Geant4 validation in High Energy Physics

Margar Simonyan
LAPP
on behalf of HEP community

XIV Geant4 workshop in Catania, Italy

Outline

1. Results From ATLAS Test-Beam
   - Tile Calorimeter
   - Hadronic End-Cap
   - Combined Test-Beam
2. CMS Test-Beam
3. Results from LHCb
4. Results from CALICE
5. Summary

Outline

1. Results From ATLAS Test-Beam
   - Tile Calorimeter
   - Hadronic End-Cap
   - Combined Test-Beam
2. CMS Test-Beam
3. Results from LHCb
4. Results from CALICE
5. Summary

Outline

1. Results From ATLAS Test-Beam
   - Tile Calorimeter
   - Hadronic End-Cap
   - Combined Test-Beam
2. CMS Test-Beam
3. Results from LHCb
4. Results from CALICE
5. Summary

Outline

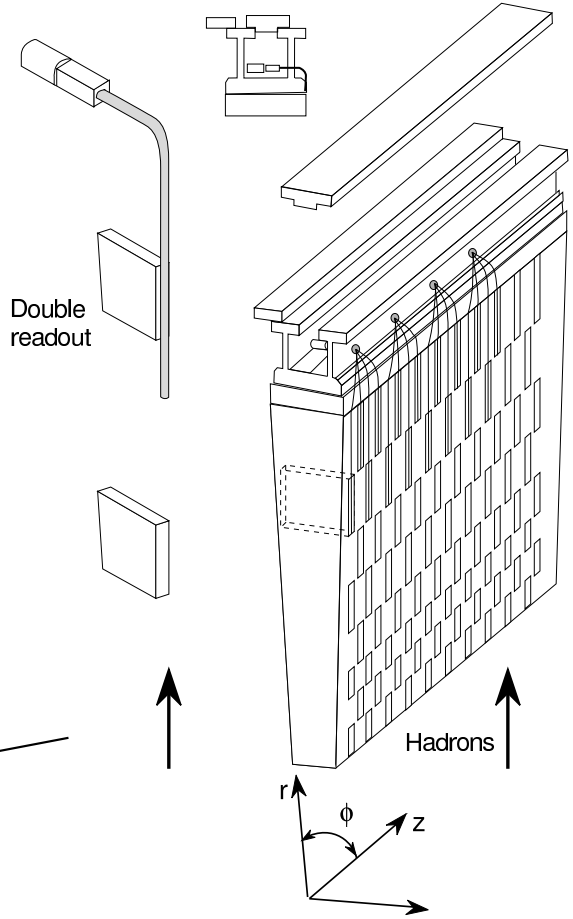
1. Results From ATLAS Test-Beam
   - Tile Calorimeter
   - Hadronic End-Cap
   - Combined Test-Beam
2. CMS Test-Beam
3. Results from LHCb
4. Results from CALICE
5. Summary

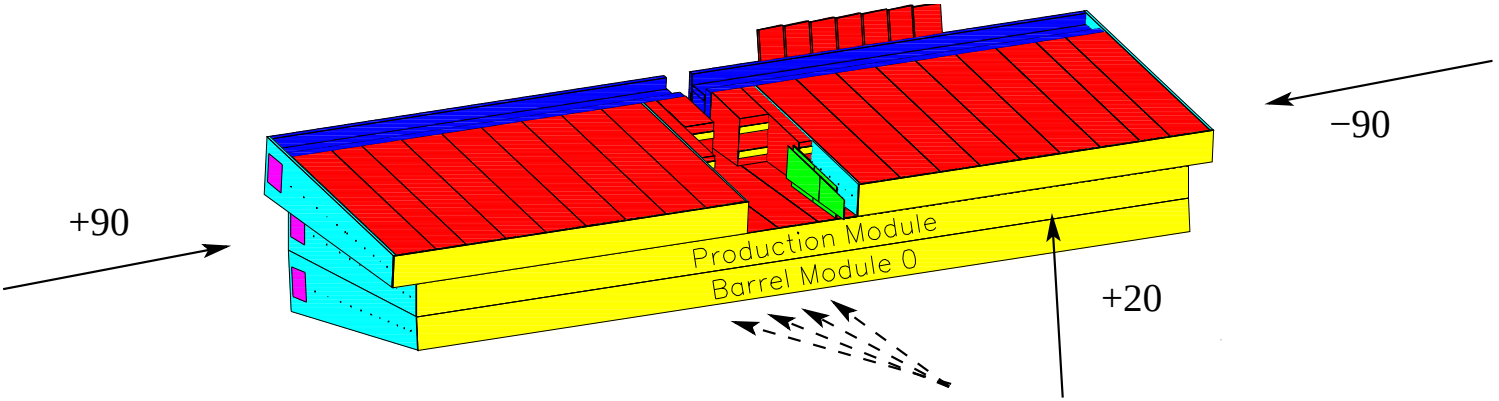
Outline

1. Results From ATLAS Test-Beam
   - Tile Calorimeter
   - Hadronic End-Cap
   - Combined Test-Beam
2. CMS Test-Beam
3. Results from LHCb
4. Results from CALICE
5. Summary

ATLAS Tile Calorimeter

- Iron-scintillator hadronic calorimeter located in the central region of the ATLAS detector.
- Scintillating tiles are placed perpendicularly to the LHC colliding beams.
- 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%.
- Comparison with Geant4 version 9.2 and 9.3β.

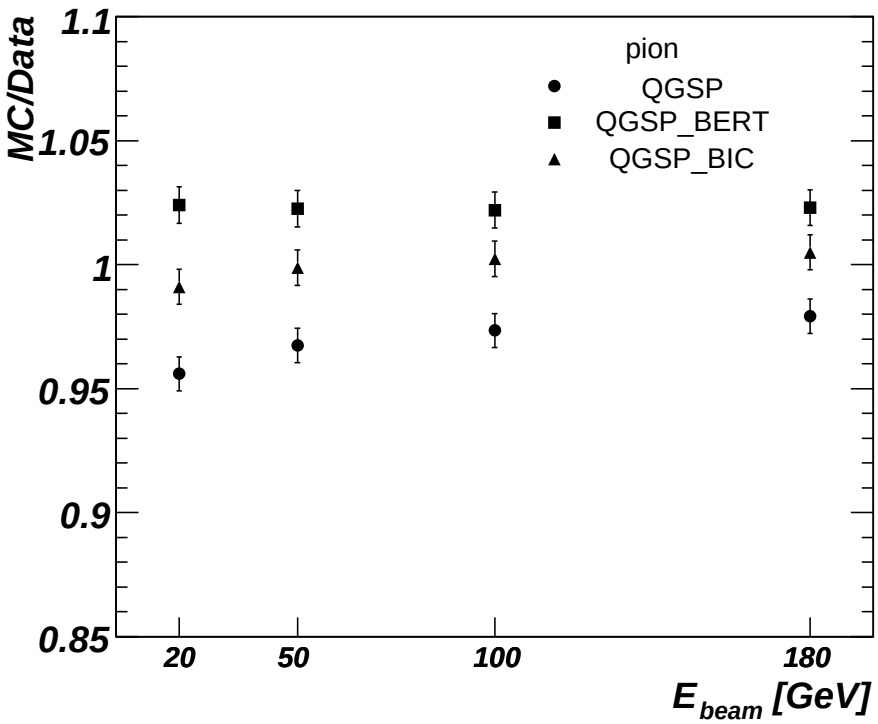




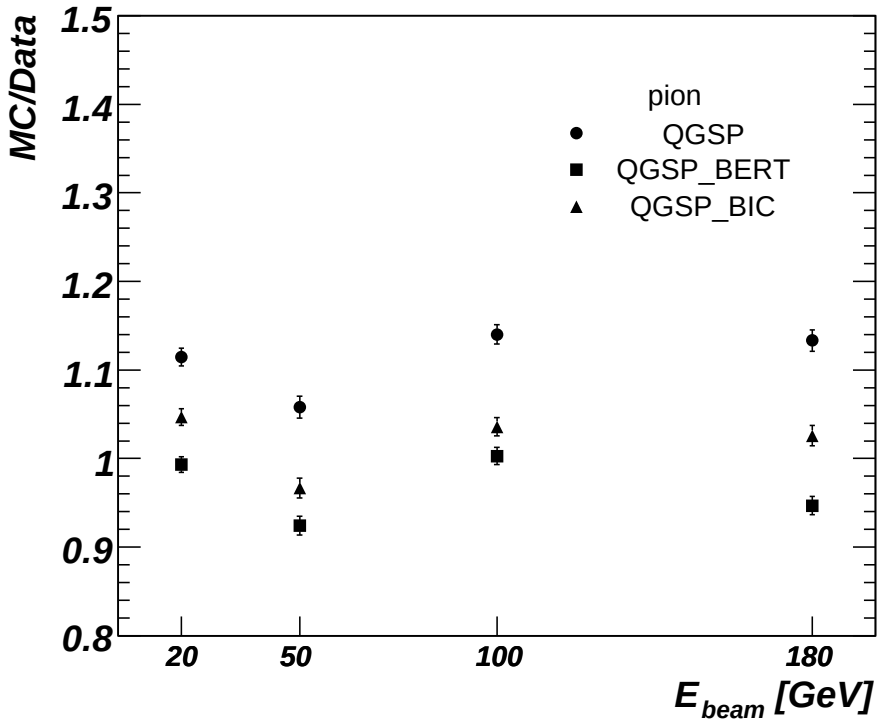
Pion Response and Resolution

Quark-Gluon String

Response



Resolution

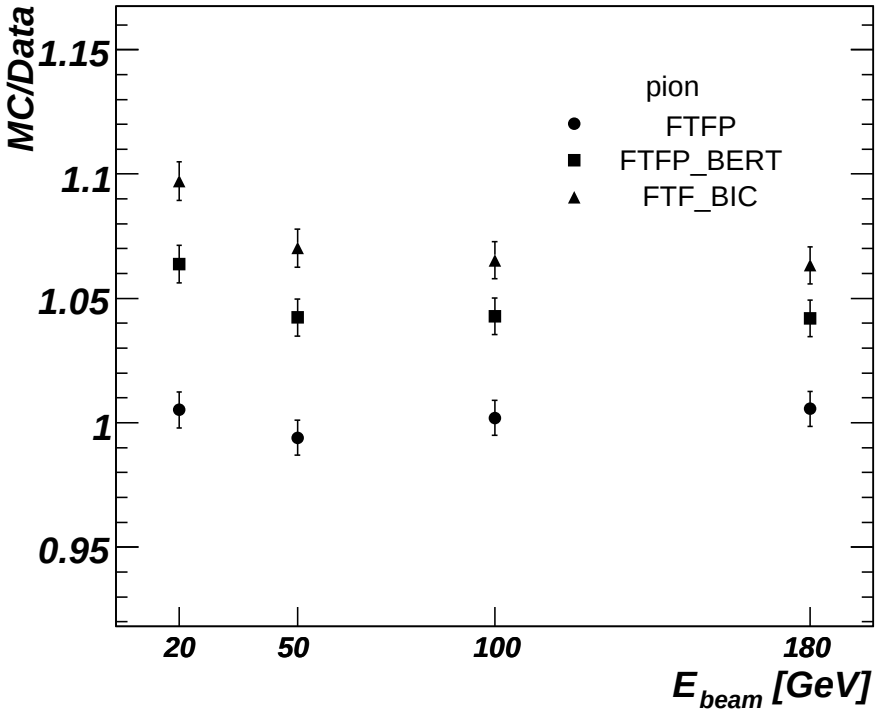


- Cascade models increase the response. QGSP_BIC describes data better.
- 10% worse resolution with QGSP, within $\pm$ 10% with cascade models.

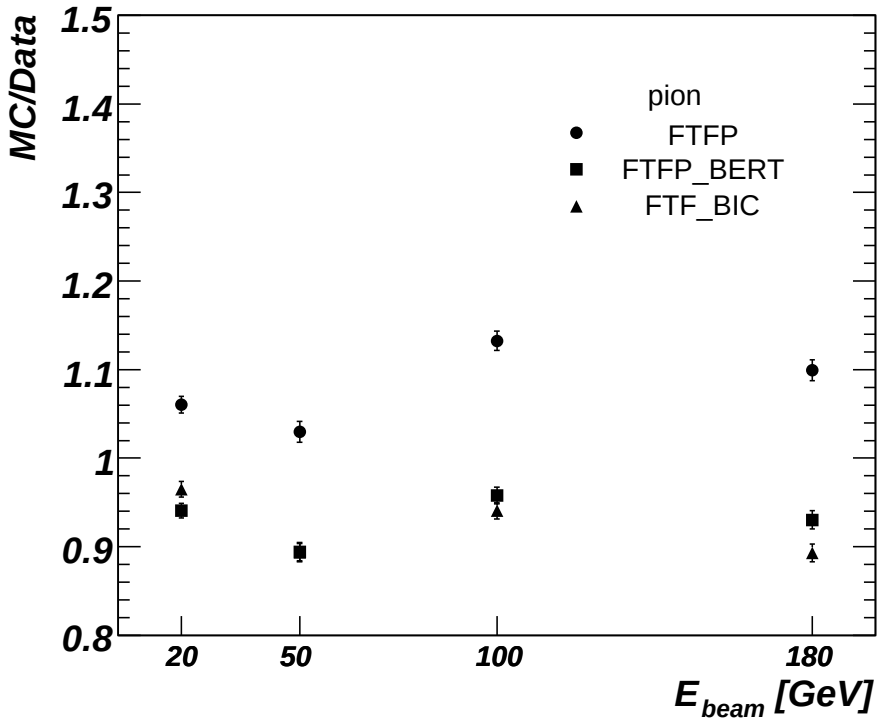
Pion Response and Resolution

Fritiof

Response



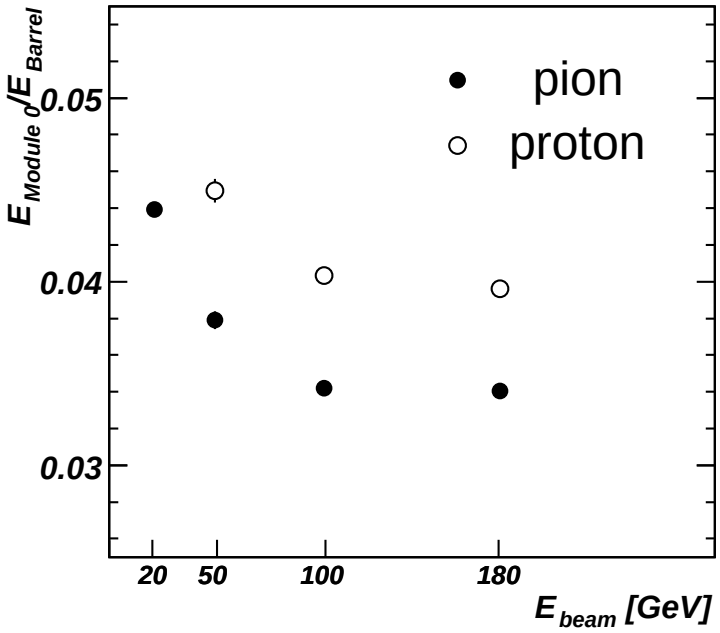
Resolution

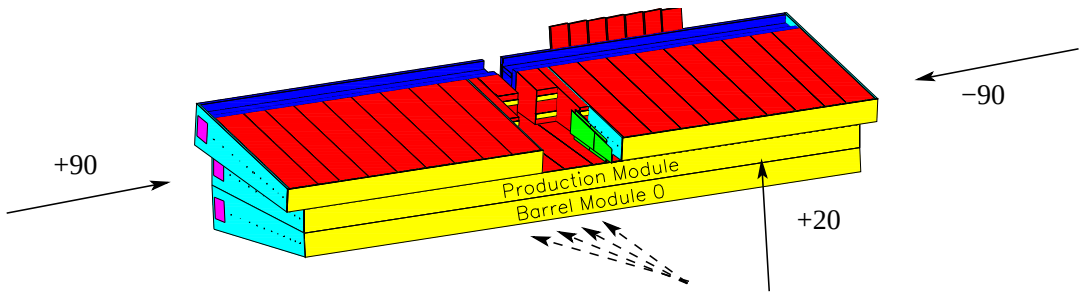


- The response is too high with cascade models. Binary cascade predicts a higher response than Bertini.
- Without cascade models the resolution is worse.

Lateral Spread

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

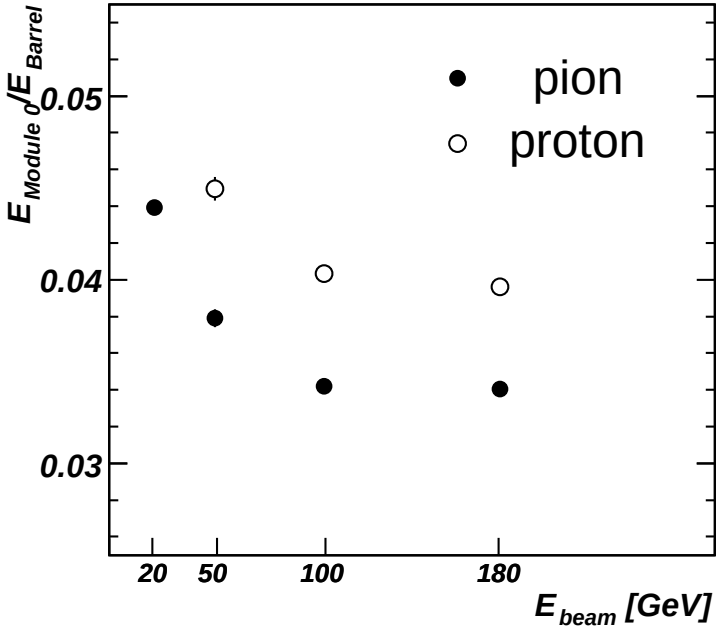


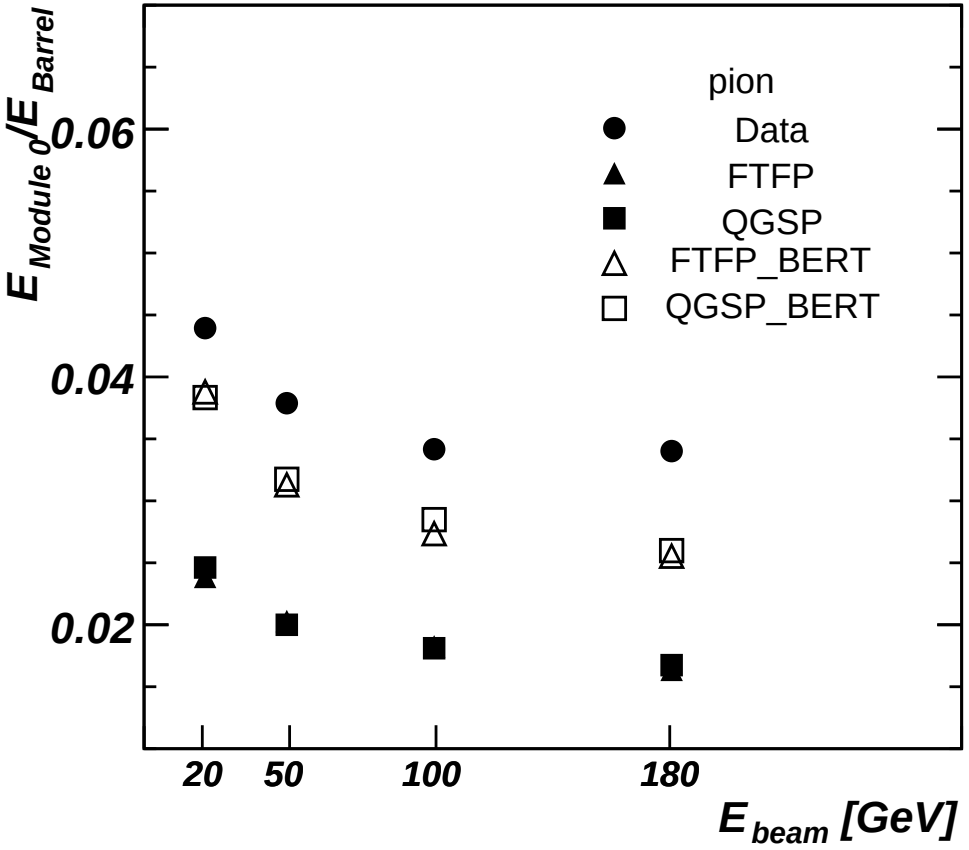


- Proton induced showers are wider than pion induced ones.
- Showers simulated using QGSP and FTFP are too narrow.
- Better description with cascade models.

