The ATLAS Level-1 Trigger System with 13TeV nominal LHC collisions

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Abstract. The Level-1 (L1) Trigger system of the ATLAS experiment at CERN's Large Hadron Collider (LHC) plays a key role in the ATLAS detector data-taking. It is a hardware system that selects in real time events containing physics-motivated signatures. Selection is purely based on calorimetry energy depositions and hits in the muon chambers consistent with muon candidates. The L1 Trigger system has been upgraded to cope with the more challenging Run2 LHC beam conditions, including increased centre-of-mass energy, increased instantaneous luminosity and higher levels of pileup. This talk summarises the improvements, commissioning and performance of the L1 ATLAS Trigger for the LHC Run2 data period.

Keywords: ATLAS Experiment, Trigger, LHC run2

Introduction

The ATLAS experiment [1] is located on the LHC at CERN. It is studying hadron hadron collisions (protons or heavy ions such as lead atoms) at a frequency of up to 40 MHz and at a center-of-mass energy of up to $\sqrt{s} = 13$ TeV. The conditions at which the LHC has been operated in Run1 and in Run2 have changed drastically leading to a significant increase of interaction rate which is not covered by the storage and CPU resources available for the physics analyses. In order to maintain the physics program intact, the selection of the events had to be significantly revised. The ATLAS trigger system [2, 3] is divided into a fast hardware system called L1 that collects the input from the detectors and reduces the rate of collisions from 40 MHz to about 100 kHz; and a High Level Trigger system based on commercial computers which reduces the rate of interesting events to 1 kHz that are recorded on disk for future analyses. A diagram of the Level-1 system is shown in Figure 1. This document will discuss the large fraction of the Level-1 constituents that were upgrade before Run2 to cope with the new LHC conditions.

1 L1 Muon trigger upgrade

In ATLAS, muon triggers are obtained from two technologies, Resistive Plate Chamber (RPC) in the barrel, and Thin Gap Chamber (TGC) in the end-caps.

Together they form the L1-Muon. Additional RPCs were installed during the Long Shutdown of the LHC (LS1) in 2013 and 2014, to recover acceptance in the ATLAS feet region. The installation and commissioning of these chambers was finished during 2015, and the system was fully enabled in the data taking in 2016. Figure 2 (left) shows the efficiency of the L1 muon triggers with $p_T > 11$ GeV as a function of the muon ϕ coordinate for 2015 and 2016 data-taking. The acceptance increase can be seen in the range $-2.2 < \phi < -0.8$, where the feet are located. In the end-caps where the rate of the L1 muon triggers is dominated by protons from the beam faking real muons, it is crucial to decrease the rate while keeping a high signal efficiency. In Run1 only the big wheels, that contain up to 3 TGC stations and are located after the end-cap toroid magnet, were used to trigger the events, while in Run2 the rate is reduced in the range $1.0 < |\eta| < 1.3$ by requiring a coincidence between the big wheel and the hadronic tile calorimeter and in the range $1.3 < |\eta| < 1.9$ by requiring a coincidence between the big wheels and the muon small wheels, that contain 1 TGC station and is located after the end-cap toroid magnet. The rate of end-cap L1 muon triggers with $p_T > 15$ GeV measured in the data with and without the coincidence of the small and big wheel is shown in Figure 2 (right).

2 L1 Calorimeter trigger upgrade

The L1 Calorimeter (L1-Calo) system is a hardware-based system that receives signals from both the Electromagnetic and Hadronic calorimeters with a coarse granularity based on trigger towers of typical size $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ and identifies trigger objects such as electrons, taus and jets and also computes the missing transverse energy of each event. In Run2 the system underwent various major upgrades. The previous ASIC-based modules used at the pre-processing stage were replaced by almost 2000 FPGA-based daughter boards to allow a refined extraction of the energy. The new modules enable significantly improved pile-up control, such as dynamic bunch-by-bunch pedestal correction as well as an enhanced signal-to-noise ratio by the use of digital autocorrelation Finite Impulse Response filters. In the 3.2 fb^{-1} of data collected in 2015 at the beginning of Run2, about 100 events were found, which were mistimed due to jets with saturated energy that were reconstructed by the L1-Calo in the wrong bunch crossing. In the new pre-processing modules, the digitisation speed was doubled to 80 MHz which allows for improved treatment of saturated signals and refined input timing. A new algorithm taking advantage of this was deployed at the end of the 2016 data-taking, resulting in no more mistimed events recorded in the last 7 fb^{-1} of the data recorded. The firmware of the object identification hardware components was updated to allow for extra selectivity, such as energy-dependent electromagnetic isolation criteria in the cluster processor. This improves the QCD background rejection for electron triggers while keeping a good signal identification. The refined isolation algorithm allows a decrease in the rate of the L1 electron triggers with $p_T > 24$ GeV by about 10% with a signal efficiency loss of about 1%. This new algorithm was tested to check for the in-

Fig. 1: Sketch of the ATLAS Level-1 systems.

