# t

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

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

## THE TOP QUARK

Revised April 1998 by M. Mangano (CERN) and T. Trippe (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). This note collects a summary of its currently measured properties, in addition to a discussion of the experimental and theoretical issues involved in the determination of its parameters (mass, production cross section, decay branching ratios, *etc.*) and some comments on of the prospects for future improvements.

***B. Top quark production at the Tevatron:*** At the Tevatron energy, 1.8 TeV, top quarks are dominantly produced in pairs from pure QCD processes: $q\overline{q} \to t\overline{t}$ and $gg \to t\overline{t}$. The production cross section through these channels is expected to be approximately 5 pb at $m_t = 175$ GeV/c$^2$, with a dominant 90% contribution from the $q\overline{q}$ annihilation process. Smaller contributions come from the single-top production mechanisms, namely $q\overline{q}' \to W^* \to t\overline{b}$ and $qg \to q' t\overline{b}$, this last mediated by a $t$-channel virtual-$W$ exchange. The combined rate from these processes is approximately 2.5 pb at $m_t = 175$ GeV (see Ref. 1 and references therein). The actual contribution of these channels to the detected final states is further reduced relative to the dominant pair-production mechanisms, due to the lower experimental acceptances.

With a mass above the $Wb$ threshold, the top quark decay width is dominated by the two-body decay $t \to Wb$. Neglecting terms of order $m_b^2/m_t^2$ and of order $(\alpha_s/\pi)m_W^2/m_t^2$, this is predicted in the Standard Model to be [2]:

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

The use of $G_F$ in this equation accounts for the largest part of the one-loop electroweak radiative corrections, providing an expression accurate to better than 2%. The width values increase with mass, going for example from 1.02 GeV at $m_t =$ 160 GeV to 1.56 GeV at $m_t =$ 180 GeV (we used $\alpha_S(\mathrm{M_Z}) =$ 0.118). With such a correspondingly short lifetime, the top quark is expected to decay before top-flavored hadrons or $t\bar{t}$-quarkonium bound states can form.

In top decay, the $Ws$ and $Wd$ final states are expected to be suppressed relative 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 0.042 and 0.013, respectively (see our review "The Cabibbo-Kobayashi-Maskawa Mixing Matrix" in the current edition for more information).

Typical final states for the leading pair-production process therefore belong to three classes:

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

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

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

where A, B, and C are referred to as the all-jets, lepton + jets, and dilepton channels, respectively.

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 observation of $t\bar{t}$ pairs has been reported in all of the above decay modes. As discussed in detail below, the top quark production and decay properties extracted from the three different decay channels above are all consistent with each other, within the present experimental sensitivity. In particular, the $t \to Wb$ decay mode has been confirmed by the reconstruction of the $W \to jj$ invariant mass in the $\ell\overline{\nu}_\ell b\bar{b}jj$ final state [3].

The extraction of the top-quark properties from the Tevatron data requires a good understanding of the production and decay mechanisms of the top itself, as well as of the large background processes. 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 is required to provide a reliable check on the background estimates.

***C. Measured top properties:*** All direct measurements of top quark production and decay have been made by the CDF and DØ experiments at the Fermilab Tevatron collider in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV. Since the first direct experimental evidence for the top quark in 1994 [4] by CDF (a 2.8 $\sigma$ effect. See this review in our 1996 edition [5] for more details) and the conclusive observation by both CDF and DØ in 1995 [6,7], the integrated luminosity has increased to 109 pb$^{-1}$ for CDF and 125 pb$^{-1}$ for DØ, allowing significant improvements in the measurement of the top production cross section, mass, and decay properties.

DØ and CDF determine the $t\overline{t}$ cross section $\sigma_{t\overline{t}}$ from their numbers of top candidates, their estimated background, their $t\overline{t}$ acceptance, and their integrated luminosity, assuming Standard Model decays $t \to Wb$ with unity branching ratio. Table 1 shows the measured cross sections from DØ and CDF along with the range of theoretical expectations, evaluated at the $m_t$ values used by the experiments in calculating their acceptances. There is fairly good agreement between the experiments and the theoretical expectations, although the CDF values are somewhat higher than the theory values. This agreement supports the hypothesis that the excess of events over background in all of these channels is due to $t\overline{t}$ production. A joint CDF/DØ working group is expected to produce a combined cross section for the two experiments in the near future.

Future precise determinations of the top production cross section will test the current theoretical understanding of the production mechanisms [8–11]. 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.

