Performance of the of the ATLAS Liquid Argon Forward Calorimeter in Beam Tests

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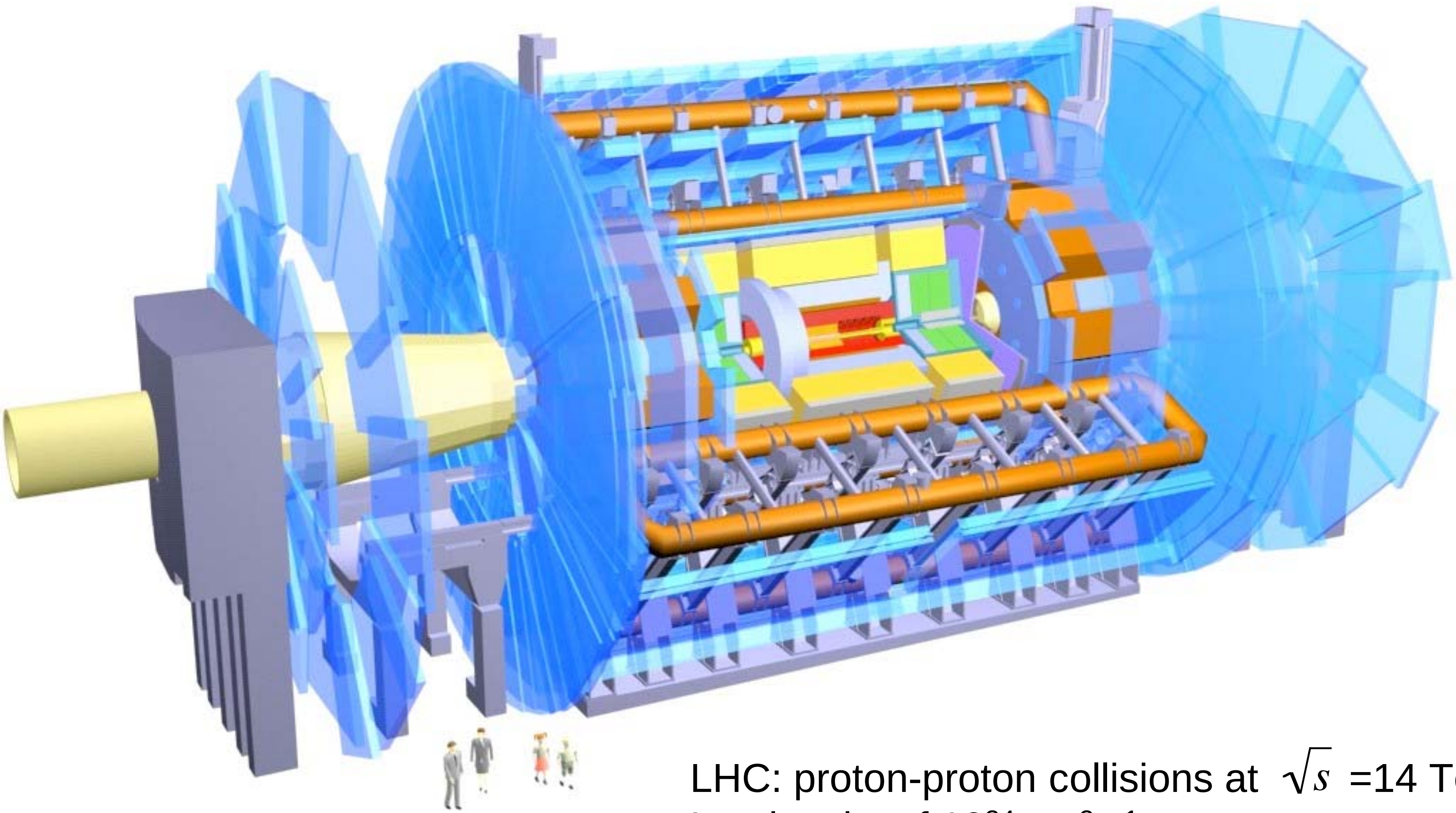
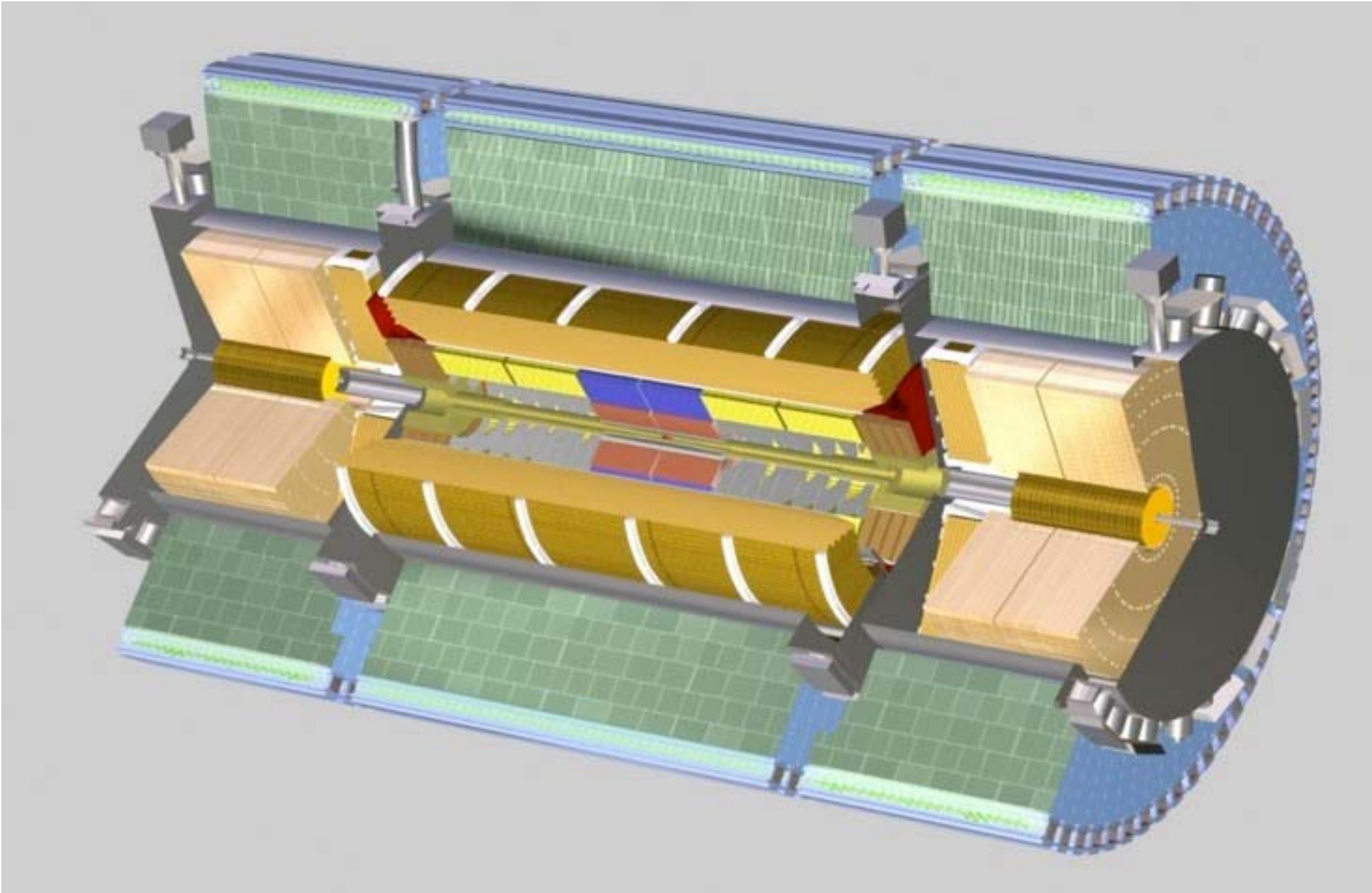
The ATLAS Detector at the LHC

