Beam Test Results from FCal, HEC and HEC+EMEC

- **ATLAS Calorimeters**
- **Forward (FCal)**
  - **1998 module 0 test**
- **Hadronic Endcap (HEC)**
  - **1998-2001 production module tests**
- **HEC + Electromagnetic Endcap (EMEC)**
  - **2002 combined test**
- **Future Endcap LAr Beam Tests**
  - **2003 FCal full system beam test**
  - **2004 FCal+HEC+EMEC combined beam tests**

ATLAS Physics Workshop

Athens, Greece

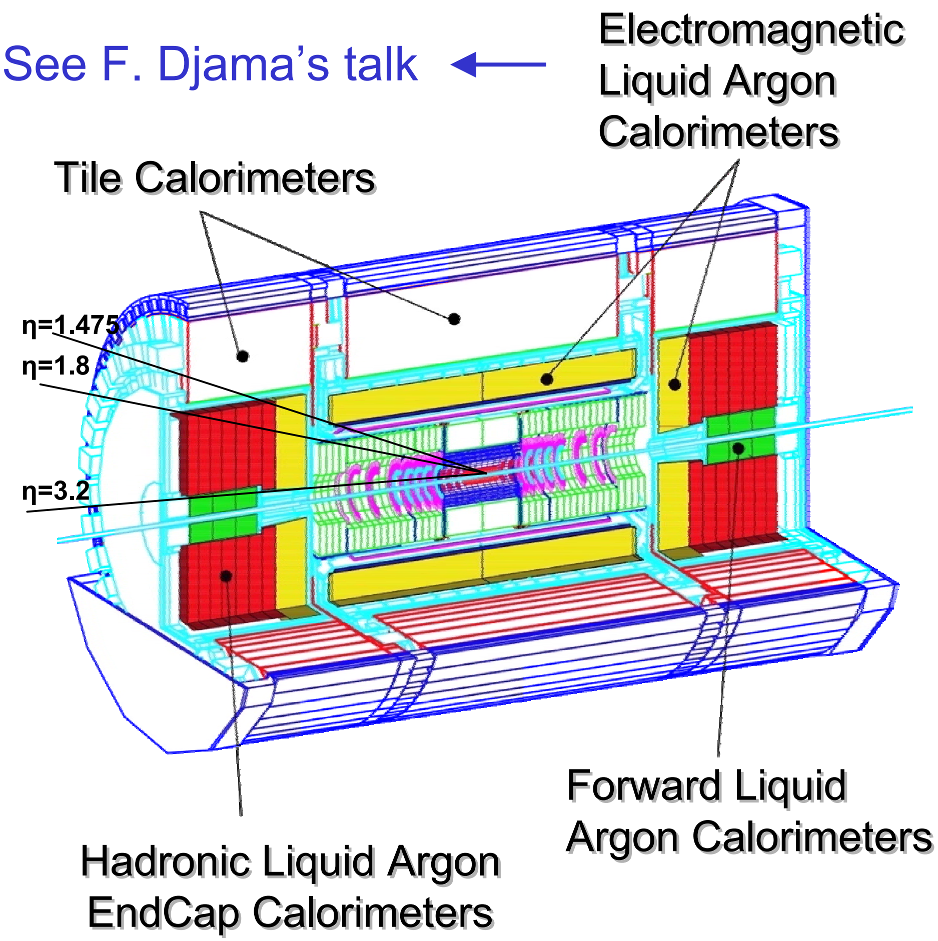
21-25 May 2003

Michel Lefebvre
University of Victoria
Physics and Astronomy

ATLAS Calorimeters

- Eletromagnetic Liquid Argon Calorimeters feature accordion Pb absorbers, highly granular readout (190,000 channels, $0.003 \le \Delta\eta \le 0.05$, $0.025 \le \Delta\varphi \le 0.1$, 2-3 longitudinal samplings), ~24-26 X_0 deep, covers $|\eta|<3.2$, presampler up to $|\eta|<1.8$;

See F. Djama's talk ←

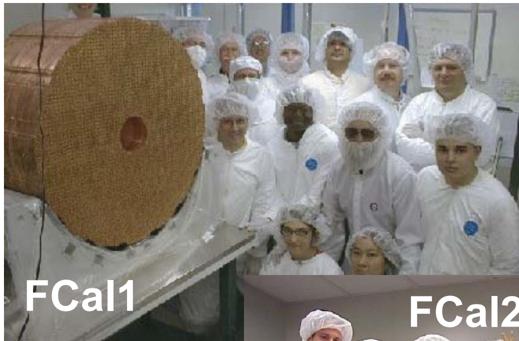


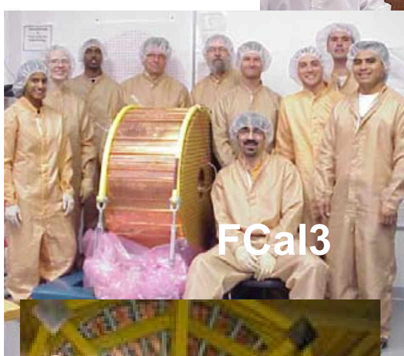
- Hadronic Tile Calorimeters feature Fe/scintillator tiled readout with $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$, 3 longitudinal samplings, coverage $|\eta|<1.7$;

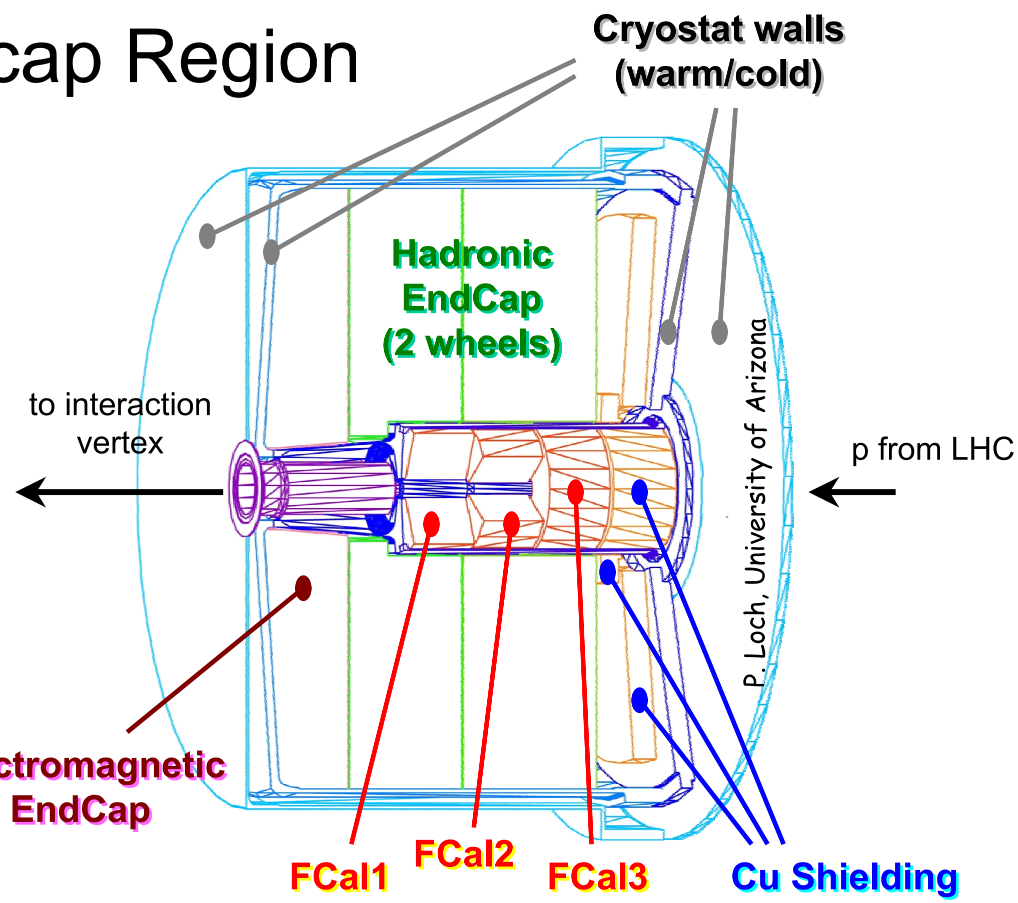
- Hadronic Liquid Argon EndCap Calorimeters have Cu absorbers in a parallel plate geometry, $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ $(1.5<|\eta|<2.5)$, $\Delta\eta \times \Delta\varphi = 0.2 \times 0.2$ $(2.5<|\eta|<3.2)$, 4 samplings;

- Forward Liquid Argon Calorimeters feature Cu (FCal1) and W (FCal2/3) absorber with cylindrical ionization chambers parallel to the beam line. Each module weights 2.1/3.9/3.8 tons and are 28/91/89 X_o and 2.7/3.7/3.6 λ deep. Principal coverage is $3.1<|\eta|<4.9$, with cells of $\Delta\eta \times \Delta\varphi \approx 0.2 \times 0.2$ – but non-projective!

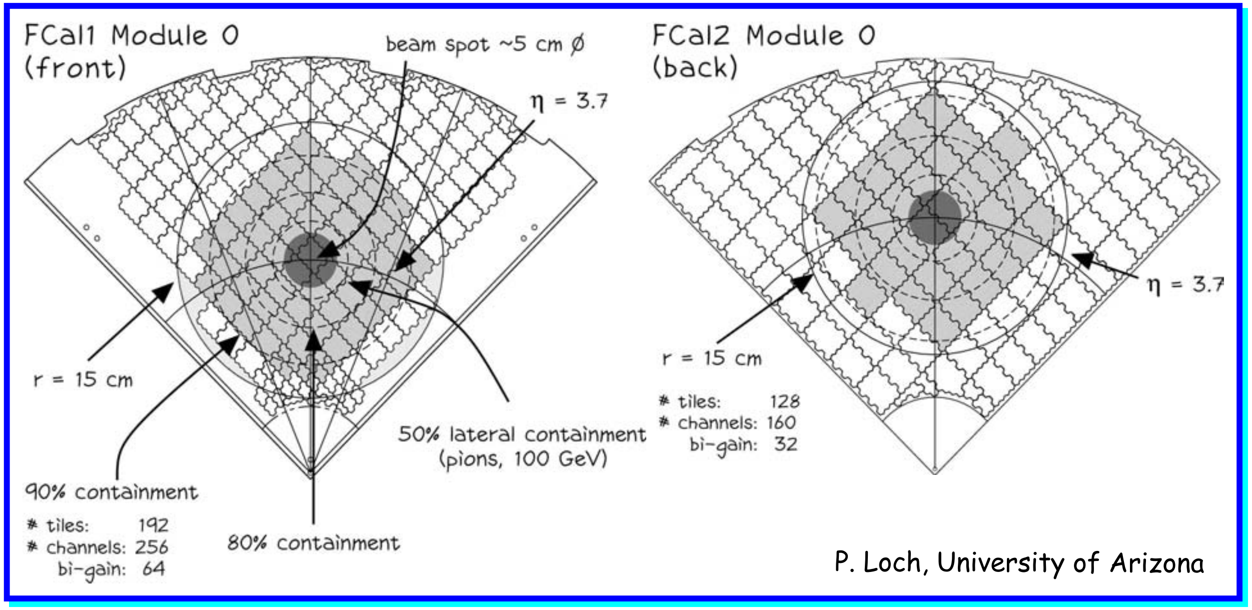
Endcap Region



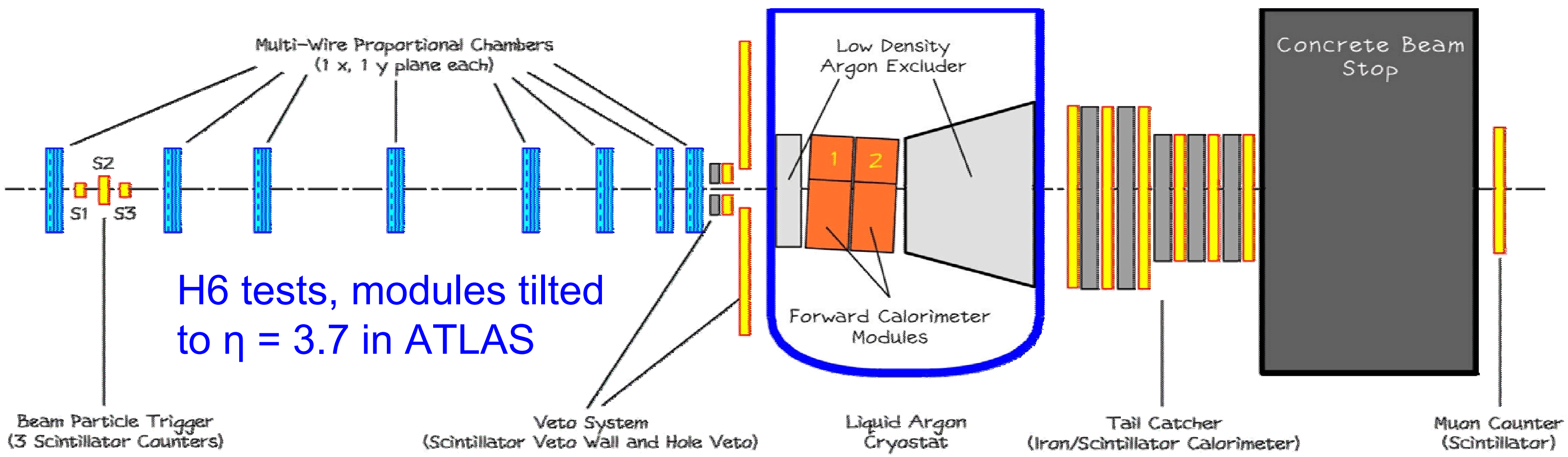




FCal “module 0” beam tests (1998)

