Non-linear energy calibration of CMS calorimeters for single pions

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Abstract

CMS calorimeter energy calibration was done in the full CMS simulated geometry for the pseudorapidity region $\eta = 0$. The samples of single pion events were generated with a set of incident energies from 10 GeV to 3 TeV. The analysis of the simulated data shows that standard calibration using just sampling coefficients for calorimeter parts with different sampling ratio gives nonlinear calorimeter response. Non-linear calibration technique was applied for improving calorimeter energy resolution and restoring the calorimeter linearity.

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1 Calorimeters geometry considered

The pion responses are obtained with GEANT simulations with a detailed description of CMS calorimeter geometry (CMSIM 115), version TDR-2/1.

The ECAL is the PbWO$_4$ one (readout number 1).

An additional 1 cm scintillator layer is placed in front of HB to compensate for the energy loss in the cables, electronics and cooling system on the back side of the ECAL, which is simulated by a uniform slab of 0.2 $\lambda$ of dead material (readout number 2).

The sampling thicknesses of copper alloy (90%Cu + 10%Zn) are 5 cm in the barrel segments, except the inner and outer plates which are 7 cm stainless steel. The 9 mm gaps between the absorber plates are filled with 4 mm scintillator planes (readout number 3).

To improve the energy measurement for late developing hadron showers, tail catcher layers are inserted in front and behind the first return yoke iron layer (RY1) (readout number 4).

The regions behind the ECAL are empty except for the scintillator layer and equivalent dead material uniform absorber layer. The effects of the CMS 4T field are fully included.

2 Data sample

We have performed a GEANT simulation of the response to pions for a set of incident energies from 10 to 3000 GeV at pseudorapidity set to 0. GHEISHA was used as a hadron interaction simulator. The sum of the energies deposited by the showers in the active elements of each readout has been stored in a disk file so that the showers could be analysed later.

3 Standard calibration

The standard calibration used just sampling coefficients for calorimeter parts with different sampling ratio. The reconstructed energy of simple shower is given by the weighted sum of the energies deposited in the readouts:

$$E_{\text{rec}} = \sum_{i=1,4} C_i E_i,$$

where:
$E_i$ - amplitude of the signal from the calorimeter longitudinal segmentation (readouts);

$C_i$ - calibration coefficients.

Coefficients $C_i$, $i = 1, 4$ are determined by the minimisation of the width of the energy distributions.

The Gaussian part of reconstructed energy distributions at various incident energies are then fitted to obtain the calorimeter energy resolution. The energy resolution is parametrised by the expression:

$$\sigma/E = a/\sqrt{E} + b.$$ 

The obtained energy resolution by the standard calibration is shown on fig. 1 and the residuals of the reconstructed energy on fig. 2.

4 Non-linear technique

The nonlinear behaviour of the calorimeter response could be solved by application of the non-linear method which improve the linearity of the calorimeter response and the energy resolution in the broad energy range. Non-linear technique is the selection of some additional parameters which provide correct energy reconstruction of the hadron shower.

Thus the reconstructed energy $E_{nl}^{rec}$ is parametrised as:

$$E_{nl}^{rec} = \sum_{i=1,4} f_i(\vec{A}, E_i)E_i,$$

where $f_i$ are non-linear functions of unknown parameters $\vec{A}$.

Large number of free parameters (more than 50) are needed to better describe the non-linearity. For such a big number of parameters minimisation performed by MINUIT is inefficient. To this end we used the specialised program REGN based on an autoregularized Newton type method\cite{2}. In the REGN computer code\cite{3} the $\chi^2$ is one of the criteria available for solving the system and for testing the mathematical model. Other criteria permit one to chose uniquely between several model functions the best one\cite{4,5,6}.

The energy resolution obtained applying non-linear calibration method is shown in fig. 1 together with results from the standard calibration. In Figure 2 the residuals of the reconstructed energies are shown for both methods. The comparison of the standard calibration
method to the non-linear technique shows clear improvement in the resolution and linearity of the reconstructed energy.

5 Summary

The CMS calorimeters pion calibration was done using two different approaches. Calibration using non-linear technique improves the resolution and linearity of the reconstructed energy.

References

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Figure 1: Energy resolution for the CMS calorimeter system (standard calibration - full points, non-linear calibration - open points).
Figure 2: Residuals of the reconstructed energy (standard calibration - full points, non-linear calibration - open points).