Right-chiral sneutrino LSP in mSUGRA: Event characteristics of NLSP at LHC

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eprint: hep-ph/0701063, Phys. Rev. D**75,** 075007

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SUSY 07

Karlsruhe

To begin with…..

- *Supersymmetry is still the most popular new physics option beyond standard model.*
- *Provides a cold dark matter candidate in the form of the lightest supersymmetric particle (LSP).*
- *Most common practice is to assume lightest neutralino to be the LSP.*
- **What about other types of LSP ? Do they alter SUSY signals at colliders ?**

The Idea:

- ***Assuming Dirac-type neutrino mass as the simplest extension to the SM one has right-handed (RH) neutrino for each fermion family.***

- ***If SUSY is the reason for a stabilized electroweak scale, then with the above hypothesis, one needs to add right-chiral sneutrinos in the list of superparticles.***

$$W_\nu^R = y_\nu \hat{H}_u \hat{L} \hat{\nu}_R^c$$

- **Is accelerator phenomenology of SUSY altered by the RH neutrino or its scalar partner ? Does the ν_R superfield help in explaining something more than just neutrino masses ?**

The Idea….

- **What are the standard SUSY signals at the LHC ? We say….**

$$jets + p_T(miss) \Rightarrow$$

$$pp \rightarrow \tilde{g}\,\tilde{g}(\tilde{q}\,\tilde{q}^*)(\tilde{q}\,\tilde{q}) \rightarrow (anti)quarks + \tilde{\chi}_1^0\,\tilde{\chi}_1^0$$

$$like\text{-}sign\ dileptons + jets + p_T(miss) \Rightarrow$$

$$pp \rightarrow \tilde{g}\,\tilde{g}(\tilde{q}\,\tilde{q}^*)(\tilde{q}\,\tilde{q}) \rightarrow \tilde{\chi}_1^\pm\,\tilde{\chi}_1^\pm \ldots . \rightarrow (anti)quarks + l^\pm l^\pm\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$$

- ***But must the lightest neutralino be the LSP ?***

- ***If RH neutrino superfield exists, then the*** $\tilde{\nu}_R$ ***is an LSP candidate.***

Advocate the idea:

- *Such sneutrinos are very weakly coupled and also more favoured than the left-chiral state.*

  …couplings proportional to the neutrino masses $(O \sim 10^{-13})$

- *Favoured over its left-chiral counterpart in a setting where masses evolve from a high scale..*

  (in our case mSUGRA)

- **It is basically the smallness of the Yukawa coupling which plays a crucial role in our understanding of the spectrum and its consequent features.**

Advocate the idea:

- ***The right-chiral sneutrino mass parameter evolves at the one-loop level as:***

$$\frac{dM^2_{\tilde{\nu}_R}}{dt} = \frac{2}{16\pi^2} y_\nu^2 \, A_\nu^2 \quad .$$

Arkani-Hamed,Hall,Murayama,Smith,Weiner (2001)
Hooper,March-Russell,West (2005)

- ***The feeble interaction suppresses its production and also accounts for low annihilation rate.***

- ***Cold dark matter candidate → relic density within allowed values.***

Asaka, Ishiwata, Moroi (2006)

➢*Thus a right-chiral sneutrino LSP in the mass range ~100 GeV is consistent in the mSUGRA framework.*

➢ *This results in new decay chains which lead to different final states at accelerator experiments.*

Consequences:

➢ *The LSP couples to all other SUSY particles with a strength*

$$y_\nu \sim m_\nu^{Dirac}$$

Consequences:

- *SUSY particle production → cascades into the NLSP.*

- *Very slow decay of the NLSP to the LSP.*

→ *LSP is cosmologically stable, but the NLSP (maybe charged) appears stable in the collider detectors.*

→ *The signal of the long-lived NLSP will be charged tracks.*

New signals at the LHC !!!

