STANDARD MODEL CONSTRAINTS ON M_{Top} AND M_{Higgs} FROM THE LEP EXPERIMENTS

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Abstract

The results reported in this paper are based on data collected during four years of running at LEP, from '90 to '94. A combined set of published and preliminary electroweak results from the four LEP experiments is used to constraint the masses of the top quark and Standard Higgs boson. The fit yelds $M_{Top} = 179 \pm 9^{+17}_{-19}\, GeV \;\; (60 < M_H < 1000\, GeV)$ in excellent agreement with the recent determination from CDF and D0 at Tevatron. Using also their direct measurement of M_{Top} in the fit we get an upper limit for M_{Higgs} : $M_{Higgs} < 900\, GeV\ at\ 95\%\ C.L.$.

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1 Introduction

During the last year important progresses have been achieved for both statistical and systematic errors on the electroweak measurements. The statistics was approximately doubled reaching a total amount of data of about ten millions of hadrons and one million of leptons. The calibration of the LEP energy scale for the high statistics scan of the Z resonance in 1993 has been finalized [3] resulting in reduced uncertainties on the Z lineshape parameters. The theoretical error associated to the luminosity determination has been decreased [4] and several reevaluations of $\alpha(M_{Z^2})$ have been recently performed [5]-[8]. Finally the direct measurement of the top quark mass has been performed by CDF [9] and D0 [10] collaborations.

The data [1] on which the fit presented in this paper is based consist of the hadronic and leptonic cross sections, the leptonic forward-backward asymmetries, the τ polarization asymmetries, the $b\bar{b}$ and $c\bar{c}$ partial widths and forward-backward asymmetries and the $q\bar{q}$ charge asymmetry.

Many aspects of the averaging procedure among the results of the four experiments and of their combination have been described in [2] and references therein.

2 Standard Model fits

Both top quark and Higgs boson haven't been produced directly at LEP but a lower limit on the Higgs mass has been setted from the four LEP experiments to $M_{Higgs} > 63.5\ GeV$ at 90% C.L. [20].

Radiative corrections introduce top mass and Higgs mass dependencies into measurable quantities and the high precision reached at LEP on the measurement of many electroweak parameters, makes them sensitive to these corrections.

Neverthless, beeing the leading contribution to the radiative corrections quadratic in M_{Top} and logarithmical in M_{Higgs} , predictions on the unknown Higgs mass are much weaker than on top mass. Among all the radiative corrections, the $Zb\bar{b}$ vertex involves the top quark in a significant way because the corresponding CKM element is big compared to that of other quarks. Furthermore, the ratio $R_b = \Gamma_b/\Gamma_{had}$ depends only on the top mass because α_s and Higgs mass corrections cancel to a large extent beeing common to all quarks. Figure 1 shows the impact of this special vertex corrections to R_b compared for example to R_d.

To infer information on the Standard Model basic parameters the LEP electroweak measurements presented in table 1 are fitted using ZFITTER [21]. Fits can also be performed adding some electroweak measurements from neutrino, $p\bar{p}$ and SLD experiments listed also in table 1.

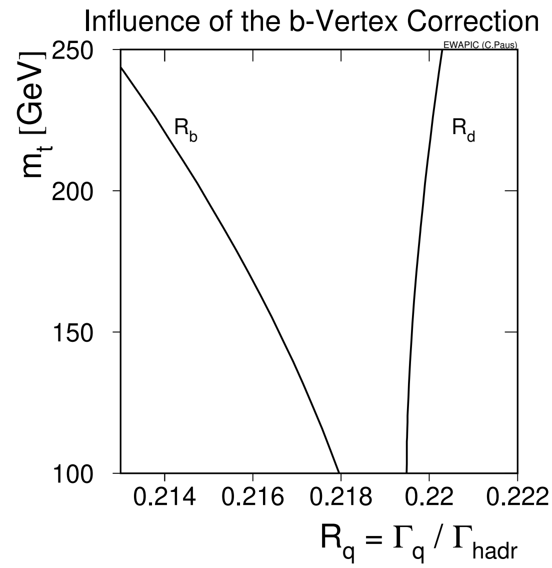

Figure 1: Influence of the $Zb\bar{b}$ vertex correction to R_b and R_d.

