Results from particle beam tests of the ATLAS liquid argon endcap calorimeters

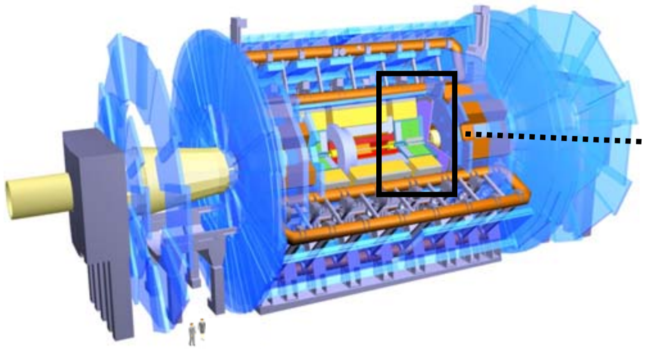
- Beam test setup
- Signal reconstruction
- Response to electrons
  - Electromagnetic Scale
- Response to pions
  - weighting using energy density

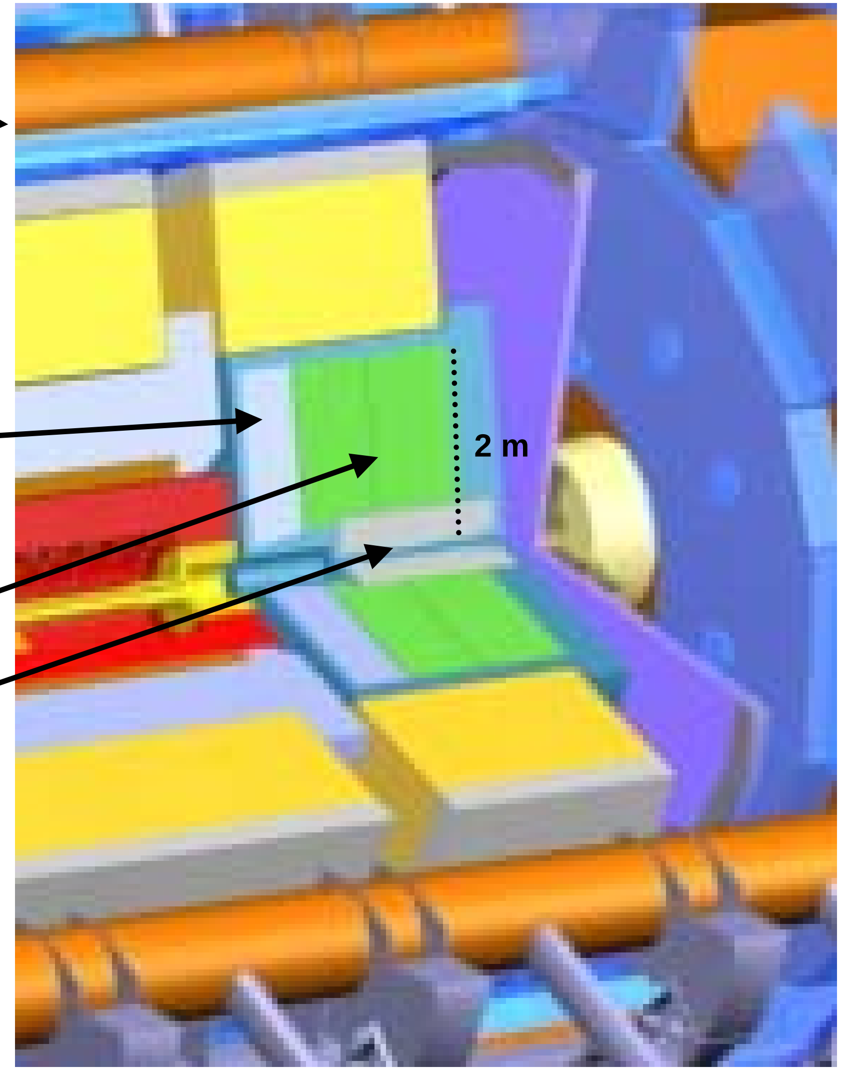
CALOR 2004
Perugia, Italy
Mar 29 – Apr 2, 2004

ATLAS HEC: Canada, China, Germany, Russia, Slovakia
ATLAS EMEC: France, Russia, Spain

Michel Lefebvre
University of Victoria
Physics and Astronomy

ATLAS Endcap LAr Calorimeters





Electromagnetic endcap
with presampler

Hadronic endcap

Forward

See M. Vincter's talk

Electromagnetic Endcap Calorimeter

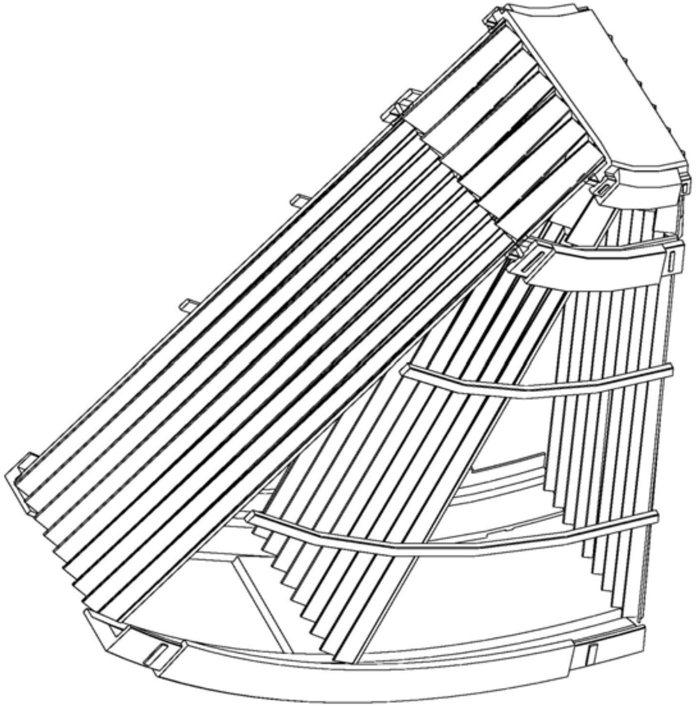
- EMEC absorber structure
  - Pb absorbers arranged radially, no azimuthal cracks
  - folding angle and wave amplitude vary with radius
  - inner and outer wheels
- EMEC readout structure
  - layer 0 (presampler)

    $\Delta\eta \times \Delta\varphi = 0.025 \times 0.1$
  - layer 1 (front): $\approx$ 2 to 4 X_o

    $\Delta\eta \times \Delta\varphi = 0.025/8 \times 0.1$
  - layer 2 (middle): $\approx$ 16 to 18 X_o

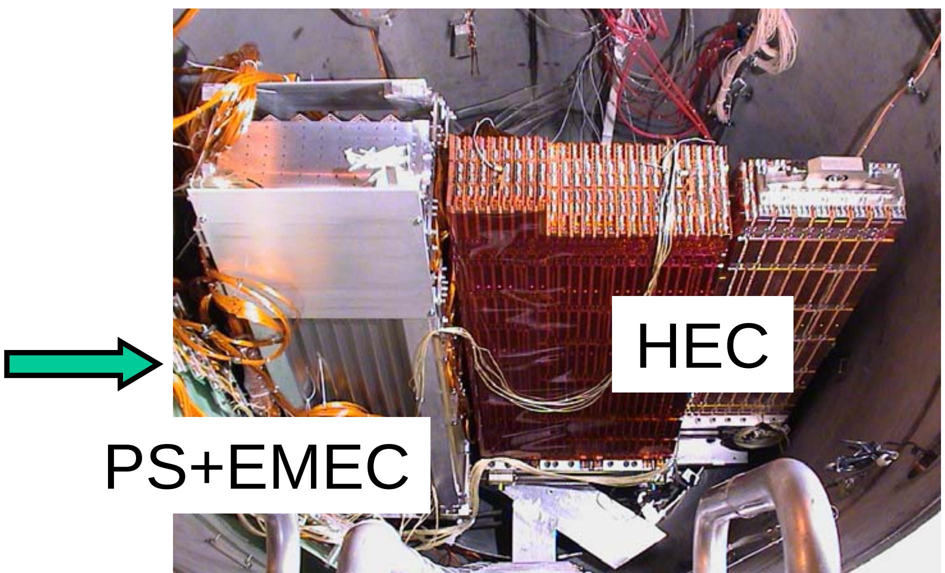
    $\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$
  - layer 3 (back): $\approx$ 2 to 4 X_o

