Available on CMS information server

CMS IN -2011/002

CMS Internal Note

20 September 2010 (v3, 18 January 2011)

Definition of calibrated ECAL RecHits and the ECAL calibration and correction scheme

Paolo Meridiani, Chris Seez

Abstract

The definition of ECAL calibrated RecHits is documented and explained. The magnitude of the calibrated RecHits is defined so that the correct energy is obtained by summing the hits in a 5×5 cluster, but the intercalibration of the RecHits is the single crystal intercalibration. Because the overall containment of a 5×5 cluster varies along the length of a supermodule, the definition has to be tied to a chosen region. This is taken to be Module 1, over which area there is almost no variation of the 5×5 cluster containment. The cluster calibration and correction scheme which is implied by the definition of the calibrated RecHits is outlined.

CMS IN seez_001

DRAFT
CMS Internal Note

2011/01/18
Head Id: 32281
Archive Id: 32274:32281
Archive Date: 2011/01/18
Archive Tag: trunk

Definition of calibrated ECAL RecHits and the ECAL calibration and correction scheme

Paolo Meridiani[1] and Chris Seez[2]

[1] ETH Zurich, Switzerland
[2] Imperial College London, UK

Abstract

The definition of ECAL calibrated RecHits is documented and explained. The magnitude of the calibrated RecHits is defined so that the correct energy is obtained by summing the hits in a 5×5 cluster, but the intercalibration of the RecHits is the single crystal intercalibration. Because the overall containment of a 5×5 cluster varies along the length of a supermodule, the definition has to be tied to a chosen region. This is taken to be Module 1, over which area there is almost no variation of the 5×5 cluster containment. The cluster calibration and correction scheme which is implied by the definition of the calibrated RecHits is outlined.

1 Introduction

This note puts together 2 earlier documents that defined ECAL "Calibrated RecHits" [1][2]. Small changes have been made to ease the flow and minimise repetition, and some figures and references have been added.

2 Description of ECAL RecHits

The signals from the ECAL channels are reconstructed from the time frames of consecutive samples to form uncalibrated RecHits which are measured in ADC counts and have values proportional to the signal amplitude in each channel.

Calibrated RecHits are obtained from the uncalibrated RecHits. This note aims to make clear the definition of calibrated RecHits chosen by the ECAL community. The definition allows a clear distinction to be made between *corrections* (applied to clusters and superclusters) and *calibration* (applied to RecHits).

The estimated energy of an electromagnetic particle, obtained from the ECAL, can be expressed as:

$$E_{e/\gamma} = F \times \sum_{cluster} Gc_i A_i \tag{1}$$

where the sum is over the crystals in a cluster. A_i are the reconstructed amplitudes in ADC counts (the uncalibrated RecHits). The combination Gc_iA_i is the calibrated RecHit. The corrections are indicated here by F, and can include separate contributions from many effects. What is at issue in the choice of the calibrated RecHit definition is the choice of exactly what factors are included in Gc_i, and what factors are left as corrections in F.

The calibration of the RecHit has a component that is entirely relative, corresponding to the intercalibration. However the definition must include a choice of the magnitude also. In the formula above, the relative component is indicated by c_i and the choice of magnitude by G, which sets the absolute energy scale.

3 Corrections and calibration

Since making a definition of calibrated RecHits amounts to choosing which factors and effects are included in the corrections, F, and which are included in the calibrated RecHits it is useful to review the various corrections which have been made to clusters in order to obtain accurate energy estimates with the best resolution.

1. Corrections related to tracker material: various corrections have been applied to electron and converted photon superclusters to take account of losses due to the tracker material. Because of bremsstrahlung and conversions in the tracker material, and bending in the magnetic field, not all energy reaches the ECAL, and not all the energy reaching the ECAL is collected in a supercluster.

2. Corrections to take account of the variation of clustered energy as a function of the shower position with respect to the crystal boundaries. These *local containment corrections* have been extensively studied in the test beam, where the lack of material in front of the ECAL and the near perfect intercalibration allow the effect of these corrections to be seen most clearly.

