY MODES

Γ_1 Δ(2390) → $N\pi$
Γ_2 Δ(2390) → ΣK

Δ(2390) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.08 ± 0.04	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.07 ± 0.04	HOEHLER	79	IPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(2390) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
<0.015	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(2390) REFERENCES

CANDLIN	84	NP B238 477	+Lowe Peach Scotland+	(EDIN RAL LOWC)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP

Δ(2400) G_{39}

$I(J^P) = \frac{3}{2}(\frac{9}{2}^-)$ Status **

OMITTED FROM SUMMARY TABLE

Δ(2400) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2300 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2468 ± 50	HOEHLER	79	IPWA	$\pi N \to \pi N$
2200 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$

Δ(2400) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
330 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
480 ± 100	HOEHLER	79	IPWA	$\pi N \to \pi N$
450 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$

Δ(2400) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2260 ± 60	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
320 ± 160	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2400) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
7 ± 4	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−3 ± 3	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2400) DECAY MODES

Γ_1 Δ(2400) → $N\pi$

Γ_2 Δ(2400) → ΣK

Δ(2400) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.05 ± 0.02	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 06 ± 0 03	HOEHLER	79	IPWA	$\pi N \to \pi N$
0.10 ± 0.03	HENDRY	78	MPWA	$\pi N \to \pi N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(2400) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
<0 015	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(2400) REFERENCES

CANDLIN	84	NP B238 477	+Lowe Peach Scotland+	(EDIN RAL LOWC)
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)
HOEHLER	79	PDAT 12 1	+Kalser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)

Δ(2420) $H_{3,11}$

$I(J^P) = \frac{3}{2}(\frac{11}{2}^+)$ Status ****

Most of the results published before 1975 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**)

In addition results in this region from production experiments, which used to be listed separately as the next entry, have been entirely omitted They too may be found in our 1982 edition

Δ(2420) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2380 to 2450 OUR ESTIMATE				
2400 ± 125	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2416 ± 17	HOEHLER	79	IPWA	$\pi N \to \pi N$
2400 ± 60	HENDRY	78	MPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
2400	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
2358 0 ± 9 0	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$

Δ(2420) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
300 to 500 OUR ESTIMATE				
450 ± 150	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
340 ± 28	HOEHLER	79	IPWA	$\pi N \to \pi N$
460 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
400	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$
202.2 ± 45 0	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$

Δ(2420) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2360 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

−2 × IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
420 ± 100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2420) ELASTIC POLE RESIDUE

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
16 ± 8	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
−9 ± 11	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

Δ(2420) DECAY MODES

Γ_1 Δ(2420) → $N\pi$

Γ_2 Δ(2420) → ΣK

Δ(2420) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.05 to 0.15 OUR ESTIMATE				
0 08 ± 0 03	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0 08 ± 0 015	HOEHLER	79	IPWA	$\pi N \to \pi N$
0 11 ± 0 02	HENDRY	78	MPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages fits limits etc • • •				
0 22	CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to$ Δ(2420) $\to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 016	CANDLIN	84	DPWA	$\pi^+ p \to \Sigma^+ K^+$

Δ(2420) REFERENCES

CANDLIN	84	NP B238 477	+Lowe Peach Scotland+	(EDIN RAL LOWC)
CHEW	80	Toronto Conf 123		(LBL) IJP
CUTKOSKY	80	Toronto Conf 19	+Forsyth Babcock Kelly Hendrick	(CMU LBL) IJP
Also	79	PR D20 2839	Cutkosky Forsyth Hendrick Kelly	(CMU LBL)
HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)

Δ(2750) $I_{3,13}$

$I(J^P) = \frac{3}{2}(\frac{13}{2}^-)$ Status **

OMITTED FROM SUMMARY TABLE

Δ(2750) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2794 ± 80	HOEHLER	79	IPWA	$\pi N \to \pi N$
2650 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$

Baryon Full Listings
Δ(2750), Δ(2950), Δ(~3000)

Δ(2750) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
350 ± 100	HOEHLER	79	IPWA	$\pi N \to \pi N$
500 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$

Δ(2750) DECAY MODES

Γ_1 Δ(2750) → $N\pi$

Δ(2750) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0 04 ± 0 015	HOEHLER	79	IPWA	$\pi N \to \pi N$
0 05 ± 0 01	HENDRY	78	MPWA	$\pi N \to \pi N$

Δ(2750) REFERENCES

HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)

Δ(2950) $K_{3,15}$

$I(J^P) = \frac{3}{2}(\frac{15}{2}^+)$ Status * *

OMITTED FROM SUMMARY TABLE

Δ(2950) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2990 ± 100	HOEHLER	79	IPWA	$\pi N \to \pi N$
2850 ± 100	HENDRY	78	MPWA	$\pi N \to \pi N$

Δ(2950) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
330 ± 100	HOEHLER	79	IPWA	$\pi N \to \pi N$
700 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$

Δ(2950) DECAY MODES

Γ_1 Δ(2950) → $N\pi$

Δ(2950) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0 04 ± 0 02	HOEHLER	79	IPWA	$\pi N \to \pi N$
0 03 ± 0.01	HENDRY	78	MPWA	$\pi N \to \pi N$

Δ(2950) REFERENCES

HOEHLER	79	PDAT 12 1	+Kaiser Koch Pietarinen	(KARL) IJP
Also	80	Toronto Conf 3	Koch	(KARL) IJP
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)

Δ(~3000 REGION) PARTIAL-WAVE ANALYSES

We list here miscellaneous high-mass candidates for isospin-3/2 resonances found in partial-wave analyses

Our 1982 edition also had a Δ(2850) and a Δ(3230) The evidence for them was deduced from total cross-section and 180° elastic cross-section measurements The Δ(2850) has been resolved into the Δ(2750) $I_{3\,13}$ and Δ(2950) $K_{3\,15}$ The Δ(3230) is perhaps related to the $K_{3\,13}$ of HENDRY 78 and to the $L_{3\,17}$ of KOCH 80

Δ(~3000) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
3300	[1] KOCH	80	IPWA	$\pi N \to \pi N$ $L_{3\,17}$ wave
3500	[1] KOCH	80	IPWA	$\pi N \to \pi N$ $M_{3\,19}$ wave
2850 ± 150	HENDRY	78	MPWA	$\pi N \to \pi N$ $I_{3\,11}$ wave
3200 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$ $K_{3\,13}$ wave
3300 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$ $L_{3\,17}$ wave
3700 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$ $M_{3\,19}$ wave
4100 ± 300	HENDRY	78	MPWA	$\pi N \to \pi N$ $N_{3\,21}$ wave

Δ(~3000) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
700 ± 200	HENDRY	78	MPWA	$\pi N \to \pi N$ $I_{3\,11}$ wave
1000 ± 300	HENDRY	78	MPWA	$\pi N \to \pi N$ $K_{3\,13}$ wave
1100 ± 300	HENDRY	78	MPWA	$\pi N \to \pi N$ $L_{3\,17}$ wave
1300 ± 400	HENDRY	78	MPWA	$\pi N \to \pi N$ $M_{3\,19}$ wave
1600 ± 500	HENDRY	78	MPWA	$\pi N \to \pi N$ $N_{3\,21}$ wave

Δ(~3000) DECAY MODES

Γ_1 Δ(~3000) → $N\pi$

Δ(~3000) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0 06 ± 0 02	HENDRY	78	MPWA	$\pi N \to \pi N$ $I_{3\,11}$ wave
0 045 ± 0.02	HENDRY	78	MPWA	$\pi N \to \pi N$ $K_{3\,13}$ wave
0 03 ± 0 01	HENDRY	78	MPWA	$\pi N \to \pi N$ $L_{3\,17}$ wave
0 025 ± 0.01	HENDRY	78	MPWA	$\pi N \to \pi N$ $M_{3\,19}$ wave
0 018 ± 0 01	HENDRY	78	MPWA	$\pi N \to \pi N$ $N_{3\,21}$ wave

Δ(~3000) FOOTNOTES

[1] In addition, KOCH 80 reports some evidence for an S_{31} Δ(2700) and a P_{33} Δ(2800)

Δ(~3000) REFERENCES

KOCH	80	Toronto Conf 3		(KARL) IJP
HENDRY	78	PRL 41 222		(IND LBL) IJP
Also	81	ANP 136 1	Hendry	(IND)

NOTE ON THE $S = +1$ BARYON SYSTEM

The evidence for strangeness +1 baryon resonances was reviewed in our 1976 edition [1] and has been reviewed more recently by Kelly[2] and by Oades [3] New partial-wave analyses[4,5] appeared in 1984 and 1985, and both claimed that the P_{13} and perhaps other waves resonate However the results permit no definite conclusion the same story heard for 15 years The standards of proof must simply be more severe here than in a channel in which many resonances are already known to exist The present skepticism against baryons not made of three quarks and the lack of any experimental activity in this area make it likely that another 15 years will pass before the issue is decided Nothing new at all has been published in this area since our 1986 edition [6] and we simply refer to that for listings of the $Z_0(1780)$ P_{01} $Z_0(1865)$ D_{03} $Z_1(1725)$ P_{11} $Z_1(2150)$ and $Z_1(2500)$

References

1 Particle Data Group, Rev Mod Phys **48** S188 (1976)

2 R L Kelly, in *Proceedings of the Meeting on Exotic Resonances* (Hiroshima, 1978) ed I Endo et al

3 G C Oades, in *Low and Intermediate Energy Kaon-Nucleon Physics* (1981), ed E Ferrari and G Violini

4 K Hashimoto Phys Rev **C29** 1377 (1984)

5 R A Arndt and L D Roper, Phys Rev **D31** 2230 (1985)

6 Particle Data Group Phys Lett **170B** 289 (1986)

NOTE ON Λ AND Σ RESONANCES

I. Introduction

There are essentially no new results on Λ and Σ resonances for this edition The field remains at a standstill It can only be revived if one of the lower energy accelerators becomes a kaon factory What follows is the review from our 1986 edition it summarizes "recent" progress and problems (For another brief overview, see Tripp [1])

Table 1 is an attempt to evaluate the status both overall and channel by channel, of each Λ and Σ resonance in the full Baryon Listings the evaluations are of course partly subjective A blank indicates there is no evidence at all either the relevant couplings are small or the resonance does not really exist The main Baryon Summary Table includes only the established resonances (overall status 3 or 4 stars) A number of the 1- and 2-star entries may eventually disappear, but there are certainly many resonances yet to be discovered underlying the established ones

Table 1 The status of the Λ and Σ resonances Only those with an overall status of *** or **** are included in the main Baryon Table

			Status as seen in --			
Particle	$L_{I\,2J}$	Overall status	$N\bar{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
Λ(1116)	P_{01}	****				$N\pi$ (weakly)
Λ(1405)	S_{01}	****	****	F	****	
Λ(1520)	D_{03}	****	****	o	****	$\Lambda\pi\pi$ $\Lambda\gamma$
Λ(1600)	P_{01}	***	***	r	**	
Λ(1670)	S_{01}	****	****	b	****	$\Lambda\eta$
Λ(1690)	D_{03}	****	****	i	****	$\Lambda\pi\pi$ $\Sigma\pi\pi$
Λ(1800)	S_{01}	***	***	d	**	$N\bar{K}^*$ $\Sigma(1385)\pi$
Λ(1810)	P_{01}	***	***	d	**	$N\bar{K}^*$
Λ(1820)	F_{05}	****	****	e	****	$\Sigma(1385)\pi$
Λ(1830)	D_{05}	****	***	n	****	$\Sigma(1385)\pi$
Λ(1890)	P_{03}	****	****	F	**	$N\bar{K}^*$, $\Sigma(1385)\pi$
Λ(2000)		*		o	*	$\Lambda\omega$, $N\bar{K}^*$
Λ(2020)	F_{07}	*	*	r	*	
Λ(2100)	G_{07}	****	****	b	***	$\Lambda\omega$ $N\bar{K}^*$
Λ(2110)	F_{05}	***	**	i	*	$\Lambda\omega$, $N\bar{K}^*$
Λ(2325)	D_{03}	*	*	d		$\Lambda\omega$
Λ(2350)		***	***	d	*	
Λ(2585)		**	**	e		
				n		
Σ(1193)	P_{11}	****				$N\pi$ (weakly)
Σ(1385)	P_{13}	****		****	****	
Σ(1480)		*	*	*	*	
Σ(1560)		**		**	**	
Σ(1580)	D_{13}	**	*	*		
Σ(1620)	S_{11}	**	**	*	*	
Σ(1660)	P_{11}	***	***	*	**	
Σ(1670)	D_{13}	****	****	****	****	several others
Σ(1690)		**	*	**	*	$\Lambda\pi\pi$
Σ(1750)	S_{11}	***	***	**	*	$\Sigma\eta$
Σ(1770)	P_{11}	*				
Σ(1775)	D_{15}	****	****	****	***	several others
Σ(1840)	P_{13}	*	*	**	*	
Σ(1880)	P_{11}	**	**	**		$N\bar{K}^*$
Σ(1915)	F_{15}	****	***	****	***	$\Sigma(1385)\pi$
Σ(1940)	D_{13}	***	*	***	**	quasi-2-body
Σ(2000)	S_{11}	*		*		$N\bar{K}^*$, $\Lambda(1520)\pi$
Σ(2030)	F_{17}	****	****	****	**	several others
Σ(2070)	F_{15}	*	*		*	
Σ(2080)	P_{13}	**		**		
Σ(2100)	G_{17}	*		*	*	
Σ(2250)		***	***	*	*	
Σ(2455)		**	*			
Σ(2620)		**	*			
Σ(3000)		*	*	*		
Σ(3170)		*				multi-body

**** Good clear and unmistakable
*** Good but in need of clarification or not absolutely certain
** Not established needs confirmation
* Evidence weak could disappear

None of the Λ's and Σ's proposed since the mid 1970's couple strongly to the main 2-body decay channels $N\bar{K}$ $\Lambda\pi$ and $\Sigma\pi$ and thus they seldom appear in cross sections or invariant mass distributions However when the reactions $\bar{K}N \to \bar{K}N$ $\bar{K}N \to \Lambda\pi$ and $\bar{K}N \to \Sigma\pi$ are analyzed some of the partial-wave amplitudes traverse small more-or-less resonance-like circles The question in each case is Is this really a resonance, or is it an idle meander? Is the effect even real or is it the result of imperfect data and analysis?

II. Formation experiments

(by G P Gopal, Rutherford Appleton Laboratory)

Partial-wave analyses have been made mainly for the $N\bar{K}$, $\Lambda\pi$, and $\Sigma\pi$ channels, but there are also a few results for the ΞK, $\Lambda\omega$, and some quasi-2-body channels. Early analyses usually covered only the range of a single bubble chamber experiment. Although the amplitudes from analyses in neighboring mass ranges often did not join smoothly, they did give fairly reliable information about the strongly coupled resonances. More recent analyses have used the Breit-Wigner forms of the dominant resonances as input to provide constraints in determining the overall amplitudes and thus in learning about the less prominent resonances. Besides covering wider ranges, some of the more ambitious of the analyses at the lower energies have treated several channels simultaneously, so that unitarity constraints are automatically satisfied and only a single mass and width is obtained for each resonance.

In the mid and late 1970's, much new data became available. Results from several large K^-p bubble chamber experiments were published[2-5] and other bubble chamber experiments studied K^-n reactions[6] and K_L^0p reactions.[7] Counter experiments measured the $K^-p \to \bar{K}^0n$ total and differential cross sections at low energies,[8] the K^-p polarizations down to 1630 MeV for the first time,[9] the K^-p polarizations from 1700 to 1900 MeV with an order of magnitude increase in statistics,[10] the K^-n elastic angular distributions from 1600 to 1800 MeV[11] and from 1900 to 2300 MeV,[12] and the 180° K^-p and 0° $\Sigma^-\pi^+$ differential cross sections from 1550 to 1900 MeV.[13]

More recently, there have been new measurements of K^-n elastic scattering between 1600 and 1740 MeV.[14] Also, new total and differential cross-section data on K^-p, $\bar{K}^0n$, $\Sigma^\pm\pi^\mp$, and $\Lambda\pi^0$ between 1437 and 1486 MeV have became available.[15] They clearly show the onset of P-wave amplitudes by 1450 MeV, which brings into question analyses of low energy data that assumed only S waves were significant. Finally there are new $\Sigma^\pm\pi^+$ differential cross-section and polarization distributions in a region where data were sparse, from 1650 to 1715 MeV.[16]

We now compare the more recent analyses with each other and with the data. Some of the data have yet to be incorporated into any analysis.

The $N\bar{K}$ channel. The most recent analysis[17] is an update of the old Rutherford Lab-Imperial College (RLIC 77) analysis.[18] As before, it is a conventional energy-dependent analysis with the added constraint that the masses and widths of the resonances had to be consistent with those determined in the inelastic channels analyzed previously: $\Lambda\pi$, $\Sigma\pi$, $\Lambda(1520)\pi$, $\Sigma(1385)\pi$, and $N\bar{K}^*(892)$. The analysis also goes closer to threshold, covering 1470 to 2170 MeV. It does not include the data from a number of the more recent experiments mentioned above. As before, angular distributions (a total of 5110 data points) were fit directly. The new amplitudes differ little from the RLIC 77 amplitudes. However, the K^-n data removed some of the uncertainties in the Σ resonances.

The LBL-Mt Holyoke-CERN analysis[19] covers the narrower range of 1500 to 1940 MeV and also includes most of the new data. It is an energy-dependent analysis using a unitary background parametrized in terms of scattering lengths. The cusp effects at the $\Lambda\eta$ and $\Sigma\eta$ thresholds are included by introducing a square-root singularity in the energy variation of the widths of the appropriate resonances. This group's own high-statistics charge-exchange data[8] (which do not agree with bubble chamber measurements) all but kill the less well-established resonances.

The University College, London (UCL) K-matrix energy-dependent analysis[20] covers from 1540 to 2000 MeV. The $N\bar{K}$ amplitudes are consistent with those of the other analyses over most of this range. However at the low end there are major differences, due to the absence of constraints from the $\Lambda(1520)$, which lies just outside the range covered. The K^-n angular distributions and K^-p polarization measurements are not fit very well.

The above analyses, all below 2200 MeV, are complemented by the College de France-Saclay (CdF-S) energy-dependent analysis[5] covering from 2070 to 2440 MeV. Besides the conventional polynomial parametrization of the background amplitudes, also tried is a parametrization using constraints imposed by the duality hypothesis (that s-channel backgrounds come exclusively from the t-channel Pomeron exchange amplitude). With 30 fewer free parameters, the results are consistent with the conventional approach.

The $\Sigma\pi$ channel. There is very little agreement, particularly about the lower partial waves, between the two multichannel analyses.[18,20] The low-energy $K_L^0p \to \Sigma^0\pi^+$ data[7] are better explained by the RLIC 77 amplitudes than by the UCL amplitudes. At the high end, there is good continuity between the RLIC 77 amplitudes and those from the single-channel analysis of the CdF-S collaboration[5] covering from 2070 to 2440 MeV. The $\Lambda(1520)$ and $\Lambda(2110)$ resonances, which lie outside the range covered by the UCL analysis, clearly provide strong constraints.

The $\Lambda\pi$ channel. This isospin-1 channel has been the subject of many energy-dependent and -independent analyses (for example, RLIC 77,[18] UCL,[20] Baillon-Litchfield,[21] de Bellefon-Berthon,[22] and Van Horn[23]). However, even the widespread use of the method of Barrelet zeroes has not helped to resolve the Σ spectrum, probably because most Σ resonances simply do not couple strongly to the $N\bar{K}$ initial state.

Quasi-2-body channels The Rutherford Lab-Imperial College group has made energy-dependent analyses of the Λ(1520)π, Σ(1385)π, and $N\bar{K}^*(892)$ channels over the widest ranges for which data are available. The data were extracted from the appropriate 3-particle final states by making 4-variable fits to an incoherent superposition of quasi-2-body final states and 3-particle Lorentz-invariant phase space. The quality of the fits suggests a maximum model-dependent systematic uncertainty of 10%. The Λω channel has been analyzed from threshold to 2440 MeV by the CdF-S collaboration.[5]

Sign conventions for resonance couplings In terms of the isospin-0 and -1 elastic scattering amplitudes A_0 and A_1, the amplitude for $K^-p \to \bar{K}^0 n$ scattering is $\pm(A_1 - A_0)/2$, where the sign depends on conventions used in conjunction with the Clebsch-Gordan coefficients (such as, is the baryon or the meson the "first" particle). If this reaction is partial-wave analyzed and if the overall phase is chosen so that, say, the Σ(1775) D_{15} amplitude at resonance points along the positive imaginary axis (points "up"), then any Σ at resonance will point "up" and any Λ at resonance will point "down" (along the negative imaginary axis). Thus the phase at resonance determines the isospin. The above ignores background amplitudes in the resonating partial waves.

That is the basic idea. In a similar but somewhat more complicated way, the phases of the $\bar{K}N \to \Lambda\pi$ and $\bar{K}N \to \Sigma\pi$ amplitudes for a resonating wave help determine the SU(3) multiplet to which the resonance belongs. Again, a convention has to be adopted for some overall arbitrary phases: which way is "up"? Our convention is that of Levi-Setti[24] and is shown in Fig. 1, which also compares experimental results with theoretical predictions for the signs of several resonances. In the Listings, a + or − sign in front of a measurement of an inelastic resonance coupling indicates the sign (the *absence* of a sign means that the sign is not determined, *not* that it is positive). For more details, see Appendix II of our 1982 edition.[25]

Argand plots Figure 2 shows some representative Argand plots of partial-wave amplitudes. For the $N\bar{K}$ channel we show the amplitudes from RLIC 77[18] and from LBL-Mt Holyoke-CERN,[19] and for the Λπ and Σπ channels we show those from RLIC 77[18] and from UCL.[20]

Errors on masses and widths The errors quoted on resonance parameters from partial-wave analyses are often only statistical, and the parameters can change by more than these errors when a different parametrization of the waves is used. Furthermore, the different analyses use more or less the same data, so it is not really appropriate to treat the different determinations of the resonance parame-

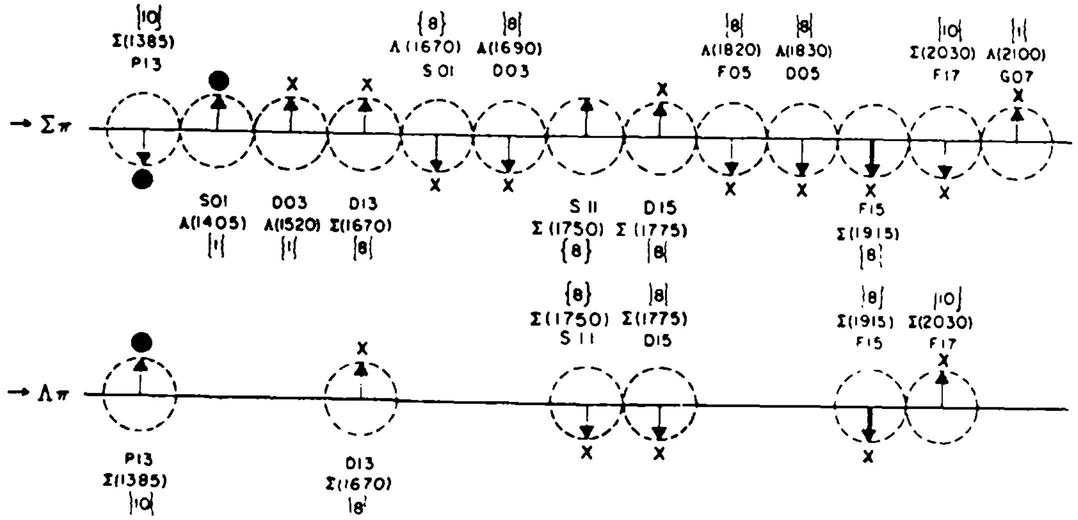


Fig. 1. The signs of the imaginary parts of resonating amplitudes in the $\bar{K}N \to \Lambda\pi$ and Σπ channels. The signs of the Σ(1385) and Λ(1405) marked with a •, are set by convention, and then the others are determined relative to them. The signs required by the SU(3) assignments of the resonances are shown with an arrow, and the experimentally determined signs are shown with an X.

Baryon Full Listings
Λ's and Σ's

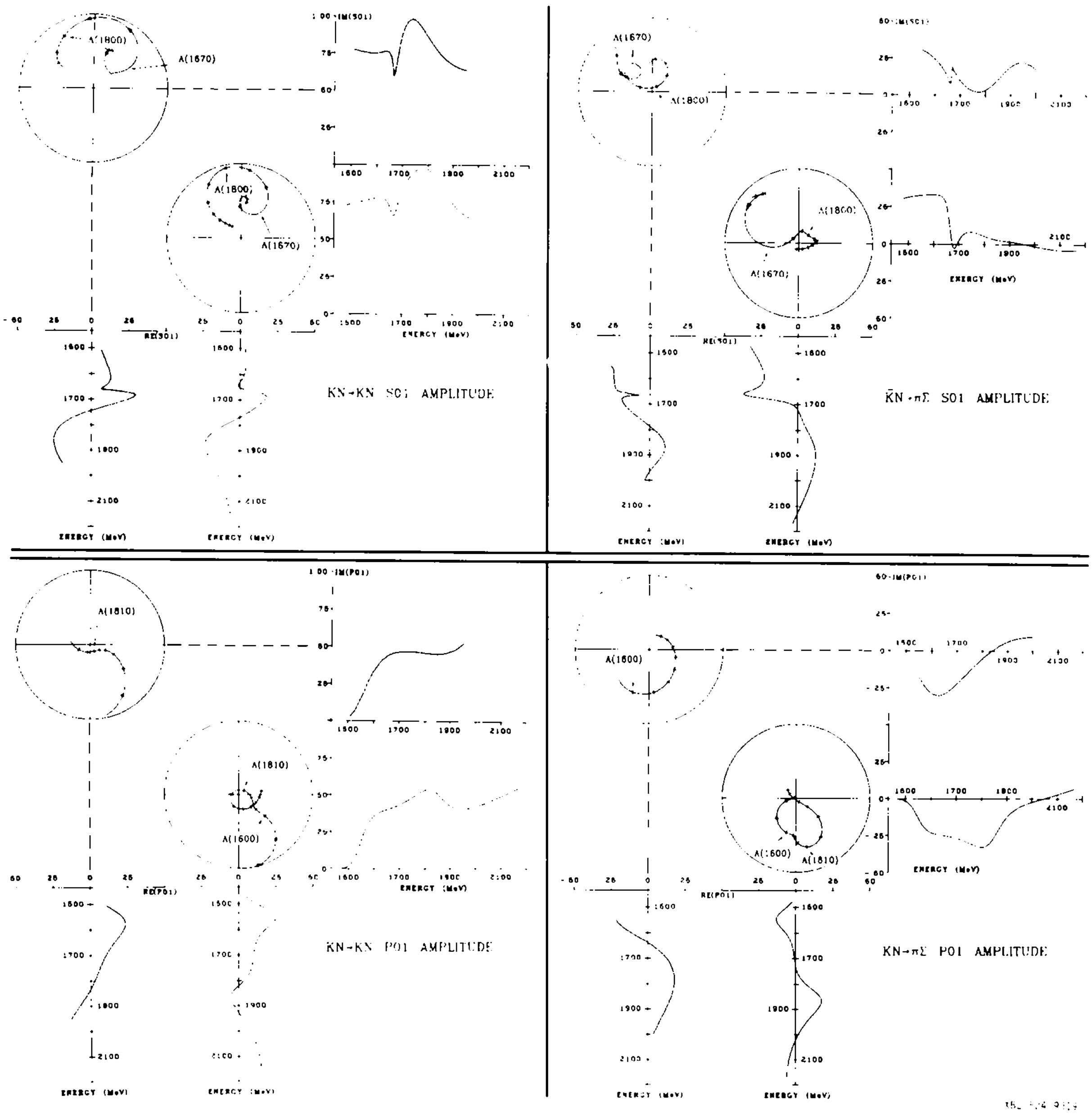


Fig 2(a) The $L_{I\,2J}$ = S_{01} and P_{01} partial-wave amplitudes for $\bar{K}N$ scattering in the elastic and $\Sigma\pi$ channels The lower plot for each amplitude is from GOPAL 77 the upper plots for the elastic amplitudes are from ALSTON 78 and the upper plots for the $\Sigma\pi$ amplitudes are from MARTIN 77 In the Argand plots the ticks are at integral multiples of 50 MeV, and the established resonances are shown at their nominal positions [the S_{01} Λ(1405) is of course below threshold and is not shown] The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots

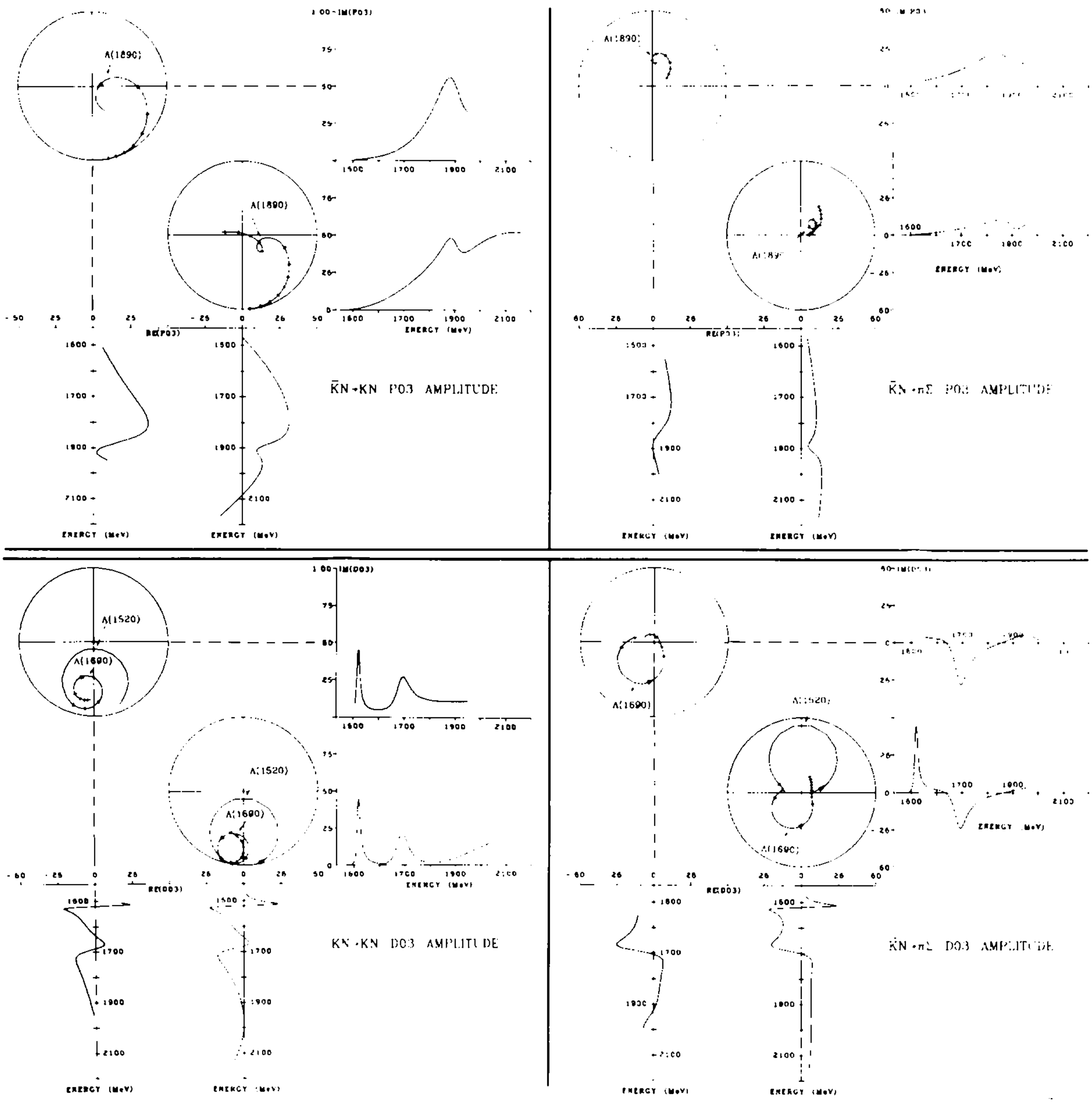


Fig 2(b) The $L_{I\,2J} = P_{03}$ and D_{03} partial-wave amplitudes for $\bar{K}N$ scattering in the elastic and $\Sigma\pi$ channels. The lower plot for each amplitude is from GOPAL 77, the upper plots for the elastic amplitudes are from ALSTON 78 and the upper plots for the $\Sigma\pi$ amplitudes are from MARTIN 77. In the Argand plots the ticks are at integral multiples of 50 MeV and the established resonances are shown at their nominal positions. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots.

Baryon Full Listings
Λ's and Σ's

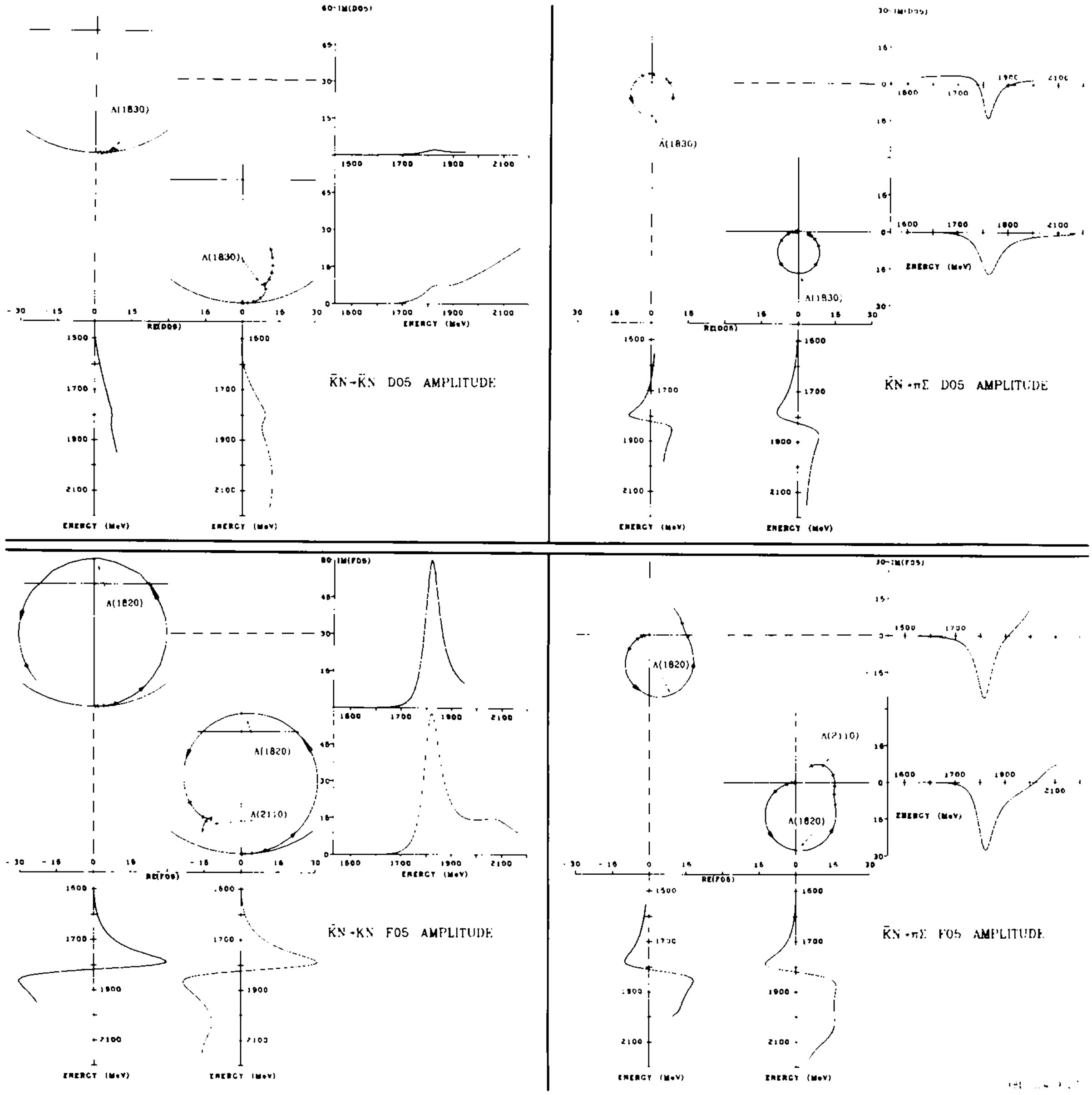


Fig. 2(c) The $L_{I\,2J} = D_{05}$ and F_{05} partial-wave amplitudes for $\bar{K}N$ scattering in the elastic and $\Sigma\pi$ channels. The lower plot for each amplitude is from GOPAL 77, the upper plots for the elastic amplitudes are from ALSTON 78, and the upper plots for the $\Sigma\pi$ amplitudes are from MARTIN 77. In the Argand plots, the ticks are at integral multiples of 50 MeV and the established resonances are shown at their nominal positions. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots.

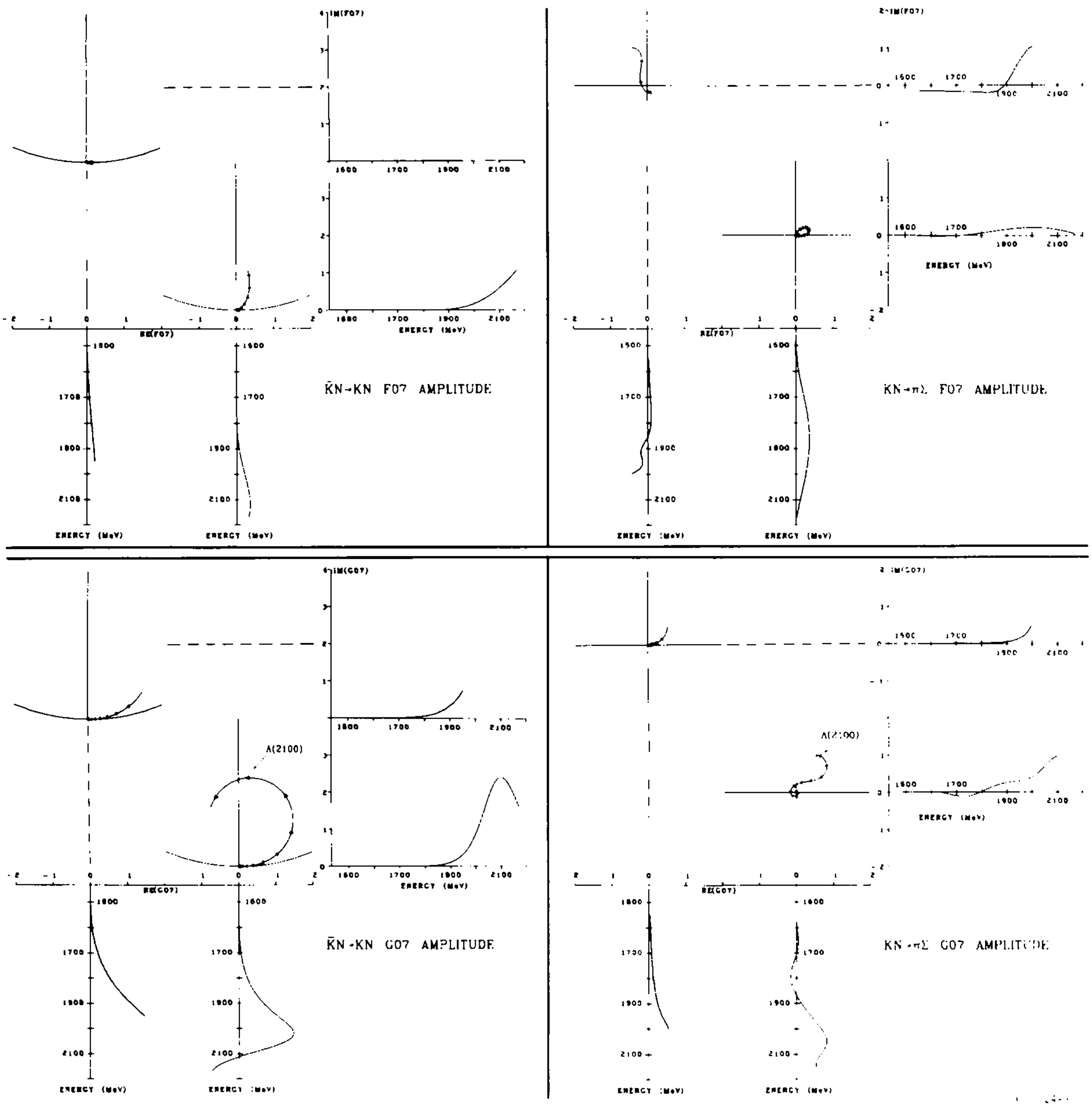
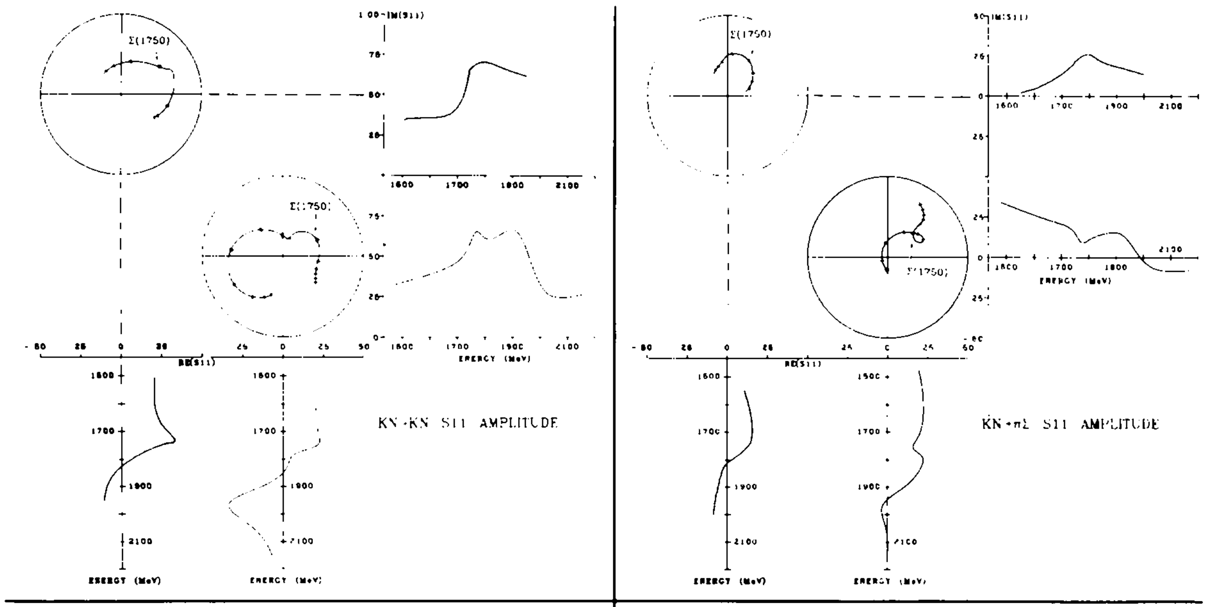


Fig. 2(d). The $L_{I\,2J} = F_{07}$ and G_{07} partial-wave amplitudes for $\bar{K}N$ scattering in the elastic and $\Sigma\pi$ channels. The lower plot for each amplitude is from GOPAL 77, the upper plots for the elastic amplitudes are from ALSTON 78 and the upper plots for the $\Sigma\pi$ amplitudes are from MARTIN 77. In the Argand plots the ticks are at integral multiples of 50 MeV and the established resonance is shown at its nominal position. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots.



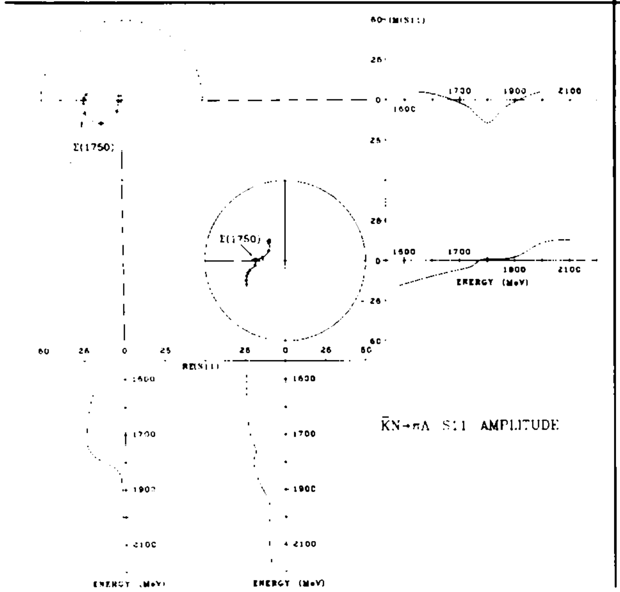
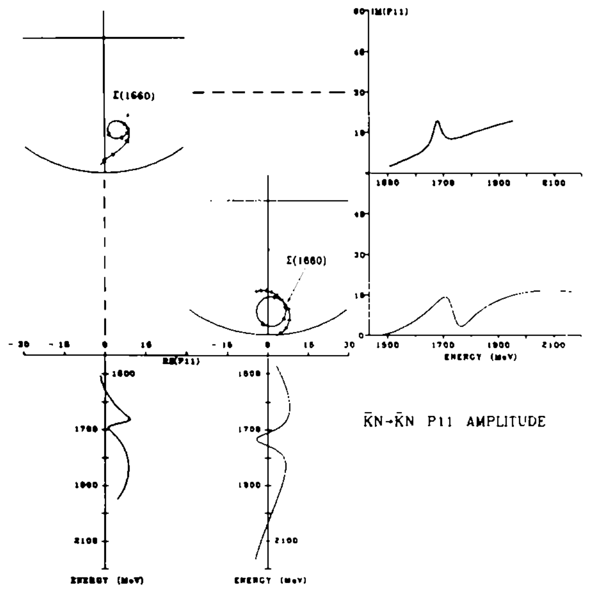
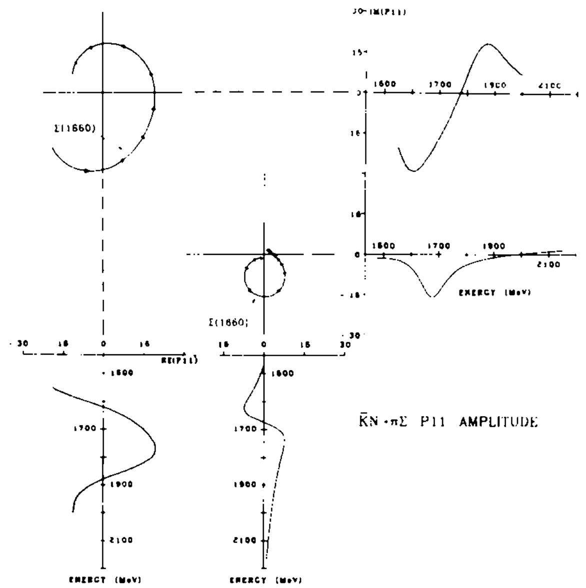


Fig. 2(e) The $L_{I\,2J} = S_{11}$ partial-wave amplitudes for $\bar{K}N$ scattering in the elastic, $\Lambda\pi$ and $\Sigma\pi$ channels. The lower plot for each amplitude is from GOPAL 77, the upper plot for the elastic amplitude is from ALSTON 78, and the upper plots for the $\Lambda\pi$ and $\Sigma\pi$ channels are from MARTIN 77. In the Argand plots, the ticks are at integral multiples of 50 MeV and the established resonance is shown at its nominal position. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots.





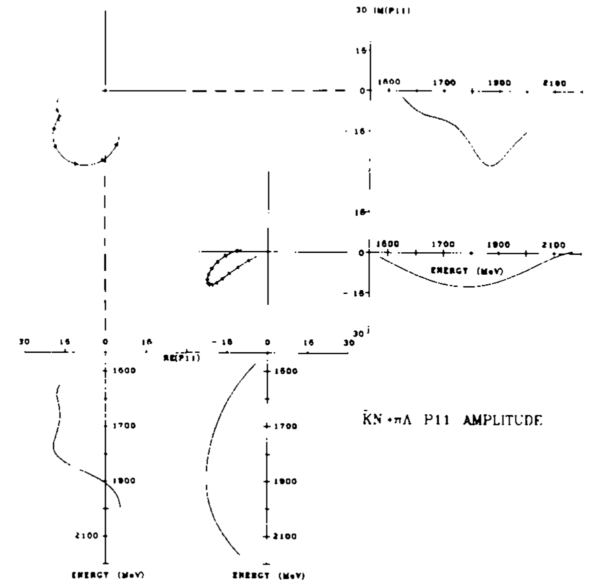
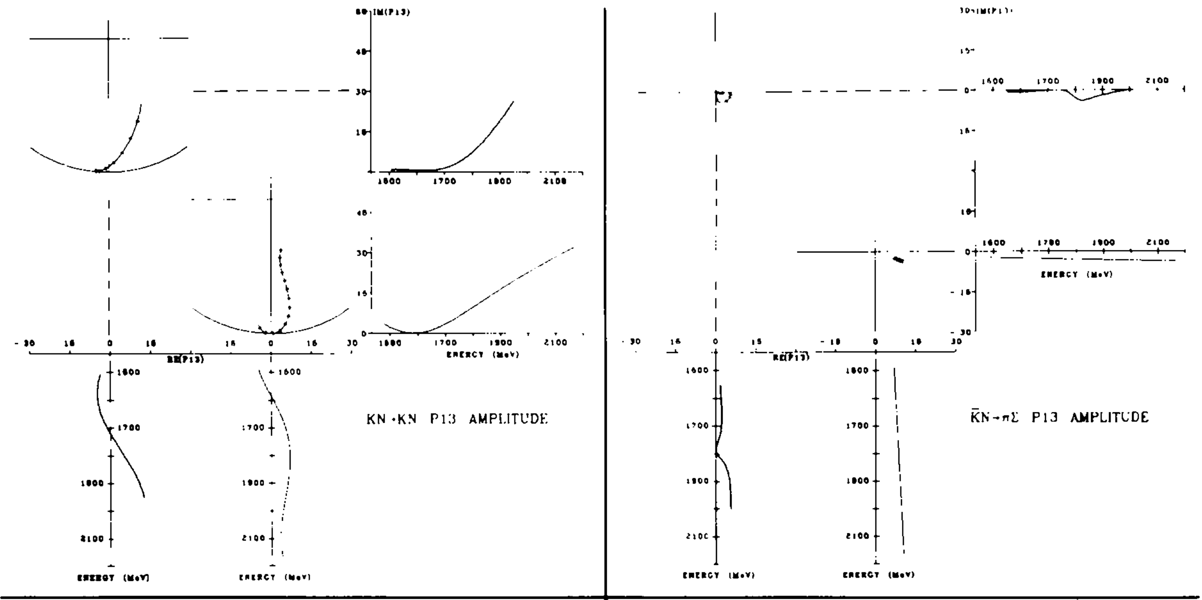


Fig. 2(f). The $L_{I\,2J} = P_{11}$ partial-wave amplitudes for $\bar{K}N$ scattering in the elastic, $\Lambda\pi$, and $\Sigma\pi$ channels. The lower plot for each amplitude is from GOPAL 77, the upper plot for the elastic amplitude is from ALSTON 78, and the upper plots for the $\Lambda\pi$ and $\Sigma\pi$ channels are from MARTIN 77. In the Argand plots, the ticks are at integral multiples of 50 MeV, and the established resonance is shown at its nominal position. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots.



