Evolution and Performance of Electron and Photon Triggers in ATLAS in the Year 2011

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Abstract—Electron and photon triggers are used for signal selection in a wide variety of ATLAS physics analyses. Further dedicated triggers are provided for the collection of $J/\psi \rightarrow e^+ e^-$, $W \rightarrow e\nu$ and QCD background samples for calibration, efficiency and fake rate measurements. In the 2011 proton-proton data-taking, the increasing luminosity and pile-up conditions at the LHC demanded the use of progressively higher energy thresholds and tighter selections to control the trigger rates. This proceedings summarize the evolution and performance of ATLAS electron and photon triggers used in 2011 data-taking.

I. INTRODUCTION

The ATLAS is one of two general purpose detectors at the Large Hadron Collider (LHC) at CERN designed for wide variety of physics searches [1]. The ATLAS is a forward-backward symmetric detector and consists of one barrel part (barrel) and two endcap parts (endcaps). During 2011 the LHC was providing proton collisions with up to 20 MHz bunch crossing rate at a center of mass energy of 7 TeV.

The ATLAS physics programme relies on the efficient performance of the trigger system to select events of potential interest from the QCD background processes dominant at the LHC. Events with electrons and photons in the final state are important for many physics studies including Standard Model (SM) precision physics such as top and W cross-section and mass measurements, Higgs boson searches and QCD background samples for calibration, efficiency and fake rate measurements. In the 2011 proton-proton data-taking period, the increasing luminosity and pile-up conditions at the LHC demanded the use of progressively higher energy thresholds and tighter selections to control the trigger rates. This proceedings summarize the evolution and performance of ATLAS electron and photon triggers used in 2011 data-taking.

II. ELECTRON AND PHOTON IDENTIFICATION IN THE TRIGGER AND OFFLINE

A. Offline Identification

Electron and photon identification is accomplished by a set of $\eta$- and $E_T$-dependent cuts on identification variables which are calculated in the offline reconstruction [4], [5]. Such variables are calculated based on the energy deposition in the ATLAS calorimeters or its inner detector activated points forming tracks (e.g. isolation cones for isolation of $\gamma$ candidates or a nice position matching between clusters and tracks). Identification is aimed at rejecting electron or photon backgrounds (heavy flavour, neutral and charged mesons in jets) while maintaining high signal efficiencies.

The standard offline selection defines three operating points for electrons (loose, medium, tight) and two for photons (loose, tight) at defined levels of background rejection. Cut values defined at the loose operating point are common for both electrons and photons. For tighter operating points cuts on additional variables are added. A re-optimised set of cuts (plus-plus) was defined for electron selection providing three additional operating points (loose++, medium++, tight++) with improved performance over the standard set for a higher pileup environment. In the plus-plus re-optimized identification, more variables are used and the cut values of each operating point are varied.

B. Online Identification

The identification of electrons and photons at the HLT is performed using similar variables to those used offline with loose, medium and tight operating points for electrons and loose for photons. In the trigger menu, the electron identifications loose1, medium1 and tight1 were implemented to trigger on plus-plus offline electrons.

III. TRIGGER MENU AND RATES EVOLUTION

The convention used for the trigger signature naming indicates that for example 2e12_medium is a two-electron trigger with medium identification requirements at HLT and $E_T > 12$ GeV cut applied at EF on both trigger objects, while g80_loose is a single photon trigger with a threshold of 80 GeV and loose identification criteria.

In some triggers to reduce the rate the decision is not evaluated for each event. This is achieved by setting the prescale factor (PS) to a certain value. For example if PS is set to 2 then the decision is evaluated for every second event and such trigger is called prescaled.
As the instantaneous luminosity of the LHC increased, numerous measures were taken to control the overall output rate of the $\gamma/\gamma$ triggers. The rates of the single electron triggers at a fixed reference luminosity were reduced by raising thresholds and tightening cuts as detailed below, keeping as high as possible the efficiency for the interesting objects. The photon trigger selection was unchanged throughout 2011, however the threshold of the unprescaled single photon trigger was raised from 60 GeV to 80 GeV at a luminosity of $1 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$.

