A Critical Look at Precision Electroweak Data at High Energy – a Hint for Physics beyond the Standard Model ?

A. Gurtu

Tata Institute of Fundamental Research, Colaba, Bombay 400 005, India

Abstract

High energy electroweak data, including the recent measurement of M_{top} is analyzed within the basic framework of the standard model. While the experimentally measured value of $R_b (= \Gamma(Z^0 \rightarrow b\bar{b})/\Gamma(Z^0 \rightarrow \text{hadrons}))$ implies a low value of M_{top} , rest of the data demands a much higher value. Estimates of M_{Higgs} within the SM framework including and excluding this R_b measurement are given. Next this discrepancy is expressed in terms of a new parameter, $\Delta\Gamma_{b\bar{b}}^{NSM}$, the excess $b\bar{b}$ production compared to that expected from a the SM fit. This parameter is determined to be $(9.4 \text{ to } 12.8) \pm 5.0 \text{ MeV}$, implying an *excess* of over 10000 $b\bar{b}$ events in each LEP experiment after the 1993 data is fully analyzed. The origin of these events could be non-minimal Higgs pair production which should be thoroughly searched for in the full data sample of $\sim 2 \times 10^6$ events per LEP experiment. Unless this discrepancy eventually turns out to be a fluctuation one may be witnessing at LEP the advent of physics beyond the standard model.

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During 1993 the four LEP collaborations augmented their stock of Z^0 by ~ 3 million, leading to a total of ~ 8 million events collected to date. Equally importantly, an energy scan was performed at LEP during 1993 and the effective use of transverse beam depolarization led to significantly smaller LEP energy systematics: 4 MeV on M_Z and 3 MeV on Γ_Z . Asymmetry measurements of Z^0 decay at LEP now lead to an uncertainty of only 5×10^{-4} on $\sin^2 \theta_w^{\text{eff}}$ and increasingly sophisticated tagging of $Z^0 \rightarrow b\bar{b}$ events has led to a 1 % accuracy in the determination of $R_b (= \Gamma(Z^0 \rightarrow b\bar{b})/\Gamma(Z^0 \rightarrow \text{hadrons}))$. The A_{LR} measurements at SLD have also become precise enough so that the error on $\sin^2 \theta_w^{\text{eff}}$ derived from it is now only 1×10^{-3} .

While the detailed analyses of all 1993 data, including in particular, heavy flavour tagging and tau polarization, will take some time, the ‘standard’ lineshape analysis of the full data sample has already been carried out by the LEP collaborations leading to new (preliminary) values for the Z^0 parameters. We critically examine this precise electroweak data for internal consistency as well as compatibility with the Standard Model (SM) to see if any chink appears in the SM armour. Our analysis is based on the electroweak data as finalised by the LEP Electroweak Working Group for presentations at the 1994 Winter conferences at La Thuile and Moriond[1] which, assuming lepton universality, is presented in tables 1,2 and 3. In addition we use the recently available results from the CDF collaboration on M_{top} [2]: $M_{\text{top}} = 174 \pm 16$ GeV.

We note that LEP data alone leads to a value of $\sin^2 \theta_w^{\text{eff}} = 0.2322 \pm 0.0005$ ($\chi^2/\text{DOF} = 6.3/5$) whereas the measurement of A_{LR} by the SLD yields $\sin^2 \theta_w^{\text{eff}} = 0.2294 \pm 0.0010$ giving a final average of 0.2317 ± 0.0004 ($\chi^2/\text{DOF} = 12.8/6$). The LEP and SLD values differ by 2.5σ . While this indicates a disagreement between two experimental values, this is not intrinsically interesting from the point of view of non-standard physics.

We now come to the second and potentially more interesting inconsistency in the data which has been known for some time but is now sharpened due to the decrease in errors. Within the SM framework the experimental value of R_b implies a low value of M_{top} which is inconsistent with the rest of the electroweak data which seems to demand a rather high M_{top} value: in particular the direct observation of top by CDF. We shall attempt to quantify this effect and point out some directions to resolve this inconsistency.

We begin by fitting the data given in tables 1-3 within the SM framework[3], allowing M_{top} and α_s to be free parameters. Keeping in mind the small sensitivity of the data to the Higgs mass the fits are carried out for fixed values of $M_{\text{Higgs}} = 60, 300, 1000$ GeV. These results are shown in the upper part of table 4.¹ At the bottom of the table we present fit results floating all the parameters simultaneously.

