BI-TP 96/14
KA-TP-11-96
May 1996

hep-ph/9605268 8 May 1996

IMPLICATIONS OF ELECTROWEAK PRECISION DATA ON BOUNDS ON THE HIGGS-BOSON MASS†

S. Dittmaier[1], D. Schildknecht[1] and G. Weiglein[2]
[1] Fakultät für Physik, Universität Bielefeld, D-33615 Bielefeld, Germany
[2] Institut für Theoretische Physik, Universität Karlsruhe, D-76128 Karlsruhe, Germany

Abstract

Carefully analyzing the dependence of the bounds on the Higgs-boson mass M_{H} derived from the observables $\bar{s}^2_{\mathrm{W}}(\mathrm{LEP})$, $\bar{s}^2_{\mathrm{W}}(\mathrm{SLD})$, Γ_{l}, M_{W}, Γ_{T}, Γ_{h}, as well as R_{b} and R_{c}, and considering the uncertainties in $\alpha(M^2_{\mathrm{Z}})$ and $\alpha_{\mathrm{s}}(M^2_{\mathrm{Z}})$, we find that a stronger bound than $40\,\mathrm{GeV} \lesssim \mathrm{M_H} \lesssim 1\,\mathrm{TeV}$ at the 1σ level can hardly be deduced at present, even if the experimental information on the top-quark mass m_{t} from direct production is taken into account.

†To appear in the proceedings of the XXXIth RECONTRES DE MORIOND, "Electroweak interactions and unified theories", Les Arcs, Savoie - France, March 9-16, 1996.

IMPLICATIONS OF ELECTROWEAK PRECISION DATA ON BOUNDS ON THE HIGGS-BOSON MASS

S. Dittmaier[1], D. Schildknecht[1] and G. Weiglein[2]
[1] Fakultät für Physik, Universität Bielefeld, D-33615 Bielefeld, Germany
[2] Institut für Theoretische Physik, Universität Karlsruhe, D-76128 Karlsruhe, Germany

Presented by D. Schildknecht.

Abstract

Carefully analyzing the dependence of the bounds on the Higgs-boson mass M_{H} derived from the observables $\bar{s}^2_{\mathrm{W}}(\mathrm{LEP})$, $\bar{s}^2_{\mathrm{W}}(\mathrm{SLD})$, Γ_{l}, M_{W}, Γ_{T}, Γ_{h}, as well as R_{b} and R_{c}, and considering the uncertainties in $\alpha(M^2_{\mathrm{Z}})$ and $\alpha_{\mathrm{s}}(M^2_{\mathrm{Z}})$, we find that a stronger bound than $40\,\mathrm{GeV} \lesssim \mathrm{M_H} \lesssim 1\,\mathrm{TeV}$ at the 1σ level can hardly be deduced at present, even if the experimental information on the top-quark mass m_{t} from direct production is taken into account.

Various groups have recently analyzed the bounds on the mass of the Higgs scalar which can be obtained from the precision electroweak data in conjunction with the W-boson and the top-quark mass [1]. In this note we give a brief account of the results [2] of our recent two-parameter $(m_{\rm t}, M_{\rm H})$ fits to the 1995 electroweak data [3, 4, 5].

Our results are presented in the $(m_{\rm t}, M_{\rm H})$ plane of Fig. 1. The $(m_{\rm t}, M_{\rm H})$ fits have been carried out in various distinct steps which are indicated in the caption of Fig. 1. This procedure allows us to give a detailed and transparent account of the dependence of the bounds on $M_{\rm H}$ on the experimental input used in the fits.

The quality of the fits in the first two columns of Fig. 1, based on $(\Gamma_{\rm l}, \bar{s}^2_{\rm W}, M_{\rm W})$ and $(\Gamma_{\rm l}, \bar{s}^2_{\rm W}, M_{\rm W}, \Gamma_{\rm T}, \Gamma_{\rm h})$, respectively, is excellent, reflecting the well-known agreement between Standard Model (SM) and experiment for these observables. Based on $\bar{s}^2_{\rm W}(\rm LEP) = 0.23186 \pm 0.00034$, and taking into account the uncertainties induced by the errors in the electromagnetic and strong couplings, displayed in the second and third rows of Fig. 1, we find that a stronger bound than $40\,{\rm GeV} \lesssim {\rm M_H} \lesssim 1\,{\rm TeV}$ can hardly be deduced from these data. Note that this conclusion remains upon taking into account the experimental value [6] of $m_{\rm t} = 180 \pm 12\,{\rm GeV}$. A significantly reduced future error in $m_{\rm t}$, however, will improve the bound on $M_{\rm H}$.

