Tracking techniques for long-lived higgsinos with the ATLAS detector

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Searching for long-lived particles at the LHC: Fifth workshop of the LHC LLP Community

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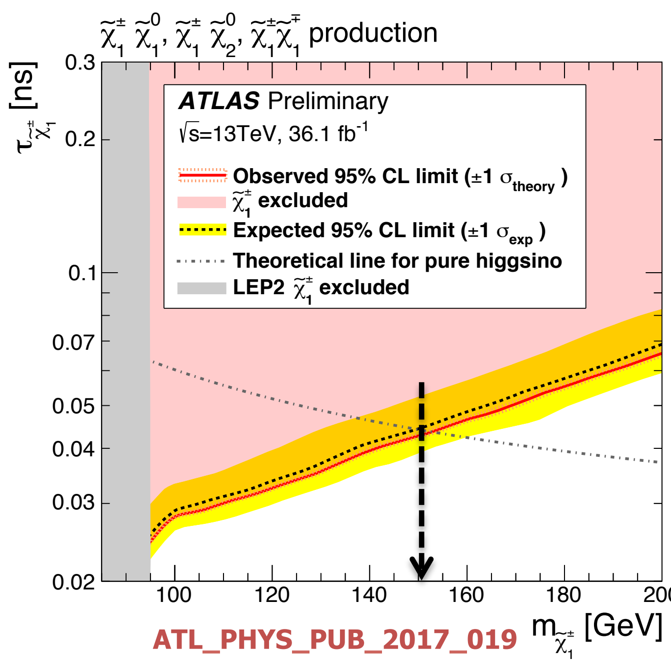
Introduction

⇨ Long-lived higgsinos are a promising signal for BSM physics that could be naturally realized at the electroweak scale

⇨ The mean lifetime of the charged higgsino state:

$$c\tau[\text{mm}] \sim 7 \times \left[\left(\frac{\Delta m \left(\tilde{\chi}_1^{\pm}, \tilde{\chi}_{1,2}^{0} \right)}{340 \text{ MeV}} \right)^3 \sqrt{1 - \frac{m_{\pi^{\pm}}^2}{\Delta m \left(\tilde{\chi}_1^{\pm}, \tilde{\chi}_{1,2}^{0} \right)^2}} \right]^{-1}$$

→ Tracks lengths of ~7 to 14 mm → extremely difficult to reconstruct!



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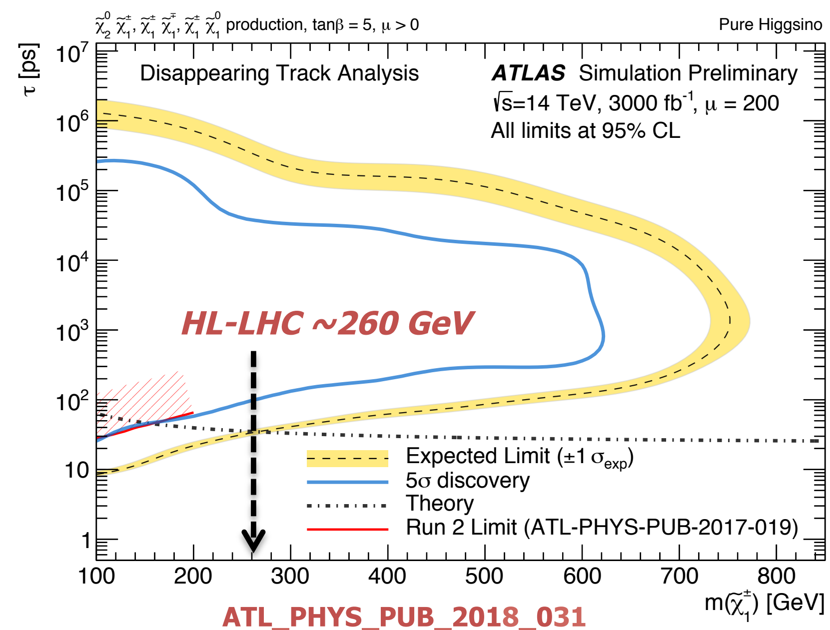

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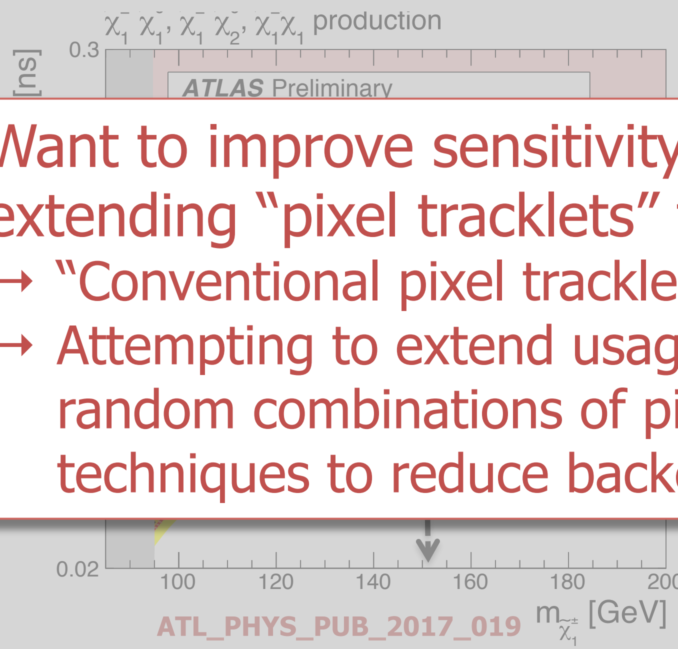

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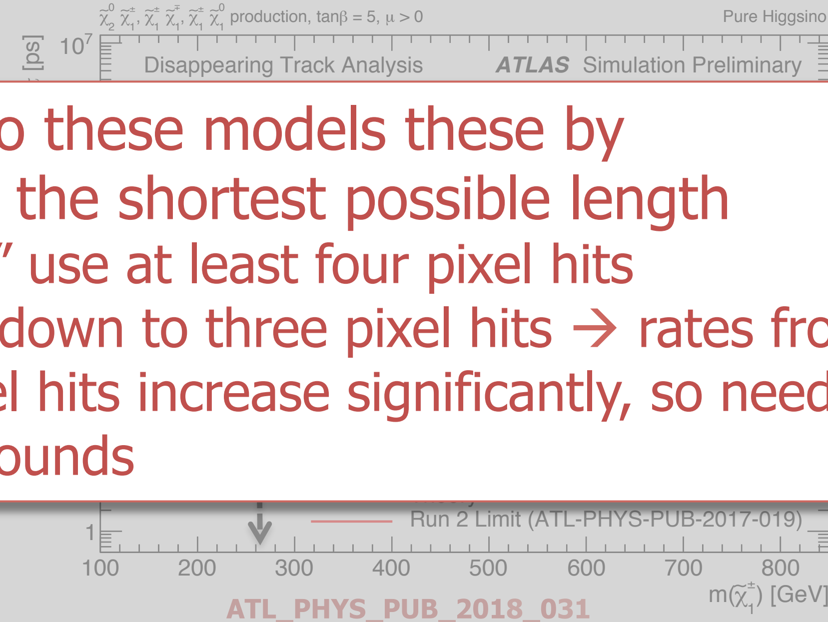

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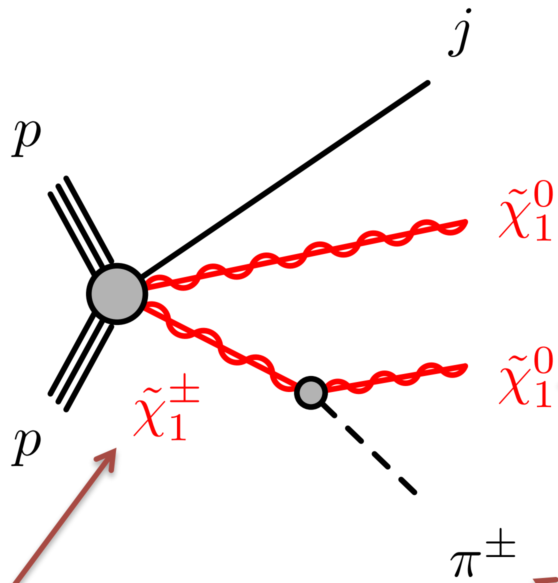
Want to improve sensitivity to these models these by extending "pixel tracklets" to the shortest possible length

- → "Conventional pixel tracklets" use at least four pixel hits
- → Attempting to extend usage down to three pixel hits → rates from random combinations of pixel hits increase significantly, so need techniques to reduce backgrounds