3. Corrections due to effects at very high energies. These fall into two categories: effects due to the energy dependence of clustering and superclustering algorithms (which might be eliminated or reduced by modification or redesign of the algorithms), and effects due to longitudinal shower leakage at very high energies.
4. In the barrel: corrections due to the 6 *mm* voids between modules within a supermodule, and between supermodules.
5. Corrections due to dead or saturated channels.
6. The overall containment factor which accounts for the fraction of incident particle energy reconstructed in a cluster. This is different between barrel and endcaps. It also decreases slightly along the length of the barrel supermodules due to shower leakage from the increasingly exposed sides of the stepped crystals. This effect is measured with excellent precision in the test beam and the relative decrease is very well reproduced by GEANT shower Monte Carlo.

It is generally agreed that the first 4 of these corrections should remain as cluster corrections, and not be included in the definition of calibrated RecHits. The detailed reasons for not including these corrections in the definition of calibrated RecHits vary from case to case, but in general, the reason is that the correction cannot be made a constant value for each crystal, but is rather a function of some variable other than the channel ID – for example: it depends on the shower position with respect to the crystal, or it depends on the incident particle identity (unconverted photon, converted photon or electron).

Current work on corrections to dead or saturated channels focusses on correcting the RecHits before and independently of the clustering, but this has no relevance for the definition of calibrated RecHits.

Making a decision as to how overall containment should be handled is more difficult. It could be wholly absorbed in the definition of calibrated RecHits, so that for a chosen clustering algorithm (5×5) there was no correction. Or, on the contrary, calibrated RecHits could be defined in terms of the Monte Carlo so that an overall containment correction, measured with Monte Carlo data, would be needed for all clusters.

The definition that has been adopted, after much discussion, is an interesting compromise solution where the factor is split into two components. The magnitude of the calibrated RecHits is defined so that the correct energy is obtained by summing the hits in a 5×5 cluster, but the intercalibration of the RecHits is the single crystal intercalibration. This solution has the advantage of freeing the definition from dependence on the Monte Carlo model, while at the same time preserving single crystal intercalibration which is widely perceived as more obvious or natural. Because the overall containment of a 5×5 cluster varies along the length of a supermodule, the definition has to be tied to a chosen region of supermodules. This is chosen to be Module 1, over which area there is almost no variation ($< 0.2\%$) of the 5×5 cluster containment [3].

4 The definition

Calibrated RecHits are defined such that a 5×5 crystal cluster will give the correct energy for an unconverted photon of 50 GeV incident in Module 1. The shower should be away from the module borders. This is ensured by excluding the trigger towers on the module boundary. The Calibrated RecHits are defined on the 2×3 central trigger towers of the first module of the

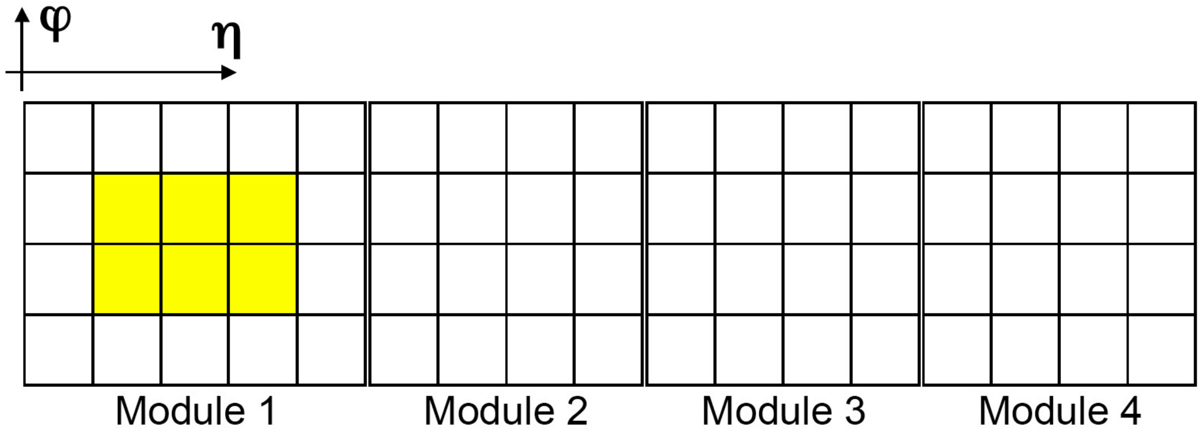

Figure 1: Diagramatic representation of a supermodule showing modules and trigger towers. The 2×3 trigger tower region on which the calibrated RecHits are defined is highlighted.

supermodules, as shown in Fig. 1. A benefit of this definition is that the tracker material in front of the ECAL is thinnest here, and so unconverted photons and electrons which radiate little are most common: this is convenient for fixing the Calibrated RecHit energy scale.

