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Geant4 Simulation for LHC experiments

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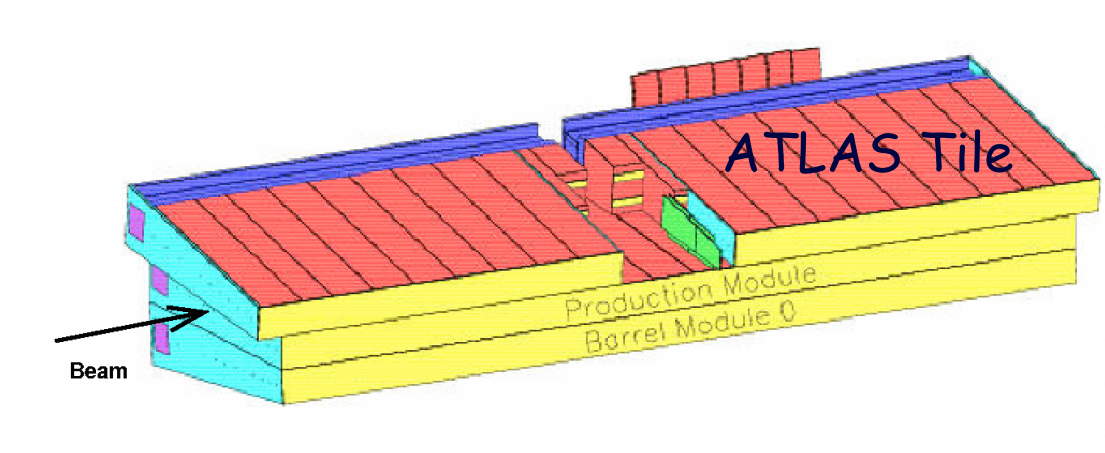
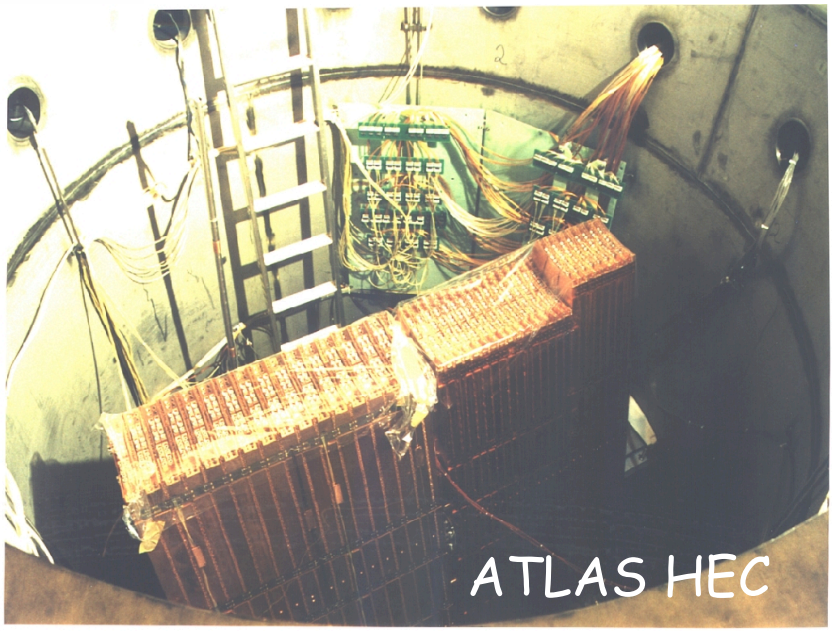
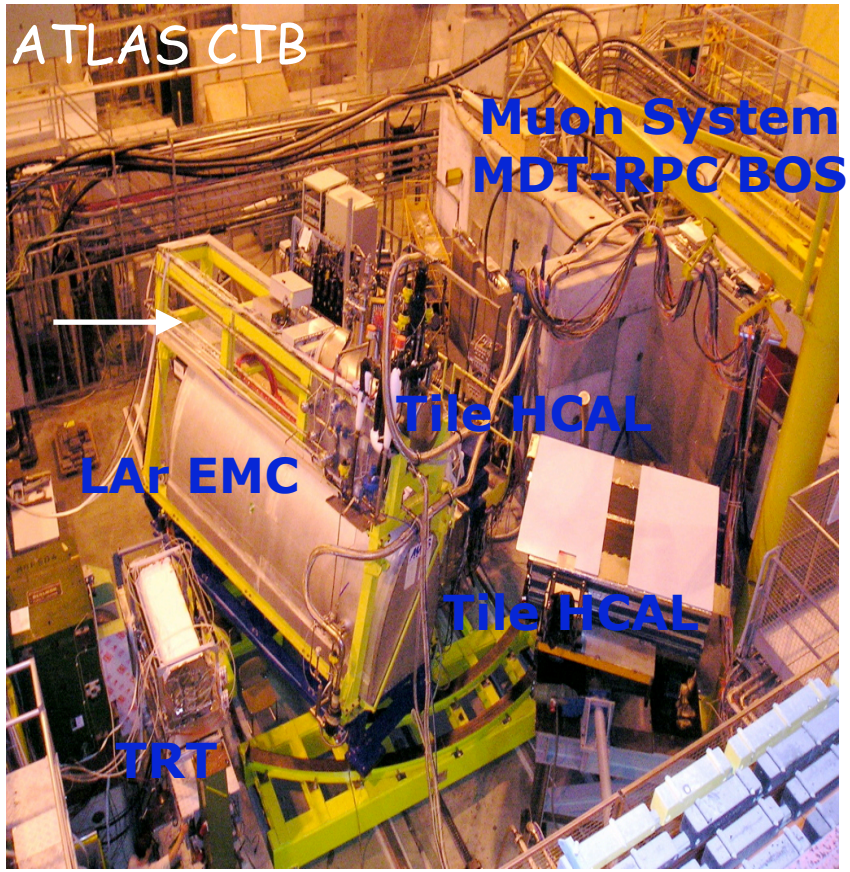
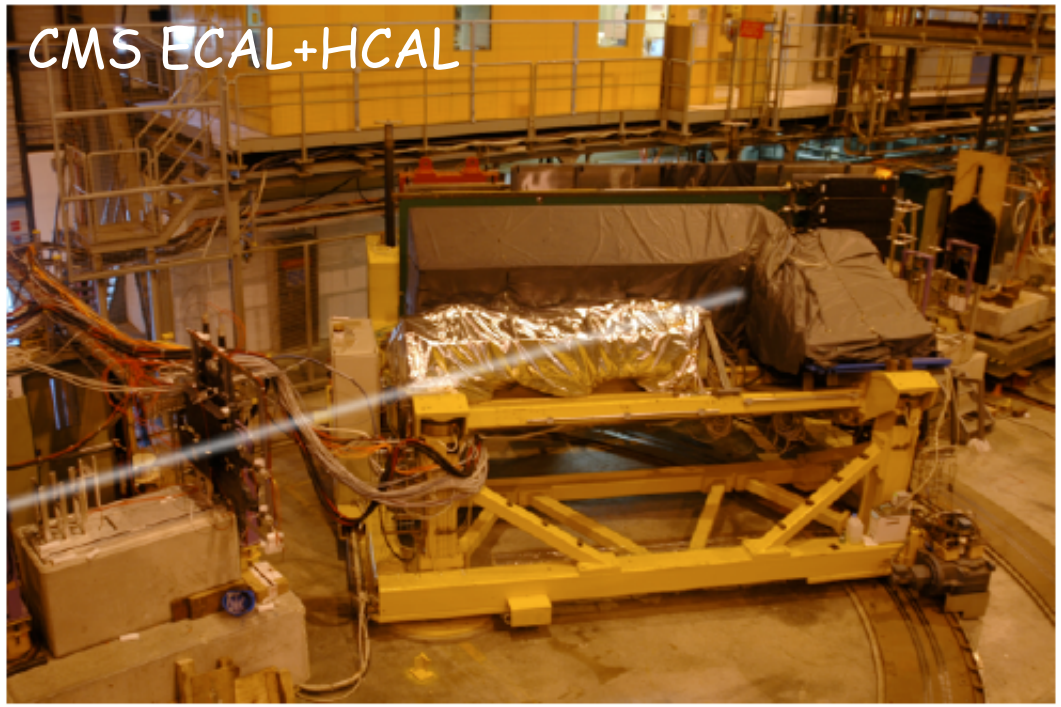
Introduction

- We report on the validation of Geant4 simulations for LHC experiments, based on test-beam data
- We focus here on calorimeter observables that are sensitive to hadronic physics
- These are the LHC calorimeter test-beam set-ups that we refer to:
  - ATLAS Tile : **Fe-Sci**
  - ATLAS HEC : **Cu-LAr**
  - ATLAS combined barrel : **Pb-LAr** (EM) + **Fe-Sci** (HAD)
  - CMS combined : **PbWO4** crystals (EM) + **Brass-Sci** (HAD)


