Tests of Local Hadron Calibration Approaches in ATLAS Combined Beam Tests

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Outline

Introduction

☼ Factors responsible for nonlinearity and for degradation of resolution of hadrons

Combined beam tests of ATLAS endcap and forward calorimeters

☼ Shower shape studies for Geant4 physics lists validation

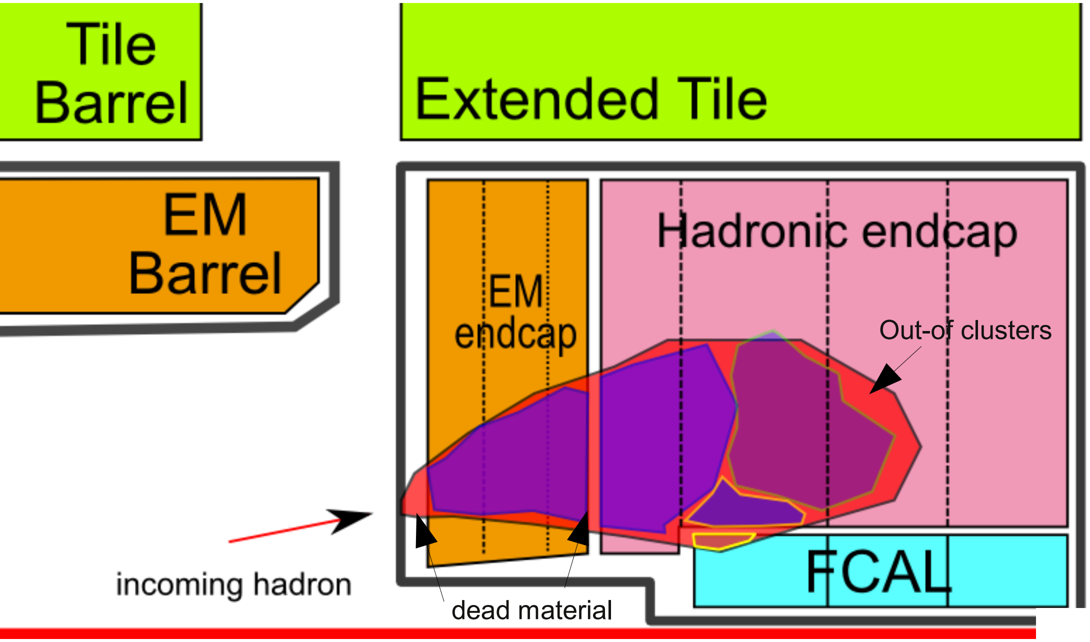
☼ Application of Local Hadron Calibration

Combined beam tests of ATLAS barrel detectors

☼ Application of layer correlation method

Summary

Hadronic shower in ATLAS calorimeter

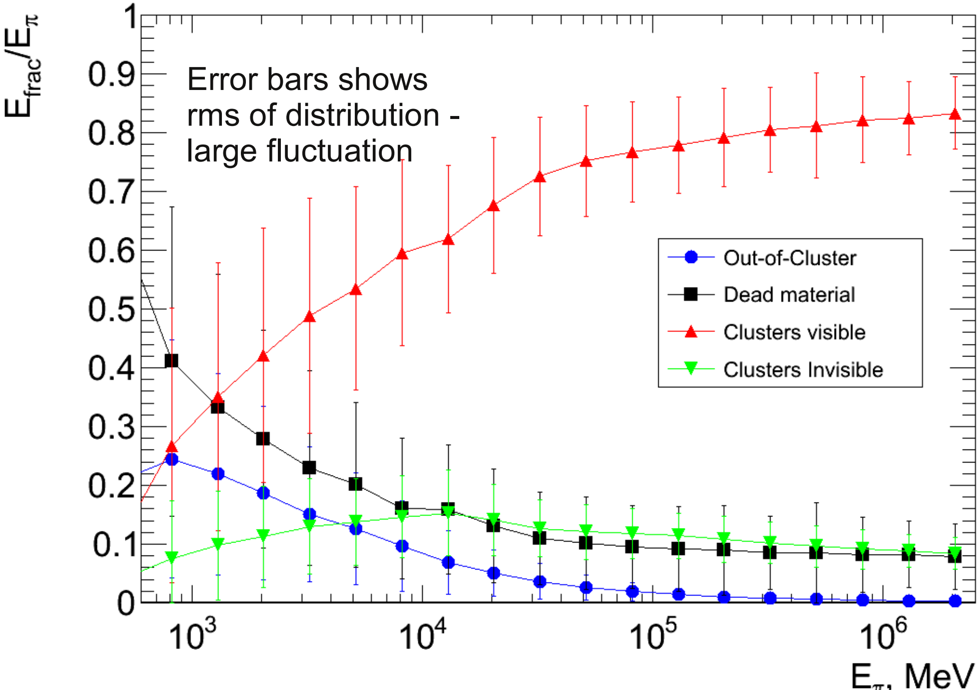


☼ Factors responsible for nonlinearity and degradation of resolution of hadrons

- e/h>1 for each calorimeter system (invisible energy)
- energy deposited in non-instrumented regions
- energy deposited outside of any reconstructed calorimeter objects (clusters)

☼ For 10 GeV pions at η~2.5

- O(60%) - energy in reconstructed clusters
- O(15%) - invisible energy in clusters
- O(15%) - energy in dead material
- O(10%) - out-of-cluster energy
- contributions depend on pion energy and are the subject of large fluctuations



Calibration techniques (software compensation) are used to recover linearity and improve resolution.

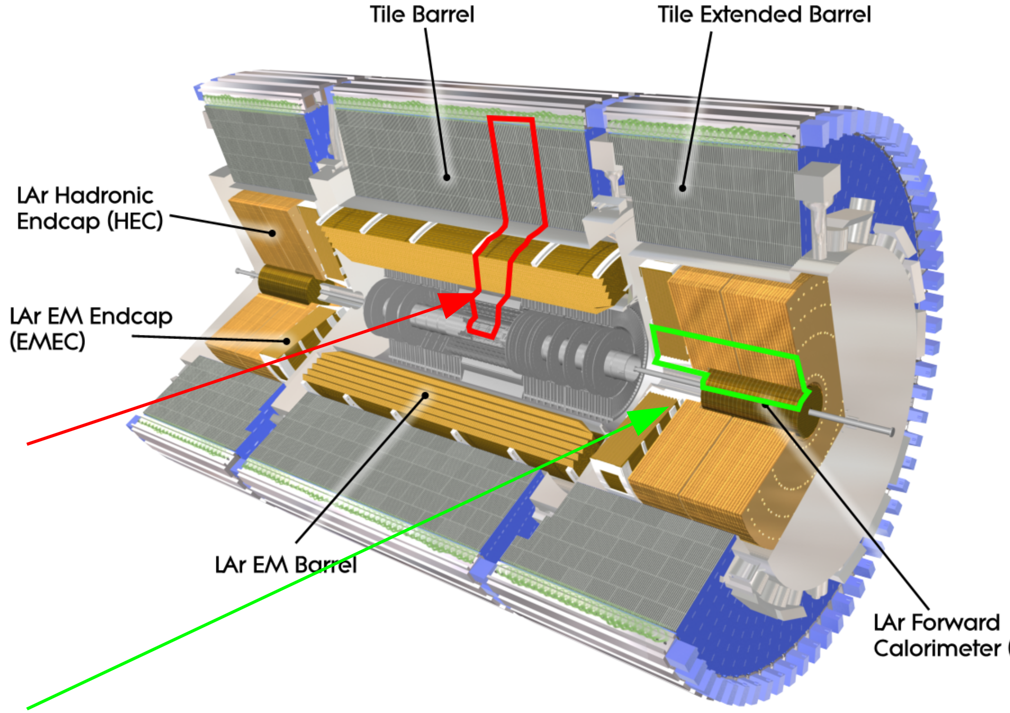
General long-term ATLAS strategy to use simulation to calibrate detector response to hadrons

ATLAS calorimeter combined beam test program

Two combined tests in 2004 of the ATLAS barrel and endcap regions closed extensive program of beam tests started in 1996

- Combined beam test included full slice of the ATLAS Barrel region at η~0.45
  - Pixel detector, silicon strip semiconductor tracker (SCT), transition radiation tracker (TRT), LAr and Tile calorimeter and the muon spectrometer