**Table 1:** Cross section for $t\bar{t}$ production in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV from DØ ($m_t = 173.3$ GeV/c$^2$), CDF ($m_t = 175$ GeV/c$^2$), and theory.

| $t\bar{t}$ cross section | Source | Ref. | Method |
|---|---|---|---|
| $4.1 \pm 2.0$ pb | DØ | [12] | lepton + jets |
| $8.2 \pm 3.5$ pb | DØ | [12] | lepton + jets/$\mu$ |
| $6.3 \pm 3.3$ pb | DØ | [12] | dileptons + $e\nu$ |
| $5.5 \pm 1.8$ pb | DØ | [12] | Ref. 12 combined |
| $5.0 - 5.8$ pb | Theory | [8–11] | at $m_t = 173.3$ GeV/c$^2$ |
| $6.7^{+2.0}_{-1.7}$ pb | CDF | [13] | lepton + jet |
| $8.2^{+4.4}_{-3.4}$ pb | CDF | [14] | dileptons |
| $10.1^{+4.5}_{-3.6}$ pb | CDF | [15] | all jets |
| $7.6^{+1.8}_{-1.5}$ pb | CDF | [13] | Refs. 13–15 combined |
| $4.75 - 5.5$ pb | Theory | [8–11] | at $m_t = 175$ GeV/c$^2$ |

The top mass has been measured in the lepton + jets and dilepton channels by both DØ and CDF, and in the all-jets channel by CDF. At present, the most precise measurements come from the lepton + jets channel with four or more jets and large missing $E_T$. In this channel, each event is 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 are the $t\overline{t}$ daughters. The shape of the distribution of fitted top masses from these events is compared to templates expected from a mixture of background and signal distributions for a series of assumed top masses. This comparison yields values of the likelihood as a function of top mass, from which a best value of the top mass and its error are obtained. The results are shown in Table 2. The systematic error, the second error shown, is comparable to the statistical error and is primarily due to uncertainties in the jet energy scale and the Monte Carlo modeling.

Less precise determinations of the top mass come from the dilepton channel with two or more jets and large missing $E_T$, and from the all-jets channel. In the dilepton channel a kinematically constrained fit is not possible because there are two missing neutrinos, so experiments must use other mass estimators than the reconstructed top mass. Any quantity which is correlated with top mass can be used as a mass estimator. DØ uses the fact that if $m_t$ is assumed, the $t\overline{t}$ system can be reconstructed (up to a four-fold ambiguity). They compare the resulting kinematic configurations to expectations from $t\overline{t}$ production and obtain a weight *vs* $m_t$ curve for each event, which they coarsely histogram to obtain four shape-sensitive quantities as their multidimensional mass estimator.

Their method yields a significant increase in precision over one-dimensional estimators. CDF does two analyses, one using the $b$ quark jet energy and the other using the $\ell\,b$-jet invariant mass. Both DØ and CDF obtain the top mass and error from these mass estimators using the same template likelihood method as for the lepton + jets channel. CDF also measures the mass in the all-jets channel using events with six or more jets, at least one of which is tagged as a $b$ jet by the presence of a secondary vertex.

**Table 2:** Top mass measurements from DØ and CDF.

| $m_t$ (GeV/c$^2$) | Source | Ref. | Method |
|---|---|---|---|
| $173.3 \pm 5.6 \pm 5.5$ | DØ | [16] | lepton + jets |
| $168.4 \pm 12.3 \pm 3.6$ | DØ | [17] | dileptons |
| $172.1 \pm 5.2 \pm 4.9$ | DØ | [16] | DØ combined |
| $175.9 \pm 4.8 \pm 4.9$ | CDF | [18] | lepton + jet |
| $161 \pm 17 \pm 10$ | CDF | [14] | dileptons |
| $186 \pm 10 \pm 12$ | CDF | [15] | all jets |
| $173.8 \pm 3.5 \pm 3.9$ * | PDG | | PDG Average |

* Average does not include CDF all jets. See text.

As seen in Table 2, all top mass results are in good agreement, giving further support to the hypothesis that these events are due to $t\bar{t}$ production. A joint CDF/DØ working group is expected to produce a combined CDF/DØ average top mass in the near future, taking into account correlations between the systematic errors in the different measurements. In the meantime, the PDG obtains an average top mass as follows.