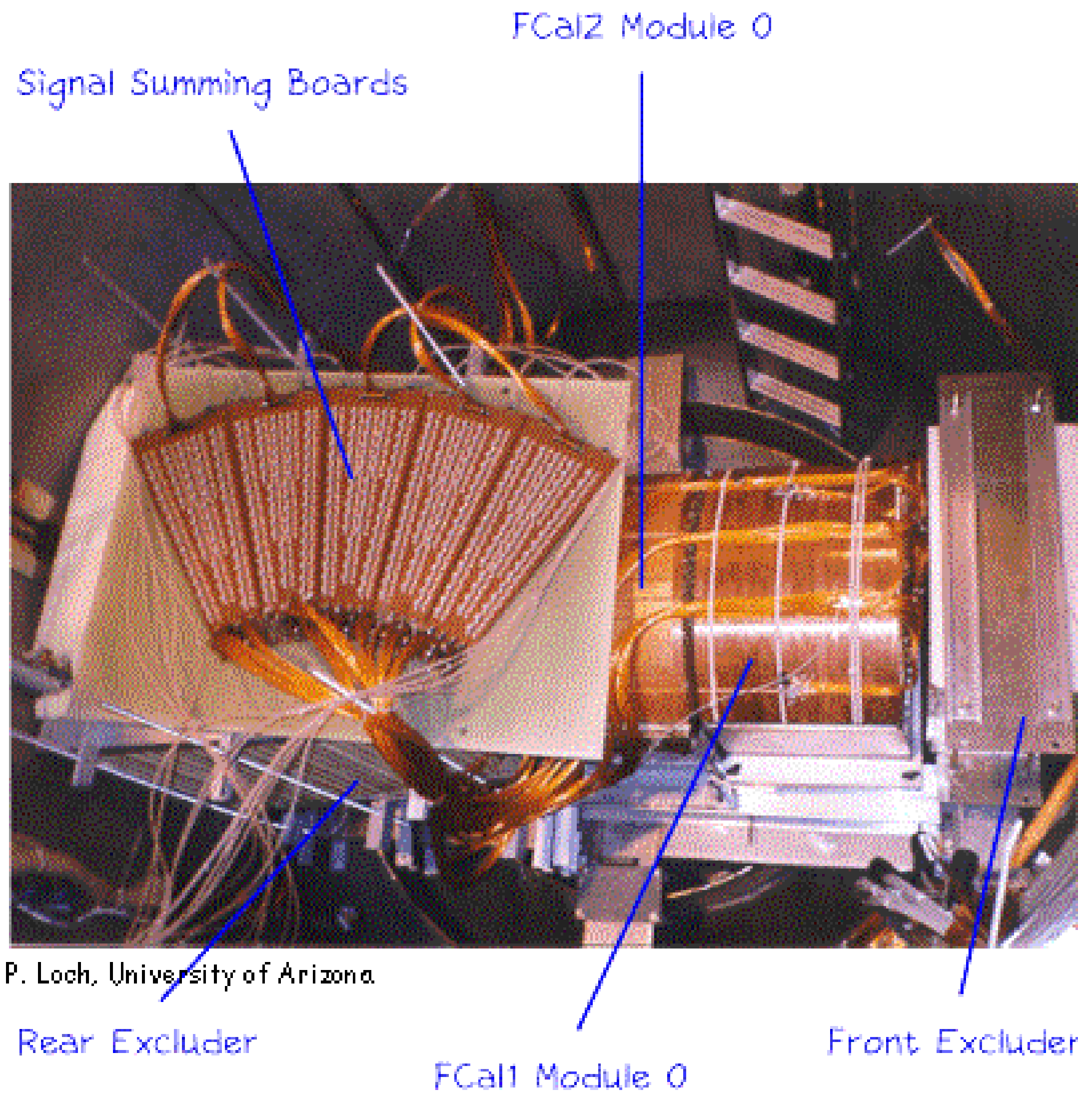


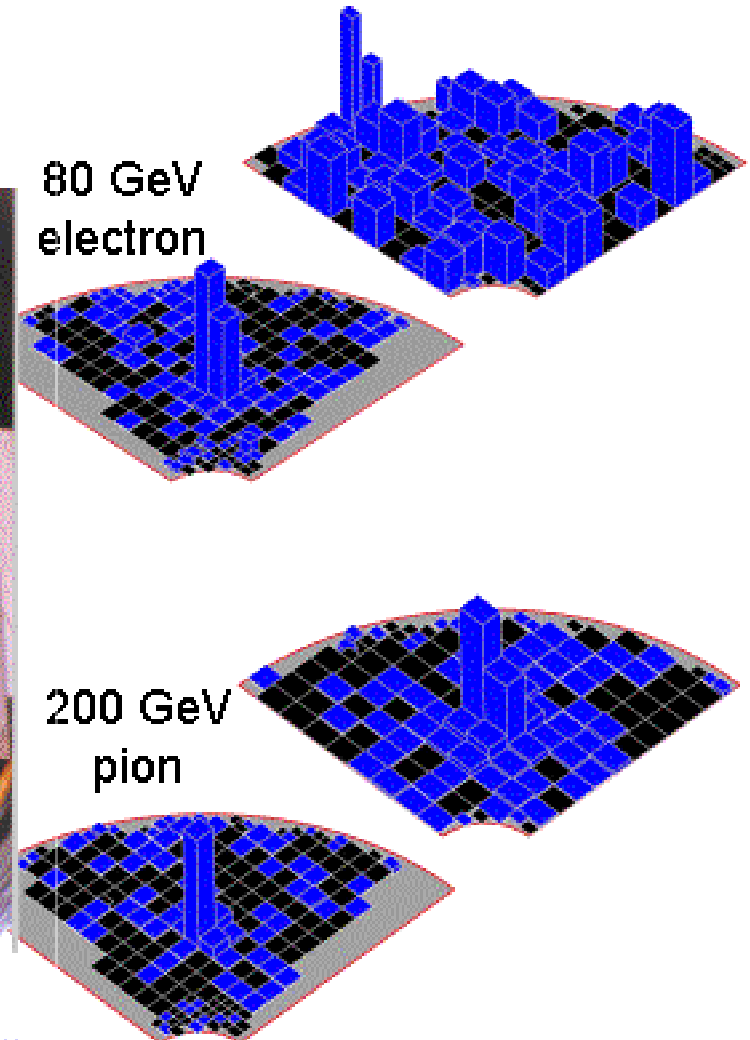
- pre-production prototypes of the electromagnetic (FCal1) and first hadronic (FCal2) modules, built to confirm simulated performance estimates and establish production techniques for the final modules;
- ¼ azimuthal segments at full depth, sufficient for lateral electromagnetic and hadronic shower containment



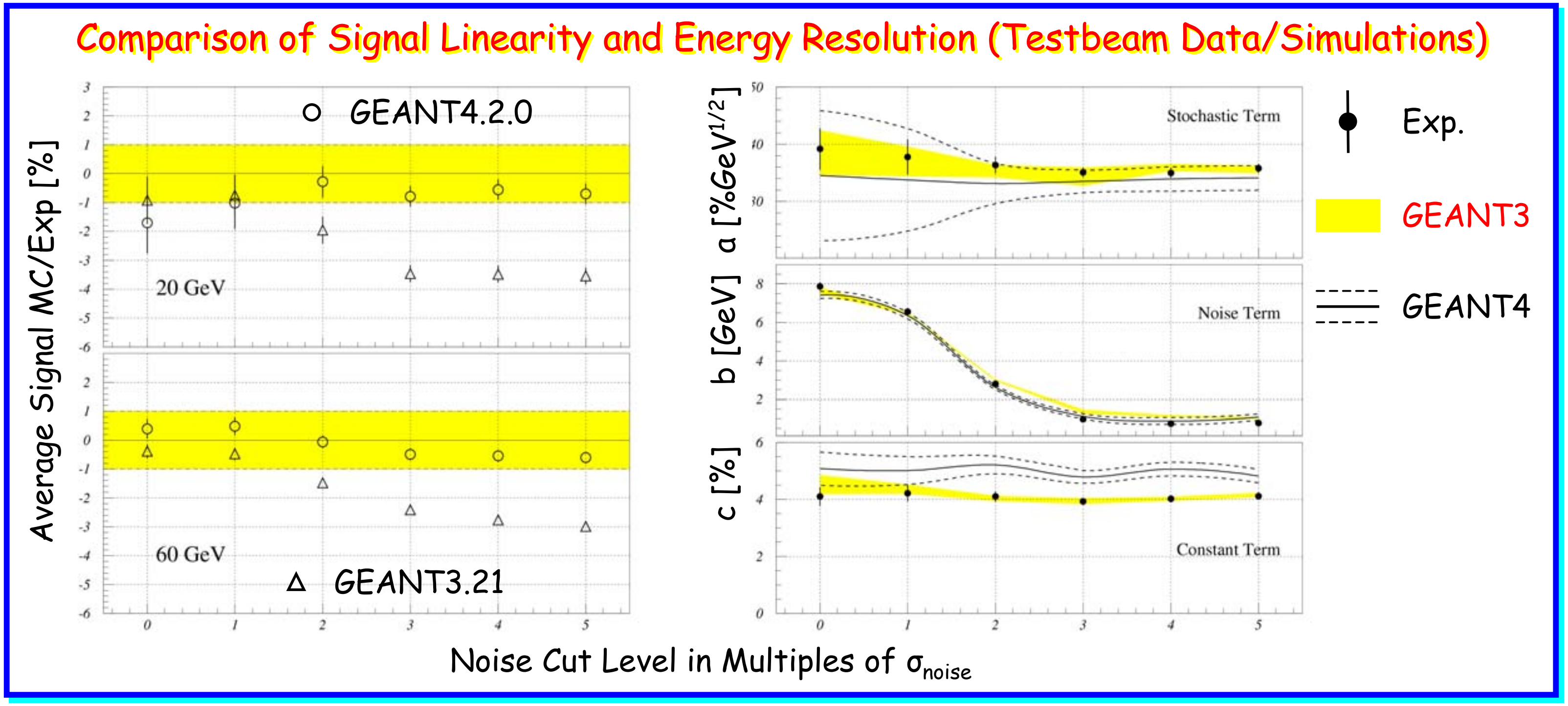
H6 tests, modules tilted to η = 3.7 in ATLAS

FCal “module 0” beam tests (1998)





