# Endcap Hadronic Testbeam Data Analysis

# Electron and Pion Results from April 1998

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## The Data

- Electron data were analysed at 4 different impact points:
  - Point D, Cell 5: $x = -100$ mm $y = +83$ mm
  - Point E, Cell 78: $x = +100$ mm $y = +83$ mm
  - Point H, Cell 3: $x = -100$ mm $y = -67$ mm
  - Point I, Cell 76: $x = +100$ mm $y = -67$ mm

| Energy (GeV) | point D Run # | point E Run # | point H Run # | point I Run # |
|---|---|---|---|---|
| 20 | 7353 | 7350 | 7352 | 7351 |
| 40 | 7298 | 7291 | 7295 | 7294 |
| 60 | 7255 | 7259 | 7253 | 7260 |
| 80 | 7299 | 7311 | 7303 | |
| 100 | 7334 | 7341 | 7330 | 7342 |
| 119.1 | 7065 | 7088 | 7071 | 7079 |

# Electron Analysis

## Clustering, Energy Reconstruction

- A three cell cluster was chosen to reconstruct the energy of the electrons. A map of the chosen cells is presented in Figure 1 for each impact point.
- Trigger cuts: physics, not muon, not random, three cell "subcluster signal shape" requirement (described later).
- Using the 3 cell cluster, the energy was reconstructed and fit in a $\pm 3\sigma$ range for each run, as shown in Figure 2. Signal peaks were reconstructed using the hec_adc digital filtering peak finding package.

# Electron Analysis

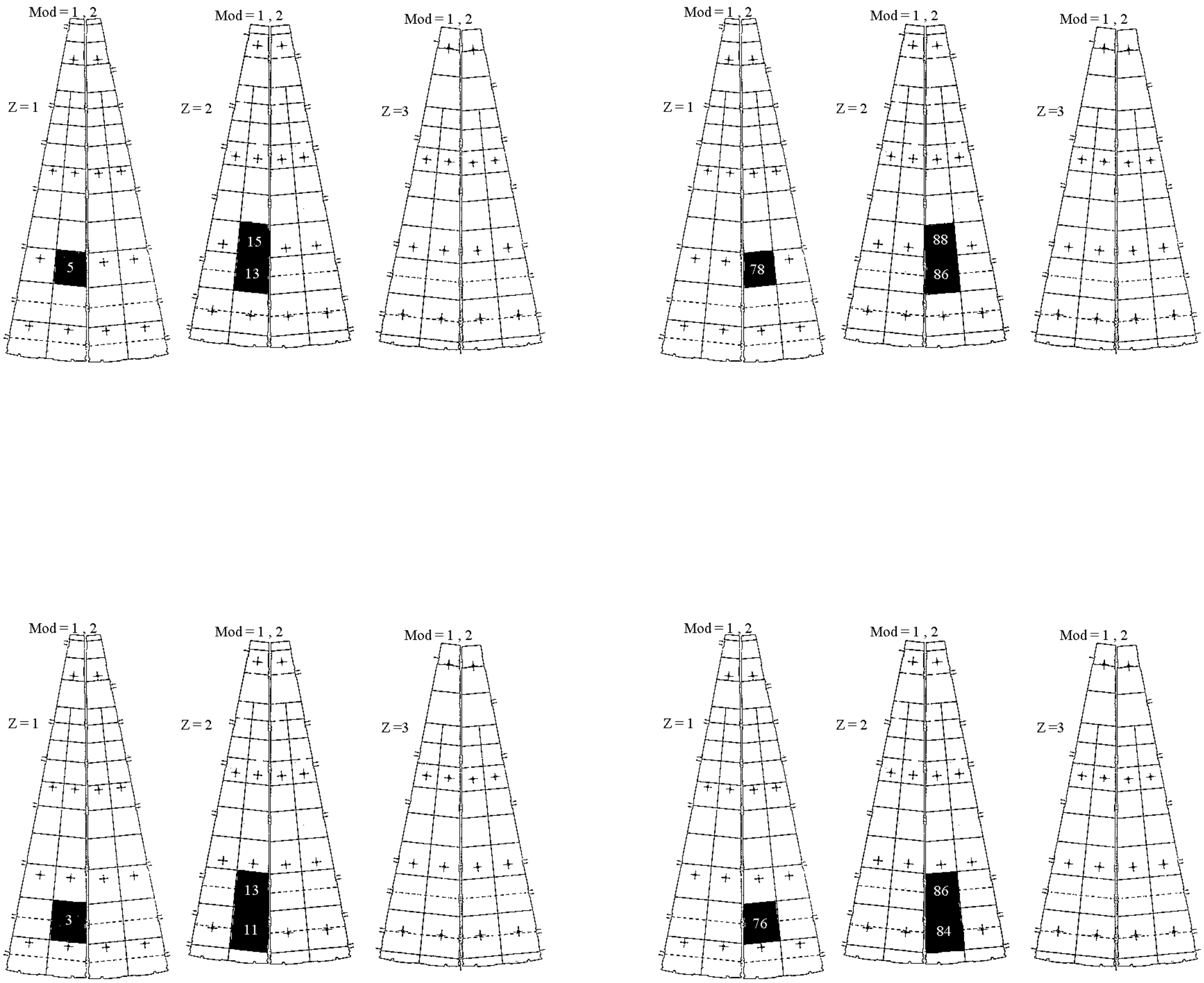



Figure 1: Map of cells used in electron clusters: points D, E, I, H (clockwise).

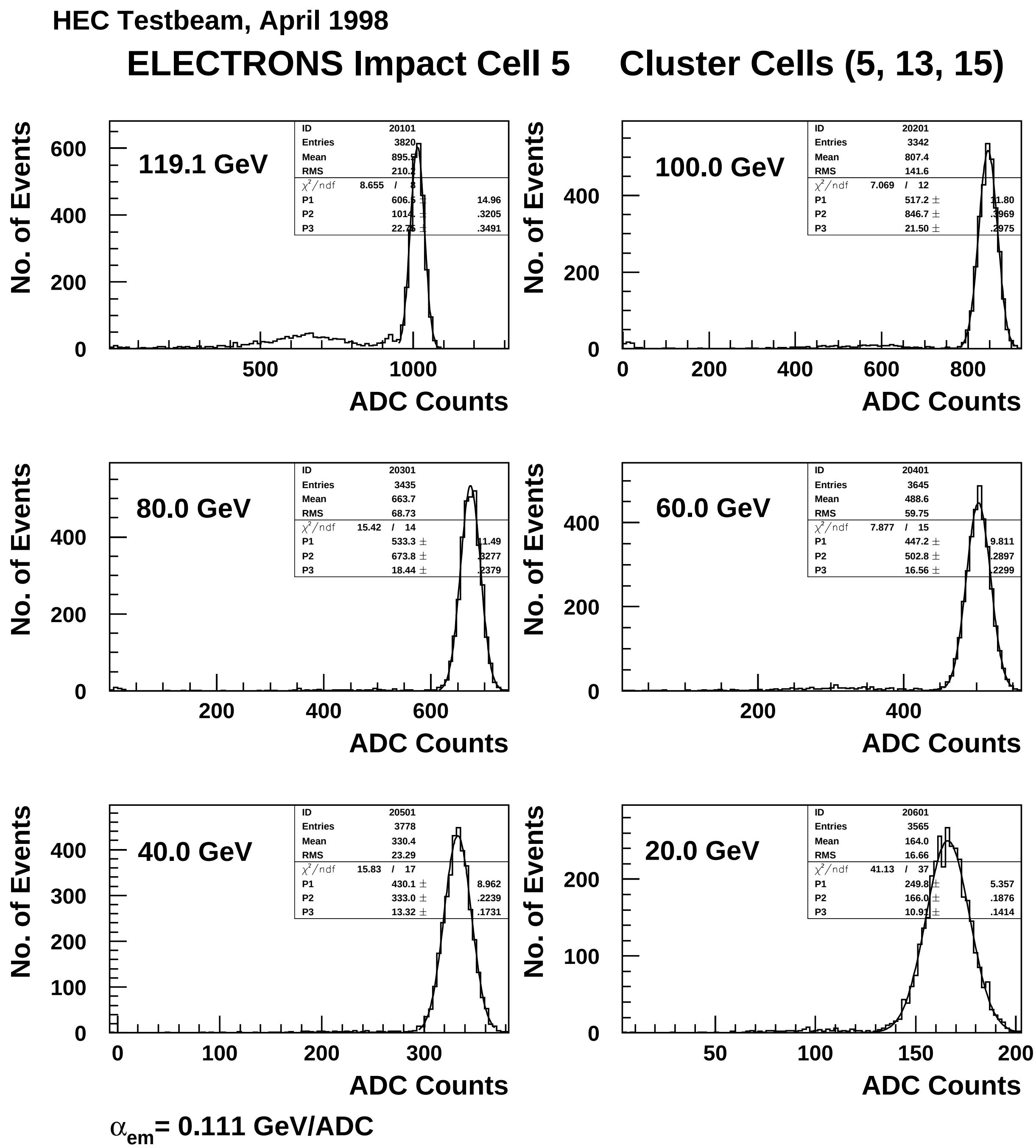



Figure 2: Electron cluster energy (uncalibrated data) for a typical impact point.

