PROCEEDINGS OF SCIENCE

Neutrino mass textures and slepton flavor violation with a determined θ_{13}

Mario E. Gómez[*][†]
Dpt. de Física Aplicada, Universidad de Huelva,
21071, Huelva, Spain
E-mail: `mario.gomez@dfa.uhu.es`

We investigate the prospects for detection of lepton flavour violation (LFV) in sparticle production and decays at a Linear Collider (LC). We select models In the framework of the Constrained Minimal Supersymmetric Standard Model (CMSSM) with see-saw neutrinos and use models that fit the latest neutrino data to evaluate signals of LFV on sleptons.

VIII International Workshop on the Dark Side of the Universe,
June 10-15, 2012
Rio de Janeiro, Brazil

PoS(DSU 2012)027

---

[*] Speaker.

[†] Work supported by the Spanish MCINN Consolider-Ingenio 2010 Programme under grant MultiDark CSD2009-00064 and the projects FPA2011-23781 and P07FQM02962 founded by the Spanish MINECO and the Junta de Andalucia respectively.

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike Licence.

1. introduction

Data from both atmospheric [1] and solar [2] neutrinos have confirmed the existence of neutrino oscillations with near-maximal $\nu_\mu - \nu_\tau$ mixing (Super-Kamiokande) and large $\nu_e \to \nu_\mu$ mixing (SNO). Recently, concrete evidence on the possible range of the θ_{13} has been found [3, 4]. Later data [5, 6] further constrain the range of of θ_{13}. These observations would also imply violation of the corresponding charged-lepton numbers, which in supersymmetric theories might be significant and observable in low-energy experiments [7, 8, 9].

A strong constraint on radiative decays is the recent MEG's upper limit on BR($\mu \to e\gamma$) [10], SUSY models can explain this limits with sparticles with masses in the TeV range. The recent measurement of the higgs boson mass [11, 12] is compatible with a large SUSY spectrum that still can be the TeV range. This makes difficult to observe slepton flavour oscillations at LHC [13, 14], where sleptons are spected to appear in neutralino decays $\chi_2 \to \chi + l_a^\pm l_b^\mp$ ($a \neq b$, here χ is the lightest neutralino, assumed to be the lightest supersymmetric particle (LSP), and χ_2 is the second-lightest neutralino). However a Linear Collider (LC) may find SUSY LFV signals with larger SUSY masses [15, 16].

In this presentation we consider a minimal supersymmetric version of the seesaw mechanism for neutrino masses with a SU(5) model of the Yukawa structure, implemented such that neutrino constraints are satisfied while we choose a set of SUSY parameters satisfying phenomenological constraints to evaluate the LFV violation signals in a future LC.

2. Flavour violating slepton production with *see-saw* neutrinos.

Charged-lepton flavour violation at a LC may occur directly in slepton pair production. Processes leading to lepton production in the decays of a pair of sleptons include

$$\begin{aligned} e^+e^- &\to \tilde{\ell}_i^- \tilde{\ell}_j^+ \to \tau^\pm \mu^\mp \tilde{\chi}_1^0 \tilde{\chi}_1^0, \\ e^+e^- &\to \tilde{\nu}_i \tilde{\nu}_j^c \to \tau^\pm \mu^\mp \tilde{\chi}_1^+ \tilde{\chi}_1^-. \end{aligned} \tag{2.1}$$

Slepton production may also result from the the cascade decays of the heavier gauginos, however these models are subdominant in models with LFV arising by complementing the CMSSM with a *see-saw* mechanism to explain neutrino masses[16].

In the unrotated charged-lepton flavour basis $\tilde{\ell}_i = (\tilde{e}_L, \tilde{\mu}_L, \tilde{\tau}_L, \tilde{e}_R^*, \tilde{\mu}_R^*, \tilde{\tau}_R^*)$, the charged slepton mass matrix is:

$$M_{\tilde{\ell}}^2 = \begin{pmatrix} M_{LL}^2 & M_{LR}^2 \\ M_{RL}^2 & M_{RR}^2 \end{pmatrix}, \tag{2.2}$$

where

$$\begin{aligned} M_{LL}^2 &= m_\ell^\dagger m_\ell + M_L^2 - \frac{1}{2}(2m_W^2 - m_Z^2)\cos 2\beta \; I, \\ M_{RR}^2 &= m_\ell^\dagger m_\ell + M_R^2 - (m_Z^2 - m_W^2)\cos 2\beta \; I, \\ M_{LR}^2 &= (A^e - \mu \tan\beta) \; m_\ell, \\ M_{RL}^2 &= (M_{LR}^2)^\dagger. \end{aligned} \tag{2.3}$$

