Inner Detector Trigger Performance in Run 2 and Plans for Run 3

Harry Simpson on behalf of the ATLAS TDAQ Collaboration

July 9th 2022

ICHEP 2022

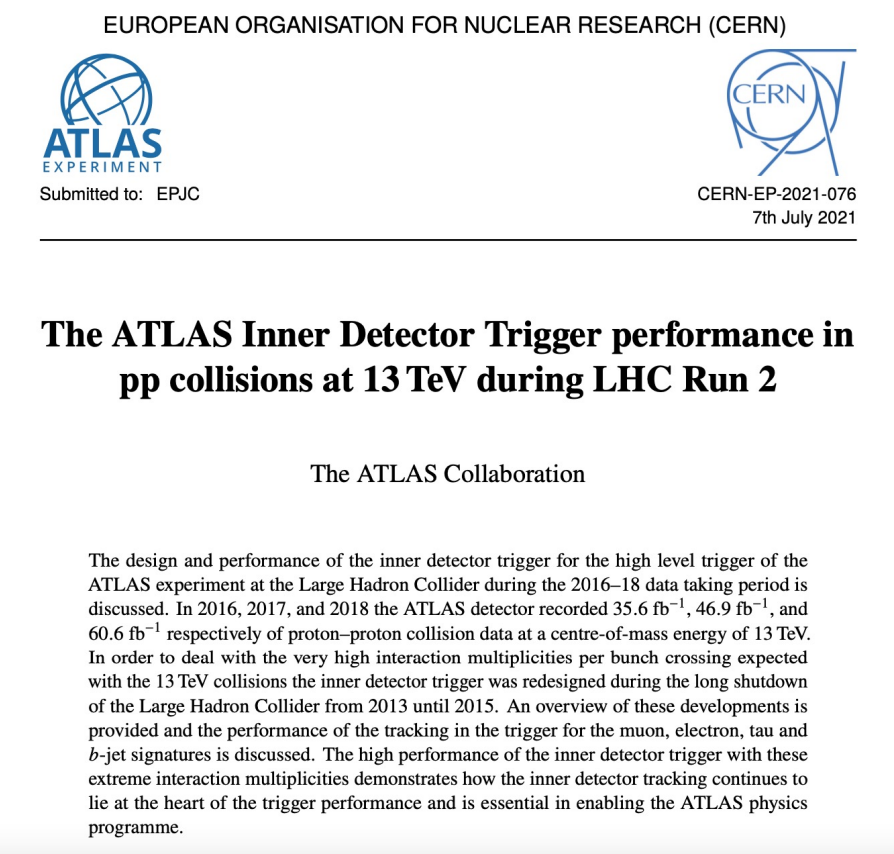
UNIVERSITY OF SUSSEX

ATLAS EXPERIMENT

Introduction

Eur. Phys. J. C 82 (2022) 206

Without this:



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: EPJC

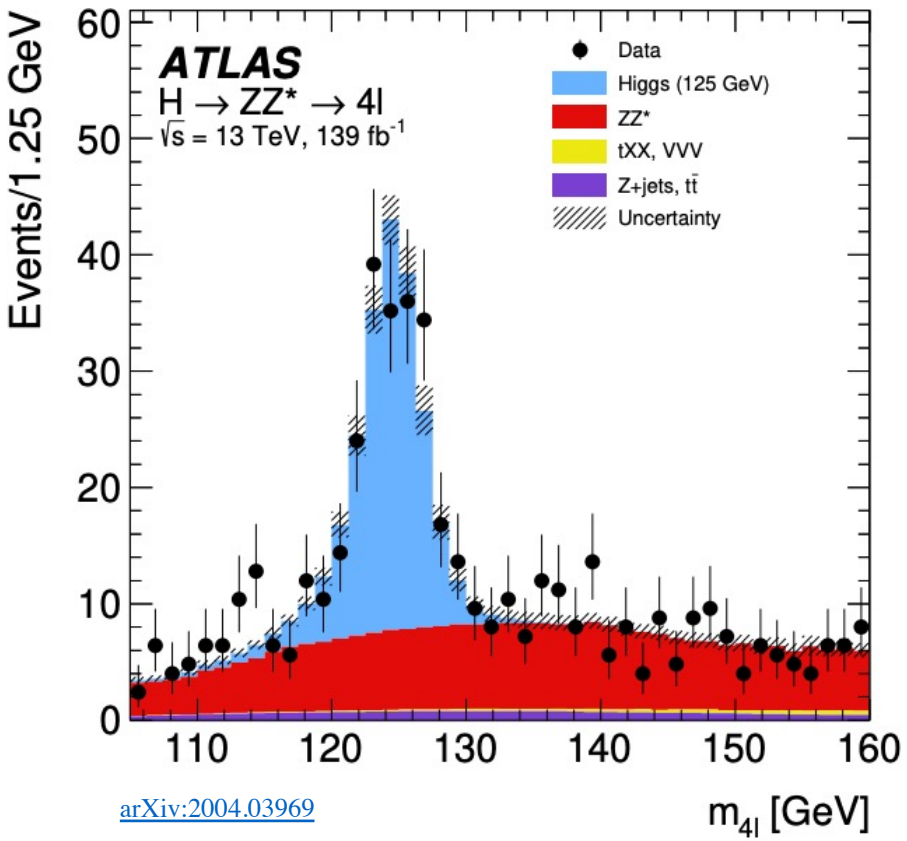
CERN-EP-2021-076
7th July 2021

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

The ATLAS Collaboration

The design and performance of the inner detector trigger for the high level trigger of the ATLAS experiment at the Large Hadron Collider during the 2016–18 data taking period is discussed. In 2016, 2017, and 2018 the ATLAS detector recorded 35.6 fb^{-1}, 46.9 fb^{-1}, and 60.6 fb^{-1} respectively of proton–proton collision data at a centre-of-mass energy of 13 TeV. In order to deal with the very high interaction multiplicities per bunch crossing expected with the 13 TeV collisions the inner detector trigger was redesigned during the long shutdown of the Large Hadron Collider from 2013 until 2015. An overview of these developments is provided and the performance of the tracking in the trigger for the muon, electron, tau and *b*-jet signatures is discussed. The high performance of the inner detector trigger with these extreme interaction multiplicities demonstrates how the inner detector tracking continues to lie at the heart of the trigger performance and is essential in enabling the ATLAS physics programme.

Analyses like this would not be possible:



arXiv:2004.03969

Every H→4l event was selected because of the successful operation of tracking in the leptonic triggers

The ATLAS Inner Detector

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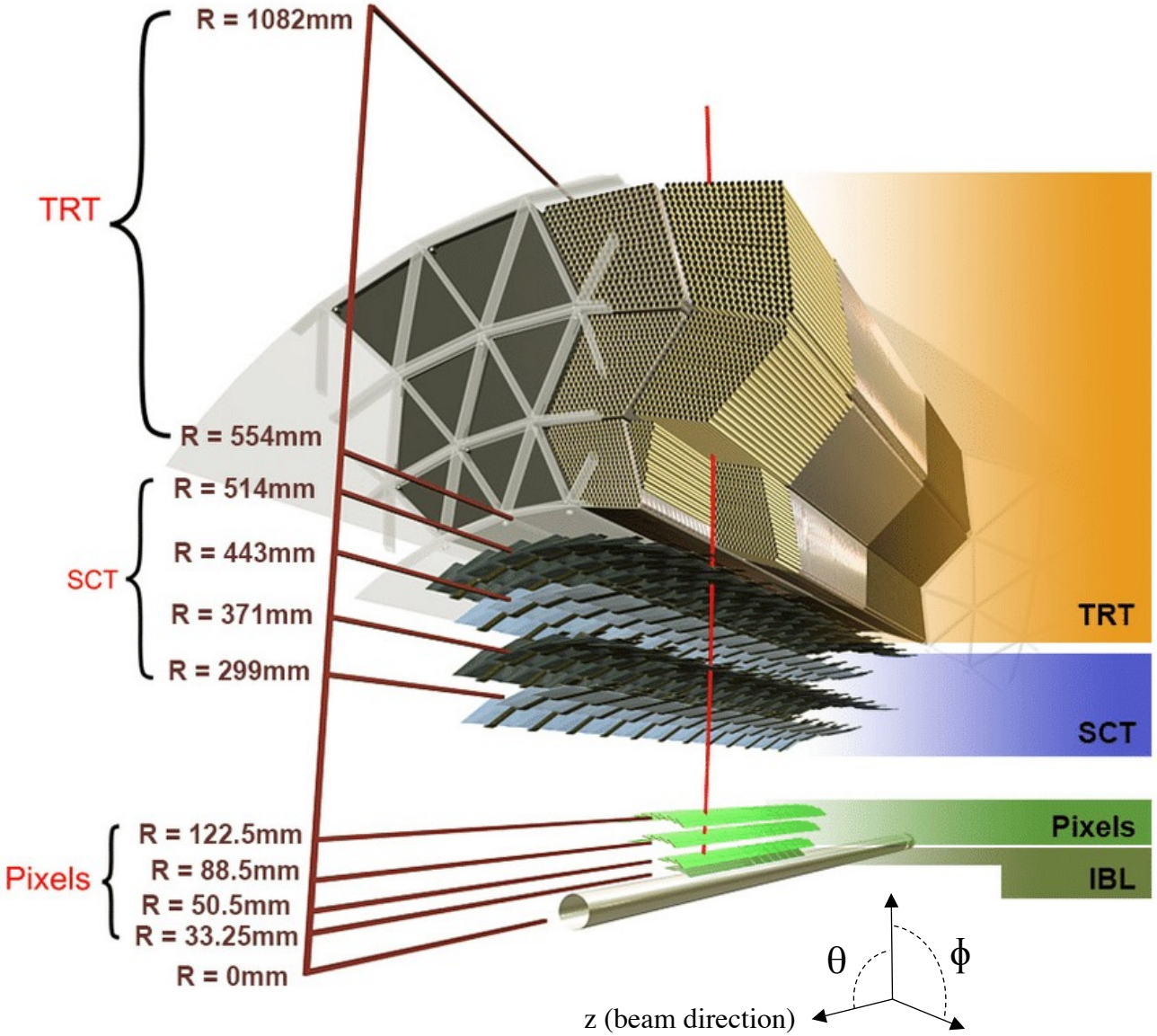
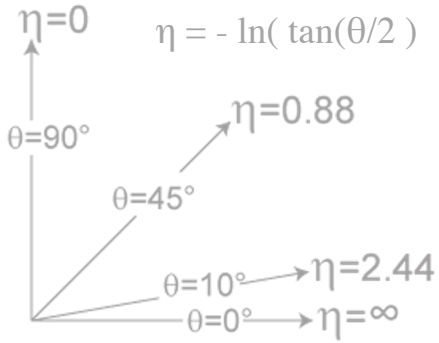


Inner Detector is comprised of 3 sub-systems:

- **Pixel Detector**
  - 3 silicon pixel layers
  - Additional IBL pixel layer
  - 4 measurements per track
- **Semiconductor Tracker (SCT)**
  - Double-sided silicon strips
  - 4 barrel & 9 endcap layers
  - 8 measurements per track
- **Transition Radiation Tracker (TRT)**
  - layers of straw cylindrical drift tubes
  - track reconstruction up to $|\eta| = 2.0$



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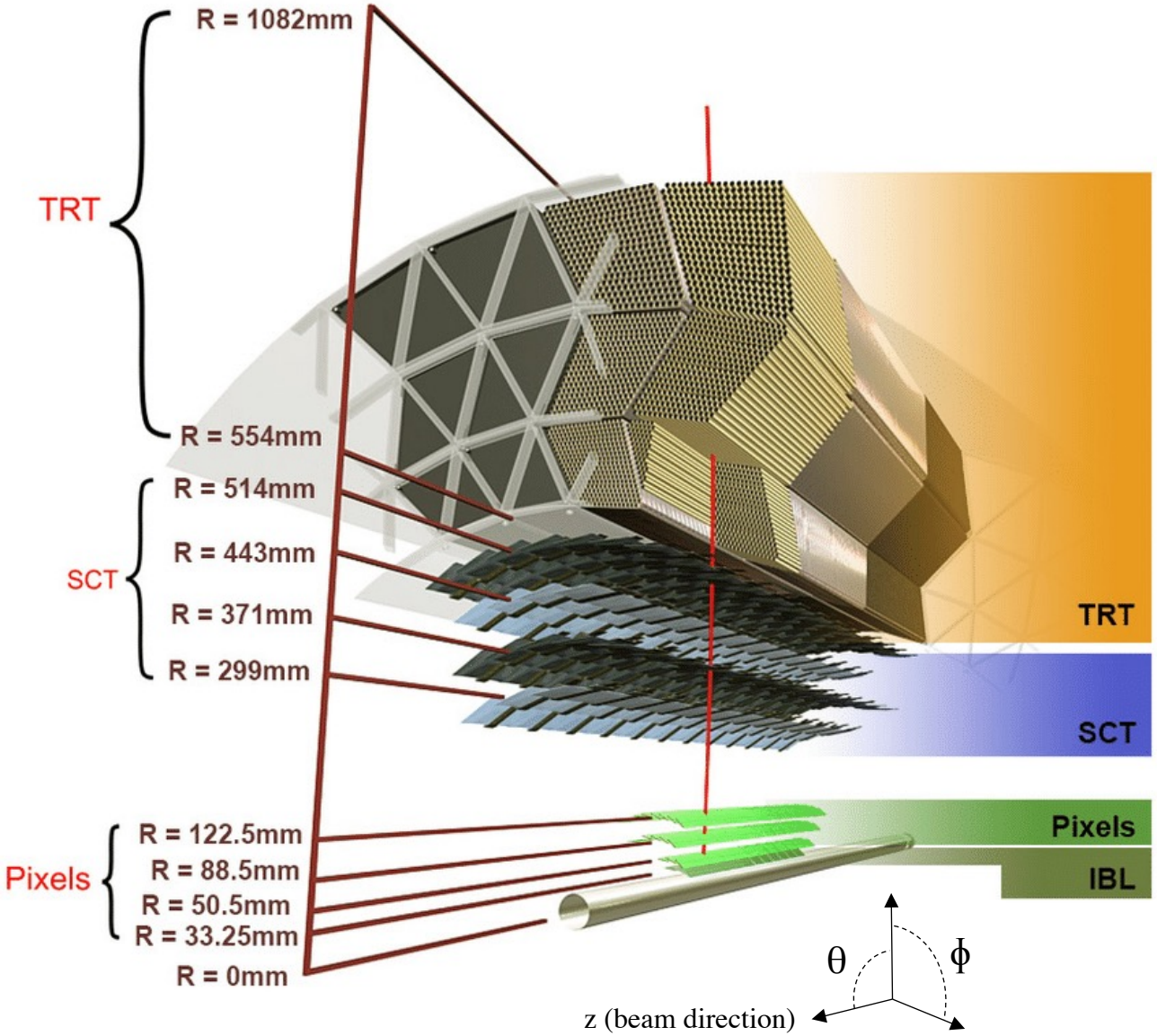

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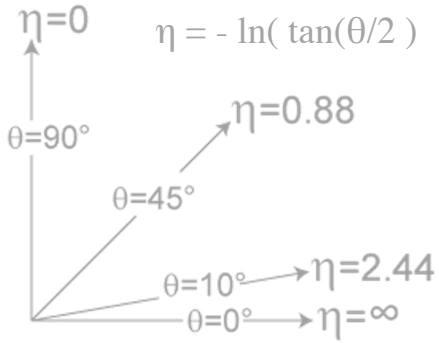

