Summary of G4 Validation Results of ATLAS and CMS

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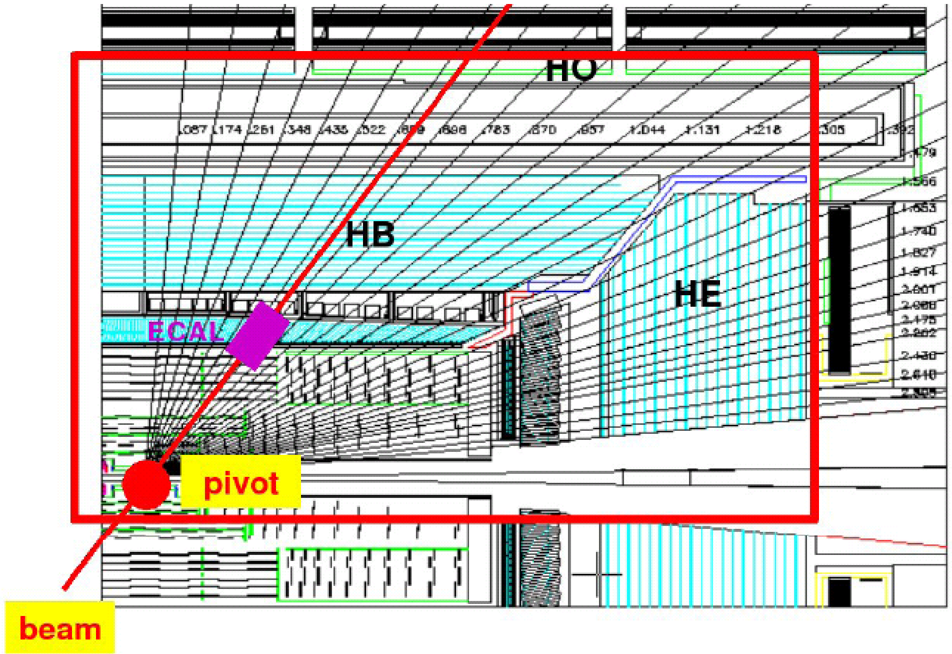
Outline:

o) Electron
o) Muons
o) Pions and Protons
   energy response and resolution
   shower shapes

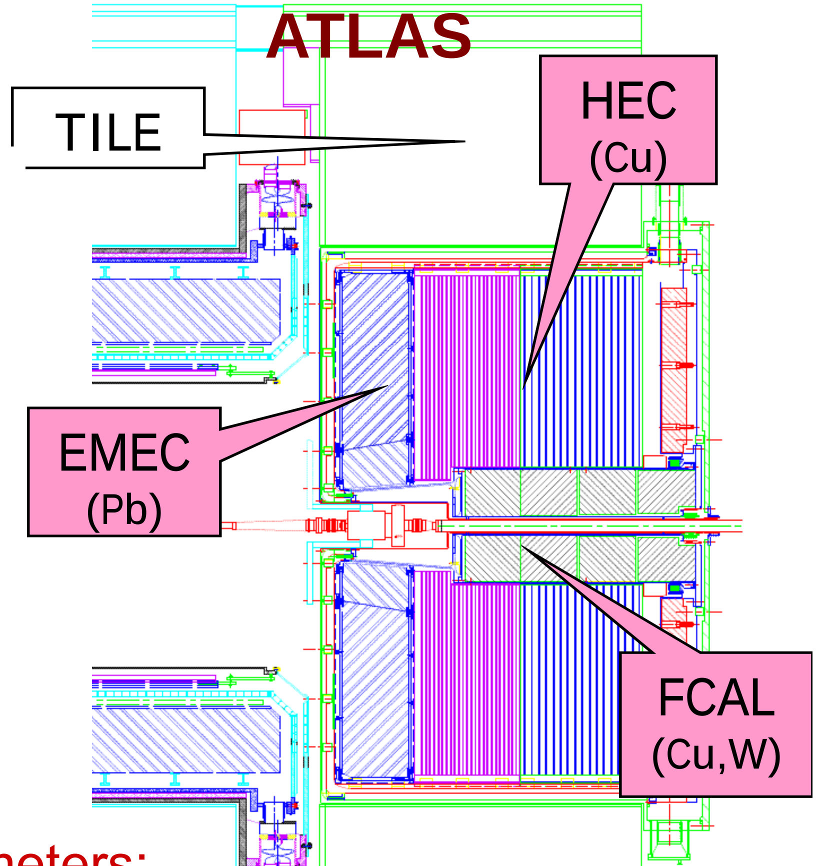
Bla bla

CMS



ECAL:
$PbWO_4$ crystals

HCAL:
Brass/Scintillating tiles with wavelength shifter
Forward region:
Iron/quartz fibres



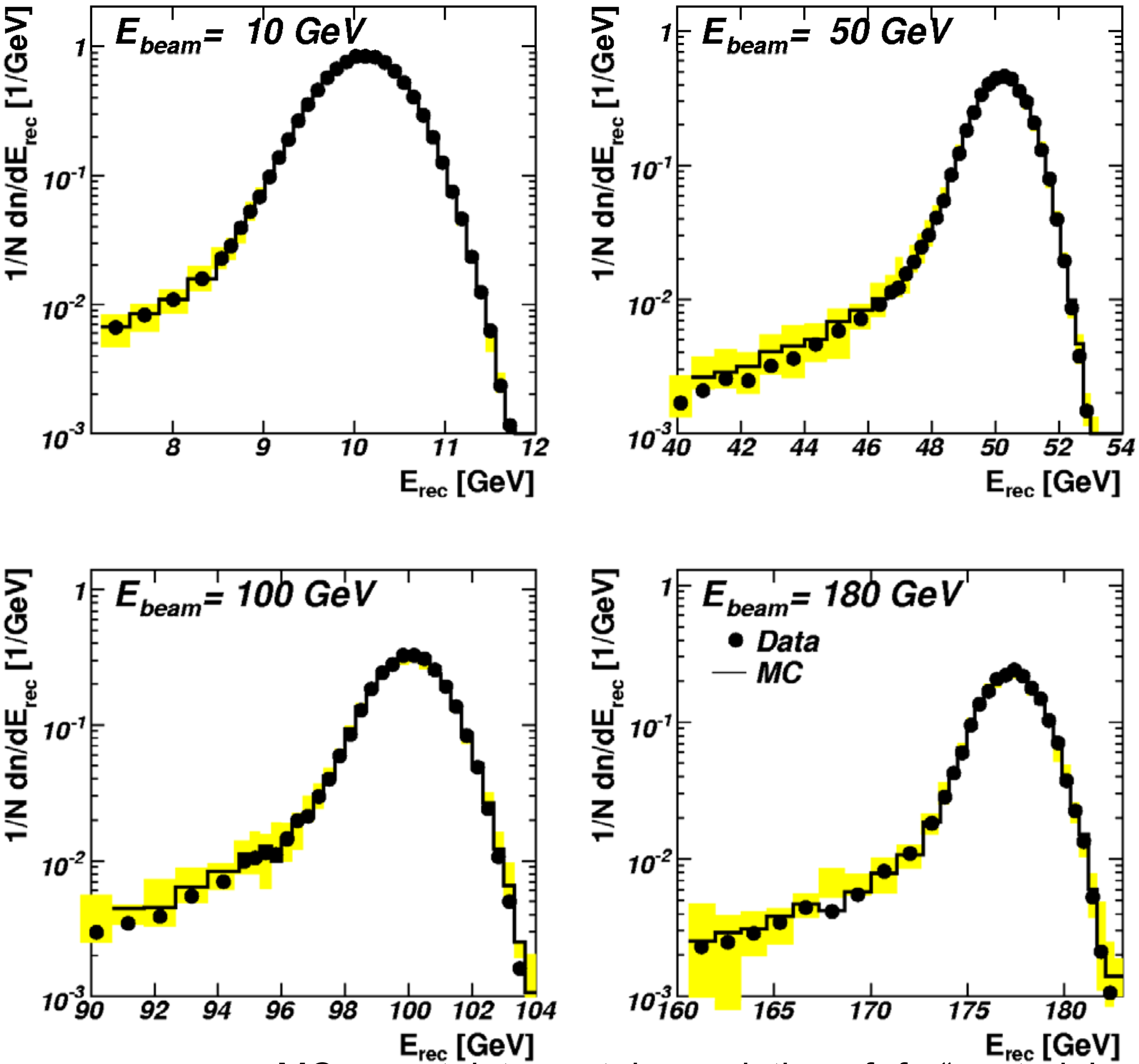
LAr Calorimeters:

- 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

Electrons

ATLAS LAr Barrel 2002 – Electron Total Energy

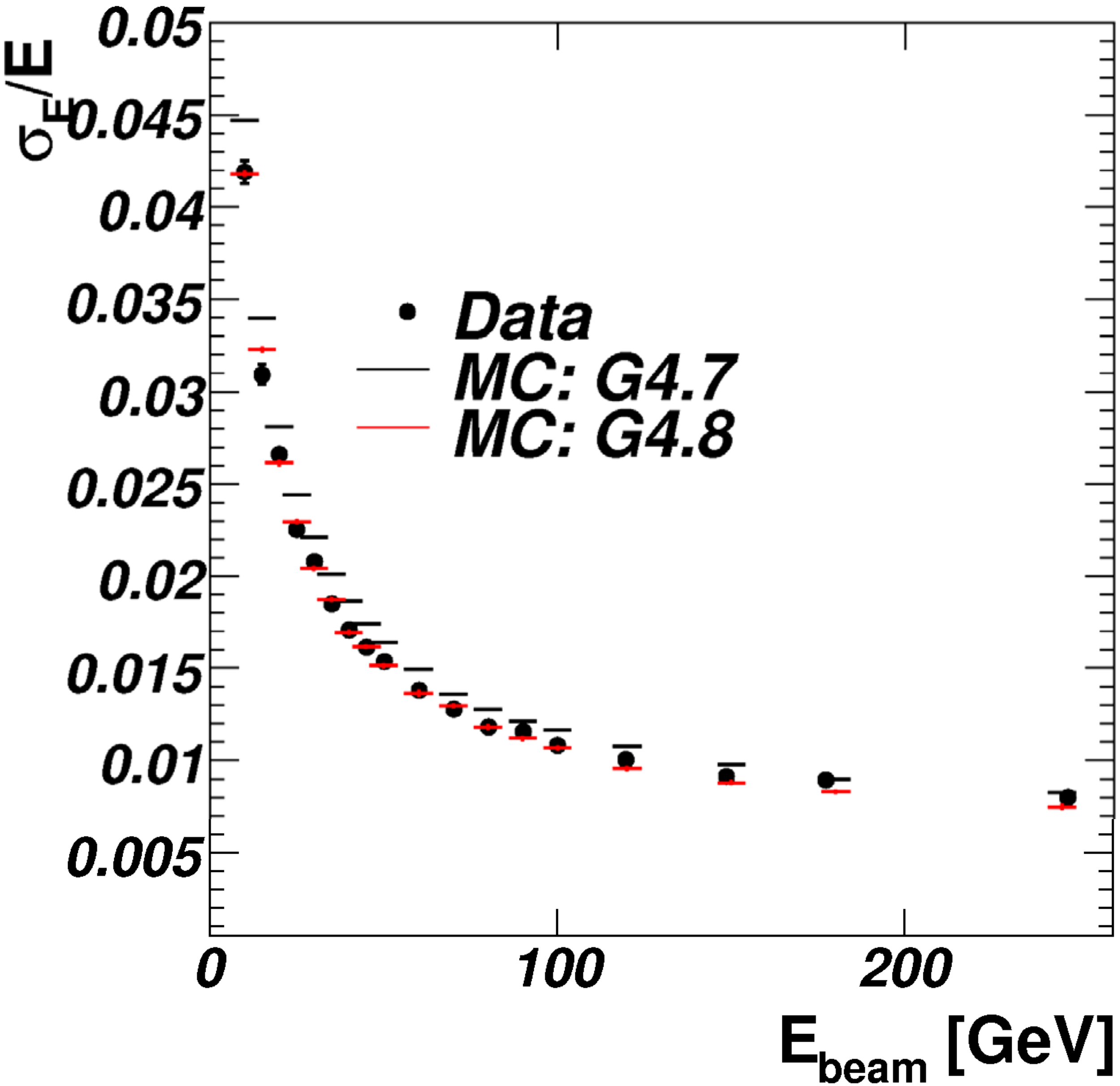


G4.8

MC uncertainty contains variation of „far“ material

Excellent description of energy distribution

ATLAS LAr Barrel 2002 – Electron Resolution

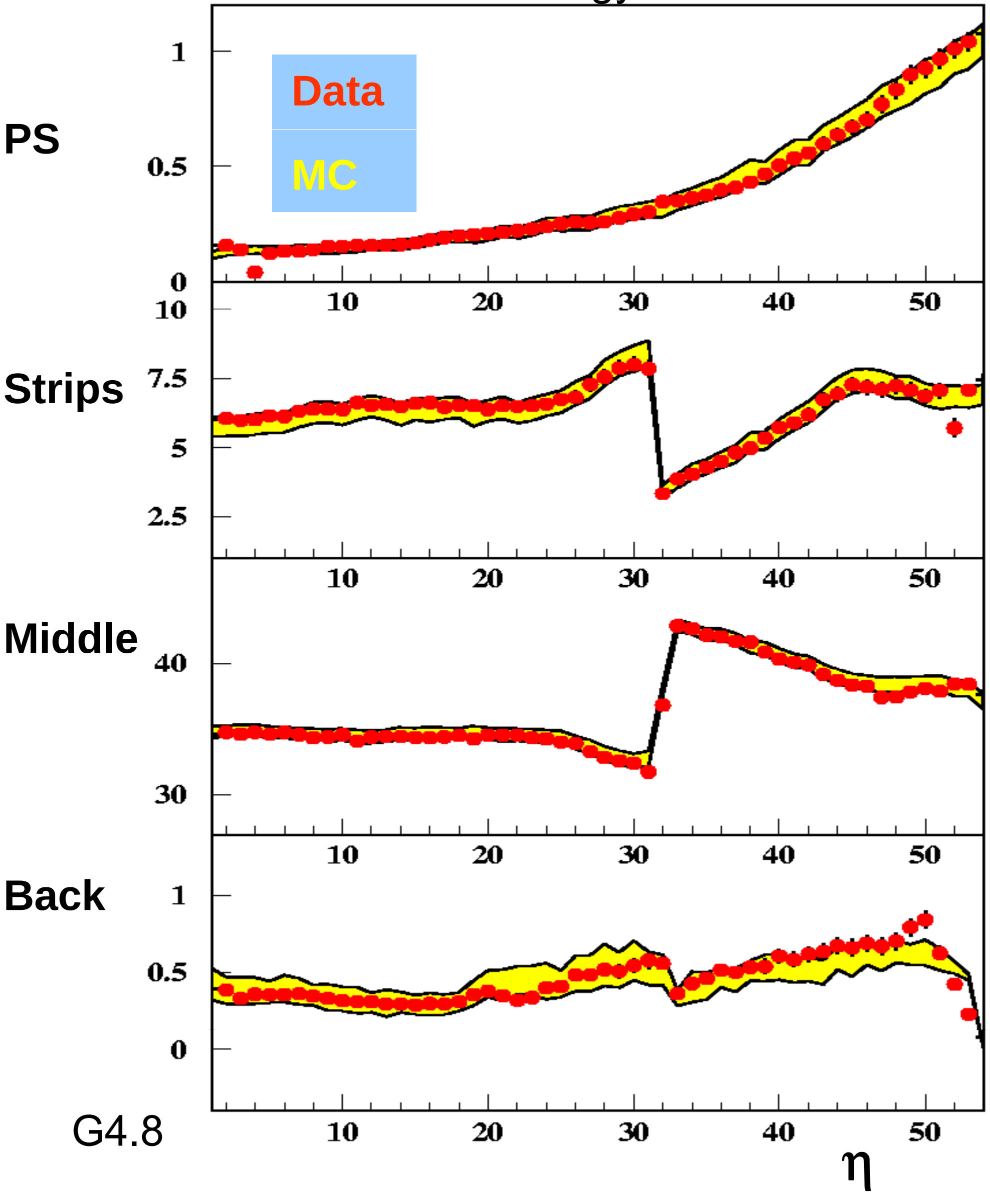


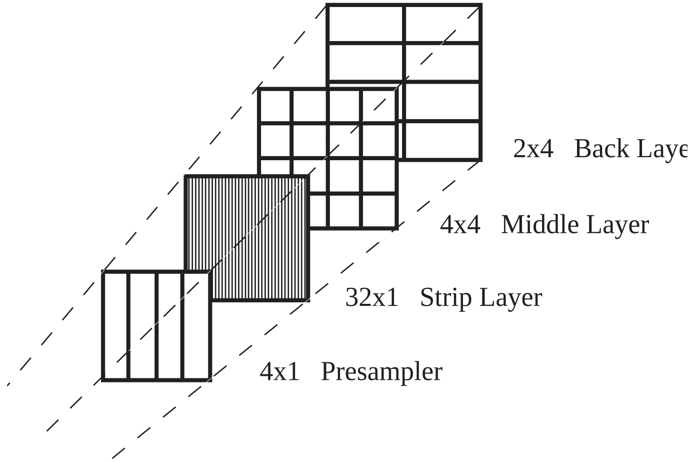
Using G4.8 also good agreement for absolute energy calibration (before 10% difference between G4 and first principle calculation)

G4.8 give good description of energy resolution

ATLAS LAr Barrel 2002 – Electron Layer Energy Sharing

Mean visible energy for 245 GeV e-





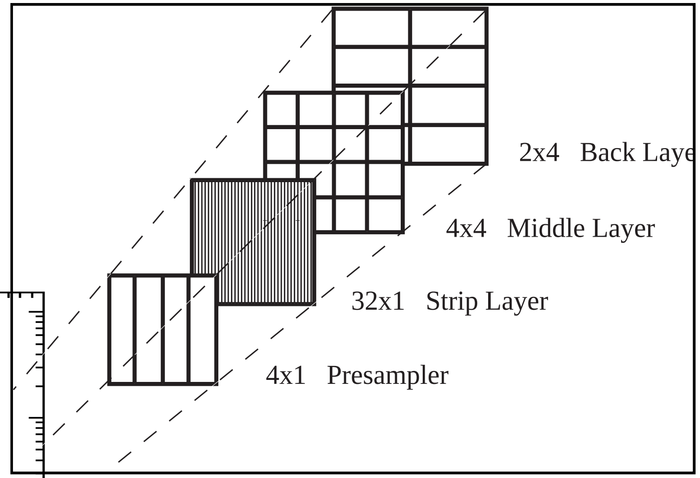
Deposited energies = f(η) in the PS and in the 3 calorimeter compartments before applying calibration factor

Using G4.8 t extract calibration factor for sampling fraction and

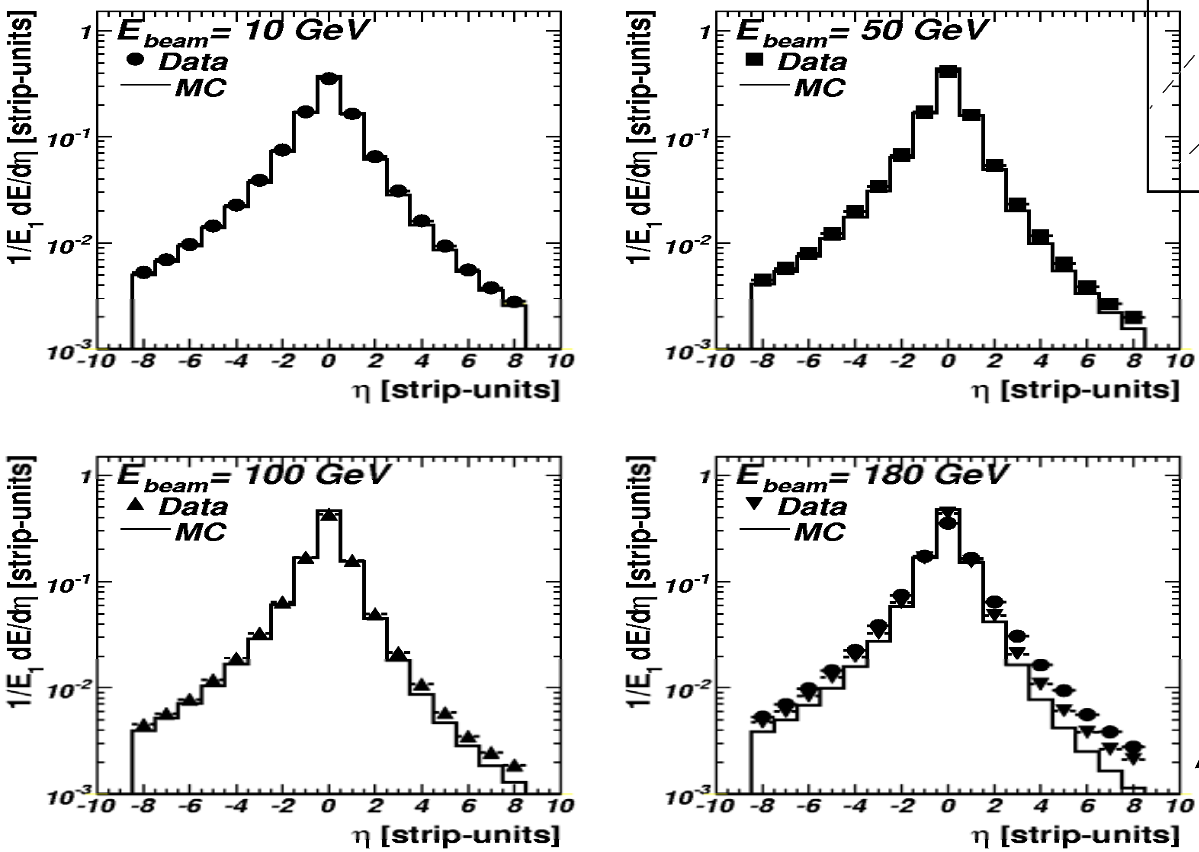
Dead material losses:

0.1% linearity and 0.4% uniformitty

ATLAS LAr Barrel 2002 – Electron Radial Profile



First layer:



MC uncertainty shown but not visible

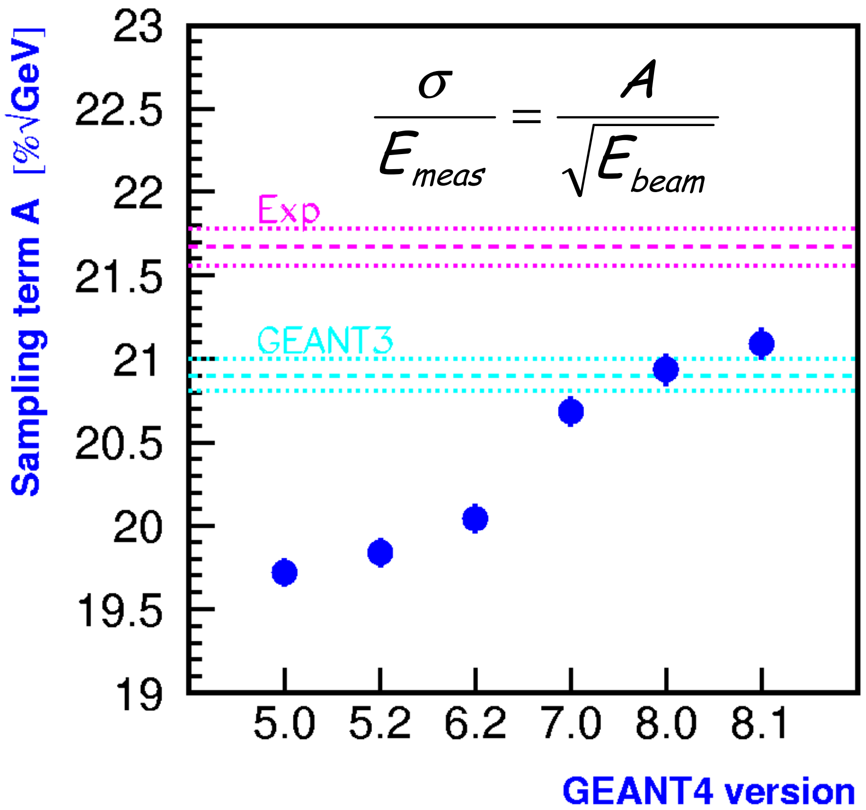
We do not know why this Is, can be
- detector geometry ?
- beam line ?
- beam divergency ?
- G4 physics problem ?

