The performance of the ATLAS Inner Detector Trigger algorithms in *pp* collisions at the LHC

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The ATLAS [1] Inner Detector trigger algorithms have been running online during data taking with proton-proton collisions at the Large Hadron Collider (LHC) since December 2009. Preliminary results on the performance of the algorithms in collisions at centre-of-mass energies of 900 GeV and 7 TeV, are discussed.

The ATLAS trigger performs the online event selection in three stages. The Inner Detector information is used in the second and third triggering stages, referred to as Level-2 trigger (L2) and Event Filter (EF) respectively, or collectively as the High Level Trigger (HLT). The HLT runs software algorithms on large farms of commercial CPUs and is designed to reject collision events in real time, keeping the most interesting few events in every thousand. The average execution times per event at L2 and the EF are around 40 ms and 4 s respectively and the Inner Detector trigger algorithms can use only a fraction of these times. Within these times, data from interesting regions of the Inner Detector have to be read out through the network, unpacked, clustered and converted to the ATLAS global coordinates. The pattern recognition follows to identify the trajectories of charged particles (tracks), which are then used in combination with information from the other subdetectors to accept or reject events depending on whether they satisfy certain trigger signatures.

1. Introduction

The Large Hadron Collider delivered the first collisions at 900 GeV in November 2009 and since March 2010 has been colliding beams with a 7 TeV centre-of-mass energy. So far the LHC has been operating at less than design luminosity with a reduced number of colliding bunches, but as of the 28th of May this year, more than 800 million events, corresponding to an integrated lunimosity of more than 14 nb^{-1} had been written to tape by the ATLAS Experiment, with a high data taking efficiency of around 90%. The current ATLAS recorded integrated luminosity is over 300 nb^{-1}.

The large event rate of the LHC makes the online selection of interesting physics events necessary and challenging in order to achieve the physics goals of the LHC. When all the colliding bunches are filled, the ATLAS Trigger will need to reduce the 40 MHz bunch crossing rate to the 200 Hz output rate from the ATLAS High Level Trigger that can be written offline.

Even at current luminosities, interesting interactions in many bunch crossings are overlaid with some number of less interesting minimum bias interactions from separate *pp* interactions in the same bunch crossing. These "pileup" interactions increase the data volume needing to be read out and compilcate the pattern recognition in the inner detector – particularly in the Pixel detector where the spatial occupancy is highest. Therefore it is important that the trigger algorithms are both fast and robust enough to ensure that rare and interesting events are not lost.

2. The Inner Detector

The ATLAS Inner Detector consists of three subsystems. The Pixel detector is nearest the beamline, consisting of 1744 silicon pixel detectors arranged in three barrel layers and three endcap layers in each of the forward (positive z) and rear (negative z) directions[1]. Each pixel is 50×400 μm. Surrounding the Pixel detector is

[1]In the right-handed ATLAS frame, z lies along the beam direction with r being the radius transverse to the beamline, y upwards and the positive x axis pointing towards the centre of the LHC machine.

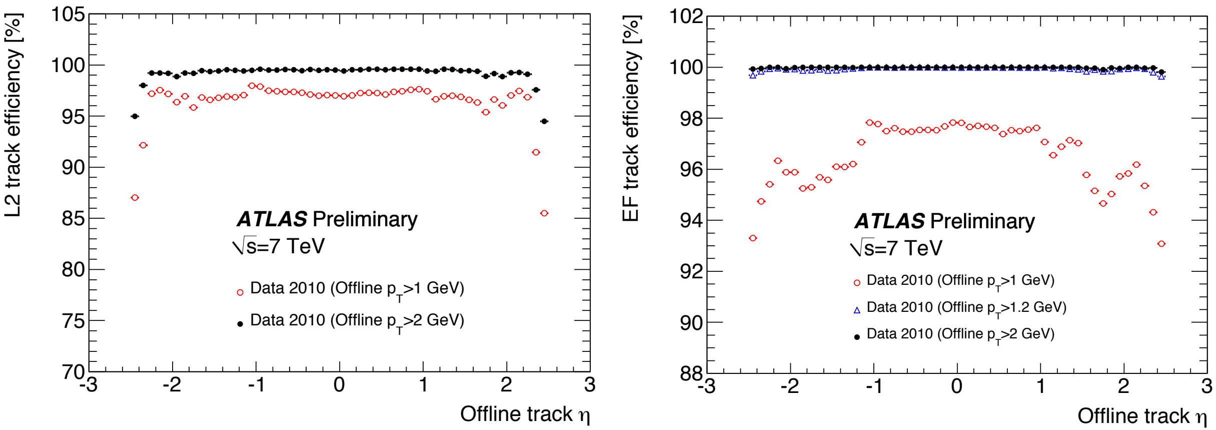

Figure 1. The efficiency for identifying offline reconstructed tracks in the minimum bias trigger for the L2 trigger (left) and the Event Filter (right) in 7 TeV Collisions. Note the different scales on the efficiency axis.

