The ATLAS Inner Detector trigger performance in pp collisions at 13 TeV during LHC Run 2

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ON BEHALF OF THE ATLAS COLLABORATION

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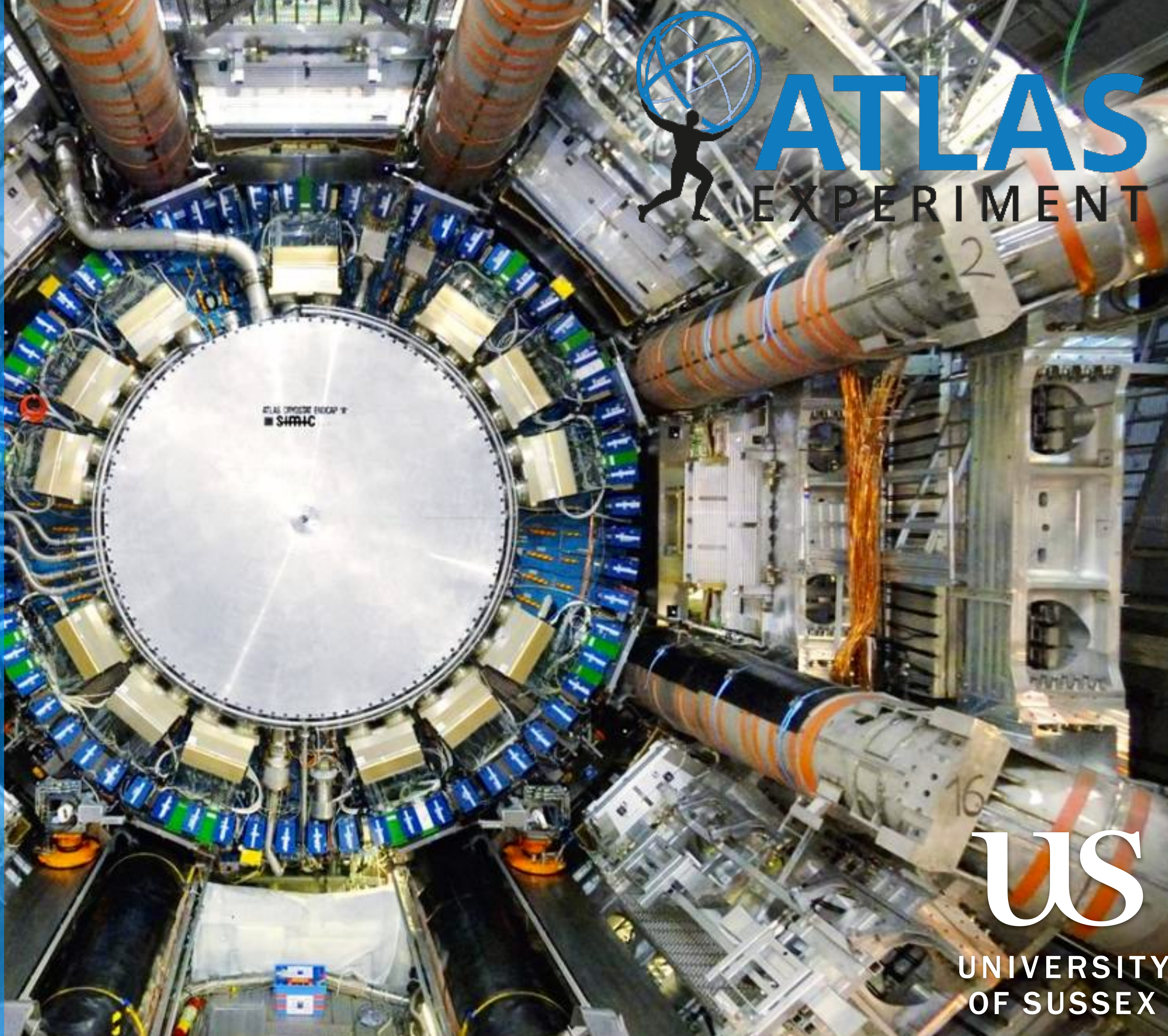
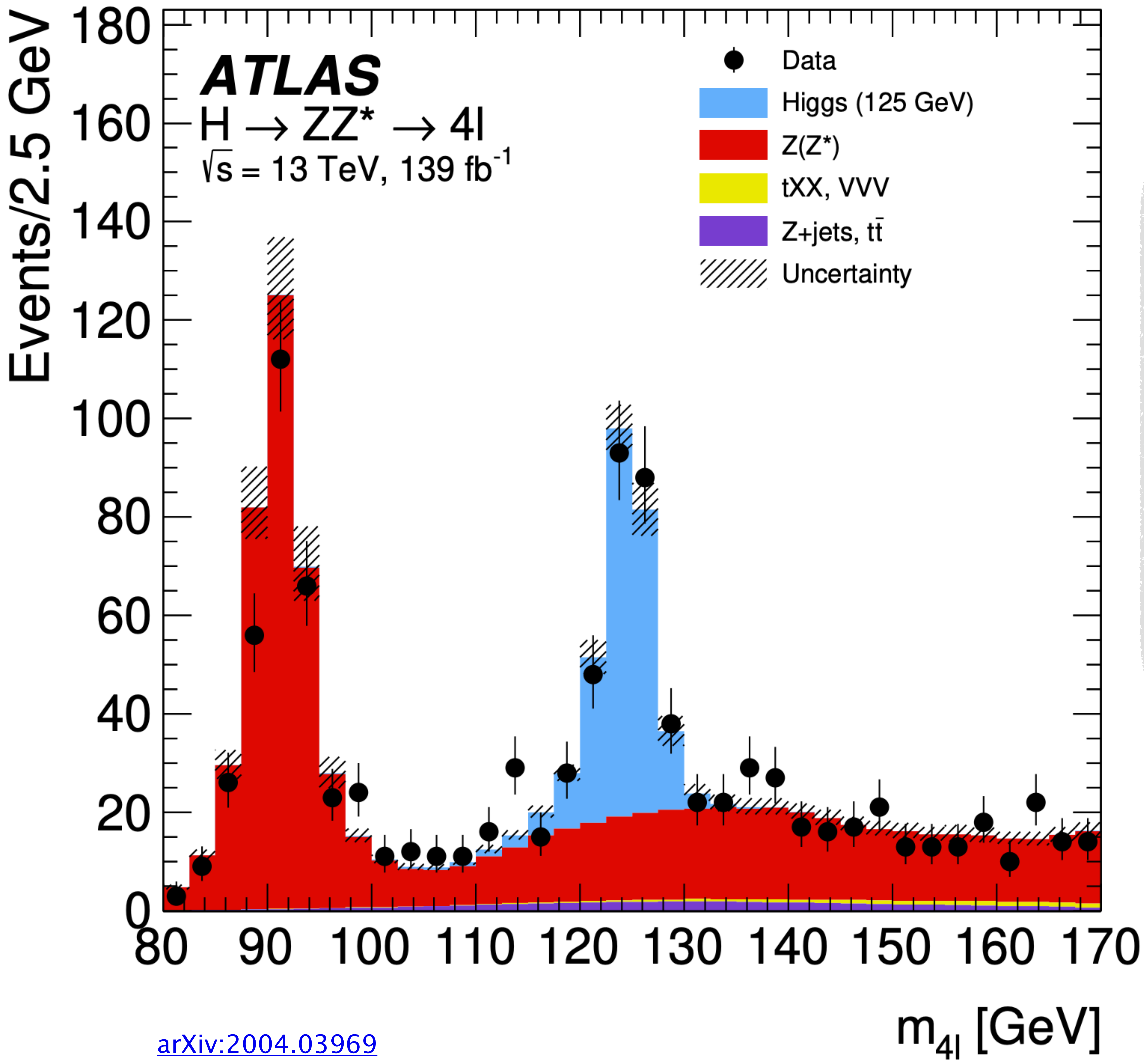


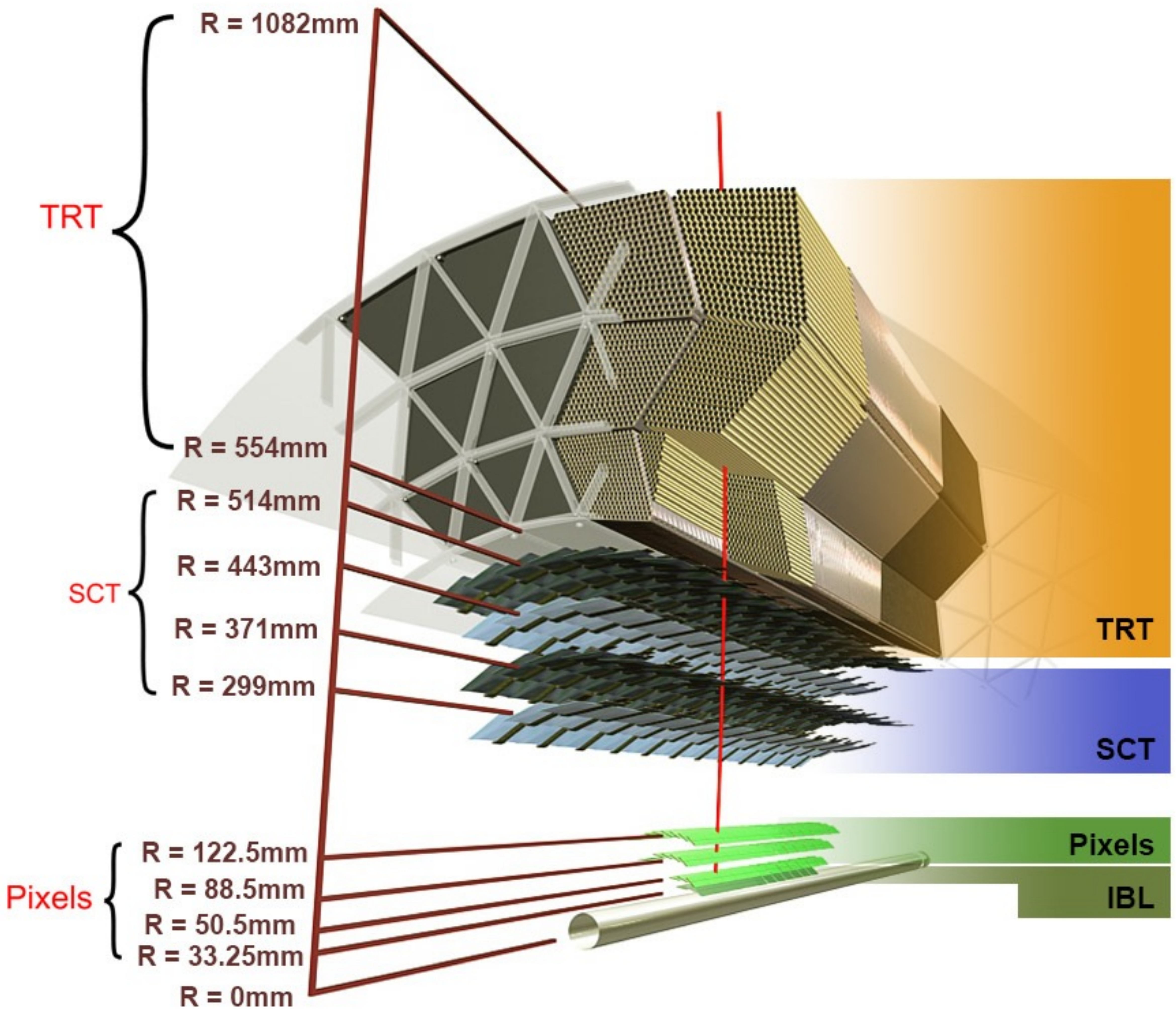
ATLAS EXPERIMENT

UNIVERSITY OF SUSSEX



arXiv:2004.03969

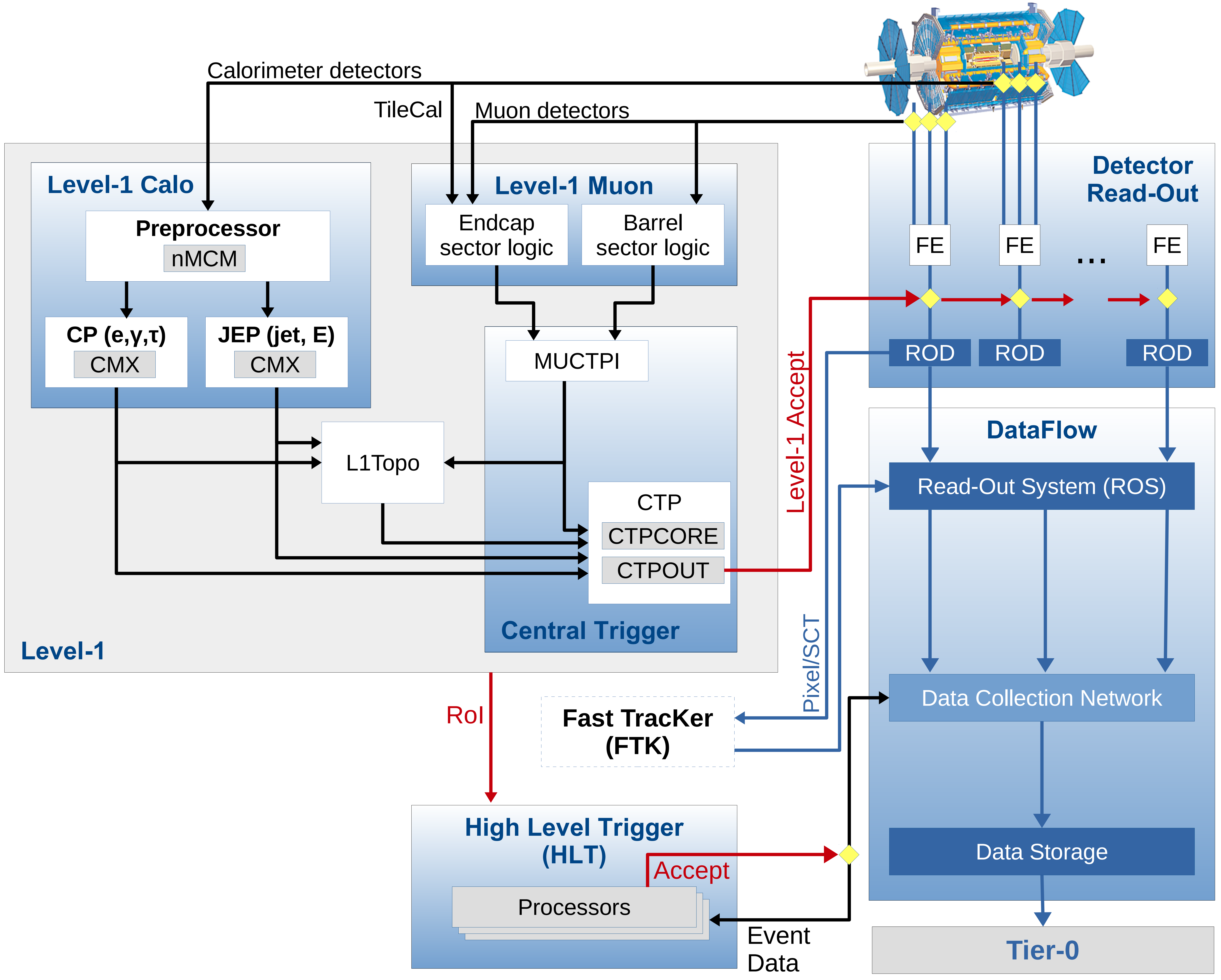
- Decay process : H→ 4ℓ (ℓ: e⁻ or μ)
  - Full Run 2 dataset
- This is **only possible** because of the **high performance of the leptonic triggers**
  - **Every** event was selected because of the successful operation of tracking in the leptonic triggers