# Electron Analysis

- The global electromagnetic scale ($\alpha_{\mathrm{em}}$) was determined by minimizing the following $\chi^2$:

$$\chi^2 = \sum_{\mathrm{runs}} \frac{\left(\alpha_{\mathrm{em}} \langle E_{\mathrm{cl}}(\mathrm{adc})\rangle - E_\circ\right)^2}{\sigma^2}$$

where $\langle E_{\mathrm{cl}}(\mathrm{adc})\rangle$ is the average from the fits shown in Figure 2.

We conclude:

$\alpha_{\mathrm{em}} \;=\; 0.11\ \mathrm{GeV/adc} \;=\; 3.4\ \mathrm{GeV}/\mu\mathrm{A}$

averaged over impact points D, E, H, & I.

## Response

- Using $\alpha_{\mathrm{em}}$, we obtain the response plot shown in Figure 3, wherein data from all four impact points is superimposed.
- The response uniformity is improved by the calibration.
- Response linearity within 1%.

# Electron Analysis

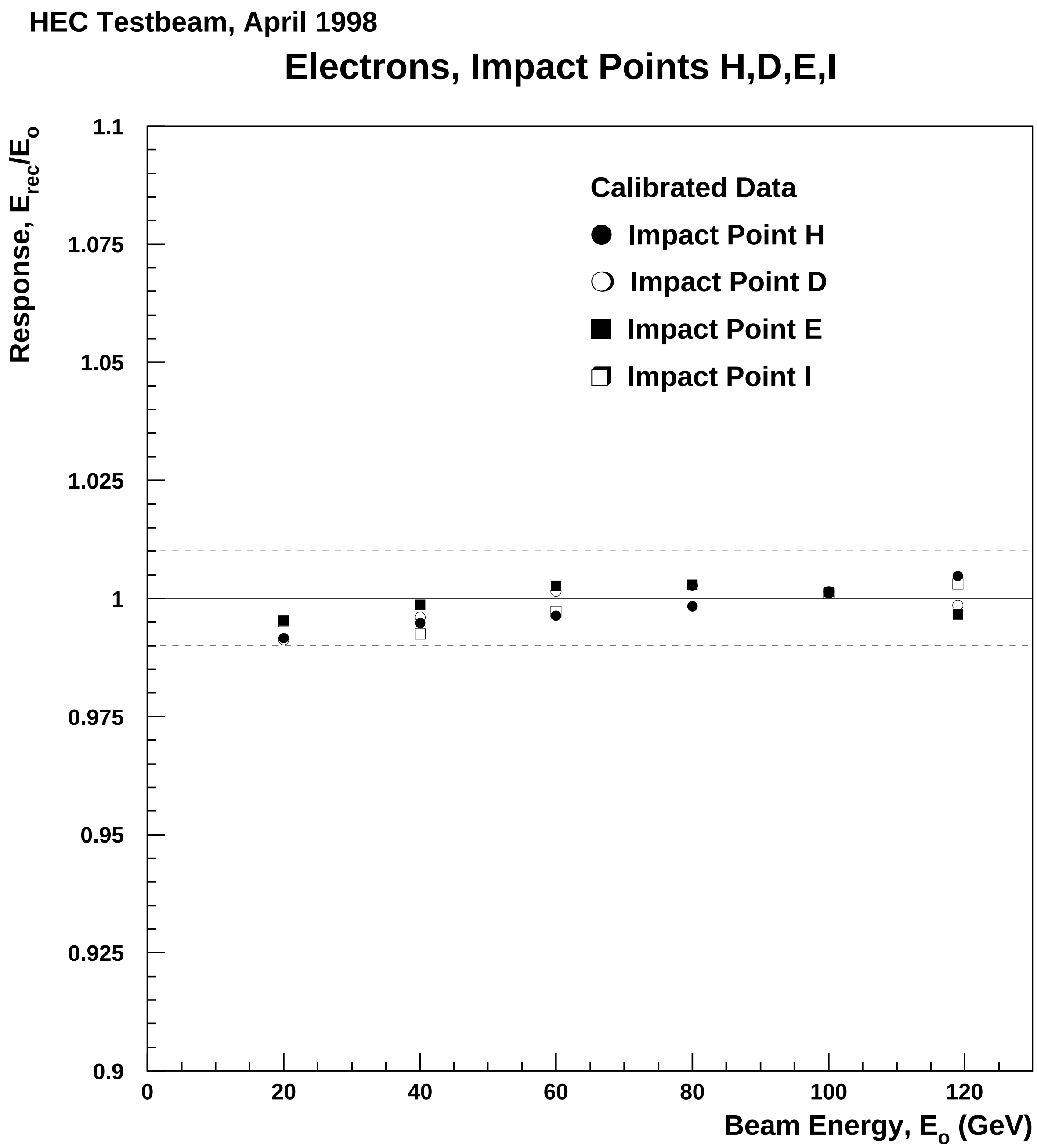



Figure 3: Electron response of calorimeter vs. energy.

## Energy Resolution

- The energy resolution curve was fit to the usual parametrization:

$$\frac{\sigma}{E} = \frac{\alpha}{\sqrt{E_\circ}} \oplus \beta \oplus \frac{\gamma}{E_\circ}$$

- This function was fit with three parameters free.
- Results of these fits are shown in Figure 4.

  We obtain a resolution of (for the 4 impact points combined, calibrated case):

$$\frac{21.5\%}{\sqrt{E_\circ}} \oplus 0.05\% \oplus \frac{0.8 \text{ GeV}}{E_\circ}$$

- Within errors, the energy resolution obtained is the same for calibrated and uncalibrated data.
- A 3% improvement in the sampling term is realized over our results presented May 1998. This is the result of the use of digital filtering and better electron isolation cuts.

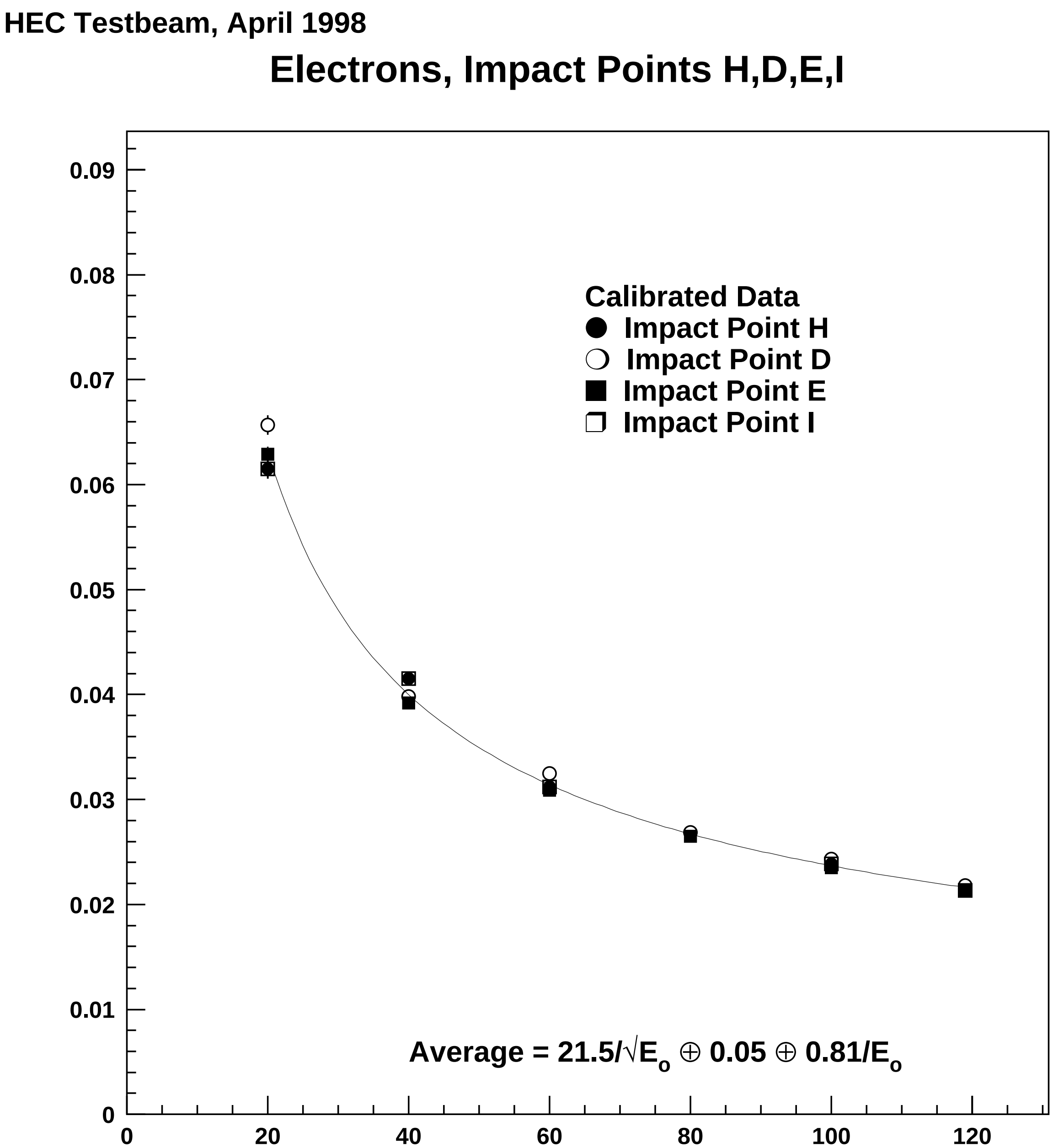



Figure 4: Electron energy resolution with 3 free parameters.

