# Vertexing Algorithms with the ATLAS Detector for the HL-LHC Upgrade

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## Abstract

We evaluate the performance of the standard vertexing algorithms used in the Large Hadron Collider (LHC) Run 1 analyses.

With the analysis framework ROOT, we develop metrics for vertexing performance and quantitatively compare the current algorithms to possible alternatives in the high pile-up regime. Our results will guide algorithm development in preparation for the High Luminosity LHC upgrade, which will begin operation in mid-2026.

## Background

- LHC—the world's most powerful microscope! High energies means small length scales.
- Collides fast-moving protons to produce new particles.
- New particles = new physics! Hints of dark matter and SUSY?

## The ATLAS Detector

- 5 story apparatus with micron precision!
- Measures charged particle tracks bending in a magnetic field

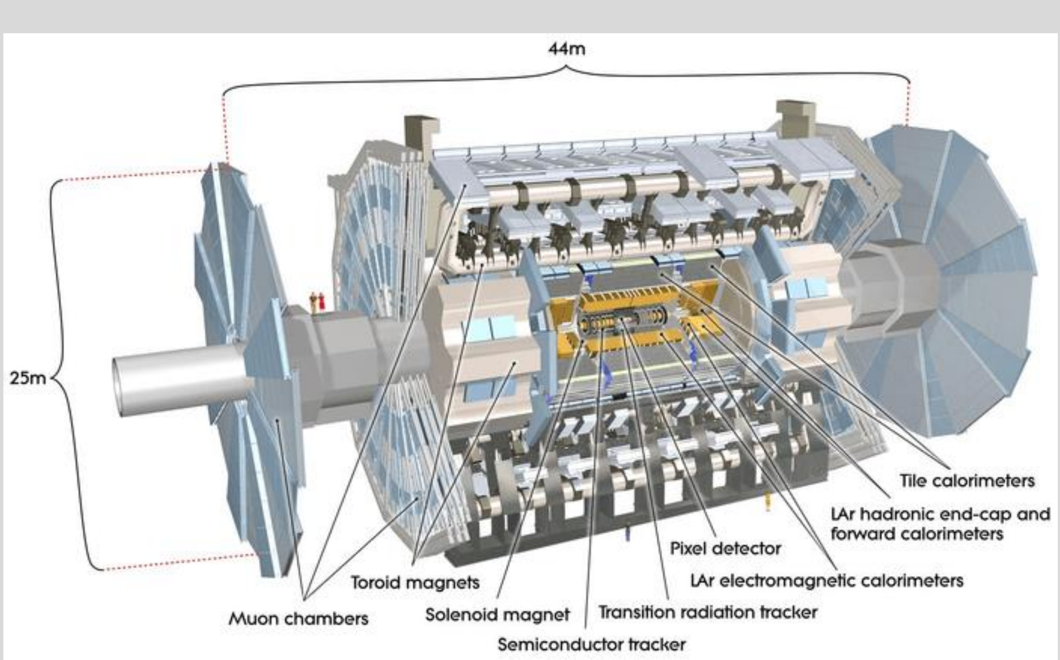



**Figure 1**: A schematic diagram of the ATLAS detector. Image credit: https://arxiv.org/pdf/0910.3081.pdf

## RESEARCH QUESTION

*How well do our current methods for vertex reconstruction work when we increase the number of collisions by a factor of ten?*

## An Intro to Vertexing

- *Primary vertices*– locations of proton-proton collisions in the detector
- *Vertexing*– the process of reconstructing vertices from particle tracks
- Two main goals: <u>position resolution</u> and <u>track-vertex association</u>