In the last three rows we give the values of the total χ^2 per degree of freedom (DOF) and the χ^2 values on the R_b and on $\sin^2 \theta_w^{\text{eff}}$ from SLD. These last two χ^2 values immediately show the afore-mentioned inconsistencies in the SM fits to the data. One

¹The fitted values are slightly different from those quoted in [1]. This difference is understood to be due to the different SM libraries used: ZFITTER4.6 in our case and the Burgers,Hollik,Martinez (BMH) library in [1].

also notes from table 4 (what has been noted earlier[3,1]) that the absolute values of the total χ^2 are lowest for the lowest Higgs mass (60 GeV, the lower experimental limit from LEP). This is also reflected in the fit where all parameters are floated: the fitted value of M_{Higgs} is compatible with the lower limit from LEP and the 1σ upper limit seems constrained to a small value of ~ 250 GeV. While this could be (and was) explained away as a peculiar fluctuation in the data in [4], the persistence of this effect with a much higher statistical significance (~ 4 times the data) now begins to cast doubt on this explanation. We will attempt to resolve this issue also in this work.

In the next step of the current analysis we ignore the R_b data point from the data set given in tables 1-3 and repeat the same fits. The results are presented in table 5.

The fitted values of M_{top} increase by about 3 GeV as the R_b data is not pulling down its value any more. What is important to note is the variation of the total χ^2/DOF as a function of M_{Higgs} : *it is almost constant* (for the fits which include SLD DATA, the variation in χ^2 is almost entirely due to the SLD data which is in disagreement with the other LEP data causing distortion in the fit). The fitted value of M_{Higgs} in the last fit also now gives a much higher 1σ upper limit of ~ 500 GeV.

Thus we conclude that in the data including R_b (table 4) the variation in χ^2 with M_{Higgs} is entirely due to the effect of an incompatible value of R_b : it demands a low M_{top} and the correlation of the effects due to M_{top} and M_{Higgs} leads to the favouring of low values of M_{Higgs} .

Thus, within the MSM framework, the current best values of M_{Higgs} are 69_{-9}^{+188} GeV using all data, and 120_{-60}^{+364} GeV if we ignore the R_b data point, the lower limit being set by the LEP searches. In figure 1 we present the corresponding 68% contours of M_{top} vs M_{Higgs} .

The last step in our analysis is to estimate quantitatively the implications of the R_b incompatibility. Since a high value of R_b indicates excess $b\bar{b}$ production compared to SM expectations we parametrize this excess in terms of a new parameter: $\Delta\Gamma_{b\bar{b}}^{\text{NSM}}$ (NSM indicating Non Standard Model). In principle one should carry out a fit in terms of a completely self-consistent model. The simplest beyond-the-SM scenario is that of the MSSM (Minimal Supersymmetric extension of the SM) which incorporates 2 Higgs doublets. *In practice*, a large number of parameters of the MSSM are unknown, thereby making a comprehensive fit to the data problematic. Our approach is a pragmatic one: that the minimal SM provides a very good description of the existing experimental data and that the specific deviation we observe in R_b can be parametrized in terms of an NSM piece. The incorporation of this extra piece, $\Delta\Gamma_{b\bar{b}}^{\text{NSM}}$, in the fits is then done in a consistent way, adding its effect in all the relevant quantities; thus the theoretical values of these various quantities become

$$\Gamma_{b\bar{b}}^{\text{TH}} = \Gamma_{b\bar{b}}^{\text{SM}} + \Delta\Gamma_{b\bar{b}}^{\text{NSM}} \quad (1)$$

$$\Gamma_Z^{\text{TH}} = \Gamma_Z^{\text{SM}} + \Delta\Gamma_{b\bar{b}}^{\text{NSM}} \quad (2)$$

$$\sigma_{\text{had}}^{\text{o,TH}} = \frac{12\pi}{M_Z^2} \frac{\Gamma_e^{\text{SM}}(\Gamma_{\text{had}}^{\text{SM}} + \Delta\Gamma_{\text{bb}}^{\text{NSM}})}{(\Gamma_Z^{\text{TH}})^2} \quad (3)$$

$$R_l^{\text{TH}} = \frac{\Gamma_{\text{had}}^{\text{SM}} + \Delta\Gamma_{\text{bb}}^{\text{NSM}}}{\Gamma_l^{\text{SM}}} \quad (4)$$

$$R_b^{\text{TH}} = \frac{\Gamma_{\text{bb}}^{\text{SM}} + \Delta\Gamma_{\text{bb}}^{\text{NSM}}}{\Gamma_{\text{had}}^{\text{SM}} + \Delta\Gamma_{\text{bb}}^{\text{NSM}}} \quad (5)$$

The results of the fits are shown in table 6.

