t

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

Charge $= \frac{2}{3}\ e$ Top $= +1$

THE TOP QUARK

(by M. Mangano at CERN and T. Trippe at LBNL)

A. Introduction: The top quark is the $Q = 2/3$, $T_3 = +1/2$ member of the weak-isospin doublet containing the bottom quark (see our review on the "Standard Model of Electroweak Interactions" for more information). The existence of a sixth quark has been expected since the discovery of the bottom quark itself and has become an absolute theoretical necessity within the Standard Model (SM) after the measurement of the $T_3 = -1/2$ weak isospin of the bottom quark [1]. While models with additional quarks but quantum numbers different from the top quark have been constructed, the simplest hypothesis that the weak doublet containing the bottom be completed into a family structure similar to the first two generations has always been the most appealing. This idea has finally been confirmed with the recent announcement of the top discovery by the CDF and DØ experiments at the Fermilab 1.8 TeV Tevatron proton-antiproton collider.

We start this note by presenting a brief historical survey of top searches. Then we discuss in more detail the essential features of top production and decay properties which were exploited to perform the discovery. Finally, we discuss the experimental and theoretical issues involved in the determination of its parameters (mass, production cross section, decay branching ratios, *etc.*) and conclude with the prospects for future improvements.

B. Some history: The first expectations for the value of the top mass used a naive extrapolation of the up- to down-type quark mass ratios in the first two generations, leading to values in the range of 10–20 GeV. Direct searches for $t\bar{t}$ pair production in e^+e^- collisions in this mass range were performed beginning in the late 70's at DESY and SLAC (see the compilation of limits in our 1990 edition [2]). These searches looked for a sudden increase in the ratio $R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ or for anomalies in the distributions of thrust and acoplanarity in hadronic events. The lower limit on the top mass was increased to 30 GeV and then to approximately 46 GeV between the end of the 80's and the beginning of the

90's, when the more powerful Tristan, SLC and LEP e^+e^- colliders began operations (see the t-Quark Particle Listings in the current edition).

In parallel to the searches in e^+e^- collisions, direct searches were performed during the 80's by the UA1 and UA2 experiments at the CERN $S\overline{p}pS$ proton-antiproton collider, $\sqrt{s} = 630$ GeV. At this energy, and at the available luminosities, the CERN experiments were sensitive to top mass values not exceeding 70 GeV, the top quark being mostly produced via an intermediate on-shell W, decaying to $t\overline{b}$. A top quark with mass below the Wb threshold was then expected to undergo a 3-body weak decay to a $bf\overline{f}'$ final state, with $f\overline{f}'$ being a weak isospin doublet such as $\nu_\ell\overline{\ell}$ or $u\overline{d}$.

Because of the overwhelming QCD background to the detection of the purely hadronic final states, the experiments looked for final states including a high momentum isolated lepton, missing transverse energy (E_T), and one or more jets. No evidence for top production was obtained (see the t-Quark Particle Listings in the current edition for the references): the 95% CL mass limits went from 41 GeV (UA1, 1988), to 60 GeV (UA1, 1990), to 69 GeV (UA2, 1990). The first limits from CDF at the Fermilab Tevatron also appeared in 1990: $m_t > 72$ GeV from searches in the $e\mu$ final states, and $m_t > 77$ GeV from searches in the e plus jets and missing E_T final states.

Further indications of a large top mass had come from the measurement of a significant B^0–$\overline{B}^0$ mixing, performed in 1986 by UA1 and Argus.

Mass limits independent of the decay mode were also set in the range $m_t > 40$ GeV via the determination of the W boson width, from the measurement in hadronic collisions of the ratio $\sigma(W \to \ell\nu_\ell)/\sigma(Z \to \ell^+\ell^-)$. With the advent of high-precision electroweak data (from deep-inelastic scattering, M_W, atomic parity violation and, most importantly, from the study of the Z-boson couplings at SLC and LEP), global fits of the SM parameters have become possible, and have provided significant indirect constraints on the value of the top mass, once more indicating a large value (see our review "Standard Model of Electroweak Interactions" in the current edition for more information).

In this edition we have shortened the Particle Listings of indirect top mass limits by omitting superseded limits and reviews published before 1994. For more complete listings see our 1994 edition [3].

C. Top quark searches at the Tevatron: The first direct limits on the top mass exceeding the threshold for the decay into real W and a bottom quark came in the early 90's from the Fermilab Tevatron collider: $m_t > 91$ GeV (CDF, 1992) and $m_t > 131$ GeV (D0, 1994).

At the Tevatron energy, 1.8 TeV, a top quark above the W mass is dominantly produced in pairs from pure QCD processes: $q\overline{q} \to t\overline{t}$ and $gg \to t\overline{t}$. For a top mass around 100 GeV, the production cross section is expected to be of the order of 100 pb and is evenly shared between the two above channels. At 150 (175, 200) GeV the cross section is about 10 (5, 2.5) pb, with approximately 80% (90%, 95%) of it due to the light quark annihilation.

For masses above the Wb threshold, and neglecting terms of order m_b^2/m_t^2, the top quark decay width is predicted in the SM to be [4]:

$$\Gamma_t = \frac{G_F m_t^3}{8\pi\sqrt{2}}(1 - \frac{M_W^2}{m_t^2})^2(1 + 2\frac{M_W^2}{m_t^2})[1 - \frac{2\alpha_s}{3\pi}(\frac{2\pi^2}{3} - \frac{5}{2})].$$

The use of G_F in this equation accounts for the largest part of the 1-loop electroweak radiative corrections, providing an expression accurate to better than 2%. The width values increase from 302 MeV (for $m_t = 120$ GeV) to 1.04 GeV ($m_t = 160$ GeV) and 2.23 GeV ($m_t = 200$ GeV). With such a correspondingly short lifetime, the top quark is expected to decay before top-favoured hadrons or $t\bar{t}$ quarkonium bound states can form.

The top quark decay is expected to be largely dominated by the Wb final state. The Ws and Wd final states are suppressed relatively to Wb by the square of the CKM matrix elements V_{ts} and V_{td}, whose values can be estimated under the assumption of unitarity of the three-generation CKM matrix to be less than 0.046 and 0.014, respectively (see our review "The Cabibbo-Kobayashi-Maskawa Mixing Matrix" in the current edition for more information).

