SLAC Beam Test 97: Performance of CsI Calorimeter

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- CsI test goals
- Energy reconstruction
  - Method
  - Performance
- Position reconstruction
  - Method
  - Performance
  - Angular resolution

Conclusion: CsI calorimeter meets GLAST requirements for energy and angular resolution

1. σ_E < 7% at 40 GeV

2. confinement radius ~ 1 deg at 40 GeV

CsI calorimeter test goals:

- **Demonstrate hodoscopic calorimetry.**

  8 layers (4x and 4y) of 3cm × 3cm × 19cm CsI(Tl) bars, recycled from Beamtest 96.

  32 active crystals, 8 dummies.

  1. Map crystal response (i.e. light collection efficiency) as fcn of position throughout array.
  2. Measure energy resolution as fcn of incident energy. Demonstrate shower profile fitting.
  3. Measure position resolution and resulting angular resolution.
  4. Test energy and position reconstruction for off-zenith beam.

- **Test elements of Baseline II Calorimeter.**

  1 bar of 2.5cm × 3cm × 32cm CsI(Tl)

  Same bar dimensions as Baseline II Calorimeter.

  2 bars of 2.5cm × 3cm × 24cm CsI(Tl)

  Two-PIN readout on each end (similar to Baseline II Calorimeter).

  3 bars of 1.5cm × 1.5cm × 19cm CsI(Tl)

  Finer segmentation gives improved shower imaging but additional electronics channels.

  1. Map light collection efficiency, measure position resolution, of Baseline II bar.
  2. Test light sharing between large and small PIN diodes.
  3. Map and measure position resolution of skinny bars.

Energy reconstruction algorithms.

- **Simplest: Sum over all crystals.**

  Look-up table corrects deposited energy and shower pathlength to typical incident energy.
  Derived from mean shower profiles.
  Resulting incident total energy will have low tail from shower fluctuations,
  particularly for calorimeter-only events, where shower starting point is uncertain.

- **More advanced: Shower-profile fitting.**

  Mean longitudinal profile is well-described by gamma distribution:

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

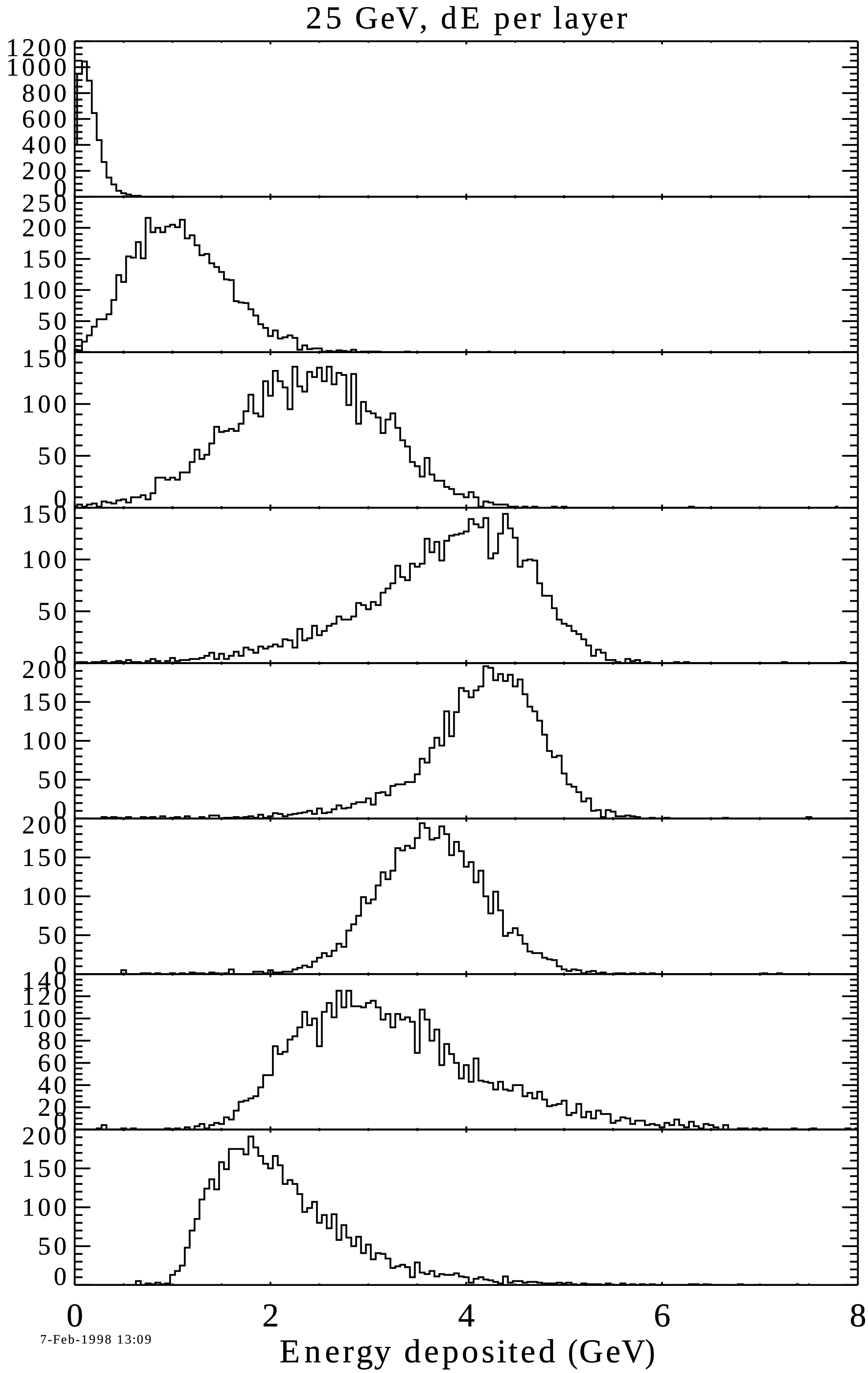
  where $t = x/X_0$, $b \approx 0.5$, and $a = 1 + bt_{max}$.

  Note b is a function of the target material, and depth of shower max t_{max} is fcn of E_0.

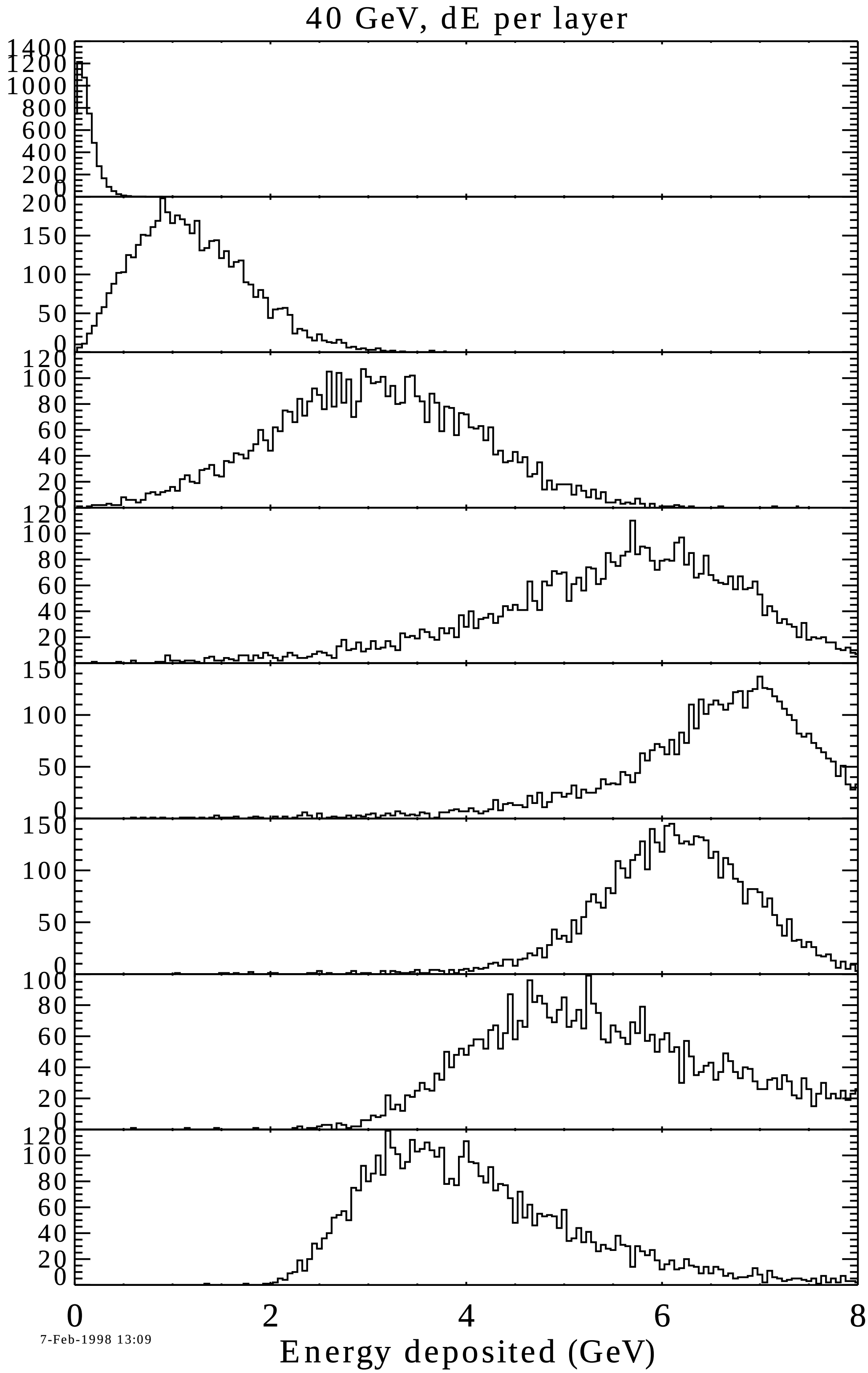
  If shower starts in tracker, fit profile model (one parameter, E_0) to observed shower profile.
  If calorimeter only, fit two-parameter model (shower-start and E_0) to observed profile.

