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Validation of GEANT4 Version 9.0 with Testbeam Data of the ATLAS Hadronic End-Cap Calorimeter

LCG Physics Validation of LHC Simulations
CERN, 17-th of October, 2007

- ATLAS hadronic end-cap calorimeter (HEC)
  - liquid argon (LAr) sampling calorimeter with parallel copper absorber plates
  - beam tests of serial modules in 2000-2001
- Stand-alone code for GEANT4 based simulations of the HEC testbeam

Content

- New round of GEANT4 simulations: **version 9.0**
  - scan over the GEANT4 range cut with electrons
  - electron energy scan
  - charged pion energy scans

- Some results were presented during the week of the ATLAS LAr calorimeter group in September 2007:
  http://indico.cern.ch/conferenceDisplay.py?confId=8261

Simulation Packages

- GEANT4 version 9.0 (without patch)
  - Release date: June 2007
  - Physics lists:
    - QGSP 3.3
    - QGSP-NQE 1.0
    - QGSP-BERT 3.3

- Previous GEANT4 versions: 8.2p1, 8.1p2, 8.0p1, 7.0p1, 6.2p2

- GEANT3
  - Version 3.21
  - G-CALOR (hadronic shower code)
  - 100 keV transport cuts and 1 MeV process cuts

- HEC geometry: the same in all GEANT4 versions and very similar in GEANT3

Time of Simulations

- Latest simulations (GEANT version 8.1 and further) were done at the Garching computer centre

- Time ratios (for 20 μm range cut):

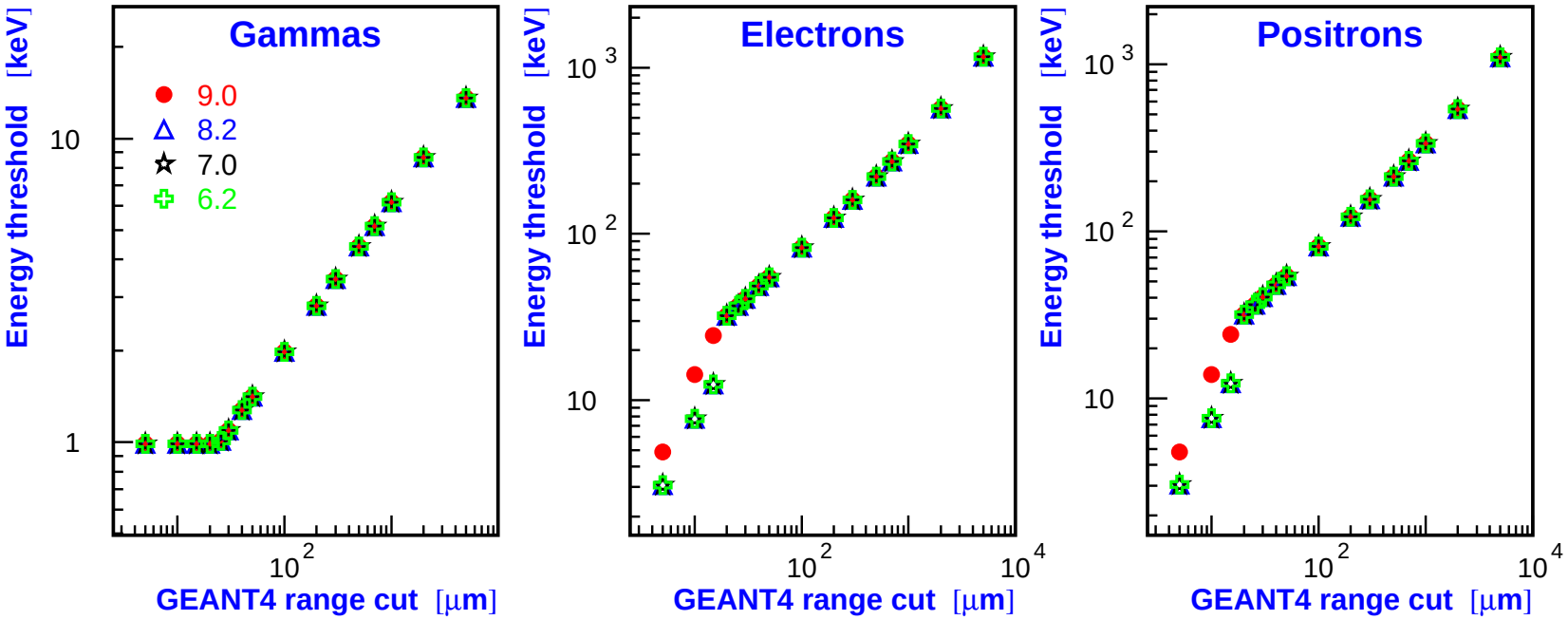
9.0	QGSP		π^-/e^-	$= 0.7$
9.0		π^-	QGSP-NQE / QGSP	$= 0.95$
9.0		π^-	QGSP-BERT / QGSP	$= 1.6$
	QGSP	e^-	9.0 / 8.1	$= 0.84$
	QGSP	π^-	9.0 / 8.1	$= 0.9$

