Available on CMS information server

CMS CR -2012/302

The Compact Muon Solenoid Experiment

Conference Report

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

12 November 2012 (v2, 15 November 2012)

Calibration of the CMS Electromagnetic Calorimeter at the LHC

Dawn Elizabeth Leslie for the CMS Collaboration

Abstract

The CMS electromagnetic calorimeter comprises 75848 lead tungstate scintillating crystals. The calibration of each channel is crucial to ensure excellent energy resolution. During data-taking in 2010 and 2011 a number of physics channels were used to compute the inter-calibration and absolute energy scale of the calorimeter. These included low mass di-photon resonances, electrons from Z and W decays and the azimuthal symmetry of low energy deposits from minimum bias events. The acquisition of the required data samples is described and results are presented for the precision of each method, together with the combined precision of the inter-calibration and absolute energy scale.

Presented at *IEEE-NSS-MIC-RTDS2012: 2012 Nuclear Science Symposium, Medical Imaging conference and RTDS workshop*

Calibration of the CMS Electromagnetic Calorimeter at the LHC

D E Leslie
Centre for Sensors and Instrumentation, School of Engineering and Design, Brunel University, Uxbridge UB8 3PH, UK
on behalf of the CMS Collaboration

***Abstract*– The CMS electromagnetic calorimeter comprises 75848 lead tungstate scintillating crystals. The calibration of each channel is crucial to ensure excellent energy resolution. During data-taking in 2010 and 2011 a number of physics channels were used to compute the inter-calibration and absolute energy scale of the calorimeter. These included low mass di-photon resonances, electrons from Z and W decays and the azimuthal symmetry of low energy deposits from minimum bias events. The acquisition of the required data samples is described and results are presented for the precision of each method, together with the combined precision of the inter-calibration and absolute energy scale.**

I. Introduction

THE electromagnetic calorimeter (ECAL) [1] of the CMS Experiment [2] at the Large Hadron Collider (LHC) is a homogeneous, hermetic detector, with high granularity. It comprises 75848 lead tungstate ($PbWO_4$) scintillating crystals. The cylindrical geometry comprises a central barrel calorimeter (EB), which is organised into 36 supermodules (SM) and it is closed at each end by an endcap calorimeter (EE) consisting of two 'dees'.

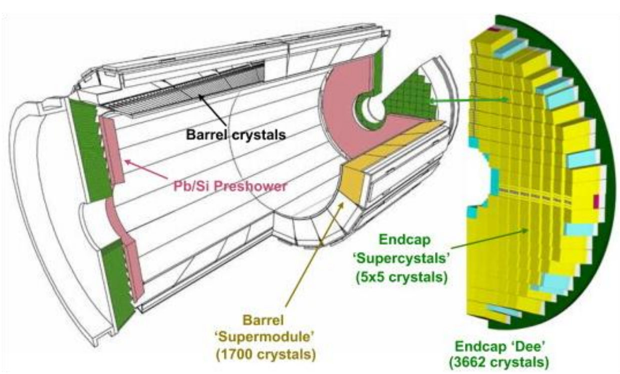

Fig. 1. Schematic layout of the CMS electromagnetic calorimeter.

The design of EB provides coverage in pseudo-rapidity up to $|\eta|<1.5$ and the encaps, each comprising 3662 crystals, extends this coverage to ±3.0. Light collection relies on avalanche photodiodes (APD) in the barrel and vacuum phototriodes (VPT) in the endcaps. A silicon/lead preshower detector (ES) is installed in front of the calorimeter in order to improve γ/π^0 discrimination. ECAL is one of the highest resolution electromagnetic calorimeters ever constructed, relying on precision calibration in order to achieve and maintain it's design performance. The energy resolution may be expressed as,

$$\sigma(E)/E = a/\sqrt{(E)} + b/E + c \tag{1}$$

where the three contributions correspond to the stochastic, noise and constant terms, respectively. The parameters a and b have been measured with electrons at test beams and found to be within design requirements [3]. The target value for the constant term c is 0.5%. As c is strongly affected by the non-uniformity in the channel-to-channel response, an accurate inter-calibration process is required to achieve this goal.

