Implementation of fourth SM Generation in Gfitter

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Abstract

With the aid of Gfitter, a theoretical model of high-energy physics can be tested and constrained by using electroweak precision data taken from LEP, SLC, and Tevatron. In this work, an implementation in Gfitter is done for a fourth Standard Model Generation. Constraints for the masses of one new fermion family for one specifical setting are found.

1 Introduction

The Standard Model is the theory that so far best describes the interactions between elementary particles (three generations of fermions), the basic constituents of matter. These interactions are divided in strong and electroweak, with their respective bosons (force carrier particles). All these particles that compose the Standard Model have been discovered experimentally, except for the Higgs Boson, a spin-0 boson generated by a scalar field, which gives mass to all particles.

Although this model accomodates three families of fermions, it cannot explain this number. Fig. 1 shows that three families of light neutrinos fit perfectly the measurements of the hadron production cross-section around the Z resonance. This means that for models that suggest extra fermion families, the mass of the new neutrinos is bounded by $m_\nu \geq M_Z/2$. Considering these theories, there are also other experimental bounds given by LEP II and Tevatron respectively[2]:

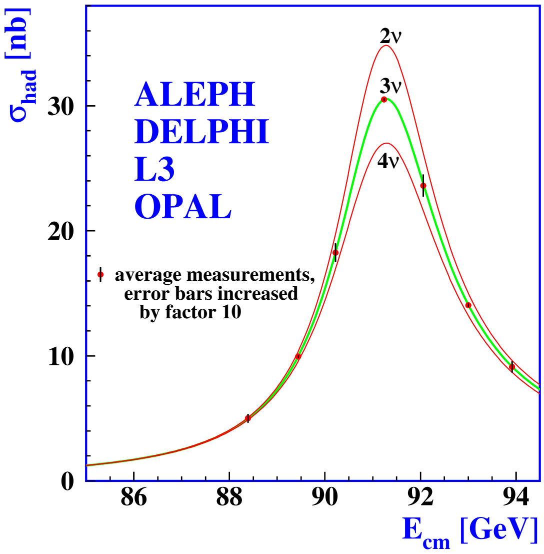


Figure 1: Measurements of the hadron production cross-section around the Z resonance. The curves indicate the predicted cross-section for two, three and four neutrino species with SM couplings and negligible mass[5].

$$m_{\ell_4} \geq 101 GeV; \qquad (1)$$
$$m_{u_4} > 258 GeV.$$

The contributions of any theory beyond Standard Model, including fourth-generation fermions, to electroweak processes can be measured by fitting theoretical predictions to the data. The high-precision electroweak data obtained from measurements at LEP, SLC, and Tevatron has been useful to test the theoretical predictions of the Standard Model, and also to constrain models beyond, by fitting them to this experimental results. The implications of any model for electroweak observables are assumed to be through loop contributions from heavier particles than the Z-boson (for instance, for SM, the top quark and the Higgs boson; for fourth-generation theories, new fermions).

Fits to electroweak data are performed by minimizing the χ^2 function given by:

$$\chi^2 = \sum_{i=1}^{N} \frac{(X_{exp_i} - X_{theo_i}(y_{mod}))^2}{\sigma^2_{exp_i}},$$

where $\{X_{exp_i}\}$ is a set of N experimental measurements, and $\{X_{theo_i}\}$ are their respective theoretical predictions, which depend on certain y_{mod} parameters of the model.

Fig. 2 shows a comparison between values predicted by theory and experimental measurements for some electroweak observables for SM [3]. As it can be seen, the difference between the fit and the measurements is always less than 3σ, which means that the Standard Model describes well electroweak processes.

2 Oblique corrections

New-physics contributions to electroweak data are parametrized by oblique corrections (STU parameters).

The oblique-parameter space is represented by the ST-plane. In general, the U parameter is small and not used in practice. Fig. 3 shows the constraints for the S and T parameters as a result of a fit to electroweak precision measurements for three different Higgs mass values [4]. It can be seen that only small contributions from beyond the Standard Model are allowed. The results for the values of the STU parameters, for a Higgs mass of $m_H = 116$ GeV ($m_H = 350$ GeV in parentheses) are the following [4]:

$$S = 0.02(-0.06) \pm 0.11,$$
$$T = 0.05(0.15) \pm 0.12,$$
$$U = 0.07(0.08) \pm 0.12.$$

3 Fourth-generation Quarks and Leptons

Following Ref. [1], a fourth-generation-fermion implementation for Gfitter was done. Fig. 4 shows the dependance of the oblique corrections on the masses of fourth-generation fermions. The contributions from quarks and leptons are considered separately on the plots: the solid line refers to lepton

