Calibrating the LDC01Sc Calorimeter

Improving the energy resolution for high-energy electrons

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Outline

Introduction
Why calibrate?

- 2 calibration constants in MokkaCaloDigi: `CalibrECAL` and `CalibrHCAL`. Scale total digitised energy.
- 1 calibration constant: layers 21 – 30 of the ECAL have twice as much tungsten absorber as layers 1 – 20 $\Rightarrow$ “double” energy depositions?
- High energy electron/photon events may have shower leakage into the HCAL.

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Minimisation procedure

An analytical solution

In general for a Monte Carlo event energy $\bar{E}$, the measured energy in the *i*th event is,

$$E_i = \sum_{\text{regions},\, j}^{J} c_j E_{ij} \tag{1}$$

and we can define the target function $= \left(\frac{\Delta E}{E}\right)^2$ as,

$$D = \frac{1}{N-1} \frac{\sum_{\text{events},\, i}^{N} \left(\sum_{\text{regions},\, j}^{J} c_j E_{ij} - \bar{E} \right)^2}{\bar{E}^2} \tag{2}$$

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Minimisation procedure
Specifically for LSC01Sc

We shall consider three regions:

- The first 20 ECAL layers
- The last 10 ECAL layers
- The whole HCAL

$\Rightarrow$ 3 calibration constants.

Will we do better including the HCAL in the energy measurement?

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Specifically for LDC01Sc (continued)

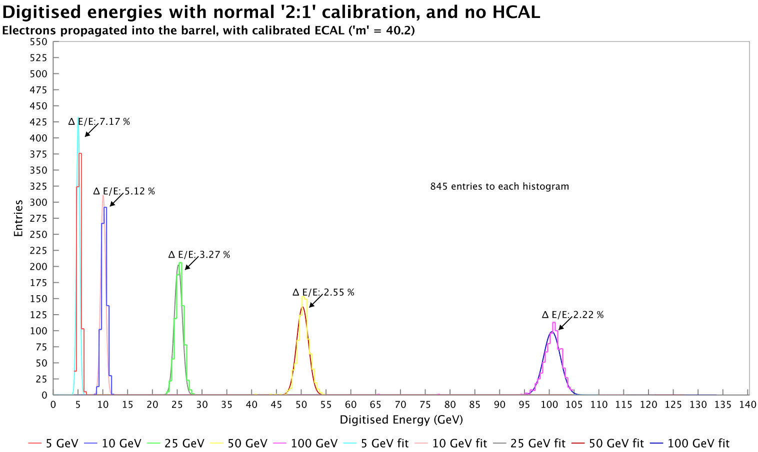
We have,

- c_1 - the global ECAL constant, set to 31.3 with the default MarlinReco steering file.
- c_2/c_1 - the interval calibration constant, presumed to be 2.0.
- c_3 - the global HCAL constant, set to 27.3 by default.

Let us consider electrons fired from the origin in the *y* direction of the calorimeter at 5, 10, 25, 50 and 100 GeV ...

The usual "2:1" calibration

Not including the HCAL at all



Concepts

Fitting to a plane of constant energy

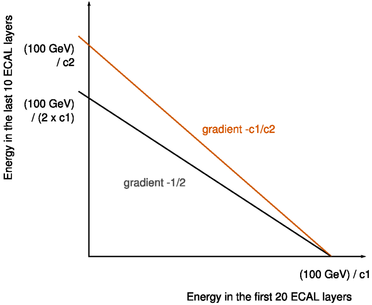


Figure: Correspondance between c_js and the ECAL energy plane

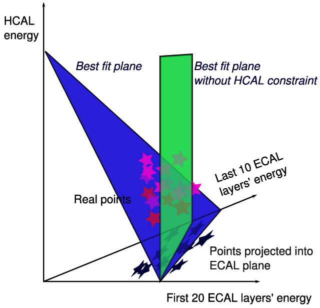
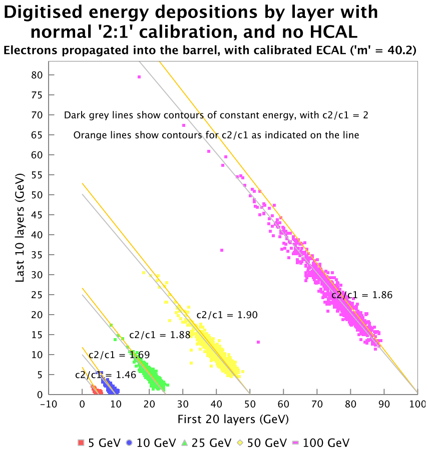


Figure: Fitting a plane in 3-space, rather than a line to 2-space

The usual “2:1” calibration

Contours of constant energy



- Points well–separated from main clusters have very large HCAL depositions
- The line of best–fit would give the wrong c_2/c_1 if the HCAL is to be considered too
- Values attached to lines show the result of individual calibration including the HCAL

Calibration Results

Calibration constants	
$\bar{E}$ (GeV)	c_2/c_1
5	1.46
10	1.69
25	1.88
50	1.90
100	1.86

Conclude:

- low energy (5, 10 GeV) results are subject to large statistical variation
- remaining values are not apparently dependent on energy
- including the HCAL $\Rightarrow c_2/c_1 \neq 2$
- let's use $c_2/c_1 = 1.88$

☛*Comment:* If the HCAL is not included, then the minimisation confirms $c_2/c_1 = 2.01$ is optimal.

