Calibration of the CMS Electromagnetic Calorimeter with cosmic muons

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Introduction

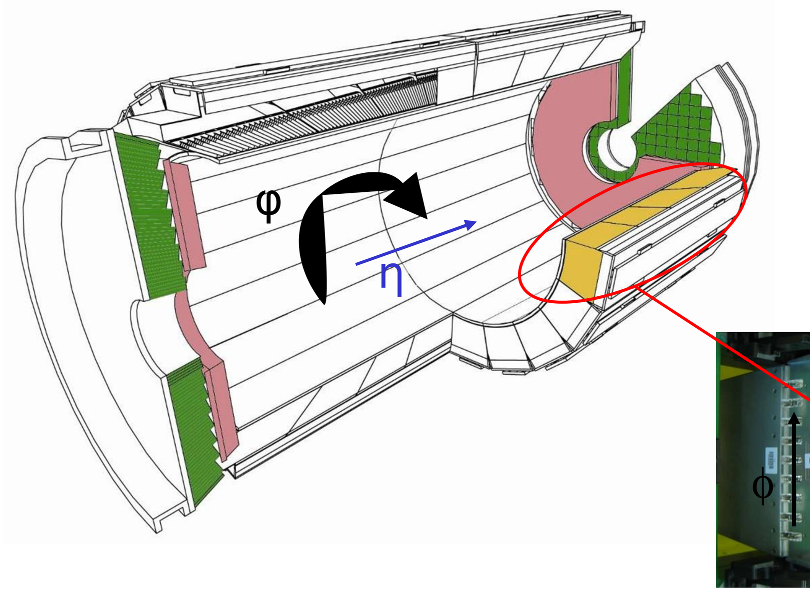
The CMS ECAL is a fine-grained hermetic calorimeter consisting of ~80000 lead tungstate crystals ($PbWO_4$) which provides fast response and radiation resistance and was designed to reach an excellent energy resolution, essential for the Higgs boson search in the $H \rightarrow \gamma\gamma$ channel.

In the barrel section, that extends to a pseudo-rapidity η of 1.479, the crystals are assembled in a 36 modular units, called *super-modules*. Each super-module contains 1700 crystals arranged into 20 crystals along φ times 85 crystals along η (see figure).

The scintillation light is read out by AvalanchePhotoDetectors (APDs), designed to work in the large magnetic field of 3.8 T.

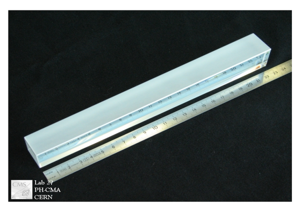
The ECAL readout has been design to measure energies up to 1.7 TeV deposited in the single crystal, while maintaining sensibility to a minimum ionizing particle, corresponding to ~250 MeV deposited energy.

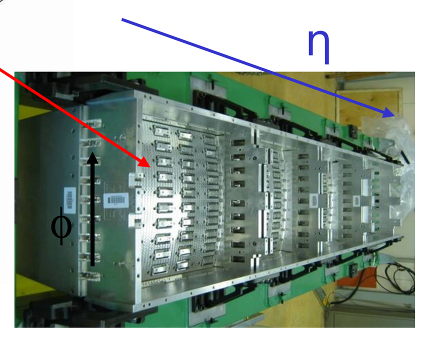
The performance of ECAL during Cosmic ray tests in 2008 are reported. These tests represent the first opportunity to exercise the entire barrel and endcap calorimeter as installed within CMS over an extended period of time. In particular, the tests performed during October-November 2008, after the closure of CMS and with the super-conducting magnet operating at 3.8T, represent the first full-scale test of CMS in its default configuration.