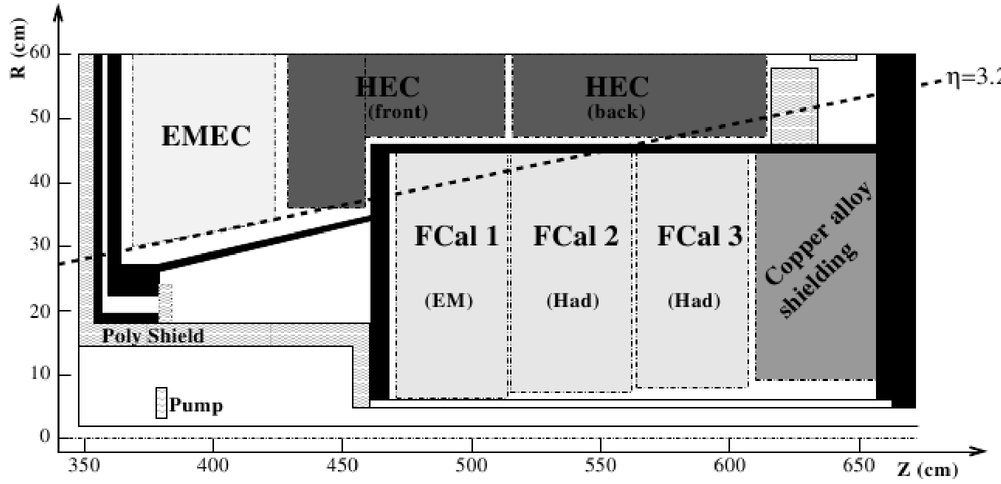
- Combined beam test of the ATLAS detectors in region of the forward crack η~3.2
  - Sector of the full azimuthal acceptance of LAr endcap and forward calorimeters



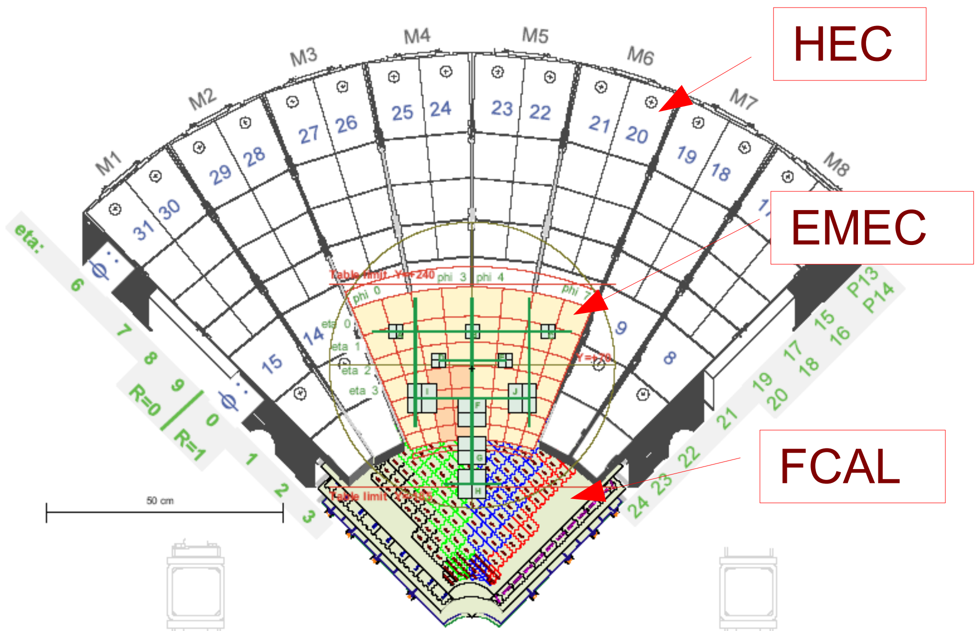
Why do we need to analyze testbeam data in these hot days of early ATLAS data?
- Testbeam has known input, early ATLAS data doesn't
- Possibility to validate in unambiguous way Geant4 simulations utilizing various physics lists
- Good opportunity to tune hadronic calibration approaches as used in the full ATLAS setup

Combined beam test of LAr detectors in endcap and forward regions

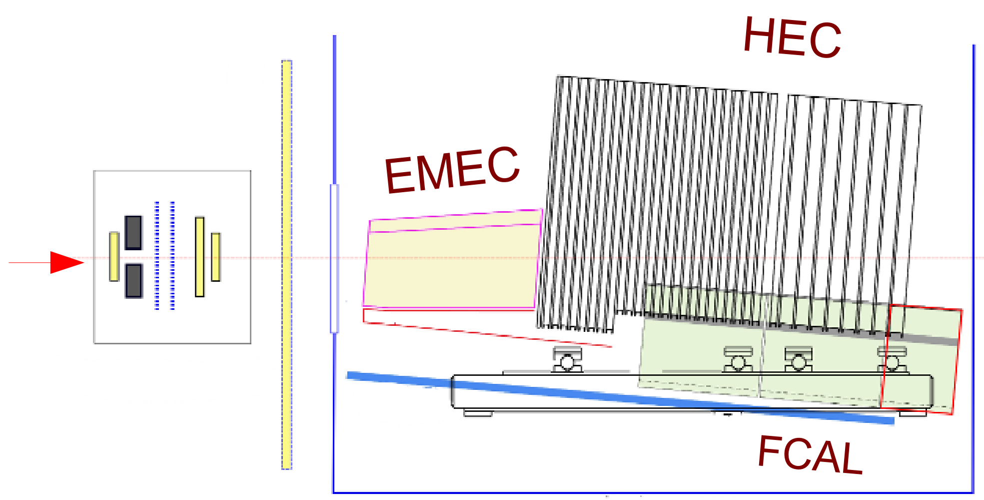
☼ Focused on the difficult region $2.5<\eta<4.0$ containing the transition from EMEC and HEC to the FCAL



- 1/8 of EMEC (module 0) Inner Wheel
- One quadrant in φ of HEC
- One quadrant in φ of FCAL



Front view of the setup with different beam impact points and position scans



Setup placed in H1 cryostat in H6 beam line of CERN SPS

Data and Monte-Carlo

Data

- Various energy and position scans were performed for e,π in the energy range 6 GeV<E<200 GeV with about 80 million triggers in total
  - Energy scans at a standard set of impact point (e.g. impact points for the endcap area corresponding to η=2.8, for the forward area corresponding to η=3.65)
  - Position X,Y scans to cover full crack region

Monte-Carlo

- Simulation with Geant 4 version 9.2 with two physics lists:

QGSP_BERT

- 0 GeV < Bertini cascade model < 9.9 GeV
- 9.5 GeV < low energy parametrised model < 25 GeV
- Quark gluon string model (>12 GeV)

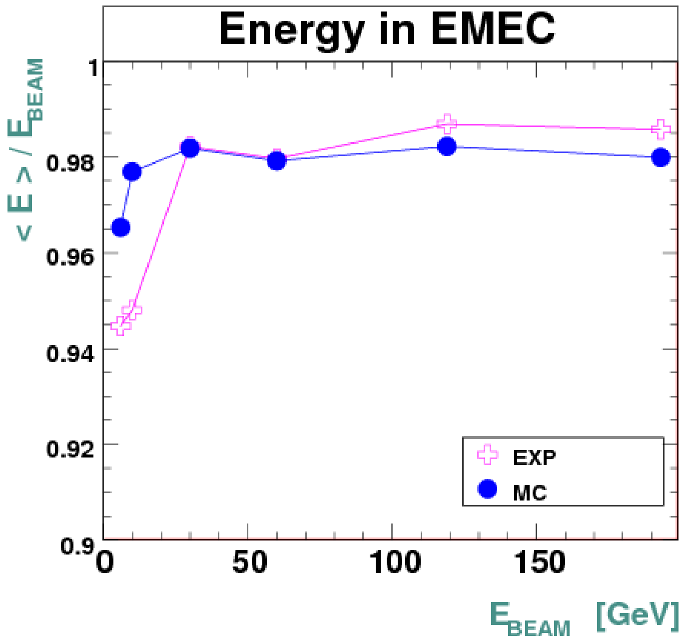
FTFP_BERT

- 0 GeV < Bertini cascade model < 5 GeV
- Fritiof diffractive string model (>4 GeV)

Reconstruction

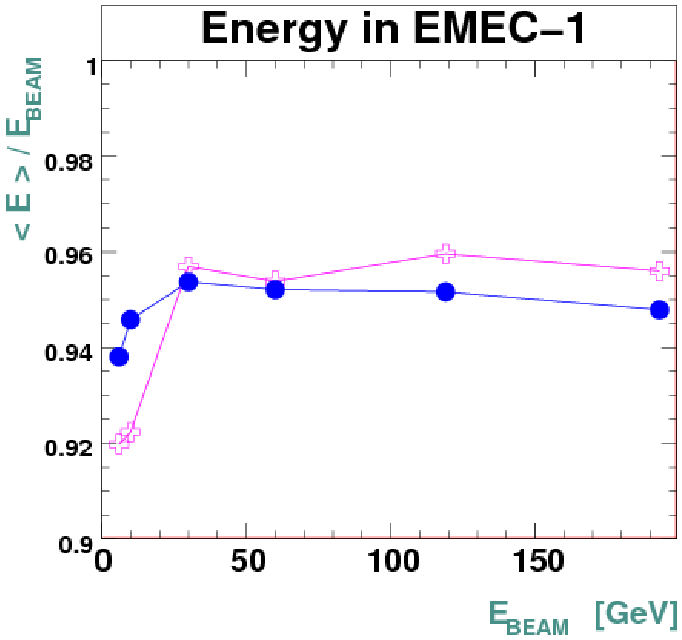
- With standard ATLAS software
  - 3d topological clustering
  - Local Hadron Calibration

