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Inter-Calibration of the CMS Electromagnetic Calorimeter with Isolated Electrons

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Abstract

The CMS Electromagnetic crystal Calorimeter (ECAL) must be precisely inter-calibrated if its full potential performance is to be realized. In this note, a detailed Monte Carlo study of in-situ inter-calibration of the ECAL crystals using isolated electrons is described. The achievable precision depends on the quality and number of available electrons per crystal. This in turn depends upon the position of the crystals and the corresponding thickness of material in front of the ECAL.

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1 Introduction

The physics reach of the CMS Electromagnetic Calorimeter (ECAL) [1], in particular the discovery potential for a low mass Standard Model Higgs particle in its two photons decay channel, depends on its excellent energy resolution. Crystal inter-calibration precision is expected to be the dominant contribution to the constant term of the energy resolution. This means that the key to fulfilling the performance design goal lies in the in-situ inter-calibration of its lead tungstate (PbWO_4) crystals using physics events.

Due to the high density (8.28 g/cm^3) and the small radiation length ($X_0 = 0.89 \text{ cm}$) of PbWO_4 , the Calorimeter is very compact and can be placed inside the Magnetic coil [2] needed for the Tracker [3]. The small value of the Molière radius (2.2 cm) matches well the very fine granularity needed by the high particle density of the events at LHC. The ECAL is made out of 75848 crystals. They are arranged into a Barrel (61200 crystals), covering the central rapidity region ($|\eta| < 1.48$) and two Endcaps (7324 crystals each) which extend the coverage up to $|\eta| < 3.0$. In the Barrel, crystals with a tapered shape, $2.2 \times 2.2 \text{ cm}^2$ front face and 23 cm length are positioned at a radius of 1.29 m. Hence the total depth is $25.8 X_0$ and the transverse granularity in η and ϕ is given by 0.0174×0.0174 . In the Endcaps, crystals with $2.47 \times 2.47 \text{ cm}^2$ front face and 22 cm length are positioned at a distance from the interaction point of 3.17 m along the beam line. Crystals are mounted in a quasi-projective geometry so that their axes make a 3° angle with respect to the vector from the nominal interaction vertex, in both η and ϕ projections. This slightly off-pointing geometry improves the hermeticity of the detector.

An initial set of inter-calibration coefficients will be available for all crystals, obtained from laboratory measurements during assembly. It has been demonstrated that these will provide a start-up calibration precision of $\approx 4\%$ [4]. Some crystals will also be pre-calibrated using an electron beam. Cosmic ray calibration of some, or all, supermodules should also provide inter-calibration values at a precision of $2\% - 3\%$ [5].

In-situ calibration with physics events will be the main tool to reduce the constant term of the energy resolution function to the design goal of 0.5% . At the start of detector operation, a fast inter-calibration method based on ϕ symmetry will be used [6], exploiting the uniformity of energy deposition as a function of ϕ at fixed η . Energetic electrons from $Z \rightarrow e^+e^-$ decays will be recorded at a sufficiently high rate, even at the initial low luminosity, to provide an inter-calibration of Calorimeter regions. Once the Tracker is aligned and fully operational, inter-calibration of different crystals can be performed using E/P measurements of isolated electrons.

In this note a detailed Monte Carlo study of inter-calibration with isolated electrons is described.

2 The Role of the E/P Ratio

The main difficulty in using electrons for inter-calibration is that they radiate in the Tracker material in front of the ECAL, and both the energy and the momentum measurement are affected. Moreover the average amount of bremsstrahlung varies with Tracker material thickness. Figure 1 shows the E/P ratio in the ECAL Barrel of electrons from W decays, where E is their energy as measured by the ECAL and P is their momentum as measured by the Tracker.

For this inter-calibration study the ECAL energy is measured by summing the 5×5 array of crystals around the crystal with the maximum signal (S25). The reasons for this choice are:

- compared to single crystal calibration, as used in the ECAL test-beam, the use of the energy sum over a 5×5 crystal array does not require the complexity of a single crystal containment correction, with all its attendant sources of possible systematic error. It also makes a better usage of the available information by using the energy deposited in other crystals than the crystal where the electron impinges;
- clustering algorithms, designed to gather and reconstruct the energy deposited in the ECAL by radiating electrons, require complicated corrections. Inter-calibrating using a 5×5 crystal sum allows these corrections to be avoided;
- the 5×5 crystal array reconstruction algorithm is what is used for the energy measurement of unconverted photons, and it is the reconstruction of unconverted photons which makes the highest demand on inter-calibration precision [1].