ATLAS Tile
Production Module
Barrel Module 0
Beam


ATLAS HEC

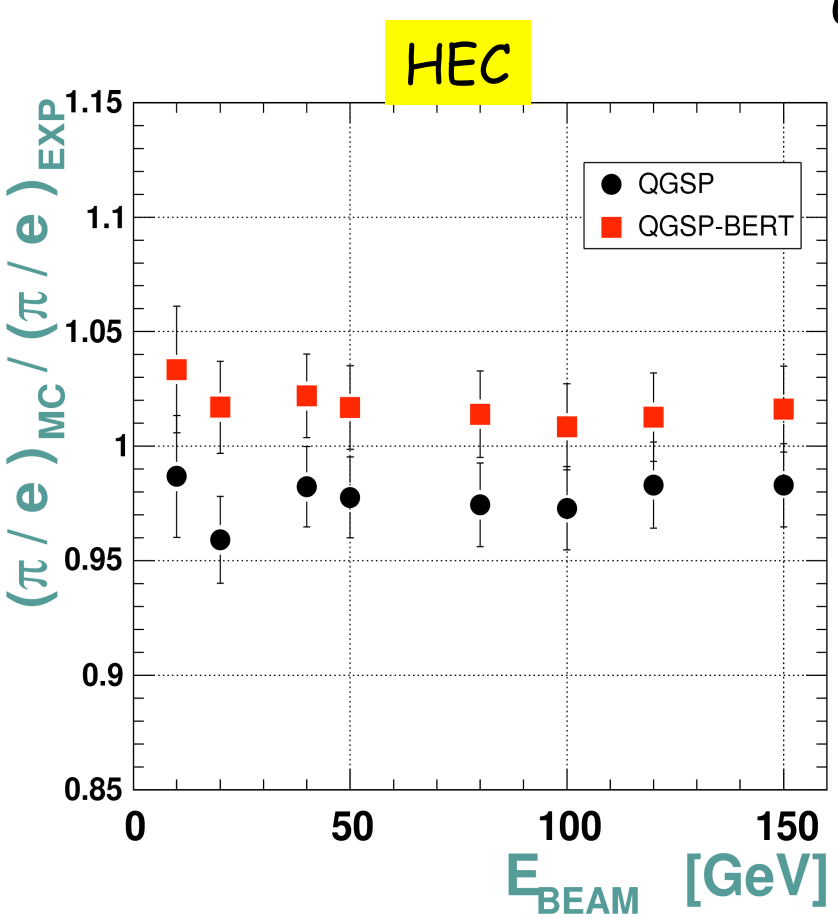

ATLAS CTB
Muon System
MDT-RPC BOS
Tile HCAL
LAr EMC
Tile HCAL
TRT

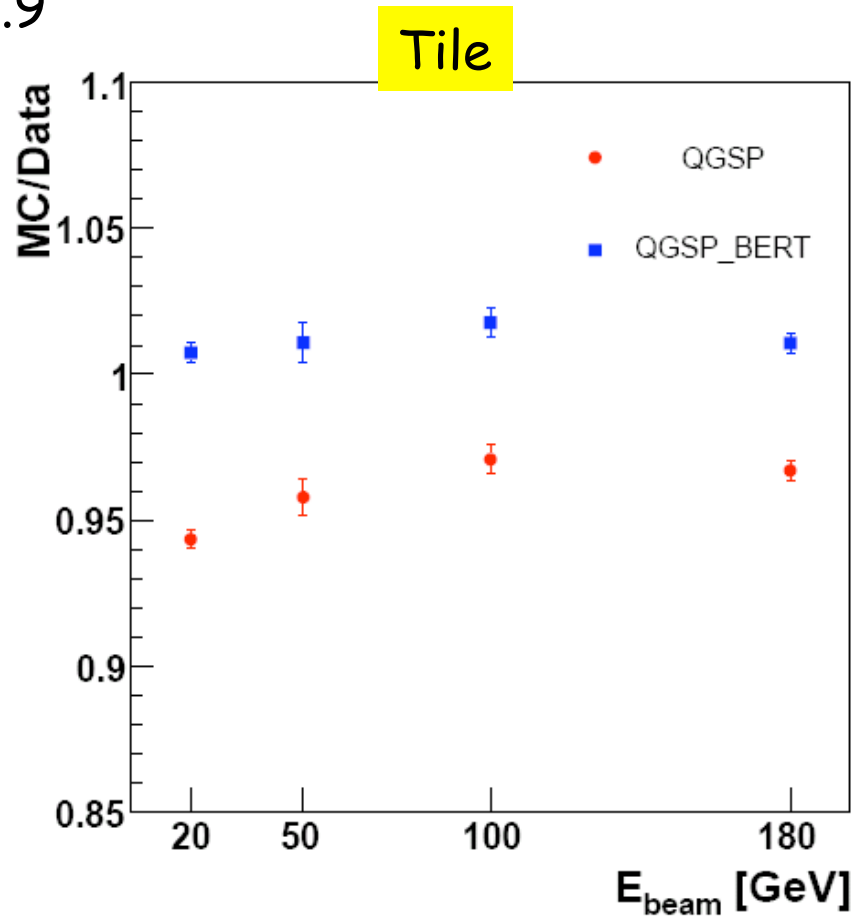

CMS ECAL+HCAL

Energy Response

Pion energy response in ATLAS stand-alone test-beams

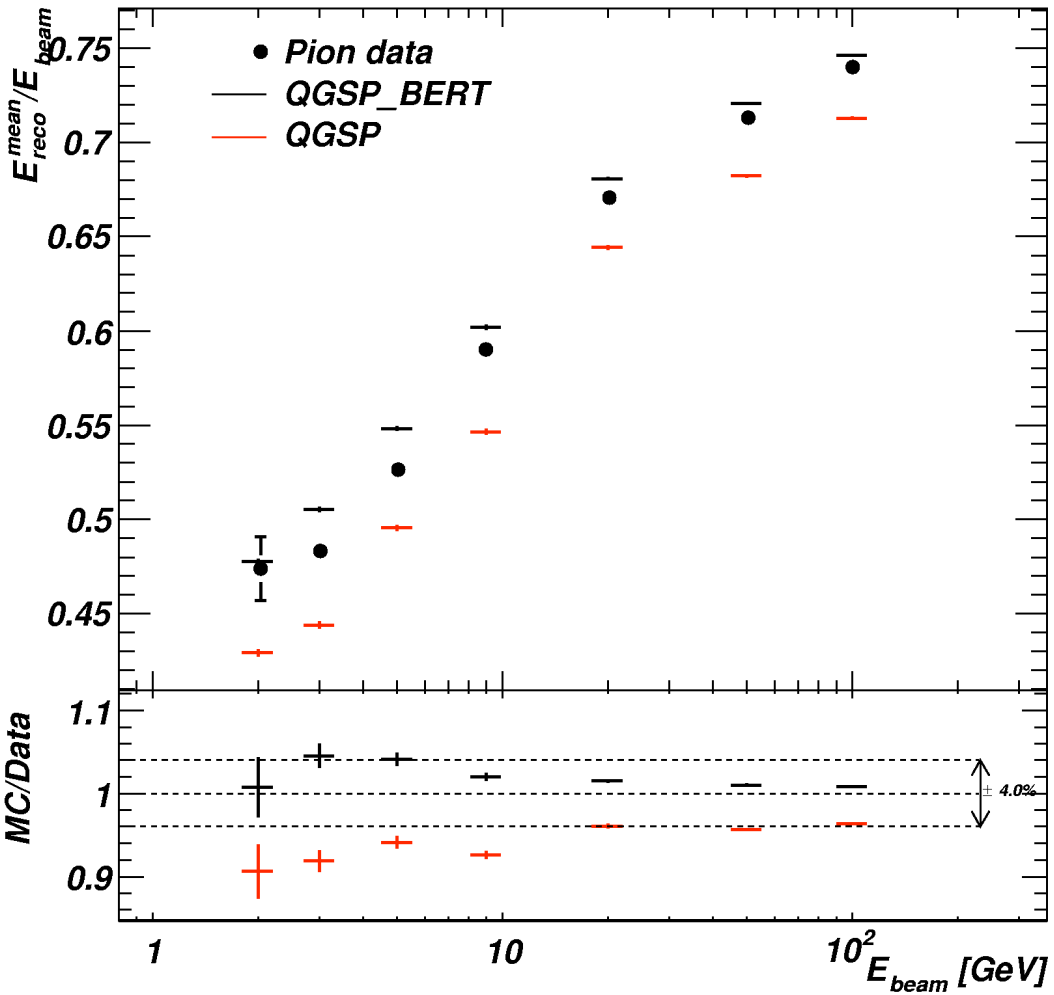
G4.9





Bertini cascade increases response for Tile and HEC by 4-5%.
In Tile and HEC response ~2% too high with QGSP_BERT.

