Up–dating for the paper “The mass of the Higgs boson in the Standard Model from precision tests” (MPI–Ph/95–39, hep–ph/9505304). *

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Abstract

The bounds on the Higgs mass in the Standard Model are re-analyzed using the precision electroweak data presented at the International Europhysics Conference on High Energy Physics, Brussels, 27 July – 2 August, 1995

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After submission of the paper [1] for publication, new data from the SLD and LEP became available. We present here an update of our fits with new measurements included. The experimental input used in the present fits is summarized in ref [2]. The bulk of the LEP results show satisfactory agreement with the earlier reports (one should note, however, the new value $A_{FB}^{b,0} = 0.0997 \pm 0.0031$). For $M_W$ we use (as previously) $80.33 \pm 0.17$ GeV which is the average value of the UA2 measurement and the new measurement reported by the CDF [3] (the D0 collaboration has not published the results of their new analysis yet). When the top quark mass is included in the fit we use the value $m_t = 181 \pm 12$ GeV. For $\Delta \alpha_{EM}^{had}$ we use the value $0.0280 \pm 0.0007$ and include it into the $\chi^2$ fit.

The most significant changes in the LEP data are $R_b = 0.2219 \pm 0.0017$, and $R_c = 0.1540 \pm 0.0074$. Since the identification of $b$ quarks is much better than of the $c$ quarks experimental collaborations also quote the value $R_b = 0.2206 \pm 0.0016$ which is obtained when the value of $R_c$ is fixed to its SM prediction $R_c = 0.172$.

The new SLD result read [8, 2]: $A_{LR}^e \equiv A_e = 0.1551 \pm 0.0040$ (which corresponds to $\sin^2 \theta_{eff}^l = 0.23049 \pm 0.00050$). The SLD collaboration also reported for the first time [2] the results $A_{LR}^b \equiv A_b = 0.841 \pm 0.053$ and $A_{LR}^c \equiv A_c = 0.606 \pm 0.090$.

The new SLD data for $A_{LR}^e$ and the LEP value still remain more than $2\sigma$ apart: although the central values are now much closer to each other, the SLD error has significantly decreased.

The newly reported results for $R_b$, $R_c$, $A_{LR}^b$, $A_{LR}^c$ have drastic effects on SM fits whose quality has significantly decreased. This indicates either large fluctuations in the present data or new physics (or both). Here we adopt the first point of view and assume that the SM is the correct low energy effective theory at the electroweak scale. In this framework we critically re-examine the bounds on the Higgs boson mass in several different versions of the fit.

We begin with the results of a fit to all the LEP, SLAC and Fermilab data described above (i.e. to $M_W$, $1 - M_W^2/M_Z^2$, $\Gamma_Z$, $\sigma_h$, $A_t$, $A_{FB}$, $R_b$, $R_c$, $A_{FB}^0$, $A_{FB}^{0,b}$, $A_{FB}^{0,c}$, $A_{LR}^b$, $A_{LR}^c$, $m_t$ and $\Delta \alpha_{EM}^{had}$). They are given in the first line of Table 1 and $1\sigma$ and $2\sigma$ bounds in the $(m_t, M_h)$ plane are shown in Fig.1. Significant upper bounds on the Higgs boson mass are obtained but the quality of the fit is poor.

### Table 1. Results of the fit to all the data [2, 3, 8]. All masses in GeV.

| $m_t$   | $\Delta m_t$ | $M_h$ | $\Delta M_h$ | $\alpha_s(M_Z)$ | $\Delta \alpha_s(M_Z)$ | $\chi^2$ | d.o.f |
|---------|--------------|-------|--------------|------------------|------------------------|---------|-------|
| 171.0   | 11.1         | 93    | $+189^{+63}_{-83}$ | 0.122            | 0.005                  | 25.0    | 14    |
| 170.5   | 10.9         | 82    | $+181^{+63}_{-85}$ | 0.122            | 0.005                  | 21.1    | 12    |

The result reported in the ref. [5] has been recently updated [7, 2] and is now close to the results reported in [4]. The result of ref. [6] is about $1\sigma$ lower than that of [4]; it is, however, based on more theoretical assumptions [2].
We now examine the impact of the observables which give the dominant contribution to $\chi^2$ on the Higgs boson mass bounds. In the second line of Table 1 there are also given the results of a fit without the two new SLAC measurements of $A^b_{LR}$ and $A^c_{LR}$. The bounds on $M_h$ are slightly stronger and the fit is a bit better.