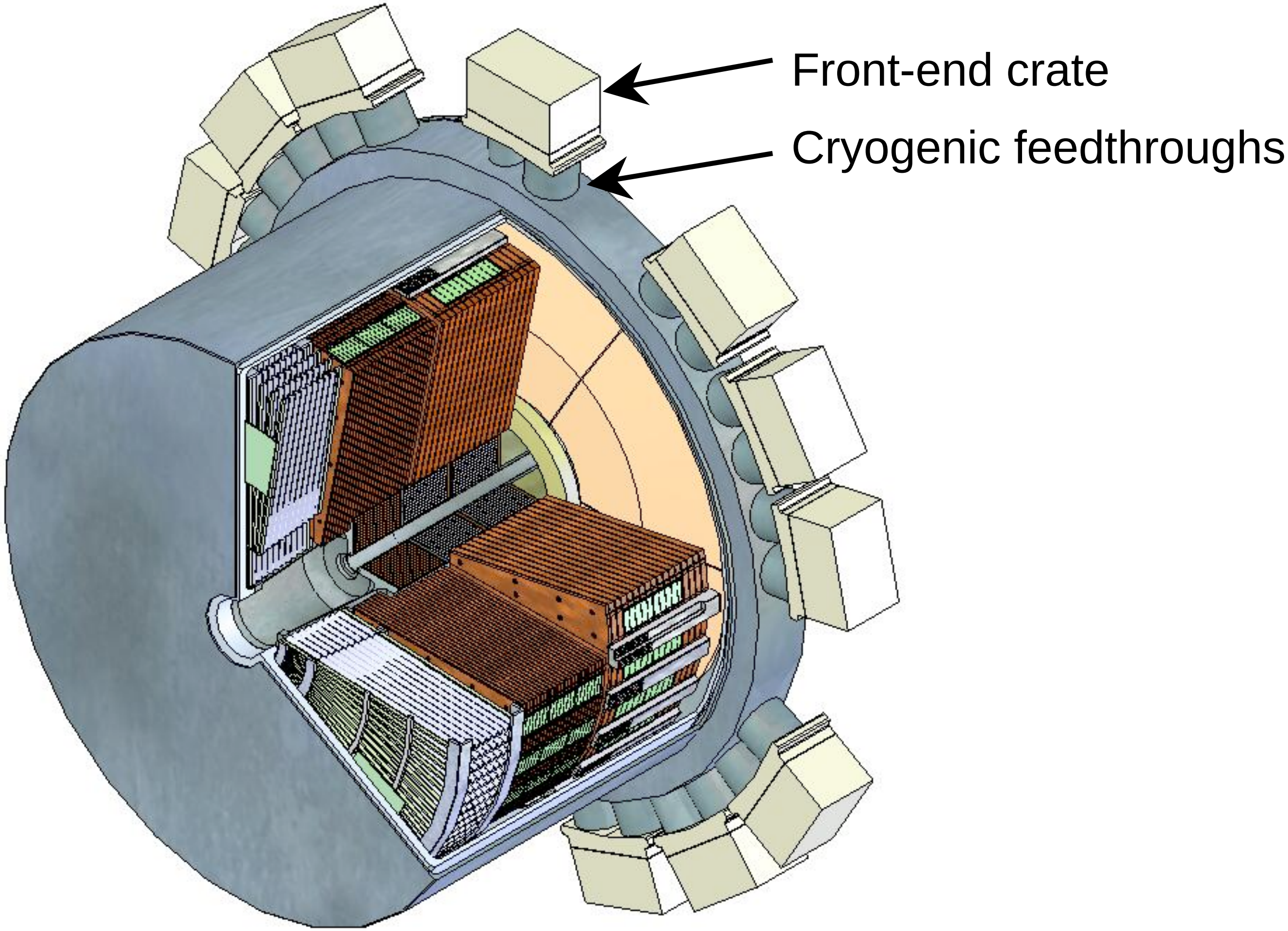


LHC: proton-proton collisions at $\sqrt{s}$ =14 TeV,
Luminosity of $10^{34} cm^{-2} s^{-1}$

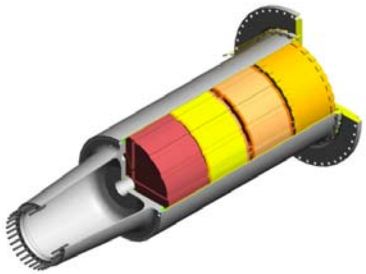
The ATLAS Calorimeters



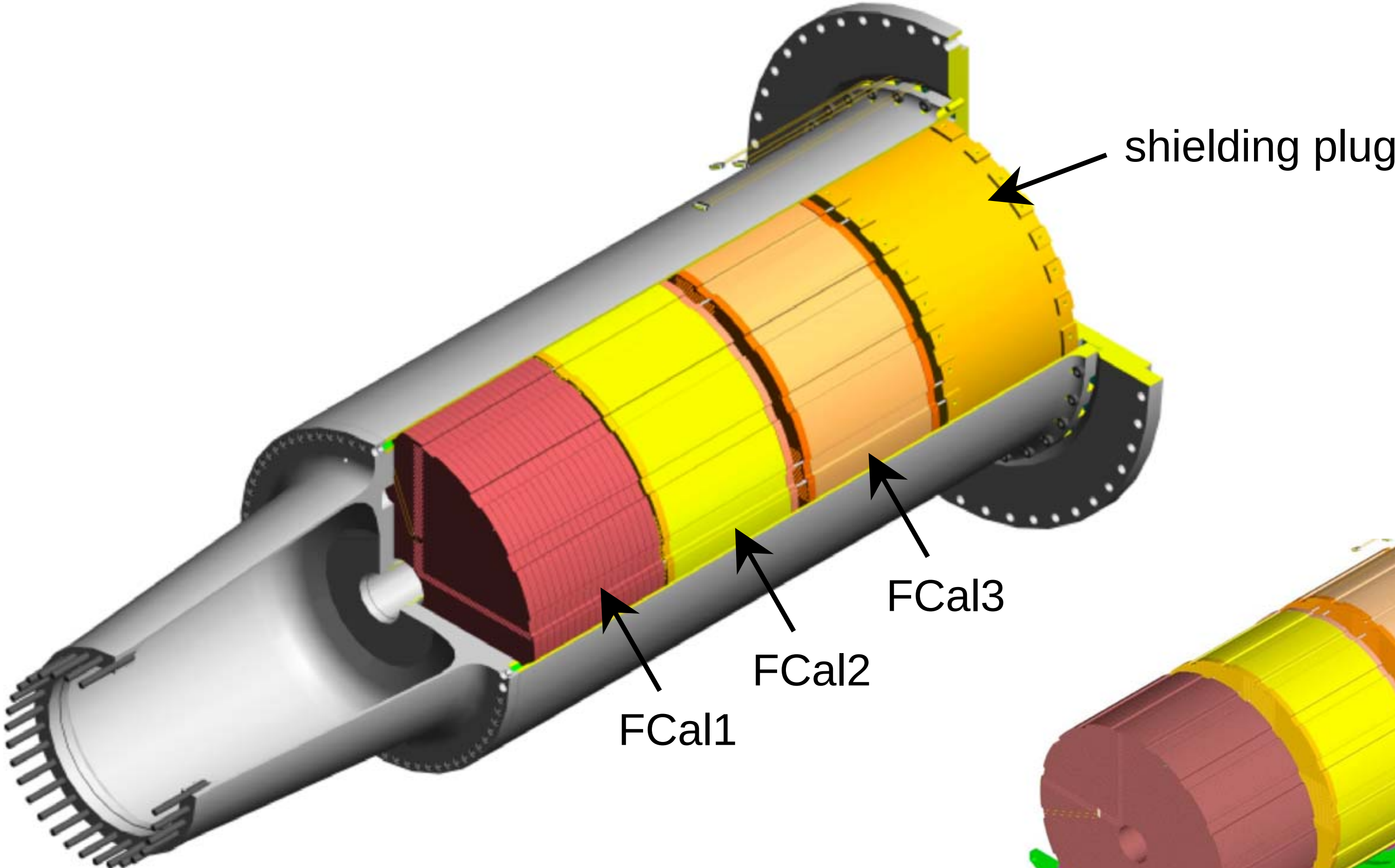
The Liquid Argon Endcap Calorimeter

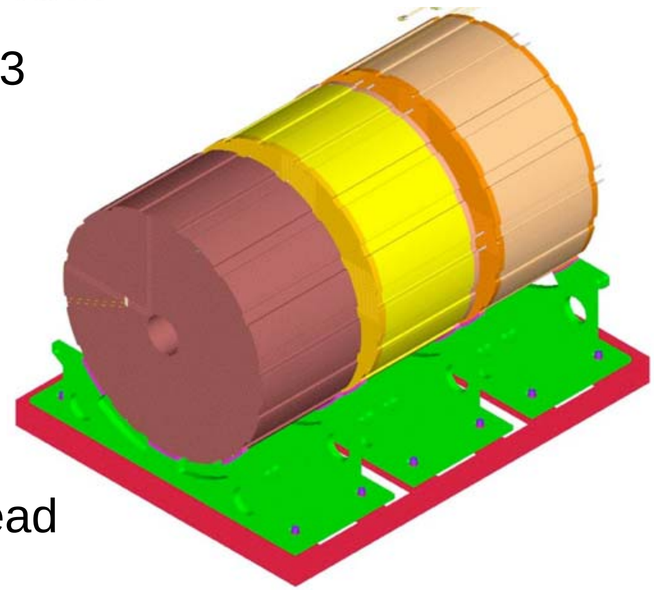


The Liquid Argon Forward Calorimeter



The Liquid Argon Forward Calorimeter

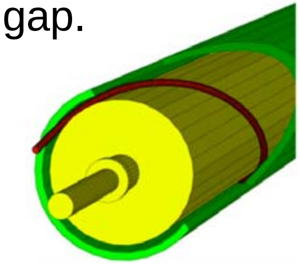




FCal "support tube" was unavailable for beam test, so custom-built stand used instead

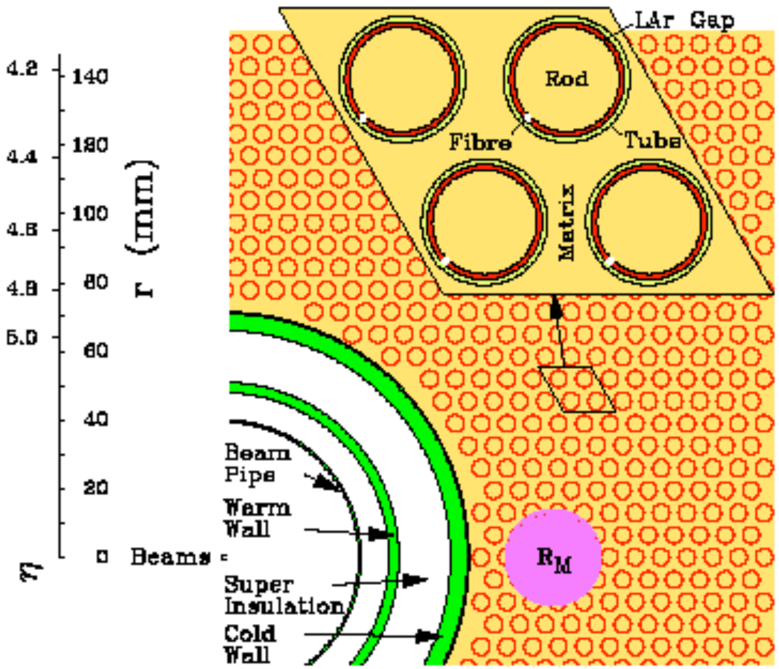
The Forward Calorimter Electrode Structure

Radiation environment near the LHC beamline requires very narrow liquid argon gaps, to avoid problems with positive-ion buildup, which distorts the electric field in the gap.