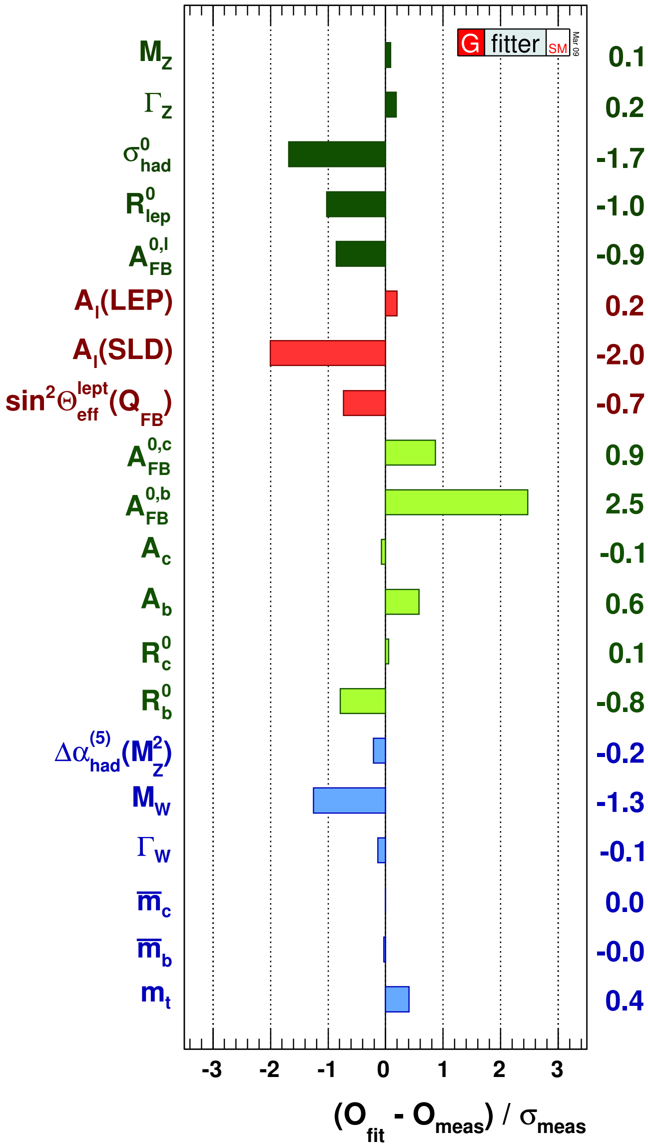


Figure 2: Comparison of fit results with direct measurements from LEP, SLD, and Tevatron for different physical observables. O_{fit} and O_{meas} represent respectively the values expected from the fit of the theory to the data and the measured values of each observable; σ_{meas} is the experimental error.

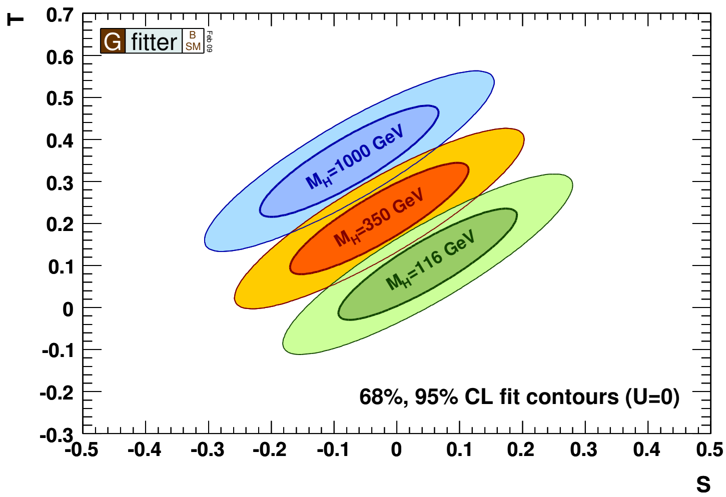


Figure 3: Allowed contours of 68% and 95% CL in the (T,S)-plane obtained from fits with $m_t = 172.4$ GeV and $M_H = 116$, 350, and 1000 GeV.

contribution only, while the dotted line refers to quark contribution. An excellent agreement between Ref. [1] and the implementation was obtained.

In this implementation, the STU parameters were substituted by the mean mass and the mass difference of the fourth-generation leptons and quarks, respectively. The parameter space for this theory was constrained as a result of the fit.

The two plots in Fig. 5 show the constraints for the mean mass and the mass difference for the fourth-generation lepton sector. For these plots, the mean quark mass has been fixed to 300 GeV, and the difference of quark masses to 50 GeV. These values were chosen in agreement with the experimental bounds in eq. (1). On the top, the mass difference of the fourth-generation leptons is left as a free parameter. We can see that for this setting the Higgs mass has an upper bound around 350 GeV. For a value of $M_H = 120$ GeV, there could be very heavy new leptons. In addition, in the plot on the bottom, it can be seen that the mass difference of fourth-generation leptons is between 40 and 95 GeV.