Lateral Spread

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

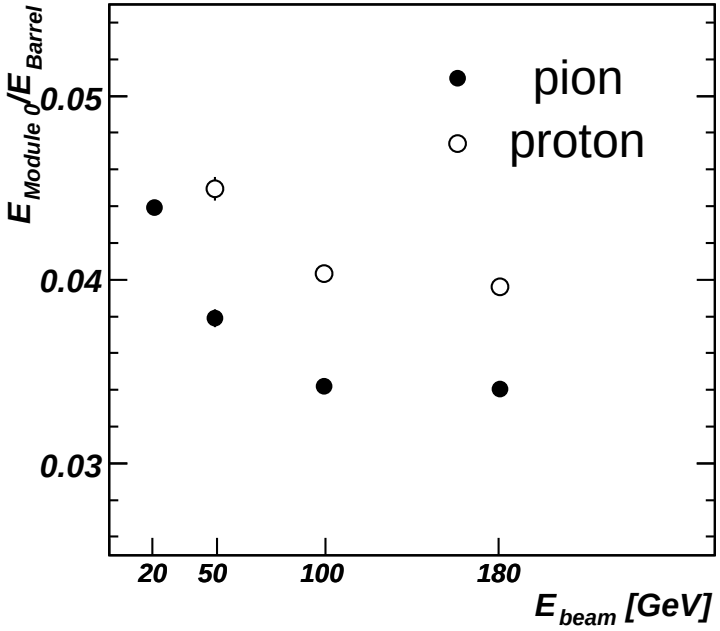


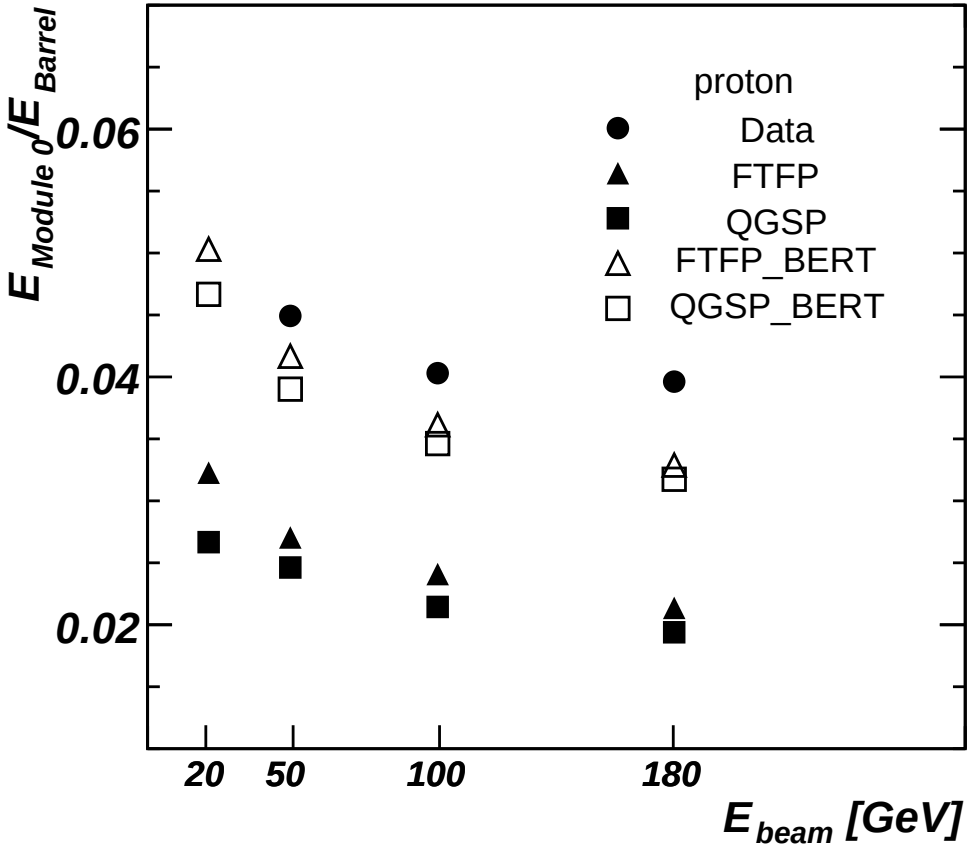


- Proton induced showers are wider than pion induced ones.
- Showers simulated using QGSP and FTFP are too narrow.
- Better description with cascade models.

Lateral Spread

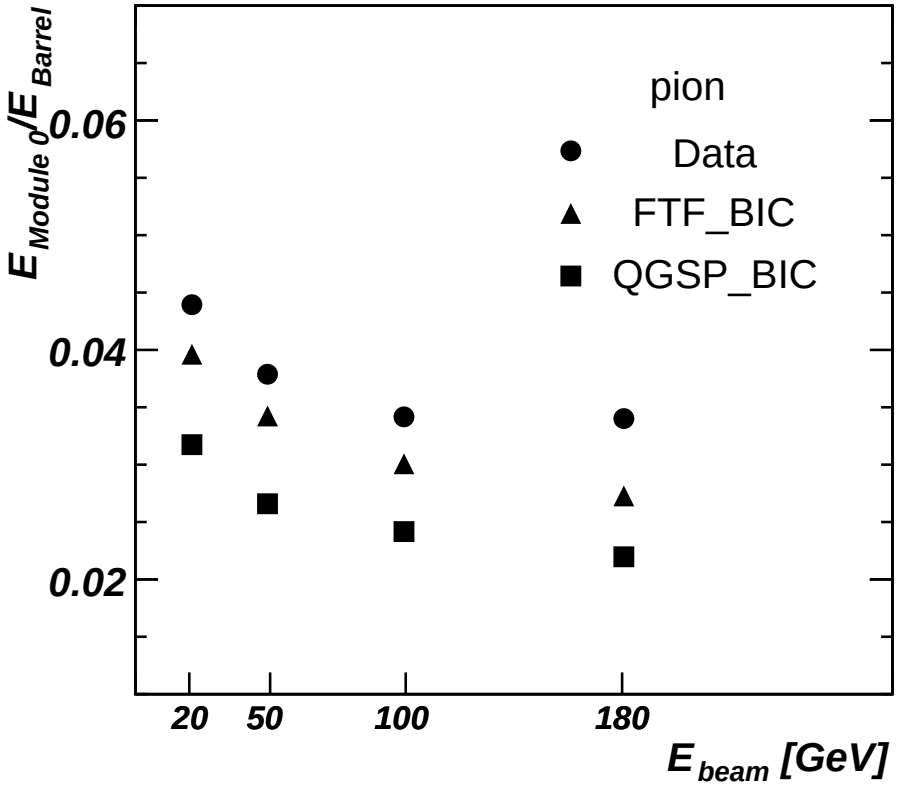
The ratio of energy measured in the bottom and central modules is an estimate of lateral spread.

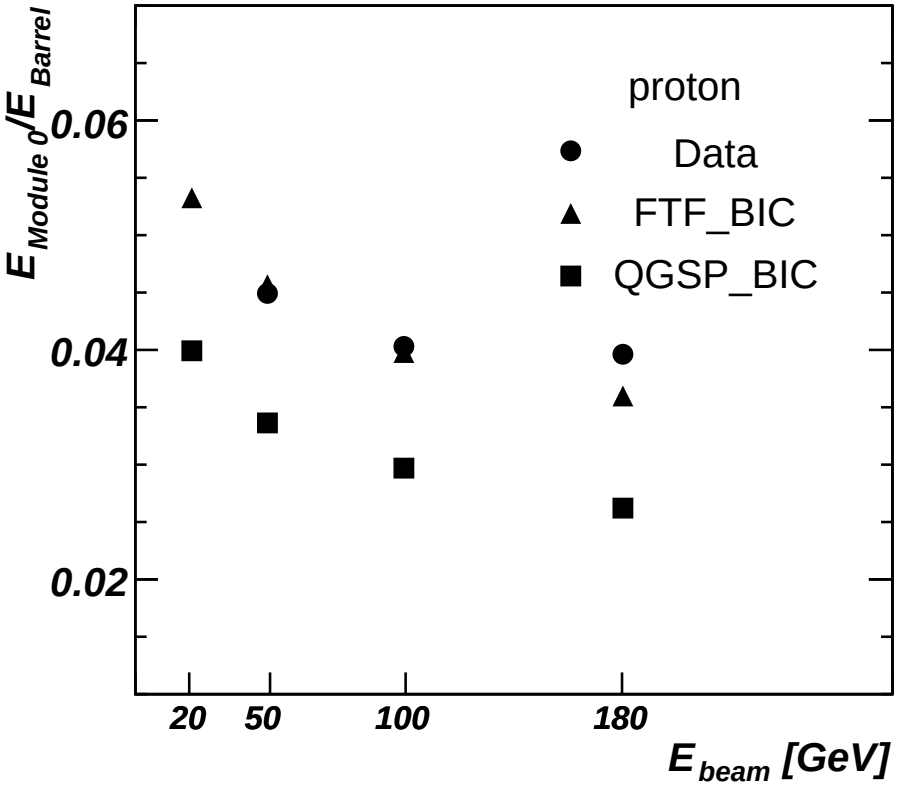




- Proton induced showers are wider than pion induced ones.
- Showers simulated using QGSP and FTFP are too narrow.
- Better description with cascade models.

Lateral Spread



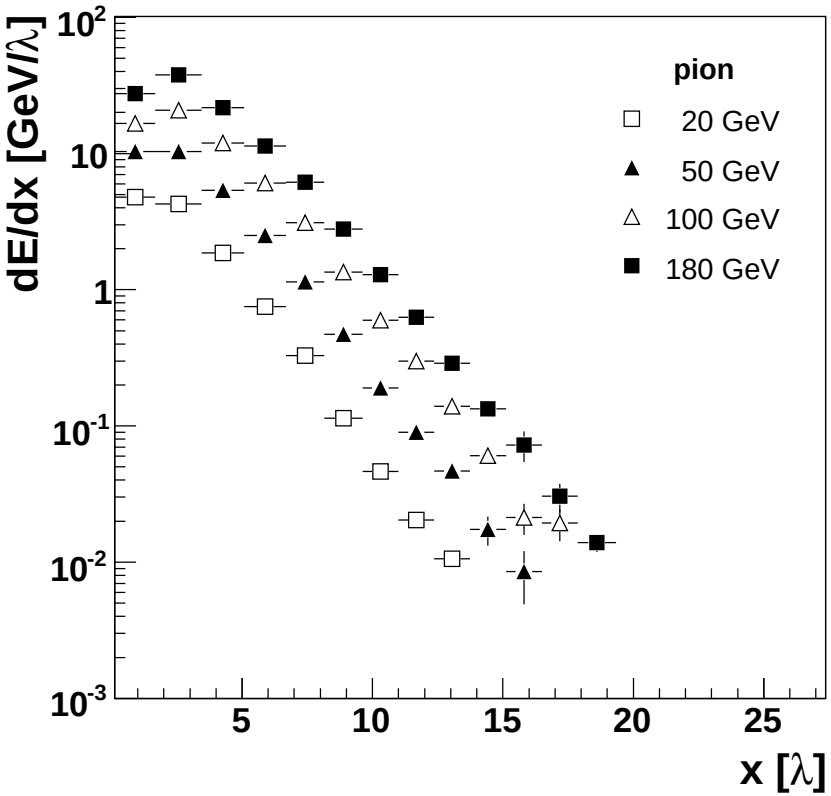


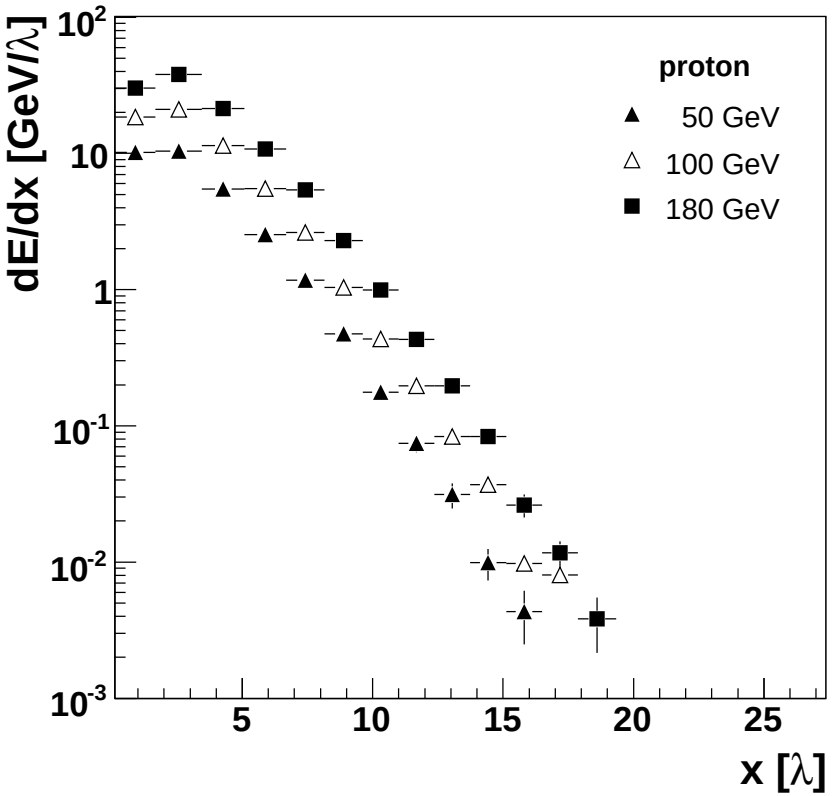
- Too narrow showers with QGSP_BIC.
- Good description with FTF_BIC.

Longitudinal Profile

Pions and Protons

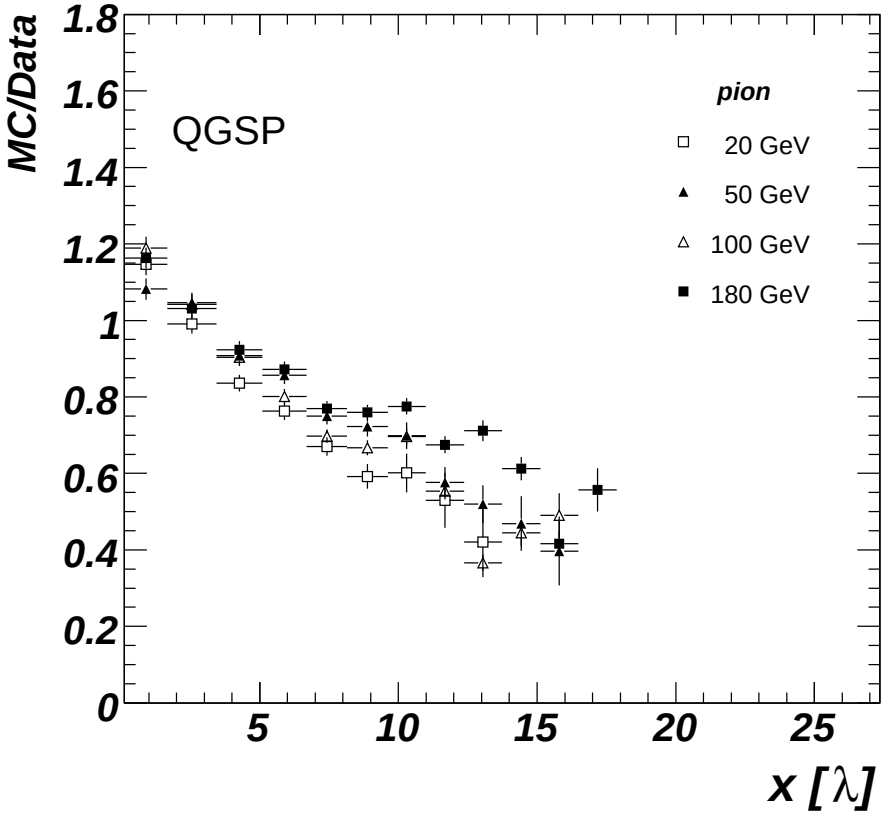
- The first measurement of longitudinal profile of pion and proton induced showers up to 20λ.

