$K^{\pm}$

$I(J^P) = \frac{1}{2}(0^-)$

THE CHARGED KAON MASS

Revised 1994 by T.G. Trippe, (LBNL).

The average of the six charged kaon mass measurements which we use in the Particle Listings is

$$m_{K^{\pm}} = 493.677 \pm 0.013 \text{ MeV (S = 2.4)} , \qquad (1)$$

where the error has been increased by the scale factor S. The large scale factor indicates a serious disagreement between different input data. The average before scaling the error is

$$m_{K^{\pm}} = 493.677 \pm 0.005 \text{ MeV} ,$$
$$\chi^2 = 22.9 \text{ for 5 D.F., Prob. } = 0.04\% , \qquad (2)$$

where the high χ^2 and correspondingly low χ^2 probability further quantify the disagreement.

The main disagreement is between the two most recent and precise results,

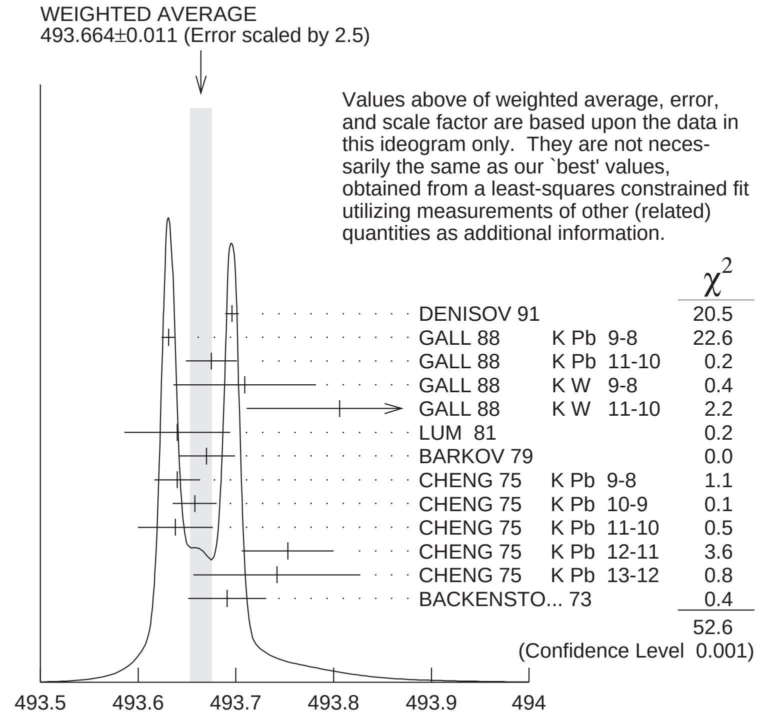
$$m_{K^{\pm}} = 493.696 \pm 0.007 \text{ MeV} \qquad \text{DENISOV 91}$$
$$m_{K^{\pm}} = 493.636 \pm 0.011 \text{ MeV (S = 1.5)} \qquad \text{GALL 88}$$
$$\text{Average} = 493.679 \pm 0.006 \text{ MeV}$$
$$\chi^2 = 21.2 \text{ for 1 D.F., Prob. } = 0.0004\% , \qquad (3)$$

both of which are measurements of x-ray energies from kaonic atoms. Comparing the average in Eq. (3) with the overall average in Eq. (2), it is clear that DENISOV 91 and GALL 88 dominate the overall average, and that their disagreement is responsible for most of the high χ^2.

The GALL 88 measurement was made using four different kaonic atom transitions, K^- Pb ($9 \rightarrow 8$), K^- Pb ($11 \rightarrow 10$), K^- W ($9 \rightarrow 8$), and K^- W ($11 \rightarrow 10$). The $m_{K^\pm}$ values they obtain from each of these transitions is shown in the Particle Listings and in Fig. 1. Their K^- Pb ($9 \rightarrow 8$) $m_{K^\pm}$is below and somewhat inconsistent with their other three transitions. The average of their four measurements is

$$m_{K^\pm} = 493.636 \pm 0.007 \; ,$$
$$\chi^2 = 7.0 \;\; \text{for 3 D.F., Prob.} \;\; = 7.2\% \; . \qquad (4)$$

This is a low but acceptable χ^2 probability so, to be conservative, GALL 88 scaled up the error on their average by S=1.5 to obtain their published error ± 0.011 shown in Eq. (3) above and used in the Particle Listings average.



$m_{K^\pm}$ (MeV)

Figure 1: Ideogram of $m_{K^\pm}$ mass measurements. GALL 88 and CHENG 75 measurements are shown separately for each transition they measured.

The ideogram in Fig. 1 shows that the DENISOV 91 measurement and the GALL 88 K^- Pb $(9 \to 8)$ measurement yield two well-separated peaks. One might suspect the GALL 88 K^- Pb $(9 \to 8)$ measurement since it is responsible both for the internal inconsistency in the GALL 88 measurements and the disagreement with DENISOV 91.

To see if the disagreement could result from a systematic problem with the K^- Pb $(9 \rightarrow 8)$ transition, we have separated the CHENG 75 data, which also used K^- Pb, into its separate transitions. Figure 1 shows that the CHENG 75 and GALL 88 K^- Pb $(9 \rightarrow 8)$ values are consistent, suggesting the possibility of a common effect such as contaminant nuclear γ rays near the K^- Pb $(9 \rightarrow 8)$ transition energy, although the CHENG 75 errors are too large to make a strong conclusion. The average of all 13 measurements has a χ^2 of 52.6 as shown in Fig. 1 and the first line of Table 1, yielding an unacceptable χ^2 probability of 0.00005%. The second line of Table 1 excludes both the GALL 88 and CHENG 75 measurements of the K^- Pb $(9 \rightarrow 8)$ transition and yields a χ^2 probability of 43%. The third [fourth] line of Table 1 excludes only the GALL 88 K^- Pb $(9 \rightarrow 8)$ [DENISOV 91] measurement and yields a χ^2 probability of 20% [8.6%]. Table 1 shows that removing both measurements of the K^- Pb $(9 \rightarrow 8)$ transition produces the most consistent set of data, but that excluding only the GALL 88 K^- Pb $(9 \rightarrow 8)$ transition or DENISOV 91 also produces acceptable probabilities.

Table 1: $m_{K^\pm}$ averages for some combinations of Fig. 1 data.

$m_{K^\pm}$ (MeV)	χ^2	D.F.	Prob. (%)	Measurements used
493.664 ± 0.004	52.6	12	0.00005	all 13 measurements
493.690 ± 0.006	10.1	10	43	no K^- Pb(9→8)
493.687 ± 0.006	14.6	11	20	no GALL 88 K^- Pb(9→8)
493.642 ± 0.006	17.8	11	8.6	no DENISOV 91

Yu.M. Ivanov, representing DENISOV 91, has estimated corrections needed for the older experiments because of improved ^{192}Ir and ^{198}Au calibration γ-ray energies. He estimates that CHENG 75 and BACKENSTOSS 73 $m_{K^{\pm}}$ values could be raised by about 15 keV and 22 keV, respectively. With these estimated corrections, Table 1 becomes Table 2. The last line of Table 2 shows that if such corrections are assumed, then GALL 88 K^- Pb $(9 \rightarrow 8)$ is inconsistent with the rest of the data even when DENISOV 91 is excluded. Yu.M. Ivanov warns that these are rough estimates. Accordingly, we do not use Table 2 to reject the GALL 88 K^- Pb $(9 \rightarrow 8)$ transition, but we note that a future reanalysis of the CHENG 75 data could be useful because it might provide supporting evidence for such a rejection.

Table 2: $m_{K^{\pm}}$ averages for some combinations of Fig. 1 data after raising CHENG 75 and BACKENSTOSS 73 values by 0.015 and 0.022 MeV respectively.

$m_{K^{\pm}}$ (MeV)	χ^2	D.F.	Prob. (%)	Measurements used
493.666 ± 0.004	53.9	12	0.00003	all 13 measurements
493.693 ± 0.006	9.0	10	53	no K^- Pb(9→8)
493.690 ± 0.006	11.5	11	40	no GALL 88 K^- Pb(9→8)
493.645 ± 0.006	23.0	11	1.8	no DENISOV 91

The GALL 88 measurement uses a Ge semiconductor spectrometer which has a resolution of about 1 keV, so they run the risk of some contaminant nuclear γ rays. Studies of γ rays following stopped π^- and Σ^- absorption in nucleii (unpublished) do not show any evidence for contaminants according to GALL 88 spokesperson, B.L. Roberts. The DENISOV 91 measurement uses a crystal diffraction spectrometer with a resolution of 6.3 eV for radiation at 22.1 keV to measure the 4f-3d transition in K^{-} ^{12}C. The high resolution and the light nucleus reduce the probability for overlap by contaminant γ rays, compared with the measurement of GALL 88. The DENISOV 91 measurement is supported by their high-precision measurement of the 4d-2p transition energy in π^{-} ^{12}C, which is good agreement with the calculated energy.

While we suspect that the GALL 88 K^{-}Pb $(9 \rightarrow 8)$ measurements could be the problem, we are unable to find clear grounds for rejecting it. Therefore, we retain their measurement in the average and accept the large scale factor until further information can be obtained from new measurements and/or from reanalysis of GALL 88 and CHENG 75 data.

We thank B.L. Roberts (Boston Univ.) and Yu.M. Ivanov (Petersburg Nuclear Physics Inst.) for their extensive help in understanding this problem.

$K^{\pm}$ MASS

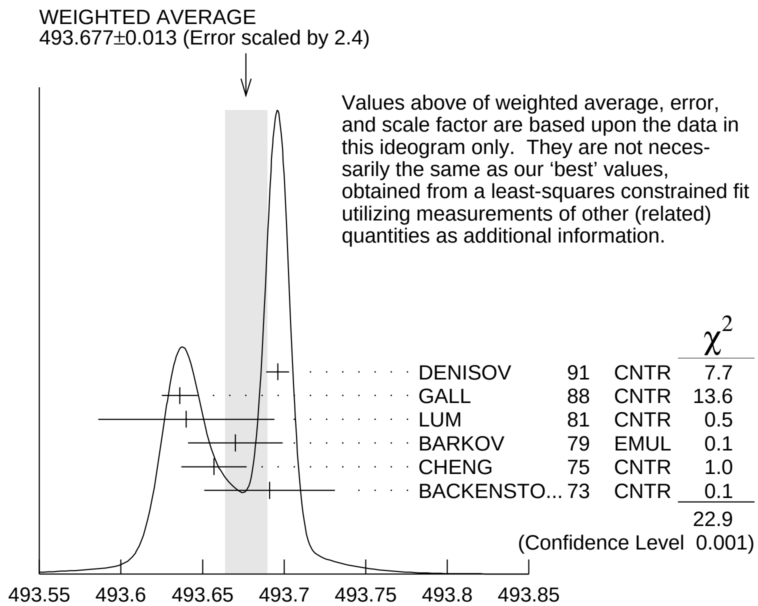
VALUE (MeV)	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
493.677±0.016 OUR FIT	Error includes scale factor of 2.8.				
493.677±0.013 OUR AVERAGE	Error includes scale factor of 2.4. See the ideogram below.				
493.696±0.007	[1] DENISOV	91	CNTR	–	Kaonic atoms
493.636±0.011	[2] GALL	88	CNTR	–	Kaonic atoms
493.640±0.054	LUM	81	CNTR	–	Kaonic atoms
493.670±0.029	BARKOV	79	EMUL	±	$e^{+}e^{-} \rightarrow K^{+}K^{-}$
493.657±0.020	[2] 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. • • •					
493.631±0.007	GALL	88	CNTR	–	K^{-}Pb $(9 \rightarrow 8)$
493.675±0.026	GALL	88	CNTR	–	K^{-}Pb $(11 \rightarrow 10)$
493.709±0.073	GALL	88	CNTR	–	K^{-}W $(9 \rightarrow 8)$
493.806±0.095	GALL	88	CNTR	–	K^{-}W $(11 \rightarrow 10)$
493.640±0.022±0.008	[3] CHENG	75	CNTR	–	K^{-}Pb $(9 \rightarrow 8)$
493.658±0.019±0.012	[3] CHENG	75	CNTR	–	K^{-}Pb $(10 \rightarrow 9)$
493.638±0.035±0.016	[3] CHENG	75	CNTR	–	K^{-}Pb $(11 \rightarrow 10)$

493.753±0.042±0.021	[3] CHENG	75	CNTR	−	K^- Pb (12→ 11)
493.742±0.081±0.027	[3] CHENG	75	CNTR	−	K^- Pb (13→ 12)
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	+	

[1] Error increased from 0.0059 based on the error analysis in IVANOV 92.

[2] This value is the authors' combination of all of the separate transitions listed for this paper.

[3] The CHENG 75 values for separate transitions were calculated from their Table 7 transition energies. The first error includes a 20% systematic error in the noncircular contaminant shift. The second error is due to a ±5 eV uncertainty in the theoretical transition energies.



$m_{K^\pm}$ (MeV)

$m_{K^+} - m_{K^-}$

Test of *CPT*.

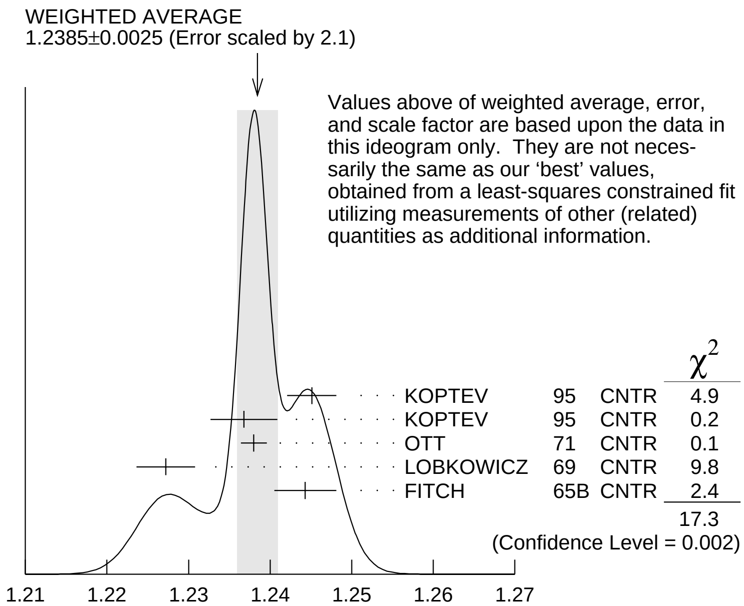
VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
−0.032±0.090	1.5M	[4] FORD	72	ASPK	±

[4] FORD 72 uses $m_{\pi^+} - m_{\pi^-} = +28 \pm 70$ keV.

$K^{\pm}$ MEAN LIFE

VALUE (10^{-8} s)	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
1.2386±0.0024 OUR FIT Error includes scale factor of 2.0.						
1.2385±0.0025 OUR AVERAGE Error includes scale factor of 2.1. See the ideogram below.						
1.2451±0.0030	250k	KOPTEV	95	CNTR		K at rest, U target
1.2368±0.0041	150k	KOPTEV	95	CNTR		K at rest, Cu target
1.2380±0.0016	3M	OTT	71	CNTR	+	K at rest
1.2272±0.0036		LOBKOWICZ	69	CNTR	+	K in flight
1.2443±0.0038		FITCH	65B	CNTR	+	K at rest
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1.2415±0.0024	400k	[5] KOPTEV	95	CNTR		K at rest
1.221 ±0.011		FORD	67	CNTR	±	
1.231 ±0.011		BOYARSKI	62	CNTR	+	
1.25 $^{+0.22}_{-0.17}$		BARKAS	61	EMUL		
1.27 $^{+0.36}_{-0.23}$	51	BHOWMIK	61	EMUL		
1.31 ±0.08	293	NORDIN	61	HBC	−	
1.24 ±0.07		NORDIN	61	RVUE	−	
1.38 ±0.24	33	FREDEN	60B	EMUL		
1.21 ±0.06		BURROWES	59	CNTR		
1.60 ±0.3	52	EISENBERG	58	EMUL		
0.95 $^{+0.36}_{-0.25}$		ILOFF	56	EMUL		

[5] KOPTEV 95 report this weighted average of their U-target and Cu-target results, where they have weighted by $1/\sigma$ rather than $1/\sigma^2$.



