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# Same-sign trileptons as a signal of sneutrino lightest supersymmetric particle

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ABSTRACT

Contrary to common expectation, a left-sneutrino can occasionally be the lightest supersymmetric particle. This has important implications in both collider and dark matter studies. We show that same-sign tri-lepton (SS3L) events at the Large Hadron Collider, with any lepton having opposite sign vetoed, distinguish such scenarios, up to gluino masses exceeding 2 TeV. The *jets* + *MET* signal rate is somewhat suppressed in this case, thus enhancing the scope of leptonic signals.

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Supersymmetry (SUSY), or a symmetry between elementary bosons and fermions, has been a matter of great interest over several decades. In the form where lepton (L) and baryon (B) numbers are conserved, SUSY offers a stable particle which is the dark matter (DM) candidate for the universe. Therefore, physicists not only ponder on possible discovery channels for SUSY at the Large Hadron Collider (LHC) [1,2] but also wish to know how, if discovered, we can identify the lightest SUSY particle (LSP) which is the DM candidate. In the minimal SUSY standard model (MSSM) or its immediate extensions, the DM candidate [3] usually is $\chi_1^0$, the lightest neutralino (a linear superposition of the 'partners' of the photon, the Z-boson and the neutral Higgs-like spinless particles), the gravitino (partner of the graviton) [4,5], or the axino (partner of an axion) [6,7]. The signals at the LHC are dominantly jets with missing transverse energy (MET) [8,9] occasionally with leptons and/or photons alongside.

In contrast, it is difficult to have a SUSY spectrum with a left-chiral sneutrino ($\tilde{\nu}_L$, the spinless partner of a neutrino) as the DM candidate. Such an LSP has unsuppressed interaction with the Z-boson and is therefore disfavoured from direct DM search experiments, unless its mass is well above a TeV. However, in case this restriction is avoided (as seen below) and one has a (left) sneutrino LSP, finding its distinct signature at the LHC is a desideratum. We show here that the scenario is distinguishable through same-sign trileptons (SS3L) at the LHC. Extensive scans carried out by us [1,2] over the parameter space fail to turn up regions where, in an R-parity conserving SUSY spectrum, containing only superpartners of Standard Model (SM) particles alone, can lead to SS3L signals with such abundance. Moreover, compared to the case of a $\chi_1^0$ LSP, the 0 *lepton* + *jets* + *MET* events get suppressed, and the leptonic final states gain more importance, thus warranting a revision of collider search strategies.

A $\tilde{\nu}_L$ DM can be allowed, if there is a mass-splitting between the scalar ($\tilde{\nu}_1$) and pseudoscalar ($\tilde{\nu}_2$) components of $\tilde{\nu}_L = \dfrac{\tilde{\nu}_1 + i\tilde{\nu}_2}{\sqrt{2}}$. The Z couples to $\tilde{\nu}_1\tilde{\nu}_2$. A splitting of a few hundred keV prevents the scattering of the lighter of $\tilde{\nu}_1$ and $\tilde{\nu}_2$ (which is the DM candidate) into the heavier one via such coupling. The energy barrier created by this split is insurmountable unless the dark matter candidate has a speed exceeding its escape velocity in our galaxy [10–13]. This mass difference can occur, for example, from a tiny Majorana neutrino mass, for which the necessary conditions have been discussed in the literature [12]. Also, the sneutrino can be the lightest in the MSSM spectrum, just above a gravitino, an axino or even a right-chiral sneutrino LSP. Such spectrum has been considered in [14,15]. All these scenarios are addressed by the SS3L signal which is otherwise highly suppressed in R-parity conserving SUSY where $R = (-1)^{(3B+L+2S)}$.