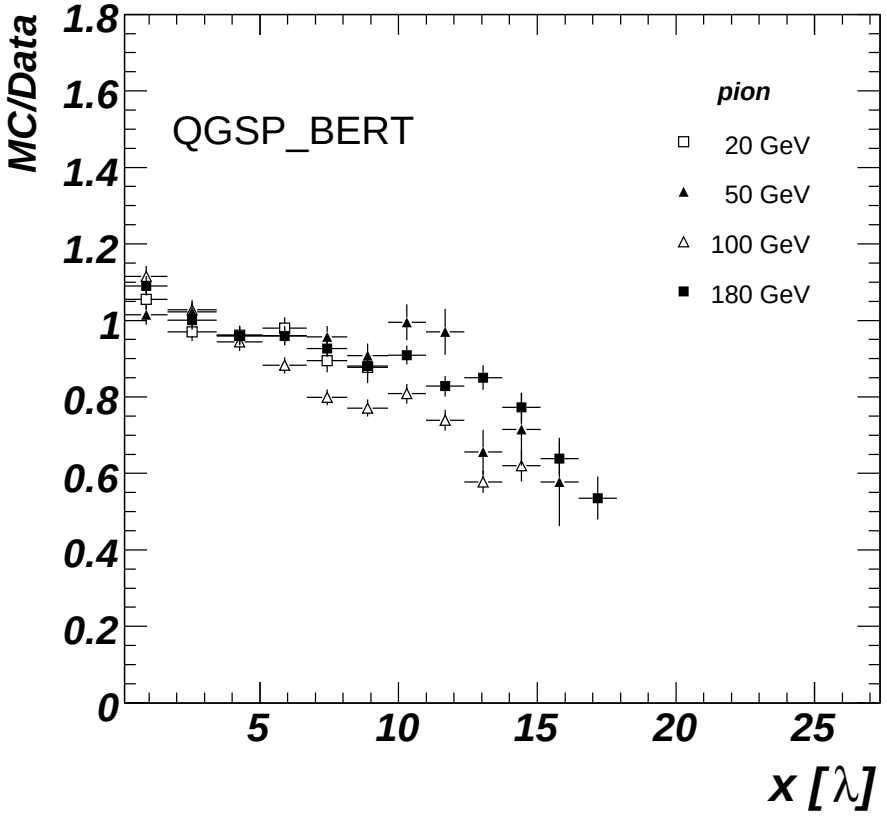




Longitudinal Profile

Pions

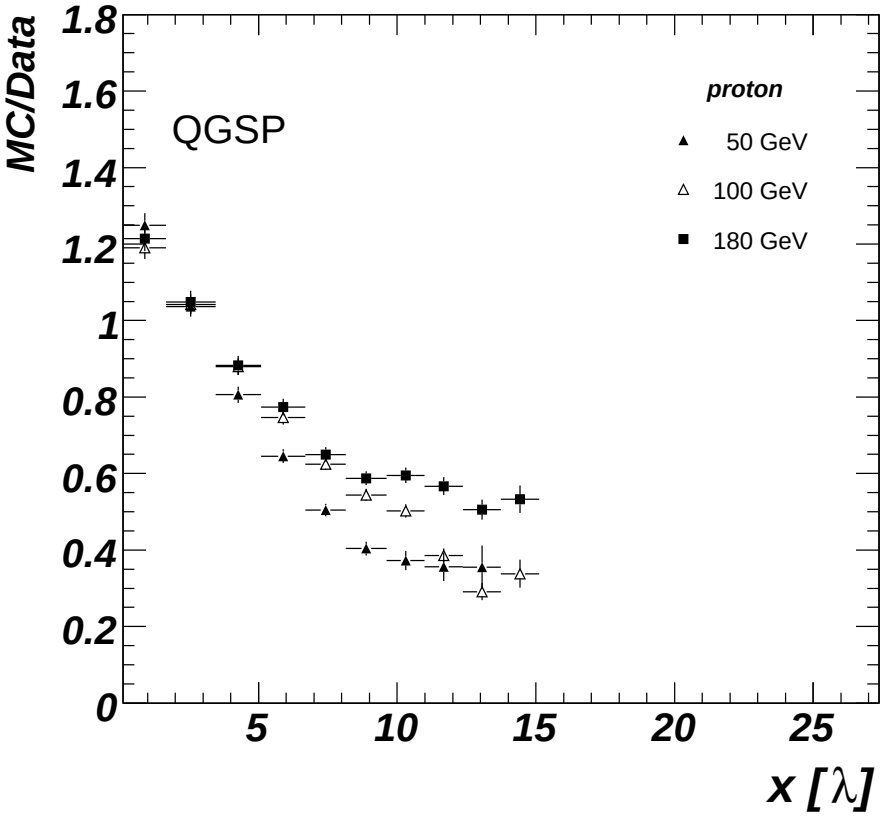


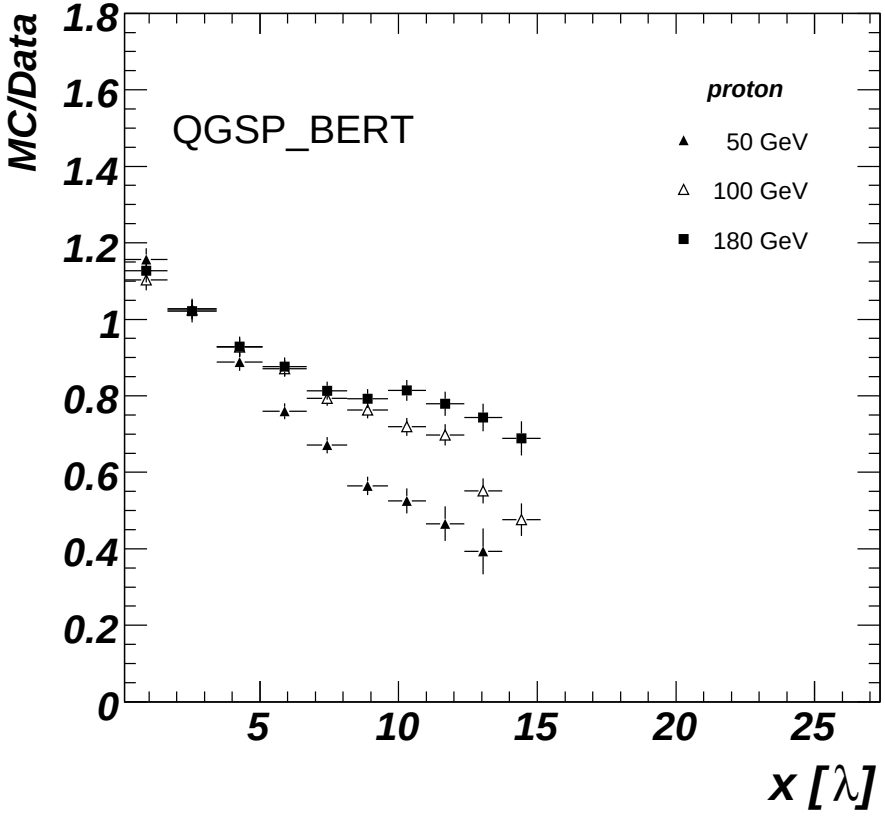


- Showers simulated with QGSP are too short, $20 - 40\%$ less energy at 10λ.
- Adding Bertini makes showers longer, up to 10λ within $\pm 15\%$.

Longitudinal Profile

Protons

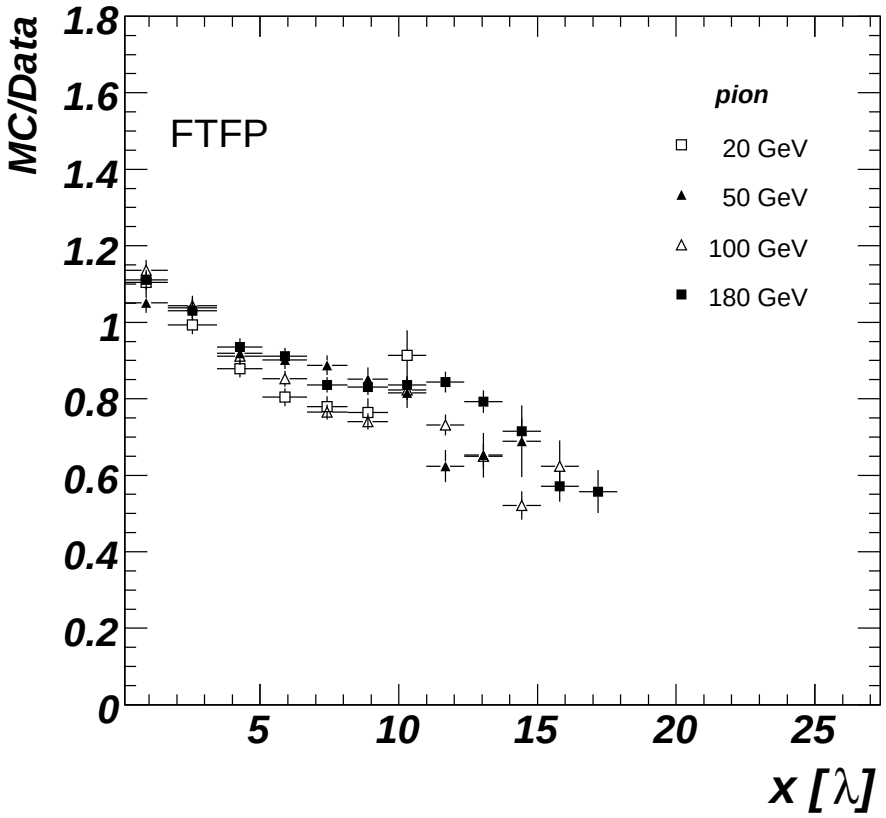


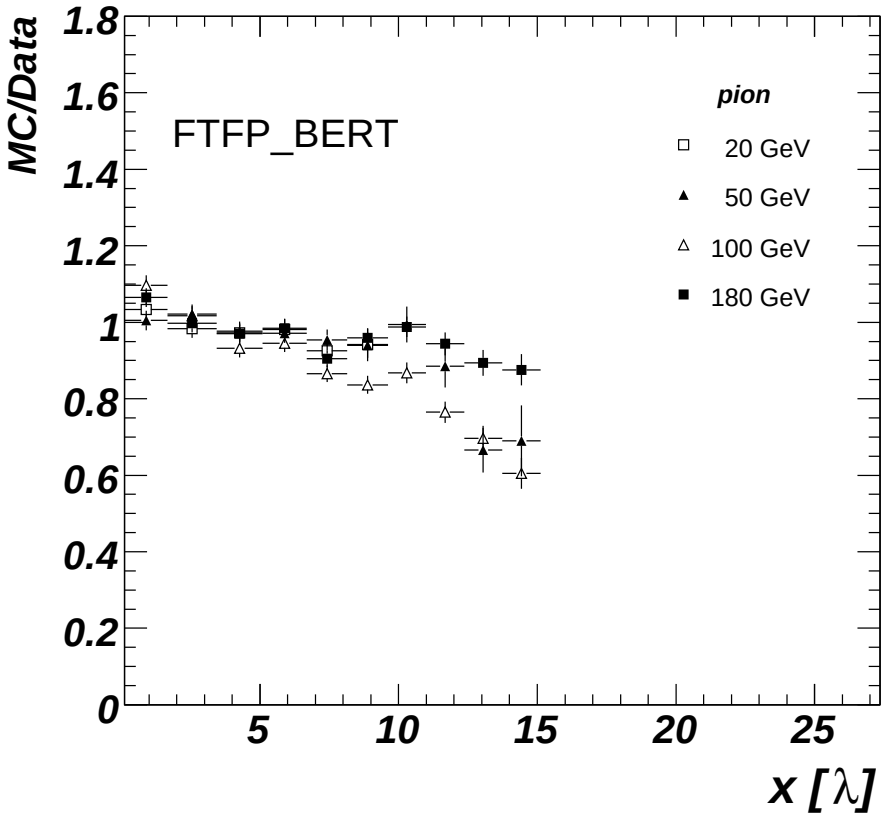


- Simulated showers are too short, at 10λ $40-60\%$ less energy.
- With Bertini at 10λ $20-40\%$ less energy.
- Protons are described worse than pions.

Longitudinal Profile

Pions

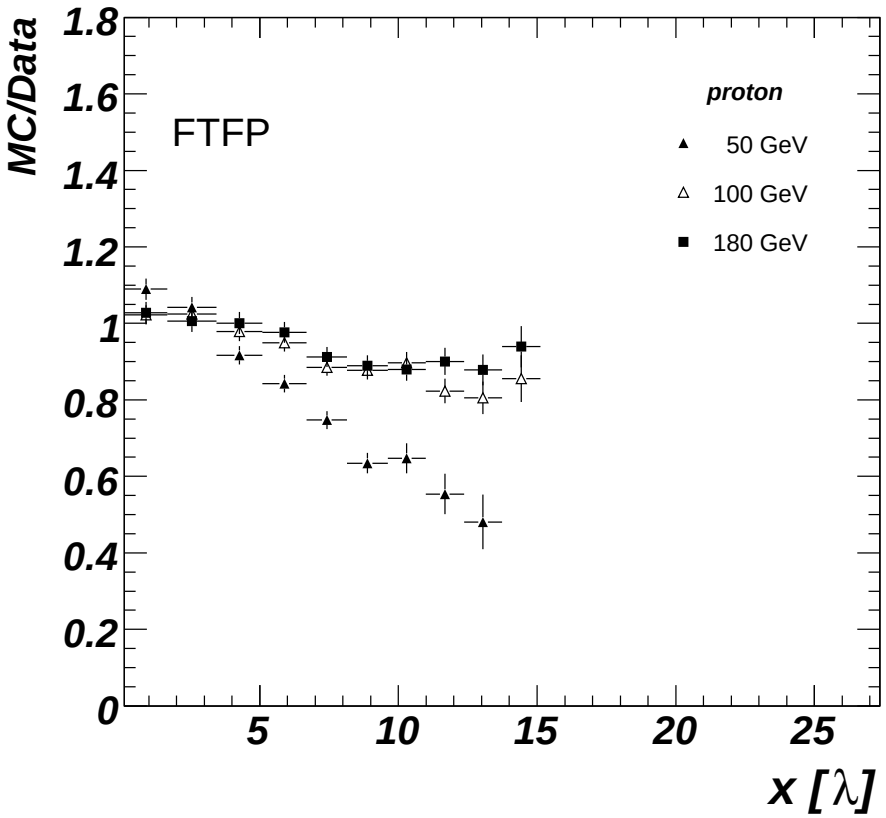


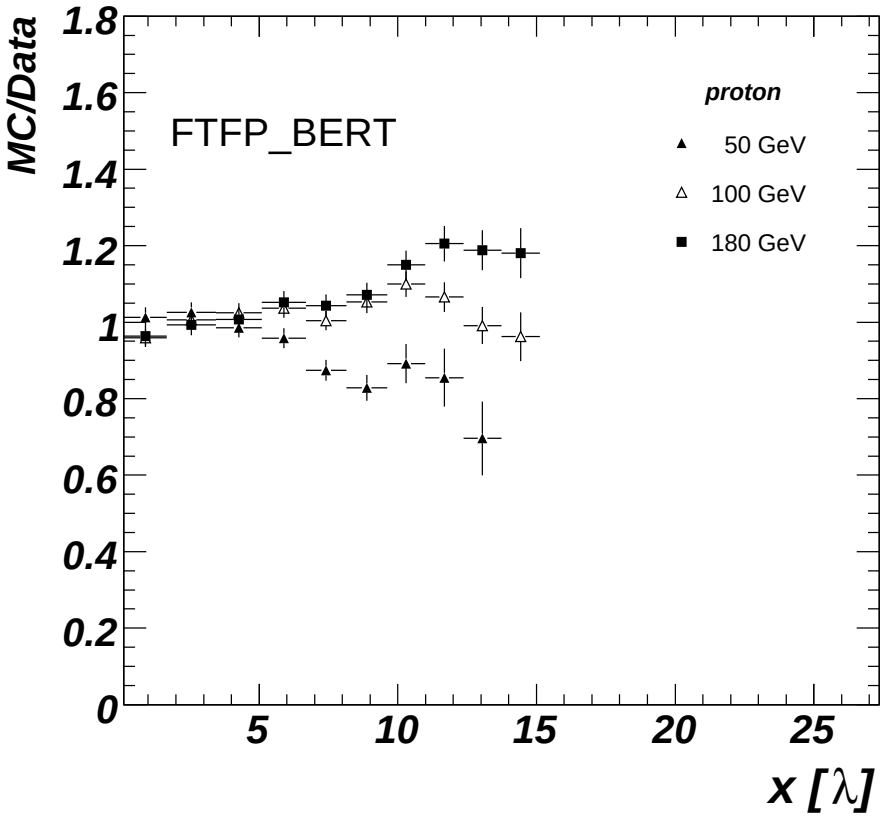


- With Fritiof model showers are a bit shorter, up to 10λ within $\pm$20%.
- With Bertini cascade MC describes data up to 10λ within $\pm$10%.

Longitudinal Profile

Protons

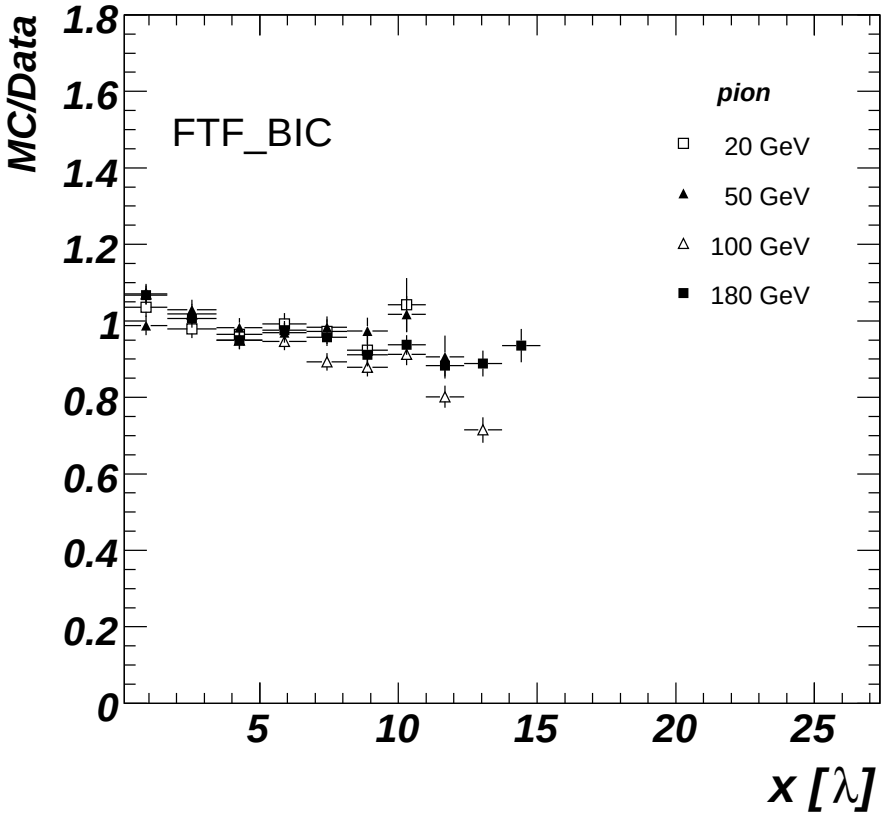


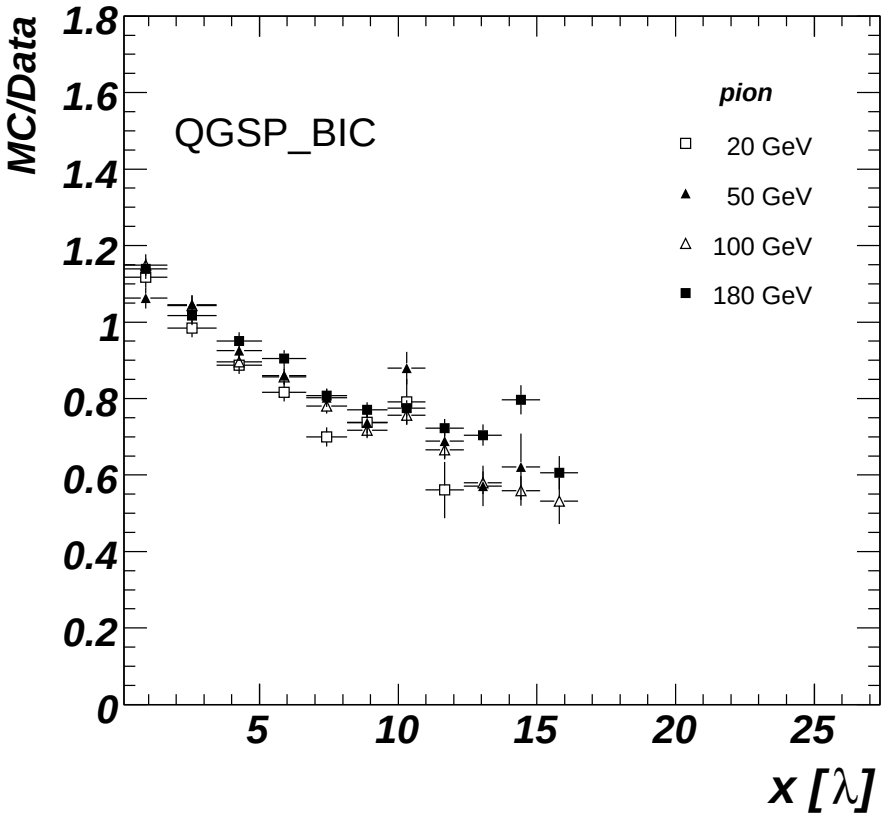


- Up to 10λ $\pm$20% agreement.
- Quite good description.