# Pion Analysis

## The Data

- Pion data at 4 impact points were analysed:
  - → Module 1
    - ∗ Point D, Cell 5: $x = -100$ mm $y = +83$ mm
    - ∗ Point H, Cell 3: $x = -100$ mm $y = -67$ mm
  - → Module 2 - HV problem
    - ∗ Point E, Cell 78: $x = +100$ mm $y = +83$ mm
    - ∗ Point I, Cell 76: $x = +100$ mm $y = -67$ mm

| Energy (GeV) | point H Run # | point d Run # | point e Run # | point i Run # |
|---|---|---|---|---|
| 20 | 7369 | 7354 | 7371 | |
| 40 | 7296 | 7297 | 7292 | 7293 |
| 60 | 7280 | 7281 | 7287 | 7285 |
| 80 | 7304 | 7300 | 7312 | 7310 |
| 100 | 7331 | 7335 | 7340 | 7343 |
| 120 | 7182 | 7196 | 7154 | 7146 |
| 180 | 7356 | 7355 | 7359 | 7360 |

# Pion Analysis

## Clustering and Energy Reconstruction Methods

- A cluster was defined for each impact point. Several cluster sizes were evaluated.Results are presented for 19 cell clusters. $\geq$ 97% of the total energy deposited in the calorimeter is contained.
- A map of the chosen cells is presented in Figure 5 for each impact point.
- The clusters are approximately symmetric with respect to one another.

# Pion Analysis

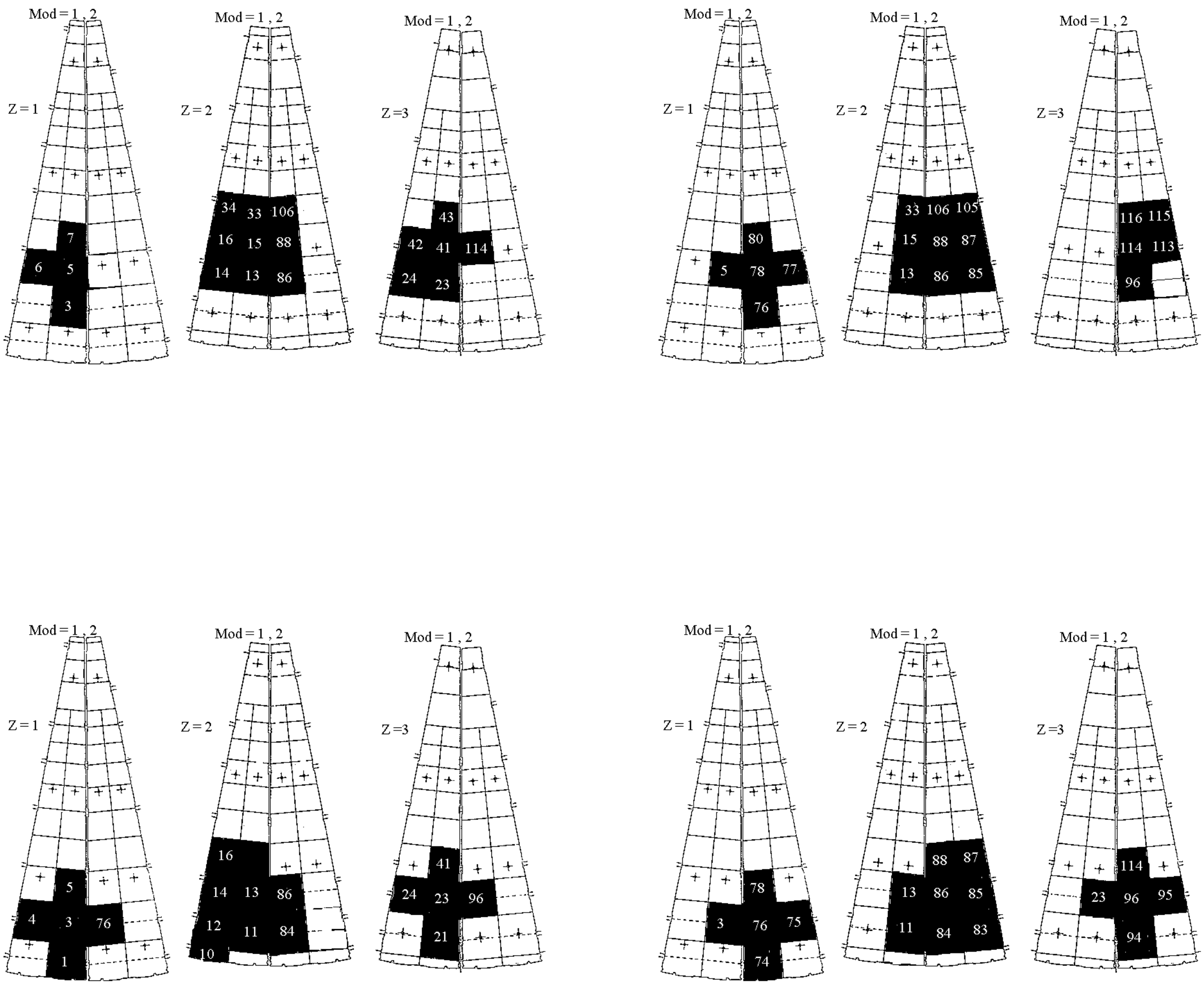



Figure 5: Map of cells used in pion clusters: points D, E, I, H (clockwise).

# Pion Analysis

Three different methods were employed to reconstruct the pion energy:

- Simple Cubic Fit
  The signal peak *for each cell* in the cluster was determined using the hec_adc cubic fit package. In order to properly treat low energy cells:

  → The signal maximum is constrained to be between the 7th and 9th time slice inclusively.

  → The maximum of signals with low energy (defined as $E \leq 10\sigma_{ped}$) is taken to be the height of the 8th time slice (i.e. cubic fit is not employed).

- Cubic Fit Over Entire Cluster
  The raw signal for each cell is summed over the entire cluster time slice by time slice:

$$E_{cluster}(i) = \sum_{j=1}^{cells} E_j(i),$$

  where i=1,..,16 time slices.
  A cubic fit is then performed on this summed signal, $E_{cluster}(i)$.

# Pion Analysis

- Digital Filtering
  The signal peak *for each cell* was determined using the hec_adc digital filtering package. Digital filtering weights were unavailable for several cells (due to a lack of calibration data). In these cases the signal peak was determined using simple cubic fit, as described above.

In all three cases energy dependent depth weights were employed.

# Pion Analysis

## Pion Sample (the Cuts)

- Trigger cuts: physics, not random, not muon
- Subcluster signal shape cut:
  - → Trigger cuts did not properly veto "zero energy" events
  - → Use 3 cell sub-cluster of cells within 19 cell pion cluster, at least one of these cells must contain signal (as defined by "Striegel signal search"). See Figure 6
- final data sample (after all cuts), point H shown in Figure 7

## Calculation of the Hadronic Scale ($\alpha_{\mathbf{had}}$)

- First obtain $\alpha_{\text{had}}$ (as for electrons). $\alpha_{\text{had}}$ =.141 GeV/adc = 4.3 GeV/$\mu$A (ave. over 4 impact points).
- To optimize the resolution, one weight for each depth ($c_z$) was calculated by minimizing the following equation for each energy:

$$\sum_{\text{events}} \frac{\left(\alpha_{\text{had}} \Sigma_z c_z E^z_{\text{cl}}(\text{adc}) - E_\circ\right)^2}{\sigma^2}$$

  Figure 8 shows the depth weights obtained for impact point H using this method.