$K^{\pm}$ mean life (10^{-8} s)

$(\tau_{K^+} - \tau_{K^-}) / \tau_{\rm average}$

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

RARE KAON DECAYS

(Revised April 2000 by L. Littenberg, BNL and G. Valencia, Iowa State University)

A. Introduction: There are several useful reviews on rare kaon decays and related topics [1–11]. The current activity in rare kaon decays can be divided roughly into four categories:

1. Searches for explicit violations of the Standard Model
2. Measurements of Standard Model parameters
3. Searches for *CP* violation
4. Studies of strong interactions at low energy.

The paradigm of Category 1 is the lepton flavor violating decay $K_L \to \mu e$. Category 2 includes processes such as $K^+ \to \pi^+ \nu \overline{\nu}$, which is sensitive to $|V_{td}|$. Much of the interest in Category 3 is focussed on the decays $K_L \to \pi^0 \ell \overline{\ell}$, where $\ell \equiv e, \mu, \nu$. Category 4 includes reactions like $K^+ \to \pi^+ \ell^+ \ell^-$ which constitute a testing ground for the ideas of chiral perturbation theory. Other reactions of this type are $K_L \to \pi^0 \gamma\gamma$, which also scales a CP-conserving background to CP violation in $K_L \to \pi^0 \ell^+ \ell^-$ and $K_L \to \gamma \ell^+ \ell^-$, which could possibly shed light on long distance contributions to $K_L \to \mu^+ \mu^-$.

B. Explicit violations of the Standard Model: Most of the activity here is in searches for lepton flavor violation (LFV). This is motivated by the fact that many extensions of the minimal Standard Model violate lepton flavor and by the potential to access very high energy scales. For example, the tree-level exchange of a LFV vector boson of mass M_X that couples to left-handed fermions with electroweak strength and without mixing angles yields $\mathrm{B}(K_L \to \mu e) = 4.7 \times 10^{-12} (148\ \mathrm{TeV}/M_X)^4$ [5]. This simple dimensional analysis may be used to read from Table 1 that the reaction $K_L \to \mu e$ is already probing scales of over 100 TeV. Table 1 summarizes the present experimental situation vis a vis LFV, along with the expected near-future progress. The decays $K_L \to \mu^\pm e^\mp$ and $K^+ \to \pi^+ e^\mp \mu^\pm$ (or $K_L \to \pi^0 e^\mp \mu^\pm$) provide complementary information on potential family number violating interactions since the former is sensitive to parity-odd couplings and the latter is sensitive to parity-even couplings. Related searches in μ and τ process are discussed in our section “Tests of Conservation Laws”.

Table 1: Searches for lepton flavor violation in K decay

Mode	90% CL upper limit	Exp't	Yr./Ref.	(Near-) future aim
$K^+ \to \pi^+ e\mu$	4.8×10^{-11}*	BNL-865	99/12	9×10^{-12} (BNL-865)
$K_L \to \mu e$	4.7×10^{-12}	BNL-871	98/13	
$K_L \to \pi^0 e\mu$	3.2×10^{-9}	FNAL-799	94/14	5×10^{-11} (KTeV)

*preliminary

Another forbidden decay currently being pursued is $K^+ \to \pi^+ X^0$, where X^0 is a very light, noninteracting particle (*e.g.* hyperphoton, axion, familon, *etc.*). The 90% CL upper limit on this process was recently improved to 1.1×10^{-10} [15]. Data already collected by BNL-787 are expected to yield a further factor ~ 2 in sensitivity to this process.

C. Measurements of Standard Model parameters: Until 1997, searches for $K^+ \to \pi^+ \nu\overline{\nu}$ were motivated by the possibility of observing non-SM physics because the sensitivity attained was far short of the SM prediction for this decay [16] and long-distance contributions were known to be negligible [2]. However, BNL-787 has attained the sensitivity at which the observation of an event can no longer be unambiguously attributed to non-SM physics. In 1997 BNL-787 observed a single candidate event and has recently released the results of further running in which no further events were seen, yielding a branching ratio of $(1.5^{+3.4}_{-1.2}) \times 10^{-10}$ [15]. Further data already collected are expected to increase the sensitivity by approximately a factor 2, and there are plans for an upgrade to the experiment to collect roughly an order of magnitude more sensitivity [17]. This reaction is now interesting from the point of view of constraining

SM parameters. The branching ratio can be written in terms of the very well-measured rate of K_{e3} as [2]:

$$\mathrm{B}(K^+ \to \pi^+ \nu\overline{\nu}) = \frac{\alpha^2 \mathrm{B}(K^+ \to \pi^o e^+ \nu)}{V_{us}^2 2\pi^2 \sin^4\theta_W} \times \sum_{l=e,\mu,\tau} |V_{cs}^* V_{cd} X_{NL}^{\ell} + V_{ts}^* V_{td} X(m_t)|^2 \qquad (1)$$

to eliminate the *a priori* unknown hadronic matrix element. Isospin breaking corrections to the ratio of matrix elements reduce this rate by 10% [18]. In Eq. (1) the Inami-Lim function $X(m_t)$ is of order 1 [19], and X_{NL}^{ℓ} is several hundred times smaller. This form exhibits the strong dependence of this branching ratio on $|V_{td}|$. QCD corrections, which are contained in X_{NL}^{ℓ}, are relatively small and now known [10] to $\leq 10\%$. Evaluating the constants in Eq. (1) with $m_t = 175$ GeV, one can cast this result in terms of the CKM parameters A, ρ and η (see our Section on "The Cabibbo-Kobayashi-Maskawa mixing matrix") [10]

$$\mathrm{B}(K^+ \to \pi^+ \nu\overline{\nu}) \approx 1.0 \times 10^{-10} A^4 [\eta^2 + (\rho_o - \rho)^2] \qquad (2)$$

where $\rho_o \equiv 1 + (\frac{2}{3}X_{NL}^{e} + \frac{1}{3}X_{NL}^{\tau})/(A^2 V_{us}^4 X(m_t)) \approx 1.4$. Thus, $\mathrm{B}(K^+ \to \pi^+ \nu\overline{\nu})$ determines a circle in the ρ, η plane with center $(\rho_o, 0)$ and radius $\approx \frac{1}{A^2}\sqrt{\frac{\mathrm{B}(K^+ \to \pi^+ \nu\overline{\nu})}{1.0 \times 10^{-10}}}$.

The decay $K_L \to \mu^+\mu^-$ also has a short distance contribution sensitive to the CKM parameter ρ. For $m_t = 175$ GeV it is given by [10]:

$$\mathrm{B}_{\mathrm{SD}}(K_L \to \mu^+\mu^-) \approx 1.7 \times 10^{-9} A^4 (\rho_o' - \rho)^2 \qquad (3)$$

where ρ_o' depends on the charm quark mass and is around 1.2. This decay, however, is dominated by a long-distance contribution from a two-photon intermediate state. The absorptive (imaginary) part of the long-distance component is calculated in terms of the measured rate for $K_L \to \gamma\gamma$ to be $\mathrm{B_{abs}}(K_L \to \mu^+\mu^-) = (7.07 \pm 0.18) \times 10^{-9}$; and it almost completely saturates the observed rate $\mathrm{B}(K_L \to \mu^+\mu^-) = (7.18 \pm 0.17) \times 10^{-9}$ [20]. The difference between the observed rate and the absorptive component can be attributed to the (coherent) sum of the short-distance amplitude and the real part of the long-distance amplitude. In order to use this mode to constrain ρ it is, therefore, necessary to know the real part of the long-distance contribution. Unlike the absorptive part, the real part of the long-distance contribution cannot be derived from the measured rate for $K_L \to \gamma\gamma$. At present, it is not possible to compute this long-distance component reliably and, therefore, it is not possible to constrain ρ from this mode in a model independent way [21]. Several models exist to estimate this long-distance component [22,23] that are sufficient to place rough bounds on new physics from the measured rate for $K_L \to \mu^+\mu^-$ [24]. The decay $K_L \to e^+e^-$ is completely dominated by long distance physics and is easier to estimate. The result, $B(K_L \to e^+e^-) \sim 9 \times 10^{-12}$ [21,23], is in good agreement with the recent measurement [25]. It is expected that studies of the reactions $K_L \to \ell^+\ell^-\gamma$, and $K_L \to \ell^+\ell^-\ell'^+\ell'^-$ for $\ell, \ell' = e$ or μ, currently under active study by the KTeV and NA48 experiments, will improve our understanding of the long distance effects in $K_L \to \mu^+\mu^-$ (the current data is parameterized in terms of α^*_K, discussed on page 25 of the K^0_L Particle Properties Listing in our 1999 WWW update).

D. Searches for direct CP violation: The mode $K_L \to \pi^0\nu\overline{\nu}$ is dominantly CP-violating and free of hadronic uncertainties [2,26]. The Standard Model predicts a branching ratio

$(3.0 \pm 1.3) \times 10^{-11}$; for $m_t = 175$ GeV it is given approximately by [10]:

$$\mathrm{B}(K_L \to \pi^0 \nu\overline{\nu}) \approx 4.1 \times 10^{-10} A^4 \eta^2 \ . \tag{4}$$

The current upper bound is $\mathrm{B}(K_L \to \pi^0 \nu\overline{\nu}) \leq 5.9 \times 10^{-7}$ [27] and KTeV (FNAL799II) is expected to place a bound of order 10^{-8} [28]. The 90% CL bound on $K^+ \to \pi^+ \nu\bar{\nu}$ provides a nearly model independent bound $B(K_L \to \pi^0 \nu\bar{\nu}) < 3 \times 10^{-9}$ [29]. A KEK experiment to reach the 10^{-10}/event level is in preparation [30]. The BNL-926 [31] proposal aims to make a $\sim$ 15% measurement of $\mathrm{B}(K_L \to \pi^0 \nu\overline{\nu})$. There is also a Fermilab EOI [32] with comparable goals.

There has been much recent theoretical work on possible contributions to ϵ'/ϵ and rare K decays within a generic supersymmetric extension of the Standard Model with R parity conservation and minimal particle content [24,33]. These conclude that contributions to rare decays much larger than those of the Standard Model are possible without violating current phenomenological constraints.

The decay $K_L \to \pi^0 e^+ e^-$ also has sensitivity to the product $A^4 \eta^2$. It has a direct CP-violating component that for $m_t = 175$ GeV is given by [10]:

$$\mathrm{B}_{\mathrm{dir}}(K_L \to \pi^0 e^+ e^-) \approx 6.7 \times 10^{-11} A^4 \eta^2 \ . \tag{5}$$

However, like $K_L \to \mu^+ \mu^-$ this mode suffers from large theoretical uncertainties due to long distance strong interaction effects. It has an indirect CP-violating component given by:

$$\mathrm{B}_{\mathrm{ind}}(K_L \to \pi^0 e^+ e^-) = |\epsilon|^2 \frac{\tau_{K_L}}{\tau_{K_S}} \mathrm{B}(K_S \to \pi^0 e^+ e^-) \ , \tag{6}$$

that has been estimated to be less than 10^{-12} [34], but that will not be known precisely until a measurement of $K_S \to \pi^0 e^+ e^-$

is available [4,35]. There is also a CP-conserving component dominated by a two-photon intermediate state that cannot be computed reliably at present. This component has an absorptive part that can be, in principle, determined from a detailed analysis of $K_L \to \pi^0\gamma\gamma$.

To understand the rate and the shape of the distribution $d\Gamma/dm_{\gamma\gamma}$ in $K_L \to \pi^0\gamma\gamma$ within chiral perturbation theory it is necessary to go beyond leading order. The measured rate and spectrum can be accommodated naturally, for example, by allowing only one of the free parameters that occur, a_V, to vary [36]. There is new data on this decay from KTeV [37] and a fit to the distribution has given $a_V = -0.72 \pm 0.05 \pm 0.06$. This value suggests that the absorptive part of the CP-conserving contribution to $K_L \to \pi^0 e^+e^-$ could be comparable to the direct CP-violating component [37,35]. The related process, $K_L \to \pi^0\gamma e^+e^-$, is potentially an additional background in some region of phase space [38]. This process has recently been observed with a branching ratio of $(2.42 \pm 0.38_{stat} \pm 0.11_{sys}) \times 10^{-8}$ [39]. Finally, BNL-845 observed a potential background to $K_L \to \pi^0 e^+e^-$ from the decay $K_L \to \gamma\gamma e^+e^-$ [40]. This has recently been confirmed with a 500-fold larger sample by FNAL-799 [41], which measured additional kinematic quantities. It has been estimated that this background will enter at the level of 10^{-11} [42], comparable to the signal level. Because of this, the observation of $K_L \to \pi^0 e^+e^-$ will depend on background subtraction with good statistics.

The current 90% CL preliminary upper bound for the process $K_L \to \pi^0 e^+e^-$ is 5.64×10^{-10} [41]. For the closely related muonic process, the corresponding upper bound is $\mathrm{B}(K_L \to \pi^0\mu^+\mu^-) \leq 3.8 \times 10^{-10}$ [43]. KTeV expects to reach a sensitivity of roughly 10^{-11} for both reactions [28].

E. Other long distance dominated modes:

The decays $K^+ \to \pi^+\ell^+\ell^-$ ($\ell = e$ or μ) are described by leading order chiral perturbation theory in terms of one parameter, ω^+ [44]. It now appears that this parameterization is not sufficient to account for both the rate and the detailed shape of the spectrum in $K^+ \to \pi^+e^+e^-$ [45] An analysis beyond leading order in chiral perturbation theory can accommodate both the rate and the spectrum [46], at the cost of introducing at least one new parameter.

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K^+ DECAY MODES

K^- modes are charge conjugates of the modes below.

