Calibration of the Electromagnetic Calorimeter of CMS

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Abstract

The electromagnetic calorimeter (ECAL) of the CMS experiment, that will take data at LHC, has been designed to get an excellent energy resolution, essential to search for di-photonic resonances. ECAL is made of lead tungstate crystals whose individual response depends on several contributions and this variation affects the resolution of the whole detector. Hence, a channel to channel intercalibration is required to get the goal performances.

The calibration of the detector at the start-up, the in-situ calibration strategies and their commissioning with first data will be reported.

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Calibration of the Electromagnetic Calorimeter of CMS

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Summary. — The electromagnetic calorimeter (ECAL) of the CMS experiment, that will take data at LHC, has been designed to get an excellent energy resolution, essential to search for di-photonic resonances. ECAL is made of lead tungstate crystals whose individual response depends on several contributions and this variation affects the resolution of the whole detector. Hence, a channel to channel intercalibration is required to get the goal performances. The calibration of the detector at the start-up and the in-situ calibration strategies will be reported.

1. – Introduction

The Compact Muon Solenoid (CMS) [1] [2] is one of the two general purpose detectors installed at the CERN LHC. Its main physics goals are the observation of the Higgs boson and the search for new physics phenomena. For a mass below 150 GeV/c², the Higgs decay into two photons is a promising signature for the discovery. In this mass range, the Higgs width is very narrow and the signal lies above an irreducible background: this led to the choice of a high resolution electromagnetic calorimeter.

The electromagnetic calorimeter (ECAL) [3] of the CMS, located within a 3.8 T superconducting solenoid, is a hermetic homogeneous calorimeter comprised of lead tungstate (PbWO₄) crystals and a lead-silicon preshower. The PbWO₄ has high density (8.3 g/cm³) and short radiation length (0.89 cm) allowing a compact design of the calorimeter, while its small Moliere radius (2 cm) guarantees a high granularity. The crystals have to withstand the high ionizing radiation levels during LHC running: the radiation hardness of the crystals enables to have only loss of light transmission without changes to the scintillation mechanism. This effect can be tracked and corrected for by monitoring the optical transparency with injected light, provided by a fiber-distributed laser system. The ECAL photo-detectors must operate in the 3.8 T field and have a sizable gain because of the low light output of PbWO₄. In the barrel avalanche photo-diodes (APDs) are used, while radiation-resistant vacuum photo-triodes are used in the end-caps.

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2. – Installation and commissioning

An excellent energy resolution is essential for different physics analyses to be performed. The stochastic and electronic noise contributions to the energy resolution of ECAL have been measured with known energy electron beams and demonstrated to be within the design requirements of the detector. The main contribution to the overall ECAL energy resolution is therefore due to the channels response uniformity. The calibration procedures are designed to determine the coefficients that equalize the crystals responses to a reference signal. Specific pre-calibration operations were designed and carried out during the commissioning phase of ECAL, to provide an acceptable detector performance at the start-up of LHC operation.

One fourth of the supermodules was exposed to electron test beams [4]. A 90 GeV/c and 120 GeV/c electron beam were used and a comparison between the coefficients measured for one supermodule at one-month interval showed a 0.3% accuracy in the calibration.

In addition, a method exploiting neutral pions measurements was studied. Data were collected with one supermodule exposed to a $\pi^0$ flux produced by a $\pi^-$ beam incident on an aluminium target. To perform the intercalibration the $\pi^0 \rightarrow \gamma \gamma$ decays were selected and the invariant mass of the reconstructed meson was used as a constraint on the energy of the photons. With this test, the viability of intercalibration method using $\pi^0 \rightarrow \gamma \gamma$ decays with collision data was established.

The most precise determination of the pre-calibration coefficients for the whole ECAL barrel is provided by a campaign of measurements performed with cosmic ray muons. Cosmic ray muons, that traversed the crystals along their length and whose direction is approximately aligned to the crystal axis, were selected so that the same amount of energy was released in each crystal. After assembly and before installation in CMS, all 36 supermodules were exposed, in turn, to cosmic ray muons for a period of about one week, on a cosmic ray stand hosting one supermodule at a time. A 2% accuracy has been obtained.

While preparing colliding beams, the LHC delivered to the CMS several beam “splash” events, when one of the beams was deliberately addressed onto collimators located 150 m away from the CMS interaction point, producing a muon flux which reached the cavern and traversed horizontally the CMS detector. The test of the local uniformity in the corresponding energy deposition allowed to validate and improve ECAL endcap intercalibrations [5].

A rapid and precise calibration of the CMS electromagnetic calorimeter can be performed in situ through online selection of neutral mesons ($\pi^0$ and $\eta$), exploiting the meson mass constraint on the energy of the two photons from $\pi^0/\eta \rightarrow \gamma \gamma$ decay.

Another technique with the very first data is the use of the invariance around beam axis of the energy flow in minimum bias events ($\phi$-symmetry).

The absolute energy scale of the calorimeter can be obtained exploiting electron decay of Z boson and its invariant mass constraint.

During LHC operation, once the CMS tracker is well aligned, the intercalibration of different crystals will be performed by comparing the momentum and energy of isolated electrons [6]. About 5 fb$^{-1}$ of integrated luminosity is required to gain the goal precision.
3. – Conclusions

Calibration performed during the commissioning phase of the detector provides an acceptable performance of the electromagnetic calorimeter of the CMS experiment for startup physics. The ultimate calibration accuracy to get an excellent energy resolution will be achieved in situ by exploiting several independent procedures.

REFERENCES