Annular gaps formed by copper tubes (cathodes) set into an absorber matrix, filled with anode rods of slightly smaller radius. Gap maintained by helically-wound radiation hard plastic fibre (PEEK).

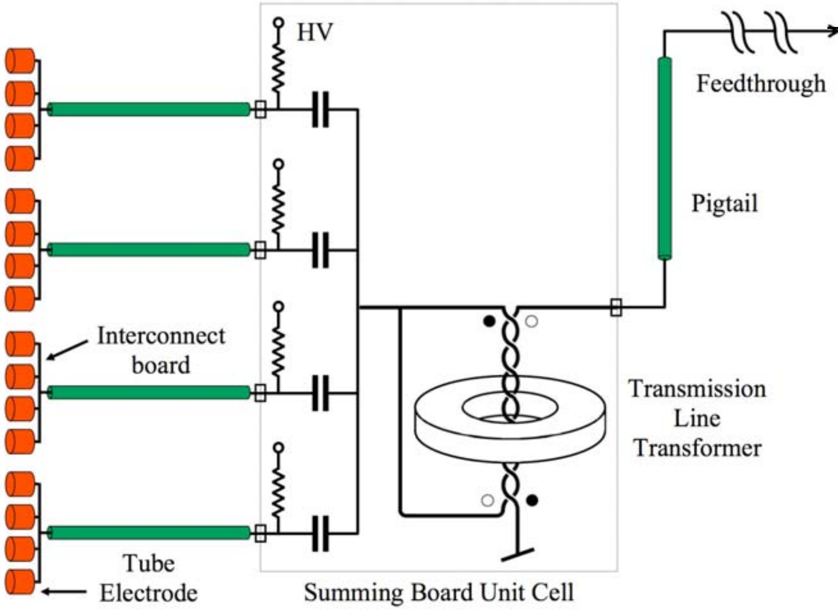
Three modules: 1 EM, 2 Hadronic (ease of construction, depth segmentation)

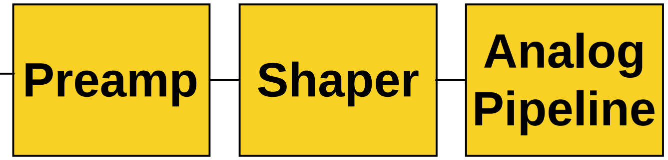


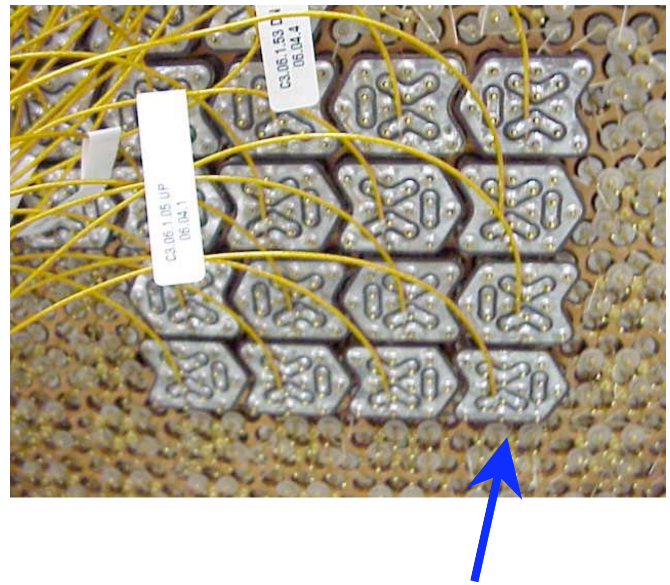
	Type	Absorber	Gap (μm)	Number of Electrodes
FCal1	EM	copper	250	12260
FCal2	HAD	tungsten	375	10200
FCal3	HAD	tungsten	500	8224

matrix and rods are part of the detector calorimeter ‘absorber’ and are composed of the same material

FCal Readout / Granularity





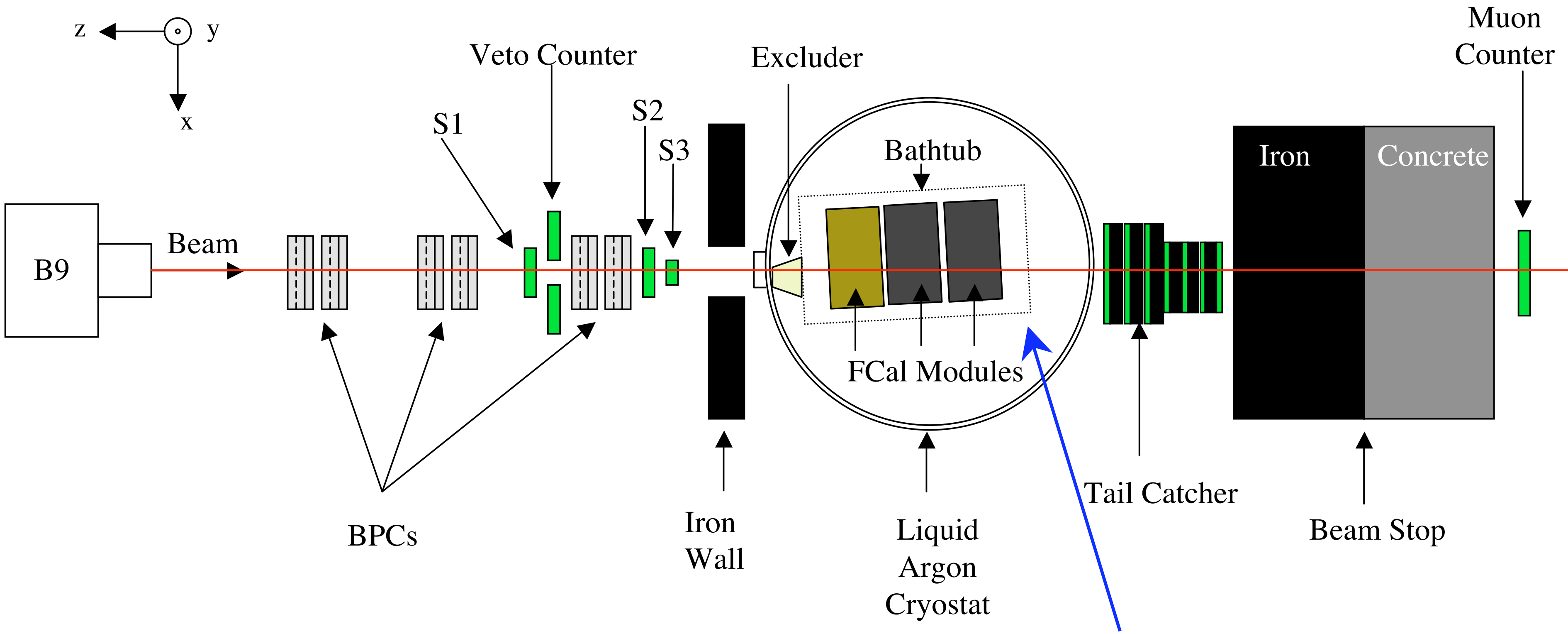


Electrodes are ganged together at module face: 4, 6, and 9 for FCal 1, 2 and 3

For most channels, four (adjacent) groups are summed in the cold:

- Provides adequate readout granularity
- Reduces need for signal feed-through channels