PoS(DSU 2012)027

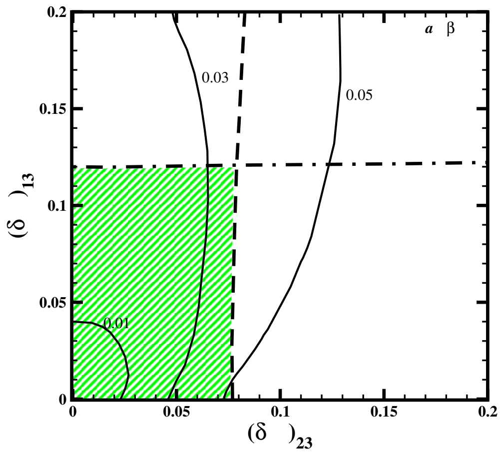

Figure 1: *Constraints on the magnitudes of the mixing parameters and possible LFV effects. The shaded area is allowed by current limits on BR($\tau \to e\gamma$) (dot-dash line) and BR($\tau \to \mu\gamma$) (dash line) using the reference point. The solid lines are contours of* $\sigma(e^+e^- \to \tau^\pm\mu^\mp + 2\chi^0)$ *in fb for* $\sqrt{s} = 2000$ GeV.

PoS(DSU 2012)027

Here we parametrize trilinear soft supersymmetry-breaking terms as $A^e_{ij}(\lambda_e)_{ij}$, where the λ_e are the respective Yukawa couplings. For universal soft terms at some high input scale, one has

$$M_L^2 = M_R^2 \ = \ m_0^2\, I, \ \ A^e_{ij} = A_0 \delta_{ij}, \tag{2.4}$$

In the minimal supersymmetric extension of the seesaw mechanism for generating neutrino masses with three heavy singlet-neutrino states N_i, the leptonic sector of the superpotential is:

$$W = N_i^c (Y_\nu)_{ij} L_j H_2 - E_i^c (Y_e)_{ij} L_j H_1 + \frac{1}{2} {N^c}_i \mathscr{M}_{ij} N_j^c + \mu H_2 H_1 \,, \tag{2.5}$$

where Y_ν is the neutrino Dirac Yukawa coupling matrix, $\mathscr{M}_{ij}$ is the Majorana mass matrix for the N_i, the L_j and H_I are lepton and Higgs doublets, and the E_i^c are singlet charged-lepton supermultiplets.

In the basis where charged leptons and heavy neutrino mass matrices are diagonal, one finds

$$\mathscr{M}_\nu = Y_\nu^T \left(\mathscr{M}^D\right)^{-1} Y_\nu v^2 \sin^2\beta, \tag{2.6}$$

where $v = 174$ GeV and $\tan\beta \equiv v_2/v_1$.

In this minimal supersymmetric version of the seesaw model for neutrino masses, renormalization of the soft supersymmetry-breaking slepton masses would occur while running from the GUT scale to the heavy neutrino mass scales. In the leading-logarithmic approximation, the non-universal renormalization of the soft supersymmetry-breaking scalar masses is given by

$$(M_{\tilde L}^2)_{ij} \ \simeq \ -\frac{1}{8\pi^2}\left(\lambda_{\nu_3}^2 V_D^{*3i} V_D^{3j} \log\frac{M_{\rm GUT}}{M_{\nu_3}} + \lambda_{\nu_2}^2 V_D^{*2i} V_D^{2j} \log\frac{M_{\rm GUT}}{M_{\nu_2}}\right)(3m_0^2 + a_0^2). \tag{2.7}$$

implying that the corresponding corrections to left-handed slepton masses are given by V_D, the Dirac neutrino mixing matrix in the basis where the charged-lepton masses are diagonal. In this approach, non-universality in the soft supersymmetry-breaking left-slepton masses is much larger than that in the right-slepton masses.