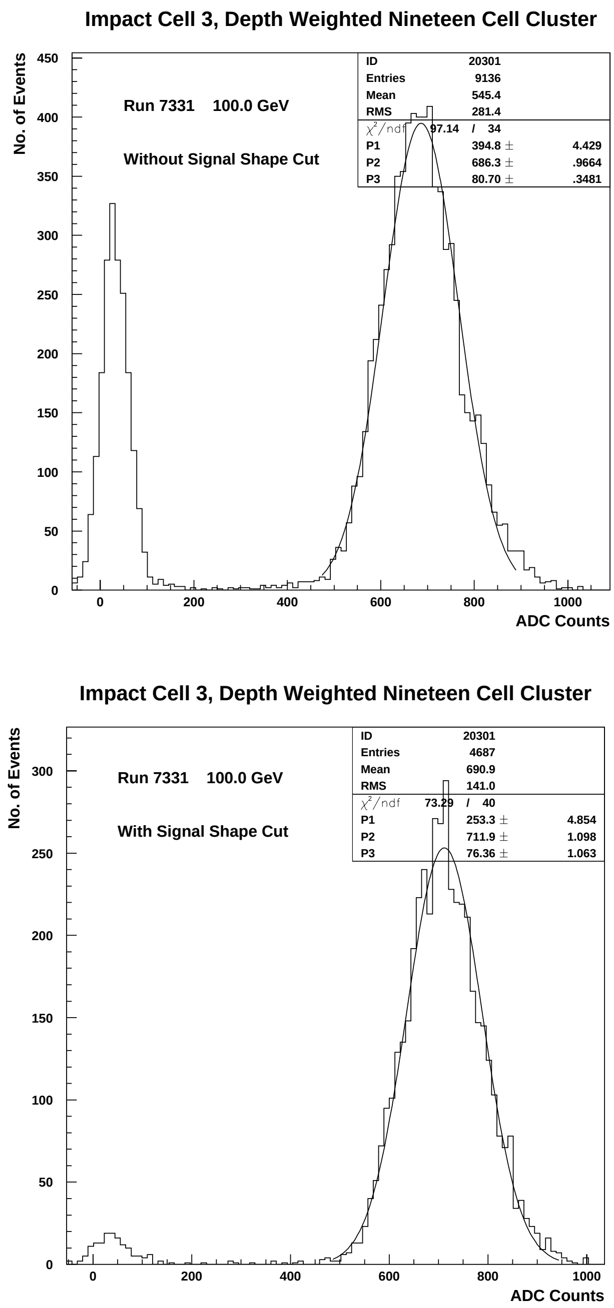



Figure 6: Data sample for point H before and after subcluster cut .

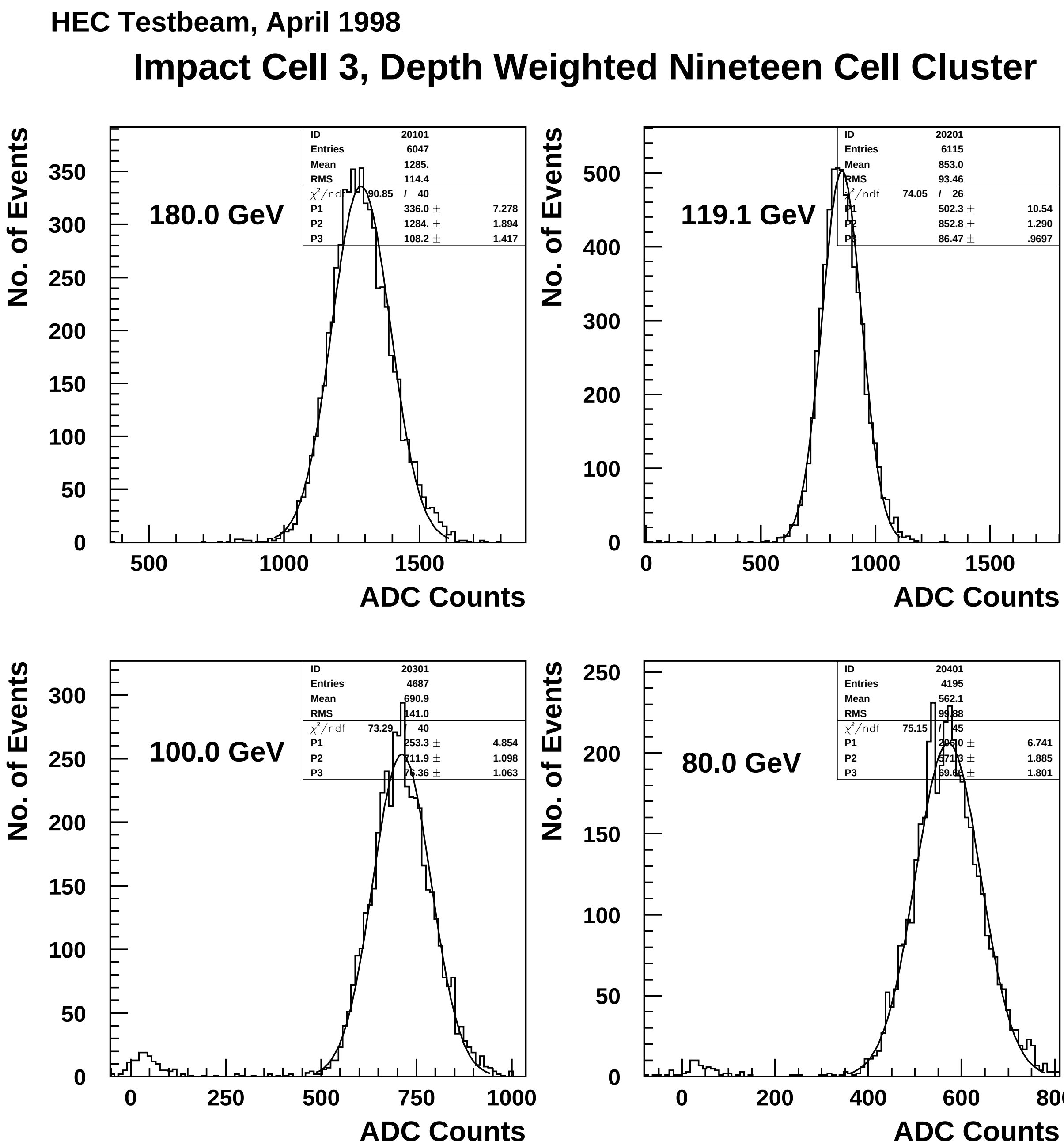
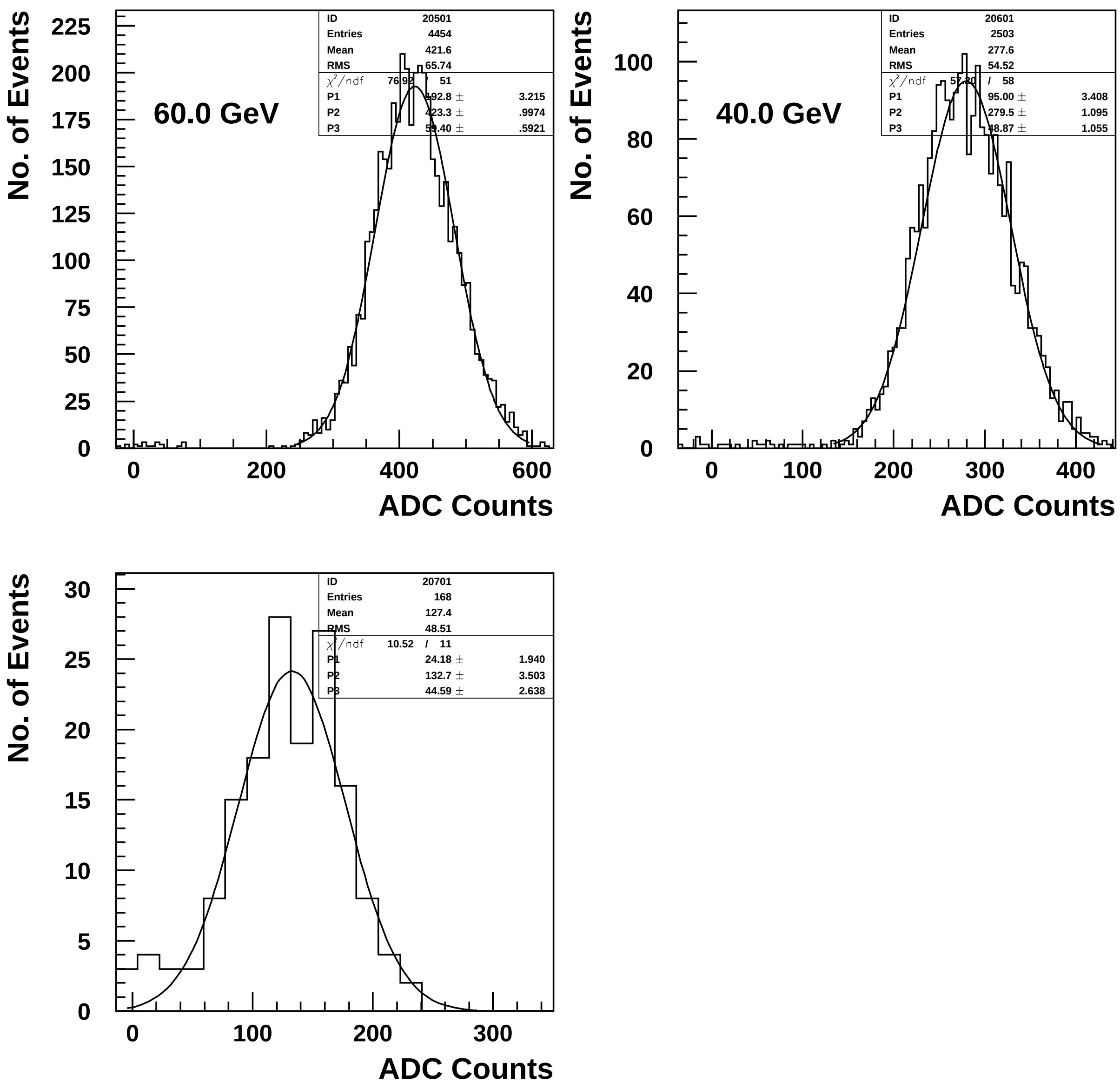



Figure 7: Data sample for point H after cuts .

