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Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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Energy Weighting for the Upgrade of the CMS HCAL

Kerstin Borras, Dirk Krücker, Isabell Melzer-Pellmann, Matthias Stein, Peter Schleper

Abstract

In these simulation studies an energy weighting method is applied to the signals of the CMS hadronic calorimeter readout with a longitudinal segmentation for a possible upgrade. Tabulated weighting factors are used to compensate for the different response of hadronic and electromagnetic energy depositions of simulated pion showers in the hadronic calorimeter. The weighting improves the relative energy resolution:

$$(\sigma_E/E)^2 = \left[\left((92.2 \pm 0.6)\% / \sqrt{E} \right)^2 + ((6.5 \pm 0.1)\%)^2 \right] \text{ (before weighting),}$$

$$(\sigma_{E,\text{weight}}/E)^2 = \left[\left((85.4 \pm 0.5)\% / \sqrt{E} \right)^2 + ((4.4 \pm 0.1)\%)^2 \right] \text{ (after weighting),}$$

where E in the square root has units of GeV.

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ENERGY WEIGHTING FOR THE UPGRADE OF THE CMS HCAL

K. Borras,¹ D. Krücker,¹ I. Melzer-Pellmann,¹ M. Stein,^{1,*} and P. Schleper²

¹*DESY, Hamburg, Germany.*

²*University of Hamburg, Hamburg, Germany.*

In these simulation studies an energy weighting method is applied to the signals of the CMS hadronic calorimeter readout with a longitudinal segmentation for a possible future upgrade. Tabulated weighting factors are used to compensate for the different response of hadronic and electromagnetic energy depositions of simulated pion showers in the hadronic calorimeter. The weighting improves the relative energy resolution:

$$\begin{aligned}(\sigma_E/E)^2 &= \left[\left((92.2 \pm 0.6)\% / \sqrt{E} \right)^2 + ((6.5 \pm 0.1)\%)^2 \right] \text{ (before weighting),} \\ (\sigma_{E,\text{weight}}/E)^2 &= \left[\left((85.4 \pm 0.5)\% / \sqrt{E} \right)^2 + ((4.4 \pm 0.1)\%)^2 \right] \text{ (after weighting),}\end{aligned}$$

where E in the square root has units of GeV.

1. INTRODUCTION

The hadronic calorimeter (HCAL) of CMS is a non compensating sampling calorimeter with an e/π -ratio of about 1.2 for 50 GeV pions [1]. Consequently, the response for electromagnetic energy depositions is larger than for hadronic ones which affects the energy measurement. An energy weighting method to compensate for the e/π -ratio is possible if one can identify the electromagnetic- or hadronic-like origin of the energy deposition within a hadronic shower. For the CMS detector upgrade Phase I a longitudinal segmentation of the HCAL towers is under consideration, improving its longitudinal granularity by a factor of four (see Fig. 1). This offers the possibility to resolve parts of particle showers. A possible readout scheme (“1-4-4-8”) is investigated here, where each digit represents the number of calorimeter cells which are read out in one channel. Other possible readout schemes has

* Electronic address: `matthias.stein@desy.de`

been investigated, too. However, it turned out that the readout scheme “1-4-4-8” yields the best result for the weighting.

2. THE METHOD AND REALIZATION

The method of the tabulated weighting factors [2, 3] is a software based method, aiming to compensate for the e/π -ratio of a calorimeter. The basic idea is to distinguish between electromagnetic and hadronic energy depositions and to find appropriate weighting factors for the compensation. The discrimination criterion is the *energy density*

$$\rho^i = E_{\text{meas}}^i / V^i, \quad (1)$$

where E_{meas}^i is the measured energy and V^i a measure for the volume in arbitrary units, both for a readout channel i .

The weighting is based on the fact that the average energy density of electromagnetic depositions is larger than for hadronic ones. In a Monte Carlo (MC) simulation it is possible to obtain weighting factors w^i as a function of the energy density ρ^i :

$$w^i(\rho^i, E_{\text{shower}}) = \left\langle \frac{E_{\text{dep}}^i}{E_{\text{meas}}^i} \right\rangle, \quad (2)$$

where E_{shower} is the total shower energy received from a 3×3 -cluster and E_{dep}^i is the deposited energy given by

$$E_{\text{dep}}^i = E_{\text{abs}}^i + E_{\text{sci}}^i + E_{\text{inv}}^i, \quad (3)$$

where E_{abs}^i is the energy deposited in the absorber, E_{sci}^i the energy deposited in the scintillator and E_{inv}^i the invisible energy (from neutrinos, nuclear excitation, etc.).