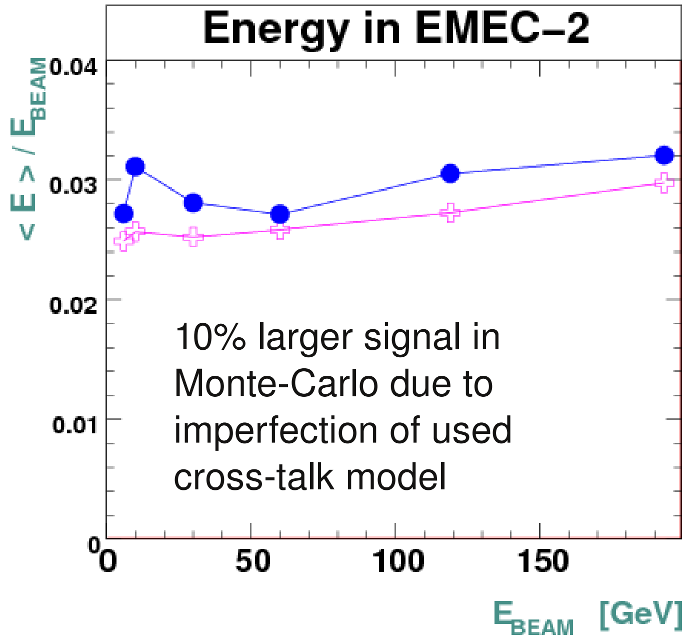
Electrons in endcap region: e.m. scale and energy in calorimeter samplings



Ratio of reconstructed energy in whole EMEC calorimeter to the beam energy as a function of beam energy

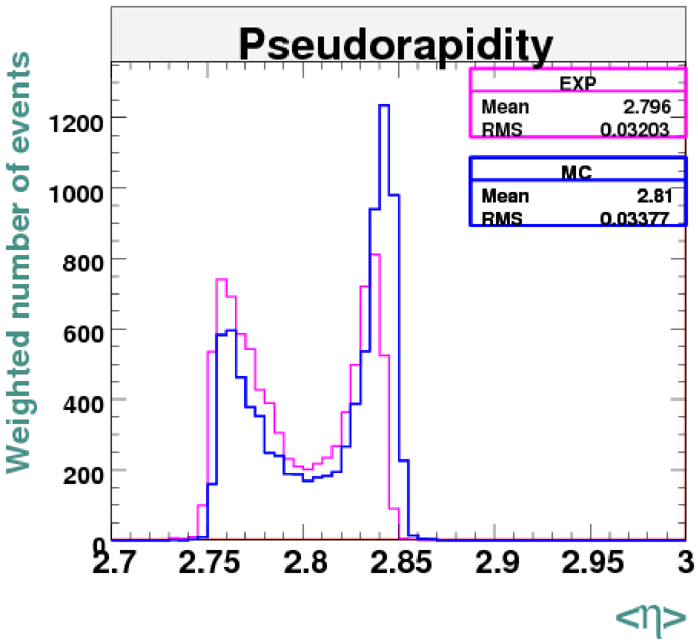
- e.m. scale is at the level of 98% of beam energy (2% lack of energy is explained by the dead material deposits)
- good agreement (<1%) between Monte-Carlo and experiment

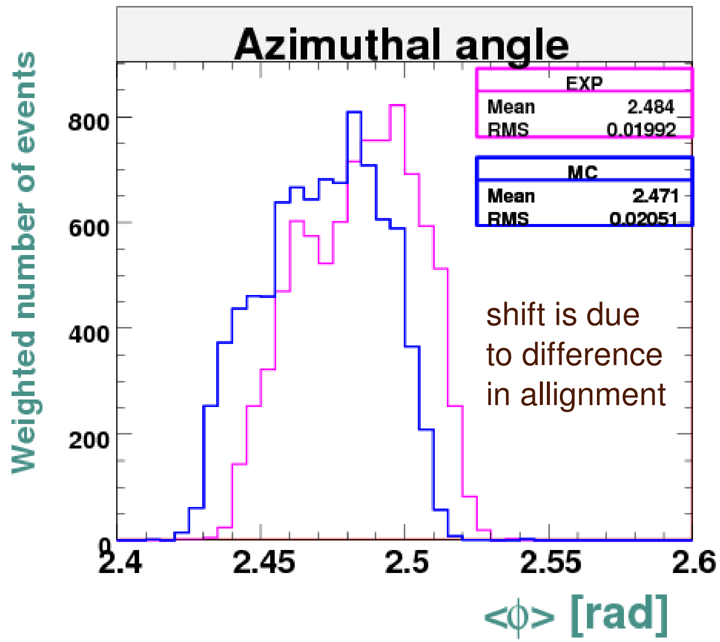




Ratio of energy reconstructed in first and second samplings of EMEC calorimeter

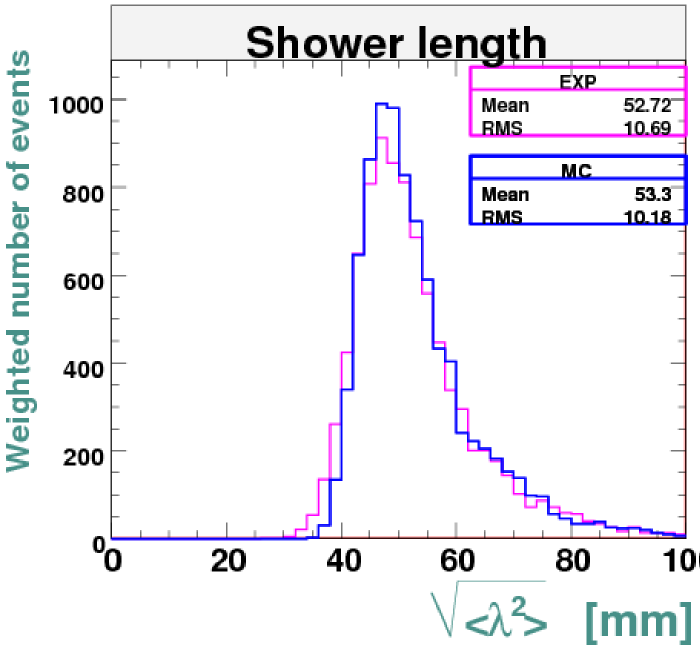
Electrons 193 GeV in endcap region: shower shape studies

