Performance of the ATLAS Trigger with Proton Collisions at the LHC

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On Behalf of the Atlas Collaboration

The ATLAS trigger has been used very successfully to collect collision data during 2009 and 2010 LHC running at centre-of-mass energies of 900 GeV, 2.36 TeV, and 7 TeV. The trigger system reduces the event rate, from the design bunch-crossing rate of 40 MHz, to an average recording rate of 200 Hz. The ATLAS trigger is composed of three levels. The first (L1) uses custom electronics to reject most background collisions, in less than 2.5 μs, using information from the calorimeter and muon detectors. The upper two trigger levels, known collectively as the High Level Trigger (HLT), are software-based triggers. As well as triggers using global event features, such as missing transverse energy, there are selections based on identifying candidate muons, electrons, photons, tau leptons or jets. We give an overview of the performance of these trigger selections based on extensive online running during LHC collisions and describe the progress towards fully commissioning these triggers. Distributions of key selection variables based on calorimeter and tracking information are shown calculated at the different trigger levels and are compared with offline reconstruction. Comparisons between data and simulations are shown for some important selection variables, already illustrating a very good level of understanding of the detector and trigger performance. We describe how the trigger has evolved with increasing LHC luminosity and give a brief overview of plans for forthcoming LHC running.

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1. Overview

When operating at the design luminosity of 10^{34} cm^{-2}s^{-1} the LHC will have a 40 MHz bunch-crossing rate, with an average of 25 interactions per bunch crossing. The purpose of the ATLAS [1] trigger is to reduce the 1 GHz interaction rate to about 200 Hz for recording and offline processing. This maximum average output rate (corresponding to ∼300 MB/s, determined by available offline resources) can be significantly exceeded for shorter periods of time.

Detector information is stored in front-end pipelines pending a decision from the L1 trigger. In order to achieve a latency of less than 2.5 μm, L1 is implemented in fast custom electronics. The L1 trigger is designed to reduce the rate to a maximum of 75 kHz. The HLT consists of two levels, L2 and Event Filter (EF), implemented on farms of commodity processors connected by fast dedicated networks. The final system will consist of about 500 L2 nodes and 1800 EF nodes, about half of which were installed in 2010. On a L1 accept, detector data are transferred to the Readout Buffers (RoB) which store events pending the L2 decision. The L2 selection is based on fast custom algorithms processing partial event data within the Regions of Interest (RoI) identified by L1. The RoI correspond to 2–4% of the full event data. The L2 trigger reduces the rate to ∼3 kHz with an average processing time of ∼40 ms. The Event Builder assembles event fragments from the RoBs for L2-accepted events, providing full event information to the Event Filter and, on a EF accept, for output to storage.

The trigger selection is configured via a trigger menu which defines trigger chains. A trigger chain specifies a sequence of reconstruction and selection algorithms which start from a L1 trigger and lead to a specific trigger signature [2]. If the requirements for one or more trigger signature are satisfied, event recording is triggered. Prescale factors can be applied to each L1 trigger and each HLT chain. A series of L1 and HLT prescale sets, covering a range of luminosities, are defined to accompany each menu. There are between 200 and 500 chains defined in the current trigger menus.

