# $t$

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

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

A REVIEW GOES HERE – Check our WWW List of Reviews

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

The $t$ quark has been observed. Its mass is sufficiently high that decay is expected to occur before hadronization. OUR EVALUATION is an AVERAGE which incorporates correlations between systematic errors of the five different measurements. The average was done by a joint CDF/DØ working group and is reported in DEMORTIER 99, an FNAL Technical Memo. They report 174.3 ± 3.2 ± 4.0 GeV, which yields "OUR EVALUATION" when statistical and systematic errors are combined.

For earlier search limits see the *Review of Particle Physics*, Phys. Rev. **D54**,1 (1996).

| *VALUE* (GeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **174.3± 5.1 OUR EVALUATION** | | | | |
| 167.4±10.3± 4.8 | [1] ABE | 99B | CDF | dilepton |
| 168.4±12.3± 3.6 | [2] ABBOTT | 98D | D0 | dilepton |
| 173.3± 5.6± 5.5 | [2] ABBOTT | 98F | D0 | lepton + jets |
| 175.9± 4.8± 5.3 | [1,3] ABE | 98E | CDF | lepton + jets |
| 186 ±10 ± 5.7 | [1,4] ABE | 97R | CDF | 6 or more jets |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| 176.0± 6.5 | [5] ABE | 99B | CDF | dilepton, lepton+jets, and all jets |
| 161 ±17 ±10 | [1] ABE | 98F | CDF | dilepton |
| 172.1± 5.2± 4.9 | [6] BHAT | 98B | RVUE | dilepton and lepton+jets |
| 173.8± 5.0 | [7] BHAT | 98B | RVUE | dilepton, lepton+jets, and all jets |
| 173.3± 5.6± 6.2 | [2] ABACHI | 97E | D0 | lepton + jets |
| 199 $^{+19}_{-21}$ ±22 | ABACHI | 95 | D0 | lepton + jets |
| 176 ± 8 ±10 | ABE | 95F | CDF | lepton + $b$-jet |
| 174 ±10 $^{+13}_{-12}$ | ABE | 94E | CDF | lepton + $b$-jet |

[1] Result is based on 109 ± 7 $pb^{-1}$ of data at $\sqrt{s} = 1.8$ TeV.

[2] Result is based on 125 $pb^{-1}$ of data at $\sqrt{s} = 1.8$ TeV.

[3] The updated systematic error is listed. See ABE 99B.

[4] ABE 97R result is based on the first observation of all hadronic decays of $t\overline{t}$ pairs. Single $b$-quark tagging with jet-shape variable constraints was used to select signal enriched multi-jet events. The updated systematic error is listed. See ABE 99B.

[5] ABE 99B result is obtained by combining the CDF results of $m_t$ (GeV)=167.4±10.3±4.8 from 8 dilepton events, $m_t$ (GeV)=175.9 ± 4.8 ± 5.3 from lepton+jet events (ABE 98E), and $m_t$ (GeV)=186.0 ± 10.0 ± 5.7 from all-jet events (ABE 97R). The systematic errors in the latter two measurements are changed in this paper.

[6] BHAT 98B result is obtained by combining the DØ results of $m_t$(GeV)=168.4 ± 12.3 ± 3.6 from 6 dilepton events and $m_t$(GeV)=173.3 ± 5.6 ± 5.5 from 77 lepton+jet events.

[7] BHAT 98B result is obtained by combining the DØ results from dilepton and lepton+jet events, and the CDF results (ABE 99B) from dilepton, lepton+jet events, and all-jet events.

## *t*-Quark Decay Branching Fractions

| *VALUE* | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| $<0.33$ | 95 | [8] ABE | 98G | CDF | $t \to q Z$ ($q$=$u$,$c$) |
| $<0.032$ | 95 | [9] ABE | 98G | CDF | $t \to q \gamma$ ($q$=$u$,$c$) |
| $0.99 \pm 0.29$ | | [10] CHIARELLI | 98 | RVUE | $t \to b W$ |
| | | [11] ABE | 97V | CDF | $\ell\tau$ + jets |

[8] ABE 98G looked for $t\bar{t}$ events where one $t$ decays into three jets and the other decays into $qZ$ with $Z \to \ell\ell$.

[9] ABE 98G looked for $t\bar{t}$ events where one $t$ decays into $q\gamma$ while the other decays into $bW$.

[10] CHIARELLI 98 measurement of B($t \to bW$) assumes that non-$W$ decays of the top quark are negligible. The corresponding 95%CL lower bounds are B$> 0.58$ and $|V_{tb}| > 0.76$ in the three-generation model assuming unitarity.

[11] ABE 97V searched for $t\bar{t} \to (\ell\nu_\ell)(\tau\nu_\tau)b\bar{b}$ events in 109 pb$^{-1}$ of $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. They observed 4 candidate events where one expects $\sim 1$ signal and $\sim 2$ background events. Three of the four observed events have jets identified as $b$ candidates.