  Profile fitting allows us to correct the low deposited E of late-starting showers,
  i.e. it removes some of the low-energy tail
  Shower fluctuations are *still* significant, shower leaks out the back of calorimeter.

Performance summary: at 40 GeV, $\sigma_E = 2.7$ GeV < 7%.



25 GeV, dE per layer
1200
1000
800
600
400
200
0
250
200
150
100
50
0
150
100
50
0
150
100
50
0
200
150
100
50
0
200
150
100
50
0
140
120
100
80
60
40
20
0
200
150
100
50
0
0
2
4
6
8
7-Feb-1998 13:09
Energy deposited (GeV)



40 GeV, dE per layer
1400
1200
1000
800
600
400
200
0
200
150
100
50
0
120
100
80
60
40
20
0
120
100
80
60
40
20
0
150
100
50
0
150
100
50
0
100
80
60
40
20
0
120
100
80
60
40
20
0
0
2
4
6
8
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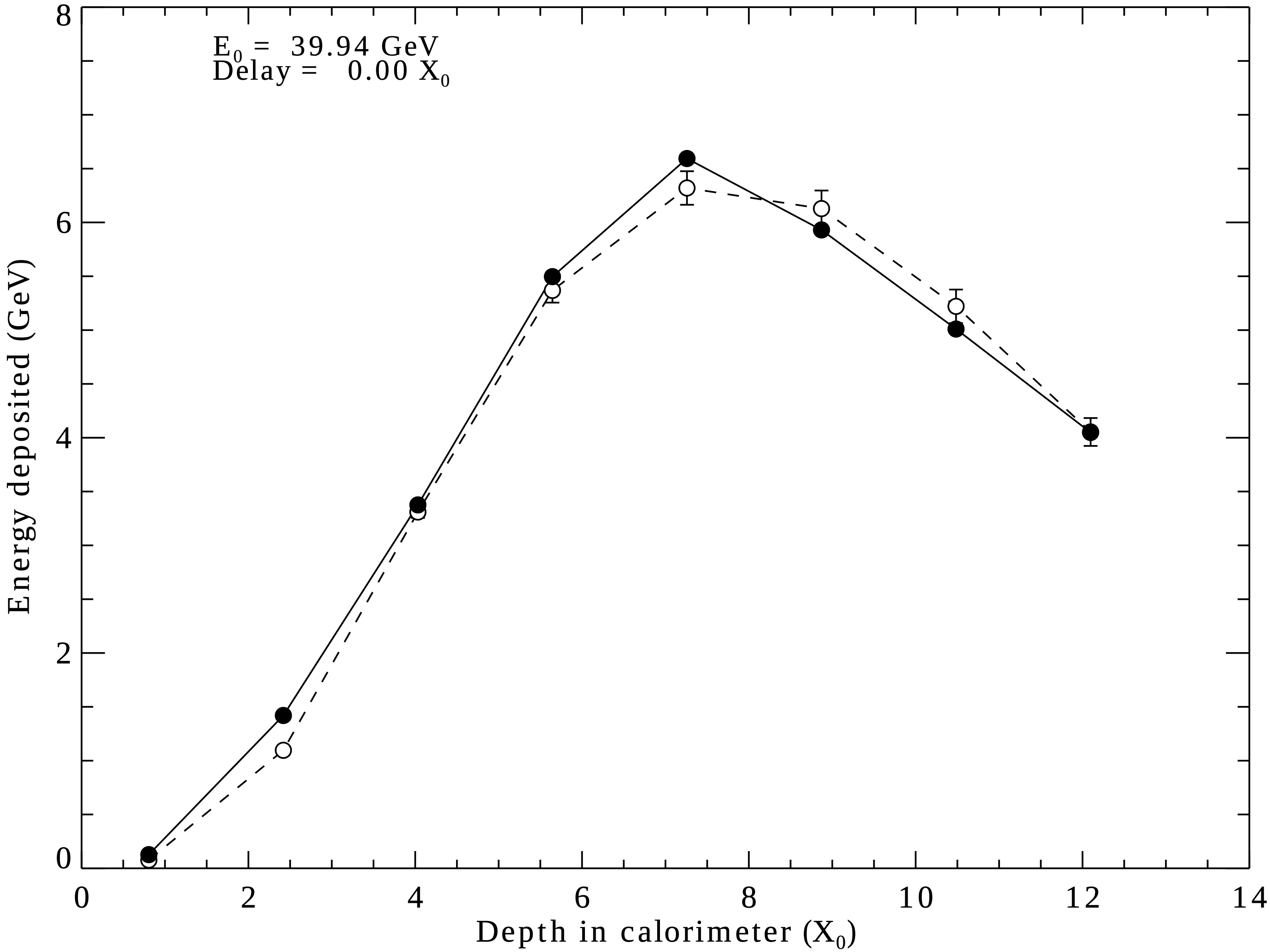
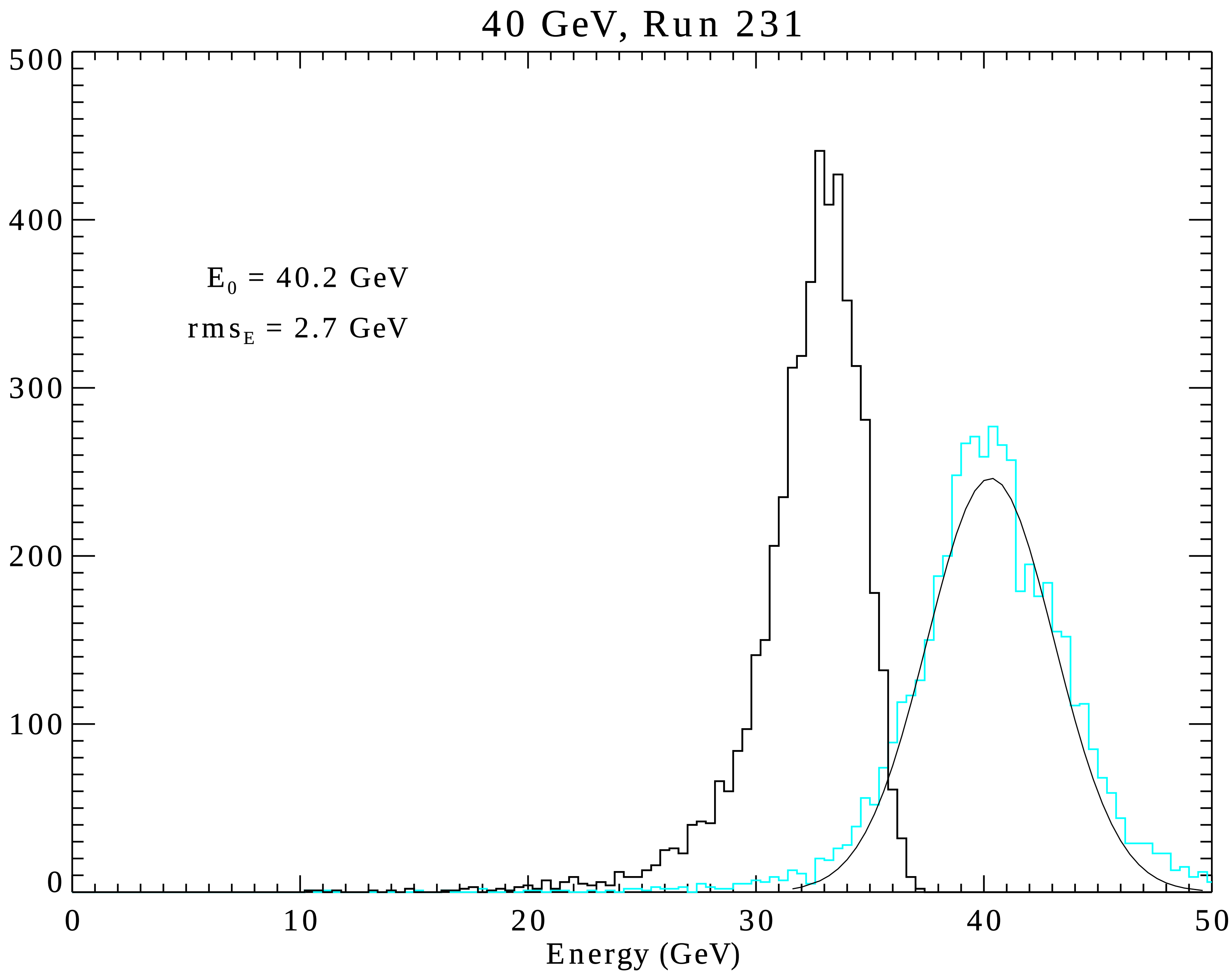
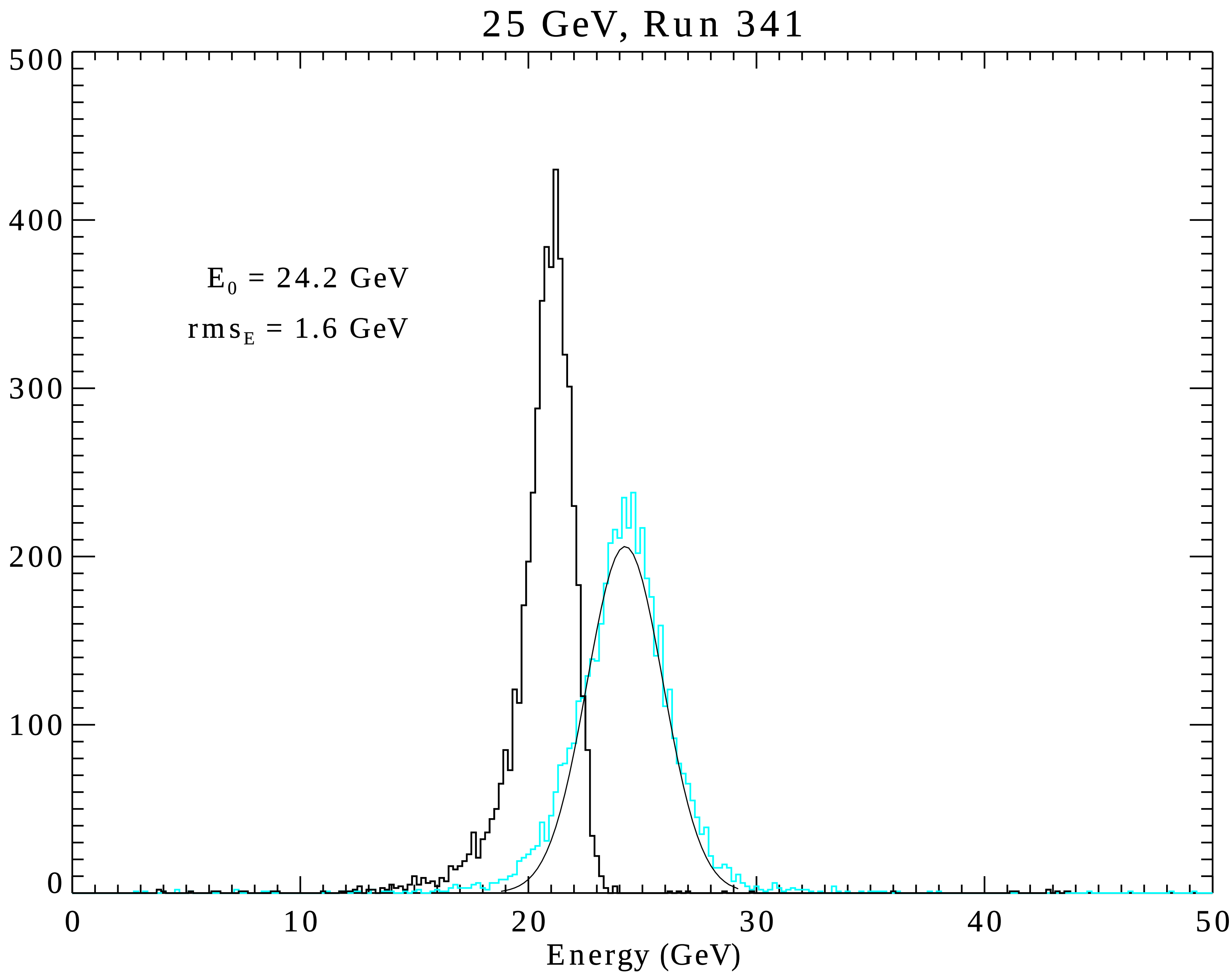
Energy deposited (GeV)