- *The NLSP can be* $\tilde{\tau}_1$ *(dominantly right-handed)*

  ➔ *allowed over a large region of parameter space*

- *Typical signature for such a long-lived NLSP would be a charged track seen in the muon chamber*

  ➔ *Kinematically differentiable*

S.K.Gupta, B.Mukhopadhyaya, SKR, PRD (2007)

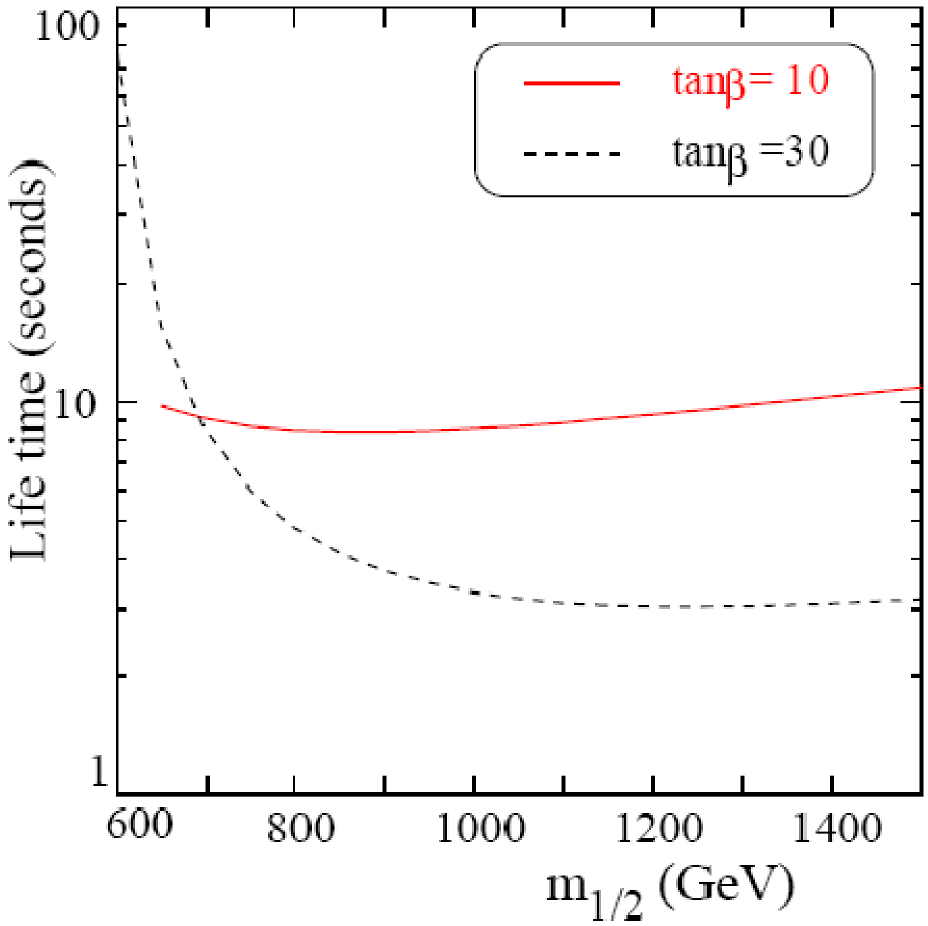


Figure 1: *Lifetime of stau NLSP against the universal gaugino mass parameter* $m_{1/2}$. *Solid (red) line is for* $tan\beta = 10$ *and the dashed (black) line is for* $tan\beta = 30$. *Other SUGRA input parameters are:* $m_0 = 100\ GeV$, $A = 100\ GeV$, $sgn(\mu) = 1$.

…..can have long-lived staus:

Supergravity theories with gravitino LSP

J.Feng et al, 2003,2004; J.Ellis et al, 2004; A. Ibarra+S.Roy, 2006….

Gauge mediated SUSY breaking with a superlight gravitino

D. Dicus+B.Dutta+S.Nandi,1997;K.M.Cheung et al, 1998,
J.Feng+T.Moroi, 1998; P.G. Mercadante et al, 2001….

MSSM with stau-neutralino near degeneracy (co-annihilation region)

S.Ambrossanio et al, 1997; Gladyshev et al., 2005; T.Jittoh et al.,2006…

Supergravity with right-sneutrino LSP

T.Asaka+K.Ishiwata+T.Moroi,2006;
S.K.Gupta+B.Mukhopadhyaya+SKR,2007

Spectrum:

- *The superparticle spectrum mimics the mSUGRA spectrum in all details except with the identity of the LSP.*

- *The mass-squared matrix for the sneutrino looks like*

$$m^2_{\tilde{\nu}} = \begin{pmatrix} M^2_{\tilde{L}} + \frac{1}{2} m^2_Z \cos 2\beta & y_\nu v (A_\nu \sin\beta - \mu \cos\beta) \\ y_\nu v (A_\nu \sin\beta \quad \mu \cos\beta) & M^2_{\tilde{\nu}_R} \end{pmatrix}$$

- *The lighter eigenstate corresponds to the LSP and is dominantly right-handed..*

$$\tilde{\nu}_1 = -\tilde{\nu}_L \sin\theta + \tilde{\nu}_R \cos\theta$$

The mixing angle:

$$\tan 2\theta = \frac{2 y_\nu v \sin\beta |\cot\beta \mu - A_\nu|}{m^2_{\tilde{\nu}_L} - m^2_{\tilde{\nu}_R}}$$

Spectrum:

- *A right-sneutrino LSP and the lighter stau* $(\tilde{\tau}_1)$ *to be the NLSP.*

- *A large mSUGRA parameter space can realize this scenario : provided* $m_0 < m_{1/2}$ *and one has* $\tan\beta$ *of the order of 10 and above.*

➔ *We present two benchmark points in the SUGRA setting consistent with experimental bounds, for our study of such long-lived staus at the LHC.*

$$(m_0, m_{1/2}, A, sign(\mu), \tan\beta)$$

Parameter	Benchmark point 1	Benchmark point 2
mSUGRA input	$m_0 = 100\ GeV,\ m_{1/2} = 600\ GeV$ $A = 100\ GeV,\ sgn(\mu) = +$ $\tan\beta = 30$	$m_0 = 110\ GeV,\ m_{1/2} = 700\ GeV$ $A = 100\ GeV,\ sgn(\mu) = +$ $\tan\beta = 10$
$\lvert\mu\rvert$	694	810
$m_{\tilde{e}_L}, m_{\tilde{\mu}_L}$	420	486
$m_{\tilde{e}_R}, m_{\tilde{\mu}_R}$	251	289
$m_{\tilde{\nu}_{eL}}, m_{\tilde{\nu}_{\mu L}}$	412	479
$m_{\tilde{\nu}_{\tau L}}$	403	478
$m_{\tilde{\nu}_{iR}}$	100	110
$m_{\tilde{\tau}_1}$	187	281
$m_{\tilde{\tau}_2}$	422	486
$m_{\chi_1^0}$	243	285
$m_{\chi_2^0}$	469	551
$m_{\chi_3^0}$	700	815
$m_{\chi_4^0}$	713	829
$m_{\chi_1^\pm}$	470	552
$m_{\chi_2^\pm}$	713	829
$m_{\tilde{g}}$	1366	1574
$m_{\tilde{u}_L}, m_{\tilde{c}_L}$	1237	1424
$m_{\tilde{u}_R}, m_{\tilde{c}_R}$	1193	1373
$m_{\tilde{d}_L}, m_{\tilde{s}_L}$	1239	1426
$m_{\tilde{d}_R}, m_{\tilde{s}_R}$	1189	1367
$m_{\tilde{t}_1}$	984	1137
$m_{\tilde{t}_2}$	1176	1365
$m_{\tilde{b}_1}$	1123	1330
$m_{\tilde{b}_2}$	1161	1358
m_{h^0}	118	118
m_{H^0}	712	941
m_{A^0}	707	935
$m_{H^\pm}$	717	944

Table 1: *Proposed benchmark points for study of stau-NLSP scenario in the SUGRA fold with right-sneutrino LSP. All superparticle masses are given in GeV. Due to very small mixing, $\tilde{\nu}_1 \simeq \tilde{\nu}_R$. The*

Two types of signals

Jets + two muon-like stau tracks (equivalent of jets + $\not{p}_T$ in MSSM)

Jets + dimuons + two muon-like stau tracks (equivalent of jets + dimuons + $\not{p}_T$ in MSSM)

Differentiator: thickness of tracks, time delay, absorption in stoppers ....

