The tracking performance of the ATLAS High Level Trigger in pp collisions at the LHC

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Abstract. At the design luminosity, the Large Hadron Collider will have a bunch crossing rate of 40 MHz with up to 25 separate pp interactions per bunch crossing. For the ATLAS detector, to reduce this large interaction rate to the 200Hz that can be written offline, a three level trigger system is employed. An essential component in achieving this large reduction is the online tracking in the High Level Trigger (HLT). The HLT consists of two components, the Level 2 (L2) and the Event Filter (EF), both of which run on farms of commodity CPUs. L2 is the earliest that data from the Inner Detector is available. The entire L2 must process each event within around 40 ms to achieve a 50 fold reduction in rate, thus custom, fast tracking algorithms are used. The EF uses components from the offline tracking to help obtain a further 10 fold reduction and achieve performance comparable to that of the offline reconstruction. Results are presented for the commisioning and performance of the HLT tracking algorithms in pp collisions from the first few months of the LHC operation and show that the track reconstruction efficiency approaches 100% for tracks with high transverse momentum.

1. Introduction

The early p-p collisions at 7 TeV center-of-mass energy produced by the LHC in 2010 provided the first opportunity to test the performance of the ATLAS Inner Detector (ID) trigger algorithms with high-p_T tracks. The algorithms were promptly commissioned and used since then in active selection online. The ID ([1]) is the system closest to the interaction point and provides precise tracking and momentum measurement of particles created in the collisions. From the inside out, it consists of a silicon **Pixel** detector (3 cylindrical layers in the Barrel and 3 disks on each side of the Endcaps), a silicon strip (**SCT**) detector (4 cylindrical layers in the Barrel and 9 disks on each side of the Endcaps) and a Transition Radiation Tracker (**TRT**). The whole structure is immersed in a 2T solenoid magnetic field. Each SCT layer consists of two sub-layers at an angle (stereo), in order to provide 3D position information.

Information from the ID is used in the 2nd and 3rd level (High Level Trigger, HLT) of the ATLAS 3-level trigger to provide online track reconstruction, which is then used from other trigger algorithms to build physics trigger objects to apply selection criteria on. Therefore the online tracking algorithms have to be fast, efficient and reasonably precise.

2. The ATLAS Trigger Structure

The ATLAS trigger system ([1], [2]) features a three-level architecture (see figure 1):
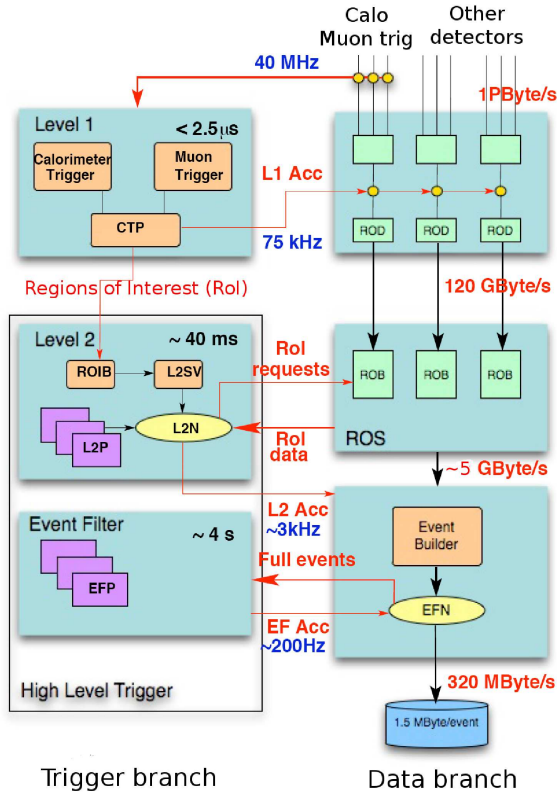
Figure 1. Schematic diagram of the ATLAS trigger system, in parallel with the data flow scheme. Some elements not mentioned in the text: the Central Trigger Processor (CTP), the RoI Builder (ROIB), the L2 Supervisor (L2SV), the L2 and EF Networks (L2N and EFN), the L2 and EF Processing units (L2P and EFP), the Read-out Drivers (RODs) and System (ROS).

- The **Level 1** (L1) trigger is hardware based. It uses coarse granularity detector data from the calorimeter and muon trigger chambers to impose a fast trigger decision and to define Regions of Interest (RoI) where detector activity is present. Its design output rate is ∼75 kHz, out of the 40 MHz of input. Currently the rates are 20 kHz and 1 MHz respectively.

- The **Level 2** (L2) trigger is software based and is run on ∼500 CPU farm nodes. It is seeded by L1, therefore only the RoIs passed to it are processed. The full detector granularity is used in those RoIs, where dedicated, fast reconstruction algorithms are executed. Its design output rate is ∼3 kHz, currently running at 4 kHz. If the event is accepted, its data fragments from all Read-Out Buffers (ROBs) are sent to the Event Builder.