In Fig. 6, we have fixed the mean lepton mass at 130 GeV and the lepton mass difference at 50 GeV obeying eq. (1); the quark mass difference and the mean quark mass are free parameters on each plot respectively. We can see that for this setting, large values for the Higgs mass are allowed, as well as a

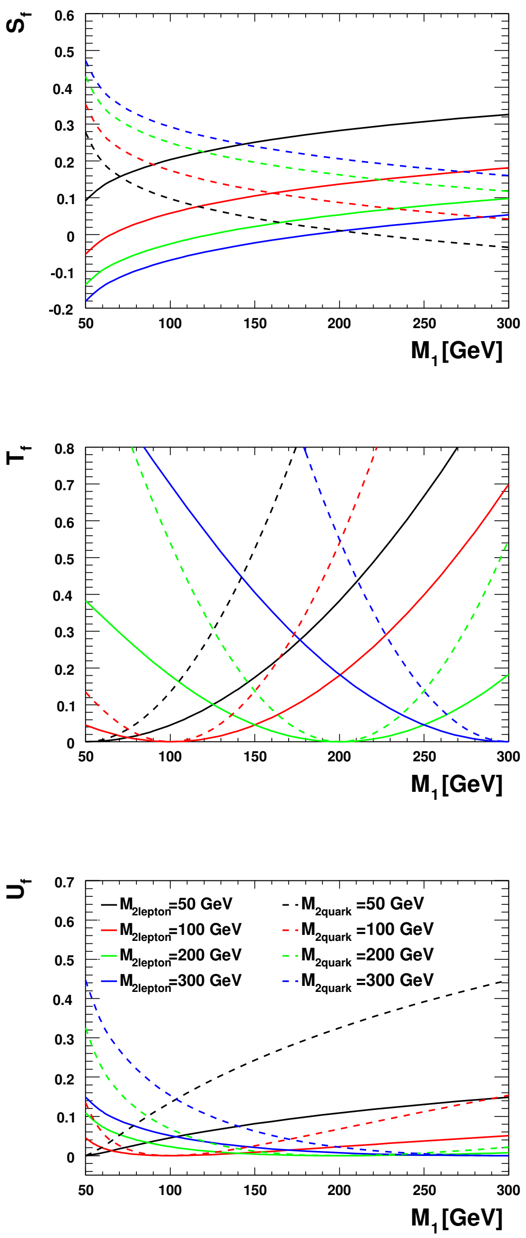
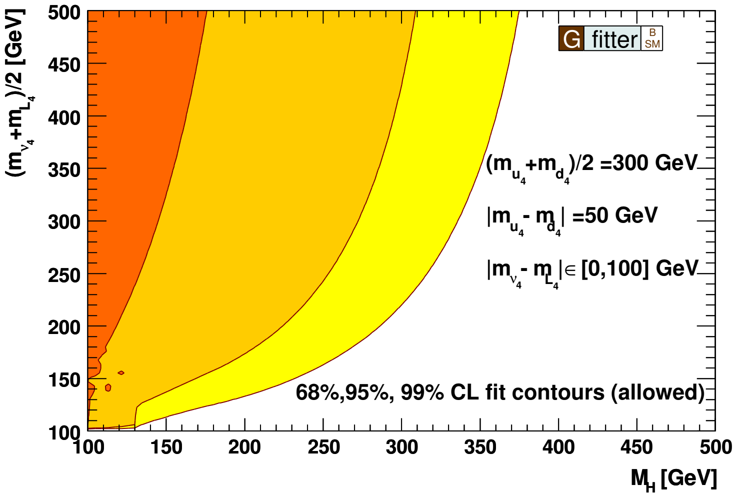


Figure 4: Contributions to the S, T, and U parameters from one extra fermion generation for different quark and lepton masses.



