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The CMS Electromagnetic Calorimeter Pre-calibration with Cosmic Rays and Test Beam Electrons

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Abstract

The electromagnetic calorimeter of the CMS experiment at the new CERN proton-proton Collider (LHC) is at an advanced stage of construction. A necessary condition for its optimal performance is a precise channel-to-channel calibration. The use of cosmic rays allows the pre-calibration of all the channels at the level of 2% before the final installation in CMS and provides an extensive functionality test, essential for the commissioning of the detector. On the other hand, a beam of electrons permits extremely precise (better than 0.5%) pre-calibration coefficients to be obtained on a fraction of the calorimeter, that can also be used as a reference for the *in situ* calibration procedures that will rely on physics data.

Introduction

The CMS (Compact Muon Solenoid) [CMS Collaboration (1994)] is one of the two multi-purpose experiments that will take data at the LHC proton-proton collider. It basically consists of a silicon central tracking device surrounded by the electromagnetic and hadron calorimetry (all immersed in a 4 T magnetic field) and by a muon detector in the return yoke.
The electromagnetic calorimeter (ECAL) [CMS Collaboration (1997)] consists of about 76,000 $PbWO_4$ scintillating crystals covering the pseudo-rapidity (η) range from 0 to 3.0 by means of a barrel part ($0 < |\eta| < 1.48$) and two endcaps ($1.48 < |\eta| < 3$). ECAL is organised in 36 super-modules (each containing 1700 crystals arranged in four modules) in the barrel and in 4 dees (each consisting of 3662 crystals) in the end-caps. Crystals in the barrel are read out by Avalanche PhotoDiodes (APD), while in the endcaps the scintillating light is detected by Vacuum Photo Triodes (VPT). Every single crystal shows a response different from the others, mostly because of the spread in the crystal light yield ($\simeq$13%) in the barrel and because of the spread of the VPT gain ($\simeq$25%) in the endcaps.

To fully exploit its physics reach, in particular in the benchmark channel H$\rightarrow \gamma\gamma$, the resolution of ECAL must be controlled at the level of 0.5% at high energies. In order to fully exploit the ECAL physics potential from the beginning of the data taking a pre-calibration is mandatory. For this purpose, various procedures have been envisaged, among which the exposure of ECAL supermodules to cosmic rays and to electron beams of different energies. The results of this procedures will be the starting value for the *in situ* intercalibration, based on well known physics channels (e.g. Z$\rightarrow$e$^+$e$^-$, W$\rightarrow$eν, $\pi^0 \rightarrow \gamma\gamma$).

1 Cosmic Rays pre-calibration

The reference signal for the calibration with cosmic rays is provided by the energy released by minimum ionising particles (about 250 MeV) crossing the ECAL crystals all along their length [W. Bertl et al. (2004)]. During the exposure to cosmic rays the APD readout gain is increased by a factor four with respect to the nominal working point. Besides enhancing the electronic signal to noise ratio to about 25, the main advantage of this method is that an external tracking device is not required to select muons aligned with the crystal axis. Since the equivalent noise with the increased gain is 10 MeV, a veto to discard muons crossing several crystals can in fact be applied on the basis of the amplitude signal observed on the eight crystals surrounding the candidate one. To compensate for the inefficiency of this veto for crystals at the supermodule boundaries, scintillator slabs have been introduced at the edges of the supermodule to provide an additional tagger for aligned muons.
The calibration strategy has been optimized by means of a GEANT4 [GEANT4 web page] based Monte Carlo simulation, which takes into account the detailed geometry of the experimental setup (Fig. 1) as well as the parametrization of the muons flux at the sea level fitted to the data [L. Bonechi (2004)].
By means of the veto on the neighbouring crystals three independent data sets can be selected, according to whether the m.i.p. crossed one single crystal or two crystals (aligned in the η or ϕ direction). Respectively, an unbinned likelihood fit method and a matrix inversion technique are used to extract the intercalibration coefficients from the three independent data sets before combining them all together.
About 5 million triggers, typically collected in ten days of data taking, ensures a statistical accuracy ranging from 1% to 2.5% according to the crystal position along η and the calibration method. After correcting for the spread introduced by the increased APD gain (about 2.5%), a detailed comparison with the coefficients from the pre-calibration with an electron beam shows an agreement over a single whole supermodule of better than 2% (Fig. 2). Since due to time constraints it is not possible to intercalibrate all the supermodules with an electron beam, the calibration with cosmics guarantees that the large majority of the ECAL channels are equalized to 2% already at the beginning of the data taking. So far 25 supermodules have been exposed to cosmic rays and intercalibrated, also providing an extremely useful test for the detector commissioning.

