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Achieving the optimal performance of the CMS ECAL in Run II

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Many physics analyses using the Compact Muon Solenoid (CMS) detector at the LHC require accurate, high resolution electron and photon energy measurements. Particularly important are decays of the Higgs boson resulting in electromagnetic particles in the final state. Di-photon events in CMS are also a very important channel in the search for Higgs boson production in association with other particles or in the search for possible new resonances of higher mass. The requirement for high performance electromagnetic calorimetry therefore remains high during LHC Run II. Following the excellent performance achieved in Run I at a center of mass energy of 7 and 8 TeV, the CMS electromagnetic calorimeter (ECAL) started operating at the LHC in Spring 2015 with proton-proton collisions at 13 TeV center-of-mass energy. The instantaneous luminosity delivered by the LHC during Run II is expected to exceed the levels achieved in Run I, using 25 ns bunch spacing. The average number of concurrent proton-proton collisions per bunch-crossing (pileup) is expected to reach up to 40 interactions in 2016. These high pileup levels necessitate a retuning of the ECAL readout and trigger thresholds and reconstruction algorithms, to maintain the best possible performance in these more challenging conditions. The energy response of the detector must be precisely calibrated and monitored to achieve and maintain the excellent performance obtained in Run I in terms of energy scale and resolution. A dedicated calibration of each detector channel is performed with physics events exploiting electrons from W and Z boson decays, photons from π^0/η decays and from the azimuthally symmetrical energy distribution of minimum bias events. This paper describes the new reconstruction algorithm and calibration strategies that we have implemented to maintain the excellent performance of the CMS ECAL throughout Run II. We will show performance results from the 2015 and 2016 data taking periods and provide an outlook on the expected Run II performance in the years to come.

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1. Introduction

The CMS electromagnetic calorimeter (ECAL) [1] is a hermetic, homogeneous detector consisting of 61,200 $PbWO_4$ crystals in the barrel (EB), and 7324 crystals in each of the two endcap sections (EE). A short radiation length (0.89 cm), small Molière radius (2.2 cm) and high radiation resistance make $PbWO_4$ crystals the appropriate material for a compact calorimeter. Avalanche photodiodes (APDs) and vacuum phototriods (VPTs) are used to collect scintillation light in EB and EE, respectively. In addition, a preshower (ES) detector made of lead absorbers and silicon strip sensors is placed in front of EE to improve the identification of closely spaced photons from π^0 decays. The ECAL was crucial for the discovery of the Higgs boson through its diphoton decay mode and continues to play an important role in searches for new physics and precision standard model measurements in LHC Run II.

2. Energy reconstruction and calibration

For LHC Run II, the bunch spacing was reduced to 25 ns and the instantaneous luminosity increased by a factor of 2. The number of inelastic collisions per bunch crossing (pileup) has reached up to 40 in 2016. To maintain the good performance of ECAL, new reconstruction algorithms and calibration strategies have been implemented.

2.1 Energy reconstruction

The ECAL energy reconstruction works as follows. The pulse from each crystal is digitized by a 12 bit ADC running at 40 MHz and a set of 10 consecutive samples is recorded for amplitude reconstruction. During LHC Run I the amplitude was estimated as a weighted sum of the 10 samples. In Run II, an algorithm is used fitting multiple superimposed pulses with fixed template shapes ("multi-fit") to mitigate the out-of-time pileup and reconstruct the signal amplitude. The multi-fit algorithm estimates the in-time signal amplitude plus up to 9 out-of-time amplitudes by minimizing the χ^2 [2]. Examples of fitted pulses for simulated events in EB and EE with 20 average pileup interactions are shown in Fig. 1.

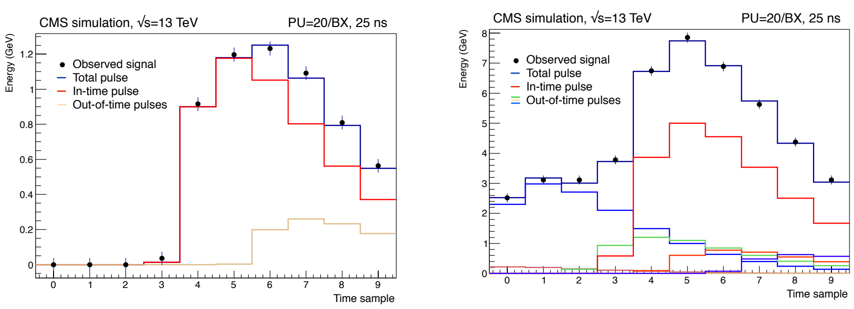

Figure 1: Examples of fitted ECAL pulses for signals in EB (left) and EE (right) with 20 pileup interactions. Dots represent the 10 digitized samples and the red distributions (other light colors) represent the fitted in-time (out-of-time) pulses. The dark blue histograms represent the sum of all the fitted contributions.

Electrons and photons usually deposit energy in several crystals. Moreover, the tracker material in front of the ECAL and the magnetic field cause the electromagnetic showers to spread along the ϕ direction. To measure the energy accurately, clustering algorithms are used to group crystals that contain deposits from the same electromagnetic shower. The shower energy can be estimated as:

$$E_{e,\gamma} = F_{e,\gamma} \cdot [G \cdot \sum_i S_i(t) \cdot C_i \cdot A_i + E_{ES}], \tag{2.1}$$

where the sum runs over all clustered crystals. The quantity A_i is the pulse amplitude, which is converted to a GeV scale by multiplying the calibration factor G, and $S_i(t)$ is a correction term that accounts for the time variations of the channel response with C_i being the inter-calibration factor. For showers in the EE the energy measured by the preshower (E_{ES}) is added. Finally, the energy correction term $F_{e,\gamma}$ is applied to take into account geometry and upstream material effects, as well as the difference between electron and photon showers.

