Performance of the ATLAS Forward Calorimeter

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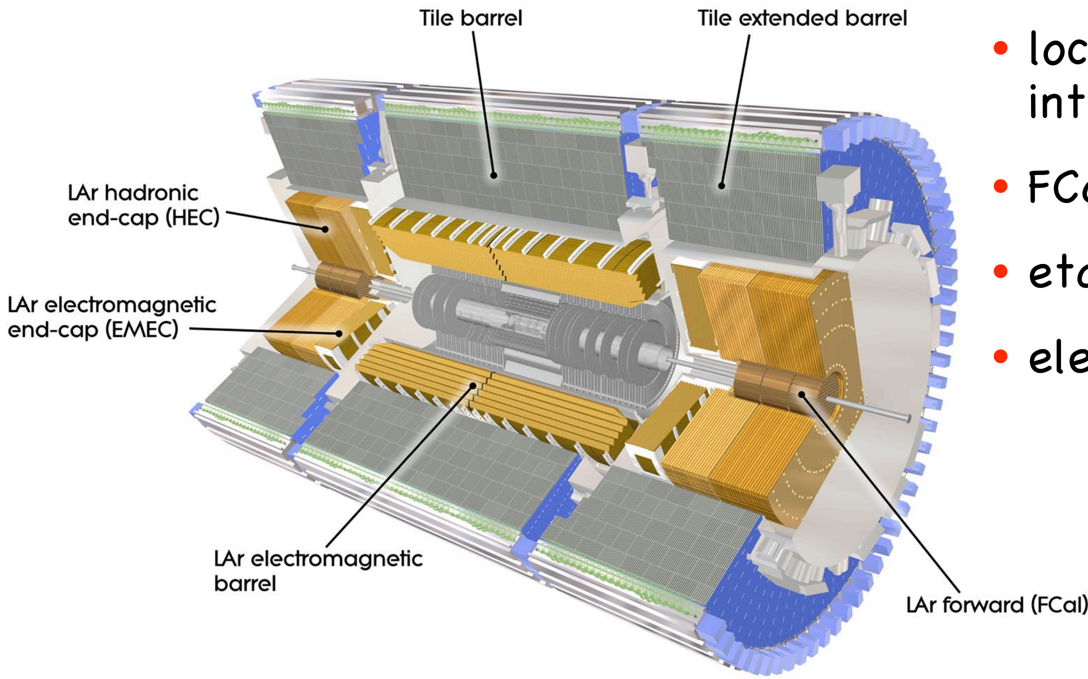
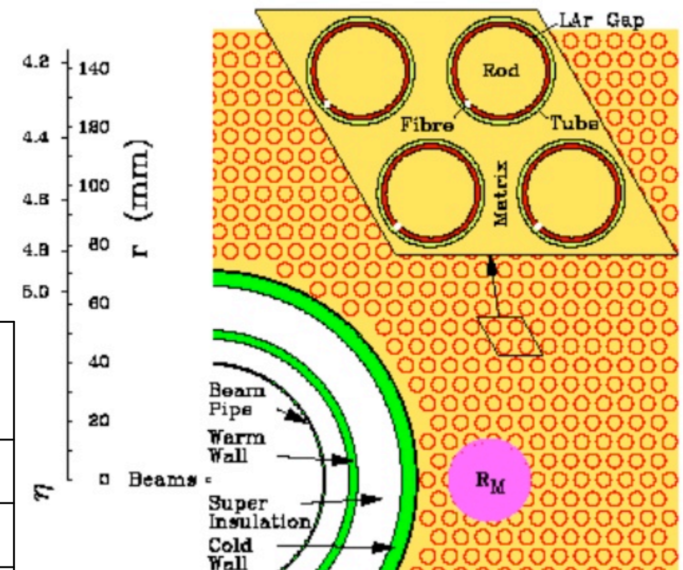
- Forward Calorimeter in ATLAS
- Forward Calorimeter in the 2003 Test Beam
- Test Beam Data Analysis & Results
  - Electron Linearity and Resolution
  - Hadron Weighting and Resolution
- Ongoing Analyses
- Summary

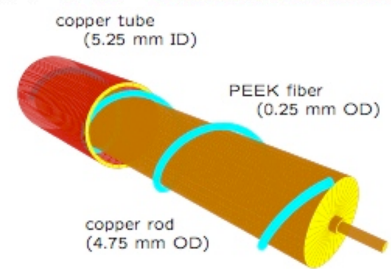
Forward Calorimeter (FCal) in ATLAS



- located in each endcap, 4.7 m from interaction point
- FCal1 (EM), FCal2,3 (hadronic)
- eta range (3.1 < |eta| < 4.9)
- electrodes lie parallel to beam pipe



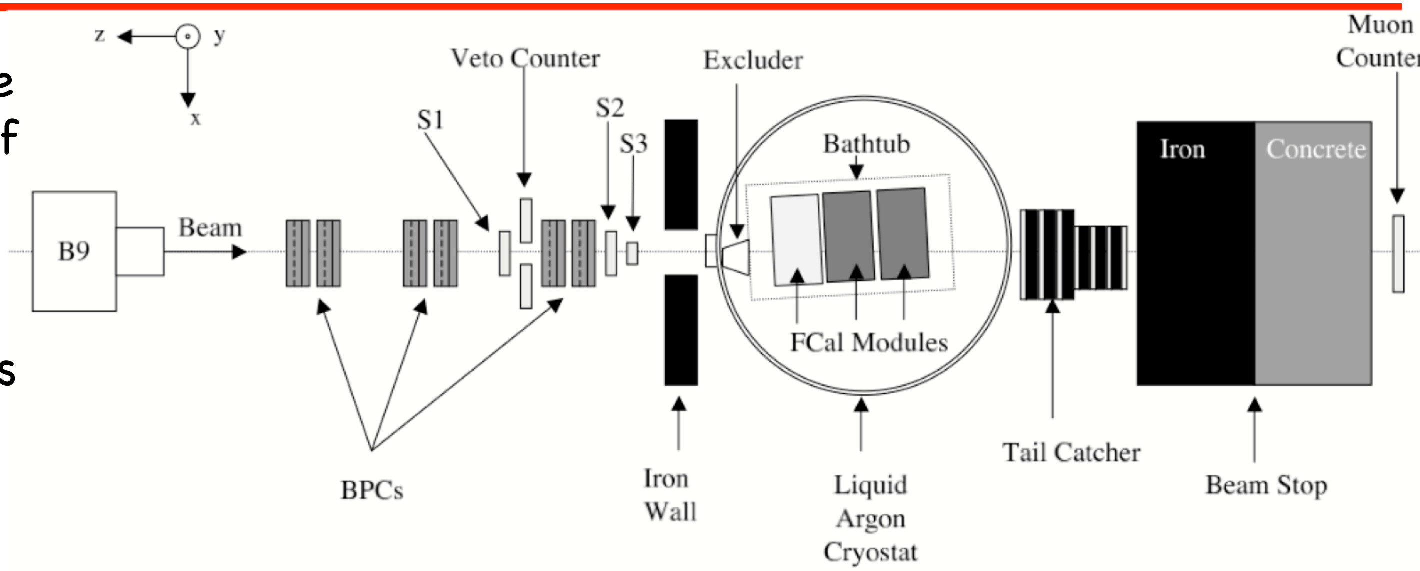
	Main Absorber	LAr Gap (width [mm])	No. Electrodes	No. Readout Channels
FCal1	Cu	0.269	12260	1008
FCal2	W	0.376	10200	500
FCal3	W	0.508	8224	254



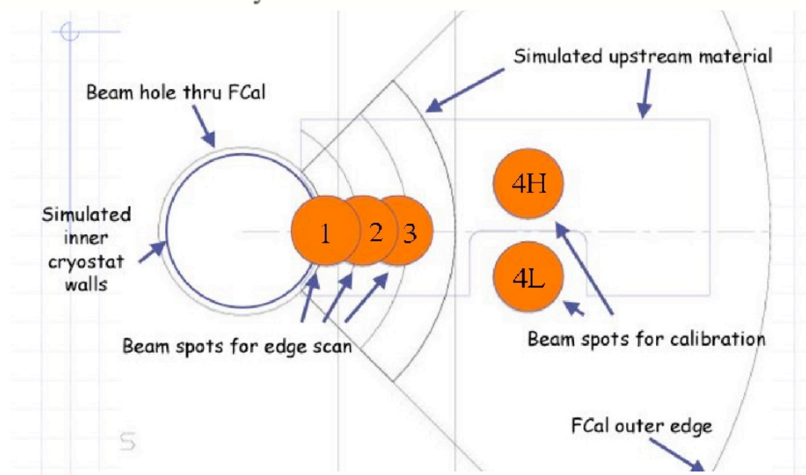
- goal is to provide good measurement of missing Et at high eta and to tag forward going jets (ex. Higgs vector boson fusion)