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Fig. 2: Left: Efficiency of the barrel L1 muon triggers with $p_T > 11$ GeV for 2015 data (blue) and for 2016 data (red) [4]. Right: Rates of the end-cap L1 muon triggers with $p_T > 15$ GeV with (blue) and without (red) the small wheel coincidence enabled [4].

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Fig. 3: Left: Efficiency of the isolated L1 electron triggers with $p_T > 24$ GeV as a function of the average number of interaction per bunch crossing, for the old isolation algorithm (in black) and for the new one (in blue) [5]. Right: Rate as a function of the Lumi-Block for the L1 di-muon triggers with $p_T > 6$ GeV (in red) and for the L1-Topo di-muon triggers with $p_T > 6$ GeV (in blue) [6].

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introduction of any biases. Figure 3 (left) shows the efficiency of the new isolation algorithm (denoted VHIM) compared to the old isolation algorithm (VHI) as a function of the number of interaction per bunch crossing. No strong dependence is observed. As in Run1, the L1-Calo system sends the multiplicities of trigger objects as well as the energy sums to the L1 Central Trigger (L1-CT) system in order to select the events. However, a brand-new system was introduced in Run2: the L1-Topo system to allow topological cuts between these objects. The bandwidths between the different L1-Calo modules was therefore increased, as well as new merger modules introduced to provide the flexibility required by this new system.

3 L1 Topological trigger upgrade

The introduction of topological cuts between trigger objects at L1 is mostly motivated by the hope to reduce significantly the rate of trigger items that are significantly dominated by physics backgrounds such as for instance the ones needed for the study of the production of hadronically decaying Higgs bosons. It also reduces the rate for low p_T trigger items such as those used in the study of B-mesons. Without the introduction of this new logic a significant fraction of the ATLAS physics program would need to be left out. The L1 Topological Trigger (L1-Topo) system consists of 2 modules each containing 2 FPGAs that allow the execution of the 110 new topological trigger algorithms in a maximum of 75ns. The whole L1 chain had to be redesigned in order to provide the energy and position of each trigger object to the L1-Topo system. This is a significant improvement compared to Run1 where only the multiplicity of each trigger item was available. The commissioning of the system is ongoing using the data from Run2. Figure 3 (right) shows the rate of the L1 di-muon triggers with $p_T > 6$ GeV with and without L1-Topo requirements on the invariant mass ($2 < m_{\mu\mu} < 9$ GeV) and the separation of the two muons ($0.2 < \Delta R_{\mu\mu} < 1.5$).

4 L1 Central trigger upgrade

The L1-CT is a hardware system which collects inputs from the other L1 systems and forms the L1-Accept. The signal from the L1-Muon is processed by the Muon to CTP Interface (MUCTPI), and is sent to the Central Trigger Processor (CTP) and to L1-Topo (via the MUCTPI-To-Topo interface, which was introduced for Run2). The MUCTPI system has received a firmware upgrade since Run1 to allow the propagation of the (η, ϕ) coordinates as well as the p_T of the highest two energetic muons in a $\Delta\eta \times \Delta\phi = 0.3 \times 0.1$ region to feed the L1-Topo system. The CTP was redesigned to double the number of trigger inputs and outputs, in order to cope with the new L1-Topo system. A new multi-partition mode, allowing to run simultaneously up to three partitions, was added to allow a more efficient commissioning and calibration of the subdetectors. The L1-CTP software was completely redesigned to be modular, more stable and more robust.

Conclusion

After the LHC and ATLAS L1 upgrades and despite the harshening of the LHC beams conditions ATLAS has taken data with a very high efficiency ($> 92\%$ in 2016). The data-taking has already restarted in 2017 and will continue until the end of Run2 in 2018, where about 100 fb^{-1} of pp collisions data at 13 TeV are expected.

References

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