    $\Delta\eta \times \Delta\varphi = 0.050 \times 0.025$

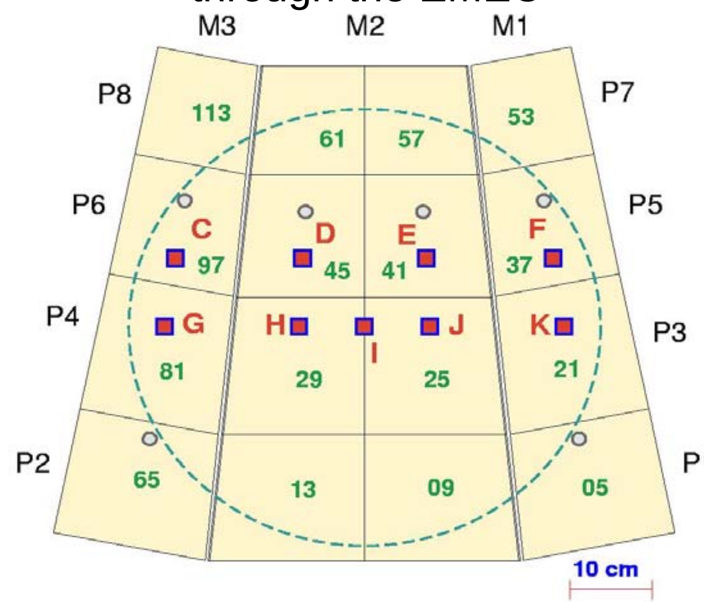


HEC-EMEC beam test configuration

- H6 beam area at the CERN SPS
  - $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$ beams with 6 GeV $\leq$ E $\leq$ 200 GeV. Here report on $e^{\pm}$, $\pi^{\pm}$.
  - 90º impact angle: non-pointing setup (not like ATLAS)
  - beam position chambers
  - optional additional material upstream (presampler studies)



front face of HEC seen through the EMEC

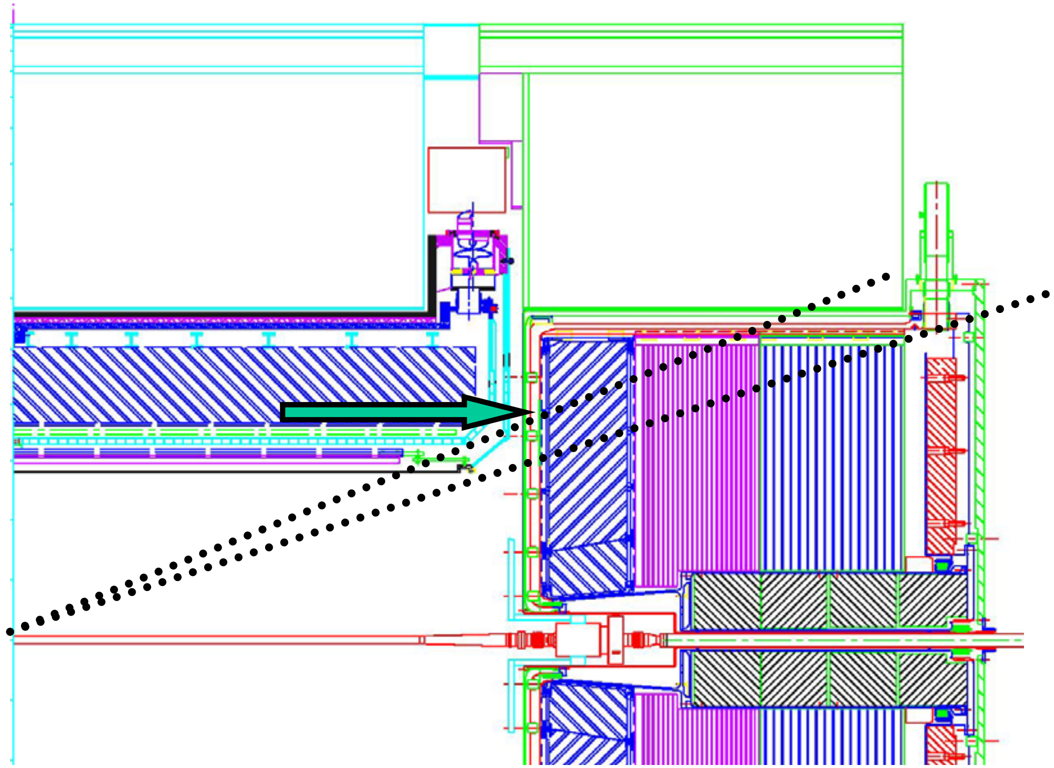


Main goals of the HEC-EMEC beam test

- Determination of the hadronic calibration constants in the ATLAS region $1.6 < |\eta| < 1.8$
- Development of hadronic energy reconstruction methods
- Monte Carlo simulation validation and extrapolation to jets

Other goals are to test

- detector operation
- electronics
- software framework



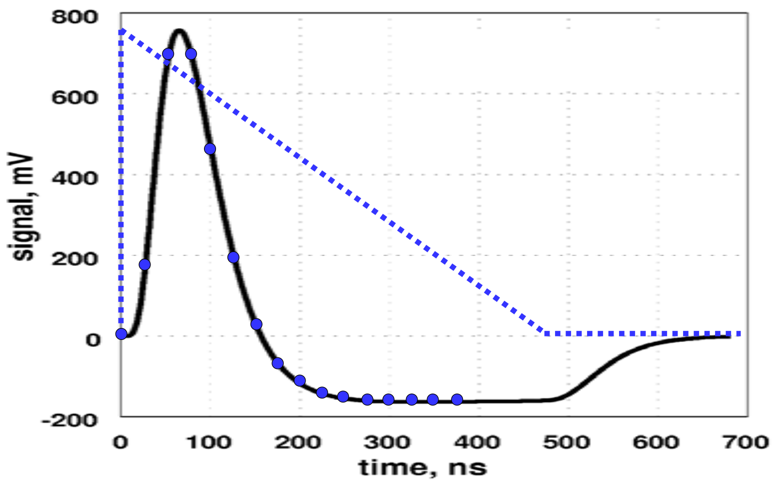
Signal reconstruction

Optimal filtering

- need known physics signal shape $g(t)$
- discrete (Δt = 25 ns) measurements (signal + noise): $y_i = Sg_i + b_i$
- autocorrelation matrix from noise runs: $B_{ij} = \langle b_i b_j \rangle - \langle b_i \rangle \langle b_j \rangle$
- estimate signal amplitude S with $\tilde{S} = \sum a_i y_i = \mathbf{a}^{\mathrm{T}}\mathbf{y}$
- minimize $\chi^2(\tilde{S}) = (\mathbf{y} - S\mathbf{g})^{\mathrm{T}} \mathbf{B}^{-1} (\mathbf{y} - S\mathbf{g})$
- solution is given by the optimal filtering weights $\mathbf{a} = \dfrac{\mathbf{B}^{-1}\mathbf{g}}{\mathbf{g}^{\mathrm{T}}\mathbf{B}^{-1}\mathbf{g}}$

Signal shape

- obtained directly from data
- or obtained from calibration pulses and detailed knowledge of difference between signal pulse shape and calibration pulse shape

