PROCEEDINGS OF SCIENCE

The Level-1 CMS Electron and Photon Trigger for the LHC Run II

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The CMS experiment implements a sophisticated two-level triggering system composed of the Level-1, instrumented by custom-design hardware boards, and a software High Level Trigger. A new Level-1 trigger architecture with improved performance is now being used to maintain high physics efficiency for the more challenging conditions experienced during Run II. The upgraded trigger benefits from an enhanced granularity of the calorimeters to optimally reconstruct electromagnetic objects. The performance of the new trigger system is presented, based on proton-proton collision data collected in 2017. We highlight the performance of the upgraded CMS electron and photon trigger in the context of Higgs boson decays into final states with photons and electrons. The selection techniques used to trigger efficiently on these benchmark analyses are presented, along with the strategies employed to guarantee efficient triggering for new resonances and other new physics signals involving electron and photon final states.

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1. Introduction

1.1 The CMS Detector

The Compact Muon Solenoid (CMS) detector, operating at the LHC (CERN, Switzerland), has been designed to study proton-proton and heavy ion collisions produced by the LHC at $\sqrt{s} = 14$TeV primarily to search for new particles and physics processes. The search for new physics crucially relies on the performance of the trigger system used to select the most interesting collisions amongst the millions occurring per second.

1.2 The CMS Electromagnetic calorimeter (ECAL)

The CMS Electromagnetic calorimeter (ECAL) is a hermetic system designed for measuring precisely the energies of electrons and photons. The CMS ECAL, composed of a barrel (EB) and two endcaps (EE), comprises 75848 lead tungstate ($PbWO_4$) scintillating crystals equipped with avalance photodiode (APD) or vacuum phototriode (VPT) light detectors in the EB and EE respectively. The Level-1 (L1) e/γ trigger is based on trigger towers (TT) of the ECAL and the hadronic calorimeter (HCAL).

1.3 CMS Trigger System

The CMS Detector has a sophisticated two-level trigger system that reduces the input data rate by a factor of 10^5. The CMS Trigger is designed for a fast selection of interesting physics events. The L1 trigger is implemented in custom hardware and its inputs are the data from the calorimeters and muon systems. It reduces the rate from about 40MHz to 100kHz, while its latency is 3.8 μs. The High Level Trigger (HLT) runs on a massive computer farm and uses refined algorithms, exploiting the full detector granularity. The output rate of the HLT is about 1kHz and its latency is 200 ms.

2. L1 e/γ Trigger Algorithm

Sophisticated algorithms have been developed in order to benefit from the capabilities offered by the trigger architecture.

2.1 Identification of e/γ candidates

- **Dynamic clustering around a seed trigger tower (TT)**:
  Clusters of towers (see Fig.1) are built from a seed tower with neighbours dynamically clustered with it. Seed tower is the trigger tower with local energy maximum and $E_T \geq 2$GeV, while neighboring energy deposits with $E_T \geq 1$GeV added to seed to form a cluster. The energy inside the cluster provides refined position of the e/γ candidate.

- **Calibration**:
  The energy correction is computed from a Look-Up-Table (LUT) with E_T, η and shape as inputs.

- **Fine-Grain veto (FG)**:
  This method uses the energy distribution within the seed TT to reject e/γ candidates with a shower profile not compatible with the electromagnetic objects.
- **H/E requirements**:
  This cut is based on the E_T^{HCAL}/E_T^{ECAL} ratio for the seed TT. It is optimized to give high efficiency for Tag & Probe selected electrons.
- **Extended H/E**:
  It extends the H/E criteria (described above), by including neighboring towers that are used in clustering. Using this extension, the loss of efficiency is minimal, while the rate dicreases about 20%.
- **Shape identification**:
  This algorithm exploits the full granularity of the e/γ cluster. It is based on LUT with E_T, η and cluster shape as inputs. It has been designed to have increasing efficiency with E_T and it is fully relaxed for $E_T \geq 70$GeV. Using this method, the jet-like cluster shapes are excluded while the efficiency on e/γ candidates reaches 99.5% (Fig.2).

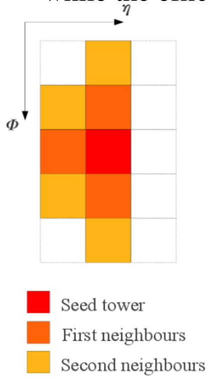

Figure 1: The L1 e/γ clustering. A candidate is formed by clustering neighbour towers (orange and yellow) if they are linked to the seed tower (red).

