How to calibrate an Electromagnetic calorimeter without electrons

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Abstract

The short answer– Have a hadron calorimeter behind the EM calorimeter. We describe a technique to calibrate the MIPP electromagnetic and hadron calorimeters simultaneously using MIPP beam at a particular beam momentum setting. At this point in time we do not have full tracking in MIPP, so it is impossible to tell the momentum of the beam particle by particle. We use the beam momentum of the beam from the MIPP beamline dipole setting MC6D. The method described will accomodate individual beam momenta when they become available. For the results presented here, the results should only be taken as a relative measure of the calibration constants.

I. METHOD

Let L_j be the live energy in calorimeter layer j. There are 18 layers in MIPP calorimeter. The first 10 are EM layers all of which are longitudinal. The next 8 are hadron calorimeter layers. There are 4 longitudinal layers each of which is divided into two transverse layers.

Then the energy deposited E_j in layer j is given in general by

$$E_j = \sum_{k=1}^{k=N} \lambda_{jk} L_k \tag{1}$$

where N is the number of layers (=18 in this case) and λ is a tensor that can be determined from a good simulation program such as Geant if need be. Note that the best measure for $E_j \neq \mu_j L_j$ where μ_j is the inverse sampling fraction [1]. This is because of correlations in the shower and λ tensor is not diagonal in general. The biggest correlation is introduced by the fact that the total energy in any shower is conserved and assuming no leakage, implies that if some layers are high the others must be low to conserve energy. Then the total energy of the shower is given by

$$E_{tot} = \sum_{j=1}^{j=N} \sum_{k=1}^{k=N} \lambda_{jk} L_k = \sum_{k=1}^{k=N} w_k L_k \tag{2}$$

where the weights $w_k \equiv \sum_{j=1}^{j=N} \lambda_{jk}$.

The weights w_k are determined by minimizing the sum of squares S^2 over an ensemble of events M, where,

$$S^2 \equiv \sum_{l=1}^{l=M} (E^l_{tot} - \sum_k w_k L^l_k)^2 \tag{3}$$

Minimizing with respect to w_j leads to

$$\sum_{k=1}^{k=N} < L_j L_k > w_k =< E_{tot} L_j > \tag{4}$$

where $<>$ implies average over the ensemble of events. The weights w_k are obtained by solving the above matrix equation by inverting the matrix $< L_j L_k >$. Eventually, we will have event by event values for E_{tot} from the tracking. For now, we will asume an average E_{tot} from the beam tune. The absolute values of the calibration constants are thus uncertain. Also the calorimeter resolution obtained from the fits will also be pessimistic, since it will have the beam momentum spread added in quadrature.

A. Iterative determination of weights

We determine the pedestals of the layers from the data and use appropriate pedestal subtraction to obtain the vector L_k. We use $\approx$ 18000 events taken with a hadron beam trigger with the beam tuned nominally to 15 GeV/c and the particle id of the beam cerenkov trigger of kaons. Figures 1 and 2 show the raw distibutions of the EM calorimeter and the hadron calorimeter ADC SUM (pedestal subtracted). A strong muon peak is evident in the hadron calorimetr raw spectrum as well as background induced to the beam interacting upstream of the HCAL. This should clean up when we have full tracking available. For now, we impose a cut in the RAW adc-pedestal sum (HRAW) in the HCAL by demanding that it lies betwen 1200 and 6500 counts. The fit algorithm is applied to events which pass this cut (15403 events out of 18805 total) and the weights worked out for 18 layers by inverting an 18x18 matrix. The LSQ package that I wrote while in DØ is used for matrix manipulations in double precision. This software in in MIPP CMS.

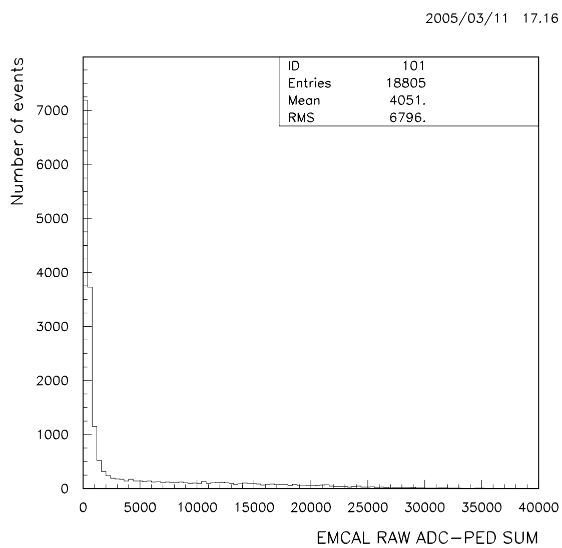

FIG. 1: Raw sum of EMCAL ADC's pedestal subtracted.