E0 = 39.94 GeV
Delay = 0.00 X0
Energy deposited (GeV)
Depth in calorimeter (X0)
0
2
4
6
8
10
12
14



40 GeV, Run 231
E_0 = 40.2 GeV
rms_E = 2.7 GeV
0
100
200
300
400
500
0
10
20
30
40
50
Energy (GeV)



25 GeV, Run 341
E_0 = 24.2 GeV
rms_E = 1.6 GeV
0
100
200
300
400
500
0
10
20
30
40
50
Energy (GeV)

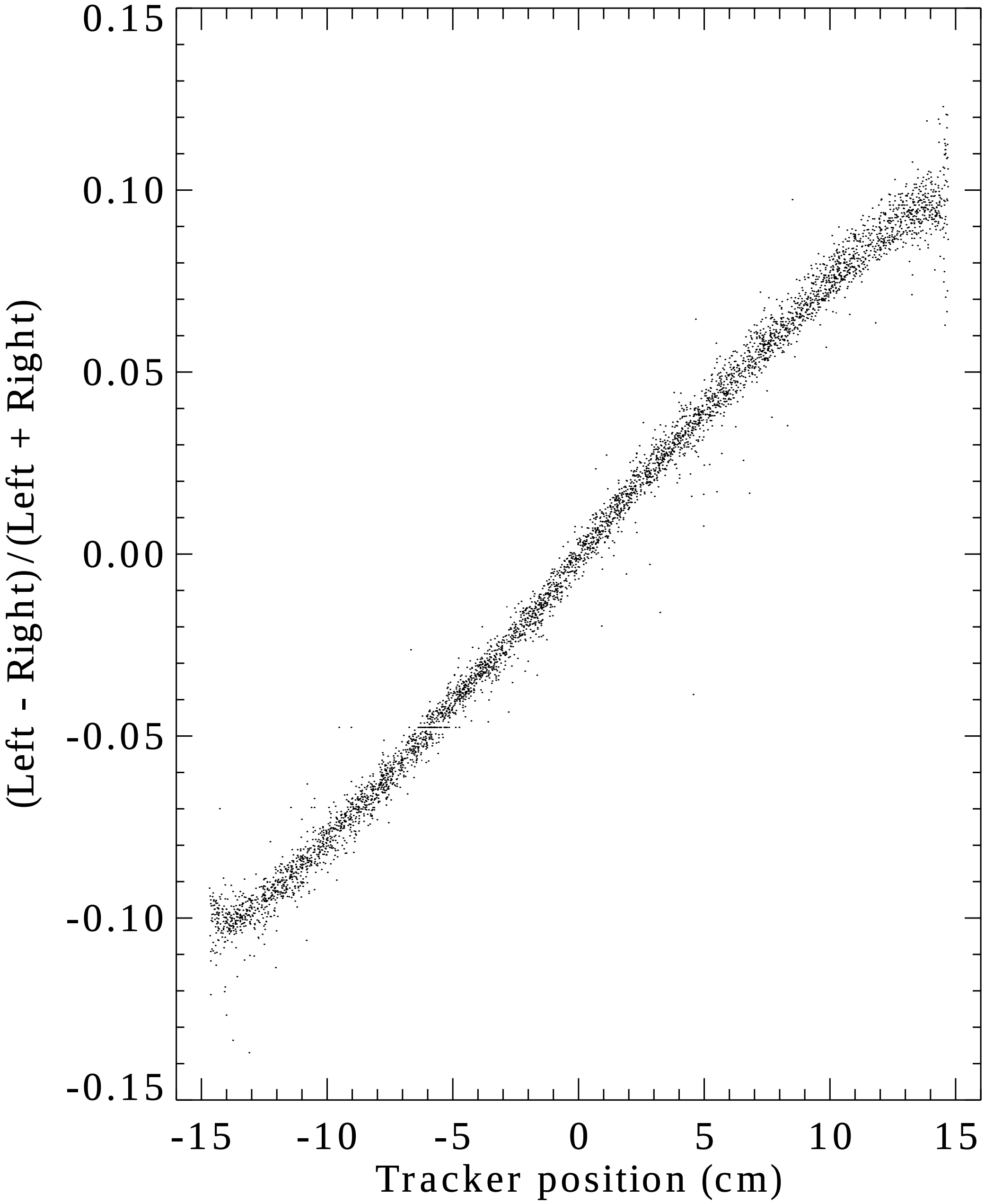
Position reconstruction.