Calibration Beam Test Beamline Setup



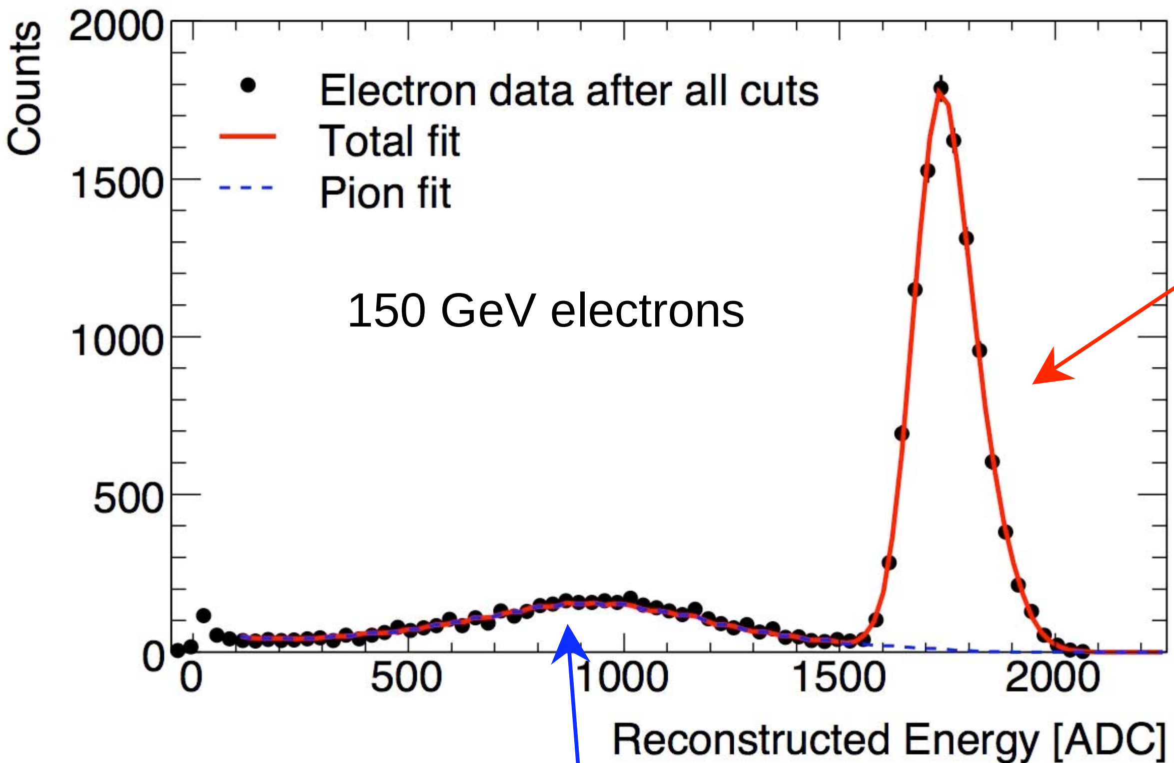
Beamline instrumentation for triggering, tracking: beam cleaning, e/h separation

Modules oriented in reproduce correct impact angle for particles from the ATLAS interaction point.

H6 Beamline in CERN North Area: electrons / hadrons/ muons ~10-200 GeV

Energy Reconstruction for Electrons

Use the FCal1 module only: sum over cells that are within an 8 cm radius cylinder centred on the beam impact point, derived from the tracking (BPCs).

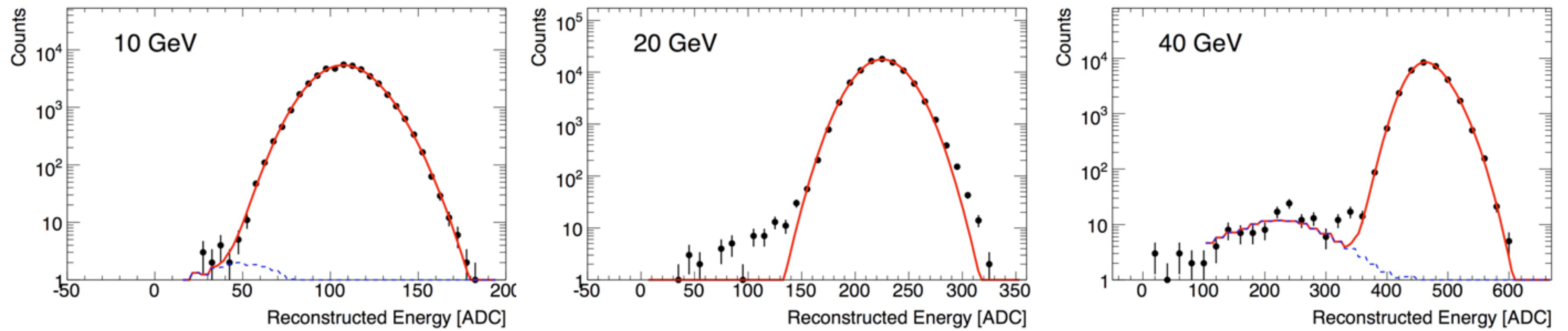


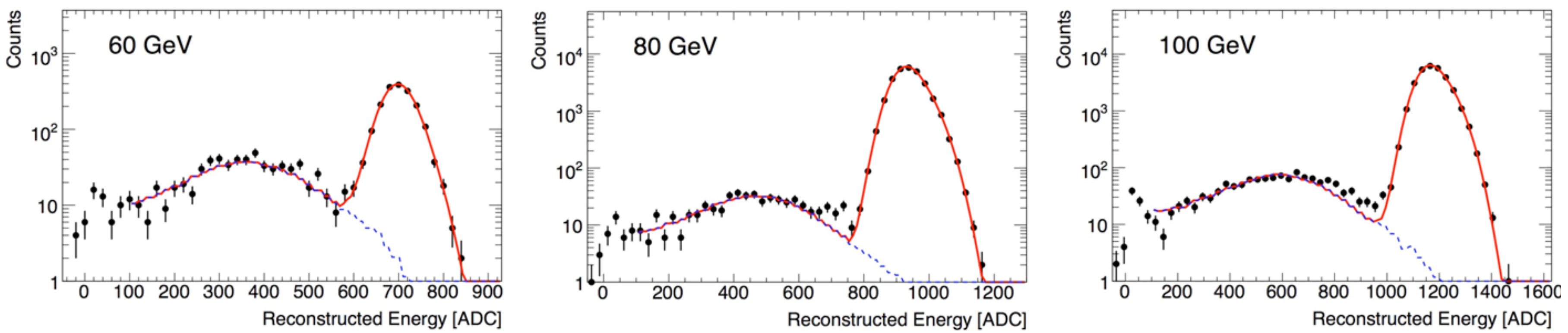
Signal shape non-Gaussian due to impact point dependence of calorimeter response

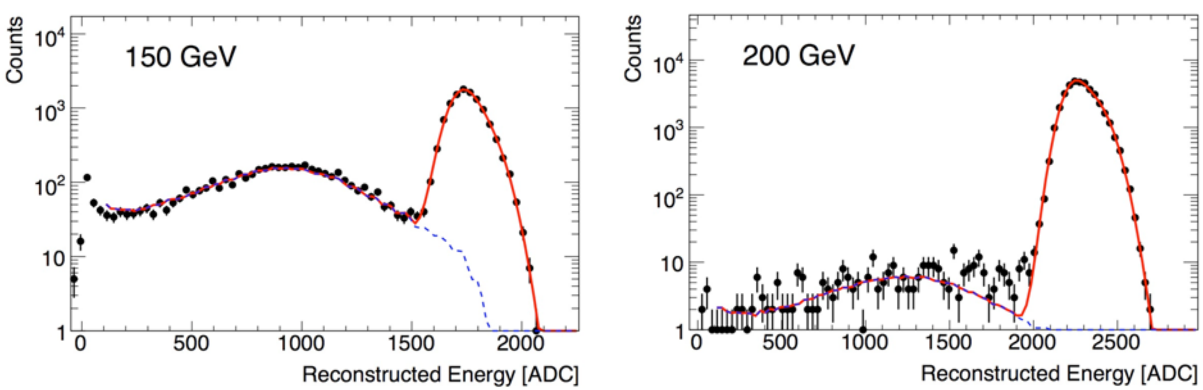
Parameterized with a double Gaussian (which provides a good description)

Low energy region (hadrons) modeled using hadron data taken at the same energy

Results for electrons (in ADC Counts)