No local containment correction is applied: the photons are incident uniformly and the 5×5 crystal cluster is centred on the crystal having the largest signal. This implies that the (multiplicative) local containment correction for uniformly incident photons has an average value of 1.

For the endcap the magnitude is defined such that, when the energy deposited in the preshower is added, a 5×5 crystal cluster will give the correct energy for E_T = 50 GeV photons in the endcap.

In the original definition of calibrated RecHits [1] the product Gc_i was defined, but no constraint was put on the sharing between G and c_i. Since then a simple definition of the sharing has been adopted. The intercalibration constants, c_i, are intended to account for variations in response and are scaled so that their mean magnitude is 1, for the barrel and endcaps independently. The magnitude is set by the G which has units of GeV/ADC counts, with 2 separate values, one for barrel and one for endcaps.

In the region of the endcaps covered by the preshower detector $(1.653 < |\eta| < 2.6)$ the energy of electromagnetic objects is obtained by adding the energy reconstructed in the preshower to that in the crystals. The fact that there is a single value of G for all endcap crystals implicitly puts any possible small difference between crystals covered by the preshower and crystals not covered by the preshower into the intercalibration constants. Possible sources of difference might be: a different fraction of energy contained in 5×5 crystals laterally and logitudinally (e.g. there is a larger rear leakage when the preshower is not in front).

5 The choice of scale

This section is intended to explain the choice of a 5×5 cluster to define the magnitude of the RecHit calibration.

- A fixed shape cluster is well defined. No further details of clustering algorithm, thresholds or cutoffs are required.

- A fixed shape algorithm gives the best energy resolution for single showers, such as those of electrons in test beam, or unconverted photons in CMS. Correcting for the shower position with respect to the crystal position improves this further (“local containment corrections”). The strongest motivation for focus on the best possible energy resolution comes from the $H \rightarrow \gamma\gamma$ search. Although the thickness of the tracker material results in a large fraction of the photons converting, the unconverted photons with superior energy resolution are also the most distinctive and have the least background. The more sensitive statistical techniques explored in the Physics TDR obtain a disproportionate fraction of the signal significance from unconverted photons.
- A 5×5 cluster has been chosen over a 3×3 cluster because it is less sensitive to the variation of the shower position than the energy contained in a 3×3 cluster and it is possible to achieve a better energy resolution without the use of a local containment correction.
- Using a 5×5 cluster makes it easier to form the link between electron calibration and unconverted photon reconstruction. When considering electron calibration in situ, it is possible to select a class of electrons that have radiated very little in the tracker material, and thus have showers very similar to unconverted photon showers when reconstructed in 5×5 crystals. This is much harder for a 3×3 cluster - there is a much higher probability that radiation in the tracker material will cause more energy to fall outside the 3×3 cluster than would be the case for an unconverted photon.

6 Implementation in CMSSW

The calibration definition described above has been implemented in CMSSW (since version 1_5_0). The SimHit energies from simulation are rescaled during digitisation. Two factors are used, one for the barrel (0.965) and one for the endcap (0.975). The values, which correspond to the containment in a 5×5 crystal array ($S25$ containment) in the reference regions for barrel and endcap, have been evaluated from a 50 GeV (constant energy) sample of unconverted photon simulated with magnetic field. Unconverted photons were selected using MC truth information, and the values for $S25$ containment were obtained from the peak value of a crystal ball function fitted to the $S25/E_{true}$ distribution. Code to perform this evaluation is now used as a validation tool run on simulated samples after the rescaling has been implemented [4]. Examples of the output of this test recently performed on $E_T = 35$ GeV photons (RelVal samples) generated with CMSSW version 394 are shown in Fig. 2. The fitted mean value of $S25/E_{true}$ deviates from 1 by much less than 0.1% indicating that these factors are well tuned.