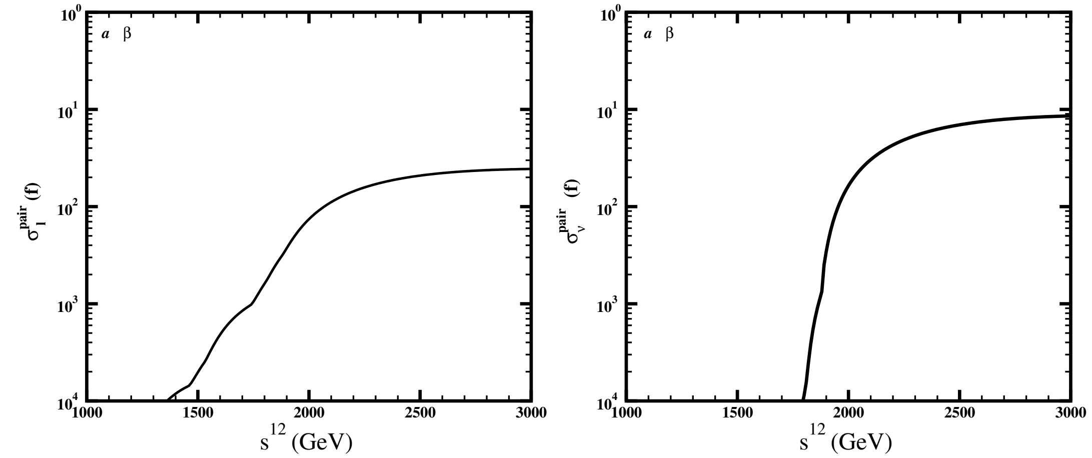

Figure 2: *The left panel shows the values of* $\sigma(e^+e^- \to \tilde{\ell}_i^- \tilde{\ell}_j^+ \to \tau^\pm \mu^\mp + 2\chi^0)$ *vs* $\sqrt{s}$ *for the benchmark point. On the right panel* $\sigma(e^+e^- \to \tilde{\nu}_i \tilde{\nu}_j^c \to \tau^\pm \mu^\mp + \tilde{\chi}_1^+ \tilde{\chi}_1^-)$ *preditions are presented.*

The recent measurement of the Higgs mass at the LHC imposes a severe constraint in the CMSSM parameter space. Althought points predicting m_h in its central value at around 125 GeV generally imply large SUSY spectrum and large neutralino relic density, it is still possible to find some points predicting m_h in the lower part of the experimental range with a moderate masses for the SUSY particles and satisfaction of all the phenomenological constraints [17]. We use as a reference:

$$\tan\beta = 45, \quad m_0 = 730\ \text{GeV}, \quad \text{M}_{1/2} = 900\ \text{GeV}, \quad \text{A}_0 = -1310\ \text{GeV}. \tag{2.8}$$

This point belong to the $\chi - \tilde{\tau}$ coannihilation region, and predicts $\Omega_\chi h^2 = 0.11$ and $m_h =$ 122 GeV.

Fig. 1 shows typical values of the LFV entries defined as:

$$\delta_{LL}^{ij} = (M_{LL}^2)^{ij}/(M_{LL}^2)^{ii}; \tag{2.9}$$

such that the limits on BR($\tau \to e\gamma$) and BR($\tau \to \mu\gamma$) are preserved.

3. An SU(5) SUSY model with massive neutrinos.

In our current work, we go beyond the above approximation by including the complete mixing effects in interesting regions of the parameter space. For the structures of the mixing matrices, as well as the heavy and light neutrino hierarchies, one must appeal to a specific GUT model. Here we consider textures obtained by combining SU(5) with a U(1) family symmetry [18, 19].

$$Y_\ell = \begin{pmatrix} \varepsilon^4 & 1.5\varepsilon^3 & 2\varepsilon \\ 0.5\varepsilon^3 & -1.9\varepsilon^2 & -0.5\varepsilon \\ 2\varepsilon^3 & -1.9\varepsilon^2 & 1.5 \end{pmatrix}; \quad Y_\nu = \begin{pmatrix} \varepsilon^{|1\pm n_1|} & \varepsilon^{|1\pm n_2|} & 1.75\varepsilon^{|1\pm n_3|} \\ \varepsilon^{|n_1|} & \varepsilon^{|n_2|} & 1.25\varepsilon^{|n_3|} \\ 1.3\varepsilon^{|n_1|} & \varepsilon^{|n_2|} & -2\varepsilon^{|n_3|} \end{pmatrix}; \tag{3.1}$$

