PROCEEDINGS OF SCIENCE

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

PoS(LHCP2020)248

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The Inner Detector (ID) trigger plays an essential role in the ATLAS trigger system, enabling the high quality reconstruction of physics objects - electron, tau, muon, *b*-jet candidates, providing access to regions of the phase space populated by these objects which span a wide range of kinematic regimes. These are essential for the core physics programme at ATLAS: Standard Model measurements; Flavour physics; and Beyond the Standard Model searches. Having highly efficient tracking trigger algorithms is therefore essential to pursue the ATLAS physics goals, both in the Run 2 analyses and for the preparations for Run 3. Here, the design and performance of the ATLAS ID trigger used at the LHC during the full Run 2 data taking period is discussed, as well as proposed developments for the start of Run 3 and beyond. The detailed efficiencies for the trigger for a wide range of physics signatures are presented. These results demonstrate the continued excellent performance of the ID trigger in the extreme pile-up conditions of Run 2. During the current 2019-2021 long shutdown, the ATLAS High-Level Trigger software is being redesigned to cope with the running conditions of Run 3 and beyond, whilst maintaining or improving upon the excellent performance from Run 2. This poses significant challenges for the design of the algorithms in terms of execution time and physics performance. Following this redesign, the ID trigger will continue to lie at the heart of the ATLAS trigger and to be central to the successful fulfilment of the ATLAS physics programme.

ATL-DAQ-PROC-2020-016
05 October 2020

The Eighth Annual Conference on Large Hadron Collider Physics-LHCP2020
25-30 May, 2020
online

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[*] Speaker

1. The ATLAS detector

The ATLAS detector [1] is one of two general-purpose experiments at the LHC [2] and has a cylindrical symmetry and an almost full solid angle coverage around the interaction point. The principle sub-systems of ATLAS are the Inner Detector (ID), the Calorimeter and the Muon Spectrometer (MS). The ID is the nearest to the interaction region, and it is used to reconstruct charged particle tracks for the selection of physics objects in nearly all trigger signatures. The ID sub-components are High-granularity Silicon detectors – Pixel [3] and microstrip (SCT) [4] – and a straw tube Transition Radiation Tracker (TRT) [5]. The innermost pixel layer, the insertable B-layer (IBL) [6], was added for the start of Run 2 to allow a more robust track reconstruction, with better impact parameter resolution and more precise vertex reconstruction. The ATLAS detector operated efficiently throughout Run 1 (2009 to early 2013), with instantaneous luminosities of up to $8 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$ and centre-of-mass energies of 7 TeV and 8 TeV. The excellent performance continued for Run 2 (2015 to 2018) with increased centre-of-mass energy of 13 TeV and a reduction in the nominal bunch spacing to 25 ns resulting in a significant increase in the number of interactions per bunch crossing and correspondingly high track multiplicities in each event. This provided a very challenging environment for the ATLAS trigger and acquisition systems [7, 8].

2. The Inner Detector Trigger

The Run 2 ATLAS Trigger system [8] consists of low latency, pipelined hardware Level 1 trigger system (L1), followed by a software High-Level Trigger (HLT) CPU farm for more detailed event reconstruction. Following an L1-accept decision, data from the detector are read out by the HLT, which uses higher granularity calorimeter information, precision measurements from the MS and information from the ID. To reduce the rate at which data must be read out from the detector, Regions of Interest (RoIs) are identified by the L1 trigger. These may contain features of interest which merit further processing. The ability of the ATLAS trigger system to process information from the ID to reconstruct particle trajectories is an essential requirement for the efficient triggering of objects, such as electrons, muons, taus and b-jets. Without an efficient particle track reconstruction it would not be possible to achieve the goals of the ATLAS physics programme. The ID trigger must therefore be able to reconstruct tracks with high efficiency across the entire range of possible physics signatures. The trigger system must also reduce the rate of events from the nominal 40 MHz bunch crossing rate to 100 kHz, at the hardware-based L1 trigger, which the software-based HLT further reduces to approximatively 1 kHz in order to record events to disk. This challenge is exacerbated by the very high track and hit multiplicities in the ID that arise from the large number of proton-proton interactions per bunch-crossing (pile-up) present during the running of the LHC.