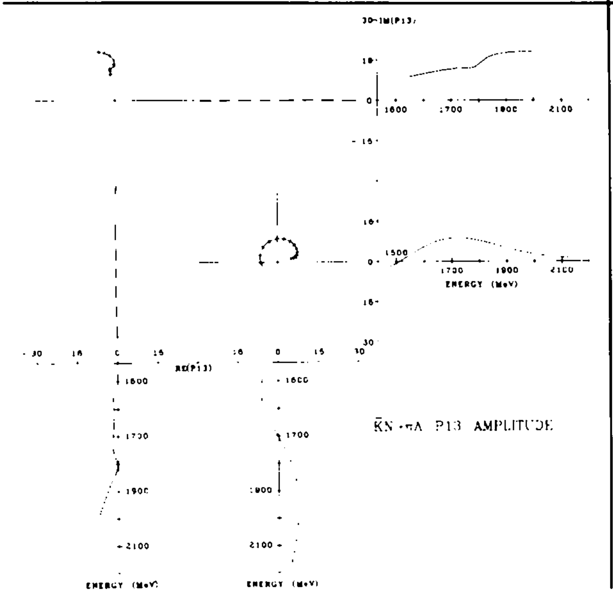
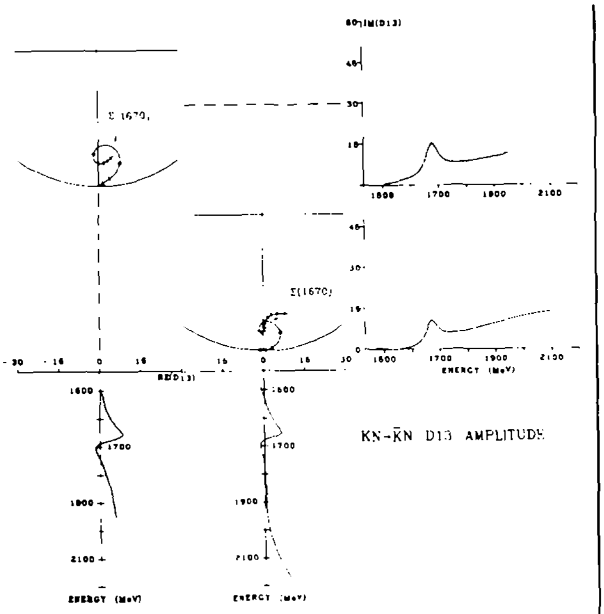
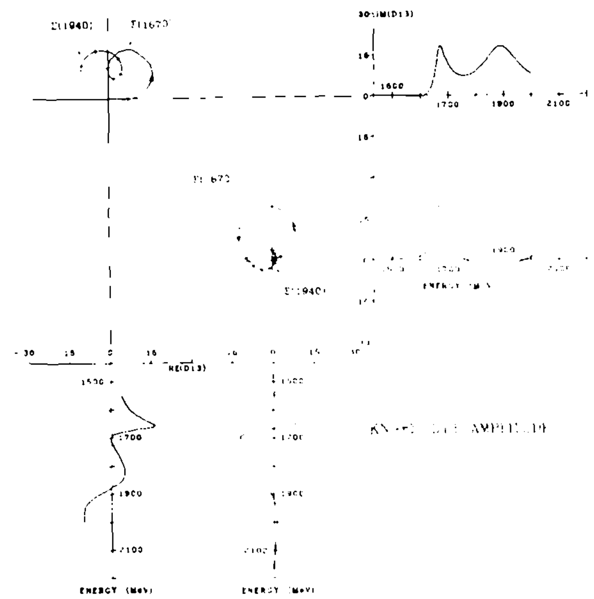


Fig. 2(g). The $L_{I\,2J} = P_{13}$ partial-wave amplitudes for $\bar{K}N$ scattering in the elastic, $\Lambda\pi$, and $\Sigma\pi$ channels. The lower plot for each amplitude is from GOPAL 77, the upper plot for the elastic amplitude is from ALSTON 78, and the upper plots for the $\Lambda\pi$ and $\Sigma\pi$ channels are from MARTIN 77. In the Argand plots, the ticks are at integral multiples of 50 MeV [the $\Sigma(1385)$ is of course below threshold and is not shown]. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots.





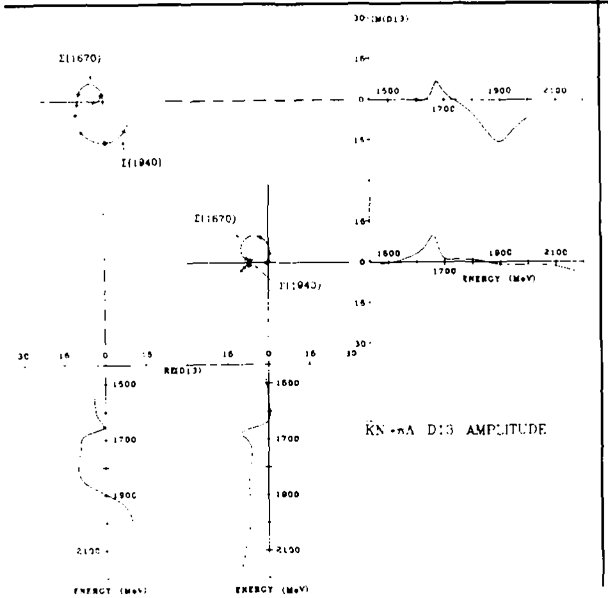
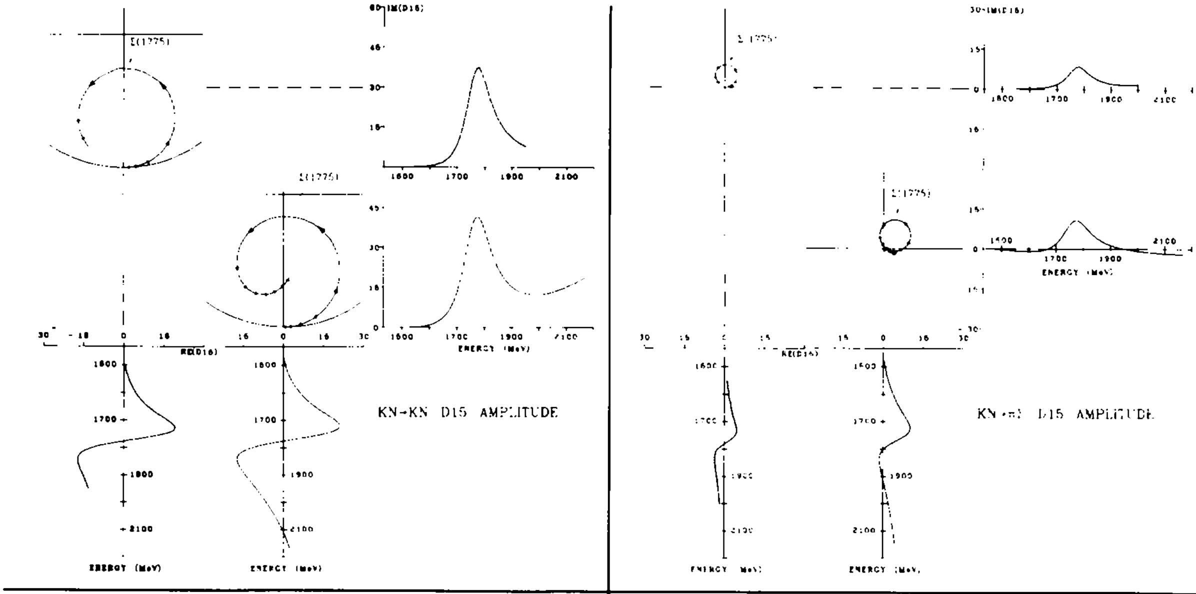


Fig. 2(h) The $L_{I\,2J} = D_{13}$ partial-wave amplitudes for $\bar{K}N$ scattering in the elastic, $\Lambda\pi$ and $\Sigma\pi$ channels. The lower plot for each amplitude is from GOPAL 77, the upper plot for the elastic amplitude is from ALSTON 78, and the upper plots for the $\Lambda\pi$ and $\Sigma\pi$ channels are from MARTIN 77. In the Argand plots, the ticks are at integral multiples of 50 MeV, and the established resonances are shown at their nominal positions. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots.



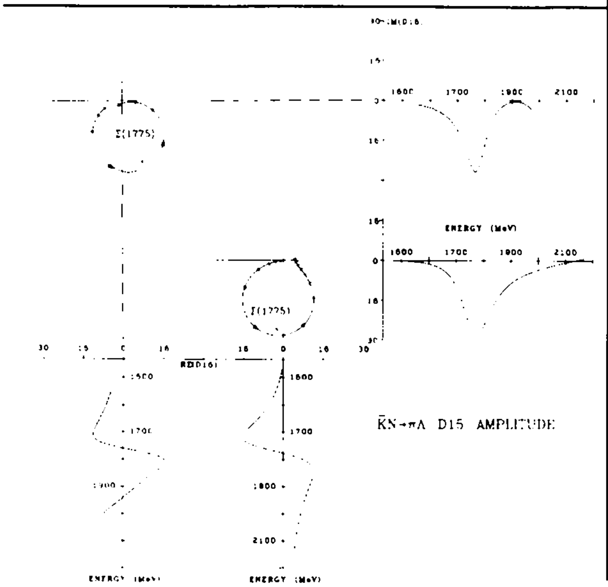
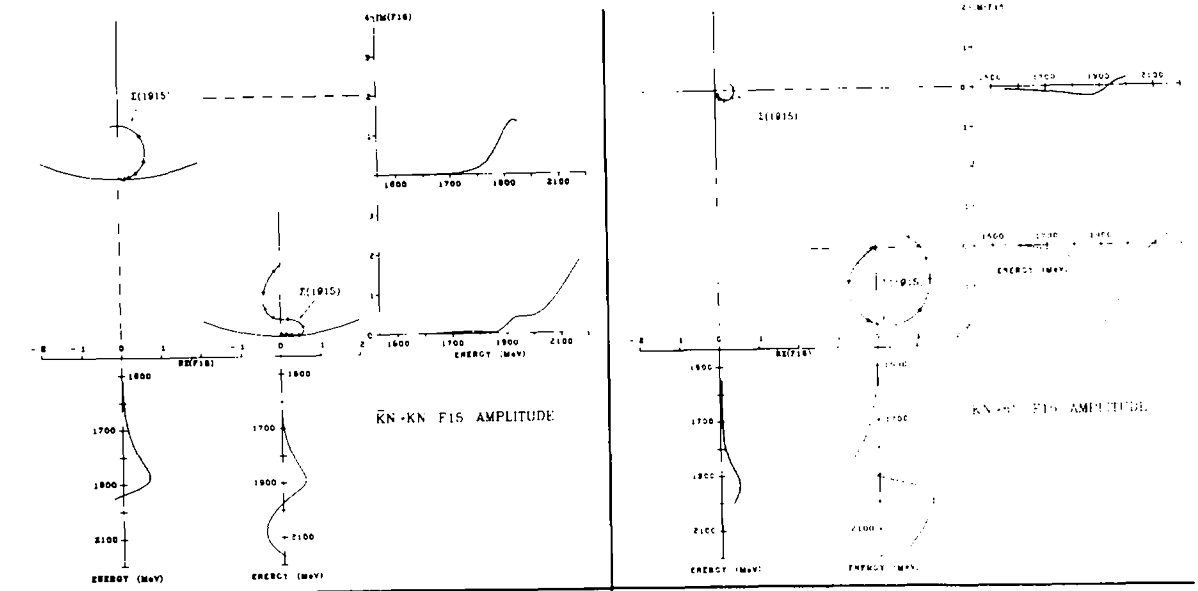


Fig. 2(i) The $L_{I\,2J} = D_{15}$ partial-wave amplitudes for $\bar{K}N$ scattering in the elastic, $\Lambda\pi$ and $\Sigma\pi$ channels. The lower plot for each amplitude is from GOPAL 77, the upper plot for the elastic amplitude is from ALSTON 78, and the upper plots for the $\Lambda\pi$ and $\Sigma\pi$ channels are from MARTIN 77. In the Argand plots, the ticks are at integral multiples of 50 MeV, and the established resonance is shown at its nominal position. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots.



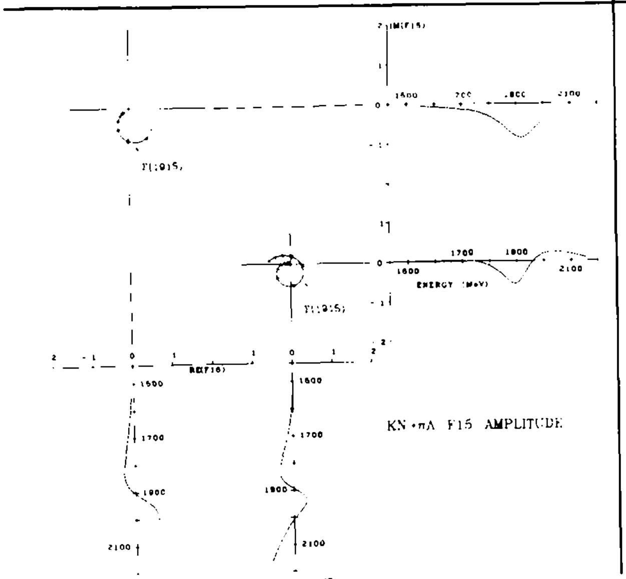
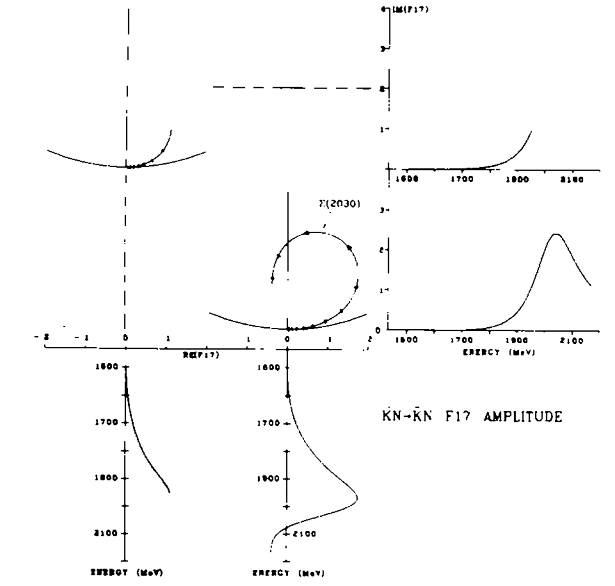
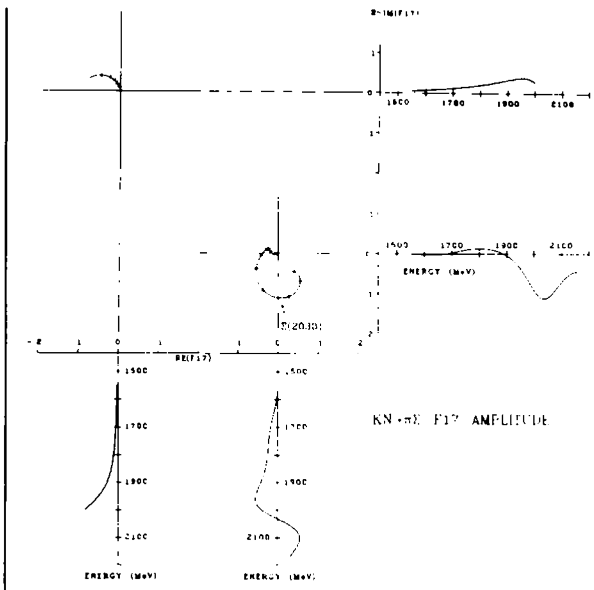


Fig. 2(j) The $I_{J,2J} = F_{15}$ partial-wave amplitudes for $\bar{K}N$ scattering in the elastic, $\Lambda\pi$ and $\Sigma\pi$ channels. The lower plot for each amplitude is from GOPAL 77, the upper plot for the elastic amplitude is from ALSTON 78, and the upper plots for the $\Lambda\pi$ and $\Sigma\pi$ channels are from MARTIN 77. In the Argand plots, the ticks are at integral multiples of 50 MeV, and the established resonance is shown at its nominal position. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots.





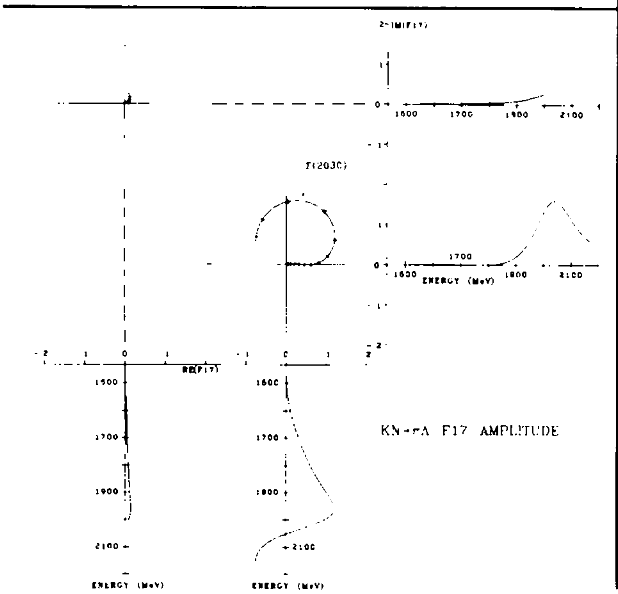


Fig 2(k) The $L_{I\,2J} = F_{17}$ partial-wave amplitudes for $\bar{K}N$ scattering in the elastic, $\Lambda\pi$ and $\Sigma\pi$ channels. The lower plot for each amplitude is from GOPAL 77, the upper plot for the elastic amplitude is from ALSTON 78, and the upper plots for the $\Lambda\pi$ and $\Sigma\pi$ channels are from MARTIN 77. In the Argand plots the ticks are at integral multiples of 50 MeV and the established resonance is shown at its nominal position. The real and imaginary parts of the amplitudes as functions of energy are shown projected in alignment with the Argand plots.

ters as independent or to average them together. In any case, the spread of the masses, widths, and branching fractions from the different analyses is certainly a better indication of the uncertainties than are the quoted errors. In the Baryon Summary Table, usually a range reflecting the spread of the values is given rather than a particular value with error.

For three states, the Λ(1520), the Λ(1820), and the Σ(1775), there is enough information to make an overall fit to the various branching fractions. It is then necessary to use the quoted errors, but the errors obtained from the fit should not be taken seriously.

III. Production experiments

Partial-wave analyses of course separate partial waves, whereas a peak in a cross section or an invariant mass distribution usually cannot be disentangled from background and analyzed for its quantum numbers, and more than one resonance may be contributing to the peak. Results from partial-wave analyses and from production experiments are generally kept separate in the Listings, and in the Baryon Summary Table results from production experiments are used only for the low-mass states. The Σ(1385) and Λ(1405) of course lie below the $\bar{K}N$ threshold and nearly everything about them is learned from production experiments, and production and formation experiments agree quite well in the case of Λ(1520) and results have been combined. There is some disagreement between production and formation experiments in the 1600-1700 MeV region; see the Note on the Σ(1670).

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19 M Alston-Garnjost et al Phys Rev **D18**, 182 (1978)
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Λ BARYONS
($S = -1$, $I = 0$)

Λ $I(J^P) = 0(\frac{1}{2}^+)$ Status * * * *

SEE STABLE PARTICLES

Λ(1405) S_{01} $I(J^P) = 0(\frac{1}{2}^-)$ Status * * * *

NOTE ON THE Λ(1405)

(by R J Hemingway, Ottawa-Carleton Institute of Physics)

The Λ(1405) is conventionally assumed to be a well-established isospin 0, strangeness −1, $J^P = 1/2^-$ resonance belonging to the $L = 1$ supermultiplet of the 3-quark system. Lying about 30 MeV below the $\bar{K}N$ threshold, the resonance can only be observed directly in the $(\Sigma\pi)^0$ subsystem of final states of production experiments. It was first reported by ALSTON 61B in the reaction $K^- p \to \Sigma\pi\pi\pi$ at 1.15 GeV/c and was subsequently seen in several other experiments. However, these observations suffered from (a) low statistics, (b) difficulties reconstructing final states involving Σ decays, (c) poor mass resolution, and

(d) uncertainties in the background, particularly that from $\Sigma(1385) \to \Sigma\pi$ whose rate was badly known. In fact, none of the experiments during the period 1962–1972 were able to demonstrate a convincing signal, much less measure the mass and width well or determine the quantum numbers.

Nevertheless, the early multichannel K-matrix analyses of low-energy $\bar{K}N$ reactions, particularly those of KIM 65 and KIM 67, strongly suggested that the Λ(1405) was an S-wave unstable bound state of the $\bar{K}N$ system. These analyses gave the Λ(1405) added authenticity.

There are actually only two production experiments with respectable signals near 1405 MeV: THOMAS 73 and HEMINGWAY 85. Both of these find a significantly asymmetric bump that cannot be fit with a Breit-Wigner function with constant parameters. The asymmetry is believed to be due to the strong coupling of the Λ(1405) with the S-wave $\bar{K}N$ channel (see DALITZ 81): the Λ(1405) width then has rapid energy dependence as the $\bar{K}N$ threshold is approached from below. The other below-threshold strangeness −1 resonance, the Σ(1385), does not show such asymmetry because its $\bar{K}N$ coupling is P wave.

Following the early work of KIM 65, KIM 67, and SAKITT 65, there has grown a literature on methods of extrapolation below the $\bar{K}N$ threshold. Most analyses constrain their fits to agree with low-energy formation data ($\bar{K}N$ total and partial cross sections in the momentum range 100–300 MeV/c), and more recently attempts have been made to also fit the production $\Sigma\pi$ spectra (see, for example, CHAO 73, VEIT 84, VEIT 85), or the radiative annihilation data from kaonic hydrogen (see, for example, VAN DIJK 84, DAREWYCH 85, BURKHARDT 85, ZHONG 86), or both at once (SCHNICK 87).

It is commonly agreed that the data can only be fitted with an S-wave pole below $\bar{K}N$ threshold, but there is controversy about the nature of this pole. For a review of this topic, see DALITZ 81. Two separate possibilities are discussed: (a) an unstable $\bar{K}N$ bound state, or (b) a true 3-quark baryon resonance. If (a) is true, we are faced with the problem of finding another $I\,J^P = 0,1/2^-$ resonance to replace the Λ(1405) in the $L = 1$ supermultiplet. On the other hand, if (b) is true, we have to understand why the Λ(1405) mass is so low. The low mass implies a very large spin-orbit splitting in the QCD-inspired nonrelativistic quark model.[1] For now, we continue to list references on $\bar{K}N$ extrapolations and related issues.

Faced with the poor experimental data and the inconclusive analyses, one could question the 4-star rating of the Λ(1405). It seems unlikely that the nature of the Λ(1405) will be decided entirely unambiguously soon. Although new data on radiative K^- capture is expected from experiment BNL-811, it will probably require a kaon factory to give an order-of-magnitude increase in both formation and production data before the issue is finally settled.

Reference

1 See, for example, N. Isgur and G. Karl, Phys. Rev. **D18** 4187 (1978).

Λ(1405) MASS

PRODUCTION EXPERIMENTS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1391 ± 1	700	[1] HEMINGWAY	85	HBC	$K^- p$ 4 2 GeV/c
~1405	400	[2] THOMAS	73	HBC	$\pi^- p$ 1 69 GeV/c
1405	120	BARBARO	68B	DBC	$K^- d$ 2 1–2 7 GeV/c
1400 ± 5	67	BIRMINGHAM	66	HBC	$K^- p$ 3 5 GeV/c
1382 ± 8		ENGLER	65	HDBC	$\pi^- p$, $\pi^+ d$ 1 68 GeV/c
1400 ± 24		MUSGRAVE	65	HBC	$\bar{p}p$ 3–4 GeV/c
1410		ALEXANDER	62	HBC	$\pi^- p$ 2 1 GeV/c
1405		ALSTON	62	HBC	$K^- p$ 1 2–0 5 GeV/c
1405		ALSTON	61B	HBC	$K^- p$ 1 15 GeV/c

EXTRAPOLATIONS BELOW $N\bar{K}$ THRESHOLD

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1406	[3] CHAO	73	DPWA	0-range fit (sol B)
1421	MARTIN	70	RVUE	Constant K matrix
1416 ± 4	MARTIN	69	HBC	Constant K-matrix
1403 ± 3	KIM	67	HBC	K matrix fit
1407 5 ± 1 2	[4] KITTEL	66	HBC	0-effective range fit
1410 7 ± 1 0	KIM	65	HBC	0-effective range fit
1409 6 ± 1 7	[4] SAKITT	65	HBC	0-effective range fit

Λ(1405) WIDTH

PRODUCTION EXPERIMENTS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
32 ± 1	700	[1] HEMINGWAY	85	HBC	$K^- p$ 4 2 GeV/c
45 to 55	400	[2] THOMAS	73	HBC	$\pi^- p$ 1 69 GeV/c
35	120	BARBARO-	68B	DBC	$K^- d$ 2 1–2 7 GeV/c
50 ± 10	67	BIRMINGHAM	66	HBC	$K^- p$ 3 5 GeV/c
89 ± 20		ENGLER	65	HDBC	
60 ± 20		MUSGRAVE	65	HBC	
35 ± 5		ALEXANDER	62	HBC	
50		ALSTON	62	HBC	
20		ALSTON	61B	HBC	

EXTRAPOLATIONS BELOW NK THRESHOLD

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
55	[3,5] CHAO	73	DPWA	0-range fit (sol B)
20	MARTIN	70	RVUE	Constant K-matrix
29 ± 6	MARTIN	69	HBC	Constant K matrix
50 ± 5	KIM	67	HBC	K matrix fit
34 1 ± 4 1	[4] KITTEL	66	HBC	
37 0 ± 3 2	KIM	65	HBC	
28 2 ± 4 1	[4] SAKITT	65	HBC	

Λ(1405) DECAY MODES

Γ_1 Λ(1405) → $\Sigma\pi$

Γ_2 Λ(1405) → $N\bar{K}$

Λ(1405) BRANCHING RATIOS

$\Gamma(N\bar{K})/\Gamma(\Sigma\pi)$ Γ_2/Γ_1

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<3	95	HEMINGWAY 85	HBC	$K^- p$ 4 2 GeV/c

Λ(1405) FOOTNOTES

[1] HEMINGWAY 85 finds the $\Sigma\pi$ mass distribution is asymmetric and a Breit-Wigner fit is poor

[2] THOMAS 73 data is fit by CHAO 73 (see next section)

[3] See also the accompanying paper of THOMAS 73

[4] Data of SAKITT 65 are used in the fit by KITTEL 66

[5] An asymmetric shape with Γ/2 = 41 MeV below resonance, 14 MeV above

Λ(1405) REFERENCES

HEMINGWAY	85	NP B253 742		(CERN) J
CHAO	73	NP B56 46	+Kraemer Thomas Martin	(RHEL CMU LOUC)
THOMAS	73	NP B56 15	+Engler Fisk Kraemer	(CMU) J
MARTIN	70	NP B16 479	+Ross	(DURH)
MARTIN	69	PR 183 1352	+Sakitt	(LOUC BNL)
BARBARO	68B	PRL 21 573	Barbaro Galtieri Chadwick+	(LRL SLAC)
KIM	67	PRL 19 1074		(YALE)
BIRMINGHAM	66	PR 152 1148		(BIRM GLAS LOIC OXF RHEL)

KITTEL	66	PL 21 349	+Otter Wacek	(VIEN)
ENGLER	65	PRL 15 224	+Fisk Kraemer Meltzer Westgard+	(CMU BNL) IJ
KIM	65	PRL 14 29		(COLU)
MUSGRAVE	65	NC 35 735	+Petmezas+	(BIRM CERN EPOL LOIC SACL)
SAKITT	65	PR 139B 719	+Day Glasser Seeman Friedman+	(UMD LRL)
ALEXANDER	62	PRL 8 447	+Kalbfleisch Miller Smith	(LRL) I
ALSTON	62	CERN Conf 311	+Alvarez Ferro Luzzi+	(LRL) I
ALSTON	61B	PRL 6 698	+Alvarez Eberhard Good+	(LRL) I

OTHER RELATED PAPERS

SCHNICK	87	PRL 58 1719	+Landau	(ORST)
JENNINGS	86	PL B176 229		(TRIU)
MALTMAN	86	PR D34 1372	+Isgur	(LANL TNTO)
ZHONG	86	PL B171 471	+Thomas Jennings Barrett	(ADLD TRIU SURR)
BURKHARDT	85	NP A440 653	+Lowe Rosenthal	(NOTT BIRM WMIU)
DAREWYCH	85	PR D32 1765	+Koniuk Isgur	(YORK TNTO)
VEIT	85	PR D31 1033	+Jennings Thomas Barrett	(TRIU ADLD SURR)
KIANG	84	PR C30 1638	+Kumar Nogami VanDijk	(DALH MCMS)
VANDIJK	84	PR D30 937		(MCMS)
VEIT	84	PL 137B 415	+Jennings Barrett Thomas	(TRIU SURR CERN)
DALITZ	81		+McGinley	(OXF)
		Low and Intermediate Energy Kaon Nucleon Physics p 381		
OADES	77	NC 42A 462	+Rasche	(AARH ZURI)
SHAW	73	Purdue Conf 417		(UCI)
BARBARO	72	LBL 555	Barbaro Galtieri	(LBL)
DOBSON	72	PR D6 3256	+McElhaney	(HAWA)
RAJASEKA	72	PR D5 610	Rajasekaran	(TATA)
CLINE	71	PRL 26 1194	+Laumann Mapp	(WISC)
MARTIN	71	PL 35B 62	+Martin Ross	(DURH LOUC RHEL)
DALITZ	67	PR 153 1617	+Wong Rajasekaran	(OXF BOMB)
DONALD	66	PL 22 711	+Edwards Lys Nisar Moore	(LIVP)
KADYK	66	PRL 17 599	+Oren Goldhaber Goldhaber Trilling	(LRL)
ABRAMS	65	PR 139B 454	+Sechi Zorn	(UMD)

Λ(1520) D_{03}

$I(J^P) = 0(\frac{3}{2}^-)$ Status ∗ ∗ ∗ ∗

Discovered by FERRO-LUZZI 62, the elaboration in WATSON 63 is *the* classic paper on the Breit-Wigner analysis of a multichannel resonance

The measurements of the mass, width, and elasticity published before 1975 are now obsolete and have been omitted They were last listed in our 1982 edition (Physics Letters **111B**)

Production and formation experiments agree quite well, so they are listed together here

Λ(1520) MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1519.50 ± 0.18 OUR AVERAGE					
1517 3 ± 1 5	300	BARBER	80D	SPEC	$\gamma p \rightarrow \Lambda(1520) K^+$
1519 ± 1		GOPAL	80	DPWA	$KN \rightarrow KN$
1517 8 ± 1 2	5k	BARLAG	79	HBC	$K^- p$ 4 2 GeV/c
1520 0 ± 0 5		ALSTON	78	DPWA	$KN \rightarrow KN$
1519 7 ± 0 3	4k	CAMERON	77	HBC	$K^- p$ 0 96–1 36 GeV/c
1519 ± 1		GOPAL	77	DPWA	$\overline{K}N$ multichannel
1519 4 ± 0 3	2000	CORDEN	75	DBC	$K^- d$ 1 4–1 8 GeV/c

Λ(1520) WIDTH

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
15.59 ± 0.27 OUR AVERAGE					
16 3 ± 3 3	300	BARBER	80D	SPEC	$\gamma p \rightarrow \Lambda(1520) K^+$
16 ± 1		GOPAL	80	DPWA	$\overline{K}N \rightarrow \overline{K}N$
14 ± 3	677	[1] BARLAG	79	HBC	$K^- p$ 4 2 GeV/c
15 4 ± 0 5		ALSTON	78	DPWA	$\overline{K}N \rightarrow \overline{K}N$
16 3 ± 0 5	4k	CAMERON	77	HBC	$K^- p$ 0 96–1 36 GeV/c
15 0 ± 0 5		GOPAL	77	DPWA	$\overline{K}N$ multichannel
15 5 ± 1 6	2000	CORDEN	75	DBC	$K^- d$ 1 4–1 8 GeV/c

Λ(1520) DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	$\Lambda(1520) \rightarrow N\overline{K}$	(44 8 ± 0 7) × 10^{-2}	1 3
Γ_2	$\Lambda(1520) \rightarrow \Sigma\pi$	(42 1 ± 0 7) × 10^{-2}	1 3
Γ_3	$\Lambda(1520) \rightarrow \Lambda\pi\pi$	(9 5 ± 0 5) × 10^{-2}	1 2
Γ_4	$\Lambda(1520) \rightarrow \Lambda\gamma$	(7 9 ± 1.4) × 10^{-3}	
Γ_5	$\Lambda(1520) \rightarrow \Sigma^0\gamma$	(1 95 ± 0 34) × 10^{-2}	
Γ_6	$\Lambda(1520) \rightarrow \Sigma\pi\pi$	(8 6 ± 0 5) × 10^{-3}	
Γ_7	$\Lambda(1520) \rightarrow \Sigma(1385)\pi$	(4 1 ± 0 5) × 10^{-2}	
Γ_8	$\Lambda(1520) \rightarrow \Sigma(1385)\pi$ ($\rightarrow \Lambda\pi\pi$)		
Γ_9	$\Lambda(1520) \rightarrow \Lambda(\pi\pi)_{S\text{-wave}}$	(1 9 ± 0 8) × 10^{-2}	

CONSTRAINED FIT INFORMATION

An overall fit to 9 branching ratios uses 24 measurements and one constraint to determine 6 parameters The overall fit has a χ^2 = 16 5 for 19 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i \delta x_j\rangle/(\delta x_i \cdot \delta x_j)$, in percent from the fit to the branching fractions $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

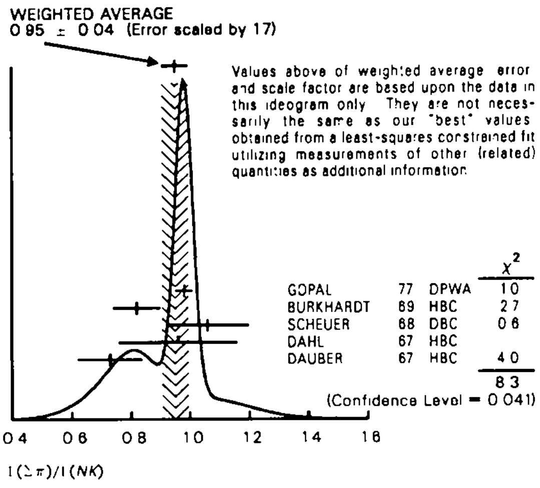
x_2	65				
x_3	29	−34			
x_4	9	8	4		
x_5	22	−21	10	2	
x_6	3	3	1	0	1
	x_1	x_2	x_3	x_4	x_5

Λ(1520) BRANCHING RATIOS

See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(\Sigma\pi)/\Gamma(NK)$ — Γ_2/Γ_1

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.940 ± 0.026 OUR FIT Error includes scale factor of 1 3				
0.95 ± 0.04 OUR AVERAGE Error includes scale factor of 1 7 See the ideogram below				
0.98 ± 0 03	[2] GOPAL	77	DPWA	KN multichannel
0 82 ± 0 08	BURKHARDT	69	HBC	$K^- p$ 0 8–1 2 GeV/c
1 06 ± 0.14	SCHEUER	68	DBC	$K^- N$ 3 GeV/c
0 96 ± 0 20	DAHL	67	HBC	$\pi^- p$ 1 6–4 GeV/c
0 73 ± 0 11	DAUBER	67	HBC	$K^- p$ 2 GeV/c
• • • We do not use the following data for averages fits limits etc • • •				
1 06 ± 0 12	BERTHON	74	HBC	Quasi 2 body σ
1 72 ± 0 78	MUSGRAVE	65	HBC	



$\Gamma(\Lambda\pi\pi)/\Gamma(N\overline{K})$ — Γ_3/Γ_1

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.213 ± 0 012 OUR FIT Error includes scale factor of 1 2				
0.202 ± 0.021 OUR AVERAGE				
0.22 ± 0 03	BURKHARDT	69	HBC	$K^- p$ 0 8–1 2 GeV/c
0 19 ± 0 04	SCHEUER	68	DBC	$K^- N$ 3 GeV/c
0 17 ± 0 05	DAHL	67	HBC	$\pi^- p$ 1 6–4 GeV/c
0.21 ± 0 18	DAUBER	67	HBC	$K^- p$ 2 GeV/c
• • • We do not use the following data for averages fits limits etc • • •				
0.27 ± 0.13	BERTHON	74	HBC	Quasi 2 body σ
0 2	KIM	71	DPWA	K matrix analysis

$\Gamma(\Sigma\pi)/\Gamma(\Lambda\pi\pi)$ — Γ_2/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
4.42 ± 0.25 OUR FIT Error includes scale factor of 1 2				
3.9 ± 0.6 OUR AVERAGE				
3 9 ± 1 0	UHLIG	67	HBC	K^-p 0 9-1 0 GeV/c
3 3 ± 1 1	BIRMINGHAM	66	HBC	K^-p 3 5 GeV/c
4 5 ± 1 0	ARMENTEROS	65C	HBC	

$\Gamma(\Lambda\gamma)/\Gamma_{total}$ — Γ_4/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0079 ± 0.0014 OUR FIT					
0.0080 ± 0.0014	238	MAST	68B	HBC	Using $\Gamma(N\bar{K})/\Gamma_{total}$=0 45

$\Gamma(\Sigma^0\gamma)/\Gamma_{total}$ — Γ_5/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.0195 ± 0.0034 OUR FIT				
0.02 ± 0 0035	[3] MAST	68B	HBC	Not measured see note

$\Gamma(N\bar{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.448 ± 0.007 OUR FIT Error includes scale factor of 1 3				
0.455 ± 0.011 OUR AVERAGE				
0 47 ± 0 02	GOPAL	80	DPWA	$K N \to K N$
0 45 ± 0 03	ALSTON	78	DPWA	$\bar{K}N \to KN$
0 448 ± 0 014	CORDEN	75	DBC	K^-d 1 4-1 8 GeV/c
• • • We do not use the following data for averages fits limits etc • • •				
0 47 ± 0 01	GOPAL	77	DPWA	See GOPAL 80
0 42	MAST	76	HBC	$K^-p \to K^0 n$

$\Gamma(\Sigma\pi)/\Gamma_{total}$ — Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.421 ± 0.007 OUR FIT Error includes scale factor of 1 3				
0.423 ± 0.011 OUR AVERAGE				
0 426 ± 0 014	CORDEN	75	DBC	K^-d 1 4-1 8 GeV/c
0 418 ± 0 017	BARBARO	69B	HBC	K^-p 0 28-0 45 GeV/c
• • • We do not use the following data for averages fits limits etc • • •				
0 46	KIM	71	DPWA	K matrix analysis

$\Gamma(\Sigma\pi\pi)/\Gamma_{total}$ — Γ_6/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.0086 ± 0.0005 OUR FIT				
0.0086 ± 0.0005 OUR AVERAGE				
0 007 ± 0 002	[4] CORDEN	75	DBC	K^-d 1 4-1 8 GeV/c
0 0085 ± 0.0006	[5] MAST	73	MPWA	$K^-p \to \Sigma\pi\pi$
0 010 ± 0 0015	BARBARO	69B	HBC	K^-p 0 28-0 45 GeV/c

$\Gamma(\Sigma(1385)\pi(\to\Lambda\pi\pi))/\Gamma(\Lambda\pi\pi)$ — Γ_8/Γ_3

The $\Lambda\pi\pi$ mode is largely due to $\Sigma(1385)\pi$ Only the values of $(\Sigma(1385)\pi)$ / $(\Lambda 2\pi)$ given by MAST 73B and CORDEN 75 are based on real 3 body partial-wave analyses The discrepancy between the two results is essentially due to the different hypotheses made concerning the shape of the $(\pi\pi)_{S\text{-wave}}$ state

VALUE	DOCUMENT ID		TECN	COMMENT
0 58 ± 0 22	CORDEN	75	DBC	K^-d 1 4-1 8 GeV/c
0 82 ± 0 10	[6] MAST	73B	IPWA	$K^-p \to \Lambda\pi\pi$
• • • We do not use the following data for averages fits limits etc • • •				
0 39 ± 0 10	[7] BURKHARDT	71	HBC	$K^-p \to (\Lambda\pi\pi)\pi$

$\Gamma(\Sigma(1385)\pi)/\Gamma_{total}$ — Γ_7/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.041 ± 0.005	CHAN	72	HBC	$K^-p \to \Lambda\pi\pi$

$\Gamma(\Lambda\pi\pi)/\Gamma_{total}$ — Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.095 ± 0.005 OUR FIT Error includes scale factor of 1 2				
0.096 ± 0.008 OUR AVERAGE Error includes scale factor of 1 6				
0 091 ± 0 006	CORDEN	75	DBC	K^-d 1 4-1 8 GeV/c
0 11 ± 0 01	[8] MAST	73B	IPWA	$K^-p \to \Lambda\pi\pi$

$\Gamma(\Lambda(\pi\pi)_{S\text{-wave}})/\Gamma(\Lambda\pi\pi)$ — Γ_9/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
0.20 ± 0.08	CORDEN	75	DBC	K^-d 1 4-1 8 GeV/c

Λ(1520) FOOTNOTES

[1] From the best-resolution sample of $\Lambda\pi\pi$ events only
[2] The $KN \to \Sigma\pi$ amplitude at resonance is +0 46 ± 0 01
[3] Calculated from $\Gamma(\Lambda\gamma)/\Gamma_{total}$, assuming SU(3) Needed to constrain the sum of all the branching ratios to be unity
[4] Much of the $\Sigma\pi\pi$ decay proceeds via $\Sigma(1385)\pi$
[5] Assumes $\Gamma(N\bar{K})/\Gamma_{total}$ = 0 46
[6] Both $\Sigma(1385)\pi$ S_{03} and $\Sigma(\pi\pi)$ P_{03} contribute
[7] The central bin (1514-1524 MeV) gives 0 74 ± 0 10 other bins are lower by 2-to 5 standard deviations
[8] Assumes $\Gamma(NK)/\Gamma_{total}$ = 0 46 ± 0 02

Λ(1520) REFERENCES

BARBER	80D	ZPHY C7 17	+Dainton Lee Marshall+	(DARE LANC SHEF)
GOPAL	80	Toronto Conf 159		(RHEL) IJP
BARLAG	79	NP B149 220	+Blokzijl Jongejans+	(AMST CERN NIJM OXF)
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
CAMERON	77	NP B131 399	+Franek Gopal Kalmus McPherson+	(RHEL LOIC) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MAST	76	PR D14 13	+Alston Garnjost Bangerter+	(LBL)
CORDEN	75	NP B84 306	+Cox Dartnell Kenyon O Neale+	(BIRM)
BERTHON	74	NC 21A 146	+Tristram+	(CDEF RHEL SACL STRB)
MAST	73	PR D7 3212	+Bangerter Alston Garnjost+	(LBL) IJP
MAST	73B	PR D7 5	+Bangerter Alston Garnjost+	(LBL) IJP
CHAN	72	PRL 28 256	+Button Shafer Hertzbach Kofler+	(MASA YALE)
BURKHARDT	71	NP B27 64	+Filthuth Kluge+	(HEID CERN SACL)
KIM	71	PRL 27 356		(HARV) IJP
Also	70	Duke Conf 161	Kim	(HARV) IJP
BARBARO	69B	Lund Conf 352	Barbaro Galtieri Bangerter Mast Tripp	(LRL)
Also	70	Duke Conf 95	Tripp	(LRL)
BURKHARDT	69	NP B14 106	+Filthuth Kluge+	(HEID EFI CERN SACL)
MAST	68B	PRL 21 1715	+Alston Bangerter Galtieri+	(LRL)
SCHEUER	68	NP B8 503	+Merrill Verglas DeWitt+	(SABRE Collab)
DAHL	67	PR 163 1377	+Hardy Hess Kirz Miller	(LRL)
DAUBER	67	PL 24B 525	+Malamud Schlein Slater Stork	(UCLA)
UHLIG	67	PR 155 1448	+Charlton Condon Glasser Yodh+	(UMD NRL)
BIRMINGHAM	66	PR 152 1148		(BIRM GLAS LOIC OXF RHEL)
ARMENTEROS	65C	PL 19 338	+Ferro Luzzi+	(CERN HEID SACL)
MUSGRAVE	65	NC 35 735	+Petmezas+	(BIRM CERN EPOL LOIC SACL)
WATSON	63	PR 131 2248	+Ferro Luzzi Tripp	(LRL) IJP
FERRO LUZZI	62	PRL 8 28	+Tripp Watson	(LRL) IJP

Λ(1600) P_{01}

$I(J^P) = 0(\frac{1}{2}^+)$ Status * * *

See also the Λ(1810) P_{01} There are quite possibly two P_{01} states in this region

Λ(1600) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1560 to 1700 OUR ESTIMATE				
1568 ± 20	GOPAL	80	DPWA	$\bar{K}N \to KN$
1703 ± 100	ALSTON	78	DPWA	$KN \to \bar{K}N$
1573 ± 25	GOPAL	77	DPWA	$\bar{K}N$ multichannel
1596 ± 6	KANE	74	DPWA	$K^-p \to \Sigma\pi$
1620 ± 10	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel
• • • We do not use the following data for averages fits limits etc • • •				
1572 or 1617	[1] MARTIN	77	DPWA	KN multichannel
1646 ± 7	[2] CARROLL	76	DPWA	Isospin-0 total σ
1570	KIM	71	DPWA	K matrix analysis

Λ(1600) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
50 to 250 OUR ESTIMATE				
116 ± 20	GOPAL	80	DPWA	$KN \to KN$
593 ± 200	ALSTON-	78	DPWA	$KN \to \bar{K}N$
147 ± 50	GOPAL	77	DPWA	$\bar{K}N$ multichannel
175 ± 20	KANE	74	DPWA	$K^-p \to \Sigma\pi$
60 ± 10	LANGBEIN	72	IPWA	KN multichannel
• • • We do not use the following data for averages fits, limits etc • • •				
247 or 271	[1] MARTIN	77	DPWA	KN multichannel
20	[2] CARROLL	76	DPWA	Isospin-0 total σ
50	KIM	71	DPWA	K matrix analysis

Λ(1600) DECAY MODES

Γ_1 Λ(1600) → NK
Γ_2 Λ(1600) → $\Sigma\pi$

$\Lambda(1600)$ BRANCHING RATIOS

See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.15 to 0.30 OUR ESTIMATE				
0 23 ± 0 04	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
0.14 ± 0 05	ALSTON-	78	DPWA	$\bar{K}N \to \bar{K}N$
0 25 ± 0 15	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel
• • • We do not use the following data for averages fits limits etc • • •				
0 24 ± 0 04	GOPAL	77	DPWA	See GOPAL 80
0 30 or 0 29	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1600) \to \Sigma\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 16 ± 0 04	GOPAL	77	DPWA	$\bar{K}N$ multichannel
−0 33 ± 0 11	KANE	74	DPWA	$K^-p \to \Sigma\pi$
0 28 ± 0.09	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel
• • • We do not use the following data for averages fits limits etc • • •				
−0 39 or −0 39	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
NOT SEEN	HEPP	76B	DPWA	$K^-N \to \Sigma\pi$

$\Lambda(1600)$ FOOTNOTES

[1] The two MARTIN 77 values are from a T matrix pole and from a Breit Wigner fit

[2] A total cross section bump with $(J+1/2)\ \Gamma_{el}/\Gamma_{total}$ = 0 04

$\Lambda(1600)$ REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL) IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
CARROLL	76	PRL 37 806	+Chiang Kycia Li Mazur Michael+	(BNL) I
HEPP	76B	PL 65B 487	+Braun Grimm Strobele+	(CERN HEID MPIM) IJP
KANE	74	LBL 2452		(LBL) IJP
LANGBEIN	72	NP B47 477	+Wagner	(MPIM) IJP
KIM	71	PRL 27 356		(HARV) IJP

$\Lambda(1670)\ S_{01}$

$I(J^P) = 0(\frac{1}{2}^-)$ Status * * * *

The measurements of the mass, width, and elasticity published before 1974 are now obsolete and have been omitted They were last listed in our 1982 edition (Physics Letters 111B)

$\Lambda(1670)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1660 to 1680 OUR ESTIMATE				
1670 8 ± 1 7	KOISO	85	DPWA	$K^-p \to \Sigma\pi$
1667 ± 5	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
1671 ± 3	ALSTON	78	DPWA	$\bar{K}N \to \bar{K}N$
1670 ± 5	GOPAL	77	DPWA	$\bar{K}N$ multichannel
1675 ± 2	HEPP	76B	DPWA	$K^-N \to \Sigma\pi$
1679 ± 1	KANE	74	DPWA	$K^-p \to \Sigma\pi$
1665 ± 5	PREVOST	74	DPWA	$K^-N \to \Sigma(1385)\pi$
• • • We do not use the following data for averages fits limits etc • • •				
1664	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$\Lambda(1670)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
25 to 50 OUR ESTIMATE				
34 1 ± 3 7	KOISO	85	DPWA	$K^-p \to \Sigma\pi$
29 ± 5	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
29 ± 5	ALSTON-	78	DPWA	$\bar{K}N \to \bar{K}N$
45 ± 10	GOPAL	77	DPWA	$\bar{K}N$ multichannel
46 ± 5	HEPP	76B	DPWA	$K^-N \to \Sigma\pi$
40 ± 3	KANE	74	DPWA	$K^-p \to \Sigma\pi$
19 ± 5	PREVOST	74	DPWA	$K^-N \to \Sigma(1385)\pi$
• • • We do not use the following data for averages fits limits, etc • • •				
12	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$\Lambda(1670)$ DECAY MODES

Γ_1 $\Lambda(1670) \to N\bar{K}$
Γ_2 $\Lambda(1670) \to \Sigma\pi$
Γ_3 $\Lambda(1670) \to \Lambda\eta$
Γ_4 $\Lambda(1670) \to \Sigma(1385)\pi$

$\Lambda(1670)$ BRANCHING RATIOS

See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.15 to 0 25 OUR ESTIMATE				
0 18 ± 0.03	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
0 17 ± 0 03	ALSTON-	78	DPWA	$\bar{K}N \to \bar{K}N$
• • • We do not use the following data for averages fits limits etc • • •				
0 20 ± 0 03	GOPAL	77	DPWA	See GOPAL 80
0 15	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1670) \to \Sigma\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 26 ± 0 02	KOISO	85	DPWA	$K^-p \to \Sigma\pi$
−0 31 ± 0 03	GOPAL	77	DPWA	$\bar{K}N$ multichannel
−0.29 ± 0 03	HEPP	76B	DPWA	$K^-N \to \Sigma\pi$
−0 23 ± 0 03	LONDON	75	HLBC	$K^-p \to \Sigma^0\pi^0$
−0 27 ± 0 02	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
−0 13	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1670) \to \Lambda\eta$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0 20 ± 0 05	BAXTER	73	DPWA	$K^-p \to$ neutrals
• • • We do not use the following data for averages fits limits etc • • •				
0 24	KIM	71	DPWA	K-matrix analysis
0 26	ARMENTEROS	69C	HBC	
0 20 or 0 23	BERLEY	65	HBC	

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1670) \to \Sigma(1385)\pi$ $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 18 ± 0 05	PREVOST	74	DPWA	$K^-N \to \Sigma(1385)\pi$

$\Lambda(1670)$ FOOTNOTES

[1] MARTIN 77 obtains identical resonance parameters from a T matrix pole and from a Breit Wigner fit

$\Lambda(1670)$ REFERENCES

KOISO	85	NP A433 619	+Sai Yamamoto Kofler	(TOKY MASA)
GOPAL	80	Toronto Conf 159		(RHEL) IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
HEPP	76B	PL 65B 487	+Braun Grimm Strobele+	(CERN HEID MPIM) IJP
LONDON	75	NP B85 289	+Yu Boyd+	(BNL CERN EPOL ORSA TORI)
KANE	74	LBL 2452		(LBL) IJP
PREVOST	74	NP B69 246	+Barloutaud+	(SACL CERN HEID)
BAXTER	73	NP B67 125	+Buckingham Corbett Dunn+	(OXF) IJP
KIM	71	PRL 27 356		(HARV) IJP
Also	70	Duke Conf 161	Kim	(HARV) IJP
ARMENTEROS	69C	Lund Paper 229	+Baillon+	(CERN HEID SACL) IJP
Values are quoted in LEVI SETTI 69				
BERLEY	65	PRL 15 641	+Connolly Hart Rahm Stonehill+	(BNL) IJP

Λ(1690) D_{03}

$I(J^P) = 0(\frac{3}{2}^-)$ Status ∗ ∗ ∗ ∗

The measurements of the mass, width, and elasticity published before 1974 are now obsolete and have been omitted They were last listed in our 1982 edition (Physics Letters **111B**)

Λ(1690) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1685 to 1695 OUR ESTIMATE				
1695 7 ± 2 6	KOISO	85	DPWA	$K^-p \to \Sigma\pi$
1690 ± 5	GOPAL	80	DPWA	$KN \to KN$
1692 ± 5	ALSTON	78	DPWA	$\overline{K}N \to \overline{K}N$
1690 ± 5	GOPAL	77	DPWA	$\overline{K}N$ multichannel
1690 ± 3	HEPP	76B	DPWA	$K^-N \to \Sigma\pi$
1689 ± 1	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits etc • • •				
1687 or 1689	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel
1692 ± 4	CARROLL	76	DPWA	isospin-0 total σ

Λ(1690) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
50 to 70 OUR ESTIMATE				
67 2 ± 5 6	KOISO	85	DPWA	$K^-p \to \Sigma\pi$
61 ± 5	GOPAL	80	DPWA	$\overline{K}N \to KN$
64 ± 10	ALSTON	78	DPWA	$KN \to KN$
60 ± 5	GOPAL	77	DPWA	$\overline{K}N$ multichannel
82 ± 8	HEPP	76B	DPWA	$K^-N \to \Sigma\pi$
60 ± 4	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits etc • • •				
62 or 62	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel
38	CARROLL	76	DPWA	isospin-0 total σ

Λ(1690) DECAY MODES

- Γ_1 Λ(1690) → NK
- Γ_2 Λ(1690) → $\Sigma\pi$
- Γ_3 Λ(1690) → $\Lambda\eta$
- Γ_4 Λ(1690) → $\Lambda\pi\pi$
- Γ_5 Λ(1690) → $\Sigma\pi\pi$
- Γ_6 Λ(1690) → $\Sigma(1385)\pi$, S-wave

