Hadronic Endcap Pion and Electron Energy Scan Analysis

Final Results from April 1998 and Preliminary Results from August 1998

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Outline

- Introduction: Draft note
- HV Problems
- Electron Analysis
- Pion Analysis
  - energy reconstruction
  - resolution, response - April
  - resolution, response - August - Preliminary
- Intrinsic e/h, e/μ - Preliminary
- Conclusions

Draft Note

- Complete summary of the April 1998 energy scan (resolution and response) analysis is available in the draft LARG Note:

  "Hadronic Endcap Modules Zero
  Pion and Electron Energy Scan Analysis
  from April 1998 Testbeam Data"

- Available from:
  - /afs/cern.ch/user/l/lefebvre/public/endcap/HEC_UVic_Apr98.ps
  - http://wwwhep.phys.uvic.ca/~uvatlas/testbeam/

- Please send comments to: lefebvre@uvic.ca before October 2, 1998, after which time a LARG note will be submitted.

HV Problems

The following subgaps were disconnected from high voltage:

Module	Depth	Gap No.	Subgap	HV reduced to
April 1998 Testbeam				
2	3 (1st half)	25-32	EST 1	Disconnected
2	3 (2nd half)	33-40	PAD 2	1200V
August 1998 Testbeam				
1	2 (2nd half)	17-24	EST 1	Disconnected
1	2 (2nd half)	17-24	EST 2	Disconnected
2	3 (1st half)	25-32	PAD 1	Disconnected

Other Hardware Problems

- crushed hardware calibration lines ⇒ No hardware calibration constants for cells:
  - 48, 94, 95, 114, 116, 144 (April 1998)
  - 48, 114, 116, 144 (August 1998)
- August calibration/digital filtering constants are not yet available
  ⇒ April constants are being used for all August data.

Electron Analysis

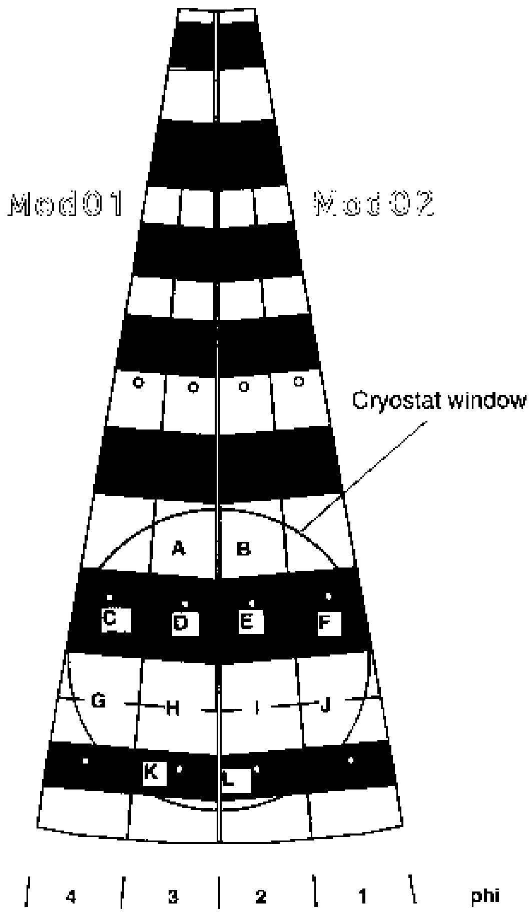


Figure 1:

Electron Data Sample and Signal Reconstruction

- Energy scan data for 20-120 GeV electrons is analysed for 4 impact points: D, E, H, I; Figure 1.
- Sample subject to trigger and signal shape cuts.

Electron Analysis

- Digital filtering signal peak reconstruction
- 3 cell cluster (size selection criterion: minimize overall resolution) with energy INDependent depth weights (1,1,2)
- E.M. scale determined by minimizing:

$$\chi^2 = \sum_{\mathrm{i}}^{\mathrm{runs}} \frac{\left(\alpha_{\mathrm{em}} \left\langle E_{\mathrm{cl,i}}(\mathrm{nA}) \right\rangle - E_{0,i}\right)^2}{\sigma_i^2} \tag{1}$$

result: $\alpha_{\mathrm{em}} = 3.41 \frac{GeV}{\mu A} = 0.112 \frac{GeV}{ADC}$

averaged over impact positions D, E, H, & I.
(Resolution is independent of α_{em})

Response

- Uniformity improved by hardware calibration.
- Linear within 1%.

Electron Analysis

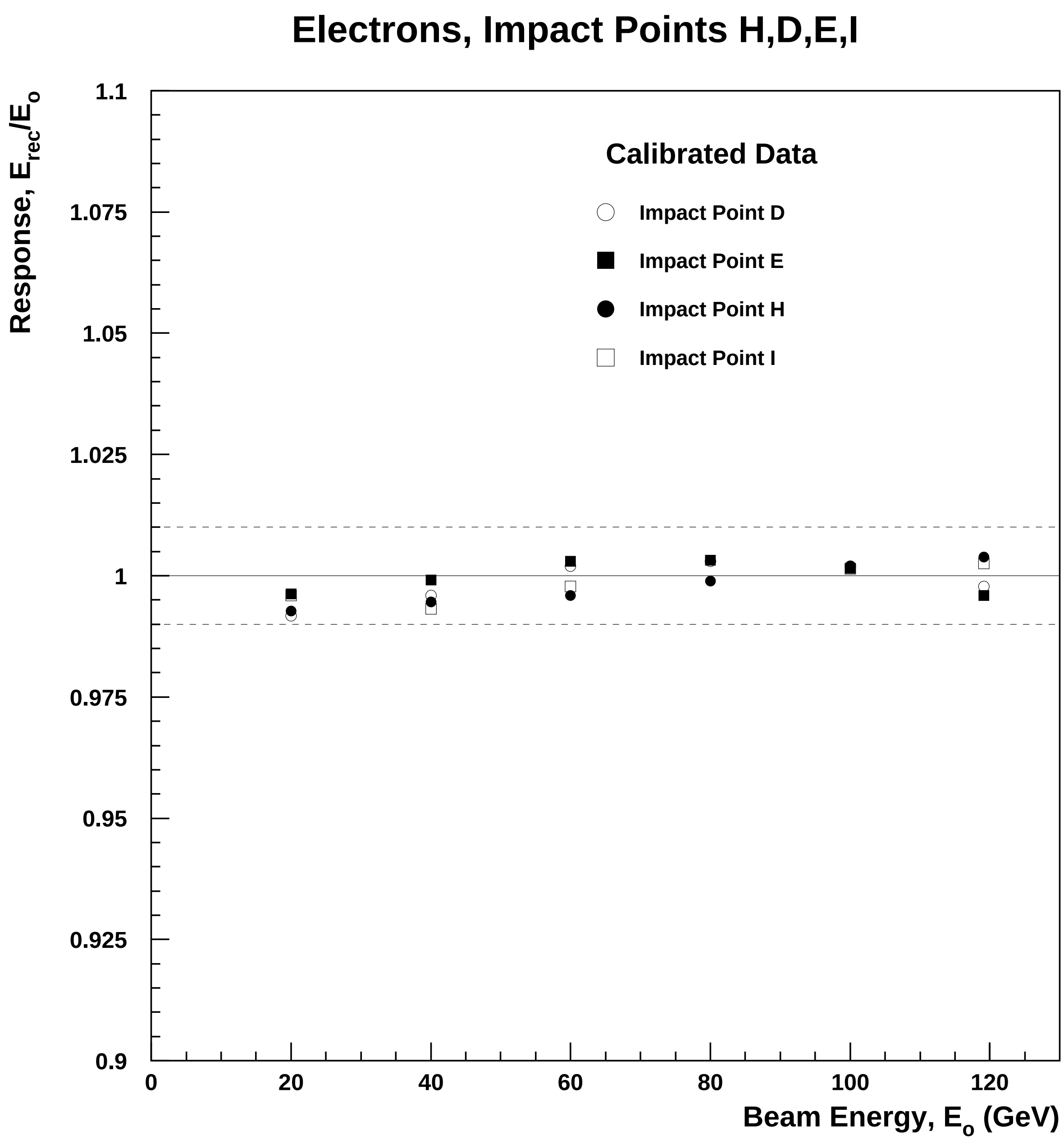


Figure 2: Electron response, ATLAS HEC April 1998 testbeam.

Electron Analysis

Resolution

Resolution is parametrized as

$$\frac{\sigma}{E} = \frac{A}{\sqrt{E_0}} \oplus B \oplus \frac{C}{E_0}, \tag{2}$$

where all 3 parameters are left free in the fit. Results:

Position	A(%GeV$^{\frac{1}{2}}$)	B(%)	C(GeV)
Module 1			
D	21.2 ± 1.1	0.7 ± 0.3	0.69 ± 0.08
H	22.7 ± 0.5	0.0 ± 1.5	0.50 ± 0.07
Module 2			
E	20.9 ± 0.9	0.7 ± 0.2	0.60 ± 0.07
I	22.8 ± 0.3	0.0 ± 0.4	0.44 ± 0.06

consistent over all impact positions.
A combined fit gives (Figure 3): $\frac{\chi^2}{\text{ndf}} = 2.03$

$$\frac{\sigma}{E} = \frac{22.1 \pm 0.8\%}{\sqrt{E_0}} \oplus 0.4 \pm 0.5\% \oplus \frac{0.55 \pm 0.07}{E_0},$$

- Noise term is consistent with noise measurements from random triggers.

Electron Analysis

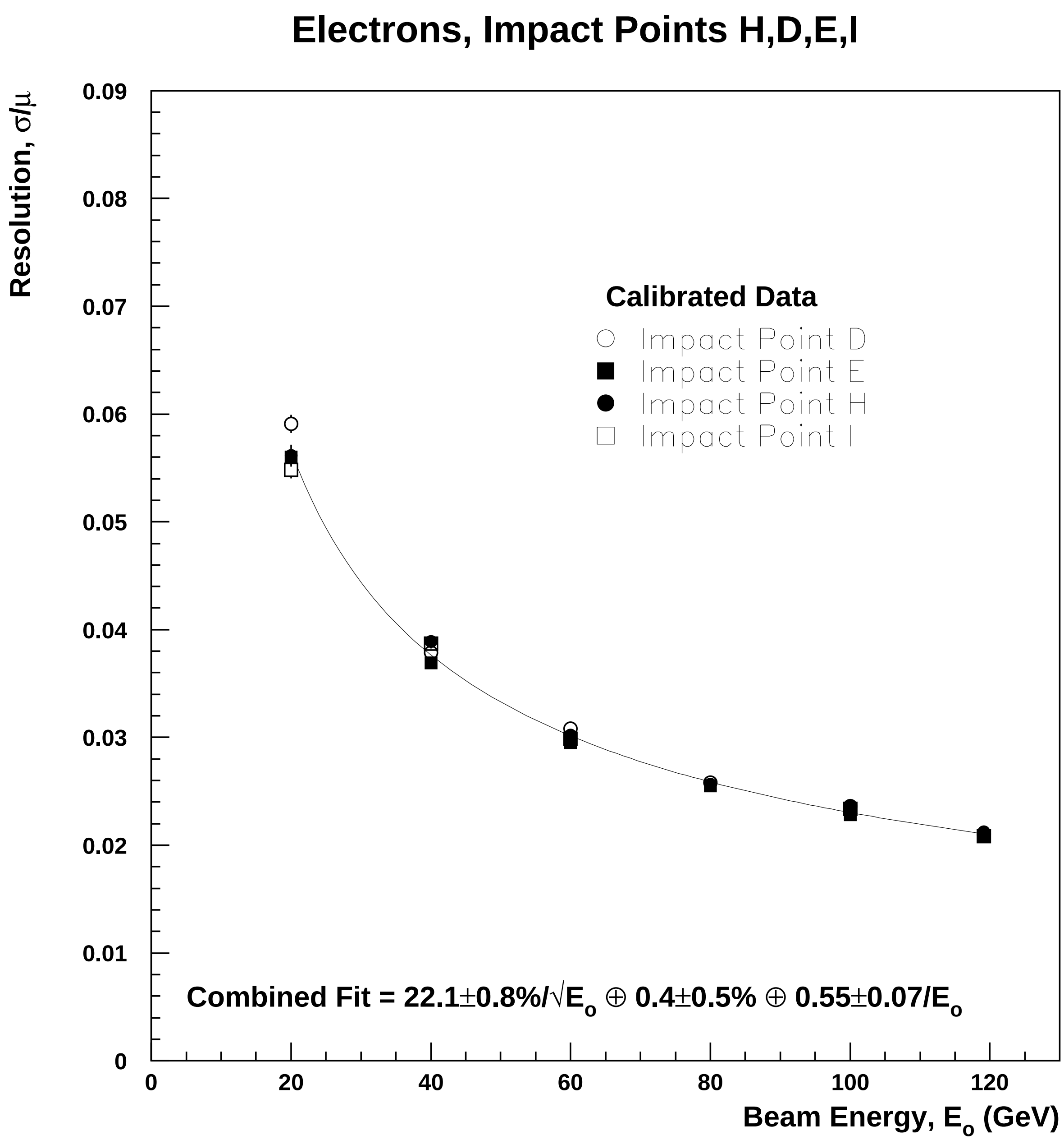


Figure 3: Electron resolution, ATLAS HEC, April 1998 testbeam.

Pion Analysis

Energy Reconstruction

- Sample subject to trigger and signal shape cuts.
- Signal is reconstructed using digital filtering.
- Pedestals were calculated over entire run (time slices 1-4), giving considerable improvement over event pedestals.
- Cell cluster sizes were chosen to optimize energy resolution, nominal size is 19 cells (typical cluster shown in Figure 4).
- Use one energy dependent weight per depth found using:

$$\frac{1}{\sigma^2}\sum_{\text{events}}\left(\alpha_{\text{had}}\sum_z c_z E^z_{\text{cl}}(\text{nA}) - E_0\right)^2 .$$

  Typical depth weights are: 1.0, 1.04, 2.4 (April 98, 180 GeV).

- Response is NOT constrained to unity (though it is possible to normalize weights to obtain flat response without affecting resolution).

Pion Analysis

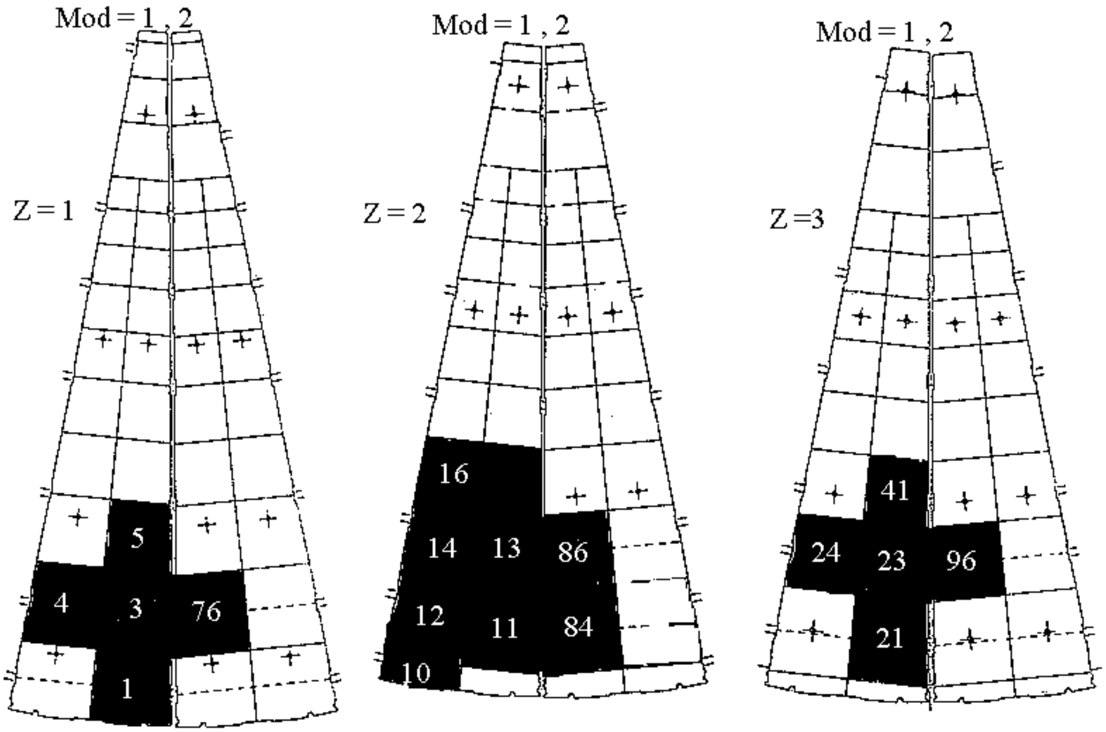


Figure 4: Map of cells chosen for 19 cell cluster centered at H (pad 3).

