Calorimeter Calibration Development

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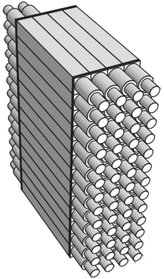
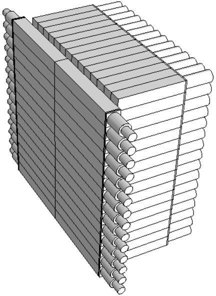
The Spectrometer Calorimeters

HMS



4×13 blocks
2×13 double sided readout blocks
2×13 single sided readout blocks

SHMS



2×13 blocks for preshower
14×16 blocks for shower

Calorimeter E/P

E/P peak should be at 1 for an electromagnetic shower

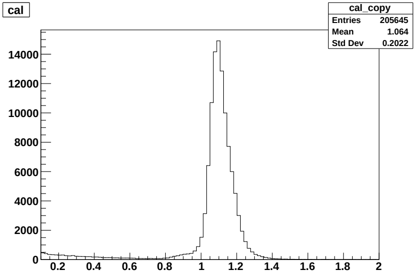


Figure: HMS Calorimeter E/P

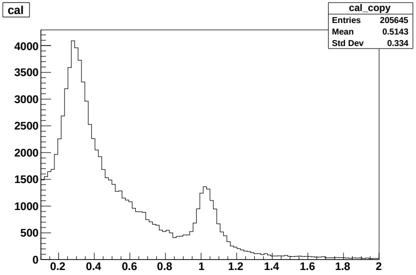
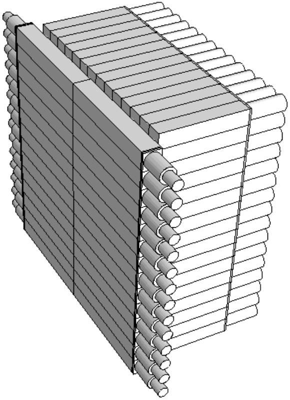


Figure: SHMS Calorimeter E/P

Block Energy

The observed energy in a calorimeter block is
$E_i = G_i A_i$
where G_i and A_i are the gain constant and raw ADC value for the ith block, respectively.

- n : number of pmts in calorimeter
- N : number of events in calibration sample
- $E_i^{(k)} = G_i A_i^{(k)}$: energy seen by ith pmt in kth event
- $E_k = \sum_i^n E_i^{(k)}$: total energy in kth event



Calorimeter Gain Constants

HMS : $4 \times 13 \times 2$ constants

```
; Calibration constants for file coin_replay_production_7593_-1.root, 41675 events processed

hcal_pos_gain_cor= 11.77,  3.49,  8.31,  8.69,  7.54, 12.06,  9.88,  9.64,  7.50, 11.21, 13.72, 11.53, 40.52,
                    8.21,  7.08,  6.06, 11.45,  6.02,  5.18,  6.34,  5.41,  8.00,  7.04, -0.12, 11.90,  2.10,
                   17.99, 10.58, 13.24, 18.92, 10.93, 14.61, 16.99, 13.03, 16.12, 20.10, 11.54, 16.21, 22.50,
                   33.75, 17.14, 20.01, 21.72, 19.47, 23.07, 26.97, 22.16, 20.87, 22.27, 23.73, 23.89, 10.94,
hcal_neg_gain_cor= 14.39, 14.96, 10.34,  9.57,  8.39,  8.33, 12.96, 16.11, 11.90, 10.17,  7.99,  8.81,-29.35,
                   12.67, 12.90, 14.02, 11.13, 15.20, 14.33, 15.38, 15.15, 14.54, 11.17, 20.49, 10.89, 13.43,
                    0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,
                    0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,
```

