Searches for long-lived, weakly interacting particles

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Status of new physics after LHC Run 1

- A lack of signs of new physics, despite extensive searches, is one of the most important results from Run 1.
- But we must keep in mind the assumptions we make in all these searches.
- One of the most common is that new particles will decay promptly.

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**ATLAS Exotics Searches**

- **Model**: Various
- **Reference**: Various
- **Limit**: Various

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**CMS Preliminary**

- **Model**: Various
- **Reference**: Various
- **Limit**: Various

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**ATLAS Preliminary**

- **Model**: Various
- **Reference**: Various
- **Limit**: Various

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**CMS Exotics Physics Group Summary – Moriond, 2015**

- **Model**: Various
- **Reference**: Various
- **Limit**: Various

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Motivations for long-lived particles

- Assuming new particles are long-lived (LL) complicates analysis strategies, background estimation, systematic uncertainties, etc.
- But there are several reasons this could be and a plethora of models that realize them:
  - heavy intermediate particles (hidden valley models, split SUSY, etc.)
  - weak couplings (couplings to $\tilde{G}$, RPV couplings, etc.)
  - very limited phase space (e.g. AMSB $\tilde{\chi}_1^\pm$ decays)
- This talk summarizes searches for weakly interacting, LL particles; i.e., searches for decay products displaced to various degrees from the interaction point.
Displaced vertices ($c\tau \sim 1 \text{ cm}$)

- Displaced vertices (DV) formed from clusters of $\geq 5$ tracks.
- Dilepton vertices formed from $e^\pm e^\mp$, $\mu^\pm \mu^\mp$, $e^\pm \mu^\mp$ pairs.
- Density map of ATLAS used to veto vertices in dense material.
- Backgrounds from accidental crossings and merged vertices taken from data.

No events observed in any of the seven signal regions.

<table>
<thead>
<tr>
<th>Channel</th>
<th>No. of background vertices ($\times 10^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DV+jet</td>
<td>$410 \pm 7 \pm 60$</td>
</tr>
<tr>
<td>DV+$E_T^{\text{miss}}$</td>
<td>$10.9 \pm 0.2 \pm 1.5$</td>
</tr>
<tr>
<td>DV+muon</td>
<td>$1.5 \pm 0.1 \pm 0.2$</td>
</tr>
<tr>
<td>DV+electron</td>
<td>$207 \pm 9 \pm 29$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channel</th>
<th>No. of background vertices ($\times 10^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+e^-$</td>
<td>$1.0 \pm 0.2 \pm 0.3$</td>
</tr>
<tr>
<td>$e^\pm \mu^\mp$</td>
<td>$2.4 \pm 0.9 \pm 1.5$</td>
</tr>
<tr>
<td>$\mu^+\mu^-$</td>
<td>$2.0 \pm 0.5 \pm 0.3$</td>
</tr>
</tbody>
</table>
Displaced vertices \((c\tau \sim 1 \text{ cm})\)

- Displaced vertices (DV) formed from clusters of \(\geq 5\) tracks.
- Dilepton vertices formed from \(e^\pm e^\mp\), \(\mu^\pm \mu^\mp\), \(e^\pm \mu^\mp\) pairs.
- Density map of ATLAS used to veto vertices in dense material.
- Backgrounds from accidental crossings and merged vertices taken from data.

- Limits set on several SUSY models.

**Graphs:***

- **Vertex-level efficiency** showing efficiency as a function of c\(\tau\) for different ATLAS Simulation scenarios.
- **Cross-section** showing cross-section as a function of c\(\tau\) for different SUSY model parameters.
Displaced $\mu\mu$ (muon chambers only) ($c\tau \sim 100$ cm)

- CMS also looked for dimuon vertices with only muon chambers, vetoing muons matching tracks from the inner tracker.
- Background estimated from candidates in data with anti-aligned momentum and position vectors.

- Zero events predicted and observed; combined with results using inner tracker to set limits on hidden valley scalars ($X$) and RPV $\tilde{\chi}^0$.
Displaced SUSY \((c\tau \sim 1 \text{ cm})\)

- Isolated \(e^\pm \mu^\mp\) pairs searched for with large transverse impact parameters (\(|d_0|\)).
- Leptons from LL particle decays have broad \(|d_0|\) distributions.
- No common vertex required.

No excess observed in any of the three signal regions.

<table>
<thead>
<tr>
<th>Signal region</th>
<th>Expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>(</td>
<td>d_0</td>
<td>\in (0.02, 0.05) \text{ cm})</td>
</tr>
<tr>
<td>(</td>
<td>d_0</td>
<td>\in (0.05, 0.1) \text{ cm})</td>
</tr>
<tr>
<td>(</td>
<td>d_0</td>
<td>\in (0.1, 2) \text{ cm})</td>
</tr>
</tbody>
</table>
Displaced SUSY ($c\tau \sim 1$ cm)

- Isolated $e^\pm \mu^\mp$ pairs searched for with large transverse impact parameters ($|d_0|$).
- Leptons from LL particle decays have broad $|d_0|$ distributions.
- No common vertex required.