Using DØ's approach to combining their own results [16], we assume a 100% correlation between the DØ lepton + jets and dilepton systematic errors for jet energy scale, signal model, and multiple interactions, and 0% correlation between their other systematic errors. CDF have not published their combined results, but we can include CDF results for lepton + jets [18] and dileptons [14] by assuming 100% correlation between the signal model errors in all four results and 100% correlation between the jet energy scale errors of the two CDF results. In addition, in a given channel, lepton + jets or dileptons, we assume a 100% correlation between systematic errors in the CDF and DØ background shapes. All other correlations are assumed to be zero. We do not include the CDF all jets channel because we do not know what correlation to assume for its signal model error. These assumptions yield a PDG average top mass of $m_t = 173.8 \pm 3.5 \pm 3.9$ GeV/$c^2$ = $173.8 \pm 5.2$ GeV/c$^2$.

Given the experimental technique used to extract the top mass, the top mass values 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 $t\overline{t}$ 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. 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 four and only four jets in the event, two of which are $b$ tagged jets and the other two of which are 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. 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 Standard Model 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.

Measurements of other properties of top decays are underway. CDF reports a direct measurement of the $t \to Wb$ branching ratio [19]. Their preliminary result, obtained by comparing the number of events with 0, 1 and 2 tagged $b$ jets and using the known tagging efficiency, is: $R = \mathrm{B}(t \to Wb)/\sum_{q=d,s,b}\mathrm{B}(t \to Wq) = 0.99 \pm 0.29$ where the error includes statistical and systematic uncertainties, or as a lower limit, $R > 0.58$ at 95% CL. Assuming that non-$W$ decays of top can be neglected, that only three generations exist, and assuming the unitarity of the CKM matrix, they extract a CKM matrix-element $|V_{tb}| = 0.99 \pm 0.15$ or $|V_{tb}| > 0.76$ at 95% CL. A more direct measurement of the $Wtb$ coupling constant will be possible when enough data have been 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. The cross-sections for these processes are proportional to $|V_{tb}|^2$, and no assumption on the number of families or the unitarity of the CKM matrix needs to be made to extract $|V_{tb}|$.

Both CDF and DØ are searching for non-Standard Model top decays, particularly those expected in supersymmetric models. CDF [20] has published a direct search for top decay to a charged Higgs and a $b$ quark followed by $H^+ \to \tau\nu_\tau$ with $\tau$ decaying to hadrons. This search focuses on large $\tan\beta$, the ratio of the vacuum expectation values for the two Higgs doublets. As $\tan\beta$ increases, the $t \to H^+b$ and $H^+ \to \tau\nu_\tau$ branching fractions are both expected to approach one, maximizing sensitivity to this mode. CDF sees no excess of events over the expected background, giving an exclusion region in the $m_{H^+}$ *vs* $\tan\beta$ plane (see their Fig. 3) which extends to $m_{H^+}$ values higher than existing LEP limits for $\tan\beta$ above 100, assuming $m_t = 175$ GeV/c$^2$ and $\sigma_{t\bar{t}} = 5.0$ pb.

DØ and CDF are looking for top disappearance via $t \to H^+b$, $H^+ \to \tau\nu$ or $c\overline{s}$. These charged Higgs decays would not be detected in the lepton + jets or dilepton cross section analyses as efficiently as $t \to W^{\pm}b$, primarily because of the absence of energetic isolated leptons in the Higgs decays. This would give rise to measured cross sections lower than the Standard Model prediction, assuming that non-Standard Model $t\overline{t}$ production is negligible. The $H^+$ is expected to decay to $\tau\nu$ at high $\tan\beta$ and to $c\overline{s}$ or $Wb\overline{b}$ at low $\tan\beta$. The $\tau\nu$ and $c\overline{s}$ modes lead to disagreement with the observed cross section and thus to exclusion regions at both low and high $\tan\beta$. At high $\tan\beta$ these experiments can potentially probe $m_{H^+}$ up to the top decay kinematic limit, while at low $\tan\beta$ the $m_{H^+}$ reach is expected to be weakened to perhaps 140 GeV. This is because at higher $m_{H^+}$ and low $\tan\beta$ the $H^+ \rightarrow Wb\overline{b}$ decay mode dominates [21] and cannot easily be distinguished from Standard Model top decay.

Searches for other possible new particles such as a supersymmetric scalar top quark ($\tilde{t}$) via $t \rightarrow \tilde{t}\,\widetilde{\chi}^0$, are under way both at CDF and DØ.

CDF reports a search for flavor changing neutral current (FCNC) decays of the top quark $t \rightarrow q\gamma$ and $t \rightarrow qZ$ [22], for which the Standard Model predicts such small rates that their observation here would indicate new physics. They assume that one top decays via FCNC while the other decays via $Wb$. For the $t \rightarrow q\gamma$ search, they search for two signatures, depending on whether the $W$ decays leptonically or hadronically. For leptonic $W$ decay, the signature is $\gamma\ell$ plus missing $E_T$ and two or more jets, while for hadronic $W$ decay, it is $\gamma$ plus four or more jets, one with a secondary vertex b tag. They observe one event ($\mu\gamma$) with an expected background of less than half an event, giving an upper limit on the top branching ratio of B($t \rightarrow q\gamma$) $< 3.2\%$ at 95% CL.