Typical final states therefore belong to three classes:

A. $t\overline{t} \to W\,b\,W\,\overline{b} \to q\,\overline{q}'\,b\,q''\,\overline{q}'''\,\overline{b}$,

B. $t\overline{t} \to W\,b\,W\,\overline{b} \to q\,\overline{q}'\,b\,\ell\,\overline{\nu}_\ell\,\overline{b}$,

C. $t\overline{t} \to W\,b\,W\,\overline{b} \to \overline{\ell}\,\nu_\ell\,b\,\ell'\,\overline{\nu}_{\ell'}\,\overline{b}$.

The final state quarks emit radiation and evolve into jets of hadrons. The precise number of jets reconstructed by the detectors varies event by event, as it depends on the decay kinematics, as well as on the precise definition of jet used in the analysis. The neutrinos are reconstructed via the large imbalance in detected transverse momentum of the event (missing E_T).

The $t\bar{t}$ production signature is by itself quite clear in all possible decay channels, due to the many kinematical constraints imposed by the sequential decay via a real W. However, the combination of the limited experimental resolution and of the large cross section for the production of 6 jets in the QCD continuum (several nb) make the search in the purely hadronic channel very difficult. Since the detection of τ leptons has small efficiency, studies have therefore mostly concentrated on final states where one (or both) W decays to either an electron or a muon. Potential physics backgrounds still exist, mainly due to associated production of one (or two) W and several jets, with the W decaying leptonically. The gain in the S/B ratio is by an approximate factor of 10 for each W which is required to decay leptonically.

The theoretical estimates of the physics backgrounds have large uncertainties, since only leading order QCD calculations are available for most of the relevant processes (W+3 and 4 jets, or WW+2 jets). While this limitation is known to affect the estimates of the overall production rates, it is believed that the LO determination of the event kinematics and of the fraction of W plus multi-jet events containing b quarks is rather accurate. In particular, one expects the E_T spectrum of these jets to fall rather steeply, the jet direction to point preferentially at small angles from the beams, and the fraction of events with b quarks to be of the order of few percent. In the case of the top signal, *vice versa*, the b fraction is $\sim 100\%$ and the jets are rather energetic, since they come from the decay of a massive object. It is therefore possible to improve the S/B ratio by either requiring the presence of a b quark, or by selecting very energetic and central kinematical configurations.

A detailed study of control samples with features similar to those of the relevant backgrounds, but free from possible top contamination (*e.g.*, a sample of Z plus multi-jet events), is required to provide a reliable check on the background estimates.

D. Top observation at CDF and DØ: The CDF experiment and the DØ experiment independently observed the production and decay of the top quark at the Fermilab Tevatron collider in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV.

The CDF experiment published the first direct experimental evidence for the top quark in 1994 [5]. They found 12 events consistent with top, containing 6 silicon vertex tags, 7 low-p_T lepton tags, and 3 dilepton events (these categories are discussed below in more detail) with estimated backgrounds of 2.3 ± 0.3, 3.1 ± 0.3, and $0.56^{+0.25}_{-0.13}$ respectively. The combined excess signal was inconsistent with backgrounds by 2.8 σ, not enough to firmly establish the existence of the top quark. Interpreting the excess events as top, they found a $t\bar{t}$ production cross section of $13.9^{+6.1}_{-4.8}$ pb, larger than the expected QCD cross section discussed below. A mass analysis of seven of these events yielded $m_t = 174 \pm 10^{+13}_{-12}$ GeV. A sample of events selected according to the expected kinematical properties of top provided additional support for the top interpretation [6].

The DØ experiment [7] found nine top candidates in their data taken during the same Tevatron run with an estimated background of 3.8 ± 0.9. They found a probability of 2.7% that this yield was consistent with backgrounds, corresponding to a 1.9 σ effect. If they assumed that the observed excess was top production, they obtained a $t\bar{t}$ production cross section of 8.2 ± 5.1 pb at $m_t = 180$ GeV.

After accumulating more than three times the amount of data, both CDF and DØ reported in 1995 [8,9] that they had conclusively observed the top quark.

The CDF experiment [8] observed top signals in two classes of events: $\ell\ell + jets$ events, which have two high-p_T leptons (e or μ) of opposite charge, large missing E_T, and at least two jets; and $\ell + jets/b$-tag events, which have one high-p_T lepton, large missing E_T, and at least three jets, of which at least one is tagged as a b jet. They tagged b jets by finding secondary vertices from b-quark decay with their silicon vertex detector or by finding low-p_T leptons from semileptonic b decay.

In 67 pb^{-1} integrated luminosity, CDF observed 37 $\ell + jets/b$-tag) events containing 27 secondary vertex b tags and 23 low-p_T lepton b tags with estimated backgrounds of 6.7 ± 2.1 and 15.4 ± 2.0 respectively. They also observed 6 $\ell\ell$ events with an estimated background of 1.3 ± 0.3 events. The combined excess signal observed in these three categories is inconsistent with the background prediction by 4.8 σ.

The DØ experiment [9] observed top signals in three classes of events: $\ell\ell + jets$ events, $\ell + jets$ events, and $\ell + jets/b$-tag events. These classes differ from those of CDF in the details of their selection cuts, but the main differences are that DØ imposes topological cuts, includes $\ell+jets$ events without a b tag if they have at least four jets, and uses soft-muon b tagging only. The topological cuts, mainly H_T, which is the scalar sum of transverse energies of the jets (and, in dilepton events, the leading electron), are very effective since the top quark is heavy, and hence top events are more spherical than background events and are produced more centrally in the detector.

In an integrated luminosity of approximately 50 pb^{-1} DØ observed 3 $\ell\ell + jets$ events, 8 $\ell + jets$ events, and 6 $\ell + jets/b$-tag events, a total of 17 top candidates. The total estimated background in these events is 3.8 ± 0.6 events. The excess signal is inconsistent with the background prediction by 4.6 σ.

E. Measured top properties: CDF and DØ both measured the top mass using single lepton events with four or more jets. Each event was subjected to a two-constraint kinematic fit to the hypothesis $t\overline{t} \rightarrow W^+ b W^- \overline{b} \rightarrow \ell \nu_\ell q \overline{q}' b \overline{b}$, assuming that the four highest E_T jets were the $t\overline{t}$ daughters. All permutations of these jets were tried, with the restriction that b-tagged jets were assigned to b quarks in the fit.