- **Each crystal provides three spatial coordinates for the energy deposited in that crystal.**
  - Crystal ID gives two coordinates, z and one of x or y, depending on the layer.
    - Gives resolution $\sigma_z = 2.5/\sqrt{12} = 0.7$cm and systematic bias to center of crystal.
  - Difference in signal between ends of crystal give third coordinate.
    - *"Longitudinal" position*.
    - Gives much better resolution, **σ_x = 0.04 - 0.3 cm**, and no bias.
    - Resolution is fcn of energy deposited, spread of shower, and shower multiplicity.

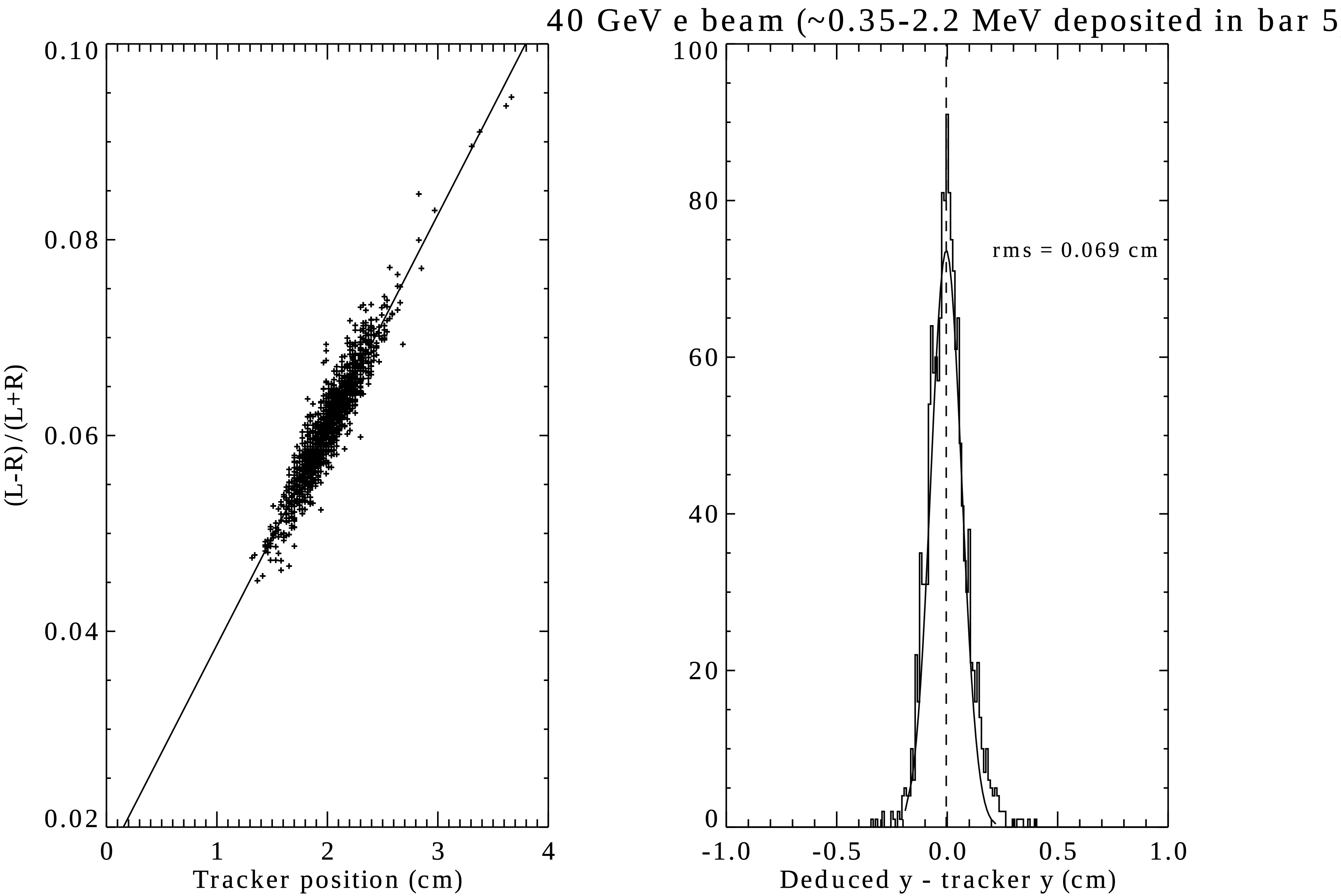
- **Longitudinal position determination.**
  - If light in one diode falls off linearly with the distance of the shower crossing from the face of the diode, then the position is proportional to the difference in diode signals from either end.
  - Scaling the difference by the total signal removes the energy dependence from the position.
  - Thus the "light asymmetry" measure:

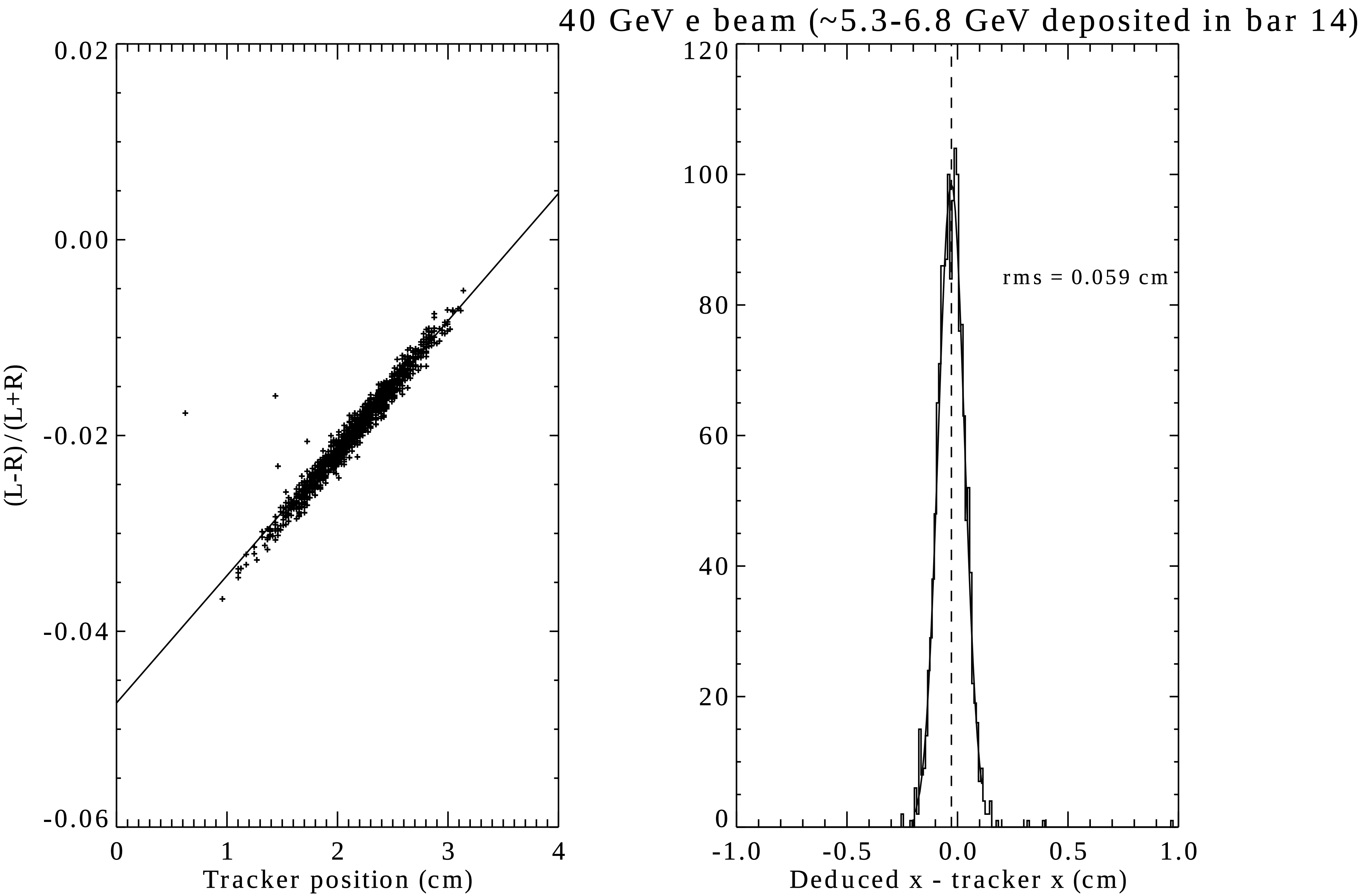
$$x = \frac{(\text{Left} - \text{Right})}{(\text{Left} + \text{Right})}$$

