Commissioning of ATLAS electron and photon trigger selection

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Abstract. First collisions at a center of mass energy of 7 TeV at the Large Hadron Collider were recorded by the ATLAS experiment at the beginning of 2010. Data selected by the hardware based Level-1 trigger were processed online by the software based High Level Trigger running without active rejection.

This paper gives an overview of the calorimeter based performance of the electron and photon triggers during the initial 2010 running period. These triggers will play a key role for the physics analyses in ATLAS. Examples of comparisons of the three trigger levels with the offline reconstruction will be presented, such as the Level-1 efficiency and the distributions of the calorimeter based selection variables used to distinguish between signal and background. This is an important step in the commissioning of the trigger system to ensure its correct functioning. Results from this first data are very encouraging. At the end a brief outlook on the commissioning steps and on the evolution of the e/γ trigger strategy with increasing luminosities will be given.

1. Introduction
The ATLAS experiment is one of the two general-purpose detectors at the LHC, the world’s largest particle accelerator, built to study the Standard Model (SM) and to search for potential new physics scenarios. Proton collisions were collected at the end of 2009 at a centre of mass energy of 900 GeV, 2.36 TeV and since March 2010 at 7 TeV. With a 25 ns bunch spacing, the bunch crossing rate at the LHC design luminosity is approximately 40 MHz, while the event data recording is limited to 200 Hz. The requirement on the trigger system is thus an event rejection factor of at least $2 \cdot 10^5$ while retaining potentially interesting events. Maximum efficiency for selected physics processes is achieved by basing trigger selections on the identification of final state objects like electrons, photons, muons, taus, jets and missing transverse energy. Among these, events containing high-$p_T$ electrons and photons in the final state play a very important role as they can be clearly identified in the detector and they provide signatures for many physics processes in the SM and beyond.

During the first months of 7 TeV collisions, data were selected using the first trigger level (L1) and subsequently processed online by the High Level Trigger (HLT). However, independent of the trigger decisions at the HLT all events were accepted as the L1 output rate was low enough. This particular running mode allows to evaluate the real time performance of the HLT triggers and compare them with the expectations before starting to actively reject events.

The first two sections of these proceedings contain a brief description of the ATLAS detector and its trigger system. This is followed by an overview of the implementation and performance
of the electron and photon triggers. Finally the commissioning plans for the higher luminosity running period will be summarized.

2. The ATLAS detector

A detailed description of the ATLAS detector can be found in [1]. The most important components for electron and photon detection are the Inner Detector (ID) tracking system and the electromagnetic (EM) calorimeter.

The ID combines three subdetector with different technologies. From the inside to outside it consists of a three-layer silicon pixel detector, a four-layer semiconductor strip detector and a transition radiation tracker composed of straw-tube proportional chambers interleaved with a radiator material for electron/hadron discrimination. These devices are immersed in a 2 T solenoidal magnetic field and provide tracking for $|\eta| < 2.5$ with a $p_T$ resolution of $\sigma_{p_T}/p_T = 0.05\%p_T \pm 1\%$.

The electromagnetic calorimeter uses lead plates as absorber interleaved with liquid Argon(LAr)-filled gaps. An accordion geometry guarantees good uniformity with no cracks in the $\phi$ direction. It is longitudinally segmented into three layers and it is divided in a barrel part and two end-cap components. The first layer has a depth of $\approx 4.3X_0$ with a fine granularity cell structure in $\eta$ direction (‘strip’ cells of size $\Delta\eta \times \Delta\phi = 0.003 \times 0.1$ for $|\eta|<1.8$, slightly larger size at larger $\eta$) for hadron rejection in the region $|\eta| < 2.5$. It is followed by a second layer of depth $\approx 16X_0$, where electromagnetic showers deposit most of their energy, with squared cells of size $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$. The last layer of depth $2X_0$ is used for evaluating and correcting for the leakage into the hadronic calorimeter. The calorimeter is designed to achieve an energy resolution of $\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$, with $E$ expressed in GeV, up to a pseudorapidity of 3.2; more details on the calorimeter performance are described in [2].

3. The ATLAS Trigger System

In order to achieve the desired data rate reduction, the ATLAS trigger system [3] is structured in three levels. The available detector granularity increases between L1 and HLT; so does the selection complexity at each level. This improves the resolution and the rejection power at the cost of longer decision time and thus lower processing rate.

