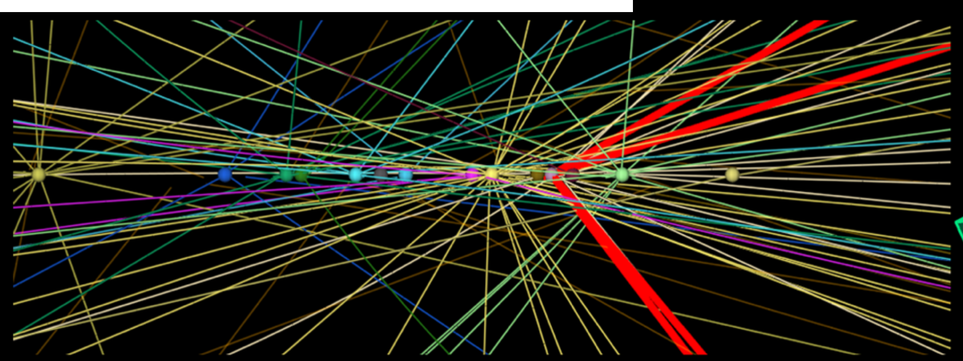
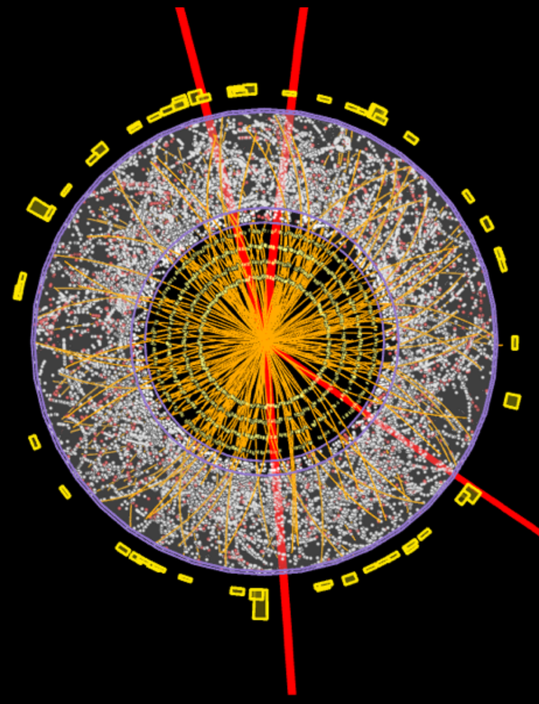
# The ATLAS Trigger for Run 3

Mark Sutton

13th October 2021







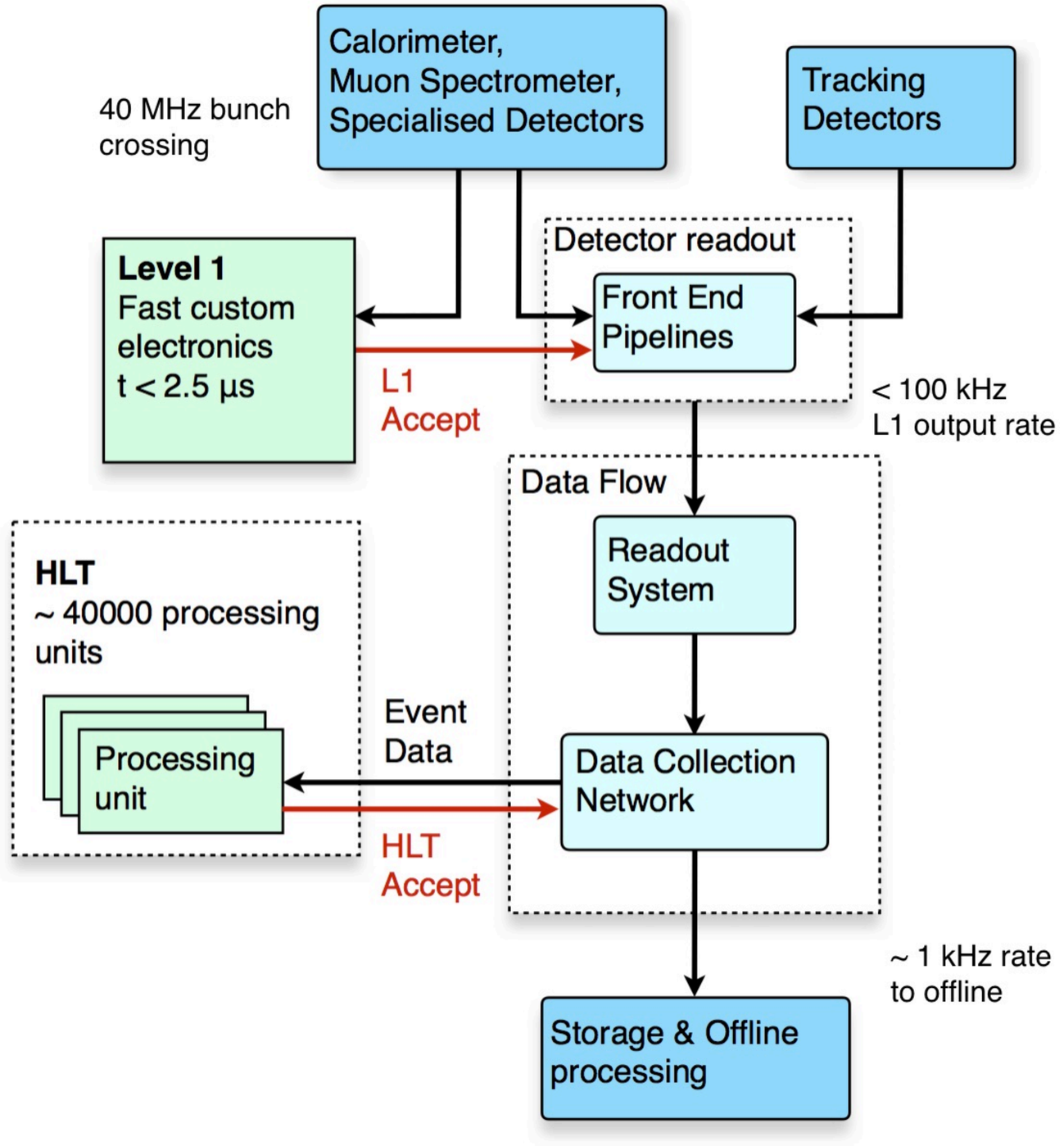
ATLAS EXPERIMENT
http://atlas.ch

Run: 204769
Event: 71902630
Date: 2012-06-10
Time: 13:24:31 CEST

LHC bunch crossing: 40 MHz
pp interactions per bunch crossing: ~ 50
Each second there are …
~ 200 million separate pp interactions
~ 1 Higgs candidate