Λ(1690) BRANCHING RATIOS

The sum of all the quoted branching ratios is more than 1 0 The two-body ratios are from partial wave analyses, and thus probably are more reliable than the three body ratios which are determined from bumps in cross sections Of the latter the $\Sigma\pi\pi$ bump looks more significant (The error given for the $\Lambda\pi\pi$ ratio looks unreasonably small) Hardly any of the $\Sigma\pi\pi$ decay can be via $\Sigma(1385)$ for then seven times as much $\Lambda\pi\pi$ decay would be required See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(NK)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.2 to 0.3 OUR ESTIMATE				
0 23 ± 0 03	GOPAL	80	DPWA	$KN \to \overline{K}N$
0 22 ± 0 03	ALSTON	78	DPWA	$KN \to KN$
• • • We do not use the following data for averages fits limits etc • • •				
0 24 ± 0 03	GOPAL	77	DPWA	See GOPAL 80
0 28 or 0 26	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(1690) \to \Sigma\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.34 ± 0 02	KOISO	85	DPWA	$K^-p \to \Sigma\pi$
− 0 25 ± 0 03	GOPAL	77	DPWA	$\overline{K}N$ multichannel
− 0 29 ± 0 03	HEPP	76B	DPWA	$K^-N \to \Sigma\pi$
− 0 28 ± 0 03	LONDON	75	HLBC	$K^-p \to \Sigma^0\pi^0$
− 0 28 ± 0 02	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
− 0 30 or − 0 28	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $NK \to \Lambda(1690) \to \Lambda\eta$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 00 ± 0 03	BAXTER	73	DPWA	$K^-p \to$ neutrals

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $NK \to \Lambda(1690) \to \Lambda\pi\pi$ — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits, limits etc • • •				
0 25 ± 0.02	[2] BARTLEY	68	HDBC	$K^-p \to \Lambda\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $NK \to \Lambda(1690) \to \Sigma\pi\pi$ — $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 21	ARMENTEROS	68C	HDBC	$K^-N \to \Sigma\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(1690) \to \Sigma(1385)\pi$, S-wave — $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ 0 27 ± 0 04	PREVOST	74	DPWA	$K^-N \to \Sigma(1385)\pi$

Λ(1690) FOOTNOTES

[1] The two MARTIN 77 values are from a T-matrix pole and from a Breit Wigner fit Another D_{03} Λ at 1966 MeV is also suggested by MARTIN 77 but is very uncertain

[2] BARTLEY 68 uses only cross section data The enhancement is not seen by PREVOST 71

Λ(1690) REFERENCES

KOISO	85	NP A433 619	+Sai Yamamoto Kofler	(TOKY MASA)
GOPAL	80	Toronto Conf 159		(RHEL) IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
CARROLL	76	PRL 37 806	+Chiang Kycia Li Mazur Michael+	(BNL) I
HEPP	76B	PL 65B 487	+Braun Grimm Strobele+	(CERN HEID MPIM) IJP
LONDON	75	NP B85 289	+Yu Boyd+	(BNL CERN EPOL ORSA TORI)
KANE	74	LBL 2452		(LBL) IJP
PREVOST	74	NP B69 246	+Barloutaud+	(SACL CERN HEID)
BAXTER	73	NP B67 125	+Buckingham Corbett Dunn+	(OXF) IJP
PREVOST	71	Amsterdam Conf		(CERN HEID SACL)
ARMENTEROS	68C	NP B8 216	+Baillon+	(CERN HEID SACL) I
BARTLEY	68	PRL 21 1111	+Chu Dowd Greene+	(TUFT FSU BRAN) I

Λ(1800) S_{01}

$I(J^P) = 0(\frac{1}{2}^-)$ Status ∗ ∗ ∗

This is the second resonance in the S_{01} wave, the first being the Λ(1670)

Λ(1800) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1720 to 1850 OUR ESTIMATE				
1841 ± 10	GOPAL	80	DPWA	$KN \to KN$
1725 ± 20	ALSTON	78	DPWA	$\overline{K}N \to \overline{K}N$
1825 ± 20	GOPAL	77	DPWA	$\overline{K}N$ multichannel
1830 ± 20	LANGBEIN	72	IPWA	KN multichannel
• • • We do not use the following data for averages, fits, limits, etc • • •				
1767 or 1842	[1] MARTIN	77	DPWA	KN multichannel
1780	KIM	71	DPWA	K-matrix analysis
1872 ± 10	BRICMAN	70B	DPWA	$KN \to KN$

Λ(1800) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
200 to 400 OUR ESTIMATE				
228 ± 20	GOPAL	80	DPWA	$KN \to KN$
185 ± 20	ALSTON	78	DPWA	$\overline{K}N \to \overline{K}N$
230 ± 20	GOPAL	77	DPWA	KN multichannel
70 ± 15	LANGBEIN	72	IPWA	KN multichannel
• • • We do not use the following data for averages fits limits etc • • •				
435 or 473	[1] MARTIN	77	DPWA	KN multichannel
40	KIM	71	DPWA	K-matrix analysis
100 ± 20	BRICMAN	70B	DPWA	$KN \to KN$

Λ(1800) DECAY MODES

- Γ_1 Λ(1800) → NK
- Γ_2 Λ(1800) → $\Sigma\pi$
- Γ_3 Λ(1800) → $\Sigma(1385)\pi$
- Γ_4 Λ(1800) → $NK^*(892)$, S=1/2, S-wave
- Γ_5 Λ(1800) → $N\overline{K}^*(892)$, S=3/2, D-wave

Λ(1800) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.25 to 0.40 OUR ESTIMATE				
0 36 ± 0 04	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
0 28 ± 0 05	ALSTON-	78	DPWA	$\bar{K}N \to \bar{K}N$
0 35 ± 0 15	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel
• • • We do not use the following data for averages fits limits etc • • •				
0 37 ± 0 05	GOPAL	77	DPWA	See GOPAL 80
1 21 or 0 70	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
0 80	KIM	71	DPWA	K-matrix analysis
0 18 ± 0 02	BRICMAN	70B	DPWA	$\bar{K}N \to \bar{K}N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1800) \to \Sigma\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− 0 08 ± 0.05	GOPAL	77	DPWA	$\bar{K}N$ multichannel
• • • We do not use the following data for averages fits limits etc • • •				
− 0.74 or − 0.43	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
0 24	KIM	71	DPWA	K matrix analysis

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1800) \to \Sigma(1385)\pi$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ 0 056 ± 0 028	[2] CAMERON	78	DPWA	$K^- p \to \Sigma(1385)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1800) \to N\bar{K}^*(892)$, S=1/2, S-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− 0 17 ± 0 03	[2] CAMERON	78B	DPWA	$K^- p \to N\bar{K}^*$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1800) \to N\bar{K}^*(892)$, S=3/2, D-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− 0 13 ± 0.04	CAMERON	78B	DPWA	$K^- p \to N\bar{K}^*$

Λ(1800) FOOTNOTES

[1] The two MARTIN 77 values are from a T matrix pole and from a Breit Wigner fit
[2] The published sign has been changed to be in accord with the baryon-first convention

Λ(1800) REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL) IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
CAMERON	78	NP B143 189	+Franek Gopal Bacon Butterworth+	(RHEL LOIC) IJP
CAMERON	78B	NP B146 327	+Franek Gopal Kalmus McPherson+	(RHEL LOIC) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
LANGBEIN	72	NP B47 477	+Wagner	(MPIM) IJP
KIM	71	PRL 27 356		(HARV) IJP
Also	70	Duke Conf 161	Kim	(HARV) IJP
BRICMAN	70B	PL 33B 511	+Ferro Luzzi Lagnaux	(CERN) IJP

Λ(1810) P_{01}

$I(J^P) = 0(\frac{1}{2}^+)$ Status * * *

Almost all the recent analyses contain a P_{01} state, and sometimes two of them, but the masses, widths, and branching ratios vary greatly See also the Λ(1600) P_{01}

Λ(1810) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1750 to 1850 OUR ESTIMATE				
1841 ± 20	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
1853 ± 20	GOPAL	77	DPWA	$\bar{K}N$ multichannel
1735 ± 5	CARROLL	76	DPWA	Isospin-0 total σ
1746 ± 10	PREVOST	74	DPWA	$K^- N \to \Sigma(1385)\pi$
1780 ± 20	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel
• • • We do not use the following data for averages fits limits etc • • •				
1861 or 1953	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
1755	KIM	71	DPWA	K matrix analysis
1800	ARMENTEROS	70	HBC	$\bar{K}N \to \bar{K}N$
1750	ARMENTEROS	70	HBC	$\bar{K}N \to \Sigma\pi$
1690 ± 10	BARBARO	70	HBC	$\bar{K}N \to \Sigma\pi$
1740	BAILEY	69	DPWA	$\bar{K}N \to \bar{K}N$
1745	ARMENTEROS	68B	HBC	$\bar{K}N \to \bar{K}N$

Λ(1810) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
50 to 250 OUR ESTIMATE				
164 ± 20	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
90 ± 20	CAMERON	78B	DPWA	$K^- p \to N\bar{K}^*$
166 ± 20	GOPAL	77	DPWA	$\bar{K}N$ multichannel
46 ± 20	PREVOST	74	DPWA	$K^- N \to \Sigma(1385)\pi$
120 ± 10	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel
• • • We do not use the following data for averages fits limits etc • • •				
535 or 585	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
28	CARROLL	76	DPWA	Isospin-0 total σ
35	KIM	71	DPWA	K matrix analysis
30	ARMENTEROS	70	HBC	$\bar{K}N \to \bar{K}N$
70	ARMENTEROS	70	HBC	$\bar{K}N \to \Sigma\pi$
22	BARBARO	70	HBC	$\bar{K}N \to \Sigma\pi$
300	BAILEY	69	DPWA	$\bar{K}N \to \bar{K}N$
147	ARMENTEROS	68B	HBC	

Λ(1810) DECAY MODES

Γ_1	Λ(1810) → $N\bar{K}$
Γ_2	Λ(1810) → $\Sigma\pi$
Γ_3	Λ(1810) → $\Sigma(1385)\pi$
Γ_4	Λ(1810) → $N\bar{K}^*(892)$, S=1/2, P-wave
Γ_5	Λ(1810) → $N\bar{K}^*(892)$, S=3/2, P-wave

Λ(1810) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.2 to 0.5 OUR ESTIMATE				
0 24 ± 0 04	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
0.36 ± 0.05	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel
• • • We do not use the following data for averages fits limits etc • • •				
0 21 ± 0.04	GOPAL	77	DPWA	See GOPAL 80
0 52 or 0 49	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
0 30	KIM	71	DPWA	K matrix analysis
0 15	ARMENTEROS	70	DPWA	$\bar{K}N \to \bar{K}N$
0 55	BAILEY	69	DPWA	$\bar{K}N \to \bar{K}N$
0 4	ARMENTEROS	68B	DPWA	$\bar{K}N \to \bar{K}N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1810) \to \Sigma\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− 0 24 ± 0 04	GOPAL	77	DPWA	$\bar{K}N$ multichannel
• • • We do not use the following data for averages fits limits etc • • •				
+ 0 25 or + 0 23	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
< 0 01	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel
0 17	KIM	71	DPWA	K matrix analysis
+ 0 20	[2] ARMENTEROS	70	DPWA	$\bar{K}N \to \Sigma\pi$
− 0 13 ± 0 03	BARBARO	70	DPWA	$\bar{K}N \to \Sigma\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1810) \to \Sigma(1385)\pi$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ 0 18 ± 0 10	PREVOST	74	DPWA	$K^- N \to \Sigma(1385)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1810) \to N\bar{K}^*(892)$, S=1/2, P-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
− 0 14 ± 0 03	[2] CAMERON	78B	DPWA	$K^- p \to N\bar{K}^*$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1810) \to N\bar{K}^*(892)$, S=3/2, P-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+ 0 35 ± 0.06	CAMERON	78B	DPWA	$K^- p \to N\bar{K}^*$

Λ(1810) FOOTNOTES

[1] The two MARTIN 77 values are from a T matrix pole and from a Breit Wigner fit
[2] The published sign has been changed to be in accord with the baryon first convention

Λ(1810) REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL) IJP
CAMERON	78B	NP B146 327	+Franek Gopal Kalmus McPherson+	(RHEL LOIC) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
CARROLL	76	PRL 37 806	+Chiang Kycia Li Mazur Michael+	(BNL) I
PREVOST	74	NP B69 246	+Barloutaud+	(SACL CERN HEID)
LANGBEIN	72	NP B47 477	+Wagner	(MPIM) IJP
KIM	71	PRL 27 356		(HARV) IJP
Also	70	Duke Conf 161	Kim	(HARV) IJP
ARMENTEROS	70	Duke Conf 123	+Baillon+	(CERN HEID SACL) IJP
BARBARO	70	Duke Conf 173	Barbaro Galtieri	(LRL) IJP
BAILEY	69	UCRL 50617 Thesis		(LLL) IJP
ARMENTEROS	68B	NP B8 195	+Baillon+	(CERN HEID SACL) IJP

Λ(1820) F_{05}

$I(J^P) = 0(\frac{5}{2}^+)$ Status * * * *

This resonance is the cornerstone for all partial-wave analyses in this region Most of the results published before 1973 are now obsolete and have been omitted They may be found in our 1982 edition (Physics Letters **111B**)

Most of the quoted errors are statistical only, the systematic errors due to the particular parametrizations used in the partial-wave analyses are not included For this reason we do not calculate weighted averages for the mass and width

Λ(1820) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1815 to 1825 OUR ESTIMATE				
1823 ± 3	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
1819 ± 2	ALSTON	78	DPWA	$\bar{K}N \to \bar{K}N$
1822 ± 2	GOPAL	77	DPWA	$\bar{K}N$ multichannel
1821 ± 2	KANE	74	DPWA	$K^- p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
1830	DECLAIS	77	DPWA	$\bar{K}N \to \bar{K}N$
1817 or 1819	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

Λ(1820) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
70 to 90 OUR ESTIMATE				
77 ± 5	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
72 ± 5	ALSTON	78	DPWA	$\bar{K}N \to \bar{K}N$
81 ± 5	GOPAL	77	DPWA	$\bar{K}N$ multichannel
87 ± 3	KANE	74	DPWA	$K^- p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits etc • • •				
82	DECLAIS	77	DPWA	$\bar{K}N \to \bar{K}N$
76 or 76	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

Λ(1820) DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	$\Lambda(1820) \to N\bar{K}$	(58 4 ± 1 7) × 10^{-2}	
Γ_2	$\Lambda(1820) \to \Sigma\pi$	(13 4 ± 1 0) × 10^{-2}	
Γ_3	$\Lambda(1820) \to \Lambda\eta$	(1 6 $^{+1\ 3}_{-0\ 6}$) × 10^{-2}	
Γ_4	$\Lambda(1820) \to \Sigma\pi\pi$	(15 ± 4) × 10^{-2}	1 6
Γ_5	$\Lambda(1820) \to \Sigma(1385)\pi$		
Γ_6	$\Lambda(1820) \to \Sigma(1385)\pi$, *P*-wave	(10 5 ± 3 5) × 10^{-2}	1 8
Γ_7	$\Lambda(1820) \to \Sigma(1385)\pi$, *F*-wave	(9 $^{+12}_{-6}$) × 10^{-3}	1 9

CONSTRAINED FIT INFORMATION

An overall fit to 6 branching ratios uses 9 measurements and one constraint to determine 6 parameters The overall fit has a χ^2 = 7 3 for 4 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i\,\delta x_j\rangle/(\delta x_i\cdot\delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

x_2	39				
x_3	5	2			
x_4	24	12	21		
x_6	-7	3	0	84	
x_7	2	1	0	-26	-5
	x_1	x_2	x_3	x_4	x_6

Λ(1820) BRANCHING RATIOS

Errors quoted do not include uncertainties in the parametrizations used in the partial wave analyses and are thus too small See also Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.55 to 0.65 OUR ESTIMATE				
0.584 ± 0.017 OUR FIT				
0.586 ± 0.017 OUR AVERAGE				
0 58 ± 0 02	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
0 60 ± 0 03	ALSTON	78	DPWA	$\bar{K}N \to \bar{K}N$
• • • We do not use the following data for averages fits limits etc • • •				
0.51	DECLAIS	77	DPWA	$\bar{K}N \to \bar{K}N$
0 57 ± 0 02	GOPAL	77	DPWA	See GOPAL 80
0 59 or 0 58	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1820) \to \Sigma\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.280 ± 0.009 OUR FIT				
−0.280 ± 0.009 OUR AVERAGE				
−0 28 ± 0 03	GOPAL	77	DPWA	$\bar{K}N$ multichannel
−0 28 ± 0 01	KANE	74	DPWA	$K^- p \to \Sigma\pi$
• • • We do not use the following data for averages fits, limits, etc • • •				
−0.25 or −0 25	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1820) \to \Lambda\eta$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN
$0.096^{+0.040}_{-0\ 020}$ OUR FIT			
$-0.096^{+0.040}_{-0.020}$	RADER	73	MPWA

$\Gamma(\Sigma\pi\pi)/\Gamma_{total}$ Γ_4/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.15 ± 0.04 OUR FIT Error includes scale factor of 1 6				
NO CLEAR SIGNAL	[2] ARMENTEROS	68C	HDBC	$K^- N \to \Sigma\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1820) \to \Sigma(1385)\pi$, *P*-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.25 ± 0.04 OUR FIT Error includes scale factor of 1 8				
0.25 ± 0.04 OUR AVERAGE Signs on measurements were ignored Error includes scale factor of 1 7				
−0 167 ± 0 054	[3] CAMERON	78	DPWA	$K^- p \to \Sigma(1385)\pi$
+0 27 ± 0 03	PREVOST	74	DPWA	$K^- N \to \Sigma(1385)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1820) \to \Sigma(1385)\pi$, *F*-wave $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.07 ± 0.05 OUR FIT Error includes scale factor of 1 9				
+0 065 ± 0.029	[3] CAMERON	78	DPWA	$K^- p \to \Sigma(1385)\pi$

Λ(1820) FOOTNOTES

[1] The two MARTIN 77 values are from a T matrix pole and from a Breit Wigner fit
[2] There is a suggestion of a bump enough to be consistent with what is expected from $\Sigma(1385) \to \Sigma\pi$ decay
[3] The published sign has been changed to be in accord with the baryon first convention

Λ(1820) REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL) IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
CAMERON	78	NP B143 189	+Franek Gopal Bacon Butterworth+	(RHEL LOIC) IJP
DECLAIS	77	CERN 77 16	+Duchon Louvel Patry Seguinot+	(CAEN CERN) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP

KANE	74	LBL 2452		(LBL)	IJP
PREVOST	74	NP B69 246	+Barloutaud+	(SACL CERN HEID)	
RADER	73	NC 16A 178	+Barloutaud+	(SACL HEID CERN RHEL CDEF)	
ARMENTEROS	68C	NP B8 216	+Baillon+	(CERN HEID SACL)	I

Λ(1830) D_{05}

$I(J^P) = 0(\frac{5}{2}^-)$ Status * * * *

For results published before 1973 (they are now obsolete) see our 1982 edition (Physics Letters **111B**)

The best evidence for this resonance is in the $\Sigma\pi$ channel

Λ(1830) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1810 to 1830 OUR ESTIMATE				
1831 ± 10	GOPAL	80	DPWA	$KN \to KN$
1825 ± 10	GOPAL	77	DPWA	$\overline{K}N$ multichannel
1825 ± 1	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
1817 or 1818	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel

Λ(1830) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
60 to 110 OUR ESTIMATE				
100 ± 10	GOPAL	80	DPWA	$KN \to KN$
94 ± 10	GOPAL	77	DPWA	KN multichannel
119 ± 3	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
56 or 56	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel

Λ(1830) DECAY MODES

Γ_1	$\Lambda(1830) \to N\overline{K}$
Γ_2	$\Lambda(1830) \to \Sigma\pi$
Γ_3	$\Lambda(1830) \to \Lambda\eta$
Γ_4	$\Lambda(1830) \to \Sigma(1385)\pi$, D-wave

Λ(1830) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances

$\Gamma(N\overline{K})/\Gamma_{total}$ $\qquad\Gamma_1/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.03 to 0.10 OUR ESTIMATE				
0 08 ± 0 03	GOPAL	80	DPWA	$KN \to KN$
0.02 ± 0 02	ALSTON-	78	DPWA	$KN \to KN$
• • • We do not use the following data for averages, fits limits etc • • •				
0 04 ± 0 03	GOPAL	77	DPWA	See GOPAL 80
0 04 or 0 04	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(1830) \to \Sigma\pi$ $\qquad(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 17 ± 0.03	GOPAL	77	DPWA	$\overline{K}N$ multichannel
−0 15 ± 0 01	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
−0 17 or −0 17	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(1830) \to \Lambda\eta$ $\qquad(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN
−0 044 ± 0 020	RADER	73	MPWA

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(1830) \to \Sigma(1385)\pi$, D-wave $\qquad(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0 141 ± 0 014	[2] CAMERON	78	DPWA	$K^-p \to \Sigma(1385)\pi$
+0 13 ± 0 03	PREVOST	74	DPWA	$K^-N \to \Sigma(1385)\pi$

Λ(1830) FOOTNOTES

[1] The two MARTIN 77 values are from a T matrix pole and from a Breit Wigner fit

[2] The CAMERON 78 upper limit on G-wave decay is 0 03 The published sign has been changed to be in accord with the baryon-first convention

Λ(1830) REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL)	IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN)	IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN)	IJP
CAMERON	78	NP B143 189	+Franek Gopal Bacon Butterworth+	(RHEL LOIC)	IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL)	IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS)	IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)	
Also	77C	NP B126 285	Martin Pidcock	(LOUC)	IJP
KANE	74	LBL 2452		(LBL)	IJP
PREVOST	74	NP B69 246	+Barloutaud+	(SACL CERN HEID)	
RADER	73	NC 16A 178	+Barloutaud+	(SACL HEID CERN RHEL CDEF)	

Λ(1890) P_{03}

$I(J^P) = 0(\frac{3}{2}^+)$ Status * * * *

For results published before 1974 (they are now obsolete) see our 1982 edition (Physics Letters **111B**)

The $J^P = 3/2^+$ assignment is consistent with all available data (including polarization) and recent partial wave analyses The dominant inelastic modes remain unknown

Λ(1890) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1850 to 1910 OUR ESTIMATE				
1897 ± 5	GOPAL	80	DPWA	$KN \to KN$
1908 ± 10	ALSTON	78	DPWA	$\overline{K}N \to \overline{K}N$
1900 ± 5	GOPAL	77	DPWA	KN multichannel
1894 ± 10	HEMINGWAY	75	DPWA	$K^-p \to \overline{K}N$
• • • We do not use the following data for averages fits limits etc • • •				
1856 or 1868	[1] MARTIN	77	DPWA	KN multichannel
1900	[2] NAKKASYAN	75	DPWA	$K^-p \to \Lambda\omega$

Λ(1890) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
60 to 200 OUR ESTIMATE				
74 ± 10	GOPAL	80	DPWA	$KN \to \overline{K}N$
119 ± 20	ALSTON	78	DPWA	$KN \to KN$
72 ± 10	GOPAL	77	DPWA	KN multichannel
107 ± 10	HEMINGWAY	75	DPWA	$K^-p \to KN$
• • • We do not use the following data for averages fits, limits, etc • • •				
191 or 193	[1] MARTIN	77	DPWA	KN multichannel
100	[2] NAKKASYAN	75	DPWA	$K^-p \to \Lambda\omega$

Λ(1890) DECAY MODES

Γ_1	$\Lambda(1890) \to NK$
Γ_2	$\Lambda(1890) \to \Sigma\pi$
Γ_3	$\Lambda(1890) \to \Lambda\omega$
Γ_4	$\Lambda(1890) \to \Sigma(1385)\pi$, P-wave
Γ_5	$\Lambda(1890) \to \Sigma(1385)\pi$, F-wave
Γ_6	$\Lambda(1890) \to NK^*(892)$, $S=1/2$, P-wave

Λ(1890) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances

$\Gamma(NK)/\Gamma_{total}$ $\qquad\Gamma_1/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.20 to 0.35 OUR ESTIMATE				
0 20 ± 0 02	GOPAL	80	DPWA	$KN \to KN$
0 34 ± 0 05	ALSTON-	78	DPWA	$KN \to KN$
0 24 ± 0 04	HEMINGWAY	75	DPWA	$K^-p \to KN$
• • • We do not use the following data for averages fits limits etc • • •				
0 18 ± 0 02	GOPAL	77	DPWA	See GOPAL 80
0 36 or 0 34	[1] MARTIN	77	DPWA	KN multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(1890) \to \Sigma\pi$ $\qquad(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 09 ± 0 03	GOPAL	77	DPWA	KN multichannel
• • • We do not use the following data for averages fits limits etc • • •				
+0 15 or +0 14	[1] MARTIN	77	DPWA	KN multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(1890) \to \Lambda\omega$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
SEEN	BACCARI	77	IPWA	$K^-p \to \Lambda\omega$
0 032	[2] NAKKASYAN	75	DPWA	$K^-p \to \Lambda\omega$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $NK \to \Lambda(1890) \to \Sigma(1385)\pi$, P-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
<0 03	CAMERON	78	DPWA	$K^-p \to \Sigma(1385)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $NK \to \Lambda(1890) \to \Sigma(1385)\pi$, F-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 126 ± 0 055	[3] CAMERON	78	DPWA	$K^-p \to \Sigma(1385)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $NK \to \Lambda(1890) \to NK^*(892)$, S=1/2, P-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 07 ± 0 03	[3,4] CAMERON	78B	DPWA	$K^-p \to NK^*$

Λ(1890) FOOTNOTES

[1] The two MARTIN 77 values are from a T-matrix pole and from a Breit Wigner fit

[2] Found in one of two best solutions

[3] The published sign has been changed to be in accord with the baryon first convention

[4] Upper limits on the P_3 and F_3 waves are each 0 03

Λ(1890) REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL) IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
CAMERON	78	NP B143 189	+Franek Gopal Bacon Butterworth+	(RHEL LOIC) IJP
CAMERON	78B	NP B146 327	+Franek Gopal Kalmus McPherson+	(RHEL LOIC) IJP
BACCARI	77	NC 41A 96	+Poulard Revel Tallini+	(SACL CDEF) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
HEMINGWAY	75	NP B91 12	+Eades Harmsen+	(CERN HEID MPIM) IJP
NAKKASYAN	75	NP B93 85		(CERN) IJP

Λ(2000)

$I(J^P) = 0(?^?)$ Status *

OMITTED FROM SUMMARY TABLE

We list here all the ambiguous resonance possibilities with a mass around 2 GeV The proposed quantum numbers are D_3 (BARBARO-GALTIERI 70 in $\Sigma\pi$), D_3+F_5, P_3+D_5, or P_1+D_3 (BRANDSTETTER 72 in $\Lambda\omega$), and S_1 (CAMERON 78B in $N\bar{K}^*$) The first two of the above analyses should now be considered obsolete See also NAKKASYAN 75

Λ(2000) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2030 ± 30	CAMERON	78B	DPWA	$K^-p \to N\bar{K}^*$
1935 to 1971	[1] BRANDSTET	72	DPWA	$K^-p \to \Lambda\omega$
1951 to 2034	[1] BRANDSTET	72	DPWA	$K^-p \to \Lambda\omega$
2010 ± 30	BARBARO-	70	DPWA	$K^-p \to \Sigma\pi$

Λ(2000) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
125 ± 25	CAMERON	78B	DPWA	$K^-p \to N\bar{K}^*$
180 to 240	[1] BRANDSTET	72	DPWA	(lower mass)
73 to 154	[1] BRANDSTET	72	DPWA	(higher mass)
130 ± 50	BARBARO-	70	DPWA	$K^-p \to \Sigma\pi$

Λ(2000) DECAY MODES

Γ_1	$\Lambda(2000) \to N\bar{K}$
Γ_2	$\Lambda(2000) \to \Sigma\pi$
Γ_3	$\Lambda(2000) \to \Lambda\omega$
Γ_4	$\Lambda(2000) \to NK^*(892)$, S=1/2, S-wave
Γ_5	$\Lambda(2000) \to NK^*(892)$, S=3/2, D-wave

Λ(2000) BRANCHING RATIOS

See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(2000) \to \Sigma\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 20 ± 0 04	BARBARO	70	DPWA	$K^-p \to \Sigma\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(2000) \to \Lambda\omega$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 17 to 0 25	[1] BRANDSTET	72	DPWA	(lower mass)
0 04 to 0 15	[1] BRANDSTET	72	DPWA	(higher mass)

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(2000) \to N\bar{K}^*(892)$, S=1/2, S-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 12 ± 0 03	[2] CAMERON	78B	DPWA	$K^-p \to N\bar{K}^*$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(2000) \to N\bar{K}^*(892)$, S=3/2, D-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0 09 ± 0 03	CAMERON	78B	DPWA	$K^-p \to NK^*$

Λ(2000) FOOTNOTES

[1] The parameters quoted here are ranges from the three best fits the lower state probably has $J \le 3/2$ and the higher one probably has $J \le 5/2$

[2] The published sign has been changed to be in accord with the baryon first convention

Λ(2000) REFERENCES

CAMERON	78B	NP B146 327	+Franek Gopal Kalmus McPherson+	(RHEL LOIC) IJP
NAKKASYAN	75	NP B93 85		(CERN) IJP
BRANDSTET	72	NP B39 13	Brandstetter Butterworth+	(RHEL CDEF SACL)
BARBARO	70	Duke Conf 173	Barbaro Galtieri	(LRL) IJP

Λ(2020) F_{07}

$I(J^P) = 0(\frac{7}{2}^+)$ Status *

OMITTED FROM SUMMARY TABLE

In LITCHFIELD 71 need for the state rests solely on a possibly inconsistent polarization measurement at 1 784 GeV/c HEMINGWAY 75 does not require this state GOPAL 77 does not need it in either $N\bar{K}$ or $\Sigma\pi$ With new K^-n angular distributions included, DECLAIS 77 sees it However, this and other new data are included in GOPAL 80 and the state is not required BACCARI 77 weakly supports it

Λ(2020) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2140	BACCARI	77	DPWA	$K^-p \to \Lambda\omega$
2117	DECLAIS	77	DPWA	$\bar{K}N \to \bar{K}N$
2100 ± 30	LITCHFIELD	71	DPWA	$K^-p \to \bar{K}N$
2020 ± 20	BARBARO	70	DPWA	$K^-p \to \Sigma\pi$

Λ(2020) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
128	BACCARI	77	DPWA	$K^-p \to \Lambda\omega$
167	DECLAIS	77	DPWA	$\bar{K}N \to \bar{K}N$
120 ± 30	LITCHFIELD	71	DPWA	$K^-p \to \bar{K}N$
160 ± 30	BARBARO	70	DPWA	$K^-p \to \Sigma\pi$

Λ(2020) DECAY MODES

Γ_1	$\Lambda(2020) \to NK$
Γ_2	$\Lambda(2020) \to \Sigma\pi$
Γ_3	$\Lambda(2020) \to \Lambda\omega$

$\Lambda(2020)$ BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances

$\Gamma(N\overline{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.05	DECLAIS	77	DPWA	$\overline{K}N \to \overline{K}N$
0.05 ± 0.02	LITCHFIELD	71	DPWA	$K^-p \to \overline{K}N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(2020) \to \Sigma\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.15 ± 0.02	BARBARO-	70	DPWA	$K^-p \to \Sigma\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(2020) \to \Lambda\omega$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
<0.05	BACCARI	77	DPWA	$K^-p \to \Lambda\omega$

$\Lambda(2020)$ REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL)
BACCARI	77	NC 41A 96	+Poulard Revel Tallini+	(SACL CDEF) IJP
DECLAIS	77	CERN 77 16	+Duchon Louvel Patry Seguinot+	(CAEN CERN) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL)
HEMINGWAY	75	NP B91 12	+Eades Harmsen+	(CERN HEID MPIM) IJP
LITCHFIELD	71	NP B30 125	+ Lesquoy+	(RHEL CDEF SACL) IJP
BARBARO	70	Duke Conf 173	Barbaro Galtieri	(LRL) IJP

$\Lambda(2100)$ G_{07}

$I(J^P) = 0(\frac{7}{2}^-)$ Status ∗∗∗∗

Discovered by COOL 66 and by WOHL 66. Most of the results published before 1973 are now obsolete and have been omitted. They may be found in our 1982 edition (Physics Letters **111B**).

This entry only includes results from partial-wave analyses. Parameters of peaks seen in cross sections and in invariant-mass distributions around 2100 MeV used to be listed in a separate entry immediately following. It may be found in our 1986 edition (Physics Letters **170B**).

$\Lambda(2100)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2090 to 2110 OUR ESTIMATE				
2104 ± 10	GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$
2106 ± 30	DEBELLEFON	78	DPWA	$\overline{K}N \to \overline{K}N$
2110 ± 10	GOPAL	77	DPWA	$\overline{K}N$ multichannel
2105 ± 10	HEMINGWAY	75	DPWA	$K^-p \to \overline{K}N$
2115 ± 10	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2094	BACCARI	77	DPWA	$K^-p \to \Lambda\omega$
2094	DECLAIS	77	DPWA	$\overline{K}N \to \overline{K}N$
2110 or 2089	[1] NAKKASYAN	75	DPWA	$K^-p \to \Lambda\omega$

$\Lambda(2100)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
100 to 250 OUR ESTIMATE				
157 ± 40	DEBELLEFON	78	DPWA	$\overline{K}N \to \overline{K}N$
250 ± 30	GOPAL	77	DPWA	$\overline{K}N$ multichannel
241 ± 30	HEMINGWAY	75	DPWA	$K^-p \to \overline{K}N$
152 ± 15	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
98	BACCARI	77	DPWA	$K^-p \to \Lambda\omega$
250	DECLAIS	77	DPWA	$\overline{K}N \to \overline{K}N$
244 or 302	[1] NAKKASYAN	75	DPWA	$K^-p \to \Lambda\omega$

$\Lambda(2100)$ DECAY MODES

	Mode
Γ_1	$\Lambda(2100) \to N\overline{K}$
Γ_2	$\Lambda(2100) \to \Sigma\pi$
Γ_3	$\Lambda(2100) \to \Lambda\eta$
Γ_4	$\Lambda(2100) \to \Xi K$
Γ_5	$\Lambda(2100) \to \Lambda\omega$
Γ_6	$\Lambda(2100) \to N\overline{K}^*(892)$, $S=3/2$, D-wave
Γ_7	$\Lambda(2100) \to N\overline{K}^*(892)$, $S=1/2$, G-wave

$\Lambda(2100)$ BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances

$\Gamma(N\overline{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.25 to 0.35 OUR ESTIMATE				
0.34 ± 0.03	GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$
0.24 ± 0.06	DEBELLEFON	78	DPWA	$\overline{K}N \to \overline{K}N$
0.31 ± 0.03	HEMINGWAY	75	DPWA	$K^-p \to \overline{K}N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.29	DECLAIS	77	DPWA	$\overline{K}N \to \overline{K}N$
0.30 ± 0.03	GOPAL	77	DPWA	See GOPAL 80

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(2100) \to \Sigma\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.12 ± 0.04	GOPAL	77	DPWA	$\overline{K}N$ multichannel
+0.11 ± 0.01	KANE	74	DPWA	$K^-p \to \Sigma\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(2100) \to \Lambda\eta$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.050 ± 0.020	RADER	73	MPWA	$K^-p \to \Lambda\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(2100) \to \Xi K$ — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.035 ± 0.018	LITCHFIELD	71	DPWA	$K^-p \to \Xi K$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.003	MULLER	69B	DPWA	$K^-p \to \Xi K$
0.05	TRIPP	67	RVUE	$K^-p \to \Xi K$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(2100) \to \Lambda\omega$ — $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.070	[2] BACCARI	77	DPWA	D_{37} wave
+0.011	[2] BACCARI	77	DPWA	G_{17} wave
+0.008	[2] BACCARI	77	DPWA	G_{37} wave
0.122 or 0.154	[1] NAKKASYAN	75	DPWA	$K^-p \to \Lambda\omega$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(2100) \to N\overline{K}^*(892)$, $S=3/2$, D-wave — $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.21 ± 0.04	CAMERON	78B	DPWA	$K^-p \to N\overline{K}^*$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Lambda(2100) \to N\overline{K}^*(892)$, $S=1/2$, G-wave — $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.04 ± 0.03	[3] CAMERON	78B	DPWA	$K^-p \to N\overline{K}^*$

$\Lambda(2100)$ FOOTNOTES

[1] The NAKKASYAN 75 values are from the two best solutions found. Each has the $\Lambda(2100)$ and one additional resonance (P_3 or F_5).
[2] Note that the three for BACCARI 77 entries are for three different waves.
[3] The published sign has been changed to be in accord with the baryon-first convention. The upper limit on the G_3 wave is 0.03.

$\Lambda(2100)$ REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL) IJP
CAMERON	78B	NP B146 327	+Franek Gopal Kalmus McPherson+	(RHEL LOIC) IJP
DEBELLEFON	78	NC 42A 403	De Bellefon Berthon Billoir+	(CDEF SACL) IJP
BACCARI	77	NC 41A 96	+Poulard Revel Tallini+	(SACL CDEF) IJP
DECLAIS	77	CERN 77 16	+Duchon Louvel Patry Seguinot+	(CAEN CERN) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
HEMINGWAY	75	NP B91 12	+Eades Harmsen+	(CERN HEID MPIM) IJP
NAKKASYAN	75	NP B93 85		(CERN) IJP
KANE	74	LBL 2452		(LBL) IJP
RADER	73	NC 16A 178	+Barloutaud+	(SACL HEID CERN RHEL CDEF)
LITCHFIELD	71	NP B30 125	+ Lesquoy+	(RHEL CDEF SACL) IJP
MULLER	69B	UCRL 19372 Thesis		(LRL)
TRIPP	67	NP B3 10	+Leith+	(LRL SLAC CERN HEID SACL)
COOL	66	PRL 16 1228	+Giacomelli Kycia Leontic Lundby+	(BNL)
WOHL	66	PRL 17 107	+Solmitz Stevenson	(LRL) IJP

Λ(2110) F_{05}

$I(J^P) = 0(\frac{5}{2}^+)$ Status * * *

For results published before 1974 (they are now obsolete), see our 1982 edition (Physics Letters **111B**). All the references have been retained.

This resonance is in the Baryon Summary Table, but the evidence for it could be better.

Λ(2110) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2090 to 2140 OUR ESTIMATE				
2092 ± 25	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
2125 ± 25	CAMERON	78B	DPWA	$K^- p \to N\bar{K}^*$
2106 ± 50	DEBELLEFON	78	DPWA	$\bar{K}N \to \bar{K}N$
2140 ± 20	DEBELLEFON	77	DPWA	$K^- p \to \Sigma\pi$
2100 ± 50	GOPAL	77	DPWA	$\bar{K}N$ multichannel
2112 ± 7	KANE	74	DPWA	$K^- p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2137	BACCARI	77	DPWA	$K^- p \to \Lambda\omega$
2103	[1] NAKKASYAN	75	DPWA	$K^- p \to \Lambda\omega$

Λ(2110) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
150 to 250 OUR ESTIMATE				
245 ± 25	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
160 ± 30	CAMERON	78B	DPWA	$K^- p \to N\bar{K}^*$
251 ± 50	DEBELLEFON	78	DPWA	$\bar{K}N \to \bar{K}N$
140 ± 20	DEBELLEFON	77	DPWA	$K^- p \to \Sigma\pi$
200 ± 50	GOPAL	77	DPWA	$\bar{K}N$ multichannel
190 ± 30	KANE	74	DPWA	$K^- p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
132	BACCARI	77	DPWA	$K^- p \to \Lambda\omega$
391	[1] NAKKASYAN	75	DPWA	$K^- p \to \Lambda\omega$

Λ(2110) DECAY MODES

Γ_1 Λ(2110) → $N\bar{K}$
Γ_2 Λ(2110) → $\Sigma\pi$
Γ_3 Λ(2110) → $\Lambda\omega$
Γ_4 Λ(2110) → $\Sigma(1385)\pi$, *P*-wave
Γ_5 Λ(2110) → $N\bar{K}^*(892)$, S=1/2, *F*-wave

Λ(2110) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances.

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.05 to 0.25 OUR ESTIMATE				
0.07 ± 0.03	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
0.27 ± 0.06	[2] DEBELLEFON	78	DPWA	$\bar{K}N \to \bar{K}N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.07 ± 0.03	GOPAL	77	DPWA	See GOPAL 80

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to$ Λ(2110) → $\Sigma\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.14 ± 0.01	DEBELLEFON	77	DPWA	$K^- p \to \Sigma\pi$
+0.20 ± 0.03	KANE	74	DPWA	$K^- p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
+0.10 ± 0.03	GOPAL	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to$ Λ(2110) → $\Lambda\omega$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
<0.05	BACCARI	77	DPWA	$K^- p \to \Lambda\omega$
0.112	[1] NAKKASYAN	75	DPWA	$K^- p \to \Lambda\omega$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to$ Λ(2110) → $\Sigma(1385)\pi$, *P*-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.071 ± 0.025	[3] CAMERON	78	DPWA	$K^- p \to \Sigma(1385)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to$ Λ(2110) → $N\bar{K}^*(892)$, S=1/2, *F*-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.17 ± 0.04	[4] CAMERON	78B	DPWA	$K^- p \to N\bar{K}^*$

Λ(2110) FOOTNOTES

[1] Found in one of two best solutions.
[2] The published error of 0.6 was a misprint.
[3] The CAMERON 78 upper limit on *F*-wave decay is 0.03. The sign here has been changed to be in accord with the baryon-first convention.
[4] The published sign has been changed to be in accord with the baryon-first convention. The CAMERON 78B upper limits on the P_3 and F_3 waves are each 0.03.

Λ(2110) REFERENCES

GOPAL	80	Toronto Conf. 159		(RHEL) IJP
CAMERON	78	NP B143 189	+Franek, Gopal, Bacon, Butterworth+	(RHEL, LOIC) IJP
CAMERON	78B	NP B146 327	+Franek, Gopal, Kalmus, McPherson+	(RHEL, LOIC) IJP
DEBELLEFON	78	NC 42A 403	De Bellefon, Berthon, Billoir+	(CDEF, SACL) IJP
BACCARI	77	NC 41A 96	+Poulard, Revel, Tallini+	(SACL, CDEF) IJP
DEBELLEFON	77	NC 37A 175	De Bellefon, Berthon, Billoir+	(CDEF, SACL) IJP
GOPAL	77	NP B119 362	+Ross, VanHorn, McPherson+	(LOIC, RHEL) IJP
NAKKASYAN	75	NP B93 85		(CERN) IJP
KANE	74	LBL 2452		(LBL) IJP

Λ(2325) D_{03}

$I(J^P) = 0(\frac{3}{2}^-)$ Status *

OMITTED FROM SUMMARY TABLE

BACCARI 77 finds this state with either $J^P = 3/2^-$ or $3/2^+$ in a energy-dependent partial-wave analyses of $K^- p \to \Lambda\omega$ from 2070 to 2436 MeV. A subsequent semi-energy-independent analysis from threshold to 2436 MeV selects $3/2^-$. DEBELLEFON 78 (same group) also sees this state in an energy-dependent partial wave analysis of $K^- p \to \bar{K}N$ data, and finds $J^P = 3/2^-$ or $3/2^+$. They again prefer $J^P = 3/2^-$, but only on the basis of model-dependent considerations.

Λ(2325) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2342 ± 30	DEBELLEFON	78	DPWA	$\bar{K}N \to \bar{K}N$
2327 ± 20	BACCARI	77	DPWA	$K^- p \to \Lambda\omega$

Λ(2325) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
177 ± 40	DEBELLEFON	78	DPWA	$\bar{K}N \to \bar{K}N$
160 ± 40	BACCARI	77	IPWA	$K^- p \to \Lambda\omega$

Λ(2325) DECAY MODES

Γ_1 Λ(2325) → $N\bar{K}$
Γ_2 Λ(2325) → $\Lambda\omega$

Λ(2325) BRANCHING RATIOS

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.19 ± 0.06	DEBELLEFON	78	DPWA	$\bar{K}N \to \bar{K}N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to$ Λ(2325) → $\Lambda\omega$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.06 ± 0.02	[1] BACCARI	77	IPWA	S_{33} wave
0.05 ± 0.02	[1] BACCARI	77	DPWA	D_{13} wave
0.08 ± 0.03	[1] BACCARI	77	DPWA	D_{33} wave

Λ(2325) FOOTNOTES

[1] Note that the three BACCARI 77 entries are for three different waves.

Λ(2325) REFERENCES

DEBELLEFON	78	NC 42A 403	De Bellefon, Berthon, Billoir+	(CDEF, SACL) IJP
BACCARI	77	NC 41A 96	+Poulard, Revel, Tallini+	(SACL, CDEF) IJP

Λ(2350) H_{09}

$I(J^P) = 0(\frac{9}{2}^+)$ Status * * *

DAUM 68 favors $J^P = 7/2^-$ or $9/2^+$. BRICMAN 70 favors $9/2^+$. LASINSKI 71 suggests three states in this region using a Pomeron + resonances model. There are now also three formation experiments from the College de France-Saclay group, DEBELLEFON 77, BACCARI 77, and DEBELLEFON 78, which find $9/2^+$ in energy-dependent partial-wave analyses of $\bar{K}N \to \Sigma\pi$, $\Lambda\omega$, and NK.

Λ(2350) MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
2340 to 2370 OUR ESTIMATE				
2370 ± 50	DEBELLEFON	78	DPWA	$KN \to KN$
2365 ± 20	DEBELLEFON	77	DPWA	$K^- p \to \Sigma\pi$
2358 ± 6	BRICMAN	70	CNTR	Total charge exchange
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2372	BACCARI	77	DPWA	$K^- p \to \Lambda\omega$
2344 ± 15	COOL	70	CNTR	$K^- p$, $K^- d$ total
2360 ± 20	LU	70	CNTR	$\gamma p \to K^+ Y^*$
2340 ± 7	BUGG	68	CNTR	$K^- p$, $K^- d$ total

Λ(2350) WIDTH

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
100 to 250 OUR ESTIMATE				
204 ± 50	DEBELLEFON	78	DPWA	$KN \to KN$
110 ± 20	DEBELLEFON	77	DPWA	$K^- p \to \Sigma\pi$
324 ± 30	BRICMAN	70	CNTR	Total charge exchange
• • • We do not use the following data for averages, fits, limits, etc. • • •				
257	BACCARI	77	DPWA	$K^- p \to \Lambda\omega$
190	COOL	70	CNTR	$K^- p$, $K^- d$ total
55	LU	70	CNTR	$\gamma p \to K^+ Y^*$
140 ± 20	BUGG	68	CNTR	$K^- p$, $K^- d$ total

Λ(2350) DECAY MODES

Γ_1 Λ(2350) → NK

Γ_2 Λ(2350) → $\Sigma\pi$

Γ_3 Λ(2350) → $\Lambda\omega$

Λ(2350) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances.

$\Gamma(NK)/\Gamma_{total}$ Γ_1/Γ

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
~0.12 OUR ESTIMATE				
0.12 ± 0.04	DEBELLEFON	78	DPWA	$KN \to KN$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $NK \to$ Λ(2350) $\to \Sigma\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
−0.11 ± 0.02	DEBELLEFON	77	DPWA	$K^- p \to \Sigma\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $NK \to$ Λ(2350) $\to \Lambda\omega$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
<0.05	BACCARI	77	DPWA	$K^- p \to \Lambda\omega$

Λ(2350) REFERENCES

DEBELLEFON	78	NC 42A 403	De Bellefon, Berthon, Billoir+	(CDEF, SACL) IJP
BACCARI	77	NC 41A 96	+Poulard, Revel, Tallini+	(SACL, CDEF) IJP
DEBELLEFON	77	NC 37A 175	De Bellefon, Berthon, Billoir+	(CDEF, SACL) IJP
LASINSKI	71	NP B29 125		(EFI) IJP
BRICMAN	70	PL 31B 152	+Ferro-Luzzi, Perreau+	(CERN, CAEN, SACL)
COOL	70	PR D1 1887	+Giacomelli, Kycia, Leontic, Li+	(BNL) I
Also	66	PRL 16 1228	Cool, Giacomelli, Kycia, Leontic, Lundby+	(BNL) I
LU	70	PR D2 1846	+Greenberg, Hughes, Minehart, Mori+	(YALE)
BUGG	68	PR 168 1466	+Gilmore, Knight+	(RHEL, BIRM, CAVE) I
DAUM	68	NP B7 19	+Erne, Lagnaux, Sens, Steuer, Udo	(CERN) JP

Λ(2585) BUMPS

$I(J^P) = 0(?^?)$ Status * *

OMITTED FROM SUMMARY TABLE

Λ(2585) MASS (BUMPS)

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
2585 ± 45	ABRAMS	70	CNTR	$K^- p$, $K^- d$ total
2530 ± 25	LU	70	CNTR	$\gamma p \to K^+ Y^*$

Λ(2585) WIDTH (BUMPS)

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
300	ABRAMS	70	CNTR	$K^- p$, $K^- d$ total
150	LU	70	CNTR	$\gamma p \to K^+ Y^*$

Λ(2585) DECAY MODES (BUMPS)

Γ_1 Λ(2585) → $N\bar{K}$

Λ(2585) BRANCHING RATIOS (BUMPS)

$(J+\frac{1}{2}) \times \Gamma(NK)/\Gamma_{total}$ Γ_1/Γ

J is not known, so only $(J+\frac{1}{2}) \times \Gamma(NK)/\Gamma_{total}$ can be given.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
1	ABRAMS	70	CNTR	$K^- p$, $K^- d$ total
0.12 ± 0.12	[1] BRICMAN	70	CNTR	Total charge exchange

Λ(2585) FOOTNOTES (BUMPS)

[1] The resonance is at the end of the region analyzed — no clear signal.

