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Electron and Photon High Level Trigger in CMS for Run II

Simon REGNARD[*†]
École polytechnique / CNRS-IN2P3, Palaiseau, France
E-mail: simon.regnard@cern.ch

The CMS experiment has been designed with a two-level trigger system. The first level is implemented on custom-designed electronics. The second level is the so-called High Level Trigger (HLT), a streamlined version of the CMS offline reconstruction software running on a computer farm. For Run II of the Large Hadron Collider, the increase in center-of-mass energy and luminosity will raise the event rate to a level challenging for the HLT algorithms. New approaches have been studied to contain the HLT rate within the available bandwidth while keeping thresholds low enough to cover the requirements of the physics analyses. The strategy mainly relies on porting online the improvements that have been applied to the offline reconstruction, thus allowing to move HLT selection closer to offline cuts. We present such changes in the definitions of HLT electrons and photons, focusing in particular on the deployment of a new clustering algorithm allowing pileup mitigation, a new Particle-Flow based isolation replacing the detector based method used in Run I, and an electron-dedicated track fitting algorithm based on a Gaussian Sum Filter.

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[*]Speaker.
[†]on behalf of the CMS Collaboration

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Introduction

Efficient triggering of electrons and photons down to low p_T values has been an important ingredient of some CMS achievements in Run I of the Large Hadron Collider (LHC), such as the discovery of the Higgs boson [1]. In Run II, as of 2015, with the increase to $\sqrt{s} = 13$ TeV of the center-of-mass energy and the halved bunch spacing, the CMS HLT will face a twofold challenge. First, the overall physics rate will increase by a factor of 4 while the HLT output rate can at best double, staying below 1 kHz. Second, the average number of pileup events per bunch crossing will reach about 45 at the peak luminosity of 1.6×10^{34} cm^{-2}s^{-1} and be aggravated by out-of-time pileup from different crossings. The strategy to keep low p_T trigger thresholds for electrons and photons relies on porting to HLT the algorithms that were successful in the offline reconstruction, thus allowing to move the HLT selection closer to offline. Three such algorithms are presented below. The CMS detector is described in detail in reference [2].

1. Particle Flow clustering

Clustering algorithms collect the energy of electrons and photons, which is usually spread in several crystals of the electromagnetic calorimeter (ECAL). In the framework of Particle Flow (PF) reconstruction [3], an new iterative clustering has been developed. It finely handles energy overlap between crystals, enabling to reconstruct individual showers, and improves the performance for low-energy clusters and robustness against pileup. A superclustering procedure then uses the PF clusters to recover possible additional bremsstrahlung and photon conversion products.

The CMS HLT is flexible enough to accomodate this powerful algorithm in a limited time budget. The main motivation is the synchronization of the reconstruction flow with offline, in particular the cluster shape observables used in electron and photon identification. The efficiency of PF superclustering at HLT is shown to remain very similar to the previous algorithm (Figure 1, left).

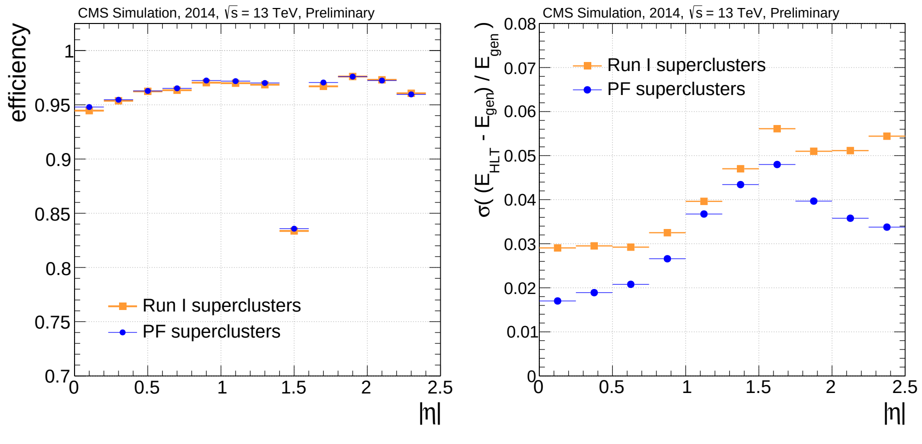

Figure 1: Efficiency of the HLT superclustering algorithm on electrons of $p_T > 5$ GeV (left, including L1 efficiency) and energy resolution of HLT electron superclusters (right), as a function of supercluster pseudorapidity. Particle Flow (PF) superclustering is compared to the algorithm used in Run I. Electrons from $Z \to ee$ events at $\sqrt{s} = 13$ TeV, $\langle PU \rangle = 40$, bunch spacing 25 ns. Superclusters are required to match ($\Delta R < 0.1$) a generated electron from the Z decay.