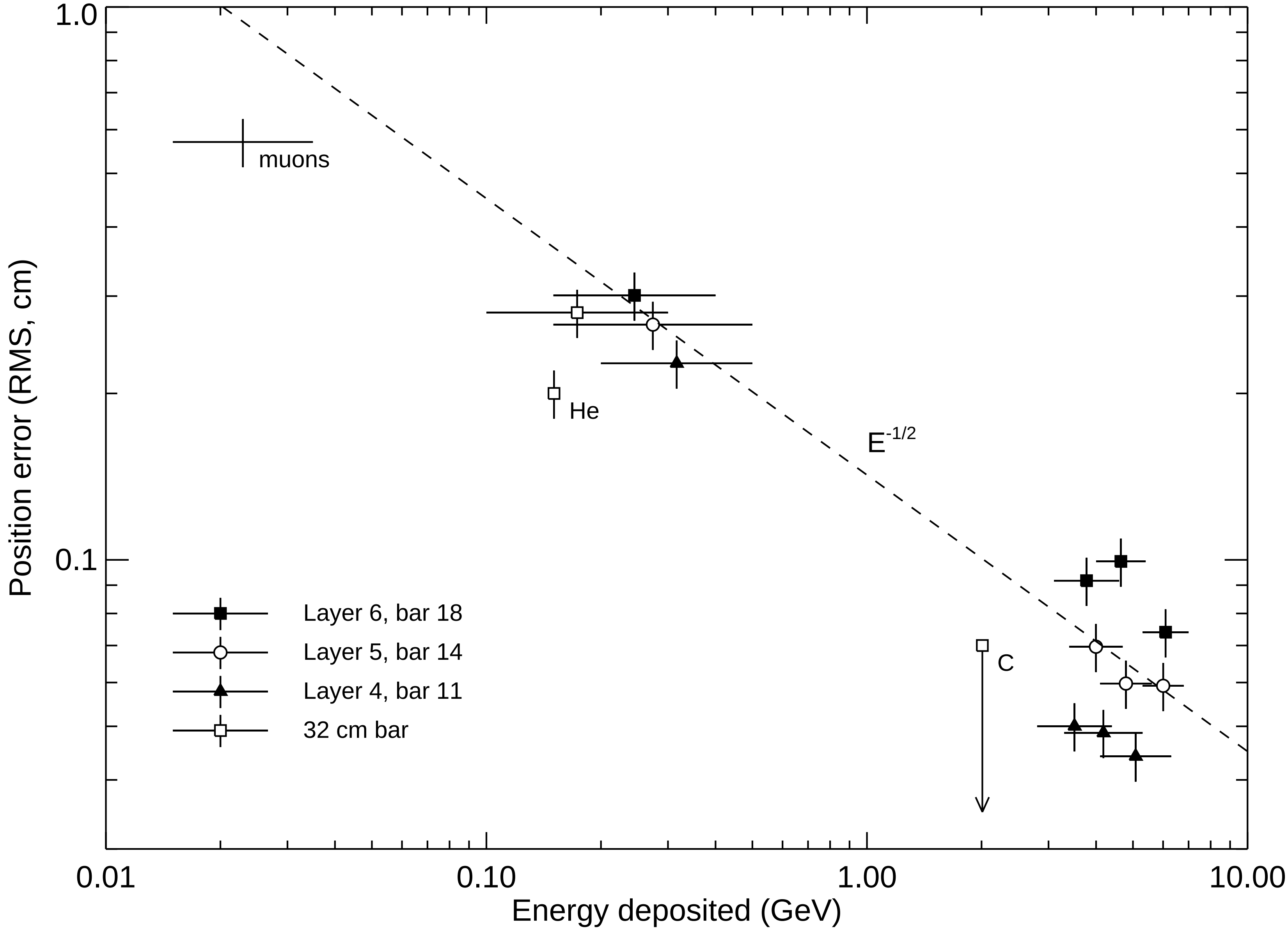
  - Light asymmetry must be mapped.
  - All results here use this simple linear model over portion of bar length.
    - Calibrated against SSD truth.



0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
(Left - Right)/(Left + Right)
-15
-10
-5
0
5
10
15
Tracker position (cm)


40 GeV e beam (~0.35-2.2 MeV deposited in bar 5)
(L-R)/(L+R)
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
Tracker position (cm)
100
80
60
40
20
0
rms = 0.069 cm
-1.0
-0.5
0.0
0.5
1.0
Deduced y - tracker y (cm)


40 GeV e beam (~5.3-6.8 GeV deposited in bar 14)
(L-R)/(L+R)
0.02
0.00
-0.02
-0.04
-0.06
0
1
2
3
4
Tracker position (cm)
120
100
80
60
40
20
0
rms = 0.059 cm
-1.0
-0.5
0.0
0.5
1.0
Deduced x - tracker x (cm)



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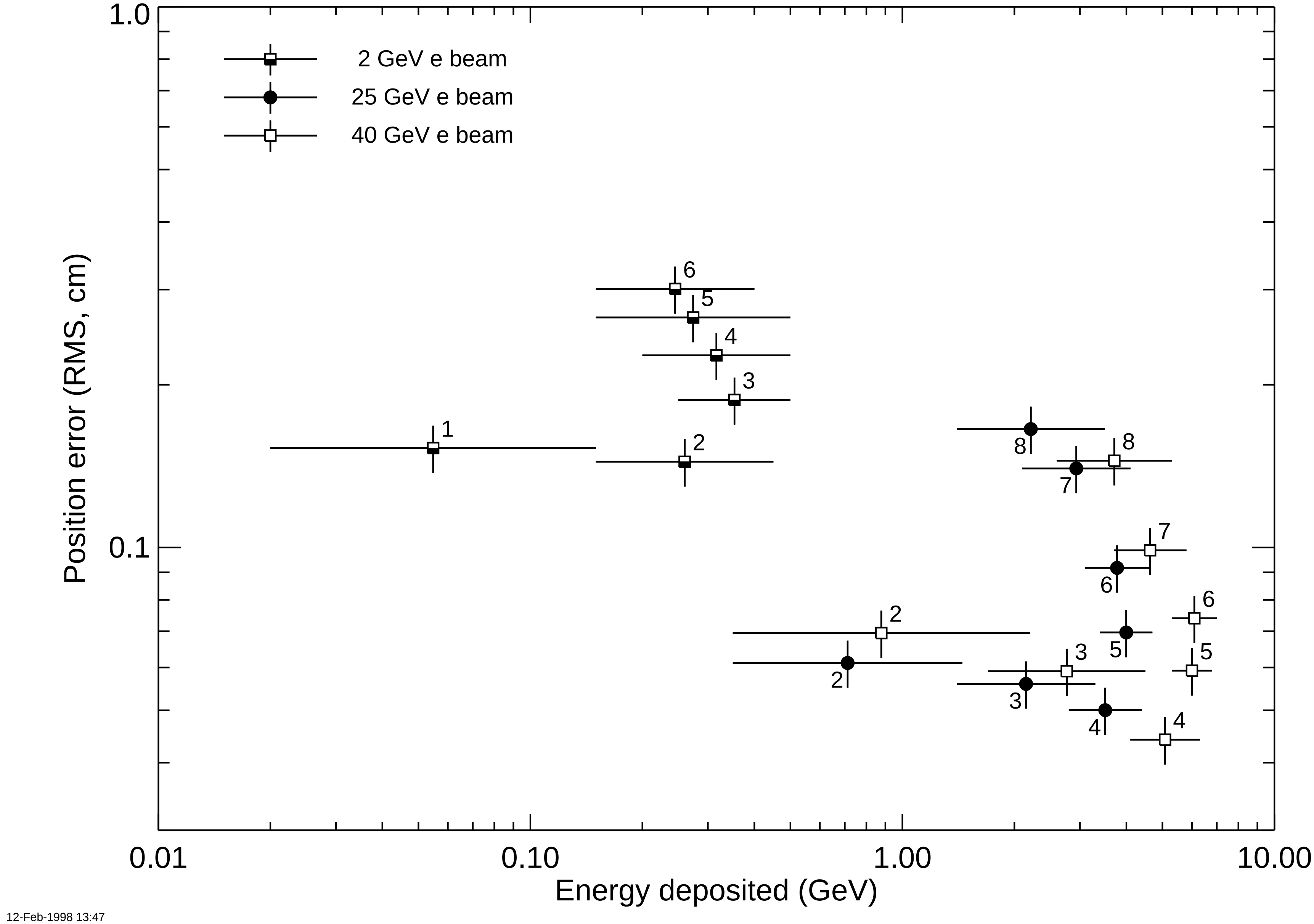


1.0
0.1
0.01
0.10
1.00
10.00
Position error (RMS, cm)
Energy deposited (GeV)
2 GeV e beam
25 GeV e beam
40 GeV e beam
12-Feb-1998 13:47

Calorimeter-only angle reconstruction algorithms.

- **Minimization of squared perpendicular distance to track axis.**
  Uses longitudinal and crystal ID positions.
  Requires numerical search in 4-D parameter space.
  Two of four parameters can be eliminated using center of mass of shower.

