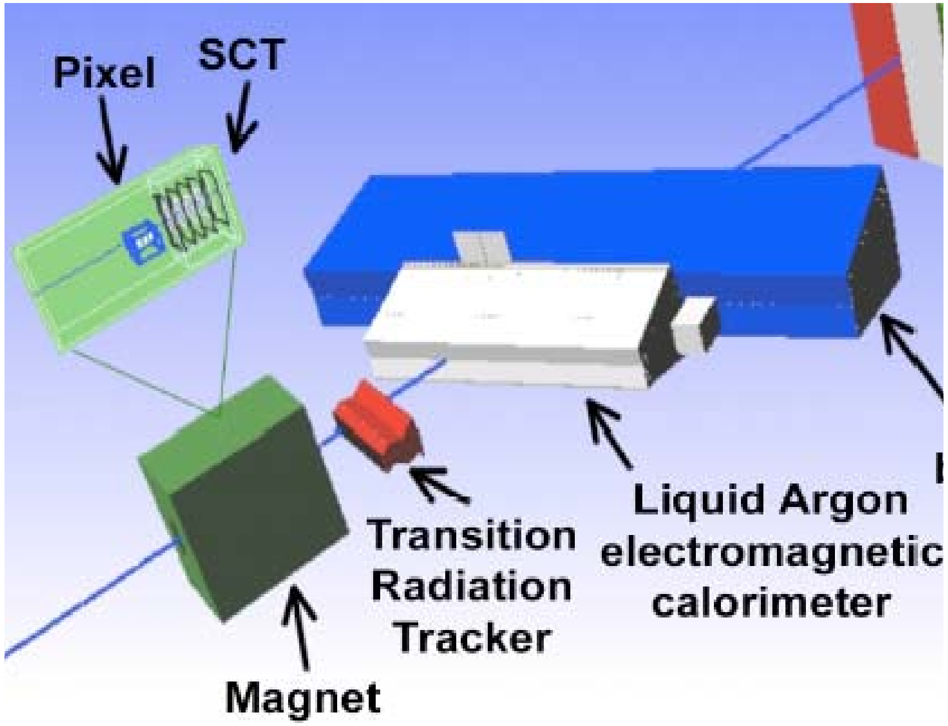
Status of MC validation in ATLAS



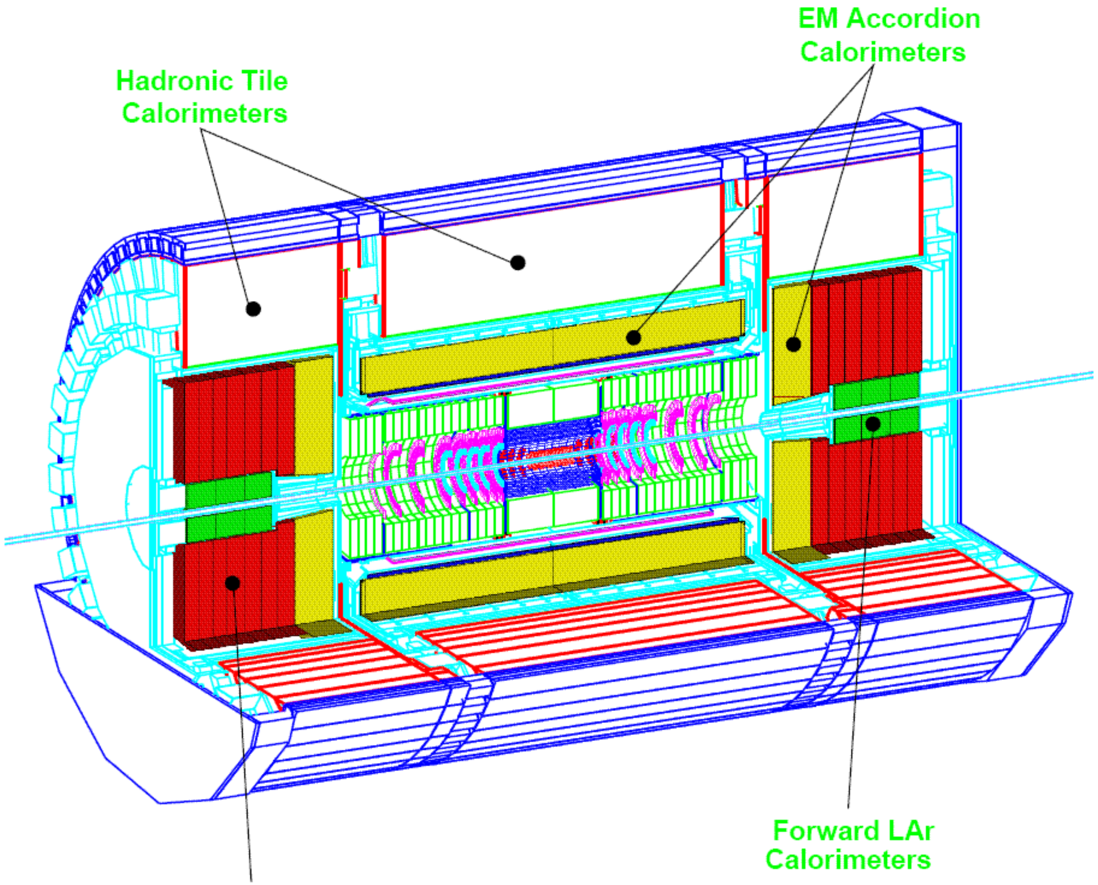
Tancredi.Carli@cern.ch

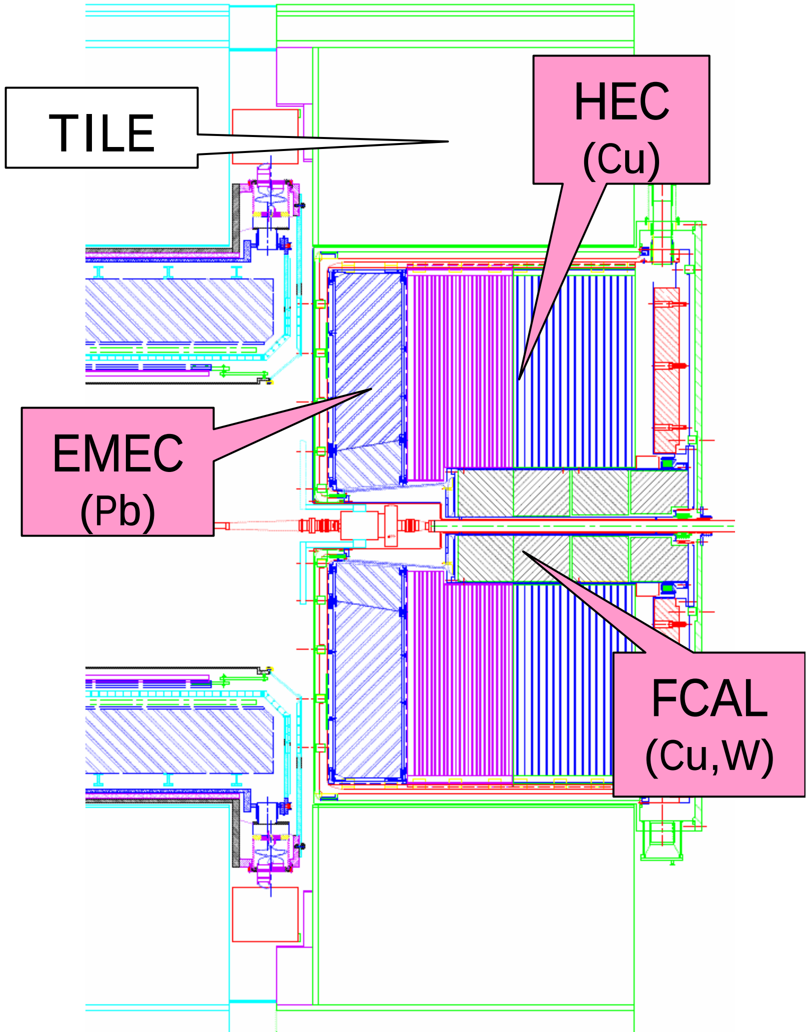
17/07/2006

- Atlas Detector and Calibration Strategy
- MC validation of whole detector
  some examples
- Electrons in LAr Barrel TB02
- Muons, pions in combined test-beam 2004
- Pions, protons in Tile calo TB02/03

I will only cover the calorimeter aspects…
inner detector and muon chambers should be included in the future

ATLAS Calorimetry





LAr Calorimeters:

- em Barrel : (|η|<1.475) [Pb-LAr]
- em End-caps : 1.4<|η|<3.2 [Pb-LAr]
- Hadronic End-cap: 1.5<|η|<3.2 [Cu-LAr]
- Forward Calorimeter: 3.2<|η|<4.9 [Cu,W-LAr]

- ~190K readout channels
- Hadronic Barrel: Scintillating Tile/Fe calorimeter

MC Validation

1) Detector geometry and test-beam set-up
   (cables, electronics, air in beam-line)

2) Detector response: physics processes in detector
   (charge collection in complicated E-fields,
   recombination, photostatistics, light attenuation,
   Birk's law)

3) Electronic signal modeling and noise

For the moment we are mostly busy with this… and start to work on 4)

4) Physics processes: Interaction of particles with detector

ATLAS plans (as baseline) to use the G4 MC for calibration of the detector

→ We need a good MC ! How good ? …to be tested in Test-Beam

Dead Materials Correction and Hadronic Calibration

Atlas records “true” energy deposition in each calorimeter cell

and in $\eta\times\phi$ grid in dead material

Energy is split 4 types: e.m./non-e.m./invisible/escaped

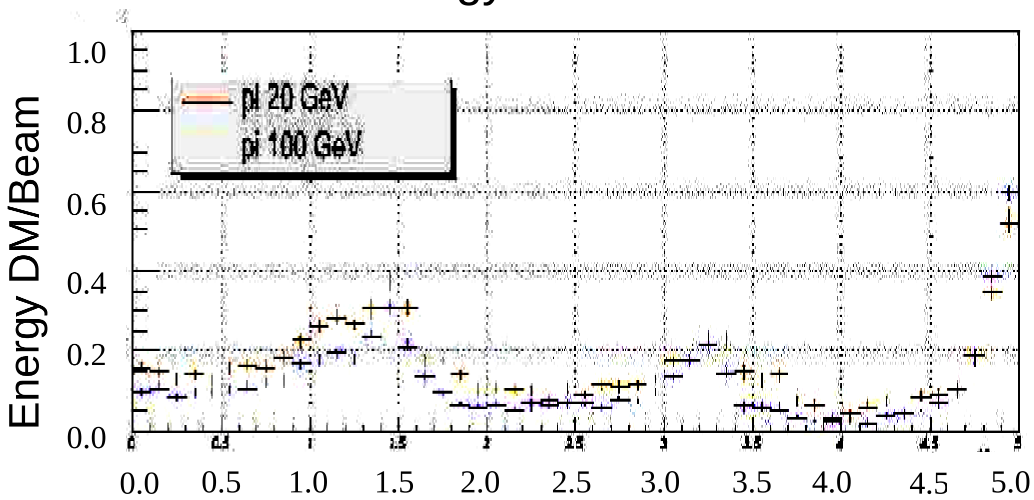
→ Atlas plans to base dead material correction, electron calibration, hadronic weighting (e/π–compensation) on MC, if possible !

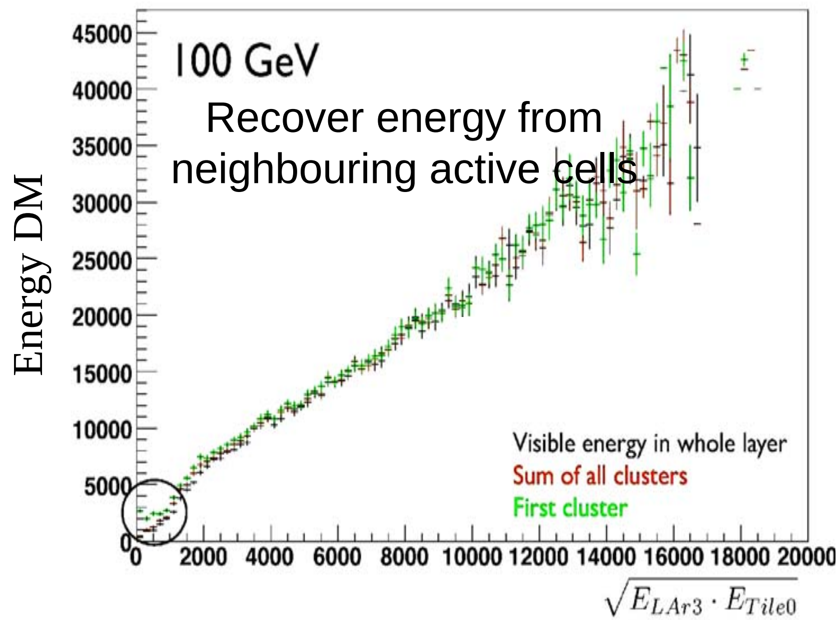
Example:

Recover energy ‘lost’ between sub detector elements

Example : The LAr-Tile crack

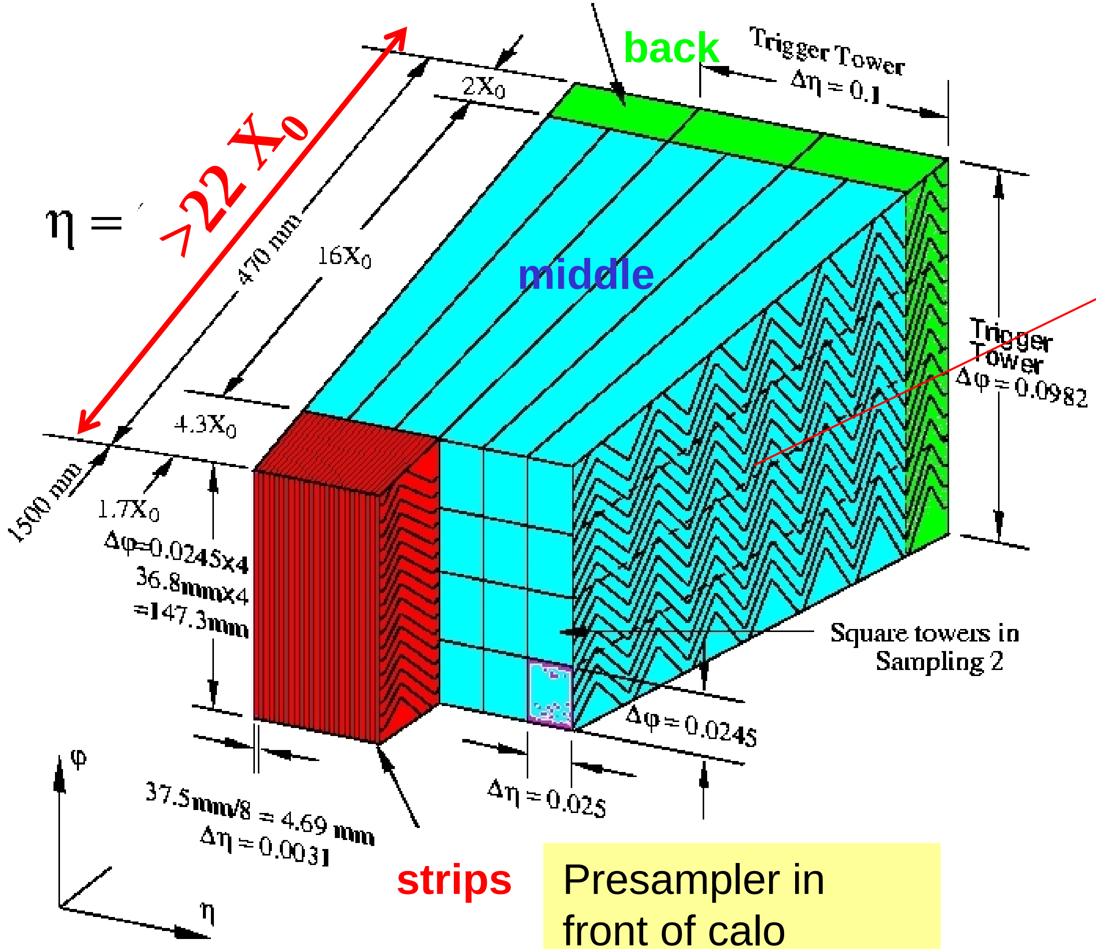
Fraction of energy lost in dead materials





The E.M. ATLAS Calorimeter

Lead/Liquid Argon sampling calorimeter with accordion shape :



Presampler in front of calo up to $\eta = 1.8$

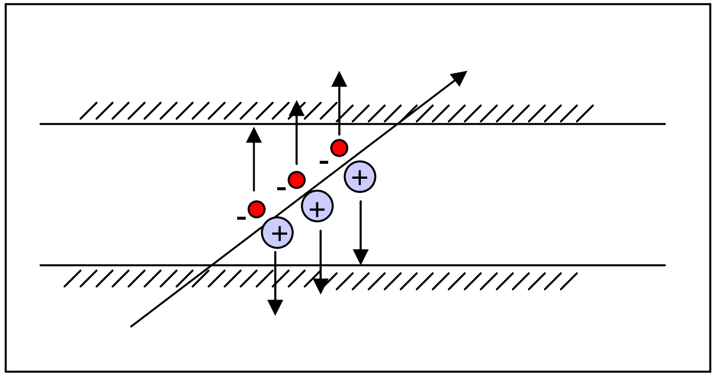
Main advantages:

- LAr as act. material inherently linear
- Hermetic coverage (no cracks)
- Longitudinal segmentation
- High granularity (Cu etching)
- Inherently radiation hard
- Fast readout possible

Lar: Sensitive Detectors and Visible Energy

Active volumes :

readout cells *sensitive detectors for* *Charge collection*



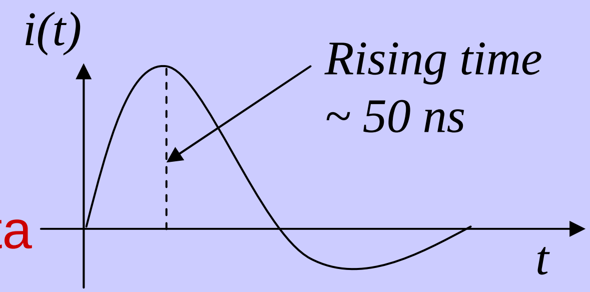
$$\frac{\Delta I_0}{\Delta E} \propto r(\varepsilon) \times v_d(\varepsilon) \times \frac{\varepsilon}{V}$$

- current
- recombination
- electric field map
- energy deposition
- drift velocity
- high voltage

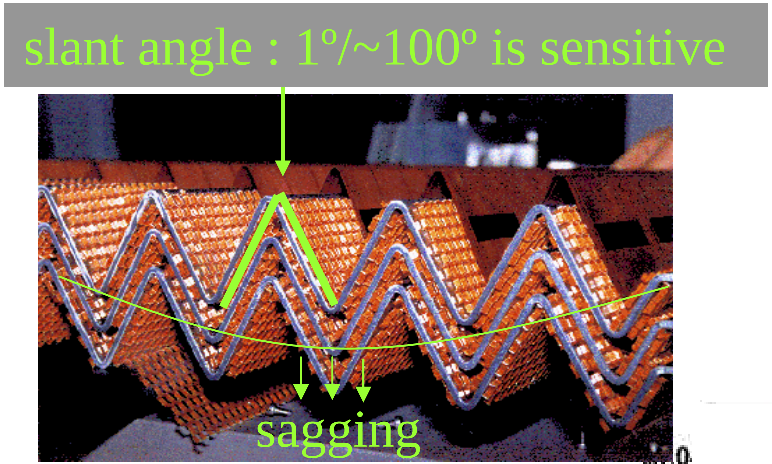
model E-field in accordion

include the electronics response

→ Signal is reconstructed as in data



Example: EM Endcap as “Detector as Built”