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	$\mu^+\nu_\mu$		(63.51 ± 0.18) %	S=1.3
Γ_2	$e^+\nu_e$		$(1.55\pm0.07)\times10^{-5}$	
Γ_3	$\pi^+\pi^0$		(21.16 ± 0.14) %	S=1.1
Γ_4	$\pi^+\pi^+\pi^-$		(5.59 ± 0.05) %	S=1.8
Γ_5	$\pi^+\pi^0\pi^0$		(1.73 ± 0.04) %	S=1.2
Γ_6	$\pi^0\mu^+\nu_\mu$		(3.18 ± 0.08) %	S=1.5
	Called $K^+_{\mu3}$.			
Γ_7	$\pi^0e^+\nu_e$		(4.82 ± 0.06) %	S=1.3
	Called K^+_{e3}.			
Γ_8	$\pi^0\pi^0e^+\nu_e$		$(2.1\pm0.4)\times10^{-5}$	
Γ_9	$\pi^+\pi^-e^+\nu_e$		$(3.91\pm0.17)\times10^{-5}$	
Γ_{10}	$\pi^+\pi^-\mu^+\nu_\mu$		$(1.4\pm0.9)\times10^{-5}$	
Γ_{11}	$\pi^0\pi^0\pi^0e^+\nu_e$		$<3.5\times10^{-6}$	CL=90%
Γ_{12}	$\mu^+\nu_\mu\nu\overline{\nu}$		$<6.0\times10^{-6}$	CL=90%
Γ_{13}	$e^+\nu_e\nu\overline{\nu}$		$<6\times10^{-5}$	CL=90%
Γ_{14}	$\mu^+\nu_\mu e^+e^-$		$(1.3\pm0.4)\times10^{-7}$	
Γ_{15}	$e^+\nu_e e^+e^-$		$(3.0^{+3.0}_{-1.5})\times10^{-8}$	
Γ_{16}	$e^+\nu_e\mu^+\mu^-$		$<5\times10^{-7}$	CL=90%
Γ_{17}	$\mu^+\nu_\mu\mu^+\mu^-$		$<4.1\times10^{-7}$	CL=90%
Γ_{18}	$\mu^+\nu_\mu\gamma$	[*a*,*b*]	$(5.50\pm0.28)\times10^{-3}$	
Γ_{19}	$\pi^+\pi^0\gamma$	[*a*,*b*]	$(2.75\pm0.15)\times10^{-4}$	
Γ_{20}	$\pi^+\pi^0\gamma$(DE)	[*b*,*c*]	$(1.8\pm0.4)\times10^{-5}$	
Γ_{21}	$\pi^+\pi^+\pi^-\gamma$	[*a*,*b*]	$(1.04\pm0.31)\times10^{-4}$	
Γ_{22}	$\pi^+\pi^0\pi^0\gamma$	[*a*,*b*]	$(7.5^{+5.5}_{-3.0})\times10^{-6}$	
Γ_{23}	$\pi^0\mu^+\nu_\mu\gamma$	[*a*,*b*]	$<6.1\times10^{-5}$	CL=90%
Γ_{24}	$\pi^0e^+\nu_e\gamma$	[*a*,*b*]	$(2.62\pm0.20)\times10^{-4}$	
Γ_{25}	$\pi^0e^+\nu_e\gamma$(SD)	[*d*]	$<5.3\times10^{-5}$	CL=90%
Γ_{26}	$\pi^0\pi^0e^+\nu_e\gamma$		$<5\times10^{-6}$	CL=90%
Γ_{27}	$\pi^+\gamma\gamma$	[*b*]	$(1.10\pm0.32)\times10^{-6}$	
Γ_{28}	$\pi^+3\gamma$	[*b*]	$<1.0\times10^{-4}$	CL=90%

Lepton Family number (*LF*), Lepton number (*L*), $\Delta S = \Delta Q$ (*SQ*) violating modes, or $\Delta S = 1$ weak neutral current (*S1*) modes

Γ_{29}	$\pi^+ \pi^+ e^- \overline{\nu}_e$	*SQ*		< 1.2	$\times 10^{-8}$	CL=90%
Γ_{30}	$\pi^+ \pi^+ \mu^- \overline{\nu}_\mu$	*SQ*		< 3.0	$\times 10^{-6}$	CL=95%
Γ_{31}	$\pi^+ e^+ e^-$	*S1*		(2.88 ± 0.13)	$\times 10^{-7}$	
Γ_{32}	$\pi^+ \mu^+ \mu^-$	*S1*		(7.6 ± 2.1)	$\times 10^{-8}$	S=3.4
Γ_{33}	$\pi^+ \nu \overline{\nu}$	*S1*		$(1.5 {}^{+3.4}_{-1.2})$	$\times 10^{-10}$	
Γ_{34}	$\mu^- \nu e^+ e^+$	*LF*		< 2.0	$\times 10^{-8}$	CL=90%
Γ_{35}	$\mu^+ \nu_e$	*LF*	[e]	< 4	$\times 10^{-3}$	CL=90%
Γ_{36}	$\pi^+ \mu^+ e^-$	*LF*		< 2.1	$\times 10^{-10}$	CL=90%
Γ_{37}	$\pi^+ \mu^- e^+$	*LF*		< 7	$\times 10^{-9}$	CL=90%
Γ_{38}	$\pi^- \mu^+ e^+$	*L*		< 7	$\times 10^{-9}$	CL=90%
Γ_{39}	$\pi^- e^+ e^+$	*L*		< 1.0	$\times 10^{-8}$	CL=90%
Γ_{40}	$\pi^- \mu^+ \mu^+$	*L*	[e]	< 1.5	$\times 10^{-4}$	CL=90%
Γ_{41}	$\mu^+ \overline{\nu}_e$	*L*	[e]	< 3.3	$\times 10^{-3}$	CL=90%
Γ_{42}	$\pi^0 e^+ \overline{\nu}_e$	*L*		< 3	$\times 10^{-3}$	CL=90%
Γ_{43}	$\pi^+ \gamma$		[f]			

[*a*] Most of this radiative mode, the low-momentum γ part, is also included in the parent mode listed without γ's.

[*b*] See the Particle Listings below for the energy limits used in this measurement.

[*c*] Direct-emission branching fraction.

[*d*] Structure-dependent part.

[*e*] Derived from an analysis of neutrino-oscillation experiments.

[*f*] Violates angular-momentum conservation.

CONSTRAINED FIT INFORMATION

An overall fit to the mean life, 2 decay rate, and 20 branching ratios uses 60 measurements and one constraint to determine 8 parameters. The overall fit has a χ^2 = 78.1 for 53 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\left\langle \delta p_i \delta p_j \right\rangle / (\delta p_i \cdot \delta p_j)$, 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_1	x_3	x_4	x_5	x_6	x_7	x_8
x_3	−58						
x_4	−41	−12					
x_5	−27	−4	21				
x_6	−48	−17	14	2			
x_7	−50	−16	34	6	39		
x_8	−3	−1	2	0	2	6	
Γ	7	2	−18	−4	−2	−6	0

	Mode	Rate (10^8 s^{-1})	Scale factor
Γ_1	$\mu^+ \nu_\mu$	0.5128 ±0.0018	1.5
Γ_3	$\pi^+ \pi^0$	0.1708 ±0.0012	1.1
Γ_4	$\pi^+ \pi^+ \pi^-$	0.0452 ±0.0004	1.8
Γ_5	$\pi^+ \pi^0 \pi^0$	0.01399±0.00032	1.2
Γ_6	$\pi^0 \mu^+ \nu_\mu$ Called $K^+_{\mu 3}$.	0.0257 ±0.0006	1.5
Γ_7	$\pi^0 e^+ \nu_e$ Called K^+_{e3}.	0.0389 ±0.0005	1.3
Γ_8	$\pi^0 \pi^0 e^+ \nu_e$	$(1.69 {}^{+0.34}_{-0.29}) \times 10^{-5}$	

$K^\pm$ DECAY RATES

$\Gamma(\mu^+ \nu_\mu)$ — Γ_1

VALUE (10^6 s^{-1})	*DOCUMENT ID*		*TECN*	*CHG*
51.28±0.18 OUR FIT Error includes scale factor of 1.5.				
51.2 ±0.8	FORD	67	CNTR	±

$\Gamma(\pi^+ \pi^+ \pi^-)$ — Γ_4

VALUE (10^6 s^{-1})	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
4.52 ±0.04 OUR FIT Error includes scale factor of 1.8.					
4.511±0.024		[6] FORD	70	ASPK	

• • • We do not use the following data for averages, fits, limits, etc. • • •

4.529±0.032	3.2M	[6] FORD	70	ASPK	
4.496±0.030		[6] FORD	67	CNTR	±

[6] First FORD 70 value is second FORD 70 combined with FORD 67.

$(\Gamma(K^+) - \Gamma(K^-)) / \Gamma(K)$

$K^\pm \rightarrow \mu^\pm \nu_\mu$ RATE DIFFERENCE/AVERAGE

Test of CPT conservation.

VALUE (%)	DOCUMENT ID		TECN
−0.54±0.41	FORD	67	CNTR

$K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$ RATE DIFFERENCE/AVERAGE

Test of CP conservation.

VALUE (%)	EVTS	DOCUMENT ID		TECN	CHG
0.07±0.12 OUR AVERAGE					
0.08±0.12		[7] FORD	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		[8] SMITH	73	ASPK	±
0.10±0.14	3.2M	[7] FORD	70	ASPK	
−0.04±0.21		[7] FORD	67	CNTR	

[7] First FORD 70 value is second FORD 70 combined with FORD 67.
[8] SMITH 73 value of $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$ rate difference is derived from SMITH 73 value of $K^\pm \rightarrow \pi^\pm 2\pi^0$ rate difference.

$K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ RATE DIFFERENCE/AVERAGE

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	

$K^\pm \rightarrow \pi^\pm \pi^0$ RATE DIFFERENCE/AVERAGE

Test of CPT conservation.

VALUE (%)	DOCUMENT ID		TECN
0.8±1.2	HERZO	69	OSPK

$K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ RATE DIFFERENCE/AVERAGE

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	±	E_π 55–90 MeV
1.0± 4.0	4000	ABRAMS	73B	ASPK	±	E_π 51–100 MeV
0.0±24.0	24	EDWARDS	72	OSPK		E_π 58–90 MeV

K^+ BRANCHING RATIOS

$\Gamma(\mu^+\nu_\mu)/\Gamma_{total}$ — Γ_1/Γ

VALUE (units 10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
63.51±0.18 OUR FIT	Error includes scale factor of 1.3.					
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		[9] ALEXANDER	57	EMUL	+	
58.5 ±3.0		[9] BIRGE	56	EMUL	+	

[9] Old experiments not included in averaging.

$\Gamma(\mu^+\nu_\mu)/\Gamma(\pi^+\pi^+\pi^-)$ — Γ_1/Γ_4

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
11.35±0.12 OUR FIT	Error includes scale factor of 1.8.				
• • • We do not use the following data for averages, fits, limits, etc. • • •					
10.38±0.82	427	[10] YOUNG	65	EMUL	+

[10] Deleted from overall fit because YOUNG 65 constrains his results to add up to 1. Only YOUNG 65 measured $(\mu\nu)$ directly.

$\Gamma(e^+\nu_e)/\Gamma_{total}$ — Γ_2/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	+

$\Gamma(e^+\nu_e)/\Gamma(\mu^+\nu_\mu)$ — Γ_2/Γ_1

VALUE (units 10^{-5})	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
2.45±0.11 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	+
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$1.8\ ^{+0.8}_{-0.6}$	8	MACEK	69	ASPK	+
$1.9\ ^{+0.7}_{-0.5}$	10	BOTTERILL	67	ASPK	+

$\Gamma(\pi^+\pi^0)/\Gamma_{total}$ — Γ_3/Γ

VALUE (units 10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
21.16±0.14 OUR FIT	Error includes scale factor of 1.1.					
21.18±0.28	16k	CHIANG	72	OSPK	+	1.84 GeV/c K^+
• • • 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		[11] ALEXANDER	57	EMUL	+	
27.7 ±2.7		[11] BIRGE	56	EMUL	+	

[11] Earlier experiments not averaged.

$\Gamma(\pi^+\pi^0)/\Gamma(\mu^+\nu_\mu)$ — Γ_3/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.3331±0.0028 OUR FIT Error includes scale factor of 1.1.						
0.3316±0.0032 OUR AVERAGE						
0.3329±0.0047±0.0010	45k	USHER	92	SPEC	+	$p\overline{p}$ at rest
0.3355±0.0057		[12] WEISSENBE...	76	SPEC	+	
0.305 ±0.018	1600	ZELLER	69	ASPK	+	
0.3277±0.0065	4517	[13] AUERBACH	67	OSPK	+	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.328 ±0.005	25k	[12] WEISSENBE...	74	STRC	+	

[12] WEISSENBERG 76 revises WEISSENBERG 74.
[13] AUERBACH 67 changed from 0.3253 ± 0.0065. See comment with ratio $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma(\mu^+\nu_\mu)$.

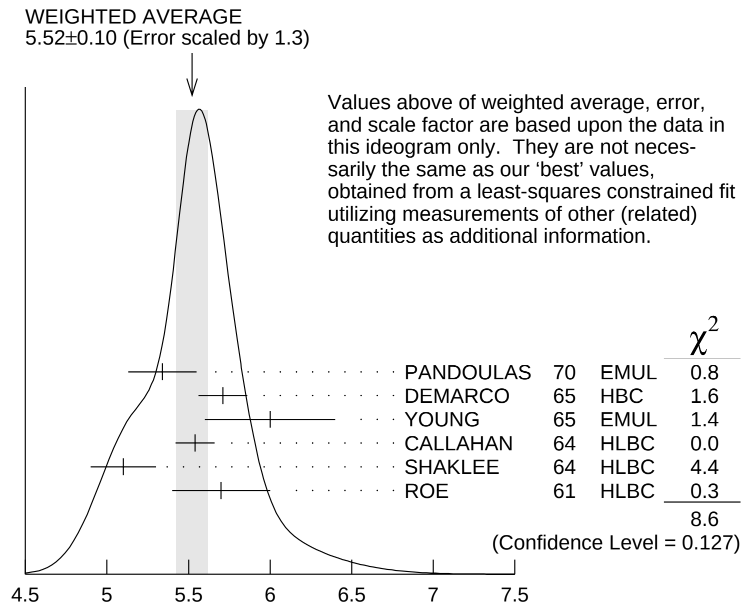
$\Gamma(\pi^+\pi^0)/\Gamma(\pi^+\pi^+\pi^-)$ — Γ_3/Γ_4

VALUE	EVTS	DOCUMENT ID		TECN	CHG
3.78±0.04 OUR FIT Error includes scale factor of 1.5.					
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_4/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
5.59±0.05 OUR FIT Error includes scale factor of 1.8.						
5.52±0.10 OUR AVERAGE Error includes scale factor of 1.3. See the ideogram below.						
5.34±0.21	693	[14] 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	[15] CHIANG	72	OSPK	+	1.84 GeV/c K^+
5.2 ±0.3		[16] TAYLOR	59	EMUL	+	
6.8 ±0.4		[16] ALEXANDER	57	EMUL	+	
5.6 ±0.4		[16] BIRGE	56	EMUL	+	

[14] Includes events of TAYLOR 59.
[15] Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{total}$, $\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{total}$, $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{total}$, and $\Gamma(\pi^0 e^+\nu_e)/\Gamma_{total}$.
[16] Earlier experiments not averaged.

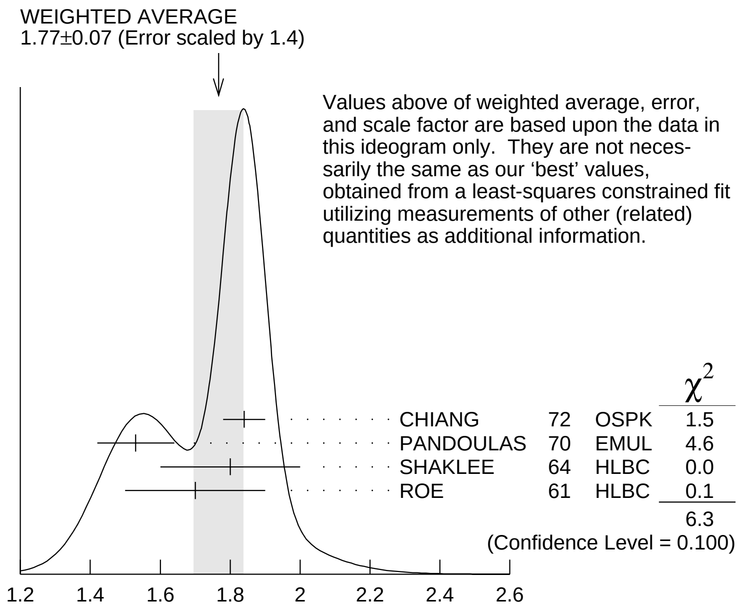


$\Gamma\left(\pi^+\pi^+\pi^-\right)/\Gamma_{total}$ (units 10^{-2})

$\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{total}$ Γ_5/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	[17] 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		[18] TAYLOR 59	EMUL	+	
2.2 ±0.4		[18] ALEXANDER 57	EMUL	+	
2.1 ±0.5		[18] BIRGE 56	EMUL	+	

[17] Includes events of TAYLOR 59.
[18] Earlier experiments not averaged.



