ECAL Calibration with Data at High Energy

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1 Introduction

One of the main objectives of the CMS experiment is to search for new physics beyond the Standard Model (SM). The Electromagnetic Calorimeter (ECAL), due to its excellent expected performance, constitutes a key tool for such searches.

The discovery of heavy resonances which subsequently decay into very energetic electromagnetic particles, is particularly promising. However, new physics could also show up as subtle deviations from the SM (in a Drell-Yan invariant mass distribution, for instance) that would requiere apropiate measurement of systematic effects if one wants to claim a discovery. If this is the case in the dielectron channel, for example, these deviations will arise in the *unexplored* energy region, i.e. with electron energies greater than 400 GeV, which is about the current largest lab-measured energy for electrons.

The present note describes a cross-check calibration method for electrons in the ECAL subdetector with real data: the leapfrog method This study is based on a high mass Drell-Yan sample and it is applied to verify the high energy behaviour of electrons and to determine systematic errors from linearity and resolution.

2 Simulated Event Sample

About 84K high-mass Drell-Yan events were simulated and reconstructed using CMSSW software version 1.1.1. The value for the PYTHIA parameter CKIN(1), which controls the lower mass cut, was set to be 1400 GeV. Only the dielectron decay channel was enabled, and the corresponding integrated luminosity was found to be about 14000 fb^{-1}. This note aims at implementing and testing the proposed calibration method which can later be translated to lower energies. Therefore the large integrated luminosity, due to the significant reduction in the cross-section as a result of the very high mass cut, does not impose any immediate limitation to the present study.

The two electrons are identified as the two hardest E_T hybrid superclusters; this means that corrections are needed and that we only look at events that have these very energetic particles in the barrel part of the ECAL. Additionally, events going into detector cracks - in η and in ϕ - have been supressed.

3 The Leapfrog Method

If there is no radiation, electrons, in a Drell-Yan process, should balance in transverse energy (E_T). Therefore, we can have events with electrons of similar E_T but with very different energies (see Fig. 1).

This property can be exploited to implement a method by which we can use the known behaviour of one of the electrons, to infer the behaviour of the other electron. It is a *tag-and-probe* method, and it relies on the energy scale up to which we know, experimentally, the ECAL response for these electromagnetic objects. Currently, the energy scale, for electrons, is known up to around 200 GeV.

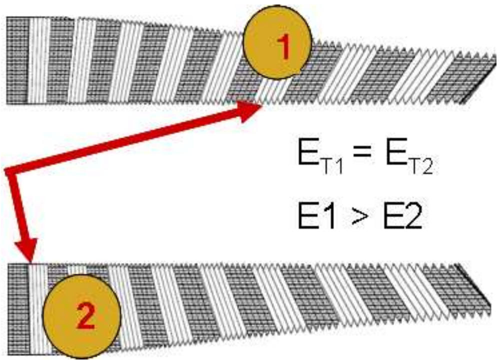


Figure 1: Electron E_T balance.

The basic idea of the *leapfrog* method is to use the well-known behaviour of some electrons (*tag* electrons) to determine, through transverse energy balance, a correction function for the unknown *probe* electrons (see Fig. 2).

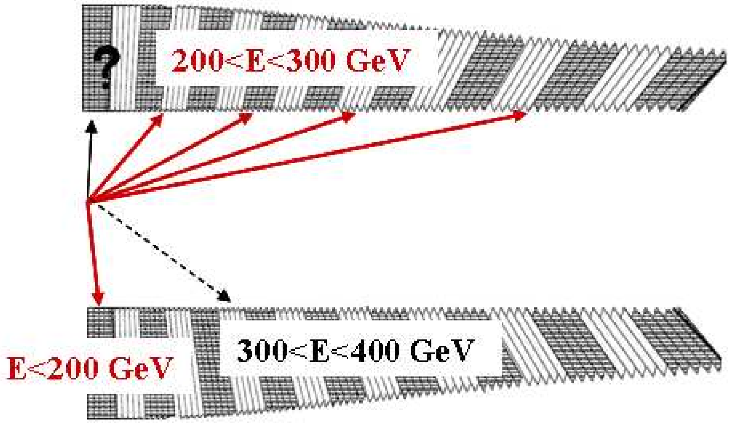


Figure 2: Schematic representation of the leapfrog method: Tag electrons with known energies ($E < 200$ GeV) at a low η region are used to measure the corrections for the probe electrons ($200 < E < 300$ GeV) at higher η regions (red arrows). A correction function, based on these mesurements, is extrapolated to a low rapidity region (black arrow). This correction function can be used to determine the behaviour of a new type of tag electrons ($200 < E < 300$ GeV) which can, in turn, be used to measure corrections for more energetic probe electrons ($300 < E < 400$ GeV, dashed arrow).