Disappearing track plus a soft-track signature



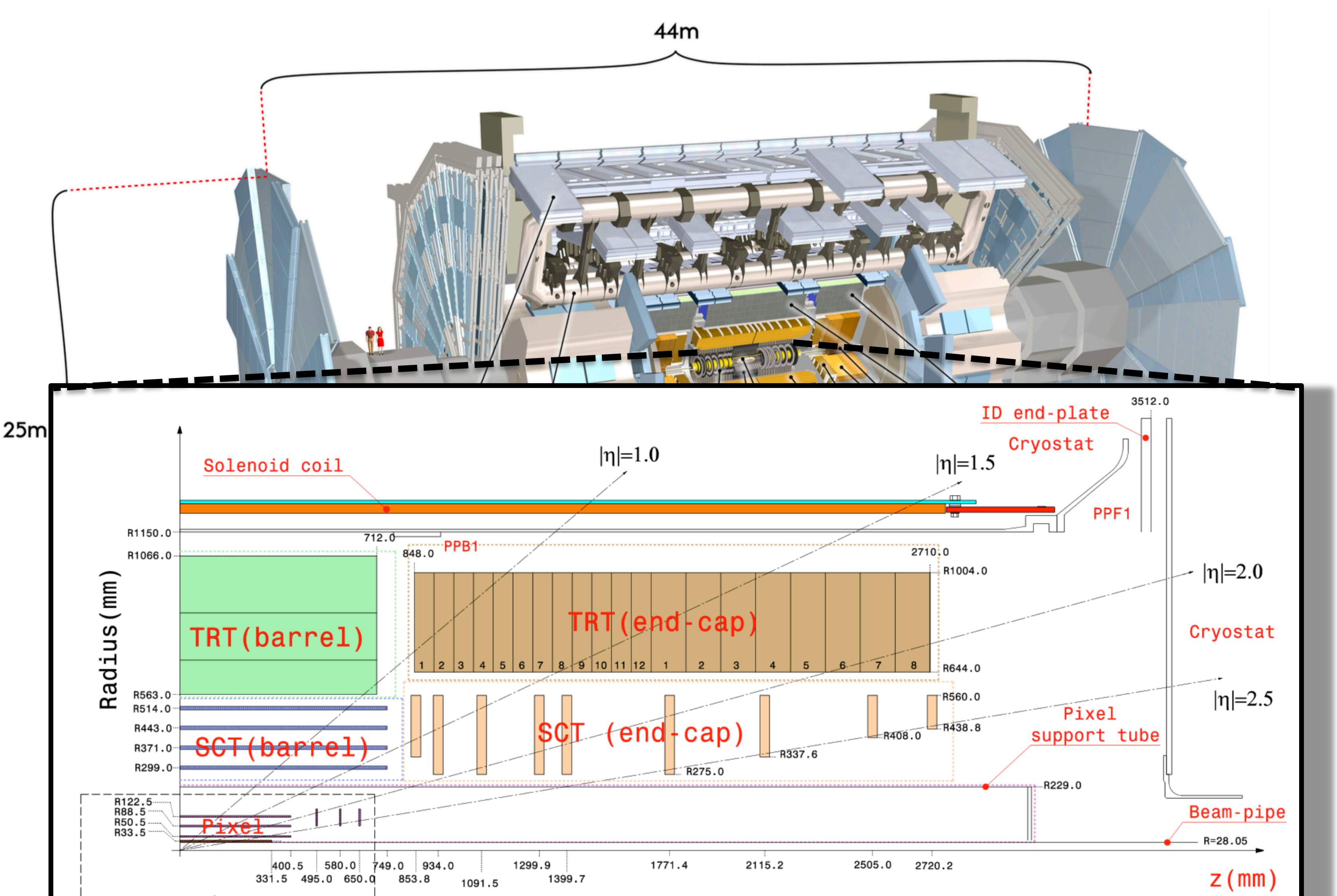
Undetected

Long-lived charged state
from compressed mass spectrum

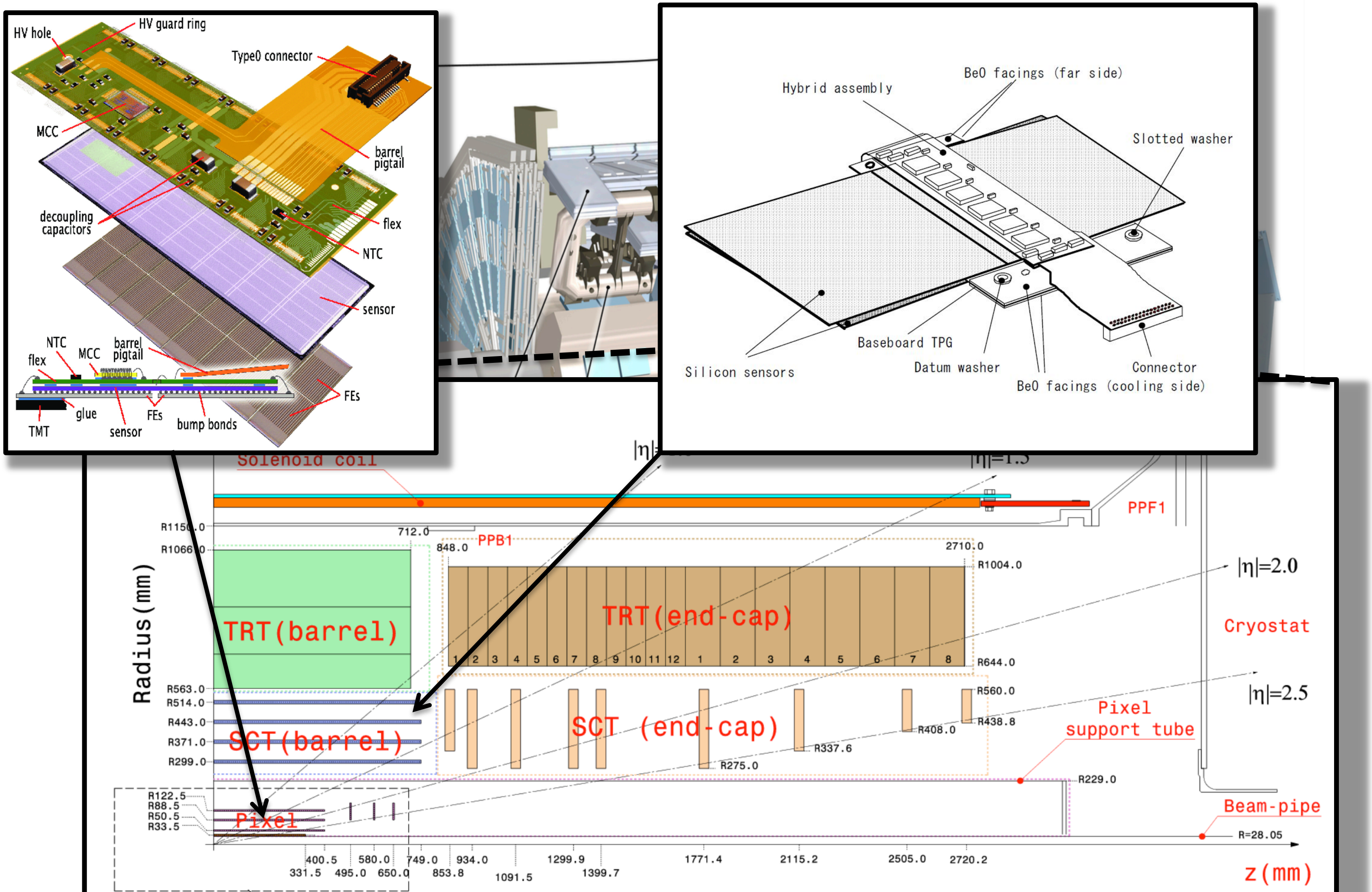
$\Delta m \left(\tilde{\chi}_1^\pm, \tilde{\chi}_{1,2}^0\right)$ ~ 300 MeV

