Hadron response and shower development in the ATLAS calorimeters

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On behalf of the ATLAS Calorimeter Group

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Outline

1. Introduction

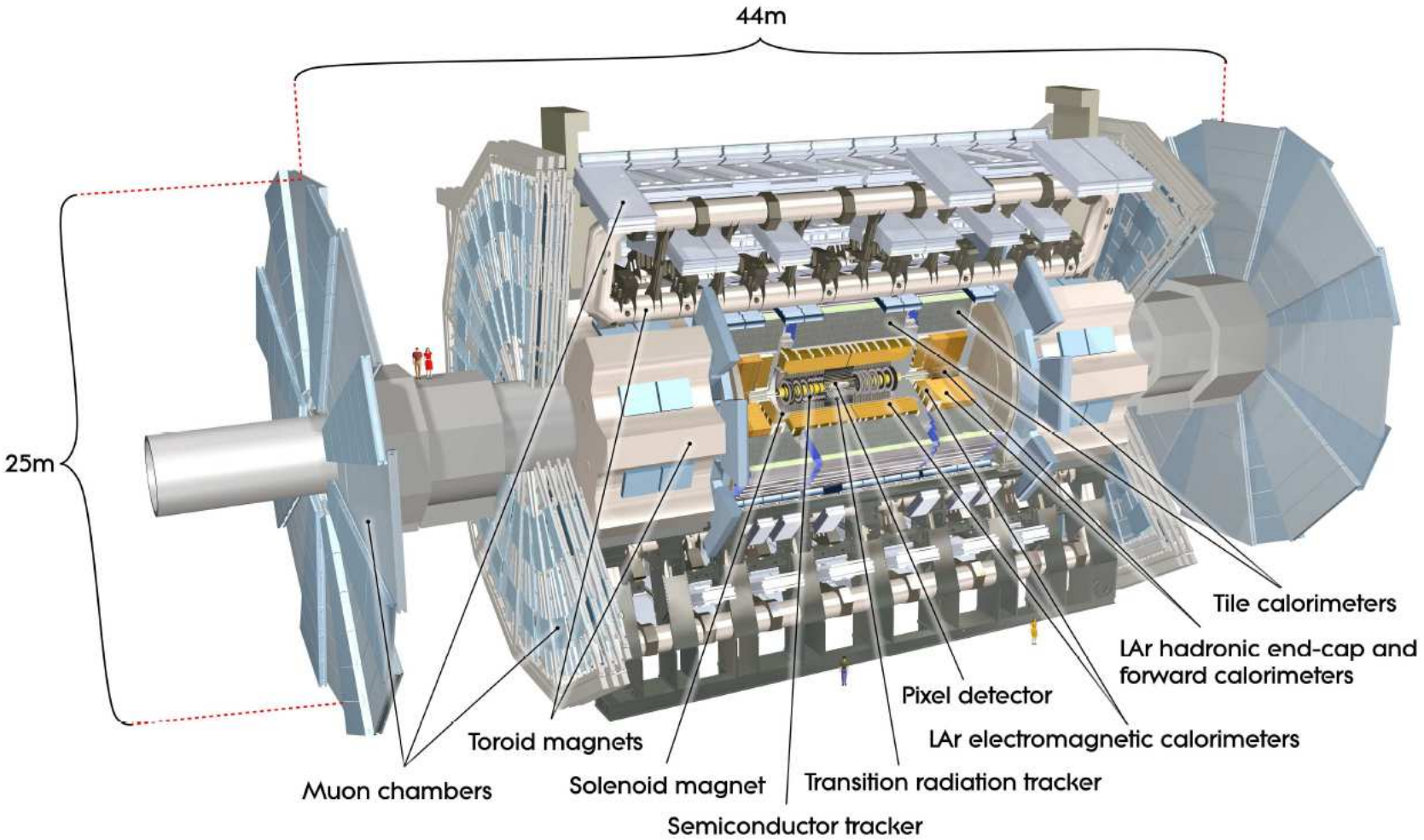
2. Barrel calorimeter combined test-beam results and comparison to MC
   - Response and resolution
   - Lateral profile

3. Barrel hadronic calorimeter (TileCal) standalone test-beam measurements
   - Difference in development of pion and proton induced showers
   - Longitudinal and Lateral Profiles
   - Impact of longitudinal leakage on energy resolution

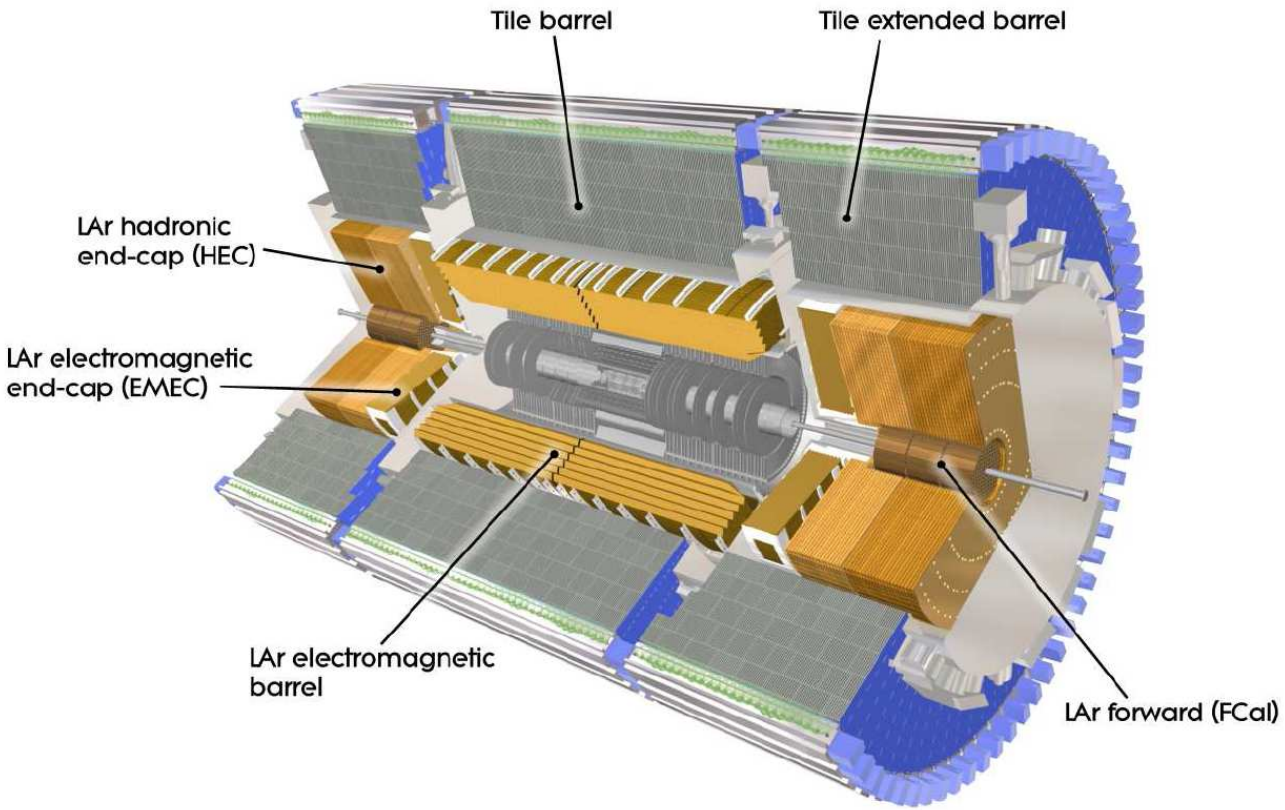
4. Conclusion

The ATLAS Detector

Large collider detector built for LHC at CERN



ATLAS Calorimerters



In the central region:

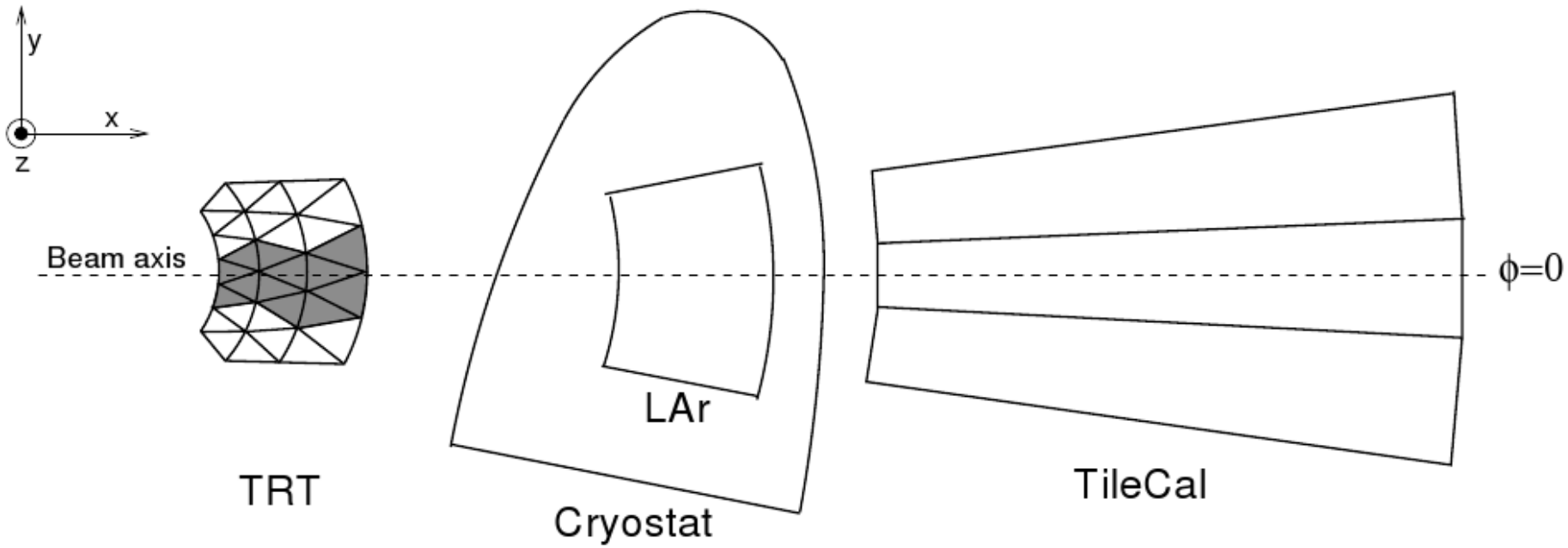
lead-liquid argon electromagnetic and iron-scintillator hadronic calorimeters.

