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The Upgrade of the ATLAS Electron and Photon Triggers for LHC Run 2 and their Performance

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Electron and photon triggers covering transverse energies from 5 GeV to several TeV are essential for signal selection in a wide variety of ATLAS physics analyses to study Standard Model processes and to search for new phenomena. Final states including leptons and photons had, for example, an important role in the discovery and measurement of the Higgs particle. Dedicated triggers are also used to collect data for calibration, efficiency and fake rate measurements. The ATLAS trigger system is divided in a hardware-based (Level 1) and a software based high level trigger (HLT), both of which were upgraded during the long shutdown of the LHC in preparation for data taking at $\sqrt{s} = 13$TeV. The increasing luminosity and more challenging pile-up conditions as well as the planned higher center-of-mass energy demanded the optimisation of the trigger selections at each level, to control the rates and keep efficiencies high. To improve the performance multivariate analysis techniques are introduced at the HLT. The evolution of the ATLAS electron and photon triggers and their performance will be presented in this talk, including new results from the 2016 LHC Run 2 operation.

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1. Introduction

Electrons and photons were essential components of a wide variety of physics analyses on ATLAS [1] during Run 1 of the LHC. Among these were precision Standard Model measurements, searches for new physics, and the discovery and subsequent measurements of the Higgs boson.

The increased energy and luminosity of the LHC in Run 2 made necessary the upgrade of the trigger system to keep event rates under control while maintaining high efficiencies for interesting processes. The ATLAS collaboration developed an ambitious upgrade program and its first stage was successfully completed during the first long shutdown (LS1) of the LHC in 2013-2014 [2].

The trigger system [3] is responsible to reduce the event rate to be recorded to about 1 kHz from the LHC beam crossing rate of 40 MHz. It is based on the Region-of-Interest (RoI) concept in which the software-based high-level trigger (HLT) reconstruction is seeded by the level-1 (L1) objects provided by the hardware trigger.

The upgrade of the L1 calorimeter trigger during the LS1 brought many improvements. The new Multi Chip Module (nMCM) in the Pre-Processor responsible for the signal processing, now features a noise autocorrelation filter to achieve better energy resolution as well as dynamic pedestal correction. The firmware upgrade of the Cluster Processor Module (CPM) allows the definition of five E_T-dependent electromagnetic and/or hadronic core isolation selections with a precision of $\Delta E_T \sim 0.5$ GeV. Moreover, the new Extended Common Merger Module (CMX) doubles the number of E_T thresholds to 16. The threshold values can currently be set by $\Delta\eta = 0.1$ granularity bringing a better trigger efficiency uniformity in pseudorapidity.

There are also new L1 topological triggers that help to reduce rates by selecting specific event topologies based on angular separation and invariant mass requirements. In particular, these topological triggers can be used for $J/\psi \to e^+e^-$ and $W \to e\nu$ triggers, which would otherwise have larger rates at L1.

In Run 1, the HLT was composed of two steps known as Level 2 (L2) and the Event Filter (EF). These have been merged into a single HLT step for Run 2, allowing for more flexibility, the use of more complex algorithms, and better harmonization between the objects reconstructed in the trigger (online) and those ultimately reconstructed with the final processing (offline). Fig. 1 shows the schematic diagram of the ATLAS trigger and data acquisition system (TDAQ) in Run 2. Some additional improvements specific to electrons and photons have been made at the HLT for Run 2. These include improvements to the HLT cluster and track reconstruction algorithms, the use of a new multivariate algorithm for energy calibration to improve the electromagnetic (EM) energy measurement in the trigger, and reoptimization of the electron and photon identification (ID) algorithms at the HLT.

In the following sections the upgraded electron and photon trigger system and its performance in data collected in 2016 collision period is presented.

2. Triggering on electrons and photons in ATLAS

In the hardware-based L1 trigger, calorimeter information is used to select electron and photon candidates by verifying that the energy deposited in a given region of the EM calorimeter passes the η-dependent E_T threshold and hadronic isolation requirements.

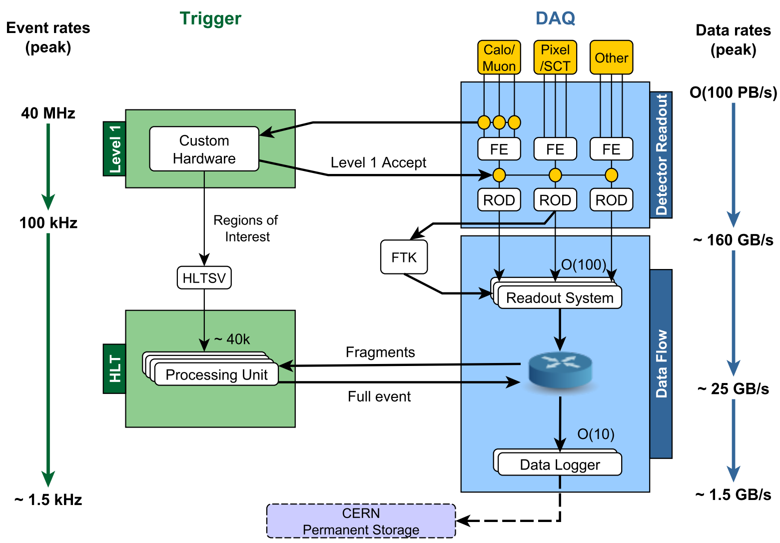

Figure 1: Schematic diagram of the ATLAS TDAQ system in Run 2.