Longitudinal Profile

Pions

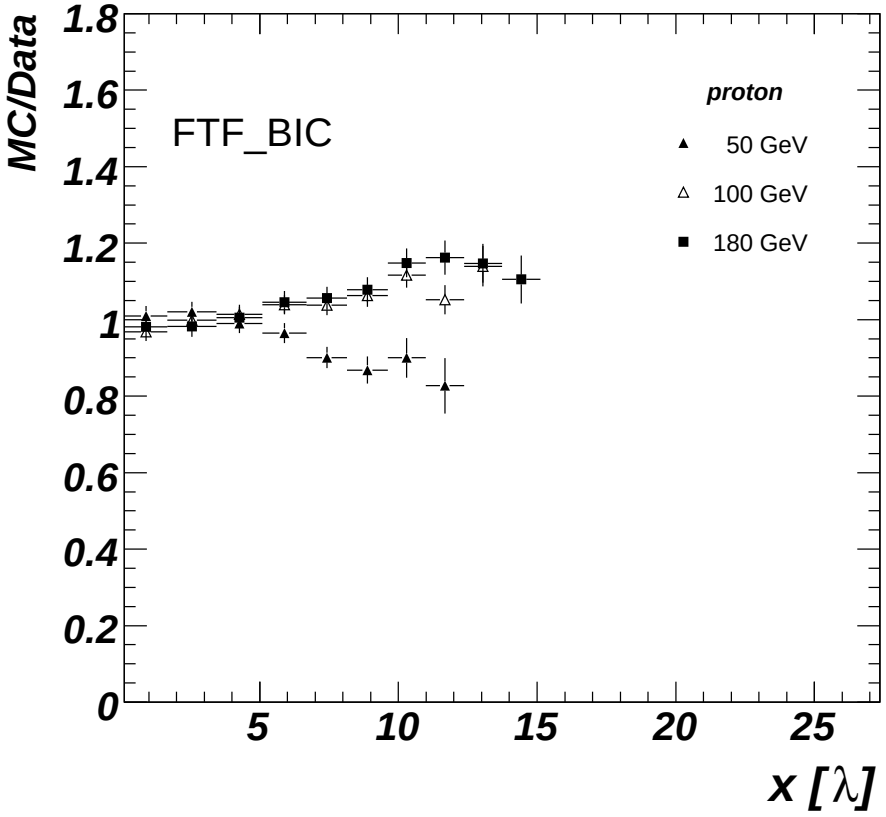


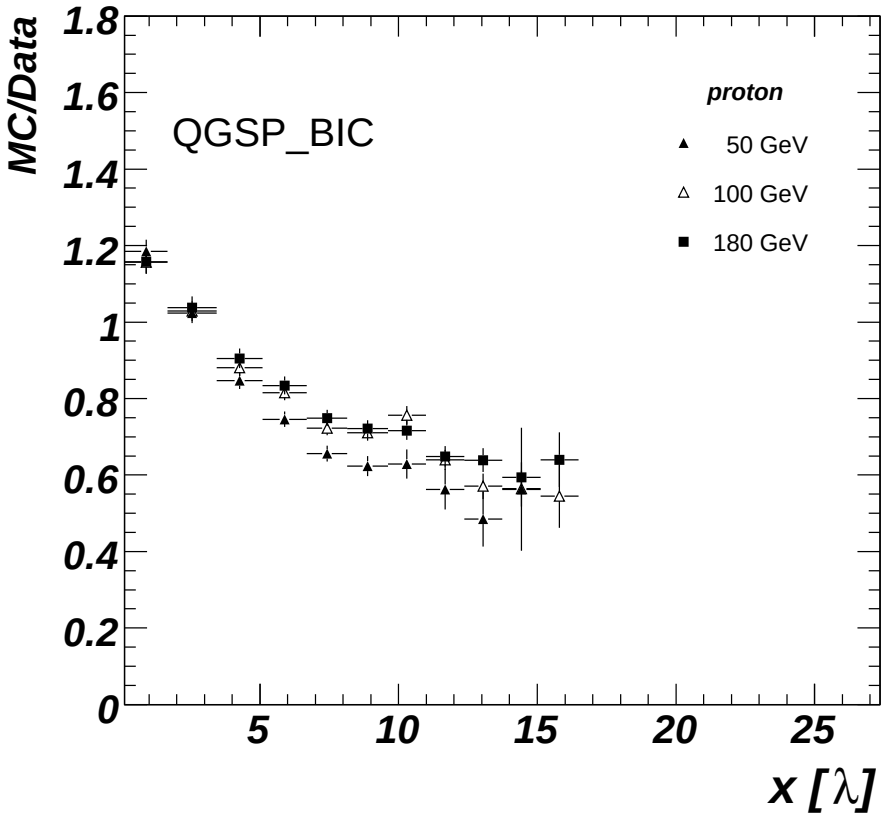


- Quite good description, up to 10λ within $\pm$10%.
- At 10λ 20% less energy is predicted.

Longitudinal Profile

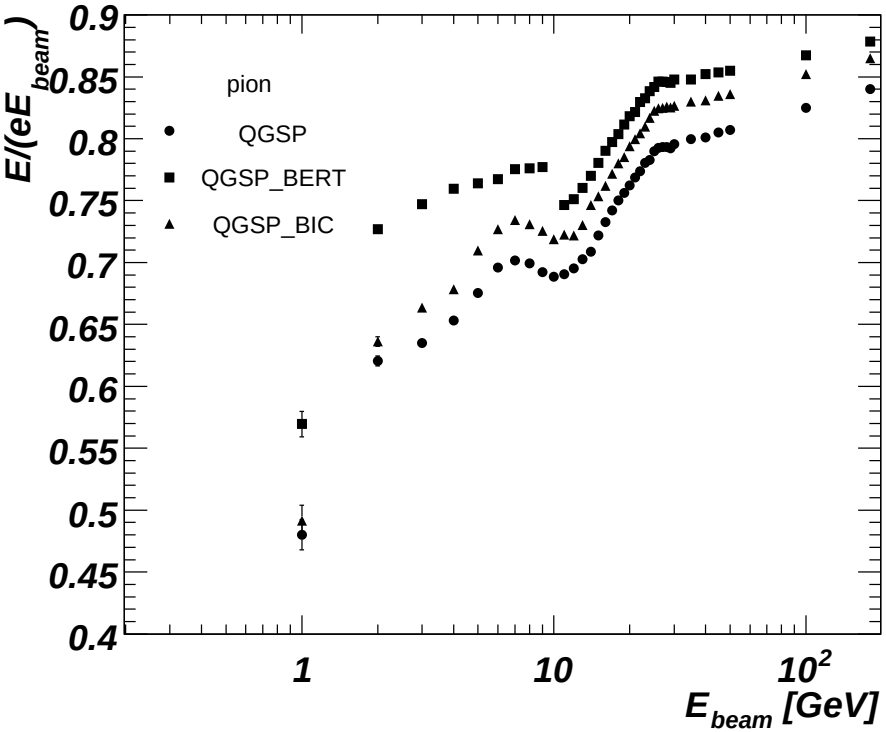
Protons

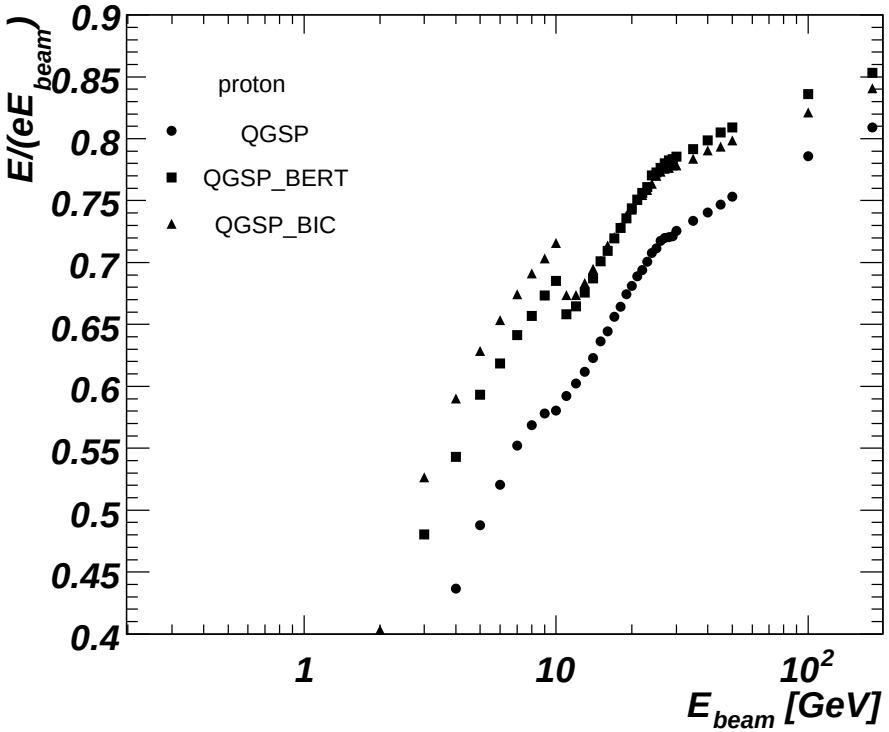




- Good description of shower development.
- Showers are too short.

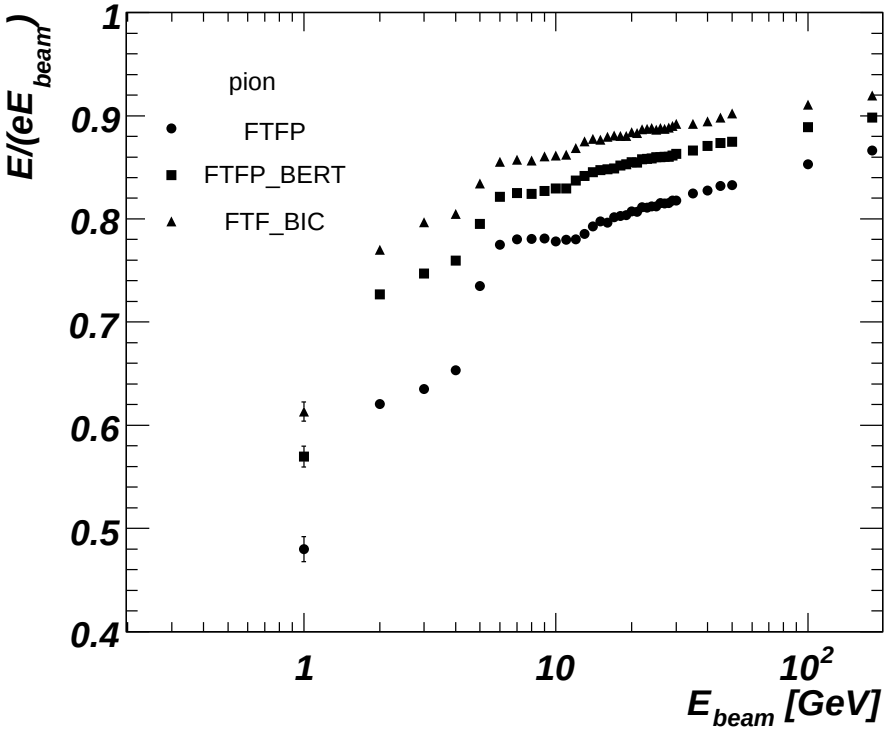
Fine Energy Scan

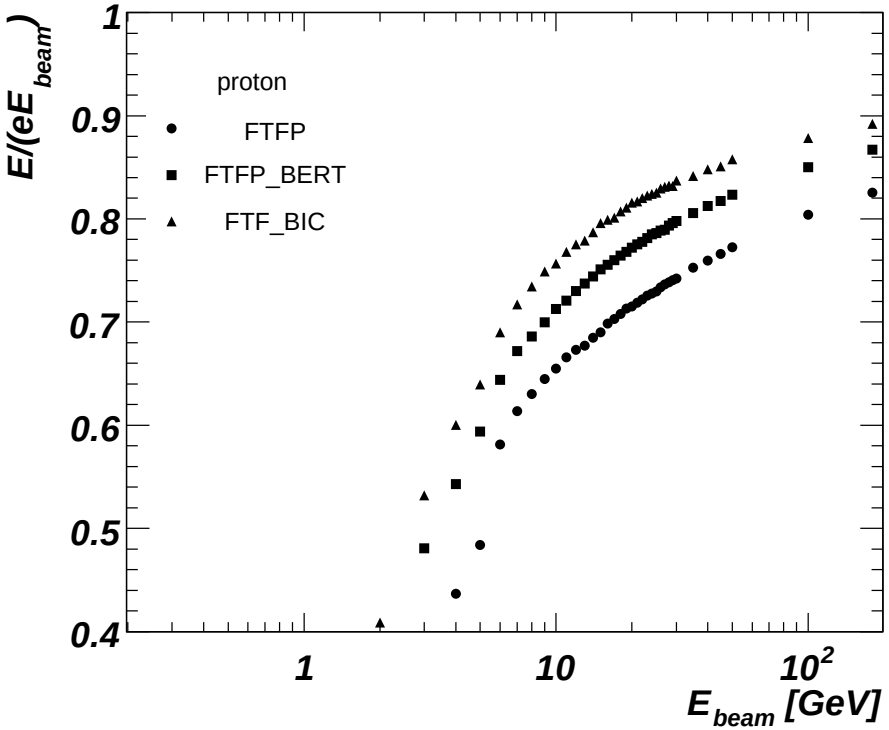




- Unphysical energy dependence of response, the effect is larger in QGSP_BERT. For protons, QGSP_BIC has the largest discontinuity.

Fine Energy Scan



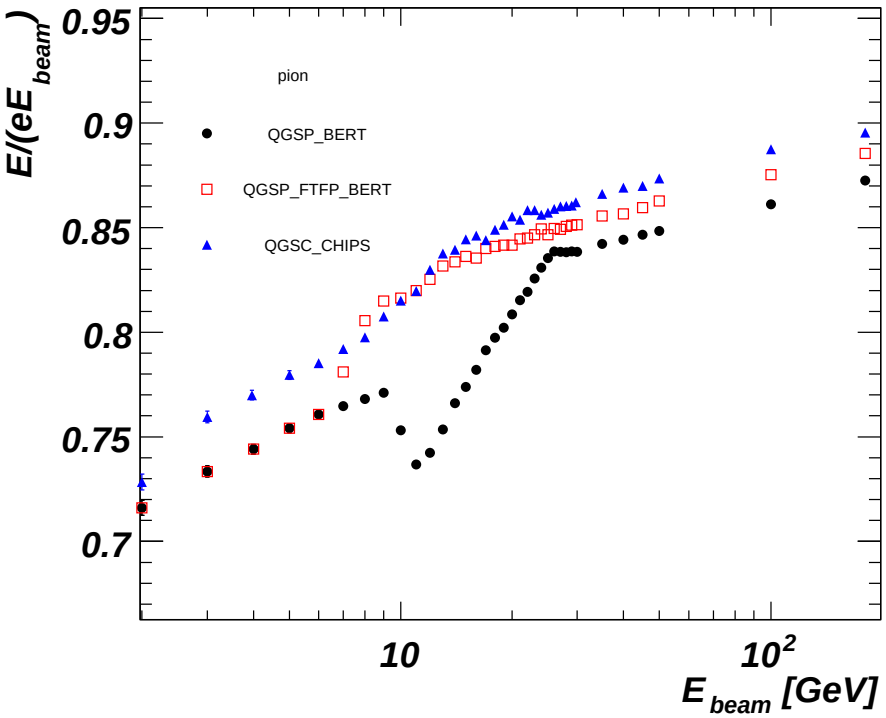


- FTF(P) is smoother than QGSP.
- Smooth energy dependence as expected.

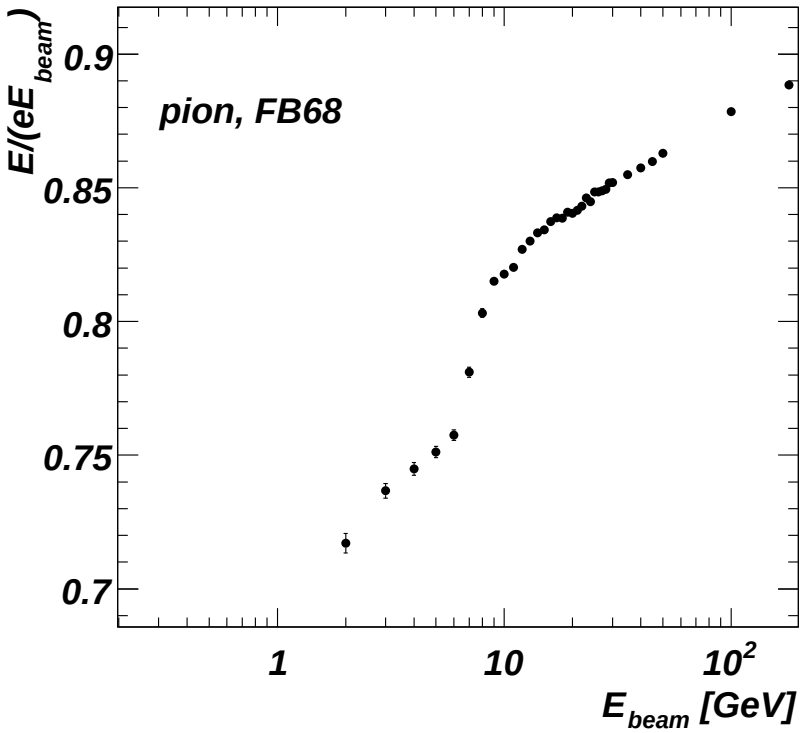
Fine Energy Scan

New physics list

In QGSP_FTFP_BERT the LEP model is replaced by FTF. The transition from BERT to FTF is 7 – 9 GeV.



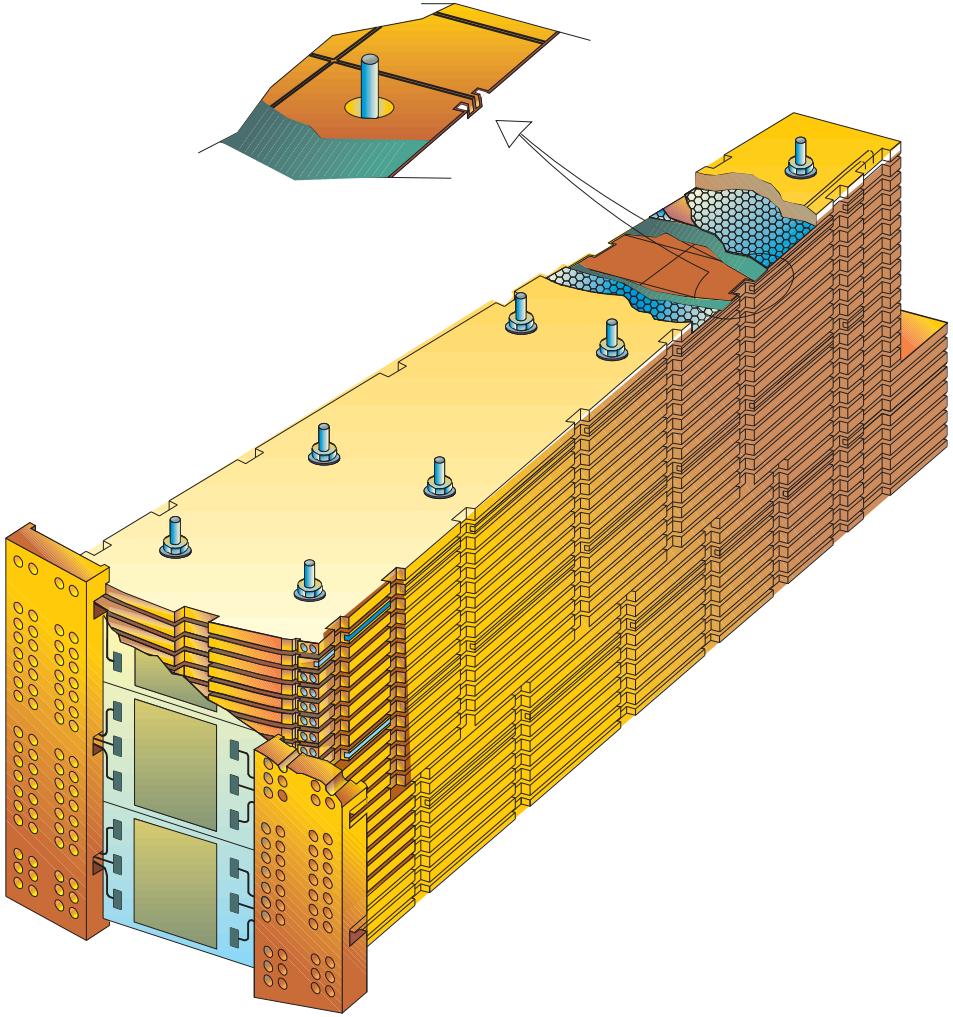
FB68 is essentially FTFP_BERT with transition from BERT to FTF moved from 3 – 4 GeV to 6 – 8 GeV.



- New physics lists predict smoother response.
- Similar performance for other observables.

