The design and performance of the ATLAS Inner Detector trigger in high pileup collisions at 13 TeV at the Large Hadron Collider

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ATLAS EXPERIMENT

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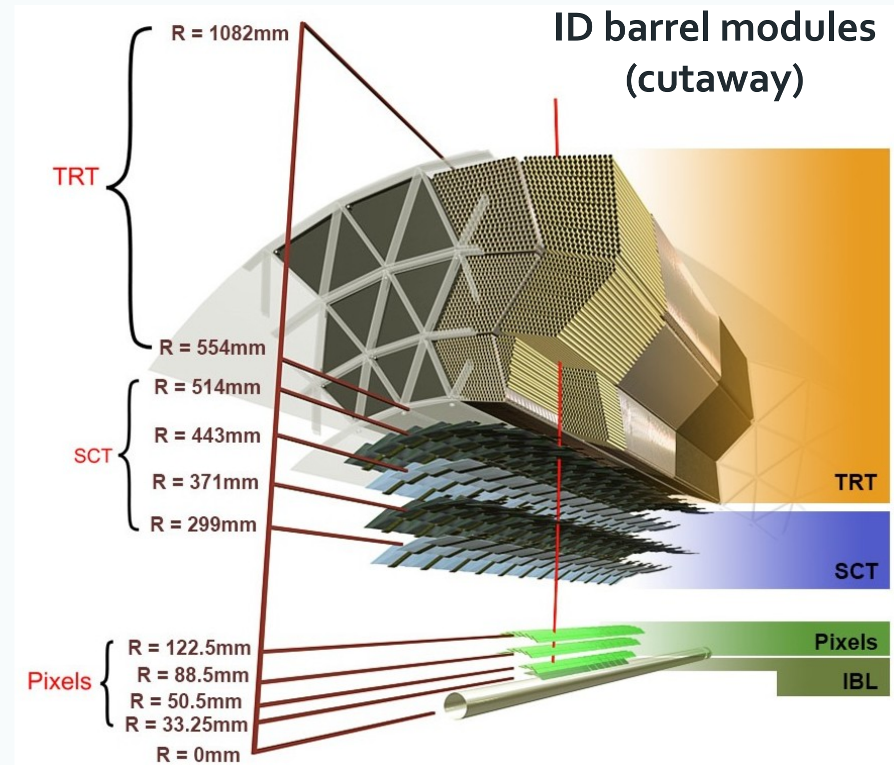
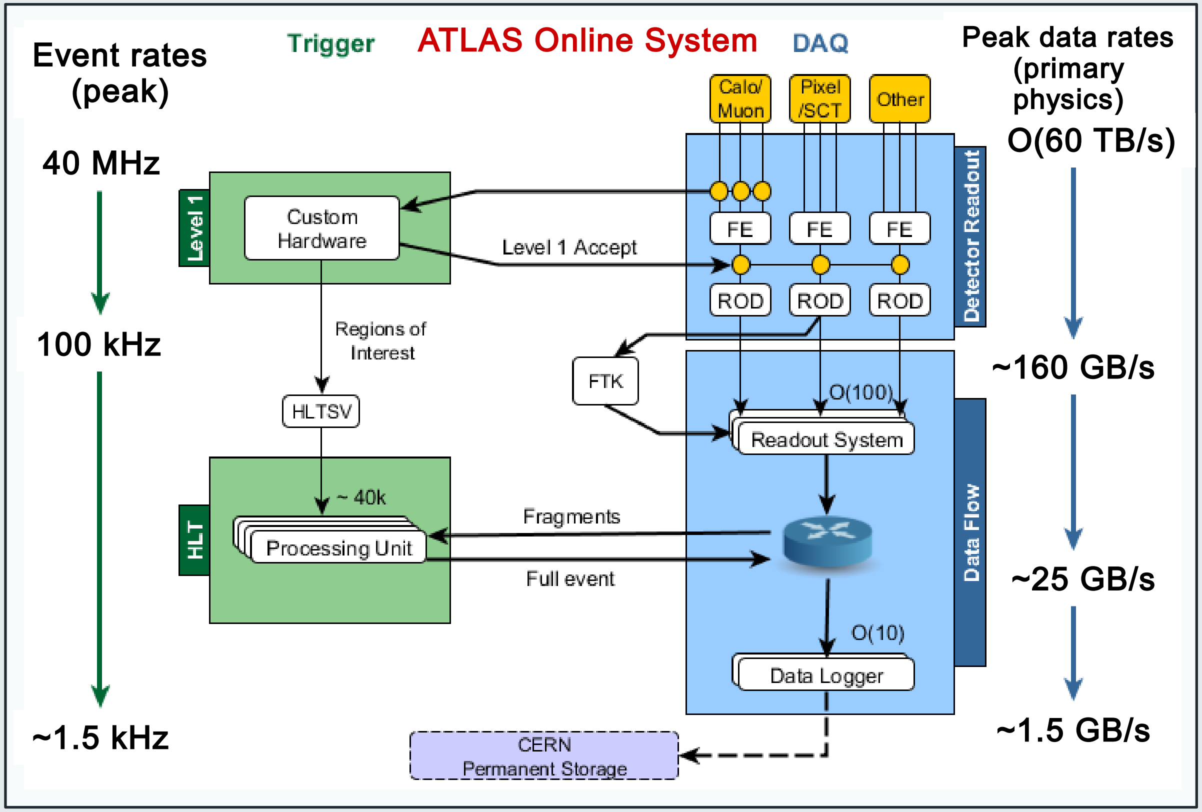
The ATLAS Inner Detector (ID):

- The **Inner Detector (ID)** is the ATLAS sub-detector dedicated to **track and vertex reconstruction**
- **3 sub-systems**, arranged in **barrel** and **endcap** configurations
  - Pixel detectors
    - **3 layers** of barrel and endcap **silicon pixel modules**
    - **+ 1 barrel layer** added for LHC **Run 2**, the Insertable B Layer (IBL)
  - Semiconducting Tracker (SCT)
    - **4 barrel + 9 endcap layers** of **stereo-doublet silicon microstrip modules**
  - Transition Radiation Tracker (TRT)
    - Barrel and endcap modules of **gaseous straw tubes**, on average **36 hits per track**



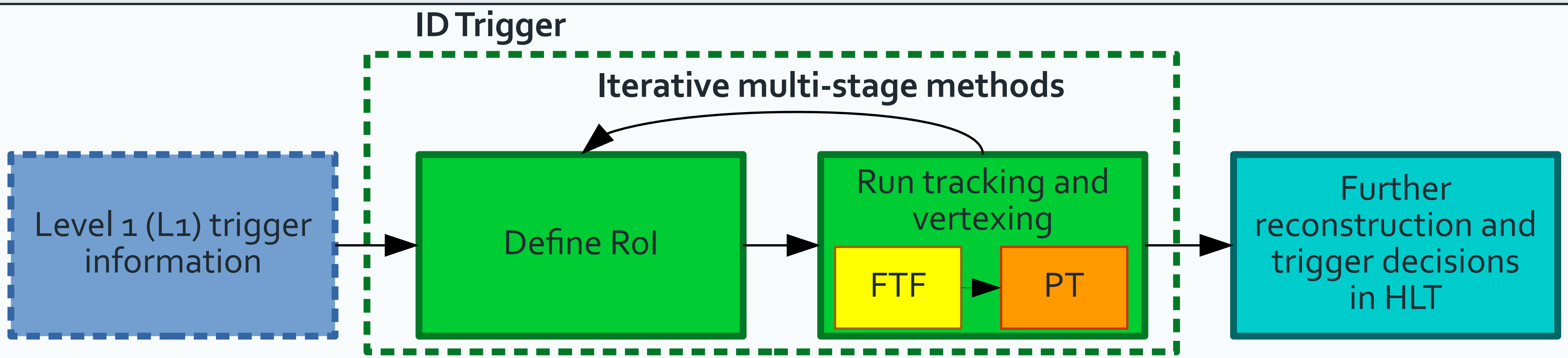
The ID Trigger system:

- The ID Trigger is the part of the **ATLAS High Level Trigger (HLT)** system which performs fast Online **track and vertex finding**
- **Tracking is essential** in triggers for nearly all physics signatures
  - Allows physics-object reconstruction with sufficient resolution to be **selected Online with controllable rates**
  - This becomes more important, but more difficult, as collision pileup increases
- However, **tracking and vertexing are CPU intensive**, and have the potential to be a bottleneck in the HLT runtime



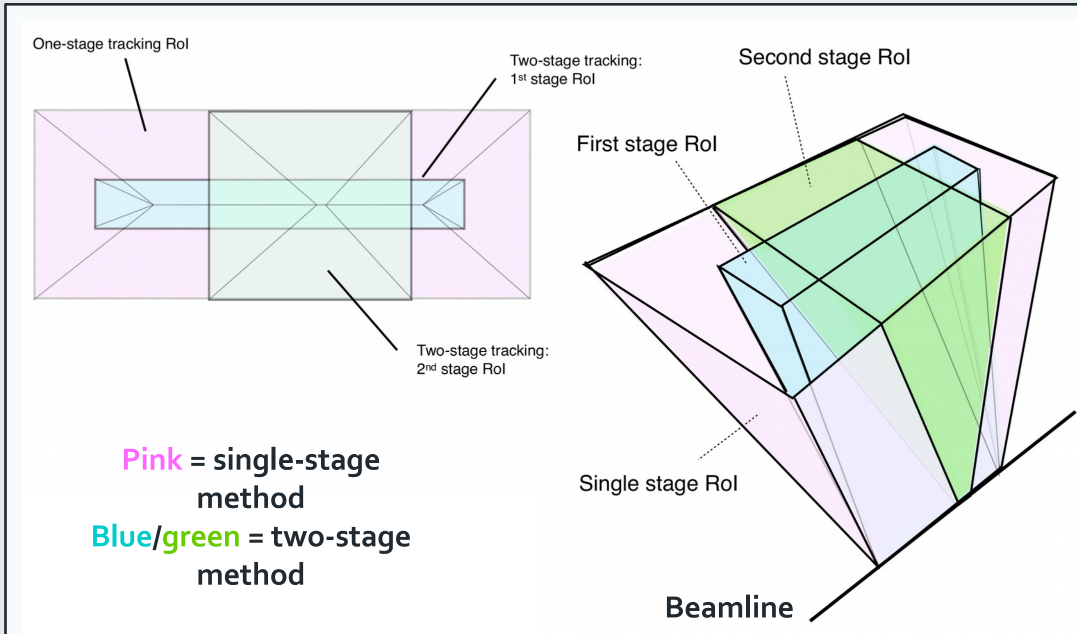
The ID Trigger system:

- Various methods are used to ensure **low timing while keeping good performance**
  - Tracking is split into: pattern recognition stage, the **Fast Track Finder (FTF)**; and **Precision Tracking (PT)**, which processes tracks and clusters from the first stage, and improves their quality while applying tighter requirements
  - Spatial **Regions of Interest (RoIs)** allow tracking and vertexing in reduced volumes
  - **Multi-stage RoI methods** define multiple RoIs in sequence to allow for reduced RoI volumes, tailored for different stages of tracking and vertexing



Multi-stage methods: Two-stage tracking

- **Added for LHC Run 2**, RoI sizes can be reduced by using multiple RoIs in sequence, reducing latency of track finding
- **Two-stage tracking:**
  1) Perform initial **FTF tracking** in **RoI** with **large range along beamline**, but **narrow width in ϕ and pseudorapidity**



  2) Determine **track or vertex of interest**
  3) Seed **second RoI** around this position, with **narrower range along beamline**, but **widened in ϕ and pseudorapidity**
  4) Perform **FTF in second RoI**, followed by **Precision Tracking**
- Employed in **jet** and **hadronic-decay tau** triggers, where z-position of the primary vertex or tau or the is not known from L1 information

Multi-stage methods: Two-stage tracking

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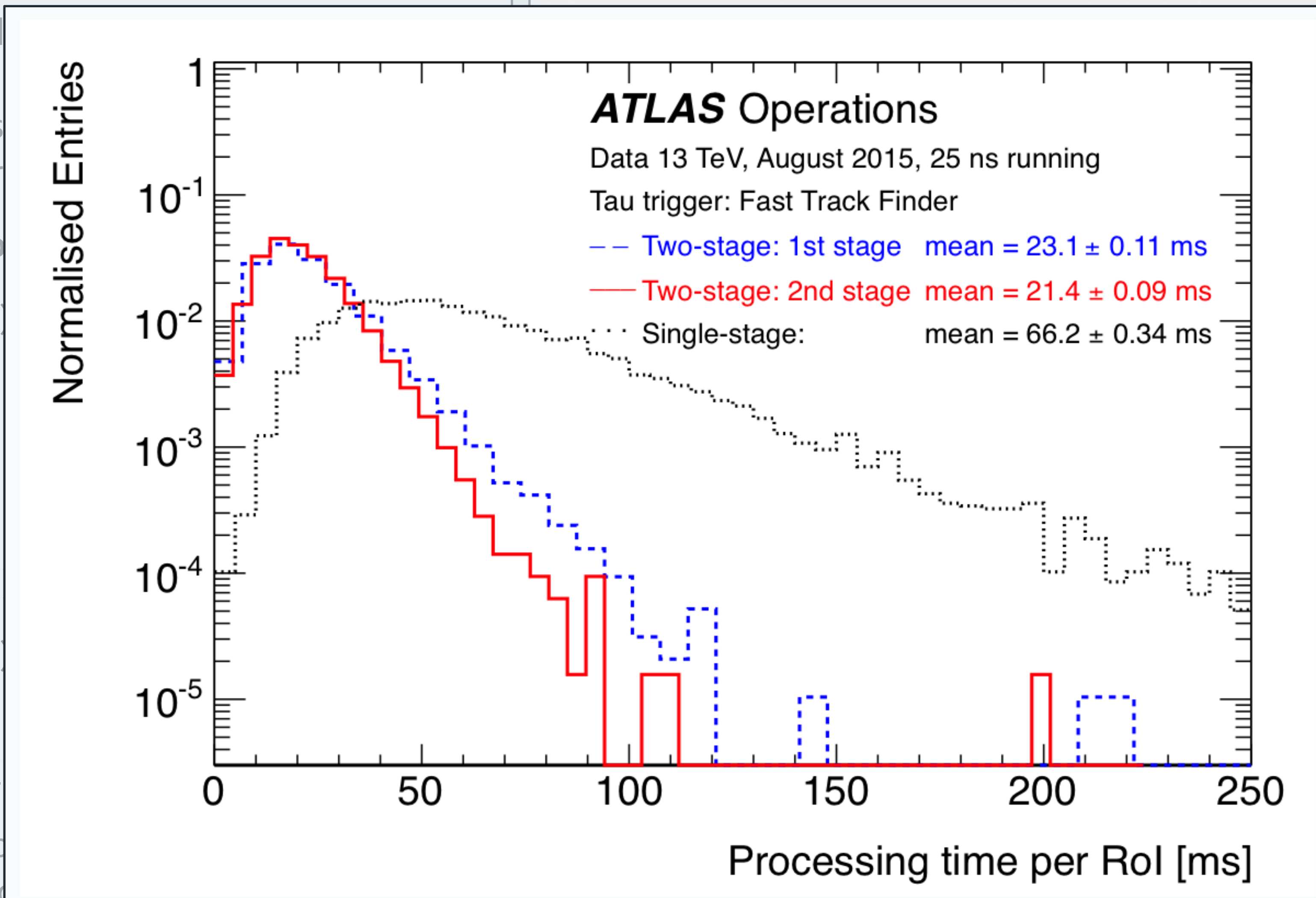
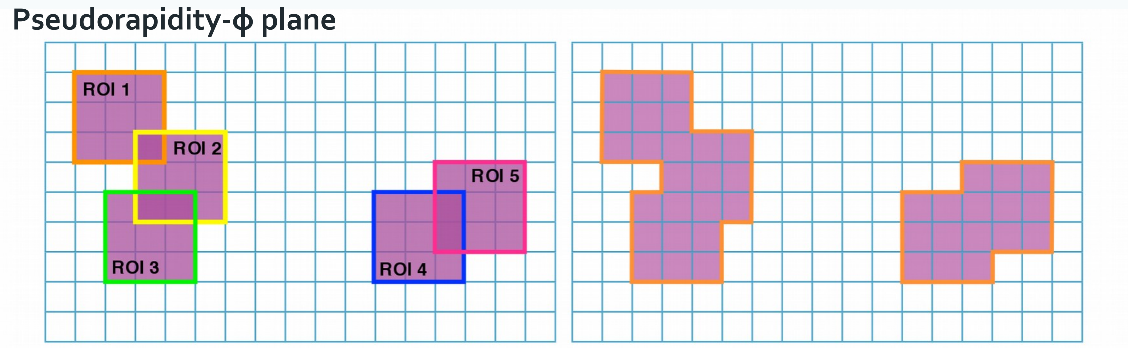