SS3L is inevitable in the scenarios discussed above, because the $\tilde{\nu}_L$ states are close in mass to the charged sleptons ($\tilde{l}_L$), as dictated by $SU(2)_L$ invariance. The latter (leaving aside the staus and their mixing) are slightly more massive, mainly because of D-term contributions. Therefore, if the lightest (gaugino-like) neutralino is the next massive state in the spectrum, it decays either to a charged slepton and an anti-lepton (or to its conjugate state) or to the left-sneutrino(s) and a neutrino, with comparable branching ratios. $\tilde{l}_L$ undergoes three-body decays, producing the corresponding sneutrino and two soft-jets or a soft lepton and a neutrino. The soft leptons do not mostly survive the event selection criteria. Thus all SUSY cascades resulting in the lightest neutralino lead

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to two leptons in about half of the cases. The Majorana nature of neutralinos causes these two leptons to be of the same type in half the cases among such events. Further, a third lepton of the same sign can come from cascades, via either a top quark or a chargino. Thus one has three (or even four) leptons of the same sign.[1]

Unlike in Refs. [14,15], our main focus is on SS3L events. Further, contrary to the brief discussion in [15], we demonstrate that SS3L may be obtained from a simple spectrum and its observation need not imply the presence of a right-slepton (in addition to a left-slepton doublet) in the low energy spectrum. We emphasize that a simple spectrum with left-sneutrino LSP, without any additional SUSY particles, may lead to the rather distinct SS3L signal. We also demonstrate that the decay mode $\tilde{t}_1 \to b\chi_1^+$ adversely affects SS3L events when $\chi_1^\pm$ decays into sleptons or sneutrinos.

Throughout our discussion we will assume the first two generations of $SU(2)_L$ doublet sleptons to be degenerate. Further, both $e$, $\mu$ will be described as *leptons* ($\ell$), and their scalar counterparts, as *sleptons* ($\tilde{\ell}$). Further, since various mechanisms may be responsible for the production of DM in the early Universe [16–18] and there may even be additional DM candidate(s) possibly from hidden sector, we will not restrict the collider analysis by assuming thermal production of sneutrinos.

For simplicity, we assume the first two families of squarks to be decoupled. A stop well within the reach of the LHC is retained, thus providing a semblance of naturalness, and the gluino is assumed to be heavier than the stop. Other than the light charged sleptons, sneutrinos and $\chi_1^0$, we have used benchmark points in the SUSY parameter space with both light and heavy $\chi_1^\pm$ and $\chi_2^0$. The parameter $\mu$ and thus the Higgsino-dominated states are kept above a TeV without any loss of generality. The channels of our interest are both $\tilde{t}_1\tilde{t}_1^*$ production, and cascade production of the lighter stop (or the anti-stop with the same rate) from the decay of the gluino ($\tilde{g}$). This is a conservative choice from the viewpoint of the SS3L signal, since larger event rates should be expected if the first two families of squarks are also produced.

We assume a bino-like $\chi_1^0$ and wino-like $\chi_1^\pm$ and $\chi_2^0$. When one has a sneutrino LSP, the first two families of $SU(2)_L$ doublet sleptons are the next-to-lightest ones (assumed to be degenerate for simplicity). The stau mass is taken to be at least a TeV; staus lighter than $\chi_1^0$ can cause some reduction to our predicted signals, but keeps it within the same order of magnitude. Based on the nature of the intermediate neutralino(s), the following scenarios have been considered as representative.