The excess partial width $\Delta\Gamma_{\text{bb}}^{\text{NSM}}$ amounts to ~ 11.5 MeV with a ~ 5 MeV error and owing to the inclusion of an additional source of hadrons the fitted value of α_s becomes somewhat smaller and the error on it increases.

In figure 2 we show the χ^2 values plotted as a function of M_{top} for the three different values of M_{Higgs} . Figure 2a depicts the situation within the SM framework (corresponding to column 3 of table 4) and figure 2b corresponds to column 3 of table 6 where we have included the new parameter $\Delta\Gamma_{\text{bb}}^{\text{NSM}}$. One clearly sees the anomalous trend of χ_{min}^2 as a function of M_{Higgs} in figure 2a and it disappears in the set of curves presented in figure 2b, thus implying, as expected, the very small sensitivity of the data to the variation of M_{Higgs} . In figure 3a the contour plot of M_{top} vs $\Delta\Gamma_{\text{bb}}^{\text{NSM}}$ is shown corresponding to column 5 of table 6 for $M_{\text{Higgs}} = 300$ GeV and figure 3b shows the contour plot of α_s vs $\Delta\Gamma_{\text{bb}}^{\text{NSM}}$. One sees, again as expected, the significant correlation of $\Delta\Gamma_{\text{bb}}^{\text{NSM}}$ with α_s .

Each LEP experiment currently has about 1.8×10^6 hadronic events corresponding to a hadronic partial width of about 1745 MeV. Thus $\Delta\Gamma_{\text{bb}}^{\text{NSM}} = (9.4 \text{ to } 12.9) \pm 4.8$ MeV implies $(10000 \text{ to } 13000) \pm 4800$ *excess* $Z^0 \rightarrow b\bar{b}$ events in each experiment after the 1993 data is fully analyzed for heavy flavour physics. Thus we briefly speculate on the origin of these events: being $b\bar{b}$ events some kind of Higgs decay seems indicated.

- SM Higgs (H_{SM}) or non-minimal h^0 produced via the bremsstrahlung process $Z \rightarrow Z^* H_{\text{SM}}/h^0$: a lower limit of ~ 60 GeV has been set by the LEP experiments due to *non-observation* of their decay modes. Thus, they cannot contribute to something which is clearly being seen at LEP. For h^0 one could say that its (production) coupling relative to the SM Higgs is extremely small, i.e., $\sin^2(\beta - \alpha)$ is small (here $\tan \beta$ refers to the ratio of the vacuum expectation values of the 2 Higgs doublets and α is the mixing angle which diagonalises the Higgs mass matrix).

- This leaves us with the process $Z \rightarrow h^0 A^0 \rightarrow b\bar{b}b\bar{b}$. The coupling of this process in the 2 Higgs doublet model is given by

$$\frac{\Gamma(Z \rightarrow h^0 A^0)}{\Gamma(Z \rightarrow \nu\bar{\nu})} = \frac{1}{2} \lambda^3 \cos^2(\beta - \alpha) \quad (6)$$

where $\lambda = ((1 - x_h^2 - x_A^2)^2 - 4x_h^2 x_A^2)^{1/2}$, $x_i = m_i/M_Z$.

We have deduced above that since h° is not seen then $\sin^2(\beta - \alpha)$ is small. If this is true, then $\cos^2(\beta - \alpha)$ must be large. Model independent searches have been made by the LEP collaborations to search for this pair production process[5]. While the regions of symmetric masses of h° and A° have been excluded to a high confidence level, the regions of asymmetric masses are not yet explored thoroughly, mainly because they tend to have low selection efficiencies. Thus it is possible that non-minimal Higgs bosons are being pair produced at LEP in a region not yet ruled out by experiment.