Extremely low momentum
p_T ~ 300 MeV

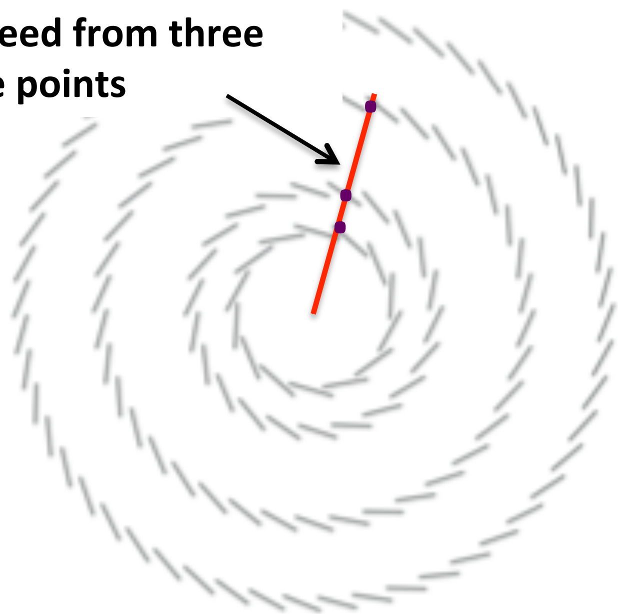
ATLAS detector



ATLAS detector



Tracklet Seeding

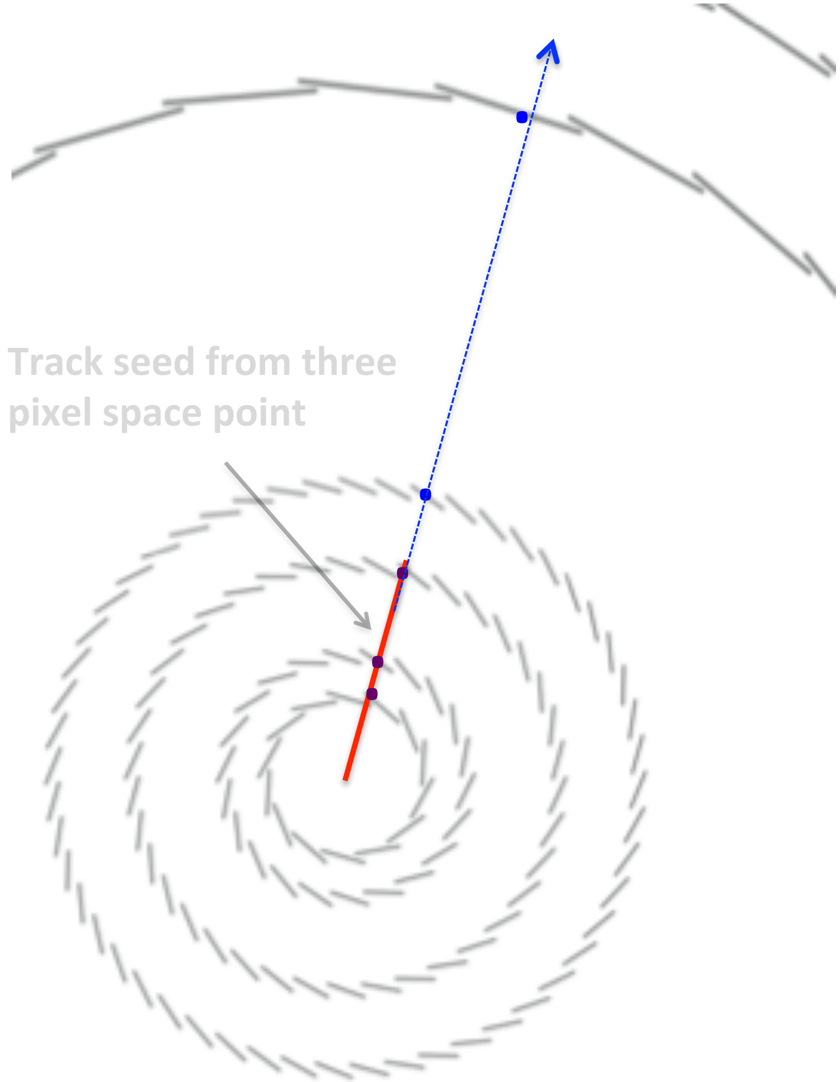


Tracklets seed from three pixel space points

Seeding requirements

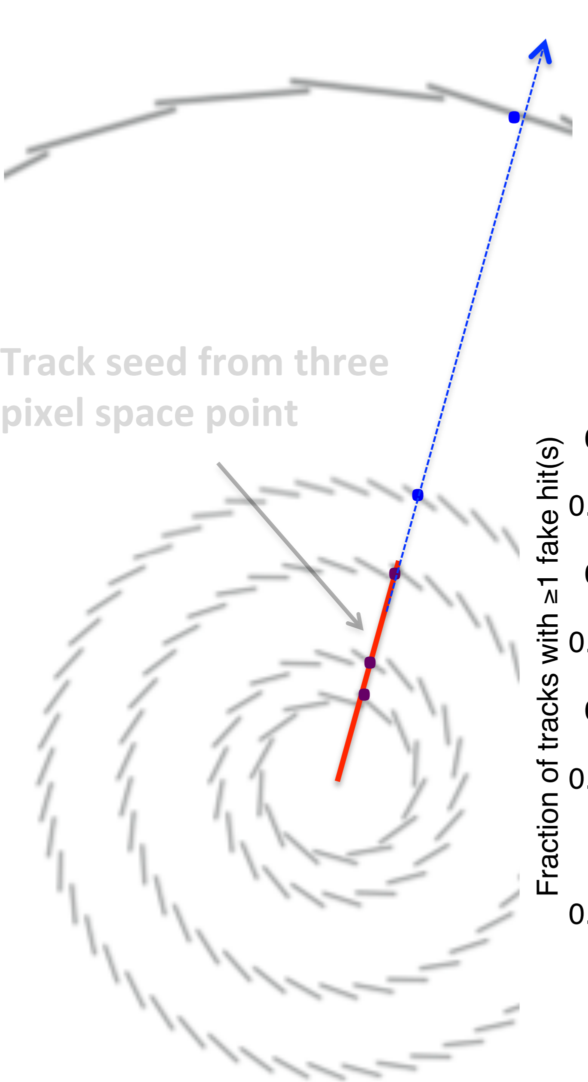
Requirement	cut
Number of space-points	==3
Max radius of space-points	< 150 mm
Transverse impact parameter d_0	<10mm
Longitudinal impact parameter z_0	<320mm
Minimum transverse momentum p_T	>5 GeV
Maximum pseudorapidity $\|\eta\|$	<2.2

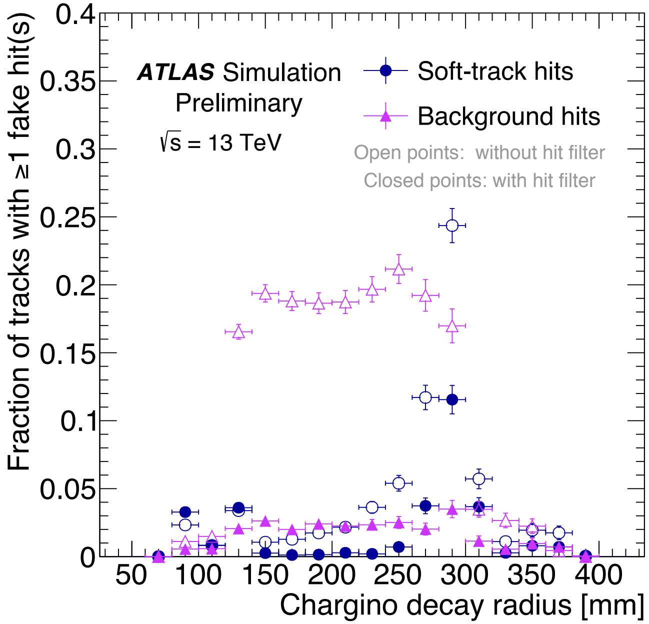
Tracklet extension

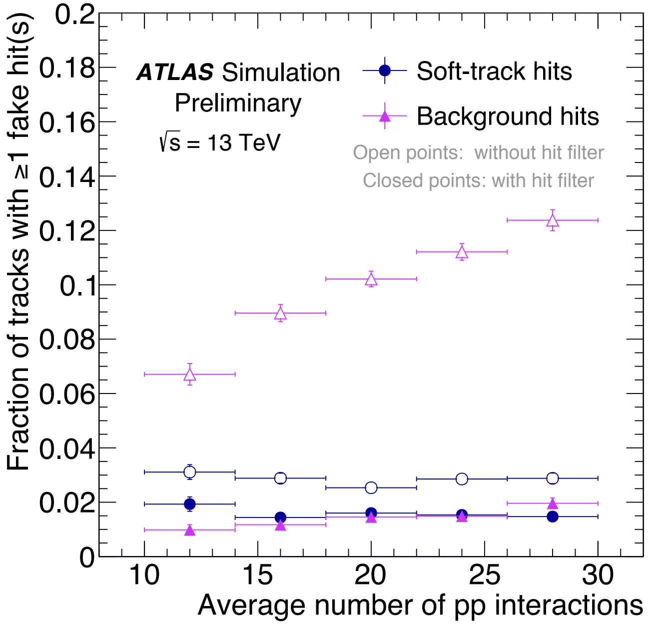


Spurious SCT clusters

- Single hits from pile-up associated to tracklets trajectory spoil the disappearing track condition (veto on SCT hits)
- Require SCT hits on both axial and stereo layers → significant reduction in fake rate, and improves disappearing track condition by over 40%!



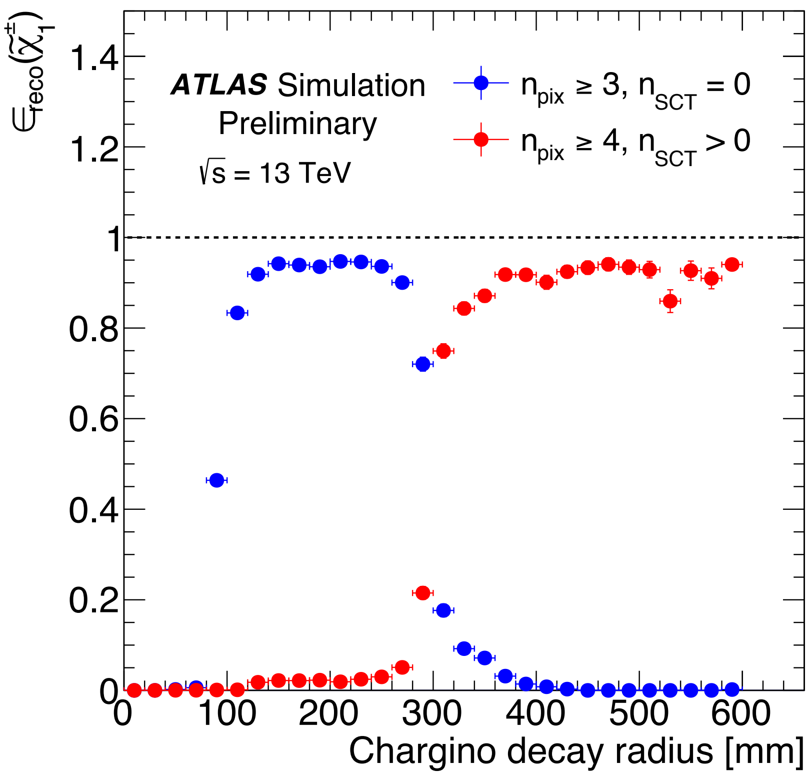


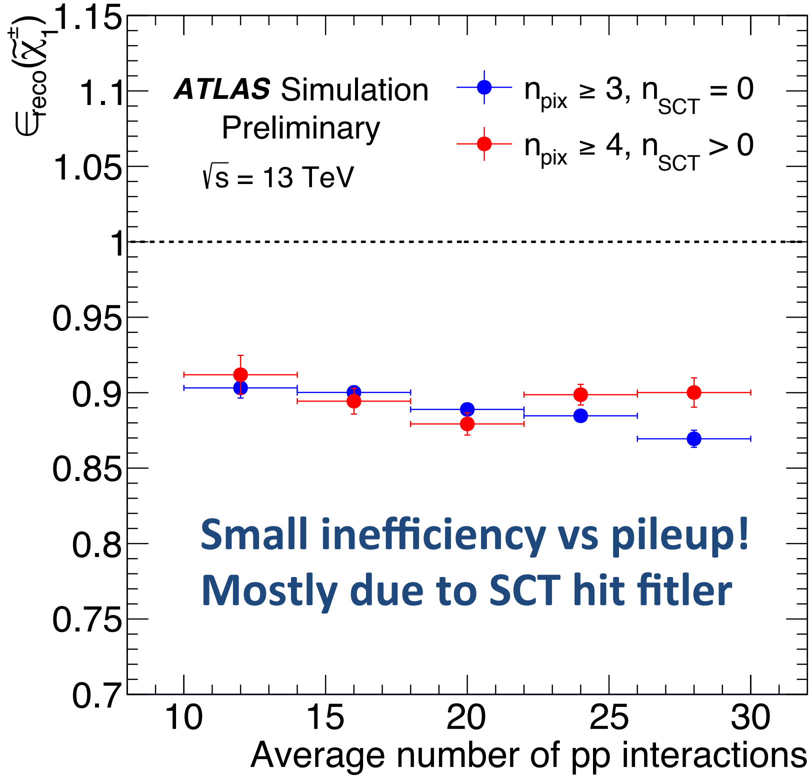


Tracklet reconstruction

⇨ Reconstruction efficiency better than 90% beyond r ~88 mm

$$\epsilon_{\mathrm{reco}}(\tilde{\chi}_1^{\pm}) = \frac{\text{number of charginos matched to a reconstructed track}}{\text{number of generated chargino particles}}$$





