Calibration of the CMS Electromagnetic Calorimeter at the LHC start up

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Introduction

The CMS electromagnetic calorimeter is designed to reach an excellent energy resolution (0.5% constant term in the energy resolution), very important for the Higgs boson search in the $H \to \gamma\gamma$ channel.

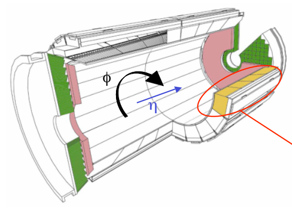
The calorimeter consists of 75.848 $PbWO_4$ scintillating crystals, organized into a barrel section and two endcap sections. The dimension of the crystals are about 25 x 25 x 230 mm^3 in the barrel ($\Delta\eta x \Delta\phi$= 0.0175 x 0.0175) and 28.6 x 28.6 x 220 mm^3 in the endcaps.

The crystals are positioned with the longitudinal axis pointing to the interaction point with a 3° tilt in η and ϕ, in the barrel region, while the tilt slightly varies with η in the endcaps.

In the barrel section, that contains 61.200 crystals, the crystals are assembled in 36 modular units, called ***super-modules***. Each super-module contains 1700 crystals arranged into 20 crystals along ϕ times 85 crystals along η. In the endcaps the crystals are arranged in a x-y grid and assembled in two Dees for each endcap.

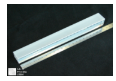
The scintillation light is read out by APD in the barrel section and by VPT in the endcaps.

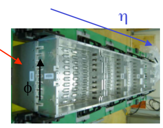
The ECAL readout has been designed to measure energies deposited in the single crystal with a dynamic range from about 35 MeV up to 1.8 TeV in the barrel and from about 60 MeV up to 3.0 TeV in the endcaps.



The CMS ECAL, schematic view

A $PbWO_4$ barrel crystal





The mechanical structure of a super-module

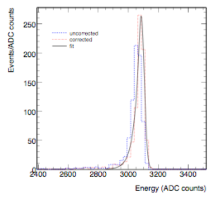
Techniques for the inter-calibration before the final detector assembly

In the ECAL barrel the spread in the crystal response after the assembly is around 13%, mainly due to the light yield differences between crystals. For the endcap the spread is larger, around 25%, with a significant contribution from variation in the VPT signal. While the final calibration of the detector will be performed in situ employing physics events, an initial channel to channel calibration (*inter-calibration*) with a better accuracy is advisable.

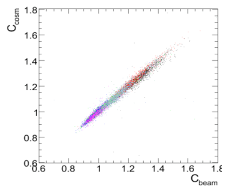
Nine super-modules (1/4 of the ecal barrel) have been calibrated in 2006 exposing them to a 120 GeV electron beam. This technique gives very precise calibrations that will also constitute a reference to study the performances of the in situ calibration at the start-up.

All the super-modules of the barrel have been calibrated with cosmic muon before the assembly. This inter-calibration is based on the equalization of the response of the different crystals to the energy (~250 MeV) deposited by traversing muons (m.i.p.), aligned with the crystal axis. Each supermodule have been exposed to cosmic muon for about 10 days in a dedicated setup collecting about 5 million events. The precision of this technique, obtained by the comparison with the electron beam calibration, is on average better than 2%, with a dependence on η due to the variation with the angle of the cosmic muon flux.

The initial intercalibration for the endcap is obtained from the laboratory measurement of the crystal LY (with a Co^{60} source) and of the VPT signal. The accuracy of this pre-calibration is at the 10% level.

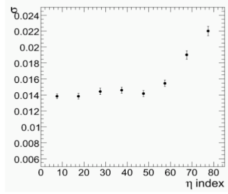


Typical distributions of the energy deposited by a 120 GeV election in one single crystal, before and after the correction for the impact point position. The calibration constants are obtained by equalizing the peak energy of the fitted distribution.

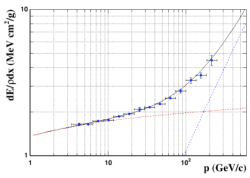


Scatter plot of the calibration coefficients from the test beam versus the ones from the cosmic muons. The different super-modules are plotted with different colours

Accuracy of the calibrations from cosmic muons versus the η index, from the comparison with test beam calibrations. η index 1 and 85 correspond respectively to the center and at the end of the barrel.