In the first row of Table 2 we show the results of a fit without $R_b$, $R_c$ and without all the $LR$ asymmetries measured by the SLD ($A^a_{LR}$ and $A^b_{LR}$, $A^c_{LR}$). The $\chi^2$ value is now excellent. The $1\sigma$ and $2\sigma$ contours in the $(m_t, M_h)$ plane are shown in Fig. 2a. The bounds on $M_h$ are very weak and critically depend on the value of $m_t$ measured in Fermilab. Without $m_t$ in the fit the included data only correlate $M_h$ with $m_t$ (as shown also in Fig. 2a) with, however, no $2\sigma$ upper bound on $M_h$.

Another observable which depends on $m_t$ but not on $M_h$ is $R_b$. The measured value, to be consistent with the SM, requires very low value of $m_t$. Thus, inclusion of $m_t$ and/or $R_b$ gives the fitted value of $m_t$ lower than the Fermilab value and, in consequence, stronger bounds on $M_h$. This is also shown in Table 2 and in Fig. 2b. Here we give the results of fits with $R_b = 0.2206 \pm 0.0016$ which is the experimental number obtained under the assumption of $R_c = 0.172$ (with the new values of $R_b$ and $R_c$ we get very similar bounds but the quality of the fit is poorer).

Table 2. Results of the fit without the SLD asymmetries.

| $m_t$ | $R_b$ | $\Delta m_t$ | $M_h$ | $\Delta M_h$ | $\alpha_s(M_Z)$ | $\Delta \alpha_s(M_Z)$ | $\chi^2$ | d.o.f |
|-------|-------|-------------|-------|-------------|------------------|-------------------------|---------|-------|
| +     | −     | +180.1      | 11.9  | 335         | $^{+529}_{-222}$ | 0.125                  | 3.2     | 9     |
| −     | +     | +152.2      | $^{+14.7}_{-12.9}$ | 52     | $^{+115}_{-29}$ | 0.123                  | 9.4     | 9     |
| +     | +     | +172.4      | 11.2  | 189         | $^{+30}_{-20}$  | 0.124                  | 11.6    | 10    |

As the next step we include in the fits the SLD value of $A^a_{LR}$. Its effect on the fits can be understood from Fig. 2a. We show there the contour of constant $A^a_{LR} = 0.1551$. It is almost parallel to the open contours which show the $m_t - M_H$ correlation without $m_t$, $R_b$ and $A^a_{LR}$ in the fit but for the same $m_t$ the correlated $M_h$ is much lower. It is clear therefore that to a very good approximation the inclusion of $A^a_{LR}$ should not alter the fitted value of $m_t$ but strengthen the bound on $M_h$. This is indeed seen in Table 3 and in Fig. 3 (small changes in $m_t$ compared to Table 2 are due to the fact that the two discussed above contours in Fig. 2 are not exactly parallel).

Table 3. Results of the fit as in Table 2 but with $A^a_{LR}$ included.

| $m_t$ | $R_b$ | $\Delta m_t$ | $M_h$ | $\Delta M_h$ | $\alpha_s(M_Z)$ | $\Delta \alpha_s(M_Z)$ | $\chi^2$ | d.o.f |
|-------|-------|-------------|-------|-------------|------------------|-------------------------|---------|-------|
| +     | −     | +176.7      | 12.0  | 125         | $^{+201}_{-89}$  | 0.122                  | 8.9     | 10    |
| −     | +     | +155.6      | 11.1  | 33          | $^{+49}_{-49}$   | 0.122                  | 14.8    | 10    |
| +     | +     | +169.6      | 10.7  | 79          | $^{+100}_{-54}$  | 0.122                  | 17.1    | 11    |
The third line in Table 3 can be compared with the second line in Table 1 to see the effect of using new values of $R_b$ and $R_c$ instead of the value of $R_b = 0.2206 \pm 0.0016$ obtained with $R_c$ fixed to its SM value. We conclude that the limits on $M_h$ are stable with respect to the treatment of $R_b$ and $R_c$ in the fit.