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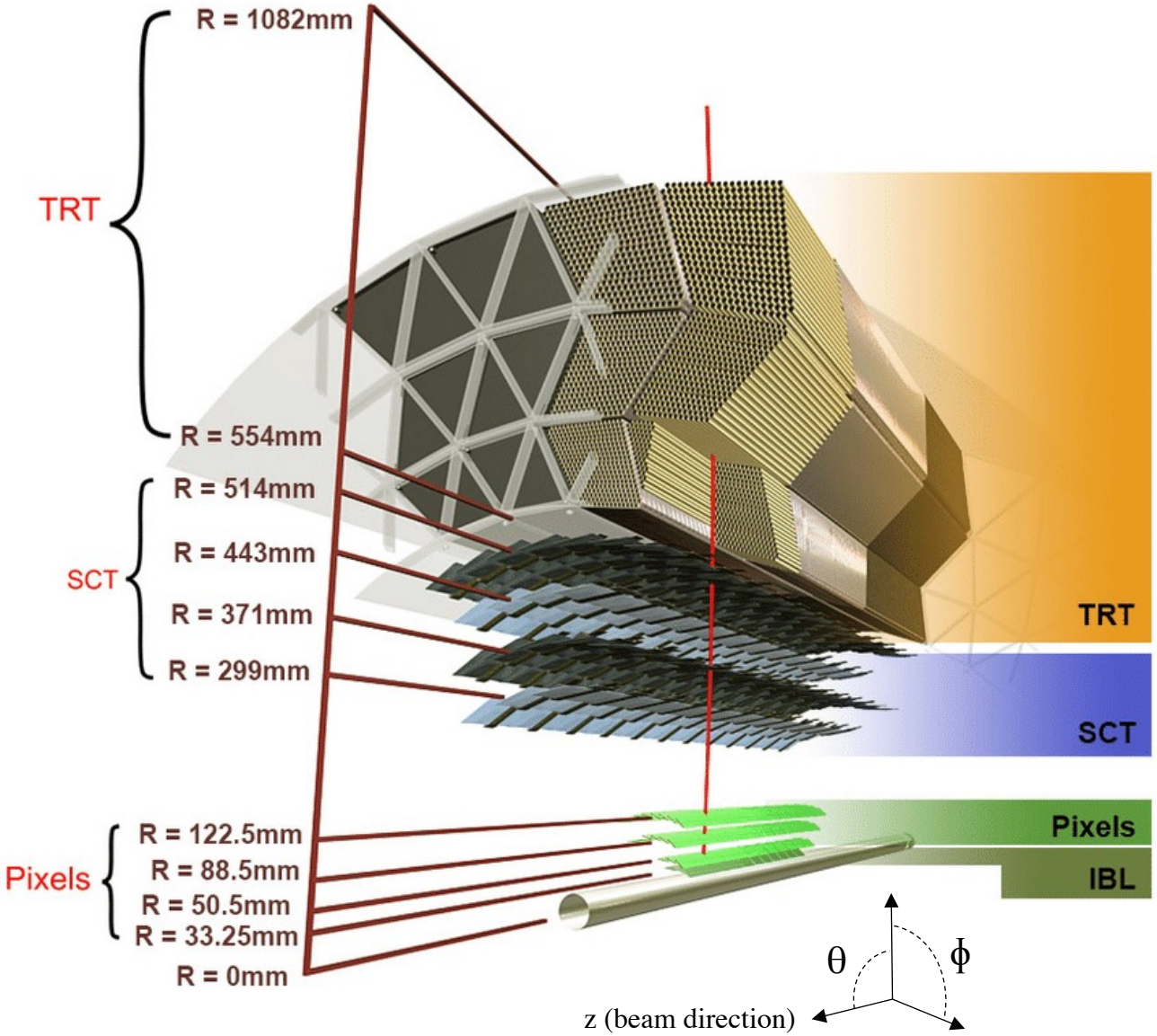

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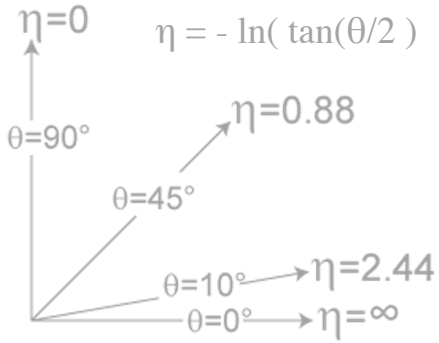

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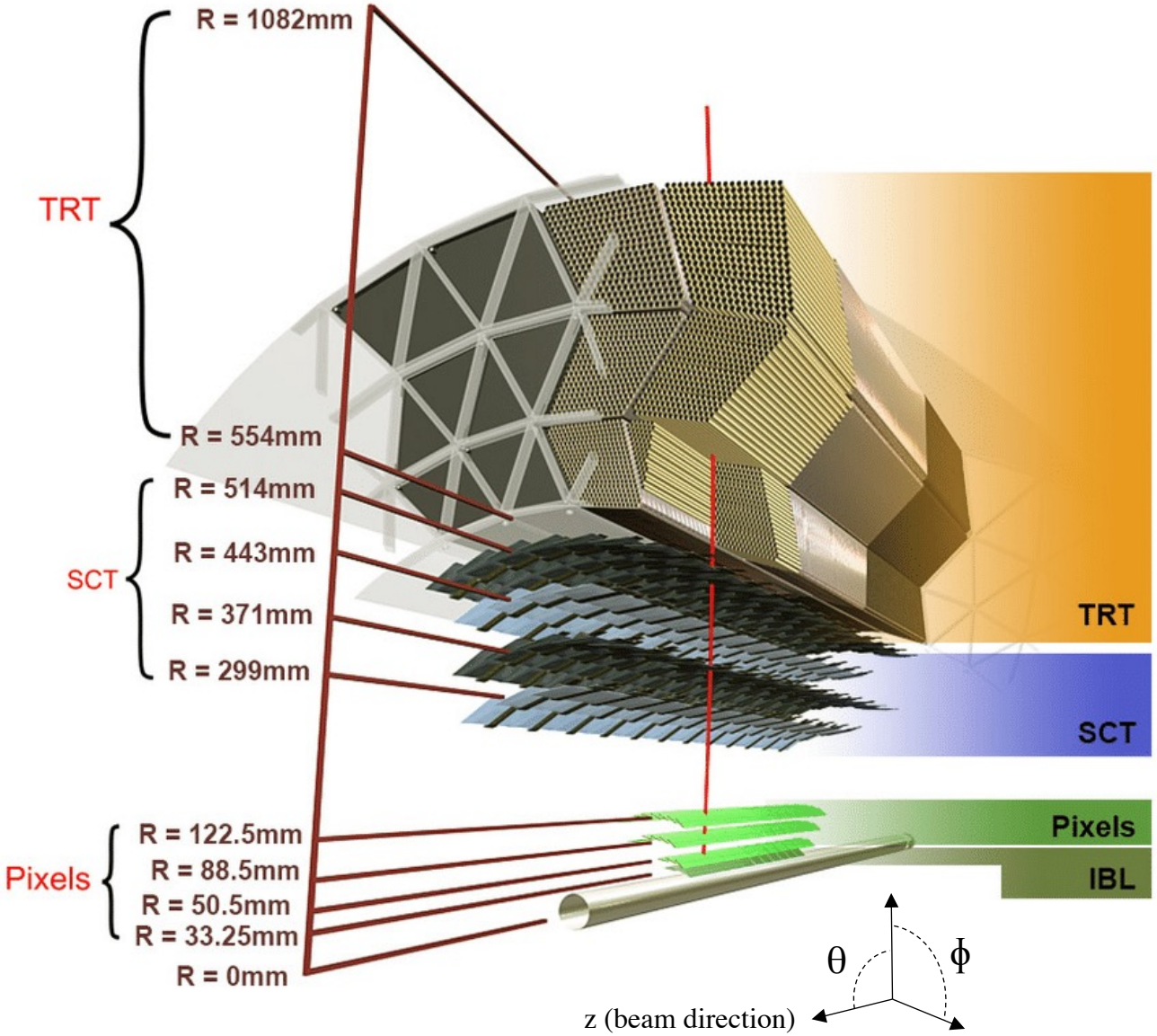

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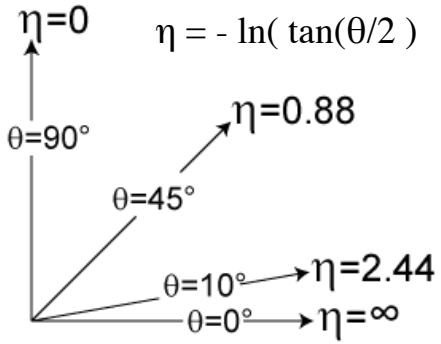
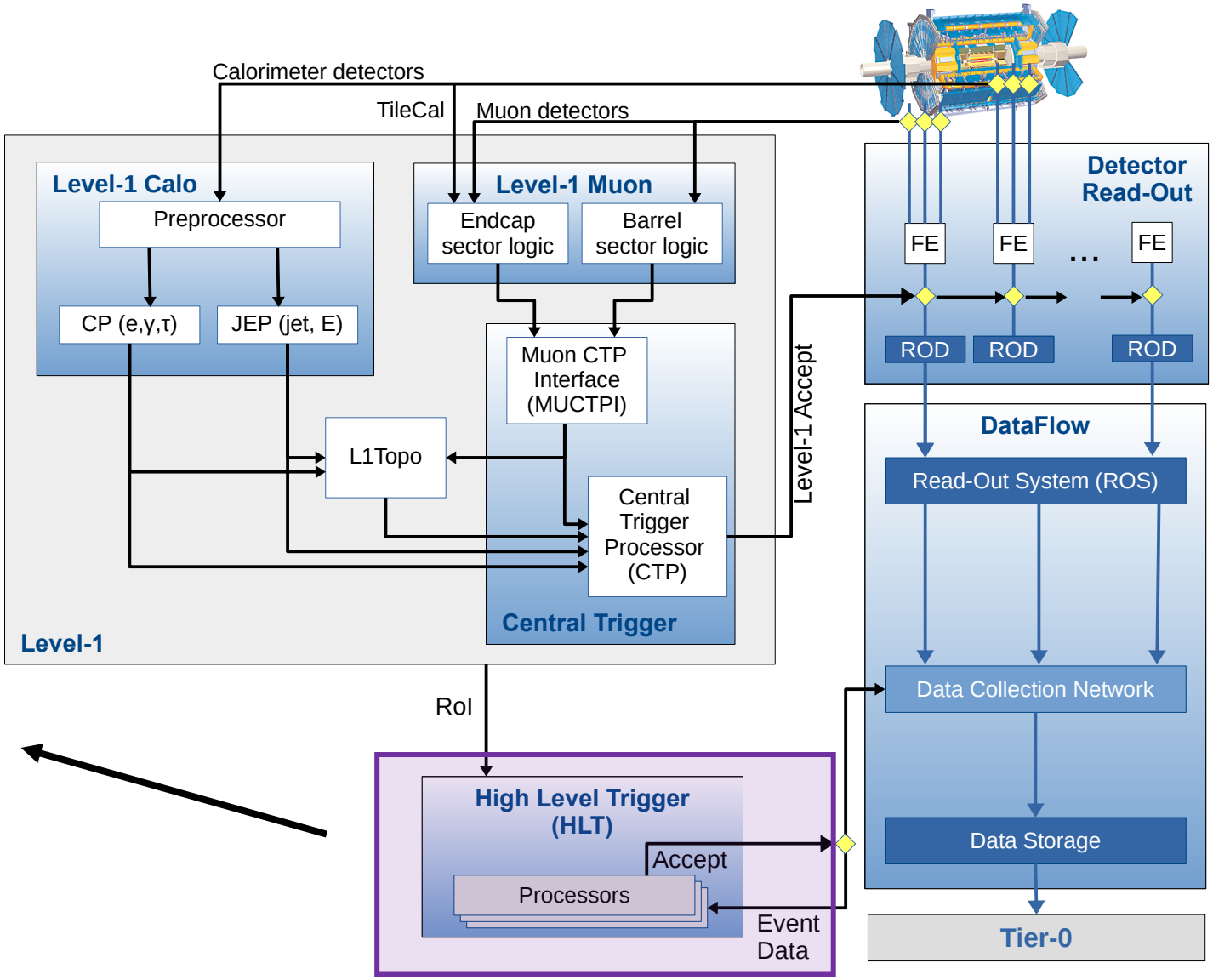


The ATLAS Trigger and Data Acquisition (TDAQ) System

High Level Trigger (HLT):

- **L1** pipelined **hardware** trigger
- Identifies **Regions of Interest** (RoIs)
- Software-based HLT
- Processes RoIs from **L1** or detector **Full-Scan**
- Information from the **silicon detectors** available
- ID Trigger performs fast, online **track** and **vertex** finding
- Runs **computationally intensive** algorithms for track reconstruction
- Accept rate of 1.2 kHz (200–500 ms)



The High Level Trigger

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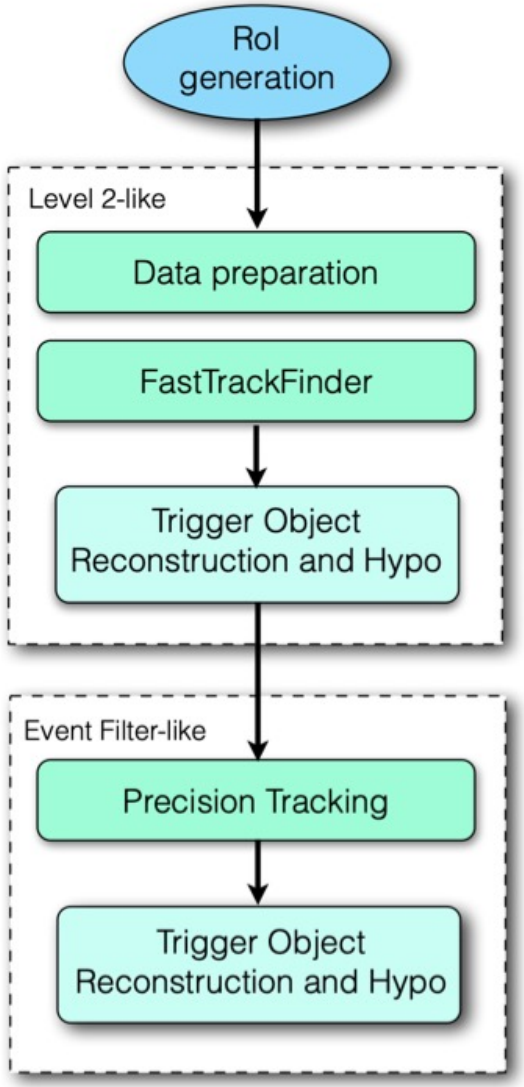
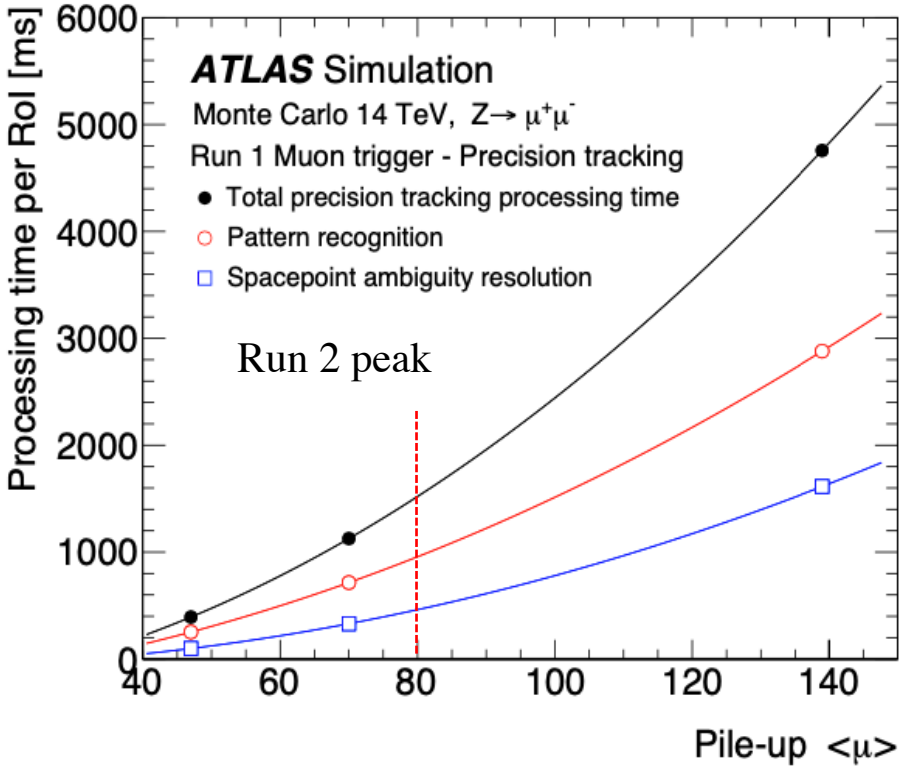