The first trigger level (L1) is implemented with custom-made electronics and uses reduced-granularity information from the muon and the calorimeter subdetectors. The goal is to rapidly identify signatures from high-$p_T$ muons, electrons/photons, jets, $\tau$-leptons as well as events with large missing or total transverse energy. The decision needs to be taken within 2.5 $\mu$s while the information is still in the detector pipeline memories. The maximum L1 output that the system can handle is currently limited to 75 kHz.

The next two levels, Level-2 (L2) and Event-Filter (EF) are software-based and collectively referred to as the High Level Trigger. The L2 is seeded by the L1 through the ‘Region-of-Interest’ (RoI) mechanism. An RoI is a detector region around the $\eta$-$\phi$ direction identified by L1; the size of the RoI depends on the trigger signature ($e/\gamma$, $\tau$, jets) and typically contains 2%-4% of the data in one event. When an event fulfill L1 selection, only full granularity detector information contained in the corresponding RoI is processed by L2. This approach guarantees a data reduction for network transfer and together with fast pattern recognition algorithms, ensure that the average L2 latency is within the allocated limits of 40 ms.

At the EF the full event information is available though currently the RoI approach is being used and offline algorithms are used for reconstruction; the average processing time is $\approx 4$ s. The maximum EF output rate is 200 Hz due to constraints imposed by computing resources for offline event processing and storage.
3.1. Electron and Photon triggers
A detailed description of the electron and photon trigger signatures and their implementation in the ATLAS trigger strategy can be found in [4]. At L1, there is no distinction between electrons and photons since only calorimetric information is available: the granularity is given by the so-called ‘Trigger Tower’ (TT), with a size of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$, whose energy is computed summing up the signals from the cells along the full depth of the EM calorimeter. L1 clusters are created using a sliding window algorithm of $4 \times 4$ trigger towers. Events are selected if at least one (or two) clusters are identified above a configurable transverse energy threshold.

At the HLT, the trigger selection proceeds in a series of steps. At L2 a fast calorimeter reconstruction is performed and, in the case of electrons, fast pattern recognition algorithms are also executed for track reconstruction. After each of these steps, hypothesis algorithms are run to select electron and photon candidates and reject background coming predominantly from jets. The signal selection is based on discriminating variables mainly exploiting the differences in the EM shower profile. For electrons tracking information and cluster-track matching quantities can also be used to reject events containing hadron fakes. The EF uses the offline reconstruction algorithms but, due to timing constraints, some corrections like the bremsstrahlung and conversion recovery are not applied. For the signal identification the HLT relies on the same (or a slightly reduced) set of selection criteria used by the offline particle identification [5]. This implementation has been adopted in order to minimize potential sources of trigger inefficiencies on events selected by the offline analyses.

The various signatures that are implemented in the trigger differ mainly in the value of the transverse energy threshold and the identification criteria applied in the hypothesis algorithms.

4. e/$\gamma$ Trigger commissioning
The following results are based on the analysis of $\approx 0.4$ $nb^{-1}$ of stable beam proton collision data collected at $\sqrt{s} = 7$ TeV in April 2010. Given the relatively low peak luminosity (up to $5 \cdot 10^{27} cm^{-2}s^{-1}$), the main source of triggered events was provided by the Minimum Bias Trigger Scintillators (MBTS) [6] selecting collision through charged particles in the forward region ($2.09 < |\eta| < 3.89$). The first level calorimeter trigger was actively used to stream out events and provide an enriched sample of events containing electromagnetic clusters. After the necessary stability checks the electron and photon HLT chains were activated in so-called flagging mode; the events were accepted independently of the HLT decision. The trigger algorithms were executed online and the decision of each chain and the reconstructed trigger objects used for making the decision were recorded into the data stream and could be analyzed offline.

This commissioning mode allows to evaluate the real time performance of the HLT and to crosscheck the trigger decisions with respect to the offline event selection, especially looking for misconfigurations or detector problems that could lead to an early rejection of events otherwise accepted by an offline analysis.

A detailed comparison of the trigger reconstruction performance with MC simulation expectations was also performed using a sample of non-diffractive minimum bias events generated with Pythia and processed with the full ATLAS simulation and reconstruction software.