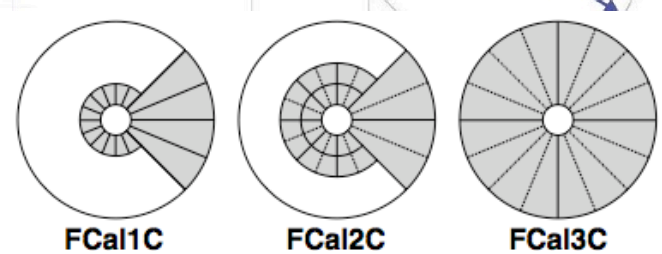
FCal Test Beam

- purpose was to measure the intrinsic response of the FCal, examine the performance under ATLAS conditions, examine the energy loss and showering near beam pipe (high eta)



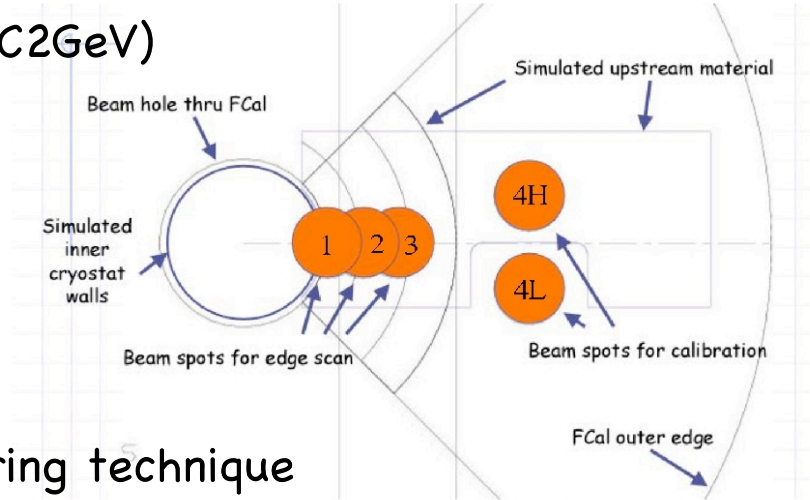
- beams of electrons and hadrons with energies of (10 - 200) GeV were directed onto one of the final ATLAS FCals using the CERN SPS H6 beam line
- five impact points (angle adjusted to correspond to ATLAS)
- wide beam spot to ensure proper sampling across FCal face (6.5 cm diameter)
- ~1000 active readout channels





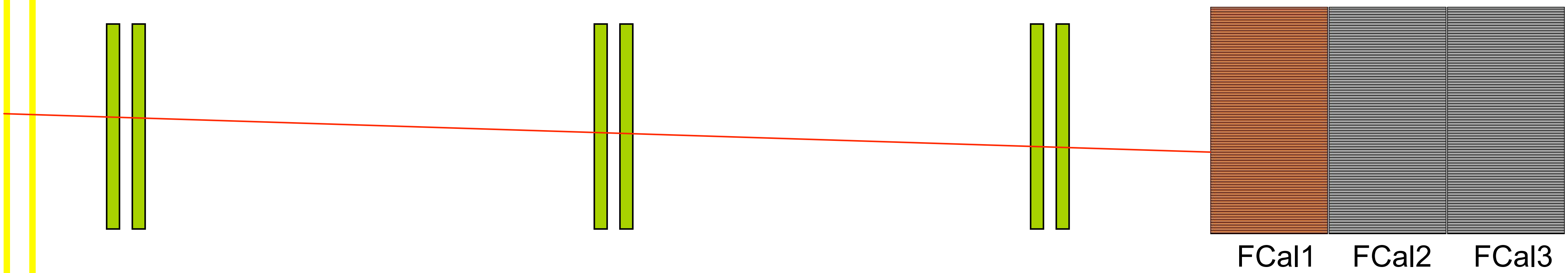
Test Beam Data Analysis: 4L Position

- minimal upstream material, fully contained showers
- measure the intrinsic response of the FCal
  - electromagnetic scale of calorimeter (ADC2GeV)
  - electron energy resolution
  - hadronic calibration scheme
  - hadron energy resolution
  - comparison of clustering algorithms
- signal pulse reconstructed using optimal filtering technique
- pedestals and noise calculated run-by-run, channel-by-channel

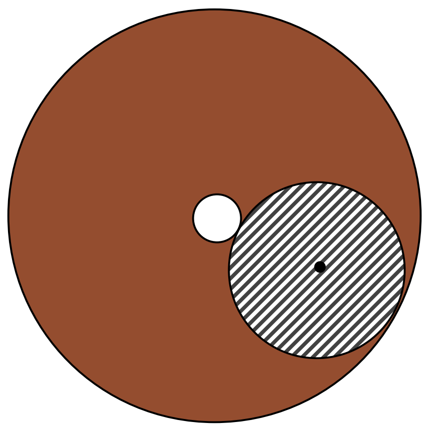


Test Beam Data Analysis: Clustering

- Cylinder clustering
  - project particle trajectory onto FCal front face using beam profile chamber (BPC) information (x, y)

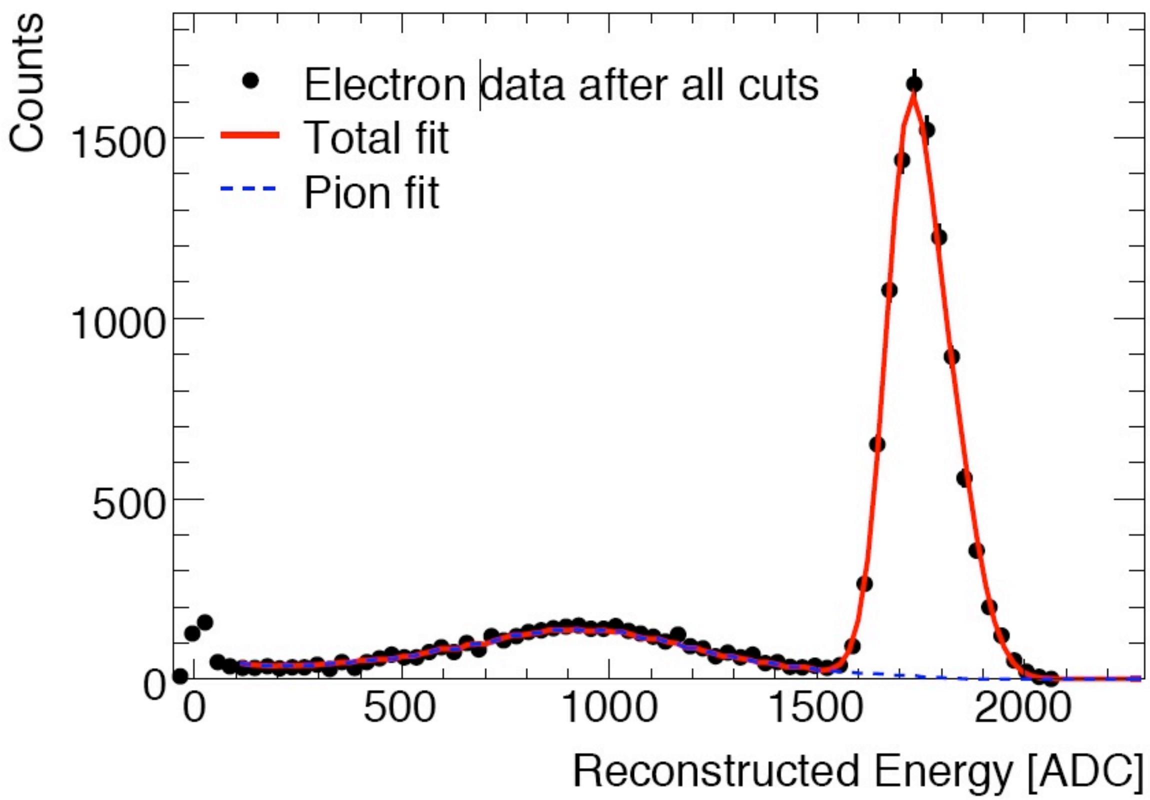


  - cluster all cells within some radial distance from cluster center (8 cm radius for electrons, 16 cm radius for hadrons)