energy resolution for hadrons and jets $\sigma_E/E = 50\%/\sqrt{E}(GeV) \oplus 3\%$.

In the forward region:

copper and tungsten as passive material with liquid argon technology.

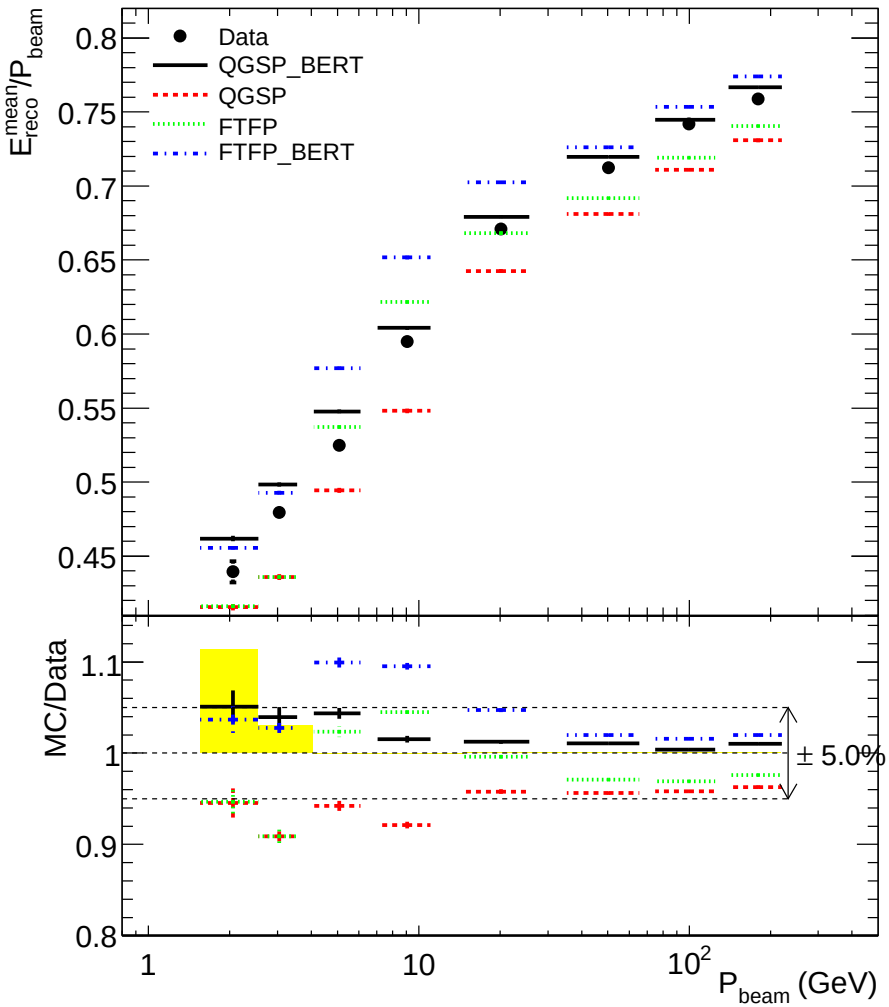
Combined Test-Beam

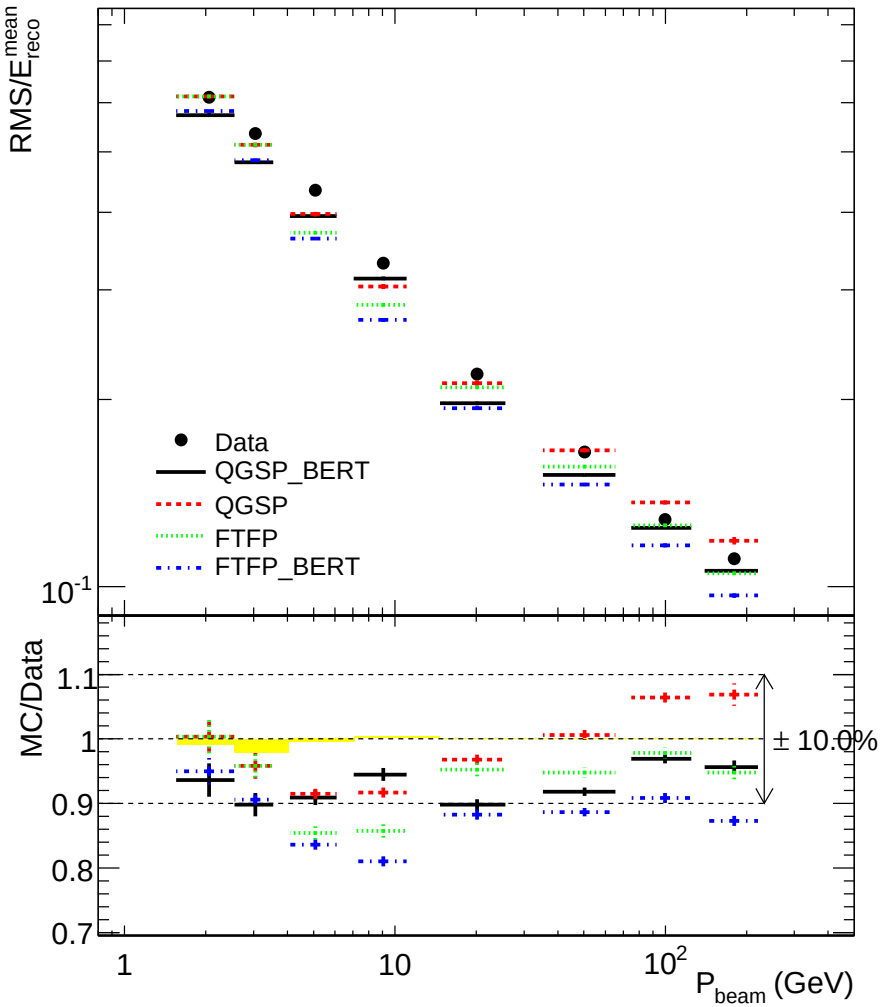


Full slice of the ATLAS detector was exposed to particles in test-beam
Only transition radiation tracker, electromagnetic and hadronic calorimeters are shown.

- Beam energy ranges from 2 to 350 GeV.
- All results are at electromagnetic energy scale, i.e. no correction for non-compensation or dead material energy losses.
- Data are compared to Geant4 simulation using version 9.1.

