Leptogenic Supersymmetry

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Based on arXiv:0903.5305
with J. Fan, V. Sanz, W. Skiba
OUTLINE

- What is Lepto-SUSY?
- Main Features
- Phenomenology. Channels with:
  - 4 leptons
  - Higgs
WHAT IS LEPTO-SUSY?

Yet another SUSY model? No...

A particular ordering of the SUSY spectrum.

Not interested in how the hierarchy of masses gets generated at high energies.

Look at what LHC can access. Striking and unusual collider signatures.
WHAT DOES “LEPTOGENIC” MEAN?

Leptogenic spectrum:

\[ m_{\tilde{g}}, m_{\tilde{q}} > m_{\tilde{\chi}^0}, m_{\tilde{\chi}^\pm} > m_{\tilde{\ell}_L} > m_h, m_{\tilde{\ell}_R} \]

Many leptons are produced in cascade decays.
Some Features

- Gauginos heavier than scalars.
- All sleptons lie at the bottom. The decay chains pass through $\tilde{\ell}_L, \tilde{\ell}_R$ and produce many leptons.
- $\tilde{\ell}_R$ NLSP: long-lived, collider stable. No significant missing energy!
- Gravitino LSP, no role at colliders.

Lepto-SUSY spectrum:

- Jets
- Leptons
- Higgses

Leptogenic Supersymmetry

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Some Features

- Higgs is produced in slepton decays. $h \rightarrow b\bar{b}$: important channel.

- Several classes of models give rise to a Lepto-SUSY spectrum
  (GMSB with large Nmess, Gaugino mediation at low-scale, AMSB ...)

- ...or just the MSSM in a region of its parameter space
PRODUCTION AND DECAY

Strong production cross-section.

Squark-pair production is the dominant process.
**PRODUCTION AND DECAY**

\[ \sqrt{s} = 14 \text{ TeV} \]

\[ pp \rightarrow \tilde{q}\tilde{q} + \tilde{q}\tilde{q} + \tilde{q}\tilde{q} \]

**Strong production cross-section.**

**Squark-pair production is the dominant process.**

**Typical final state of squark cascade decays:**
- 2 jets + (2,3,4) leptons + 2 stable charged tracks
- No significant missing energy.

\[ pp \rightarrow \tilde{q}\tilde{g} \]

**Strong production cross-section.**

**Squark-pair production is the dominant process.**

**Typical final state of squark cascade decays:**
- 2 jets + (2,3,4) leptons + 2 stable charged tracks
- No significant missing energy.
BENCHMARK POINTS

Lepto-SUSY is not in ATLAS/CMS benchmark points!

- **LS1**: squark masses ~ 1 TeV
- **LS2**: squark masses ~ 520-700 GeV
  
  sleptons ~ 110 GeV
  
  Higgs ~ 115 GeV
  
  Production cross-section (fb)
  
<table>
<thead>
<tr>
<th></th>
<th>10 TeV</th>
<th>14 TeV</th>
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<tbody>
<tr>
<td>LS1</td>
<td>680</td>
<td>2170</td>
</tr>
<tr>
<td>LS2</td>
<td>5040</td>
<td>13700</td>
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</tbody>
</table>
BENCHMARK POINT "LS1"

| mass (GeV) | gluino: $m_{\tilde{g}}$ | 1938 |
| Neutralinos: | $m_{\chi^0_1}$ | 271 |
| | $m_{\chi^0_2}$ | 302 |
| | $m_{\chi^0_3}$ | 353 |
| | $m_{\chi^0_4}$ | 676 |
| Charginos: | $m_{\chi^\pm_1}$ | 291 |
| | $m_{\chi^\pm_2}$ | 676 |
| Higgs: | $m_{h^0}$ | 115 |
| | $m_{H^0}$ | 379 |
| | $m_A$ | 379 |
| | $m_{H^\pm}$ | 387 |
| | $\mu$ | 294 |
| | $\sqrt{B_{\mu}}$ | 119 |
| Sleptons: | $m_{\tilde{\ell}_R}$ | 108 |
| | $m_{\tilde{\ell}_L}$ | 248 |
| | $m_{\tilde{\nu}}$ | 236 |
| | $m_{\tilde{\tau}_1}$ | 106 |
| | $m_{\tilde{\tau}_2}$ | 249 |
| Squarks: | $m_{\tilde{u}_L}$ | 949 |
| | $m_{\tilde{u}_R}$ | 920 |
| | $m_{\tilde{d}_L}$ | 952 |
| | $m_{\tilde{d}_R}$ | 919 |
| | $m_{\tilde{t}_1}$ | 920 |
| | $m_{\tilde{t}_2}$ | 962 |
SLEPTONS OR MUONS?

