Implications of Recent $M_{Z,W}$ and Neutral-Current Measurements for the Top-Quark Mass

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The implications of precise new Z- and W-mass and weak-neutral-current data for the top-quark and Higgs-boson masses are analyzed. It is found that (a) $\sin^2\theta_W = 0.226 \pm 0.005$ for arbitrary m_t and for all $M_H < 1$ TeV; (b) $m_t < 210$ GeV at 90% C.L.; (c) $m_t > 40$ GeV at 90% C.L., even if the direct lower limit $m_t > 78$ GeV does not apply; and (d) there is no constraint on the Higgs-boson mass.

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Precise values for the Z and W masses have recently been reported by the Mark II Collaboration at the SLAC Linear Collider[1] (SLC)

$$M_Z = 91.17 \pm 0.18 \text{ GeV}, \quad (1)$$

by the Collider Detector at Fermilab (CDF) Collaboration[2]

$$M_W = 80.0 \pm 0.2 \pm 0.5\ (\pm 0.3) \text{ GeV}, \quad M_Z = 90.9 \pm 0.3\ (\pm 0.2) \text{ GeV} \quad (2)$$

(the first uncertainty is statistical, the second in M_W is systematic, and the last, in parentheses, are correlated scale errors), and by the UA2 Collaboration at CERN[3]

$$M_W = 80.0 \pm 0.4 \pm 0.4\ (\pm 1.2) \text{ GeV}, \quad M_Z = 90.19^{+0.56}_{-0.59}\ (\pm 1.4) \text{ GeV}. \quad (3)$$

In addition, several groups have reported direct lower limits on the t-quark mass, assuming canonical charged-current decays. The most stringent is

$$m_t > 78 \text{ GeV (90\% C.L.)}, \quad (4)$$

by CDF.[4]

A number of authors[5-13] have shown that the consistency of the weak-neutral-current and boson-mass data places an upper limit on m_t, which enters via the radiative corrections. Although some of the new results are preliminary, they are sufficiently important to justify an analysis of their implications for m_t and M_H. In the following I will utilize (1)-(4), the weak-neutral-current data described in Ref. 6, and new results in $\nu_\mu e$ scattering[14] and atomic parity violation.[15]

The basic results are shown in Fig. 1. The dashed lines indicate[16] the $\pm 1\sigma$ range determined for $\sin^2\theta_W \equiv 1 - M_W^2/M_Z^2$ from the SLC M_Z value in (1) as a function of m_t. It is seen that the derived $\sin^2\theta_W$ falls rapidly with m_t. Most other determinations of $\sin^2\theta_W$ [e.g., from the individual M_W and M_Z values in (2) and (3), from atomic parity violation, from the polarized *ed* asymmetry, and from $\nu_\mu e$ scattering] exhibit a similar m_t dependence, but with larger uncertainties, and therefore do not significantly constrain m_t. They are omitted from Fig. 1 for clarity, but are included in the global fits. However, there are two determinations of $\sin^2\theta_W$ with a different m_t dependence from M_Z. The first is the ν-hadron neutral-current data, which is dominated by deep-inelastic scattering. As seen in Fig. 1, the extracted $\sin^2\theta_W$ value[17] is only weakly dependent on m_t. Clearly, the combination of M_Z with νN neutral-current data yields an upper limit of ~ 200 GeV on m_t, as was already known from earlier $M_{W,Z}$ measurements.

Similarly, the determination of $\sin^2\theta_W$ from M_W/M_Z is independent of m_t. From (2) and (3) one has $\sin^2\theta_W = 0.221 \pm 0.009$. From Fig. 1, M_W/M_Z combined with M_Z yields a somewhat weaker upper limit of around 250 GeV on m_t, as well as a lower limit of ~ 80 GeV.

The 90%-C.L. allowed region in the $\sin^2\theta_W$-m_t plane obtained by combining all of the boson-mass data in (1)-(3), the old and new weak-neutral-current data, and the direct limit in (4) is shown in Fig. 1. It is seen that the region 80 GeV $< m_t <$ 220 GeV is strongly favored. These results are for a Higgs-boson mass M_H of 100