the Semiconductor Tracker (SCT) with 8176 silicon strip detectors with an 80 μm readout pitch. The SCT wafers are arranged in pairs, back-to-back, to provide a small 40 mrad stereo angle. The SCT consists of four barrel layers, and nine wheels each in the forward and rear directions. The outermost of the Inner detector subsystems is the Transition Radiation Tracker (TRT) which consists of 2 mm radius straw drift tubes containing a Xenon (70%)-CO_2(27%)-O_2(3%) gas mix, arranged as two barrel sections with straws parallel to the beamline, and forward and rear endcaps with straws arranged radially. The Inner Detector is enclosed in a superconducting 2 T solenoid for providing track transverse momentum discrimination.

3. The ATLAS trigger and DAQ systems

To achieve the high level of event rejection required, the ATLAS trigger [2] has been designed as a three level trigger system. The first level (LVL1) trigger is a hardware, pipelined, trigger using custom electronics with reduced granularity information from the calorimeter and the muon systems for fast event reconstruction and data from taggers, such as the minimum bias trigger scintillators. The LVL1 trigger is clocked at the bunch crossing rate and delivers a decision after a fixed latency of 2.5 μs. During LVL1 processing regions of interest (RoIs) are indentified that contain features that merit additional reconstruction. On a LVL1 accept the data are read out into custom Readout Buffers where they are stored for access by the L2 system - the first stage in the ATLAS High Level Trigger (HLT). The ATLAS HLT consists of two farms of fast commodity CPUs - one farm for the L2 trigger and one for the third level, Event Filter (EF). Each CPU node consists of two quad core processors running Linux.

During the Level-2 processing the algorithms have access to the detector data with the full spacial granularity, but only for that data within the identified LVL1 regions of interest. This approach reduces the data volume and processing required at Level-2. On a Level-2 accept, the full event is constructed by the Event Builder which passes the data on to the Event Filter. This runs RoI seeded versions of the offline reconstruction algorithms but with access to the complete detector data and the full alignment and calibration. The Level-2 trigger is the first stage that has access to the Inner Detector data so after processing by the Inner Detector trigger at Level-2 it is possible to combine tracking information from the Inner Detector with calorimeter or muon system data. This enables improved particle reconstruction and rejection, essential for the identification of signatures which may signal new or rare physics, such as the presence of high transverse energy electrons and muons or final states containing b-quarks.

3.1. The Inner Detector Trigger

In the HLT, tracking is performed at both the Level-2 and EF filter stages. The Event Filter runs a modified version of the full, offline reconstruction whereas the Level-2 uses custom algorithms [3,4] based on identifying hits consistent with track roads in the Inner Detector and then fitting with a custom Kalman filter track fit for fast track reconstruction. Tracks can then be extrapolated into the TRT [5] to provide improved p_T resolution and particle identification.

4. Performance

Since the trigger selects events for reconstruction offline, it is important that the trigger is able to reproduce the performance of the offline algorithms with high efficiency and resolution. Results showing detailed comparisons between the trigger and offline reconstructions for 900 GeV centre-of-mass energy collisions are available [6] and results for collisions at 7 TeV are presented in the remainder of this paper.

For the minimum bias triggers, where so far, there is the most data, tracks are reconstructed in the entire detector rather than within an RoI and an implicit cut of 1 GeV imposed in both the L2 and the EF reconstruction since tracks below this are of less interest to subsequent stages of the trigger that use the tracks. The efficiency for reconstructing offline tracks consistent with an interaction vertex and within the acceptance of the Inner Detector are shown in figure 1 as a function of pseudorapidity. Shown are the efficiencies for tracks with offline transverse momentum, $p_T > 1$ GeV and $p_T > 2$ GeV, and additionally with $p_T > 1.2$ GeV for the EF. For the L2 trigger the efficiency for finding tracks with $p_T > 1$ GeV is better than 97% for almost the entire pseudorapidity range, and for tracks with $p_T > 2$ GeV the efficiency is better than 99%. For the Event Filter the efficiency for offline tracks with $p_T > 1.2$ GeV is approximately 100%. The efficiencies at both L2 and the EF have been seen to be remarkably stable with changing beam conditions throughout a physics run.

