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The ATLAS trigger: high-level trigger commissioning and operation during early data taking

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Abstract. The ATLAS experiment is one of the two general-purpose experiments due to start operation soon at the Large Hadron Collider (LHC). The LHC will collide protons at a centre of mass energy of 14 TeV, with a bunch-crossing rate of 40 MHz. The ATLAS three-level trigger will reduce this input rate to match the foreseen offline storage capability of 100-200 Hz.

This paper gives an overview of the ATLAS High Level Trigger focusing on the system design and its innovative features. We then present the ATLAS trigger strategy for the initial phase of LHC exploitation. Finally, we report on the valuable experience acquired through in-situ commissioning of the system where simulated events were used to exercise the trigger chain. In particular we show critical quantities such as event processing times, measured in a large-scale HLT farm using a complex trigger menu.

1. Introduction

The ATLAS [1] experiment is one of two general-purpose experiments currently being built at the Large Hadron Collider (LHC). The very short bunch-crossing interval (25 ns) and a high number of overlapped events in each bunch crossing make the LHC a very challenging environment for the trigger. Along with the highest centre of mass energy ever attained with colliding beams, the bunch-crossing period will also be extremely short (25 ns). In addition, $\sim$ 23 soft proton-proton interactions, on average, will be overlapped in each bunch crossing at design luminosity ($10^{34}cm^{-2}s^{-1}$). The environment in which the ATLAS trigger works to select hard-scattering events against a very high background of soft QCD events is thus a very challenging one. The trigger output rate will be limited to 200 Hz or less. , which means that the ATLAS trigger will aim to select around five events for every million bunch crossings. The ATLAS trigger is divided into the First-Level Trigger (LVL1), which runs in dedicated hardware, and the software-based High-Level Trigger (HLT) [2], which will run on a computer farm. The HLT is further subdivided into level 2 (LVL2) and the Event Filter (EF). This paper focuses on the commissioning and operation of the HLT for initial running.

2. The ATLAS trigger

This section gives a brief description of the ATLAS trigger system [1].

Level 1 reduces the 40 MHz input rate (bunch-crossing rate) to less than around 75 kHz (upgradable to 100 kHz). It uses (coarse granularity) data from the calorimeter and muon detector systems, but not from Inner Detector tracking detector. LVL1 must reach a decision within $2.2\mu s$. The LVL1 selection is mainly based on the identification of high transverse momentum objects in the detector. For accepted events, LVL1 passes to LVL2 the location (known as a Region of Interest, RoI) and passed thresholds of these reconstructed objects.

The LVL2 reconstruction is usually seeded by LVL1 RoIs and has access to the full detector granularity. The seeded reconstruction mode means that the trigger requests only a few percent of the detector data, leading to large savings in the necessary network bandwidth.

Within each RoI, LVL2 reconstructs physics objects using fast algorithms. The average processing time at LVL2 is 40 ms[1]. The expected output rate is around 2 kHz. It should be noted here that this is not a hard limit. Instead, it is an estimated time based on the expected number of processors running on the LVL2 CPU farm. The EF reconstruction is subsequently seeded by LVL2. The EF has, on average, four seconds to process each event (see footnote). This allows the use of the more sophisticated offline reconstruction algorithms, as well as offline-like calibration and alignment corrections. The EF an output rate will be of 200 Hz, assuming an event size of 1.5 Megabytes.

[1] A previous estimate of the available time per event gave $\sim$10 ms on 8 GHz processors. As such processors never materialized, this estimate is here updated to $\sim$40 ms on equivalent multi-core processors running at lower clock speeds. A similar update was done for the EF.

The execution of the HLT algorithms is organised by the Steering algorithm [3] based on the static configuration information and on the dynamic event data. The configuration contains a list of the active signatures (trigger menu) and their thresholds, passthrough fractions and prescale factors. The HLT signatures are divided into reconstruction steps followed by verification steps. The chain of algorithms can be stopped at any of the verification steps if it is found to be non-viable (early rejection), thus freeing resources for the next signature.

The HLT algorithms are logically divided into groups of related signatures. Currently these are known loosely as: e/γ, μ, τ, jets, B-tag, B physics, missing E_T, cosmics, minimum bias. Algorithms from one or more groups, together with configuration information such as threshold values and prescale fractions are used to build the trigger signatures that form the menu building blocks.

3. Trigger Strategy for Initial Running

The ATLAS trigger commissioning is already in progress even before proton beams are injected in the LHC. Test pulses and cosmic rays are used debug and synchronise the level 1 trigger and data acquisition hardware. This is described elsewhere in these proceedings [4].

The strategy to commission the ATLAS trigger with LHC beams will include a first phase where the timing of trigger and detector readout will be synchronised to the beam crossing. As the collision rate increases, a minimum bias trigger will be very important to obtain the data samples needed for both detector and trigger commissioning, but also for physics studies.