1. In the simple scenario (A) with just the $\chi_1^0$ within reach, direct production of a stop-antistop pair causes each (anti)stop to decay directly into $\chi_1^0$. While these $\chi_1^0$'s give rise to two same-sign leptons as already explained, the third lepton of the same sign comes from the decay of a (anti) top produced in (anti)stop decay. The number of SS3L events is further enhanced in the non-decoupling gluino case where additional (anti-)stops are produced from $\tilde{g}$ decay. It should be noted that SS4L is also possible, though with a reduced rate, if a pair of gluinos decay into two top-stop pairs. This happens when both the $W$'s, produced from the decay of two (anti)top quarks, yield leptons of identical sign.
2. In scenarios (B) and (C), in addition to the bino-like $\chi_1^0$, a wino-like chargino $\chi_1^\pm$ and the corresponding neutralino $\chi_2^0$ also occur below $\tilde{t}_1$ in the spectrum. There is consequently an additional decay mode, namely, $\tilde{t}_1 \to b\chi_1^+$. However, the branching ratio in this channel depends on the composition of $\tilde{t}_1$. While $\tilde{t}_1$ is dominantly right-type in scenario (B), significant amount of left-right mixing is allowed in scenario (C). Because of its large hypercharge, an R-type ($SU(2)_L$ singlet) $\tilde{t}_1$ will dominantly decay into $\chi_1^0$, while for an L-type ($SU(2)_L$ doublet) $\tilde{t}_1$ there is a substantial branching ratio into the $b\chi_1^\pm$ channel. In such a situation, both of the stops in the two decay chains will tend to produce charginos which tend to undergo two-body decays into charged sleptons. This makes it difficult to have SS3L final states in the direct stop pair-production, and one has to depend only on cascades from gluino decay. Thus, while both the scenarios B and C include a light chargino, scenario C represents a situation where the composition of the lighter stop tends to reduce the rate of SS3L. As we shall see below, one still expects to see this signal with a rate sufficient to discern the sneutrino-LSP scenario. It should be mentioned in addition that both scenarios B and C retain the possibility of seeing SS4L (albeit with smaller rates) whenever SS3L is allowed.

[1] This leaves out the situation where the lighter chargino is decoupled and the lighter stop is so close to $\chi_1^0$ that it decays only into $c\chi_1^0$.

**Table 1**
Mass spectra for different benchmark points. BP-A and BP-B represent scenario (A) (with only the bino-like neutralino intermediate state) and scenario (B) (with a bino-like and a wino-like neutralino together with a wino-like chargino intermediate states) respectively (see text for details). All masses are in GeV.

| Parameter | BP-A | BP-B | BP-C |
|---|---|---|---|
| $m_{\tilde{g}}$ | 1600 | 1600 | 1600 |
| $m_{\tilde{t}_1}$ | 1000 | 1000 | 1000 |
| $m_{\chi_1^0}$ | 590 | 441 | 443 |
| $m_{\chi_2^0}$ | – | 620 | 620 |
| $m_{\chi_1^+}$ | – | 620 | 620 |
| $m_{\tilde{\nu}}$ | 293 | 293 | 293 |

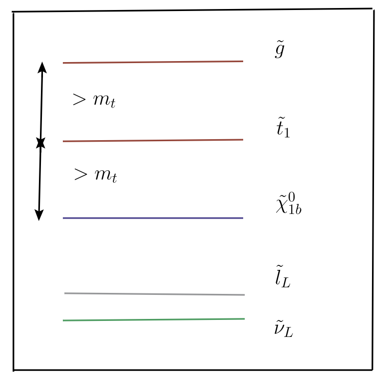


**Fig. 1.** The mass hierarchy required to obtain SS3L. In the simplest scenario, only a bino-like $\chi_1^0$ has been introduced between $\tilde{t}_1$ and the (first two generations of) slepton doublets.

All the three scenarios are allowed by the 8 TeV data so far [19]. The above discussion shows that, while BP A has no wino-like state affecting the phenomenology, even the presence of such states affects the suggested SS3L signal only if the lighter stop has a substantial left component, and thus BP B and BP C have different LHC implications. While a stop decays almost entirely into a top and the $\chi_1^0$ in BP A, this branching ratio becomes 91% in BP B and 56% in BP C. The branching ratio for $b\chi_1^\pm$ ($t\chi_2^0$), on the other hand, is 6% (3%) and 31% (13%), respectively, for BP B and C. The important aspects of the spectrum with each of the three benchmark points (BP) mentioned above are summarized in Table 1. The nature of the spectrum for BP A is also shown in Fig. 1. Note that the presence of a right-slepton above the neutralino(s) does not affect the signal.

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