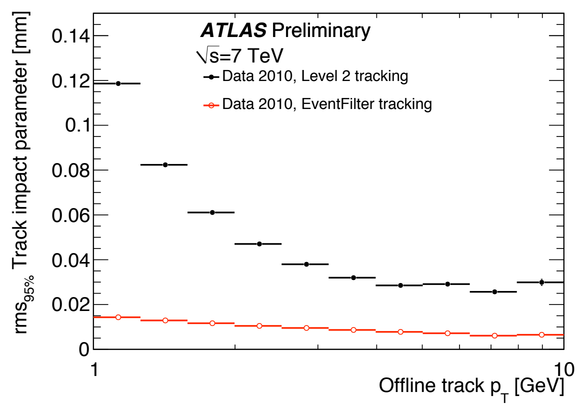

Figure 2. the variation of the resolution of the transverse impact parameter with respect to the beamline for 7 TeV data. The resolution here has been defined as the root-mean-square of the central 95% of the residual distribution.

After reconstruction the L2 tracks are used in a fast online determination of the vertex position. This position is made available to the LHC operators to provide an accurate determination of the luminous region. In addition, it can be used subsequently within the HLT itself to improve the resolution of the online track impact parameter determination.

During the 7 TeV running, the width of the observed beamline position distribution, including both the actual beam spread and vertex resolution has been seen to be around 120 μm in both x and y with a measured beam position in the transverse plane of a around 200 μm in x and 1 mm in y.

The track residuals for the online trigger tracks with respect to matching offline tracks have also been studied in some detail. These have been seen to have non-Gaussian tails at the few percent level, although both the central distributions and the tails are remarkably well reproduced by the Monte Carlo simulation.

Figure 2 shows the resolution for the transverse impact parameter, d_0 with respect to the beamline as a function of the offline track p_T for 7 TeV data. The L2 reconstruction is able to reproduce tha impact parameter found offline to

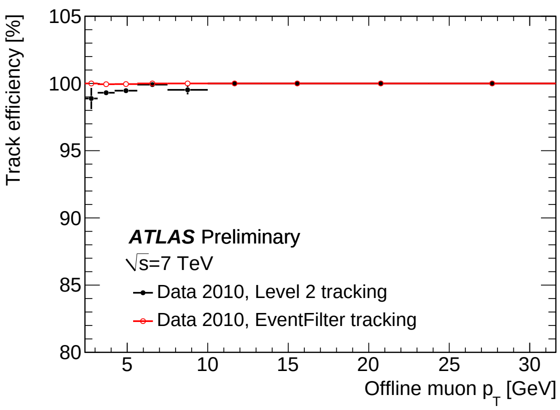

Figure 3. The efficiency for identifying offline reconstructed muons with the Inner Detector trigger for regions-of-interest identified by the muon spectrometer trigger at Level 1 and Level 2.

within around 120 μm at low p_T and to within around 30 μm at high p_T. The EF reproduces the offline impact paremeter to better than about 10 microns, significantly smaller than the intrinsic resolution of the offline reconstruction itself, so any additional resolution effects from selecting on the EF reconstruction in the trigger should be small.

With the increased luminosity becoming available, ATLAS is beginning to collect enough events to make possible detailed comparison of the Inner Detector trigger performance for physics objects - electrons, muons etc - reconstructed online within regions of interest.

Figure 3 shows the efficiency for reconstructing offline muons in the L2 and EF as a function of the offline muon transverse momentum. For these events, the LVL1 has identified a muon candidate in the muon spectrometer to produce an RoI, which has then been processed further by the L2 muon spectrometer reconstruction [7]. Muons reconstructed by the muon spectrometer trigger algorithm with an online transverse momentum greater than 4 GeV then update the RoI position and the RoI is passed to the Inner Detector trigger algorithms for further processing at L2 and in the EF. For this result, no further selection based on the Inner Detector trigger was applied, so providing an unbiased measure of the Inner Detector trigger reconstruction efficiency, which is around 100% for the EF and better than 99% for the L2.

5. Conclusions

The LHC is now routinely providing collisions at 7 TeV, with the HLT providing high precision tracks with a high efficiency. The L2 tracking has been providing an accurate online determination of the luminous region since the start of data taking in 2009.

As the luminosity increases, the tracking in the HLT will become an increasingly important factor in the selection of physics objects and already contributes to the electron trigger such that events which pass no other triggers are not written out if they do not pass the electron trigger.

It is encouraging that the performance of the HLT is remarkably well reproduced by the Monte Carlo, already after only a few months of data taking and the Inner Detector trigger is ready to play an essential rôle in the achievement of the physics goals of the ATLAS Experiement.

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