The uniformity of the response of the CMS ECAL barrel to photons has been investigated with simulated and test-beam data. With the correction method described here a uniformity within 0.2 to 0.3% can be obtained. The possible effect on the $H \rightarrow \gamma\gamma$ search is discussed.
1 Introduction

The CMS electromagnetic calorimeter (ECAL) barrel [1], made of PbWO4 crystals, is subdivided into eighteen supermodules in the azimuthal coordinate, each subdivided in eight modules along the beam axis. Each module contains 400 to 500 crystals organised in submodules of two crystals in azimuth and five crystals in rapidity. The presence of intercrystal and intermodule spaces in the ECAL degrades the measurement of photon energy. In the H → γγ search, the consequences are twofold: the reconstructed mass of the Higgs boson decaying to two photons is shifted, and the mass resolution is degraded. The method that is described here aims at improving the uniformity of the response over the full front face of the ECAL barrel.

In the following, the words gaps and cracks are used for intercrystal and intermodule spaces respectively. To reconstruct the photons, clusters are built here from 3x3 crystal matrices for example, but 5x5 clusters have been studied in the same way.

To illustrate the relevance of the correction method, it is applied to a 120 GeV/c² Higgs boson decaying to γγ, with both photons unconverted and in the barrel acceptance (16% of the events).

2 Effects of gaps and cracks

Simulated samples of 2000 single photons were generated, with energies of 10, 50 and 120 GeV, in steps of 0.05° in azimuthal and polar directions so as to scan the complete ECAL barrel front face. A detailed geometrical description of the ECAL was implemented in a GEANT-based full simulation [2]. The energy resolution was parametrized as $\frac{\Delta E}{E} = 2.7%/\sqrt{E} + 0.55\%$, with E in GeV. A noise of 50 MeV per crystal was assumed.

As an example, Fig. 1 shows the response of the ECAL barrel to 50 GeV photons in the azimuthal coordinate around one of the eighteen cracks, when the impact point is at the centre of the crystal in the polar coordinate. There are eighteen cracks in the azimuthal coordinate ($\phi$) and seven cracks in the polar coordinate ($\theta$), corresponding to the mechanical structures of the modules and supermodules. Altogether there are 342 gaps in the azimuthal coordinate and 162 in the polar coordinate, corresponding to individual crystal boundaries. The pre/post-crack structures correspond to the gaps preceding or following a crack. The depth of each structure is less important for larger clusters as 5x5 crystal matrices for example. The same structures can be seen around each azimuthal crack, as all modules are identical in that coordinate by construction. Similar structures can be observed in the polar coordinate.

These structures can be fit with polynomial functions of a single parameter Log(E2/E1), where E1 and E2 are the energy sums in the crystals on each side of the considered gap or crack within the initial 3x3 matrix. This parametrization is found to be independent of the photon energy between 10 and 120 GeV. A single function can be used to describe and correct the response over gaps in both coordinates. In the polar coordinate, all the cracks can be again described by a single parametrization, except for the central crack at rapidity $\eta = 0$. 

![Figure 1: Azimuthal response to 50 GeV photons using a 3x3 matrix to reconstruct the photon energy.](image-url)
3  Getting a uniform response from the ECAL barrel

When the method is applied to correct photons uniformly distributed in the azimuthal coordinate and in the centre of the crystal in the polar coordinate, the reconstructed energy is shifted towards the expected energy (the energy measured when the impact is far from gaps and cracks, i.e. approximately at the crystal centre), the distribution is more symmetric and narrower. The effect of the correction is shown in Fig. 2 for 50 GeV photons hitting the centre of the crystals in the polar coordinate.

![Figure 2: Effect of the corrections for azimuthal gaps and cracks for 50 GeV photons.](image)

Because the lateral and longitudinal leakage is not included at this level, the corrected energy is not centred around the incident photon energy, but around the energy measured at the centre of the crystal. From this figure it can also be noticed that the numerous gaps have a much larger contribution to the photon energy degradation than the few cracks, although the correction for a crack is larger than that for a gap.

Similarly, Fig. 3 displays the effect of the correction for photon impact points close to the corner of a crystal, i.e. close to a gap or a crack in both coordinates. Even in this most difficult situation, the energy distribution is shifted towards the expected photon energy.

The results obtained with test-beam data are shown in Fig. 4. These data were recorded during the Summer 2002, when an ECAL module was scanned in the polar coordinate with 120 GeV electrons in the absence of magnetic field. A uniformity of the response within 0.2 to 0.3% can indeed be obtained by this correction procedure.

4  Application to $H \rightarrow \gamma \gamma$

About 30000 $H \rightarrow \gamma \gamma$ events, with $m_H = 120$ GeV/c$^2$, have been generated. Photon conversions have not been considered in this study. The position of the main interaction vertex is assumed to be well measured. Figure 5 shows the effect of the implementation of the method just described on the measured photon energies of these events. Here the corrections for lateral and longitudinal shower leakage have also been included for uncorrected and corrected distributions. The shift of the mean value of the mass distribution and of its RMS results from the combination of the shifts of the single photon energy distributions in the azimuthal and polar coordinates.

The mass of the Higgs boson is better measured (the fitted mass shifts by more than 1 GeV/c$^2$) and the width of the distribution gets smaller. This effect would affect the signal-to-background ratio, thus the signal visibility. The upward shift towards the generated Higgs boson mass indicates that a better precision could be obtained by this method on the determination of the absolute Higgs boson mass value. Such measured mass shift in excess of 1 GeV/c$^2$ is comparable to the higher order corrections to the Higgs boson mass and is thus of phenomenological relevance [3].
Figure 3: Effect of the corrections for azimuthal and polar gaps and cracks for 50 GeV photons.

Figure 4: Effect of the corrections for polar gaps and cracks for 50 GeV electrons and 3x3 matrices. Test-beam data.
Figure 5: Effect of the corrections for a 120 GeV/c² Higgs boson when both photons are in the barrel and both photons are unconverted.

5 Conclusion

A uniform response to photons can be obtained for the ECAL barrel to within 0.2 to 0.3%. The procedure is independent of the photon energy from 10 to 120 GeV, and from the angular range in the acceptance of the ECAL barrel. The measurement of the mass of the Higgs boson has been addressed when the Higgs boson decays into two photons and when both photons are in the ECAL barrel and both photons are unconverted. The mass can be well measured and the width of the mass distribution gets smaller, improving signal visibility.

A uniform response to electrons and positrons over the CMS ECAL front face in the presence of the magnetic field can be obtained by a similar procedure and this topic is presently under study. With better understanding of the latter, converted photons will be considered too.

References