- In Run 1, HLT was separated into 2 CPU farms: the **Level 2 (L2)** software trigger and the **Event Filter (EF)**
- This was too slow at the higher pile-up of Run 2 (up to 80 < μ >)



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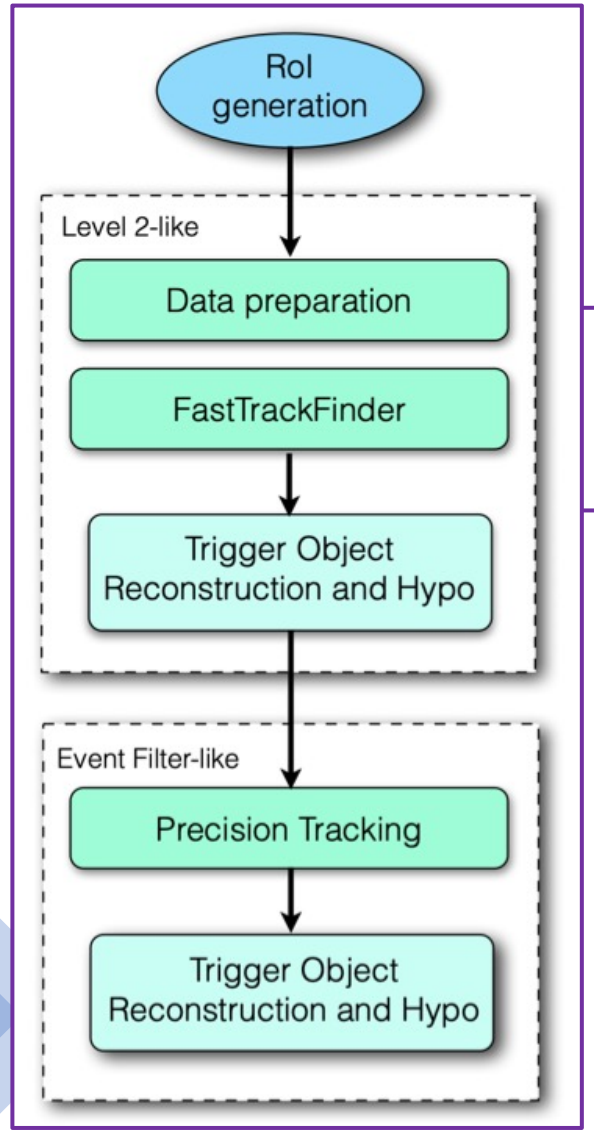

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New Strategy for Run 2 → combine L2 and EF in single tracking stage

- Retrieves ID data to generate **spacepoints** for given **RoI**
- **FastTrackFinder (FTF)** - initial fast track fit optimised for efficiency
- Optional Hypothesis algorithm – apply event selection
- **Precision Tracking** provides offline-like tracking
  - Seeded by FTF for better purity and resolution
  - Extends tracks to **TRT** and removes duplicate tracks

The High Level Trigger

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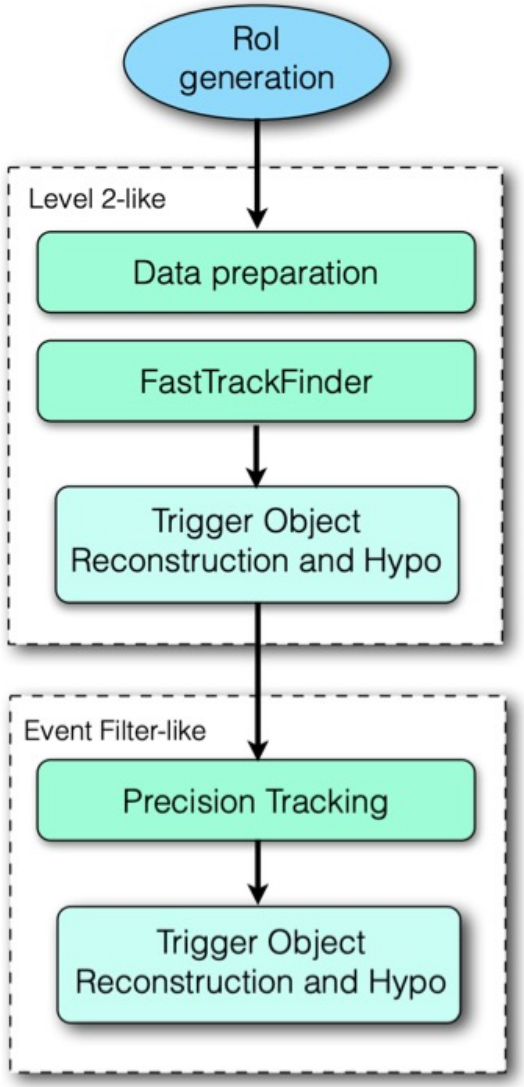

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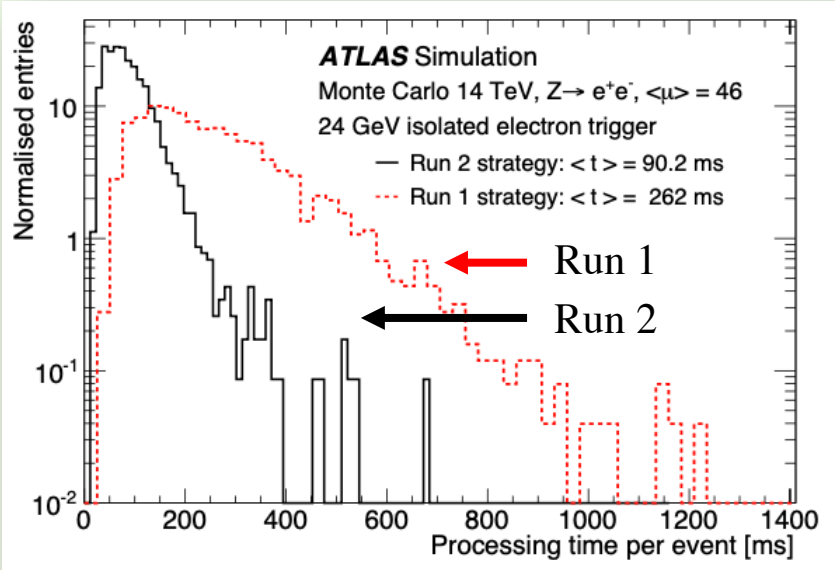
New Strategy for Run 2 → combine L2 and EF in single tracking stage

- Removes **duplicate data preparation** and pattern recognition stages
- Extensive programme of software optimisation
- Run 2 processing time is approx **3x faster** than Run 1



Multi-stage Processing

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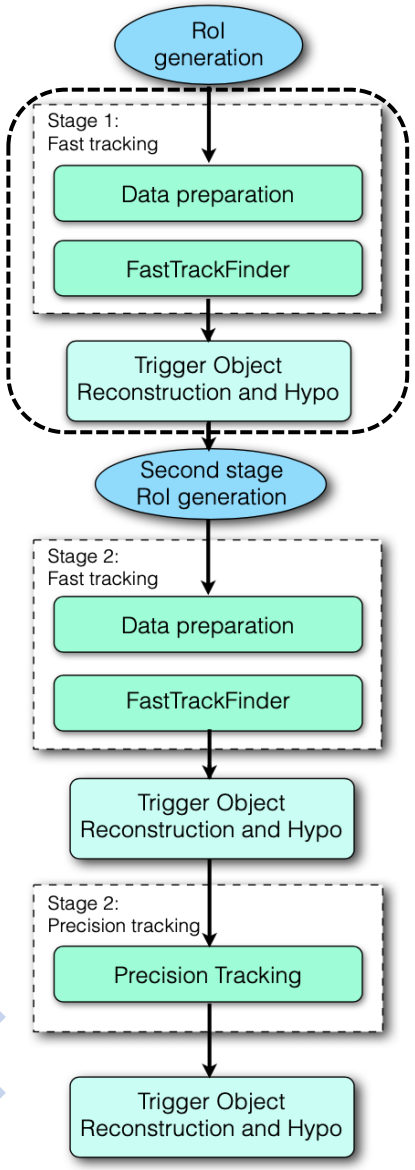


Tau Trigger

- Useful to run the tracking in a **larger RoI** than other signatures
- Very **time-consuming** in Run 1

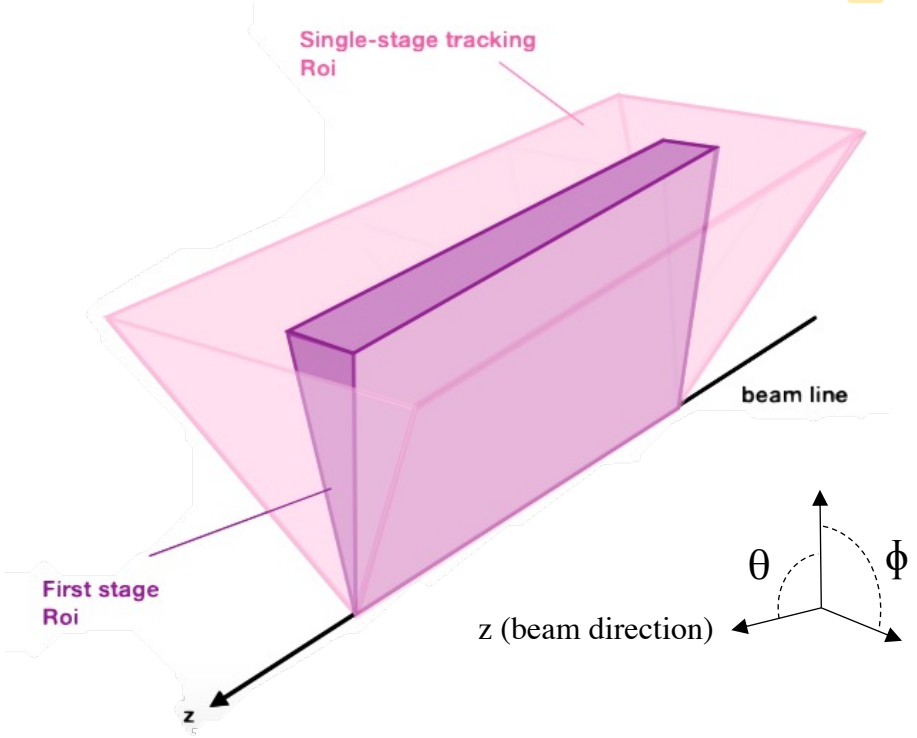
Solution → Use multi-stage tracking strategy

Stage 1

Run Fast Tracking over a **narrow RoI** along the full beam-line (Z)

Stage 2

Run Fast Tracking stage again over restricted Z region for **full η** and **ϕ**



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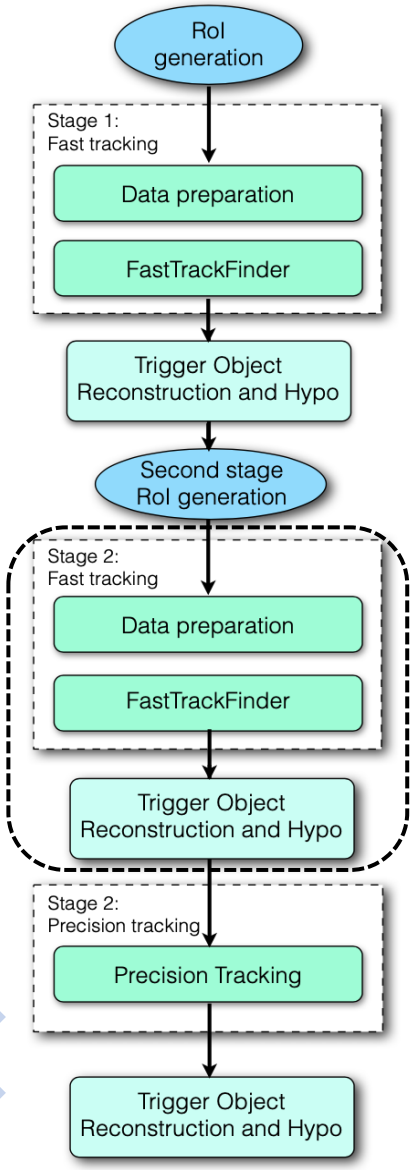

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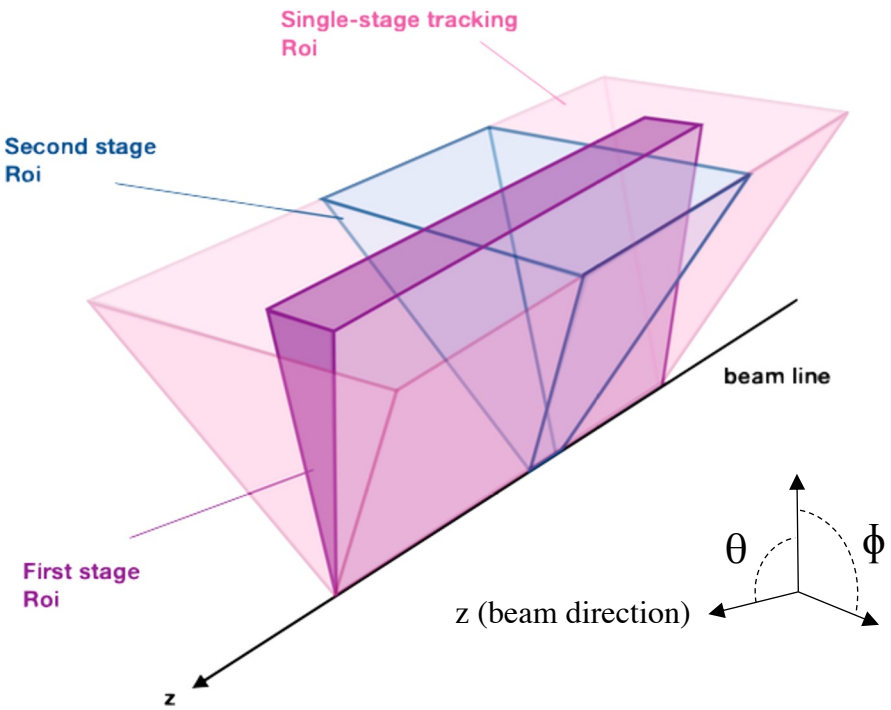
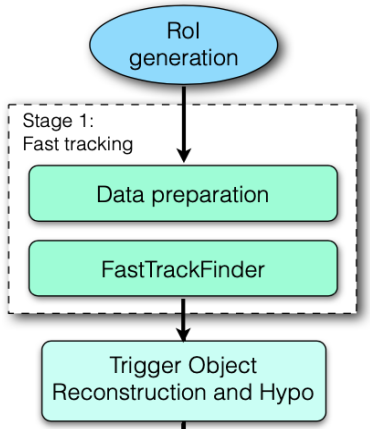