Pion energy response in ATLAS barrel combined test-beam



G4.9

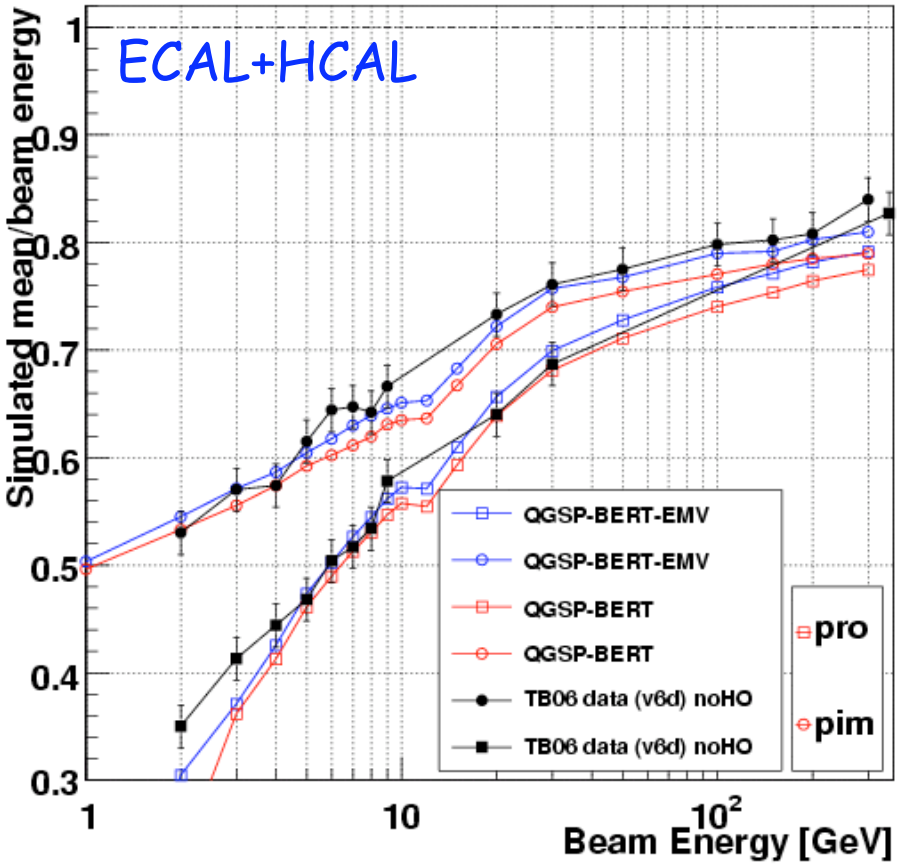
Bertini cascade model increases the response.

QGSP_BERT shows the best overall performance for the linearity (within 4%).

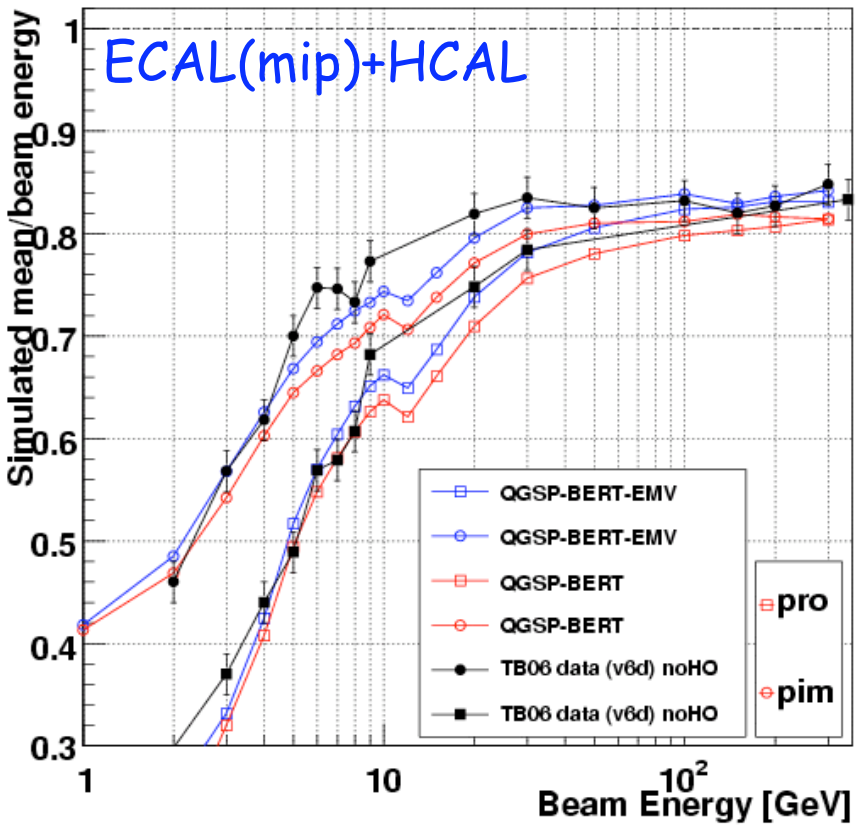
2% above 10 GeV
4% below 10 GeV

Pions and protons energy response in CMS combined test-beam

G4:9.2.b01 Response (MCideal calib.: ele50) 4.9.2.b01



G4:9.2.b01 Response (MCidealMIP calib.: ele50)

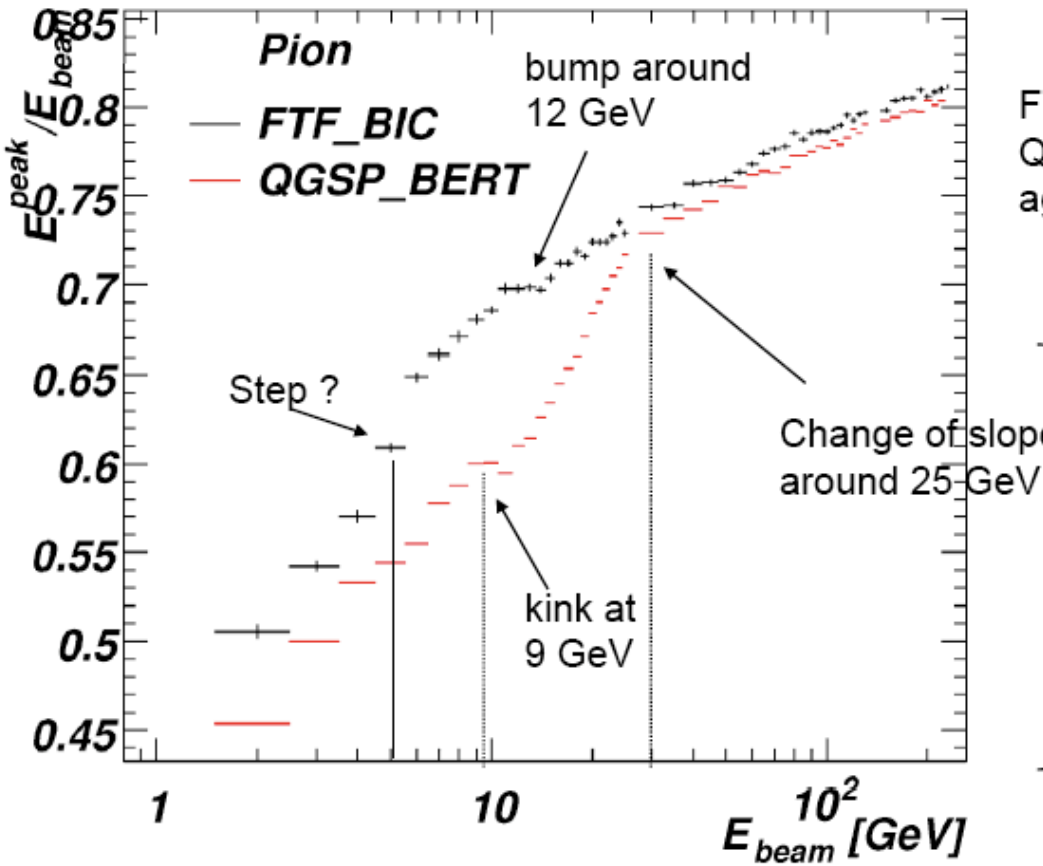


Agreement between data and simulation on energy response is within systematic uncertainty

Energy response vs. beam energy

Problem of matching models:

ATLAS Tile



FTF_BIC is more smooth
QGSP_BERT is in better agreement to data

Effect of transition between models ?