FCal: electron energy

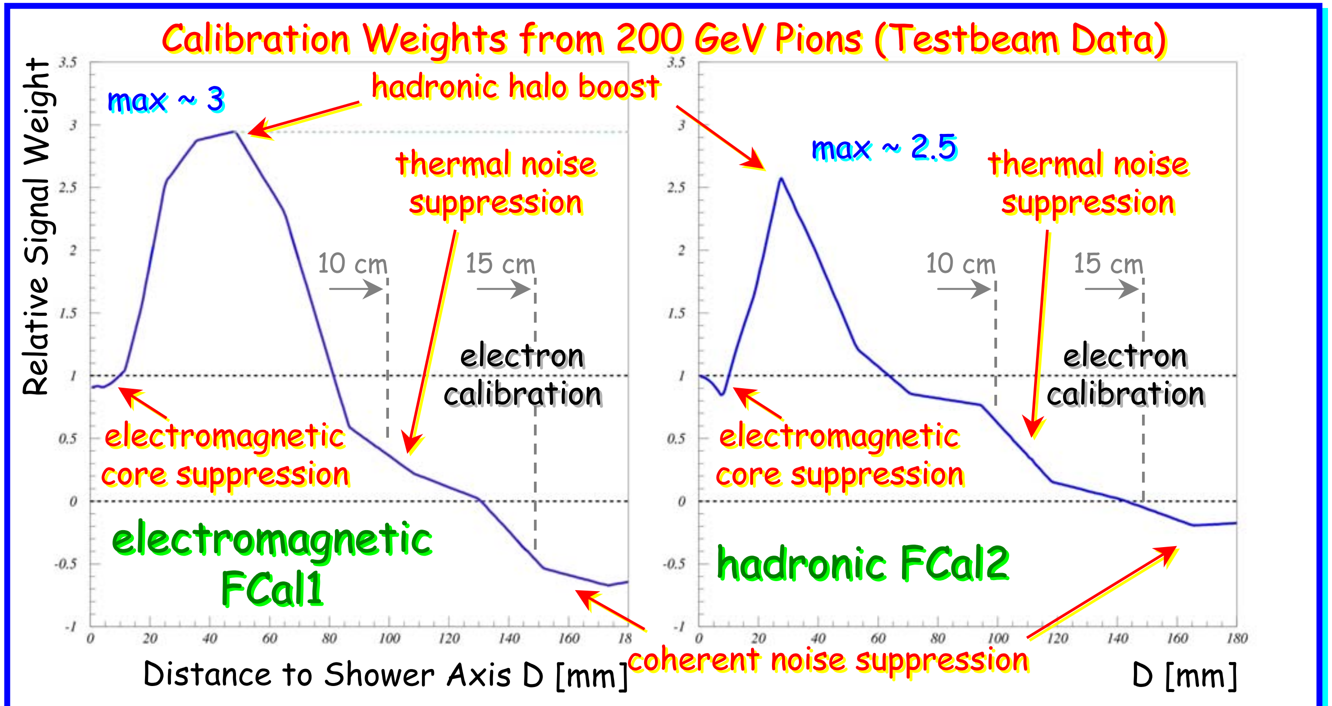


P. Loch, University of Arizona

- GEANT4 reproduces average signal within ±1% for all considered noise cuts;
- GEANT3 shows larger deviations for higher cuts, but reproduces fluctuations at higher energies better (shower dominant regime);

FCal: pion energy calibration

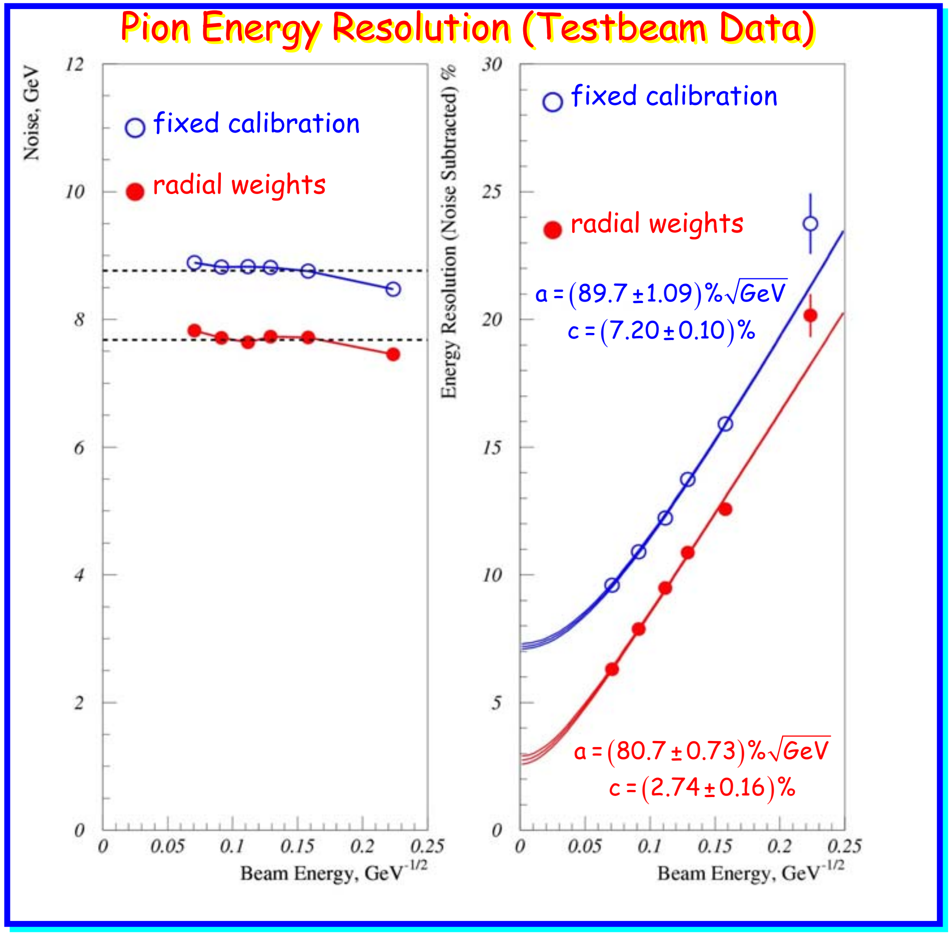
- new hadronic calibration scheme with cell signal weights depending on the radial distance of the cell to the shower axis;
- weights determined by resolution optimization fit to 200 GeV testbeam pions;
- requires reconstruction of impact point and shower axis;
- weights applied to pions and electrons (!) of all other energies to measure signal linearity, energy resolution and the e/pi signal ratio;
- GEANT4 reproduces average signal within ±1% for all considered noise cuts; GEANT3 shows larger deviations for higher cuts, but reproduces fluctuations at higher energies better (shower dominant regime);



A. Savine and P. Loch, University of Arizona

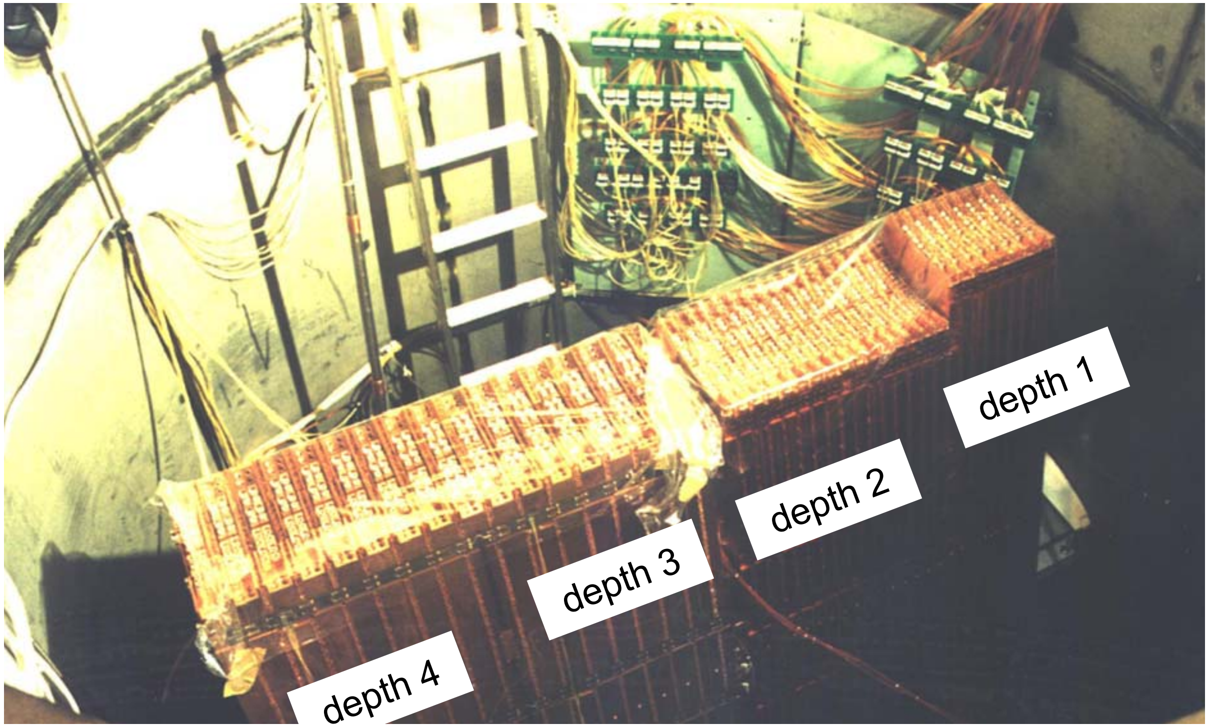
FCal: pion energy resolution

- pion signal linearity measured with "standard" fixed calibration (1 energy-independent constant/module, determined with 200 GeV pions) and "new" weighting scheme;
- significant reduction of non-linearities by a factor 1.5-2 for E_{beam} < 200 GeV by new calibration scheme;
- remaining ~4% non-linearity probably not too important for ATLAS, as typical energies are significantly higher -> expect response to higher energy jets (!!) to be more linear;
- method can work in jets in the forward direction as well, as jet shape in the FCal is more determined by hadronic shower spread than (transverse) energy flow in cone;
- ATLAS requirement of energy reconstruction $\frac{\sigma(E)}{E} = \frac{100\%}{\sqrt{E(\mathrm{GeV})}} \oplus 10\%$ exceeded

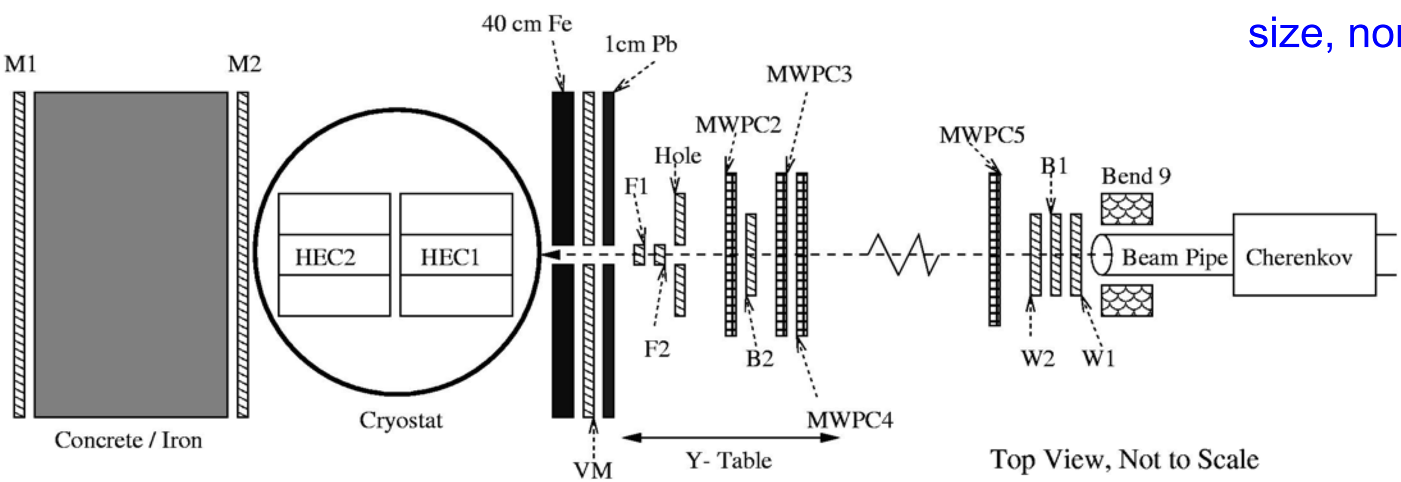


A. Savine and P. Loch, University of Arizona

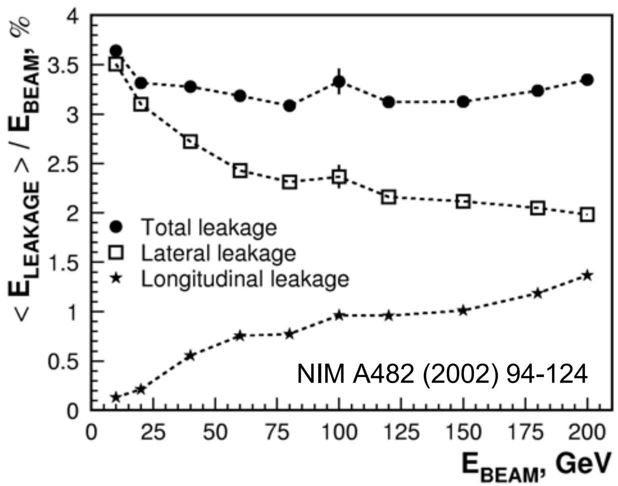
HEC beam tests



- First HEC module 0 tests in 1998;
- Results (2000 beam tests) published in **NIM A482 (2002) 94-124;**
- 3 modules (in phi) for HEC1 and 3 modules for HEC2 (3/32 of a complete endcap);
- 2 depth readout in each wheel;
- H6 tests; due to cryostat size, non-pointing setup!