- **Minimization of squared distance to track crossing-point in xy plane of each layer.**
  Can use only longitudinal data if desired.
  Longitudinal positions are far more accurate than crystal-ID and lack systematic biases.
  Eliminating crystal-ID positions eliminates corn-row effect .
  Analytic solution in xz and yz planes. Very fast.
  Progressive degradation as zenith angle increases to and beyond 45 deg.

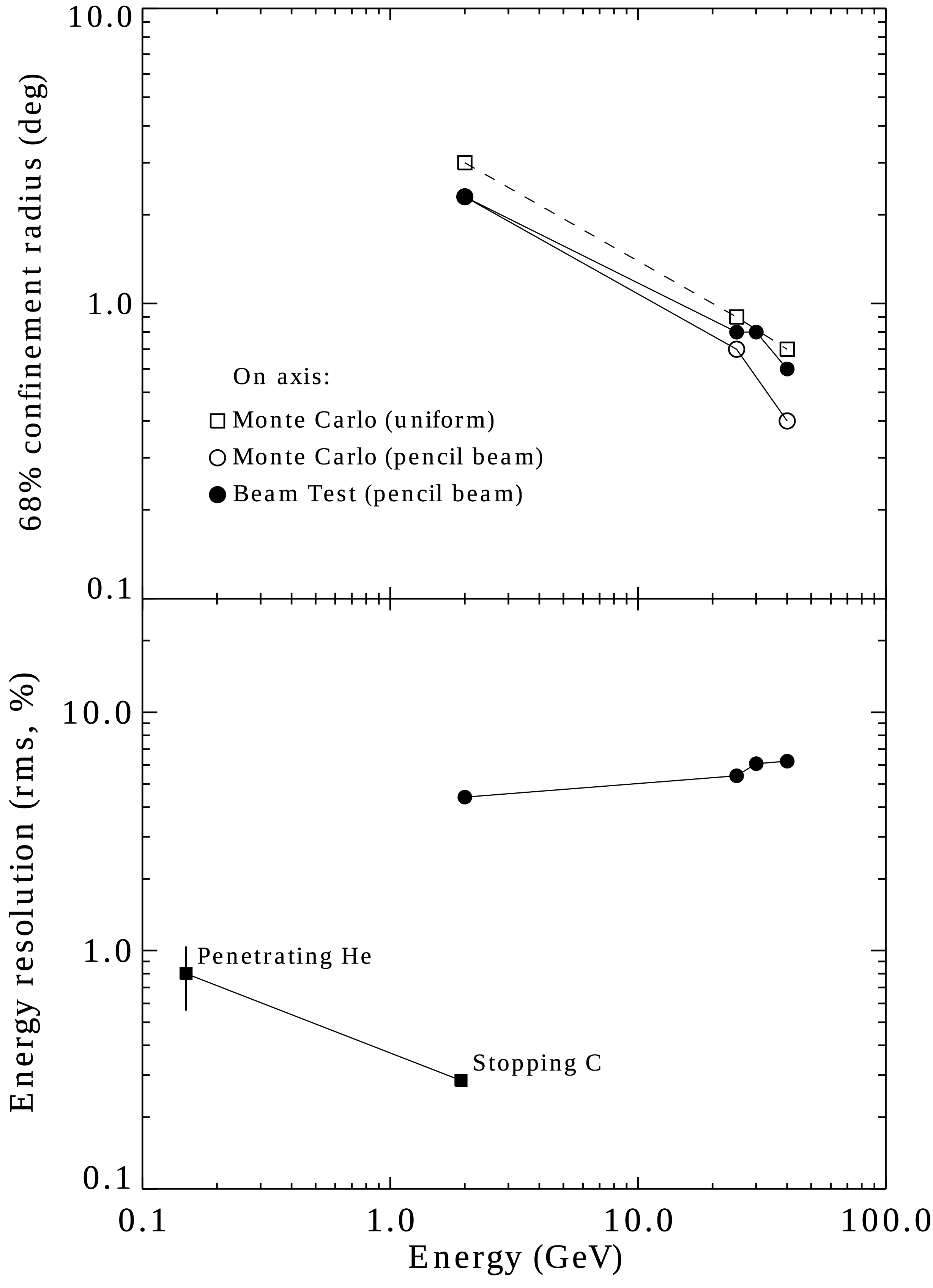
- **Connect the dots, top and bottom.**
  Draw a line between position with maximum dE in “top” and “bottom” layers.
  Works quite well for some cases, but is susceptible to corn-row effects.

What angular resolution should we expect?

68% radius ~ $\sqrt{2}\,\sigma_x / \Delta z$ (Δz ~ 18cm)

for 2 GeV beam: $\sigma_x < 4$mm, so 68% radius ~ 2 deg.

for 40 GeV beam: $\sigma_x < 2$mm, so 68% radius ~ 1 deg.



68% confinement radius (deg)
10.0
1.0
0.1
On axis:
Monte Carlo (uniform)
Monte Carlo (pencil beam)
Beam Test (pencil beam)
Energy resolution (rms, %)
10.0
1.0
0.1
Penetrating He
Stopping C
0.1
1.0
10.0
100.0
Energy (GeV)

NSCL Beam Test 98: Performance of CsI Calorimeter

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- **National Superconducting Cyclotron Laboratory, Michigan State, 27-29 Jan 1998**
- **Proton, heavy nuclei beams**