If $\bar{s}^2_{\rm W}(\rm LEP)$ is replaced by $\bar{s}^2_{\rm W}(\rm SLD) = 0.23049 \pm 0.00050$ and $\bar{s}^2_{\rm W}(\rm LEP + SLD) = 0.23143 \pm 0.00028$, respectively, as shown in the last row of Fig. 1, the contour in the $(m_{\rm t}, M_{\rm H})$ plane is strongly changed. In the case of $\bar{s}^2_{\rm W}(\rm SLD)$, the value of $m_{\rm t} \simeq 170\,{\rm GeV}$ is consistent with the results from the direct measurements at Fermilab, while the values for $M_{\rm H} = 17^{+25}_{-9}\,{\rm GeV}$ and $M_{\rm H} = 13^{+20}_{-7}\,{\rm GeV}$ are in conflict with the lower bound [7] of $M_{\rm H} > 65.2\,{\rm GeV}$ from the Higgs-boson searches at LEP. With the SLD result for $\bar{s}^2_{\rm W}$ taken by itself, the Higgs mechanism of the unmodified SM is in serious trouble. It is the prevailing opinion at present that the 2σ shift between $\bar{s}^2_{\rm W}(\rm LEP)$ and $\bar{s}^2_{\rm W}(\rm SLD)$ is due to statistical fluctuations. Accordingly, upon using the average of $\bar{s}^2_{\rm W}(\rm LEP + SLD)$ in the fits, one obtains relatively low best-fit values for $M_{\rm H}$ which are consistent with the lower bound of $M_{\rm H} > 65.2\,{\rm GeV}$. Note that the corresponding upper 1σ bound for $M_{\rm H}$ is similarly sensitive against variations in $\alpha(M^2_{\rm Z})$ and $\alpha_{\rm s}(M^2_{\rm Z})$ (not shown in the plot) as the one obtained by using $\bar{s}^2_{\rm W}(\rm LEP)$ (as shown in the plot).

According to the last column of Fig. 1, a drastic shift of the contour in the $(m_{\rm t}, M_{\rm H})$ plane towards low values of $m_{\rm t}$ and $M_{\rm H}$ occurs when including $R_{\rm b}$ in the set of observables being fitted. At the same time the quality of the fit changes drastically to $\chi^2_{\rm min}/{\rm d.o.f.} = 12/6$ in the last column, which signals the well-known discrepancy between SM prediction and experimental result for $R_{\rm b}$, and the 1σ bounds on $M_{\rm H}$ are much tighter. Moreover, the sensitivity against variations of $\alpha(M^2_{\rm Z})^{-1}$ and $\alpha_{\rm s}(M^2_{\rm Z})$ is considerably weaker.