CDF found that of their 37 $\ell + jets/b$-tag events, 19 events had four or more jets. Of these 19, $6.9^{+2.5}_{-1.9}$ were expected to be background. A fit to the mass distribution of the 19 events by the sum of the expected distributions for the $W + jets$ background and a top quark yielded $m_t = 176 \pm 8 \pm 10$ GeV where the second error is the estimated systematic uncertainty.

DØ found that of their 14 $\ell+jets$ (with and without b-tags) events, 11 had four or more jets and passed the fit. To increase the statistics and reduce mass biases, the H_T requirement was removed, yielding 27 $\ell + 4jets$ events, of which 24 passed the fit. A fit of the mass distribution to top and background contributions yielded $m_t = 199^{+19}_{-21} \pm 22$ GeV, where the second error is the estimated systematic error.

Preliminary results for the top mass based on the full (Run Ia+Ib) data set have been presented by CDF and DØ at conferences in early 1996 and are given in Table 1. Since these are preliminary results, we do not average them or include them in the data listings or summary tables.

The current average of the CDF and DØ published results is $m_t = 180 \pm 12$ GeV, where statistical and systematic errors have been combined in quadrature and where CDF and DØ systematic errors have been assumed to be independent.

Table 1: Preliminary top masses presented at conferences in early 1996. See for example Ref. 10 for CDF results and Ref. 11 for DØ results.

top quark mass	Expt.	Channel
$175.6 \pm 5.7 \pm 7.1$ GeV	CDF	lepton + jets
$159^{+24}_{-22} \pm 17$ GeV	CDF	dilepton
$187 \pm 8 \pm 12$ GeV	CDF	hadronic
$170 \pm 15 \pm 10$ GeV	DØ	lepton + jets
$158 \pm 24 \pm 10$ GeV	DØ	$e\mu$

Given the experimental technique used to extract the top mass, this value should be taken as representing the top *pole mass* (see our review "Note on Quark Masses" in the current edition).

The extraction of the value of the top mass from the analyses described requires, in addition to an understanding of the absolute energy calibration and resolution of the detectors, also an *a priori* knowledge of the structure of the final state. Given the hardness of a $t\bar{t}$ production process, jets can in fact arise not only from the top decays, but also from the initial state gluon radiation. Furthermore, quarks from the top decays can radiate additional jets. The presence of these additional jets will affect the shape of the mass spectrum, depending on the details of how the samples used for the mass determination were defined. QCD calculations used to model top production and decay are expected to be rather reliable, but residual uncertainties remain and are accounted for in the overall systematic error on the top mass.

CDF [8] and DØ [9] determined the $t\bar{t}$ cross section in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV from their numbers of top candidates, their estimated background, their $t\bar{t}$ acceptance, and their integrated luminosity. The evaluation was done under the assumption of SM decays $t \rightarrow Wb$, with unity branching ratio. Based on their number of secondary-vertex b-tagged events, CDF determined the $t\bar{t}$ cross section to be $6.8^{+3.6}_{-2.4}$ pb at $m_t = 175$ GeV. The next-to-leading-order QCD prediction [12], allowing for a variation of the renormalization and factorization scales μ in the range $0.5 < \mu/m_t < 2$ and using the MRSA set of parton densities [13], gives $4.3 < \sigma_{t\bar{t}}(\mathrm{pb}) < 5.0$ at $m_t = 175$ GeV.

Based on their 17 top candidates, DØ determined the $t\bar{t}$ cross section to be 6.4 ± 2.2 pb at their central mass value of

199 GeV or 8.2 ± 2.9 pb at 180 GeV. The QCD predictions are: $2.0 < \sigma_{t\bar{t}}(\text{pb}) < 2.4$ ($m_t = 199$ GeV), and $3.6 < \sigma_{t\bar{t}}(\text{pb}) < 4.3$ ($m_t = 180$ GeV).

More recent preliminary values of the $t\bar{t}$ cross section were given at early 1996 conferences CDF found $7.5^{+1.9}_{-1.7}$ pb at 175 GeV [14] and DØ found 5.2 ± 1.8 pb at 170 GeV [15].

The measurement of other properties of the top quark has just started. CDF reported the first direct measurement of the $t \to Wb$ branching ratio [16]. Their preliminary result, obtained by comparing the number of events with 1 and 2 tagged-b jets and using the known tagging efficiency, is: $R = \mathrm{B}(t \to Wb)/\sum_{q=d,s,b} \mathrm{B}(t \to Wq) = 0.87^{+0.13+0.13}_{-0.30-0.11}$.

F. The future: With the discovery of the top quark, future studies will follow two main tracks. Theoretically, it is hoped that the large top mass, and the tantalizing coincidence between its current value and the fundamental scale of the electroweak symmetry breaking, will lead to some understanding of the structure of fermion masses and of the symmetry breaking mechanism itself. Experimentally, the work will concentrate on reducing the errors on the mass and cross section determinations and on the measurement of more specific properties of the top quark, namely its decay branching ratios and its couplings. With a smaller error on the top mass, and with yet improved measurements of the electroweak parameters, it will be possible to get important constraints on the value of the Higgs mass. Current global fits performed within the SM and its minimal supersymmetric extension, provide indications for a relatively light Higgs (see the "H^0 Indirect Mass Limits from Electroweak Analysis" in the Particle Listings of the current edition), possibly within the range of the upcoming LEP2 experiments.

The current Tevatron data, once fully analysed, should allow the first determination of limits on rare top decay modes, such as $t \to \gamma c$ or $t \to Zc$. Studies of the decay angular distributions will allow a first direct analysis of the $V - A$ nature of the Wtb coupling, as well as providing direct information on the relative coupling of longitudinal and transverse W bosons to the top. In the SM, the fraction of decays to transversely polarized W bosons is expected to be $1/(1 + m_t^2/2M_W^2)$ (29% for $m_t = 180$ GeV). Deviations from this value would challenge the Higgs mechanism of spontaneous symmetry breaking.

Over the longer term, a direct measurement of the Wtb coupling constant will be possible when enough data will be accumulated to detect the less frequent single-top production processes, such as $q\bar{q}' \to W^* \to t\bar{b}$ and $qb \to q't$ via W exchange.