Pion Results - April 1998

- Applying depth weights gives reconstructed energies as shown in Figures 5 and 6.
- Resolution was obtained for several different cluster sizes (see Figure 7). 19 cell cluster is chosen to optimize overall resolution.
- Response and resolution are evaluated at 4 different impact positions. Figure 8 shows response varies within 6%
- Depth weights can be normalized to make response flat without affecting resolution.
  These weights are shown for two representative points in Figure 9.
- Resolution is consistent over impact positions as shown in Figure 10.

Pion Results April 1998

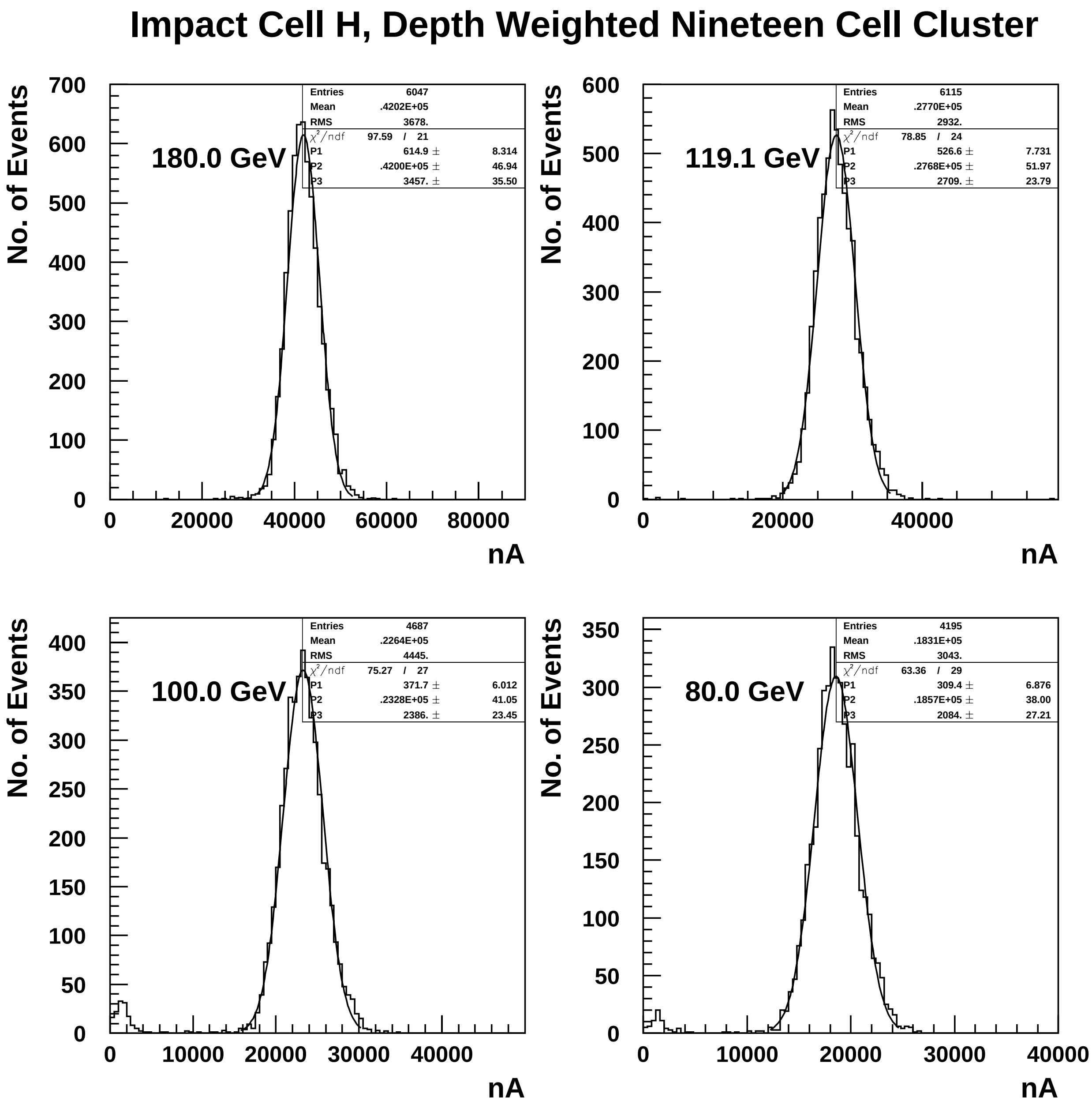


Figure 5: Reconstructed energy distributions for impact cell H. Energies 180 GeV to 80 GeV.

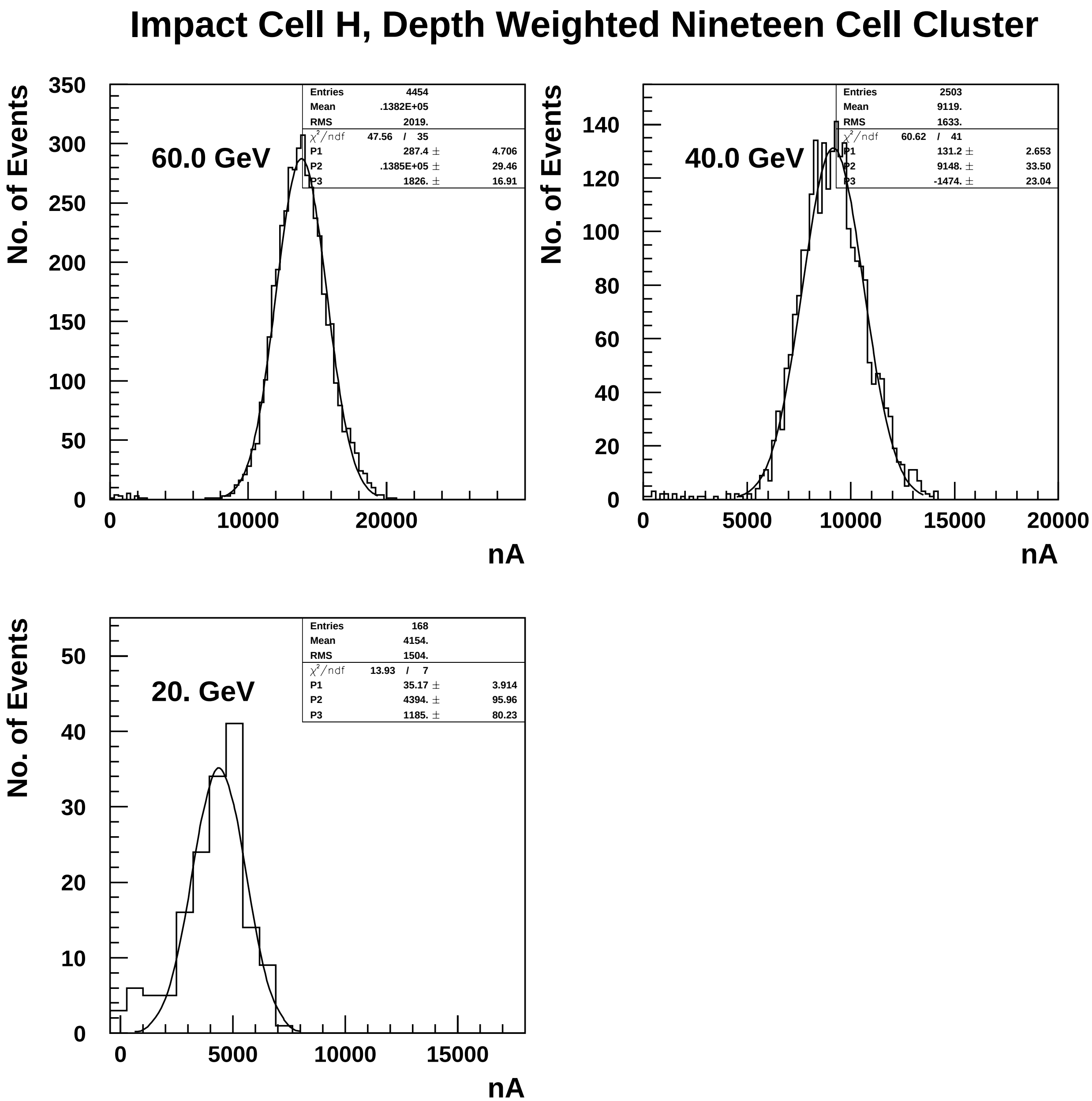


Figure 6: Reconstructed energy distributions for impact cell H. Energies 60 GeV to 20 GeV.

Pion Results April 1998

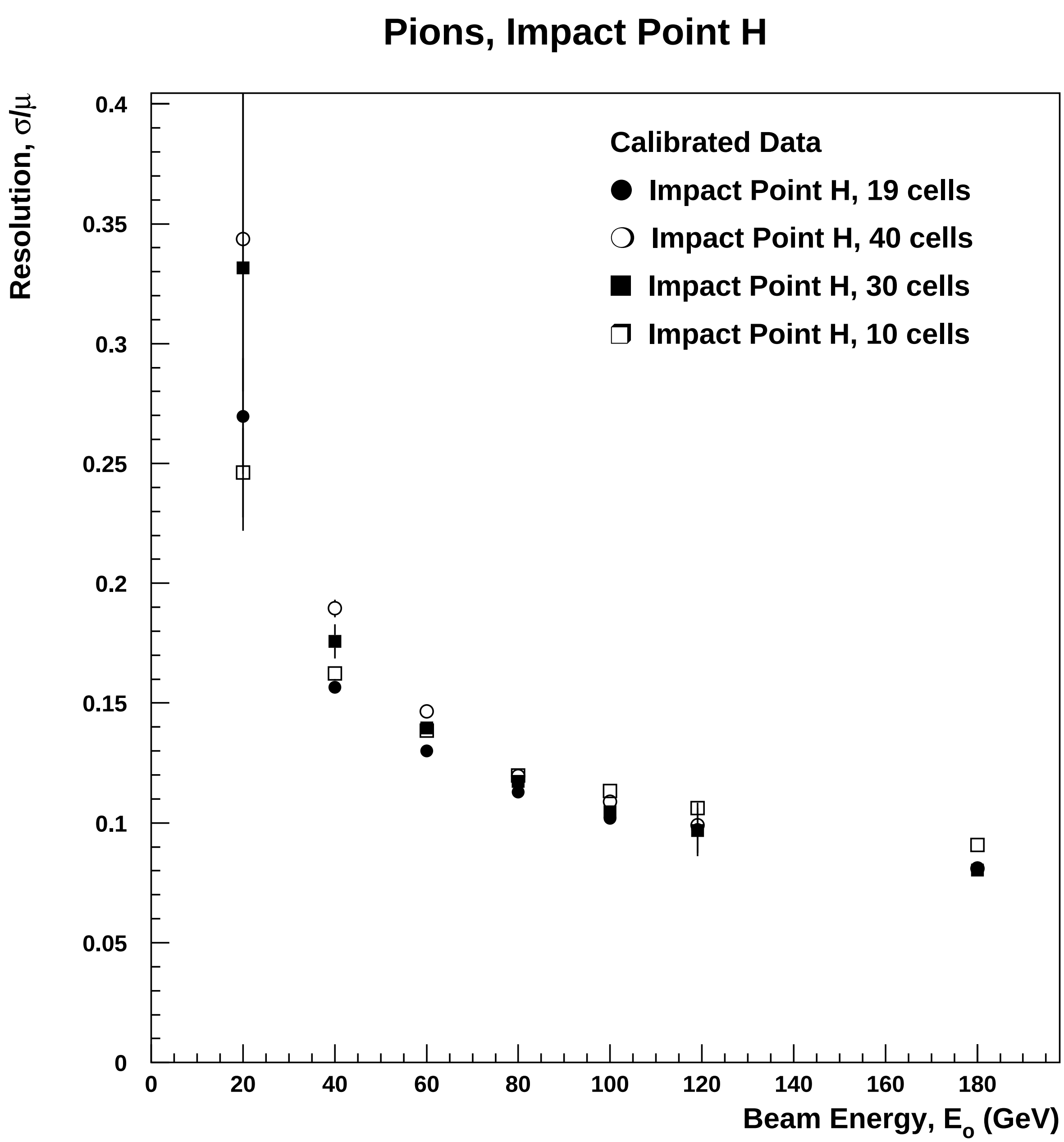


Figure 7: Comparison of energy resolution for Pions at impact position H for four different cluster sizes.

Pion Results April 1998

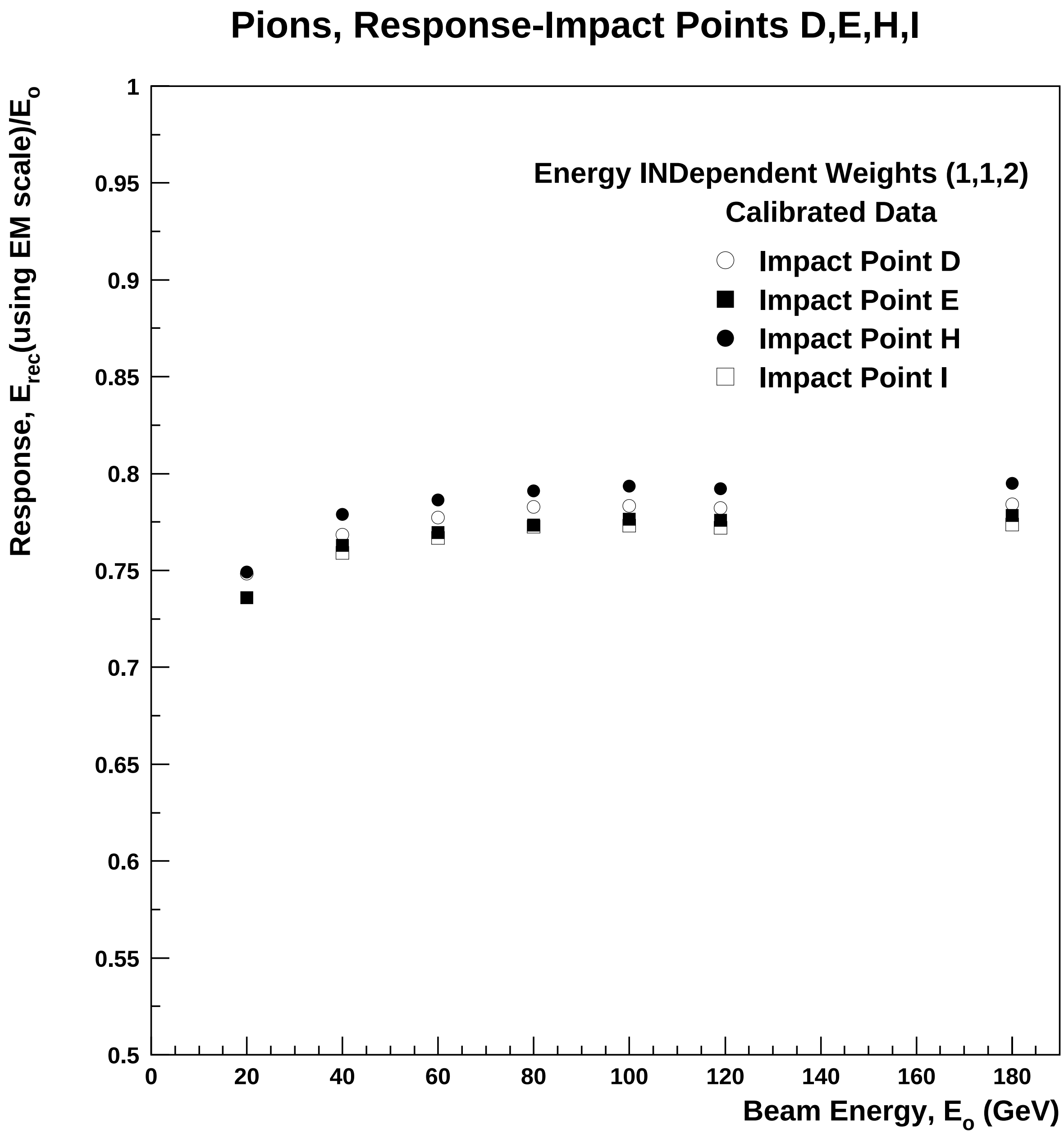


Figure 8: Response to pions using 1,1,2 depth weighting at 4 impact positions.