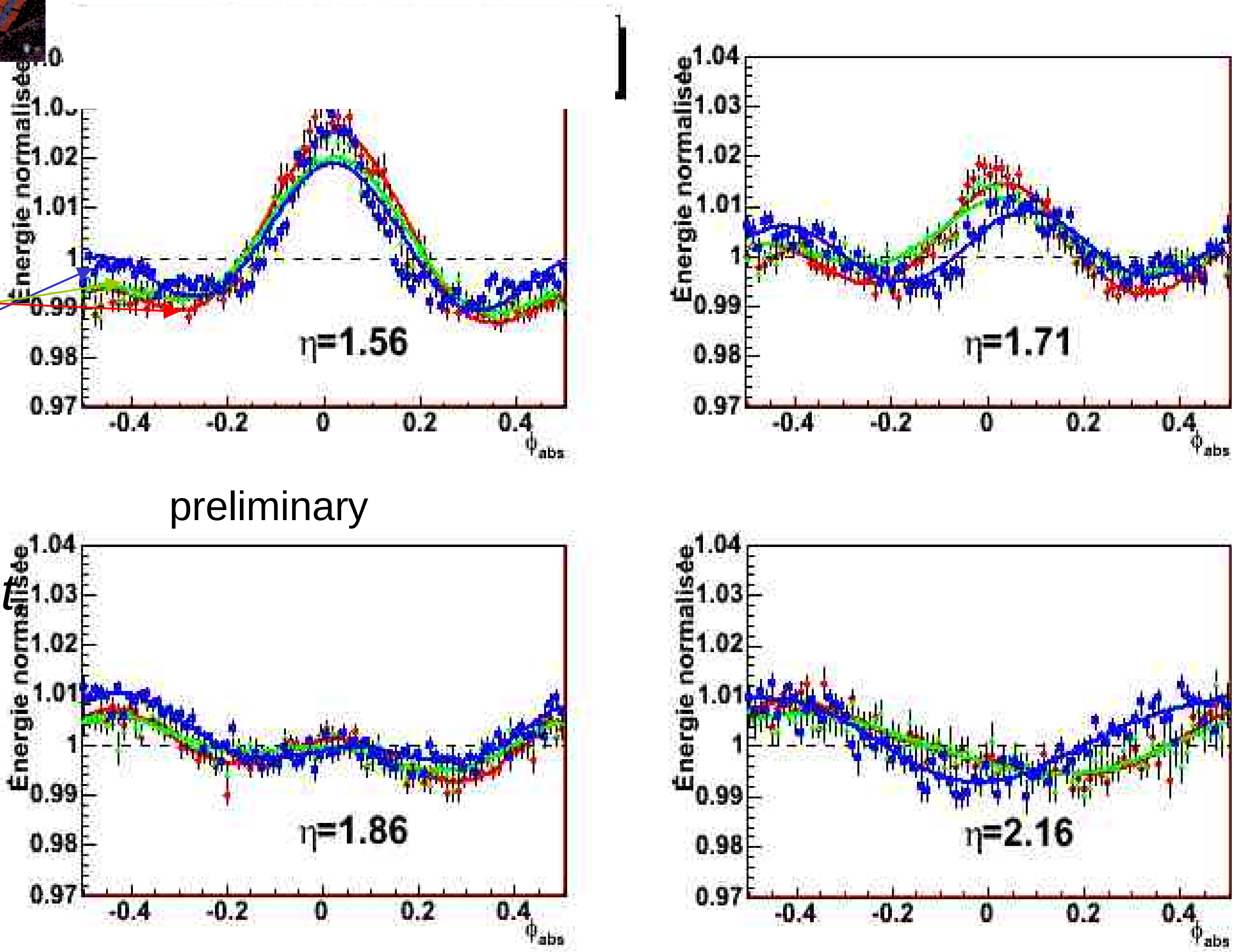
EM calorimeter : Pb absorbers
Peculiar accordion shape

standard simulation
+ charge collection
+ gap adjustment
Test Beam Data

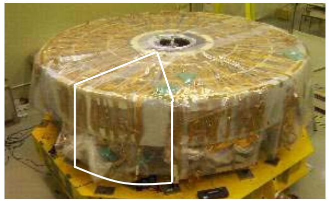
Recent efforts simulate an ‘as built detector’ : HV, sagging, misalignment, measured lead thickness, gap variations, charge collections, read-out electronics, cables etc.

ϕ-modulations :

Response to 120 GeV e-showers

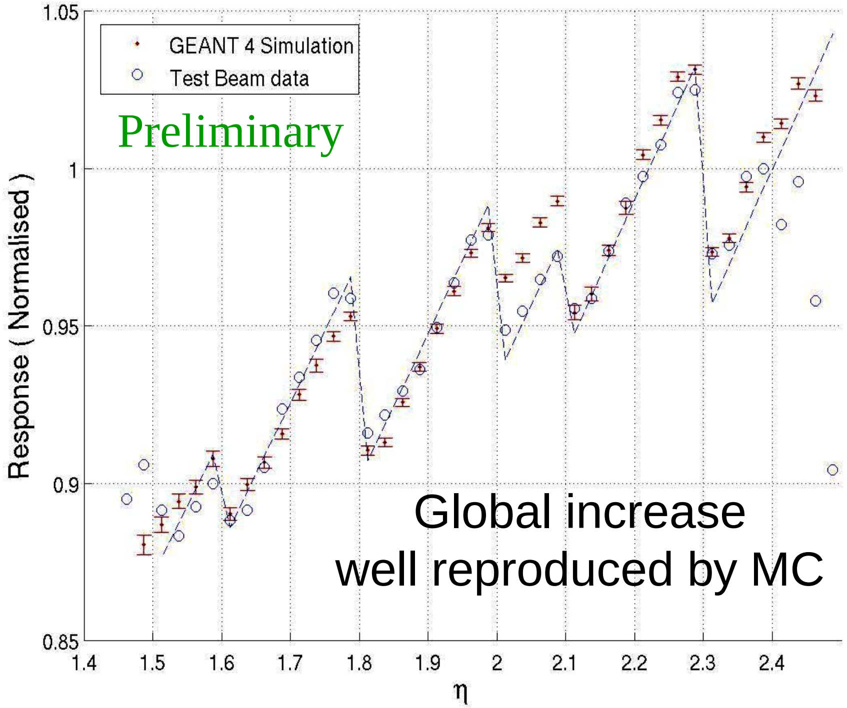


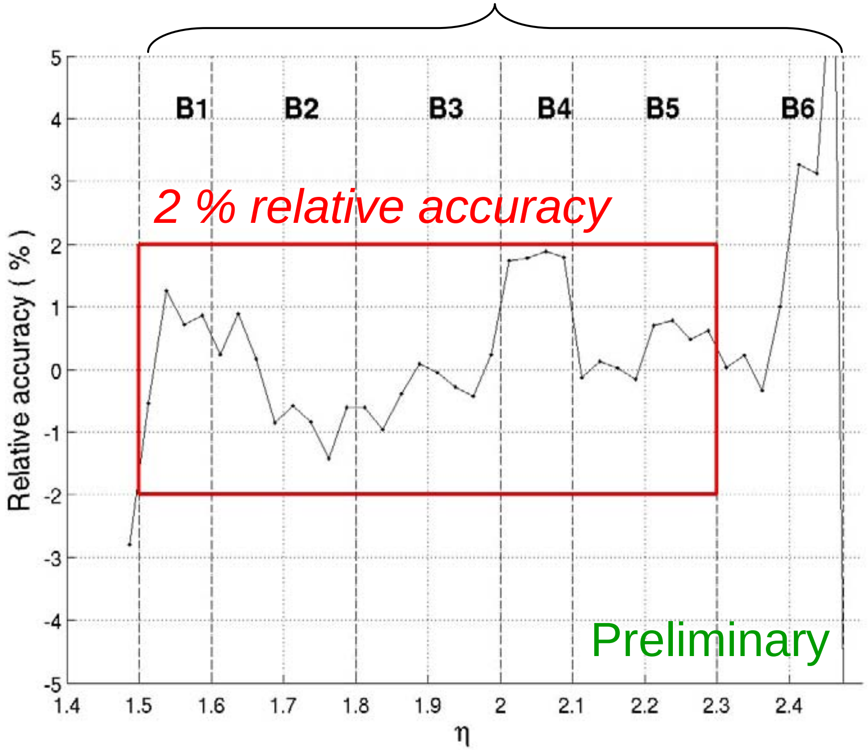
EM EndCap Cell Response



EM Endcap has complex geometry
Cell reponse depends on eta

High Voltage sectors



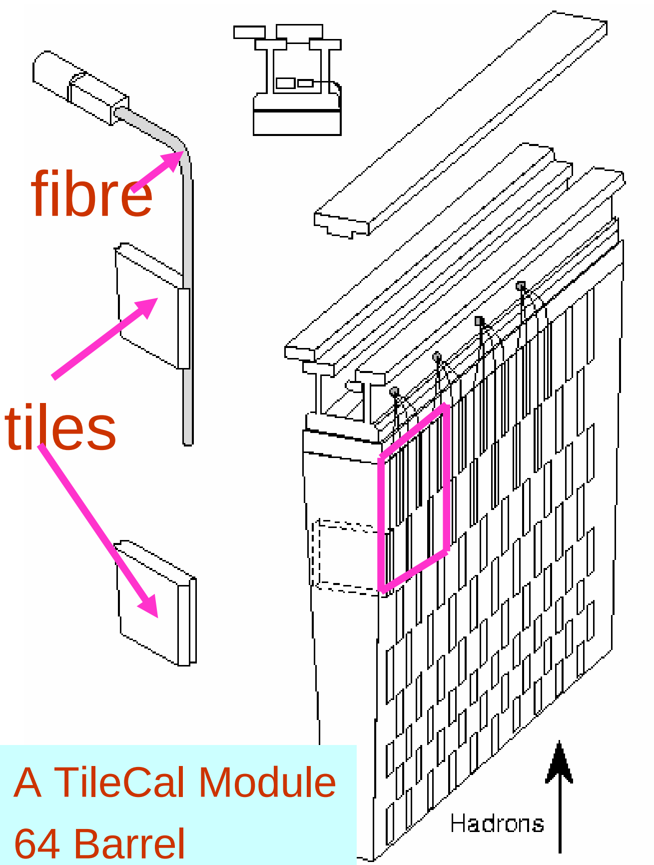


Simulation vs Test Beam
EMEC, 120 GeV electron Showers

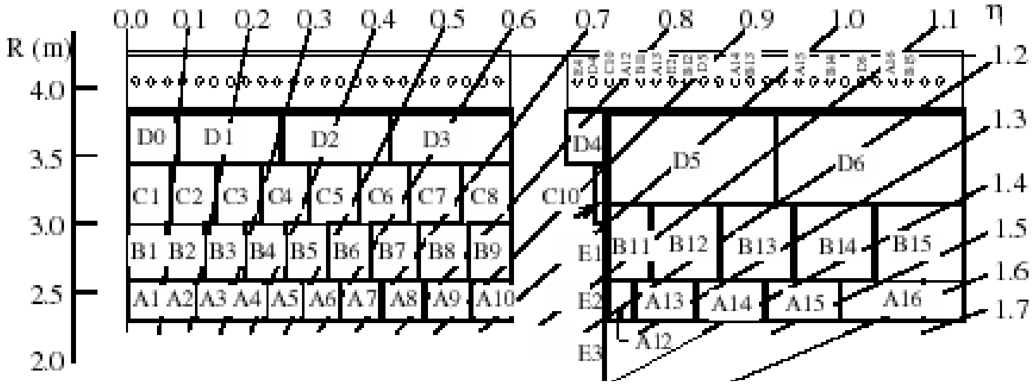
…still some work left !

The TileCal Barrel Calorimeter

Scintillating Tile/Iron Calorimeter



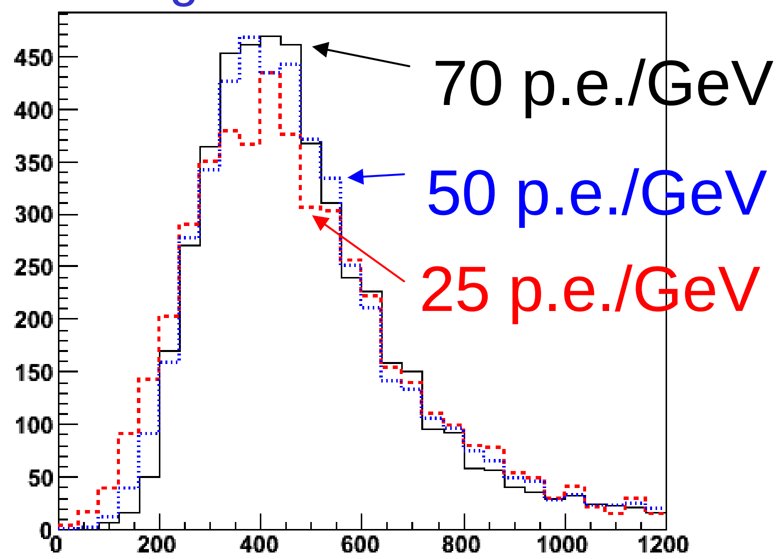
A TileCal Module
64 Barrel
2x64 Ext. Barrel



Recent improvements in MC:
→ Sampling fraction adjustement
→ electronic signal modeling and reconstruction
→ Photostatistics of photomultipliers
→ light attenuation between tile (work in progress)

Muon signal in the A cell

Example:



Test-Beams

Outline:

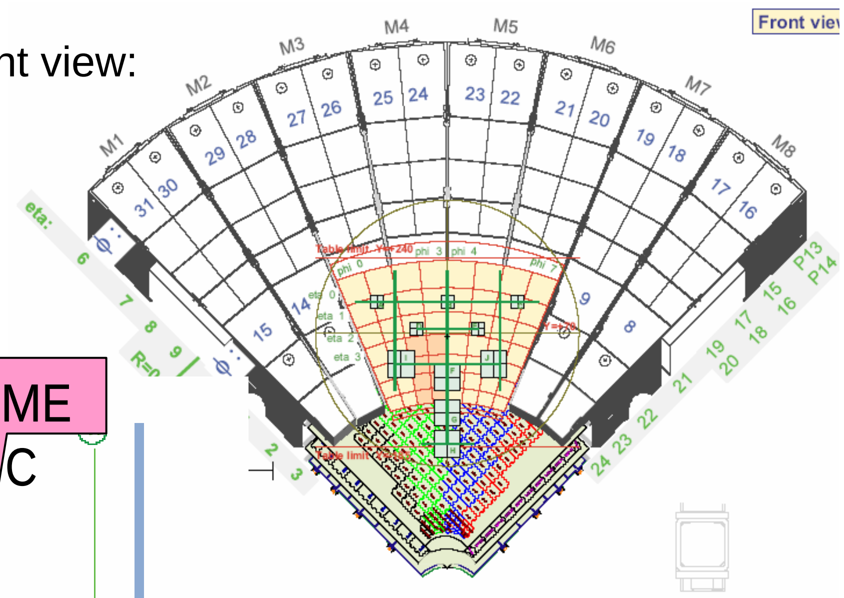
1) H6: Combined end-cap test-beam: ECAL/HEC/FCAL
2) EM LAr Barrel TB02
3) H8: combined barrel test-beam: full slice of ATLAS detector
4) Tile calorimeter standalone test-beam

We have recently finished to incorporate consistently the simulation of
All detectors and 2002-2004 test-beams in our software framework Athena

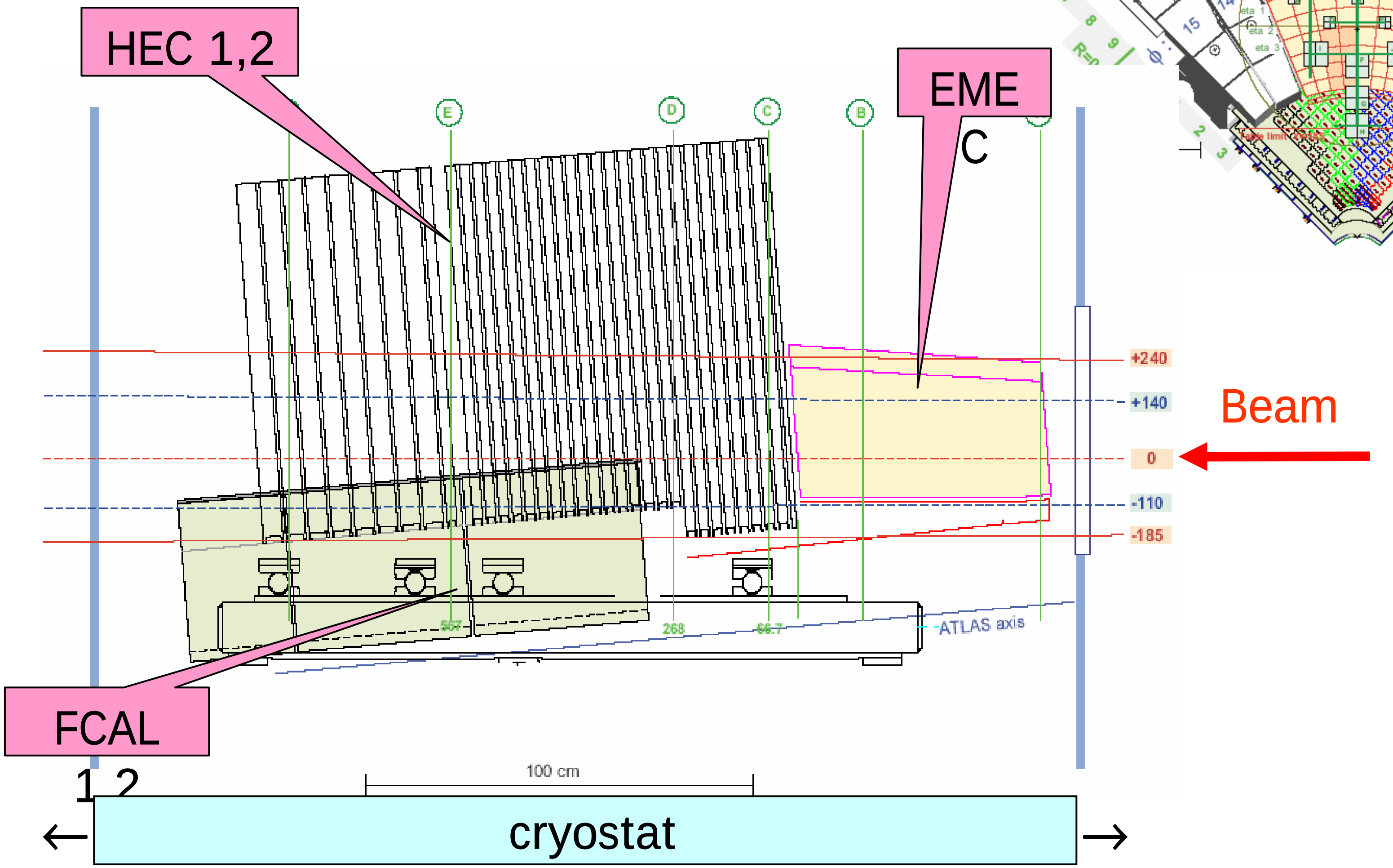
Technical work is finished, more detailed MC/Data comparisons can start

H6 Test-beam Set-up

Front view:



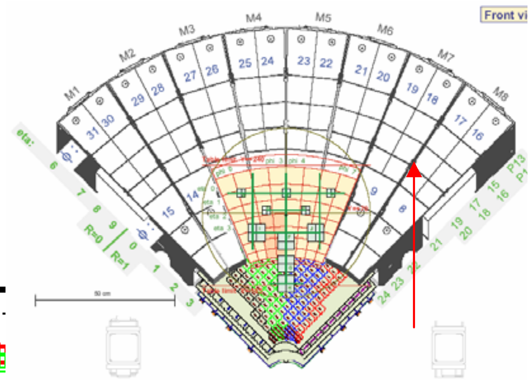
Side view:

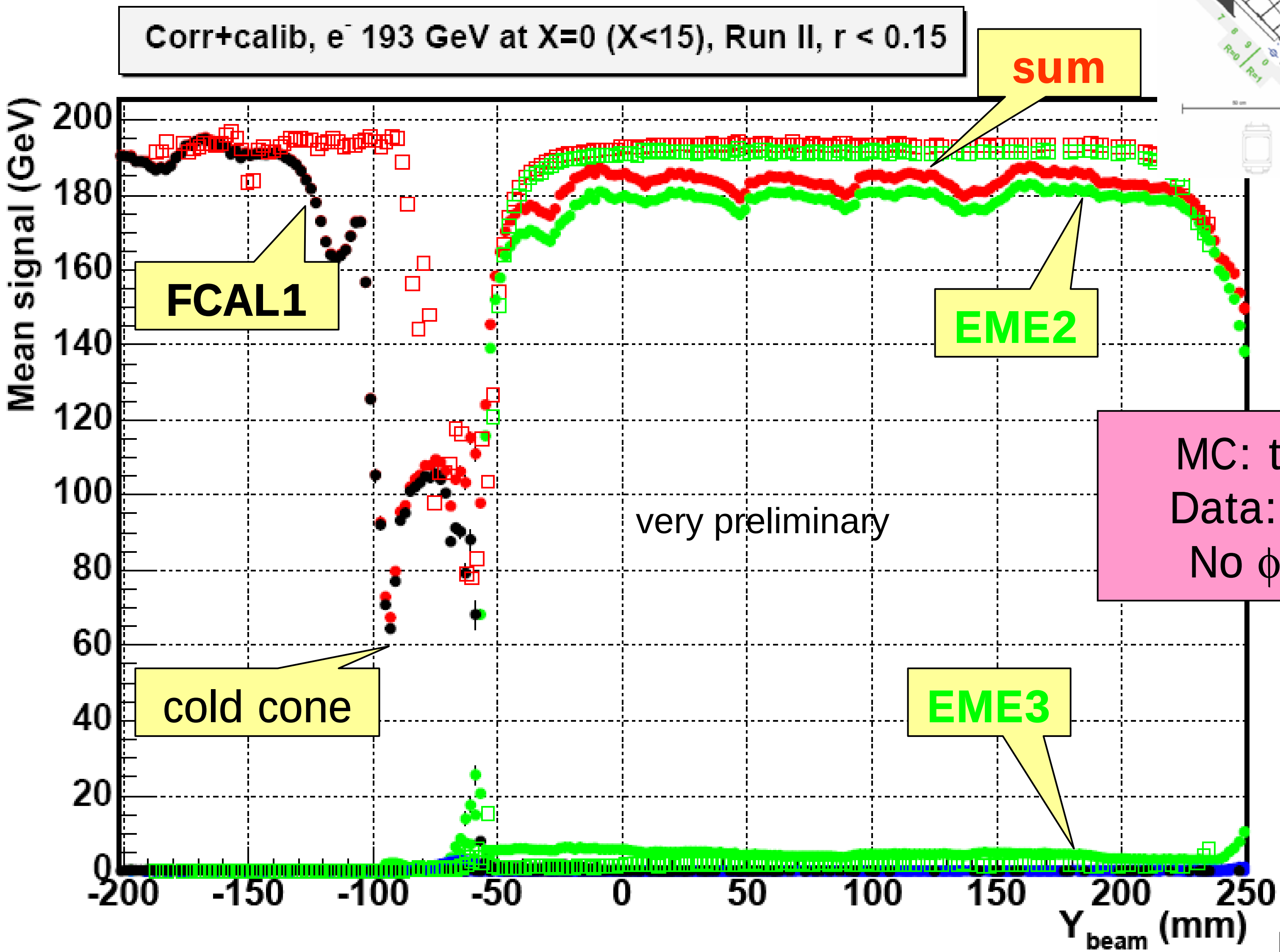


Goal: calibrate complicated region with various dead material zones and 3 different calorimeters

Electrons (193 GeV): vertical scan x=0

- MC: Open squares; Data: solid points;



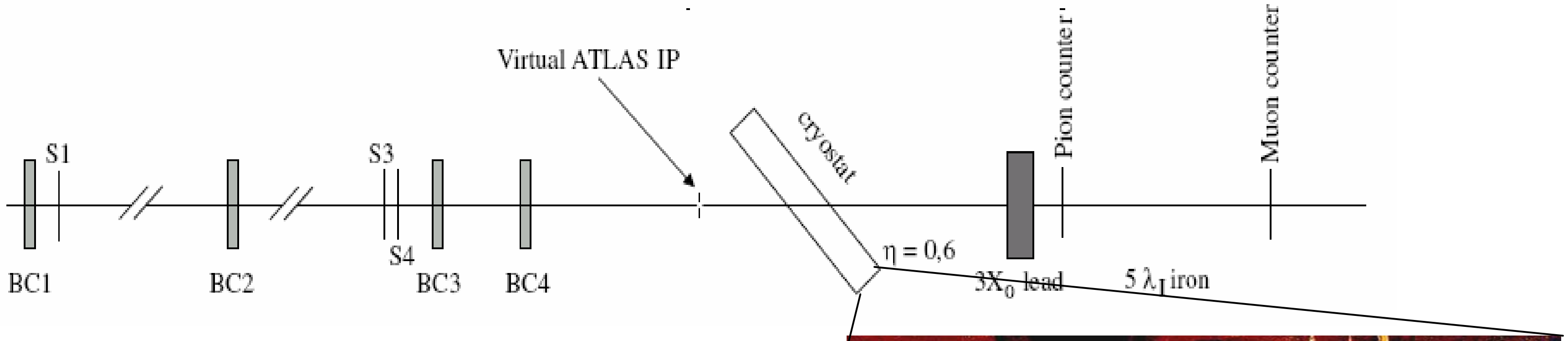


MC: total energy!
Data: 3×3 cluster!
No ϕ correction!

→ Check and improve detector description in crack region

Pion data being analysed

EM Barrel Test-Beam 2002

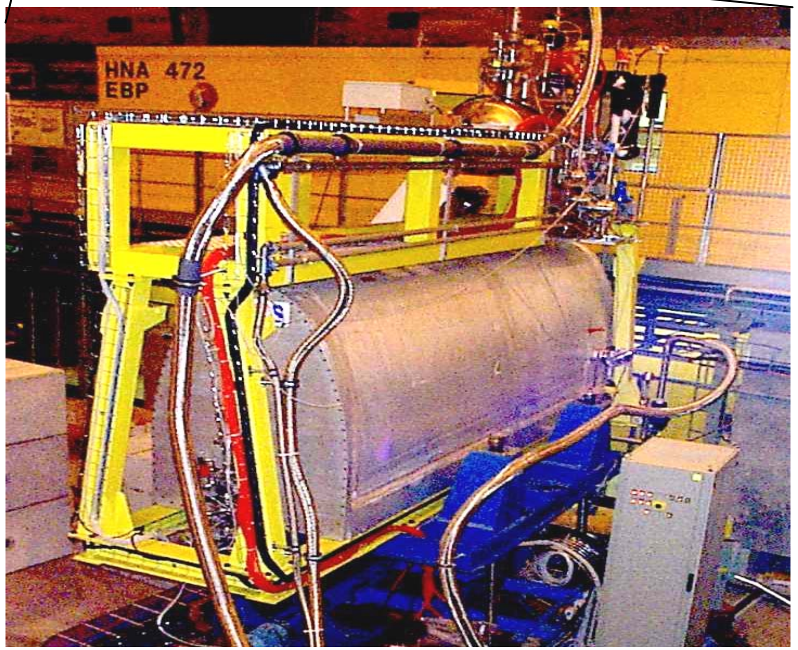


Test-beam 2002:

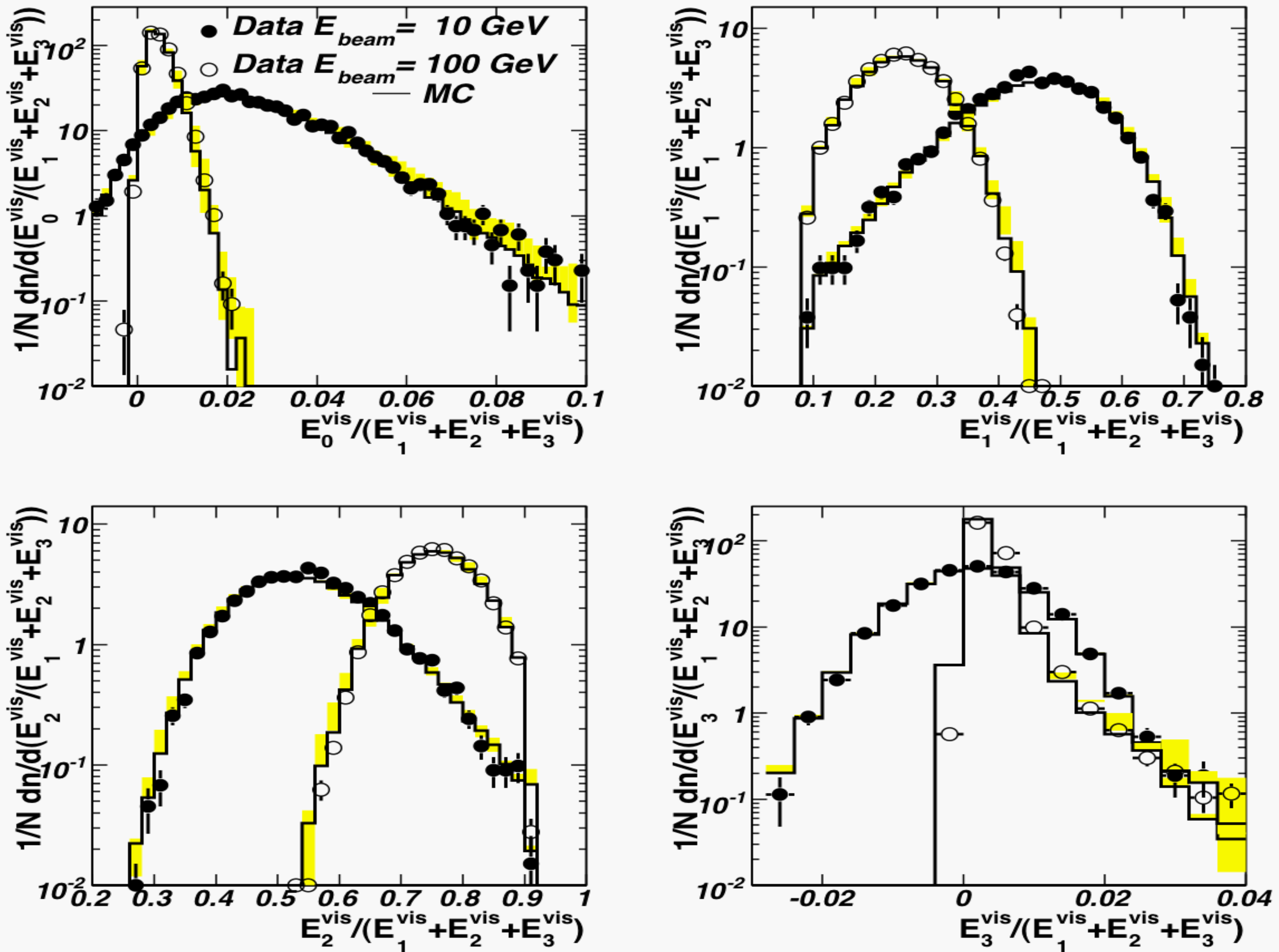
Uniformity: 3 production modules η/ϕ scan

Linarity: E-scan 10 -245 GeV at eta=0.69 phi=0.28

thanks to special set-up to measure beam energy: linearity of beam energy known to 3 10^{-4} and a constant of 11 MeV (remnant magnet field)



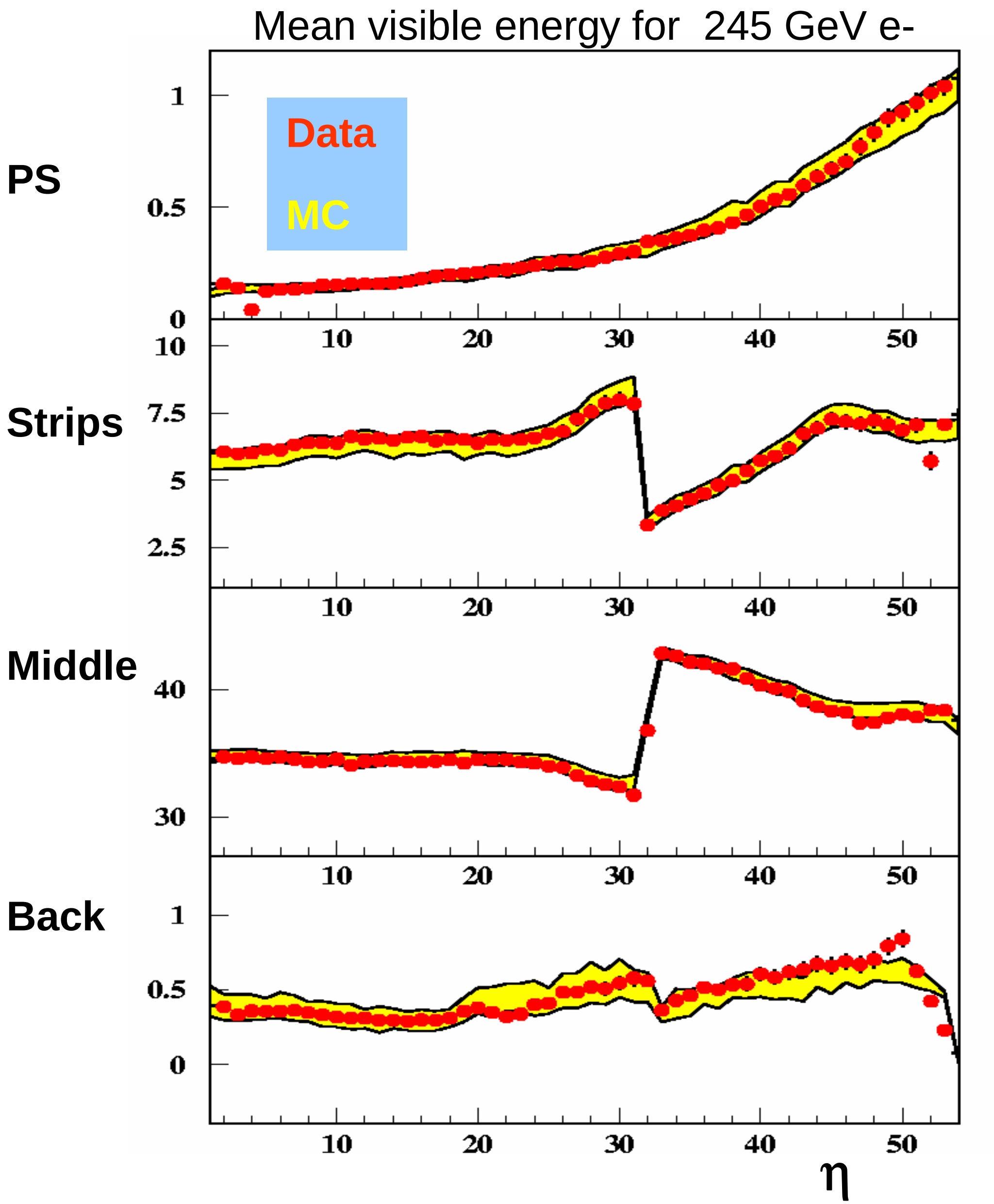
Electron: Data/MC Comparison – Layer Energy Sharing



Most difficult: correct description of DM material

Band due to uncertainties in material estimation

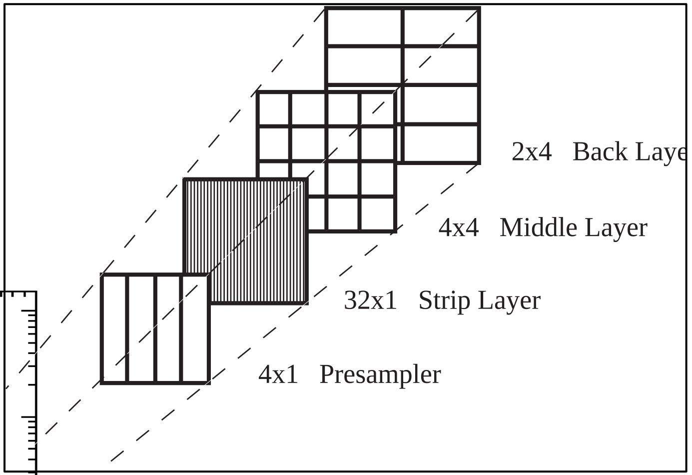
Electron: Data/MC Comparison – Layer Energy Sharing



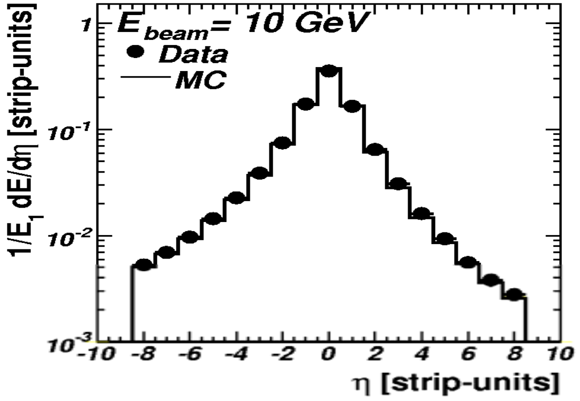
Deposited energies = f(η) in the PS and in the 3 calorimeter compartments before applying the correction factors

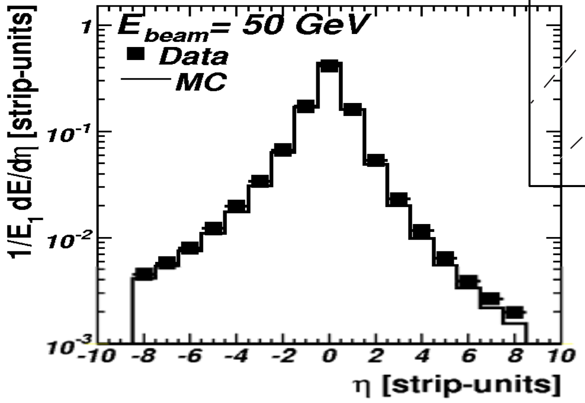
Excellent Data / Mc agreement

Electron: Data/MC Comparisons – Radial Extension

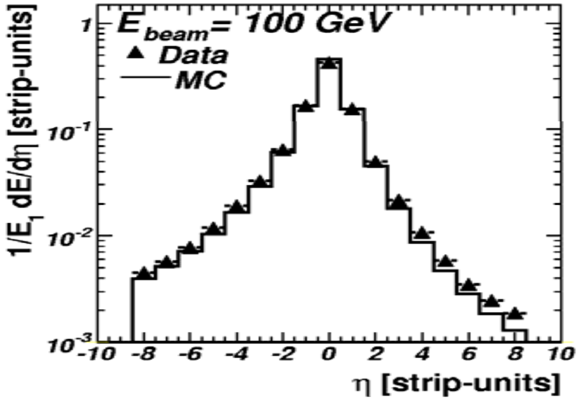


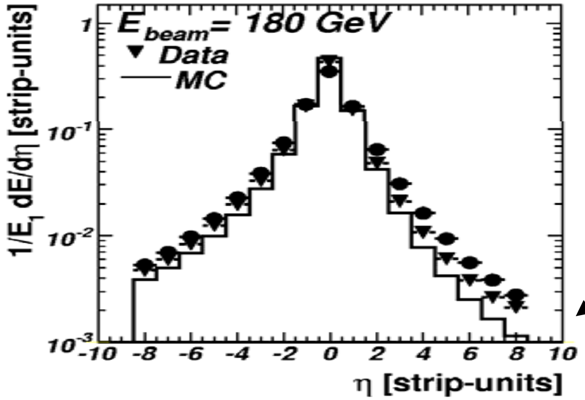
First layer:





MC uncertainty shown but not visible





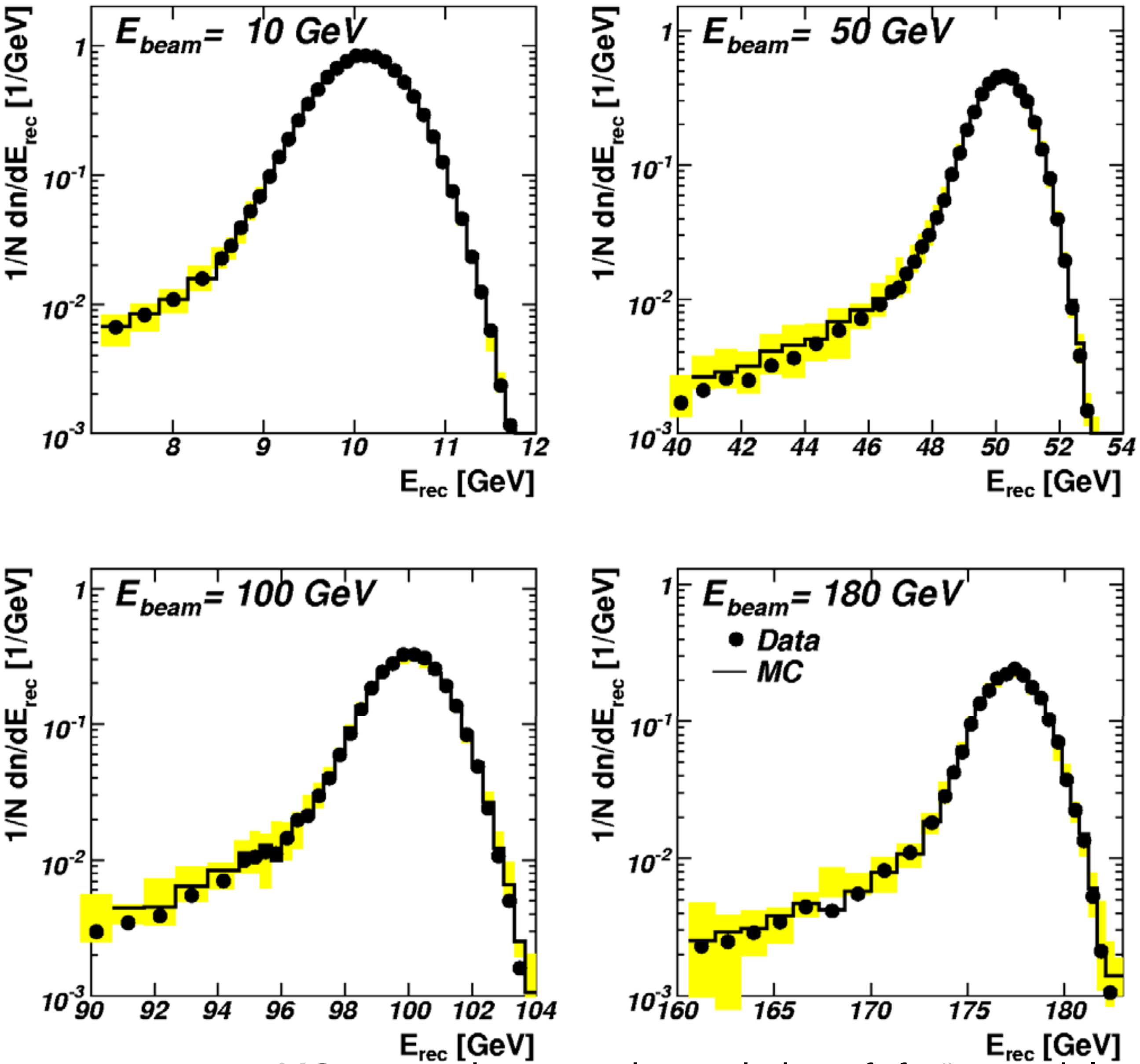
We do not know why this Is, can be

- detector geometry ?
- beam line ? distribution of material ?
- cross-talk ?
- G4 physics problem ?

