Commissioning of the ATLAS High Level Trigger with Single-Beam and Cosmic Rays

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The ATLAS experiment [1][2] is a general purpose proton-proton detector designed to exploit the full discovery potential of the Large Hadron Collider (LHC) at CERN. The goal of the ATLAS experiment is to explore the fundamental nature of matter and the basic forces that shape our universe. Its overall design is the result of the requirements of high precision muon momentum measurements, efficient tracking, large acceptance and very good electromagnetic calorimetry for electron and photon identification and measurements.

With a LHC bunch crossing rate of 40 MHz and about 23 interactions per bunch crossing, a highly selective trigger system to reduce the expected 10^9 interactions per second to an acceptable rate of a few hundred Hz is required. Sharing a large number of software components from the online event selection software to the offline physics analysis and reconstruction environment helps in understanding trigger efficiencies and allows for a common development and run environment. Using fast reconstruction algorithms, the trigger system needs to efficiently reject a huge rate of background events and still select potentially interesting ones with good efficiency.

The ATLAS trigger is based on three levels of online selection: Level-1, Level-2, and Event Filter (EF). The second and third level triggers, together known as the High Level Trigger (HLT), are software based and implemented on two farms of a total of around two thousand multi-core Personal Computers (PC) running the Linux operating system. The Level-1 trigger is implemented in custom hardware and reduces the initial event rate of 40 MHz to about 75 kHz. The Level-1 decision is based on data from the calorimeters and the muon detectors, and mainly relies on finding high transverse momentum (p_T) objects. For Level-1 accepted events, small localized Regions of Interest (RoI) in pseudo rapidity and azimuthal angle centered on the objects found are determined. The RoI information including the RoI type and the momentum threshold passed is sent to the Level-2 trigger. The Level-2 trigger selection process has to be capable of handling events at 75 kHz (upgradable to 100 kHz). It is guided by the RoI information supplied by the Level-1 trigger. It uses full granularity event data within a RoI from all detectors. In this way, only ~2% of the full event data are needed for the decision process at Level-2.

After the Level-2 selection, the complete event is then made available to the EF for the final stage of trigger processing. Here, more complex reconstruction algorithms provide a further rate reduction to about 200 Hz with typical event decision times of 1-2 s. While the Level-2 reconstructs localized regions, the baseline for the EF is a full offline-like event reconstruction guided by the *Level-2 result* and operating at a rate of few kHz (~3 kHz). It also uses more complete calibration, alignment and magnetic field data.

