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The Compact Muon Solenoid Experiment

Conference Report

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Commissioning of the CMS ECAL calibration with muons from cosmic rays and beam dumps

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Abstract

The electromagnetic calorimeter of the CMS experiment is designed to reach excellent energy resolution, essential for the discovery of narrow electromagnetic resonances, such as the Standard Model decay H$\rightarrow\gamma\gamma$. The non uniformity of the individual channels directly contributes to the calorimeter energy resolution. While the final performance will be achieved with *in situ* calibration exploiting physics events, a good performance at start-up is already offered by the result of pre-calibration procedures involving test beam data, exposure to cosmic rays and laboratory measurements of the crystal light yield and photodetector gains. During the CMS commissioning phase, muons from cosmic rays and from beam dumps were used to validate the calibrations. In particular, the measurement of the muon momentum by the tracking system allow to check the validity of the energy scale defined on a 120 GeV electron beam down to the energy released by a minimum ionising particle. Muons from beam dump data are used to improve the intercalibration of the ECAL endcaps.

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Commissioning of the CMS ECAL calibration with muons from cosmic rays and beam dumps

M. Malberti on behalf of the CMS Collaboration

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I. Introduction

The Compact Muon Solenoid (CMS) detector [1] is a general purpose detector installed at the LHC [2].

The central feature of the CMS apparatus is a superconducting solenoid, of 6 m internal diameter. Within the field volume are the silicon pixel and strip tracker, the electromagnetic calorimeter and the brass-scintillator hadronic calorimeter (HCAL). Muons are measured in gas-ionization chambers embedded in the iron return yoke.

The Electromagnetic Calorimeter (ECAL) [3] of CMS is a hermetic homogeneous calorimeter made of 75848 lead tungstate ($PbWO_4$) scintillating crystals. It consists of a central barrel region (EB) organized in 36 supermodules, each containing 1700 crystals, and two endcaps (EE) of 7324 crystals each. The scintillation light is readout by avalanche photodiodes (APDs) in the barrel and with vacuum phototriodes (VPTs) in the endcaps. Silicon preshower detectors are installed in front of the ECAL endcaps.

The fine granularity and excellent energy resolution of the calorimeter have been optimized for the detection of the Higgs boson through its electromagnetic decay. An essential issue in CMS is the channel response uniformity within ECAL, as this will contribute directly to the overall energy resolution. This uniformity is determined by the accuracy of the calibration of the relative response, or intercalibration, between different channels. The target intercalibration precision for the H $\rightarrow \gamma\gamma$ benchmark channel is 0.5%, while for most of the physics at the start-up a precision of about 1-2% will be sufficient.

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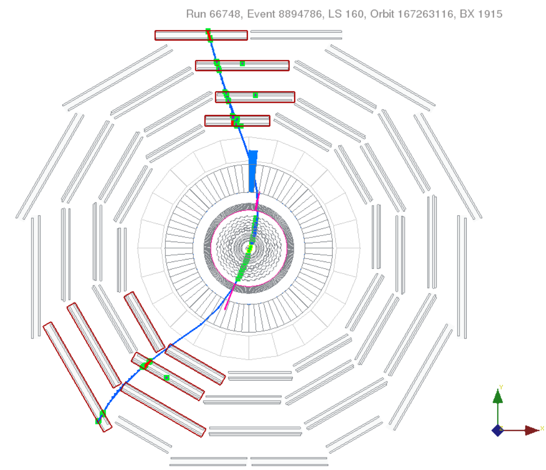

Fig. 1. An event display of a cosmic muon crossing CMS. ECAL hits are in magenta, HCAL in blue, tracker and muon hits in green.

The main sources of channel-to-channel response variation are the crystal light yield variation in the barrel, about 11%, and the spread of the photodetectors gain in the endcaps, about 25%. While the goal precision will be achieved *in situ* with physics events, pre-calibration procedures with test beam data, exposure to cosmic rays and laboratory measurements of the crystal light yield and photodetector gains, already provide good performances for the initial data taking. In particular, 9 supermodules of the ECAL barrel have been intercalibrated using 120 GeV electrons from test beam with an achieved accuracy of 0.3% [4]. The remaining 27 supermodules are intercalibrated with a precision of 1.5%-2.5%, obtained by exposure to cosmic rays [4]. For the ECAL endcaps, the intercalibration constants were determined from laboratory measurement of the light yield and of the VPT gain, with an accuracy of 7.4%. A set of 460 crystals in EE was also exposed to electrons in test beams and intercalibrated with a precision better than 1%.

