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

Ilektra A. Christidi
On behalf of the ATLAS Collaboration
Department of Physics and Astronomy, University College London, Gower st, London WC1 B6, UK
E-mail: Elektra.Christidi@cern.ch

Abstract. At the design luminosity, the Large Hadron Collider will have a bunch crossing (BC) rate of 40 MHz with up to 25 pp interactions per BC. For the ATLAS detector, to reduce this large interaction rate to the 200 Hz that can be written offline, a 3-level trigger system is employed. An essential component in achieving this large reduction is the online tracking in the High Level Trigger (HLT), which consists of the Level 2 (L2) and the Event Filter (EF). L2 is the earliest that data from the Inner Detector is available, and uses custom, fast tracking algorithms. The EF uses components from the offline tracking instead. Results are presented for the commissioning 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-pT 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):

- 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 $\sim 75$ 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 $\sim 500$ 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 $\sim 3$ kHz, currently running at 4 kHz. If the event is accepted, its data are sent to the Event Builder.

- The **Event Filter** (EF) is also software based and is run on $\sim 1600$ 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 transferred from the Read-Out Buffers (ROBs) and the processing time at L2 are minimized. For certain signatures, however, as well as for reconstructing the beam position online, tracking is performed in the whole ID, in the so-called “FullScan” mode.

### 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 $\eta$ 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 $\eta$, for data and MC.](image)

![Figure 3. Number of holes per L2 track, for data and MC.](image)

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 $|z_0sin\theta| < 1.5$ 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 $\eta$ and close to 100% for analysis-relevant $p_T$’s, as shown in figure 4. For lower $p_T$’s, the expected threshold
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 figure 6 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.

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 Jets

Online tracking is required inside the jet RoIs in order to identify b-jets. Figure 7 shows the online track finding efficiency for trigger tracks matched with offline tracks inside the jet RoI, which is flat and close to 100% for analysis-relevant $p_T$’s. 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 $\chi^2$ fit probability $>1\%$.

![Figure 7. L2 and EF tracking efficiency for jet RoIs vs $\eta$ (left) and $p_T$ (right).](image)

4.2. Track Finding Efficiency for Electrons

An electron is identified as a calorimeter cluster matched with an ID track. Figure 8 shows 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 analysis-relevant $p_T$’s. 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 8. L2 and EF tracking efficiency for electrons vs $\eta$ (left) and $p_T$ (right).](image)

4.3. Track Finding Efficiency for Taus

A tau is identified as a calorimeter cluster optionally matched to Inner Detector tracks. Apart from different cluster requirements between electron and tau candidates (eg. size, shape and hadronic energy fraction), the former require the best match to one track, whereas the latter allows looser matching to as many tracks of reasonable quality as available in the RoI. Figure 9 shows the online track finding efficiency for trigger tracks matched with offline tracks inside the tau RoI. The same selection as in the case of jet RoIs is applied to the offline tracks. The efficiency is flat and close to 100% for analysis-relevant $p_T$’s.
4.4. Track Finding Efficiency for Muons

A muon is identified as a combined Muon Spectrometer-ID track. Figure 10 shows the online track finding efficiency for trigger tracks matched with offline reconstructed muons with $p_T > 4$ GeV (for the $\eta$ plot), which is flat and close to 100% for analysis-relevant $p_T$'s.

5. Conclusions and Summary

The ATLAS HLT tracking is a crucial component of the physics objects reconstructed online and used by the experiment to trigger on. Thanks to smart and fast algorithms, robust reconstruction of ID tracks is possible both within detector RoIs and in the whole ID, as was shown with the first collision data. Those studies show that all the online tracking algorithms perform very well, with track reconstruction efficiencies close to 100%, resulting track parameters very close to the ones reconstructed offline with more precise algorithms, and behavior well reproduced by MC.

Acknowledgment

This analysis was performed by the ATLAS Inner Detector Trigger group, and feedback was also provided by the physics trigger signatures groups. This work was supported in part by the EU Marie Curie program under the ERG "Higgs-ZAP" (contract number PERG05-GA-2009-249239) and the RTN "ARTEMIS" (contract number MRTN-CT-2006-035657).

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).