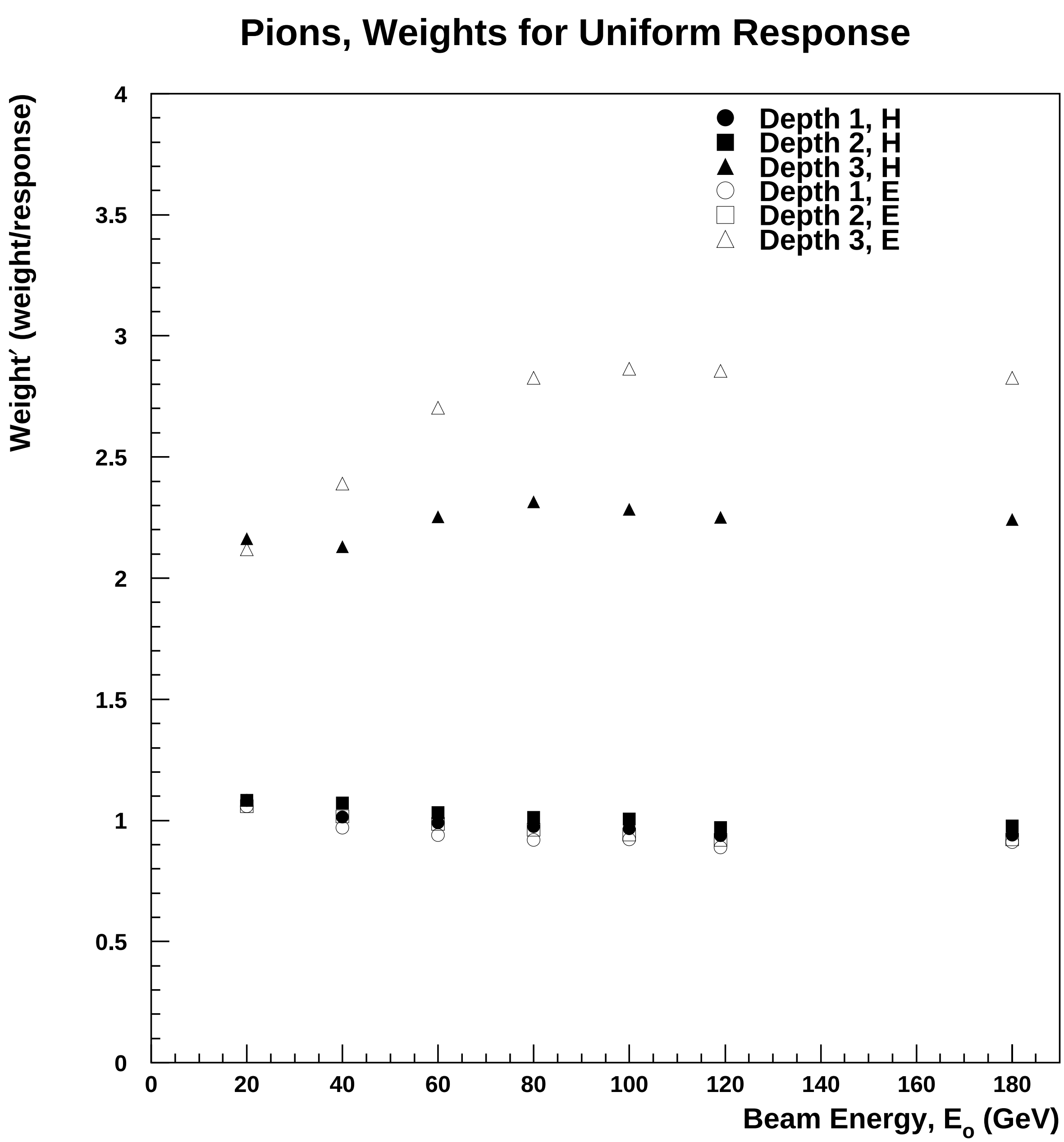


Figure 9: Depth weights for uniform response for two representative impact positions (H, Module 1 & I, Module 2). The effect of HV problems in the 3rd depth of Module 2 can be seen.

Pion Results April 1998

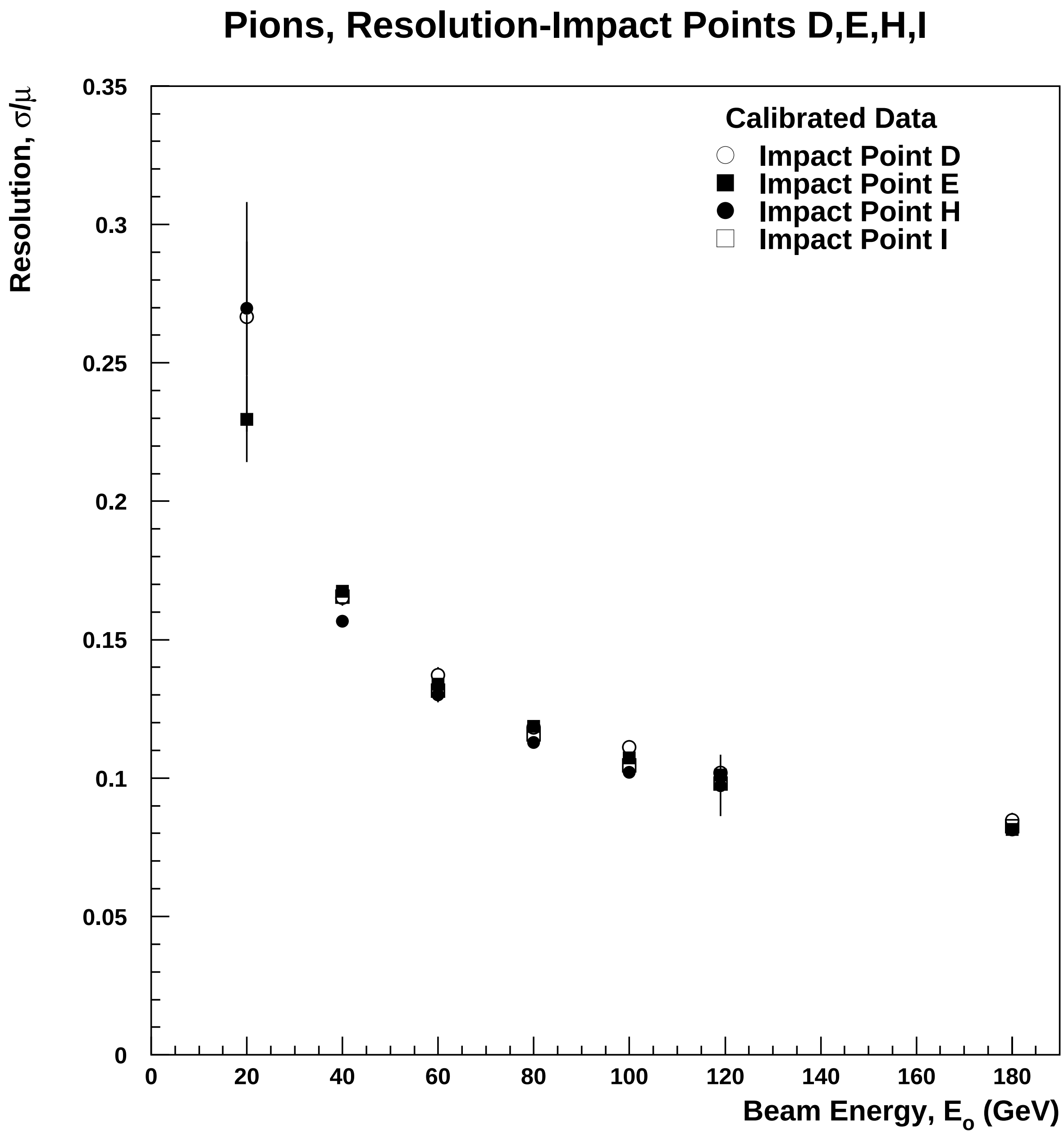


Figure 10: Overall resolution for pions at 4 impact positions.

Pion Results April 1998

- Noise is measured independently by applying depth weights to random trigger events within physics runs (ie. noise becomes run dependent). This noise is subtracted (in quadrature) and the resolution is parameterized according to

$$\frac{\sigma}{E} = \frac{A}{\sqrt{E_0}} \oplus B.$$

- Fitting resolution at each of the four impact positions gives:

Position	A(% GeV$^{\frac{1}{2}}$)	B(%)	χ^2/ndf
Module 1			
D	81 ± 4	6.0 ± 0.5	1.08
H	80 ± 2	5.3 ± 0.4	0.43
Module 2			
E	86 ± 2	4.9 ± 0.4	1.80
I	80 ± 3	5.2 ± 0.3	0.25

- A combined fit to pion resolution over four impact positions is shown in Figure 11. The fit gives:

$$\frac{\sigma}{E} = \frac{82 \pm 2\%}{\sqrt{E_0}} \oplus 5.2 \pm 0.2\% \qquad \frac{\chi^2}{\text{ndf}} = 1.6$$

Pion Results April 1998

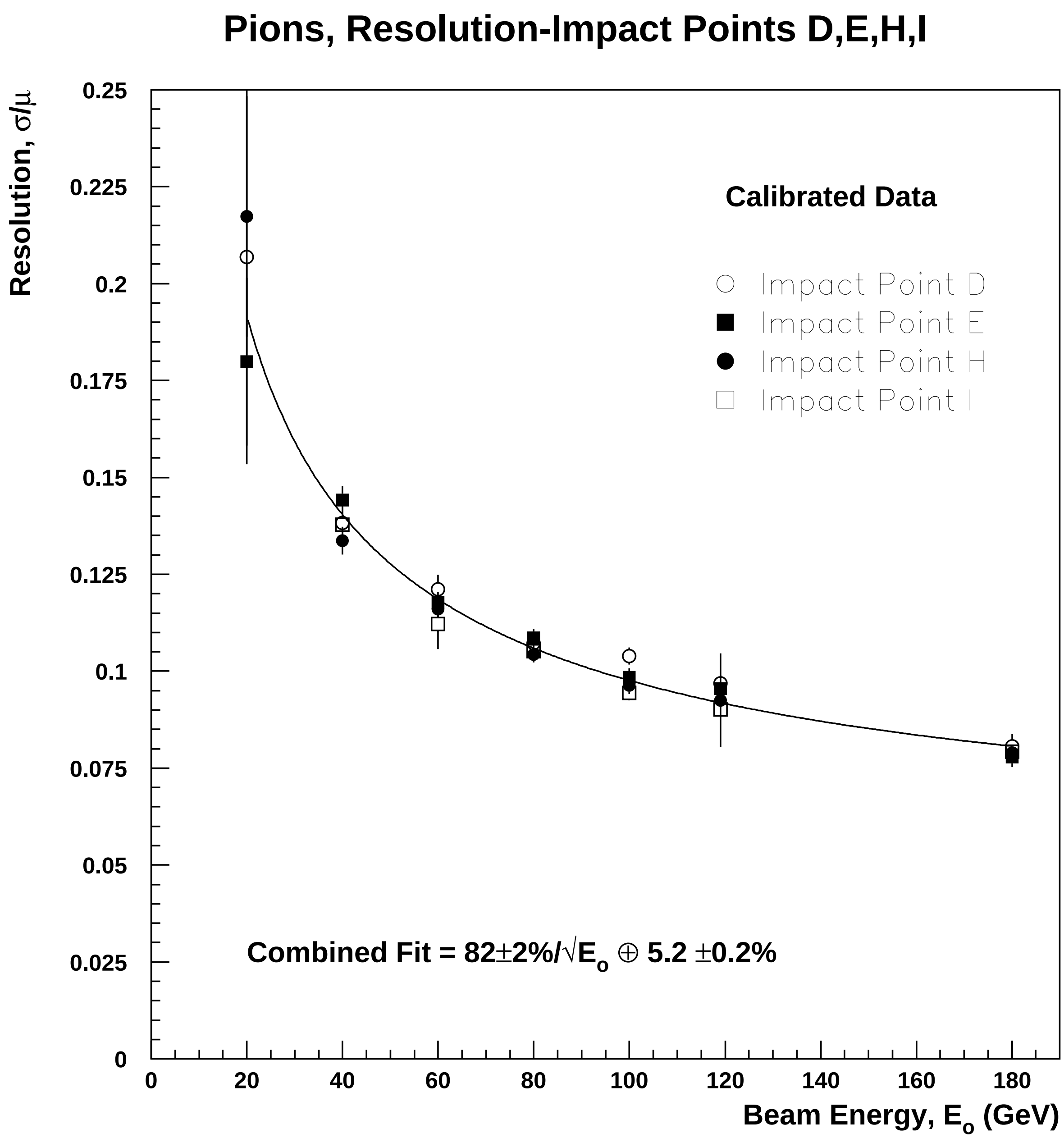


Figure 11: Combined fit on resolution (after noise subtraction) of 4 impact points.

Pion Results - August 1998

- PRELIMINARY analysis of August data
- HV problems in middle layer of module 1
- Response and resolution are evaluated at two impact points (H and I).
- August data quality is good (Figures 12 and 13).
- Response results are shown in Figure 14.
- Effect of dead sub-gaps in module 1 is evident in the difference in overall resolution shown in Figure 16.