It is necessary to select electrons that deposit most of the energy in a 5×5 crystal array: those that have lost only a small momentum fraction through bremsstrahlung emission along their trajectory in the Tracker volume, or where the bremsstrahlung is emitted relatively close to the crystal Calorimeter so that the showers from the

Figure 1: E/P distribution of electrons in the ECAL Barrel that pass the High-Level Trigger with at most 10% radiated energy (shaded green - generator level selection) and without any cut on the radiated energy.

radiated photons deposit most of their energy in the 5×5 array. In order to select these events, the information coming from the ECAL itself can be used in an effective way. A powerful discrimination can be achieved by using the ratio $S9/S25$ (Fig. 2) where $S9$ is defined as the energy deposited in the 3×3 array around the crystal with the maximum signal. $S9/S25$ is close to unity when $S25$ contains most of the electron energy.

In a similar way, the Tracker information is used not only to provide the momentum measurement, but also as an indication of the amount of bremsstrahlung emitted. For the ECAL Barrel the standard Kalman Filter tracking was used. The electrons were selected based on the number of the valid hits on a reconstructed track (Fig. 3) and the $\chi^2/n.d.f.$ of the reconstructed track (Fig. 4).

In the ECAL Endcaps the possible benefits of using a Gaussian Sum Filter technique [7] were explored. This tracking algorithm provides a measurement of the electron tracks both at the outermost (P_{out}) and innermost (P_{in}) layer of the silicon Tracker respectively. A selection cut based on the ratio of the momentum estimation in the innermost and outermost Tracker layer was used to reject electrons with large fractions of radiated energy.

Figure 5a shows the behaviour of P_{out}/P_{in} with respect to the fraction of energy the electron irradiated by bremsstrahlung (E_{brem}/E_{true}) before reaching the ECAL detector for crystals with $1.98 \leq \eta < 2.15$. The track reconstruction algorithm needs a few layers of the Tracker to be sensitive to changes in curvature of the particle trajectory, hence very late bremsstrahlung cannot be seen by the (P_{out}/P_{in}) selection. In order to take this effect into account, an effective bremsstrahlung energy E_{brem}^{eff} , defined as the energy radiated at radii smaller than 80 cm, has been defined. Figure 5b shows the behaviour of P_{out}/P_{in} with respect to E_{brem}^{eff}/E_{true} for crystals with $1.98 \leq \eta < 2.15$. The effectiveness of the P_{out}/P_{in} cut in selecting non-radiative electrons is clearly visible in the plots.

3 Calibration Algorithms

The energy measurement contains the contribution of many crystals, each with its own calibration constant. In order to extract those constants the individual crystal contributions must be deconvoluted. This is done by minimizing the difference between the energy and momentum measurements. Two algorithms to achieve this minimization have been considered: an iterative technique and a matrix inversion algorithm.

3.1 The L3 Iterative Algorithm

This algorithm was used for the in-situ calibration of the BGO crystals in the L3/LEP experiment [8]. The basic steps of this algorithm are:

Figure 2: Distribution of $S9/S25$ for electrons in the ECAL Barrel that pass the High-Level Trigger with at most 10% radiated energy (shaded green - generator level selection) and without any cut on the radiated energy.

Figure 3: Distribution of the number of valid hits for electrons in the ECAL Barrel that pass the High-Level Trigger with at most 10% radiated energy (shaded green - generator level selection) and without any cut on the radiated energy.

Figure 4: Distribution of $\chi^2/\text{n.d.f.}$ for electrons in the ECAL Barrel that pass the High-Level Trigger with at most 10% radiated energy (shaded green - generator level selection) and without any cut on the radiated energy.

Figure 5: (a) P_{out}/P_{in} versus E_{brem}/E_{true} , for crystals with $1.98 \leq \eta < 2.15$; (b) P_{out}/P_{in} with respect to E_{brem}^{eff}/E_{true} for crystals with $1.98 \leq \eta < 2.15$. The black markers indicate the position of the peak of a gaussian fit, performed in each bin separately.

