THE ATLAS TRIGGER SYSTEM UPGRADE AND PERFORMANCE IN RUN 2

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The ATLAS trigger has been used very successfully for the online event selection during the first part of the LHC Run-2 in 2015/16 at a centre-of-mass energy of 13 TeV. The trigger system is composed of a hardware Level-1 trigger and a software-based high-level trigger; it reduces the event rate from the bunch-crossing rate of 40 MHz to an average recording rate of about 1 kHz. The excellent performance of the ATLAS trigger has been vital for the ATLAS physics program of Run-2, selecting interesting collision events for wide variety of physics signatures with high efficiency. The trigger selection capabilities of ATLAS during Run-2 have been significantly improved compared to Run-1, in order to cope with the higher event rates and pile-up which are the result of the almost doubling of the center-of-mass collision energy and the increase in the instantaneous luminosity of the LHC. In order to prepare for the anticipated further luminosity increase of the LHC in 2017/18, improving the trigger performance remains an ongoing endeavour. Thereby coping with the large number of pile-up events is one of the most prominent challenges.

Keywords: ATLAS, Trigger

1. Introduction

The ATLAS experiment [1] at the LHC is a multi-purpose particle physics experiment which covers a wide variety of physics interests. In order to cover many areas of physics, the trigger system needs to be able to record a wide range of interesting events, while staying within detector and computing constraints, and being able to handle increasingly more difficult running conditions.

2. Overview of the ATLAS Trigger System

The ATLAS trigger system [2] is a two level system consisting of a hardware based level-1 (L1) system, and a software based high level trigger (HLT), and can be seen schematically in Figure 1. The L1 trigger uses custom electronics to trigger on information from the calorimeters and the muon detectors. The trigger information is passed to the central trigger processor (CTP) which makes the L1 trigger decision. The L1 trigger system reduces the rate from the 40 MHz collision rate to less than 100 kHz. Between Run 1 and Run 2, many of the hardware components were updated to improve the performance for higher luminosity. Among these updates were improvements to the signal processing for L1 calorimeter triggers, and improved coincidence logic for L1 muon triggers.

In addition to the upgrade of existing hardware, a new hardware based trigger using custom FPGAs was introduced to provide topological selections, such as invariant masses or angular selections, between L1 trigger objects. This allows additional rejection at L1 for many signatures that would otherwise have too high a rate, such as low p_T dimuon triggers.

The HLT takes input from the L1 trigger in the form of a region-of-interest (RoI). A RoI is a geometric region (in eta and phi) of the detector which is defined by the L1 trigger type and the thresholds passed. The HLT reconstructs physics objects using similar software as is used to reconstruct objects offline using a dedicated computing farm. Events passing the HLT selection (with

