Displaced and delayed searches not using displaced vertices @ ATLAS + CMS

R Rosten (OSU) on Behalf of ATLAS and CMS

7th June 2021

LHCP9
Introduction

• Q: How can we look for LLPs that do not leave a reconstructable vertex?
• A: Is the LLP charged? What can it couple to? How long is its lifetime?

• Rich field of signatures depending on the answer to the above… answer
• Just as displaced vertex LLP searches require careful analysis of data, non-vertex searches are challenging and varied

• Focus on one search each for ATLAS & CMS

LHCP 9th Edition
Displaced Leptons

- Previous ATLAS and CMS LLP searches for lepton pairs mostly focused on leptons with a shared vertex.
- Consider decay of charged LLP to lepton and neutral daughter, ex: GMSB SUSY slepton decay.
- Could reconstruct a kinked track, but no need – focus on leptons, ignore slepton tracks.
- No ISR/MET requirement needed.
Displaced Leptons

- Do not need slepton track, but do rely on displaced decay to suppress leptons from PV
- Need **large radius tracking** to reconstruct **high-$d_0$** tracks
  - Standard tracking runs first
  - Leftover hits used for large radius tracking allowing for $d_0$ up to 300 mm
- Further **modify lepton reconstruction** to remove requirements on $d_0$ and the number of Pixel hits
Displaced Leptons

- Trigger on MS-only muon or loose “photon”
- Reduce backgrounds from interaction with materials by requiring $\Delta R > 0.2$
- Remove single muon cosmic ray muons by tagging as cosmic muons with a inline segment on the opposite side of ATLAS
- Background “dominated” by:
  - combinatorial fakes for $\mu e$ and $ee$: estimated with ABCD method using the two leptons’ quality
  - cosmic rays for $\mu \mu$: estimated with ABCD using tag and quality info
- Background <1 event, observation 0 events
Displaced Leptons

- **Previous limits** on slepton mass of \(~90\text{ GeV}\) from LEP for \(\tilde{\mu}\) and \(\tilde{e}\), and from OPAL for \(\tilde{\tau}\)
- Limits on \(\tilde{\tau}\) limited due to branching fraction of \(\tau\) to leptons
- Lack of constraints on MET, jets, and vertices invites reinterpretation under other models
LLPs in the Endcap MS

- CMS MS is wonderfully dense
  - Excellent coverage with sensitive muon chambers to detect activity
  - Large amount of steel with full coverage to absorb background
LLPs in the Endcap MS

LLPs in CMS EMS

- Seek isolated cluster of hits in the CMS MS endcap
- Trigger on MET from decay + ISR jet
- Offline require $p_T^{\text{miss}} > 200$ GeV and at least one jet with $p_T > 50$ GeV
- Suppress background from W and top production by vetoing on hard electrons and muons
- Punch through jets
- Hard bremsstrahlung from muons
- SM particles, ex $K_L^0$
- Hopefully signal

Background after all cuts primarily SM particles from pileup – independent of $p_T^{\text{miss}}$
LLPs in the Endcap MS

- Background suppressed by vetoing on clusters with any hits on innermost $\phi$-rings of stations with least amount of shielding.
- Reject clusters with $|\eta| > 2.4$ to suppress muon bremsstrahlung background.
- Have a dedicated cluster identification algorithm with a factor of 3 suppression of remaining background.
LLPs in the Endcap MS

- Final background determined with ABCD method using $N_{\text{hits}}$ and $\Delta \phi(p_T^\text{miss}, \text{cluster})$
  - Predicted background: $2.0 \pm 1.0$
  - Observed events: 3

- Resulting limits best yet at $ct > 100$ m for low $m_S$
  - Factor of 6 improvement for $m_S = 7$ GeV
  - Factor of 2 improvement for heavier masses
Summary

• Diverse array of signatures from LLPs that do not involve a reconstructed vertex

• Challenges much the same as with vertex searches – triggering, dedicated reconstruction, etc