Response and Resolution



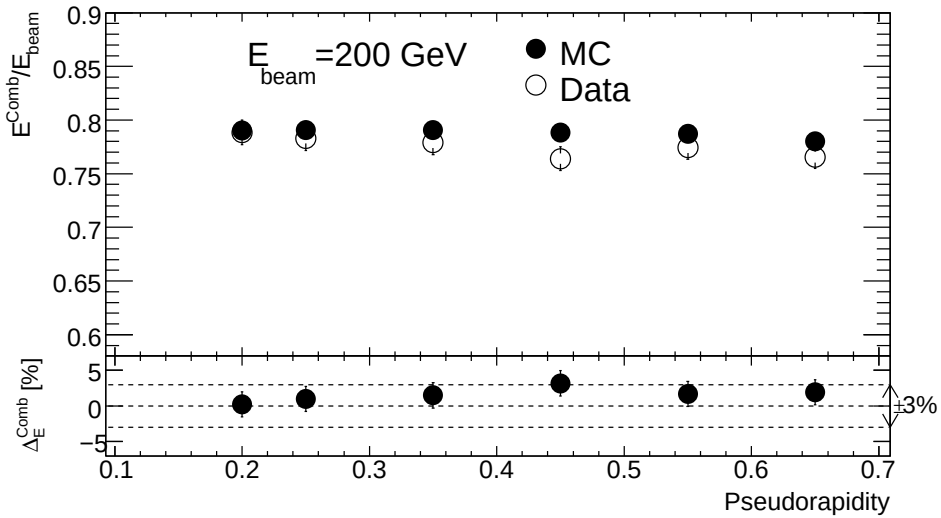


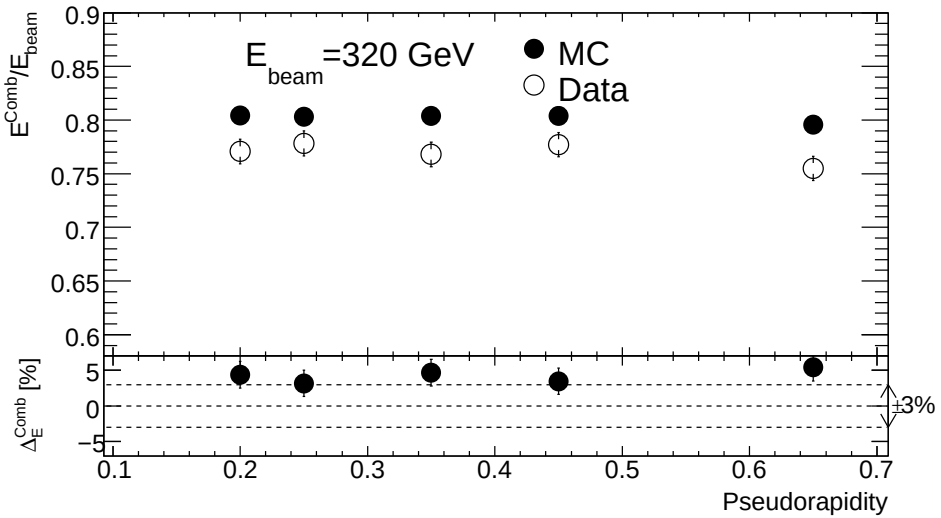
QGSP_BERT describes the response within ±5%

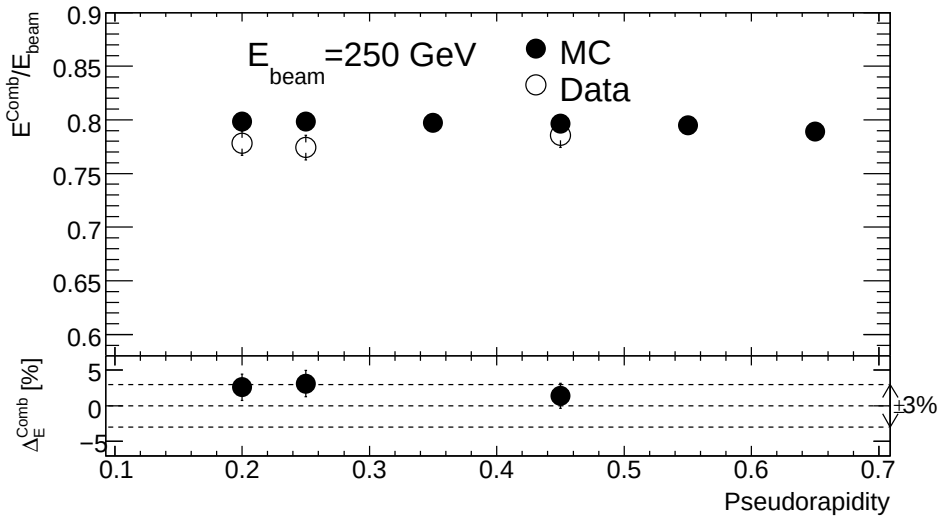
QGSP_BERT predict better resolution (RMS/mean) than measured in data but still within 10%

