**GlueX Document**
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# Understanding the BCAL Energy Resolution and Calibration

## A Progress Report

*Alex R. Dzierba*

One of the goals for the upcoming calorimeter workshop, scheduled for July 2006, is to understand the energy resolution of BCAL using data from the September 2006 beam test. This involves looking at the energy response as a function of position along the module and angle of incidence. This also involves understanding the calibration of the module. This note is a progress report.

**Initial Calibration:** The gains of the 36 PMT's were initially balanced by looking at the response to cosmic rays. Blake Leverington calibrated the module[1] using a Monte Carlo approach and also by minimizing the width of the distribution of the quantity:

$$\frac{\Delta E}{E_{beam}} = \frac{E_{beam} - E_{cal}}{E_{beam}} \tag{1}$$

where the overall calibration constant $C$ is chosen so the mean of the quantity $C \cdot \sum_i ADC_i / E_{beam}$ is unity. The minimization technique then determines the excursions from unity for each of the calibration constants $c_i$ for each of the PMT's. Blake's results for the calibration constants are shown in Figure 1.

**Readout Segmentation:** As a reminder, each end of the module is readout in 18 segments of equal cross-section (1.5 in $\times$ 1.5 in) arranged in three sectors (top, middle and bottom) and six layers. Segments 1 through 6 are in the top sector, segments 7 through 12 in the middle and segments 13 through 18 in the bottom. The photon beam enters the middle sector and goes through layer 1 first and the resulting shower exits through layer 6. Layer 1 consists of segments 1, 7 and 13 while layer 6 consists of segments 6, 12 and 18.

Blake noted that except for segment 8, the calibration constants are near unity. Segment 8 is the segment in the second layer and the middle sector and the segment that receives most of the energy for Run 2334, used in the determining the calibration constants. For this run the beam was incident near the module center at normal incidence.

**Re-visiting the Calibration:** Blake was following the suggestion made by several of us when he determined the calibration constants using the minimization technique. One of the pitfalls of the technique, however, is that it can lead to ambiguous results because, for example, different north/south gain adjustments can yield the same calorimeter sum, which is what is used in equation 1. Other constraints can be applied for Run 2334, like equal response from North and South and comparison with expected longitudinal energy deposition as a function of beam energy. Finally, information from other runs at normal incidence, but for different beam positions along the module taking into account light attenuation, will provide additional constraints.

[1] GlueX-doc-791-v1.

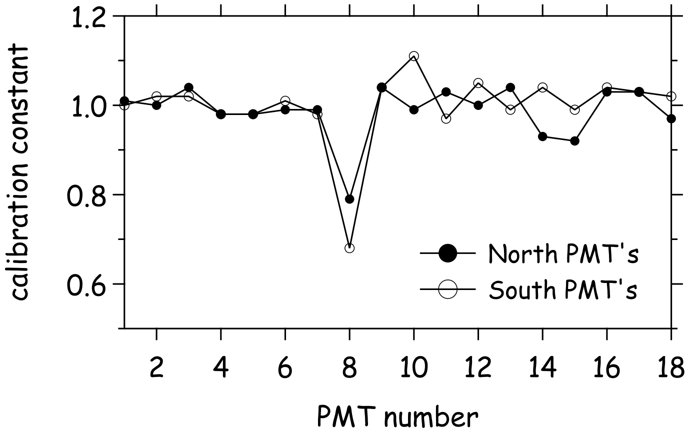


Figure 1: Calibration constants for individual BCAL PMT's determined by minimizing the width of the distribution in the quantity defined in equation 1.

The bulk of my initial analysis is with Run 2334. I started by setting all the calibration constants $c_i$ equal to unity and then looking at the North/South ratios for various segments. For segments 7, 8 and 9 (the segments with the most energy) the means of the ratios were 0.9, 1.18 and 0.80. For segment 8, applying the calibration constants obtained using the minimization technique drives the mean from 1.18 to 1.37.

Step 1 was to adjust the calibration constants from unity to achieve the same response for North and South. This will be refined later by using information from normal incidence runs at z positions of $\pm 100$ and $\pm 50$ cm along with independently measured attenuation information.

I then looked at energy deposition in layers and compared that to the epected mean longitudinal profile in an electromagnetic cascade[2]:

$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)} \tag{2}$$

where $t$ is thickness in radiation lengths, $E_0$ is the energy of the particle initiating the shower, $b \approx 0.5$, and

$$\frac{a-1}{b} = t_{max} = \ln\left(\frac{E_0}{E_c}\right) + 0.5 \tag{3}$$

with $E_c \approx 800$ MeV$/Z_{eff}$. From the note by Zisis and others[3] we have $Z_{eff} \approx 73$ for the Pb/SciFi matrix and a radiation length of 1.3 cm. Equation 2 can then be used to compare the expected fractional energy deposition in each layer with data. This is shown in Figure 2.