For Run 2, the ID trigger tracking is performed in two steps, the *fast track finder* (FTF) followed by the *precision tracking*. The FTF consists of a trigger specific pattern recognition stage [9] seeded by the L1 RoIs, whereas the precision tracking relies heavily on offline tracking algorithms [10] and uses seeded information from the FTF. Although the FTF and precision tracking run in distinct steps, because both algorithms are generally executed in a single RoI, the two steps together constitute a *single tracking stage* for that RoI.

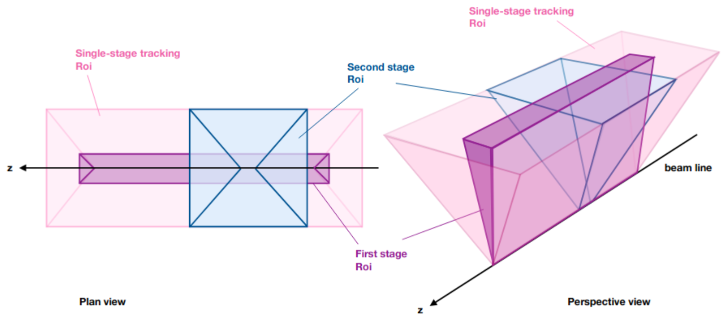

Figure 1: Schematic illustrating the RoIs from the single-stage and two-stage tau lepton trigger tracking, shown in plan view ($x - z$ plane) along the transverse direction and in perspective view. The z-axis is along the beam line.

For more complex objects, such as hadronically decaying taus, a *multi-stage* tracking process is used (Figure 1). In such a case, a first stage runs the FTF in a narrow RoI in both η and ϕ but fully extended along the beamline to identify the leading tau tracks. The second stage follows by executing the FTF again, now followed by the precision tracking, but this time in a wider RoI in both η and ϕ, centred on the z position of the leading track identified by the first stage and with a much smaller range about this z position.

3. Performance results from Run 2 data

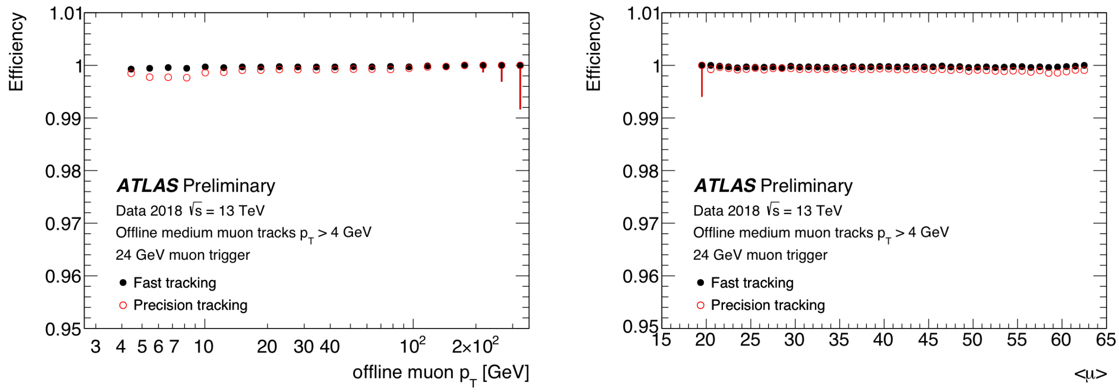

Figure 2: The ID tracking efficiency [11] for the 24 GeV muon trigger, as a function of the offline muon transverse momentum (left) and the mean pile-up interaction multiplicity, $<\mu>$, (right). Bayesian-estimated statistical uncertainties are shown.

The tracking efficiency for the trigger with respect to the offline tracking has been determined using a number of support triggers. These triggers are essentially identical to the physics triggers and operate by reconstructing the tracks in the trigger as normal, but then selecting on the objects reconstructed in the MS or calorimeter only, with no selection on the tracking information from the ID. In this way, it is possible to estimate the efficiency of the tracking, unbiased by the ID track reconstruction itself.