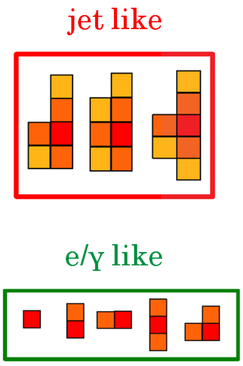

Figure 2: Examples of cluster shapes. Shape veto is used to exclude jet-like candidates.

2.2 Isolation

The L1 Isolation for e/γ is essentially a cut on energy in an isolation region around the cluster: $\mathbf{E_{6x9}} + \mathbf{H_{6x9}} - \mathbf{E_{2x5}} - \mathbf{H_{1x2}} < \mathbf{Iso.cut}$, where $\mathbf{E_{nxm}}$ and $\mathbf{H_{nxm}}$ are the energy deposits on ECAL and HCAL respectively in a **nxm** window of TTs around the cluster. The isolation cut (**Iso.cut**) value depends on E_T, η and a pile-up estimator. Pile-up is estimated from the number of TTs with $E_T \geq 0$ in the central calorimeter. The Isolation is implemented as a LUT. Two Isolation working points are used and correspond to two different relaxation schemes (Loose, Tight), as a function of E_T.

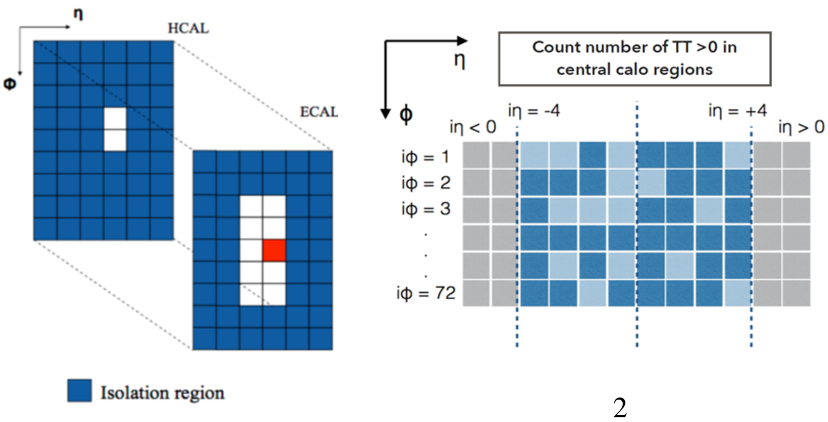

Figure 3: Left: A L1 e/γ candidate is considered as isolated if the E_T in the isolation region (blue) is smaller than a given value. Right: Pile-Up level is estimated using number of TTs with $E_T > 0$ and $-4 \leq i\eta \leq 4$.

3. Performance of the L1 e/γ Trigger in 2017 data

3.1 Efficiency

The Level-1 trigger efficiency is evaluated for e/γ objects used to seed the SingleElectron High Level Trigger. It is computed with the Tag & Probe method as a function of the offline-reconstructed e/γ transverse energy. Two isolation criteria are applied at Level-1: Loose and Tight Isolation. The efficiency reaches high plateau while its sharp increase reflects good energy resolution (Fig.4). Combination of thresholds (Fig.5) increases the acceptance for equal total rate. Using isolation, the efficiency versus pile-up is high and robust (Fig.6). Loose Isolation increases the efficiency at low E_T; It is used for Cross Triggers, e.g. isolated e/γ plus μ, τ or missing E_T (Fig.7).

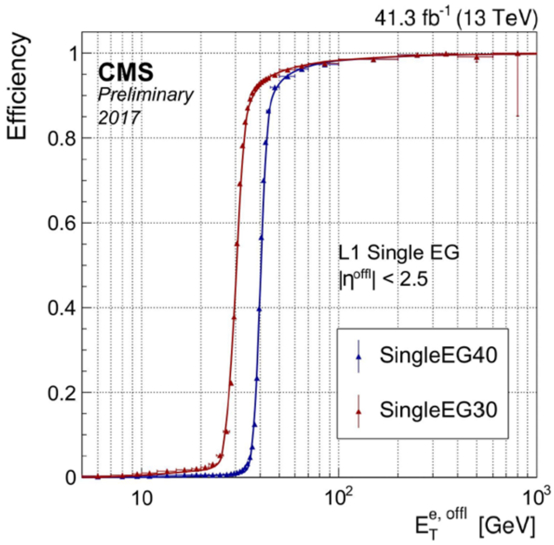

Figure 4: L1 trigger Efficiency curves as a function of the offline supercluster transverse energy for E_T threshold of 40 (blue) and 30 (red) GeV.