The known variation of the $S25$ containment as a function of η in the barrel is discussed in more detail in the next section.

7 Effect of magnetic field

Since the original adoption of the definition of calibrated RecHits further information has been obtained, from detailed Monte Carlo study, about the behaviour of the shower containment in the CMS magnetic field. The results obtained require that the phrase “single crystal intercalibration” be understood as referring to single crystal intercalibration in the *test beam*. Almost all intercalibration techniques employed *in situ* use clusters, and scale to the “single crystal intercalibration” with a cluster containment factor, so this complication is no hardship. The

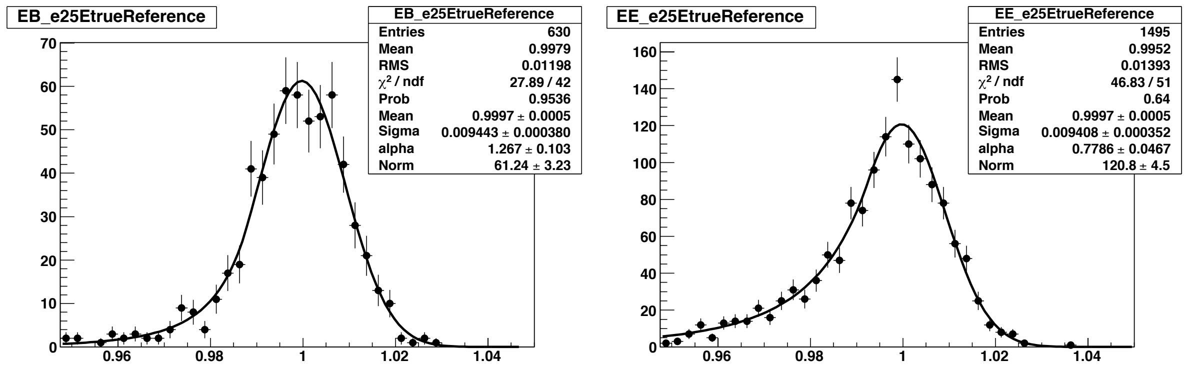

Figure 2: $S25/E_{true}$ for $E_T = 35$ GeV photons generated with CMSSW 394 for (left) unconverted photons incident in Module 1, excluding the trigger towers on the module boundaries, and (right) for unconverted photons incident in the endcaps.

magnetic field effect is explained in the following subsection.

7.1 Single crystal response in the barrel

The energy contained in a single crystal varies so much with the location of a shower that it is necessary to specify more tightly the meaning of a signal in a "single crystal". In test beam work the single crystal response is taken as the signal given by showers located at the point of maximum response. Simulation shows that the signal measured like this is a constant fraction of the shower energy in the barrel – i.e. E_1/E_{gen} is constant versus η. (The first 5 crystals, type 1 crystals, are an exception because of their atypical size/shape).

However, when the simulation is made for unconverted photons in full CMS, it is found that the ratio of the single crystal signal with a 4T magnetic field, to the signal with the field off, varies by as much as 3% along the length of the barrel. As the crystals, and the showers, tilt from near normal to the field at $\eta = 0$ to an inclination of about 25° at $\eta = 1.5$ the spreading of the shower in the field decreases and the energy contained by the crystals increases. This is shown in Fig. 3 which is taken from Ref. [5].

Fortunately, the ratio of 5×5 cluster containment with field off to that with field on is constant along the length of the barrel, to very good approximation (< 0.2%). Thus the funtional form of E_{25}/E_{gen} versus η is the same with and without field. We refer to this shape as $f(\eta)_{5\times5}$. It can also be determined with GEANT simulation that in test beam conditions (i.e. no field) the shapes versus η of E_{25}/E_{gen} and E_{25}/E_1 are the same. GEANT simulation reproduces the shape versus η of E_{25}/E_1 measured in the test beam [3]. So $f(\eta)_{5\times5}$ is very well defined.