•Good description also for asymmetry

Problems in tails at large energy
Might be a problem for particle ID in Atlas

Electron: Data/MC Comparisons – Total Energy

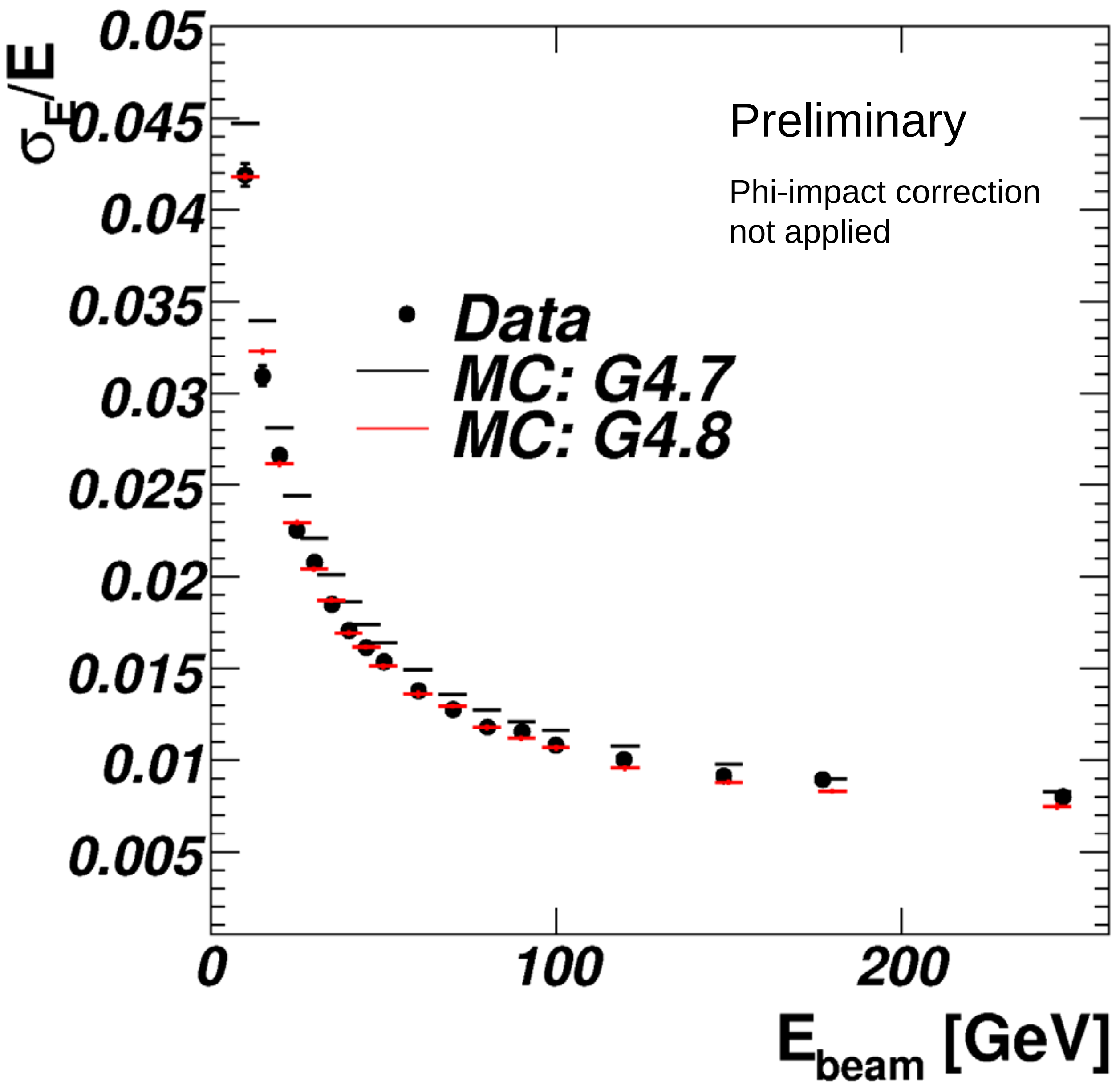


MC uncertainty contains variation of „far“ material

Need to fold in acceptance correction for electrons having lost large energy in „far“ material (from beam-line simulation)

mean visible energy is reproduced within 0.1% (energy linearity)

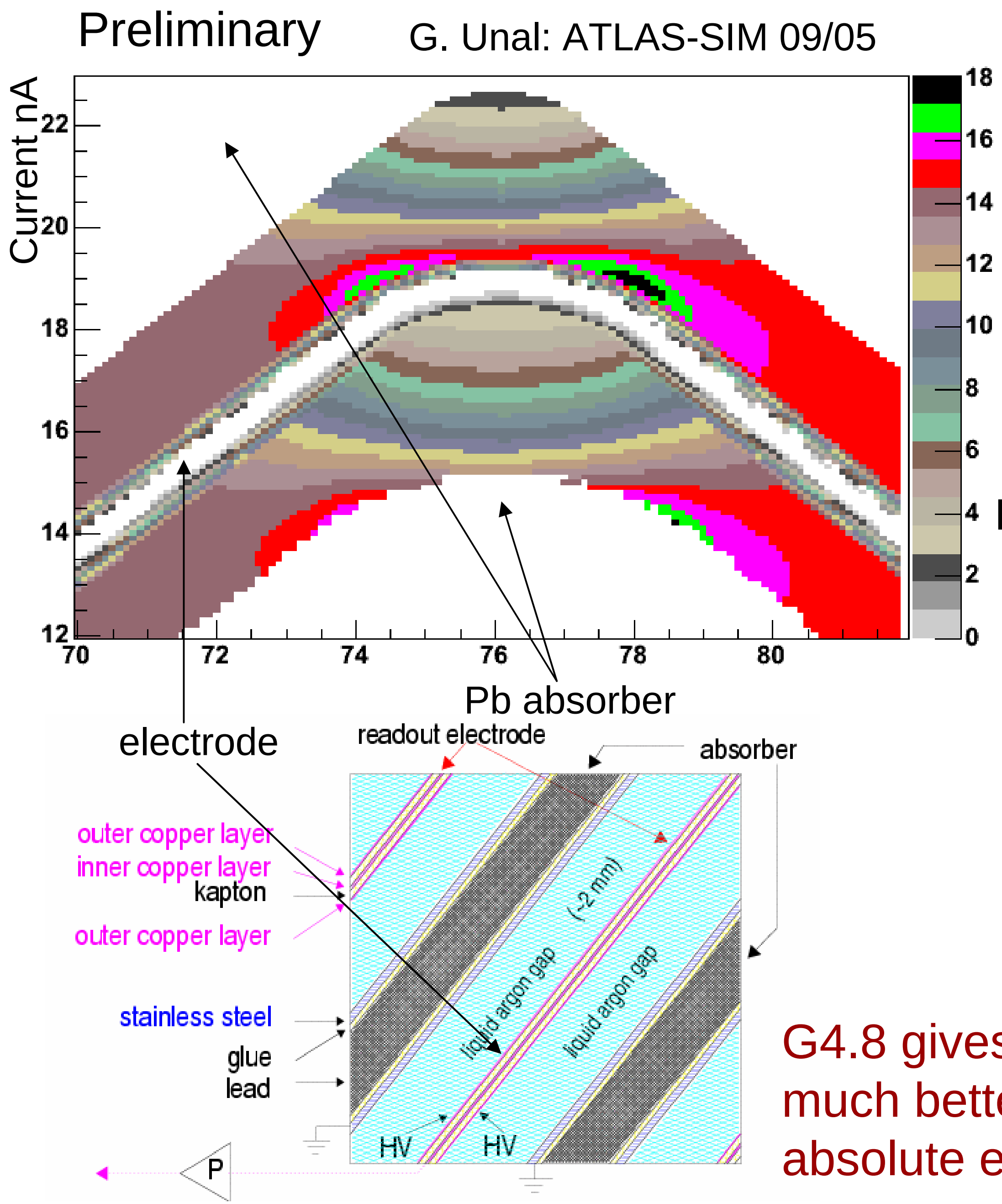
Electron: Data MC Comparison - Resolution

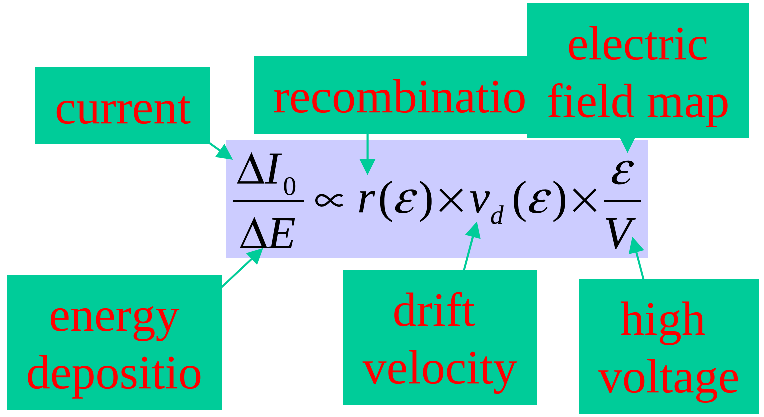


Resolution is much better described in new G4 version !

G4.8 has completely revised multiple-scattering

Current to Energy Factor in ATLAS Barrel EM Calorimeter





$$\frac{\Delta I_0}{\Delta E} \propto r(\varepsilon) \times v_d(\varepsilon) \times \frac{\varepsilon}{V}$$

From calculation using field-maps:

$$\langle f_{I/E} \rangle = 14.2\ nA/MeV$$

From comparison of data and MC:

$$G4.7: f_{I/E} = 16.0\ nA/MeV$$

$$G4.8: f_{I/E} = 14.4\ nA/MeV$$

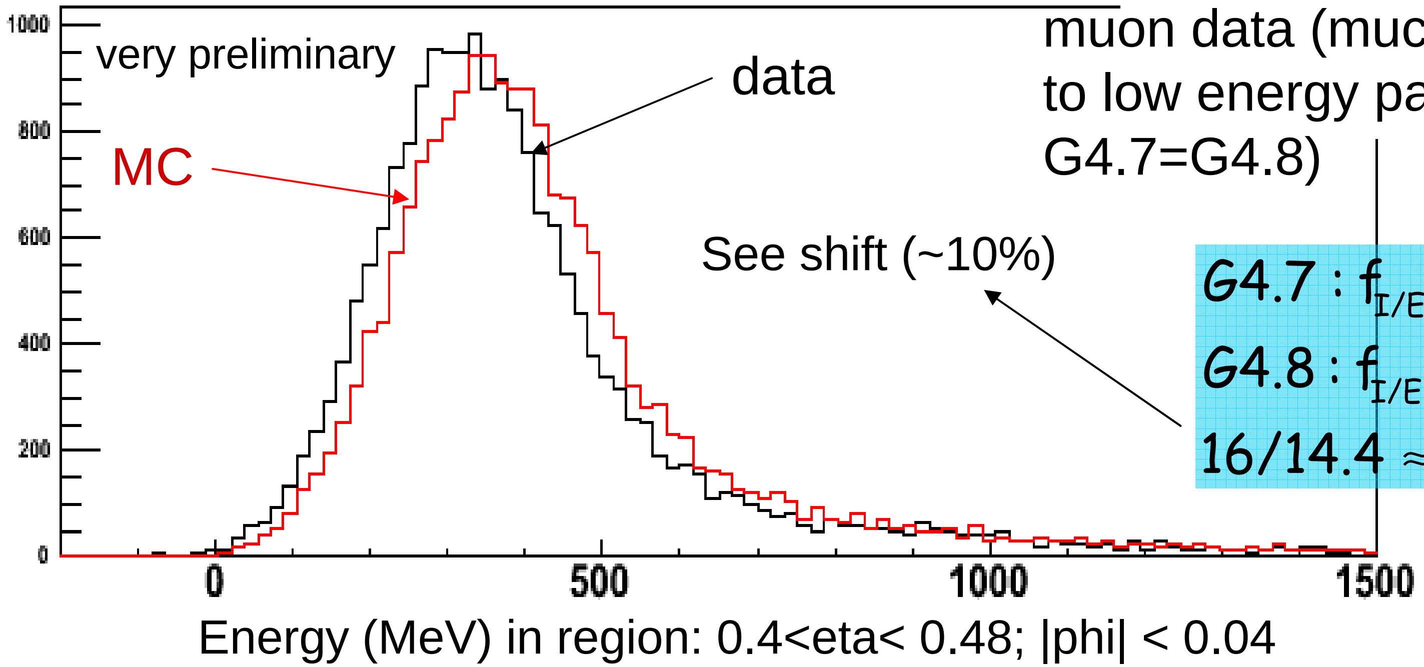
G4.8 gives
much better understanding of
absolute energy scale from first principles !

Current to Energy Conversion: Electron/Muon

$$E_{dep}^{tot} = \frac{1}{f_{I/E}} \frac{1}{f_{samp}} I^{vis}$$

ATLAS data calibrated with G4.7
G4.8 visible energy increases
→ sampling fraction rises
→ $f_{I/E}$ is found to be lower when comparing visible energy in data and MC
→ better agreement with first principle calculation and consistent with muon data (much less sensitive to low energy particles therefore G4.7=G4.8)

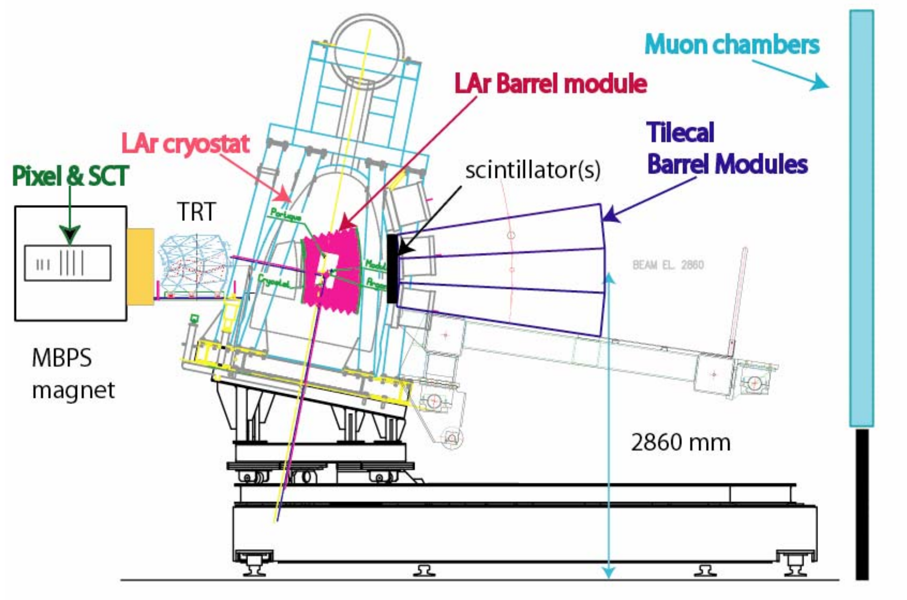
Muons with E=150 GeV:



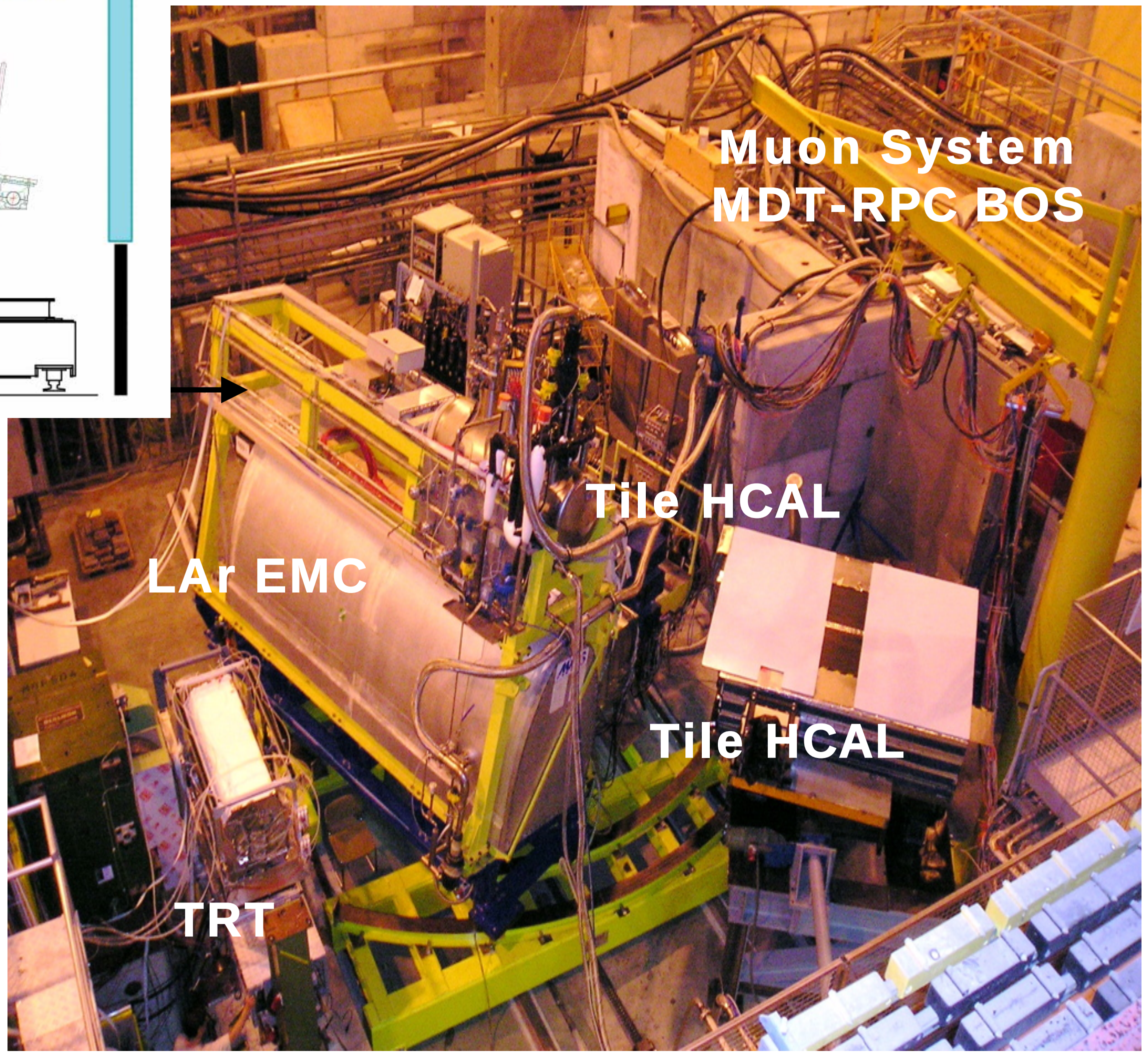
$$G4.7: f_{I/E} = 16.0\,nA/MeV$$
$$G4.8: f_{I/E} = 14.4\,nA/MeV$$
$$16/14.4 \approx 10\%$$

