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Calibration of the Electromagnetic Calorimeter of the CMS experiment

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Abstract

The electromagnetic calorimeter (ECAL) of the CMS experiment is an homogeneous, hermetic detector with high granularity. Its potential performances are outstanding in terms of energy resolution, dynamic range and noise level. These characteristics make the calorimeter the most powerful device in the search of the decay in two photons of the Higgs particle. However, the energy resolution depends crucially on the channel to channel intercalibration precision. Therefore, great attention must be given to the calibration process. In this contribution we will describe the strategy that the ECAL group has devised to calibrate the detector. We will report on the pre-calibration processes that have already been performed, the strategies for intercalibration at startup and those foreseen when sufficient statistics will be accumulated to use W and Z events. For the normal data taking regime, an intercalibration precision of 0.5% should be reached, while the response of the detector will be monitored regularly.

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Calibration of the Electromagnetic Calorimeter of the CMS experiment

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The electromagnetic calorimeter (ECAL) of the CMS experiment is an homogeneous, hermetic detector with high granularity. Its potential performances are outstanding in terms of energy resolution, dynamic range and noise level. These characteristics make the calorimeter the most powerful device in the search of the decay in two photons of the Higgs particle. However, the energy resolution depends crucially on the channel to channel intercalibration precision. Therefore, great attention must be given to the calibration process. In this contribution we will describe the strategy that the ECAL group has devised to calibrate the detector. We will report on the pre-calibration processes that have already been performed, the strategies for intercalibration at startup and those foreseen when sufficient statistics will be accumulated to use W and Z events. For the normal data taking regime, an intercalibration precision of 0.5% should be reached, while the response of the detector will be monitored regularly.

1. Introduction

The CMS electromagnetic calorimeter (ECAL) has a cylinder-like geometry composed of a *barrel* and two *endcaps* of lead tungstate (PbWO₄) scintillating crystals. The *cylinder* has a length of about 7m and a radius of about 1.4m. The almost 76000 crystals, each 26 radiation length long, are arranged in a projective geometry. The barrel is composed of 36 supermodules of 1700 crystals, the endcap of 4 D-shaped modules. The crystals are read by APD in the barrel and VPT in the endcap. For a full description of the detector see references [1], [2]. To fully exploit the capabilities of this highly granular, hermetic, high resolution detector it is essential to calibrate it with a precision of the order of 0.5%. In the following we describe the strategy that the CMS collaboration has devised to achieve the best possible calibration in three time spans: before the beginning of the experiment, at startup, and in a medium and long term.

2. Impact of calibration precision on energy resolution

The energy resolution of the CMS ECAL in the barrel region can be parametrized in the form [3]:

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{3.37\%}{\sqrt{E}}\right)^2 + \left(\frac{0.11\%}{E}\right)^2 + (0.25\%)^2$$

The first term is statistical, the second is the noise term and the constant term is the one affected by corrections and inter-calibrations. Inter-calibration precision plays a crucial role in the detection of the $H \rightarrow \gamma\gamma$ decay, where the constant term dominates. Mis-calibration has a dramatic effect on the experimental width of the Higgs resonance. Excellent mass resolution is needed to distinguish the resonance from the background.

3. Precalibrations with electron beam and cosmic muons

Before installation in the CMS detector, 9 of the 36 supermodules of the barrel were precisely calibrated using the H4 electron beamline at Cern, using electrons of 90 and 120 GeV with a momentum spread around 0.09%. The intercalibration precision achieved with this technique is 0.3%. The reproducibility of the calibration has been tested by studying the distribution of the difference between the inter-calibration constants from a supermodule exposed to beam in two occasions separated by an interval of one month. The mean of the distribution is 1.5×10^{-4} while

the sigma is 3×10^{-3} , showing an excellent reproducibility. In the energy reconstruction process, the main correction to be applied is the one accounting for dependence of the crystal response on the point of impact. The remaining 27 supermodules will rely on the calibration performed using cosmic ray muons. The inter-calibration precision is between 1.5% and 2.5% depending on the pseudorapidity. The plot on figure 1 shows the intercalibration precision as a function of eta index for one of the supermodules. The precision is defined as the RMS spread of the difference between intercalibration coefficients obtained from the test beam and cosmic ray data. For this measurement, the coincidence of two planes of scintillator was used to trigger the data acquisition system. Muons along the axis of the crystals were selected by vetoing neighboring channels offline. For the endcaps, intercalibrations at startup will rely on laboratory measurements of light yield and photodetector (VPT) gain, giving a precision around 9%.

Figure 1. Intercalibration precision obtained by calibrating the barrel using cosmic muons as a function of pseudorapidity. One unit of eta index corresponds to $\Delta\eta=0.0175$.

4. Intercalibration with first data

It is very important to start the experiment with a reasonable intercalibration for several reasons, the most important of which is the fact that the electromagnetic trigger will not function properly otherwise. In this section we describe the means by which the ECAL will be reasonably well intercalibrated at startup ([4]).