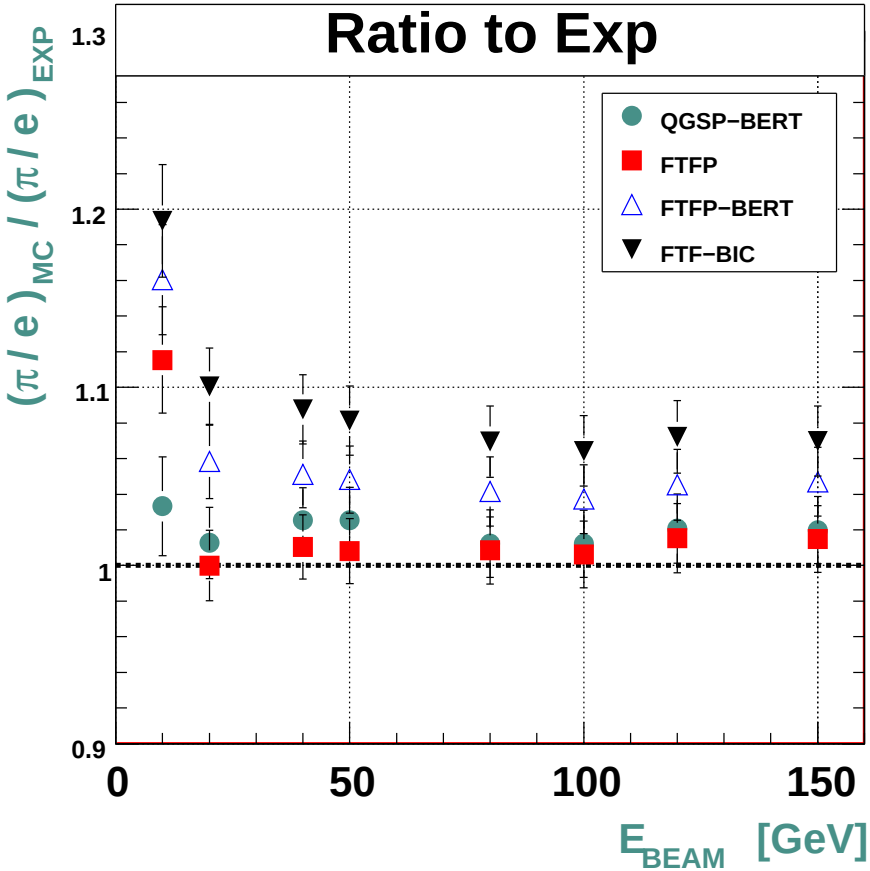
ATLAS Hadronic End-Cap Test-Beam

- Liquid argon sampling calorimeter with copper absorber plates.
- Beam test of HEC modules in 2000-2001.
- Comparison with Geant4 version 9.2.

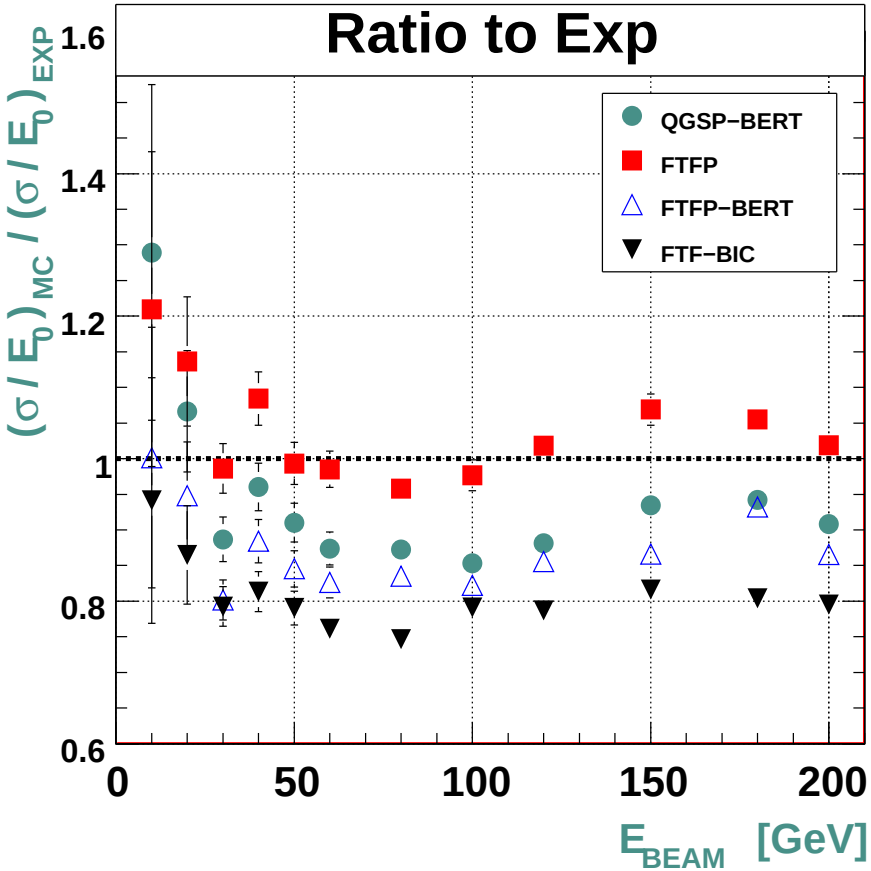


Pion Response and Resolution

Response



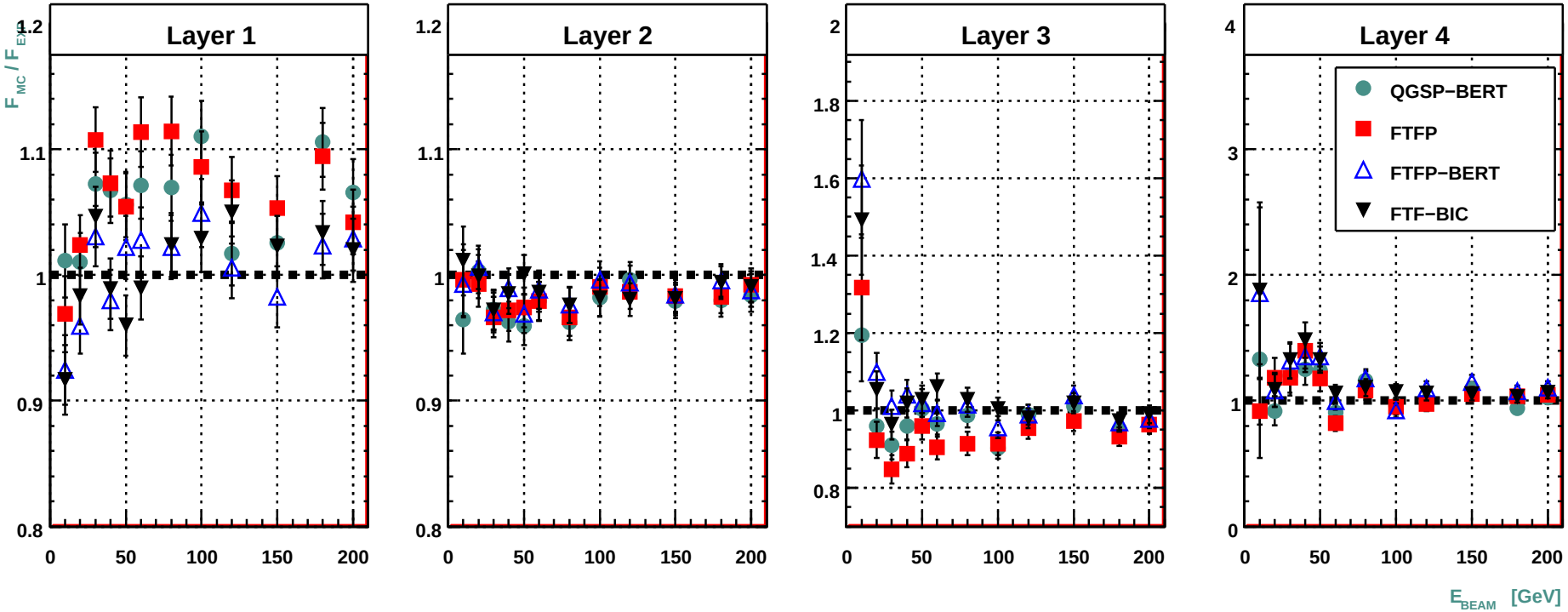
Resolution



- FTFP and QGSP_BERT describe the response within $\pm$ 4%, FTF_BIC is too high.
- FTFP describes the resolution well, other physics lists predict too good resolution.

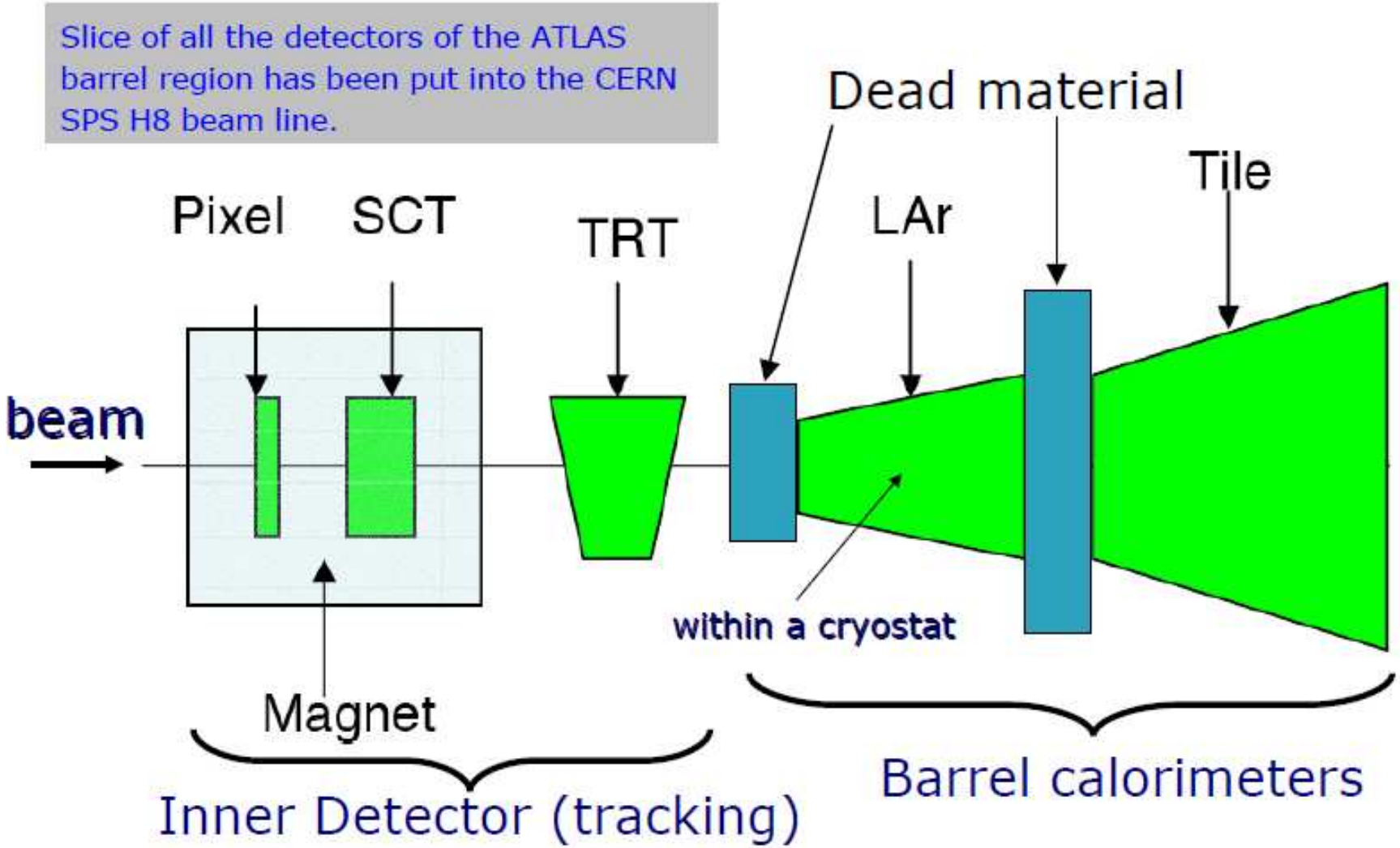
Energy Fraction in Longitudinal Layers

The depth of the layers is 1.5, 2.9, 3.0 and 2.8 λ.



- Fraction of energy in the second (main) layer is described within a few percent by all physics lists.
- Physics lists with shower models predict longitudinal shower development quite well.

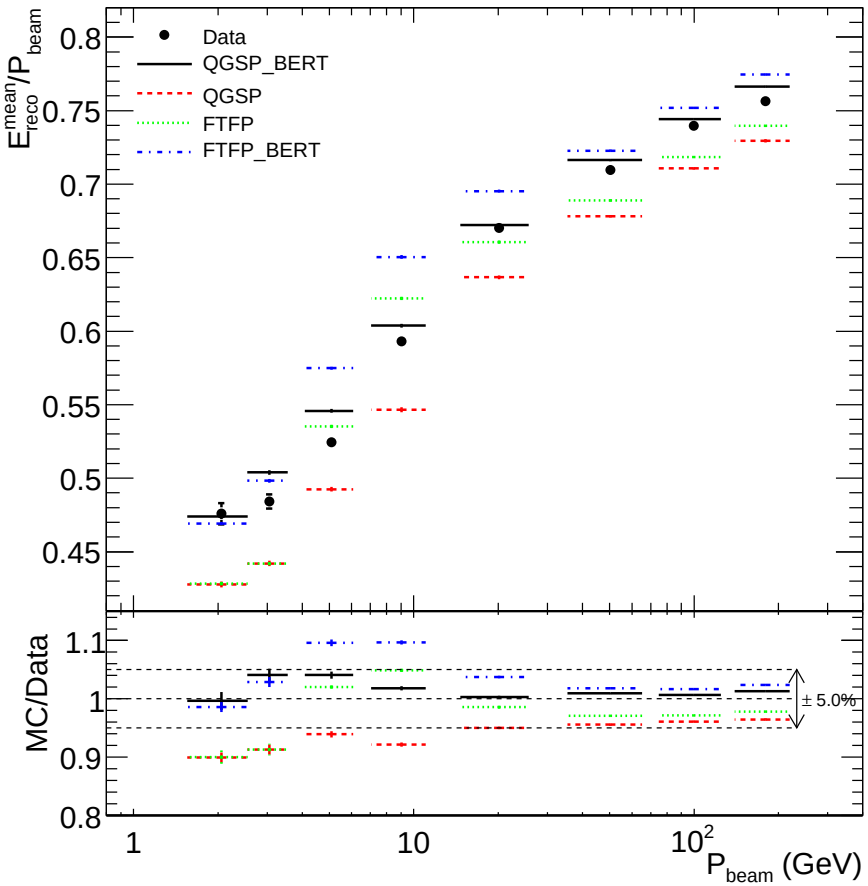
ATLAS Combined Test-Beam



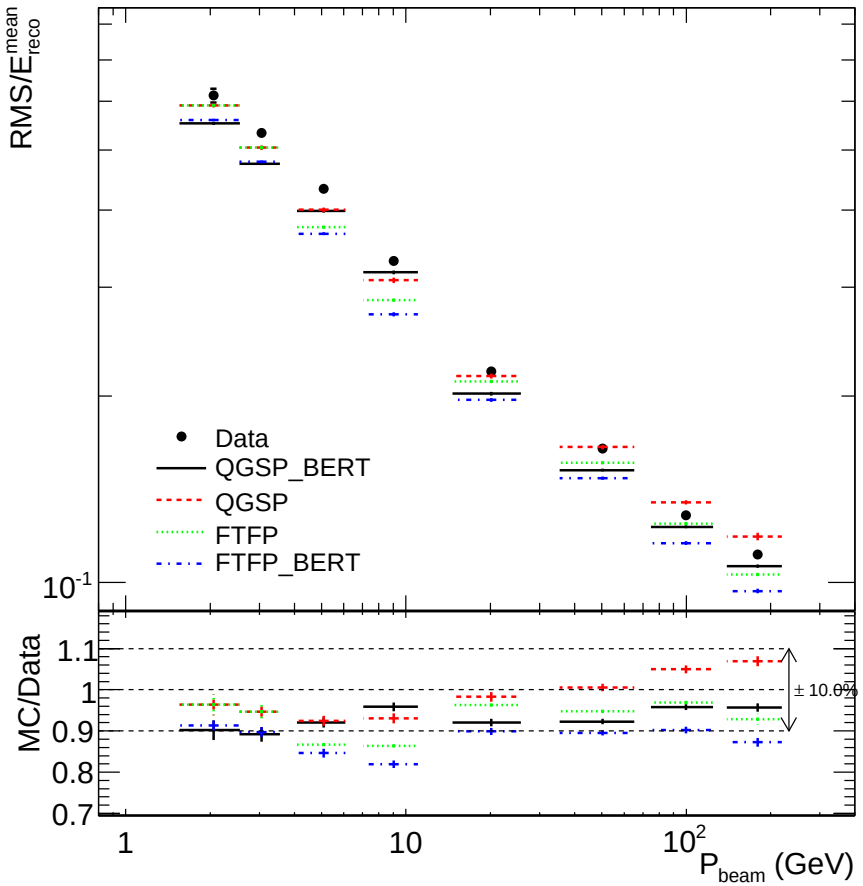
- Very low pion beam energies.
- Comparison with Geant4 version 9.2.

ATLAS Combined Test-Beam

Response



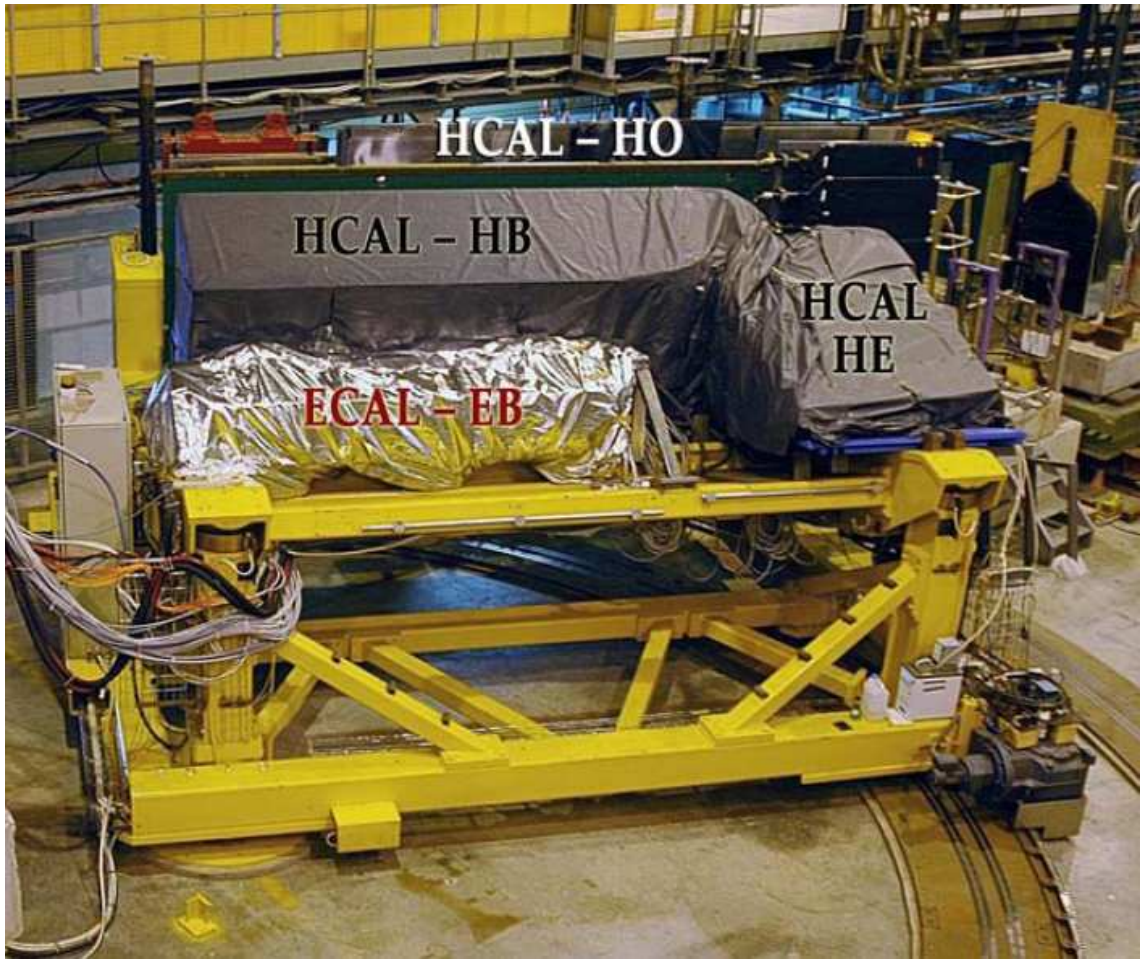
Resolution



- QGSP_BERT describes data within ± 5%. The resolution is slightly better than in data.

