Prospects for SUSY Discovery and Measurements with the ATLAS Detector at the LHC

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Outline

1. Introduction
2. Inclusive searches of $E^\text{miss}_T$ signatures
3. Exclusive measurements
4. Long-lived heavy particles
5. Conclusions
Supersymmetry

- Symmetry: bosons $\leftrightarrow$ fermions
- Consider minimal extension of SM
- At LHC: production of strongly interacting SUSY particles
- Cross-section mostly dependent on particle masses
- Decay chains model dependent

Topics covered:
- $R$-parity conserving scenarios only
- $E_T^{\text{miss}}$ signatures
- Long-lived heavy particles

Benchmark models:
- mSUGRA
- NUHM
- GMSB
Emission of hard jets and leptons
If the lightest SUSY particle is neutral and weakly interacting
⇒ Missing energy in the detector

Main backgrounds:
- $Z/W + \text{jets}$
- $t\bar{t}$
- QCD events
Inclusive searches of $E_T^{\text{miss}}$ signatures

Exclusive measurements

Long-lived heavy particles

Conclusions

$E_T^{\text{miss}}$ signatures: zero- and one-lepton modes

$E_T^{\text{miss}} > 100$ GeV + 4 jets + 0 (left) or 1 (right) lepton

Effective Mass $= \sum_{\text{jets, } \ell} p_T + E_T^{\text{miss}}$

Lepton requirement to bring background down to manageable levels
Inclusive searches of $E_T^{\text{miss}}$ signatures

Exclusive measurements

Long-lived heavy particles

Conclusions

$E_T^{\text{miss}}$ signatures: other modes

- Broad spectrum of $E_T^{\text{miss}}$ signatures (not covered here):
  - Two and three leptons + jets
  - $\tau$-jets + jets
  - $b$-jets + jets
  - Multi leptons (No requirements on the number of jets)
    \[ \implies \text{Direct production of } \tilde{\chi}^0 \text{ and } \tilde{\chi}^\pm \]
  - Photons + jets
    \[ \implies \tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma \]

- All signals and backgrounds studied with fully detailed Geant 4 simulations
Precise estimate of background relies on both MC and data

Control samples needed for data driven estimates

Example: reverse one selection cut

**Signal region** \( M_T \equiv \vec{p}_{T,\ell} \cdot \vec{E}_T^{\text{miss}} > 100 \text{ GeV} \)

**Control region** \( M_T \equiv \vec{p}_{T,\ell} \cdot \vec{E}_T^{\text{miss}} < 100 \text{ GeV} \)

- Background shape from control sample
- Normalize to number of events in signal sample in a region where SUSY contribution is small \((E_T^{\text{miss}} < 200 \text{ GeV})\)
Systematic effects

- Detector response challenges
  - Lepton identification efficiency
  - Jet energy scale and jet response tails
  - Missing $E_T$ shape

- Theoretical uncertainties
  - Parton Density Functions
  - Normalization of background
  - EW and QCD corrections at NLO

- SUSY contamination in control samples
mSUGRA and GMSB scan
- 1 fb$^{-1}$ $\sim$ 1 year of LHC operation
- Reach up to gluino and squark masses $\sim O(1$ TeV$)$
- Stat. and syst. uncertainty on background included
Mass spectrum informations from cascade kinematic

\[ \tilde{q}_L \rightarrow \tilde{\chi}^0_2 q \rightarrow (\ell^\mp \ell^\pm q) \rightarrow \tilde{\chi}^0_1 \ell^- \ell^+ q \]

Endpoints in invariant mass distributions

- $\ell^+ + \ell^-$
- $\ell^+ + \ell^- + q$
- $\ell^\pm + q$

For instance

\[ M_{\ell\ell}^{\text{edge}} = m_{\tilde{\chi}^0_2} \sqrt{1 - \frac{m^2_{\ell}}{m^2_{\tilde{\chi}^0_2}}} \sqrt{1 - \frac{m^2_{\tilde{\chi}^0_1}}{m^2_{\ell}}} \]
Leptonic signatures

- Background significantly reduced by subtracting $e^\pm \mu^\mp$
- $M_{\ell\ell}^{\text{edge}} = 52.7 \pm 2.4 \text{ (stat)} \pm 0.2 \text{ (syst)} \text{ GeV}$
- Consistent with true value 53.6 GeV
Other signatures

- $\tau^+\tau^-$ invariant mass

  ![Graph showing $\tau^+\tau^-$ invariant mass](image)

  - $L - R$ mixing may enhance $\tau^+\tau^-$ with respect to $\ell^+\ell^-$
  - No sharp edge because of neutrino presence

- Higgs to $b\bar{b}$ in SUSY events

  ![Graph showing Higgs to $b\bar{b}$ in SUSY events](image)

  - $E_T^{\text{miss}}$ requirement suppresses QCD background
  - Competitive with SM channels
Long-lived heavy particles: trigger issues

- Assume the lightest SUSY particle is charged or strongly interacting
- Penetrating charged track ⇐⇒ “heavy slow muons”
- For $\beta \sim 0.8 \Rightarrow$ Time of flight 15 ns longer than muons

- ATLAS muon system provides excellent time of flight resolution (0.7 ns)
  ⇒ Precise mass reconstruction and muon rejection
- But very high LHC bunch-crossing rate (25 ns)
  - Particle could be assigned to the wrong bunch crossing and not read out
  - Appropriate triggering scheme is critical
Long-lived heavy particles: discovery reach

Stable sleptons

Example: 100 GeV slepton
Discovery largely independent of the model characteristics

$R$-hadrons

<table>
<thead>
<tr>
<th>Sample</th>
<th>Events/fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 GeV gluino</td>
<td>$6.4 \times 10^3$</td>
</tr>
<tr>
<td>1 TeV gluino</td>
<td>10.7</td>
</tr>
<tr>
<td>1.6 TeV gluino</td>
<td>0.1</td>
</tr>
<tr>
<td>300 GeV stop</td>
<td>70.0</td>
</tr>
<tr>
<td>600 GeV stop</td>
<td>3.9</td>
</tr>
<tr>
<td>1 TeV stop</td>
<td>0.1</td>
</tr>
<tr>
<td>QCD events</td>
<td>$\lesssim 1$</td>
</tr>
<tr>
<td>$Z \rightarrow \mu \mu$</td>
<td>$\lesssim 1$</td>
</tr>
</tbody>
</table>

Characteristic “heavy slow muon” signature
May also undergo charge flipping in the calorimeter
Conclusions

- New physics expected to appear at the TeV scale
- $R$-parity conserving SUSY scenarios are well motivated
- Extensive studies of signatures:
  - With $E_T^{\text{miss}}$
  - With long-lived heavy particles

$\Rightarrow$ Reach up to gluino and squark masses $\sim O(1 \text{ TeV})$ for 1 fb$^{-1}$

- Discovery relies on good knowledge of backgrounds
  - Interplay between MC and data-driven estimations