The calibrated RecHits are thus defined as having a barrel intercalibration as given by single crystal intercalibration in the test beam. To obtain the correct energy of an ECAL shower produced by an unconverted photon by summing a 5×5 array of crystals, the sum must be divided by $f(\eta)_{5\times5}$. To obtain intercalibration constants from an *in situ* intercalibration procedure which uses showers reconstructed in clusters the appropriate cluster correction must be taken out.

A 5×5 crystal sum is used to reconstruct unconverted photons, and the barrel Hybrid superclustering algorithm used for electrons and converted photons in the barrel is based on strips of 5 crystals. The Hybrid algorithm is designed to result in a 5×5 array of crysals for unconverted photons or photons converting close to the ECAL, and for electrons which radiate very little.

The $f(\eta)_{5\times5}$ correction is applied to the sum of crystals in Hybrid superclusters and further corrections are based on this corrected sum.

Other algorithms are envisaged for other purposes, and they will require appropriate correction functions - e.g. $f(\eta)_{3\times3}$ for 3×3 clusters.

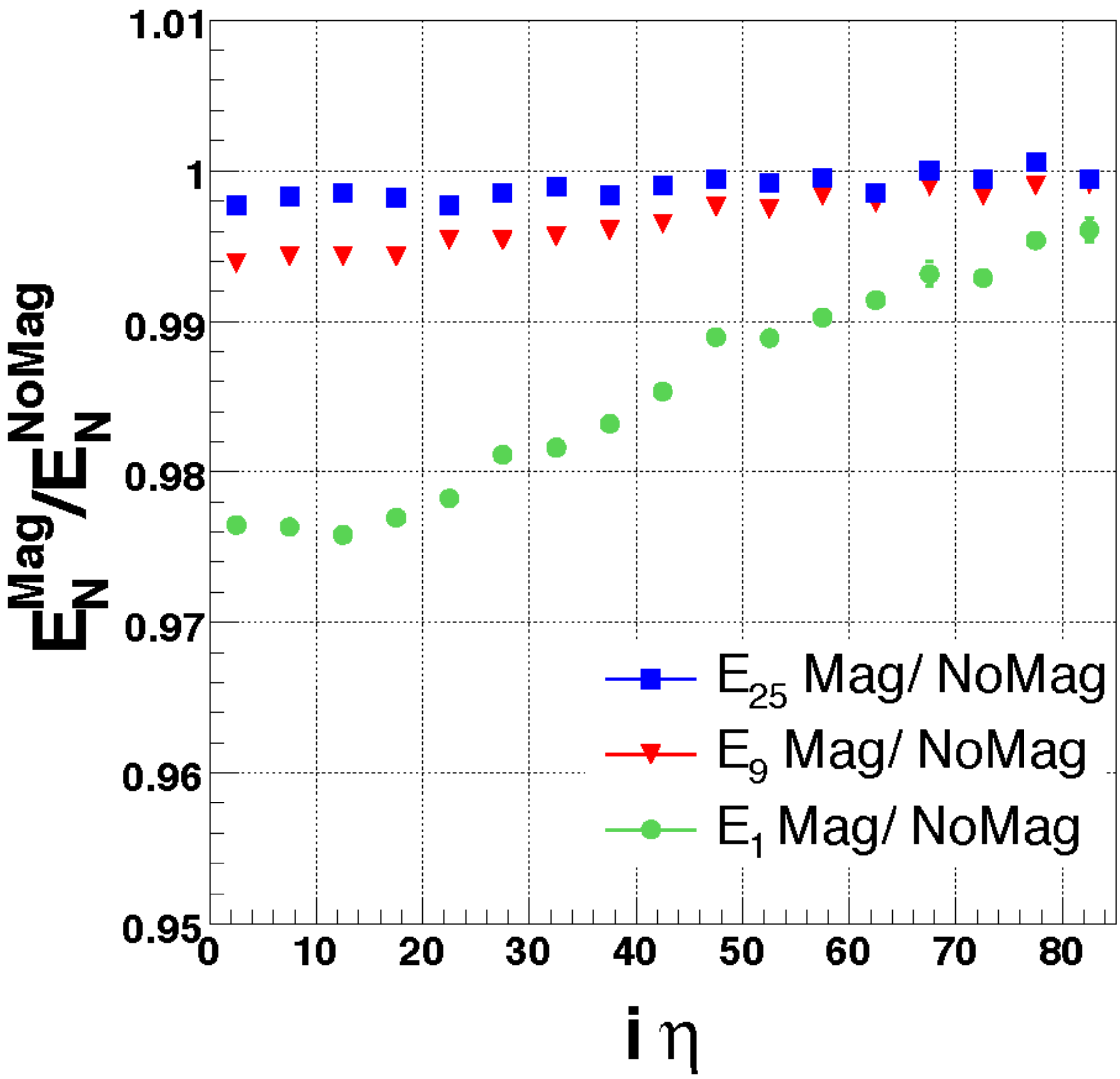

Figure 3: Ratio of energy found in ECAL crystals in CMS magnetic field to that found in zero field, for a single crystal (solid circles), a 3x3 matrix (triangles) and a 5x5 matrix (squares), shown as a function crystal index number in the barrel.

8 The correction scheme

The detailed definition of calibrated RecHits is supplemented by a correction scheme, many features of which are already implied by the definition. The energy of unconverted photons is reconstructed using a 5×5 crystal sum. The original clustering/pattern recognition step is made using the standard clustering algorithms, which are also used for energy reconstruction of electrons and converted photons. The choice to treat the cluster as an unconverted photon and sum the energy in 5×5 is currently made based on the $R9$ variable ($R9 = E_{3\times3}/E_{sc}$).

There are three groups of corrections:

- The correction of barrel clusters for overall average containment as compared to Module 1. This is the $f(\eta)_{5\times5}$ correction in the barrel, which is applied by default to the Hybrid superclusters, which are based on strips of 5 crystals and tend to be 5×5 clusters when formed from showers created by unconverted photons.

  The use of 3×3 clusters for π^0 reconstruction requires an overall scale shift, as well as a small $f(\eta)$ correction for the barrel.