Events which pass the L1 trigger selection are then processed by the HLT. At this stage, electron and photon candidates are reconstructed as clusters of energy deposited in the EM calorimeter. They are identified by making extensive use of calorimeter shower shapes and energy ratios. Tracking information is used only for electron identification at the HLT. An electron is identified if a track matching the EM cluster satisfies requirements relying on the transition radiation tracker information, track-cluster matching, and tracking quantities [4, 5].

3. Performance of electron and photon triggers

3.1 Energy calibration

Cluster energy calibration corrects the measured energy for losses upstream of the calorimeter as well as for lateral and longitudinal energy leakage outside the calorimeter cluster. The online reconstruction uses a simplified version of the offline method relying on boosted decision trees to determine the correction factors. Separate calibrations are used for electrons and photons, however photons are not separated into converted and unconverted categories at the HLT, which is a major source of the remaining differences with respect to offline reconstruction. Fig. 2 shows the energy resolution for electrons with respect to the offline calibration as a function of pseudorapidity (on the left) and a comparison of the measured resolution to the expectation from $Z \to e^+e^-$ Monte Carlo simulation (on the right). The resolution is excellent across the pseudorapidity range except in the transition region between the barrel and endcap EM calorimeters at $1.37 < |\eta| < 1.52$ where a large amount of material is present upstream of the calorimeter.

3.2 Trigger rates and performances

For electron identification, to improve the purity of the triggered data sample, a likelihood-

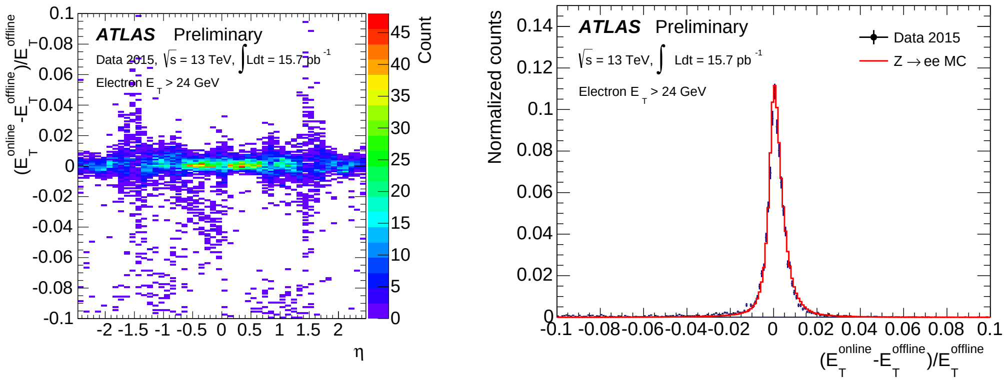

Figure 2: Electron energy resolution online with respect to the offline reconstruction as a function of pseudorapidity (on the left) and a comparison of the measured resolution to the expectation from $Z \to e^+e^-$ Monte Carlo simulation (on the right) [6].

based approach was adopted online that was successfully used offline already in Run 1. It uses input from calorimeter shower-shapes, tracking, track-cluster matching and a new electron probability derived from transition radiation information measured in the ATLAS Transition Radiaton Tracker. Likelihood-based selection was used during 2015 to trigger on electrons and reoptimized for 2016 conditions providing about a factor two improvement in background rejection for the same signal efficiency with respect to the optimised cut-based electron selection of Run 1.

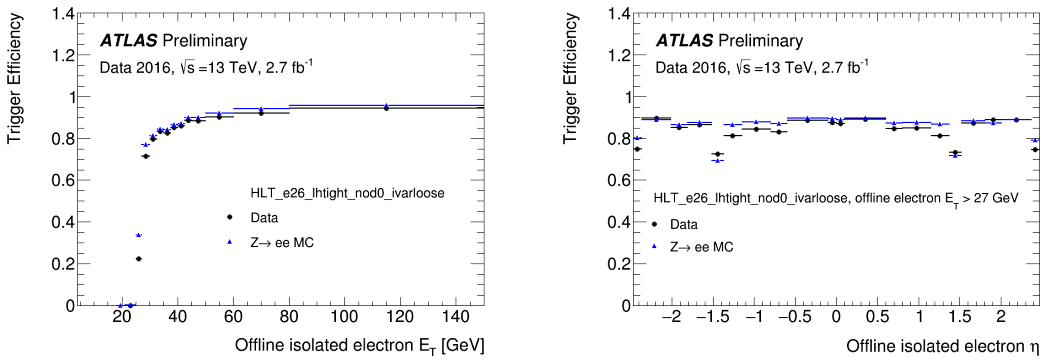

Figure 3: Efficiency of electron trigger requiring $E_T > 26$ GeV, a likelihood-based tight identification and a loose isolation, as a function of E_T (left) and as a function of η (right) comparing data (black) and MC (blue) [6].