A comparison between these measurements and the Standard Model predictions as a function of M_{Top} is shown in figure 2. The bands in the Standard Model predictions correspond to the linear sum of the extimated variations of each quantity due to a change of the strong coupling constant $\alpha_s(M_Z^2) = 0.123 \pm 0.006$ within its error and to a change of M_{Higgs} from 60 to 1000 GeV ($M_Z = 91.1887\ GeV$).

LEP		
$lineshape\ and\ lepton\ asymmetries:$	M_Z	$91.1887 \pm 0.0022\ GeV$
	Γ_Z	$2.4971 \pm 0.0032\ GeV$
	σ_h^0	$41.492 \pm 0.081\ nb$
	$R_l = \Gamma_{had}/\Gamma_l$	20.800 ± 0.035
	$A_{FB}^{0,l}$	0.0172 ± 0.0013
$\tau\ polarization:$	A_τ	0.140 ± 0.008
	A_e	0.137 ± 0.009
$b\ and\ c\ quark\ results:$	$R_b = \Gamma_{b\bar{b}}/\Gamma_{had}$	0.2204 ± 0.0020
	$R_c = \Gamma_{c\bar{c}}/\Gamma_{had}$	0.1606 ± 0.0095
	$A_{FB}^{0,b}$	0.1015 ± 0.0036
	$A_{FB}^{0,c}$	0.0760 ± 0.0089
$q\bar{q}\ charge\ asymmetry:$	$sin^2\theta_{eff}(< Q_{FB} >)$	0.2320 ± 0.0016
$p\bar{p}\ experiments:$	m_W	$80.26 \pm 0.16\ GeV$
$\nu N\ experiments:$	$1 - m_W^2/m_Z^2$	0.2253 ± 0.0047
$SLC:$	$sin^2\theta_{eff}^{SLD}$	0.2294 ± 0.0010

Table 1: Data input to the combined Standard Model fit. The $p\bar{p}$ collider data are from UA2 [15],CDF [16]- [17] and D0 [18] experiments. The neutrino experiment data are from CDHS [12],CHARM [13] and CCFR [14]. The $sin^2\theta_{eff}^{SLD}$ [11] SLC value comes from the SLD determination of the left-right asymmetry.

The measurements X_i are combined in a global fit which parametrizes each of them as:

$$X_i = f_i(\alpha(M_Z^2), M_Z, M_t, M_H, \alpha_s(M_Z^2)).$$

Several reevaluations of $\alpha(M_{Z^2})$ have been recently performed [5]- [8] spanning the range from $\alpha(M_Z^2) = 1/(129.08 \pm 0.10)$ [5] to $\alpha(M_Z^2) = 1/(128.896 \pm 0.090)$ [7]. Results presented here are obtained using $\alpha(M_Z^2) = 1/(128.896 \pm 0.090)$. Its uncertainty produces a 4 GeV indetermination on the M_{Top} result. Using instead $\alpha(M_Z^2) = 1/(129.08 \pm 0.10)$ produces a shift of $-9\ GeV$ on the M_{Top} determination.

The higgs mass is fixed to 300 GeV and the change of parameter results when varying M_{Higgs} in the interval $60 \leq M_{Higgs} \leq 1000\ GeV$ is quoted as an additional uncertainty.