• ATLAS & CMS have many ongoing searches in addition to recent results – remain competitive

Look forward to continued LLP papers and advances as we approach Run-III and beyond!
BackUp
Non-vertex based LLP search

Summary Plots

Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.
Summary Plots

Non-vertex based LLP search

Low EMF jet from neutral LLP decay does not use vertexing

ATLAS Long-lived Particle Searches* - 95% CL Exclusion

Status: March 2021

- RPV: displaced v+ + muon
- RPV: displaced tau+ + tau -
- GOM: displaced muon
- OMEG: non-softening or delayed
- OMEG: displaced tauon
- AMBG: non-vertex based LLP search
- EmBG: non-vertex based LLP search
- Stealth SUSY: 2 MS vertexes
- Soft SUSY: large pixel e/MS
- Soft SUSY: displaced v+ + e
- Soft SUSY: displaced v+ + e

<table>
<thead>
<tr>
<th>Model</th>
<th>Signature</th>
<th>Lifetime limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPV 1</td>
<td>displaced v+ + muon</td>
<td>600 - 2.1 mm</td>
<td>ATLAS-CONF-2021-003</td>
</tr>
<tr>
<td>RPV 2</td>
<td>displaced tau+ + tau -</td>
<td>620 - 10 mm</td>
<td>ATLAS-CONF-2021-005</td>
</tr>
<tr>
<td>GOM 1</td>
<td>displaced muon</td>
<td>600 - 1 mm</td>
<td>ATLAS-CONF-2021-106</td>
</tr>
<tr>
<td>OMEG 1</td>
<td>displaced tauon</td>
<td>600 - 1 mm</td>
<td>ATLAS-CONF-2021-106</td>
</tr>
<tr>
<td>AMBG 1</td>
<td>non-vertex based LLP search</td>
<td>600 - 1 mm</td>
<td>ATLAS-CONF-2021-106</td>
</tr>
<tr>
<td>EmBG 1</td>
<td>non-vertex based LLP search</td>
<td>600 - 1 mm</td>
<td>ATLAS-CONF-2021-106</td>
</tr>
<tr>
<td>Stealth SUSY 1</td>
<td>2 MS vertexes</td>
<td>600 - 1 mm</td>
<td>ATLAS-CONF-2021-106</td>
</tr>
<tr>
<td>Soft SUSY 1</td>
<td>large pixel e/MS</td>
<td>600 - 1 mm</td>
<td>ATLAS-CONF-2021-106</td>
</tr>
<tr>
<td>Soft SUSY 2</td>
<td>displaced v+ + e</td>
<td>600 - 1 mm</td>
<td>ATLAS-CONF-2021-106</td>
</tr>
<tr>
<td>Soft SUSY 3</td>
<td>displaced v+ + e</td>
<td>600 - 1 mm</td>
<td>ATLAS-CONF-2021-106</td>
</tr>
<tr>
<td>Soft SUSY 4</td>
<td>displaced v+ + e</td>
<td>600 - 1 mm</td>
<td>ATLAS-CONF-2021-106</td>
</tr>
</tbody>
</table>

*Only a selection of the available channels is shown.
Calratio + MS

- Calratio/CR jet: Jet from a neutral LLP decaying in the hadronic calorimeter
  - Has a dedicated trigger
  - MLP used to identify jets from displaced
  - BDTs (2) used to separate signal from background

- MS vertex: Reconstructed vertex from a neutral LLP decaying in the MS
  - Has a dedicated trigger
  - Dedicated vertexing algorithm performs tracking and vertex finding in the MS
  - Search for two MS vertices, or one vertex and an associated object
Delayed Photons

- Consider photon resulting from a neutral LLP decay
  - Shower axis will not align with IP-originating photon
  - Photon timing will be $< c$
- Use a dedicated photon trigger targeting skewed shower shape
- Remove prompt timing requirement for reconstruction and use the spatial distribution of energy to ID candidates
- Saw order of magnitude improvements in limit on neutralino lifetime