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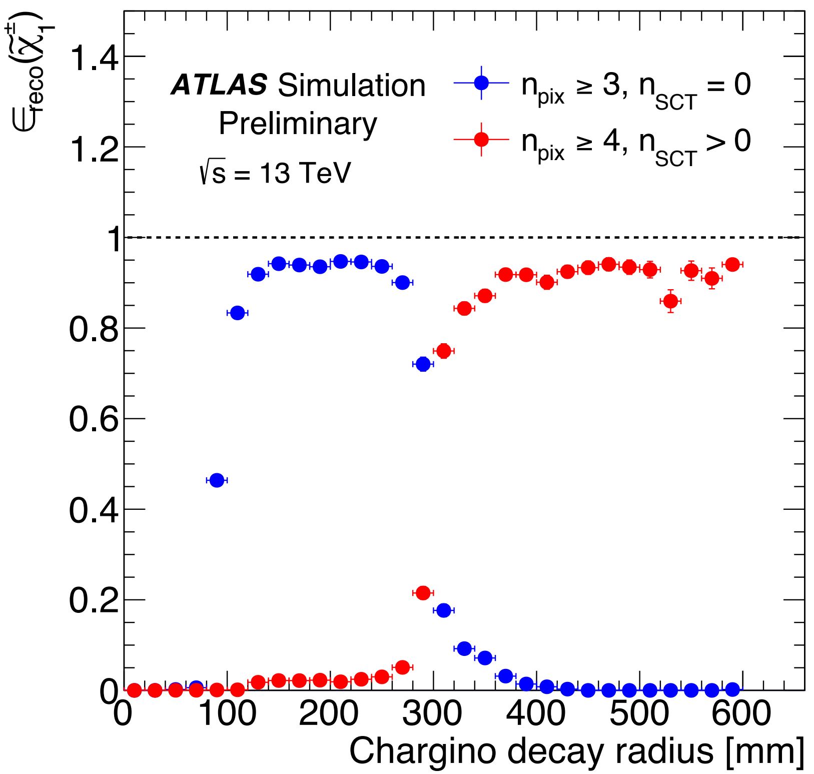
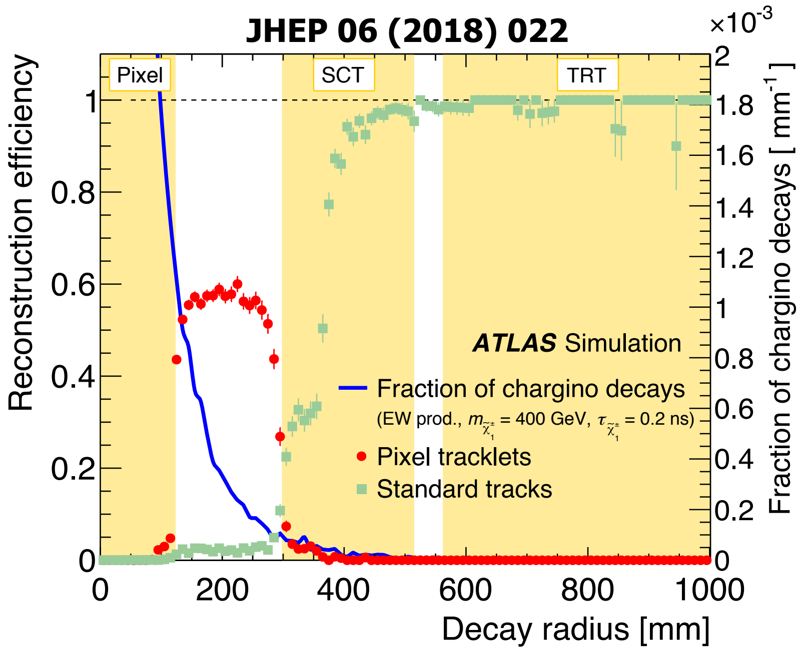
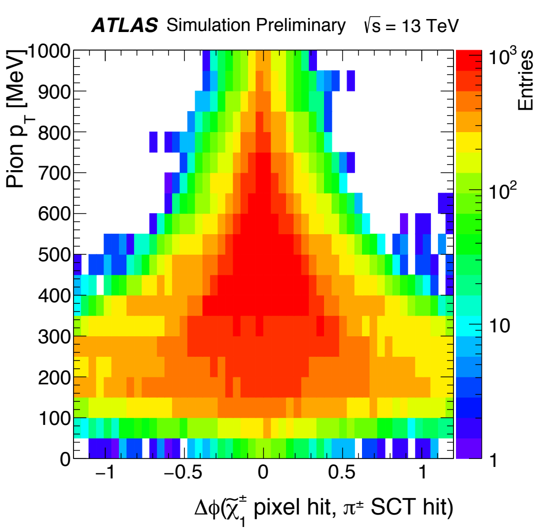


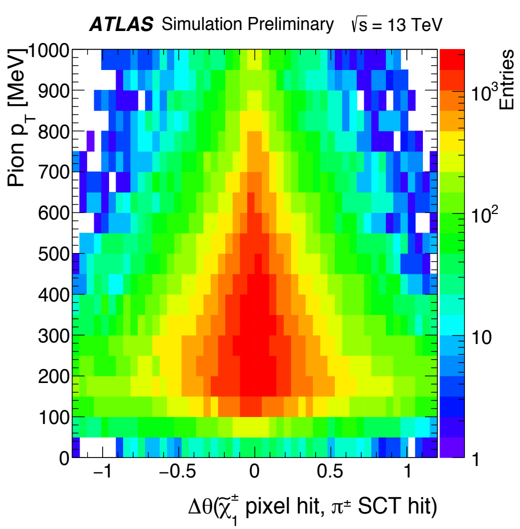


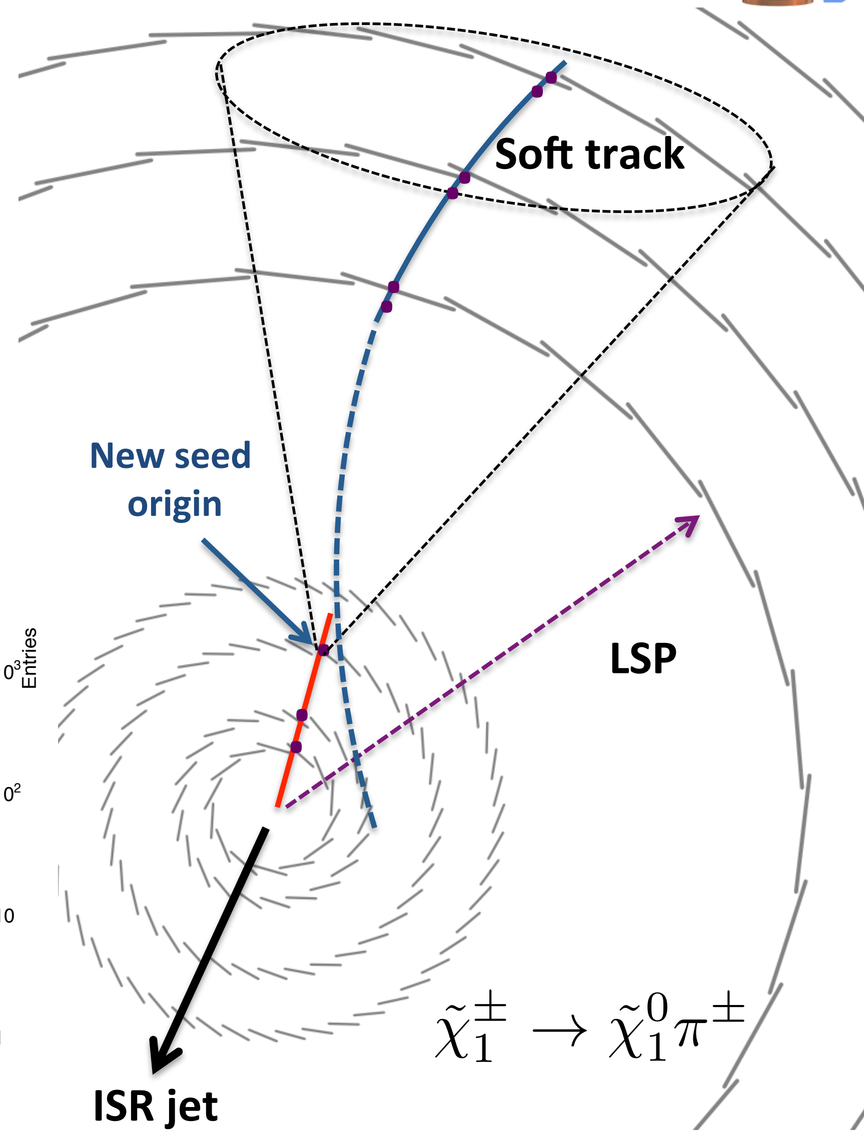
Significant improvements in overall efficiency and towards shorter track lengths compared to previous ATLAS reconstruction algorithms !!

