LHC signals of a Supersymmetry scenario with right chiral neutrinos

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Plan of the Talk

- Right-chiral sneutrino LSP in mSugra
- Signals of Stau NLSP at the LHC
- Signals of Stop NLSP at the LHC
- Summary and Conclusion

Right-chiral sneutrino LSP in mSugra

Neutrino

Neutrinos have mass and standard model (SM) does not have any explanation for it.

Recently, in neutrino oscillation experiments it was found that

$$\begin{aligned} \left(\Delta m_\nu^2\right)_{\mathrm{atom}} &= 2.8 \times 10^{-3}\ \mathrm{eV}^2 \\ \left(\Delta m_\nu^2\right)_{\mathrm{solar}} &= 7.9 \times 10^{-5}\ \mathrm{eV}^2 \end{aligned}$$

The WMAP data put an upper bound on the summed ν mass:

$$\sum m_\nu < 2.0 eV (95\% CL)$$

Since there are three types of neutrinos, we get
$m_\nu \simeq .67$ eV.

Right-chiral sneutrino LSP in mSugra

Neutrino mass in MSSM

To incorporate Dirac type neutrino mass, MSSM can be extended by introduction of an additional superfield N.

$$W = Y_t\, \hat{Q}\hat{H}_u\hat{\bar{U}} - Y_b\, \hat{Q}\hat{H}_d\hat{\bar{D}} - Y_e\, \hat{L}\hat{H}_d\hat{\bar{E}} + Y_\nu\, \hat{L}\hat{H}_u\, \hat{\bar{N}} + \mu\, \hat{H}_d \cdot \hat{H}_u$$

$m_\nu = y_\nu < \hat{H}_u >= y_\nu\ v\ sin\beta$

with $v^2 = {v_d}^2 + {v_u}^2$, and, $tan\beta = v_u/v_d$

Mass of heaviest ν can be approximated as:

$$\sqrt{(\Delta m_\nu^2)_{\text{atom}}} \text{ or } \sqrt{(\Delta m_\nu^2)_{\text{solar}}}$$

which gives $y_\nu \sin\beta \sim 10^{-13} - 10^{-11}$ (too small)

Right chiral sneutrino LSP in mSugra

Since $Q_\nu = 0 = T_{3L}^{\tilde{\nu_R}},\ T_{3L}^{\tilde{\nu_L}} = 1/2$

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

where $M_{\tilde{L}}$ is the soft scalar mass for the left-handed sleptons and $M_{\tilde{\nu}_R}$ for the right-handed sneutrino.

Clearly, $M_{\tilde{\nu}_L} \neq M_{\tilde{\nu}_R}$ because of the D-term contribution for the former.

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

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

No additional contribution due to RGE in right sneutrino mass.
Other RGE's remain unaffected because of small y_ν.

Right chiral sneutrino LSP in mSugra

Thus, for a wide range of $m_{1/2} > m_0$, one naturally has sneutrino LSPs which will be dominated by

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

The mixing angle θ is given as

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

which is clearly suppressed due to small y_ν.
Note:If neutrinos are majorana type, we will never have sneutrino LSP as m_{ν_R} will be very heavy and hence the right sneutrino too.

NLSPs

In this scenario the lightest neutralino is the most natural candidate for Next-to-LSP (NLSP).

Other possibilities include a lighter $\tilde{\tau}_1$, lighter chargino $\chi^{+}{}_1$, a colored NLSP such as lighter $\tilde{t}_1$ or $\tilde{b}_1$.

The most favorable candidate for NLSP other than the lightest neutralino are lighter staus and lighter stops as the mixing is larger in third fermion sector.

NLSPs

These NLSPs will be long-lived as their decays are dirven by tiny neutrino Yukawa coupling.

If the NLSP is neutral, collider signatures will be similar to usual SUSY signature with huge amount of missing energy.