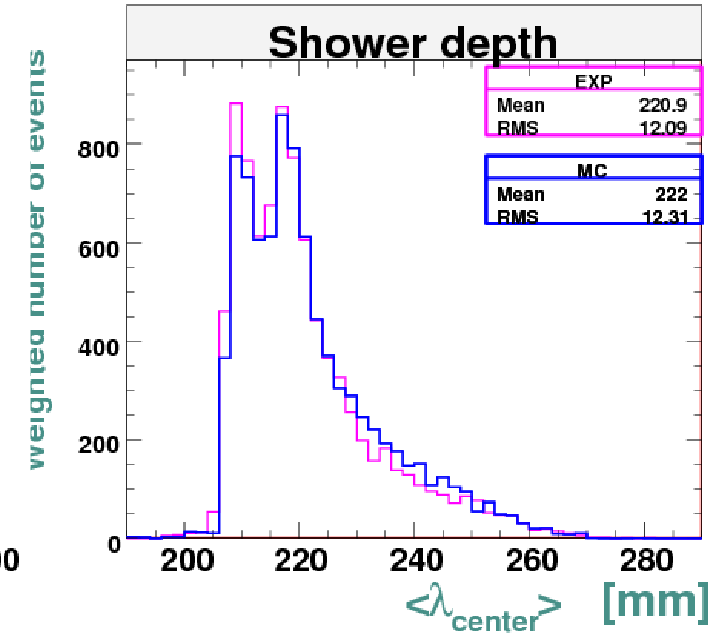


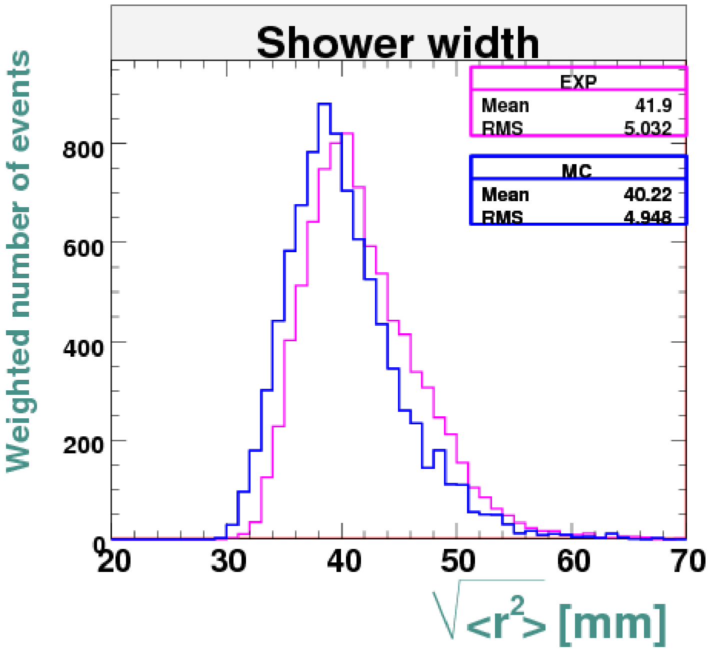


Reconstructed coordinates and shower shape parameters

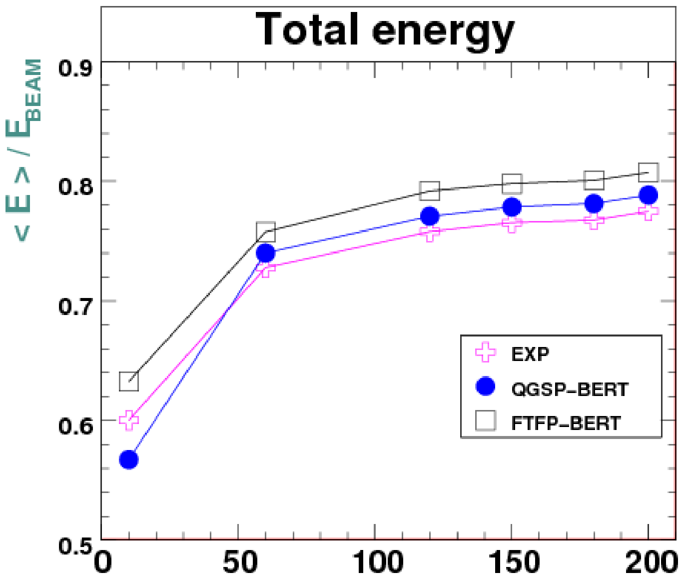
- generally good agreement between Monte-Carlo and experiment





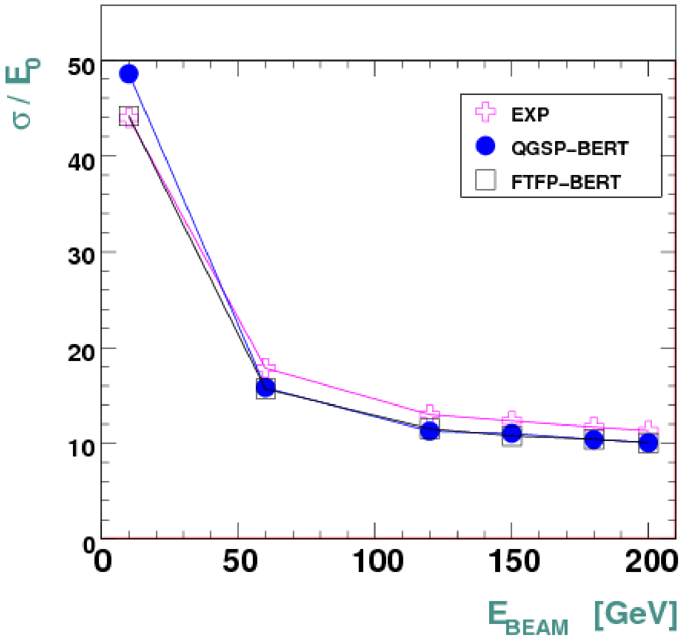


Pions in endcap region: energy response and resolution at e.m. scale



Ratio of reconstructed energy at e.m. scale to the beam energy as a function of beam energy

- Monte-Carlo predicts higher response than seen in the experiment (+4% for FTFP_BERT, +2% for QGSP_BERT)

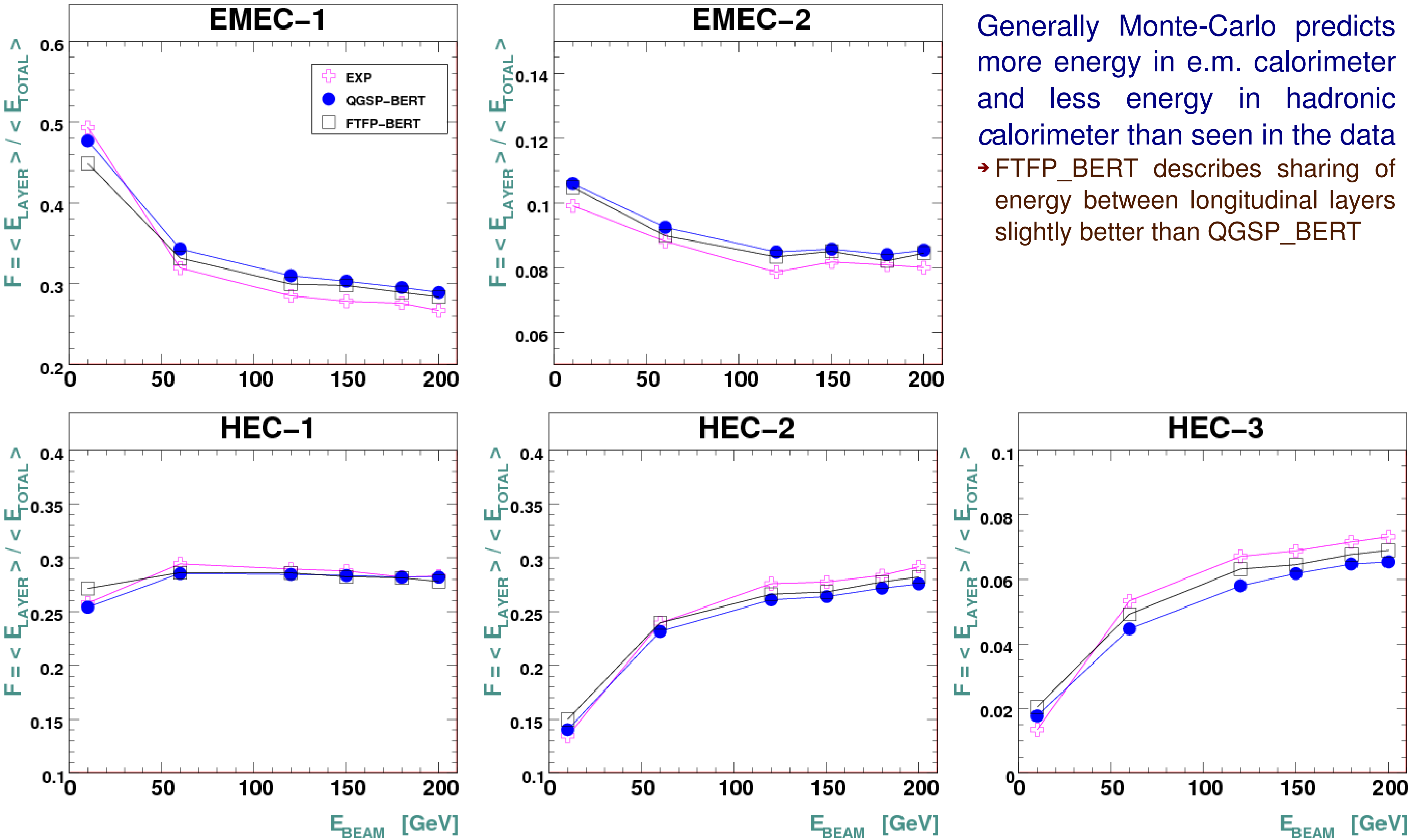


Energy resolution at e.m. scale as a function of beam energy

- Monte-Carlo in comparison to the experiment predicts a better resolution by about 20%

Pions in endcap region: energy in calorimeter parts at e.m. scale

Ratio of energy in different calorimeter samplings to the total energy in the calorimeter .vs. beam energy

