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Slepton LSP Decays: Trilinear versus Bilinear R-parity Breaking

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Abstract

Charged sleptons can be the lightest supersymmetric particles in superymmetric models where R-parity is broken. Their decay properties can be used to obtain information about the relative importance of the bilinear and trilinear R-parity violating couplings. We show that in some specific scenarios it is even possible to decide whether bilinear or trilinear terms give the dominant contribution to the neutrino mass matrix.

1 Introduction

The most general form for the R-parity violating and lepton number violating part of the superpotential is given by

$$W_{\not R_p} = \varepsilon_{ab} \left[\frac{1}{2} \lambda_{ijk} \widehat{L}_i^a \widehat{L}_j^b \widehat{E}_k + \lambda'_{ijk} \widehat{L}_i^a \widehat{Q}_j^b \widehat{D}_k + \epsilon_i \widehat{L}_i^a \widehat{H}_u^b \right] \ . \tag{1}$$

Taking into account the asymmetry of λ_{ijk} in i and j, there are nine different λ_{ijk}, 27 λ'_{ijk} and three ϵ_i, for a total of 39 parameters.

Two interesting consequences of the terms in Eq. (1) are (i) they will necessarily contribute to the (Majorana) neutrino mass matrix and (ii) the ligthest supersymmetric particle (LSP) will decay. Indeed it is exactly the observation that the LSP decays through the same R-parity violating operators that also govern the entries in the neutrino mass matrix, which allows one to study consequences of neutrino physics for collider physics and vice versa. Several articles have investigated the consequences of Eq. (1) for neutrino physics [1]-[18].

2 Slepton $\not{R}_p$ decays

In the present note we assume that the $\tilde{\tau}_1$ (mainly $\tilde{\tau}_R$) is the LSP and that also the other ligther sleptons $\tilde{e}_1$ and $\tilde{\mu}_1$ decay mainly via $\not{R}_p$ vertices (for a detailed discussion see [19]). Possible final states are either $\ell_i \nu_j$ or $q\bar{q}'$. In the following we first compare the corresponding slepton decays for the two cases: (i) the decay properties of the sleptons are completely determined by bilinear R-parity breaking (ii) the decay properties of the sleptons are dominated by the trilinear parameters.

Case (i) has been studied in [21]. Two results which are different from those for case (ii) are:

$$Br(\tilde{e}_1 \to e \sum \nu) \simeq 1 \ , \tag{2}$$

$$Br(\tilde{\ell}_1 \to hadronic\ final\ states) \ll 1\ (too\ small\ to\ be\ observable)\ . \tag{3}$$

Case (ii) has been studied in Ref. [19]. For $\lambda' \lesssim \lambda$ and for $\tilde{\ell}_1 \simeq \tilde{\ell}_R$ we have found

$$Br(\tilde{\ell}_1 \to (e,\mu,\tau)) \simeq \frac{1}{2}\left[1 - \frac{(\lambda^2_{23\tilde{\ell}}, \lambda^2_{13\tilde{\ell}}, \lambda^2_{12\tilde{\ell}})}{\sum_{i<j} \lambda^2_{ij\tilde{\ell}}}\right] \ . \tag{4}$$

This leads to

$$Br(\tilde{\ell}_1 \to (e,\mu,\tau)) \lesssim 0.5 \ . \tag{5}$$

This is different from (2). If $\lambda' \gg \lambda$ then decays into hadronic final states should be observable, which then is different from (3). So in fact, the two cases (i) and (ii) should be distinguishable.

3 Neutrino Physics versus Collider Physics

As a next step we consider some examples how the neutrino mass matrix may be generated by the terms in Eq. (1) and discuss the consequences for collider physics. In order to reduce the number of parameters, the numerical calculations were performed in a constrained version of the MSSM. We have scanned the parameters in the following ranges: $M_{1/2} \in [0, 1.2]$ TeV, $|\mu| \in [0, 2.5]$ TeV, $m_0 \in [0, 1.2]$ TeV, A_0/m_0 and $B_0/m_0 \in [-3, 3]$ and $\tan\beta \in [2.5, 10]$. All randomly generated points were subsequently tested for consistency with the stationary conditions of the scalar potencial as well as for phenomenological constraints from supersymmetric particle searches. The $\not{R}_p$ parameters were chosen in order to fulfill the requirements of the scenarios to be discussed and the requirements from neutrino physics [20]: $0.3 < \sin^2\theta_{Atm} < 0.7, 1.2 \times 10^{-3}$ eV^2 $< \Delta m^2_{Atm} < 4.8 \times 10^{-3}$ eV$^2, 0.29 < \tan^2\theta_\odot < 0.86, 5.1 \times 10^{-5}$ eV^2 $< \Delta m^2_\odot < 1.9 \times 10^{-4}$ eV$^2, \sin^2\theta_{13} < 0.05$.

