Signatures of GMSB with non-pointing photons at the ATLAS Detector

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Outline

• GMSB Theory
• ATLAS LArCalorimeter
• Signature of Non-pointing photons
• Photon Reconstruction
• Photon Identification
• Event Selection
• Extraction of Neutralino lifetime
  • using photon direction
  • using calorimeter timing
• Conclusion
**Theory**

- SUSY is a good candidate for physics beyond the SM.
- In GMSB, the symmetry is broken by gauge interactions through messenger gauge fields.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Lambda )</td>
<td>SUSY Breaking Scale</td>
</tr>
<tr>
<td>( M )</td>
<td>Messenger Mass Scale</td>
</tr>
<tr>
<td>( \tan \beta )</td>
<td>Ratio of Higgs VEVs</td>
</tr>
<tr>
<td>( N )</td>
<td>Number of Higgs mass parameter</td>
</tr>
<tr>
<td>( \text{sign}(\mu) )</td>
<td>Sign of Higgs mass parameter</td>
</tr>
<tr>
<td>( C_{\text{grav}} )</td>
<td>Scale factor of Gravitino coupling</td>
</tr>
</tbody>
</table>

- If \( N=1 \), \( \tan \beta \) is low, the NLSP is \( \tilde{\chi}_{1}^{0} \).
- BR of neutralino to Gravitino plus photon is 97%.

<table>
<thead>
<tr>
<th>Name</th>
<th>NLO (LO) ( \sigma ) [pb]</th>
<th>( \Lambda ) [TeV]</th>
<th>( M_{m} ) [TeV]</th>
<th>( C_{G} )</th>
<th>( c\tau ) [mm]</th>
<th>( M_{\tilde{\chi}_{1}^{0}} ) [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMSB1</td>
<td>7.8 (5.1)</td>
<td>90</td>
<td>500</td>
<td>1.0</td>
<td>1.1</td>
<td>118.8</td>
</tr>
<tr>
<td>GMSB2</td>
<td>7.8 (5.1)</td>
<td>90</td>
<td>500</td>
<td>30.0</td>
<td>9.5 \times 10^{2}</td>
<td>118.8</td>
</tr>
<tr>
<td>GMSB3</td>
<td>7.8 (5.1)</td>
<td>90</td>
<td>500</td>
<td>55.0</td>
<td>3.2 \times 10^{3}</td>
<td>118.8</td>
</tr>
</tbody>
</table>
Non-pointing photons

- In certain GMSB scenarios the $\tilde{\chi}_0^1$ could be relatively long-lived.
- If decay length is comparable to the size of the ATLAS inner detector, high pT photons could enter the calorimeter at angles ($\eta_\gamma$) deviating significantly from the nominal pointing angle ($\eta_2$).
  - i.e. $\eta_\gamma \neq \eta_2$

define:
- $\eta_2$ as “detector eta” of photon
- $\eta_\gamma$ as “truth eta” of photon

($\eta_\gamma$ is corrected for z-co-ordinate of primary vertex)
ATLAS Detector

- Tracking extends to $|\eta| = 2.5$
  - Pixel, SemiConductor and Transition Radiation Trackers

- Calorimeter:
  - Liquid Argon EM Calorimeter (Lar EM)
  - Tile Calorimeter
  - Barrel calorimeter extends to:
    $$ \eta = 1.475 \ (|z| < 320 \text{ cm}) $$
  - Endcap calorimeter consists of two coaxial wheels covering $1.375 < |\eta| < 2.5$ and $2.5 < |\eta| < 3.2$

- Muon chambers sit outside of calorimeter systems

Please see talks by Olivier Arnaez and Mauro Donega on the egamma performance and reconstruction / identification for more details.
LAr EM Calorimeter

- fine segmentation in 1st sampling devoted to pi0/gamma separation in eta.
- accordion structure to reduce gaps
- towers “point” to nominal interaction point