Figure 3 shows the fractional energy deposition using equation 2 compared with fractional energy deposition for the first two BCAL layers using calibration from N/S balancing (filled diamonds) and using calibration from the minimization technique (open diamonds).

[2] See the *Passage of Charged Particles Through Matter* section of the Particle Data Booklet.
[3] *BCAL Radiation Length Calculations*, GlueX-doc-439.

**Please note:** I am using the term *calibration using N/S gain balancing* very loosely here – this is not a real calibration, just doing the N/S balancing and not paying attention to layer-to-layer correlations or sector-to-sector correlations. The next step is to use information from other runs to constrain the calibration.

**Information from other runs:** Figure 4 shows the fractional energy deposition in the six layers as a function of beam energy for normal incidence at $z = -1.2$ cm using calibration from (a) North/South balancing and from (b) minimization and at 40° at $z = -1.2$ cm using calibration from (c) North/South balancing and from (d) minimization. Figure 5 shows the fraction of beam energy deposited in the top, middle and bottom sectors as a function of beam energy for normal incidence at $z$ positions of (a) $-1.2$ cm, (b) $-50$ cm, (a) $-100$ cm and (d) at an angle of 40° at $z = -1.2$ cm. It is interesting that the fractional energy deposition for the top and bottom sectors are different for the normal incidence runs by a little more than a factor of two but top and bottom are similar for the 40° run. Any ideas here about the beam angles?

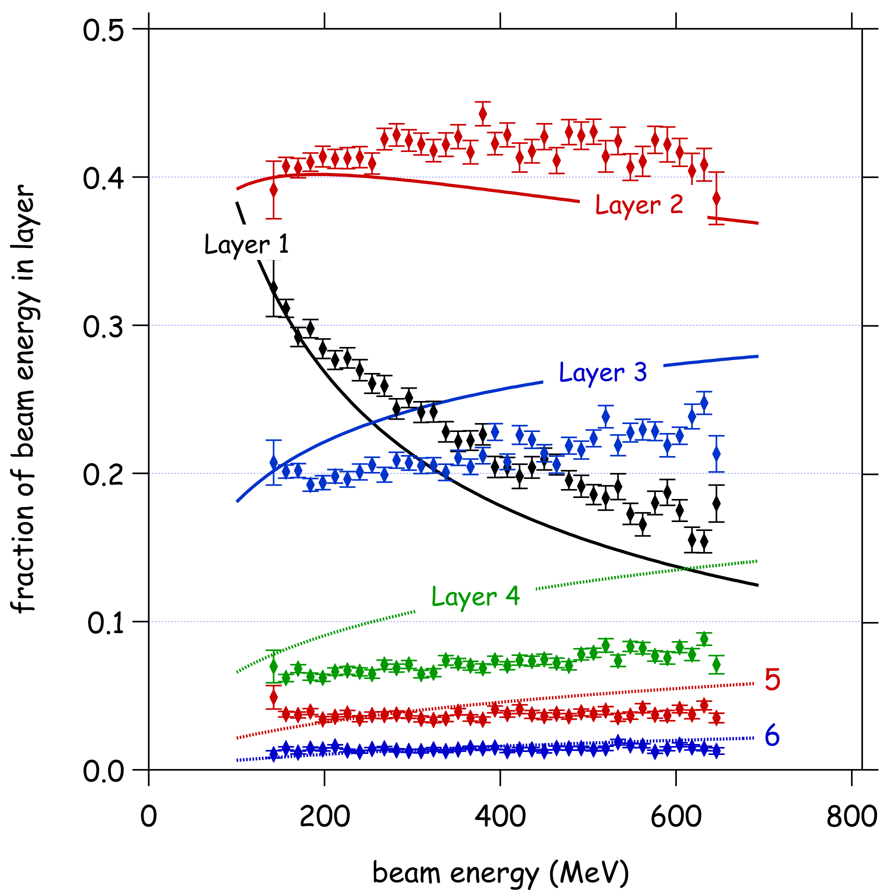


Figure 2: Fractional energy deposition per BCAL layer as a function of photon beam energy for Run 2334 after N/S gain balancing. The curves are the expected results using equation 2. This can then be used to adjust/check layer to layer calibrations.