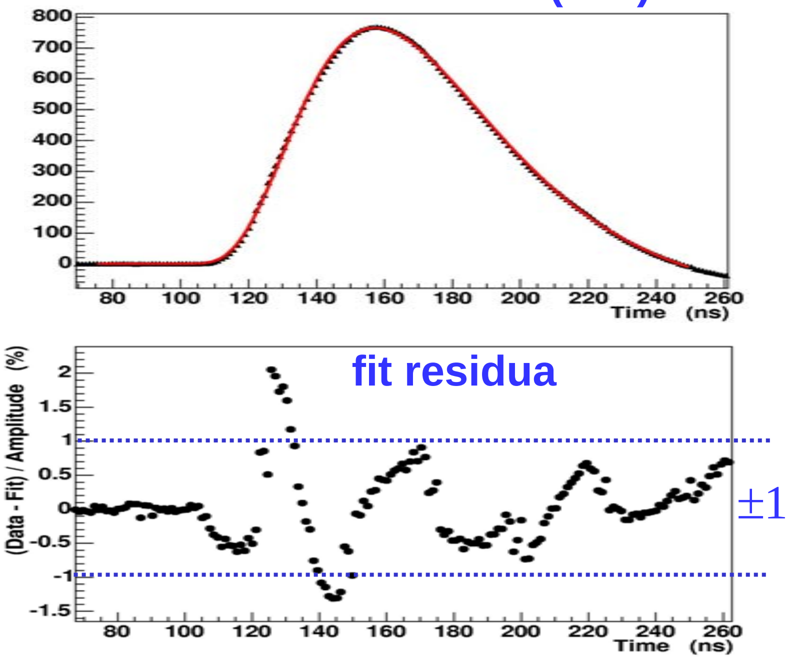


HEC calibration: ADC to nA

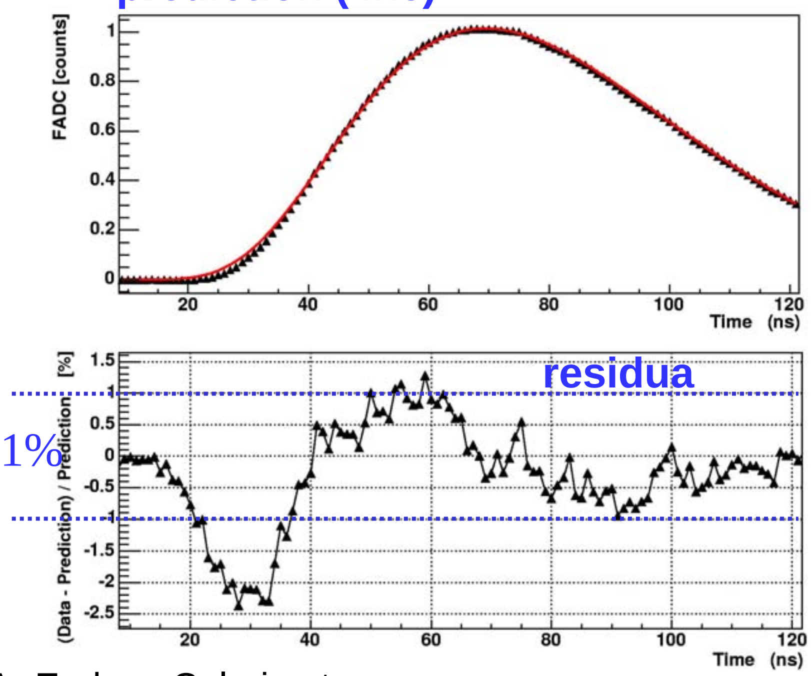
Calibration pulse height

- crucial to understand the channel-by-channel variation in the difference in pulse height and shape between data and calibration signals
- electronics modeling
- predict signal pulse from calibration pulse to about 1%

calibration signal (points)
electronics function fit (line)

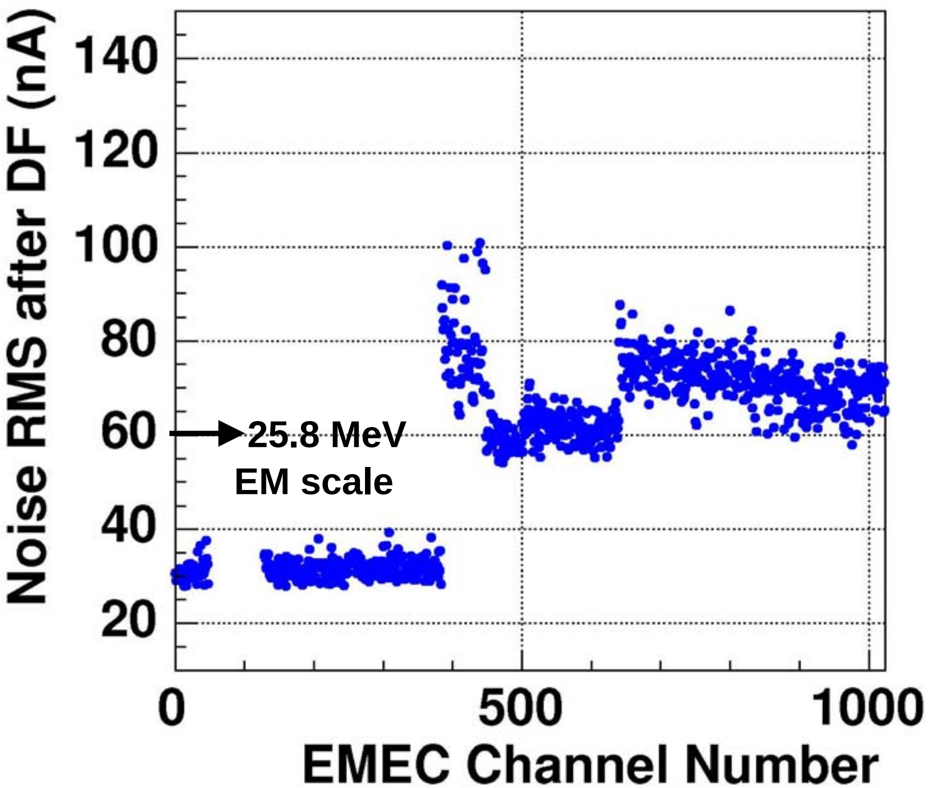


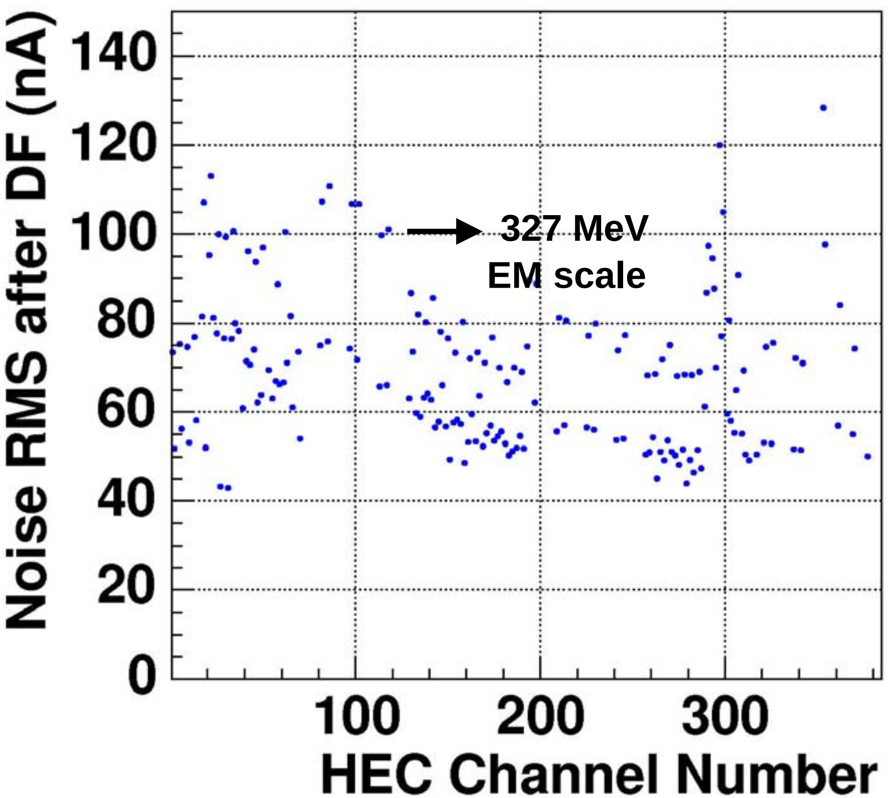
data signal (points)
prediction (line)



Electronic noise

- Electronic noise obtain directly from data
  - EMEC: use muon data and remove hit cells
  - HEC: use first 5 time samples (which are out of signal region)

