Long lived SUSY searches in ATLAS and CMS

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on behalf of the ATLAS and CMS Collaborations

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• Long-lived particles naturally arise in a variety of BSM theories

• In SUSY theories common mechanisms include:
  
  - small couplings
    - e.g. R-Parity Violation
  
  - off-shell decays
    - e.g. split-SUSY with squarks mass > 10 TeV
  
  - phase-space
    - Small mass splitting
      - e.g. AMSB

• Benchmarks often chosen as representative simplified models
  - re-interpretation material is key to ensure full exploration of coverage
**Experimental strategy**

- Best experimental strategy depends on the properties of the particle

  - **Electric charge**
    - charged
    - neutral
  - **Mass**
  - **Lifetime**
    - \sim prompt \ldots stable
  - **Decay products**
    - hadrons
    - leptons
    - weakly interacting

**Direct detection**

- If LLP minimally interacting and escapes detector \( \rightarrow E_T \)

**Indirect detection**

- “Isolated” activity inconsistent with expected prompt or instrumental background

- Different parts of ATLAS/CMS detector used depending on signature
Focus on **new results** since LHCP 2017

<table>
<thead>
<tr>
<th>Category</th>
<th>Run 1</th>
<th>Run 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prompt analysis (jets + $E_T$)</td>
<td>✅</td>
<td></td>
</tr>
<tr>
<td>Displaced vertices in ID</td>
<td>✅</td>
<td>✅</td>
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<tr>
<td>Displaced vertices in MS</td>
<td></td>
<td>✅</td>
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<tr>
<td>“Isolated” non-prompt jets</td>
<td>✅</td>
<td>✅</td>
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<tr>
<td>Displaced jets in Had.Cal.</td>
<td></td>
<td>✅</td>
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<tr>
<td>Displaced leptons</td>
<td>✅</td>
<td>✅</td>
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<tr>
<td><strong>Stopped particles</strong></td>
<td>✅</td>
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<tr>
<td>Non-prompt photons</td>
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<td>✅</td>
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<tr>
<td>Time-of-flight measurements</td>
<td>✅</td>
<td>✅</td>
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<tr>
<td>Disappearing track</td>
<td></td>
<td>✅</td>
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<tr>
<td>Large ionization deposits</td>
<td>✅</td>
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</tbody>
</table>
• Prompt analyses have sensitivity to “slightly” displaced objects too

• Example: long-lived $\tilde{g}$ benchmark

• Multijet search including long-lived model
  - efficiency lowers w/ lifetime due to decay outside detector or jets with no associated tracks
  - ATLAS relaxed some requirements to increase efficiency for displaced objects
  - Systematics for displaced objects needed to be re-evaluated
    • e.g. JES, B-tagging,…
Complementarity and coverage

- Extensive study for variable R-parity violating couplings
  - Re-interpretation of existing prompt searches in long-lived regimes
Displaced Vertices with jets

- Target decays of LLP to jets within the beam-pipe
- Signal extracted using binned fit of displaced vertices distance $d_{VV}$
  - dedicated vertex reconstruction algorithm
- Background from mis-measured tracks
  - data-driven, single-vertex position and un-correlation assumption
  - correction for merged vertices and heavy-flavor component

**Signal Region**

Trigger: $\Sigma p_T^{\text{jets}}$
- $H_T > 800/900$ GeV
- $\geq 4$ offline jets
- $p_T > 20$ GeV, $|\eta| < 2.5$
- $\geq 2$ DV
- $n\text{Tracks} \geq 5$
- $0.1 < "r(DV)" < 20$ mm
Displaced Vertices with jets

- Best sensitivity for $0.1 \text{ mm} < c\tau_0 < 100 \text{ mm}$
  - No significant excess found
- Results interpreted in simplified models ($\tilde{g}$ and $\tilde{t}$ production)
- Re-interpretation material defining fiducial phase-space
Displaced Vertices with MET

- Displaced vertices (DV) in events with large $E_T (> 200 \text{ GeV})$
- Dedicated tracking algorithms studied in detail, very efficient
- Background from hadronic interactions and large-angle accidental crossing
  - $\text{exp. } 0.02^{+0.02}_{-0.01}$
  - data-driven

Signal Region
- $\geq 1 \text{ DV}$
- $m(\text{DV}) > 5 \text{ GeV}$
- nTracks $\geq 5$
- Material map veto
Select isolated jets non compatible with prompt activity

**Displaced jets**

- \(H_T\)-based trigger + track-less jet
- Trackless requirements as main discriminant variables

\[
\alpha_{\text{jet}}(PV) = \frac{\sum_{\text{tracks} \in PV} p_T^{\text{tracks}}}{\sum_{\text{tracks}} p_T^{\text{tracks}}} \quad \alpha_{\text{max}} = \max_{\text{PV}}(\alpha_{\text{jet}}(PV))
\]

**Stopped particles**

- Dedicated trigger when no collisions expected
- Search for isolated decays in the calorimeter or muon spectrometer