2. Trigger Performance

The ATLAS trigger was enabled incrementally during 2010, starting with a L1-based selection, and enabling HLT rejection as needed to match increasing LHC luminosity. At the start of 2010 running, luminosity was such that it was possible to record all collisions triggered by the L1 Minimum Bias (MBTS) trigger [3]. The MBTS trigger is based on scintillators installed in each end-cap covering the pseudo-rapidity region of $2.09 < | \eta | < 3.84$. The MBTS_1 trigger requires at least one counter above threshold in coincidence with a filled LHC bunch, this trigger is 99.7% efficient for collisions with at least one track with transverse momentum p$_T$ > 500 MeV. As luminosity increased above about 2×10^{27} cm^{-2}s^{-1}, the MBTS trigger was prescaled and other L1 triggers became the principal triggers for physics. Fig. 1 shows L1 rates as a function of instantaneous luminosity (measured in 2 minute intervals) for various triggers: MBTS_1, MBTS_4_4 (4 counts in each end-cap), electron/photon (EM), jet (J) and muon (MU) L1 triggers. The number gives the nominal threshold (GeV). During this early period the HLT was operated in monitoring mode, with the algorithms running online but not rejecting events. This enabled validation of the HLT, such that rejection could be progressively enabled as required. The HLT was fully active from August 2010 when the luminosity reached 2×10^{30} cm^{-2}s^{-1}. The luminosity subsequently rose by
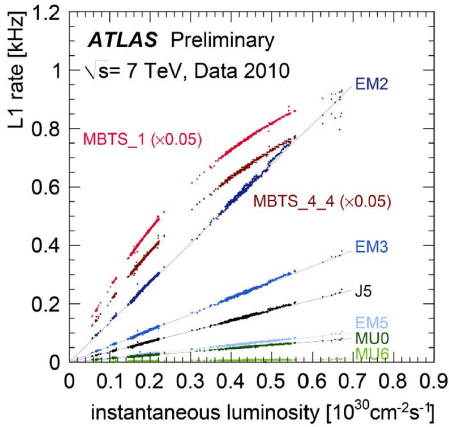
Figure 1: Rates for various L1 triggers (MBTS rates scaled by 0.05). The MBTS_1 rate saturates approaching the frequency of the colliding bunches.
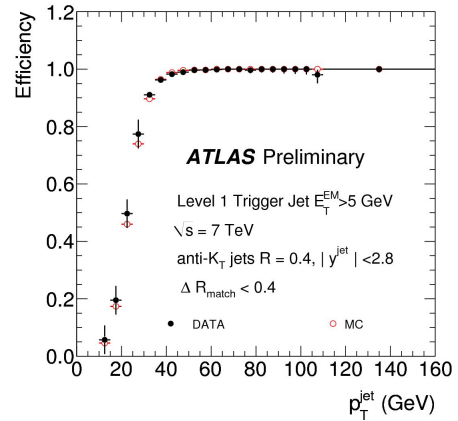
Figure 2: L1 jet trigger efficiency versus calibrated offline jet p_T shown for data and MC simulation.

two orders of magnitude during the remainder of the 2010 data taking period, during which time the trigger (L1 and HLT) was instrumental in selecting the data for physics.

The L1 jet trigger sums transverse energy (E_T) in the Electro-Magnetic (EM) and hadronic calorimeters in a relatively large cone (0.8×0.8 in $\eta \times \phi$, where ϕ is the angle measured in a plane perpendicular to the beam-pipe). The L1 jet trigger efficiency is shown in Fig. 2, for the lowest threshold, as a function of the calibrated offline jet p_T reconstructed using the anti-kt algorithm [4]. The lowest jet threshold is nominally 5 GeV (the cut applied to the uncalibrated EM-scale L1 jet), but in practice full efficiency is only reached at about 40 GeV. There is good agreement between data and Monte Carlo simulation.

The L1 electron/photon trigger sums transverse energy in the EM calorimeter in a relatively small ($\eta \times \phi = 0.2 \times 0.2$) cone. The efficiency is shown as a function of offline cluster E_T in Fig. 3 for data and MC. This shows full efficiency above the threshold and good agreements with simulation. The calorimeter clustering is repeated at the HLT using full granularity information, and including information from the EM pre-sampler. Selections are applied based on various cluster shape parameters, such as R_η which is the ratio of transverse energy in a 3×7 window to that in a 7×7 window (dimensions in $\eta \times \phi$ using calorimeter cell units of $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$). Fig. 4 shows the distribution of R_η calculated at the EF for offline electron candidates. The distribution is peaked towards $R_\eta = 1$ for electrons. The shape of the distribution is well modeled by simulation. After the calorimetry-based selection, tracks are reconstructed in the ID and cluster-track matching cuts are applied. In Fig. 5 the efficiency for reconstructing tracks at L2 and the EF is shown for offline electron candidates passing the L1 trigger, demonstrating 100% efficiency for electrons with $p_T > 5$ GeV.