A look at Fig. 2 is illuminating in order to understand the results in the last column of Fig. 1. The SM prediction $R^{\rm th}_{\rm b}$ for $R_{\rm b}$ increases appreciably with decreasing values of $m_{\rm t}$, but is extremely insensitive against variations in $M_{\rm H}$. Inclusion of the (enhanced) experimental value of $R^{\rm exp}_{\rm b}$ in the fit necessarily leads to a strong decrease in $m_{\rm t}$, viz. $m^{\rm fit}_{\rm t} = 148^{+14}_{-12}\,{\rm GeV}$, a value which is significantly below the experimental value of $m_{\rm t} = 180 \pm 12\,{\rm GeV}$. The $(m_{\rm t}, M_{\rm H})$ correlation in the contours corresponding to the set of observables $(\Gamma_{\rm l}, \bar{s}^2_{\rm W}, M_{\rm W}, \Gamma_{\rm T}, \Gamma_{\rm h})$ then yields the low values of $M_{\rm H}$ which appear in the last column of Fig. 1. Effectively, including $R_{\rm b}$ in the fit thus appears equivalent to imposing a fixed (and low) value of $m_{\rm t}$. In fact, chosing a low value such as $m_{\rm t} = 148\,{\rm GeV}$ as input in a single-parameter $M_{\rm H}$ fit to $(\Gamma_{\rm l}, \bar{s}^2_{\rm W}, M_{\rm W}, \Gamma_{\rm T}, \Gamma_{\rm h})$, one arrives at values of $M_{\rm H} < 100\,{\rm GeV}$ (see discussion in Ref. [2]). Moreover, when evaluating $R_{\rm b}$ for the best-fit values (using $\bar{s}^2_{\rm W}(\rm LEP)$) of $(m_{\rm t}, M_{\rm H}) = (148^{+14}_{-12}\,{\rm GeV}, 54^{+88}_{-29}\,{\rm GeV})$, the resulting theoretical prediction, $R^{\rm th}_{\rm b} = 0.2164^{-0.0005}_{+0.0004}$ (with the errors indicating the changes by varying $m_{\rm t}$ within the 1σ limits), still lies more than 3σ below the experimental value of $R_{\rm b} = 0.2219 \pm 0.0017$. In addition, the low value for $m^{\rm fit}_{\rm t}$ is at variance with the Fermilab measurements so that the low central value and tight bound obtained for $M_{\rm H}$ by including $R_{\rm b}$ in the fit