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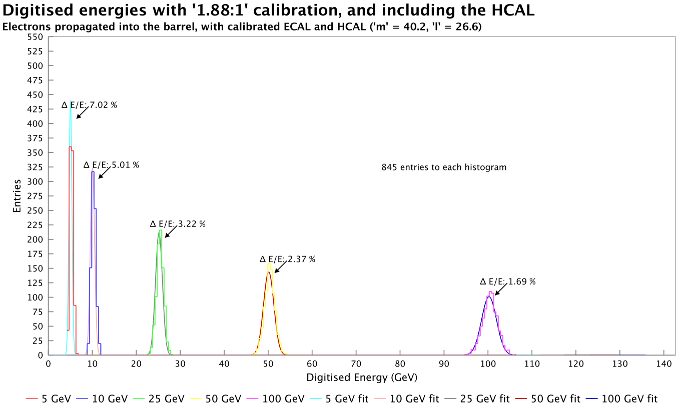
Post calibration

Energy resolution improves significantly



☛At 100 GeV, $\Delta E/E = 2.22\%$ before, now 1.69% ⇒ 31% improvement.

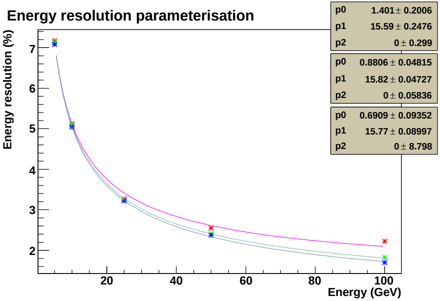
With $c_2/c_1 = 1.88$, and an average of c_1 ⇒ `CalibrECAL` = 40.2 and an average of c_3 ⇒ `CalibrHCAL` = 26.6

Energy resolution

Use MINUIT to fit a function of the form,

$$f(E) = \frac{\Delta E}{E} = a \oplus \frac{b}{\sqrt{E}} \oplus \frac{c}{E}$$

- Top line: "2:1", no HCAL
- Middle line: "2:1", with HCAL
- Bottom line: 1.88:1, with HCAL



☛ *a* term (corresponding to shower leakage) is reduced

✔ Modest but significant improvement on the resolution.

Summary

- Including the HCAL in high–energy events is important
- Global calibration constants c_1, c_3 have been determined (not very interesting)
- Including the HCAL $\Rightarrow$ interval calibration should be,

$$\frac{c_2}{c_1} = 1.88$$

  ...and NOT 2.0!
- ✔ ...and they don't change much with energy

Further details will soon be available from my webpage:
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Further work

Deficiencies in the analysis presented:

- Need to simulate with photons and pions
- A more complete error propagation analysis is required
- Quantitative justification for discarding the low–energy results
- Check for systematic geometric effects
- Include ECAL endcaps in the calibration
- Need to include this work in a MarlinReco processor?

Supplementary Material

4 Numerics

On the “2:1” calibration
If the HCAL is negelected

Neglecting the HCAL, we find c_2/c_1 as follows:

Calibration constants	
$\bar{E}$ (GeV)	c_2/c_1
5	1.54
10	1.74
25	1.96
50	2.01
100	2.01

✔ Confirms that “2:1” is acceptable.

Energy resolutions
For the three scenarios considered

Energy resolution

Energy (GeV)	With "2:1", no HCAL $\Delta E/E$	σ	With "2:1", with HCAL $\Delta E/E$	σ	With "1.88:1", with HCAL $\Delta E/E$	σ
5	7.17	0.35	7.13	0.33	7.08	0.31
10	5.12	0.13	5.10	0.13	5.04	0.14
25	3.27	0.07	3.25	0.08	3.22	0.08
50	2.55	0.07	2.41	0.07	2.37	0.06
100	2.22	0.07	1.82	0.05	1.69	0.05

All values are in percent unless otherwise specified. All errors are absolute.
Energy resolutions are calculated using the histogram mean and RMS value. The errors are provided for indicative purposes only, according to the following expression:

$$\left(\frac{\sigma_{\Delta E/E}}{\Delta E/E}\right)^2 = \left(\frac{\sigma_{\bar{x}}}{\bar{x}}\right)^2 + \left(\frac{\sigma_\sigma}{\sigma}\right)^2. \quad (3)$$

This depends on Gaussian fit parameters (computed by ROOT), which provide the error on the standard deviation σ_σ and error on the mean $\sigma_{\bar{x}}$.

Calibration constants

From no calibration to complete calibration

Taking $c_2/c_1 = 1$ and including the HCAL, starting with `CalibrECAL` = 31.3, and `CalibrHCAL` = 27.3, we find:

Calibration constants						
Energy (GeV)	$\bar{x}$ (GeV)	σ (GeV)	$\Delta E/E$	c_1	c_2/c_1	c_3
5	3.76 ± 0.20	0.45 ± 0.02	$0.071 \pm 6.7\%$	1.28	1.46	1.42
10	7.48 ± 0.02	0.50 ± 0.01	$0.055 \pm 2.0\%$	1.29	1.69	0.93
25	18.33 ± 0.03	0.78 ± 0.02	$0.045 \pm 2.9\%$	1.28	1.88	0.84
50	35.82 ± 0.06	1.32 ± 0.04	$0.043 \pm 3.3\%$	1.28	1.90	0.84
100	69.81 ± 0.11	2.47 ± 0.07	$0.041 \pm 3.0\%$	1.29	1.86	0.85

Calibration constants determined for the uncalibrated calorimeter. $\bar{x}$ and σ refer to the Gaussian fit's mean and standard deviation applied to each histogram.