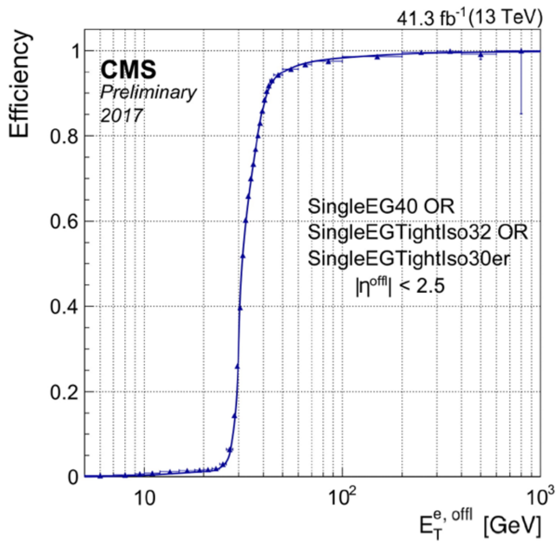

Figure 5: L1 trigger Efficiency curve drawn for a SingleEG strategy present at L1: e/γ with $E_T > 40$GeV without isolation OR e/γ with $E_T > 32$GeV and Tight Isolation OR e/γ with $E_T > 30$GeV, tight isolation and $|\eta|$<2.1 .

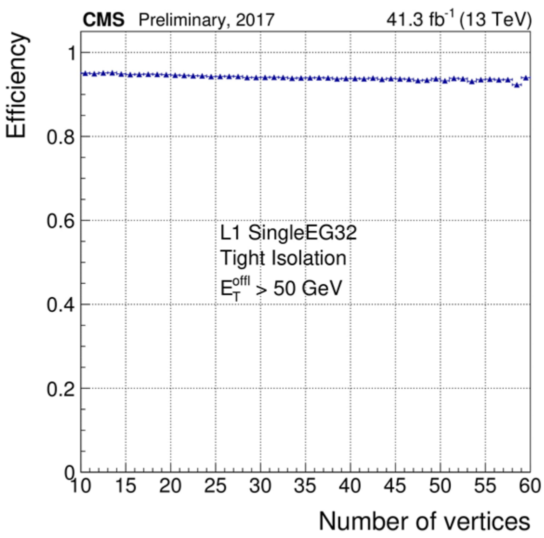

Figure 6: L1 trigger Efficiency versus pile-up. Tight isolation and a trigger threshold of $E_T > 32$GeV are applied.

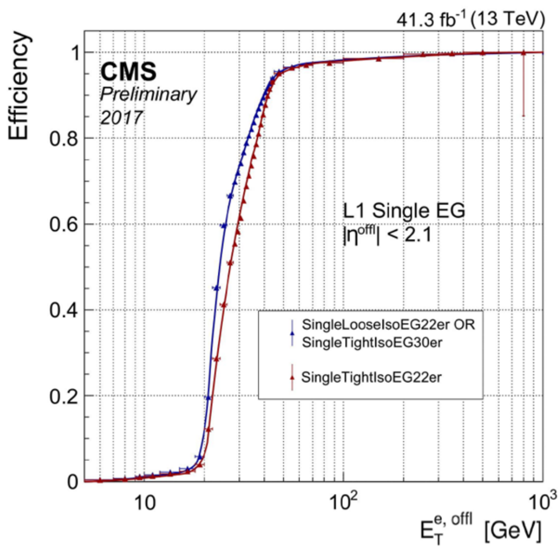

Figure 7: L1 trigger Efficiency curves using Tight and Loose isolation with η restriction ($|\eta| < 2.1$).

3.2 Resolution

The resolution for azimuthal angle (Fig.8) and pseudo rapidity (Fig.9) between the L1 e/γ candidates and the offline reconstructed electrons is high for both barrel and endcaps. The energy resolution (Fig.10) is computed with respect to the transverse energy of the offline electron supercluster. The asymmetry on the barrel is due to the Bremsstrahlung radiation, which increases with η. For the endcap, the Bremsstrahlung radiation is emitted in the same direction as the e/γ candidate, since it spirals towards the detector. The profile of the energy resolution as a function of η (Fig.11) is expected due to the increase of the material budget in front of the calorimeter peaking in the region between the barrel and the endcap. For higher η, the corrections to the change of crystal responses are more consequent due to the radiations induced by the intense LHC running conditions. The ECAL Front End electronics is also subject to higher noise in this particular region.