4.1. L1 performance
The L1 calorimetric triggers proved a very good operational stability and reliability over the entire data taking period as reported in Figure 1. It shows the fraction of events collected with the MBTS trigger passing each of the three lower EM signatures, $L1_{EM2}$, $L1_{EM3}$ and $L1_{EM5}$ with a transverse energy ($E_T$) threshold approximatively at 3, 4 and 6 GeV$^1$. At an $E_T$ transverse energy at L1 is the result of signal ADC conversion where 1bit corresponds to a deposited energy of $\approx 1$ GeV. The notation $EM2$ indicates that the bit count is required to be $\geq 3$ GeV.
instantaneous luminosity of $10^{27} \text{cm}^{-2}\text{s}^{-1}$ the L1_EM2 was found to be 1.5 Hz. The visible step in Figure 1 is due to the update of the timing calibration constants performed to improve the signal reconstruction and energy resolution performance (see [7]).

![Figure 1](image1.png)

**Figure 1.** Fraction of events collected by the MBTS trigger satisfying the 3 lowest $E_T$ L1 EM signatures as a function of time.

![Figure 2](image2.png)

**Figure 2.** L1 efficiency for the 3 lowest $E_T$ L1 EM signatures as a function of the raw offline cluster $E_T$.

The energy resolution has been evaluated by comparing the L1 electromagnetic clusters to the offline ones. Figure 2 shows the L1 efficiency as function of the raw\(^2\) offline cluster $E_T$, computed requiring an angular matching criteria with $\Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2} < 0.15$ between the offline and the trigger objects. No selection on offline cluster shower shapes has been applied; the offline cluster is required to have $|\eta| < 2.5$ and not coming from the transition region between the barrel and end-cap calorimeters ($1.37 < |\eta| < 1.52$).

A good agreement in the shape of the trigger turn on is found for the 3 lowest threshold L1 triggers: the threshold position in MC is shifted towards higher value by less than 0.5 GeV. A few GeV above the threshold these triggers become fully efficient thus minimizing any bias on offline sample.

### 4.2. HLT performance

In order to evaluate the HLT performance, the level of agreement between offline and trigger selection variables needs to be assessed. For the following analysis the HLT electron and photon candidates were matched to an offline electron candidate, requiring a minimal distance of $\Delta R < 0.15$; the transition region of the calorimeters was again excluded. HLT chains were seeded by the L1 calorimetric trigger and the minimum $E_T$ of the sample reflects the lower L1 threshold of 3 GeV. For the selected sample the distributions of kinematics and signal/background discriminating variables have been compared at the different trigger levels with the offline distributions as well as with the expectations from MC simulations. Since no identification criteria have been applied to offline reconstructed candidates, the distributions are still dominated by fakes. For the comparisons presented in the following, the Monte Carlo distributions are normalised to the number of events in the data sample.

As an example, Figure 3 and 4 show the distribution of two of the $e/\gamma$ identification variables at EF for data and MC simulation. The first, called $R_\eta$ is defined as the ratio of the energy

\(^2\)The $E_T^{\text{Raw}}$ is defined as the uncalibrated cluster transverse energy of the cluster before correction for losses in the upstream material that are not applied at L1.
Figure 3. Data/MC comparison for the $R_{\eta}$ identification variable computed at EF.

Figure 4. Data/MC comparison for the $E_{\text{ratio}}$ identification variable computed at EF.

deposited in $\Delta \eta \times \Delta \phi = 3 \times 7$ cluster cells of the second layer of the EM calorimeter divided by the energy found in $7 \times 7$ cells. This quantity peaks towards one for electrons and photons which have showers well contained within $3 \times 7$ cells; hadronic showers have a broader spectrum$^3$. A second variable, shown in Figure 4, is called $E_{\text{ratio}}$ and it is computed as the difference between the highest and the second highest cell energy deposit in the first layer of the EM calorimeter divided by the sum of the two energy deposits. This variable peaks at one for single particle initiated showers and it tends towards lower values for showers initiated by more than one particle like a photon pair coming from $\pi_0$.

The figures show a reasonable agreement between data and simulations and similar behavior is seen for other variables. The small shift in the data to slightly lower values for $R_{\eta}$ can partly be explained by the MC cross-talk modelling in the second sampling while the shift of the first layer variable are traced back to some missing material description in the current MC simulation. The same shifts are also observed for offline reconstructed objects and documented in [5].