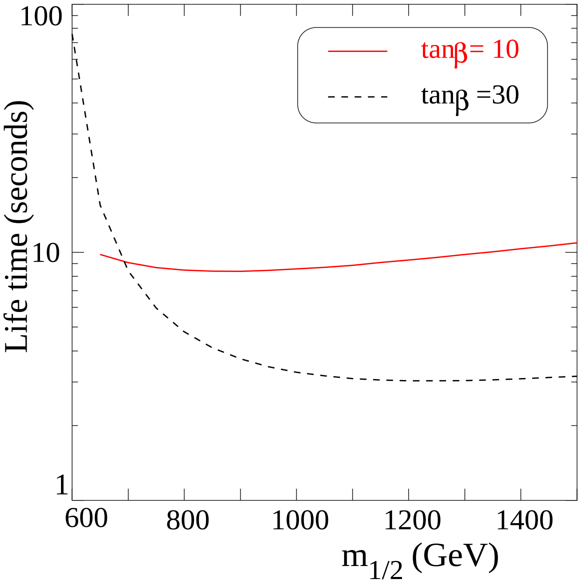
Signals of meta-stable charged NLSP will qualitatively differ as they carry "no" missing energy.

Signals of the Stau NLSP

In mSUGRA, the scenario of stau NLSP and sneutrino LSP can be realized with a small scalar mass, m_0, below the gaugino mass, $m_{1/2}$ with $tan\beta \geq 10$.

This gives a completely new possibility to explore a SUGRA region which was mostly disallowed by the charged LSP search so far and hence remained untouched in the context of colliders.

Signals of the Stau NLSP



Signals of the Stau NLSP

These meta-stable staus will decay far outside the detector. Their behavior can be traced from a slow moving "fat" muon-like chraged track emerging out of the muon chamber.

Also, since staus are 'stable' at collider scales, SUSY cascades of produced superparticles will practically end at the stau NLSPs.

Thus, if such a scenario exists,

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Thus, if such a scenario exists,
In experiments, we expect to observe SUSY with 'no' missing energy
And a sneutrino cold dark matter candidate...

Signals of the Stau NLSP

To study collider signatures of such a long-lived NLSP, we propose two benchmark points allowed by the following experimental and observational constraints:

$b \to s\gamma$

Contribution to the invisible Z boson decay width

$g_\mu - 2$

Corrections to the ρ -parameter

Lower bounds on Higgs and sparticle masses

Constraint due to Ω_{CDM}.

Signals of the Stau NLSP

Parameter	Benchmark point 1	Benchmark point 2
mSUGRA input	$m_0 = 100\ GeV,\ m_{1/2} = 600\ GeV$ $A = 100\ GeV,\ sgn(\mu) = +$ $\tan\beta = 30$	$m_0 = 110\ GeV,\ m_{1/2} = 700\ GeV$ $A = 100\ GeV,\ sgn(\mu) = +$ $\tan\beta = 10$
$\|\mu\|$	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
$m_{\tilde{\nu}_{1R}}$	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

Signals of the Stau NLSP

We analyse two different final states, viz.

- $2\tilde{\tau}_1 + 2(\text{or more})$ *jets* $(p_T > 50\ \text{GeV})$
- $2\tilde{\tau}_1 + \text{dimuon} + 2(\text{or more})$ *jets* $(p_T > 50\ \text{GeV})$

The low energy mass spectrum schematically takes the following form:

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

which would suggest that all superparticle productions at the LHC would finally end at the sneutrino LSP.

Signals of the Stau NLSP

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

We produced SUSY through all possible production modes and allowed superaprticles to decay into lighter staus.

The signals arise mostly from the direct decay of gluinos and squarks into the lightest neutralino, with the latter decaying into a tau and a lighter stau, and the tau decaying hadronically in turn.

To make χ_1^0 decay $\tilde{\tau}_1 \bar{\tau}$, we modified the decay table in PYTHIA and demanded χ_1^0 not to be LSP.

The effects of ISR, FSR and hadronization are taken into account.