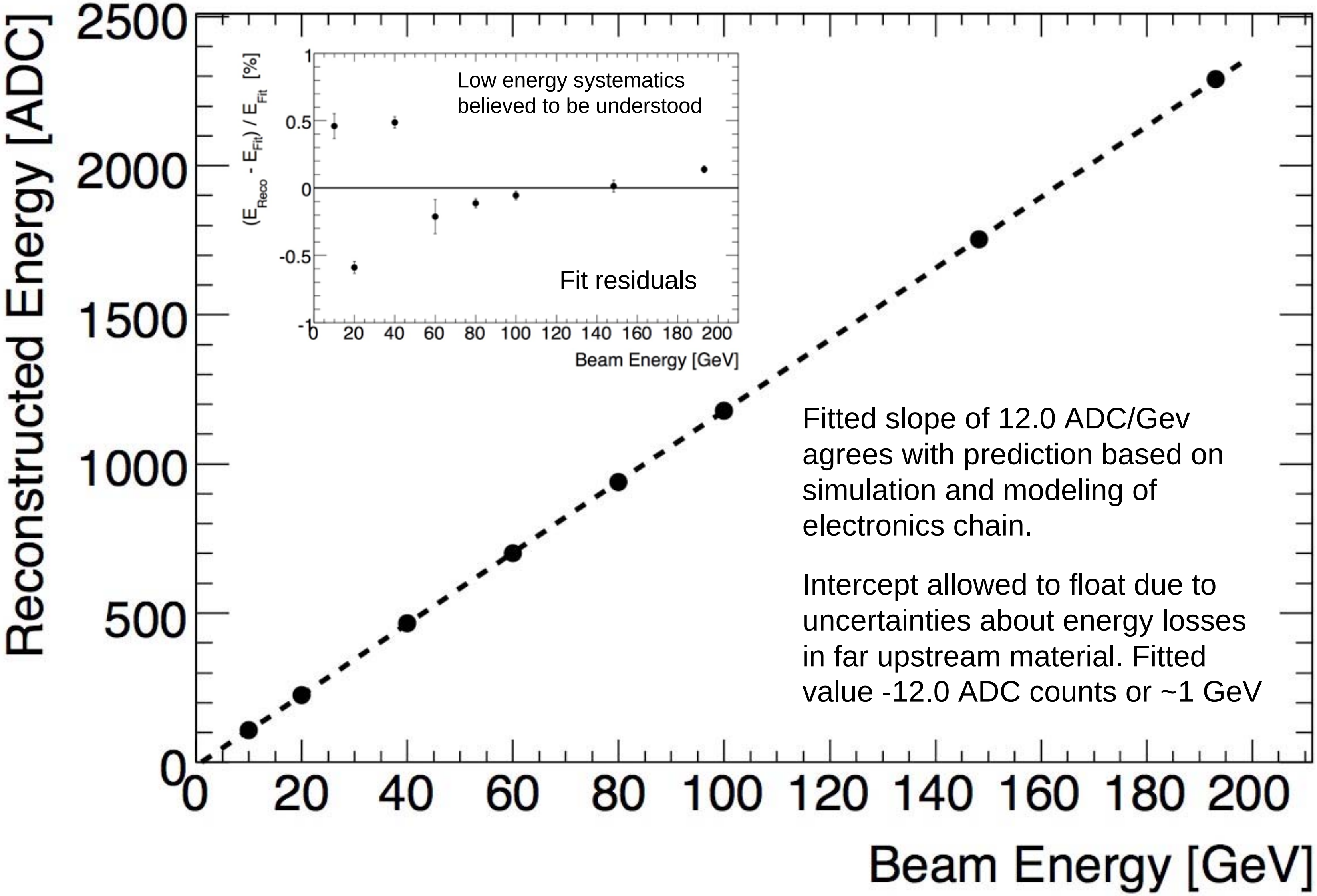






N.B. At 20 Gev fit is DG only. No hadron data recorded at this energy, for modeling of contribution to low energy part of spectrum

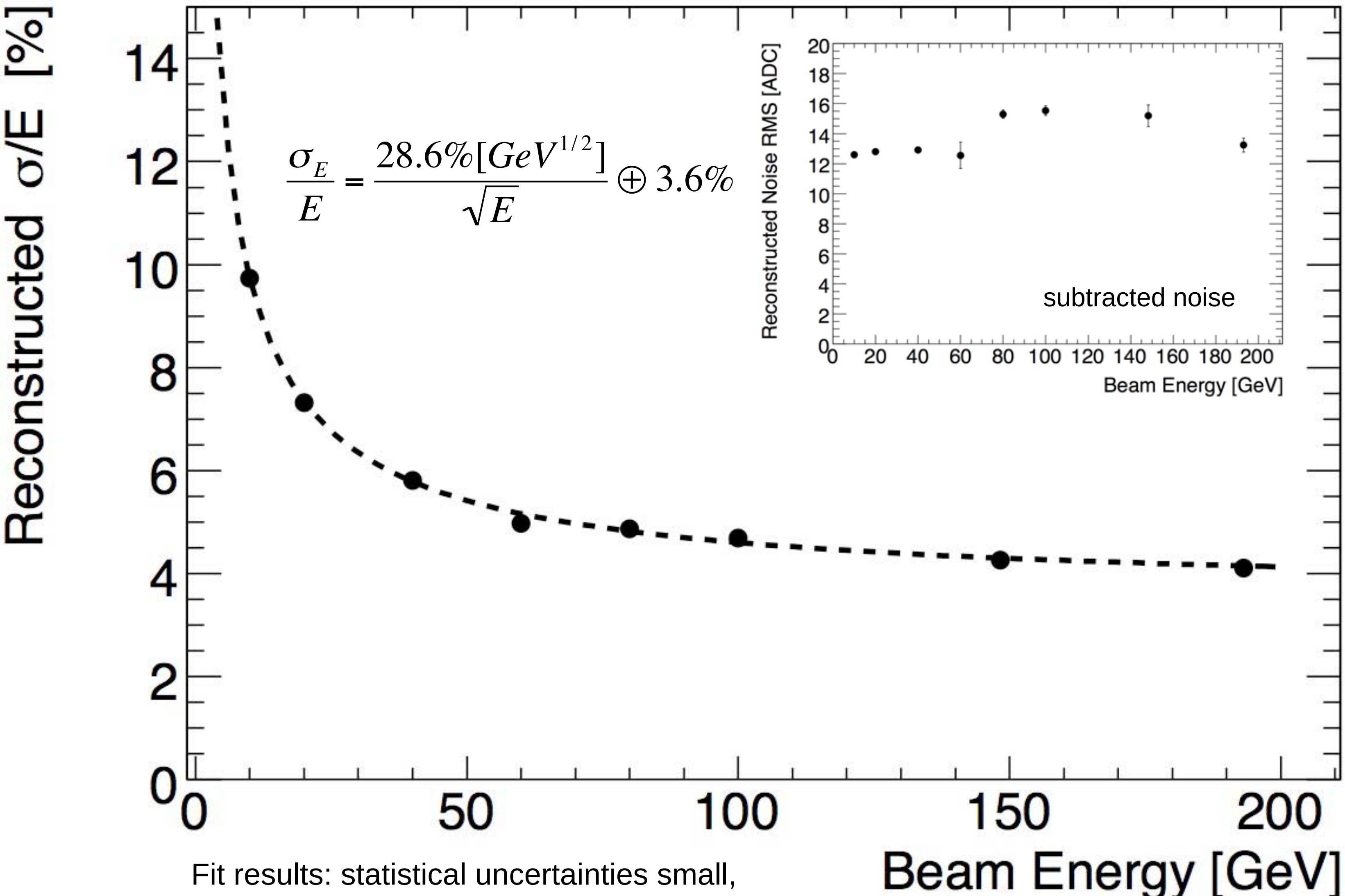
Linearity of Response to Electrons



Fitted slope of 12.0 ADC/Gev agrees with prediction based on simulation and modeling of electronics chain.

Intercept allowed to float due to uncertainties about energy losses in far upstream material. Fitted value -12.0 ADC counts or ~1 GeV

Energy Resolution for Electrons



Fit results: statistical uncertainties small, systematics still under investigation

Hadronic Energy Reconstruction

Two methods: each calculates weights by minimizing $\chi^2 = \sum_{i=1}^{nevents} (E_{beam} - E_{reco,i})^2$

Cylindrical clustering as for electrons (but 16 cm radius) around beam impact point: sum cells reconstructed at the electromagnetic scale, using one weight per module (flat weights):

$$E_{reco} = \alpha_1 g_1(ADC_{FCal1}) + \alpha_2 g_2(ADC_{FCal2}) + \alpha_3 g_3(ADC_{FCal3})$$

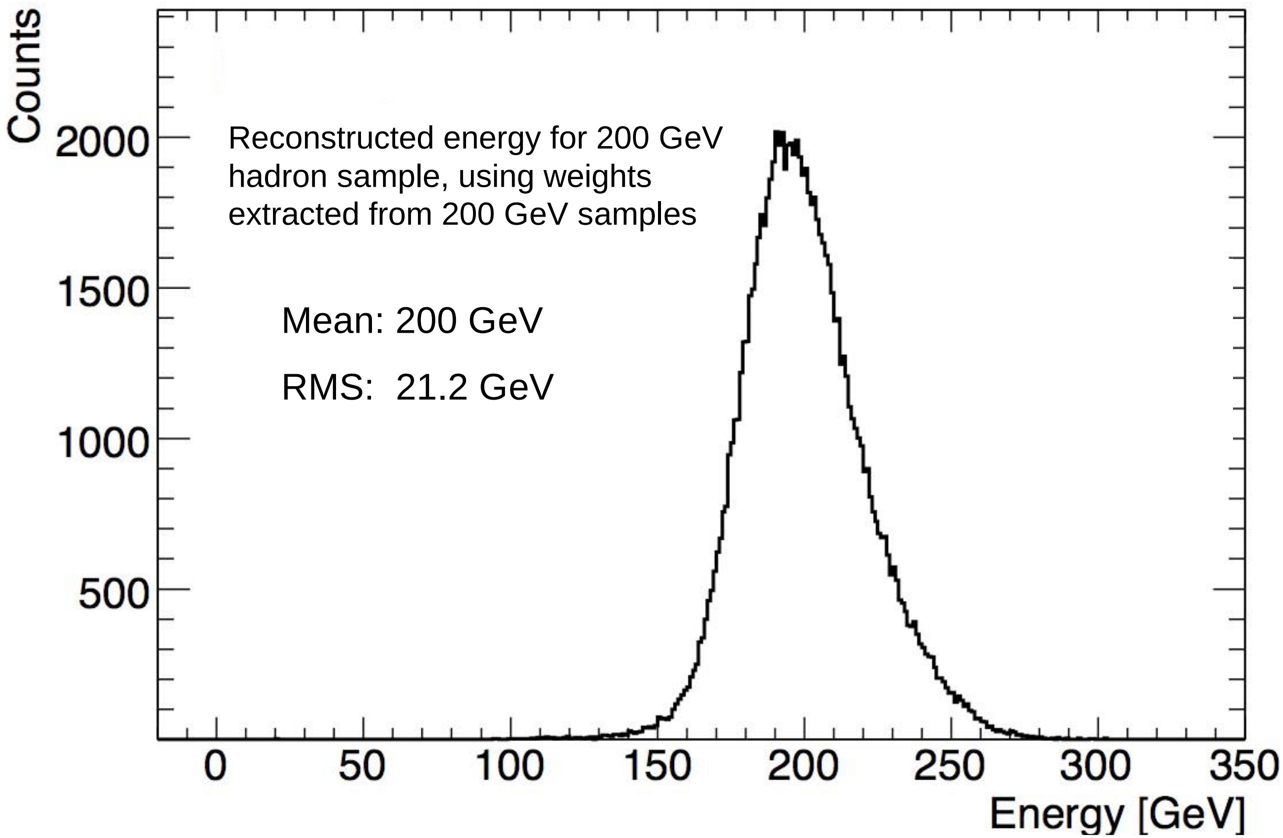
Where the α's are individual EM scale factors and the g's are the fitted weights.