$\Gamma\left(\pi^+\pi^0\pi^0\right)/\Gamma_{\text{total}}$ (units 10^{-2})

$\Gamma(\pi^+\pi^0\pi^0)/\Gamma(\pi^+\pi^0)$ — Γ_5/Γ_3

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	[19] LUCAS 73B	HBC	−	Dalitz pairs only

[19] LUCAS 73B gives $N(\pi 2\pi^0) = 574 \pm 5.9\%$, $N(2\pi) = 3564 \pm 3.1\%$. We quote $0.5N(\pi 2\pi^0)/N(2\pi)$ where 0.5 is because only Dalitz pair π^0's were used.

$\Gamma(\pi^+\pi^0\pi^0)/\Gamma(\pi^+\pi^+\pi^-)$ — Γ_5/Γ_4

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	+	

$\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{\text{total}}$ — Γ_6/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
3.18±0.08 OUR FIT Error includes scale factor of 1.5.					
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		[20] TAYLOR 59	EMUL	+	
5.9 ±1.3		[20] ALEXANDER 57	EMUL	+	
2.8 ±1.0		[20] BIRGE 56	EMUL	+	

[20] Earlier experiments not averaged.

$\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma(\mu^+\nu_\mu)$ — Γ_6/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	CHG
0.0501±0.0013 OUR FIT Error includes scale factor of 1.5.					
0.0488±0.0026 OUR AVERAGE					
0.054 ±0.009	240	ZELLER	69	ASPK	+
0.0480±0.0037	424	[21] GARLAND	68	OSPK	+
0.0486±0.0040	307	[22] AUERBACH	67	OSPK	+

[21] 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).

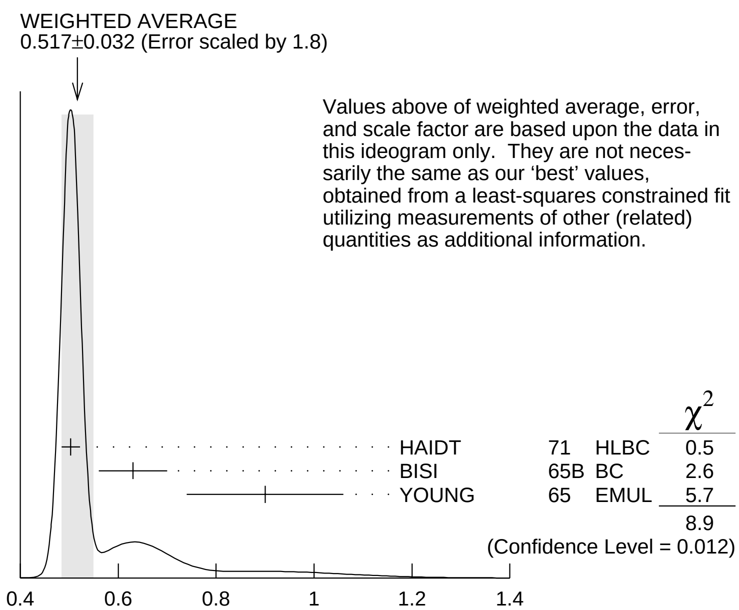
[22] AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ-spectrum calculation into agreement with GAILLARD 70 appendix B.

$\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma(\pi^+\pi^+\pi^-)$ — Γ_6/Γ_4

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.569±0.014 OUR FIT Error includes scale factor of 1.5.						
0.517±0.032 OUR AVERAGE Error includes scale factor of 1.8. See the ideogram below.						
0.503±0.019	1505	[23] HAIDT	71	HLBC	+	
0.63 ±0.07	2845	[24] 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	[23] EICHTEN	68	HLBC	+	

[23] HAIDT 71 is a reanalysis of EICHTEN 68.

[24] Error enlarged for background problems. See GAILLARD 70.



$\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma(\pi^+\pi^+\pi^-)$

$\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ — Γ_6/Γ_7

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.660±0.015 OUR FIT	Error includes scale factor of 1.5.					
0.680±0.013 OUR AVERAGE						
0.705±0.063	554	[25] LUCAS	73B	HBC	−	Dalitz pairs only
0.698±0.025	3480	[26] CHIANG	72	OSPK	+	1.84 GeV/c K^+
0.667±0.017	5601	BOTTERILL	68B	ASPK	+	
0.703±0.056	1509	[27] CALLAHAN	66B	HLBC		
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.670±0.014		[28] HEINTZE	77	SPEC	+	
0.67 ±0.12		WEISSENBE...	76	SPEC	+	
0.608±0.014	1585	[29] BRAUN	75	HLBC	+	
0.596±0.025		[30] HAIDT	71	HLBC	+	
0.604±0.022	1398	[30] EICHTEN	68	HLBC		

[25] LUCAS 73B gives N($K_{\mu 3}$) = 554 ± 7.6%, N(K_{e3}) = 786 ± 3.1%. We divide.

[26] CHIANG 72 $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ is statistically independent of CHIANG 72 $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma_{\text{total}}$ and $\Gamma(\pi^0 e^+ \nu_e)/\Gamma_{\text{total}}$.

[27] From CALLAHAN 66B we use only the $K_{\mu 3}/K_{e3}$ ratio and do not include in the fit the ratios $K_{\mu 3}/(\pi \pi^+ \pi^0)$ and $K_{e3}/(\pi \pi^+ \pi^0)$, since they show large disagreements with the rest of the data.

[28] HEINTZE 77 value from fit to λ_0. Assumes μ-e universality.

[29] BRAUN 75 value is from form factor fit. Assumes μ-e universality.

[30] HAIDT 71 is a reanalysis of EICHTEN 68. Only individual ratios included in fit (see $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^+ \pi^+ \pi^-)$ and $\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\pi^+ \pi^+ \pi^-)$).

$\left[\Gamma(\pi^+ \pi^0) + \Gamma(\pi^0 \mu^+ \nu_\mu)\right]/\Gamma_{\text{total}}$ — $(\Gamma_3+\Gamma_6)/\Gamma$

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
24.34±0.15 OUR FIT	Error includes scale factor of 1.2.				
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	+

$\Gamma(\pi^0 e^+ \nu_e)/\Gamma_{\text{total}}$ — Γ_7/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
4.82±0.06 OUR FIT	Error includes scale factor of 1.3.					
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		[31] ALEXANDER	57	EMUL	+	
3.2 ±1.3		[31] BIRGE	56	EMUL	+	

[31] Earlier experiments not averaged.

$\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu)$ Γ_7/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	CHG
0.0759±0.0011 OUR FIT Error includes scale factor of 1.4.					
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	[32] AUERBACH	67	OSPK	+

[32] AUERBACH 67 changed from 0.0797 ± 0.0054. See comment with ratio $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\mu^+ \nu_\mu)$. The value 0.0785 ± 0.0025 given in AUERBACH 67 is an average of AUERBACH 67 $\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu)$ and CESTER 66 $\Gamma(\pi^0 e^+ \nu_e)/\left[\Gamma(\mu^+ \nu_\mu) + \Gamma(\pi^+ \pi^0)\right]$.

$\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\pi^+ \pi^0)$ Γ_7/Γ_3

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.2280±0.0035 OUR FIT Error includes scale factor of 1.3.						
0.221 ±0.012	786	[33] LUCAS	73B	HBC	−	Dalitz pairs only

[33] LUCAS 73B gives N(K_{e3}) = 786 ± 3.1%, N(2π) = 3564 ± 3.1%. We divide.

$\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\pi^+ \pi^+ \pi^-)$ Γ_7/Γ_4

VALUE	EVTS	DOCUMENT ID		TECN	CHG
0.862±0.011 OUR FIT Error includes scale factor of 1.3.					
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	[34] HAIDT	71	HLBC	+
0.94 ±0.09	854	BELLOTTI	67B	HLBC	
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	[34] EICHTEN	68	HLBC	+
0.90 ±0.16	37	YOUNG	65	EMUL	+

[34] HAIDT 71 is a reanalysis of EICHTEN 68.

$\Gamma(\pi^0 e^+ \nu_e)/\left[\Gamma(\mu^+ \nu_\mu) + \Gamma(\pi^+ \pi^0)\right]$ $\Gamma_7/(\Gamma_1+\Gamma_3)$

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG
5.70±0.08 OUR FIT Error includes scale factor of 1.4.					
6.01±0.15 OUR AVERAGE					
5.92±0.65		[35] WEISSENBE...	76	SPEC	+
6.16±0.22	5110	ESCHSTRUTH	68	OSPK	+
5.89±0.21	1679	CESTER	66	OSPK	+

[35] Value calculated from WEISSENBERG 76 ($\pi^0 e \nu$), ($\mu\nu$), and ($\pi\pi^0$) values to eliminate dependence on our 1974 ($\pi 2\pi^0$) and ($\pi\pi^+\pi^-$) fractions.

$\Gamma(\pi^0\pi^0 e^+\nu_e)/\Gamma(\pi^0 e^+\nu_e)$ — Γ_8/Γ_7

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	CHG
$4.3^{+0.9}_{-0.7}$ OUR FIT						
$4.1^{+1.0}_{-0.7}$ 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	+

$\Gamma(\pi^0\pi^0 e^+\nu_e)/\Gamma_{total}$ — Γ_8/Γ

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	CHG
2.1 ±0.4 OUR FIT					
2.54±0.89	10	BARMIN	88B	HLBC	+

$\Gamma(\pi^+\pi^- e^+\nu_e)/\Gamma(\pi^+\pi^+\pi^-)$ — Γ_9/Γ_4

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	CHG
6.99±0.30 OUR AVERAGE Error includes scale factor of 1.2.					
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	+
• • • We do not use the following data for averages, fits, limits, etc. • • •					
6.7 ±1.5	69	BIRGE	65	FBC	+

$\Gamma(\pi^+\pi^-\mu^+\nu_\mu)/\Gamma_{total}$ — 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	+

$\Gamma(\pi^+\pi^-\mu^+\nu_\mu)/\Gamma(\pi^+\pi^+\pi^-)$ — Γ_{10}/Γ_4

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	+

$\Gamma(\pi^0\pi^0\pi^0 e^+\nu_e)/\Gamma_{total}$ — Γ_{11}/Γ

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN	CHG
<3.5	90	0	BOLOTOV	88	SPEC	−
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<9	90	0	BARMIN	92	XEBC	+

$\Gamma(\mu^+ \nu_\mu \nu \overline{\nu})/\Gamma_{\text{total}}$ — Γ_{12}/Γ

VALUE (units 10^{-6})	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
<6.0	90	0	[36] PANG	73	CNTR	+

[36] PANG 73 assumes μ spectrum from ν-ν interaction of BARDIN 70.

$\Gamma(e^+ \nu_e \nu \overline{\nu})/\Gamma(e^+ \nu_e)$ — Γ_{13}/Γ_2

VALUE	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
<3.8	90	0	HEINTZE	79	SPEC	+

$\Gamma(\mu^+ \nu_\mu e^+ e^-)/\Gamma(\pi^+ \pi^- e^+ \nu_e)$ — Γ_{14}/Γ_9

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
3.3±0.9	14	[37] DIAMANT-...	76	SPEC	+	$m_{e^+e^-} > 140$ MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
27. ±8.	14	[37] DIAMANT-...	76	SPEC	+	Extrapolated BR

[37] DIAMANT-BERGER 76 gives this result times our 1975 $\pi^+ \pi^- e \nu$ BR ratio. The second DIAMANT-BERGER 76 value is the first value extrapolated to 0 to include low mass $e^+ e^-$ pairs. More recent calculations (BIJNENS 93) of this extrapolation disagree with those of DIAMANT-BERGER 76.

$\Gamma(e^+ \nu_e e^+ e^-)/\Gamma(\pi^+ \pi^- e^+ \nu_e)$ — Γ_{15}/Γ_9

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
$\mathbf{0.76^{+0.76}_{-0.38}}$	4	[38] DIAMANT-...	76	SPEC	+	$m_{e^+e^-} > 140$ MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$5.4\ ^{+5.4}_{-2.7}$	4	[38] DIAMANT-...	76	SPEC	+	Extrapolated BR

[38] DIAMANT-BERGER 76 gives this result times our 1975 $\pi^+ \pi^- e \nu$ BR ratio. The second DIAMANT-BERGER 76 value is the first value extrapolated to 0 to include low mass $e^+ e^-$ pairs. More recent calculations (BIJNENS 93) of this extrapolation disagree with those of DIAMANT-BERGER 76.

$\Gamma(e^+ \nu_e \mu^+ \mu^-)/\Gamma_{\text{total}}$ — Γ_{16}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*
$\mathbf{<5 \times 10^{-7}}$	90	ADLER	98	B787

$\Gamma(\mu^+ \nu_\mu \mu^+ \mu^-)/\Gamma_{\text{total}}$ — Γ_{17}/Γ

VALUE (units 10^{-7})	*CL%*	*DOCUMENT ID*		*TECN*	*CHG*
<4.1	90	ATIYA	89	B787	+

$\Gamma(\mu^+ \nu_\mu \gamma)/\Gamma_{\text{total}}$ — Γ_{18}/Γ

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
5.50±0.28 OUR AVERAGE						
6.6 ±1.5		[39,40] DEMIDOV	90	XEBC		P(μ) <231.5 MeV/c
6.0 ±0.9		BARMIN	88	HLBC	+	P(μ) <231.5 MeV/c
5.4 ±0.3		[41] AKIBA	85	SPEC		P(μ) <231.5 MeV/c

• • • We do not use the following data for averages, fits, limits, etc. • • •

3.5 ±0.8		[40,42] DEMIDOV	90	XEBC		$E(\gamma) > 20$ MeV
3.2 ±0.5	57	[43] BARMIN	88	HLBC	+	$E(\gamma) > 20$ MeV
5.8 ±3.5	12	WEISSENBE...	74	STRC	+	$E(\gamma) > 9$ MeV

[39] $P(\mu)$ cut given in DEMIDOV 90 paper, 235.1 MeV/c, is a misprint according to authors (private communication).
[40] DEMIDOV 90 quotes only inner bremsstrahlung (IB) part.
[41] Assumes μ-e universality and uses constraints from $K \rightarrow e\nu\gamma$.
[42] Not independent of above DEMIDOV 90 value. Cuts differ.
[43] Not independent of above BARMIN 88 value. Cuts differ.

$\Gamma(\pi^+\pi^0\gamma)/\Gamma_{total}$ — Γ_{19}/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. • • •							
$1.5^{+1.1}_{-0.6}$			[44] LJUNG	73	HLBC	+	$T\pi^+$ 55–80 MeV
$2.6^{+1.5}_{-1.1}$			[44] LJUNG	73	HLBC	+	$T\pi^+$ 55–90 MeV
$6.8^{+3.7}_{-2.1}$		17	[44] LJUNG	73	HLBC	+	$T\pi^+$ 55–102 MeV
2.4 ±0.8		24	EDWARDS	72	OSPK		$T\pi^+$ 58–90 MeV
<1.0		0	[45] 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

[44] The LJUNG 73 values are not independent.
[45] MALTSEV 70 selects low π^+ energy to enhance direct emission contribution.