## Indirect *t*-Quark Mass from Standard Model Electroweak Fit

"OUR EVALUATION" below is from the fit to electroweak data described in the "Electroweak Model and Constraints on New Physics" section of this Review. This fit result does not include direct measurements of $m_t$. The central value and first uncertainty are for $M_H = M_Z$. The second uncertainty is the shift from changing $M_H$ to 300 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* |
|---|---|---|---|---|
| **170 ± 7 (+14) OUR EVALUATION** | | | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| $172.0^{+5.8}_{-5.7}$ | [12] DEBOER | 97B | RVUE | Electroweak + Direct |
| $157^{+16}_{-12}$ | [13] ELLIS | 96C | RVUE | $Z$ parameters, $m_W$, low energy |
| $175 \pm 11^{+17}_{-19}$ | [14] ERLER | 95 | RVUE | $Z$ parameters, $m_W$, low energy |
| $180 \pm 9^{+19}_{-21} \mp 2.6 \pm 4.8$ | [15] MATSUMOTO | 95 | RVUE | |
| $157^{+36}_{-48}{}^{+19}_{-20}$ | [16] ABREU | 94 | DLPH | $Z$ parameters |
| $158^{+32}_{-40} \pm 19$ | [17] ACCIARRI | 94 | L3 | $Z$ parameters |
| $132^{+41}_{-48}{}^{+24}_{-18}$ | [18] AKERS | 94 | OPAL | $Z$ parameters |

| | | | | | | |
|---|---|---|---|---|---|---|
| 190 | $^{+39}_{-48}$ | $^{+12}_{-14}$ | [19] ARROYO | 94 | CCFR | $\nu_\mu$ iron scattering |
| 184 | $^{+25}_{-29}$ | $^{+17}_{-18}$ | [20] BUSKULIC | 94 | ALEP | $Z$ parameters |
| 153 | $\pm 15$ | | [21] ELLIS | 94B | RVUE | Electroweak |
| 177 | $\pm$ 9 | $^{+16}_{-20}$ | [22] GURTU | 94 | RVUE | Electroweak |
| 174 | $^{+11}_{-13}$ | $^{+17}_{-18}$ | [23] MONTAGNA | 94 | RVUE | Electroweak |
| 171 | $\pm 12$ | $^{+15}_{-21}$ | [24] NOVIKOV | 94B | RVUE | Electroweak |
| 160 | $^{+50}_{-60}$ | | [25] ALITTI | 92B | UA2 | $m_W$, $m_Z$ |

[12] DEBOER 97B result is from the five-parameter fit which varies $m_Z$, $m_t$, $m_H$, $\alpha_s$, and $\alpha(m_Z)$ under the contraints: $m_t$=175 $\pm$ 6 GeV, $1/\alpha(m_Z)$=128.896 $\pm$ 0.09. They found $m_H$=141$^{+140}_{-77}$ GeV and $\alpha_s(m_Z)$=0.1197 $\pm$ 0.0031.

[13] ELLIS 96C result is a the two-parameter fit with free $m_t$ and $m_H$, yielding also $m_H$=65$^{+117}_{-37}$ GeV.

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

[15] 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 $\delta\alpha_{\rm had} = 0.0283 \pm 0.0007$.

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

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

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

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

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

[21] 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.

[22] 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, $M_W$, $\nu N$, and SLD electroweak data available in spring 1994.

[23] 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.

[24] 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.

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

## *t*-Quark REFERENCES


| | | | | |
|---|---|---|---|---|
| ABE | 99B | PRL 82 271 | F. Abe+ | (CDF Collab.) |
| Also | 99G | PRL 82 2808 (erratum) | F. Abe+ | (CDF Collab.) |
| DEMORTIER | 99 | FNAL-TM-2084 | L. Demortier+ | (CDF/D0 Working Group) |
| (In preparation, May 1999) | | | | |
| ABBOTT | 98D | PRL 80 2063 | B. Abbott+ | (D0 Collab.) |
| ABBOTT | 98F | PR D58 052001 | B. Abbott+ | (D0 Collab.) |
| ABE | 98E | PRL 80 2767 | F. Abe+ | (CDF Collab.) |
| ABE | 98F | PRL 80 2779 | F. Abe+ | (CDF Collab.) |
| ABE | 98G | PRL 80 2525 | F. Abe+ | (CDF Collab.) |
| BHAT | 98B | IJMP A13 5113 | P.C. Bhat, H.B. Prosper, S.S. Snyder | |
| CHIARELLI | 98 | IJMP A13 2883 | G. Chiarelli | |
| ABACHI | 97E | PRL 79 1197 | S. Abachi+ | (D0 Collab.) |
| ABE | 97R | PRL 79 1992 | F. Abe+ | (CDF Collab.) |
| ABE | 97V | PRL 79 3585 | F. Abe+ | (CDF Collab.) |
| DEBOER | 97B | ZPHY C75 627 | W. de Boer, A. Dabelstein, W. Hollik+ | |
| ELLIS | 96C | PL B389 321 | +Fogli, Lisi | (CERN, BARI) |
| ABACHI | 95 | PRL 74 2632 | +Abbott, Abolins, Acharya, Adam+ | (D0 Collab.) |
| ABE | 95F | PRL 74 2626 | +Akimoto, Akopian, Albrow, Amendolia+ | (CDF Collab.) |
| ERLER | 95 | PR D52 441 | +Langacker | (PENN) |
| MATSUMOTO | 95 | MPL A10 2553 | | (KEK) |
| ABE | 94E | PR D50 2966 | +Albrow, Amendolia, Amidei, Antos+ | (CDF Collab.) |
| Also | 94F | PRL 73 225 | Abe, Albrow, Amidei, Antos, Anway-Weise+ | (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) |
| 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+) | |
| ALITTI | 92B | PL B276 354 | +Ambrosini, Ansari, Autiero, Bareyre+ | (UA2 Collab.) |