Multi-stage Processing – SuperRoIs



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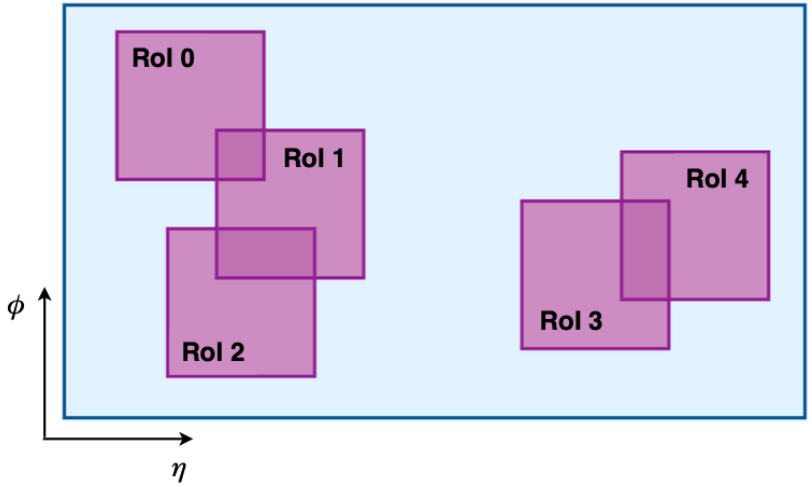
Multi-stage tracking also used in **b-jet triggers**

- Separate RoI created for each jet with $E_T > 30$ GeV
- Run FTF to reconstruct tracks in narrow regions of **η** and **ϕ** for each jet



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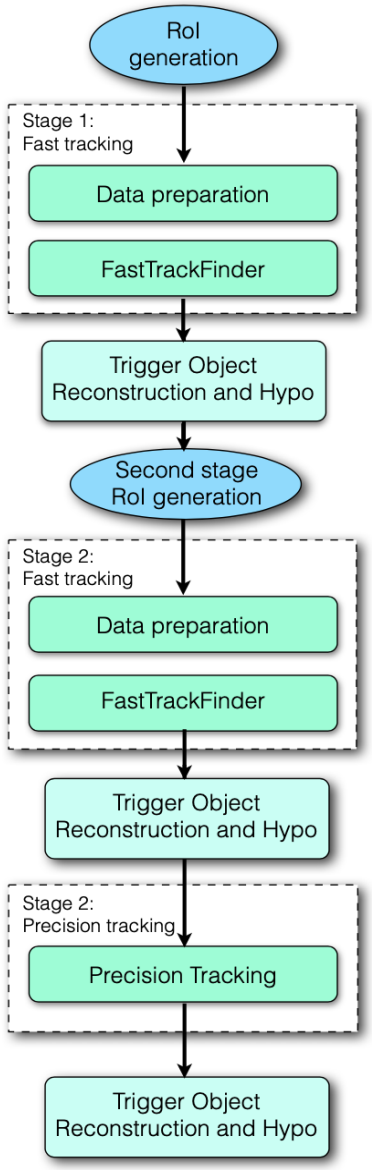
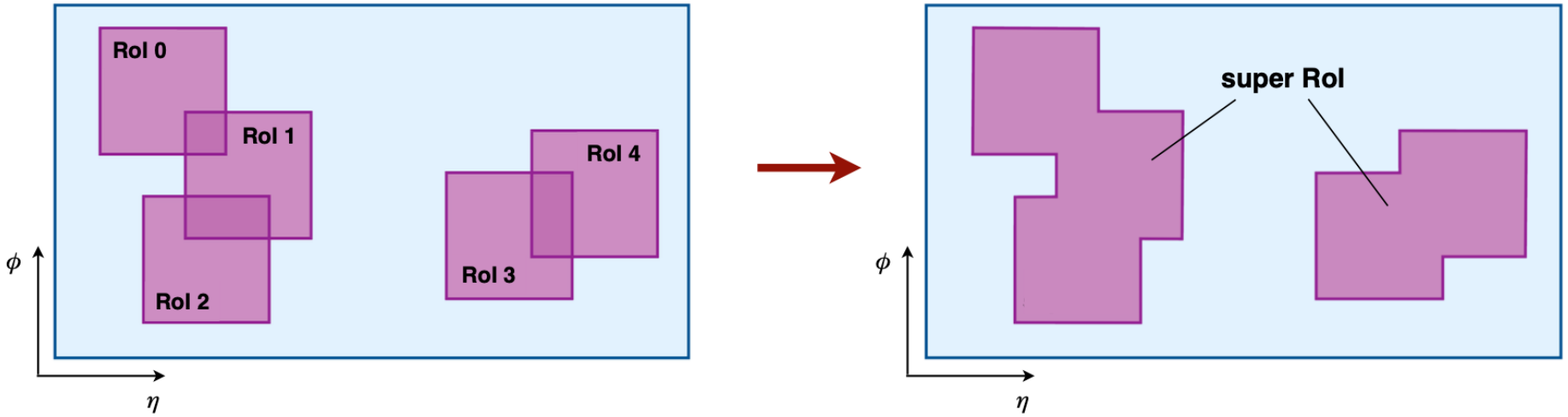


Multi-stage tracking also used in **b-jet triggers**

- Separate RoI created for each jet with $E_T > 30$ GeV
- Run FTF to reconstruct tracks in narrow regions of **η** and **ϕ** for each jet
  - Individual RoIs merged into **SuperRoi** to <u>prevent overlapping regions being processed twice</u>
  - Tracks in SuperRoI used for primary vertex reconstruction
  - Run **second-stage tracking:** FTF, precision tracking, secondary vertexing and b-tagging algorithm over these **modified SuperRoIs**



Signature Timing Performance

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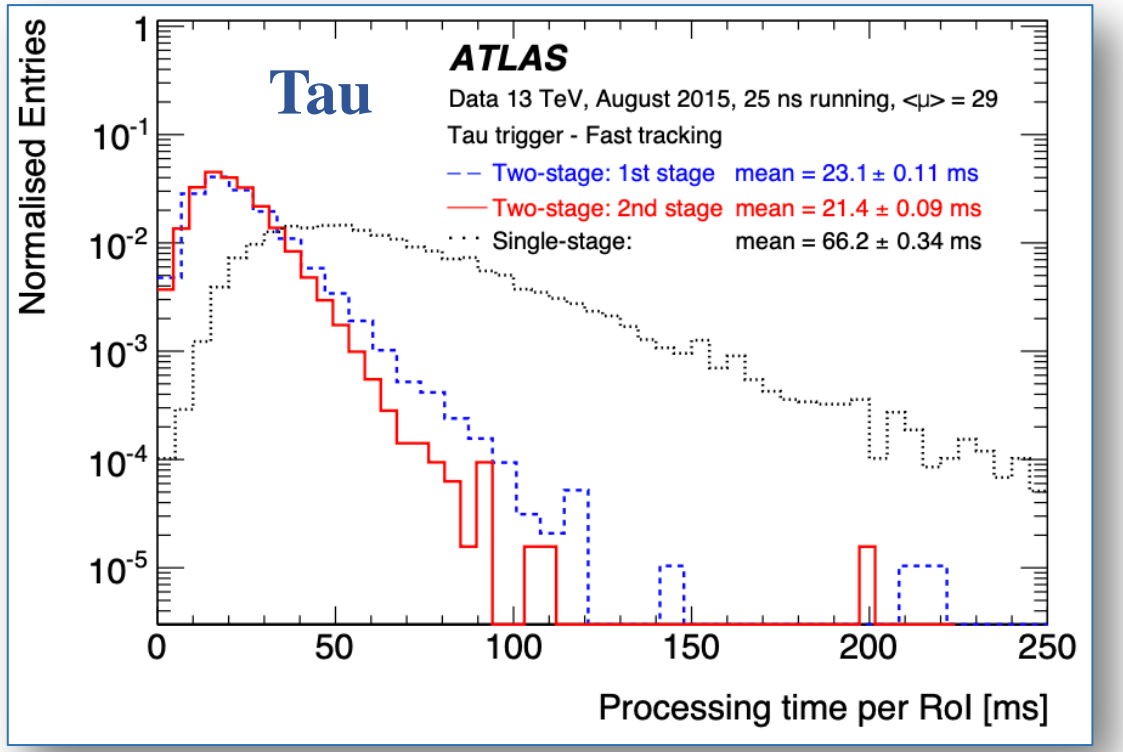


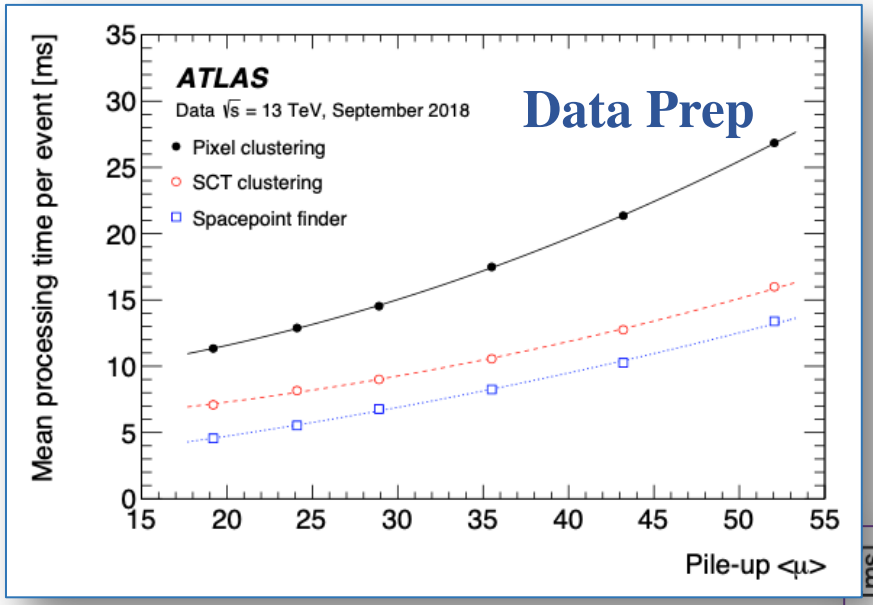
Taus:

- **Multi-stage tracking** reduces overall FTF stage by ~ 30% compared to single stage tracking
- Also reduces average **Precision Tracking** computation time from 12 ms to 5 ms

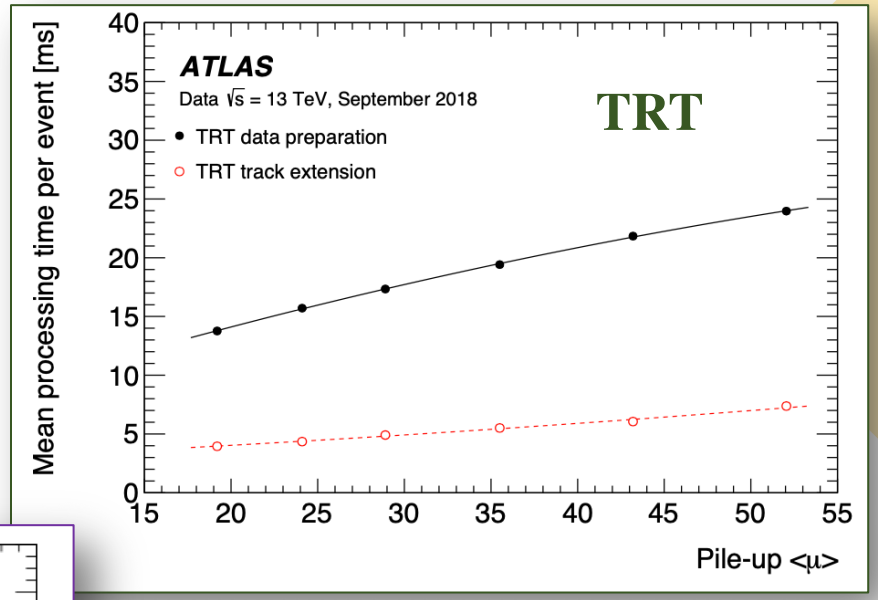
General:

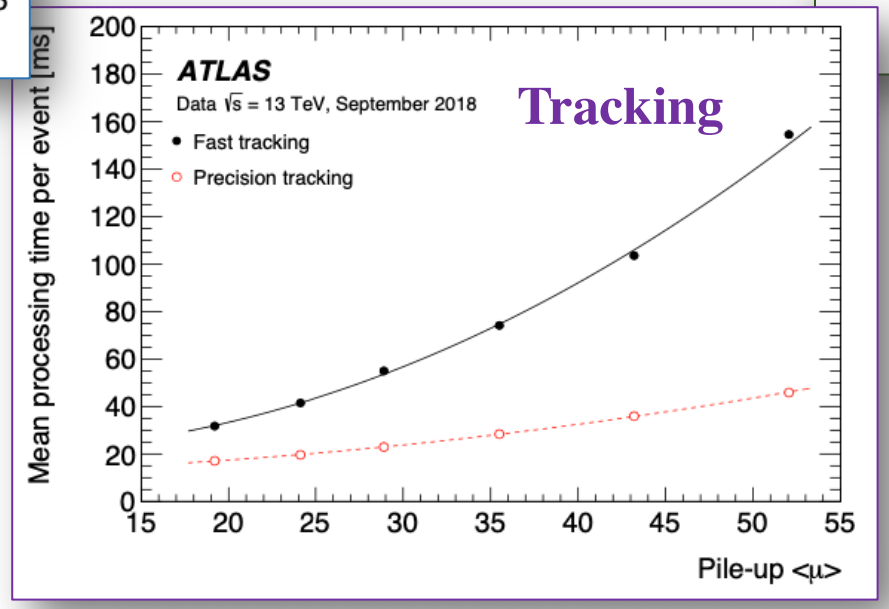
- Electron triggers are the **fastest** of all the signatures
- Data preparation and TRT extension are **fast**
- Additional muon and b-jet plots in the back-up (slide 30)

Total Timing Performance



Total time spent in the **ID Trigger** per event at high pile-up is less than 300 ms





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Lepton Tracking Performance and Resolution

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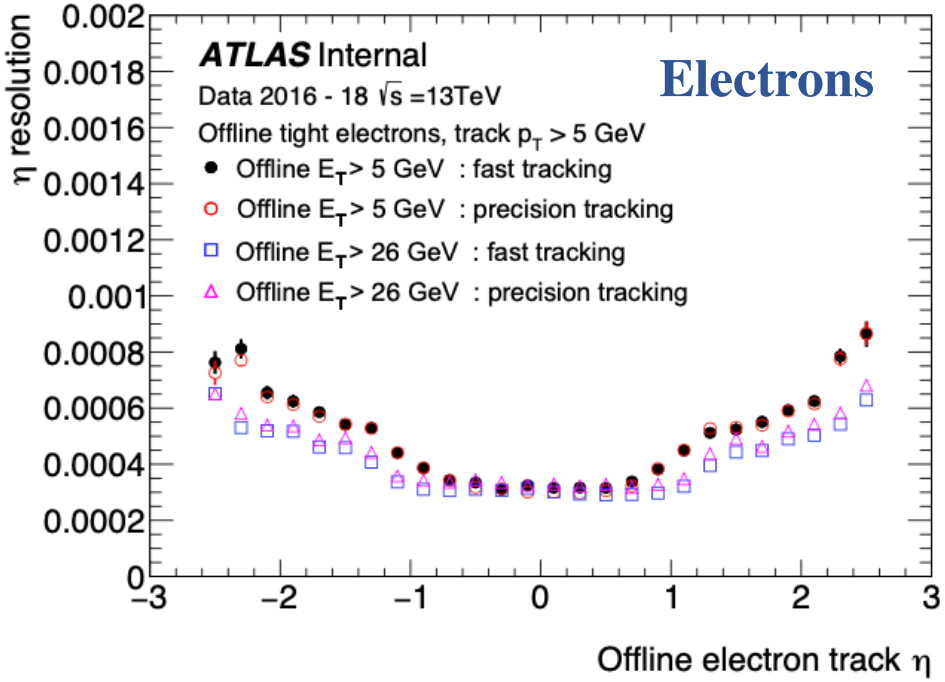
Tracking efficiency and resolutions measured by **comparing** tracks found by **online trigger algorithms** to tracks found by **full offline track reconstruction**

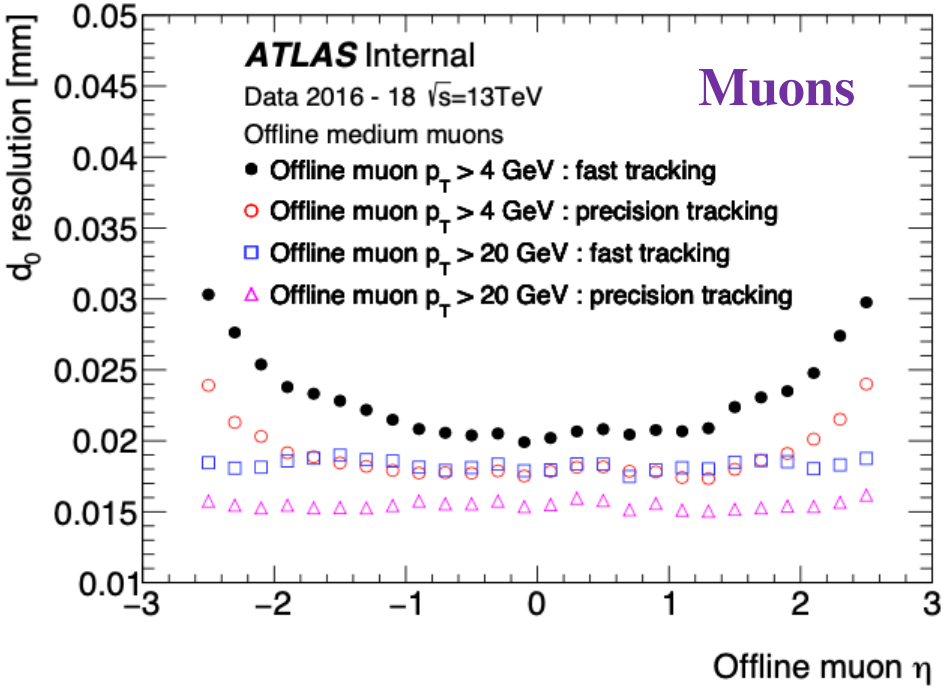
Use ID performance chains → like standard chains but do **not select** on any **tracking quantities**.