- collect the events with electrons contained in the (η, ϕ) region to be inter-calibrated.
- Iterate over those events, and in each iteration:
 - loop over all crystals in the region. For each crystal, i , calculate a correction factor, K_i , to the calibration coefficient c_i of that crystal;
 - apply the correction factors to the calibration coefficients.
- Iterate until the calibration coefficients converge.

Figure 6: Calibration precision versus internal iterations of the L3 algorithm.

The algorithm reaches the convergence within 20 internal iterations, as shown in Fig. 6.

Each correction factor K_i is found by summing over all the calibration events involving crystal i . There are N_i events where crystal i contributes to the 5×5 sum. The sum is defined as follows:

$$K_i = \frac{1}{\sum_{j=1}^{N_i} w_{j,i}} \sum_{j=1}^{N_i} \frac{P_j}{E_j^{5 \times 5}} w_{j,i} \quad (1)$$

A weight $w_{j,i}$ is assigned to each event j involving crystal i proportional to the fraction of the total energy deposited in crystal i , so $w_{j,i} = E_{j,i}/E_j^{5 \times 5}$. P_j is the electron momentum measured in the Tracker.

3.2 The Matrix Inversion Algorithm

Extracting the inter-calibration coefficients can alternatively be expressed as the problem of minimizing the quantity:

$$|\mathcal{E} \times \bar{c} - \mathcal{P}| \quad (2)$$

where the $\bar{c}$ is the vector of the calibration constants running on n crystals, $\mathcal{P}$ is the vector of electron-track momenta running on m events and $\mathcal{E}$ is the $m \times n$ matrix of the energy depositions in the crystals for each event. In the ideal situation of a perfect detector response with sufficient statistics, the matrix $\mathcal{E}$ has a rank equal to n and the problem can be reduced to solving a linear system. In real life the fluctuations of the energy depositions in crystals and the size of the matrix (dimensions up to $60k \times 18M$) impose the use of standard numerical recipes in order to perform the minimization.

Using the characteristic almost-diagonal behavior of such a matrix, two approaches have been tested: the Householder [9] decomposition and a χ^2 minimization [10]. In all conditions the results, both in terms of precision and speed of the algorithm, are similar to the L3 iterative method showing no dependence on the technique used.

4 The Event Sample

In this study, $p+p \rightarrow W+X$ ($W \rightarrow e\nu$) events generated using PYTHIA [11] have been used. The final state particles at generator level have been rotated for each event so that the electrons are always in the positive η half and the first ϕ quadrant of the CMS detector (throughout the note η , ϕ define the particle's position at the ECAL). Thus, a factor of eight increase in the number of electrons per crystal is obtained. These events were fully simulated (Geant4 [12]) and digitized with pile-up corresponding to a luminosity of $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$. A generator level preselection was applied by requiring electrons to have $|\eta| \leq 2.7$ and $P_T > 25 \text{ GeV}/c$.

The available $W \rightarrow e\nu$ event sample has an equivalent integrated luminosity of $\approx 10 \text{ fb}^{-1}$ (using the leading-order PYTHIA cross section).

5 Regional Inter-Calibration

Due to the variation of the average value of the E/P distribution with pseudo-rapidity, caused by the variation of the amount of material in front of the ECAL, the calibration task is divided into two steps: first, crystals are inter-calibrated in small regions in η where the average value of the E/P distribution is rather constant. Obtaining the inter-calibration coefficients in such small regions is extremely fast. In the second step the small regions are inter-calibrated with each other. A final step might be needed to set the absolute energy scale. For the final correction to the absolute scale, the use of constraints to the nominal mass of the Z in $Z \rightarrow e^+e^-$ events is under study.

To test the calibration algorithms, a Gaussian mis-calibration has been applied crystal by crystal, with a spread of 4% around 1. This initial mis-calibration represents a conservative estimate of the residual mis-calibration expected from the pre-calibration of the crystals at start-up. If the initial mis-calibration per crystal is e_i and the calibration algorithms end up with a factor c_i which corrects the mis-calibration, then the width of the $e_i \times c_i$ distribution reflects the final calibration precision that can be achieved, while the position of the peak of that distribution reveals possible biases.

5.1 Optimization Procedure for the Algorithms under Test

In order to reach an accurate estimate of the calibration precision, the complete calibration procedure is repeated for a large number (50) of different mis-calibration sets. The final results are thus independent of the mis-calibration set.

