Tracking techniques for long-lived higgsinos with the ATLAS detector

Matthew Gignac

Searching for long-lived particles at the LHC: Fifth workshop of the LHC LLP Community
May 27th – 29th, 2019
Introduction

- Long-lived higgsinos are a promising signal for BSM physics that could be naturally realized at the electroweak scale.
- The mean lifetime of the charged higgsino state:

\[ c\tau[\text{mm}] \sim 7 \times \left( \frac{\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)}{340 \text{ MeV}} \right)^3 \sqrt{1 - \frac{m_{\pi^\pm}^2}{\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)^2}} \]

Tracks lengths of ~7 to 14 mm → extremely difficult to reconstruct!

\[ m(\tilde{\chi}_1^0) \sim \tau \]

\[ \text{Observed 95\% CL limit (±1\sigma_{\text{theory}})} \]
\[ \tilde{\chi}_1^0 \text{ excluded} \]
\[ \text{Expected 95\% CL limit (±1\sigma_{\text{exp}})} \]
\[ \text{Theoretical line for pure higgsino} \]
\[ \text{LEP2} \tilde{\chi}_1^0 \text{ excluded} \]
Long-lived higgsinos are a promising signal for BSM physics that could be naturally realized at the electroweak scale.

The mean lifetime of the charged higgsino state:

\[ c\tau[\text{mm}] \sim 7 \times \left( \frac{\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)}{340 \text{ MeV}} \right)^3 \left( 1 - \frac{m_{\pi^\pm}^2}{\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)^2} \right)^{-1} \]

Tracks lengths of \( \sim 7 \) to 14 mm \( \rightarrow \) extremely difficult to reconstruct!

Want to improve sensitivity to these models these by extending “pixel tracklets” to the shortest possible length.

→ “Conventional pixel tracklets” use at least four pixel hits.

→ Attempting to extend usage down to three pixel hits \( \rightarrow \) rates from random combinations of pixel hits increase significantly, so need techniques to reduce backgrounds.
Disappearing track plus a soft-track signature

Long-lived charged state from compressed mass spectrum

\[ \Delta m \left( \tilde{\chi}^\pm_1, \tilde{\chi}^0_1, \tilde{\chi}^0_{1,2} \right) \sim 300 \text{ MeV} \]

Extremely low momentum

\[ p_T \sim 300 \text{ MeV} \]
ATLAS detector
ATLAS detector
Tracklet Seeding

Tracklets seed from three pixel space points

Seeding requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of space-points</td>
<td>(\geq 3)</td>
</tr>
<tr>
<td>Max radius of space-points</td>
<td>(&lt; 150) mm</td>
</tr>
<tr>
<td>Transverse impact parameter (d_0)</td>
<td>(&lt; 10) mm</td>
</tr>
<tr>
<td>Longitudinal impact parameter (z_0)</td>
<td>(&lt; 320) mm</td>
</tr>
<tr>
<td>Minimum transverse momentum (p_T)</td>
<td>(&gt; 5) GeV</td>
</tr>
<tr>
<td>Maximum pseudorapidity (</td>
<td>\eta</td>
</tr>
</tbody>
</table>

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Tracklet extension

Track seed from three pixel space point
Spurious SCT clusters

- Single hits from pile-up associated to tracklets trajectory spoil the disappearing track condition (veto on SCT hits)
- Require SCT hits on both axial and stereo layers → significant reduction in fake rate, and improves disappearing track condition by over 40%!
Tracklet reconstruction

- Reconstruction efficiency better than 90% beyond $r \sim 88$ mm

$$\epsilon_{\text{reco}}(\tilde{\chi}_1^\pm) = \frac{\text{number of charginos matched to a reconstructed track}}{\text{number of generated chargino particles}}$$

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**ATLAS Simulation Preliminary**

- $\sqrt{s} = 13$ TeV

**Small inefficiency vs pileup!**

- Mostly due to SCT hit filter
Tracklet reconstruction

- Reconstruction efficiency better than 90% beyond $r \sim 88$ mm

$$\epsilon_{\text{reco}}(\tilde{\chi}_1^\pm) = \frac{\text{number of charginos matched to a reconstructed track}}{\text{number of generated chargino particles}}$$