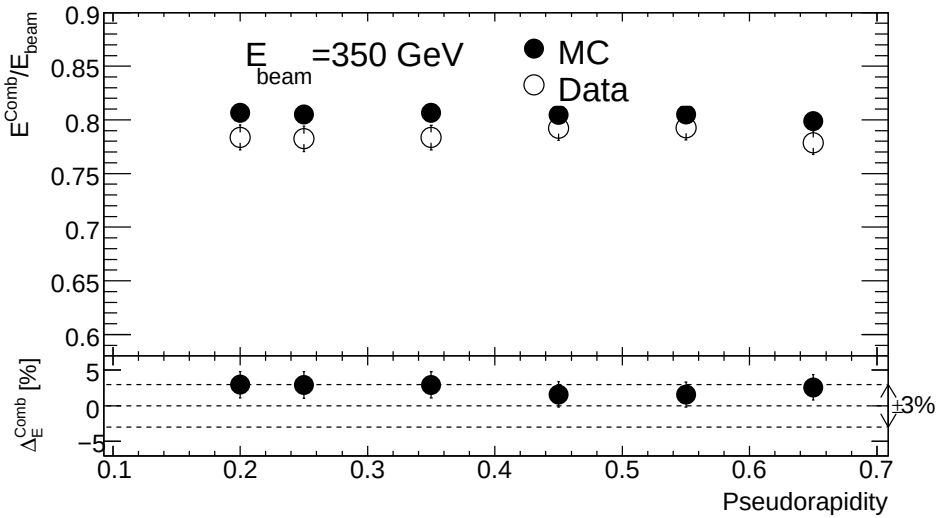
Response at high energies

Response as function of pseudo-rapidity



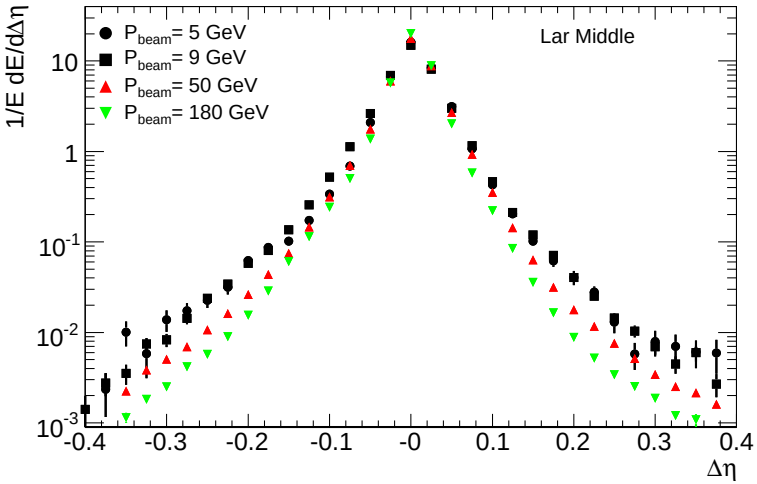


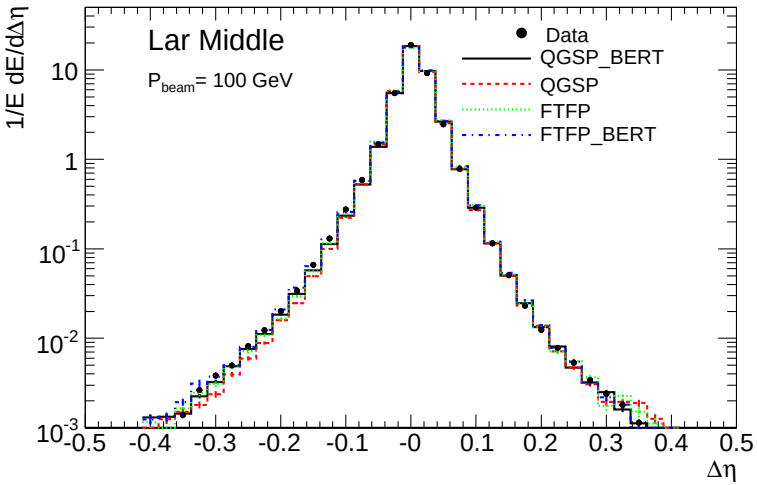


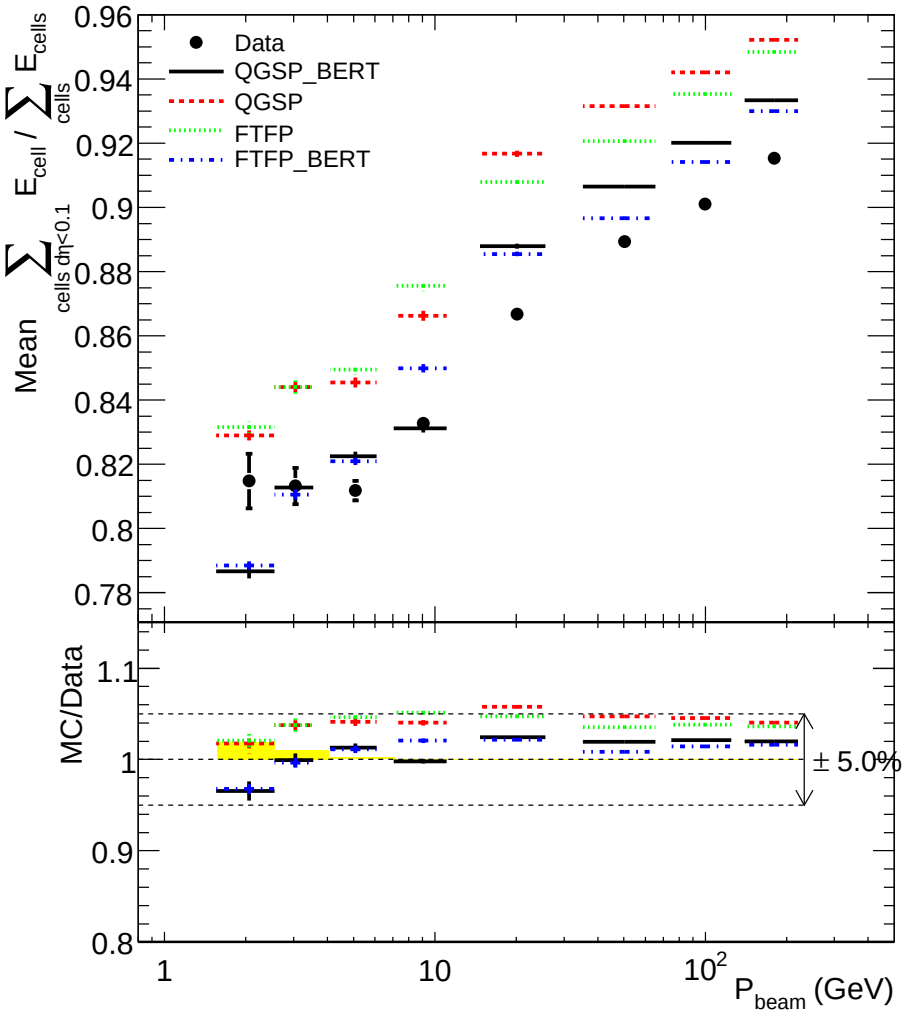


QGSP_BERT predicts higher response, nevertheless within 5%

Lateral Profile







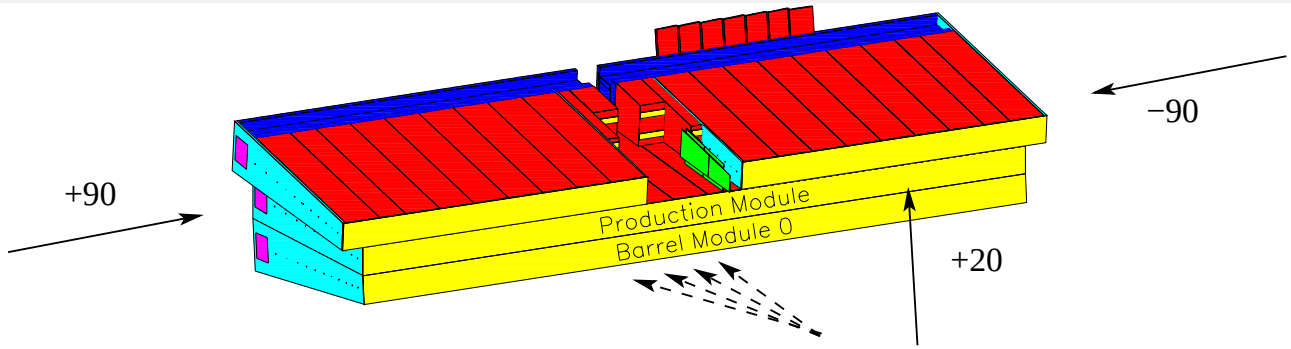
Geant4 predicts narrower showers compared to data.

The fraction of energy in the core is described within ±5%

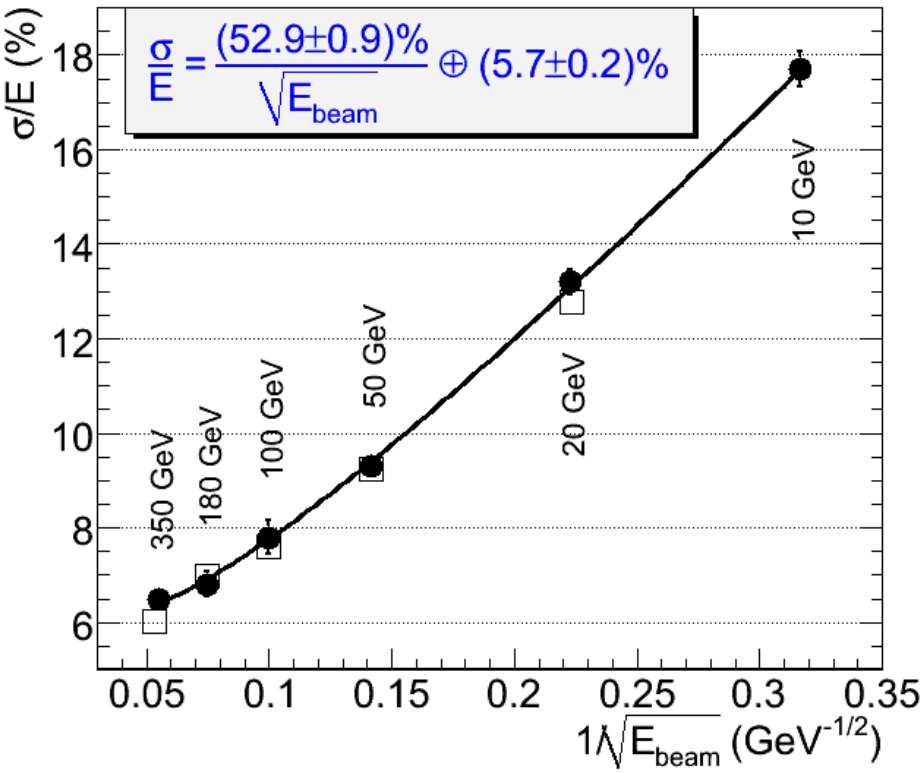
TileCal Test Beam Setup

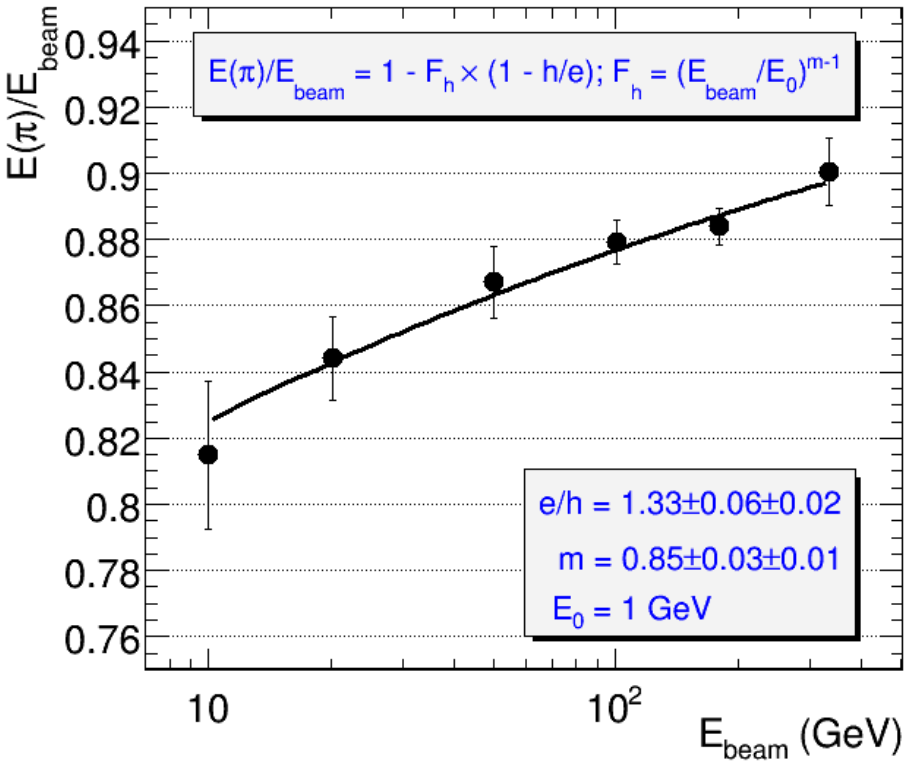
Special Runs

- Beam impinging the detector from the side.
- The depth is more than 25 nuclear interaction lengths (λ).
- Longitudinally showers are fully contained.
- Lateral containment of showers is more than 99%.
- Pion/proton separation is done by Cherenkov detector.
- Data are compared to Geant4 simulation using version 9.3.