Pion Results August 1998 - Preliminary

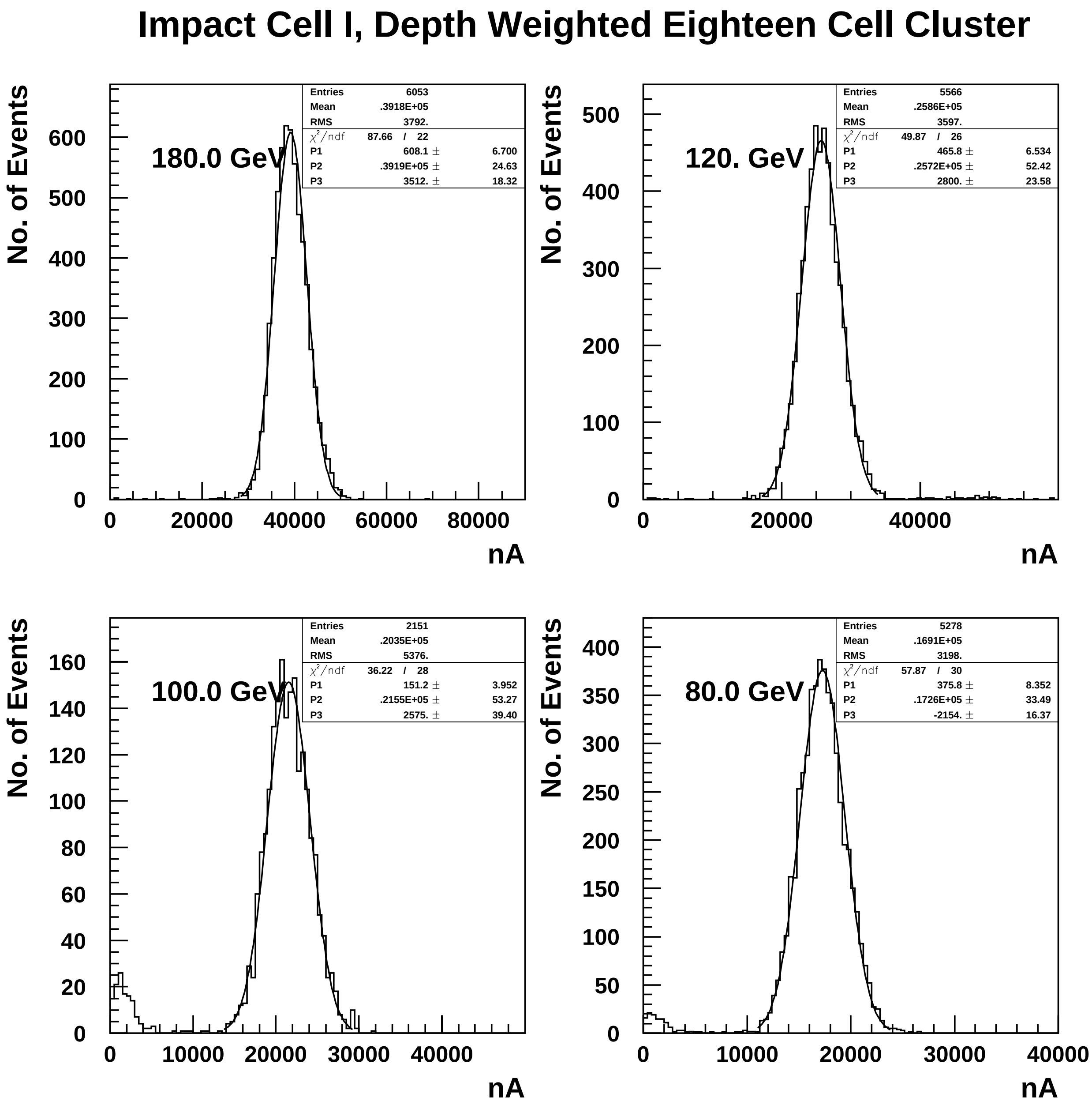


Figure 12:

Pion Results August 1998 - Preliminary

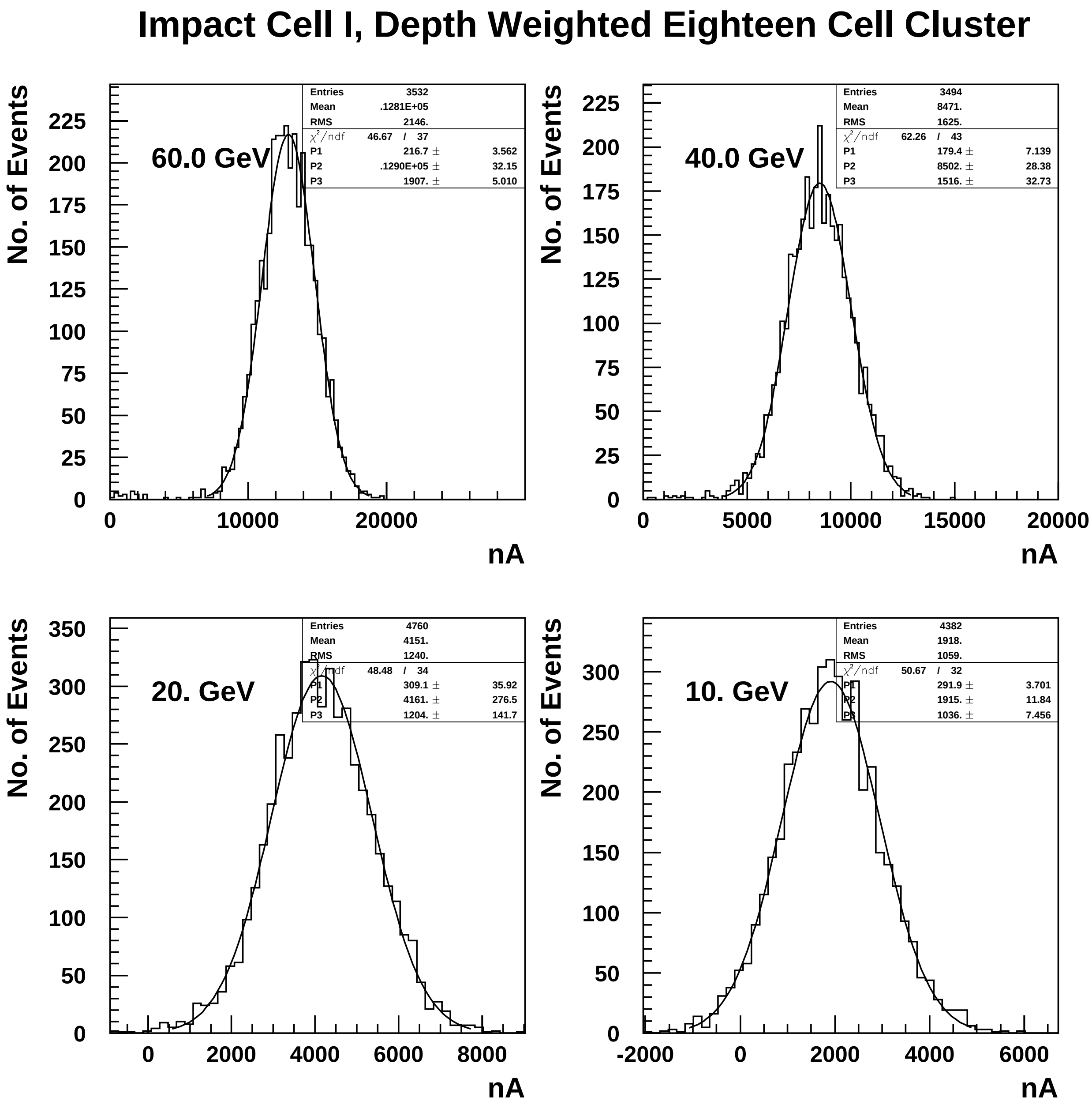


Figure 13:

Pion Results August 1998 - Preliminary

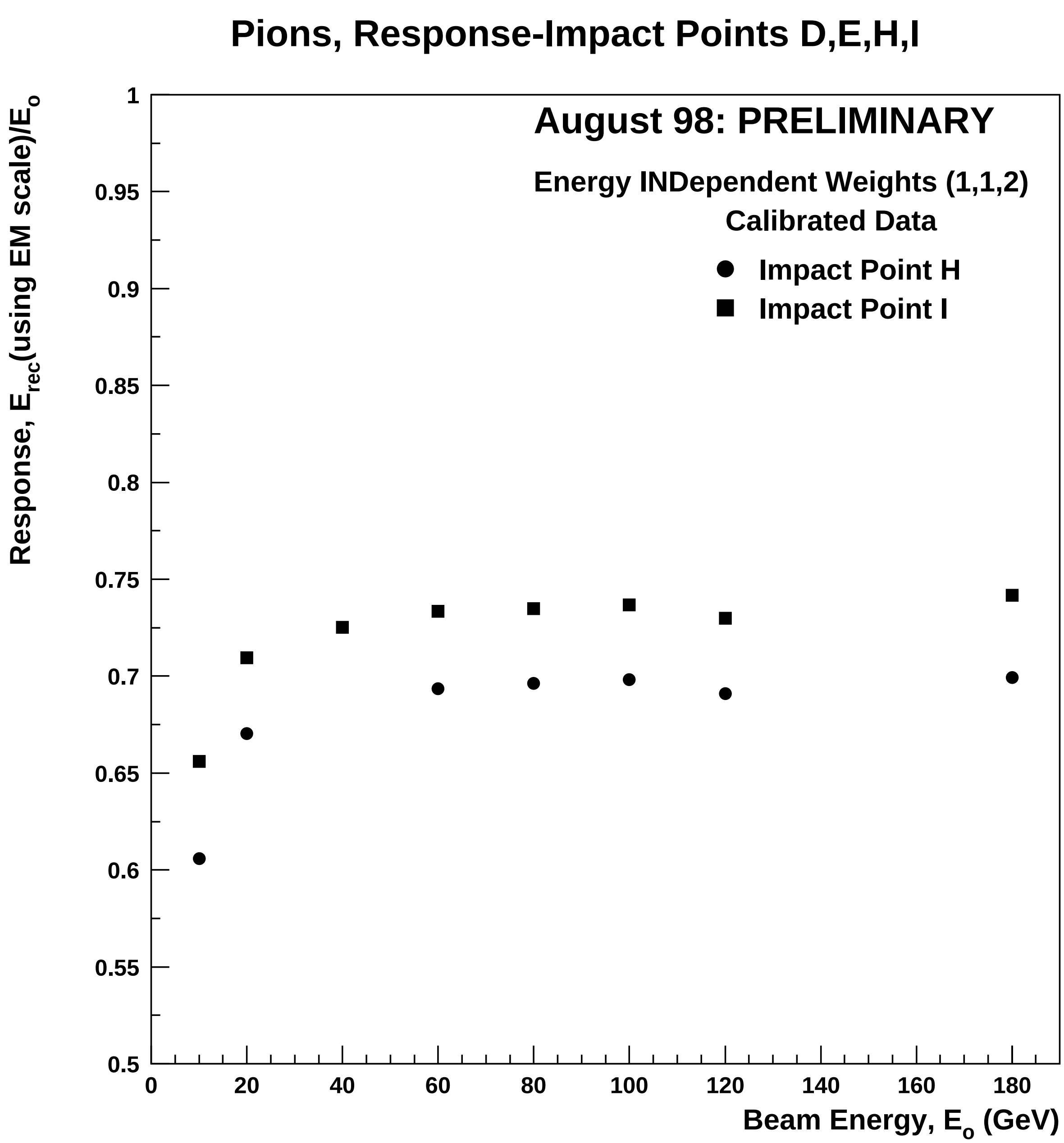


Figure 14:

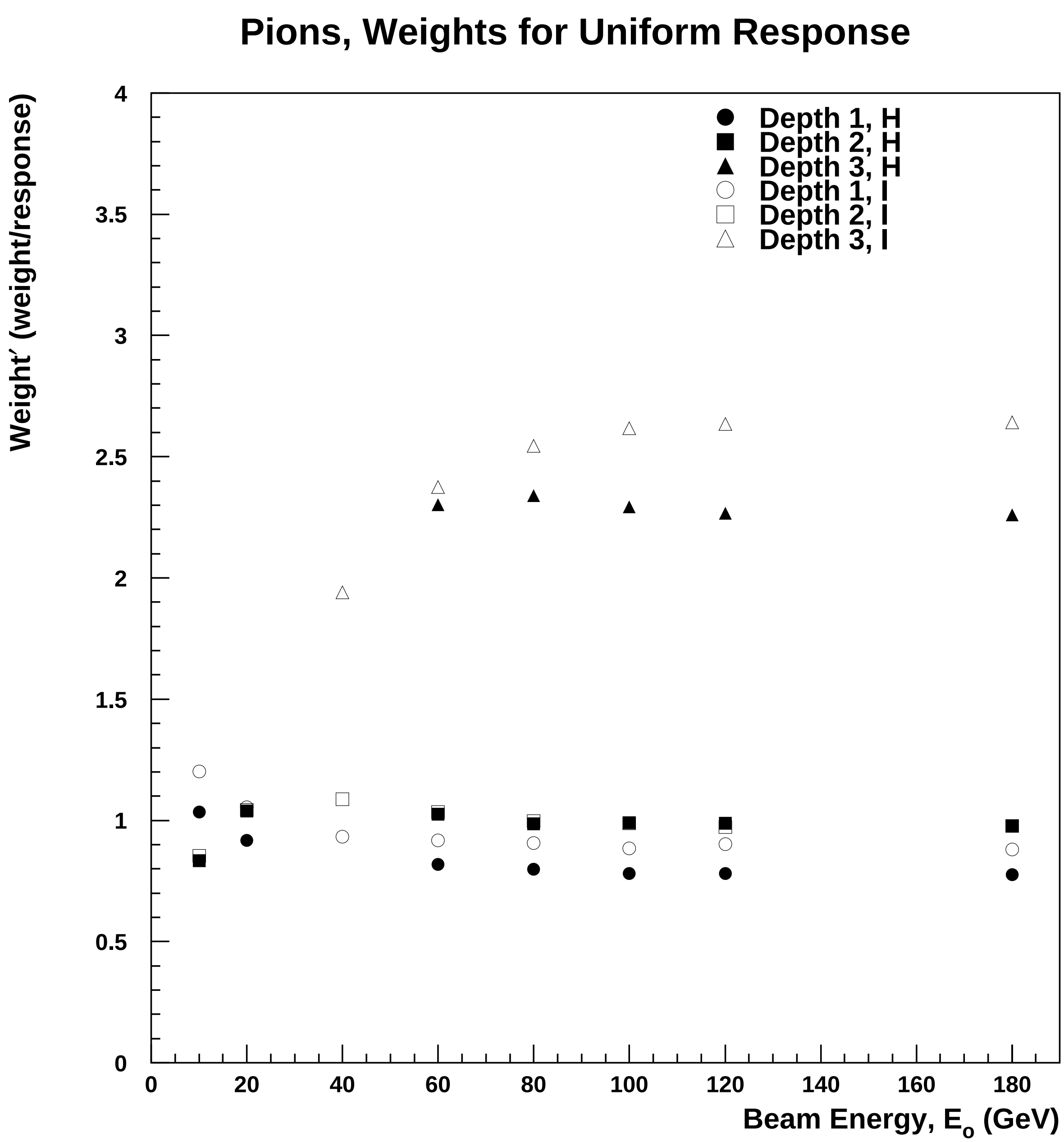


Figure 15: Depth weights for flat response for two representative impact positions (H, Module 1 & I, Module 2). Weights for the 3rd depth of low energy (10-20 GeV) runs are fixed to 2. HV problems in the second depth of module 1 affect all weights in module 1. The effect of HV problems in the 3rd depth of module 1 can be seen.

Pion Results August 1998 - Preliminary

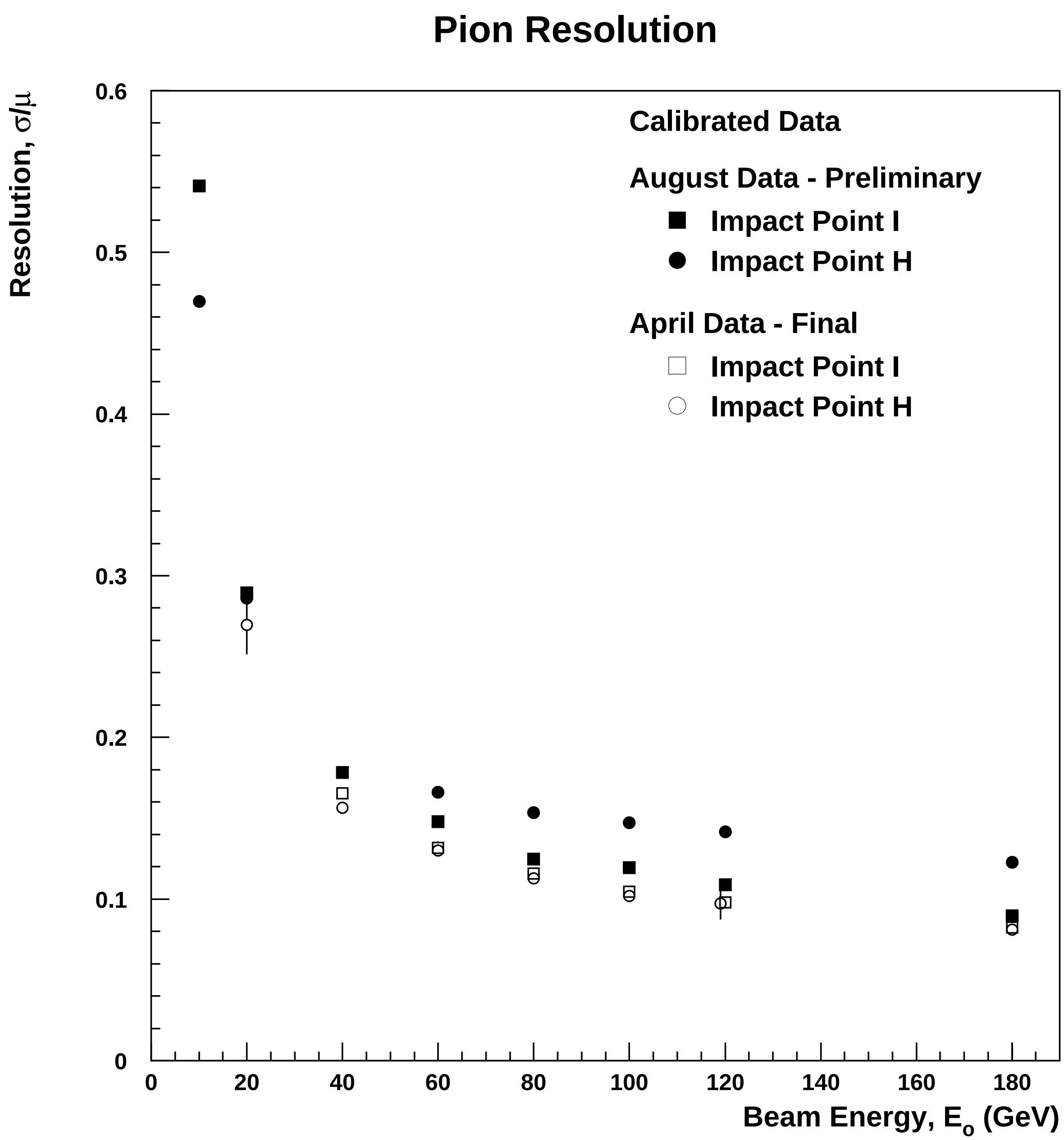


Figure 16: Overall resolution for pions at impact positions H, I.

