Searches for supersymmetric particles with macroscopic or stable lifetimes using the ATLAS detector

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We haven’t found BSM yet, though

LHC gives us a great potential to find BSM.

Most of analyses focus on the particles (e.g., Higgs):

• Generating and decaying at interaction point of two beams, **AND**
• Going through the detectors with speed of light ($\beta = 1$).

However, this strategy could miss **Long-lived particles**.

We need to develop dedicated techniques to exploit full potential of the ATLAS detector!!
Physics making long-lived particles

Taking an example from $\pi^\pm$ decay ($c\tau \sim 7.8$ m):

\[
\frac{\hbar}{\tau} = \frac{f_\pi^2}{256\pi m_\pi} \left[ \frac{g^2}{M_W^2} \frac{m_\mu}{m_\pi} \left( m_\pi^2 - m_\mu^2 \right) \right]^2
\]

- Small coupling constant
- Helicity suppression
- Heavy intermediate particle
- Small mass difference

Effects shown above could appear in various new physics.
Signatures of long-lived particles

Muon system (MS)
- RPC, MDT, TGC, CSC

Calorimeter (Calo)
- LAr, Tile

Inner detector (ID)
- Pixel, SCT, TRT

Decay of (stopped) LLP inside Calo

Displaced vertex from LLP

Displaced late photon from LLP

Track of LLP with large dE/dx (and low velocity)
Recent searches in ATLAS experiment

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- RPC, MDT, TGC, CSC

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NEW

SUSY-2016-32 – Accepted by PRD
13 TeV, 36 fb\(^{-1}\)

SUSY-2016-06 – JHEP 06 (2018) 022
13 TeV, 36 fb\(^{-1}\)

ATLAS-CONF-2019-006
13 TeV, 136 fb\(^{-1}\)
Search for long-lived $\tilde{\chi}^{\pm}$

$\tilde{W}^0/\tilde{H}^0$ LSP in SUSY are strong candidates for DM.

- **Thermal relic implicates** $M_{\tilde{W}} \sim 2.7$ TeV, or $M_{\tilde{H}} \sim 1.1$ TeV.
- **$\tilde{W}^{\pm}/\tilde{H}^{\pm}$** with small mass splitting makes its lifetime long:
  - $\tilde{W}^{\pm}$: $\Delta M \sim 160$ MeV $\rightarrow c\tau \sim 6$ cm
  - $\tilde{H}^{\pm}$: $\Delta M \sim 350$ MeV $\rightarrow c\tau \sim 1$ cm

Use “short” isolated high $p_T$ tracks requiring 4 silicon hits:

- After Run2, Insertable B-layer (IBL) at $R = 3.2$ cm improves sensitivity.
Search for long-lived $\tilde{\chi}^\pm$

In pure-Wino LSP model, Chargino masses up to 460 GeV are excluded.

In pure-Higgsino LSP model, Chargino masses up to 152 GeV are excluded.
Heavy squark in Split SUSY could make $\tilde{g}$ long-lived.

- Massive $\tilde{g}$ leaves large $dE/dx$ in ATLAS detector
- Pixel detector can provide $dE/dx$ information.

Require 7 silicon hits (> 37 cm) with high $dE/dx$.

- Sensitive to longer lifetime than the disappearing track search.
- Look for isolated and high-momentum track.
- Mass of long-lived particles can be calculated by $p/\beta\gamma$. 
Search using timing in Calo + Muon

Hadron Calo and Muon detectors

- Provide good timing resolution as a result of challenging calibration

$\rightarrow \beta < 0.75$ is required

- Use dE/dx information in Pixel as well.

The best sensitivity for stable particle!
Results of dE/dx based searches

SUSY-2016-32 – Accepted by PRD

Pixel dE/dx only

Gluino with 10 ns lifetime excluded up to 2 TeV
Mild excess: $2.4\sigma$ local in stable selection.

Stable Gluino excluded up to 2 TeV
Status of long-lived $\tilde{g}$ search

$\tilde{g}$ (R-hadron) $\rightarrow$ qq $\tilde{\chi}_1^0$; $m(\tilde{\chi}_1^0) = 100$ GeV

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* Note that gently modified to make the event cleaning criteria 'safe' for LLPs

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**Interpretation from prompt decay search***

**Displaced vertex**

**Pixel dE/dx**

**Pixel dE/dx + Calo + Muon**

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* RPC CL 2-6 jets arXiv:1712.02332 (\(\sqrt{s}=13\) TeV, 36 fb\(^{-1}\))
* RPC CL 2-6 jets ATLAS-CONF-2018-003 (\(\sqrt{s}=13\) TeV, 36 fb\(^{-1}\))
* Displaced vertices arXiv:1710.04901 (\(\sqrt{s}=13\) TeV, 33 fb\(^{-1}\))
* Pixel dE/dx arXiv:1808.04095 (\(\sqrt{s}=13\) TeV, 36.1 fb\(^{-1}\))
* Stable charged arXiv:1902.01636 (\(\sqrt{s}=13\) TeV, 31.6 fb\(^{-1}\))
* Stopped gluino arXiv:1310.6584 (\(\sqrt{s}=7,8\) TeV, 5.0, 23 fb\(^{-1}\))
Displaced vertex with muon

R-parity violation would make LSP long-lived.

• Benchmark: semi-leptonic decay of $\tilde{t}$

Trigger:

• Muon reconstructed in MS or Missing $E_T$

Signal selections:

• Veto material region using hadronic interaction
• DV with at least 3 tracks, and $M_{DV} > 20$ GeV
• Isolated non-prompt muon

Data-driven background estimation

• Cosmic-ray
• Heavy flavor decay
• Instrumental fakes
Simulated Signal Event
Top Squark Pair Production

\( m(\tilde{t}) = 1.5 \text{ TeV}, \quad \tau(\tilde{t}) = 1 \text{ ns} \)

\( \tilde{t} \rightarrow \mu j \)
Displaced vertex with muon

No excess observed neither in MET nor muon trigger selection.

Around ~0.1 ns lifetime, stop mass up to 1.75 TeV is excluded.
Conclusion

Long-lived particles appear in various physics models.

- Many types of unconventional signatures.
- Creative analysis techniques exploiting all aspects of our detector.
- Huge efforts done with LHC-Run2 data.

For long-lived particle search, the DV+muon analysis is the first result with LHC-Run2 full dataset.

No BSM yet, however we will come up with more searches with LHC Run-2 dataset soon!!