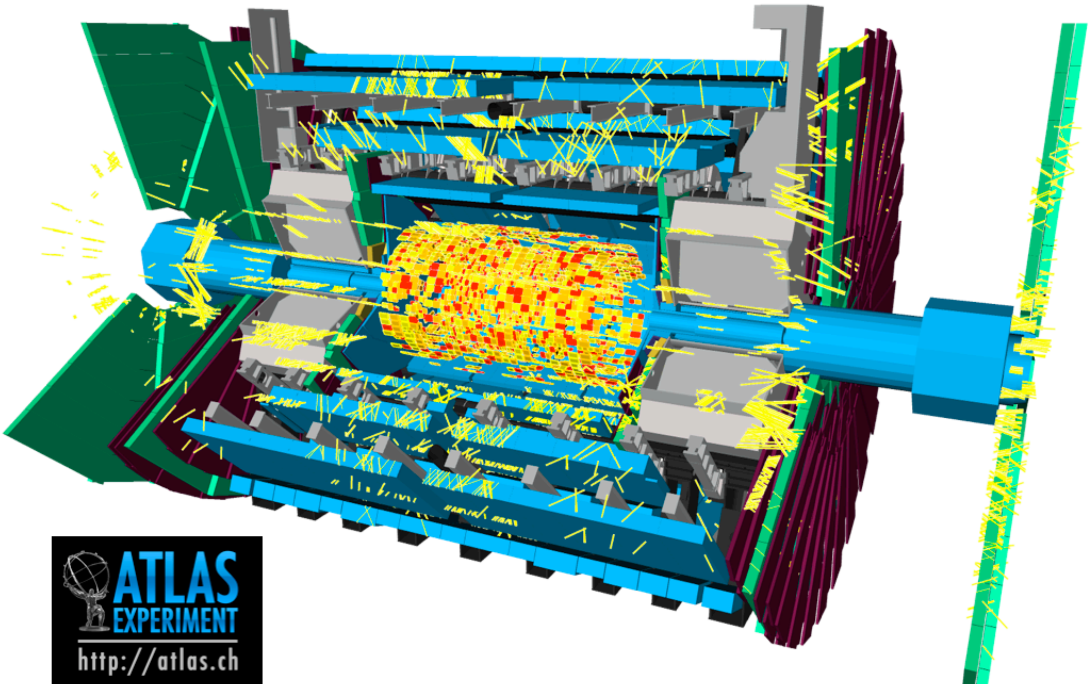
To achieve a fast rejection, the event processing in the HLT selection (both Level-2 and EF) proceeds in *steps* each including either feature extraction algorithms reconstructing useful quantities for triggering, or hypothesis algorithms rejecting or accepting according to conditions applied to these quantities. By aiming at the earliest possible rejection of background events reduces the network data traffic and processing time to manageable levels. A sequence of steps in the HLT to trigger on a specific candidate signature such as electron, photon, muon, etc. is called a *slice*. In order to ease the development of the trigger, ATLAS decided to re-use some elements of the offline framework inside the HLT. Among the advantages is the provision of the functions converting detector readout data to algorithms input by the detector experts. Additionally, it is easier to develop the HLT algorithms and perform trigger efficiency studies. Disadvantages include an increased dependence of HLT on the offline software releases and the fact that the offline algorithms tend to be too time consuming and not robust enough to be run online. In spite of these, it has been found to be more advantageous than disadvantageous.

The recent LHC startup and short single-beam run in September 2008 provided a "stress test" of the trigger system. The ATLAS detector started recording events where the first proton beams circulating in the

LHC were dumped against collimators near the ATLAS experiment. These events, named "splash events", produced a cascade of pions and muons that were detected by the different sub-detectors in ATLAS, as seen in the figure. After opening all collimators, the proton beams were allowed to circulate along the LHC tunnel and caused beam-gas events be produced near ATLAS. During this period, event recording in ATLAS was triggered by the Level-1 alone. The HLT was running in real time with no rejection. It was scrutinizing the Level-1 RoI content and directing the events according to it into the different recording "streams". The HLT algorithms were tested offline through the recorded data soon after the single beam data was taken. This enabled testing of the reconstruction algorithms in both Level-2 and EF without any bias, and allowed the debugging of the whole software.

Following this period, ATLAS continued to collect cosmic-ray events for detector alignment and calibration purposes. During the cosmic-ray data taking, the HLT was running in real time accepting all events which allowed the algorithms be exercised online. This period allowed testing the reconstruction and selection algorithms, as well as the framework and steering, with the full-scale ATLAS detector and readout system. The trigger commissioning was happening in parallel with the commissioning of each subdetector system. This created a fast-changing environment to which the trigger needed to adapt. Foremost, the HLT configuration system proved to be flexible enough to adapt to the quick changes of the selection menu. The monitoring of the algorithm performance was also tested with the full system. Track-finding, muon identification and calorimeter reconstruction algorithms were all tested under different conditions stressing the robustness of the whole software.

In conclusion, this paper will describe the trigger design and its innovative features, such as the step-wise reconstruction and the RoI mechanism. The main focus of the paper will be on the valuable experience gained running the trigger during the recent commissioning period. It will emphasize the commissioning of the HLT algorithms, monitoring and configuration.



first beam event seen in ATLAS

REFERENCES

[1] The ATLAS Collaboration, B. Aad et al., "The ATLAS Experiment at the CERN Large Hadron Collider", JINST (2008) 3 S08003.
[2] The ATLAS Collaboration, "Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics", CERN-OPEN-2008-020, Geneva, 2008, to appear.