In the following we will discuss two scenarios with non-zero trilinear couplings:

Scenario I is defined by $\lambda'_{ijk} \ll \lambda_{ijk}$ and the assumption that the atmospheric mass scale is generated by the bilinear parameters, whereas the solar mass scale is due to the loop generated neutrino mass matrix, which depends on λ_{ijk}. If the couplings λ_{ij1} and λ_{ij2} are not much larger than λ_{ij3} [1] the leading contribution comes from the $\tilde{\tau}_i - \tau$ loop and

[1] Whether this is indeed the case may be checked, in principle, by a comparison of the decay length of the sleptons.

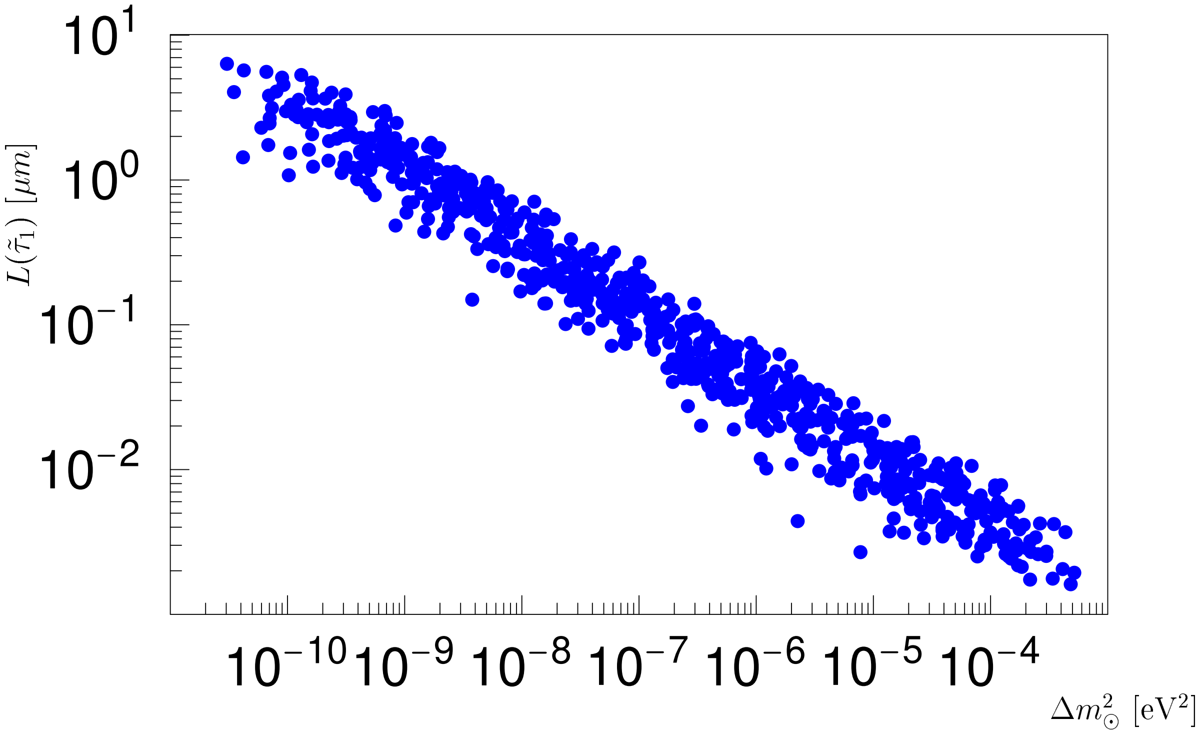

Figure 1: Stau decay length in [μm] versus solar mass squared difference $\Delta m^2_\odot$ [eV^2] in scenario I, defined as λ_{ijk} being responsible for the solar mass scale. If the trilinear loop is responsible for the solar mass, the stau will decay with a length too small to be measured.

the contributions of all other $\tilde{\ell}_i - \ell$ loops are subleading. In such a scenario the scalar tau will decay with a very short decay length. This is demonstrated in Fig. 1, where we plot the decay length $L(\tilde{\tau}_1)$ as a function of the solar mass squared difference, to be expected in stau pair production at a linear collider with $\sqrt{s} = 800$ GeV. Note that one expects to be able to measure decay lengths down to 10 μm [22] in an event-by-event analysis.

For other λ_{ijk} ($\neq \lambda_{ij3}$) to provide the solar mass scale, the decay lengths of the corresponding sleptons would have to be even shorter [19]. Therefore if a finite decay length for $\tilde{e}_1$ and $\tilde{\mu}_1$ is found λ_{ij1} and λ_{ij2} *can not contribute significantly* to the neutrino mass matrix. In the case that a stau decay length larger than $O(1)\mu$m is measured the reasoning above implies that the λ_{ij3} induced loops cannot contribute significantly to the neutrino mass matrix (see Fig. 1).

Scenario II is defined by $\lambda_{ijk} \ll \lambda'_{ijk}$ and the assumption that λ'_{ijk} do not follow an *inverse* hierarchy. Now the main contribution of the trilinears λ'_{ijk} to the neutrino mass matrix is given by the $\tilde{b}_i - b$ loop, since it is largest due to the larger left-right mixing expected in the sbottom sector and $m_d \ll m_s \ll m_b$.

