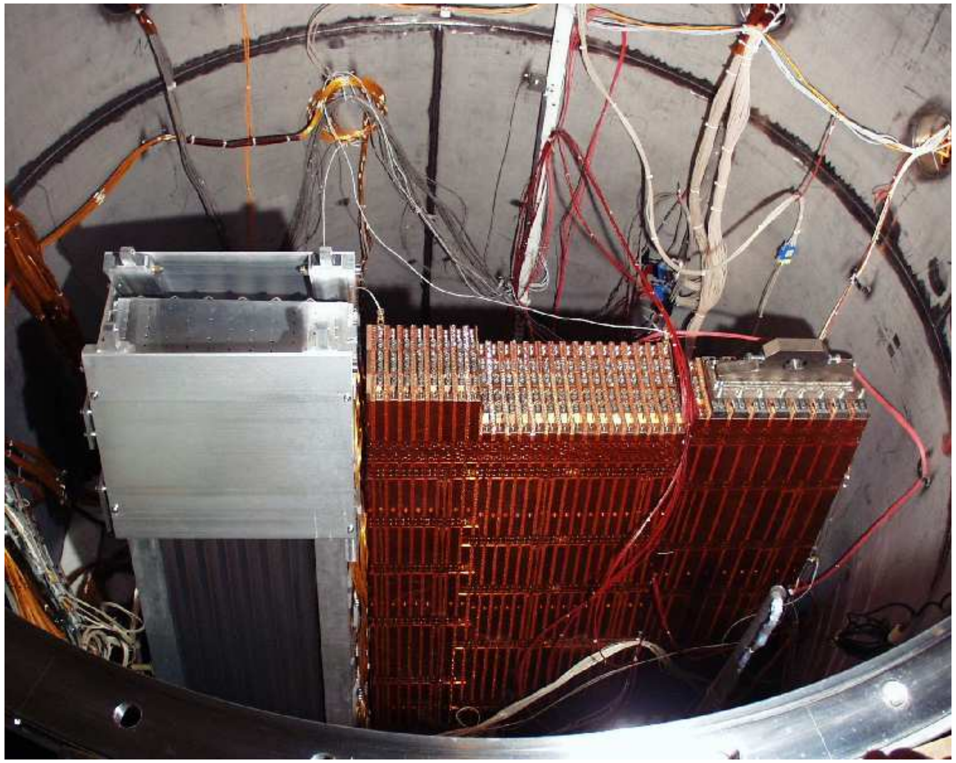
Hadronic Physics Validation with the ATLAS EMEC / HEC Combined Testbeam

- Article (submitted to NIM)
  “Hadronic Calibration of the ATLAS Liquid Argon End-Cap Calorimeter in the Pseudorapidity Region $1.6 < |\eta| < 1.8$ in Beam Tests”
  - pion energy reconstruction at EM-scale
  - pion energy reconstruction with the cluster weighting approach
- Additional analysis of π^+/π^- difference

Combined EMEC / HEC Testbeam (2002)

- Setup:
  - 1 EMEC module
  - 3 HEC1 modules
  - 2 HEC2 half-modules

- Energy/position scans with
  - electrons
  - muons
  - charged pions
    (10 - 200 GeV)



Monte Carlo for the Combined Testbeam

- Geant3
  - version 3.21
  - 100 keV transport and 1 MeV production thresholds
  - GCALOR

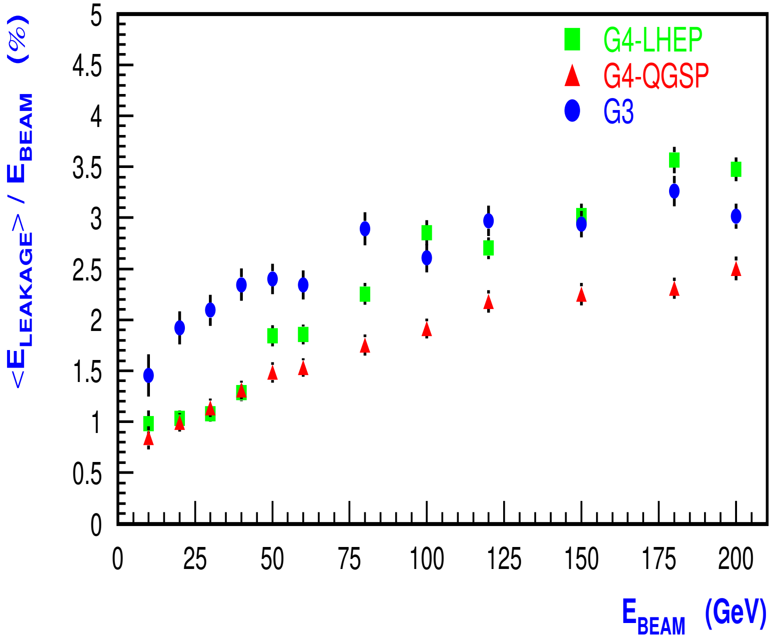
- Geant4
  - version 5.0p1
  - 700 μm range cut
  - hadronic physics lists:
    - LHEP (version 3.3)
    - QGSP (version 2.3)

- “Leakage detectors” — virtual detectors in MC

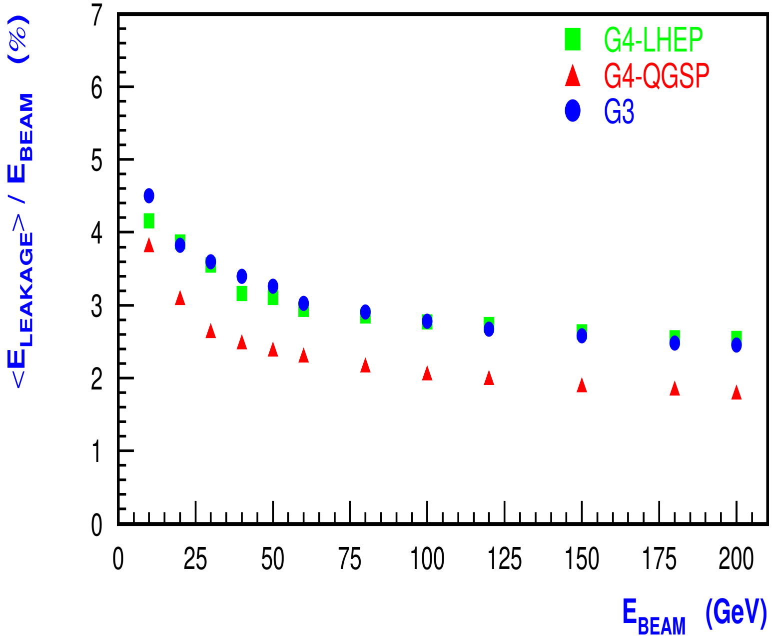
- Experimental and MC data: the same analysis procedure