This correction has a functional dependence on energy and rapidity. We directly parametrize the rapidity dependence, assuming a smooth parabolic behaviour. The energy dependence, however, is accounted for by binning the energy spectrum for the *probe* electron. The advantage of such a way of proceeding is two-fold. First, we stop worrying about the functional form of the energy dependence, but instead, we control the size of the binning. Second, we don't have to deal with instabilities that would arise in a *brute force* global fit, for example, due to strong energy dependence in statistical errors.

The method demands that we start out by using only those events for which we have a piece of experimental information, meaning, we know the true behaviour of at least one of the electrons in the event. Then, we can *leapfrog* in energy by using the correction function, not only to correct the energy of the *probe* electrons, in this first set of events, but also to prepare a new type of *tag* electrons, in a new and more energetic set of events, which we can later use to infer the correction function for the next energy bin.

This is an iterative procedure whose precision is limited by how well the electrons E_T are balanced.

4 Calibration using the Leap-frog Method

We limit the energy of the electrons in our sample to be in the range $700-2000$ GeV. This allows us to be safe from electronics saturation effects that take place at about 1.7 TeV in the barrel. Applying the leapfrog method on electrons that deposit energies above the saturation threshold in a single crystal will need a more careful study.

We also require an angular cut between electrons of $\Delta\phi > 3.11$, which guarantees a very well balance in E_T (see Fig. 3). In a future study we will describe a procedure that accounts for hadronic recoil which will improve the balance.

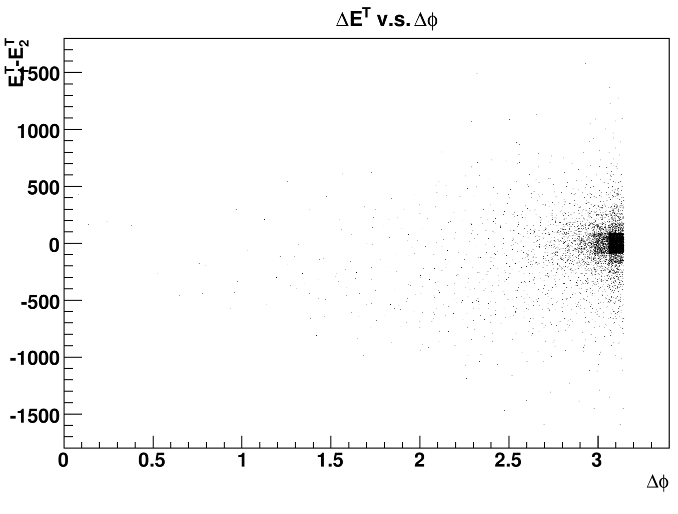


Figure 3: Electron E_T balance v.s. $\Delta\phi$.

We assume we known the energy scale up to 1000 GeV. This lets us have enough events with *probe* electrons well distributed along most of the rapidity region. Additionally, we make bins in energy of 150 GeV, starting at 1000 GeV, for the *probe* electrons. Increasing lack of statistics, as we go up in energy, forces us to expand the last energy bin ($1400-2000$ GeV) to a size of 550 GeV.

The calibration process begins by obtaining the correction factor $F = E_{probe}^{true}/E_{probe}$ for all the events that have a tagable electron, i.e. with $700 < E_{tag} < 1000$ GeV , and a probe electron with energy E_{probe} within the first energy bin ($1000 - 1150$ GeV). Here, E_{probe}^{true} is the energy for the *probe* electron after having recalculated it based on the transverse energy balance, and assuming a very small angular error.

We then make five rapidity bins, and for each one of them the corresponding correction factor distribution is fitted to a Gaussian law. The mean and the error on the mean are taken as the points and the errors, respectively, in Figure 4. This plot shows a very good agreement between the correction factors calculated using E_T balance, and those from the Monte Carlo truth.