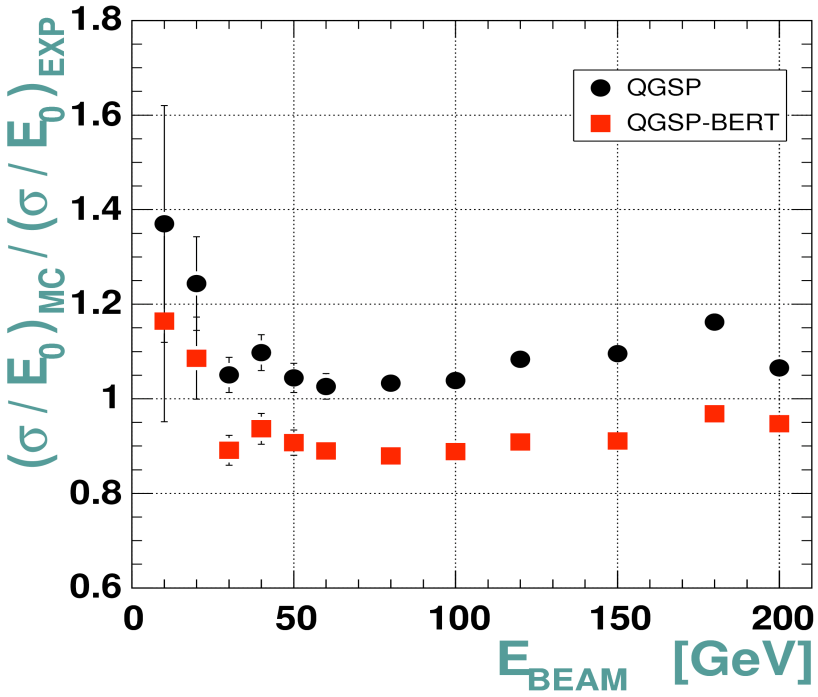
QGSP_BERT:
- 0-9.9 GeV Bertini intra-nuclear cascade (BERT)
- 9.5-25 GeV low energy parameterised model (LEP)
- >12 GeV QGSP

FTF_BIC:
- 0-5 GeV binary cascade model (BIC)
- 0-5 GeV LEP for capture and fission processes
- >5 GeV Fritiof model (FTF)

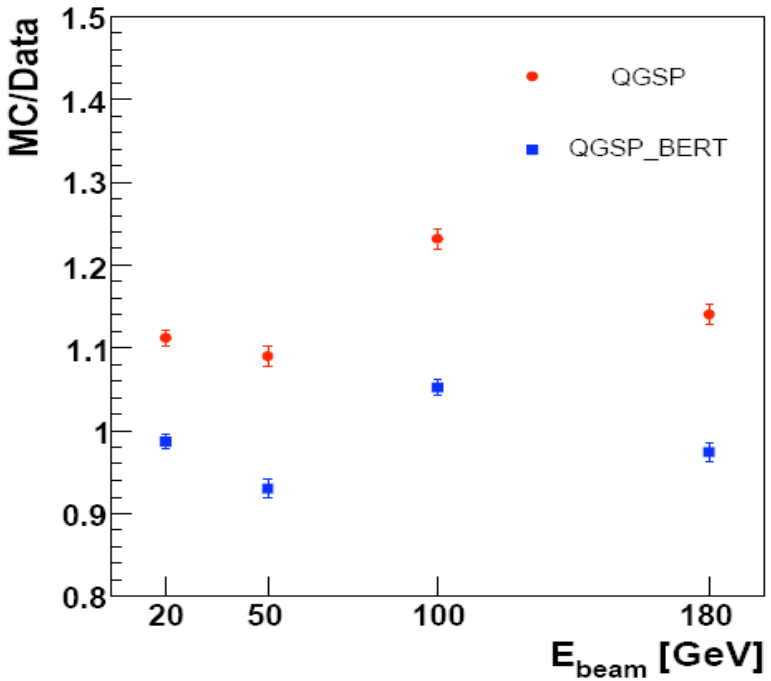
Energy Resolution

Pion resolution in ATLAS stand-alone test-beams

HEC



Tile

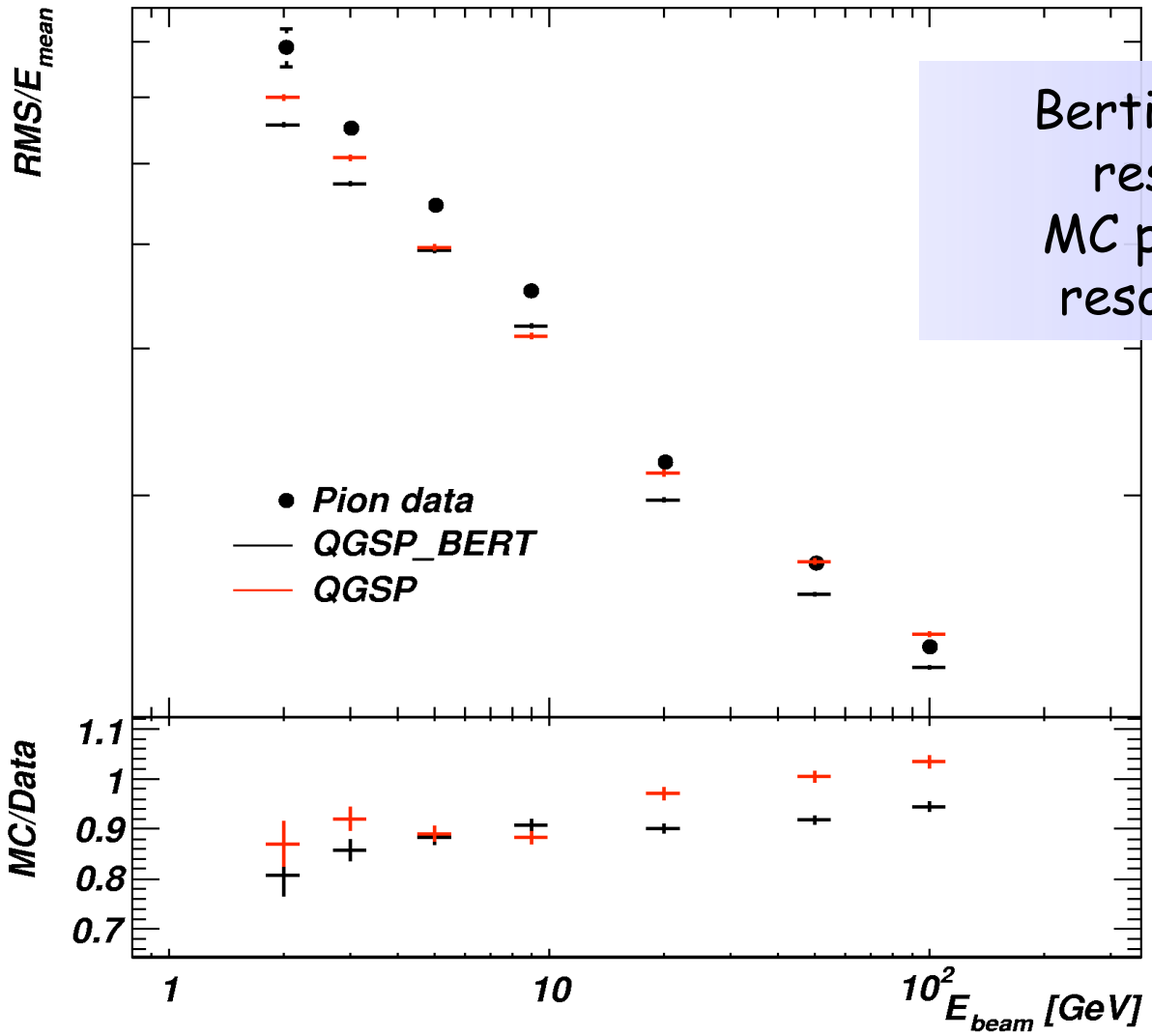


Bertini cascade makes resolution better:

in Tile: better agreement with data (±10 %).