Λ(2585) REFERENCES (BUMPS)

ABRAMS	70	PR D1 1917	+Cool, Giacomelli, Kycia, Leontic, Li+	(BNL) I
Also	66	PRL 16 1228	Cool, Giacomelli, Kycia, Leontic, Lundby+	(BNL) I
BRICMAN	70	PL 31B 152	+Ferro-Luzzi, Perreau+	(CERN, CAEN, SACL)
LU	70	PR D2 1846	+Greenberg, Hughes, Minehart, Mori+	(YALE)

Σ BARYONS
($S = -1$, $I = 1$)

Σ^+

$I(J^P) = 1(\frac{1}{2}^+)$ Status * * * *

SEE STABLE PARTICLES

Σ^0

$I(J^P) = 1(\frac{1}{2}^+)$ Status * * * *

SEE STABLE PARTICLES

Σ^-

$I(J^P) = 1(\frac{1}{2}^+)$ Status * * * *

SEE STABLE PARTICLES

$\Sigma(1385)$ P_{13}

$I(J^P) = 1(\frac{3}{2}^+)$ Status * * * *

Discovered by ALSTON 60 Early measurements of the mass and width for combined charge states have been omitted They may be found in our 1984 edition (Rev Mod Phys 56, No 2 Part II April 1984)

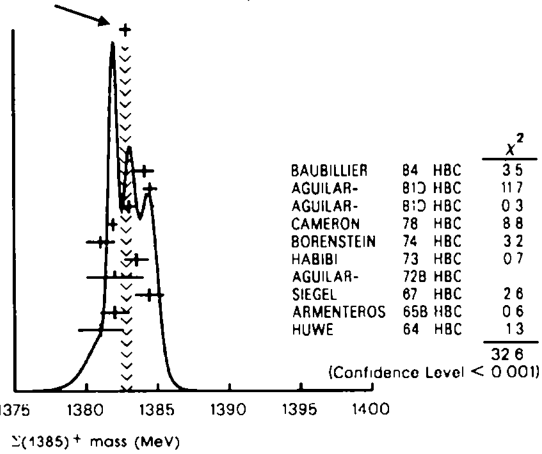
We average only the most significant determinations We do not average results from inclusive experiments with large backgrounds or results which are not accompanied by some discussion of experimental resolution Nevertheless systematic differences between experiments remain (See the ideograms in the Listings below) These differences could arise from interference effects that change with production mechanism and/or beam momentum They can also be accounted for in part by differences in the parametrizations employed (See BORENSTEIN 74 for a discussion on this point) Thus BORENSTEIN 74 uses a Breit-Wigner with energy-independent width, since a *P*-wave was found to give unsatisfactory fits CAMERON 78 uses the same form On the other hand HOLMGREN 77 obtains a good fit to their $\Lambda\pi$ spectrum with a *P*-wave Breit-Wigner, but includes the partial width for the $\Sigma\pi$ decay mode in the parametrization AGUILAR-BENITEZ 81D gives masses and widths for five different Breit-Wigner shapes The results vary considerably Only the best-fit *S*-wave results are given here

Σ(1385) MASSES

$\Sigma(1385)^+$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
1382.8 ± 0.4	**OUR AVERAGE**	Error includes scale factor of 2.0 See the ideogram below		
1384.1 ± 0.7	1897	BAUBILLIER 84	HBC	$K^- p$ 8.25 GeV/c
1384.5 ± 0.5	5256	AGUILAR 81D	HBC	$K^- p \to \Lambda\pi\pi$ 4.2 GeV/c
1383.0 ± 0.4	9361	AGUILAR 81D	HBC	$K^- p \to \Lambda 3\pi$ 4.2 GeV/c
1381.9 ± 0.3	6900	CAMERON 78	HBC	$K^- p$ 0.96–1.36 GeV/c
1381 ± 1	6846	BORENSTEIN 74	HBC	$K^- p$ 2.18 GeV/c
1383.5 ± 0.85	2300	HABIBI 73	HBC	$K^- p \to \Lambda\pi\pi$
1382 ± 2	400	AGUILAR 72B	HBC	$K^- p \to \Lambda\pi$ s
1384.4 ± 1.0	1260	SIEGEL 67	HBC	$K^- p$ 2.1 GeV/c
1382 ± 1	750	ARMENTEROS 65B	HBC	$K^- p$ 0.9–1.2 GeV/c
1381.0 ± 1.6	859	HUWE 64	HBC	$K^- p$ 1.22 GeV/c
• • • We do not use the following data for averages fits limits etc • • •				
1385.1 ± 1.2	600	BAKER 80	HYBR	$\pi^+ p$ 7 GeV/c
1383.2 ± 1.0	750	BAKER 80	HYBR	$K^- p$ 7 GeV/c
1381 ± 2	7k	[1] BAUBILLIER 79B	HBC	$K^- p$ 8.25 GeV/c
1391 ± 2	2k	CAUTIS 79	HYBR	$\pi^+ p$ / $K^- p$ 11.5 GeV
1390 ± 2	100	[1] SUGAHARA 79B	HBC	$\pi^- p$ 6 GeV/c
1385 ± 3	22k	[1,2] BARREIRO 77B	HBC	$K^- p$ 4.2 GeV/c
1385 ± 1	2594	HOLMGREN 77	HBC	See AGUILAR 81D
1380 ± 2		[1] BARDADIN 75	HBC	$K^- p$ 14.3 GeV/c
1382 ± 1	3740	[3] BERTHON 74	HBC	$K^- p$ 1263–1843 MeV/c
1390 ± 6	46	AGUILAR 70B	HBC	$K^- p \to \Sigma\pi$ s 4 GeV/c
1383 ± 8	62	[4] BIRMINGHAM 66	HBC	$K^- p$ 3.5 GeV/c
1378 ± 5	135	LONDON 66	HBC	$K^- p$ 2.24 GeV/c
1384.3 ± 1.9	250	[4] SMITH 65	HBC	$K^- p$ 1.8 GeV/c
1382.6 ± 2.1	250	[4] SMITH 65	HBC	$K^- p$ 1.95 GeV/c
1375.0 ± 3.9	170	COOPER 64	HBC	$K^- p$ 1.45 GeV/c
1376.0 ± 3.9	154	[4] ELY 61	HLBC	$K^- p$ 1.11 GeV/c

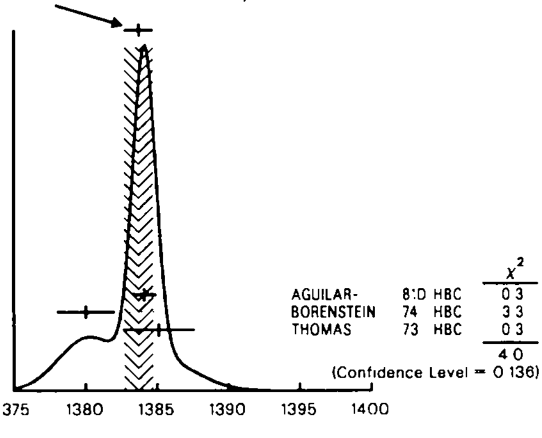
WEIGHTED AVERAGE
1382.8 ± 0.4 (Error scaled by 2.0)



$\Sigma(1385)^0$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
1383.7 ± 1.0	**OUR AVERAGE**	Error includes scale factor of 1.4 See the ideogram below		
1384.1 ± 0.8	5722	AGUILAR 81D	HBC	$K^- p \to \Lambda 3\pi$ 4.2 GeV/c
1380 ± 2	3100	[5] BORENSTEIN 74	HBC	$K^- p \to \Lambda 3\pi$ 2.18 GeV/c
1385.1 ± 2.5	240	[4] THOMAS 73	HBC	$\pi^- p \to \Lambda\pi^0 K^0$
• • • We do not use the following data for averages fits limits etc • • •				
1389 ± 3	500	[6] BAUBILLIER 79B	HBC	$K^- p$ 8.25 GeV/c

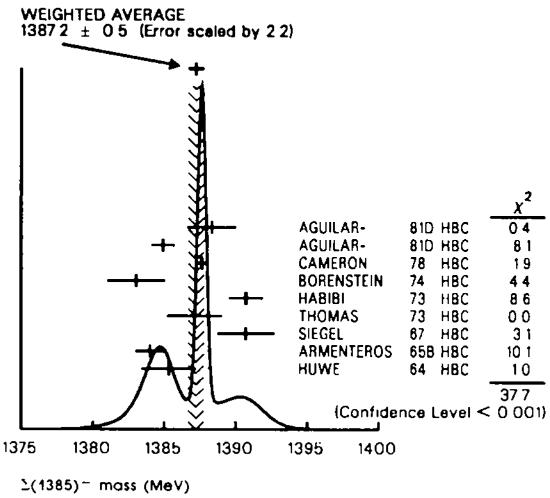
WEIGHTED AVERAGE
1383.7 ± 1.0 (Error scaled by 1.4)



$\Sigma(1385)^-$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
1387.2 ± 0.5	**OUR AVERAGE**	Error includes scale factor of 2.2 See the ideogram below		
1388.3 ± 1.7	620	AGUILAR 81D	HBC	$K^- p \to \Lambda\pi\pi$ 4.2 GeV/c
1384.9 ± 0.8	3346	AGUILAR 81D	HBC	$K^- p \to \Lambda 3\pi$ 4.2 GeV/c
1387.6 ± 0.3	9720	CAMERON 78	HBC	$K^- p$ 0.96–1.36 GeV/c
1383 ± 2	2303	BORENSTEIN 74	HBC	$K^- p$ 2.18 GeV/c
1390.7 ± 1.2	1900	HABIBI 73	HBC	$K^- p \to \Lambda\pi\pi$
1387.1 ± 1.9	630	[4] THOMAS 73	HBC	$\pi^- p \to \Lambda\pi^- K^+$
1390.7 ± 2.0	370	SIEGEL 67	HBC	$K^- p$ 2.1 GeV/c
1384 ± 1	1380	ARMENTEROS 65B	HBC	$K^- p$ 0.9–1.2 GeV/c
1385.3 ± 1.9	1086	[4] HUWE 64	HBC	$K^- p$ 1.15–1.30 GeV/c
• • • We do not use the following data for averages fits limits, etc • • •				
1383 ± 1	4.5k	[1] BAUBILLIER 79B	HBC	$K^- p$ 8.25 GeV/c
1380 ± 6	150	[1] SUGAHARA 79B	HBC	$\pi^- p$ 6 GeV/c
1387 ± 3	12k	[1,2] BARREIRO 77B	HBC	$K^- p$ 4.2 GeV/c
1391 ± 3	193	HOLMGREN 77	HBC	See AGUILAR 81D
1383 ± 2		[1] BARDADIN- 75	HBC	$K^- p$ 14.3 GeV/c
1389 ± 1	3060	[3] BERTHON 74	HBC	$K^- p$ 1263–1843 MeV/c

1389 ±9	15	LONDON	66	HBC	$K^- p$ 2.24 GeV/c
1391.5±2.6	120	[4] SMITH	65	HBC	$K^- p$ 1.8 GeV/c
1399.8±2.2	58	[4] SMITH	65	HBC	$K^- p$ 1.95 GeV/c
1392.0±6.2	200	COOPER	64	HBC	$K^- p$ 1.45 GeV/c
1382 ±3	93	DAHL	61	DBC	$K^- d$ 0.45 GeV/c
1376.0±4.4	224	[4] ELY	61	HLBC	$K^- p$ 1.11 GeV/c



Σ(1385)⁻ − Σ(1385)⁺ MASS DIFFERENCE

VALUE (MeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−2 to +6	95	[7] BORENSTEIN	74	HBC	$K^- p$ 2.18 GeV/c
7.2±1.4		[7] HABIBI	73	HBC	$K^- p \to \Lambda\pi\pi$
6.3±2.0		[7] SIEGEL	67	HBC	$K^- p$ 2.1 GeV/c
11 ±9		[7] LONDON	66	HBC	$K^- p$ 2.24 GeV/c
9 ±6		LONDON	66	HBC	$\Lambda 3\pi$ events
2.0±1.5		[7] ARMENTEROS	65B	HBC	$K^- p$ 0.9–1.2 GeV/c
7.2±2.1		[7] SMITH	65	HBC	$K^- p$ 1.8 GeV/c
17.2±2.0		[7] SMITH	65	HBC	$K^- p$ 1.95 GeV/c
17 ±7		[7] COOPER	64	HBC	$K^- p$ 1.45 GeV/c
4.3±2.2		[7] HUWE	64	HBC	$K^- p$ 1.22 GeV/c
0.0±4.2		[7] ELY	61	HLBC	$K^- p$ 1.11 GeV/c

Σ(1385)⁰ − Σ(1385)⁺ MASS DIFFERENCE

VALUE (MeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−4 to +4	95	[7] BORENSTEIN	74	HBC	$K^- p$ 2.18 GeV/c

Σ(1385)⁻ − Σ(1385)⁰ MASS DIFFERENCE

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2.0±2.4	[7] THOMAS	73	HBC	$\pi^- p \to \Lambda\pi^- K^+$

Σ(1385) WIDTHS

Σ(1385)⁺ WIDTH

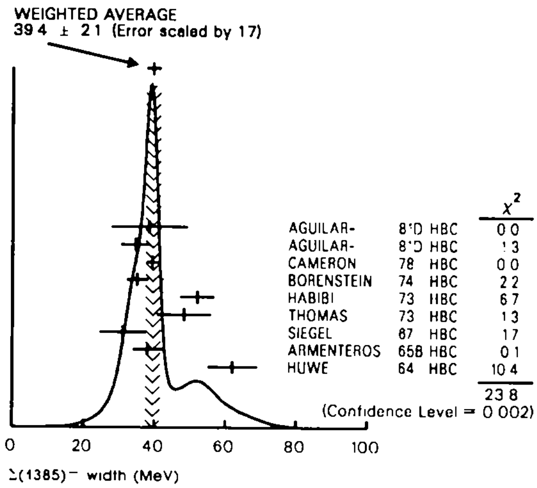
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
35.8± 0.8	**OUR AVERAGE**				
37.2± 2.0	1897	BAUBILLIER	84	HBC	$K^- p$ 8.25 GeV/c
35.1± 1.7	5256	AGUILAR	81D	HBC	$K^- p \to \Lambda\pi\pi$ 4.2 GeV/c
37.5± 2.0	9361	AGUILAR	81D	HBC	$K^- p \to \Lambda 3\pi$ 4.2 GeV/c
35.5± 1.9	6900	CAMERON	78	HBC	$K^- p$ 0.96–1.36 GeV/c
34.0± 1.6	6846	[8] BORENSTEIN	74	HBC	$K^- p$ 2.18 GeV/c
38.3± 3.2	2300	[9] HABIBI	73	HBC	$K^- p \to \Lambda\pi\pi$
32.5± 6.0	400	AGUILAR	72B	HBC	$K^- p \to \Lambda\pi$'s
36 ± 4	1260	[9] SIEGEL	67	HBC	$K^- p$ 2.1 GeV/c
32.0± 4.7	750	[9] ARMENTEROS	65B	HBC	$K^- p$ 0.95–1.20 GeV/c
46.5± 6.4	859	[9] HUWE	64	HBC	$K^- p$ 1.15–1.30 GeV/c
• • • We do not use the following data for averages, fits, limits, etc. • • •					
40 ± 3	600	BAKER	80	HYBR	$\pi^+ p$ 7 GeV/c
37 ± 2	750	BAKER	80	HYBR	$K^- p$ 7 GeV/c
37 ± 2	7k	[1] BAUBILLIER	79B	HBC	$K^- p$ 8.25 GeV/c
30 ± 4	2k	CAUTIS	79	HYBR	$\pi^+ p$ / $K^- p$ 11.5 GeV
30 ± 6	100	[1] SUGAHARA	79B	HBC	$\pi^- p$ 6 GeV/c
43 ± 5	22k	[1,2] BARREIRO	77B	HBC	$K^- p$ 4.2 GeV/c
34 ± 2	2594	HOLMGREN	77	HBC	See AGUILAR 81D
40.0± 3.2		[1] BARDADIN	75	HBC	$K^- p$ 14.3 GeV/c
48 ± 3	3740	[3] BERTHON	74	HBC	$K^- p$ 1263–1843 MeV/c
33 ±20	46	[9] AGUILAR	70B	HBC	$K^- p \to \Sigma\pi$'s 4 GeV/c
25 ±32	62	[9] BIRMINGHAM	66	HBC	$K^- p$ 3.5 GeV/c
30.3± 7.5	250	[9] SMITH	65	HBC	$K^- p$ 1.8 GeV/c
33.1± 8.3	250	[9] SMITH	65	HBC	$K^- p$ 1.95 GeV/c
51 ±16	170	[9] COOPER	64	HBC	$K^- p$ 1.45 GeV/c
48 ±16	154	[9] ELY	61	HLBC	$K^- p$ 1.11 GeV/c

Σ(1385)⁰ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
36 ± 5	**OUR AVERAGE**				
34.8± 5.6	5722	AGUILAR-	81D	HBC	$K^- p \to \Lambda 3\pi$ 4.2 GeV/c
39.3±10.2	240	[9] THOMAS	73	HBC	$\pi^- p \to \Lambda\pi^0 K^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
53 ± 8	3100	[10] BORENSTEIN	74	HBC	$K^- p \to \Lambda 3\pi$ 2.18 GeV/c
30 ± 9	106	CURTIS	63	OSPK	$\pi^- p$ 1.5 GeV/c

Σ(1385)⁻ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
39.4± 2.1	**OUR AVERAGE**	Error includes scale factor of 1.7. See the ideogram below.			
38.4±10.7	620	AGUILAR	81D	HBC	$K^- p \to \Lambda\pi\pi$ 4.2 GeV/c
34.6± 4.2	3346	AGUILAR	81D	HBC	$K^- p \to \Lambda 3\pi$ 4.2 GeV/c
39.2± 1.7	9720	CAMERON	78	HBC	$K^- p$ 0.96–1.36 GeV/c
35 ± 3	2303	[8] BORENSTEIN	74	HBC	$K^- p$ 2.18 GeV/c
51.9± 4.8	1900	[9] HABIBI	73	HBC	$K^- p \to \Lambda\pi\pi$
48.2± 7.7	630	[9] THOMAS	73	HBC	$\pi^- p \to \Lambda\pi^- K^+$
31.0± 6.5	370	[9] SIEGEL	67	HBC	$K^- p$ 2.1 GeV/c
38.0± 4.1	1382	[9] ARMENTEROS	65B	HBC	$K^- p$ 0.95–1.20 GeV/c
62 ± 7	1086	HUWE	64	HBC	$K^- p$ 1.15–1.30 GeV/c
• • • We do not use the following data for averages, fits, limits, etc. • • •					
44 ± 4	4.5k	[1] BAUBILLIER	79B	HBC	$K^- p$ 8.25 GeV/c
58 ± 4	150	[1] SUGAHARA	79B	HBC	$\pi^- p$ 6 GeV/c
45 ± 5	12k	[1,2] BARREIRO	77B	HBC	$K^- p$ 4.2 GeV/c
35 ±10	193	HOLMGREN	77	HBC	See AGUILAR 81D
47 ± 6		[1] BARDADIN	75	HBC	$K^- p$ 14.3 GeV/c
40 ± 3	3060	[3] BERTHON	74	HBC	$K^- p$ 1263–1843 MeV/c
29.2±10.6	120	[9] SMITH	65	HBC	$K^- p$ 1.80 GeV/c
17.1± 8.9	58	[9] SMITH	65	HBC	$K^- p$ 1.95 GeV/c
88 ±24	200	[9] COOPER	64	HBC	$K^- p$ 1.45 GeV/c
40		DAHL	61	DBC	$K^- d$ 0.45 GeV/c
66 ±18	224	[9] ELY	61	HLBC	$K^- p$ 1.11 GeV/c



Σ(1385) POLE POSITIONS

Σ(1385)⁺ REAL PART

VALUE	DOCUMENT ID		COMMENT
1379 ± 1	LICHTENBERG	74	Extrapolates HABIBI 73

Σ(1385)⁺ −IMAGINARY PART

VALUE	DOCUMENT ID		COMMENT
17.5 ± 1.5	LICHTENBERG	74	Extrapolates HABIBI 73

Σ(1385)⁻ REAL PART

VALUE	DOCUMENT ID		COMMENT
1383 ± 1	LICHTENBERG	74	Extrapolates HABIBI 73

Σ(1385)⁻ — IMAGINARY PART

VALUE	DOCUMENT ID		COMMENT
22.5 ± 1.5	LICHTENBERG	74	Extrapolates HABIBI 73

Σ(1385) DECAY MODES

Γ_1 Σ(1385) → $\Lambda\pi$
Γ_2 Σ(1385) → $\Sigma\pi$
Γ_3 Σ(1385) → $\Lambda\gamma$
Γ_4 Σ(1385) → $\Sigma\gamma$
Γ_5 Σ(1385) → NK

Σ(1385) BRANCHING RATIOS

$\Gamma(\Sigma\pi)/\Gamma(\Lambda\pi)$ — Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.135 ± 0.011 OUR AVERAGE					
0.20 ± 0.06	DIONISI	78B	HBC	±	$K^-p \to Y^*KK$
0.16 ± 0.03	BERTHON	74	HBC	+	K^-p 1.26–1.84 GeV/c
0.11 ± 0.02	BERTHON	74	HBC	−	K^-p 1.26–1.84 GeV/c
0.21 ± 0.05	BORENSTEIN	74	HBC	+	$K^-p \to \Lambda\pi^+\pi^-$, $\Sigma^0\pi^+\pi^-$
0.18 ± 0.04	MAST	73	MPWA	±	$K^-p \to \Lambda\pi^+\pi^-$, $\Sigma^0\pi^+\pi^-$
0.10 ± 0.05	THOMAS	73	HBC	−	$\pi^-p \to \Lambda K\pi$, $\Sigma K\pi$
0.16 ± 0.07	AGUILAR-	72B	HBC	+	K^-p 3.9, 4.6 GeV/c
0.13 ± 0.04	COLLEY	71B	DBC	−0	K^-N 1.5 GeV/c
0.13 ± 0.04	PAN	69	HBC	+	$\pi^+p \to \Lambda K\pi$, $\Sigma K\pi$
0.08 ± 0.06	LONDON	66	HBC	+	K^-p 2.24 GeV/c
0.163 ± 0.041	ARMENTEROS	65B	HBC	±	K^-p 0.95–1.20 GeV/c
0.09 ± 0.04	HUWE	64	HBC	±	K^-p 1.2–1.7 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.04	ALSTON	62	HBC	±0	K^-p 1.15 GeV/c
0.04 ± 0.04	BASTIEN	61	HBC	±	

$\Gamma(\Lambda\gamma)/\Gamma_{total}$ — Γ_3/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.17 ± 0.17	1	MEISNER	72	HBC	1 event only

$\Gamma(\Lambda\gamma)/\Gamma(\Lambda\pi)$ — Γ_3/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.06	90	COLAS	75	HLBC	K^-p 575–970 MeV

$\Gamma(\Sigma\gamma)/\Gamma(\Lambda\pi)$ — Γ_4/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.05	90	COLAS	75	HLBC	K^-p 575–970 MeV

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to$ Σ(1385) $\to \Lambda\pi$ — $(\Gamma_5\Gamma_1)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		CHG	COMMENT
+0.586 ± 0.319	[11] DEVENISH	74B	0	Fixed-t dispersion rel

Σ(1385) FOOTNOTES

[1] From fit to inclusive $\Lambda\pi$ spectrum
[2] Includes data of HOLMGREN 77
[3] The errors are statistical only. The resolution is not unfolded
[4] The error is enlarged to $\Gamma/N^{1/2}$. See the note on the $K^*(892)$ mass in the 1984 edition
[5] From a fit to $\Lambda\pi^0$ with the width fixed at 34 MeV
[6] From fit to inclusive $\Lambda\pi^0$ spectrum with the width fixed at 40 MeV
[7] Redundant with data in the mass Listings
[8] Results from $\Lambda\pi^+\pi^-$ and $\Lambda\pi^+\pi^-\pi^0$ combined by us
[9] The error is enlarged to $4\Gamma/N^{1/2}$. See the note on the $K^*(892)$ mass in the 1984 edition
[10] Consistent with +, 0 and − widths equal
[11] An extrapolation of the parametrized amplitude below threshold

Σ(1385) REFERENCES

BAUBILLIER	84	ZPHY C23 213	+	(BIRM, CERN, GLAS, MSU, LPNP)
AGUILAR	81D	AFIS A77 144	Aguilar-Benitez, Salicio	(MADR)
BAKER	80	NP B166 207	+Chima, Dornan, Gibbs, Hall, Miller+	(LOIC)
BAUBILLIER	79B	NP B148 18	+	(BIRM, CERN, GLAS, MSU, LPNP)
CAUTIS	79	NP B156 507	+Ballam, Bouchez, Carroll, Chadwick+	(SLAC)
SUGAHARA	79B	NP B156 237	+Ochiai, Fukui, Cooper+	(KEK, OSKC, KINK)
CAMERON	78	NP B143 189	+Franek, Gopal, Bacon, Butterworth+	(RHEL, LOIC)
DIONISI	78B	PL 78B 154	+Armenteros, Diaz	(CERN, AMST, NIJM, OXF)
BARREIRO	77B	NP B126 319	+Berge, Ganguli, Blokzijl+	(CERN, AMST, NIJM)
HOLMGREN	77	NP B119 261	+Aguilar-Benitez, Kluyver+	(CERN, AMST, NIJM)
BARDADIN	75	NP B98 418	Bardadin-Otwinowska+	(SACL, EPOL, RHEL)
COLAS	75	NP B91 253	+Farwell, Ferrer, Six	(ORSA)
BERTHON	74	NC 21A 146	+Tristram+	(CDEF, RHEL, SACL, STRB)
BORENSTEIN	74	PR D9 3006	+Kalbfleisch, Strand+	(BNL, MICH)
DEVENISH	74B	NP B81 330	+Froggatt, Martin	(DESY, NORD, LOUC)
LICHTENBERG	74	PR D10 3865		(IND)
Also	74B	Private Comm	Lichtenberg	(IND)
HABIBI	73	Nevis 199 Thesis		(COLU)
Also	73	Purdue Conf 387	Baltay, Bridgewater, Cooper+	(COLU, BING)
MAST	73	PR D7 3212	+Bangerter, Alston-Garnjost+	(LBL) IJF
Also	73B	PR D7 5	Mast, Bangerter, Alston-Garnjost+	(LBL) IJF
THOMAS	73	NP B56 15	+Engler, Fisk, Kraemer	(CMU) JP
AGUILAR	72B	PR D6 29	Aguilar-Benitez, Chung, Eisner, Samios	(BNL)
MEISNER	72	NC 12A 62		(UNC, LBL)
COLLEY	71B	NP B31 61	+Cox, Eastwood, Fry+	(BIRM, EDIN, GLAS, LOIC)
AGUILAR	70B	PRL 25 58	Aguilar-Benitez, Barnes, Bassano+	(BNL, SYRA)
PAN	69	PRL 23 808	+Forman	(PENN) I
SIEGEL	67	UCRL 18041 Thesis		(LRL)
BIRMINGHAM	66	PR 152 1148		(BIRM, GLAS, LOIC, OXF, RHEL)
LONDON	66	PR 143 1034	+Rau, Goldberg, Lichtman+	(BNL, SYRA) J
ARMENTEROS	65B	PL 19 75	+	(CERN, HEID, SACL)
SMITH	65	UCLA Thesis		(UCLA)
COOPER	64	PL 8 365	+Filthuth, Fridman, Malamud+	(CERN, AMST)
HUWE	64	UCRL 11291 Thesis		(LRL) JP
Also	69	PR 180 1824	Huwe	(LRL)
CURTIS	63	PR 132 1771	+Coffin, Meyer, Terwilliger	(MICH) J
ALSTON	62	CERN Conf 311	+Alvarez, Ferro-Luzzi+	(LRL)
BASTIEN	61	PRL 6 702	+Ferro-Luzzi, Rosenfeld	(LRL)
DAHL	61	PRL 6 142	+Horwitz, Miller, Murray, White	(LRL)
ELY	61	PRL 7 461	+Fung, Gidal, Pan, Powell, White	(LRL) J
ALSTON	60	PRL 5 520	+Alvarez, Eberhard, Good, Graziano+	(LRL) I

Σ(1480) BUMPS

$I(J^P) = 1(?^?)$ Status: *

OMITTED FROM SUMMARY TABLE

These are peaks seen in $\Lambda\pi$ and $\Sigma\pi$ spectra in the reaction $\pi^+p \to (Y\pi)K^+$ at 1.7 GeV/c. Also, the Y polarization oscillates in the same region.

MILLER 70 suggests a possible alternate explanation in terms of a reflection of $N(1675) \to \Lambda K$ decay. However, such an explanation for the $(\Sigma^+\pi^0)K^+$ channel in terms of $\Delta(1650) \to \Sigma K$ decay seems unlikely (see PAN 70). In addition such reflections would also have to account for the oscillation of the Y polarization in the 1480 MeV region.

HANSON 71, with less data than PAN 70, can neither confirm nor deny the existence of this state. MAST 75 sees no structure in this region in $K^-p \to \Lambda\pi^0$.

ENGELEN 80 performs a multichannel analysis of $K^-p \to pK^0\pi^-$ at 4.2 GeV/c. They observe a 3.5 standard-deviation signal at 1480 MeV in pK^0 which cannot be explained as a reflection of any competing channel.

Σ(1480) MASS (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1480	120	ENGELEN	80	HBC	+	$K^-p \to (pK^0)\pi^-$
1485 ± 10		CLINE	73	MPWA	−	$K^-d \to (\Lambda\pi^-)p$
1479 ± 10		PAN	70	HBC	+	$\pi^+p \to (\Lambda\pi^+)K^+$
1465 ± 15		PAN	70	HBC	+	$\pi^+p \to (\Sigma\pi)K^+$

Σ(1480) WIDTH (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
80 ± 20	120	ENGELEN	80	HBC	+	$K^- p \to (pK^0)\pi^-$
40 ± 20		CLINE	73	MPWA	−	$K^- d \to (\Lambda\pi^-)p$
31 ± 15		PAN	70	HBC	+	$\pi^+ p \to (\Lambda\pi^+)K^+$
30 ± 20		PAN	70	HBC	+	$\pi^+ p \to (\Sigma\pi)K^+$

Σ(1480) DECAY MODES (PRODUCTION EXPERIMENTS)

Γ_1 Σ(1480) → $N\bar{K}$
Γ_2 Σ(1480) → $\Lambda\pi$
Γ_3 Σ(1480) → $\Sigma\pi$

Σ(1480) BRANCHING RATIOS (PRODUCTION EXPERIMENTS)

$\Gamma(\Sigma\pi)/\Gamma(\Lambda\pi)$ — Γ_3/Γ_2

VALUE	DOCUMENT ID		TECN	CHG
0 82 ± 0 51	PAN	70	HBC	+

$\Gamma(N\bar{K})/\Gamma(\Lambda\pi)$ — Γ_1/Γ_2

VALUE	DOCUMENT ID		TECN	CHG
0 72 ± 0 50	PAN	70	HBC	+

$\Gamma(N\bar{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
SMALL	CLINE	73	MPWA	$K^- d \to (\Lambda\pi^-)p$

Σ(1480) REFERENCES (PRODUCTION EXPERIMENTS)

ENGELEN	80	NP B167 61	+Jongejans Dionisi+	(NIJM AMST CERN OXF)
MAST	75	PR D11 3078	+Alston Garnjost Bangerter+	(LBL)
CLINE	73	LNC 6 205	+Laumann Mapp	(WISC) IJP
HANSON	71	PR D4 1296	+Kalmus Loule	(LBL) I
MILLER	70	Duke Conf 229		(PURD)
PAN	70	PR D2 49	+Forman Ko Hagopian Selove	(PENN)
Also	69	PRL 23 808	Pan Forman	(PENN) I
Also	69B	PRL 23 806	Pan Forman	(PENN) I

Σ(1560) BUMPS

$I(J^P) = 1(?^?)$ Status * *

OMITTED FROM SUMMARY TABLE

This entry lists peaks reported in mass spectra around 1560 MeV without implying that they are necessarily related

DIONISI 78B observes a 6 standard-deviation enhancement at 1553 MeV in the charged $\Lambda/\Sigma\pi$ mass spectra from $K^- p \to (\Lambda/\Sigma)\pi K\bar{K}$ at 4 2 GeV/c in a CERN ISR experiment. LOCKMAN 78 reports a narrow 6 standard-deviation enhancement at 1572 MeV in $\Lambda\pi^\pm$ from the reaction $pp \to \Lambda\pi^+\pi^- X$ These enhancements are unlikely to be associated with the Σ(1580) (which has not been confirmed by several recent experiments -- see the next entry in the Listings)

CARROLL 76 observes a bump at 1550 MeV (as well as one at 1580 MeV) in the isospin-1 $\bar{K}N$ total cross section, but uncertainties in cross section measurements outside the mass range of the experiment preclude estimating its significance

See also MEADOWS 80 for a review of this state

Σ(1560) MASS (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1553 ± 7	121	DIONISI	78B	HBC	±	$K^- p \to (Y\pi)K\bar{K}$
1572 ± 4	40	LOCKMAN	78	SPEC	±	$pp \to \Lambda\pi^+\pi^- X$

Σ(1560) WIDTH (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
79 ± 30	121	DIONISI	78B	HBC	±	$K^- p \to (Y\pi)K\bar{K}$
15 ± 6	40	[1] LOCKMAN	78	SPEC	±	$pp \to \Lambda\pi^+\pi^- X$

Σ(1560) DECAY MODES (PRODUCTION EXPERIMENTS)

Γ_1 Σ(1560) → $\Lambda\pi$
Γ_2 Σ(1560) → $\Sigma\pi$

Σ(1560) BRANCHING RATIOS (PRODUCTION EXPERIMENTS)

$\Gamma(\Sigma\pi)/[\Gamma(\Lambda\pi)+\Gamma(\Sigma\pi)]$ — $\Gamma_2/(\Gamma_1+\Gamma_2)$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0 35 ± 0 12	DIONISI	78B	HBC	±	$K^- p \to (Y\pi)K\bar{K}$

$\Gamma(\Lambda\pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
SEEN	LOCKMAN	78	SPEC	±	$pp \to \Lambda\pi^+\pi^- X$

Σ(1560) FOOTNOTES (PRODUCTION EXPERIMENTS)

[1] The width observed by LOCKMAN 78 is consistent with experimental resolution

Σ(1560) REFERENCES (PRODUCTION EXPERIMENTS)

MEADOWS	80	Toronto Conf 283		(CINC)
DIONISI	78B	PL 78B 154	+Armenteros Diaz	(CERN AMST NIJM OXF) I
LOCKMAN	78	CEN DPHPE 78 01	+Meyer Rander Poster Schlein+	(UCLA SACL)
CARROLL	76	PRL 37 806	+Chiang Kycia Li Mazur Michael+	(BNL) I

Σ(1580) D_{13}

$I(J^P) = 1(\frac{3}{2}^-)$ Status * *

OMITTED FROM SUMMARY TABLE

Seen in the isospin-1 $\bar{K}N$ cross section at BNL (LI 73, CARROLL 76) and in a partial-wave analysis of $K^- p \to \Lambda\pi^0$ for c m energies 1560–1600 MeV by LITCHFIELD 74 LITCHFIELD 74 finds $J^P = 3/2^-$ Not seen by ENGLER 78 or by CAMERON 78C (with larger statistics in $K^0_L p \to \Lambda\pi^+$ and $\Sigma^0\pi^+$)

Σ(1580) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1583 ± 4	[1] CARROLL	76	DPWA	Isospin 1 total σ
1582 ± 4	[2] LITCHFIELD	74	DPWA	$K^- p \to \Lambda\pi^0$

Σ(1580) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
15	[1] CARROLL	76	DPWA	Isospin-1 total σ
11 ± 4	[2] LITCHFIELD	74	DPWA	$K^- p \to \Lambda\pi^0$

Baryon Full Listings
Σ(1580), Σ(1620)

Σ(1580) DECAY MODES

Γ_1 $\Sigma(1580) \to N\overline{K}$
Γ_2 $\Sigma(1580) \to \Lambda\pi$
Γ_3 $\Sigma(1580) \to \Sigma\pi$

Σ(1580) BRANCHING RATIOS

See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(N\overline{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
+0 03 ± 0.01	[2] LITCHFIELD	74	DPWA	$\overline{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Sigma(1580) \to \Lambda\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
NOT SEEN	CAMERON	78C	HBC	$K^0_L p \to \Lambda\pi^+$
NOT SEEN	ENGLER	78	HBC	$K^0_L p \to \Lambda\pi^+$
+0 10 ± 0 02	[2] LITCHFIELD	74	DPWA	$K^- p \to \Lambda\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Sigma(1580) \to \Sigma\pi$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
NOT SEEN	CAMERON	78C	HBC	$K^0_L p \to \Sigma^0\pi^+$
NOT SEEN	ENGLER	78	HBC	$K^0_L p \to \Sigma^0\pi^+$
+0 03 ± 0.04	[2] LITCHFIELD	74	DPWA	$\overline{K}N$ multichannel

Σ(1580) FOOTNOTES

[1] CARROLL 76 sees a total-cross-section bump with $(J+1/2)$ Γ_{el} / Γ_{total} = 0 06

[2] The main effect observed by LITCHFIELD 74 is in the $\Lambda\pi$ final state, the $\overline{K}N$ and $\Sigma\pi$ couplings are estimated from a multichannel fit including total cross section data of LI 73

Σ(1580) REFERENCES

CAMERON 78C NP B132 189 +Capiluppi+ (BGNA EDIN GLAS PISA RHEL) I
ENGLER 78 PR D18 3061 +Keyes Kraemer Tanaka Cho+ (CMU ANL)
CARROLL 76 PRL 37 806 +Chiang Kycia Li Mazur Michael+ (BNL) I
LITCHFIELD 74 PL 51B 509 (CERN) IJP
LI 73 Purdue Conf 283 (BNL) I

OTHER RELATED PAPERS

ENGLER 76 PL 63B 231 +Keyes Kraemer Schiereth Tanaka+ (CMU ANL) I

Σ(1620) S_{11}

$I(J^P) = 1(\frac{1}{2}^-)$ Status * *

OMITTED FROM SUMMARY TABLE

The S_{11} state at 1697 MeV reported by VANHORN 75 is tentatively listed under the Σ(1750) CARROLL 76 sees two bumps in the isospin-1 total cross section near this mass

Production experiments are listed separately in the next entry

Σ(1620) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1600 ± 6	[1] MORRIS	78	DPWA	$K^- n \to \Lambda\pi^-$
1608 ± 5	[2] CARROLL	76	DPWA	Isospin 1 total σ
1633 ± 10	[3] CARROLL	76	DPWA	Isospin 1 total σ
1630 ± 10	LANGBEIN	72	IPWA	$\overline{K}N$ multichannel
1620	KIM	71	DPWA	K matrix analysis

Σ(1620) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
87 ± 19	[1] MORRIS	78	DPWA	$K^- n \to \Lambda\pi^-$
15	[2] CARROLL	76	DPWA	Isospin-1 total σ
10	[3] CARROLL	76	DPWA	Isospin-1 total σ
65 ± 20	LANGBEIN	72	IPWA	$\overline{K}N$ multichannel
40	KIM	71	DPWA	K-matrix analysis

Σ(1620) DECAY MODES

Γ_1 $\Sigma(1620) \to N\overline{K}$
Γ_2 $\Sigma(1620) \to \Lambda\pi$
Γ_3 $\Sigma(1620) \to \Sigma\pi$

Σ(1620) BRANCHING RATIOS

$\Gamma(N\overline{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.22 ± 0 02	LANGBEIN	72	IPWA	$\overline{K}N$ multichannel
0 05	KIM	71	DPWA	K-matrix analysis

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Sigma(1620) \to \Lambda\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.12 ± 0 02	[1] MORRIS	78	DPWA	$K^- n \to \Lambda\pi^-$
NOT SEEN	BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$
0 15	KIM	71	DPWA	K matrix analysis

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Sigma(1620) \to \Sigma\pi$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
NOT SEEN	HEPP	76B	DPWA	$K^- N \to \Sigma\pi$
0 40 ± 0 06	LANGBEIN	72	IPWA	$\overline{K}N$ multichannel
0 08	KIM	71	DPWA	K-matrix analysis

Σ(1620) FOOTNOTES

[1] MORRIS 78 obtains an equally good fit without including this resonance

[2] Total cross section bump with $(J+1/2)$ Γ_{el} / Γ_{total} is 0 06 seen by CARROLL 76

[3] Total cross-section bump with $(J+1/2)$ Γ_{el} / Γ_{total} is 0 04 seen by CARROLL 76

Σ(1620) REFERENCES

MORRIS 78 PR D17 55 +Albright Colleraine Kimel Lannutti (FSU) IJP
CARROLL 76 PRL 37 806 +Chiang Kycia Li Mazur Michael+ (BNL) I
HEPP 76B PL 65B 487 +Braun Grimm Strobele+ (CERN HEID MPIM) IJP
BAILLON 75 NP B94 39 +Litchfield (CERN RHEL) IJP
VANHORN 75 NP B87 145 (LBL) IJP
Also 75B NP B87 157 VanHorn (LBL) IJP
LANGBEIN 72 NP B47 477 +Wagner (MPIM) IJP
KIM 71 PRL 27 356 (HARV) IJP
Also 70 Duke Conf 161 Kim (HARV) IJP

Σ(1620) PRODUCTION EXPERIMENTS

$I(J^P) = 1(?^?)$

Formation experiments are listed separately in the previous entry

The results of CRENNELL 69B at 3 9 GeV/c are not confirmed by SABRE 70 at 3 0 GeV/c However, at 4 5 GeV/c, AMMANN 70 sees a peak at 1642 MeV which on the basis of branching ratios they do not associate with the Σ(1670) See MILLER 70 for a review of these conflicts

Σ(1620) MASS (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1642 ± 12		AMMANN	70	DBC		$K^- N$ 4 5 GeV/c
1618 ± 3	20	BLUMENFELD	69	HBC	+	$K^0_L p$
1619 ± 8		CRENNELL	69B	DBC	±	$K^- N \to \Lambda\pi\pi\pi$
• • • We do not use the following data for averages fits limits etc • • •						
1616 ± 8		CRENNELL	68	DBC	±	See CRENNELL 69B

Σ(1620) WIDTH (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
55 ± 24		AMMANN	70	DBC		$K^- N$ 4 5 GeV/c
30 ± 10	20	BLUMENFELD	69	HBC	+	
72^{+22}_{-15}		CRENNELL	69B	DBC	±	

• • • We do not use the following data for averages, fits limits etc • • •

66 ± 16	CRENNELL	68	DBC	± See CRENNELL 69B

Σ(1620) DECAY MODES (PRODUCTION EXPERIMENTS)

Γ_1 Σ(1620) → $N\bar{K}$
Γ_2 Σ(1620) → $\Lambda\pi$
Γ_3 Σ(1620) → $\Sigma\pi$
Γ_4 Σ(1620) → $\Lambda\pi\pi$
Γ_5 Σ(1620) → Σ(1385)π
Γ_6 Σ(1620) → Λ(1405)π

Σ(1620) BRANCHING RATIOS (PRODUCTION EXPERIMENTS)

$\Gamma(\Lambda\pi\pi)/\Gamma(\Lambda\pi)$ Γ_4/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	CHG
~2.5	14	BLUMENFELD	69	HBC	+

$\Gamma(N\bar{K})/\Gamma(\Lambda\pi)$ Γ_1/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.4 ± 0 4	AMMANN	70	DBC		K^-p 4 5 GeV/c
0 0 ± 0.1	CRENNELL	68	DBC	+	See CRENNELL 69B

$\Gamma(\Lambda\pi)/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	CHG
LARGE	CRENNELL	68	DBC	±

$\Gamma(\Sigma(1385)\pi)/\Gamma(\Lambda\pi)$ Γ_5/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0 3	95	AMMANN	70	DBC		K^-p 4 5 GeV/c
0.2 ± 0.1		CRENNELL	68	DBC	±	

$\Gamma(\Sigma\pi)/\Gamma(\Lambda\pi)$ Γ_3/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<1.1	95	AMMANN	70	DBC	K^-N 4 5 GeV/c

$\Gamma(\Lambda(1405)\pi)/\Gamma(\Lambda\pi)$ Γ_6/Γ_2

VALUE	DOCUMENT ID		TECN	COMMENT
0 7 ± 0 4	AMMANN	70	DBC	K^-p 4 5 GeV/c

Σ(1620) REFERENCES (PRODUCTION EXPERIMENTS)

AMMANN	70	PRL 24 327	+Garfinkel Carmony Gutay+	(PURD IND)
Also	73	PR D7 1345	Ammann Carmony Garfinkel+	(PURD IUPU)
MILLER	70	Duke Conf 229		(PURD)
SABRE	70	NP B16 201	Barloutaud Merrill Schever+	(SABRE Collab)
BLUMENFELD	69	PL 29B 58	+Kalbfleisch	(BNL) I
CRENNELL	69B	Lund Paper 183	+Karshon Lai O Neill Scarr+	(BNL CUNY) I
Results are quoted in LEVI SETTI 69C				
Also	69C	Lund Conf	Levi Setti	(EFI)
CRENNELL	68	PRL 21 648	+Delaney Flaminio Karshon+	(BNL CUNY) I

Σ(1660) P_{11}

$I(J^P) = 1(\frac{1}{2}^+)$ Status * * *

For results published before 1974 (they are now obsolete), see our 1982 edition (Physics Letters 111B)

Σ(1660) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1630 to 1690 OUR ESTIMATE				
1665 1 ± 11 2	[1] KOISO	85	DPWA	$K^-p \to \Sigma\pi$
1670 ± 10	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
1679 ± 10	ALSTON-	78	DPWA	$\bar{K}N \to \bar{K}N$
1676 ± 15	GOPAL	77	DPWA	$\bar{K}N$ multichannel
1668 ± 25	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
1670 ± 20	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
1565 or 1597	[2] MARTIN	77	DPWA	$\bar{K}N$ multichannel
1660 ± 30	[3] BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
1671 ± 2	[4] PONTE	75	DPWA	$K^-p \to \Lambda\pi^0$

Σ(1660) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
40 to 200 OUR ESTIMATE				
81.5 ± 22 2	[1] KOISO	85	DPWA	$K^-p \to \Sigma\pi$
152 ± 20	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
38 ± 10	ALSTON	78	DPWA	$\bar{K}N \to \bar{K}N$
120 ± 20	GOPAL	77	DPWA	$\bar{K}N$ multichannel
230 $^{+165}_{-60}$	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
250 ± 110	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits, etc • • •				
202 or 217	[2] MARTIN	77	DPWA	$\bar{K}N$ multichannel
80 ± 40	[3] BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
81 ± 10	[4] PONTE	75	DPWA	$K^-p \to \Lambda\pi^0$

Σ(1660) DECAY MODES

Γ_1 Σ(1660) → $N\bar{K}$
Γ_2 Σ(1660) → $\Lambda\pi$
Γ_3 Σ(1660) → $\Sigma\pi$

Σ(1660) BRANCHING RATIOS

See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.1 to 0.3 OUR ESTIMATE				
0.12 ± 0 03	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
0 10 ± 0.05	ALSTON-	78	DPWA	$\bar{K}N \to \bar{K}N$
• • • We do not use the following data for averages fits limits, etc • • •				
<0 04	GOPAL	77	DPWA	See GOPAL 80
0 27 or 0 29	[2] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to$ Σ(1660) $\to \Lambda\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
< 0 04	GOPAL	77	DPWA	$\bar{K}N$ multichannel
0 12 $^{+0\ 12}_{-0\ 04}$	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
• • • We do not use the following data for averages fits, limits etc • • •				
−0 10 or −0 11	[2] MARTIN	77	DPWA	$\bar{K}N$ multichannel
−0.04 ± 0 02	[3] BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
+0.16 ± 0 01	[4] PONTE	75	DPWA	$K^-p \to \Lambda\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to$ Σ(1660) $\to \Sigma\pi$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 13 ± 0 04	[1] KOISO	85	DPWA	$K^-p \to \Sigma\pi$
−0 16 ± 0 03	GOPAL	77	DPWA	$\bar{K}N$ multichannel
−0 11 ± 0 01	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
−0 34 or −0.37	[2] MARTIN	77	DPWA	$\bar{K}N$ multichannel
NOT SEEN	HEPP	76B	DPWA	$K^-N \to \Sigma\pi$

Σ(1660) FOOTNOTES

[1] The evidence of KOISO 85 is weak
[2] The two MARTIN 77 values are from a T-matrix pole and from a Breit Wigner fit
[3] From solution 1 of BAILLON 75 not present in solution 2
[4] From solution 2 of PONTE 75 not present in solution 1

Σ(1660) REFERENCES

KOISO	85	NP A433 619	+Sai Yamamoto Kofler	(TOKY MASA)
GOPAL	80	Toronto Conf 159		(RHEL) IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
HEPP	76B	PL 65B 487	+Braun Grimm Strobele+	(CERN HEID MPIM) IJP
BAILLON	75	NP B94 39	+Litchfield	(CERN RHEL) IJP
PONTE	75	PR D12 2597	+Hertzbach Button Shafer+	(MASA TENN UCR) IJP
VANHORN	75	NP B87 145		(LBL) IJP
Also	75B	NP B87 157	VanHorn	(LBL) IJP
KANE	74	LBL 2452		(LBL) IJP

Baryon Full Listings
Σ(1670)

NOTE ON THE Σ(1670) REGION

Production experiments The measured $\Sigma\pi/\Sigma\pi\pi$ branching ratio for produced Σ(1670)'s is strongly dependent on momentum transfer This was first discovered by EBERHARD 69, who suggested that there exist two Σ resonances with the same mass and quantum numbers one with a large $\Sigma\pi\pi$ [mainly $\Lambda(1405)\pi$] decay mode produced peripherally, and the other with a large $\Sigma\pi$ decay mode produced at larger angles These results were confirmed by AGUILAR-BENITEZ 70, ASPELL 74, ESTES 74, and TIMMERMANS 76 The most likely quantum numbers for both the $\Sigma\pi$ and the $\Lambda(1405)\pi$ states are D_{13} There is also possibly a third Σ, the Σ(1690) in the Listings, the main evidence for which is a large $\Lambda\pi/\Sigma\pi$ branching ratio These topics have been reviewed by EBERHARD 73 and by MILLER 70

Formation experiments Two states are also observed near this mass in formation experiments One of these, the Σ(1670) D_{13}, has the same quantum numbers as those observed in production and has a large $\Sigma\pi/\Sigma\pi\pi$ branching ratio, it may well be the Σ(1670) produced at larger angles (see TIMMERMANS 76) The other state, the Σ(1660) P_{11}, has different quantum numbers from those seen in production, and its $\Sigma\pi/\Sigma\pi\pi$ branching ratio is unknown Thus its relation to the produced Σ(1670)'s is obscure

Σ(1670) D_{13}

$I(J^P) = 1(\frac{3}{2}^-)$ Status ∗ ∗ ∗ ∗

For most results published before 1974 (they are now obsolete), see our 1982 edition (Physics Letters **111B**)

Results from production experiments are listed separately in the next entry

Σ(1670) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1665 to 1685 OUR ESTIMATE				
1665 1 ± 4 1	KOISO	85	DPWA	$K^-p \to \Sigma\pi$
1682 ± 5	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
1679 ± 10	ALSTON-	78	DPWA	$\bar{K}N \to \bar{K}N$
1670 ± 5	GOPAL	77	DPWA	$\bar{K}N$ multichannel
1670 ± 6	HEPP	76B	DPWA	$K^-N \to \Sigma\pi$
1685 ± 20	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
$1659\ ^{+12}_{-5}$	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
1670 ± 2	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
1667 or 1668	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
1650	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$
1671 ± 3	PONTE	75	DPWA	$K^-p \to \Lambda\pi^0$ (sol 1)
1655 ± 2	PONTE	75	DPWA	$K^-p \to \Lambda\pi^0$ (sol 2)

Σ(1670) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
40 to 80 OUR ESTIMATE				
65.0 ± 7 3	KOISO	85	DPWA	$K^-p \to \Sigma\pi$
79 ± 10	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
56 ± 20	ALSTON	78	DPWA	$\bar{K}N \to \bar{K}N$
50 ± 5	GOPAL	77	DPWA	$\bar{K}N$ multichannel
56 ± 3	HEPP	76B	DPWA	$K^-N \to \Sigma\pi$
85 ± 25	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
32 ± 11	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
79 ± 6	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
46 or 46	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
80	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$
44 ± 11	PONTE	75	DPWA	$K^-p \to \Lambda\pi^0$ (sol 1)
76 ± 5	PONTE	75	DPWA	$K^-p \to \Lambda\pi^0$ (sol 2)

Σ(1670) DECAY MODES

Γ_1	Σ(1670) → $N\bar{K}$
Γ_2	Σ(1670) → $\Lambda\pi$
Γ_3	Σ(1670) → $\Sigma\pi$
Γ_4	Σ(1670) → $\Lambda\pi\pi$
Γ_5	Σ(1670) → $\Sigma\pi\pi$
Γ_6	Σ(1670) → Σ(1385)π
Γ_7	Σ(1670) → Σ(1385)π, S-wave
Γ_8	Σ(1670) → Λ(1405)π
Γ_9	Σ(1670) → Λ(1520)π

Σ(1670) BRANCHING RATIOS

See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.07 to 0.13 OUR ESTIMATE				
0 10 ± 0 03	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
0 11 ± 0 03	ALSTON-	78	DPWA	$\bar{K}N \to \bar{K}N$
• • • We do not use the following data for averages fits limits etc • • •				
0 08 ± 0 03	GOPAL	77	DPWA	See GOPAL 80
0 07 or 0 07	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1670) \to \Lambda\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 17 ± 0 03	[2] MORRIS	78	DPWA	$K^-n \to \Lambda\pi^-$
0 13 ± 0.02	[2] MORRIS	78	DPWA	$K^-n \to \Lambda\pi^-$
+0 10 ± 0 02	GOPAL	77	DPWA	$\bar{K}N$ multichannel
+0 06 ± 0 02	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
+0 09 ± 0 02	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
+0.018 ± 0 060	DEVENISH	74B		Fixed-t dispersion rel
• • • We do not use the following data for averages, fits, limits etc • • •				
+0 08 or +0 08	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
+0 05	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$
0 08 ± 0 01	PONTE	75	DPWA	$K^-p \to \Lambda\pi^0$ (sol 1)
0 17 ± 0 01	PONTE	75	DPWA	$K^-p \to \Lambda\pi^0$ (sol 2)

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1670) \to \Sigma\pi$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.20 ± 0.02	KOISO	85	DPWA	$K^-p \to \Sigma\pi$
+0 21 ± 0 02	GOPAL	77	DPWA	$\bar{K}N$ multichannel
+0.20 ± 0 01	HEPP	76B	DPWA	$K^-N \to \Sigma\pi$
+0 21 ± 0 03	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits, etc • • •				
+0 18 or +0 17	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$\Gamma(\Lambda\pi\pi)/\Gamma_{total}$ Γ_4/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
<0 11	ARMENTEROS68E	HBC	K^-p (Γ_1=0 09)

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1670) \to \Sigma(1385)\pi$, S-wave $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.11 ± 0.03	PREVOST	74	DPWA	$K^-N \to \Sigma(1385)\pi$
• • • We do not use the following data for averages fits limits, etc • • •				
0 17 ± 0 02	[3] SIMS	68	DBC	$K^-N \to \Lambda\pi\pi$

$\Gamma(\Sigma\pi\pi)/\Gamma_{total}$ Γ_5/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits limits etc • • •			
<0 14	[4] ARMENTEROS68E	HBC	K^-p, K^-d (Γ_1=0 09)

$\Gamma(\Lambda(1405)\pi)/\Gamma_{total}$ Γ_8/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits, limits etc • • •			
<0 06	ARMENTEROS68E	HBC	K^-p K^-d (Γ_1=0 09)