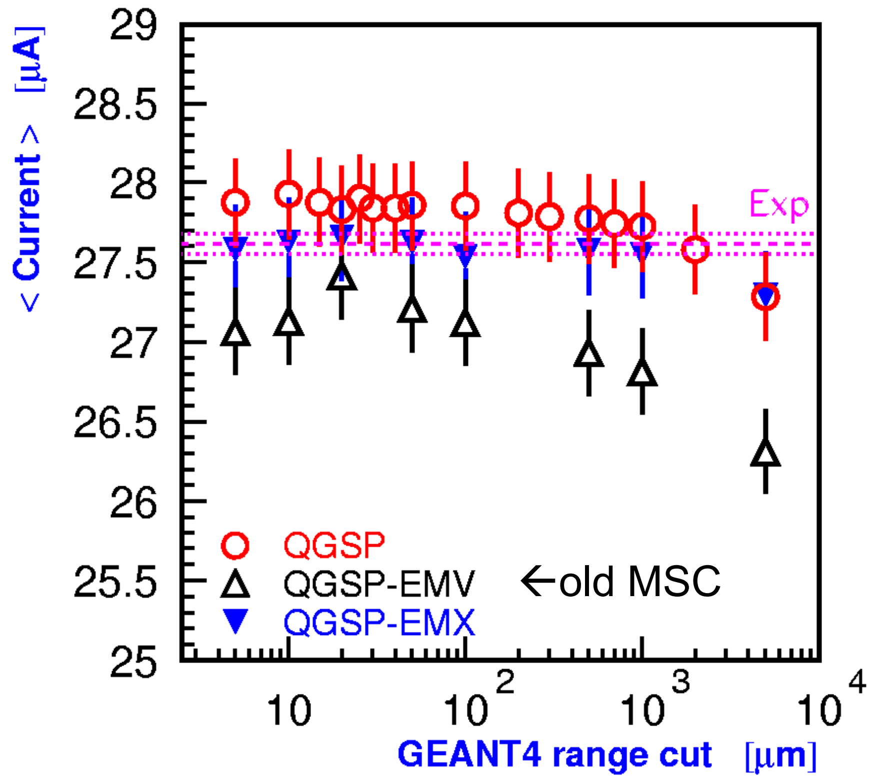
Good description also for asymmetry

G4.8

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

ATLAS HEC: Electron Resolution



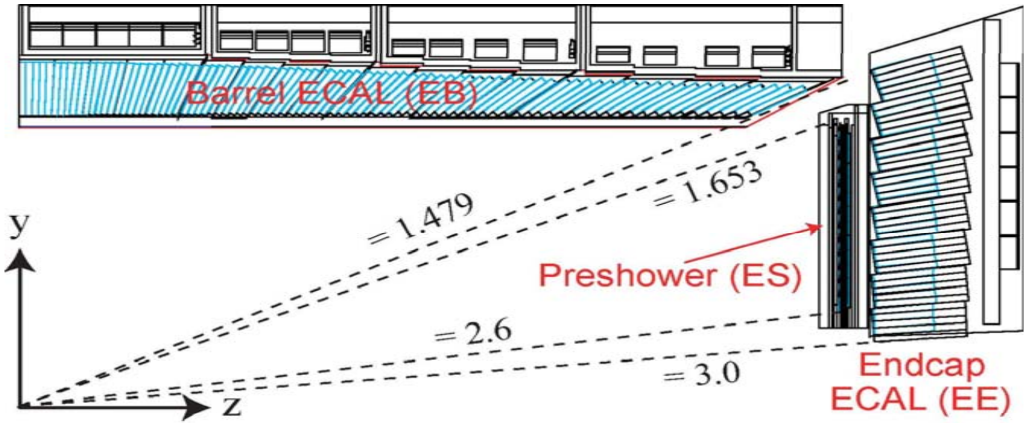


Steady improvement in G4
Resolution in MC better than in data

(in contrast to LAr Barrel where MC had worse resolution, but is now in good agreement)

G4.8

CMS ECAL Barrel: Radial Profile Electrons

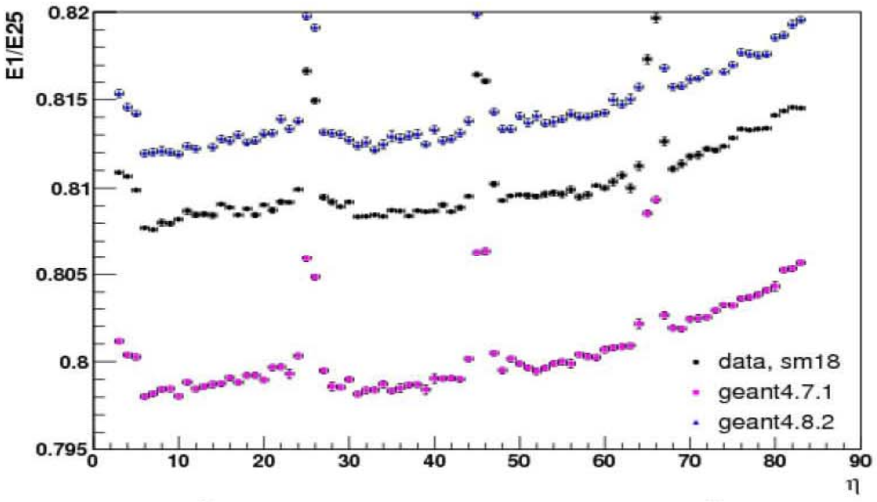


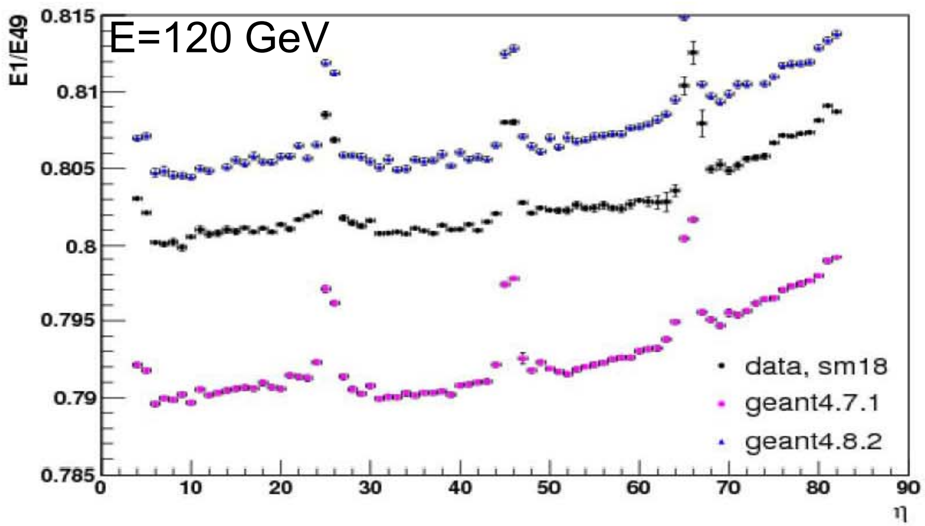
61200 $PbWO_4$ crystals

1 X0 = 0.89 cm
Moliere radius = 2.19 cm

~ 24 x 24 x 230 mm3 (25.8 X0)
$\Rightarrow \Delta\eta \times \Delta\varphi = 0.0175 \times 0.0175$

- Lateral shower profile: ratios of energy deposit in crystal on beam and 5x5 crystals





– Change between G4.7.1p02 QGSP and G4.8.2p01 QGSP_EMV: ~ 1.5% (QGSP ~ QGSP_EMV, but slower)

– η trend reproduced

Good description of data by G4.8

Conclusion on Electrons

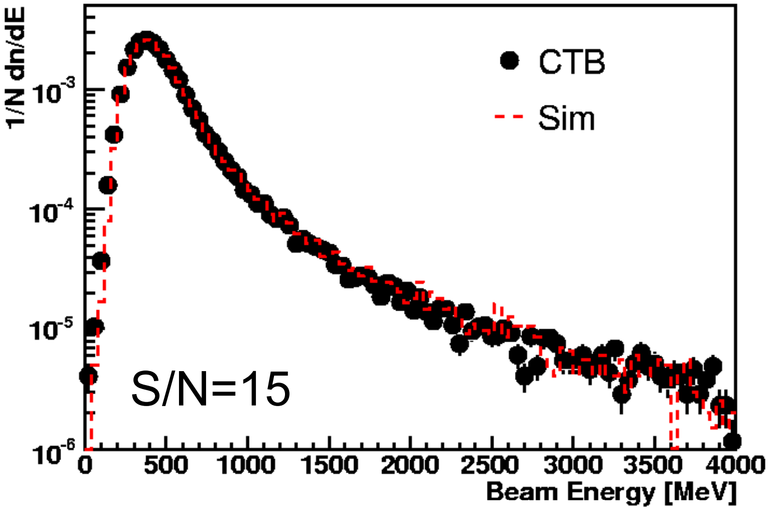
- In ATLAS Lar Barrel: good description of energy response, resolution longitudinal and radial profile
- In ATLAS HEC: steady improvement, resolution a bit too good
- CMS ECAL: radial profile well reproduced (rest: work in progress)

Muons

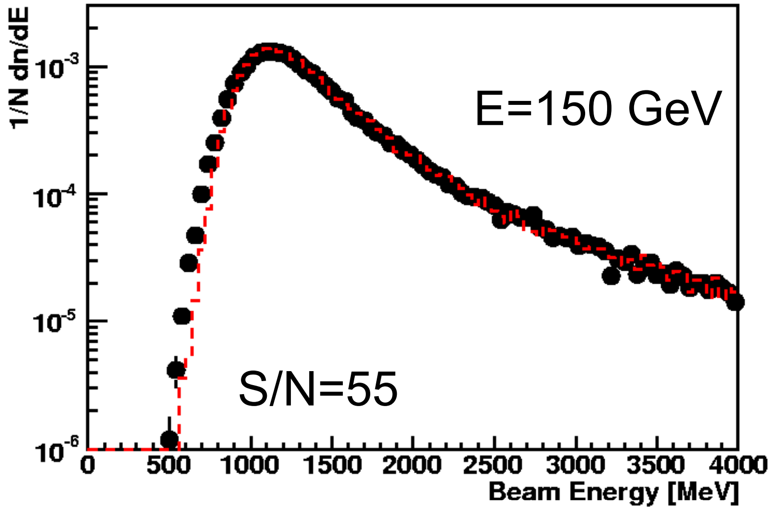
ATLAS Tile Barrel 2004: Muon Energy in Tile

Here, distributions are shifted such that peaks agree

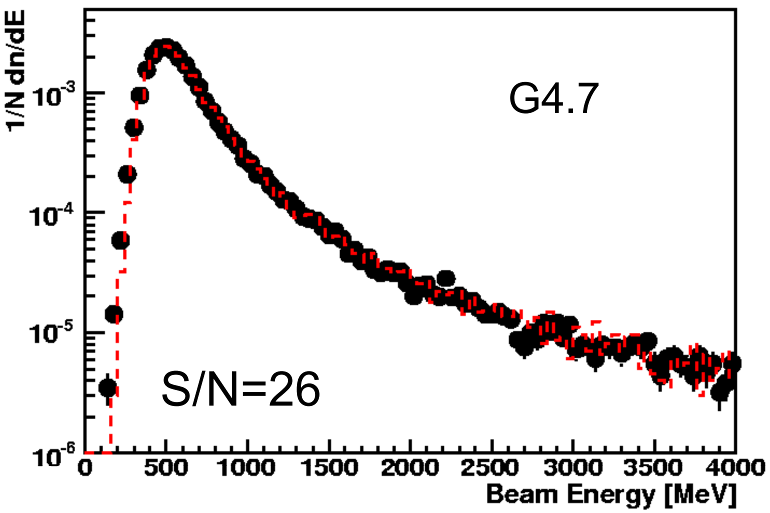
A cell

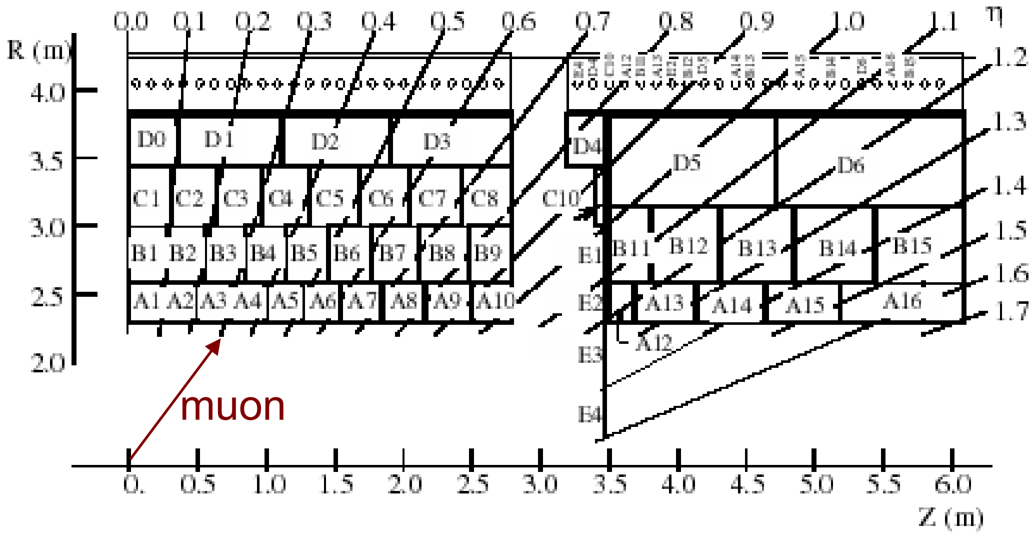


BC cell



D cell





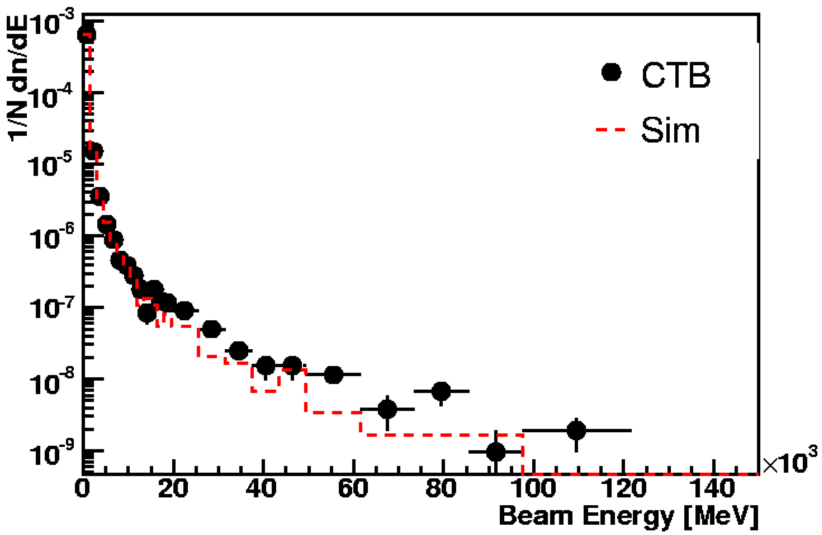
Data/MC agreement in peak region 15%, Data a bit wider

(might be instrumental effect due to Tile row non-uniformity, fibres, light attenuation etc.)

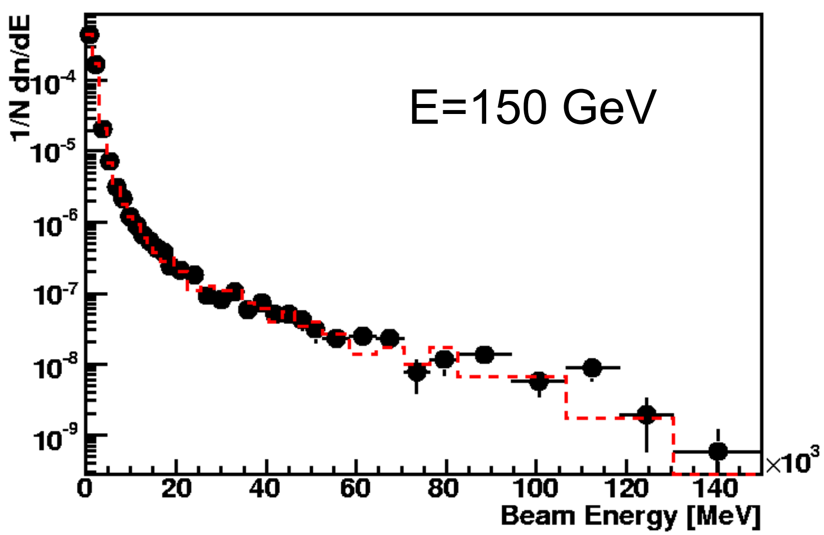
ATLAS Tile Barrel 2004: Muon Energy in Tile

Here, distributions are shifted such that peaks agree

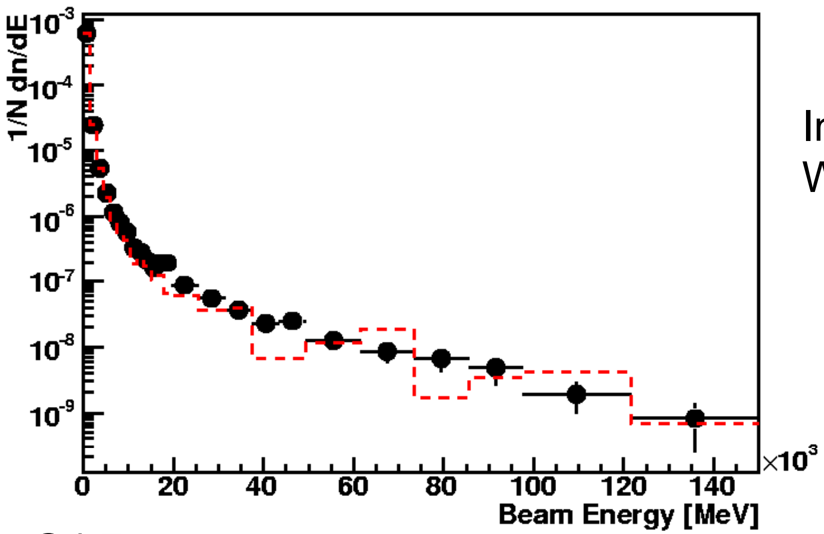
A cell



BC cell



D cell

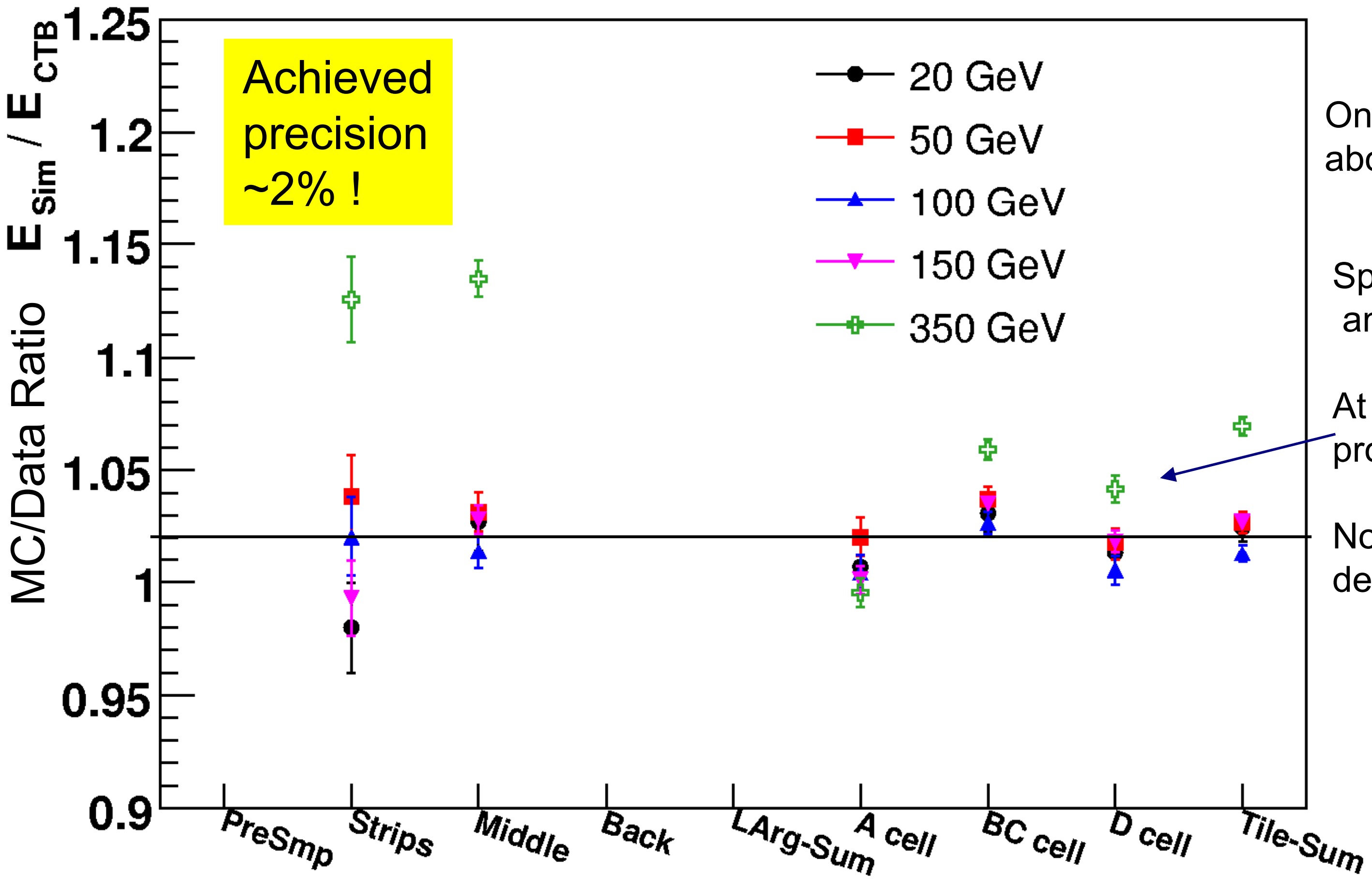


G4.7

In rare cases muons loose all energy in calorimeter.
Well described by MC

→ implementation of radiative processes ok

ATLAS LAr/Tile Barrel 2004: MC/Data Mean Energy



On average, MC higher by about 2% in both LAr and Tile

Spread of 1.4% E_{muon} and layers (systematics)

At 350 GeV, pion contamination prohibits precision comparisons

No clear trend in energy dependence

G4.7

→ G4 MC describes the measured signal to ~ 2% with an uncertainty of ~1.5%

→ proves good quality of G4 and understanding of detector

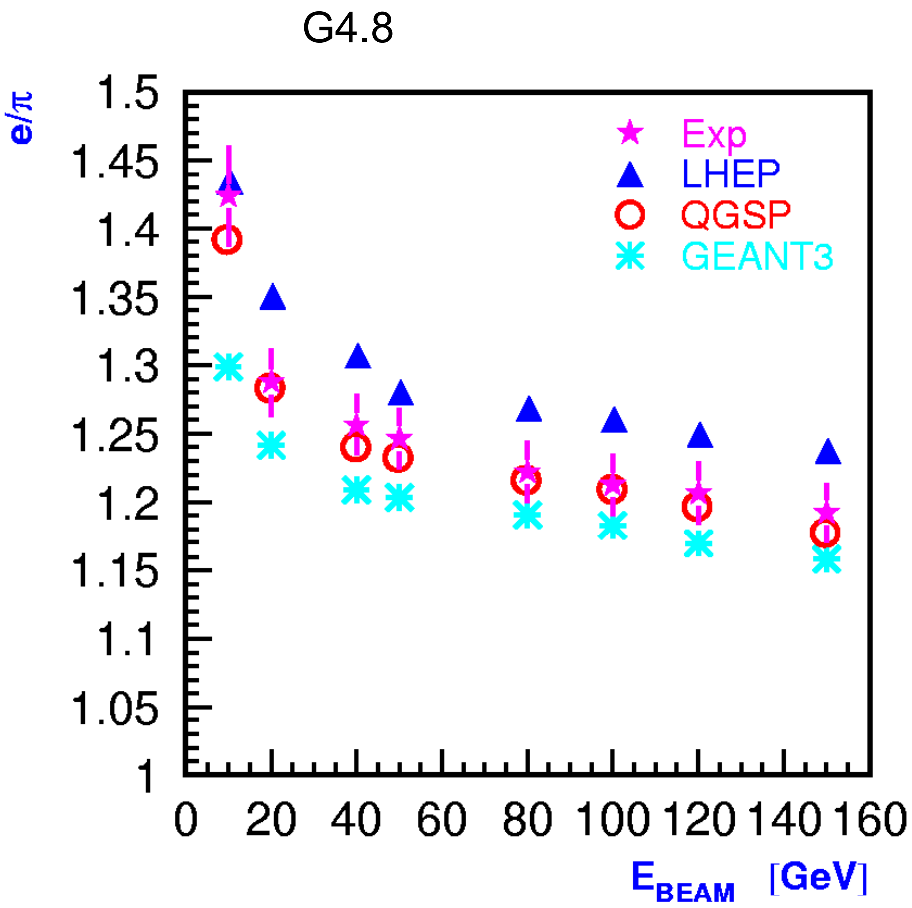
→ muons provide reference signal to calibrate within a few % (absolute energy scale)

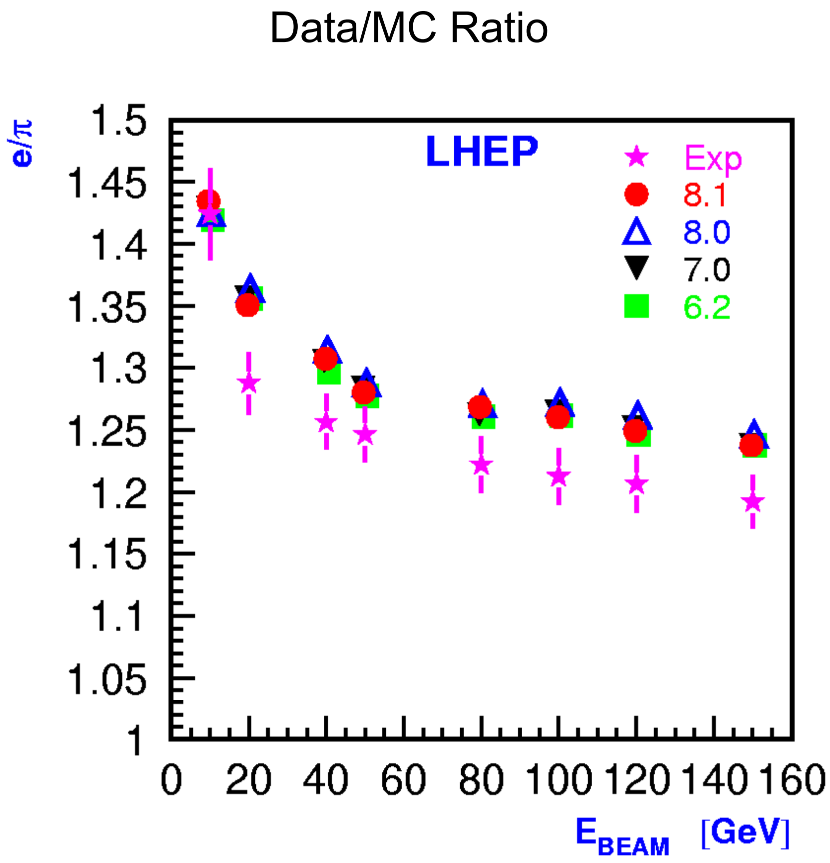
Conclusion on Muons

ATLAS Barrel: Tile and Lar calorimeter
energy distribution and mean energy deposit well described (~2%)

