Lepton flavour violating slepton decays to test type-I and II seesaw at the LHC

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Abstract. Searches at the LHC of lepton flavour violation (LFV) in slepton decays can indirectly test both type-I and II seesaw mechanisms. Assuming universal flavour-blind boundary conditions, LFV in the neutrino sector is related to LFV in the slepton sector by means of the renormalization group equations. Ratios of LFV slepton decay rates result to be a very effective way to extract the imprint left by the neutrino sector. Some neutrino scenarios within the type-I seesaw mechanism are studied. Moreover, for both type-I and II seesaw mechanisms, a scan over the minimal supergravity parameter space is performed to estimate how large LFV slepton decay rates can be, while respecting current low-energy constraints.

INTRODUCTION

Neutrino experiments [1, 2, 3, 4, 5] have firmly established that neutrinos have mass and their flavours mix. Many theoretical models have been proposed to explain current neutrino data [6], being the seesaw mechanism [7, 8, 9, 10, 11, 12] one of the most popular solutions. Although standard seesaw type models are not directly testable (as they require an inaccessible very high energy scale where lepton number is violated), they can be indirectly tested under certain circumstances. If universal flavour-blind boundary conditions (like mSugra) are assumed, then LFV in the neutrino sector is related to LFV in the slepton sector [13].

SEESAW TYPE-I

Results presented in this section are based on [14]. Here we study the relations between LFV in the neutrino and the slepton sectors in the framework of the νCMSSM, the Constrained Minimal Supersymmetric Standard Model with three additional singlet neutrino superfields. One of the main inconveniences of this model is that the number of parameters at high energies is much larger than the number of observables at low energies. Nevertheless this obstacle can be circumvented by assuming certain neutrino scenarios, which fix some of the parameters. This enables to establish relations between the rest of the parameters and the observables. For qualitative understanding, the left-slepton LFV decays can be approximately expressed as

$$\text{Br}(\tilde{\eta}_l \rightarrow l_j \chi^0_1) \propto (\Delta M^2_{ij})_{ij} \propto (Y^*_\nu L L Y^*_\nu L Y_l L)^2 ;$$

(1)
We can parametrize the neutrino Yukawa matrix in terms of observables as \[ (2) \]
\[
Y_\nu = \frac{p}{2} i \sigma_2 \overleftrightarrow{\nu U} \left[ \overleftrightarrow{m_\nu U} \right]^* R \overleftrightarrow{\hat{m}_\nu} \hat{U} ;
\]
where \( \hat{m}_\nu \) and \( \hat{M}_R \) are diagonal matrices with the light and the heavy neutrino mass eigenvalues, respectively; \( U \) is the leptonic mixing matrix and \( R \) is a complex orthogonal matrix. This way, the left-slepton LFV decays are related to neutrino parameters. In order to eliminate most of the dependence on the supersymmetric parameters, we work with ratios of LFV decay rates. Thus, for example, the ratio of stau LFV decays can be expressed in terms of the parameter \( r_{13}^2 \),
\[
\frac{Br(\tilde{\tau}_2 \rightarrow e + \chi^0_1)}{Br(\tilde{\tau}_2 \rightarrow \mu + \chi^0_1)} \sim \frac{\sqrt{\Delta M^2_{13}}}{\sqrt{\Delta M^2_{23}}} \frac{r_{13}^2}{r_{23}^2} ;
\]
which only depends on neutrino parameters. As an example, Fig. 1 shows the expected ratio of stau LFV decays \( (r_{13}^2)^2 \) as a function of the neutrino mixing angle \( s_{13}^2 \).