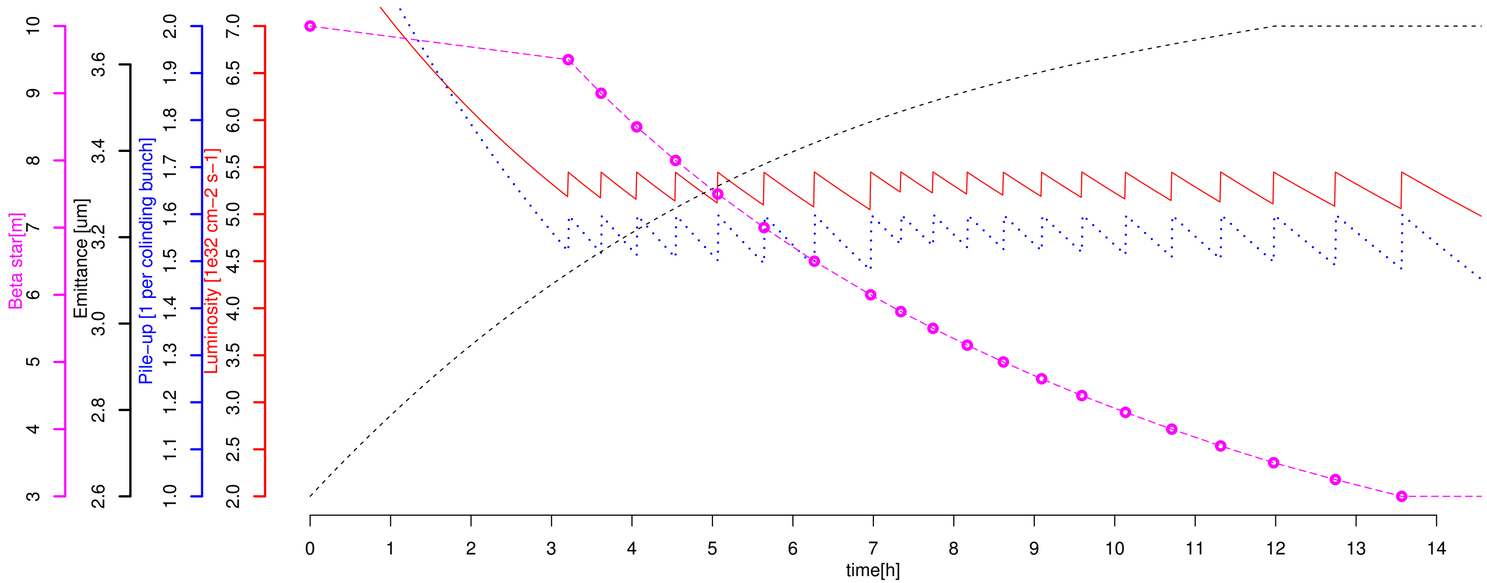
# The ATLAS Trigger

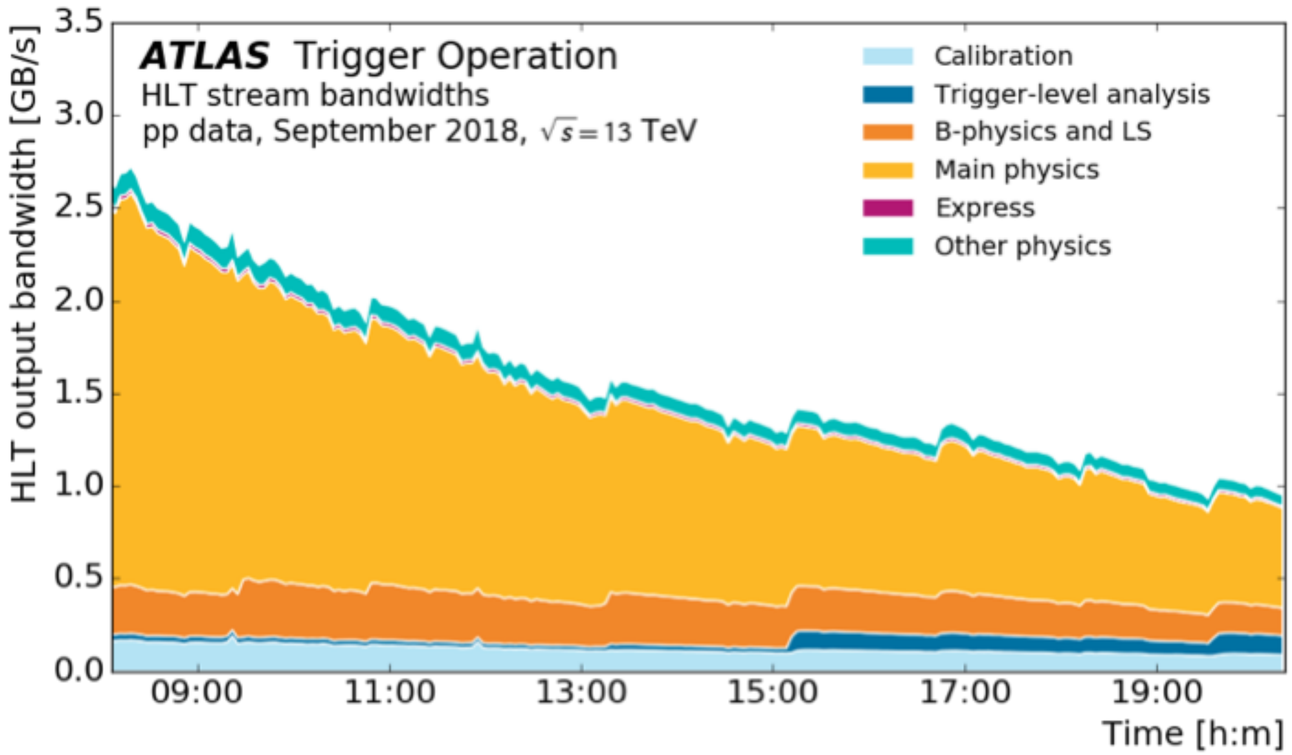
- ATLAS as a **two level** trigger …
- Hardware pipelined Level 1 system
- Level 1 runs fast reconstruction with dedicated limited granularity detector readout
  - **Calorimeter** and **Muon Spectrometer** only
  - Identifies **Regions of Interest** (RoI) for processing in the HLT with full detector granularity
  - Low latency: ~ 2.5 μs
  - Output rate ~ 100 kHz
- Software High Level Trigger (HLT) system
  - Large homogeneous CPU farm
  - Reads out the data only in the RoI for the event
  - Runs increasingly complex algorithms with the full granularity data
  - Since Run 2, each event is fully processed on a single node
  - Output rate ~ 1 kHz