Once the weighting factors are obtained from a Monte Carlo simulation, they can be applied to data (here: simulated data) to yield a weighted energy

$$E_{\text{weight}}^i = E_{\text{meas}}^i \cdot w^i. \quad (4)$$

For the realization of the weighting method, a simulation of the CMS HCAL is necessary. In the presented studies, this is done via a Geant3 [4] standalone simulation, since the deposited energy E_{dep}^i left in a readout channel i of the HCAL, including the absorber energy, is presently not available in the CMS software. GCALOR is chosen as shower generator, in

order to make the simulation as realistic as possible [5]. A simulated test beam of pions with an energy of 50 GeV is used to calibrate the HCAL. Since the weighting factors depend on the shower energy, it is necessary to create a set of them for multiple simulated test beam energies. This is done for the following energies: (10, 20, 30, 50, 100, 150, 225, 300) GeV. However, for any energy which does not correspond to one of these energies, an *interpolation* of the weighting factors is required. Here, a linear interpolation is used.

3. RESULTS

The relative energy resolution and linearity before and after weighting using the “1-4-4-8” design, are shown in Figs. 2 and 3, respectively. Both results are obtained from a Gaussian fit. The 80 GeV sample is a statistically independent test sample for which no weighting factors exist. The final result is obtained by interpolation between weighting factors of different energies only.

The energy resolution is

$$\begin{aligned} (\sigma_E/E)^2 &= \left[\left((92.2 \pm 0.6)\% / \sqrt{E} \right)^2 + ((6.5 \pm 0.1)\%)^2 \right] \text{ (before weighting),} \\ (\sigma_{E,\text{weight}}/E)^2 &= \left[\left((85.4 \pm 0.5)\% / \sqrt{E} \right)^2 + ((4.4 \pm 0.1)\%)^2 \right] \text{ (after weighting),} \end{aligned}$$

where E in the square root has units of GeV.

4. CONCLUSION / OUTLOOK

Applying the weighting method to the CMS HCAL with the readout design “1-4-4-8”, the sampling term and constant term of the energy resolution improve. As the energy distributions contain non-Gaussian tails (especially for lower energies), the improvement of the linearity is more pronounced for the mean of the distributions than for the mean of a Gaussian fit.

The entry at 80 GeV of the energy resolution (for which no weighting factors exist) is in good agreement with the other energies. This is an important consistency check. However, for the linearity there is a kink at 80 GeV. This can be explained by the *linear* interpolation of the weighting factors. In further investigations different interpolation methods should be studied systematically in order to avoid this effect.

Test beam results of the CMS HCAL can be found in [6]. To test the weighting method with non simulated data, the weighting factors can be applied to test beam data of a CMS HCAL test setup. First investigations look very promising and showed an even larger improvement of the energy measurement, using a two-dimensional fit of the weighting factors (in the ρ - E_{beam} -plane), instead of a one-dimensional linear interpolation.

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ИСПОЛЬЗОВАНИЕ МЕТОДА ВЗВЕШЕННЫХ ЭНЕРГИЙ ПРИ МОДЕРНИЗАЦИИ АДРОННОГО КАЛОРИМЕТРА CMS

К. Боррас, Д. Крюкер, И. Мелзер-Пеллман, М. Штейн, П. Шелепер

Рассматривается применение метода взвешенных энергий обработки данных с адронного калориметра CMS при использовании схемы считывания после будущей модернизации. Весовые факторы, рассчитанные отдельно, используются для компенсации разницы отклика калориметра на адронную и электромагнитную составляющую пионного ливня. В результате улучшение разрешения по энергии составляет

$$(\sigma_E/E)^2 = \left[\left((92.2 \pm 0.6)\% / \sqrt{E} \right)^2 + ((6.5 \pm 0.1)\%)^2 \right] \text{ (до взвешивания),}$$

$$(\sigma_{E,\text{weight}}/E)^2 = \left[\left((85.4 \pm 0.5)\% / \sqrt{E} \right)^2 + ((4.4 \pm 0.1)\%)^2 \right] \text{ (после взвешивания),}$$

где E под корнем измеряется в ГэВ'ах.

Figure captions

Fig. 1. Sketch of a possible readout scheme (“1-4-4-8”) for the CMS HCAL after the upgrade.

Fig. 2. Energy resolution before (solid line) and after (dashed line) the weighting with the 1-4-4-8 design.

Fig. 3. Linearity before (solid line) and after (dashed line) the weighting with the 1-4-4-8 design.

Figures

Figure 1. Stein, Fig. 1

Figure 2. Stein, Fig. 2

Figure 3. Stein, Fig. 3