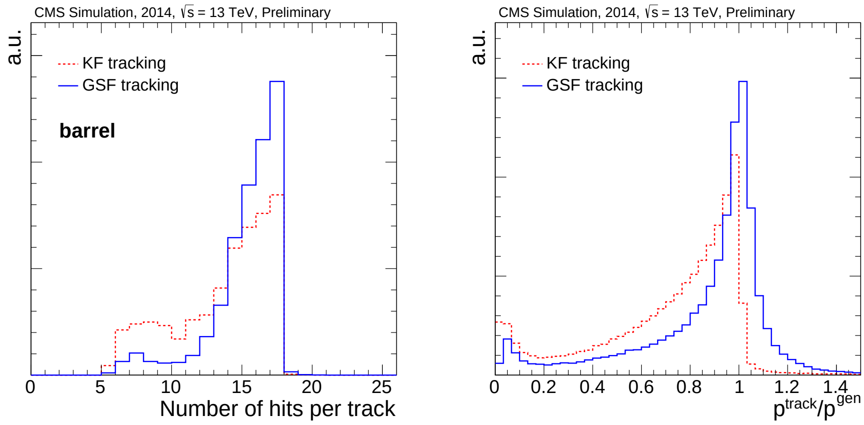

Figure 2: Number of reconstructed hits per track in the barrel (left) and ratio between the reconstructed track momentum and the generated one (right) for electrons tracks at HLT. Distributions are shown for tracks reconstructed with the Gaussian Sum Filter and the Kalman Filter. Similar selection as in Figure 1.

Most importantly, the energy resolution of PF superclusters will benefit from new regression-based energy corrections. Figure 1 (right) displays the improvement obtained with offline corrections, but a dedicated training is planned for the HLT.

2. GSF tracking

Electrons have unique tracking challenges in CMS, because they often radiate bremsstrahlung photons in the silicon tracker before reaching the ECAL. Since this energy loss cannot be modelled with a single Gaussian distribution, the Kalman Filter (KF) [4] used in Run I for HLT electrons is not optimal. An electron-dedicated method based on the Gaussian Sum Filter (GSF) [5] has thus been ported to HLT. First, track hits are collected with a relaxed χ^2, to better accomodate deviations due to bremsstrahlung (Figure 2, left). Then, in the final fit, the energy loss is approximated as a sum of Gauss functions with well-chosen means, widths, and relative amplitudes, used to propagate a set of weighted components instead of a single trajectory. This improves the estimation of the electron momentum (Figure 2, right) and position. Tests performed on 8 TeV data showed that GSF tracking at HLT provides a 25 % rate reduction with respect to KF tracking, for a similar efficiency.

3. Particle Flow isolation

In Run I, CMS has been using different isolation techniques to discriminate prompt electrons and photons from those arising from hadronic processes. Detector isolation, which was used at HLT, is defined as the sum of calorimeter deposits and track transverse momenta in a geometrical cone of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.3$ around the electron or photon direction at the interaction vertex. In most physics analyses, PF isolation is used instead, whereby the transverse momenta of individual charged and neutral PF candidates are summed. This approach better handles detector noise and allows the removal of the electron or photon energy in a way consistent with the PF framework. For the Run II HLT, a simplified PF-based setup has been implemented: the time-consuming PF reconstruction is not run, since using PF intermediary products such as PF clusters

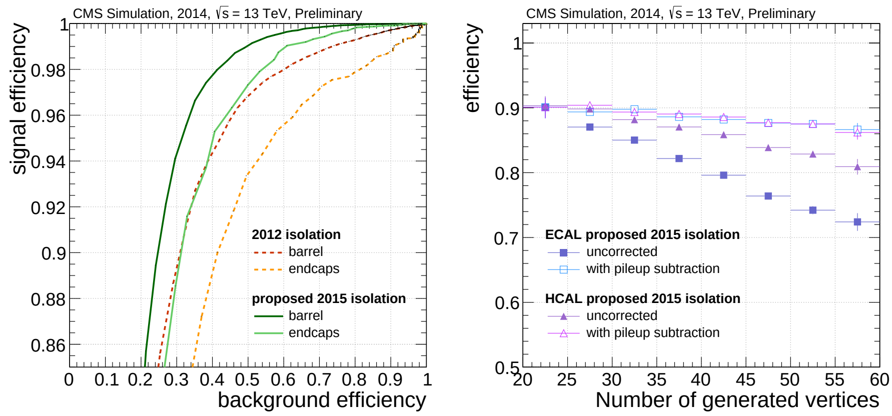

Figure 3: (Left) Performance curves of pileup-corrected electron isolation at HLT, comparing the detector based setup used in Run I to the simplified PF-based method. (Right) Signal efficiency of the latter method in the barrel, with and without pileup subtraction, with working points adapted for illustration purposes. The signal selection is similar to Figure 1, while background objects are triggered from a QCD sample.

and tracks already provides a neat performance gain with respect to the less tuned detector setup of Run I (Figure 3, left).

As isolation is known to be very sensitive to in-time and out-of-time pileup, a pileup subtraction strategy was also ported to HLT. It relies on the FastJet technique [6], where the contribution of pileup in the cone is defined as the product between the median of the energy density distribution of neutral particles within the area of any jet in the event, and an effective area tuned separately for the barrel and the endcaps, so as to make the signal efficiency almost flat as a function of the number of pileup vertices (Figure 3, right).

Conclusion

A series of advanced reconstruction and selection techniques has been implemented in the CMS HLT, which will contribute to maintaining high triggering performance for electrons and photons in the challenging luminosity and pileup conditions of Run II data taking of the LHC.

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