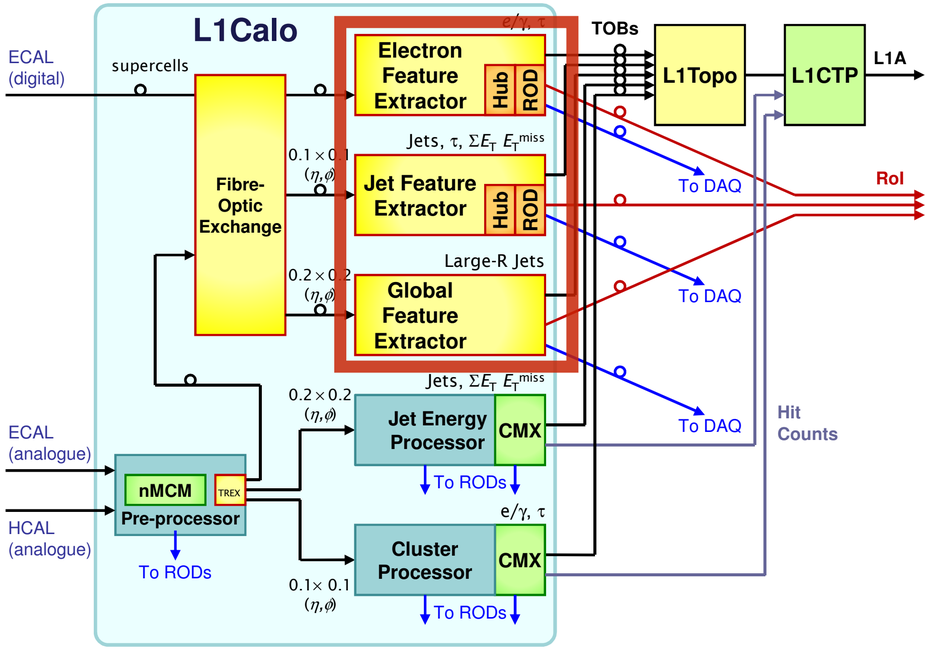


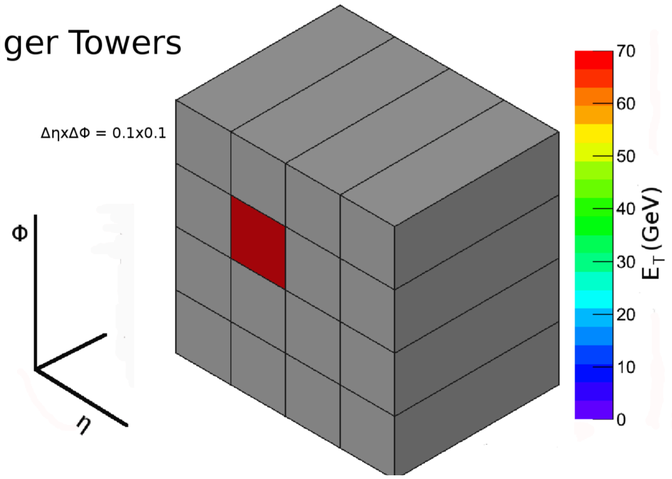
# Run conditions in Run 2 and Run 3

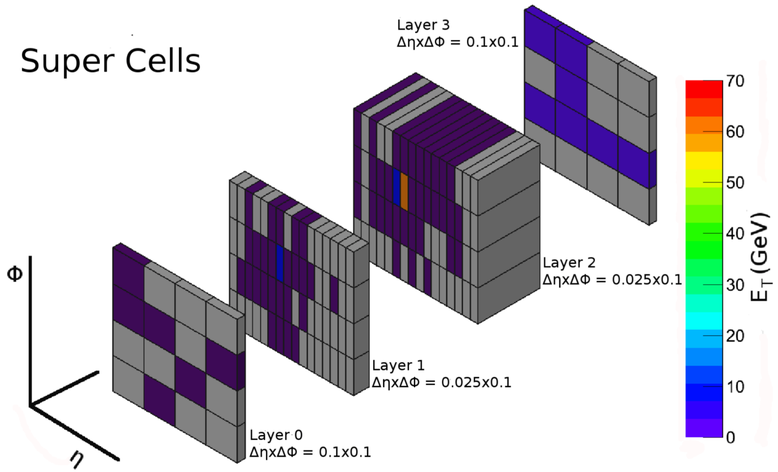
- Typical running Run 2
  - 2015: 0.5 × $10^{34}$ $cm^{-2}$ $s^{-1}$ max <μ> ~ 18
  - 2016: 1.3 × $10^{34}$ $cm^{-2}$ $s^{-1}$ max <μ> ~ 40
  - 2017: 1.6 × $10^{34}$ $cm^{-2}$ $s^{-1}$ max <μ> ~ 70
  - 2018: 2.1 × $10^{34}$ $cm^{-2}$ $s^{-1}$ max <μ> ~ 60
- Expected Run 3
  - 2.1 × $10^{34}$ $cm^{-2}$ $s^{-1}$ max <μ> ~ 60
  - Luminosity levelling for the first part of the run by adjustment of the betatron function at both ATLAS and CMS
- HLT and L1 menu and prescale updated to accommodate the LHC conditions and filling scheme
- Calibration and Debug stream besides physics streams
- Dynamically configured during the data taking for decay of instantaneous luminosity