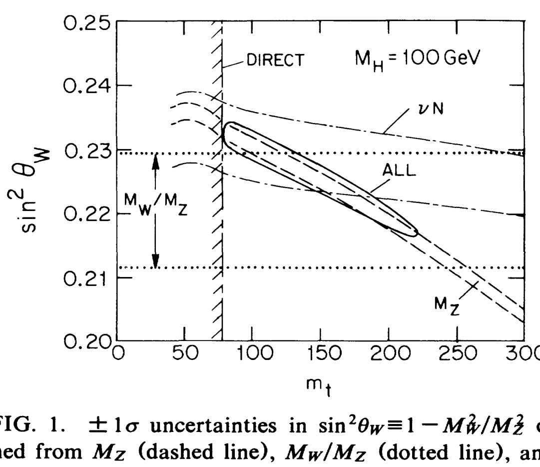

FIG. 1. $\pm 1\sigma$ uncertainties in $\sin^2\theta_W \equiv 1 - M_W^2/M_Z^2$ determined from M_Z (dashed line), M_W/M_Z (dotted line), and νN neutral-current data (dash-dotted line) as a function of m_t for $M_H = 100$ GeV. Also shown is the direct lower limit from the nonobservation of the t in $\bar{p}p \to \bar{t}t + X$ (long-short line), and the region (solid line) in $\sin^2\theta_W$-m_t allowed by all data at 90% C.L. ($\Delta\chi^2 = 4.6$).

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TABLE I. 90%-C.L. upper and lower limits on m_t in GeV obtained from (a) M_Z, M_W; (b) M_z plus νN neutral-current data; and (c) all boson-mass and neutral-current data; for $M_H = 10$, 100, and 1000 GeV. The upper limits in square brackets include the direct lower limit in (4) (which renormalizes the probability distribution). The lower limits are obtained from the boson-mass and neutral-current data only. The last column gives the best fit and $\pm 1\sigma$ uncertainty.

	Upper Limits			Lower Limits		
M_H	M_Z, M_W	$M_Z + \nu N$	All	M_Z, M_W	All	All
10	237 [243]	159 [174]	176 [182]	45	39	128^{+45}_{-53}
100	245 [249]	168 [179]	186 [190]	56	51	140^{+43}_{-52}
1000	258 [261]	188 [195]	207 [208]	86	91	165^{+38}_{-46}

GeV. The qualitative picture is similar for other M_H values, although the precise m_t limits exhibit some sensitivity to M_H.

Detailed limits[18] on m_t are shown in Table I for various assumptions, including the data set used (to illustrate sensitivity), the Higgs-boson mass, and whether or not the direct limit in (4) is incorporated. One sees the following: (a) $m_t < 180$, 190, and 210 GeV at 90% C.L. for $M_H = 10$, 100, and 1000 GeV, respectively, using all data. (b) The indirect (boson-mass plus neutral-current) data alone provide a nontrivial 90%-C.L. lower limit $m_t > 40$, 50, and 90 GeV for $M_H = 10$, 100, and 1000 GeV. This is weaker than the direct limit in (4), but is nevertheless of some importance: It would continue to hold in some extensions of the standard model (e.g., if the t decays into b plus charged Higgs boson) for which the direct limit is not valid.[19] (c) If m_t and M_H were known, M_Z in Eq. (1) would determine $\sin^2\theta_W$ to $\sim \pm 0.0013$. However, it is obvious from Fig. 1 that $\sin^2\theta_W$ and m_t are strongly correlated (the correlation is ~ -0.97 for large m_t). From the global fit one obtains

$$\sin^2\theta_W = 0.2264 \pm 0.0054 \tag{5}$$

for arbitrary m_t and for any $M_H < 1$ TeV (i.e., the uncertainty is mainly due to m_t). (d) The existing data yield no useful constraint on M_H: The χ^2 for the best fits vary by < 0.3 as M_H varies from 10 to 1000 GeV, and the central value of $\sin^2\theta_W$ (for arbitrary m_t) varies by ≤ 0.0001. However, from Table I the upper and lower limits on m_t are rather sensitive to a large M_H. Further implications of the new data will be discussed elsewhere.[20]

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[16] The formalism is described in Ref. 6.

[17] The uncertainty for νN includes a realistic estimate of the theoretical uncertainty, which is dominated by the c-quark threshold in $\nu N \to \mu^- X$. In particular, the effective c-quark mass (1.5 ± 0.3 GeV) is fit to the data simultaneously with $\sin^2\theta_W$ for each m_t. If this were not done (i.e., if m_c were fixed) then $\sin^2\theta_W$ would *increase* slightly with m_t for $m_t > 150$ GeV.

[18] The $\chi^2(m_t)$ distribution (minimized with respect to $\sin^2\theta_W$ for each m_t) is not completely Gaussian, so the confidence limits are obtained from a probability distribution $P(m_t) = C \times \exp(-\Delta\chi^2/2)$, where C is a normalization factor.

[19] The Mark II Collaboration has recently given the lower limit $m_t > 41$ GeV for a t decaying by $t \to bH^+$, A Weinstein, in the Proceedings of Ref. 1.

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