- The **Event Filter** (EF) is also software based and is run on ∼1600 CPU farm nodes. It is seeded by L2, but the whole event and full detector granularity is accessible. Given the longer execution time available, offline-like algorithms are used for a better trigger object determination. Its design output rate is about 200 Hz, currently running at 350 Hz.

The L2 and EF are collectively referred to as the **HLT**.

A crucial aspect of the ATLAS L2 trigger is that, for most physics signatures, it is designed to process only detector RoIs. Those correspond to a few percent of a total event and there are only few of them identified in every L1-accepted event. As a result, both the amount of data transfered from the ROBs to the L2 processors and the processing time at L2 are minimized.

2.1. The Inner Detector Tracking Trigger Algorithms
The ID trigger tracking is used in the online identification of many physics signatures, like leptons, B-hadrons and b-jets. It relies on the different topology of tracks associated with hard interactions compared to underlying events, namely the z position of their origin and their p_T.

The dedicated, fast L2 tracking algorithms consist of the following steps:

- Space point (SP) formation: 3D SP's are created from pixel and SCT clusters in each of their layers.
- Pattern recognition: The baseline pattern recognition for HLT tracking is based on the Silicon detectors (Pixel and SCT) and only results for the Si-based tracking are presented here. Two alternative algorithms based on histogramming or combinatorial method are available ([2]). One of them is chosen for each of the trigger signatures with a pattern recognition tuning optimal to a given environment.
- Track fitting: performed on the prototrack found by the pattern recognition, using an extended Kalman filter fitting method.
- TRT extension: The Si-based fitted track is finally extended to the TRT and re-fitted including matching TRT hits if any are found ("inside-out" strategy).

At the EF level, the offline tracking algorithms ([3]) are adapted to the RoI driven execution and configured for finding the trigger signal tracks. Less precise knowledge of the detector conditions and calibration with respect to the offline environment and optimisation for execution speed are also taken into account and cause only minor differences with the offline reconstruction outcome.

3. Performance In FullScan Mode

The performance of the Full Scan instance of the L2 and EF algorithms is first reviewed, i.e. trigger tracks are sought for in the whole ID instead of a physics-object-defined RoI. The events were selected by the minimum bias trigger, without using any information on HLT tracks. For the comparisons with the data, 7 TeV minimum bias MC was used.

As an example of the remarkable agreement with MC, the number of pixel hits per EF track as a function of η is shown in figure 2 and the number of holes per L2 track in figure 3. A hole is defined as an ID layer in which an offline track has a hit but the matched L2 track does not.
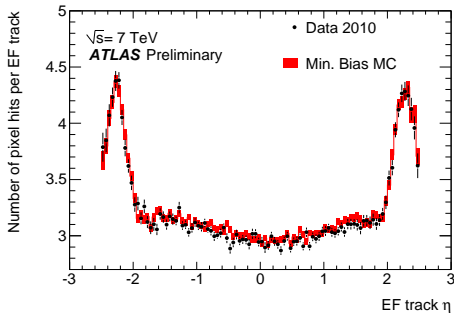

Figure 2. Number of pixel hits per EF track as a function of η, for data and MC.
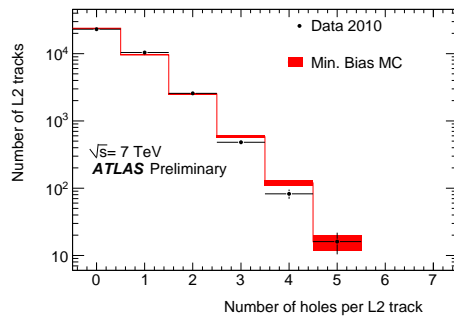
Figure 3. Number of holes per L2 track, for data and MC.

The trigger tracks were geometrically matched to the more precise offline reconstructed ones as a reference for assessing their performance. The offline track selection is:

- $|\eta| < 2.5$, transverse momentum $p_T > 1$GeV (unless otherwise stated)
- Longitudinal and transverse impact parameter with respect to the beam line $|z_0 sin\theta| < 1.5$mm and $|d_0| < 1.5$mm respectively.
- Number of pixel hits > 0, number of SCT clusters > 5