$\Gamma(\pi^+\pi^0\gamma(\mathrm{DE}))/\Gamma_{total}$ — Γ_{20}/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_{21}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1.04±0.31 OUR AVERAGE						
1.10±0.48	7	BARMIN	89	XEBC		$E(\gamma) > 5$ MeV
1.0 ±0.4		STAMER	65	EMUL	+	$E(\gamma) > 11$ MeV

$\Gamma(\pi^+\pi^0\pi^0\gamma)/\Gamma(\pi^+\pi^0\pi^0)$ — Γ_{22}/Γ_5

VALUE (units 10^{-4})	DOCUMENT ID		TECN	CHG	COMMENT
$\mathbf{4.3^{+3.2}_{-1.7}}$	BOLOTOV	85	SPEC	−	$E(\gamma) > 10$ MeV

$\Gamma(\pi^0 \mu^+ \nu_\mu \gamma)/\Gamma_{total}$ — Γ_{23}/Γ

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
<6.1	90	0	LJUNG	73	HLBC	+	$E(\gamma) > 30$ MeV

$\Gamma(\pi^0 e^+ \nu_e \gamma)/\Gamma(\pi^0 e^+ \nu_e)$ — Γ_{24}/Γ_7

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.54±0.04 OUR AVERAGE Error includes scale factor of 1.1.						
0.46±0.08	82	[46] BARMIN	91	XEBC		$E(\gamma) > 10$ MeV, $0.6 < \cos\theta_{e\gamma} < 0.9$
0.56±0.04	192	[47] BOLOTOV	86B	CALO	−	$E(\gamma) > 10$ MeV
0.76±0.28	13	[48] ROMANO	71	HLBC		$E(\gamma) > 10$ MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1.51±0.25	82	[46] BARMIN	91	XEBC		$E(\gamma) > 10$ MeV, $\cos\theta_{e\gamma} < 0.98$
0.48±0.20	16	[49] LJUNG	73	HLBC	+	$E(\gamma) > 30$ MeV
$0.22^{+0.15}_{-0.10}$		[49] LJUNG	73	HLBC	+	$E(\gamma) > 30$ MeV
0.53±0.22		[48] ROMANO	71	HLBC	+	$E(\gamma) > 30$ MeV
1.2 ±0.8		BELLOTTI	67	HLBC	+	$E(\gamma) > 30$ MeV

[46] BARMIN 91 quotes branching ratio $\Gamma(K \to e\pi^0 \nu\gamma)/\Gamma_{all}$. The measured normalization is $[\Gamma(K \to e\pi^0\nu) + \Gamma(K \to \pi^+\pi^+\pi^-)]$. For comparison with other experiments we used $\Gamma(K \to e\pi^0\nu)/\Gamma_{all} = 0.0482$ to calculate the values quoted here.

[47] $\cos\theta(e\gamma)$ between 0.6 and 0.9.

[48] 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.

[49] 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.

$\Gamma(\pi^0 e^+ \nu_e \gamma(\text{SD}))/\Gamma_{total}$ — Γ_{25}/Γ

Structure-dependent part.

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN	CHG
<5.3	90	BOLOTOV	86B	CALO	−

$\Gamma(\pi^0 \pi^0 e^+ \nu_e \gamma)/\Gamma_{total}$ — Γ_{26}/Γ

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
<5	90	0	BARMIN	92	XEBC	+	$E_\gamma > 10$ MeV

$\Gamma(\pi^+ \gamma\gamma)/\Gamma_{total}$ — Γ_{27}/Γ

All values given here assume a phase space pion energy spectrum.

VALUE (units 10^{-7})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
11 ± 3 ±1		31	[50] KITCHING	97	B787		

• • • We do not use the following data for averages, fits, limits, etc. • • •

$<$ 10		90	0	ATIYA	90B	B787		$T\pi$ 117–127 MeV
$<$ 84		90	0	ASANO	82	CNTR	+	$T\pi$ 117–127 MeV
-420	± 520		0	ABRAMS	77	SPEC	+	$T\pi$ <92 MeV
$<$ 350		90	0	LJUNG	73	HLBC	+	6–102, 114–127 MeV
$<$ 500		90	0	KLEMS	71	OSPK	+	$T\pi$ <117 MeV
-100	± 600			CHEN	68	OSPK	+	$T\pi$ 60–90 MeV

[50] KITCHING 97 is extrapolated from their model-independent branching fraction $(6.0 \pm 1.5 \pm 0.7) \times 10^{-7}$ for 100 MeV/c<P_{π^+} < 180 MeV/c using Chiral Perturbation Theory.

$\Gamma(\pi^+ 3\gamma)/\Gamma_{total}$ Γ_{28}/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

$\Gamma(\pi^+\pi^+ e^- \overline{\nu}_e)/\Gamma_{total}$ Γ_{29}/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	+

$\Gamma(\pi^+\pi^+ e^- \overline{\nu}_e)/\Gamma(\pi^+\pi^- e^+ \nu_e)$ Γ_{29}/Γ_9

Test of $\Delta S = \Delta Q$ rule.

VALUE (units 10^{-4})	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*
< 3	90	3	[51] BLOCH	76	SPEC
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<130.	95	0	BOURQUIN	71	ASPK

[51] BLOCH 76 quotes 3.6×10^{-4} at CL = 95%, we convert.

$\Gamma(\pi^+\pi^+ \mu^- \overline{\nu}_\mu)/\Gamma_{total}$ Γ_{30}/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_{31}/Γ

Test for $\Delta S = 1$ weak neutral current. Allowed by combined first-order weak and electromagnetic interactions.

VALUE (units 10^{-7})	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
2.88±0.13 OUR AVERAGE							
2.94±0.05±0.14		10300	[52] APPEL	99	SPEC	+	
2.75±0.23±0.13		500	[53] ALLIEGRO	92	SPEC	+	
2.7 ±0.5		41	[54] BLOCH	75	SPEC	+	

• • • We do not use the following data for averages, fits, limits, etc. • • •

< 17	90		CENCE	74	ASPK	+	Three track evts
< 2.7	90		CENCE	74	ASPK	+	Two track events
<320	90		BEIER	72	OSPK	±	
< 44	90		BISI	67	DBC	+	
< 8.8	90		CLINE	67B	FBC	+	
< 24.5	90	1	CAMERINI	64	FBC	+	

[52] APPEL 99 establishes vector nature of this decay and determines form factor $f(Z)$= $f_0(1+\delta Z)$, Z=M^2_{ee}/m^2_K, δ=2.14 ± 0.13 ± 0.15.
[53] ALLIEGRO 92 assumes a vector interaction with a form factor given by λ = 0.105 ± 0.035 ± 0.015 and a correlation coefficient of −0.82.
[54] BLOCH 75 assumes a vector interaction.

$\Gamma(\pi^+\mu^+\mu^-)/\Gamma_{total}$ — Γ_{32}/Γ

Test for ΔS = 1 weak neutral current. Allowed by higher-order electroweak interactions.

VALUE (units 10^{-8})	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
7.6 ±2.1 OUR AVERAGE	Error includes scale factor of 3.4.					
9.22±0.60±0.49		402	MA	00	B865	+
5.0 ±0.4 ±0.9		207	[55] ADLER	97C	B787	+
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 23	90		ATIYA	89	B787	+
<240	90		BISI	67	DBC	+
<300	90		CAMERINI	65	FBC	+

[55] ADLER 97C gives systematic error 0.7 × 10^{-8} and theoretical uncertainty 0.6 × 10^{-8}, which we combine in quadrature to obtain our second error.

$\Gamma(\pi^+\nu\overline{\nu})/\Gamma_{total}$ — Γ_{33}/Γ

Test for ΔS = 1 weak neutral current. Allowed by higher-order electroweak interactions.

VALUE (units 10^{-9})	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
$\mathbf{0.15^{+0.34}_{-0.12}}$ **OUR AVERAGE**							
$\mathbf{0.15^{+0.34}_{-0.12}}$		1	ADLER	00	B787		
• • • We do not use the following data for averages, fits, limits, etc. • • •							
$0.42^{+0.97}_{-0.35}$		1	ADLER	97	B787		
< 2.4	90		ADLER	96	B787		
< 7.5	90		ATIYA	93	B787	+	$T(\pi)$ 115–127 MeV
< 5.2	90		[56] ATIYA	93	B787	+	
< 17	90	0	ATIYA	93B	B787	+	$T(\pi)$ 60–100 MeV
< 34	90		ATIYA	90	B787	+	
< 140	90		ASANO	81B	CNTR	+	$T(\pi)$ 116–127 MeV
< 940	90		[57] CABLE	73	CNTR	+	$T(\pi)$ 60–105 MeV
< 560	90		[57] CABLE	73	CNTR	+	$T(\pi)$ 60–127 MeV
<57000	90	0	[58] LJUNG	73	HLBC	+	
< 1400	90		[57] KLEMS	71	OSPK	+	$T(\pi)$ 117–127 MeV

[56] Combining ATIYA 93 and ATIYA 93B results. Superseded by ADLER 96.
[57] 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.
[58] LJUNG 73 assumes vector interaction.

$\Gamma(\mu^- \nu e^+ e^+)/\Gamma(\pi^+ \pi^- e^+ \nu_e)$ — Γ_{34}/Γ_9

Test of lepton family number conservation.

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	CHG
<0.5	90	0	[59] DIAMANT-...	76	SPEC	+

[59] DIAMANT-BERGER 76 quotes this result times our 1975 $\pi^+ \pi^- e \nu$ BR ratio.

$\Gamma(\mu^+ \nu_e)/\Gamma_{total}$ — Γ_{35}/Γ

Forbidden by lepton family number conservation.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
<0.004	90	0	[60] 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		[60] COOPER	82	HLBC		Wideband ν beam

[60] COOPER 82 and LYONS 81 limits on ν_e observation are here interpreted as limits on lepton family number violation in the absence of mixing.

$\Gamma(\pi^+ \mu^+ e^-)/\Gamma_{total}$ — Γ_{36}/Γ

Test of lepton family number conservation.

VALUE (units 10^{-10})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
< 2.1	90	0	LEE	90	SPEC	+	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
<11	90	0	CAMPAGNARI	88	SPEC	+	In LEE 90
<48	90	0	DIAMANT-...	76	SPEC	+	

$\Gamma(\pi^+ \mu^- e^+)/\Gamma_{total}$ — Γ_{37}/Γ

Test of lepton family number conservation.

VALUE (units 10^{-9})	CL%	EVTS	DOCUMENT ID		TECN	CHG
< 7	90	0	[61] DIAMANT-...	76	SPEC	+
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<28	90		[61] BEIER	72	OSPK	±

[61] Measurement actually applies to the sum of the $\pi^+ \mu^- e^+$ and $\pi^- \mu^+ e^+$ modes.

$\Gamma(\pi^- \mu^+ e^+)/\Gamma_{total}$ — Γ_{38}/Γ

Test of total lepton number conservation.

VALUE (units 10^{-9})	CL%	EVTS	DOCUMENT ID		TECN	CHG
< 7	90	0	[62] DIAMANT-...	76	SPEC	+
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<28	90		[62] BEIER	72	OSPK	±

[62] Measurement actually applies to the sum of the $\pi^+ \mu^- e^+$ and $\pi^- \mu^+ e^+$ modes.

$\Gamma(\pi^+ \mu^- e^+)/\Gamma_{total}$ — Γ_{37}/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_{39}/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	−

$\Gamma(\pi^- e^+ e^+)/\Gamma(\pi^+ \pi^- e^+ \nu_e)$ — Γ_{39}/Γ_9

Test of total lepton number conservation.

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	CHG
<2.5	90	0	[63] DIAMANT-...	76	SPEC	+

[63] DIAMANT-BERGER 76 quotes this result times our 1975 BR ratio.

$\Gamma(\pi^- \mu^+ \mu^+)/\Gamma_{total}$ — Γ_{40}/Γ

Forbidden by total lepton number conservation.

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN
<1.5	90	[64] LITTENBERG	92	HBC

[64] LITTENBERG 92 is from retroactive data analysis of CHANG 68 bubble chamber data.

$\Gamma(\mu^+ \overline{\nu}_e)/\Gamma_{total}$ — Γ_{41}/Γ

Forbidden by total lepton number conservation.

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<3.3	90	[65] COOPER	82	HLBC	Wideband ν beam

[65] COOPER 82 limit on $\overline{\nu}_e$ observation is here interpreted as a limit on lepton number violation in the absence of mixing.

$\Gamma(\pi^0 e^+ \overline{\nu}_e)/\Gamma_{total}$ — Γ_{42}/Γ

Forbidden by total lepton number conservation.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.003	90	[66] COOPER	82	HLBC	Wideband ν beam

[66] COOPER 82 limit on $\overline{\nu}_e$ observation is here interpreted as a limit on lepton number violation in the absence of mixing.

$\Gamma(\pi^+ \gamma)/\Gamma_{total}$ — 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	[67] KLEMS	71	OSPK	+

[67] Test of model of Selleri, Nuovo Cimento **60A** 291 (1969).

K^+ LONGITUDINAL POLARIZATION OF EMITTED μ^+

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
<−0.990	90	[68] AOKI	94	SPEC	+	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<−0.990	90	IMAZATO	92	SPEC	+	Repl. by AOKI 94
−0.970±0.047		[69] YAMANAKA	86	SPEC	+	
−1.0 ±0.1		[69] CUTTS	69	SPRK	+	
−0.96 ±0.12		[69] COOMBES	57	CNTR	+	

[68] AOKI 94 measures ξP_μ =−0.9996 ± 0.0030 ± 0.0048. The above limit is obtained by summing the statistical and systematic errors in quadrature, normalizing to the physically significant region ($|\xi P_\mu| < 1$) and assuming that ξ=1, its maximum value.

[69] Assumes ξ=1.

DALITZ PLOT PARAMETERS FOR $K \to 3\pi$ DECAYS

Revised 1999 by T.G. Trippe (LBNL).

The Dalitz plot distribution for $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$, $K^\pm \to \pi^0\pi^0\pi^\pm$, and $K^0_L \to \pi^+\pi^-\pi^0$ can be parameterized by a series expansion such as that introduced by Weinberg [1]. We use the form

$$\left|M\right|^2 \propto 1 + g\frac{(s_3 - s_0)}{am^2_{\pi^+}} + h\left[\frac{s_3 - s_0}{m^2_{\pi^+}}\right]^2 + j\,\frac{(s_2 - s_1)}{m^2_{\pi^+}} + k\left[\frac{s_2 - s_1}{m^2_{\pi^+}}\right]^2 + f\,\frac{(s_2 - s_1)}{m^2_{\pi^+}}\frac{(s_3 - s_0)}{m^2_{\pi^+}} + \cdots\ , \qquad (1)$$

where $m^2_{\pi^+}$ has been introduced to make the coefficients g, h, j, and k dimensionless, and

$$s_i = (P_K - P_i)^2 = (m_K - m_i)^2 - 2m_K T_i\ ,\ i = 1, 2, 3,$$

$$s_0 = \frac{1}{3}\sum_i s_i = \frac{1}{3}(m^2_K + m^2_1 + m^2_2 + m^2_3)$$

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 $K^+ \to \pi^+\pi^+\pi^-$ as for $K^- \to \pi^-\pi^-\pi^+$.

Since different experiments use different forms for $\left|M\right|^2$, 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].