Hadronic Shower Shapes

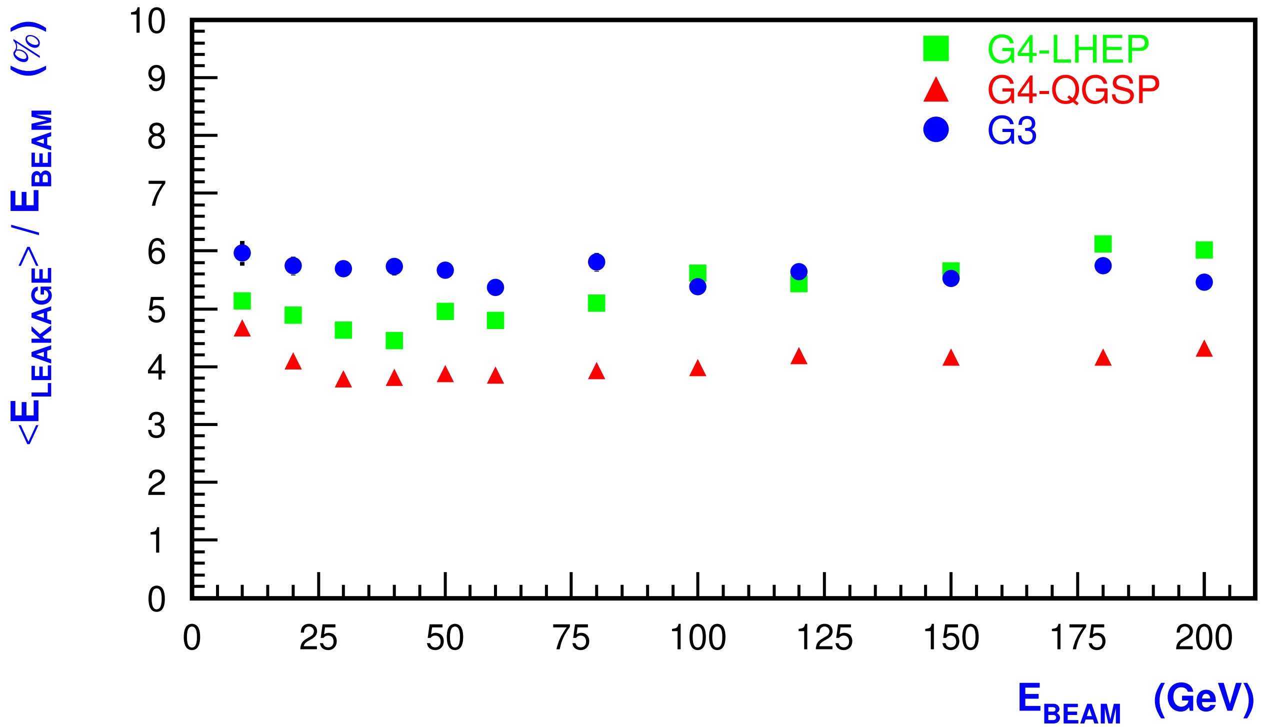
Leakage outside calorimeter modules



Longitudinal leakage



Lateral leakage

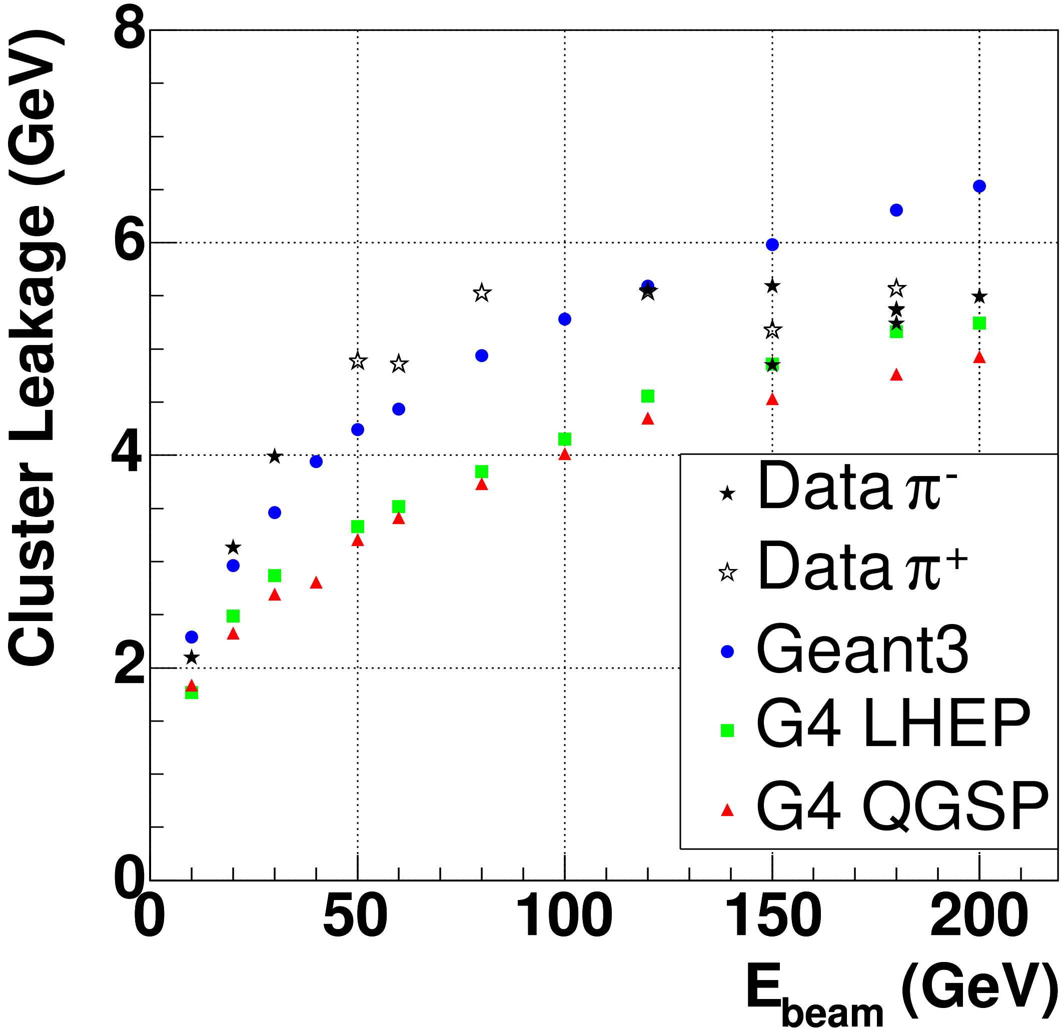


Total leakage outside modules

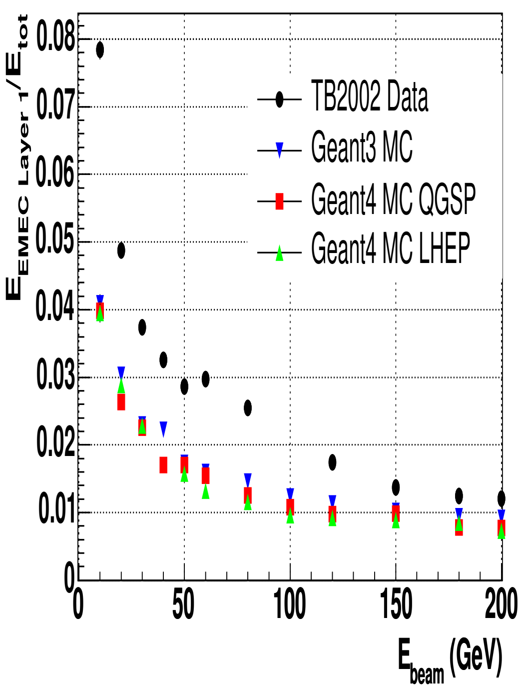
Geant3 ~ 6 % QGSP ~ 4 % LHEP ~ 5 - 6 %

First signal of a different shower shape for different hadron packages! QGSP predicts a more compact shower shape.