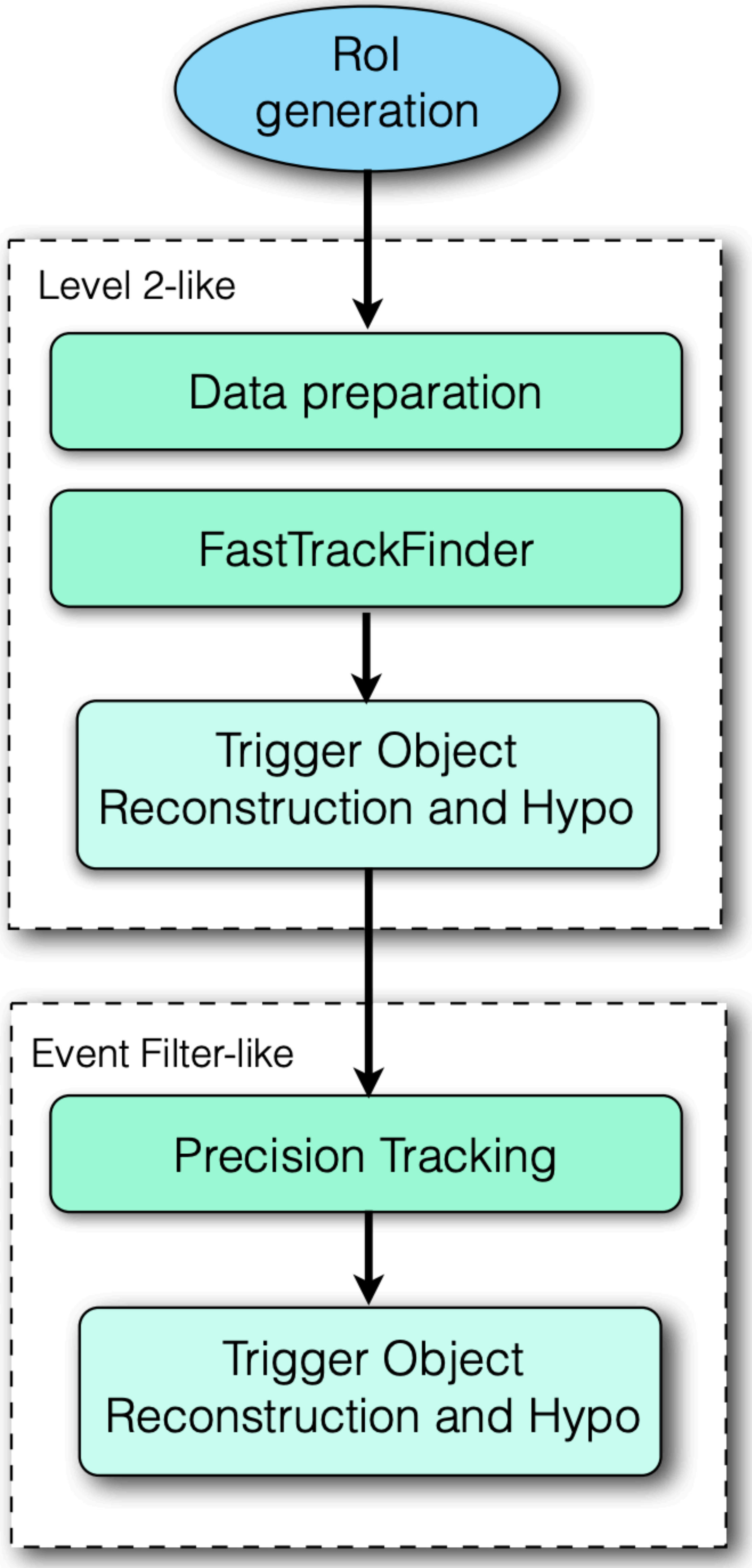


- The **Inner Detector (ID)** is the ATLAS sub-detector dedicated to track and vertex reconstruction

- Consists of **3 sub-systems**
  - **Pixel detector** – closest to beam line and interaction point
    - 3 layers of barrel and endcap silicon pixel modules, and..
    - Insertable B layer (IBL) ←added in Run2
  - **Semiconductor tracker (SCT)**
    - 4 barrel and 9 endcap layers of silicon micro-strip modules
  - **Transition Radiation Tracker (TRT)**
    - Barrel and endcap modules of straw drift tubes

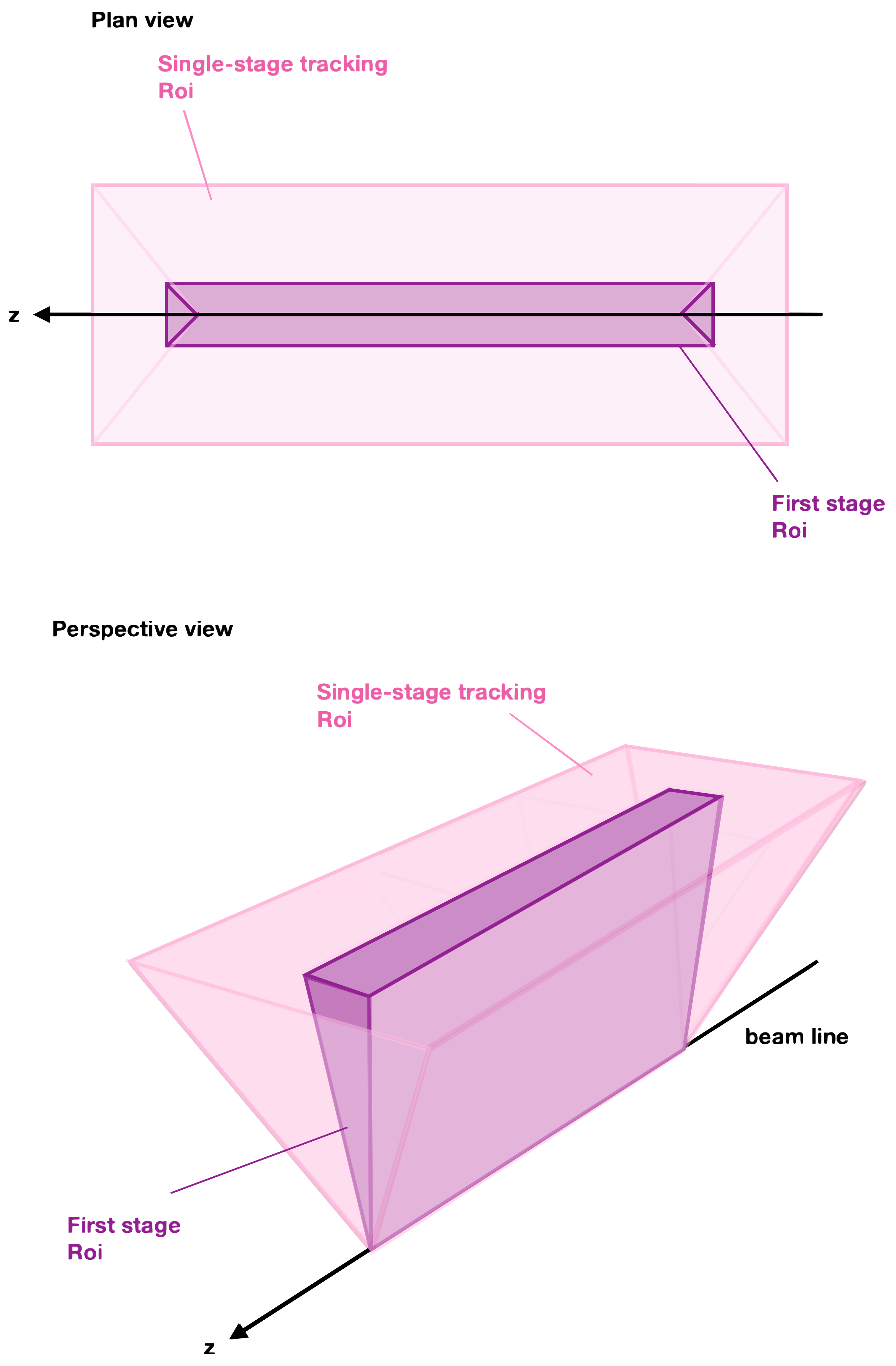
- **ATLAS trigger system** is separated in a **hardware stage** called **Level 1 (L1)** and a **software stage** called **High Level Trigger (HLT)**
  - L1 : Identifies **Regions of Interest (RoI)**
  - HLT : Processes RoIs identified by L1
- **ID trigger** is part of **HLT** system and performs fast Online Track and Vertex finding
- Tracks are essential in triggers for nearly all physics signatures
- As pileup increases tracking becomes even more important
- **Tracking is the most complex aspect of the trigger and is very computationally intensive**