References

1. S. Weinberg, Phys. Rev. Lett. **4**, 87 (1960).
2. Particle Data Group, Phys. Lett. **111B**, 69 (1982).

ENERGY DEPENDENCE OF $K^{\pm}$ DALITZ PLOT

$|\text{matrix element}|^2 = 1 + gu + hu^2 + kv^2$

where $u = (s_3 - s_0) / m_\pi^2$ and $v = (s_1 - s_2) / m_\pi^2$

LINEAR COEFFICIENT g_{τ^+} FOR $K^+ \to \pi^+\pi^+\pi^-$

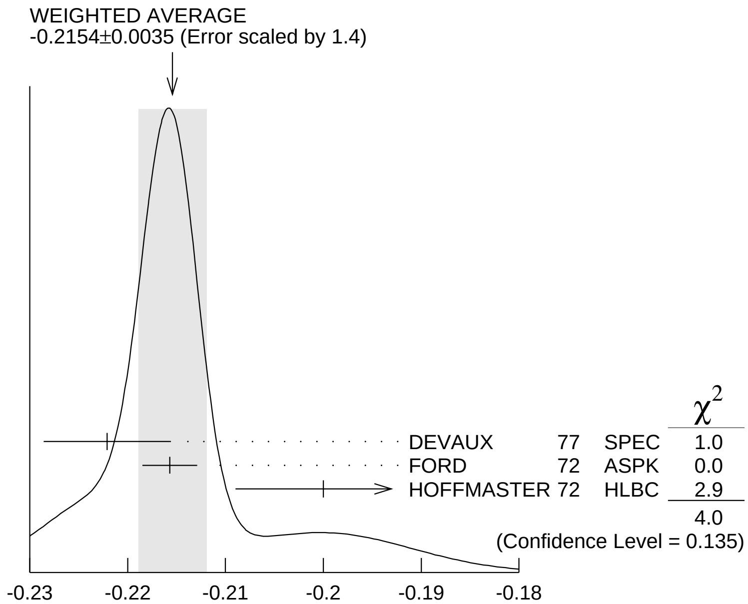
Some experiments use Dalitz variables x and y. In the comments we give a_y = coefficient of y term. See note above on "Dalitz Plot Parameters for $K \to 3\pi$ Decays." For discussion of the conversion of a_y to g, see the earlier version of the same note in the *Review* published in Physics Letters **111B** 70 (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	[70] HOFFMASTER	72	HLBC	+	

• • • We do not use the following data for averages, fits, limits, etc. • • •

−0.196	±0.012	17898	[71] GRAUMAN	70	HLBC	+	a_y=0.228 ± 0.030
−0.218	±0.016	9994	[72] BUTLER	68	HBC	+	a_y=0.277 ± 0.020
−0.22	±0.024	5428	[72,73] ZINCHENKO	67	HBC	+	a_y=0.28 ± 0.03

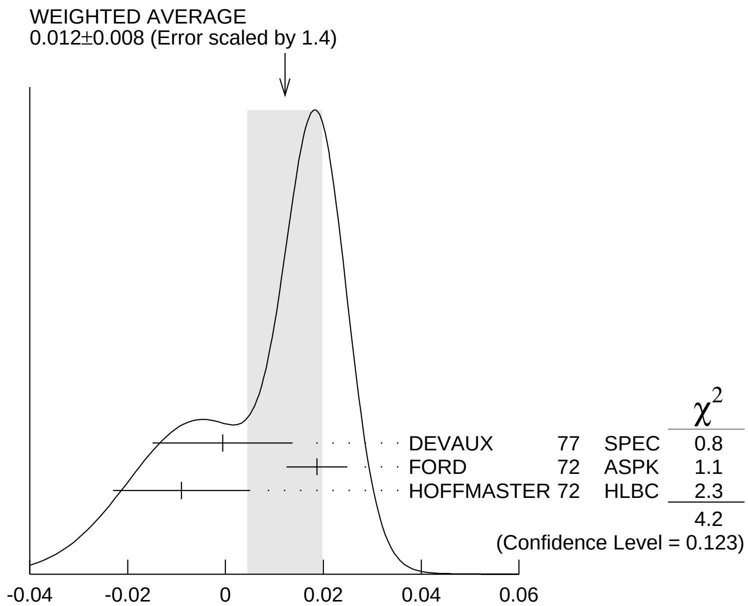
[70] HOFFMASTER 72 includes GRAUMAN 70 data.
[71] Emulsion data added — all events included by HOFFMASTER 72.
[72] Experiments with large errors not included in average.
[73] Also includes DBC events.



Linear energy dependence for $K^+ \rightarrow \pi^+\pi^+\pi^-$

QUADRATIC COEFFICIENT *h* FOR $K^+ \rightarrow \pi^+\pi^+\pi^-$

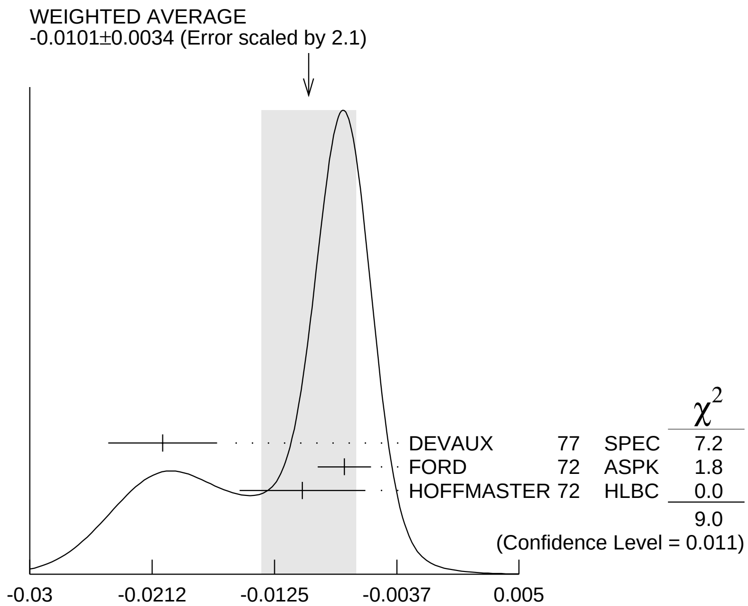
VALUE		EVTS	DOCUMENT ID		TECN	CHG
0.012	**±0.008**	**OUR AVERAGE**	Error includes scale factor of 1.4. See the ideogram below.			
−0.0006	±0.0143	225k	DEVAUX	77	SPEC	+
0.0187	±0.0062	750k	FORD	72	ASPK	+
−0.009	±0.014	39819	HOFFMASTER	72	HLBC	+



Quadratic coefficient h for $K^+ \to \pi^+\pi^+\pi^-$

QUADRATIC COEFFICIENT k FOR $K^+ \to \pi^+\pi^+\pi^-$

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 k for $K^+ \rightarrow \pi^+\pi^+\pi^-$

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 *Review* published in Physics Letters **111B** 70 (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	[74] LUCAS	73	HBC	−	a_y=0.252 ± 0.011
−0.190 ±0.023	5778	[75,76] MOSCOSO	68	HBC	−	a_y=0.242 ± 0.029
−0.220 ±0.035	1347	[77] FERRO-LUZZI	61	HBC	−	a_y=0.28 ± 0.045

[74] Quadratic dependence is required by K^0_L experiments. For comparison we average only those $K^{\pm}$ experiments which quote quadratic fit values.
[75] Experiments with large errors not included in average.
[76] Also includes DBC events.
[77] No radiative corrections included.

QUADRATIC COEFFICIENT h FOR $K^- \rightarrow \pi^-\pi^-\pi^+$

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 $K^- \rightarrow \pi^-\pi^-\pi^+$

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	−

$(g_{\tau^+} - g_{\tau^-})$ / $(g_{\tau^+} + g_{\tau^-})$ FOR $K^\pm \rightarrow \pi^\pm\pi^+\pi^-$

A nonzero value for this quantity indicates *CP* violation.

VALUE (%)	EVTS	DOCUMENT ID		TECN
−0.70±0.53	3.2M	FORD	70	ASPK

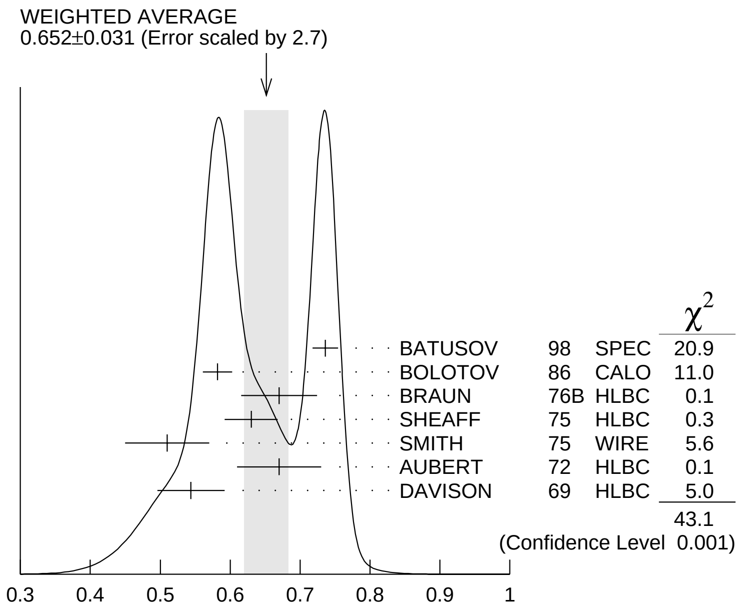
LINEAR COEFFICIENT g FOR $K^\pm \rightarrow \pi^\pm\pi^0\pi^0$

Unless otherwise stated, all experiments include terms quadratic in $(s_3 - s_0) / m^2_{\pi^+}$. See note above on "Dalitz Plot Parameters for $K \rightarrow 3\pi$ Decays."

See BATUSOV 98 for a discussion of the discrepancy between their result and others, especially BOLOTOV 86. At this time we have no way to resolve the discrepancy so we depend on the large scale factor as a warning.

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.652±0.031 OUR AVERAGE	Error includes scale factor of 2.7. See the ideogram below.					
0.736±0.014±0.012	33k	BATUSOV	98	SPEC	+	
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	[78] BERTRAND	76	EMUL	+	
0.484±0.084	574	[79] LUCAS	73B	HBC	−	Dalitz pairs only
0.527±0.102	198	[78] PANDOULAS	70	EMUL	+	
0.586±0.098	1874	[79] BISI	65	HLBC	+	Also HBC
0.48 ±0.04	1792	[79] KALMUS	64	HLBC	+	

[78] Experiments with large errors not included in average.
[79] Authors give linear fit only.

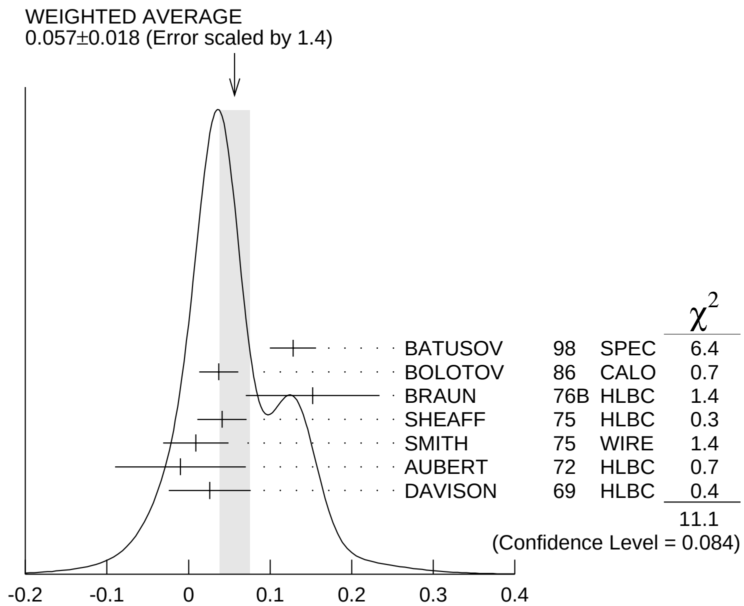


Linear energy dependence for $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$

QUADRATIC COEFFICIENT h FOR $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.057±0.018 OUR AVERAGE		Error includes scale factor of 1.4. See the ideogram below.				
0.128±0.015±0.024	33k	BATUSOV	98	SPEC	+	
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	[80] BERTRAND	76	EMUL	+	
0.018±0.124	198	[80] PANDOULAS	70	EMUL	+	

[80] Experiments with large errors not included in average.



Quadratic coefficient h FOR $K^{\pm} \rightarrow \pi^{\pm}\pi^0\pi^0$

QUADRATIC COEFFICIENT k FOR $K^{\pm} \rightarrow \pi^{\pm}\pi^0\pi^0$

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
0.0197±0.0045±0.0029	33k	BATUSOV	98	SPEC	+

$K^{\pm}_{\ell 3}$ AND $K^{0}_{\ell 3}$ FORM FACTORS

Written by T.G. Trippe (LBNL).

Assuming that only the vector current contributes to $K \rightarrow \pi\ell\nu$ decays, we write the matrix element as

$$M \propto f_+(t)\left[(P_K + P_\pi)_\mu \overline{\ell}\gamma_\mu(1+\gamma_5)\nu\right] + f_-(t)\left[m_\ell \overline{\ell}(1+\gamma_5)\nu\right] , \quad (1)$$

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. $K_{\mu 3}$ 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) $\boldsymbol{K_{\mu 3}}$ ***experiments***. Analyses of $K_{\mu 3}$ data frequently assume a linear dependence of f_+ and f_- on t, *i.e.*,

$$f_{\pm}(t) = f_{\pm}(0)\left[1 + \lambda_{\pm}(t/m_{\pi}^2)\right] \tag{2}$$

Most $K_{\mu 3}$ 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) $\boldsymbol{\lambda_+, \xi(0)}$ ***parametrization***. Analyses of $K_{\mu 3}$ data often introduce the ratio of the two form factors

$$\xi(t) = f_-(t)/f_+(t) \ . \tag{3}$$

The $K_{\mu 3}$ 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 $K_{\mu 3}$ 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

$$A = m_K\left(2E_\mu E_\nu - m_K E'_\pi\right) + m_\mu^2\left(\frac{1}{4}E'_\pi - E_\nu\right) \ ,$$

$$B = m_\mu^2\left(E_\nu - \frac{1}{2}E'_\pi\right) \ ,$$

$$C = \frac{1}{4}m_\mu^2 E'_\pi \ ,$$

$$E'_\pi = E_\pi^{\max} - E_\pi = \left(m_K^2 + m_\pi^2 - m_\mu^2\right)/2m_K - E_\pi \ . \tag{4}$$

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 $\lambda_+, \xi(0)$, and their correlation.

Method B. By measuring the $K_{\mu 3}/K_{e3}$ 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:

$$\Gamma(K^\pm_{\mu 3})/\Gamma(K^\pm_{e3}) = 0.6457 + 1.4115\lambda_+ + 0.1264\xi(0) + 0.0192\xi(0)^2 + 0.0080\lambda_+\xi(0) \ ,$$

$$\Gamma(K^0_{\mu 3})/\Gamma(K^0_{e3}) = 0.6452 + 1.3162\lambda_+ + 0.1264\xi(0) + 0.0186\xi(0)^2 + 0.0064\lambda_+\xi(0) \ . \quad (5)$$

This cannot determine λ_+ and $\xi(0)$ simultaneously but simply fixes a relationship between them.

Method C. By measuring the muon polarization in $K_{\mu 3}$ decay. In the rest frame of the K, the μ is expected to be polarized in the direction $\mathbf{A}$ with $\mathbf{P} = \mathbf{A}/\left|\mathbf{A}\right|$, where $\mathbf{A}$ is given (Cabibbo and Maksymowicz [3]) by

$$\mathbf{A} = a_1(\xi)\mathbf{p}_\mu - a_2(\xi)\left[\frac{\mathbf{p}_\mu}{m_\mu}\left(m_K - E_\pi + \frac{\mathbf{p}_\pi \cdot \mathbf{p}_\mu}{\left|\mathbf{p}_\mu\right|^2}(E_\mu - m_\mu)\right) + \mathbf{p}_\pi\right] + m_K \mathrm{Im}\xi(t)(\mathbf{p}_\pi \times \mathbf{p}_\mu) \ . \quad (6)$$

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) $\boldsymbol{\lambda_+, \lambda_0}$ ***parametrization***. Most of the more recent $K_{\mu 3}$ analyses have parameterized 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

$$f_0(t) = f_+(t) + \left[t/(m_K^2 - m_\pi^2)\right] f_-(t) \ . \tag{7}$$

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:

$$f_0(t) = f_0(0) \left[1 + \lambda_0(t/m_\pi^2)\right] \ . \tag{8}$$

With the assumption that $f_0(0) = f_+(0)$, the two parametrizations, $(\lambda_+, \xi(0))$ and (λ_+, λ_0) are equivalent as long as correlation information is retained. (λ_+, λ_0) correlations tend to be less strong than $(\lambda_+, \xi(0))$ 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 Particle Listings in section $\xi_{\rm A}$, $\xi_{\rm B}$, or $\xi_{\rm C}$ 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 $K_{\mu 3}^0$ 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. (1), would contain

$$+2m_K\, f_S\, \overline{\ell}(1+\gamma_5)\nu$$
$$+(2f_T/m_K)(P_K)_\lambda (P_\pi)_\mu\, \overline{\ell}\, \sigma_{\lambda\mu}(1+\gamma_5)\nu \ , \tag{9}$$

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. Reports **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).