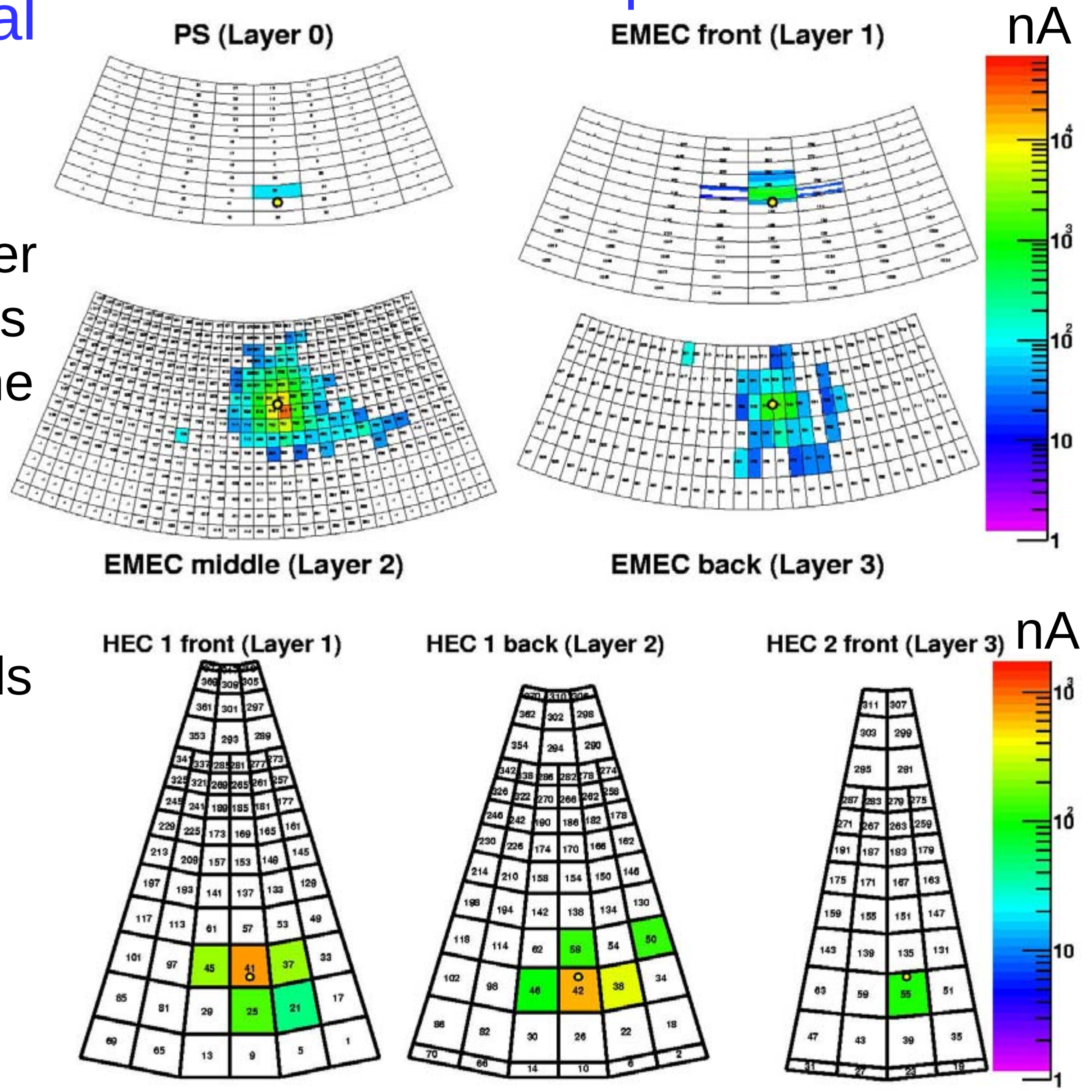




Clustering

180 GeV pion

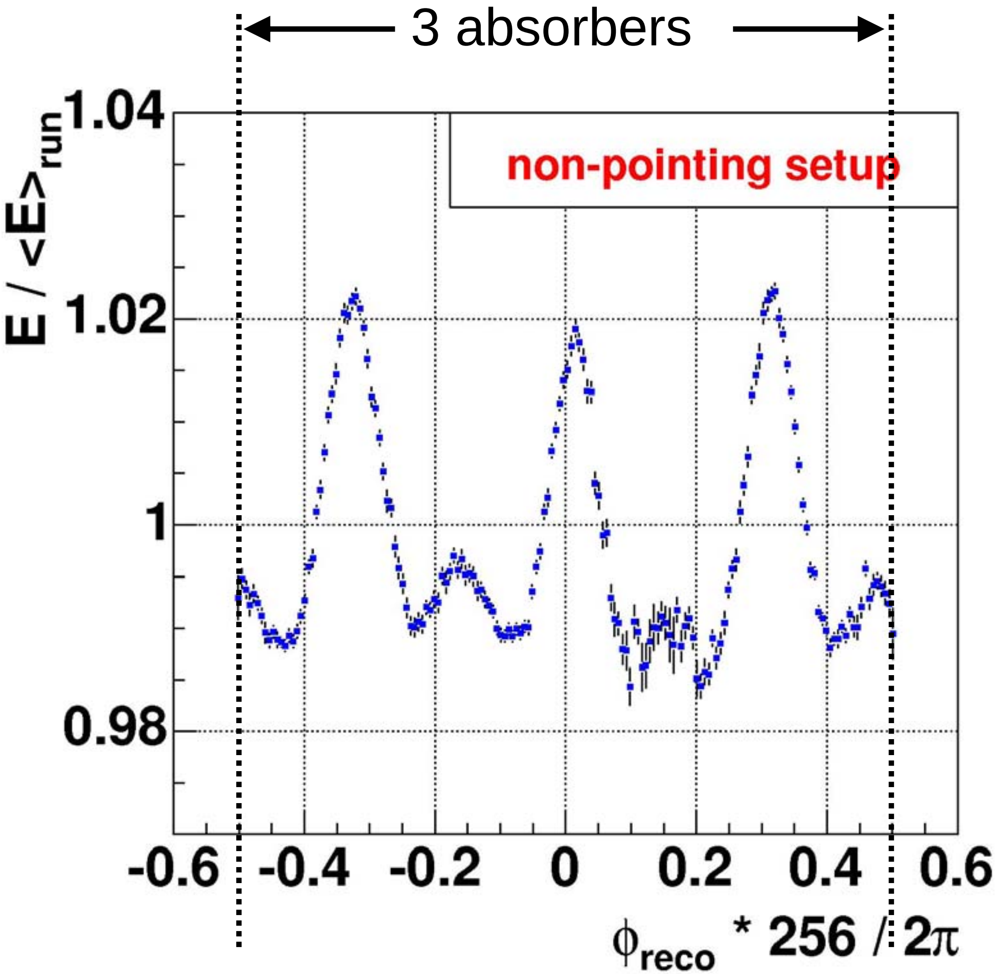
- Cell-based topological nearest neighbor cluster algorithm
  - clusters are formed per layer using neighbours (that share at least one corner)
  - $E_{seed} > 4\sigma_{noise}$
  - $|E_{cell}| > 2\sigma_{noise}$
  - include neighbour cells with $|E_{cell}| > 3\sigma_{noise}$



Electrons: geometrical corrections

- φ-dependent correction required
  - electric field and sampling fraction non-uniformities
  - non-pointing setup
  - well understood

- Other smaller η-dependent corrections neglected in this analysis



Electrons: EMEC electromagnetic scale

- Needed as reference for hadronic calibration
- Obtained from beam test data

$$E_{\text{beam}} = E_{\text{dep}} + E_{\text{leak}} = \langle E_{\text{reco}} \rangle + \langle E_{\text{leak}} \rangle$$

where $E_{\text{reco}} = E_{\text{em}}^{\text{EMEC}} \equiv \alpha_{\text{em}}^{\text{EMEC}} I_{\text{vis}}^{\text{EMEC}}$

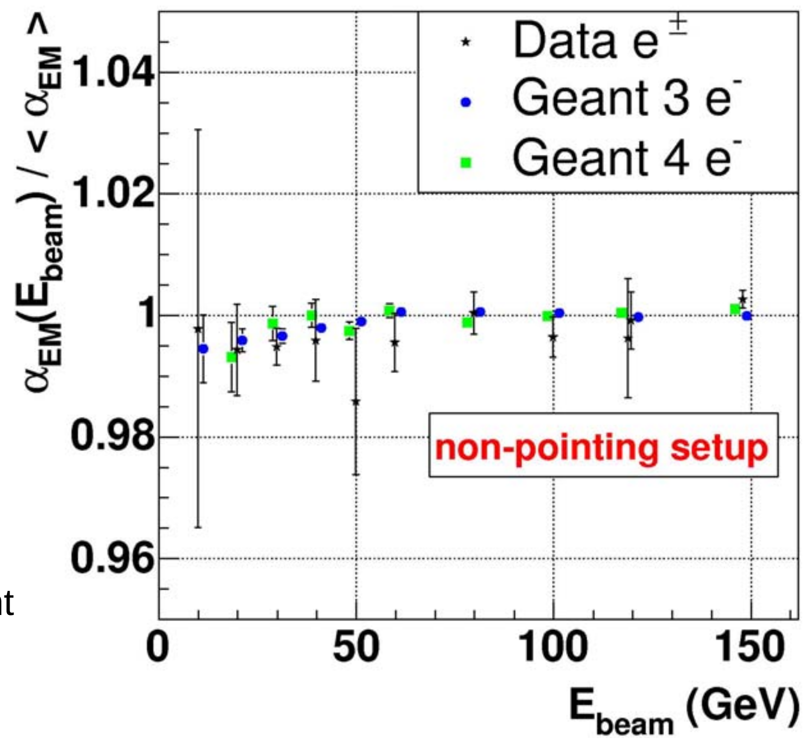
The leakage is only outside the cluster, hence measurable. It is < 3% for E_{beam} > 30 GeV

$$\alpha_{\text{em}}^{\text{EMEC}} = \frac{E_{\text{beam}} - \langle E_{\text{leak}} \rangle}{\langle I_{\text{vis}}^{\text{EMEC}} \rangle}$$

$$= (0.430 \pm 0.001 \pm 0.009) \ \text{MeV/nA}$$

signal shape uncertainties and η dependent corrections which have not been applied