The L1 tau trigger [5] uses a cone of $\eta \times \phi = 0.2 \times 0.2$ to sum energy in the EM and Hadronic calorimeters. Isolation requirements can be imposed at L1 for both the electron/photon and tau triggers, but were not used in 2010 running. In the HLT a tau candidate is identified as a well collimated calorimeter cluster with a small number of associated Inner Detector tracks. The number of associated L2 tracks is shown in Fig. 6, demonstrating good agreement between data
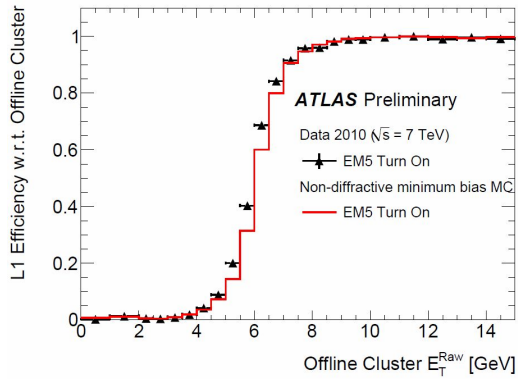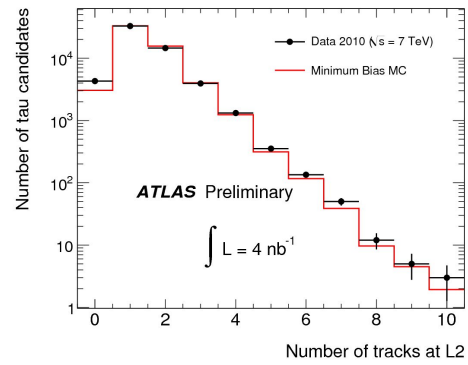
Figure 3: Efficiency versus offline cluster E_T (EM scale) for the 5 GeV L1 EM threshold.
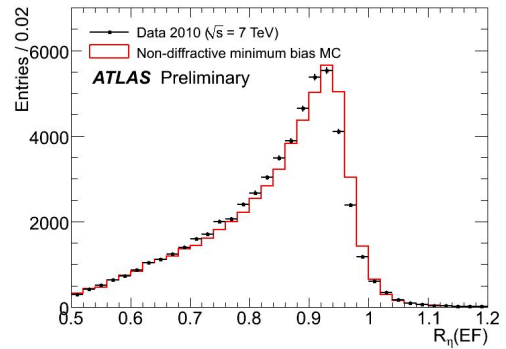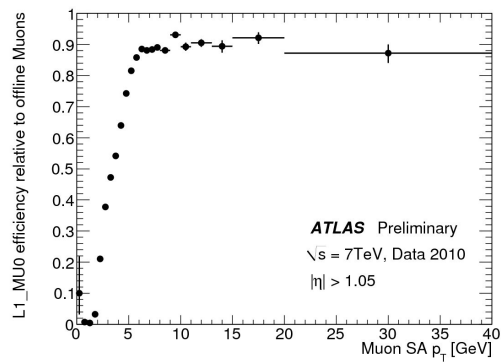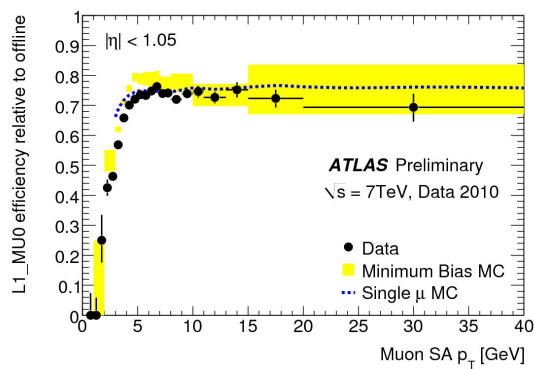

