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Calibration of the CMS Electromagnetic Calorimeter with first LHC data

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Abstract

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Calibration of the CMS Electromagnetic Calorimeter with first LHC data

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The electromagnetic calorimeter (ECAL) of the CMS experiment is a high-granularity, homogeneous, hermetic detector made of lead tungstate crystals. Its potential performances are outstanding in terms of energy resolution, dynamic range and noise level. However, the energy resolution depends crucially on the channel to channel inter-calibration precision. Thus, intercalibrating ECAL in situ at the LHC to achieve the designed energy resolution approaching 0.5% for high-energy unconverted photons is essential to fully exploit the physics reach of the detector, particularly for the discovery of the Higgs boson in the two-photon decay channel. A detailed description of the strategies for in situ calibration of the calorimeter in 2010 is given, focusing on the crystal inter-calibration with the ϕ -symmetry and π^0 methods. Preliminary results based on first collision data are presented.

1. INTRODUCTION

The electromagnetic calorimeter (ECAL) [1] of the CMS experiment is an homogeneous, hermetic detector made of about 76000 lead tungstate (PbWO₄) scintillating crystals. It has a cylinder-like geometry with a central barrel (EB) closed at each end by an endcap (EE). EB is organized in 36 supermodules and provides coverage in pseudorapidity up to $|\eta| < 1.5$. The two endcaps consist of four half-disks, each containing 3662 crystals, and extend the η coverage to ± 3.0 . The scintillation light is detected by avalanche photodiodes (APDs) in the barrel and vacuum phototriodes (VPTs) in the endcaps. The EE is additionally instrumented with a preshower detector (ES) on its front faces, consisting of a two layer lead-silicon sampling calorimeter. The ECAL energy resolution can be parametrized as:

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c \quad (1)$$

where the three contributions correspond to the stochastic, noise, and constant terms, respectively. The parameters a and b have been measured with electrons at test beams and were found to be within the design requirements [2]. The target value for the constant term is 0.5%; since c is strongly affected by the non uniformity in the

channel-to-channel response, an accurate inter-calibration strategy is necessary to achieve this goal.

In the following we describe the procedure developed by the CMS Collaboration for deriving the corrections for variations in the channel response across the detector (*inter-calibration constants*). The measurement of the barrel supermodule relative scale performed with the first LHC data is also presented.

2. PRE-CALIBRATION

An extensive 10 year long pre-calibration program [3] was carried out on ECAL to provide an acceptable performance at startup.

The main sources of non uniformity in the channel-to-channel response are the crystal light yield variation in the barrel, about 13% at construction, and the gain spread of the photodetectors in the endcaps, about 25%. Laboratory measurements of these parameters have been used to provide preliminary estimates of the inter-calibration coefficients, with an achieved precision of 5% in the EB and 8% in EE.

Nine barrel supermodules and about five hundred endcap crystals were calibrated using electron beams of 90 and 120 GeV at CERN. With a precision of 0.3%, this technique is the most accurate

inter-calibration performed so far and provides a benchmark for any further inter-calibration procedure.

Before the installation in CMS, all the barrel supermodules were commissioned in turn on a cosmic ray stand for a period of about one week. From these data, inter-calibration constants with an accuracy better than 1.5% over most of the volume of a supermodule, rising to 2.2% at the outer end (corresponding to $|\eta| < 1.5$) were derived.

After installation in the LHC, circulating beams were stopped in collimators 150 m away from CMS in September 2008 and November 2009. The resulting beam dump events were used to intercalibrate EE crystals. The precision achieved is 6%.

Based on all these measurements a set of pre-calibration constants was derived. In the barrel it was decided to select the best calibration available and combine constants from different sources only when the precision was comparable; in the endcaps calibration coefficients coming from different sources were always combined. The precision achieved with the pre-calibration process is between 0.3% and 2.2% in EB and 5% in EE (below 1% for the 500 crystals calibrated with beam). These pre-calibration coefficients were used in the first reconstruction of LHC data; in situ calibration methods determine the corrections to these factors.