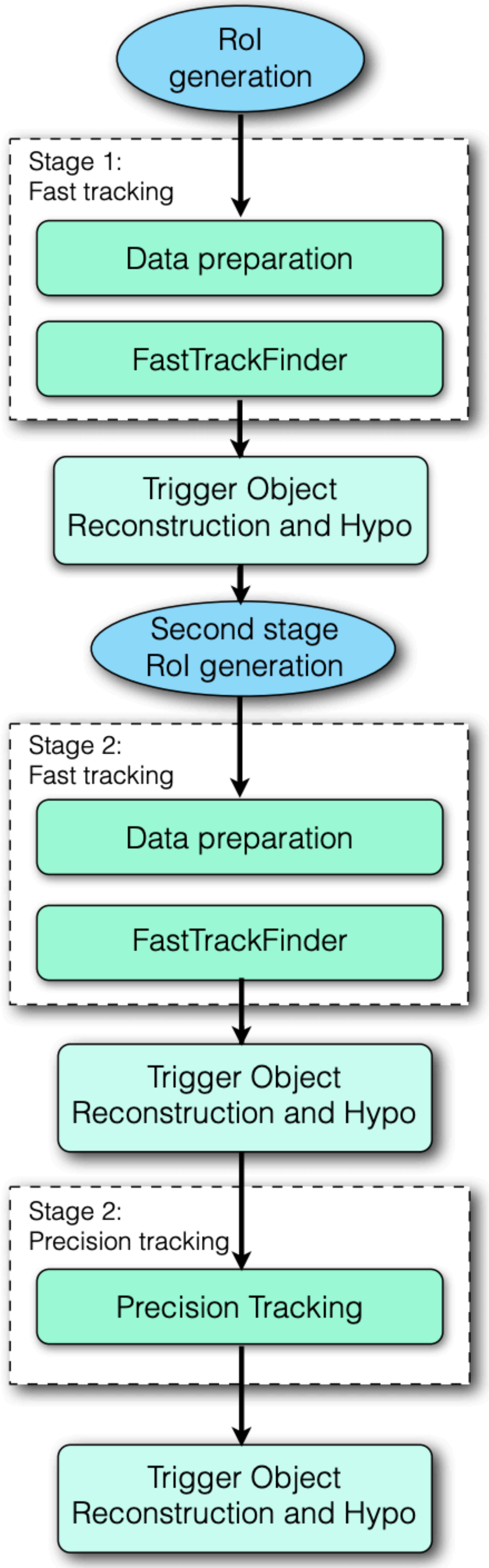


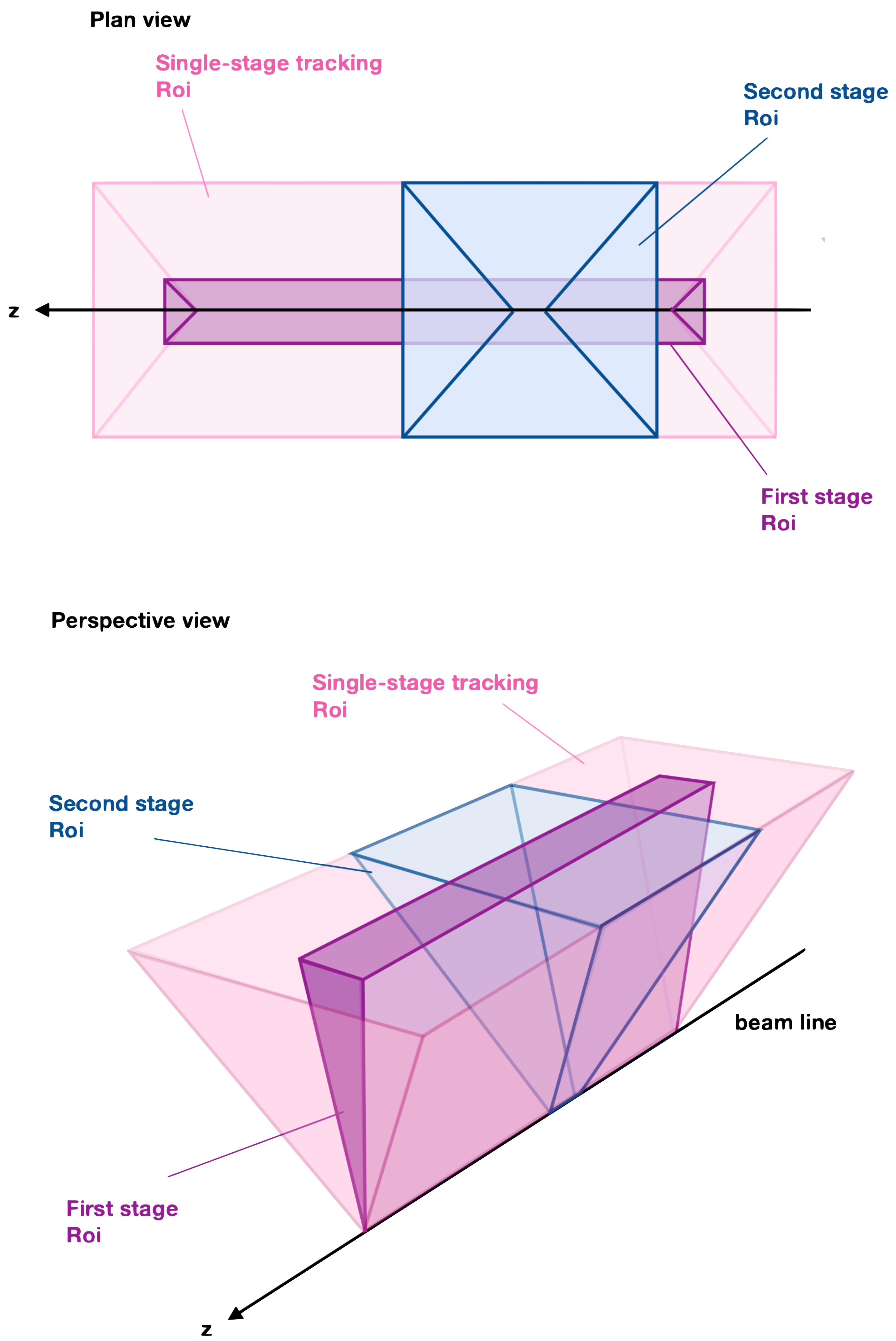
- The HLT needs to reduce peak data rates from ~100 kHz → ~1.5 kHz
  - Pixel and SCT cannot be readout at L1, earliest they can be used is in HLT

- To ensure speed whilst maintaining high performance two main strategies are used
  - <u>Baseline **single stage** strategy</u>
    - Data preparation
      - Detector elements are reconstructed for given spatial RoI
    - Fast tracking
      - **Fast Track Finder (FTF)** algorithm
      - Optimised for track finding efficiency providing initial track fit and track parameters
    - Precision tracking
      - **Precision tracking** algorithm
      - Applies offline track fit using tracks from FTF, extend tracks to the TRT and runs the ambiguity solver algorithm to remove duplicate tracks



- **<u>Multistage</u>** <u>strategy</u>
  - **Stage 1**
    - Performs initial FTF tracking in a **narrow width RoI** but **extended along the entire beamline**
      - Determines tracks or Vertex of interest
  - **Stage 2**
    - Seed second **RoI in a narrow range along the beamline**, but **wider in η and φ**
    - Perform second stage FTF
    - Followed by Precision tracking





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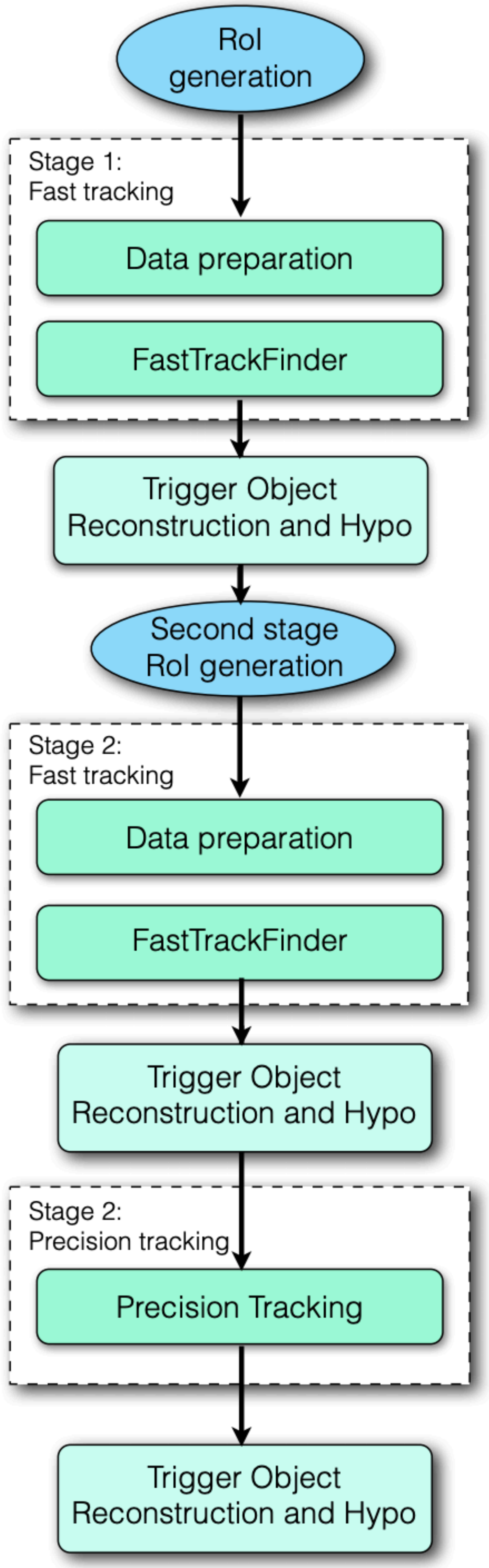
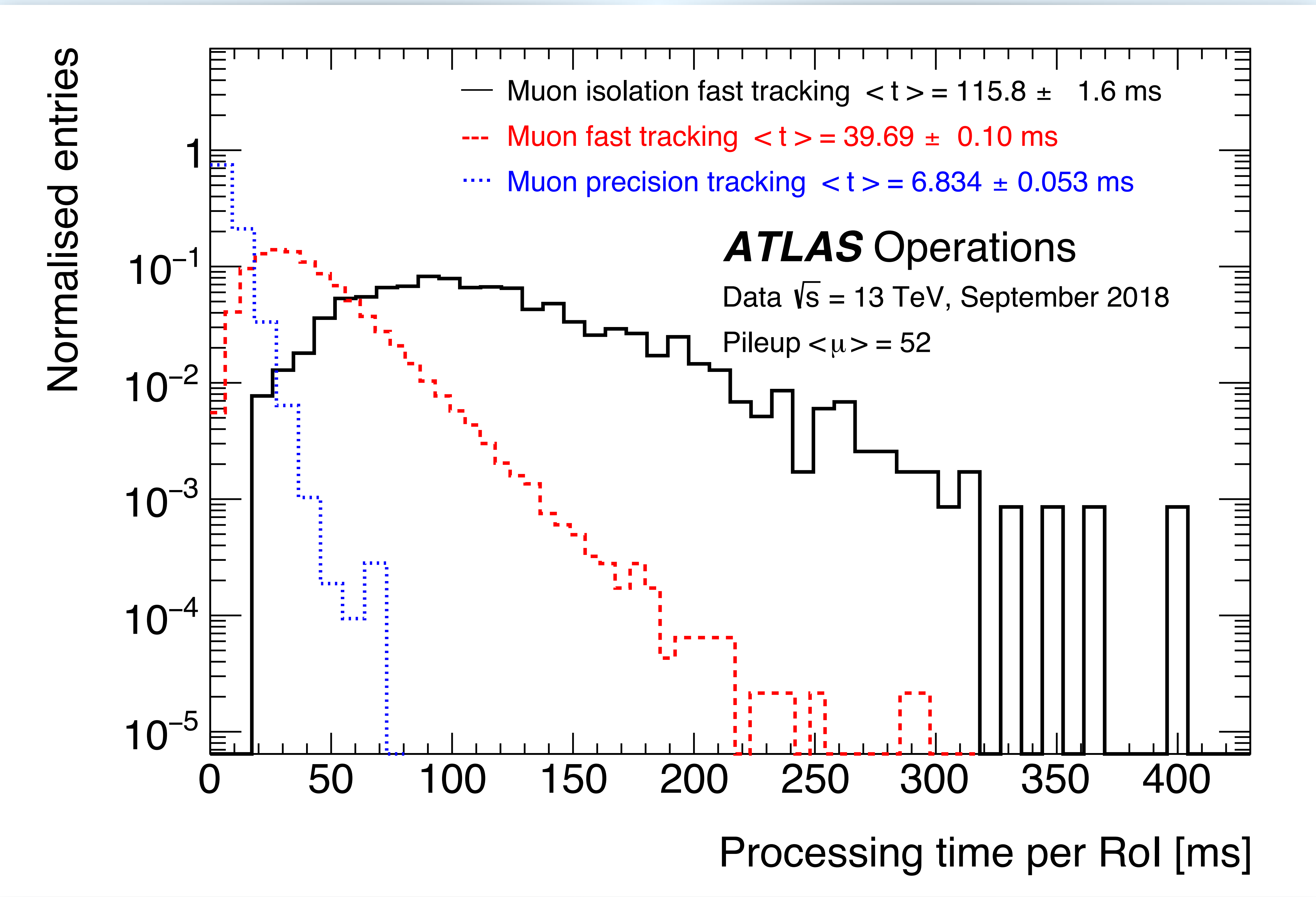


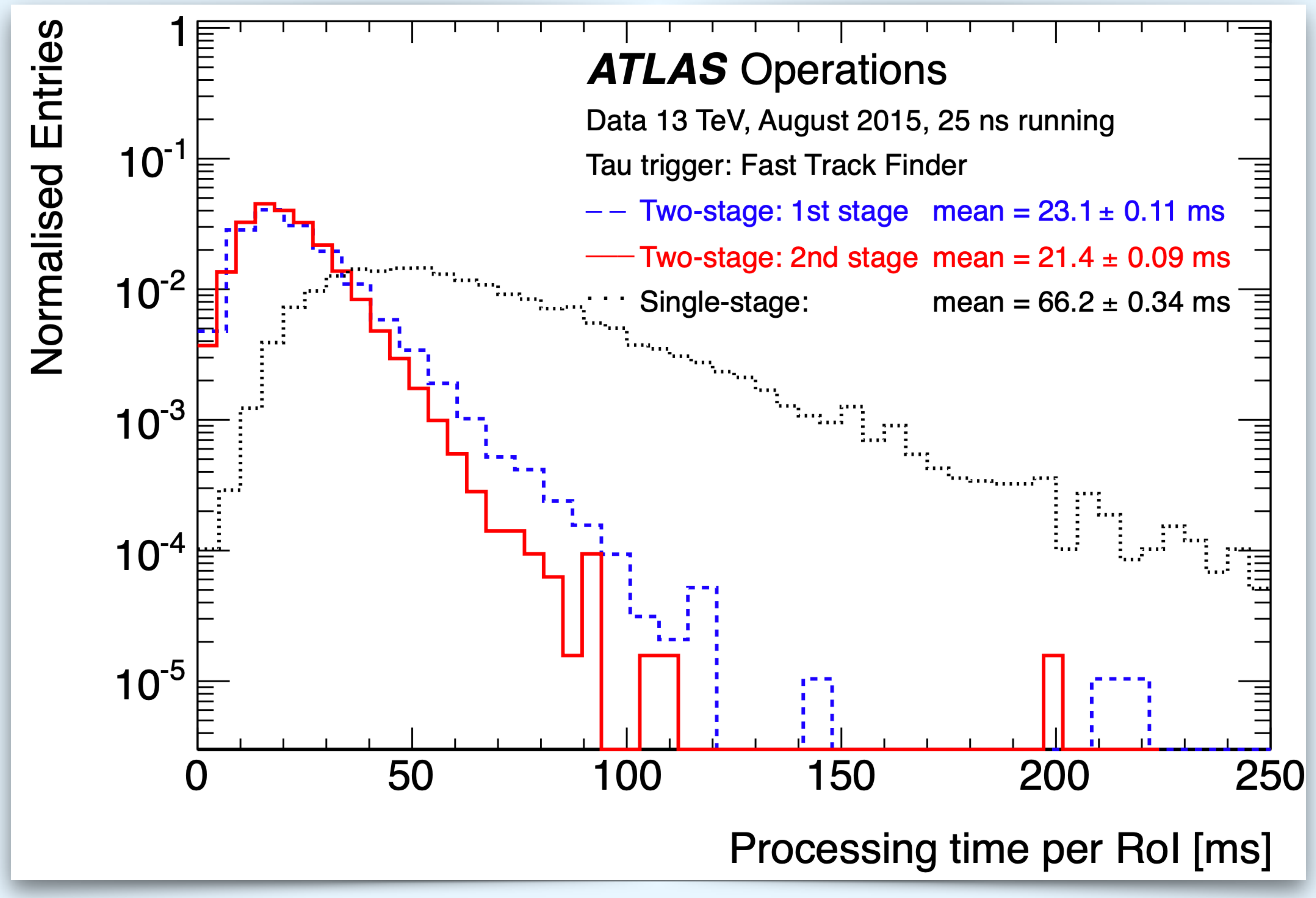
all shown public plots may be found : [HLTTrackingPublicResults]