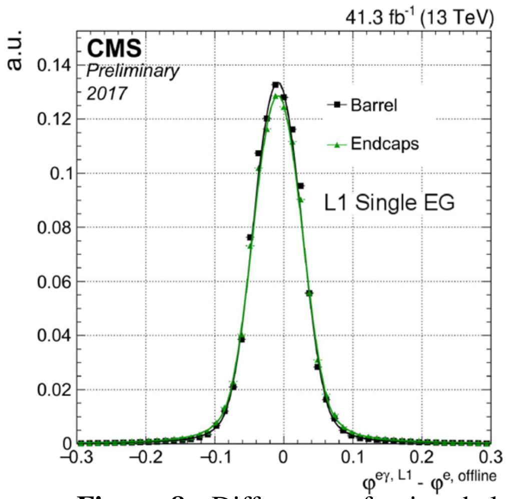

Figure 8: Difference of azimuthal angle between the L1 e/γ candidates and the offline reconstructed electrons.

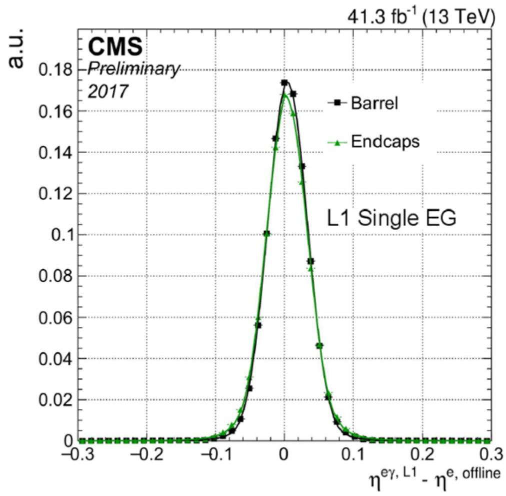

Figure 9: Difference of pseudo rapidity between the L1 e/γ candidates and the offline reconstructed electrons.

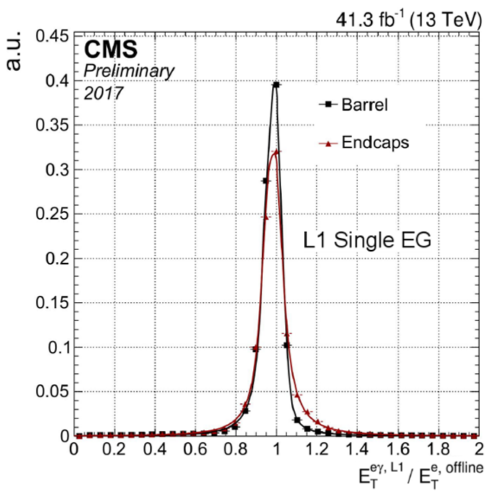

Figure 10: Transverse energy for L1 e/γ candidates with respect to the offline supercluster transverse energy.

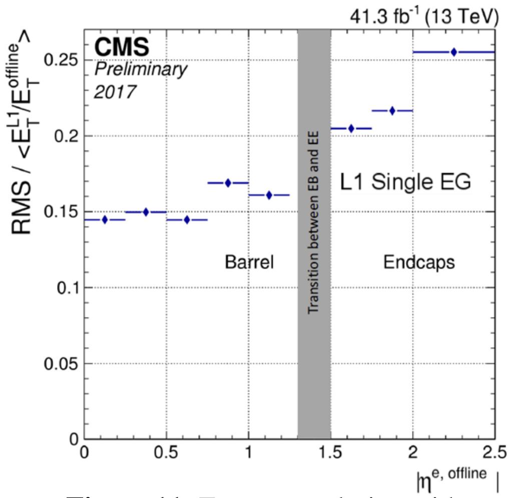

Figure 11: Energy resolution with respect to offline electrons as a function of the η of the electron supercluster.

4. Conclusion

The CMS Level-1 trigger for electrons and photons has delivered very high performance at the high luminosity and associated pile-up conditions of 2017.

References

[1] CMS Collaboration, *CMS technical design report for the Level-1 Trigger Upgrade*, CERN-LHCC-2013-011, CMS-TDR-012 (2013)

[2] CMS Collaboration, *Level-1 E/Gamma performance on 2017 data*, CMS DP-2018/003 (2018)

[3] CMS Collaboration, A.Zabi, *The CMS Level-1 Calorimeter Trigger for LHC Run II*, CMS-CR-2016-360 (2016)