3. IN SITU CALIBRATION

Several methods have been developed for the calibration in situ. Two of them, the ϕ -*symmetry* and the $\pi^0(\eta)$ method, were meant to provide a fast inter-calibration at the LHC startup.

The first is based on the assumption that the energy flow in minimum-bias events is invariant around the beam axis. Therefore, the calibration is performed by comparing the total energy deposited in each crystal with the mean of the distribution of the total energies for all crystals in the same ring. This method inter-calibrates channels at the same pseudorapidity; other techniques are needed to inter-calibrate regions at different $|\eta|$.

The $\pi^0(\eta)$ method uses unconverted photons from π^0 and η decays, reconstructed in fixed arrays of crystals. The π^0/η candidates are selected based on shower shape and kinematical cuts and the crystal inter-calibration coefficients are derived through an iterative procedure in which the π^0/η mass is used to constrain the photon energy.

At the time of writing, a first set of in situ crystal-by-crystal inter-calibration constant has been estimated for the barrel by applying these two methods on the available statistics (123 nb^{-1}). A precision of 1.2% has been achieved in the central part of the barrel, in good agreement with Monte Carlo expectation. Details can be found in [4].

In the long term the most promising technique to intercalibrate the calorimeter is the one using the E/p peak for isolated electrons from the $W \rightarrow e\nu$ decay. Electrons which radiate a small fraction of their energy are selected and the track momentum measured in the silicon tracker is compared with the calorimetric energy in a 5×5 crystal matrix. This method has not been applied yet.

Due to radiation damage the transparency of the crystals will change in the course of the LHC life. These variations will be monitored and corrected using a laser-based system. At the moment, due to the low instantaneous luminosity, crystal transparency changes have negligible effect on the ECAL response.

4. BARREL SUPERMODULE SCALES WITH THE FIRST LHC DATA

As explained in section 2, test beam and cosmic ray data provided an intra-module inter-calibration. The consistency of the relative scale among supermodules was checked with the first LHC data. The measurement was performed with the 0.01 nb^{-1} collected in 2009 at $\sqrt{s} = 900 \text{ GeV}$ and repeated in 2010 with the first 8.8 nb^{-1} collected at $\sqrt{s} = 7 \text{ TeV}$. Results were found consistent. In particular, it was assessed the fact that three supermodules have a scale miscalibration greater than 2%.

Figure 1 shows, for the 2010 data, the comparison of the supermodule scales derived with the ϕ -*symmetry* and the π^0 method. The agreement

between the two sets of results is good. Since the inter-calibrations with the two techniques are performed independently, a comparison between their results provides a useful cross-check. The supermodule scales obtained with the two methods were combined and the precision on the resulting values was derived from the distribution of the scales for supermodules which were pre-calibrated at the test beam. The width of this distribution, 0.5%, is the convolution of the precision of the test beam pre-calibration and the in situ inter-calibration, and gives therefore an upper limit on the systematic error of the in situ measurement.

The π^0 invariant mass distribution obtained with 0.31 nb^{-1} is shown in figure 2, with the fit superimposed. The selected sample contains about $1.4 \cdot 10^7$ signal π^0 decays. The π^0 peak width and the S/B ratio were found in good agreement with the results obtained on fully simulated minimum bias events.

Figure 1. Barrel relative supermodule scales derived by means of the ϕ -symmetry and the π^0 method.

Figure 2. π^0 invariant mass distribution obtained with 0.31 nb^{-1} .

5. CONCLUSION

Thanks to an extensive pre-calibration process, the electromagnetic calorimeter of the CMS experiment has recently started taking data with a inter-calibration precision between 1.5% and 2.2% in the barrel and around 5% in the endcap. The supermodule relative scales were checked with the first data collected at LHC using ϕ -symmetry and π^0 methods. Results from the two techniques were found consistent. With the sample size currently available (123 nb^{-1}) an inter-calibration precision of 1.2% has been achieved in the central region of the barrel.

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