Observation: Kinematic separation of muonic and stable stau tracks is possible at the LHC

Signatures of stau-NLSP at LHC

We concentrate on the following final states:

- $2\tilde{\tau}_1 + 2(\text{or more})\ jets\ (p_T > 100\ \text{GeV})$
- $2\tilde{\tau}_1 + \text{dimuon} + 2(\text{or more})\ jets\ (p_T > 100\ \text{GeV})$

The low energy spectrum takes the form:

$$m_{\tilde{\nu}_1} < m_{\tilde{\tau}_1} < m_{\tilde{\chi}_1^0} < m_{\tilde{e}_1,\tilde{\mu}_1} < \ldots < m_{\tilde{g}}$$

Due to the long-lived nature the stau-NLSP will almost always decay outside the detector

→ Characteristic signals like charged track with large transverse momenta..

→ Will have high specific ionization due to their slow motion within the detector.

We focus on the kinematics of processes producing these particles at the LHC.

$2\tilde{\tau}_1$ + hard jets

→ ***To select our final states, we demand the following requirements on our sample events:***

- Each $\tilde{\tau}_1$ should have $p_T > 30$ GeV.
- Both the $\tilde{\tau}_1$'s should satisfy $|\eta| \leq 2.5$
- $\Delta R_{\tilde{\tau}_1 \tilde{\tau}_1} \geq 0.2$, to ensure that the $\tilde{\tau}_1$'s are well resolved in space.
- At least two jets with $p_T > 100$ GeV (hard jets).

→ ***In addition we have rejected events having photons with:***

$|\eta_\gamma| \leq 2.5$ and $p_{T_\gamma} \geq 25$ GeV.

$$2\tilde{\tau}_1 + \text{hard jets}$$

→ ***The final states arise mostly from the direct decay of gluinos and squarks, into the lightest neutralino, which decays into a tau and lighter stau.***

→ ***The tau decays hadronically.***

→ ***We use Pythia interfaced with ISASUGRA for our event generation (modified to include right-sneutrino LSP and decay of lightest neutralino).***