**Calibration and Resolution:** Blake and I find that the different inter-PMT calibration does not seem to affect statistical term in the parameterization:

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} + b \tag{4}$$

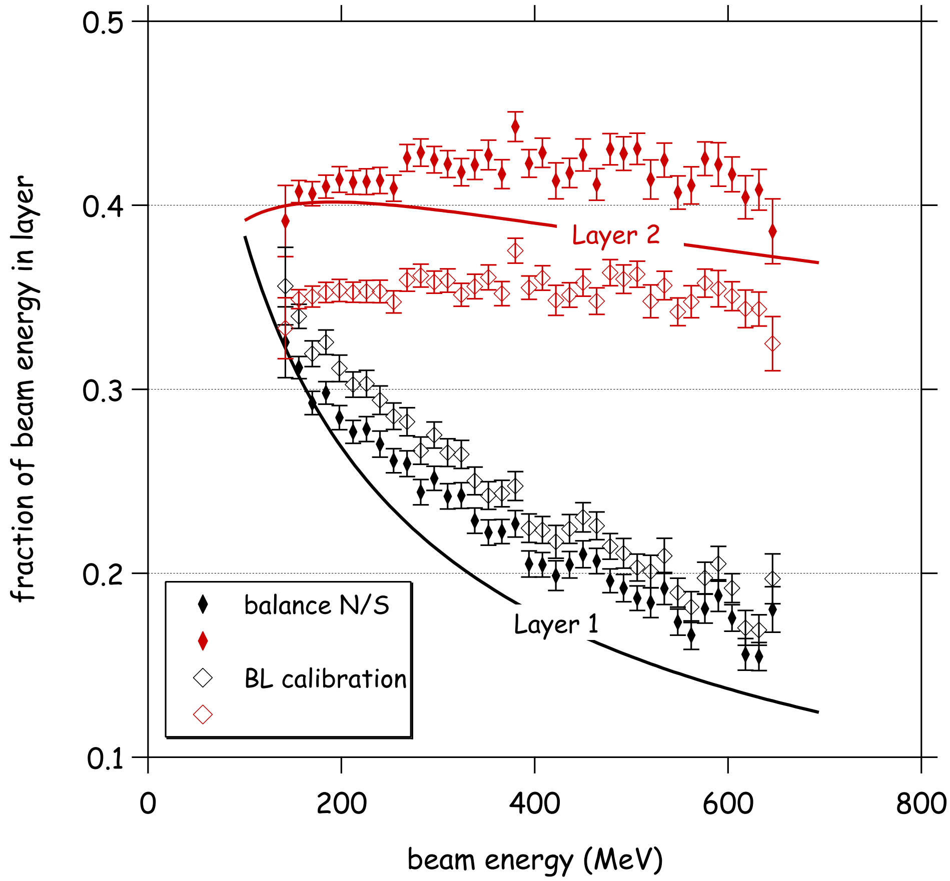


Figure 3: Fractional energy deposition using equation 2 compared with fractional energy deposition for the first two BCAL layers using calibration from N/S balancing (filled diamonds) and using calibration from the minimization technique (open diamonds).

but it does affect the floor term.

**Resolution and Position:** For completeness, I include here the preliminary results on resolution for different positions along the module that I posted earlier. Please refer to Figure 6 show the results of Gaussian fits to the distribution in the quantity defined by equation 1 for bins of beam energy. The resulting mean (left panel) and sigma (right panel) as a function of beam energy are shown. For the sigma, the curves are the results of fits to equation 4. For this preliminary analysis I assume inter-PMT calibration constants of unity and the over calibration is determined by setting the mean of the ratio of beam energy to calorimeter energy to unity. The same calibration constant was used for all the runs.

**Next Steps:** The next steps will be to use North/South correlations (including attenuation), layer-to-layer correlations and perhaps sector-to-sector to help pin down the calibration and then energy resolution.