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**Graphs and Figures**

- **ATLAS Simulation**
  - Preliminary
  - $\sqrt{s} = 13$ TeV

- **Reconstruction efficiency**
  - $n_{\text{pix}} \geq 3$, $n_{\text{SCT}} = 0$
  - $n_{\text{pix}} \geq 4$, $n_{\text{SCT}} > 0$

- **Chargino decay radius**
  - $0 \, \text{mm}$ to $600 \, \text{mm}$

- **Efficiency vs. Decay radius**
  - Pixel tracklets
  - Standard tracks
  - ATLAS Simulation

- **Fraction of chargino decays**
  - $m_{\tilde{\chi}} = 400$ GeV, $\tau_{\tilde{\chi}} = 0.2$ ns

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Significant improvements in overall efficiency and towards shorter track lengths compared to previous ATLAS reconstruction algorithms!!
RoI soft-track seeding

- A Region of Interest (RoI) technique developed to reconstruct soft-track
  - Tracklets define a RoI to search for seeds
  - Dynamically set the origin in each RoI to the last pixel tracklet measurement
  - Apply impact parameter requirements relative to this new origin
  - Perform track finding using SCT hits only
- Reduces execution times by over an order of magnitude: \(~30\) s/evt \(\rightarrow\) \(1-2\) s/evt
Soft-track reconstruction efficiency

- Efficiency evaluated after successful reconstruction of a tracklet with the same criteria used during the soft-track seeding stage.
- Achieve ~50-60% for tracks with $p_T > 300$ MeV.

![Graphs showing efficiency as a function of soft-track $p_T$ and $d_0$.]
Two-track vertex fit

Two-track vertex fit performed to estimate decay position of the chargino

ISR jet

Low $p_T$ track

"Pixel tracklet"
Vertex efficiency

- Two-track vertex fit performed with pixel-tracklet and soft-track
- Tracking efficiency factored out from vertex efficiency:

$$\epsilon_{vtx}(x) = \frac{N_{\text{truth}}(\text{vertex reconstructed} \mid \text{seed tracks reconstructed})}{N_{\text{truth}}(\text{seed tracks reconstructed})}$$

- Inefficiency due to collinear configurations
- Stable as a function of pileup!
## Vertex Position Resolution

- Position resolution studied in signal by taking difference between reconstructed and generated decay position
- Extract resolution with double gaussian model for the “core” and “tails”
- Resolution dominated by the tails

<table>
<thead>
<tr>
<th>r (mm)</th>
<th>$\sigma_{x}^{\text{core}}$ (mm)</th>
<th>$\sigma_{x}^{\text{tail}}$ (mm)</th>
<th>$\sigma_{y}^{\text{core}}$ (mm)</th>
<th>$\sigma_{y}^{\text{tail}}$ (mm)</th>
<th>$\sigma_{z}^{\text{core}}$ (mm)</th>
<th>$\sigma_{z}^{\text{tail}}$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r &lt; 150$</td>
<td>$0.49 \pm 0.04$ (27%)</td>
<td>$2.92 \pm 0.10$ (73%)</td>
<td>$0.49 \pm 0.07$ (22%)</td>
<td>$2.86 \pm 0.10$ (78%)</td>
<td>$0.65 \pm 0.08$ (18%)</td>
<td>$3.69 \pm 0.20$ (82%)</td>
</tr>
<tr>
<td>$150 &lt; r &lt; 300$</td>
<td>$0.52 \pm 0.03$ (38%)</td>
<td>$2.41 \pm 0.06$ (62%)</td>
<td>$0.52 \pm 0.03$ (33%)</td>
<td>$2.36 \pm 0.05$ (67%)</td>
<td>$0.66 \pm 0.06$ (25%)</td>
<td>$3.28 \pm 0.13$ (75%)</td>
</tr>
</tbody>
</table>

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Conclusions

- Techniques for the reconstruction of short pixel tracklets with the ATLAS detector were presented
  - Efficient reconstruction of tracklets with as few as three pixel hits
  - Improved efficiency in high pile-up environment with a dedicated hit filter
  - Targeted the low momentum charged particle from the decay of the chargino
  - Developed two-track vertexing methods to estimate decay position of the chargino with a position resolution O(1) mm