Signals of the Stau NLSP

To select our final states, we used the following basic cuts

- Each $\tilde{\tau}_1$ should have $p_T > 30$ GeV.
- Both the $\tilde{\tau}_1$'s should satisfy $|\eta| \leq 2.5$, to ensure that they lie within the coverage of the muon detector.
- $\Delta R_{\tilde{\tau}_1 \tilde{\tau}_1} \geq 0.2$, to ensure that the $\tilde{\tau}_1$'s are well resolved in space.
- At least two jets with $p_T > 50$ GeV (hard jets), and $|\eta_j| \leq 2.7$
- $\Delta R_{jj} \geq 0.4$, $\Delta R_{\tilde{\tau}_1 j} \geq 0.2$
- $\not{E}_T > 30$ GeV

Signals of the Stau NLSP

Background

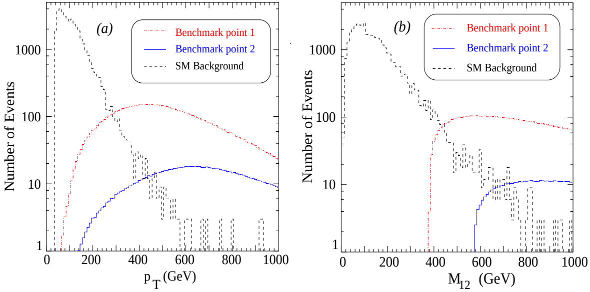
As the charged tracks are similar to muons, events with two or more hard jets and two central muons will constitute SM background.

The leading contribution to such final states comes from top-pair production and its subsequent decay into dimuons.

The subleading contributions are due to weak boson pair production.

Signals of the Stau NLSP

Integrated Luminosity$= 30 fb^{-1}$

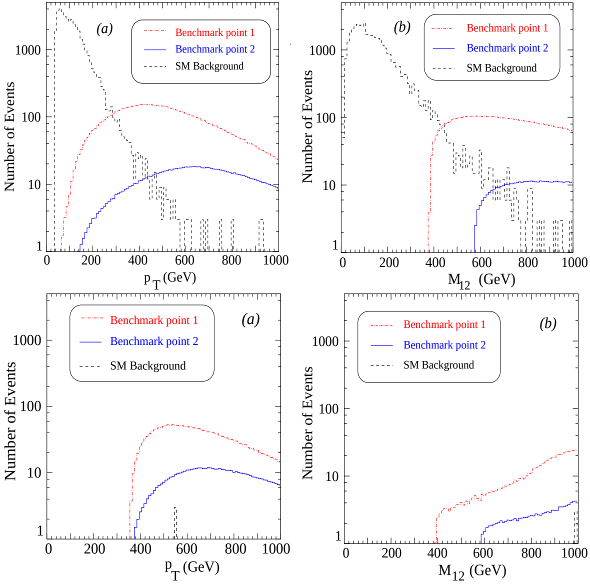


Signals of the Stau NLSP

The background is almost reducible with the imposition of stronger event selection criteria.

We found that $p_T > 350$ GeV on each of the charged tracks can reduce background considerably.

Signals of the Stau NLSP



Signals of the Stau NLSP

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

Signals of the Stau NLSP

SUSY with and without right sneutrino LSP

A pair of high-p_T muons can also arise from SUSY cascades decays together with hard jets.

Signals in the present scenario will be more affected with the imposition of a stronger $\not{E}_T$ cut compared to usual SUSY signals.

Signals of the Stau NLSP

An Example

The signal rate at benchmark point 1 becomes about 48% of its original value when we demand $\not{E}_T > 100$ GeV.

At a a nearby point in the parameter space (with neutralino LSP) i.e. ($m_0 = 200$ GeV, $m_{1/2} = 600$ GeV, $A = 100$ GeV, $\tan\beta = 30$, $sgn(\mu) = +$ve), the same $\not{E}_T$ cut allows about 97% survival of the *jets* $+$ *dimuons* $+ \not{E}_T$ signal.

Clearly, response to $\not{E}_T$ cuts turns out to be an effective tool to distingusih between the two SUSY scenario.