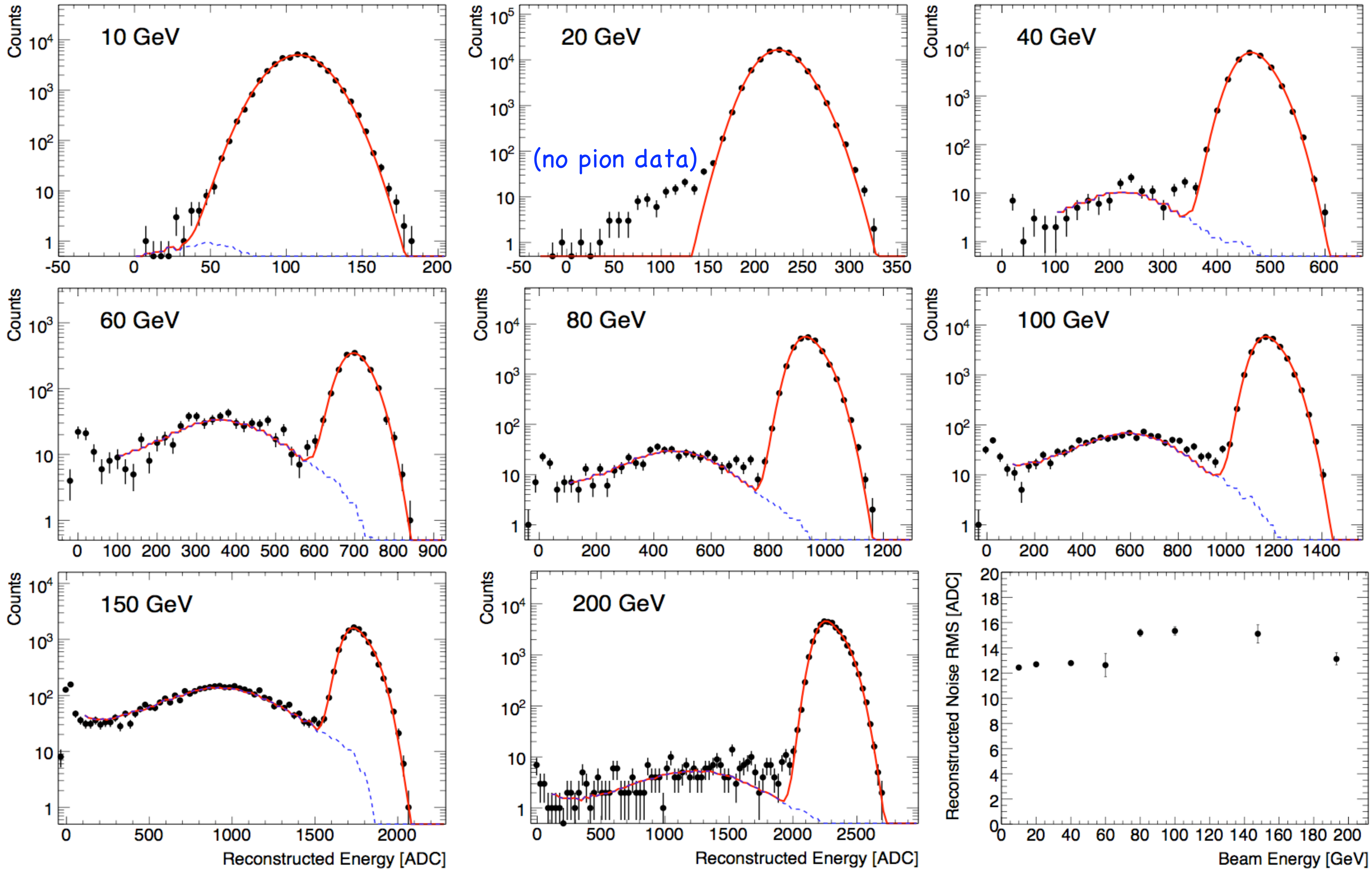
Electron Data Analysis

- cluster all cells within an 8 cm cylinder radius of the cluster center in FCal1
- fit electron energy peak with double Gaussian
    - main peak and high energy tail due to impact point dependence (particle strikes liquid argon or absorber)
- model the remaining pion background using pion data (at the same energy) to understand high energy pion tail under electron peak

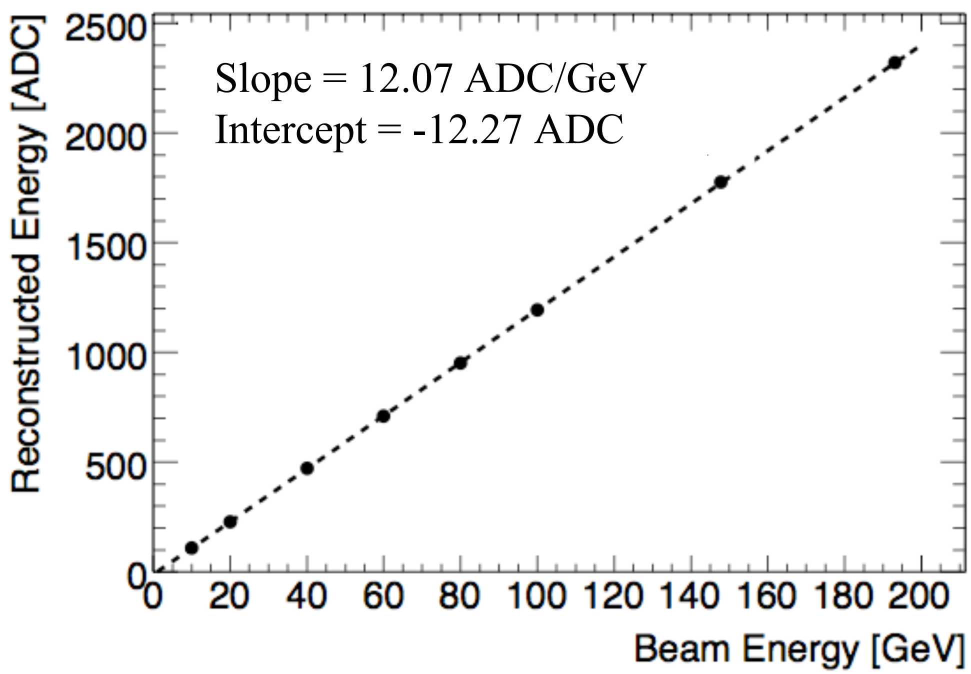


Electron Energy Distributions

▪ Electron data
Total fit
Pion data

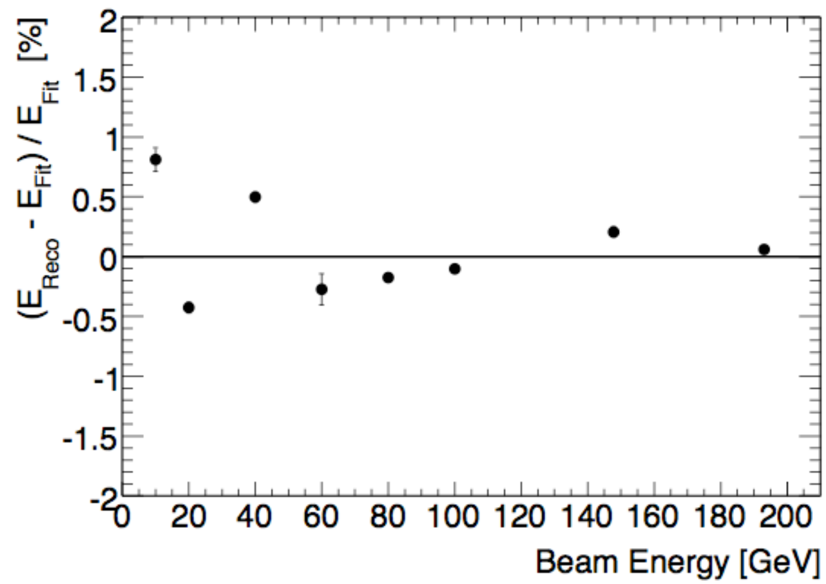


Electron Linearity & Residual



- fit ADC2GeV conversion factor for FCal1
- best fit slope:
  12.07 ± 0.07(stat) ± 0.07(sys) ADC/GeV
- predictions:
  - FCal1 12.0 ADC/GeV
  - FCal2 6.1 ADC/GeV
  - FCal3 5.4 ADC/GeV