SHMS : $2 \times 14 + 14 \times 16$ constants

```
; Calibration constants for file coin_replay_production_7593_-1, 6533 events processed

pcal_neg_gain_cor =  0.00,  0.00, 22.61, 15.02, 18.03, 15.02, 24.36, 26.88, 15.83, 23.12, 19.41, 19.19, 13.80,  0.00,
pcal_pos_gain_cor =  0.00,222.36, 19.33, 16.10, 17.13, 17.26, 14.24, 12.58, 20.52, 15.42, 25.98, 23.76, 51.38,  0.00,
pcal_arr_gain_cor =  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,
                     0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,
                     0.00,  0.00,  8.80, 36.28, 86.44, 43.84, 61.08,125.44,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,
                     0.00,  0.00, 41.90, 43.09, 37.38, 29.52, 75.21, 56.09, 63.07,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,
                     0.00,  0.00, 32.40, 28.92, 60.47, 49.88, 42.39, 34.53, 33.22, 61.13, 80.23, 92.40, 30.59,152.99,  0.00,  0.00,
                     0.00,  0.00, 29.15, 63.12, 18.28, 39.35, 39.46, 47.32, 68.22, 32.92, 71.96, 51.57, 70.43, 13.65,  0.00,  0.00,
                     0.00,  0.00, 66.08, 41.76, 25.13, 45.44, 55.14, 41.62, 34.74, 34.79, 29.16, 23.06, 34.49, 33.30, 65.70,  0.00,
                     0.00, 62.41, 17.31, 13.39, 16.95, 12.37, 16.37, 20.01, 13.30, 16.64, 24.40, 19.99, 27.67, 16.22,  5.24,  0.00,
                     0.00,  0.00, 36.06, 32.74, 50.13, 40.32, 23.38, 43.49, 57.33, 83.60, 21.87, 58.93, 27.28, 24.91,  0.00,  0.00,
                     0.00,  0.00, 21.66, 42.78, 24.42, 57.00, 40.05, 56.92, 46.05, 45.52, 44.89, 41.68, 53.24, 30.79, 51.94,  0.00,
                     0.00,  0.00,104.23, 37.47, 31.23, 46.41, 22.20, 74.10,  0.00,  0.00,  0.00,  0.00, 38.51, 23.31,  0.00,  0.00,
                     0.00,  0.00,  0.00,  0.00,169.49,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,
                     0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,
                     0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,
```

Note HMS has zeroed gain constants on negative sides without PMTs

Note SHMS has zeroed gain constants for perfectly good blocks/PMTs!!!

Algorithm

The gain constant for each block is determined by minimizing the χ^2, which is defined as the squared difference between a know energy(track momentum for electron) to the measured energy in the calorimeter.

- $\chi^2 = \sum_k^N (P^{(k)} - \sum_i^n G_i A_i^{(k)})^2 = \sum_k^N ((P^{(k)2}) + (\sum_i^n G_i A_i^{(k)})^2 - 2P^{(k)} \sum_i^n G_i A_i^{(k)})$
- $\frac{\partial \chi^2}{\partial G_i} = 0$
- $\sum_k^N 2(\sum_i^n G_i A_i^{(k)}) A_j^{(k)} - 2P_k \sum_i^n G_i A_i^{(k)} = 0$
- $\sum_k^N \sum_i^n G_i A_i^{(k)} A_j^{(k)} = \sum_k^N P_k \sum_i^n G_i A_i^{(k)}$
- $\mathcal{Q} G = \vec{q_e}$
- $Q_l m = \sum_i^N E_l^i A_m^i$

$$\mathcal{Q}\vec{\alpha} = \vec{q_e} \tag{1}$$

N data $\vec{q_e}$ with different standard deviation σ and a common relative normalization error of ϵ. mean value is not affected but standard derivation is.