A precise determination of the top production cross section will test the current theoretical understanding of the production mechanisms. The current state of the art amounts to complete calculations at the next-to-leading order in QCD [12], as well as efforts to resum classes of potentially large logarithmic corrections coming from multiple soft gluon emission in the intial state [17]. A precise understanding of top production at the Tevatron is important for the extrapolation to the higher energies of future colliders, like the LHC, where the expected large cross section will enable more extensive studies.

Discrepancies in rate between theory and data, on the other hand, would be more exciting and might indicate the presence of exotic production channels, as predicted in some models. In this case, one should also expect a modification of kinematical distributions such as the invariant mass of the top pair or the top quark transverse momentum.

As discussed in the previous sections, some of the current uncertainty in the determination of the top mass from the reconstruction of its final state jets arises from theoretical uncertainties in the modeling of the radiation in these very hard events. The current data, once fully analyzed, will presumably help improve our theoretical understanding. At the same time, the larger samples that will become available in the future will allow more strict selection criteria, leading to purer samples of top quarks. For example, requesting the presence of two secondary-vertex b tags in the event, in addition to two and only two central jets of high-E_T, should largely reduce the possibility of erroneously including jets not coming from the top decays into the mass reconstruction. This will significantly improve the mass resolution and will make it less sensitive to the theoretical uncertainties.

Finally, the large mass of the top quark leaves open the possibility of top decays into yet unobserved particles beyond the SM. For example, current limits on the masses of a charged Higgs (H^+) or of a supersymmetric scalar top quark ($\tilde{t}$) and neutralino ($\widetilde{\chi}^0$), cannot exclude the existence of decays such as $t \to H^+ b$ or $t \to \tilde{t}\,\widetilde{\chi}^0$. The first channel, in particular, has been used extensively in the past in direct top searches (see the Particle Listings in the current edition). Both these exotic modes are currently under investigation at CDF and DØ.

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t-Quark Mass in $p\overline{p}$ Collisions

The t quark has now been observed. Its mass is sufficiently high that decay is expected to occur before hadronization.

Preliminary results for the top mass based on the full (Run Ia+Ib) data set have been presented by CDF and DØ at conferences in early 1996:

$m_t = 175.6 \pm 5.7 \pm 7.1$ GeV	CDF	lepton + jets
$m_t = 159^{+24}_{-22} \pm 17$ GeV	CDF	dilepton
$m_t = 187 \pm 8 \pm 12$ GeV	CDF	hadronic
$m_t = 170 \pm 15 \pm 10$ GeV	DØ	lepton + jets
$m_t = 158 \pm 24 \pm 10$ GeV	DØ	$e\mu$

Because of the high current interest, we mention these preliminary results here but do not average them or include them in the Listings or Tables. See the note on the top quark for references.

Search limits, which are now primarily of historical interest, are based on the assumption that no nonstandard decay modes such as $t \to bH^+$ are available, except as noted in the comments.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
180±12 OUR AVERAGE					
$199^{+19}_{-21} \pm 22$		[1] ABACHI	95	D0	ℓ + jet
$176 \pm 8 \pm 10$		[2] ABE	95F	CDF	ℓ + b-jet
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[3] ABACHI	95B	D0	$\ell\ell$ + jets, ℓ + jets
>128	95	[4] ABACHI	95F	D0	$\ell\ell$ + jets, ℓ + jets
		[5] ABE	95O	CDF	
		[6] ABE	95V	CDF	
		[7] ABE,F	95	CDF	W + ≥ 4 jets
>131	95	[8] ABACHI	94	D0	$\ell\ell$ + jets, ℓ + jets
$174 \pm 10^{+13}_{-12}$		[9] ABE	94E	CDF	ℓ + b-jet
>118	95	[9] ABE	94E	CDF	$\ell\ell$
		[10] ABE	94H	CDF	$t \to bH^+$, $H^+ \to \tau^+\nu_\tau$
		[11] ABE	94I	CDF	$t \to bH^+$, $H^+ \to \tau^+\nu_\tau$
> 91	95	[12] ABE	92	CDF	$\ell\ell$, ℓ + b-jet
		[13] ALITTI	92F	UA2	$t \to bH^+$, $H^+ \to \tau^+\nu_\tau$
> 60	95	[14] ALBAJAR	91B	UA1	$t \to bH^+$, $H^+ \to \tau^+\nu_\tau$
		[15] BAER	91B	RVUE	$t \to \widetilde{t}_1 \widetilde{\chi}^0_1$
> 72	95	[16] ABE	90B	CDF	e + μ
> 77	95	[17] ABE	90C	CDF	e + jets + missing E_T
> 69	95	[18] AKESSON	90	UA2	e + jets + missing E_T
> 60	95	ALBAJAR	90B	UA1	e or μ + jets, $\mu\mu$ + jet
		[19] BARGER	90E	RVUE	$t \to bH^+$
> 41	95	[20] ALBAJAR	88	UA1	e or μ + jets

[1] ABACHI 95 search for $\ell\ell$+jets ($e\mu$, ee, and $\mu\mu$) and ℓ+jets (ℓ=e or μ). The ℓ+jets search is done in two ways, using either topological cuts or requiring μ tagging. They observe 17 (3 $\ell\ell$, 6 ℓ+b-jets, and 8 ℓ+jets topological) events with an expected background of 3.8 ± 0.6. These seven analysis channels combine to give a 4.6 standard deviation effect. The mass fit is from 24 ℓ+4-jet events obtained with looser cuts.

[2] ABE 95F search for $\ell\ell$ (ee, $e\mu$, and $\mu\mu$) final states and ℓ + b-jet final states. They find 37 ℓ + b-jet candidates containing 27 secondary vertex tags and 23 lepton tags with expected backgrounds of 6.7 ± 2.1 and 15.4 ± 2.0 respectively. They find 6 $\ell\ell$ events with an expected background of 1.3 ± 0.3 These three observations combine to give a 4.8 standard deviation effect. The mass fit is from 19 ℓ+4-jet events with a b-tag. The shape of the mass distribution is consistant with top and this increases the significance of the effect to 5.0σ.

[3] ABACHI 95B searched for dilepton channels $e\mu$+ jets, ee+ jets, $\mu\mu$+ jets, and singleletpon channels e+ jets and μ+ jets with and without b tagging. They found 9 events where 3.8 ± 0.9 events are expected from background. Based on an integrated luminosity of 13.5 ± 1.6pb^{-1}. These analyses combine to give a 1.9 standard deviation effect. Assuming that the observed excess signal is due to top quark production, the cross section is 8.2 ± 5.1 pb for m_t = 180 GeV.