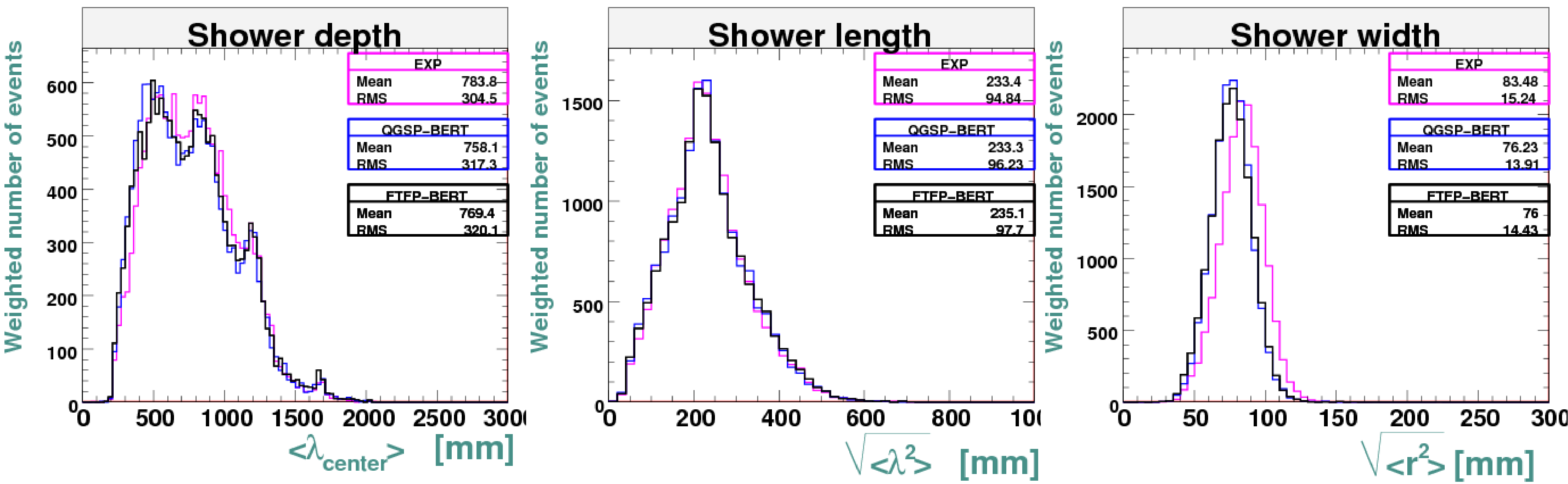


Generally Monte-Carlo predicts more energy in e.m. calorimeter and less energy in hadronic calorimeter than seen in the data

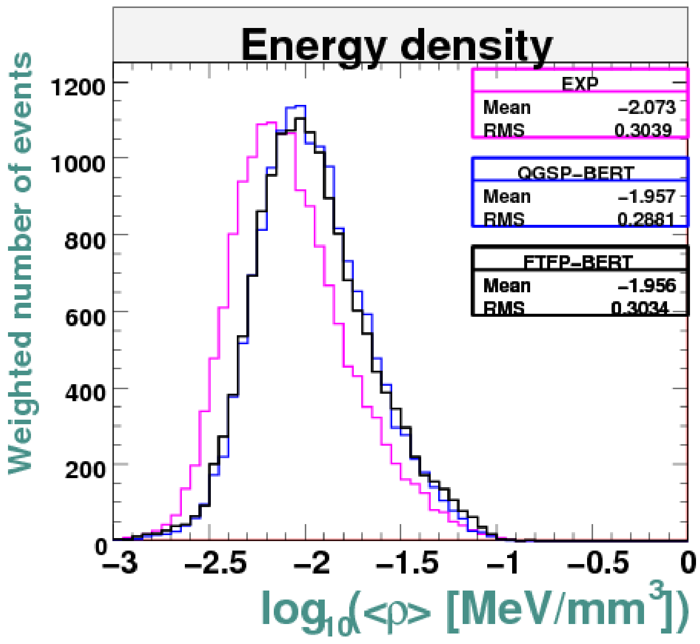
- FTFP_BERT describes sharing of energy between longitudinal layers slightly better than QGSP_BERT

Pions in endcap region: shower shape studies

- Comparison of shower depth (left), shower length (center) and shower width (right) in Monte-Carlo and experiment
  - 200 GeV pions
  - QGSP_BERT and FTFP_BERT physics lists show similar results
  - Shower depth: shower starts slightly earlier in Monte-Carlo
  - Shower length: very good agreement in description
  - Shower width: Monte-Carlo has more compact shower

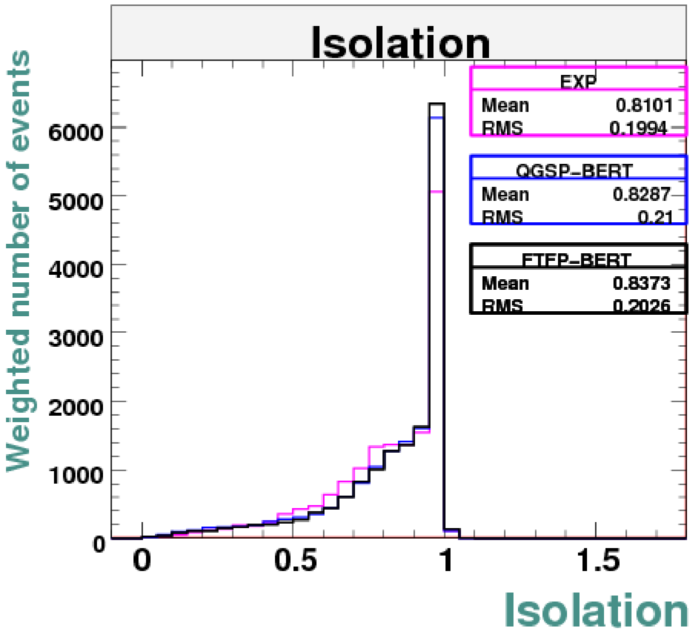


Charged Pions in endcap region: energy density and cluster isolation



Comparison of average cluster energy density in Monte-Carlo and Experiment

- slightly denser shower in Monte-Carlo due to more compact shower size



Comparison of degree of cluster isolation in Monte-Carlo and Experiment

- isolation is a fraction of cells on the outer cluster perimeter which are not included in any other cluster
- good agreement between Monte-Carlo and Experiment – adequate description of cell noise and similar clustering

Shower shape summary for endcap region

Electromagnetic showers

- Good description of e.m. scale, energy sharing between calorimeter samplings and shower shape parameters

Hadronic showers

- More compact shower size in Monte-Carlo for both physics lists
  - Seen as smaller shower width, larger average shower density
  - No difference between QGSP_BERT and FTFP_BERT

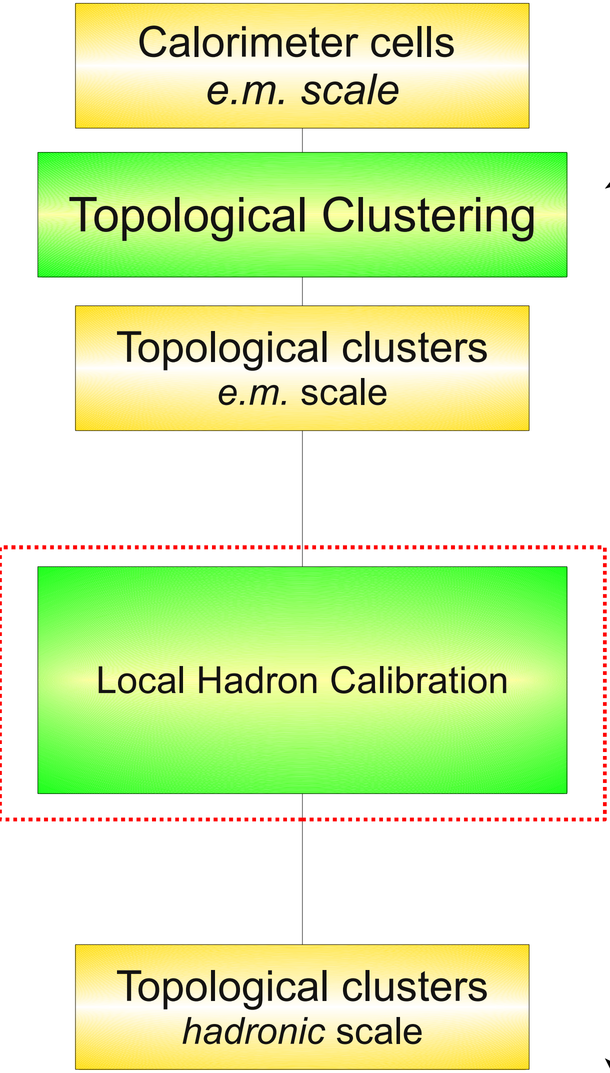
- Shower starts earlier in Monte-Carlo
  - Seen as larger energy deposition in electromagnetic calorimeter and smaller shower depth
  - FTFP_BERT describes data slightly better than QGSP_BERT

- Total energy response is overestimated in Monte-Carlo
  - FTFP_BERT predicts +4%, QGSP_BERT predicts +2% more energy than in the experiment

- Monte-Carlo in comparison to the experiment predicts a better resolution by about 20%

Local Hadron Calibration

- Calibration of topological clusters to particle level
  - ➔ Based on single pion simulations & GEANT4 truth energy deposits