Multi-stage methods: Super RoIs

- **Added for LHC Run 2**, RoI overlap can be avoided by combining RoIs
- **Super RoIs:**
  - Define RoIs with **large range along beamline**, but **narrow width in ϕ and pseudorapidity**, and **combine into a single region**
  - Perform **tracking and vertexing over the combined region**



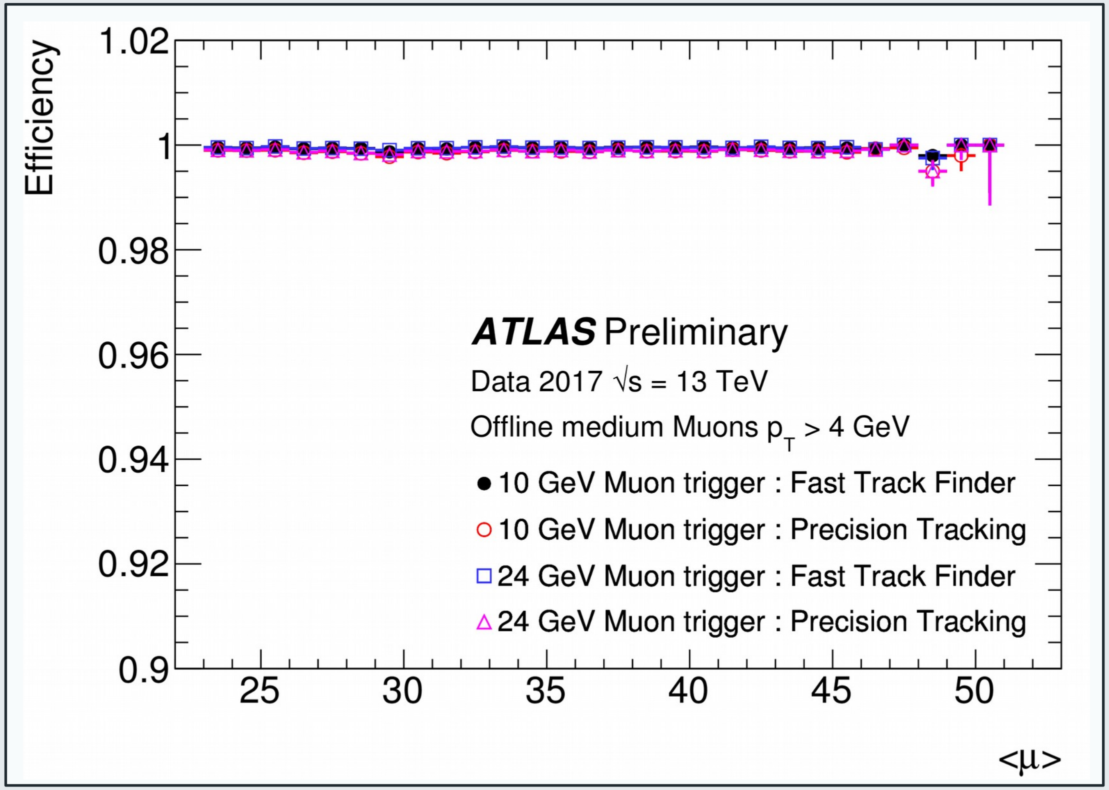
(a) Standard ROI approach (b) Super-ROI approach

- Avoids multiple processing and double counting of tracks that could occur when using multiple RoIs
- Employed in ***b*-quark jet triggers**, along with **two-stage tracking**
  1) Perform initial **FTF tracking** in **Super RoI defined around jets** passing L1 trigger
  2) Perform **primary vertex reconstruction** using Super RoI track collection
  3) Define individual **secondary RoIs around jets**, originating from the primary vertex
  4) Perform **FTF in secondary RoIs**, followed by **Precision Tracking**, and **secondary vertexing** needed for *b*-hadron tagging

Performance in 2017 data: Definitions of performance evaluation

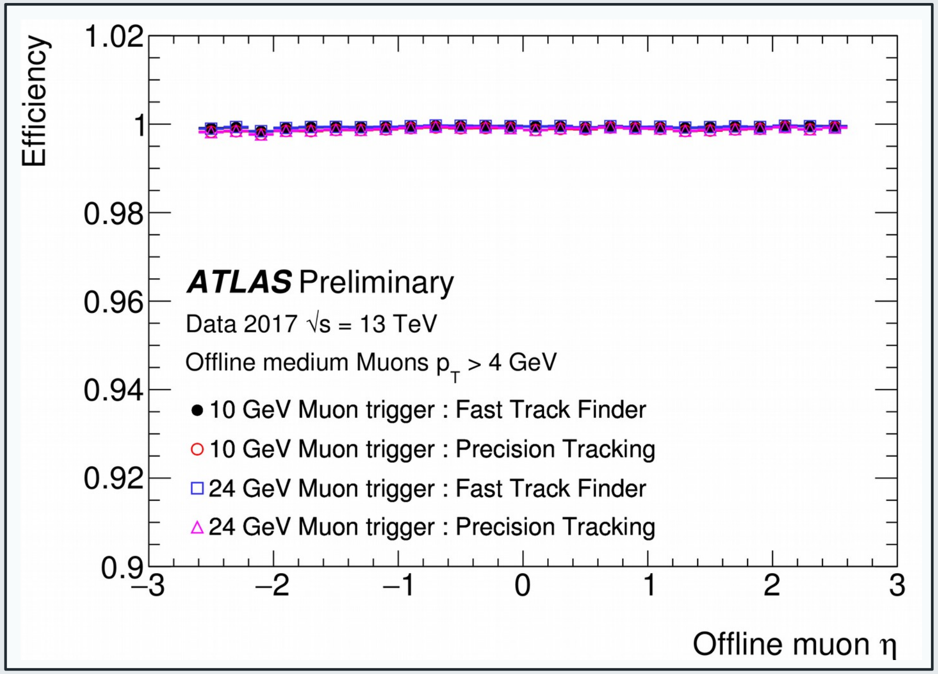
- Plots produced from 13 TeV collisions, using **current 2017 dataset**
- Events are taken from **dedicated performance triggers**
  - **Tracks are not used in trigger decision making**, so as not to bias the performance
  - Other than this, the **triggers are identical to triggers used for Physics data taking**
- **Performance** is measured by matching and comparing **tracks found by Online ID trigger algorithms** (FTF and Precision Tracking) to **tracks found by full Offline track reconstruction**
  - For muon trigger performance, the **Offline track matched to the Offline-reconstructed muon is used**
  - For jet trigger performance, **all Offline tracks** from within the RoIs are used
- More plots can be found in the backup slides