Signals of the Stau NLSP

Dimuon and two staus with two or more jets

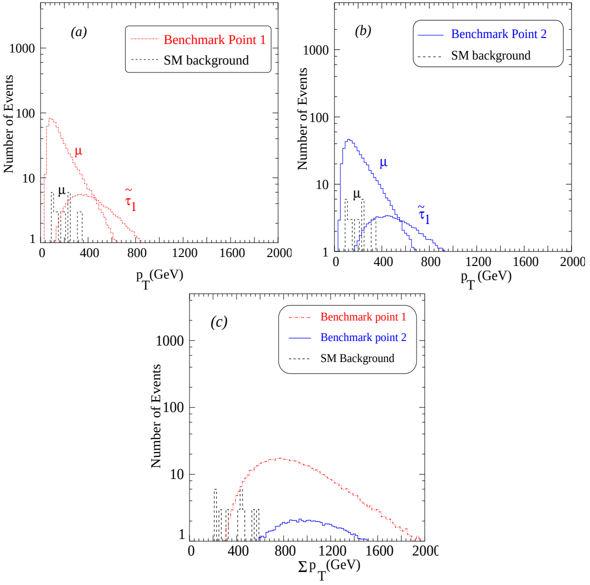
The motivation for studying this signal is that it is expected to be relatively less surrounded with the SM background.

Such final states will require cascade decays of gluinos and squarks involving the charginos and heavier neutralinos.

Major sources of bakground is ZZZ production with at least two Z's decaying leptonically.

The same basic cuts are found to be sufficient in reducing the SM backgrounds in the form of four muons together with two or more jets with $p_T > 50$ GeV.

Signals of the Stau NLSP



Signals of the Stau NLSP

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

Signals of a stop NLSP

Signals of a stop NLSP

Among the colored NLSPs, a lighter stop is the most favorable candidate beacause of the larger top Yukawa coupling.

Within SUGRA, such a scenario of stop NLSP and right-sneutrino LSP can never be realized as to have a light stop ($m_{\tilde{t}_1} \geq 240$ GeV, CDF bound), m_0 and A_0 should be large. But this result in tachyons.

We found that the above scenario can be accommodated once we relax the universality in third generation sfermion masses.

The additional SUGRA parameters are

$m_{\tilde{t}_L}, m_{\tilde{t}_R}, m_{\tilde{b}_R}, m_{\tilde{\tau}_l}, m_{\tilde{\tau}_R}, m_{\tilde{\nu}_R}$

A large non-universal SUGRA parameter space ($m_0 < m_{1/2}$) is allowed for $1.8 < |A| < 3$ TeV.

Signals of the Stop NLSP

- Signal 1
  two stop tracks
  Backgrounds $\mu^+\mu^-$ WW, WZ, ZZ pair productions

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  two stop tracks
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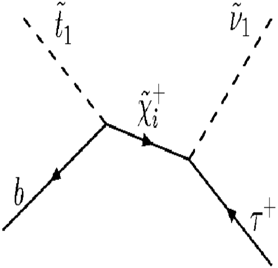
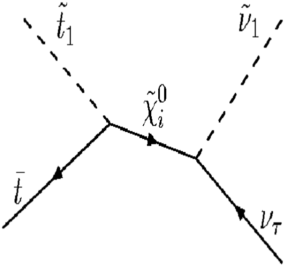
- Signal 2 *two stop track* + *two leptons* + *two jets* + *missing* E_T
  Backgrounds $ttll$, WZZ, ZZZ productions

Signals of the Stop NLSP

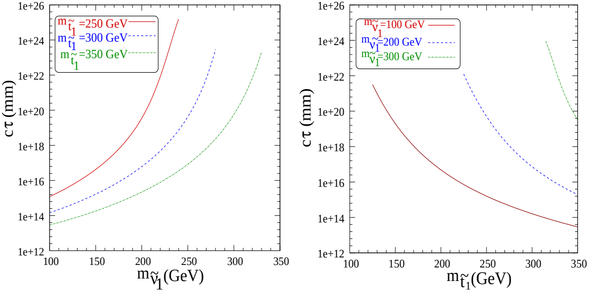
- Signal 1
  two stop tracks
  Backgrounds $\mu^+\mu^-$ WW, WZ, ZZ pair productions
- Signal 2 *two stop track* $+$ *two leptons* $+$ *two jets* $+$ *missing* E_T
  Backgrounds $ttll$, WZZ, ZZZ productions
- Signal 3
  two stop track $+$ *one lepton* $+$ *two jets* $+$ *two* $b's$ $+$ *missing* E_T
  Backgrounds $ttl\nu$, ZZZ productions