The assembled CMS detector, operated with a magnetic filed of 3.8 T, has been commissioned with cosmic muons, collecting more than 600 million events. The muon energy deposition in ECAL barrel has been studied as a function of the muon momentum measured by the tracker system and it has show a good agreement with the values expected for the $PbWO_4$. This represents an indication that the pre-calibration can be applied to the detector in the operating conditions and that the energy scale derived with 120 GeV electron can be applied down to the energy deposited by a m.i.p. Given the direction of the cosmic muons this measurement is performed only in the ECAL barrel region.



Stopping power as a function of the muon momentum, as measured in ECAl (blue dots). The continuous black line represents the expected values for the PbWO4. The dashed lines are the collision loss (red) and the bremsstrahlung radiation.

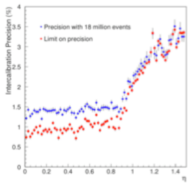
Calibration with the first data

Different promising techniques to calibrate ECAL with the first LHC data have been developed: the ϕ-symmetry and the study of $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ decays.

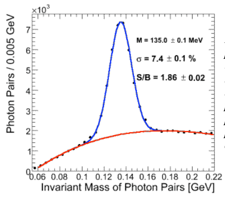
The ϕ-simmetry calibration is based on the assumption that the average energy deposited in each channel is symmetric in ϕ for minimun bias events; the relative calibration between rings at different η can be obtained from the pre-calibrations and from the study of $Z \to ee$ events. For the ϕ-symmetry calibration a specific data stream containing only the relevant calorimetric information has been designed allowing a storage rate of about 1 kHz. Given the large statistics available the accuracy of this method will be limited by the non uniformity along ϕ of the material inside the detector, and it will vary with η from ~1% in the central region to ~4% at the barrel end. The performance of the ϕ-simmetry calibration is currently under study.

For the calibration with $\pi^0 \to \gamma\gamma$, in order to increase the affordable storage rate of π^0 events, a dedicated trigger has been designed that stores only the calorimeter information in the region around the π^0 candidate. The selection of the $\pi^0 \to \gamma\gamma$ candidates is made cutting on the E_T of the calorimeter objects, on the em cluster shape variables and on isolation. The expected rate is about 1 kHz with a S/B under the peak ($\pm$ 2σ) of 1.9. The $\pi^0 \to \gamma\gamma$ mass is extracted from a singal+background fit to the invariant mass distribution and it is used to equalize the different channels. With an integrated luminosity of 5pb^{-1} a calibration accuracy at the 0.5% level will be reached in most of the barrel.

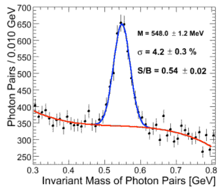
Similarly the calibration with $\eta \to \gamma\gamma$ would reach a 0.5% level accuracy with about 150 pb^{-1} of data, given the smaller production rate, and it will represent a valuable cross check of the calibration from the $\pi^0 \to \gamma\gamma$ decays with photons of slightly higher energies. As for the ϕ-simmetry, the calibration with $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ decays in the endcap region is currently under investigation.



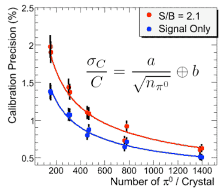
Precison of the ϕ-symmetry calibration vs η. The systematic limit is shown in red.



Invariant mass of photon pairs passing the π^0 selections. The background is fitted by a 4th order polynomial and the position of the fitted peak is used for the calibration.



Invariant mass of photon pairs passing the η selections. The background is fitted by a 4th order polynomial and the position of the fitted peak is used for the calibration.



Precision of the calibration from π^0 as a function of the number of π^0 per crystal, for an expected S/B=2.1. The expected precision of the method on a MC sample containing only the signal is also reported for comparison.

Conclusions

The ECAL detector have been pre-calibrated with an accuracy better than 2% in the barrel and around 10% in the endcap, giving good performances already at the start up.

Different techniques for the ECAL inter-calibration with few pb^{-1} of integrated luminosity have been studied and promise a good accuracy in the barrel region. The performances of these techniques for the endcap region are currently under study.