Pion Results August 1998 - Preliminary

- Figure 16 also shows worsening resolution from April to August at impact point I. Possible reasons:
  - two cells from layer 2 of module 1 are used in cluster about pad I
  - April digital filtering weights and calibration constants are used on August data
  - timing problems?
- As in April sample, noise is pre-subtracted and a two parameter fit is made in Figure 17. Fit gives:

$$\frac{\sigma}{E} = \frac{86 \pm 1\%}{\sqrt{E_0}} \oplus 5.7 \pm 0.2\% \qquad \frac{\chi^2}{\text{ndf}} = 3.1$$

Pion Results August 1998 - Preliminary

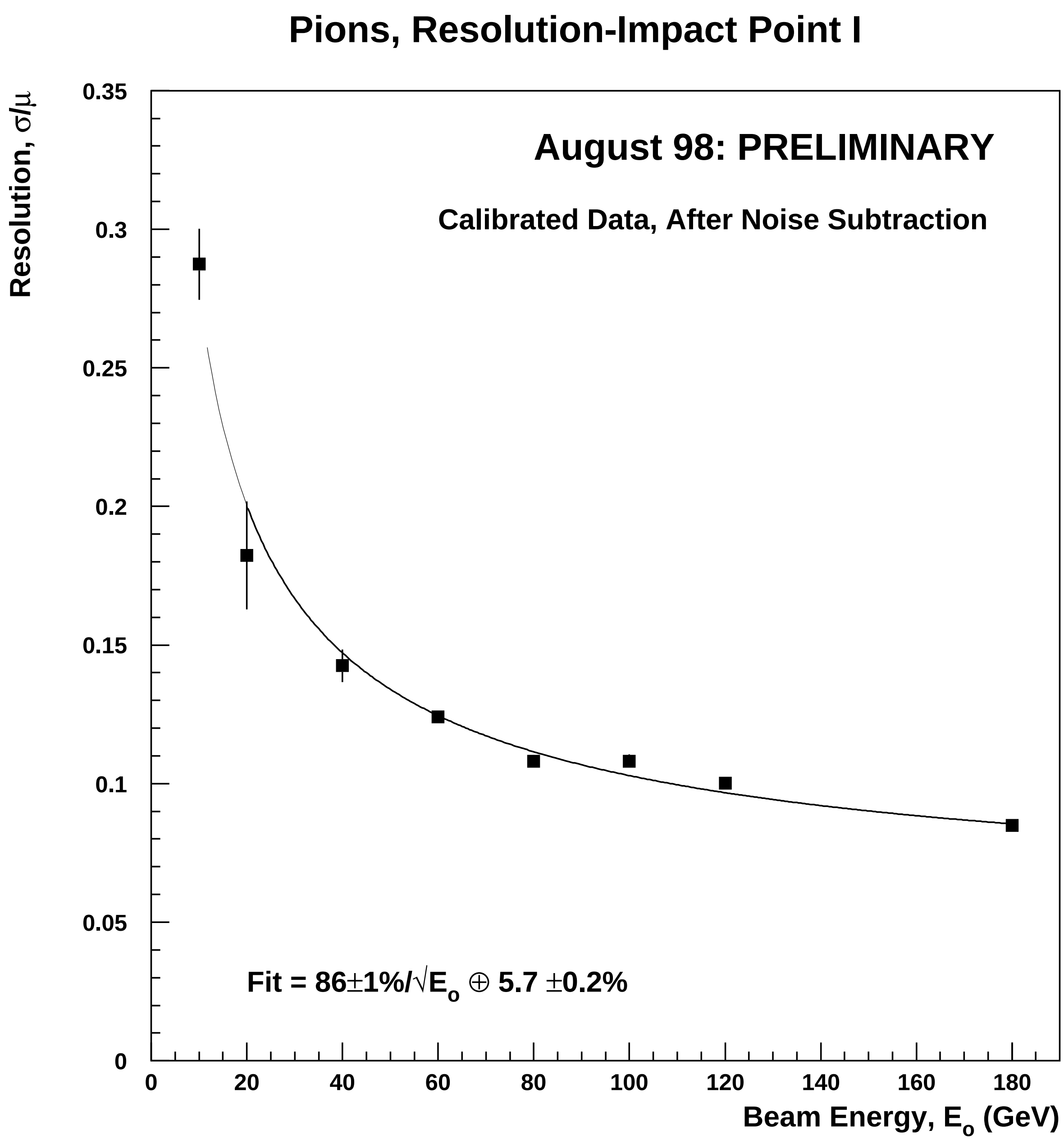


Figure 17: Resolution for position I after pre-subtraction of noise.

Intrinsic e/h - Preliminary

Intrinsic $\frac{e}{h}$

$\frac{e}{\pi} = \frac{\alpha_{had}}{\alpha_{em}}$ has form [1]

$$e/\pi = \frac{1}{1 - aE_o^{m-1}} \quad \text{where } a = \frac{1-\frac{h}{e}}{E_{scale}^{m-1}} \Rightarrow \frac{e}{h} = \frac{1}{1 - aE_{scale}^{m-1}}$$

and "on physical grounds, E_{scale} ought to be $\simeq$ 1 GeV; fits to simulation results give values in this range..."

Assumptions:

- fine sampling
- uniform sampling
- full containment

[1] Groom, Don, "What really goes on in a hadron calorimeter?", presented at *VII International Conference on Calorimetry in High Energy Physics* at the University of Arizona, Tucson, Arizona, November 9-14, 1997. Refer to `http://pdg.lbl.gov/~deg/calor97.html`.
Nuclear Instruments and Methods in Physics Research A 338 (1994) 336-347.

Intrinsic e/h - Preliminary

A fit is performed (Figure 18)using:

- April 1998 data
- Digital Filtering, energy independent depth weights 1,1,2 (1,1,2.67)
- 40 cell cluster for both pion and electron data

Results:

Impact Position	$\frac{e}{h}\Big|^{\rm eff}$ ±stat.err
D, Mod. 1	1.569±0.006
H, Mod. 1	1.621±0.006
E, Mod. 2	1.58±0.03
I, Mod. 2	1.64±0.03

Weighted average: $\langle\frac{e}{h}\rangle^{\rm eff} = 1.592 \begin{array}{l}\pm 0.004\ \textit{stat.}\\ \pm 0.03\ \textit{syst.}\end{array}$

- Effect of E_{scale} variation is small (syst. error).
- Similar results for 19 cell cluster (effect of leakage small).

Intrinsic e/h - Preliminary

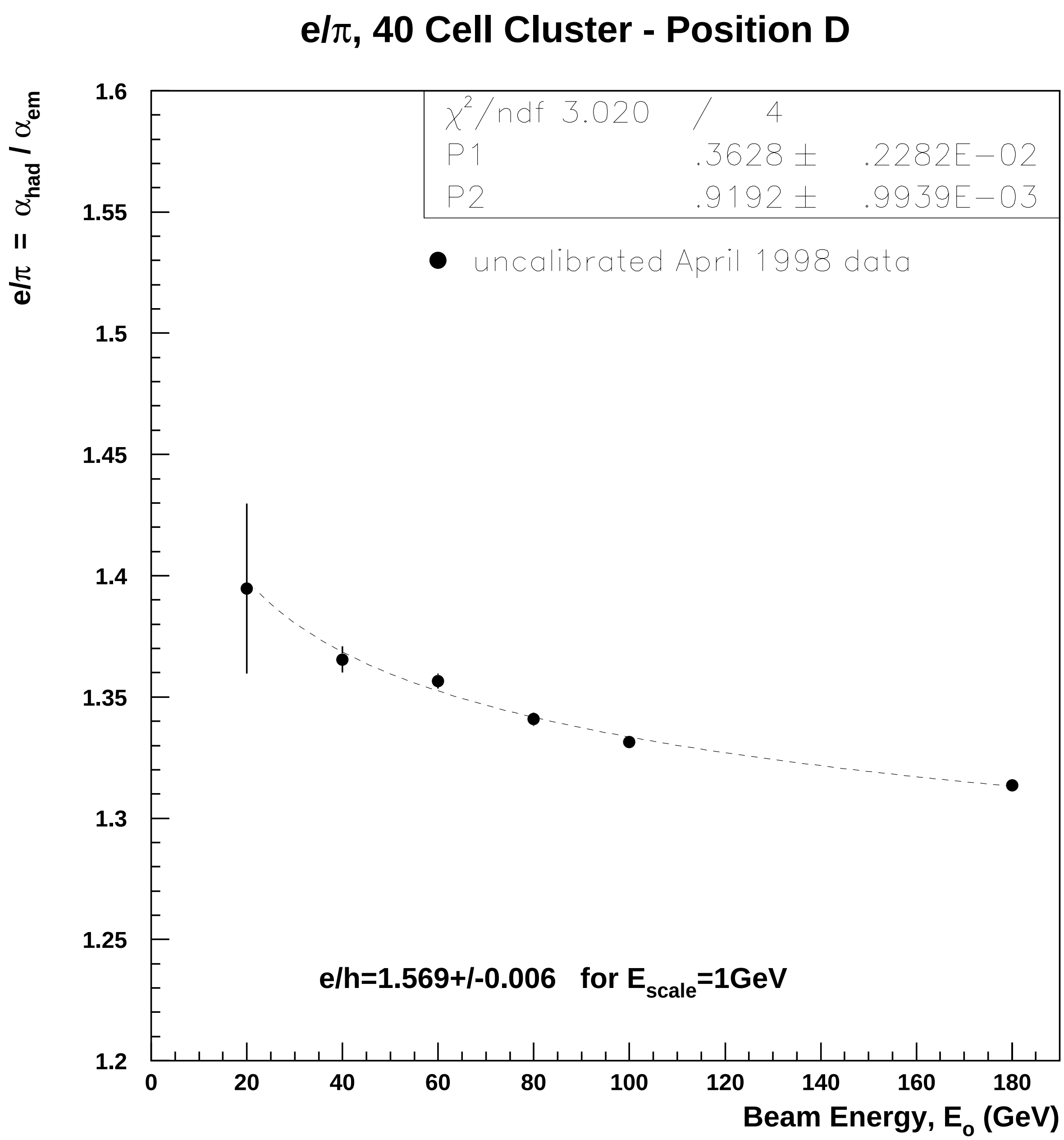


Figure 18:

Intrinsic e/h - Preliminary

- The same fit to M.C. data [2] gives (Figure 19):

Monte Carlo	$\frac{e}{h}\vert_{\rm mc}$ ±stat.err
GCALOR	1.37±0.01
GFLUKA	1.23±0.02
GHEISHA	1.23±0.02

  using:

  - impact position D
  - 144 cell cluster
  - energy independent depth weights 1,1,2

- The HEC has been modelled [3] using the CYLINDER hadronic calorimeter M.C. which predicts:
  $\frac{e}{h}\big|_{\rm mc} = 1.58$ (GEANT 3.21 - GCALOR)

This analysis: $\langle\frac{e}{h}\rangle^{\rm eff} = 1.592 \begin{array}{l}\pm 0.004\ \textit{stat.}\\ \pm 0.03\ \textit{syst.}\end{array}$

[2]Thanks to A. Kiryunin for supplying M.C. data
[3]Grauges, Eugeni, ATL-TILECAL-98-158, May 1997, p.143.