Muon RoI - Timing performance

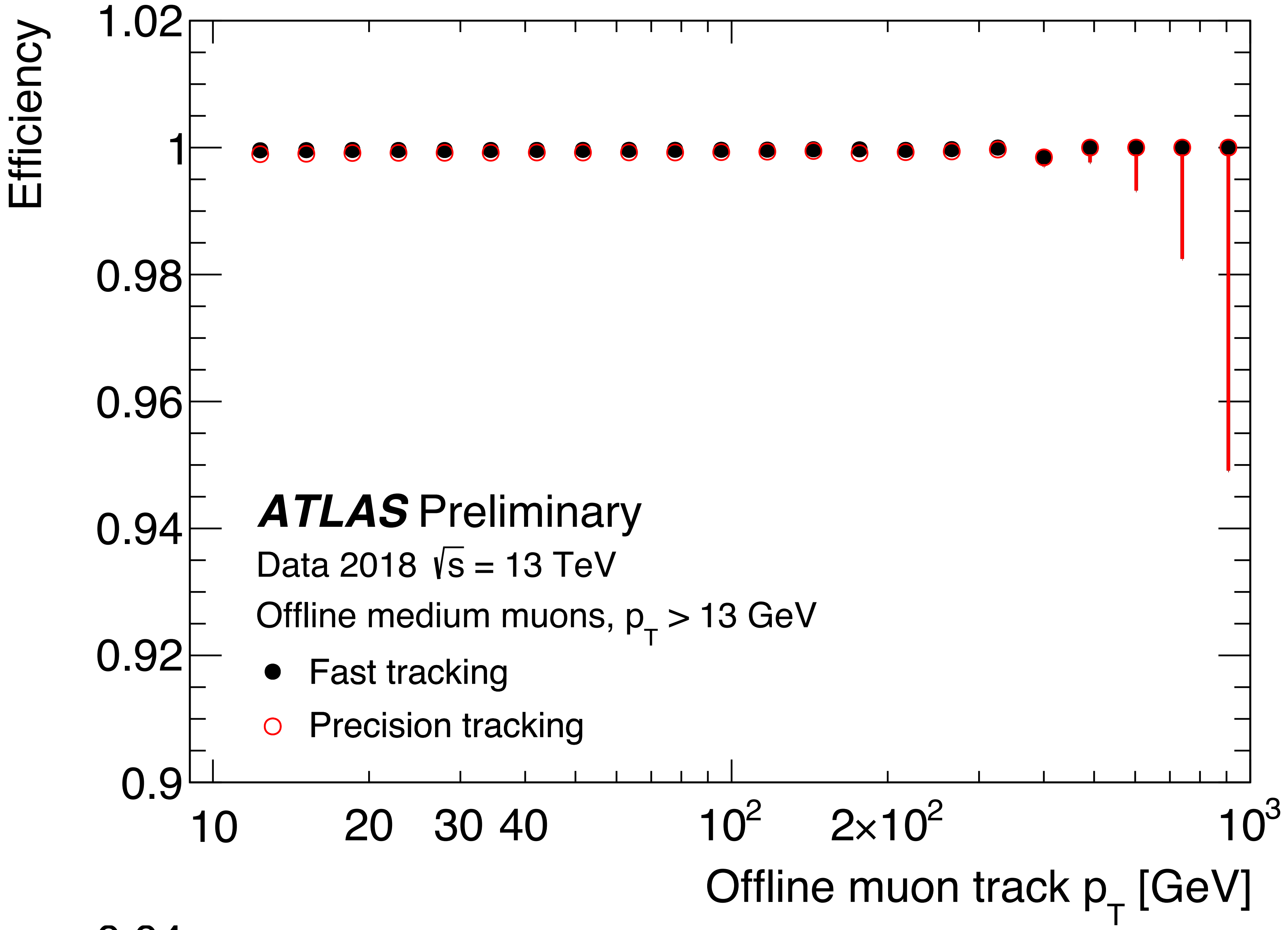


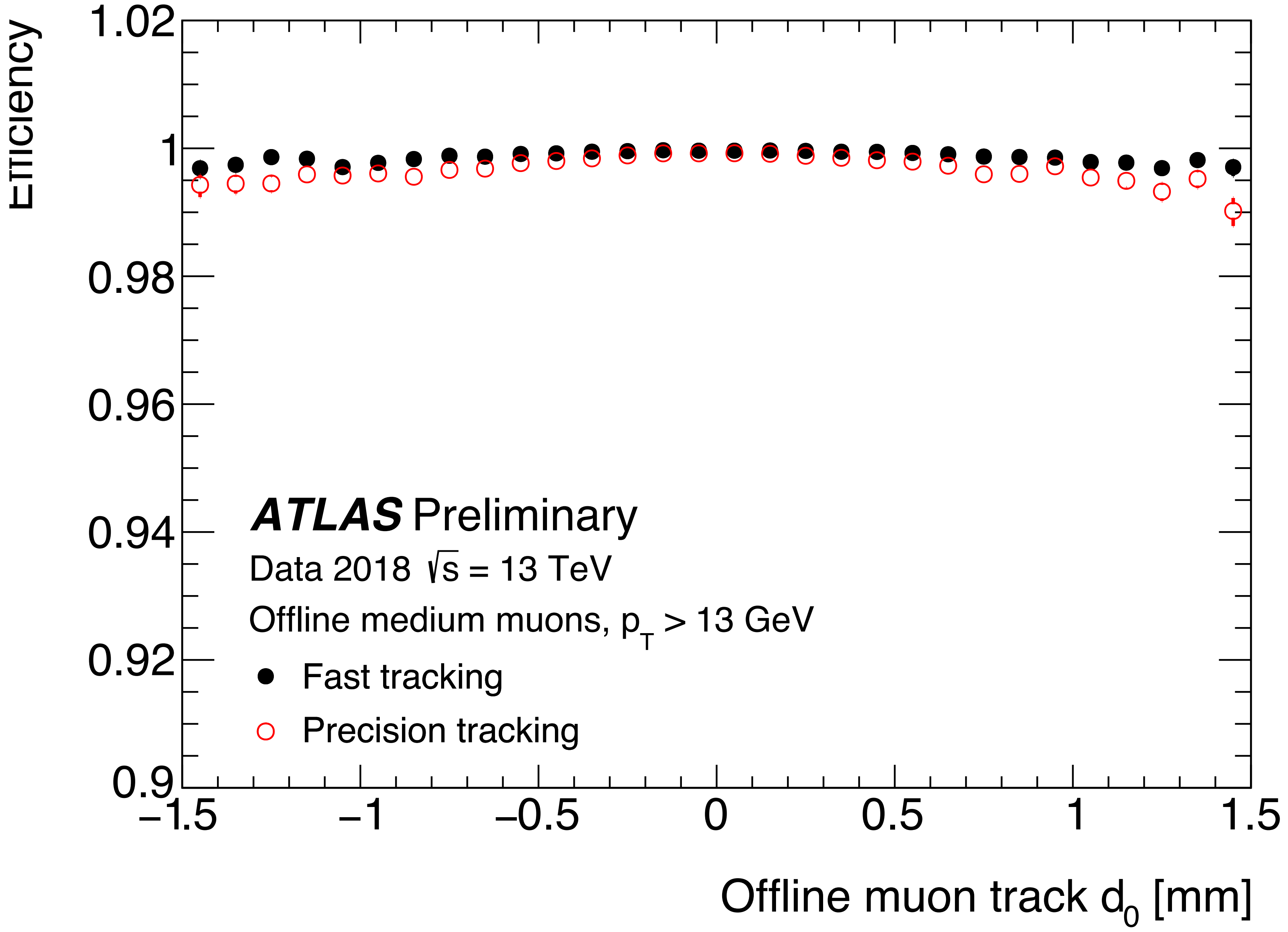
- **Fast Track Finder** runs in ~40 ms per RoI
- **Precision tracking** only runs in ~7 ms per RoI
- Isolation tracking is run in a wider RoI, after selection of full muon candidates, to establish muon isolation
  - Runs in ~116 ms per RoI

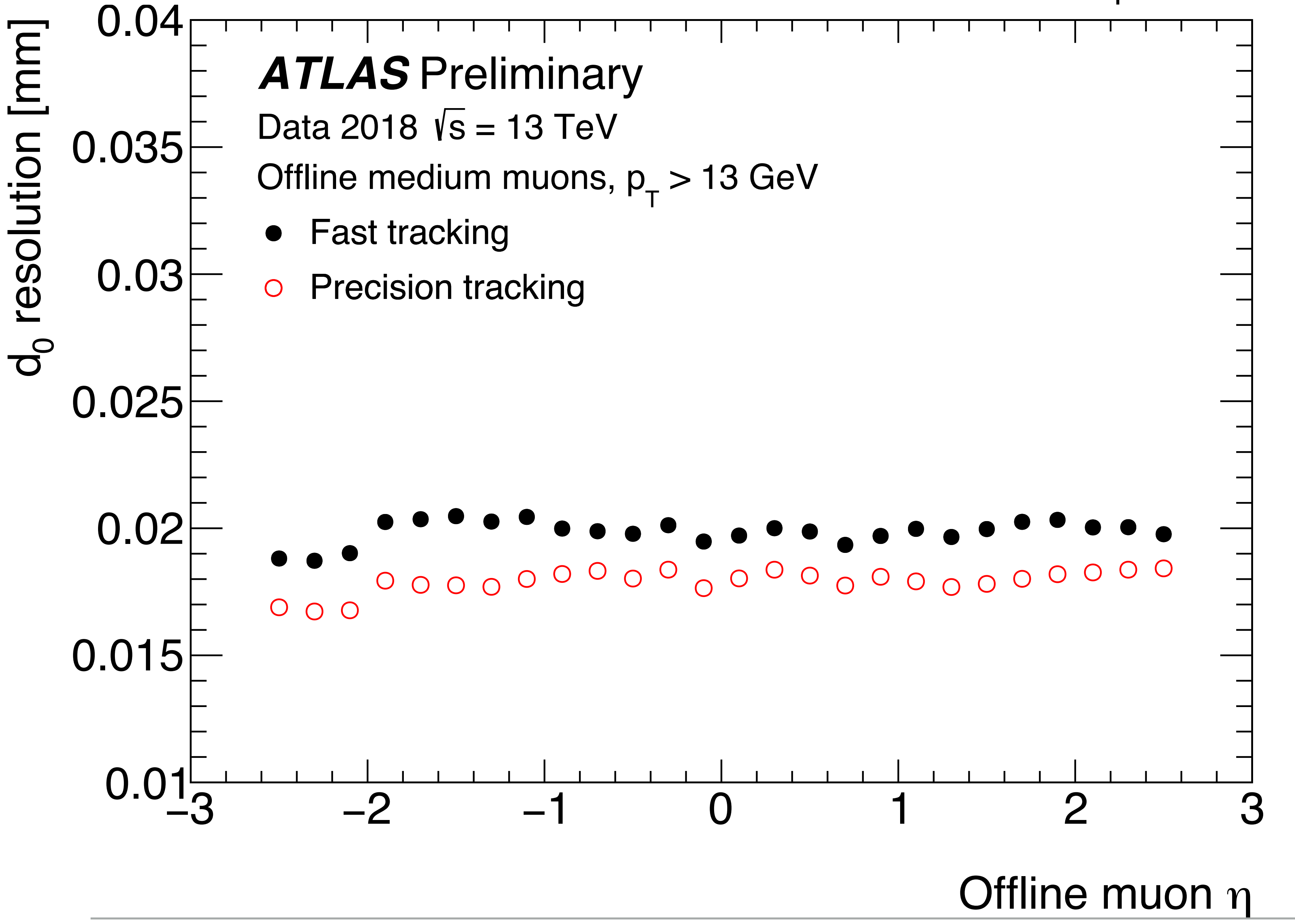
Tau RoI - Timing performance



- **Multistage tracking** reduces FTF computation time ~66ms→~46ms (combining 1st and 2nd stage)
  - Although part of detector about tau track is processed twice, **overall volume is lower** than if done by single stage

