Figure 6: Distribution of hadronic-interaction vertex candidates in $|\eta| < 2.4$ and $|z| < 400$ mm for data and the Pythia 8 MC simulation with the updated geometry model. 

(a) The $x$–$y$ view zooming-in to the beam pipe, IPT, IBL staves and (c), (d) of the pixel detector. Some differences between the data and the Pythia 8 MC simulation, observed at the position of some of the cooling pipes in the next-to-innermost layer (PIX1), are due to mis-modelling of the coolant fluids, as discussed in Ref. [9].

6.1 Radial and pseudorapidity regions

For the hadronic interaction and photon conversion analyses, the measurable ID volumes are divided into several groups by radii, which are referred to hereafter as radial regions. Table 3 lists the radial regions.
Motivation
Semi-leptonic LLP decays
R-parity Violating Supersymmetry

The Analysis
[SUSY-2018-33](https://example.com), 136 fb⁻¹
Muon Spectrometer only / $E_{T}^{\text{miss}}$ trigger
Non-standard reconstruction
Inner Detector Displaced Vertex + Muon

This talk
Overview of the analysis
Personal take on where we could improve
R-parity violating Supersymmetry (SUSY)

small $\lambda'$ couplings result in a long-lived lightest SUSY particle, undergoes semi-leptonic decay

Most interested in lifetimes $\tau \approx \mathcal{O}(\text{ps}) - \mathcal{O}(10 \text{ ns})$
- long-lived particle decays result in Inner Detector displaced vertices
- also complementary to prompt searches

One of several ATLAS searches designed to cover long-lived RPV signatures
In general
use stop → μ + jet as a benchmark
but remain open minded to other signals
eg. LLP → μ + 2 jets, cascade decays, lighter masses etc

We know from previous versions of the analysis
we can have ~0 expected background
and retain excellent signal efficiency

Define two levels of selection for vertices and muons
1. pre-selection - loose, lets us study backgrounds
2. full selection - tight, strong background rejection
Trigger Strategy

Used two ways to trigger on displaced muons
MSOnly trigger
new: $E_T^{miss}$ trigger

Orthogonal SRs
different backgrounds
eg. cosmics v. fake muons

Lesson: $E_T^{miss}$ trigger has
better signal efficiency
lower backgrounds

$E_T^{miss}$ Trigger
$E \sim 100$
any $d0$

MSOnly Trigger
$E \sim 65$
pT, $\eta$, $d0$ dependent

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Non-standard Reconstruction

Inner Detector Tracking

standard ATLAS tracking requires $|d_0| < 10$ mm
large radius tracking is an additional pass of tracking with loosened impact parameter and hit requirements

Secondary Vertexing

forms vertices using tracks with $p_T > 1$ GeV and $|d_0| > 2$ mm

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**ATL-PHYS-PUB-2017-014**

**ATL-PHYS-PUB-2019-013**
Muon Selection

Pre-selection: Transverse impact parameter, $|d0|>2$ mm
- $E_{T\text{miss}}$ trigger selection: $p_T > 25$ GeV, $|\eta|<2.5$
- Muon trigger selection: $p_T > 62$ GeV, $|\eta|<1.05$

Full selection: dedicated vetoes to reject muons from backgrounds
- cosmics, heavy flavor decays and algorithm fakes
- also used to form control regions for background estimation

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Displaced Vertex Pre-selection

Fiducial volume
R_{xy} < 300 \text{ mm} \text{ and } |Z| < 300 \text{ mm}
ensures displaced tracks can be
reconstructed by strip detector

Displacement
R_{xy} > 4 \text{ mm}

Material veto
to reject hadronic interactions

Common to ATLAS
SUSY DV analyses
Displaced Vertex Final Selection

At least 3 tracks and mass > 20 GeV
designed to reject random track crossings
## Results

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>Expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{T}^{\text{miss}}$ trigger</td>
<td>$0.43 \pm 0.16 \text{ (stat.)} \pm 0.16 \text{ (syst.)}$</td>
<td>0</td>
</tr>
<tr>
<td>Muon trigger</td>
<td>$1.88 \pm 0.20 \text{ (stat.)} \pm 0.28 \text{ (syst.)}$</td>
<td>1</td>
</tr>
</tbody>
</table>

### Diagram

*Stop R-Hadron, $pp \rightarrow \tilde{t}\tilde{t}$, $\tilde{t} \rightarrow \mu q$*

ATLAS

$\sqrt{s}=13 \text{ TeV}$, 136 fb$^{-1}$, All limits at 95% CL

- **Expected Excl. Limit ($\pm 1,2 \sigma_{\text{exp}}$)
- **Observed Limit ($\pm 1 \sigma_{\text{SUSY}}$)

![Graph](image_url)
Room for improvement

We did a great job with DV+muon
probed interesting phase space, and made
many interesting improvements w.r.t Run 1 version

If only we had more time,
or more analyzers..