[4] ABACHI 95F searched for dilepton channels $e\mu+$ jets, $ee+$ jets, $\mu\mu+$ jets, and single-lepton channels e + jets and μ + jets with and without b tagging. The lower mass bound supersedes that of ABACHI 94 and is weaker as a result of a recalibration of the integrated luminosity. Assuming that the observed excess signal is due to top quark production, the cross section is 8.2 ± 5.1 pb (9.2 ± 5.7 pb) for m_t = 180 GeV (160 GeV).

[5] ABE 95O find evidence for top production in the jet E_T distributions of $W + \geq 3$ jet events, based on an integrated luminosity of 19.3pb^{-1}. The observed distributions are consistent with m_t = 170 GeV. Supersed by ABE 95V.

[6] ABE 95V find evidence for top production in the jet E_T distributions of $W + \geq 3$ jet events, based on an integrated luminosity of 67pb^{-1}.

[7] ABE,F 95 compared the total transverse energy distribution of the $W + \geq 4$-jet data with that expected from all known backgrounds and found 3.8σ deviation in the shape. The distribution agrees well with a linear combination of background and $t\overline{t}$ events, the agreement being best for m_t = 180 GeV.

[8] ABACHI 94 search for $e\mu$ + jets, ee + jets, e + jets, and μ + jets. Production cross section with soft-gluon resummation of LAENEN 94 is used. The limit decreases to >122 GeV if $\mathcal{O}(\alpha_s{}^3)$ cross section is employed for comparison with ABE 92. Superseded by ABACHI 95F.

[9] ABE 94E search for ee, $e\mu$, and $\mu\mu$ dilepton final states and single lepton + b-jet final states. They observe a total of 15 top topology tags (12 events of which three are doubly tagged) with an expected background of $5.96^{+0.49}_{-0.44}$. The mass determination is from 7 single-lepton + b-jet events which have four jets. Their $\ell\ell$ limit uses the production cross section with soft gluon resummation from LAENEN 94. Superseded by ABE 95F.

[10] ABE 94H searched for $t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu_\tau$ with τ decaying hadronically. The search was done in the region 45 GeV $< m_{H^+} < m_t - m_b$ and 55 GeV $< m_t < m_W + m_b$. See their Fig. 3 for the 95% CL excluded regions in the (m_{H^+}, m_t) plane for B($H^+ \rightarrow \tau^+\nu_\tau$) = 1, 0.75, and 0.5.

[11] ABE 94I searched for $t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu_\tau$, $\tau^+ \rightarrow \ell^+\nu_\ell\overline{\nu}_\tau$. The search was done in the region 45 GeV $< m_{H^+} < m_t - m_b$ and 62 GeV $< m_t <$ 110 GeV. See their Fig. 2 for the 95% CL excluded regions in the (m_{H^+}, m_t) plane for B($H^+ \rightarrow \tau^+\nu_\tau$) = 1, 0.75, and 0.5. The entire region of the plane is excluded for B($H^+ \rightarrow \tau^+\nu_\tau$) > 0.75 when $m_t < m_W + m_b$.

[12] ABE 92 search for ee, $e\mu$, $\mu\mu$ dilepton final states and (e or μ) plus a b-quark jet. The b jet is tagged by a soft muon. The 90%CL limit is 95 GeV. Superseded by ABE 94E $\ell\ell$ limit.

[13] ALITTI 92F search for $t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu_\tau$ with τ^+ decaying hadronically. m_t between 50 and 70 GeV is excluded if $m_t - m_{H^+} = m_b + (\lesssim$ a few–10 GeV). See their Figs. 5,6 for the excluded region for B($H^+ \rightarrow \tau^+\nu_\tau$) = 1, 0.5.

[14] ALBAJAR 91B searched for the decay $t \rightarrow H^+ b$ using single muon and dimuon events and assuming B($H^+ \rightarrow \tau^+\nu$) $\geq$ 0.95. The limit holds for $m_{H^+} \lesssim m_t - m_b -$ (3–6) GeV.

[15] BAER 91B argue that a top quark as light as 60 GeV (65 GeV, if the minimal SUSY framework is assumed) may have escaped detection at CDF if a supersymmetric decay mode is open.

[16] ABE 90B exclude the region 28–72 GeV.

[17] ABE 90C cannot exclude $m_t <$ 40 GeV, but this region is ruled out by other experiments. They study events with an energetic electron, missing transverse energy and two or more jets. Only the $t\overline{t}$ contribution (not $W \rightarrow tb$) is relevant for these masses. See also ABE 91.

[18] AKESSON 90 searched for events having an electron with $p_T >$ 12 GeV, missing momentum > 15 GeV, and a jet with $E_T >$ 10 GeV, $|\eta| <$ 2.2, and excluded m_t between 30 and 69 GeV.

[19] BARGER 90E claim that ABE 90C data exclude most regions of two-Higgs-doublet models with $m_t <$ 80 GeV even if $t \rightarrow bH^+$ decay is allowed.

[20] ALBAJAR 88 value quoted here is revised using the full $O(\alpha_s^3)$ cross section of ALTARELLI 88. Superseded by ALBAJAR 90B.

Indirect t-Quark Mass from Standard Model Electroweak Fit

"OUR EVALUATION" below is from the fit to electroweak data described in the "Standard Model of Electroweak Interactions" section of this Review. This fit result does not include direct measurements of m_t. The second error corresponds to m_H=300^{+700}_{-240} GeV.

The RVUE values are based on the data described in the footnotes. RVUE's published before 1994 and superseded analyses are now omitted. For more complete listings of earlier results, see the 1994 edition (Physical Review **D50** 1173 (1994)).