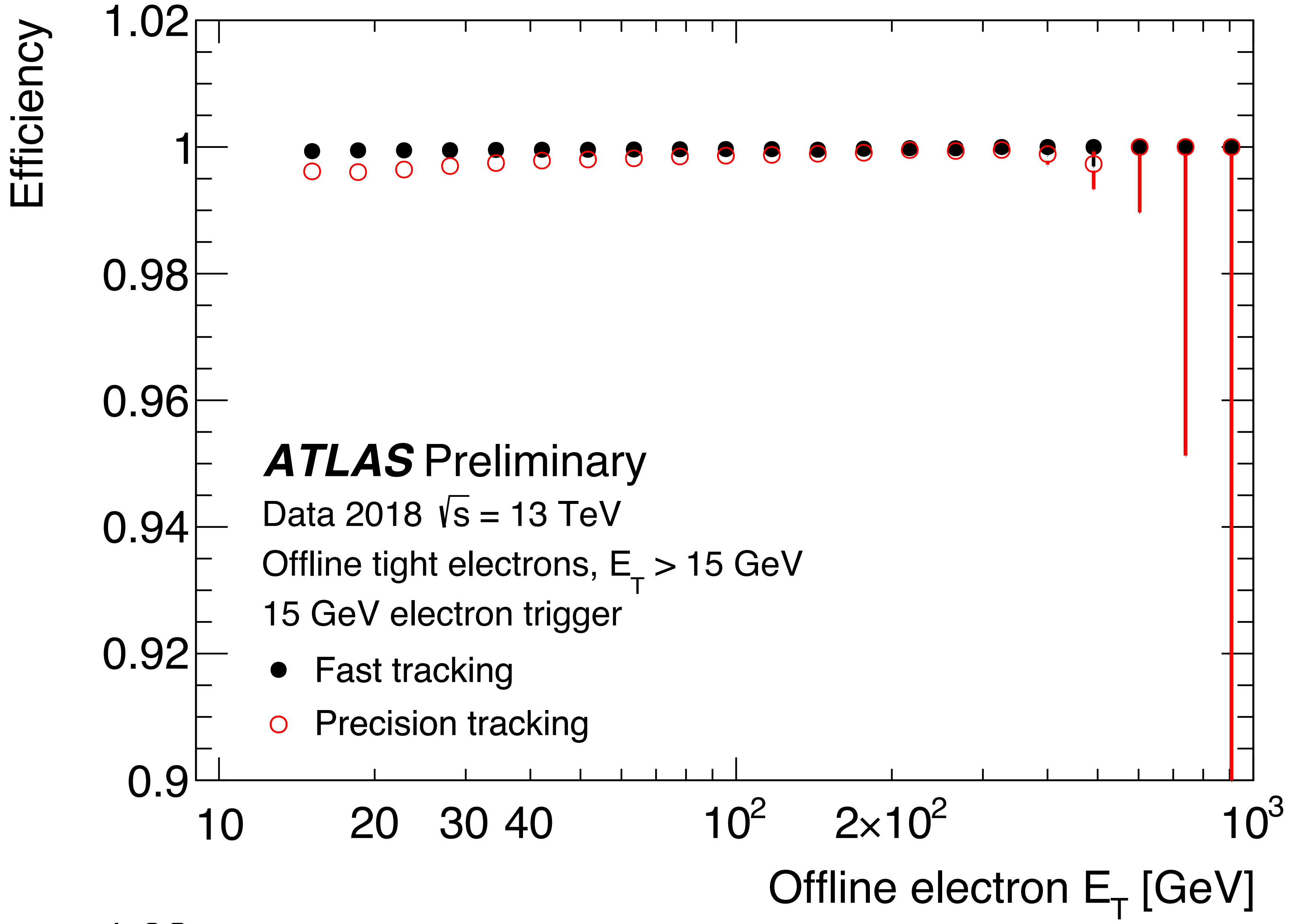


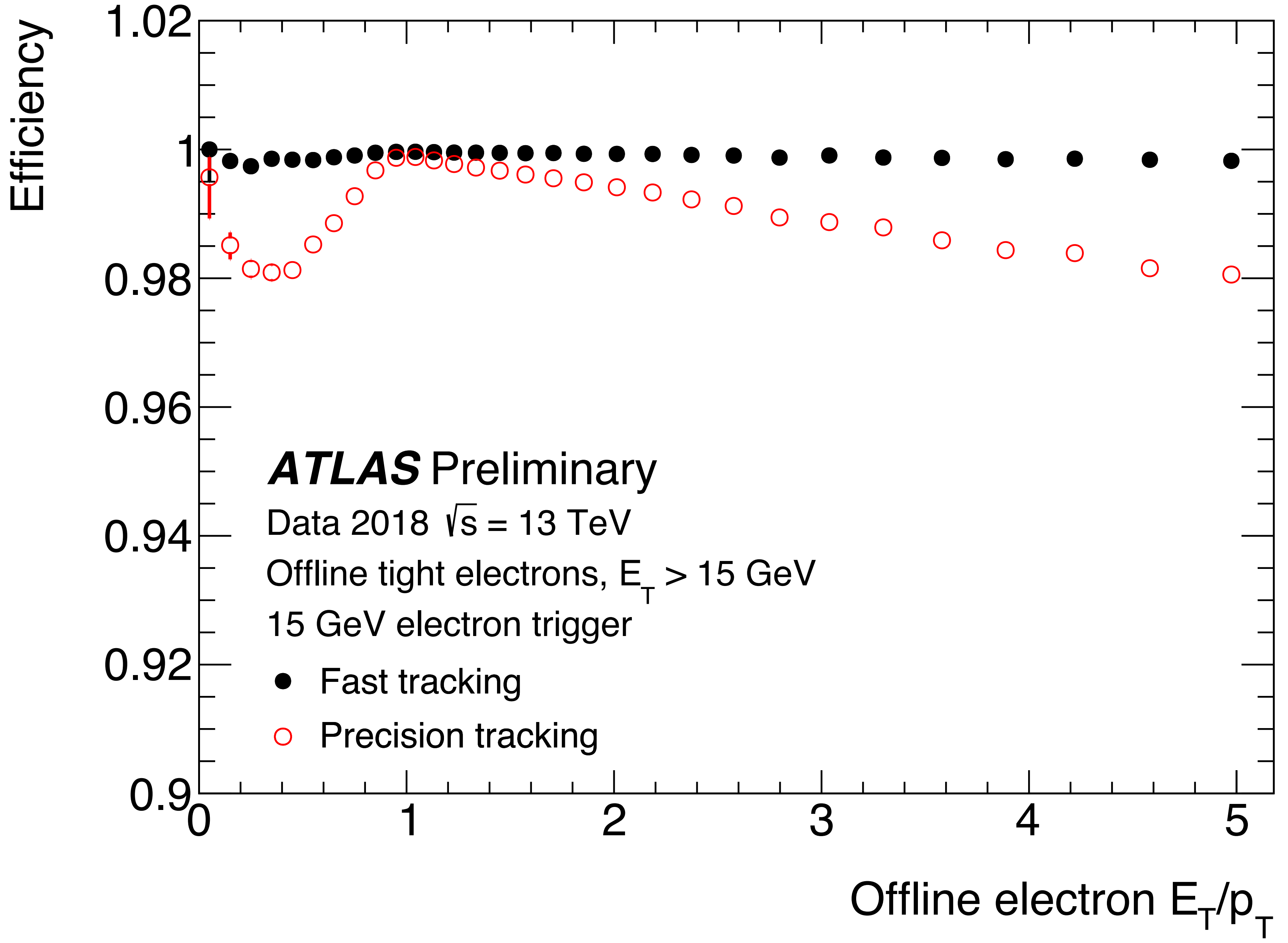


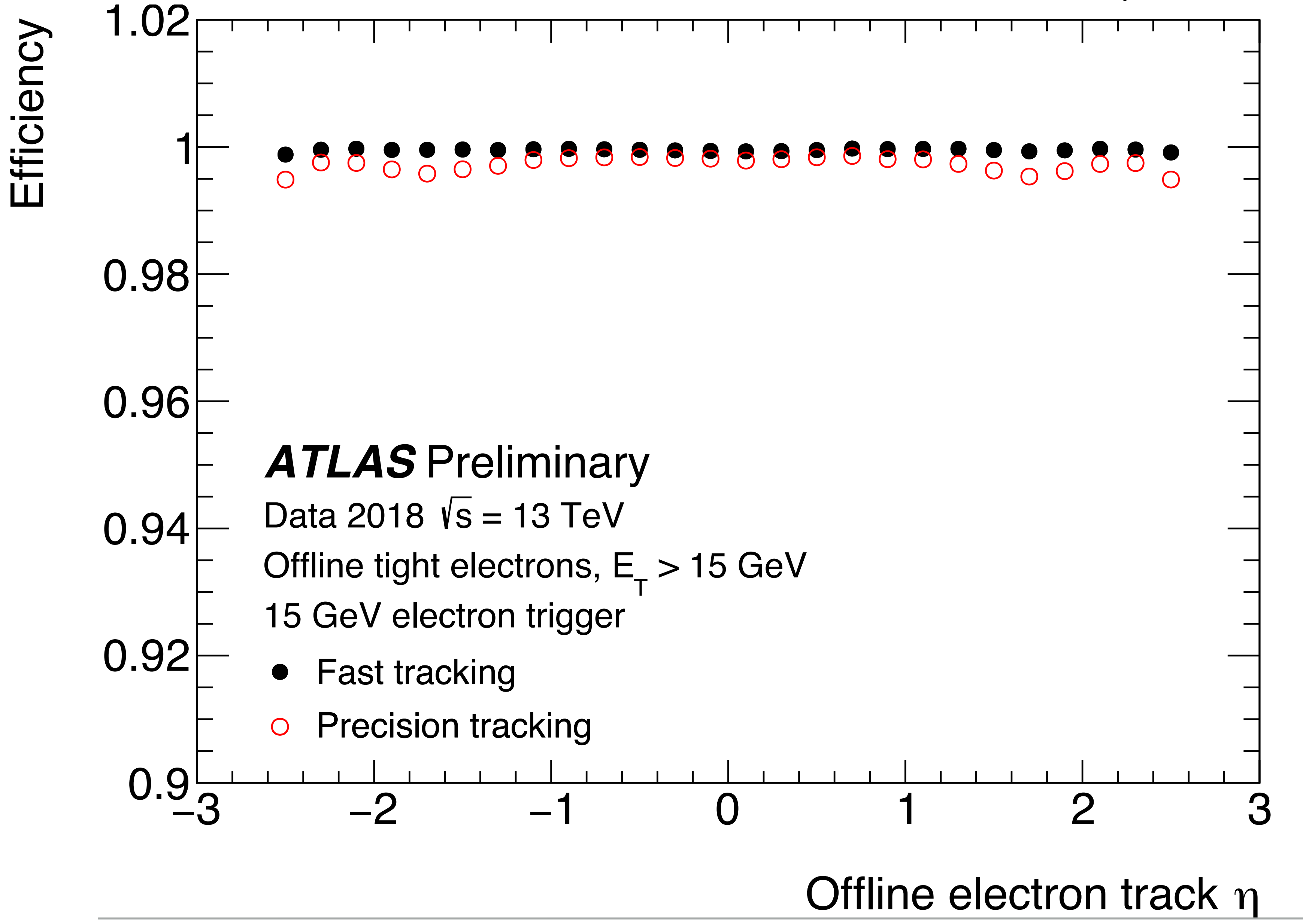


- **High efficiency seen up to ~1 TeV**
- **Above 99% efficiency** even at large transverse impact parameter values (d_0)
- Resolution better than ~20 μm for full range of pseudorapidity (η) values

- Tracking efficiency and resolutions are measured by comparing tracks found by **online trigger algorithms** to tracks found by **full offline track reconstruction**
- A **Tag and Probe** analysis is used to select muon candidates coming from the decay of Z boson
  - Tag muon – fully selected in Muon Spectrometer and Inner Detector
  - Probe muon – selected based on Muon spectrometer reconstruction without use of ID trigger tracks
    - Unbiased by ID trigger reconstruction