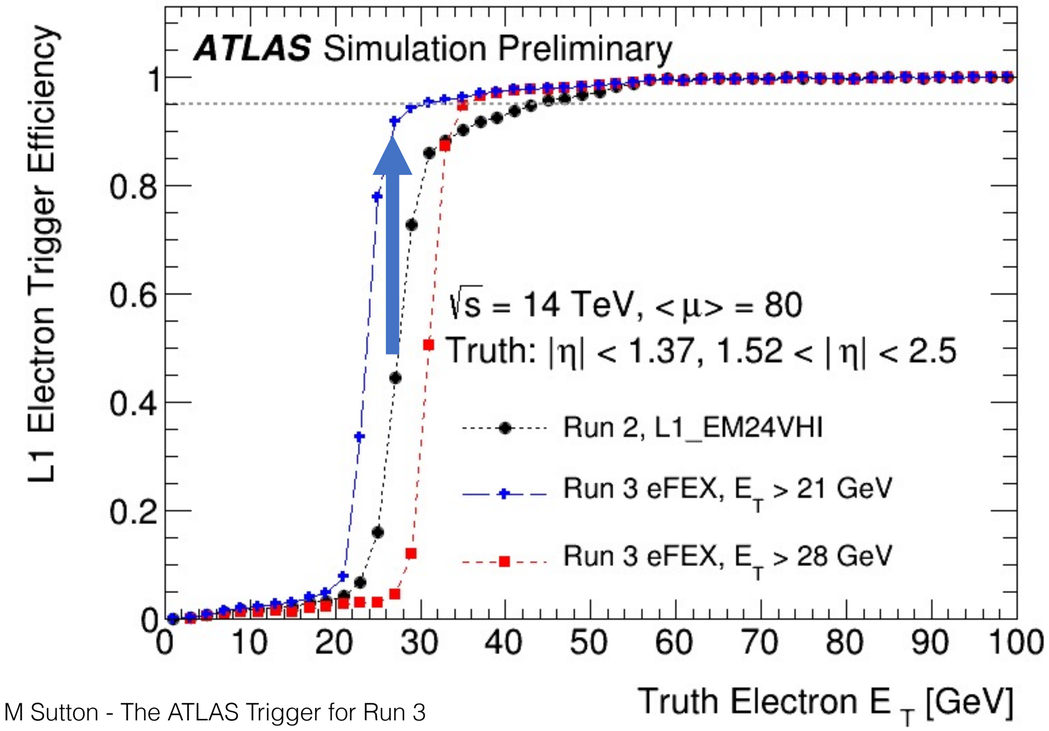


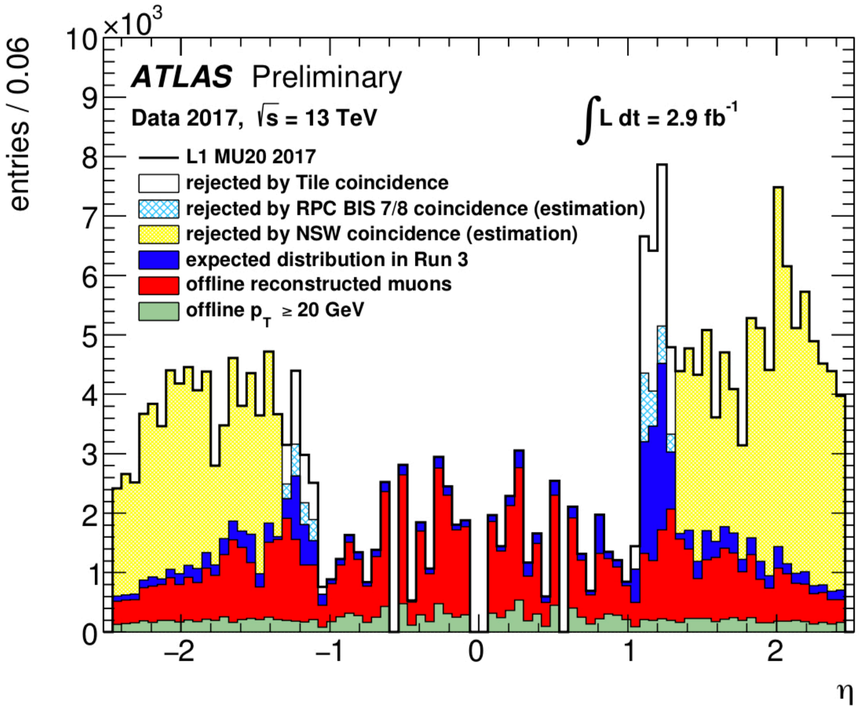




# Level 1 upgrade for Run 3

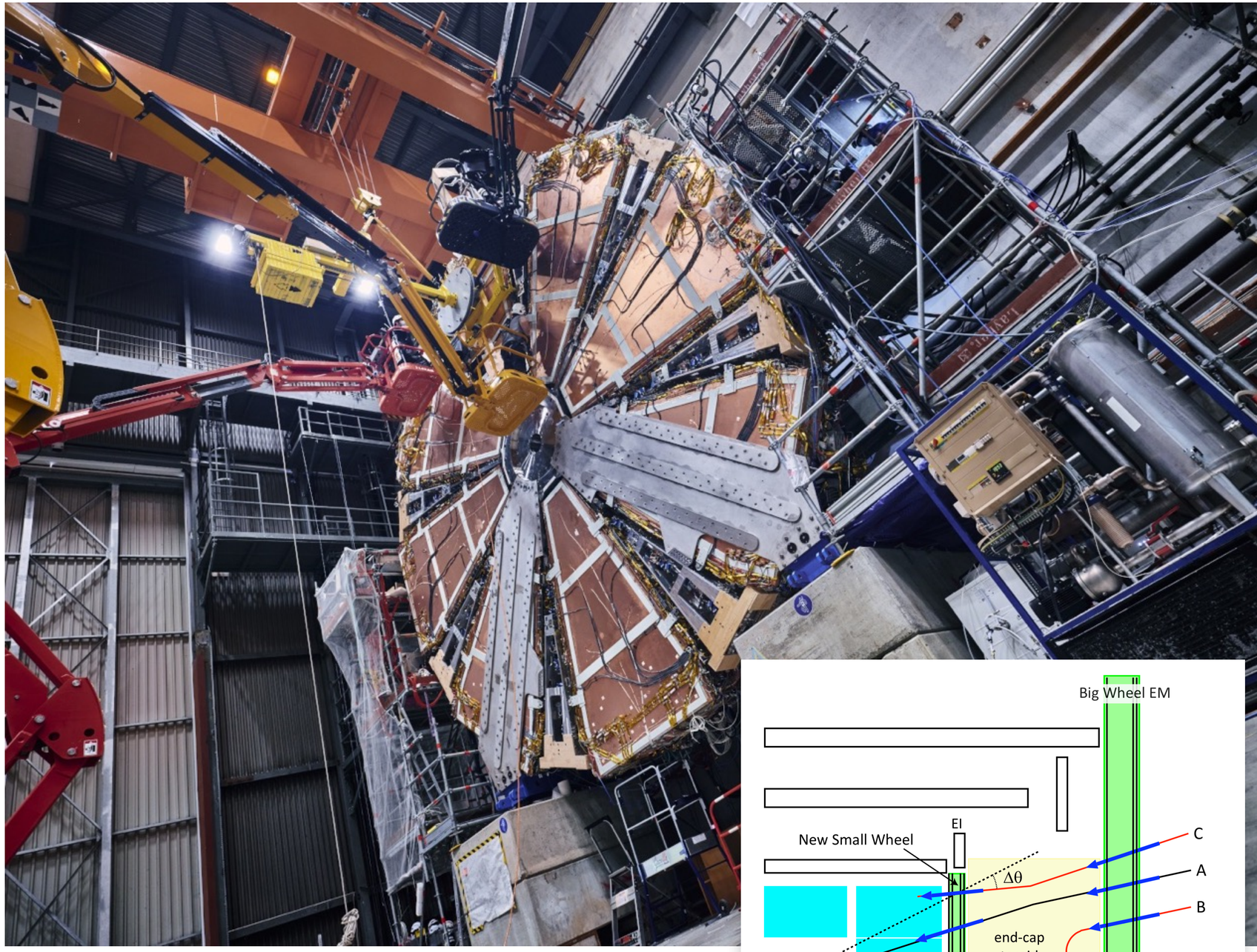
- L1 calorimeter design reasonably old > 15 years
- Older hardware
  - Limited reconstruction, jets electrons etc with low granularity primitive, square sliding window algorithms
  - Level 1 resolution for jets and elections etc very shallow rising edge
  - High L1 rate for needed efficiency in the HLT
- Redesign to add new improved reconstruction
  - eFEX - electron and tau
  - jFEX - jets
  - gFEX - global
- Will allow more fine grained reconstruction and sharper trigger turn on …