A second order polynomial fit to these points gives the resulting η-dependent correction function for the first energy bin. In particular, the parameter which regulates the energy scale for this first bin is found to be 1.046 ± 0.019.

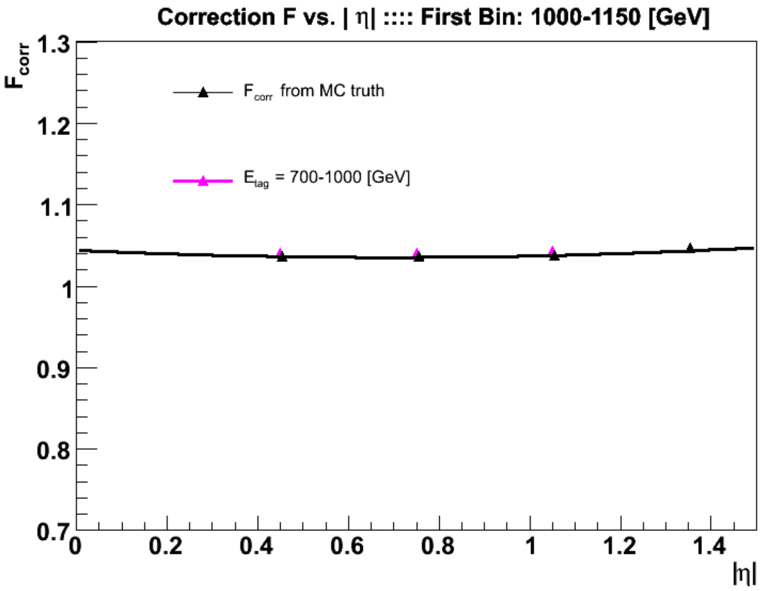


Figure 4: Correction Factor v.s. $|\eta|$ for the first energy bin. Points in magenta show the corrections using E_T balance. Black points show the Monte Carlo truth corrections. A second polynomial fit for the black points is also shown.

Correcting for higher energy bins requieres more careful considerations because we now have to deal with several types of *tag* electrons, and the errors introduced in determining the correction function, with which we prepare them, have to be taken into account and properly propagated.

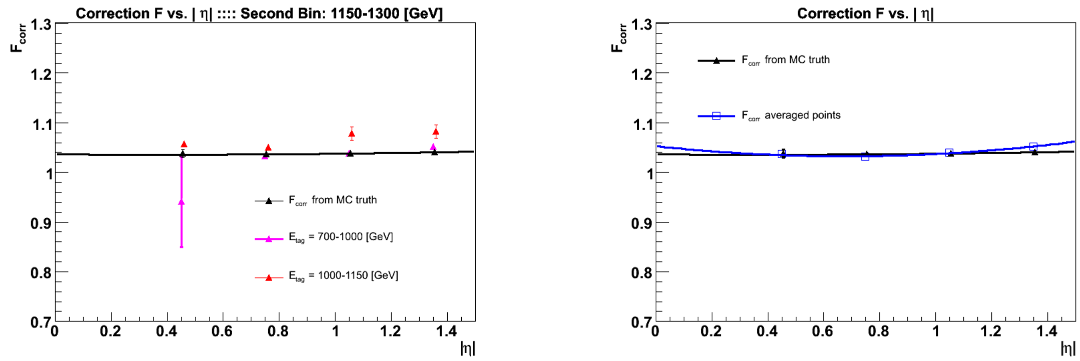
Taking as an example the second energy bin ($1150 - 1300$ GeV), there are two types of *tag* electrons that can be used. Those with $700 < E_{tag} < 1000$ GeV and those, brand new, with $1000 < E_{tag} < 1150$ GeV. Unlike events with the former type of *tags*, those with the latter type will introduce a systematic error in the energy correction factors for the *probe* electrons.