Then the track finding efficiency of the trigger tracking algorithms is defined as the percentage of offline reconstructed tracks that are matched to a trigger track, and is flat in η and close to
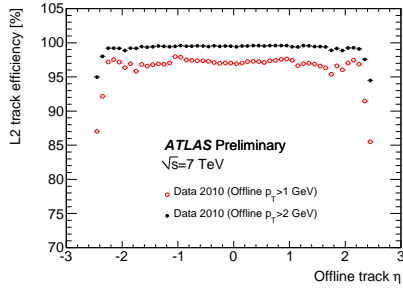
Figure 4. L2 tracking efficiency vs η for two p_T thresholds.
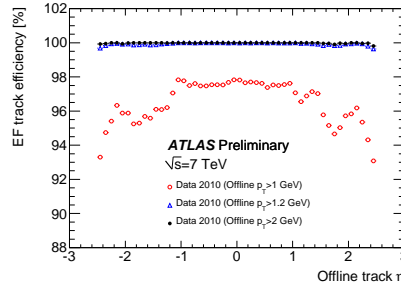

Figure 5. EF tracking efficiency vs η for three p_T thresholds.
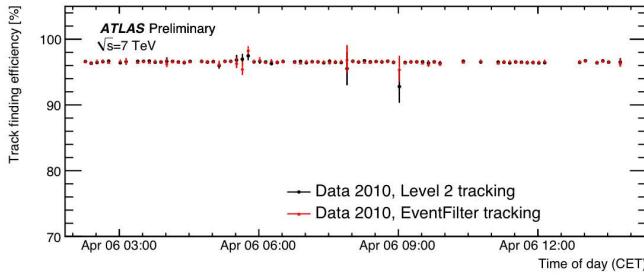

Figure 6. L2 and EF tracking efficiency vs time.

100% for reasonable p_T, as shown in figures 4 and 5. The stability of the two algorithms is shown in figure 6 for a run during which the beam conditions changed radically.

The online and matched offline track parameters at the point of closest approach to the interaction point were compared. Good agreement was found between the two sets of tracks, as shown in figures 7 and 8 for d_0 as an example, as one would expect for the same track reconstructed by two different algorithms. The $\sigma_{95\%}$ quoted is the RMS of the part of the distribution that contains 95% of the entries as counted from the highest bin and outwards.
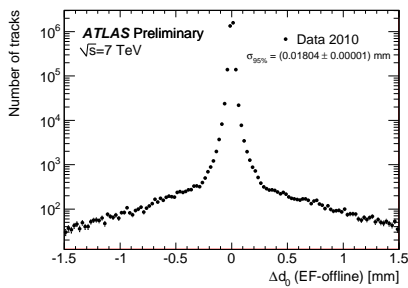
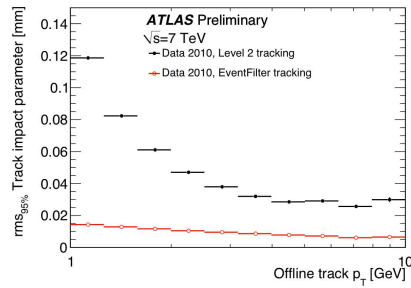**Figure 7.** Difference in d_0 between the EF tracks and their corresponding matched offline tracks.

Figure 8. Difference in d_0 between the L2 and EF tracks and their corresponding matched offline tracks vs offline p_T.

4. Performance In Region-of-Interest mode
The tracks reconstructed by the HLT algorithms are used, together with other detector information, to identify physics objects and test whether they satisfy various trigger signature hypotheses in order to decide whether to keep the event or not. In this section, the performance

of the online algorithms with respect to such objects of interest is presented. The events were selected online by special triggers used to monitor the physics chains, which applied no requirements on the existence of HLT tracks.

4.1. Track Finding Efficiency for Muons

A muon is identified as a combined Muon Spectrometer-Inner Detector track. Figures 9 and 10 show the online track finding efficiency for trigger tracks matched with offline reconstructed muons with $p_T > 4$GeV (for the η plot), which is flat and close to 100% for reasonable p_T.
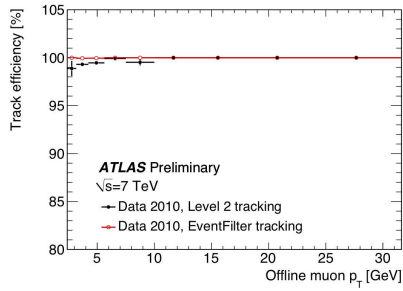
Figure 9. L2 and EF tracking efficiency for muons vs p_T.
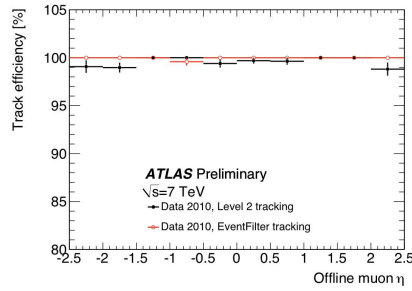
Figure 10. L2 and EF tracking efficiency for muons vs η.