Pions and Protons

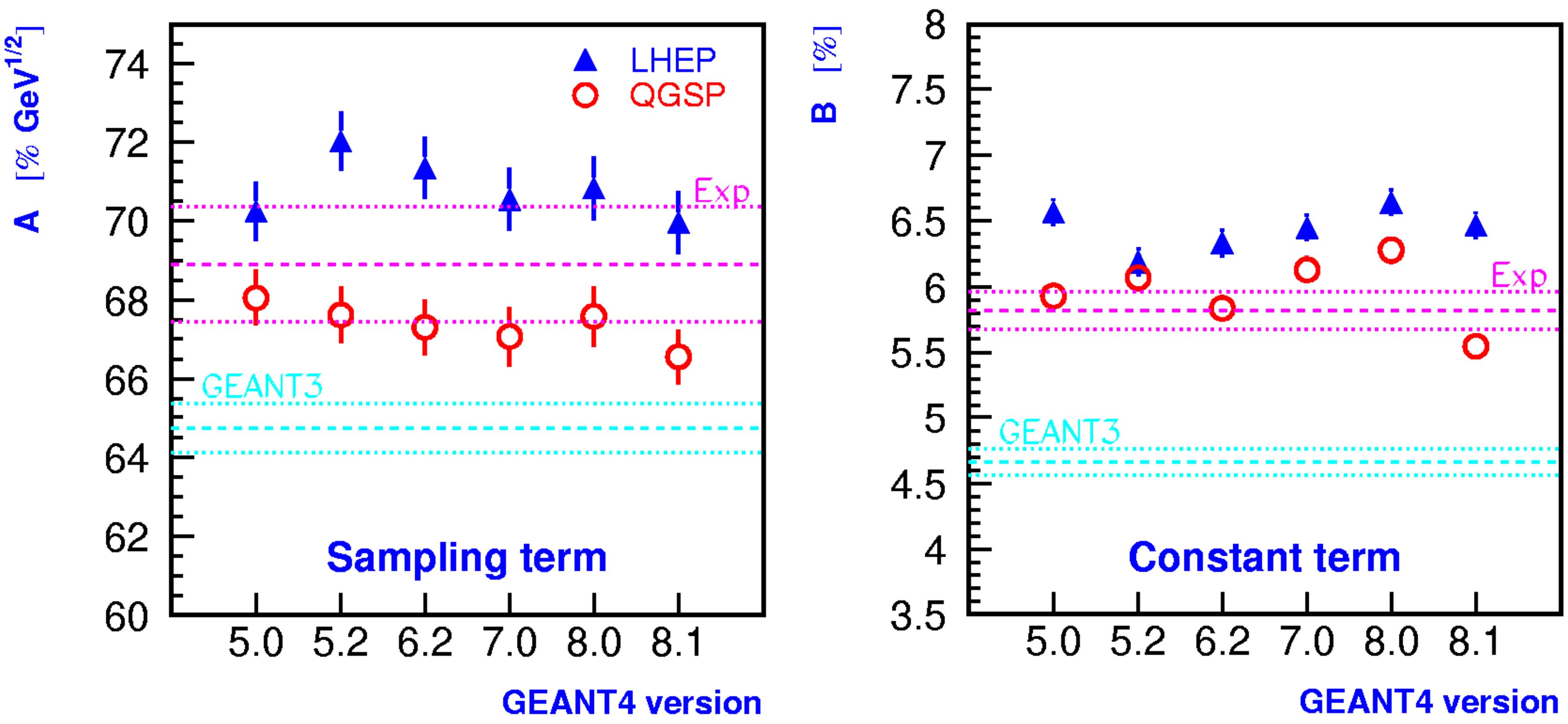
Atlas HEC: Ratio Electron/Pion Response





QGSP describes data well
LHEP predicts larger e/pi
Geant3 is systematically lower

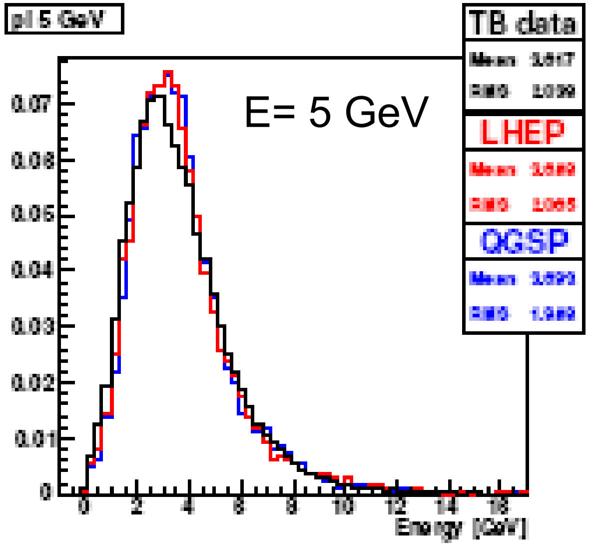
Atlas HEC: Pion Energy Resolution



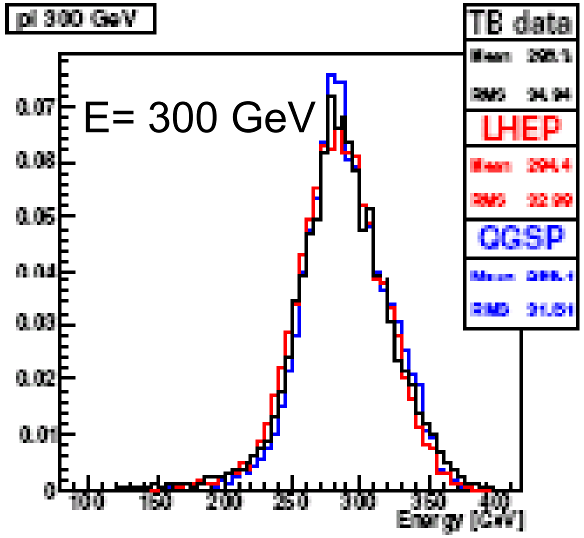
G4 describes resolution quite well, QGSP a bit better than LHEP
Some changes between G4 version
G3 predicts too good resolution

CMS: Pion Energy Response

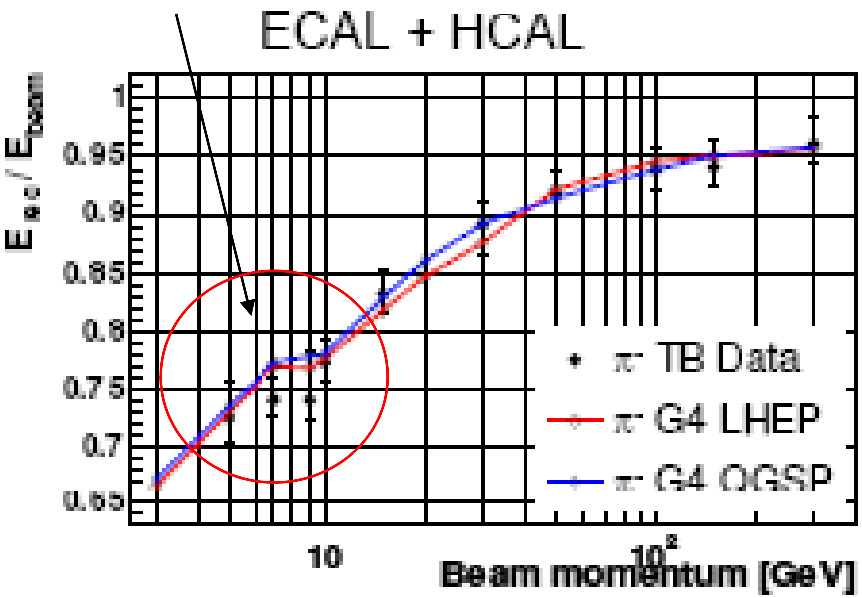
Examples energy distributions:

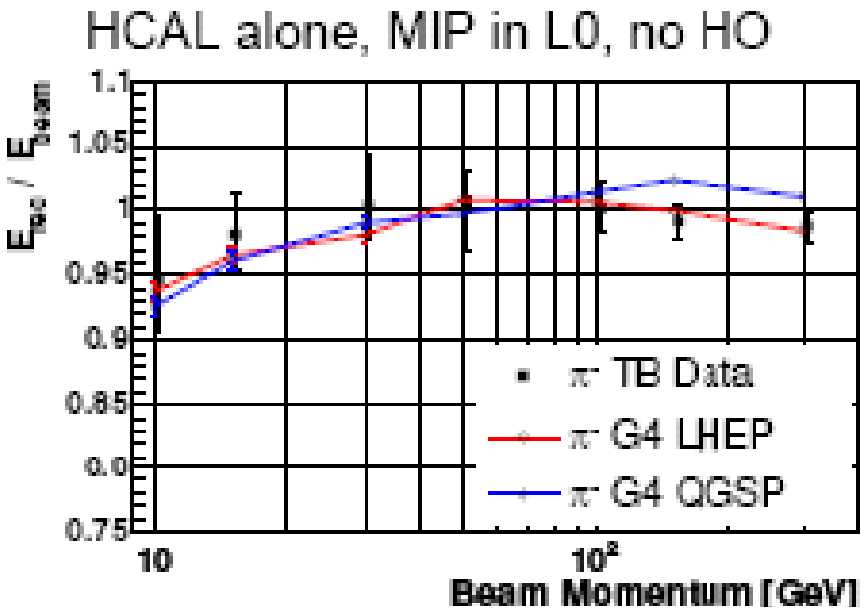


G4.6.2



To be understood

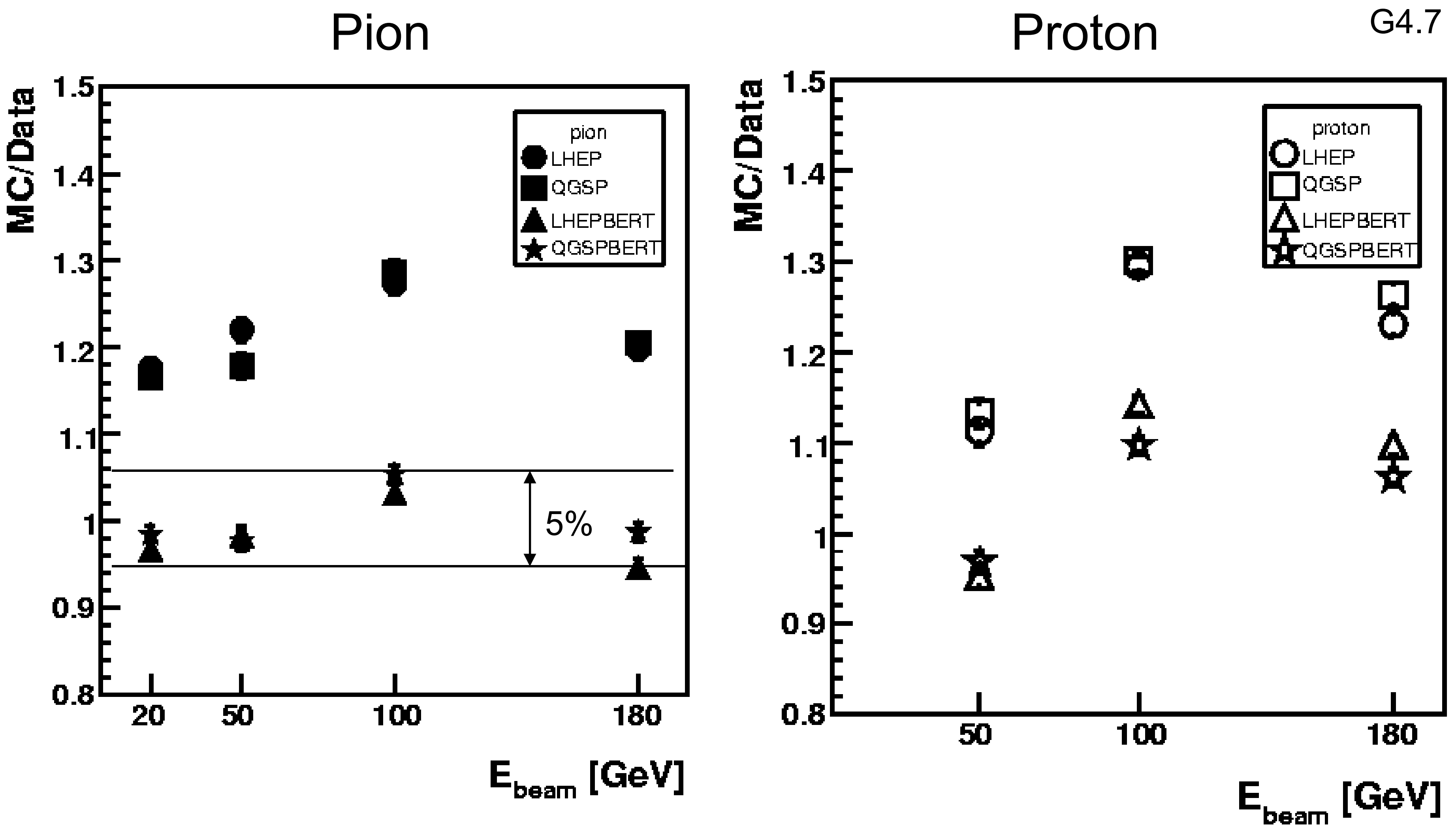




Generally good description

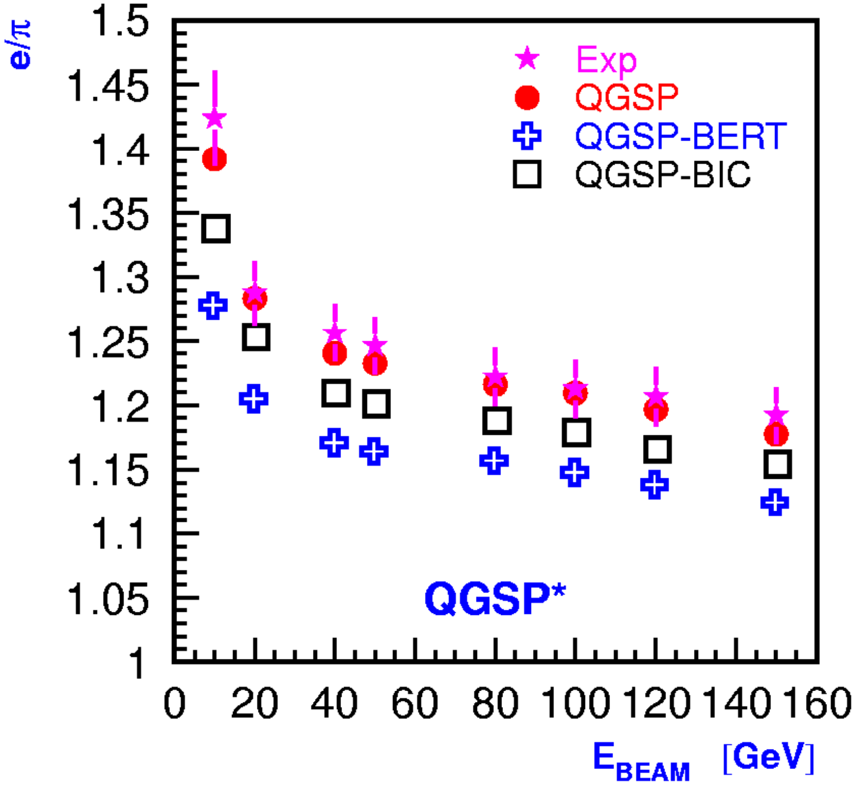
QGSP: higher response at high energy
Probably due to shorted showers

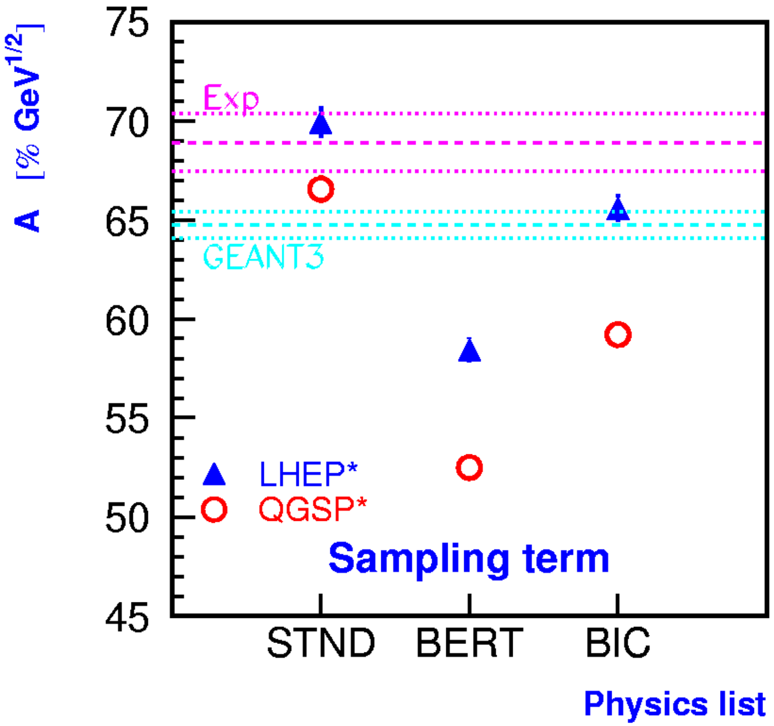
Atlas Tile: Pion and Proton Resolutions

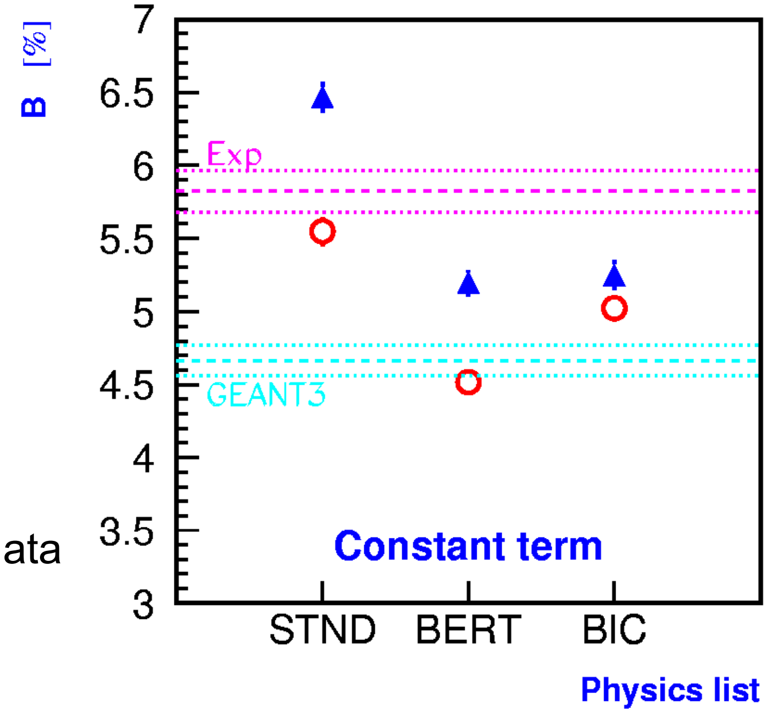


Resolution for pions agrees within 5% when nuclear cascade models are used
…also proton resolution better described (10%)

ATLAS HEC: e/pi Ratio







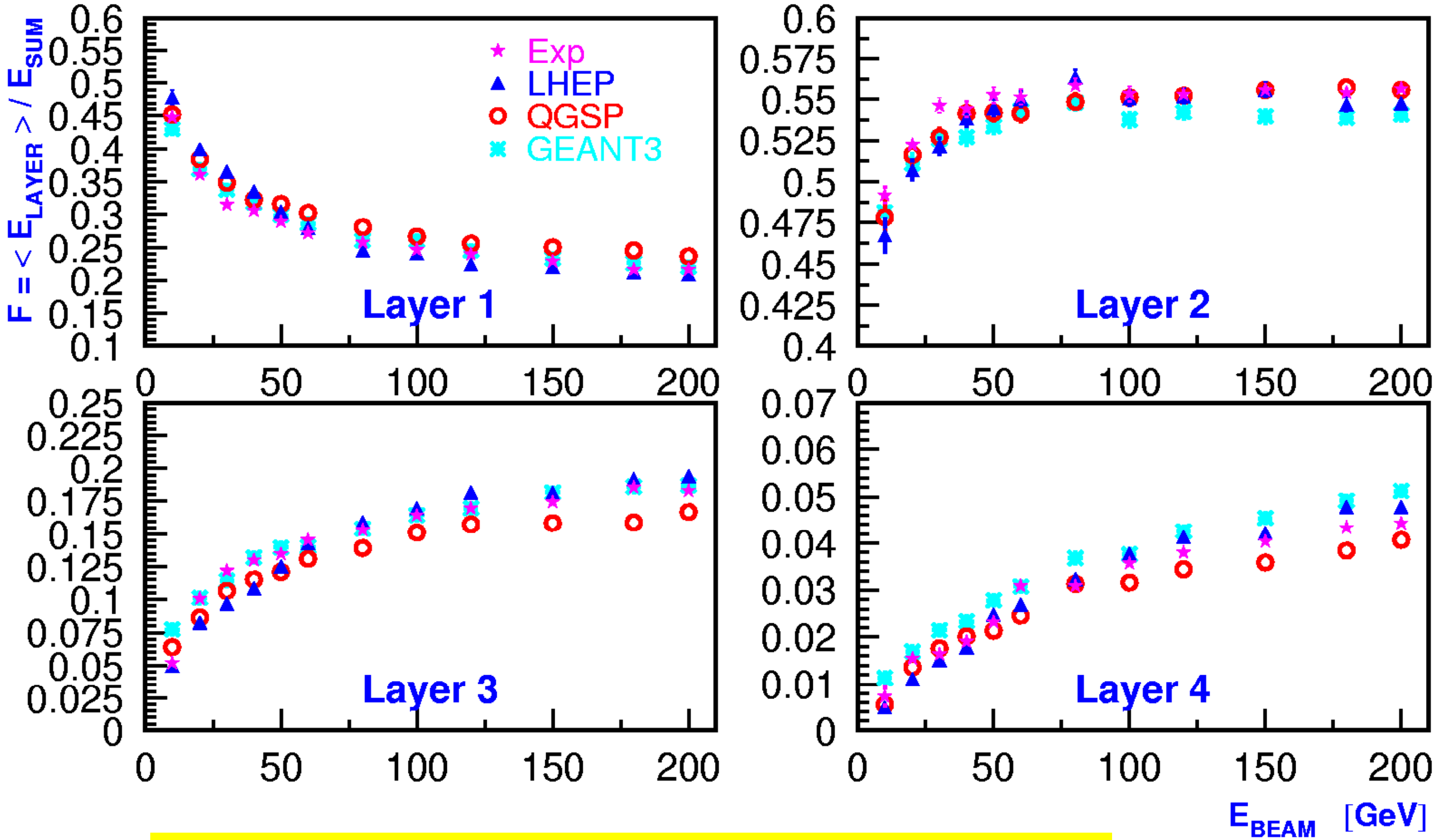
Adding cascade models response is lowered by ~5%
(presently investigating, if effect can be recovered by
introducing Birks law)

Resolution becomes better and does not agree with data

G4.8

Atlas HEC: Pion Energy Fraction in Longitudinal Layers

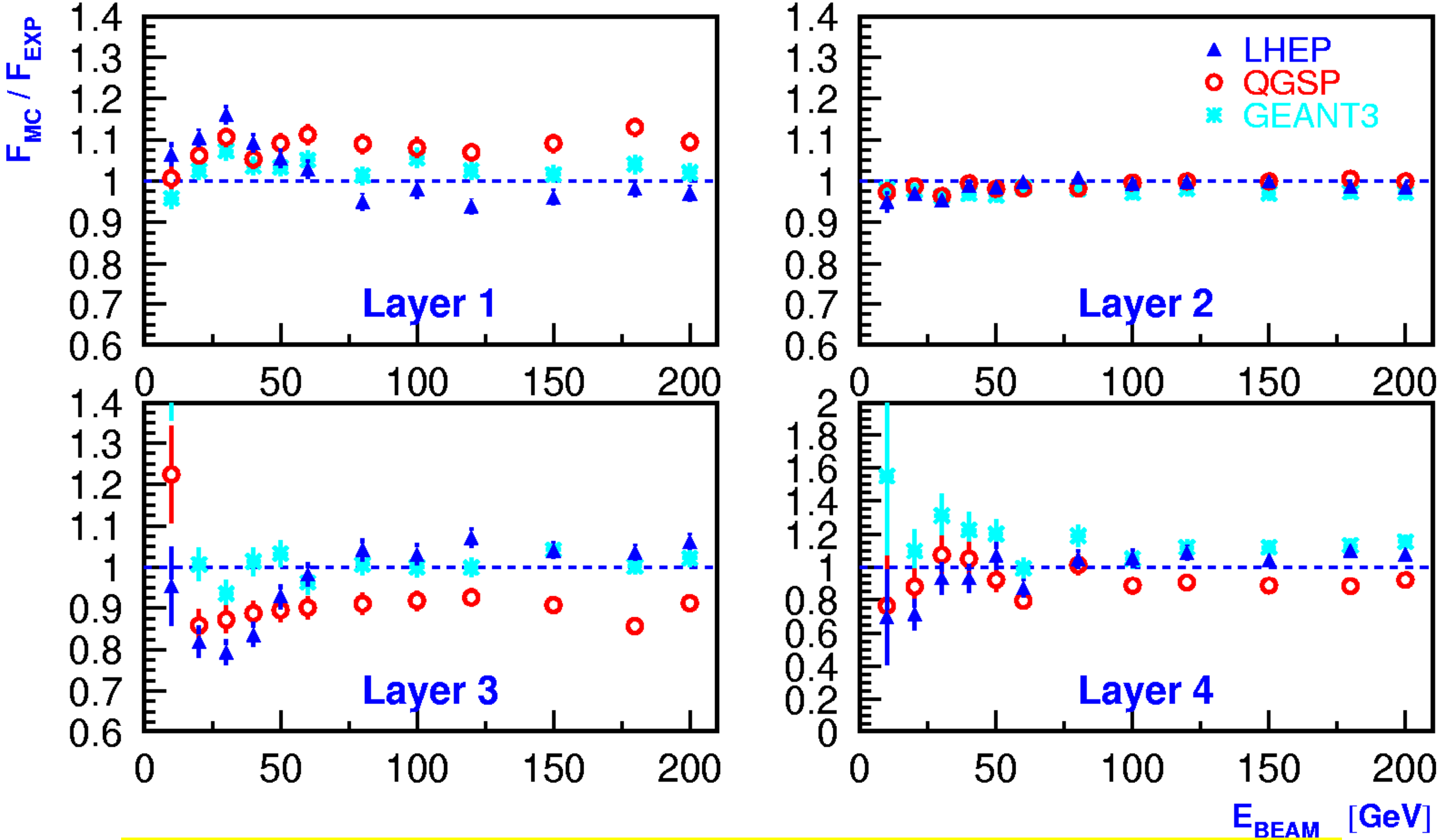
Long. Layers: 1.5/2.9/3.0/2.8 interaction length



