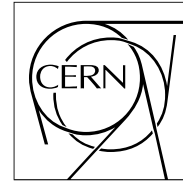


The Compact Muon Solenoid Experiment  
**Conference Note**

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# Inter-calibration of the CMS Barrel Electromagnetic Calorimeter Using $\pi^0 \rightarrow \gamma\gamma$ Decays

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## Abstract

Inter-calibrating the electromagnetic calorimeter (ECAL) of the CMS detector *in situ* at the LHC to achieve the energy resolution approaching 0.5% at high energy is going to be important to fully exploit the physics reach of the detector, particularly for the discovery of the Higgs boson in the two-photon decay channel. In this paper we evaluate the potential of a calibration technique that makes use of photon pairs produced in neutral pion decays,  $\pi^0 \rightarrow \gamma\gamma$ . Such photon pairs will be selected from the QCD events accepted by the Level-1 triggers using an online filter farm. Assuming a Level-1 trigger rate of 12.5 kHz, the rate of suitable neutral pions is found to be about 0.9 kHz.

We show that 95% of the barrel electromagnetic calorimeter can be calibrated to at least 1% (0.5%) precision after several days (weeks) of data-taking in the low-luminosity scenario of LHC,  $\mathcal{L} = 2 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ . In addition, we show that a 1% calibration precision is achieved with  $\pi^0$  decays produced in the  $\pi^-$  test beam runs during November 2006. The obtained calibration constants are successfully used for the reconstruction of 50 GeV electrons from the test beam data.

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# 1 Introduction

The Compact Muon Solenoid (CMS) barrel electromagnetic calorimeter consists of 61200 lead tungstate crystals arranged in 170  $\eta$ -rings of 360 crystals each. The ECAL energy resolution has been determined in test beams to be  $\frac{\sigma(E)}{E} = \frac{2.9\%}{\sqrt{E(\text{GeV})}} \oplus \frac{0.130 \text{ GeV}}{E} \oplus 0.4\%$  [1], for electrons incident on the center of crystals. For electrons and photons with energies above 100 GeV, the energy resolution is dominated by the constant term. As a consequence, the performance of the CMS ECAL at the LHC will depend mainly on the quality of its calibration and monitoring. Achieving the design-goal calibration precision of 0.5% will be particularly important for a discovery of the Higgs boson in the decay channel  $H \rightarrow \gamma\gamma$ , one of the primary goals of the LHC physics program. Several other calibration strategies have already been considered by the CMS ECAL community[2]. In this paper, we investigate the feasibility of inter-calibrating the CMS ECAL barrel region ( $|\eta| < 1.479$ ) with photon pairs produced by  $\pi^0 \rightarrow \gamma\gamma$ .

## 2 Selection of $\pi^0$ Candidates in the ECAL Barrel

A sample of about four million fully simulated QCD events is used for selection and calibration exercise. The low-luminosity scenario,  $\mathcal{L} = 2 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ , is assumed.

Photon pairs produced in neutral pion decays are planned to be selected on an online filter farm from all events accepted by the Level 1 (L1) trigger. To facilitate the future transition to the demanding environment of the online filter farm, the selection of  $\pi^0$  candidates decays is based on ECAL variables from localized regions around the  $\pi^0$  candidates.

The energy of photon candidates is defined as the sum of energies deposited in crystals forming the  $3 \times 3$  matrix centered on the crystal with the highest energy deposit,  $S_9 \equiv \sum_{3 \times 3} C_i \cdot E_i$ , where  $C_i$  denotes the crystal's calibration constant and  $E_i$  the energy deposited in this crystal. The direction of flight is obtained by calculating the weighted averages of the positions of the constituent crystals, where the weight is given by the logarithm of the crystal energy.

Only photon candidates with transverse energy above 1 GeV are considered. The  $S_4/S_9$  and  $S_9/S_{25}$  ratios are required to be above 0.9. Here, the quantities  $S_9$  and  $S_{25}$  correspond to the energies deposited in the  $3 \times 3$  and  $5 \times 5$  crystal matrices centered on the crystal with the highest energy deposit, respectively. The quantity  $S_4$  is the highest value of energies deposited in the four possible combinations of  $2 \times 2$  crystal matrices containing the most energetic crystal. The  $\pi^0$  candidates are then selected by requiring more than 3.5 GeV transverse energy. To remove pairs with one or more converted photons, a cut on the sum of energy depositions around the  $\pi^0$  candidate is also applied. The average energy of the selected  $\pi^0$ 's is found to be about 8 GeV.