Intrinsic e/h - Preliminary

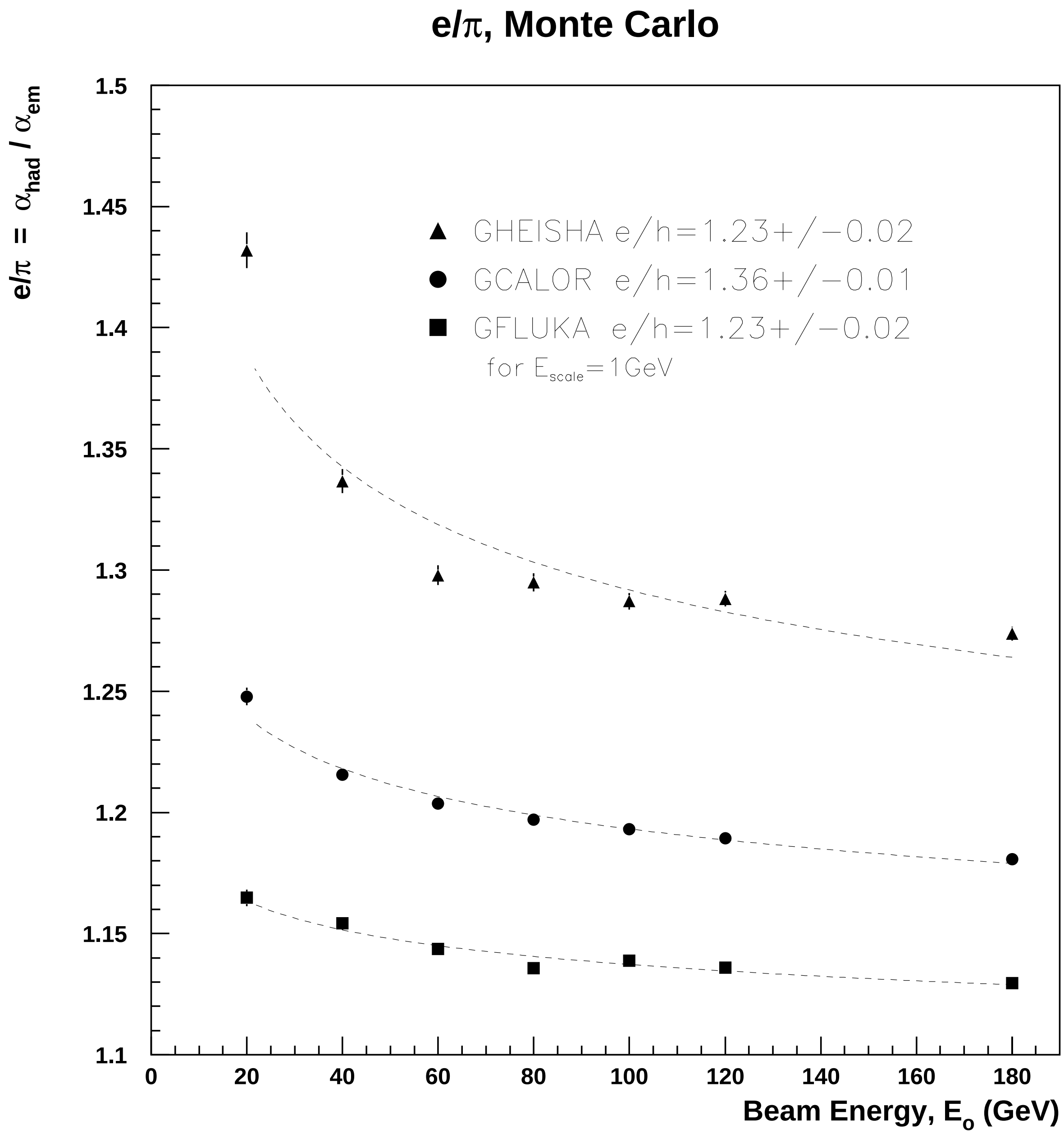


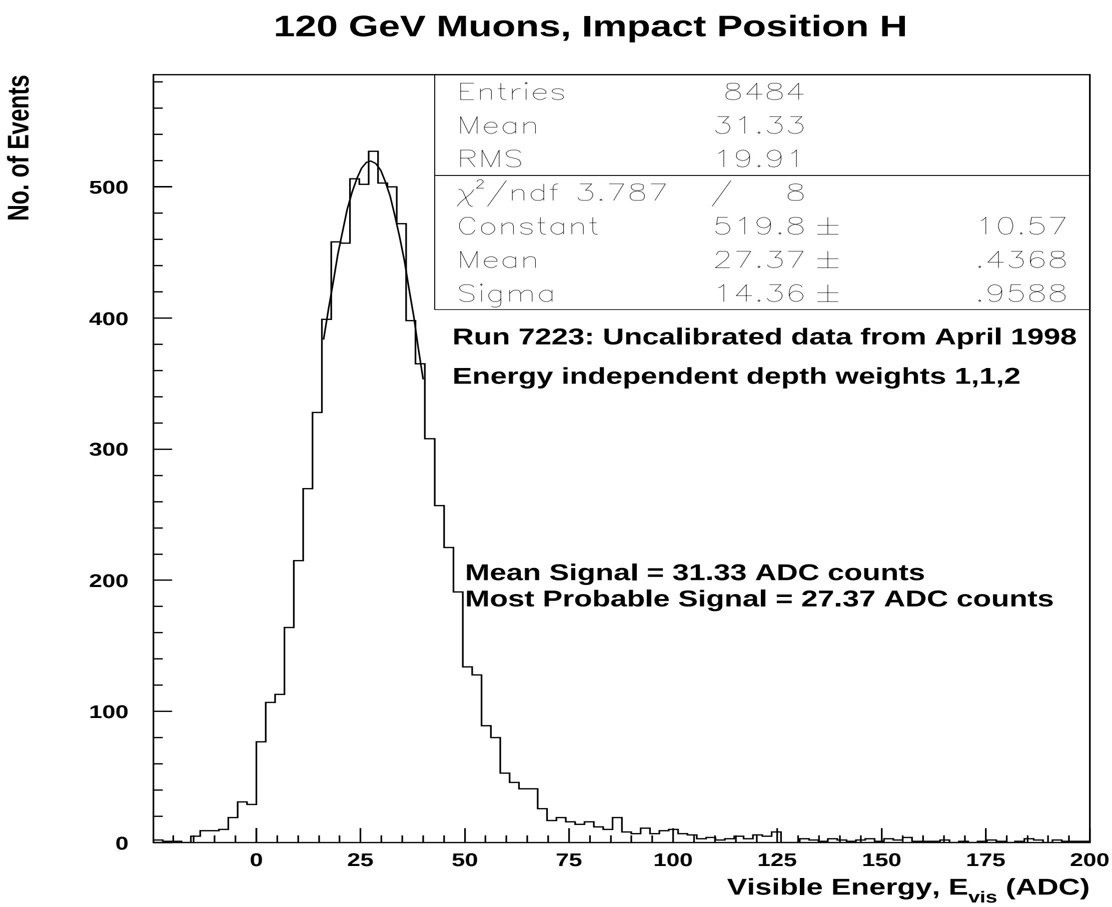
Figure 19: Monte Carlo data for impact position D, 144 cell cluster, depth weights (1,1,2).

e/μ - Preliminary

$\frac{e}{\mu}$

Constant sampling fraction
$\Rightarrow$ energy independent depth weights (1,1,2)

consistent with using front wheel of HEC only, depth weights (1,1,0)



Use most probable energy $\rightarrow$ $E_{vis}^{\mu,\ 120GeV} = 27.37\ ADC$.

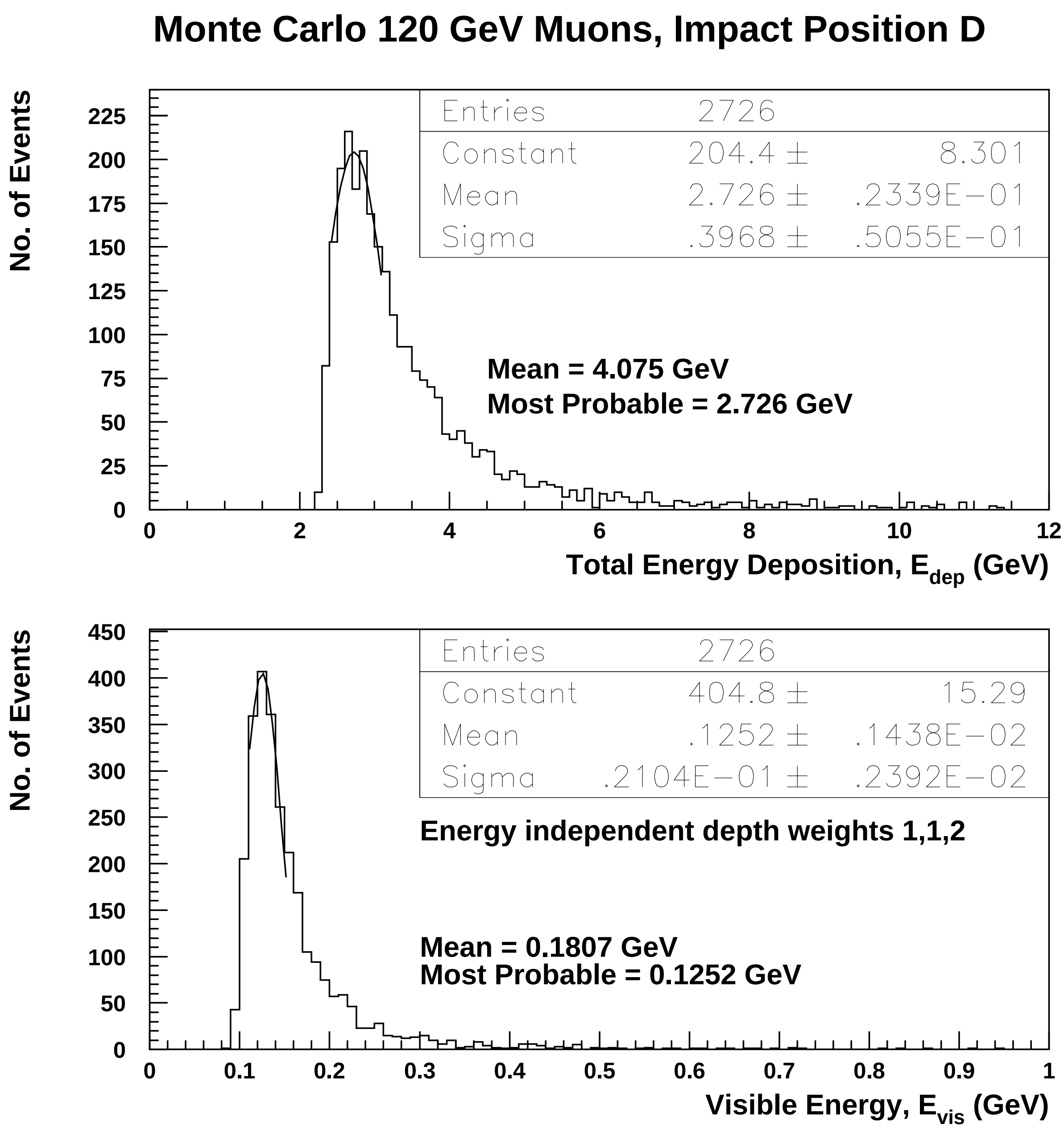


Figure 20: Thanks to A. Kiryunin for providing the ntuples from the MC simulation of 120GeV muons on impact position D.

e/μ - Preliminary

For $(24 \times 2.5 + 16 \times 5)$ cm Cu + (40×0.8) cm Ar,
$E^{mip}_{Th,dep} \; = \; 0.095 \; GeV$.   PDG mean!
For (56×0.8) cm Ar, $E^{mip}_{Th,vis} \; = \; 1.800 \; GeV$.   PDG mean!

$$\frac{e}{\mu_{120\mathrm{GeV}}} \;=\; \frac{1}{\alpha_{em}} \times \frac{E^{\mu,120GeV}_{MC,dep}}{E^{\mu,120GeV}_{vis}} \;=\; 0.96 \tag{3}$$

$$\frac{e}{\mu_{120\mathrm{GeV}}}\Big|_{\mathrm{MC}} \;=\; \frac{1}{\alpha^{MC}_{em}} \times \frac{E^{\mu,120GeV}_{MC,dep}}{E^{\mu,120GeV}_{MC,vis}} \;=\; 0.94 \tag{4}$$

$$\frac{e}{mip} \;=\; \frac{1}{\alpha_{em}} \times \frac{E^{mip}_{Th,dep}}{E^{\mu,120GeV}_{vis} \times \frac{E^{mip}_{Th,vis}}{E^{\mu,120GeV}_{MC,vis}}} \;=\; 0.83 \tag{5}$$

$E^{\mu,120GeV}_{vis}$ is corrected by normalizing using MC result, refer to CERN-PPE/96-173, "Response of the ATLAS Tile Calorimeter Prototype to Muons", p. 10.

$$\frac{e}{mip}\Big|_{\mathrm{Th+MC}} \;=\; \frac{1}{\alpha^{MC}_{em}} \times \frac{E^{mip}_{Th,dep}}{E^{mip}_{Th,vis}} \;=\; 0.82 \tag{6}$$

Calculations using the first wheel of HEC only (DW=1,1,0) give similar results.
Note: $\alpha_{em} \; = \; 0.1043 \; GeV/ADC$ $\alpha^{MC}_{em} \; = \; 23.132$.

Conclusions

- draft note on April analysis available for comments (http://wwwhep.phys.uvic.ca/~uvatlas/testbeam/)
- April electron response within 1%, final resolution for 3 cell cluster, digital filtering (combined fit on 4 impact positions):

$$\frac{\sigma}{E} = \frac{22.1 \pm 0.8\%}{\sqrt{E_0}} \oplus 0.4 \pm 0.5\% \oplus \frac{0.55 \pm 0.07}{E_0}$$

- April pion results for 19 cell cluster, digital filtering (combined fit on 4 impact positions) :

$$\frac{\sigma}{E} = \frac{82 \pm 2\%}{\sqrt{E_0}} \oplus 5.2 \pm 0.2\%$$

- PRELIMINARY August pion analysis shows siginificant worsening of resolution in module 2 due to HV problems. Parameterization of resolution at position I yields:

$$\frac{\sigma}{E} = \frac{86 \pm 1\%}{\sqrt{E_0}} \oplus 5.7 \pm 0.2\%$$

- Monte Carlo prediction from July meeting, including leakage is $\frac{\sigma}{E} = \frac{65\%}{\sqrt{E_0}} \oplus 5\%$

  This is not in agreement with our results.

Conclusions

- Evaluation of intrinsic e/h yields

  $$\langle \frac{e}{h} \rangle = 1.592 \begin{array}{l} \pm 0.004\ stat. \\ \pm 0.03\ syst. \end{array}$$

  Discrepancy between data and MC from HEC community.
  Agrees well with MC from TILECAL community.

- Evaluation of e/μ yields

  $$\frac{e}{\mu_{120\mathrm{GeV}}} = 0.96$$

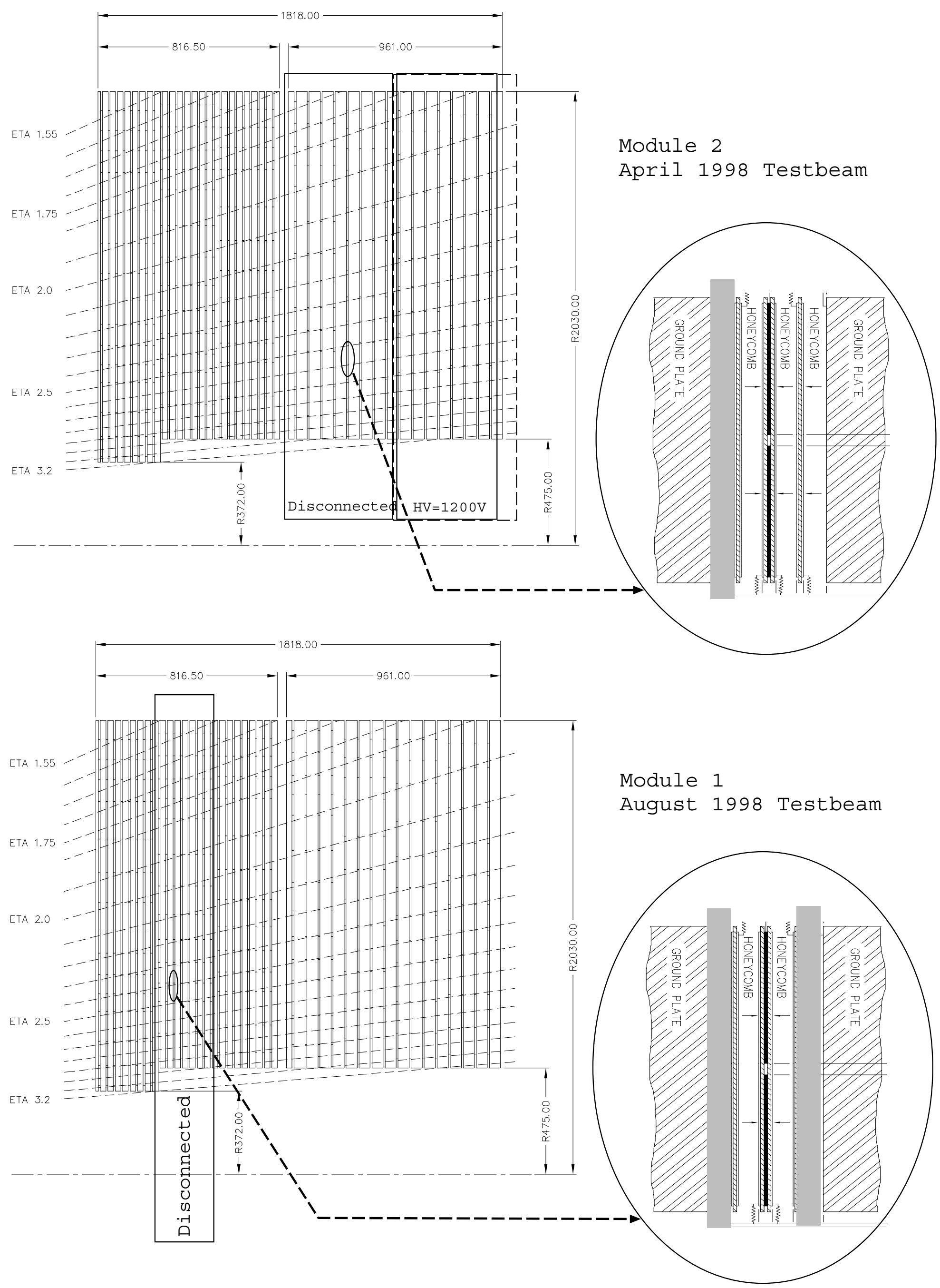
  $$\frac{e}{\mu_{120\mathrm{GeV}}}\Big|_{\mathrm{MC}} = 0.94$$

  $$\frac{e}{mip} = 0.83$$

  $$\frac{e}{mip}\Big|_{\mathrm{Th+MC}} = 0.82$$

- Special thanks to A. Kiryunin, A. Minaenko, P. Schacht and H. Stenzel for many useful discussions.