- timing capability
  - for E>1GeV, in barrel:
    - $\sigma_{\text{time}} < 1$ ns
- directional resolution
  - shower barycentre in $\eta$ is measured in 2 positions in depth; i.e. in 1st and 2nd sampling.
  - $\sigma_\vartheta \sqrt{E} < 75$ (mrad$\sqrt{\text{GeV}}$)
  - (excluding crack region between barrel and endcap calorimeters)

Moliere radius in liquid argon is 10.1cm.
Typical width for 40 GeV shower of unconverted pointing photon, at $\eta=0.3$ is 15.5 mrad (~2.5cm)
Photon Reconstruction

- A “sliding window” clustering algorithm is used to find showers produced by electrons and photons in the LAr calorimeter.
  - Cells are clustered in 3x7 fixed size rectangles (η×φ).
  - Position of rectangle/window is adjusted so that it contains transverse energy at a local maximum.

- Photons used:
  - Originate from neutralino decay occurring inside volume of inner detector.
  - pT > 20 GeV.
  - |detector eta| < 2.5.
  - Match if within ΔR=0.2 of truth photon.

As photons become more “non-pointing, the energy can be deposited in more cells. This reduces the chance that the sliding window algorithm can correctly identify the photon.

Work ongoing to optimize clustering and photon reconstruction for non-pointing photons.
Photon Identification

- Photon Id is based on variables describing shape of energy deposit.
- non-pointing photons can have a wider shower profile than pointing photons
- Variables based on shower width highly biased w.r.t. photons produced from long-lived neutralino.
- Use only photon id selection that are unbiased w.r.t neutralino decay length

\[ \text{e.g.: ratio of energy in 3x7 to 7x7 window in 2nd sampling layer} \]

\[ \text{width of cluster in second sampling} \]

The photon Id cuts can be loosened, in order to be unbiased, at the cost of increasing the fraction of jets identified as photons from 0.19+/- 0.03 % to 0.70 +/-0.07 %
Event Selection: Trigger

- 2 strategies considered
  - Trigger directly on photon(s)
  - Trigger on jets (and missing E_t)

- Standard photons triggers are inefficient for non-pointing photons

- Can successfully trigger on jets (and missing E_t triggers)

<table>
<thead>
<tr>
<th>Trigger</th>
<th>L1</th>
<th>L1+L2</th>
<th>L1+L2+EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single γ (E_T&gt;55 GeV)</td>
<td>90.19 ± 1.08</td>
<td>46.04 ± 1.81</td>
<td>36.88 ± 1.75</td>
</tr>
<tr>
<td>Two γ (E_T&gt;17 GeV)</td>
<td>34.13 ± 1.72</td>
<td>17.77 ± 1.39</td>
<td>12.87 ± 1.22</td>
</tr>
<tr>
<td>One jet (E_T&gt;65 GeV) plus missing E_T&gt;70 GeV</td>
<td>80.38 ± 0.56</td>
<td>80.24 ± 0.56</td>
<td>71.81 ± 0.64</td>
</tr>
<tr>
<td>Three jets (E_T&gt;65 GeV)</td>
<td>79.80 ± 0.57</td>
<td>79.66 ± 0.57</td>
<td>79.62 ± 0.57</td>
</tr>
</tbody>
</table>

Trigger efficiency for GMSB3 sample (generated mean lifetime 10.7 ns) and L=10^{33}cm^{-2}s^{-1}
Event Selection

- Require $N_{\text{jets}} \geq 4$ with $p_T > 50$ GeV
- Require leading jet $p_T > 100$ GeV
- Missing $E_T > 100$ GeV
- Missing $E_T > 0.2 \times M_{\text{eff}}$
  - Where $M_{\text{eff}}$ is scalar sum of Missing $E_T$ and $p_T$ of 4 leading jets