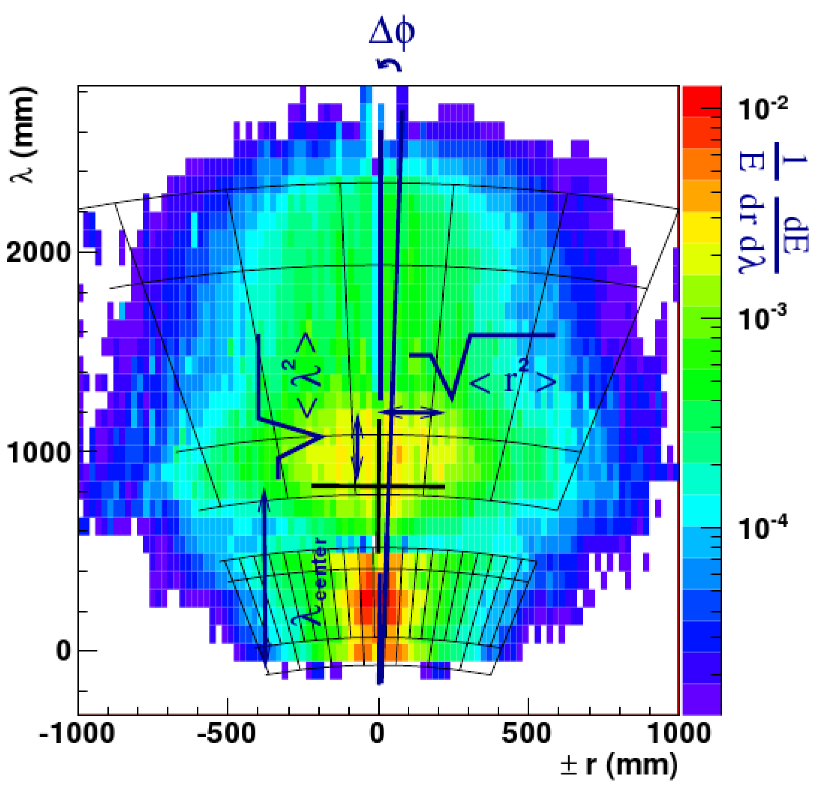
- Cluster making starts from calorimeter cells at e.m. scale
  - ➔ Starting from seed $|E_{cell}|>4\eta_{noise}$, expanding in 3D around neighbors with $|E_{cell}|>2\eta_{noise}$, finally adding perimeter cells $|E_{cell}|>0$, split clusters around local maxima

1. Classification to identify e.m. and non-e.m. parts of the shower
2. H1-style cells weighting for clusters classified as hadronic to account for non-compensation of the calorimeter
3. Correction for energy deposited in calorimeter cells outside of any clusters due to noise thresholds
4. Recovers lost energy in dead material in front and between calorimeter modules

- Clusters are calibrated to the particle level
  - ➔ Provides different jet algorithms with single input
  - ➔ Factorization of different effects

Local Hadron Calibration

- Local Hadron Calibration constants have been derived using dedicated Monte-Carlo simulation
  - Neutral and charged pions with flat energy distributions (in logarithmic scale) between 1GeV and 2 TeV
  - Flat coverage of whole acceptance in ηxφ space



Step 1: Classification probabilities

$$\eta, E_{cluster}, log10(\lambda_{center}), log10(\rho_{cell})$$

Step 2: H1-style cell weights

$$W_i = \langle E_{true} / E_{reco} \rangle$$

$$i = bin\#(E_{cluster}, \eta_{cluster}, sampling, E_{cell} / V_{cell})$$

Step 3: Out-Of-Cluster correction weights

$$W_i = \langle 1 + E_{OutOfCluster} / E_{cluster} \rangle$$

$$i = bin\#(E_{cluster}, \lambda_{cluster}, \eta_{cluster})$$

Step 4: Dead Material Weights

$$E_{DM} \sim \sqrt{E_{EME3} \cdot E_{HEC0}}$$

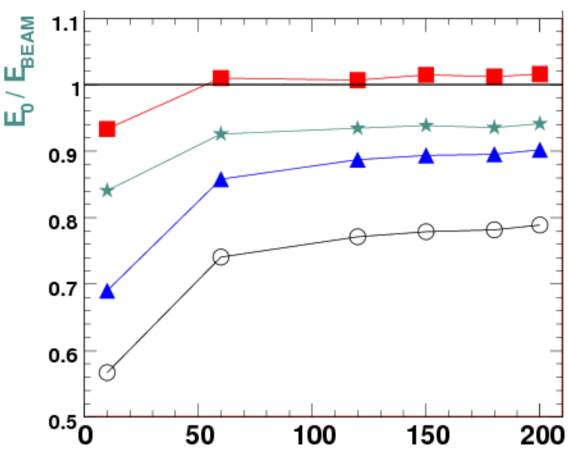
$$i = bin\#(E_{cluster}, \lambda_{cluster}, \eta_{cluster})$$

- Four different sets of correction coefficients have been obtained using ATLAS/Testbeam geometry and QGSP_BERT/FTFP_BERT physics list

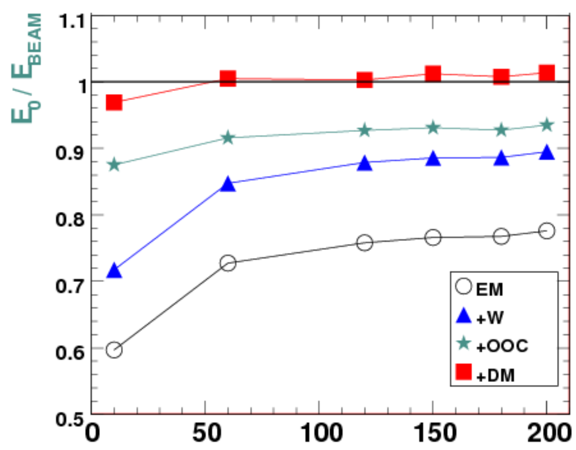
Charged Pions in endcap region: energy responce

- Plots show the responce for Monte-Carlo (left) and Experiment (right) after each step of local hadronic calibration (constants for ATLAS geometry and QGSP_BERT, FTP_BERT lists)
  - Each step of the calibration improves linearity
  - After the last step response is close to one and its linearity stays within ± 2% (except at low energies)

Monte-Carlo, QGSP_BERT

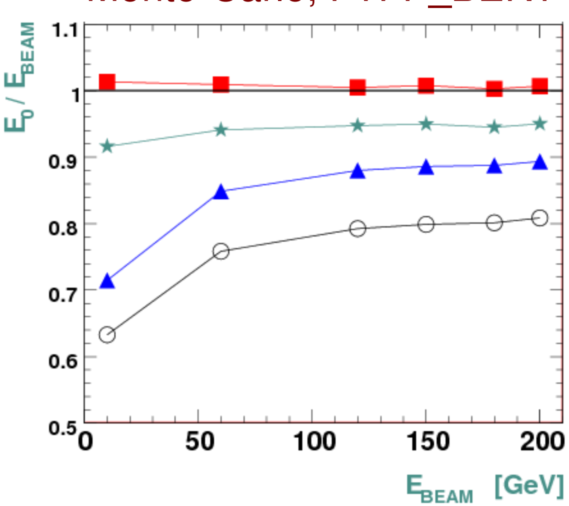


EXP using QGSP_BERT

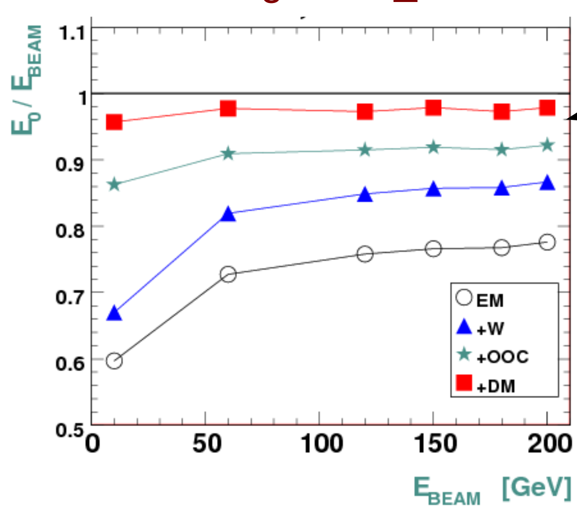


- ○ e.m. scale,
- ▲ after weighting
- ☆ after OOC correction
- ■ after DM correction

