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

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Abstract
Carefully analyzing the dependence of the bounds on the Higgs-boson mass $M_H$ derived from the observables $\bar{s}_W^2 (\text{LEP})$, $\bar{s}_W^2 (\text{SLD})$, $\Gamma_1$, $M_W$, $\Gamma_T$, $\Gamma_h$, as well as $R_b$ and $R_c$, and considering the uncertainties in $\alpha(M_Z^2)$ and $\alpha_s(M_Z^2)$, we find that a stronger bound than $40 \text{ GeV} \lesssim M_H \lesssim 1 \text{ TeV}$ at the $1\sigma$ 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.

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Abstract

Carefully analyzing the dependence of the bounds on the Higgs-boson mass $M_H$ derived from the observables $\bar{s}_W^2$ (LEP), $\bar{s}_W^2$ (SLD), $\Gamma_l$, $M_W$, $\Gamma_T$, $\Gamma_h$, as well as $R_b$ and $R_c$, and considering the uncertainties in $\alpha(M_Z^2)$ and $\alpha_s(M_Z^2)$, we find that a stronger bound than $40 \text{GeV} \lesssim M_H \lesssim 1 \text{TeV}$ 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. In this note we give a brief account of the results of our recent two-parameter ($m_t, M_H$) fits to the 1995 electroweak data.

Our results are presented in the ($m_t, M_H$) plane of Fig. The ($m_t, M_H$) fits have been carried out in various distinct steps which are indicated in the caption of Fig. This procedure allows us to give a detailed and transparent account of the dependence of the bounds on $M_H$ on the experimental input used in the fits.

The quality of the fits in the first two columns of Fig. based on $(\Gamma_1, \sigma_W, M_W)$ and $(\Gamma_1, \sigma_W, M_W, \Gamma_T, \Gamma_h)$, respectively, is excellent, reflecting the well-known agreement between Standard Model (SM) and experiment for these observables. Based on $s_w^2$(LEP) = 0.23186 ± 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. we find that a stronger bound than $40 \text{ GeV} \lesssim M_H \lesssim 1 \text{ TeV}$ can hardly be deduced from these data. Note that this conclusion remains upon taking into account the experimental value of $m_t = 180 \pm 12 \text{ GeV}$. A significantly reduced future error in $m_t$, however, will improve the bound on $M_H$.

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

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

A look at Fig. is illuminating in order to understand the results in the last column of Fig. The SM prediction $R_b^{\text{th}}$ for $R_b$ increases appreciably with decreasing values of $m_t$, but is extremely insensitive against variations in $M_H$. Inclusion of the (enhanced) experimental value of $R_b^{\text{exp}}$ in the fit necessarily leads to a strong decrease in $m_t$, viz. $m_t^{\text{fit}} = 148^{+14}_{-12} \text{ GeV}$, a value which is significantly below the experimental value of $m_t = 180 \pm 12 \text{ GeV}$. The ($m_t, M_H$) correlation in the contours corresponding to the set of observables $(\Gamma_1, g_W, M_W, \Gamma_T, \Gamma_h)$ then yields the low values of $M_H$ which appear in the last column of Fig. Effectively, including $R_b$ in the fit thus appears equivalent to imposing a fixed (and low) value of $m_t$. In fact, choosing a low value such as $m_t = 148 \text{ GeV}$ as input in a single-parameter $M_H$ fit to $(\Gamma_1, s_w^2, M_W, \Gamma_T, \Gamma_h)$, one arrives at values of $M_H < 100 \text{ GeV}$ (see discussion in Ref. 2). Moreover, when evaluating $R_b$ for the best-fit values (using $s_w^2$(LEP)) of $(m_t, M_H) = (148^{+14}_{-12} \text{ GeV}, 54^{+88}_{-29} \text{ GeV})$, the resulting theoretical prediction, $R_b^{\text{th}} = 0.2164^{+0.0005}_{-0.0004}$ (with the errors indicating the changes by varying $m_t$ within the $1\sigma$ limits), still lies more than $3\sigma$ below the experimental value of $R_b = 0.2219 \pm 0.0017$. In addition, the low value for $m_t^{\text{fit}}$ is at variance with the Fermilab measurements so that the low central value and tight bound obtained for $M_H$ by including $R_b$ 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”: $\Gamma_l, \bar{s}_2^W(LEP), M_W$,
(ii) “all data \ $R_c, R_b$”: $\Gamma_T, \Gamma_h$ are added to set (i),
(iii) “all data \ $R_c$”: $\Gamma_T, \Gamma_h, \Gamma_b$ 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 1$\sigma$ 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 $\bar{s}_2^W(LEP)$ by $\bar{s}_2^W(SLD)$ (fourth row). In all plots the empirical value of the top-quark mass, $m_{t\ exp} = 180 \pm 12$ GeV, is indicated.
Figure 2: The theoretical value of $R_b$ as a function of $m_t$ is compared to $R_b^{\text{exp}}$. The sensitivity of $R_b$ on $M_H$ is so small that it is invisible in the plot. The fit result for $m_t$, $m_t^\text{fit}$, obtained in the $(m_t, M_H)$ fit shown in the third column of Fig. 1 and the Fermilab experimental value, $m_t^{\text{exp}}$, are also indicated.

appears unreliable. This conclusion is strengthened by the fact that a simple phenomenological modification of the $Z \rightarrow b\bar{b}$ 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 $M_H \lesssim 1$ TeV. Keeping in mind the sensitive dependence of the fit results for $M_H$ on the data on $R_b$ and $s_W^2$ (SLD) and on variations in $\alpha(M_Z^2)$ and $\alpha_s(M_Z^2)$, we conclude that a stronger upper bound on $M_H$ can hardly be deduced from the data at present.

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