$\Gamma_i\Gamma_f/\Gamma^2_{total}$ in $N\bar{K} \to \Sigma(1670) \to \Lambda(1405)\pi$ — $\Gamma_1\Gamma_8/\Gamma^2$

VALUE	DOCUMENT ID		TECN	COMMENT
0.007 ± 0 002	[5] BRUCKER	70	DBC	$K^-N \to \Sigma\pi\pi$
• • • We do not use the following data for averages, fits limits etc • • •				
<0 03	BERLEY	69	HBC	K^-p 0 6–0 82 GeV/c

$\Gamma(\Lambda(1405)\pi)/\Gamma(\Sigma(1385)\pi)$ — Γ_8/Γ_6

VALUE	DOCUMENT ID		TECN	COMMENT
0 23 ± 0 08	BRUCKER	70	DBC	$K^-N \to \Sigma\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $NK \to \Sigma(1670) \to \Lambda(1520)\pi$ — $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 081 ± 0 016	[6] CAMERON	77	DPWA	P wave decay

Σ(1670) FOOTNOTES

[1] The two MARTIN 77 values are from a T matrix pole and from a Breit Wigner fit

[2] Results are with and without an S_{11} Σ(1620) in the fit

[3] SIMS 68 uses only cross section data Result used as upper limit only

[4] Ratio only for Σ2π system in I = 1 which cannot be Σ(1385)

[5] Assuming the Λ(1405)π cross section bump is due only to $3/2^-$ resonance

[6] The CAMERON 77 upper limit on F-wave decay is 0 03

Σ(1670) REFERENCES

KOISO	85	NP A433 619	+Sai Yamamoto Kofler	(TOKY MASA)	
GOPAL	80	Toronto Conf 159		(RHEL)	IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN)	IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN)	IJP
MORRIS	78	PR D17 55	+Albright Colleraine Kimel Lannutti	(FSU)	IJP
CAMERON	77	NP B131 399	+Franek Gopal Kalmus McPherson+	(RHEL LOIC)	IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL)	IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS)	IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)	
Also	77C	NP B126 285	Martin Pidcock	(LOUC)	IJP
DEBELLEFON	76	NP B109 129	De Bellefon Berthon	(CDEF)	IJP
HEPP	76B	PL 65B 487	+Braun Grimm Strobele+	(CERN HEID MPIM)	IJP
BAILLON	75	NP B94 39	+Litchfield	(CERN RHEL)	IJP
PONTE	75	PR D12 2597	+Hertzbach Button Shafer+	(MASA TENN UCR)	IJP
VANHORN	75	NP B87 145		(LBL)	IJP
Also	75B	NP B87 157	VanHorn	(LBL)	IJP
DEVENISH	74B	NP B81 330	+Froggatt Martin	(DESY NORD LOUC)	
KANE	74	LBL 2452		(LBL)	IJP
PREVOST	74	NP B69 246	+Barloutaud+	(SACL CERN HEID)	
BRUCKER	70	Duke Conf 155	+Harrison Sims Albright Chandler+	(FSU)	I
BERLEY	69	PL 30B 430	+Hart Rahm Willis Yamamoto	(BNL)	
ARMENTEROS	68E	PL 28B 521	+Baillon+	(CERN HEID SACL)	I
SIMS	68	PRL 21 1413	+Albright Bartley Meer+	(FSU TUFT BRAN)	

Σ(1670) BUMPS

$I(J^P) = 1(?^?)$

Formation experiments are listed separately in the preceding entry

Probably there are two states at the same mass with the same quantum numbers, one decaying to Σπ and Λπ, the other to Λ(1405)π See the note in front of the preceding entry

Σ(1670) MASS (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1670 ± 4		[1] CARROLL	76	DPWA		Isospin 1 total σ
1675 ± 10		[2] HEPP	76	DBC	−	K^-N 1 6–1 75 GeV/c
1665 ± 1		APSELL	74	HBC		K^-p 2 87 GeV/c
1688 ± 2 or 1683 ± 5	1200	BERTHON	74	HBC	0	Quasi-2 body σ
1670 ± 6		AGUILAR	70B	HBC		$K^-p \to \Sigma\pi\pi$ 4 GeV
1668 ± 10		AGUILAR-	70B	HBC		$K^-p \to \Sigma 3\pi$ 4 GeV
1660 ± 10		ALVAREZ	63	HBC	+	K^-p 1 51 GeV/c
• • • We do not use the following data for averages fits limits etc • • •						
1668 ± 10	150	[3] FERRERSORIA	81	OMEG	−	π^-p 9 12 GeV/c
1655 to 1677		TIMMERMANS	76	HBC	+	K^-p 4 2 GeV/c
1665 ± 5		BUGG	68	CNTR		K^-p d total σ
1661 ± 9	70	PRIMER	68	HBC	+	See BARNES 69E
1685		ALEXANDER	62C	HBC	−0	π^-p 2-2 2 GeV/c

Σ(1670) WIDTH (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
67 0 ± 2 4		APSELL	74	HBC		K^-p 2 87 GeV/c
110 ± 12		AGUILAR	70B	HBC		$K^-p \to \Sigma\pi\pi$ 4 GeV
135 +40 −30		AGUILAR	70B	HBC		$K^-p \to \Sigma 3\pi$ 4 GeV
40 ± 10		ALVAREZ	63	HBC	+	
• • • We do not use the following data for averages, fits, limits etc • • •						
90 ± 20	150	[3] FERRERSORIA	81	OMEG	−	π^-p 9 12 GeV/c
52		[1] CARROLL	76	DPWA		Isospin 1 total σ
48 to 63		TIMMERMANS	76	HBC	+	K^-p 4 2 GeV/c
30 ± 15		BUGG	68	CNTR		
60 ± 20	70	PRIMER	68	HBC	+	See BARNES 69E
45		ALEXANDER	62C	HBC	−0	

Σ(1670) DECAY MODES (PRODUCTION EXPERIMENTS)

Γ_1	$\Sigma(1670) \to N\bar{K}$
Γ_2	$\Sigma(1670) \to \Lambda\pi$
Γ_3	$\Sigma(1670) \to \Sigma\pi$
Γ_4	$\Sigma(1670) \to \Lambda\pi\pi$
Γ_5	$\Sigma(1670) \to \Sigma\pi\pi$
Γ_6	$\Sigma(1670) \to \Sigma(1385)\pi$
Γ_7	$\Sigma(1670) \to \Lambda(1405)\pi$

Σ(1670) BRANCHING RATIOS (PRODUCTION EXPERIMENTS)

$\Gamma(N\bar{K})/\Gamma(\Sigma\pi)$ — Γ_1/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
<0 03		TIMMERMANS	76	HBC	+	K^-p 4 2 GeV/c
<0.10		BERTHON	74	HBC	0	Quasi 2-body σ
<0 2		AGUILAR	70B	HBC		
<0 26		BARNES	69E	HBC	+	K^-p 3 9–5 GeV/c
0 025		BUGG	68	CNTR	0	Assuming J = 3/2
<0 24	0	PRIMER	68	HBC	+	K^-p 4 6–5 GeV/c
<0 6		LONDON	66	HBC	+	K^-p 2 25 GeV/c
<0 19	0	ALVAREZ	63	HBC	+	K^-p 1 15 GeV/c
≥0 5 ± 0 25		SMITH	63	HBC	−0	

$\Gamma(\Lambda\pi)/\Gamma(\Sigma\pi)$ — Γ_2/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0 76 ± 0 09		ESTES	74	HBC	0	K^-p 2 1 2 6 GeV/c
0 45 ± 0 15		BARNES	69E	HBC	+	K^-p 3 9–5 GeV/c
0 15 ± 0 07		HUWE	69	HBC	+	
0 11 ± 0 06	33	BUTTON	68	HBC	+	K^-p 1 7 GeV/c
• • • We do not use the following data for averages fits limits, etc • • •						
≤0 45 ± 0 07		TIMMERMANS	76	HBC	+	K^-p 4 2 GeV/c
0 55 ± 0 11		BERTHON	74	HBC	0	Quasi 2-body σ
0	0	PRIMER	68	HBC	+	See BARNES 69E
<0 6		LONDON	66	HBC	+	K^-p 2 25 GeV/c
1 2	130	ALVAREZ	63	HBC	+	K^-p 1 15 GeV/c
1 2		SMITH	63	HBC	−0	

$\Gamma(\Lambda\pi\pi)/\Gamma(\Sigma\pi)$ — Γ_4/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
<0 6		LONDON	66	HBC	+	K^-p 2 25 GeV/c
0 56	90	ALVAREZ	63	HBC	+	K^-p 1 15 GeV/c
0 17		SMITH	63	HBC	−0	

$\Gamma(\Sigma\pi\pi)/\Gamma(\Sigma\pi)$ — Γ_5/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
LARGEST AT SMALL ANGLES		ESTES	74	HBC	0	K^-p 2 1 2 6 GeV/c
• • • We do not use the following data for averages fits limits etc • • •						
<0 2		[2] HEPP	76	DBC	−	K^-N 1 6–1 75 GeV/c
0 56	180	ALVAREZ	63	HBC	+	K^-p 1 15 GeV/c

$\Gamma(\Lambda(1405)\pi)/\Gamma(\Sigma\pi)$ — Γ_7/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1 8 ± 0 3 to 0.02 ± 0 07		[3,4] TIMMERMANS	76	HBC	+	K^-p 4 2 GeV/c
LARGEST AT SMALL ANGLES		ESTES	74	HBC	±	K^-p 2 1 2 6 GeV/c
3 0 ± 1.6	50	LONDON	66	HBC	+	K^-p 2 25 GeV/c
• • • We do not use the following data for averages fits limits, etc • • •						
0 58 ± 0 20	17	PRIMER	68	HBC	+	See BARNES 69E

$\Gamma(\Sigma\pi)/\Gamma(\Sigma\pi\pi)$ — Γ_3/Γ_5

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
VARIES WITH PROD ANGLE	[5] APSELL	74	HBC	+	K^-p 2 87 GeV/c
1 39 ± 0 16	BERTHON	74	HBC	0	Quasi 2 body σ
2 5 to 0 24	[4] EBERHARD	69	HBC		K^-p 2 6 GeV/c
<0 4	BIRMINGHAM	66	HBC	+	K^-p 3 5 GeV/c
0 30 ± 0 15	LONDON	66	HBC	+	K^-p 2 25 GeV/c

$\Gamma(\Lambda(1405)\pi)/\Gamma(\Sigma\pi\pi)$ — Γ_7/Γ_5

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0 97 ± 0 08	TIMMERMANS	76	HBC		K^-p 4 2 GeV/c
1 00 ± 0 02	APSELL	74	HBC		K^-p 2 87 GeV/c
$0.90^{+0.10}_{-0.16}$	EBERHARD	65	HBC	+	K^-p 2 45 GeV/c

$\Gamma(\Lambda(1405)\pi)/\Gamma(\Sigma(1385)\pi)$ — Γ_7/Γ_6

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
<0 8	EBERHARD	65	HBC	+	K^-p 2 45 GeV/c

$\Gamma(\Lambda\pi\pi)/\Gamma(\Sigma\pi\pi)$ — Γ_4/Γ_5

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0 35 ± 0 2	BIRMINGHAM	66	HBC	+	K^-p 3 5 GeV/c

$\Gamma(\Lambda\pi)/\Gamma(\Sigma\pi\pi)$ — Γ_2/Γ_5

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
<0 2	BIRMINGHAM	66	HBC	+	K^-p 3 5 GeV/c

$\Gamma(\Lambda\pi)/[\Gamma(\Lambda\pi) + \Gamma(\Sigma\pi)]$ — $\Gamma_2/(\Gamma_2+\Gamma_3)$

VALUE	DOCUMENT ID		TECN
<0 6	AGUILAR	70B	HBC

$\Gamma(\Sigma(1385)\pi)/\Gamma(\Sigma\pi)$ — Γ_6/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
≤0 21 ± 0 05	TIMMERMANS	76	HBC	K^-p 4 2 GeV/c

Σ(1670) QUANTUM NUMBERS (PRODUCTION EXPERIMENTS)

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
$J^P = 3/2^-$	400	BUTTON	68	HBC	±	$\Sigma^0\pi$
$J^P = 3/2^-$		EBERHARD	67	HBC	+	Λ(1405)π
$J^P = 3/2^+$		LEVEQUE	65	HBC		Λ(1405)π

Σ(1670) FOOTNOTES

[1] Total cross section bump with $(J+1/2)\ \Gamma_{el}/\Gamma_{total}$ = 0 23
[2] Enhancements in Σπ and Σππ cross sections
[3] Backward production in the $\Lambda\pi^-K^+$ final state
[4] Depending on production angle
[5] APSELL 74, ESTES 74, and TIMMERMANS 76 find strong branching ratio dependence on production angle as in earlier production experiments

Σ(1670) REFERENCES (PRODUCTION EXPERIMENTS)

FERRERSORIA	81	NP B178 373	+Treille Rivet Volte+	(CERN CDEF EPOL LALO)
CARROLL	76	PRL 37 806	+Chiang Kycia Li Mazur Michael+	(BNL) I
HEPP	76	NP B115 82	+Braun Grimm Stroebele+	(CERN HEID MPIM) I
TIMMERMANS	76	NP B112 77	+Engelen+	(NIJM CERN AMST OXF) JP
APSELL	74	PR D10 1419	+Ford Gourevitch+	(BRAN UMD SYRA TUFT) I
BERTHON	74	NC 21A 146	+Tristram+	(CDEF RHEL SACL STRB)
ESTES	74	LBL 3827 Thesis		(LBL)
AGUILAR	70B	PRL 25 58	Aguilar Benitez Barnes Bassano+	(BNL SYRA)
BARNES	69E	BNL 13823	+Chung Eisner Flaminio+	(BNL SYRA)
EBERHARD	69	PRL 22 200	+Friedman Pripstein Ross	(LRL)
HUWE	69	PR 180 1824		(LRL)
BUGG	68	PR 168 1466	+Gilmore Knight+	(RHEL BIRM CAVE) I
BUTTON	68	PRL 21 1123	Button-Shafer	(MASA LRL) JP
PRIMER	68	PRL 20 610	+Goldberg Jaeger Barnes Dornan+	(SYRA BNL)
EBERHARD	67	PR 163 1446	+Pripstein Shively Kruse Swanson	(LRL ILL) IJP
BIRMINGHAM	66	PR 152 1148		(BIRM GLAS LOIC OXF RHEL)
LONDON	66	PR 143 1034	+Rau Goldberg Lichtman+	(BNL SYRA) IJ
EBERHARD	65	PRL 14 466	+Shively Ross Siegal Ficenec+	(LRL ILL) I
LEVEQUE	65	PL 18 69	+	(SACL EPOL GLAS LOIC OXF RHEL) JP
ALVAREZ	63	PRL 10 184	+Alston Ferro Luzzi Huwe+	(LRL) I
SMITH	63	Athens Conf 67		(LRL)
ALEXANDER	62C	CERN Conf 320	+Jacobs Kalbfleisch Miller+	(LRL) I

Σ(1690) BUMPS

$I(J^P) = 1(?^?)$ Status * *

OMITTED FROM SUMMARY TABLE

See the note preceding the Σ(1670) Listings Seen in production experiments only, mainly in Λπ

Σ(1690) MASS (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1698 ± 20	70	[1] GODDARD	79	HBC	+	π^+p 10 3 GeV/c
1707 ± 20	40	[2] GODDARD	79	HBC	+	π^+p 10 3 GeV/c
1698 ± 20	15	ADERHOLZ	69	HBC	+	π^+p 8 GeV/c
1682 ± 2	46	BLUMENFELD	69	HBC	+	K^0_Lp
1700 ± 20		MOTT	69	HBC	+	K^-p 5 5 GeV/c
1694 ± 24	60	[3] PRIMER	68	HBC	+	K^-p 4 6–5 GeV/c
1700 ± 6		[4] SIMS	68	HBC	−	$K^-N \to \Lambda\pi\pi$
1715 ± 12	30	COLLEY	67	HBC	+	K^-p 6 GeV/c

Σ(1690) WIDTH (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
240 ± 60	70	[1] GODDARD	79	HBC	+	π^+p 10 3 GeV/c
130^{+100}_{-60}	40	[2] GODDARD	79	HBC	+	π^+p 10 3 GeV/c
142 ± 40	15	ADERHOLZ	69	HBC	+	π^+p 8 GeV/c
25 ± 10	46	BLUMENFELD	69	HBC	+	K^0_Lp
130 ± 25		MOTT	69	HBC	+	K^-p 5 5 GeV/c
105 ± 35	60	[3] PRIMER	68	HBC	+	K^-p 4 6–5 GeV/c
62 ± 14		[4] SIMS	68	HBC	−	$K^-N \to \Lambda\pi\pi$
100 ± 35	30	COLLEY	67	HBC	+	K^-p 6 GeV/c

Σ(1690) DECAY MODES (PRODUCTION EXPERIMENTS)

Γ_1 Σ(1690) → $N\bar{K}$
Γ_2 Σ(1690) → Λπ
Γ_3 Σ(1690) → Σπ
Γ_4 Σ(1690) → Σ(1385)π
Γ_5 Σ(1690) → Λππ (including Σ(1385)π)

Σ(1690) BRANCHING RATIOS (PRODUCTION EXPERIMENTS)

$\Gamma(N\bar{K})/\Gamma(\Lambda\pi)$ — Γ_1/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
SMALL		GODDARD	79	HBC	+	π^+p 10 2 GeV/c
<0 2		MOTT	69	HBC	+	K^-p 5 5 GeV/c
0.4 ± 0 25	18	COLLEY	67	HBC	+	6/30 events

$\Gamma(\Sigma\pi)/\Gamma(\Lambda\pi)$ — Γ_3/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
SMALL		GODDARD	79	HBC	+	π^+p 10 2 GeV/c
<0 4	90	MOTT	69	HBC	+	K^-p 5 5 GeV/c
0.3 ± 0 3		COLLEY	67	HBC	+	4/30 events

$\Gamma(\Sigma(1385)\pi)/\Gamma(\Lambda\pi)$ — Γ_4/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
<0 5	MOTT	69	HBC	+	K^-p 5 5 GeV/c

$\Gamma(\Lambda\pi\pi$ (including $\Sigma(1385)\pi))/\Gamma(\Lambda\pi)$ — Γ_5/Γ_2

VALUE	DOCUMENT ID	TECN	CHG	COMMENT
2 0±0 6	BLUMENFELD 69	HBC	+	31/15 events
0 5±0 25	COLLEY 67	HBC	+	15/30 events

$\Gamma(\Sigma(1385)\pi)/\Gamma(\Lambda\pi\pi$ (including $\Sigma(1385)\pi))$ — Γ_4/Γ_5

VALUE	DOCUMENT ID	TECN	CHG	COMMENT
LARGE	SIMS 68	HBC	−	$K^- N \to \Lambda\pi\pi$
SMALL	COLLEY 67	HBC	+	$K^- p$ 6 GeV/c

Σ(1690) FOOTNOTES (PRODUCTION EXPERIMENTS)

[1] From $\pi^+ p \to (\Lambda\pi^+)K^+$ J · 1/2 is not required by the data
[2] From $\pi^+ p \to (\Lambda\pi^+)(K\pi)^+$ J · 1/2 is indicated, but large background precludes a definite conclusion
[3] See the Σ(1670) Listings AGUILAR BENITEZ 70B with three times the data of PRIMER 68 find no evidence for the Σ(1690)
[4] This analysis, which is difficult and requires several assumptions and shows no unambiguous Σ(1690) signal suggests $J^P = 5/2^+$ Such a state would lead all previously known Y^* trajectories

Σ(1690) REFERENCES (PRODUCTION EXPERIMENTS)

GODDARD	79	PR D19 1350	+Key Luste Prentice Yoon Gordon+	(TNTO BNL) IJ
AGUILAR	70B	PRL 25 58	Aguilar Benitez Barnes Bassano+	(BNL SYRA)
ADERHOLZ	69	NP B11 259	+Bartsch+	(AACH BERL CERN JAGL WARS) I
BLUMENFELD	69	PL 29B 58	+Kalbfleisch	(BNL) I
MOTT	69	PR 177 1966	+Ammar Davis Kropac Slate+	(NWES ANL) I
Also	67	PRL 18 266	Derrick Fields Loken Ammar+	(ANL NWES) I
PRIMER	68	PRL 20 610	+Goldberg Jaeger Barnes Dornan+	(SYRA BNL) I
SIMS	68	PRL 21 1413	+Albright Bartley Meer+	(FSU TUFT BRAN) I
COLLEY	67	PL 24B 489		(BIRM GLAS LOIC MUNI OXF RHEL) I

Σ(1750) S_{11}

$I(J^P) = 1(\frac{1}{2}^-)$ Status * * *

For most results published before 1974 (they are now obsolete), see our 1982 edition (Physics Letters 111B)

There is evidence for this state in many partial-wave analyses, but with wide variations in the mass, width, and couplings The latest analyses indicated significant couplings to $N\bar{K}$ and $\Lambda\pi$, as well as to $\Sigma\eta$ whose threshold is at 1746 MeV (JONES 74)

Σ(1750) MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1730 to 1800 OUR ESTIMATE			
1756 ± 10	GOPAL 80	DPWA	$\bar{K}N \to KN$
1770 ± 10	ALSTON 78	DPWA	$KN \to \bar{K}N$
1770 ± 15	GOPAL 77	DPWA	$\bar{K}N$ multichannel
• • • We do not use the following data for averages, fits limits, etc • • •			
1800 or 1813	[1] MARTIN 77	DPWA	$\bar{K}N$ multichannel
1715 ± 10	[2] CARROLL 76	DPWA	Isospin-1 total σ
1730	DEBELLEFON 76	IPWA	$K^- p \to \Lambda\pi^0$
1780 ± 30	BAILLON 75	IPWA	$\bar{K}N \to \Lambda\pi$ (sol 1)
1700 ± 30	BAILLON 75	IPWA	$KN \to \Lambda\pi$ (sol 2)
1697^{+20}_{-10}	VANHORN 75	DPWA	$K^- p \to \Lambda\pi^0$
1785 ± 12	CHU 74	DBC	Fits $\sigma(K^- n \to \Sigma^-\eta)$
1760 ± 5	[3] JONES 74	HBC	Fits $\sigma(K^- p \to \Sigma^0\eta)$
1739 ± 10	PREVOST 74	DPWA	$K^- N \to \Sigma(1385)\pi$

Σ(1750) WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
60 to 160 OUR ESTIMATE			
64 ± 10	GOPAL 80	DPWA	$KN \to \bar{K}N$
161 ± 20	ALSTON 78	DPWA	$KN \to \bar{K}N$
60 ± 10	GOPAL 77	DPWA	KN multichannel
• • • We do not use the following data for averages fits limits etc • • •			
117 or 119	[1] MARTIN 77	DPWA	KN multichannel
10	[2] CARROLL 76	DPWA	Isospin-1 total σ
110	DEBELLEFON 76	IPWA	$K^- p \to \Lambda\pi^0$
140 ± 30	BAILLON 75	IPWA	$\bar{K}N \to \Lambda\pi$ (sol 1)
160 ± 50	BAILLON 75	IPWA	$KN \to \Lambda\pi$ (sol 2)
66^{+14}_{-12}	VANHORN 75	DPWA	$K^- p \to \Lambda\pi^0$
89 ± 33	CHU 74	DBC	Fits $\sigma(K^- n \to \Sigma^-\eta)$
92 ± 7	[3] JONES 74	HBC	Fits $\sigma(K^- p \to \Sigma^0\eta)$
108 ± 20	PREVOST 74	DPWA	$K^- N \to \Sigma(1385)\pi$

Σ(1750) DECAY MODES

Γ_1	$\Sigma(1750) \to N\bar{K}$
Γ_2	$\Sigma(1750) \to \Lambda\pi$
Γ_3	$\Sigma(1750) \to \Sigma\pi$
Γ_4	$\Sigma(1750) \to \Sigma\eta$
Γ_5	$\Sigma(1750) \to \Sigma(1385)\pi$
Γ_6	$\Sigma(1750) \to \Lambda(1520)\pi$

Σ(1750) BRANCHING RATIOS

See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
0.1 to 0 4 OUR ESTIMATE			
0.14 ± 0.03	GOPAL 80	DPWA	$KN \to KN$
0 33 ± 0 05	ALSTON 78	DPWA	$\bar{K}N \to \bar{K}N$
• • • We do not use the following data for averages fits limits etc • • •			
0 15 ± 0.03	GOPAL 77	DPWA	See GOPAL 80
0 06 or 0 05	[1] MARTIN 77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1750) \to \Lambda\pi$ — $(\Gamma_1\Gamma_2)^{½}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
0 04 ± 0 03	GOPAL 77	DPWA	KN multichannel
• • • We do not use the following data for averages fits limits etc • • •			
−0 10 or −0.09	[1] MARTIN 77	DPWA	KN multichannel
−0 12	DEBELLEFON 76	IPWA	$K^- p \to \Lambda\pi^0$
−0 12 ± 0 02	BAILLON 75	IPWA	$KN \to \Lambda\pi$ (sol 1)
−0 13 ± 0 03	BAILLON 75	IPWA	$KN \to \Lambda\pi$ (sol 2)
−0 13 ± 0 04	VANHORN 75	DPWA	$K^- p \to \Lambda\pi^0$
−0 120 ± 0.077	DEVENISH 74B		Fixed t dispersion rel

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1750) \to \Sigma\pi$ — $(\Gamma_1\Gamma_3)^{½}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
−0 09 ± 0 05	GOPAL 77	DPWA	KN multichannel
• • • We do not use the following data for averages, fits limits etc • • •			
+0 06 or +0 06	[1] MARTIN 77	DPWA	$\bar{K}N$ multichannel
0 13 ± 0 02	LANGBEIN 72	IPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1750) \to \Sigma\eta$ — $(\Gamma_1\Gamma_4)^{½}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
0 23 ± 0 01	[3] JONES 74	HBC	Fits $\sigma(K^- p \to \Sigma^0\eta)$
• • • We do not use the following data for averages fits limits etc • • •			
SEEN	CLINE 69	DBC	Threshold bump

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1750) \to \Sigma(1385)\pi$ — $(\Gamma_1\Gamma_5)^{½}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
+0 18 ± 0 15	PREVOST 74	DPWA	$K^- N \to \Sigma(1385)\pi$

$(\Gamma_i\Gamma_f)^{½}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1750) \to \Lambda(1520)\pi$ — $(\Gamma_1\Gamma_6)^{½}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •			
0 032 ± 0 021	CAMERON 77	DPWA	P wave decay

Σ(1750) FOOTNOTES

[1] The two MARTIN 77 values are from a T-matrix pole and from a Breit Wigner fit
[2] A total cross section bump with $(J+1/2)\ \Gamma_{el}/\Gamma_{total}$ = 0 30
[3] An S-wave Breit Wigner fit to the threshold cross section with no background and errors statistical only

Σ(1750) REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL) IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
CAMERON	77	NP B131 399	+Franek Gopal Kalmus McPherson+	(RHEL LOIC) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
CARROLL	76	PRL 37 806	+Chiang Kycia Li Mazur Michael+	(BNL) I
DEBELLEFON	76	NP B109 129	De Bellefon Berthon	(CDEF) IJP
BAILLON	75	NP B94 39	+Litchfield	(CERN RHEL) IJP
VANHORN	75	NP B87 145		(LBL) IJP
Also	75B	NP B87 157	VanHorn	(LBL) IJP
CHU	74	NC 20A 35	+Bartley+	(PLAT TUFT BRAN) IJP
DEVENISH	74B	NP B81 330	+Froggatt Martin	(DESY NORD LOUC)
JONES	74	NP B73 141		(CHIC) IJP
PREVOST	74	NP B69 246	+Barloutaud+	(SACL CERN HEID)
LANGBEIN	72	NP B47 477	+Wagner	(MPIM) IJP
CLINE	69	LNC 2 407	+Laumann Mapp	(WISC)

Σ(1770) P_{11}

$I(J^P) = 1(\frac{1}{2}^+)$ Status *

OMITTED FROM SUMMARY TABLE

Evidence for this state now rests solely on solution 1 of BAILLON 75, (see the footnotes) but the $\Lambda\pi$ partial-wave amplitudes of this solution are in disagreement with amplitudes from most other $\Lambda\pi$ analyses

Σ(1770) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1738 ± 10	[1] GOPAL	77	DPWA	$\overline{K}N$ multichannel
1770 ± 20	[2] BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$
1772	[3] KANE	72	DPWA	$K^-p \to \Sigma\pi$

Σ(1770) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
72 ± 10	[1] GOPAL	77	DPWA	$\overline{K}N$ multichannel
80 ± 30	[2] BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$
80	[3] KANE	72	DPWA	$K^-p \to \Sigma\pi$

Σ(1770) DECAY MODES

Γ_1	$\Sigma(1770) \to N\overline{K}$
Γ_2	$\Sigma(1770) \to \Lambda\pi$
Γ_3	$\Sigma(1770) \to \Sigma\pi$

Σ(1770) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances

$\Gamma(N\overline{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0 14 ± 0 04	[1] GOPAL	77	DPWA	$\overline{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Sigma(1770) \to \Lambda\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
< 0 04	GOPAL	77	DPWA	$\overline{K}N$ multichannel
−0 08 ± 0.02	[2] BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Sigma(1770) \to \Sigma\pi$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
< 0 04	GOPAL	77	DPWA	$\overline{K}N$ multichannel
−0 108	[3] KANE	72	DPWA	$K^-p \to \Sigma\pi$

Σ(1770) FOOTNOTES

[1] Required to fit the isospin 1 total cross section of CARROLL 76 in the $\overline{K}N$ channel The addition of new K^-p polarization and K^-n differential cross-section data in GOPAL 80 find it to be more consistent with the Σ(1660) P_{11}

[2] From solution 1 of BAILLON 75 not present in solution 2

[3] Not required in KANE 74 which supersedes KANE 72

Σ(1770) REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL)
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
CARROLL	76	PRL 37 806	+Chiang Kycia Li Mazur Michael+	(BNL) I
BAILLON	75	NP B94 39	+Litchfield	(CERN RHEL) IJP
KANE	74	LBL 2452		(LBL) IJP
KANE	72	PR D5 1583		(LBL)

Σ(1775) D_{15}

$I(J^P) = 1(\frac{5}{2}^-)$ Status * * * *

Discovered by GALTIERI 63, this resonance plays the same role as cornerstone for isospin-1 analyses in this region as the Λ(1820) does in the isospin-0 channel

For most results published before 1974 (they are now obsolete), see our 1982 edition (Physics Letters **111B**)

Σ(1775) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1770 to 1780 OUR ESTIMATE				
1778 ± 5	GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$
1777 ± 5	ALSTON	78	DPWA	$\overline{K}N \to \overline{K}N$
1774 ± 5	GOPAL	77	DPWA	$\overline{K}N$ multichannel
1775 ± 10	BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$
1774 ± 10	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
1772 ± 6	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits etc • • •				
1772 or 1777	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel
1765	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$

Σ(1775) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
105 to 135 OUR ESTIMATE				
137 ± 10	GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$
116 ± 10	ALSTON	78	DPWA	$\overline{K}N \to \overline{K}N$
130 ± 10	GOPAL	77	DPWA	$\overline{K}N$ multichannel
125 ± 15	BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$
146 ± 18	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
154 ± 10	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
102 or 103	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel
120	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$

Σ(1775) DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	$\Sigma(1775) \to N\overline{K}$	$(43\ 0 \pm 2\ 4) \times 10^{-2}$	1 8
Γ_2	$\Sigma(1775) \to \Lambda\pi$	$(15\ 1 \pm 1\ 4) \times 10^{-2}$	
Γ_3	$\Sigma(1775) \to \Sigma\pi$	$(2\ 1 \pm 0\ 7) \times 10^{-2}$	1 6
Γ_4	$\Sigma(1775) \to \Sigma\pi\pi$		
Γ_5	$\Sigma(1775) \to \Sigma(1385)\pi$, D-wave	$(8\ 3 \pm 0\ 9) \times 10^{-2}$	1 1
Γ_6	$\Sigma(1775) \to \Lambda(1520)\pi$	$(19\ 1 \pm 2\ 4) \times 10^{-2}$	2 2

CONSTRAINED FIT INFORMATION

An overall fit to 8 branching ratios uses 16 measurements and one constraint to determine 6 parameters The overall fit has a $\chi^2 = 26\ 4$ for 11 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i\,\delta x_j\rangle/(\delta x_i\cdot\delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

x_2	9			
x_3	19	2		
x_5	47	4	9	
x_6	45	4	8	21
	x_1	x_2	x_3	x_5

Σ(1775) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances Also the errors quoted do not include uncertainties due to the parametrization used in the partial wave analyses and are thus too small

$\Gamma(N\overline{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.37 to 0.43 OUR ESTIMATE				
0.430 ± 0 024 OUR FIT Error includes scale factor of 1 8				
0.391 ± 0.017 OUR AVERAGE				
0 40 ± 0 02	GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$
0 37 ± 0 03	ALSTON	78	DPWA	$\overline{K}N \to \overline{K}N$
• • • We do not use the following data for averages fits limits etc • • •				
0 41 ± 0 03	GOPAL	77	DPWA	See GOPAL 80
0 37 or 0 36	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to \Sigma(1775) \to \Lambda\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.255 ± 0.013 OUR FIT Error includes scale factor of 1 1				
−0.262 ± 0.015 OUR AVERAGE				
−0 28 ± 0 03	GOPAL	77	DPWA	$\overline{K}N$ multichannel
−0 25 ± 0 02	BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$
$-0\ 28\ ^{+0\ 04}_{-0.05}$	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
−0 259 ± 0 048	DEVENISH	74B		Fixed t dispersion rel

• • • We do not use the following data for averages fits limits etc • • •

−0 29 or −0 28	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
−0 30	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1775) \to \Sigma\pi$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.095 ± 0.014 OUR FIT Error includes scale factor of 1 6				
0.098 ± 0.016 OUR AVERAGE Error includes scale factor of 1 8				
+0 13 ± 0.02	GOPAL	77	DPWA	$\bar{K}N$ multichannel
0 09 ± 0 01	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
+0 08 or +0 08	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1775) \to \Lambda(1520)\pi$ $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0 286 ± 0 016 OUR FIT Error includes scale factor of 1 9				
0.303 ± 0.009 OUR AVERAGE Signs on measurements were ignored				
−0 305 ± 0 010	[2] CAMERON	77	DPWA	$K^-p \to \Lambda(1520)\pi^0$
0 31 ± 0 02	BARLETTA	72	DPWA	$K^-p \to \Lambda(1520)\pi^0$
0 27 ± 0 03	ARMENTEROS	65C	HBC	$K^-p \to \Lambda(1520)\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $NK \to \Sigma(1775) \to \Sigma(1385)\pi$, D-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.189 ± 0.009 OUR FIT				
0.188 ± 0.010 OUR AVERAGE Signs on measurements were ignored				
−0.184 ± 0 011	[3] CAMERON	78	DPWA	$K^-p \to \Sigma(1385)\pi$
+0 20 ± 0 02	PREVOST	74	DPWA	$K^-N \to \Sigma(1385)\pi$
• • • We do not use the following data for averages fits limits etc • • •				
0 32 ± 0 06	SIMS	68	DBC	$K^-N \to \Lambda\pi\pi$
0 24 ± 0 03	ARMENTEROS	67C	HBC	$K^-p \to \Lambda\pi\pi$

$\Gamma(\Lambda\pi)/\Gamma(N\bar{K})$ Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0.35 ± 0.04 OUR FIT Error includes scale factor of 1 2				
0.33 ± 0.05	UHLIG	67	HBC	K^-p 0 9 GeV/c

$\Gamma(\Sigma\pi\pi)/\Gamma_{total}$ Γ_4/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
0 12	[4] ARMENTEROS	68C	HDBC	$K^-N \to \Sigma\pi\pi$

$\Gamma(\Sigma(1385)\pi$, D-wave$)/\Gamma(NK)$ Γ_5/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0 192 ± 0.030 OUR FIT Error includes scale factor of 1 3				
0.25 ± 0.09	UHLIG	67	HBC	K^-p 0 9 GeV/c

$\Gamma(\Lambda(1520)\pi)/\Gamma(N\bar{K})$ Γ_6/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0.44 ± 0.07 OUR FIT Error includes scale factor of 2 3				
0.28 ± 0.05	UHLIG	67	HBC	K^-p 0 9 GeV/c

Σ(1775) FOOTNOTES

[1] The two MARTIN 77 values are from a T matrix pole and from a Breit Wigner fit
[2] This rate combines P-wave- and F-wave decays The CAMERON 77 results for the separate P wave- and F-wave decays are −0 303 ± 0 010 and −0 037 ± 0 014 The published signs have been changed here to be in accord with the baryon-first convention
[3] The CAMERON 78 upper limit on G-wave decay is 0 03
[4] For about 3/4 of this the $\Sigma\pi$ system has I = 0 and is almost entirely $\Lambda(1520)$ For the rest the $\Sigma\pi$ has I = 1 which is about what is expected from the known $\Sigma(1775) \to \Sigma(1385)\pi$ rate as seen in $\Lambda\pi\pi$

Σ(1775) REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL) IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
CAMERON	78	NP B143 189	+Franek Gopal Bacon Butterworth+	(RHEL LOIC) IJP
CAMERON	77	NP B131 399	+Franek Gopal Kalmus McPherson+	(RHEL LOIC) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
DEBELLEFON	76	NP B109 129	De Bellefon Berthon	(CDEF) IJP
BAILLON	75	NP B94 39	+Litchfield	(CERN RHEL) IJP
VANHORN	75	NP B87 145		(LBL) IJP
Also	75B	NP B87 157	VanHorn	(LBL) IJP
DEVENISH	74B	NP B81 330	+Froggatt Martin	(DESY NORD LOUC)
KANE	74	LBL 2452		(LBL) IJP
PREVOST	74	NP B69 246	+Barloutaud+	(SACL CERN HEID)
BARLETTA	72	NP B40 45		(EFI) IJP
Also	66	PRL 17 841	Fenster Gelfand Harmsen+	(CHIC ANL CERN) IJP
ARMENTEROS	68C	NP B8 216	+Baillon+	(CERN HEID SACL) I
SIMS	68	PRL 21 1413	+Albright Bartley Meer+	(FSU TUFT BRAN)
ARMENTEROS	67C	ZPHY 202 486	+Ferro Luzzi+	(CERN HEID SACL)
UHLIG	67	PR 155 1448	+Charlton Condon Glasser Yodh+	(UMD NRL)
ARMENTEROS	65C	PL 19 338	+Ferro Luzzi+	(CERN HEID SACL) IJP
GALTIERI	63	PL 6 296	+Hussain Tripp	(LRL) IJ

Σ(1840) P_{13}

$I(J^P) = 1(\frac{3}{2}^+)$ Status *

OMITTED FROM SUMMARY TABLE

For the time being, we list together here all resonance claims in the P_{13} wave between 1700 and 1900 MeV

Σ(1840) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1798 or 1802	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
1720 ± 30	[2] BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
1925 ± 200	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
1840 ± 10	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel

Σ(1840) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
93 or 93	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
120 ± 30	[2] BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
65^{+50}_{-20}	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
120 ± 10	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel

Σ(1840) DECAY MODES

Γ_1	$\Sigma(1840) \to N\bar{K}$
Γ_2	$\Sigma(1840) \to \Lambda\pi$
Γ_3	$\Sigma(1840) \to \Sigma\pi$

Σ(1840) BRANCHING RATIOS

See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0 or 0	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
0 37 ± 0.13	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1840) \to \Lambda\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0 03 or +0 03	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
+0.11 ± 0 02	[2] BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
+0 06 ± 0 04	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
+0 122 ± 0 078	DEVENISH	74B		Fixed t dispersion rel
0 20 ± 0 04	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $NK \to \Sigma(1840) \to \Sigma\pi$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 04 or −0 04	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
0 15 ± 0 04	LANGBEIN	72	IPWA	$\bar{K}N$ multichannel

Σ(1840) FOOTNOTES

[1] The two MARTIN 77 values are from a T matrix pole and from a Breit Wigner fit
[2] From solution 1 of BAILLON 75 not present in solution 2

Σ(1840) REFERENCES

MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
BAILLON	75	NP B94 39	+Litchfield	(CERN RHEL) IJP
VANHORN	75	NP B87 145		(LBL) IJP
Also	75B	NP B87 157	VanHorn	(LBL) IJP
DEVENISH	74B	NP B81 330	+Froggatt Martin	(DESY NORD LOUC)
LANGBEIN	72	NP B47 477	+Wagner	(MPIM) IJP

Σ(1880) P_{11}

$I(J^P) = 1(\frac{1}{2}^+)$ Status * *

OMITTED FROM SUMMARY TABLE

A P_{11} resonance is suggested by several partial-wave analyses, but with wide variations in the mass and other parameters We list here all claims which lie well above the P_{11} Σ(1770)

Σ(1880) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1826 ± 20	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
1870 ± 10	CAMERON	78B	DPWA	$K^-p \to N\bar{K}^*$
1847 or 1863	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
1960 ± 30	[2] BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
1985 ± 50	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
1898	[3] LEA	73	DPWA	Multichannel K matrix
~1850	ARMENTEROS	70	IPWA	$\bar{K}N \to \bar{K}N$
1950 ± 50	BARBARO	70	DPWA	$K^-N \to \Lambda\pi$
1920 ± 30	LITCHFIELD	70	DPWA	$K^-N \to \Lambda\pi$
1850	BAILEY	69	DPWA	$\bar{K}N \to \bar{K}N$
1882 ± 40	SMART	68	DPWA	$K^-N \to \Lambda\pi$

Σ(1880) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
86 ± 15	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
80 ± 10	CAMERON	78B	DPWA	$K^-p \to N\bar{K}^*$
216 or 220	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
260 ± 40	[2] BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
220 ± 140	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
222	[3] LEA	73	DPWA	Multichannel K-matrix
~ 30	ARMENTEROS	70	IPWA	$\bar{K}N \to \bar{K}N$
200 ± 50	BARBARO	70	DPWA	$K^-N \to \Lambda\pi$
170 ± 40	LITCHFIELD	70	DPWA	$K^-N \to \Lambda\pi$
200	BAILEY	69	DPWA	$\bar{K}N \to \bar{K}N$
222 ± 150	SMART	68	DPWA	$K^-N \to \Lambda\pi$

Σ(1880) DECAY MODES

- Γ_1 Σ(1880) → $N\bar{K}$
- Γ_2 Σ(1880) → $\Lambda\pi$
- Γ_3 Σ(1880) → $\Sigma\pi$
- Γ_4 Σ(1880) → $N\bar{K}^*(892)$, S=1/2, P-wave
- Γ_5 Σ(1880) → $N\bar{K}^*(892)$, S=3/2, P-wave

Σ(1880) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.06 ± 0.02	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
0.27 or 0.27	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
0.31	[3] LEA	73	DPWA	Multichannel K-matrix
0.20	ARMENTEROS	70	IPWA	$\bar{K}N \to \bar{K}N$
0.22	BAILEY	69	DPWA	$\bar{K}N \to \bar{K}N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1880) \to \Lambda\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.24 or −0.24	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
−0.12 ± 0.02	[2] BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
$+0.05\,^{+0.07}_{-0.02}$	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
−0.169 ± 0.119	DEVENISH	74B		Fixed-t dispersion rel
−0.30	[3] LEA	73	DPWA	Multichannel K-matrix
−0.09 ± 0.04	BARBARO-	70	DPWA	$K^-N \to \Lambda\pi$
−0.14 ± 0.03	LITCHFIELD	70	DPWA	$K^-N \to \Lambda\pi$
−0.11 ± 0.03	SMART	68	DPWA	$K^-N \to \Lambda\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1880) \to \Sigma\pi$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.30 or +0.29	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
NOT SEEN	[3] LEA	73	DPWA	Multichannel K-matrix

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1880) \to N\bar{K}^*(892)$, S=1/2, P-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.05 ± 0.03	[4] CAMERON	78B	DPWA	$K^-p \to N\bar{K}^*$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1880) \to N\bar{K}^*(892)$, S=3/2, P-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.11 ± 0.03	CAMERON	78B	DPWA	$K^-p \to N\bar{K}^*$

Σ(1880) FOOTNOTES

[1] The two MARTIN 77 values are from a T-matrix pole and from a Breit Wigner fit
[2] From solution 1 of BAILLON 75 not present in solution 2
[3] Only unconstrained states from table 1 of LEA 73 are listed
[4] The published sign has been changed to be in accord with the baryon-first convention

Σ(1880) REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL) IJP
CAMERON	78B	NP B146 327	+Franek Gopal Kalmus McPherson+	(RHEL LOIC) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
BAILLON	75	NP B94 39	+Litchfield	(CERN RHEL) IJP
VANHORN	75	NP B87 145		(LBL) IJP
Also	75B	NP B87 157	VanHorn	(LBL) IJP
DEVENISH	74B	NP B81 330	+Froggatt Martin	(DESY NORD LOUC)
LEA	73	NP B56 77	+Martin Moorhouse+	(RHEL LOUC GLAS AARH) IJP
ARMENTEROS	70	Duke Conf 123	+Baillon+	(CERN HEID SACL) IJP
BARBARO	70	Duke Conf 173	Barbaro Galtieri	(LRL) IJP
LITCHFIELD	70	NP B22 269		(RHEL) IJP
BAILEY	69	UCRL 50617 Thesis		(LLL) IJP
SMART	68	PR 169 1330		(LRL) IJP

Σ(1915) F_{15}

$I(J^P) = 1(\frac{5}{2}^+)$ Status * * * *

Discovered by COOL 66 For results published before 1974 (they are now obsolete), see our 1982 edition (Physics Letters **111B**)

This entry only includes results from partial-wave analyses Parameters of peaks seen in cross sections and invariant-mass distributions in this region used to be listed in in a separate entry immediately following They may be found in our 1986 edition (Physics Letters **170B**)

Σ(1915) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1900 to 1935 OUR ESTIMATE				
1937 ± 20	ALSTON	78	DPWA	$\bar{K}N \to \bar{K}N$
1894 ± 5	[1] CORDEN	77C		$K^-n \to \Sigma\pi$
1909 ± 5	[1] CORDEN	77C		$K^-n \to \Sigma\pi$
1920 ± 10	GOPAL	77	DPWA	$\bar{K}N$ multichannel
1900 ± 4	[2] CORDEN	76	DPWA	$K^-n \to \Lambda\pi^-$
1920 ± 30	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
1914 ± 10	HEMINGWAY	75	DPWA	$K^-p \to \bar{K}N$
$1920\,^{+15}_{-20}$	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
1920 ± 5	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
NOT SEEN	DECLAIS	77	DPWA	$\bar{K}N \to \bar{K}N$
1925 or 1933	[3] MARTIN	77	DPWA	$\bar{K}N$ multichannel
1915	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$

Σ(1915) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
80 to 160 OUR ESTIMATE				
161 ± 20	ALSTON-	78	DPWA	$\bar{K}N \to \bar{K}N$
107 ± 14	[1] CORDEN	77C		$K^-n \to \Sigma\pi$
85 ± 13	[1] CORDEN	77C		$K^-n \to \Sigma\pi$
130 ± 10	GOPAL	77	DPWA	$\bar{K}N$ multichannel
75 ± 14	[2] CORDEN	76	DPWA	$K^-n \to \Lambda\pi^-$
70 ± 20	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
85 ± 15	HEMINGWAY	75	DPWA	$K^-p \to \bar{K}N$
102 ± 18	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
162 ± 25	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits etc • • •				
171 or 173	[3] MARTIN	77	DPWA	$\bar{K}N$ multichannel
60	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$

Σ(1915) DECAY MODES

- Γ_1 Σ(1915) → $N\bar{K}$
- Γ_2 Σ(1915) → $\Lambda\pi$
- Γ_3 Σ(1915) → $\Sigma\pi$
- Γ_4 Σ(1915) → Σ(1385)π, *P*-wave
- Γ_5 Σ(1915) → Σ(1385)π, *F*-wave

Σ(1915) BRANCHING RATIOS

See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.05 to 0.15 OUR ESTIMATE				
0.03 ± 0 02	[4] GOPAL	80	DPWA	$KN \to \bar{K}N$
0 14 ± 0 05	ALSTON	78	DPWA	$KN \to KN$
0 11 ± 0 04	HEMINGWAY	75	DPWA	$K^-p \to KN$
• • • We do not use the following data for averages fits limits, etc • • •				
0 05 ± 0.03	GOPAL	77	DPWA	See GOPAL 80
0 08 or 0 08	[3] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1915) \to \Lambda\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 09 ± 0 03	GOPAL	77	DPWA	$\bar{K}N$ multichannel
−0 10 ± 0.01	[2] CORDEN	76	DPWA	$K^-n \to \Lambda\pi^-$
−0 06 ± 0 02	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
−0 09 ± 0.02	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
−0 087 ± 0 056	DEVENISH	74B		Fixed *t* dispersion rel
• • • We do not use the following data for averages fits limits etc • • •				
−0 09 or −0 09	[3] MARTIN	77	DPWA	$\bar{K}N$ multichannel
−0 10	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1915) \to \Sigma\pi$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.17 ± 0 01	[1] CORDEN	77C		$K^-n \to \Sigma\pi$
−0 15 ± 0 02	[1] CORDEN	77C		$K^-n \to \Sigma\pi$
−0 19 ± 0 03	GOPAL	77	DPWA	$\bar{K}N$ multichannel
−0 16 ± 0 03	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages fits limits etc • • •				
−0 05 or −0 05	[3] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1915) \to \Sigma(1385)\pi$, *P*-wave — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
<0 01	CAMERON	78	DPWA	$K^-p \to \Sigma(1385)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1915) \to \Sigma(1385)\pi$, *F*-wave — $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0 039 ± 0 009	[5] CAMERON	78	DPWA	$K^-p \to \Sigma(1385)\pi$

Σ(1915) FOOTNOTES

[1] The two entries for CORDEN 77C are from two different acceptable solutions
[2] Preferred solution 3 see CORDEN 76 for other possibilities
[3] The two MARTIN 77 values are from a T-matrix pole and from a Breit Wigner fit
[4] The mass and width are fixed to the GOPAL 77 values due to the low elasticity
[5] The published sign has been changed to be in accord with the baryon first convention

Σ(1915) REFERENCES

GOPAL	80	Toronto Conf 159		(RHEL) IJP
ALSTON	78	PR D18 182	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
Also	77	PRL 38 1007	Alston Garnjost Kenney+	(LBL MTHO CERN) IJP
CAMERON	78	NP B143 189	+Franek Gopal Bacon Butterworth+	(RHEL LOIC) IJP
CORDEN	77C	NP B125 61	+Cox Kenyon O Neale Stubbs Sumorok+	(BIRM) IJP
DECLAIS	77	CERN 77 16	+Duchon Louvel Patry Seguinot+	(CAEN CERN) IJP
GOPAL	77	NP B119 362	+Ross VanHorn McPherson+	(LOIC RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock Moorhouse	(LOUC GLAS) IJP
Also	77B	NP B126 266	Martin Pidcock	(LOUC)
Also	77C	NP B126 285	Martin Pidcock	(LOUC) IJP
CORDEN	76	NP B104 382	+Cox Dornell Kenyon O Neale+	(BIRM) IJP
DEBELLEFON	76	NP B109 129	De Bellefon Berthon	(CDEF) IJP
BAILLON	75	NP B94 39	+Litchfield	(CERN RHEL) IJP
HEMINGWAY	75	NP B91 12	+Eades Harmsen+	(CERN HEID MPIM) IJP
VANHORN	75	NP B87 145		(LBL) IJP
Also	75B	NP B87 157	VanHorn	(LBL) IJP
DEVENISH	74B	NP B81 330	+Froggatt Martin	(DESY NORD LOUC)
KANE	74	LBL 2452		(LBL) IJP
COOL	66	PRL 16 1228	+Giacomelli Kycia Leontic Lundby+	(BNL)

Σ(1940) D_{13}

$I(J^P) = 1(\frac{3}{2}^-)$ Status * * *

For results published before 1974 (they are now obsolete), see our 1982 edition (Physics Letters 111B)

Not all analyses require this state It is not required by the GOYAL 77 analysis of $K^-n \to (\Sigma\pi)^-$ nor by the GOPAL 80 analysis of $K^-n \to K^-n$ See also HEMINGWAY 75

Σ(1940) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1900 to 1950 OUR ESTIMATE				
1920 ± 50	GOPAL	77	DPWA	$\bar{K}N$ multichannel
1950 ± 30	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
1949^{+40}_{-60}	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
1935 ± 80	KANE	74	DPWA	$K^-p \to \Sigma\pi$
1940 ± 20	LITCHFIELD	74B	DPWA	$K^-p \to \Lambda(1520)\pi^0$
1950 ± 20	LITCHFIELD	74C	DPWA	$K^-p \to \Delta(1232)K$
• • • We do not use the following data for averages fits limits, etc • • •				
1886 or 1893	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
1940	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$ F_{17} wave

Σ(1940) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
150 to 300 OUR ESTIMATE				
170 ± 25	CAMERON	78B	DPWA	$K^-p \to N\bar{K}^*$
300 ± 80	GOPAL	77	DPWA	$\bar{K}N$ multichannel
150 ± 75	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
160^{+70}_{-40}	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
330 ± 80	KANE	74	DPWA	$K^-p \to \Sigma\pi$
60 ± 20	LITCHFIELD	74B	DPWA	$K^-p \to \Lambda(1520)\pi^0$
70^{+30}_{-20}	LITCHFIELD	74C	DPWA	$K^-p \to \Delta(1232)K$
• • • We do not use the following data for averages fits limits etc • • •				
157 or 159	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

Σ(1940) DECAY MODES

- Γ_1 Σ(1940) → $N\bar{K}$
- Γ_2 Σ(1940) → $\Lambda\pi$
- Γ_3 Σ(1940) → $\Sigma\pi$
- Γ_4 Σ(1940) → Λ(1520)π, *P*-wave
- Γ_5 Σ(1940) → Λ(1520)π, *F*-wave
- Γ_6 Σ(1940) → Δ(1232)*K*, *S*-wave
- Γ_7 Σ(1940) → Δ(1232)*K*, *D*-wave
- Γ_8 Σ(1940) → Σ(1385)π, *S*-wave
- Γ_9 Σ(1940) → $N\bar{K}^*(892)$, *S*=3/2, *S*-wave

Σ(1940) BRANCHING RATIOS

See Sign conventions for resonance couplings in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.2 OUR ESTIMATE				
<0 04	GOPAL	77	DPWA	$\bar{K}N$ multichannel
0 14 or 0 13	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1940) \to \Lambda\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0 06 ± 0 03	GOPAL	77	DPWA	$\bar{K}N$ multichannel
−0 04 ± 0 02	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
$-0.05^{+0\ 03}_{-0\ 02}$	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$
−0 153 ± 0 070	DEVENISH	74B		Fixed *t* dispersion rel
• • • We do not use the following data for averages, fits limits etc • • •				
−0 15 or −0 14	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

Baryon Full Listings
Σ(1940), Σ(2000)

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1940) \to \Sigma\pi$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.08 ± 0.04	GOPAL	77	DPWA	$\bar{K}N$ multichannel
−0.14 ± 0.04	KANE	74	DPWA	$K^-p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
+0.16 or +0.16	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1940) \to \Lambda(1520)\pi$, P-wave $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
< 0.03	CAMERON	77	DPWA	$K^-p \to \Lambda(1520)\pi^0$
−0.11 ± 0.04	LITCHFIELD	74B	DPWA	$K^-p \to \Lambda(1520)\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1940) \to \Lambda(1520)\pi$, F-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.062 ± 0.021	CAMERON	77	DPWA	$K^-p \to \Lambda(1520)\pi^0$
−0.08 ± 0.04	LITCHFIELD	74B	DPWA	$K^-p \to \Lambda(1520)\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1940) \to \Delta(1232)\bar{K}$, S-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.16 ± 0.05	LITCHFIELD	74C	DPWA	$K^-p \to \Delta(1232)\bar{K}$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1940) \to \Delta(1232)\bar{K}$, D-wave $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.14 ± 0.05	LITCHFIELD	74C	DPWA	$K^-p \to \Delta(1232)\bar{K}$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1940) \to \Sigma(1385)\pi$, S-wave $(\Gamma_1\Gamma_8)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.066 ± 0.025	[2] CAMERON	78	DPWA	$K^-p \to \Sigma(1385)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(1940) \to N\bar{K}^*(892)$, S=3/2, S-wave $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.09 ± 0.02	[3] CAMERON	78B	DPWA	$K^-p \to N\bar{K}^*$

Σ(1940) FOOTNOTES

[1] The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit.
[2] The published sign has been changed to be in accord with the baryon-first convention.
[3] Upper limits on the D_1 and D_3 waves are each 0.03.