# L1 Muon Trigger

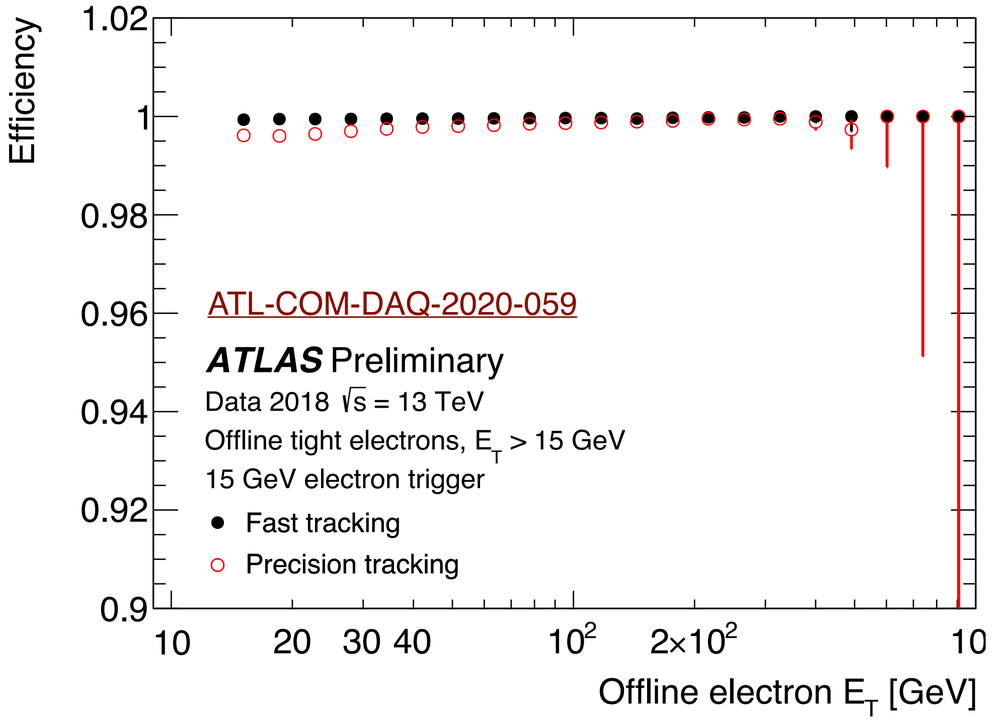
- New improved hardware algorithms to use better coincidences between the components in the Muon Spectrometer
- New Small Wheels being added - one for each end
  - Extra muon station will be useful in the trigger to reject non-pointing fakes
- (The “Small Wheel” is actually very large, but small by comparison with the ATLAS Big Wheel)

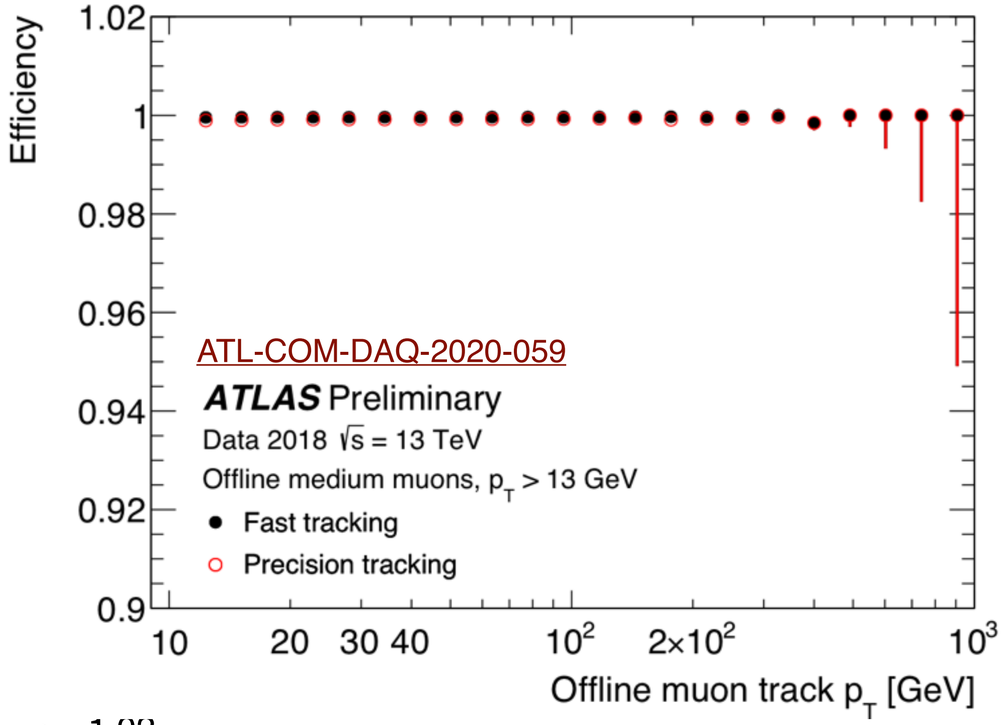


# High Level Trigger

- Input ~ 100 kHz
- Output 1 - 1.5 kHz
- Required processing ~ 800 ms
- HLT farm being upgraded wit new machines
- Runs full reconstruction at full detector granularity with in the Rois, typically runs
    1. Calorimeter or Muon reconstruction in the RoI identified by L1
    2. Then runs the Fast tracking
    3. Then runs some hypothesis algorithm to reject events
    4. Runs improved, and slower, Calorimeter or Muon reconstruction
    5. Then refits the tracks, or processes the tracks again
    6. The reconstructs final analysis objects - Electrons, Taus, Muon, jets etc
    7. Runs final physics selection to decide to keep the event or not

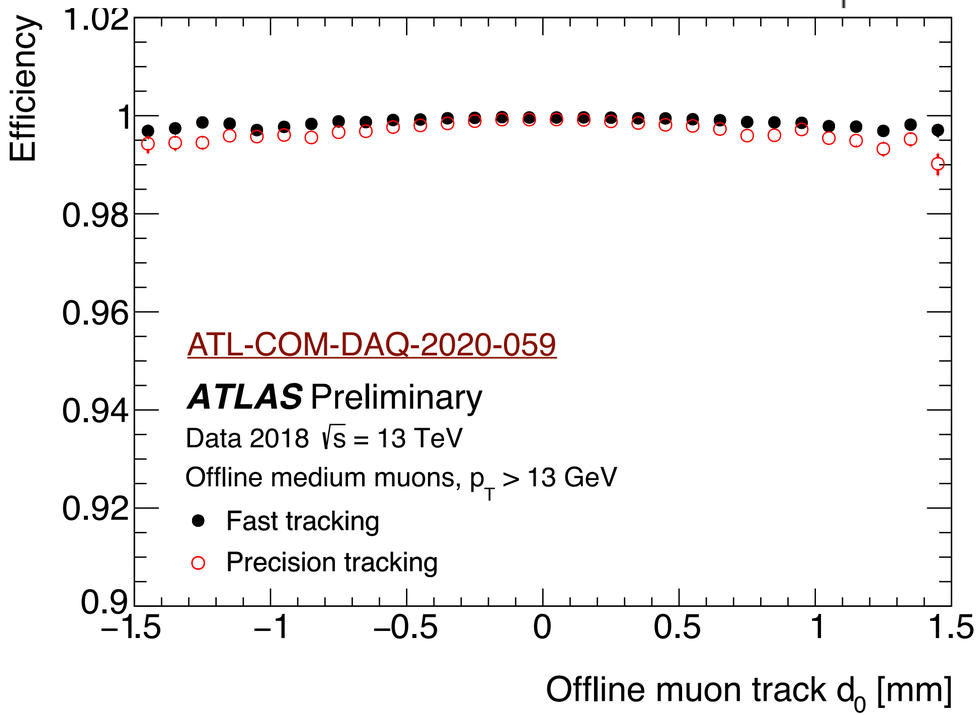
- The biggest Sussex trigger contribution is the Inner Detector trigger to run the tracking
    - We lead the development here and are one of the biggest contributing institutes
- Also make significant contributes towards the Egamma trigger
    - Electrons and photons trigger and
    - The Core software, trigger configuration, and calibration and debug streams