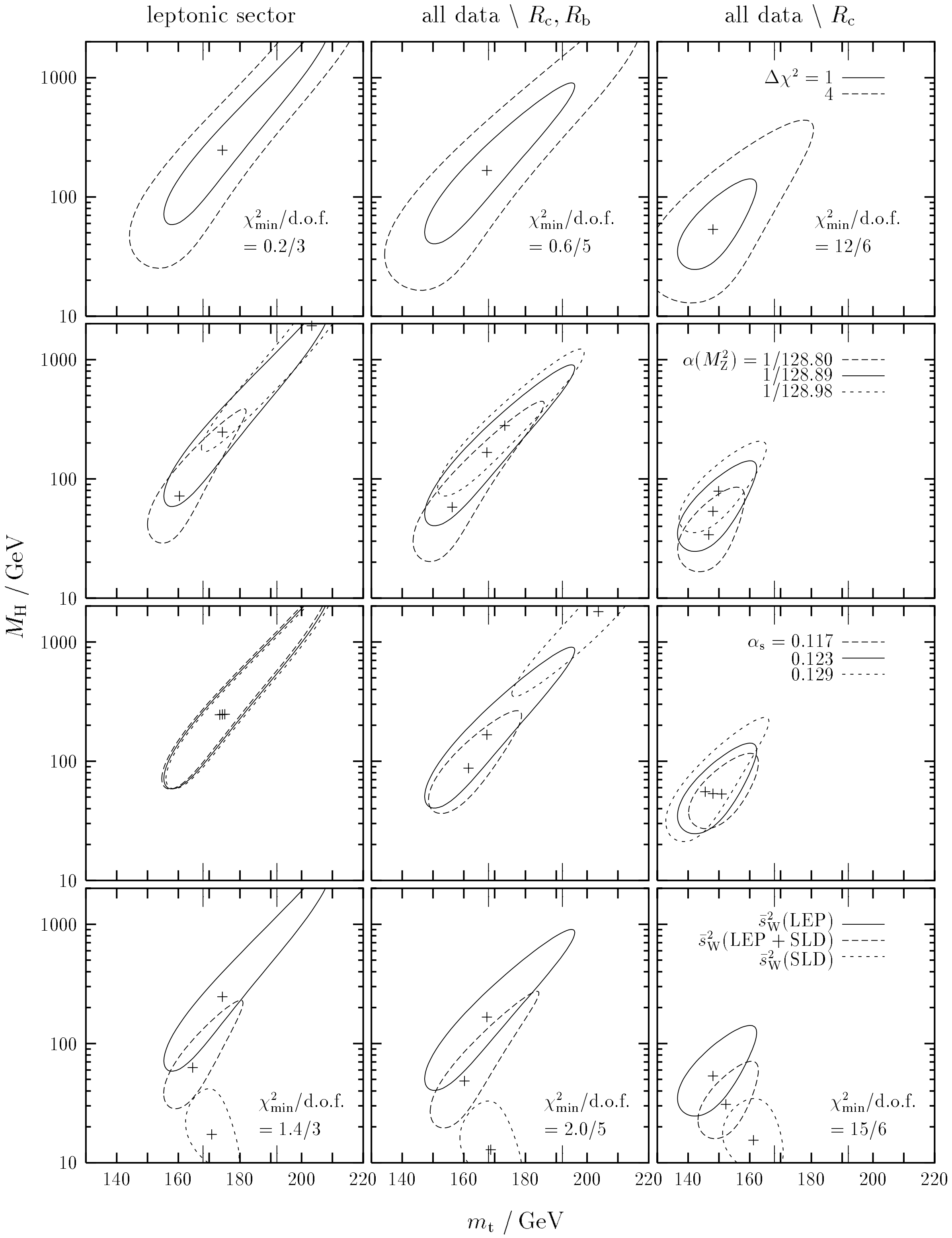
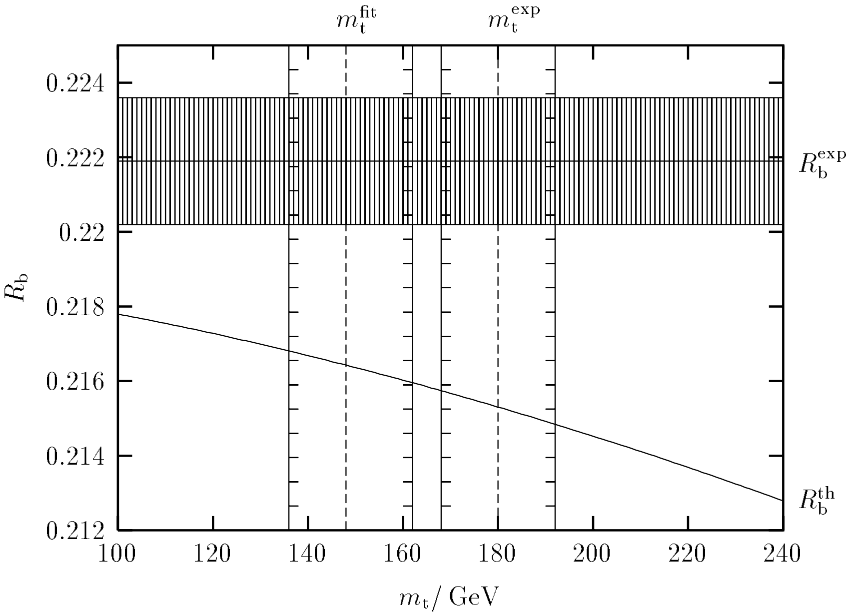


Figure 1: The results of the two-parameter (m_t, M_H) fits within the SM. The three different columns refer to the different sets of experimental data used in the corresponding fits,
(i) "leptonic sector": $\Gamma_l, \bar{s}^2_W(\mathrm{LEP}), M_W$,
(ii) "all data $\backslash R_c, R_b$": Γ_T, Γ_h are added to set (i),
(iii) "all data $\backslash R_c$": $\Gamma_T, \Gamma_h, \Gamma_b$ are added to the set (i).
For the fits in the first row the central values of $\alpha(M_Z^2)^{-1} = 128.89 \pm 0.09$ and $\alpha_s(M_Z^2) = 0.123 \pm 0.006$ have been used. The 1σ contours of the first row are repeated in the other rows and compared there to the results obtained when replacing $\alpha(M_Z^2)^{-1}$ (second row) and $\alpha_s(M_Z^2)$ (third row) by their upper and lower limits and when replacing $\bar{s}^2_W(\mathrm{LEP})$ by $\bar{s}^2_W(\mathrm{SLD})$ (fourth row). In all plots the empirical value of the top-quark mass, $m_t^{exp} = 180 \pm 12\,\mathrm{GeV}$, is indicated.