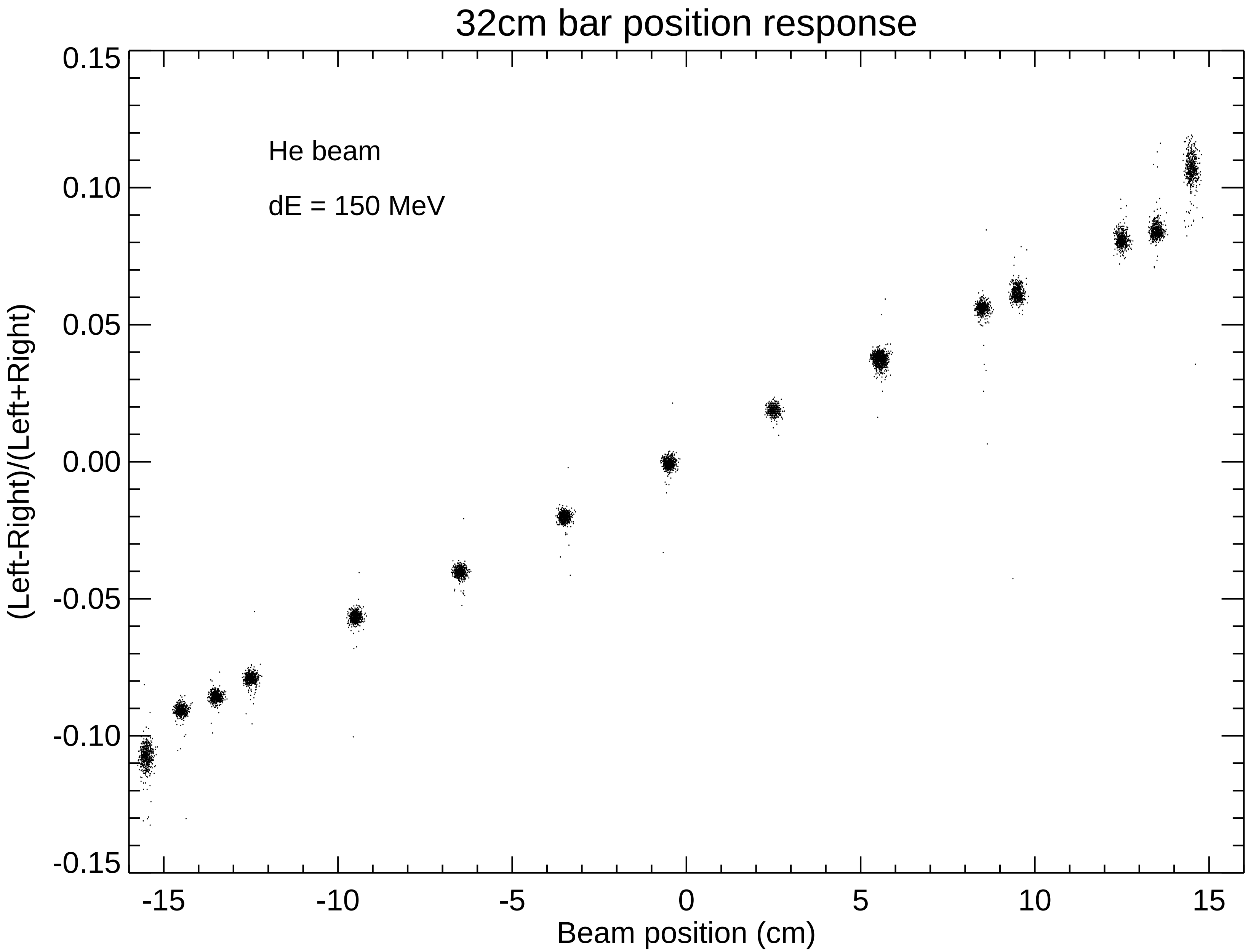
  H, H_2^+, He, and C

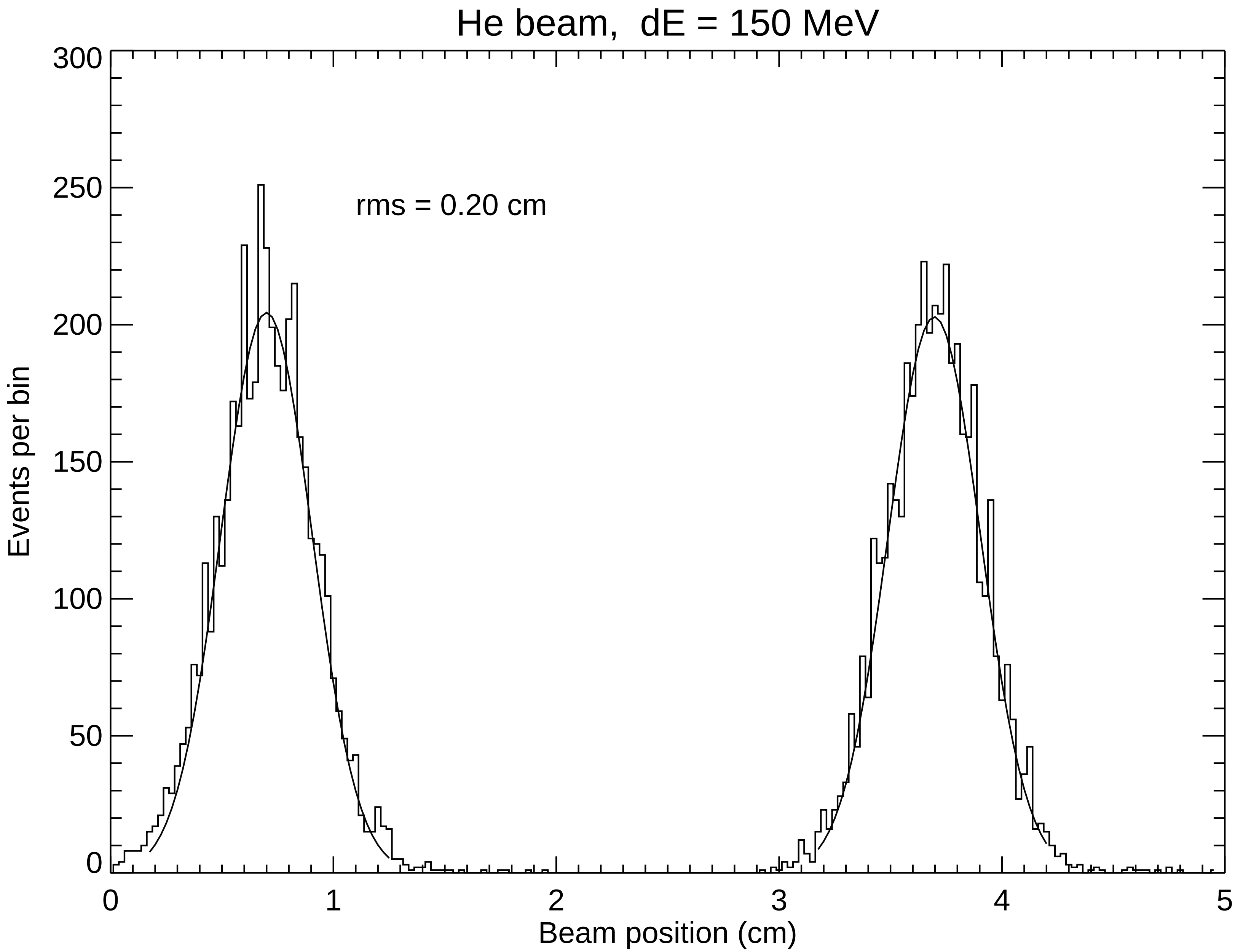
  Beam energy = 160.6 MeV/n

  good beam: $\Delta p/p \sim 0.1\%$ $\Delta x < 1$mm.

  He penetrates CsI bar, deposits 150 MeV ($\Delta E_{Landau} \approx 2$ MeV).

  C stops within CsI bar, deposits full beam energy, 2 GeV.
- **Test goals:**
  1. Map light collection in 32cm bar with "hairless" beam.
     Simpler measure of intrinsic energy and position resolution of CsI crystals.
  2. Study direct energy deposition in PIN photodiode.
  3. Hadronic radiation damage in CsI
     ~10 kRad over full 24cm bar.
  4. Alternative ACD detector technology.


32cm bar position response
He beam
dE = 150 MeV
(Left-Right)/(Left+Right)
Beam position (cm)
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-15
-10
-5
0
5
10
15



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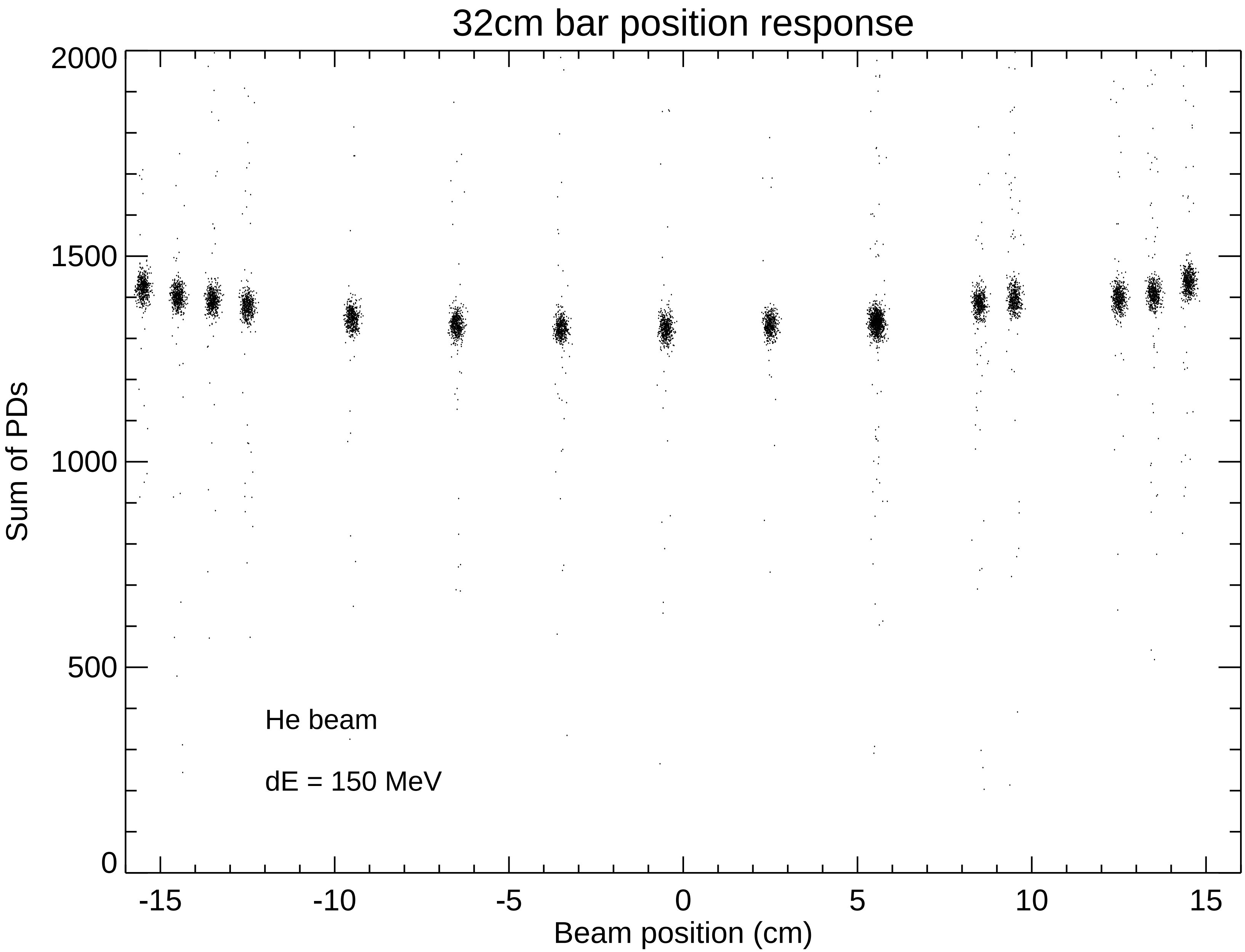
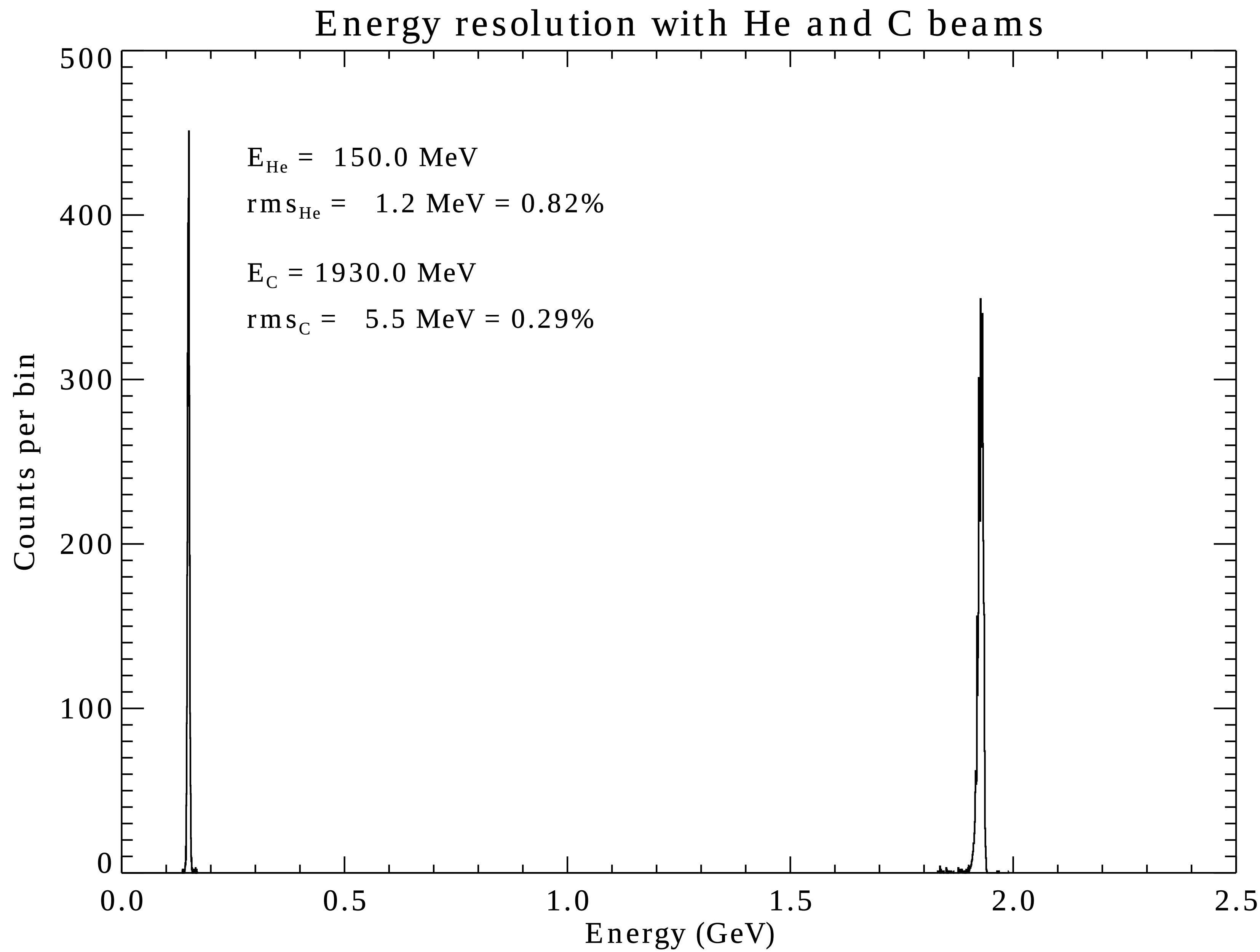