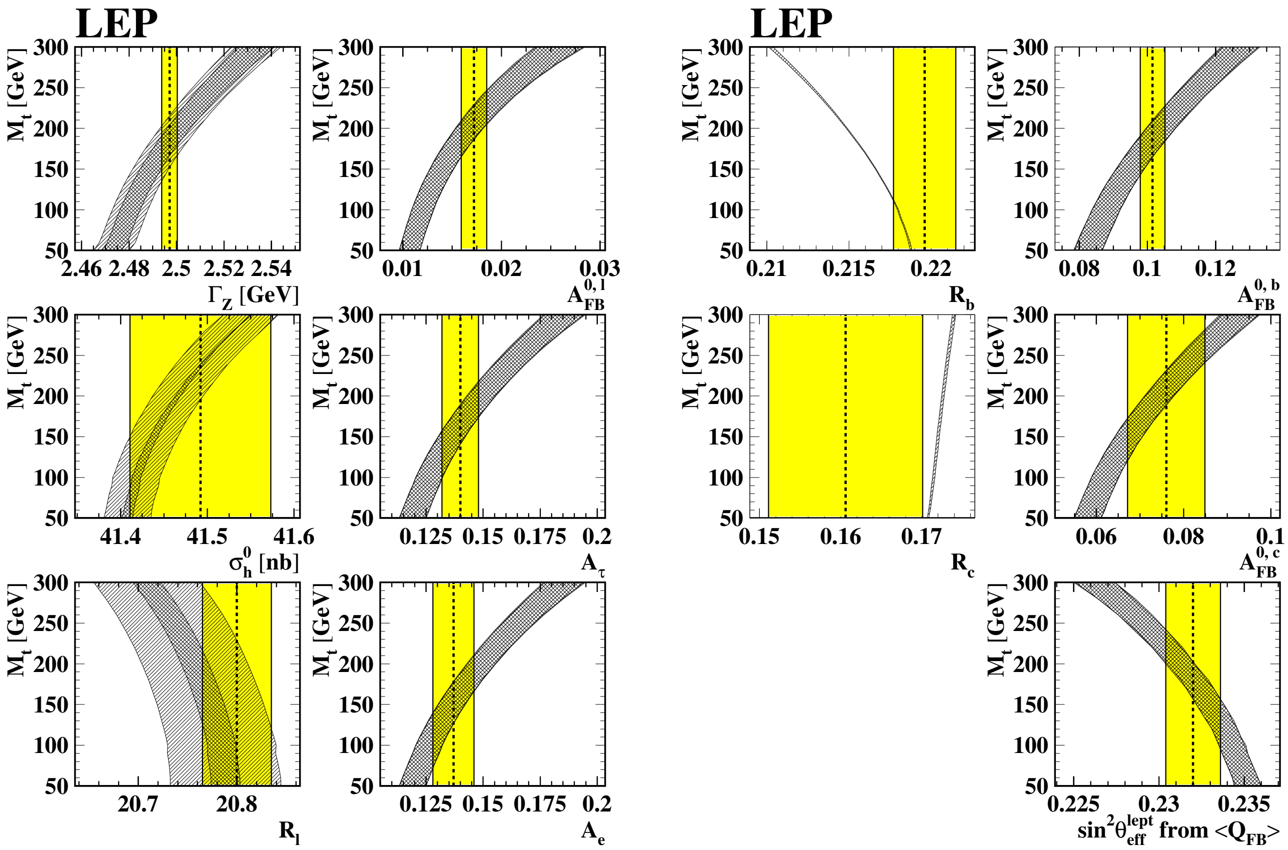

Figure 2: Comparison of LEP measurements with the Standard Model prediction as a function of M_{Top}. The cross-hatched area shows the variation of the Standard Model prediction with M_{Higgs} spanning the interval $60 \leq M_{Higgs}(GeV) \leq 1000$ and the singly-hatched area corresponds to a variation of $\alpha_s(M_Z^2)$ within the interval $\alpha_s(M_Z^2) = 0.123 \pm 0.006$. The total width of the band corresponds to the linear sum of both uncertainties. The experimental errors on the parameters are indicated as vertical bands. For the comparison of R_b with its prediction, R_c has been fixed to the Standard Model value.