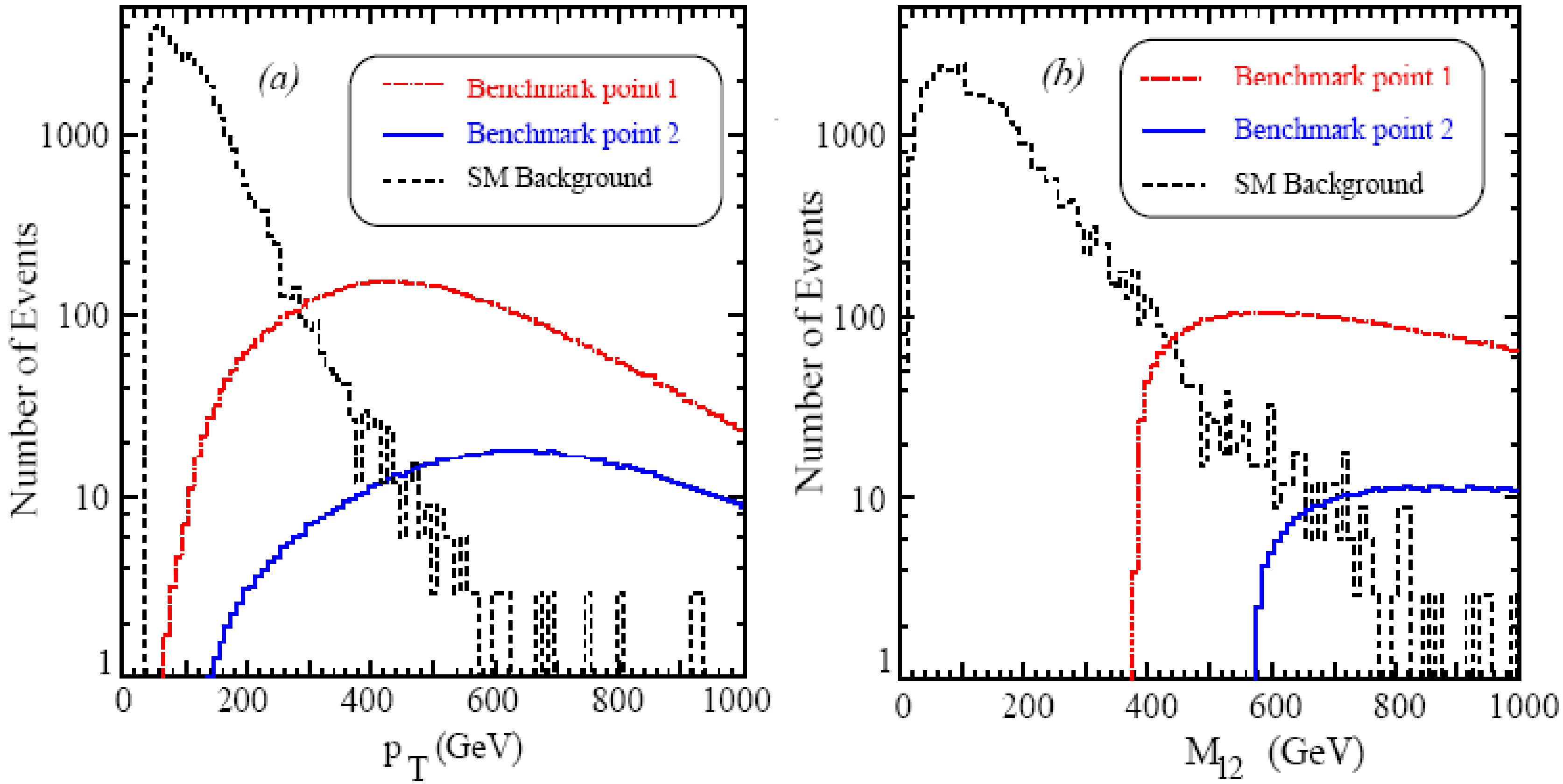


Figure 2: *Kinematic distributions for the signal* $2\tilde{\tau}_1 + (\geq 2)$ *hard jets. In (a) the transverse momentum distributions for the harder* $\tilde{\tau}_1$ *is shown and (b) shows the invariant mass distribution for the* $\tilde{\tau}_1$ *pair. The dash-dot-dash (red) histograms are for benchmark point 1 and the solid (blue) histogram for benchmark point 2. The dashed (black) histograms show the corresponding SM background.*

$$2\tilde{\tau}_1 + \text{hard jets}$$

→ ***The standard model background would be due to events with two or more hard jets and two central muons which will fake the signal.***

→ ***The leading contribution comes from top-pair production and its subsequent decay into dimuons, with similar topology as that of the signal.***

→ ***The cuts are as before…***

Background is almost completely reducible with the imposition of strong event selection criteria…..

Cuts	Background	Benchmark point 1	Benchmark point 2
Basic	39617	8337	1278
Basic + $p_T > 350$ GeV	5	2587	737

Table 2: *The expected number of events for the signal and background with the different cuts imposed on the selection of events. We have assumed an integrated luminosity of 30 fb^{-1} at the LHC to generate the events.*

