The Compact Muon Solenoid Experiment

Conference Report

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14 June 2012 (v3, 11 July 2012)

Calibration of the CMS Electromagnetic Calorimeter with LHC collision data

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Abstract

The CMS ECAL is one of the highest resolution electromagnetic calorimeters ever constructed, but relies upon precision calibration in order to achieve and maintain its design performance. Variations in light collected from the lead tungstate crystals, due to intrinsic differences in crystals/photodetectors, as well as variations with time due to radiation damage for example, need to be taken into account. Sophisticated and effective methods of inter-crystal and absolute calibration have been devised, using collision data from the 2011 LHC run and a dedicated light injection system. For inter-calibration, low mass particle decays (π^0 and η) to two photons are exploited, as well as the azimuthal symmetry of the average energy deposition at a given pseudorapidity. Absolute calibration has been performed using Z decays into electron-positron pairs. The 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 the momentum is measured in the CMS tracker) with/without these re-calibrations applied.

Presented at *12th Pisa Meeting on Advanced Detectors*

Calibration of the CMS Electromagnetic Calorimeter with LHC collision data

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Abstract

The CMS ECAL is a high resolution electromagnetic calorimeter which relies upon precision calibration in order to achieve and maintain its design performance. Variations in light collected from the lead tungstate crystals, due to intrinsic differences in crystals/photodetectors, as well as variations with time due to radiation damage for example, need to be taken into account. Sophisticated and effective methods of inter-crystal and absolute calibration have been devised, using collision data from the 2011 LHC run and a dedicated light injection system. For inter-calibration, low mass particle (π^0 and η) decays to two photons are exploited, as well as the azimuthal symmetry of the average energy deposition at a given pseudorapidity. The 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 the momentum is measured in the CMS tracker) with/without these re-calibrations applied. Absolute calibration has been performed using Z decays into electron-positron pairs.

Key words: Electromagnetic calorimeter, calibration

PACS: 29.40.Vj

1. Introduction

The electromagnetic calorimeter (ECAL) [1] of the CMS experiment is a homogeneous, near-hermetic detector made of 75848 lead-tungstate (PbWO_4) crystals. The barrel (EB) is organized into 36 supermodules and is closed at each end by endcaps (EE), each consisting of two dees. For light collection it is equipped with avalanche photodiodes (APD) in the barrel part and vacuum phototriodes (VPT) in the endcaps. A silicon/lead pre-shower detector (ES) is installed in front of the endcaps to improve the γ/π^0 discrimination.

ECAL is a crucial detector for several physics studies, above all the search the Higgs boson through its $\gamma\gamma$ decay. The Higgs discovery potential depends on ECAL energy and position resolution which in turn rely on stability of the channel response over extended periods of time and on the precision of their energy calibration. In the following sections the calibration procedures and the results obtained in 2011 will be discussed.

2. Correction of the radiation induced response change of the ECAL channels

During LHC cycles the ECAL response varies depending on the irradiation conditions. The predominant loss of channel response is due to the crystal transparency degradation. This effect takes place on a time scale of hours and can cause transparency changes of a few percent during LHC fill/interfill periods, depending on the instantaneous and integrated luminosity. Another important radiation-induced effect which currently

cannot be disentangled from the transparency loss, is the VPT ageing. To maintain the ECAL design performance, a laser monitoring system was designed to detect the overall response change for each channel at the level of 0.2%. This is done by means of a laser with a wavelength of 440 nm, close to the PbWO_4 emission peak [2]. During the LHC beam abort gaps, laser pulses are injected every 40 minutes into each crystal via optical fibres. The channel response is normalized to the laser pulse magnitude, measured using silicon PN photo-diodes. To reach the required precision, the signal is corrected for changes in laser pulse width and amplitude. The PN linearity and stability have been studied with dedicated laser amplitude scans. The response variation measured throughout 2011 has an exponential behaviour with a saturation level which depends on the dose rate. The average changes observed during the year are about 2-3% in the barrel and up to 40% at $|\eta| = 2.7$ in the endcaps, in agreement with the expectations for the achieved instantaneous luminosity.