$K^{\pm}_{\ell 3}$ 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 $K^{\pm}_{\mu 3}$ value except in the $K^{\pm}_{e3}$ sections.

$d\xi(0)/d\lambda_+$ is the correlation between $\xi(0)$ and λ_+ in $K^{\pm}_{\mu 3}$.

$d\lambda_0/d\lambda_+$ is the correlation between λ_0 and λ_+ in $K^{\pm}_{\mu 3}$.

t = momentum transfer to the π in units of m^2_π.

DP = Dalitz plot analysis.

PI = π spectrum analysis.

MU = μ spectrum analysis.

POL= μ polarization analysis.

BR = $K^{\pm}_{\mu 3}/K^{\pm}_{e3}$ branching ratio analysis.

E = positron or electron spectrum analysis.

RC = radiative corrections.

λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN $K^{\pm}_{e3}$ DECAY)

For radiative correction of $K^{\pm}_{e3}$ Dalitz plot, see GINSBERG 67 and BECHERRAWY 70.

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.0276±0.0021 OUR AVERAGE						
0.018 ±0.007	3k	ARTEMOV	97B	SPEC	−	DP
0.0284±0.0027±0.0020	32k	[81] AKIMENKO	91	SPEC		PI, no RC
0.029 ±0.004	62k	[82] BOLOTOV	88	SPEC		PI, no RC
0.027 ±0.008		[83] 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		[84] BRAUN	74	HLBC	+	$K_{\mu 3}/K_{e3}$ vs. t

[81] AKIMENKO 91 state that radiative corrections would raise λ_+ by 0.0013.

[82] BOLOTOV 88 state radiative corrections of GINSBERG 67 would raise λ_+ by 0.002.

[83] 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.

[84] BRAUN 74 is a combined $K_{\mu3}$-K_{e3} result. It is not independent of BRAUN 73C ($K_{\mu3}$) and BRAUN 73B (K_{e3}) form factor results.

$\xi_A = f_-/f_+$ (determined from $K^{\pm}_{\mu3}$ spectra)

The parameter ξ is redundant with λ_0 below and is not put into the Meson Summary Table.

VALUE	$d\xi(0)/d\lambda_+$	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
−0.31±0.15 OUR EVALUATION			Error includes scale factor of 1.6. Correlation is $d\xi(0)/d\lambda_+ = -14$. From a fit discussed in note on $K_{\ell3}$ 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	[85] ARNOLD	74	HLBC	+	DP
−0.57±0.24	−9	6527	[86] MERLAN	74	ASPK	+	DP
−0.36±0.40	−19	1897	[87] BRAUN	73C	HLBC	+	DP
−0.62±0.28	−12	4025	[88] ANKENBRA...	72	ASPK	+	PI
+0.45±0.28	−15	3480	[89] CHIANG	72	OSPK	+	DP
−1.1 ±0.56	−29	3240	[90] HAIDT	71	HLBC	+	DP
−0.5 ±0.8	−26	2041	[91] 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	[92] CALLAHAN	66B	FBC	+	μ, λ_+=0
+0.7 ±0.5		87	GIACOMELLI	64	EMUL	+	MU+BR,λ_+=0
−0.08±0.7			[93] JENSEN	64	XEBC	+	DP+BR
+1.8 ±0.6		76	BROWN	62B	XEBC	+	DP+BR, λ_+=0

[85] ARNOLD 74 figure 4 was used to obtain ξ_A and $d\xi(0)/d\lambda_+$.

[86] MERLAN 74 figure 5 was used to obtain $d\xi(0)/d\lambda_+$.

[87] BRAUN 73C gives $\xi(t) = -0.34 \pm 0.20$, $d\xi(t)/d\lambda_+ = -14$ for $\lambda_+ = 0.027$, $t = 6.6$. We calculate above $\xi(0)$ and $d\xi(0)/d\lambda_+$ for their $\lambda_+ = 0.025 \pm 0.017$.

[88] ANKENBRANDT 72 figure 3 was used to obtain $d\xi(0)/d\lambda_+$.

[89] CHIANG 72 figure 10 was used to obtain $d\xi(0)/d\lambda_+$. Fit had $\lambda_- = \lambda_+$ but would not change for $\lambda_- = 0$. L.Pondrom, (private communication 74).

[90] 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_+.

[91] KIJEWSKI 69 figure 17 was used to obtain $d\xi(0)/d\lambda_+$ and errors.

[92] 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_+. t unknown.

[93] JENSEN 64 gives $\lambda^{\mu}_+ = \lambda^e_+ = -0.020 \pm 0.027$. $d\xi(0)/d\lambda_+$ unknown. Includes SHAKLEE 64 $\xi_B(K_{\mu3}/K_{e3})$.

$\xi_B = f_-/f_+$ (determined from $K^\pm_{\mu 3}/K^\pm_{e3}$)

The $K^\pm_{\mu 3}/K^\pm_{e3}$ 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 $K^\pm_{\mu 3}/K^\pm_{e3}$ ratio $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma(\pi^0 e^+\nu_e)$, with the exception of HEINTZE 77. The parameter ξ is redundant with λ_0 below and is not put into the Meson Summary Table.

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
−0.31±0.15 OUR EVALUATION		Error includes scale factor of 1.6. Correlation is $d\xi(0)/d\lambda_+ = -14$. From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition, PL **111B** (April 1982).				
−0.12±0.12	55k	[94] HEINTZE	77	CNTR	+	λ_+=0.029
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.0 ±0.15	5825	CHIANG	72	OSPK	+	λ_+=0.03, fig.10
−0.81±0.27	1505	[95] HAIDT	71	HLBC	+	λ_+=0.028, fig.8
−0.35±0.22		[96] BOTTERILL	70	OSPK	+	λ_+=0.045±0.015
+0.91±0.82		ZELLER	69	ASPK	+	λ_+=0.023
−0.08±0.15	5601	[96] BOTTERILL	68B	ASPK	+	λ_+=0.023±0.008
−0.60±0.20	1398	[95] EICHTEN	68	HLBC	+	See note
+1.0 ±0.6	986	GARLAND	68	OSPK	+	λ_+=0
+0.75±0.50	306	AUERBACH	67	OSPK	+	λ_+=0
+0.4 ±0.4	636	CALLAHAN	66B	FBC	+	λ_+=0
+0.6 ±0.5		BISI	65B	HBC	+	λ_+=0
+0.8 ±0.6	500	CUTTS	65	OSPK	+	λ_+=0
$-0.17^{+0.75}_{-0.99}$		SHAKLEE	64	XEBC	+	λ_+=0

[94] Calculated by us from λ_0 and λ_+ given below.

[95] EICHTEN 68 has $\lambda_+ = 0.023 \pm 0.008$, $t = 4$, independent of λ_-. Replaced by HAIDT 71.

[96] BOTTERILL 70 is re-evaluation of BOTTERILL 68B with different λ_+.

$\xi_C = f_-/f_+$ (determined from μ polarization in $K^\pm_{\mu 3}$)

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 $K^\pm_{\mu 3}$, see GINSBERG 71. The parameter ξ is redundant with λ_0 below and is not put into the Meson Summary Table.

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
−0.31±0.15 OUR EVALUATION		Error includes scale factor of 1.6. Correlation is $d\xi(0)/d\lambda_+ = -14$. From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition, PL **111B** (April 1982).				
−0.25±1.20	1585	[97] BRAUN	75	HLBC	+	POL, t=4.2
−0.95±0.3	3133	[98] CUTTS	69	OSPK	+	Total pol. t=4.0
−1.0 ±0.3	6000	[99] 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	[100] MERLAN	74	ASPK	+	POL, $d\xi(0)/d\lambda_+ = +1.7$
$-1.4\ \pm1.8$	397	[101] CALLAHAN	66B	FBC	+	Total pol.
$-0.7\ ^{+0.9}_{-3.3}$	2950	[101] CALLAHAN	66B	FBC	+	Long. pol.
$+1.2\ ^{+2.4}_{-1.8}$	2100	[101] BORREANI	65	HLBC	+	Polarization
-4.0 to $+1.7$	500	[101] CUTTS	65	OSPK	+	Long. pol.

[97] BRAUN 75 $d\xi(0)/d\lambda_+ = \xi t = -0.25\times4.2 = -1.0$.

[98] CUTTS 69 $t = 4.0$ was calculated from figure 8. $d\xi(0)/d\lambda_+ = \xi t = -0.95\times4 = -3.8$.

[99] BETTELS 68 $d\xi(0)/d\lambda_+ = \xi t = -1.0\times4.9 = -4.9$.

[100] MERLAN 74 polarization result (figure 5) not possible. See discussion of polarization experiments in note on "$K_{\ell3}$ Form Factors" in the 1982 edition of this *Review* [Physics Letters **111B** (1982)].

[101] t value not given.

Im(ξ) in $K^\pm_{\mu3}$ DECAY (from transverse μ pol.)

Test of T reversal invariance.

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
$-$0.014$\pm$0.014 OUR AVERAGE						
$-0.013\pm0.016\pm0.003$	3.9M	ABE	99S	CNTR	+	p_T K^+ at rest
-0.016 ± 0.025	20M	CAMPBELL	81	CNTR	+	Pol.
$-0.3\ ^{+0.3}_{-0.4}$	3133	CUTTS	69	OSPK	+	Total pol. fig.7
$-0.1\ \pm0.3$	6000	BETTELS	68	HLBC	+	Total pol.
$0.0\ \pm1.0$	2648	CALLAHAN	66B	FBC	+	MU
$+1.6\ \pm1.3$	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	[102] BLATT	83	CNTR		Polarization

[102] Combined result of MORSE 80 ($K^0_{\mu3}$) and CAMPBELL 81 ($K^+_{\mu3}$).

λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN $K^\pm_{\mu3}$ DECAY)

See also the corresponding entries and footnotes in sections ξ_A, ξ_C, and λ_0. For radiative correction of $K^\pm_{\mu3}$ Dalitz plot, see GINSBERG 70 and BECHERRAWY 70.

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.031$\pm$0.008 OUR EVALUATION	Error includes scale factor of 1.6. From a fit discussed in note on $K_{\ell3}$ form factors in 1982 edition, PL **111B** (April 1982).					
Average is meaningless.						
0.014 ± 0.024	3k	ARTEMOV	97B	SPEC	$-$	DP
$+0.050\pm0.013$	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	[103] 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
$0.0\ \pm0.05$	444	CALLAHAN	66B	FBC	+	PI

• • • We do not use the following data for averages, fits, limits, etc. • • •

0.029±0.024	3000	[104] ARTEMOV	97	SPEC	−	DP

[103] ANKENBRANDT 72 λ_+ from figure 3 to match $d\xi(0)/d\lambda_+$. Text gives 0.024 ± 0.022.

[104] Superseded by ARTEMOV 97B.

λ_0 (LINEAR ENERGY DEPENDENCE OF f_0 IN $K^\pm_{\mu 3}$ 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
0.006±0.007 OUR EVALUATION			Error includes scale factor of 1.6. Correlation is $d\lambda_0/d\lambda_+ = -0.16$. From a fit discussed in note on $K_{\ell 3}$ form factors in 1982 edition, PL **111B** (April 1982).				
Average is meaningless.							
+0.058±0.020	0.0	3k	[105] ARTEMOV	97B	SPEC	−	DP
+0.029±0.011	−0.37	3973	WHITMAN	80	SPEC	+	DP
+0.019±0.010	+0.03	55k	[106] HEINTZE	77	SPEC	+	BR
+0.008±0.097	+0.92	1585	[107] BRAUN	75	HLBC	+	POL
−0.040±0.040	−0.62	490	ARNOLD	74	HLBC	+	DP
−0.019±0.015	+0.27	6527	[108] MERLAN	74	ASPK	+	DP
−0.008±0.020	−0.53	1897	[109] BRAUN	73C	HLBC	+	DP
−0.026±0.013	+0.03	4025	[110] ANKENBRA...	72	ASPK	+	PI
+0.030±0.014	−0.21	3480	[110] CHIANG	72	OSPK	+	DP
−0.039±0.029	−1.34	3240	[110] HAIDT	71	HLBC	+	DP
−0.056±0.024	+0.69	3133	[107] CUTTS	69	OSPK	+	POL
−0.031±0.045	−1.10	2041	[110] KIJEWSKI	69	OSPK	+	PI
−0.063±0.024	+0.60	6000	[107] BETTELS	68	HLBC	+	POL
+0.058±0.036	−0.37	444	[110] CALLAHAN	66B	FBC	+	PI
• • • We do not use the following data for averages, fits, limits, etc. • • •							
+0.062±0.024	0.0	3000	[111] ARTEMOV	97	SPEC	−	DP
−0.017±0.011			[112] BRAUN	74	HLBC	+	$K_{\mu 3}/K_{e3}$ vs. t

[105] ARTEMOV 97B does not give $d\lambda_0/d\lambda_+$ so we take it to be zero.

[106] HEINTZE 77 uses $\lambda_+ = 0.029 \pm 0.003$. $d\lambda_0/d\lambda_+$ estimated by us.

[107] λ_0 value is for $\lambda_+ = 0.03$ calculated by us from $\xi(0)$ and $d\xi(0)/d\lambda_+$.

[108] 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 $d\lambda_0/d\lambda_+$.

[109] 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.

[110] λ_0 calculated by us from $\xi(0)$, λ^μ_+, and $d\xi(0)/d\lambda_+$.

[111] ARTEMOV 97 does not give $d\lambda_0/d\lambda_+$ so we take it to be zero. Superseded by ARTEMOV 97B.

[112] 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 $K^{\pm}_{e3}$ DECAY

Ratio of scalar to f_+ couplings.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.084±0.023 OUR AVERAGE Error includes scale factor of 1.2.							
0.070±0.016±0.016		32k	AKIMENKO	91	SPEC		λ_+, f_S, f_T, ϕ fit
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 $K^{\pm}_{e3}$ DECAY

Ratio of tensor to f_+ couplings.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.38±0.11 OUR AVERAGE Error includes scale factor of 1.1.							
$0.53\ ^{+0.09}_{-0.10}\pm0.10$		32k	AKIMENKO	91	SPEC		λ_+, f_S, f_T, ϕ fit
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 $K^{\pm}_{\mu 3}$ DECAY

Ratio of tensor to f_+ couplings.

VALUE	EVTS	DOCUMENT ID		TECN
0.02±0.12	1585	BRAUN	75	HLBC

DECAY FORM FACTORS FOR $K^{\pm} \rightarrow \pi^+\pi^- e^{\pm}\nu_e$

Given in ROSSELET 77, BEIER 73, and BASILE 71C.

DECAY FORM FACTOR FOR $K^{\pm} \rightarrow \pi^0\pi^0 e^{\pm}\nu$

Given in BOLOTOV 86B and BARMIN 88B.

$K^{\pm} \rightarrow \ell^{\pm}\nu\gamma$ FORM FACTORS

For definitions of the axial-vector F_A and vector F_V form factor, see the "Note on $\pi^{\pm} \rightarrow \ell^{\pm}\nu\gamma$ and $K^{\pm} \rightarrow \ell^{\pm}\nu\gamma$ Form Factors" in the $\pi^{\pm}$ section. In the kaon literature, often different definitions $a_K = F_A/m_K$ and $v_K = F_V/m_K$ are used.