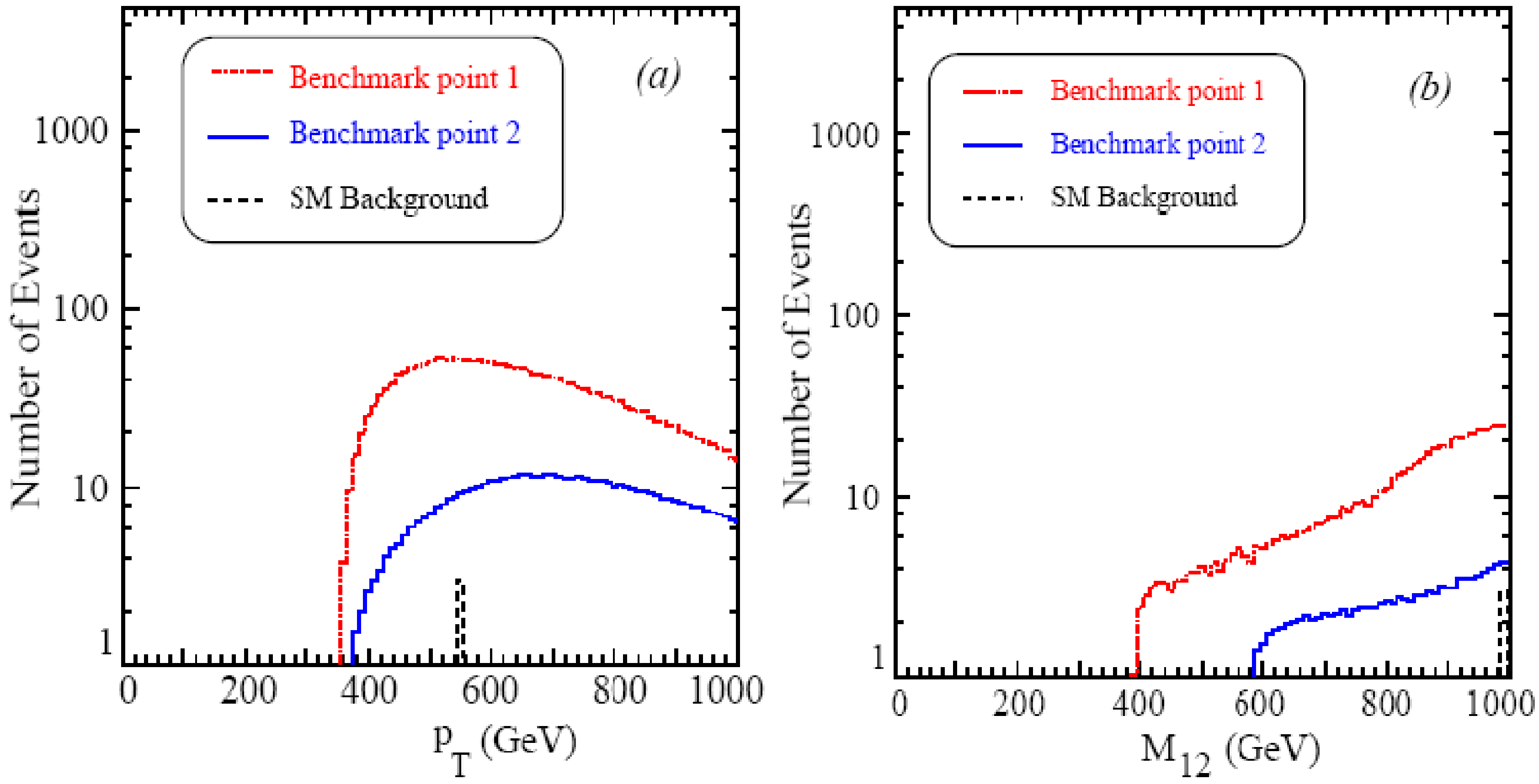


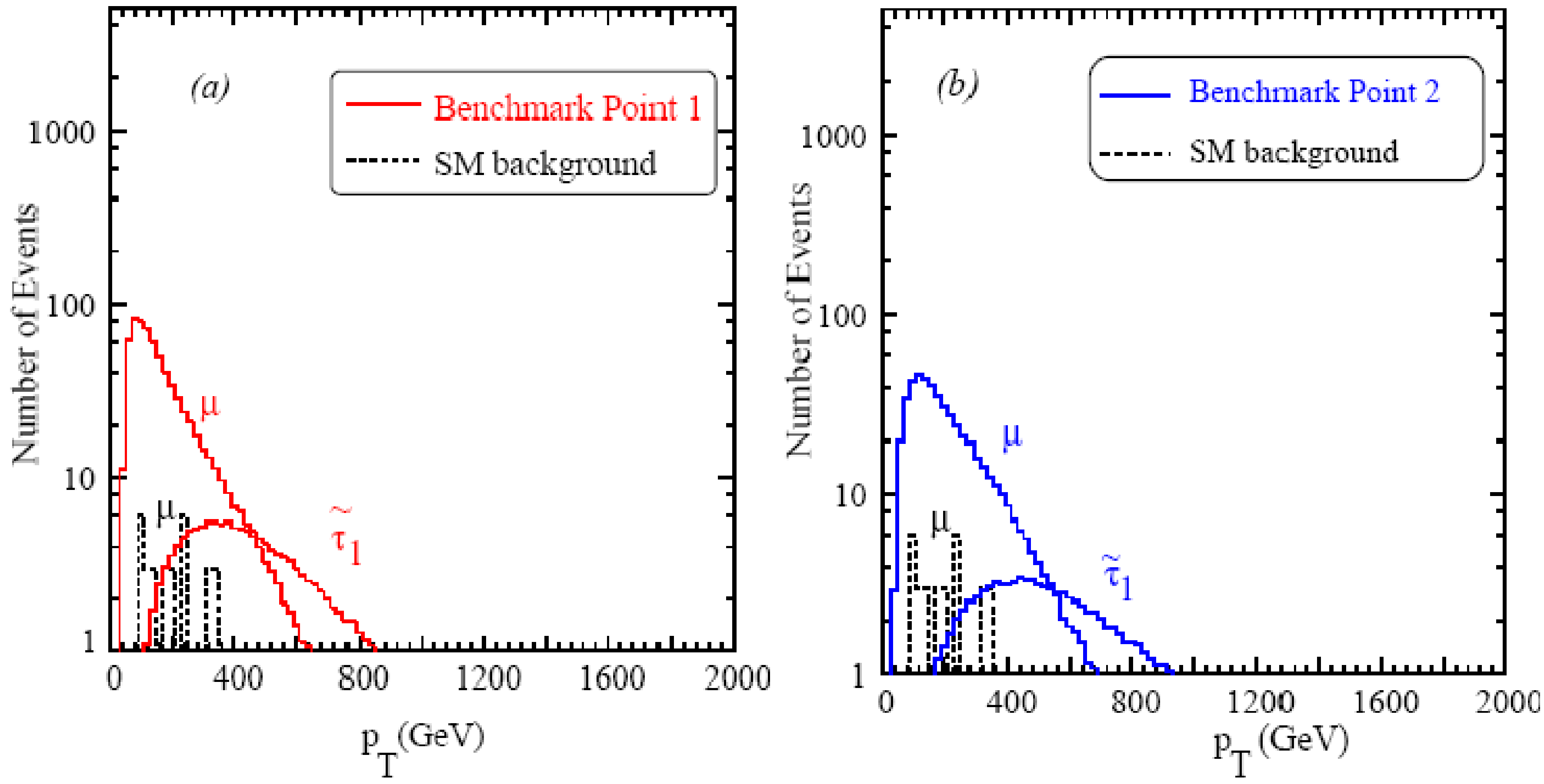
Figure 3: *Kinematic distributions for the signal* $2\tilde{\tau}_1 + (\geq 2)$ *hard jets after imposing the stronger cut,* $p_T > 350$ *GeV on both charged tracks. In (a) the transverse momentum distributions for the harder* $\tilde{\tau}_1$ *is shown and (b) shows the invariant mass distribution for the* $\tilde{\tau}_1$ *pair. We follow the same notation as in Figure 2.*