RoI soft-track seeding

- ⇨ A Region of Interest (RoI) technique developed to reconstruct soft-track
  - Tracklets define a RoI to search for seeds
  - Dynamically set the origin in each RoI to the last pixel tracklet measurement
  - Apply impact parameter requirements relative to this new origin
  - Perform track finding using SCT hits only
- Reduces execution times by over an order of magnitude: ~30 s/evt → 1-2 s/evt

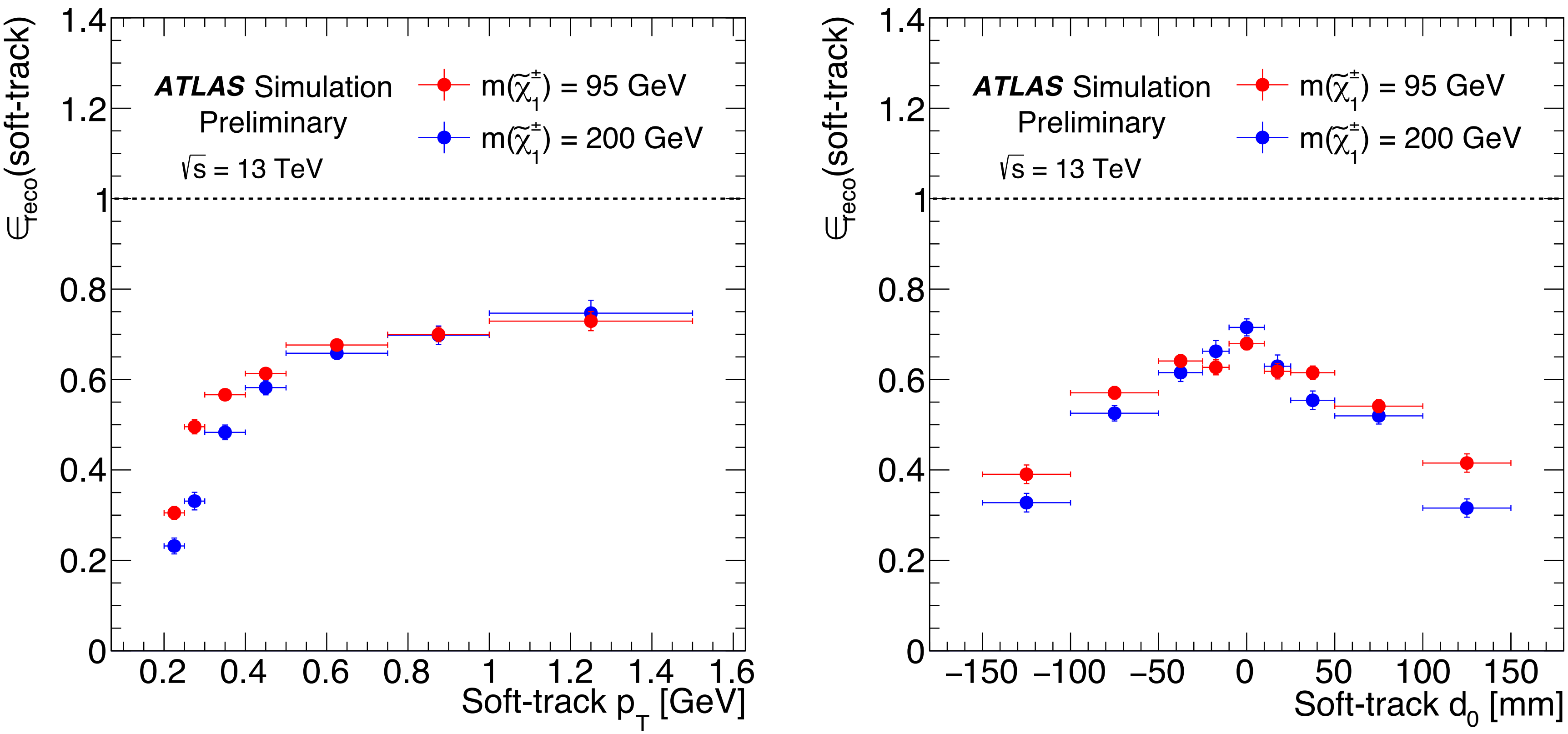




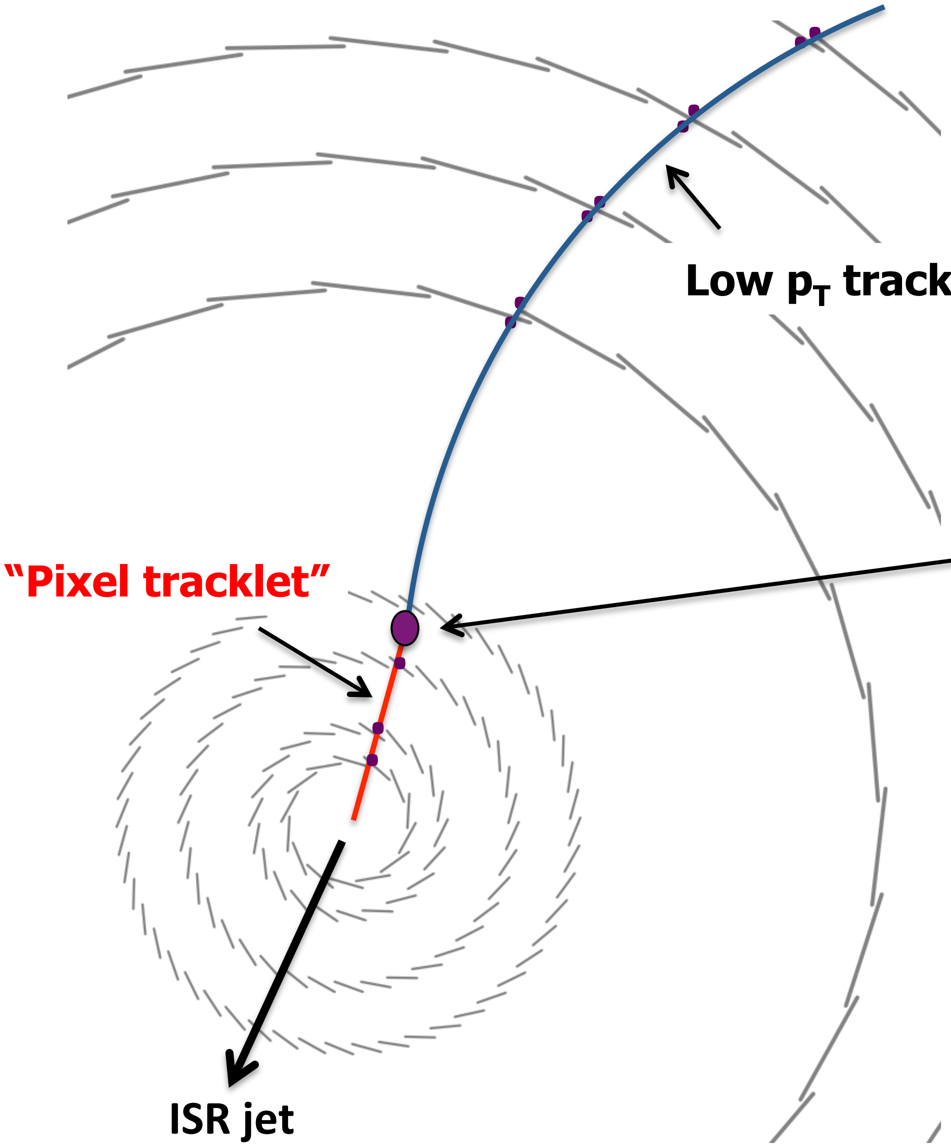


Soft-track reconstruction efficiency

- ⇨ Efficiency evaluated after successful reconstruction of a tracklet with the same criteria used during the soft-track seeding stage
- ⇨ Achieve ~50-60% for tracks with p_T > 300 MeV



Two-track vertex fit

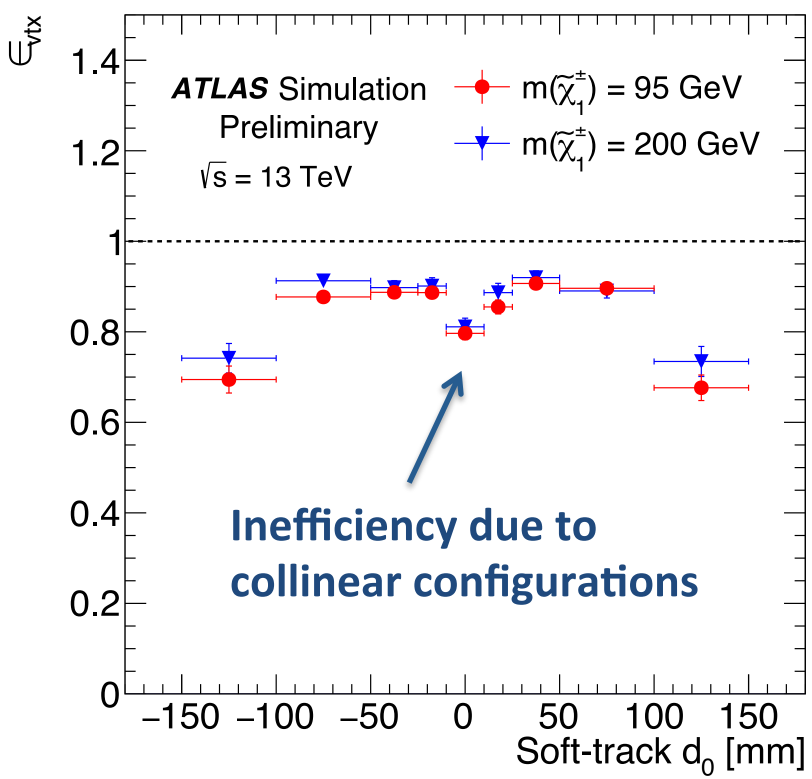


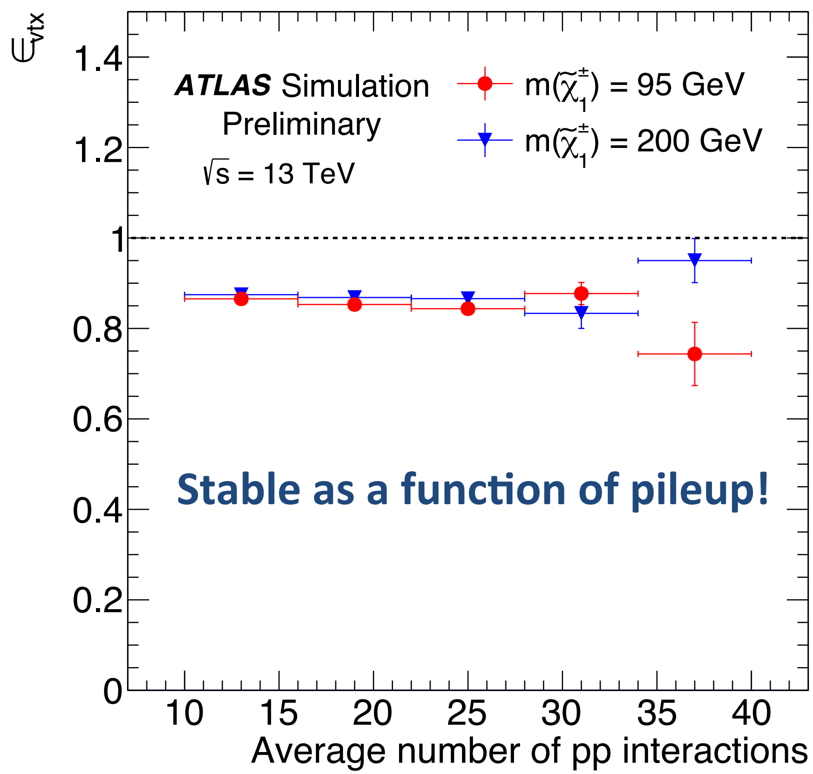
Two-track vertex fit performed to estimate decay position of the chargino