2 Test Beam Electrons pre-calibration

The test took place at CERN during summer 2006 on a beam of electrons of well defined energy (dE/E $<$ 0.1%). The electron beam hit each crystal of nine ECAL supermodules irradiated in a geometrical configuration, so as to to mimic the CMS geometry and come from the direction, with respect to the crystals, of the nominal interaction point in the CMS detector. The beam has been set to the energies of 120 GeV and 90 GeV, allowing the study of systematic effects due to the energy on the pre-calibration. More than 3,000 electrons hit every crystal of the supermodules. The impact position of the particles on the crystals front face was measured by a set of scintillating fiber arrays placed upstream along the beam. The data taking was performed and controlled by means of the final tools designed for CMS, as well as the processing of the data and the reconstruction of the particles' energy

[Adzic et al. (2006)].

The intercalibration techniques applied are based both on the energy deposited in each single crystal and on the energy deposited in a cluster of 5×5 crystals (S25), built event by event around the one hit by the electron. In the first case, the pre-calibration is calculated by equalizing the maximal response of each crystal to a reference value. The clustering based algorithms, which will be used during the data taking as well [L. Agostino et al. (2006)], equalize the energy deposited in each crystals cluster to the one of the electron beam.

Figure 3 shows the energy reconstructed as S25 before and after the intercalibration in a whole supermodule, with no corrections for global or local variations of the energy deposit in the detector. The reproducibility of the pre-calibration measurements has been tested by performing the procedure twice, with a time interval of one month, on the same supermodule. Figure 4 shows the distribution of the relative difference of the two measures for all the crystals of a supermodule. The width of the distribution is 0.27%, corresponding to an error on the coefficients of about 0.2%. Similarly, the distribution of the relative difference between the measurements performed at 90 GeV and 120 GeV has been built; its width is smaller than 0.4%.

Conclusions

The CMS electromagnetic calorimeter needs to be calibrated with high accuracy to fully exploit its physics reach. Already before its installation, pre-calibration procedures take place: cosmic muons measurements provide an intercalibration at the level of 2% on all the channels, while an electron testbeam has been used to provide a very precise measurement of the coefficients (better than 0.5%) on a fraction of the detector.

3 Figures

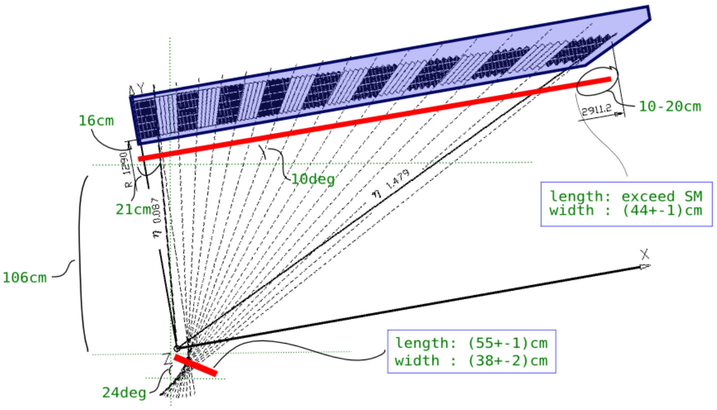

Figure 1: View of the experimental setup of the exposure of the ECAL supermodules to cosmic rays. Each supermodule is inclined by 10° to increase the mun flux through the fourth module. The scintillators providing a quasi pointing trigger are also sketched.

References

[CMS Collaboration (1994)] CMS Collaboration, CMS Technical Proposal, CERN/LHCC 94-38.

[CMS Collaboration (1997)] CMS Collaboration, The Elecromagnetic Calorimeter Project TDR, CERN/LHCC 97-33.

[W. Bertl et al. (2004)] W. Bertl *et al.*, Feasibility of Intercalibration of CMS ECAL Super-modules with Cosmic Rays, CMS NOTE-2004/036 and Eur. Phys. J. C http://dx.doi.org/10.1140/epjcd/s2005-02-007-y.

[GEANT4 web page] See http://geant4.web.cern.ch/geant4/.

[L. Bonechi (2004)] L. Bonechi, Misure di raggi cosmici a terra con l'esperimento ADAMO, Ph.D, Thesis, Università degli Studi di Firenze, 2004 (in Italian).