PoS(DSU 2012)027

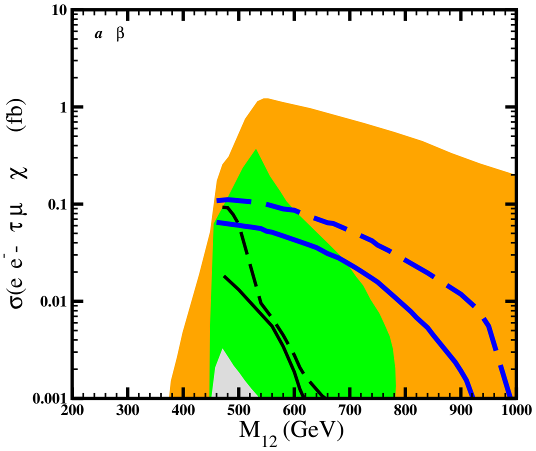

Figure 3: *The shaded areas show the possible ranges of* $\sigma(e^+e^- \to \tau^\pm\mu^\mp + 2\chi^0)$ *for* $m_0 < 1000$ GeV *and* $\tan\beta = 45$ *assuming* $A_0 = 0$*. We take* $\sqrt{s}$ *fixed to* 500 GeV *(grey),* 1000 GeV *(green) and* 2000 GeV *(orange). The solid lines present the possible values for models along the center of the WMAP strips, with the lines corresponding to* $\sqrt{s}$*=500, 1000, 2000* GeV *being progressively thicker. The corresponding predictions for* $\sigma(e^+e^- \to \tau^\pm e^\mp + 2\chi^0)$ *are shown by the dashed lines.*

PoS(DSU 2012)027

$$M_N = \begin{pmatrix} \varepsilon^{2|n_1|} & \varepsilon^{|n_1+n_2|} & -1.3\varepsilon^{|n_1+n_3|} \\ \varepsilon^{|n_1+n_2|} & \varepsilon^{2|n_2|} & \varepsilon^{|n_2+n_2|} \\ -1.3\varepsilon^{|n_1+n_3|} & \varepsilon^{|n_2+n_3|} & -\varepsilon^{2|n_3|} \end{pmatrix} \tag{3.2}$$

with $\varepsilon \sim 0.2$ as the preferred value. The coefficients in front af the powes of ε are not predicted by the theory and are chosen such that neutrino mixing angles are inside of the experimental range:

$$sin^2\theta_{12} = 0.020; \quad sin^2\theta_{13} = 0.29; \quad sin^2\theta_{23} = 0.61. \tag{3.3}$$

Appropriate choices of the unspecified U(1) charges, such as $n_1 = 2, n_2 = -1, n_3 = 1$, lead to interesting phenomenology. In particular example that we are considering, the LFV entries in the slepton mass matrices, defined as in eq. (2.9), are of the order:

$$(\delta_{LL})_{13} = 0.02, \ (\delta_{LL})_{23} = 0.02, \ (\delta_{LL})_{12} = 0.004. \tag{3.4}$$

Fig. 2 displays the dependence of the results on the available $\sqrt{s}$. Clearly, at the LC, higher values of $\sqrt{s}$ provide accessible cross sections for heavier sparticle spectra, a potential advantage of the LC over the LHC, where it is relatively difficult to reach large values of the scalar masses. As $\sqrt{s} = 2P_{cm}$ increases, it becomes possible to produce on-shell sleptons with larger masses. We should underline that the effects due to the kinematics are as relevant as those from the LFV mixing parameters.

In Fig. 3 we present the maximum values of the cross sections in the CMSSM at $tan\beta = 45$ and $A_0 = 0$. The shaded areas show the possible ranges of $\sigma(e^+e^- \to \tau^\pm\mu^\mp + 2\chi^0)$, and we note that points along the WMAP strips (solid lines) generally have high values of the cross sections. The dashed lines show the possible values of $\sigma(e^+e^- \to \tau^\pm e^\mp + 2\chi^0)$ along the WMAP strips.