- Allows unbiased estimation of the tracking efficiency

A **Tag and Probe technique** is used to select **same flavour lepton** candidates coming from the **decay of Z boson**



Resolution **better than 20 μm** for full range of η for p_T > 20 GeV muons



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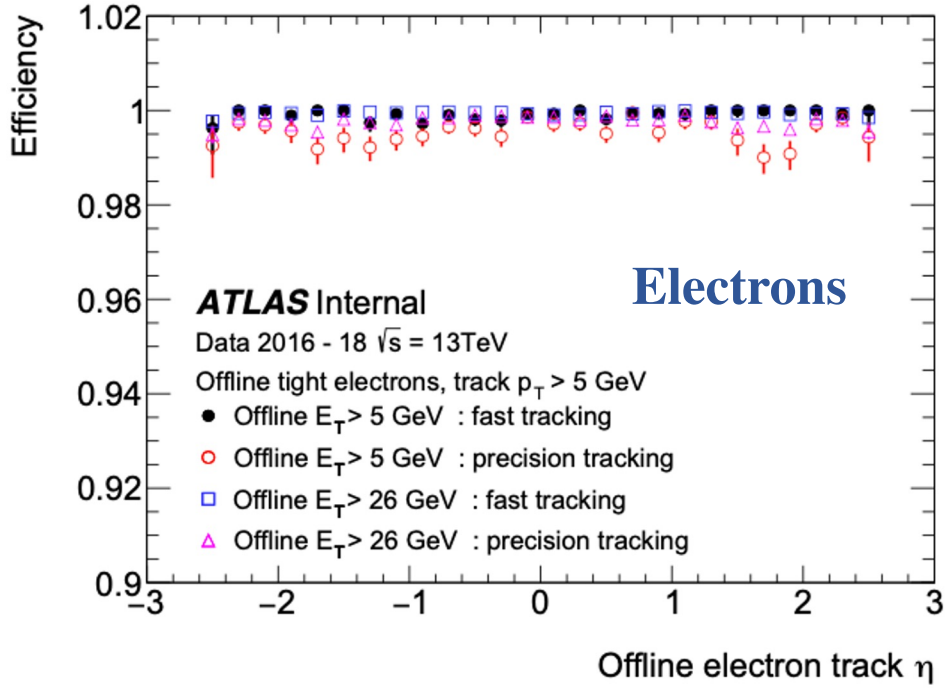
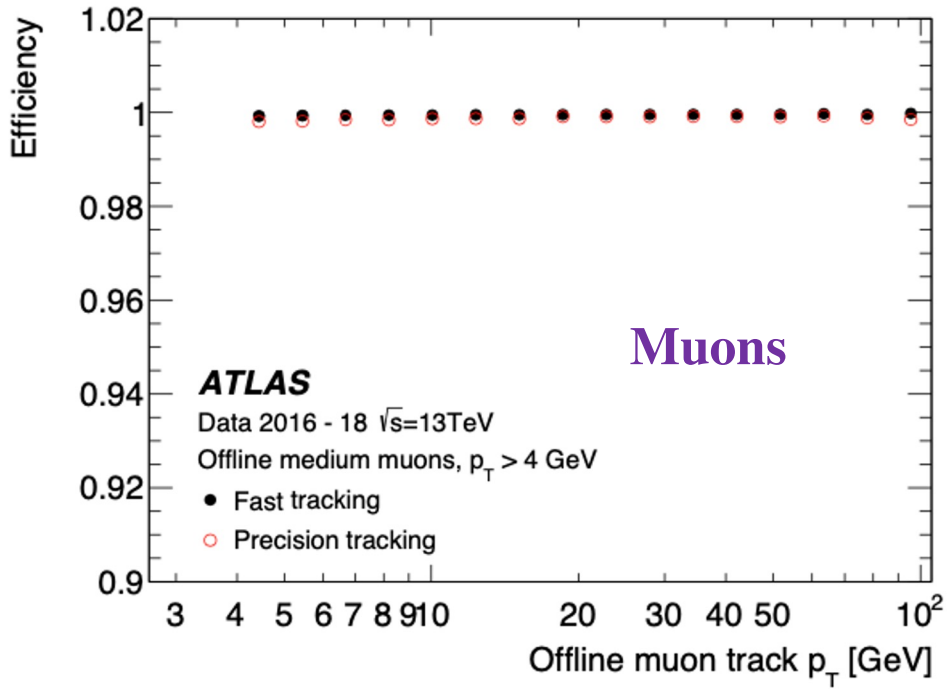


Efficiencies **above 99%** for all p_T spectrum

Small inefficiencies for electrons near transition between **barrel** and **endcap**



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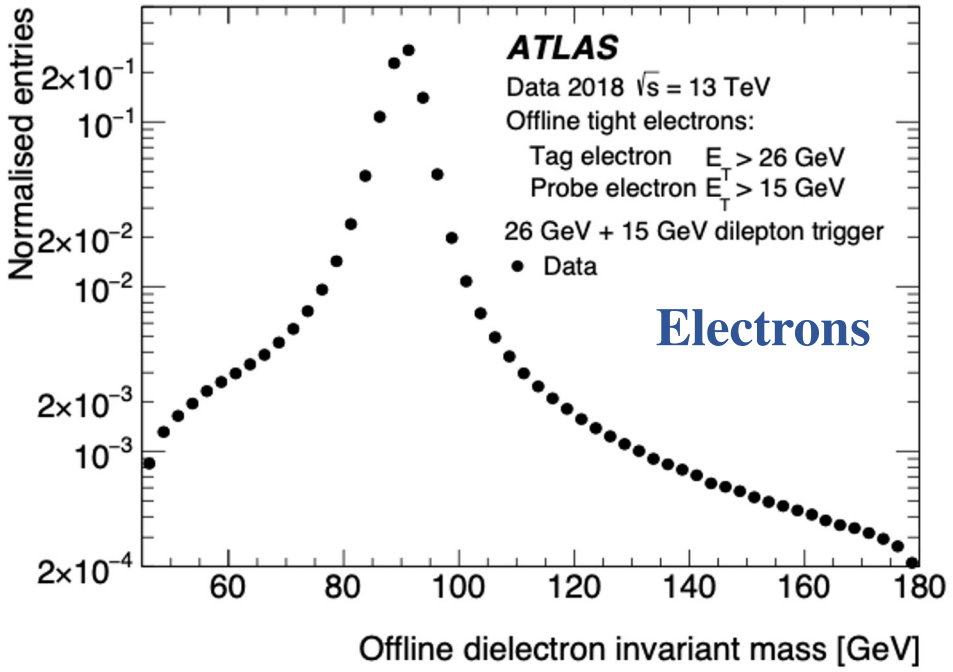
- Allows unbiased estimation of the tracking efficiency

A **Tag and Probe technique** is used to select **same flavour lepton** candidates coming from the **decay of Z boson**

- Tag reduces trigger rate
- Z mass improves purity
- Better statistics
- Unbiased measurement



Tau/bjet Performance and Resolution

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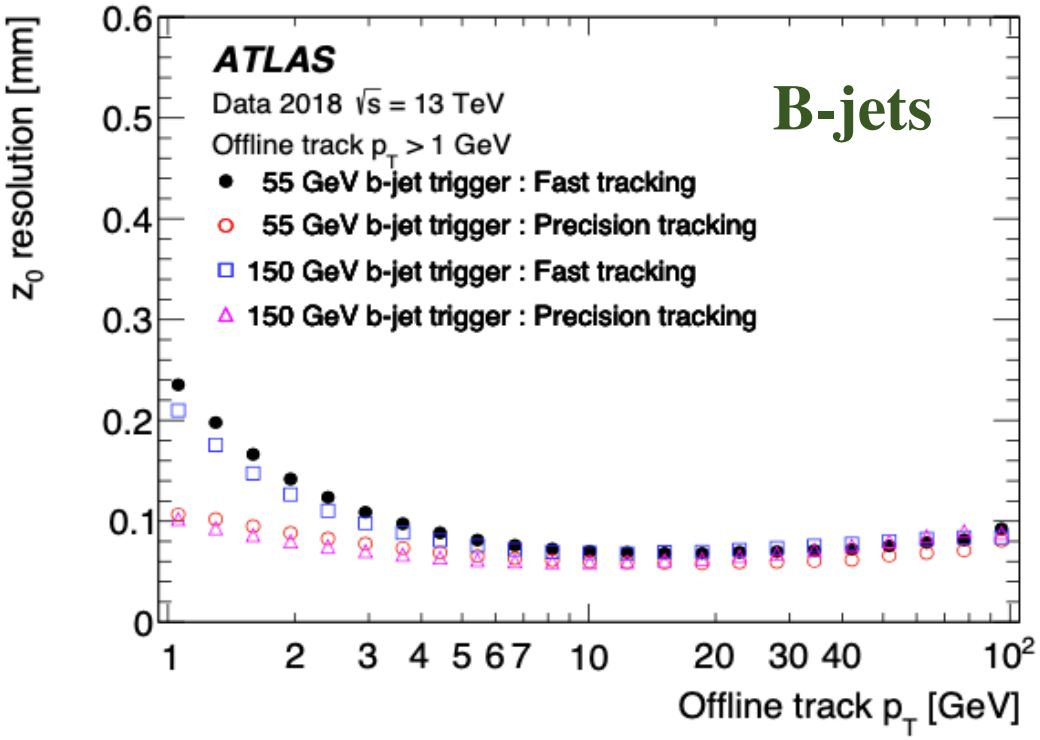
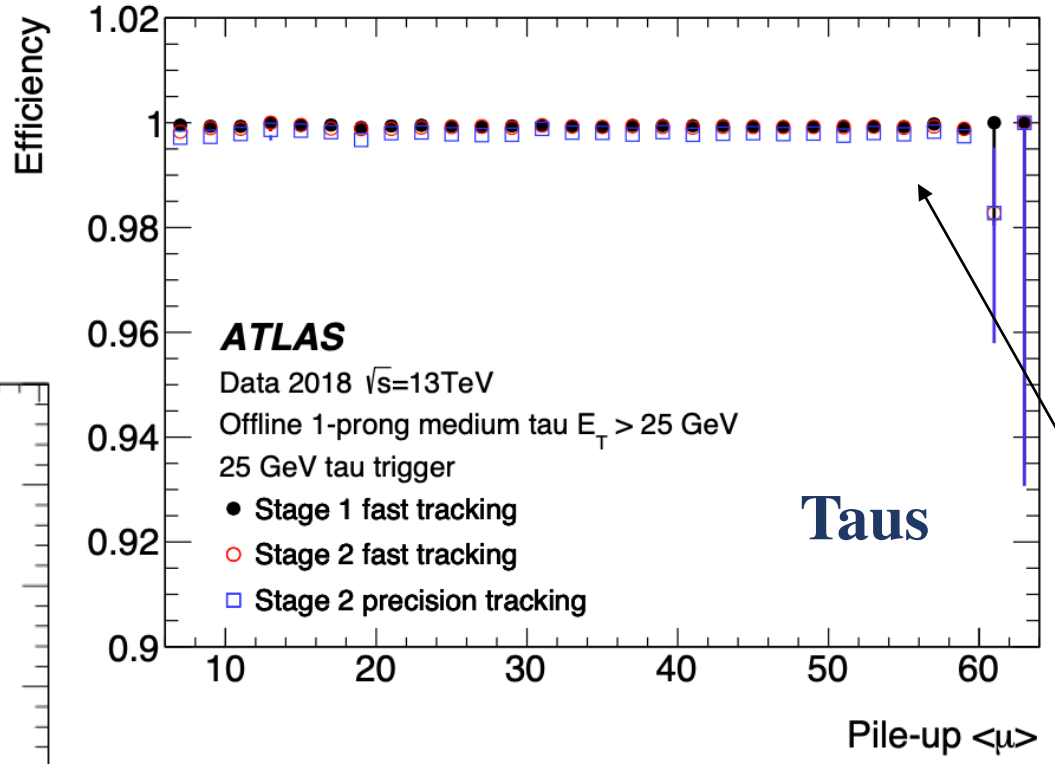
Very good resolutions for b-jet track z-vertex position, $\mathbf{z_0}$, particularly for precision tracking





Efficiency almost constant at **high pile-up**

High efficiency for $E_T \geq 25$ GeV offline taus candidate.