Figures


1818.00
816.50
961.00
ETA 1.55
ETA 1.75
ETA 2.0
ETA 2.5
ETA 3.2
R2030.00
R475.00
R372.00
Disconnected
HV=1200V
Module 2
April 1998 Testbeam
GROUND PLATE
HONEYCOMB
HONEYCOMB
HONEYCOMB
GROUND PLATE
1818.00
816.50
961.00
ETA 1.55
ETA 1.75
ETA 2.0
ETA 2.5
ETA 3.2
R2030.00
R475.00
R372.00
Disconnected
Module 1
August 1998 Testbeam
GROUND PLATE
HONEYCOMB
HONEYCOMB
GROUND PLATE

Figures

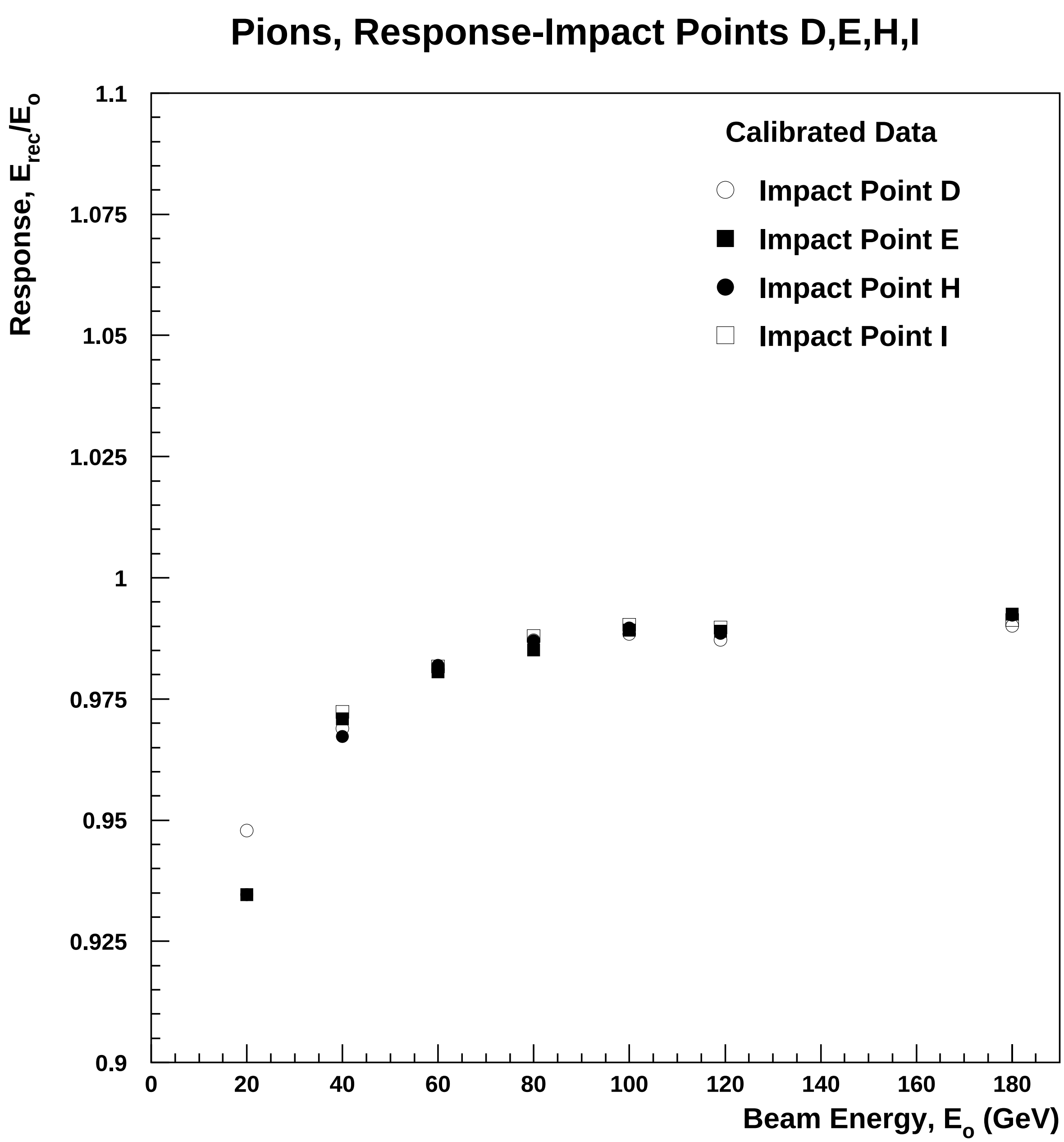


Figure 21: Response to pions at 4 impact positions using energy dependent depth weights, April data.

Figures

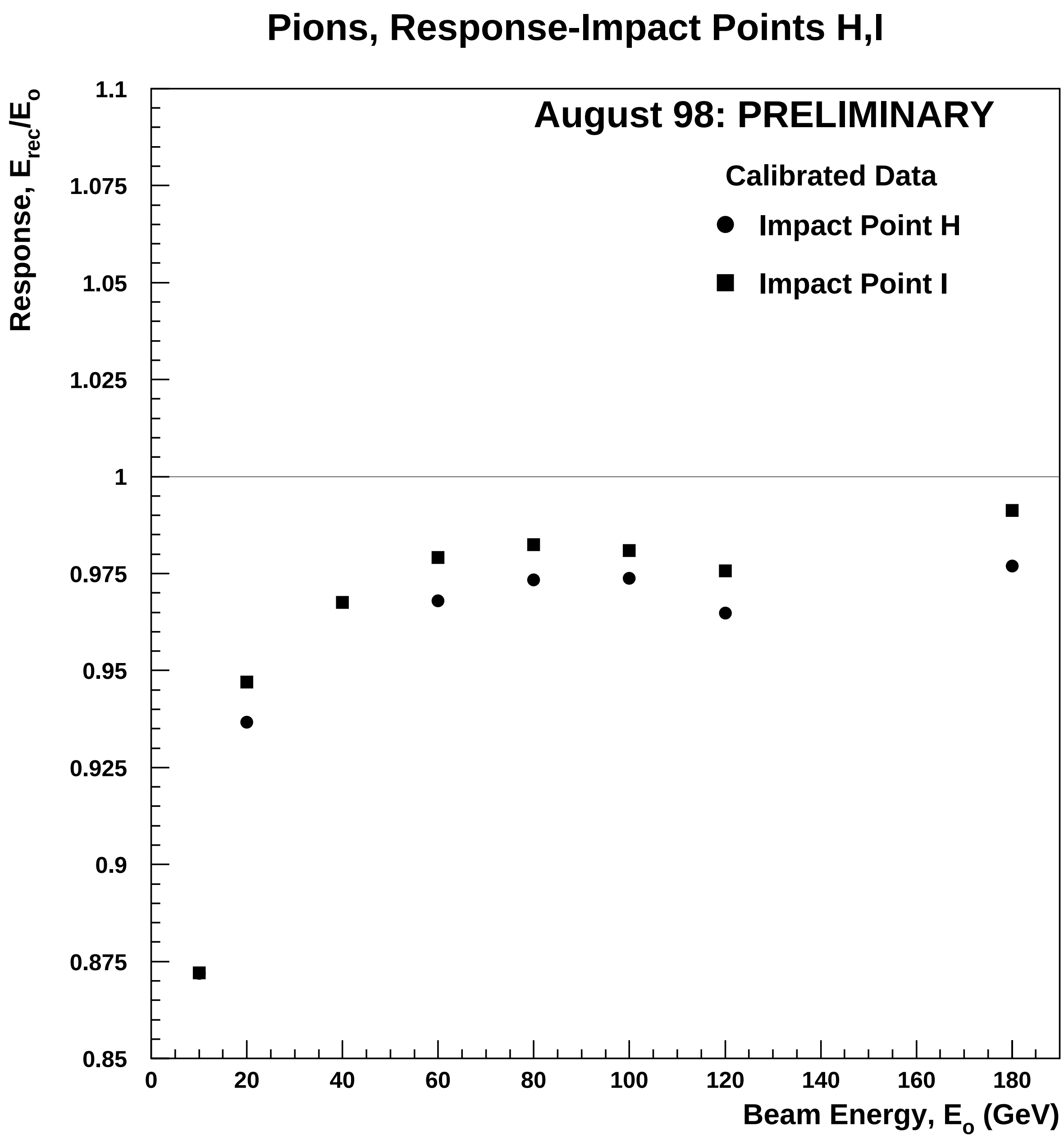


Figure 22: Response to pions at 4 impact positions using energy dependent depth weights - August data.

Figures

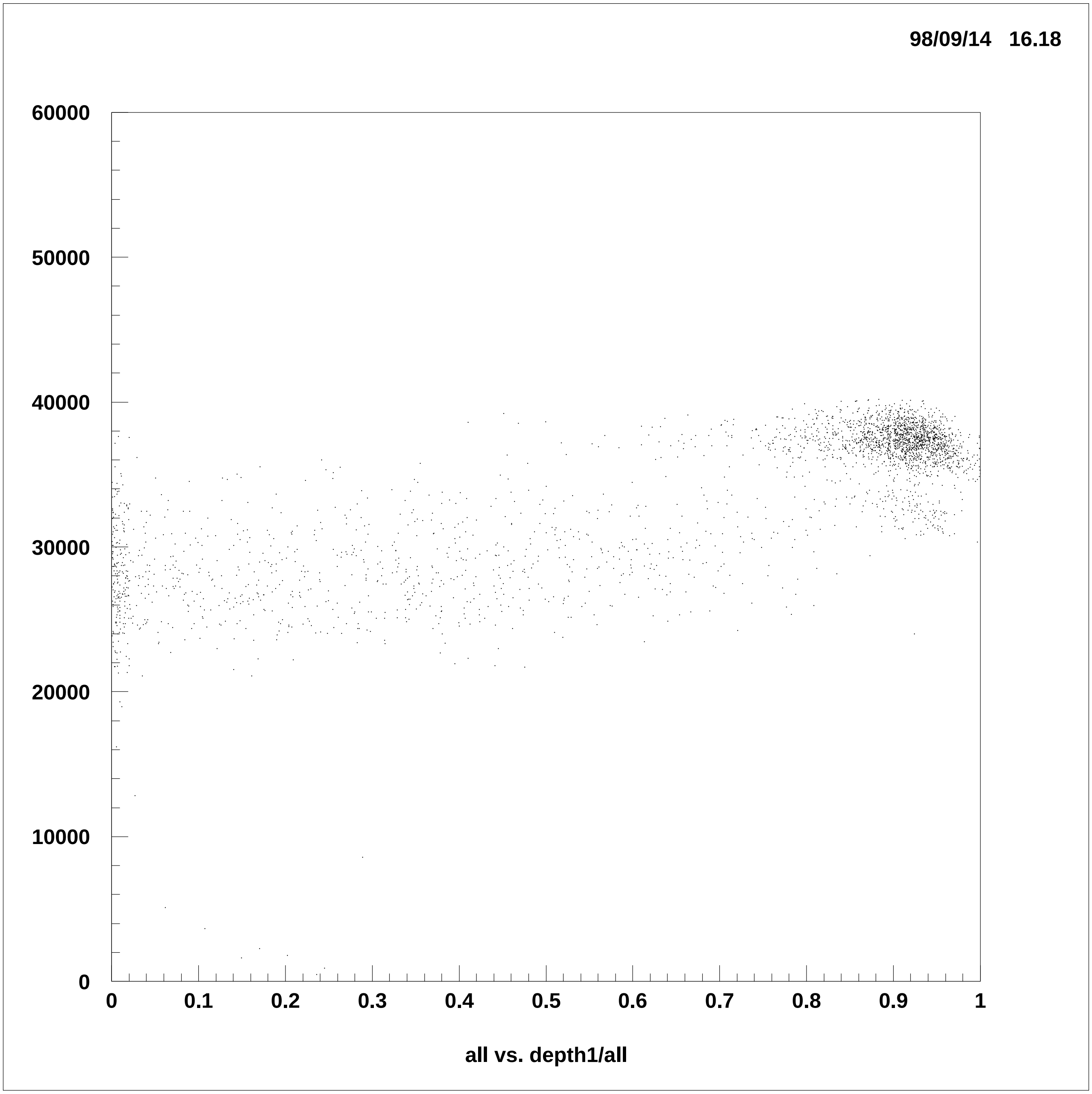


Figure 23: $\frac{energy\ in\ depth1}{total\ energy}$ vs. total energy for 120 GeV electron run with energy independent depth weights 112, April testbeam period.

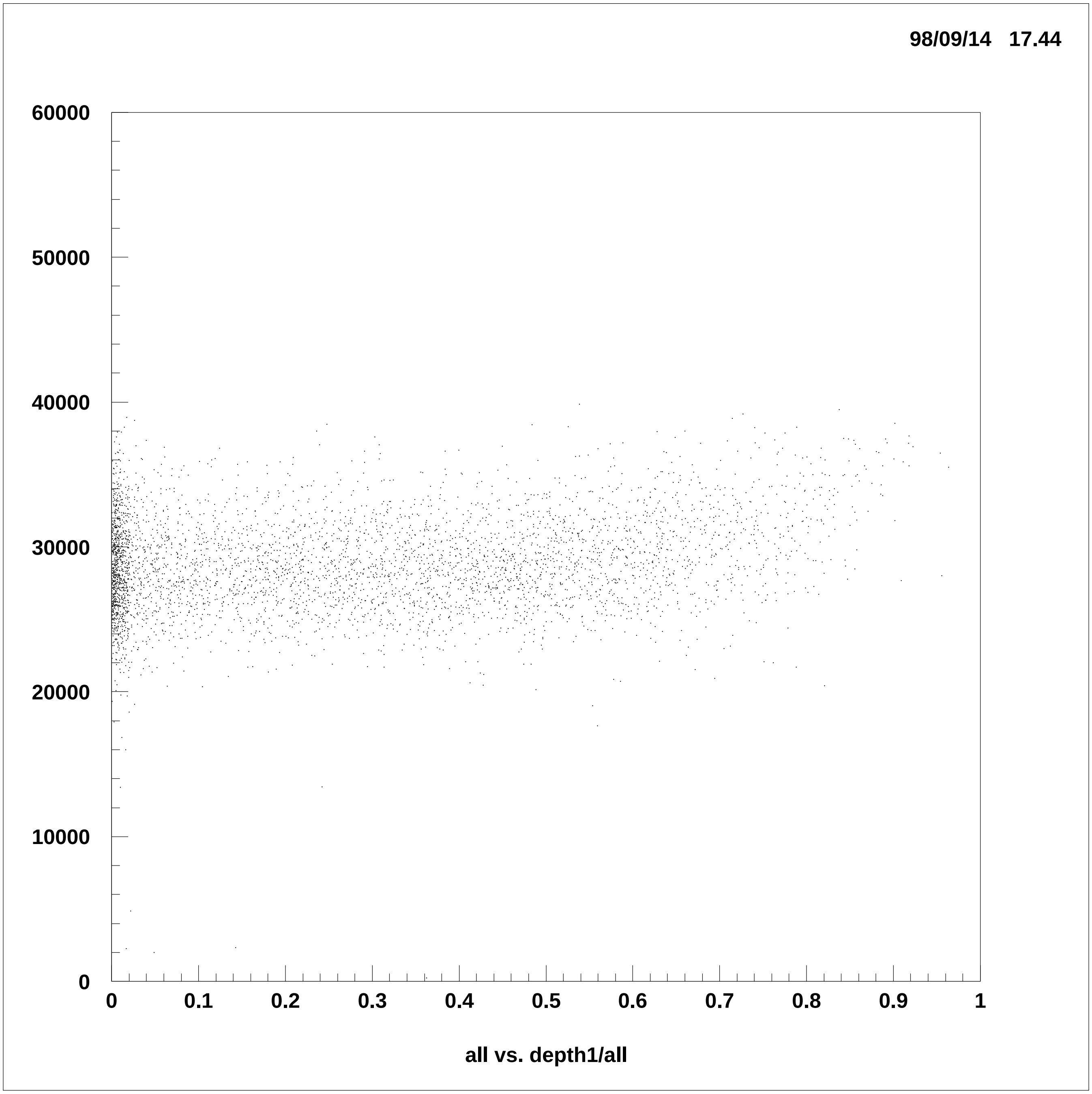


Figure 24: $\frac{energy\ in\ depth1}{total\ energy}$ vs. total energy for 120 GeV pion run with energy independent depth weights 112, April testbeam period.