- Limits set on RPV stop pair production in a “displaced SUSY” model.
Displaced lepton jets (LJ) \((c\tau \sim 10 \text{ cm})\)

- Displaced LJs formed by clustering muons and calo. deposits isolated from ID tracks.
- Cosmic background estimated from empty bunch crossing data.
- Multijets estimated with data-driven ABCD method.

Data well-described by backgrounds.

<table>
<thead>
<tr>
<th></th>
<th>All LJ pair types</th>
<th>TYPE2-TYPE2 LJs excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>119</td>
<td>29</td>
</tr>
<tr>
<td>Cosmic rays</td>
<td>(40 \pm 11 \pm 9)</td>
<td>(29 \pm 9 \pm 29)</td>
</tr>
<tr>
<td>Multi-jets (ABCD)</td>
<td>(70 \pm 58 \pm 11)</td>
<td>(12 \pm 9 \pm 2)</td>
</tr>
<tr>
<td>Total background</td>
<td>(110 \pm 59 \pm 14)</td>
<td>(41 \pm 12 \pm 29)</td>
</tr>
</tbody>
</table>
Displaced lepton jets (LJ) \( (c\tau \sim 10 \text{ cm}) \)

- Displaced LJs formed by clustering muons and calorimeter deposits isolated from ID tracks.
- Cosmic background estimated from empty bunch crossing data.
- Multijets estimated with data-driven ABCD method.

- Limits set on dark photons \( (\gamma_d) \).

\[
\begin{align*}
\text{Max } \sum p_T & \text{ [GeV]} \\
|\Delta\phi| & \text{ [rad]} \\
\end{align*}
\]

\[
\begin{align*}
\text{ATLAS} & \text{ 20.3 fb}^{-1} \sqrt{s} = 8 \text{ TeV} \\
\end{align*}
\]

\[
\begin{align*}
\text{95\% CL Limit on } \sigma \times \text{BR}(H \rightarrow 4\gamma + X) & \text{ [pb]} \\
\text{Dark photon } c\tau [\text{mm}] & \\
\end{align*}
\]
Displaced dijets ($c\tau \sim 10\,\text{cm}$)

- Displaced vertices formed from tracks in pairs of jets.
- Several variables used to select vertices compatible with signal.
- Multijet background estimated from data with ABCDEFGH method.
- Two sets of selections considered; background describes the data well for both.

<table>
<thead>
<tr>
<th></th>
<th>Loose selection</th>
<th>Tight selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected</td>
<td>$1.56 \pm 0.25 \pm 0.47$</td>
<td>$1.13 \pm 0.15 \pm 0.50$</td>
</tr>
<tr>
<td>Observed</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Andrew Hart (The Ohio State University) Long-lived, weakly interacting particles
Displaced dijets ($c\tau \sim 10 \text{ cm}$)

- Displaced vertices formed from tracks in pairs of jets.
- Several variables used to select vertices compatible with signal.
- Multijet background estimated from data with ABCDEFGH method.
- Limits set on hidden valley scalars ($X$).

![Graph showing Di jets / 1 unit vs. Vertex track multiplicity with data and SM background, and CMS limits on $X$ mass and cross-section.](image)
Trackless jets ($c\tau \sim 100 \text{ cm}$)

- Pairs of trackless jets are used to search for particles decaying in the HCAL.
- No tracks in the ID and little energy in the ECAL.
- Multijet and cosmic backgrounds estimated from data.

- No excess of events observed.

<table>
<thead>
<tr>
<th>Background</th>
<th>Expected events</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM Multi-jets</td>
<td>23.2 ± 8.0</td>
</tr>
<tr>
<td>Cosmic rays</td>
<td>0.3 ± 0.2</td>
</tr>
<tr>
<td>Total Expected Background</td>
<td>23.5 ± 8.0</td>
</tr>
<tr>
<td>Data</td>
<td>24</td>
</tr>
</tbody>
</table>
Trackless jets ($c\tau \sim 100$ cm)

- Pairs of trackless jets are used to search for particles decaying in the HCAL.
- No tracks in the ID and little energy in the ECAL.
- Multijet and cosmic backgrounds estimated from data.
- Limits set on hidden valley pions ($\pi_v$).
Conclusion

- ATLAS and CMS have performed several searches for new weakly interacting, LL particles.
- These searches help fill important gaps in coverage left by more traditional searches where new physics could hide.
- Conversely, a future discovery by one of these searches would be a striking sign of new physics.

- Stay tuned for even more exciting results during Run 2!