TileCal Performance

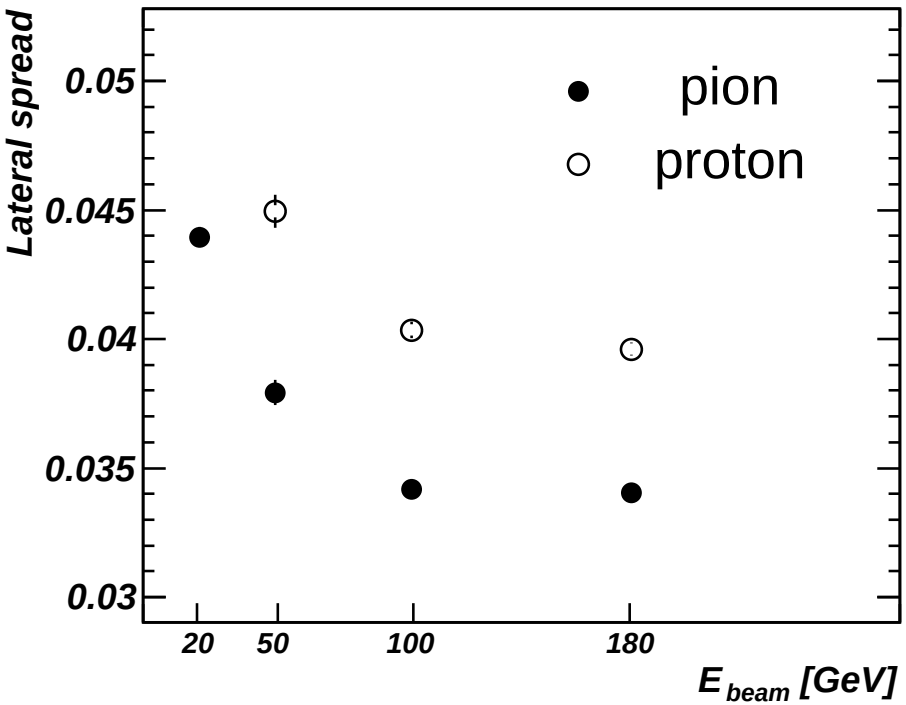


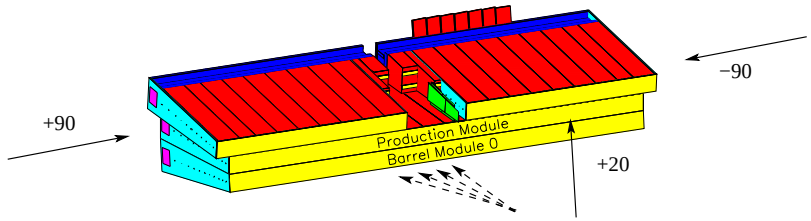


Good performance in terms of energy resolution

Lateral Spread

The ratio of energy measured in the bottom and central modules is an estimate of lateral spread.





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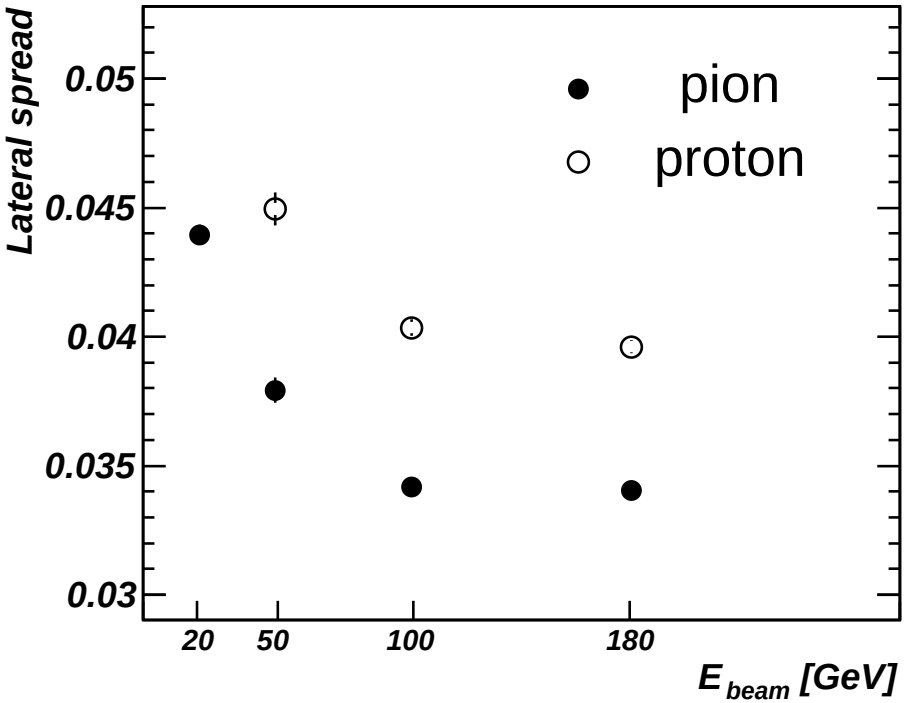

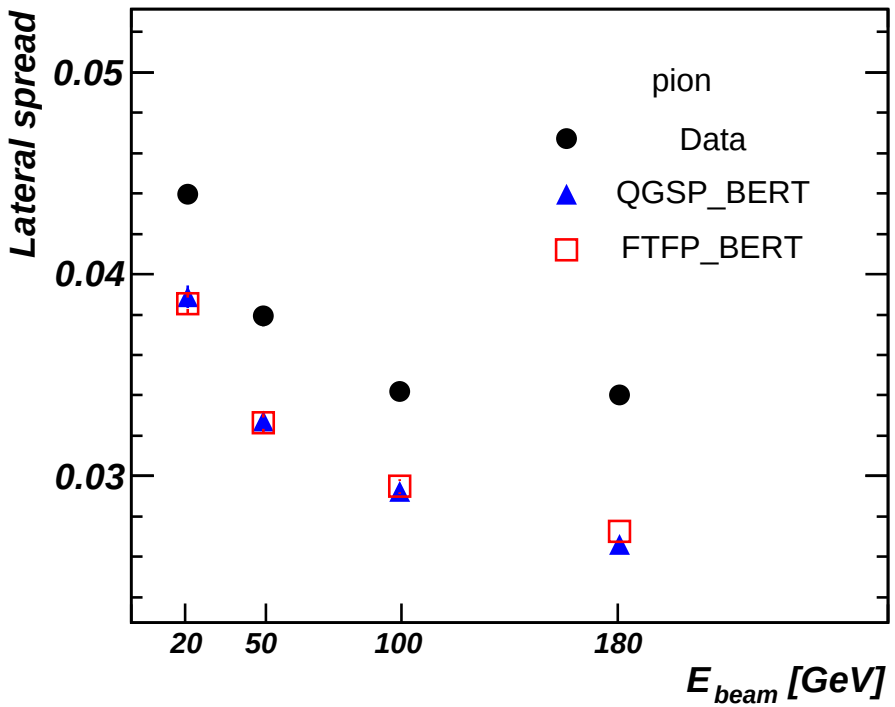

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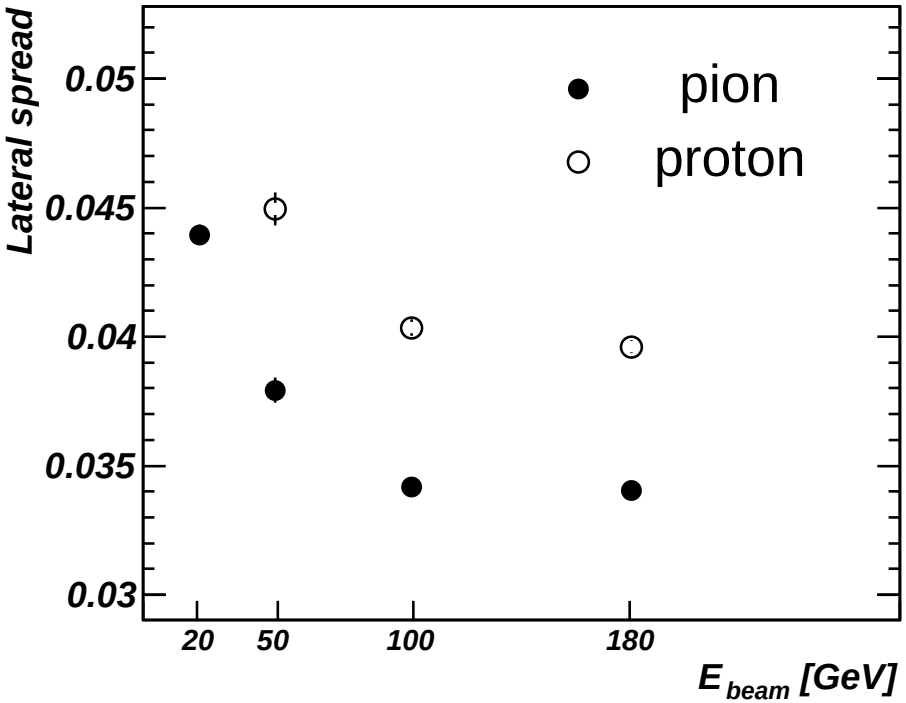

