Long lived SUSY searches in ATLAS and CMS

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on behalf of the ATLAS and CMS Collaborations

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Physics motivation

- 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**
  - ~prompt
  - stable

- **Lifetime**
  - ~prompt
  - stable

- **Decay products**
  - hadrons
  - leptons
  - weakly interacting

**Direct detection**

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

**Indirect detection**

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

- Different parts of ATLAS/CMS detector used depending on signature
**Search program**

### Most recent result

<table>
<thead>
<tr>
<th>ID</th>
<th>C</th>
<th>M</th>
<th>L</th>
<th>n</th>
<th>o</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prompt analysis (jets+E$_T$)</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Run-2</td>
</tr>
<tr>
<td>Displaced vertices in ID</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Run-2</td>
</tr>
<tr>
<td>Displaced vertices in MS</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Run-1</td>
</tr>
<tr>
<td>“Isolated” non-prompt jets</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Run-2</td>
</tr>
<tr>
<td>Displaced jets in Had.Cal.</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Run-1</td>
</tr>
<tr>
<td>Displaced leptons</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>Run-1</td>
</tr>
<tr>
<td>Stopped particles</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Run-2</td>
</tr>
<tr>
<td>Non-prompt photons</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Run-1</td>
</tr>
<tr>
<td>Time-of-flight measurements</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Run-2</td>
</tr>
<tr>
<td>Disappearing track</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Run-2</td>
</tr>
<tr>
<td>Large ionization deposits</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Run-2</td>
</tr>
</tbody>
</table>

**Focus on new results** since LHCP 2017
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
- 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: $\Sigma p_T^{jets}$
- $H_T > 800/900 \text{ GeV}$
- $\geq 4$ offline jets
- $p_T > 20 \text{ GeV, } |\eta| < 2.5$
- $\geq 2$ DV
- $n\text{Tracks} \geq 5$
- $0.1 < \text{“}r(DV)\text{“} < 20 \text{ mm}$
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 $E_T (> 200$ GeV)
- Dedicated tracking algorithms studied in detail, very efficient
- Background from hadronic interactions and large-angle accidental crossing
  - exp. $0.02^{+0.02}_{-0.01}$
  - data-driven

**Signal Region**
- $\geq 1$ DV
- $m(DV) > 10$ GeV
- $n$Tracks $\geq 5$
- 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

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

**Stopped particles**

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

![Graph showing jets and cross-sections](image)
**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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**Figure:**

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

- ATLAS Preliminary
  - $\sqrt{s} = 13\text{ TeV}, 36.1 \text{ fb}^{-1}$
  - Observed 95% CL limit ($\pm 1 \sigma_{\text{theory}}$)
  - $\tilde{\chi}_i^\pm$ excluded
  - Expected 95% CL limit ($\pm 1 \sigma_{\text{exp}}$)
  - Theoretical line for pure higgsino
  - LEP2 $\tilde{\chi}_i^\pm$ excluded

- 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
Future prospects

- 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

ATLAS Simulation

Pure-higgsino scenario tested up to ~150 GeV! (first time since LEP)
• Focus on longer lifetimes
  – Veto activity in outer layers of silicon tracker and calorimeter
• New High-Level Trigger on $E_T (>75 \text{ GeV}) +$ isolated $50 \text{ GeV}$ track

<table>
<thead>
<tr>
<th>Run period</th>
<th>Estimated number of background events</th>
<th>Observed events</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leptons</td>
<td>Spurious tracks</td>
</tr>
<tr>
<td>2015</td>
<td>0.1 ± 0.1</td>
<td>0.1 ± 0.1</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**

- $700 \text{ GeV} \tilde{\chi}_1^\pm$ ($c_\tau = 10 \text{ cm}$)
- $700 \text{ GeV} \tilde{\chi}_1^0$ ($c_\tau = 100 \text{ cm}$)
- $700 \text{ GeV} \tilde{\chi}_1^0$ ($c_\tau = 1000 \text{ cm}$)

**Results**

- $\tau_{\tilde{\chi}_1^{\pm}}$ [ns]
- $B (\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 \pi^+) = 100$
- 95% CL limit
- 95% expected
- 68% expected
- Median expected
- Observed
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

\( \tilde{\chi}_1^\pm, \tilde{\chi}_1^0, \tilde{\chi}_1^0, \tilde{\chi}_1^0, \tilde{\chi}_2^0 \) production, \( \tan\beta = 5, \mu > 0 \)

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

All limits at 95% CL
Displaced jets

CMS Jet-Jet: $pp \rightarrow X' X'^0, X'^0 \rightarrow q\bar{q}$

CMS B-Lepton: $pp \rightarrow t\bar{t}^*, t \rightarrow bl$

2.6 fb$^{-1}$ (13 TeV)

$\sigma \times B^2$ upper limit at 95% CL [fb]

$\sigma_0$ [$X^0$] [mm]

$m_{X^0}$ [GeV]

$m_t$ [GeV]

Exp. limit ± $\sigma_{\text{exp}}$

Obs. limit

$m_{X^0}$ = 50 GeV

$m_{X^0}$ = 100 GeV

$m_{X^0}$ = 300 GeV

Jun 7, 2018 -- LHCP

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