32cm bar position response
Sum of PDs
2000
1500
1000
500
0
-15
-10
-5
0
5
10
15
Beam position (cm)
He beam
dE = 150 MeV



Energy resolution with He and C beams
E_He = 150.0 MeV
rms_He = 1.2 MeV = 0.82%
E_C = 1930.0 MeV
rms_C = 5.5 MeV = 0.29%
Counts per bin
0
100
200
300
400
500
0.0
0.5
1.0
1.5
2.0
2.5
Energy (GeV)

Alternate ACD detector technology:

- **Plastic scintillator with PIN photodiode readout.**

  Photodiodes are poor match to typical plastic scintillators.

  Diode sensitivity peaks in red.

  Plastics emit in blue. Need red scintillator.

  Bicron 430

  Peak emissivity: 580 nm

  30 cm square, 1cm thick.

  Readout:

  Two 1 cm^2 PINs (S3590-03, 300μm thick) on edge.

  Two 1.8x1.8 cm^2 PINs (S3204-03, 300μm thick) on face.

  Does it work?

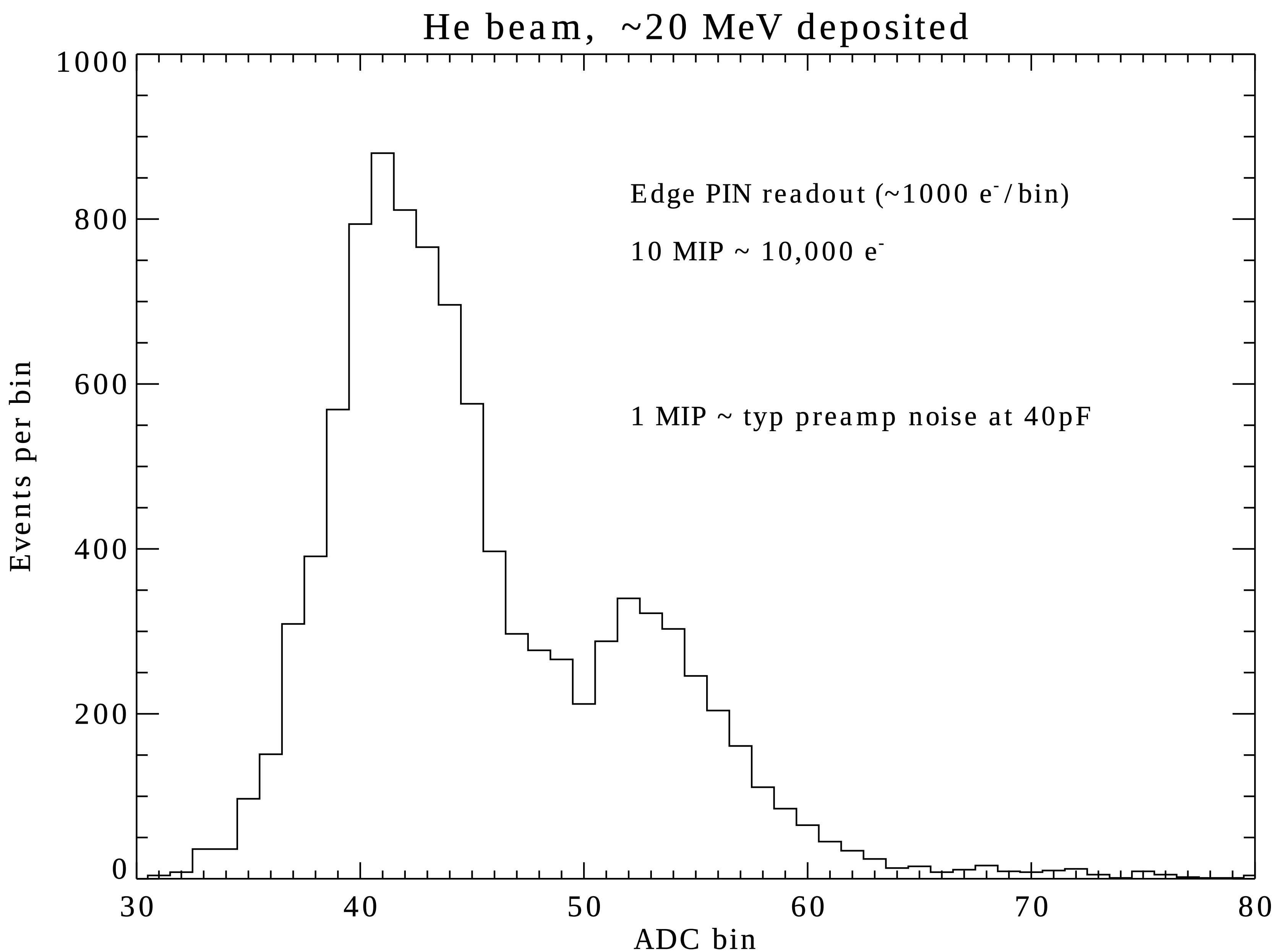
  Bicron says 15,000 to 35,000 e / MeV with PIN readout.

  Best CsI and PIN systems have ~40,000 e/MeV and ~50-100 keV noise floor.

  Since 1 MIP is >1 MeV and the ACD doesn't have to be completely hermetic,

  it's not a completely stupid idea.

  Try proton and He test beams….


He beam, ~20 MeV deposited
Edge PIN readout (~1000 e-/bin)
10 MIP ~ 10,000 e-
1 MIP ~ typ preamp noise at 40pF
Events per bin
ADC bin
0
200
400
600
800
1000
30
40
50
60
70
80