Calibration Formalism

Currently used algorithm

1. Initialize all gain constant to be $G_i = 1$
2. Build vectors and matrix from event sample

- $\bar{P} = \frac{1}{N}\sum_k^N P^{(k)}$
- $\vec{q_e} = q_{e,i} = \frac{1}{N}(\sum_k^N E_i^{(k)} P^{(k)})$
- $\vec{q_0} = q_{0,i} = \frac{1}{N}(\sum_k^N E_i^{(k)})$
- $\mathcal{Q} = \frac{1}{N}\sum_k^N \begin{bmatrix} E_1^2 & E_1E_2 & \dots \\ E_1E_2 & E_2^2 & \dots \\ \vdots & \ddots & \\ E_1E_n & \dots & E_n^2 \end{bmatrix}^{(k)}$

$$\mathcal{Q}\vec{\alpha} = \vec{q_e}$$

Solve for $\vec{\alpha}$

$$\Delta_E = \bar{P} - \vec{\alpha}\cdot\vec{q_e}$$

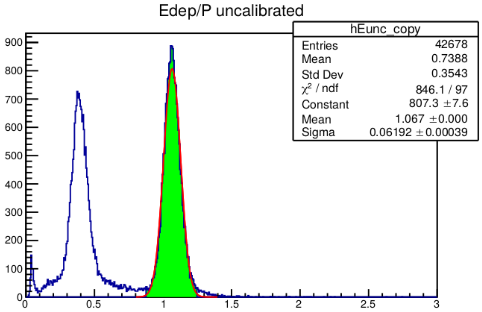
$$\mathcal{Q}\vec{x} = \vec{q_0}$$

Solve for $\vec{x}$

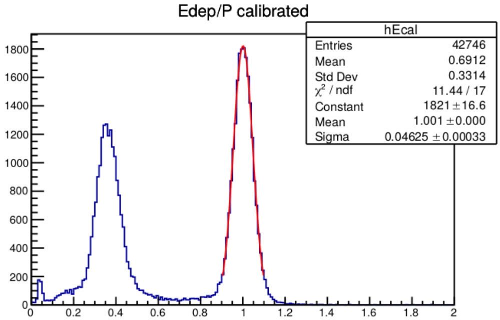
$$t_2 = \vec{q_0}\cdot\vec{x}$$

$$G' = (\frac{\Delta_E}{t2}\vec{x}) + \vec{\alpha}$$

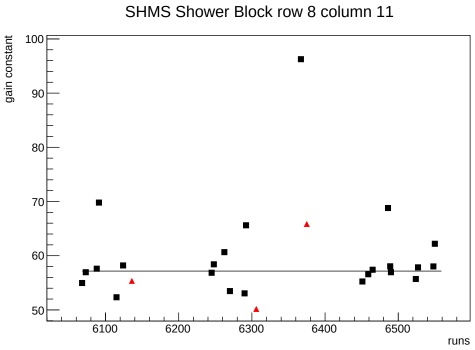
Typical selection



Result after calibration

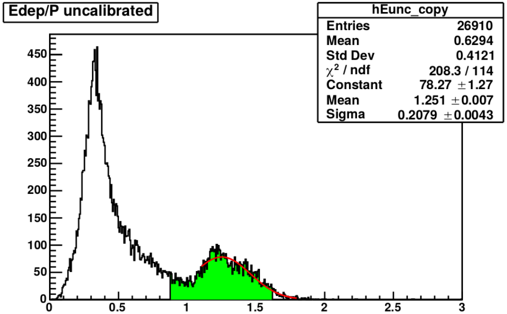


gain constant analysis



gain constant for one block for several runs. Black points are gain constant for 8-11 block for that run, Red points are the runs which doesn't have enough events to calibrate(150 events). The line is the average of gain constants weighted by the number of events per run. // We use the weighted average for the block instead of the value from single calibration, so that the gain constant would be the result of all existing calibrations with enough selected events.

Backup



in `input.dat`: set gaussian fit range. in `THcPShowerCalib.h`: set LoThr and HiThr

```
fLoThr = gmean - 1.8*gsigma;
fHiThr = gmean + 1.8*gsigma;
```

Use SHMS as example, some electrons are detected by SHMS, We know that electron peak should locate at 1, which means sum of energy measured by each pmt should be equal to momentum.

$$\sum_{i}^{252} E_i * \alpha_{ci} = E = P \tag{2}$$

i: Blocks
N: Number of events(tracks)
j: number of hits per events