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CMS electron and photon performance at $\sqrt{s} = 13$ TeV

Francesco Micheli on behalf of the CMS Collaboration[*]
ETH, Zurich
E-mail: `francesco.micheli@cern.ch`

The Compact Muon Solenoid (CMS) detector is one of the two multi-purpose experiments operating at the CERN Large Hadron Collider (LHC). Many aspects of its broad physics program depend on the ability to trigger, reconstruct and identify events with electrons and photons in the final state.
The full process of electron and photon reconstruction in CMS is presented in this contribution. Reconstruction algorithms, starting from tracker hits and energy deposits in the electromagnetic calorimeter, are described. Current identification algorithms are compared with the previous ones, focusing on the improvements achieved in obtaining the ultimate precision in Run II energy measurements.

Particular attention is given to the evolution of detector conditions and identification criteria towards the different years of data-taking. The contribution covers extensively the results from 2016 and 2017 dataset of LHC, with quick highlights from the ongoing 2018 data-taking.

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[*] Speaker.

1. Introduction

Having a well performing electron and photon reconstruction is crucial for the physics program of the Compact Muon Solenoid (CMS) experiment [1]. Indeed high energy photons or electrons are fundamental for checking the predictions of the standard model (SM) for particle physics and for the precise determination of the Higgs boson couplings. These particles are also fundamental for searches of particles predicted by theories beyond the standard model. The CMS Electromagnetic Calorimeter (ECAL) has a key-role in the identification of these particles. It is a homogeneous calorimeter of about 80 thousands lead tungstate (PbWO4) crystals. It is composed of a central section, the barrel (EB), while two endcaps (EE) cover the forward part. A photon or an electron appears in ECAL as an energy deposit which spreads out into several crystals (a "supercluster"). Since electrons are charged particles, their trajectory is also reconstructed in the multi-layer silicon tracker in front of ECAL. CMS developed reconstruction algorithms able to exploit the interplay between clustering and tracking in order to achieve the best energy resolution. These algorigthms recover secondary photons and electrons from bremsstrahlung and photon pair production.

The data-taking conditions for ECAL and the tracker changed throughout the different years of data-taking. In particular:

- Regarding ECAL, the 2016 dataset has been recently reprocessed with better understanding of ECAL low-level calibrations.
- Regarding the tracker, the pixel detector has been upgraded for the 2017 data taking.

These changes significantly improved the CMS detector's performance with a positive impact on all analysis selecting events with photons and electrons in the final state. The most important results are summarized in the next sections.

2. Results for 2016 dataset

As mentioned in the previous section, an improved description of ECAL low-level quantities has been implemented. In particular, a better description of ECAL pedestals and improved calibrations have been derived and included in the tuning of reconstruction algorithms. These improvements lead to better performance and a better agreement between data and simulations. This agreement is fundamental for the optimization of analyses and efficiency estimation. It also avoids additional sources of systematic uncertainties due to the mismodeling of the detector.

Fig. 2 shows the distribution of the width of the supercluster in pseudorapidity (η) for photons in the endcap coming from $Z \rightarrow \mu\mu\gamma$ decays. The distribution obtained with simulations is shown in blue, while real data are represented with open black markers. The comparison between the prompt reconstruction (left) and the final reconstruction (right) is shown. As can be seen from the ratio between the two distributions, shown at the bottom of the plot, the reprocessing has improved significantly the agreement between data and simulations.

3. Results for 2017 dataset

The pixel layers comprising the silicon tracker have been upgraded for the 2017 data taking [2]. The most important changes can be summarized as follows:

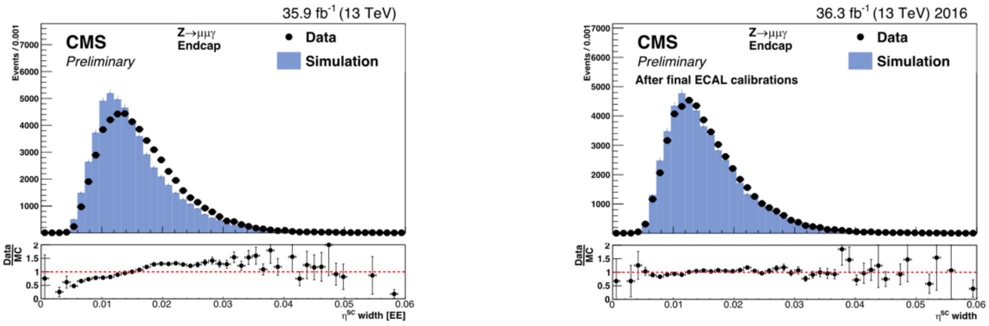

Figure 1: Distributions of η_{SC} width for electrons in the ECAL endcap. The left (right) plot shows the comparison between data and simulations before (after) the derivation of final corrections and calibrations.

