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

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Abstract. The design and performance of the ATLAS Inner Detector (ID) trigger algorithms running online on the high level trigger (HLT) processor farm for 13 TeV LHC collision data with high pile-up are discussed. The HLT ID tracking is a vital component in all physics signatures in the ATLAS trigger for the precise selection of the rare or interesting events necessary for physics analysis without overwhelming the offline data storage in terms of both size and rate. To cope with the high expected interaction rates in the 13 TeV LHC collisions the ID trigger was redesigned during the 2013-15 long shutdown. The performance of the ID trigger in Run 2 from 13 TeV LHC collisions exceeded expectations as the pile-up increased throughout the run periods. The detailed efficiencies and resolutions of the trigger in a wide range of physics signatures spanning the entire Run 2 production luminosity data-taking are presented, to demonstrating that the trigger responded well under the extreme pile-up conditions. The performance of the ID trigger algorithms in ever higher pile-up collisions illustrates how the ID trigger continued to enable the ATLAS physics program and will continue to do so in the future.

1 Introduction — The ATLAS detector and trigger

The ATLAS experiment [1] at the Large Hadron Collder (LHC) [2] is a general purpose, cylindically symmetric detector with almost full solid angle coverage around the interaction point. The principle ATLAS detector sub-systems consist of the Inner Detector (ID), Calorimeter and the Muon Spectrometer.

The ID is the closest sub-detector to the beam pipe and first to measure the products of collisions, including the secondary decay products of short-lived particles from the primary interaction. The ID is composed of three sub-systems: the silicon Pixel Detector and Insertable B-Layer (IBL) closest to the beampipe, which is surrounded by the Semiconductor Tracker (SCT), which is in turn surrounded by the Transition Radiation Tracker (TRT), which, in addition to tracking, can be used for particle identification. Each of the silicon sub-detectors is further divided into a central barrel part, with concentric cylindrical layers, and end-caps, consisting of disks perpendicular to the beam pipe. The angular acceptence of the ID is $|\eta| < 2.5$. Surrounding the ID is the 2 T superconducting solenoid to provide the momentum reconstruction for the tracking and allows the ID to reconstruct tracks with $p_T > 0.5$ GeV.

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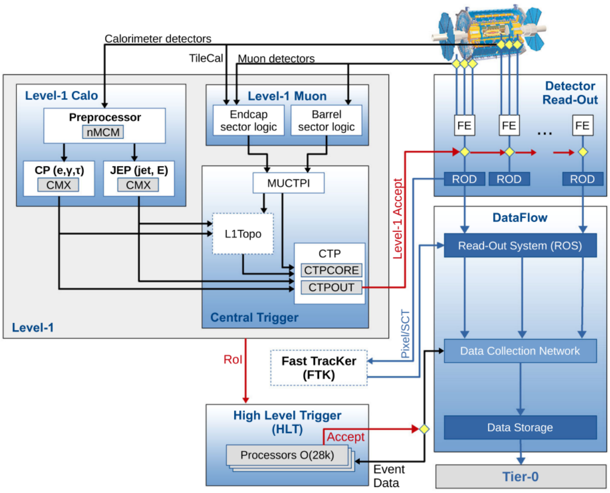

Figure 1: A schematic of the ATLAS Trigger and Data Acquisition system [4].

The trigger system is an essential component of any collider experiment as it is responsible for deciding whether or not to keep an event from any given bunch-crossing for later study. The ATLAS trigger system [3] – for which the infrastructure is displayed in Figure 1 – is able to reduce the rate of data stored from the nominal 40 MHz buch crossing rate to approximately 1 kHz which can be written tp offline storage. For Run-II, events are processed by the online two tiered trigger system consisting of the hardware Level 1 (L1) trigger and the High Level Trigger (HLT), with each tier requiring events to meet increasingly demanding criteria.

The L1 trigger is used to identify Regions of Interest (RoIs) at L1 to be subsequently processed with the full detector granularity in the HLT. To deal with the higher event rates for Run II, the L1 trigger sub-systems, consisting primarily of the calorimeter trigger (L1Calo) and muon spectrometer trigger (L1Muon) were upgraded with the addition of new topological trigger modules (L1Topo) to further reduce the event rate before reaching the Central Trigger Processor (CTP).