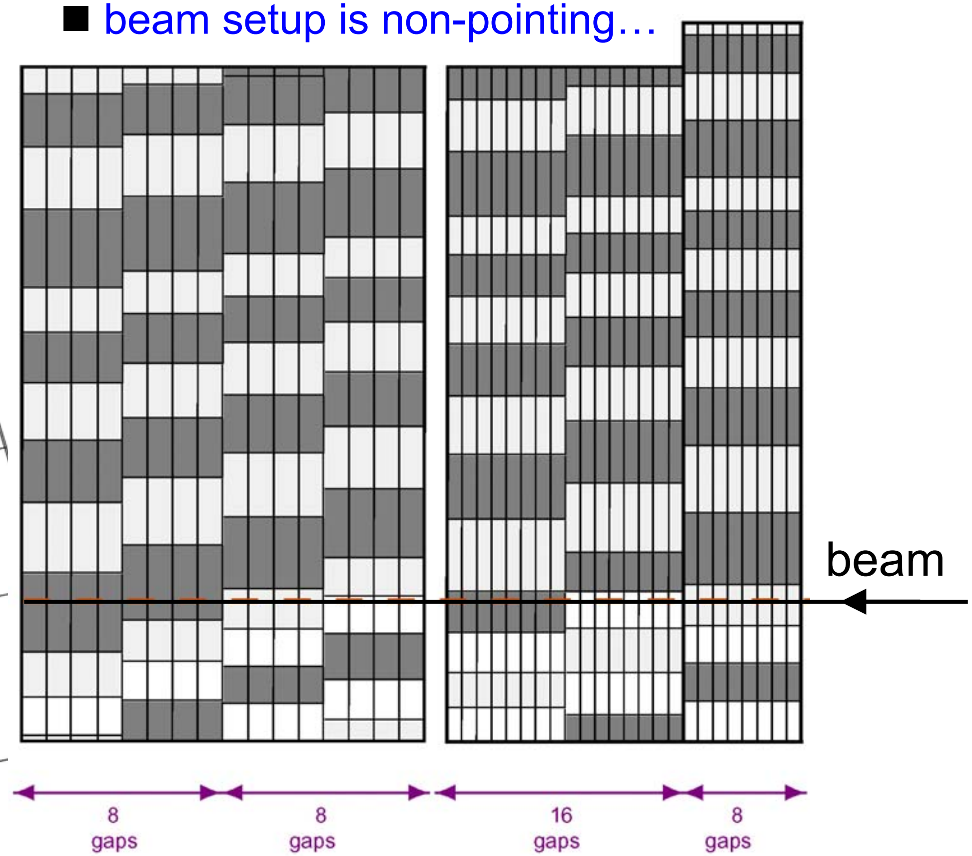


HEC beam tests



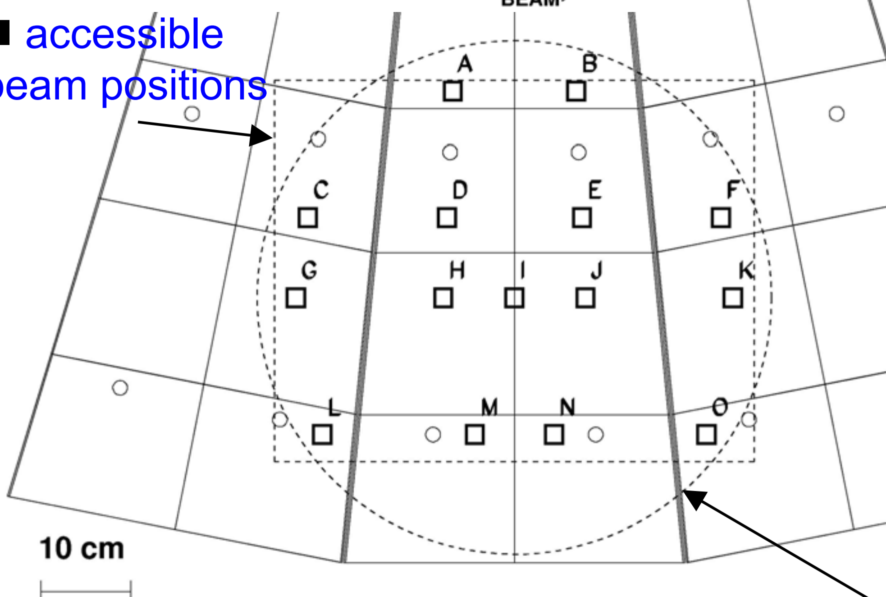
- total leakage about 3.2%

- beam setup is non-pointing…



back wheel: HEC2 front wheel: HEC1

- accessible beam positions

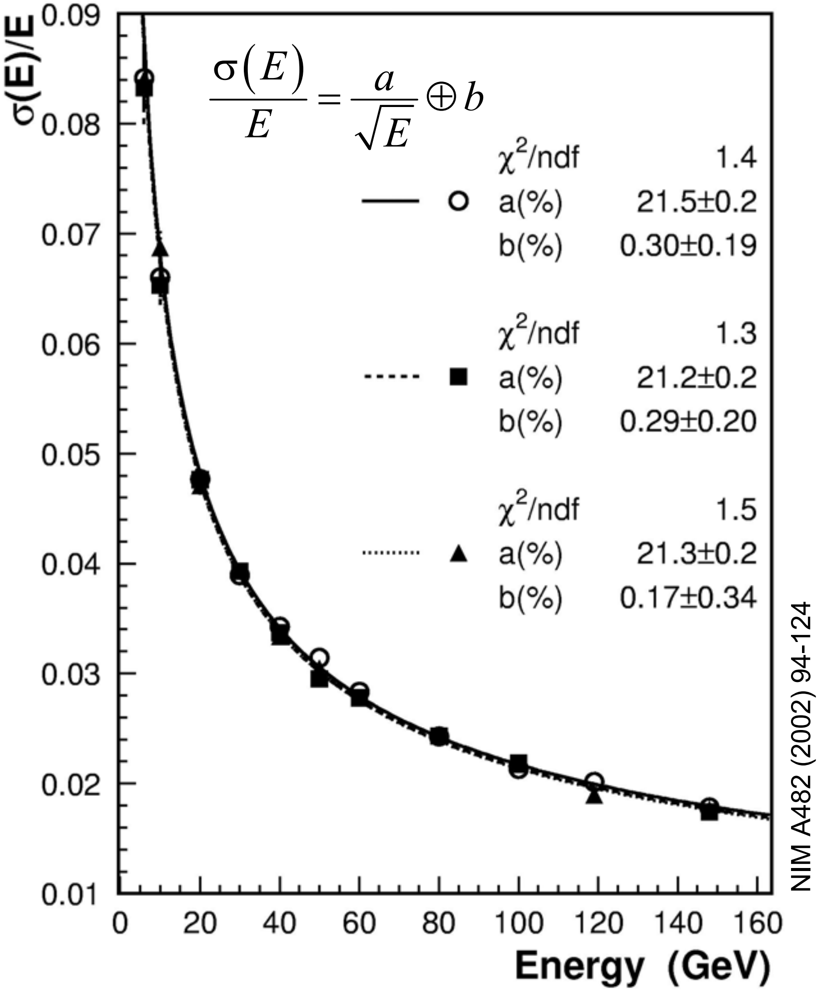


3 modules in azimuth

- cryostat beam window

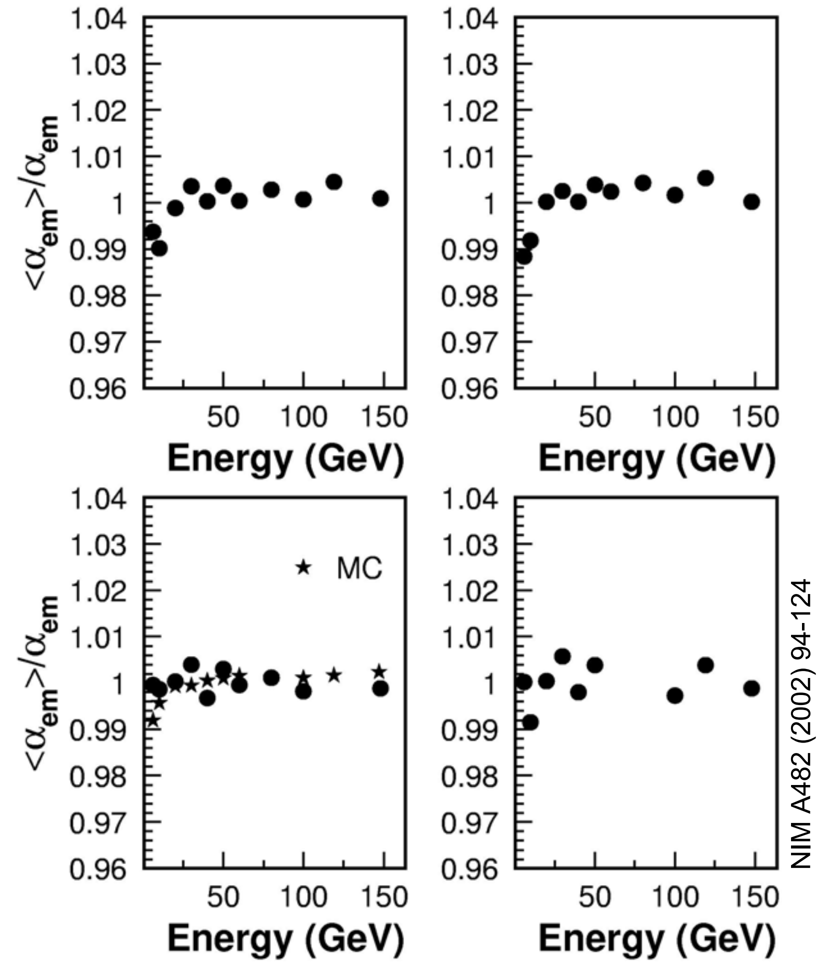
HEC: electron energy

- energy resolution for 3 different impact points
- 2.93±0.03 MeV/nA



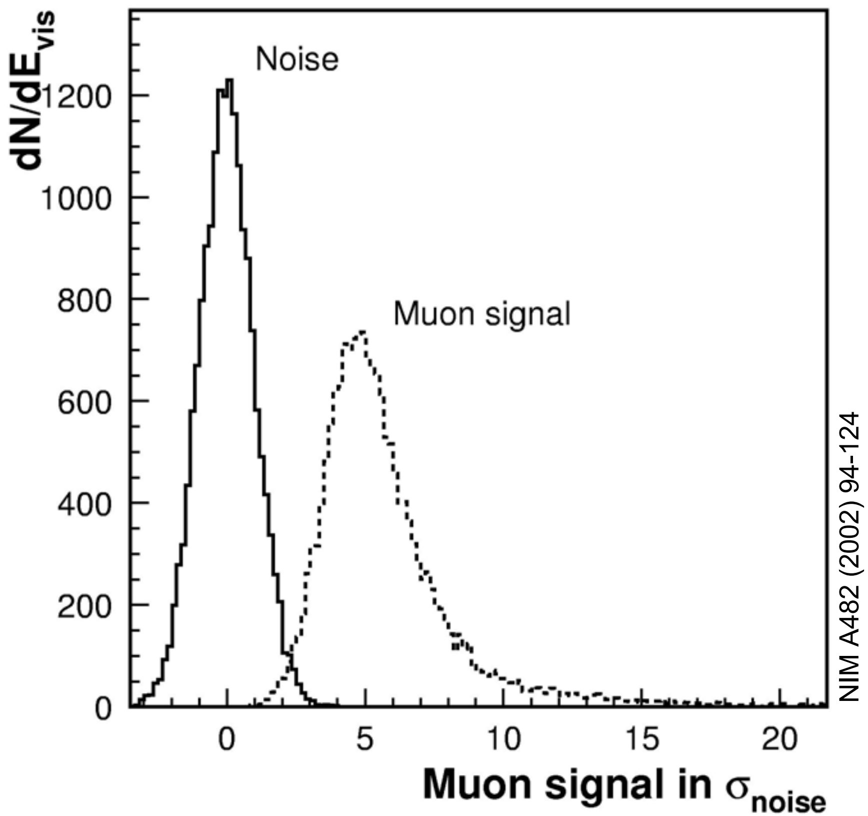
- response linearity for 4 different impact points is well within ±1%.

