Energy Weighting for the Upgrade of the Hadronic Calorimeter of CMS

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In these simulation studies an energy weighting method is applied to the signals of the CMS hadronic calorimeter with a possible readout scheme after the 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 from
$(\sigma_E/E)^2 = [((92.5 \pm 0.6)\%/E)^2 + ((6.5 \pm 0.1)\%)^2]\ \mathrm{GeV}^2$ to
$(\sigma_{E,weight}/E)^2 = [((85.5 \pm 0.5)\%/E)^2 + ((4.4 \pm 0.1)\%)^2]\ \mathrm{GeV}^2$.

1 Introduction

The hadronic calorimeter (HCAL) of CMS is a non-compensating sampling calorimeter with an $e/\pi-$ratio of about 1.2 [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 $e/\pi-$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 discussed, improving its longitudinal granularity by a factor of four (see Fig. 1). This offers the possibility to resolve single 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.

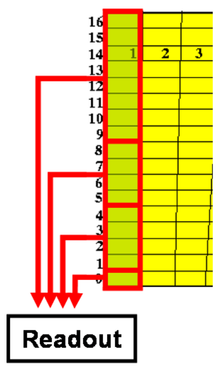

Figure 1: Sketch of a possible readout scheme ("1-4-4-8") for the CMS HCAL after the upgrade.

2 The Method and Realization

The method of the tabulated weighting factors [2] is software based. Its principle is to distinguish between electromagnetic and hadronic energy depositions in the HCAL and to find appropriate weighting factors for the compensation. The discrimination criterion is the *energy density*

$$\rho^i = E^i_{dep}/V^i, \tag{1}$$

where E^i_{dep} is the deposited energy and V^i a measure for the volume in arbitrary units (number of layers per readout channel), both for a readout channel i, and

$$E^i_{dep} = E^i_{abs} + E^i_{sci} + E^i_{inv}, \tag{2}$$

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

The weighting is based on the fact that the average energy density of electromagnetic depositions is larger than for hadronic ones. In a MC simulation it is possible to obtain weighting factors w^i as a function of the energy density (see Figure 2)

$$w^i\left(\rho^i, E_{shower}\right) = \left\langle \frac{E^i_{dep}}{E^i_{meas}} \right\rangle, \tag{3}$$

where E_{shower} is the total shower energy received from a cluster algorithm of a $3 \times 3-$cluster and E^i_{meas} is the scintillator energy times a calibration factor.

These weighting factors are applied to data (here: simulated data) to yield a weighted energy

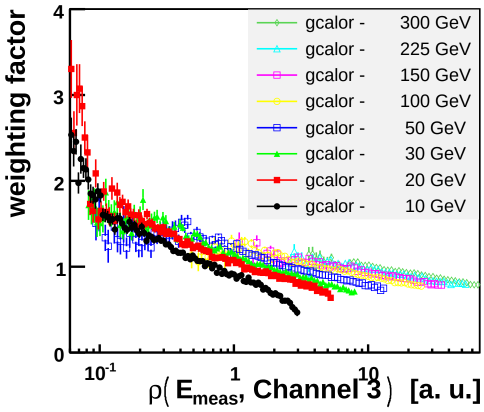

Figure 2: Weighting factors for the third channel of the readout scheme "1-4-4-8".

$$E^i_{weight} = E^i_{meas} \cdot w^i. \tag{4}$$

For the realization of the weighting method, a simulation of the CMS HCAL is necessary. This is done via a Geant3 [3] standalone simulation, as the deposited energy E^i_{dep} left in a readout channel i of the HCAL, including the absorber energy, is presently not available in the CMS software. In order to make the simulation as realistic as possible [4], *Gcalor* is chosen as shower generator. 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 Figure 3 and Figure 4, 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.

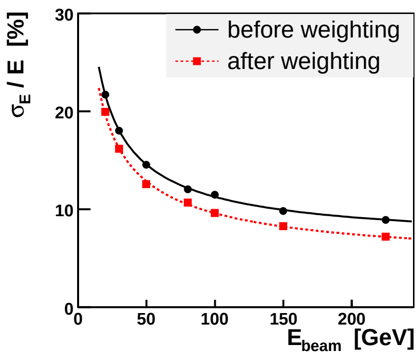

Figure 3: Energy resolution before (black) and after (red, dashed) the weighting with the 1-4-4-8 design.

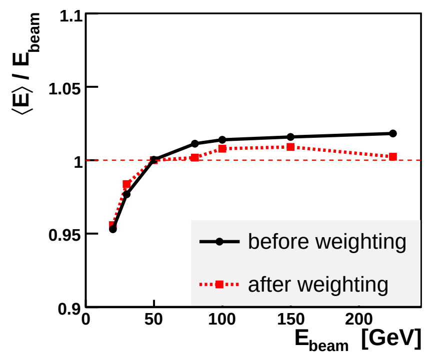

Figure 4: Linearity before (black) and after (red, dashed) the weighting with the 1-4-4-8 design.

The energy resolution is

$$(\sigma_E/E)^2 = [((92.5 \pm 0.6)\%/E)^2 + ((6.5 \pm 0.1)\%)^2]\ \mathrm{GeV}^2 \qquad \text{(before weighting)},$$
$$(\sigma_{E,weight}/E)^2 = [((85.5 \pm 0.5)\%/E)^2 + ((4.4 \pm 0.1)\%)^2]\ \mathrm{GeV}^2 \qquad \text{(after weighting)}.$$

4 Conclusion

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 here [5].

References

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