Searches with a Disappearing-Track Signature

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LHC Searches for Long-Lived BSM Particles
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Introduction / motivations

- Only sfermions (Gauginos and Higgsinos) are within LHC reach
- Can go after gluinos or EW-inos... that's it!

- **Gluino lifetime depends on** $m_0$

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**Split SUSY**

Nima

Reason for splitting:

- fermions carry R-symmetry
- scalars don't

Scalar

- Unification \( \checkmark \)
- Dark Matter \( \checkmark \)
- No Flavor, CP, moduli,... problems

Gluino

- Fermions

$c_T \approx 10^{-5} m \left( \frac{m_\tilde{g}}{\text{PeV}} \right)^4 \left( \frac{\text{TeV}}{m_\tilde{g}} \right)^5$
Introduction / motivations

- **EW-ino phenomenology depends on SUSY spectrum**

- Light Bino only: $pp \rightarrow$ invisible!
  - mono-jet+MET?
  - Out of luck?
  - ILC? $\mu$-collider?

- Light Wino and Bino
  - Heavy Higgsinos
    - Bino LSP: $\chi_1^+ \chi_1^- \rightarrow W^+W^- (+\text{MET})$, $\chi_1^+ \chi_2^0 \rightarrow W^+h (+\text{MET})$
    - Wino LSP: Disappearing track ($\sim 10$ cm, $\Delta m \sim 165$ MeV)
  - Light Higgsinos: $W^+W^- (+\text{MET})$, $W^+h (+\text{MET})$ and $Zh$ (or $Z^*$) and hh (or $h^*$)

- Higgino LSP
  - Only light Higgsinos: Disappearing track ($\sim 1$ cm, $\Delta m \sim 355$ MeV)
  - Light Gravitino: hh (+MET), possibly displaced?
Long-lived Chargino

- Chargino becomes long-lived when nearly-degenerate with the LSP
- Phenomenology identical to Anomaloy-Mediated SUSY Breaking (AMSB)

- Light Wino and Bino, heavy Higgsinos, Wino LSP
  - Lifetime \( \sim 50 \text{ mm} \), \( \Delta m \sim 165 \text{ MeV} \) from EW contribution

- Higgsino LSP, only light Higgsinos
  - Lifetime \( \sim 5 \text{ mm} \), \( \Delta m = \frac{1}{2} \alpha m_Z = \sim 355 \text{ MeV} \)

\[ pp \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^0 + \text{jet} \, , \, pp \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- + \text{jet} \]

Need \( p_T > 90 \text{ GeV} \) ISR for MET trigger: \( \sim 15\% \) of cross-section
ATLAS Disappearing track search

- Chargino travels through some layers then decays to a soft pion (not reconstructed) + MET

- Look for high-pt isolated track with few hits in outer tracking layer
  - Track needs at least 3 inner pixel hits and 1 silicon strip hit
  - Require <5 outer-tracker (TRT) hits

![Diagram of charged particle decay](image.png)
Improved ATLAS disappearing track search

- Large improvement from customized track reconstruction
  - *(Needs access to data with all tracker hits saved...)*

- Require just 1 Si strip layer (instead of 3) and no TRT
  - Decay volume moves to $r > \sim 300$ mm and widens
  - Efficiency $100\times$ larger for $c\tau = 50$ mm (165 MeV)
Improved ATLAS disappearing track search

- Background track pT shapes fit to data
  - No excess seen at high pT :( 

- Exclude chargino <270 GeV in AMSB with $\Delta m \sim 165$ MeV
CMS Run1 search for disappearing tracks

- CMS has recently published a very similar search with very similar sensitivity and results
- Takes advantage of more tracking layers to reduce fake-track background
- Additional pattern-recognition issues (outer hits can form an alternate track)

<table>
<thead>
<tr>
<th>Event source</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrons</td>
<td>$&lt;0.49$ (stat) $&lt;0.50$ (stat+syst)</td>
</tr>
<tr>
<td>Muons</td>
<td>$0.64^{+1.47}_{-0.53}$ (stat) $\pm 0.32$ (syst)</td>
</tr>
<tr>
<td>Taus</td>
<td>$&lt;0.55$ (stat) $&lt;0.57$ (stat+syst)</td>
</tr>
<tr>
<td>Fake tracks</td>
<td>$0.36^{+0.47}_{-0.23}$ (stat) $\pm 0.13$ (syst)</td>
</tr>
<tr>
<td>Data</td>
<td>2</td>
</tr>
</tbody>
</table>

- Have $Pt > 50$ GeV.
- Be isolated.
- Deposit $< 10$ GeV in calorimeter.
- Not be identified $e$, $\mu$ or $\tau$. 
CMS Run1 search for disappearing tracks

- Slightly better (expected) mass reach, slightly worse (expected) small-lifetime reach
- Nice “model-independent” plot of cross-section exclusion
Lots of room for gains!