The level 1 calorimeter and muon triggers will then be used with loose thresholds. This will allow the study of quantities for which simulated data gives unreliable results or which are sensitive to the poorly known low-energy behaviour of the detector. Only during or after this phase will the HLT come into operation. At first it will run in pass-through mode for events accepted by high-prority LVL1 signatures. Eventually, more restrictive selections will be used in the HLT, as collision luminosity grows and a solid knowledge of the detector is acquired. A full menu comprising around 200 signatures at each level and aimed at initial running was designed and implemented in the ATLAS software. This includes both signatures aimed at physics studies, and also prescaled signatures with lower thresholds, needed for monitoring and understanding the trigger.

4. High-Level Trigger Commissioning

A test was performed in Spring 2007 , where the trigger software was run in playback mode on simulated or real (cosmic-ray) events [5]. These events were preselected by level 1 and the event fragments, corresponding to different parts of the ATLAS detector, preloaded into the memory of the readout system. A subset of the final HLT farm was used for this test. A complex trigger menu was used, which included signatures for selecting $e^{\pm}$, γ, $\mu^{\pm}$, $\tau^{\pm}$, and jets. These runs allow the study of the network configuration and its effect on algorithm timing, software and network stability, configuration of the trigger software through an online database, etc.

Figure 1 shows the total processing time for accepted (left) and rejected (right) events at LVL2. The data shown here consisted of a sample of around six thousand simulated events, containing a mixture of around 60% di-jet events, and 40% events W or Z events, decaying to various final states. These events were used repeatedly to simulate long runs. The structure of the histograms is due to several interrelated factors: the number of RoIs selected by LVL1, the different execution times of the algorithms which are run in different RoI types, and the access times needed to retrieve data fragments. The mean execution times observed are encouraging. For example, even if the execution time for accepted events (98 ms) is above the nominal time budget of 40 ms, one should remember that most events that reach this level are then rejected (average processing time of 31 ms). It should also be noted that the sample composition is not

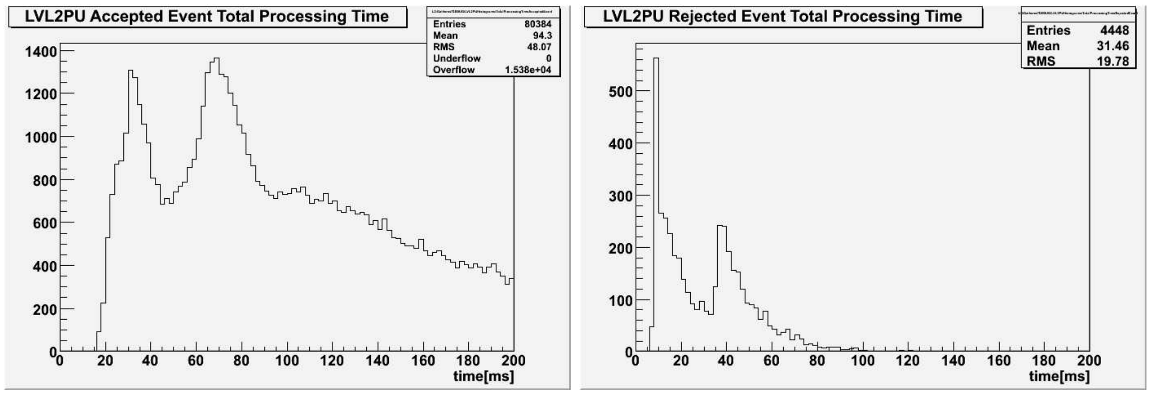

Figure 1. Total processing time for events which passed the trigger selection at LVL2 (left) and EF (right) in playback tests using the HLT farm.