2.2 Energy calibration

In-situ ECAL calibrations with physics events had been performed in Run I to improve the energy resolution [3]. During Run II, the calibration procedures remain the same, while triggers and data streams are optimized to maintain the best possible performance in the challenging conditions.

Response correction: Radiation causes a degradation in crystal transparency and VPT response. The transparency loss will partially recover in the absence of irradiation. The correction coefficients of the ECAL response changes are measured with a laser based light monitoring system and validated using the ratio of the ECAL energy to the track momentum (E/p).

Inter-calibration: The purpose of inter-calibration is to equalize the variations in channel response due to different crystal light-yield and photo-detector gains. The inter-calibration factors are measured using multiple methods, including the use of the azimuthal symmetry of energy deposit in minimum bias events, the diphoton invariant mass of π^0 and η^0 decays, the E/p ratio of electrons from W and Z decays, and the mass peak of Z $\rightarrow e^+e^-$ decays. The combined coefficient is obtained by taking the mean value of individual corrections weighted by their respective precisions. Fig. 2 shows the precisions of the inter-calibration constants for the 2015 data.

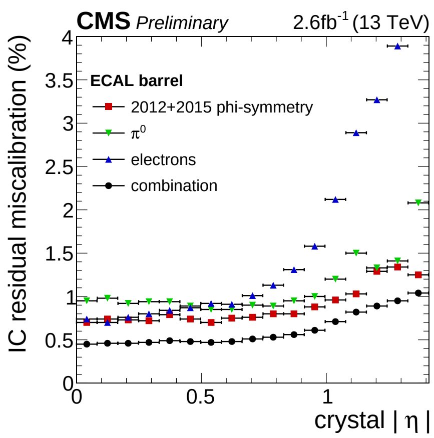

Figure 2: Precisions of the EB inter-calibration methods, as a function of pseudo rapidity, for the dataset recorded during 2015.

Energy scale calibration: The absolute ADC to GeV scale factor is determined separately in EB and EE using the Z $\rightarrow e^+e^-$ invariant mass peak, matching the reconstructed mass in data to that in simulation.

3. ECAL Run II Performance

The ECAL has been operating in stable conditions throughout the 2015 and 2016 LHC Run II operation. The analysis using 2.5 fb^{-1} collision data collected in 2015 shows that a relative energy resolution between 1.4-3% for electrons is achieved in EB, and 3-4% for EE. The resolutions for low and high bremsstrahlung electrons are shown in Fig. 3

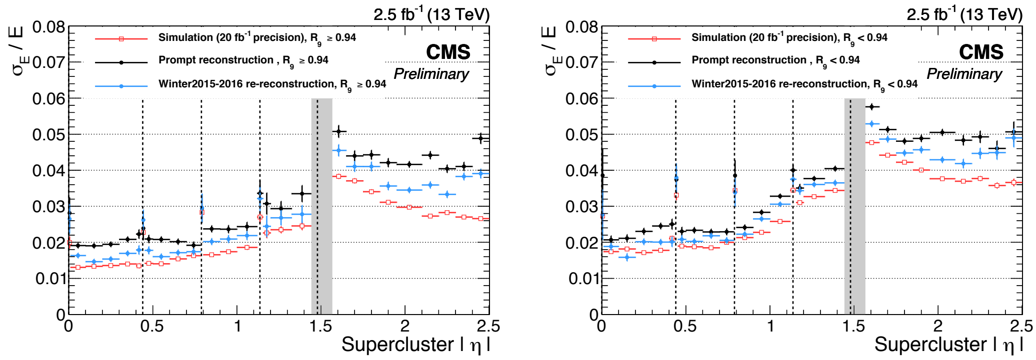

Figure 3: Relative electron energy resolution unfolded in bins of pseudo rapidity for the barrel and the endcaps using electrons from Z $\rightarrow ee$ decays. The resolution is shown for low (left) and high (right) bremsstrahlung electrons ($R_9 > 0.94$ and $R_9 < 0.94$ respectively, with $R_9 = E_{3x3}/E_{\text{Supercluster}}$).

4. Conclusion

To ensure an excellent performance of the CMS ECAL during the LHC Run II, new amplitude reconstruction algorithms and calibration strategies have been implemented to cope with the increased number of pileup interactions. The analysis using collision data collected in 2015 at $\sqrt{s} = 13$ TeV shows that ECAL has achieved excellent energy resolution during Run II operation.

References

[1] CMS Collaboration, *The CMS experiment at the CERN LHC*, *JINST 0803 (2008) S08004*

[2] Andrea Massironi, *Precision electromagnetic calorimetry at the highest energy and intensity proton-proton collider: CMS ECAL performance at LHC Run 2 and prospects for high luminosity LHC*, in proceedings of *IEEE NSS-MIC 2015*

[3] CMS Collaboration, *Energy calibration and resolution of the CMS electromagnetic calorimeter in pp collisions at $\sqrt{s}$ = 7 TeV*, *JINST 8 (2013) P09009* [hep-ex/1306.2016].