Searches for Supersymmetry with the ATLAS Detector

- R-Parity Violating Decays
- Resonance SUSY-Production: RPV and scalar gluons
- Metastable Particles: AMSB

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On behalf of the ATLAS Collaboration

EPS2013, Stockholm, 19.7.2013
Content

- R-parity violation in
  - leptonic decays
  - hadronic decays
  - production and decay

- resonant production in extended supersymmetric models
  - scalar gluons

- compressed supersymmetric scenarios
  - meta-stable particles in AMSB models

- see also talk by Massimo Corradi on long-lived particle searches (12:00, 19.7.2013)
standard searches for SUSY assume R-parity conservation (RPC)

\[ R = (-1)^{3(B-L)+2s} \]

and rely on

- pair production of SUSY particles
- stable lightest SUSY particle (LSP) \( \rightarrow \) missing transverse energy

R-parity violation (RPV) can be allowed as long as either lepton or baryon number conservation is applied

\[ L_{RPV} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \kappa_i L_i H_2 + \lambda''_{ijk} U_i \overline{U}_j \overline{D}_k \]

search strategies need to be adjusted to considered scenario

- final states with low Standard Model background
- missing \( E_T \) from neutrinos
- single particle/resonance production
SUSY Searches with 4 or more Leptons

- High lepton multiplicity can be realised in SUSY with lepton number violation
- Assume SUSY pair-production (RPC)
  - Gluino or chargino pairs
- And prompt decay of neutralino LSP (RPV)
  - Light leptons (e/μ) and hadronic taus (τ_{had})
- Search for final states with four or more leptons with missing E_T from neutrinos

- 5 signal regions
  - 2 dedicated for RPV
- See also Sam King (18.15, 19.7.)

<table>
<thead>
<tr>
<th>SR</th>
<th>N(e+μ)</th>
<th>N(τ)</th>
<th>mis E_T [GeV]</th>
<th>M_{eff} [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR0</td>
<td>≥4</td>
<td>≥0</td>
<td>&gt;75 or</td>
<td>&gt;600</td>
</tr>
<tr>
<td>SR1</td>
<td>=3</td>
<td>≥1</td>
<td>&gt;100 or</td>
<td>&gt;400</td>
</tr>
</tbody>
</table>

- Z veto

H_T = scalar sum of p_T
m_{eff} = H_T + missing E_T
SUSY Searches with 4 or more Leptons

**ATLAS Preliminary**

**Experimental LSP mass range:**
- $10 \text{ GeV} < m_{\tilde{\chi}_1}^0 < 10 \text{ GeV}$

---

**SR0 no Z**

$m_{\tilde{\chi}_1^\pm} < 0.75 \text{ TeV}$

---

**SR1 no Z**

$m_{\tilde{g}} < 1.4 \text{ TeV}$

---

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**Experimental LSP mass range:**
- $10 \text{ GeV} < m_{\tilde{\chi}_1}^0 < 10 \text{ GeV}$

---

**SR0 no Z**

$m_{\tilde{\chi}_1^\pm} < 0.4 \text{ TeV}$

---

**SR1 no Z**

$m_{\tilde{g}} < 1.0 \text{ TeV}$
Massive Resonance decaying to 2 x 3 Jets

- pair production of massive particles decaying into three jets each
- interpretation in terms of RPV prompt gluino decays into three light quark jets
- two orthogonal search strategies:
  - high $\tilde{g}$ mass: resolved analysis
    reconstruct all 6 jets ($R=0.4$) using multi-jet triggers
  - low $\tilde{g}$ mass: boosted analysis
    reconstruct 2 large jets ($R=1$) with substructure using single-jet triggers

\[ \tilde{g} \rightarrow q\bar{q} \rightarrow qqq \quad (m_\tilde{q} \gg m_\tilde{g}) \]
> lepton number violation can lead to decays of heavy particles into pairs of different generation leptons

> search for resonance in \(e\mu, e\tau_{\text{had}}, \mu\tau_{\text{had}}\) final states

> interpretation in terms of sneutrino resonance (Z’ also possible)

> limit on visible cross section: 3.2/42/40 fb
> lepton number violation can lead to decays of heavy particles into pairs of different generation leptons

> search for resonance in $e\mu$, $e\tau$, $\mu\tau$ final states

> exclusion

$e\mu$: $\lambda_{311}^{'} > 0.003$

at $m_{\tilde{\nu}_\tau} = 500$ GeV

$e\tau$: $\lambda_{311}^{'} > 0.01$

$\lambda_{i3k} = 0.07$

$\mu\tau$: $\lambda_{311}^{'} > 0.01$
> pair production of massive scalar particles decaying into two jets each

> interpretation in terms of scalar gluons (s gluon) in extended SUSY or hyperpions in compositeness models

> jets paired into s gluon candidates based on $\Delta R \sim 1$ and similar masses

> define signal (and background) regions on $\frac{|m_1 - m_2|}{m_1 + m_2} < 0.15$ and $|\cos \theta^*| < 0.5$
Particles decaying to Same-Sign Dileptons and $b$ Jets

- scalar gluons can decay into $t\bar{t}$ pairs if mass is above threshold
- final state with four top quarks → search for same sign dilepton pairs and $b$-jets
- $b'$ signal region:
  - two same sign light leptons ($e/\mu$), ≥1 $b$-jets, $m_{E_T} > 40$ GeV and $H_T > 650$ GeV
- scalar gluon signal region:
  - $b'$ SR and ≥2 $b$-jets