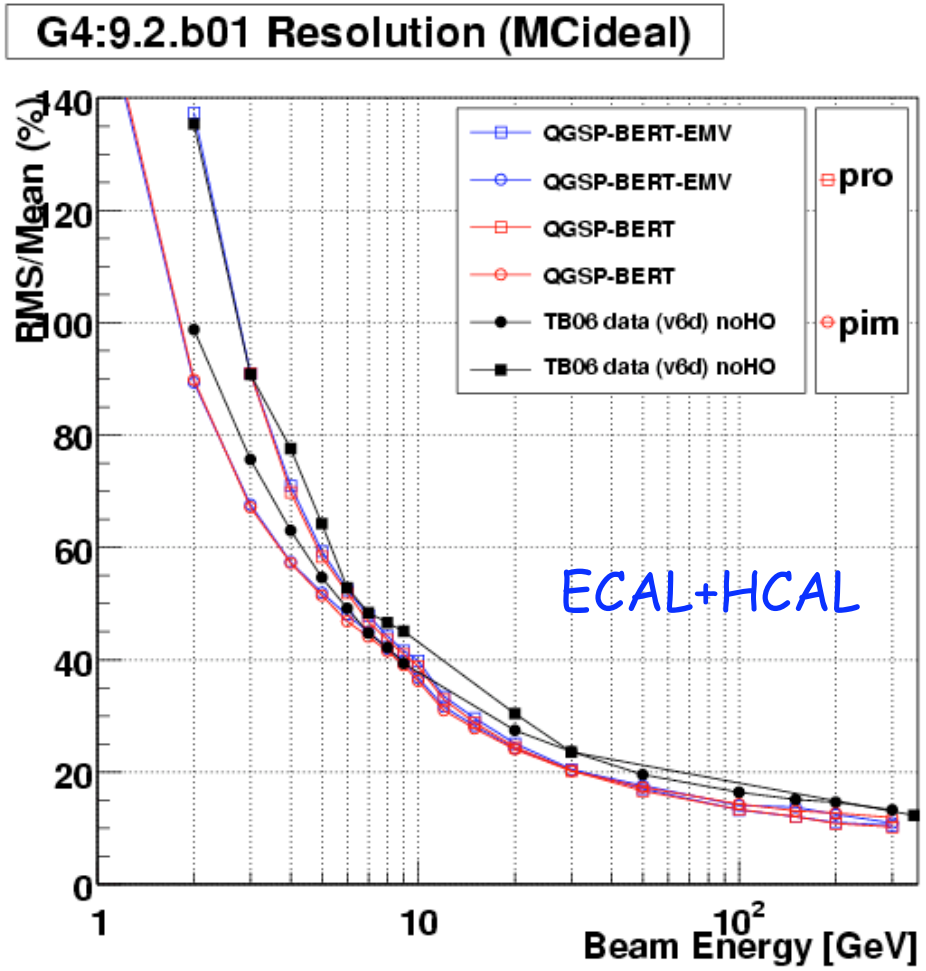
in HEC: MC resolution too good by -10%.

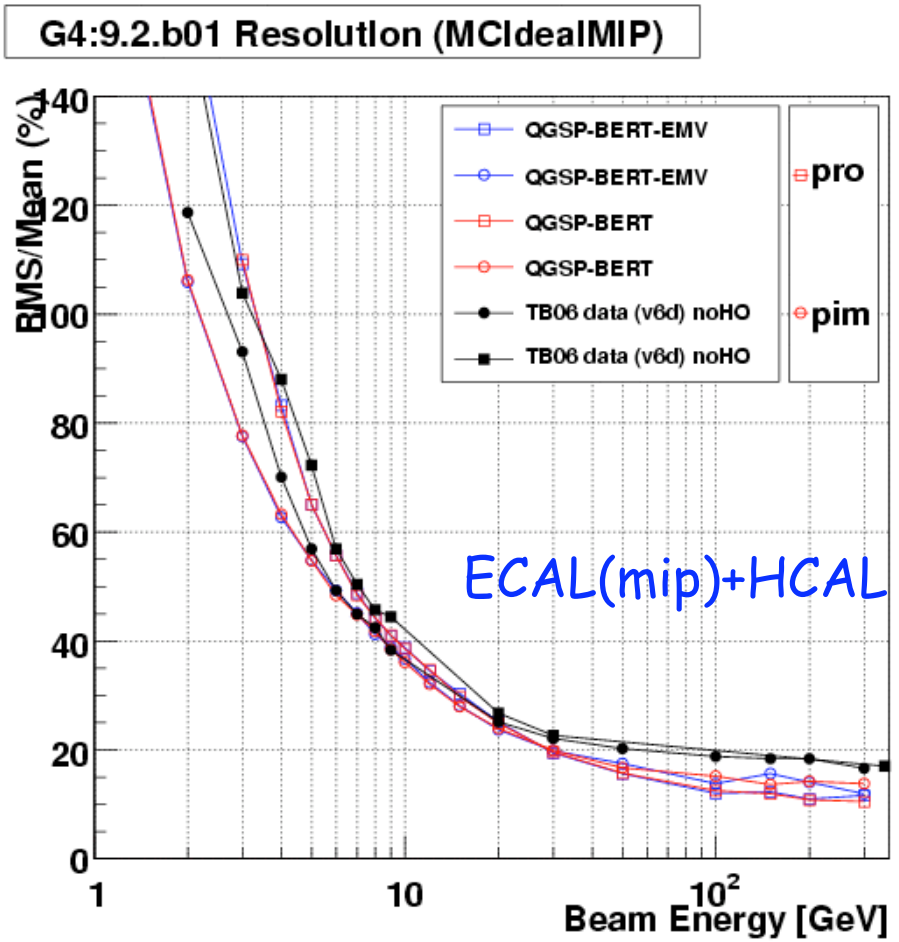
Pion resolution in ATLAS barrel combined test-beam



Bertini cascade makes resolution better
MC predicts too good resolution -5 ÷ -10%