After the 1st determination of weights, the energy deposited is worked out and then a cut is imposed based on total energy (TSUM) deposited in the calorimeter $11.25 < TSUM < 18.75$ GeV. The HRAW cut is discontinued after the first iteration. The weights are determined using events that pass this cut. This process is repeated for a total of 10 iterations. Convergence is obtained for all the weights. The HCAL weights are fixed at the end of 10

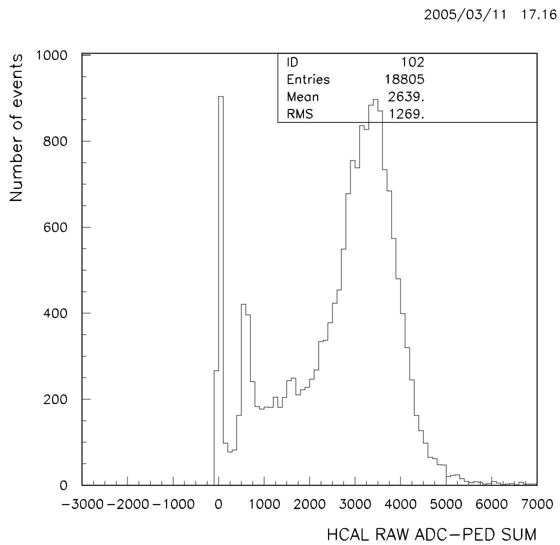

FIG. 2: Raw sum of HCAL ADC's pedestal subtracted. A muon peak is evident as well as the hadron energy deposit due to the beam

iterations. The number of events accepted after 10 iterations is 14954. Figure 3 gives the total energy in the calorimeters at the end of 10 iterations. A Gaussian fit is performed on the hadronic peak, which gives (a pessimistic) $\sigma(E)/E$ of 14.1%. The EMCAL weights now

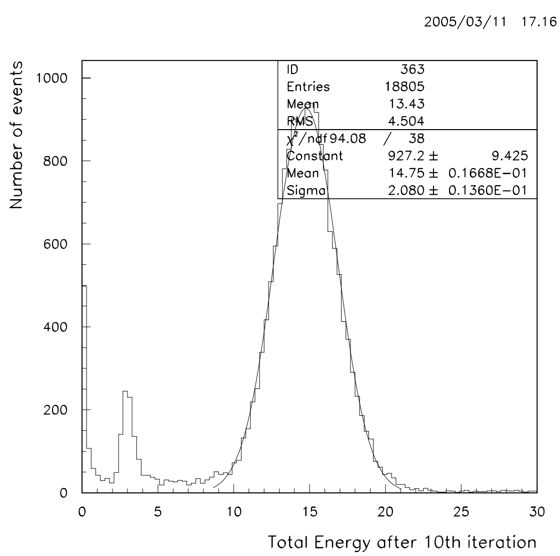

FIG. 3: The total energy using weights at the end of 10 iterations. A Gaussian fit is performed

reflect the calibration constants that should be used when reconstructing hadronic energy. In principle, there could be variation of the EM calibration constants as a function of the

EM FRACTION of the event. Figure 4 shows the distribution of the electomagnetic fraction of the event, for events which satisfy the TSUM cut after 10 iterations. Figure 5 shows the scatter plot of total energy vs EM FRACTION for all events. We impose a cut of

