Effects of Sfermion Mixing induced by RGE in the CMSSM

Mario E. Gómez
Department of Applied Physics, University of Huelva, 21071 Huelva, Spain
Sven Heinemeyer
Instituto de Física de Cantabria (CSIC-UC), 39005 Santander, Spain
Muhammad Rehman
Instituto de Física de Cantabria (CSIC-UC), 39005 Santander, Spain
January 22, 2016

Abstract

Even within the Constrained Minimal Supersymmetric Standard Model (CMSSM) it is possible to induce sfermion flavor mixing through the Renormalization Group Equations (RGE) when the full structure of the Yukawa couplings is considered. We analyse the impact of including those effects on the accurate computation of $B$-physics observables, electroweak precision observables (EWPO) and the Higgs boson mass predictions.

1 Introduction

Supersymmetric (SUSY) extensions of the Standard Model (SM) [1] come with many promises to become the next step in the search for new physics. They offer a solution to the hierarchy problem, a candidate to Dark Matter and many new particles at the range of the energy of the LHC. Now, with the data of the first run of the LHC we have new bounds for the SUSY observables which constraint the SUSY parameters. We study the impact of these bounds to the SUSY contribution to some of the SM well measured observables. In particular, we include on our analysis flavor violating (FV) contributions arising from the new SUSY particles.

We work in the framework of the Minimal Supersymmetric extension of the SM (MSSM), with the additional assumption that SUSY is broken by universal soft terms at the grand unification scale (GUT). In this framework, called constrained MSSM (CMSSM), there is FV only in the squark sector. This arises due to the presence of the Yukawa couplings in the RGE’s, such that the FV is
only due the CKM matrix. Hence, this is the Minimal Flavor Violation (MFV) scenario [2]. However, this is not enough to explain the experimental evidence for neutrino flavor oscillations. In order to account for those, we must enlarge the CMSSM. This can achieved by augmenting the CMSSM with a "see-saw" mechanism od type I. The resulting model, called "CMSSM-seesaw I" predicts also FV in the lepton sector (LFV).

We present in the next sections some results on FV predictions on the CMSSM and their contribution to the evaluation of electroweak precision observables (EWPO), in particular $M_W$ and the effective weak leptonic mixing angle, $\sin^2 \theta_{\text{eff}}$. The effects on other observables like $B$ physics observables (BPO), in particular $\text{BR}(B \to X_s \gamma)$, $\text{BR}(B_s \to \mu^+ \mu^-)$ and $\Delta M_{B_s}$, as well as the masses of the neutral and charged Higgs bosons in the MSSM were found to be small. We refer the reader to ref. [3, 4] for further details of our computation and a complete list of references.

![Figure 1: Contours of $\delta^{QLL}_{23}$ (left) and $\delta^{ULR}_{23}$ (right) in the $m_0-m_{1/2}$ plane for $\tan \beta = 45$ and $A_0 = -3000$ GeV in the CMSSM.](image)

2 Scalar fermion sector with flavor mixing

The MSSM is defined by the superpotential:

$$W_{\text{MSSM}} = \epsilon_{\alpha\beta}(Y_{ii} e_i H_1^\alpha e_i H_2^\beta + Y_{ij} d_j H_1^\alpha D_i^\beta + Y_{ij} H_2^\beta U_i^\alpha Q_j^\beta + \mu H_1^\alpha H_2^\beta)$$

where $L_i$ represents the chiral multiplet of a $SU(2)_L$ doublet lepton, $E_i^c$ a $SU(2)_L$ singlet charged lepton, $H_1$ and $H_2$ two Higgs doublets with opposite hypercharge. Similarly $Q$, $U$ and $D$ represent chiral multiplets of quarks of
a $SU(2)_L$ doublet and two singlets with different $U(1)_Y$ charges. Three generations of leptons and quarks are assumed and thus the subscripts $i$ and $j$ run over 1 to 3. The symbol $\epsilon_{\alpha\beta}$ is an anti-symmetric tensor with $\epsilon_{12} = 1$. SUSY is "softly broken" by a scalar potential with bilinear and trilinear combinations of the superpartners. Within the Constrained MSSM the soft SUSY-breaking parameters are assumed to be universal at the Grand Unification scale $M_{GUT} \sim 2 \times 10^{16}$ GeV. All the scalars are assumed to have the same mass, $m_0$, the trilinear soft terms are proportional to their respective Yukawa couplings and fermionic partners of the gauge bosons have a common mass $m_{1/2}$. Since the soft terms are universal, at the GUT scale, they are invariant under superfield rotations. Hence, it is possible to work in the basis in which the Yukawa couplings are $y_{ij} = 0$. Therefore, we require radiative symmetry breaking to fix $A$ and fermionic partners of the gauge bosons have a common mass $m_{1/2}$. Since $\delta_{ij}$ show a decoupling effect, as it is displayed in fig. 1 for the case of $\delta_{i3}^{ULR}$. However, for $\delta_{32}^{QLL}$ we found a non decoupling effect. The increase of this term with $m_0$ produces important contributions to the EWPO as we will see in the next section.
3 Computation of some observables including squark FV.

