Search for supersymmetry with displaced dileptons at the ATLAS experiment

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Supersymmetry

- Symmetry between fermions and bosons
- Every Standard Model particle gets superpartner
- Spin differs by 1/2
- Minimal supersymmetric Standard Model:
Search for displaced dileptons

- Search for massive long-lived particles decaying to two charged leptons (e or $\mu$)
- Experimental signature: Displaced vertices in the inner detector with two leptons
- Sensitive to lifetimes of about 1 ps to 1 ns
- Model independent search interpreted in supersymmetric models

Example of a $R$-parity violating model
Displaced vertex with two oppositely charged leptons \((e^+e^-, e^\pm\mu^\mp\text{ or } \mu^+\mu^-)\)

- Displacement: 4 mm in transverse plane to all \(pp\) collisions of the bunch crossing
- Fiducial volume:
  - Vertices inside detector material are vetoed
  - Invariant mass \(m_{DV} > 10\text{ GeV}\)
• Total vertex selection efficiency always below 20%
  → Main efficiency loss from vertex reconstruction efficiency (≈ 20 - 30%)

• Significantly higher efficiencies if the long-lived particle ($\tilde{\chi}_1^0$) heavy
  → More energy to trigger on
Plot shows origin of displaced vertices with two tracks in a $t \bar{t}$ Monte Carlo sample

- Mostly vertices without leptons
- Random crossing of tracks dominant background for $m_{DV} > 10$ GeV
**Dilepton vertices from hadron decays**

- Validation region on data with inverted mass cut: $m_{DV} < 10 \text{ GeV}$
- Most $\mu\mu$ vertices from displaced $J/\psi$ particles of $B$-hadron decays
- No dilepton vertex with $m_{DV} > 5.2 \text{ GeV}$ observed
  → Background from hadron decays negligible
Random crossings

- Unrelated lepton tracks can randomly cross and form a vertex
- Dominant background of this search
Unrelated lepton tracks can randomly cross and form a vertex

Dominant background of this search

Estimation procedure for signal regions:
  - Collect all electrons and muons in data passing our selection criteria
  - Randomly select lepton pairs from this collection
Random crossings

- Unrelated lepton tracks can randomly cross and form a vertex
- Dominant background of this search
- Estimation procedure for signal regions:
  - Collect all electrons and muons in data passing our selection criteria
  - Randomly select lepton pairs from this collection
  - Run vertex algorithm on each pair
  - Count number of vertices passing vertex selection
Unrelated lepton tracks can randomly cross and form a vertex

Dominant background of this search

Estimation procedure for signal regions:

- Collect all electrons and muons in data passing our selection criteria
- Randomly select lepton pairs from this collection
- Run vertex algorithm on each pair
- Count number of vertices passing vertex selection
- Calculate crossing probability \( p_{\text{xing}} = \frac{\text{Number of vertices found in this procedure}}{\text{Number of lepton pairs used}} \)
- Estimate: Number of lepton pairs in data \( \times p_{\text{xing}} \)
Validation region: Same procedure using vertices with two non-leptonic tracks

Very similar vertex selection as in signal regions

Prediction agrees within 20% to observation:

<table>
<thead>
<tr>
<th>VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of track pairs</td>
</tr>
<tr>
<td>Avg. crossing prob.</td>
</tr>
<tr>
<td>Predicted vertices</td>
</tr>
<tr>
<td>Observed vertices</td>
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</tbody>
</table>
Background estimate for signal regions

<table>
<thead>
<tr>
<th>SR</th>
<th>$N_{vx}^{\text{est}} / 10^{-4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ee</td>
<td>$1.1 \pm 0.3 \text{ (stat.)}^{+0.3}_{-0.5} \text{ (syst.)}$</td>
</tr>
<tr>
<td>$e\mu$</td>
<td>$6.3 \pm 2.0 \text{ (stat.)}^{+1.4}_{-2.3} \text{ (syst.)}$</td>
</tr>
<tr>
<td>$\mu\mu$</td>
<td>$5.8 \pm 2.4 \text{ (stat.)}^{+1.3}_{-3.8} \text{ (syst.)}$</td>
</tr>
</tbody>
</table>

- Random crossing background is of order $10^{-4}$ for all SRs
  → Any vertex observed would hint for a signal
- One of the smallest backgrounds estimated for an ATLAS search
- Total uncertainties on the estimates not larger than 80%
Event display of a dicosmic event

Displaced dileptons
Cosmic muons

- Cosmic muon sometimes reconstructed as a back-to-back muon pair
- Back-to-backness: $\Delta R_{\text{cosmic}} = \sqrt{(\eta_1 + \eta_2)^2 + (|\Delta \phi| - \pi)^2}$
- Veto cosmic muons in signal regions by requiring: $\Delta R_{\text{cosmic}} > 0.04$
- Invert cosmic veto to study back-to-backness of cosmic muons:

\[ \text{Dimuon pairs} \]

\[ \begin{align*}
\text{ATLAS Work in progress} \\
\sqrt{s} = 13 \text{ TeV, 32.7 fb}^{-1} \\
\text{Cosmic rays control region} \\
\text{Red: All dimuon pairs (scaled)} \\
\text{Black: DV matched dimuon pairs}
\end{align*} \]
Model-independent search for displaced vertices with two leptons

Interpreted in supersymmetric models

Dominant background from random crossings of leptons

Data-driven estimate of random crossings

Background is of order $10^{-4}$ for all SRs

Potential signal can be identified very clearly in data