Include ≈ 2% φ-dependent geometrical response corrections



Linearity better than ±0.5%

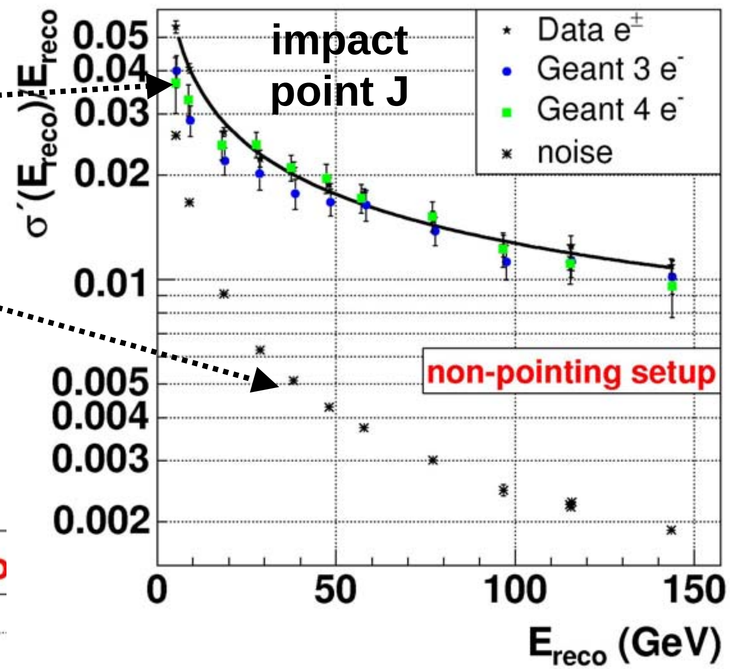
- MC simulation: See D. Salihagic's talk

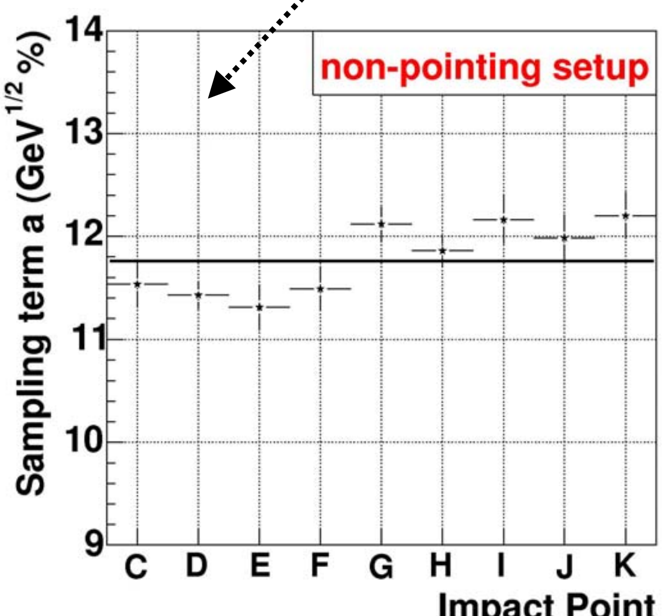
Electrons: energy resolution

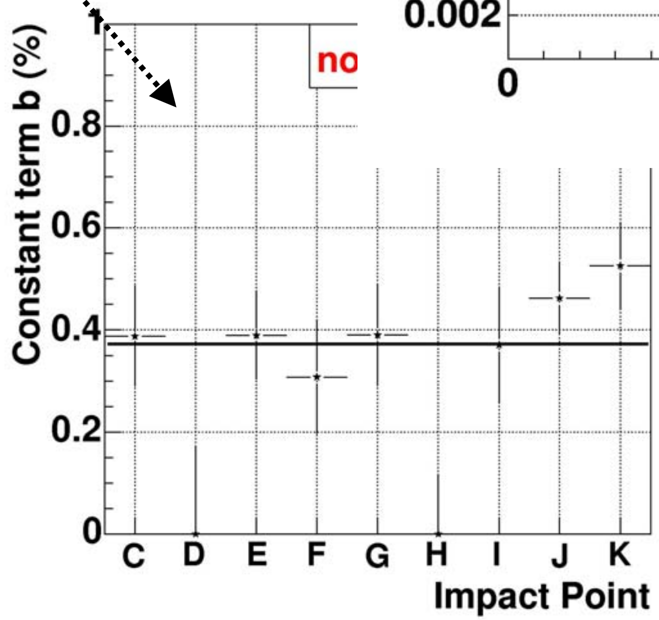
$$E_{\text{reco}} = E_{\text{em}}^{\text{EMEC}} = \alpha_{\text{em}}^{\text{EMEC}} I_{\text{vis}}^{\text{EMEC}}$$

$$\sigma\left(E_{\text{reco}}\right) = \sigma'\left(E_{\text{reco}}\right) \oplus \sigma_{\text{noise}}$$

$$\frac{\sigma'\left(E_{\text{reco}}\right)}{\left\langle E_{\text{reco}} \right\rangle} = \frac{a}{\sqrt{E_{\text{reco}}}} \oplus b$$







Note: non-pointing setup!!

possibly some η dependence, due to η variation of sampling fraction and weak η dependence of electric field

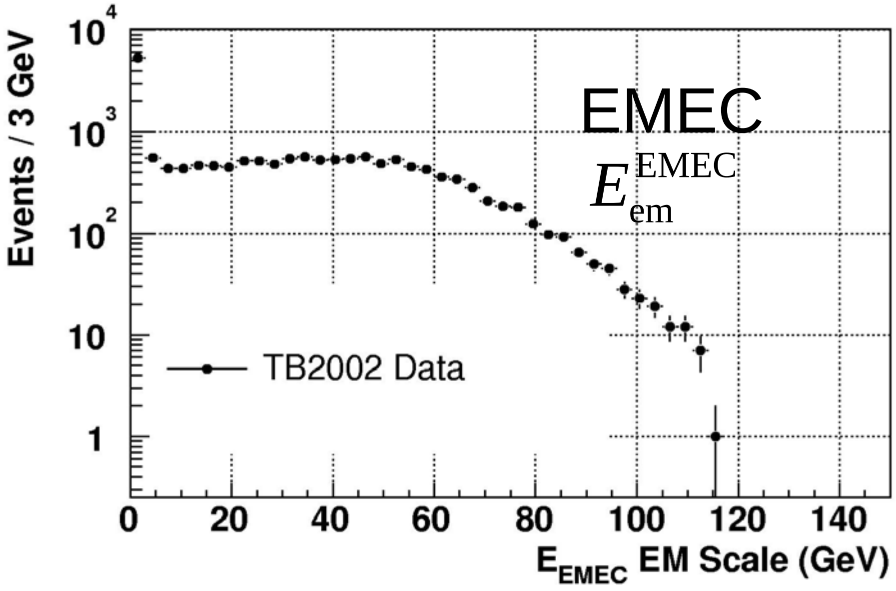
Pions: response

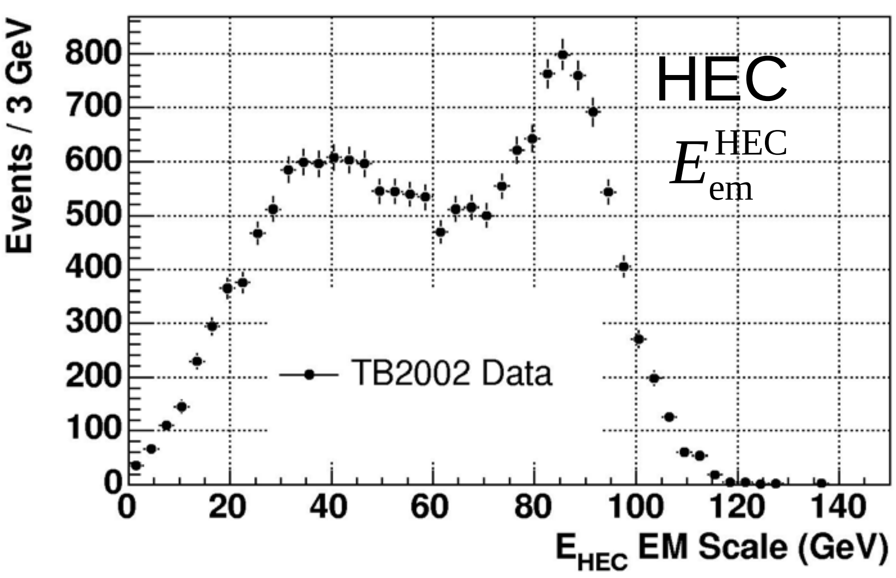
- Use HEC EM scale from previous TB, modified by new electronics, and EMEC EM scale obtained here

$$\alpha_{em}^{EMEC} = (0.430 \pm 0.001 \pm 0.009) \text{ MeV/nA} \qquad E_{em}^{EMEC} \equiv \alpha_{em}^{EMEC} I_{vis}^{EMEC}$$

$$\alpha_{em}^{HEC} = (3.27 \pm 0.03 \pm 0.03) \text{ MeV/nA} \qquad E_{em}^{HEC} \equiv \alpha_{em}^{HEC} I_{vis}^{HEC}$$

- Example: 120 GeV pions in EM scale





Pions: cluster weighting

- EMEC and HEC are non-compensating calorimeters
  - corrections (weights) are required (over the EM scale constants)
  - various weighting methods are being investigated
- Cluster weights as a function of EM energy density

$$E_{\text{beam}} = E_{\text{dep}} + E_{\text{leak}} = \langle E_{\text{reco}} \rangle + \langle E_{\text{leak}} \rangle$$