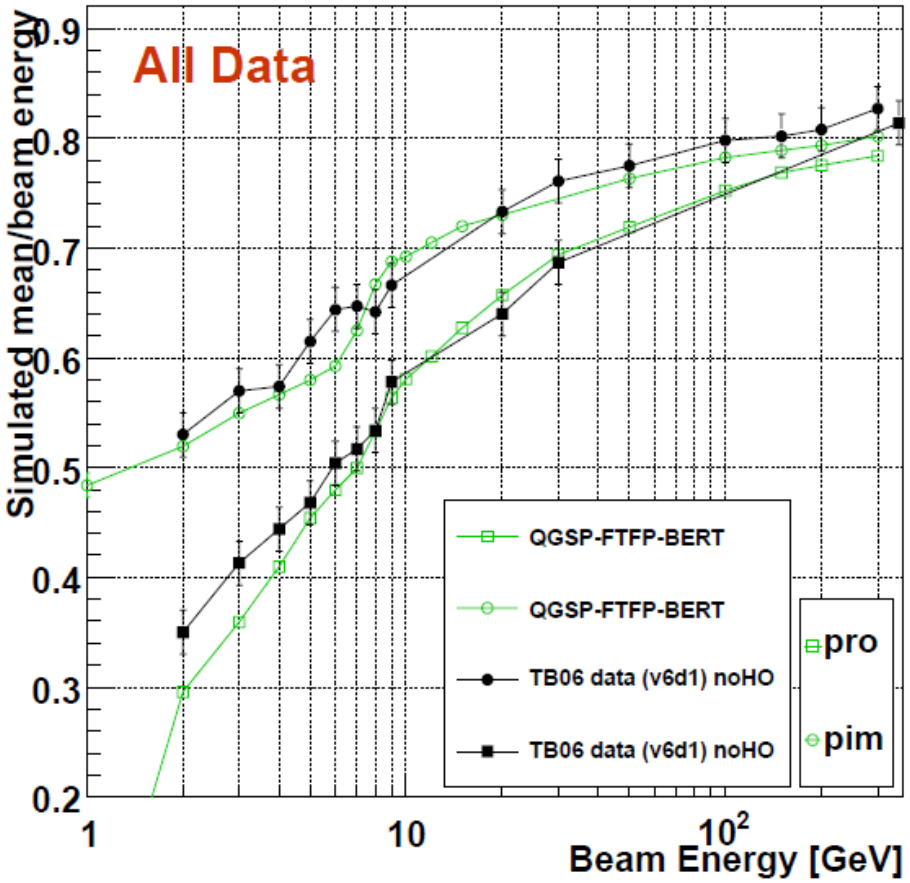
CMS Barrel Calorimeter

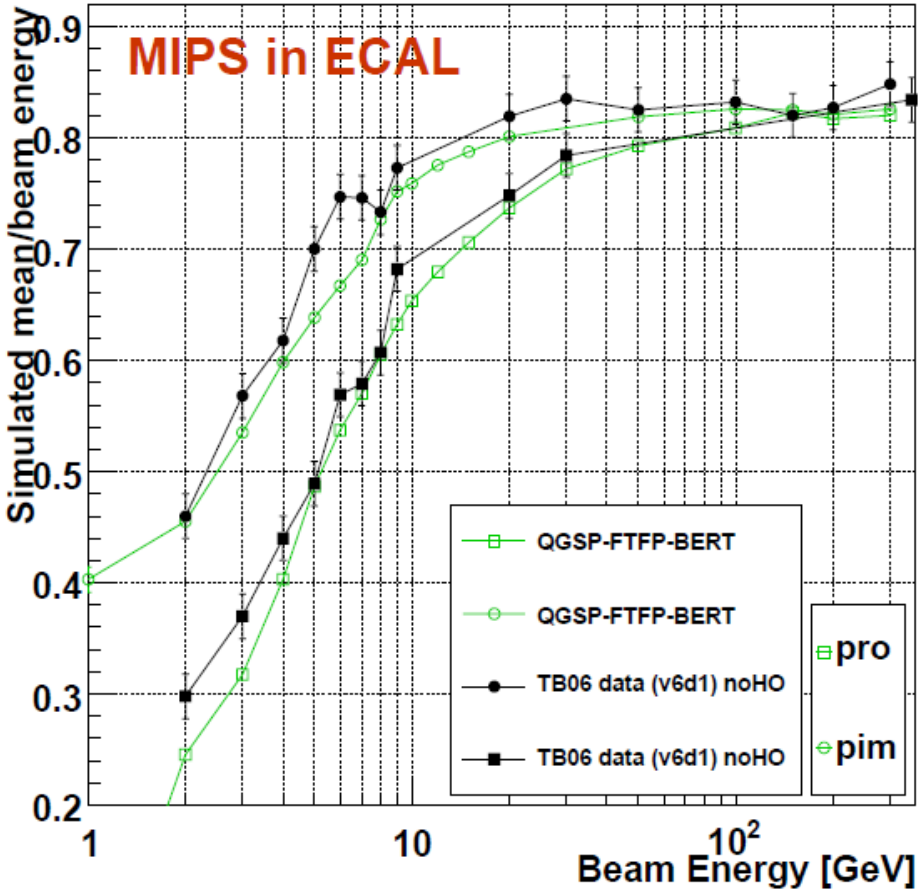
- Lead-tungstate crystal ($PbWO_4$) electromagnetic calorimeter.
- Brass-scintillator hadronic calorimeter.
- Comparison with Geant4 version 9.2 and 9.3β.



Hadron Response

QGSP_FTFP_BERT

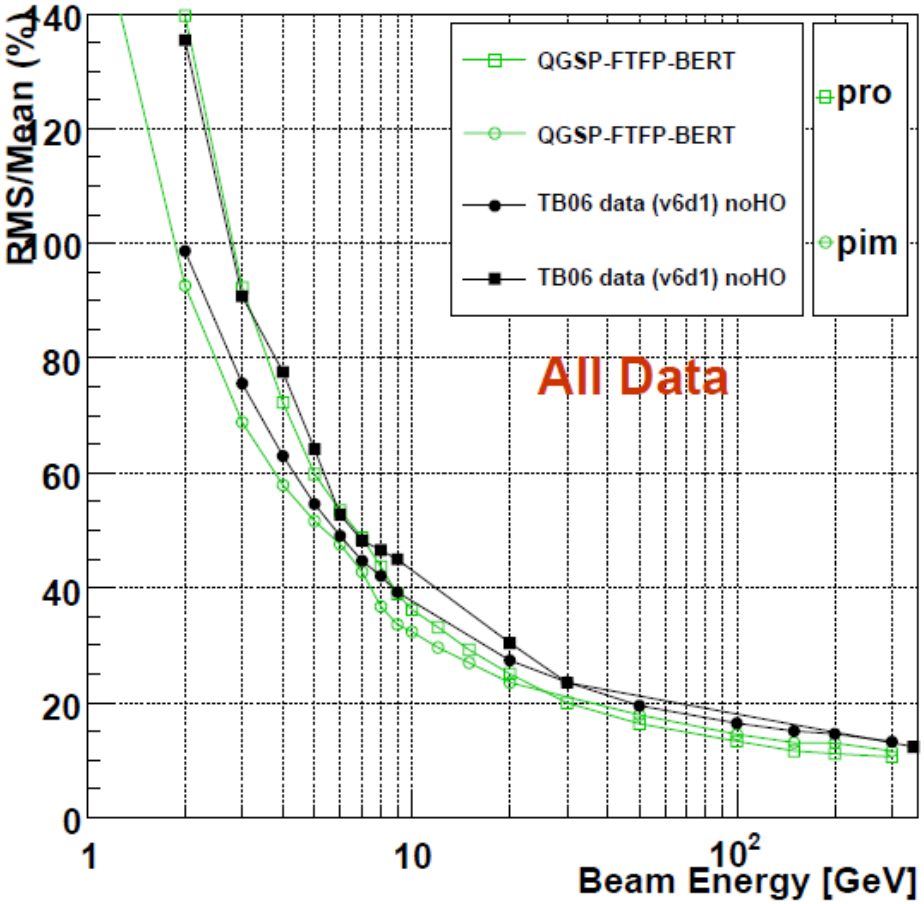


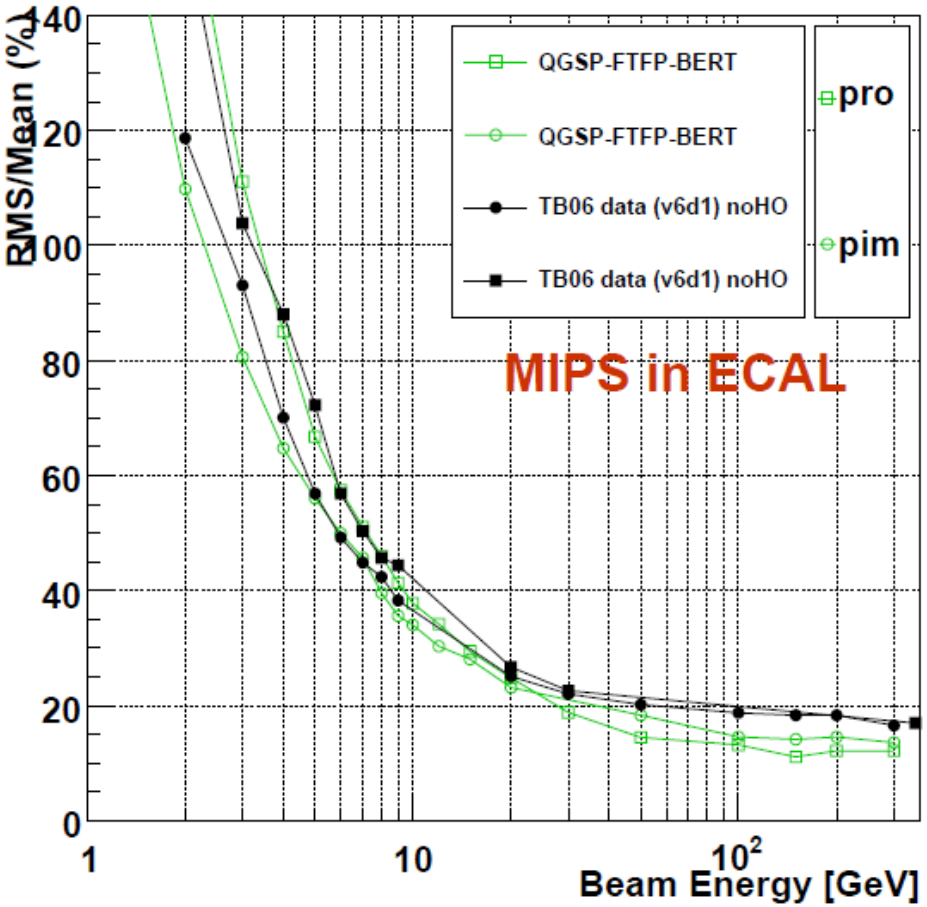


- Overall agreement is good.

Hadron Resolution

QGSP_FTFP_BERT

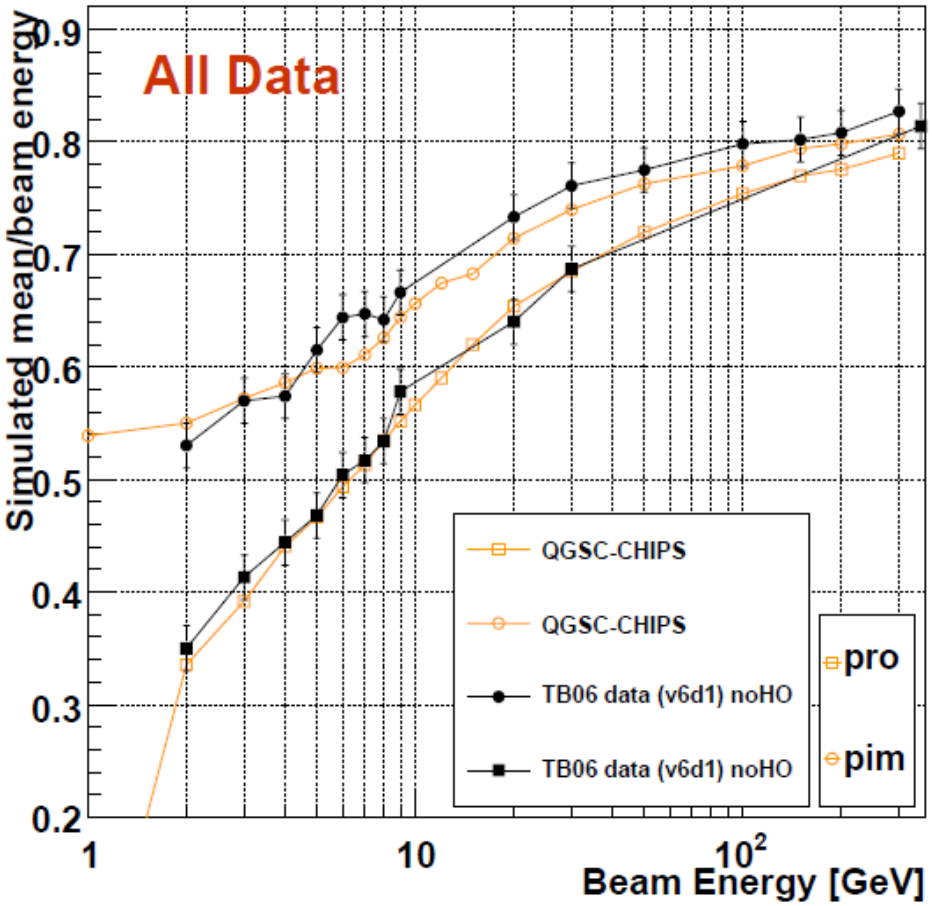


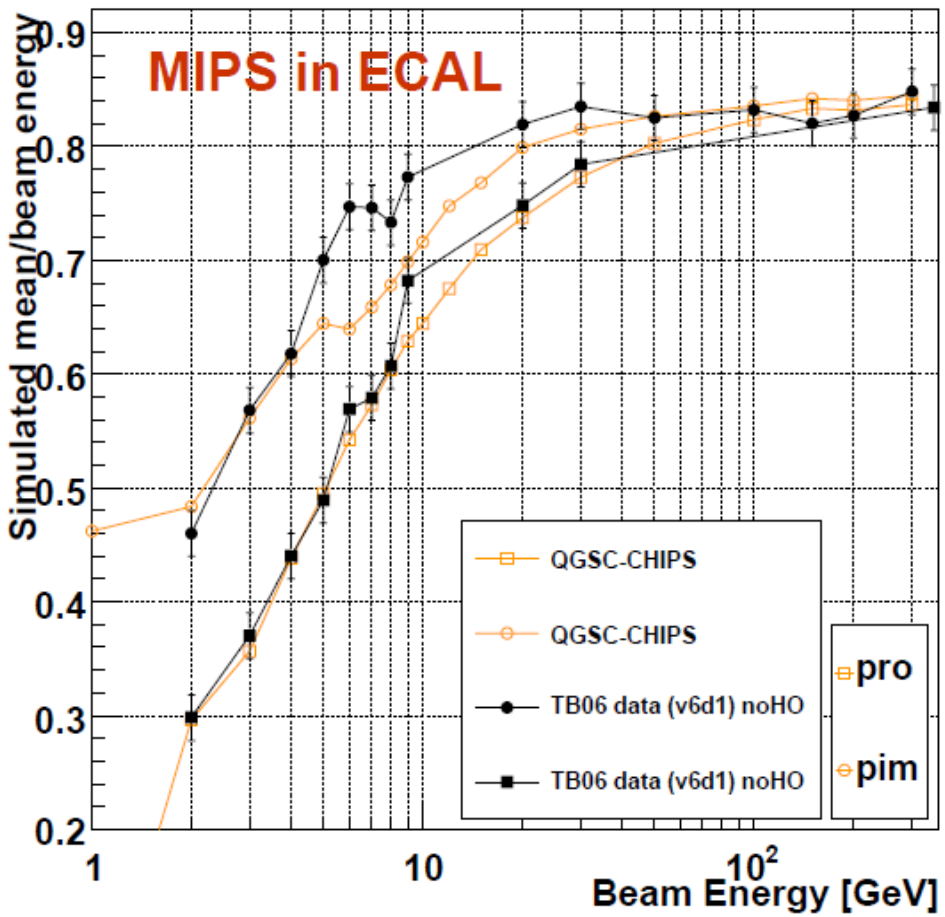


- Reasonable description of hadron resolution, but too good at high energies.

