The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

04 October 2010 (v3, 11 November 2010)

Calibration of the CMS Electromagnetic Calorimeter with first LHC data

Valentina Sola for the CMS Collaboration

Abstract

The first 7 TeV LHC collisions recorded with the CMS detector have been used to perform a channel-by-channel calibration of the electromagnetic calorimeter (ECAL). Decays of π^0 and η into two photons as well as the azimuthal symmetry of the average energy deposition at a given pseudorapidity are utilized to equalize the response of the individual channels. The ECAL comprises a central *barrel* section and two *endcaps*. Based on an integrated luminosity of up to 250 nb^{-1} , a channel-by-channel *in-situ* calibration precision of 0.6% has been achieved in the barrel ECAL in the pseudorapidity region $\eta < 0.8$. The energy scale of the ECAL has been investigated and found to agree with the simulation to within 1% in the barrel and 3% in the endcaps.

Presented at ICATPP 2010 : ICATPP Conference on Cosmic Rays for Particle and Astroparticle Physics

Calibration of the CMS Electromagnetic Calorimeter with first LHC data

V. Sola

*INFN Sezione di Torino, Università di Torino, Torino, Italy
on behalf of the CMS Collaboration*

The first 7 TeV LHC collisions recorded with the CMS detector have been used to perform a channel-by-channel calibration of the electromagnetic calorimeter (ECAL). Decays of π^0 and η into two photons as well as the azimuthal symmetry of the average energy deposition at a given pseudorapidity are utilized to equalize the response of the individual channels. The ECAL comprises a central *barrel* section and two *endcaps*. Based on an integrated luminosity of up to 250 nb^{-1} , a channel-by-channel *in-situ* calibration precision of 0.6% has been achieved in the barrel ECAL in the pseudorapidity region $|\eta| < 0.8$. The energy scale of the ECAL has been investigated and found to agree with the simulation to within 1% in the barrel and 3% in the endcaps [1].

1. Introduction

The electromagnetic calorimeter (ECAL) of the Compact Muon Solenoid (CMS) experiment consists of a barrel section (EB) and two endcaps (EE). The EB contains 61 200 lead tungstate crystals arranged in 170 η -rings of 360 PbWO_4 crystals each. It is subdivided into 36 supermodules each containing 1700 crystals and provides coverage in pseudorapidity up to $|\eta| < 1.5$. The two ECAL Endcap (EE) subsystems consist of four half-disk Dees, each containing 3662 crystals. The EE provides a coverage of $1.5 < |\eta| < 3.0$. The scintillation light is detected by avalanche photodiodes (APDs) in the EB and vacuum phototriodes (VPTs) in the EE.

The ECAL energy resolution has been measured in test beams to be [2]:

$$\frac{\sigma(E)}{E} = \frac{2.8\%}{\sqrt{E(\text{GeV})}} \oplus \frac{12\%}{E(\text{GeV})} \oplus 0.3\%, \quad (1)$$

where the three contributions correspond to the stochastic, noise, and constant terms, respectively. This result was obtained in the absence of magnetic field, with almost no inert material in front of the calorimeter and with the beam aligned on the centres of crystals.

The high resolution of the ECAL is particularly important for a discovery of the Higgs boson in the decay channel $H \rightarrow \gamma\gamma$, where the constant term dominates.

This article describes results of the first crystal-by-crystal calibrations and global energy response measurements of the CMS ECAL at the LHC, performed during the first months of operation.

2. The pre-calibration

The relative channel response spread affects the constant term of the energy resolution of the electromagnetic calorimeter. The main sources of channel-by-channel response variation are the crystal light yield differences of the barrel, about 13% at construction, and the gain spread of the photodetectors in the endcaps, about 25%.

All the channels have been pre-calibrated prior to installation with laboratory measurements of crystal light yield and photo-detector gain during the construction phase (all EB and EE channels), with test beam electrons (9 EB supermodules and about 500 EE crystals) and with cosmic ray muons (all EB channels). After installation in the LHC, circulating beams were stopped in collimators 150 m away from CMS in September 2008 and November 2009. The resulting *beam dump* events have been used to improve pre-calibration precision.