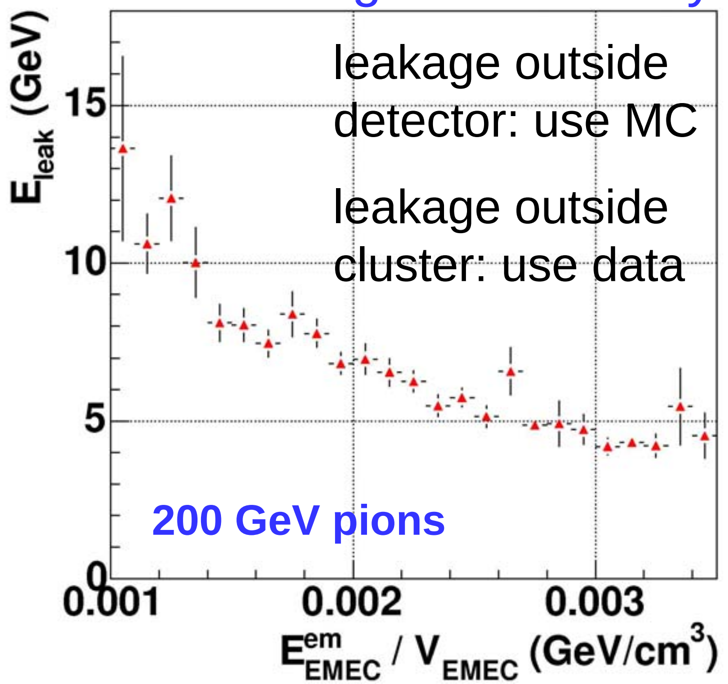
$$E_{\text{reco}} = w^{\text{EMEC}} E_{\text{em}}^{\text{EMEC}} + w^{\text{HEC}} E_{\text{em}}^{\text{HEC}}$$

  - the weights should be obtained from MC... not yet available
  - we consider the (H1) form

$$w = C_1 \exp\left(-C_2 \rho_{\text{em}}\right) + C_3$$

$$\rho_{\text{em}} = \frac{E_{\text{em}}}{V}$$ EM energy over cluster volume

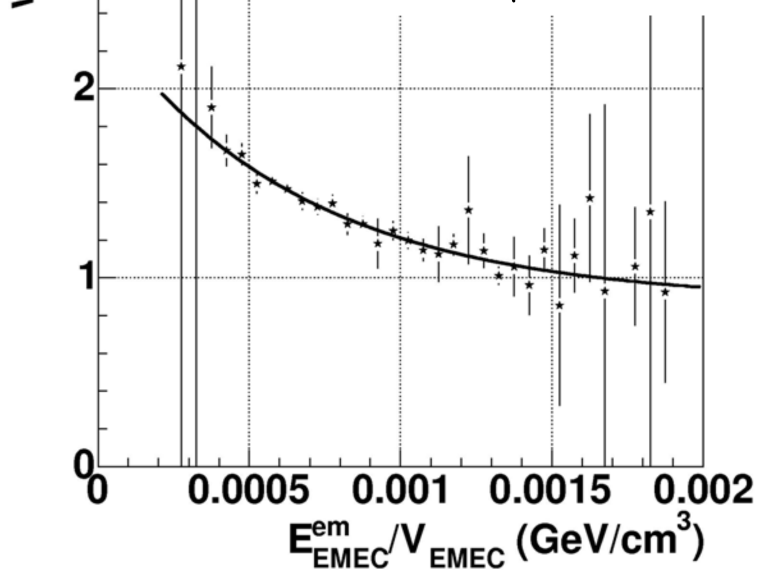
total leakage vs *E* density

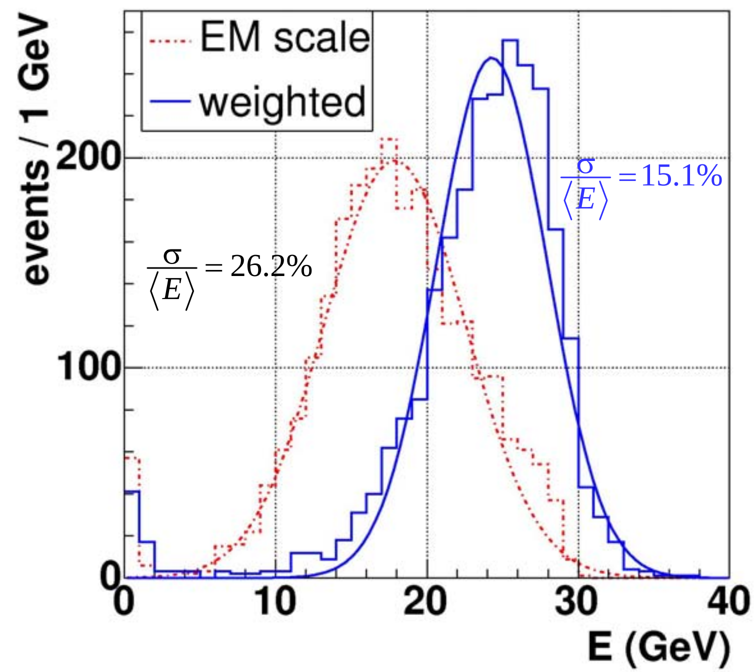


Pions: test of cluster weighting procedure

- 30 GeV pions with no energy deposited in the HEC
  - test the procedure without the need for MC **(except for part of lateral leakage)**
  - only EMEC weights required
  - data agrees well with the proposed weights form

$$w^{\mathrm{EMEC}} = \left\langle \frac{E_{\mathrm{beam}} - E_{\mathrm{leak}}}{E_{\mathrm{em}}^{\mathrm{EMEC}}} \right\rangle$$





Pions: cluster weights

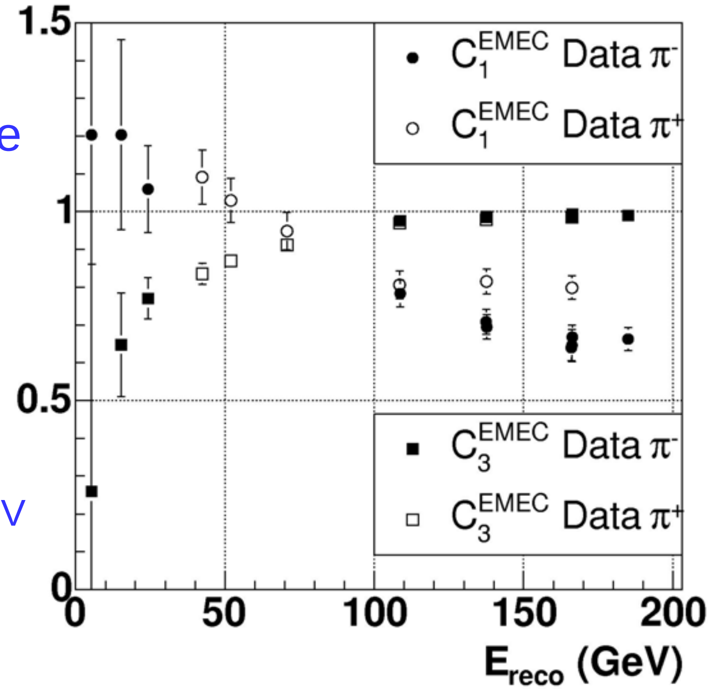
- Obtain weights through the minimization of

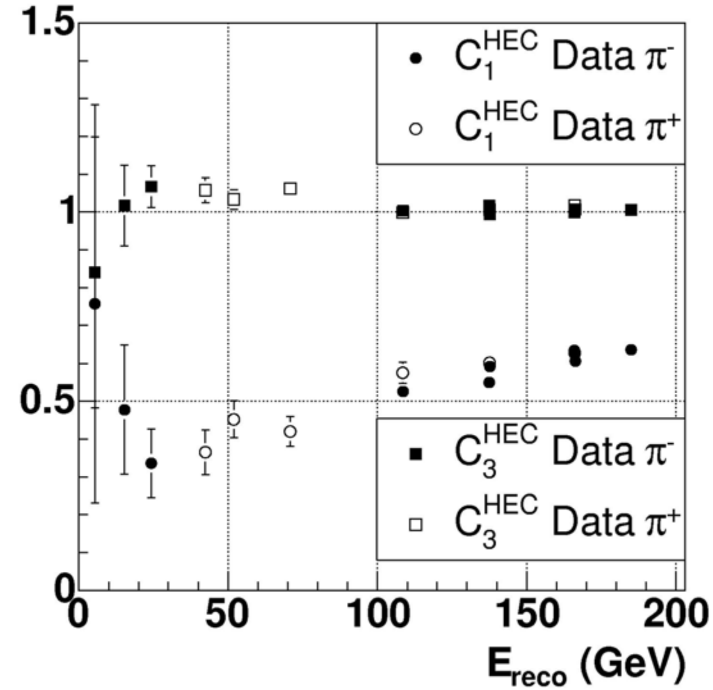
$$\sum_{\text{events}} \left\{ \frac{\left[E_{\text{beam}} - E_{\text{leak}} - E_{\text{reco}}^{\text{EMEC}}\left(\rho_{\text{em}}^{\text{EMEC}}; C_j^{\text{EMEC}}\right) - E_{\text{reco}}^{\text{HEC}}\left(\rho_{\text{em}}^{\text{HEC}}; C_j^{\text{HEC}}\right) \right]}{\sigma_{\text{noise}}} \right\}^2$$

where σ_{noise} is the total electronics noise; cluster noise and electronics noise contribution to the leakage estimate