To summarize, we have examined closely all the electroweak data available today. Estimates of M_{Higgs} within the SM framework have been obtained, the data favouring $M_{\text{Higgs}} \leq 500$ GeV. The one significant inconsistency within the SM interpretation is due to the measured value of R_b which requires a small value of M_{top} in contrast to the rest of the data, in particular the recent direct measurement of $M_{\text{top}} = 174 \pm 16$ GeV. We have, therefore, gone outside the purview of the SM and introduced a new parameter, $\Delta\Gamma_{b\bar{b}}^{\text{NSM}}$, to quantify this effect of excessive $b\bar{b}$ partial width in Z° decay. Large numbers ($\sim 10^4$) of excess $b\bar{b}$ events should be present in each LEP experiment if one includes the 1993 data which has not yet been fully analyzed for heavy flavour production. An interpretation in terms of pair produced non-minimal higgs bosons seems viable. The difficulty in searching for these signals has been due to the low selection efficiencies of $b\bar{b}$ events and of this higgs signal. With much higher statistics and silicon vertex detectors and sophisticated neural network techniques now available for tagging $b\bar{b}$ events at LEP it should be possible to investigate the entire $h^\circ - A^\circ$ mass plane allowed in LEP 100. In addition to looking for this signal *per se* one should also examine the distribution of the number of jets in the tagged $b\bar{b}$ events. Due to its massive nature the b quark should lead to less gluon bremsstrahlung, i.e., less number of multi-jet events, in the normal QCD $Z^\circ \rightarrow b\bar{b}$ events. On the other hand non-minimal higgs pair production would lead to 4 $b\bar{b}$ quarks in the final state and larger frequency of multi-jet events within the tagged $b\bar{b}$ sample. This could provide at least a qualitative indication of a non-minimal higgs signal. Thus, unless the high measured value of R_b turns out to be one more statistical fluctuation one may have evidence of new physics beyond the SM once all the data collected now has been fully analyzed.

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Table 1 : Electroweak results at Moriond - March 1994

Measurement	Result
a) <u>LEP</u> lineshape and lepton asymmetries: M_Z Γ_Z σ_{had}^0 R_l $A_{\text{FB}}^{\text{o},l}$ + correlation matrix (table 2)	$91.1895 \pm 0.0044 \text{ GeV}$ $2.4969 \pm 0.0038 \text{ GeV}$ $41.51 \pm 0.12 \text{ nb}$ 20.789 ± 0.040 0.0170 ± 0.0016
τ polarization asymmetries: A_τ A_e	0.150 ± 0.010 0.120 ± 0.012
b and c quark results: $\Gamma_{b\bar{b}}/\Gamma_{\text{hadron}}$ $\Gamma_{c\bar{c}}/\Gamma_{\text{hadron}}$ $A_{\text{FB}}^{\text{o},b}$ $A_{\text{FB}}^{\text{o},c}$ + correlation matrix (table 3)	0.2208 ± 0.0024 0.170 ± 0.014 0.0960 ± 0.0043 0.070 ± 0.011
$q\bar{q}$ charge asymmetry: $\sin^2\theta_w^{\text{eff}}$ from $\langle Q_{\text{FB}} \rangle$	0.2320 ± 0.0016
b) <u>p$\bar{p}$ and νN</u> M_W (CDF, CDF prel, D0 prel, UA2) $1 - M_W^2/M_Z^2$ (νN)	$80.23 \pm 0.18 \text{ GeV}$ 0.2256 ± 0.0047
c) <u>SLC</u> $\sin^2\theta_w^{\text{eff}}$ from A_e	0.2294 ± 0.0010

Table 2 : Correlation matrix for fit to LEP cross section and lepton forward backward asymmetry data assuming lepton unversality

	M_Z	Γ_Z	σ_{had}^o	R_l	$A_{\text{FB}}^{o,l}$
M_Z	1.000	0.031	0.003	0.010	0.038
Γ_Z	0.031	1.000	-0.091	0.001	0.002
σ_{had}^o	0.003	-0.091	1.000	0.114	0.002
R_l	0.010	0.001	0.114	1.000	0.004
$A_{\text{FB}}^{o,l}$	0.038	0.002	0.002	0.004	1.000

Table 3 : Correlation matrix for fit to LEP heavy flavour data

	R_b	R_c	$A_{\text{FB}}^{o,b}$	$A_{\text{FB}}^{o,c}$
R_b	1.000	-0.384	-0.057	0.061
R_c	-0.384	1.000	-0.023	-0.025
$A_{\text{FB}}^{o,b}$	-0.057	-0.023	1.000	0.209
$A_{\text{FB}}^{o,c}$	0.061	-0.025	0.209	1.000