One way of accounting for these errors is to separate the contributions to the χ^2 function used in the fit, depending on which type of tag was used. The first term in expression (1) is the contribution from those events which use a *tag* with energy < 1000 GeV. The other two terms comprise the contribution from the events that use *tags* with higher energies. A free parameter (δ) is input to the fit. It shifts all the points in the same way the error on the energy scale correction does. The size of this shift is limited by introducing the term $(\delta/\sigma_\delta)^2$. We will have as many terms with δ parameters (and corresponding limiting terms) as types of *tags* are used.

$$\chi^2 = \sum_{<1000} \frac{(f-y)^2}{\sigma_y^2} + \sum_{>1000} \frac{[f - y\cdot(1+\delta)]^2}{\sigma_y^2} + \left(\frac{\delta}{\sigma_\delta}\right)^2 \tag{1}$$

Figure 5(a) shows a plot similar to the one shown in Figure 4, but now with two set of points for each rapidity bin, those comming from tags that are well-known, and those which have tags that were prepared using a previous correction function. A fit for these points, using the modified χ^2 function above, gives $\delta \pm \delta_{err} = -0.02 \pm 0.004$. This value agrees very well with the error in the energy scale from the previous energy bin fit.

The aforementioned set of points now have to be properly averaged and then refitted to find the correction function for the current energy bin. Figure 5(b) shows the averaged points which are gotten by following three basic steps. First, the points that carry systematic erros comming from a previous energy bin fit are shifted by a value δ. Second, the statistical and systematic errors (δ_{err}) are added in quadrature. And finally, a weighted average is performed. Figure A-1 shows the fits for all energy bins.



(a) Different tag points

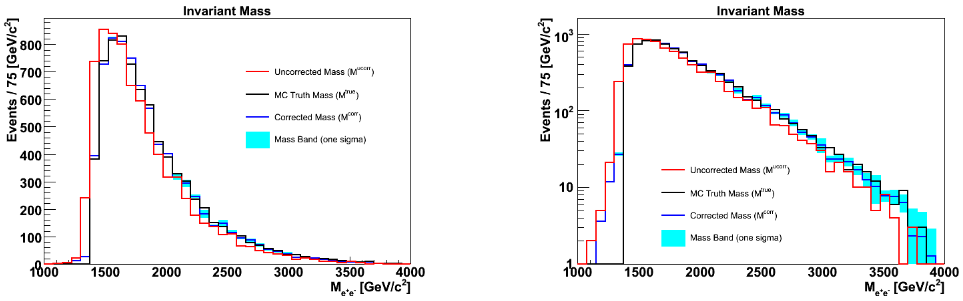
(b) Averaged points

Figure 5: Correction Factor v.s. $|\eta|$ for the second energy bin.

Once the whole energy spectrum is covered and η-dependent correction functions for each energy bin are determined, an invariant mass distribution plot can be made. Figure

6(a) presents such a plot. The corrected mass histogram (in blue), which is determined using the central values of the parameters for each of the correction functions, shows a good agreement with the the Monte Carlo truth histogram. In addition to the uncorrected mass distribution, which is shown in red, a 1σ uncertainty band is also presented. This band is calulated by performing several pseudo experiments in which we throw random values for the parameters of the correction functions within their respective erros. Then, the distribution of the number of events, for each mass bin, is fitted to a Gaussian law and the one sigma upper and lower limits are taken. Figure 6(b) shows the same invariant mass distribution with a vertical log scale which makes the uncertainty band more apparent to the eye.

Figure 7 shows the fractional difference in the number of events between the corrected mass and the Monte Carlo truth mass, for each mass bin.



(a) (b)

Figure 6: Invariant mass distribution. Normal and log scale.

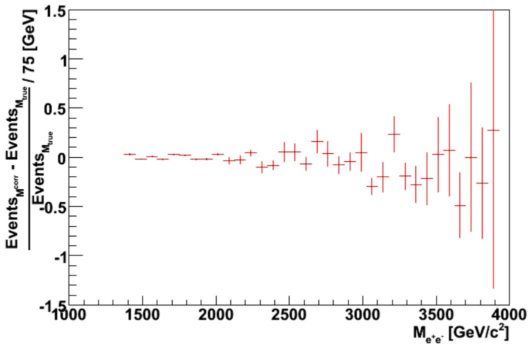


Figure 7: Fractional difference in the number of events between the corrected mass and the Monte Carlo truth mass for each mass bin

5 Summary

We have presented a calibration method for high energy electrons in the ECAL using real data: the leapfrog method. We have shown that the behaviour of high energy electrons can be determined using this method, and that systematic errors from linearity and resolution on the MC prediction of the Drell-Yan slope can be measured in data. The precision of the method is limited by the electrons E_T balance. In a future study we will present an improvement for the balance procedure which implies accounting for the direction of hadronic recoil.