Inter-calibration constants coming from different sources are combined as a weighted average. The precision of a given calibration method is determined empirically by comparing the new inter-calibration constants to those derived at the test beams. The comparison for the EE constants (derived from the combination of laboratory measurements and beam dump calibration) is shown in Figure 1 (left) for a subset of 162 of those crystals exposed to the test beam.

The channel-by-channel calibration precision at the start-up at 7 TeV is estimated to be:

- EB: about 0.5% for the 9 supermodules calibrated with test beams and 1.4% to 1.8%, depending on pseudorapidity, for the other 27 supermodules;
- EE: below 1% in the ~ 500 crystals calibrated with beam and about 5% elsewhere;

In the rest of the article, a crystal-by-crystal calibration constant is defined as a multiplicative factor c_i relative to the precalibration constant derived for this crystal: $C_i = C_i^{precalib} \cdot c_i$.

Fig. 1. Left: Relative difference between the inter-calibration coefficients measured at the test beam and the coefficients derived from the combination of all other available measurements (laboratory, 2008 and 2009 beam dump data) in the EE. Right: Precision of ϕ -symmetry method as a function of number of events for ring at $|\text{crystal } \eta \text{ index}| = 8$.

3. Calibration with the ϕ -symmetry method

The ϕ -symmetry method is based on the expectation that for a large sample of minimum bias events the total deposited transverse energy (E_T) should be the same for all crystals in a ring at fixed pseudorapidity (η). Inter-calibration in ϕ is performed by comparing the total transverse energy (ΣE_T) deposited in one crystal with the mean of the total ΣE_T collected by crystals at the same absolute value of η . In the EB, crystals are arranged in 85 pairs of rings symmetric in pseudorapidity with 360 crystals along ϕ in each ring. In the determination of the transverse energy sum, only deposits with energies between lower and upper thresholds are considered. The former is applied to remove the noise contribution, the latter is applied to avoid a possible bias from very high E_T deposits. The ϕ inhomogeneities of the detector are taken into account introducing a data driven correction.

3.1. Crystal-by-crystal calibration

The ϕ -symmetry inter-calibration procedure has been applied on $1.6 \cdot 10^8$ minimum bias events and inter-calibration constants c_i are derived for all crystals in the EB. The calibration precision is estimated as the distribution of the c_i for each ring of constant η . The width of the distribution gives the convolution of the precision of the pre-calibration supermodule with the precision of this method. For the nine test-beam calibrated supermodules, the expected pre-calibration precision is about 0.5%, several times better than expected

for the ϕ -symmetry method. Therefore, the width of distribution of the c_i limited to those supermodules gives an upper bound of the inter-calibration precision achieved with the ϕ -symmetry method. The width of the c_i distribution is estimated by performing a Gaussian fit and extracting the sigma. Figure 1 (right) shows the inter-calibration precision as a function of the number of events for η -ring 8. The measured points are fitted with the function $\sqrt{c^2 + s^2/N}$. The fitted value of c (the constant term) suggests that the systematic limit of the method is nearly reached.

4. Calibration with π^0 and η decays

An inter-calibration technique based on reconstructing $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$ decays has been studied using both the simulations and a dedicated test-beam study.

The photon candidates are reconstructed using a simple 3×3 window clustering algorithm that requires that the energy deposited in a seed crystal is above 0.5 GeV. The cluster energy is then computed as the sum of nine crystal energies. The shape of the cluster energy deposition should be consistent with that of an electromagnetic shower produced by an unconverted photon. To be considered in the combinatorial selection of di-photon pairs, a photon candidate is required to have a transverse energy above 0.3 GeV. The π^0 candidates are then selected by requiring their transverse energy to be above 0.9 GeV and an invariant mass below $0.25 \text{ GeV}/c^2$. Figure 2 shows the invariant mass distributions of the selected π^0 candidates after all selection cuts both for data and simulated minimum bias events, for the EB. In total, close to $4.3 \cdot 10^7$ signal π^0 decays are selected from the 250 nb^{-1} of data collected at 7 TeV.