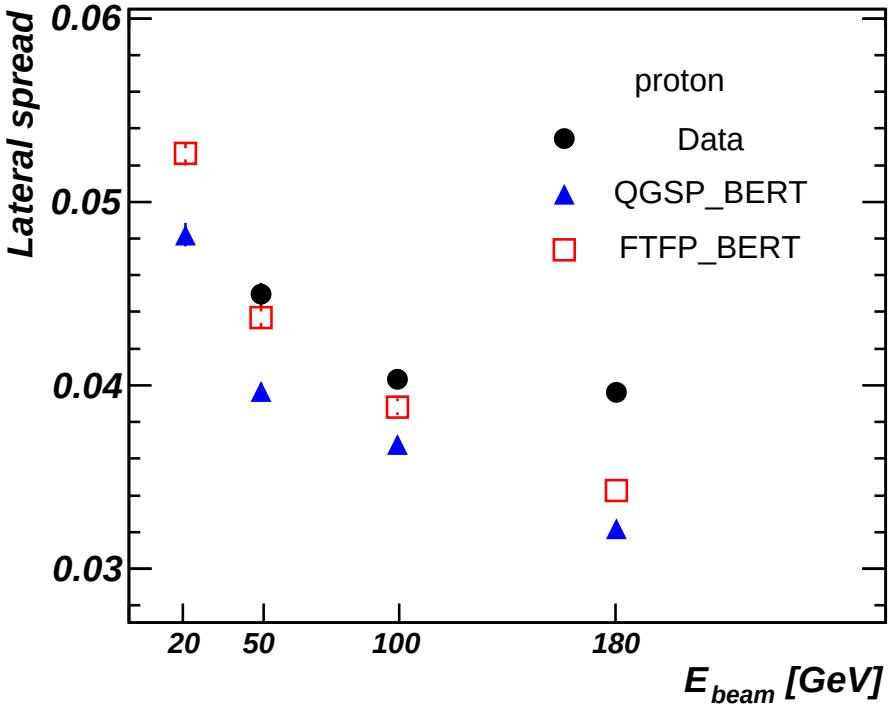

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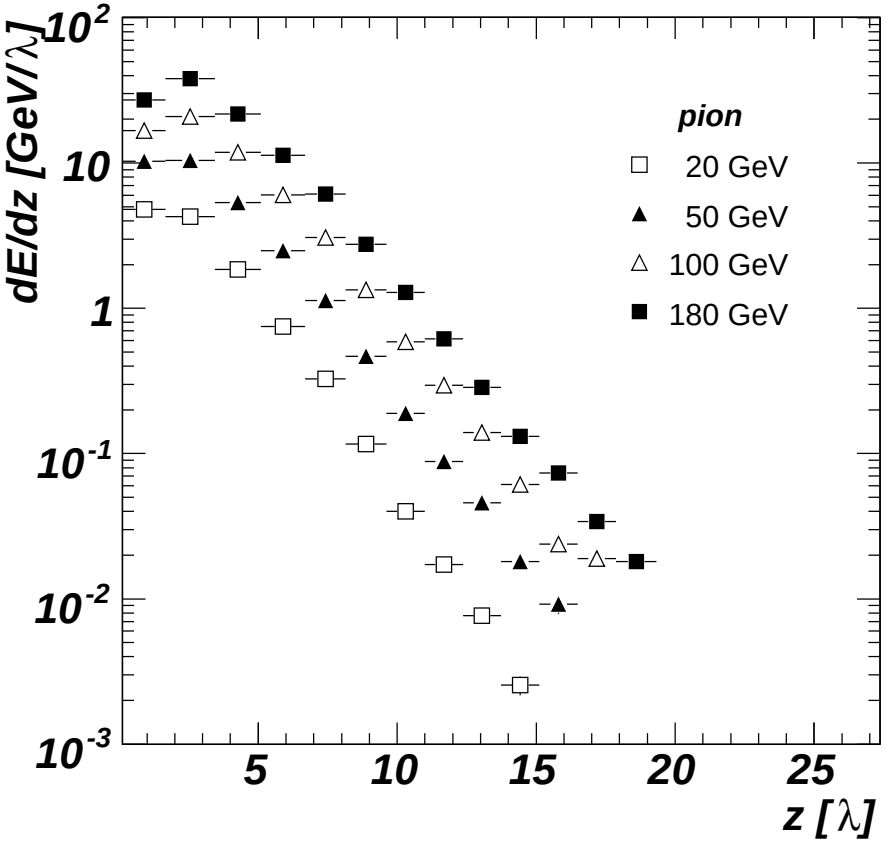
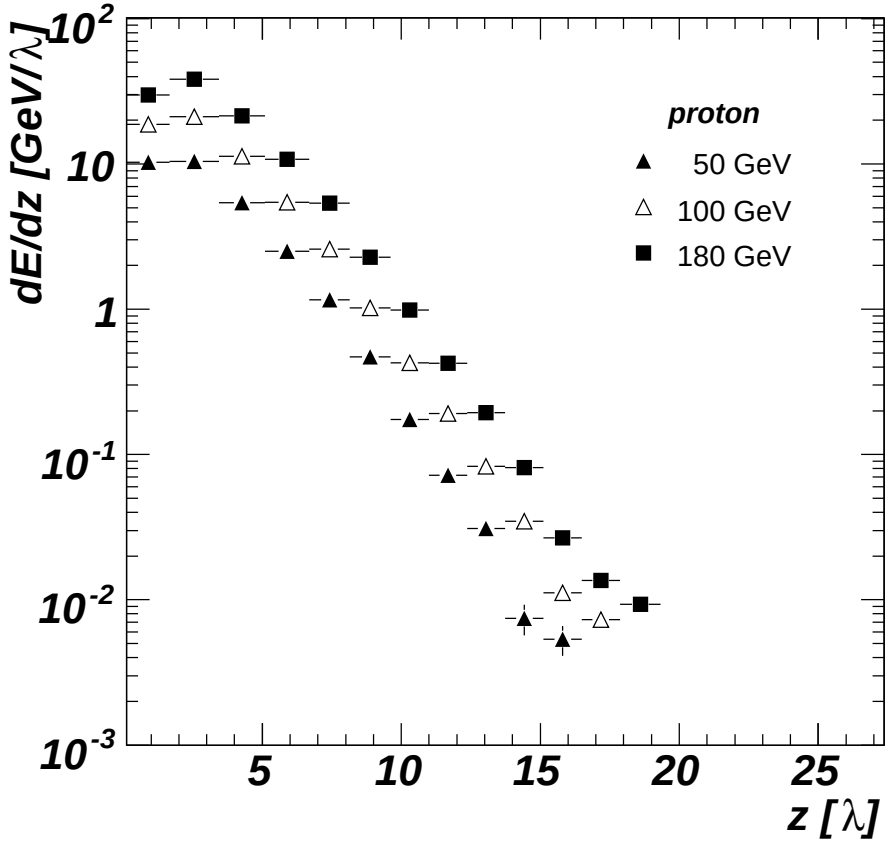
Longitudinal Profile

- The first measurement of longitudinal profile of pion and proton induced showers up to 20λ.





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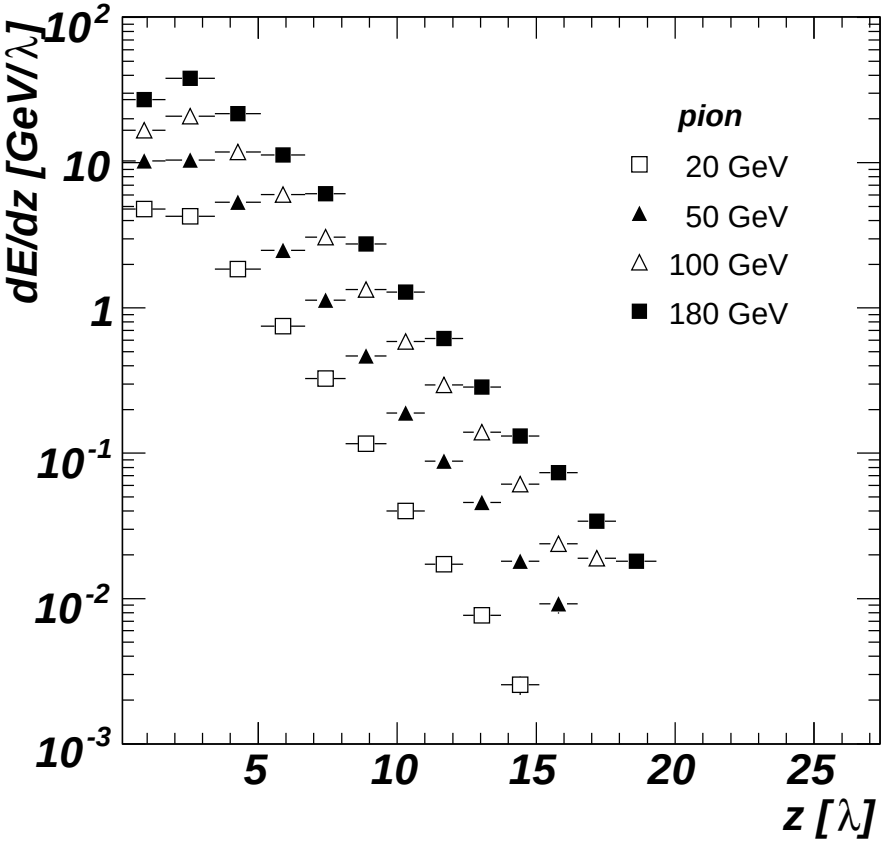