Pions and protons energy resolution in CMS combined test-beam

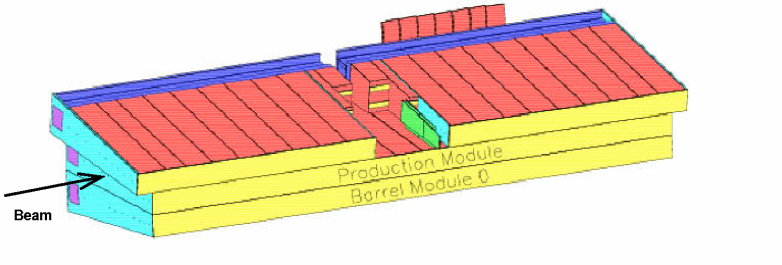


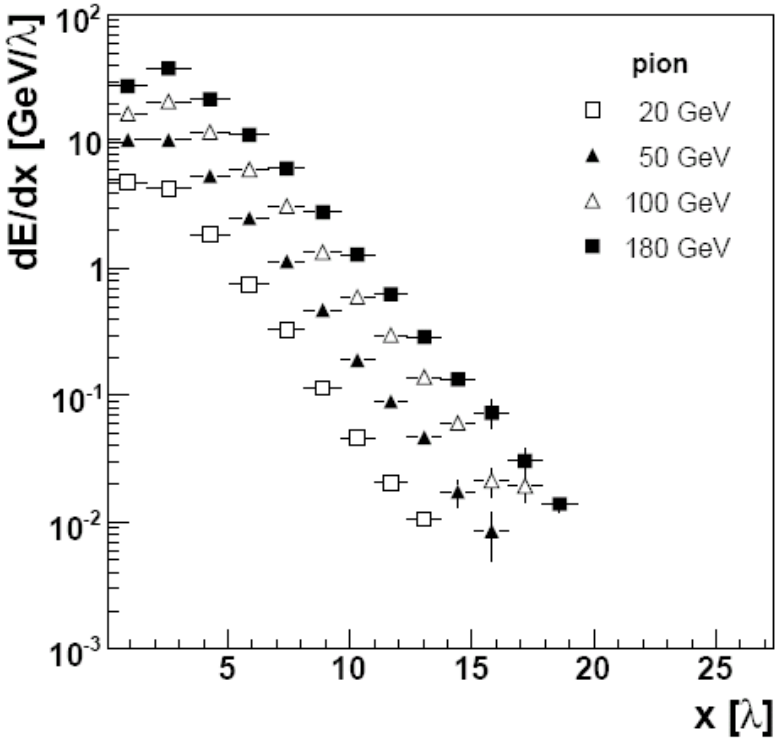


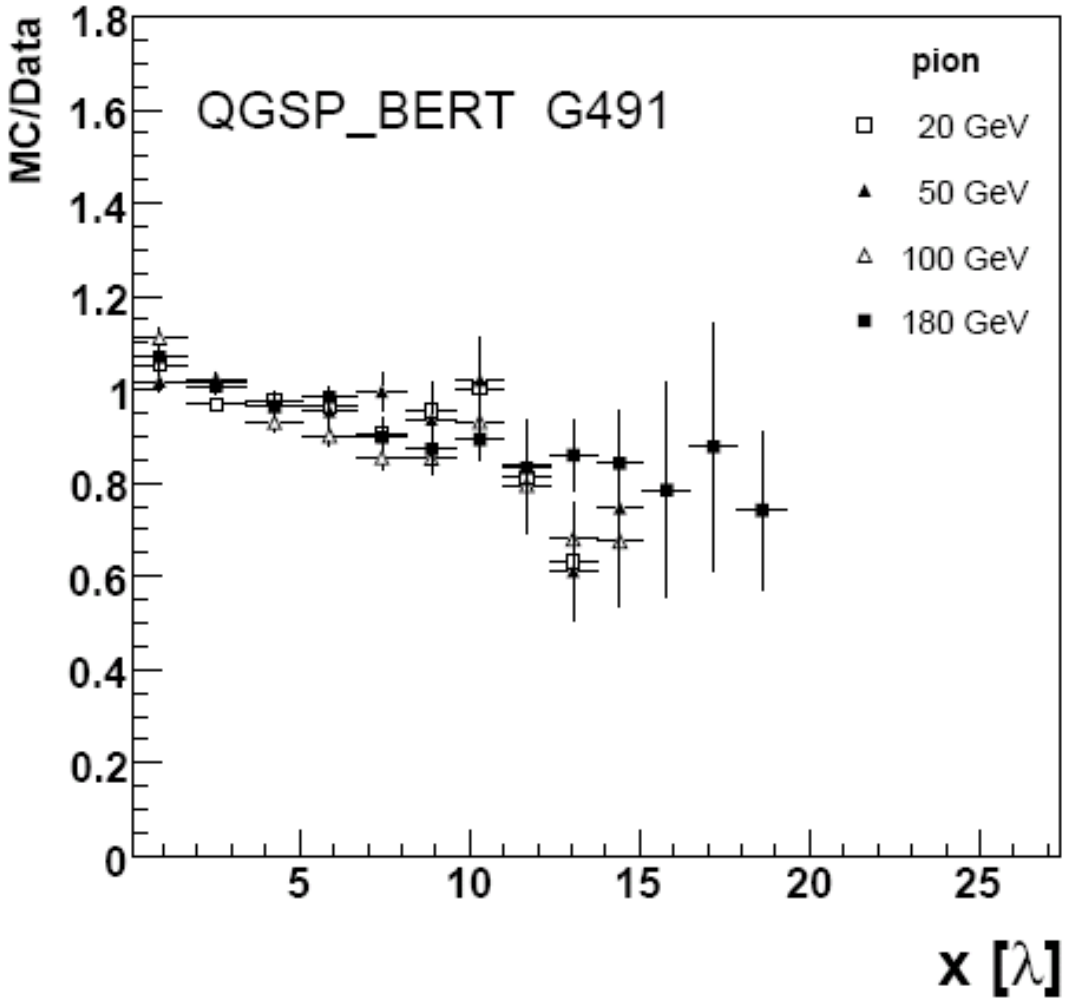
Resolution is too good in Monte Carlo

Longitudinal shower shape

Pion longitudinal shower profile in stand-alone ATLAS TileCal test-beam at 90°

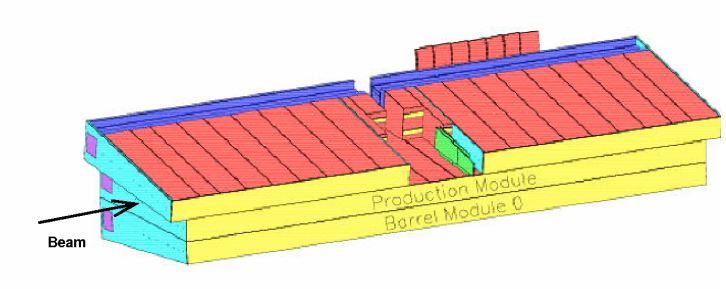


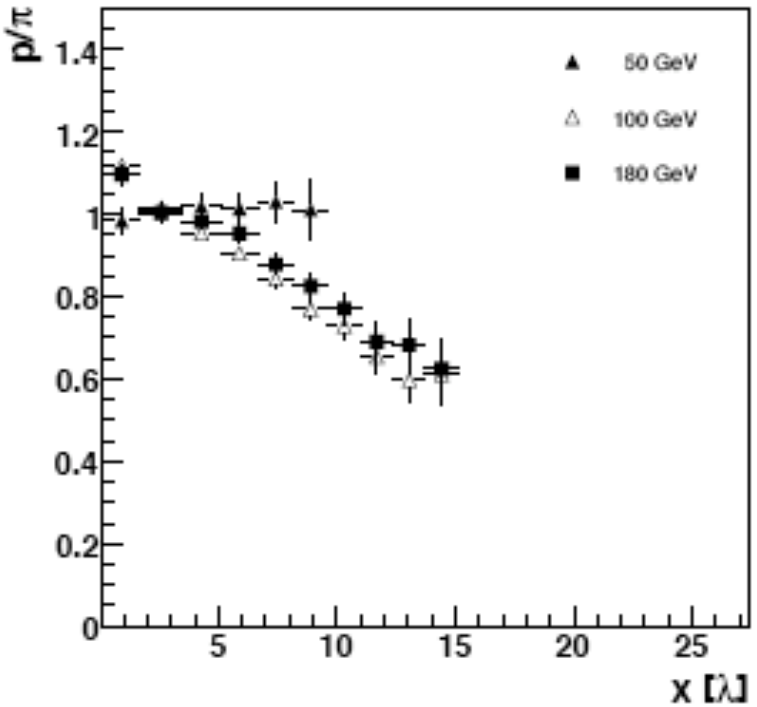


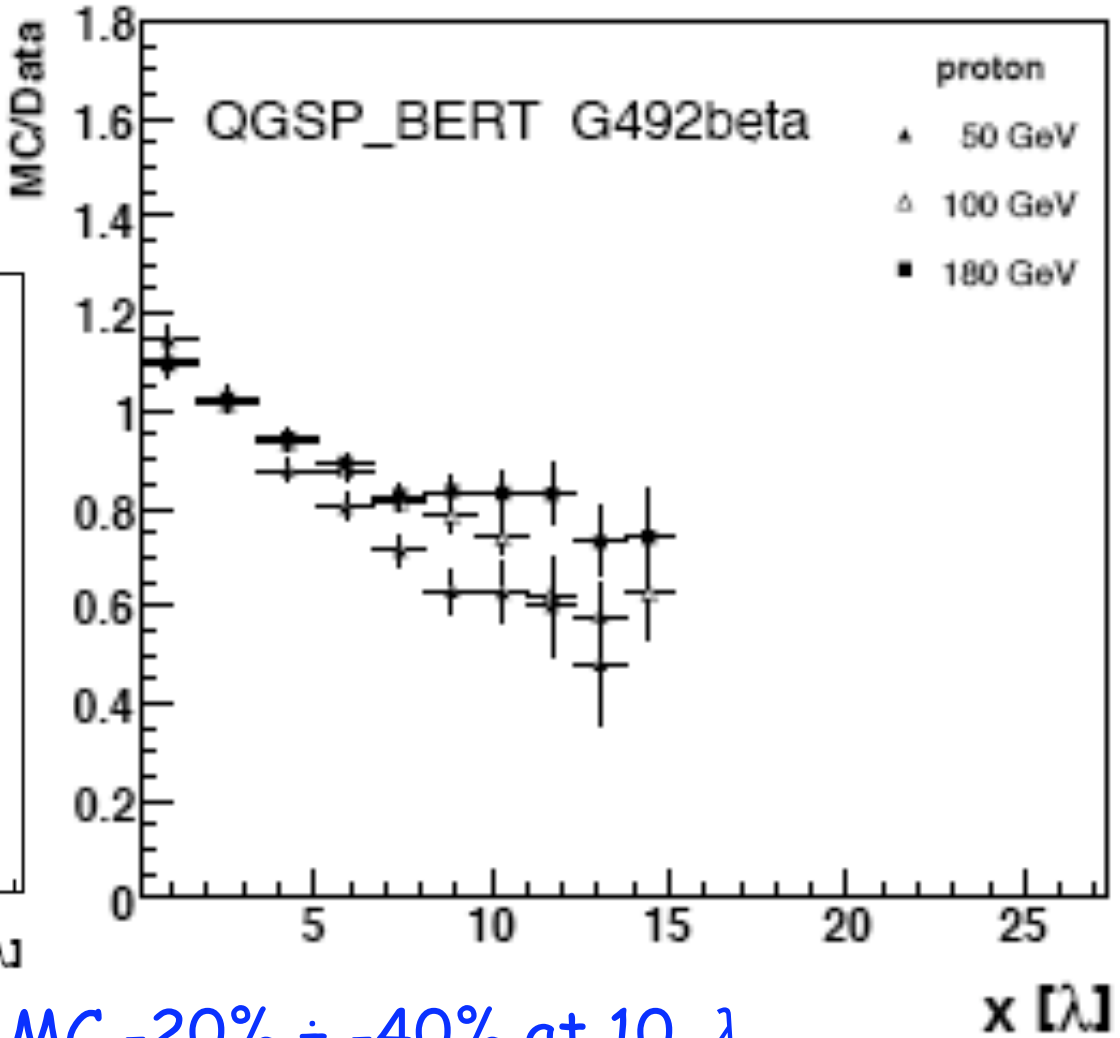


MC within ~ ±10% up to 10 λ .