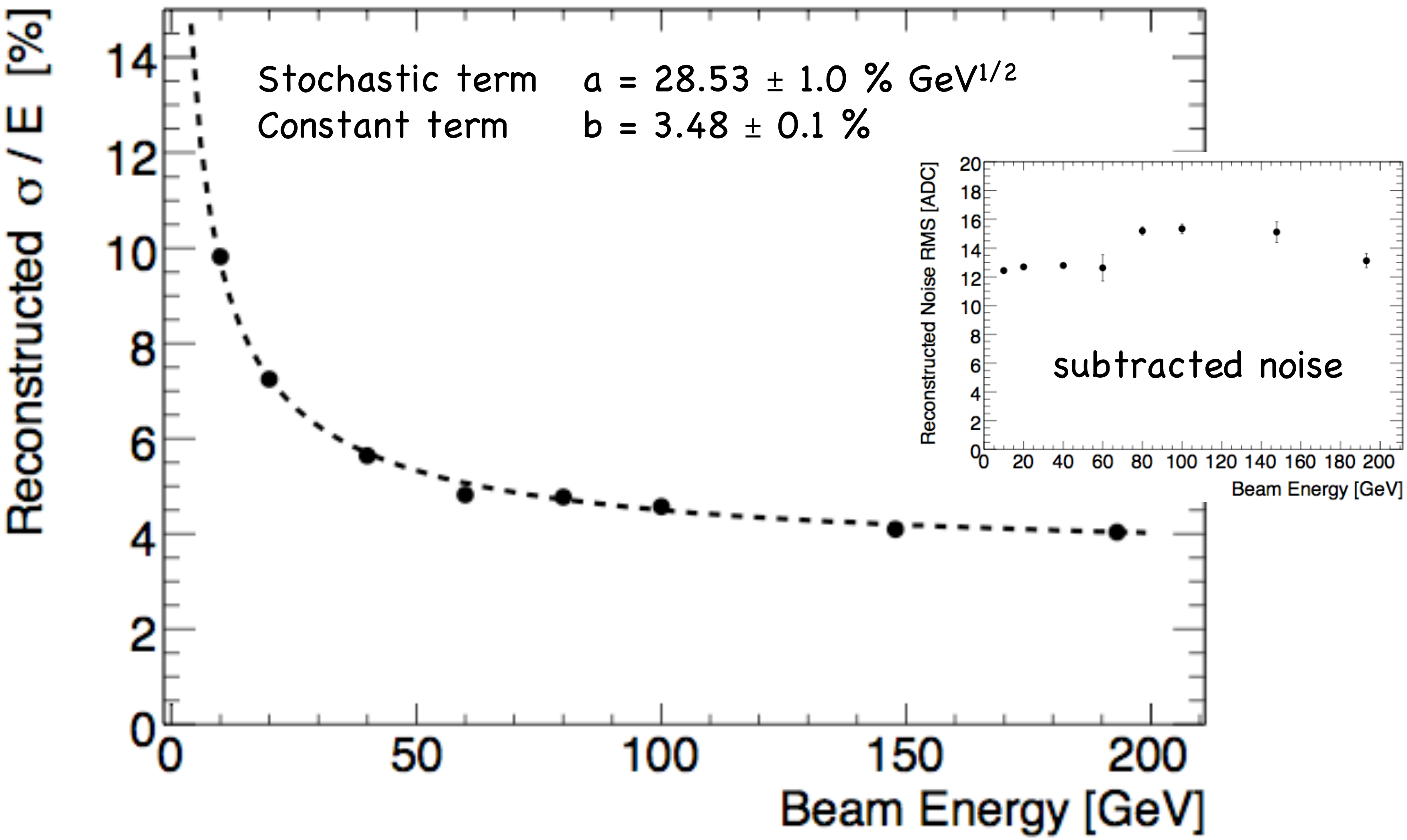
- linearity of response within ± 0.8% across energies from 10 GeV to 200 GeV



Electron Energy Resolution: 4L Position

Energy resolution function (noise subtracted)

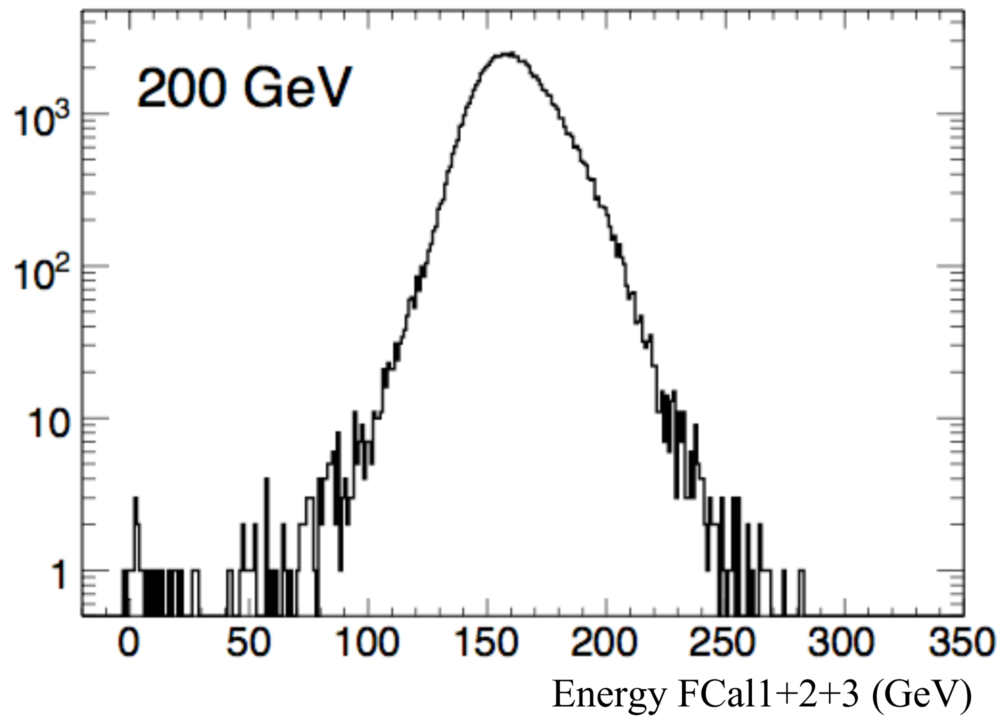
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b$$



Hadron Data Analysis

- analysis of hadron data in 4L position similar to electron analysis
- energy deposited in FCal1+2+3 within a 16 cm cylinder cluster
- determine mean energy response and width of this variation by fitting energy distribution with a double Gaussian
- use electromagnetic scale, as predicted by models

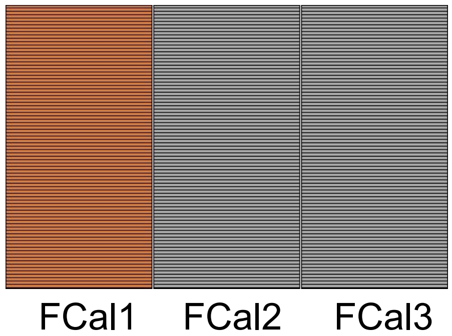
Example:
- 200 GeV pions
- electromagnetic scale



- similar plots for other pion energies [10, 40, 60, 80, 100, 120, 150] GeV

Hadron Calibration

- FCal is a non-compensating calorimeter
- design a hadronic weighting scheme to calibrate hadronic energy deposition

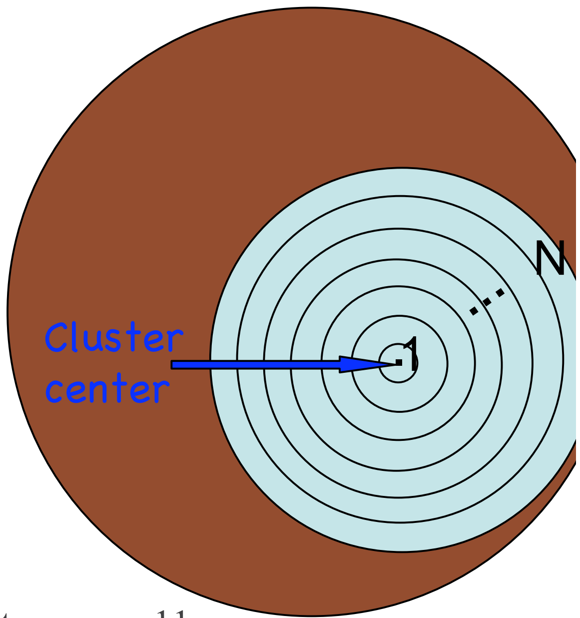


Flat weighting

- uses modular/longitudinal segmentation of calorimeter
- 3 calibration constants (each module)
- minimize energy resolution and require the beam energy equals mean reconstucted energy

