PROCEEDINGS OF SCIENCE

CMS Level-1 Electron/Photon trigger performance

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Since March 2010 the Large Hadron Collider (LHC) has provided high energy proton collisions with an instantaneous luminosity that has risen by several orders of magnitude to around $4 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at the end of 2011 corresponding to millions of collisions per second. With this unprecedented collision rate, efficient triggering on electrons and photons has become a major challenge for LHC experiments. The Compact Muon Solenoid (CMS) experiment uses a two-level trigger system. The first level (L1) is based on coarse information coming from calorimeters and muon detectors, accepting up to 100kHz of events per second. A High-Level Trigger (HLT) then combines fine-grain information from all sub-detectors to reduce this rate further to about 200-300Hz. At L1 the electron/photon trigger 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 optimization and performance of this system in terms of electron and photon triggering efficiency are presented.

The 2011 Europhysics Conference on High Energy Physics-HEP 2011,
July 21-27, 2011
Grenoble, Rhône-Alpes France

PoS(EPS-HEP2011)407

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1. Introduction

The Compact Muon Solenoid (CMS) has been designed to study proton-proton and heavy-ion collisions produced by the Large Hadron Collider (LHC) in order to search for signs of new particles and processes, such as the Higgs boson - thought to be responsible for electroweak symmetry breaking in the Standard Model [1]. The cross-sections for production of postulated particles (such as the Higgs boson) are extremely small when compared to the huge cross-section of QCD-induced background processes. From the millions of collisions produced per second only 100-300 events per second can be stored offline. This means that the trigger system, that selects the collisions most likely to contain new physics, has to be highly performant.

Within the CMS data acquisition architecture [2], the trigger system is organized in two consecutive steps [3] : the Level-1 (L1) trigger, based on coarse information from the calorimeters and the muon systems (output rate maximum 100 kHz), followed by the High-Level Trigger (HLT), implementing precise selection algorithms (in commercial PCs) based on finer granularity and higher resolution information provided by all CMS sub-detectors in regions of interest identified at L1 (output rate of 100-300 Hz).

The CMS electromagnetic calorimeter (ECAL) measures the energies and positions of incident electrons and photons, which are used for both triggering and offline analysis purposes. 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. The ECAL and L1 trigger hardware

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 (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 from $|\eta| < 3.0$. 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. 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).

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 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 a transverse energy threshold of 12 GeV, would be caused by spikes. At high luminosity these would be the dominant component of the 100kHz CMS L1 trigger rate band width [4].

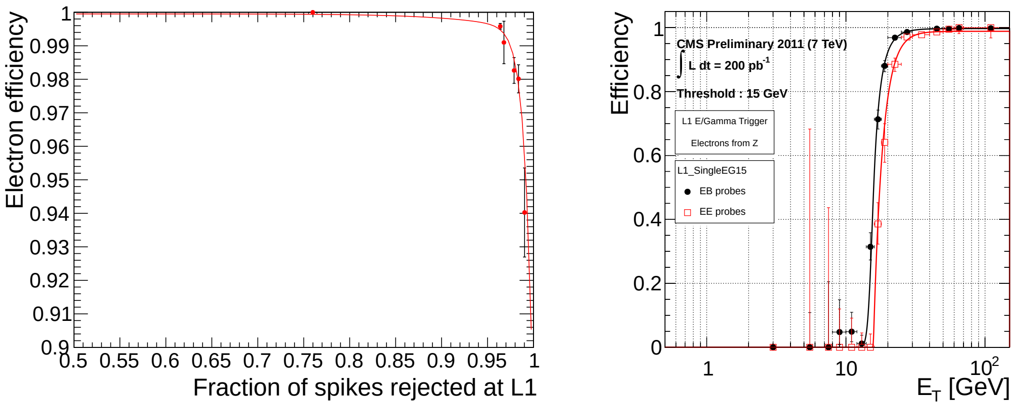
In the CMS ECAL the energy of an electromagnetic (EM) shower is distributed over several crystals, with up to 80% of the total energy in a central crystal (where the electron/photon is incident) and most of the remaining energy in the four adjacent crystals. This lateral distribution can be used to discriminate 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.

As the sFGVB threshold is a single value, the electron/photon efficiency depends upon the particle energy: the higher the threshold, the more low-energy real EM deposits would be initially flagged as spikes. However, these fake spikes may not pass the killing threshold energy so they would still be accepted. With a very low sFGVB threshold, spikes could be accepted due to neighbouring crystals having noise. A detailed emulation of the full L1 chain has been developed in order to optimize the two thresholds - to remove as large a fraction of the anomalous signals as possible whilst maintaining excellent efficiency for real electron/photon signals.

In order to determine the removal efficiency, data were taken without the sFGVB or killing thresholds active. Spike signals identified offline 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, and 18 GeV), combined with six sFGVB thresholds (152, 258, 289, 350, 456, 608 MeV). Figure 1(a) 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). This configuration has been used during all 2011 data taking. The electron efficiency and spike killing fraction have been maintained throughout, thus securing the effective L1 bandwidth despite the large changes in instantaneous luminosity.



(a) (b)

Figure 1: (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)

4. L1 electron/photon performance

The trigger efficiency has been measured with electrons from Z→ee events, using a tag and probe method in order to obtain a pure electron sample. The tag electron is required to trigger the event at L1. The second, or 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 1(b) 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 which 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 $10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ to more than $4 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. 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.

References

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