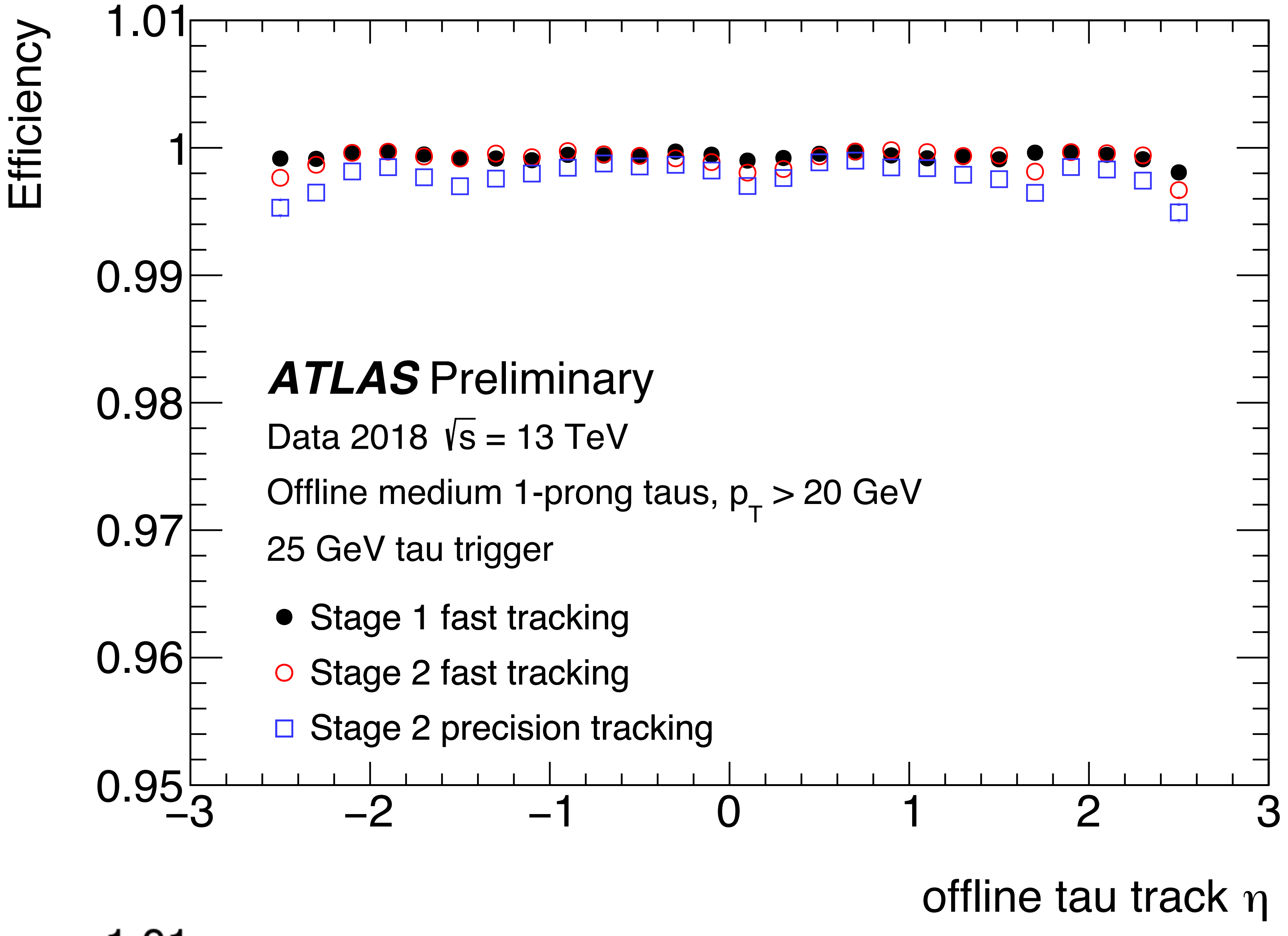


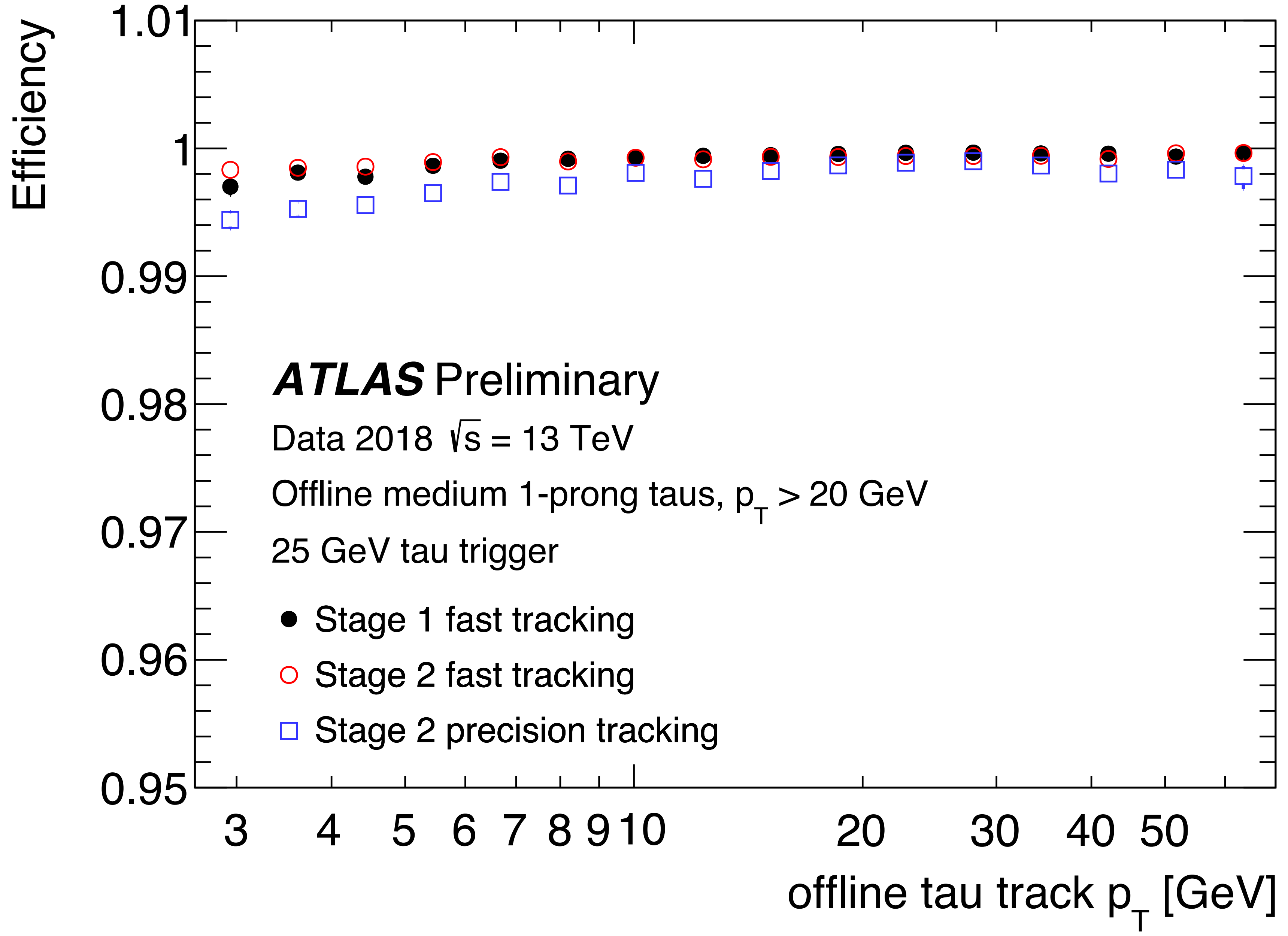
- Selection for **electron tag and probe** consistent with Z mass
  - Greatly **reduces background** for fake electron candidates
- Efficiencies very high for all pT spectrum
  - Electrons E_T > 15 GeV that have radiated up to 80% of their energy as photons **still better than 98%**

- **$E_T/p_T > 1$**
  - Bremsstrahlung electrons
- **$E_T/p_T < 1$**
  - electrons with less well reconstructed track p_T
    - p_T greater than deposited energy

Shorthand notation:

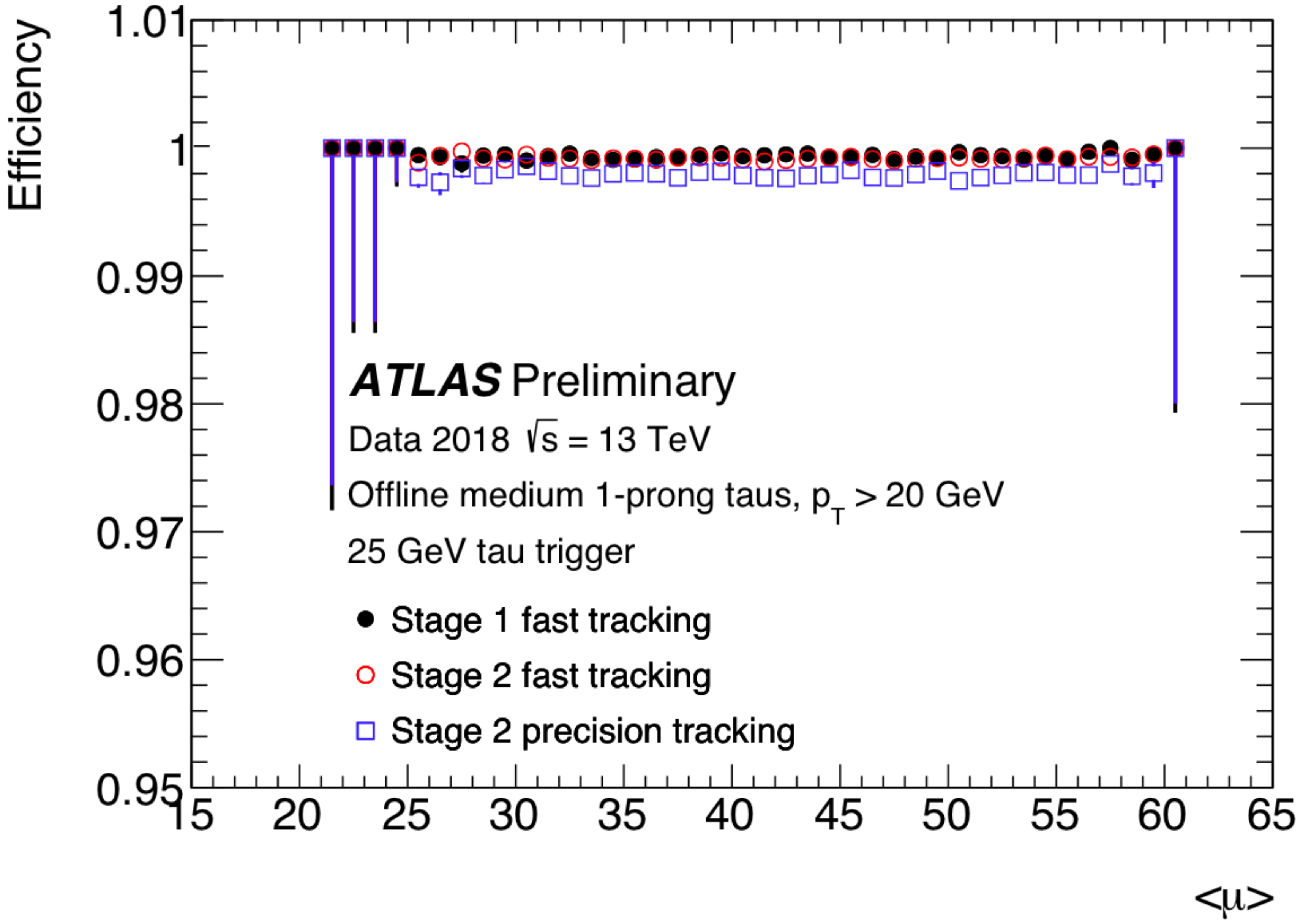
- Transverse energy of calorimeter cluster : E_T
- Transverse momentum of track in ID : p_T