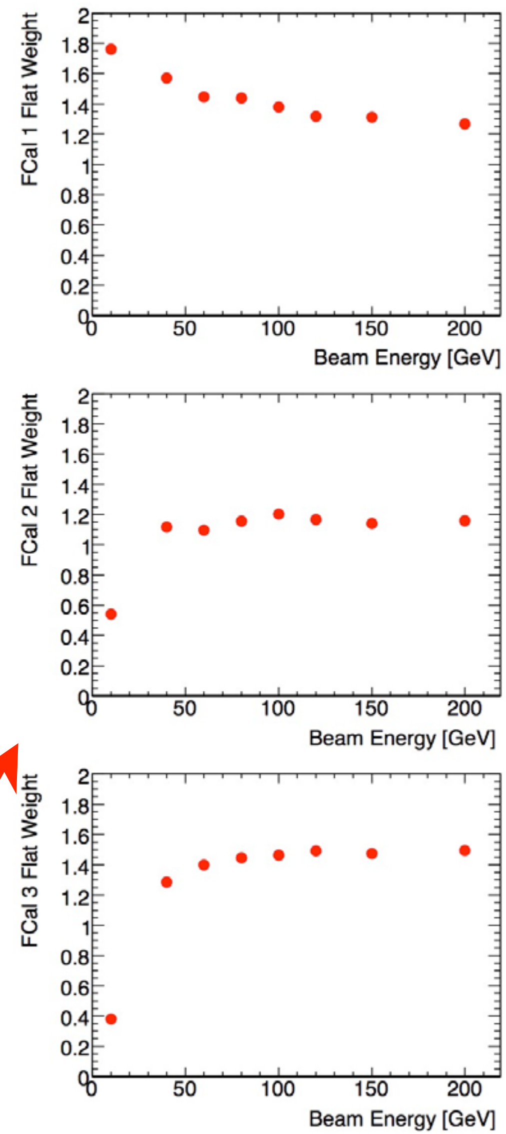
EM scale factors: 12.0 ADC/GeV (FCal1); 6.1 ADC/GeV (FCal2); 5.4 ADC/Gev (FCal3)

Taken from predictions: verified here for FCal1, and for ratio FCal1/FCal2 using previous beam test data with electrons into each (prototype) module, separately.

Weights extracted at each energy. Flat weight results shown here are obtained with the weights extracted from the highest energy sample (200 Gev). Reconstruction with all sets of weights is done for systematic studies

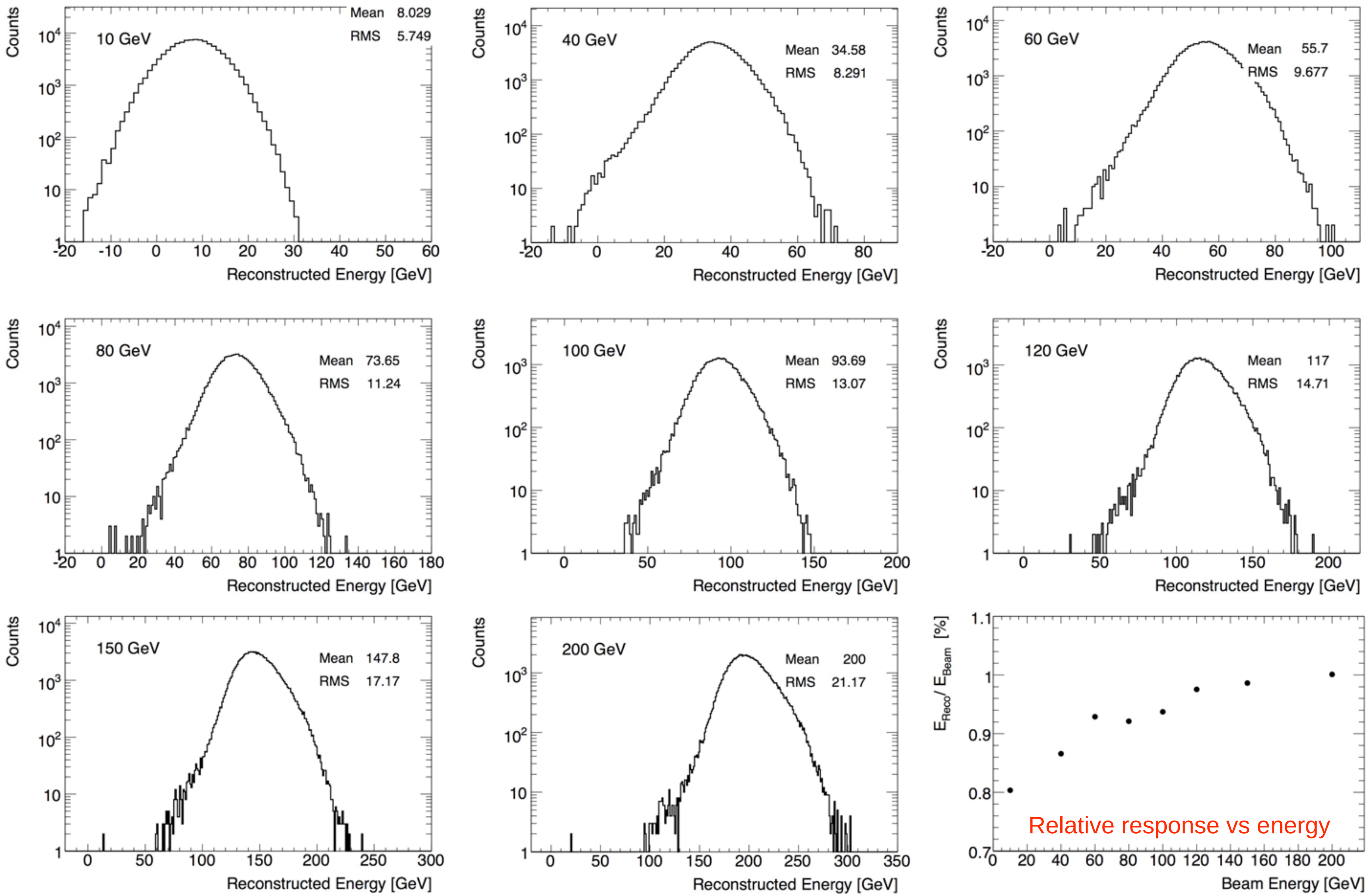
Hadronic Energy Reconstruction (Flat Weights)



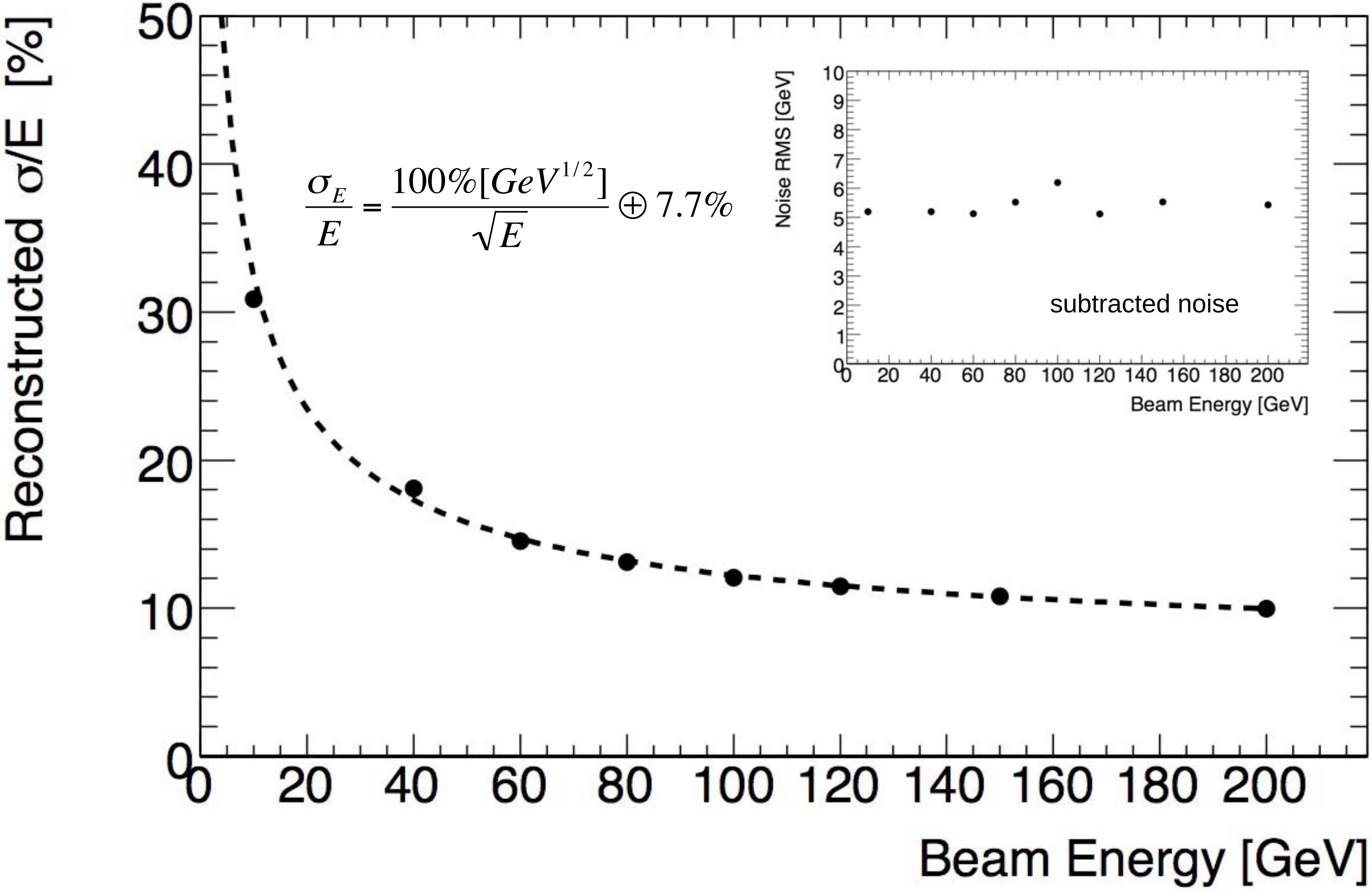


Weights extracted from data taken at each energy point, for each of the three FCal modules. For systematic studies, reconstruction is also done using sets of weights extracted from hadron data at other energies (100,120,150 GeV)