Signals of a stop NLSP





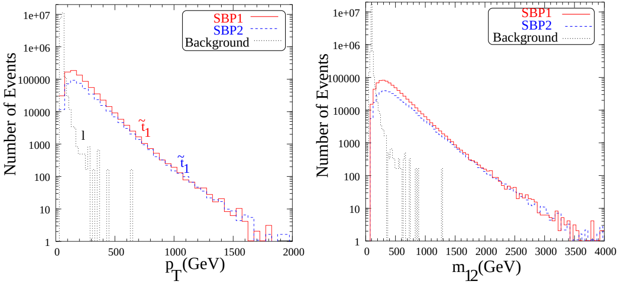
Signals of a stop NLSP



Signals of a stop NLSP

	Parameter	SBP1	SBP2	SBP3	SBP4
IN	m_0, $m_{1/2}$, A	184,600,-2400	370,650,-2600	540,700,-2500	325,800,-3000
P	$m_{\tilde{t}_L}$,$m_{\tilde{t}_R}$,$m_{\tilde{b}_R}$	600,301,500	700,400,500	1000,200,750	1000,260,750
UT	$m_{\tilde{\tau}_L}$,$m_{\tilde{\tau}_R}$	500,500	750,750	750,750	750,750
	$\|\mu\|$	1363	1459	1479	1750
	$m_{\tilde{e}_L}$,$m_{\tilde{\mu}_L}$	461	585	713	659
	$m_{\tilde{e}_R}$,$m_{\tilde{\mu}_R}$	244	415	528	336
	$m_{\tilde{\nu}_{eL}}$,$m_{\tilde{\nu}_{\mu L}}$	450	576	735	648
	$m_{\tilde{\nu}_{\tau L}}$	581	765	1071	865
O	$m_{\tilde{\nu}_{eR}}$,$m_{\tilde{\nu}_{\mu R}}$	184	370	540	325
U	$m_{\tilde{\tau}_1}$	316	555	871	544
T	$m_{\tilde{\tau}_2}$	595	775	1077	873
P	$m_{\chi_1^0}$	253	276	299	342
U	$m_{\chi_2^0}$	485	528	571	652
T	$m_{\chi_3^0}$	1359	1455	1478	1756
	$m_{\chi_4^0}$	1361	1457	1481	1748
	$m_{\chi_1^\pm}$	488	532	574	657
	$m_{\chi_2^\pm}$	1363	1459	1483	1750
	$m_{\tilde{g}}$	1367	1477	1594	1790
	$m_{\tilde{u}_L}$,$m_{\tilde{c}_L}$	1260	1391	1530	1653
	$m_{\tilde{u}_R}$,$m_{\tilde{c}_R}$	1222	1350	1502	1612
	$m_{\tilde{d}_L}$,$m_{\tilde{s}_L}$	1263	1394	1532	1655
	$m_{\tilde{d}_R}$,$m_{\tilde{s}_R}$	1207	1337	1470	1580
	$m_{\tilde{t}_1}$	240	273	296	330
	$m_{\tilde{t}_2}$	1109	1203	1443	1544
	$m_{\tilde{b}_1}$	1075	1174	1423	1534
	$m_{\tilde{b}_2}$	1209	1284	1476	1615
	m_{h^0}	116	117	121	120
	m_{H^0}	1305	1429	1507	1706
	m_{A^0}	1297	1421	1498	1695
	$m_{H^\pm}$	1308	1432	1510	1708