Better than ~99% across all η values

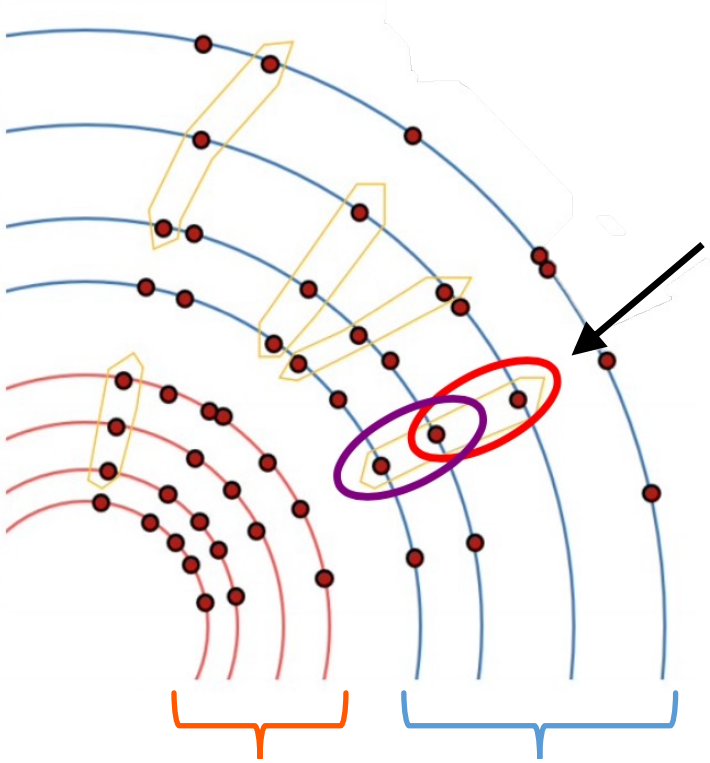
Improvements for Run 3

- ML based Track Seeding
- Full Scan Tracking for Jet/Missing Transverse Energy (MET) Signatures
- Unconventional Tracking

Track Seeding

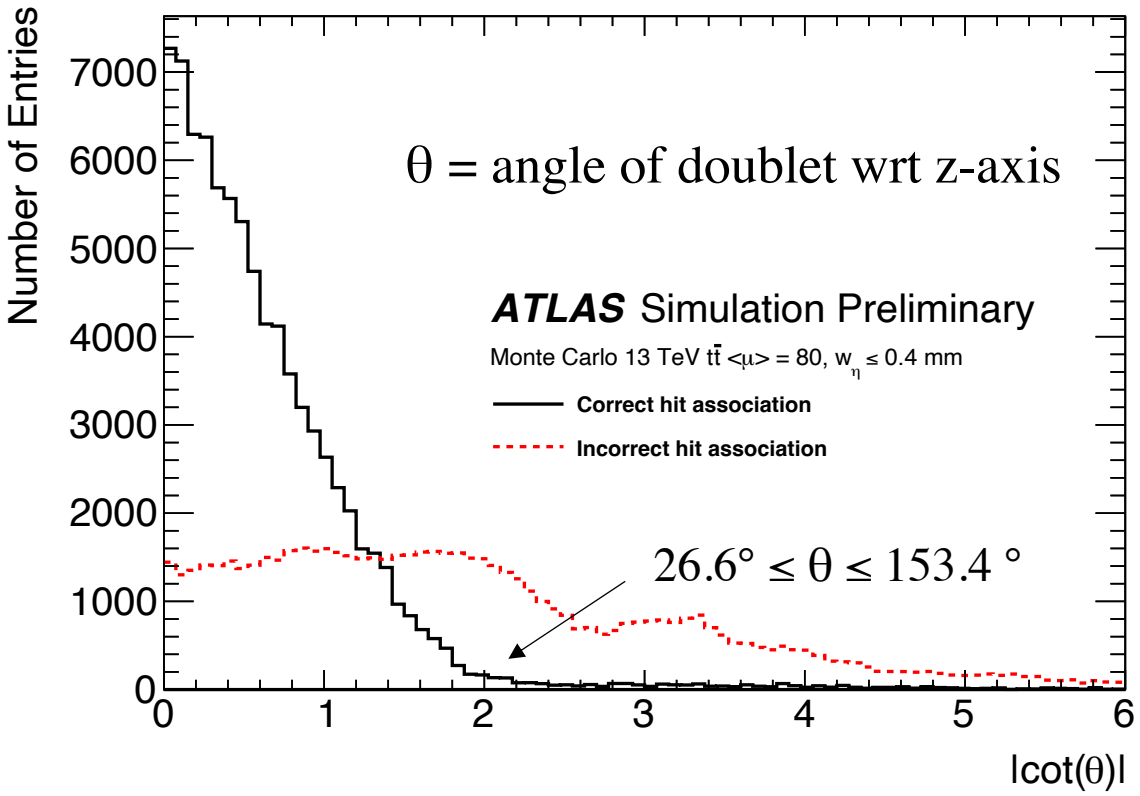
No. seeds dramatically increases with **number of hits** → time consuming in a **high pile-up** environment

ATL-COM-DAQ-2021-003



Pairs of doublets form **triplets** (seeding)

1st step in combining hits into tracks

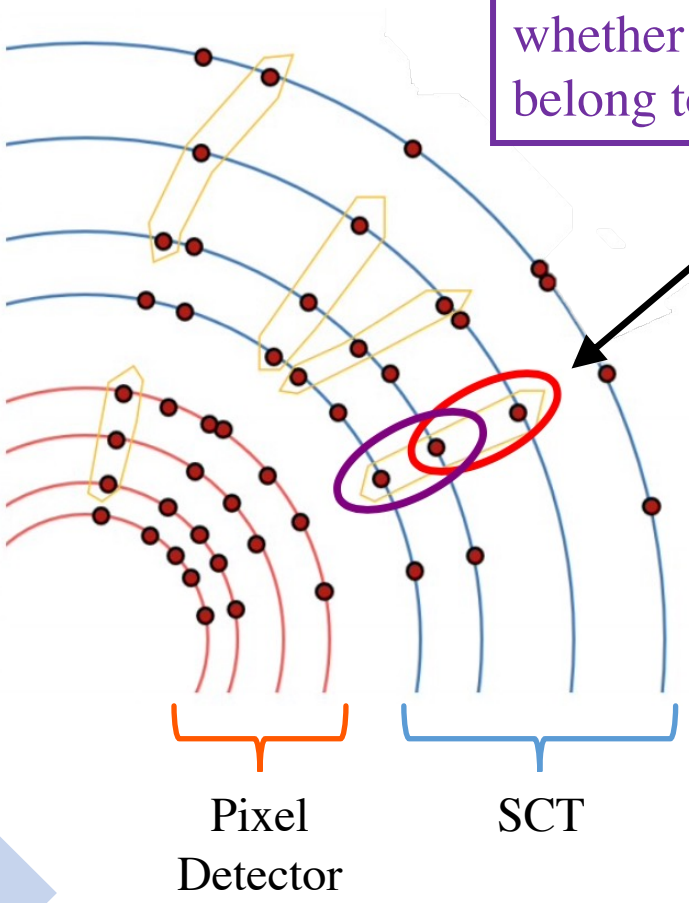


Reject bad seeds early on → reduce time spent on **track seeding**
save CPU time in **tracking** stage

ML based Track Seeding

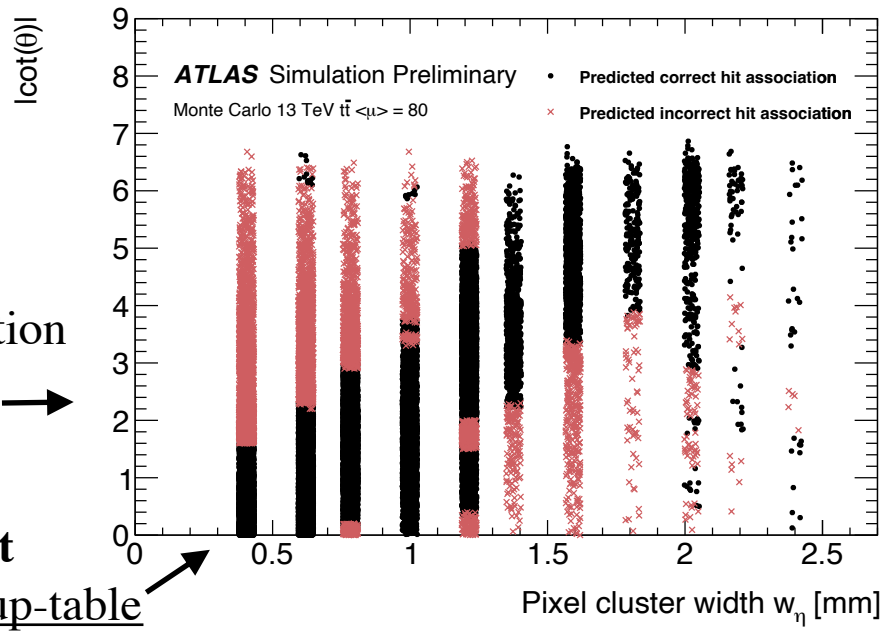
ATL-COM-DAQ-2021-003

Train a **classifier** to predict whether a doublet of **spacepoints** belong to the same track



Base classification on inclination angle, **θ** and width of pixel clusters (in η), $\mathbf{w_\eta}$

Use predicted region of **correct association** to a track as look-up-table



- **Faster** seeding and track fitting
- Small loss in efficiency when using ML vs not

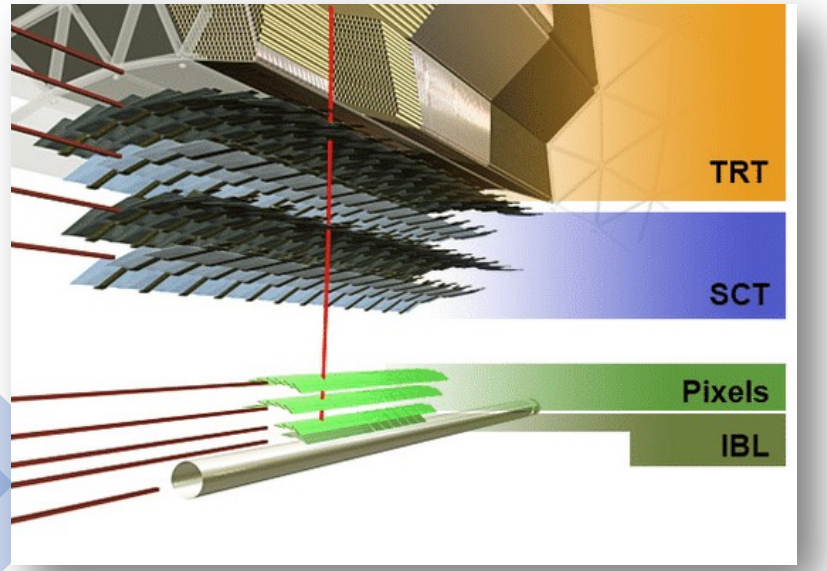
$< \mu >$	Efficiency Loss (%)	Total Speed-up Factor
40	0.7	1.6×
60	0.7	2.1×
80	1.1	2.3×

Total Speed-up Factor	Seed Generation	Seed Processing	Track Fitting
2.3×	1.3×	3.3×	1.5×

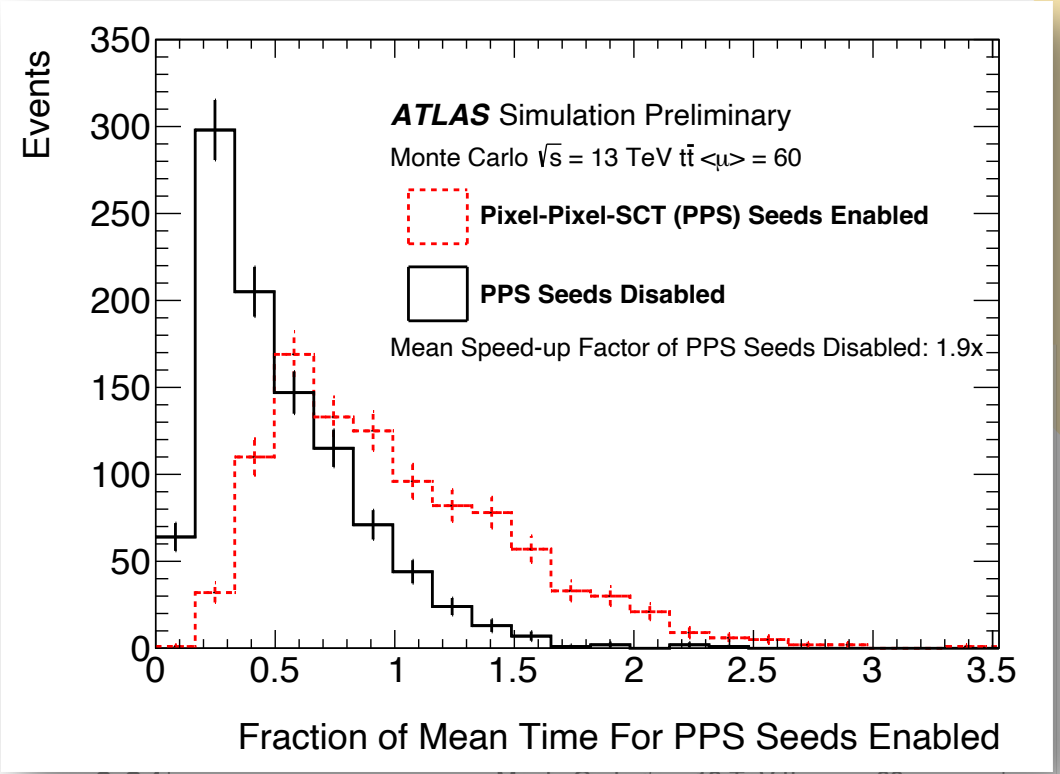
Optimization of Full Scan Tracking for Jet and MET Triggers

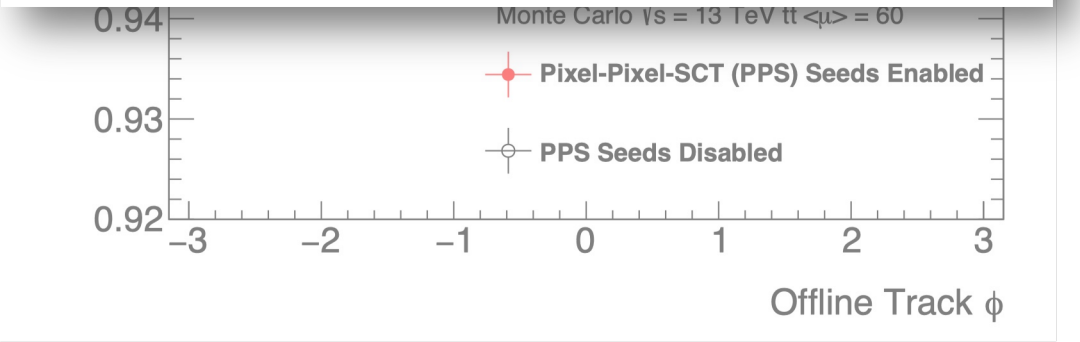
ATL-COM-DAQ-2022-022

- **Triplets** formed with a mix of Pixel detector (Pixels) and SCT hits
- Mixed seeds (e.g. **PPS**) were more time consuming to process
- Likely due to larger gap between the Pixels and SCT than between individual layers



- Using **'PPP'** and **'SSS'** only speeds up mean FTF event processing time by **1.9x**
- <1% drop in efficiency

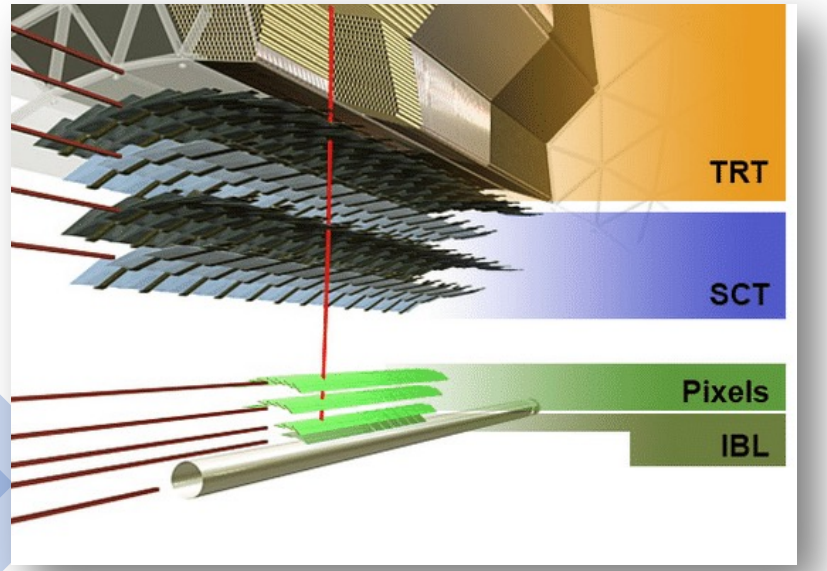




Optimization of Full Scan Tracking for Jet and MET Triggers

ATL-COM-DAQ-2022-022

- **Triplets** formed with a mix of Pixel detector (Pixels) and SCT hits
- Mixed seeds (e.g. **PPS**) were more time consuming to process
- Likely due to larger gap between the Pixels and SCT than between individual layers