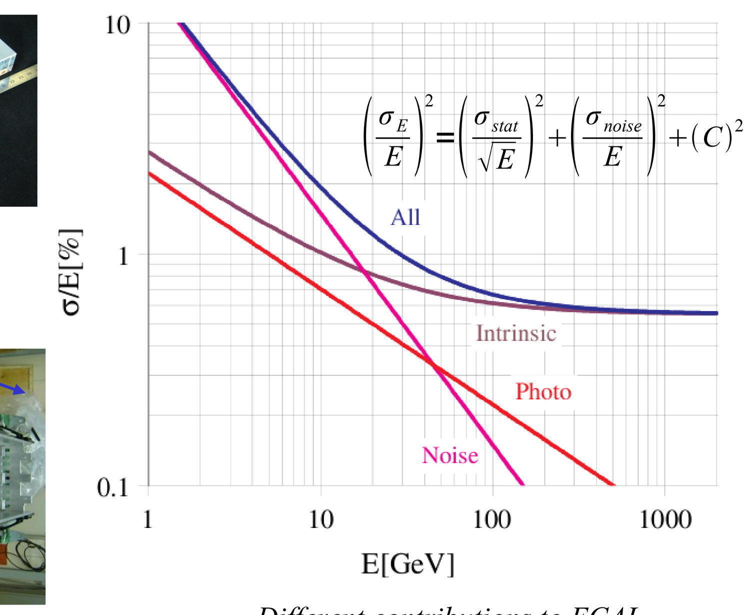
The CMS ECAL, schematic view

A $PbWO_4$ barrel crystal. Its dimensions are 25x25x230mm ($\Delta\varphi \times \Delta\eta$ = 0.0175 x 0.0175)





The mechanical structure of a super-module

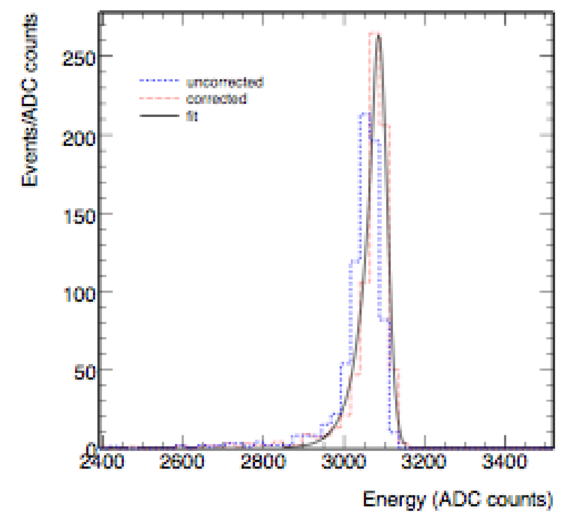


Different contributions to ECAL energy resolution

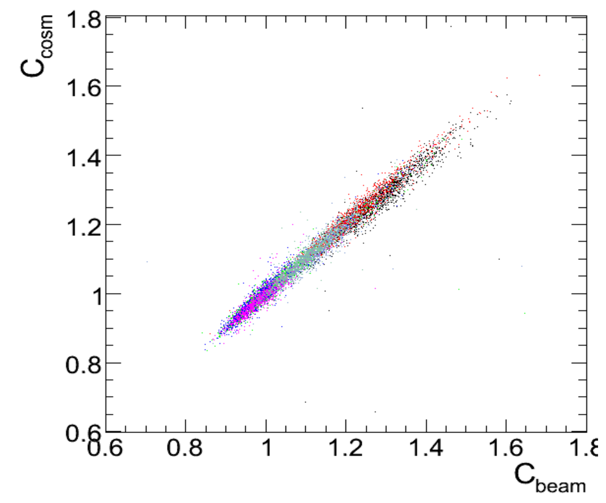
Pre-calibration before the final detector assembly

In the ECAL barrel, the spread in the crystal response after the assembly is around 13%, mainly due to the light yield differences between crystals. While the final calibration of the detector will be performed in situ employing physics events, an initial channel-to-channel calibration (*inter-calibration*) with a better accuracy is advisable.

- Nine super-modules (1/4 of the ecal barrel) have been calibrated in 2006 exposing them to a **120 GeV electron beam**. This technique gives very precise calibrations (**permill level**) that will also constitute a reference to study the performances of the in situ calibration at the start-up.
- All the super-modules of the barrel have been calibrated with **cosmic muons** before the assembly. This inter-calibration is based on the equalization of the response of the different crystals to the energy deposited by traversing muons (m.i.p.), aligned with the crystal axis. Each supermodule have been exposed to cosmic muon for about 10 days in a dedicated setup collecting about 5 million events. The precision of this technique, obtained by the comparison with the electron beam calibration, is on average **better than 2%**, with a dependence on η due to the variation with the angle of the cosmic muon flux.