Σ(1940) REFERENCES

GOPAL	80	Toronto Conf. 159		(RHEL)
CAMERON	78	NP B143 189	+Franek, Gopal, Bacon, Butterworth+	(RHEL, LOIC) IJP
CAMERON	78B	NP B146 327	+Franek, Gopal, Kalmus, McPherson+	(RHEL, LOIC) IJP
CAMERON	77	NP B131 399	+Franek, Gopal, Kalmus, McPherson+	(RHEL, LOIC) IJP
GOPAL	77	NP B119 362	+Ross, VanHorn, McPherson+	(LOIC, RHEL) IJP
GOYAL	77	PR D16 2746	+Sodhi	(DELH)
MARTIN	77	NP B127 349	+Pidcock, Moorhouse	(LOUC, GLAS) IJP
Also	77B	NP B126 266	Martin, Pidcock	(LOUC)
Also	77C	NP B126 285	Martin, Pidcock	(LOUC) IJP
DEBELLEFON	76	NP B109 129	De Bellefon, Berthon	(CDEF) IJP
BAILLON	75	NP B94 39	+Litchfield	(CERN, RHEL) IJP
HEMINGWAY	75	NP B91 12	+Eades, Harmsen+	(CERN, HEID, MPIM) IJP
VANHORN	75	NP B87 145		(LBL) IJP
Also	75B	NP B87 157	VanHorn	(LBL) IJP
DEVENISH	74B	NP B81 330	+Froggatt, Martin	(DESY, NORD, LOUC)
KANE	74	LBL 2452		(LBL) IJP
LITCHFIELD	74B	NP B74 19	+Hemingway, Baillon+	(CERN, HEID) IJP
LITCHFIELD	74C	NP B74 39	+Hemingway, Baillon+	(CERN, HEID) IJP

Σ(2000) S_{11}

$I(J^P) = 1(\frac{1}{2}^-)$ Status: *

OMITTED FROM SUMMARY TABLE

We list here all reported S_{11} states lying above the Σ(1750) S_{11}.

Σ(2000) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1944 ± 15	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
1955 ± 15	GOPAL	77	DPWA	$\bar{K}N$ multichannel
1755 or 1834	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
2004 ± 40	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$

Σ(2000) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
215 ± 25	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
170 ± 40	GOPAL	77	DPWA	$\bar{K}N$ multichannel
413 or 450	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
116 ± 40	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$

Σ(2000) DECAY MODES

Γ_1	$\Sigma(2000) \to N\bar{K}$
Γ_2	$\Sigma(2000) \to \Lambda\pi$
Γ_3	$\Sigma(2000) \to \Sigma\pi$
Γ_4	$\Sigma(2000) \to \Lambda(1520)\pi$
Γ_5	$\Sigma(2000) \to N\bar{K}^*(892)$, S=1/2, S-wave
Γ_6	$\Sigma(2000) \to N\bar{K}^*(892)$, S=3/2, D-wave

Σ(2000) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances.

$\Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.51 ± 0.05	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
0.44 ± 0.05	GOPAL	77	DPWA	See GOPAL 80
0.62 or 0.57	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2000) \to \Lambda\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.08 ± 0.03	GOPAL	77	DPWA	$\bar{K}N$ multichannel
−0.19 or −0.18	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel
NOT SEEN	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
$+0.07^{+0.02}_{-0.01}$	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2000) \to \Sigma\pi$ $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.20 ± 0.04	GOPAL	77	DPWA	$\bar{K}N$ multichannel
+0.26 or +0.24	[1] MARTIN	77	DPWA	$\bar{K}N$ multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2000) \to \Lambda(1520)\pi$ $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.081 ± 0.021	[2] CAMERON	77	DPWA	P-wave decay

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2000) \to N\bar{K}^*(892)$, S=1/2, S-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.10 ± 0.02	[2] CAMERON	78B	DPWA	$K^-p \to N\bar{K}^*$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2000) \to N\bar{K}^*(892)$, S=3/2, D-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.07 ± 0.03	CAMERON	78B	DPWA	$K^-p \to N\bar{K}^*$

Σ(2000) FOOTNOTES

[1] The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit.
[2] The published sign has been changed to be in accord with the baryon-first convention.

Σ(2000) REFERENCES

GOPAL	80	Toronto Conf. 159		(RHEL) IJP
CAMERON	78B	NP B146 327	+Franek, Gopal, Kalmus, McPherson+	(RHEL, LOIC) IJP
CAMERON	77	NP B131 399	+Franek, Gopal, Kalmus, McPherson+	(RHEL, LOIC) IJP
GOPAL	77	NP B119 362	+Ross, VanHorn, McPherson+	(LOIC, RHEL) IJP
MARTIN	77	NP B127 349	+Pidcock, Moorhouse	(LOUC, GLAS) IJP
Also	77B	NP B126 266	Martin, Pidcock	(LOUC)
Also	77C	NP B126 285	Martin, Pidcock	(LOUC) IJP
BAILLON	75	NP B94 39	+Litchfield	(CERN, RHEL) IJP
VANHORN	75	NP B87 145		(LBL) IJP
Also	75B	NP B87 157	VanHorn	(LBL) IJP

Σ(2030) F_{17}

$I(J^P) = 1(\frac{7}{2}^+)$ Status ****

Discovered by COOL 66 and by WOHL 66. For most results published before 1974 (they are now obsolete), see our 1982 edition (Physics Letters **111B**).

This entry only includes results from partial-wave analyses. Parameters of peaks seen in cross sections and invariant-mass distributions around 2030 MeV may be found in our 1984 edition, Rev. Mod. Phys. 56 (April 1984, Part II).

Σ(2030) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2025 to 2040 OUR ESTIMATE				
2036 ± 5	GOPAL	80	DPWA	$KN \to \bar{K}N$
2038 ± 10	CORDEN	77B		$K^- N \to NK^*$
2040 ± 5	GOPAL	77	DPWA	$\bar{K}N$ multichannel
2030 ± 3	[1] CORDEN	76	DPWA	$K^- n \to \Lambda\pi^-$
2035 ± 15	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
2038 ± 10	HEMINGWAY	75	DPWA	$K^- p \to \bar{K}N$
2042 ± 11	VANHORN	75	DPWA	$K^- p \to \Lambda\pi^0$
2020 ± 6	KANE	74	DPWA	$K^- p \to \Sigma\pi$
2035 ± 10	LITCHFIELD	74B	DPWA	$K^- p \to \Lambda(1520)\pi^0$
2020 ± 30	LITCHFIELD	74C	DPWA	$K^- p \to \Delta(1232)\bar{K}$
2025 ± 10	LITCHFIELD	74D	DPWA	$K^- p \to \Lambda(1820)\pi^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2027 to 2057	GOYAL	77	DPWA	$K^- N \to \Sigma\pi$
2030	DEBELLEFON	76	IPWA	$K^- p \to \Lambda\pi^0$

Σ(2030) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
150 to 200 OUR ESTIMATE				
172 ± 10	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
137 ± 40	CORDEN	77B		$K^- N \to NK^*$
190 ± 10	GOPAL	77	DPWA	$\bar{K}N$ multichannel
201 ± 9	[1] CORDEN	76	DPWA	$K^- n \to \Lambda\pi^-$
180 ± 20	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
172 ± 15	HEMINGWAY	75	DPWA	$K^- p \to \bar{K}N$
178 ± 13	VANHORN	75	DPWA	$K^- p \to \Lambda\pi^0$
111 ± 5	KANE	74	DPWA	$K^- p \to \Sigma\pi$
160 ± 20	LITCHFIELD	74B	DPWA	$K^- p \to \Lambda(1520)\pi^0$
200 ± 30	LITCHFIELD	74C	DPWA	$K^- p \to \Delta(1232)\bar{K}$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
260	DECLAIS	77	DPWA	$\bar{K}N \to \bar{K}N$
126 to 195	GOYAL	77	DPWA	$K^- N \to \Sigma\pi$
160	DEBELLEFON	76	IPWA	$K^- p \to \Lambda\pi^0$
70 to 125	LITCHFIELD	74D	DPWA	$K^- p \to \Lambda(1820)\pi^0$

Σ(2030) DECAY MODES

	Mode
Γ_1	$\Sigma(2030) \to N\bar{K}$
Γ_2	$\Sigma(2030) \to \Lambda\pi$
Γ_3	$\Sigma(2030) \to \Sigma\pi$
Γ_4	$\Sigma(2030) \to \Xi K$
Γ_5	$\Sigma(2030) \to \Lambda(1820)\pi$, *P*-wave
Γ_6	$\Sigma(2030) \to \Lambda(1520)\pi$, *D*-wave
Γ_7	$\Sigma(2030) \to \Lambda(1520)\pi$, *G*-wave
Γ_8	$\Sigma(2030) \to \Delta(1232)\bar{K}$, *F*-wave
Γ_9	$\Sigma(2030) \to \Delta(1232)\bar{K}$, *H*-wave
Γ_{10}	$\Sigma(2030) \to \Sigma(1385)\pi$, *F*-wave
Γ_{11}	$\Sigma(2030) \to N\bar{K}^*(892)$, *S*=1/2, *F*-wave
Γ_{12}	$\Sigma(2030) \to N\bar{K}^*(892)$, *S*=3/2, *F*-wave

Σ(2030) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances.

$\Gamma(N\bar{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.17 to 0.23 OUR ESTIMATE				
0.19 ± 0.03	GOPAL	80	DPWA	$\bar{K}N \to \bar{K}N$
0.18 ± 0.03	HEMINGWAY	75	DPWA	$K^- p \to \bar{K}N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.15	DECLAIS	77	DPWA	$\bar{K}N \to \bar{K}N$
0.24 ± 0.02	GOPAL	77	DPWA	See GOPAL 80

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2030) \to \Lambda\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.18 ± 0.02	GOPAL	77	DPWA	$\bar{K}N$ multichannel
+0.20 ± 0.01	[1] CORDEN	76	DPWA	$K^- n \to \Lambda\pi^-$
+0.18 ± 0.02	BAILLON	75	IPWA	$\bar{K}N \to \Lambda\pi$
+0.20 ± 0.01	VANHORN	75	DPWA	$K^- p \to \Lambda\pi^0$
+0.195 ± 0.053	DEVENISH	74B		Fixed-*t* dispersion rel
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.20	DEBELLEFON	76	IPWA	$K^- p \to \Lambda\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2030) \to \Sigma\pi$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.09 ± 0.01	[2] CORDEN	77C		$K^- n \to \Sigma\pi$
−0.06 ± 0.01	[2] CORDEN	77C		$K^- n \to \Sigma\pi$
−0.15 ± 0.03	GOPAL	77	DPWA	$\bar{K}N$ multichannel
−0.10 ± 0.01	KANE	74	DPWA	$K^- p \to \Sigma\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.085 ± 0.02	[3] GOYAL	77	DPWA	$K^- N \to \Sigma\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2030) \to \Xi K$ — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.023	MULLER	69B	DPWA	$K^- p \to \Xi K$
<0.05	BURGUN	68	DPWA	$K^- p \to \Xi K$
<0.05	TRIPP	67	RVUE	$K^- p \to \Xi K$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2030) \to \Lambda(1820)\pi$, *P*-wave — $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.14 ± 0.02	CORDEN	75B	DBC	$K^- n \to NK\pi^-$
0.18 ± 0.04	LITCHFIELD	74D	DPWA	$K^- p \to \Lambda(1820)\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2030) \to \Lambda(1520)\pi$, *D*-wave — $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.114 ± 0.010	[4] CAMERON	77	DPWA	$K^- p \to \Lambda(1520)\pi^0$
0.14 ± 0.03	LITCHFIELD	74B	DPWA	$K^- p \to \Lambda(1520)\pi^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.10 ± 0.03	[5] CORDEN	75B	DBC	$K^- n \to NK\pi^-$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2030) \to \Lambda(1520)\pi$, *G*-wave — $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.146 ± 0.010	[4] CAMERON	77	DPWA	$K^- p \to \Lambda(1520)\pi^0$
0.02 ± 0.02	LITCHFIELD	74B	DPWA	$K^- p \to \Lambda(1520)\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2030) \to \Delta(1232)\bar{K}$, *F*-wave — $(\Gamma_1\Gamma_8)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.16 ± 0.03	LITCHFIELD	74C	DPWA	$K^- p \to \Delta(1232)\bar{K}$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.17 ± 0.03	[5] CORDEN	75B	DBC	$K^- n \to NK\pi^-$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2030) \to \Delta(1232)\bar{K}$, *H*-wave — $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.00 ± 0.02	LITCHFIELD	74C	DPWA	$K^- p \to \Delta(1232)\bar{K}$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2030) \to \Sigma(1385)\pi$, *F*-wave — $(\Gamma_1\Gamma_{10})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.153 ± 0.026	[4] CAMERON	78	DPWA	$K^- p \to \Sigma(1385)\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2030) \to N\bar{K}^*(892)$, *S*=1/2, *F*-wave — $(\Gamma_1\Gamma_{11})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.06 ± 0.03	[4] CAMERON	78B	DPWA	$K^- p \to NK^*$
−0.02 ± 0.01	CORDEN	77B		$K^- d \to NNK^*$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2030) \to N\bar{K}^*(892)$, *S*=3/2, *F*-wave — $(\Gamma_1\Gamma_{12})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.04 ± 0.03	[6] CAMERON	78B	DPWA	$K^- p \to N\bar{K}^*$
−0.12 ± 0.02	CORDEN	77B		$K^- d \to NNK^*$

Σ(2030) FOOTNOTES

[1] Preferred solution 3; see CORDEN 76 for other possibilities.
[2] The two entries for CORDEN 77C are from two different acceptable solutions.
[3] This coupling is extracted from unnormalized data.
[4] The published sign has been changed to be in accord with the baryon-first convention.
[5] An upper limit.
[6] The upper limit on the G_3 wave is 0.03.

Σ(2030) REFERENCES

GOPAL	80	Toronto Conf. 159	(RHEL) IJP
CAMERON	78	NP B143 189	+Franek, Gopal, Bacon, Butterworth+ (RHEL, LOIC) IJP
CAMERON	78B	NP B146 327	+Franek, Gopal, Kalmus, McPherson+(RHEL, LOIC) IJP
CAMERON	77	NP B131 399	+Franek, Gopal, Kalmus, McPherson+(RHEL, LOIC) IJP

Baryon Full Listings
Σ(2030), Σ(2070), Σ(2080), Σ(2100)

CORDEN 77B NP B121 365 +Cox Kenyon O Neale Stubbs Sumorok+ (BIRM) IJP
CORDEN 77C NP B125 61 +Cox Kenyon O Neale Stubbs Sumorok+ (BIRM) IJP
DECLAIS 77 CERN 77 16 +Duchon Louvel Patry Seguinot+ (CAEN CERN) IJP
GOPAL 77 NP B119 362 +Ross VanHorn McPherson+ (LOIC RHEL) IJP
GOYAL 77 PR D16 2746 +Sodhi (DELH) IJP
CORDEN 76 NP B104 382 +Cox Dartnell Kenyon O Neale+ (BIRM) IJP
DEBELLEFON 76 NP B109 129 De Bellefon Berthon (CDEF) IJP
BAILLON 75 NP B94 39 +Litchfield (CERN RHEL) IJP
CORDEN 75B NP B92 365 +Cox Dartnell Kenyon O Neale+ (BIRM) IJP
HEMINGWAY 75 NP B91 12 +Eades Harmsen+ (CERN HEID MPIM) IJP
VANHORN 75 NP B87 145 (LBL) IJP
Also 75B NP B87 157 VanHorn (LBL) IJP
DEVENISH 74B NP B81 330 +Froggatt Martin (DESY NORD LOUC)
KANE 74 LBL 2452 (LBL) IJP
LITCHFIELD 74B NP B74 19 +Hemingway Baillon+ (CERN HEID) IJP
LITCHFIELD 74C NP B74 39 +Hemingway Baillon+ (CERN HEID) IJP
LITCHFIELD 74D NP B74 12 +Hemingway Baillon+ (CERN HEID) IJP
MULLER 69B UCRL 19372 Thesis (LRL)
BURGUN 68 NP B8 447 +Meyer Pauli Tallini+ (SACL CDEF RHEL)
TRIPP 67 NP B3 10 +Leith+ (LRL SLAC CERN HEID SACL)
COOL 66 PRL 16 1228 +Giacomelli Kycia Leontic Lundby+ (BNL)
WOHL 66 PRL 17 107 +Solmitz Stevenson (LRL) IJP

Σ(2070) F_{15}

$I(J^P) = 1(\frac{5}{2}^+)$ Status *

OMITTED FROM SUMMARY TABLE

This state suggested by BERTHON 70B finds support in GOPAL 80 with new K^-p polarization and K^-n angular distributions. The very broad state seen in KANE 72 is not required in the later (KANE 74) analysis of $\overline{K}N \to \Sigma\pi$.

Σ(2070) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2051 ± 25	GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$
2057	KANE	72	DPWA	$K^-p \to \Sigma\pi$
2070 ± 10	BERTHON	70B	DPWA	$K^-p \to \Sigma\pi$

Σ(2070) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
300 ± 30	GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$
906	KANE	72	DPWA	$K^-p \to \Sigma\pi$
140 ± 20	BERTHON	70B	DPWA	$K^-p \to \Sigma\pi$

Σ(2070) DECAY MODES

Γ_1 Σ(2070) → $N\overline{K}$
Γ_2 Σ(2070) → $\Sigma\pi$

Σ(2070) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances.

$\Gamma(N\overline{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.08 ± 0.03	GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to$ Σ(2070) → $\Sigma\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.104	KANE	72	DPWA	$K^-p \to \Sigma\pi$
+0.12 ± 0.02	BERTHON	70B	DPWA	$K^-p \to \Sigma\pi$

Σ(2070) REFERENCES

GOPAL 80 Toronto Conf 159 (RHEL) IJP
KANE 74 LBL 2452 (LBL)
KANE 72 PR D5 1583 (LBL)
BERTHON 70B NP B24 417 +Vrana Butterworth+ (CDEF RHEL SACL) IJP

Σ(2080) P_{13}

$I(J^P) = 1(\frac{3}{2}^+)$ Status * *

OMITTED FROM SUMMARY TABLE

Suggested by some but not all partial-wave analyses across this region.

Σ(2080) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2091 ± 7	[1] CORDEN	76	DPWA	$K^-n \to \Lambda\pi^-$
2070 to 2120	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$
2120 ± 40	BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$ (sol 1)
2140 ± 40	BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$ (sol 2)
2082 ± 4	COX	70	DPWA	See CORDEN 76
2070 ± 30	LITCHFIELD	70	DPWA	$K^-N \to \Lambda\pi$

Σ(2080) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
186 ± 48	[1] CORDEN	76	DPWA	$K^-n \to \Lambda\pi^-$
100	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$
240 ± 50	BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$ (sol 1)
200 ± 50	BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$ (sol 2)
87 ± 20	COX	70	DPWA	See CORDEN 76
250 ± 40	LITCHFIELD	70	DPWA	$K^-N \to \Lambda\pi$

Σ(2080) DECAY MODES

Γ_1 Σ(2080) → $N\overline{K}$
Γ_2 Σ(2080) → $\Lambda\pi$

Σ(2080) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances.

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{K} \to$ Σ(2080) → $\Lambda\pi$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.10 ± 0.03	[1] CORDEN	76	DPWA	$K^-n \to \Lambda\pi^-$
−0.10	DEBELLEFON	76	IPWA	$K^-p \to \Lambda\pi^0$
−0.13 ± 0.04	BAILLON	75	IPWA	$\overline{K}N \to \Lambda\pi$ (sol 1&2)
−0.16 ± 0.03	COX	70	DPWA	See CORDEN 76
−0.09 ± 0.03	LITCHFIELD	70	DPWA	$K^-N \to \Lambda\pi$

Σ(2080) FOOTNOTES

[1] Preferred solution 3; see CORDEN 76 for other possibilities, including a D_{15} at this mass.

Σ(2080) REFERENCES

CORDEN 76 NP B104 382 +Cox Dartnell Kenyon O Neale+ (BIRM) IJP
DEBELLEFON 76 NP B109 129 De Bellefon Berthon (CDEF) IJP
Also 75 NP B90 1 De Bellefon Berthon Brunet+ (CDEF SACL) IJP
BAILLON 75 NP B94 39 +Litchfield (CERN RHEL) IJP
COX 70 NP B19 61 +Islam Colley+ (BIRM EDIN GLAS LOIC) IJP
LITCHFIELD 70 NP B22 269 (RHEL) IJP

Σ(2100) G_{17}

$I(J^P) = 1(\frac{7}{2}^-)$ Status *

OMITTED FROM SUMMARY TABLE

Σ(2100) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2060 ± 20	BARBARO-	70	DPWA	$K^-p \to \Lambda\pi^0$
2120 ± 30	BARBARO-	70	DPWA	$K^-p \to \Sigma\pi$

Σ(2100) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
70 ± 30	BARBARO-	70	DPWA	$K^-p \to \Lambda\pi^0$
135 ± 30	BARBARO-	70	DPWA	$K^-p \to \Sigma\pi$

$\Sigma(2100)$ DECAY MODES

Γ_1	$\Sigma(2100) \to N\bar{K}$
Γ_2	$\Sigma(2100) \to \Lambda\pi$
Γ_3	$\Sigma(2100) \to \Sigma\pi$

$\Sigma(2100)$ BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2100) \to \Lambda\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.07 ± 0.02	BARBARO-	70	DPWA	$K^-p \to \Lambda\pi^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2100) \to \Sigma\pi$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.13 ± 0.02	BARBARO	70	DPWA	$K^-p \to \Sigma\pi$

$\Sigma(2100)$ REFERENCES

BARBARO 70 Duke Conf 173 Barbaro Galtieri (LRL) IJP

$\Sigma(2250)$

$I(J^P) = 1(?^?)$ Status * * *

Results from partial-wave analyses are too weak to warrant separating them from the production and cross-section experiments. LASINSKI 71 in KN using a Pomeron + resonances model, and DEBELLEFON 76, DEBELLEFON 77, and DEBELLEFON 78 in energy-dependent partial-wave analyses of $\bar{K}N \to \Lambda\pi$, $\Sigma\pi$, and $N\bar{K}$, respectively, suggest two resonances around this mass.

$\Sigma(2250)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2210 to 2280 OUR ESTIMATE				
2270 ± 50	DEBELLEFON	78	DPWA	D_5 wave
2210 ± 30	DEBELLEFON	78	DPWA	G_9 wave
2275 ± 20	DEBELLEFON	77	DPWA	D_5 wave
2215 ± 20	DEBELLEFON	77	DPWA	G_9 wave
2300 ± 30	[1] DEBELLEFON	75B	HBC	$K^-p \to \Xi^{*0}K^0$
2251^{+30}_{-20}	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$ F_5 wave
2280 ± 14	AGUILAR	70B	HBC	K^-p 3.9, 4.6 GeV/c
2237 ± 11	BRICMAN	70	CNTR	Total charge exchange
2255 ± 10	COOL	70	CNTR	K^-p, K^-d total
2250 ± 7	BUGG	68	CNTR	K^-p, K^-d total
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2260	DEBELLEFON	76	IPWA	D_5 wave
2215	DEBELLEFON	76	IPWA	G_9 wave
2250 ± 20	LU	70	CNTR	$\gamma p \to K^+Y^*$
2245	BLANPIED	65	CNTR	$\gamma p \to K^+Y^*$
2299 ± 6	BOCK	65	HBC	$\bar{p}p$ 5.7 GeV/c

$\Sigma(2250)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
60 to 150 OUR ESTIMATE				
120 ± 40	DEBELLEFON	78	DPWA	D_5 wave
80 ± 20	DEBELLEFON	78	DPWA	G_9 wave
70 ± 20	DEBELLEFON	77	DPWA	D_5 wave
60 ± 20	DEBELLEFON	77	DPWA	G_9 wave
130 ± 20	[1] DEBELLEFON	75B	HBC	$K^-p \to \Xi^{*0}K^0$
192 ± 30	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$ F_5 wave
100 ± 20	AGUILAR	70B	HBC	K^-p 3.9, 4.6 GeV/c
164 ± 50	BRICMAN	70	CNTR	Total charge exchange
230 ± 20	BUGG	68	CNTR	K^-p, K^-d total
• • • We do not use the following data for averages, fits, limits, etc. • • •				
100	DEBELLEFON	76	IPWA	D_5 wave
140	DEBELLEFON	76	IPWA	G_9 wave
170	COOL	70	CNTR	K^-p, K^-d total
125	LU	70	CNTR	$\gamma p \to K^+Y^*$
150	BLANPIED	65	CNTR	$\gamma p \to K^+Y^*$
21^{+17}_{-21}	BOCK	65	HBC	$\bar{p}p$ 5.7 GeV/c

$\Sigma(2250)$ DECAY MODES

Γ_1	$\Sigma(2250) \to N\bar{K}$
Γ_2	$\Sigma(2250) \to \Lambda\pi$
Γ_3	$\Sigma(2250) \to \Sigma\pi$
Γ_4	$\Sigma(2250) \to N\bar{K}\pi$
Γ_5	$\Sigma(2250) \to \Xi(1530)K$

$\Sigma(2250)$ BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances

$\Gamma(N\bar{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
<0.1 OUR ESTIMATE				
0.08 ± 0.02	DEBELLEFON	78	DPWA	D_5 wave
0.02 ± 0.01	DEBELLEFON	78	DPWA	G_9 wave

$(J+\frac{1}{2}) \times \Gamma(N\bar{K})/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.16 ± 0.12	BRICMAN	70	CNTR	Total charge exchange
0.42	COOL	70	CNTR	K^-p, K^-d total
0.47	BUGG	68	CNTR	

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2250) \to \Lambda\pi$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.16 ± 0.03	VANHORN	75	DPWA	$K^-p \to \Lambda\pi^0$ F_5 wave
• • • We do not use the following data for averages, fits, limits, etc. • • •				
+0.11	DEBELLEFON	76	IPWA	D_5 wave
−0.10	DEBELLEFON	76	IPWA	G_9 wave
−0.18	BARBARO	70	DPWA	$K^-p \to \Lambda\pi^0$ G_9 wave

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2250) \to \Sigma\pi$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.06 ± 0.02	DEBELLEFON	77	DPWA	D_5 wave
−0.03 ± 0.02	DEBELLEFON	77	DPWA	G_9 wave
+0.07	BARBARO	70	DPWA	$K^-p \to \Sigma\pi$ G_9 wave

$\Gamma(N\bar{K})/\Gamma(\Sigma\pi)$ — Γ_1/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.18	BARNES	69	HBC	1 standard dev limit

$\Gamma(\Lambda\pi)/\Gamma(\Sigma\pi)$ — Γ_2/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.18	BARNES	69	HBC	1 standard dev limit

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Sigma(2250) \to \Xi(1530)K$ — $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
0.18 ± 0.04	[1] DEBELLEFON	75B	HBC	$K^-p \to \Xi^{*0}K^0$

$\Sigma(2250)$ FOOTNOTES

[1] Seen in the (initial and final state) D_5 wave. Isospin not determined.

$\Sigma(2250)$ REFERENCES

DEBELLEFON	78	NC 42A 403	De Bellefon, Berthon, Billoir+	(CDEF, SACL) IJP
DEBELLEFON	77	NC 37A 175	De Bellefon, Berthon, Billoir+	(CDEF, SACL) IJP
DEBELLEFON	76	NP B109 129	De Bellefon, Berthon	(CDEF) IJP
Also	75	NP B90 1	De Bellefon, Berthon, Brunet+	(CDEF, SACL) IJP
DEBELLEFON	75B	NC 28A 289	De Bellefon, Berthon, Billoir+	(CDEF, SACL)
VANHORN	75	NP B87 145		(LBL) IJP
Also	75B	NP B87 157	VanHorn	(LBL) IJP
LASINSKI	71	NP B29 125		(EFI) IJP
AGUILAR	70B	PRL 25 58	Aguilar-Benitez, Barnes, Bassano+	(BNL, SYRA)
BARBARO	70	Duke Conf 173	Barbaro-Galtieri	(LRL) IJP
BRICMAN	70	PL 31B 152	+Ferro-Luzzi, Perreau+	(CERN, CAEN, SACL)
COOL	70	PR D1 1887	+Giacomelli, Kycia, Leontic, Li+	(BNL) I
Also	66	PRL 16 1228	Cool, Giacomelli, Kycia, Leontic, Lundby+	(BNL) I
LU	70	PR D2 1846	+Greenberg, Hughes, Minehart, Mori+	(YALE)
BARNES	69	PRL 22 479	+Flaminio, Montanet, Samios+	(BNL, SYRA)
BUGG	68	PR 168 1466	+Gilmore, Knight+	(RHEL, BIRM, CAVE) I
BLANPIED	65	PRL 14 741	+Greenberg, Hughes, Kitching, Lu+	(YALE, CEA)
BOCK	65	PL 17 166	+Cooper, French, Kinson+	(CERN, SACL)

Σ(2455) BUMPS

$I(J^P) = 1(?^?)$ Status * *

OMITTED FROM SUMMARY TABLE

There is also some slight evidence for Y^* states in this mass region from the reaction $\gamma p \to K^+ X$ see GREENBERG 68

Σ(2455) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2455 ± 10	ABRAMS	70	CNTR	$K^- p$, $K^- d$ total
2455 ± 7	BUGG	68	CNTR	$K^- p$, $K^- d$ total

Σ(2455) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
140	ABRAMS	70	CNTR	$K^- p$, $K^- d$ total
100 ± 20	BUGG	68	CNTR	

Σ(2455) DECAY MODES

Γ_1 Σ(2455) → $N\bar{K}$

Σ(2455) BRANCHING RATIOS

$(J+\frac{1}{2}) \times \Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0 39	ABRAMS	70	CNTR	$K^- p$, $K^- d$ total
0 05 ± 0.05	[1] BRICMAN	70	CNTR	Total charge exchange
0.3	BUGG	68	CNTR	

Σ(2455) FOOTNOTES

[1] Fit of total cross section given by BRICMAN 70 is poor in this region

Σ(2455) REFERENCES

ABRAMS	70	PR D1 1917	+Cool Giacomelli Kycia Leontic Li+	(BNL) I
Also	67E	PRL 19 678	Abrams Cool Giacomelli Kycia Leontic+	(BNL)
BRICMAN	70	PL 31B 152	+Ferro Luzzi Perreau+	(CERN CAEN SACL)
BUGG	68	PR 168 1466	+Gilmore Knight+	(RHEL BIRM CAVE) I
GREENBERG	68	PRL 20 221	+Hughes Lu Minehart+	(YALE)

Σ(2620) BUMPS

$I(J^P) = 1(?^?)$ Status * *

OMITTED FROM SUMMARY TABLE

Σ(2620) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2542 ± 22	DIBIANCA	75	DBC	$K^- N \to \Xi K \pi$
2620 ± 15	ABRAMS	70	CNTR	$K^- p$, $K^- d$ total

Σ(2620) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
221 ± 81	DIBIANCA	75	DBC	$K^- N \to \Xi K \pi$
175	ABRAMS	70	CNTR	$K^- p$, $K^- d$ total

Σ(2620) DECAY MODES

Γ_1 Σ(2620) → $N\bar{K}$

Σ(2620) BRANCHING RATIOS

$(J+\frac{1}{2}) \times \Gamma(N\bar{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0 32	ABRAMS	70	CNTR	$K^- p$, $K^- d$ total
0 36 ± 0 12	BRICMAN	70	CNTR	Total charge exchange

Σ(2620) REFERENCES

DIBIANCA	75	NP B98 137	+Endorf	(CMU)
ABRAMS	70	PR D1 1917	+Cool Giacomelli Kycia Leontic Li+	(BNL) I
Also	67E	PRL 19 678	Abrams Cool Giacomelli Kycia Leontic+	(BNL)
BRICMAN	70	PL 31B 152	+Ferro Luzzi Perreau+	(CERN CAEN SACL)

Σ(3000) BUMPS

$I(J^P) = 1(?^?)$ Status *

OMITTED FROM SUMMARY TABLE

Seen as an enhancement in $\Lambda\pi$ and KN invariant mass spectra and in the missing mass of neutrals recoiling against a K^0

Σ(3000) MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
3000	EHRLICH	66	HBC	0	$\pi^- p$ 7 91 GeV/c

Σ(3000) DECAY MODES

Γ_1 Σ(3000) → $N\bar{K}$

Γ_2 Σ(3000) → $\Lambda\pi$

Σ(3000) REFERENCES

EHRLICH	66	PR 152 1194	+Selove Yuta	(PENN) I

Σ(3170) BUMPS

$I(J^P) = 1(?^?)$ Status *

OMITTED FROM SUMMARY TABLE

Seen by AMIRZADEH 79 as a narrow 6 5-standard-deviation enhancement in the reaction $K^- p \to Y^{*+} \pi^-$ using data from independent high statistics bubble chamber experiments at 8 25 and 6 5 GeV/c The dominant decay modes are multibody, multistrange final states and the production is via isospin-3/2 baryon exchange Isospin 1 is favored

Not seen in a $K^- p$ experiment in LASS at 11 GeV/c (ASTON 85B)

Σ(3170) MASS (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3170 ± 5	35	AMIRZADEH	79	HBC	$K^- p \to Y^{*+} \pi^-$

Σ(3170) WIDTH (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
<20	35	[1] AMIRZADEH	79	HBC	$K^- p \to Y^{*+} \pi^-$

Σ(3170) DECAY MODES (PRODUCTION EXPERIMENTS)

Γ_1 $\Sigma(3170) \to \Lambda K \overline{K} \pi$'s
Γ_2 $\Sigma(3170) \to \Sigma K \overline{K} \pi$'s
Γ_3 $\Sigma(3170) \to \Xi K \pi$'s

Σ(3170) BRANCHING RATIOS (PRODUCTION EXPERIMENTS)

$\Gamma(\Lambda K \overline{K} \pi\text{'s})/\Gamma_{\text{total}}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
SEEN	AMIRZADEH	79	HBC	$K^- p \to Y^{*+} \pi^-$

$\Gamma(\Sigma K \overline{K} \pi\text{'s})/\Gamma_{\text{total}}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
SEEN	AMIRZADEH	79	HBC	$K^- p \to Y^{*+} \pi^-$

$\Gamma(\Xi K \pi\text{'s})/\Gamma_{\text{total}}$ Γ_3/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
SEEN	AMIRZADEH	79	HBC	$K^- p \to Y^{*+} \pi^-$

Σ(3170) FOOTNOTES (PRODUCTION EXPERIMENTS)

[1] Observed width consistent with experimental resolution

Σ(3170) REFERENCES (PRODUCTION EXPERIMENTS)

ASTON 85B PR D32 2270 +Carnegie+ (SLAC CARL CNRC CINC)
AMIRZADEH 79 PL 89B 125 + (BIRM CERN GLAS MSU LPNP CAMB+) I
Also 80 Toronto Conf 263 Kinson+ (BIRM CERN GLAS MSU LPNP) I

NOTE ON Ξ RESONANCES

The accompanying table gives our evaluation of the present status of the Ξ resonances Not much is known about Ξ resonances This is because (1) they can only be produced as a part of a final state, and so the analysis is more complicated than if direct formation were possible, (2) they are produced with small cross sections (typically a few μb), and (3) the final states are topologically complicated and difficult to study with electronic techniques Thus our early information about Ξ resonances came entirely from bubble chamber experiments, where the numbers of events are small, and only in recent years have electronic experiments made significant contributions

Since our 1986 edition, the CERN-SPS Ξ beam experiment at 116 GeV (BIAGI 87 and BIAGI 87C) has published new information on several Ξ resonances In particular, there is additional evidence for the Ξ(1690) and Ξ(1950), and we have advanced these states to 3-star status and the main Baryon Table Little, however, can be said about the widths, branching fractions, or quantum numbers of these states, and there may well be more than one Ξ near 1950 MeV

For a detailed earlier review, see Meadows [1]

Table I The status of the Ξ resonances Only those with an overall status of *** or **** are included in the Baryon Summary Table

			Status as seen in --				
Particle	$L_{2I\,2J}$	Overall status	$\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
Ξ(1318)	P_{11}	****					Decays weakly
Ξ(1530)	P_{13}	****	****				
Ξ(1620)		*	*				
Ξ(1690)		***		***	**		
Ξ(1820)	D_{13}	***	**	***	**	**	
Ξ(1950)		***	**	**		*	
Ξ(2030)		***		**	***		
Ξ(2120)		*		*			
Ξ(2250)		**					3-body decays
Ξ(2370)		**					3-body decays
Ξ(2500)		*		*	*		3-body decays

**** Good clear, and unmistakable
*** Good, but in need of clarification or not absolutely certain
** Not established, needs confirmation
* Evidence weak, could disappear

References

1 B T Meadows, in *Proceedings of the IV th International Conference on Baryon Resonances* (Toronto, 1980), ed N Isgur, p 283

Ξ BARYONS
(S = −2, I = 1/2)

Ξ^0

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status ****

SEE STABLE PARTICLES

Ξ^-

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status ****

SEE STABLE PARTICLES

Ξ(1530) P_{13}

$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$ Status ****

This is the only Ξ resonance whose properties are all reasonably well known Spin-parity $3/2^+$ is favored by the data

We use only those determinations of the mass and width that are accompanied by some discussion of systematics and resolution

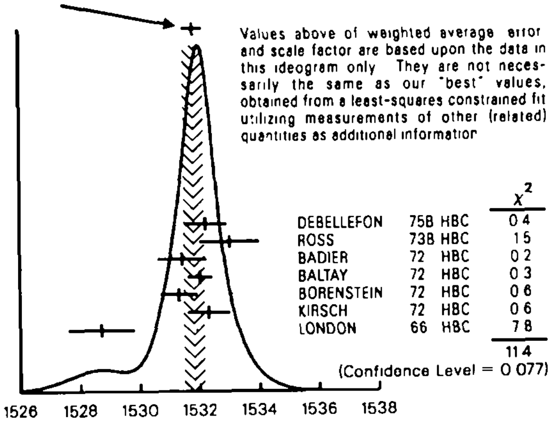
Baryon Full Listings
Ξ(1530)

Ξ(1530) MASSES

Ξ(1530)⁰ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1531.80 ± 0.32	**OUR FIT**	Error includes scale factor of 1.3			
1531.78 ± 0.34	**OUR AVERAGE**	Error includes scale factor of 1.4. See the ideogram below.			
1532.2 ± 0.7		DEBELLEFON	75B	HBC	$K^- p \to \Xi^- \bar{K}\pi$
1533 ± 1		ROSS	73B	HBC	$K^- p \to \Xi \bar{K}\pi(\pi)$
1531.4 ± 0.8	59	BADIER	72	HBC	$K^- p$ 3.95 GeV/c
1532.0 ± 0.4	1262	BALTAY	72	HBC	$K^- p$ 1.75 GeV/c
1531.3 ± 0.6	324	BORENSTEIN	72	HBC	$K^- p$ 2.2 GeV/c
1532.3 ± 0.7	286	KIRSCH	72	HBC	$K^- p$ 2.87 GeV/c
1528.7 ± 1.1	76	LONDON	66	HBC	$K^- p$ 2.24 GeV/c
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1532.1 ± 0.4	1244	ASTON	85B	LASS	$K^- p$ 11 GeV/c
1532.1 ± 0.6	2700	[1] BAUBILLIER	81B	HBC	$K^- p$ 8.25 GeV/c
1530 ± 1	450	BIAGI	81	SPEC	SPS hyperon beam
1527 ± 6	80	SIXEL	79	HBC	$K^- p$ 10 GeV/c
1535 ± 4	100	SIXEL	79	HBC	$K^- p$ 16 GeV/c
1533.6 ± 1.4	97	BERTHON	74	HBC	Quasi 2-body σ

WEIGHTED AVERAGE
1531.78 ± 0.34 (Error scaled by 1.4)



Ξ(1530)⁰ mass (MeV)

Ξ(1530)⁻ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1535.0 ± 0.6	**OUR FIT**				
1535.2 ± 0.8	**OUR AVERAGE**				
1534.5 ± 1.2		DEBELLEFON	75B	HBC	$K^- p \to \Xi^- \bar{K}\pi$
1535.3 ± 2.0		ROSS	73B	HBC	$K^- p \to \Xi \bar{K}\pi(\pi)$
1536.2 ± 1.6	185	KIRSCH	72	HBC	$K^- p$ 2.87 GeV/c
1535.7 ± 3.2	38	LONDON	66	HBC	$K^- p$ 2.24 GeV/c
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1540 ± 3	48	BERTHON	74	HBC	Quasi-2-body σ
1534.7 ± 1.1	334	BALTAY	72	HBC	$K^- p$ 1.75 GeV/c

MIXED CHARGES (− and 0)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1532 ± 2		BADIER	64	HBC	$K^- p$ 3 GeV/c
1535	20	BERTANZA	62	HBC	$K^- p$ 2.3 GeV/c
1529 ± 5	55	PJERROU	62	HBC	$K^- p$ 1.8 GeV/c

Ξ(1530)⁻ − Ξ(1530)⁰ MASS DIFFERENCE

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
3.2 ± 0.6	**OUR FIT**			
2.9 ± 0.9	**OUR AVERAGE**			
2.7 ± 1.0	BALTAY	72	HBC	$K^- p$ 1.75 GeV/c
2.0 ± 3.2	MERRILL	66	HBC	$K^- p$ 1.7–2.7 GeV/c
5.7 ± 3.0	PJERROU	65B	HBC	$K^- p$ 1.8–1.95 GeV/c
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3.9 ± 1.8	[2] KIRSCH	72	HBC	$K^- p$ 2.87 GeV/c
7 ± 4	[2] LONDON	66	HBC	$K^- p$ 2.24 GeV/c

Ξ(1530) WIDTHS

Ξ(1530)⁰ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
9.1 ± 0.5	**OUR AVERAGE**				
9.5 ± 1.2		DEBELLEFON	75B	HBC	$K^- p \to \Xi^- \bar{K}\pi$
9.1 ± 2.4		ROSS	73B	HBC	$K^- p \to \Xi \bar{K}\pi(\pi)$
11 ± 2		BADIER	72	HBC	$K^- p$ 3.95 GeV/c
9.0 ± 0.7		BALTAY	72	HBC	$K^- p$ 1.75 GeV/c
8.4 ± 1.4		BORENSTEIN	72	HBC	$\Xi^- \pi^+$
11.0 ± 1.8		KIRSCH	72	HBC	$\Xi^- \pi^+$
7 ± 7		BERGE	66	HBC	$K^- p$ 1.5–1.7 GeV/c
8.5 ± 3.5		LONDON	66	HBC	$K^- p$ 2.24 GeV/c
7 ± 2		SCHLEIN	63B	HBC	$K^- p$ 1.8–1.95 GeV/c
• • • We do not use the following data for averages, fits, limits, etc. • • •					
12.8 ± 1.0	2700	[1] BAUBILLIER	81B	HBC	$K^- p$ 8.25 GeV/c
19 ± 6	80	[3] SIXEL	79	HBC	$K^- p$ 10 GeV/c
14 ± 5	100	[3] SIXEL	79	HBC	$K^- p$ 16 GeV/c

Ξ(1530)⁻ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
$9.9^{+1.7}_{-1.9}$	**OUR AVERAGE**			
9.6 ± 2.8	DEBELLEFON	75B	HBC	$K^- p \to \Xi^- K\pi$
8.3 ± 3.6	ROSS	73B	HBC	$K^- p \to \Xi K\pi(\pi)$
$7.8^{+3.5}_{-7.8}$	BALTAY	72	HBC	$K^- p$ 1.75 GeV/c
16.2 ± 4.6	KIRSCH	72	HBC	$\Xi^- \pi^0$, $\Xi^0 \pi^-$

Ξ(1530) POLE POSITIONS

Ξ(1530)⁰ REAL PART

VALUE	DOCUMENT ID	COMMENT
1531.6 ± 0.4	LICHTENBERG 74	Using HABIBI 73

Ξ(1530)⁰ IMAGINARY PART

VALUE	DOCUMENT ID	COMMENT
4.45 ± 0.35	LICHTENBERG 74	Using HABIBI 73

Ξ(1530)⁻ REAL PART

VALUE	DOCUMENT ID	COMMENT
1534.4 ± 1.1	LICHTENBERG 74	Using HABIBI 73

Ξ(1530)⁻ IMAGINARY PART

VALUE	DOCUMENT ID	COMMENT
$3.9^{+1.75}_{-3.9}$	LICHTENBERG 74	Using HABIBI 73

Ξ(1530) DECAY MODES

Γ_1 Ξ(1530) → Ξπ
Γ_2 Ξ(1530) → Ξγ

Ξ(1530) BRANCHING RATIOS

$\Gamma(\Xi\gamma)/\Gamma_{total}$ Γ_2/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.04	90	KALBFLEISCH 75	HBC	$K^- p$ 2.18 GeV/c

Ξ(1530) FOOTNOTES

[1] BAUBILLIER 81B is a fit to the inclusive spectrum. The resolution (5 MeV) is not unfolded.
[2] Redundant with data in the mass Listings.
[3] SIXEL 79 doesn't unfold the experimental resolution of 15 MeV.