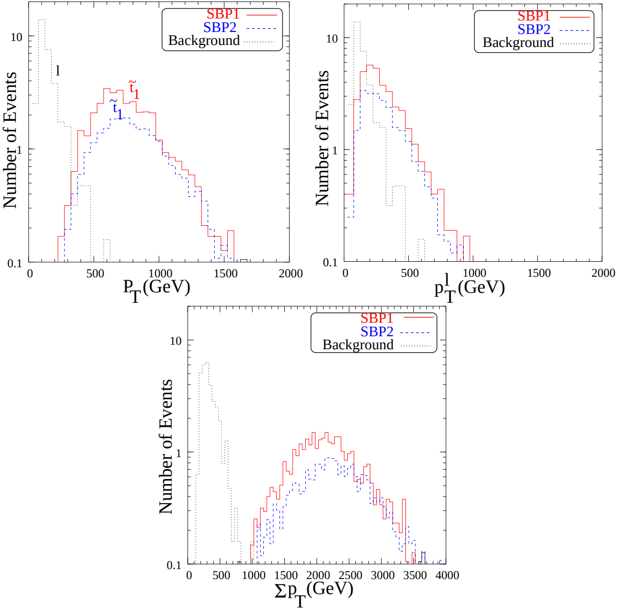
Signals of a stop NLSP



Signals of a stop NLSP

Cuts	SB1	SB2	SB3	SB4	BKG
$p_{T_{\tilde{t}_1}} > 25$ GeV, $\lvert\eta_{\tilde{t}_1}\rvert < 2.5$ and $\Delta R_{\tilde{t}_1\tilde{t}_1} > 0.2$	754,645	406,614	272,992	158,638	19,814,927
$p_{T_{\tilde{t}_1}} > 200$ GeV	236,873	155,336	116,480	77,428	3,106
$m_{\tilde{t}_1\tilde{t}_1} > 1400$ GeV	6,180	5,671	4,986	4,324	0

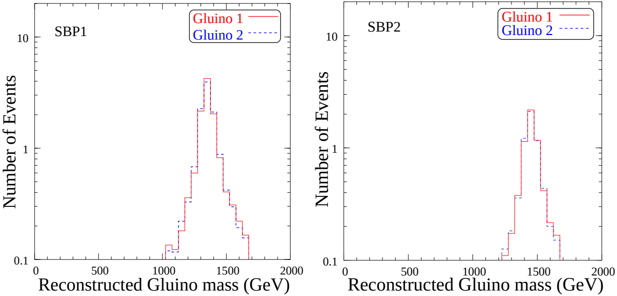
Signals of a stop NLSP



Signals of a stop NLSP

Cuts	SB1	SB2	SB3	SB4	BKG
$p_{T_{\tilde{t}_1,l}} > 25$ GeV, $\|\eta_{\tilde{t}_1}\| < 2.5$, $p_{T_j} > 50$ GeV, $\|\eta_j\| < 2.5$, $\Delta R_{\tilde{t}_1\tilde{t}_1} > 0.2$, $\Delta R_{jj} > 0.2$, $\Delta R_{\tilde{t}_1 j} > 0.2$ and $\not{E}_T > 30$ GeV	44	29	15	9	32.5
$\Sigma p_T > 800$ GeV	44	29	15	9	0

Signals of a stop NLSP



Signals of a stop NLSP

Cuts	SB1	SB2	SB3	SB4	BKG
$p_{T_{\tilde{t}_1,l}} > 25$ GeV, $\|\eta_{\tilde{t}_1,l}\| < 2.5$ $p_{T_{j,b}} > 50$ GeV, $\|\eta_{j,b}\| < 2.5$ $\Delta R_{\tilde{t}_1 \tilde{t}_1} > 0.2$, $\Delta R_{jj} > 0.2$ $\Delta R_{\tilde{t}_1 j} > 0.2$ and $\not{E}_T > 30$ GeV	28	18	9	5	17
$\Sigma p_T > 600$ GeV	28	18	9	5	0

Summary and conclusions

We have studied SUSY scenarios with long-lived stau and stop NLSP and right-chiral sneutrino as the LSP.

The superparticle cascades culminating into the production of charged-track pairs give rise to very distinct collider signatures in both of these cases.

Although the charged tracks tend to fake muonic signals, our analysis reveals considerable difference in their kinematic characters which can be used to distinguish between them.

Gluino reconstruction is possible in case of stop-tracks. This togather with event rates can be helpful in distinguishing the stop-NLSP scenario from other charged-NLSP scenarios.