Simultaneously non-linear energy calibration of CMS calorimeters for single pions and electrons

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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 5 GeV to 3 TeV and for single electrons from 5 to 500 GeV. 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 simultaneously for pion and electron beams which is preparation for jets energy reconstruction. It improve calorimeter energy resolution for pions and restore the calorimeter linearity.

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1 Calorimeters geometry considered

The pion and electron 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 λ 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 filed 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 of 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 5 to 3000 GeV and to electrons from 5 to 500 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 uses sampling coefficients for calorimeter parts with different sampling ratio. The reconstructed energy E^{rec} of simple shower is given by the weighted sum of the energies deposited in the readouts:

$$E^{rec} = \sum_{i=1,4} c_i E_i,$$

where:

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

c_i - calibration coefficients, determined by the minimisation of the width of the energy distributions.

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

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

The energy resolution obtained by the standard calibration with simultaneously fit of pion and electron events is shown in fig. 1a) and 1b) and the residuals of the reconstructed energy in fig. 2a) and 2b) (open points).

4 Non-linear technique

The linear behaviour of the calorimeter response could be restored 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 energy depended parameters which provide correct energy reconstruction of the showers.

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 N unknown parameters A_j, j = 1, N and measured readout signals E_i.

The system is solved with autoregularized Newton type method[2] by minimisation of the χ^2 functional (REGN code[3])

$$\chi^2 = \sum_{j=1,M} W_j (E_j^{in} - E_{nl,j}^{rec})^2,$$

where M is number of generated set of energies multiplied by the number of generated events at each energy and W_j are statistical weights.

In the REGN computer code the χ^2 is one of the different criteria available for solving of the system and for testing the mathematical model. The other criteria permit one to chose uniquely between several model functions the best one[/4,5,6/].

This technique was applied for single pions calibration[/7/]. The obtained energy resolution after applying the non-linear calibration method for simultaneously fit of pion and electron beams is shown on fig. 1a) and 1b) (full points). Resolution for pions becomes better in comparison to standard linear calibration. A small degradation of electron energy resolution is observed. The comparison of standard calibration method to the non-linear technique gives a significant improvement in the linearity of the reconstructed energy for both pions and electrons (fig. 2a) and 2b)) (full points).

The unification of our technique with the most clear physical approaches[8,9,10] can give better energy resolution because we can test strait different energy dependences of unknown parameters which depends of interaction cross-sections and calorimeters construction details.

5 Summary

The CMS calorimeters simultaneously pion and electron calibration was done using linear and non-linear approaches. The standard calibration method gives huge deviation from linearity of the reconstructed energy. The calibration using non-linear technique improves behaviour of the energy resolution for pions and restores the calorimeter linearity. Such non-linear technique can be tested successfully for pions, electrons and jets cases simultaneously.

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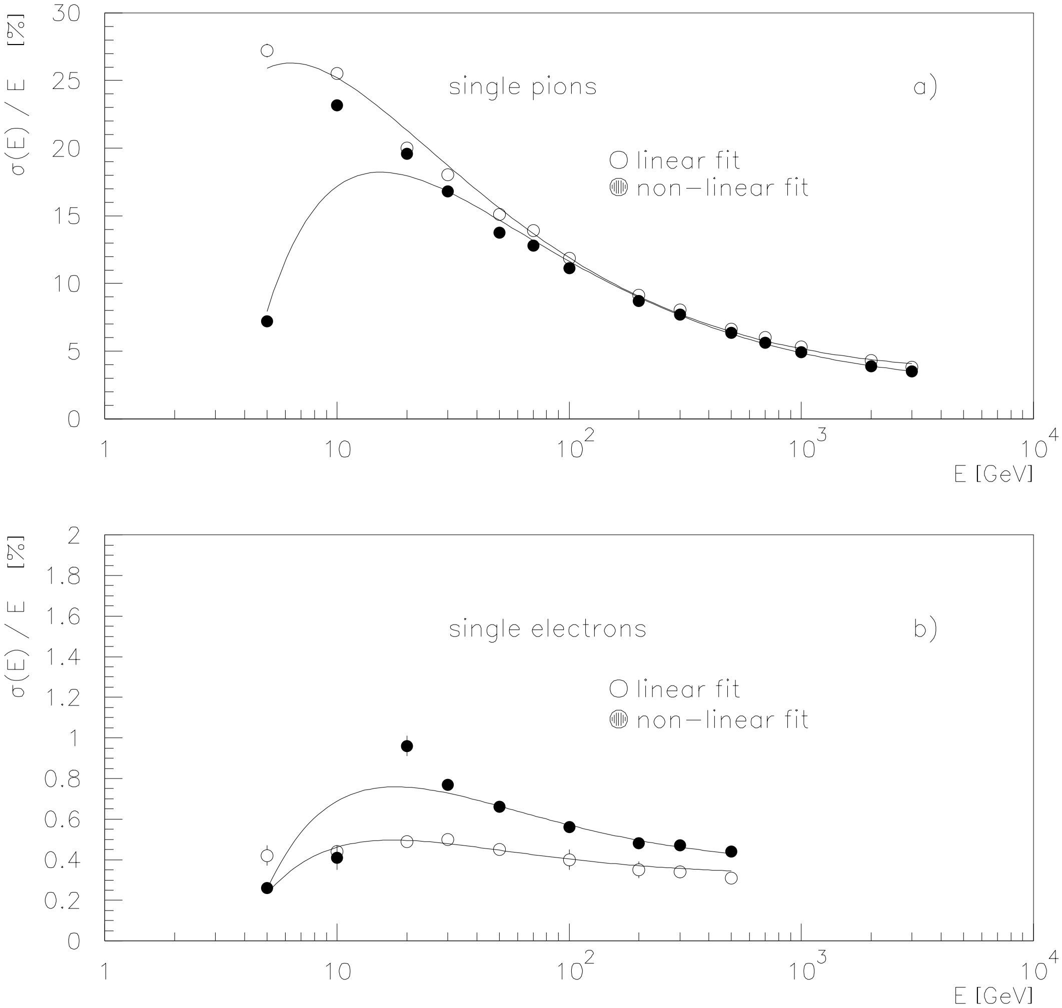