II. Commissioning with muons from cosmic rays

During October-November 2008 the CMS Collaboration performed a month-long data taking exercise, known as the Cosmic Run At Four Tesla (CRAFT) [5], with the goal of commissioning the experiment for an extended operating period. With all the subdetectors participating, CMS recorded about 270 millions of cosmics ray triggered events with the solenoid at its nominal axial magnetic field strength of 3.8 T. An event display of a cosmic muon crossing CMS is shown in Fig. 1 for illustration.

CRAFT data were exploited to measure the muon specific energy loss in lead tungstate as a function of the muon momentum. This measurement allowed to check the global energy scale and local energy scale in the ECAL barrel.

A. Validation of the global energy scale in the ECAL barrel

The muon stopping power dE/dx has been measured for muons in a momentum range between 5 GeV and 1 TeV. Single muons reconstructed in the inner tracker with an associated energy deposit in both the upper and lower half of ECAL barrel were considered. The typical muon energy release in ECAL is about 300 MeV. In order to increase the sensitivity to low energy deposits the APD gain was raised from the nominal gain 50 to 200. In this condition the equivalent energy noise corresponds to 9.5 MeV per readout channel. Events with small angle ($<30^{\circ}$) between the muon track and the crystals axis were selected. Only energy deposits in the bottom half of ECAL are used for the measurement as a correct estimate of the muon momentum requires that it is measured upstream of the energy release.

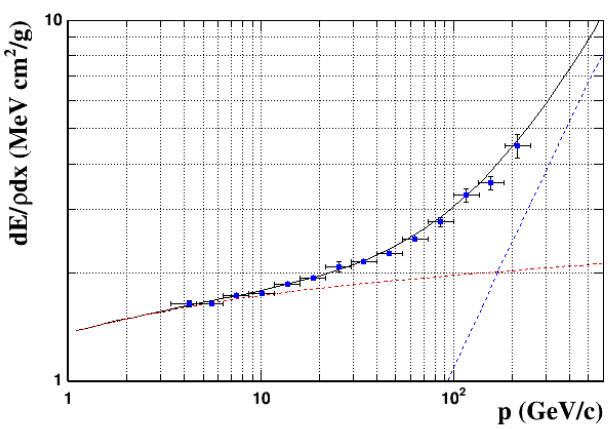

Fig. 2. Stopping power of cosmic muons traversing ECAL as a function of the muon momentum as measured in the tracker. Experimental data (dots) are compared to the total stopping power (dE/ρdx) in $PbWO_4$ (black continuous line). The dashed lines are the contributions due to collision losses (red) and radiative losses (blue).

Figure 2 shows the muon stopping power measure as a function of the muon momentum. Absolute measured values of energy loss are in agreement with expectations [8] within an overall uncertainty of about 2%, to which the statistical accuracy (1%) and the systematic uncertainties related to online data reduction and clustering thresholds (1.6%) and to the uncertainty in the containment corrections (1.0%) contribute [7]. The result is dominated by the precision of the measurements in the momentum region below 10 GeV/c, where radiation losses are negligible and shows that the energy scale set with 120 GeV electrons in test beam still holds in the sub-GeV ($\sim$300 MeV) region. The dE/dx measurement is in agreement with expectations over the full momentum range and a comparison of collision losses with radiative losses allows to derive the muon critical energy in $PbWO_4$.

B. Validation of the local energy scale in the ECAL barrel

A check of the pre-calibration constants for different barrel supermodules was performed by comparing the stopping power distributions for cosmic ray muons after the constants were applied. The 14 supermodules with highest acceptance to the vertical muon flux and muons with momentum below 10 GeV were considered in the study. Figure 3-top shows the mean stopping power for each supermodule, plotted as a function of the pre-calibration values, averaged over the supermodule. The spread of the measurements is about 1.1% (RMS). The measurement of dE/dx as a function of the η index of the crystals validates the ring intercalibration with a precision of 0.8% (Fig.3-bottom). The uniformity of the detector response is thus verified at the 1% level, which is consistent with the combination of the statistical uncertainty ($\sim$0.4%) of the measurements with the systematic uncertainties due to the scale dependence on the angle between the muon track and the crystal axis (0.5%) and to the variation in average muon momentum in different EB regions ($\leq$0.5%) [6].