Fig. 3 shows the efficiency of an electron trigger using likelihood-based tight identification and a requirement of 26 GeV in electron E_T, and a loose isolation with respect to offline isolated electrons satisfying offline likelihood-based tight identification. The efficiency is computed using electrons from $Z \to e^+e^-$ decay on both data and MC simulated events. The performance of the single electron triggers is stable across all the pseudorapidity range, and the agreement between data and MC in the efficiency measurement is very good.

During Run 2, the identification of photons is done using a cut-based selection as in Run 1. Nevertheless, the cut values applied were reoptimized for the Run 2 conditions. Fig. 4 shows the efficiency of photon triggers applying cut-based loose identification and different requirements on the photon E_T with respect to offline photons satisfying the tight identification. The efficiency of photon triggers is very close to 100% for photons with E_T exceeding the trigger threshold by a few GeV. In addition it is constant all across the pseudorapidity range.

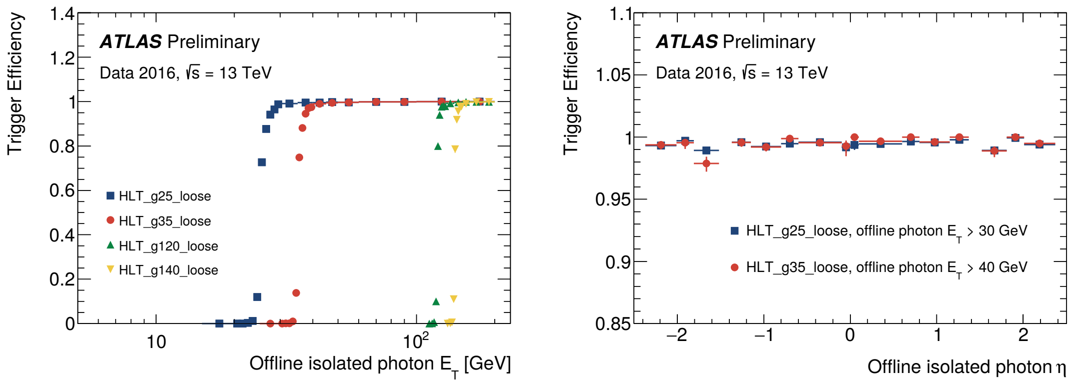

Figure 4: Efficiency of photon triggers requiring cut-based loose identification for different E_T thresholds, as a function of E_T (left) and as a function of η (right) [6].

Fig. 5 shows the output HLT rates for different photon and electron triggers as a function of LHC instantaneous luminosity measured by ATLAS during the first half of the 2016 data taking. Both photon and electron trigger rates have a roughly linear dependence on the instantaneous luminosity. In addition, the use of a likelihood-based tight identification on electrons reduces the rate by around 20% with respect to likelihood-based medium identification without a significant loss in efficiency.

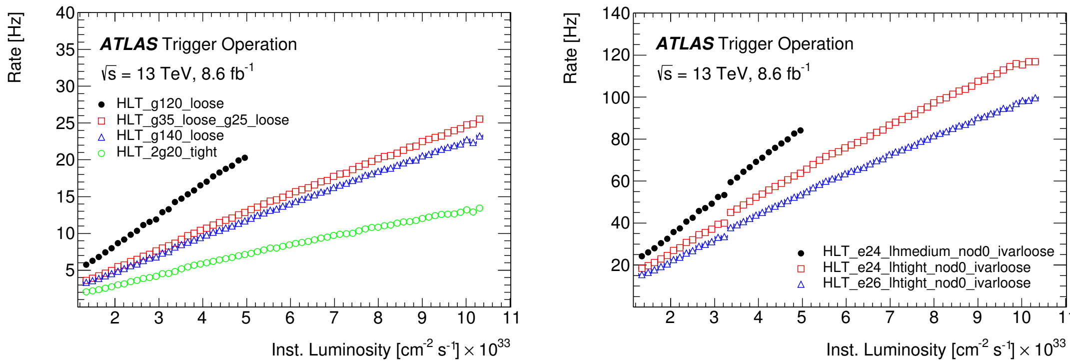

Figure 5: Output HLT rate of photon triggers (left) and electron triggers (right) as a function of the instantaneous luminosity during 2016 data taking [6].

4. Outlook

During the 2013-2014 long shutdown, the trigger system incorporated many improvements that had a significantly positive impact on the electron and photon triggers during the ongoing Run 2. In spite of the higher center-of-mass energy and higher pile-up conditions in Run 2 with respect to those in Run 1, the ATLAS trigger system was able to select electrons and photons with a performance as good as that of Run 1 and keeping similar thresholds.

References

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