Figure 5. HLT trigger levels resolution on $R_{\eta}$ variable with respect to offline reconstruction.

Figure 6. HLT trigger levels resolution on $E_{\text{ratio}}$ variable with respect to offline reconstruction.

Another crucial check is the agreement between the different trigger levels and the offline reconstruction on the signal identification variables; this is a key ingredient in understanding

$^3$ Values of $R_{\eta}$ above 1 are due to the noise contribution that can lead to negative signals in some cells.
the trigger effect on the offline analyses. Examples are provided in Figure 5 and 6 where the difference between offline and HLT levels on the $R_\eta$ and $E_{\text{ratio}}$ variables are shown for selected objects. For most of the clusters, trigger and offline calculations agree well and the broader resolution at L2 is due to the faster, and thus less refined, clustering algorithm and calibration. For both trigger levels the resolution is below few percent.

The presented results, for the example discussed above and also for the other selection variables not shown, provides evidence that the initial trigger selection criteria implementation developed using MC simulations are safe and robust for the HLT to be activated in rejection mode.

5. Conclusions

The calorimeter based performance of the ATLAS electron and photon triggers during the first months of LHC collisions at 7 TeV was presented in this paper. In the first phase of data taking at 7 TeV, data were collected with the L1 trigger since the event rate at the initial luminosity was low enough to be written directly to mass storage. For commissioning purposes the HLT was running online without rejecting any events.

The L1 $e/\gamma$ triggers show good performance in terms of stability and high efficiency with respect to offline candidates above the trigger threshold. The selected events have been used for the first analysis concerning electrons and photons (W/Z, inclusive electrons and prompt photons). Studies on the performance of the software based trigger were crucial for preparing the HLT to start working in rejection mode for LHC luminosities above $10^{29} \text{cm}^{-2}\text{s}^{-1}$ when the output of the lowest L1 EM triggers needs to be limited in order to keep the data saving rate within the requirements. Data/MC comparisons showed that the distribution for the selection variables in the trigger are reasonably well modeled by the simulation. A good agreement between trigger and offline variables has been found showing that the $e/\gamma$ triggers are working correctly; electron and photon offline candidates are selected by the HLT with minimal bias on offline reconstruction.

Based partly on the studies reported in this paper, the decision has been taken to activate the first low $E_T$ HLT chains in rejection mode at the end of May 2010 when the LHC luminosity exceeded for the first time $10^{29} \text{cm}^{-2}\text{s}^{-1}$. With increasing luminosity more triggers will apply rejection at HLT in order to better fill the allocated bandwidth while still keeping good efficiency with respect to events containing low and medium energy electrons and photons. With higher integrated luminosity (> $1 \text{pb}^{-1}$) a sample of isolated electrons from $J/\Psi \rightarrow ee$, $W \rightarrow e\nu$ and $Z \rightarrow ee$ will be collected. This will allow to repeat the performance measurement described in this note on a very pure signal sample and evaluate with data-driven methods the trigger efficiencies to be used in physics measurements.

References

[1] The ATLAS Collaboration, G. Aad et al., The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008).
[2] The ATLAS Collaboration, H. Zhang, The ATLAS Liquid Argon Calorimeter: overview and performance, these proceedings.
[3] The ATLAS Collaboration, G. Aad et al., Expected performance of the ATLAS experiment: detector, trigger and physics, e-Print: arXiv:0901.0512 [hep-ex], (2008).
[4] The ATLAS Collaboration, G. Aad et al., Performance of the Electron and Photon Trigger in p-p Collisions at $\sqrt{s}=900 \text{ GeV}$, ATLAS-CONF-2010-022, Geneva, (2010).
[5] The ATLAS Collaboration, D. Banfi, Electron and photon reconstruction and identification with the ATLAS Detector, these proceedings.
[6] The ATLAS Collaboration, G. Aad et al., Performance of the Minimum Bias Trigger in p-p Collisions at $\sqrt{s}=900 \text{ GeV}$, ATLAS-COM-CONF-2010-025, Geneva, (2010).
[7] The ATLAS Collaboration, J. T. Childers, ATLAS Level-1 Calorimeter Trigger Hardware: Initial Timing and Energy Calibration, these proceedings.