The flavor violating parameters, generated from the RGE running, enter at one loop in the computation of the physical observables. Numerically, the results have been obtained using the code FeynHiggs [6], which contains the complete set of one-loop corrections from (flavor violating) squark and slepton contributions as given in ref. [7].

![Figure 2: Contours of $\Delta M_W^{MFV}$ in GeV (left) and $\sin^2 \theta_{\text{eff}}$ in the $m_0 - m_{1/2}$ plane for $\tan \beta = 45$ and $A_0 = -3000$ GeV in the CMSSM.](image)

EWPO, which are known with a great accuracy, have the potential to allow a discrimination between quantum effects of the SM and SUSY models. Examples are the $W$-boson mass $M_W$ and the $Z$-boson observables, such as the effective leptonic weak mixing angle $\sin^2 \theta_{\text{eff}}$, whose present experimental uncertainties are $\delta M_W^{\text{exp, today}} \sim 15$ MeV and $\delta \sin^2 \theta_{\text{eff}}^{\text{exp, today}} \sim 15 \times 10^{-5}$. The experimental uncertainty will further be reduced to $\sim 4$ MeV and $\sim 1.3 \times 10^{-5}$ respectively in future linear colliders.

To show explicitly the contribution of the FV entries to the different observables, we compare the full contribution with the value obtained by setting all $\delta_{ij}^{FAB} = 0$. The results for $\Delta M_W^{MFV} = M_W - M_W^{\text{MSSM}}$ and $\Delta \sin^2 \theta_{\text{eff}}^{MFV} = \sin^2 \theta_{\text{eff}} - \sin^2 \theta_{\text{eff}}^{\text{MSSM}}$ (where $M_W^{\text{MSSM}}$ and $\sin^2 \theta_{\text{eff}}^{\text{MSSM}}$ are the obtained values with all $\delta_{ij}^{FAB} = 0$) are displayed on fig. 2. We can observe a non-decoupling behavior for the EWPO similar as the one observed in some of the $\delta_{23}^{QLL}$ as shown in fig. 1. The FV contributions to $M_W$ and $\sin^2 \theta_{\text{eff}}$ can be above the experimental uncertainty at some regions of the space of parameters. Therefore,
FV contributions can not be neglected in their evaluation. Particularly, in view of a future improved experimental accuracies.

The FV contribution to other observables turn out to be small, the full FV computation does not lead to significant differences respect the common approach of setting all the $\delta_{ij}^{F,AB} = 0$. In the case of the lightest MSSM Higgs boson, the uncertainties arising from the theoretical computation are larger than the experimental precision of the Higgs mass discovered at the LHC. Even though, we find that the values for $\Delta M_H^{MFV} = M_H - M_H^{MSSM}$ that enter in the theoretical prediction are far below the experimental precision. Similarly, we found that for BPO the approach of taking $\delta_{ij}^{F,AB} = 0$ is justified.

4 Conclusion

We studied the impact of including MFV entries on the sfermion mass matrices as they arise naturally on the CMSSM when the CKM matrix is included in the RGE’s. After a careful evaluation of several precision observables, we conclude that the effect is not very significant for BPO and Higgs boson masses. However, EWPO receive contributions that show a non-decoupling behavior as the values of the SUSY spectrum increases. For instance, those effects can be larger than the current experimental accuracy in $M_W$ and $\sin^2\theta_{\text{eff}}$. Taking those effects correctly into account places new upper bounds on $m_0$ that are neglected in recent phenomenological analyses. Further applications to FV Higgs decays can be found in ref. [8]. Our conclusions can also apply to popular neutrino motivated extensions of the CMSSM like the CMSSM-seesaw I.

5 Acknowledgements

This work is supported by by the Spanish MICINN’s Consolider-Ingenio 2010 Programme under grant MultiDark CSD2009-00064. The authors also acknowledge further support from CICYT (S.H. and M.R. from the grant FPA 2013-40715-P and M.E.G. from FPA2011-23781).

References

[1] H. Haber and G. Kane, Phys. Rept. 117 (1985) 75;

[2] A. Buras et al., Phys. Lett. B 500 (2001) 161.

[3] M. E. Gómez, S. Heinemeyer and M. Rehman, Eur. Phys. J. C 75 (2015) 9, 434.
[4] M. E. Gómez, T. Hahn, S. Heinemeyer and M. Rehman, Phys. Rev. D 90 (2014) 7, 074016

[5] W. Porod, Comput. Phys. Commun. 153 (2003) 275 [arXiv:hep-ph/0301101].

[6] S. Heinemeyer, W. Hollik and G. Weiglein, Comput. Phys. Commun. 124 (2000) 76; T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak and G. Weiglein, Comput. Phys. Commun. 180 (2009) 1426;

[7] M. Arana-Catania, S. Heinemeyer, M. J.Herrero and S. Peñaranda, JHEP 1205 (2012) 015

[8] M. E. Gómez, S. Heinemeyer and M. Rehman, arXiv:1511.04342 [hep-ph].