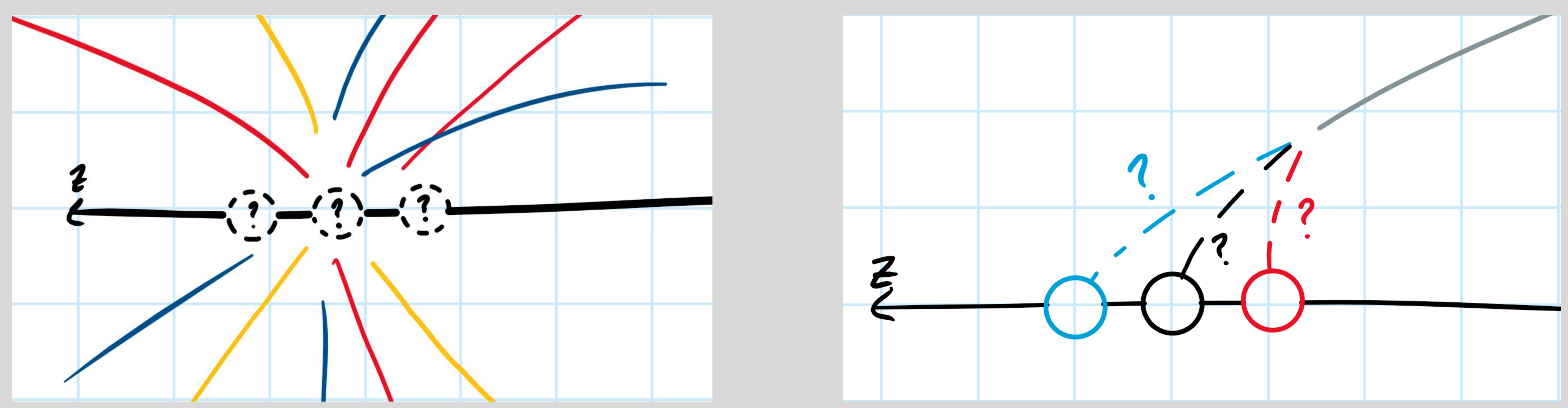
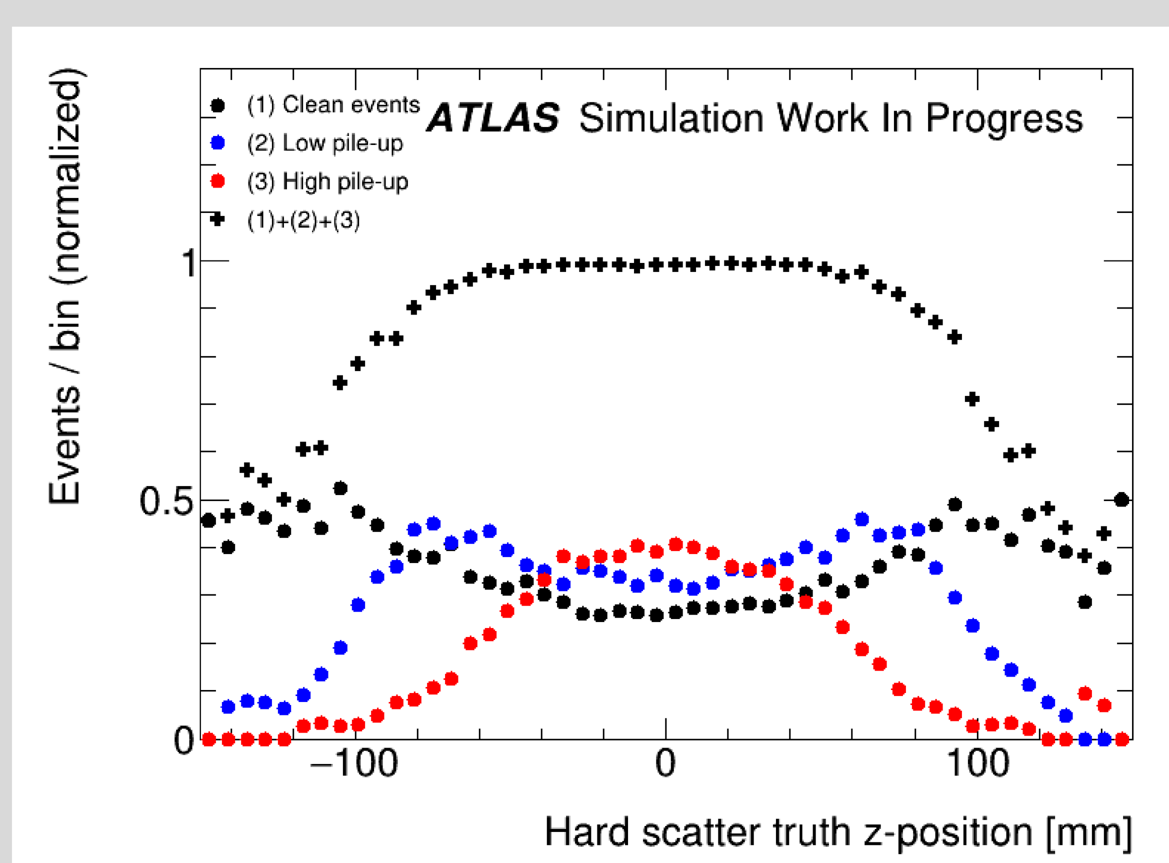