Monte-Carlo, FTFP_BERT



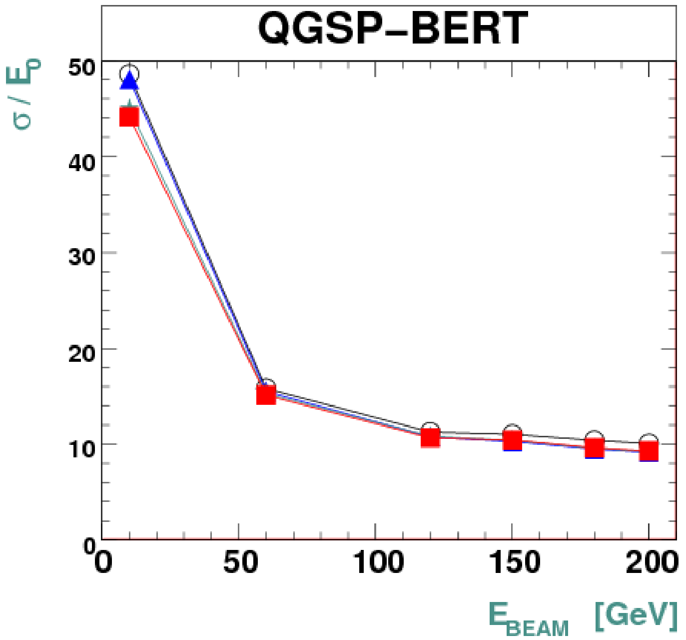
EXP using FTFP_BERT

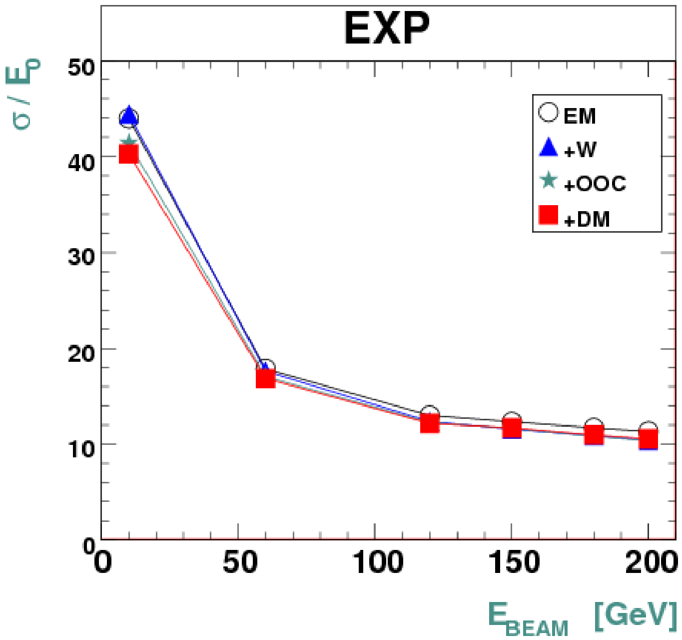


Usage of FTFP_BERT list for Experiment leads to undershoot in final response due to wrong initial e.m. scale provided by FTFP_BERT list

Charged Pions in endcap region: energy resolution

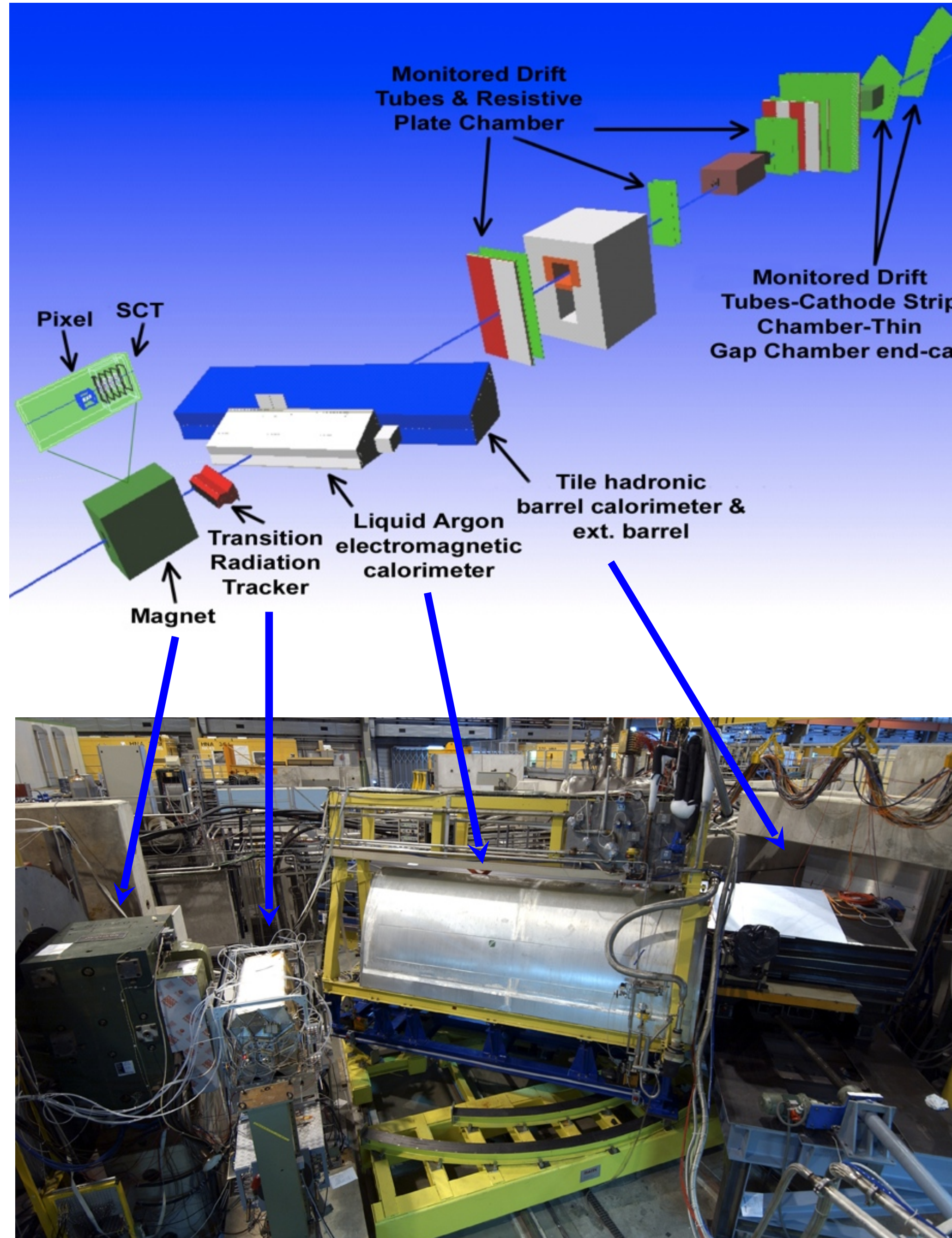
- Plots show the energy resolution for Monte-Carlo, QGSP_BERT list (left) and Experiment (right) after each step of local hadronic calibration
  - Each step of the calibration slightly improves the resolution
  - After the last step applied the resolution is improved by 5-10%





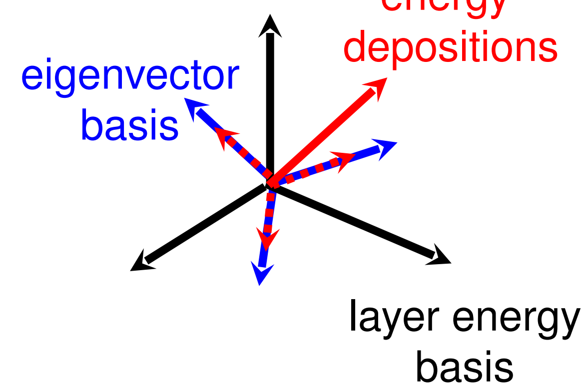
Barrel combined beam test

- H8 SPS beamline at CERN North Area.
- Took place summer/fall 2004.
- η ~ 0.45
- All subsystem in the barrel region (Pixel, SCT, TRT, LAr, Tile, Muon spectrometer) together, in a configuration similar to full ATLAS.
- In addition: Beam chamber detectors and trigger scintillators.
- e,γ, π, p, μ beams from 1 to 350 GeV
- 90 million events collected in total.