Whichever minimization algorithm is being used, either the matrix inversion or the iterative algorithm, it is itself iterated with the selection procedure. After a first minimization, having obtained a first set of calibration constants, the E/P width is improved. The best calibration precision is achieved by reselecting events and repeating the minimization process several times using the updated calibration constants as a starting point. Typically two to five iterations are needed in order to reach the best precision.

6 Event Selection and Selection Stability

The event selection is based on variables which are correlated with the amount of bremsstrahlung emission and consequently measure the quality of the energy and momentum reconstruction.

For electrons in the ECAL Barrel these variables are: the number of valid hits and the $\chi^2/\text{n.d.f.}$ of the electron track, the S9/S25 measured by the ECAL, and the ratio S25/P itself, which provides the calibration.

The choice of the specific value for a selection cut is made by finding an optimal point in the four-dimensional space of the four selection variables. The optimum point is dependent on both the number and the quality of the input events, both of which depend on the average amount of bremsstrahlung in the region considered. The optimization is performed by scanning the space of the selection variables and choosing the points which give the best precision in the determination of the calibration constants.

This method of optimization of the selection cuts requires the use of simulated data. If the agreement between the distributions of selection variables in simulated and real data is inadequate, the selection cuts derived from simulated data might not reach the optimal accuracy when applied to real data. It is thus very important to establish how dependent the results are on the precise values of the selection cuts. The broader distributed the optimal points are (in the phase-space of the selection variables), the less sensitive the results are expected to be to disagreements between simulation and data. The "sizes" of these minima have been deeply investigated. It was also investigated whether there is a significant dependence of the optimal point on the number of available events per crystal, or on the iteration. In all cases it was shown that the global minimum is quite wide.

Figure 7: Calibration resolution in ECAL Barrel for selection points around the global minimum.

The calibration precision for the restricted parameter space is shown in Fig. 7. A mean calibration precision of $0.98 \pm 0.07\%$ can be achieved by keeping quite relaxed selection criteria for crystals in the middle of the Barrel. Another characteristic of the minimum is that it can be approached with quite different numbers of selected events per crystal, revealing the trade-off between quality and statistics in the calibration procedure. The optimum selection efficiency in the Barrel varies with η and has a mean value around 30%.

For electrons in the ECAL Endcaps the energy is measured as in the Barrel by the sum of the amplitudes of a fixed array of 5×5 crystals around the crystal with the maximum signal (S25). The energy measured by the preshower

is added to S25, improving the precision of the reconstructed energy.

In order to be sure that most of the electron energy is collected in the 5×5 crystal array, tight cuts are applied to select electrons that have lost only a small momentum fraction through bremsstrahlung emission along their trajectory in the Tracker volume, or that have emitted only relatively close to the ECAL Endcap front face.

As for the Barrel, the event selection is based on the variables most sensitive to the fraction of bremsstrahlung emitted by the electrons. They are the ratio between the momentum measured at the ECAL front face and at the vertex (P_{out}/P_{in}), the ratio between the energies collected in a 3×3 and in a 5×5 crystal matrix ($S9/S25$) and the ratio $S25/P_{in}$, where P_{in} is the track momentum at the vertex.

Figure 8 shows the selected events, after applying all the cuts over the total dataset, in the $1.98 \leq \eta < 2.15$ range, at the end of the calibration process.

Figure 8: The selected events (shaded blue) compared to the total dataset, at the end of a calibration process, for crystals with $1.98 \leq \eta < 2.15$. As expected, the peaks of the distributions overlap. Their peak positions are below 1, since the energy is reconstructed by means of the 5×5 matrix around the maximum signal crystal.

The selection cuts are chosen by scanning the phase space of the selection variables and taking the points which give the best precision (global minimum) in the determination of the calibration constants. As in the Barrel case, the optimal point is dependent on both the number and the quality of the input events, both of which depend on the average amount of bremsstrahlung in the region considered and therefore on η . At the optimal points, the selection efficiency is ranging from 10% to 30%. The event selection is tuned separately for different η regions of the ECAL Endcaps.

7 Results on Achievable Precision

7.1 Precision Versus Pseudo-rapidity

The calibration precision versus η (Fig. 9) achievable for a fixed integrated luminosity reflects the Tracker material distribution. There are less electrons that have radiated only a small portion of their energy at higher η . Less events are selected by the High-Level Trigger (HLT) and these are still, on average, worse reconstructed electrons. The results shown are the estimated precision for 5.0fb^{-1} of integrated luminosity in the ECAL Barrel (9a) and 7.2fb^{-1} in the ECAL Endcaps (9b). The errors on the points are obtained from the variation between the results from different initial mis-calibration sets (50 sets were used) and different event selections.