Ξ(1530) REFERENCES

ASTON	85B	PR D32 2270	+Carnegie+	(SLAC, CARL, CNRC, CINC)
BAUBILLIER	81B	NP B192 1	+	(BIRM, CERN, GLAS, MSU, LPNP)
BIAGI	81	ZPHY C9 305	+ (BRIS, CAMB, GEVA, HEID, LAUS, LOQM, RHEL)	
SIXEL	79	NP B159 125	+Bottcher+	(AACH, BERL, CERN, LOIC, VIEN)
DEBELLEFON	75B	NC 28A 289	De Bellefon, Berthon, Billoir+	(CDEF, SACL)
KALBFLEISCH	75	PR D11 987	+Strand, Chapman	(BNL, MICH)
BERTHON	74	NC 21A 146	+Tristram+	(CDEF, RHEL, SACL, STRB)
LICHTENBERG	74	PR D10 3865		(IND)
Also	74B	Private Comm.	Lichtenberg	(IND)
HABIBI	73	Nevis 199 Thesis		(COLU)
ROSS	73B	Purdue Conf. 355	+Lloyd, Radojicic	(OXF)
BADIER	72	NP B37 429	+Barrelet, Charlton, Videau	(EPOL)
BALTAY	72	PL 42B 129	+Bridgewater, Cooper, Gershwin+	(COLU, BING)
BORENSTEIN	72	PR D5 1559	+Danburg, Kalbfleisch+	(BNL, MICH) I
KIRSCH	72	NP B40 349	+Schmidt, Chang+	(BRAN, UMD, SYRA, TUFT) I
BERGE	66	PR 147 945	+Eberhard, Hubbard, Merrill+	(LRL) I
LONDON	66	PR 143 1034	+Rau, Goldberg, Lichtman+	(BNL, SYRA) IJ
MERRILL	66	UCRL 16455 Thesis		(LRL) JP
PJERROU	65B	PRL 14 275	+Schlein, Slater, Smith, Stork, Ticho	(UCLA)
BADIER	64	Dubna Conf. 1 593	+Demoulin, Barloutaud+	(EPOL, SACL, ZEEM) I
SCHLEIN	63B	PRL 11 167	+Carmony, Pjerrou, Slater, Stork, Ticho	(UCLA) IJP
BERTANZA	62	PRL 9 180	+Brisson, Connolly, Hart+	(BNL, SYRA) IJ
PJERROU	62	PRL 9 114	+Prowse, Schlein, Slater, Stork, Ticho	(UCLA) I

OTHER RELATED PAPERS

MAZZUCATO	81	NP B178 1	+Pennino+	(AMST CERN NIJM OXF)
BRIEFEL	77	PR D16 2706	+Gourevitch Chang+	(BRAN UMD SYRA TUFT)
BRIEFEL	75	PR D12 1859	+Gourevitch+	(BRAN UMD SYRA TUFT)
HUNGERBU	74	PR D10 2051	Hungerbuhler Majka+	(YALE FNAL BNL PITT)
BUTTON	66	PR 142 883	Button Shafer Lindsey Murray Smith	(LRL) JP

Ξ(1620)

$I(J^P) = \frac{1}{2}(?^?)$ Status *

OMITTED FROM SUMMARY TABLE

What little evidence there is consists of weak signals in the $\Xi\pi$ channel A number of other experiments (e g , BORENSTEIN 72 and HASSALL 81) have looked for but not seen any effect

Ξ(1620) MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1624 ± 3	31	BRIEFEL	77	HBC	K^-p 2 87 GeV/c
1633 ± 12	34	DEBELLEFON	75B	HBC	$K^-p \to \Xi^- K\pi$
1606 ± 6	29	ROSS	72	HBC	K^-p 3 1–3 7 GeV/c

Ξ(1620) WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
22 5	31	[1] BRIEFEL	77	HBC	K^-p 2 87 GeV/c
40 ± 15	34	DEBELLEFON	75B	HBC	$K^-p \to \Xi^- K\pi$
21 ± 7	29	ROSS	72	HBC	$K^-p \to \Xi^-\pi^+ K^{*0}(892)$

Ξ(1620) DECAY MODES

Γ_1 Ξ(1620) → $\Xi\pi$

Ξ(1620) FOOTNOTES

[1] The fit is insensitive to values between 15 and 30 MeV

Ξ(1620) REFERENCES

HASSALL	81	NP B189 397	+Ansorge Carter Neale+	(CAMB MSU)
BRIEFEL	77	PR D16 2706	+Gourevitch Chang+	(BRAN UMD SYRA TUFT)
Also	70	Duke Conf 317	Briefel+	(BRAN UMD SYRA TUFT)
Also	75	PR D12 1859	Briefel Gourevitch+	(BRAN UMD SYRA TUFT)
DEBELLEFON	75B	NC 28A 289	De Bellefon Berthon Billoir+	(CDEF SACL)
BORENSTEIN	72	PR D5 1559	+Danburg Kalbfleisch+	(BNL MICH) I
ROSS	72	PL 38B 177	+Buran Lloyd Mulvey Radojicic	(OXF) I

OTHER RELATED PAPERS

HUNGERBU	74	PR D10 2051	Hungerbuhler Majka+	(YALE FNAL BNL PITT)
SCHMIDT	73	Purdue Conf 363		(BRAN)
KALBFLEISCH	70	Duke Conf 331		(BNL) I
APSELL	69	PRL 23 884	+	(BRAN UMD SYRA TUFT)
BARTSCH	69	PL 28B 439	+	(AACH BERL CERN LOIC VIEN)

Ξ(1690)

$I(J^P) = \frac{1}{2}(?^?)$ Status * * *

DIONISI 78 sees a threshold enhancement in both the neutral and negatively charged ΣK mass spectra in $K^-p \to (\Sigma K)K\pi$ at 4 2 GeV/c The data from the ΣK channels alone cannot distinguish between a resonance and a large scattering length Weaker evidence at the same mass is seen in the corresponding $\Lambda\bar{K}$ channels, and a coupled-channel analysis yields results consistent with a new Ξ

BIAGI 81 sees an enhancement at 1700 MeV in the diffractively produced ΛK^- system A peak is also observed in the ΛK^0 mass spectrum at 1660 MeV that is consistent with a 1720 MeV resonance decaying to $\Sigma^0\bar{K}^0$, with the γ from the Σ^0 decay not detected

BIAGI 87 provides further confirmation of this state in diffractive dissociation of Ξ^- into ΛK^- The significance claimed is 6 7 standard deviations

Ξ(1690) MASSES

Ξ(1690)⁰ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1699 ± 5	175	[1] DIONISI	78	HBC	K^-p 4 2 GeV/c
1684 ± 5	183	[2] DIONISI	78	HBC	K^-p 4 2 GeV/c

Ξ(1690)⁻ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1691 1 ± 1 9 ± 2 0	104	BIAGI	87	SPEC	Ξ^-Be 116 GeV
1700 ± 10	150	[3] BIAGI	81	SPEC	Ξ^-H 100 135 GeV
1694 ± 6	45	[4] DIONISI	78	HBC	K^-p 4 2 GeV/c

Ξ(1690) WIDTHS

Ξ(1690)⁰ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
44 ± 23	175	[1] DIONISI	78	HBC	K^-p 4 2 GeV/c
20 ± 4	183	[2] DIONISI	78	HBC	K^-p 4 2 GeV/c

Ξ(1690)⁻ WIDTH

VALUE (MeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 8	90	104	BIAGI	87	SPEC	Ξ^-Be 116 GeV
47 ± 14		150	[3] BIAGI	81	SPEC	Ξ^-H 100 135 GeV
26 ± 6		45	[4] DIONISI	78	HBC	K^-p 4 2 GeV/c

Ξ(1690) DECAY MODES

Γ_1 Ξ(1690) → ΛK
Γ_2 Ξ(1690) → ΣK
Γ_3 Ξ(1690) → $\Xi\pi$
Γ_4 Ξ(1690) → $\Xi^-\pi^+\pi^0$
Γ_5 Ξ(1690) → $\Xi^-\pi^+\pi^-$
Γ_6 Ξ(1690) → Ξ(1530)π

Ξ(1690) BRANCHING RATIOS

$\Gamma(\Lambda\bar{K})$ — Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
SEEN	104	BIAGI	87	SPEC	−	Ξ^-Be 116 GeV

$\Gamma(\Sigma\bar{K})/\Gamma(\Lambda\bar{K})$ — Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
2 7 ± 0 9	DIONISI	78	HBC	0	K^-p 4 2 GeV/c
3 1 ± 1 4	DIONISI	78	HBC	−	K^-p 4 2 GeV/c

$\Gamma(\Xi\pi)/\Gamma(\Sigma\bar{K})$ — Γ_3/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
<0 09	DIONISI	78	HBC	0	K^-p 4 2 GeV/c

$\Gamma(\Xi^-\pi^+\pi^0)/\Gamma(\Sigma\bar{K})$ — Γ_4/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
<0 04	DIONISI	78	HBC	0	K^-p 4 2 GeV/c

$\Gamma(\Xi^-\pi^+\pi^-)$ — Γ_5

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
POSSIBLY SEEN	4	BIAGI	87	SPEC	−	Ξ^-Be 116 GeV

$\Gamma(\Xi^-\pi^+\pi^-)/\Gamma(\Sigma\bar{K})$ — Γ_5/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
<0 03	DIONISI	78	HBC	−	K^-p 4 2 GeV/c

$\Gamma(\Xi(1530)\pi)/\Gamma(\Sigma\bar{K})$ — Γ_6/Γ_2

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
<0 06	DIONISI	78	HBC	−	K^-p 4 2 GeV/c

Ξ(1690) FOOTNOTES

[1] From a fit to the Σ^+K^- spectrum
[2] From a coupled channel analysis of the Σ^+K^- and $\Lambda\bar{K}^0$ spectra
[3] A fit to the inclusive spectrum from $\Xi^-N \to \Lambda K^-X$
[4] From a coupled channel analysis of the Σ^0K^- and ΛK^- spectra

Ξ(1690) REFERENCES

BIAGI	87	ZPHY C34 15	+	(BRIS CERN GEVA HEID LAUS LOQM RAL) I
BIAGI	81	ZPHY C9 305	+	(BRIS CAMB GEVA HEID LAUS LOQM RHEL)
DIONISI	78	PL 80B 145	+Diaz Armenteros+	(CERN AMST NIJM OXF) I

Ξ(1820)

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ Status * * *

The clearest evidence is an 8-standard-deviation peak in ΛK^- seen by GAY 76 TEODORO 78 favors $J=3/2$ but cannot make a parity discrimination BIAGI 87C is consistent with $J=3/2$ and favors negative parity for this J-value

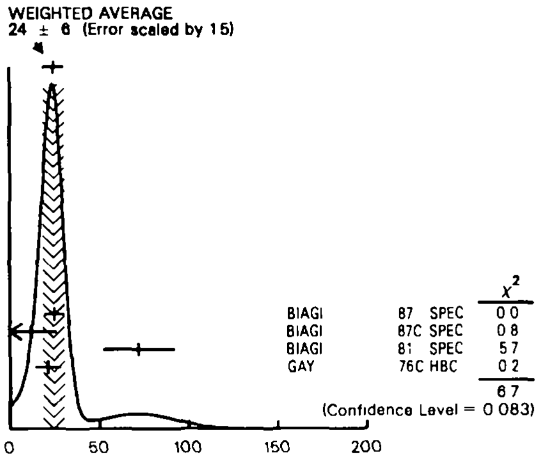
Ξ(1820) MASS

We only average the measurements that appear to us to be most significant and best determined

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1823.4 ± 1.4 OUR AVERAGE						
1819 4 ± 3 1 ± 2.0	280	[1] BIAGI	87	SPEC	0	Ξ^- Be → (ΛK^-) X
1826 ± 3 ± 1	54	BIAGI	87C	SPEC	0	Ξ^- Be → (ΛK^0) X
1822 ± 6		JENKINS	83	MPS	−	$K^- p \to K^+$ (MM)
1830 ± 6	300	BIAGI	81	SPEC	−	SPS hyperon beam
1823 ± 2	130	GAY	76C	HBC	−	$K^- p$ 4 2 GeV/c
• • • We do not use the following data for averages fits limits etc • • •						
1797 ± 19	74	BRIEFEL	77	HBC	0	$K^- p$ 2 87 GeV/c
1829 ± 9	68	BRIEFEL	77	HBC	−0	$\Xi(1530)\pi$
1860 ± 14	39	BRIEFEL	77	HBC	−	$\Sigma^- \overline{K}^0$
1870 ± 9	44	BRIEFEL	77	HBC	0	$\Lambda \overline{K}^0$
1813 ± 4	57	BRIEFEL	77	HBC	−	ΛK^-
1807 ± 27		DIBIANCA	75	DBC	−0	$\Xi\pi\pi$, $\Xi^*\pi$
1762 ± 8	28	[2] BADIER	72	HBC	−0	$\Xi\pi$, $\Xi\pi\pi$ YK
1838 ± 5	38	[2] BADIER	72	HBC	−0	$\Xi\pi$ $\Xi\pi\pi$ YK
1830 ± 10	25	[3] CRENNELL	70B	DBC	−0	3 6, 3 9 GeV/c
1826 ± 12		[4] CRENNELL	70B	DBC	−0	3 6 3 9 GeV/c
1830 ± 10	40	ALITTI	69	HBC	−	Λ, ΣK
1814 ± 4	30	BADIER	65	HBC	0	ΛK^0
1817 ± 7	29	SMITH	65C	HBC	−0	ΛK^0, ΛK^-
1770		HALSTEINSLID	63	FBC	−0	K^- freon 3 5 GeV/c

Ξ(1820) WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
24 ± 6 OUR AVERAGE		Error includes scale factor of 1 5 See the ideogram below				
24 6 ± 5 3	280	[1] BIAGI	87	SPEC	0	Ξ^- Be → (ΛK^-) X
12 ± 14 ± 1 7	54	BIAGI	87C	SPEC	0	Ξ^- Be → (ΛK^0) X
72 ± 20	300	BIAGI	81	SPEC	−	SPS hyperon beam
21 ± 7	130	GAY	76C	HBC	−	$K^- p$ 4 2 GeV/c
• • • We do not use the following data for averages, fits limits, etc • • •						
99 ± 57	74	BRIEFEL	77	HBC	0	$K^- p$ 2 87 GeV/c
52 ± 34	68	BRIEFEL	77	HBC	−0	$\Xi(1530)\pi$
72 ± 17	39	BRIEFEL	77	HBC	−	$\Sigma^- \overline{K}^0$
44 ± 11	44	BRIEFEL	77	HBC	0	$\Lambda \overline{K}^0$
26 ± 11	57	BRIEFEL	77	HBC	−	ΛK^-
85 ± 58		DIBIANCA	75	DBC	−0	$\Xi\pi\pi$ $\Xi^*\pi$
51 ± 13		[2] BADIER	72	HBC	−0	Lower mass
58 ± 13		[2] BADIER	72	HBC	−0	Higher mass
103 $^{+38}_{-24}$		[3] CRENNELL	70B	DBC	−0	3 6 3 9 GeV/c
48 $^{+36}_{-19}$		[4] CRENNELL	70B	DBC	−0	3 6, 3 9 GeV/c
55 $^{+40}_{-20}$		ALITTI	69	HBC	−	Λ, $\Sigma \overline{K}$
12 ± 4		BADIER	65	HBC	0	$\Lambda \overline{K}^0$
30 ± 7		SMITH	65B	HBC	−0	ΛK
< 80		HALSTEINSLID	63	FBC	−0	K^- freon 3 5 GeV/c



Ξ(1820) width (MeV)

Ξ(1820) DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale
Γ_1	Ξ(1820) → $\Lambda \overline{K}$	$(53 \pm 7) \times 10^{-2}$	1 2
Γ_2	Ξ(1820) → $\Xi\pi$	$(18 \pm 5) \times 10^{-2}$	1 1
Γ_3	Ξ(1820) → $\Sigma \overline{K}$	$(16^{+7}_{-6}) \times 10^{-2}$	1 5
Γ_4	Ξ(1820) → $\Xi\pi\pi$ (not $\Xi(1530)\pi$)		
Γ_5	Ξ(1820) → $\Xi(1530)\pi$	$(14^{+4}_{-5}) \times 10^{-2}$	1 1

CONSTRAINED FIT INFORMATION

An overall fit to 8 branching ratios uses 8 measure ments and one constraint to determine 4 parame- ters The overall fit has a $\chi^2 = 6\ 0$ for 5 degrees of freedom

The following *off-diagonal* array elements are the correlation coefficients $\langle\delta x_i\, \delta x_j\rangle/(\delta x_i\ \delta x_j)$ in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$ The fit constrains the x_i whose labels appear in this array to sum to one

x_2	−54		
x_3	40	−41	
x_5	48	44	41
	x_1	x_2	x_3

Ξ(1820) BRANCHING RATIOS

The dominant modes seem to be ΛK and (perhaps) $\Xi(1530)\pi$ but the branching fractions are very poorly deter mined

$\Gamma(\Lambda \overline{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.53 ± 0.07 OUR FIT	Error includes scale factor of 1 2				
0.30 ± 0.15	ALITTI	69	HBC	−	$K^- p$ 3 9-5 GeV/c

$\Gamma(\Xi\pi)/\Gamma_{total}$ Γ_2/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.18 ± 0.05 OUR FIT	Error includes scale factor of 1 1				
0.10 ± 0 10	ALITTI	69	HBC	−	$K^- p$ 3 9-5 GeV/c

$\Gamma(\Xi\pi)/\Gamma(\Lambda \overline{K})$ Γ_2/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
0.33 ± 0.12 OUR FIT						
0.20 ± 0.20		BADIER	65	HBC	0	$K^- p$ 3 GeV/c
• • • We do not use the following data for averages fits limits etc • • •						
<0 36	95	GAY	76C	HBC	−	$K^- p$ 4 2 GeV/c

$\Gamma(\Xi\pi)/\Gamma(\Xi(1530)\pi)$ — Γ_2/Γ_5

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$1.3^{+0.6}_{-0.4}$ OUR FIT Error includes scale factor of 1 1					
$1.5^{+0.6}_{-0.4}$	APSELL	70	HBC	0	$K^- p$ 2 87 GeV/c

$\Gamma(\Sigma\bar{K})/\Gamma_{total}$ — Γ_3/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.16 ± 0.07 OUR FIT Error includes scale factor of 1 5					
0.30 ± 0.15	ALITTI	69	HBC	−	$K^- p$ 3 9–5 GeV/c
• • • We do not use the following data for averages, fits limits etc • • •					
<0 02	TRIPP	67	RVUE		Use SMITH 65C

$\Gamma(\Sigma\bar{K})/\Gamma(\Lambda\bar{K})$ — Γ_3/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.30 ± 0.15 OUR FIT Error includes scale factor of 1 6					
0.24 ± 0.10	GAY	76C	HBC	−	$K^- p$ 4 2 GeV/c

$\Gamma(\Xi(1530)\pi)/\Gamma_{total}$ — Γ_5/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$0.14^{+0.04}_{-0.05}$ OUR FIT Error includes scale factor of 1 1					
0.30 ± 0.15	ALITTI	69	HBC	−	$K^- p$ 3 9–5 GeV/c
• • • We do not use the following data for averages fits, limits, etc • • •					
SEEN	ASTON	85B	LASS		$K^- p$ 11 GeV/c
NOT SEEN	[5] HASSALL	81	HBC		$K^- p$ 6 5 GeV/c
<0 25	[6] DAUBER	69	HBC		$K^- p$ 2 7 GeV/c

$\Gamma(\Xi(1530)\pi)/\Gamma(\Lambda\bar{K})$ — Γ_5/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
$0.26^{+0.09}_{-0.10}$ OUR FIT					
0.26 ± 0.13	SMITH	65C	HBC	−0	$K^- p$ 2 45–2 7 GeV/c
• • • We do not use the following data for averages fits, limits etc • • •					
1 0 ±0 3	GAY	76C	HBC	−	$K^- p$ 4 2 GeV/c

$\Gamma(\Xi\pi\pi$ (not $\Xi(1530)\pi$))$/\Gamma(\Lambda\bar{K})$ — Γ_4/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.30 ± 0.20	BIAGI	87	SPEC	−	Ξ^- Be 116 GeV
• • • We do not use the following data for averages fits limits etc • • •					
<0 14	[7] BADIER	65	HBC	0	1 st dev limit
>0 1	SMITH	65C	HBC	−0	$K^- p$ 2 45–2 7 GeV/c

$\Gamma(\Xi\pi\pi$ (not $\Xi(1530)\pi$))$/\Gamma(\Xi(1530)\pi)$ — Γ_4/Γ_5

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
CONSISTENT WITH ZERO	GAY	76C	HBC	−	$K^- p$ 4 2 GeV/c
• • • We do not use the following data for averages, fits limits etc • • •					
0.3 ± 0 5	[8] APSELL	70	HBC	0	$K^- p$ 2 87 GeV/c

$\Xi(1820)$ FOOTNOTES

[1] BIAGI 87 also sees weak signals in the in the $\Xi^-\pi^+\pi^-$ channel at 1782 6 ± 1 4 MeV (Γ = 6 0 ± 1 5 MeV) and 1831 9 ± 2 8 MeV (Γ = 9.6 ± 9 9 MeV)
[2] BADIER 72 adds all channels and divides the peak into lower and higher mass regions The data can also be fitted with a single Breit-Wigner of mass 1800 MeV and width 150 MeV
[3] From a fit to inclusive $\Xi\pi$ $\Xi\pi\pi$ and ΛK^- spectra
[4] From a fit to inclusive $\Xi\pi$ and $\Xi\pi\pi$ spectra only
[5] Including $\Xi\pi\pi$
[6] DAUBER 69 uses in part the same data as SMITH 65C
[7] For the decay mode $\Xi^-\pi^+\pi^0$ only This limit includes $\Xi(1530)\pi$
[8] Or less Upper limit for the 3-body decay

$\Xi(1820)$ REFERENCES

BIAGI	87	ZPHY C34 15	+ (BRIS CERN GEVA HEID LAUS LOQM RAL)	
BIAGI	87C	ZPHY C34 175	+ (BRIS CERN GEVA HEID LAUS LOQM RAL)	JP
ASTON	85B	PR D32 2270	+Carnegie+ (SLAC CARL CNRC CINC)	
JENKINS	83	PRL 51 951	+Albright Diamond+(FSU BRAN LBL CINC SMAS)	
BIAGI	81	ZPHY C9 305	+ (BRIS CAMB GEVA HEID LAUS LOQM RHEL)	
HASSALL	81	NP B189 397	+Ansorge Carter Neale+ (CAMB MSU)	
TEODORO	78	PL 77B 451	+Diaz Dionisi Blokzijl+ (AMST CERN NIJM OXF)	JP
BRIEFEL	77	PR D16 2706	+Gourevitch Chang+ (BRAN UMD SYRA TUFT)	
Also	69	PRL 23 884	Apsell+ (BRAN UMD SYRA TUFT)	
GAY	76	NC 31A 593	+Jeanneret Bogdanski+ (NEUC LAUS LIVP LPNP)	
GAY	76C	PL 62B 477	+Armenteros Berge+ (AMST CERN NIJM)	IJ
DIBIANCA	75	NP B98 137	+Endorf (CMU)	
BADIER	72	NP B37 429	+Barrelet Charlton Videau (EPOL)	
APSELL	70	PRL 24 777	+ (BRAN UMD SYRA TUFT)	I
CRENNELL	70B	PR D1 847	+Karshon Lai O Neall Scarr Schumann (BNL)	
ALITTI	69	PRL 22 79	+Barnes Flaminio Metzger+ (BNL SYRA)	I
DAUBER	69	PR 179 1262	+Berge Hubbard Merrill Miller (LRL)	
TRIPP	67	NP B3 10	+Leith+ (LRL SLAC CERN HEID SACL)	
BADIER	65	PL 16 171	+Demoulin Goldberg+ (EPOL SACL AMST)	I
SMITH	65B	Athens Conf 251	+Lindsey (LRL)	
SMITH	65C	PRL 14 25	+Lindsey Button Shafer Murray (LRL)	IJP
HALSTEINSLID	63	Siena Conf 1 73	+ (BERG CERN EPOL RHEL LOUC)	I

— — OTHER RELATED PAPERS — —

TEODORO	78	PL 77B 451	+Diaz Dionisi Blokzijl+ (AMST CERN NIJM OXF)	JP
BRIEFEL	75	PR D12 1859	+Gourevitch+ (BRAN UMD SYRA TUFT)	
SCHMIDT	73	Purdue Conf 363	(BRAN)	
MERRILL	68	PR 167 1202	+Shafer (LRL)	
SMITH	64	PRL 13 61	+Lindsey Murray Button Shafer+ (LRL)	IJP

$\Xi(1950)$

$I(J^P) = \frac{1}{2}(?^?)$ Status ＊＊＊

We list here everything reported between 1875 and 2000 MeV The accumulated evidence for a Ξ near 1950 MeV seems strong enough to include a $\Xi(1950)$ in the main Baryon Table, but not much can be said about its properties In fact there may be more than one Ξ near this mass

$\Xi(1950)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1944 ± 9	129	BIAGI	87	SPEC	Ξ^- Be → $(\Xi^-\pi^+)\pi^-$ X
1963 ± 5 ± 2	63	BIAGI	87C	SPEC	Ξ^- Be → $(\Lambda\bar{K}^0)$ X
1937 ± 7	150	BIAGI	81	SPEC	SPS hyperon beam
1961 ± 18	139	BRIEFEL	77	HBC	2 87 $K^- p \to \Xi^-\pi^+$ X
1936 ± 22	44	BRIEFEL	77	HBC	2 87 $K^- p \to \Xi^0\pi^-$ X
1964 ± 10	56	BRIEFEL	77	HBC	$\Xi(1530)\pi$
1900 ± 12		DIBIANCA	75	DBC	$\Xi\pi$
1952 ± 11	25	ROSS	73C		$(\Xi\pi)^-$
1956 ± 6	29	BADIER	72	HBC	$\Xi\pi$ $\Xi\pi\pi$ YK
1955 ± 14	21	GOLDWASSER	70	HBC	$\Xi\pi$
1894 ± 18	66	DAUBER	69	HBC	$\Xi\pi$
1930 ± 20	27	ALITTI	68	HBC	$\Xi^-\pi^+$
1933 ± 16	35	BADIER	65	HBC	$\Xi^-\pi^+$

$\Xi(1950)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
100 ± 31	129	BIAGI	87	SPEC	Ξ^- Be → $(\Xi^-\pi^+)\pi^-$ X
25 ± 15 ± 1 2	63	BIAGI	87C	SPEC	Ξ^- Be → (ΛK^0) X
60 ± 8	150	BIAGI	81	SPEC	SPS hyperon beam
159 ± 57	139	BRIEFEL	77	HBC	2 87 $K^- p \to \Xi^-\pi^+$ X
87 ± 26	44	BRIEFEL	77	HBC	2 87 $K^- p \to \Xi^0\pi^-$ X
60 ± 39	56	BRIEFEL	77	HBC	$\Xi(1530)\pi$
63 ± 78		DIBIANCA	75	DBC	$\Xi\pi$
38 ± 10		ROSS	73C		$(\Xi\pi)^-$
35 ± 11	29	BADIER	72	HBC	$\Xi\pi$ $\Xi\pi\pi$ YK
56 ± 26	21	GOLDWASSER	70	HBC	$\Xi\pi$
98 ± 23	66	DAUBER	69	HBC	$\Xi\pi$
80 ± 40	27	ALITTI	68	HBC	$\Xi^-\pi^+$
140 ± 35	35	BADIER	65	HBC	$\Xi^-\pi^+$

$\Xi(1950)$ DECAY MODES

Γ_1 $\Xi(1950) \to \Lambda\bar{K}$
Γ_2 $\Xi(1950) \to \Sigma\bar{K}$
Γ_3 $\Xi(1950) \to \Xi\pi$
Γ_4 $\Xi(1950) \to \Xi(1530)\pi$
Γ_5 $\Xi(1950) \to \Xi\pi\pi$ (not $\Xi(1530)\pi$)

$\Xi(1950)$ BRANCHING RATIOS

$\Gamma(\Sigma\bar{K})/\Gamma(\Lambda\bar{K})$ — Γ_2/Γ_1

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<2 3	90	0	BIAGI	87C	SPEC	Ξ^- Be 116 GeV

$\Gamma(\Sigma\bar{K})/\Gamma_{total}$ — Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
POSSIBLY SEEN	17	HASSALL	81	HBC	$K^- p$ 6 5 GeV/c

$\Gamma(\Xi\pi)/\Gamma(\Xi(1530)\pi)$ Γ_3/Γ_4

VALUE	DOCUMENT ID		TECN
$2.8^{+0.7}_{-0.6}$	APSELL	70	HBC

$\Gamma(\Xi\pi\pi \text{ (not } \Xi(1530)\pi))/\Gamma(\Xi(1530)\pi)$ Γ_5/Γ_4

VALUE	DOCUMENT ID		TECN
0.0±0.3	APSELL	70	HBC

Ξ(1950) REFERENCES

BIAGI	87	ZPHY C34 15	+ (BRIS CERN GEVA HEID LAUS LOQM RAL)
BIAGI	87C	ZPHY C34 175	+ (BRIS CERN GEVA HEID LAUS LOQM RAL)
BIAGI	81	ZPHY C9 305	+ (BRIS CAMB GEVA HEID LAUS LOQM RHEL)
HASSALL	81	NP B189 397	+Ansorge Carter Neale+ (CAMB MSU)
BRIEFEL	77	PR D16 2706	+Gourevitch Chang+ (BRAN UMD SYRA TUFT)
Also	70	Duke Conf 317	Briefel+ (BRAN UMD SYRA TUFT)
DIBIANCA	75	NP B98 137	+Endorf (CMU)
ROSS	73C	Purdue Conf 345	+Lloyd Radojicic (OXF)
BADIER	72	NP B37 429	+Barrelet Charlton Videau (EPOL)
APSELL	70	PRL 24 777	+ (BRAN UMD SYRA TUFT) I
GOLDWASSER	70	PR D1 1960	+Schultz (ILL)
DAUBER	69	PR 179 1262	+Berge Hubbard Merrill Miller (LRL) I
ALITTI	68	PRL 21 1119	+Flaminio Metzger Radojicic+ (BNL SYRA) I
BADIER	65	PL 16 171	+Demoulin Goldberg+ (EPOL SACL AMST) I

Ξ(2030)

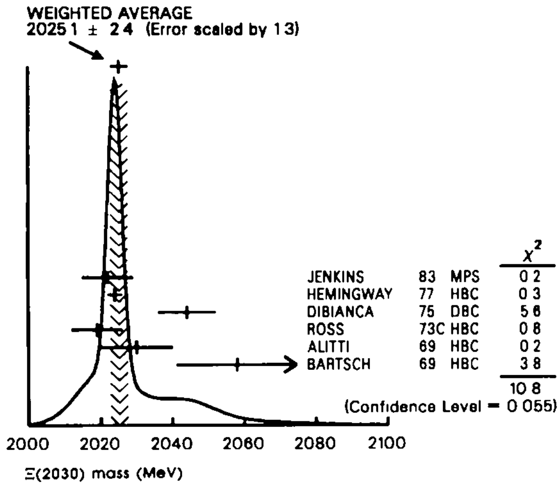
$I(J^P) = \frac{1}{2}(\geq\frac{5}{2}^?)$ Status ***

The evidence for this state has been much improved by HEMINGWAY 77, who see an eight standard deviation enhancement in $\Sigma\overline{K}$ and a weaker coupling to $\Lambda\overline{K}$. ALITTI 68 and HEMINGWAY 77 observe no signals in the $\Xi\pi\pi$ (or $\Xi(1530)\pi$) channel, in contrast to DIBIANCA 75. The decay $(\Lambda/\Sigma)K\pi$ reported by BARTSCH 69 is also not confirmed by HEMINGWAY 77.

A moments analysis of the HEMINGWAY 77 data indicates at a level of three standard deviations that $J \geq 5/2$.

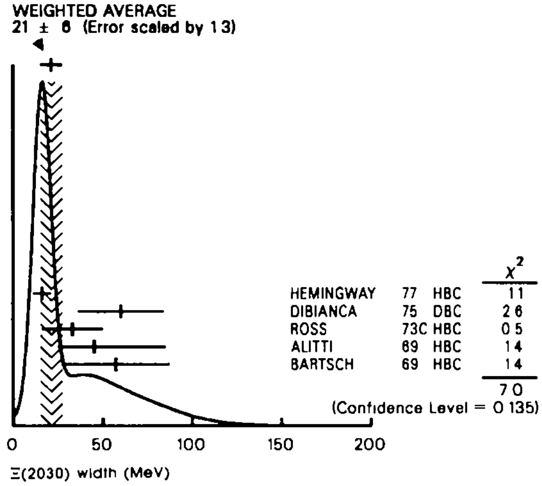
Ξ(2030) MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
2025.1 ± 2.4	**OUR AVERAGE**	Error includes scale factor of 1.3. See the ideogram below.				
2022 ± 7		JENKINS	83	MPS	−	$K^-p \to K^+$ MM
2024 ± 2	200	HEMINGWAY	77	HBC	−	K^-p 4.2 GeV/c
2044 ± 8		DIBIANCA	75	DBC	−0	$\Xi\pi\pi$, $\Xi^*\pi$
2019 ± 7	15	ROSS	73C	HBC	−0	$\Sigma\overline{K}$
2030 ± 10	42	ALITTI	69	HBC	−	K^-p 3.9–5 GeV/c
2058 ± 17	40	BARTSCH	69	HBC	−0	K^-p 10 GeV/c



Ξ(2030) WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
21 ± 6	**OUR AVERAGE**	Error includes scale factor of 1.3. See the ideogram below.				
16 ± 5	200	HEMINGWAY	77	HBC	−	K^-p 4.2 GeV/c
60 ± 24		DIBIANCA	75	DBC	−0	$\Xi\pi\pi$, $\Xi^*\pi$
33 ± 17	15	ROSS	73C	HBC	−0	$\Sigma\overline{K}$
45^{+40}_{-20}		ALITTI	69	HBC	−	K^-p 3.9–5 GeV/c
57 ± 30		BARTSCH	69	HBC	−0	K^-p 10 GeV/c



Ξ(2030) DECAY MODES

Γ_1 $\Xi(2030) \to \Xi\pi$
Γ_2 $\Xi(2030) \to \Lambda\overline{K}$
Γ_3 $\Xi(2030) \to \Sigma\overline{K}$
Γ_4 $\Xi(2030) \to \Xi(1530)\pi$
Γ_5 $\Xi(2030) \to \Xi\pi\pi$ (not $\Xi(1530)\pi$)
Γ_6 $\Xi(2030) \to \Lambda\overline{K}\pi$
Γ_7 $\Xi(2030) \to \Sigma\overline{K}\pi$

Ξ(2030) BRANCHING RATIOS

$\Gamma(\Xi\pi)/[\Gamma(\Xi\pi)+\Gamma(\Lambda\overline{K})+\Gamma(\Sigma\overline{K})+\Gamma(\Xi(1530)\pi)]$ $\Gamma_1/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_4)$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.30	ALITTI	69	HBC	−	1 standard dev. limit

$\Gamma(\Xi\pi)/\Gamma(\Sigma\overline{K})$ Γ_1/Γ_3

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.19	95	HEMINGWAY	77	HBC	−	K^-p 4.2 GeV/c

$\Gamma(\Lambda\overline{K})/[\Gamma(\Xi\pi)+\Gamma(\Lambda\overline{K})+\Gamma(\Sigma\overline{K})+\Gamma(\Xi(1530)\pi)]$ $\Gamma_2/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_4)$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.25±0.15	ALITTI	69	HBC	−	K^-p 3.9–5 GeV/c

$\Gamma(\Lambda\overline{K})/\Gamma(\Sigma\overline{K})$ Γ_2/Γ_3

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.22±0.09	HEMINGWAY	77	HBC	−	K^-p 4.2 GeV/c

$\Gamma(\Sigma\overline{K})/[\Gamma(\Xi\pi)+\Gamma(\Lambda\overline{K})+\Gamma(\Sigma\overline{K})+\Gamma(\Xi(1530)\pi)]$ $\Gamma_3/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_4)$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.75±0.20	ALITTI	69	HBC	−	K^-p 3.9–5 GeV/c

$\Gamma(\Xi(1530)\pi)/[\Gamma(\Xi\pi) + \Gamma(\Lambda\overline{K}) + \Gamma(\Sigma\overline{K}) + \Gamma(\Xi(1530)\pi)]$ $\Gamma_4/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_4)$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.15	ALITTI	69	HBC	−	1 standard dev. limit

$[\Gamma(\Xi(1530)\pi) + \Gamma(\Xi\pi\pi\ (\text{not}\ \Xi(1530)\pi))]/\Gamma(\Sigma\overline{K})$ $(\Gamma_4+\Gamma_5)/\Gamma_3$

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.11	95	[1] HEMINGWAY	77	HBC	−	$K^- p$ 4.2 GeV/c

$\Gamma(\Lambda\overline{K}\pi)/\Gamma_{total}$ Γ_6/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
SEEN	BARTSCH	69	HBC	$K^- p$ 10 GeV

$\Gamma(\Lambda\overline{K}\pi)/\Gamma(\Sigma\overline{K})$ Γ_6/Γ_3

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.32	95	HEMINGWAY	77	HBC	−	$K^- p$ 4.2 GeV/c

$\Gamma(\Sigma\overline{K}\pi)/\Gamma_{total}$ Γ_7/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
SEEN	BARTSCH	69	HBC	$K^- p$ 10 GeV

$\Gamma(\Sigma\overline{K}\pi)/\Gamma(\Sigma\overline{K})$ Γ_7/Γ_3

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<0.04	95	[2] HEMINGWAY	77	HBC	−	$K^- p$ 4.2 GeV/c

Ξ(2030) FOOTNOTES

[1] For the decay mode $\Xi^-\pi^+\pi^-$ only.
[2] For the decay mode $\Sigma^\pm K^-\pi^\mp$ only.

Ξ(2030) REFERENCES

JENKINS	83	PRL 51 951	+Albright, Diamond+ (FSU, BRAN, LBL, CINC, SMAS)
HEMINGWAY	77	PL 68B 197	+Armenteros+ (AMST, CERN, NIJM, OXF) IJ
Also	76C	PL 62B 477	Gay, Armenteros, Berge+ (AMST, CERN, NIJM)
DIBIANCA	75	NP B98 137	+Endorf (CMU)
ROSS	73C	Purdue Conf. 345	+Lloyd, Radojicic (OXF)
ALITTI	69	PRL 22 79	+Barnes, Flaminio, Metzger+ (BNL, SYRA) I
BARTSCH	69	PL 28B 439	+ (AACH, BERL, CERN, LOIC, VIEN)
ALITTI	68	PRL 21 1119	+Flaminio, Metzger, Radojicic+ (BNL, SYRA)

Ξ(2120)

$I(J^P) = \frac{1}{2}(?^?)$ Status: *

OMITTED FROM SUMMARY TABLE

Ξ(2120) MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
2137 ± 4	18	[1] CHLIAPNIK...	79	HBC	$K^+ p$ 32 GeV/c
2123 ± 7		[2] GAY	76C	HBC	$K^- p$ 4.2 GeV/c

Ξ(2120) WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
<20	18	[1] CHLIAPNIK...	79	HBC	$K^+ p$ 32 GeV/c
25 ± 12		[2] GAY	76C	HBC	$K^- p$ 4.2 GeV/c

Ξ(2120) DECAY MODES

Γ_1 $\Xi(2120) \to \Lambda\overline{K}$

Ξ(2120) BRANCHING RATIOS

$\Gamma(\Lambda\overline{K})/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
SEEN	[1] CHLIAPNIK...	79	HBC	$K^+ p \to (\overline{\Lambda} K^+) X$
SEEN	[2] GAY	76C	HBC	$K^- p$ 4.2 GeV/c

Ξ(2120) FOOTNOTES

[1] CHLIAPNIKOV 79 does not uniquely identify the K^+ in the $(\overline{\Lambda} K^+)$ X final state. It also reports bumps with fewer events at 2240, 2540, and 2830 MeV.
[2] GAY 76C sees a 4 standard deviation signal. However, HEMINGWAY 77, with more events from the same experiment, points out that the signal is greatly reduced if a cut is made on the 4-momentum u. This suggests an anomalous production mechanism if the Ξ(2120) is real.

Ξ(2120) REFERENCES

CHLIAPNIK...	79	NP B158 253	Chliapnikov, Gerdyukov+ (CERN, BELG, MONS)
HEMINGWAY	77	PL 68B 197	+Armenteros+ (AMST, CERN, NIJM, OXF)
GAY	76C	PL 62B 477	+Armenteros, Berge+ (AMST, CERN, NIJM)

Ξ(2250)

$I(J^P) = \frac{1}{2}(?^?)$ Status: * *

OMITTED FROM SUMMARY TABLE

The evidence for this state is mixed. BARTSCH 69 sees a bump of not much statistical significance in $\Lambda K\pi$, $\Sigma K\pi$, and $\Xi\pi\pi$ mass spectra. GOLDWASSER 70 sees a narrower bump in $\Xi\pi\pi$ at a higher mass. Not seen by HASSALL 81 with 45 events/μb at 6.5 GeV/c. Seen by JENKINS 83. Perhaps seen by BIAGI 87.

Ξ(2250) MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
2189 ± 7	66	BIAGI	87	SPEC	−	Ξ^-Be → $(\Xi^-\pi^+\pi^-)$ X
2214 ± 5		JENKINS	83	MPS	−	$K^- p \to K^+$ MM
2295 ± 15	18	GOLDWASSER	70	HBC	−	$K^- p$ 5.5 GeV/c
2244 ± 52	35	BARTSCH	69	HBC		$K^- p$ 10 GeV/c

Ξ(2250) WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
46 ± 27	66	BIAGI	87	SPEC	−	Ξ^-Be → $(\Xi^-\pi^+\pi^-)$ X
< 30		GOLDWASSER	70	HBC	−	$K^- p$ 5.5 GeV/c
130 ± 80		BARTSCH	69	HBC		

Ξ(2250) DECAY MODES

Γ_1 $\Xi(2250) \to \Xi\pi\pi$
Γ_2 $\Xi(2250) \to \Lambda\overline{K}\pi$
Γ_3 $\Xi(2250) \to \Sigma\overline{K}\pi$

Ξ(2250) REFERENCES

BIAGI	87	ZPHY C34 15	+ (BRIS, CERN, GEVA, HEID, LAUS, LOQM, RAL)
JENKINS	83	PRL 51 951	+Albright, Diamond+ (FSU, BRAN, LBL, CINC, SMAS)
HASSALL	81	NP B189 397	+Ansorge, Carter, Neale+ (CAMB, MSU)
GOLDWASSER	70	PR D1 1960	+Schultz (ILL)
BARTSCH	69	PL 28B 439	+ (AACH, BERL, CERN, LOIC, VIEN)

Ξ(2370)

$I(J^P) = \frac{1}{2}(?^?)$ Status: * *

OMITTED FROM SUMMARY TABLE

Ξ(2370) MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
2356 ± 10		JENKINS	83	MPS	−	$K^- p \to K^+$ MM
2370	50	HASSALL	81	HBC	−0	$K^- p$ 6.5 GeV/c
2373 ± 8	94	AMIRZADEH	80	HBC	−0	$K^- p$ 8.25 GeV/c
2392 ± 27		DIBIANCA	75	DBC		$\Xi 2\pi$

$\Xi(2370)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
80	50	HASSALL	81	HBC	−0	K^-p 6 5 GeV/c
80 ± 25	94	AMIRZADEH	80	HBC	−0	K^-p 8 25 GeV/c
75 ± 69		DIBIANCA	75	DBC		$\Xi 2\pi$

$\Xi(2370)$ DECAY MODES

Γ_1 $\Xi(2370) \rightarrow \Lambda K \pi$
Includes $\Gamma_4 + \Gamma_6$
Γ_2 $\Xi(2370) \rightarrow \Sigma \bar{K} \pi$
Includes $\Gamma_5 + \Gamma_6$
Γ_3 $\Xi(2370) \rightarrow \Omega^- K$
Γ_4 $\Xi(2370) \rightarrow \Lambda K^*(892)$
Γ_5 $\Xi(2370) \rightarrow \Sigma \bar{K}^*(892)$
Γ_6 $\Xi(2370) \rightarrow \Sigma(1385) \bar{K}$

$\Xi(2370)$ BRANCHING RATIOS

$\Gamma(\Lambda \bar{K} \pi)/\Gamma_{total}$ — Γ_1/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
SEEN	AMIRZADEH	80	HBC	−0	K^-p 8 25 GeV/c

$\Gamma(\Sigma K \pi)/\Gamma_{total}$ — Γ_2/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
SEEN	AMIRZADEH	80	HBC	−0	K^-p 8 25 GeV/c

$[\Gamma(\Lambda K \pi) + \Gamma(\Sigma \bar{K} \pi)]/\Gamma_{total}$ — $(\Gamma_1+\Gamma_2)/\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
SEEN	50	HASSALL	81	HBC	−0	K^-p 6 5 GeV/c

$\Gamma(\Omega^- K)/\Gamma_{total}$ — Γ_3/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0 09 ± 0.04	[1] KINSON	80	HBC	−	K^-p 8 25 GeV/c

$[\Gamma(\Lambda \bar{K}^*(892)) + \Gamma(\Sigma \bar{K}^*(892))]/\Gamma_{total}$ — $(\Gamma_4+\Gamma_5)/\Gamma$

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0 22 ± 0 13	[1] KINSON	80	HBC	−	K^-p 8 25 GeV/c

$\Gamma(\Sigma(1385) K)/\Gamma_{total}$ — Γ_6/Γ

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.12 ± 0 08	[1] KINSON	80	HBC	−	K^-p 8 25 GeV/c

$\Xi(2370)$ FOOTNOTES

[1] KINSON 80 is a reanalysis of AMIRZADEH 80 with 50% more events

$\Xi(2370)$ REFERENCES

JENKINS	83	PRL 51 951	+Albright Diamond+(FSU BRAN LBL CINC SMAS)
HASSALL	81	NP B189 397	+Ansorge Carter Neale+ (CAMB MSU)
AMIRZADEH	80	PL 90B 324	+ (BIRM CERN GLAS MSU LPNP) I
KINSON	80	Toronto Conf 263	+ (BIRM CERN GLAS MSU LPNP) I
DIBIANCA	75	NP B98 137	+Endorf (CMU)

$\Xi(2500)$

$I(J^P) = \frac{1}{2}(?^?)$ Status *

OMITTED FROM SUMMARY TABLE

The ALITTI 69 peak might be instead the $\Xi(2370)$ or might be neither the $\Xi(2370)$ nor the $\Xi(2500)$

$\Xi(2500)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
2505 ± 10		JENKINS	83	MPS	−	$K^-p \rightarrow K^+$ MM
2430 ± 20	30	ALITTI	69	HBC	−	K^-p 4 6–5 GeV/c
2500 ± 10	45	BARTSCH	69	HBC	−0	K^-p 10 GeV/c

$\Xi(2500)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG
150^{+60}_{-40}	ALITTI	69	HBC	−
59 ± 27	BARTSCH	69	HBC	−0

$\Xi(2500)$ DECAY MODES

Γ_1 $\Xi(2500) \rightarrow \Xi \pi$
Γ_2 $\Xi(2500) \rightarrow \Lambda \bar{K}$
Γ_3 $\Xi(2500) \rightarrow \Sigma \bar{K}$
Γ_4 $\Xi(2500) \rightarrow \Xi \pi \pi$
Γ_5 $\Xi(2500) \rightarrow \Xi(1530) \pi$
Γ_6 $\Xi(2500) \rightarrow \Lambda \bar{K} \pi + \Sigma K \pi$

$\Xi(2500)$ BRANCHING RATIOS

$\Gamma(\Xi \pi)/[\Gamma(\Xi \pi) + \Gamma(\Lambda \bar{K}) + \Gamma(\Sigma \bar{K}) + \Gamma(\Xi(1530) \pi)]$ — $\Gamma_1/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_5)$

VALUE	DOCUMENT ID		TECN	COMMENT
<0 5	ALITTI	69	HBC	1 standard dev limit

$\Gamma(\Lambda \bar{K})/[\Gamma(\Xi \pi) + \Gamma(\Lambda K) + \Gamma(\Sigma \bar{K}) + \Gamma(\Xi(1530) \pi)]$ — $\Gamma_2/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_5)$

VALUE	DOCUMENT ID		TECN	CHG
0 5 ± 0 2	ALITTI	69	HBC	−

$\Gamma(\Sigma K)/[\Gamma(\Xi \pi) + \Gamma(\Lambda \bar{K}) + \Gamma(\Sigma \bar{K}) + \Gamma(\Xi(1530) \pi)]$ — $\Gamma_3/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_5)$

VALUE	DOCUMENT ID		TECN	CHG
0 5 ± 0 2	ALITTI	69	HBC	−

$\Gamma(\Xi(1530) \pi)/[\Gamma(\Xi \pi) + \Gamma(\Lambda \bar{K}) + \Gamma(\Sigma \bar{K}) + \Gamma(\Xi(1530) \pi)]$ — $\Gamma_5/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_5)$

VALUE	DOCUMENT ID		TECN	COMMENT
<0 2	ALITTI	69	HBC	1 standard dev limit

$\Gamma(\Xi \pi \pi)/\Gamma_{total}$ — Γ_4/Γ

VALUE	DOCUMENT ID		TECN	CHG
SEEN	BARTSCH	69	HBC	−0

$\Gamma(\Lambda \bar{K} \pi) + \Gamma(\Sigma \bar{K} \pi)/\Gamma_{total}$ — Γ_6/Γ

VALUE	DOCUMENT ID		TECN	CHG
SEEN	BARTSCH	69	HBC	−0

$\Xi(2500)$ REFERENCES

JENKINS	83	PRL 51 951	+Albright Diamond+(FSU BRAN LBL CINC SMAS)
ALITTI	69	PRL 22 79	+Barnes Flaminio Metzger+ (BNL SYRA) I
BARTSCH	69	PL 28B 439	+ (AACH BERL CERN LOIC VIEN)

Ω BARYONS
($S = -3$, $I = 0$)

Ω^-

$I(J^P) = 0(\frac{3}{2}^+)$ Status * * * *

SEE STABLE PARTICLES

$\Omega(2250)^-$

Status * * *

$\Omega(2250)^-$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
2252 ± 9 OUR AVERAGE					
2253 ± 13	44	ASTON	87B	LASS	$K^- p$ 11 GeV/c
2251 ± 9 ± 8	78	BIAGI	86B	SPEC	SPS Ξ^- beam

$\Omega(2250)^-$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
55 ± 18 OUR AVERAGE					
81 ± 38	44	ASTON	87B	LASS	$K^- p$ 11 GeV/c
48 ± 20	78	BIAGI	86B	SPEC	SPS Ξ^- beam

$\Omega(2250)^-$ DECAY MODES

Γ_1 $\Omega(2250)^- \rightarrow \Xi^- \pi^+ K^-$

Γ_2 $\Omega(2250)^- \rightarrow \Xi(1530)^0 K^-$

$\Omega(2250)^-$ BRANCHING RATIOS

$\Gamma(\Xi(1530)^0 K^-)/\Gamma(\Xi^- \pi^+ K^-)$ Γ_2/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
~1 0	44	ASTON	87B	LASS	$K^- p$ 11 GeV/c
0.70 ± 0 20	49	BIAGI	86B	SPEC	Ξ^-Be 116 GeV/c

$\Omega(2250)^-$ REFERENCES

ASTON	87B	PL B194 579	+Awaji Bienz Bird+ (SLAC NAGO CINC TOKY)
BIAGI	86B	ZPHY C31 33	+ (LOQM GEVA RAL HEID LAUS BRIS CERN)

$\Omega(2380)^-$

Status * *

OMITTED FROM SUMMARY TABLE

$\Omega(2380)^-$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
2384 ± 9 ± 8	45	BIAGI	86B	SPEC	SPS Ξ^- beam

$\Omega(2380)^-$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
26 ± 23	45	BIAGI	86B	SPEC	SPS Ξ^- beam

$\Omega(2380)^-$ DECAY MODES

Γ_1 $\Omega(2380)^- \rightarrow \Xi^- \pi^+ K^-$

Γ_2 $\Omega(2380)^- \rightarrow \Xi(1530)^0 K^-$

Γ_3 $\Omega(2380)^- \rightarrow \Xi^- \overline{K}{}^*(892)^0$

$\Omega(2380)^-$ BRANCHING RATIOS

$\Gamma(\Xi(1530)^0 K^-)/\Gamma(\Xi^- \pi^+ K^-)$ Γ_2/Γ_1

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0 44	90	9	BIAGI	86B	SPEC	Ξ^-Be 116 GeV/c

$\Gamma(\Xi^- \overline{K}{}^*(892)^0)/\Gamma(\Xi^- \pi^+ K^-)$ Γ_3/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0 5 ± 0.3	21	BIAGI	86B	SPEC	Ξ^-Be 116 GeV/c

$\Omega(2380)^-$ REFERENCES

BIAGI	86B	ZPHY C31 33	+ (LOQM GEVA RAL HEID LAUS BRIS CERN)

CHARMED BARYONS
($C = +1$)

Λ_c^+

$I(J^P) = 0(\frac{1}{2}^+)$ Status * * * *

SEE STABLE PARTICLES

$\Sigma_c(2455)$

$I(J^P) = 1(?^?)$ Status * * *

$\Sigma_c(2455)$ MASSES

The mass measurements here are redundant with the mass difference measurements that follow We get the masses by adding the $\Sigma_c(2455)$-Λ_c^+ mass differences to the Λ_c^+ mass

$\Sigma_c(2455)^{++}$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
2452.2 ± 1.7 OUR FIT Error includes scale factor of 1 4						
• • • We do not use the following data for averages fits limits etc • • •						
2449 ± 3	2	JONES	87	HBC	++	νp in BEBC
2480	1	ADAMOVICH	84	EMUL	++	γA (OMEGA)
2454 ± 5	1	BOSETTI	82	HBC	++	See JONES 87
2425 ± 10	6	BALTAY	79	HLBC	++	ν Ne-H in 15-ft
>2439	1	BARISH	77B	DBC	++	νd in 12 ft
2426 ± 12	1	CAZZOLI	75	HBC	++	νp in BNL 7-ft

$\Sigma_c(2455)^+$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
2452.9 ± 3.4 OUR FIT Error includes scale factor of 1 1						
• • • We do not use the following data for averages fits limits etc • • •						
2457 ± 4	1	CALICCHIO	80	HBC	+	νp in BEBC TST

$\Sigma_c(2455)^0$ MASS

See the note in the Σ_c^{++}-Σ_c^0 MASS DIFFERENCE section below

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits, limits, etc • • •						
2462 ± 26	1	AMMAR	86	EMUL	0	νA
~2460	9	KNAPP	76	SPEC	0	γBe

$\Sigma_c(2455) - \Lambda_c^+$ MASS DIFFERENCES

$\Sigma_c^{++} - \Lambda_c^+$ MASS DIFFERENCE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
167.4 ± 0.8 OUR FIT						
167.4 ± 0.8 OUR AVERAGE						
168 2 ± 0 5 ± 1 6	92	ALBRECHT	88D	ARG	++	e^+e^- ~ 10 GeV
167 4 ± 0 5 ± 2 0	46	DIESBURG	87	SPEC	++	nA ~600 GeV
167 ± 1	2	JONES	87	HBC	++	νp in BEBC
168 ± 3	6	BALTAY	79	HLBC	++	ν Ne H in 15 ft
• • • We do not use the following data for averages fits limits etc • • •						
166 ± 1	1	BOSETTI	82	HBC	++	See JONES 87
166 ± 15	1	CAZZOLI	75	HBC	++	νp in BNL 7 ft

$\Sigma_c^+ - \Lambda_c^+$ MASS DIFFERENCE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
168.0 ± 3.0 OUR FIT						
168 ± 3	1	CALICCHIO	80	HBC	+	νp in BEBC TST

$\Sigma_c^0 - \Lambda_c^+$ MASS DIFFERENCE

See the note in the Σ_c^{++}-Σ_c^0 MASS DIFFERENCE section below

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages fits limits etc • • •						
167 0 ± 0 5 ± 1 6	70	ALBRECHT	88D	ARG	0	e^+e^- ~ 10 GeV
178 2 ± 0 4 ± 2 0	85	DIESBURG	87	SPEC	0	nA ~600 GeV
163 ± 2	1	AMMAR	86	EMUL	0	νA

$\Sigma_c(2455)$ MASS DIFFERENCES

$\Sigma_c^{++} - \Sigma_c^0$ MASS DIFFERENCE

The two results are completely incompatible which is all the more surprising since the two experiments agree about the $\Sigma_c(2455)^{++}$-Λ_c^+ mass difference At least one of the experiments is wrong here, and there is no point in averaging them

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages fits limits etc • • •				
1 2 ± 0 7 ± 0 3	ALBRECHT	88D	ARG	e^+e^- ~ 10 GeV
− 10 8 ± 2 9	DIESBURG	87	SPEC	nA ~600 GeV