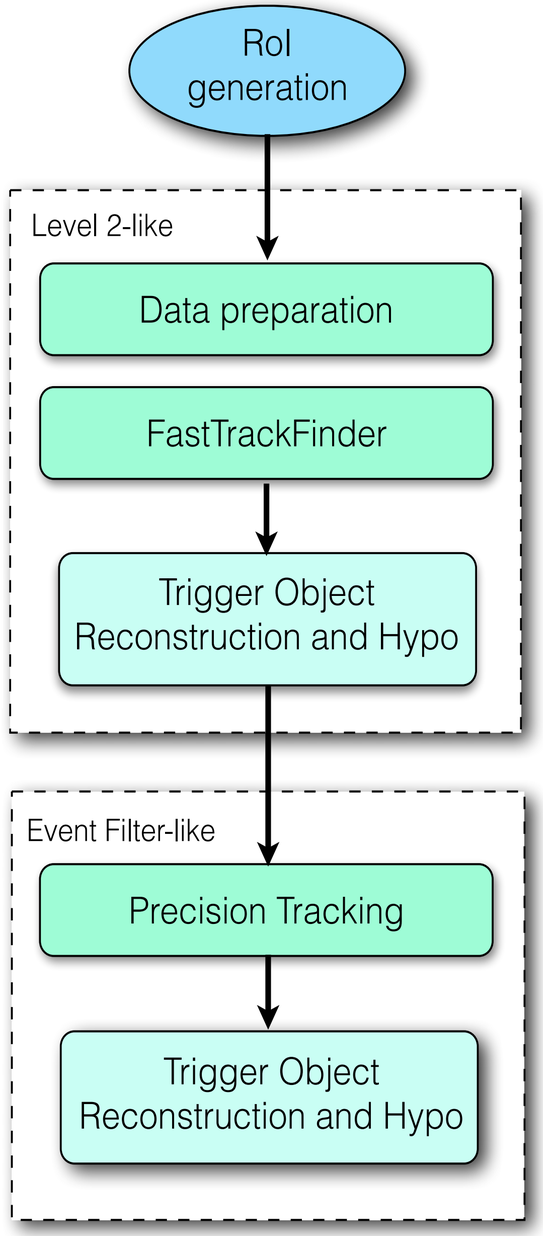


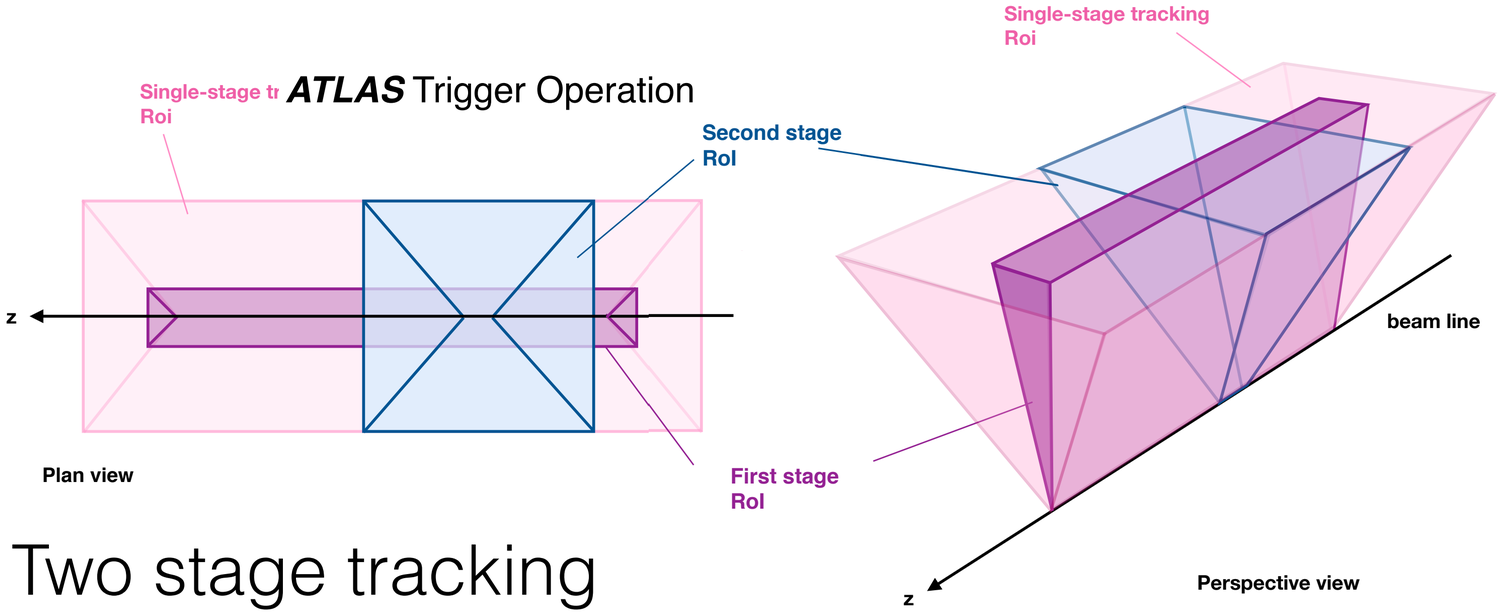




# ID Trigger overview

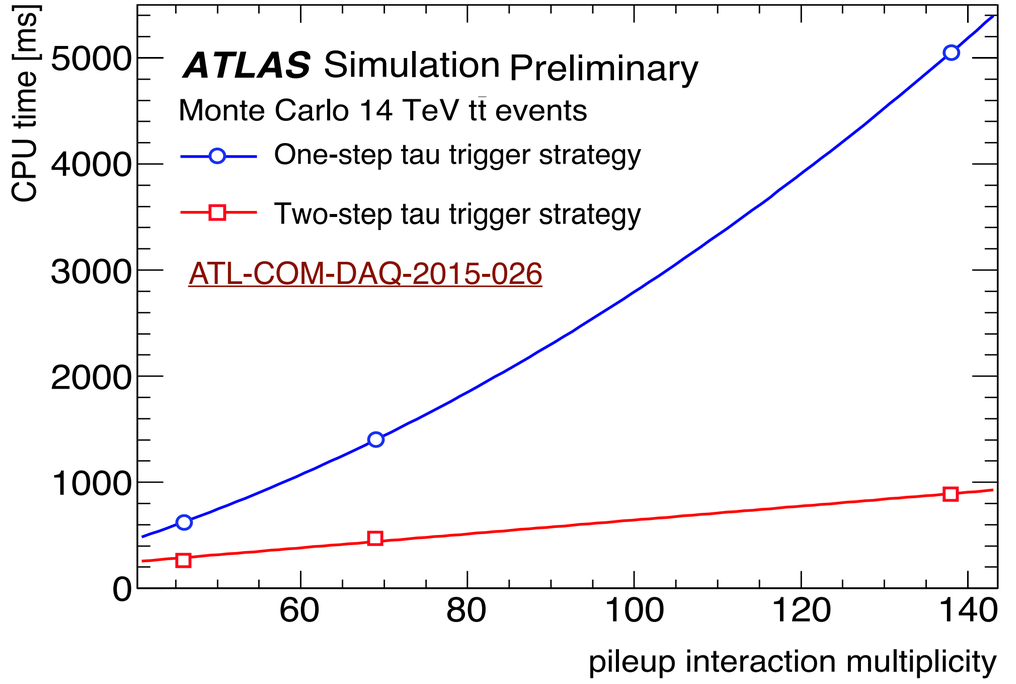
- The raw detector data within the RoI requested from the Readout system
- The data preparation then runs once per RoI
- Pixel and SCT clustering, transformation to spacepoints
  - **Fast tracking** is expected ( custom seeding, combinatorial track following, fast track fit )
  - Fast tracks used to seed the **Precision Tracking**
    - Resolved ambiguities in the pattern recognition, rejects potential fake tracks, runs the offline track fit
- Trigger signatures, used in the nearly all trigger signatures, muons, electrons etc