7.2 Precision Versus Azimuthal Angle

The calibration precision was extensively studied in different ϕ regions keeping the same η interval. As is shown in Fig. 10 there is no evidence of any ϕ dependence. There are only relatively small variations of the Tracker

Figure 9: (a) Calibration precision versus η for 5fb^{-1} of integrated luminosity in the Barrel. (b) Calibration precision versus η for 7.2fb^{-1} of integrated luminosity in the Endcaps.

material in ϕ , and it appears they are small enough not to have any effect for the integrated luminosity used and the precision achieved.

Figure 10: Calibration precision versus ϕ in the ECAL Barrel.

7.3 Precision Versus Statistics

The calibration resolution achievable is strongly dependent on the available statistics. The resolution can be nicely fit by a function of the number of electrons per crystal output by the High-Level Trigger (i.e. the number of electrons available to be used for calibration):

$$\text{resolution} = \frac{A}{\sqrt{\text{HLTevents per Crystal}}} \oplus C \quad (3)$$

The parameters A and C depend on η and have larger values as η increases. In Fig. 11a the resolution versus the average number of HLT electrons per ECAL Barrel crystal is shown for three different η regions. The third

point along each line gives the precision for 5fb^{-1} of integrated luminosity. In Fig. 11b the resolution versus the average number of HLT electrons per ECAL Endcap crystal is presented for the $1.98 \leq \eta < 2.15$ range. The points represent the precision after the complete inter-calibration procedure. The error bars are obtained from the variation between the results from different initial mis-calibration sets and the event selection instability.

Figure 11: (a) Calibration precision versus HLT events per crystal for different η regions in the Barrel. (b) Calibration precision versus HLT events per crystal for the $1.98 \leq \eta < 2.15$ range at the Endcaps.

The constant term C also represents the limit on the precision that can be reached with infinite statistics. In Tab. 1 the fitted values of A and C are shown for the different η regions (the fitted curves are shown in Fig. 11).

Table 1: A and C parameters for different η regions.

η	A (%)	C (%)
0.000-0.261	6.19	0.12
0.783-0.957	10.7	0.27
1.305-1.479	15.0	0.42
1.980-2.150	30.2	0.75

7.4 The Effect of Module Boundaries

For electrons which hit crystals at the module boundaries there is a loss in the collected energy. The calibration procedure artificially increases the coefficients for these crystals to compensate for this loss (Fig. 12). The effect can easily be corrected for from data by comparing the mean values of the calibration coefficients at the borders (Fig. 13) and those in the rest of the region.

By rescaling the crystals energy content by the ratio of the mean value in these crystals to the mean in the rest of the region, the precision is kept at the same level even for these crystals (Fig. 14). The module boundaries appear both in η and ϕ and the correction procedure works well in both cases, even including the corners where the losses are even larger.

7.5 Calibration of Very Large Regions after Boundary Corrections

After the energy correction for the crystals at module boundaries the calibration of large regions is possible. Comparing the calibration precision in a small region of crystals with that of a region with an order of magnitude more crystals, it was found that calibration precision is only very slightly degraded.

The size of the large region is extended only in ϕ while in η a small interval was used in order to avoid the effect of E/P variation with η . This technique can significantly reduce the further problem of inter-calibrating the regions to each other, which is dealt with in section 7.7.

Figure 12: True/Estimated calibration coefficients versus ϕ in the ECAL Barrel.

Figure 13: True/Estimated calibration coefficients for crystals in the module boundaries in the ECAL Barrel.

Figure 14: True/Estimated calibration coefficients after module boundary corrections versus ϕ in the ECAL Barrel.

7.6 Dead Crystals

It is inevitable that there will be a few non-functioning channels (dead crystals). A dead crystal greatly affects the calibration constants of surrounding crystals in a 3×3 window. As in the case of crystals at the module boundaries, the calibration procedure artificially increases the coefficients of the neighboring crystals in order to compensate for the energy loss caused by the dead crystal. Inter-calibrating small regions that include one or more dead crystals results in an overall bias of the calibration constants.