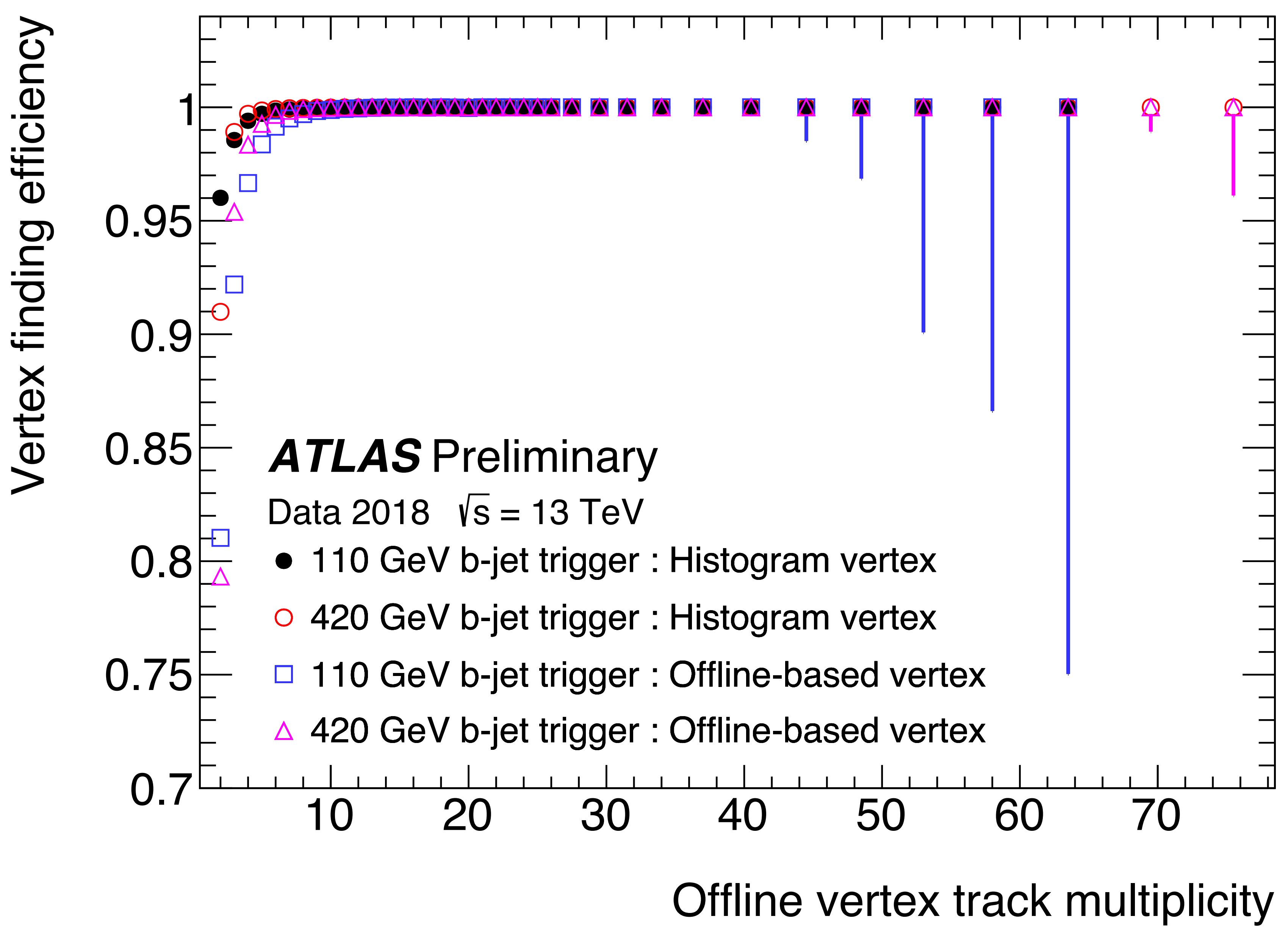


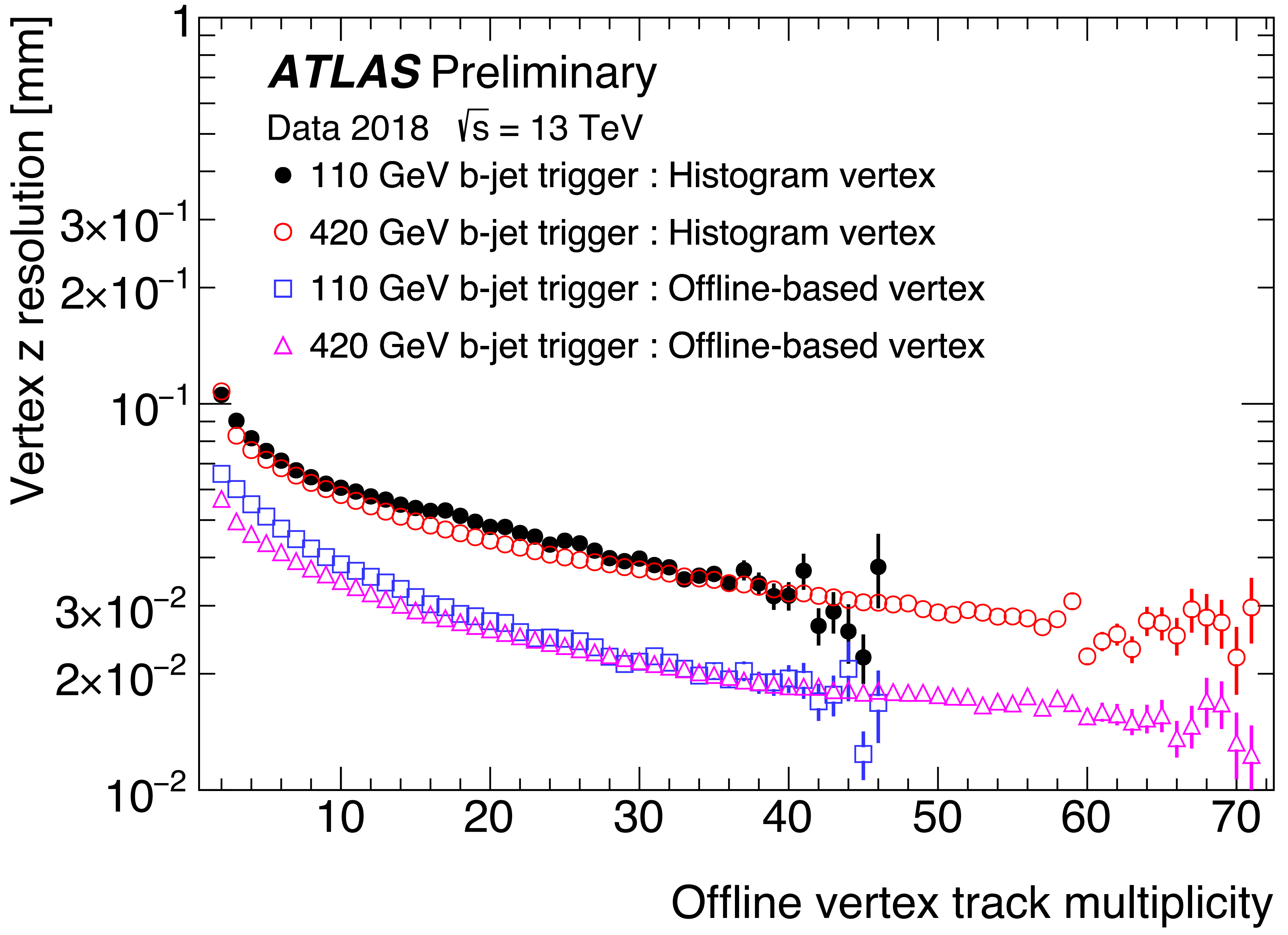
- **High** efficiency for 25 GeV offline taus candidates much better than ~99% across all pseudorapidity values (η) and for full p_T range

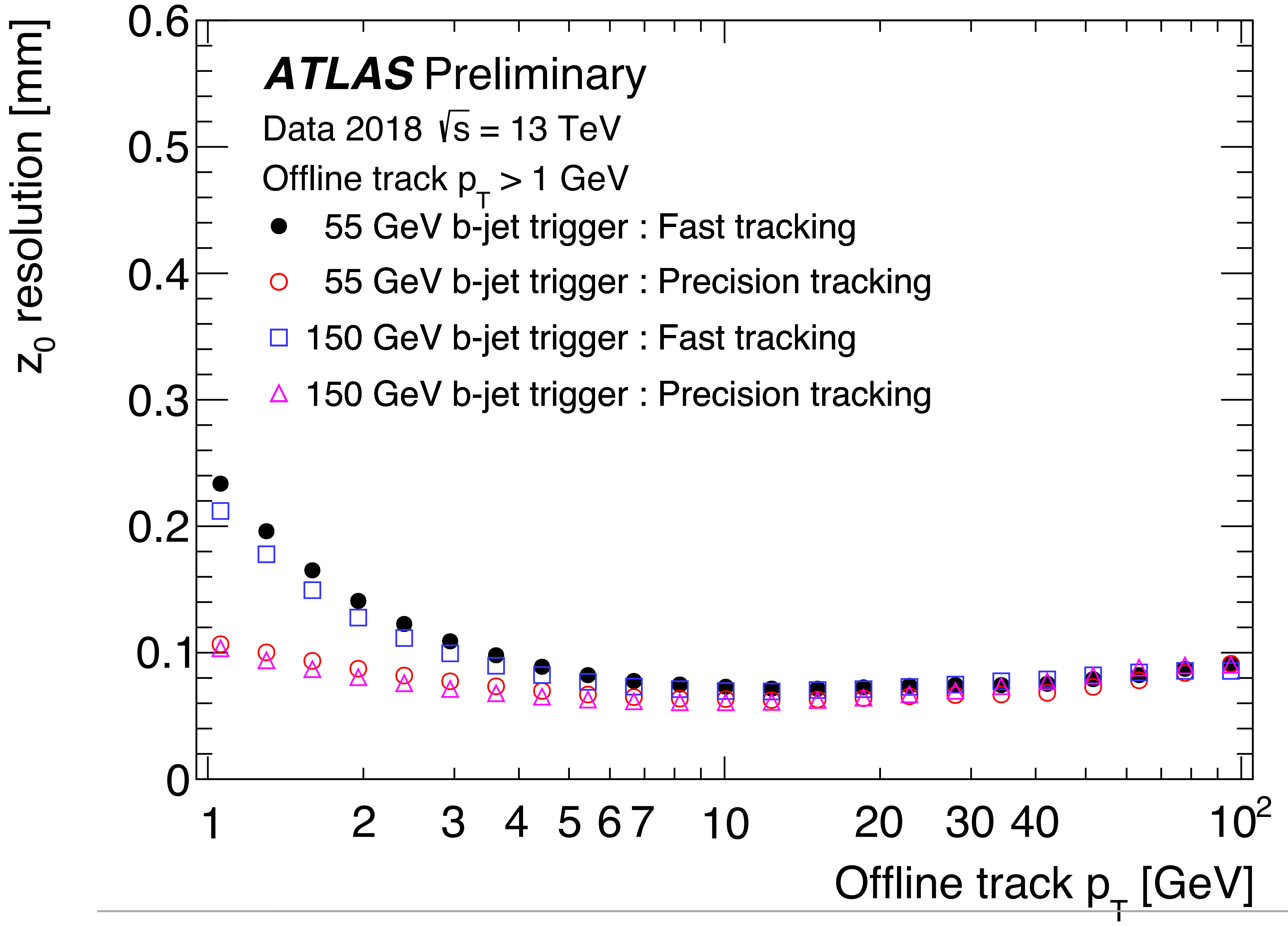
- Second stage fast tracking resolution better than first stage at lower p_T
  - Low momentum tracks bend out of narrower first-stage-RoI in the magnetic field and are not fully reconstructed



- Efficiency is approximately **constant at high pileup** interaction multiplicities





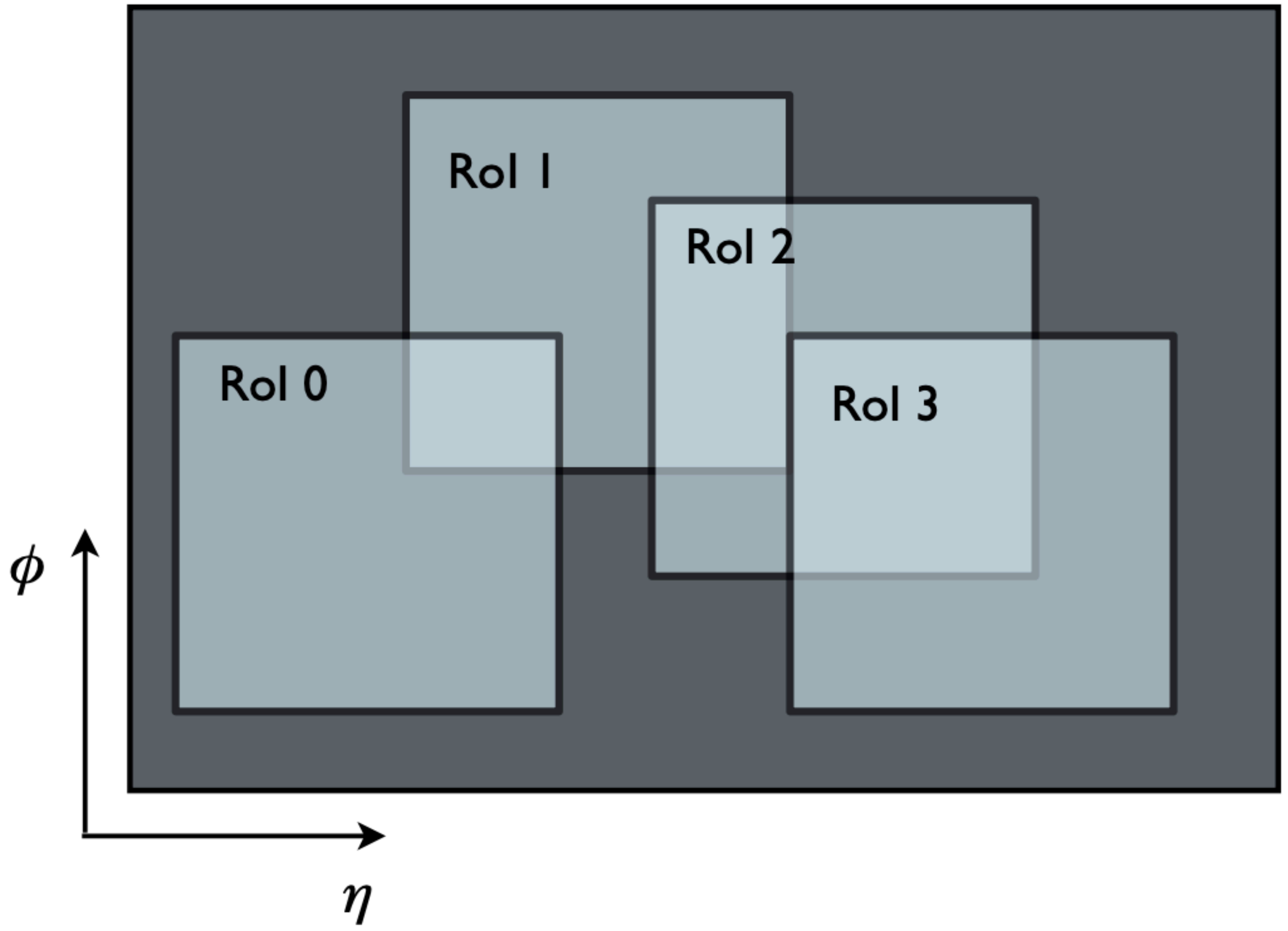


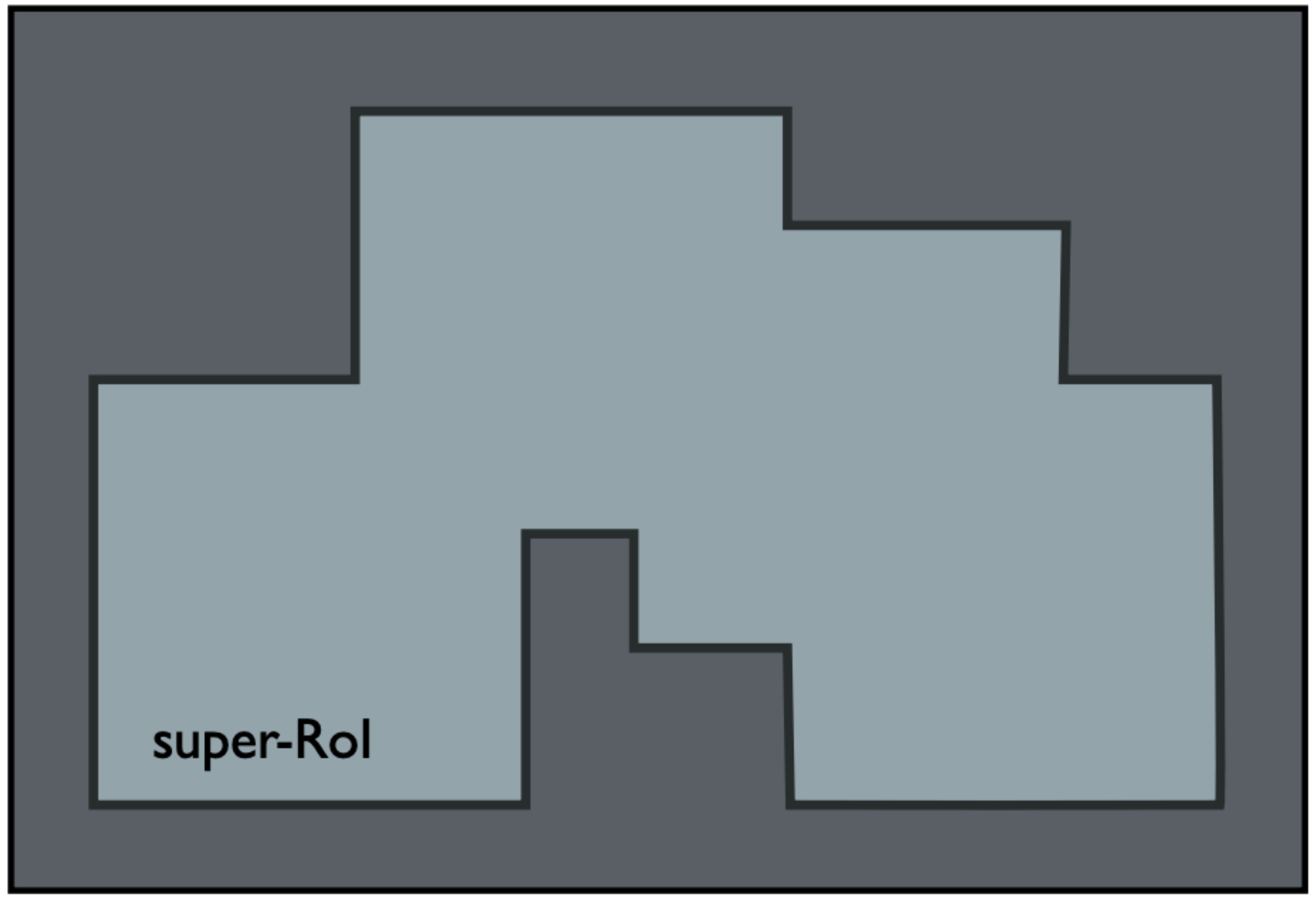
- For bjets the vertex reconstruction runs two algorithms
  - **Simple histogramming** algorithm
  - **Offline-based vertex** algorithm
- Histogramming algorithm has higher efficiency for low track multiplicities
  - "softer" requirements of track quality allow for reconstruction of vertices with lower track multiplicity
- Offline-based algorithm has better resolution
  - As good as 20 μm for longitudinal impact parameter (z_0) with increasing vertex track multiplicity

