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CMS Electromagnetic Calorimeter status and
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Abstract. The Electromagnetic Calorimeter (ECAL) of the Compact Muon Solenoid (CMS)
detector will play a crucial role in new physics searches at the Large Hadron Collider (LHC) as well as in Standard Model precision measurements. The first LHC beams have been used to finalize the commissioning of ECAL read-out and trigger. The precision of the inter-channel synchronization and calibration has been verified and improved with in-situ data. The quality of the offline data reconstruction has been investigated with physics signals, in particular with di-photon states. A review of the CMS ECAL detector status and performance is presented in this note.

1. Introduction
The CMS detector is a multipurpose detector which will be used to perform precision Standard Model measurements and new physics searches [1]. The CMS ECAL plays a central role in the physics program of the CMS detector: ECAL was designed to have an outstanding electromagnetic energy resolution [2][3]. This is essential for particle searches such as the Higgs boson. For a low mass Higgs boson, \( m_H < 150 \) GeV, a promising decay channel for its discovery is the \( H \rightarrow \gamma\gamma \) channel which leads to a di-photon final state. A good di-photon mass energy resolution is essential to discriminate an expected signal with small cross section over a large and irreducible Standard Model background. The ECAL energy resolution was demonstrated to be \( \Delta E/E < 0.5\% \) for \( E > 100 \) GeV using electron testbeams [4].

The CMS ECAL is a homogeneous crystal calorimeter and consists of a barrel (EB) section and two endcaps (EE) made in total of 75848 PbWO\(_4\) crystals, with a 3 \( X_0 \) lead - silicon strip preshower (ES) detector in the endcap section. The calorimeter is immersed within the 3.8 T magnetic field, produced by the CMS magnet. The scintillation light is read-out by a pair of avalanche photodiodes (APDs) for each EB crystal and a vacuum phototriode for each EE crystal. The small Moliere radius \( (R_M \approx 2.19 \) cm\) in combination with the large number of crystals results in a fine granularity for the lateral shower shape. In the forward region the granularity is further improved by the preshower detector (ES) \(|1.65| < \eta < |2.6|\) which consists of 2 orthogonal planes of silicon strips. Each silicon sensor measures 63 \( \times \) 63 mm\(^2\), with an active area of 61 \( \times \) 61 mm\(^2\) divided into 32 strips (1.0 mm pitch).

2. Detector precalibration prior to LHC collisions
The ECAL was precalibrated prior to its installation inside the CMS detector. About 25\% (3\%) of the EB (EE) was intercalibrated with a precision of 0.5\% using electron beams. The rest of the

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ECAL detector was intercalibrated using a combination of precalibration data from laboratory measurements, cosmic stands and beam splash data, resulting in about $1 - 2\%$ precision in EB and about $5\%$ in EE. The energy scale was set by the testbeam and validated in-situ by measuring the cosmic muon stopping power in the PbWO$_4$ crystals [5]. Apart from the obtained energy precalibrations, these extensive tests also helped to accumulate large operational experience with the detector. After the first LHC collision in November of 2009, only few hours were needed in order to observe the first $\pi^0$ candidates (Fig. 1). The $\pi^0 \rightarrow \gamma\gamma$ decay is now part of the CMS online data quality monitoring and provides an important stream for further improvement of the detector intercalibration in-situ.

![ CMS Preliminary Data $\sqrt{s}=7$ TeV](image)

**Figure 1.** $\pi^0$ peak reconstructed in CMS data for 7 TeV center of mass energy collisions. About 1.5 M candidates are found for an integrated luminosity of about 0.43 nb$^{-1}$.