Variations in channel response from the $PbWO_4$ crystals, due to intrinsic differences in the crystals and/or associated photodetectors as well as, for example, variations in transparency with time due to radiation damage, need to be taken into account. Sophisticated and effective methods of inter-crystal and absolute calibration have been devised using collision data and a dedicated light-injection system. For inter-calibration, low-mass particle decays (π^0 and η) to $\gamma\gamma$ and $W\rightarrow e\nu$ events are exploited, as well as the azimuthal symmetry of the average energy deposition of a given pseudo-rapidity. Absolute calibration has been achieved by reconstructing $Z\rightarrow e^-e^+$ events. A light injection system monitors the channel response in real time and enables the re-calibration of the measured energies over time. This is cross-checked by the comparison of E/p measurements of electrons from W decays (where E is measured in the ECAL and p in the tracker).

II. Inter Calibration

Prior to installation, the ECAL was calibrated using a combination of laboratory measurements, test-beam electrons and cosmic-ray muons [4]. These methods measured the crystal light yield and photodetector gain of all EB and EE channels. Following installation at the LHC, 'splash' events (i.e. secondary particles or 'debris' arising from the beam being stopped by a collimator) were used to improved the precision of the initial EB and EE calibration. Figure 2 shows the precision of channel inter-calibration using energy deposits, as a function of pseudo-rapidity in the ECAL barrel and endcap detectors [5]. Inter-calibration constants, derived before LHC start-up (ie. from test beam, cosmic rays, beam splash and lab measurements) and derived from in-situ calibration (from ϕ-symmetry, $\pi^0\rightarrow\gamma\gamma$ and $\eta\rightarrow\gamma\gamma$ decays) have

Manuscript received November 16, 2012.

been used in the 2010 combination, whilst in 2011, the calibration constants obtained with high energy electrons have been added. The 2011 combination includes the 2010 constants. Inter-calibration precision at small η in EB is ~0.5% and is better than 1% in all η rings. EE inter-calibration precision is ~2% in the central part of EE and better than 4% up to the limit of precision electron and photon acceptance at |η|= 2.5.

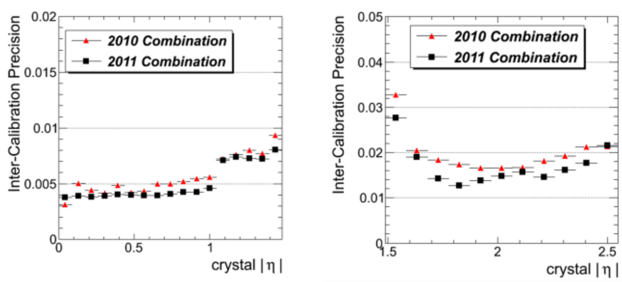

Fig. 2. Precision of channel inter-calibration as a function of pseudo-rapidity, η, in the ECAL barrel and endcap detectors.

III. ECAL Response Monitoring

During LHC cycles, the ECAL response varies, depending on the instantaneous luminosity conditions. The predominant loss of channel response is from crystal transparency degradation. This effect occurs on a timescale of hours and can give rise to a change in transparency of a few percent. To maintain the ECAL design performance, a laser monitoring (LM) system was designed to monitor the change in response of each channel, at the level of 0.2%. The response of each channel is monitored every ~45 minutes by means of a blue laser, with a peak wavelength (λ=440 nm) close to the $PbWO_4$ emission peak. During LHC beam gaps, laser pulses are injected into each crystal via a system of optical fibres and the channel response is normalised to the laser pulse magnitude, measured using silicon PN photodiodes. To provide corrections with the required precision, the signal is corrected for the laser pulse width and amplitude change. Figure 3 shows the relative response to laser light, averaged over all crystals in bins of pseudo-rapidity, η, for the 2011 and early 2012 data taking periods [5]. The range | η |<1.5 corresponds to the barrel and larger values of η correspond to the endcaps.

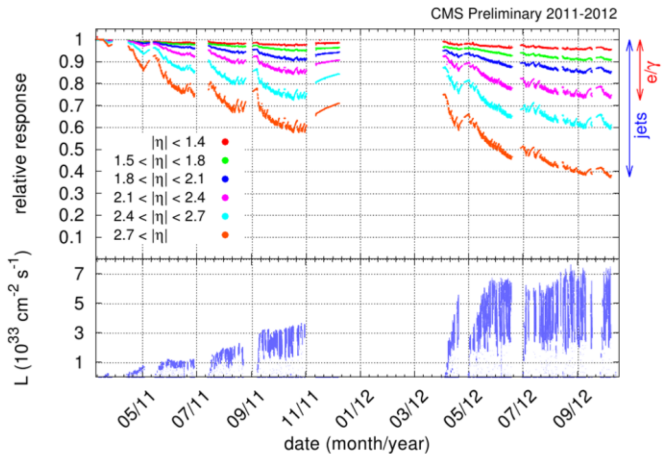

Fig. 3. Relative response to laser light (λ=440 nm) averaged over all crystals in bins of η for the 2011 and 2012 data.