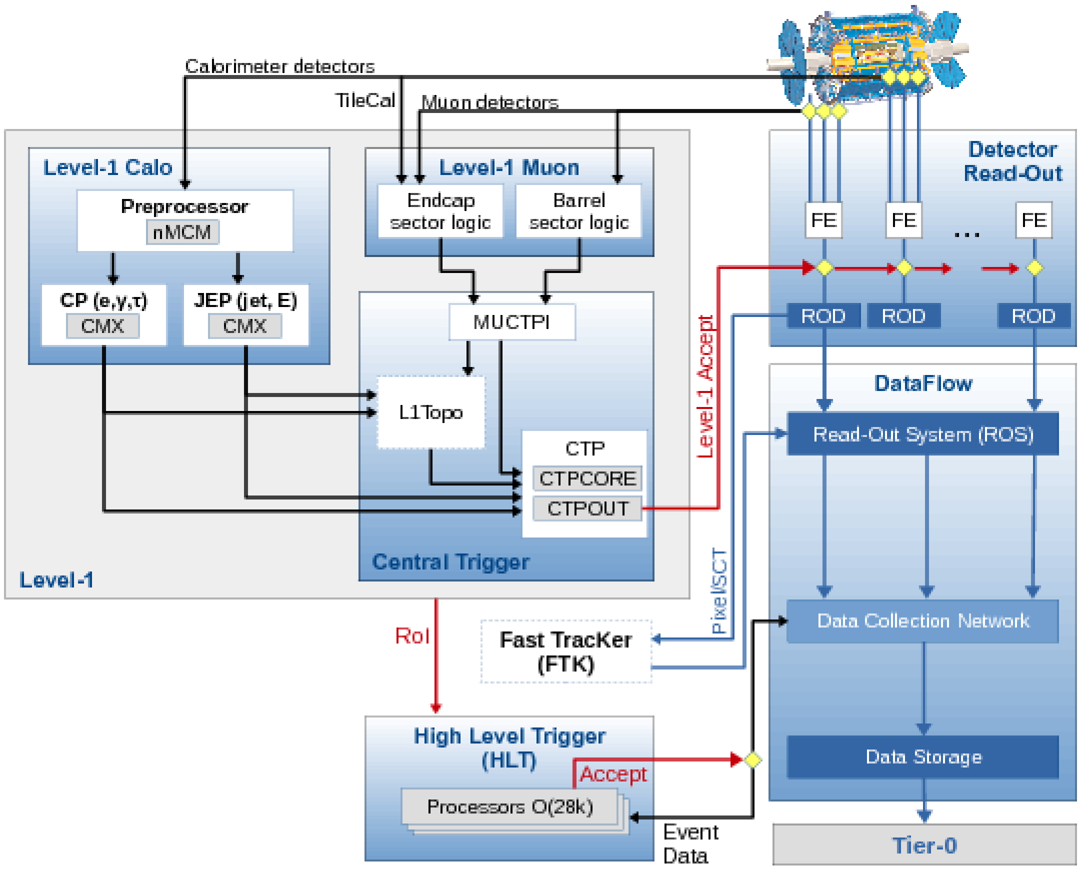

Figure 1. A schematic overview of the ATLAS trigger system consisting of the hardware based L1 trigger, the software based HLT, and the dataflow system

a physics output rate of ~1 kHz) are recorded and later fully reconstructed for use by physics analyses. The HLT was also upgraded between Run 1 and Run 2. The algorithms were updated to more closely match the offline reconstruction. Additionally, the two step approach of Run 1 was merged into a single step for Run 2 to make better use of the resources.

The Fast Tracker (FTK) is a hardware based tracking system that identifies tracks based on matching hits from the pixel and silicon strip detectors to a bank of patterns. It is currently under commissioning, and in the future, will allow for full detector tracking to be done at the HLT.

3. Updates for 2017

As the luminosity and pileup provided by the LHC have increased steadily throughout Run 2, many updates were implemented in the trigger to cope with the more difficult running conditions. The ultimate goals with improvements were to decrease the trigger rates (to keep the trigger thresholds as low as possible to maximize physics output), and to decrease the processing time at the HLT, while maintaining a high efficiency.

For electron and photon triggers, electromagnetic isolation was introduced at L1. This resulted in a 10-15% reduction in the rate without any significant loss in efficiency as shown in Figure 2. At the HLT, the electron identification, which is based on a multivariate likelihood method, was optimised using 2016 data for more precise electron identification. Isolation was also added at the HLT for photon triggers, which allowed for lower thresholds for photon triggers which is important for low mass diphoton searches.