Three areas where we can do better
Trigger strategy
Additional signal region(s) for smaller lifetimes
Improved vertex efficiency at larger displacement
Trigger Improvements

for cluster-based $E_{T}^{\text{miss}} < 180$ GeV

MSonly Trigger
$|\eta| < 1.05$
$E \sim 65\%$

Current Status
high $pT$ threshold
no endcaps (high rates)
drop off in Efficiency v. $d0$

Not great for light LLPs!
Trigger Improvements

for cluster-based $E_{T\text{miss}} < 180$ GeV

- **Run 2**: Add prompt muon trigger
  - Improves AxE for $p_T > 60$ GeV
  - Adds new phase space: lighter LLPs

**Challenge**: Requires different data stream!

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**Graph**

- **[Run 2]** prompt muon
  - $E \sim 90\%$
  - $d_0(\mu)$ [mm] vs. $p_T(\mu)$ [GeV]

- **MSonly Trigger**
  - $|\eta| < 1.05$
  - $E \sim 65\%$
  - $E \sim 65\%$
Trigger Improvements

Possibilities in Run 3...

Moderate $d_0$, low $p_T$ muons should be able to do this already, useful for slightly displaced $\tau \rightarrow \mu$

Extend MSOnly trigger to endcaps managed in 2018 for $p_T > 80$ GeV, better with New Small Wheel?

Displaced ID tracks at HLT??

for cluster-based $E_{T^{\text{miss}}} < 180$ GeV

[Run 2] prompt muon $E \sim 90\%$

[Run 3] add endcaps? $E \sim 85\%$

[Run 3] HLT w/ displaced ID tracks??

[Run 3] moderate $d_0$ displacement

leading $p_T(\mu)$ [GeV]

$d_0(\mu)$ [mm]
New SRs needed with additional selections you can go closer to pp-interaction point

**Option 1:**
add a **2 DV Signal Region** challenge: rethink vertex reconstruction

**Option 2:**
Use standard prompt triggers, require multiple slightly displaced muons and/or jets may not even need vertexing
Could we do better?

...part of the challenge is reduced tracking efficiency at large radii...

...but we also know there are reconstructed tracks NOT included in displaced vertices...

I think we can do better...
Conclusions

Presented overview of ATLAS DV+muon analysis
  first ATLAS LLP analysis with full Run 2 dataset
  common displaced vertex strategy within ATLAS SUSY
  new trigger strategy and muon selection with respect to Run 1

Also shared some ideas for where we can improve
  improvements to trigger strategy
  new signal regions to target smaller lifetimes
  and reconstruction efficiency for larger displacements
Figure 6: Distribution of hadronic-interaction vertex candidates in $|\phi| < 2.4$ and $|z| < 400$ mm for data and the Pythia 8 MC simulation with the updated geometry model.

(a), (b) The $x$–$y$ view zooming-in to the beam pipe, IPT, IBL staves and (c), (d) of the pixel detector. Some differences between the data and the Pythia 8 MC simulation, observed at the position of some of the cooling pipes in the next-to-innermost layer (PIX1), are due to mis-modelling of the coolant fluids, as discussed in Ref. [9].

6.1 Radial and pseudorapidity regions

For the hadronic interaction and photon conversion analyses, the measurable ID volumes are divided into several groups by radii, which are referred to hereafter as radial regions. Table 3 lists the radial regions.
Motivation: R-parity violating supersymmetry

ATLAS has several analyses looking for displaced vertices

DV+muon uniquely sensitive to $\lambda'_{2jk}$

<table>
<thead>
<tr>
<th>Coupling</th>
<th>Physics Signature</th>
<th>Example Detector Signature</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_{ijk}$</td>
<td>leptonic LLP decays $ee, \mu\mu, \mu e, \ldots$</td>
<td>di-lepton DV</td>
</tr>
<tr>
<td>$\lambda'_{1jk}$</td>
<td>semi-leptonic LLP decays $l_q, l_q q$</td>
<td>DV+electron</td>
</tr>
<tr>
<td>$\lambda'_{2jk}$</td>
<td>hadronic LLP decays $qq, qqq$</td>
<td>DV+muon</td>
</tr>
<tr>
<td>$\lambda''_{ijk}$</td>
<td></td>
<td>DV+jets</td>
</tr>
</tbody>
</table>
Background estimation

\[ N_{S\text{Revents}} = TF \times N_{C\text{Revents}} \]

Invert muon vetos one by one - obtain \( N_{C\text{Revents}} \) for each muon background

transfer factors measured in events with no preselected DVs
Selection Efficiency

**ATLAS**

\[ \text{Efficiency} \]

- **Initial Filter**
  - Data, \( \sqrt{s} = 13 \text{ TeV}, 136 \text{ fb}^{-1} \)
  - \( m(t) = 1.4 \text{ TeV}, \tau(t) = 0.01 \text{ ns} \)
  - \( m(t) = 1.4 \text{ TeV}, \tau(t) = 0.1 \text{ ns} \)
  - \( m(t) = 1.4 \text{ TeV}, \tau(t) = 1 \text{ ns} \)

- **Muon Trigger Selection**
  - Data, \( \sqrt{s} = 13 \text{ TeV}, 136 \text{ fb}^{-1} \)
  - \( m(t) = 1.4 \text{ TeV}, \tau(t) = 0.01 \text{ ns} \)
  - \( m(t) = 1.4 \text{ TeV}, \tau(t) = 0.1 \text{ ns} \)
  - \( m(t) = 1.4 \text{ TeV}, \tau(t) = 1 \text{ ns} \)
Parametrized efficiencies provided as Aux material