$\Sigma_c(2455)$ DECAY MODES

Γ_1 $\Sigma_c(2455) \to \Lambda_c^+ \pi$

$\Sigma_c(2455)$ REFERENCES

ALBRECHT	88D	PL B (accepted)	+Boeckmann Glaeser+	(ARGUS Collab)
DIESBURG	87	PRL 59 2711	+Ladbury+	(COLO ILL FNAL BGNA MILA INFN)
JONES	87	ZPHY C36 593	+Jones+	(BIRM CERN LOIC MPIM OXF LOUC)
AMMAR	86	JETPL 43 515	+Ammosov Bakic Baranov Burnett+	(ITEP)
		Translated from ZETFP 43 401		
ADAMOVICH	84	PL 140B 119	+Alexandrov Bolta Bravo+	(WA58 Collab)
BOSETTI	82	PL 109B 234	+Graessler+	(AACH BONN CERN MPIM OXF)
CALICCHIO	80	PL 93B 521	+	(BARI BIRM BRUX CERN EPOL RHEL+)
BALTAY	79	PRL 42 1721	+Caroumbalis French Hibbs+	(COLU BNL) I
BARISH	77B	PR D15 1	+Derrick Dombeck Musgrave+	(ANL PURD)
KNAPP	76	PRL 37 882	+Lee Leung Smith+	(COLU HAWA ILL FNAL)
CAZZOLI	75	PRL 34 1125	+Cnops Connolly Louttit Murtagh+	(BNL)

Ξ_c^+ was A^+

$I(J^P) = ?(?^?)$ Status * * *

SEE STABLE PARTICLES

Ω_c^0 was T^0

$I(J^P) = ?(?^?)$ Status *

SEE STABLE PARTICLES
OMITTED FROM SUMMARY TABLE

BOTTOM (BEAUTY) BARYON

Λ_b^0

$I(J^P) = ?(?^?)$ Status *

SEE STABLE PARTICLES
OMITTED FROM SUMMARY TABLE

NOTE ON DIBARYON RESONANCES

Dibaryons were reviewed in our last edition[1] and have been reviewed more extensively by Locher, Sainio, and Svarc.[2] The most important recent result is from Shypit et al.,[3] who claim to have conclusively ruled out broad dibaryon resonances in the NN $^1D_2$ $^3F_3$, and $^3P_2$ waves with masses between about 2100 and 2250 MeV The experiment measured spin correlation parameters for the reaction $pp \to np\pi^+$ at six beam energies from 492 to 796 MeV and made an isobar analysis to find the amplitudes and phases of the $pp \to N\Delta$ amplitudes Broad resonant-like behavior of the dominant amplitudes was ruled out Dibaryons in this range would have to decay largely into the $N\Delta$ channel, as the NN and πd branching fractions of possible resonances are rather small

References

1 Particle Data Group, Phys Lett **170B**, 337 (1986)
2 M P Locher M E Sainio, and A Svarc, Adv Nucl Phys **17**, 47 (1986)
3 R L Shypit et al , Phys Rev Lett **60**, 901 (1988)

$S = 0$ DIBARYONS

$NN(2170)$ $^1D_2$

$I(J^P) = 1(2^+)$ Status *

OMITTED FROM SUMMARY TABLE

$NN(2170)$ MASS

These are Breit-Wigner masses in the NN $^1D_2$ wave

VALUE (MeV)	DOCUMENT ID		COMMENT
2176	[1] HIROSHIGE	85	$\pi d \to \pi d$ (uses Lyon ampl)
2176 ± 6	STRAKOVSKII	84	$\pi^+ d \to pp$ PWA
2200	[2] LOCHER	83	$\pi d \to \pi d$ PWA
2140 to 2160	DAKHNO	82	$pn \to pp\pi^-$ cross sec
2170	HOFTIEZE	81	$\pi d \to pn\pi$ ampl analysis
2140	[3] KANAI	81	$\pi d \to \pi d$ PWA (sol B & C)
2180	ARVIEUX	80	$\pi d \to \pi d$ PWA
2185	[4] KAMO	80	$pp \to \pi^+ d$ PWA
2170	HOSHIZAKI	79	$NN \to NN$ PWA
• • • We do not use the following data for averages fits limits etc • • •			
2263 to 2340	[5] BAKKER	84	$NN \to NN$ P-matrix analysis
2116	[6] UEDA	82	$NN \to NN$ PWA, Faddeev fit

$NN(2170)$ WIDTH

VALUE (MeV)	DOCUMENT ID		COMMENT
124	[1] HIROSHIGE	85	$\pi d \to \pi d$ (uses Lyon ampl)
107 ± 23	STRAKOVSKII	84	$\pi^+ d \to pp$ PWA
85	[1] LOCHER	83	$\pi d \to \pi d$ PWA
50 to 100	DAKHNO	82	$pn \to pp\pi^-$ cross sec
75	HOFTIEZE	81	$\pi d \to pn\pi$ ampl analysis
56 or 54	[3] KANAI	81	$\pi d \to \pi d$ PWA (sol B & C)
134	[4] KAMO	80	$pp \to \pi^+ d$ PWA
100 to 150	HOSHIZAKI	79	$NN \to NN$ PWA
• • • We do not use the following data for averages fits limits, etc • • •			
100 to 200	GRACH	84B	$NN \to NN$ P matrix analysis
50	[7] FERREIRA	83	πd forward amplitude
61	[6] UEDA	82	$NN \to NN$ PWA, Faddeev fit

$NN(2170)$ ELASTICITY

VALUE	DOCUMENT ID		COMMENT
0 1	HOSHIZAKI	79	$NN \to NN$ PWA
• • • We do not use the following data for averages fits limits etc • • •			
0 3 to 0 5	GRACH	84B	$NN \to NN$ PWA

$NN(2170)$ $\pi^- d$ INELASTICITY

VALUE	DOCUMENT ID		COMMENT
0 49	[1] HIROSHIGE	85	$\pi d \to \pi d$ (uses Lyon ampl)
0.29	[8] SMITH	84	$\pi d \to \pi d$ PWA
0 29	[2] LOCHER	83	$\pi d \to \pi d$ PWA
0.26	KANAI	81	$\pi d \to \pi d$ PWA
• • • We do not use the following data for averages fits, limits, etc • • •			
0.09	[7] FERREIRA	83	πd forward amplitude

$NN(2170)$ POLE POSITION

REAL PART

Approximately equals the Breit-Wigner mass

VALUE (MeV)	DOCUMENT ID		COMMENT
2148	ARNDT	87	$NN \to NN$ scattering analysis
2120 to 2150	[9] BHANDARI	83	$NN \to NN$ M-matrix fit
2150	EDWARDS	81	$NN \to NN$ K matrix fit
• • • We do not use the following data for averages, fits, limits etc • • •			
2150 to 2170	GRACH	84B	Fits $NN \to NN$ PWA
2149 to 2150	[10] KLOET	83B	$NN \to NN$ coupled channel fit
2110	[10] UEDA	82	$NN \to NN$ PWA, Faddeev fit
2045	BHANDARI	81	$NN \to NN$ K-matrix fit
2135	BHANDARI	81	$NN \to NN$ M-matrix fit
2153	[11] KLOET	81B	$NN \to NN$ potential model fit

IMAGINARY PART

Approximately equals one-half the Breit-Wigner width

VALUE (MeV)	DOCUMENT ID		COMMENT
63	ARNDT	87	$NN \to NN$ scattering analysis
80 to 100	[9] BHANDARI	83	$NN \to NN$ M matrix fit
56	EDWARDS	81	$NN \to NN$ K matrix fit
• • • We do not use the following data for averages, fits limits etc • • •			
39 to 45	[10] KLOET	83B	$NN \to NN$ coupled channel fit
54	[10] UEDA	82	$NN \to NN$ PWA, Faddeev fit
110	BHANDARI	81	$NN \to NN$ K matrix fit
90	BHANDARI	81	$NN \to NN$ M matrix fit
46	[11] KLOET	81B	$NN \to NN$ potential model fit

$NN(2170)$ |RESIDUE|/Im(POLE POSITION)

|residue|/Im(pole position) approximately equals Breit-Wigner elasticity

VALUE	DOCUMENT ID		COMMENT
0 16	ARNDT	87	$NN \to NN$ scattering analysis
0.1 to 0 3	[9] BHANDARI	83	$NN \to NN$ M-matrix fit
0 29	EDWARDS	81	$NN \to NN$ K-matrix fit
• • • We do not use the following data for averages fits, limits etc • • •			
0 175	BHANDARI	81	$NN \to NN$ K matrix fit
0 2	BHANDARI	81	$NN \to NN$ M matrix fit

$NN(2170)$ FOOTNOTES

[1] The HIROSHIGE 85 effect is in the $^3P_2$ wave of the $d\pi$ system
[2] LOCHER 83 is a resonance fit to the vector polarization
[3] The KANAI 81 fit with no resonances was very poor and other fits with fewer than four resonances were not tried
[4] KAMO 80 did not try fits with fewer than six resonances
[5] BAKKER 84 actually gives the P-matrix pole position
[6] UEDA 82 reports as the mass, but does not explain how it was calculated from the pole position
[7] FERREIRA 83 fixed the resonance mass
[8] SMITH 84 is a Faddeev + resonance fit to the vector analyzing power varing only the elasticity the mass and width were fixed at LOCHER 83 values
[9] BHANDARI 83 claims the $^1D_2$ is an $N\Delta$ bound state
[10] Not a good fit to the partial-wave amplitudes
[11] KLOET 81B does not show the goodness of fit to $^1D_2$

$NN(2170)$ REFERENCES

ARNDT 87 PR D35 128 +Hyslop Roper (VPI)
HIROSHIGE 85 PL 150B 41 +Watari Takabayashi+ (OSKC HIRO)
BAKKER 84 NP A424 563 +Grach, Narodetskii (VRIJ ITEP)
GRACH 84B SJNP 39 56 +Narodetskii Shmatikov (ITEP)
Translated from YAF 39 91
Also 84 ZPHY C21 229 Grach Narodetskii Shmatikov (ITEP)
SMITH 84 PR C29 2206 +Mathie Boschitz Ottermann+ (KARL SIN+)
STRAKOVSKII 84 SJNP 40 273 +Kravtsov Ryskin (LENI)
Translated from YAF 40 429
Also 84 JP G9 L187 Kravtsov Tyskin Strakovskii (LENI)
BHANDARI 83 PR D27 296 (VPI)
Also 83B LNC 38 251 Bhandari (NMSU)
FERREIRA 83 JP G9 169 +Munguia (PUCB)
KLOET 83B PR C27 430 +Tjon (ITPU)
LOCHER 83 PL 121B 227 +Saino (SIN)
DAKHNO 82 PL 114B 409 +Kravtsov Lobachev Makarov Medvedev+ (LENI)
Also 82B SJNP 36 83 Dakhno Kravtsov Lobachev Makarov+ (LENI)
Translated from YAF 36 143
UEDA 82 PL 119B 281 (OSAK)
BHANDARI 81 PRL 46 1111 +Arndt Roper Verwest (VPI TAMU)
EDWARDS 81 PR D23 1978 (ANL)
HOFTIEZE 81 PR C23 407 +Baker Clement Dragoset+ (RICE HOUS BONN)
KANAI 81 PTP 65 266 +Minaka Nakamura+ (TMU KAGO TWAS SAGA)
KLOET 81B PL 106B 24 +Tjon (RUTG UTRE)
ARVIEUX 80 NP A350 205 +Rinat (GREN REHO SACL)
KAMO 80 LNC 29 289 +Watari (OSAK)
Also 80B PTP 64 2144 Kamo Watari Yonezawa (OSAK HIRO)
HOSHIZAKI 79 PTP 61 129 (KYOT)

OTHER RELATED PAPERS

SVARC 85 NP A434 329C (SIN)
BYSTRICKI 84 NC 82 385 +Deregel Lehar+ (SACL GEVA TRST MONT)
COMBES 84 NP A431 703 +Berthet+ (IPN SACL STRB FRAS CAEN)
KATAYAMA 84 NP A423 410 +Kajita Koiso Kubota Sai Sakamoto+ (TOKY)
ABLEEV 83 NP A393 491 +Abdushukurov Avramenko Dimitrov+ (JINR)
ARNDT 83 PR D28 97 +Roper Bryan Clark Verwest+ (VPI TAMU MSU)
KLOET 83 NP A392 271 +Tjon (ITPU)
LISOWSKI 82 PRL 49 255 +Shamu Auchampaugh King Moore+ (LASL)
ARGAN 81 PRL 46 96 +Audit Debotton Faure Martin (SACL)
ARVIEUX 81 PL 103B 99 (GREN SACL)
BOLGER 81 PRL 46 167 +Boschitz Probstle Smith (KARL SIN ERLA+)
GREIN 81 JP G7 1355 +Locher (SIN)
HOLT 81 PRL 47 472 +Specht Stephenson Zeidman+ (ANL LASL+)
KLOET 81 NP A364 346 +Silbar (RUTG LASL)
MINEHART 81 PRL 46 1185 +Boswell Davis Day McCarthy+ (VIRG LASL)
MIZUTANI 81 PL 107B 177 +Fayard Lamot Nahabetian (LYON REGE)
RINAT 81 PL 104B 182 +Arvieux (GREN REHO SACL)
TAMAS 81 NP A358 347 (SACL)
FRASCARIA 80 PL 91B 345 +Brissaud Didelez Perrin+ (IPN GREN NEUC)
KUBODERA 80 JP G6 171 +Locher Myhrer Thomas (SIN NORD TRIU)
HIDAKA 77 PL 70B 479 +Beretvas Nield Spinka+ (ANL)

$NN(2250)$ $^3F_3$

$I(J^P) = 1(3^-)$ Status *

OMITTED FROM SUMMARY TABLE

$NN(2250)$ MASS

These are Breit Wigner masses in the NN $^3F_3$ wave

VALUE (MeV)	DOCUMENT ID		COMMENT
2240 ± 5	[1] TATISCHEFF	85	$^3He p \to d X$
2236	JAUCH	84	$NN \to NN\pi$ Deck + resonance
2170 ± 5	STRAKOVSKII	84	$\pi^+ d \to pp$ PWA
2251 to 2266	BHANDARI	82	$NN \to NN$ PWA
2220 to 2260	DAKHNO	82	$pn \to pp\pi^-$ σ (or $^3D_3/^3G_3$)
2200 ± 10	[2] SHAMU	82	np total cross section fit
2260	[3] KANAI	81	$\pi d \to \pi d$ PWA (sol B & C)
2296 ± 11	IKEDA	80	$\gamma d \to pn$ PWA (sol A)
2307 ± 12	IKEDA	80	$\gamma d \to pn$ PWA (sol B)
2185	[4] KAMO	80	$pp \to \pi^+ d$ PWA
2220	HOSHIZAKI	78	$NN \to NN$ PWA
• • • We do not use the following data for averages fits limits etc • • •			
2310	[5] GREIN	82	Fits NN foward amplitudes
2155	[6] UEDA	82	$NN \to NN$ PWA Faddeev fit
2260 (fixed)	[7] IKEDA	80	$\gamma d \to pn$ PWA (sol A)
2390	[5] GREIN	78	Fits NN forward amplitudes

$NN(2250)$ WIDTH

VALUE (MeV)	DOCUMENT ID		COMMENT
16 ± 3	[1] TATISCHEFF	85	$^3He p \to d X$
120	JAUCH	84	$NN \to NN\pi$ Deck + resonance
142 ± 9	STRAKOVSKII	84	$\pi^+ d \to pp$ PWA
70 to 100	BHANDARI	82	$NN \to NN$ PWA
100 to 200	DAKHNO	82	$pn \to pp\pi^-$ σ (or $^3D_3/^3G_3$)
134 ± 9	[2] SHAMU	82	np total cross section fit
181 or 171	[3] KANAI	81	$\pi d \to \pi d$ PWA (sol B & C)
177 ± 32	IKEDA	80	$\gamma d \to pn$ PWA (sol A)
213 ± 54	IKEDA	80	$\gamma d \to pn$ PWA (sol B)
81	[4] KAMO	80	$pp \to \pi^+ d$ PWA
50 to 100	HOSHIZAKI	78	$NN \to NN$ PWA
• • • We do not use the following data for averages fits limits etc • • •			
75	[8] FERREIRA	83	πd forward amplitude
60	[6] UEDA	82	$NN \to NN$ PWA Faddeev fit
200 (fixed)	[7] IKEDA	80	$\gamma d \to pn$ PWA (sol A)
290	[5] GREIN	78	Fits NN forward amplitudes

NN(2250) ELASTICITY

VALUE	DOCUMENT ID		COMMENT
0.21	JAUCH	84	$NN \to NN\pi$ Deck + resonance
0 11 to 0.13	[9] BHANDARI	82	$NN \to NN$ PWA
0 096 ± 0 012	[10] SHAMU	82	np total cross section fit
0.2	HOSHIZAKI	78	$NN \to NN$ PWA
• • • We do not use the following data for averages, fits, limits etc • • •			
0 05	[8] FERREIRA	83	πd forward amplitude

NN(2250) POLE POSITION

REAL PART

Approximately equals the Breit Wigner mass

VALUE (MeV)	DOCUMENT ID		COMMENT
2183	ARNDT	87	$NN \to NN$ scattering analysis
2210 to 2220	[11] BHANDARI	83	$NN \to NN$ M-matrix fit
2218 to 2200	BHANDARI	82	$NN \to NN$ Breit-Wigner fit
2185	EDWARDS	81	$NN \to NN$ K-matrix fit
2175	KLOET	81	$NN \to NN$ potential model fit
• • • We do not use the following data for averages fits, limits, etc • • •			
2148 to 2149	[12] KLOET	83	$NN \to NN$ coupled channel fit
2162 to 2173	[13] KLOET	83	$NN \to NN$ coupled channel fit
2134	[12] UEDA	82	$NN \to NN$ PWA, Faddeev fit
2211	[12] VERWEST	82	$NN \to NN$ potential model fit
2190	BHANDARI	81	$NN \to NN$ K matrix fit
2215	BHANDARI	81	$NN \to NN$ M-matrix fit

IMAGINARY PART

Approximately equals one half the Breit-Wigner width

VALUE (MeV)	DOCUMENT ID		COMMENT
79	ARNDT	87	$NN \to NN$ scattering analysis
60 to 80	[11] BHANDARI	83	$NN \to NN$ M-matrix fit
45 to 60	BHANDARI	82	$NN \to NN$ Breit Wigner fit
70	EDWARDS	81	$NN \to NN$ K-matrix fit
43	KLOET	81	$NN \to NN$ potential model fit
• • • We do not use the following data for averages, fits limits, etc • • •			
33 to 38	[12] KLOET	83	$NN \to NN$ coupled channel fit
43 to 48	[13] KLOET	83	$NN \to NN$ coupled channel fit
52	[12] UEDA	82	$NN \to NN$ PWA Faddeev fit
35	[12] VERWEST	82	$NN \to NN$ potential model fit
65	BHANDARI	81	$NN \to NN$ K-matrix fit
70	BHANDARI	81	$NN \to NN$ M-matrix fit

NN(2250) |RESIDUE|/Im(POLE POSITION)

VALUE	DOCUMENT ID		COMMENT
0 18	ARNDT	87	$NN \to NN$ scattering analysis
0 1 to 0 2	[11] BHANDARI	83	$NN \to NN$ M-matrix fit
0 08 to 0.13	BHANDARI	82	$NN \to NN$ Breit-Wigner fit
0 30	EDWARDS	81	$NN \to NN$ K-matrix fit
• • • We do not use the following data for averages fits, limits, etc • • •			
0 15	BHANDARI	81	$NN \to NN$ K-matrix fit
0 15	BHANDARI	81	$NN \to NN$ M-matrix fit

NN(2250) FOOTNOTES

[1] The TATISCHEFF 85 state assignment is not certain
[2] SHAMU 82 is an np resonance
[3] The KANAI 81 fit with no resonances was very poor, and other fits with fewer than four resonances were not tried
[4] KAMO 80 did not try fits with fewer than six resonances
[5] GREIN 78 and GREIN 82 see no $^1D_2$ resonance
[6] UEDA 82 reports as the mass, but does not explain how it was calculated from the pole position
[7] IKEDA 80 gives two other solutions with poorer fits to the data
[8] FERREIRA 83 fixed the resonance mass
[9] BHANDARI 82 reports the $d\pi$ branching ratio to be 0 2 to 0 3 and the $N\Delta$ branching ratio to be 0 6 to 0 7
[10] This SHAMU 82 np value is equivalent to 0 19 ± 0.02 for pp
[11] BHANDARI 83 claims the $^3F_3$ is not an $N\Delta$ bound state
[12] Not a good fit to the partial-wave amplitudes
[13] KLOET 83 found two nearby $^3F_3$ poles

NN(2250) REFERENCES

ARNDT	87	PR D35 128	+Hyslop Roper	(VPI)
TATISCHEFF	85	PL 154B 107		(IPN)
Also	84	PRL 52 2022	Tatischeff Berthet Combes Didelez+	(IPN+)
JAUCH	84	PL 143B 509	+Konig Kroll	(WUPP)
STRAKOVSKII	84	SJNP 40 273	+Kravtsov Ryskin	(LENI)
		Translated from YAF 40 429		
Also	84	JP G9 L187	Kravtsov Tyskin Strakovskii	(LENI)
BHANDARI	83	PR D27 296		(VPI)
Also	83B	LNC 38 251	Bhandari	(NMSU)
FERREIRA	83	JP G9 169	+Munguia	(PUCB)
KLOET	83	NP A392 271	+Tjon	(ITPU)
BHANDARI	82	LNC 34 65		(VPI)
DAKHNO	82	PL 114B 409	+Kravtsov Lobachev Makarov Medvedev+	(LENI)
Also	82B	SJNP 36 83	Dakhno Kravtsov Lobachev Makarov+	(LENI)
		Translated from YAF 36 143		
GREIN	82	NP A377 505	+Kroll	(SIN WUPP)
SHAMU	82	PR D25 2008	+Soga Shilts Lisowski	(WMIU LASL)
UEDA	82	PL 119B 281		(OSAK)
VERWEST	82	PR C25 482		(TAMU)
BHANDARI	81	PRL 46 1111	+Arndt Roper Verwest	(VPI TAMU)
EDWARDS	81	PR D23 1978		(ANL)
KANAI	81	PTP 65 266	+Minaka Nakamura+	(TMU KAGO TWAS SAGA)
KLOET	81	NP A364 346	+Silbar	(RUTG LASL)
IKEDA	80	NP B172 509	+Arai, Fujii Fujii Iwasaki+	(TOKY KEK INUS)
KAMO	80	LNC 29 289	+Watari	(OSAK)
Also	80B	PTP 64 2144	Kamo Watari Yonezawa	(OSAK HIRO)
GREIN	78	NP B137 173	+Kroll	(KARL, WUPP)
HOSHIZAKI	78	PTP 60 1796		(KYOT)

OTHER NN

Status *

OMITTED FROM SUMMARY TABLE

This is a collection of miscellaneous possible observations of NN dibaryons See TATISCHEFF 87 for a review

OTHER NN MASS

These are Breit-Wigner masses

VALUE (MeV)	DOCUMENT ID		COMMENT
2121 ± 3	TATISCHEFF	87	p^3He, ^{3}He$p \to d X$
2192 ± 3	TATISCHEFF	87	p^3He $\to d X$
2240 ± 5	TATISCHEFF	87	p^3He $\to d X$
2014 ± 2	BOCK	86	$\gamma d \to (pp)\pi^-$
1922 0 ± 1.3	AZIMOV	85	πC or πNe $\to (pp) X$
1940.0 ± 0 4	AZIMOV	85	πC or πNe $\to (pp) X$
2017 0 ± 1 3	AZIMOV	85	πC or πNe $\to (pp) X$
2016 ± 3	BAIRAMOV	84	πC $\to (pp) X$
2014 ± 10	GLAGOLEV	84B	$dp \to (pp)n$
2162 ± 10	GLAGOLEV	84B	$dp \to (pp)n$
2030 ± 20	SIEMIARCZUK	84	$dp \to p\pi^+$ (missing mass)
2143 ± 20	SIEMIARCZUK	84	$dp \to p\pi^+$ (missing mass)
2020 ± 10	SIEMIARCZUK	84	$dp \to p(pn)$
2130 ± 10	SIEMIARCZUK	84	$dp \to p(pn)$
2384 ± 20	SIEMIARCZUK	84	$dp \to p\pi^+$ (missing mass)
2179 ± 1	STRAKOVSKII	84	$\pi^+ d \to pp$ PWA $^3P_1$
2035 ± 15	ZIELINSKI	84B	$\alpha p \to dn(pp)$
2137 ± 15	ZIELINSKI	84B	$\alpha p \to dn(pp)$
1936 ± 2	BESLIU	83	
1962 ± 2	BESLIU	83	
2480	[1] LOCHER	83	$\pi d \to \pi d$ PWA, $^1G_4$
2036 ± 15	ZELINSKI	83	$\alpha p \to (pp)pnn$
2126 ± 15	ZELINSKI	83	$\alpha p \to (pp)pnn$
• • • We do not use the following data for averages fits, limits, etc • • •			
1820	LAFRANCE	87	$NN \to NN$ PWA, $^3S_1$-$^3D_1$
2000	LAFRANCE	87	$NN \to NN$ PWA, $^3S_0$
2122 ± 1	TATISCHEFF	87B	See TATISCHEFF 87
2198 ± 1	TATISCHEFF	87B	See TATISCHEFF 87
2233 ± 1 6	TATISCHEFF	87B	See TATISCHEFF 87
1930	ERMAKOV	86	pAr $\to (pp) X$
1960	ERMAKOV	86	pAr $\to (pp) X$
2192 ± 3	TATISCHEFF	85	See TATISCHEFF 87
2124 ± 3	TATISCHEFF	85	See TATISCHEFF 87
2240 ± 5	TATISCHEFF	85	See TATISCHEFF 87
1961 ± 2	[2] BAIRAMOV	84	πC $\to (pp) X$
2179 to 2190	[3] BAKKER	84	$NN \to NN$ P-matrix $^1S_0$
2021 to 2236	[3] BAKKER	84	$NN \to NN$ P-matrix $^3S_1$
2268 to 2272	[3] BAKKER	84	$NN \to NN$ P-matrix, $^1P_1$
2324 to 2329	[3] BAKKER	84	$NN \to NN$ P-matrix, $^3P_1$
2160 to 2170	[3] VESELOV	84	$NN \to NN$ P-matrix, $^3S_1$
2362	AKEMOTO	83	$\pi^- d \to \pi^- d$ $d\sigma/d\Omega$
2429	AKEMOTO	83	$\pi^- d \to \pi^- d$ $d\sigma/d\Omega$
2722	AKEMOTO	83	$\pi^- d \to \pi^- d$ $d\sigma/d\Omega$
2060	FERREIRA	83	πd forward amplitude, $^3P_1$
2250	GREIN	82	Forward NN $^3S_1$ or $^3D_3$
2230	ARGAN	81	$\gamma d \to p X$ cross sections

VALUE (MeV)	DOCUMENT ID		COMMENT
2290	[4] KANAI	81	$\pi d \to \pi d$ PWA (sol B) $^3P_2$
2300	[4] KANAI	81	$\pi d \to \pi d$ PWA (sol C) $^3P_2$
2510	[4] KANAI	81	$\pi d \to \pi d$ PWA (sol B) $^1G_4$
2530	[4] KANAI	81	$\pi d \to \pi d$ PWA (sol C) $^1S_0$
2250	GREIN	80	Forward NN $^3S_1$ or $^3D_3$
2190	HASHIMOTO	80	$NN \to NN$ $^1F_3$ assumed bkgd
2352 ± 69	IKEDA	80	$\gamma d \to pn$ PWA (sol A) $^3S_1$
2380 (fixed)	IKEDA	80	$\gamma d \to pn$ PWA (sol A) $^3S_1$
2290 ± 14	IKEDA	80	$\gamma d \to pn$ PWA (sol C) $^3P_2$
2380 (fixed)	IKEDA	80	$\gamma d \to pn$ PWA (sol C) $^3S_1$
2377 ± 17	IKEDA	80	$\gamma d \to pn$ PWA (sol B) $^3D_3$
2100	[5] KAMO	80	$pp \to \pi^+ d$ PWA, $^1S_0$
2117	[5] KAMO	80	$pp \to \pi^+ d$ PWA $^3P_2$
2148	[5] KAMO	80	$pp \to \pi^+ d$ PWA, $^3F_2$
2159	[5] KAMO	80	$pp \to \pi^+ d$ PWA $^3P_1$
2170 ± 10	ALADASHVILI	76	$dp \to (pp)n$

OTHER NN WIDTH

VALUE (MeV)	DOCUMENT ID		COMMENT
25 ± 2	TATISCHEFF	87	p^3He, ^{3}He$p \to d$ X
25 ± 6	TATISCHEFF	87	p^3He $\to d$ X
16 ± 3	TATISCHEFF	87	p^3He $\to d$ X
4.5 ± 2.0	BOCK	86	$\gamma d \to (pp)\pi^-$
11.0 ± 3.6	AZIMOV	85	πC or πNe $\to (pp)$ X
10.0 ± 4.5	AZIMOV	85	πC or πNe $\to (pp)$ X
5 ± 2	AZIMOV	85	πC or πNe $\to (pp)$ X
30 ± 14	BAIRAMOV	84	πC $\to (pp)$ X
63 ± 28	GLAGOLEV	84B	$dp \to (pp)n$
18 ± 26	GLAGOLEV	84B	$dp \to (pp)n$
64 ± 20	SIEMIARCZUK	84	$dp \to p\pi^+$ (missing mass)
62 ± 20	SIEMIARCZUK	84	$dp \to p\pi^+$ (missing mass)
45 ± 20	SIEMIARCZUK	84	$dp \to p(pn)$
20 ± 10	SIEMIARCZUK	84	$dp \to p(pn)$
80 ± 20	SIEMIARCZUK	84	$dp \to p\pi^+$ (missing mass)
86 ± 2	STRAKOVSKII	84	$\pi^+ d \to pp$ PWA $^3P_1$
30 ± 23	ZIELINSKI	84B	$\alpha p \to dn(pp)$
59 ± 20	ZIELINSKI	84B	$\alpha p \to dn(pp)$
6.0 ± 1.4	BESLIU	83	
9 ± 2	BESLIU	83	
150	[1] LOCHER	83	$\pi d \to \pi d$ PWA, $^1G_4$
27 ± 25	ZELINSKI	83	$\alpha p \to (pp)pnn$
41 ± 38	ZELINSKI	83	$\alpha p \to (pp)pnn$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
25 ± 2	TATISCHEFF	85	See TATISCHEFF 87
25 ± 6	TATISCHEFF	85	See TATISCHEFF 87
16 ± 3	TATISCHEFF	85	See TATISCHEFF 87
11 ± 4	[2] BAIRAMOV	84	πC $\to (pp)$ X
317	AKEMOTO	83	$\pi^- d \to \pi^- d$ $d\sigma/d\Omega$
103	AKEMOTO	83	$\pi^- d \to \pi^- d$ $d\sigma/d\Omega$
223	AKEMOTO	83	$\pi^- d \to \pi^- d$ $d\sigma/d\Omega$
50	FERREIRA	83	πd forward amplitude, $^3P_1$
40	ARGAN	81	$\gamma d \to p$ X cross sections
139	[4] KANAI	81	$\pi d \to \pi d$ PWA (sol B) $^3P_2$
150	[4] KANAI	81	$\pi d \to \pi d$ PWA (sol C) $^3P_2$
122	[4] KANAI	81	$\pi d \to \pi d$ PWA (sol B) $^1G_4$
66	[4] KANAI	81	$\pi d \to \pi d$ PWA (sol C) $^1S_0$
100	GREIN	80	Forward NN, $^3S_1$ or $^3D_3$
50	HASHIMOTO	80	$NN \to NN$ $^1F_3$ assumed bkgd
342 ± 69	IKEDA	80	$\gamma d \to pn$ PWA (sol A) $^3S_1$
200 (fixed)	IKEDA	80	$\gamma d \to pn$ PWA (sol A) $^3S_1$
263 ± 55	IKEDA	80	$\gamma d \to pn$ PWA (sol C) $^3P_2$
200 (fixed)	IKEDA	80	$\gamma d \to pn$ PWA (sol C) $^3S_1$
214 ± 52	IKEDA	80	$\gamma d \to pn$ PWA (sol B) $^3D_3$
315	[5] KAMO	80	$pp \to \pi^+ d$ PWA $^1S_0$
58	[5] KAMO	80	$pp \to \pi^+ d$ PWA $^3P_2$
5	[5] KAMO	80	$pp \to \pi^+ d$ PWA $^3F_2$
51	[5] KAMO	80	$pp \to \pi^+ d$ PWA $^3P_1$
50	ALADASHVILI	76	$dp \to (pp)n$

OTHER NN ELASTICITY

VALUE	DOCUMENT ID		COMMENT
0.06	[6] SMITH	84	$\pi d \to \pi d$ PWA $^1G_4$
0.13	[1] LOCHER	83	$\pi d \to \pi d$ PWA $^1G_4$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.12	HASHIMOTO	80	$NN \to NN$ $^1F_3$ assumed bkgd

OTHER NN POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		COMMENT
2163	ARNDT	87	$NN \to NN$ analysis $^3P_2$-$^3F_2$
2210	ARNDT	87	$NN \to NN$ analysis $^3F_4$ $^3H_4$

IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		COMMENT
75	ARNDT	87	$NN \to NN$ analysis $^3P_2$-$^3F_2$
78	ARNDT	87	$NN \to NN$ analysis $^3F_4$-$^3H_4$

OTHER NN |RESIDUE|/Im(POLE POSITION)

VALUE (MeV)	DOCUMENT ID		COMMENT
0.10	ARNDT	87	$NN \to NN$ analysis $^3P_2$
0.0037	ARNDT	87	$NN \to NN$ analysis $^3F_2$
0.023	ARNDT	87	$NN \to NN$ analysis $^3F_4$
0.00051	ARNDT	87	$NN \to NN$ analysis $^3H_4$

OTHER NN FOOTNOTES

[1] LOCHER 83 is a resonance fit to the vector polarization.
[2] This BAIRAMOV 84 effect disappears for $p_{lab} > 300$ MeV/c.
[3] These are actually the P-matrix pole positions.
[4] The KANAI 81 fit with no resonances was very poor, and other fits with fewer than four resonances were not tried.
[5] KAMO 80 did not try fits with fewer than six resonances.
[6] SMITH 84 is a Faddeev + resonance fit to the vector analyzing power varying only the elasticity; the mass and width were fixed at the LOCHER 83 values.

OTHER NN REFERENCES

ARNDT	87	PR D35 128	+Hyslop, Roper	(VPI)
LAFRANCE	87	PR D34 1341	+Lomon	(MIT)
TATISCHEFF	87	PR C36 1995	+Berthet, Combes, Comets, Didelez+	(IPN, SACL)
TATISCHEFF	87B	EPL 4 671	+Comets, Le Bornec, Willis+	(IPN, SACL, STRB)
BOCK	86	NP A459 573	+Ruhm, Althoff, Anton, Ferber+	(PUIB)
ERMAKOV	86	SJNP 44 90	+Stabnikov, Tverskoi, Shabelskii	(LINP)
AZIMOV	85	SJNP 42 579	+Allaberdin, Edgorov, Inogamov+	(UZBEK)
		Translated from YF 42 913.		
TATISCHEFF	85	PL 154B 107		(IPN)
Also	84	PRL 52 2022	Tatischeff, Berthet, Combes, Didelez+	(IPN+)
BAIRAMOV	84	SJNP 39 26	+Budagov, Dvornik, Lomakin, Milov+	(JINR)
		Translated from YAF 39 44.		
BAKKER	84	NP A424 563	+Grach, Narodetskii	(VRIJ, ITEP)
GLAGOLEV	84B	JINR N5 84		(JINR)
		As reported in TATISCHEFF 85B (SJNP A446 353C).		
SIEMIARCZUK	84	PL 137B 434	+Zielinski	(WINR, WARS)
Also	83	PL 128B 367	Siemiarczuk, Stepanyak, Zielinski	(WINR)
SMITH	84	PR C29 2206	+Mathie, Boschitz, Ottermann+	(KARL, SIN+)
STRAKOVSKII	84	SJNP 40 273	+Kravtsov, Ryskin	(LENI)
		Translated from YAF 40 429.		
Also	84	JP G9 L187	Kravtsov, Tyskin, Strakovskii	(LENI)
VESELOV	84	SJNP 39 456	+Grach, Narodetskii	(ITEP)
		Translated from YAF 39 719.		
ZIELINSKI	84B	SJNP 40 306	+Sobchak, Stepanyak+	(WINR+)
		Translated from YAF 40 482.		
Also	84	ZPHY A317 335	Glagolev, Lebedev, Shuravleva+	(JINR+)
AKEMOTO	83	PRL 50 400	+Baba, Endo, Himeniya, Inoue+	(HIRO, UOEH)
BESLIU	83	JINR D1 83 815	+Allaberdin, Edgorov, Inogamov+	(JINR)
		As reported in TATISCHEFF 85B (SJNP A446 353C).		
FERREIRA	83	JP G9 169	+Munguia	(PUCB)
LOCHER	83	PL 121B 227	+Saino	(SIN)
ZELINSKI	83	JINR 1 83 566	+	(JINR)
		As reported in TATISCHEFF 85B (SJNP A446 353C).		
GREIN	82	NP A377 505	+Kroll	(SIN, WUPP)
ARGAN	81	PRL 46 96	+Audit, Debotton, Faure, Martin	(SACL)
KANAI	81	PTP 65 266	+Minaka, Nakamura+ (TMU, KAGO, TWAS, SAGA)	
GREIN	80	PL 96B 176	+Kronig, Kroll	(SIN, WUPP)
HASHIMOTO	80	PTP 64 1693	+Hoshizaki	(KYOT)
IKEDA	80	NP B172 509	+Arai, Fujii, Fujii, Iwasaki+	(TOKY, KEK, INUS)
KAMO	80	LNC 29 289	+Watari	(OSAK)
Also	80B	PTP 64 2144	Kamo, Watari, Yonezawa	(OSAK, HIRO)
ALADASHVILI	76	NP A274 486	+Glagolev+	(JINR, WARS, WINR)

S = −1 DIBARYON

$\Lambda N(2130)$ $^3S_1$

$I(J^P) = \frac{1}{2}(1^+)$ Status: * *

OMITTED FROM SUMMARY TABLE

We list here bumps seen in ΛN or ΣN mass spectra. It is not always claimed that the bump is a resonance. In particular, the bump near 2130 MeV is sometimes explained in terms of the ΣN threshold.

$\Lambda N(2130)$ MASS

VALUE (MeV)	DOCUMENT ID		COMMENT
2130	PIEKARZ	87	$K^- d \to \pi^-$ X
2129.8 ± 2.0	PIGOT	85	$K^- d \to \pi^-$ X, $\pi^+ d \to K^+$ X
2320	GOYAL	80B	$K^- d \to (\Sigma^- p)\pi^+\pi^-$
2130	GOYAL	78	$K^- d \to (\Lambda p)\pi^+\pi^-\pi^-$
2129.0 ± 0.4	BRAUN	77	$K^- d \to (\Lambda p)\pi^-$
2125.2 ± 2.5	SHAHBAZIAN	73	nC $\to (\Lambda p)$ X
2129	EASTWOOD	71	$K^- d \to (\Lambda p)\pi^-$
2127 ± 1	SIMS	71	$K^- d \to (\Lambda p)\pi^-$ $(\Lambda N)\pi\pi$

Baryon Full Listings
DIBARYONS

2130	ALEXANDER	69	$K^- d \to (\Lambda N)\pi^-$
2128 7 ±0 2	TAN	69	$K^- d \to (\Lambda p)\pi^-$
2126	CLINE	68	$K^- d \to (\Lambda p)\pi^-$
2098 ±6	COHN	64	$\Sigma^- {}^4He \to (\Lambda n){}^3H$
• • • We do not use the following data for averages fits limits etc • • •			
2257 4 ±2 3	[2] SHAHBAZIAN	82	$nC \to (\Lambda p)$ X (fit 1)
2350.8 ±2 4	[2] SHAHBAZIAN	82	$nC \to (\Lambda p)$ X (fit 1)
2495 2 ±8 7	SHAHBAZIAN	82	$nC \to (\Lambda p \pi^\pm)$ X
2115	SODHI	75	$K^- d \to (\Lambda p)\pi^- \pi^0$
2251 4 ±3 9	SHAHBAZIAN	73	$nC \to (\Lambda p)$ X
2110	[3] JAIN	69	K^- emulsion $\to (\Lambda p)$ X
2138 8 ±0 7	TAN	69	$K^- d \to (\Lambda p)\pi^-$

ΛN(2130) WIDTH

VALUE (MeV)	DOCUMENT ID		COMMENT
16 7 ± 2 8	PIGOT	85	$K^- d \to \pi^-$ X $\pi^+ d \to K^+$ X
5 9 ± 1 6	BRAUN	77	$K^- d \to (\Lambda p)\pi^-$
20 6 ± 5 2	SHAHBAZIAN	73	$nC \to (\Lambda p)$ X
10	EASTWOOD	71	$K^- d \to (\Lambda p)\pi^-$
8 ± 1	SIMS	71	$K^- d \to (\Lambda p)\pi^-$ $(\Lambda N)\pi\pi$
7 0 ± 0 6	TAN	69	$K^- d \to (\Lambda p)\pi^-$
20 $^{+15}_{-5}$	COHN	64	$\Sigma^- {}^4He \to (\Lambda n){}^3H$
• • • We do not use the following data for averages fits, limits etc • • •			
18 1 ± 1 1	[2] SHAHBAZIAN	82	$nC \to (\Lambda p)$ X (fit 1)
44 2 ± 2.2	[2] SHAHBAZIAN	82	$nC \to (\Lambda p)$ X (fit 1)
204 7 ± 5 6	SHAHBAZIAN	82	$nC \to (\Lambda p \pi^\pm)$ X
25	GOYAL	80B	$K^- d \to (\Sigma^- p)\pi^+\pi^-$
150	SODHI	75	$K^- d \to (\Lambda p)\pi^- \pi^0$
21 1 ± 5 4	SHAHBAZIAN	73	$nC \to (\Lambda p)$ X
20	[3] JAIN	69	K^- emulsion $\to (\Lambda p)$ X
9 1 ± 2.4	TAN	69	$K^- d \to (\Lambda p)\pi^-$
< 10	CLINE	68	$K^- d \to (\Lambda p)\pi^-$

ΛN(2130) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		COMMENT
2129	DOSCH	80	$K^- d \to (\Lambda p)\pi^-$ $^3S_1$ wave
2128	[4] TAKAHASHI	80	$YN \to YN$ $^3S_1$ wave
2132	[5] NAGELS	79	$YN \to YN$ $^3D_1$ wave (Q=1)
2137	[5] NAGELS	79	$YN \to YN$ $^3D_1$ (Q=0)
• • • We do not use the following data for averages fits limits, etc • • •			
2148	[4] TAKAHASHI	80	$YN \to YN$ $^1P_1$ wave

IMAGINARY PART

Approximately equals one half Breit Wigner width

VALUE (MeV)	DOCUMENT ID		COMMENT
5	DOSCH	80	$K^- d \to (\Lambda p)\pi^-$ $^3S_1$ wave
4 2	[4] TAKAHASHI	80	$YN \to YN$ $^3S_1$ wave
2 4	[5] NAGELS	79	$YN \to YN$ $^3D_1$ wave (Q=1)
2 6	[5] NAGELS	79	$YN \to YN$ $^3D_1$ wave (Q=0)
• • • We do not use the following data for averages fits limits etc • • •			
8	[4] TAKAHASHI	80	$YN \to YN$ $^1P_1$ wave

ΛN(2130) FOOTNOTES

1 GOYAL 78 sees another uncertain peak at 2195–2210 MeV
2 A simultaneous fit to $p\Lambda$ invariant mass and elastic scattering effective cross sections
3 GOYAL 71 raises doubts about the experimental procedure used in JAIN 69
4 TAKAHASHI 80 gives fits with and without a $^3S_1$ resonance
5 NAGELS 79 reports pole positions for two different $^3D_1$ charge states

ΛN(2130) REFERENCES

PIEKARZ 87 NP A463 205C (BRAN)
PIGOT 85 NP B249 172 +DeBrion Caillet Cheze+ (ROMA SACL VAND)
SHAHBAZIAN 82 NP A374 73C +Temnikov Timonina (JINR)
DOSCH 80 ZPHY C3 249 +Stamatescu (HEID)
GOYAL 80B PTP 64 700 +Misra (DELH)
TAKAHASHI 80 NP A336 347 +Iwamura Kimura Kume (TOKY)
NAGELS 79 PR D20 1633 +Rijken Deswart (NIJM)
GOYAL 78 PR D18 948 +Sodhi (DELH)
BRAUN 77 NP B124 45 +Grimm Hepp Stroebele Thoel+ (HEID MPIM)
SODHI 75 NP B97 403 +Goyal (DELH)
SHAHBAZIAN 73 NP B53 19 +Timonina (JINR)
EASTWOOD 71 PR D3 2603 +Fry Heathcote Islam+ (BIRM EDIN GLAS LOIC)
GOYAL 71 PR D3 1259 (DELH)
SIMS 71 PR D3 1162 +O Neal Albright Brucker Lannutti (FSU)
ALEXANDER 69 PRL 22 483 +Hall Jew Kalmus Kernan (LBL UCR)
JAIN 69 PR 187 1816 (BUFF)
TAN 69 PRL 23 395 (SLAC)
CLINE 68 PRL 20 1452 +Laumann Mapp (WISC)
COHN 64 PRL 13 668 +Bhatt Bugg (ORNL TENN)

— — OTHER RELATED PAPERS ——

AERTS 85 NP B253 116 +Dover (CERN IPN)
D AGOSTINI 81 PL 104B 330 (ROMA SACL VAND)
KIMURA 81 PTP 65 649 +Iwamura Takahashi (TOKY)
TOKER 81 NP A362 405 +Gal Eisenberg (HEBR TELA)
MIZUNO 79 PTP 62 1691 (TOKY)
ROOSEN 79 NC B49 217 +VanderVelde Wilquet Wickens+ (LOUC BRUX)
DOSCH 78 PR D18 4071 +Hepp (HEID)
KADYK 71 NP B27 13 +Alexander Chan Gaposchkin Trilling (LBL)
BUNNELL 70 PR D2 98 +Derrick Fields Hyman Keyes (NWES ANL)
ALEXANDER 68 PR 173 1452 +Karshon Shapira+ (REHO HEID)
PIROUE 64 PL 11 164 (PRIN)

$S = -2$ DIBARYON

$S = -2$ DIBARYON

OMITTED FROM SUMMARY TABLE

We list here bumps seen in an $S = -2$ two-baryon mass spectra

$S = -2$ DIBARYON MASS

VALUE (MeV)	DOCUMENT ID		COMMENT
2480	[1] GOYAL	80	$K^- d \to (\Xi^- p)K^0$
2365 3 ±9 6	SHAHBAZIAN	73	nC $\pi^- C \to (\Lambda\Lambda)$ X
2367 ±4	[2] BEILLIERE	72	$K^- A \to (\Lambda\Lambda)$ X

$S = -2$ DIBARYON WIDTH

VALUE (MeV)	DOCUMENT ID		COMMENT
47.0 ± 15.7	SHAHBAZIAN	73	nC $\pi^- C \to (\Lambda\Lambda)$ X

$S = -2$ DIBARYON FOOTNOTES

1 GOYAL 80 also sees a shoulder at 2360 MeV
2 WILQUET 75 with more events from the same experiment, no longer saw the bump

$S = -2$ DIBARYON REFERENCES

GOYAL 80 PR D21 607 +Misra Sodhi (DELH)
WILQUET 75 PL 57B 97 +Knight+ (BRUX CERN RAL TUFT LOUC)
SHAHBAZIAN 73 NP B53 19 +Timonina (JINR)
BEILLIERE 72 PL 39B 671 +Mayeur+ (BRUX CERN TUFT LOUC)

— — OTHER RELATED PAPERS ——

AERTS 85 NP B253 116 +Dover (CERN IPN)
WALCHER 85 NP A434 343C (MPIH)
D AGOSTINI 82 NP B209 1 (INFN SACL VAND CERN)
CARROLL 78 PRL 41 777 +Chiang Johnson Kycia Kl+ (BNL PRIN)

ACCESSING AND USING PARTICLE PHYSICS DATABASES

A number of publicly accessible computer databases containing particle physics information now exist at various institutions. Some of these databases are for literature searching, allowing the user to locate papers of interest, while others contain actual numerical data. The following discussion gives some idea of what is available and how to get started accessing and using these databases. The three locations covered are SLAC, Rutherford Appleton Laboratory (RAL), and Serpukhov.

The SLAC Particle Physics Databases

The databases of interest at SLAC are: (1) HEP, a literature-searching guide for all particle physics journal articles, preprints, reports, theses, etc., indexed by the standard bibliographic quantities; (2) DATAGUIDE, an adjunct to HEP, which indexes papers containing experimental data by accelerator, detector, beam momentum, reactions and particles studied; (3) PARTICLES (formerly RPP), containing the Full Listings from this Review of Particle Properties, indexed by particle and particle property; (4) REACTIONS, containing numerical data (e.g., cross sections, polarizations, etc.) on reactions; and (5) EXPERIMENTS, a guide to current and past particle physics experiments, indexed similarly to the HEP and DATAGUIDE databases.

All these databases are managed by the SPIRES database management system, which runs interactively under VM/CMS on SLAC's IBM 3081 computer. To enter SPIRES once you are logged onto the computer, key in SPIRES. You can then obtain information about the database in which you are interested by typing, say, EXPLAIN PARTICLES. To actually access the database, enter, for example, SELECT PARTICLES. You may then find out what terms are available on which you may search by keying in SHOW INDICES. To see the form of the contents of a particular index, say the PP (particle property) index of the PARTICLES database, key in BROWSE PP; this will give you an idea of what kinds of expressions appear in this index, and thus will suggest what form you should use in your search. Then to do an actual search for information, say for the RPP Full Listings on the η meson mass, you would key in a command like FIND PP ETA MASS, followed by the command TYPE; this would print out the Listings for the η mass. At any time, you may get help by typing in such commands as EXPLAIN, EXPLAIN EXPLAIN, SHOW INDICES, EXPLAIN BROWSE, EXPLAIN FIND, EXPLAIN TYPE, etc. When you are finished searching, key in EXIT, which gets you out of SPIRES.

Anyone who has an account on the SLAC computing system can access these databases online. If you do not have an account and cannot find anyone who does (at main laboratories, ask at the library), please contact SLAC directly. More information on how to access and search the databases can be found in the report "A User's Guide to Particle Physics Computer-Searchable Databases on the SLAC-SPIRES System," LBL-19173, available from the Particle Data Group, Bldg. 50, Room 308, Lawrence Berkeley Laboratory, Berkeley, CA 94720, USA. An extensive wall poster, "A Guide to VM SPIRES," is available from the Library, SLAC, P.O. Box 4349, Stanford, CA 94309, USA. You may also contact Alan Rittenberg at LBL (CMS-id AXRVX, tel. 415-486-4723 or 451-4723 on FTS) or Louise Addis at SLAC (CMS-id ADDIS, tel. 415-926-2411).

The Durham-RAL Particle Physics Databases

These databases contain compilations of current and past experimental particle physics data (e.g., reaction cross sections, polarizations, etc.) and are available for interactive searching under VM/CMS on both the Rutherford Appleton Laboratory (RAL) and CERN central computers. The topics include (1) two-body (and quasi-two-body) reactions, (2) hadron and photon one- and two-particle inclusive distributions, (3) lepton-produced inclusive data (i.e., deep inelastic scattering structure functions, etc.), and (4) data from e^+e^- annihilations. The databases also include a subset of the HEP literature-searching guide taken from the SLAC databases from 1980 onwards which are linked to the reaction data compilation to inform users whenever data is available in the databases. Also included are the EXPERIMENTS and PARTICLES databases from the SLAC system (see previous section).

The databases run under the Berkeley Database Management System and are menu-driven with full on-line help information to facilitate easy use. They can be accessed by anyone having network access to the RAL or CERN computers. For PSS access to RAL, the relevant address is 23422351919169 (then 2); a guest account (PDG, password HEPDATA) is available at RAL for those who do not have their own CMS account. An EXEC file, HEPDATA, resident on the user-disk (UDISK) gives interactive access to the databases. The data are retrieved using simple keyword-based searches, and resulting data records can be listed on the terminal, sent to a printer, or transferred to the user's own machine as desired.

To insure that the databases are up to date, experimentalists are urged to send their data to the compilers as soon as it is made publicly available.

For more information, or a new user guide (1988 edition), please contact Mike Whalley at Durham University, England (mrw@ukacrl or mrw@cernvm) or Dick Roberts at RAL (rgr@ukacrl). At CERN, user guides may also be obtained from Alec Hester of the CERN library (hes@cernvm).

The Serpukhov Particle Physics Databases

Many of the databases referred to above are available at Serpukhov in the USSR. Please contact V.V. Ezhela for more information.

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