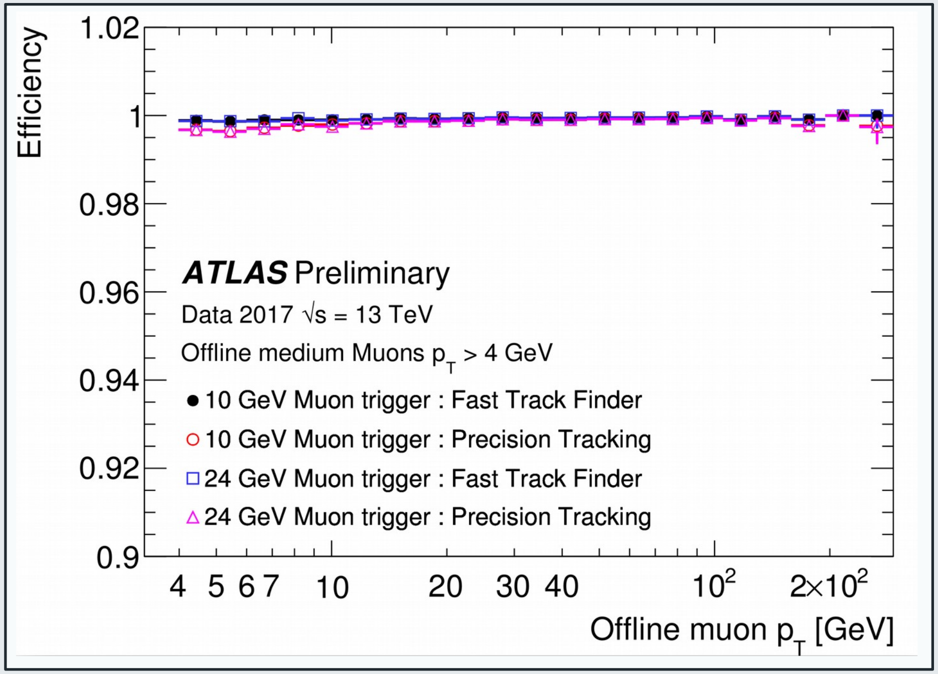
Performance in 2017 data, Muon triggers: Efficiency vs average collision pileup



- **Efficiency >99% as a function of pileup**, including at highest pileup conditions in LHC 2017 running
- ID Trigger has been optimised to be **robust up to a pileup of 80**, and could possibly maintain performance beyond this

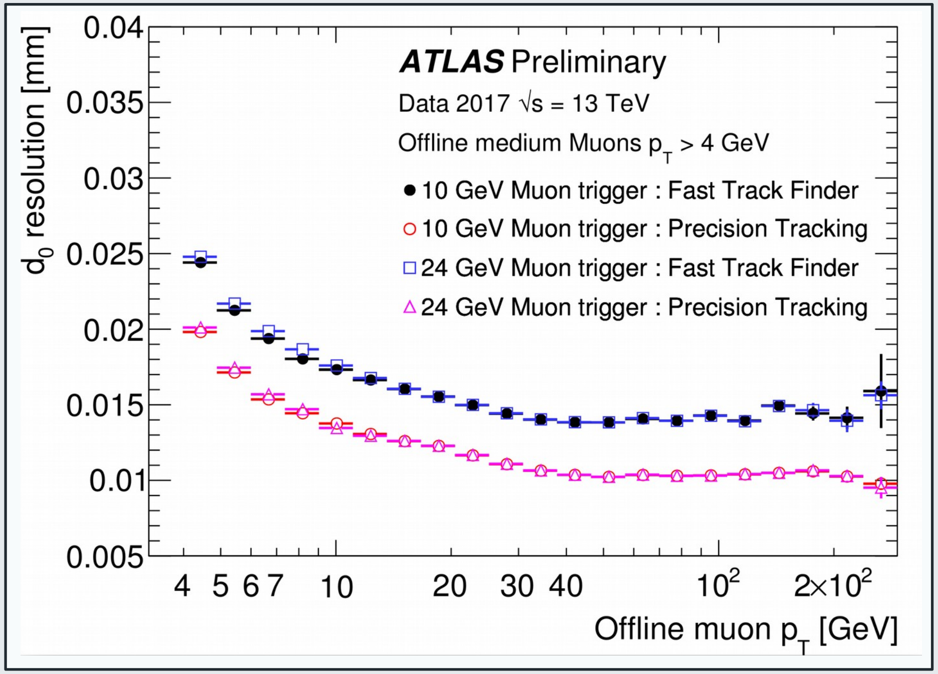
Performance in 2017 data, Muon triggers: Efficiency vs Offline muon pseudorapidity and p_T

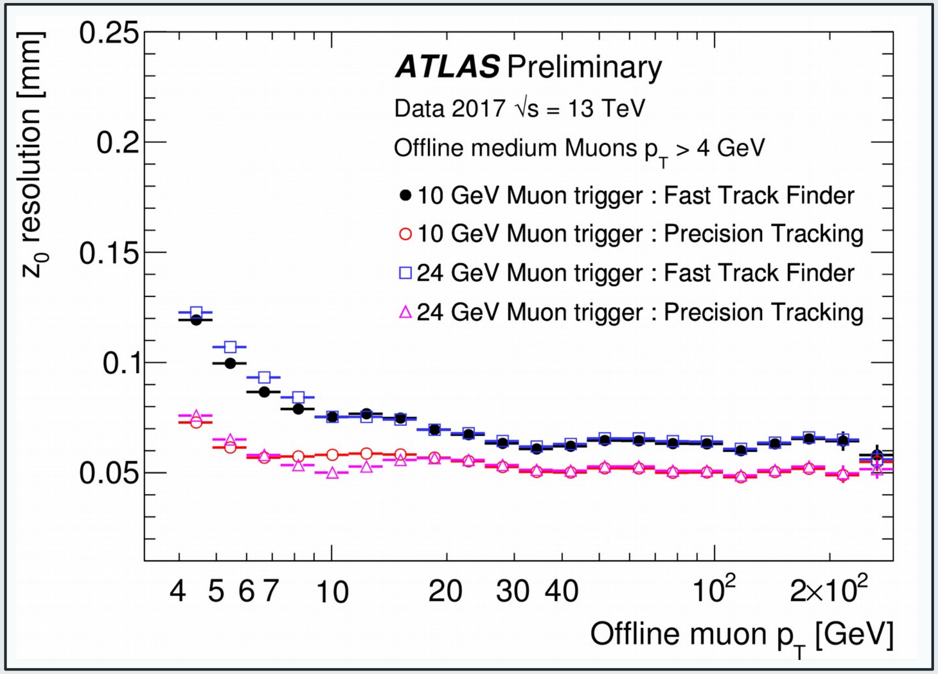




- **Efficiency for muons uniformly ~100%** across muon pseudorapidity and p_T

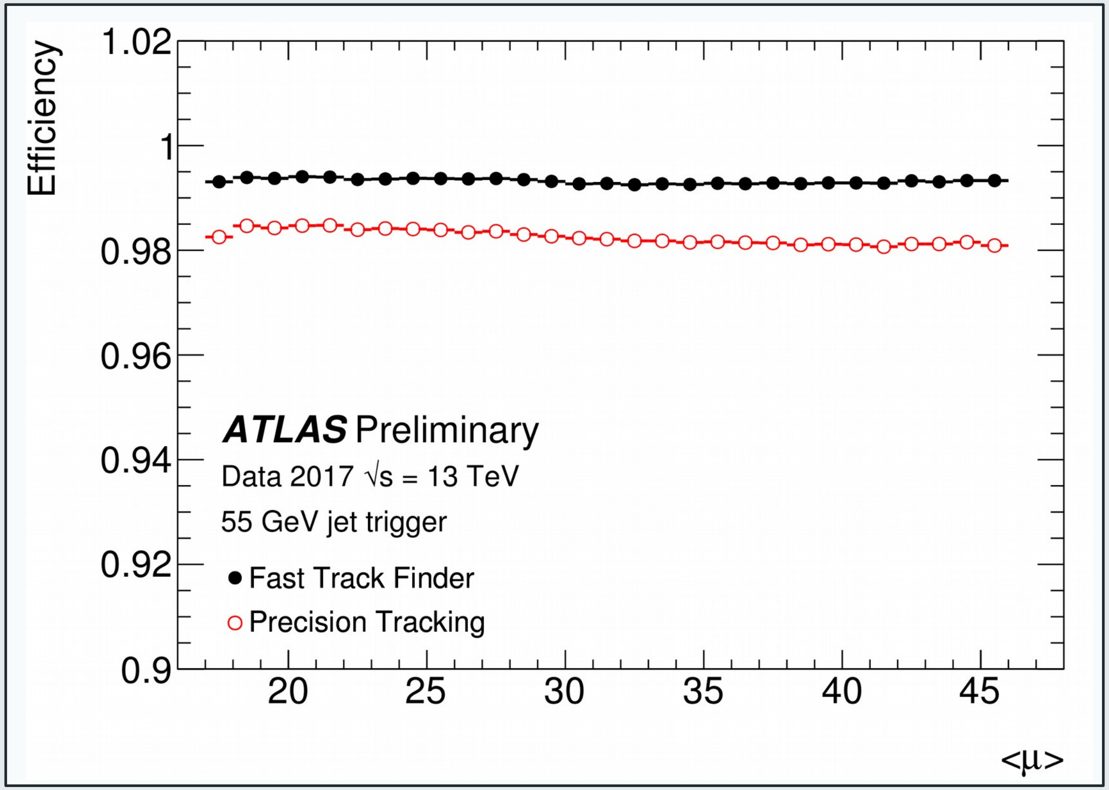
Performance in 2017 data, Muon triggers: d_0 and z_0 resolution vs Offline muon p_T





