Performance and Development of the ATLAS Inner Detector Trigger

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Abstract: The performance of the ATLAS inner detector (ID) trigger algorithms running online on the high level trigger (HLT) processor farm during LHC Run 1 is presented. The prospects for a full redesign of the ID trigger afforded by the 2013-2014 long shut-down are discussed. The ID trigger HLT algorithms are essential for many signatures within the ATLAS trigger. The performance of the algorithms for electrons, muons and taus is presented. During the long shutdown, an additional layer of pixels - the “insertable B-layer” (IBL) will be added to the ATLAS detector. Simulation of the effects this will have on the performance of the current HLT algorithms is presented. The ATLAS HLT software will also be developed to run as a more flexible single stage rather than the two distinct levels present during the Run 1 operation. Ongoing studies and potential development relating to this will be discussed briefly.

Keywords: ATLAS; Inner Detector; High Level Trigger; Performance.

1. Introduction

The LHC¹ has now completed Run 1, after data taking periods at a centre-of-mass (CoM) energy of 7 TeV in 2010 and 2011 and CoM energy of 8 TeV in 2012, delivering a combined luminosity of 25 fb^{-1} . Conditions became more challenging between 2011 and 2012. In addition to increased CoM energy, the average number of separate *pile-up* interactions occurring per bunch crossing also increased from an average of 9 in 2011 to an average of 20 during 2012. In 2015 Run 2 will begin with an even higher CoM energy of 13 TeV and expected 50 pile-up interactions or more per event.

1.1. ATLAS Inner Detector

The ATLAS² sub-detector closest to the interaction region is the inner detector (ID), which is surrounded by a 2 T superconducting solenoid, electromagnetic and hadronic calorimeters, and finally the muon chambers. The ID is designed to allow precise tracking and vertexing close to the point of interaction, and is comprised of three types of detector. The pixel detector is made up of 1744 silicon pixel modules, each containing 46,080

50x400 μm pixels. These are arranged into three layers in the barrel and the end-caps. Surrounding this is the Semi-Conductor Tracker (SCT), another silicon detector, but with 4088 microstrip detectors, each containing 780 readout strips of 80 μm pitch. These are arranged in back-to-back wafers with 40 mrad stereo angle, in four layers in the barrel and nine in the end-caps. The outermost component of the ID is the Transition Radiation Tracker (TRT). This uses 4 mm diameter straw drift tubes arranged parallel to the beam-pipe in the barrel and radially in the endcaps, filled with a gas mix of Xe(70%)CO₂(27%)O₂(3%). As well as tracking information over a larger volume, transition radiation in the TRT allows electrons and positrons to be distinguished from other particles. When triggering on high momentum single particles, the particle trajectories reconstructed in the ID subdetectors are essential.

1.2. *ATLAS Trigger*

An effective trigger system is crucial to deal with a large nominal bunch crossing rate (40 MHz) and reduce this to a manageable rate for recording (400 Hz) without discarding events containing potentially interesting physics. During Run 1 a three tier trigger system was employed, consisting of Level 1 (L1) and the High Level Trigger (HLT), which is split into Level 2 (L2) and the Event Filter (EF). The L1 trigger is purely hardware based and uses coarse granularity information from the calorimeter and muon systems to identify a region of interest (RoI) which is then passed on to L2. This reduces the rate to 75 kHz in approximately 2.5 μs . The software based L2 then uses full granularity information within the RoI, including hits from within the inner detector (ID). Various algorithms can be used to reconstruct tracks from the space-points in the ID, and in 2012 the algorithm with best performance for a given slice was used. Processing events within approximately 40 ms, the L2 system reduces the rate to approximately 5 kHz. The EF uses algorithms based on the offline software and must process the full granularity data for the full event in approximately 4 s.