**Figure 2**: Illustrations of the two main goals of vertexing.
**Left**: Reconstructing vertices from tracks (position resolution)
**Right**: Associating tracks to reconstructed vertices (track-vertex association)

## Events, Hard Scatter, Pile-Up

- LHC collides protons in bunches every 25 ns
- In each bunch crossing (*"event"*) about 20-40 actual collisions ($\mu$)
- In each event, one special *"hard scatter"* (HS) vertex + many others (*"pile-up"*)
- HS produces many high-energy tracks– the physics process we want to study!
- Can categorize events by quality of the HS.



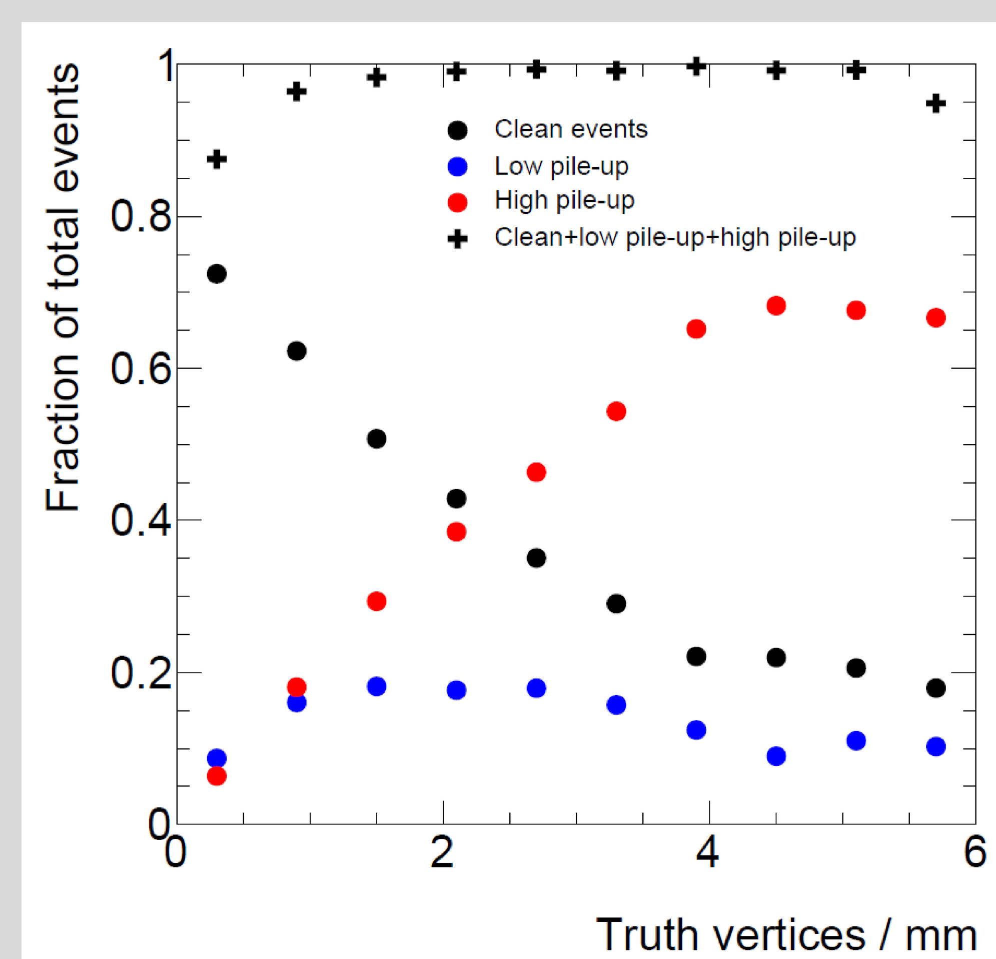




**Figure 3**: Classification of Run 1 events.

**Above**: Event classification depends strongly on the local density of vertices around the hard scatter. High density → high pile-up contamination.