G4.8 gives consistent picture for electrons and muons

ATLAS Barrel Combined Test-beam 2004



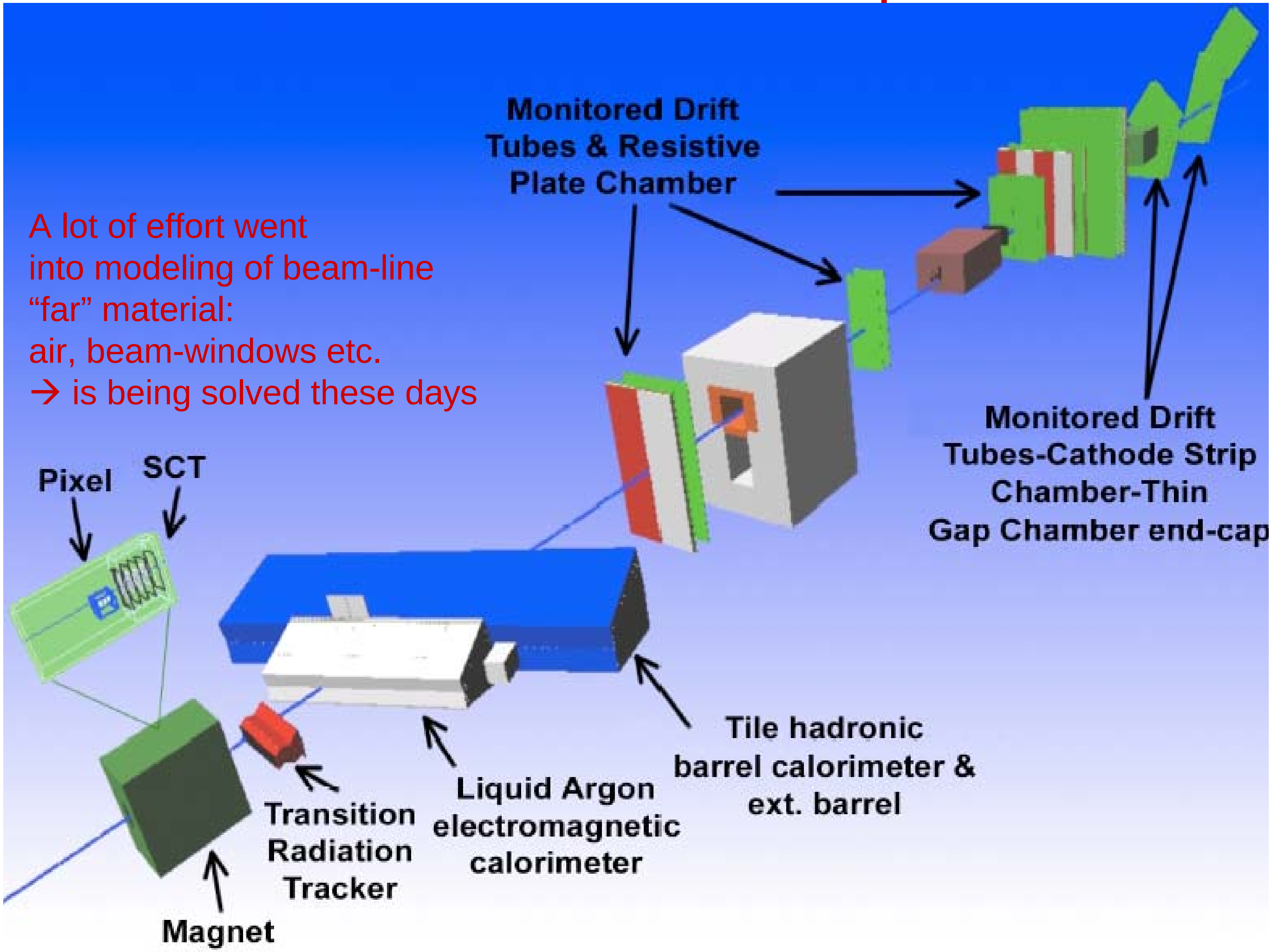
Full η -slice of ATLAS detector



- Drift chambers: beam position
- Scintillators: trigger
- Calorimeters on η moving table
- H8 beam: e, γ, μ, π and p
- Energy: 1 to 350 GeV

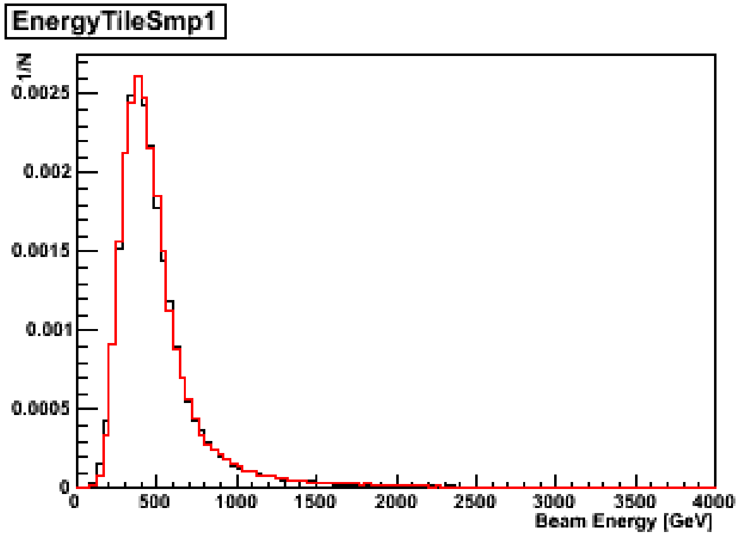
H8 G4 Simulation Setup

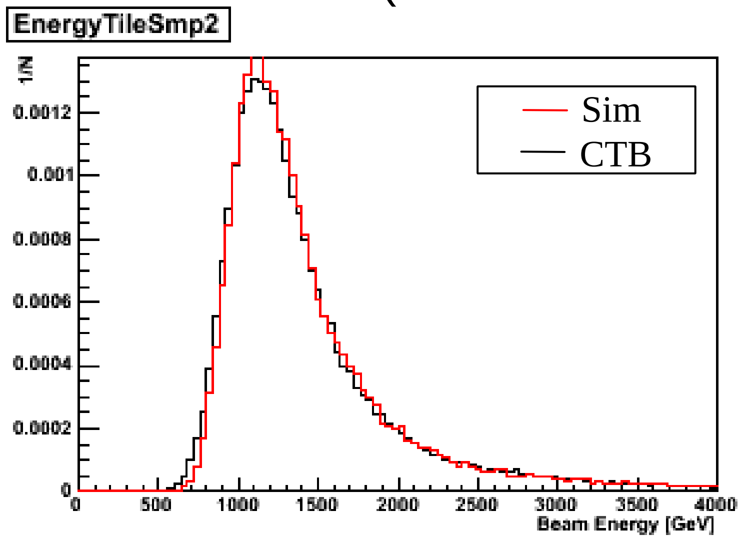
A lot of effort went
into modeling of beam-line
“far” material:
air, beam-windows etc.
→ is being solved these days

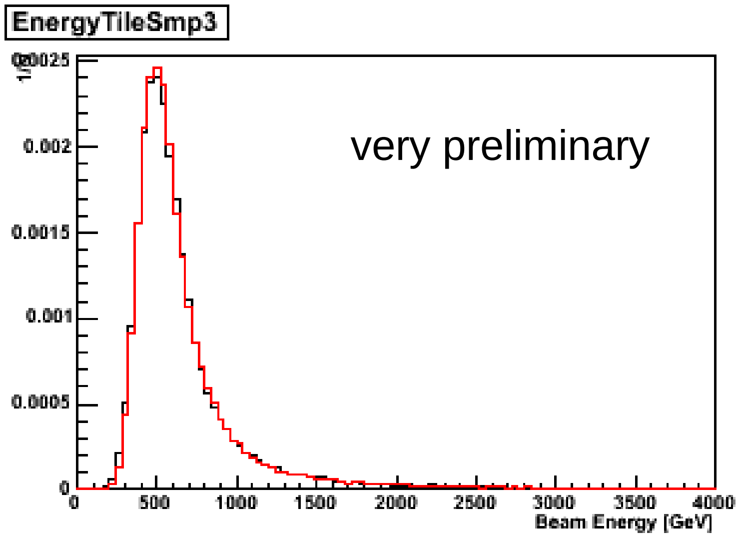


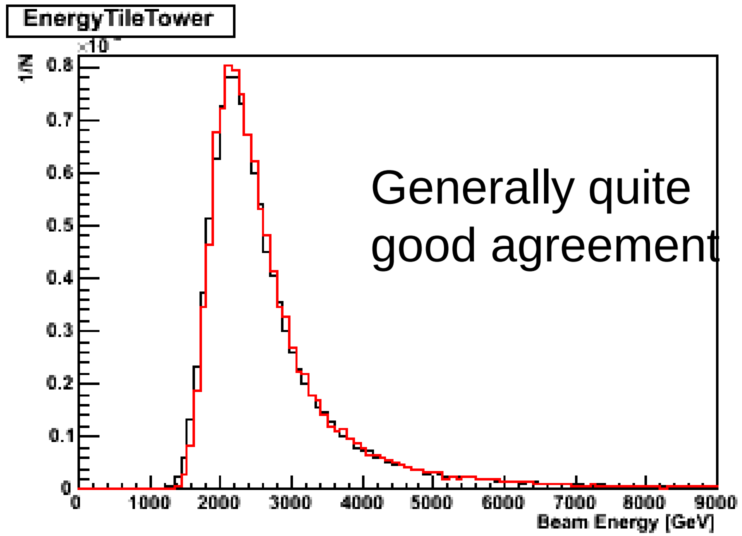
Muon: MC/CTB Comparison in Tile - Peak

- 150 GeV run, ~80000 events
- Energy in 3 samplings and tower
- MC distribution artificially shifted down by 4% (probably due to light attenuation)
- Need careful adjustment of muon impact point in simulation (must be same as in data)





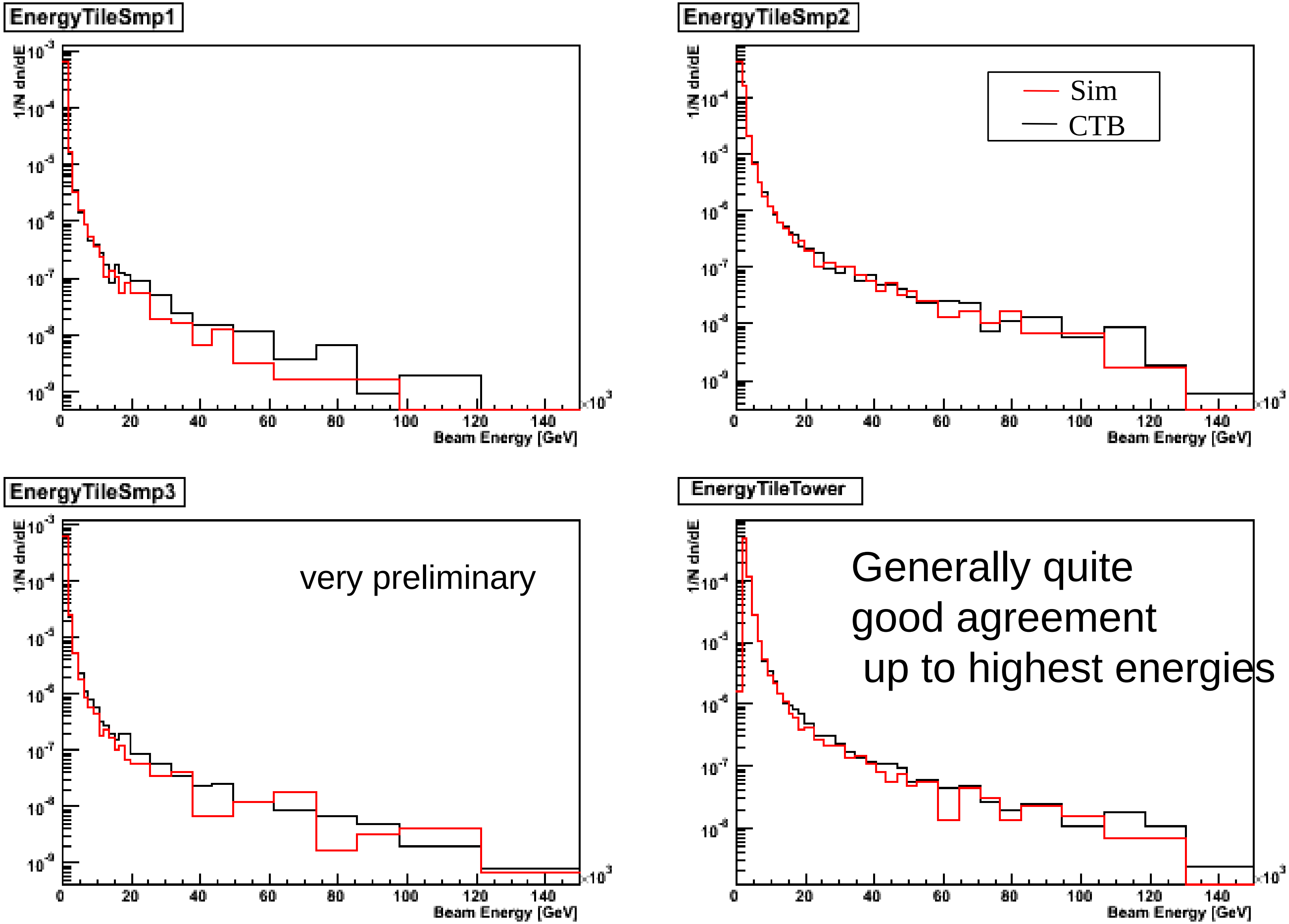




Muon: MC/CTB Comparison in Tile - Tail

- 150 GeV run, ~80000 events
- Energy in 3 samplings and tower

Simulation includes:
Ionisation, pair-production, Bremsstrahlung etc.

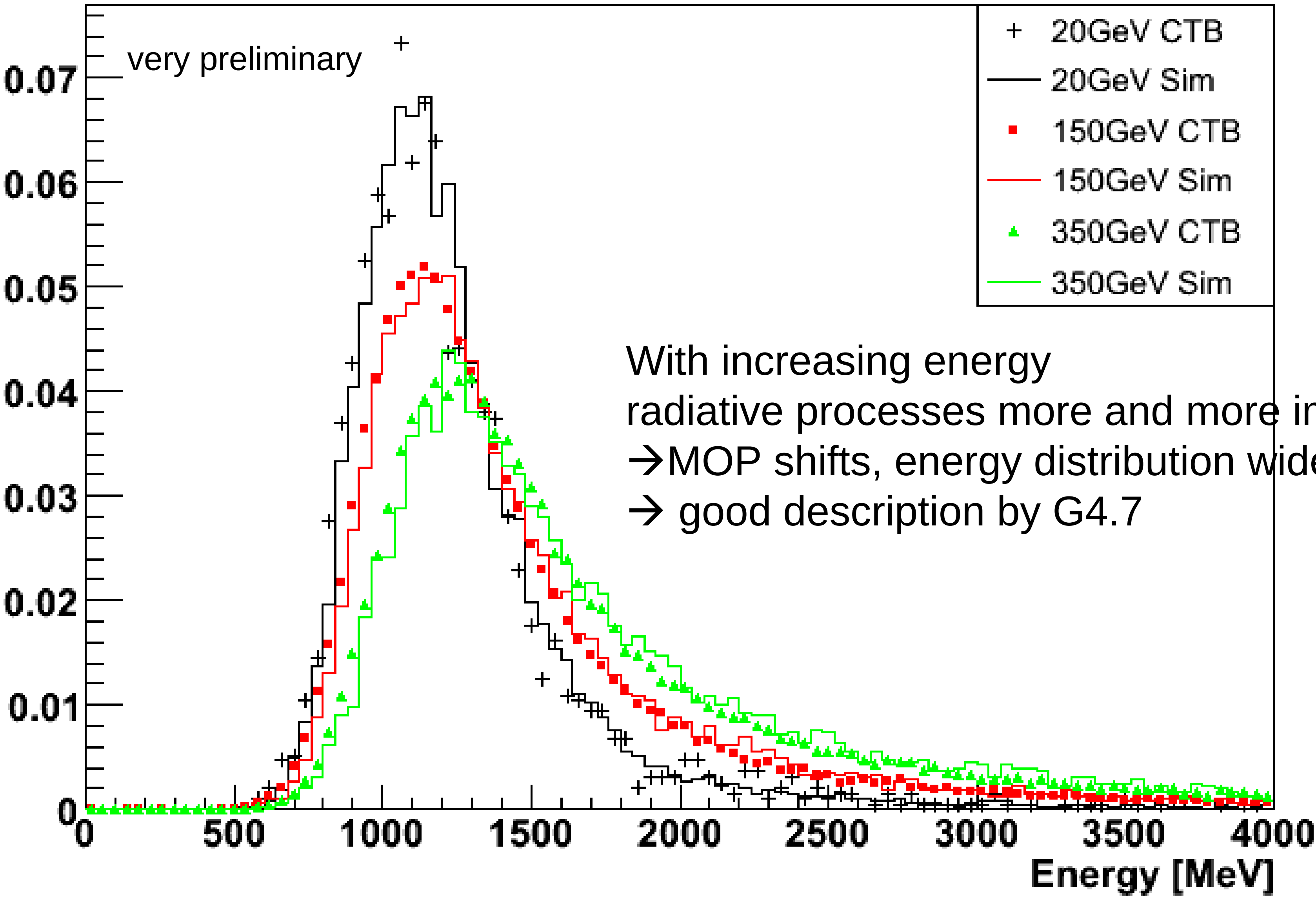


very preliminary

Generally quite good agreement up to highest energies

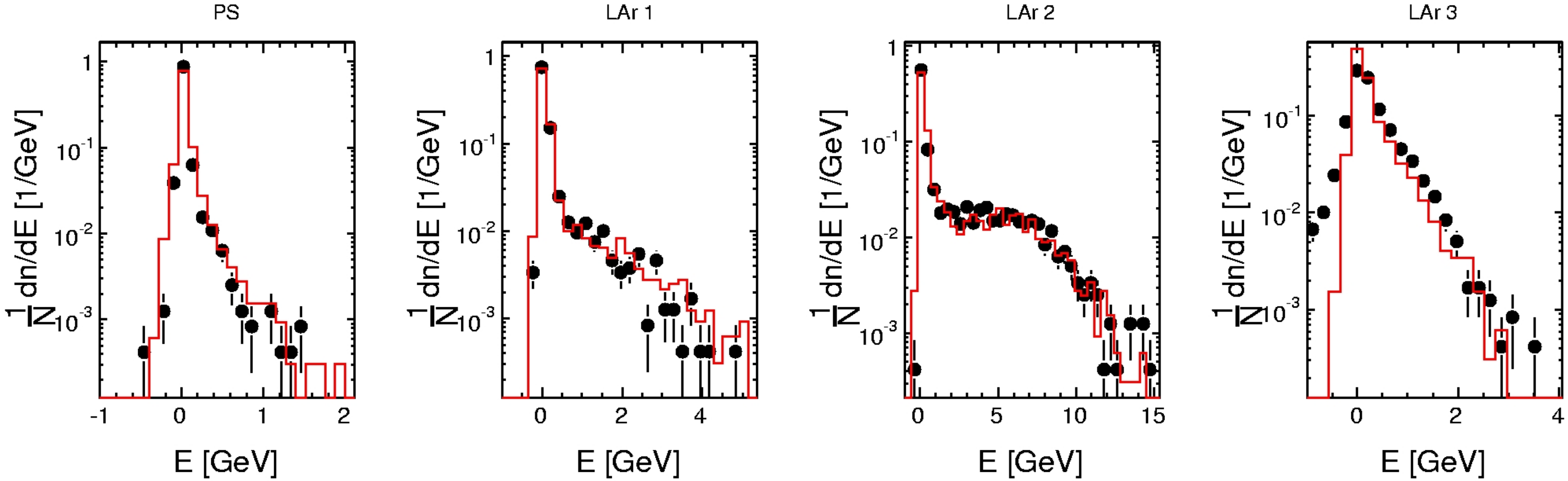
Muon: MC/CTB Comparison – Energy Dependence