Long-lived sleptons hits like muons with lower $\beta$

Fast sleptons ($\beta > 0.9$) misidentified as muons

Many sleptons are very fast in the signal

[ATLAS TDR 2008]
Focus on channels with:

- 2 hard jets
- ≥ 4 lepton-like particles (leptons or stable sleptons)

New channels for SUSY searches!

- Almost background-free.
- Statistically significant excesses of events already at low luminosity (≤ 1 fb⁻¹).
- Mass reconstruction of several sparticle states.
- Higgs can be discovered in the \( h \rightarrow b\bar{b} \) mode.
$pp \to \tilde{q} \tilde{q} \chi^0 j j \chi^0 j j \tilde{\ell}_R \ell \tilde{\ell}_R \ell$

seen as muons

Event selection:

- $n_\ell = 4$ (including sleptons)
- $n_{jet} \geq 2$

with standard cuts

- $|\eta_{jet}| < 2.5, \quad |\eta_\ell| < 2.5$
- $p_{T,jet} > 15 \text{ GeV}, \quad p_{T,\ell} > 10 \text{ GeV}$
- $\Delta R_{jj,\ell\ell,\ell j} > 0.4$

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<tbody>
<tr>
<td>$\sigma$ (fb)</td>
<td>220</td>
<td>690</td>
</tr>
<tr>
<td>Events at 0.2 fb$^{-1}$</td>
<td>45</td>
<td>140</td>
</tr>
</tbody>
</table>
4-LEPTONS CHANNEL

It allows $\chi_{1}^{0}, \chi_{3}^{0}, \tilde{q}$ mass reconstruction.

Channel with no MET. No MET cut imposed.

Hard cuts on the $p_T$ of the leading jet can be applied and suppress the BG efficiently.

All SM BGs are below 1 fb.
OSL pairs selected according to minimal $\Delta R$ separation.

sleptons identified \hspace{1cm} sleptons misidentified

Further pairing with the nearest jet
HIGGS CHANNEL

Standard lore:

- No Higgs searches in b-bbar, due to large BG.

In Lepto-SUSY:

- Higgs is copiously produced in slepton decays $\tilde{\ell}_L \rightarrow h \tilde{\ell}_R$, and then decays to b-bbar.

- BG efficiently suppressed by lepton multiplicity.

- $h \rightarrow b\bar{b}$ is a discovery channel.
HIGGS CHANNEL

Analysis (simple-minded and conservative):
- ask for \( n_\ell = 3, 4 \) and \( n_{\text{jet}} \geq 4 \)
- order jets in pT and ask 4th pT>25 GeV
- assume 1st and 2nd jets are from squarks
- form invariant mass of 3rd and 4th jets

\[ n_\ell = 3, 4 \]
\[ n_{\text{jet}} \geq 4 \]

\[ \tilde{q} \rightarrow \tilde{q} \]
\[ \ell \rightarrow \tilde{\tau}_1 \]
\[ \mu \rightarrow \tilde{\tau}_2 \]

\[ h^0 \rightarrow b \]
\[ \chi^0 \rightarrow \tilde{b} \]
\[ \chi^0 \rightarrow \tilde{\ell}_R \]

NB: No b-tagging. Not precisely known at early stages.

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<tbody>
<tr>
<td>( \sigma ) (fb)</td>
<td>100</td>
<td>320</td>
</tr>
<tr>
<td>Events at 0.2 fb(^{-1})</td>
<td>20</td>
<td>64</td>
</tr>
</tbody>
</table>
14 TeV to 10 TeV is a factor of $\sim 1/3$

Combinatorial BG: more detailed analysis needed.

Under study by ATLAS coll.
DISCOVERY PROSPECTS

- The ease of multi-leptonic channels (~absence of BG) implies a tremendous discovery potential of LHC.

- The discovery of the stable slepton is possible with the very first data.

- Most of the sparticle spectrum can be reconstructed (at least 10 clean events) with

\[
0.2 - 0.4 \text{ fb}^{-1} \text{ at } 10 \text{ TeV} \quad \text{(for TeV-squarks)}
\]

- Prospects of Higgs discovery in the \( h \rightarrow b\bar{b} \) channel may be good with \( \leq 1 \text{ fb}^{-1} \) at 14 TeV. Significance of this channel requires full simulation.
CONCLUSIONS

Leptogenic SUSY spectra are characterized by many leptons in the final state of $pp$ collisions.

They arise in several well-motivated models.

Extremely clean (almost BG-free) channels. One of the most “LHC-friendly” SUSY scenarios.

Different from standard SUSY searches.

Relevant for very early stage of LHC. It can be discovered/ruled out with $\sim 0.2 \text{ fb}^{-1}$ at 10 TeV.
CONCLUSIONS

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Different from standard SUSY searches.

Relevant for very early stage of LHC. It can be discovered/ruled out with $\sim 0.2$ fb$^{-1}$ at 10 TeV.

If you see many leptons... remember LEPTO-SUSY !!!