Figures

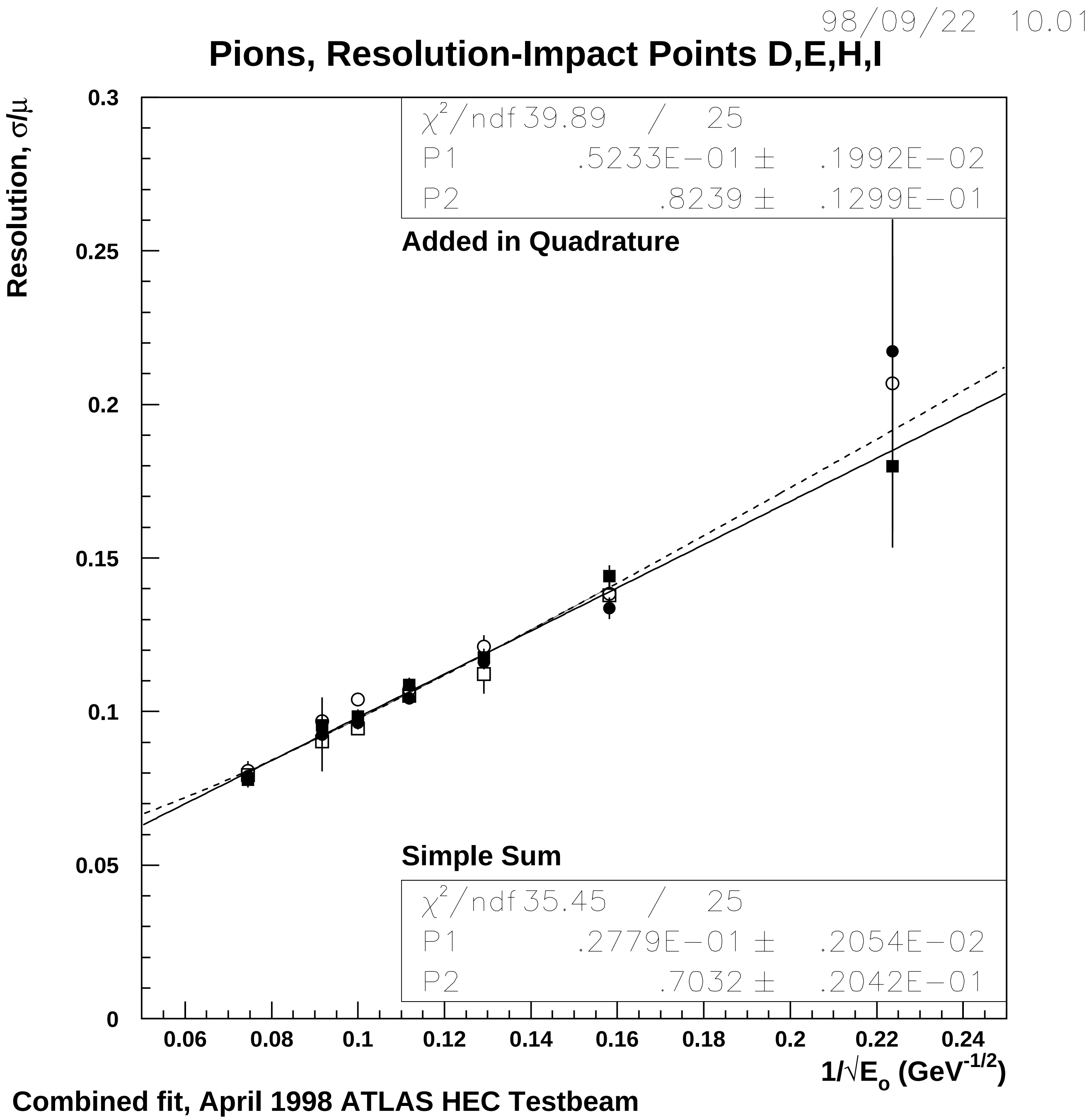


Figure 25: April 1998 Testbeam combined fit: comparison of $\frac{\sigma}{E} = \frac{A}{\sqrt{E_o}} + B$ parametrization (solid line, bottom fit results) and $\frac{\sigma}{E} = \frac{A}{\sqrt{E_o}} \oplus B$ parametrization (dashed line, top fit results).

Figures

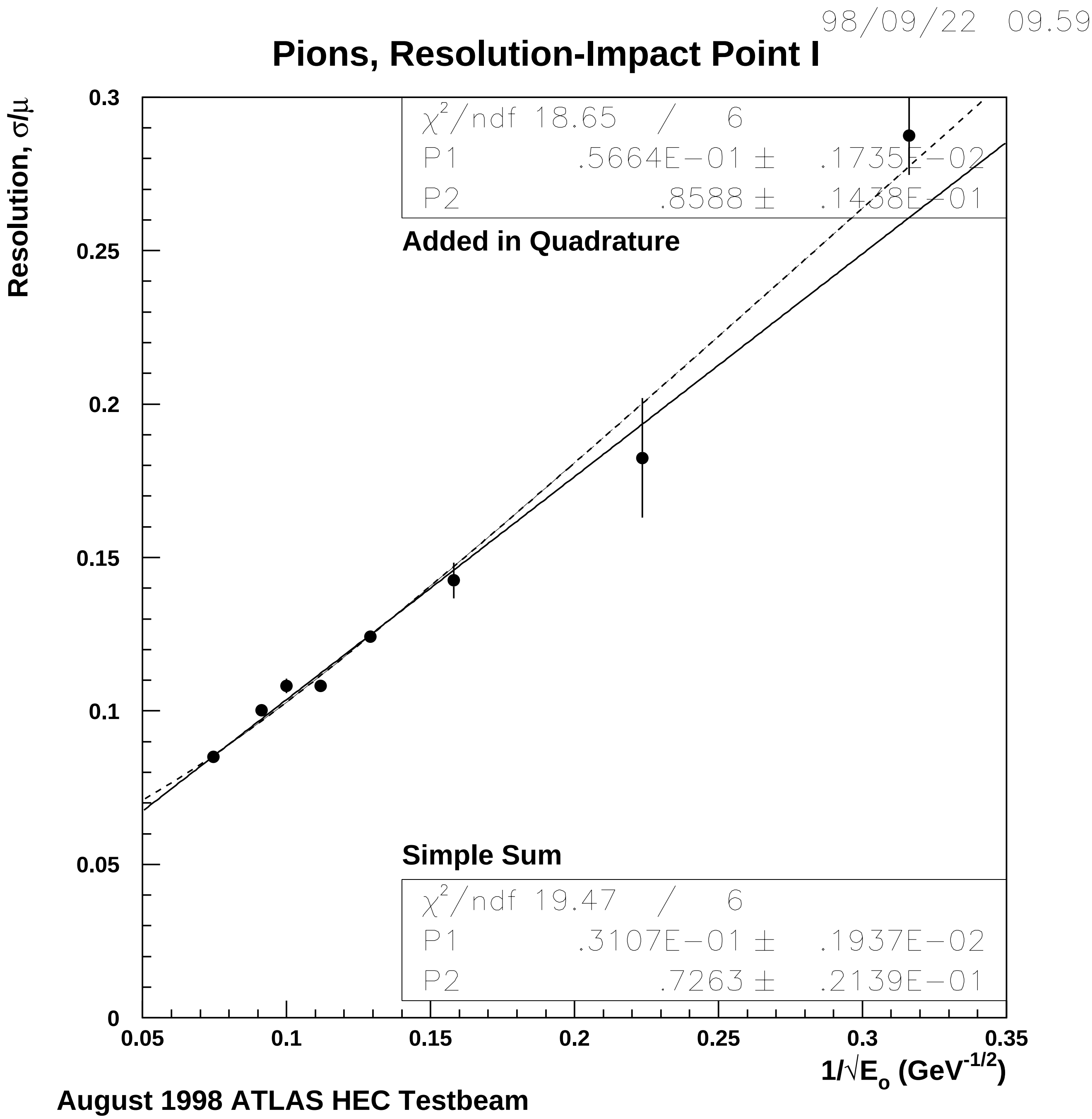


Figure 26: August 1998 Testbeam, impact position I: comparison of $\frac{\sigma}{E} = \frac{A}{\sqrt{E_o}} + B$ parametrization (solid line, bottom fit results) and $\frac{\sigma}{E} = \frac{A}{\sqrt{E_o}} \oplus B$ parametrization (dashed line, top fit results).

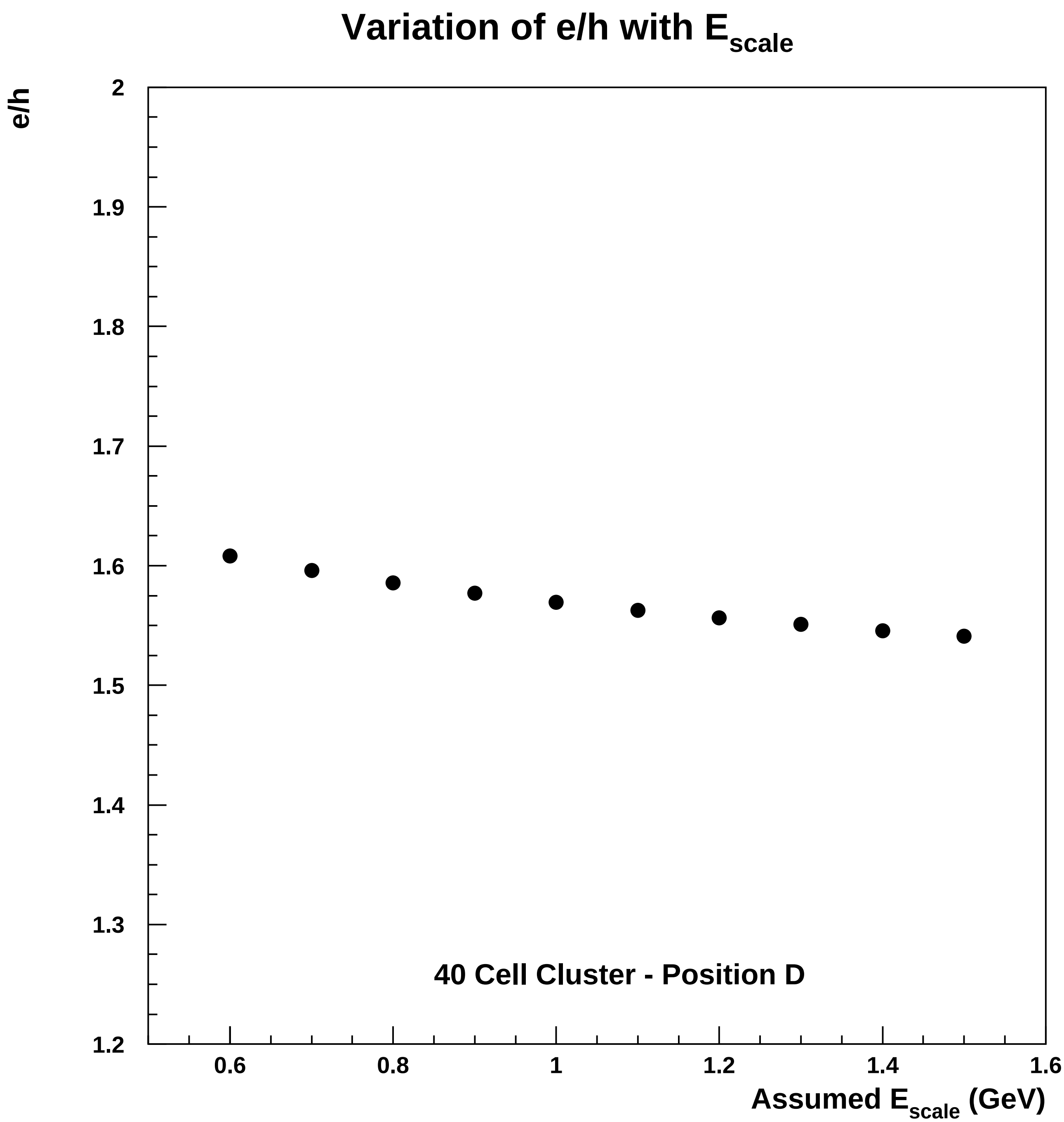


Figure 27: Varitation of e/h with E_{scale} (Impact Position D, April 1998 Testbeam).

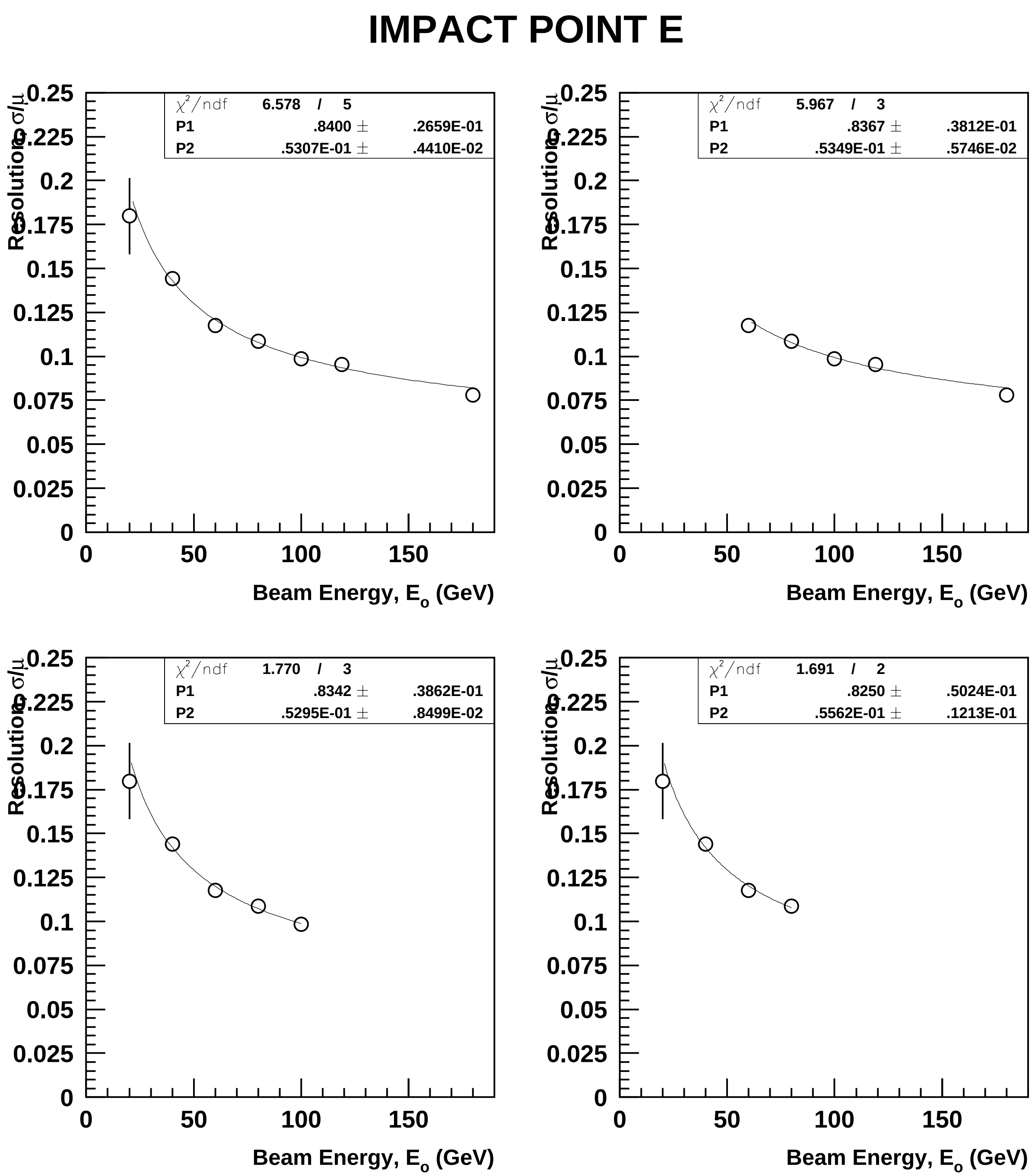


Figure 28: April 1998 Testbeam impact position E: fits to different regions of the resolution curve. Samping term and constant term results do not vary within reported error.