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The Compact Muon Solenoid Experiment

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Use of Artificial Neural Networks for Improvement of CMS Hadron Calorimeter Resolution

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Abstract

The Compact Muon Solenoid (CMS) experiment features an electromagnetic calorimeter (ECAL) composed of lead tungstate crystals and a sampling hadronic calorimeter (HCAL) made of brass and scintillator, along with other detectors. For hadrons, the response of the electromagnetic and hadronic calorimeters is inherently different. Because sampling calorimeters measure a fraction of the energy spread over several measuring towers, the energy resolution as well as the linearity are not easily preserved, especially at low energies. Several sophisticated algorithms have been developed to optimize the resolution of the CMS calorimeter system for single particles. One such algorithm, based on the artificial neural network application to the combined electromagnetic and hadronic calorimeter system, was developed and applied to test beam data using particles in the momentum range of 2-300 GeV/c. The method improves the energy measurement and linearity, especially at low energies below 10 GeV/c.

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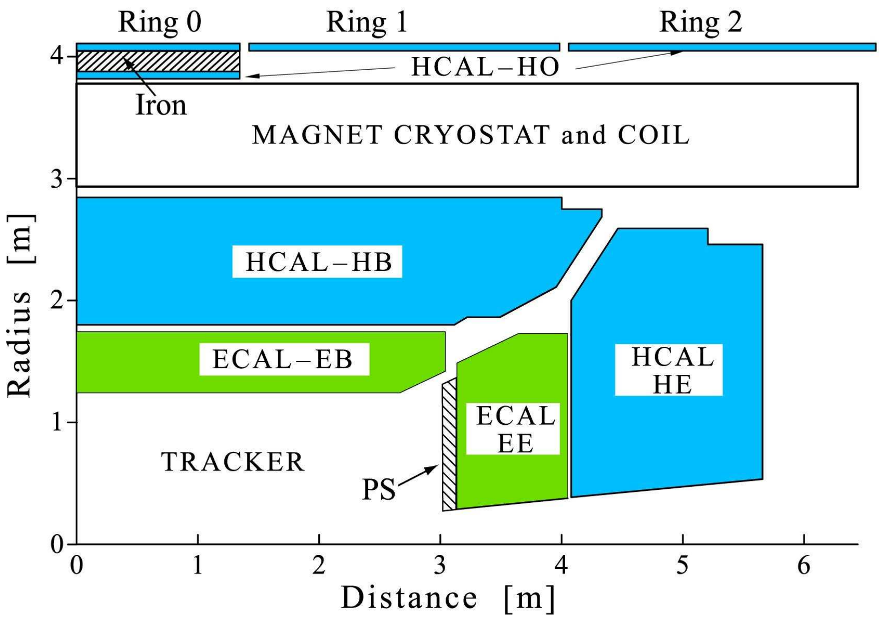

Figure 1: The central section of the CMS detector (quarter view)

1 Introduction

A neural network-based multivariate algorithm is applied to charged pions with momenta between 2 and 300 GeV/c collected during the 2006 CERN Test Beam. The total energy deposited by secondary particles in the active material of the calorimeters is proportional to that of the incident particle. In the standard method of calorimeter calibration, each tower is treated independently and assigned a multiplicative calibration constant that converts the signal to energy. We report the results of a new calibration method based on neural networks to measure the energy of charged pions.

2 Experimental Setup

In the Compact Muon Solenoid (CMS) detector there are several distinct calorimeters [1]. Two inner sampling hadronic calorimeters called HCAL-BARREL (HB) and HCAL-ENDCAP (HE) are located inside the magnet cryostat and coil (Fig. 1). An HCAL-OUTER (HO) calorimeter is installed outside of the magnet cryostat and the HCAL-FORWARD (HF) calorimeters are located on the beam line at either edge of the CMS detector. Two electromagnetic calorimeters ECAL-BARREL (EB) and ECAL-ENDCAP (EE) are located inside the hadron calorimeter. In addition there is the pre-shower layer (PS) in front of EE.

Figure 2 shows the experimental setup and various calorimeters involved in the CMS 2006 Test Beam (TB06). The H2 test beam has a motion table where detector components can be mounted. By rotating and tilting the table the beam can be directed to various parts of the detector. Two HCAL-BARREL wedges, 4.7 m long, subtending 40° in azimuth, an ECAL-BARREL (EB) super module, 4m in length and subtending 20° in azimuth and an HO layer placed downstream of HB were mounted on the table. In the H2 test beam, as will be true of the CMS detector, particles first impinge on EB, then HB, and the remaining energy is measured by HO. The point of rotation and tilt correspond to the center of the CMS detector.