- Very good resolutions for bjet tracking for longitudinal impact parameter (z_0)
  - Better than ~12 μm for full p_T spectrum for Precision tracking
  - Slightly lower for the fast tracking, as expected

- The ID trigger is **fundamental to achieving the required performance of the ATLAS trigger** system
- Performance in terms of efficiency, resolutions and processing time for the most important tracking related signatures for the high luminosity Run 2 have been presented
  - **Excellent tracking performance** is observed even at high pileup multiplicities
    - Tracking **efficiency largely independent of pileup** interaction multiplicity
- **ID trigger continues to provide excellent performance in Run 2,** outperforming the already excellent performance in Run 1, thus allowing the continuation of the ATLAS physics program
- To handle the expected conditions of LHC Run 3, there are ongoing changes to the ATLAS software infrastructure, to make use of new developments and allow increased used of multi-threading
  - ID trigger is **undergoing an extensive reimplementation** of many aspects of the processing

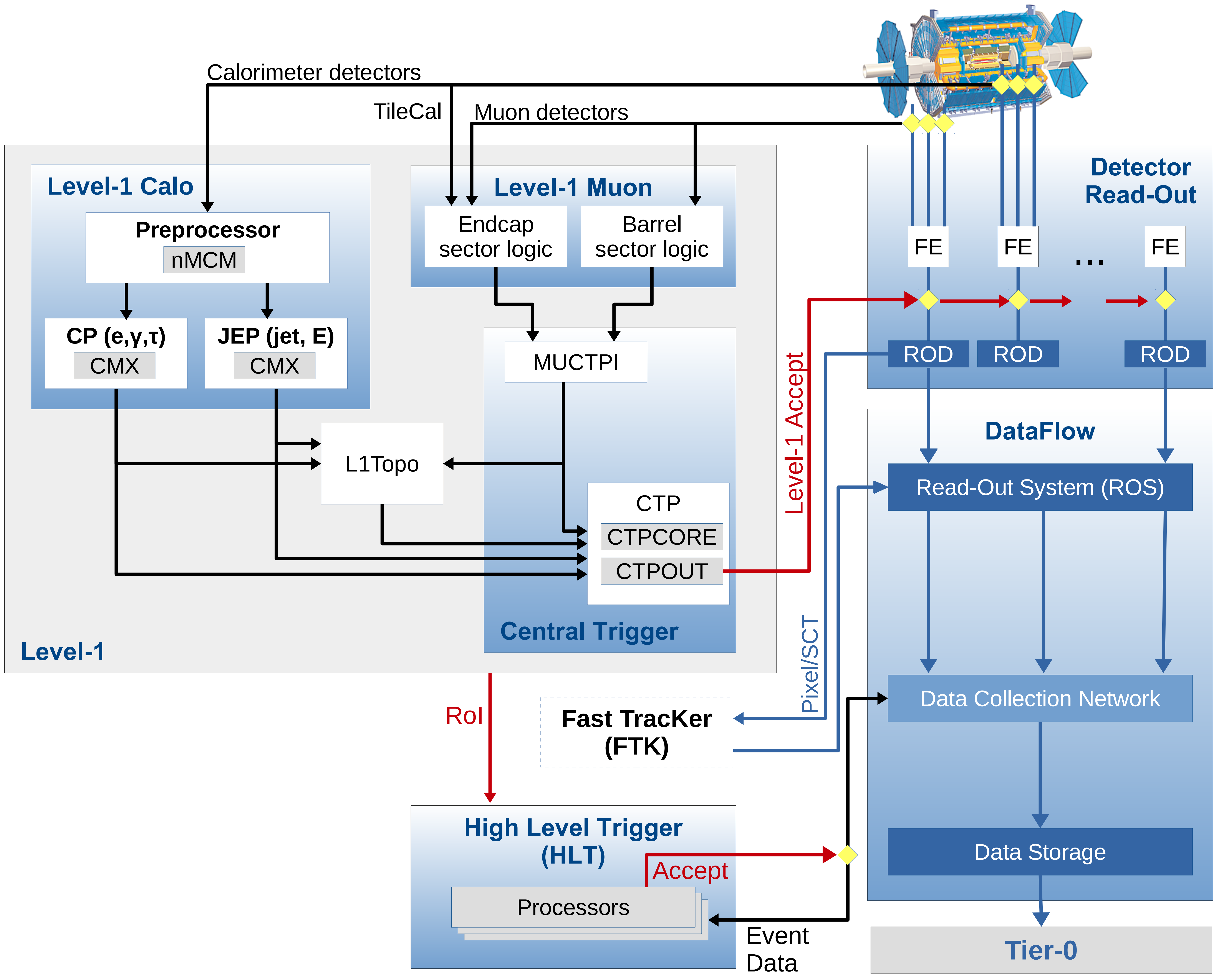
BACKUP



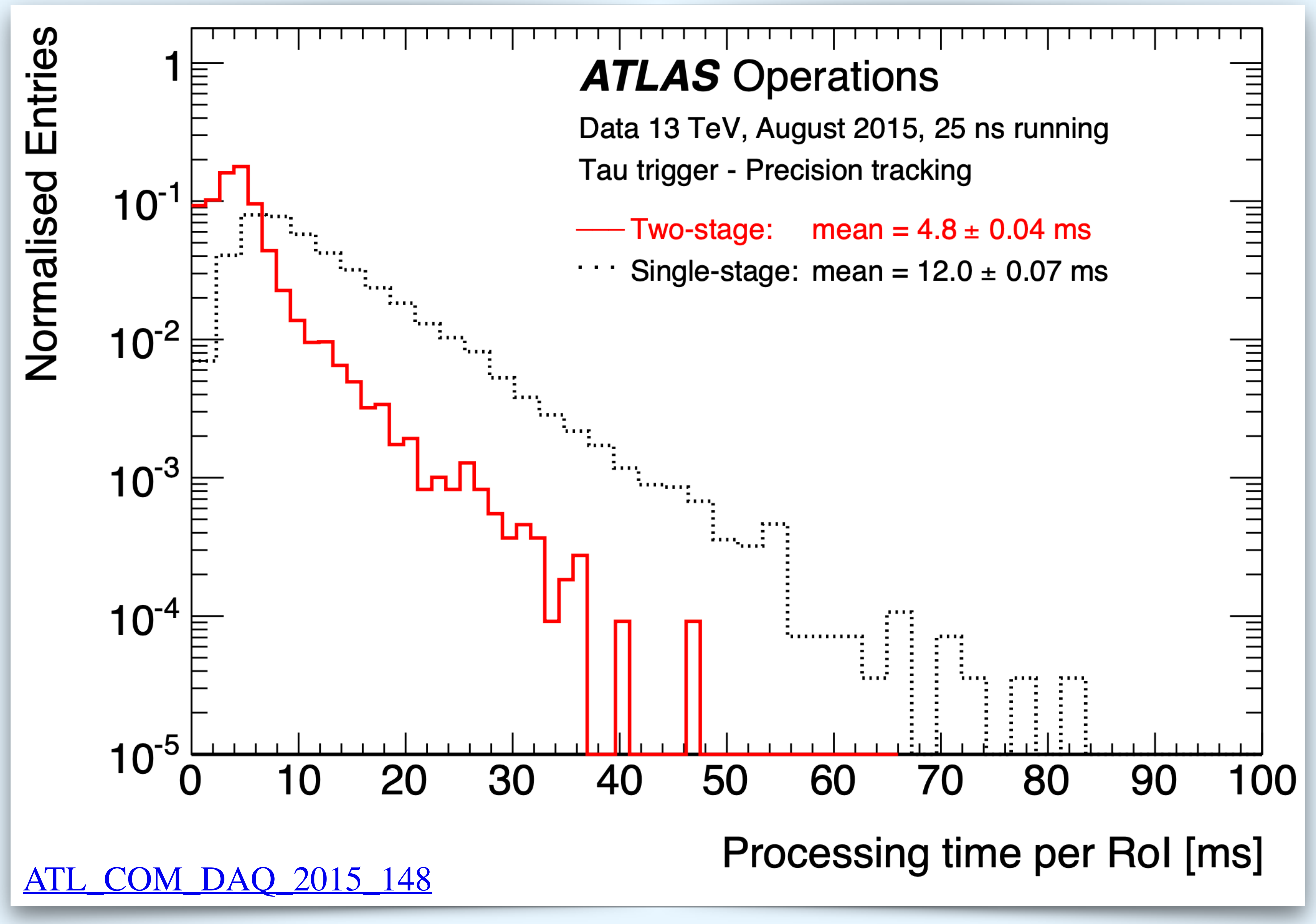


- Employed in **b-jet jet triggers** in the multistage tracking process
  - Performs FTF tracking to reconstruct tracks in narrow regions of η and φ around the jet axis, for each jet
  - To prevent multiple processing of overlapping regions the **RoIs are aggregated into a SuperRoI**
  - The tracks found in this **SuperRoI are used then used for the primary vertex reconstruction** to define a wider RoI around the jet axes
  - These wider **SuperRoIs are then used for the second-stage reconstruction** which runs FTF, precision tracking, secondary vertexing and b-tagging algorithm

- **L1**
  - Reduces rate to 100 kHz
  - <2.5 μs
  - Hardware based
- **HLT**
  - Reduces rate to ~1.5 kHz
  - Between ~200ms and ~500ms
    - depending on pileup conditions
  - Software based
  - Previous two software stages of Run 1 were merged into a single HLT stage for Run 2

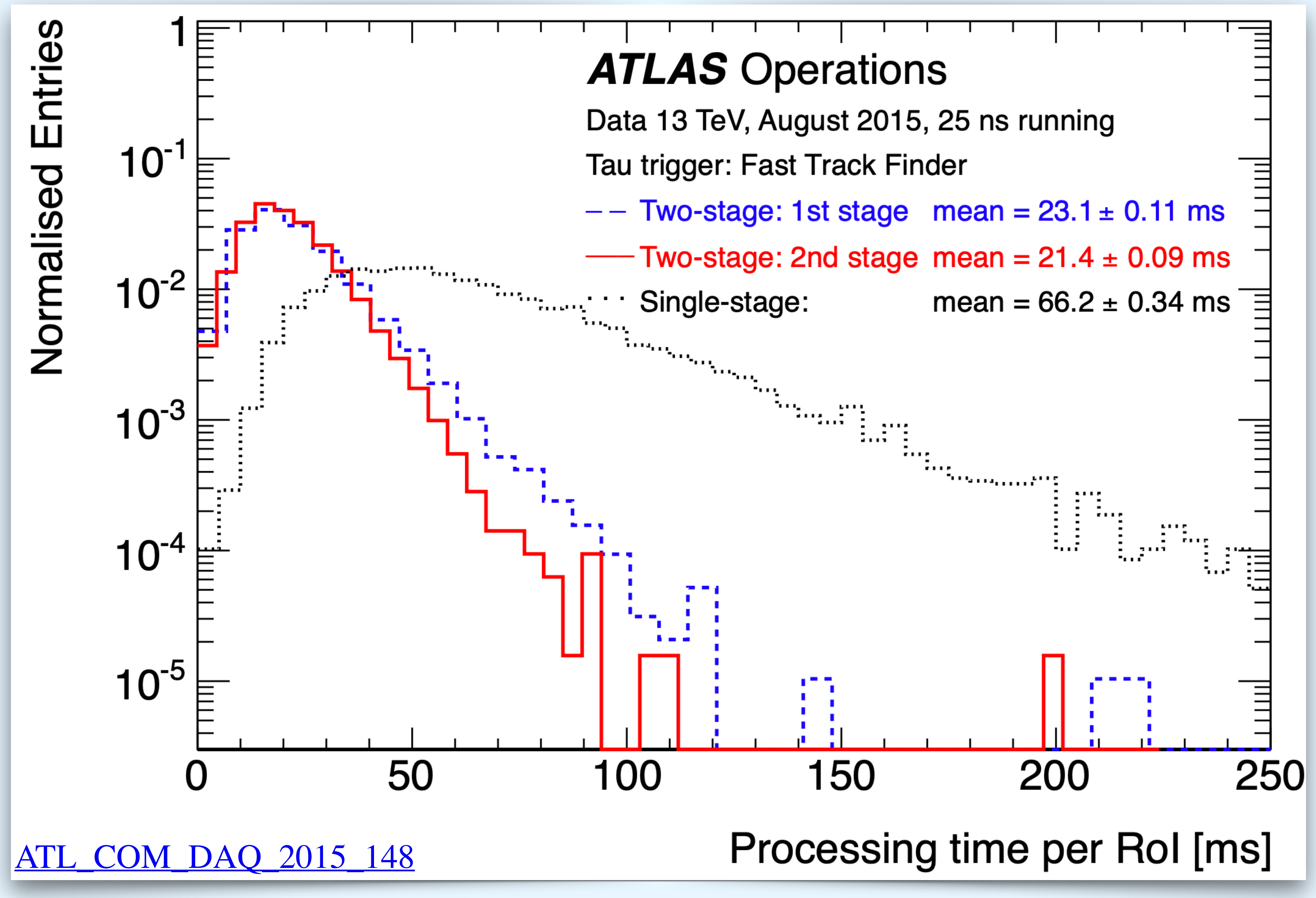


Tau RoI - Precision tracking timing performance



- **Multistage tracking** reduces average computation time ~12 ms → ~5 ms

Tau RoI - Fast Track Finder timing performance



- **Multistage tracking** reduces average computation time ~66 ms → ~45 ms

- **Tau trigger** average timing reduced by ~30% by implementing multistage tracking