For the $t \rightarrow qZ$ FCNC search, they look for $Z \rightarrow \mu\mu$ or $ee$ and $W \rightarrow$ hadrons, giving a $Z$ plus four jet signature. They observe one $\mu\mu$ event with an expected background of 1.2 events, giving an upper limit on the top branching ratio of B($t \rightarrow qZ$) $< 33\%$ at 95% CL. Both the $\gamma$ and $Z$ limits are non-background subtracted (i.e. conservative) estimates.

Studies of the decay angular distributions are also in progress using the current data sets. They 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 Standard Model, the fraction of decays to transversely polarized $W$ bosons is expected to be $1/(1 + m_t^2/2M_W^2)$ (30% for $m_t = 175$ GeV. Deviations from this value would challenge the Higgs mechanism of spontaneous symmetry breaking.

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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. OUR EVALUATION is an AVERAGE which incorporates correlations as described in the note "The Top Quark"' above.

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

| *VALUE* (GeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **173.8± 5.2 OUR EVALUATION** | | | | |
| 168.4±12.3± 3.6 | [1] ABBOTT | 98D | D0 | $\ell\ell$ + jets |
| 173.3± 5.6± 5.5 | [1] ABBOTT | 98F | D0 | $\ell$ + jets |
| 175.9± 4.8± 4.9 | [2] ABE | 98E | CDF | $\ell$ + jets |
| 161 ±17 ±10 | [2] ABE | 98F | CDF | $\ell\ell$ + jets |

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

| | | | |
|---|---|---|---|
| 173.3 ± 5.6 ± 6.2 | [1] ABACHI | 97E D0 | $\ell$ + jets |
| 186 ± 10 ± 12 | [2,3] ABE | 97R CDF | 6 or more jets |
| 199 $^{+19}_{-21}$ ± 22 | ABACHI | 95 D0 | $\ell$ + jets |
| 176 ± 8 ± 10 | ABE | 95F CDF | $\ell$ + $b$-jet |
| 174 ± 10 $^{+13}_{-12}$ | ABE | 94E CDF | $\ell$ + $b$-jet |

[1] Result is based on 125 $\mathrm{pb}^{-1}$ of data at $\sqrt{s}$ = 1.8 TeV.
[2] Result is based on 109 ± 7 $\mathrm{pb}^{-1}$ of data at $\sqrt{s}$ = 1.8 TeV.
[3] 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. Not used in OUR EVALUATION because of unknown correlations in the systematic errors. A joint CDF-DØ working group is considering how to include these results.

## $t$-Quark Decay Branching Fractions

| VALUE (%) | DOCUMENT ID | TECN | COMMENT |
|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | |
| | [4] ABE | 97V CDF | $\ell\tau$ + jets |

[4] ABE 97V searched for $t\overline{t} \rightarrow (\ell\nu_\ell)(\tau\nu_\tau)b\overline{b}$ events in 109 $\mathrm{pb}^{-1}$ of $p\overline{p}$ 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 $^{+5.8}_{-5.7}$ | [5] DEBOER | 97B RVUE | Electroweak + Direct |
| 157 $^{+16}_{-12}$ | [6] ELLIS | 96C RVUE | $Z$ parameters, $m_W$, low energy |
| 175 ± 11 $^{+17}_{-19}$ | [7] ERLER | 95 RVUE | $Z$ parameters, $m_W$, low energy |
| 180 ± 9 $^{+19}_{-21}$ ∓ 2.6 ± 4.8 | [8] MATSUMOTO | 95 RVUE | |
| 157 $^{+36}_{-48}$ $^{+19}_{-20}$ | [9] ABREU | 94 DLPH | $Z$ parameters |
| 158 $^{+32}_{-40}$ ± 19 | [10] ACCIARRI | 94 L3 | $Z$ parameters |
| 132 $^{+41}_{-48}$ $^{+24}_{-18}$ | [11] AKERS | 94 OPAL | $Z$ parameters |

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

[5] 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.

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

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

[8] 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 $\delta\alpha_{\text{had}} = 0.0283 \pm 0.0007$.

[9] 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.

[10] 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.

[11] 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.

[12] 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.

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

[14] 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.

[15] 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.

[16] 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.

[17] 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.

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

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