**FIGURE 1.** Square ratio \( (r_{23}^2)^2 \) versus \( s_{13}^2 \) for the case of degenerate heavy neutrinos and real \( R \). The dark line corresponds to light neutrino mass splitting fixed to their best fit point values \[6\] and leptonic mixing angles \( \theta_{12} \) and \( \theta_{23} \) fixed to their tribimaximal values \[16\]. The red (dark) band corresponds to light neutrino mass splittings in their \( 3\sigma \) allowed range and leptonic mixing angles \( \theta_{12} \) and \( \theta_{23} \) fixed to their tribimaximal values. The orange (light) band corresponds to light neutrino mass splittings and leptonic mixing angles in their \( 3\sigma \) allowed range. Each column corresponds to a different value of the Dirac phase: \( \delta = 0 \) (first column) and \( \delta = \pi \) (second column). Each row corresponds to a different neutrino scenario: strict normal hierarchy (first row) and strict inverse hierarchy (second row).

In order to check the validity of our analytical estimated ratio of stau LFV decays, we have performed a numerical calculation with the program package SPHENO \[17\] for the
mSugra standard points SPS1a’ [18] and SPS3 [19]. Our results show that the ratio of the stau LFV decays follows very accurately the analytical estimate. For more details, see [14]. For a similar analysis, but for seesaw type-II, see [20].

SCAN

Results presented in this section are based on [21]. Although stau LFV decays have been studied for two specific SUSY benchmark points (SPS1a’ and SPS3), a more general study over the mSugra parameter space is necessary. For both seesaw type-I and II (details on the realization of the type-II seesaw can be found in [22]), we have estimated the maximum number of events of the opposite-sign dilepton signal $\chi_2^0 \rightarrow \chi_1^0 \mu \tau$, which can be searched for at the LHC\(^1\). To do so, we have used program packages SPHENO [17] and PROSPINO [23, 24, 25, 26, 27]. For more details, see [21].

Fig. 2 shows the production cross section $\sigma(\chi_0^2)$ at leading order times the branching ratio of $\chi_2^0 \rightarrow \chi_1^0 \mu \tau$ as a function of $m_{1-2}$ for different values of $m_0$, in seesaw type-I (left panel) and II (right panel). Assuming a luminosity $\mathcal{L} = 100 \text{ fb}^{-1}$, there are regions in the parameter space where the estimated number of events of the opposite-sign dilepton signal $\chi_2^0 \rightarrow \chi_1^0 \mu \tau$ can be of the order of $10^3$.

CONCLUSION

We have shown that the $\nu$CMSSM (SUSY seesaw type-I with mSugra boundary conditions) can be indirectly tested at the LHC by measuring the ratio of stau LFV decay rates. We have performed a numerical analysis of the absolute values of stau LFV decays in both type-I and II seesaw and we have shown that there exist regions of the mSugra parameter space where the estimated number of events of the opposite-sign dilepton signal $\chi_2^0 \rightarrow \chi_1^0 \mu \tau$ can be as much as of the order of $10^3$.

\(^1\) Note that a complete Monte Carlo analysis would be needed, but this is out of the scope of this work.
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REFERENCES