### 2.1 Selection Efficiency and Purity

The obtained invariant mass distribution is fitted to a combination of a Gaussian and a polynomial function (see Figure 1). The selection efficiency is then calculated as the ratio of the number of selected  $\pi^0$ 's which match with generator-level  $\pi^0$ 's within  $\pm 3\sigma_{fit}$  around the mass peak to the total number of simulated QCD events which passed L1 trigger. However, the signal-to-background ratio ( $S/B$ ) is estimated using a narrower window of  $\pm 2\sigma_{fit}$  because the calibration performance is dominated by photon pairs near the peak. The total  $\pi^0$  rate is found to be  $0.87 \pm 0.03 \text{ kHz}$ , assuming a L1 event rate 12.5 kHz [3], while the  $S/B$  ratio is found to be about two.

## 3 Calibration with $\pi^0 \rightarrow \gamma\gamma$ Decays

Several calibration algorithms have been studied and found to produce consistent results. One them is described below.

For a given crystal, the invariant mass distribution is obtained from all  $\pi^0$  candidates for which one of the photons is centered on this crystal. Iteratively, the calibration constants are updated according to the peak positions of such distributions. The energy and direction of each photon candidate are recalculated using the updated calibration constants. An initial miscalibration, typically about 4%, is applied before the first iteration. The calibration precision is then estimated as the R.M.S. of the distribution of the products of the initial miscalibration and final calibration constants.

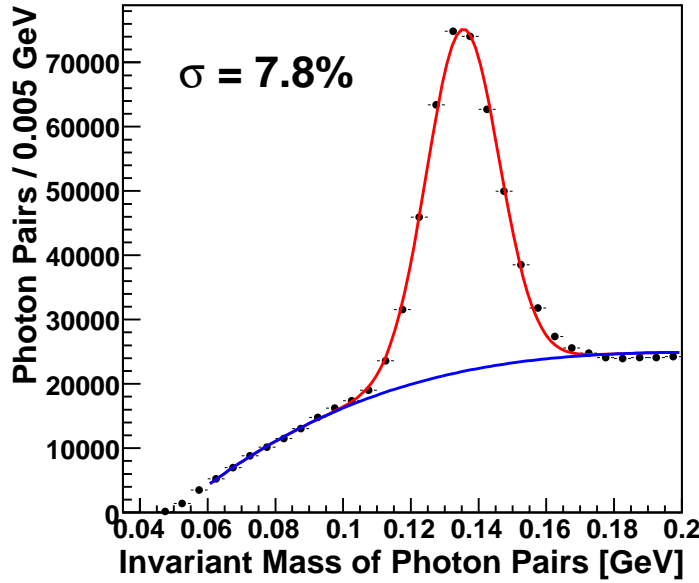


Figure 1: The  $\gamma\gamma$  invariant mass distributions together with the results of the fit to a combination of a Gaussian and a polynomial.

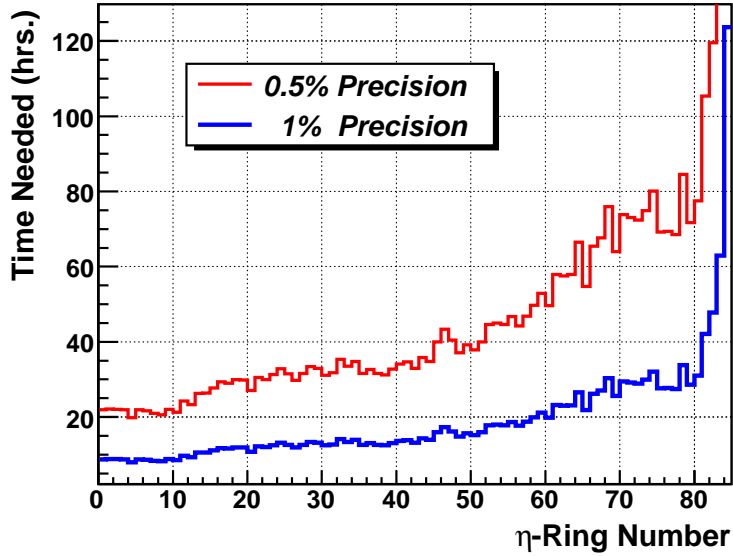


Figure 2: Time of continuous data-taking required to achieve calibration precisions of 1% and 0.5% for crystals in different  $\eta$ -rings.