Low energy decrease mainly due to $0.6X_o$ material in front of calo

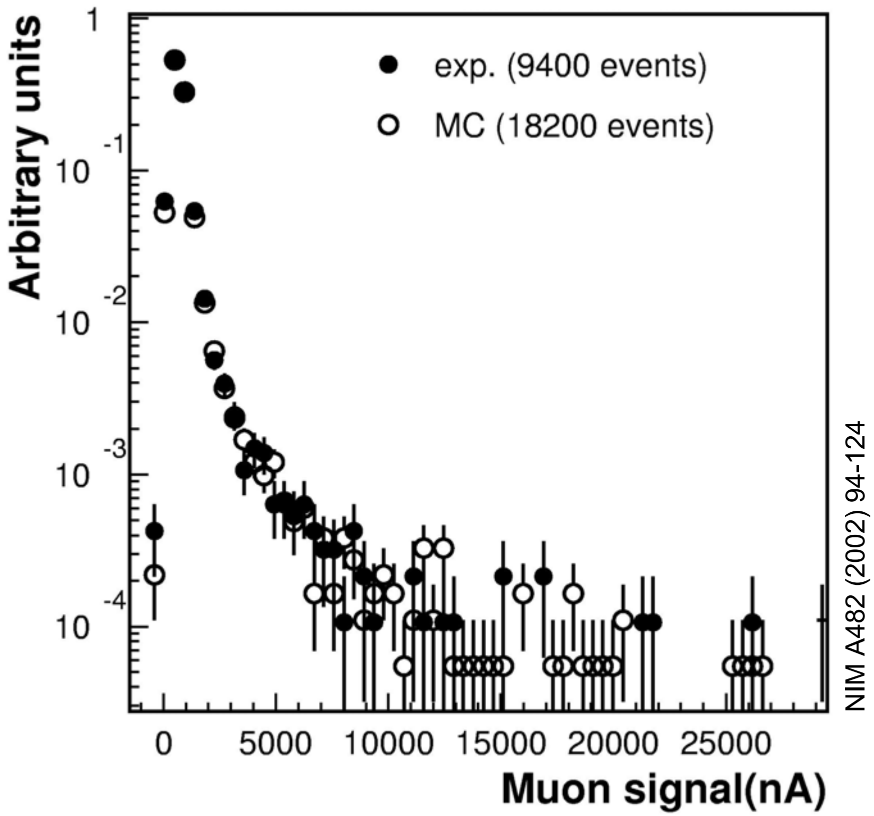


HEC: muon response

- 180 GeV muon response: HEC can see muons



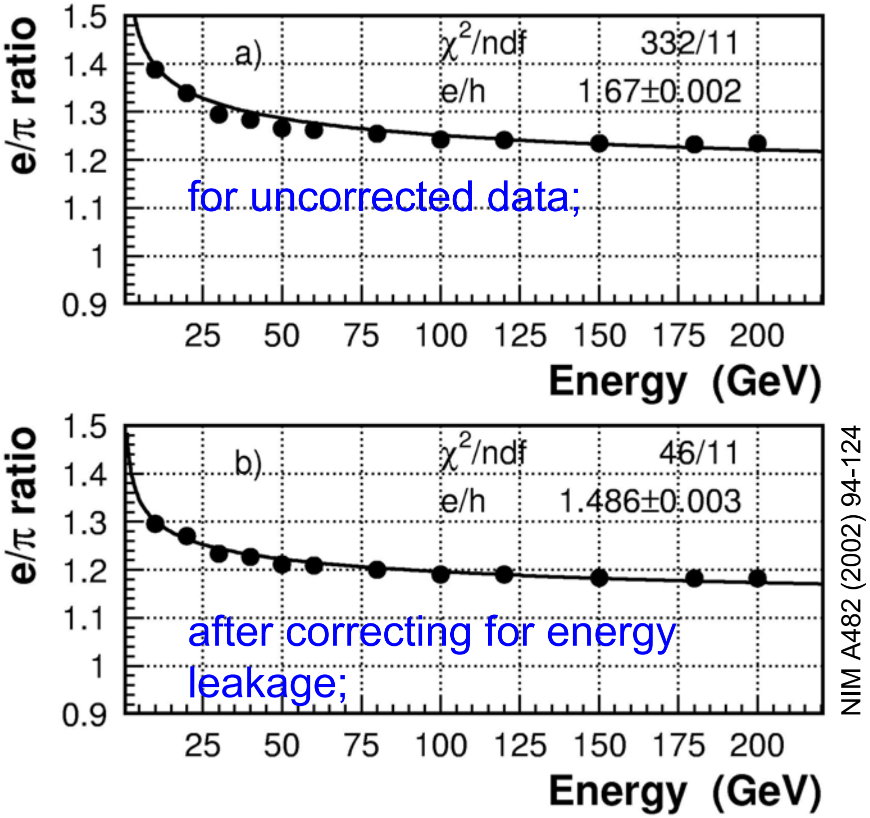
- 120 GeV muon response compared with simulation



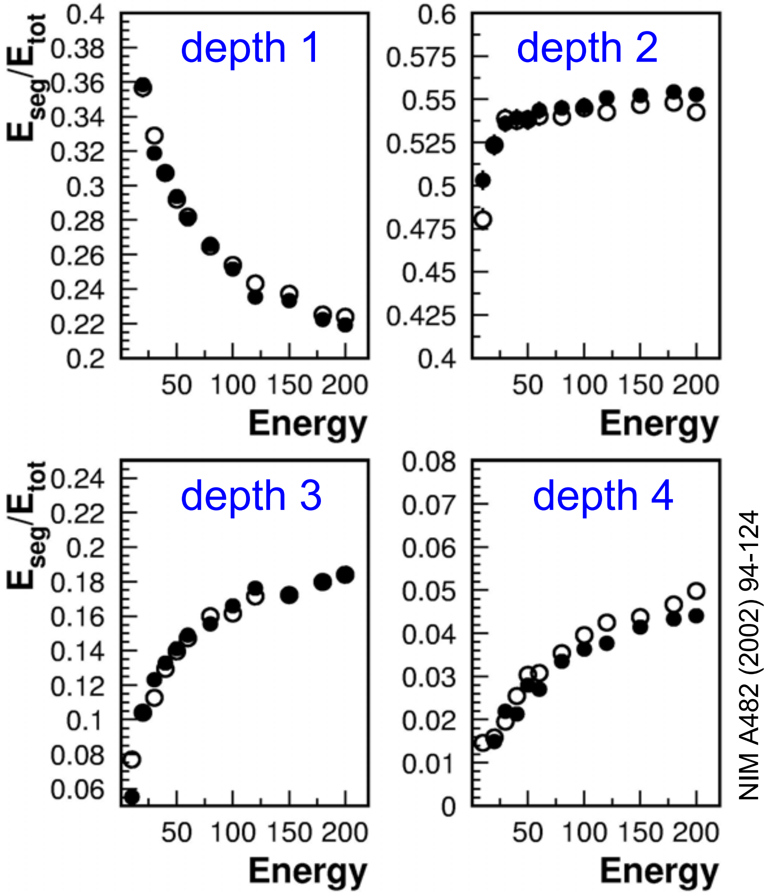
HEC: pion energy response

■ energy dependence of the e/π ratio

$$e/\pi = \frac{e/h}{1+(e/h-1)f_\pi^\circ} \quad \Rightarrow \quad e/h \sim 1.5$$

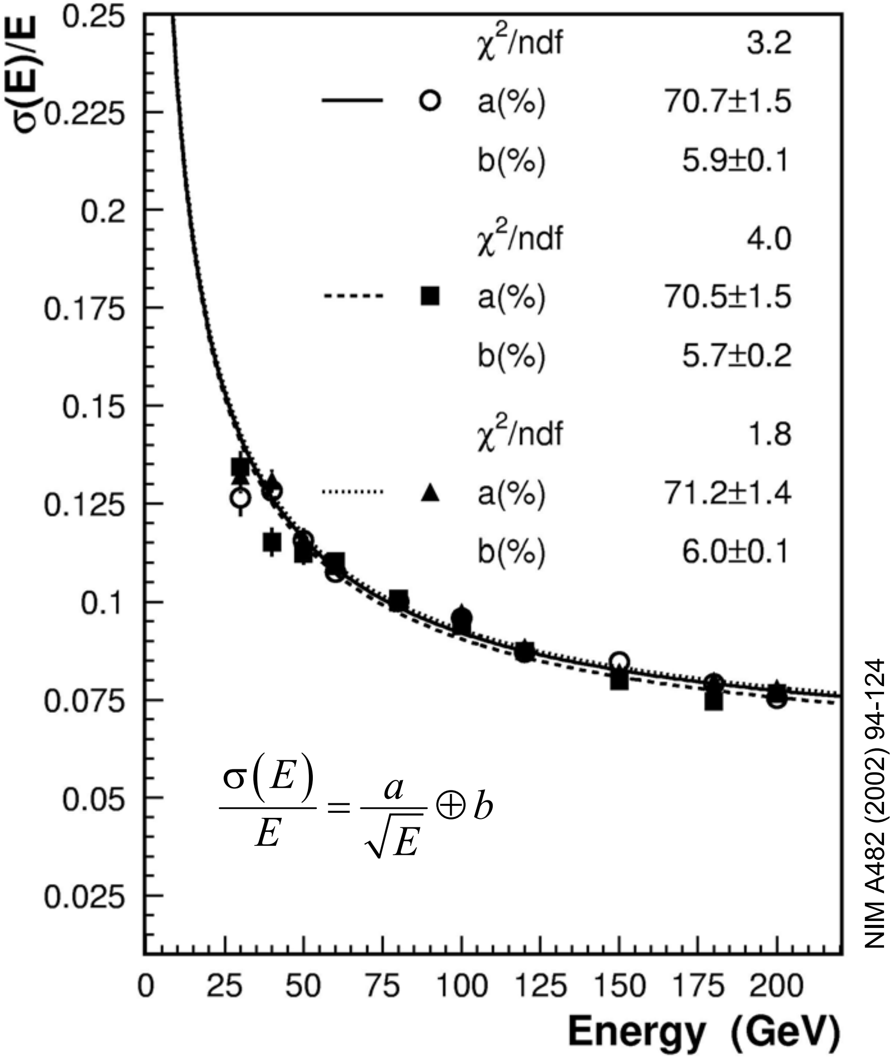


■ energy dependence of the mean energy fraction deposited in the longitudinal depth segments; open points are GCALOR; agreement is also good for lateral shower shape



HEC: pion energy resolution

■ energy resolution for 3 different impact points after electronic noise subtracted in quadrature



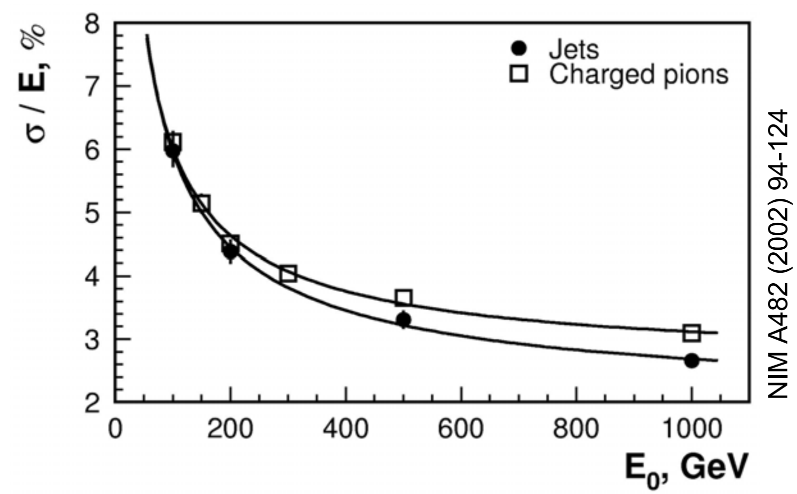
■ intrinsic energy resolution is obtained after correcting for energy leakage; the result is a = (62.2 ±1.8)% GeV$^{1/2}$ and b = (5.2 ± 0.2)%