To reduce the over all system complexity and allow for better dynamic resource-sharing between algorithms, for Run-II the Level 2 trigger and Event Filter farms from Run-I [5] were combined into a single HLT farm with several thousand CPUs. The HLT is the first level that information is available from the tracking detectors, and for Run-II the track reconstruction for trigger physics signature was divided into two distinct parts: a Fast Track Finder stage (FTF) followed by a Precision Tracking stage based on the offline track fit.

Run-II also introduced an new more advanced multistage approach to reduce the detector volume of the RoIs requiring the precision tracking, by adding additional fast tracking stages. This was used for taus and b-jet triggers. The first stage is to use the FTF algorithm to identify leading tracks in an RoI fully extended in z at the interaction region, but narrow in η and ϕ. The leading fast tracks are then used to construct a second-stage RoI, originating from a more precise z-position at the beam line, but wider in angular width. The FTF is then run again in this wider second stage RoI, followed by the Precision Tracking. This allows faster execution

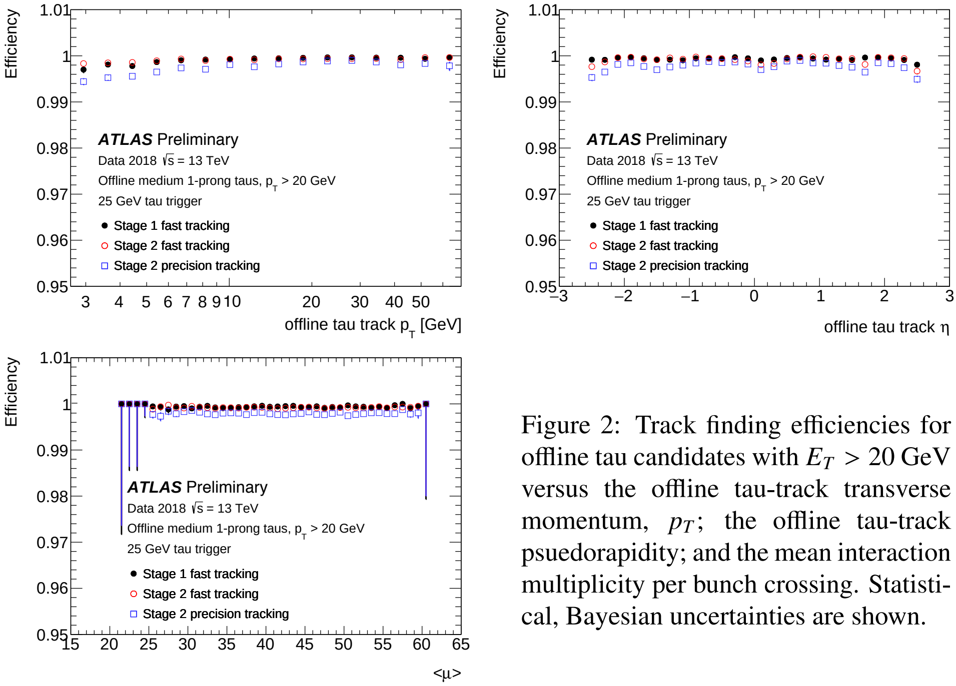

Figure 2: Track finding efficiencies for offline tau candidates with $E_T > 20$ GeV versus the offline tau-track transverse momentum, p_T; the offline tau-track psuedorapidity; and the mean interaction multiplicity per bunch crossing. Statistical, Bayesian uncertainties are shown.

of the tracking algorithms since they run in a significantly reduced volume with respect to Run-I.

In 2017, a new hardware Fast TracKer (FTK) system [6] was introduced to assist with the CPU challenges presented with increased luminosities and is expected to be fully commisioned during Run-II. The objective of the FTK is to provide track reconstruction using particle look-up tables stored in hardware memory chips for pattern recognition for $|\eta| < 2.4$ to run after the L1 accept, but before the HLT processing. This will allow charged particle reconstruction for all L1 accepted events.