A comprehensive correction procedure for dead channels might be to parameterize the energy content of the crystals in the 5×5 matrix as function of (Energy, η , ϕ , impact point). This might be achieved by looking in η areas without dead crystals and making the one-to-one correspondence.

Another way is to correlate sums of energies and then use this correlation to estimate the energy of the dead crystal. A crude study of this method was found to partially correct the biases caused by the dead crystal, but this is a problem that needs more extensive investigation.

7.7 Variation of the E/P Peak Versus η and the Calibration of the Small Regions

After crystal inter-calibration in small regions, regions have to be calibrated among themselves.

Figure 15: Peak of E/P distribution versus η . Starting from top to the bottom, the lines represent: no event selection, tight selection and with less than 1% radiated energy (generator level selection).

This task is accomplished by selecting electrons with minimum energy loss due to bremsstrahlung. After this selection, the resulting positions of the peaks of the E/P distributions that are found are consistent with the pseudorapidity dependence of shower containment. The E/P peak value dependence is about 0.5% over the length of the ECAL half Barrel. The peak of the E/P distribution at low η is at about 0.975. This is illustrated in Fig. 15 which shows the fitted peak of the E/P distribution as a function of η for electrons after different levels of selection. For comparison, the variation of E/P is shown after a selection using Monte Carlo information, requiring the electrons to have less than 1% radiated energy.

Even in the absence of bremsstrahlung, not all the energy of a shower is contained in 25 crystals. Thus, using uncalibrated simulated events, where the signal in each crystal is represented by the energy deposited in the crystal, the E/P peak is not located at exactly 1.0, but rather at ≈ 0.97 (at low η).

A further test that was performed was to correct the reconstructed energy as a function of η by this variation, and perform the inter-calibration for crystals in a region covering the full η range but in a limited interval in ϕ . Since there is no ϕ dependence the full (2π) ϕ interval could be used. The same precision as in the case of small regions was achieved.

The remaining calibration task, after inter-calibration of the full detector, is the determination of the absolute

energy scale. The absolute scale can be set by constraints on the invariant mass of the Z, using its decay into two electrons. This issue is discussed in [13].

7.8 Background Contamination

The single electron HLT rate of the di-jet background was estimated to be 27Hz at low luminosity [14]. For the ECAL Barrel the rate is 16Hz and one third of this rate comes from $b/c \rightarrow e$ decays. For the Endcaps the rate is 11Hz with one sixth coming from $b/c \rightarrow e$ decays. Such decays might be useful in the calibration process, increasing the overall calibration statistics. Applying a baseline calibration selection (valid track hits > 8 , $\chi^2/\text{n.d.f.} < 2.0$, $S9/S25 > 0.935$ and events in a window of 3σ around the S25/P peak) a rejection factor of 7.0 for the background in the ECAL Barrel was found. The S25/P distribution of the remaining background is very similar to the signal electrons (Fig. 16). Unfortunately the number of Monte Carlo background events after selection is far too low in order to use them in a study which mixes both signal and background events.

If the background turns out to be ineffective for calibration purposes, it can be significantly reduced using isolation cuts. For example, an isolation cut based on the number of tracks in a cone around the calibration electron [14] can reduce the background by a factor of 10, keeping 98% of the signal. In Tab. 2 the final estimated rates for the signal and di-jet background are given for the ECAL Barrel.

Table 2: Rates for signal ($W \rightarrow e\nu$) and di-jet background for the ECAL Barrel.

Selection	$W \rightarrow e\nu$ (Hz)	di-jet background (Hz)
HLT	6.0	16.0
HLT $\oplus$ Calib. Selection	1.9	2.3
HLT $\oplus$ Calib. Selection $\oplus$ track isolation	1.9	0.24

Figure 16: E/P distribution for signal and background after the HLT and a baseline calibration selection (Blue/dark shading: signal, red/light shading: background) for the ECAL Barrel.