$F_A + F_V$, SUM OF AXIAL-VECTOR AND VECTOR FORM FACTOR FOR $K \rightarrow e\nu_e\gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.148±0.010 OUR AVERAGE					
0.147±0.011	51	[113] HEINTZE	79	SPEC	$K \rightarrow e\nu\gamma$
$0.150^{+0.018}_{-0.023}$	56	[114] HEARD	75	SPEC	$K \rightarrow e\nu\gamma$

[113] HEINTZE 79 quotes absolute value of $|F_A + F_V| \sin\theta_c$. We use $\sin\theta_c = V_{us} = 0.2205$.
[114] HEARD 75 quotes absolute value of $|F_A + F_V| \sin\theta_c$. We use $\sin\theta_c = V_{us} = 0.2205$.

$F_A + F_V$, SUM OF AXIAL-VECTOR AND VECTOR FORM FACTOR FOR $K \rightarrow \mu\nu_\mu\gamma$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 0.23	90	[115] AKIBA	85	SPEC	$K \rightarrow \mu\nu\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−1.2 to 1.1	90	DEMIDOV	90	XEBC	$K \rightarrow \mu\nu\gamma$

[115] AKIBA 85 quotes absolute value.

$F_A - F_V$, DIFFERENCE OF AXIAL-VECTOR AND VECTOR FORM FACTOR FOR $K \rightarrow e\nu_e\gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
<0.49	90	[116] HEINTZE	79	SPEC	$K \rightarrow e\nu\gamma$

[116] HEINTZE 79 quotes $|F_A - F_V| < \sqrt{11}\,|F_A + F_V|$.

$F_A - F_V$, DIFFERENCE OF AXIAL-VECTOR AND VECTOR FORM FACTOR FOR $K \rightarrow \mu\nu_\mu\gamma$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
−2.2 to 0.3 OUR EVALUATION					
−2.2 to 0.6	90	DEMIDOV	90	XEBC	$K \rightarrow \mu\nu\gamma$
−2.5 to 0.3	90	AKIBA	85	SPEC	$K \rightarrow \mu\nu\gamma$

$K^{\pm}$ REFERENCES

ADLER	00	PRL 84 3768	S. Adler *et al.*	(BNL 787 Collab.)
MA	00	PRL 84 2580	H. Ma *et al.*	(BNL 865 Collab.)
ABE	99S	PRL 83 4253	M. Abe *et al.*	(KEK-E246 Collab.)
APPEL	99	PRL 83 4482	R. Appel *et al.*	(BNL 865 Collab.)
ADLER	98	PR D58 012003	S. Adler *et al.*	(BNL 787 Collab.)
BATUSOV	98	NP B516 3	V.Y. Batusov *et al.*	
ADLER	97	PRL 79 2204	S. Adler *et al.*	(BNL 787 Collab.)
ADLER	97C	PRL 79 4756	S. Adler *et al.*	(BNL 787 Collab.)
ARTEMOV	97	PAN 60 218	V.M. Artemov *et al.*	(JINR)
		Translated from YAF 60 277.		
ARTEMOV	97B	PAN 60 2023	V.M. Artemov *et al.*	
		Translated from YAF 60 2205.		

KITCHING	97	PRL 79 4079	P. Kitching *et al.*	(BNL 787 Collab.)
ADLER	96	PRL 76 1421	S. Adler *et al.*	(BNL 787 Collab.)
KOPTEV	95	JETPL 61 877	V.P. Koptev *et al.*	(PNPI)
		Translated from ZETFP 61 865.		
AOKI	94	PR D50 69	M. Aoki *et al.*	(INUS, KEK, TOKMS)
ATIYA	93	PRL 70 2521	M.S. Atiya *et al.*	(BNL 787 Collab.)
Also	93C	PRL 71 305 (erratum)	M.S. Atiya *et al.*	(BNL 787 Collab.)
ATIYA	93B	PR D48 R1	M.S. Atiya *et al.*	(BNL 787 Collab.)
BIJNENS	93	NP B396 81	J. Bijnens, G. Ecker, J. Gasser	(CERN, BERN)
ALLIEGRO	92	PRL 68 278	C. Alliegro *et al.*	(BNL, FNAL, PSI+)
BARMIN	92	SJNP 55 547	V.V. Barmin *et al.*	(ITEP)
		Translated from YAF 55 976.		
IMAZATO	92	PRL 69 877	J. Imazato *et al.*	(KEK, INUS, TOKY+)
IVANOV	92	THESIS	Ivanov	(PNPI)
LITTENBERG	92	PRL 68 443	L.S. Littenberg, R.E. Shrock	(BNL, STON)
USHER	92	PR D45 3961	T. Usher *et al.*	(UCI)
AKIMENKO	91	PL B259 225	S.A. Akimenko *et al.*	(SERP, JINR, TBIL+)
BARMIN	91	SJNP 53 606	V.V. Barmin *et al.*	(ITEP)
		Translated from YAF 53 981.		
DENISOV	91	JETPL 54 558	A.S. Denisov *et al.*	(PNPI)
		Translated from ZETFP 54 557.		
Also	92	THESIS	Ivanov	(PNPI)
ATIYA	90	PRL 64 21	M.S. Atiya *et al.*	(BNL 787 Collab.)
ATIYA	90B	PRL 65 1188	M.S. Atiya *et al.*	(BNL 787 Collab.)
DEMIDOV	90	SJNP 52 1006	V.S. Demidov *et al.*	(ITEP)
		Translated from YAF 52 1595.		
LEE	90	PRL 64 165	A.M. Lee *et al.*	(BNL, FNAL, VILL, WASH+)
ATIYA	89	PRL 63 2177	M.S. Atiya *et al.*	(BNL 787 Collab.)
BARMIN	89	SJNP 50 421	V.V. Barmin *et al.*	(ITEP)
		Translated from YAF 50 679.		
BARMIN	88	SJNP 47 643	V.V. Barmin *et al.*	(ITEP)
		Translated from YAF 47 1011.		
BARMIN	88B	SJNP 48 1032	V.V. Barmin *et al.*	(ITEP)
		Translated from YAF 48 1719.		
BOLOTOV	88	JETPL 47 7	V.N. Bolotov *et al.*	(ASCI)
		Translated from ZETFP 47 8.		
CAMPAGNARI	88	PRL 61 2062	C. Campagnari *et al.*	(BNL, FNAL, PSI+)
GALL	88	PRL 60 186	K.P. Gall *et al.*	(BOST, MIT, WILL, CIT+)
BARMIN	87	SJNP 45 62	V.V. Barmin *et al.*	(ITEP)
		Translated from YAF 45 97.		
BOLOTOV	87	SJNP 45 1023	V.N. Bolotov *et al.*	(INRM)
		Translated from YAF 45 1652.		
BOLOTOV	86	SJNP 44 73	V.N. Bolotov *et al.*	(INRM)
		Translated from YAF 44 117.		
BOLOTOV	86B	SJNP 44 68	V.N. Bolotov *et al.*	(INRM)
		Translated from YAF 44 108.		
YAMANAKA	86	PR D34 85	T. Yamanaka *et al.*	(KEK, TOKY)
Also	84	PRL 52 329	R.S. Hayano *et al.*	(TOKY, KEK)
AKIBA	85	PR D32 2911	Y. Akiba *et al.*	(TOKY, TINT, TSUK, KEK)
BOLOTOV	85	JETPL 42 481	V.N. Bolotov *et al.*	(INRM)
		Translated from ZETFP 42 390.		
BLATT	83	PR D27 1056	S.R. Blatt *et al.*	(YALE, BNL)
ASANO	82	PL 113B 195	Y. Asano *et al.*	(KEK, TOKY, INUS, OSAK)
COOPER	82	PL 112B 97	A.M. Cooper *et al.*	(RL)
PDG	82	PL 111B	M. Roos *et al.*	(HELS, CIT, CERN)
PDG	82B	PL 111B 70	M. Roos *et al.*	(HELS, CIT, CERN)
ASANO	81B	PL 107B 159	Y. Asano *et al.*	(KEK, TOKY, INUS, OSAK)
CAMPBELL	81	PRL 47 1032	M.K. Campbell *et al.*	(YALE, BNL)
Also	83	PR D27 1056	S.R. Blatt *et al.*	(YALE, BNL)
LUM	81	PR D23 2522	G.K. Lum *et al.*	(LBL, NBS+)
LYONS	81	ZPHY C10 215	L. Lyons, C. Albajar, G. Myatt	(OXF)
MORSE	80	PR D21 1750	W.M. Morse *et al.*	(BNL, YALE)
WHITMAN	80	PR D21 652	R. Whitman *et al.*	(ILLC, BNL, ILL)
BARKOV	79	NP B148 53	L.M. Barkov *et al.*	(NOVO, KIAE)
HEINTZE	79	NP B149 365	J. Heintze *et al.*	(HEIDP, CERN)
ABRAMS	77	PR D15 22	R.J. Abrams *et al.*	(BNL)
DEVAUX	77	NP B126 11	B. Devaux *et al.*	(SACL, GEVA)
HEINTZE	77	PL 70B 482	J. Heintze *et al.*	(HEIDP, CERN)
ROSSELET	77	PR D15 574	L. Rosselet *et al.*	(GEVA, SACL)
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BLOCH	76	PL 60B 393	P. Bloch *et al.*	(GEVA, SACL)
BRAUN	76B	LNC 17 521	H.M. Braun *et al.*	(AACH3, BARI, BELG+)
DIAMANT-...	76	PL 62B 485	A.M. Diamant-Berger *et al.*	(SACL, GEVA)
HEINTZE	76	PL 60B 302	J. Heintze *et al.*	(HEIDP)

SMITH	76	NP B109 173	K.M. Smith *et al.*	(GLAS, LIVP, OXF+)
WEISSENBE...	76	NP B115 55	A.O. Weissenberg *et al.*	(ITEP, LEBD)
BLOCH	75	PL 56B 201	P. Bloch *et al.*	(SACL, GEVA)
BRAUN	75	NP B89 210	H.M. Braun *et al.*	(AACH3, BARI, BRUX+)
CHENG	75	NP A254 381	S.C. Cheng *et al.*	(COLU, YALE)
HEARD	75	PL 55B 324	K.S. Heard *et al.*	(CERN, HEIDH)
HEARD	75B	PL 55B 327	K.S. Heard *et al.*	(CERN, HEIDH)
SHEAFF	75	PR D12 2570	M. Sheaff	(WISC)
SMITH	75	NP B91 45	K.M. Smith *et al.*	(GLAS, LIVP, OXF+)
ARNOLD	74	PR D9 1221	C.L. Arnold, B.P. Roe, D. Sinclair	(MICH)
BRAUN	74	PL 51B 393	H.M. Braun *et al.*	(AACH3, BARI, BRUX+)
CENCE	74	PR D10 776	R.J. Cence *et al.*	(HAWA, LBL, WISC)
Also	73	Thesis unpub.	D.B. Clarke	(WISC)
KUNSELMAN	74	PR C9 2469	R. Kunselman	(WYOM)
MERLAN	74	PR D9 107	S. Merlan *et al.*	(YALE, BNL, LASL)
WEISSENBE...	74	PL 48B 474	A.O. Weissenberg *et al.*	(ITEP, LEBD)
ABRAMS	73B	PRL 30 500	R.J. Abrams *et al.*	(BNL)
BACKENSTO...	73	PL 43B 431	G. Backenstoss *et al.*	(CERN, KARLK, KARLE+)
BEIER	73	PRL 30 399	E.W. Beier *et al.*	(PENN)
BRAUN	73B	PL 47B 185	H.M. Braun, M. Cornelssen	(AACH3, BARI, BRUX+)
Also	75	NP B89 210	H.M. Braun *et al.*	(AACH3, BARI, BRUX+)
BRAUN	73C	PL 47B 182	H.M. Braun, M. Cornelssen	(AACH3, BARI, BRUX+)
Also	75	NP B89 210	H.M. Braun *et al.*	(AACH3, BARI, BRUX+)
CABLE	73	PR D8 3807	G.D. Cable *et al.*	(EFI, LBL)
LJUNG	73	PR D8 1307	D. Ljung, D. Cline	(WISC)
Also	72	PRL 28 523	D. Ljung	(WISC)
Also	72	PRL 28 1287	D. Cline, D. Ljung	(WISC)
Also	69	PRL 23 326	U. Camerini *et al.*	(WISC)
LUCAS	73	PR D8 719	P.W. Lucas, H.D. Taft, W.J. Willis	(YALE)
LUCAS	73B	PR D8 727	P.W. Lucas, H.D. Taft, W.J. Willis	(YALE)
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Also	72	PL 40B 699	G.D. Cable *et al.*	(EFI, LBL)
SMITH	73	NP B60 411	K.M. Smith *et al.*	(GLAS, LIVP, OXF+)
ABRAMS	72	PRL 29 1118	R.J. Abrams *et al.*	(BNL)
ANKENBRA...	72	PRL 28 1472	C.M. Ankenbrandt *et al.*	(BNL, LASL, FNAL+)
AUBERT	72	NC 12A 509	B. Aubert *et al.*	(ORSAY, BRUX, EPOL)
BEIER	72	PRL 29 678	E.W. Beier *et al.*	(PENN)
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CLARK	72	PRL 29 1274	A.R. Clark *et al.*	(LBL)
EDWARDS	72	PR D5 2720	R.T. Edwards *et al.*	(ILL)
FORD	72	PL 38B 335	W.T. Ford *et al.*	(PRIN)
HOFFMASTER	72	NP B36 1	S. Hoffmaster *et al.*	(STEV, SETO, LEHI)
BASILE	71C	PL 36B 619	P. Basile *et al.*	(SACL, GEVA)
BOURQUIN	71	PL 36B 615	M.H. Bourquin *et al.*	(GEVA, SACL)
GINSBERG	71	PR D4 2893	E.S. Ginsberg	(MIT)
HAIDT	71	PR D3 10	D. Haidt	(AACH, BARI, CERN, EPOL, NIJM+)
Also	69	PL 29B 691	D. Haidt *et al.*	(AACH, BARI, CERN, EPOL+)
KLEMS	71	PR D4 66	J.H. Klems, R.H. Hildebrand, R. Stiening	(CHIC+)
Also	70	PRL 24 1086	J.H. Klems, R.H. Hildebrand, R. Stiening	(LRL+)
Also	70B	PRL 25 473	J.H. Klems, R.H. Hildebrand, R. Stiening	(LRL+)
OTT	71	PR D3 52	R.J. Ott, T.W. Pritchard	(LOQM)
ROMANO	71	PL 36B 525	F. Romano *et al.*	(BARI, CERN, ORSAY)
SCHWEINB...	71	PL 36B 246	W. Schweinberger	(AACH, BELG, CERN, NIJM+)
STEINER	71	PL 36B 521	H.J. Steiner	(AACH, BARI, CERN, EPOL, ORSAY+)
BARDIN	70	PL 32B 121	D.Y. Bardin, S.N. Bilenky, B.M. Pontecorvo	(JINR)
BECHERRAWY	70	PR D1 1452	T. Becherrawy	(ROCH)
BOTTERILL	70	PL 31B 325	D.R. Botterill *et al.*	(OXF)
FORD	70	PRL 25 1370	W.T. Ford *et al.*	(PRIN)
GAILLARD	70	CERN 70-14	J.M. Gaillard, L.M. Chounet	(CERN, ORSAY)
GINSBERG	70	PR D1 229	E.S. Ginsberg	(HAIF)
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Also	69	PRL 23 737	J.U. Grauman *et al.*	(STEV, SETO, LEHI)
MALTSEV	70	SJNP 10 678	E.I. Maltsev *et al.*	(JINR)
		Translated from YAF 10 1195.		

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