

Triggering on electrons and photons with CMS

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Abstract. Throughout the year 2011, the Large Hadron Collider (LHC) has operated with an instantaneous luminosity that has risen continually to around $4 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$. With this prodigious high-energy proton collisions rate, efficient triggering on electrons and photons has become a major challenge for the LHC experiments. The Compact Muon Solenoid (CMS) experiment implements a sophisticated two-level online selection system that achieves a rejection factor of nearly 10^6 . The first level (L1) is based on coarse information coming from the calorimeters and the muon detectors while the High-Level Trigger (HLT) combines fine-grain information from all sub-detectors. In this intense hadronic environment, the L1 electron/photon trigger provides a powerful tool to select interesting events. It is based upon information from the Electromagnetic Calorimeter (ECAL), a high-resolution detector comprising 75848 lead tungstate (PbWO_4) crystals in a “barrel” and two “endcaps”. The performance as well as the optimization of the electron/photon trigger are presented.

1 Introduction

The CMS detector has been designed to study the result of proton-proton and heavy ion collisions produced by the LHC. These experiments are conducted with the purpose of searching for new particles and processes as well as revealing the very nature of the elementary particle interactions [1]. From the millions of collisions produced per second only 300 events per second can be stored offline. Such a huge number of collisions is necessary as these physics signatures are rare compare to the profusion of QCD-induced background processes. The search for new physics crucially relies on the trigger system performance that is used to select them [2]. The CMS trigger system is organised in two consecutive steps [3] : the Level-1 trigger performs an event selection (custom-made electronics processors) based on coarse energy deposits in the calorimeters and the muon systems (output rate up to 100 kHz), followed by the HLT, implementing precise selection algorithms (in commercial computers) based on finer granularity and higher resolution information from all sub-detectors in regions of interest identified at L1 (output rate about 300 Hz). The CMS ECAL provides a precise measurement of the energies and positions of incident electrons and photons for both triggering and offline analysis purposes. The energy measured by the hadronic calorimeter (HCAL) is used to better identify and isolate electromagnetic signals. A set of configuration parameters enables the performance of the electron/photon trigger to be optimized for the wide range of luminosities expected at the LHC.

2 From ECAL to the Level-1 trigger

2.1 ECAL and the trigger primitive generation

The CMS ECAL, composed of a Barrel (EB) and two Endcaps (EE), comprises 75848 lead tungstate (PbWO_4) scintillating crystals equipped with avalanche photodiode (APD) or vacuum phototriode

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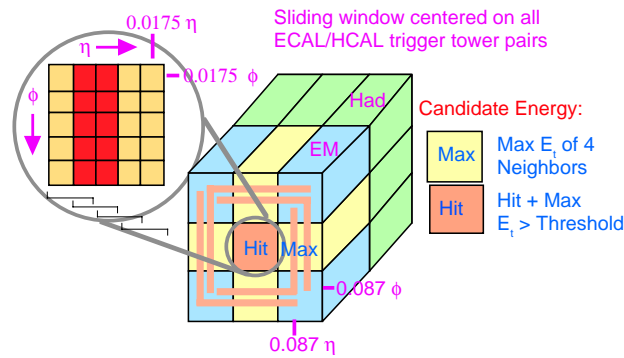


Fig. 1. The Level-1 electron/photon trigger algorithm. The candidate E_T is the sum of the central TP (orange) and highest E_T TT from the 4 broadside neighbours (yellow). The Fine Grain profile (left box) and the ratio with HCAL TT energy H/E (green) are used as vetoes while the quiet corners (orange) are used to separate isolated from non-isolated candidates. The HCAL TTs are aligned with the ECAL TTs in pseudorapidity.

(VPT) light detectors in the EB and EE respectively. A Preshower detector (ES), based on silicon sensors, is placed in front of the endcap crystals to aid particle identification. The ECAL is highly segmented, radiation tolerant and has a compact and hermetic structure, covering the pseudorapidity range to $|\eta| < 3.0$. Its target resolution is 0.5% for high-energy electrons/photons. It provides excellent identification and energy measurements of electrons and photons, which are crucial to searches for many new physics signatures. In the EB, 5 strips of 5 crystals (along the azimuthal direction) are combined into trigger towers (TTs) corresponding to a 5×5 array of crystals. The arrangement in the EE is similar but more complicated due to the X-Y layout of the crystals. The transverse energy (E_T) detected by the crystals in a single TT is summed into a trigger primitive (TP) by the front-end electronics and sent to off-detector Trigger Concentrator Cards (TCCs) via optic fibres.