# Pion Analysis

HEC Testbeam, April 1998

**Impact Cell 3, Depth Weighted Nineteen Cell Cluster**



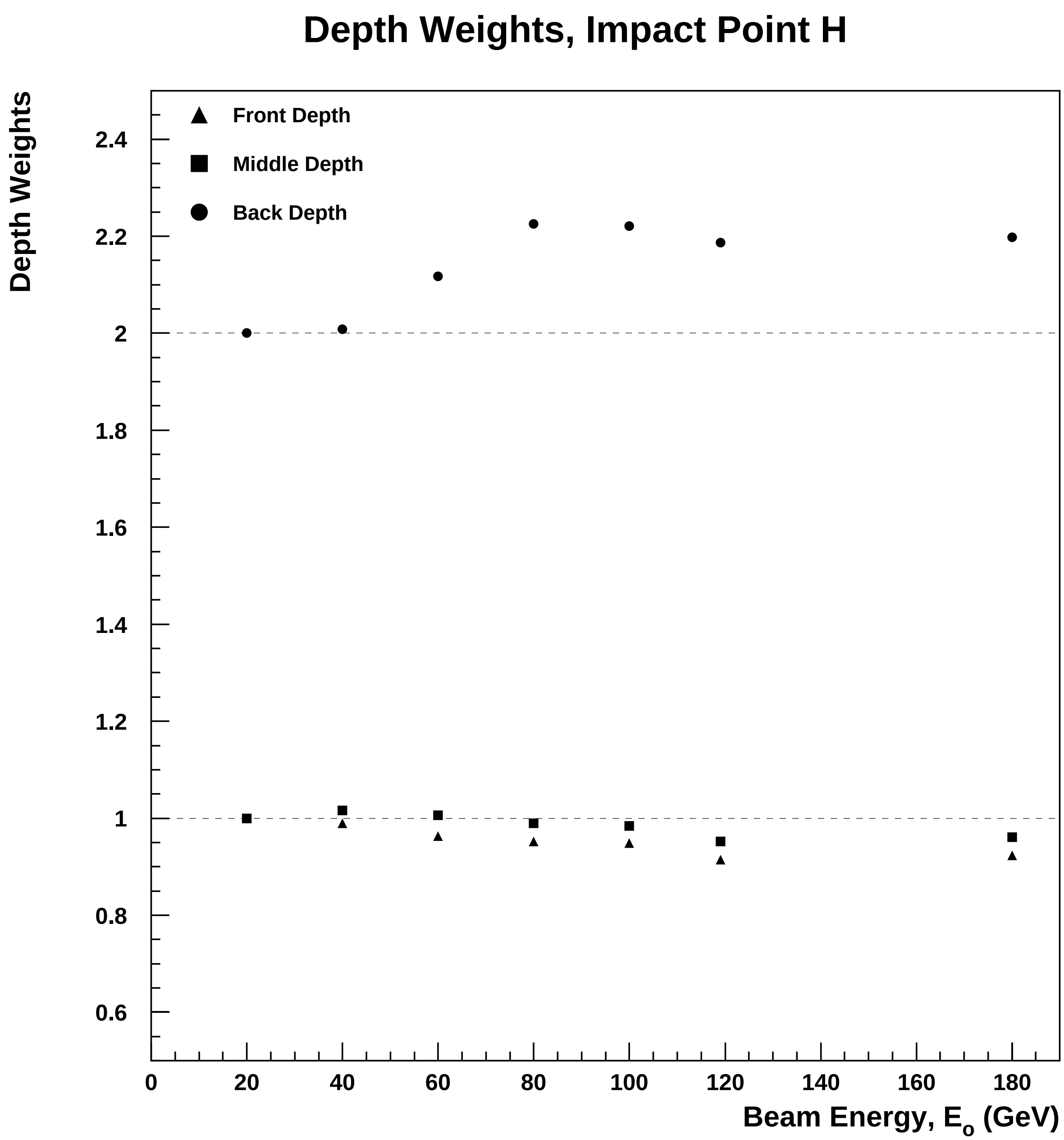



Figure 8: Depth weights obtained for pions, impact point H .

## Resolution and Response, Point H

- Results of the resolution fits on a 19 cell cluster with 3 free parameters are shown in Figure 9. For this impact point, using digital filtering, we obtain a resolution of:

$$\frac{71\%}{\sqrt{E_\circ}} \oplus 5.8\% \oplus \frac{5.4 \text{ GeV}}{E_\circ} \text{ 19 Cells, Uncalibrated Data}$$

$$\frac{88\%}{\sqrt{E_\circ}} \oplus 4.6\% \oplus \frac{3.9 \text{ GeV}}{E_\circ} \text{ 19 Cells, Calibrated Data}$$

- The results for different cluster sizes are presented in Figure 10 and are summarized below

$$\frac{89\%}{\sqrt{E_\circ}} \oplus 5.8\% \oplus \frac{3.6 \text{ GeV}}{E_\circ} \text{ 10 Cells, Calibrated Data}$$

$$\frac{75\%}{\sqrt{E_\circ}} \oplus 5.2\% \oplus \frac{6.3 \text{ GeV}}{E_\circ} \text{ 30 Cells, Calibrated Data}$$

- Figure 11 shows that the response for pions at this impact point varies by about 7% from 20-180 GeV. Calibration does not seem to effect these results