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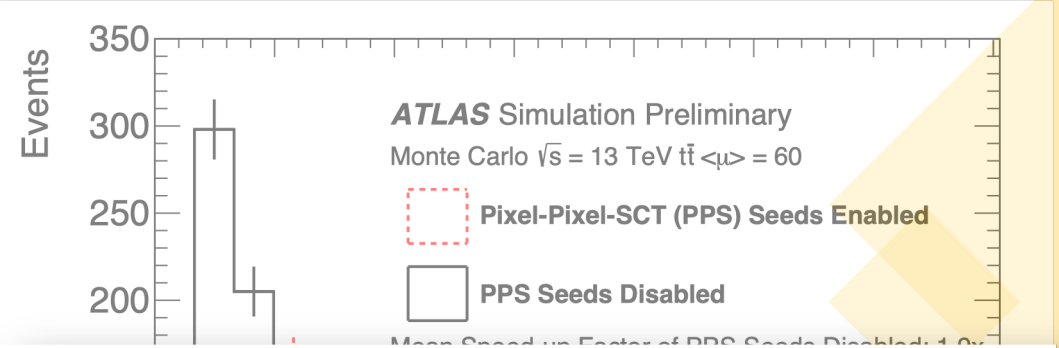
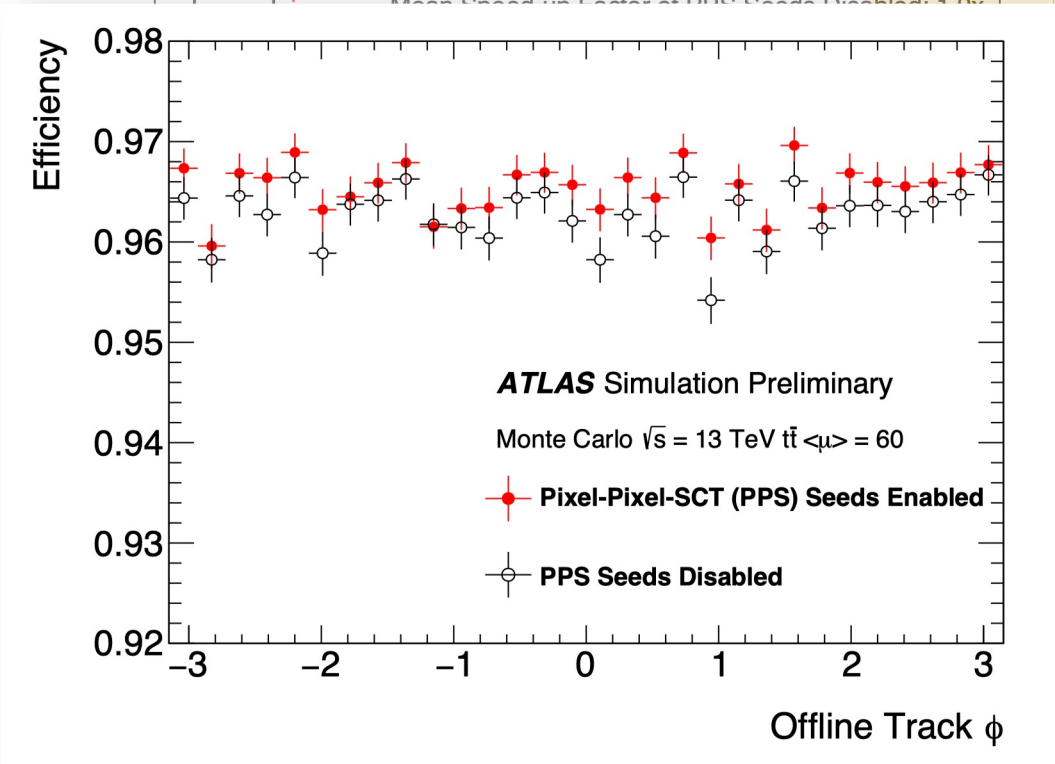
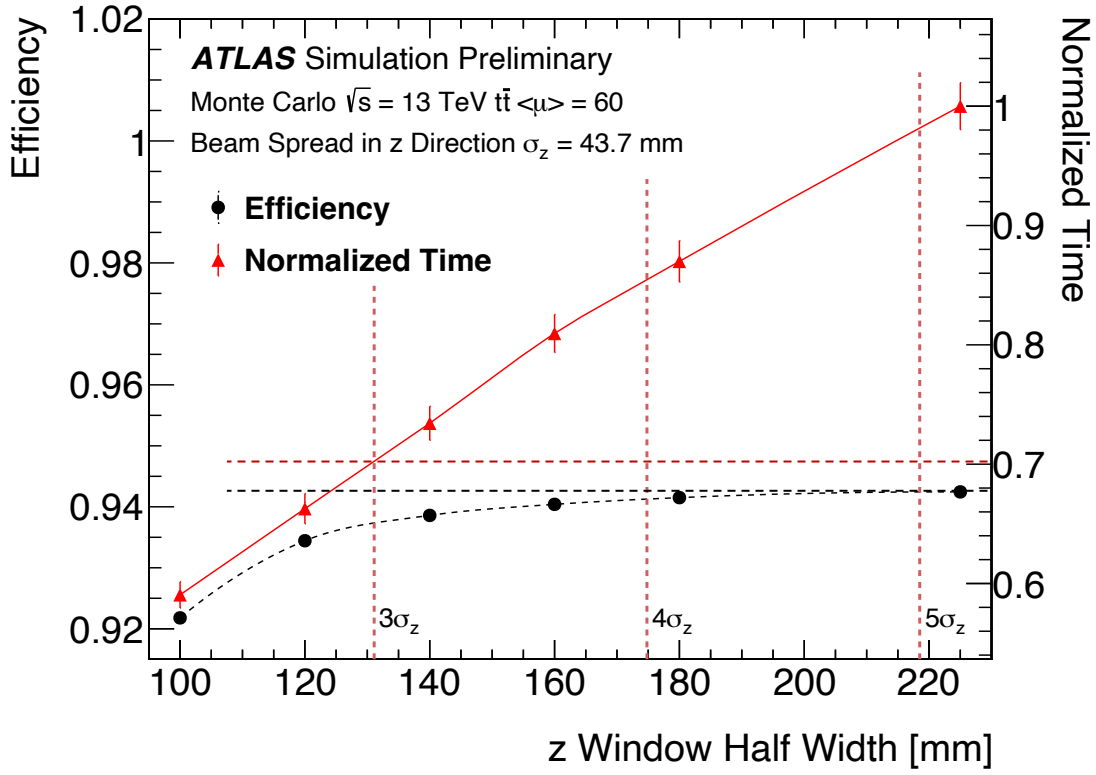




Full Scan Z-width + Unconventional Tracking for LLPs

ATL-COM-DAQ-2022-022

- **Restricting Z RoI** width in reduces processing time
- <1% efficiency decrease for up to **30% faster processing time** at z = 130 mm



CPU time normalized to mean time for z = 225 mm

Long-Lived Particles (LLPs)

- Standard tracking used in Run 2 **not viable** for most LLP signatures
- Searches **relied on calorimeter/muon spectrometer** but these had low acceptance for LLPs

New Run 3 triggers to directly target events with **disappearing tracks** and **displaced leptons**

- Disappearing Track Trigger
  - Improves acceptance over pure MET Trigger
- Large Radius tracking (LRT)
  - Reduced fakes and improved processing time

Link to ICHEP Poster

ATL-COM-DAQ-2022-023

Conclusion

ID Trigger is a **crucial** part of the ATLAS trigger system

- Excellent tracking performance during Run 2
  - Tracking efficiency is very high compared to offline tracking, even at high pile-up multiplicities
- Without the ID Trigger, it would not be possible to achieve the performance needed for the ATLAS physics program

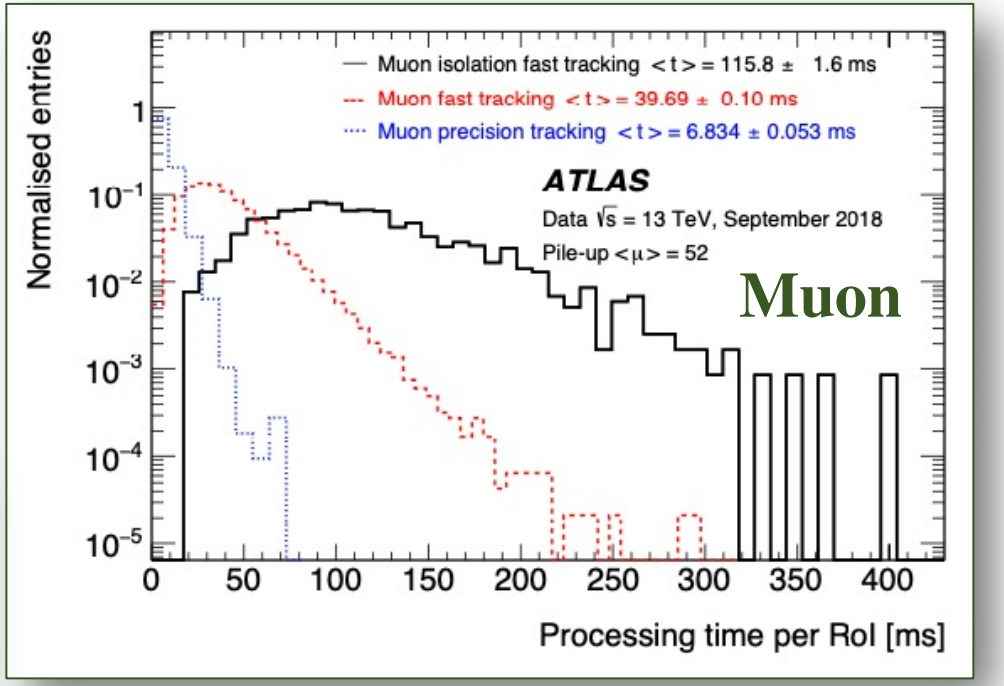
Significant **improvements** to the trigger in preparation for Run 3 conditions

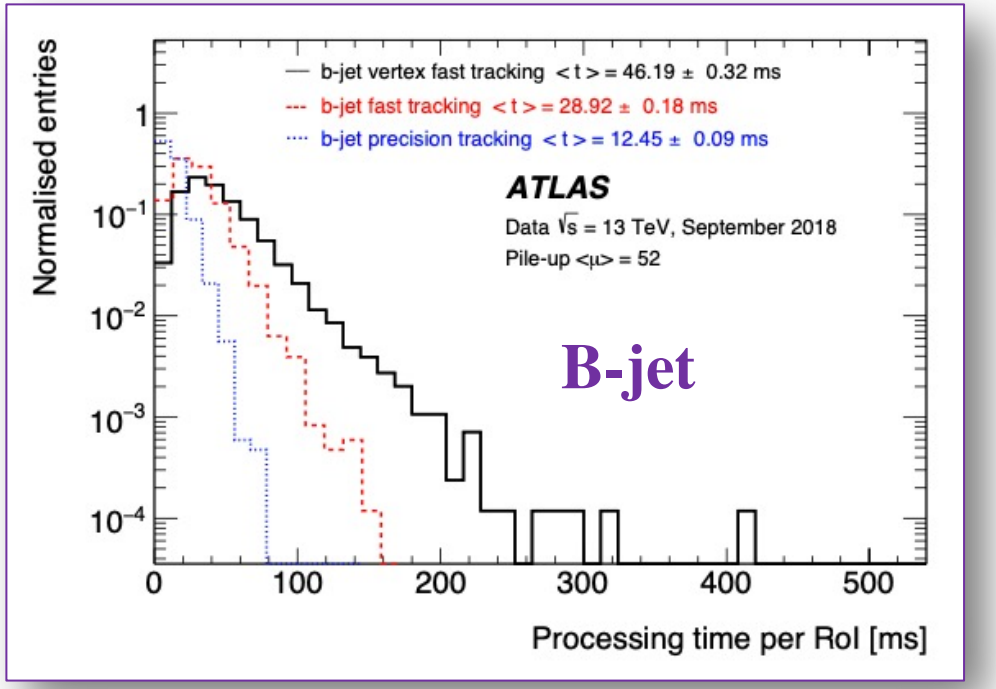
- Improvements to tracking algorithms
- Expanded use of Full Scan tracking
- New triggers targeting LLPs

Back-up

Signature Timing Performance

- **Pattern recognition** for the first stage tracking ran only for tracks with **$p_T > 5$ GeV**
- **Vertex tracking** is the longest due to volume of the detector to be processed
- **Execution time** for vertexing is fast compared to tracking

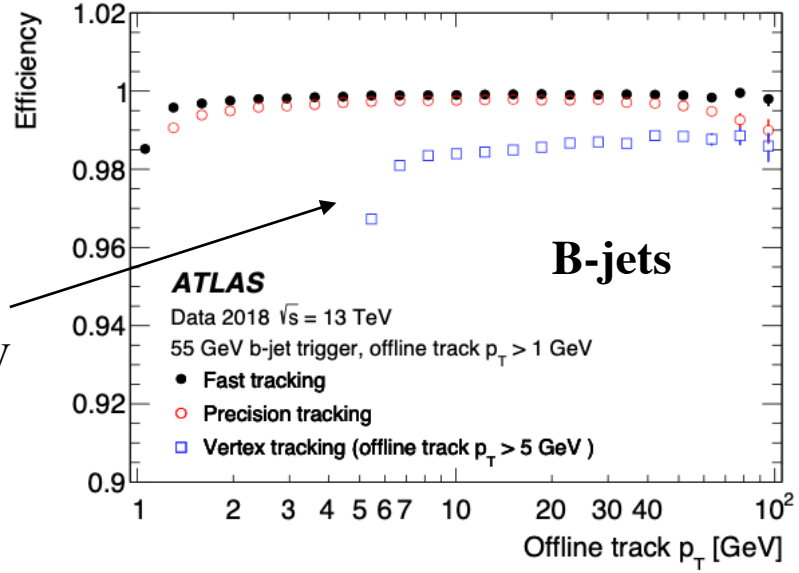


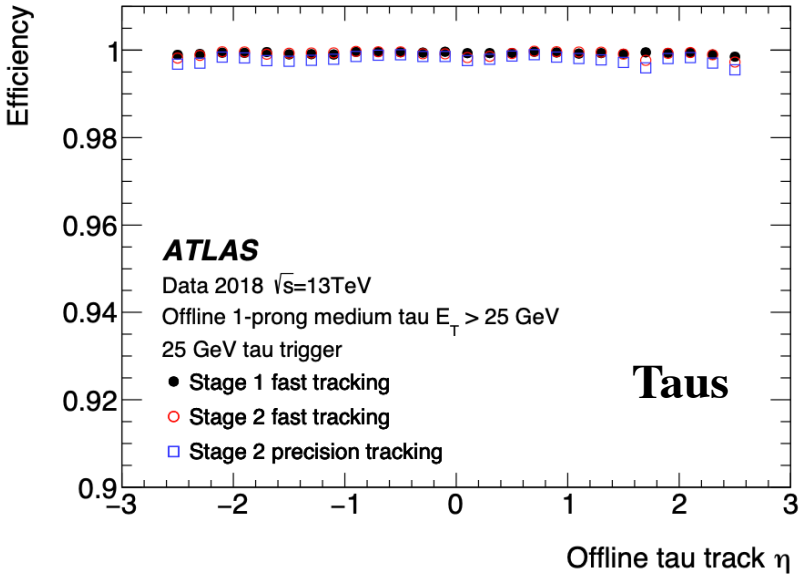


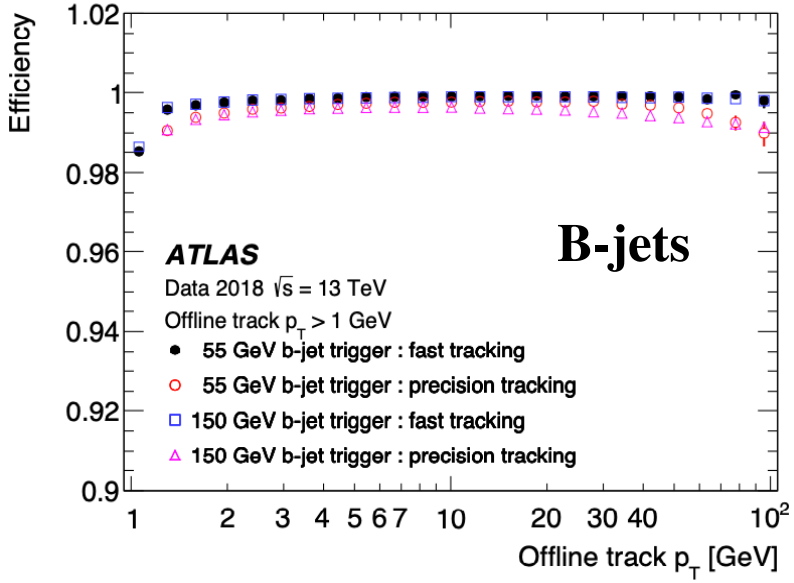
- **Clustering and Spacepoint** formation is fast: 4-10 ms
- **FTF** mean of 40 ms, **PT** of 7 ms
- **TRT** extension is also fast: under 10 ms
- Sum of mean times < 200 ms