■ Monte Carlo extrapolation to jets in ATLAS:

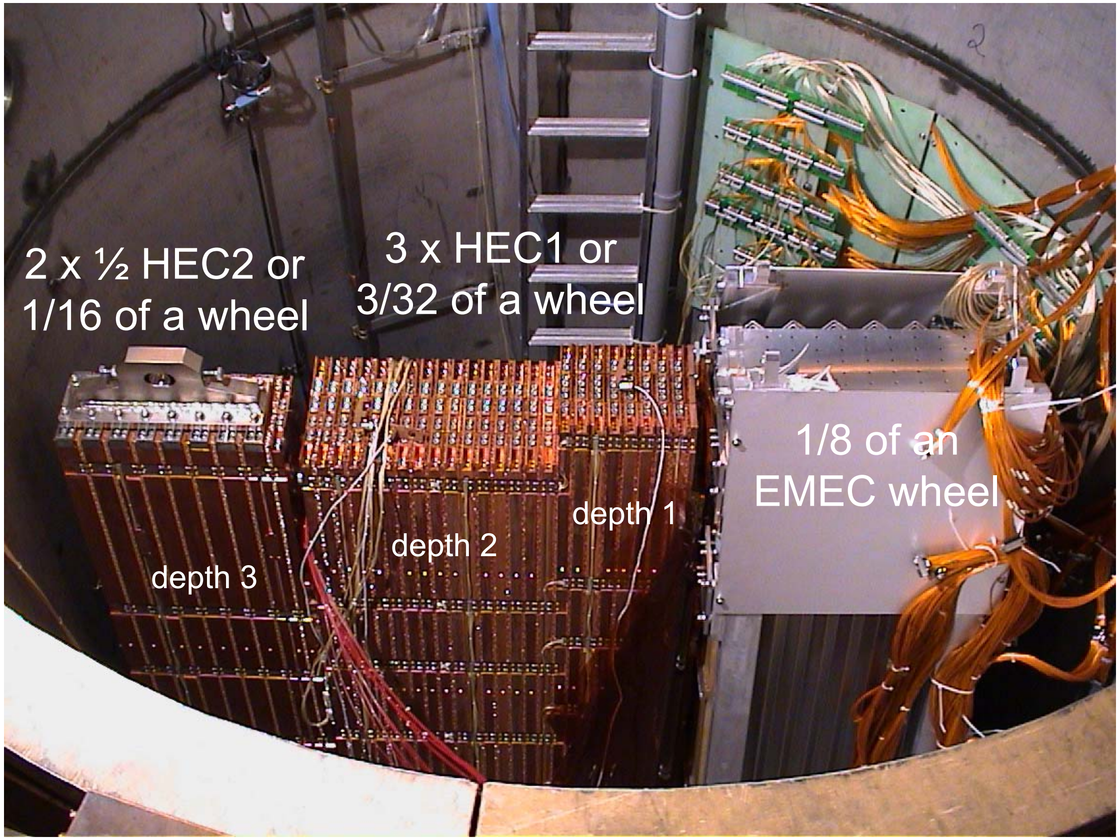
pions: a = (54 ± 2)% GeV$^{1/2}$
b = (2.6 ± 0.1)%

jets: a = (56 ±3)% GeV$^{1/2}$
b = (2.0 ± 0.2)%

meets ATLAS requirements



HEC+EMEC combined beam test

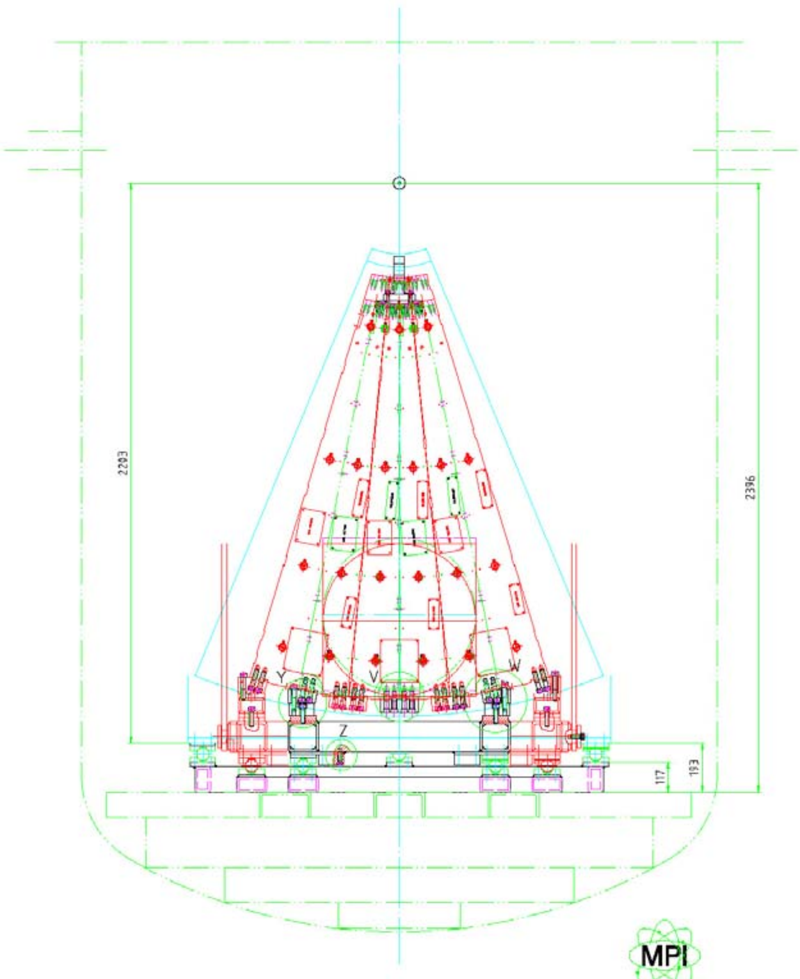


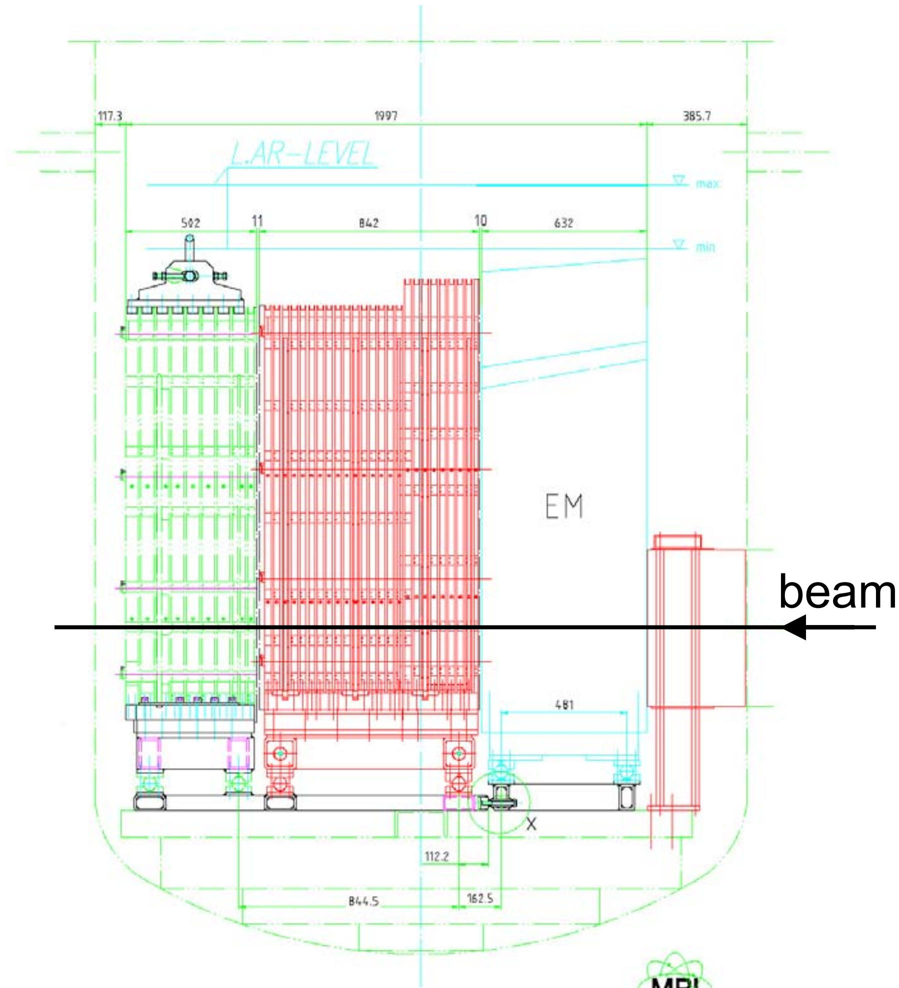
L. Betev, Frankfurt University, Germany

- summer 2002; first combined test in the endcap region;
- EMEC included the presampler for a total of 4 readout depths;
- all results very preliminary!!!