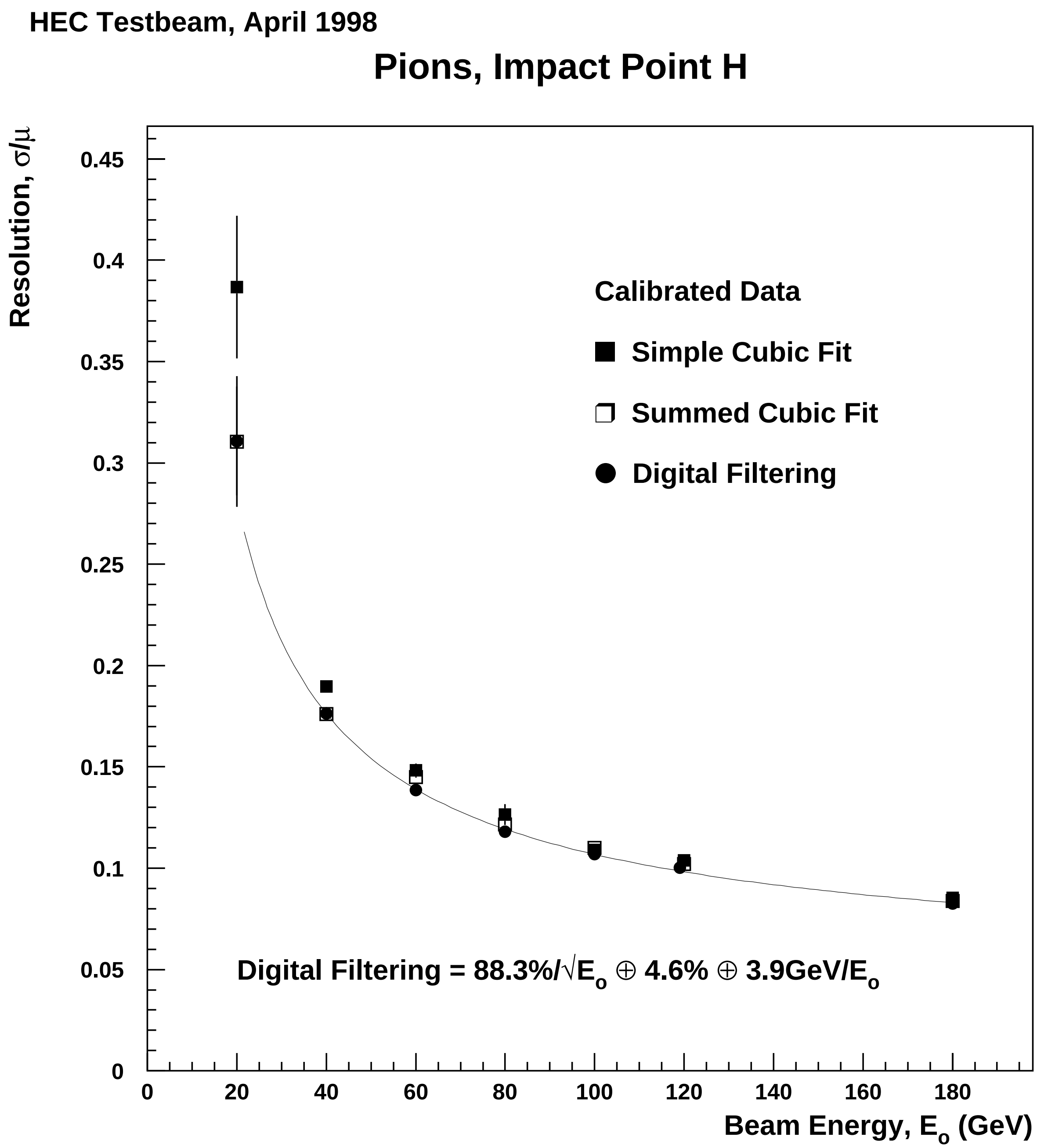



Figure 9: Resolution results obtained for three different fitting methods

# Pion Analysis

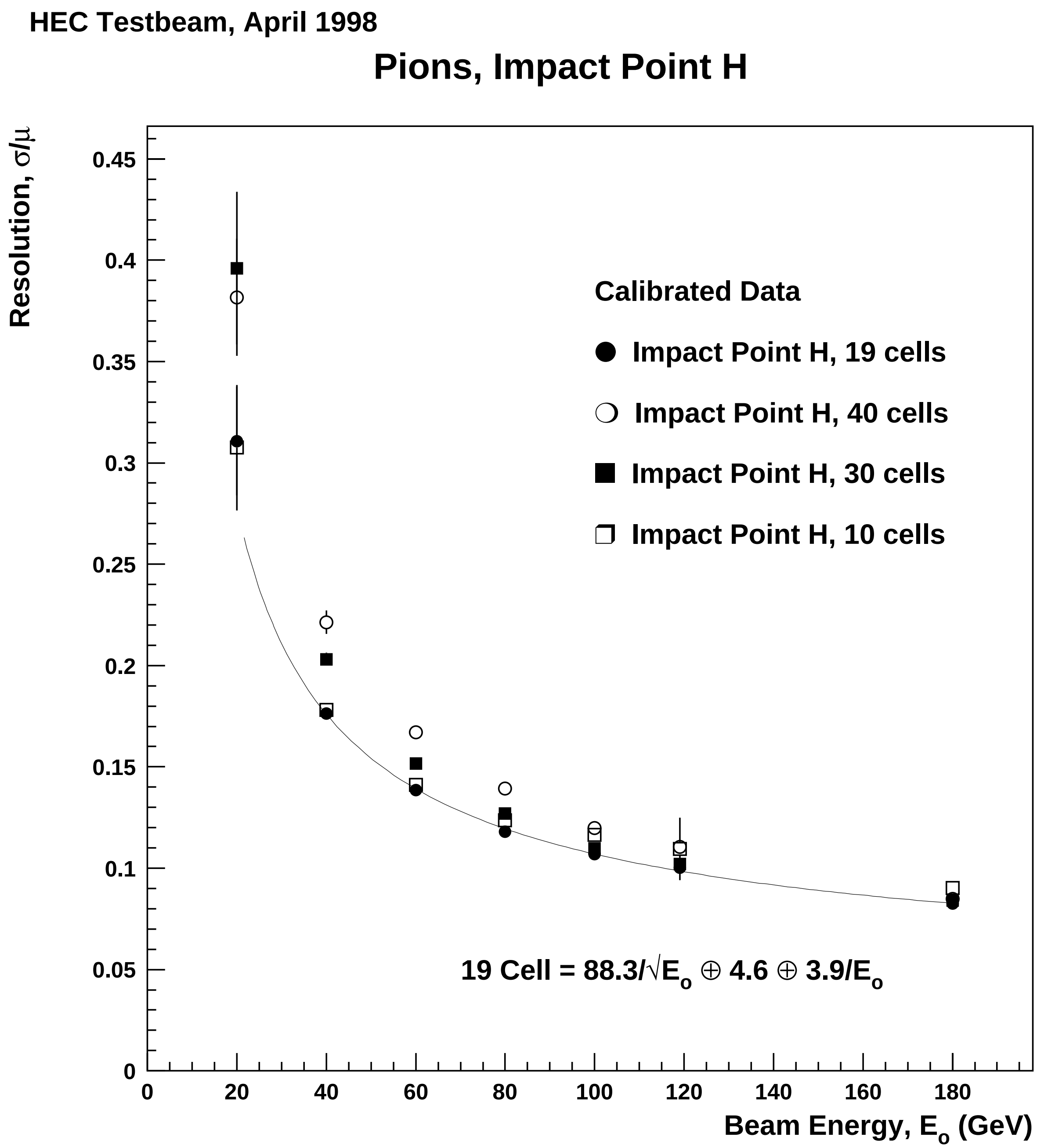



Figure 10: Resolution results obtained for four different cluster sizes

# Pion Analysis

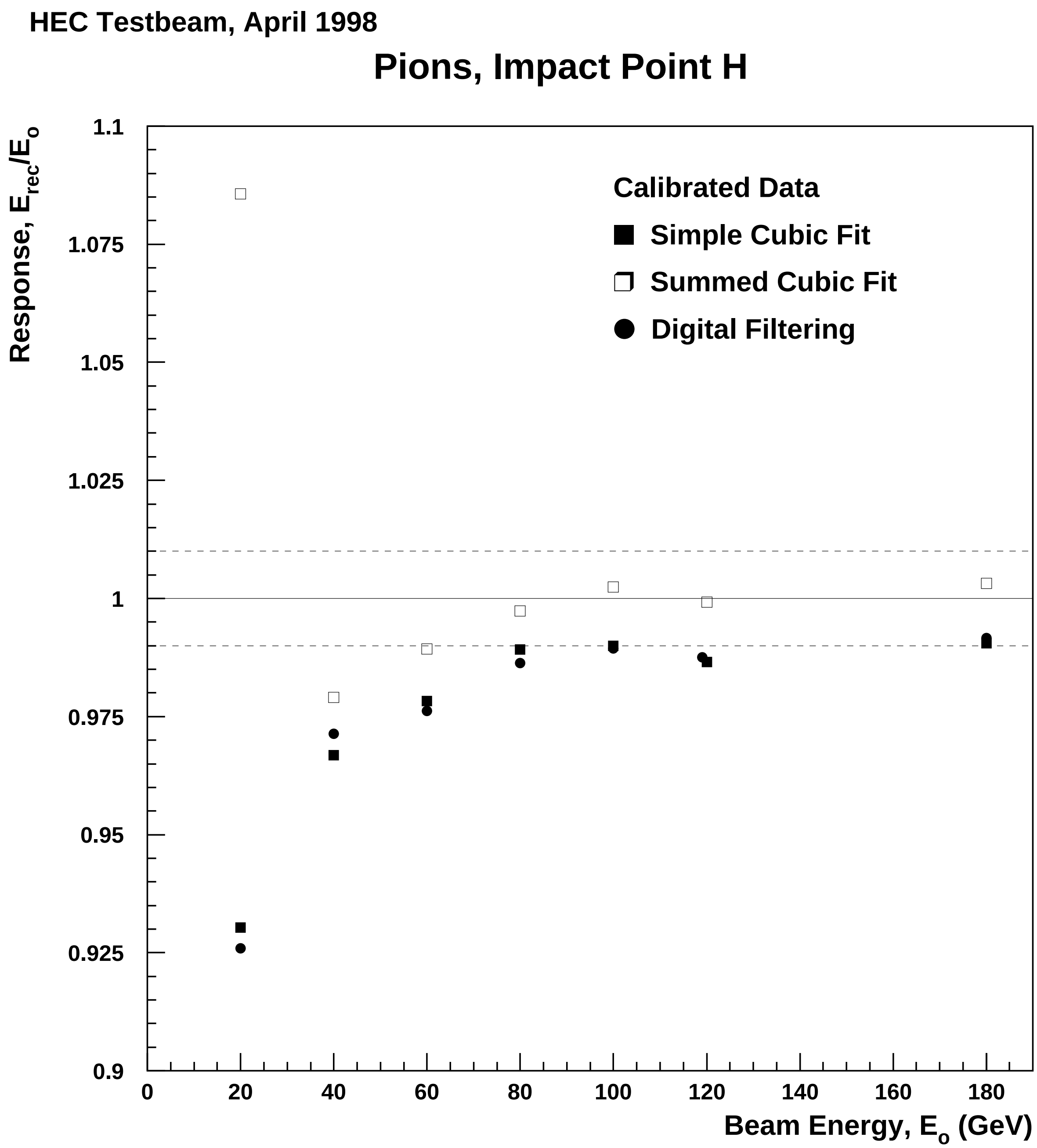



Figure 11: Pion response at impact point H .