2. Performance of the High Level Trigger (HLT) during Run 1

2.1. *Electron Efficiencies*

The efficiency of the HLT for electrons was measured using a tag and probe study using the $Z \rightarrow e^+e^-$ events. In this study, a tag lepton is required to

Fig. 1. Efficiency of the electron trigger as a function of p_T and μ as a function of the offline track matched to the electron candidate.

be reconstructed in the electromagnetic calorimeter and the inner detector, and a probe lepton requires only the calorimeter reconstruction (although leptons with inner detector hits are not vetoed). These are matched to offline electron tracks in order to reduce the contribution from background processes. The efficiency of a given trigger algorithm depends on whether there is a match between an ID trigger track, and the offline track matched to the probe, which satisfies $\Delta R < 0.03$. Additionally the tag and probe lepton are required to have $p_T > 24$ GeV and 15 GeV respectively, $|\eta| < 2.5$, and an invariant mass of the pair between 70 and 120 GeV. This final requirement is to identify genuine electrons from the decay of a Z boson. Figure 1 shows the efficiencies resulting from this study on a small sample of the 2012 data. It can be seen that a high efficiency is achieved at high p_T for EF and L2 despite the challenging conditions in 2012. The performance as a function of the average number of interactions per bunch crossing, $\langle\mu\rangle$, reflects improvements made in the short shutdown before 2012, with very little dependence of efficiency on $\langle\mu\rangle$, and an excellent efficiency seen for this high pile-up data.

2.2. Muon and Tau Efficiencies

The performance of the muon and tau triggers in 2011 were both evaluated with respect to offline objects.³ Dedicated HLT monitoring triggers were used to select events based only on online calorimeter or muon spectrometer information, in which the ID trigger algorithms were executed but not used for the event selection. For events passing these triggers, offline muon and tau track candidates within the RoIs were selected and matching an HLT trigger track within $\Delta R < 0.05$ with an offline track within the same RoI was attempted. This was used as a measure of the HLT algorithm effi-

Fig. 2. Efficiency of the muon trigger (left) and tau trigger (right) as a function of p_T of the offline muon or tau candidates respectively.

ciencies. The offline reconstructed tracks were subject to quality cuts based on offline selection used for these objects. The efficiency for the muon and tau triggers as a function of p_T during the 2011 is displayed in Figure 2. The EF efficiency is close to 100% for all p_T and the L2 also maintains a reasonable efficiency at higher p_T for both muon and tau triggers.

3. Development for Run 2

3.1. Effect of the IBL on HLT Algorithm Resolutions

During the long shutdown, an additional layer of pixels closer to the interaction point than the current inner layer will be inserted. The resulting impact was simulated by studying truth muons from Monte Carlo $t\bar{t}$ events containing either one or two muons.⁴ Resolutions for the transverse impact parameter, d_0 , as a function of signed p_T for the L2 and EF algorithms with and without inclusion of hits from the IBL are shown in Figure 3. An improvement of around 25% is seen. A similar improvement is observed for the track vertex and pseudorapidity resolutions.

3.2. HLT Algorithm Development

For Run 2 the L2 and EF stages of the HLT will be modified to run on a single node, which will reduce the amount of data requested, as information can be shared by both the L2 and EF systems.⁴ The operation of the HLT will still be similar to the separate tiers used before, with a fast tracking stage followed by more detailed tracking, but with increased sharing of information between the two stages. There will also be input to the HLT from the Fast Tracker(FTK)⁵ system which will be installed during Run 2. This is a hardware system that will perform tracking in the ID for events

Fig. 3. Comparison of the d_0 resolution as a function of p_T with and without including IBL hits.

after acceptance by Level 1, but before the Level 2 execution. In addition to these changes the HLT algorithms are undergoing a detailed programme of monitoring and software profiling. This is being used to optimise the code wherever possible, using e.g. vectorisation to improve CPU times.

4. Conclusions

The good performance of the ATLAS inner detector algorithms for electrons have been maintained during 2012 despite the increasingly challenging conditions. In particular the dependence on pileup has been reduced, with Level 2 and Event Filter efficiencies maintained for average numbers of interactions per bunch crossing up to 40. In 2011 the tau and muon triggers also performed well, with slight drops in efficiency for higher pile-up already addressed before the 2012 run. The effect of the IBL being added during the current long shutdown is simulated, suggesting this will improve the d_0 resolution at high p_T to around 10 microns, with a 25% improvement seen for all resolutions considered.

References

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