Largest energy in layer 2
Hadronic shower penetrates deeper as energy increases

G4.81

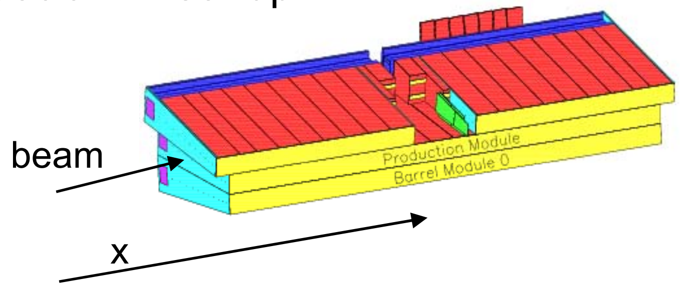
Atlas HEC: Pion Energy Fraction in Longitudinal Layer Ratios

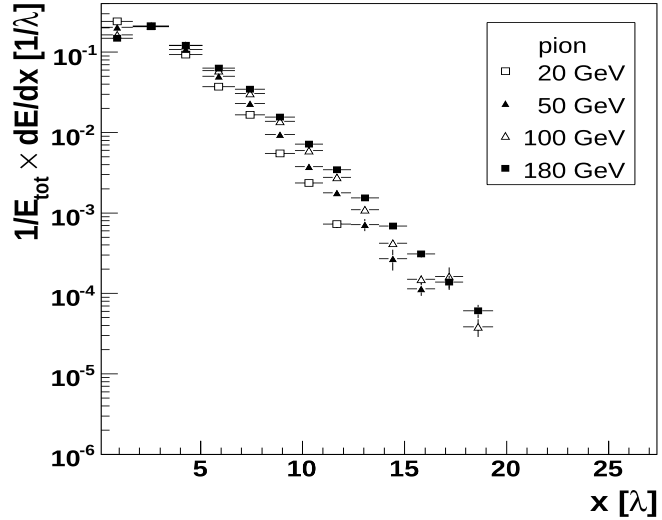


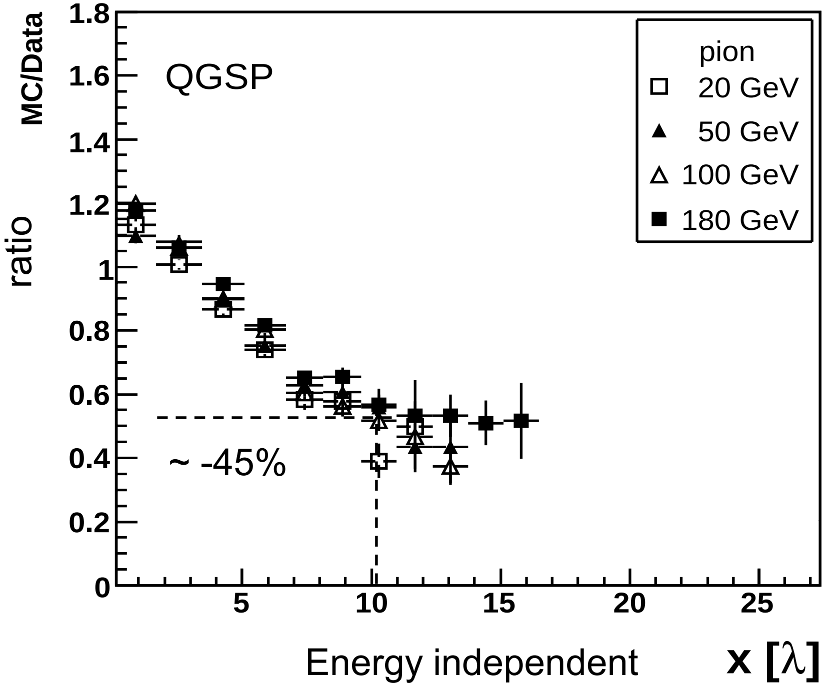
Energy in layer 2 within 5% for all simulations
QGSP: hadronic shower start earlier and and earlier (means are 10-20% off)
LHEP: different trends, but starts too early and too long
G3: better than G4

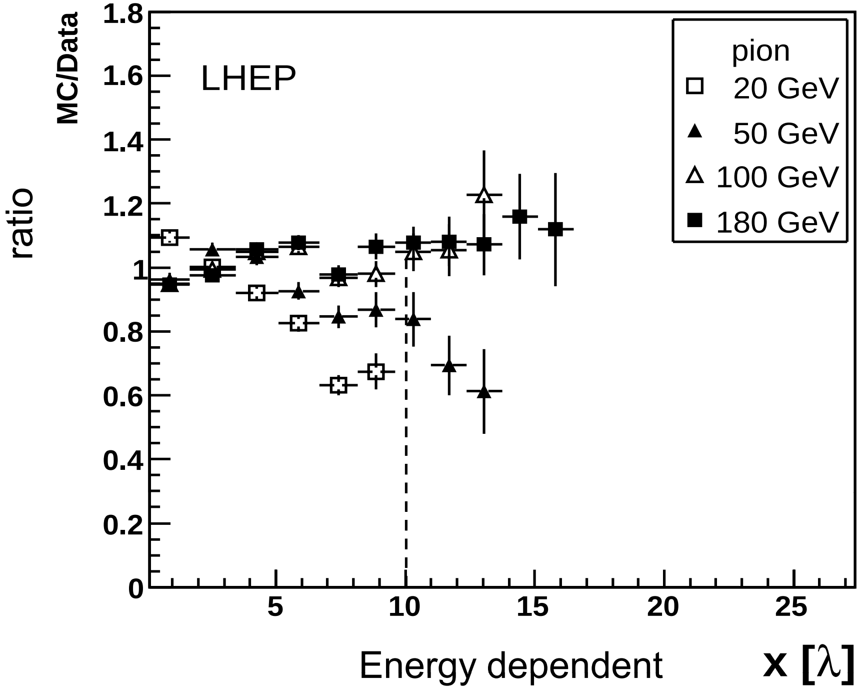
Atlas Tile: Pion Shower Profile

Special TB set-up:



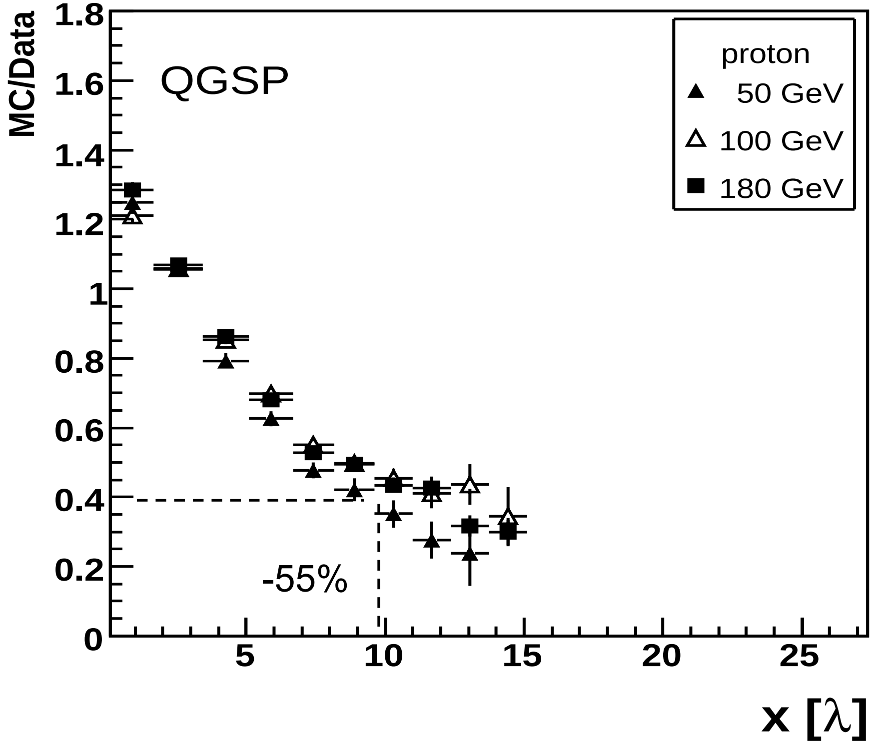


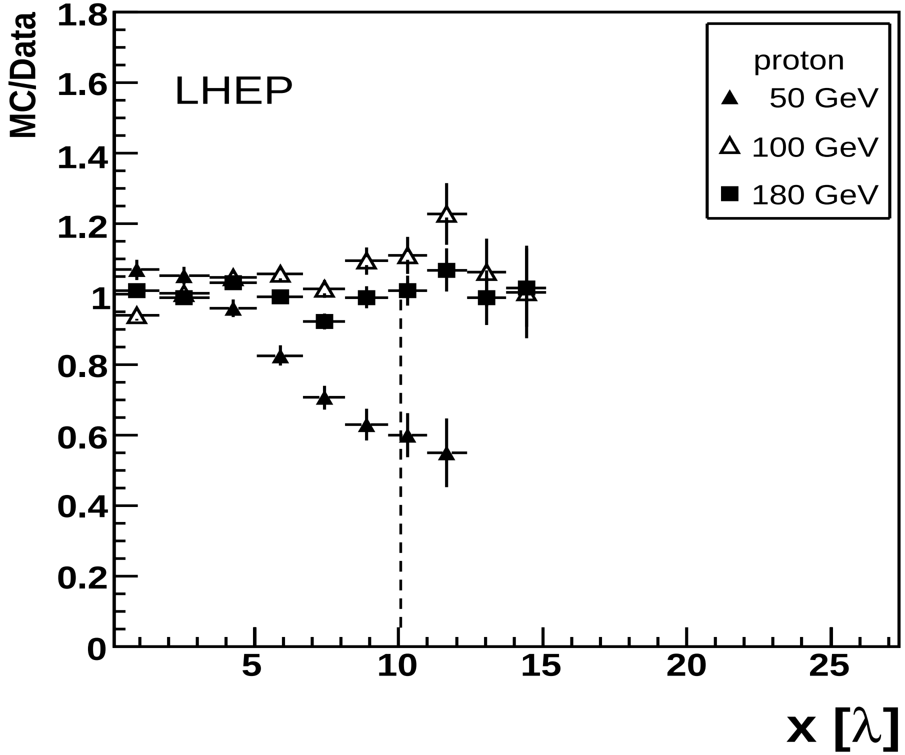




- QGSP predicts too short showers.
- LHEP describes shower profile at high energies quite well.

Atlas Tile: Proton Shower Profile

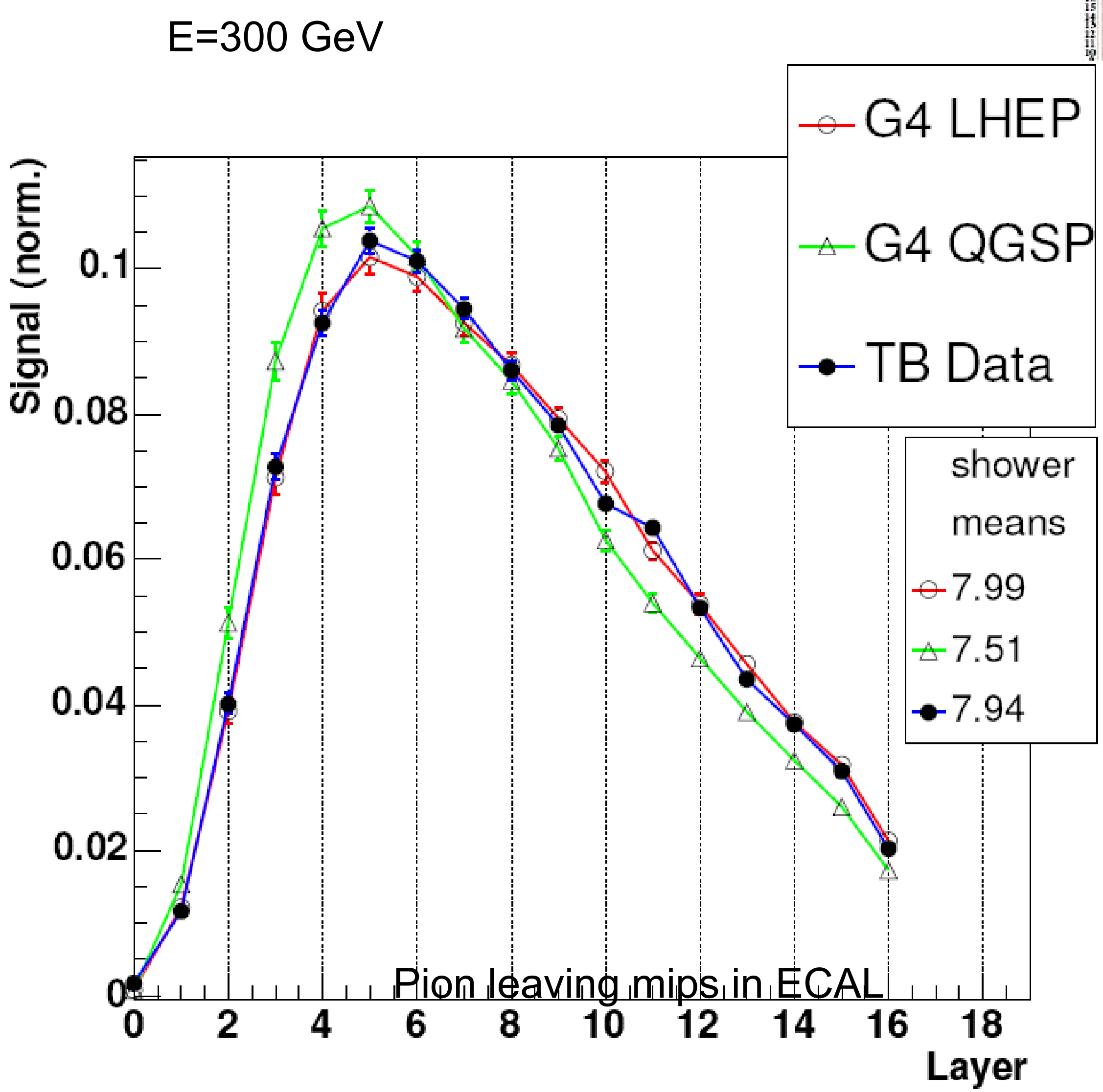


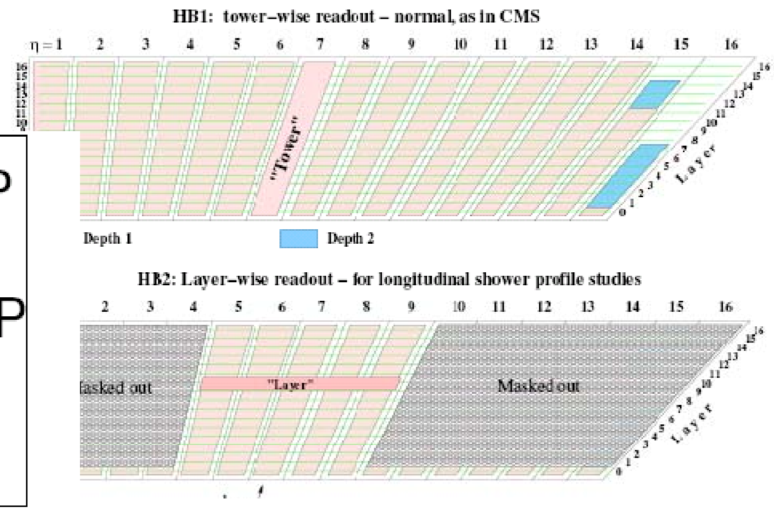


Protons worse described than pions

- QGSP predicts too short showers
- LHEP describes shower profile at high energies quite well.

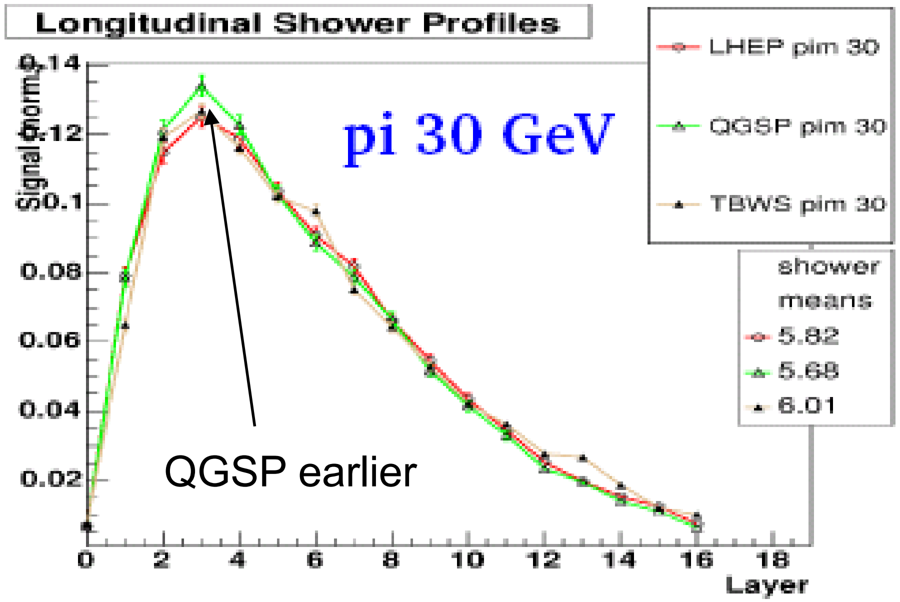
CMS: Pion HCAL Longitudinal Shower Profile

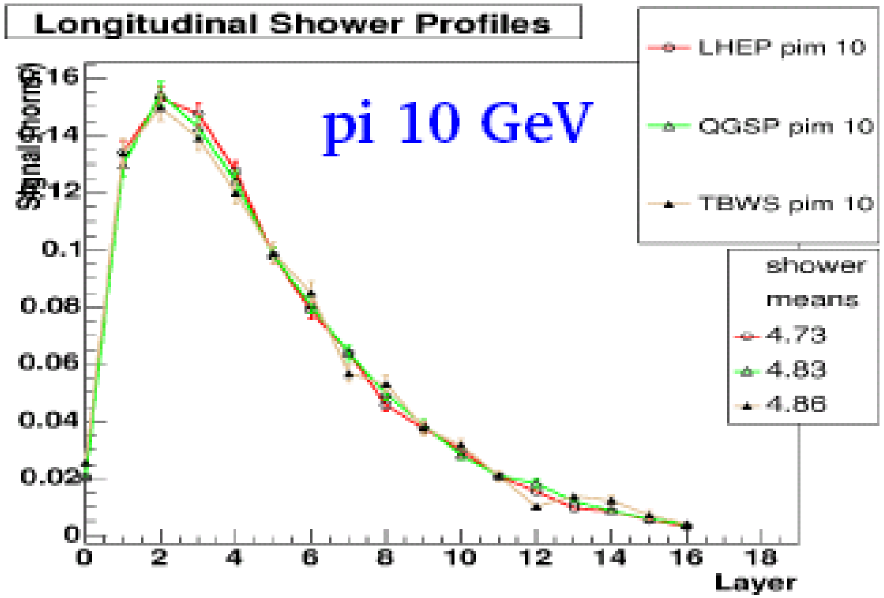


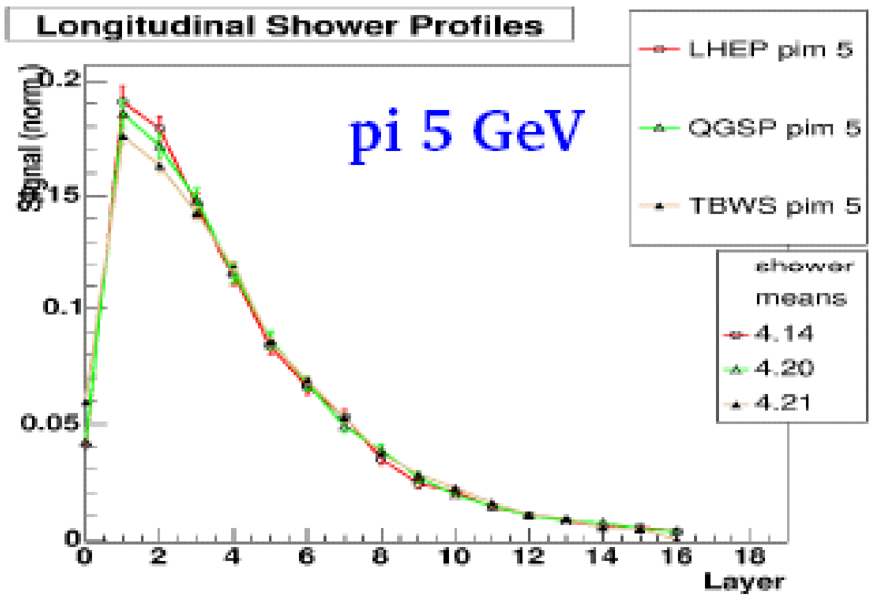


Data well described by LHEP
QGSP predicts too short showers

CMS: Pion HCAL Longitudinal Shower Profile



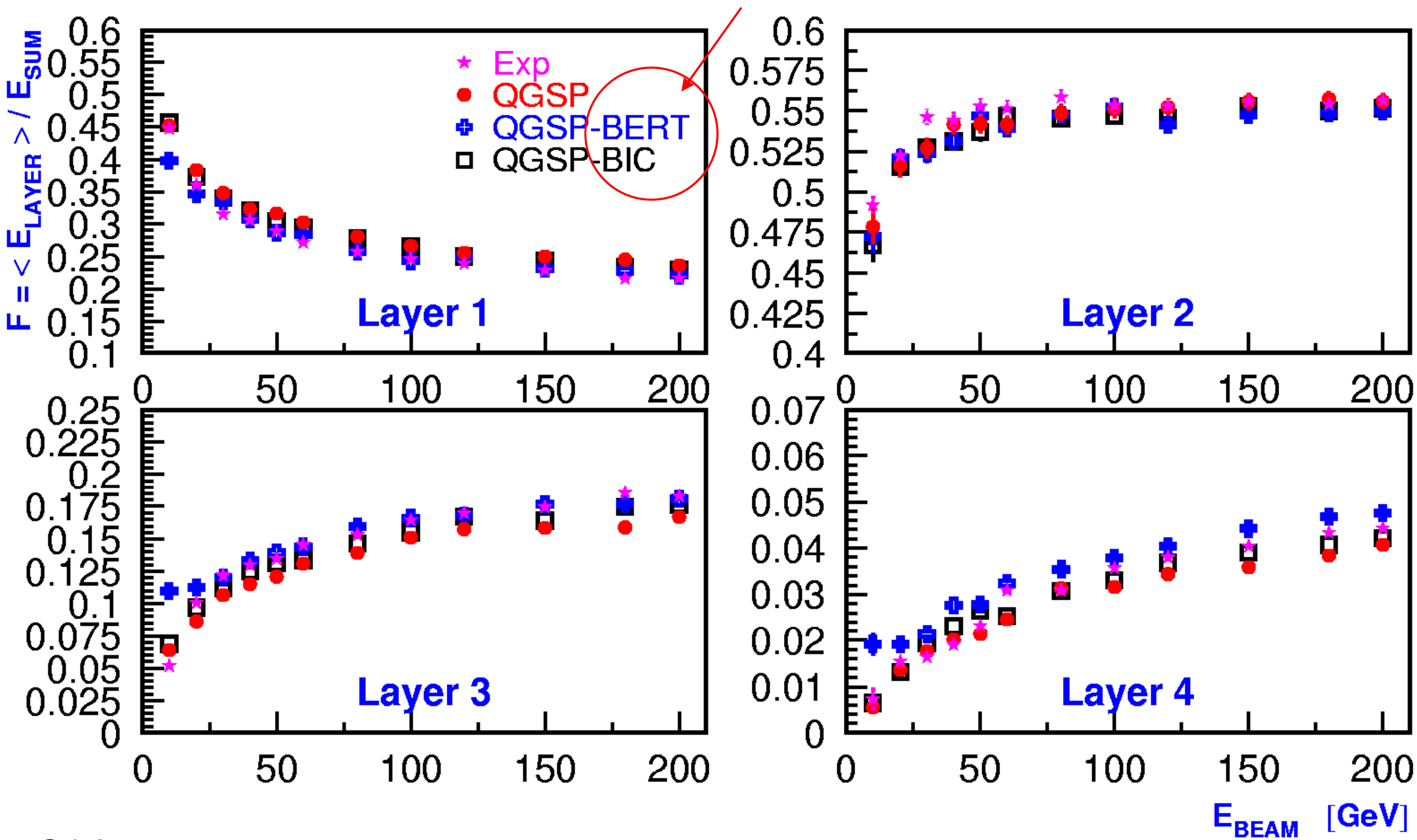




LHEP and QGSP show good agreement with test beam data at low and intermediate energies