# Pion Analysis

## Comparison, 4 Impact Points

- The pion energy resolution was obtained (using digital filtering) at 4 different impact points (H,D,E,I). The results were consistent at all 4 points. This is shown in Figure 12.
- The response for pions was also obtained for each of these impact positions. The results are overlayed in Figure 13.
- Results are reasonably consistent in different impact points, despite HV problems in module 2.

# Pion Analysis

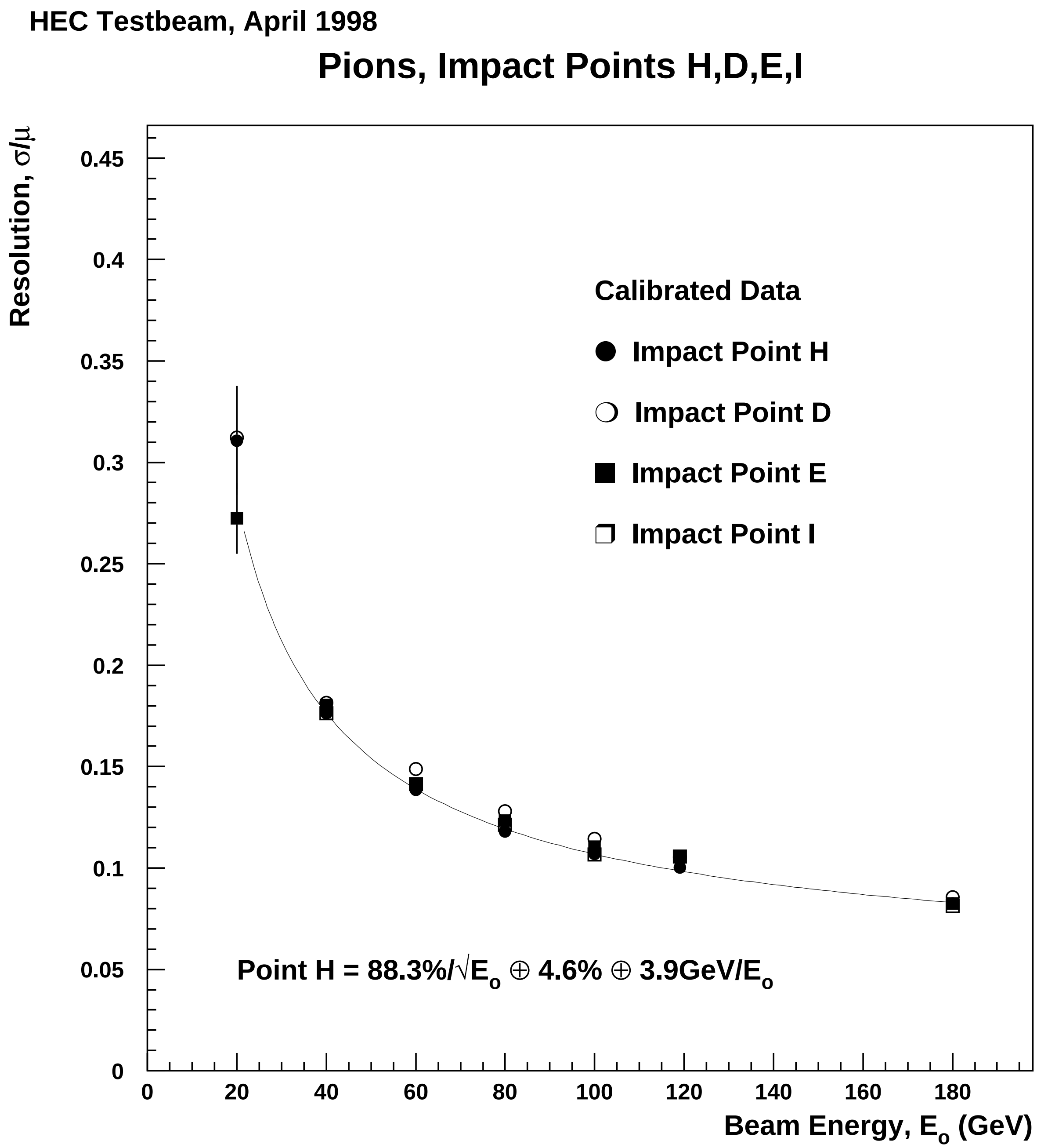



Figure 12: Energy resolution for pions at 4 different impact points (digital filtering)

# Pion Analysis

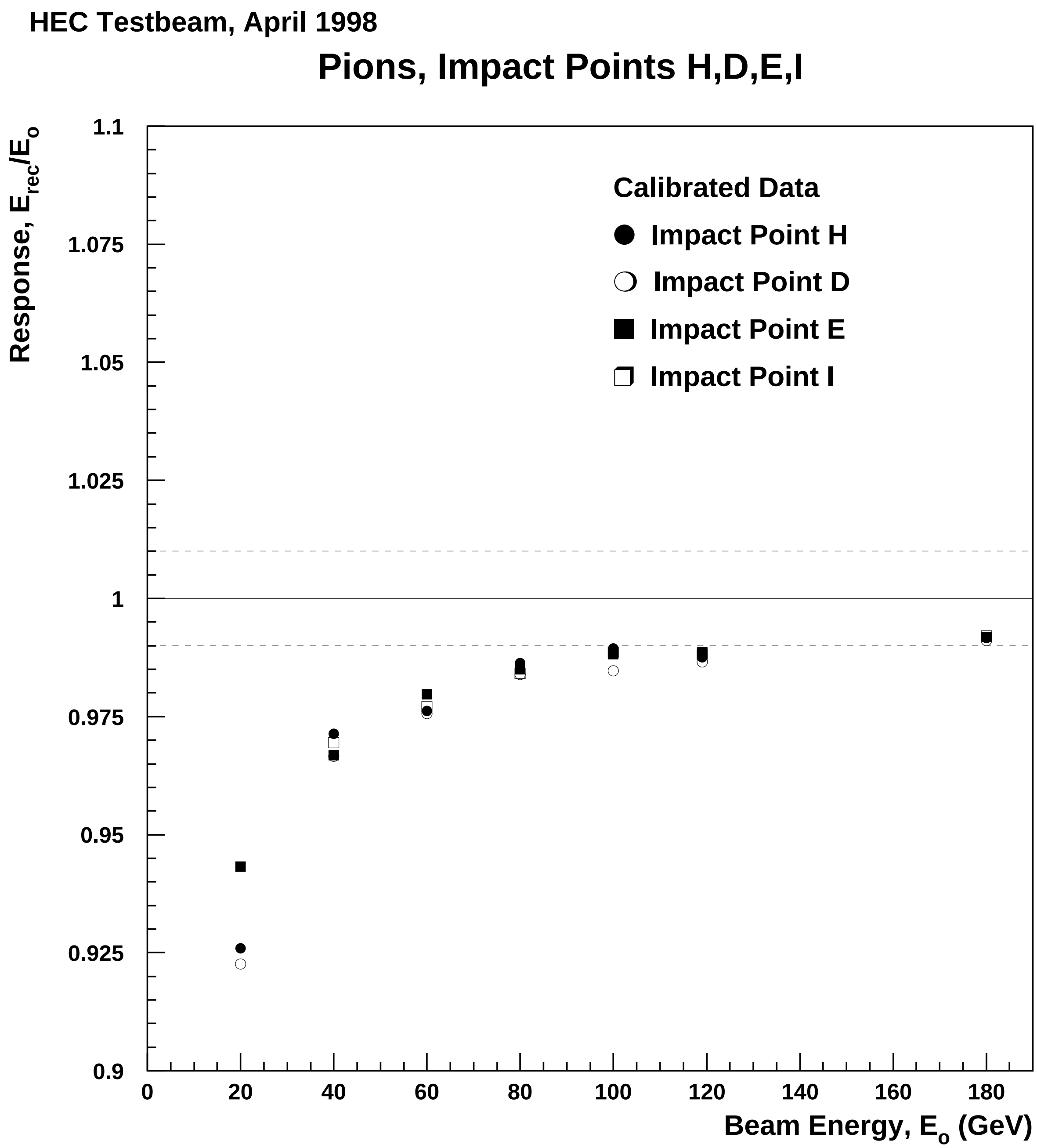



Figure 13: Response for pions at 4 different impact points

## Effect of HV Problem in Module 2

- 1 dead sub-gap (of 4) in each LAr gap in first half of back compartment, lower voltage (1200V) in 1/4 gaps of back half of back compartment.
- Expected effect: signal ≈3/4 of module 1 in back compartment due to dead gaps. Low voltage gaps are not expected to significantly affect results.
- The total energy (adc counts) in the third depth was compared for modules 1 and 2 for 180 GeV pions. The factor of 3/4 is verified.
- HV problems should lead to different depth weighting in module 1 and 2 for the back depth. Figure 15 shows the behaviour of the depth weights in the third compartment in modules 1 and 2. Again the factor of 3/4 is verified at high energy.