<table>
<thead>
<tr>
<th>$N_\gamma$</th>
<th>$N_{\text{OSFF}}$</th>
<th>Signal</th>
<th>$\sum$ Background</th>
<th>Sig</th>
<th>$N_W$</th>
<th>$N_Z$</th>
<th>$N_{\ell\bar{\ell}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>825.2</td>
<td>929.6</td>
<td>27.1</td>
<td>274.4</td>
<td>21.0</td>
<td>632.8</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>265.2</td>
<td>73.0</td>
<td>33.2</td>
<td>8.7</td>
<td>1.4</td>
<td>63.0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>255.8</td>
<td>51.7</td>
<td>35.7</td>
<td>19.5</td>
<td>2.0</td>
<td>30.1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>68.6</td>
<td>1.4</td>
<td>1.4</td>
<td>8.7</td>
<td>1.4</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>12.5</td>
<td>0.1</td>
<td>12.5</td>
<td>0.2</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>4.7</td>
<td>0.0</td>
<td>4.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

$tt\bar{t}$ is major source of background

- Event selection can be optimised by requiring 1 photon and 1 opposite-sign-same-flavour (OSSF) pair of leptons.

Integrated luminosity = $1 fb^{-1}$
GMSB Events

Distributions show signal and SM background distributions before and after requirements on leptons and photons in the event.
• Define $Z'$ as the photon’s projected longitudinal impact parameter

• The $Z'$ distribution is plotted for all photons
  • (corrected for vertex displacement)

• Exponential function is fitted from 50 mm to 500 mm
  • to exclude vertex effects
  • to ensure decay occurs inside volume of inner detector

• Record slope of exponential:
  - (sys error due to Reconstruction efficiency = $0.05 \times 10^{-3}$)
  - GMSB2: Generated $\tau = 3.17 \text{ns}$
    - Slope = $-4.35(6) \times 10^{-3}$
  - GMSB3: Generated $\tau = 10.7 \text{ns}$
    - Slope = $-3.8(2) \times 10^{-3}$
Extracting lifetime: Projected Longitudinal Impact Parameter

- Need a calibration curve to relate slope back to lifetime.
- Need full simulation of many lifetime samples for accurate determination of calibration curve.

Example calibration plot, produced from Toy MC.
Extracting lifetime: Timing (I)

- MC truth information to calibration plot to directly relate cluster time to lifetime of neutralino.
- Plot extracted neutralino lifetime distribution.
- Exponential distribution modified by resolution and acceptance effects.
  - Exponential fitted between 0.2 and 1 ns
  - Mean lifetime: \( \tau = 1/\text{slope} \)

Cluster time:

\[ t_{\text{cluster}} = t_{\text{measured}} - t_{\text{prompt}} \]
Extracting lifetime: Timing (II)

- **GMSB2 (Generated mean lifetime of 3.17 ns)**
  - No photon selection: \(2.9 \pm 0.2\) ns
  - Full unbiased photon selection: \(3.0 \pm 0.2\) ns

- **GMSB3 (Generated mean lifetime of 10.7 ns)**
  - No photon selection: \(9 \pm 4\) ns
  - Full unbiased photon selection: \(19 \pm 19\) ns

- Any dependence of photon id efficiency on neutralino lifetime biases the result
- Large errors for GMSB3 sample due to lack of statistics over limited fitting range
  - Sys error \(\sim 1(10)\) ns for GMSB2 (GMSB3) sample.

Method limited by limited range of exponential fit.
Work ongoing to use more sophisticated fitting
Summary

- GMSB SUSY has signature similar to standard MSSM SUSY, plus two high $p_T$ photons.
- The ATLAS calorimeters have been designed with good timing and directional resolution
- Non-pointing photons provide unique signature
- Techniques are being developed to optimize detection of non-pointing photons at ATLAS
- Techniques are being developed to extract lifetime of neutralino using timing and directional information from LAr Calorimeter
- Future work to assess the use of photon conversions which should give useful cross-check of lifetime measurement