3 Test Beam 2006 Energy Correction Method

A test beam calibration and energy correction procedure called the TB06 method [2] is used for benchmark comparison of resolution and energy response. For hadron beams, such as π^-, the overall calorimeter response is lower compared to that of electrons and the e/π ratio varies from about a factor of 2 at 3 GeV/c to a factor of about 1.25 at 300 GeV/c. The pion data are corrected by a function, such that the mean value of the calorimeter energy measurement is equal to the beam momentum for values from 2 to 300 GeV/c. This correction is applied to the

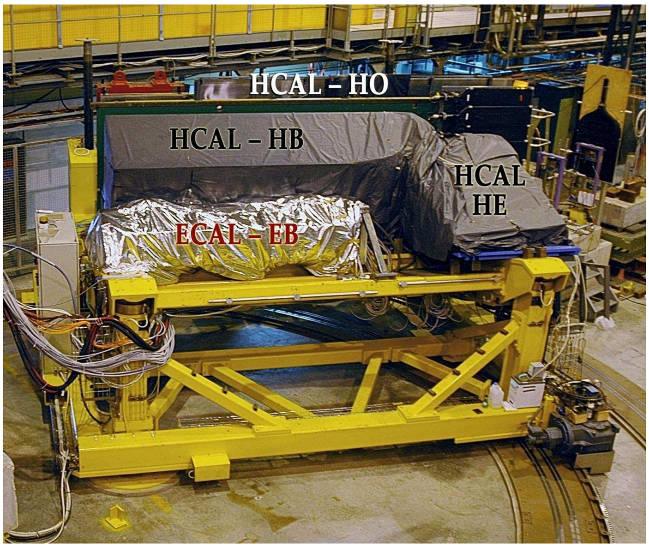

Figure 2: CMS Test Beam facility

sums of energy in EB and HB. Then, a correction that depends on the relative energy deposition between EB and HB is applied.

4 Multivariate Method

A Neural Network (ANN) is used to model a particle shower, mapping individual inputs to calorimeter towers and a single output to known beam momenta. A typical ANN with 1 hidden layer, ANN(1), is shown in Fig. 3. A linearized version of the ANN without the hidden layer, ANN(0) is also used in this study. The back propagation technique with early stopping to avoid overtraining is used to train the networks [3]. In order to guard against bias, the data are split into disjoint training and testing sets. Moreover, the training and testing errors are monitored during training to make sure the testing error does not increase, a sign of overtraining. ANN functions that are used differ slightly (but crucially) from the norm in that the output bias is fixed at zero. Fixing the bias at zero is a simple way to avoid the solution in which the training merely sets the output bias equal to the target. Typically, about 1,000 events are sufficient for the training.

5 Energy Response Comparison between TB06 and ANN Methods

Figure 4 shows the comparison in calorimeter response between the TB06 method (left) and the ANN(1) method (right) for π^- beams with momenta of 3, 9 and 100 GeV/c. The resolution obtained with the ANN(0) and the TB06 method are very similar (Fig. 5), while the ANN(1) method shows clear improvement. The mean of the response obtained with the ANN(1) method is closer to the true beam momentum than that obtained with the TB06 method, especially at lower momenta (Fig. 6); that is, the bias of the ANN(1) method is lower.

6 Discussion

The fact that the ANN(1) method produces markedly better results than ANN(0) and TB06 is a clear indication that the mapping between tower energies and incident momentum in the CMS calorimeters is non-linear and that these non-linearities need to be accounted for in order to make optimal use of the calorimetric data.

In the CMS experiment, the calorimeters will be used to measure the energy of jets. Since a jet is a collection of particles, each requiring a non-linear mapping between tower energies and particle energy, it is plausible that neural networks could be useful in the context also. We are currently exploring their possible utility for improving jet energy measurements.

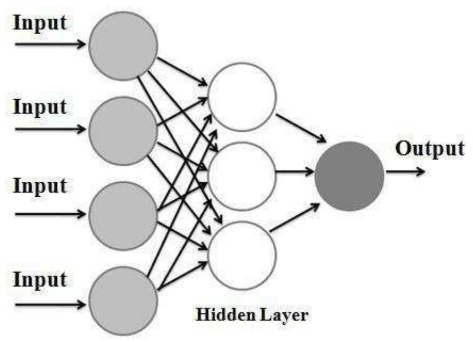

Figure 3: A typical ANN architecture with 1 input layer, 1 hidden layer and 1 output used in this study