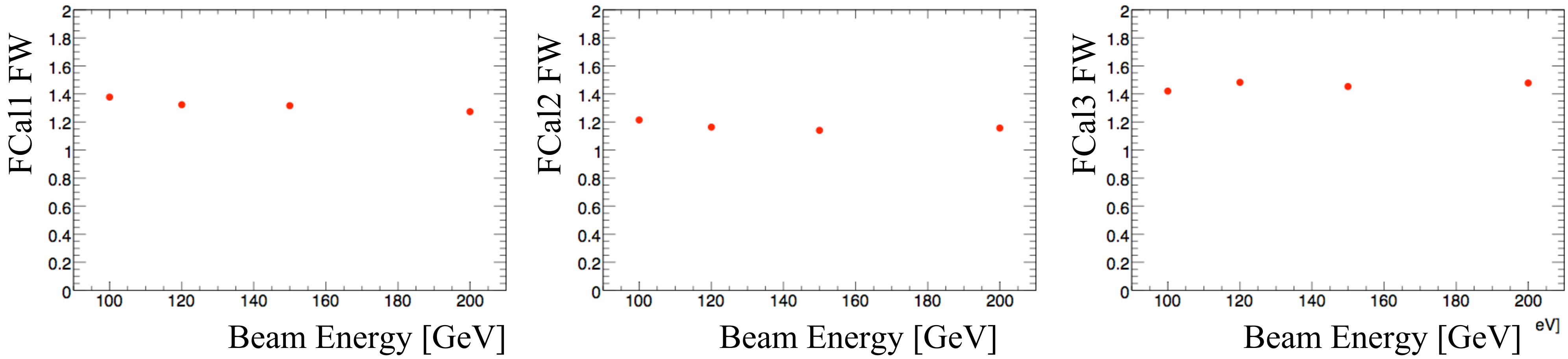
Radial weighting

- uses very fine transverse segmentation, and coarse longitudinal segmentation of calorimeter
- Nx3 calibration constants (where N = number of radial slices from cluster center)
- minimize energy resolution to extract calibration constants

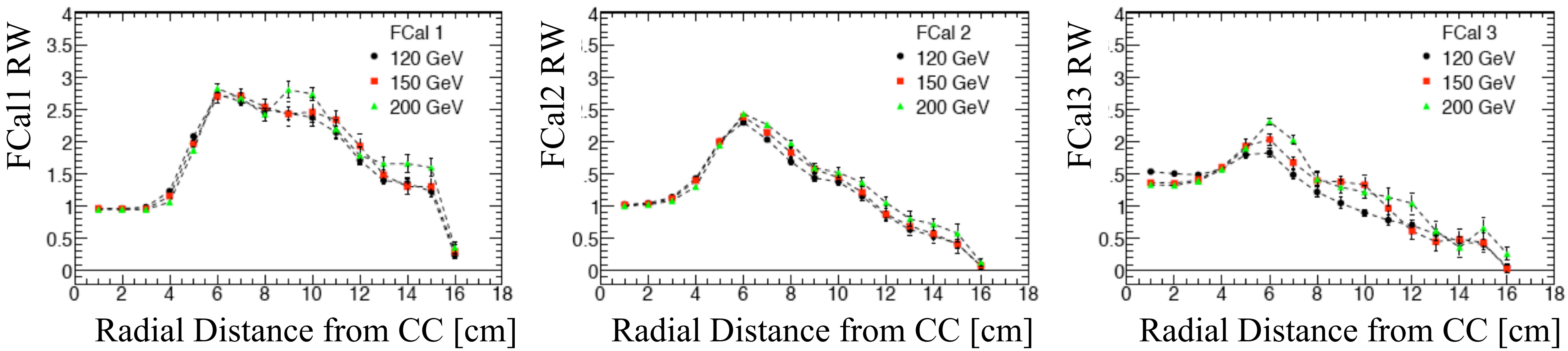


Hadron Weights

Flat weights (FW)

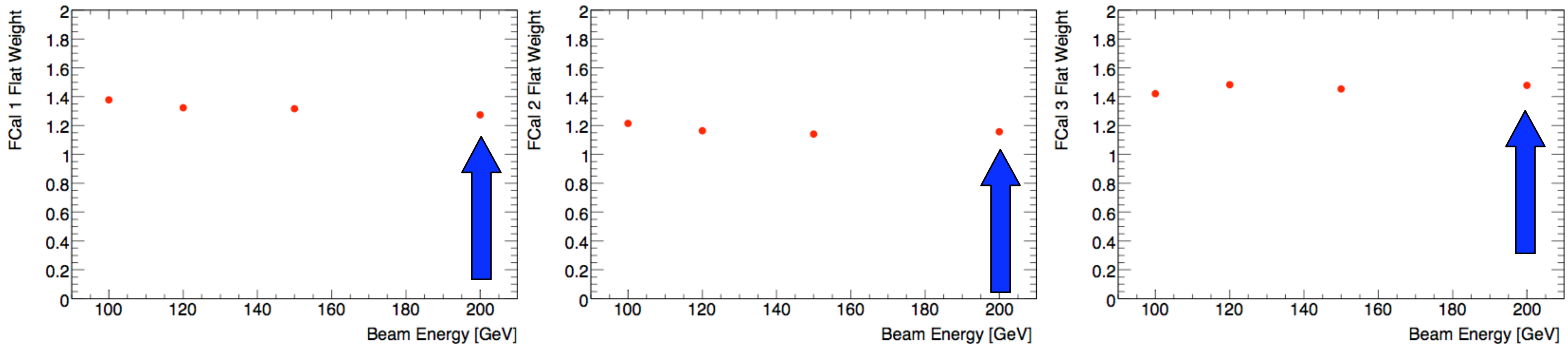


Radial weights (RW)