Table 4 : Fits to Electroweak data in the SM framework

	LEP DATA	LEP, M_W , νN DATA	LEP, M_W , νN , SLD DATA	LEP, M_W , νN , SLD, M_{top} DATA
$M_{Higgs} = 60$ GeV M_{top} (GeV) α_s χ^2/DOF χ^2 on R_b χ^2 on SLD data	150^{+12}_{-13} $0.125 \pm .005$ 10.5/9 3.2 —	149 ± 11 $0.125 \pm .005$ 10.5/11 3.2 —	157 ± 10 $0.124 \pm .005$ 17.3/12 3.6 6.1	162 ± 8 $0.123 \pm .005$ 18.1/12 3.9 5.2
$M_{Higgs} = 300$ GeV M_{top} (GeV) α_s χ^2/DOF χ^2 on R_b χ^2 on SLD data	169^{+11}_{-12} $0.127 \pm .005$ 11.2/9 4.3 —	168 ± 10 $0.127 \pm .005$ 11.4/11 4.2 —	177 ± 9 $0.125 \pm .005$ 19.3/12 4.8 7.2	176 ± 8 $0.126 \pm .005$ 19.4/12 4.7 7.3
$M_{Higgs} = 1000$ GeV M_{top} (GeV) α_s χ^2/DOF χ^2 on R_b χ^2 on SLD data	186^{+10}_{-11} $0.129 \pm .005$ 12.7/9 5.5 —	184^{+9}_{-10} $0.129 \pm .005$ 12.8/11 5.3 —	193 ± 9 $0.128 \pm .005$ 21.4/12 6.0 7.6	189 ± 8 $0.128 \pm .005$ 22.5/12 5.6 8.6
M_{top} (GeV) M_{Higgs} (GeV) α_s χ^2/DOF χ^2 on R_b χ^2 on SLD data	152^{+23}_{-14} 73^{+286}_{-13} $0.125 \pm .005$ 10.4/8 3.3 —	150^{+21}_{-13} 71^{+266}_{-11} $0.125 \pm .005$ 10.5/10 3.2 —	157^{+13}_{-10} $60^{+??}_{-0}$ $0.124 \pm .005$ 17.3/11 3.6 6.1	163^{+14}_{-9} 69^{+188}_{-9} $0.123 \pm .005$ 18.1/11 3.9 5.6

Table 5 : Fits to Electroweak data in the SM framework ignoring the R_b data point

	LEP DATA	LEP, M_W , νN DATA	LEP, M_W , νN , SLD DATA	LEP, M_W , νN , SLD, M_{top} DATA
$M_{Higgs} = 60$ GeV M_{top} (GeV) α_s χ^2/DOF χ^2 on SLD data	153^{+12}_{-13} $0.125 \pm .005$ 6.9/8 —	151 ± 11 $0.125 \pm .005$ 7.0/10 —	160^{+9}_{-10} $0.124 \pm .005$ 13.4/11 5.7	164 ± 8 $0.123 \pm .005$ 14.0/11 5.2
$M_{Higgs} = 300$ GeV M_{top} (GeV) α_s χ^2/DOF χ^2 on SLD data	173 ± 11 $0.126 \pm .005$ 6.4/8 —	171 ± 10 $0.126 \pm .005$ 6.7/10 —	179 ± 9 $0.125 \pm .005$ 14.1/11 6.7	178 ± 8 $0.125 \pm .005$ 14.2/11 6.9
$M_{Higgs} = 1000$ GeV M_{top} (GeV) α_s χ^2/DOF χ^2 on SLD data	190^{+10}_{-11} $0.128 \pm .005$ 6.5/8 —	187^{+9}_{-10} $0.129 \pm .005$ 6.8/10 —	196 ± 9 $0.127 \pm .005$ 14.7/11 7.1	191 ± 8 $0.128 \pm .005$ 16.1/11 8.1
M_{top} (GeV) M_{Higgs} (GeV) α_s χ^2/DOF χ^2 on SLD data	177^{+32}_{-33} $388^{+??}_{-328}$ $0.127 \pm .009$ 6.4/7 —	167^{+38}_{-24} $224^{+??}_{-164}$ $0.126 \pm .006$ 6.6/9 —	158^{+30}_{-11} 60^{+481}_{-0} $0.124 \pm .005$ 13.4/10 5.6	169^{+16}_{-12} 120^{+364}_{-60} $0.124 \pm .005$ 13.8/10 5.9