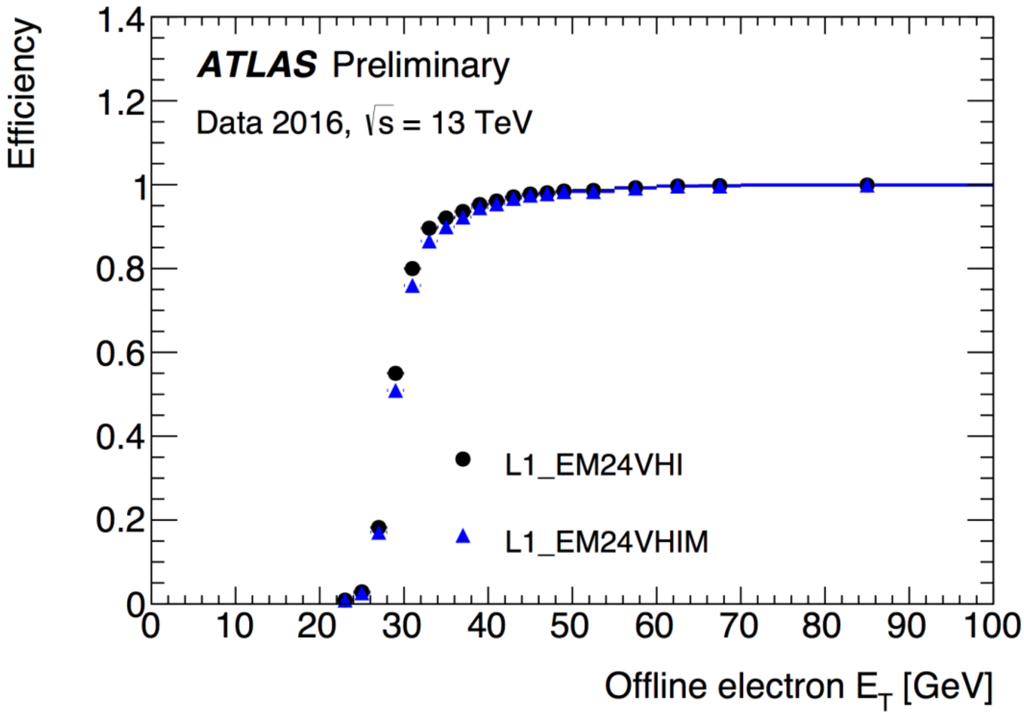

Figure 2. The L1 electron efficiency as a function of offline electron E_T with a tighter isolation (blue triangles) compared to the previously used looser isolation (black circles). The tighter isolation reduces the trigger rate by 10-15% without significant losses in efficiency [3]

The L1 muon trigger was optimised to keep rates low by improving the coincidence of hits between different layers of the muon spectrometer and also improving the overlap removal between L1 muons. At the HLT, the resolution of the fast muon finding algorithm for forward muons was improved by including hits from the Cathode Strip Chambers (CSCs), which were not previously considered. This helped reduce the rate at which the more precise (and more cpu intensive) muon finding algorithms are run. These changes also have impacts on specialised low p_T dimuon triggers that are designed to look for muons coming from decays of B hadrons with additional requirements on the dimuon mass. Since the L1 trigger rate of low p_T dimuon triggers is large relative to the available bandwidth, such triggers are a primary user of L1Topo triggers. By adding additional requirements on the dimuon mass at L1, a larger fraction of low p_T dimuon events are able to be recorded.

Tau triggers also benefit from L1Topo triggers. An example use case is the Higgs to ditau search which implemented a cut on the angular distance between the two taus. This reduced the rate of di-tau triggers by a factor of 2-4, as seen in Figure 3, without cutting into the Higgs signal efficiency. At the HLT, the tau energy calibration and boosted decision trees that are used for tau identification were updated to closely match the offline tau reconstruction.

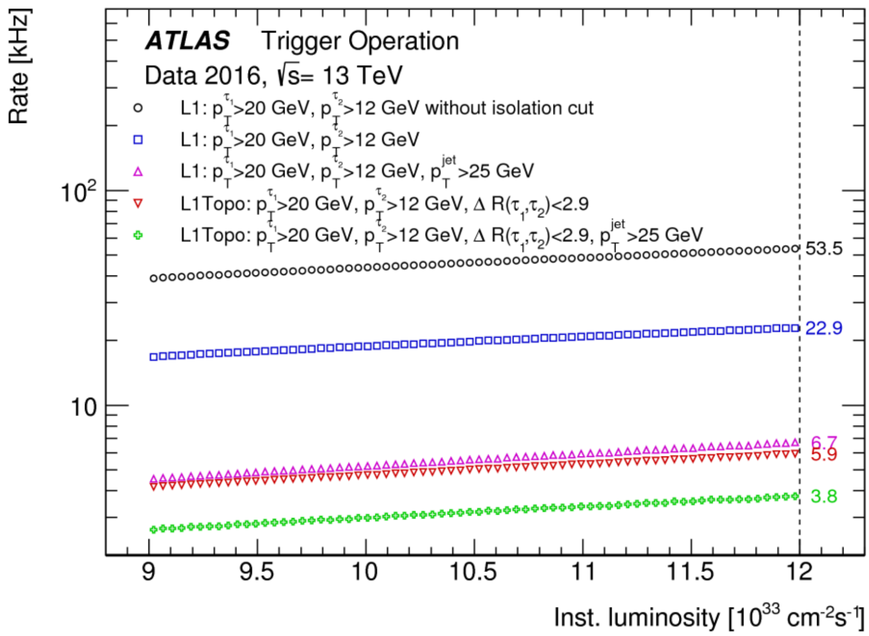

Figure 3. The rates of L1 tau triggers as a function of instantaneous luminosity. The L1Topo triggers including a ΔR cut (red triangles and green circles) have a rate of 2-4 times lower than the equivalent triggers without the ΔR cut (blue squares and pink triangles respectively) without any loss in efficiency for the physics analysis [4]