8 Effect of Mis-Calibration on the Higgs Mass Resolution

Having a final set of inter-calibration coefficients for the ECAL Barrel obtained after collecting 5fb^{-1} of integrated luminosity, it is useful to see the effect of these coefficients on the Higgs mass reconstruction. The reconstructed Higgs mass is shown in Fig. 17 for three cases. The black line is the reconstructed mass without any mis-calibration of the crystals. The red line shows the Higgs mass reconstructed using the residual mis-calibration constants and the blue line with 4% initial mis-calibration without corrections. In Fig. 18 the relative resolution on the Higgs mass is shown as a function of a Gaussian mis-calibration applied to the crystals. In the upper curve, the resolution

Figure 17: Higgs mass resolution in the ECAL Barrel with no mis-calibration (empty black), after final calibration corrections (shaded red) and with 4% initial mis-calibration without corrections (empty blue).

Figure 18: Relative Higgs mass resolution in the ECAL Barrel versus initial mis-calibration (no calibration corrections applied). Lines and points are described in section 8.

is defined as the half width of the narrowest window containing 68.3% of the total statistics. In the lower curve, the resolution is defined from a Gaussian fit around the peak position of the reconstructed mass distribution. The mass resolution using the calibration constants obtained as described (and shown in Fig. 17) is less than 1% and appears equivalent to a Gaussian mis-calibration of 0.8% (red stars in Fig. 18).

9 Systematics

It is assumed that the Tracker can be well aligned with 5fb^{-1} of data. However, in order to study the effect of a mis-aligned/mis-calibrated Tracker, the track momentum was smeared by 1%(2%). The calibration precision is reduced relatively to the normal one by 9%(30%). If instead the true momentum of the track is used, the calibration accuracy is improved relatively to the normal one by 40%.

Another interesting test is the increase of initial mis-calibration to 8%. Such a high value represents the calibration uncertainties if no pre-calibration is applied to the crystals. In that case the calibration precision is reduced relatively to the normal one by 1.5% and only in the last 10 crystals the relative reduction reaches the 8%.

For very high values of initial mis-calibration, even the HLT selection might be affected. But for the expected initial mis-calibration of 4% no effects on the HLT efficiency were observed.

10 Conclusions

In this note, a method for an in-situ inter-calibration of the ECAL crystals using isolated electrons is described. The precision depends on the pseudo-rapidity of the crystals, the number and the reconstruction quality of the selected electrons per crystal. The target of 0.5% calibration precision is achieved with 5fb^{-1} of integrated luminosity for the low pseudo-rapidity region ($|\eta| < 1.0$). For larger rapidities the calibration precision decreases, reaching the 1.4% at the last ten Barrel crystals. In the Endcaps, following the Tracker material budget, the precision varies between 1% and 2%.

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References

- [1] CMS Collaboration, "*The Electromagnetic Calorimeter Project, Technical Design Report*", CERN/LHCC **97-33** (1997).
- [2] CMS Collaboration, "*The Magnet Project, Technical Design Report*", CERN/LHCC **97-10** (1997).
- [3] CMS Collaboration, "*The Tracker Project, Technical Design Report*", CERN/LHCC **98-6** (1998).
- [4] Adzic P. et al., "*Results of the first performance tests of the CMS electromagnetic calorimeter*", CMS NOTE **2005-020**.
- [5] Bonesini M. et al., "*Inter-calibration of the CMS electromagnetic calorimeter with cosmic rays before installation*", CMS NOTE **2005-023**.
- [6] Futyan D., "*Intercalibration of ECAL Crystals in Phi Using Symmetry of Energy Deposition*", CMS NOTE **2002-031**.
- [7] Baffioni S. et al., "*Electron Reconstruction in CMS*", CMS NOTE in preparation.
- [8] Favara A. et al., "*Calibration of the L3 BGO Calorimeter Using an RFQ Accelerator*", Nucl. Phys. (Proc. Supp) **78** (1999) 465-470.
- [9] Householder S. A., "*A Glossary for Numeric Analysis*", Oak Ridge National Laboratory, Oak Ridge, Tenn. (1958).
- [10] Eidelman S. et al., Particle Data Group, Review of particle physics, Phys. Lett. **B592** (2004).
- [11] Sjostrand T. et al., Computer Physics Commun. **135** (2001) 238.
- [12] GEANT4 Collaboration, S. Agostinelli et al., "*GEANT4: A simulation toolkit*", Nucl. Instrum. and Methods **A506** (2003) 250-303.
- [13] Paramatti R. et al., "*Use of $Z \rightarrow e^+e^-$ events for ECAL calibration*", CMS NOTE in preparation.
- [14] W. Adam et al., "*The CMS High Level Trigger*", hep-ex/0512077, accepted by EPJ Nov 2005.