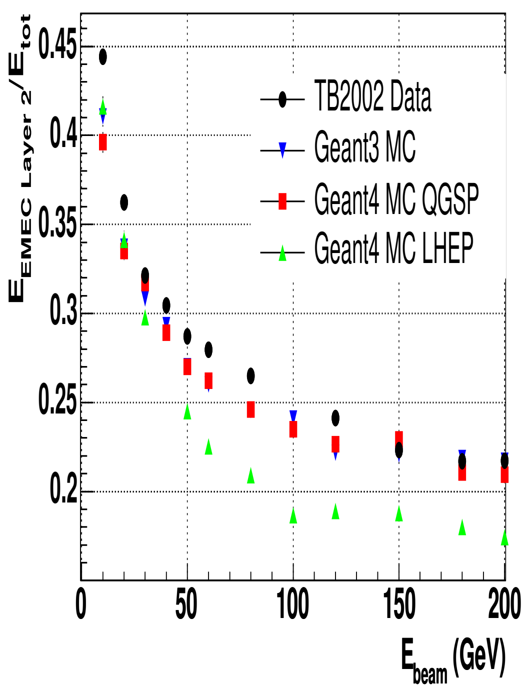
Leakage outside pion clusters



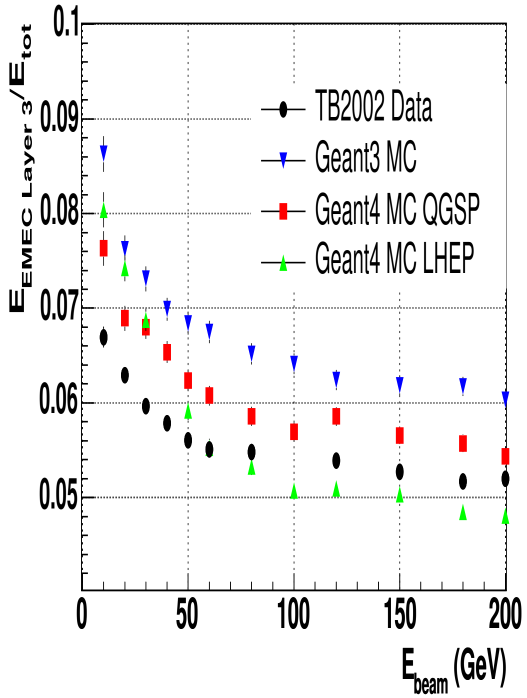
Average energies in EMEC compartments



EMEC 1

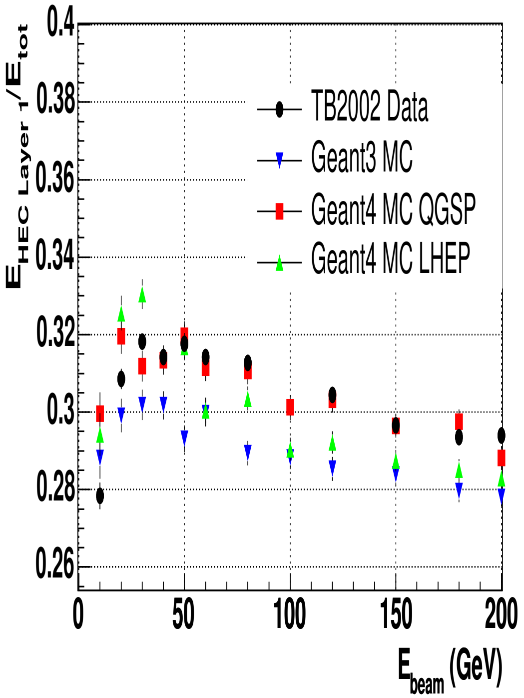


EMEC 2

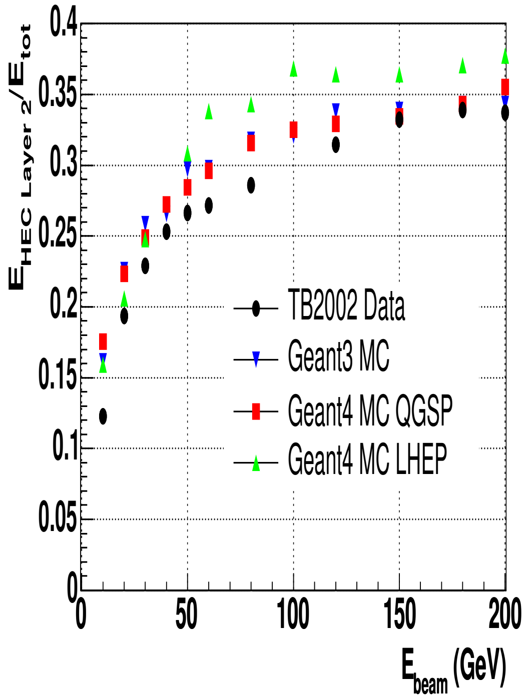


EMEC 3

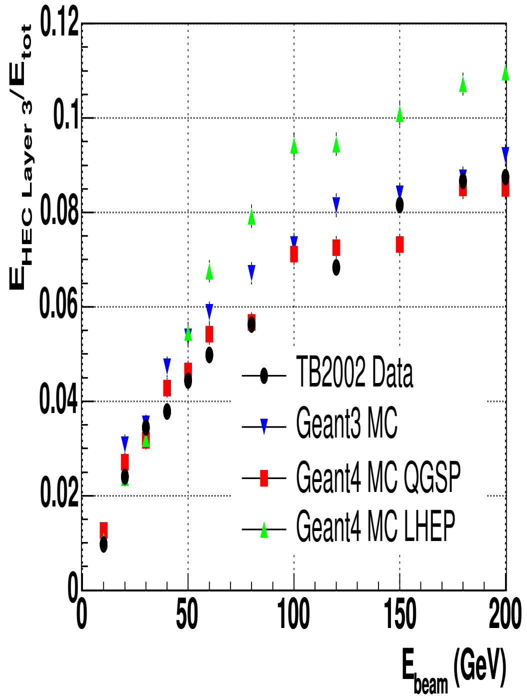
Average energies in HEC layers



HEC layer 1

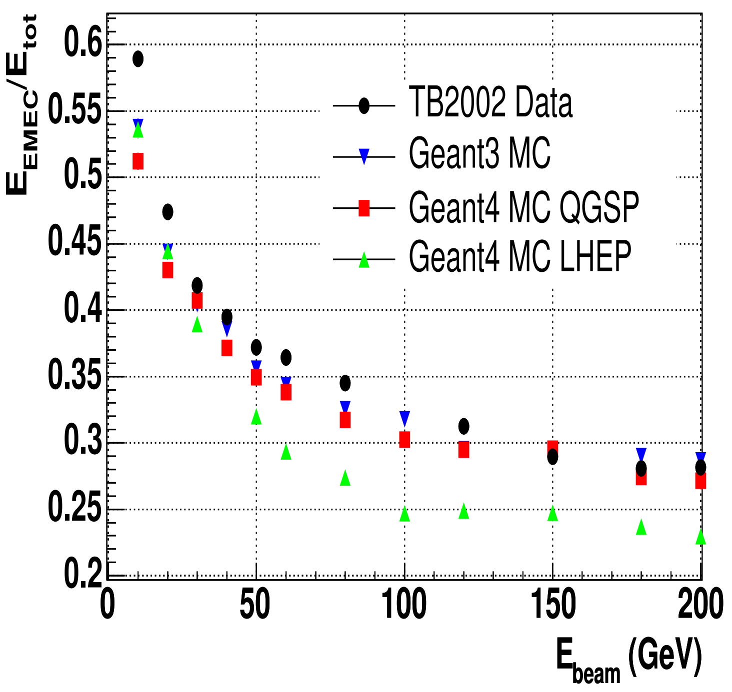


HEC layer 2

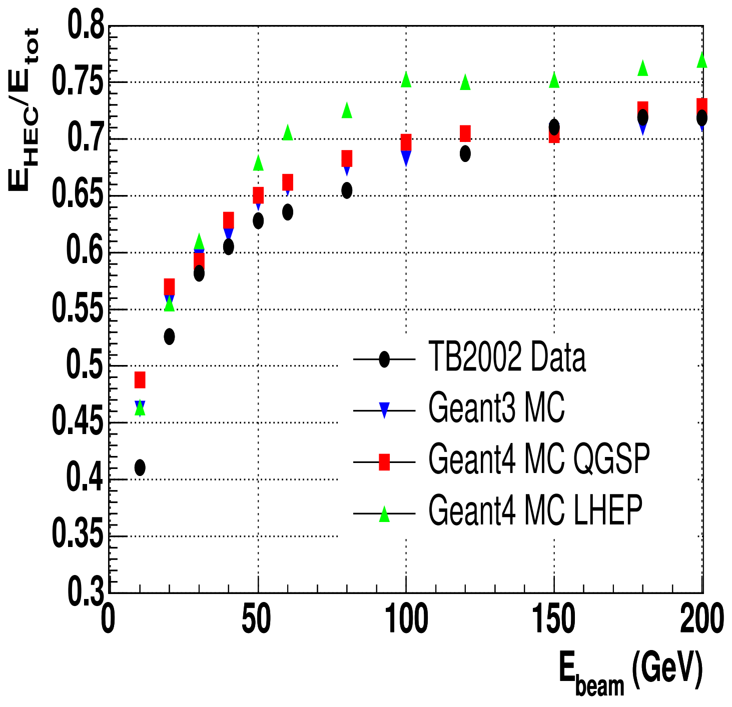


HEC layer 3

Average energies in EMEC and HEC



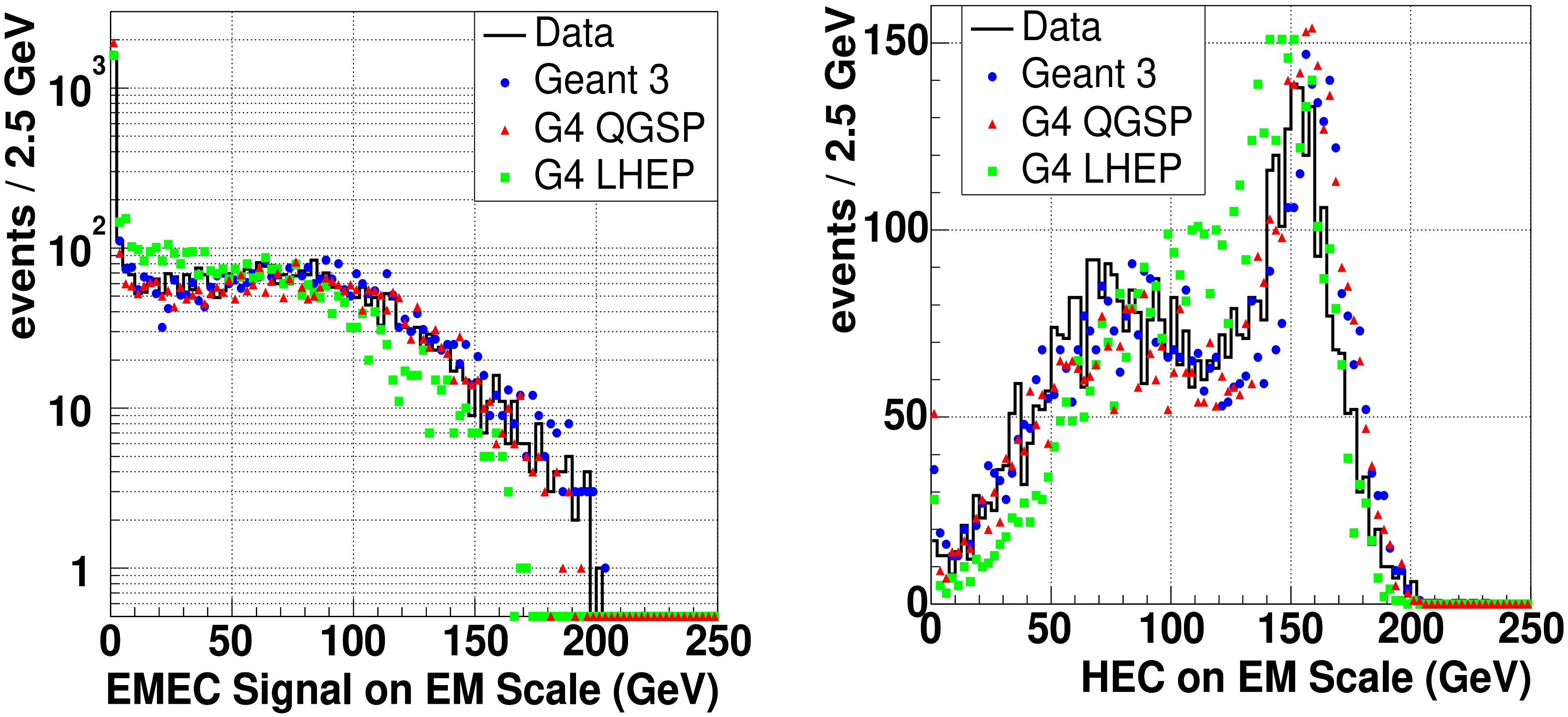
EMEC



HEC

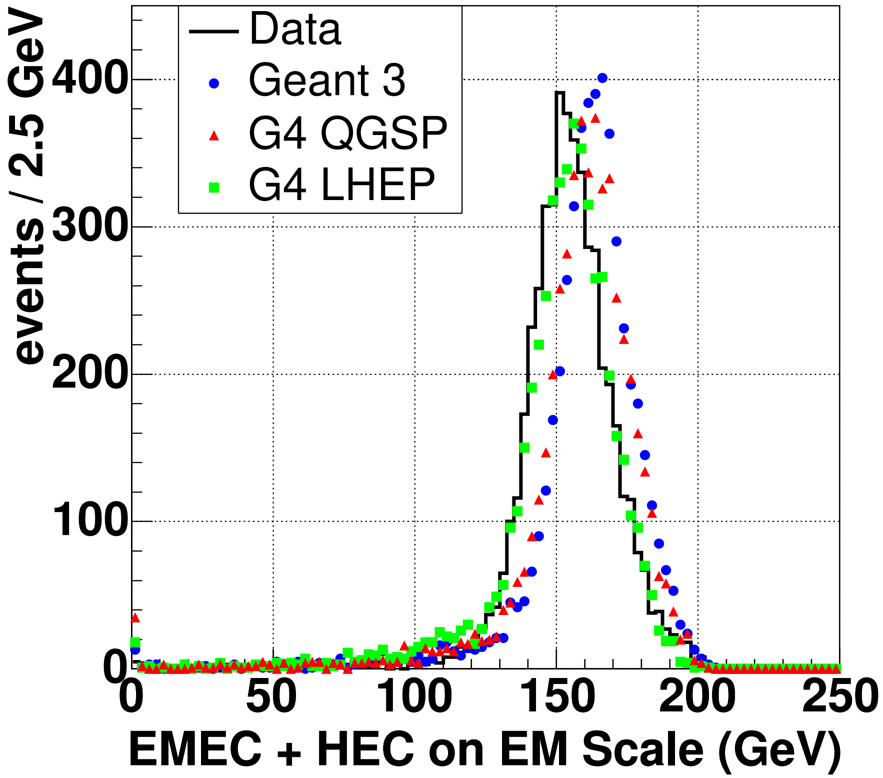