Hadron Response

QGSC_CHIPS

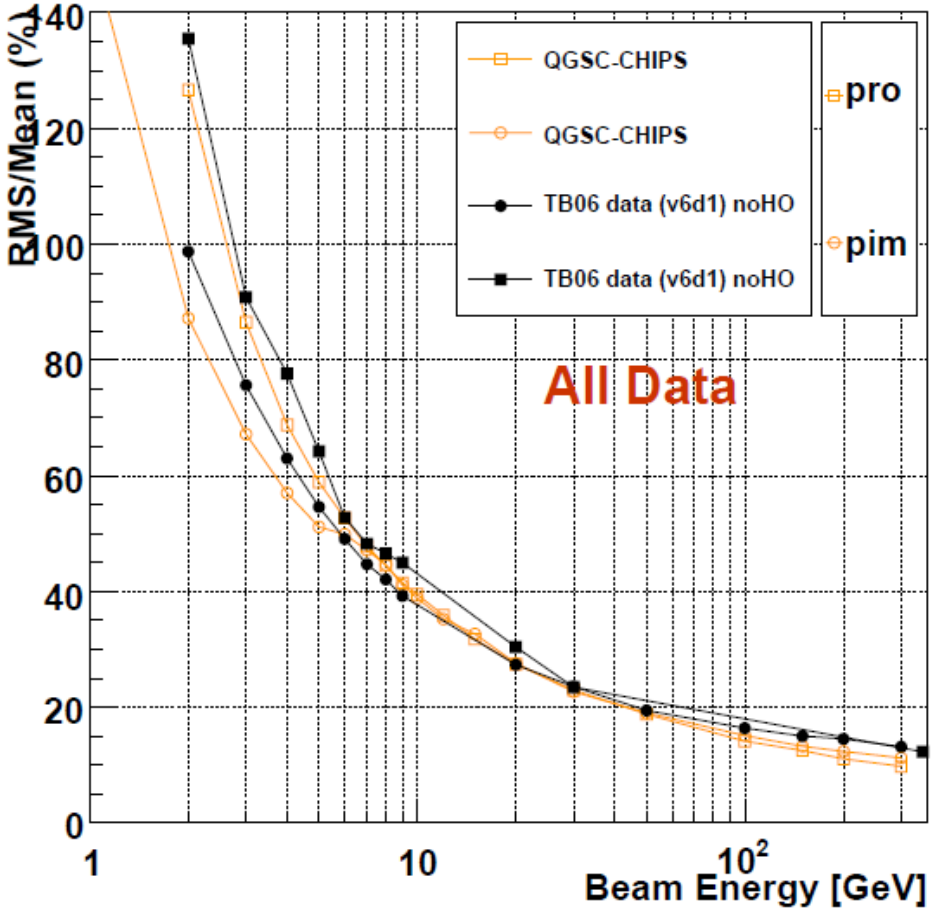


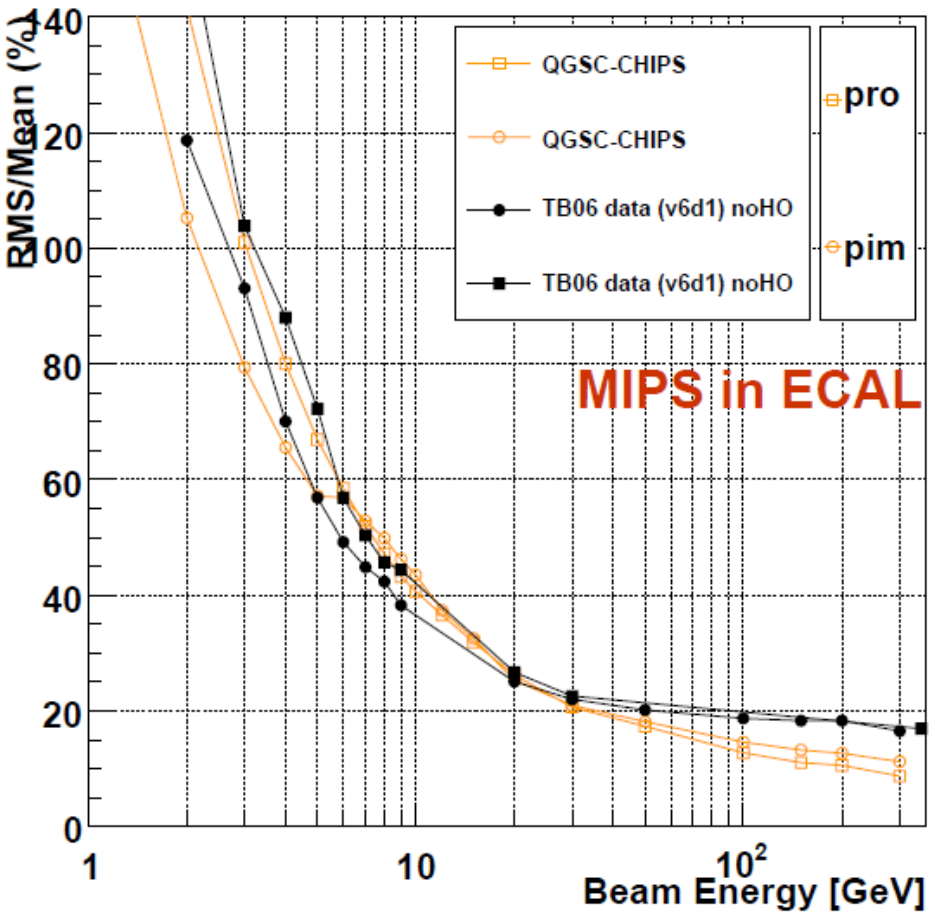


- Good agreement of MC and data for protons.
- Description of π^- response is worse, particularly for MIPs in ECAL.

Hadron Resolution

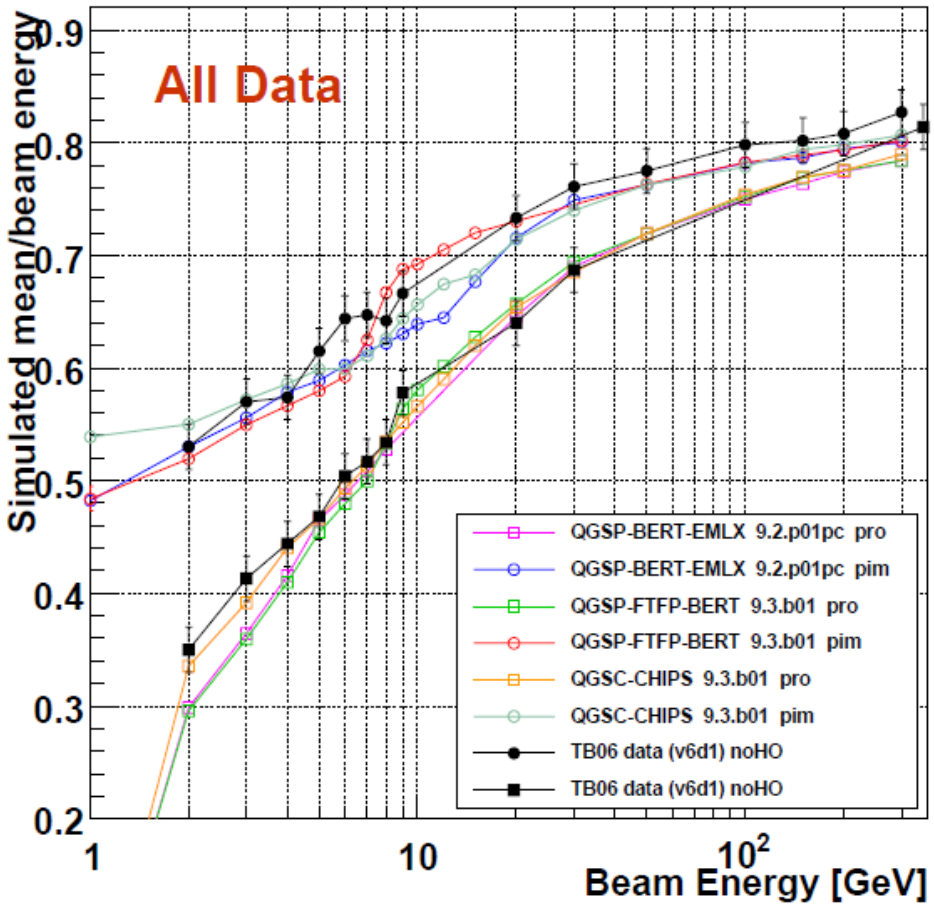
QGSC_CHIPS

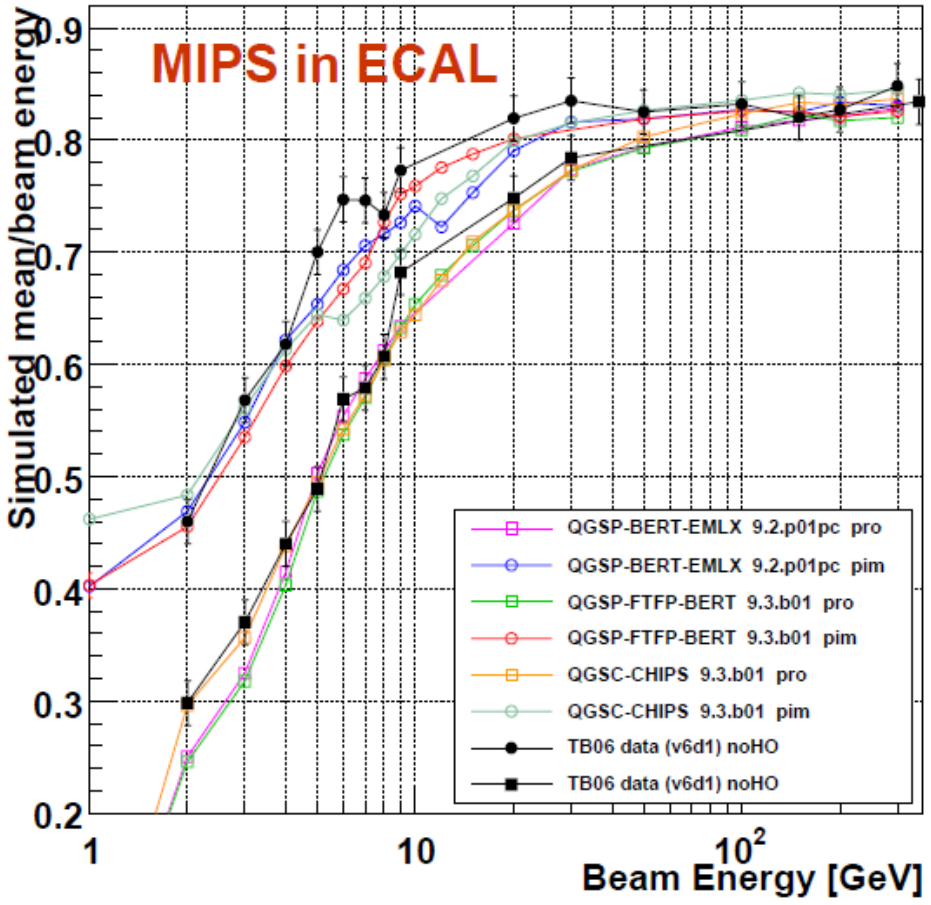




- Resolution is better in MC at high energies for MIPs in ECAL.

Hadron Response

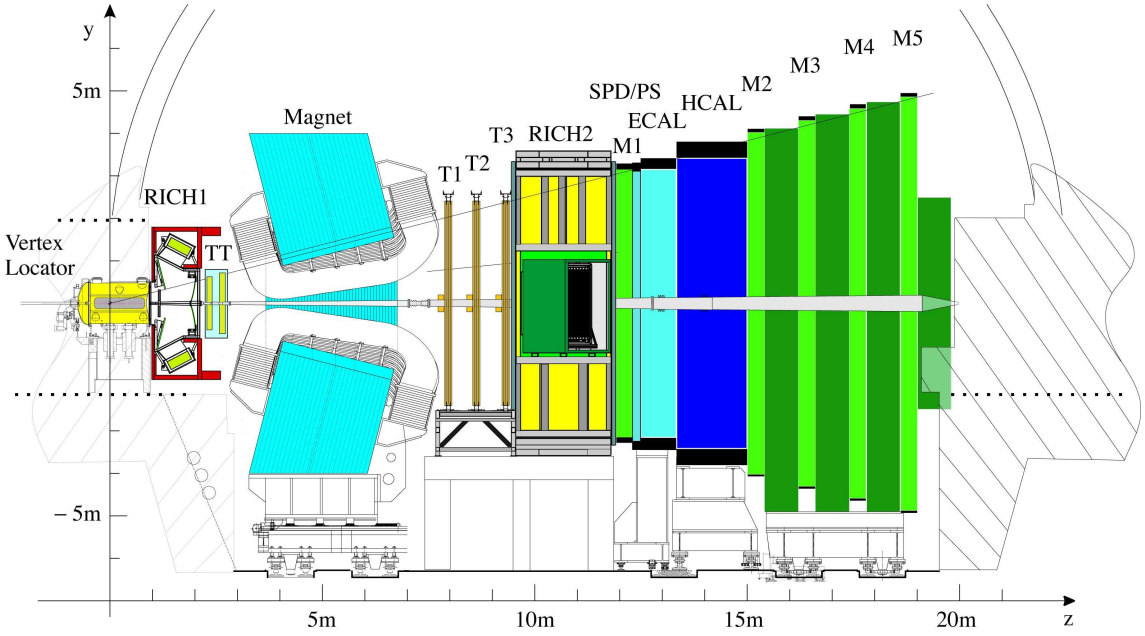




- QGSP_FTFP_BERT describes data as good as QGSP_BERT_EML or better.
- QGSC_CHIPS is comparable over a large region.

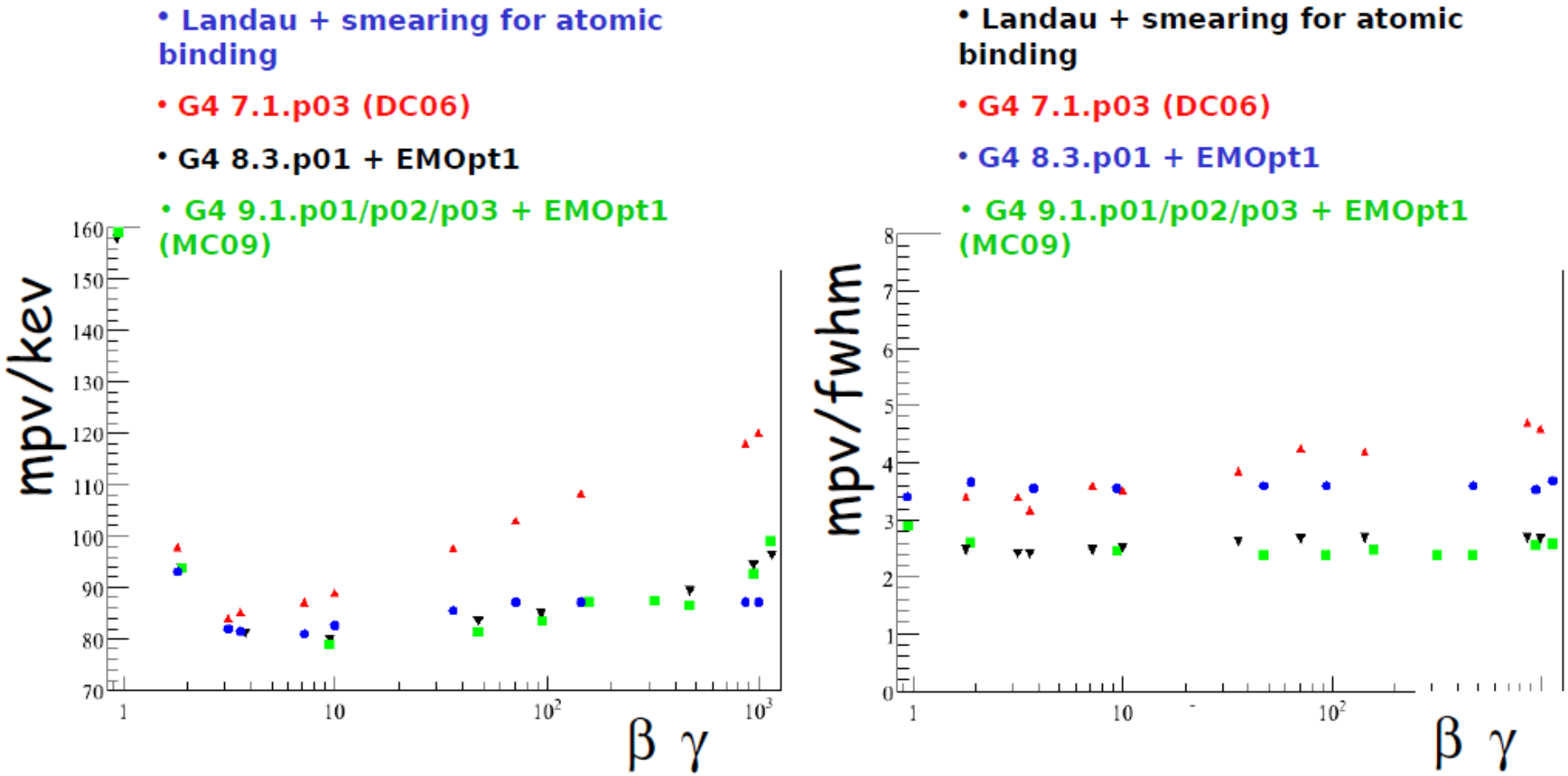
LHCb detector

- LHCb is a single arm forward spectrometer.
- Hadronic calorimeter mainly used for trigger purpose.
- Simulation requirements:
  - Description of dE/dx in thin Silicon detectors.
- Comparison with Geant4 version 7.1, 8.3 and 9.1.



Energy deposition in thin Si detectors

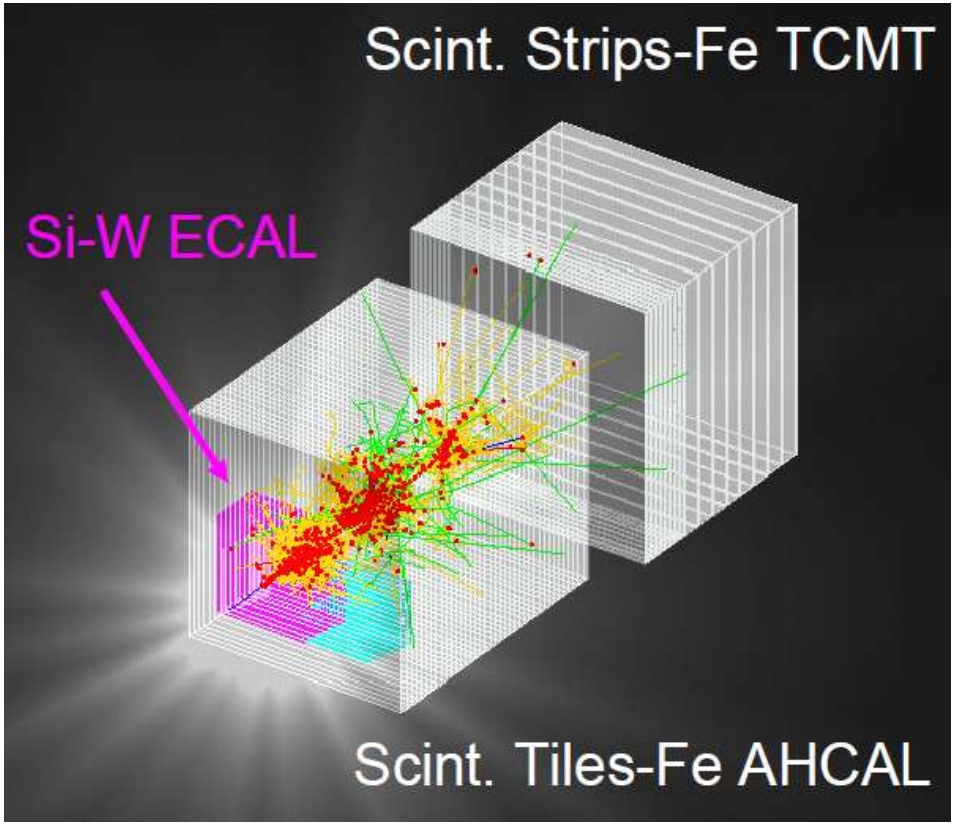
Results of simulation compared to simple model describing data



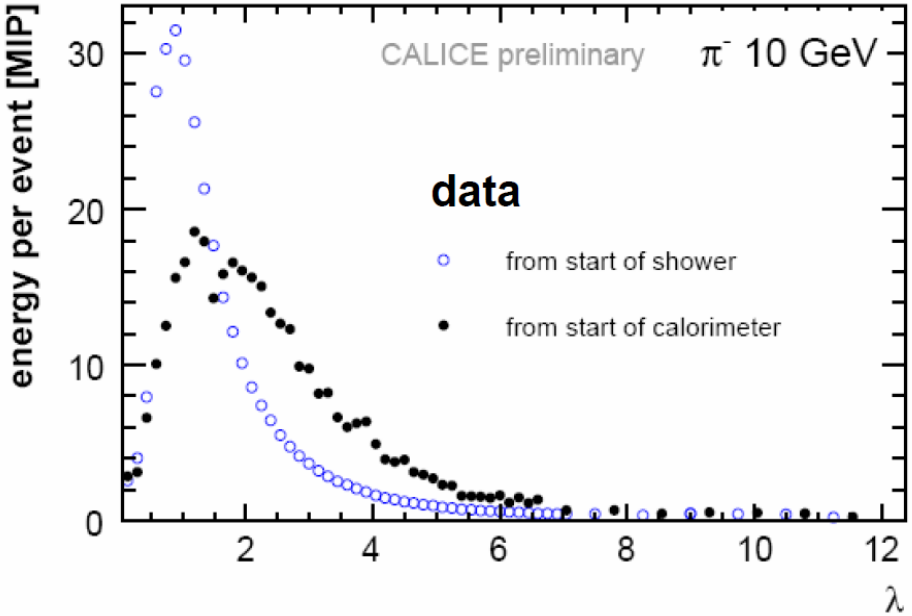
- Much better agreement with recent Geant4 versions.