A. L1 Optimisation

Until summer 2011, when the LHC instantaneous luminosity was less than $2.3 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$, the following eight L1 electromagnetic trigger thresholds were used either singly or combined to seed HLT triggers: EM3, EM5, EM7, EM10, EM12, EM14, EM16, EM30 (where the number refers to the cluster transverse energy threshold). From September 2011, in preparation for instantaneous luminosities above $3 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$, some of these thresholds were adjusted in order to keep the overall L1 accept rate at or below 60 kHz. Instead of significantly increasing the trigger thresholds at the expense of reduced acceptance for physics analyses, an $\eta$-dependent optimization of thresholds and a hadronic leakage requirement were applied on EM10 and EM16 which were subsequently re-named EM10VH and EM16VH. The letters $vh$ were added to the HLT signature names for those triggers seeded by L1 items with $\eta$-dependent thresholds and a hadronic leakage requirement, e.g. e22vh_medium1.

B. L1-HLT Threshold Separation

The differences between the HLT and L1 thresholds were reduced for some triggers in order to keep the L1 rates within the allowed bandwidth without raising the threshold at the HLT and hence the offline analysis. For example, the seed of the 2e12_medium trigger was changed from 2EM7 to 2EM10 when the luminosity reached $1.5 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$. To reflect this change in the L1 seed the letter 'T' (for tighter L1 requirement) was added to the HLT trigger name, i.e. 2e12T_medium. The lower threshold was used at L1 before because of difference of resolution between L1 and HLT.

C. HLT Optimisation

At the HLT the energy thresholds were raised and the identification cuts tightened to reduce the L2 rate and maintain the EF output rate at about 400 Hz on average per LHC fill. The EF threshold for the single electron trigger was raised from 20 GeV to 22 GeV in August 2011 (when the luminosity exceeded $2 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$). At L2, the medium and tight electron identification criteria were brought closer to the EF level selections and, for luminosities $\geq 3 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$ (September), the re-optimised electron identification criteria were deployed, moving from the medium to medium1 selections, in order to avoid further raising the threshold.

The EF rates of the single electron and photon triggers are shown in Figures 1(a) and 1(b), respectively, as a function of instantaneous luminosity. The rates of all triggers varied linearly with luminosity, and Fig 1(a) illustrates how the strategy described above managed to keep the single electron trigger rate below 70 Hz during 2011.

IV. ELECTRON AND PHOTON TRIGGER PERFORMANCE

A. L1 Trigger

The performance of L1 EM triggers was evaluated with a data-driven Tag&Probe method on $Z \rightarrow ee$ events [4]. In this method reconstructed electrons passing the lowest unprescaled single electron trigger are identified as tags. A second reconstructed electron is identified as a probe if the invariant mass computed from the Tag&Probe pair is close to the Z boson mass (80 GeV < $m_{ee}$ < 100 GeV). The efficiencies of L1 EM triggers can be estimated for probe electrons that are associated to a L1 signal. The efficiencies are calculated with respect to offline electrons passing the medium++ identification selection.

Figure 2 shows the efficiencies of the L1 EM16 and EM16VH triggers as a function of the electron $p_T$ and $\eta$. The implementation of the $\eta$-dependent thresholds on EM16VH resulted in a shift of the efficiency curve towards higher $p_T$ values in comparison with EM16 (Fig. 2(a)). The hadronic leakage requirement has a negligible effect on the L1 efficiency of offline-identified electrons up to $p_T \approx 200$ GeV since a hadronic leakage cut is applied offline relative to the electron $p_T$ value.

B. HL1 Tracking

The efficiency of the HL1 tracking algorithms was measured on data using events selected by HL1 tracking monitoring triggers. In these triggers, electron candidates are selected only with calorimeter information to avoid any bias from the tracking identification. Figure 3 shows the efficiency of the L2 and EF tracking as a function of the $p_T$ and $\eta$ of the offline electron satisfying the tight identification. The EF tracking, which uses algorithms closer to the ones used offline, shows very high efficiency, close to 100% from about 4 GeV offline electron $p_T$ and very small dependences on the electron $\eta$. The L2 tracking, which uses less sophisticated algorithms due to timing constraints, shows a slower turn-on curve and dependences of the order of 2% on the electron $\eta$.