Vertex efficiency

- ⇨ Two-track vertex fit performed with pixel-tracklet and soft-track
- ⇨ Tracking efficiency factored out from vertex efficiency:

$$\epsilon_{\mathrm{vtx}}(x) = \frac{N_{\mathrm{truth}}(\text{vertex reconstructed} \mid \text{seed tracks reconstructed})}{N_{\mathrm{truth}}(\text{seed tracks reconstructed})}$$

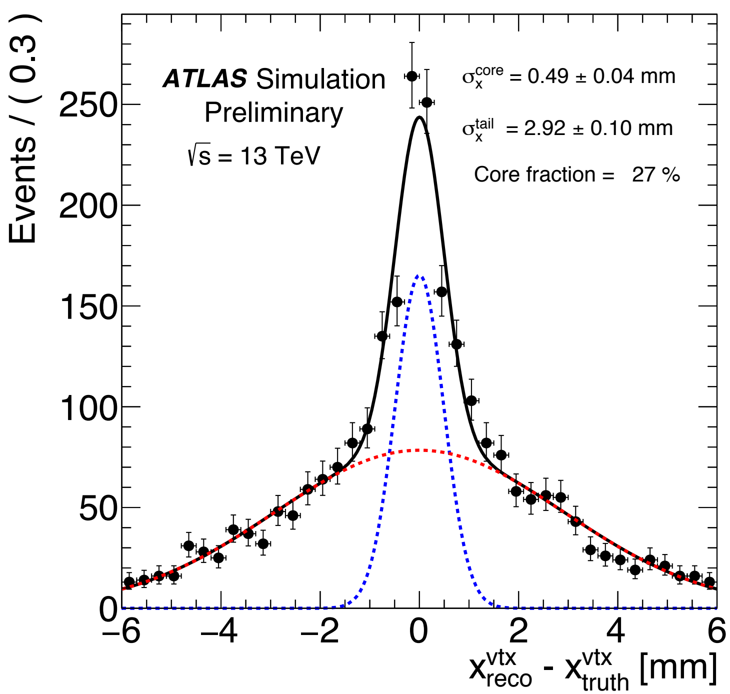


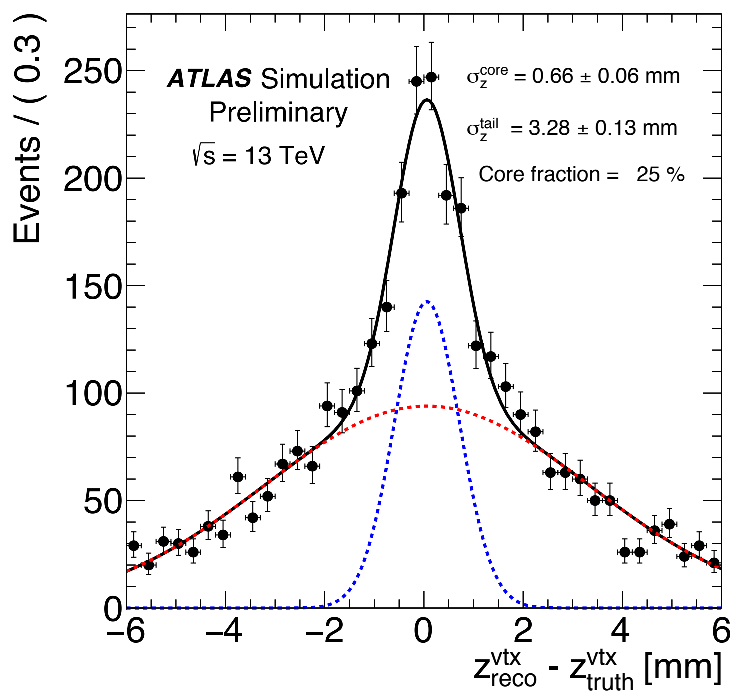


Vertex Position Resolution

- ⇨ Position resolution studied in signal by taking difference between reconstructed and generated decay position
- ⇨ Extract resolution with double gaussian model for the "core" and "tails"
- ⇨ Resolution dominated by the tails

	$r < 150$ mm	150 mm $< r < 300$ mm
σ_x^{core}	0.49 ± 0.04 mm (27%)	0.52 ± 0.03 mm (38%)
σ_x^{tail}	2.92 ± 0.10 mm (73%)	2.41 ± 0.06 mm (62%)
σ_y^{core}	0.49 ± 0.07 mm (22%)	0.52 ± 0.03 mm (33%)
σ_y^{tail}	2.86 ± 0.10 mm (78%)	2.36 ± 0.05 mm (67%)
σ_z^{core}	0.65 ± 0.08 mm (18%)	0.66 ± 0.06 mm (25%)
σ_z^{tail}	3.69± 0.20 mm (82%)	3.28 ± 0.13 mm (75%)





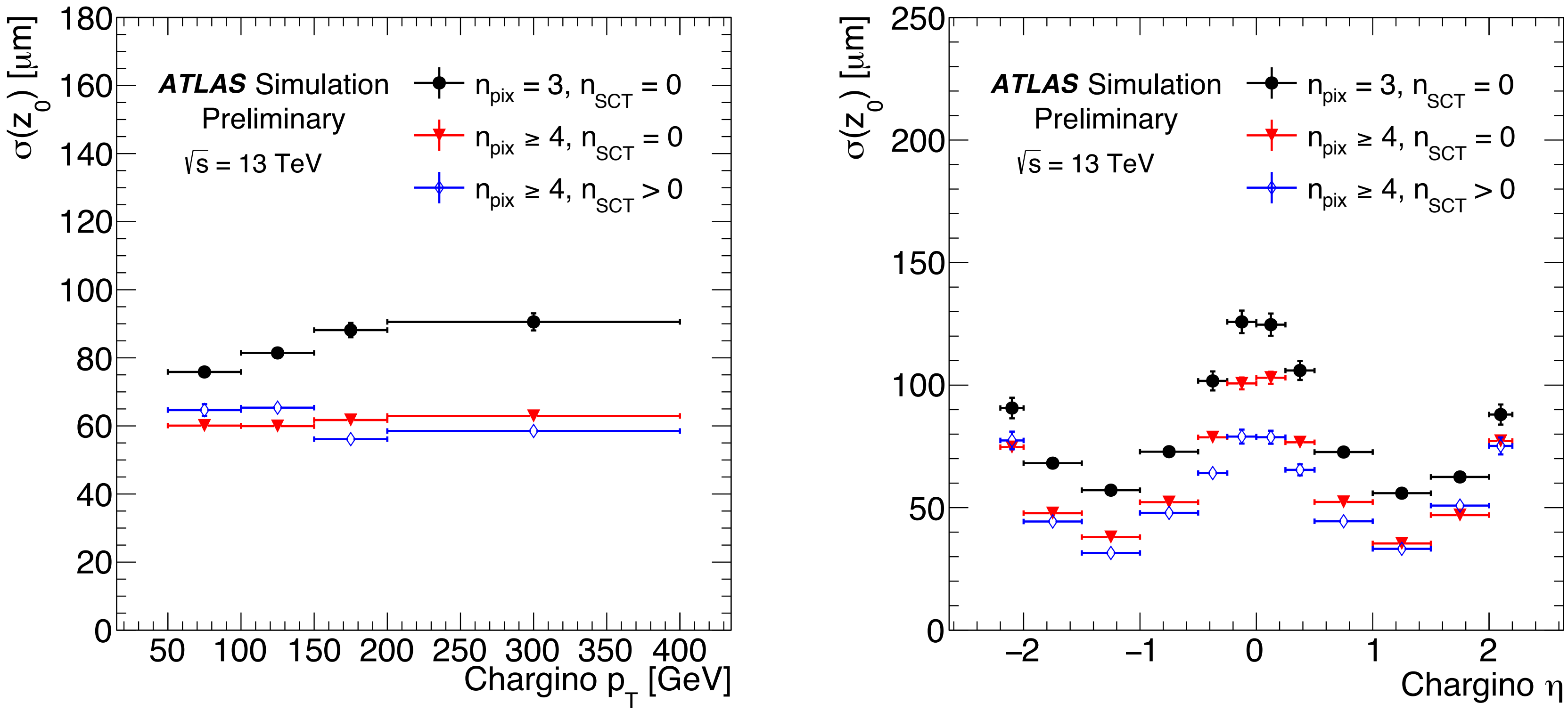
Conclusions

- ⇨ Techniques for the reconstruction of short pixel tracklets with the ATLAS detector were presented
  - Efficient reconstruction of tracklets with as few as three pixel hits
  - Improved efficiency in high pile-up environment with a dedicated hit filter
  - Targeted the low momentum charged particle from the decay of the chargino
  - Developed two-track vertexing methods to estimate decay position of the chargino with a position resolution O(1) mm
- ⇨ Inclusion of the soft-track is expected to help significantly reduce the overwhelming fake pixel tracklet background
- ⇨ Performance of these techniques documented into a PUB note:
  - *Performance of tracking and vertexing techniques for a disappearing track plus soft track signature with the ATLAS detector*
    - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2019-011/