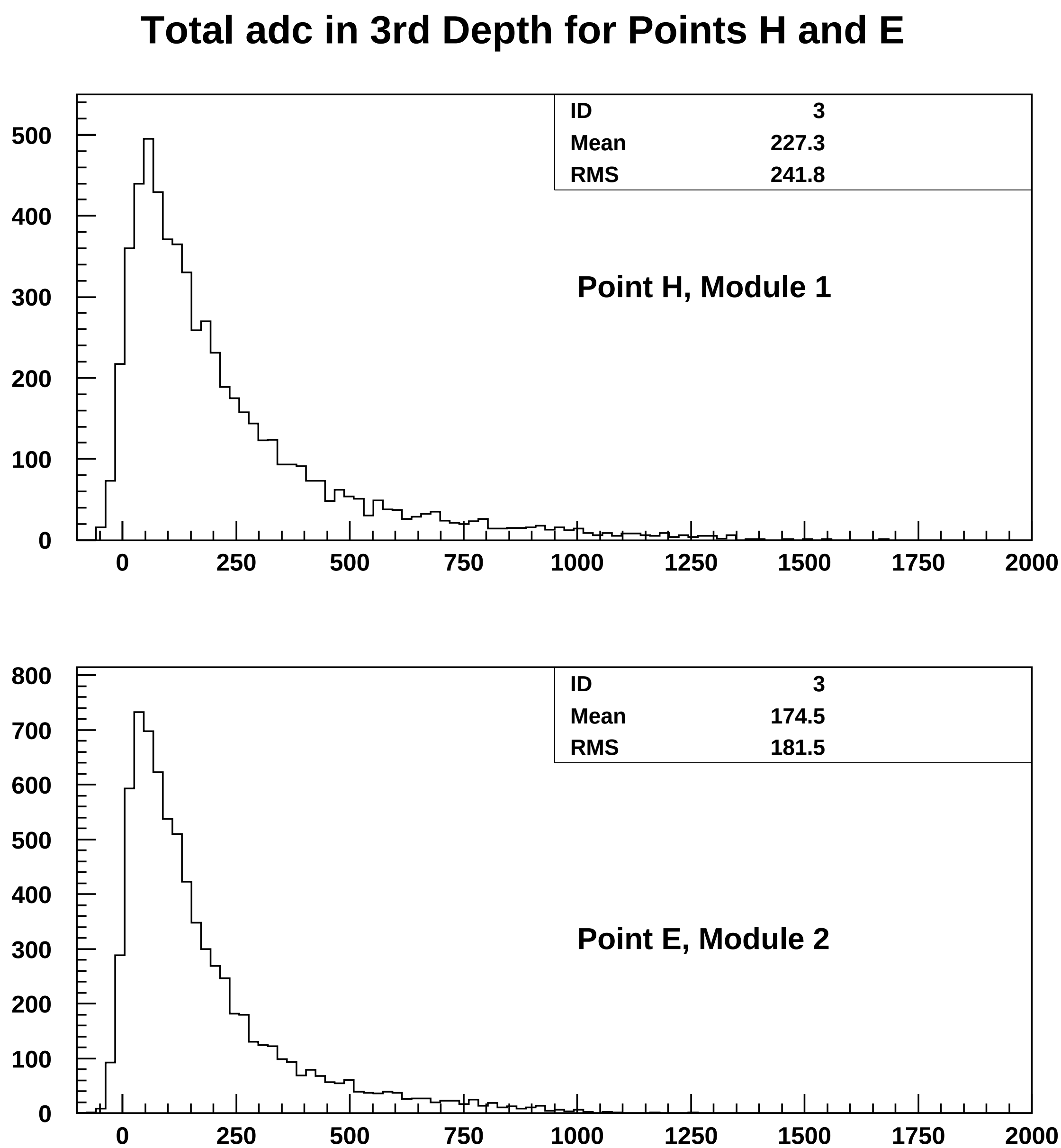



Figure 14: Total energy (adc) in the back compartment for 180 GeV pions .

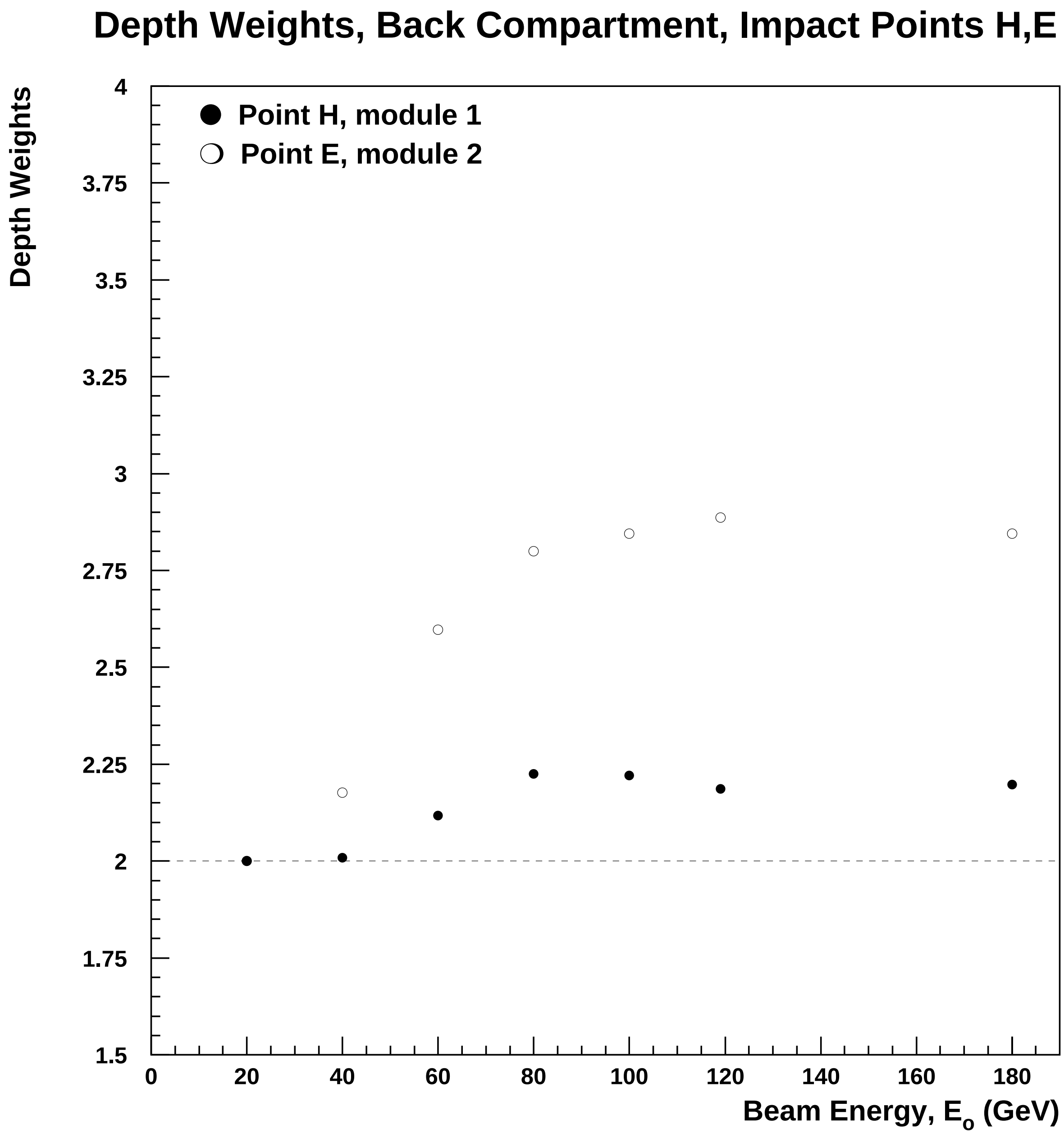



Figure 15: Behaviour of depth weights with energy in modules 1 and 2 .

# Conclusions

- Digital filtering leads to a consistent treatment for all energies.
- Electron results energy resolution as expected and response varies within 1% at all impact points.
- subcluster signal shape effective in isolating pion sample (particularly at low energies) from "zero energy" events. Presence of large number of "zero energy" events not fully understood.
- Pion energy resolution (calibrated):

| Module 1 | Module 2 |
|---|---|
| D | E |
| $\frac{109\%}{\sqrt{E_\circ}} \oplus 2.5\% \oplus \frac{2.3\ \mathrm{GeV}}{E_\circ}$ | $\frac{106\%}{\sqrt{E_\circ}} \oplus 2.2\% \oplus \frac{2.3\ \mathrm{GeV}}{E_\circ}$ |
| H | I |
| $\frac{88\%}{\sqrt{E_\circ}} \oplus 4.6\% \oplus \frac{3.9\ \mathrm{GeV}}{E_\circ}$ | |

- Response for pions varies by up to 7%, consistent over impact positions .
- Energy dependent weights allow recovery of performance in HV-affected module 2.
- More data needed at 20 GeV.