VALUE (GeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
$179 \pm 8^{+17}_{-20}$ OUR EVALUATION				
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$175 \pm 11^{+17}_{-19}$	[21] ERLER	95	RVUE	Z parameters, m_W, low energy
$180 \pm 9^{+19}_{-21} \mp 2.6 \pm 4.8$	[22] MATSUMOTO	95	RVUE	
$157^{+36}_{-48}{}^{+19}_{-20}$	[23] ABREU	94	DLPH	Z parameters
$158^{+32}_{-40} \pm 19$	[24] ACCIARRI	94	L3	Z parameters
$132^{+41}_{-48}{}^{+24}_{-18}$	[25] AKERS	94	OPAL	Z parameters
$190^{+39}_{-48}{}^{+12}_{-14}$	[26] ARROYO	94	CCFR	ν_μ iron scattering
$184^{+25}_{-29}{}^{+17}_{-18}$	[27] BUSKULIC	94	ALEP	Z parameters
153 ± 15	[28] ELLIS	94B	RVUE	Electroweak
$177 \pm 9^{+16}_{-20}$	[29] GURTU	94	RVUE	Electroweak
$174^{+11}_{-13}{}^{+17}_{-18}$	[30] MONTAGNA	94	RVUE	Electroweak
$171 \pm 12^{+15}_{-21}$	[31] NOVIKOV	94B	RVUE	Electroweak
160^{+50}_{-60}	[32] ALITTI	92B	UA2	m_W, m_Z

[21] ERLER 95 result is from fit with free m_t and $\alpha_s(m_Z)$, yielding $\alpha_s(m_Z) = 0.127(5)(2)$.

[22] MATSUMOTO 95 result is from fit with free m_t to Z parameters, M_W, and low-energy neutral-current data. The second error is for $m_H = 300^{+700}_{-240}$ GeV, the third error is for $\alpha_s(m_Z) = 0.116 \pm 0.005$, the fourth error is for $\delta\alpha_{\text{had}} = 0.0283 \pm 0.0007$.

[23] ABREU 94 value is for $\alpha_s(m_Z)$ constrained to 0.123 ± 0.005. The second error corresponds to $m_H = 300^{+700}_{-240}$ GeV.

[24] ACCIARRI 94 value is for $\alpha_s(m_Z)$ constrained to 0.124 ± 0.006. The second error corresponds to $m_H = 300^{+700}_{-240}$ GeV.

[25] AKERS 94 result is from fit with free α_s. The second error corresponds to m_H=300^{+700}_{-240} GeV. The 95%CL limit is m_t <210 GeV.

[26] ARROYO 94 measures the ratio of the neutral-current and charged-current deep inelastic scattering of ν_μ on an iron target. By assuming the SM electroweak correction, they obtain $1-m^2_W/m^2_Z = 0.2218 \pm 0.0059$, yielding the quoted m_t value. The second error corresponds to $m_H = 300^{+700}_{-240}$ GeV.

[27] BUSKULIC 94 result is from fit with free α_s. The second error is from m_H=300^{+700}_{-240} GeV.

[28] ELLIS 94B result is fit to electroweak data available in spring 1994, including the 1994 A_{LR} data from SLD. m_t and m_H are two free parameters of the fit for $\alpha_s(m_Z) = 0.118 \pm 0.007$ yielding m_t above, and $m_H = 35^{+70}_{-22}$ GeV. ELLIS 94B also give results for fits including constraints from CDF's direct measurement of m_t and CDF's and DØ 's production cross-section measurements. Fits excluding the A_{LR} data from SLD are also given.

[29] GURTU 94 result is from fit with free m_t and $\alpha_s(m_Z)$, yielding m_t above and $\alpha_s(m_Z) = 0.125 \pm 0.005^{+0.003}_{-0.001}$. The second errors correspond to $m_H = 300^{+700}_{-240}$ GeV. Uses LEP, M_W, νN, and SLD electroweak data available in spring 1994.

[30] MONTAGNA 94 result is from fit with free m_t and $\alpha_s(m_Z)$, yielding m_t above and $\alpha_s(m_Z) = 0.124$. The second errors correspond to $m_H = 300^{+700}_{-240}$ GeV. Errors in $\alpha(m_Z)$ and m_b are taken into account in the fit. Uses LEP, SLC, and M_W/M_Z data available in spring 1994.

[31] NOVIKOV 94B result is from fit with free m_t and $\alpha_s(m_Z)$, yielding m_t above and $\alpha_s(m_Z) = 0.125 \pm 0.005 \pm 0.002$. The second errors correspond to $m_H = 300^{+700}_{-240}$ GeV. Uses LEP and CDF electroweak data available in spring 1994.

[32] ALITTI 92B assume m_H = 100 GeV. The 95%CL limit is m_t < 250 GeV for m_H < 1 TeV.

MASS LIMITS for t Quark or Hadron Independent of t Decay Mode

These limits are derived from $\Gamma(W)$ values shown in the W width section. Independent of the top decay mode, any W decay to $t\overline{b}$ would increase the total width of the W boson. Since the discovery of top, this section is of historical interest only.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>62	95	[33] ABE	95W	CDF	$E_{\rm cm}^{p\overline{p}}$= 1800 GeV
>62	95	[34] ABE	94B	CDF	$E_{\rm cm}^{p\overline{p}}$= 1800 GeV
>45	95	[35] ABE	92I	CDF	$E_{\rm cm}^{p\overline{p}}$= 1800 GeV
>53	95	[36] ALITTI	92	UA2	$E_{\rm cm}^{p\overline{p}}$= 630 GeV
>55	95	[37] ALITTI	92	RVUE	
>43	95	[38] ABE	91C	CDF	$E_{\rm cm}^{p\overline{p}}$= 1800 GeV
>38	90	[39] ALBAJAR	91	UA1	$E_{\rm cm}^{p\overline{p}}$= 630 GeV
>51	90	[40] ALBAJAR	91	RVUE	$\Gamma(W)$

[33] ABE 95W result is from $\Gamma(W \rightarrow e\nu_e)/\Gamma(W) = 0.1094 \pm 0.0033(\text{stat}) \pm 0.0031(\text{syst.})$. In addition they obtain $\Gamma(W) = 2.064 \pm 0.060(\text{stat}) \pm 0.059(\text{syst.})$.

[34] ABE 94B result is from $\Gamma(W) = 2.063 \pm 0.061 \pm 0.060$ GeV. Superseded by ABE 95W.

[35] ABE 92I data include both e and μ final states. The result is derived from $\Gamma(W)$=2.16 ± 0.17 GeV. At 90%CL, the limit is >49 GeV.

[36] ALITTI 92 result is derived from $\Gamma(W) = 2.10 \pm 0.16$ GeV.

[37] Limit is from combined data of ALBAJAR 91, ALITTI 92, and ABE 90: $\Gamma(W) = 2.15 \pm 0.11$ GeV.