Additional slides

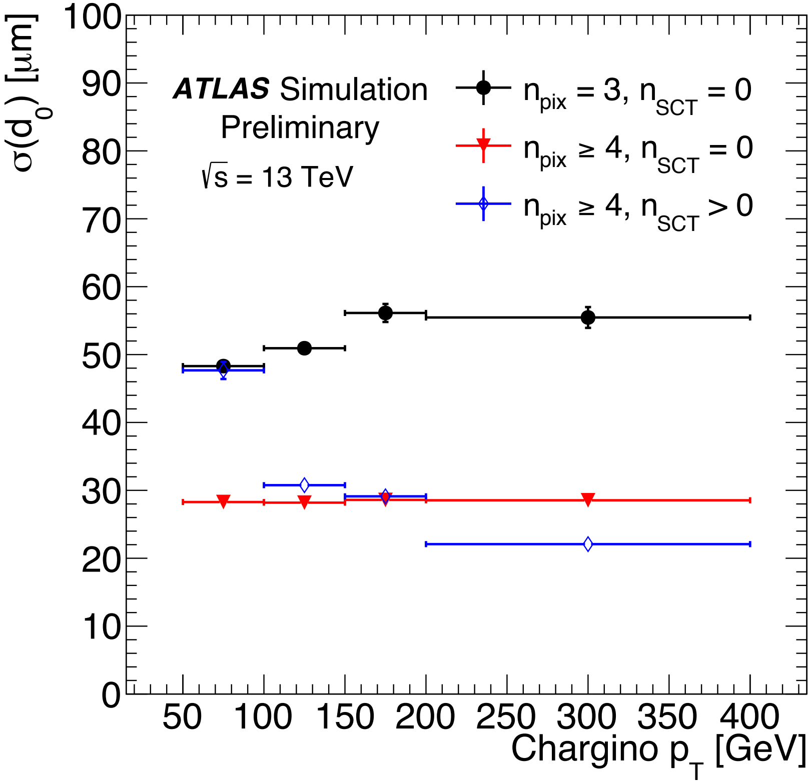
Tracklet IP resolution

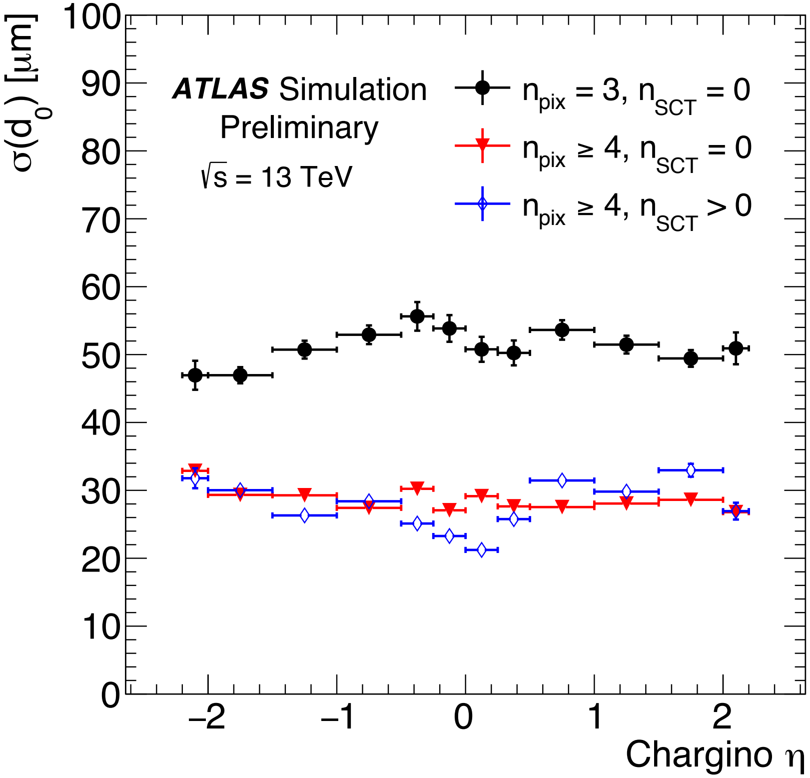
- Impact parameter resolution with respect to the beam spot
  - Small differences between 4-pixel and 4-pixel plus SCT hit categories → z_0 resolution main driven by presence of pixel hits
  - Resolution of z_0 IP depends highly on incident angle → cluster sharing in the forward regions improves the single hit resolution



Pixel tracklet IP resolution

⇨ Transverse d_0 impact parameter resolution





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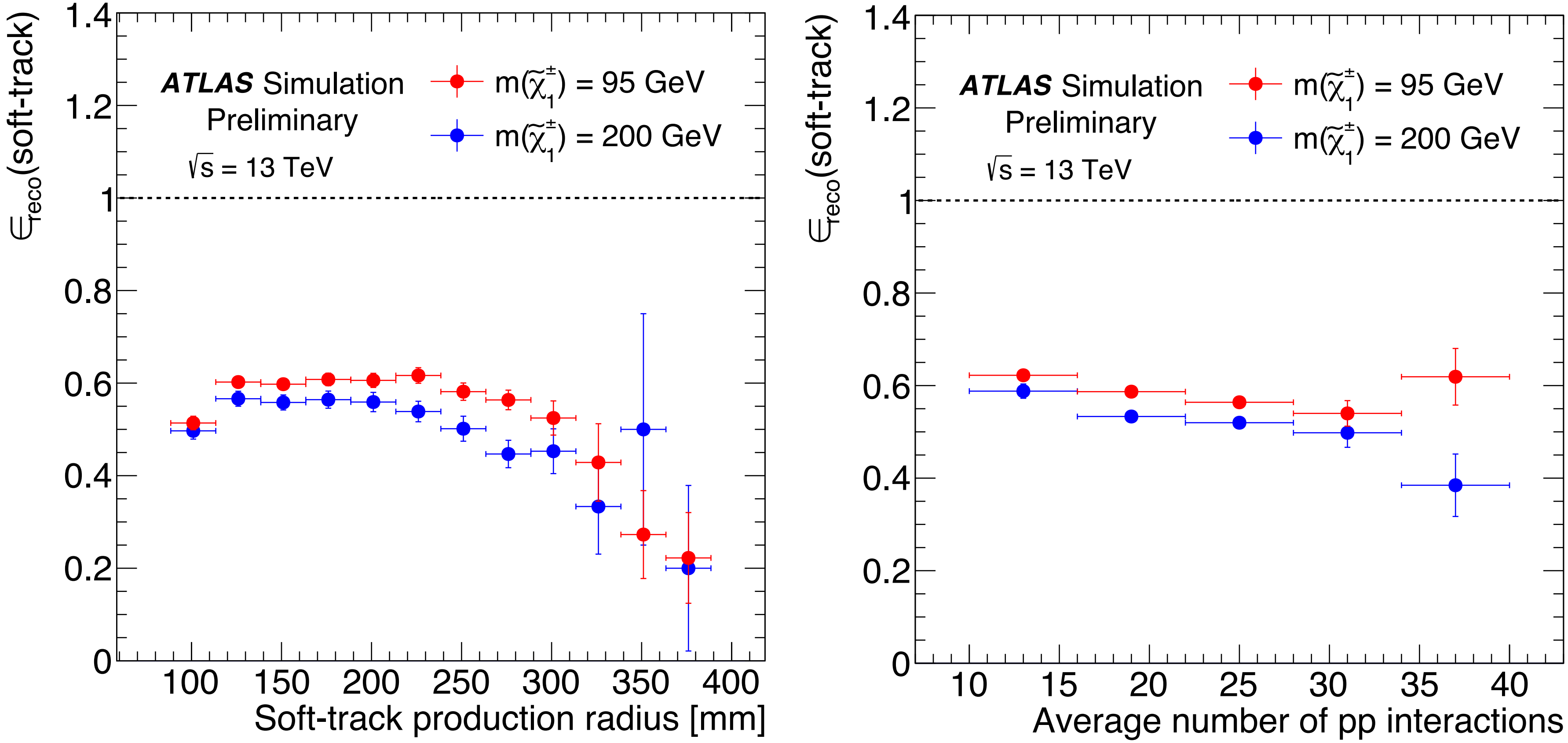
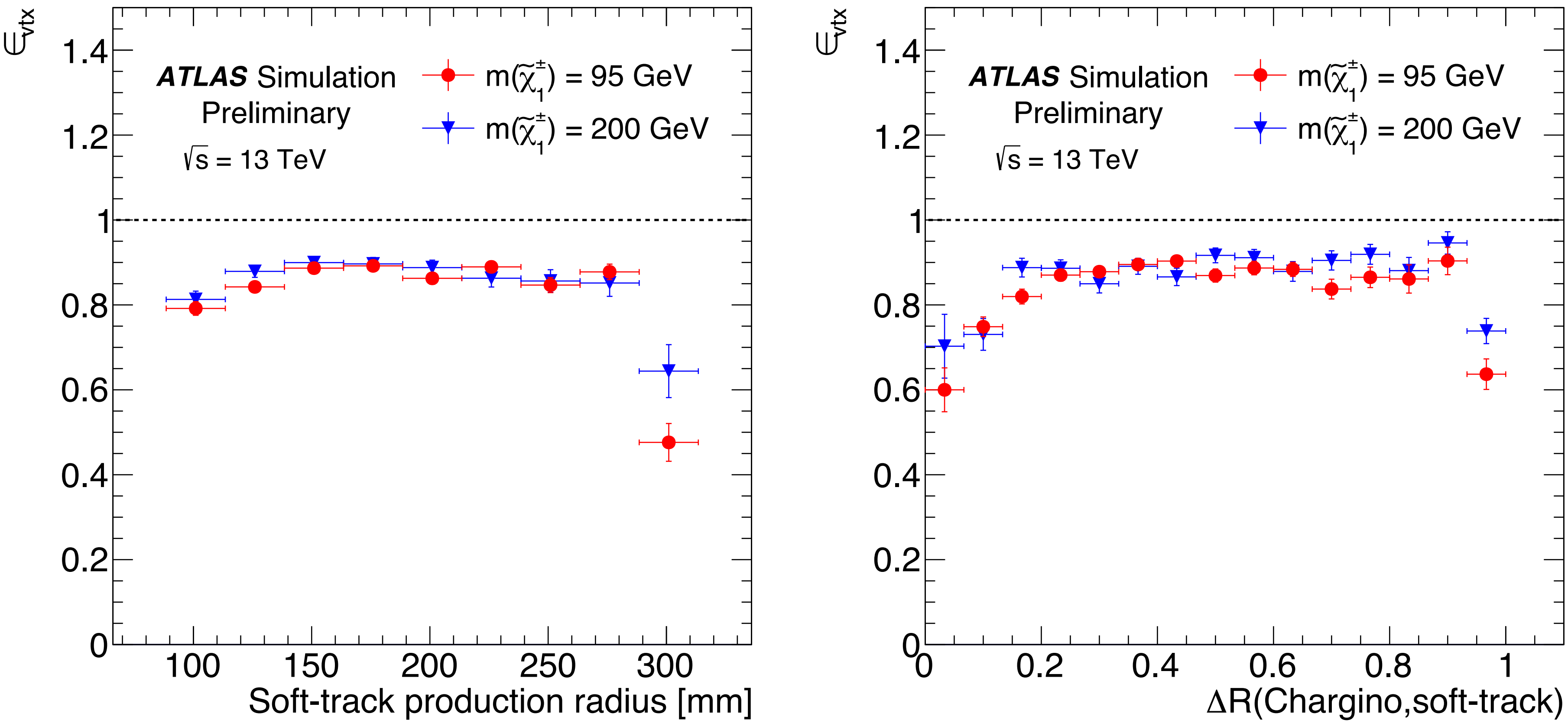
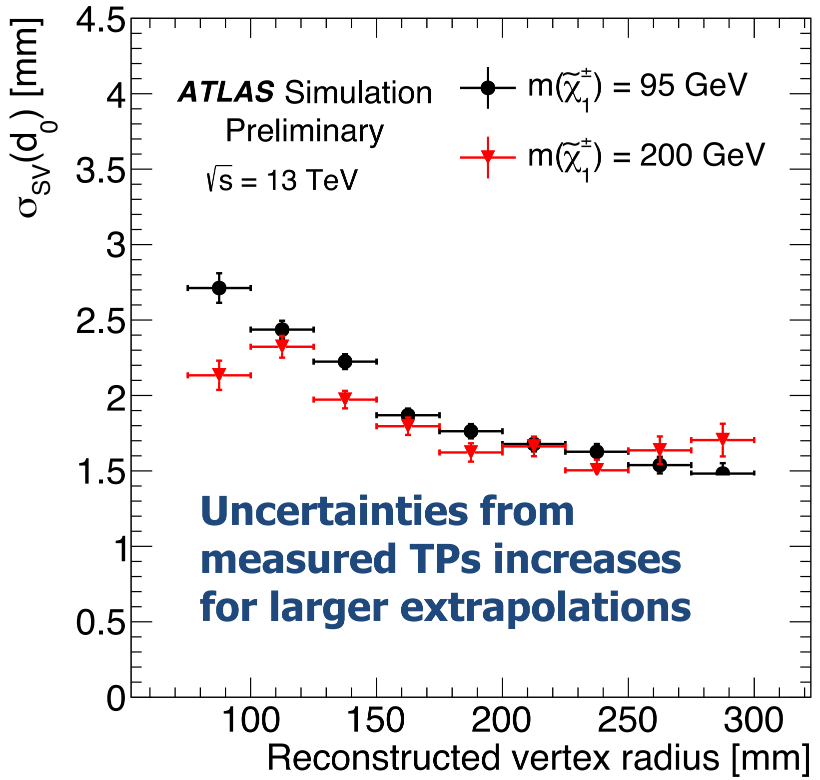