Proton longitudinal shower profile in stand-alone ATLAS TileCal test-beam at 90°







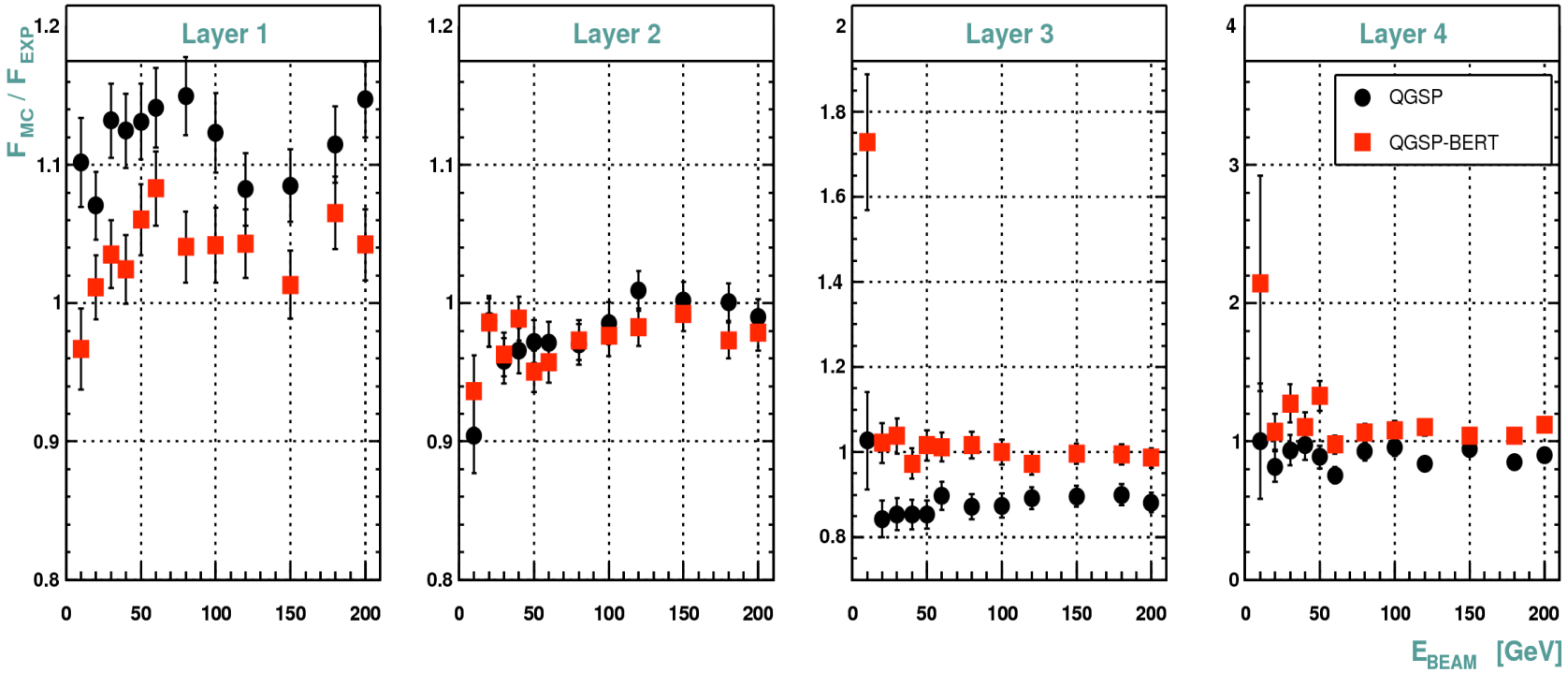
MC -20% ÷ -40% at 10 λ .

Pion longitudinal shower profile in stand-alone ATLAS HEC test-beam

Four HEC longitudinal layers: 8/16/8/8 LAr gaps, 1.5/2.9/3.0/2.8 λ

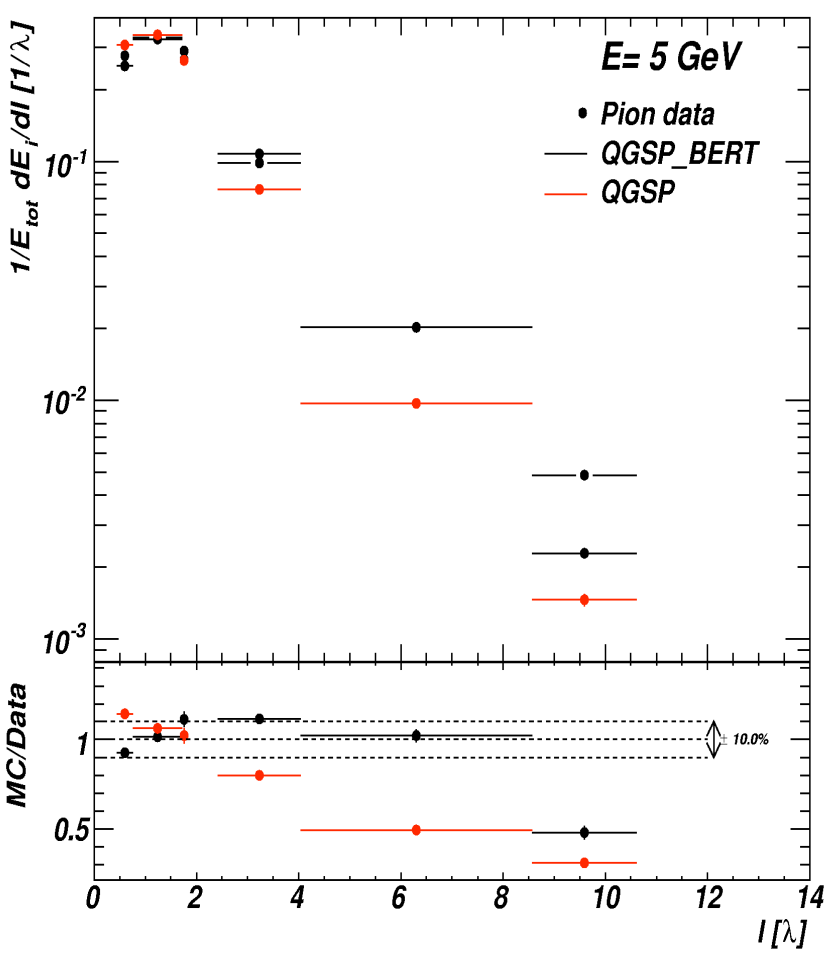
$F = < E_{LAYER} > / E_{SUM}$, where $E_{SUM} = \Sigma < E_{LAYER} >$

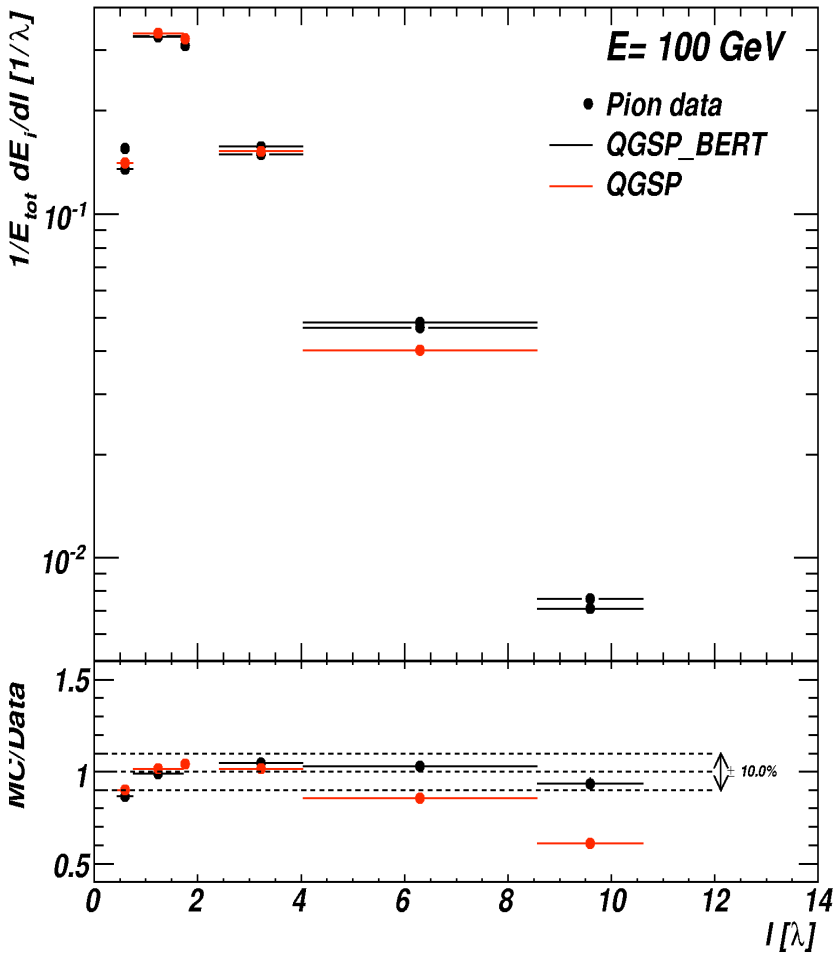
G490



QGSP starts/ends too early, QGSP_BERT with ±10 % (still a bit too early)
Problem at 10 GeV.