<table>
<thead>
<tr>
<th>Selection step</th>
<th>Channel $ee$</th>
<th>Channel $e\mu$</th>
<th>Channel $\mu\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{jets} \geq 2$</td>
<td>371 ± 53</td>
<td>344 ± 60</td>
<td>127 ± 24</td>
</tr>
<tr>
<td>$N_{b-jets} \geq 1$</td>
<td>90 ± 16</td>
<td>139 ± 28</td>
<td>47 ± 14</td>
</tr>
<tr>
<td>$E_{miss} &gt; 40$ GeV</td>
<td>55 ± 8</td>
<td>100 ± 17</td>
<td>37 ± 10</td>
</tr>
<tr>
<td>$H_T &gt; 650$ GeV</td>
<td>3 ± 0.6</td>
<td>10 ± 1.0</td>
<td>2 ± 1.2</td>
</tr>
<tr>
<td>$N_{b-jets} \geq 2$</td>
<td>1 ± 0.25</td>
<td>6 ± 0.5</td>
<td>1 ± 1.2</td>
</tr>
</tbody>
</table>

- see also talk by Antonella Succurro (15:15, 18.7.)
> Charginos and neutralinos are almost degenerated in mass in Anomaly Mediated SUSY Breaking (AMSB)

- $\Delta m_{\tilde{\chi}_1} = m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} \sim 160$ MeV
- Chargino is metastable with significant lifetime $\tau = 0.2$ ns/6cm
  → disappearing tracks in inner detector

> Veto events with leptons and select events with at least one jet and missing $E_T$

> Dedicated track selection:

- Isolated high $p_T$ track from interaction point
- Hits in PIXEL($\geq$3) and SCT($\geq$2)
- Track pointing to TRT and number of TRT hits less than five (out of 32)

> High efficiency for charginos decaying after the PIXEL and before the TRT detector
interpret as limits on the chargino mass and either chargino lifetime $\tau$ or mass difference $\Delta m_{\tilde{\chi}_1^\pm}$

$m_{\tilde{\chi}_1^\pm} < 270$ GeV for AMSB ($\tau = 0.2\text{ns} / \Delta m_{\tilde{\chi}_1} = 160$ MeV)
Conclusion and Outlook

> certain SUSY models predict interesting signatures
  - R-parity violation: multi-lepton final states, resonances
  - compressed mass spectra: long lifetime and disappearing tracks
  - and many more

> these analyses need different searches strategies compared to standard missing $E_T$ based R-parity conserving searches

> no evidence for SUSY found so far

> limits on SUSY model parameters competitive with corresponding R-parity conserving searches

> 20 fb$^{-1}$ of 8 TeV data allows significant increase in exclusion limits over previous searches
  - more searches in preparation
### ATLAS SUSY Searches - 95% CL Lower Limits

**Model** | $e$, $\mu$, $\tau$, $\gamma$ | Jets | $E_{T}^{miss}$ | $\mathcal{L} dt [fb^{-1}]$ | Mass limit | Reference
--- | --- | --- | --- | --- | --- | ---
MSUGRA/CMSSM | 0 | 2-6 jets | Yes | 20.3 | 1.7 TeV | m($\tilde{t}$)-m($\tilde{g}$)
MSUGRA/CMSSM | 1 | 2-6 jets | Yes | 20.3 | 1.2 TeV | m($\tilde{t}$)-m($\tilde{g}$)
MSUGRA/CMSSM | 0 | 7-10 jets | Yes | 20.3 | 1.1 TeV | m($\tilde{t}$)-m($\tilde{g}$)
$\tilde{q}$, $\tilde{g}$, $\tilde{q}$$\tilde{q} W$/$Z$ & $\tilde{q}$$\tilde{q} W$/$Z$ | 2 | 1-2 jets | Yes | 20.3 | 1.1 TeV | m($\tilde{t}$)-m($\tilde{g}$)
GMSB/CT NLSP | 2 | 1-2 jets | Yes | 20.3 | 1.24 TeV | m($\tilde{t}$)-m($\tilde{g}$)
GMSB/CT NLSP | 1-2 $\tau$ | 0-2 jets | Yes | 20.3 | 1.7 TeV | m($\tilde{t}$)-m($\tilde{g}$)
GGM (ino NLSP) | 2 | 1-2 jets | Yes | 20.3 | 1.07 TeV | m($\tilde{t}$)-m($\tilde{g}$)
GGM (ino NLSP) | 1 | 1-2 jets | Yes | 20.3 | 1.4 TeV | m($\tilde{t}$)-m($\tilde{g}$)
GGM (higgsino-bino NLSP) | 1 | 1-2 jets | Yes | 20.3 | 1.3 TeV | m($\tilde{t}$)-m($\tilde{g}$)
Gravitino LSP | 0 | mono-jet | Yes | 20.3 | 1.2 TeV | m($\tilde{t}$)-m($\tilde{g}$)

**Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1$\sigma$ theoretical signal cross section uncertainty.*
Backup
Large Hadron Collider (LHC)

> 2010/2011: $\sqrt{s} = 7$ TeV pp
> 2012: $\sqrt{s} = 8$ TeV pp

> Outstanding 2012 Performance

- $\sim 7.7 \times 10^{33}$ cm$^{-2}$s$^{-1}$ peak lumi
- $\sim 23.3$ fb$^{-1}$ delivered

![Graph showing ATLAS Online Luminosity](image)

- Bunch spacing 50 ns

![Graph showing recorded luminosity vs mean number of interactions](image)
General-purpose Experiment: ATLAS

Emphasis on excellent jet and missing-$E_T$ (MET) resolution, particle identification, and standalone muon reconstruction