3. **Channel timing synchronization**
In September 2008 the LHC was running in single beam mode; the proton beam was stopped in a collimator about 150 m away from the CMS interaction point. These beam splashes produced an intense flux of muons crossing the CMS detector in the direction along the beam pipe. The response of the ECAL detector in LHC beam splashes was used to synchronize the detector. The hardware (online) synchronization was done with the granularity of a trigger tower (5 x 5 channels) in steps of 1.04 ns. The residual spread of the individual channels’ timing within a trigger tower was further reduced offline. Overall, an RMS spread at the level of 300 ps is achieved (Fig. 2). The ECAL timing resolution was assessed by comparing the timing of neighboring crystals belonging to the same cluster. The timing resolution was found in collision data to be less than 1 ns for energies above $E > 1$ GeV (Fig. 3).
4. Status of the detector during 2008-2010 running
The ECAL detector was operating continuously during 2008-2010 taking calibration, cosmic and collision data whenever possible. In total more than 99% of channels are fully functional for physics. Typically the channels which are excluded in the read-out are seen as white regions in the occupancy plots (Fig. 4, Fig. 6 and Fig. 5). A fraction of those channels have a broken data-link. However most of them can be recovered using the information of the trigger primitives. In total only $\sim 0.15\%$ of channels have neither data nor trigger information and are accounted as non functional regions of the detector.

5. Comparison of collision data and Monte Carlo (MC) simulation
Establishing agreement between data and MC at the level of a single ECAL crystal is a necessary step towards understanding and predicting physics backgrounds with the help of MC simulation. The MC detector noise model was extensively studied and developed prior to the LHC start-up benefiting from the knowledge of the energy intercalibrations and was tuned to reproduce the noise measured in-situ using pedestal runs.

The energy spectrum of the individual channels matches very well what is expected from the simulation of minimum bias collisions (Fig. 7). Apart from the energy distribution very good agreement is also observed in the azimuthal occupancy of the channel with the highest reconstructed transverse energy (Fig. 8). Variations as a function of $\phi$, fairly reproduced in MC, reflect modularity and the inhomogeneity of the energy equivalent noise in the ECAL.

The overall good agreement between data and MC reflects the level of understanding of the detector. In addition to the normal scintillation signals, some anomalous signals are observed in a small fraction of collision data with a rate about 1 per 1000 minimum bias events on 900 GeV collision data. These anomalous signals have a distinct pulse shape and are uniformly distributed in the EB while they are not seen in EE where the read-out is done by the VPTs. The origin of the anomalous signals appears to be mainly due to highly ionizing particles which give an
Figure 4. ECAL EB occupancy plots (mean energy per crystal) averaged over many LHC beam splash events. Energy modulations are a combination of the energy flow traversing CMS and geometry effects.

Figure 5. EE- occupancy plots (mean energy per crystal) averaged over many LHC beam splash events.

Figure 6. EE+ occupancy plots (mean energy per crystal) averaged over many LHC beam splash events.

Instantaneous charge deposition in the pre-amplification region of the APDs. These signals are not accompanied by a shower generation in the crystal’s body. They are efficiently suppressed by a quality selection such as the 1-E4/E1<0.95 where E1 is the energy of the seed crystal and E4 is the energy of the four crystals having a common face with the seeding crystal (Fig. 9).

Electron and photon objects used in physics analysis are reconstructed as clustered energy in the ECAL. An electromagnetic shower deposits its energy in several ECAL crystals; superclusters (clusters of clusters) of crystals extended along $\phi$ (bending direction) are used to
Figure 7. Energy spectrum in the individual EB channels. Data and MC correspond to the same integrated luminosity. Event quality and signal quality selections are applied.

Figure 8. Azimuth distributions of the EB channel with highest reconstructed transverse energy ($E_T$).

Figure 9. At the cluster level the anomalous signals appear as energy in a single crystal, while in electromagnetic showers the energy is typically shared between neighboring crystals. This fact is used to tag anomalous signals. E4/E1: ratio of the energy deposit in one crystal (E1) over the energy in the four crystals (E4) having a common face with this crystal.

reconstruct the electromagnetic energy. The number of expected super-clusters and their transverse energy ($E_T$) are in very good agreement with the observed distribution in the data (Fig. 10 and Fig. 11). The good agreement between data and MC at the level of super-clusters is essential for the understanding of the electron and of the photon objects and controlling the expected physics background.

6. Conclusions
The CMS ECAL detector is fully functional and within the design specifications. More than 99% of the channels are operational and in good health for physics. The precalibrations have provided a good reference point for the start-up and in-situ $\pi^0$ calibration efforts are now ongoing. Apart
from a good energy calibration and resolution, CMS ECAL has also very good timing alignment and a timing resolution which is at the sub-nanosecond level. The comparison of the data versus the MC simulation shows a good overall understanding of the detector.

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