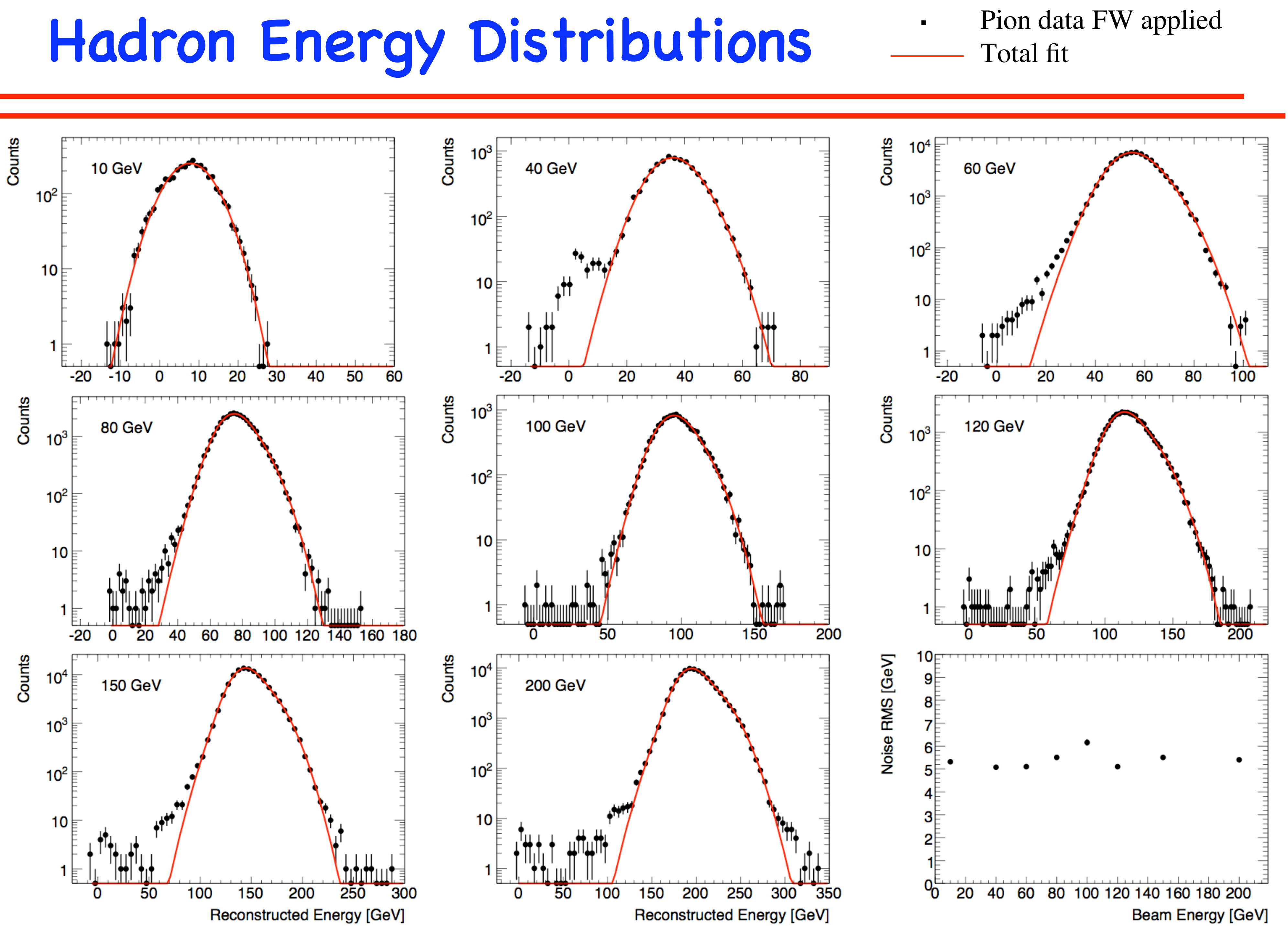
Hadron Weights

Flat weights (FW)



- apply the flat weights extracted with the 200 GeV data…

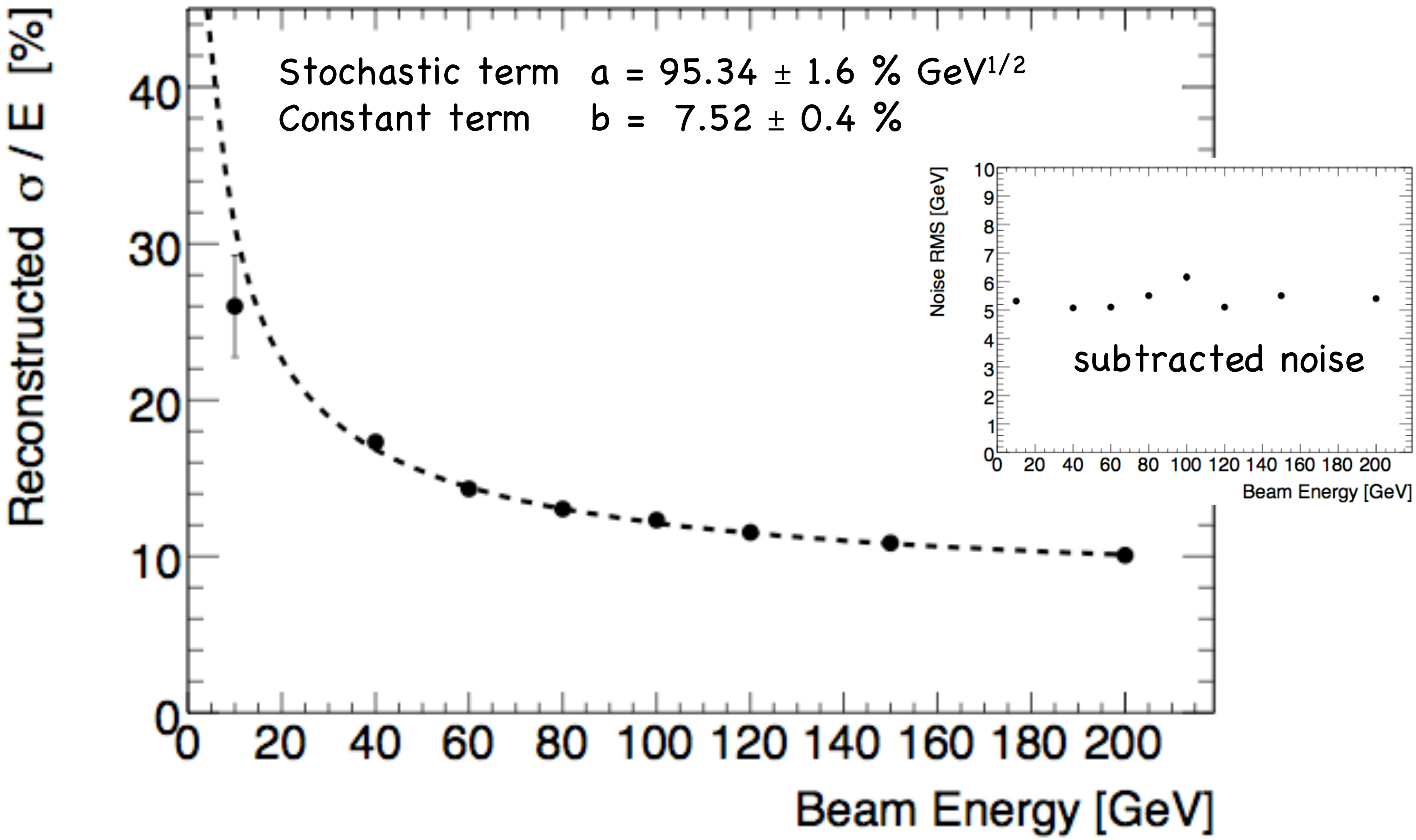
Hadron Energy Distributions



Hadron Energy Resolution (FW): 4L Position

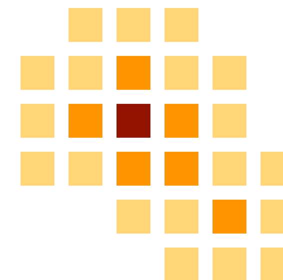
Energy resolution function (noise subtracted)

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b$$

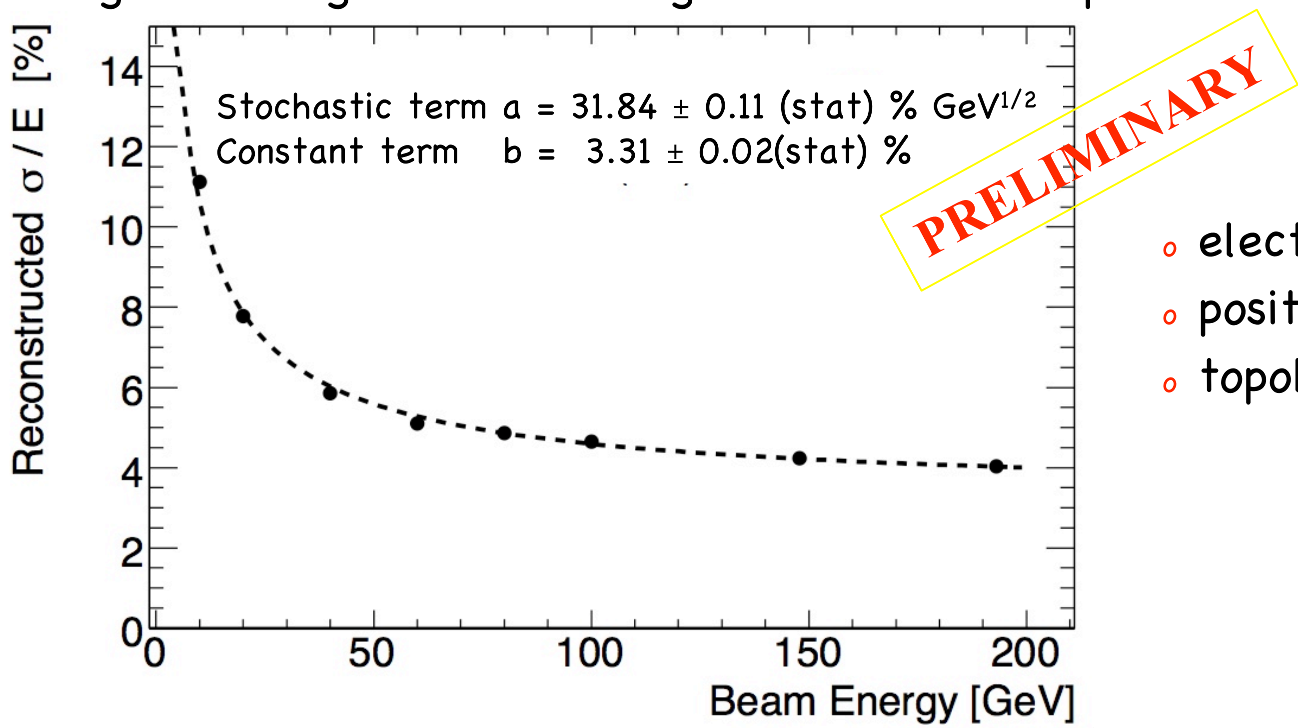


Ongoing Analyses: Topological Clustering

- Topological clustering
  - Include cells in cluster based on the significance of their energy over their noise (calculated for each cell run-by-run)
  - Cluster seeded if cell energy/noise > 4σ
  - Cluster expands if neighboring cell energy/noise > 2σ
  - Cluster all neighboring cells if cell energy/noise > 0σ



