Commissioning and performance of the ATLAS trigger with proton collisions at the LHC

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The ATLAS trigger has been used successfully to collect cosmic ray and single-beam events, and collision data during the 2009–2010 LHC running at center-of-mass energies of 900 GeV and 7 TeV. The three levels of the ATLAS trigger have been extensively exercised under different conditions and many of its components have been commissioned to be ready for active event selection. We describe the status for the commissioning of the trigger selections using first LHC data collected in the ATLAS experiment. Plans for the evolution of the trigger during the forthcoming LHC running are also briefly discussed.

1 Introduction

The ATLAS experiment [1] is one of the two general-purpose detectors at the Large Hadron Collider (LHC). It collected proton-proton collisions at the end of 2009 at a center-of-mass energy of 900 GeV and continues to accumulate data at $\sqrt{s} = 7$ TeV since March 2010. The proton-beam running was preceded by many months of collecting cosmic-ray data, which allowed for exercising the ATLAS trigger system and eased its commissioning with beam.

In the following sections, a brief overview of the ATLAS trigger system is given, which is followed by a discussion on the commissioning status and performance of calorimeter and tracking-based triggers. Complementary information on the performance of electron, photon, tau, muon, jet, and missing-energy trigger signatures can be found in [2].

2 ATLAS trigger system

The ATLAS trigger system [1] consists of three levels:

- The Level 1 (L1) trigger is purely hardware based. It uses coarse granularity detector data from the calorimeters and muon trigger chambers only to impose a fast (latency $<$ 2.5 μs) trigger decision and define Regions of Interest (RoI) with large energy deposits or potential muon tracks, respectively. Its maximum output rate is about 75 kHz, out of 40 MHz of collision input. If the event is accepted, the detector data are passed from their front-end electronics to Read Out Buffers (ROB) to be later accessed by subsequent trigger levels.
- The Level 2 (L2) trigger is software based and is run on a large farm of processors. It is seeded by L1 and only information of those RoIs which pass certain configurable thresholds

is processed. The detector information is available with full granularity within the RoIs, for which dedicated, fast reconstruction algorithms are executed (average execution time per event about 40 ms). The maximum output rate of L2 to the next trigger level is about 3 kHz. If the event is accepted, the data fragments from all ROBs are sent to the Event Builder. It synchronizes and combines this information to build the complete event and forwards it to the PC farm of the next trigger level.

- The Event Filter (EF) is also software based. It is seeded by L2 and the complete detector data for the event processing are available. Given the larger available resources for reconstruction at the EF (about 4 s per event), offline-like algorithms are used for a better trigger object determination. Its average output rate is about 200 Hz, sufficient for the offline data storage system to handle.

The L2 and EF are collectively referred to as the High Level Trigger (HLT).

3 Commissioning of the L1 trigger

The initial timing synchronization of the ATLAS detectors and triggers made use of so called *splash events*, where a proton beam was steered into a collimator, thereby producing an approximately plane shower of charged particles over most of the ATLAS detector. This allowed quick timing calibration of many trigger inputs with respect to the beams with an accuracy of ±5 ns. The final L1 calorimeter synchronization adjustments are based on collision data which can be timed to a precision of 2 ns.

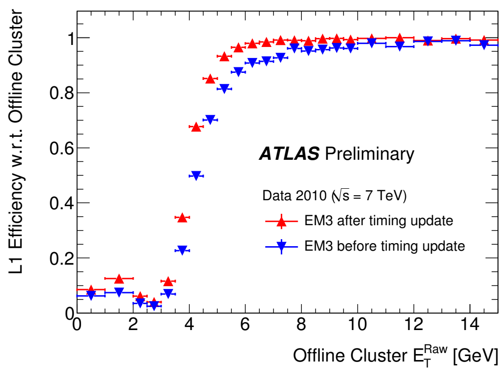

Figure 1: L1 efficiency for the electromagnetic trigger with a 3 GeV threshold (EM3) as a function of the uncalibrated offline cluster E_T for two timing settings.