Hadronic Energy Reconstruction



FCal Energy Resolution for Hadrons



Hadronic Energy Reconstruction with Radial Weights

Exploits the fine transverse segmentation of the FCal [see A. Savine Calor 2000 proceedings].

Transverse or radial weighting of cells according to the distance from the beam impact point (taken from the tracking). No clustering (sum is over all instrumented cells).

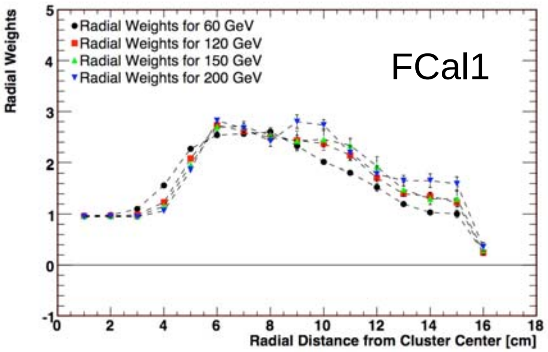
$$E_{reco} = \sum_{j=1}^{ncells} S_j \times W_k(R) \qquad W_k(R) = \begin{cases} W_1 & R < R_1 \\ W_N & R > R_N \\ W_k \times \dfrac{R_{k+1} - R}{R_{k+1} - R_k} + W_{k+1} \times \dfrac{R - R_k}{R_{k+1} - R_k} & \text{otherwise} \end{cases}$$

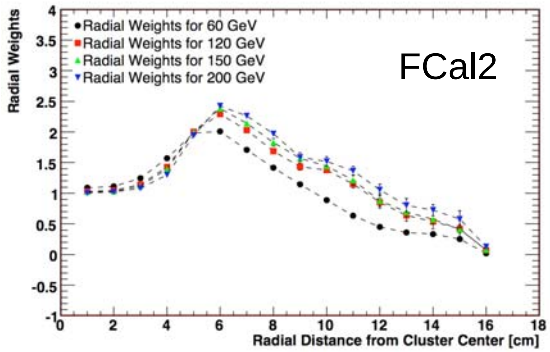
Radial weights $W_k(R)$ obtained by interpolation between set of radial weights $W_k(R_k)$ at discrete distances R_k, where $k = 1,2,\ldots..N$. Here the weights are calculated for distances up to 16cm from the particle impact point (in 1*cm* steps).

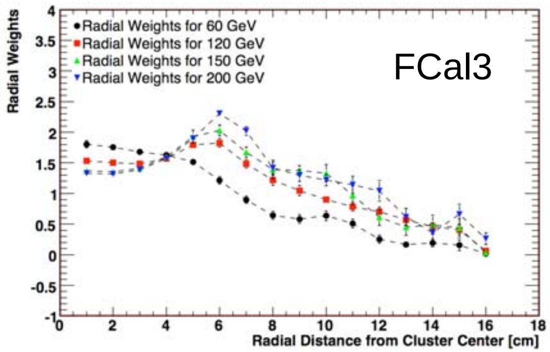
Here S_j is the energy of cell *j* reconstructed at the EM scale.

$N = 16$ for each module, giving a total of 48 free parameters to be fitted.

Energy Dependence of FCal Radial Weights





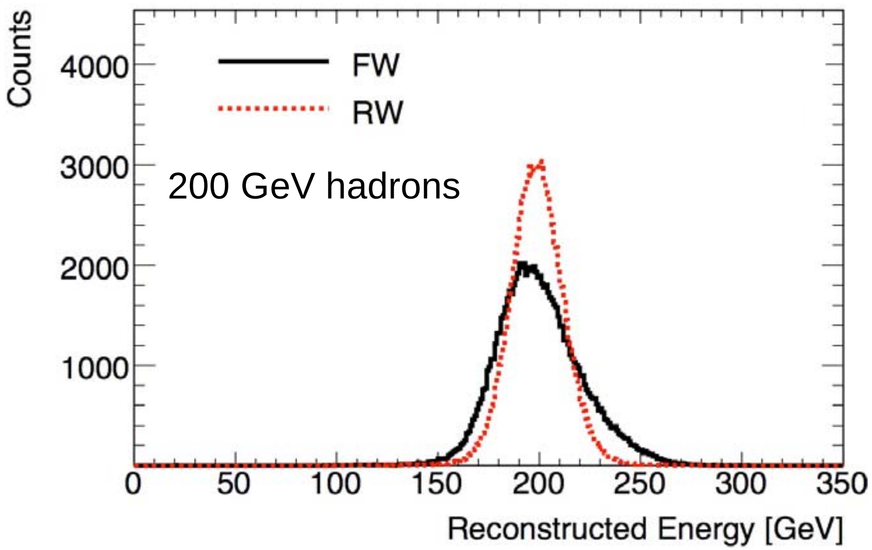


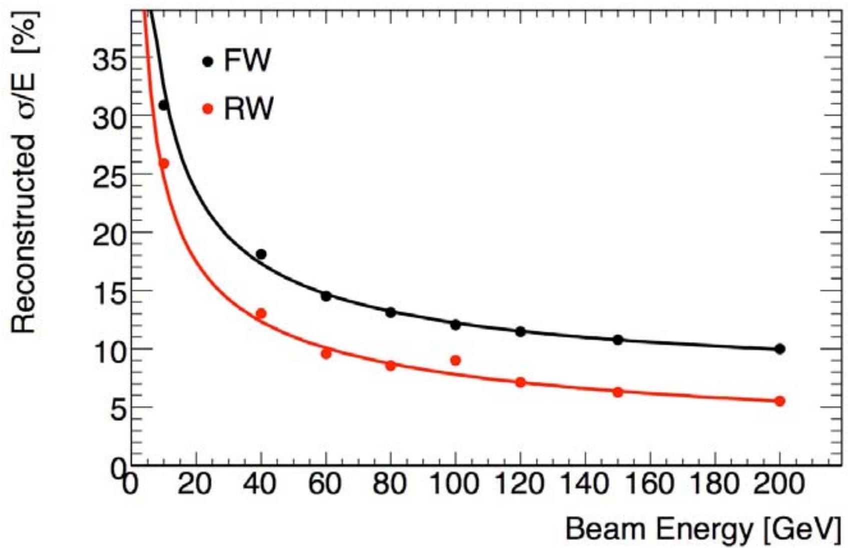
Energy dependence relatively weak for the higher energy samples. Results have been obtained using three sets of weights:

- ✓ Radial weights extracted from 120 GeV hadron data
- ✓ Radial weights extracted from 200 GeV hadron data
- ✓ Average radial weights from 120,150,200 GeV hadron data

Results are the very similar for the three sets of weights. Results shown here are those obtained using the weights derived from the 200 GeV data sample.

Hadronic Energy Resolution (Radial Weights)





Sampling term in resolution function improves from 100% to 78%

Resolution at 200 GeV improves from 10 GeV to ~5 GeV

Optimal application of this technique is still under investigation, as are other weighting techniques that are proposed for hadronic reconstruction at ATLAS.