[38] ABE 91C result is derived from $\Gamma(W) = 2.12 \pm 0.20$ GeV. At 90%CL, the limit is > 48 GeV.

[39] ALBAJAR 91 result is derived from $\Gamma(W) = 2.18^{+0.26}_{-0.24} \pm 0.04$ GeV.

[40] Limit is from combined data of ALBAJAR 91, ALITTI 90C, and ABE 90.

MASS LIMITS for Top Hadrons in e^+e^- Collisions

The last column specifies measured quantities: S = Sphericity, T = Thrust.

For limits prior to 1987, see our 1990 edition, Physics Letters **B239**, p. VII.167 (1990). Since the discovery of top, this section is of historical interest only.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[41] ADRIANI	93G	L3	Quarkonium
>41.8	95	ADRIANI	93M	L3	$\Gamma(Z)$
>43	95	[42] ABREU	91F	DLPH	$\Gamma(Z)$
>30.2	95	ABE	90D	VNS	Event shape
>44.5	95	[42] ABREU	90D	DLPH	Event shape
>44.0	95	[42,43] ABREU	90D	DLPH	$t \rightarrow bH^+$, $H^+ \rightarrow c\overline{s}$, $\tau^+\nu$
>33.5	95	[44] ABREU	90D	DLPH	$\Gamma(Z \rightarrow \text{hadrons})$
>44.5	95	[45] AKRAWY	90B	OPAL	Acoplanarity
>44.3	95	[46] AKRAWY	90B	OPAL	$t \rightarrow bH^+$, $H^+ \rightarrow c\overline{s}$, $\tau\nu$
>45.8	95	[42] DECAMP	90F	ALEP	isolated charged particle and aplanarity
>40.7	95	[47] ABRAMS	89C	MRK2	Event shape
>42.5	95	ABRAMS	89C	MRK2	$t \rightarrow bH^+$, $H^+ \rightarrow c\overline{s}$
>29.9	95	[48] ADACHI	89C	TOPZ	μ
>29.9	95	[49] ENO	89	AMY	μ, e
>25.8	95	[50] ADACHI	88	TOPZ	R, T, Acoplanarity
>25.9	95	[51] IGARASHI	88	AMY	T + (μ,e)
>25.9	95	[52] SAGAWA	88	AMY	R, T
none $E_{\rm cm}$=50	95	[53] ABE	87	VNS	R, T, Acoplanarity
>25.5	95	[54] YOSHIDA	87	VNS	R, T, Acoplanarity

[41] ADRIANI 93G search for vector quarkonium states near Z and give limit on quarkonium-Z mixing parameter δm^2 <(10–30) GeV^2 (95%CL) for the mass 88–94.5 GeV. Using Richardson potential, a 1S toponium state is excluded for the mass range 87.9–88.7, 89.1–94.3 GeV. This range is very sensitive to the potential choice.

[42] Search was near the Z peak at LEP.

[43] Assumed $m_{H^+} < m_t - 6$ GeV.

[44] Superseded by ABREU 91F.

[45] AKRAWY 90B search was restricted to data near the Z peak at $E_{\rm cm}$ = 91.26 GeV at LEP. The excluded region is between 23.4 and 44.5 GeV if no H^+ decays exist.

[46] AKRAWY 90B limit applies for any H^+ branching ratio B($c\overline{s}$). Limit increases to 45.2 GeV if B($c\overline{s}$) = 1. The lower end of the excluded region is m_{H^+} + 5 GeV.

[47] The ABRAMS 89C limit from an isolated track search is 40.0 GeV.

[48] ADACHI 89C search was at $E_{\rm cm}$ = 56.5–60.8 GeV at TRISTAN using multi-hadron events accompanying muons.

[49] ENO 89 search at $E_{\rm cm}$ = 50–60.8 GeV at TRISTAN.

[50] ADACHI 88 set limit σ(top) < 8.2 pb at CL=95% for top-flavored-hadron production from event shape analyses at $E_{\rm cm}$ = 52 GeV. By using the quark-parton model cross-section formula with first-order QCD corrections near the threshold, the above limit leads to a lower mass limit of 25.8 GeV at 95% confidence level for top quarks.

[51] IGARASHI 88 searches for leptons in low-thrust events and gives $\Delta R(t) <$ 0.15 (95% CL) at $E_{\rm cm}$ = 50–52 GeV.

[52] SAGAWA 88 set limit σ(top) < 6.1 pb at CL=95% for top-flavored hadron production from event shape analyses at $E_{\rm cm}$ = 52 GeV. By using the quark parton model cross-section formula near threshold, the above limit leads to lower mass bounds of 25.9 GeV for charge 2/3 quarks.

[53] ABE 87 set limit σ(top) < 16 pb at CL=95% for top-flavored hadron production, which should be compared with the full top-quark production cross section of 45.9 pb.

[54] YOSHIDA 87 set limit σ(top) < 17 pb at CL=95% for top-flavored hadron production from event shape analyses at $E_{\rm cm}$ = 52 GeV. This limit should be compared with the full top-quark production cross section of 34 pb, which takes into account the effect of weak neutral current but neglects its axial-vector coupling contribution expected to be suppressed near threshold. After considering the radiative effects, top quarks of mass below 25.5 GeV can be excluded by the above limit.