Once the response corrections are derived, a fast validation is performed for the barrel by applying them to the data and checking the stability of the reconstructed di-photon mass from $\pi^0/\eta \rightarrow \gamma\gamma$ decays. This procedure takes place within 48 hours after the data-taking, before the CMS prompt data reconstruction starts. Afterwards, the stability of the energy scale is measured for both barrel and endcaps by comparing the energy E reconstructed by ECAL and the track momentum p estimated by the tracker for electrons produced in $W \rightarrow e\nu$ decays. The E/p scale studied as a function of time in 2011 was found stable to within 0.12% in the barrel and 0.45% in the endcaps after the response corrections have been applied, as shown in Figure 1. The E/p technique can also be used to measure in situ the parameter α which scales the response change measured by the

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Figure 1: History plot for 2011 data of the ratio of electron energy E , measured in the ECAL, to the electron momentum p , measured in the tracker for EB (upper plot) and EE (lower plot).

laser monitoring system (R/R_0) to optimally correct the signal S from electromagnetic showers: $S/S_0 = (R/R_0)^\alpha$. A residual slope in the S/S_0 vs R/R_0 plot obtained after the application of the laser corrections can be interpreted as a deviation of α from the assumed value. The analysis performed on 2011 data showed that the value of α measured in test beams for a subset of crystals before the calorimeter installation is adequate for the barrel but needs an effective scaling in the endcaps.

3. Single channel calibration

There is a difference in response from one channel to another, mainly due to crystal light yield variation and, in EE, different VPT response. To normalize the response across channels various steps have been employed. To provide acceptable performance at the startup, channels have been pre-calibrated with laboratory measurements of crystal light yield and photo-detector gain (all ECAL), test-beam electrons (9 EB SM and ~ 500 EE crystals), cosmic ray muons (all EB SM) and "splash" events (all ECAL), reaching an average precision of 1.5% in the barrel and 5% in the endcaps at the beginning of the 7 TeV data-taking [3]. To further improve this precision several methods have been developed, all applied to collision data after applying the laser measurement corrections.

The ϕ -symmetry method is based on the assumption that for a large number of zero-bias events the total collected transverse energy (ΣE_T) is the same for all crystals in rings at fixed pseudorapidity. The inter-calibration is performed by comparing the ΣE_T deposited in one crystal with the mean ΣE_T collected by crystals at the same $|\eta|$. The precision of this method ranges between 1.4% in the central ($|\eta| < 1$) barrel to 4-6% in the endcaps and is limited by the non-uniformity of the material in front of ECAL; however, it is fast (one inter-calibration every 1-2 weeks in 2011) and can be used to monitor the relative stability of the calibration.

In the π^0/η method, the invariant mass of photon pairs from π^0/η is used to obtain the channel inter-calibration coefficients. The photon candidates are reconstructed in 3×3 crystal matrices. An iterative procedure is applied in which the π^0/η mass peak of the events collected in each crystal is fitted with a gaussian and a fourth order polynomial describing the background, and the calibration constants are updated to correct the fitted mass value. One set of inter-calibration constants per month in EB and one every 3 months in EE were provided with a precision of 0.5 (1)% in the central (outer) barrel and 2-3% in the endcaps. The Precision is dominated by systematic errors.

The W electron method uses single electrons from $W \rightarrow e\nu$ decays. Calibration is performed using an iterative procedure by fitting $E(\text{ECAL})/p(\text{tracker})$ distributions for each crystal. With the entire sample accumulated in 2011 (~ 120 electrons/crystal in EB) it was possible to provide the first set of inter-calibration factors with a precision of 4% in the endcaps and ranging between 1% (central EB) and 4% in the barrel. In this case the precision is still limited by statistics.

Results from the three inter-calibration methods were compared, found in good agreement and combined. The precision of the resulting inter-calibration constants is 0.5% for the central barrel and 0.9% in the rest of EB; in EE it is around 2% in the central part and better than 4% at the edges.

The final check of the inter-calibration and response corrections is performed using $Z \rightarrow e^+e^-$ events. The study of the Z mass resolution as a function of time showed that without corrections the resolution worsened by approximately 15% in the barrel and by more than 100% in the endcap during the 2011 data taking; applying inter-calibration and laser corrections the relative mass resolution was found stable to within 4% in all ECAL.

$Z \rightarrow e^+e^-$ events were also used to derive the ECAL global energy scale with a statistical precision of 0.1% in both EB and EE. The systematic uncertainty is currently 0.6% in the barrel and 1.5% in the endcaps.

4. Conclusion

During 2011 data taking a lot of effort was put to reach and maintain ECAL design performance. The laser monitoring system was able to provide adequate corrections for response changes. A single-channel inter-calibration precision of 0.5% (0.9%) in the central (outer) barrel has been achieved and maintained in all 2011. In EE the inter-calibration precision is 2-4%. Improvements are expected in 2012 from the increased statistics and further refinements of the calibration methods.

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