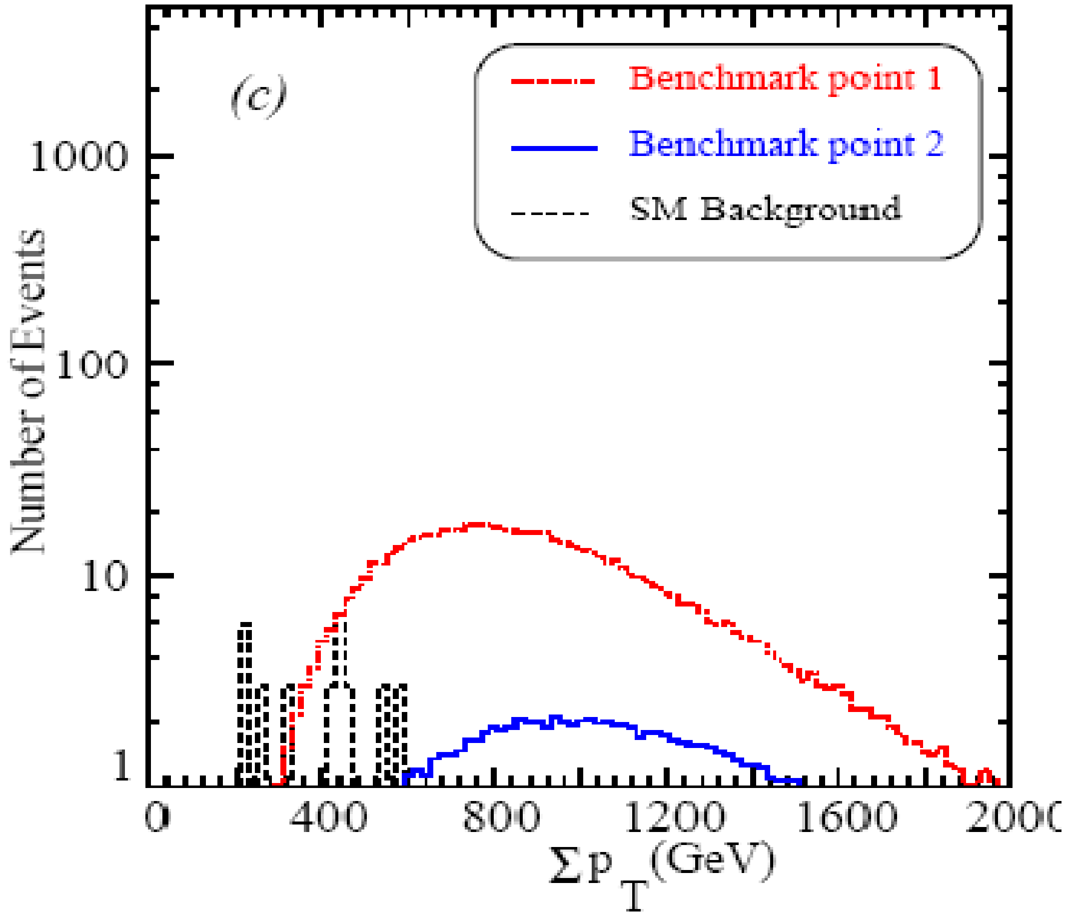
Dimuon and two staus with two or more jets

→ ***This is a very clean signal due to the stringent demand on the hardness of jets.***

→ ***Such final states will appear in cascade decays involving the charginos and heavier neutralinos.***

→ ***The same basic cuts as before are good enough to kill the SM background of 4 μ's together with 2 (or more) jets with a p_T > 100 GeV.***


(a)
Benchmark Point 1
SM background
Number of Events
1000
100
10
1
μ
μ
$\tilde{\tau}_1$
0
400
800
1200
1600
2000
p_T (GeV)
(b)
Benchmark Point 2
SM background
Number of Events
1000
100
10
1
μ
μ
$\tilde{\tau}_1$
0
400
800
1200
1600
2000
p_T (GeV)



$\sum p_T$ → ***corresponds to the scalar sum of the individual transverse momenta of the charged tracks in the muon chamber.***

Final States	Background	Benchmark point 1	Benchmark point 2
$2\tilde{\tau}_1 + 2\mu$	83	689	103
$2\tilde{\tau}_1 + 2\mu + (\geq 2)$ hard jets	29	686	103
$2\tilde{\tau}_1 + 2\mu + (\geq 2)$ hard jets ($\sum p_T > 600$ GeV)	0	553	89

Table 3: *The expected number of events for the signal and background with the different cuts imposed on the selection of events.* $\sum p_T$ *corresponds to the scalar sum of the individual transverse momenta of the charged tracks in the muon chamber. Choice of integrated luminosity is the same as Table 2.*

Conclusions:

- *We have studied a scenario motivated in the SUGRA framework where the LSP is a dominantly right-chiral sneutrino with the lighter stau as the NLSP.*

- *The stau-NLSP tends to fake muonic signals in the muon chamber due to its quasistable nature.*

- *We have shown that such tracks reveal considerable difference in their kinematic characters → straight forward discrimination possible !!*

- *Due to its striking similarity in the mass spectrum with SUGRA having neutralino LSP, more work needed to uncover its signatures at LHC.*