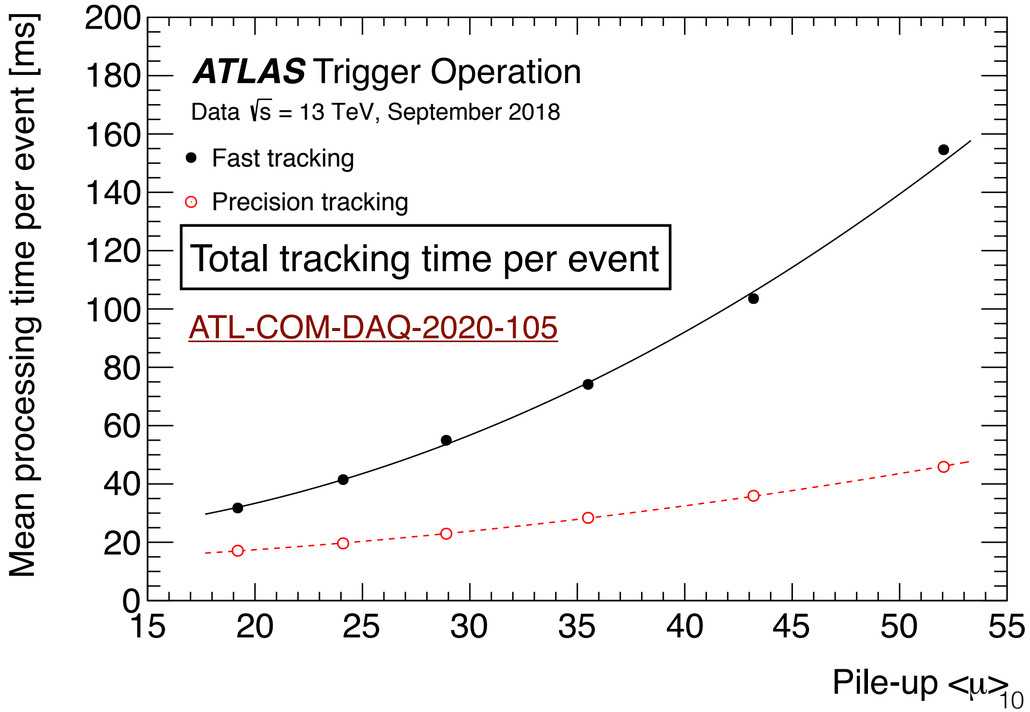






# Two stage tracking



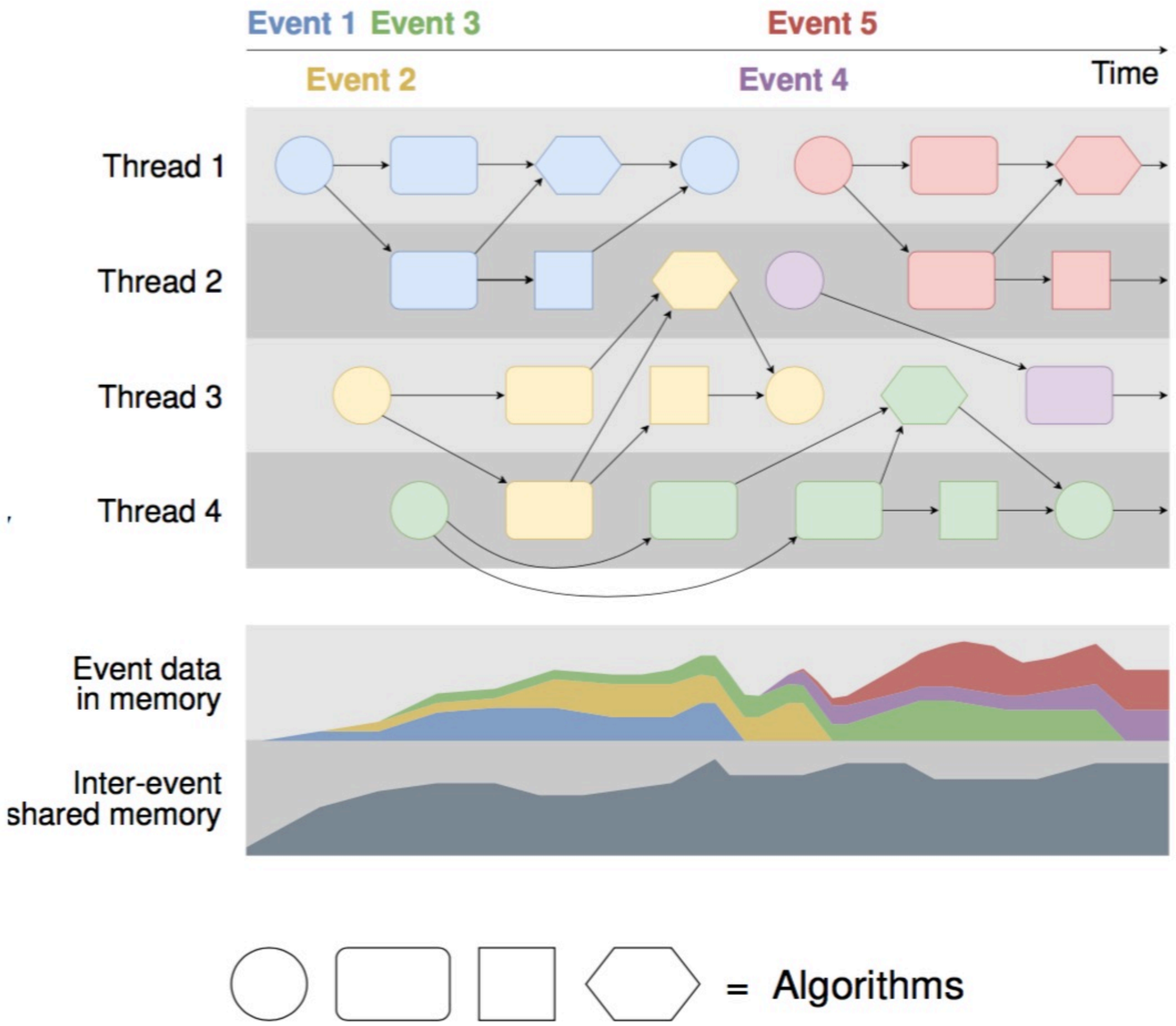

- Despite using custom pattern recognition for some signatures, eg Taus and b-jets, even this may still be too time consuming because of the wide RoIs, needed, eg 0.8 × 0.8 for the jets
- Adopt a two stage approach
  - First stage:
    - Run the fast tracking in narrow RoIs, but extended the full length of the luminous region in z
      - For the tau trigger identify the likely leading tau decay product track vertex
      - For b-jets run tracking only in the jet core for all jets, use the tracks to reconstruct the event vertex
  - Second stage
    - Run the fast tracking again, but now with the full width RoI, but tight around the z position identified in the first stage
- Signifiant saving in the overall CPU for the tau and b-jet triggers
- Overall time to run the actual tracking algorithms around 160 ms per event — 290 ms including all data preparation etc