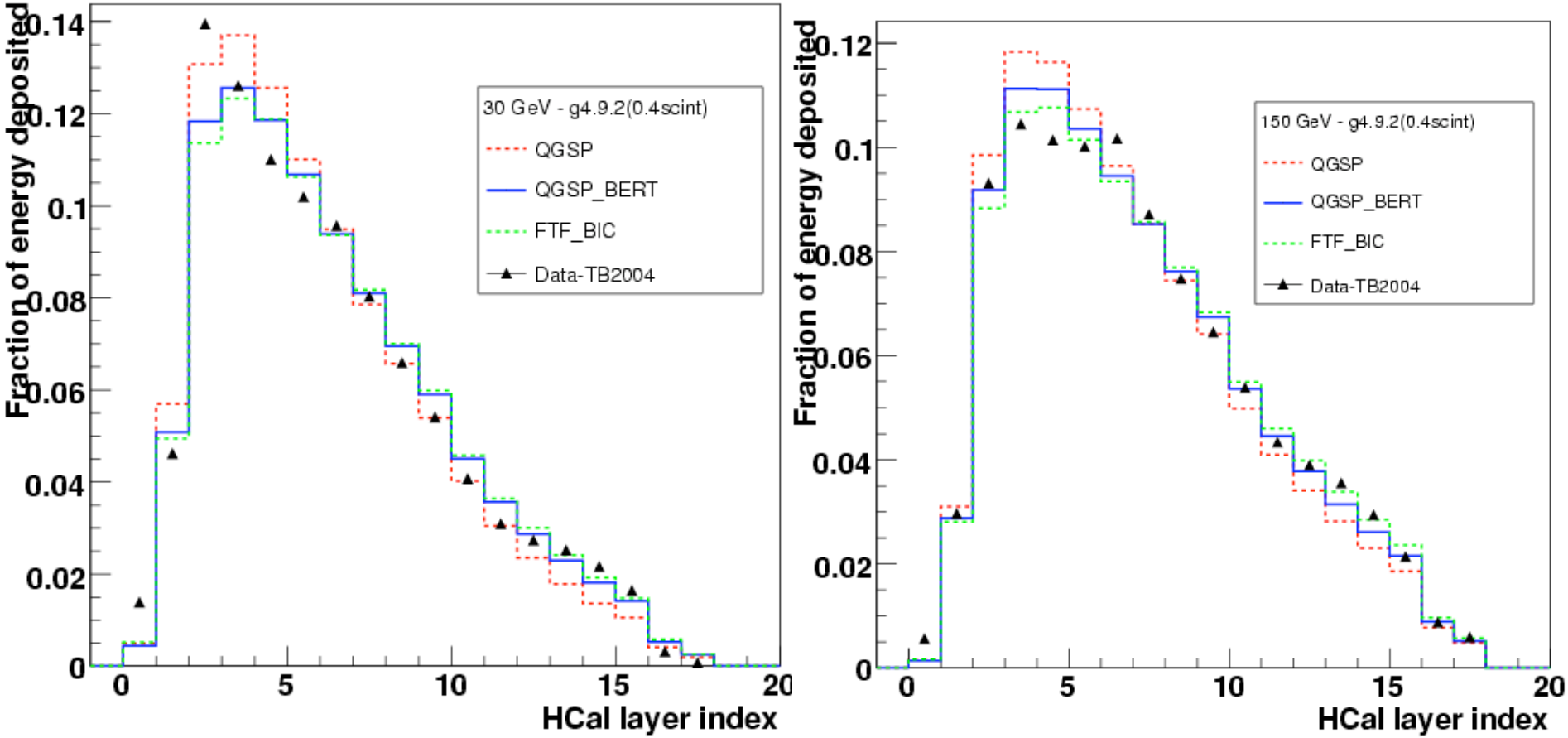
Pion longitudinal shower profile in ATLAS barrel combined test-beam





QGSP_BERT describes data within ±10%.

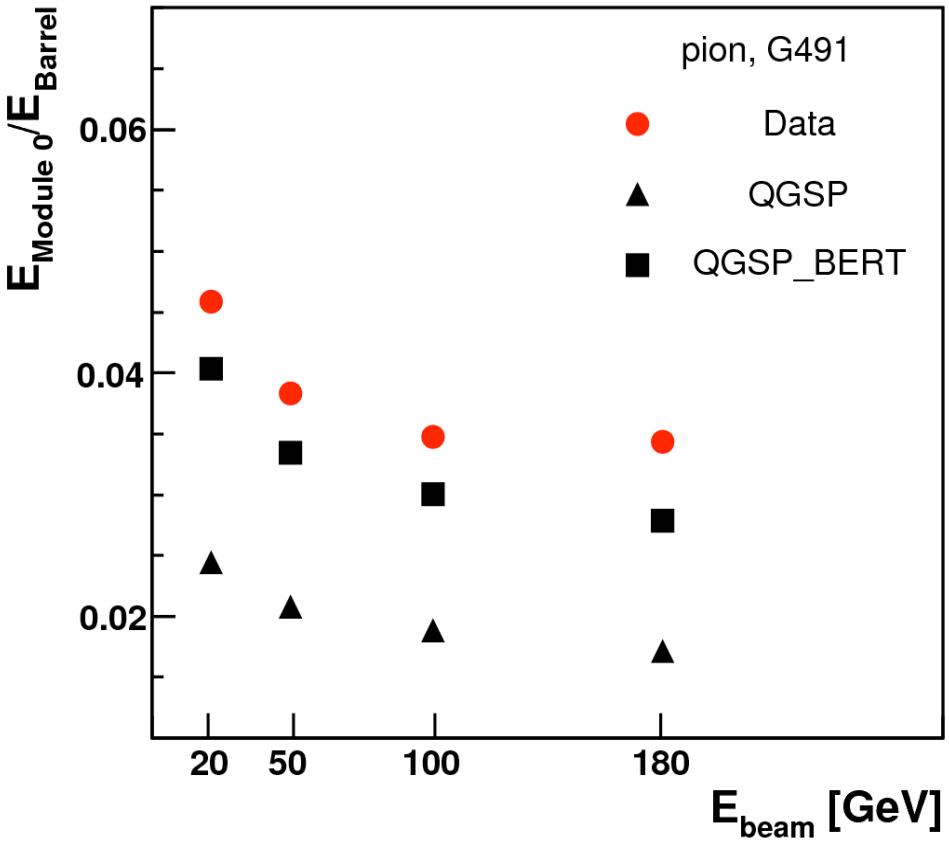
Pion longitudinal shower profile in CMS combined test-beam

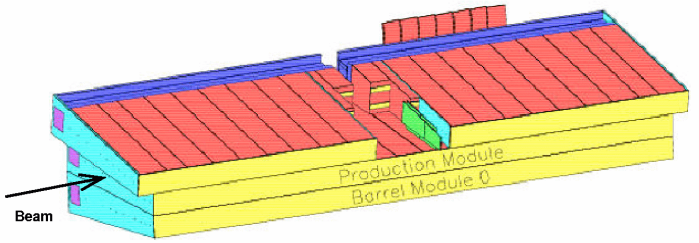


- QGSP produces shorter showers than data
- QGSP_BERT showers are as long as in the data.
- Similar trend at all energies

Lateral shower shape

Pion lateral spread in stand-alone ATLAS TileCal test-beam @90°





Bertini cascade makes shower wider, which is in better agreement with data, but data are still a bit wider.

Summary and Outlook

- The LHC experiments have carried out extensive tests of the Geant4 physics models and validated them with test beam data.
- ATLAS and CMS have chosen QGSP_BERT(_EMV) as the default Physics List.
  Fritiof-based Physics Lists, FTF_BIC and FTFP_BERT show interesting features.
- There are some remaining issues in hadronic physics
  1) Discontinuity in energy response at the model boundaries
  2) Proton longitudinal shower profiles are shorter than data in QGS-based Physics Lists (diffraction)
  3) Lateral shower profiles are a bit narrower than data (not an issue for LHC experiments, but for ILC it could be important….)