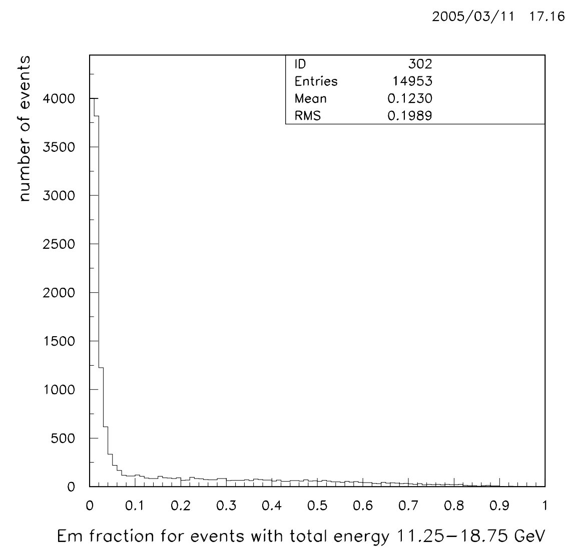

FIG. 4: Emfraction of events that pass the total energy cut after 10 iterations

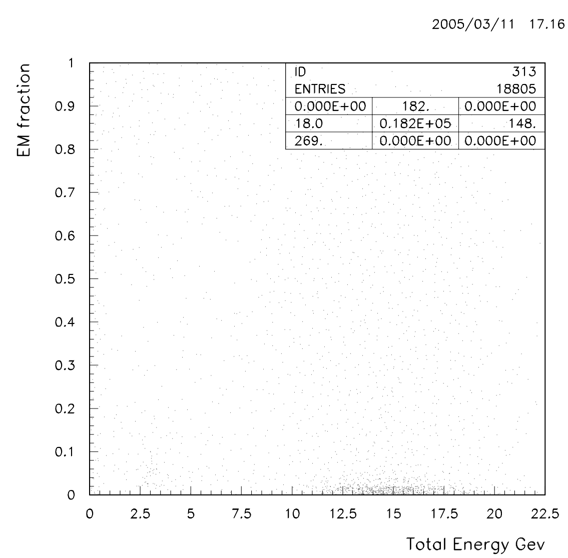

FIG. 5: Scatter plot of EM FRACTION vs Total Energy of event

$0.4 < EMFRACTION < 1.0$. A total of 1843 events pass this cut and reflect a subsample of events that have an early start of the hadronic shower process by depositing a significant amount of energy as π^0's in the EM calorimeter. We then determine the energy in the HCAL for each event and subtract this from the beam energy to obtain the amount of energy in the EMCAL. The plot of this energy is shown figure 6(a) with no EM Fraction cut and (b) with the EM fraction cut. We then iterate for another 5 iterations, constraining the total EM energy to be (Beam Energy-HCAL energy) and holding the HCAL weights constant. Figure 7 shows the variation of the hadron calorimeter weights at the end of each iteration

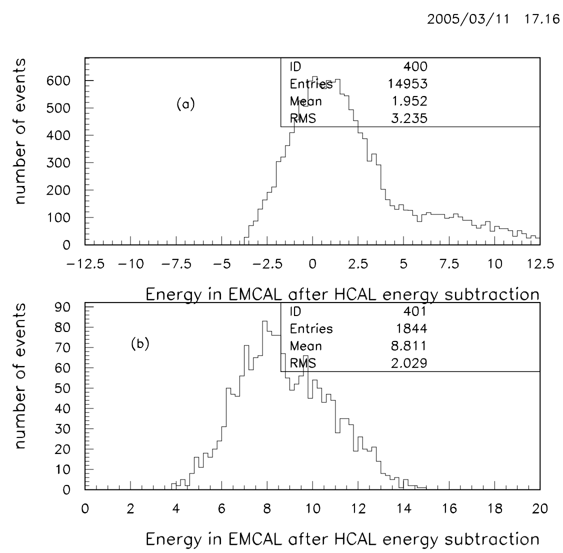

FIG. 6: (a) Energy left in EM Calorimeter after subtracting the total hadronic energy from the beam momentum. The negative energies are due to resolution effects for small EM fractions (b)Energy left in EM calorimeter after EM Fraction cut is applied.

as a function of iteration number. Figure 8 shows the EM calorimeter weights for the first 10 iterations and then for the next 5 iterations with the EM fraction cut. Table I gives the numerical values of the calibration constants for no EM FRACTION cut (i.e. at the end of 10 iterations), with $0.4 < EMFRACTION < 1.0$ and $0.6 < EMFRACTION < 1.0$ (727 events surviving).