# High Level Trigger framework upgrade for Run 3

- The ATLAS code framework has been upgraded to make use of multi-threading
  - Athena → Ahena “MT”
  - Reduces memory footprint as shared components - magnetic field map, geometry, etc - can be shared between events being processed concurrently
  - Events, trigger chains, and algorithms can run concurrently within individual events, with multiple events processed concurrently

- Meant rewriting the way all the data is accessed within the code
  - Rewrites to many of the algorithms
  - Complicated rewrite of the way that the different algorithms are executed for the different trigger chains in the Trigger
- Now different chains can execute concurrently, algorithms rewritten to be thread safe

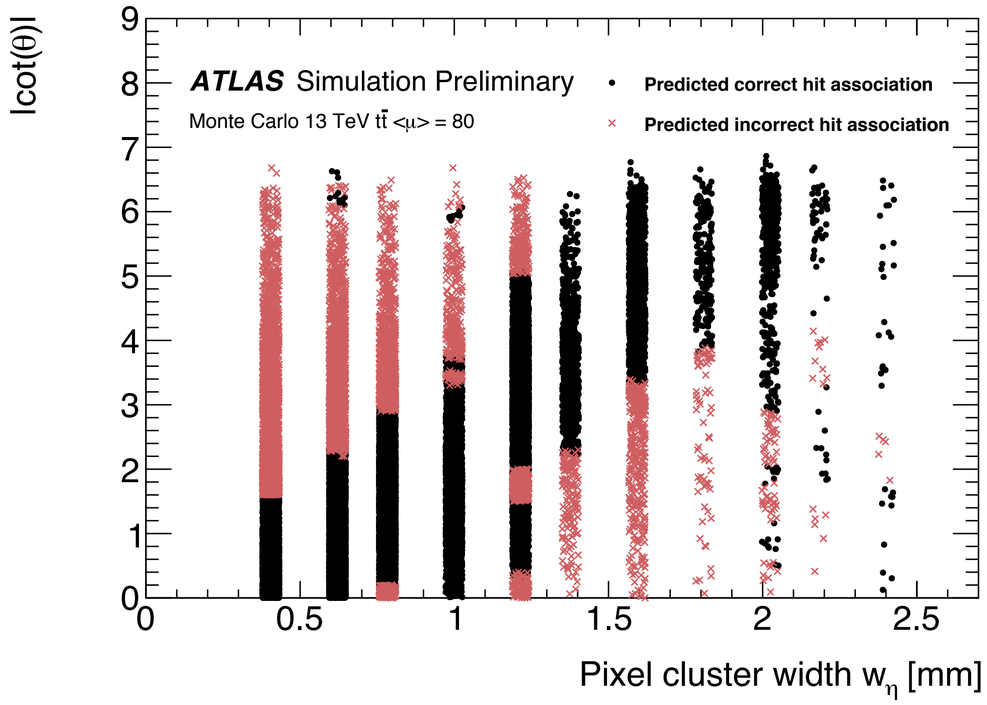


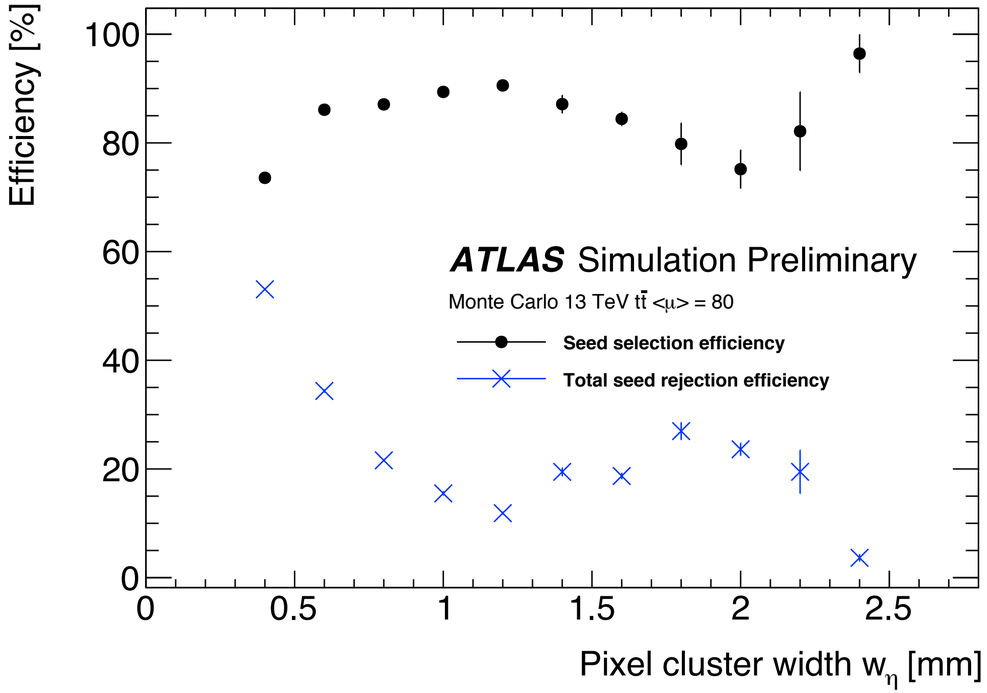
# Further HLT Devolpments for Run 3

- HLT algorithm developments for Run 3
  - Many new features are being developed
- Increased sharing of online and offline tools within the common AthenaMT framework e.g. Machine Learning implementation for online tracking
  - Improved reconstruction of electron tracks for the Electron trigger

- Online tracking is important for hadronic objects, jets, Missing ET (MET) as well as tracking-based objects (b-jets, and taus, electrons
- In Run 2 the tracking was not used for the MET trigger
  - Following the cancellation of the ATLAS FTK projects, for Run 3 the HLT tracking in the **full detector** has being implemented
  - This full detector tracking instance will be shared between the jet and MET triggers
    - Very costly to run, many changes introduced to reduce the fullscan tracking time
    - Jet rate ~ 18 kHz, currently the new FS tracking takes up ~ 45 % of the entire HLT farm processing
  - A significant improvement is the use of machine learning to filter the pixel spacepoints before the tracking

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



# Outlook

- The ATLAS Trigger system has performed extremely well over the years, and particularly during Run 2 in no small part due to the dedicated contribution from University of Sussex personnel
- For Run 3 the L1 trigger hardware is being upgraded, and the HLT framework has been rewritten to make use of extensive parallelism
  - This has been a very long and arduous task, but is now coming together and is beginning to bear fruit

- The start of LHC Run 3 is only around 6 months away - due to restart in late Spring 2022
  - Much work still remains to done but we at Sussex are currently making leading contributions into many different facets of the HLT development, with a contribution which belies the reasonably small size of the Sussex group
- The start up of the LHC next year will be an extremely interesting time for us all