In summary, all together, QGSP and Geant3 describe experimental energy sharing between longitudinal layers better (but not layer-by-layer).

Reconstruction at EM-Scale



200 GeV pions

Both Geant3 and QGSP describe the EMEC and HEC experimental data reasonably well, but



200 GeV pions

LHEP yields the best agreement with data for the total signal.

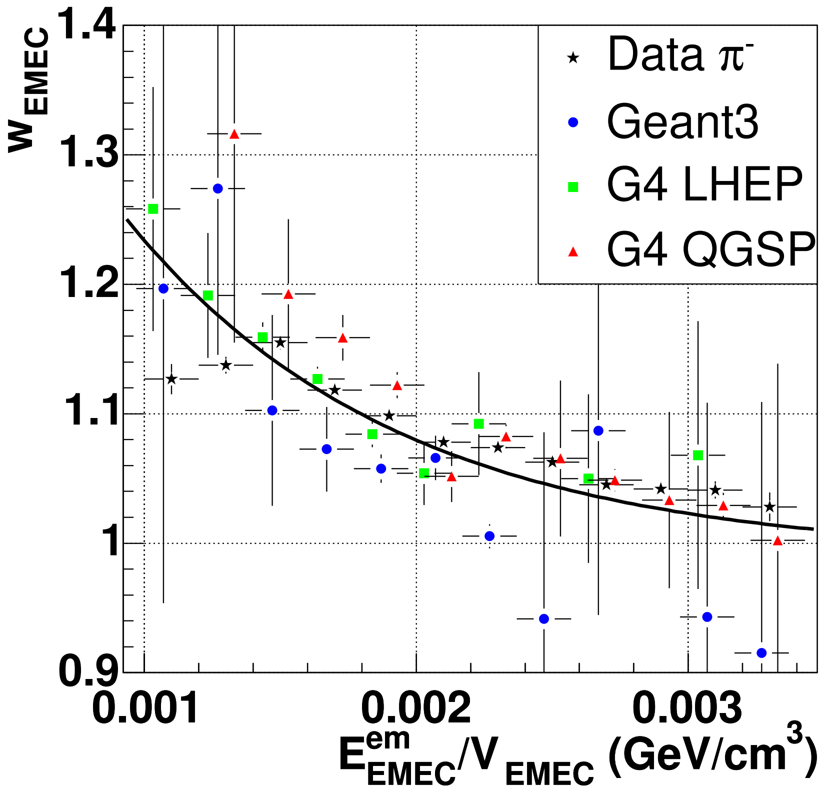
Reconstruction with Cluster Weighting Approach

- Reconstructed energy $E^{\mathrm{reco}} = w \times E$
- Weights $w = C_1 \exp\left(-C_2 \times E/V\right) + C_3$
- χ^2-fit