Figure 2: The theoretical value of R_b as a function of m_t is compared to $R_\mathrm{b}^\mathrm{exp}$. The sensitivity of R_b on M_H is so small that it is invisible in the plot. The fit result for m_t, $m_\mathrm{t}^\mathrm{fit}$, obtained in the $(m_\mathrm{t}, M_\mathrm{H})$ fit shown in the third column of Fig. 1, and the Fermilab experimental value, $m_\mathrm{t}^\mathrm{exp}$, are also indicated.



appears unreliable. This conclusion is strengthened by the fact that a simple phenomenological modification of the $\mathrm{Z} \to \mathrm{b}\bar{\mathrm{b}}$ vertex, as discussed in Ref. [2], leads to values of m_t compatible with the result of the direct searches and removes the stringent upper bounds on M_H.

In Ref. [2] also the effect of including/excluding the observable R_c has been analyzed. The results for m_t and M_H are only very weakly affected by including R_c.

In summary, we find that the SM fits to the precision data at the Z-boson resonance and M_W favor a Higgs-boson mass lying in the perturbative regime of $M_\mathrm{H} \lesssim 1\,\mathrm{TeV}$. Keeping in mind the sensitive dependence of the fit results for M_H on the data on R_b and $\bar{s}_\mathrm{W}^2(\mathrm{SLD})$ and on variations in $\alpha(M_\mathrm{Z}^2)$ and $\alpha_\mathrm{s}(M_\mathrm{Z}^2)$, we conclude that a stronger upper bound on M_H can hardly be deduced from the data at present.

References

[1] G. Montagna, O. Nicrosini, G. Passarino and F. Piccinini, *Phys. Lett.* **B335** (1994) 484;
V.A. Novikov, L.B. Okun, A.N. Rozanov and M.I. Vysotskii, *Mod. Phys. Lett.* **A9** (1994) 2641;
J. Erler and P. Langacker, *Phys. Rev.* **D52** (1995) 441;
S. Matsumoto, *Mod. Phys. Lett.* **A10** (1995) 2553;
Z. Hioki, TOKUSHIMA 95-04, hep-ph/9510269;
K. Kang and S.K. Kang, BROWN-HET-979, hep-ph/9503478;
P.H. Chankowski and S. Pokorski, *Phys. Lett.* **B356** (1995) 307; hep-ph/9509207;
J. Ellis, G.L. Fogli and E. Lisi, *Z. Phys.* **C69** (1996) 627.

[2] S. Dittmaier, D. Schildknecht, and G. Weiglein, BI-TP 96/06, hep-ph/9602436.

[3] The LEP Collaboration ALEPH, DELPHI, L3 and OPAL and the LEP Electroweak Working Group, Data presented at the 1995 Summer Conferences, LEPEWWG/95-02.

[4] SLD Collaboration: K. Abe et al., *Phys. Rev. Lett.* **73** (1994) 25;
SLD Collaboration: K. Abe et al., contributed paper to EPS-HEP-95, Brussels, eps0654.

[5] UA(2) Collaboration: J. Alitti et al., *Phys. Lett.* **B276** (1992) 354;
CDF Collaboration: F. Abe et al., *Phys. Rev. Lett.* **65** (1990) 2243, *Phys. Rev.* **D43** (1991) 2070;
CDF Collaboration: F. Abe et al., *Phys. Rev. Lett.* **75** (1995) 11;
DØ Collaboration: C.K. Jung, Proc. of the XXVII Int. Conf. on High Energy Physics, Glasgow, July 1994, eds. P.J. Bussey and I.G. Knowles.

[6] CDF collaboration, F. Abe et al., *Phys. Rev. Lett.* **74** (1995) 2626;
DØ collaboration, S. Abachi et al., *Phys. Rev. Lett.* **74** (1995) 2632.

[7] J.F. Grivaz, LAL-95-83, Proc. Int. EPS Conf. on High-Energy Physics, Brussels, 1995.