2.2 Electron/Photon trigger path and algorithm

The TCCs forward groups of TPs to the Regional Calorimeter Trigger (RCT), which in turn combines pairs of TPs into L1 trigger candidates in each region of interest (4×4 TT). The Global Calorimeter Trigger (GCT) then sends the four most energetic candidates to the Global Trigger (GT), which generates the final L1 decision by applying E_T threshold cuts (named EG thresholds in the case of ECAL-based candidates). The electron/photon algorithm is based on a 3×3 trigger tower sliding window as shown in Figure 1. The E_T of an electron/photon candidate corresponds to the central TP of the sliding window summed with the largest deposit in one of its 4 neighbour towers adjacent by side. Electromagnetic showers being characterized by a compact lateral extension, candidates must have their central tower containing 2 adjacent strips with a significant fraction of the tower E_T (typically 90%). This criterion characterized by 1 bit is called the Fine Grain (FG) veto bit that is enabled only for candidates with $E_T > 4$ GeV. Moreover, the associated HCAL energy contribution is required to be below a threshold (typically $H/E < 5\%$ only for the central tower and for candidates with $E_T > 2$ GeV). Non-isolated electron/photon candidates require passing the previous criteria. In addition, the isolated candidates must have a quiet neighbourhood characterized by at least five adjacent TT among the 8 nearest ones with their transverse energy below a threshold of 3.5 GeV.

3 Online anomalous signals and their suppression

Anomalous signals were observed in the EB shortly after collisions began in the LHC: these were identified as being due to direct ionization within the APDs on single crystals, thus producing fake

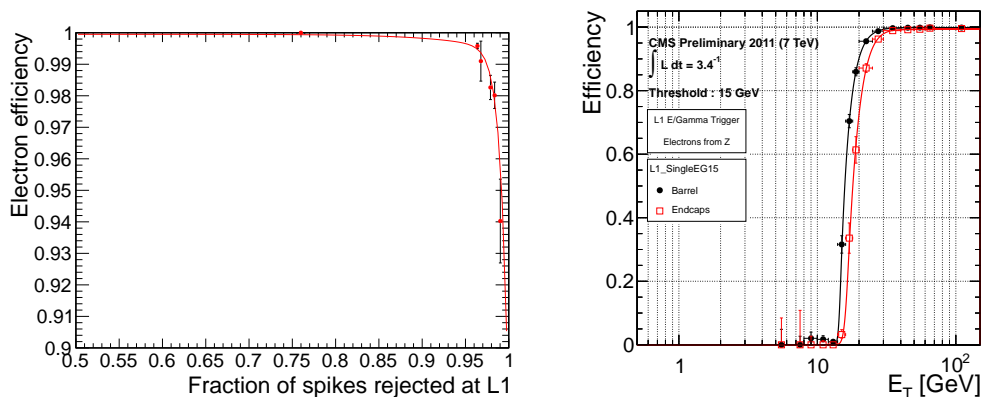


Fig. 2. (a) Electron efficiency as a function of the spike rejection at L1 (spike removal “sFGVB” threshold set to 258 MeV; “killing threshold” set to 8 GeV). (b) Electron trigger efficiency at L1 (“EG” threshold : 15 GeV E_T), as a function of E_T for electrons in the ECAL Barrel (black dots) and Endcaps (red dots). An unbinned likelihood fit was used.

isolated signals, with high apparent energy. These “spikes” can induce large trigger rates at both L1 and HLT if not removed from the trigger decision. On average, one spike with $E_T > 3$ GeV is observed per 370 minimum bias triggers in CMS at $\sqrt{s} = 7$ TeV. If untreated, 60% of the EM trigger candidates, above an EG threshold of 12 GeV, would be caused by spikes. At high luminosity these would be the dominant component of the 100 kHz CMS L1 trigger rate band width [4].