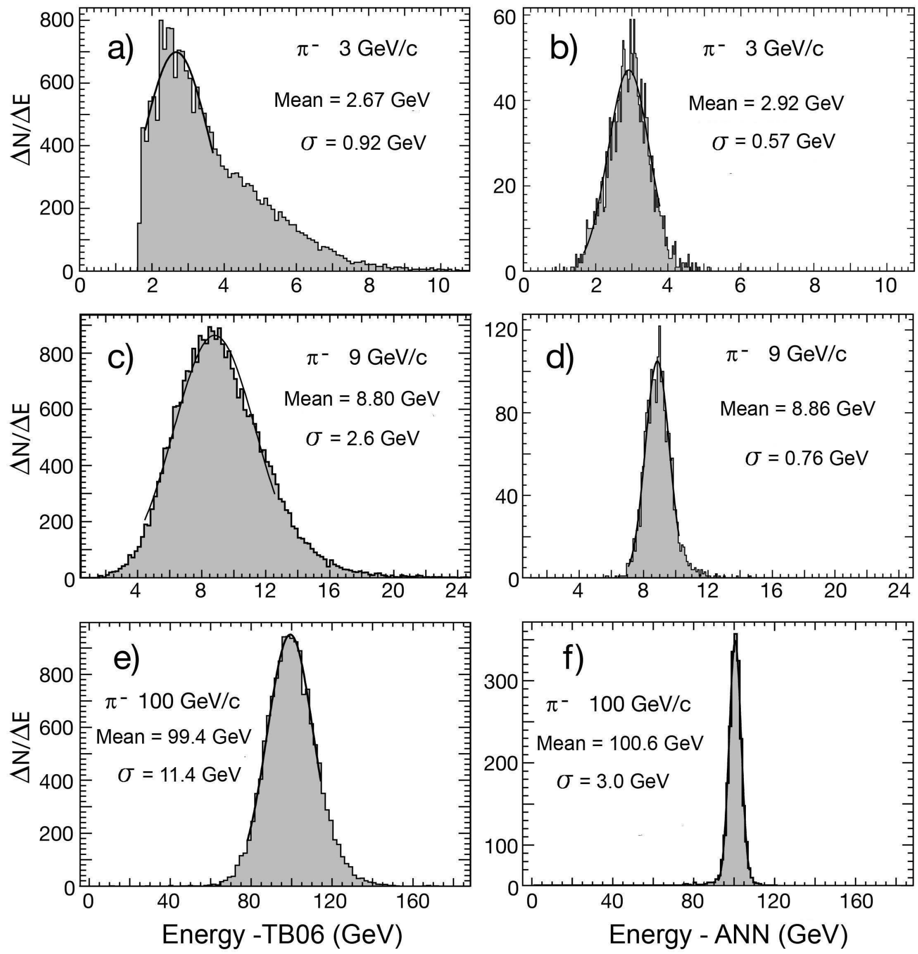

Figure 4: Calorimeter response to various π^- beams using the TB06 method (left) and the multivariate method (right). Errors shown do not include systematics.

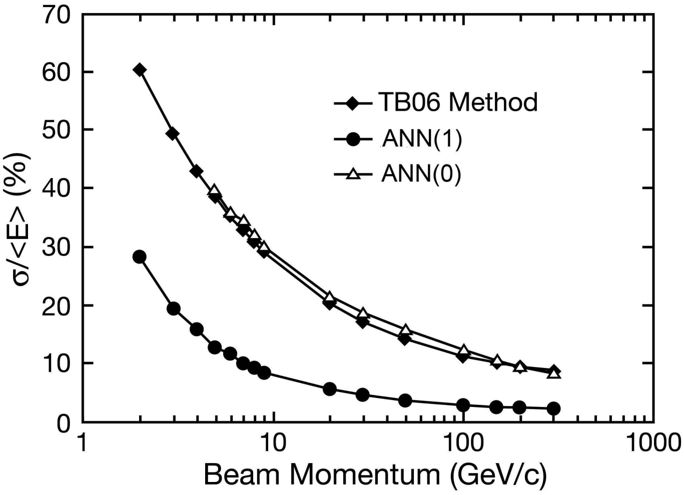

Figure 5: Comparison of calorimeter resolution obtained with the TB06, ANN(1) and linear ANN(0) methods for beam momenta 2-300 GeV/c.

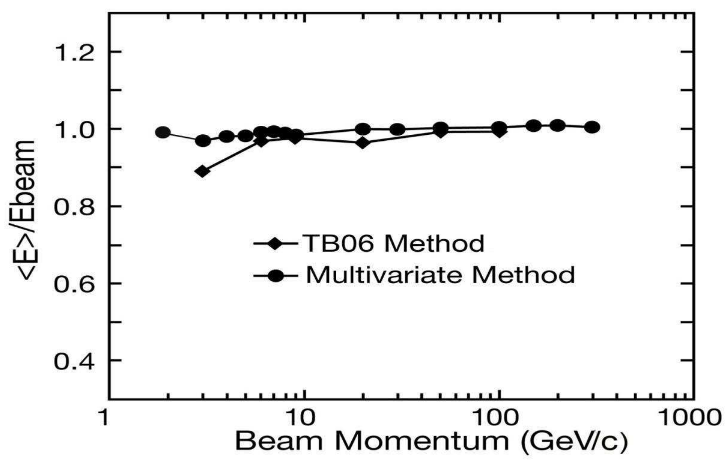

Figure 6: Comparison of mean energy response for the TB06 and the ANN(1) methods

7 Conclusions

A nonlinear ANN based method leads to sizable improvement in the calorimeter resolution for single particles.We find that a linear neural network shows very similar performance to the TB06 method. This is evidence that non-linearities are crucial and must be accounted for in order to make optimal use of the CMS calorimeters.

References

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