C. Electron Triggers

The efficiencies of the HL1 electron selection were measured with respect to offline electrons on $Z \rightarrow ee$ events using a Tag&Probe method. For measuring the HL1 efficiencies, the tag is defined as the offline electron matching an online electron passing the lowest unprescaled single electron trigger. The tag electron is also required to have $p_T > 25$ GeV, to satisfy the tight++ offline electron identification and to lie within $|\eta| < 2.47$, excluding the transition region between the barrel and the endcaps. A second electron with opposite charge to the tag is considered as a probe if the invariant mass of the

\[ \Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \] satisfies $\Delta R < 0.15$.

\[ 1 \text{An offline electron is considered to match an online electron if the distance between them in the } (\eta, \phi) \text{ space } \Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \text{ satisfies } \Delta R < 0.15. \]
Fig. 1. EF trigger rates as function of instantaneous luminosity for single electron (a) and photon (b) triggers. Vertical dashed lines mark instantaneous luminosity ranges when they were used as main triggers for physics analysis.

Fig. 2. Efficiencies of L1 EM16 and EM16VH triggers as a function of offline electron $p_T$ (a) and $\eta$ (b) using the Tag&Probe method on $Z \rightarrow ee$ events. The offline electron is required to satisfy medium++ identification. Right plot shows the efficiency for electrons with $p_T > 25$ GeV.

Fig. 3. The efficiency of the L2 and EF tracking as a function of the $p_T$ (a) and $\eta$ (b) of offline tight electron track selected by a dedicated tracking monitoring trigger that applies calorimeter selection only.

electron pair lies in the range $80 \text{ GeV} < m_{ee} < 100 \text{ GeV}$. The trigger efficiency is the fraction of probes matching an online electron passing the trigger selection at the EF.

Figure 4 shows the efficiencies of the e20_medium, e22_medium and e22vh_medium1 triggers measured with data relative to medium++ offline electrons. The efficiency of e20_medium is computed relative to offline electrons with $p_T > 21$ GeV and the efficiencies e22_medium and e22vh_medium1 are computed relative to offline electrons with $p_T > 23$ GeV. Between 25 and 35 GeV the efficiency is slowly increasing before finally reaching the plateau value at about 35 GeV. Inefficiencies of these triggers mainly arise from the resolution of reconstruction and identification variables at the HLT with respect to offline. Due to timing constraints the HLT reconstruction algorithms (especially the L2 tracking) are less refined than the corresponding offline algorithms. In addition, the trigger-offline resolution for the electron identification variables result in some trigger inefficiencies which affect in particular the e22vh_medium1 trigger.

The unprescaled di-electron triggers used for the largest part of 2011 applied 12 GeV $E_T$ thresholds at the HLT on both electrons and medium identification criteria. The L1 seed of the di-electron triggers evolved during 2011 and this is reflected in the evolution of HLT trigger name used,
i.e. 2e12\_medium, 2e12T\_medium and 2e12Tvh\_medium, depending on the instantaneous luminosity delivered by the LHC. The tighter requirement on the L1 seed, especially its increased threshold, resulted in a slower turn-on from e12\_medium to e12T\_medium and to e12Tvh\_medium. For e12\_medium the efficiency plateau is reached at about 20 GeV, whereas for the other two triggers at about 25 GeV. All three triggers follow a similar efficiency profile as function of \( \eta \). At the efficiency plateau the three triggers show very high efficiencies, 97 - 99%.

D. Photon Triggers

The photon triggers g60\_loose and g80\_loose are the lowest uprescaled single photon triggers and along with 2g20\_loose are used in many analysis such as \( H \to \gamma\gamma \) and searches for physics beyond the SM. Photon triggers use only calorimeter information. The efficiencies of the photon triggers g20\_loose, g80\_loose, g60\_loose and 2g20\_loose were measured on data using a Bootstrap approach. In this method the efficiency of the trigger selection with respect to offline photons is factorized as the HLT selection efficiency relative to the L1 seed, multiplied by the L1 seed efficiency relative to a sample of Minimum Bias triggered events. The HLT efficiencies of g20\_loose, g60\_loose and g80\_loose relative to their respective L1 seeds as functions of offline tight photon \( p_T \) and \( \eta \) are shown in Figure 5. The photon trigger efficiencies show rapid turn-on curves with no significant dependence on the offline photon \( \eta \).