Atlas HEC: Pion Energy Fraction in Longitudinal Layer Ratios

Nuclear cascade models in low energy regime

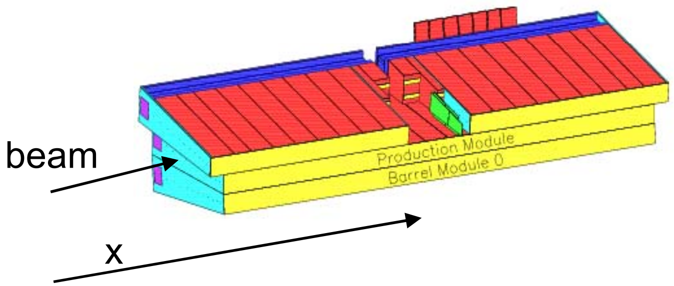


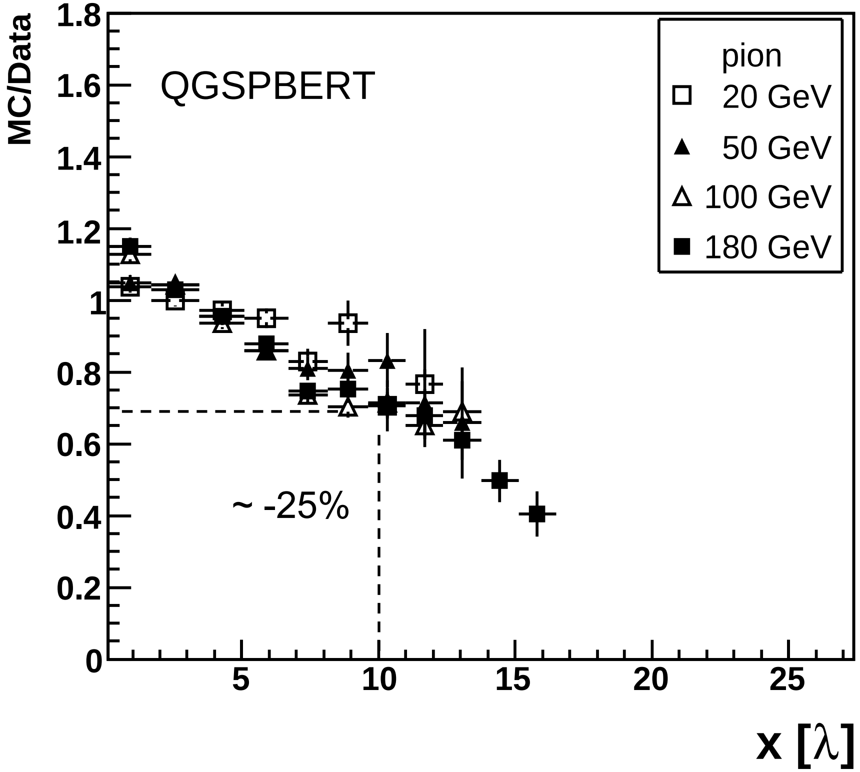
G4.8

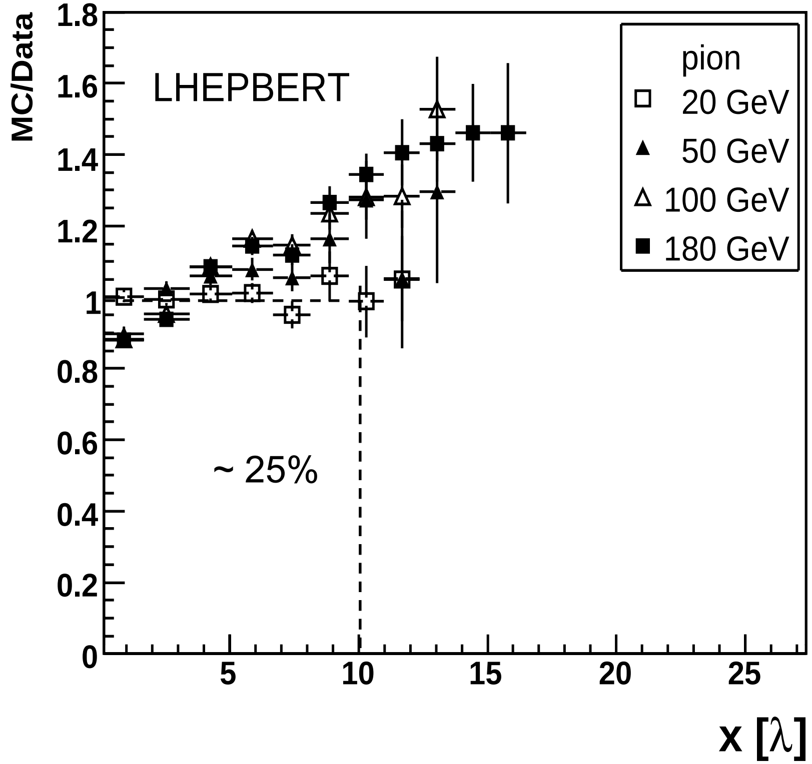
QGSP-BERT: good description of shower profile (except low beam energies)

QGSP-BIC: certain improvements with respect to QGSP

Atlas Tile: Pion Shower Profile

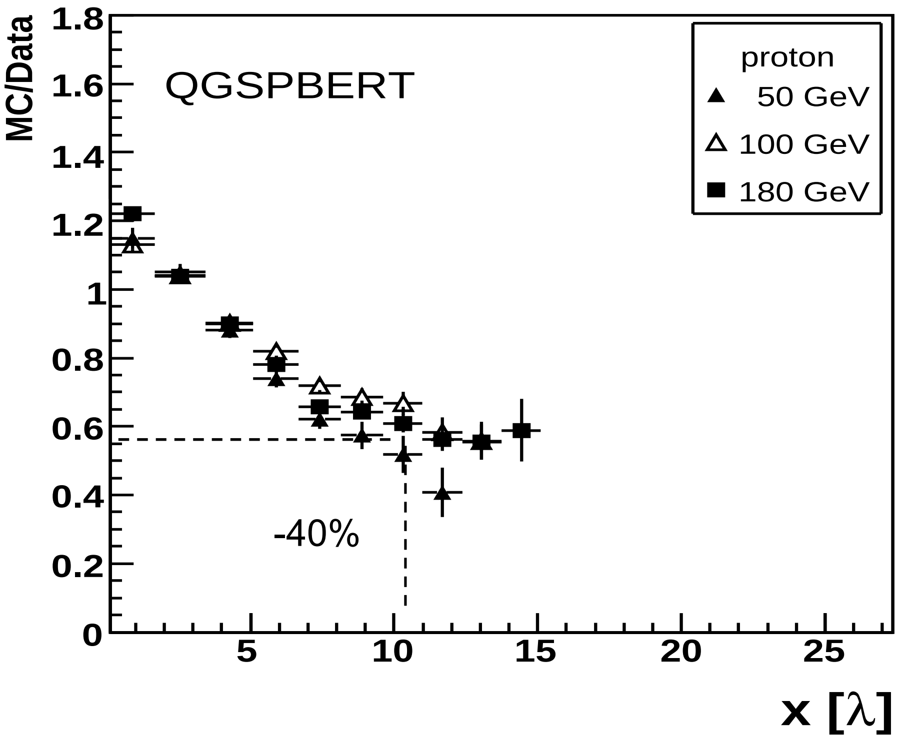


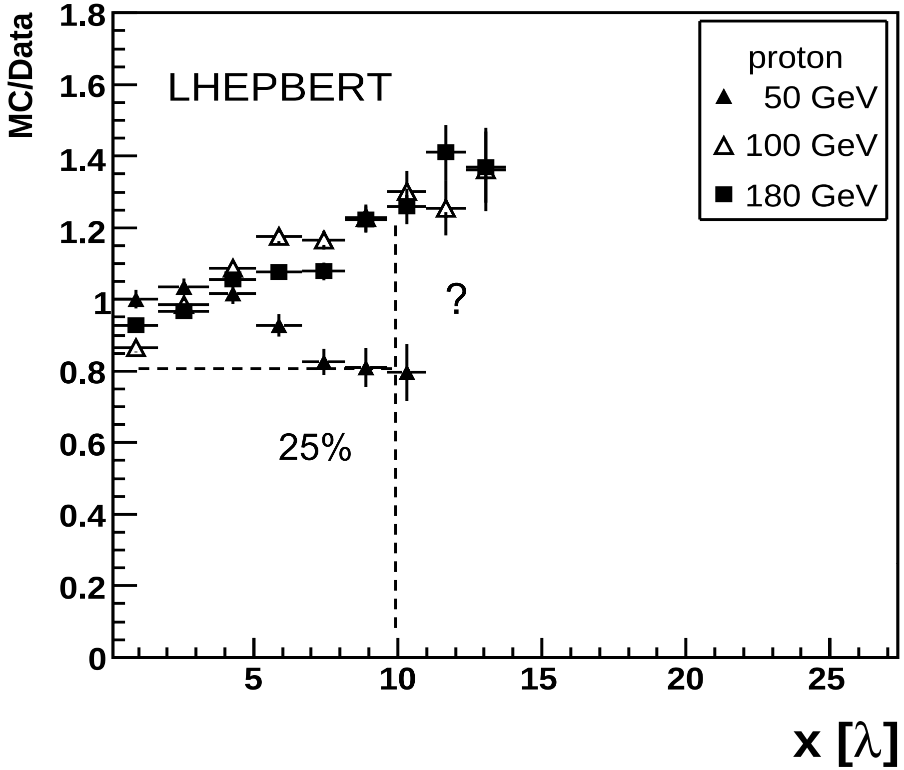




- QGSPBERT still predicts too short showers, but the description improves: at 10 lambda: from 45% to 25 %
- LHEPBERT predicts longer showers.

Atlas Tile: Proton Shower Profile



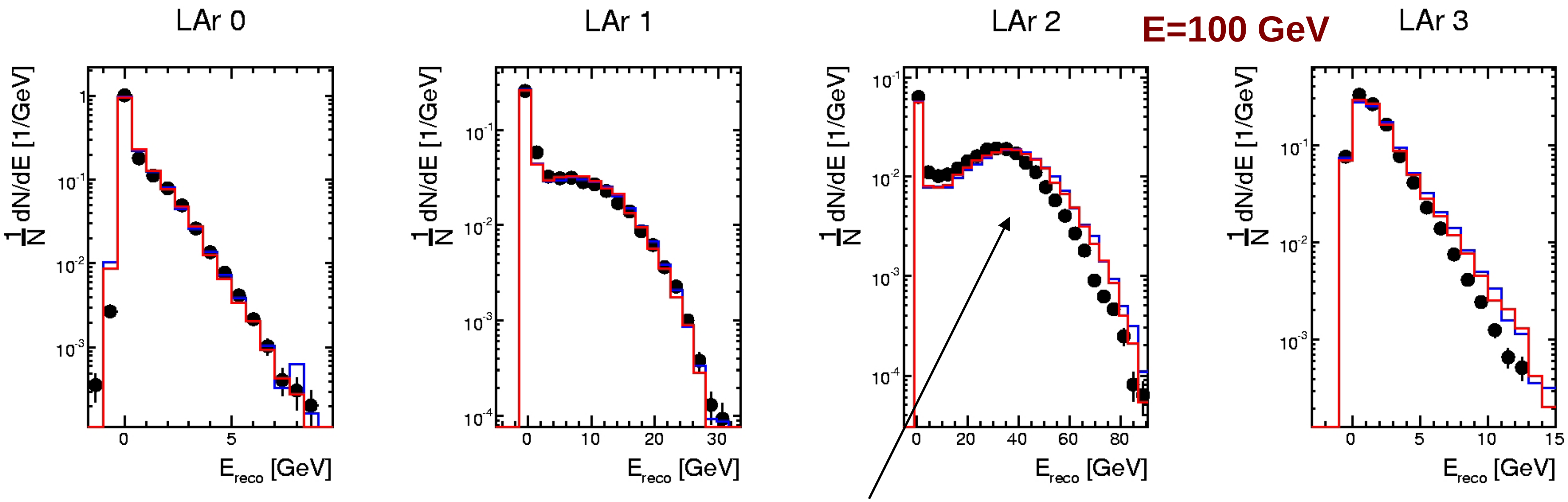


Strange energy dependence

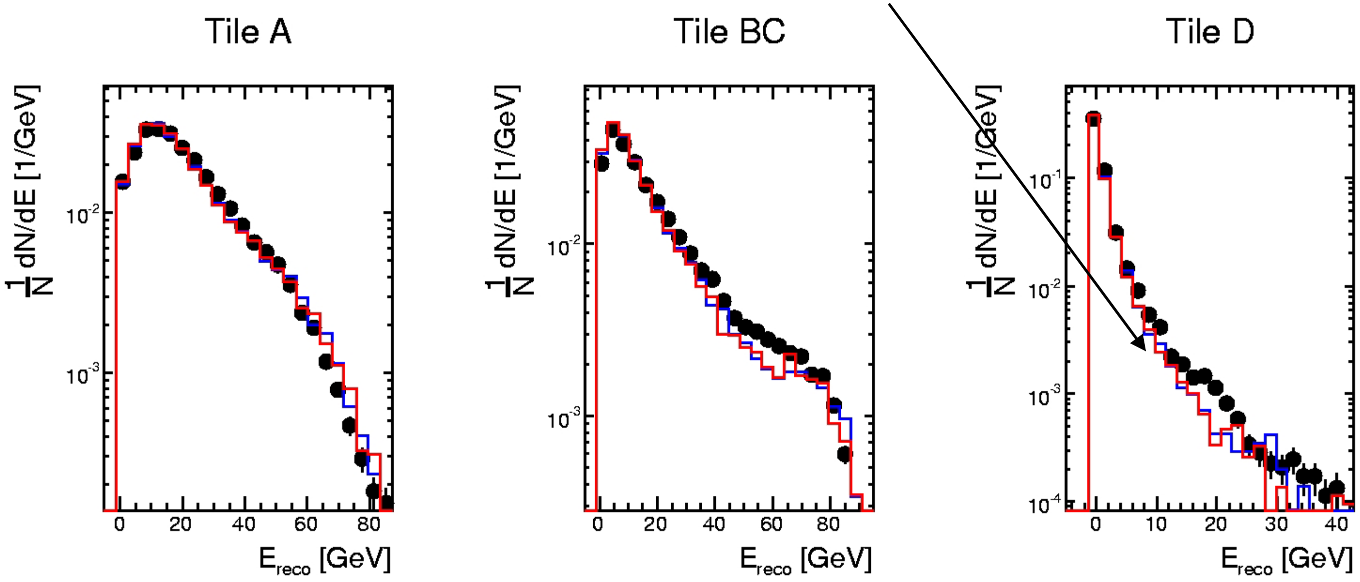
- QGSP still too short showers (at 10 lambda 55% → 40%)
- LHEPBERT shower are longer at high energies.

ATLAS LAr/Tile Barrel 2004: Pion/Proton Data/MC

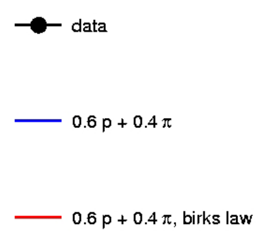
E=100 GeV



QGSP_BERT gives reasonable description
but starts and ends too early



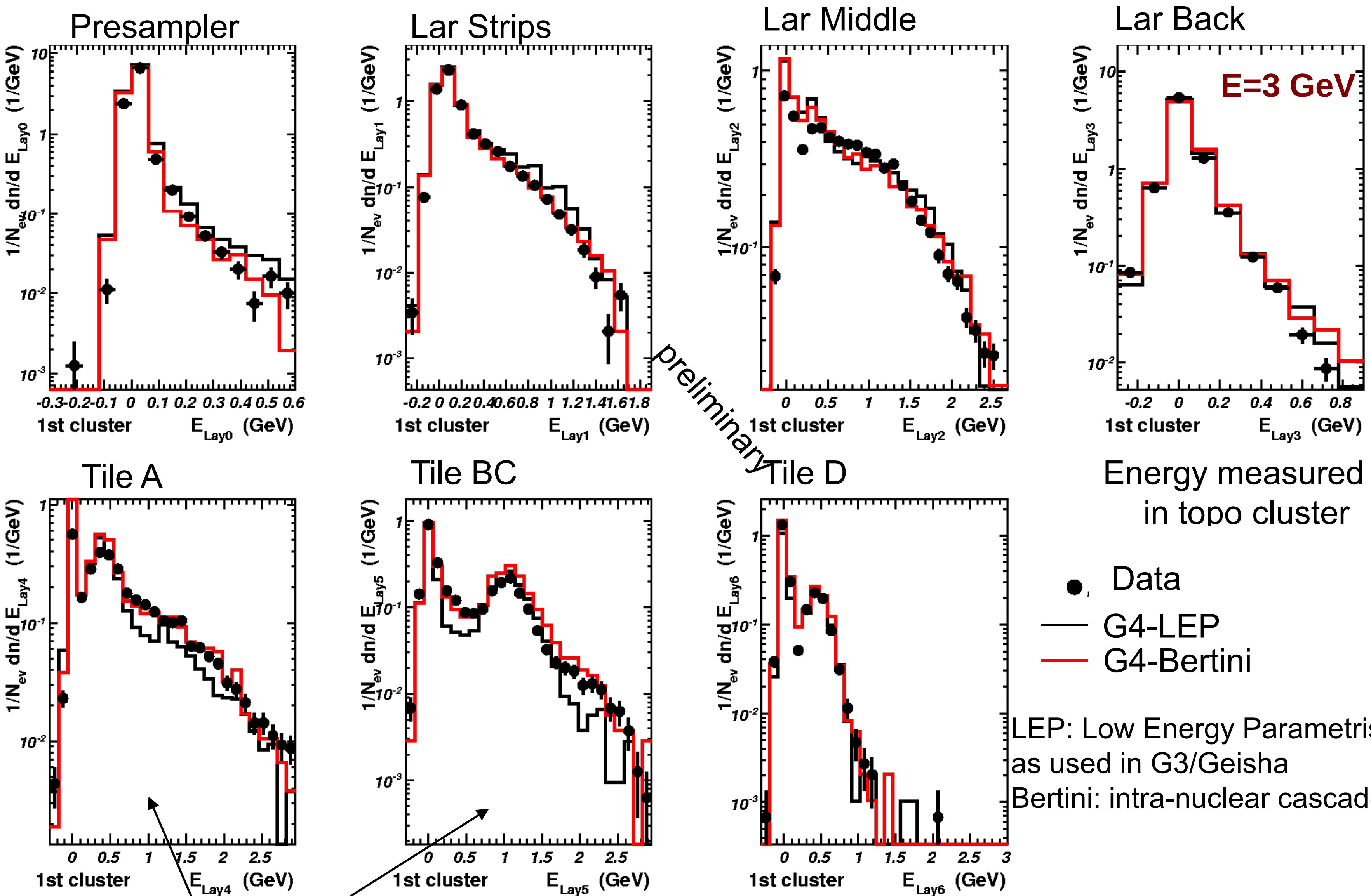
Here positive beam !
From 2002 H8 analysis:
~50% pion / ~50% protons
need to mix proton in MC



G4-QGSP_BERT
With/without Birks law

G4.7

ATLAS LAr/Tile Barrel 2004: Pion Layer Energies



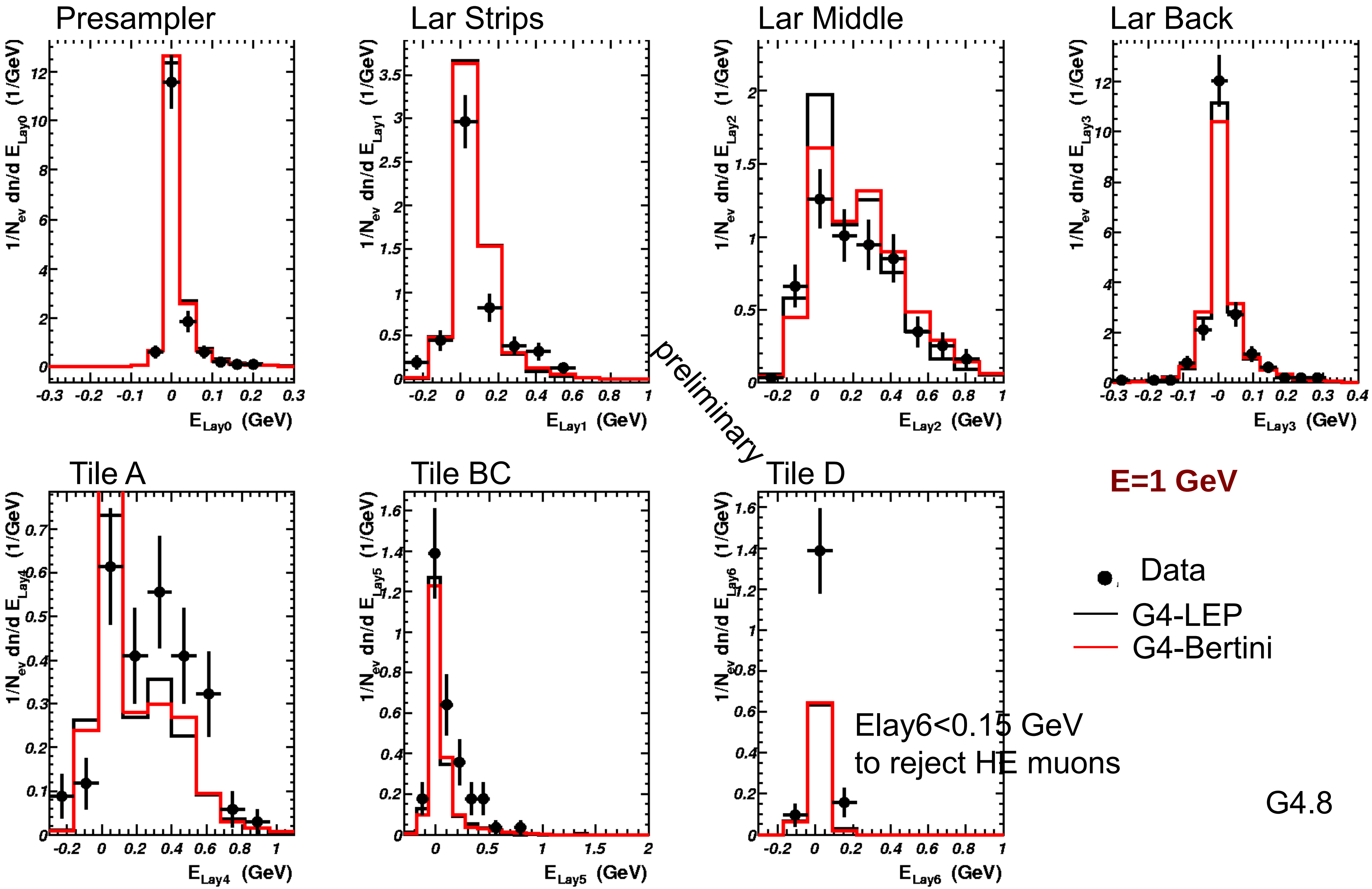
Energy measured in
in topo cluster

LEP: Low Energy Parametrised
as used in G3/Geisha
Bertini: intra-nuclear cascade model

Bertini good for 1-3 GeV, for 5-9 GeV seems to be out of reliable region.

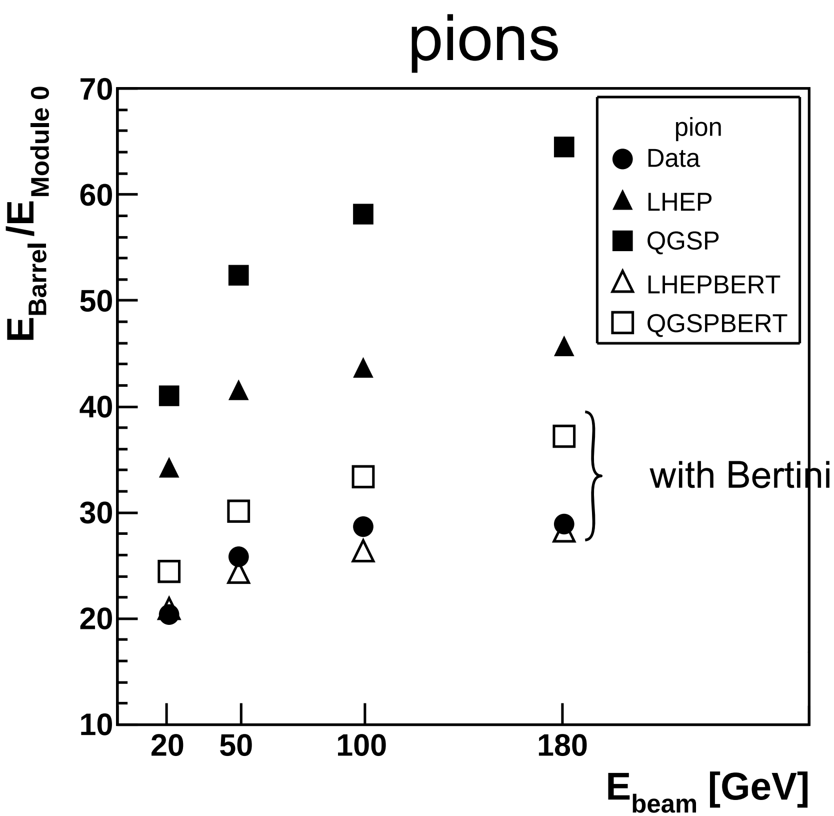
G4.8

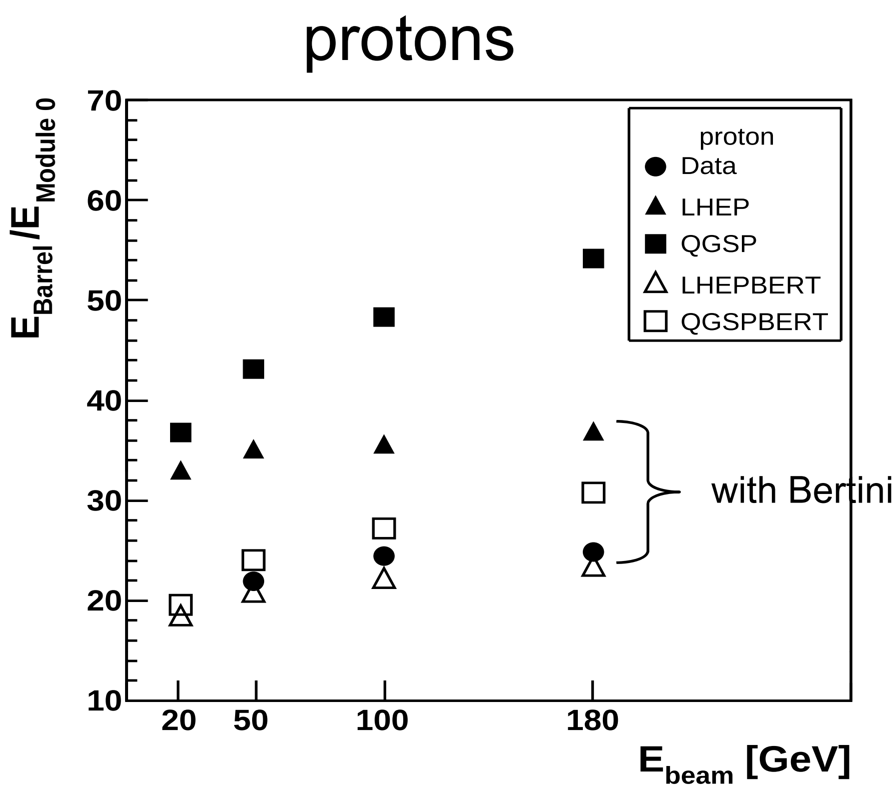
ATLAS LAr/Tile Barrel 2004: Pion Layer Energies



Data sample pretty small…, models more or less identical, probably dominated by ionisation

Atlas Tile: Lateral Spread

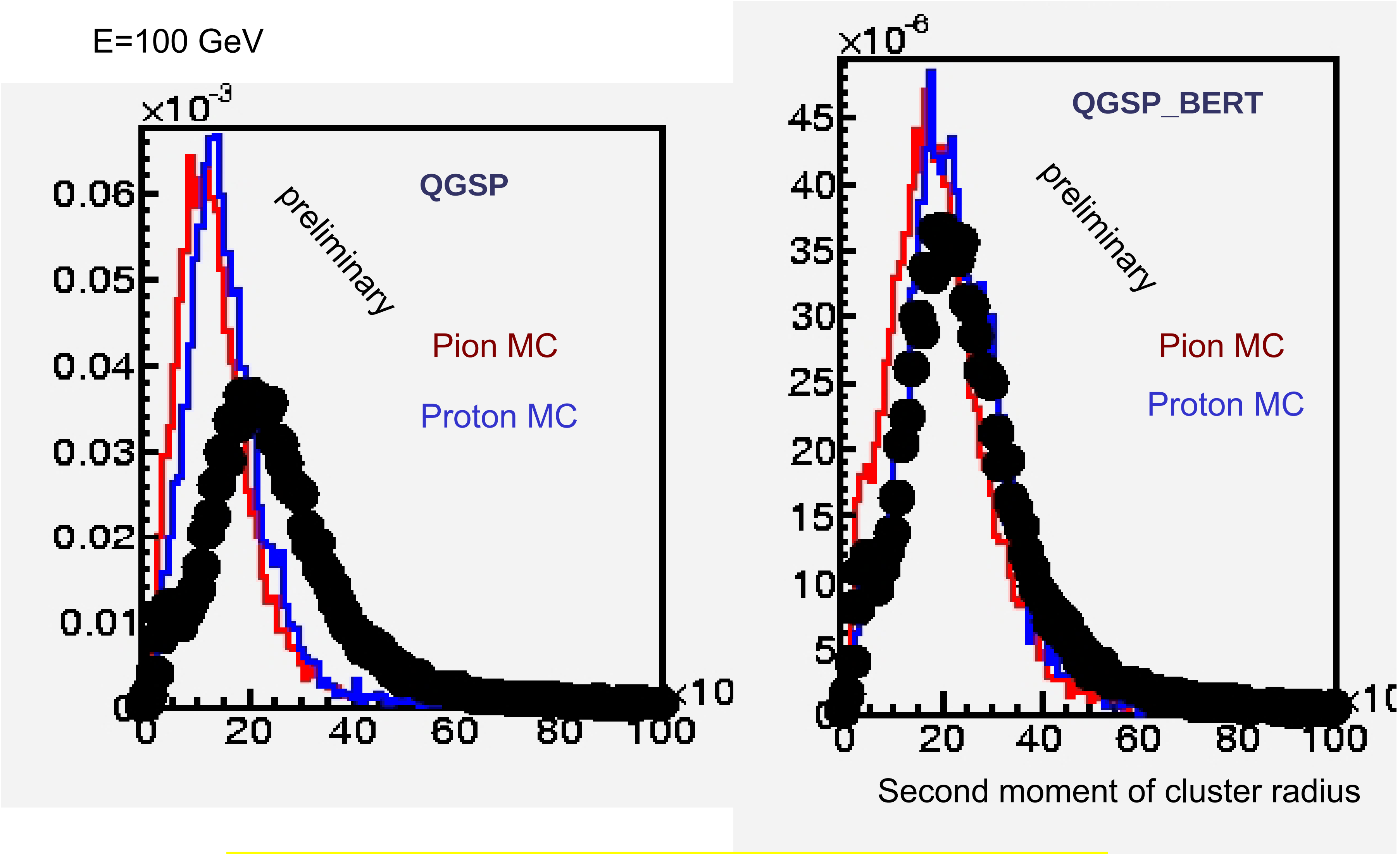




- QGPS and LHEP predict too narrow showers.
- The description much improves with the Bertini model.