Figures 2 and 3 show the tracking efficiency of the ID trigger for offline muon and tau decay tracks, respectively. The efficiency is significantly better than 99% and approximately constant as a function of the mean pile-up interaction multiplicity, $<\mu>$. Moreover, the processing time for the combined multi-stage tau tracking is significantly less than the single-stage tracking in the wider RoI which it replaces, for both the FTF and precision tracking, as can be seen in Figure 4.

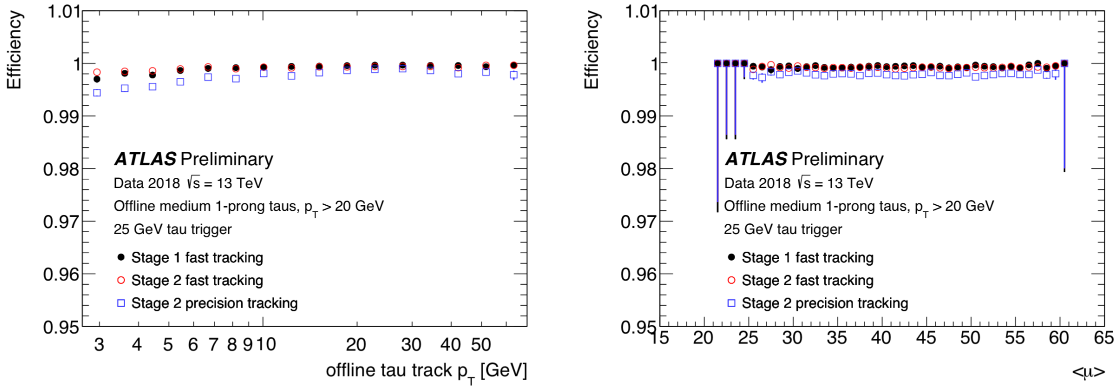

Figure 3: The ID tracking efficiency [11] for the 25 GeV one-prong tau trigger, as a function of the offline tau track transverse momentum (left) and the mean pile-up interaction multiplicity, $<\mu>$, (right). Bayesian-estimated statistical uncertainties are shown.

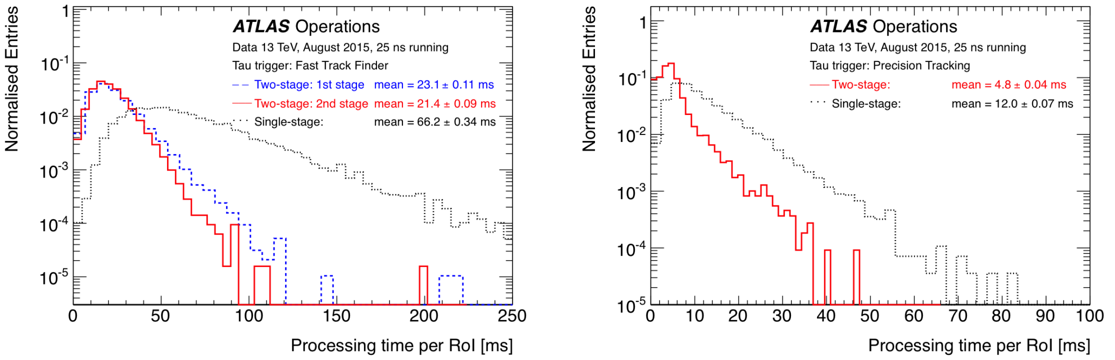

Figure 4: The ID trigger tau tracking processing time [11] for the FTF (left) and the precision tracking (right) comparing the single-stage and two-stage tracking approach.

4. Conclusions

The ATLAS inner detector trigger was significantly modified in order to operate with the extremely demanding conditions in Run 2. The design and performance of the ID trigger in Run 2 have been presented. The results for the detailed efficiencies and processing timing for the different physics signatures show how the continued excellent performance of the ID trigger remains central to the successful fulfilment of the ATLAS physics programme. For Run 3 starting in 2022, the trigger is being redesigned to cope with the increasingly challenging future running conditions, whilst maintaining or improving upon the excellent performance from Run 2. These developments include multithreaded trigger reconstruction and the introduction of new track-based signatures.

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