V. SUPPLEMENTARY TRIGGERS

A. Triggers for \( J/\psi \to e^+e^- \) Selection

Electrons from \( J/\psi \) decays are used to measure the identification efficiencies for low and medium \( p_T \) electrons. Unlike for the \( Z \to ee \) sample, a single electron trigger cannot be used for such low \( p_T \) electrons (\( p_T < 15 \) GeV) to collect the probe sample as the trigger rate is too high. Dedicated di-electron triggers were therefore developed for the HLT in order to record such events while keeping the probe electron as unbiased as possible. These \( J/\psi \) triggers require tight identification criteria for one electron and a very loose selection on the other electron; typically only an electromagnetic cluster reconstructed above some \( E_T \) threshold is required. The combination of the tight tag selection and an invariant mass cut on the electron pair between 1 and 6 GeV gives a rejection factor of more than 1000 at the HLT.

The \( J/\psi \) triggers provide a significant contribution to the 2011 measurements of the offline electron identification efficiencies in the \( p_T \) range 15-20 GeV, with about 12,500 probes, allowing a systematic comparison with the results obtained from Z and W samples. In the \( p_T < 15 \) GeV range, electrons from \( J/\psi \) decay provided unique information on the low-\( p_T \) electron identification efficiency with about 47,500 electron probes, critical for analyses such as \( H \to 4\text{-leptons} \).

B. W Tag&Probe Triggers

The W Tag&Probe triggers are designed to select W candidates decaying to an electron and a neutrino with a minimal trigger bias on the electron selection for studies of reconstruction and identification performance of medium- and low-\( p_T \) electrons. For this purpose the event is tagged by the missing transverse energy significance of the neutrino, defined as \( \approx E_T^\text{miss} / \sqrt{\sum E_T^{cell}} \), where \( E_T^\text{miss} \) is the reconstructed missing transverse energy in the event and \( \sum E_T^{cell} \) is the scalar sum of the cell transverse energies in the calorimeters. The electron probe has the least possible identification bias.

The W Tag&Probe triggers contributed significantly to the measurement of the offline electron identification efficiencies, especially in the low to medium \( p_T \) range. The numbers of electron probes collected in 2011 pp collision data are \( \approx 55000 \) in the \( p_T \) range 15-20 GeV and \( \approx 19000 \) in the \( p_T \) range 20-25 GeV. These numbers can be compared to the numbers of electron probes collected by the single electron trigger used in the Z Tag&Probe analysis: \( \approx 34000 \) (\( p_T \approx 15-20 \) GeV) and \( \approx 80000 \) (\( p_T \approx 20-25 \) GeV).

C. Supporting Triggers for Background Estimations

A variety of triggers were developed for the support of specific physics or trigger studies. These triggers were designed...
to collect background-enriched samples for data-driven studies of background contamination in physics analyses or assess and monitor the HLT performance, e.g. calorimeter and tracking efficiencies at L2 and EF.

In the case of $e/\gamma$ final states, data-driven methods for the estimation of the background contamination in signal samples often require loose electron identification criteria to provide background-enriched data samples. Such samples cannot be collected by the unprescaled electron triggers used to collect signal samples since these apply stringent identification cuts to limit their rates. Dedicated prescaled triggers were therefore introduced with looser identification requirements or no identification at all.

During the 2011 $pp$ data-taking, up to 7 Hz were allocated to these triggers for background estimation studies and their rates were kept approximately constant, by prescale adjustment during the course of the LHC fills.

VI. SUMMARY

During 2011 the LHC instantaneous luminosity increased from $5 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$ at the beginning of the proton-proton collision data-taking period to $3.7 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$ in November 2011. The increase of the luminosity and the resulting increased pile-up posed challenges for the different $e/\gamma$ triggers.

To cope with the instantaneous luminosity rise several changes were made for electron triggers. The electron triggers were found to be highly efficient throughout the year, with efficiencies ranging between 95% and 99%.

The photon triggers were running stably with efficiencies close to 100% during 2011 and no re-optimization was needed for higher instantaneous luminosity.

Specialized triggers were set up to collect unbiased electron samples from $J/\psi \rightarrow e^+e^-$ and $W \rightarrow e\nu$ events for offline studies of the electron reconstruction and identification efficiencies.

A set of supporting triggers were also set up to collect control samples for background estimations in physics analyses, for example in the W cross section measurement.

The $e/\gamma$ triggers showed stable operations and a reliable performance during 2011 proton-proton data-taking.

REFERENCES