2 Performance results from 2018 data

Figure 2 shows the track finding efficiency [7] of the Inner Detector (ID) trigger for tracks from offline medium quality 1-prong tau candidates with offline transverse momentum (p_T) greater than 20 GeV. The efficiencies are shown as functions of the offline tau-track transverse momentum (p_T) and psuedorapidity. Also shown is the efficiency versus the mean offline interaction multiplicity per bunch crossing. The efficiency is evaluated with a 25 GeV tau trigger configured to select only on the online calorimeter cluster. The offline tracks from the tau candidates are required to have no missing hits from those expected in the pixel detector, and a tight overall selection on the total number of silicon hits. The efficiency is better than 99% for all psuedorapidities and shows no degradation at higher pile-up.

Figure 3 shows the track finding efficiency [7] of the Inner Detector (ID) trigger for tracks from offline medium quality muon candidates as a function of the offline muon transverse momentum (p_T), pseudorapidity and track z position reconstructed at the beam line, and asa a function of the mean interaction multiplicity per bunch crossing. In all cases, the efficiency is evaluated with a 24 GeV muon trigger configured to select only on the track segment reconstructed in the Muon Spectrometer. Offline muon candidates are required to have at

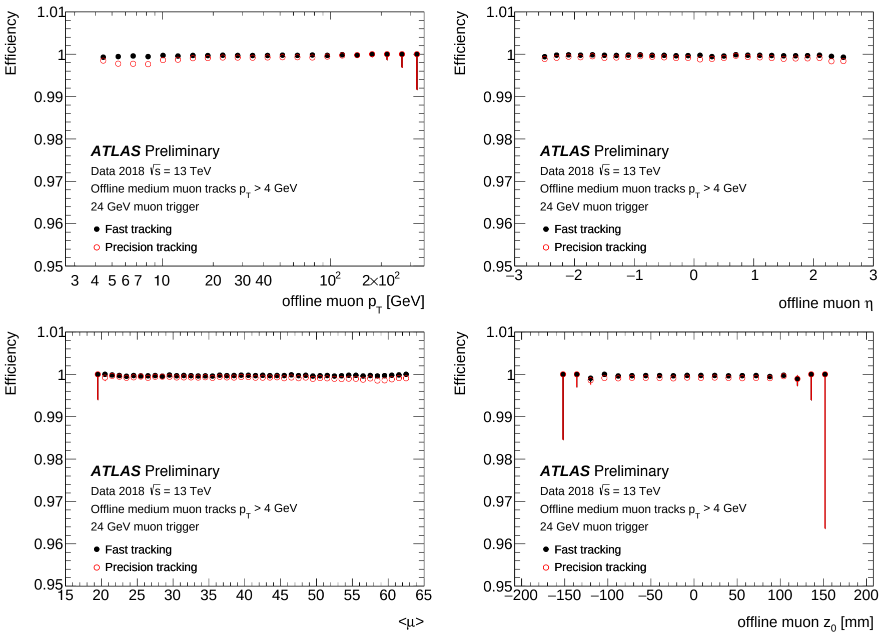

Figure 3: Track finding efficiencies for muon candidates with respect to offline medium muons as a function of offline muon transverse momentum, psuedorapidity, and position at the beamline, and the mean interaction multiplicity. Statistical, Bayesian uncertainties are shown

least one pixel cluster, at least 4 SCT clusters, and no more than two missing hits from the silicon detectors where such hits would be expected. Also if expected, they should have at least one hit in the innermost pixel layer. The selection for offline muon candidates from below the trigger threshold is biased in favour of candidates that appear to be higher in p_T from the Muon Spectrometer trigger than the full offline reconstruction.

The muons are well reconstructed with consistently flat efficiencies that are close to 100%. For all cases of both the tau and muon triggers, the efficiencies remain consistently high, even at low p_T and high η, with efficiencies observed to be generally higher for the fast tracking stage. The new seeding for the second stage tracking for the taus in 2018 significantly improves the efficiencies from previous years.

3 Conclusion

The design and performance of the ATLAS tracking trigger system redesigned for Run-II has been presented. The performance of the Inner Detector tracking for muons and taus using data collected during 2018 has been presented. The tau trigger efficiencies are better than 99%, while the muon trigger efficiency is very close to 100%. Even with the more demanding Run-II conditions, the ID trigger performance is as good as, or better than the correpsonding Run 1 performance.

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