Table 6 : Fits to Electroweak data in the SM framework with an additional piece $\Delta\Gamma_{b\bar{b}}^{\text{NSM}}$

	LEP DATA	LEP, M_W , νN DATA	LEP, M_W , νN , SLD DATA	LEP, M_W , νN , SLD, M_{top} DATA
$M_{\text{Higgs}} = 60 \text{ GeV}$				
$M_{\text{top}} \text{ (GeV)}$	153 ± 12	151 ± 11	160 ± 10	164 ± 8
α_s	$0.107 \pm .010$	$0.108 \pm .010$	$0.106 \pm .010$	$0.105 \pm .010$
$\Delta\Gamma_{b\bar{b}}^{\text{NSM}} \text{ (MeV)}$	9.4 ± 5.0	9.3 ± 5.0	9.8 ± 5.0	10.1 ± 5.0
χ^2/DOF	$6.9/8$	$7.0/10$	$13.4/11$	$14.0/11$
$\chi^2 \text{ on SLD data}$	—	—	5.7	5.2
$M_{\text{Higgs}} = 300 \text{ GeV}$				
$M_{\text{top}} \text{ (GeV)}$	173 ± 11	171 ± 10	179 ± 9	178 ± 8
α_s	$0.106 \pm .010$	$0.107 \pm .010$	$0.105 \pm .010$	$0.105 \pm .010$
$\Delta\Gamma_{b\bar{b}}^{\text{NSM}} \text{ (MeV)}$	10.9 ± 5.0	10.8 ± 5.0	11.3 ± 5.0	11.3 ± 5.0
χ^2/DOF	$6.4/8$	$6.6/10$	$14.1/11$	$14.2/11$
$\chi^2 \text{ on SLD data}$	—	—	6.7	6.9
$M_{\text{Higgs}} = 1000 \text{ GeV}$				
$M_{\text{top}} \text{ (GeV)}$	190^{+10}_{-11}	187^{+9}_{-10}	196 ± 9	191 ± 8
α_s	$0.106 \pm .010$	$0.107 \pm .010$	$0.104 \pm .010$	$0.106 \pm .010$
$\Delta\Gamma_{b\bar{b}}^{\text{NSM}} \text{ (MeV)}$	12.4 ± 5.0	12.2 ± 5.0	12.8 ± 5.0	12.4 ± 5.0
χ^2/DOF	$6.5/8$	$6.8/10$	$14.7/11$	$16.1/11$
$\chi^2 \text{ on SLD data}$	—	—	7.1	8.1
$M_{\text{top}} \text{ (GeV)}$	177^{+32}_{-33}	167^{+38}_{-24}	160^{+28}_{-10}	169^{+16}_{-13}
$M_{\text{Higgs}} \text{ (GeV)}$	$390^{+??}_{-330}$	$225^{+??}_{-165}$	60^{+495}_{-0}	120^{+364}_{-60}
α_s	$0.106 \pm .010$	$0.107 \pm .010$	$0.106 \pm .010$	$0.105 \pm .010$
$\Delta\Gamma_{b\bar{b}}^{\text{NSM}} \text{ (MeV)}$	11.2 ± 7.2	10.5 ± 6.0	9.8 ± 5.0	10.5 ± 5.1
χ^2/DOF	$6.4/7$	$6.6/9$	$13.4/10$	$13.8/12$
$\chi^2 \text{ on SLD data}$	—	—	5.7	5.9

Figure captions

Figure 1 : M_{top} vs M_{Higgs} contour plots. The solid curve corresponds to the fit where all the data is used, the dashed curve when R_b is ignored. The lower limit of $M_{\text{Higgs}} = 60$ GeV is taken from LEP searches.

Figure 2 : Plot of χ^2 as a function of M_{top} using LEP + Collider + νN data, (a) for standard model fits (table 4, column 3), (b) for fits including the new parameter $\Delta\Gamma_{b\bar{b}}^{\text{NSM}}$ (table 6, column 3)

Figure 3 : Contour plots (68%) for fit corresponding to column 5 of table 6, where all parameters (including M_{Higgs}) are floated, a) M_{top} vs $\Delta\Gamma_{b\bar{b}}^{\text{NSM}}$, b) α_s vs $\Delta\Gamma_{b\bar{b}}^{\text{NSM}}$

Fig 1

Fig 2a

Fig 3a

Fig 3b