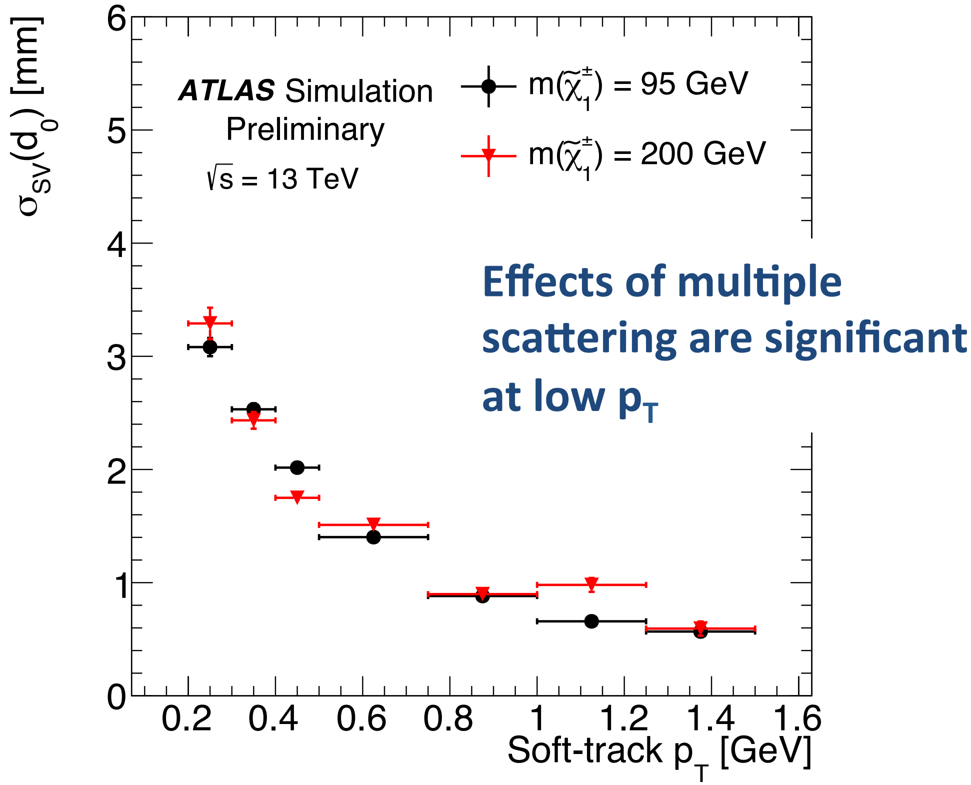
Vertexing efficiency



SV Impact Parameters

- Impact parameter resolution relative to the fitted secondary vertex
- Soft-track only use SCT measurements → degraded performance in pointing resolution further from the SCT detector





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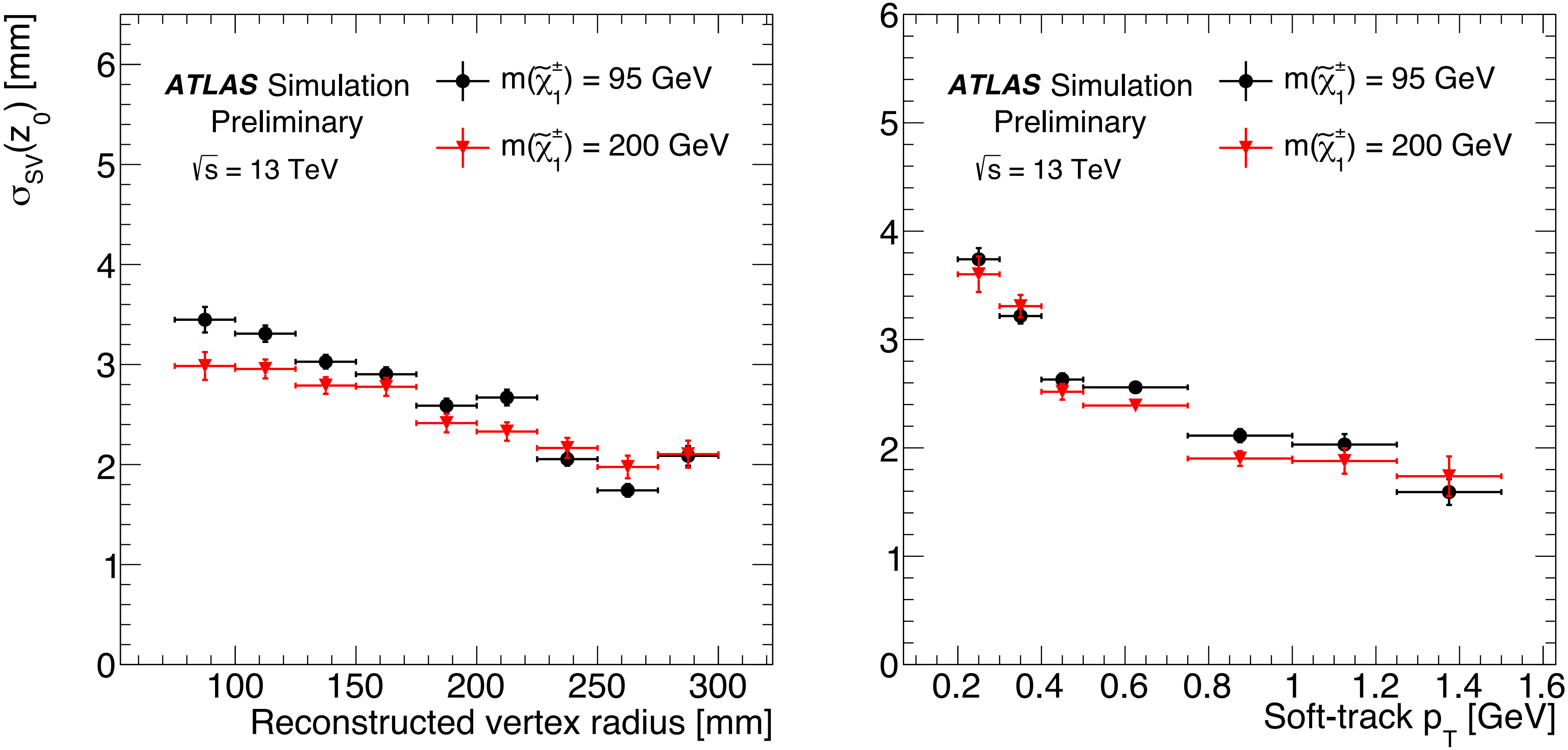

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