Figure 4: EF R_η distribution for MC and data.
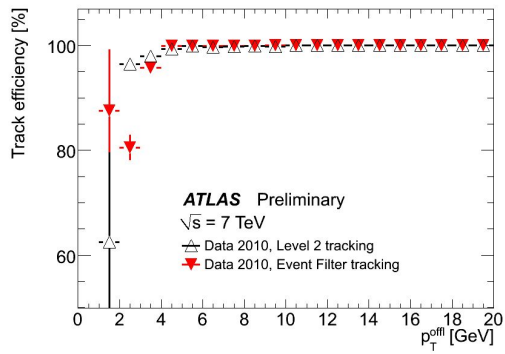
Figure 5: L2 and EF tracking efficiency for offline reconstructed electrons.

Figure 6: Distribution of the number of L2 tracks in tau RoI for data and MC.

Figure 7: Efficiency versus offline muon p_T for the lowest threshold RPC (left) and TGC (right) triggers.

and simulation.

The L1 muon trigger is based on dedicated detectors; Resistive Plate Chambers (RPC) in the barrel ($|\eta| < 1.05$) and Thin Gap Chambers (TGC) in the end-caps. The RPC efficiency is shown as a function of offline muon p_T for the lowest trigger threshold in Fig. 7 (left). This includes a loss of $\sim$20% due to support structures etc. The corresponding TGC efficiency is shown in Fig. 7 (right). At the HLT, the L1 trigger is confirmed using information from the precision muon detectors to form muon track segments. The efficiency for reconstructing tracks segments is more than 98% with repect to L1 for muons with $p_T > 4$ GeV. Muon segments are then combined with Inner Detector tracks to form combined muon candidates.

In addition to the RoI-based triggers, there are L1 Missing E_T (MET) and Total E_T (TE) triggers based, respectively, on vector and scalar sums of calorimeter cell energy over the entire calorimeter. At L2 they are corrected using muon information and at the EF they are recalculated using information from both the calorimeter and muon detector. Up to a luminosity of $\sim 10^{30}$ cm^{-2}s^{-1}, it was possible to run with an un-prescaled 10 GeV MET threshold. This was raised, in steps, to 30 GeV as luminosity rose to 2×10^{32} cm^{-2}s^{-1}. In addition to single MET items, the menu contains combined triggers such as tau plus MET used, for example, as a trigger for W$\rightarrow \tau\nu$.

3. Summary

The ATLAS trigger has been successfully commissioned and has been instrumental in delivering the data for ATLAS physics analysis. There is generally excellent agreement between quantities calculated online, using fast trigger algorithms, and those reconstructed offline. There is also good agreement between data and MC simulation for these quantities and for measured trigger efficiencies. The trigger has been demonstrated to function very well, meeting operational requirements and evolving to meet the demands of rapidly increasing LHC luminosity. The trigger selection will continue to evolve to meet future demands via progressive increase of pre-scales, tightening of selection cuts, application of isolation requirements as appropriate and increased use of higher multiplicity and multi-object triggers. As a result of the very good performance of the trigger in this years running and offline studies confirming the scaling to higher luminosities, we are confident that the trigger will continue to meet the challenges of running in 2011 and beyond.

4. Acknowledgements

References

[1] The ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST*, **3** (2008) S08003 (2008) [`doi: 10.1088/1748-0221/3/08/S08003`]

[2] S. George for the ATLAS Collaboration, *The ATLAS High Level Trigger Configuration and Steering Software: Experience with 7 TeV Collisions*, *In these proceedings*.

[3] R. Kwee for the ATLAS Collaboration, *Minimum Bias Trigger in ATLAS In these proceedings*.

[4] M.Cacciari *et al.*, *The anti-kt jet clustering algorithm*, *JHEP*, **804** (2008) p63

[5] M. Shamim for the ATLAS Collaboration, *Performance of the ATLAS tau trigger with 7 TeV collision data at the LHC*, *In these proceedings*.