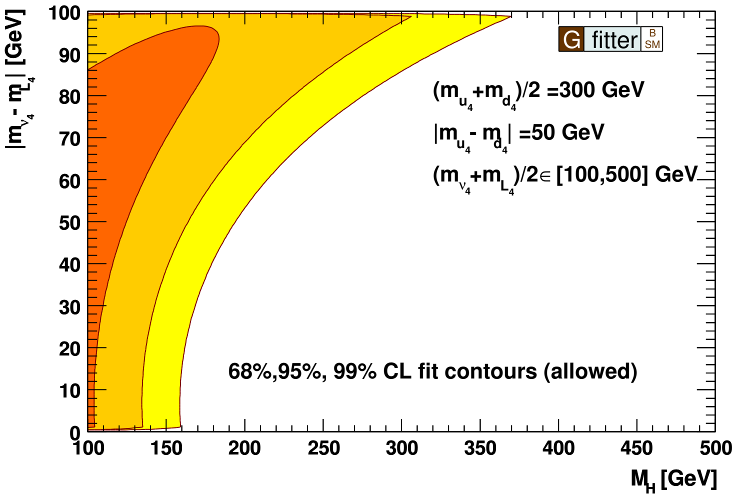


Figure 5: Constraints for the lepton parameters. The quark contribution is fixed. Top: Contours for the 68 %, 95 %, and 99% CL in the $(m_{\nu_4} + m_{\ell_4})/2$-$M_H$ plane. Bottom: Contours for the 68 %, 95 %, and 99% CL in the $|m_{\nu_4} - m_{\ell_4}|$-M_H plane.

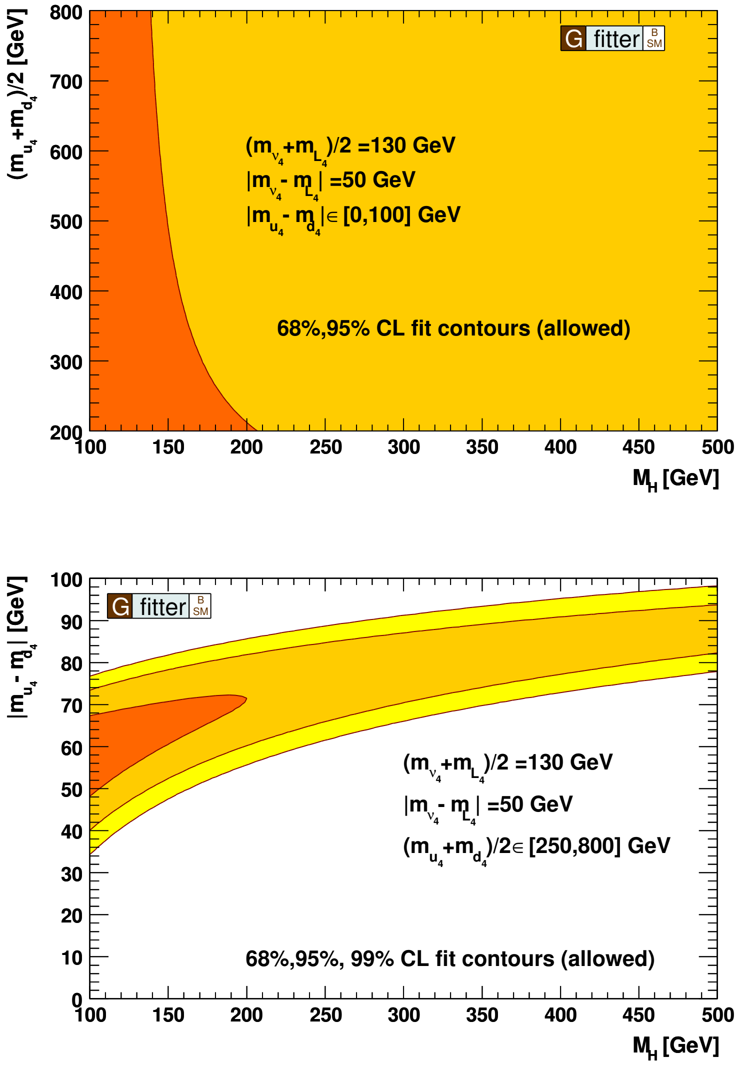


Figure 6: Constraints for the quark sector. The lepton contribution is fixed. Top: Contours for the 68 and 95% CL in the $(m_{u_4} + m_{d_4})/2$-M_H plane. Bottom: Contours for the 68 %, 95 %, and 99% CL in the $|m_{u_4} - m_{d_4}|$-M_H plane.

large range of new-quark mean masses. Besides, for any value of M_H, there is a difference of 40 to 90 GeV between the masses of the new-generation quarks.

4 Summary

As we have seen, the Standard Model describes well the electroweak data. Oblique corrections in this sector are small. Therefore, also new physics contributions to electroweak processes need to be small.

It was possible to constrain the parameter space for the fourth fermion generation. As a result, we found that in this model large Higgs masses are allowed, in contrast with the Standard Model prediction ($M_H \leq 150$ Gev [4]).

For the tested settings, the mass difference of the new quark sector, as well as the new lepton secton, is always below 100 GeV. The absolute masses of the new fermions could be in the energy range of the LHC. Therefore, the fourth generation could be tested here.

References

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[5] The ALEPH, DELPHI, L3, OPAL, SLD Collaborations, the LEP Electroweak Working Group, the SLD Electroweak and Heavy, Phys.Rept. **427:257** (2006) [arXiv: hep-ex/0509008v3].