For η candidates, the same selection and reconstruction methods are used except that the transverse energy cuts are tightened to $E_T^\gamma > 0.5 \text{ GeV}$ and $E_T^{\gamma\gamma} > 2.5 \text{ GeV}$. In addition, a veto cut is applied to reject photons coming from di-photon candidates within the 3σ window around the fitted π^0 peak.

4.1. Inter-calibration Results

To investigate the potential of the $\pi^0 \rightarrow \gamma\gamma$ inter-calibration, two independent calibration algorithms are used. Both algorithms are based on an iterative procedure where the inter-calibration constants are updated after each iteration step.

Fig. 2. π^0 invariant mass reconstructed from photon pairs for the data (left) and simulation (right).

Nine supermodules in this region have been pre-calibrated to a precision of about 0.5% in the test-beams. Crystals in those supermodules are used to estimate the in-situ inter-calibration precision in the same way as for the ϕ -symmetry method. In the region $|\text{crystal } \eta \text{ index}| \leq 45$, the crystal-by-crystal calibration precision is found to be 1.2%. The systematic limit on the precision of this method has not yet been reached and the current inter-calibration accuracy is dominated by the statistical uncertainty.

4.2. The ECAL energy scale with π^0 and η decays

The absolute scale of the ECAL, the ADC to GeV conversion factor, has been measured during the test beam campaign for EB and EE separately. In-situ, the ECAL energy scale will be determined by reconstructing di-electron and di-photon invariant mass peaks. A first measurement can be done using π^0 and η reconstructed decays.

The energy scale is derived by measuring the ratio of the reconstructed invariant mass peak position between data and Monte Carlo. Assuming perfect simulation of the material in front of ECAL and alignment of the detector, this ratio provides the correction to be applied to the ECAL scale. More conservatively, we consider this measurement as an indication of the current ECAL scale accuracy.

The EB scale is found to agree with the simulation at a level of 1%, with the measured mass shift $-0.7\% \pm 0.02\%$ (stat.) $\pm 0.9\%$ (syst.). In the EE, the scale is found to agree with the simulation to about 3%. The average mass shift is measured to be $+2.5\% \pm 0.2\%$ (stat.) $\pm 2.2\%$ (syst.).

5. Combination of the in-situ inter-calibration results

The inter-calibrations with the ϕ -symmetry and π^0 methods are performed independently and a comparison between their results provides a useful cross-check. The crystal-by-crystal calibration constants obtained with the two methods are combined together with the beam dump constants. The precision of the resulting constants is shown in Figure 3 as a function of crystal pseudorapidity. The assumed 0.5% test beam precision is not negligible with respect to the combination precision and therefore subtracted in quadrature. For the central barrel ($|\text{crystal } \eta \text{ index}| \leq 45$) the combined inter-calibration precision is found to be 0.6%.

Fig. 3. Precision of combined inter-calibration constants (beam dump, ϕ -symmetry and π^0) as a function of crystal pseudorapidity.

6. Summary

Using the first 250 nb⁻¹ collected with the CMS detector in 2010 at a center of mass energy of 7 TeV, studies of the CMS ECAL calibration methods and procedures are carried out. The achieved channel-by-channel calibration precision in the central barrel with the sample size currently available is about 0.6%.

The global energy response scale of the ECAL is also studied, and found to agree with the expectation to within about 1% in the barrel and 3% in the endcaps. The calibration of the CMS ECAL will continue to improve with the upcoming LHC data, with collection of large samples of neutral pion decays as well as W and Z bosons decaying into energetic and isolated electrons.

References

1. CMS Collaboration, “Electromagnetic calorimeter calibration with 7 TeV data”, CMS PAS **EGM-10-003** (2010).
2. CMS Collaboration, “The CMS experiment at the CERN LHC”, JINST **0803** (2008) S08004.