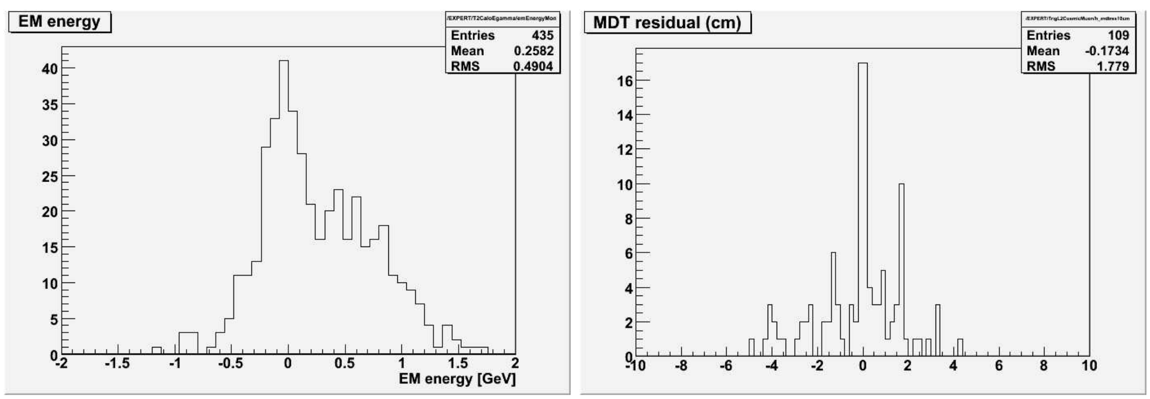

Figure 2. Energy deposited in the ATLAS calorimeter by cosmic-ray muons (left) and the residuals between the reconstructed muon tracks at LVL2 and the hit positions in the monitored drift tube (MDT) muon detectors (right).

representative of real data, and was chosen for study purposes only. The average processing time for the event filter was found to be of the order of a few hundred miliseconds.

Figure 2 shows measurements obtained at LVL2 during a cosmic-ray run in June 2007 [6]. The energy lost in the liquid Argon calorimeter (LAr) by cosmic-ray muons is shown on the left-hand side. The histogram shows a peak centered at zero which corresponds to noise (due to fluctuations in the readout pedestal and noise, the energy measured in the LAr can be negative). The shoulder which can be observed at positive values corresponds to energy deposits due to showers induced by cosmic rays. On the right-hand side, the residuals between the muon tracks reconstructed at LVL2 using dedicated trigger detectors (resistive plate chambers, RPC) and the hit positions in the monitored drift tube (MDT) precision chambers is shown. The histogram spread of 1.8 cm is in agreement with the RPC resolution and the fact that the charge drift velocity in the MDT chambers was uncalibrated.

5. Conclusions

The ATLAS HLT is being exercised in realistic tests running on the final computer farm and with cosmic-ray events. A strategy for commissioning the trigger with LHC beams was developed in view of data taking next year.

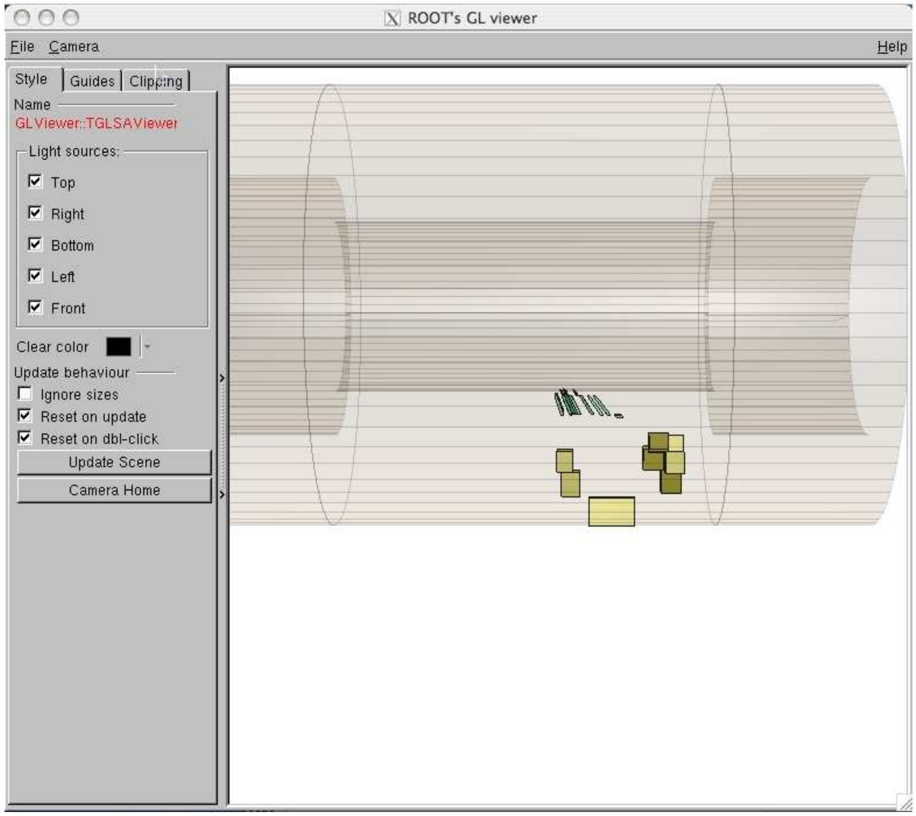

Figure 3. Event display of the ATLAS LAr calorimeter showing energy deposits originated by cosmic-ray muons. The structure of the calorimeter cells can be seen in the picture, with thin cells closer to the centre of the detector and larger cells on the outer layers of the calorimeter.

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