II. CONCLUSIONS

We have outlined a method that enables EM calorimeter weights to be determined with a hadron beam using a least squares method. The method will improve considerably when full tracking and particle id is available in MIPP. When finding hadronic energies, we should use the EM constants worked out with no EM Fraction cut. When determining electromagnetic

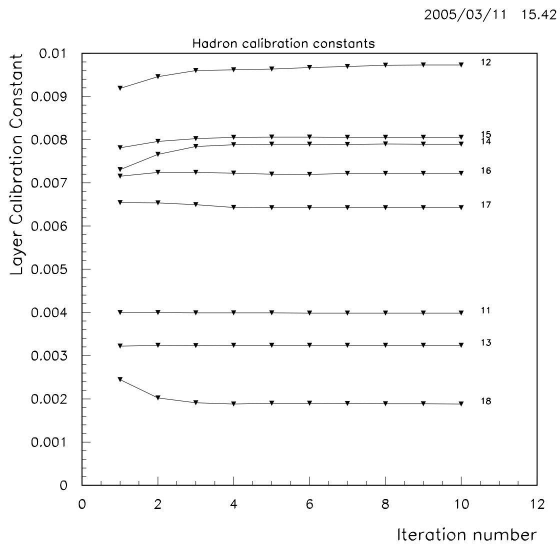

FIG. 7: Hadron Calorimeter weights as a function of iteration number for the first 10 iterations. Note swift convergence. The layer number (11-18) is indicated at the end of each curve.

energies, we should extrapolate the EM constants to a large EM fraction (till they are stable). This can be currently done with a higher statistic run. One should also compare these weights with those obtained with 5 GeV tagged electrons that are available in MIPP.

The author wishes to thank Durga Rajaram for providing the data in a format digestible to the LSQ package.

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[1] The fact that inverse sampling fraction method of calibration produces poorer resolution is shown in "On Sampling Fractions and Electron Shower Shapes", Alexander Peryshkin and Rajendran Raja, DØ Note 1215, MIPP Note 36, http://ppd.fnal.gov/experiments/e907/notes/MIPPnotes/public/pdf/MIPP0036/MIPP0036.pdf The linear least squares method results in weights that contain information on correlations between layers.

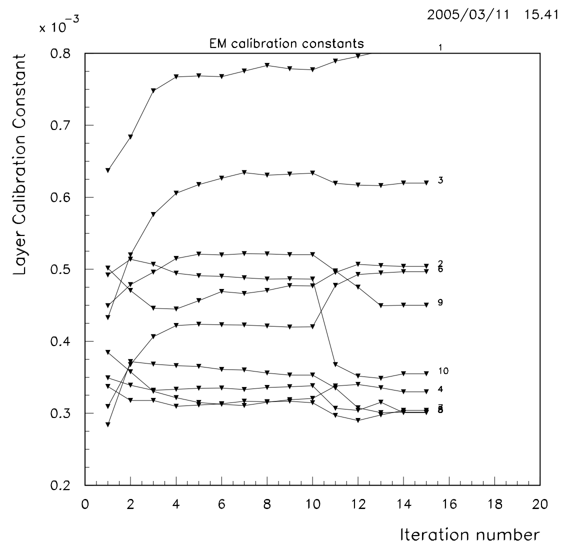

FIG. 8: EM Calorimeter weights as a function of iteration number for 15 iterations At the end of 10 iterations, the EM FRACTION cut is applied to ddetermine the weights for more electromagnetic events. The layer number (1-10) is indicated at the end of each curve.

TABLE I: Calibration constants with no EM Fraction cut, and with EM Fraction cuts

Layer	Calibration Constant $0.0 < EMFraction < 1.0$	Weight $0.4 < EMFraction < 1.0$	Calibration Constant $0.6 < EMFraction < 1.0$
1	0.77695E-03	0.74129E-03	0.80404E-03
2	0.47682E-03	0.52666E-03	0.50390E-03
3	0.63349E-03	0.58347E-03	0.61980E-03
4	0.32052E-03	0.31322E-03	0.32965E-03
5	0.35300E-03	0.37084E-03	0.30135E-03
6	0.41998E-03	0.43178E-03	0.49661E-03
7	0.31443E-03	0.32329E-03	0.30390E-03
8	0.33813E-03	0.32971E-03	0.30088E-03
9	0.52018E-03	0.50859E-03	0.45013E-03
10	0.48636E-03	0.42490E-03	0.35488E-03
11	0.39828E-02		
12	0.97286E-02		
13	0.32370E-02		
14	0.78953E-02		
15	0.80534E-02		
16	0.72175E-02		
17	0.64265E-02		
18	0.18830E-02		