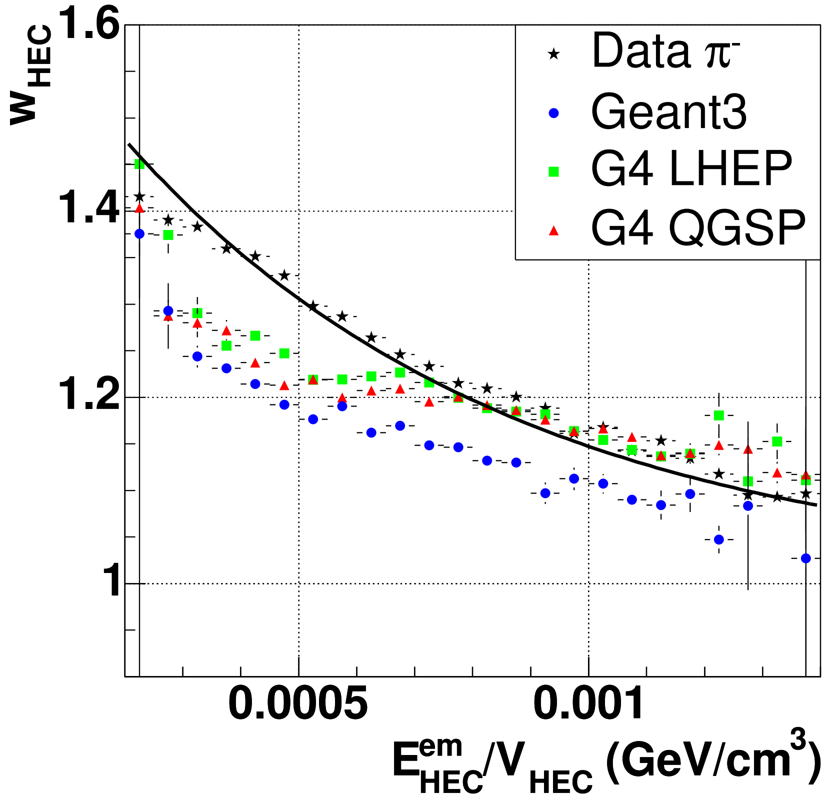
$$\chi^2 = \sum_{\mathrm{events}} \frac{\left[E_{\mathrm{beam}} - E_{\mathrm{leak}} - E^{\mathrm{reco}}_{\mathrm{HEC}}(C^{\mathrm{H}}_1, C^{\mathrm{H}}_2, C^{\mathrm{H}}_3) - E^{\mathrm{reco}}_{\mathrm{EMEC}}(C^{\mathrm{EM}}_1, C^{\mathrm{EM}}_2, C^{\mathrm{EM}}_3)\right]^2}{(\sigma^{\mathrm{reco}}_{\mathrm{noise}})^2 + (\sigma^{\mathrm{leak}}_{\mathrm{noise}})^2}$$