We consider the two limiting cases:

- Scenario IIA: Bilinear R-parity breaking responsible for solar physics, λ'_{i33} for the atmospheric mass scale
- Scenario IIB: Bilinear R-parity breaking responsible for atmospheric physics, λ'_{i33} for the solar mass scale

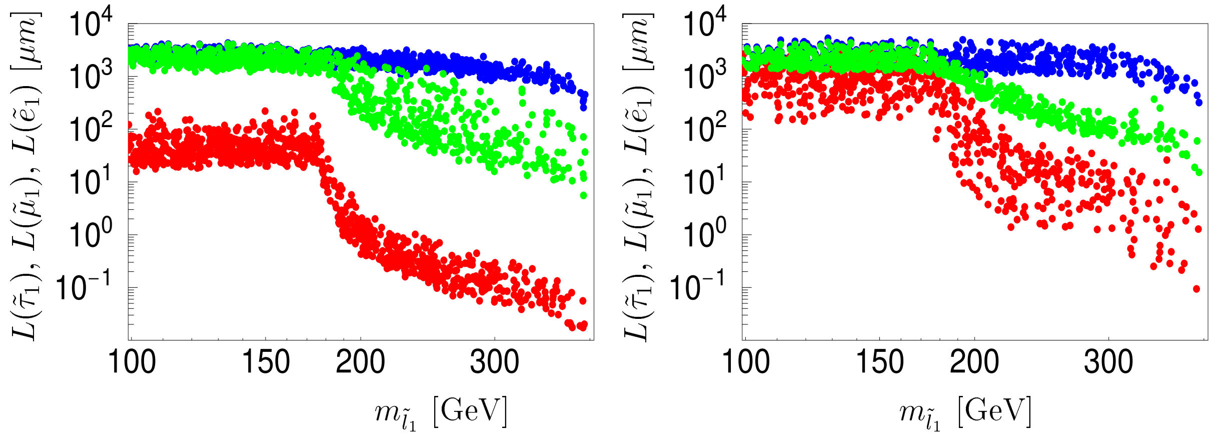

Figure 2: Decay lengths for $\tilde{\tau}_1$, $\tilde{\mu}_1$ and $\tilde{e}_1$, $L(\tilde{\tau}_1)$, $L(\tilde{\mu}_1)$, $L(\tilde{e}_1)$ $[\mu m]$, (bottom to top) versus the mass of the decaying particle, $m_{\tilde{l}_1}$ [GeV]. On the left panel: Scenario IIA, right panel scenario IIB. The plots assume that only λ'_{i33} are different from zero, see text.

Considering scenario IIA first, we assume for simplicity that only the λ'_{i33} are non-zero. In Fig. 2 (to the left) we show the calculated decay lengths for $\tilde{\tau}_1$, $\tilde{\mu}_1$ and $\tilde{e}_1$ in scenario IIA. The threshold for the $\tilde{\tau}_1$ and $\tilde{\mu}_1$ decays into $\bar{t}b$ is clearly visible. For the $\tilde{e}_1$ it is invisible due to the negligible left-right mixing dictated by the small electron Yukawa coupling. The decay of the $\tilde{e}_1$ is completely dominated by the final state $e\sum\nu$, induced by the bilinear terms [21]. For $\tilde{\tau}_1$ below the $\bar{t}b$ threshold the decay is dominated by the final state $\bar{c}b$, which is induced from λ'_{333} due to the non-zero value of V_{cb}, with a branching ratio into $\tau\sum\nu$ being a few percent. Above threshold the branching ratio for decays into $\bar{t}b$ quickly grows to more than 99 %, with the final state $\bar{c}b$ being suppressed by a factor of V_{cb}^2 and the final state $\tau\sum\nu$ is tiny. For the decay of the $\tilde{\mu}_1$, on the other hand, below the $\bar{t}b$ threshold $\mu\sum\nu$ dominates, with a branching ratio into $\bar{c}b$ of about $\sim$ (1-20) %. Above threshold $\bar{t}b$ becomes quickly dominant, but (some) percent of the decays still go to $\mu\sum\nu$. Decays $\tilde{e}_{i1} \to e_j\sum\nu$ for $i \neq j$ are always very small, due to the assumed smallness of λ_{ijk}.

Turning to scenario IIB, in the right panel of Fig. 2 we plot the calculated decay lengths of the charged scalar leptons as a function of the charged scalar mass. The main difference to scenario IIA is that the $\tilde{\tau}_1$ now decays with a visible length. This can be traced to the fact that smaller values of λ'_{i33} are needed in this scenario since the solar mass scale is smaller than the atmospheric one.

4 Summary

We have studied the decay properties of a right charged scalar lepton LSP in a general model of R-parity violation containing both bilinear and trilinear terms. In some cases we have found that bilinears and trilinears can be clearly distinguished. Especially noteworthy is that in trilinear-only models all right charged scalar lepton LSPs should obey $Br(\tilde{\ell}_1 \to (e,\mu,\tau)\sum\nu_i) < 0.5$. This is to be contrasted with the bilinear model prediction [21] $Br(\tilde{e}_1 \to e\sum\nu_i) \simeq 1$. We have shown that in some specific scenarios it is even possible to decide whether bilinear or trilinear terms give the dominant contribution to the neutrino mass matrix.

Acknowledgments

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