Electrons: Scan over the Range Cut

- 100 GeV electrons
- GEANT4 range cut: 5 μm - 5 mm
- Physics list: QGSP
- 5000 events per cut
- Analysed variables:
  - energy thresholds versus range cuts in LAr and copper
  - mean energy depositions in LAr gaps and in copper plates
  - signal in the most loaded cell

Scan over the range cut with electrons

Energy threshold VS Range cut in LAr

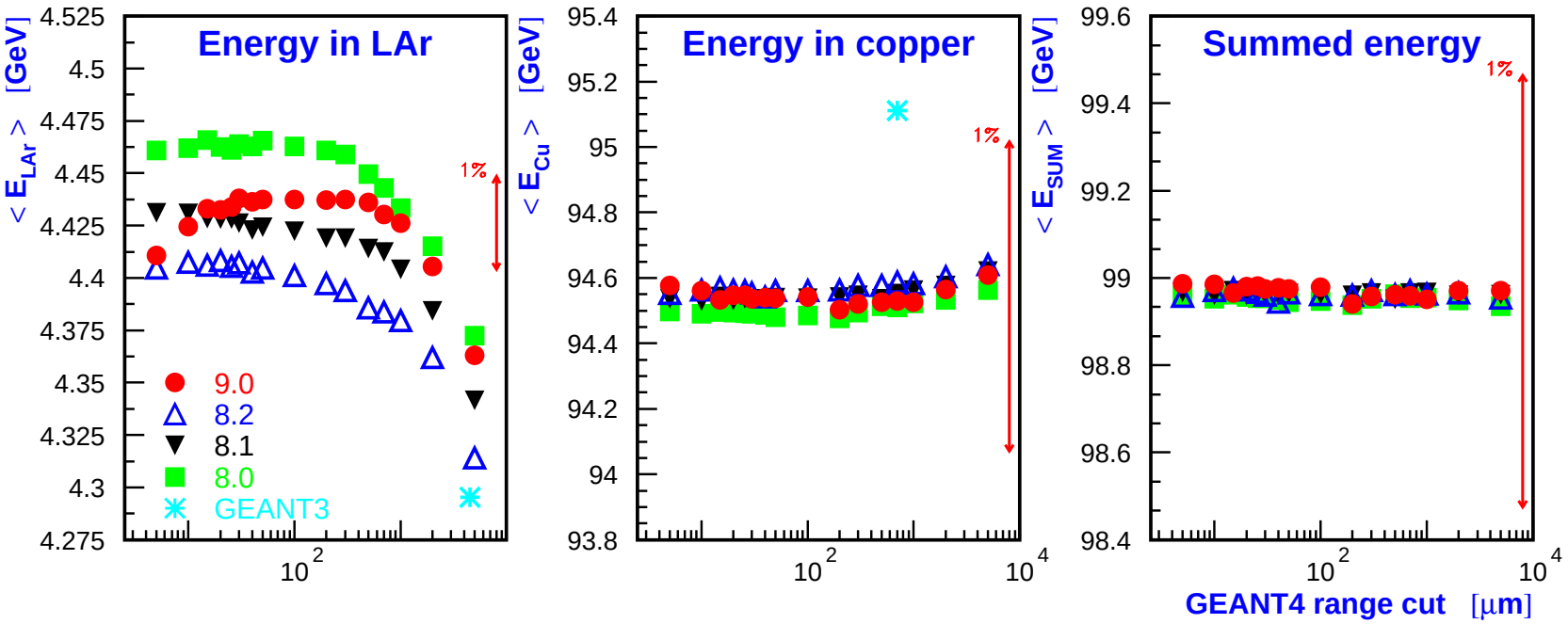