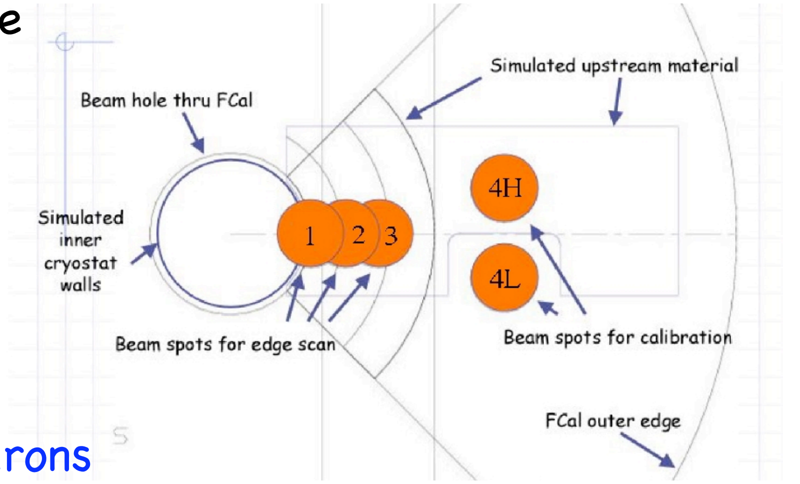
- Testing seed/neighbor/cell configurations with comparisons to cylinder clustering



- electrons
- position 4L
- topological clustering 4/2/0

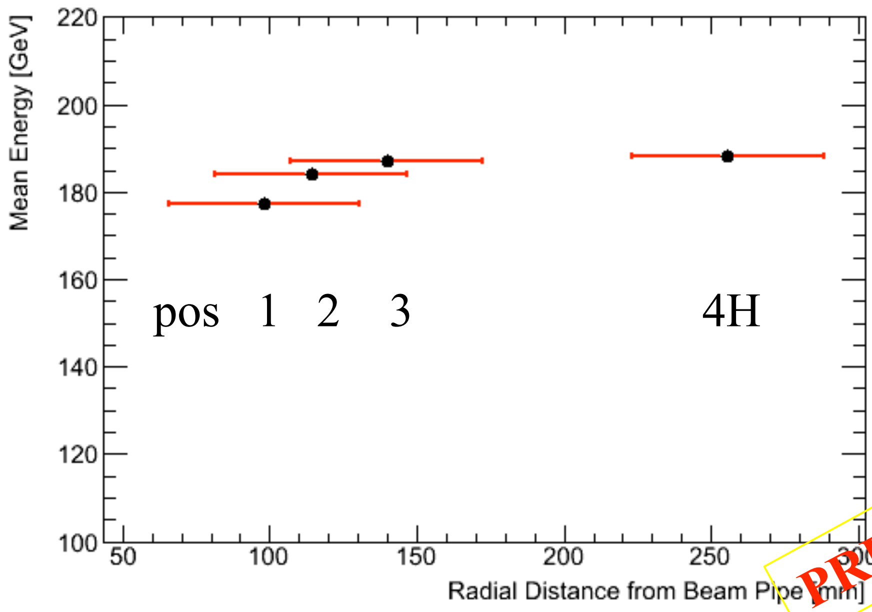
Ongoing Analyses: Inner Edge

- examine the energy loss and showering near beam pipe (high eta), and ensure this is correctly modeled in the Monte Carlo
- preliminary look a results with topological clustering 4/2/0 for 200 GeV electrons and pions
- mean reconstructed energy vs average beam impact position



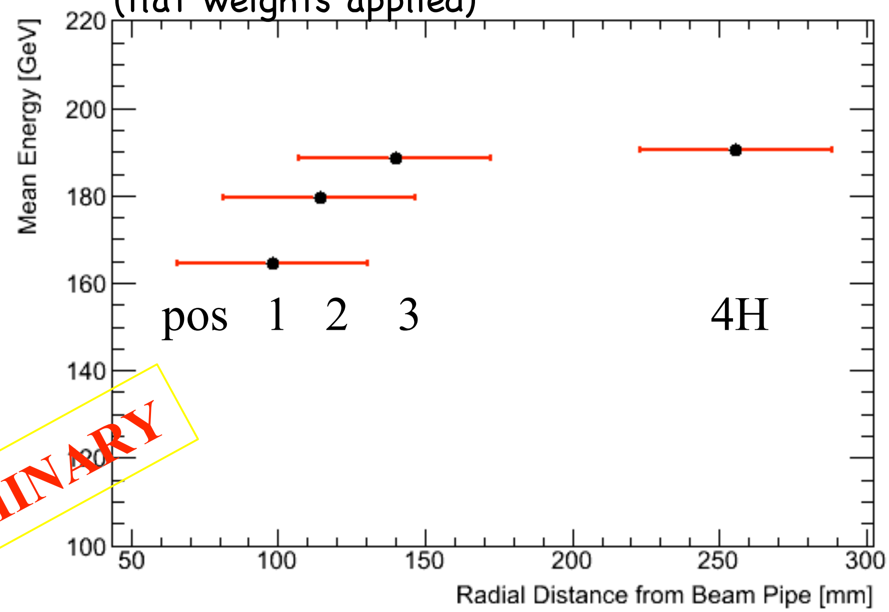
Electrons

Energy clustered in FCal1



Hadrons

Energy clusterd in FCal1+2+3
(flat weights applied)



PRELIMINARY

Summary

- the ATLAS forward calorimeter (FCal) has been studied using electron and hadron test beam data at a range of energies (10 GeV - 200 GeV)
- FCal intrinsic energy resolutions (4L position) using cylinderical clustering and flat weights:
  - Electron $\frac{\sigma_E}{E} = \frac{28.53\%\mathrm{GeV}^{1/2}}{\sqrt{E}} \oplus 3.48\%$
  - Hadron $\frac{\sigma_E}{E} = \frac{95.34\%\mathrm{GeV}^{1/2}}{\sqrt{E}} \oplus 7.52\%$

Requirements

$$\frac{\sigma_E}{E} = \frac{35\%\mathrm{GeV}^{1/2}}{\sqrt{E}} \oplus 5\%$$

$$\frac{\sigma_E}{E} = \frac{100\%\mathrm{GeV}^{1/2}}{\sqrt{E}} \oplus 10\%$$

- ongoing analyses to investigate different clustering algorithms used in ATLAS, and energy loses and splashing due to the beam pipe
- references:

  - "Energy calibration of the ATLAS Liquid Argon Forward Calorimeter", 2008 JINST 3 P02002
  - "Electron signals in the Forward Calorimeter prototype for ATLAS", 2007 JINST 2 P11001
  - "The ATLAS Forward Calorimeters", 2008 JINST 3 P02010

Additional Slides

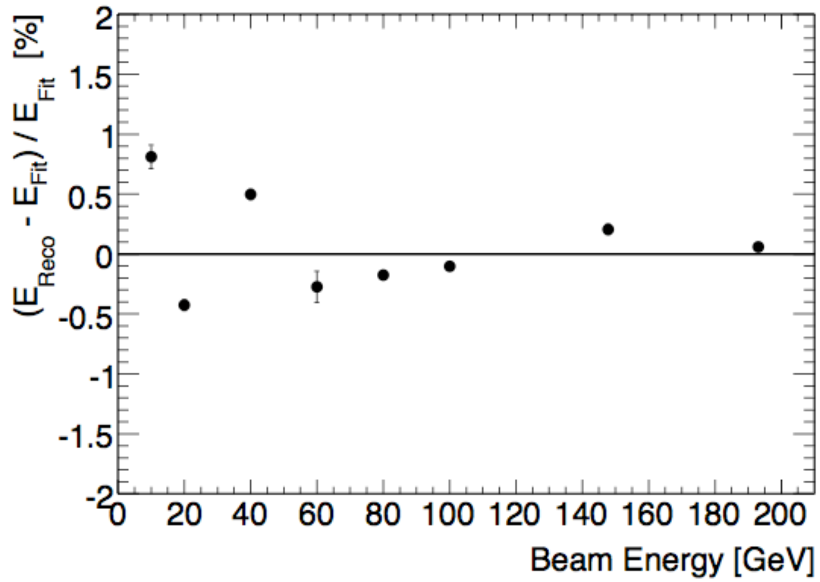
Electron Systematic Uncertainties

- fitting technique (double Gaussian vs single Gaussian, pion modeling)
- cylinder cluster size (on avg 99% of energy within 8 cm cylinder)
- impact point dependence