The good performance of the first level calorimeter trigger during 7 TeV running can be inferred from the behavior of the trigger turn-on curves. An example is shown in Fig. 1. The figure was made using p-p collision data from 2010 and shows the efficiency of the electromagnetic calorimeter trigger with a 3-GeV-threshold (EM3) as a function of the transverse energy calculated offline, using uncalibrated clusters. It shows the improvements in the turn-on behavior after timing adjustments have been made. The L1 efficiency is rapidly approaching the plateau at 100%.

The first level muon trigger is a real time system which uses dedicated trigger detectors. The system uses information from two types of detectors: Resistive Plate Chambers (RPC) in the central region ($|\eta| < 1.05$) and Thin Gap Chambers (TGC) in the forward region ($1.05 < |\eta| < 2.4$) [1]. The RPC and TGC triggers were earlier commissioned with cosmic rays and splashes, and are now being fine tuned with the ongoing p-p collision runs at 7 TeV. The higher rate of muon triggers in the forward region has allowed accurate timing calibration of the TGC system within 3 ns. Synchronization of the RPC trigger is still ongoing as an insufficient data volume has been collected in the central region so far.

4 Performance of the HLT reconstruction

The HLT commissioning strategy consists of several steps. During the first data-taking period with low luminosity, the HLT algorithms were disabled online to ensure no impact on data taking. They were running offline in quasi-real time instead to check against possible errors, crashes and timeouts. Once no problems have been found they were deployed online.

In the second phase, data were selected by the L1 trigger and subsequently processed online by the HLT. However, all events were accepted independent of the HLT decision for further studies as low luminosities allowed the trigger to be based solely on L1. The HLT performance was studied offline in detail. Once it was fully understood and turned out to be satisfactory w.r.t. the offline requirements and at the same time peak luminosities exceeded $O(10^{29})$ cm^{-2}s^{-1}, the HLT rejection was turned on for first low-E_T thresholds to reduce the output rate and provide higher purity events.

The HLT reconstruction is based on the calorimeters and the muon spectrometer which made use of tracking information from the inner detector where appropriate. Final physics objects are built then from calorimeter clusters and tracks which constitute electrons, photons, muons, taus, and jets.

The details of the calorimeter trigger reconstruction and performance are described in [3]. Figure 2 shows the E_T spectrum as reconstructed at L2 for electromagnetic clusters for $\sim 9\ \mu$b^{-1} of stable beam data collected with 900 GeV collisions and $\sim 400\ \mu$b^{-1} of stable beam data collected with 7 TeV collisions. Also a comparison with the minimum bias MC is overlaid which shows a very good agreement with the data.

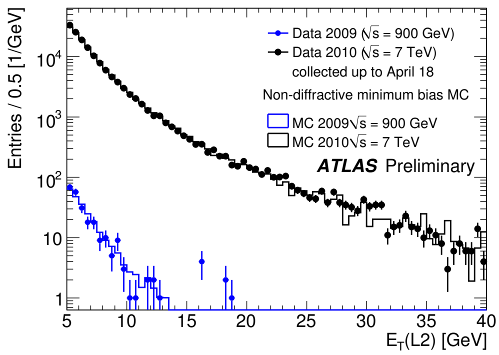

Figure 2: E_T spectrum of reconstructed clusters for data collected with 900 GeV and 7 TeV collisions. A comparison with a minimum bias MC is also shown.

The performance of the HLT track reconstruction has been assessed using data from running periods where the LHC delivered stable beam collisions during which time the ATLAS inner detector components were powered and read out. The events were selected online by the minimum bias trigger as described in [4], without using any information on HLT tracks. In the early low luminosity running period, the low track multiplicity allowed us to reconstruct all tracks at the HLT as the rate of RoI-based tracks was insufficient for these studies. Those trigger tracks were then matched geometrically to the more precise offline reconstructed ones as a reference for assessing their performance. Details of the tracking analysis are described in [5, 6]. The 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 for a reasonable p_T cut, as shown in Fig. 3.