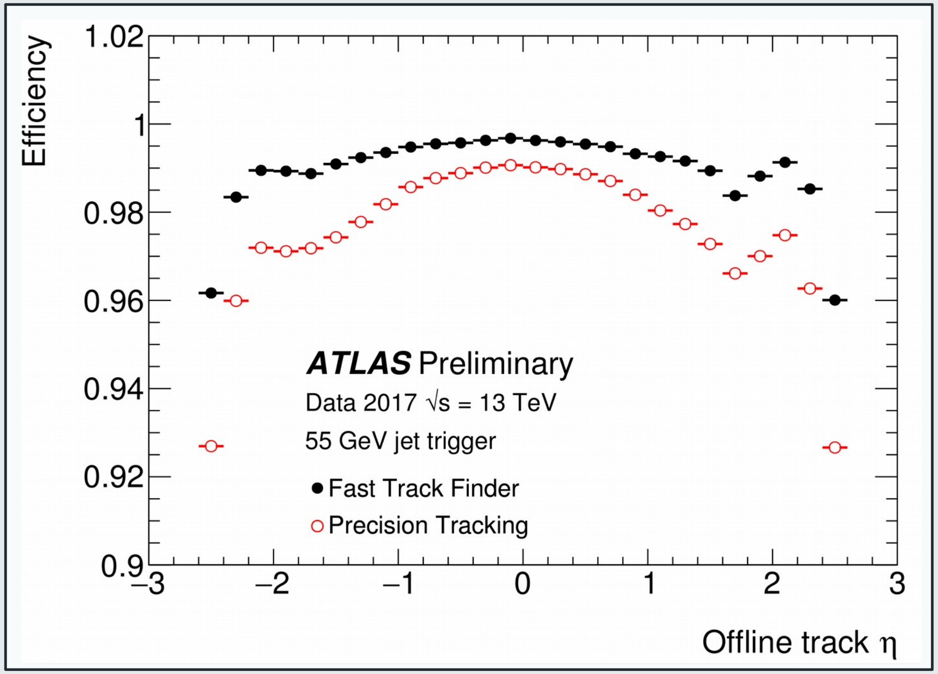
- **Excellent spatial resolution**
  - Down to ~10 µm at best
- **Precision tracking algorithm improves resolution**

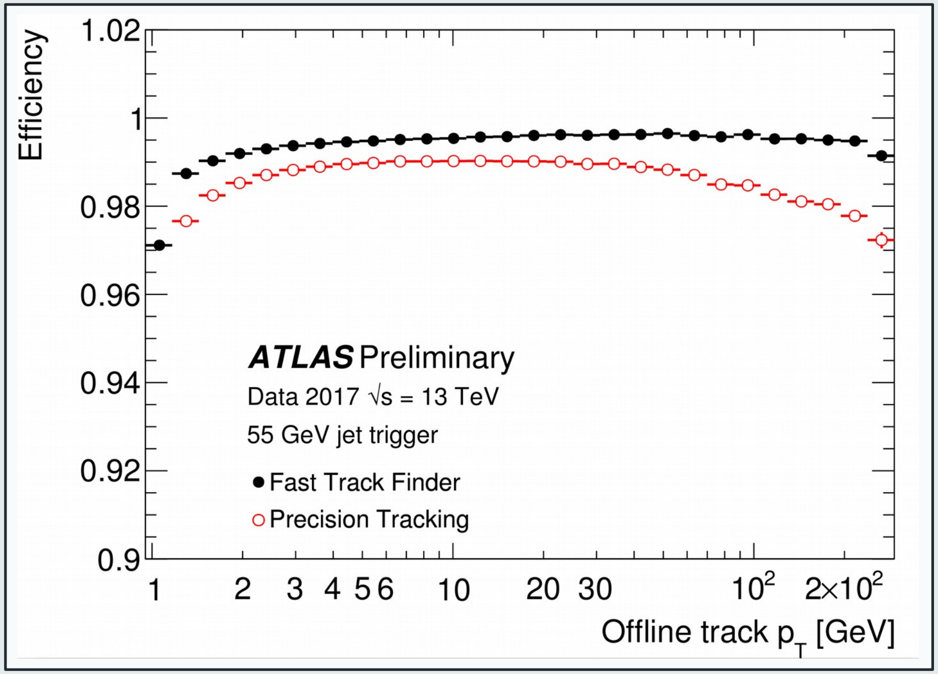
Performance in 2017 data, Jet triggers: Efficiency vs average collision pileup



- Similar to muon triggers, **efficiency shows little dependence on pileup**, including high pileup conditions

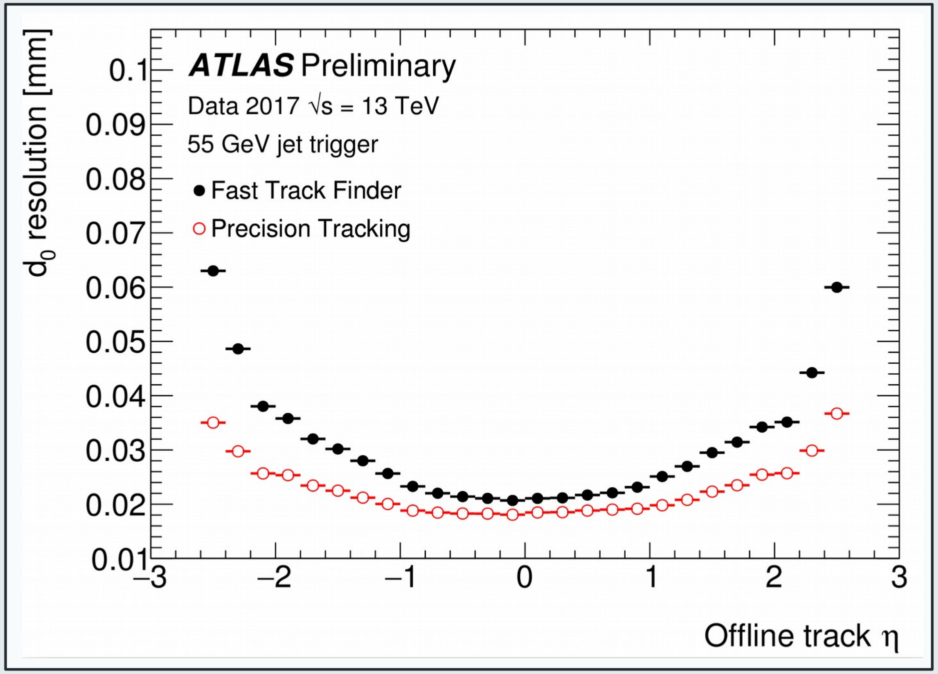
Performance in 2017 data, Jet triggers: Efficiency vs Offline track pseudorapidity and p_T