Atlas Lar/Tile Barrel: Shower Radius

E=100 GeV

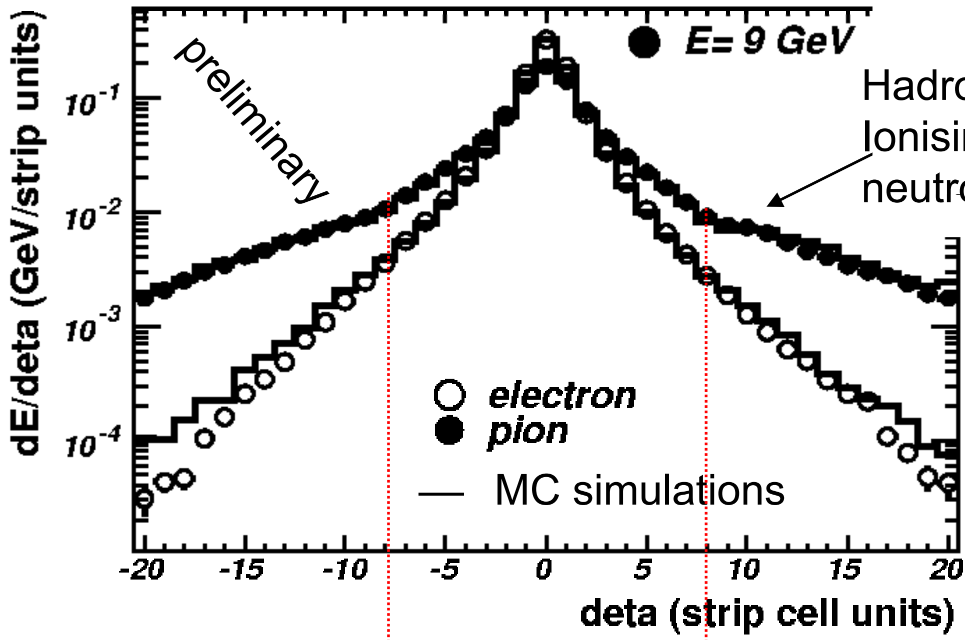


G4.7

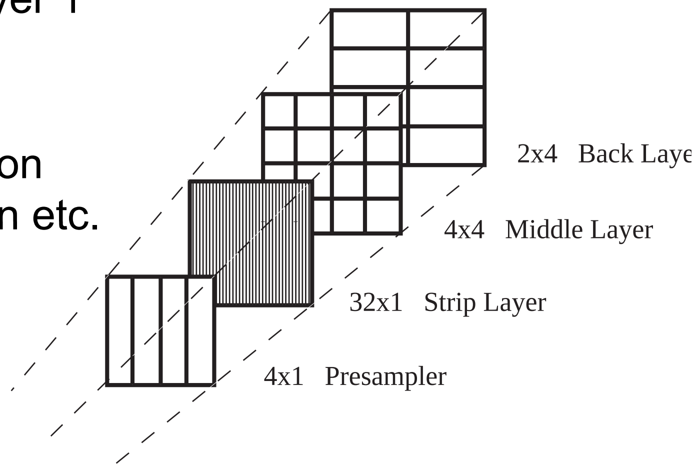
Good description, if pion/proton mix in beam is considered and Bertini nucleon cascade model is assumed

Example: Electron and Pion Lateral Profile in Lar Layer 1

Transverse energy flow around cell with maximal energy in layer 1



Hadron "halo"
Ionising Pion/proton
neutron interaction etc.

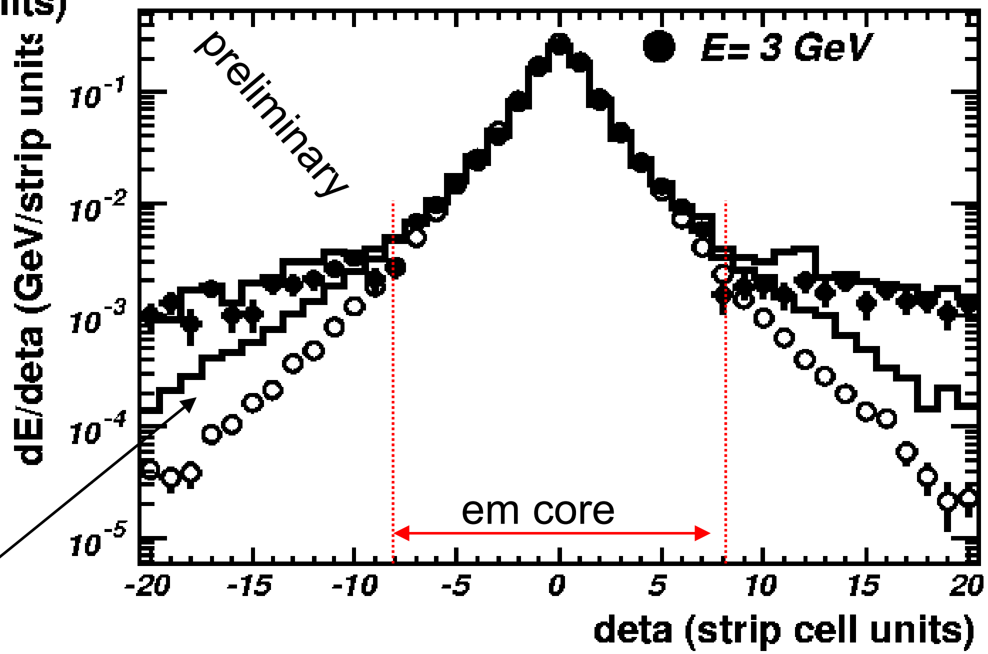


Good description of pions
(model dependence small)

em core

size of standard electron cluster
containing 95% of energy
in whole calorimeter

Em core compacter for electrons E>5 GeV
Similar to pions 1<E<3 GeV



G4.8

Strange tail for electrons
far from shower axis ?
Noise treatment ? G4 physics ?

Conclusion on Pions and Protons

Energy Response

ATLAS/HEC: energy response QGSP ok
resolutions ok (QGSP and LHEP)
Bertini created problems with energy response and resolution
CMS/HCAL: good energy response except at low energy
ATLAS/Tile: resolution 20% worse in MC
adding Bertini: resolution is ok

Shower Profile:

QGSP starts and ends too early in ATLAS/HEC, CMS/HCAL, ATLAS/Tile

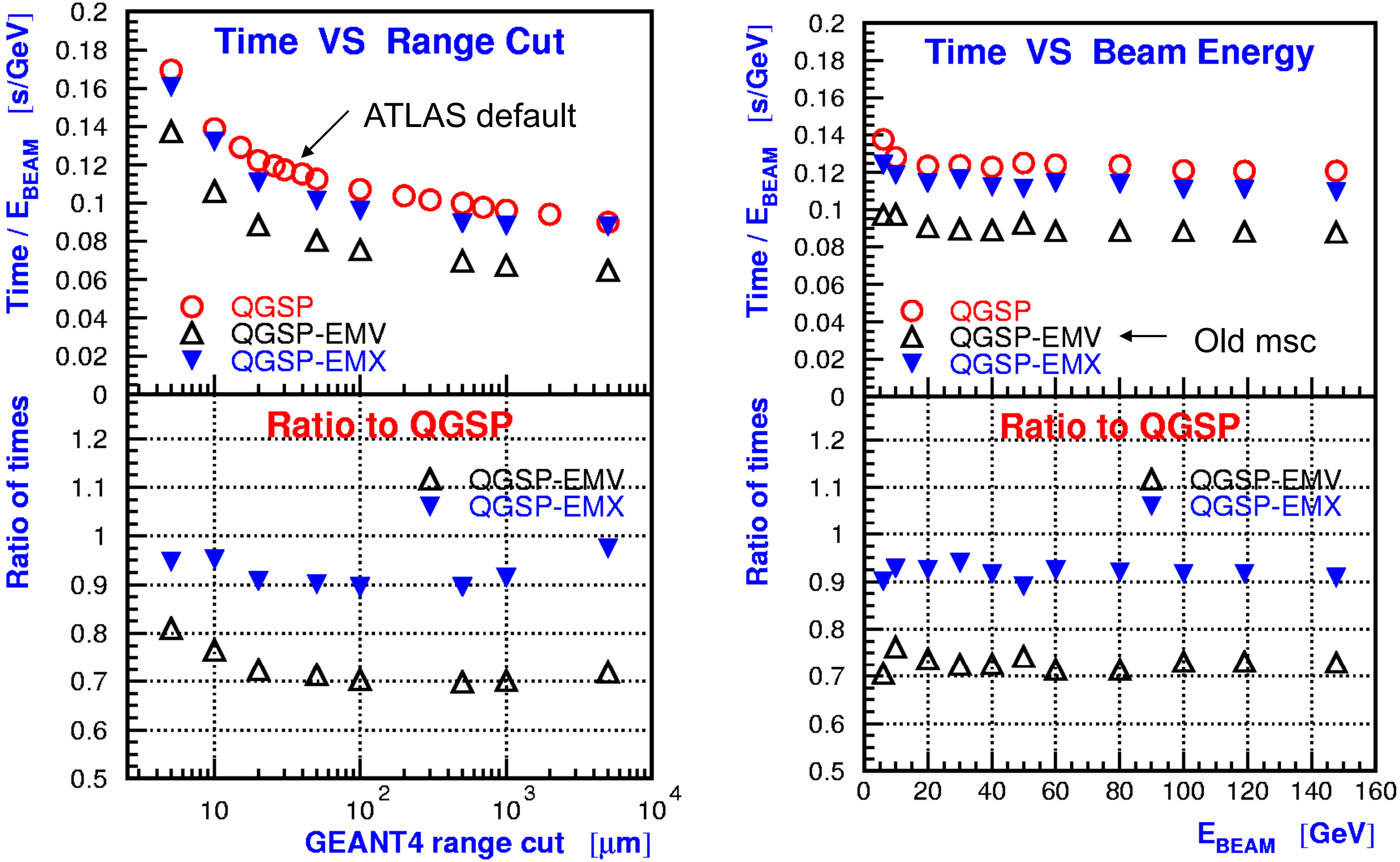
ATLAS/HEC: LHEP starts to oearly, ends too late
CMS/HCAL: LHEP ok
ATLAS/Tile: LHEP ok, but strange energy behaviour

Bertini nuclear cascade model:

Widens shower longitudinally and laterally
ATLAS HEC, Tile and Lar/Tile: shower profiles in better agreement with data

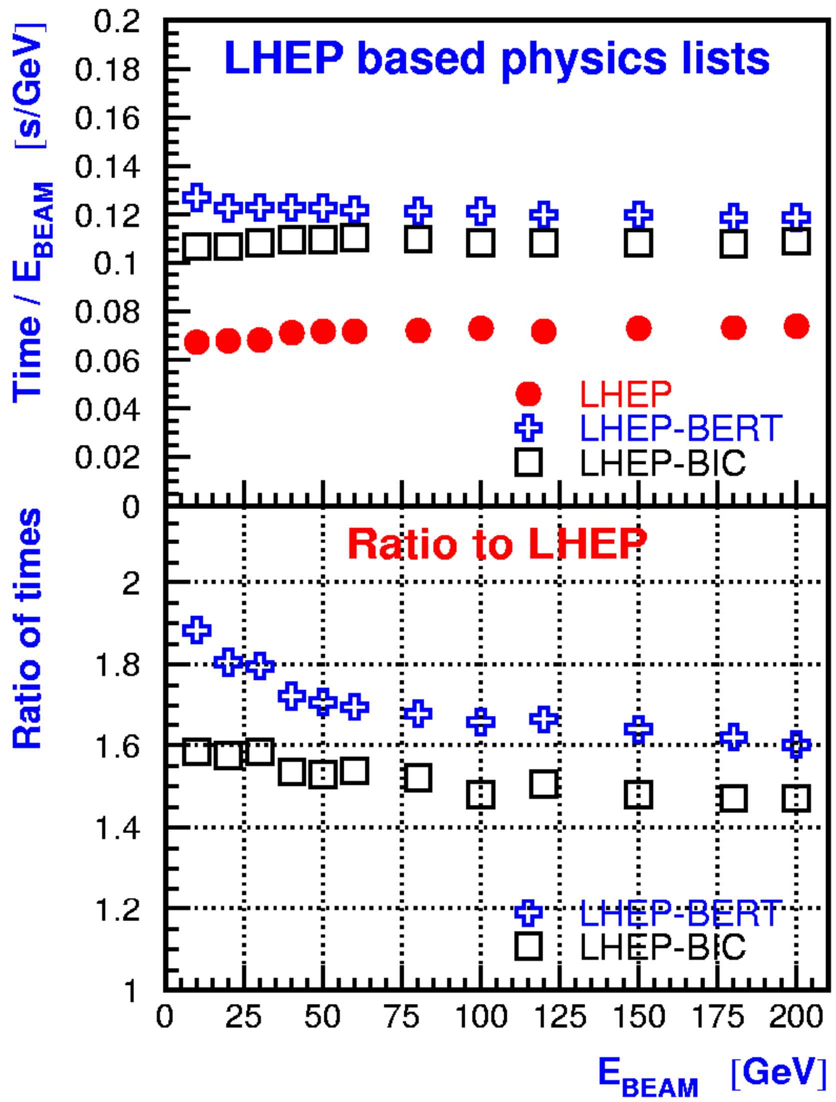
CPU Performance

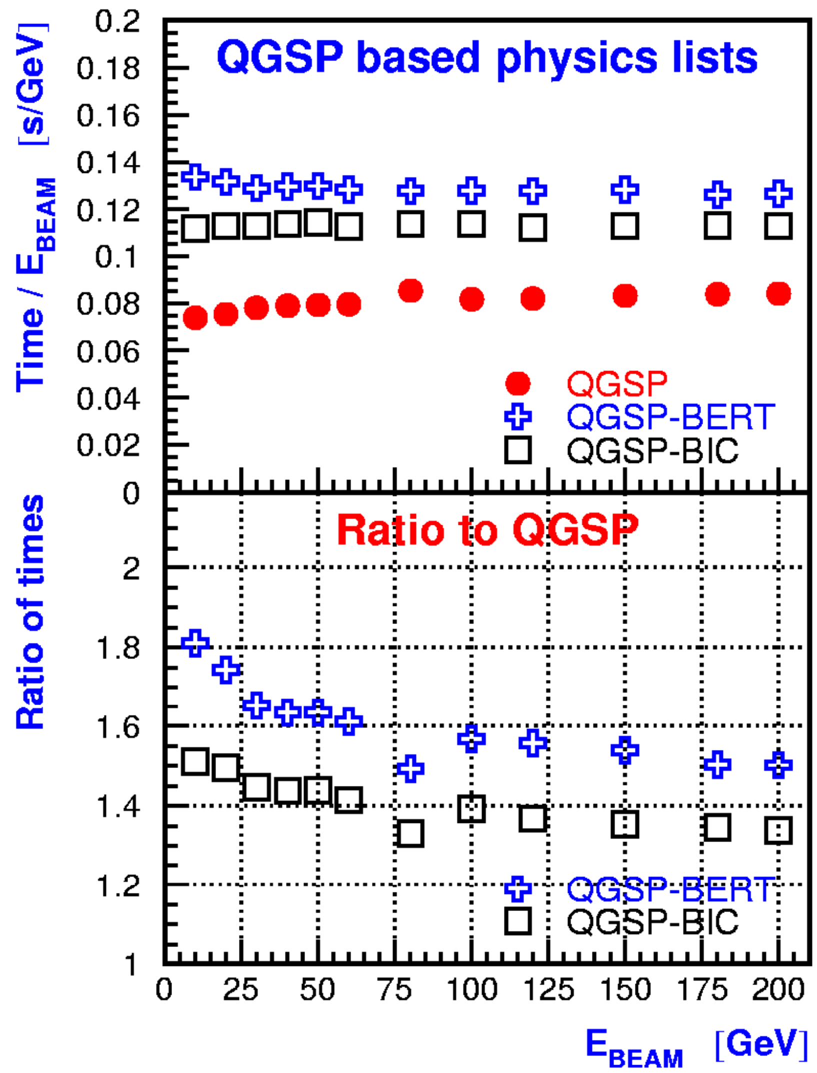
ATLAS HEC: Timing Performance vs Range Cut



G4.8

ATLAS HEC: Timing Performance





G4.8

Full Atlas Detector: Timing Performance

Using msc from G4.7

Range cut 1mm

CPU time per event (kSI2K)

	G4.7	G4.8	G4.8 1mm	G4.8 msc71
Susy	896	2020	1690	
$Z \rightarrow ee$	890	1916	1573	850
$Z \rightarrow \mu\mu$	713	1369	1202	642
$Z \rightarrow \tau\tau$	750	1428	1254	744
$H \rightarrow llll$	862	1788	1430	884
Jets	686	1442	1365	701

G4.8 with old msc needs about the same time as G4.7
New multi-scattering leads to about x2 time issue

No optimisation yet of range cuts

Full CMS Detector: Timing Performance

Electromagnetic and Hadron calorimeter
2000 single pion events
100 GeV pions generated separately
in the barrel (IηI ≈ 0.3) and the endcap (IηI ≈ 2.1) detectors with in a small φ window

Geant Version	Physics List	Barrel	Endcap
4.7.1.p02	QGSP 2.8	8.32 sec/event	7.44 sec/event
4.8.1.p01	QGSP 3.1	12.37 sec/event	10.19 sec/event
4.8.1.p01	QGSP_EMV old msc	8.56 sec/event	7.29 sec/event

Conclusions

Electromagnetic physics gives good description of the data
New multiple scattering treatment improves the data/MC description,
but increases a lot the need of CPU

Description of pions and protons reaches reasonable level,
it becomes more and more mature and trustable
but further improvements are possible
QGSP start and ends too early and showers are too narrow
LHEP: better overall description, but has also problems

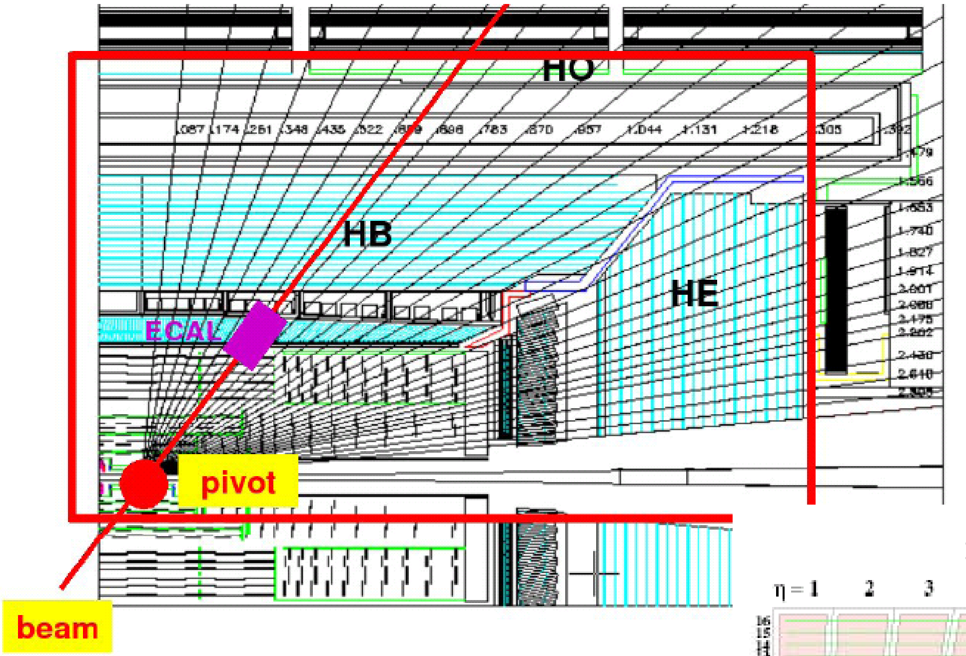
Adding Bertini nuclear cascade models make shower longer and wider
And improves description, but for Atlas HEC problem with e/pi and resolutions

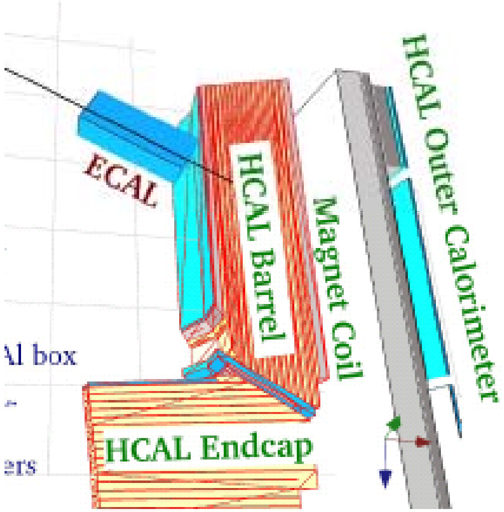
CPU time is a problem (currently ATLAS uses 4 times more CPU for simulation than forseen in computing model)
When Bertini models will be used, this becomes even wors

Is there room for better CPU performance by simple code improvements ?
Code revision by professional programmers ?