In the CMS ECAL the energy of an electromagnetic (EM) shower is distributed over several crystals, with up to 80% of the total energy in a central crystal (where the electron/photon is incident) and most of the remaining energy in the four adjacent crystals. This lateral distribution can be used to discriminate spikes from EM signals. A “Swiss-cross” topological variable $s = 1 - E_4/E_1$ (E_1 : E_T of the central crystal; E_4 : summed E_T of the 4 adjacent crystals) has been implemented offline to serve this purpose. A similar topological variable has also been developed for the on-detector electronics: the “strip Fine Grain Veto Bit” (sFGVB). Every TP has an associated sFGVB that is set to 1 (signifying a true EM energy deposit) if any of its 5 constituent strips has at least two crystals with E_T above a programmable “sFGVB threshold”, of the order of a few hundred MeV. If the sFGVB is set to zero, and the trigger tower E_T is greater than a “killing threshold”, the energy deposition is considered spike-like. The trigger tower energy is set to zero and the tower will not contribute to the triggering of CMS for the corresponding event. A detailed emulation of the full L1 chain has been developed in order to optimize the two thresholds.

In order to determine the removal efficiency, data were taken without the sFGVB or killing thresholds active. Spike signals identified offline (with the “Swiss cross”) were then matched to L1 candidates in the corresponding RCT region and the emulator used to evaluate the fraction of L1 candidates that would have been eliminated. In a similar fashion the efficiency for triggering on real electrons/photons could be estimated.

Three killing thresholds have been emulated ($E_T = 8, 12, \text{ and } 18$ GeV), combined with six sFGVB thresholds (152, 258, 289, 350, 456, 608 MeV). Figure 2 shows the electron efficiency (fraction of electrons triggered after spike removal) versus the L1 spike rejection fraction, for all sFGVB thresholds mentioned above (one point for each threshold value) and a killing threshold of 8 GeV. The optimum configuration was chosen to be an sFGVB threshold of 258 MeV and a killing threshold of 8 GeV. This corresponds to a rejection of 96% of the spikes, whilst maintaining a trigger efficiency for electrons above 98%. With these thresholds the efficiency for higher energy electrons is even larger: 99.6% for electrons with $E_T > 20$ GeV. This optimized configuration was tested online at the beginning of 2011. It gave a rate reduction factor of about 3 (for an EG threshold of 12 GeV), and up to a factor of 10 for E_T sum triggers (which calculate the total EM energy in the whole calorimeter system).

4 Performance of the Level-1 electron/photon trigger

The trigger efficiency has been measured with electrons from $Z \rightarrow ee$ events, using a tag and probe method. The tag electron is required to trigger the event at L1. The probe electron is used for the efficiency studies. Both tag and probe electrons are required to pass tight identification and isolation cuts. The triggering efficiency is given by the fraction of probes which trigger a given EG threshold, as a function of the probe E_T . In order to trigger, the location of the highest energy trigger tower within the electron supercluster must match a corresponding region of an L1 candidate in the RCT.

The trigger efficiency curves are shown in Figure 2 for an EG threshold of 15 GeV. The transverse energy on the x-axis is obtained from the fully reconstructed offline energy. In the EE this energy includes the preshower energy that is not available at L1. As a consequence the trigger efficiency turn-on point for the EE is shifted to the right with respect to the EB. For both EB and EE, corrections for crystal transparency changes are not currently available at L1, which further affects the turn-on curve. The width of the turn-on curves is partly determined by the coarse trigger granularity, since only pairs of trigger towers are available for the formation of L1 candidates, which leads to lower energy resolution at L1. In the EE the material budget in front of the detector causes more bremsstrahlung which, together with the more complex trigger tower geometry in the EE, causes the turn-on curve to be wider than that for the EB. The main sources of inefficiency are caused by masked regions (noisy or faulty : 0.2% in the Barrel and 1.3% in the Endcaps), giving a plateau of 99.7% in the EB and 98.8% in the EE. The effect on efficiency of the L1 spike removal has been verified to be negligible, but this will require further optimization as the number of collisions per bunch crossing increases in the future.

5 Conclusion

Over the course of 2011 the instantaneous luminosity provided by the LHC has increased from about $10^{30} \text{cm}^{-2} \text{s}^{-1}$ to more than $4 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$. Optimizing the electron/photon trigger performance, including the rejection of spikes, has been a major challenge. A reprogramming of the front-end electronics and ECAL TCC has allowed the implementation and optimization of a spike killer at L1, which rejects a majority of spikes (>96%) whilst having a negligible impact on electron/photon triggering efficiency. The results presented here display excellent overall performance of the electron/photon trigger and demonstrate the flexibility of this system.

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