The constraints obtained on the remaining free and unconstrained parameters are shown in table 2. The top mass value obtained from these fits is in excellent agreement with the mass values reported by the CDF and D0 collaborations:

$$CDF: M_{Top} = 176 \pm 8 \pm 10\ GeV, \qquad D0: M_{Top} = 199^{+19}_{-21} \pm 22\ GeV.$$

This result gives a relevant proof of the big predictive power of the Standard Model and confirms that the bulk of radiative corrections to the electroweak observables is really due to the top quark.

The $\alpha_s(M_Z^2)$ values are in very good agreement with that obtained from event shape measurement at LEP: $\alpha_s(M_Z^2) = 0.123 \pm 0.006$ [19]. The $\alpha_s(M_Z^2)$ values are stable against a variation of $\alpha(M_Z^2)$.

The residuals beetween the input measurements and the Standard Model predictions calculated with the parameter set get from the fit to all data, in unit of their errors, are shown in figure 3.

The measurement of R_b causes the largest χ^2 contribution of all LEP data. Since c-quark events are the main source of background in the R_b analysis, the values of R_b and R_c are strongly anticorrelated as shown in figure 4. The agreement between the measured R_b and its Standard Model prediction improves from 2.4 to 2.1 standard deviations if the value of R_c is fixed to the Standard Model value $R_c = 0.171$. Also shown are the 68% and 95% C.L. contours in the $R_b - R_c$ plane; the largest one covers also the Standard Model prediction for the M_{Top} value obtained from the fit.

	LEP	LEP + $p\bar{p}$ and νN data + SLD
M_t(GeV)	$176 \pm 10^{+17}_{-19}$	$179 \pm 9^{+17}_{-19}$
$\alpha_s(M_Z^2)$	$0.126 \pm 0.004 \pm 0.003$	$0.125 \pm 0.004 \pm 0.003$
$\chi^2/(d.o.f.)$	9.0/11	15/12

Table 2: Results of fits to LEP and other electroweak precision data for M_{Top} and $\alpha_s(M_Z^2)$. The central values and the first errors quoted refer to $M_{Higgs} = 300\ GeV$. The second errors correspond to the variation of the central value when varying M_{Higgs} in the interval $60 \leq M_{Higgs} \leq 1000\ GeV$.

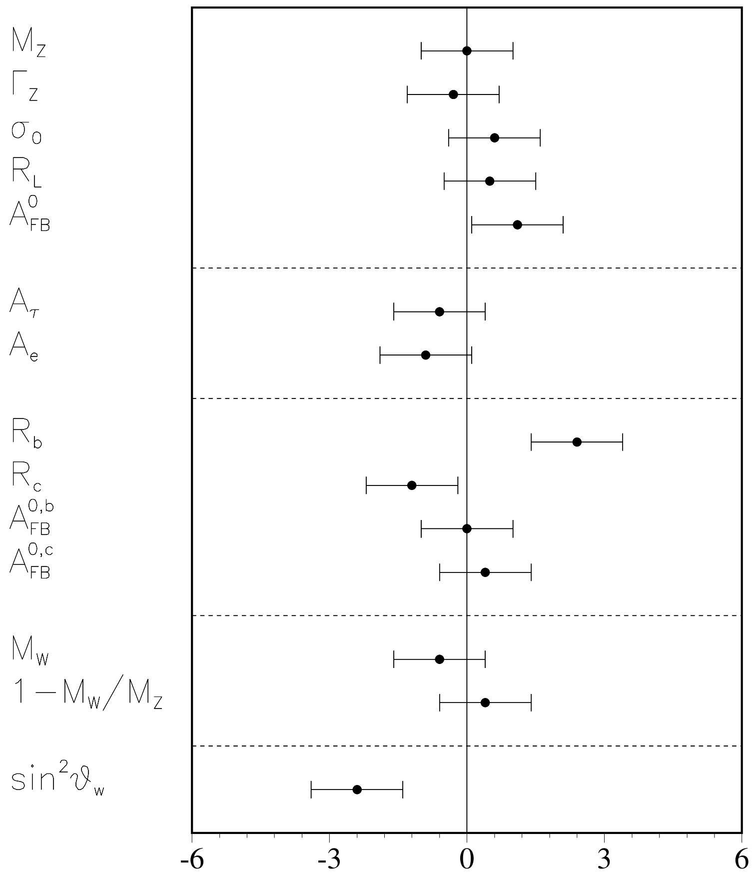

Figure 3: Residuals between the input measurements and their Standard Model predictions calculated using the fit results to all data (last column of table 2), in unit of their errors.