Figure 1: Energy resolution for the CMS calorimeter system (standard calibration - open points, non-linear calibration - full points).

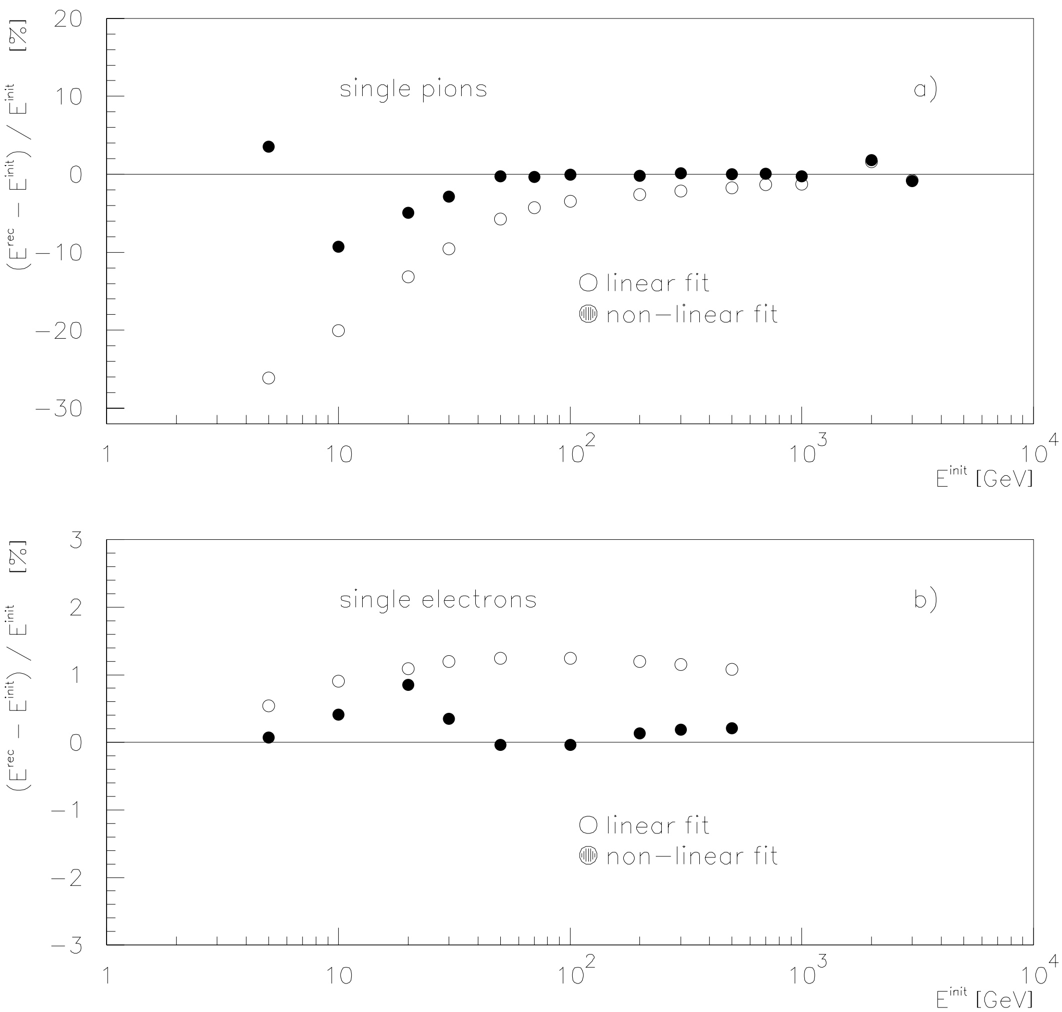

Figure 2: Residuals of the reconstructed energy (standard calibration - open points, non-linear calibration - full points).