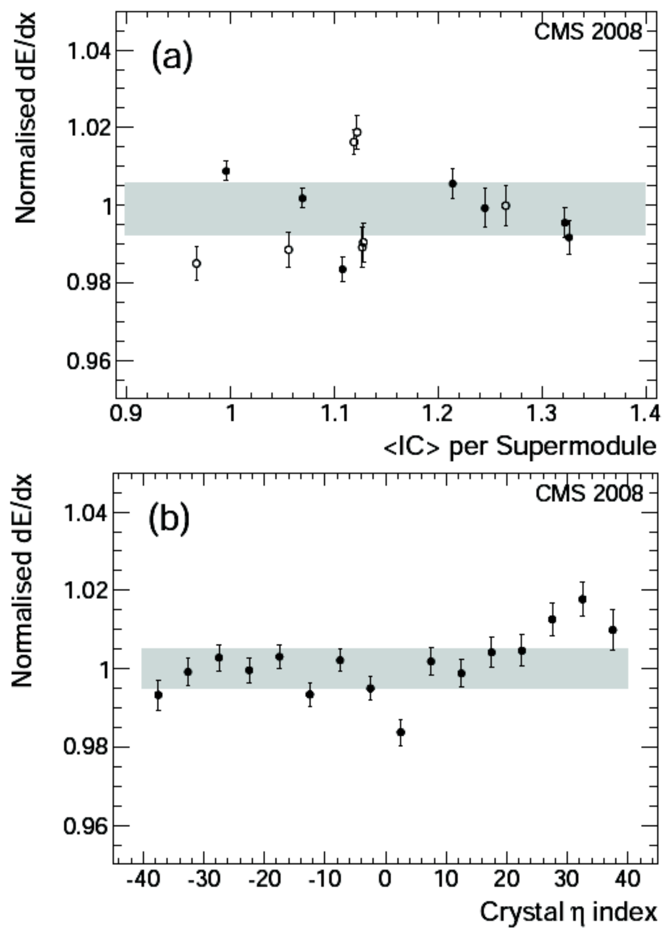

Fig. 3. Mean stopping power versus the mean pre-calibration constants,$< IC >$ for 14 supermodules. The filled circles indicate supermodules located in the upper hemisphere of ECAL (top). Mean stopping power versus the index of the crystals in the η coordinate (bottom). The shaded region represents the systematic error on the measurement of dE/dx.

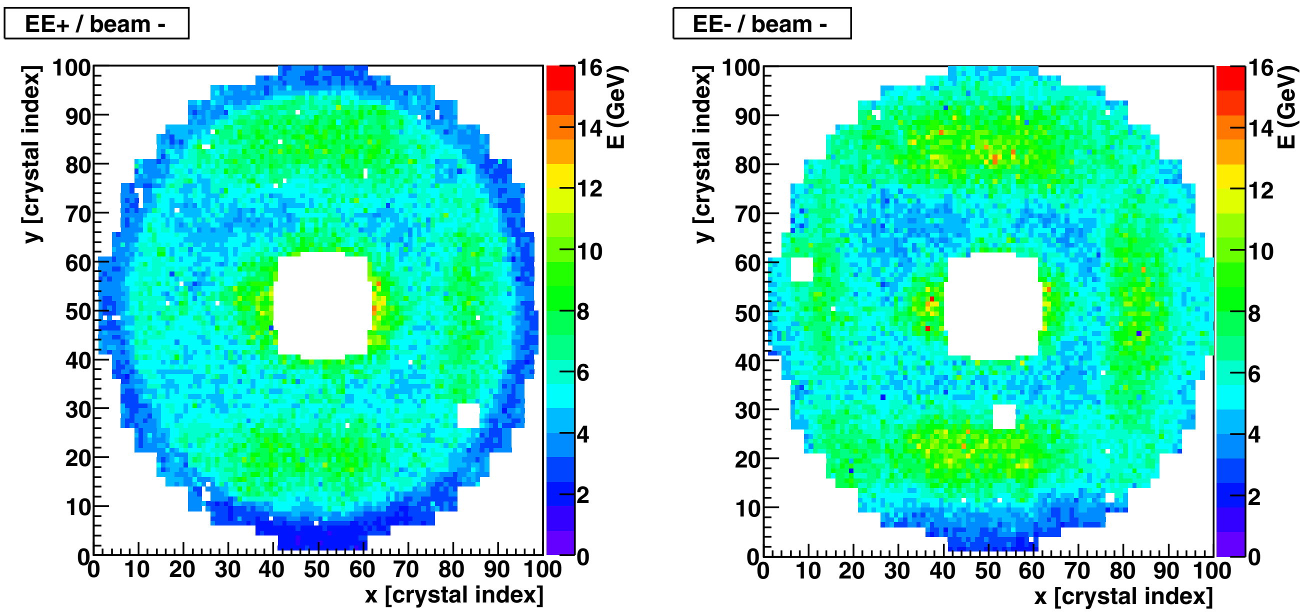

Fig. 4. Maps of the average energy deposited in the ECAL endcaps crystals by muons from beam dumps.