E — cluster energy at EM-scale
V — cluster volume

Cluster weights VS cluster density

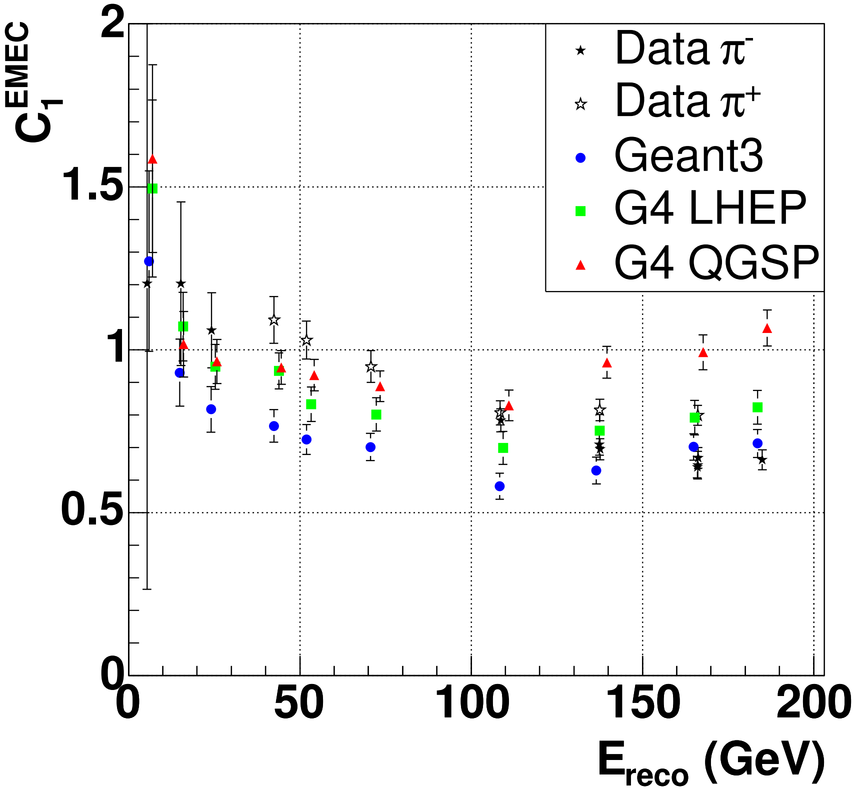


EMEC clusters

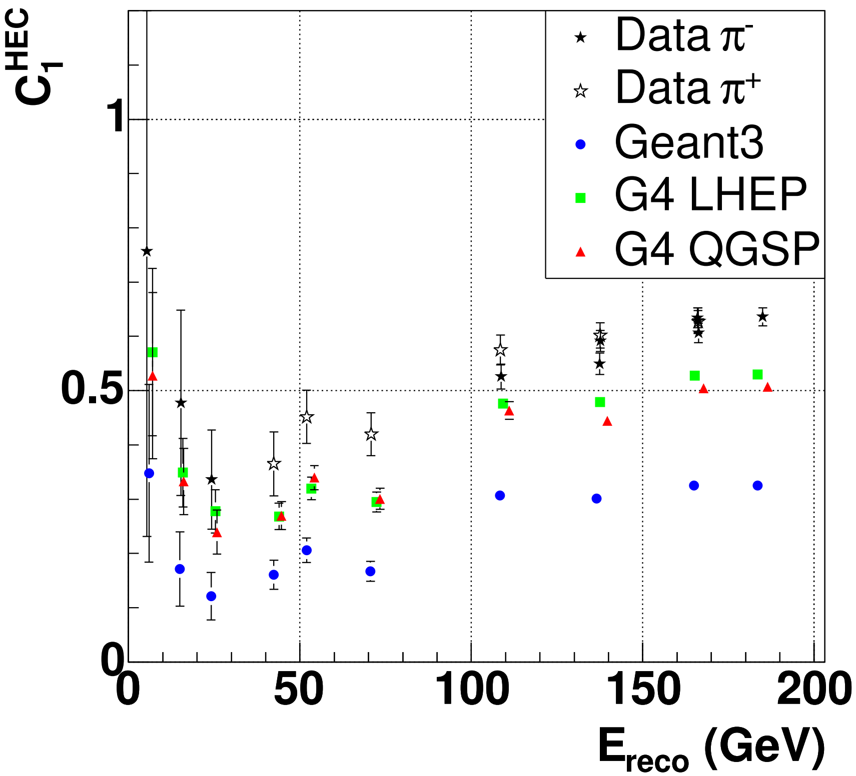


HEC clusters

Weighting parameters

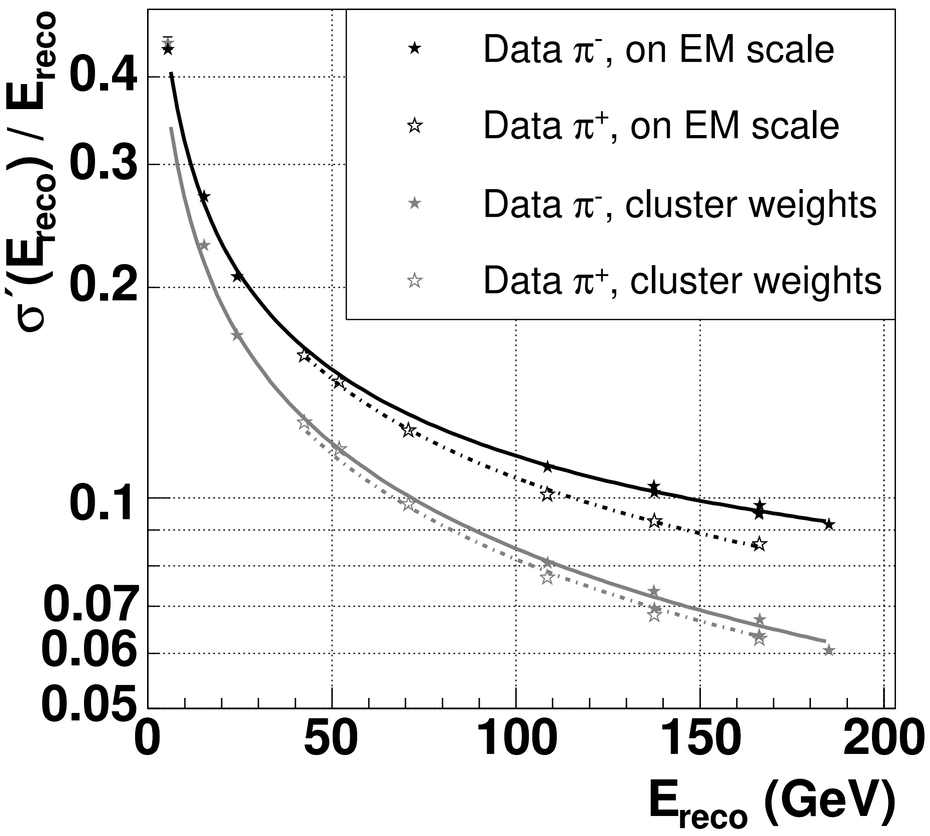


EMEC



HEC

Experimental energy resolution

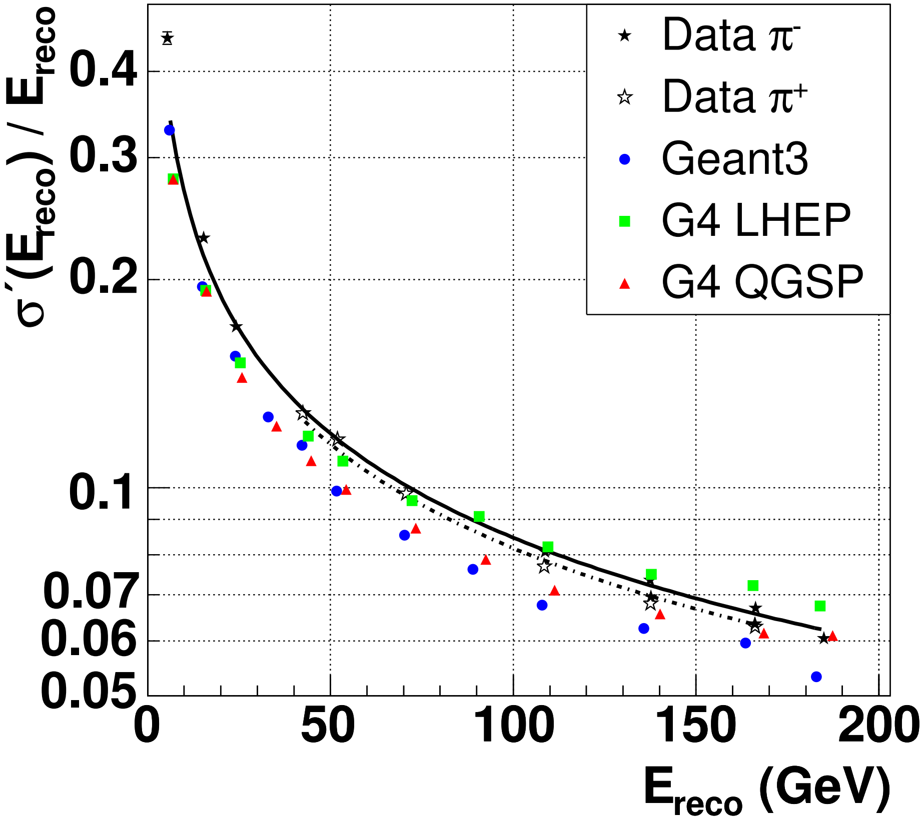


$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus b$$

After weighting

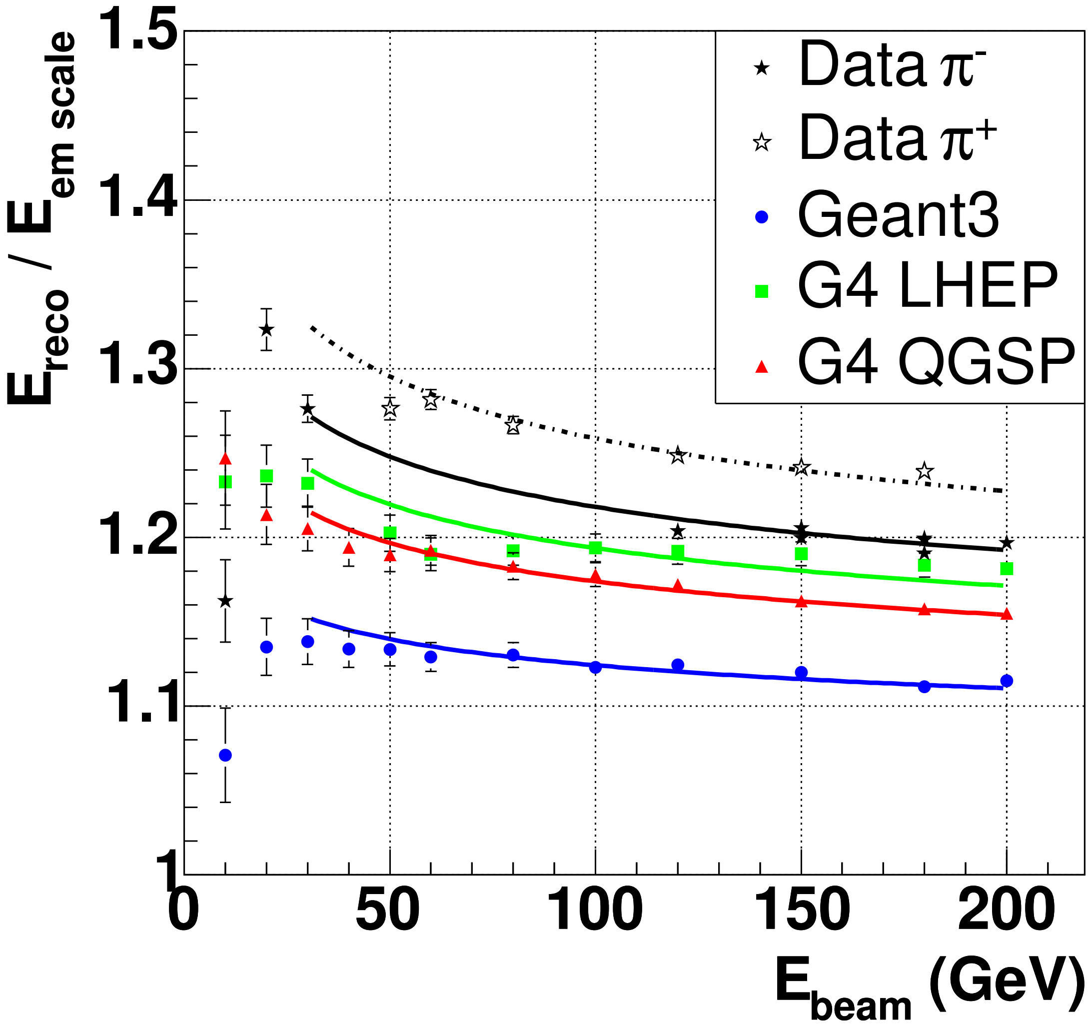
- sampling term a
  - π^- : (84.6±0.3) % $\sqrt{GeV}$
  - π^+ : (81.7±0.4) % $\sqrt{GeV}$
- constant term b — zero within errors

MC energy resolution: negative pions



- Geant3
  - $a = (73.3 \pm 0.5)\ \%\ \sqrt{GeV}$
  - b — zero within errors
- QGSP
  - $a = (72.3 \pm 0.9)\ \%\ \sqrt{GeV}$
  - $b = (2.5 \pm 0.3)\ \%$
- LHEP
  - $a = (74.0 \pm 0.5)\ \%\ \sqrt{GeV}$
  - $b = (4.1 \pm 0.1)\ \%$