Tile Sampling 2

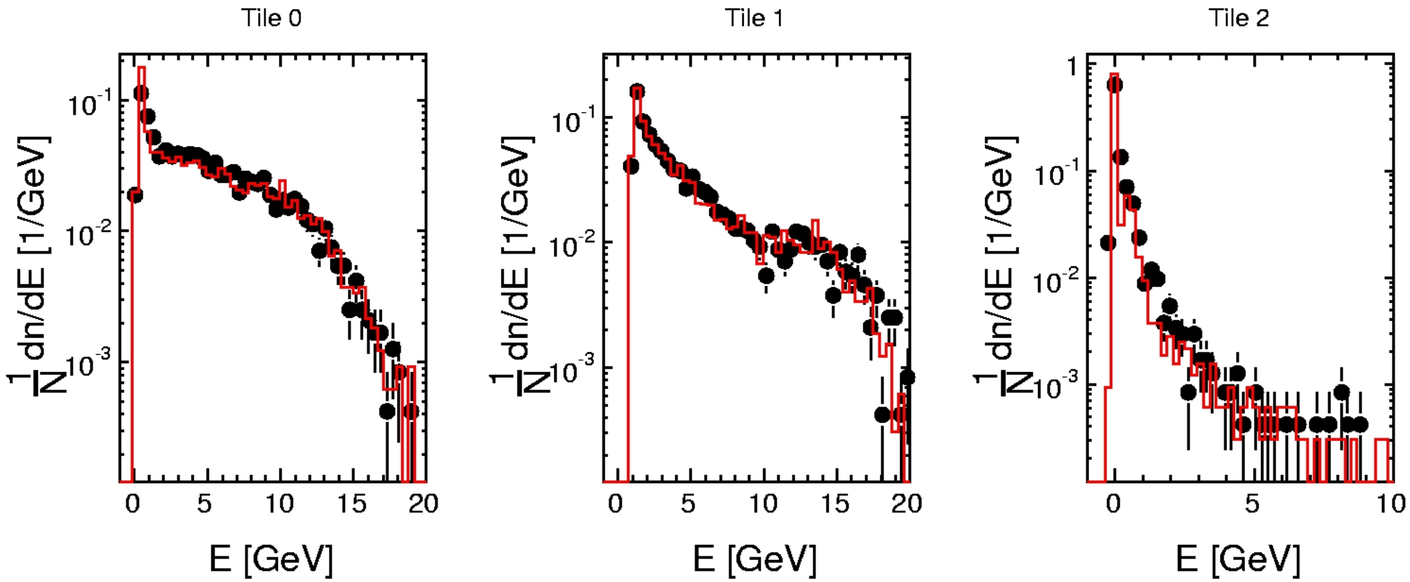


With increasing energy
radiative processes more and more important
→MOP shifts, energy distribution widens
→ good description by G4.7

Pion: MC/CTB Comparison – E=20 GeV



very preliminary



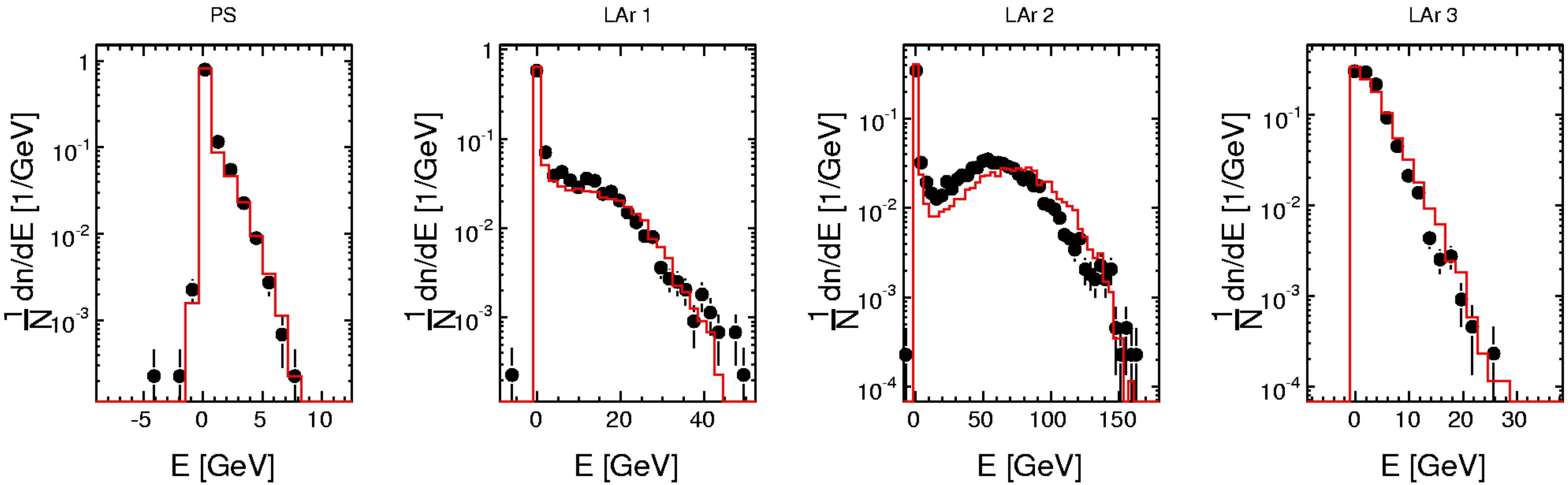
MC

Data

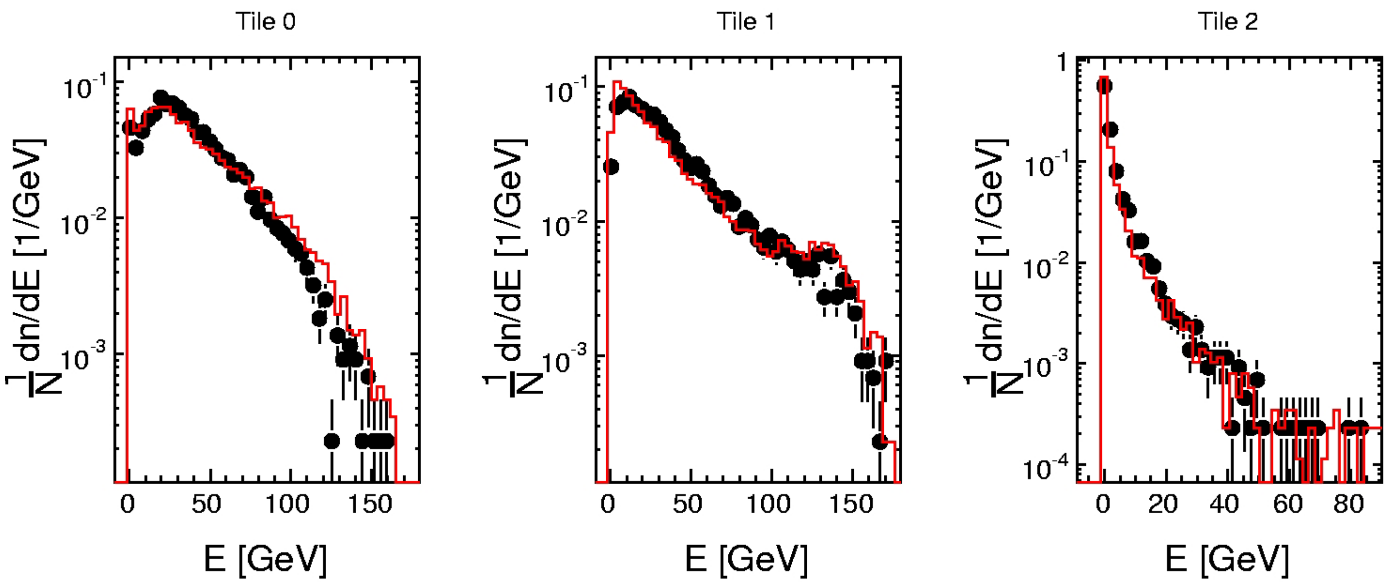
MC: G4.7 QGSP

describes data well
(to be quantified)

Pion: MC/CTB Comparison – E=180 GeV



very preliminary

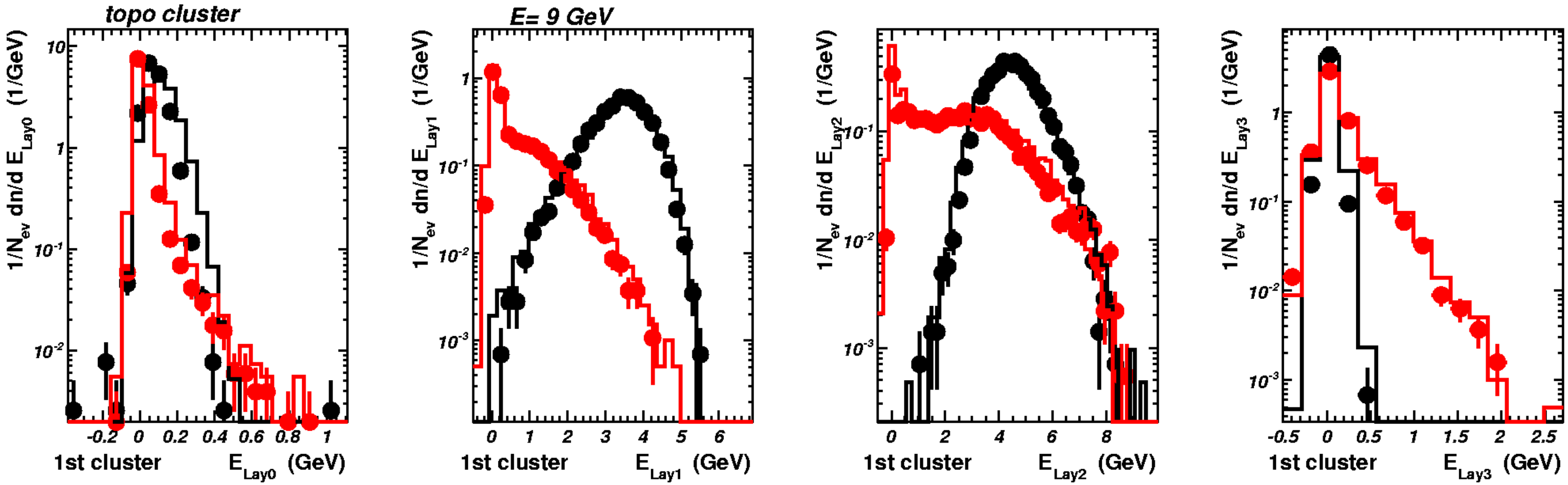


MC: G4.7 QGSP

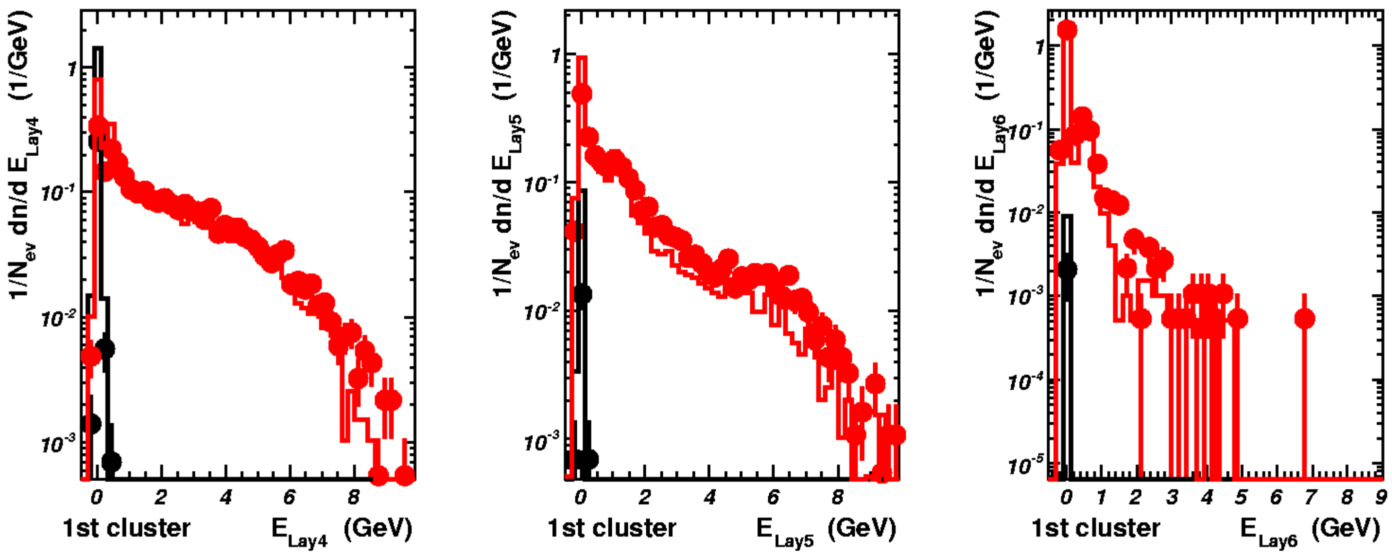
Shower starts and ends earlier in MC

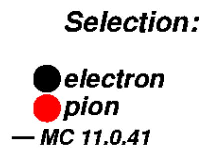
Pion: MC/CTB Comparison – E=9 GeV

Very Low Energy beam line



very preliminary



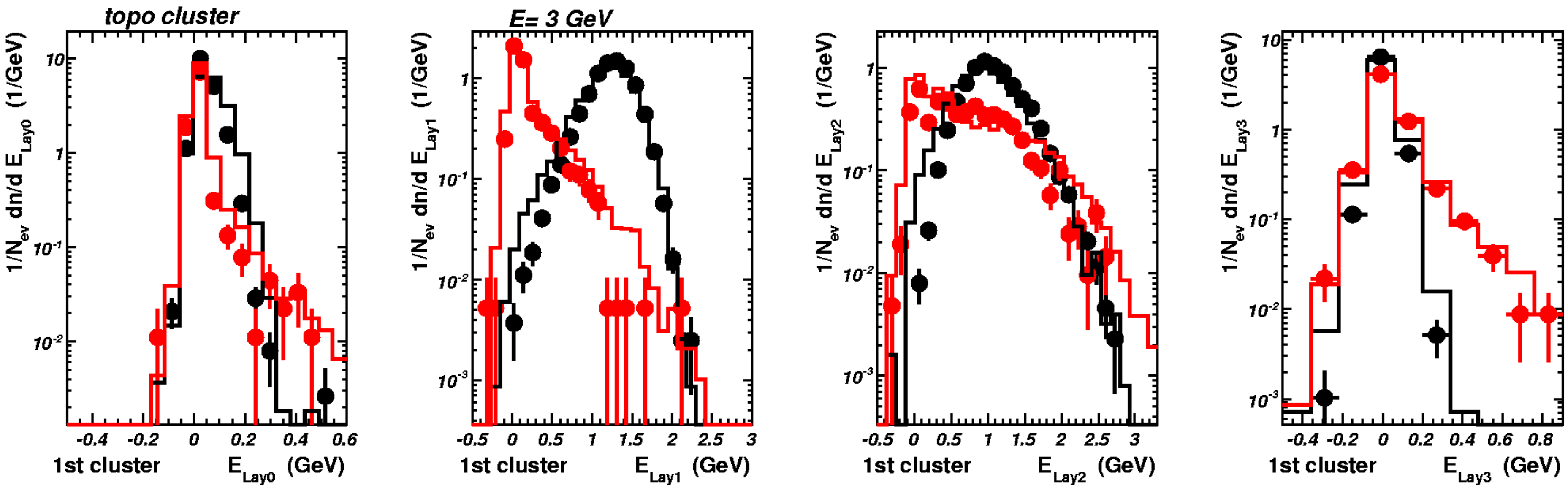


MC: G4.7 QGSP

MC gives reasonable description of data

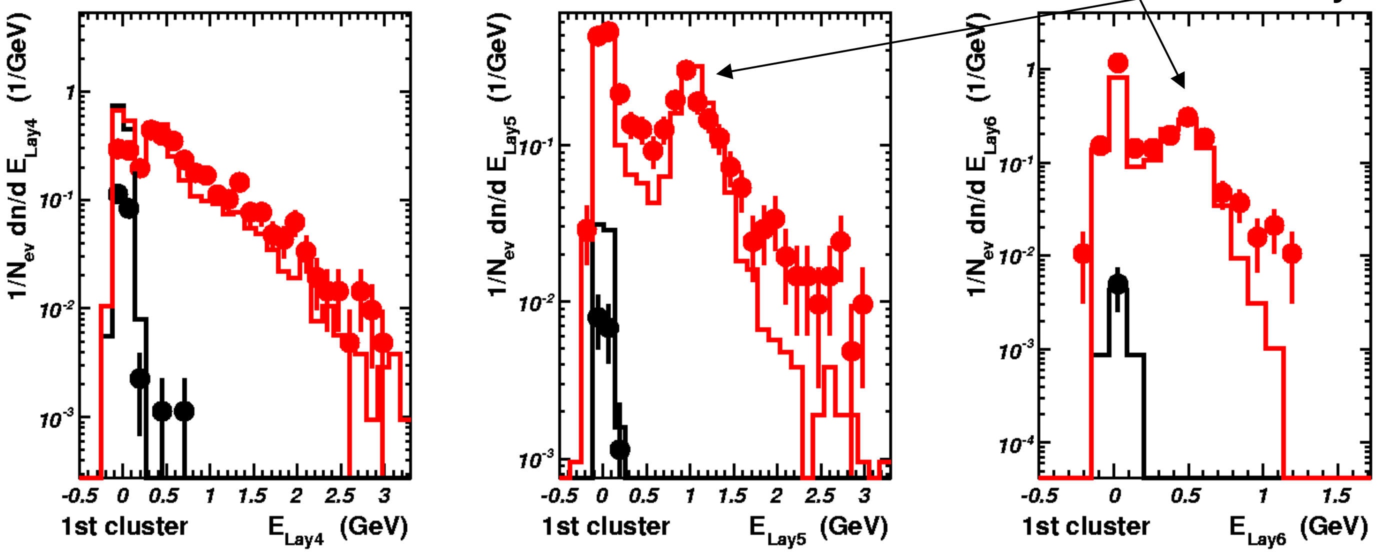
Pion: MC/CTB04 Comparison – E=3 GeV

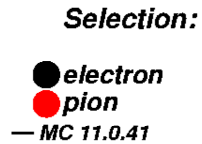
Very Low Energy beam line



very preliminary

Pion decays $\pi \rightarrow \mu\ \nu$

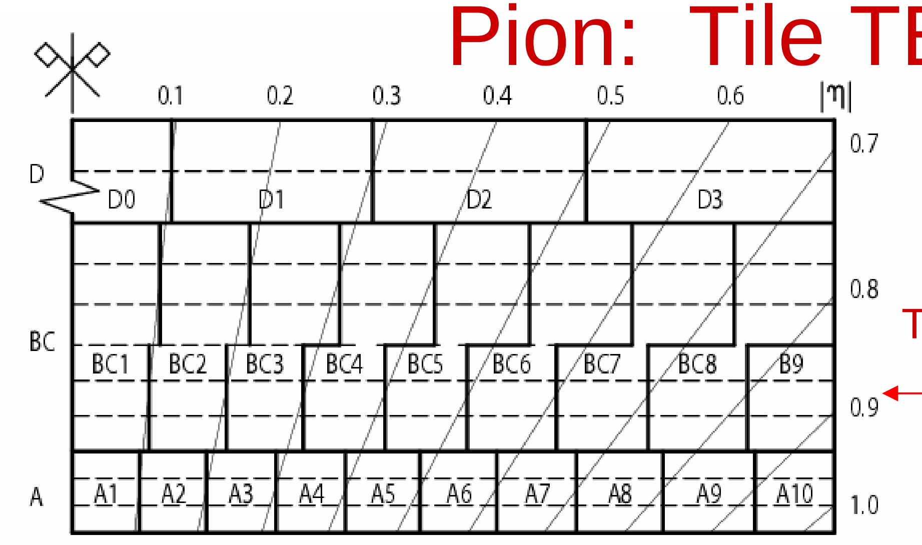




MC: G4.7 QGSP

Shower starts and ends earlier in MC
…to be quantified

Pion: Tile TB02/03 (90 degree)