Increase of energy thresholds for electrons and positrons in LAr for 5-15 μm range cuts for version **9.0** w.r.t. previous versions.

No changes for copper in the studied interval of range cuts (5 μm - 5 mm).

Scan over the range cut with electrons

Energy depositions in HEC



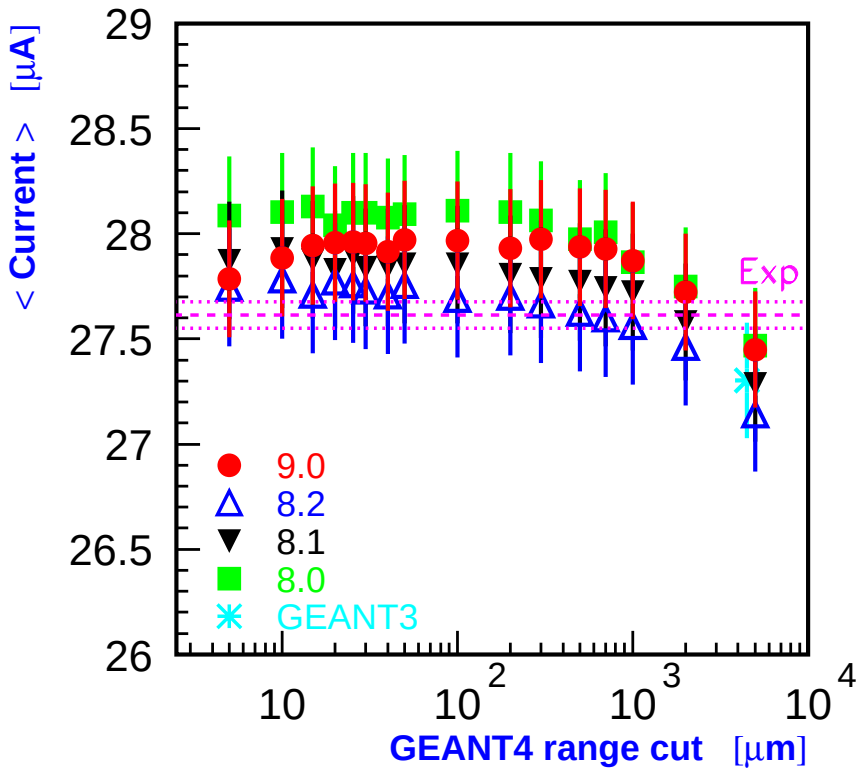
Certain changes of the behaviour of the visible energy in LAr as a function of the range cut in version **9.0**.

Changes of the signal in LAr between GEANT4 versions are at the level of ∼1%.