Small effect 0.1-0.2%

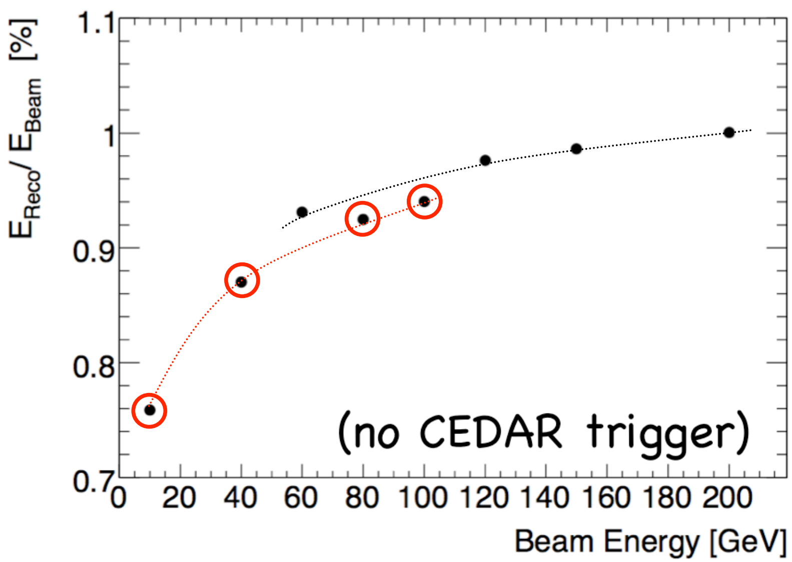
- beam conditions
  - high energy electrons from secondary beam, polarity determined by H8 beamline (single polarity)
  - low energy electrons are from tertiary beam and are of mixed polarity
  - assign systematic uncertainties at 10 GeV of 0.9 % (and 20 GeV of 0.6 %)

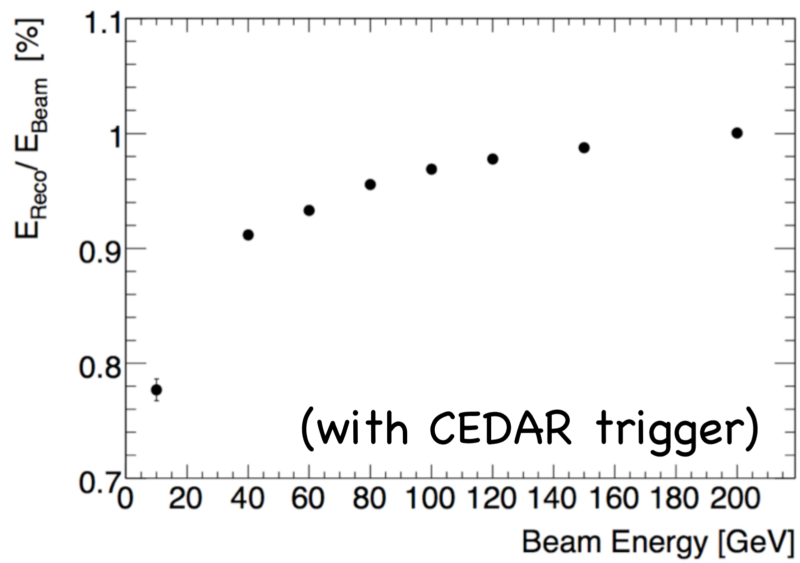
- upstream energy losses due to presence of upstream detectors/material (losses nonlinear with beam energy)



Hadron Systematic Uncertainties

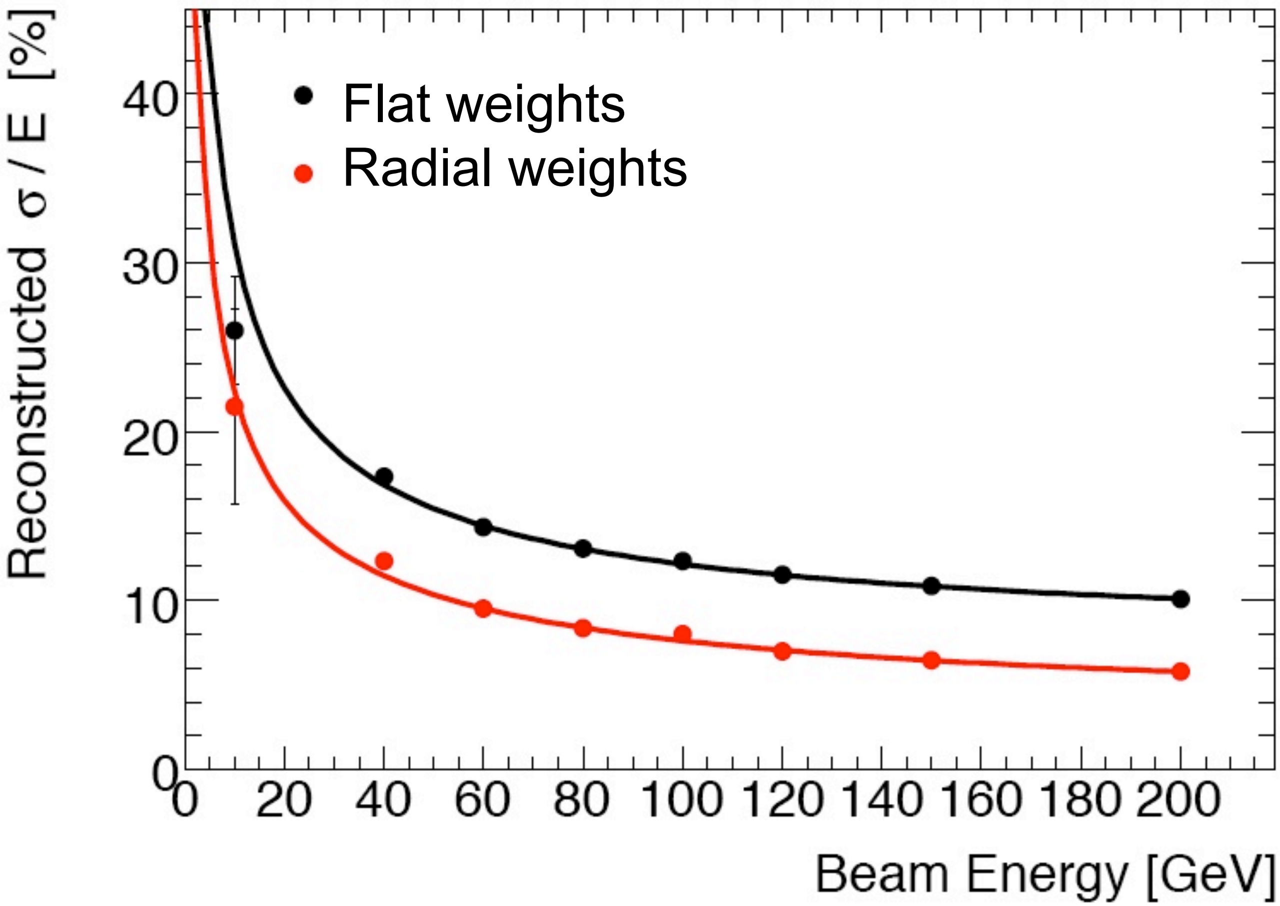
- largest systematic uncertainty from choice of flat weights applied to all energy points (recall: we used weights extracted with 200 GeV pion data)
  - instead apply weights from 100 GeV, 120 GeV, 150 GeV
  - stochastic term varied by ~1.6% GeV$^{1/2}$ and constant term varied by ~0.4%
- particle type (pi+ vs pi-)
  - there was an observable difference between data taken with pi+ beams vs pi- beams
  - motivated use of CEDAR trigger (removes protons from pion beam)





Hadron Energy Resolution (FW and RW)

- energy resolution of the two hadronic weighting schemes: flat weights and radial weights
- the use of the radial weighting technique improves the resolution and is under further study



$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b$$

Flat Weights
a = 95.34 % GeV$^{1/2}$
b = 7.52 %

Radial Weights
a = 70.0 % GeV$^{1/2}$
b = 3.00 %