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

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Abstract—ATLAS is one of the two general-purpose detectors at the Large Hadron Collider (LHC). Using fast reconstruction algorithms, its trigger system needs to efficiently reject a huge rate of background events and still select potentially interesting ones with good efficiency. After a first processing level using custom electronics, the trigger selection is made by software running on two processor farms, designed to have a total of around 2000 multi-core machines in a system called High-Level Trigger (HLT). The 2008 LHC startup and short single-beam run provided a “stress test” of the trigger. Following this period, ATLAS continued to collect cosmic-ray events for detector alignment and calibration purposes. These running periods allowed testing the HLT in different running conditions. This paper focuses on the experience gained in running the trigger in the fast-changing environment of the detector commissioning.

Index Terms—Data acquisition, detectors, elementary particles, trigger, ATLAS commissioning, triggers.

I. INTRODUCTION

THE ATLAS experiment [1] is one of two general-purpose experiments installed at the Large Hadron Collider (LHC) at CERN, Geneva, Switzerland. At the design LHC luminosity ($10^{34} \text{ cm}^{-2} \text{ s}^{-1}$), the very short bunch-crossing interval (25 ns) and approximately 23 overlapped events in each bunch crossing make the LHC a very challenging environment that poses severe requirements to the detector design. The trigger system needs to reduce the input event rate by more than five orders of magnitude. At the same time, it needs to ensure that the data recorded on disk for further analysis is composed of selected events that might contain new physics to be discovered at the 14-TeV center-of-mass proton–proton collisions to be produced at the LHC.

ATLAS has chosen a trigger scheme with three distinct levels. The first-level trigger (L1) is based on custom electronics and takes information from the calorimeter and muon detectors. It provides to the Level-2 trigger (L2) the areas of the detector where possible interesting signatures might be located, so called regions of interest (RoIs). The L2 uses special algorithms working with partial data reconstructed around the RoIs to select interesting events. After a positive decision, the events are fully assembled and handed over to the third-level trigger (so-called Event Filter, EF) for further selection. L2 and EF are collectively called the High-Level Trigger (HLT).

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They have the task to reduce the event rate from the $\sim 75 \text{ kHz}$ output from L1 to $\sim 200 \text{ Hz}$ that can be stored on disk for further analysis. A detailed description of the HLT, its software infrastructure, and monitoring system can be found in [2].

Section II describes the environment in which the HLT commissioning has been carried out and the specific conditions of the cosmic ray run. Section III details the HLT results from the commissioning runs. The summary is given in Section IV.

II. COMMISSIONING WITH DATA

During 2008, the HLT was commissioned using the single-beam LHC operation and cosmic data. There are specific differences between both types of running.

For the first beams in the LHC, the priorities of ATLAS running were stability and reliability. For this purpose, silicon detectors were turned off or ran at low-bias voltage, and a simple trigger configuration based only on L1 decisions was used. The HLT was used only for tagging events and for routing them to the corresponding output data streams. Algorithms, except those crucial for the routing task, were not exercised online. The data collected during the short run with the LHC beams were mostly useful for adjusting the timing of the L1 triggers—in particular, the timing of the signals from the beam pickup system (BPTX) [3] and the minimum-bias trigger scintillators (MBTS) [4]. Detailed results of this operation can be found in [2]. HLT algorithms were later tested offline on those events with muon and calorimeter RoIs in time with the BPTX or the MBTS. However, due to limited statistics (less than a thousand events), such tests were mostly related to basic functionality.

A more complete test of the HLT was possible during the subsequent cosmic ray runs. In 2008, starting on September 13, ATLAS collected 216 million events until the end of October, representing a total of 453 TB of data. While many cosmic runs had been taken in recent years as part of the detector commissioning, these new runs presented the first opportunity to fully exercise the whole detector, including the recently installed pixel detector. Fig. 1 shows the collection history of these events detailing the L1 items that triggered them. It is important to note that during part of this period, L2 algorithms were actively used to route events into different files. The complete HLT infrastructure and the recovery procedures for problematic events were thoroughly tested. About 3% of the events that caused data-taking problems, mainly due to corrupted raw data fragments or event timeouts, were written to a separate debug stream. Those events, which did not cause a disruption in the data-taking run, were reanalyzed by rerunning the trigger event selection code offline. They were eventually reinjected into the analysis sample.

Cosmic rays present particular challenges to the HLT, which has been designed to perform best for collision events. Since

Fig. 1. History of recorded cosmic events after September 13, 2008, for different trigger items.

Fig. 2. The distribution of R_η , the shower shape in the second sampling of the electromagnetic calorimeter.

no LHC clock is present, the timing of the event is provided by the muon trigger chambers, and the corresponding jitter can adversely affect the readout of some of the subdetectors, particularly those that rely on the drift of charge carriers, such as the transition radiation tracker (TRT) or the monitored drift tube (MDT) precision muon chambers. Furthermore, L2 algorithms for fast tracking in the inner detector and the muon spectrometer normally require tracks pointing toward the beam axis with a small impact parameter to the center of the detector. Neither of these requirements is satisfied for most of the cosmic tracks. Finally, cosmic muons rarely provide the kind of signatures that initiate chains associated to nonmuon physics objects in the trigger menu, like calorimeter clusters or jet signatures. This severely limits the statistics that can be used to test a lot of the trigger chains prepared for the LHC collision run.

Despite these constraints, an effort was made to exercise all the menu chains during the cosmic ray running. By relaxing various selection thresholds and requirements, both L2 and EF algorithms from all groups of trigger objects were successfully run and tested.