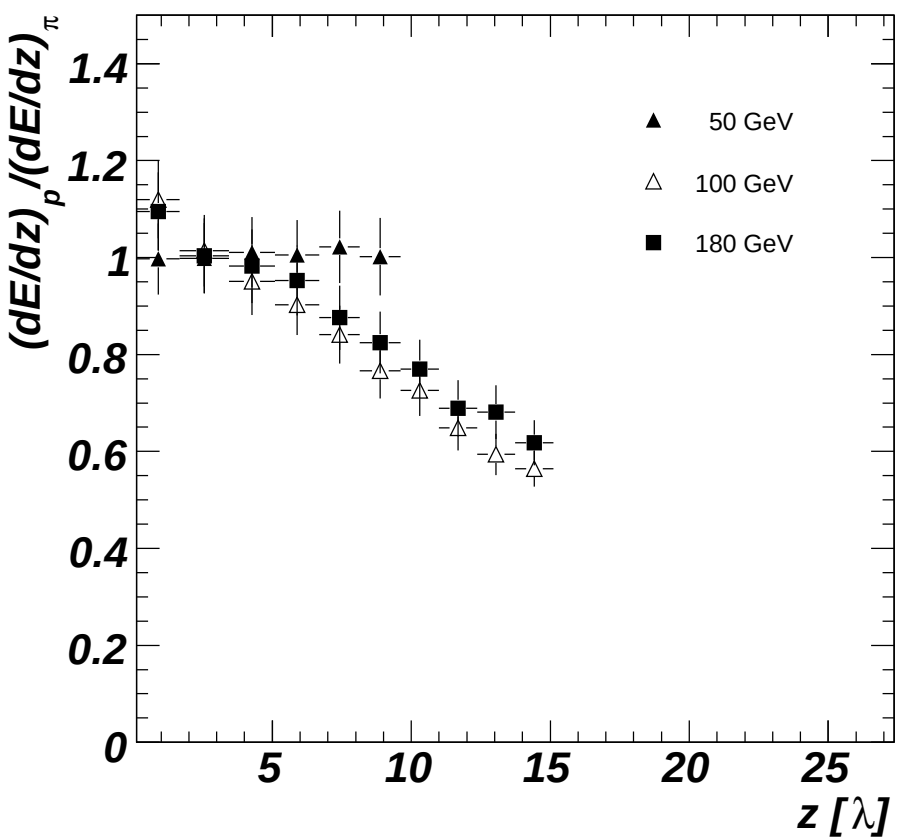

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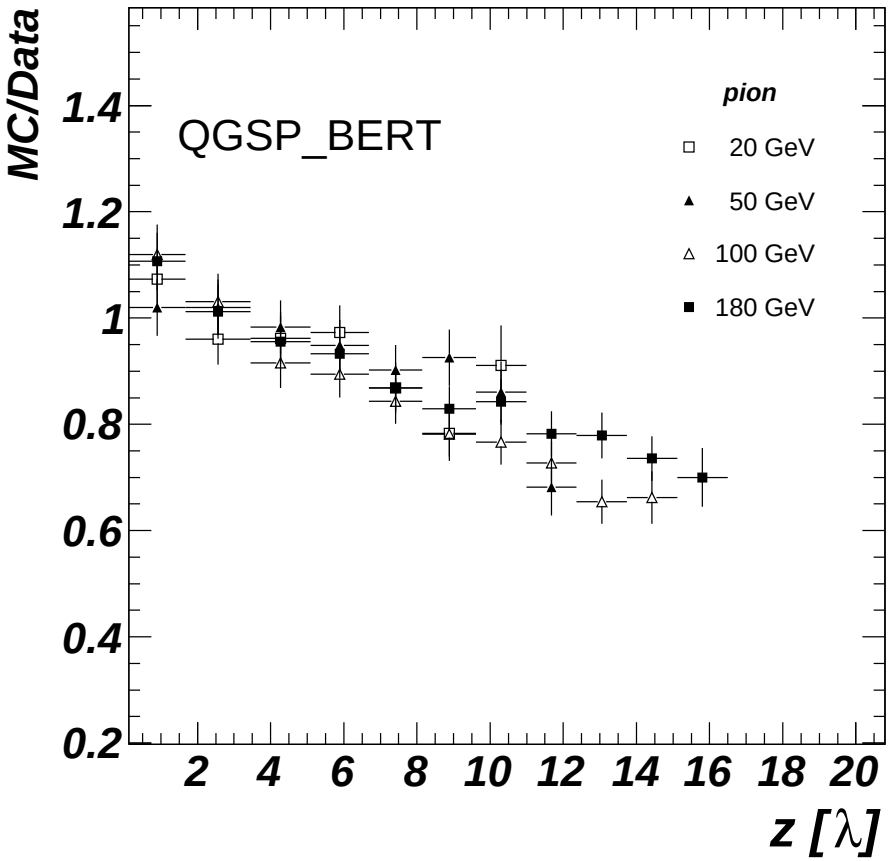
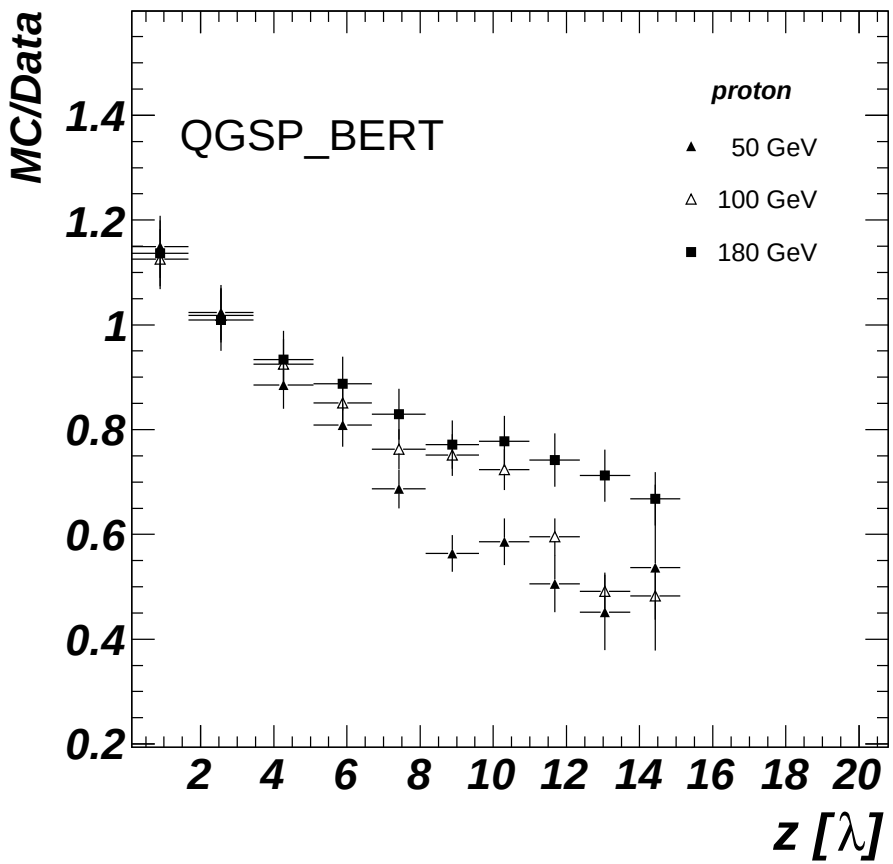




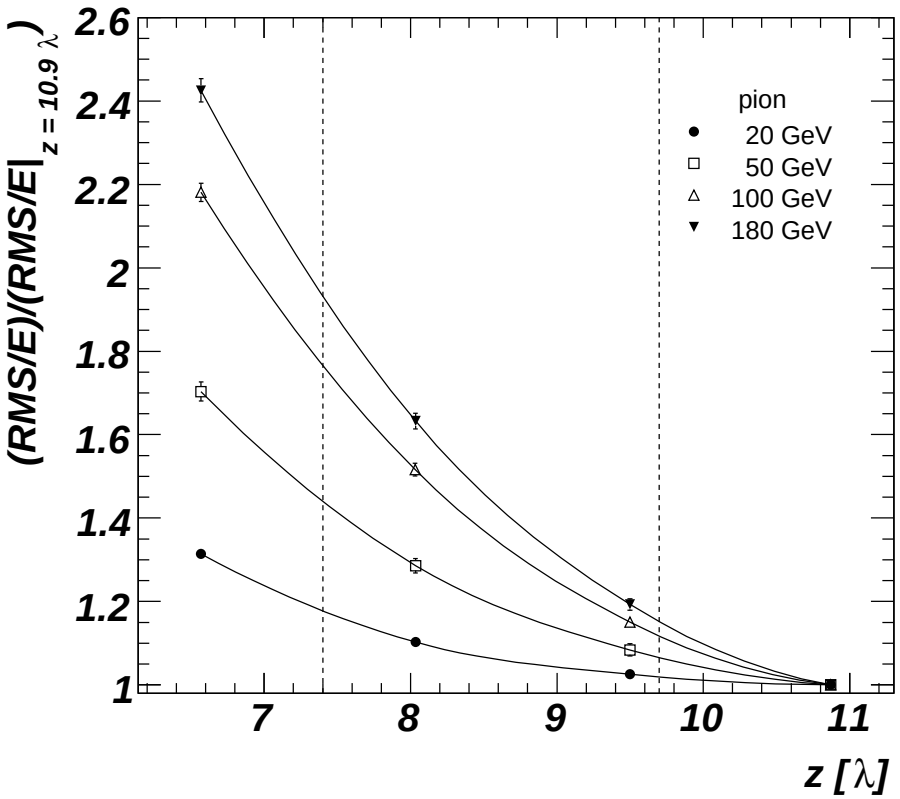
At 10 λ 10–20% less energy is predicted.