Scan over the range cut with electrons

Signal in one cell

- Cell with the maximal average signal (most loaded cell)
- Visible energy $\Rightarrow$ Current
- Conversion factor (from detailed modeling of the HEC electronic chain): 7.135 μA/GeV with an uncertainty of ± 1 %
- Experiment (averaging over 11 runs): mean$\pm$RMS
- MC results are in agreement with experimental values

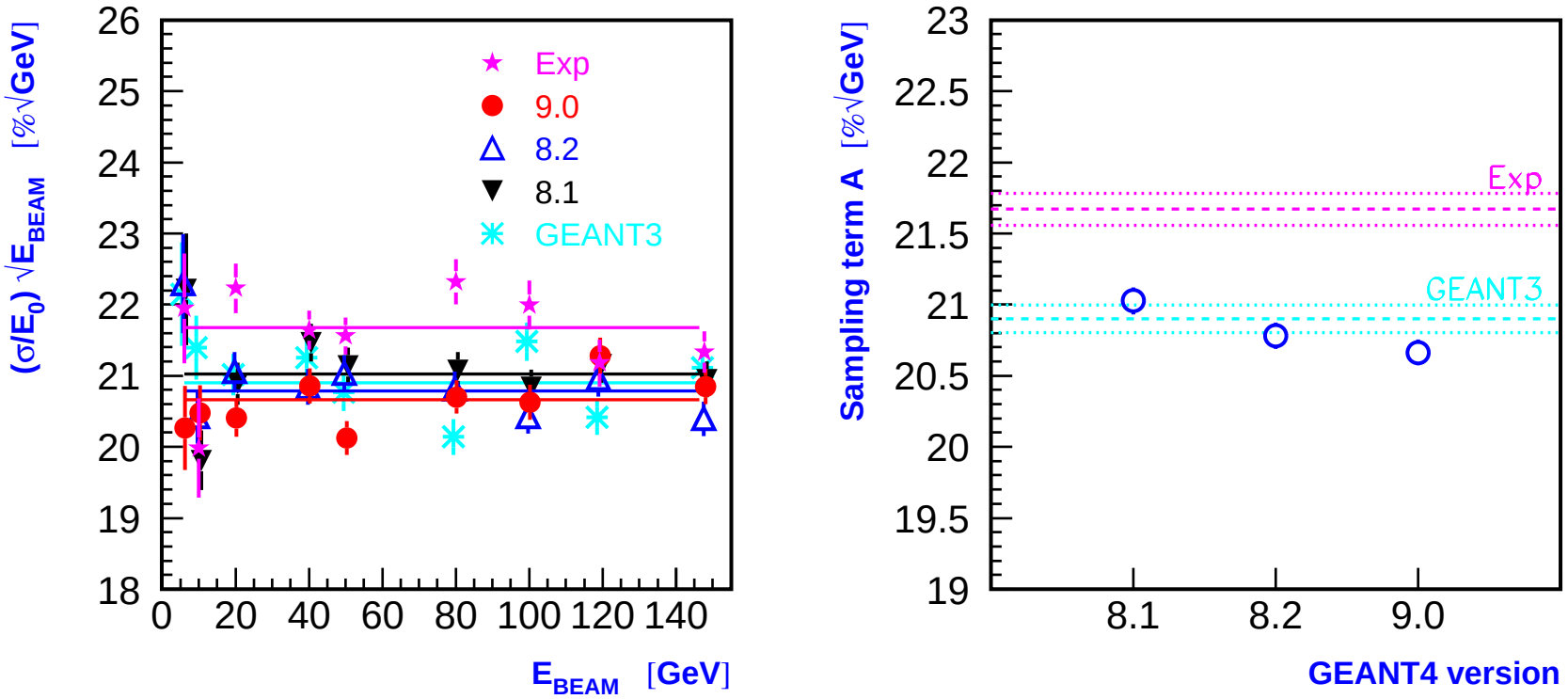


Electrons: Energy Scan

- Beam energies: 6 - 147.8 GeV
- GEANT4 range cut: 20 μm
- Physics list: QGSP
- 5000 events per beam energy
- Energy reconstruction:
  - following experimental procedure
  - cluster of the fix size
  - Gaussian fit: E_0 and σ
- Analysed variables:
  - energy resolution $\sigma/E_0 = A/\sqrt{E_{BEAM}}$