Ratio e/π

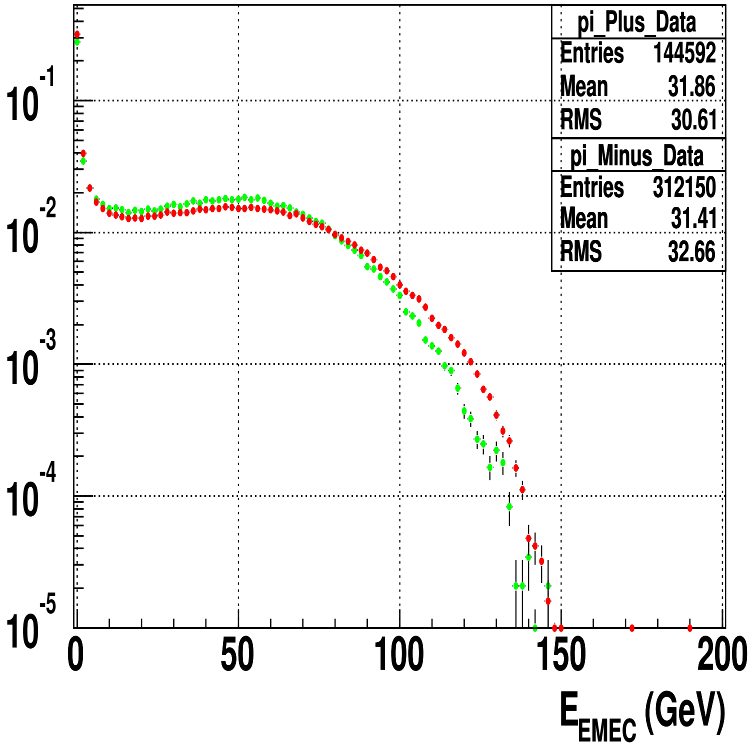


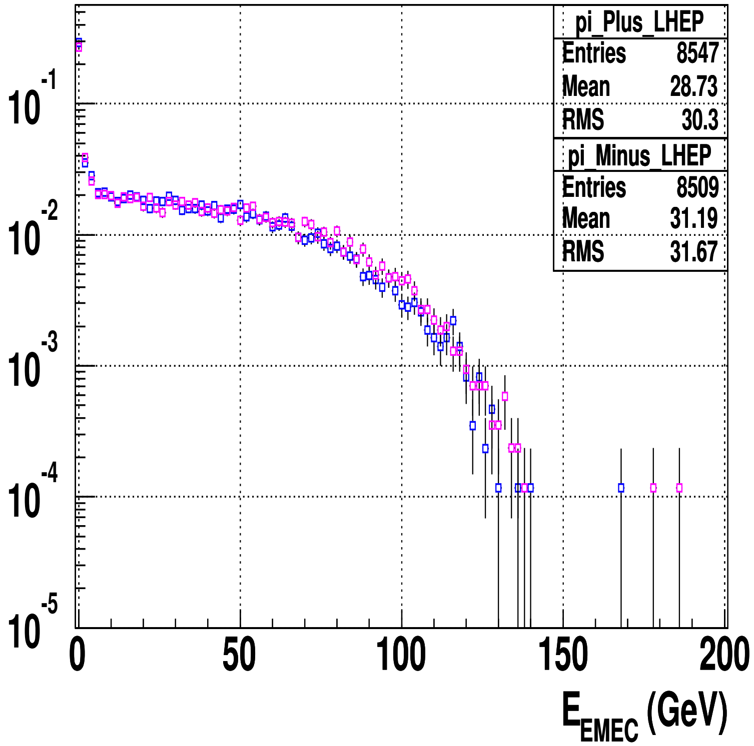
1.5
1.4
1.3
1.2
1.1
1
0
50
100
150
200
E_{reco} / $E_{em\ scale}$
E_{beam} (GeV)
Data π^-
Data π^+
Geant3
G4 LHEP
G4 QGSP

Difference between π^+ and π^-

- Experimental difference:
  - negative pions produce larger signals
  - energy resolution is larger for negative pions
- Simulation of additional MC samples
  - Geant4, version 5.0p1
  - two hadronic physics lists (LHEP and QGSP)
  - charged pions of both signs
- Results for 150 GeV beams