### 3.1 Performance of the $\pi^0 \rightarrow \gamma\gamma$ Calibration

Before crystal-to-crystal calibration, a correction depending on  $\eta$  and  $\phi$  index of crystals is applied in order to remove the systematic effects due to the gaps between the ECAL modules and due to the implementation of a noise-suppression algorithm. The dependence of the calibration precision on the number of selected signal  $\pi^0$  decays,  $n_{\pi^0}$ , and  $S/B$  ratio is determined by varying  $n_{\pi^0}$  and  $S/B$  separately. Then we translate the obtained results into the time needed to achieve a given level of calibration precision for different  $\eta$  regions of ECAL. Figure 2 shows that the time required to achieve a 0.5% precision ranges from about 20 hours for  $|\eta| \simeq 0$  to about 130 hours for  $|\eta| \simeq 1.4$ .

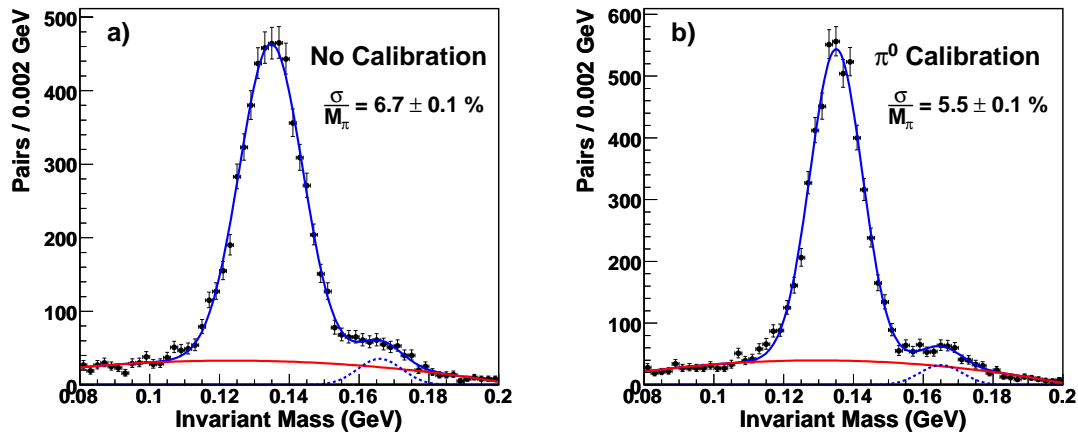


Figure 3: Reconstructed  $\pi^0$  mass peak a) before and b) after applying the  $\pi^0$  calibration constants. Each distribution was fitted to a double-gaussian plus a second order polynomial function and the obtained peak resolution is indicated on the plots.

### 3.2 $\pi^0$ Calibration in Test Beams

Further calibration studies are carried out using  $\pi^0$  decays produced in the  $\pi^-$  test beam runs performed in November 2006 (see Figure 3). The average energy of the selected  $\pi^0$  candidates is found to be about 8GeV. Using a sample of approximately 140  $\pi^0$ 's per crystal we achieve a calibration precision of  $1.0 \pm 0.1\%$ , which is consistent with the statistics-limited expectation of 0.9%. Thus, no noticeable limiting factors on the calibration performance are observed. This study also confirms that the CMS ECAL is capable of reconstructing the low-energy photons produced in  $\pi^0 \rightarrow \gamma\gamma$  decays. In addition, It has been verified that the calibration constants obtained from  $\pi^0$  calibration can be applied at higher energy(e.g. 50 GeV electrons) without loss of accuracy.

## 4 Conclusions

We have presented the results from a study of the potential for a calibration of the CMS barrel ECAL with photons from  $\pi^0 \rightarrow \gamma\gamma$  decays. We have shown that the majority of the barrel calorimeter, up to  $|\eta| < 1.4$ , can be inter-calibrated to at least a 1% (0.5%) precision after about 30 (130) hours of continuous data-taking in the low-luminosity scenario of LHC. The  $\pi^0$  calibration method has been successfully applied to the test beam data.

## Acknowledgments

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## References

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