The area with $m_h > 120$ GeV correspond to values of $m_{1/2} > 750$ GeV, this implies cross sections of the order of 0.01 fb.

4. Conclusions

A future LC will provide an optimal environment for the study of LFV, whereas the LHC is limited to specific channels that have significant backgrounds. The fact that the LC opens up additional possibilities may prove significant for making the link between observable cross sections, neutrino physics and flavour model building.

So far we considered parameters on the CMSSM. However, the cross sections expected in non-minimal extensions of the theory might not only enhance channels that in the current scheme are more suppressed, but could also enable a comparison of the allowed range of mixing parameters in different models.

PoS(DSU 2012)027

References

[1] Y. Fukuda *et al.* [Super-Kamiokande Collaboration], Phys. Rev. Lett. **81** (1998) 1562.

[2] Y. Fukuda *et al.* [Super-Kamiokande Collaboration], Phys. Rev. Lett. **82** (1999) 1810; Phys. Rev. Lett. **82** (1999) 2430; Q. R. Ahmad *et al.* [SNO Collaboration], Phys. Rev. Lett. **87** (2001) 071301.

[3] K. Abe *et al.* [T2K Collaboration], Phys. Rev. Lett. **107** (2011) 041801 [arXiv:1106.2822 [hep-ex]].

[4] P. Adamson *et al.* [MINOS Collaboration], Phys. Rev. Lett. **107** (2011) 181802 [arXiv:1108.0015 [hep-ex]].

[5] F. P. An *et al.* [DAYA-BAY Collaboration], arXiv:1203.1669 [hep-ex].

[6] J. K. Ahn *et al.* [RENO Collaboration], arXiv:1204.0626 [hep-ex].

[7] J. Hisano, T. Moroi, K. Tobe and M. Yamaguchi, Phys. Rev. D **53** (1996) 2442.

[8] M. E. Gómez, G. K. Leontaris, S. Lola and J. D. Vergados, Phys. Rev. D **59** (1999) 116009; J. R. Ellis, M. E. Gómez, G. K. Leontaris, S. Lola and D. V. Nanopoulos, Eur. Phys. J. C **14** (2000) 319;

[9] M. E. Gómez, S. Lola, P. Naranjo and J. Rodriguez-Quintero, JHEP **1006** (2010) 053.

[10] J. Adam *et al.* [MEG Collaboration], Phys. Rev. Lett. **107** (2011) 171801 [arXiv:1107.5547 [hep-ex]].

[11] G. Aad *et al.* [ATLAS Collaboration], Phys. Lett. B **716** (2012) 1 [arXiv:1207.7214 [hep-ex]].

[12] S. Chatrchyan *et al.* [CMS Collaboration], Phys. Lett. B **716** (2012) 30 [arXiv:1207.7235 [hep-ex]].

[13] J. Hisano, R. Kitano and M. M. Nojiri, Phys. Rev. D **65** (2002) 116002; I. Hinchliffe and F. E. Paige, Phys. Rev. D **63** (2001) 115006; D.Carvalho, J. Ellis, M. Gómez, S. Lola, J.Romao, Phys. Lett. B **618** (2005) 162.

[14] E. Carquín, J. Ellis, M. E. Gómez, S. Lola and J. Rodríguez-Quintero, JHEP 0905 (2009) 026.

[15] J. Hisano, M. M. Nojiri, Y. Shimizu and M. Tanaka, Phys. Rev. D **60**, 055008 (1999).

[16] E. Carquin, J. Ellis, M. E. Gomez and S. Lola, JHEP **1111**, 050 (2011).

[17] O. Buchmueller, R. Cavanaugh, M. Citron, A. De Roeck, M. J. Dolan, J. R. Ellis, H. Flacher and S. Heinemeyer *et al.*, arXiv:1207.7315 [hep-ph].

[18] G. Altarelli and F. Feruglio, Phys. Lett. B **451** (1999) 388.

[19] S. Lola and G.G. Ross, Nucl. Phys. B **553** (1999) 81.