CALIC Calorimeter

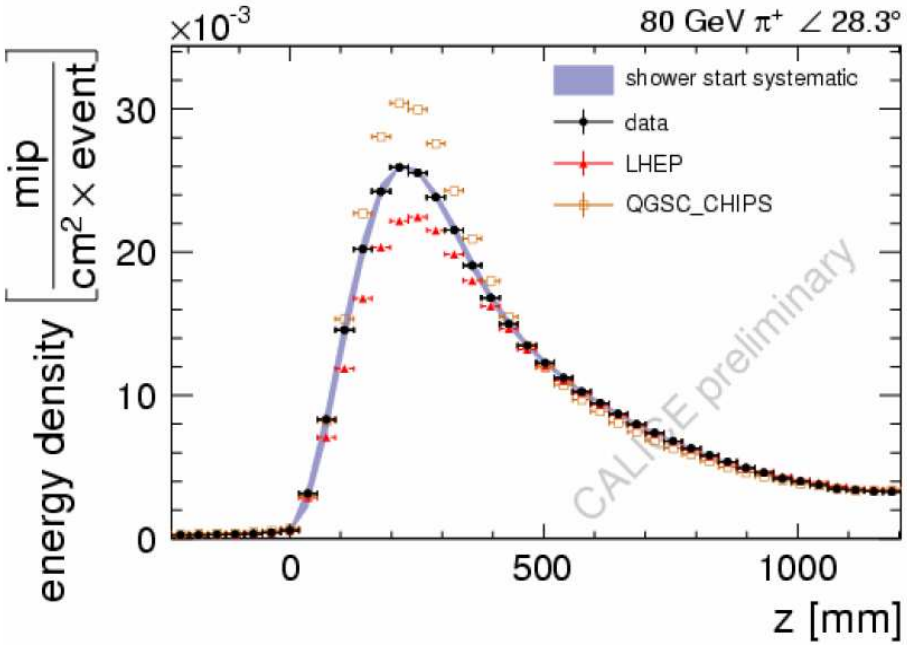
- Silicon-Tungsten electromagnetic calorimeter.
- Scintillator-Steel hadron calorimeter.
- Comparison with Geant4 version 9.2.



Longitudinal Shower Profile

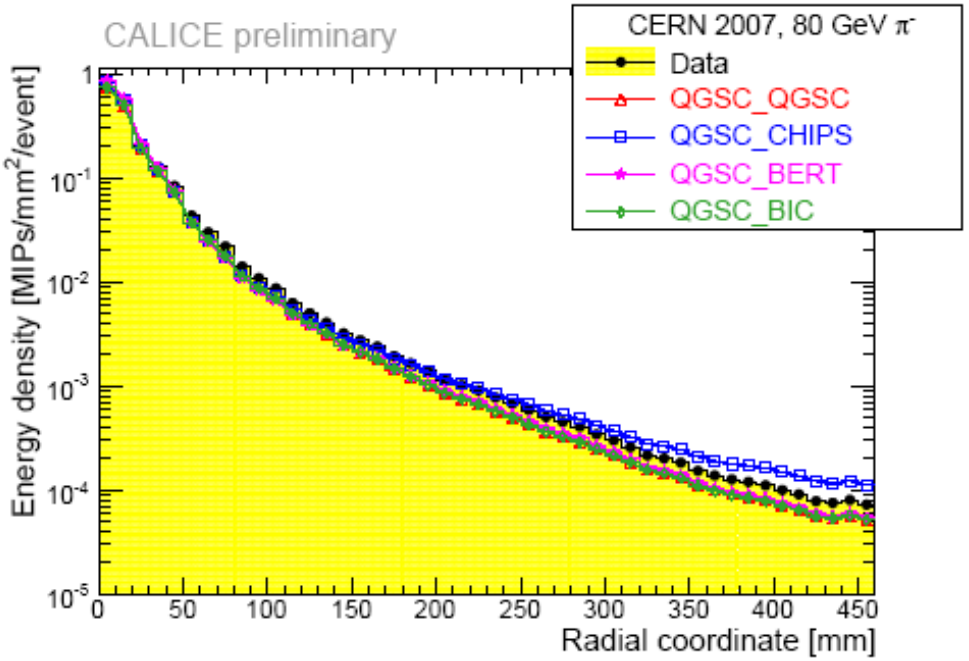


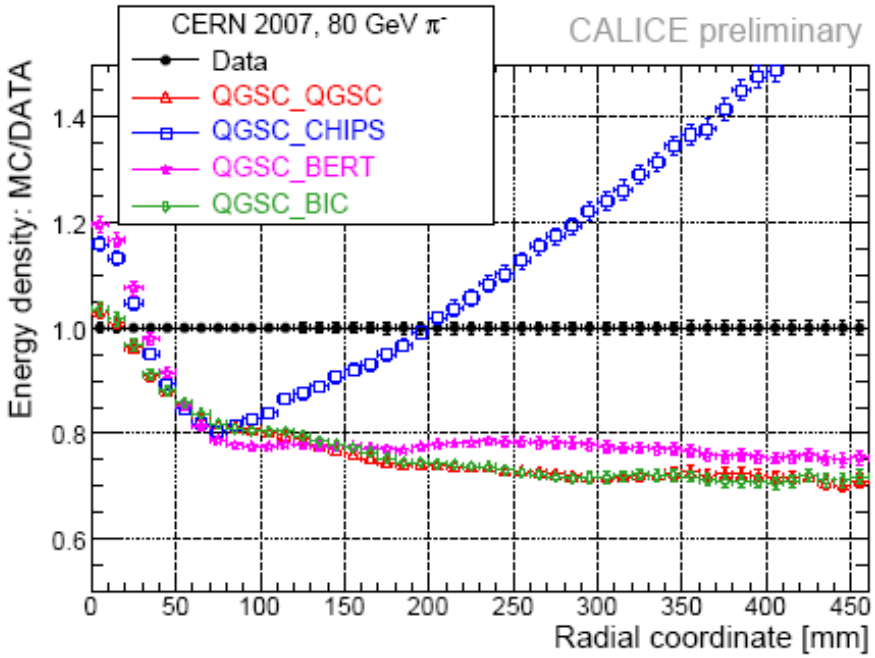
- Thanks to fine granularity showers' start point can be accurately reconstructed.



- Significant disagreement at shower maximum.

Lateral Shower Profile





- Most Geant4 physics lists predict too narrow showers.
- Strange behavior in QGSP_CHIPS.

Summary

Pion observable description by Geant4

physics list	response	resolution	longitudinal	radial
QGSP	low	worse	too short	too narrow
QGSP_BERT	ok	ok	short	narrow
QGSP_BIC	ok	ok	short	too narrow
FTFP	ok	worse	short	too narrow
FTFP_BERT	high	better	short	narrow
FTF_BIC	too high	better	ok	narrow

Proton observable description by Geant4

physics list	response	resolution	longitudinal	radial
QGSP	low	worse	too short	too narrow
QGSP_BERT	ok	ok	too short	narrow
QGSP_BIC	ok	ok	too short	too narrow
FTFP	low	worse	short	too narrow
FTFP_BERT	ok	ok	ok	narrow
FTF_BIC	high	ok	ok	ok

Conclusion

- Hadronic showers simulated by QGSP are too short and too narrow.
- FTFP predicts too narrow showers, response is high, longitudinal development description is better than in case of QGSP.
- Addition of cascade models results in longer and wider showers as well as higher response and better resolution, which is generally in better agreement with the data.
- Non-smooth response dependence on beam energy is observed in QGS based physics lists in the interaction model transition regions. FTF based lists predict smoother response.
- New physics lists predict smoother response dependence on the beam energy.

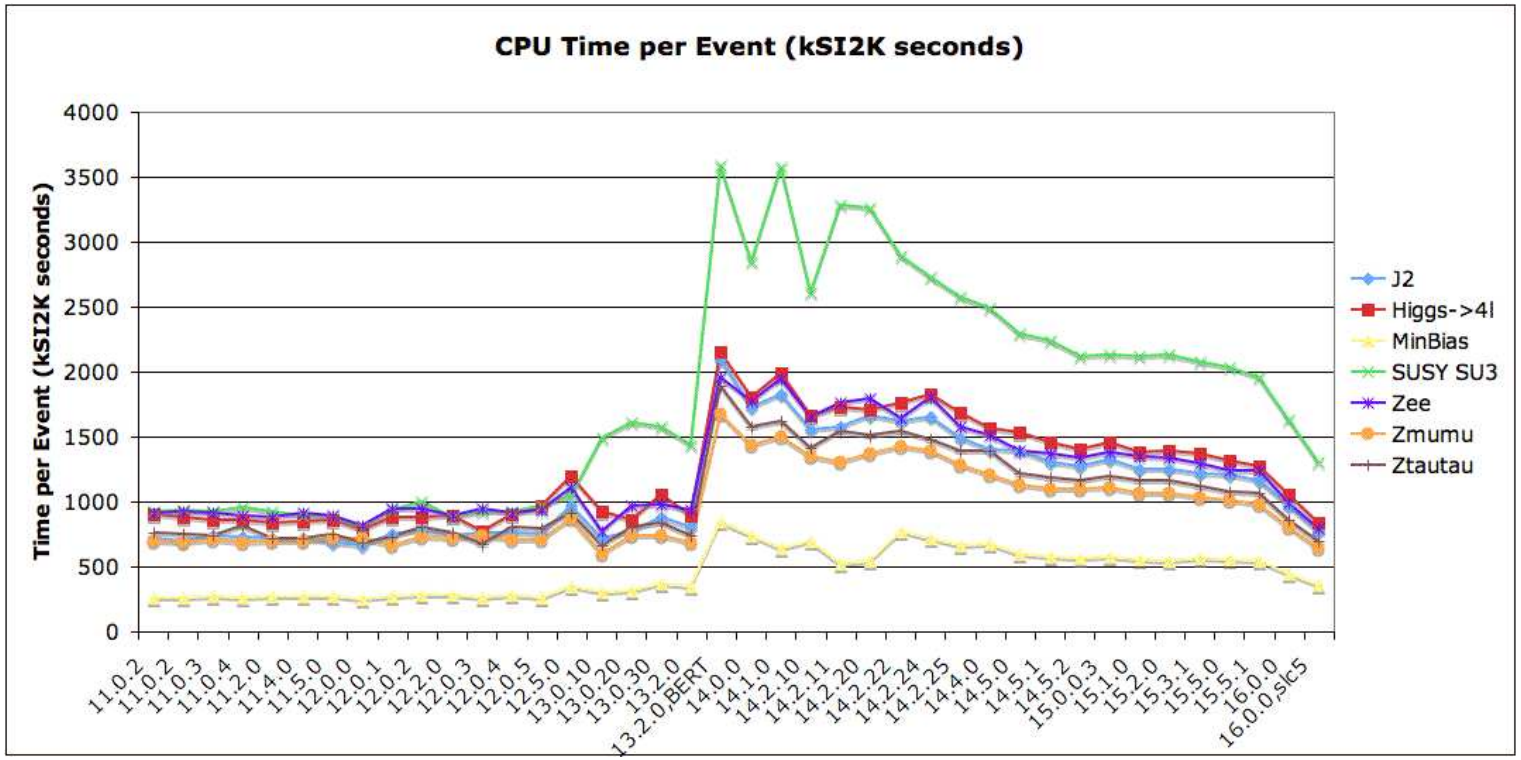
Acknowledgment

- Many thanks to colleagues having provided the plots
  - ATLAS: Tancredi Carli, Andrei Kiryunin, Zachary Marshall.
  - CMS: Sunanda Banerjee.
  - LHCb: Silvia Miglioranzi.
  - CALICE: Erika Garutti, David Ward, Benjamin Lutz.

And thank you for your attention!

Backup

Time per event

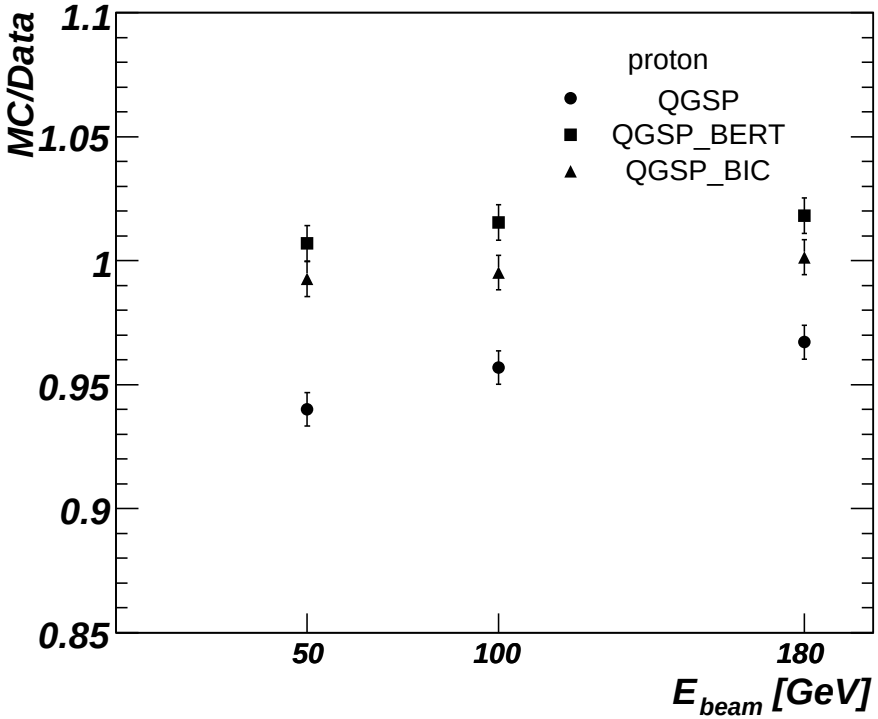


- Significant increase of simulation time by the use of Bertini model.
- Can be decreased by various optimizations.

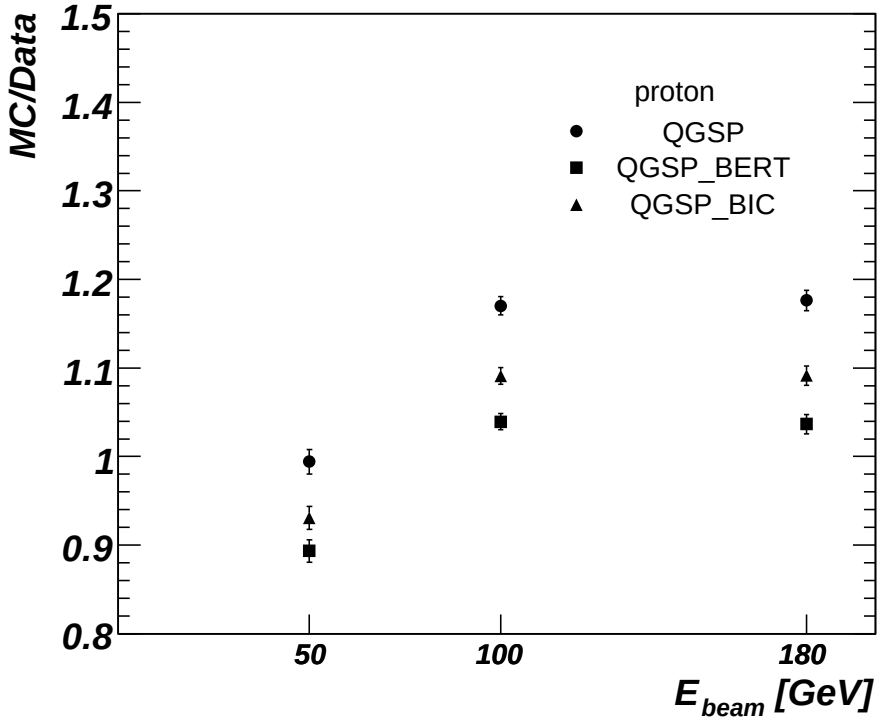
Proton Response and Resolution

Quark-Gluon String

Response



Resolution

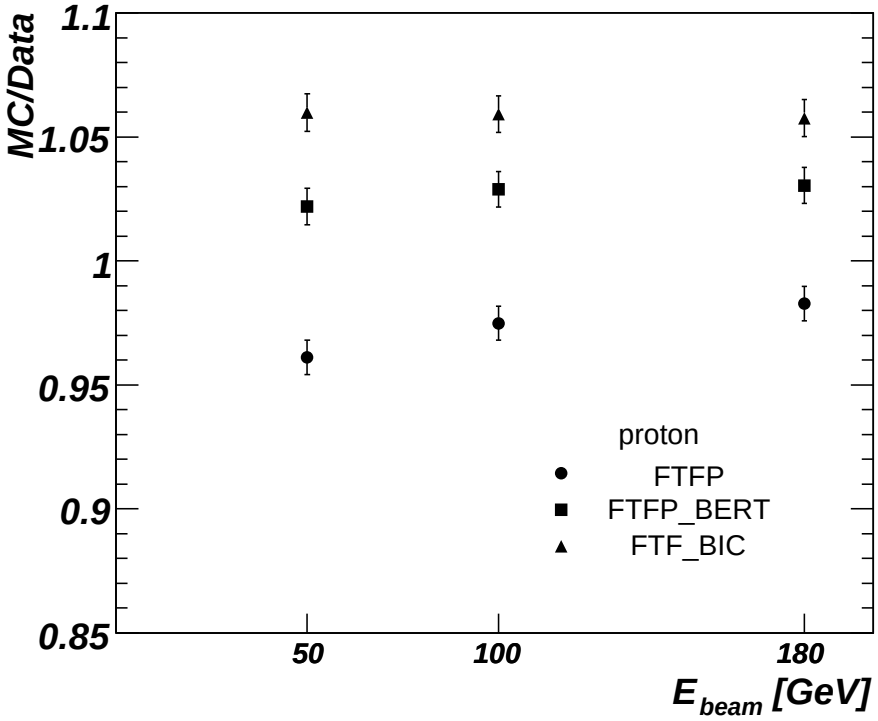


- Cascade models describe proton response, QGSP is too low.
- QGSP alone gives worse resolution.

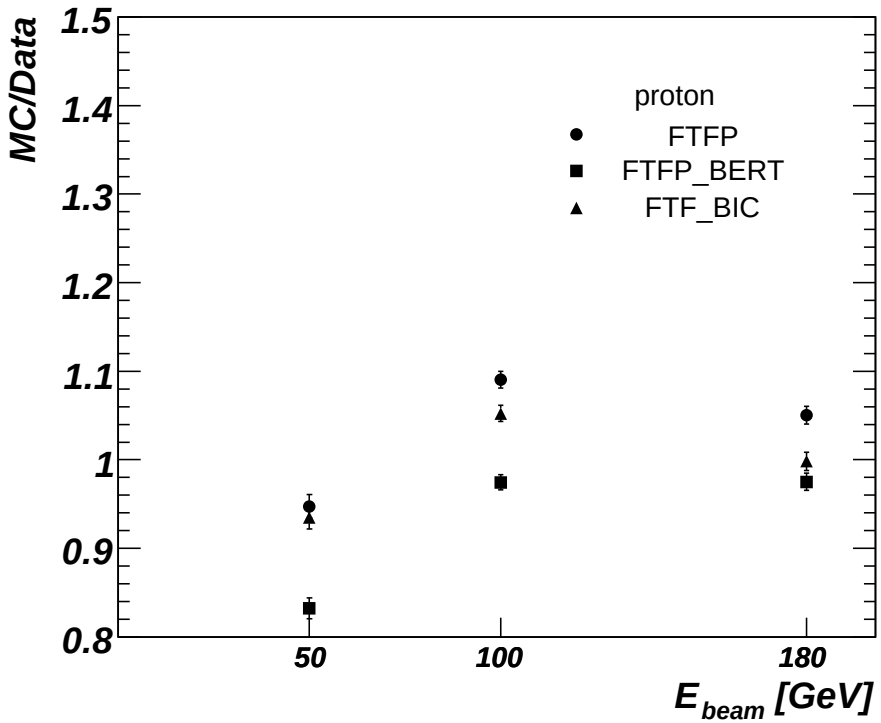
Proton Response and Resolution

Fritiof

Response



Resolution



- FTFP_BERT is in better agreement with data. Binary cascade predicts a higher response than Bertini.
- Within $\pm$ 10% with cascade models.