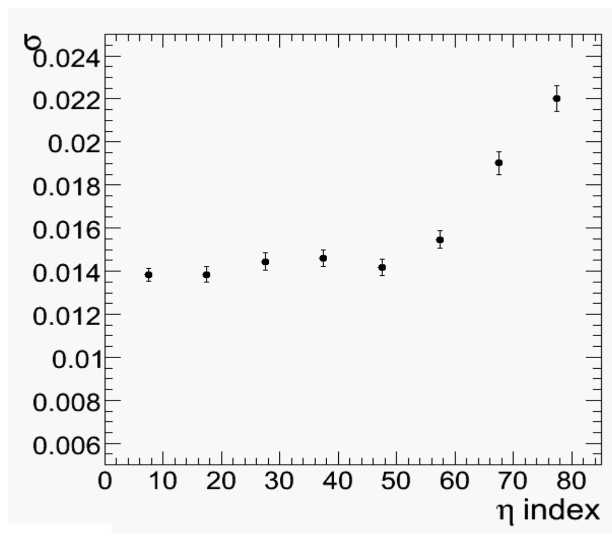


Typical distributions of the energy deposited by a 120 GeV election in one single crystal, before and after the correction for the impact point position. The calibration constants are obtained by equalizing the peak energy of the fitted distribution.



Scatter plot of the calibration coefficients from the test beam versus the ones from the cosmic muons. The different super-modules are plotted with different colours

Accuracy of the calibrations from cosmic muons versus the η index, from the comparison with test beam calibrations. η index 1 and 85 correspond respectively to the center and at the end of the barrel.



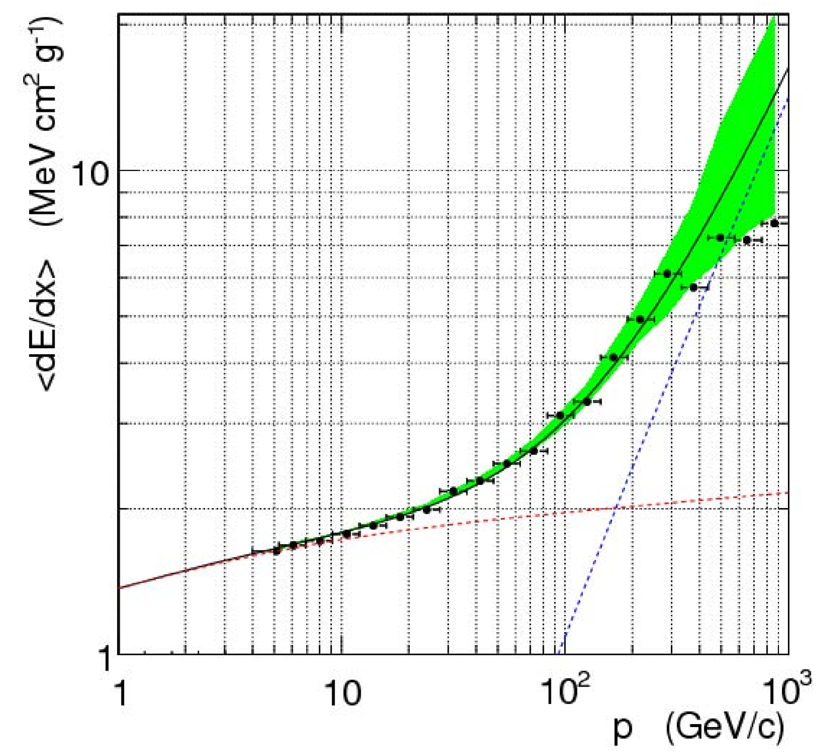
Check of the calibration with CRAFT data

The assembled CMS detector has been commissioned with cosmic muons in Fall 2008, collecting more than 600 million events during CRAFT runs (CosmicRunAtFourTesla). The **muon stopping power dE/dx** in lead tungstate has been computed thanks to:

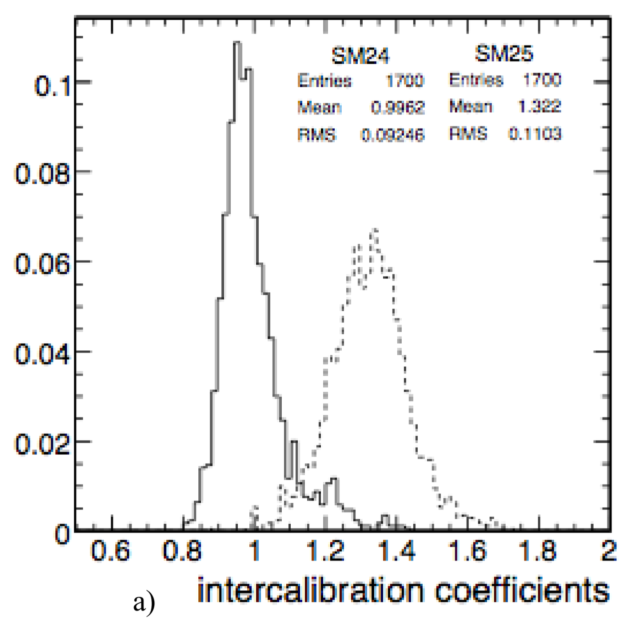
- the measurement of the muon energy loss in ECAL via clusterization algorithms that collects different crystal energy losses (ΔE)
- the measurement of the muon momentum in the inner silicon tracking system (p)
- finite-step track extrapolation through the ECAL volume to estimate the path length in $PbWO_4$ (Δx)

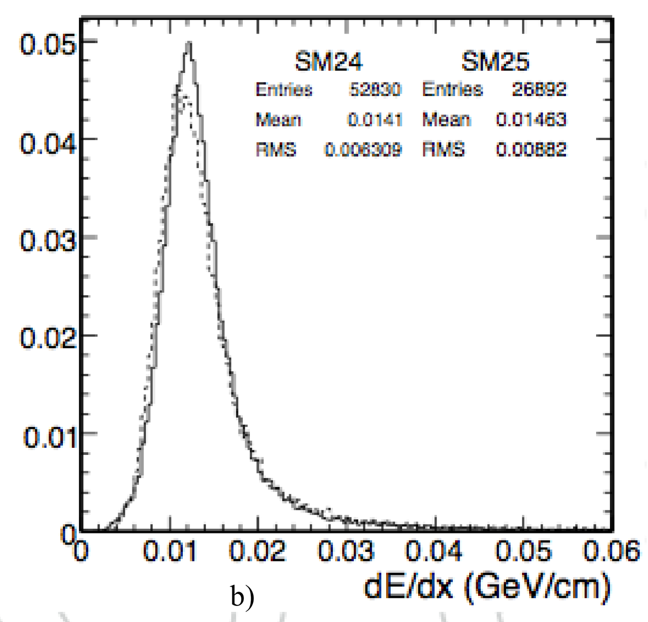
Comparison of measured <dE/dx> vs. p with the expected values allow to check the global energy scale of the calorimeter. Given the systematics connected to the ECAL exposure to the muon flux and the energy clusterization algorithm, the energy scale fixed at test-beam (~100 GeV) is transported to the cavern for ~250 MeV muons at the level of few percents.