t-Quark REFERENCES

ABACHI	95	PRL 74 2632	+Abbott, Abolins, Acharya, Adam+	(D0 Collab.)
ABACHI	95B	PRL 74 2422	+Abbott, Abolins, Acharya, Adam, Adams+	(D0 Collab.)
ABACHI	95F	PR D52 4877	+Abbott, Abolins, Acharya, Adam, Adams+	(D0 Collab.)
ABE	95F	PRL 74 2626	+Akimoto, Akopian, Albrow, Amendolia+	(CDF Collab.)
ABE	95O	PR D51 4623	+Albrow, Amendolia, Amidei, Antos+	(CDF Collab.)
ABE	95V	PR D52 R2605	+Akimoto, Akopian, Albrow, Amendolia+	(CDF Collab.)
ABE	95W	PR D52 2624	+Albrow, Amendolia, Amidei, Antos+	(CDF Collab.)
ABE,F	95	PRL 75 3997	Abe, Akimoto, Akopian, Albrow, Amendolia+	(CDF Collab.)
ERLER	95	PR D52 441	+Langacker	(PENN)
MATSUMOTO	95	MPL A10 2553		(KEK)
ABACHI	94	PRL 72 2138	+Abbott, Abolins, Acharya, Adam+	(D0 Collab.)
ABE	94B	PRL 73 220	+Albrow, Amidei, Anway-Wiese+	(CDF Collab.)
ABE	94E	PR D50 2966	+Albrow, Amendolia, Amidei, Antos+	(CDF Collab.)
Also	94F	PRL 73 225	Abe, Albrow, Amidei, Antos, Anway-Weise+	(CDF Collab.)
ABE	94H	PRL 72 1977	+Albrow, Amidei, Anway-Wiese, Apollinari+	(CDF Collab.)
ABE	94I	PRL 73 2667	+Albrow, Amidei, Antos, Anway-Wiese+	(CDF Collab.)
ABREU	94	NP B418 403	+Adam, Adye, Agasi+	(DELPHI Collab.)
ACCIARRI	94	ZPHY C62 551	+Adam, Adriani, Aguilar-Benitez+	(L3 Collab.)
AKERS	94	ZPHY C61 19	+Alexander, Allison+	(OPAL Collab.)
ARROYO	94	PRL 72 3452	+King, Bachman+	(COLU, CHIC, FNAL, ROCH, WISC)
BUSKULIC	94	ZPHY C62 539	+Casper, De Bonis, Decamp, Ghez, Goy+	(ALEPH Collab.)
ELLIS	94B	PL B333 118	+Fogli, Lisi	(CERN, BARI)
GURTU	94	MPL A9 3301		(TATA)
LAENEN	94	PL B321 254	+Smith, van Neerven	(FNAL, UTRE, LEID)
MONTAGNA	94	PL B335 484	+Nicrosini, Passarino, Piccinini	(INFN, PAVI, CERN, TORI)
NOVIKOV	94B	MPL A9 2641	+Okun, Rozanov, Vysotsky	(GUEL, CERN, ITEP)
PDG	94	PR D50 1173	Montanet+	(CERN, LBL, BOST, IFIC+)
ADRIANI	93G	PL B313 326	+Aguilar-Benitez, Ahlen, Alcaraz, Aloisio+	(L3 Collab.)
ADRIANI	93M	PRPL 236 1	+Aguilar-Benitez, Ahlen, Alcaraz, Aloisio+	(L3 Collab.)
ABE	92	PRL 68 447	+Amidei, Apollinari, Atac, Auchincloss+	(CDF Collab.)
Also	92G	PR D45 3921	Abe, Amidei, Apollinari, Atac, Auchincloss+	(CDF Collab.)
ABE	92I	PRL 69 28	+Amidei, Apollinari, Atac, Auchincloss+	(CDF Collab.)
ALITTI	92	PL B276 365	+Ambrosini, Ansari, Autiero, Bareyre+	(UA2 Collab.)
ALITTI	92B	PL B276 354	+Ambrosini, Ansari, Autiero, Bareyre+	(UA2 Collab.)
ALITTI	92F	PL B280 137	+Ambrosini, Ansari, Autiero, Bareyre+	(UA2 Collab.)
ABE	91	PR D43 664	+Amidei, Apollinari, Atac, Auchincloss+	(CDF Collab.)
ABE	91C	PR D44 29	+Amidei, Apollinari, Atac, Auchincloss+	(CDF Collab.)
ABREU	91F	NP B367 511	+Adam, Adami, Adye, Akesson+	(DELPHI Collab.)
ALBAJAR	91	PL B253 503	+Albrow, Allkofer, Ankoviak, Apsimon+	(UA1 Collab.)
ALBAJAR	91B	PL B257 459	+Albrow, Allkofer, Ankoviak, Apsimon+	(UA1 Collab.)
BAER	91B	PR D44 725	+Drees, Godbole+	(FSU, DESY, BOMB, UCD, HAWA)
ABE	90	PRL 64 152	+Amidei, Apollinari, Atac, Auchincloss+	(CDF Collab.)
ABE	90B	PRL 64 147	+Amidei, Apollinari, Atac, Auchincloss+	(CDF Collab.)
ABE	90C	PRL 64 142	+Amidei, Apollinari, Atac+	(CDF Collab.)
Also	91	PR D43 664	Abe, Amidei, Apollinari, Atac, Auchincloss+	(CDF Collab.)
ABE	90D	PL B234 382	+Amako, Arai, Asano+	(VENUS Collab.)
ABREU	90D	PL B242 536	+Adam, Adami, Adye, Alekseev, Allaby+	(DELPHI Collab.)
AKESSON	90	ZPHY C46 179	+Alitti, Ansari, Ansorge, Bagnaia+	(UA2 Collab.)
AKRAWY	90B	PL B236 364	+Alexander, Allison, Allport, Anderson+	(OPAL Collab.)
ALBAJAR	90B	ZPHY C48 1	+Albrow, Allkofer, Andrieu, Ankoviak+	(UA1 Collab.)

ALITTI	90C	ZPHY C47 11	+Ansari, Ansorge, Bagnaia+	(UA2 Collab.)
BARGER	90E	PR D41 3421	+Hewett, Phillips	(WISC, RAL)
DECAMP	90F	PL B236 511	+Deschizeaux, Lees, Minard+	(ALEPH Collab.)
ABRAMS	89C	PRL 63 2447	+Adolphsen, Averill, Ballam+	(Mark II Collab.)
ADACHI	89C	PL B229 427	+Aihara, Doser, Enomoto, Fujii+	(TOPAZ Collab.)
ENO	89	PRL 63 1910	+Auchincloss, Blanis, Bodek, Budd+	(AMY Collab.)
ADACHI	88	PRL 60 97	+Aihara, Dijkstra+	(TOPAZ Collab.)
ALBAJAR	88	ZPHY C37 505	+Albrow, Allkofer+	(UA1 Collab.)
ALTARELLI	88	NP B308 724	+Diemoz, Martinelli, Nason	(CERN, ROMA, ETH)
IGARASHI	88	PRL 60 2359	+Myung, Chiba, Hanaoka+	(AMY Collab.)
SAGAWA	88	PRL 60 93	+Mori, Abe+	(AMY Collab.)
ABE	87	JPSJ 56 3763	+Amako, Arai+	(VENUS Collab.)
YOSHIDA	87	PL B198 570	+Chiba, Endo+	(VENUS Collab.)