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**Jet \(\alpha_{\text{max}}\)**

- Data
- Multijet
- 1 mm
- 10 mm
- 100 mm
- 1000 mm

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**CMS**

- Data
- Multijet
- 1 mm
- 10 mm
- 100 mm
- 1000 mm

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**95% CL upper limits**

- Observed
- Median expected
- 68% expected
- 95% expected

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**CMS**

- \(E_T > 170 \text{ GeV}\)

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**\(\tilde{b} \rightarrow \tilde{t}^0\)**

- 2015 + 2016: 38.6 fb\(^{-1}\) (13 TeV)

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**\(\sigma_{\text{theory}}(m_{\tilde{t}} = 800 \text{ GeV})\)**

- \(\tau [s]\)
Disappearing track

- Direct search for charginos with short lifetime
  - ATLAS: pixel-only tracks (4 pixel layers within 12 cm of I.P.) and dedicated signal region for strongly-produced charginos
  - CMS: New High-Level Trigger on $E_T$ (>75 GeV) + isolated 50 GeV track
- Binned likelihood fit to $p_T$ spectrum of isolated tracklets
  - fake and mis-measured tracks dominate expected background

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**CMS**

- $\tan\beta = 5$, $\mu > 0$
- $\mathcal{B}(\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 \pi^\pm) = 100\%$
- 95% CL limit
  - 95% expected
  - 68% expected
  - Median expected
  - Observed

**ATLAS**

- Pure-higgsino scenario tested up to ~150 GeV! (first time since LEP)
Conclusions

- SUSY inherently has several mechanisms that can produce massive long-lived particles
  - New analyses have seen significant work on re-interpretation material to allow detailed scans for truly unexplored parameter space

- The reach of prompt searches can extend well into the long-lived domain, more systematic studies of such coverage are being performed

- The potential of the full run-2 dataset is still being explored
  - e.g. the searches often require a good understanding of the detector
  - Future detector upgrades can offer new capabilities in exploring these unique signatures, see Claudia Gemme's talk in UPG/FUT III session
• Several recent studies to ensure a long-lived program at HL-LHC
  – exciting new sensitivity and detector capabilities to explore

See Claudia Gemme's talk in the UPG/FUT III session tomorrow
Disappearing track - ATLAS

- Explicit search for charginos with (only) very short lifetime
  - pixel-only track reconstruction (4 pixel layers within 12 cm of I.P.)
  - dedicated signal region for strongly-produced charginos
- Binned likelihood fit to $p_T$ spectrum of isolated tracklets
  - fake and mis-measured tracks dominate expected background
Disappearing track - CMS

- Focus on longer lifetimes
  - Veto activity in outer layers of silicon tracker and calorimeter
- New High-Level Trigger on $\not{E}_T (>75$ GeV) + isolated 50 GeV track

<table>
<thead>
<tr>
<th>Run period</th>
<th>Estimated number of background events</th>
<th>Observed events</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Leptons</td>
<td>Spurious tracks</td>
</tr>
<tr>
<td>2015</td>
<td>0.1 ± 0.1</td>
<td>$0^{+0.1}_{-0}$</td>
</tr>
<tr>
<td>2016A</td>
<td>2.0 ± 0.4 ± 0.1</td>
<td>0.4 ± 0.2 ± 0.4</td>
</tr>
<tr>
<td>2016B</td>
<td>3.1 ± 0.6 ± 0.2</td>
<td>0.9 ± 0.4 ± 0.9</td>
</tr>
<tr>
<td>Total</td>
<td>5.2 ± 0.8 ± 0.3</td>
<td>1.3 ± 0.4 ± 1.0</td>
</tr>
</tbody>
</table>

CMS Simulation

- $700$ GeV $\chi^0_1$ ($c = 10$ cm)
- $700$ GeV $\chi^0_1$ ($c = 100$ cm)
- $700$ GeV $\chi^0_1$ ($c = 1000$ cm)

B ($\chi^+_1 \rightarrow \chi^0_1 \pi^+$) = 100%

95% CL limit

- 95% expected
- 68% expected
- Median expected

- Observed

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Disappearing track: ATLAS-CMS results

- Low lifetime:
  - loss of efficiency from tracking reconstruction
  - pixel-only tracklets allows ATLAS sensitivity to lower lifetimes

- Longer lifetime:
  - loss of efficiency from disappearing track requirement and trigger
  - Current CMS strategy allows better sensitivity to longer lifetimes (using “longer” tracks)
Disappearing tracks – HL-LHC

\[^{\pm, 0}_1 \chi, \chi_1, \chi_1^0, \chi_2, \chi_2^0\] production, \(\tan\beta = 5, \mu > 0\)

**ATLAS Simulation**

\(\sqrt{s} = 14\text{ TeV}, L = 3000\text{ fb}^{-1}\)

All limits at 95% CL

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**Expected limit \((\pm 1 \sigma_{\text{exp}})\)**

**Theory**

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