HEC+EMEC combined beam test

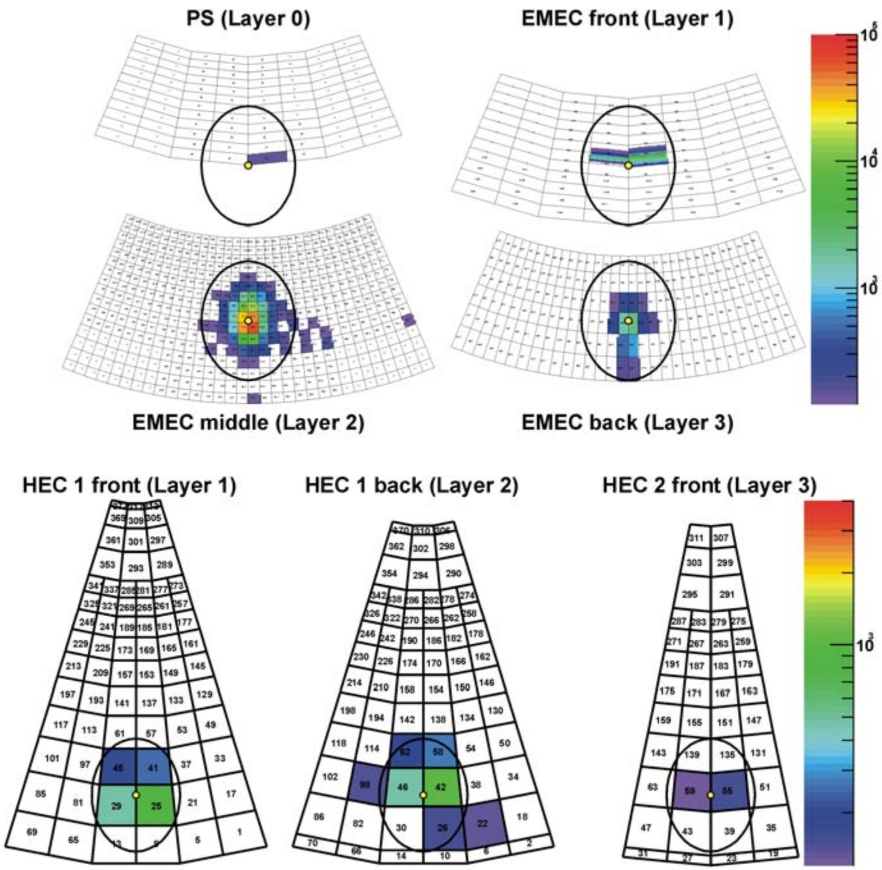
- beam setup is non-pointing…



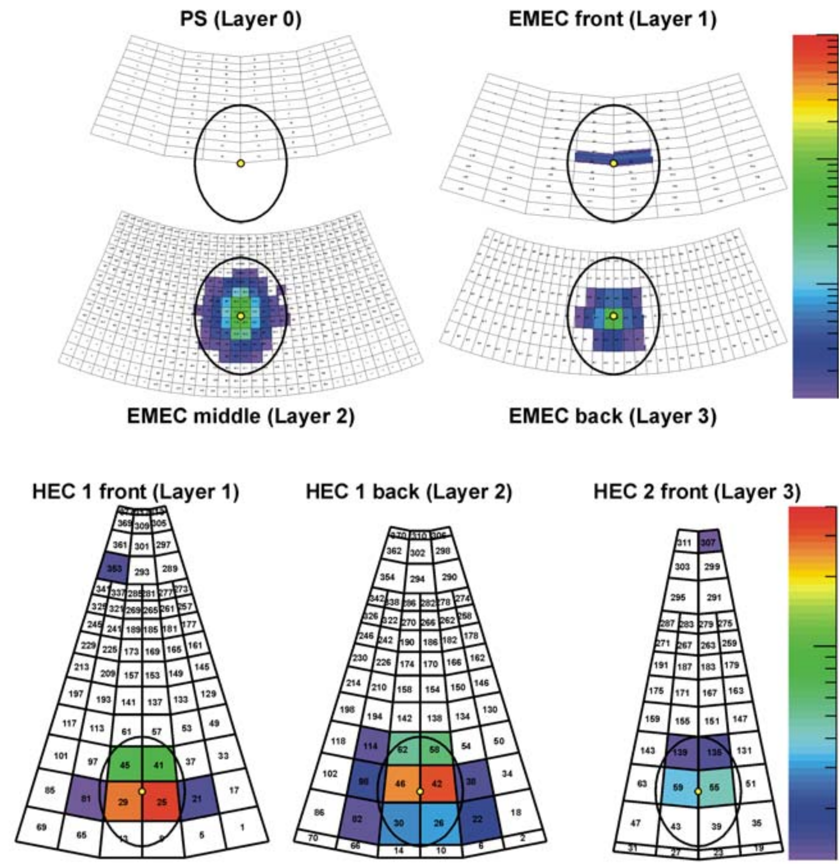


HEC+EMEC: typical signal for electrons and pions

electrons



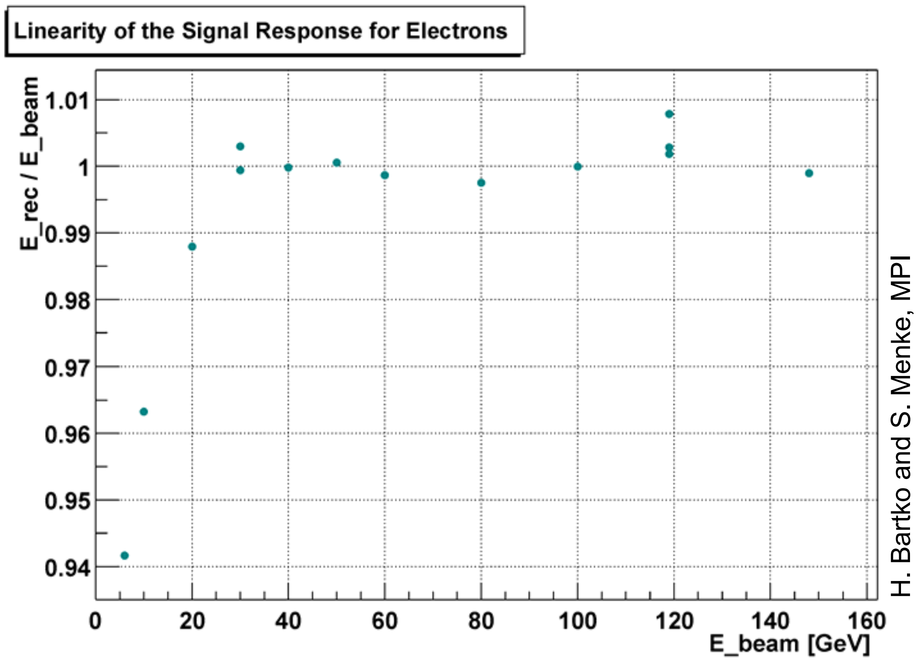
pions



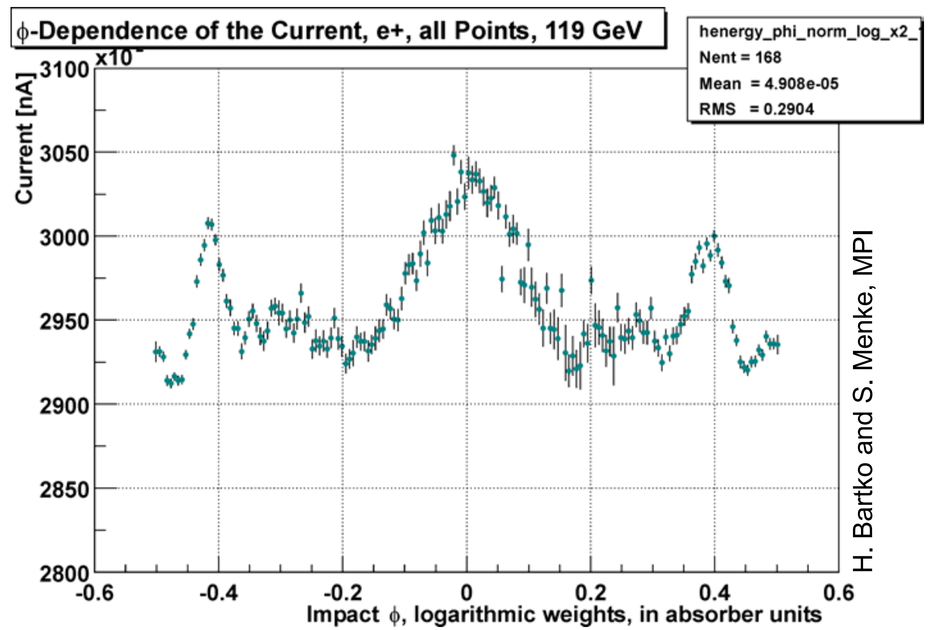
H. Bartko and S. Menke, MPI

HEC+EMEC: electron response

- linearity of response

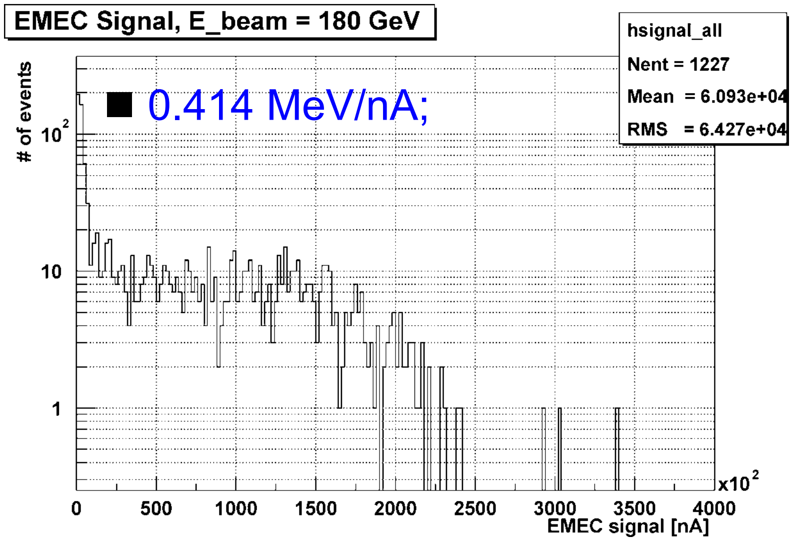


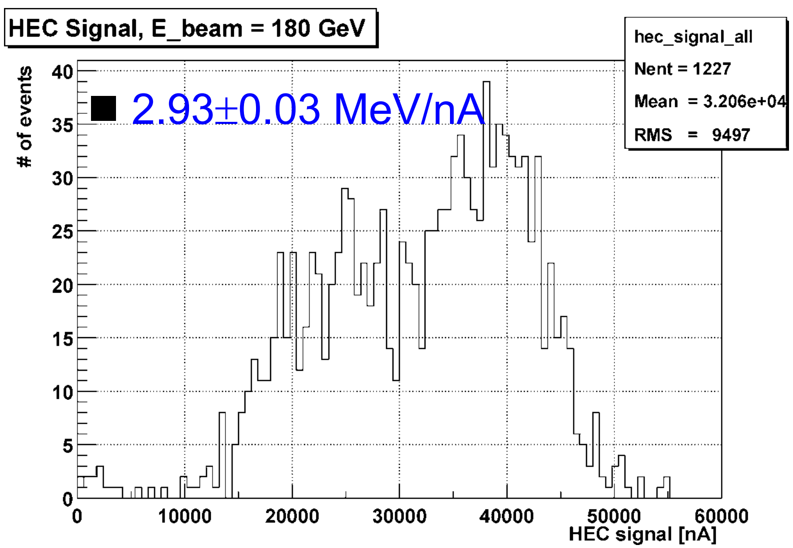
- effect of accordion geometry



- 0.414 MeV/nA;
- decrease at low energy under investigation
- shower shape under way

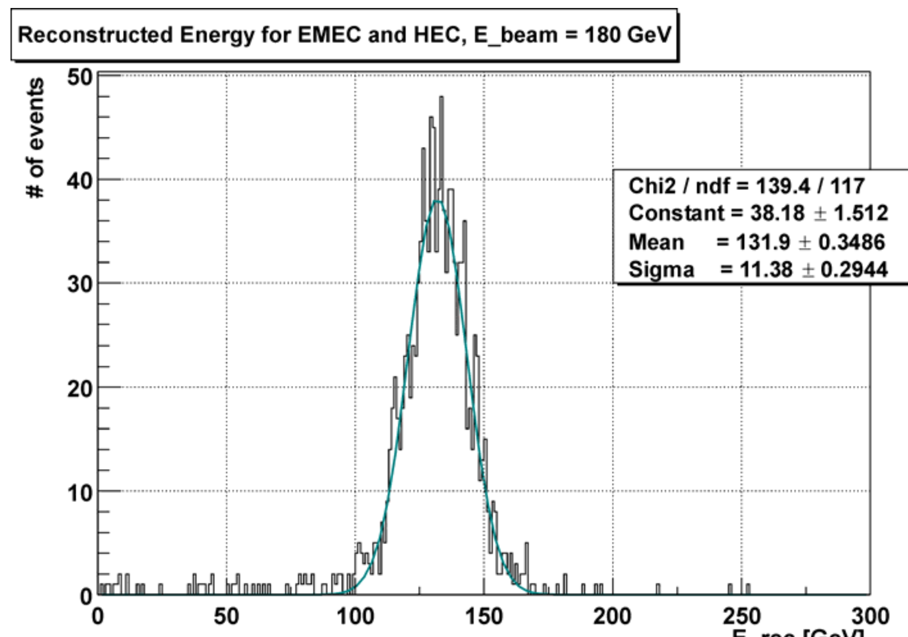
HEC+EMEC: pion energy reconstruction





■ combine EMEC and HEC response (EM scale) with one weight for the HEC

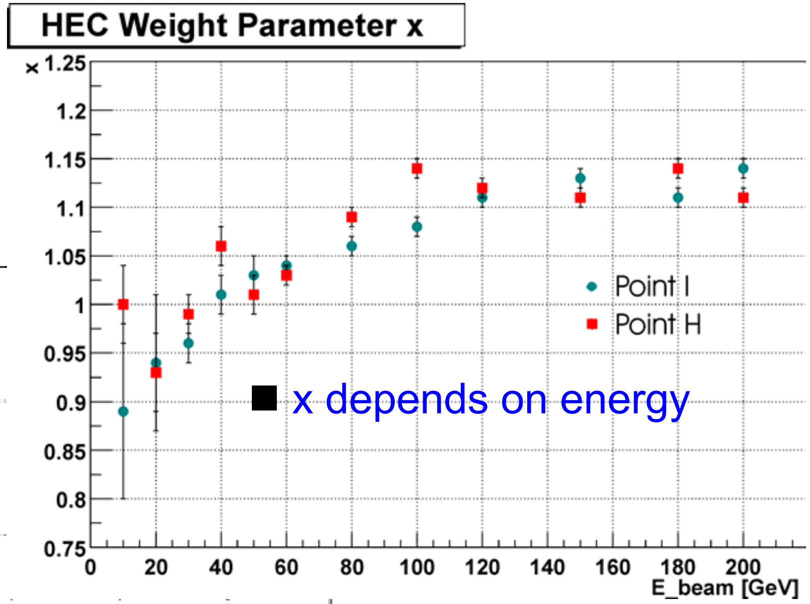
$$E = E^{\mathrm{EM}}_{\mathrm{EMEC}} + x \cdot E^{\mathrm{EM}}_{\mathrm{HEC}}$$