Jet triggers are categorised based on the size of the cone in which the jet is reconstructed, and also whether or not the jet is tagged as coming from a *b*-quark (*b*-jet). The *b*-jet triggers use a boosted decision tree (BDT) in order to distinguish *b*-jets from light jets or charm jets. These BDTs were retuned for 2017 to gain greater rejection for a fixed efficiency. The small radius (R=0.4) jet triggers were updated to include tracking and jet shape information. This improved the resolution of the trigger jets relative to offline jets, which in turn allowed for a lower p_T threshold on the jets without increasing the output rate. Large radius (R=1.0) jet triggers were also updated to include jet grooming techniques [5] to reduce the rate dependence on pile up. These techniques include trimming (where a reclustering of jet constituents into subjets is performed and then subjets with p_T below some threshold are dropped), and the addition of a mass cut to distinguish jets coming from the decay of a heavy object (*W*/*Z*/Higgs bosons) from jets coming from the QCD background. These techniques allowed for a lower p_T threshold without increasing the output rate. The large radius jet efficiency for a fixed output rate with and without a requirement on the jet mass can be seen in Figure 4.

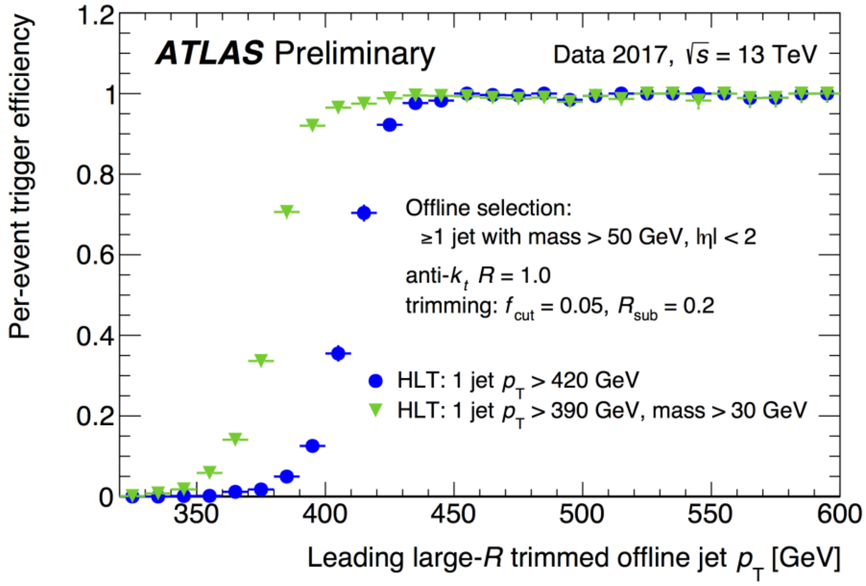

Figure 4. The jet trigger efficiency as a function of offline reconstructed jet p_T for jets reconstructed using a cone size of ΔR=1.0. By adding a requirement on the jet mass to be above 30 GeV (green triangles), it is possible to move the threshold from 420 GeV (blue circles) to 390 GeV without increasing the output rate [6]

The missing transverse energy (MET) triggers were updated to reduce the rate dependence on pile up. At L1, the calorimeter noise cuts were retuned with increasing pile up. This decreased the pile up dependence on the L1 MET rates. At the HLT, a new algorithm, PUFit, was introduced. The MET is calculated as the negative sum of all topological calorimeter clusters. To correct for effects from pile up, first the topological clusters are grouped into towers. These towers are then split into high and low energy towers. The contribution of pile up to the high energy towers is taken by fitting the low energy towers, and this contribution is then subtracted from the high energy towers. This event-by-event fitting of the pile up contribution significantly reduced the rate dependence on pile up without losing efficiency. This resulted in being able to run with a lower MET threshold at higher luminosities than would be possible otherwise.

4. Conclusion

The ATLAS trigger system has been successfully operating throughout Run 2 to collect events suitable for a wide range of physics analyses. Many improvements have been implemented in order to cope with increasing luminosity and pile up in order to keep the trigger rates and thresholds low while maintaining a high efficiency.

References

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