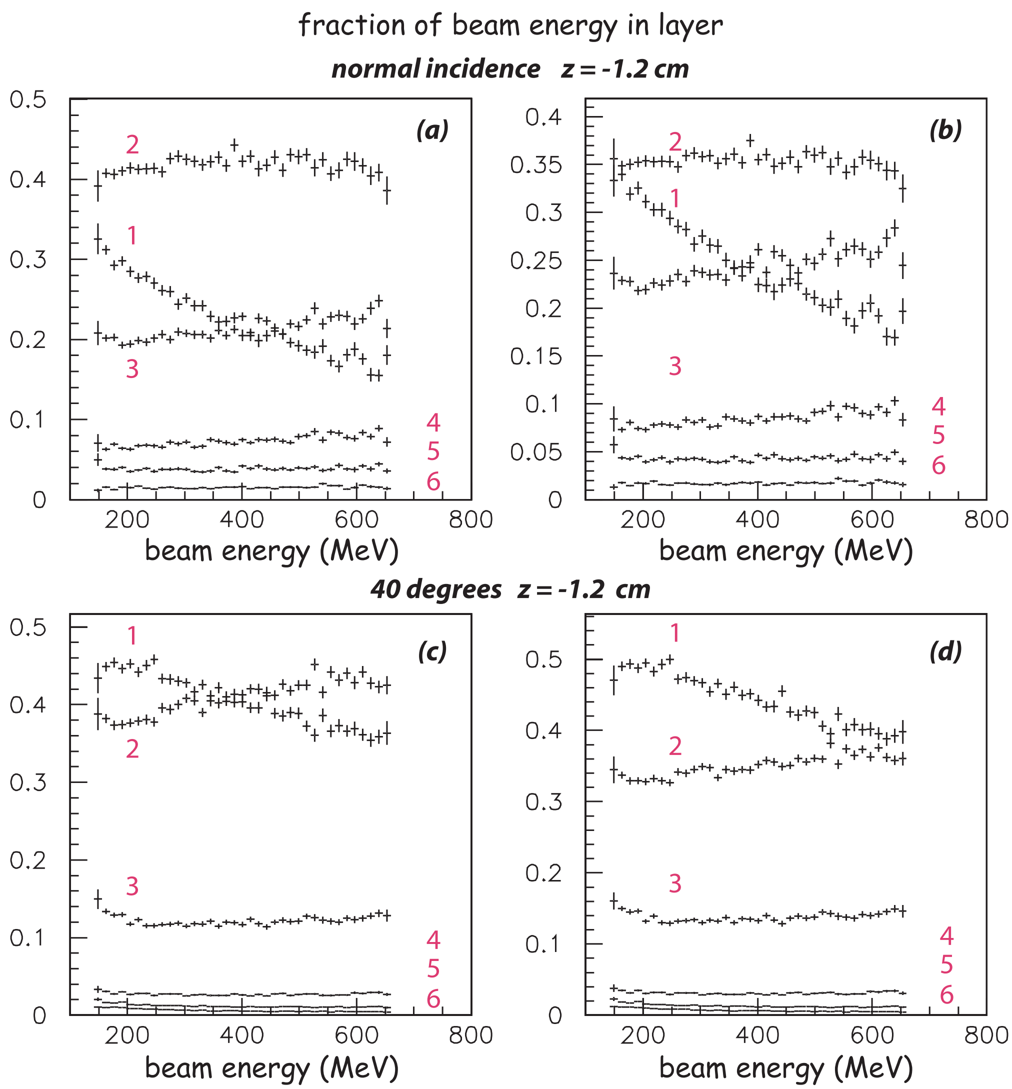


Figure 4: Fractional energy deposition in the six layers as a function of beam energy for normal incidence at $z = -1.2$ cm using calibration from (a) North/South balancing and from (b) minimization and at 40° at $z = -1.2$ cm using calibration from (c) North/South balancing and from (d) minimization.