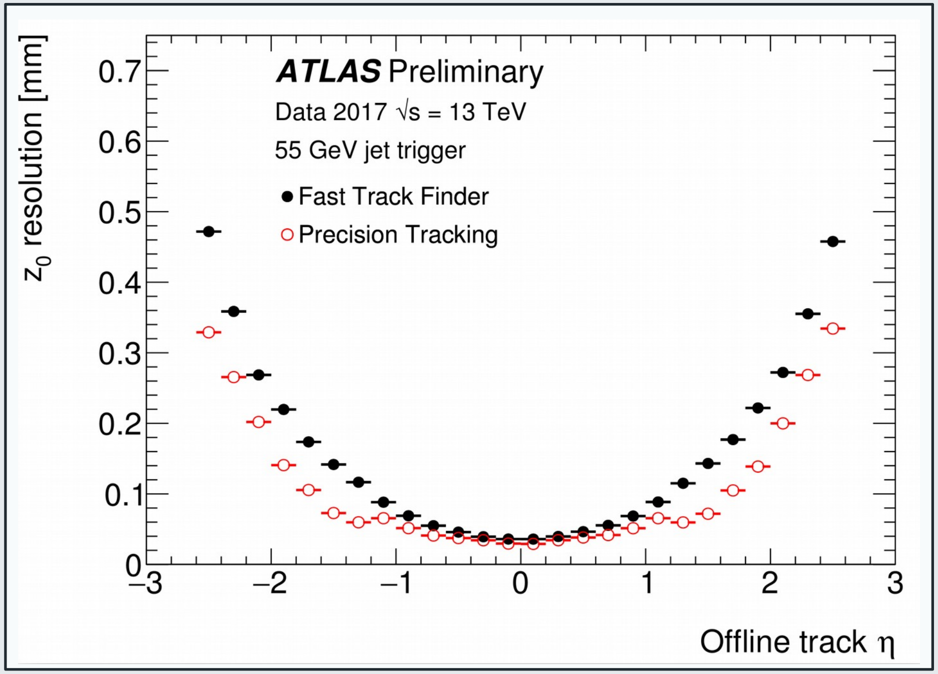




- Efficiency for central pseudorapidity >98%
- Efficiency generally >98% as a function of p_T

Performance in 2017 data, Jet triggers: d_0 and z_0 resolution vs Offline track pseudorapidity





- **Good resolution performance**
- Resolution degrades as a function of pseudorapidity due to **tracks passing through more detector material**, giving **larger multiple scattering** for tracks at larger angles

Conclusions:

- The ATLAS trigger **could not achieve the needed rate reduction and high efficiencies without the ID Trigger**
- **Multi-stage RoI methods** used in Run 2 to keep latency low while maintaining excellent performance
  - **Two-stage tracking** reduces spatial volume in which tracking will be run
  - **Super RoIs** avoid multiple processing and double counting of tracks
- **Excellent tracking performance** seen in high rate and pileup conditions in data taken in 2017 so far
  - **Tracking efficiency insensitive to pileup**, including at highest pileup conditions observed
- **The ID Trigger continues to provide excellent performance** and will do so in the future!

Image references:

- **Slide 2:** Inner Detector cutaway
  ATL-PHYS-PUB-2015-018
  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2015-018
- **Slide 3, 18:** ATLAS Online System schematic, ATLAS Trigger System schematic
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsDAQ
- **Slide 4:** Two-stage tracking diagram and timing plot
  HLT Tracking Public Results
- **Slides 8 – 13, 19 – 21:** 2017 data performance plots
  HLT Tracking Public Results
- **Slide 17:** Inner Detector schematic
  ATL-PHYS-PUB-2015-050
  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2015-050

Backup

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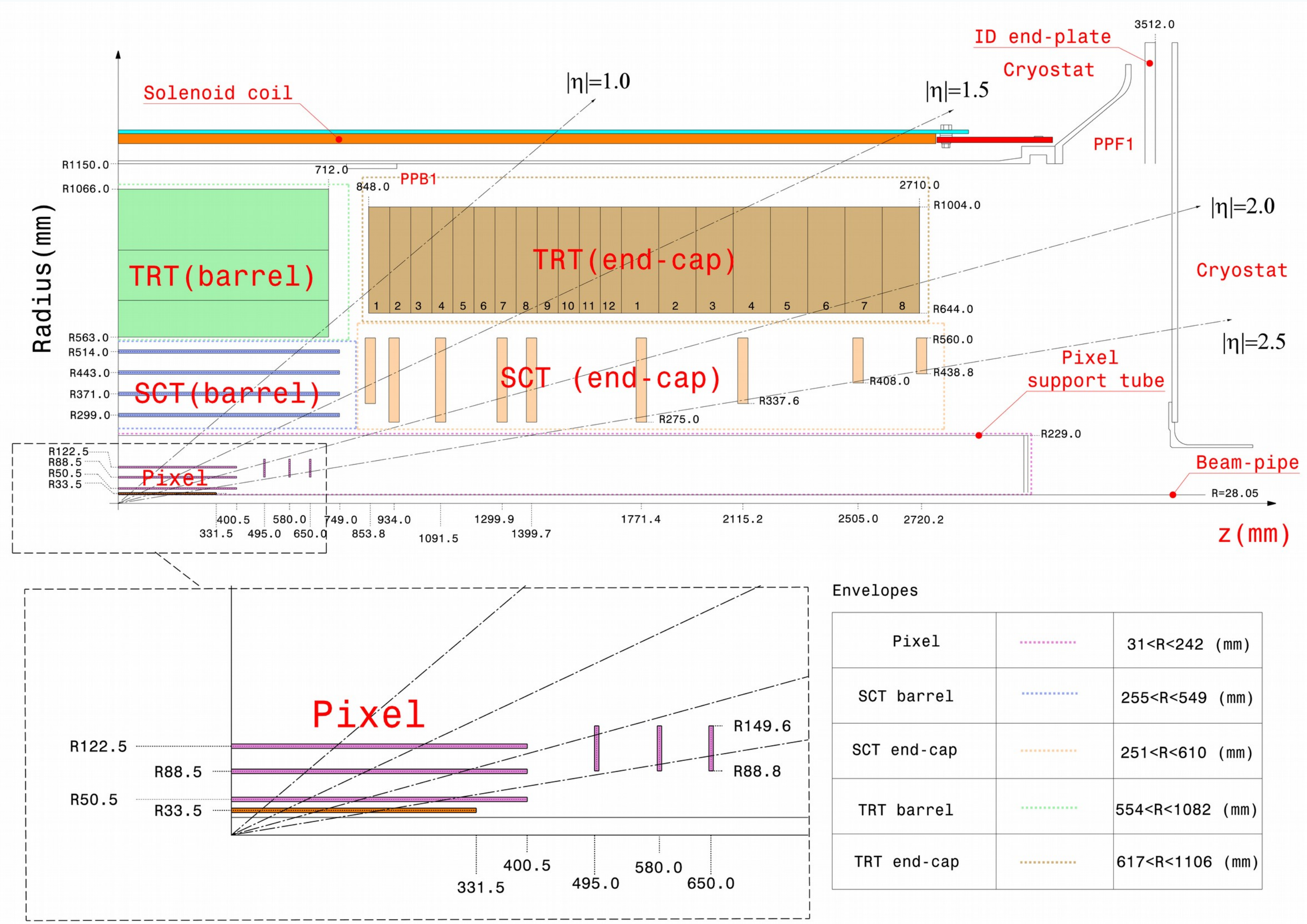
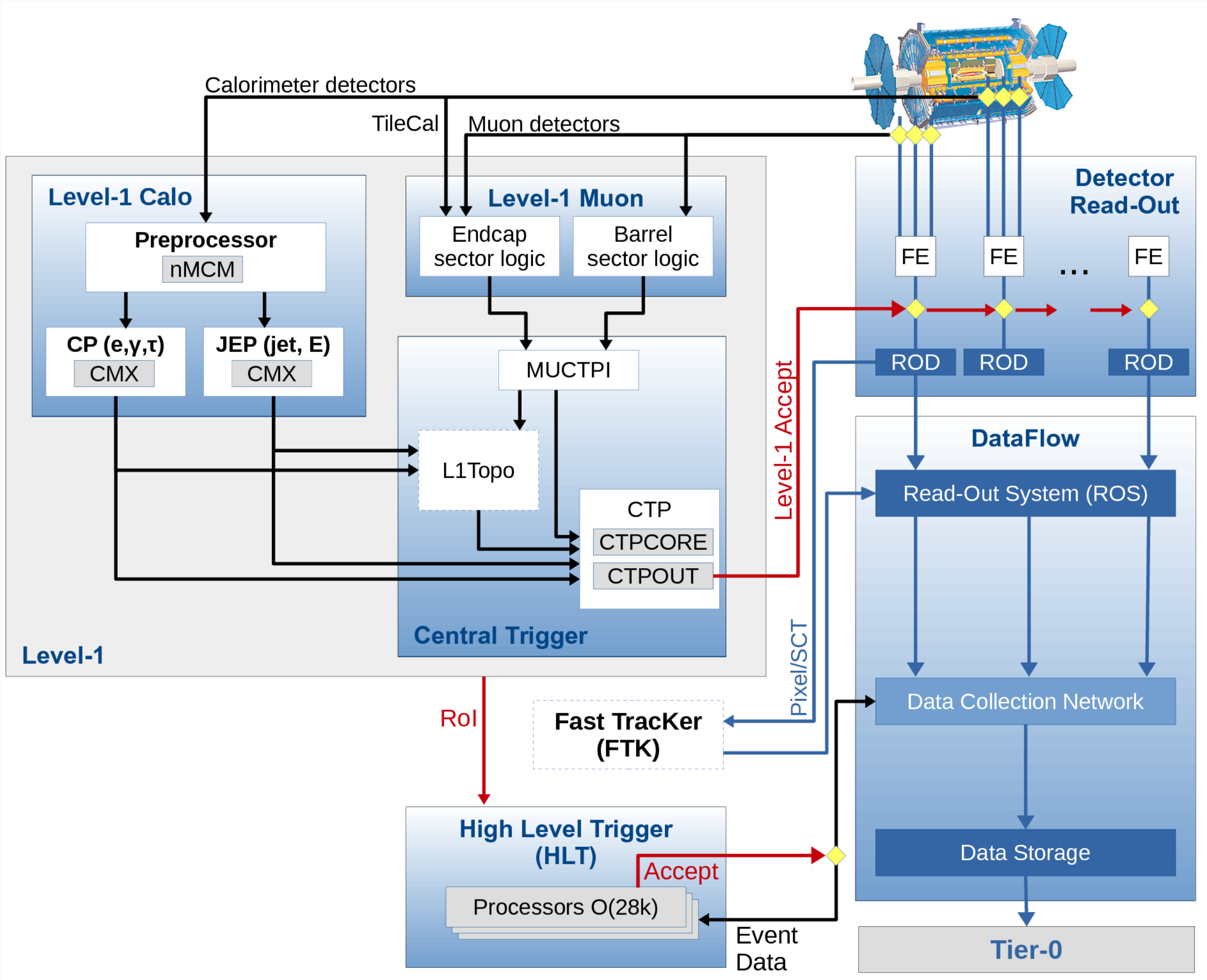
Schematic of Inner Detector:



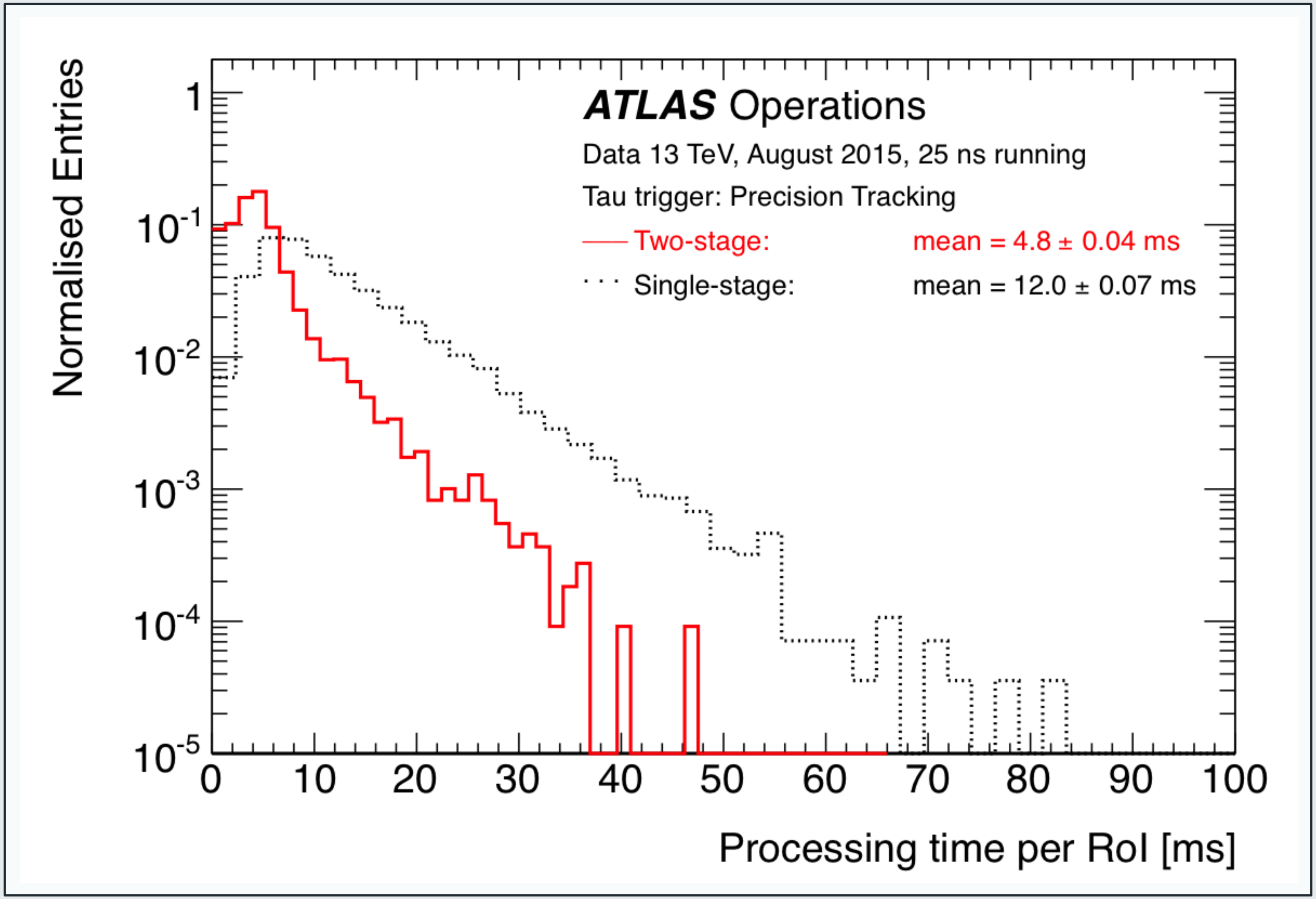
Envelopes

Pixel		31<R<242 (mm)
SCT barrel		255<R<549 (mm)
SCT end-cap		251<R<610 (mm)
TRT barrel		554<R<1082 (mm)
TRT end-cap		617<R<1106 (mm)