The details of the HLT muon trigger reconstruction are described in [7]. Figure 4 shows the efficiency of L2 muon tracks reconstructed using the muon spectrometer alone relative to offline reconstructed muons with a nominal threshold set to 4 GeV as a function of the transverse momentum p_T measured by the offline reconstruction. Data were collected at $\sqrt{s} = 7$ TeV. A requirement of a L1 muon trigger has been imposed on the trigger selection, while the offline selection requires a reconstructed muon with a cut $p_T > 2$ GeV, momentum $p > 4$ GeV with

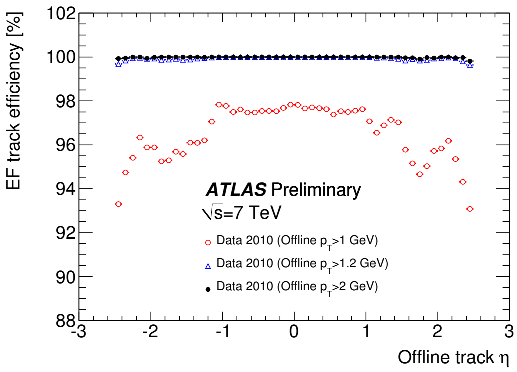

Figure 3: Integrated EF track-finding efficiency for three p_T thresholds.

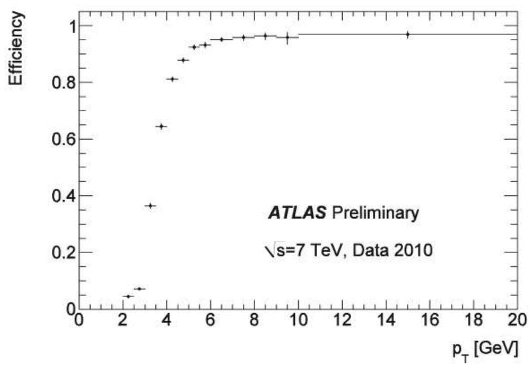

Figure 4: Efficiency of reconstructing a L2 muon in the muon spectrometer w.r.t. offline muons.

the number of hits in the inner detector to be larger than five. Also a match with a L1 RoI was required.

5 Summary

The commissioning of the ATLAS trigger with the first proton-proton collisions is ongoing. The HLT has been exercised and validated in the online running at event output rates low enough for writing to tape all L1-triggered events i.e. at instantaneous luminosities up to $O(10^{29})$ cm^{-2}s^{-1}. At higher luminosity conditions, the HLT has gradually been enabled to provide the additional rejection needed to keep the total output data rate to tape to around 200 Hz. As of now, the peak luminosity at which ATLAS has operated is $O(10^{30})$ cm^{-2}s^{-1} and the lowest-p_T electron, photon, tau, muon, and missing E_T triggers are providing additional HLT rejection. Over the next months, the LHC luminosity is expected to rise by more than two orders of magnitude and most of the HLT is supposed to be in active selection mode by then.

References

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

[2] The ATLAS Collaboration, R. Mackeprang, "Reconstruction and selection of physics objects in the ATLAS high level trigger", these proceedings.

[3] The ATLAS Collaboration, "ATLAS High Level Calorimeter Trigger Software Performance for First LHC Collision Events", ATLAS-CONF-2010-030.

[4] The ATLAS Collaboration, "Performance of the Minimum Bias Trigger in p-p Collisions at $\sqrt{s}$ = 900 GeV", ATLAS-CONF-2010-025.

[5] The ATLAS Collaboration, "Performance of the ATLAS Inner Detector Trigger algorithms in p-p collisions at $\sqrt{s}$=900 GeV", ATLAS-CONF-2010-014.

[6] The ATLAS Collaboration, A. Ferretto, "Performance of the ATLAS Inner Detector trigger algorithms in p-p collisions at center-of-mass energies of 900 GeV and 7 TeV", these proceedings.

[7] The ATLAS Collaboration, "ATLAS Muon Trigger Performance in cosmic rays and pp collisions at $\sqrt{s}$ = 900 GeV", ATLAS-CONF-2010-013.