4.2. Track Finding Efficiency for Electrons

An electron is identified as a calorimeter cluster matched with an Inner Detector track. Figures 11 and 12 show the online track finding efficiency for trigger tracks matched with offline reconstructed electrons with cluster $E_T > 5$GeV, which is flat and close to 100% for reasonable p_T. The efficiency loss for low-p_T EF tracks is caused by too tight track-cluster matching criteria. It is therefore not an inefficiency of the tracking algorithm and has been fixed in subsequent trigger software releases.
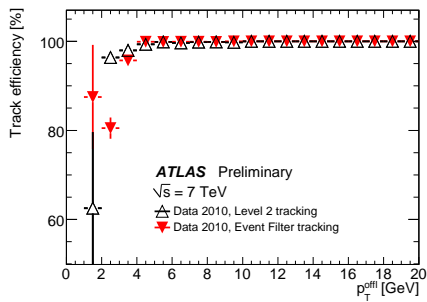

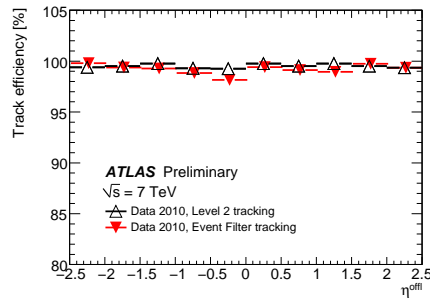**Figure 11.** L2 and EF tracking efficiency for electrons vs p_T.

Figure 12. L2 and EF tracking efficiency for electrons vs η.

4.3. Track Finding Efficiency for Taus

A tau is identified as a Calorimeter cluster matched to one or three Inner Detector tracks. Figures 13 and 14 show the online track finding efficiency for trigger tracks matched with offline tracks inside the tau RoI. In addition to the offline selection in the FullScan study, the tracks

are also required to have at least 1 hit in the first pixel layer, at least 2 pixel hits, at least 7 total Si hits, and χ^2 fit probability >1%. The efficiency is flat and close to 100% for reasonable p_T.
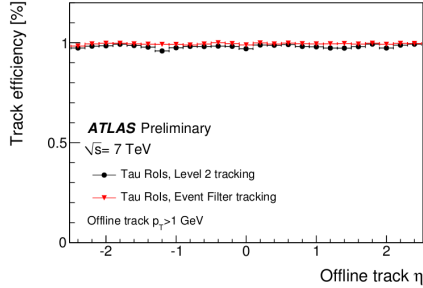

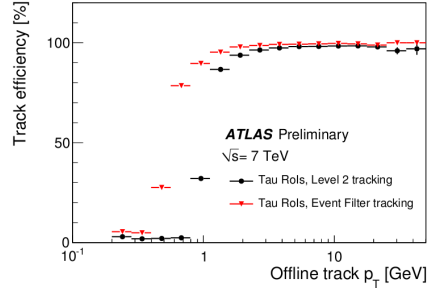**Figure 13.** L2 and EF tracking efficiency for tau RoIs vs p_T.

Figure 14. L2 and EF tracking efficiency for tau RoIs vs η.

4.4. Track Finding Efficiency for Jets

Online tracking is required inside the jet RoIs in order to identify b-jets. Figure 15 and 16 show the online track finding efficiency for trigger tracks matched with offline tracks inside the jet RoI, which is flat and close to 100% for reasonable p_T. The same selection as in the case of tau RoIs is applied to the offline tracks.
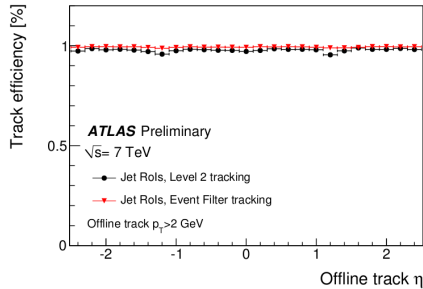

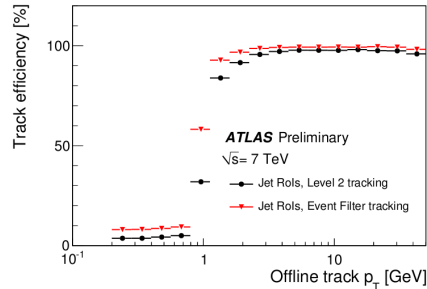**Figure 15.** L2 and EF tracking efficiency for jet RoIs vs p_T.

Figure 16. L2 and EF tracking efficiency for jet RoIs vs η.

References

[1] ATLAS Collaboration, G. Aad *et al.*, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3** (2008) S08003.

[2] ATLAS Collaboration, G. Aad *et al.*, *Expected Performance of the ATLAS Experiment - Detector, Trigger and Physics*, arXiv:0901.0512 [hep-ex].

[3] ATLAS Collaboration, G. Aad *et al.*, *Performance of the ATLAS Silicon Pattern Recognition Algorithm in Data and Simulation at $\sqrt{s}$=7 TeV*, ATLAS-CONF-2010-072 (2010).