To a very good approximation, the upper bounds result from a combination of $m_t - M_h$ correlation given by a fit to all but $R_b$ electroweak data and the upper bound on $m_t$ obtained from $R_b$ and the direct measurement of $m_t$. The SLD $A_{LR}^c$ result has important impact on $m_t - M_h$ correlation in the direction of lowering the values of $M_h$ for given $m_t$ (as seen in Fig. 3a).

We also note that inclusion of the SLD result in the fits gives lower value of $\alpha_s(M_Z)$. This follows from the fact that the $m_t - M_h$ values required by the value of $A_{LR}^c$ tend to increase $\Gamma_h$, i.e. a lower value of $\alpha_s(M_Z)$ is now needed.

Finally one can add a few remarks related to the new values of $R_b$ and $R_c$. Following earlier references [4] we have discussed in the original version of the paper the possibility of new physics in $R_b$ and studied the upper bounds on $M_h$ in a toy model which reproduces all the results of the SM and has an ad hoc correction to the $Z \rightarrow \ell \ell$ width, so that $R_b \approx 0.22$. Then the fitted value of $\alpha_s(M_Z) = 0.108$ and the observable $R_b$ becomes irrelevant (its contribution to $\chi^2 \approx 0$) from the point of view of the limits on $M_h$. In this toy model the limits on $M_h$ were similar to the SM limits without $R_b$ in the fit (somewhat weaker due to the smaller value of $\alpha_s(M_Z)$). With the new data the discussion remains valid provided we use the value of $R_b$ extracted under the assumption of $R_c$ fixed to the SM value and disregard the new $R_c$ measurement. If, however, we include both measurements, $R_b$ and $R_c$, and consider a toy model with new physics in both variables, so that $R_c \approx 0.1540$ and $R_b \approx 0.222$ then the fitted value of $\alpha_s(M_Z) = 0.178 \pm 0.005$. This is easy to understand: with $\Gamma_{Z^0 \rightarrow \text{had}} = 1744.8 \pm 3.0$ the sum $\Gamma_{Z^0 \rightarrow \ell \ell} + \Gamma_{Z^0 \rightarrow t\bar{t}}$ is now much smaller than in the SM and we get $\Gamma_{Z^0 \rightarrow \text{had}} - \Gamma_{Z^0 \rightarrow \ell \ell} - \Gamma_{Z^0 \rightarrow t\bar{t}}$ large. Of course, also in this toy model the observables $R_b$ and $R_c$ become irrelevant for the bounds on $M_h$ and we get them similar to the SM fit without $R_b$ in the fit. However, the large value of the fitted $\alpha_s(M_Z)$ casts doubts on the measurement of $R_c$, unless new physics also alters the light quark sector. (We thank H.E. Haber and C. Wagner for the discussion on this point.)

Our results, in part which overlaps, are in very good agreement with recent fits presented in [10].

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FIGURE CAPTIONS

Figure 1.
Contours of $\Delta \chi^2 = 1$ and $\Delta \chi^2 = 4$ for the $\chi^2$ fit to all LEP, SLD and Fermilab data.

Figure 2.
Contours of $\Delta \chi^2 = 1$ and $\Delta \chi^2 = 4$ for the $\chi^2$ fits without the asymmetries measured at SLD ($A_{LR}^b$, $A_{LR}^b$, $A_{LR}^c$): a) without $R_b$, $R_c$, b) with $R_b = 0.2206 \pm 0.0016$ ($R_c = 0.172$ fixed) included.
In both figures results of the fits without/with the Fermilab value for $m_t$ included are marked as $1, 2\sigma_{-t}/1, 2\sigma_{+t}$. In the right bottom corner of Fig. 2a the line of constant $A_{LR}^c = 0.1551$ as measured at SLAC is also shown.

Figure 3.
As in Fig. 2 but with the SLD result for $A_{LR}^c$ included.