Signature Performance and Resolution

Vertex tracking runs on tracks with $p_T > 5$ GeV

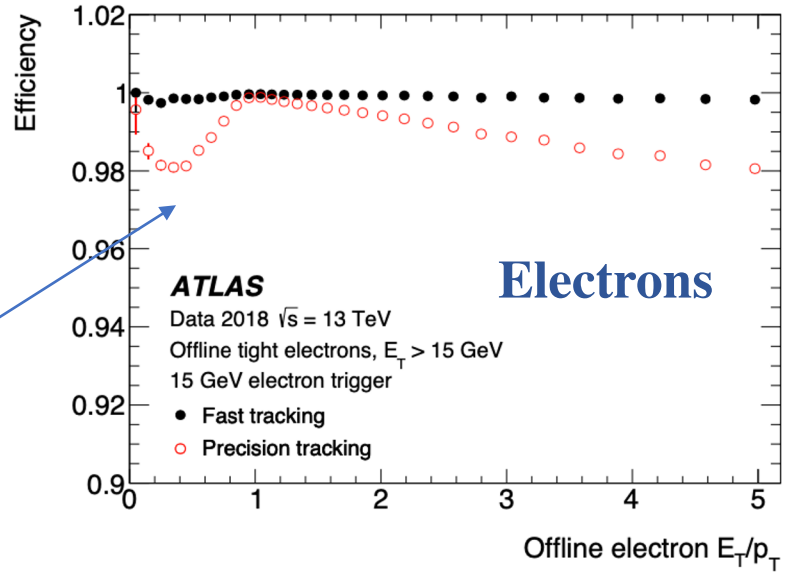




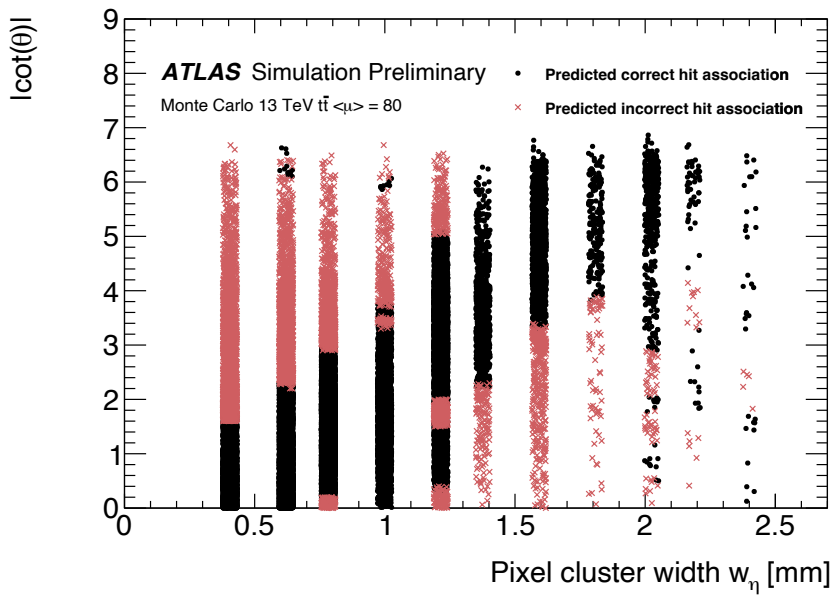


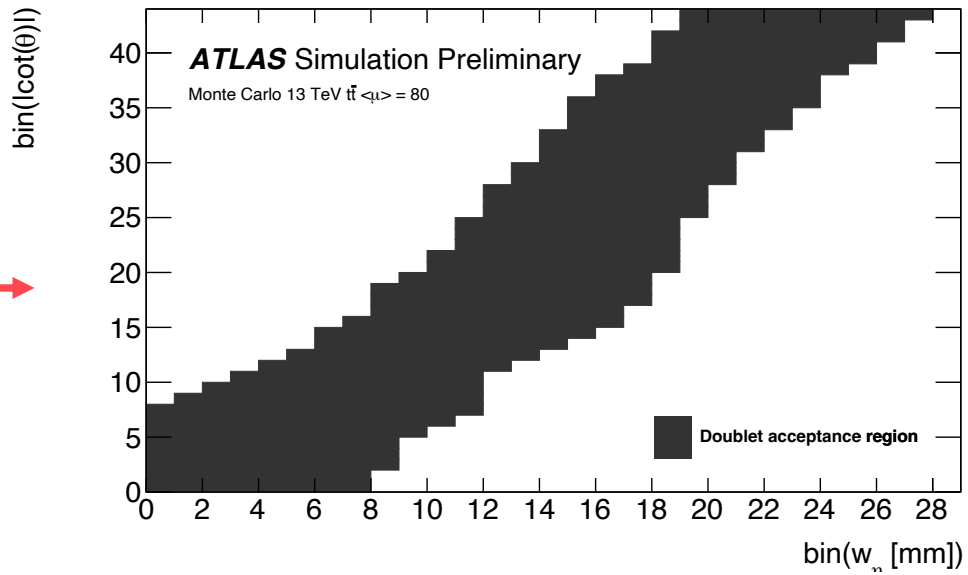
Reduction in efficiency for candidates where the offline track p_T is poorly reconstructed

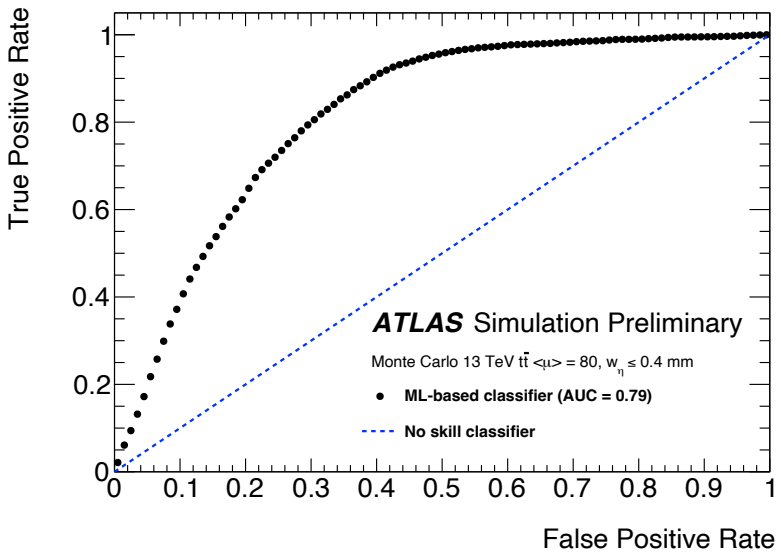
- **$E_T/p_T > 1$:** Bremsstrahlung
- **$E_T/p_T < 1$:** electrons with less well constructed track p_T



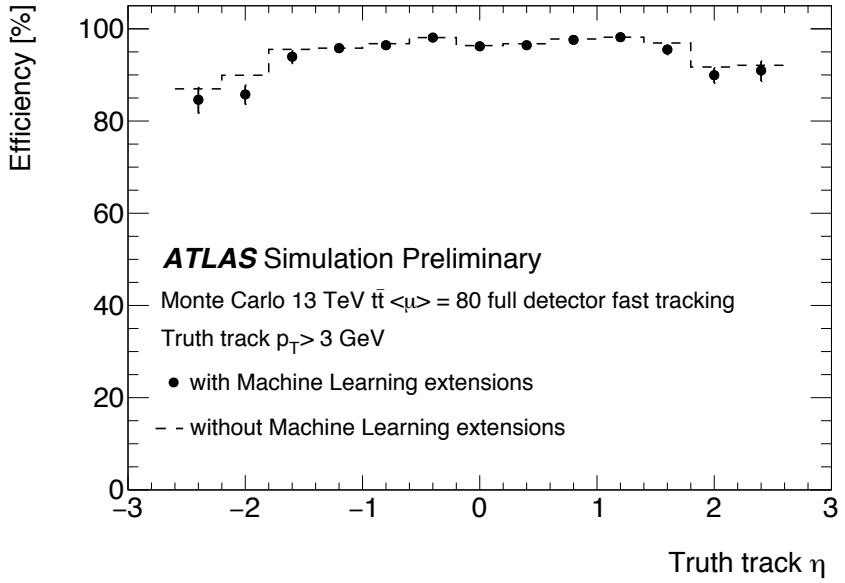
ML based Track Seeding



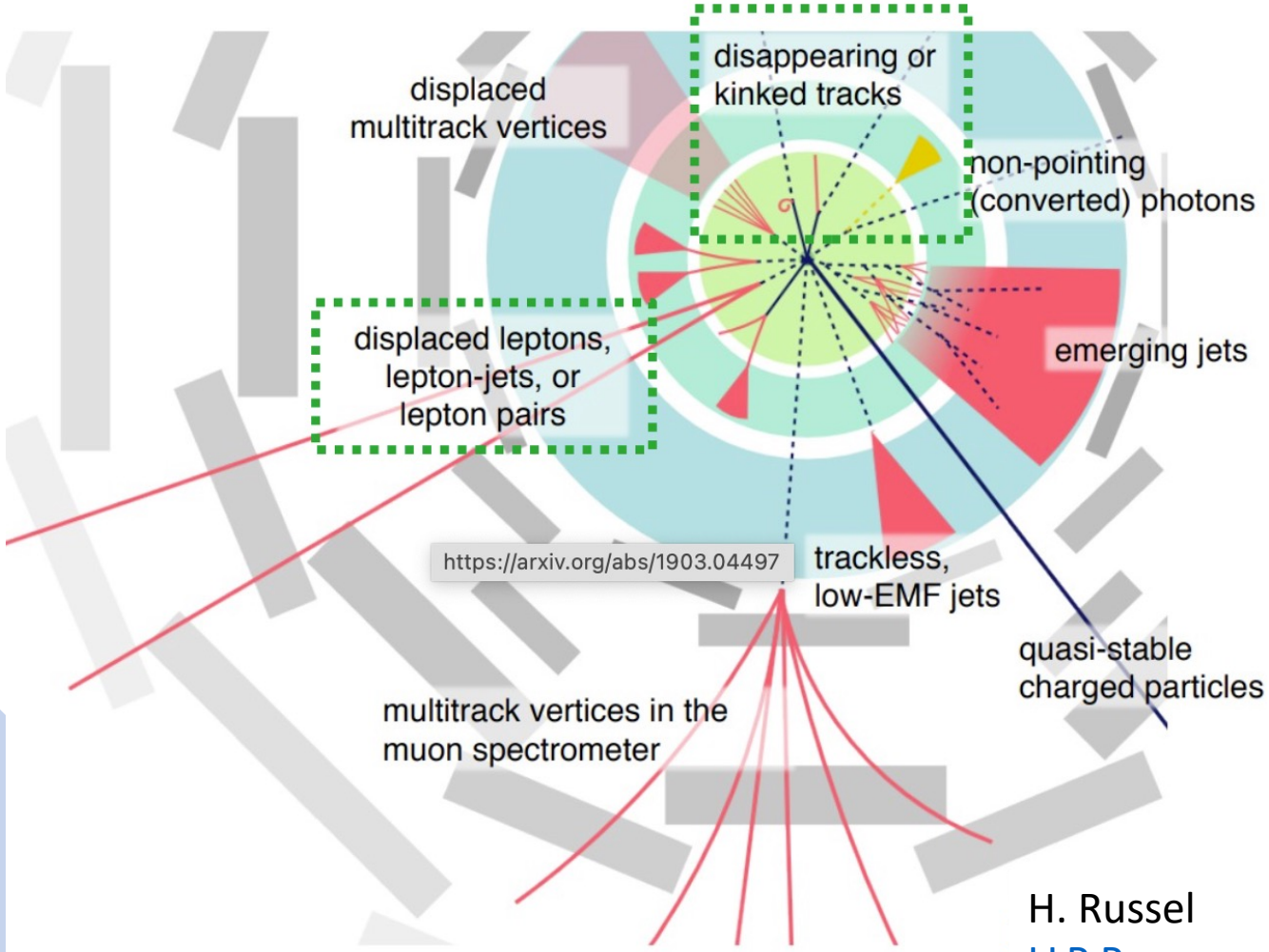




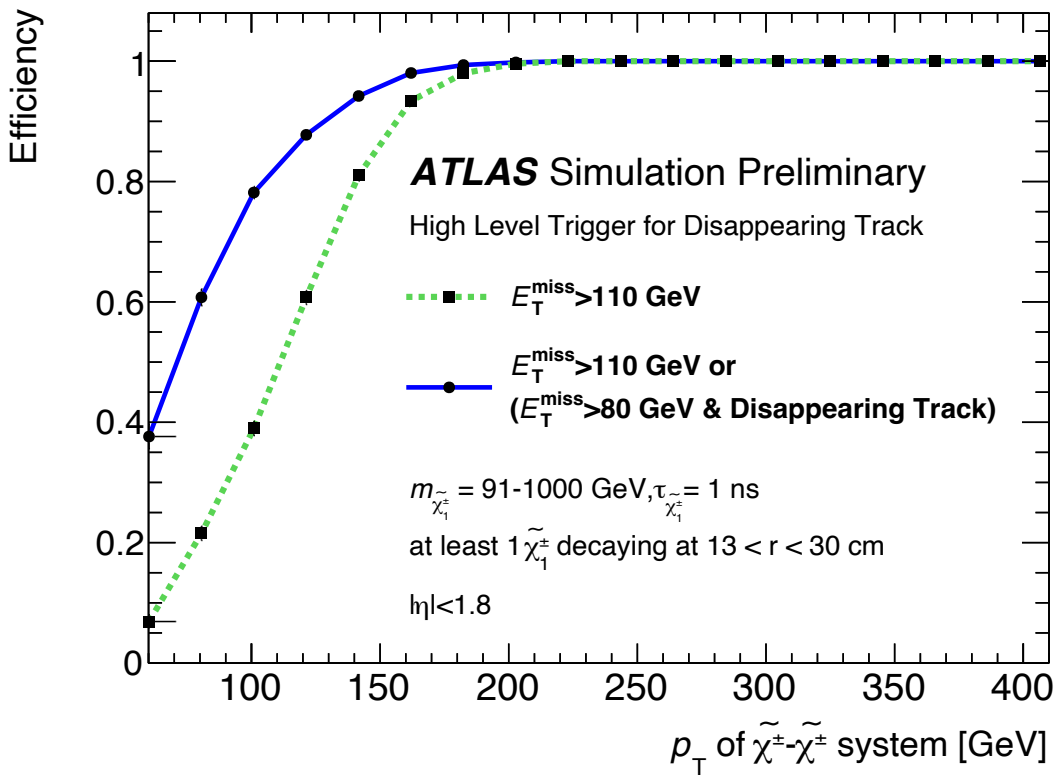
- Predicted acceptance region becomes **look-up-table**
- Small sacrifice in efficiency



Unconventional Tracking



H. Russel
LLP Paper



Improves acceptance over pure MET trigger for lower momentum models!