CMS: Test-beam Setup

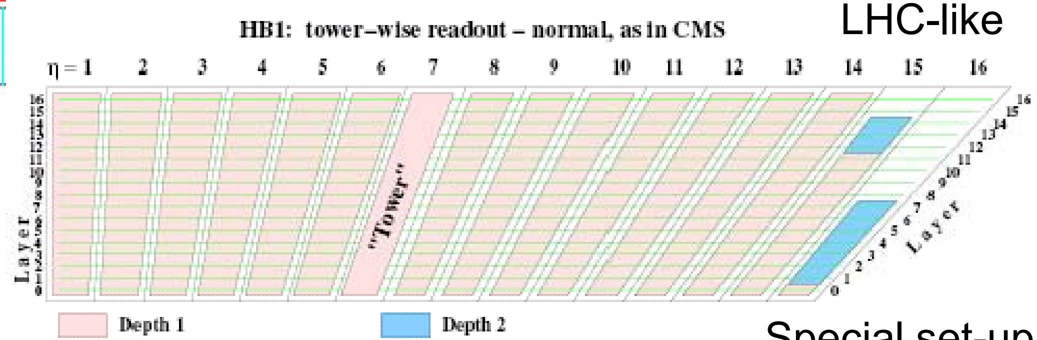
Tb 2004: Ecal prototype 7x7 cristals HCal production module



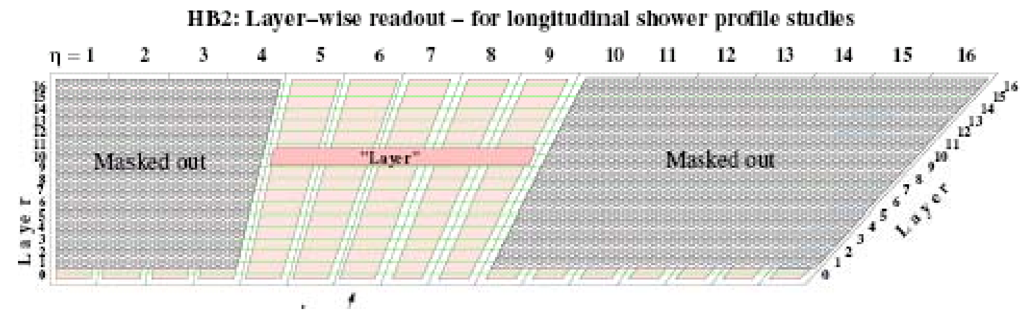


Special read-out to allow for longitudinal profile study:

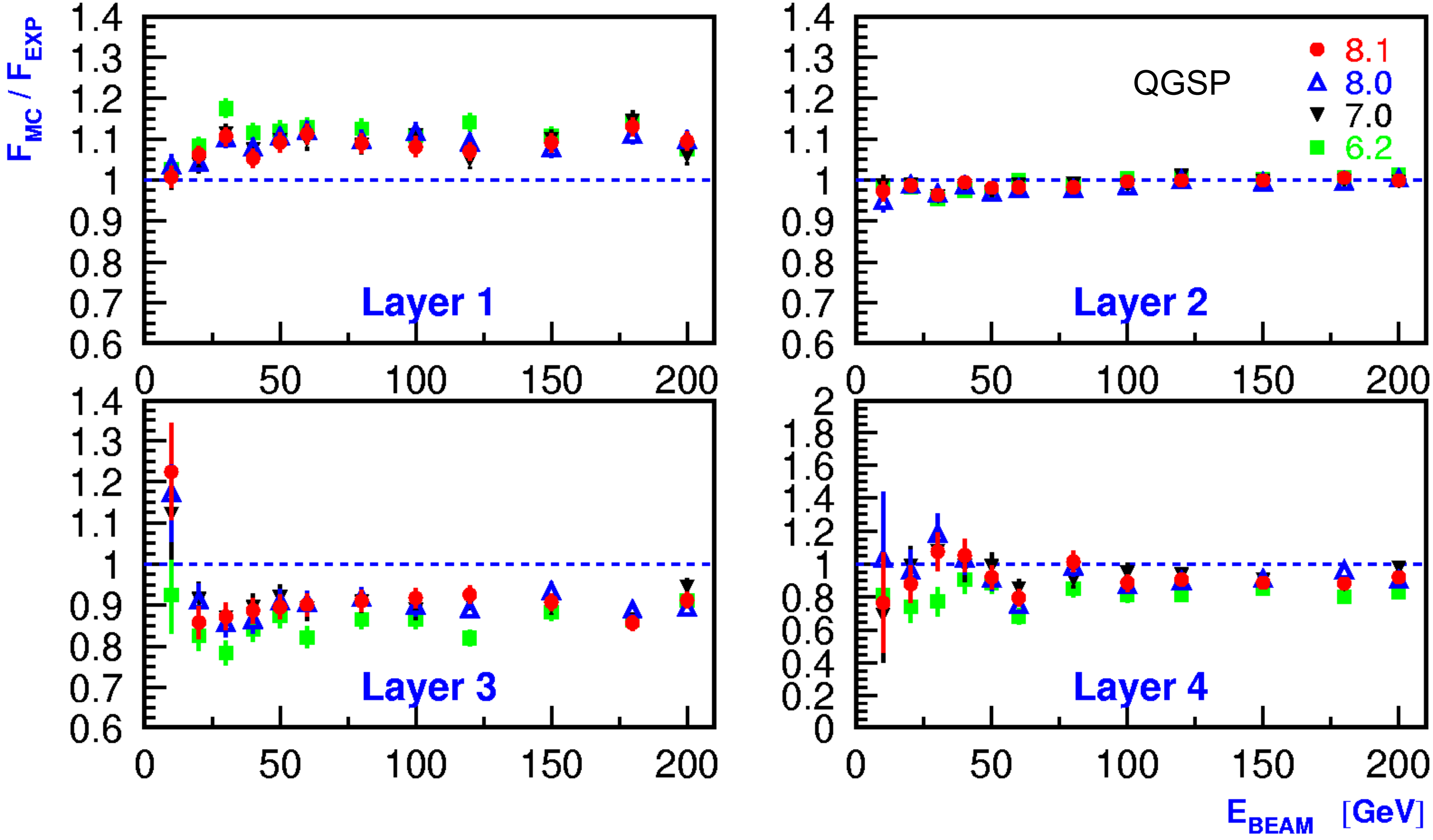
LHC-like



Special set-up

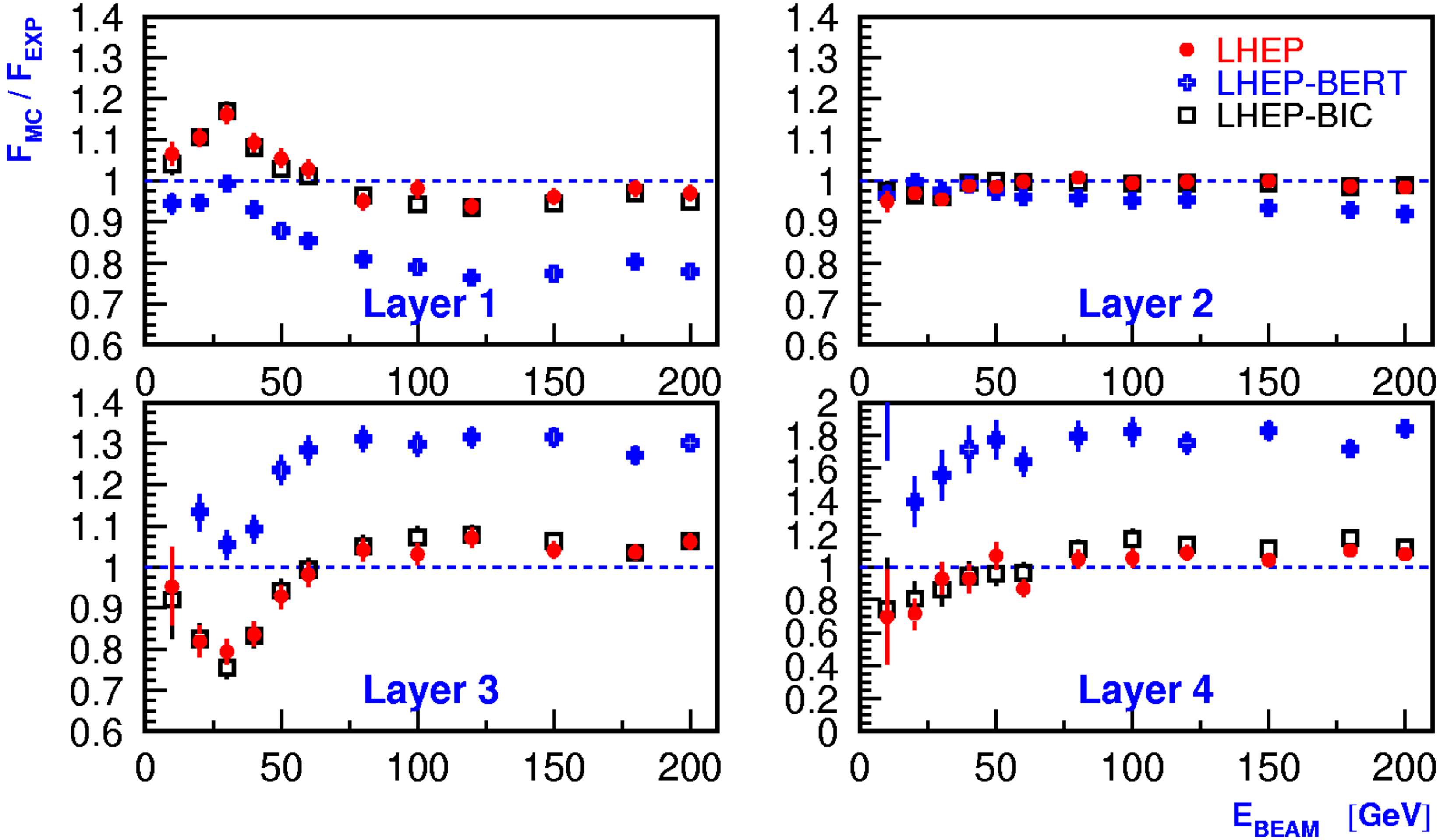


Atlas HEC: Pion Energy Fraction in Longitudinal Layer Ratios



QGSP: certain improvements between G4 versions from 6.2 to 7.0, then stable

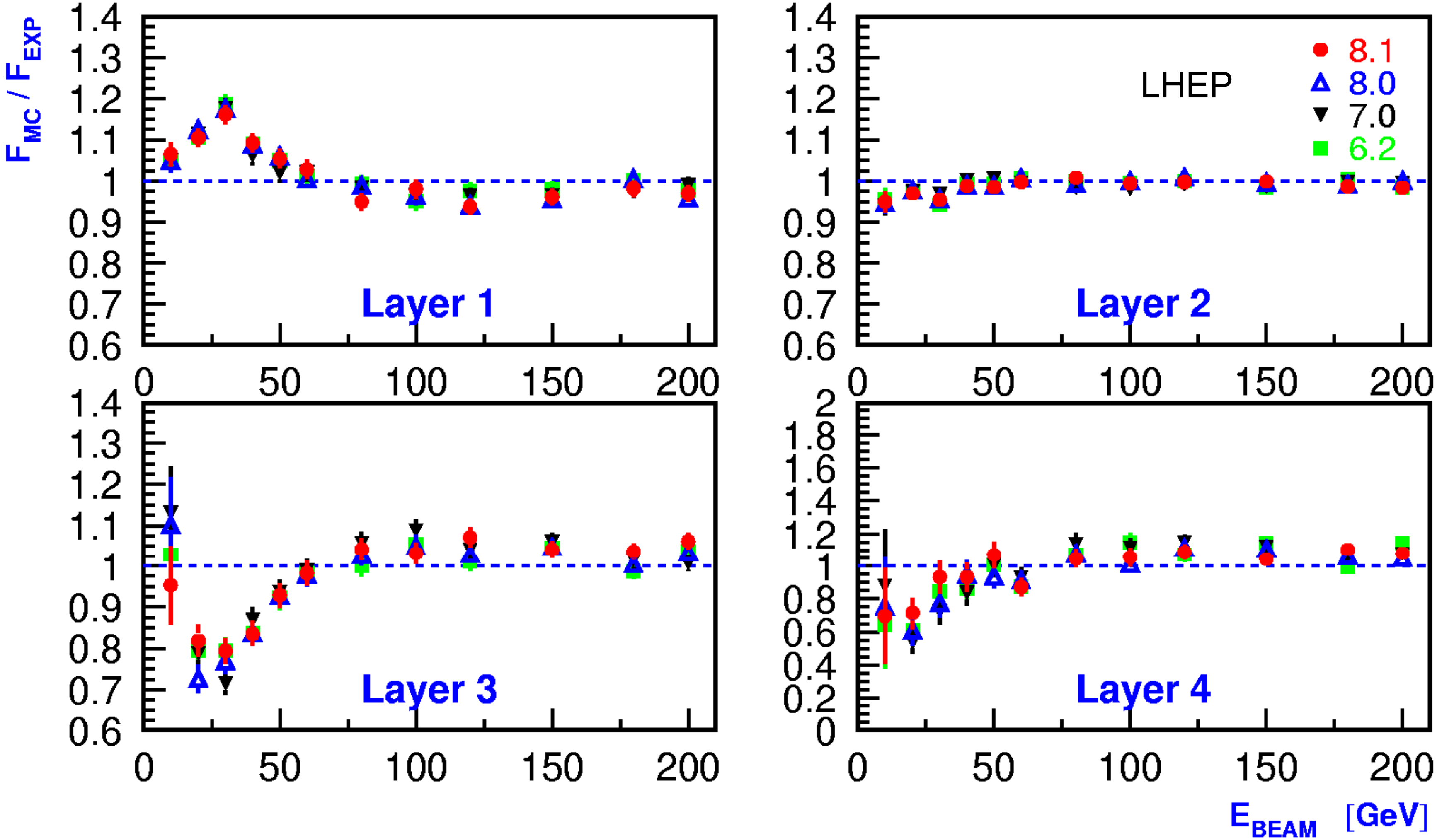
Atlas HEC: Pion Energy Fraction in Longitudinal Layer Ratios



LHEP-BERT: shower starts too late
LHEP-BIC: close to standard LHEP

G4.8

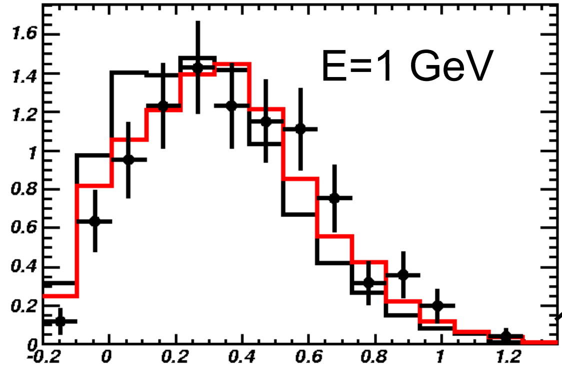
Atlas HEC: Pion Energy Fraction in Longitudinal Layer Ratios

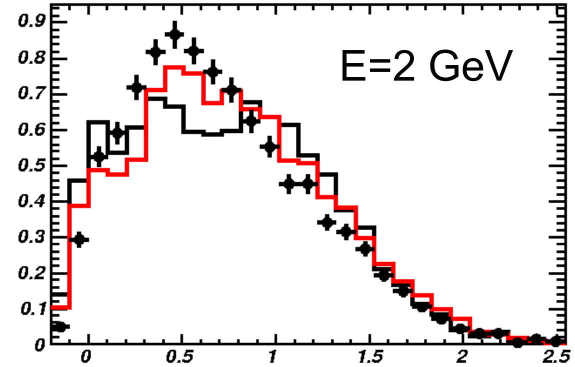


No difference between G4 versions

G4.8

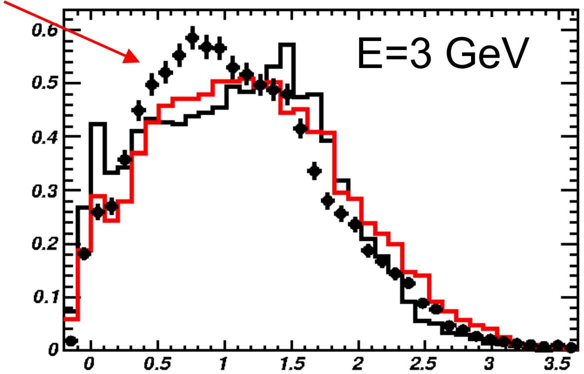
ATLAS LAr/Tile Barrel 2004: Total Energy

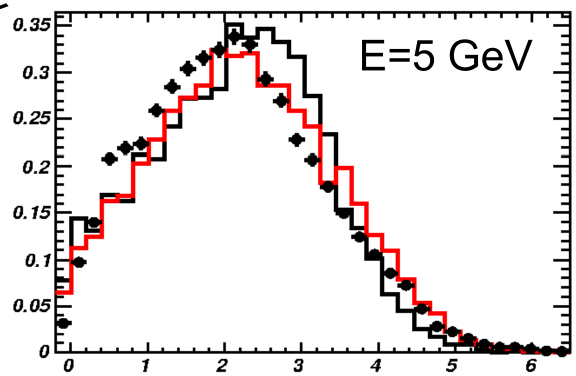




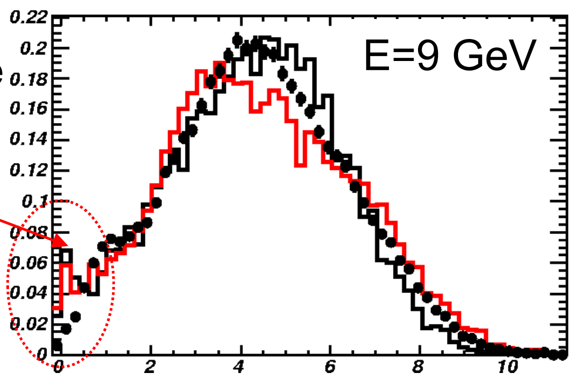
preliminary

to be investigated





Problem due S1 trigger missing in simulation



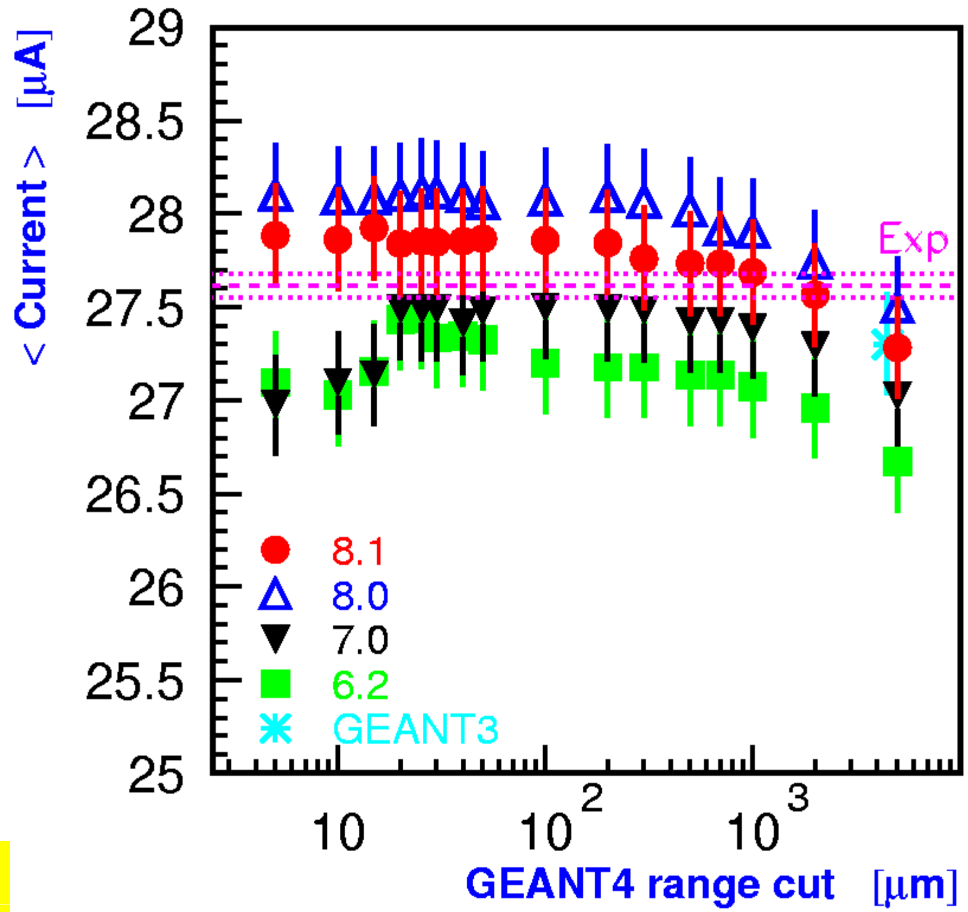
G4.8

● Data
— G4-LEP
— G4-Bertini

Bertini good for 1-3 GeV,
for 5-9 GeV out of reliable region.

→ good description, but more work is needed on MC and data !

ATLAS HEC- Signal in one Cell

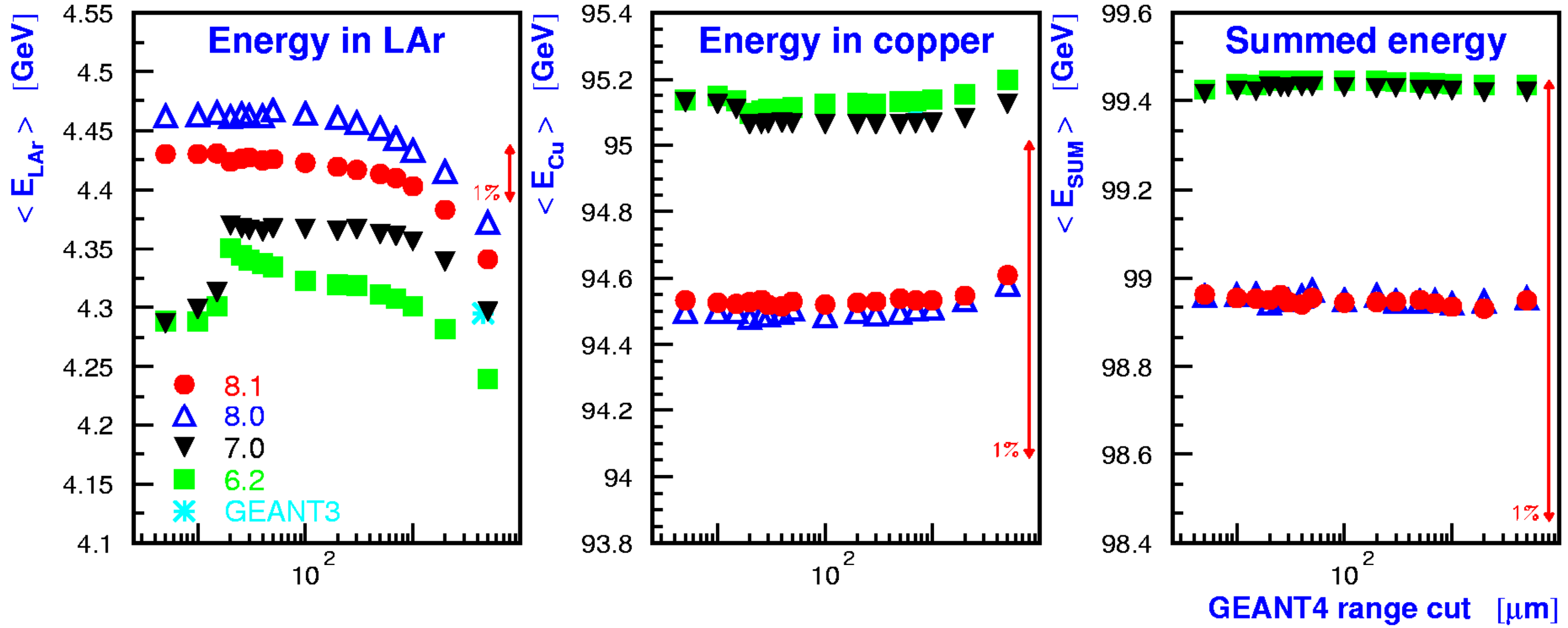


Convert visible energy to current using factor from detailed Modeling of the HEC electronics 7.135 μA/GeV with 1% uncertainty

MC results are in good agreement with experimental value

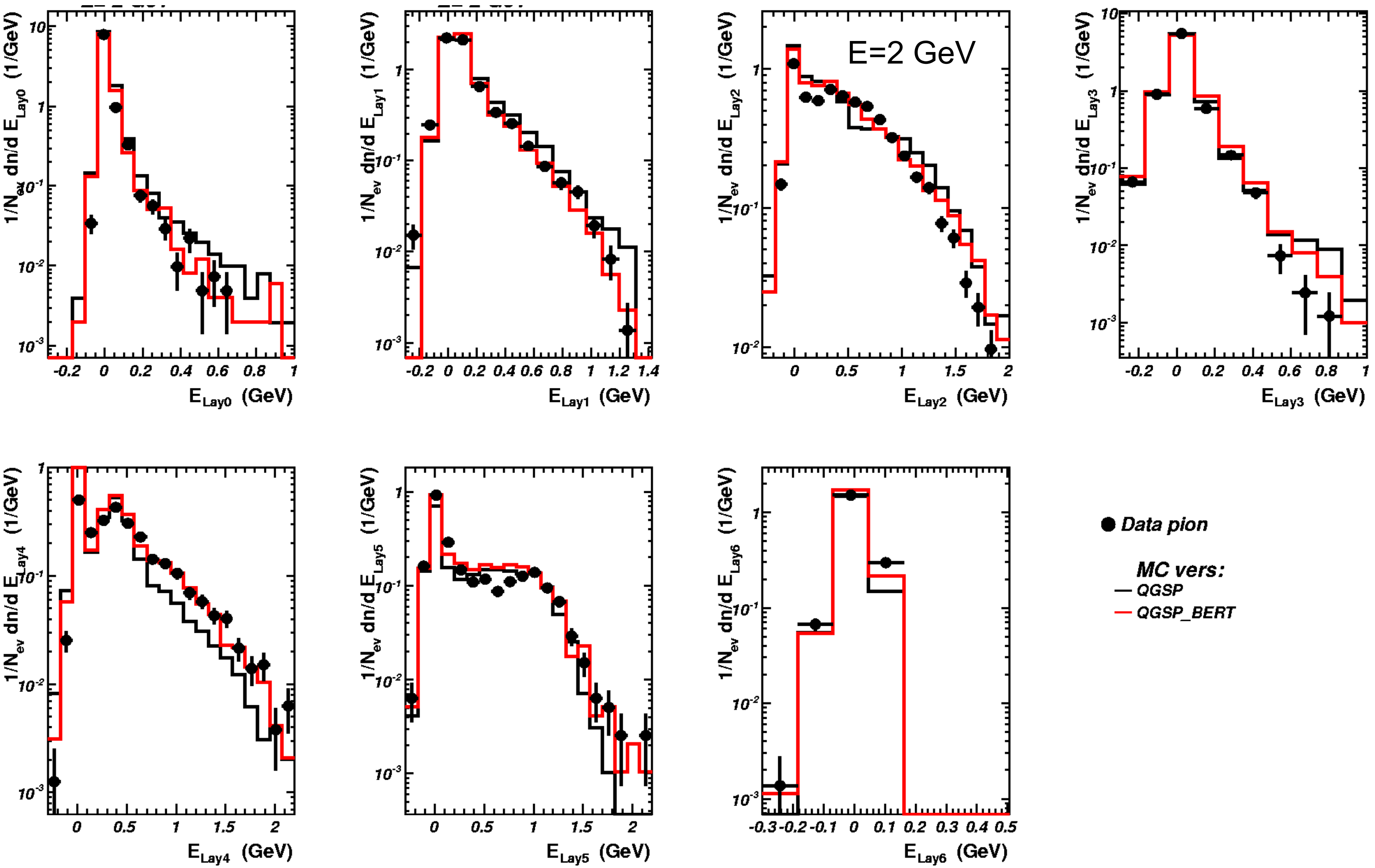
G4.8

ATLAS HEC- Mean Energy



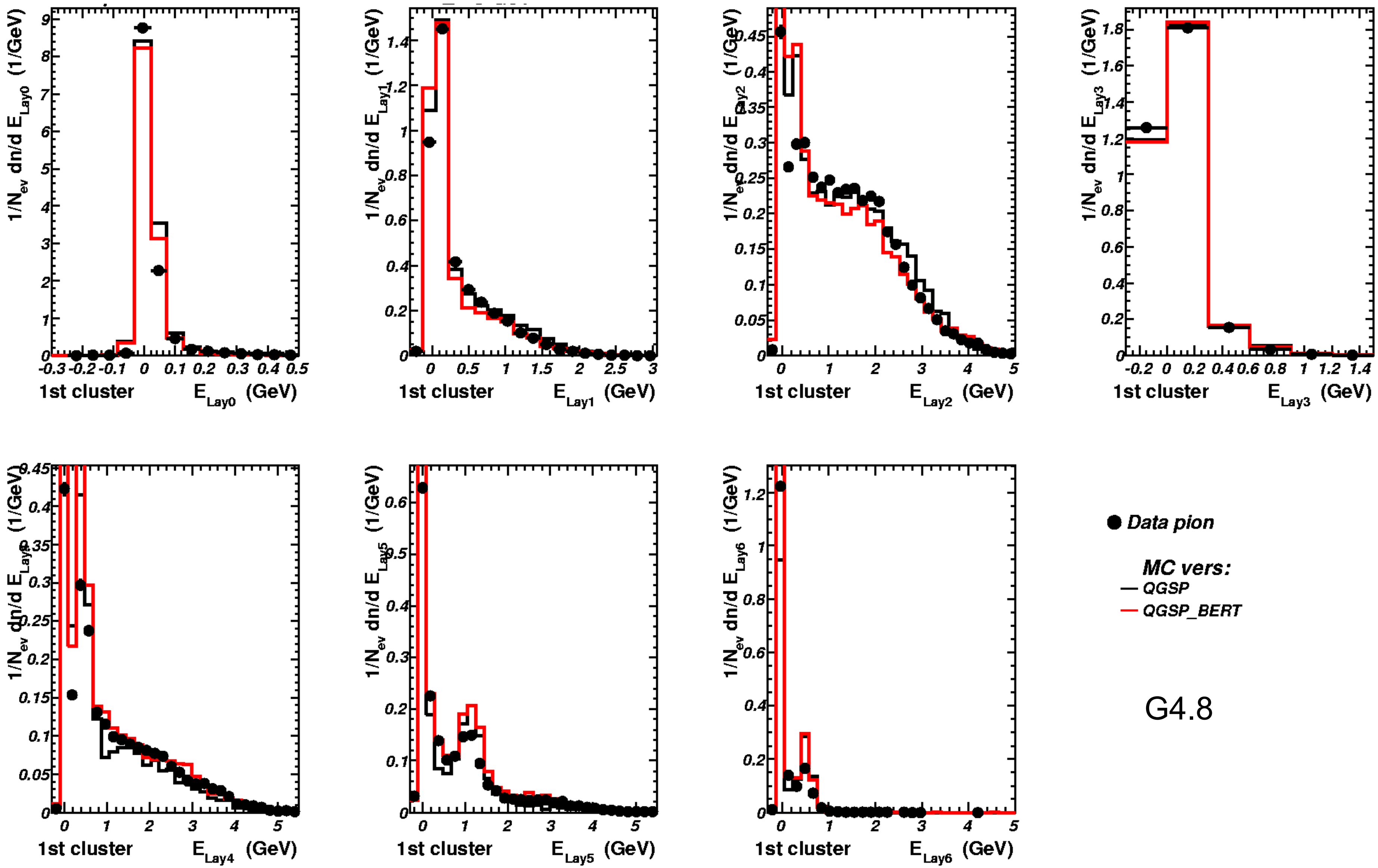
Broader plateau of the visible energy in Lar as function of range cut
Increase of visible energy
Decrease of the total deposited energy