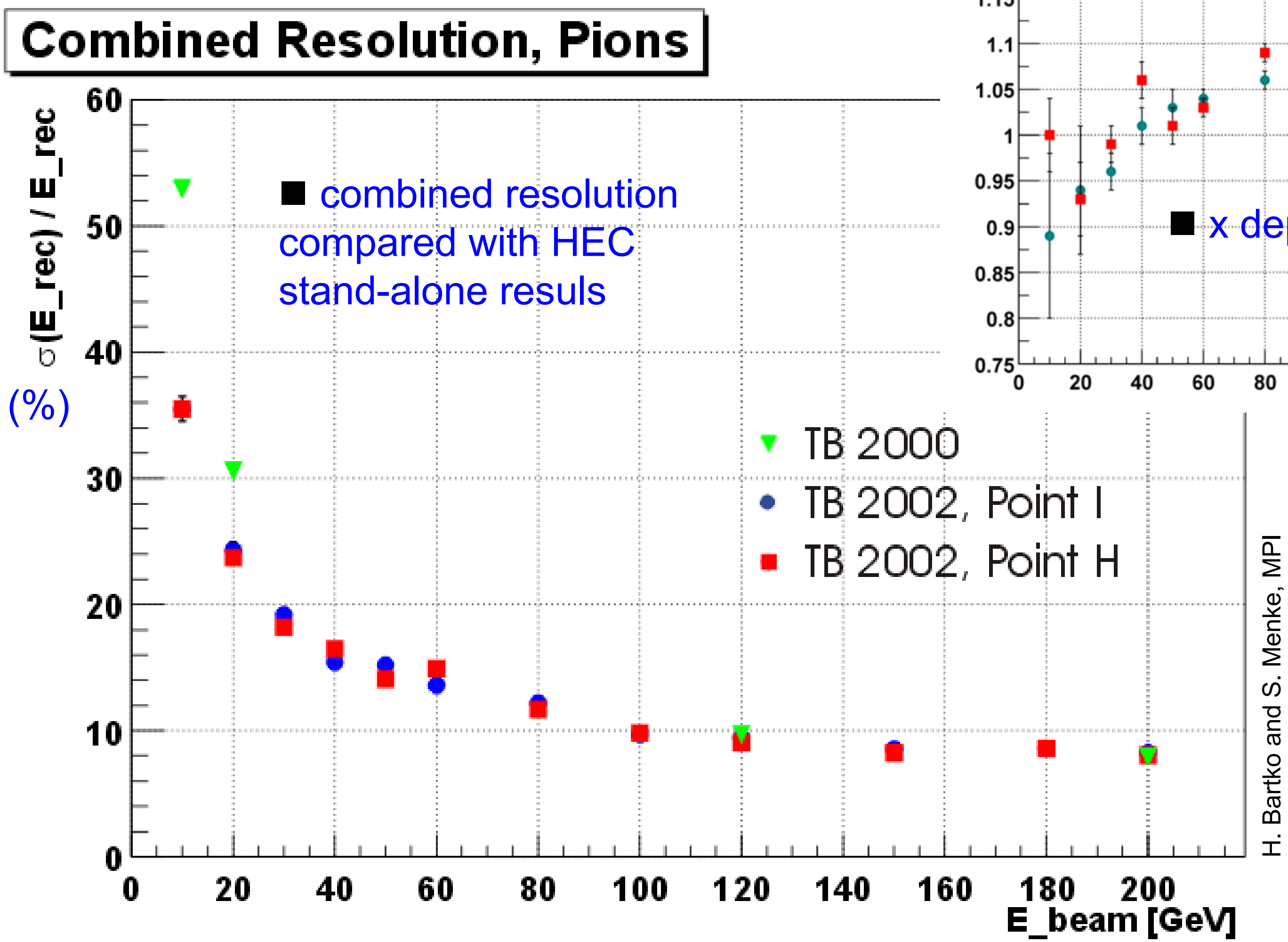


H. Bartko and S. Menke, MPI

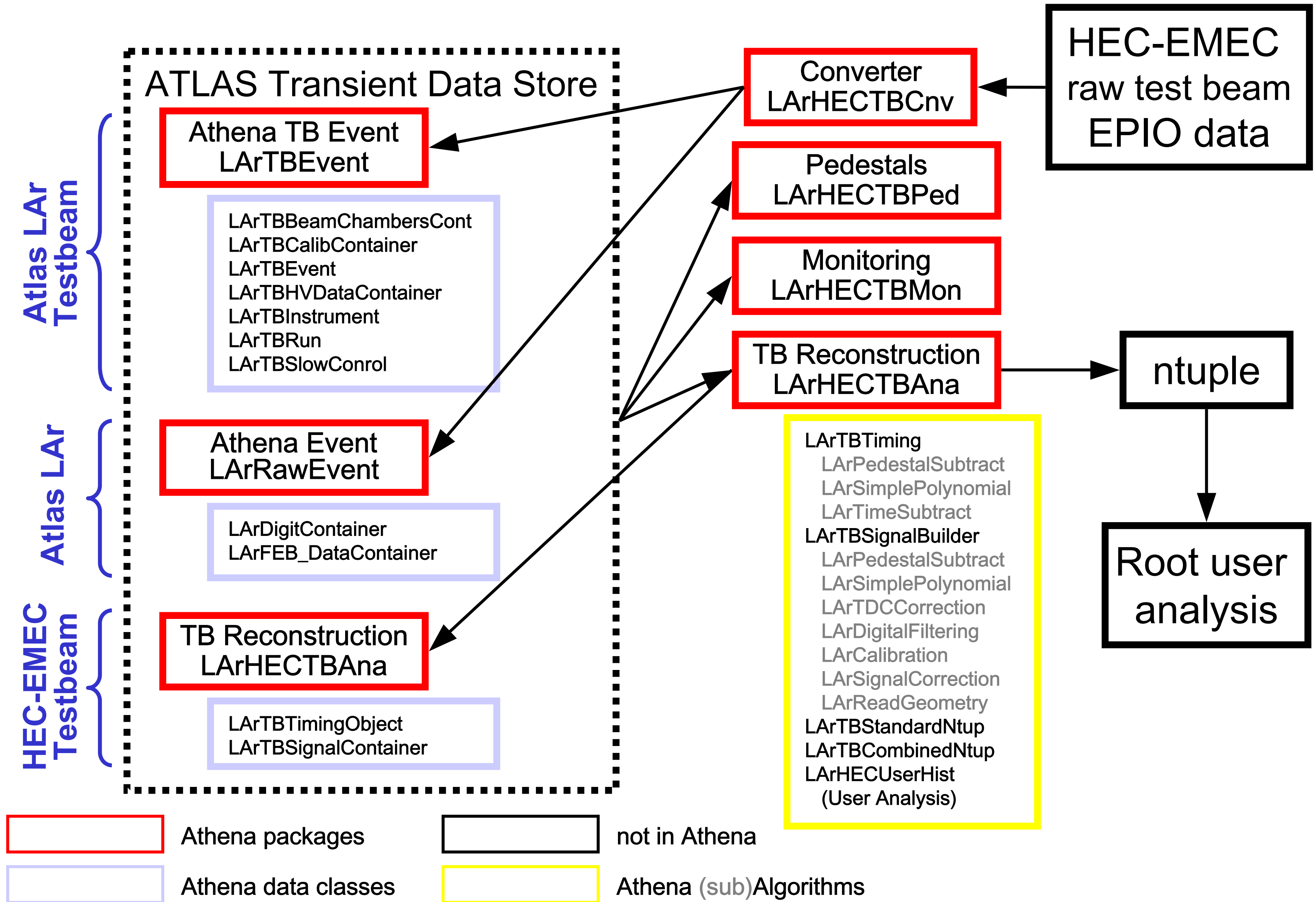
■ at 180 GeV, the optimum energy resolution obtained is 8.6% for x ≈ 1.12

HEC+EMEC: pion energy resolution

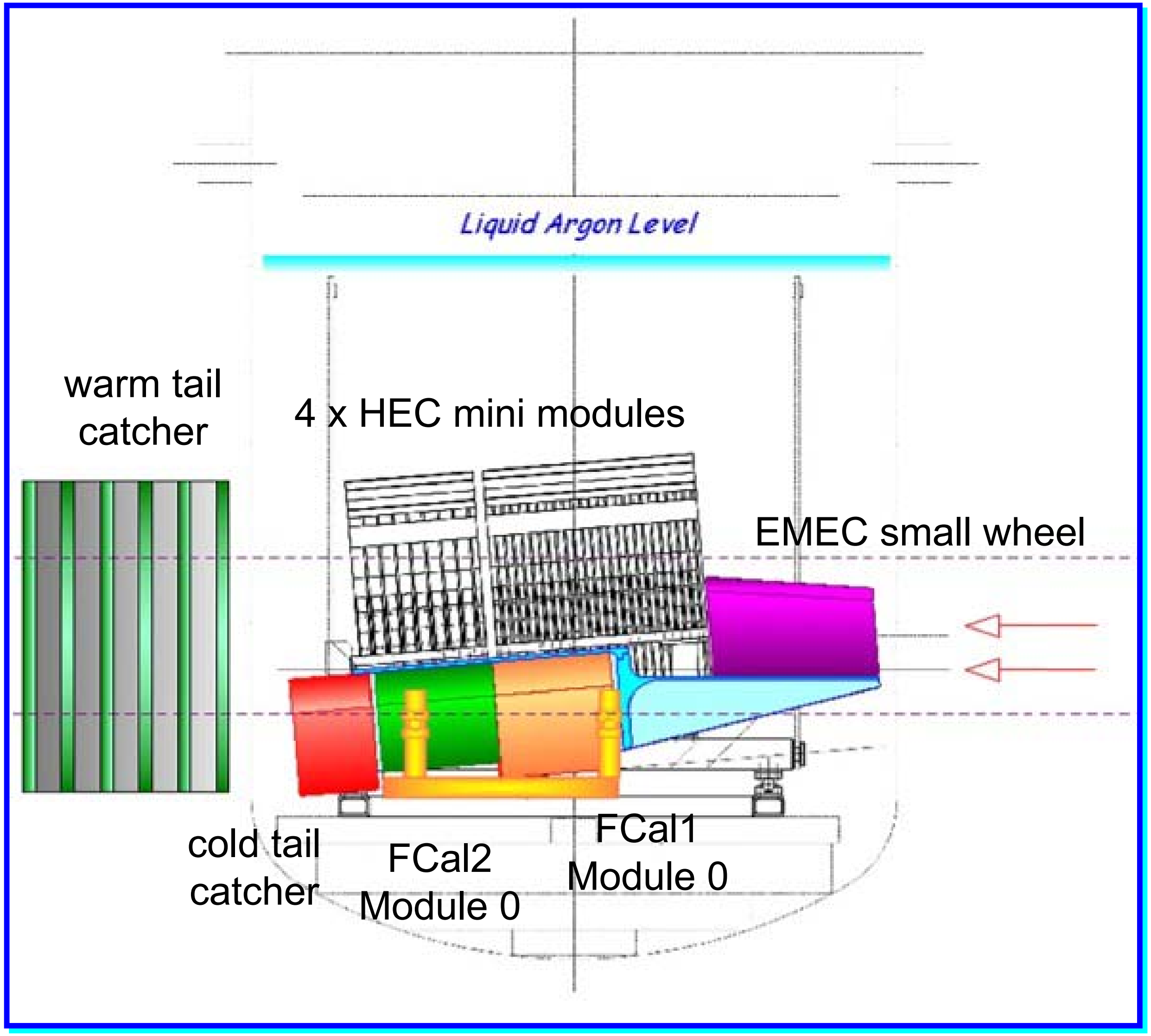




HEC+EMEC: Athena software



FCal and FCal+HEC+EMEC



Peter Loch, Leif Shaver, John Rutherfoord

- FCal full system test: summer 2003;
- FCal+HEC+EMEC beam tests: spring-summer 2004;
- requires purpose built HEC mini modules;
- production of a cold tail catcher; brass/LAr 16 X_o and 1.6 λ;
- production of a warm tail catcher; Fe/Scintillator

Summary

- **FCal**
  - **1998 module 0 beam test: FCal meets ATLAS requirements**
  - **2003 full calibration beam test starting next month**
- **HEC**
  - **1998-2001 production module tests: HEC meets ATLAS requirements**
- **HEC+EMEC**
  - **2002 combined test done: data analysis progressing**
  - **First use of Athena during tests (monitoring) and for analysis**
- **FCal+HEC+EMEC**
  - **2004 combined beam test under preparation**