1. Y. Fukuda, et al., *Phys. Rev. Lett.* **81**, 1562–1567 (1998), [hep-ex/9807003](https://arxiv.org/abs/hep-ex/9807003).
2. S. Abe, et al., *Phys. Rev. Lett.* **100**, 221803 (2008), [0801.4589](https://arxiv.org/abs/0801.4589).
3. C. Arpesella, et al., *Phys. Rev. Lett.* **101**, 091302 (2008), [0805.3843](https://arxiv.org/abs/0805.3843).
4. B. Aharmim, et al., *Phys. Rev. Lett.* **101**, 111301 (2008), [0806.0989](https://arxiv.org/abs/0806.0989).
5. P. Adamson, et al., *Phys. Rev. Lett.* **101**, 111301 (2008), [0806.0989](https://arxiv.org/abs/0806.0989).
6. T. Schwetz, M. Tortola, and J. W. F. Valle, *New J. Phys.* **10**, 113011 (2008), [0808.2016](https://arxiv.org/abs/0808.2016).
7. P. Minkowski, *Phys. Lett.* **B67**, 421 (1977).
8. M. Gell-Mann, P. Ramond, and R. Slansky, “Complex spinors and unified theories,” in *Supergravity*, edited by P. van Nieuwenhuizen, and D. Freedman, North Holland Publ. Co., Amsterdam, 1979.
9. T. Yanagida, “Horizontal gauge symmetry and masses of neutrinos,” in *Proc. of the Workshop on the Baryon Number of the Universe and Unified Theories, National Laboratory for High Energy Physics (KEK), February 13-14, 1979*, edited by O. Sawada, and A. Sugamoto, National Laboratory for High Energy Physics, Tsukuba, Japan, 1979.
10. R. N. Mohapatra, and G. Senjanovic, *Phys. Rev. Lett.* **44**, 912 (1980).
11. J. Schechter, and J. W. F. Valle, *Phys. Rev. D22*, 2227 (1980).
12. J. Schechter, and J. W. F. Valle, *Phys. Rev. D25*, 774 (1982).
13. F. Borzumati, and A. Masiero, *Phys. Rev. Lett.* **57**, 961 (1986).
14. M. Hirsch, J. W. F. Valle, W. Porod, J. C. Romao, and A. Villanova del Moral, *Phys. Rev. D78*, 013006 (2008), [0804.4072](https://arxiv.org/abs/0804.4072).
15. J. A. Casas, and A. Ibarra, *Nucl. Phys.* **B618**, 171–204 (2001), [hep-ph/0103065](https://arxiv.org/abs/hep-ph/0103065).
16. P. F. Harrison, D. H. Perkins, and W. G. Scott, *Phys. Lett. B530*, 167 (2002), [hep-ph/0202074](https://arxiv.org/abs/hep-ph/0202074)
17. W. Porod, *Comput. Phys. Commun.* **153**, 275–315 (2003), [hep-ph/0301101](https://arxiv.org/abs/hep-ph/0301101)
18. J. A. Aguilar-Saavedra, et al., *Eur. Phys. J. C46*, 43–60 (2006), [hep-ph/0511344](https://arxiv.org/abs/hep-ph/0511344)
19. B. C. Allanach, et al., *Eur. Phys. J. C25*, 113–123 (2002), [hep-ph/0202233](https://arxiv.org/abs/hep-ph/0202233)
20. M. Hirsch, S. Kaneko, and W. Porod, *Phys. Rev. D78*, 093004 (2008), [0806.3361](https://arxiv.org/abs/0806.3361)
21. J. N. Esteves, et al., *JHEP* **05**, 003 (2009), [0903.1408](https://arxiv.org/abs/0903.1408)
22. A. Rossi, *Phys. Rev. D66*, 075003 (2002), [hep-ph/0207006](https://arxiv.org/abs/hep-ph/0207006)
23. W. Beenakker, R. Hopker, M. Spira, and P. M. Zerwas, *Nucl. Phys.* **B492**, 51–103 (1997), [hep-ph/9610499](https://arxiv.org/abs/hep-ph/9610499)
24. W. Beenakker, M. Kramer, T. Plehn, M. Spira, and P. M. Zerwas, *Nucl. Phys.* **B515**, 3–14 (1998), [hep-ph/9710451](https://arxiv.org/abs/hep-ph/9710451)
25. W. Beenakker, et al., *Phys. Rev. Lett.* **83**, 3780–3783 (1999), [Erratum-ibid. 2008 100 029901](https://arxiv.org/abs/hep-ph/9906298)
26. M. Spira, “Higgs and SUSY particle production at hadron colliders,” in *Proc. of the 10th Int. Conf. on Supersymmetry and Unification of Fundamental Interactions, SUSY 02, DESY Hamburg, June 17-23, 2002*, edited by P. Nath, P. M. Zerwas, and C. Grosche, DESY, Hamburg, 2002, vol. 1, pp. 217–26, [hep-ph/0211145](https://arxiv.org/abs/hep-ph/0211145)
27. T. Plehn, *Czech. J. Phys.* **55**, B213–B220 (2005), [hep-ph/0410063](https://arxiv.org/abs/hep-ph/0410063)