III. RESULTS FROM THE 2008 RUNNING

An example output from the electron–photon feature extractions is shown in Fig. 2, where R_η , the shower shape in η -direction in the second electromagnetic calorimeter sampling (a measurement of the narrowness of the cluster), is shown. The online histograms from L2 and EF lie on top of each other in excellent

agreement, therefore showing that all HLT algorithms were executed correctly and that the needed calibration constants were correctly loaded in both trigger levels during the online running.

Most extensive studies were possible for the muon reconstruction, for which the high statistics obtained by relaxing the pointing track requirement allowed efficiency and rejection studies to be performed. For instance, the end-cap MDT cluster finding efficiency in the L2 was found to be 93%, with almost all of the inefficiency identified to be due to detector or timing issues. The L2 calorimeter algorithm, which searches low transverse momentum muons, was tested on arun taken with no magnetic field. In order to reduce the effect of the electronic noise, the energy measured in the calorimeter was requested to be above 300 MeV. The fact that tracks do not point to the interaction point resulted in low selection efficiency, which was in agreement with Monte Carlo predictions. The reconstructed tracks of cosmic muons have an up–down distribution as expected for pointing tracks able to pass through the full calorimeter, as is shown in Fig. 3 (left). The measurement of the energy deposition of these particles shows a peak at approximately 2.5 GeV (see Fig. 3, right), which is consistent with the energy loss of a minimum ionizing particle.

The EF muon algorithm was tested by comparing its track position determination to the one reconstructed offline. Fig. 4 shows this comparison for the pseudorapidity variable. Although the EF algorithm is the same as the one used in the offline reconstruction, some non-Gaussian tails in the reconstruction can be observed. They are most likely due to different settings for handling the RoI-based strategy with respect to the offline reconstruction, where the complete event is available and a non-RoI-based reconstruction of the complete event is performed.

Beyond these exercises toward the commissioning of the trigger system itself, the HLT played an important role in the commissioning of the ATLAS Inner detector (pixel and microstrip silicon detectors, and the TRT). Only a small percentage of the cosmic muons that trigger the L1 muon chambers traverse the Inner Detector (ID). The high L1 muon rate (~ 500 Hz) prevents recording all these events. A fast and proper alignment of the ID requires a large sample of events containing nonbiased tracks traversing the ID volume. Since ID tracking is not possible at L1, an essential task for the L2 was to select events that contain these tracks.

This task required significant modifications to the L2 tracking algorithms. The design of the algorithms using the silicon detectors (pixel and microstrips) is such that the efficiency drops dramatically for tracks with transverse impact parameter (d_0) with respect to the interaction region beyond a few millimeters. For cosmic tracks, however, good efficiency is required for values up to hundreds of millimeters. Another issue arises due to the presence of noisy modules that produce tens of fake hits. With no pointing RoIs, the algorithms have to run with data from the whole detector and in a very clean environment with only a few hits from the cosmic tracks. Therefore, such noise hits can abnormally damage the performance of tracking algorithms unless they are properly taken into account.

To overcome these problems, new cosmic triggers were defined to run in parallel with the regular trigger menu. These chains were initiated by any L1 signature (muon, calorimeter, MBTS) and ran the modified L2 tracking algorithms. For the

Fig. 3. (left) Azimuthal angle distribution of muons selected by the L2 calorimeter algorithms and (right) their energy distribution.

Fig. 4. Difference in η of the track reconstructed offline and the same track reconstructed by the EF muon selection algorithm. The curve shows the Gaussian fit to the central part of the histogram.

Fig. 5. History of tracks recorded with pixel hits for different conditions of magnetic field during the cosmic ray run in 2008.

TRT-based tracking algorithm, we used the same data preparation and software machinery as the one designed for collisions. However, the pattern recognition strategy was changed. The other silicon-based algorithms were run with settings close to the collision values, but a new pattern recognition developed for cosmic rays shifted the hits in the entire Si detector to account for the high impact parameter. Overall, an effort was made to exercise as much of the regular L2 software as possible.

Fig. 5 shows the number of collected tracks from cosmic rays that traversed the pixel detector. It should be highlighted that a

good level of robustness had been achieved by the end of October, and that when the ID was reincorporated into the global run following a month-long break, the HLT was running very smoothly despite some changes to the detector configuration. Measurements of the collection efficiency for events containing “golden silicon” tracks (offline tracks with at least three hits in the upper and three hits in the lower barrel of the Si detectors) indicated that more than 99% of such events were retained by at least one of the three algorithms used in the L2 tracking selection.

IV. SUMMARY

The complete HLT infrastructure (L2 and EF algorithms, HLT steering, streaming, and monitoring capabilities) has been exercised during the last months of 2008 and tested to work under actual data-taking conditions. The HLT played a crucial role in collecting the inner detector tracks that were necessary to perform the detector alignment. Studies of the muon and calorimeter signatures provided useful feedback to these detectors systems and played a role in the online monitoring and the data quality. Finally, the HLT infrastructure was used for tagging data and diverting interesting events into the relevant data streams.

The overall process was also a test of the HLT operation cycle. Commissioning was performed while the HLT was serving the other subsystems. The issues of running on actual data were resolved as the data taking was proceeding. A good balance was achieved between stability and responsiveness to the requests of the subsystems and to the detector conditions.

The 2008 data-taking run has been an invaluable experience to be ready to start data-taking with LHC collisions in 2009.

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