- An additional 4th layer has been added to allow for a better electron seeding using quadruplets.
- The most external barrel layer has been moved closer to the strip detector to improve the extrapolation of tracks.
- The amount of material is reduced by moving electronic boards and services.

Fig. 3 (left) shows the material budget (normalized to the radiation length) for the tracker as a function of the pseudorapidity. The green histogram shows the detector present during 2016 data-taking, while the 2017 one is showed with black markers. It can be seen that, even with a detector with more layers and thus better resolution, the moving of services allows for less material budget in front of ECAL.

An important effect of the upgraded detector is a better reconstruction efficiency and a lowering of fake rate, i.e. particles misidentified as electrons. An increased reconstruction efficiency over the full E_T and η phase-space is observed with significant improvements in the low-E_T or high η region. Fig. 3 (right) shows the fake rate, measured on Drell-Yan simulated events after the reconstruction step without additional identification criteria. The plot shows the fake rate for low-p_T electrons as a function of the number of simultaneous interactions per bunch crossing. It can be seen, comparing the two years, that a significative reduction (of about 30%) is achieved in 2017.

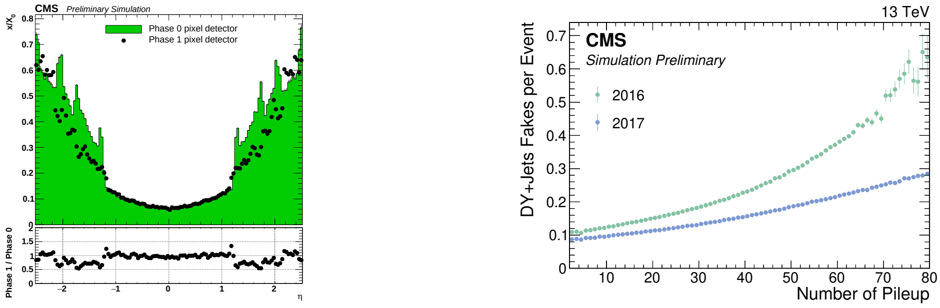

Figure 2: Left: Material budget in CMS tracker as a function of pseudorapidity (η) for different year of data-taking. Right: Fake-rate as a function of number of pile-up vertexes for 2016 and 2017 datasets.

After having reconstructed electrons and photons, identification selections are derived to separate real prompt electrons/photons from backgrounds (jets, conversions and non-prompt particles). Several selections are derived, with both multivariate (MVA) and cut-based approaches. Fig. 3 shows the background efficiency versus the signal efficiency for different selections derived on Drell-Yan events. The solid lines represent ROC curves for MVA-based selections while the points refer to the cut-based approach with different working points (corresponding roughly to 70%, 80% and 90% signal efficiencies). With respect to previous identification algorithms the 2017 ones use more advanced machine learning techniques (like hyperparameter optimization with XGBoost software [3]), are more robust against pile-up and more flexible.

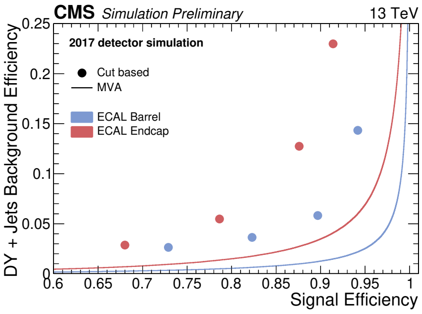

Figure 3: ROC curves and working points for MVA-based and cut-based identification selections.

4. Conclusion

A summary of results for photon and electron reconstruction with the CMS detector for the Run II of LHC has been presented. The results show excellent efficiency and good modelling of the detector resulting in good agreement between data and simulations.

For the 2016 dataset, a reprocessing with a better understanding of low-level ECAL calibrations has been described. For the 2017 dataset, it has been shown the presence of an upgraded pixel detector and the optimization of the techniques used for reconstruction and identification algorithms improved trigger, reconstruction and identification efficiency, despite the harsh experimental conditions. A first look at data collected in 2018 shows that CMS is performing as expected, further improvements are expected for the future re-optimizing and improving the current algorithms.

References

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[2] The CMS Collaboration, "CMS Technical Design Report for the Pixel Detector Upgrade", CERN-LHCC-2012-016. CMS-TDR-11, Sep 2012

[3] Tianqi Chen and Carlos Guestrin, "XGBoost: A Scalable Tree Boosting System", Proceedings of KDD '16. ACM, New York, NY, USA, 785-794. DOI: https://doi.org/10.1145/2939672.2939785