[Adzic et al. (2006)] Adzic, P., et al. 2006, European Physical Journal C, 46, 23

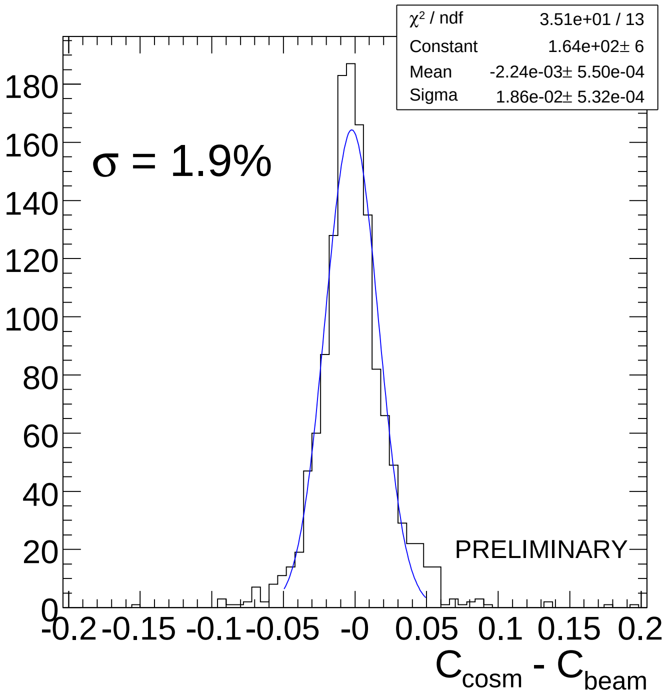

Figure 2: Comparison between the cosmic rays intercalibrations and the coefficients obtained by exposing the same ECAL supermodule (SM18) to an electron beam of 120 GeV. Crystals on the module boundaries have not been considered. An extensive study of possible sources of systematic uncertainties is ongoing.

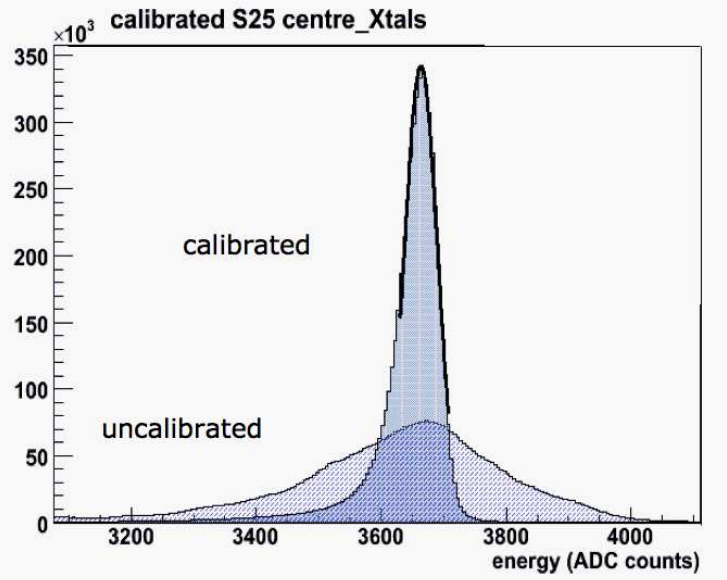

Figure 3: The energy reconstructed as S25 before and after the intercalibration in a whole supermodule.

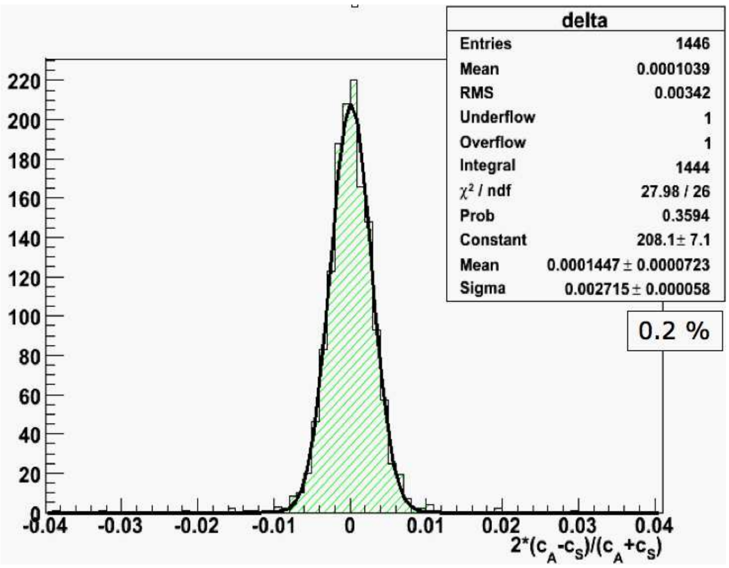

Figure 4: The relative difference of two pre-calibration measures for all the crystals of a supermodule. The width of the distribution is 0.27%, corresponding to an error on the coefficients of about 0.2%.

[L. Agostino et al. (2006)] L. Agostino *et al.*, CMS NOTE 2006/021