At 10 λ 20–40% less energy in MC.

- Simulated showers are shorter than data.
- The description of longitudinal development of proton induced showers is worse compared to pion induced ones.

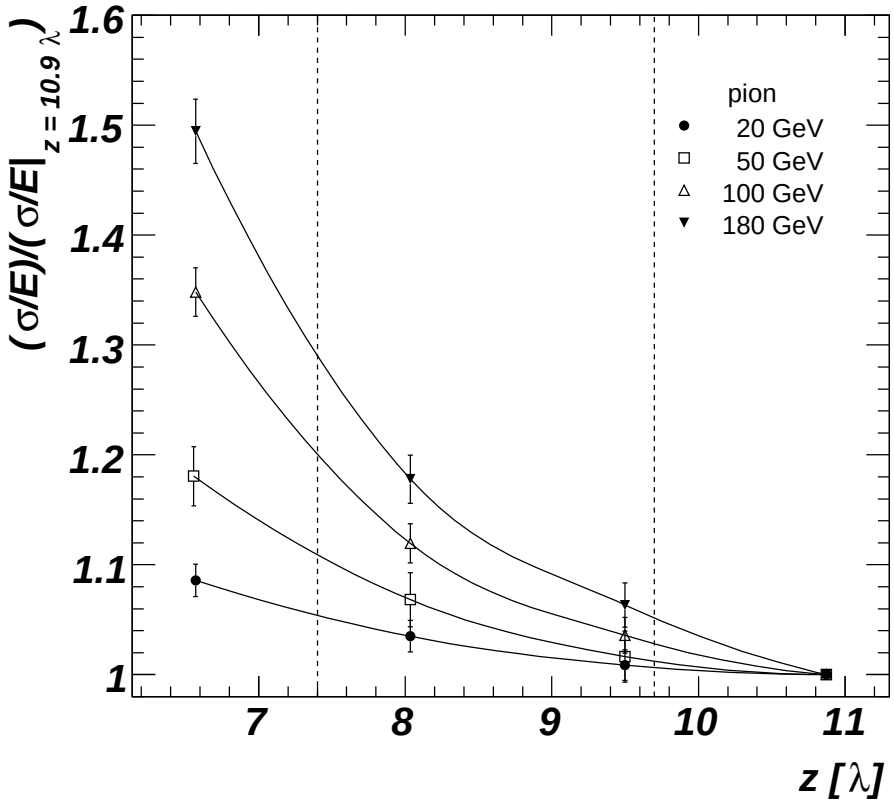
Impact of longitudinal leakage on energy resolution

Resolution is defined as RMS/mean ratio



Large impact due to events with large leakage

Resolution is defined as $\sigma/peak$ ratio using Gaussian fit with $\pm 2\sigma$



Small impact since tails are not taken into account

Vertical lines indicate the depth of Tile calorimeter alone and combined with EM calorimeter at $\eta = 0$.

Conclusion

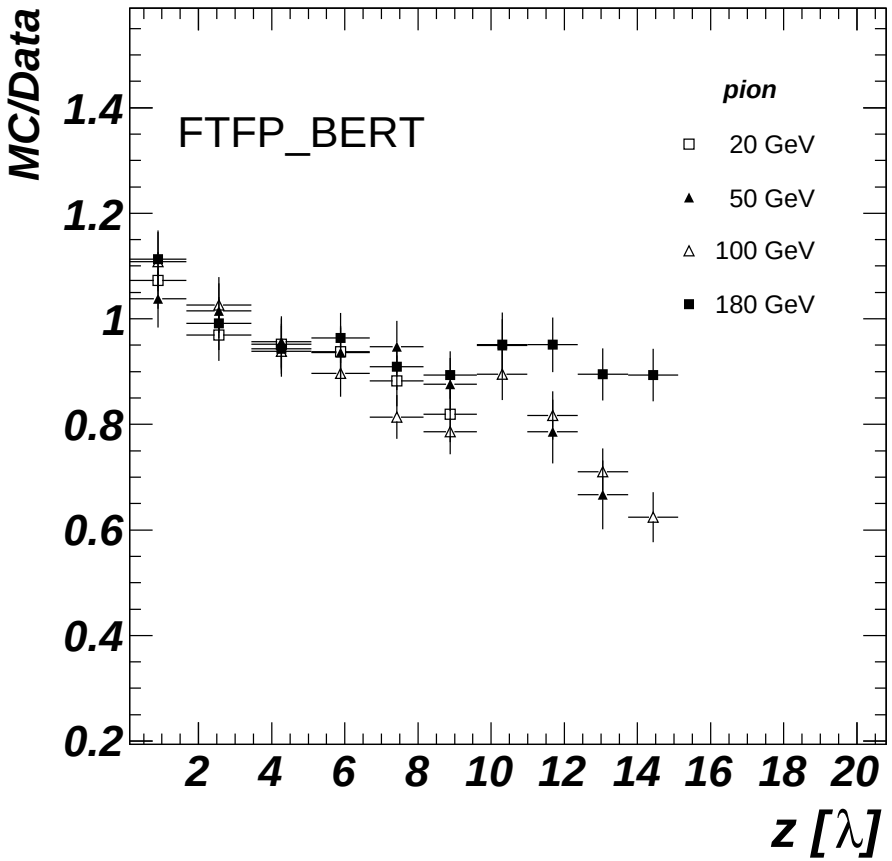
- The response of the ATLAS calorimeters to hadrons is described within 5% in the energy range 2–350 GeV.
- Simulation is able to describe the resolution with 10% accuracy.
- Proton induced showers are shorter than pion induced ones, but they are laterally wider.
- Geant4 models predict shorter and narrower showers compared to the data.
- Addition of Bertini cascade model results in longer and wider showers as well as higher response and better resolution, which is generally in better agreement with the data.

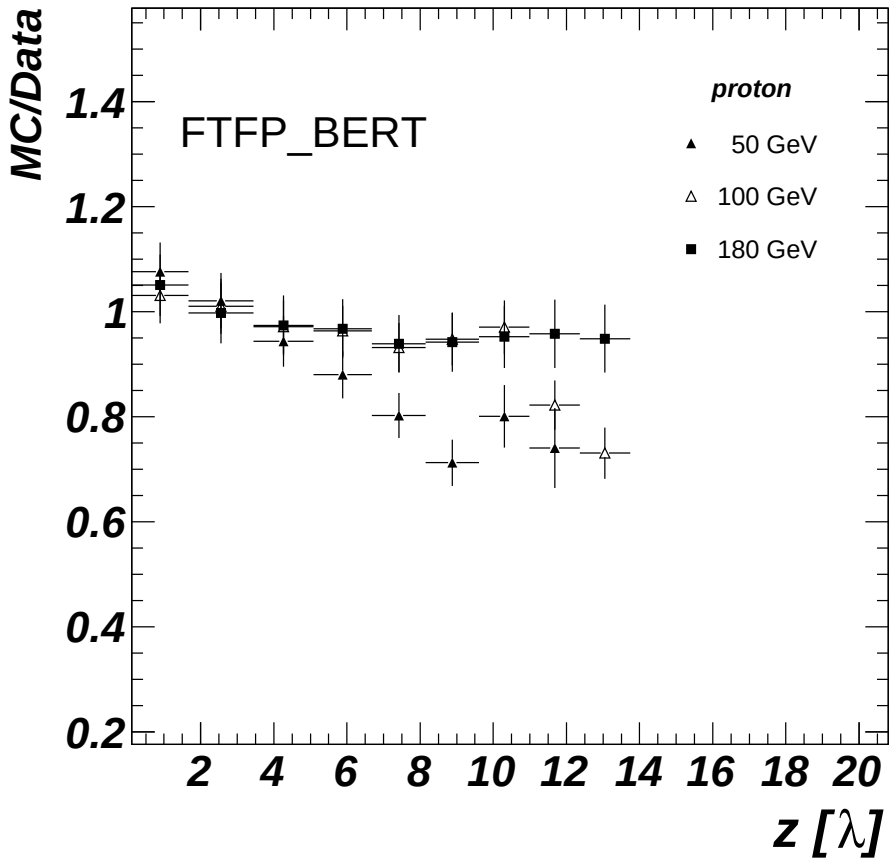
Backup

More information can be found in:

- Measurement of pion and proton response and longitudinal shower profiles up to 20 nuclear interaction lengths with the ATLAS Tile calorimeter, *NIM A, 615 (2010) pp. 158–181*
- Study of energy response and resolution of the ATLAS barrel calorimeter to hadrons of energy from 20 to 350 GeV, *accepted in NIM*
- Study of the response of the ATLAS central calorimeter to pions of energies from 3 to 9 GeV, *NIM A 607 (2009) pp. 372–386*
- Response and Shower Topology of 2 to 180 GeV Pions Measured with the ATLAS Barrel Calorimeter at the CERN Test-beam and Comparison to Monte Carlo Simulations, *ATLAS Public note*

Longitudinal Profile





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Geant4 Models