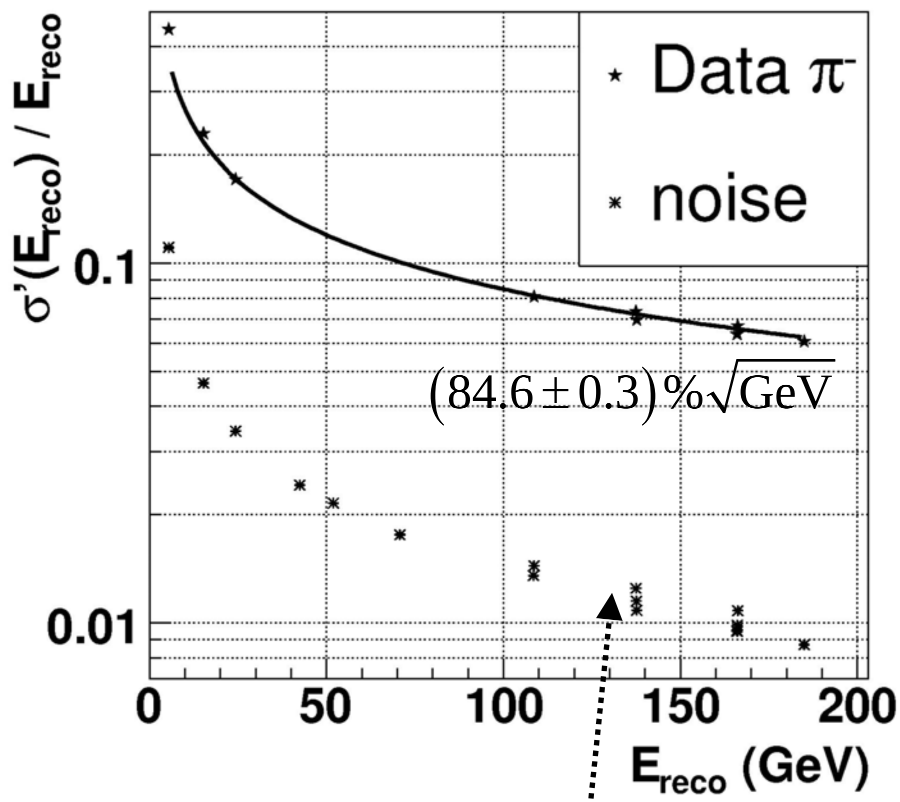
Energy dependence of weights

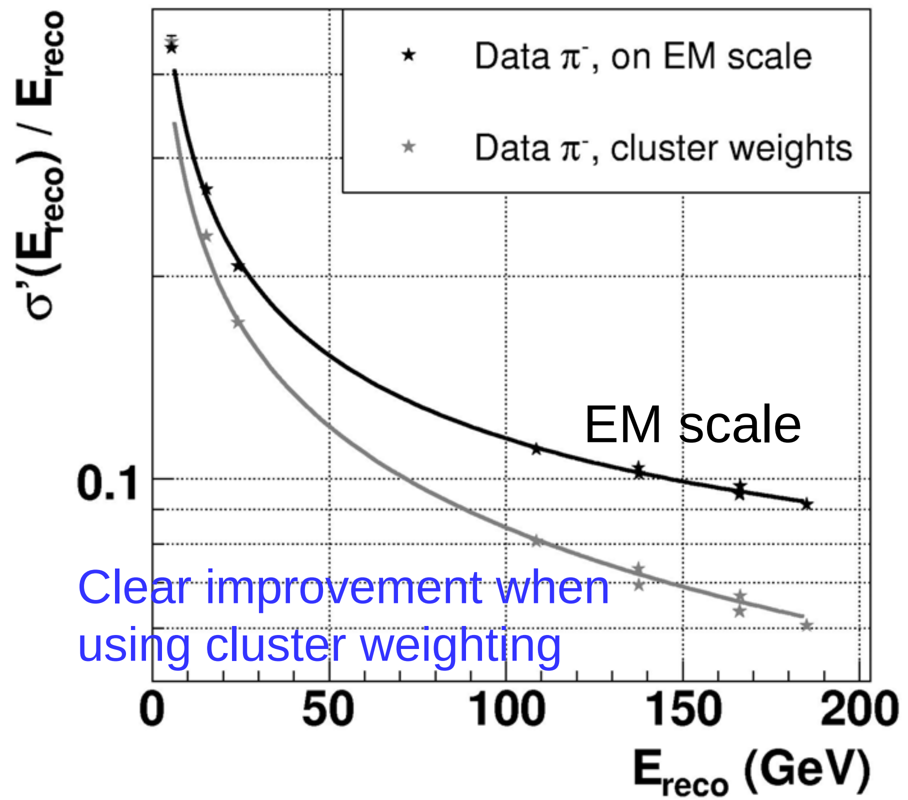
C_1 and C_2 strongly correlated; C_2 fixed to 1500 cm^3/GeV





Pions: energy resolution





$$\sigma(E_{\mathrm{reco}}) = \sigma'(E_{\mathrm{reco}}) \oplus \sigma_{\mathrm{noise}}$$

$$\frac{\sigma'(E_{\mathrm{reco}})}{\langle E_{\mathrm{reco}} \rangle} = \frac{a}{\sqrt{E_{\mathrm{reco}}}} \oplus b$$

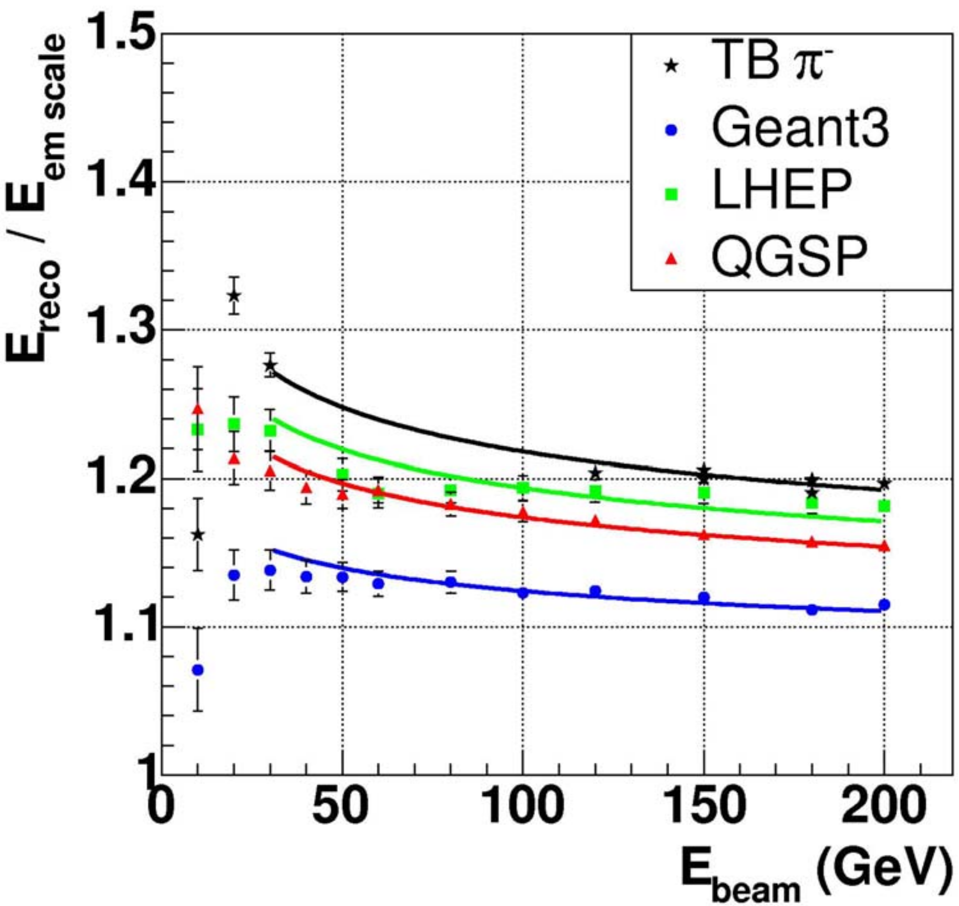
constant term compatible with zero

- Weighting also attempted at cell level: similar results

Pions: e/π ratio

- **Effective e/π ratio**
  - obtained from the cluster weighting function
  - composite calorimeter: e/h has no direct interpretation... with this warning:
  - π^{-}: e/h = 1.69 ± 0.1
    using Groom's with E_o' = 1 GeV and m = 0.85
- **MC simulation: See D. Salihagic's talk**