**Left**: Event classification also depends on the position of the hard scatter vertex within the beam spot. Closer to the center → more pile-up.

## High-η tracks

- Tracks are described with an angular variable η (eta).
- High-η tracks are difficult to correctly associate to vertices because they run almost parallel to the collision region.

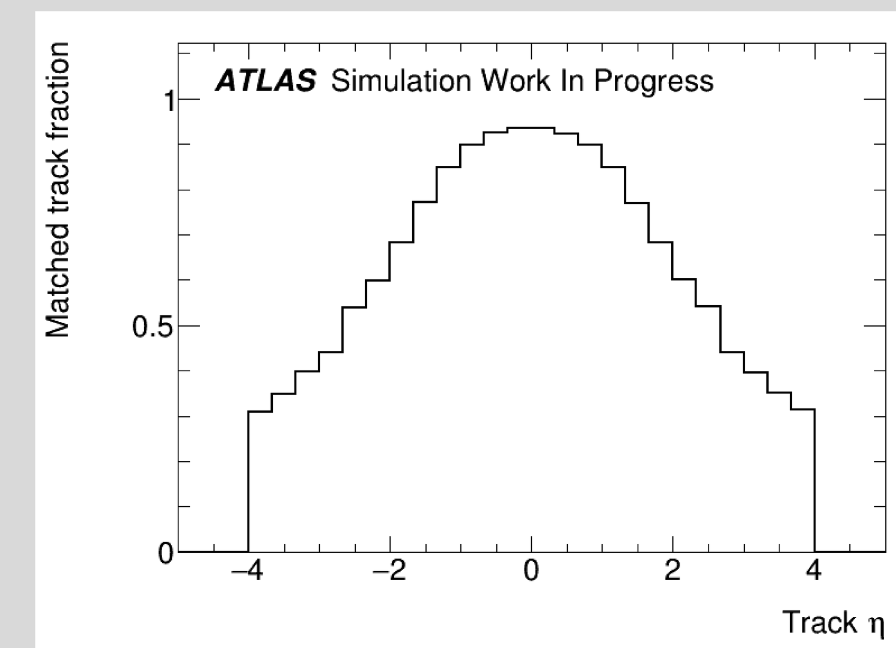



**Figure 4**: As tracks get closer to the beamline, the chance of correctly associating that track to its vertex drops sharply.

## Conclusions

- Even at μ=200, hard scatter reconstruction > 95% efficient!
- But pile-up still lost to merging (many sim vertices, only one reconstructed)
- High-η tracks especially hard to correctly assign to vertices.
- Takeaway: can improve by reducing merging losses, developing better methods for track-vertex association.

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