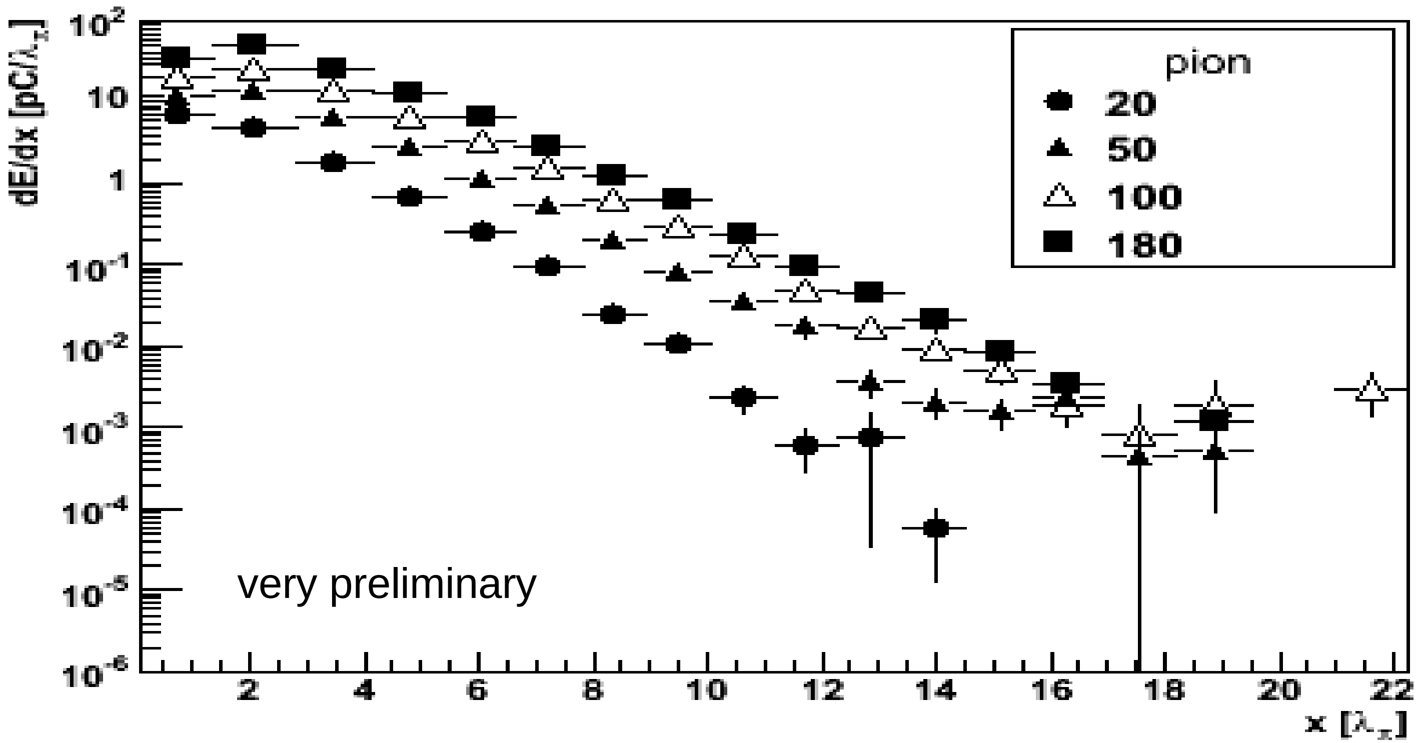


Test beam

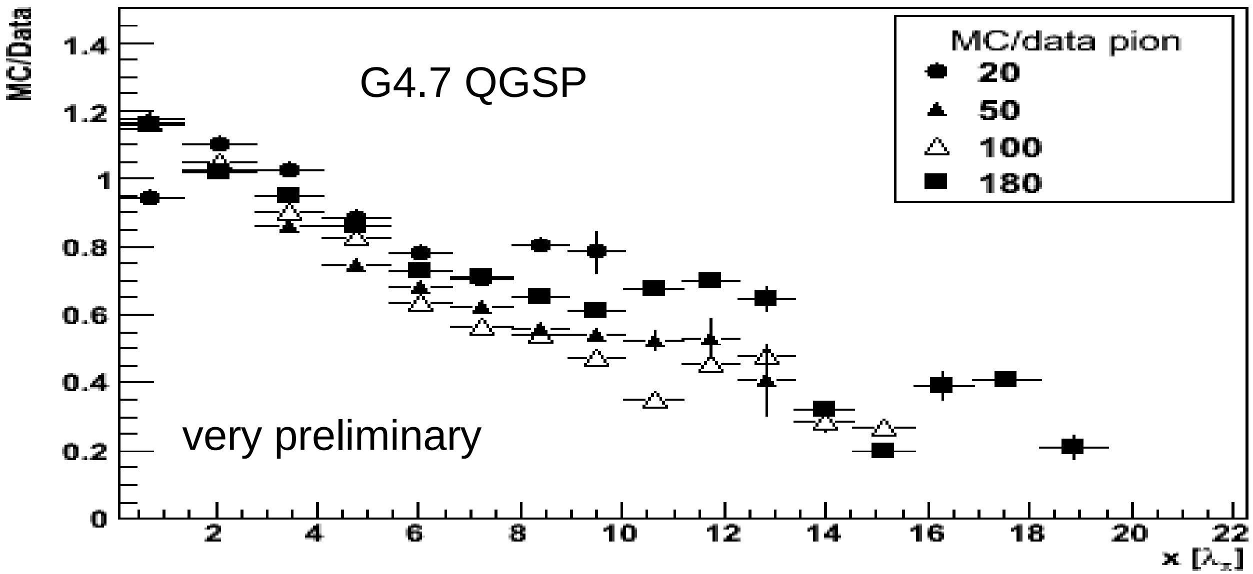
Trick:
By rotating calorimeter by 90 degree
Tile Calorimeter is infinitely long
(and has active/passive material
orthogonal to beam as classical
calorimeter)

Particle entering
in ATLAS

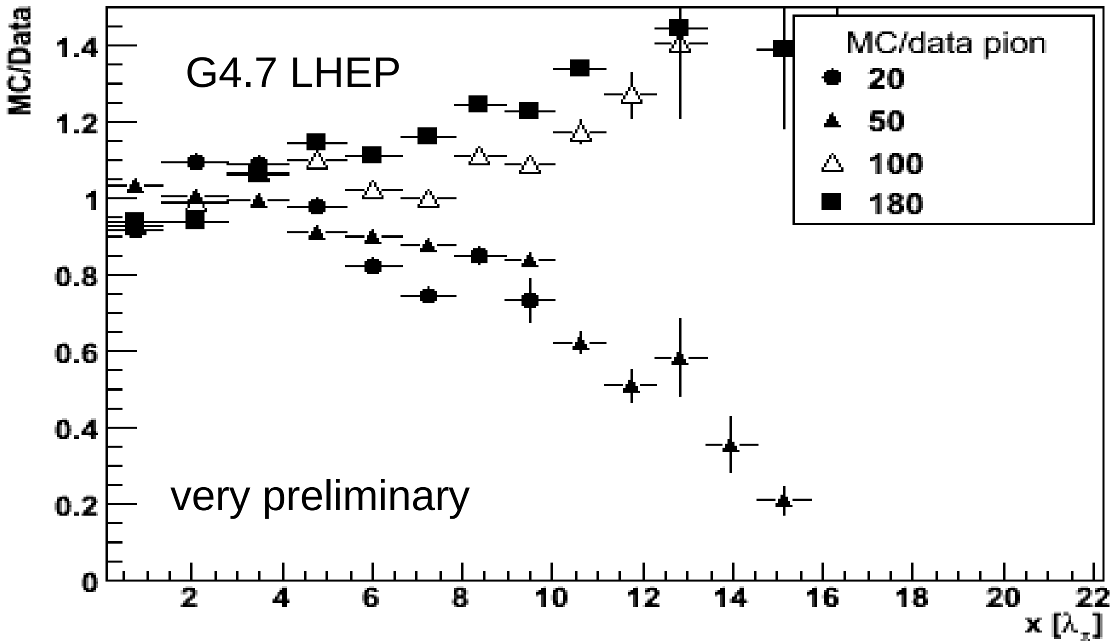
→ Ideal device to study longitudinal shower shape



Pion: Tile TB02/03 (90 degree) – Ratio MC/Data

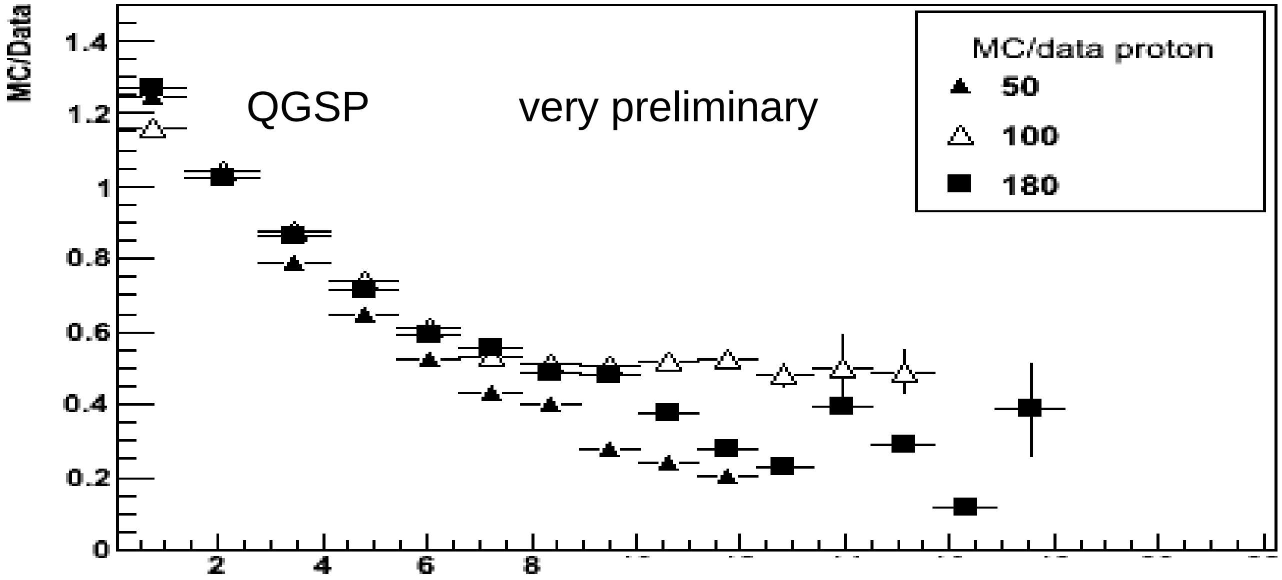


QGSP:
Shower starts and ends earlier

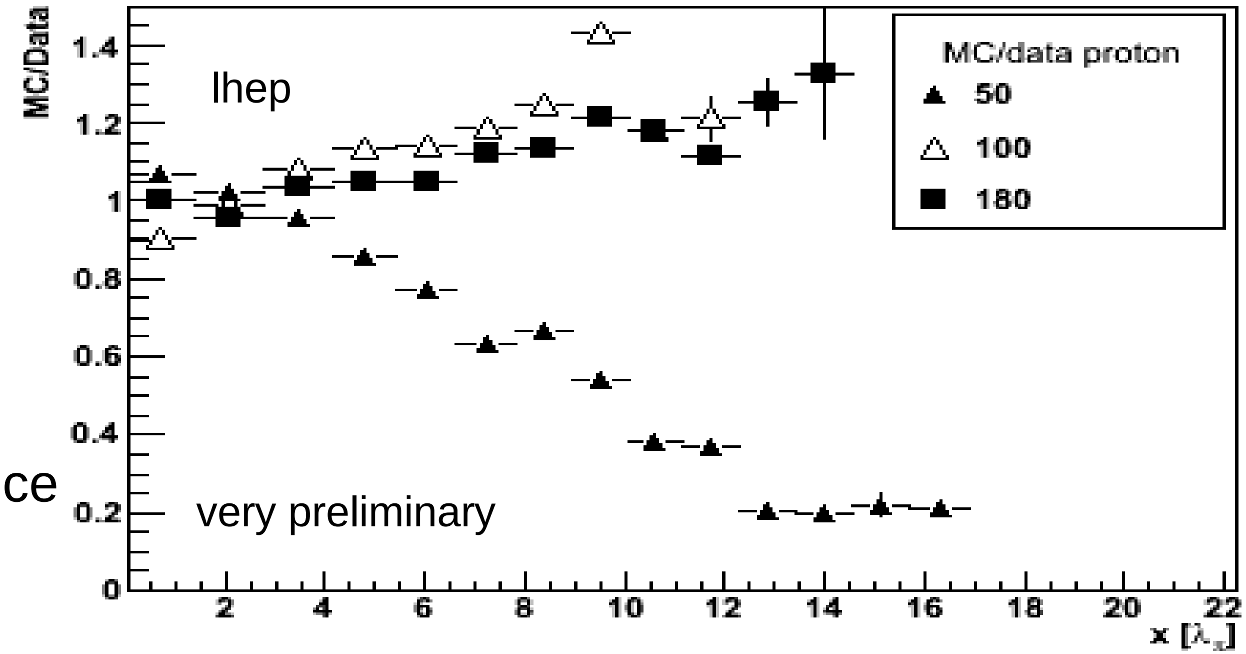


LHEP:
within 20% in first
8 interaction length
strong energy dependence

Proton: Tile TB02/03 (90 degree) -Ratio MC/Data



QGSP:
Shower starts and ends earlier



LHEP:
within 20% in first
8 interaction length
strong energy dependence

Conclusion

Atlas has recently included all test-beam simulations in the software framework Athena

Validation is needed for detector geometry, detector response and physics lists

Since Atlas plans to base calibration on MC, a comprehensive validation of basic quantities and reconstruction algorithms are necessary

G4 allowed to extract calibration constants to calibrate the electron with a linearity of 0.1%

G4.8 gives better description of resolution and gives a more consistent picture for electrons and muons

Description of pion is reasonable for low energy, but at high energy QGSP gives showers that start and end earlier

For the Tile calorimeter LHEP is within +-20% up the 8 interaction length

LAr electronic calibration

Optimal Filtering Coefficients

ADC to GeV

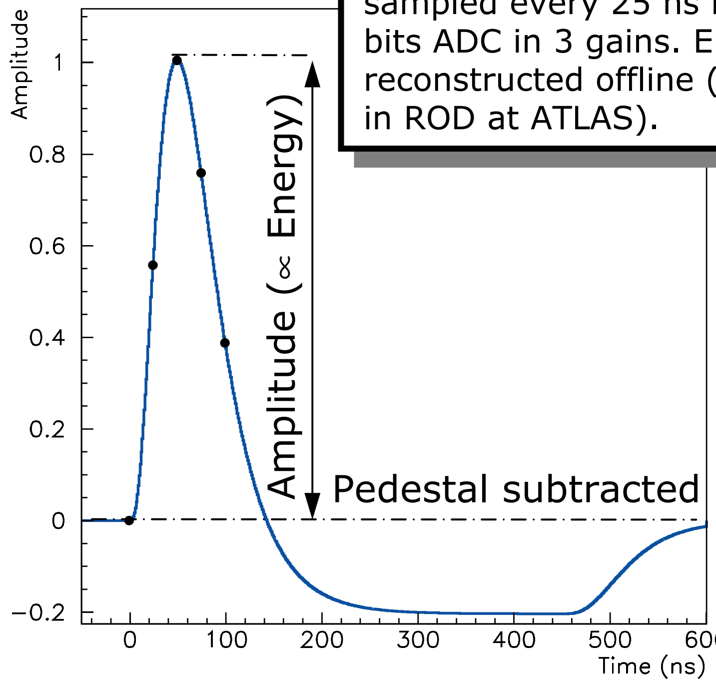
Pedestals

$$E = \sum_{j=1}^{2} F_j \left(\sum_{i=1}^{5} a_i \left(ADC_i - P \right) \right)^j$$

Energy

Raw Samples

The ionization signal is sampled every 25 ns by a 12 bits ADC in 3 gains. Energy is reconstructed offline (online in ROD at ATLAS).



pedestals and noise

Cells are read with no input signal to obtain:

- Pedestal
- Noise
- Noise autocorrelation (OFC computation)

Every 8 hours

ADC → MeV conversion

F = ADC2DAC × DAC2μA × μA2MeV × f_{samp}

- Scan input current (DAC)
- Fit DAC vs ADC curve with a second order polynomial, outside of saturation region

Every 8 hours

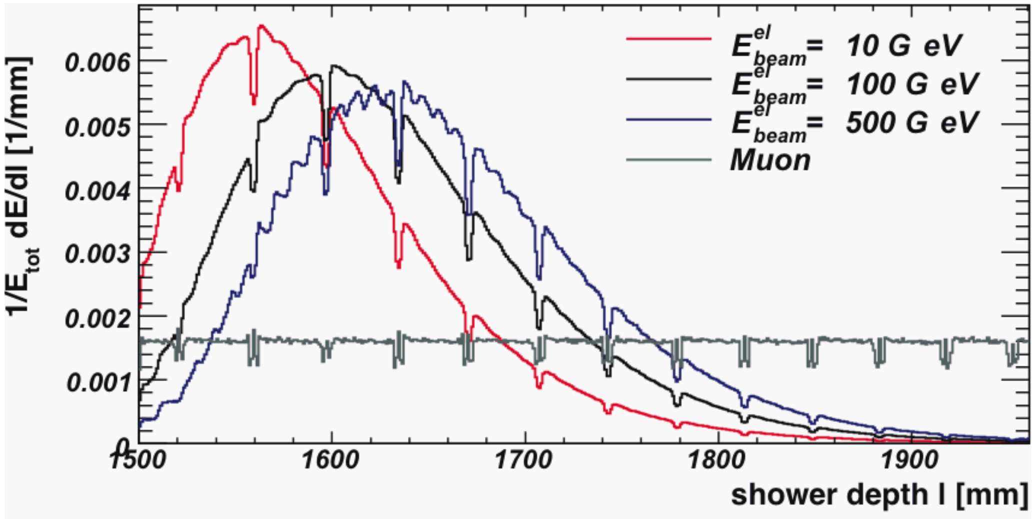
response to current pulse

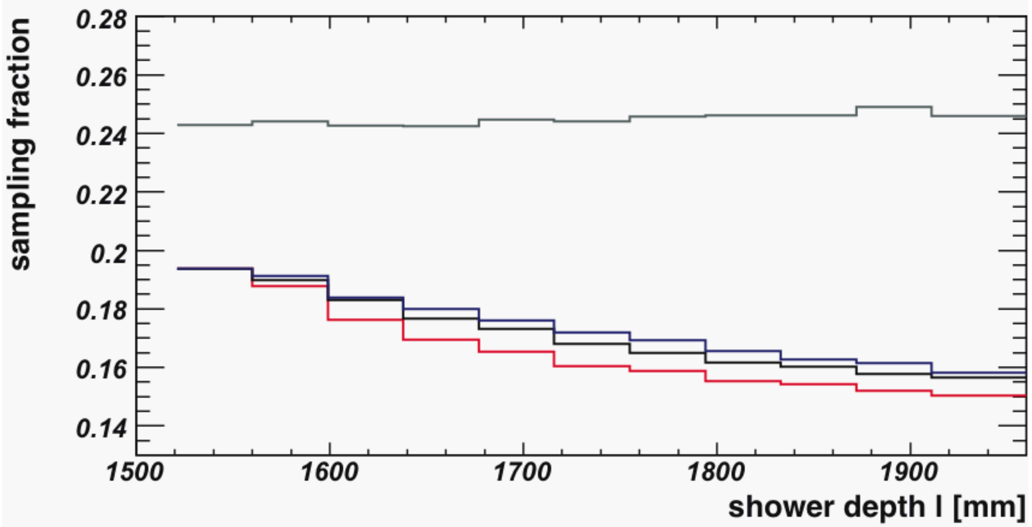
All cells are pulsed with a known current signal:

- A delay between calibration pulses and DAQ is introduced
- The full calibration curve is reconstructed (Δt=1ns)

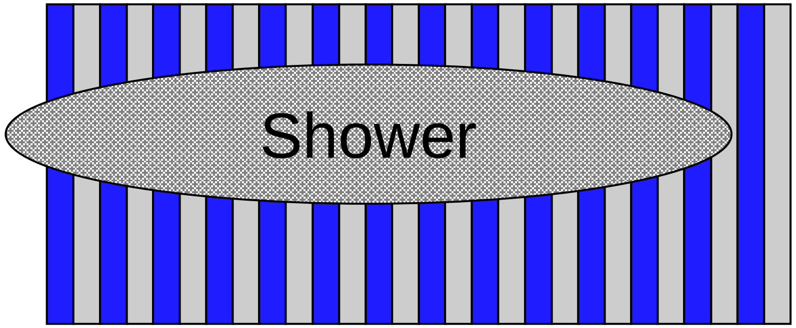
Every change of cabling

On the Calibration of longitudinally Segmented Sampling Calorimeter





$$E_{rec} = d\ E_{acc},\ d = 1/f_{samp} = \frac{E_{act} + E_{pas}}{E_{act}}$$



Samp.frac. depends on shower composition.
Many short-ranged, low-energy particles are created and absorbed in the Pb
(much higher cross-section
for photo-electric effect in Pb than LAr)
Sampl. fract. decreases with depth and radius as such particles become more and more towards the tails of the shower

Use one sampling fraction for all compartments →apply energy dependent correction

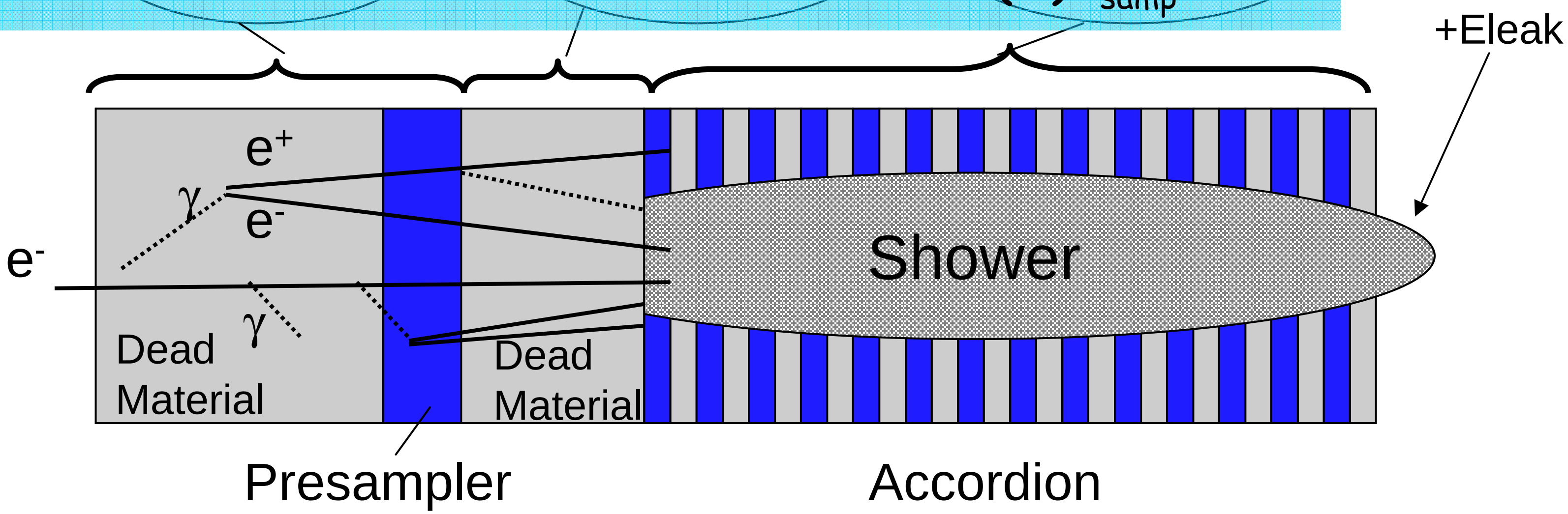
Final Calibration Formula

Offset: energy lost by beam electron passing dead material in front of calorimeter

Slope: energy lost by particles produced in DM (seeing effectively a smaller amount of dead material) in front of calorimeter

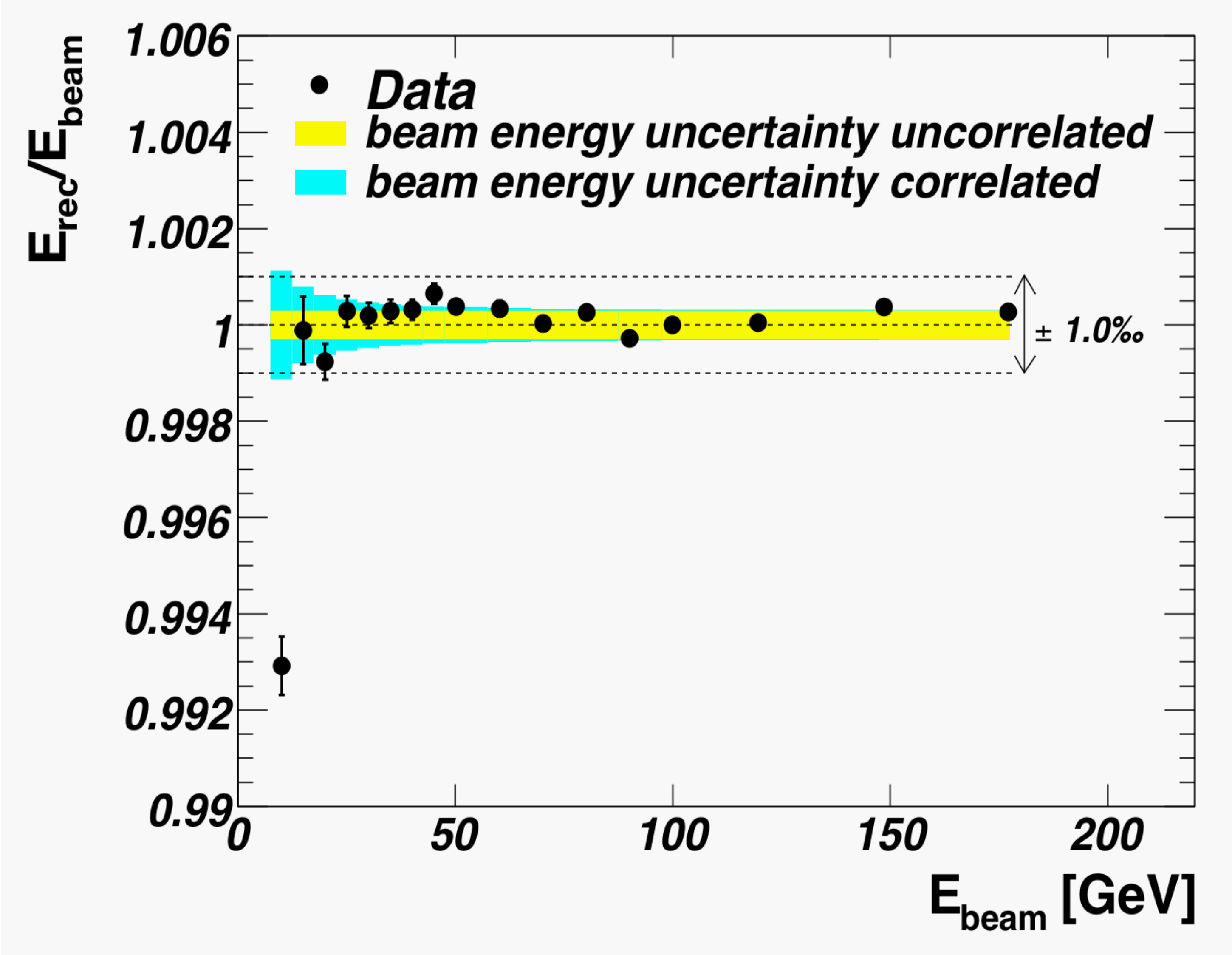
Correction to sampling fraction in accordion:
- intrinsic E-dependence of s.f.
- I/E conversion
- out-of-cluster correction

$$E_{rec} = a(E) + b(E)\,E_{PS} + c(E)\sqrt{E_{PS}\,E_{strips}} + \frac{1}{d(E)\,f_{samp}^{E=100}}\,E_{acc}$$



- Good linearity and resolution achieved
- Constants depend on impact point (upstream material) and on the energy.
  - Can be parameterized.
- Constants are derived from a MC simulation of the detector setup.

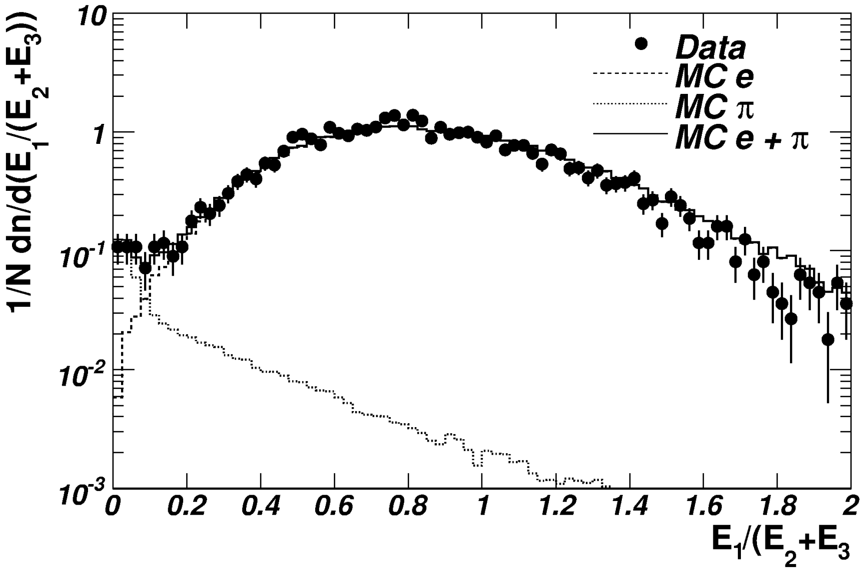
Linearity Result



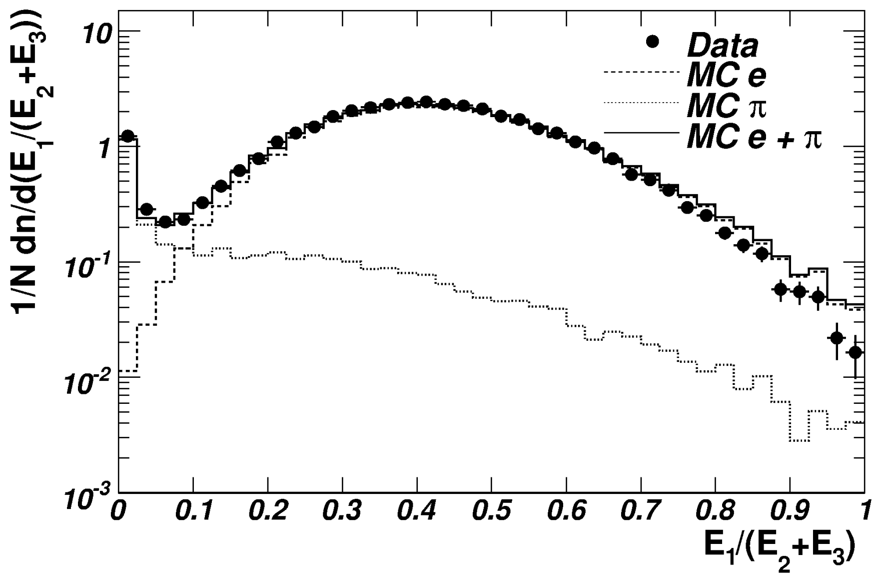
within 1% for 15-180 GeV, E=10 GeV 4 per mil too low, reason unclear…

Data/MC Comparisons – Layer Fractions

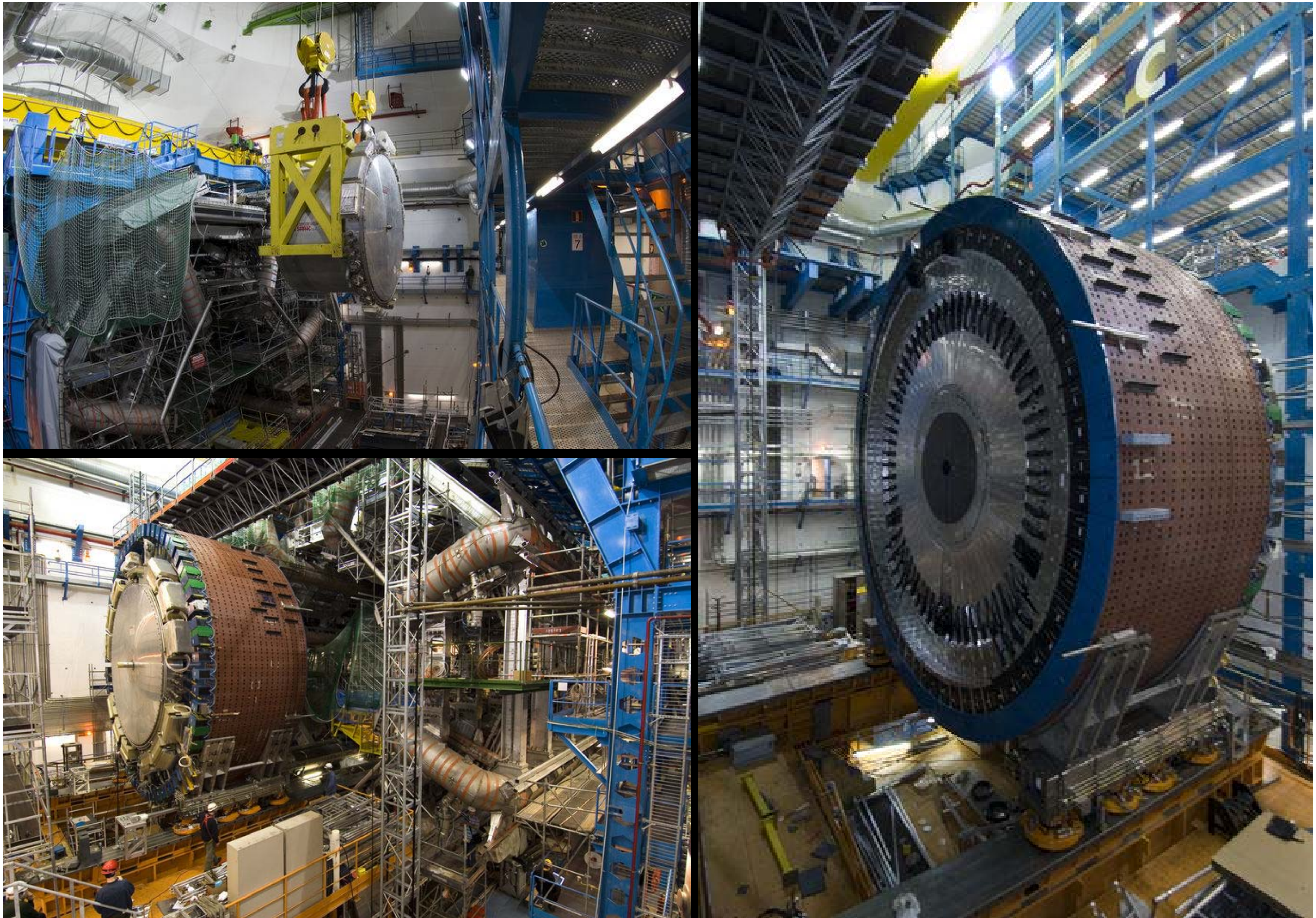
E=10 GeV



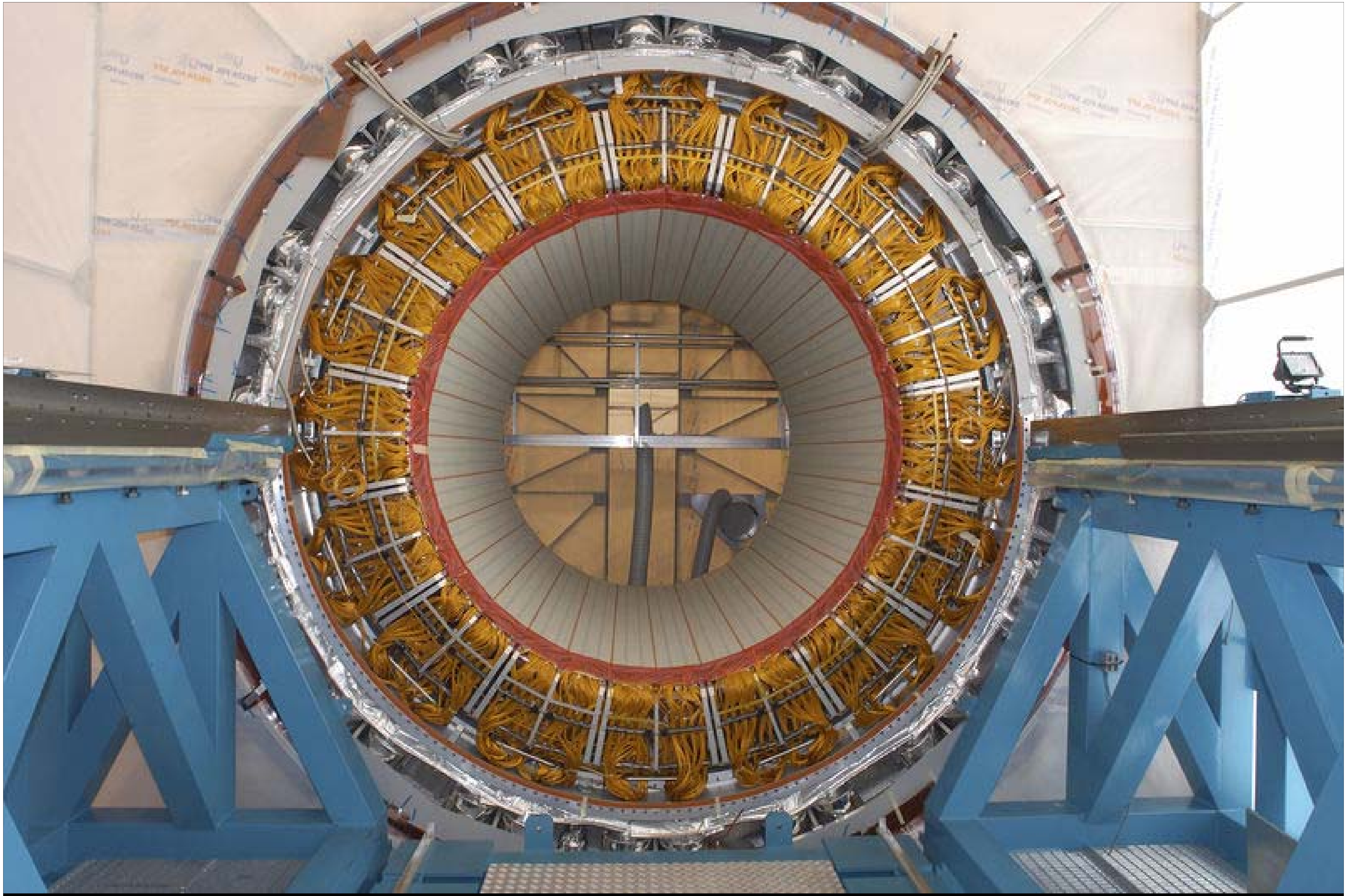
E=50 GeV



- Fraction of under electron peak can be estimated by looking at late showers: $E_1/(E_2+ E_3)$
- Pions depositing most of energy in Lar deposit large fraction electromagnetically,
  but shower later than electrons
- f MC-pion + (1-f) MC-electron gives good description of MC
- Effect of pion contamination on reconstructed energy can be estimated from simulated energy distributions -> effect is negliable
- shift of energy distribution with/without $E_1/(E_2+ E_3)$ is negliable



ATLAS endcap calorimeters installation, winter-spring 2006



M-wheel inside the cryostat, March 2003