III. Commissioning with muons from beam dumps

A validation of the endcap pre-calibration constants was performed using beam-induced muons from 41 events recorded by CMS with the magnet at 0 T during LHC beam commissioning in September 2008. The spray of O(10^5) muons produced from the LHC primary beams impinging on collimators 150 m upstream of the CMS detector produced large (TeV) energy deposits, illuminating all the active channels. In EE, the average energy per crystal was approximately 5 GeV/event (Fig.4). A lower energy deposition in the external region of the endcap downstream to the beam direction is visible, due to the shielding effect of ECAL barrel. White regions correspond to channels masked form the readout.

A. Intercalibration of the ECAL endcaps

As the energy flux is not uniform over the entire endcaps neither is predicted, an intercalibration strategy can rely on the assumption of local uniformity of the energy deposition, which is supported by Fig. 4, to first approximation.

The intercalibration procedure is performed in two steps: first, using the local uniformity hypothesis, an intercalibration within a supercrystal (5×5 crystals matrix) is performed and, then, pre-calibration coefficients averaged on 5×5 crystals matrices are used to intercalibrate between supercrystals. The intercalibration coefficients obtained with this method have been validated against those obtained from test beam measurement on a set of 460 endcap crystals. The agreement is a the level of 10.4% (RMS) [6], limited by the validity of the local unifimity assumption.

The comparison over the entire endcaps between coefficients from beam dump data and pre-calibration coeffiecients shows an agreement of about 13%: this figure is consistent with the precisions of the individual sets and validates the intercalibration method over the entire endcaps. Finally, the weighted average between intercalibration constants from beam dumps and from laboratory measurement has been computed and compared to test beam measurements for a representative subset of 162 crystals, coming from the manufactured crystal sample that comprises greater than 80% of the installed crystals and having the best understood light yield measurements. An improvement on the precision from 7.4% to 6.3% is observed (Fig. 5), in agreement with the expected precision from the combination of the two sets of measurements. Further improvements are moreover envisaged with beam dumps data collected in November 2009, exploiting the preshower to measure the energy flux.

IV. Conclusions

Data collected during the CRAFT and the LHC commissioning phase in 2008 allowed the validation of the CMS ECAL calibration. Using cosmic ray muons in the ECAL barrel, the global energy scale obtained with 120 GeV electrons in test beams has been validated at the 2% level down to the sub-GeV region and the local energy scale has been checked to 1%. The ECAL endcaps intercalibration has been validated using muons from beam dumps and an improvement on the precision of intercalibartion constants has been found from the combination of the measurements with beam induced muons and laboratory data.

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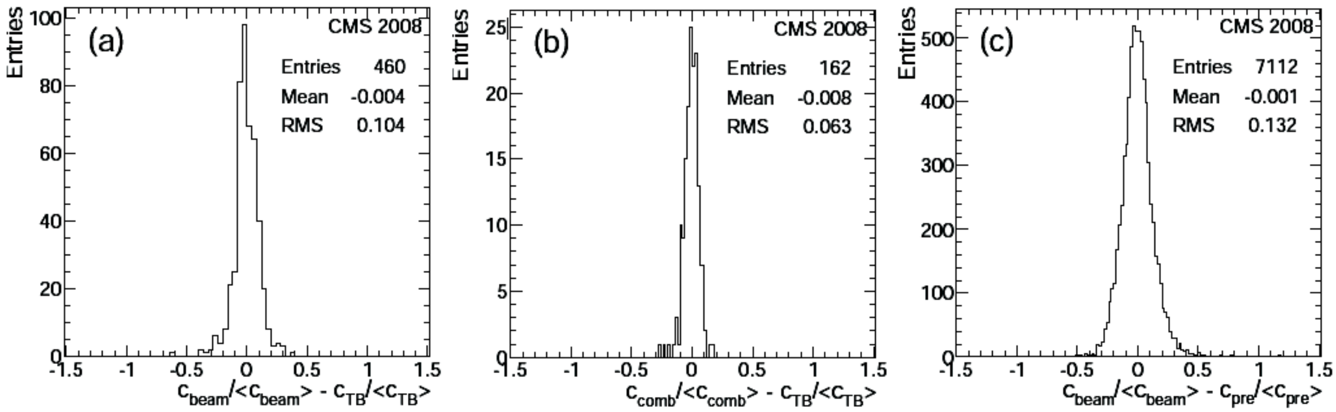

Fig. 5. Validation of EE pre-calibration constants using beam-induced muons. (a) Comparison between normalized beam-induced muon and test beam coefficients for 460 crystals. (b) Comparison of the normalized combined beam-induced muon and pre-calibration coefficients to those derived from test beam data for the sub-sample of 162 reference crystals. (c) Comparison between normalized beam-induced muon and pre-calibration constants for the entire positive endcap.

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