Appendix A: Additional Plots

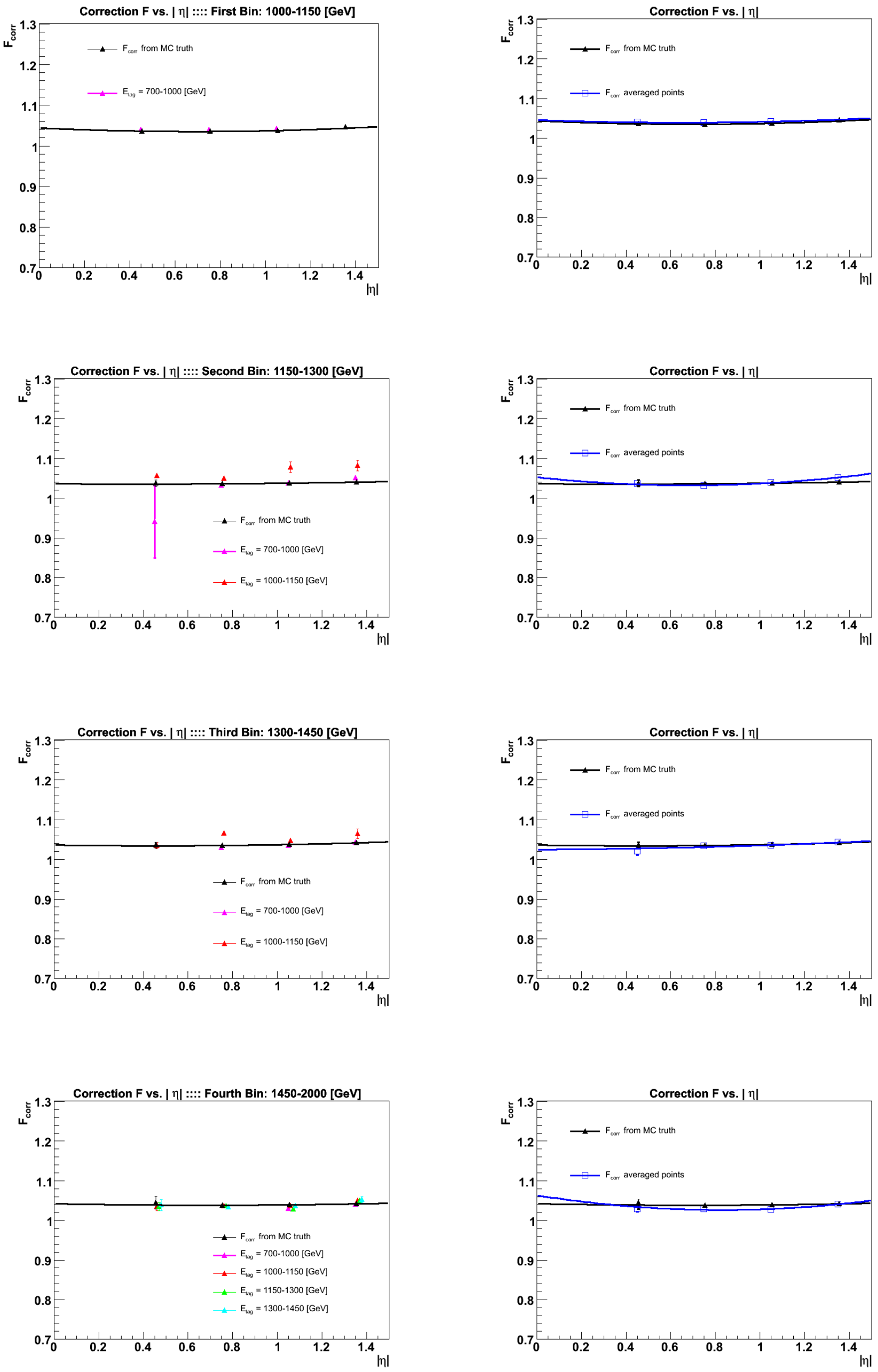


Figure A-1: Correction Factor v.s. $|\eta|$ for all energy bins.