THANK YOU
BACK-UP SLIDES
**BACKGROUND (1)**

- **SM background in (3,4) leptons + 4 jets:** $t\bar{t}$ +jets, W/Z+jets, WZ+jets, ZZ+jets, QCD jets.

- **Rate for jets faking leptons $\sim 10^{-4}$** (ATLAS TDR)
- **b-decay producing isolated leptons $\sim 5 \times 10^{-3}$**

Significant cross-section suppression:
- e.g. for QCD jets faking 4 leps: $10^8 \text{ pb} \times (10^{-4})^4 = 10^{-5} \text{ fb}$

- **Possibility to apply hard cuts on $p_T$ of the leading jet and lepton, without losing signal.**

- **Efficient BG suppression.**
BACKGROUND (2)

SM BGs generated with ALPGEN and MG.

All < 1 fb after the cuts:

\[ n_\ell \geq 3 \]
\[ n_j \geq 4 \]
\[ p_{j1}^T > 200 \text{ GeV} \]
\[ p_{j4}^T > 25 \text{ GeV} \]
\[ n_\mu \geq 2 \]
\[ p_T^{(\ell)} > 50 \text{ GeV} \]
\[ \Delta R_{\ell \ell, \ell j, j j} > 0.4 \]
Varying missing ET cuts

combinatorial BG
TEVATRON LIMITS

Only apply to slepton pair production (8 fb in our case). Not constrained by TeVatron

[Search for charged massive stable particles with D0 detector (2008)]
5-LEPTONS CHANNEL

\[ pp \rightarrow \tilde{q} \tilde{q} \chi^+ j \bar{\nu}_L \tilde{\ell}_L \tilde{\ell}_R \]

\[ pp \rightarrow \tilde{q} \chi^0 j \bar{\nu}_L \tilde{\ell}_R \]

\[ \sigma \text{ (fb)} \]

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</tr>
</thead>
<tbody>
<tr>
<td>\sigma</td>
<td>137</td>
<td>426</td>
</tr>
<tr>
<td>Events at 0.2 fb(^{-1})</td>
<td>27</td>
<td>85</td>
</tr>
</tbody>
</table>

\[ E_T \text{ due to neutrino} \]

\[ \tilde{\chi}^\pm \text{ mass reconstr. also possible with transverse mass.} \]
6-LEPTONS CHANNEL

\[ pp \rightarrow \tilde{\ell}_L, \tilde{\ell}_R, j, \tilde{\chi}^0_3, \tilde{\chi}^0_4, \ell, \ell' \]

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>( \sigma ) (fb)</td>
<td>70</td>
<td>225</td>
</tr>
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<td>Events at 0.2 fb(^{-1})</td>
<td>14</td>
<td>45</td>
</tr>
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\( \tilde{\ell}_L \), other neutralinos and squarks can also be reconstructed but with lower statistics than in \( 4 \ell \).
PARAMETER SPACE

Model-independent parametrization of soft masses:

\[ \tilde{m}^2(R) = \sum_{i=1}^{3} C_2(R_i) K_i \]

\[ K_i = \frac{\alpha_i}{\pi} m_i^2 n_i^2 \]

\( n_i \): dimensionless numbers.

In the Higgs sector:

\[ \delta \equiv -m_{H_d}^2 + m_{H_u}^2 = -\frac{\alpha_3 \lambda_t^2}{4\pi^3} m_3^2 n_4^2 \]

Assuming gaugino mass unification, and \( A=0 \), 7 parameters: \( m_3, n_i \ (i = 1, 2, 3, 4), \tan \beta, \sign \mu \)

Parameter space of lepto-SUSY:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>2000 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_1 )</td>
<td>[2, 5]</td>
<td>4.8</td>
</tr>
<tr>
<td>( n_2 )</td>
<td>[0.5, 6]</td>
<td>3.9</td>
</tr>
<tr>
<td>( n_3 )</td>
<td>&gt; 1.8</td>
<td>2.2</td>
</tr>
<tr>
<td>( n_4 )</td>
<td>&gt; 1.75</td>
<td>6.7</td>
</tr>
<tr>
<td>( \tan \beta )</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>( \sign \mu )</td>
<td></td>
<td>+</td>
</tr>
</tbody>
</table>

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MODELS WITH LEPTO-SUSY

Lepto-SUSY spectra are realized for $n_i = \mathcal{O}(1 - 10)$.

Examples:

- Gaugino mediation at low-scale:
  no large log contribution from RGE.

- Gauge mediation with large $N_m$:
  $n_i \propto \frac{1}{\sqrt{N_m}} \sqrt{\frac{\pi}{\alpha_i}}$

- Supersoft SUSY breaking:
  D-term SUSY breaking is communicated to the visible sector through higher dim operators. Scalar masses naturally suppressed wrt gaugino masses.