ATLAS LAR/Tile Barrel: Layer Energies



ATLAS LAR/Tile Barrel: Layer Energies

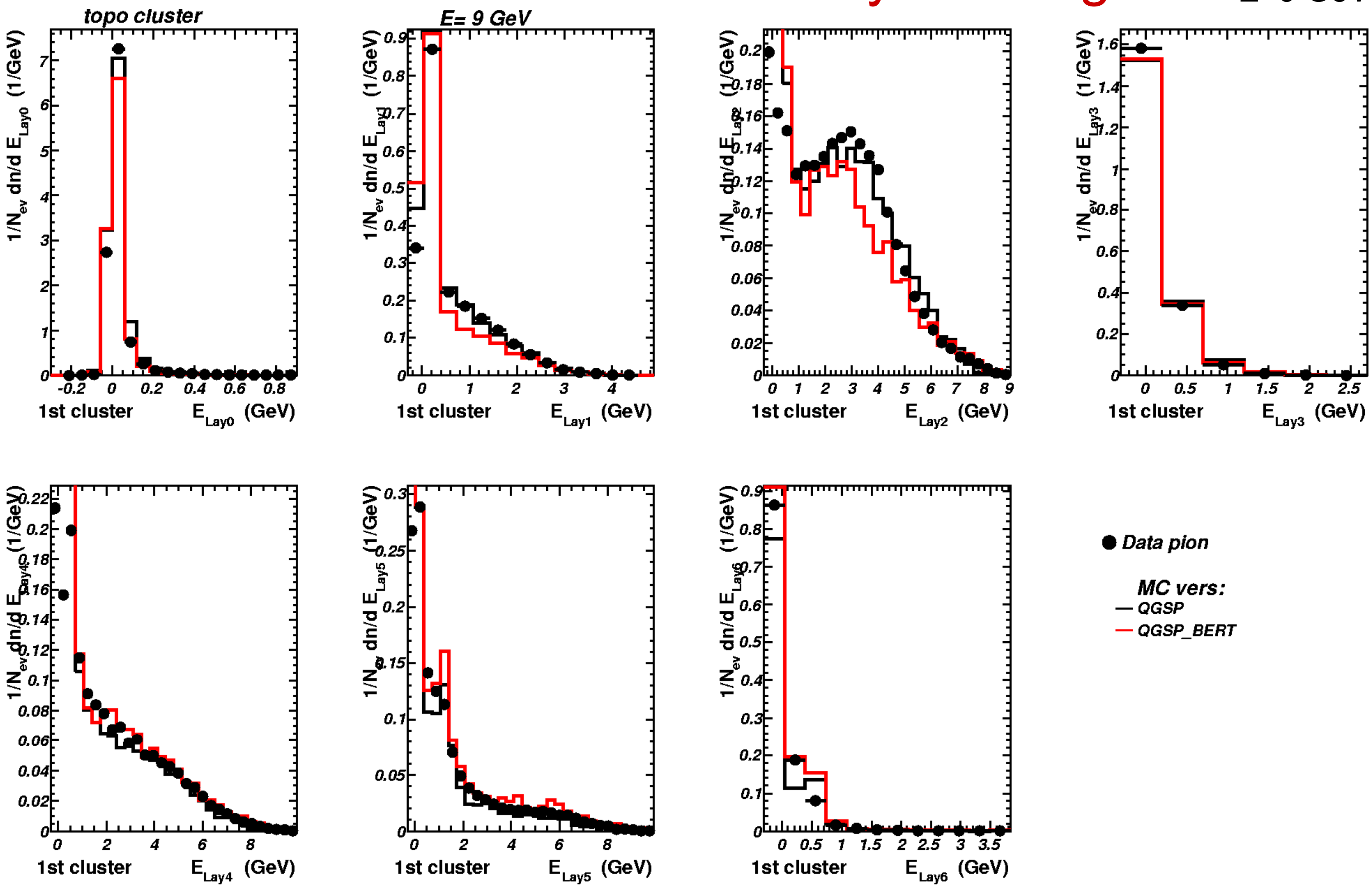
E=5 GeV



Bertini starts too late, effect of Birks small

ATLAS LAR/Tile Barrel: Layer Energies

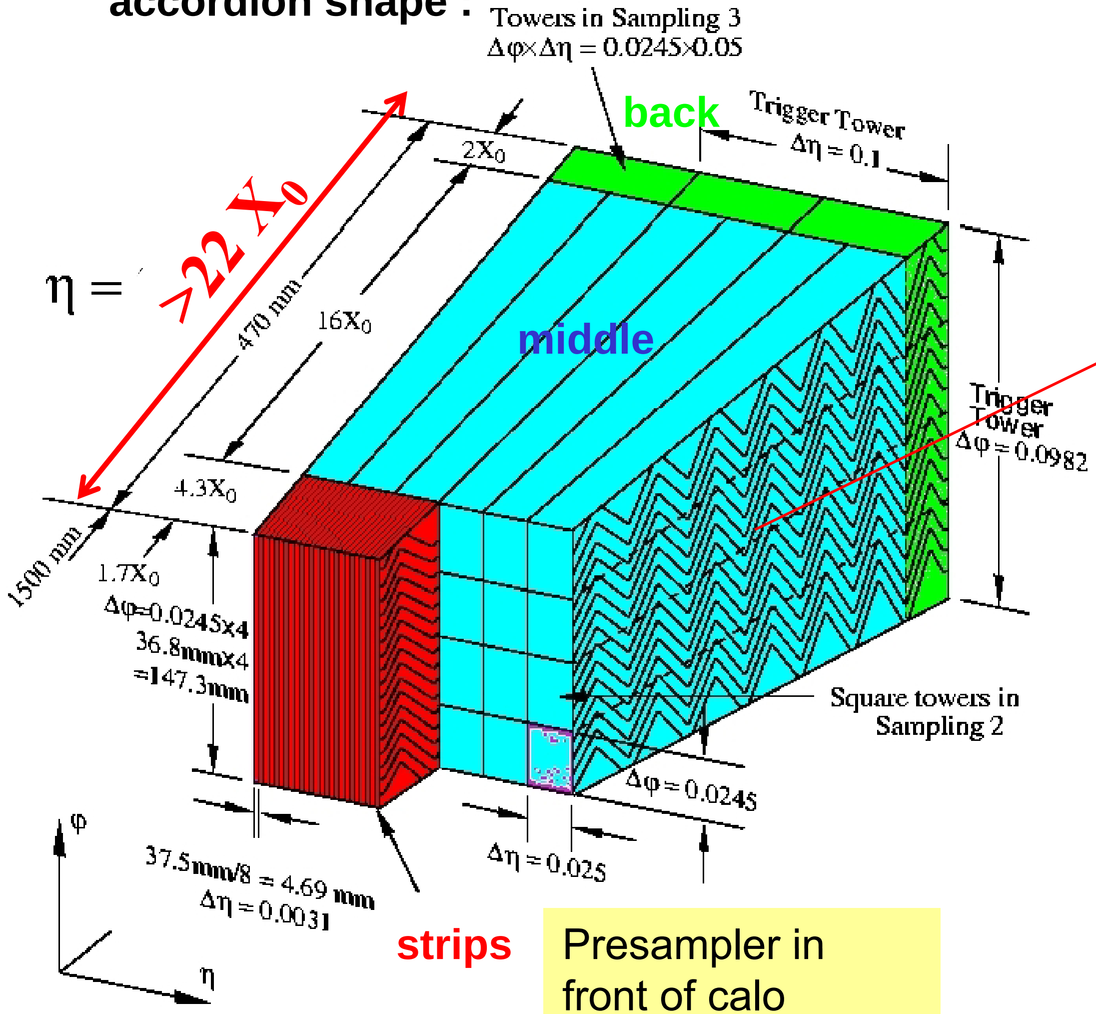
E=9 GeV



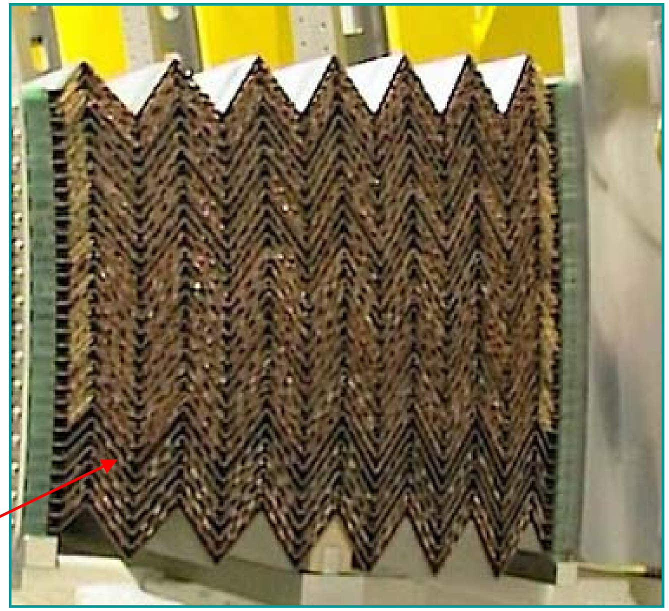
Bertini is off (starts and ends too late), Bertini with Emax 9→ 5 better

The E.M. ATLAS Calorimeter

Lead/Liquid Argon sampling calorimeter with accordion shape :



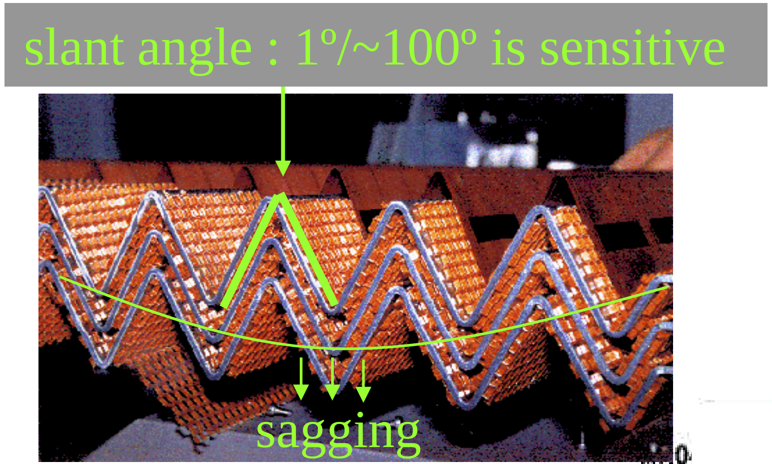
Presampler in front of calo up to $\eta = 1.8$



Main advantages:

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

Example: EM Endcap as "Detector as Built"

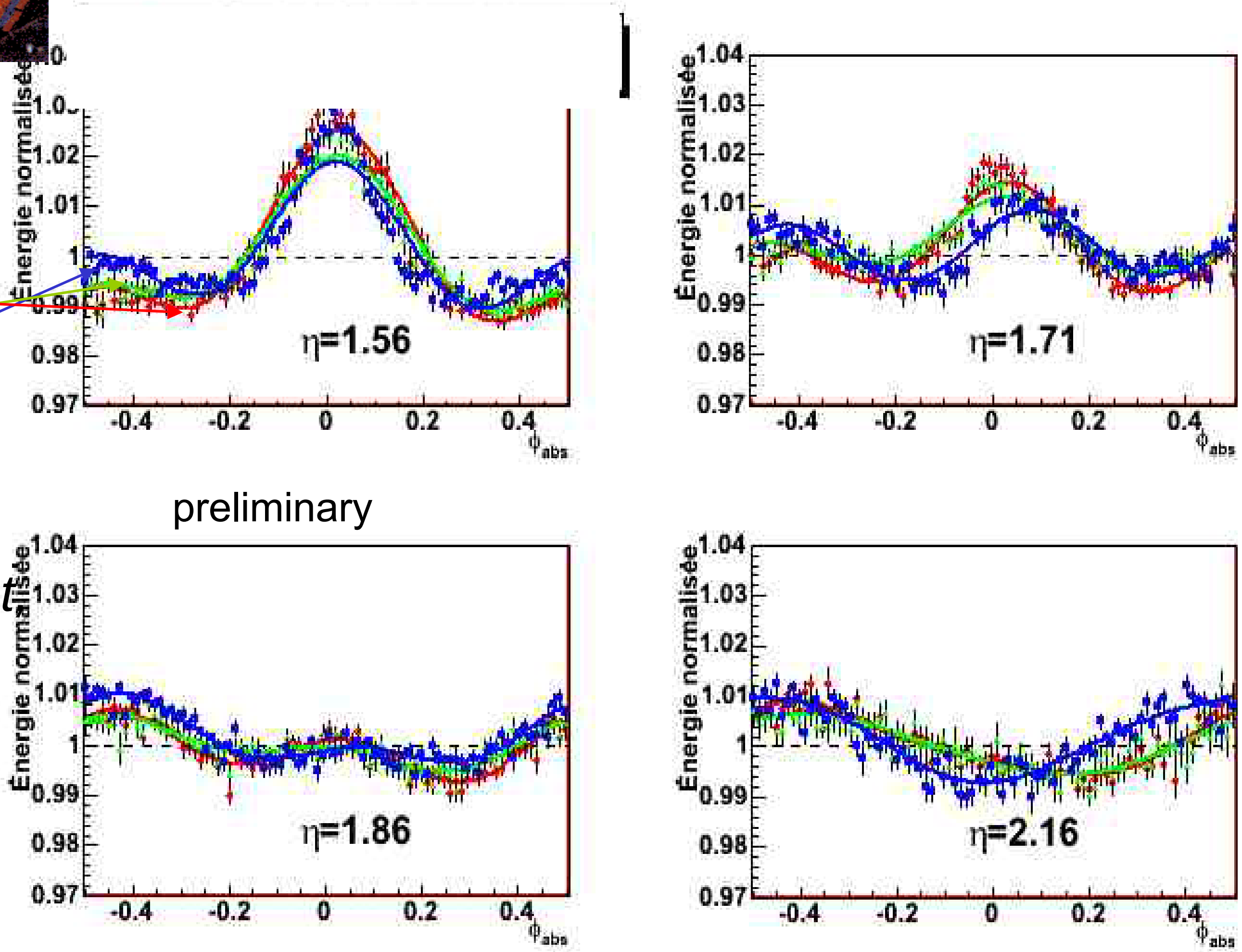


EM calorimeter : Pb absorbers
Peculiar accordion shape

ϕ-modulations :

Response to 120 GeV e-showers

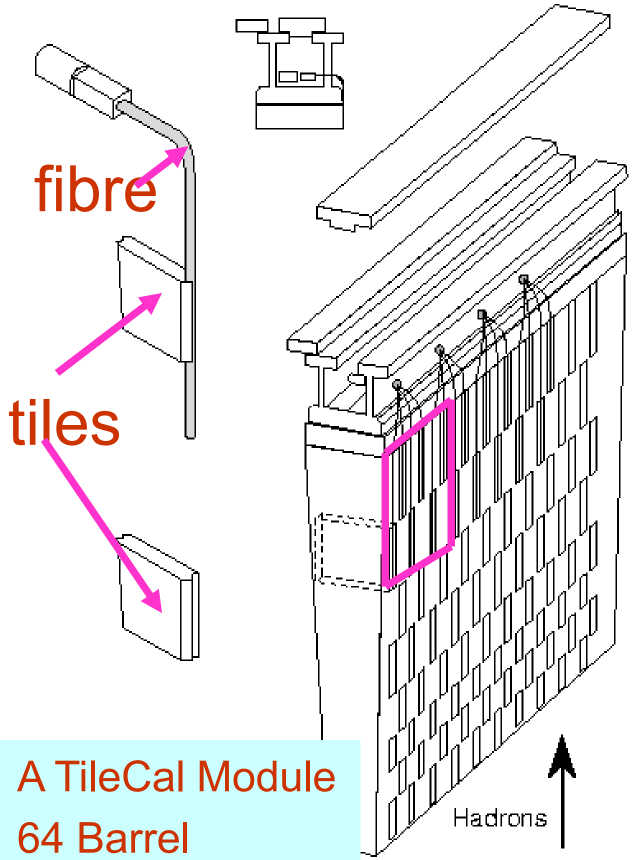
standard simulation
+ charge collection
+ gap adjustment
Test Beam Data



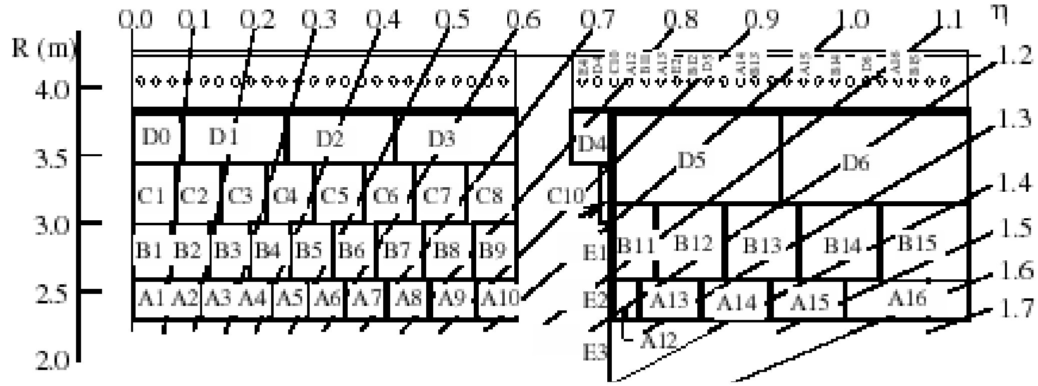
Recent efforts simulate an 'as built detector' :
HV, sagging, misalignment,
measured lead thickness,
gap variations,
charge collections,
read-out electronics,
cables etc.

The TileCal Barrel Calorimeter

Scintillating Tile/Iron Calorimeter



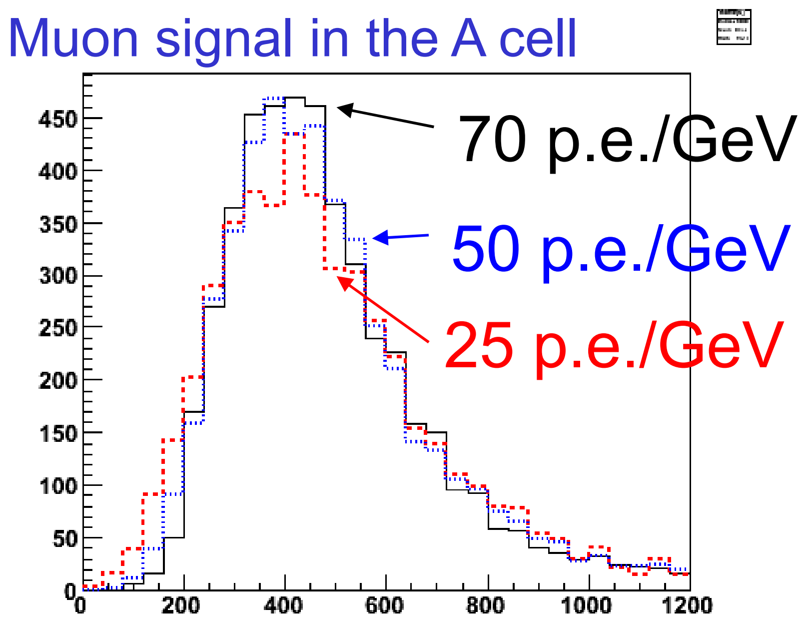
A TileCal Module
64 Barrel
2x64 Ext. Barrel



Recent improvements in MC:

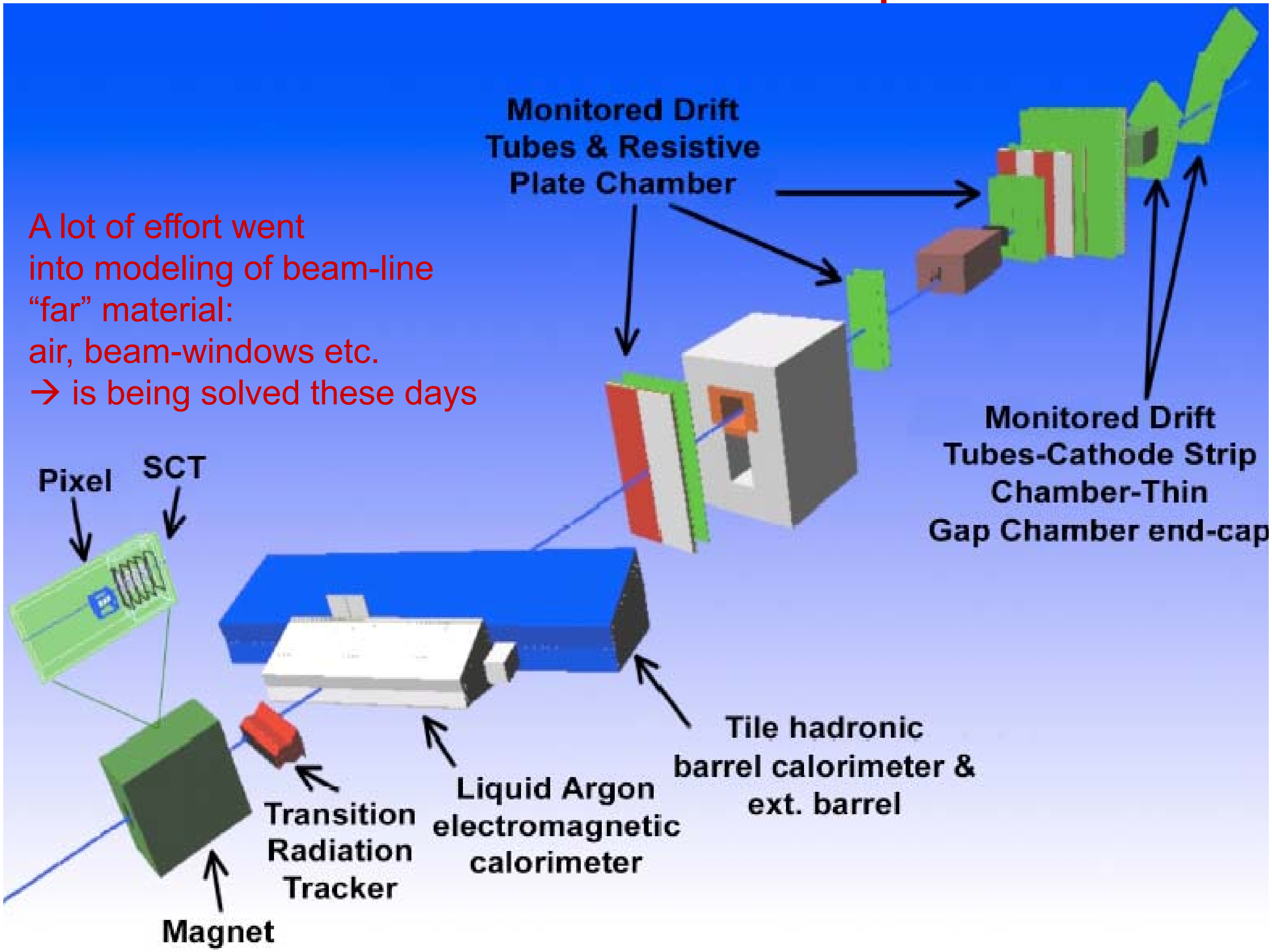
→ Sampling fraction adjustment
→ electronic signal modeling and reconstruction
→ Photo statistics of photomultipliers
→ light attenuation between tile (work in progress)

Example:



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



CMS ECAL: Electron Shower Profile

Energies in 5x5 matrix for E=120 GeV

Data

1.0 %	2.4%	0.7%
3.1%	81.8%	3.0%
1.0%	3.0%	1.1%

MC

1.1 %	2.5%	0.9%
3.0%	82.0%	2.9%
1.0%	2.7%	1.0%

Agreement of G4 with data is good
Also: contributions to energy resolutions well understood