4.1. Intercalibration with $\pi^0 \rightarrow \gamma\gamma$

A powerful calibration method uses unconverted photons pairs that are reconstructed in fixed arrays of crystals and form a π^0 decay candidate, based on shower shape and kinematical cuts. Simulations show that a 0.5% calibration precision can be achieved in a few days even at startup luminosities. This method requires a special software trigger, since the transverse energy of the calibration π^0 is of the order of a few GeV, well below the acceptance threshold of the normal CMS High Level Trigger. In figure 2 we show the invariant mass of photon pairs with π^0 selection cuts, reconstructed from a sample of QCD events.

Figure 2. Invariant mass of photon pairs on a simulated sample of QCD events, with π^0 selection cuts

4.2. Intercalibration with azimuthal symmetry of energy deposits

The azimuthal symmetry of energy deposits from minimum bias events can be exploited to intercalibrate rings of crystals at constant pseudorapidity. Conversions and radiation in the tracker material define the systematic limit to this method. In contrast, the method is very fast, allowing to obtain calibration constants in a few hours with 1 kHz of minimum bias trigger rate, even at low luminosities. The plots in figure 3 show the intercalibration precision obtained with 18 millions of simulated minimum bias events in blue, while the limit on precision, assuming no knowledge of tracker material, is in red. The worsening of the precision at $\eta = 1$ is due to the increase of material in front of the calorimeter. In the endcap the trend as a function of eta is reversed: intercalibration precision goes from 4% at low pseudorapidities, to less than 1% at high pseudorapidities, reflecting the distribution of material in the tracker.

4.3. Intercalibration with $Z \rightarrow ee$ decays

Z decays are valuable in a number of tasks, such as tuning of corrections, setting the absolute energy scale or intercalibrate regions of the calorimeter. In particular, it can provide ring by ring inter-calibration to be used in conjunction with azimuthal symmetry. The estimated precision is 3% at $10pb^{-1}$ and 1% at $100pb^{-1}$.

5. Medium and long term strategy

In this section we will describe the ways in which we intend to calibrate the calorimeter once sufficient statistics on physics signals will be accumulated.

5.1. Intercalibration with isolated electrons

The most promising method to intercalibrate the calorimeter with about $5fb^{-1}$ is the one using the E/p peak for isolated electrons from the $W \rightarrow e\nu$ decay. The track momentum is compared with the calorimetric energy in the 5×5 crystal matrix. Electrons which radiate a small fraction of their energy must be selected. This method requires a fully functional and well aligned tracker. The plot

Figure 3. Intercalibration precision achievable with the azimuthal symmetry method as a function of pseudorapidity for simulated minimum bias events. The red points show the systematic limit.

in figure 4 shows the inter-calibration precision as a function of pseudorapidity with $5fb^{-1}$ in the barrel and $7fb^{-1}$ in the endcap. The precision is mostly between 0.4% and 1.5%. With $30fb^{-1}$, a precision below 0.5% everywhere in the barrel and below 1% in the endcap will be achievable.

5.2. Absolute energy scale with $Z \rightarrow \mu\mu\gamma$

The $Z \rightarrow \mu\mu\gamma$ decay provides a method to determine the absolute energy scale using a nearly background-free signal, with no need of bremsstrahlung recovery corrections. The expected rate is 1 γ /crystal at $1fb^{-1}$ per unit of photon rapidity for photons between 15 and 30 GeV of transverse energy.

5.3. Crystal stability

The transparency of the crystals will change in the course of the LHC cycle due to radiation damage, and is partly recovered over a few hours without beam. A laser system will accurately monitor

Figure 4. Intercalibration precision obtained from simulation using isolated electrons as a function of pseudorapidity

the transparency of each crystal by injecting light during the LHC abort gaps. The plot in figure 5 shows the expected evolution of the transparency based on test beam data. The plot in figure 5 illustrates the stability after laser corrections measured during dedicated irradiation runs at the test beam.

6. Summary

The electromagnetic calorimeter of the CMS experiment will start data taking with a calibration between 1.5% and 2.5% in the barrel and around 9% in the endcap. The level of precision reached in the barrel is such that the width of the Z resonance is not affected. A few hours of running will allow to consolidate intercalibration constants in the barrel and significantly improve in the endcap using azimuthal symmetry, soon to be complemented by inter-ring intercalibration provided by $Z \rightarrow ee$. A few days of running should be sufficient to lower the intercalibration precision in the barrel to 0.5% with $\pi_0 \rightarrow \gamma\gamma$. Studies are ongoing to apply this method to the endcaps as well. With about 5 fb^{-1} , isolated electrons from $W \rightarrow e\nu$ will intercalibrate most of the barrel at a 0.5 % level and the whole calorimeter below 1.5%. With more statistics, levels will be

Figure 5. Effect of radiation damage on crystal response during a test beam, and response after laser corrections are applied.

low 0.5 % in the barrel and 1% in the endcap can be reached. The energy scale will be set by $Z \rightarrow ee$ and $Z \rightarrow \mu\mu\gamma$. The laser monitoring system will be used to properly take into account the variation of the transparency of the crystals with accumulated dose.

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