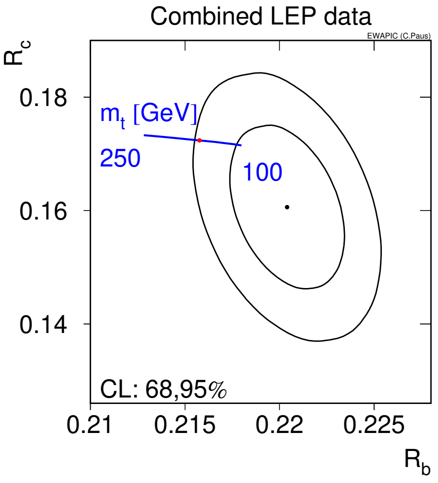

Figure 4: The 68% and 95% C.L. contours in the $R_b - R_c$ plane. The straight line is the Standard Model prediction when varying M_{Top} from 100 to 250 GeV. The dot on that line corresponds to the fitted M_{Top} value.

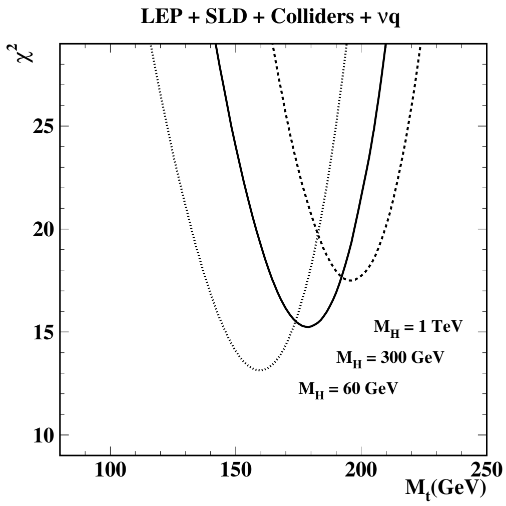

Figure 5: The variation of the χ^2 of the fit to all data as a function of the top mass for three different Higgs masses.

Also the $sin^2\theta_{eff}^{SLD}$ measured from SLD is 2.4 standard deviation apart of the predicted value, and it will pull M_t toward a slightly higher value.

The χ^2 values for the Standard Model fit as a function of M_{Top} for three values of M_{Higgs} show that the minimum of these curves occurs at different values of χ^2 (figure 5). The effects of M_{Higgs} and M_{Top} are strongly correlated for most observables which weakens the determination of M_{Higgs} ; top quark mass needs to be measured independently, as in R_b or through the direct measurement, to disentangle the effects.

Constraining M_{Top} to the values from CDF and D0 and fitting all the data (LEP + νN + $p\bar{p}$ + SLD) we obtain:

$$M_{Top} = 171^{+12}_{-10}\ GeV$$

$$\alpha_s(M_Z^2) = 0.125 \pm 0.004$$

$$M_{Higgs} = 100^{+230}_{-76}\ GeV$$

with a $\chi^2/d.o.f. = 15/13$ (from the direct search: $M_H > 63.5\ GeV\ at\ 95\%\ C.L.$).

Figure 6 shows the 68% C.L. contour in the M_{Top} -M_{Higgs} plane with and without the M_{Top} Tevatron constraint.