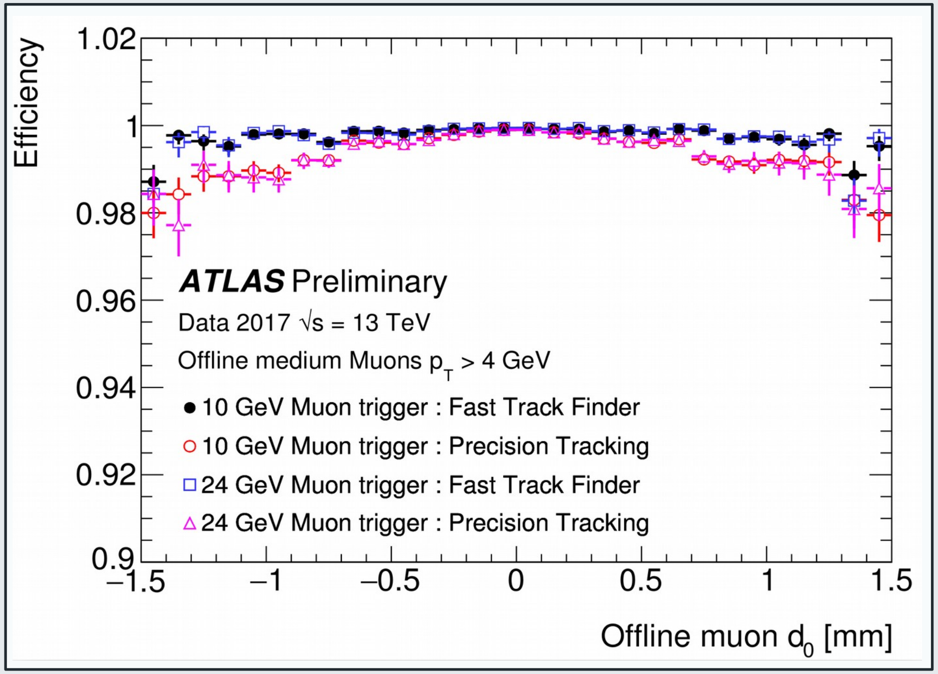
Schematic of ATLAS Trigger System:

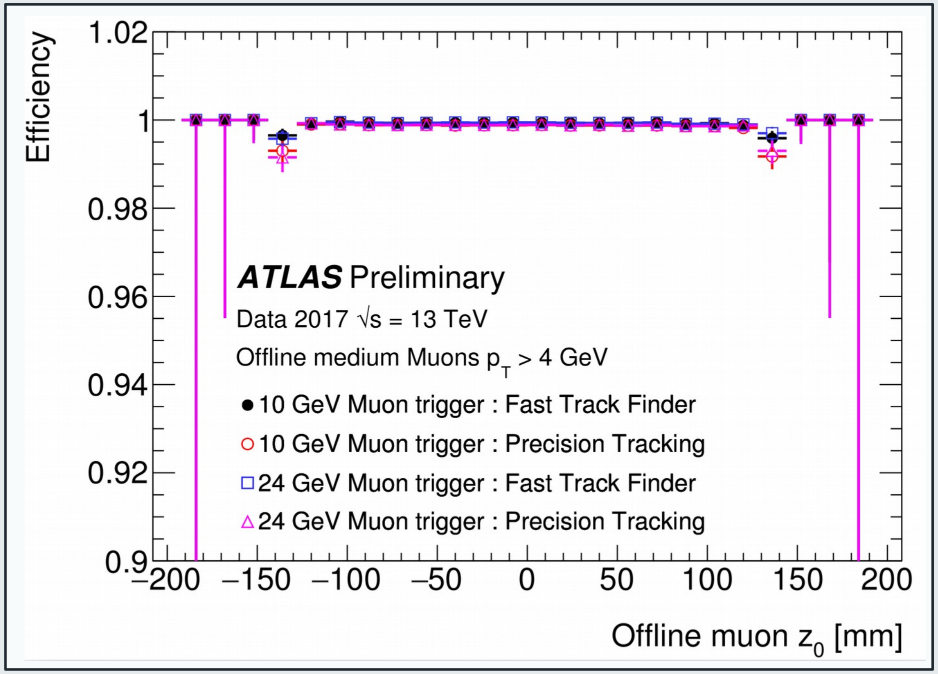


Multi-stage methods: Two-stage tracking; percision tracking timing

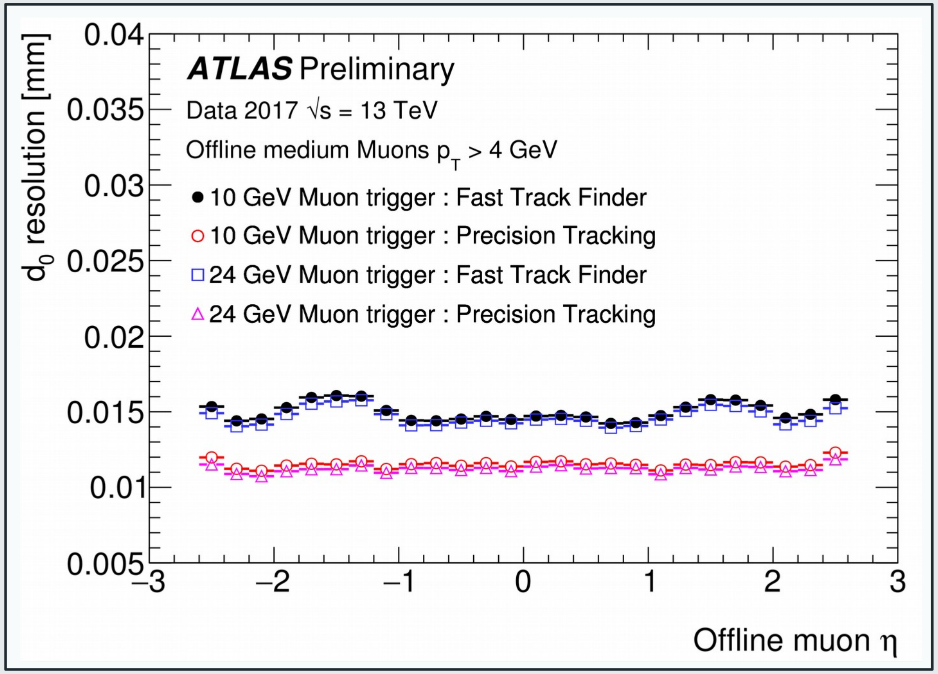


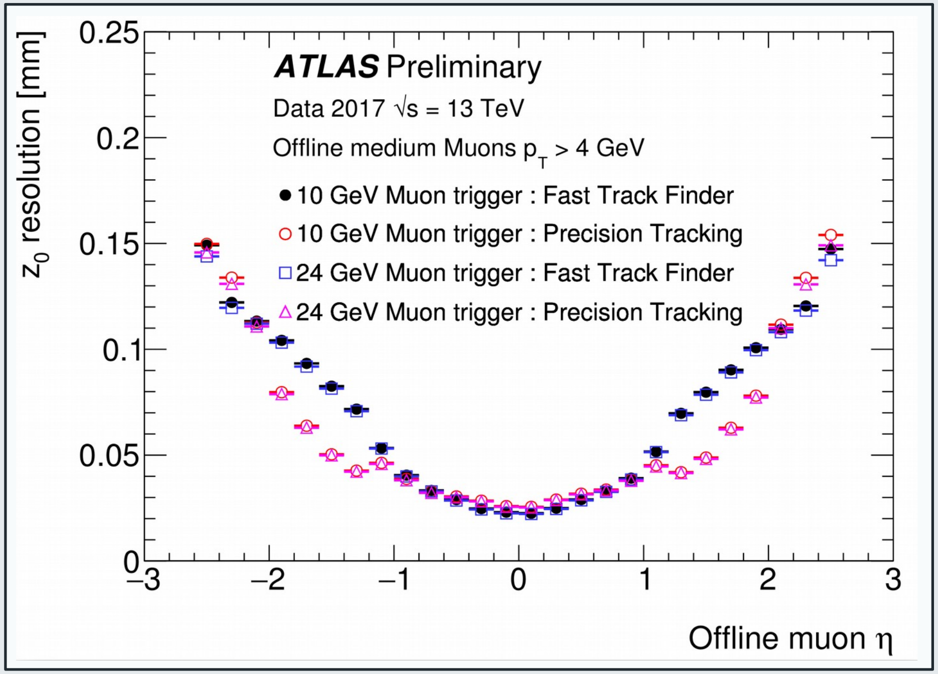
Performance in 2017 data, Muon triggers: Efficiency vs Offline muon d_0 and z_0





Performance in 2017 data, Muon triggers: d_0 and z_0 resolution vs Offline muon pseudorapidity





Performance in 2017 data, Jet triggers: Efficiency vs Offline track z_0