- As opposed to most other BSM searches, selection efficiency for disappearing tracks is *tiny*! (At ATLAS too!)

<table>
<thead>
<tr>
<th>Chargino mass [GeV]</th>
<th>500</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chargino $c\tau$ [cm]</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Trigger</td>
<td>13%</td>
<td>13%</td>
</tr>
<tr>
<td>Basic selection</td>
<td>8.9%</td>
<td>9.0%</td>
</tr>
<tr>
<td>High-$p_T$ isolated track</td>
<td>0.14%</td>
<td>4.4%</td>
</tr>
<tr>
<td>Candidate track</td>
<td>0.10%</td>
<td>2.9%</td>
</tr>
<tr>
<td>Disappearing track</td>
<td>0.095%</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

(CMS efficiencies from Run 1)

- Need ISR for triggering
  - Are there other production channels we could use? VBF?

- Need to be very boosted / tail of exponential lifetime
  - Can we reconstruct shorter tracks?
  - Can we boost the chargino more?
Improved disappearing track search

- Eventual sensitivity with 14 TeV and *same short-track analysis* 
  ~500 GeV for $\Delta m \sim 165$ MeV
- Going to need even shorter tracks to reach the ~5 mm lifetime case...

![Graph showing $\tau$ vs. $m_{\chi_i}$](image)

- $\tau \sim 0.2$ ns, ~165 MeV, 50mm
- 0.02 ns, ~355 MeV, 5mm
Detector Upgrades

- New silicon layer installed!
- Many trigger upgrades also installed... (including L1 VBF trigger)
- ...

Original

Updated
IBL installation!

Where did that wire go??
IBL installation!

Never mind, got it!
Improved disappearing track search

- Eventual sensitivity with 14 TeV and *same short-track analysis* ~500 GeV for $\Delta m \sim 165$ MeV
- Going to need even shorter tracks to reach the ~5 mm lifetime case
  - Insertable B-Layer (IBL) added
  - Could have $r>150$ mm tracks using just 4 pixel hits?!

![](image)

New IBL pixel layer at radius of ~26mm

Sensitivity:~500 GeV for $\Delta m \sim 165$ MeV, 50mm

$T \sim 0.2$ ns, ~165 MeV, 50mm

$S\sqrt{s} = 14$ TeV

Sensitive up to ~800 GeV for 50mm and ~200 GeV for 5mm lifetime using 4-pixel IBL tracks?
Super improved disappearing track search

- **How to find even shorter tracks?**
  - 150 mm → 50 mm tracks gives ~25 times larger Higgsino efficiency
    - Sensitivity for chargino of 5mm lifetime goes from ~200 to ~400 GeV
- **New tracking layers at small radii?**
  - Most important in central eta region
- **Need to maintain ~30% 1/pT resolution at pT=~100 GeV ...**
  - High resolution pixels (in r-phi), small scattering
- **Any other ways? Boosted in forward direction? Pixel disks?**
  - Asymmetric collisions ala BaBar?
Other effects of light charginos

- \( \text{BR}(h \rightarrow \gamma\gamma) \) can be enhanced \( \sim 20\% \) (or suppressed \( \sim 40\% \)) by light charginos

- Long-term LHC can measure \( \text{BR}(h \rightarrow \gamma\gamma) \) to \( \pm 5\% \)

- Sensitive to Chargino masses up to \( \sim 200 \text{ GeV} \)

“Mini-split”

Chargino mass

\( h \rightarrow \gamma\gamma \) enhancement
(Far-)Future of Disappearing Track Searches

- Reconstructing very short tracks (with good momentum resolution!) is essential for mass reach
- 15 cm tracks seem possible at ATLAS

If we could reconstruct 10 cm tracks at a 100 TeV detector:
  - Wino sensitivity from 3.5 → 4.5 TeV
  - Higgsino from ~600 GeV → 1 TeV!

- Short tracks should perhaps be a design goal of future detectors (and accelerators?)

M. Low and L.T. Wang
arXiv: 1404.0682
Exploring other possibilities: *milliQan@LHC*

- Milli-charged particles = new particles with electric charge $\sim 10^{-3}$
- Easy to add to SM: “dark U(1)” (with massless dark photon) mixing through kinetic term → dark fermion milli-charged under SM
- Currently weak direct limits for fermion mass $> 100$ MeV
- Would need new detector to see them at LHC...
- $\sim 1$ photo-electron in 1.4m long scintillator
- Require triple coincidence in time window

arXiv:1410.6816