- Inclusion of the soft-track is expected to help significantly reduce the overwhelming fake pixel tracklet background

- Performance of these techniques documented into a PUB note:
  - Performance of tracking and vertexing techniques for a disappearing track plus soft track signature with the ATLAS detector
Additional slides
Impact parameter resolution with respect to the beam spot

- Small differences between 4-pixel and 4-pixel plus SCT hit categories \( \rightarrow \) \( z_0 \) resolution main driven by presence of pixel hits
- Resolution of \( z_0 \) IP depends highly on incident angle \( \rightarrow \) cluster sharing in the forward regions improves the single hit resolution
Pixel tracklet IP resolution

⇒ Transverse $d_0$ impact parameter resolution

\[ \sigma(d_0) \] vs. 

\begin{align*}
\text{Chargino } p_T &\text{ [GeV]} \\
\text{Chargino } \eta &\text{ [GeV]} \\
\end{align*}

\( \sqrt{s} = 13 \text{ TeV} \)

\text{ATLAS Simulation}

Preliminary

$\eta_{\chi^0}$

$m_{\chi^0}$

$n_{\text{pix}} = 3, n_{\text{SCT}} = 0$

$n_{\text{pix}} \geq 4, n_{\text{SCT}} = 0$

$n_{\text{pix}} \geq 4, n_{\text{SCT}} > 0$

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Soft-track reconstruction efficiency

\[ \epsilon_{\text{reco}}(\text{soft-track}) \]

**ATLAS Simulation Preliminary**

\[ \sqrt{s} = 13 \text{ TeV} \]

Average number of pp interactions

- \( m(\tilde{\chi}_1^\pm) = 95 \text{ GeV} \)
- \( m(\tilde{\chi}_1^\mp) = 200 \text{ GeV} \)
Vertexing efficiency

**ATLAS Simulation**

Preliminary

$\sqrt{s} = 13$ TeV

- $m(\tilde{\chi}_1^\pm) = 95$ GeV
- $m(\tilde{\chi}_1^\pm) = 200$ GeV

Soft-track production radius [mm]

$\xi_{\chi}$

0.2 0.4 0.6 0.8 1

0 0.2 0.4 0.6 0.8 1

$\Delta R$(Chargino, soft-track)
SV Impact Parameters

- Impact parameter resolution relative to the fitted secondary vertex
- Soft-track only use SCT measurements → degraded performance in pointing resolution further from the SCT detector

Effects of multiple scattering are significant at low $p_T$

Uncertainties from measured TPs increases for larger extrapolations
SV Impact Parameters

\[ \sigma_{SV}(z) \] [mm]

\begin{align*}
&\text{Reconstructed vertex radius [mm]} \\
&\begin{array}{c}
0 & 100 & 150 & 200 & 250 & 300 \\
\end{array}
\end{align*}

\begin{align*}
&\text{ATLAS Simulation} \\
&\text{Preliminary} \\
&\sqrt{s} = 13 \text{ TeV} \\
&\begin{array}{c}
\blackbullet & m(\tilde{\chi}_1^+) = 95 \text{ GeV} \\
& m(\tilde{\chi}_1^\pm) = 200 \text{ GeV} \\
\end{array}
\end{align*}

\begin{align*}
&\text{Soft-track } p_T [\text{GeV}] \\
&\begin{array}{c}
0 & 0.2 & 0.4 & 0.6 & 0.8 & 1 & 1.2 & 1.4 & 1.6 \\
\end{array}
\end{align*}

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SV Impact Parameters

\[ \sigma_{SV}(d_0) [\text{mm}] \]

**ATLAS Simulation**

Preliminary

\( \sqrt{s} = 13 \text{ TeV} \)

\( m(\tilde{\chi}_1^\pm) = 95 \text{ GeV} \)

\( m(\tilde{\chi}_1^\pm) = 200 \text{ GeV} \)

\[ \eta \text{ (Soft-track)} \]

\[ z_{SV} \]

\[ \text{[mm]} \]