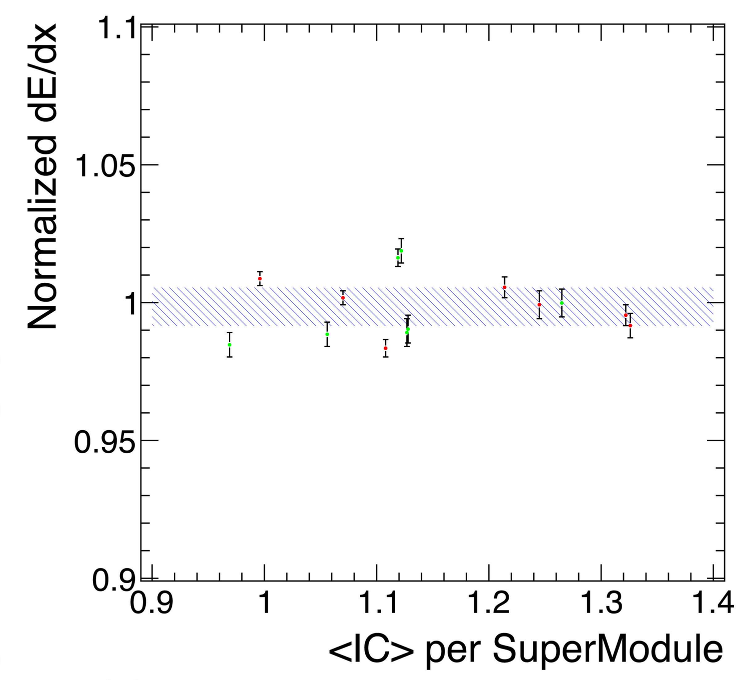
Local dE/dx measurement in barrel sub-regions (14 super-modules / 16 η rings) also allow a check of the inter-calibration scale. Only muons with p < 10 GeV/c have been selected for these tests, so that energy loss via ionization is the dominant process. The uniformity of ECAL response is found at the level of 1%.

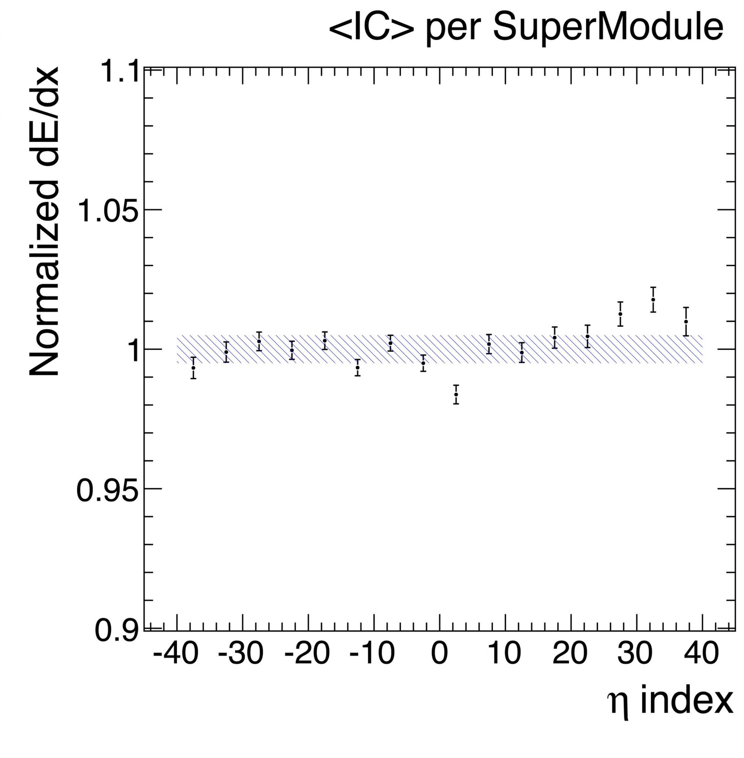


Stopping power as a function of the muon momentum, as measured in ECAl (blue dots). The continuous black line represents the expected values for the $PbWO_4$. The dashed lines are the collision loss (red) and the bremsstrahlung radiation.









Validation of EB inter-calibration constants using cosmic-ray muons:

a)distribution of inter-calibration constants for 2 super-modules, calculated prior to installation
b) measured dE/dx distributions for the same SMs using cosmic muons, after inter-calibration constants have been applied
c) average dE/dx versus mean inter-calibration constants for 14 supermodules: spread is at 1.5%
d) average dE/dx computed for different η rings: spread is at 0.6%

Conclusions

The ECAL detector have been pre-calibrated, before its installation in the cavern, with an accuracy at the level of 1.5% in the barrel and around 10% in the endcap, giving good performances already at the start up.

The first data taken with all the sub-detectors in their final configuration have shown that the previously determined energy scale and channel-to-channel inter-calibration have preserved after CMS installation in the pit, within the precision attainable with cosmic muons underground.

Different techniques for the ECAL inter-calibration with few pb^{-1} of integrated luminosity have been studied and promise a good accuracy in the barrel region. The performances of these techniques for the endcap region are currently under study.