Layer Correlation Method

- Alternative approach to standard ATLAS Local Hadron Calibration for single pions in testbeam
- Use clustered energy in 7 calorimeter layers as a SIGNAL
  - 4 layers of LAr + 3 layers of Tile calorimeters

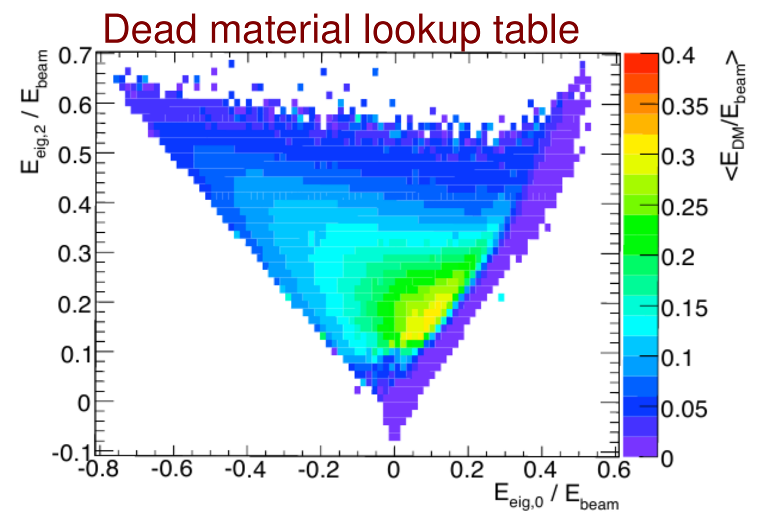


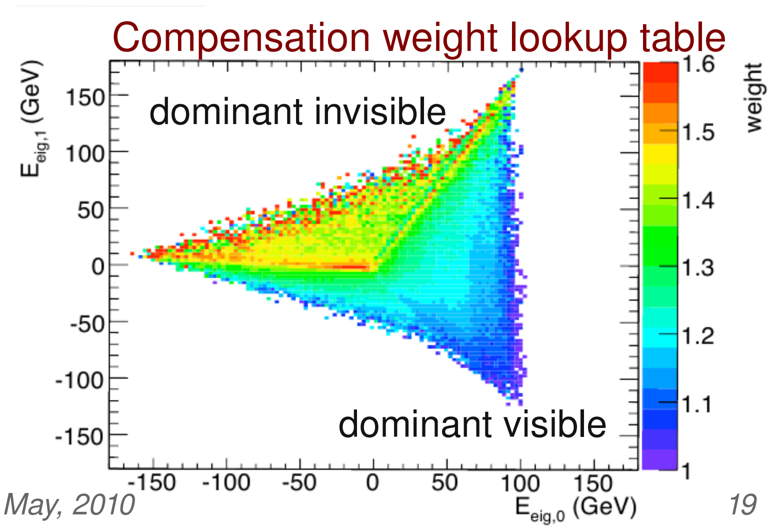
- Correction is a function of linear combination of layer energies with largest expected fluctuations
  - An event is regarded as a point in 7-dim vector space of calorimeter layer energy deposits
  - It's coordinates is expressed in a new basis of eigenvectors of covariance matrix
  - Eigenvectors are ordered according eigenvalues to find which account most for shower fluctuation

$$E^{\rm rec}_{\rm eig0} \approx \frac{1}{\sqrt{6}}(-2E_{\rm LAr,middle} + E_{\rm Tile,A} + E_{\rm Tile,BC}),$$

$$E^{\rm rec}_{\rm eig1} \approx \frac{1}{\sqrt{2}}(-E_{\rm Tile,A} + E_{\rm Tile,BC}),$$

$$E^{\rm rec}_{\rm eig2} \approx \frac{1}{\sqrt{3}}(E_{\rm LAr,middle} + E_{\rm Tile,A} + E_{\rm Tile,BC}).$$

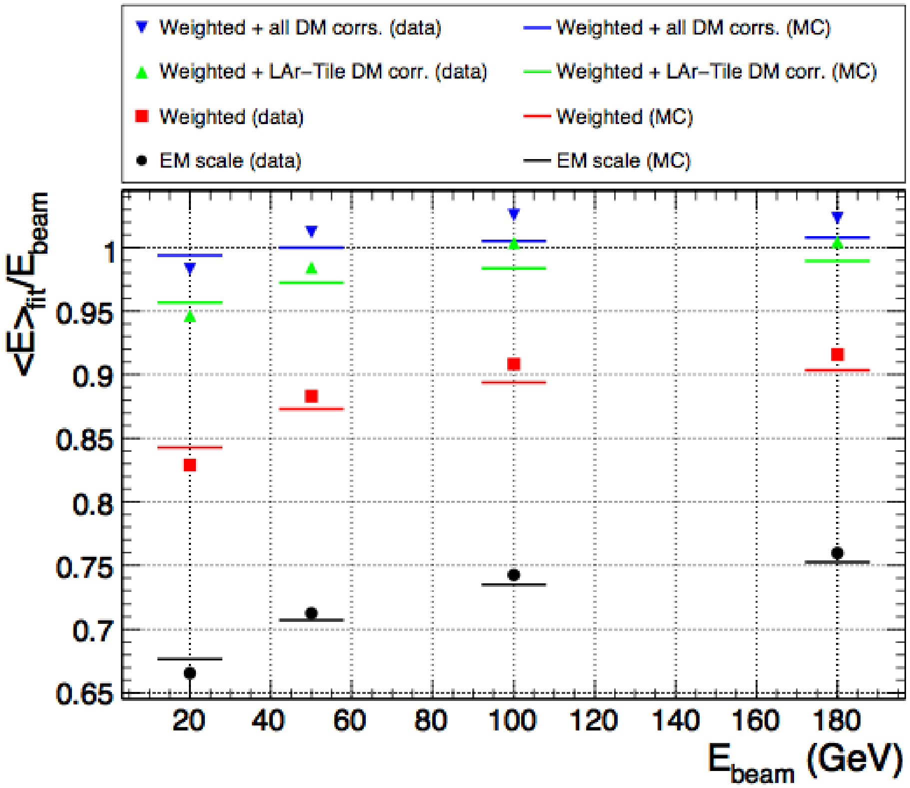




- These variables are used as input to build lookup tables for compensation weights and dead material corrections

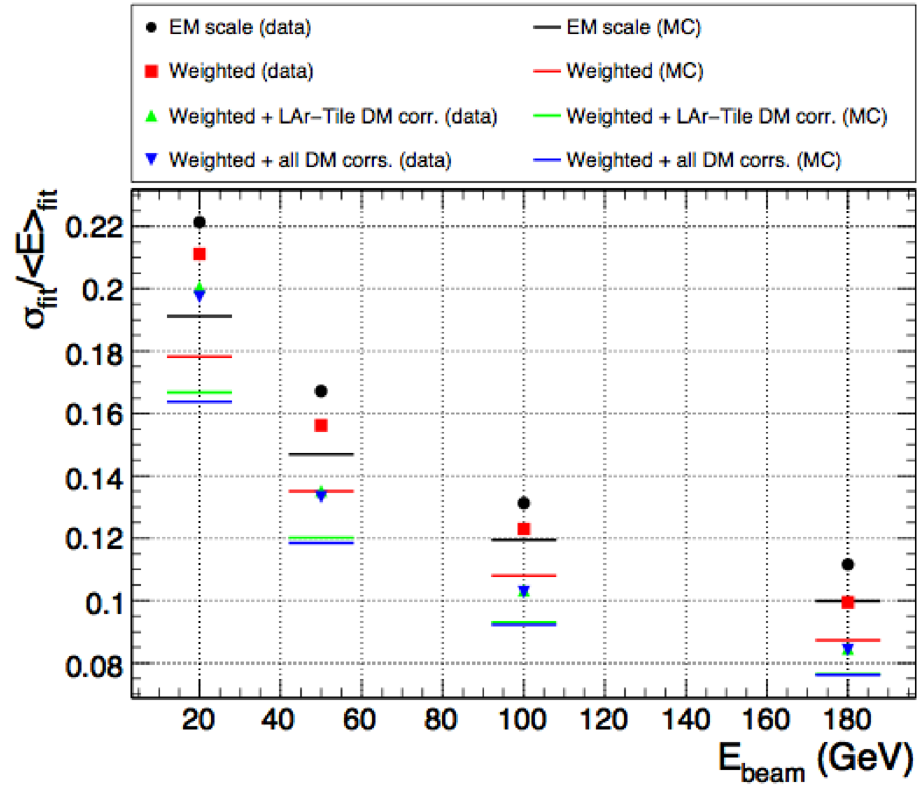
Layer Correlation Method performance

Response



After successfully applying all correction, linearity is restored to within 3%

Energy resolution



Method allows to improve energy resolution for both, Monte-Carlo and Experiment by 11-25% compared to electromagnetic scale, but Monte-Carlo is too optimistic.

Conclusion

- Different methods of hadronic calibration are studied with usage of data obtained during combined beam tests of ATLAS calorimeters
- Local Hadron Calibration procedure is a simulation based technique used in ATLAS to calibrate topological clusters from e.m. scale to particle level
- This procedure has been validated using ATLAS LAr combined beam test data in endcap region
  - Linearity is recovered within 2%, the energy resolution is improved by 5-10% in comparison to e.m. scale for both simulation and data
- Basic shower quantities have been studied using QGSP_BERT and FTFP_BERT physics lists
  - The simulation predicts somewhat larger pion response at the electromagnetic scale, coupled with better energy resolution and more compact shower size than seen in the data
- Layer Correlation Method has been applied for hadronic signal calibration to pion energy reconstruction in 2004 ATLAS combined beam test
  - Pion linearity is improved to within 3%, relative energy resolution improvement achieves 11 to 25%