Signals in EMEC

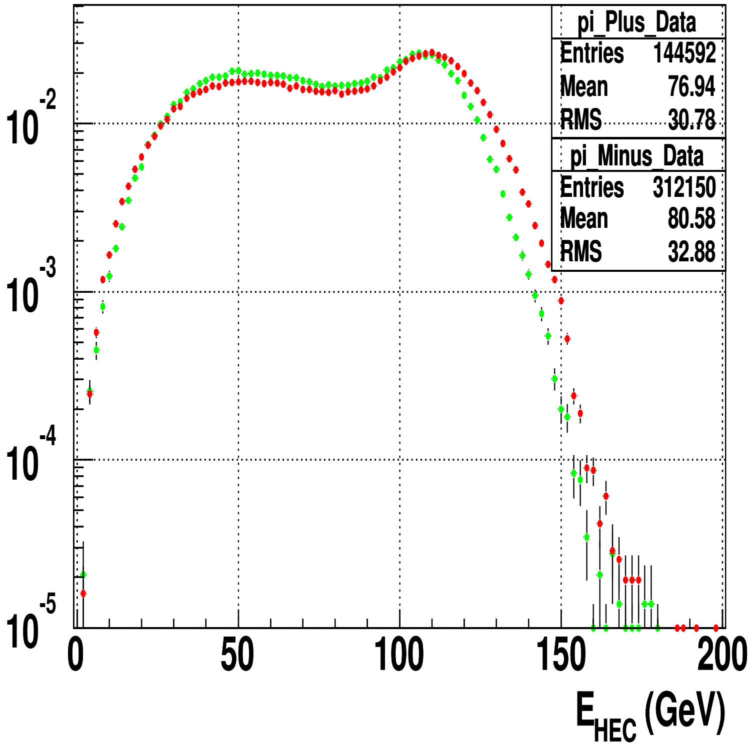




Data
π^+: green dots
π^-: red dots

LHEP
π^+: blue open squares
π^-: pink open squares

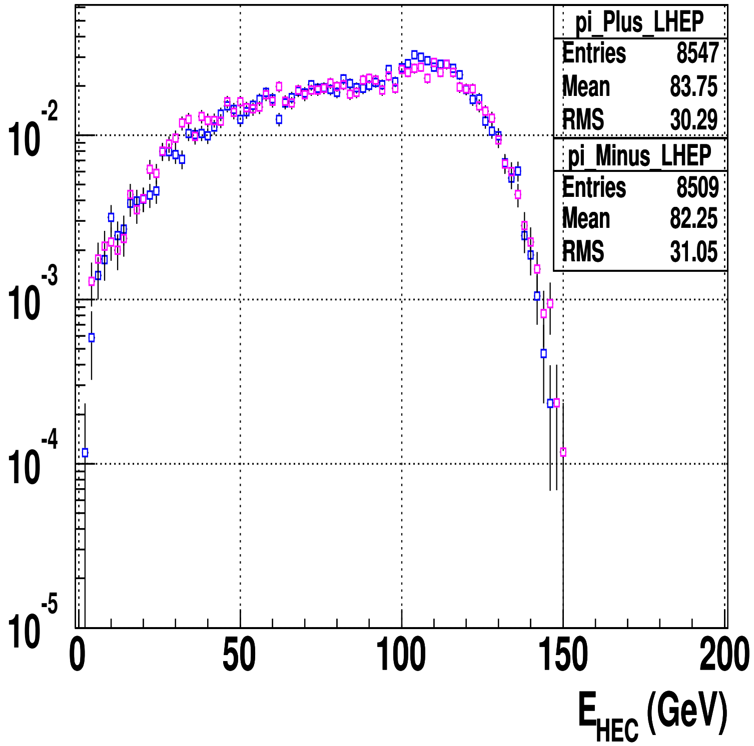
Signals in HEC



Data

π^+: green dots

π^-: red dots

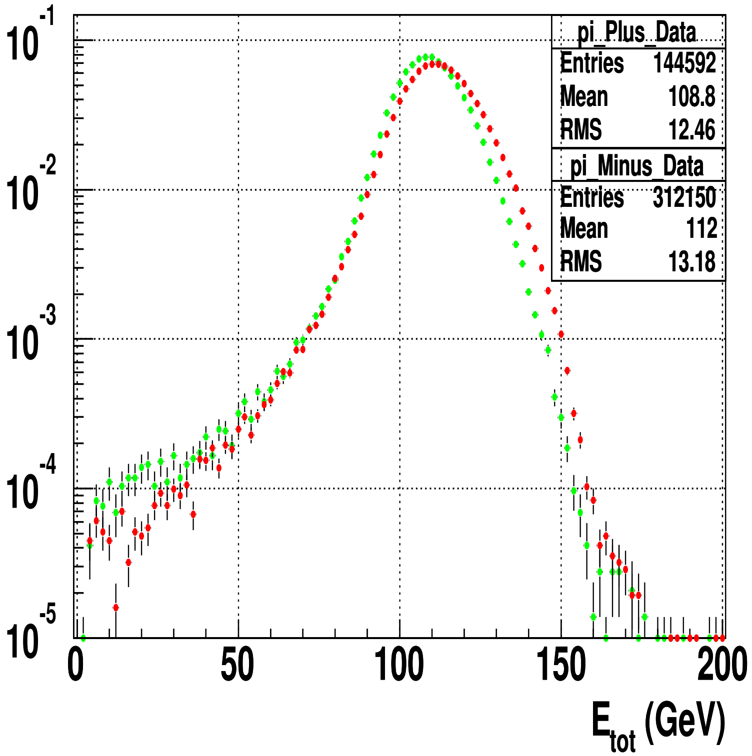


LHEP

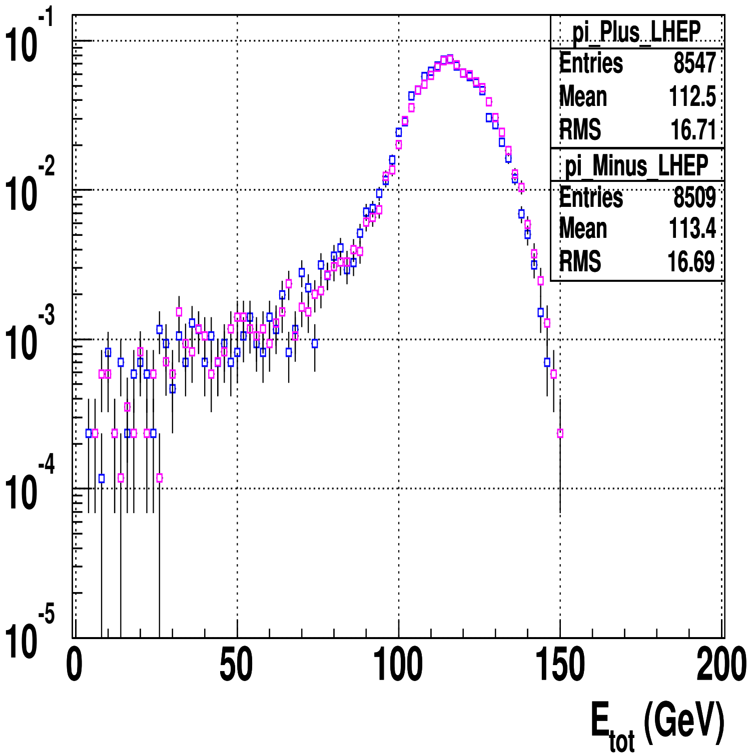
π^+: blue open squares

π^-: pink open squares

Total signals

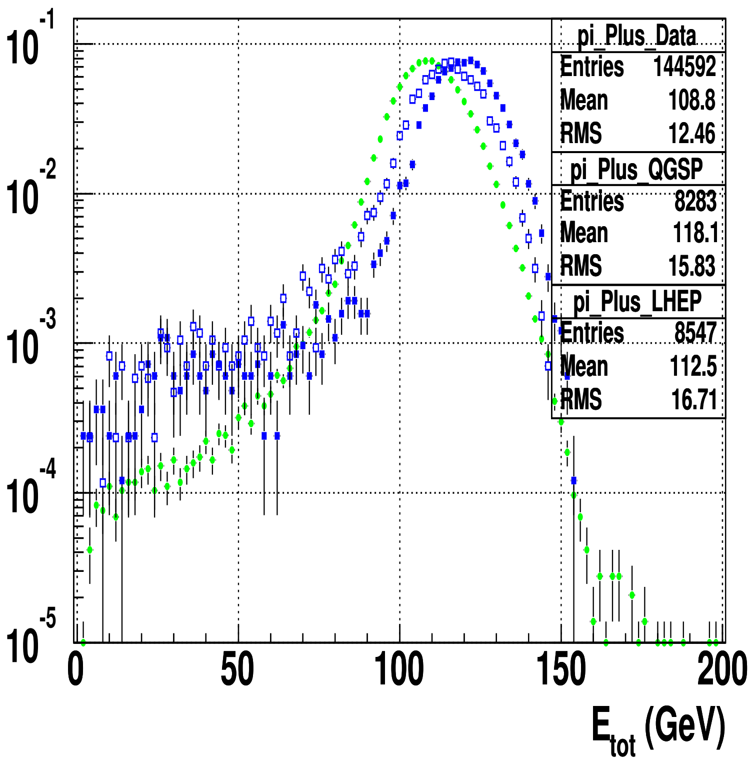


Data
π^+: green dots
π^-: red dots



LHEP
π^+: blue open squares
π^-: pink open squares

Total signals

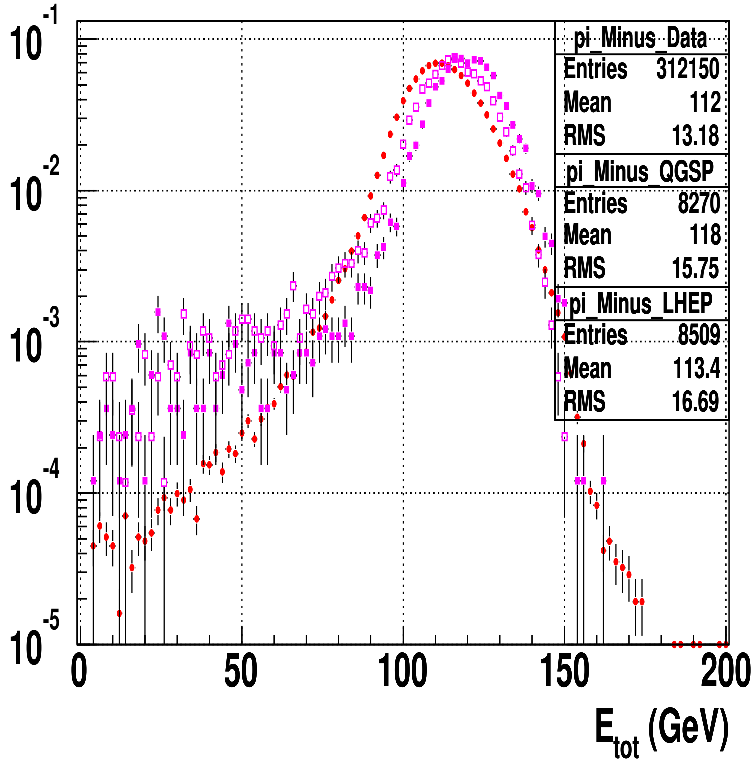


π^+

Data: green dots

LHEP: blue open squares

QGSP: blue squares



π^-

Data: red dots

LHEP: pink open squares

QGSP: pink squares

Conclusions

- Transfer of weighting constants from the beam test to ATLAS is only possible when using MC simulations
- In general Geant4 yields the better description of the data, obtained in the combined beam tests of EMEC / HEC
- But Geant4 fails to describe the details of hadronic shower fluctuations at the level required to apply weighting techniques
- Observed experimental difference between π^+ and π^- requires additional studies:
  - special attention to runs with charged pions of different sign in the coming combined testbeam of EMEC / HEC / FCal
  - expertise from Geant4 collaboration is expected