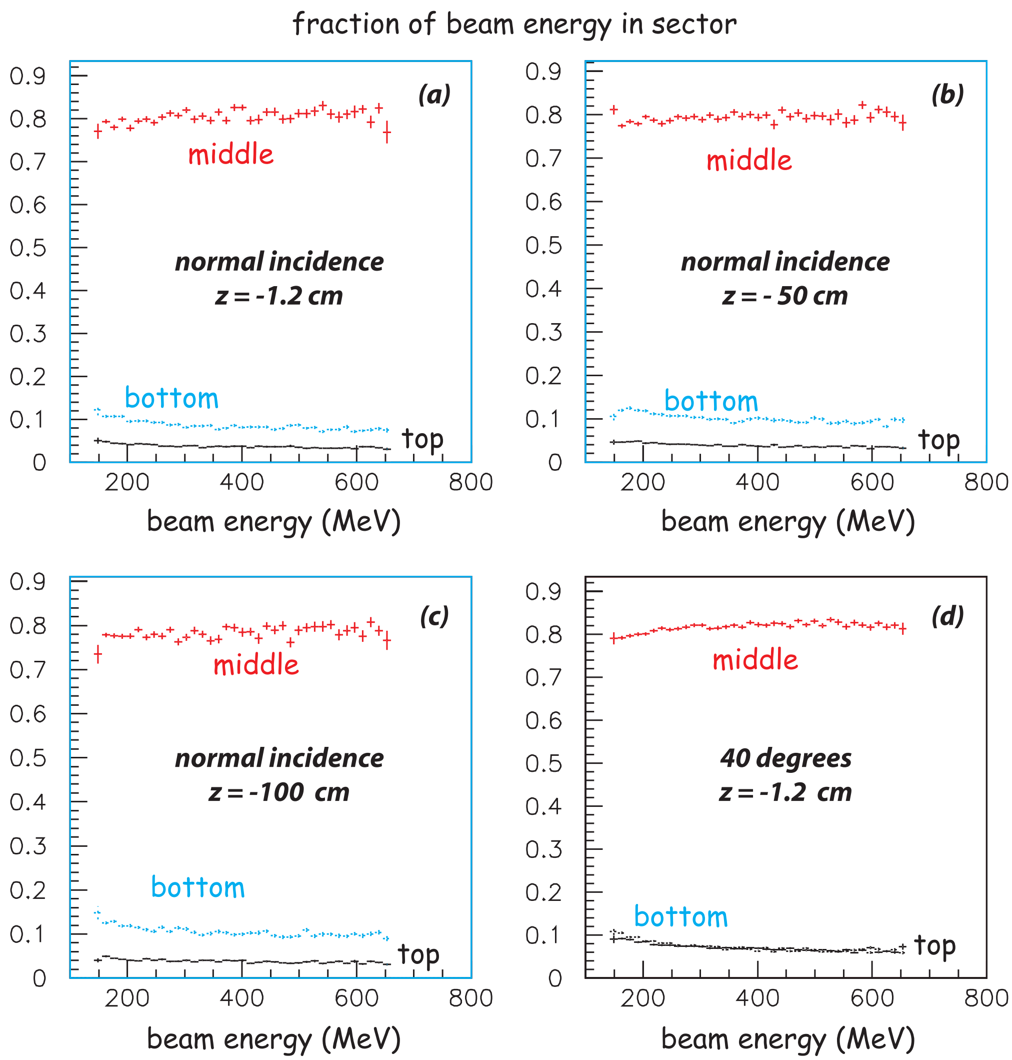


Figure 5: Fraction of beam energy deposited in the top, middle and bottom sectors as a function of beam energy for normal incidence at $z$ positions of (a) $-1.2$ cm, (b) $-50$ cm, (a) $-100$ cm and (d) at an angle of $40°$ at $z = -1.2$ cm.

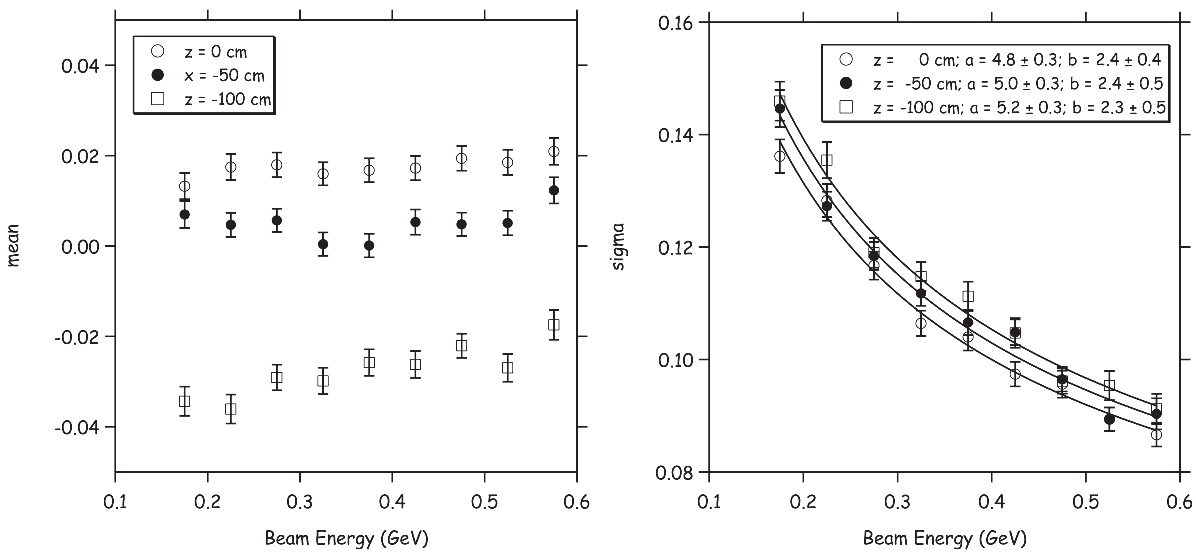


Figure 6: Results of Gaussian fits to the distribution in the quantity defined by equation 1 for bins of beam energy. The resulting mean (left panel) and sigma (right panel) as a function of beam energy are shown. For the sigma, the curves are the results of fits to equation 4.