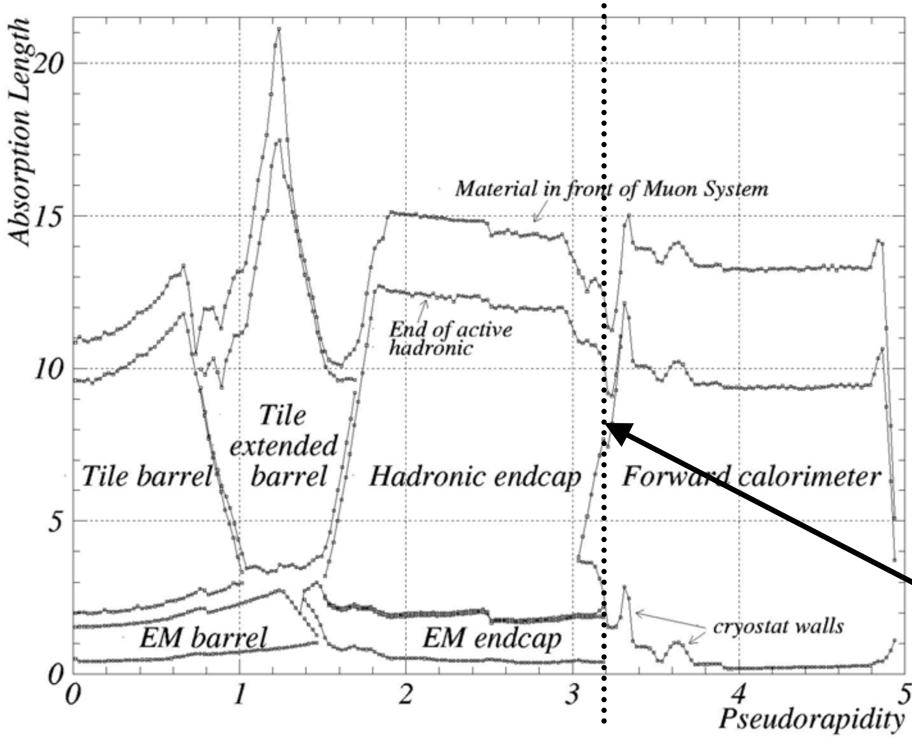
$$\left.\frac{e}{\pi}\right|_{\text{effective}} = \left\langle \frac{E_{\text{reco}}}{E_{\text{em}}^{\text{EMEC}} + E_{\text{em}}^{\text{HEC}}} \right\rangle$$

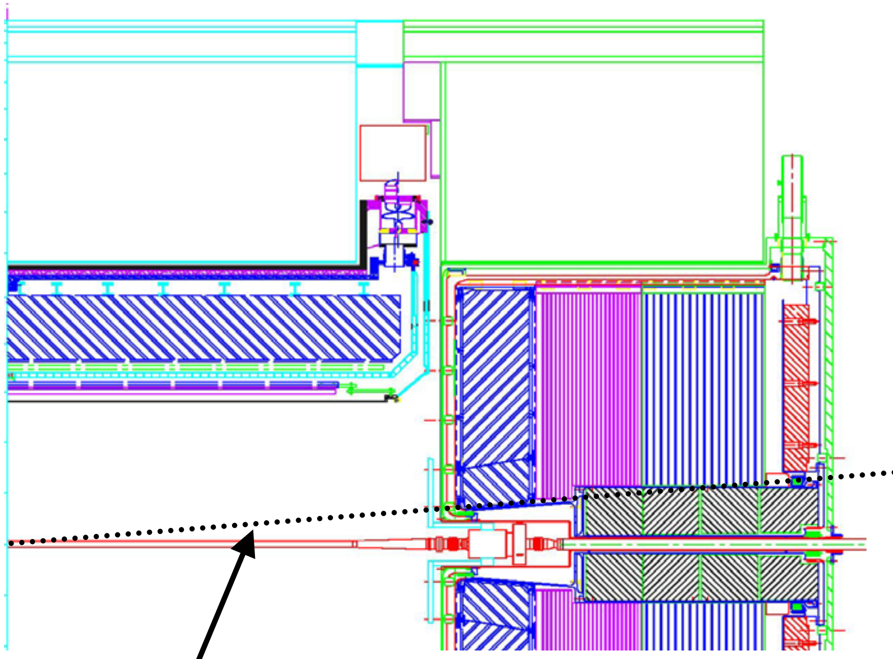


2004 HEC-EMEC-FCAL beam test

- Address the |η| interface region

absorption length budget

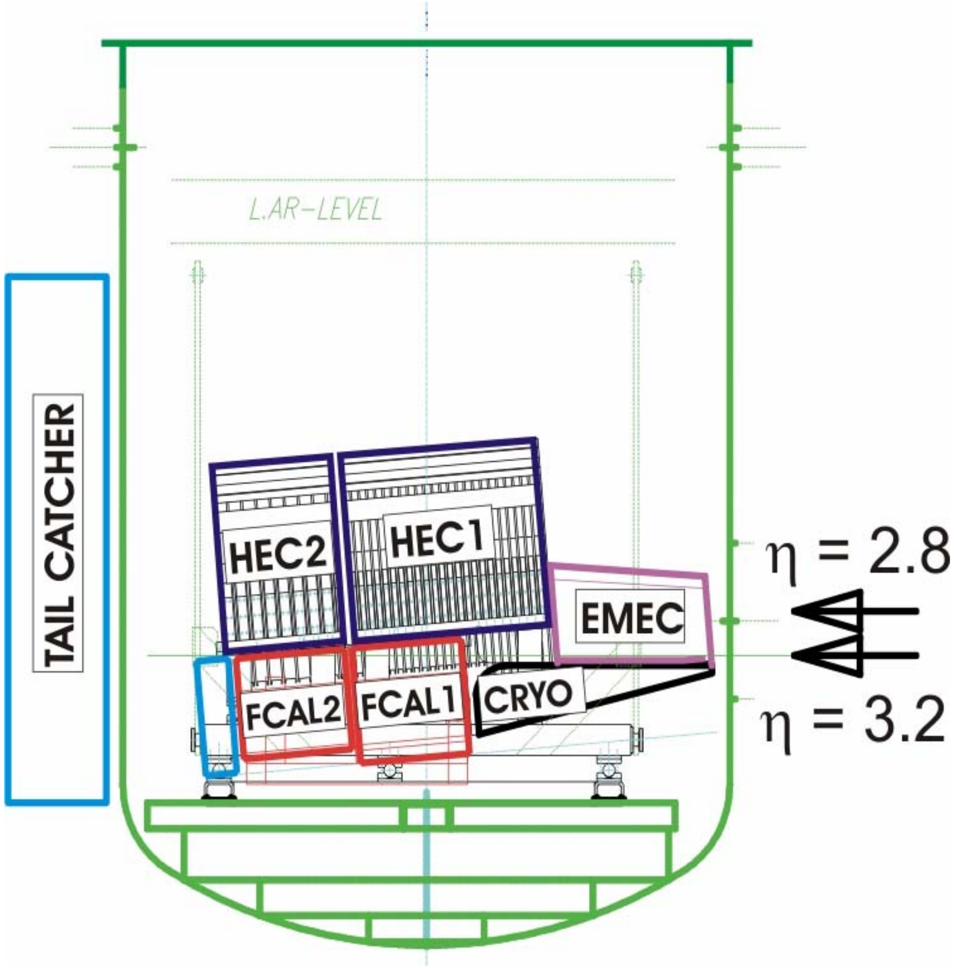




interface around |η| ≈ 3.2

2004 HEC-EMEC-FCAL beam test

- Summer 2004 HEC-EMEC-FCAL combined beam test



- Focus on energy reconstruction in the $2.8 < |\eta| < 3.2$ region
  - special mini-HEC modules to fit in test beam cryostat
  - cold and warm tail catchers
  - beam starts in May

Conclusions

- ATLAS LAr EMEC-HEC beam tests, $1.6 < |\eta| < 1.8$
  - $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$ beam with 6 GeV $\leq$ E $\leq$ 200 GeV. Results reported: $e^{\pm}$,$\pi^{\pm}$
- Electronics calibration method to be used in ATLAS
  - optimal filter weights
  - detailed electronic calibration procedure for ADC to nA
  - development of the related software tools
- Test of first steps toward an hadronic calibration strategy
  - clustering; to be improved including 3D clusters and pileup
  - cluster and/or cell weighting
- Remaining calibration tasks
  - use of validated Monte Carlo simulations
  - jet reconstruction and particle identification in jets
- Upcoming HEC-EMEC-FCAL beam tests, $2.8 < |\eta| < 3.2$
  - three-calorimeter forward region