- Correction for the effects of radiation in the tracker. This applies only to superclusters and is parameterised as the product of two corrections:

  The first correction attempts to use the supercluster properties to measure, event-by-event, the amount of showering in the tracker material. At present the best parameter found is the supercluster spread in ϕ (specifically, the log-weighted RMS of the energy distribution in ϕ). We assume that, to first approximation, this correction is insensitive to small inaccuracies in the description of the tracker material. The intention is to obtain this correction from Monte Carlo.

  The second correction is a purely empirical correction $f(\eta, E_T)$ which corrects for residual energy scale imperfections after the first correction. This second correction has to be obtained from data. In fact, this is the *only* correction that has to be obtained *in situ* from data, all the others being obtained from test beam, or test beam validated Monte Carlo.

- After the above corrections the energy scale is fully corrected. The peak of an E_{SC}/E_{true} distribution should be at 1. The remaining corrections, "local containment" and "module boundary", will be made such as to leave the peak position of an E_{SC}/E_{true} distribution unchanged. Their justification is in narrowing the peak and reducing the tails.

More details on superclustering and supercluster energy corrections can be found in Ref. [6].

References

[1] P. Meridiani and C. Seez, "ECAL calibration and the denition of calibrated RecHits", *Document* **http://cmsdoc.cern.ch/cms/performance/ecal/calib-def.pdf** (2007).

[2] P. Meridiani and C. Seez, "Addendum to ECAL calibration and the denition of calibrated RecHits", *Document* **http://cmsdoc.cern.ch/cms/performance/ecal/addendum.pdf** (2007).

[3] F. Cossutti et al., "Pseudorapidity dependence of the energy containment at the 2006 ECAL testbeam", *CMS Detector Note* **DN2007/005** (2007).

[4] The CMSSW code can be found in Validation/EcalClusters/. An example configuration file for creating a root tree is in /test/ContainmentCorrectionAnalyzer_cfg.py, and the macro that does the fit is in test/photonContainmentAnalysis.C.

[5] J. Zhang, C. Seez, and P. Meridiani, "Lateral Containment Variation in EB", *Slides* **http://cmsdoc.cern.ch/cms/performance/ecal/slides/m017-4.pdf** (2007).

[6] M. Anderson et al., "Review of clustering algorithms and energy corrections in ECAL", *CMS Internal Note* **IN2010/008** (2010).