Figure 7 shows $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ as a function of M_{Higgs} . Taking and interval in $\Delta\chi^2$ of about four, corresponding to a two-sided 95 % probability range, we get:

$$M_{Higgs} < 900\ GeV \quad at\ 95\%\ C.L.$$

By the end of '95 we can expect some improvements [22] on the uncertainties of quantities like the LEP energy, luminosity, the M_{Top} Tevatron measurement, the M_W and $sin^2\theta_{eff}^{SLD}$. Simulating these improvements and taking into account the increase in statistics and a reasonable extrapolation on the systematic errors, the fit sensitivity will probably increase by a factor of about 1.5 as shown in figure 8.

Under the assumption that the position of the minimum will remain the same, the upper 95% C.L. limit could probably be reduced from 900 GeV to 500 GeV.

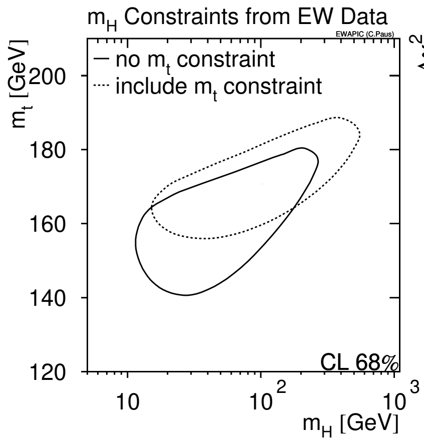

Figure 6: The 68% C.L. contour in the M_{Top} - M_{Higgs} plane with and without the M_{Top} Tevatron constraint to the fit.

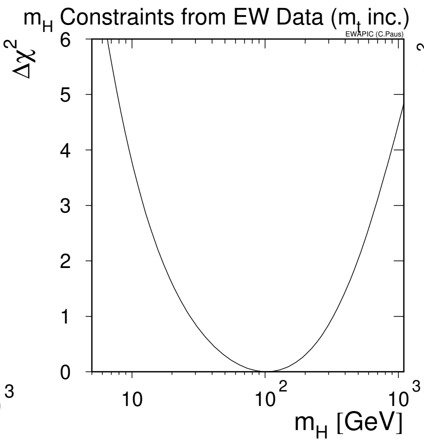

Figure 7: $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ versus M_{Higgs} fitting all the electroweak data and including the Tevatron constraint for M_{Top} .

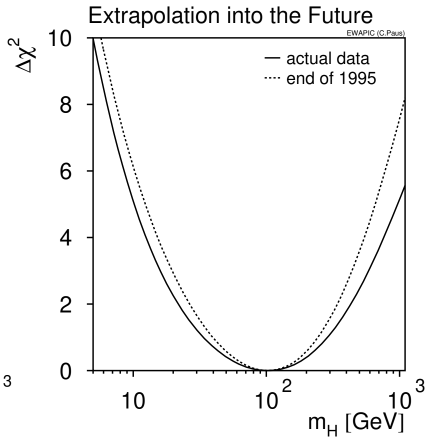

Figure 8: Extrapolation of $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ versus M_{Higgs} including all the improvements expected by the end of 1995.

3 Conclusions

The TOP mass measured at LEP is in excellent agreement with its direct measurement. We obtain

$$M_{Top} = 179 \pm 9^{+17}_{-19}\ GeV \quad (60 < M_{Higgs} < 1000\ GeV)$$

compared with its direct determinations:

$$CDF:\ 176 \pm 8 \pm 10\ GeV \quad D0\ :\ 199^{+19}_{-21} \pm 22\ GeV.$$

To constraint also M_{Higgs} , the M_{Top} direct measurement from CDF and D0 is needed and we get:

$$M_{Top} = 171^{+12}_{-10}\ GeV$$

$$M_{Higgs} = 100^{+230}_{-76}\ GeV.$$

We can set an upper limit for the Higgs mass:

$$M_{Higgs} < 900\ GeV\ at\ 95\%\ C.L.$$

(direct search lower limit: $M_{Higgs} > 63.5\ GeV\ at\ 95\%\ C.L.$)

If the central value obtained from the fit to M_{Higgs} will remain the same, a tighter upper limit could be expected at the end of ‘95.

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