The flat-weighted results alone are adequate to meet ATLAS performance requirements

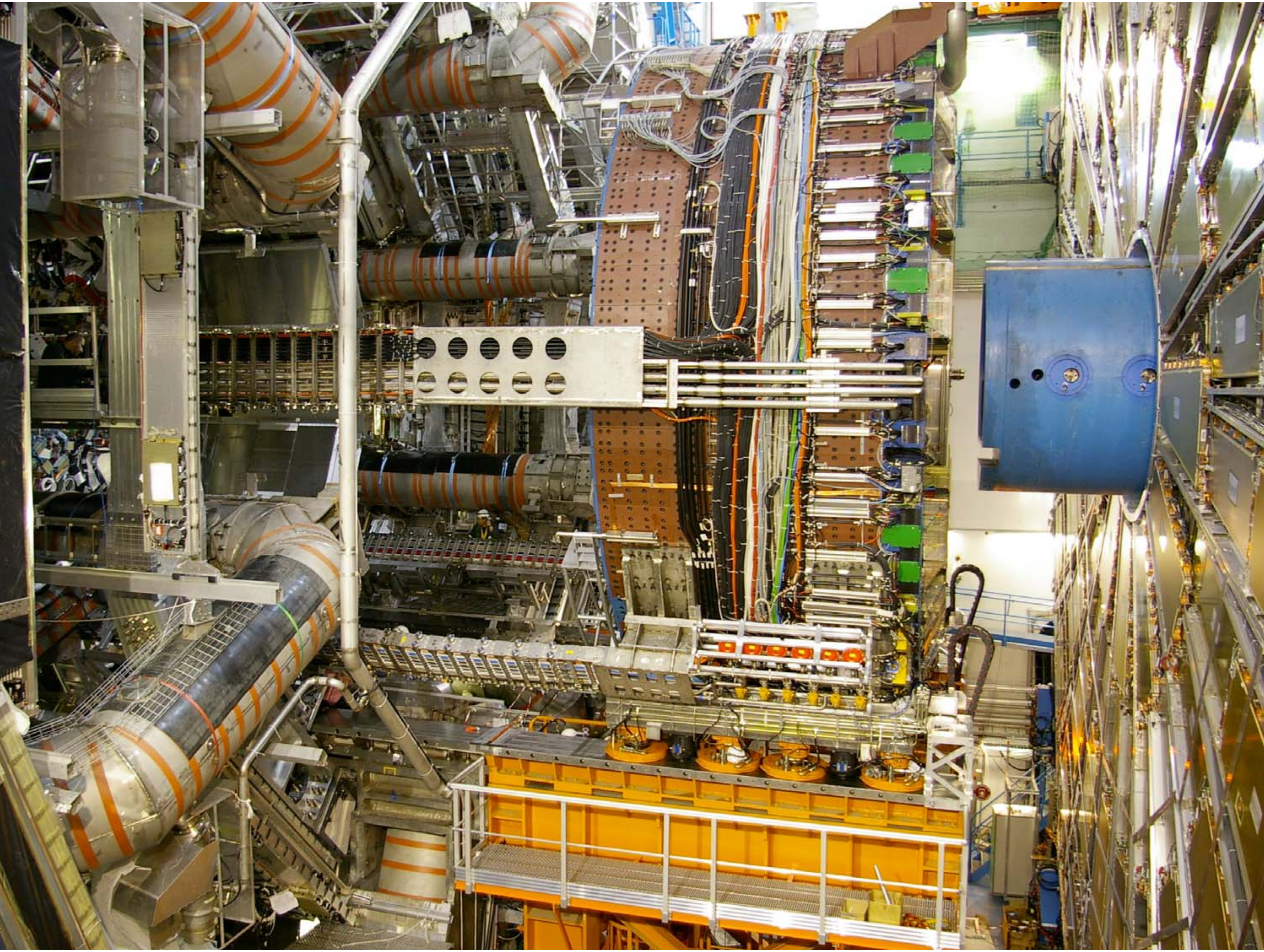
Summary & Outlook

- The three modules of the forward calorimeter for ATLAS have been tested in electron and hadron beams, at energies from 10-200 GeV.
- In-situ calibration of the FCal is difficult due to the absence of tracking information in this region of pseudo-rapidity.
- Response to electrons is linear over this energy range to at least 0.5%
- Resolution performance is

$$\frac{\sigma_E}{E} = \frac{28.6\%[GeV^{1/2}]}{\sqrt{E}} \oplus 3.6\%$$ *for electrons*

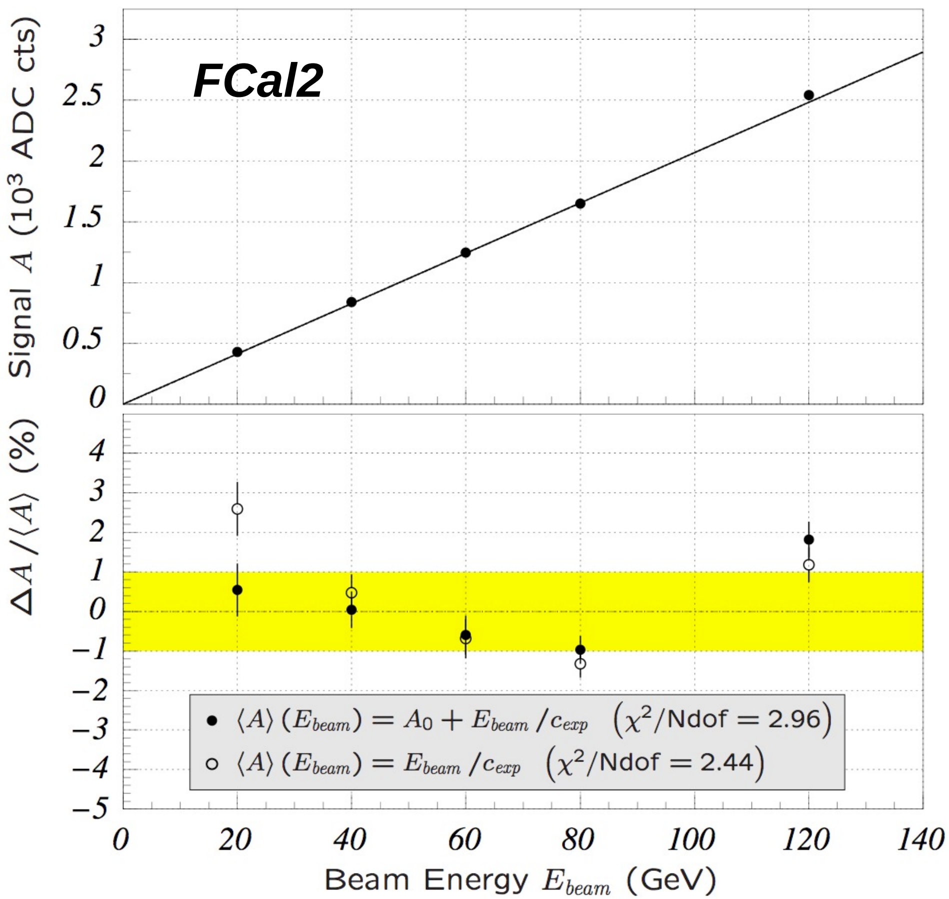
$$\frac{\sigma_E}{E} = \frac{100\%[GeV^{1/2}]}{\sqrt{E}} \oplus 7.7\%$$ *for hadrons*

- This meets or exceeds ATLAS requirements.
- Both ATLAS Endcap Cryostats are currently in the ATLAS cavern. They are full of liquid argon and are powered and read out. Calibration runs using a pulser system are performed regularly, and cosmic data taking is underway with both the LAr Barrel and LAr Endcap Calorimeters.
- And of course, we look forward to data taking next year.



Additional Slides

EM Energy Scale of Hadronic Modules



Beam tests in 1998 included separate tests of FCal1 and FCal2 module prototypes with electrons. Allows for the extraction of the ratio of the FCal1 and FCal2 EM Scales

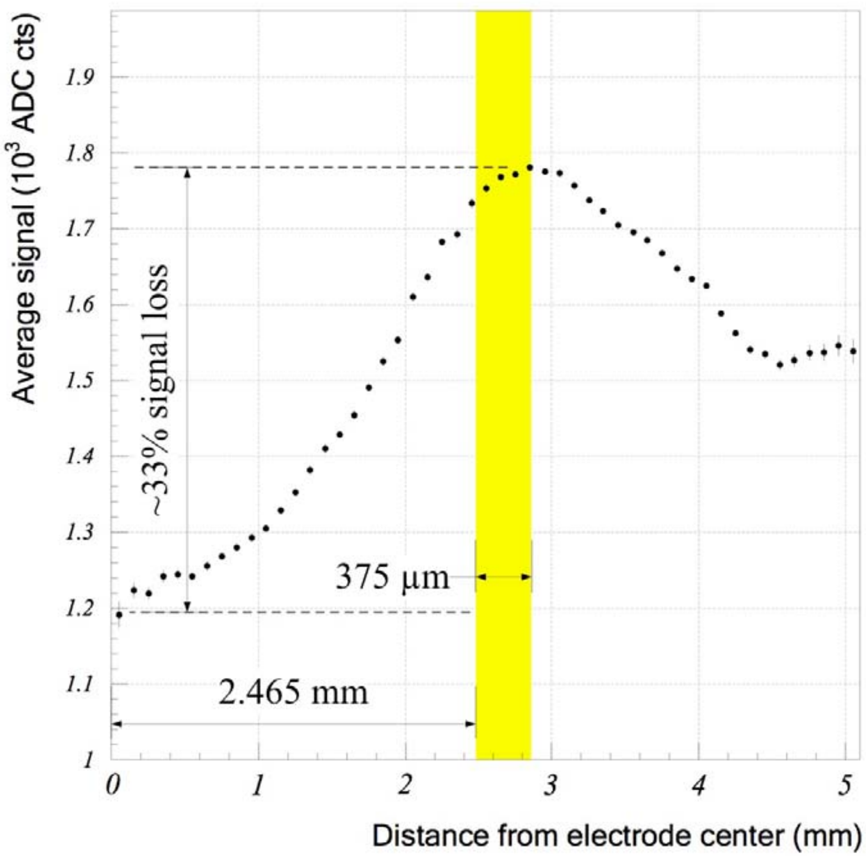
1.852 ± 0.041± 0.022 (measurement)

1.908 ± 0.027 (simulation)

Measurement need correction for different electronics: ratio of e SFs of 1.425

Impact Point Dependence of FCal Response

Effect illustrated first using the FCal2 for which the effect is more pronounced due to the much denser absorber structure (tungsten).



Effect less pronounced in the FCal1 module: trough to peak variation is about 10% rather than the 30% effect seen in the tungsten