IV. ECAL Calibration

As shown in Figure 3, the relative response to laser light is exponential in behaviour and reaches a saturation level depending on the dose rate. The average change is ~2-3% in the barrel, reaching ~40% for |η|=2.7. Recovery of the crystals during periods without irradiation is also visible. Response corrections are determined and applied.

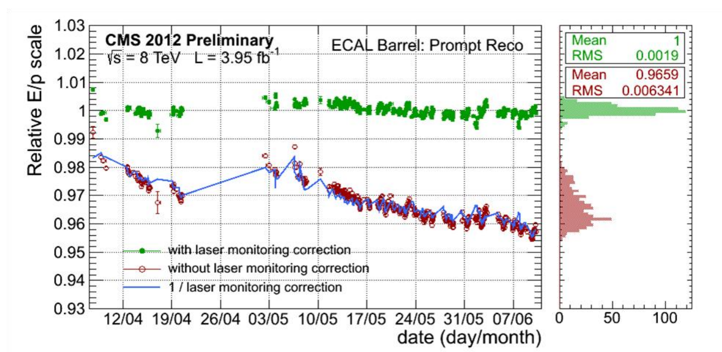

Fig. 4. Single electron energy scale stability in the ECAL barrel before and after laser monitoring correction, measured used W→eν events.

Figure 4 shows the single electron energy scale (E/p) stability during the 2012 run, measured using W→eν events [4]. After corrections from LM, the EB RMS stability is ~0.19%. Figures 5 [5] and 6 [7] show examples of invariant mass distributions of electrons and photons measured in the barrel. Data such as these illustrate the excellent instrumental resolution of ECAL.

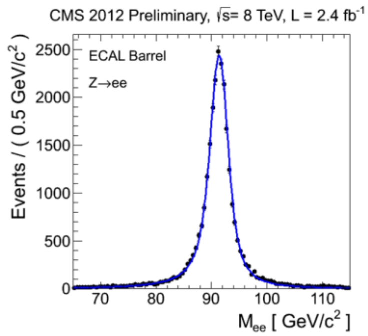

Fig. 5. Z→ee invariant mass distribution measured in the ECAL barrel.

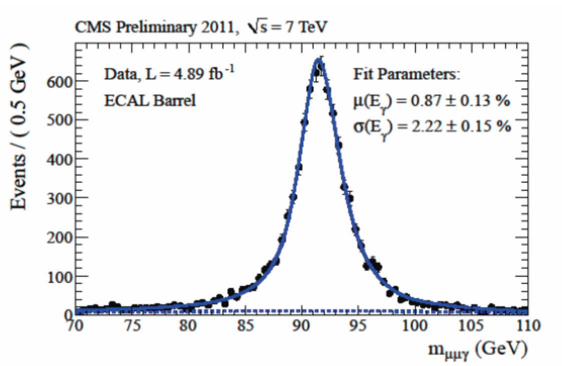

Fig. 6. Z→μμγ invariant mass distribution measured in the ECAL barrel.

V. CONCLUSIONS

An extensive pre-calibration process of the CMS ECAL has afforded an inter-calibration precision of 1.5 - 2.0 % in the barrel and around 5 % in the endcaps [4]. The combined precision of the inter-calibration and absolute energy scale at low η in EB is ~0.5% and is better than 1% in all η rings. EE inter-calibration precision is ~2% in the central part of EE and better than 4% up to the limit of electron and photon acceptance at |η|= 2.5.

REFERENCES

[1] CMS Collaboration, 'Performance and operation of the CMS electromagnetic calorimeter', JINST 5:T03010, 2010
[2] CMS Collaboration, 'The CMS Experiment at the CERN LHC', JINST3:S08004, 2008
[3] Adzic P et al., 'Energy resolution of the barrel of the CMS Electromagnetic Calorimeter', JINST 2:P04004, 2007
[4] The CMS ECAL Group, 'Intercalibration of the barrel electromagnetic calorimeter of the CMS experiment at start-up', JINST 3:P10007, 2008
[5] CMS Performance Note, CMS DP-2012/015, 2012
[6] CMS Performance Note, CMS DP-2012/0NN, 2012
[7] CMS Performance Note, CMS DP-2012/007, 2012