Electron energy scans

Electron energy resolution



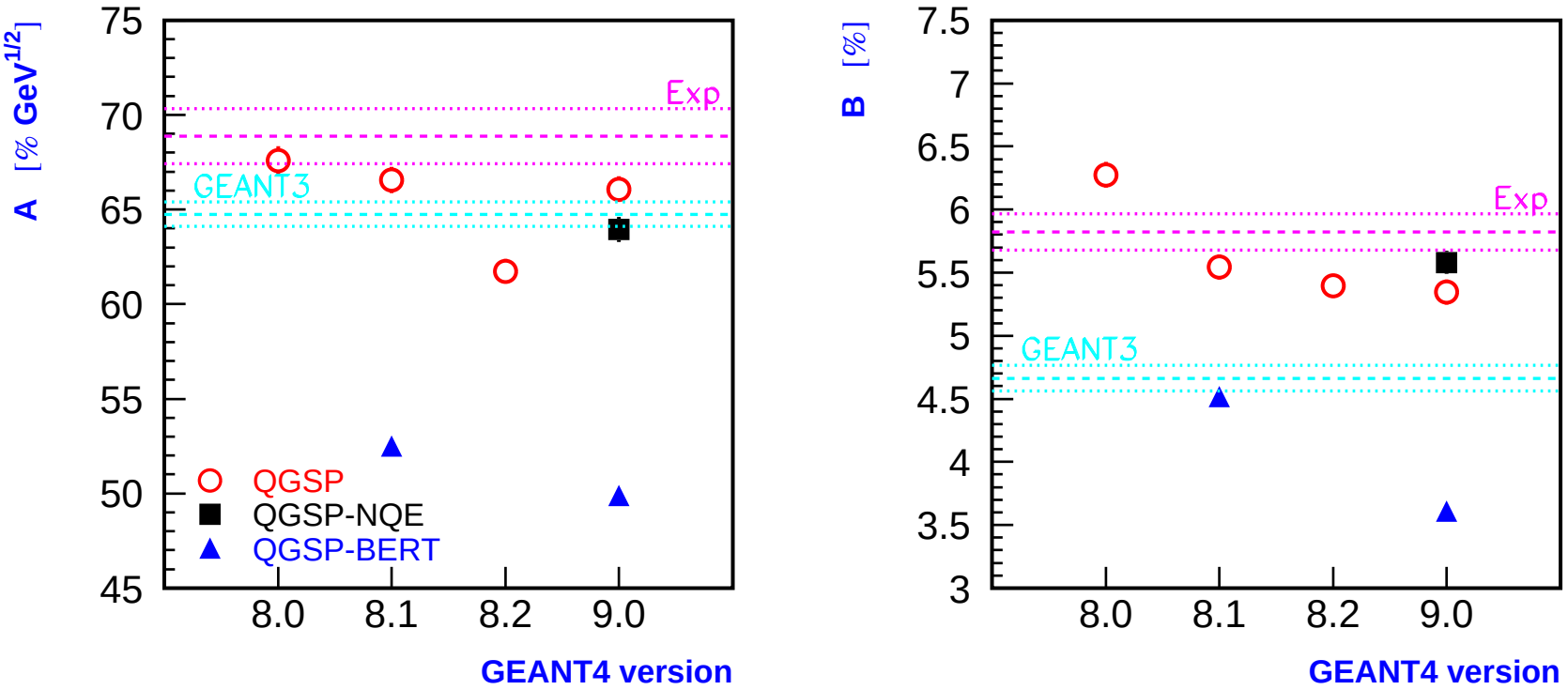
Predicted values of electron energy resolution are too optimistic.

Charged Pions: Energy Scans

- Beam energies: 10 - 200 GeV
- GEANT4 range cut: 20 μm
- Physics lists: QGSP, QGSP-NQE and QGSP-BERT
- 5000 events per beam energy and physics list
- Energy reconstruction:
  - similar as for electrons
- Analysed variables:
  - energy resolution
    $\sigma/E_0 = A/\sqrt{E_{BEAM}} \oplus B$
  - ratio e/π
    ratio of energies in electron and pion clusters
  - fraction of energies in HEC longitudinal layers

Charged pion energy scans

Pion energy resolution



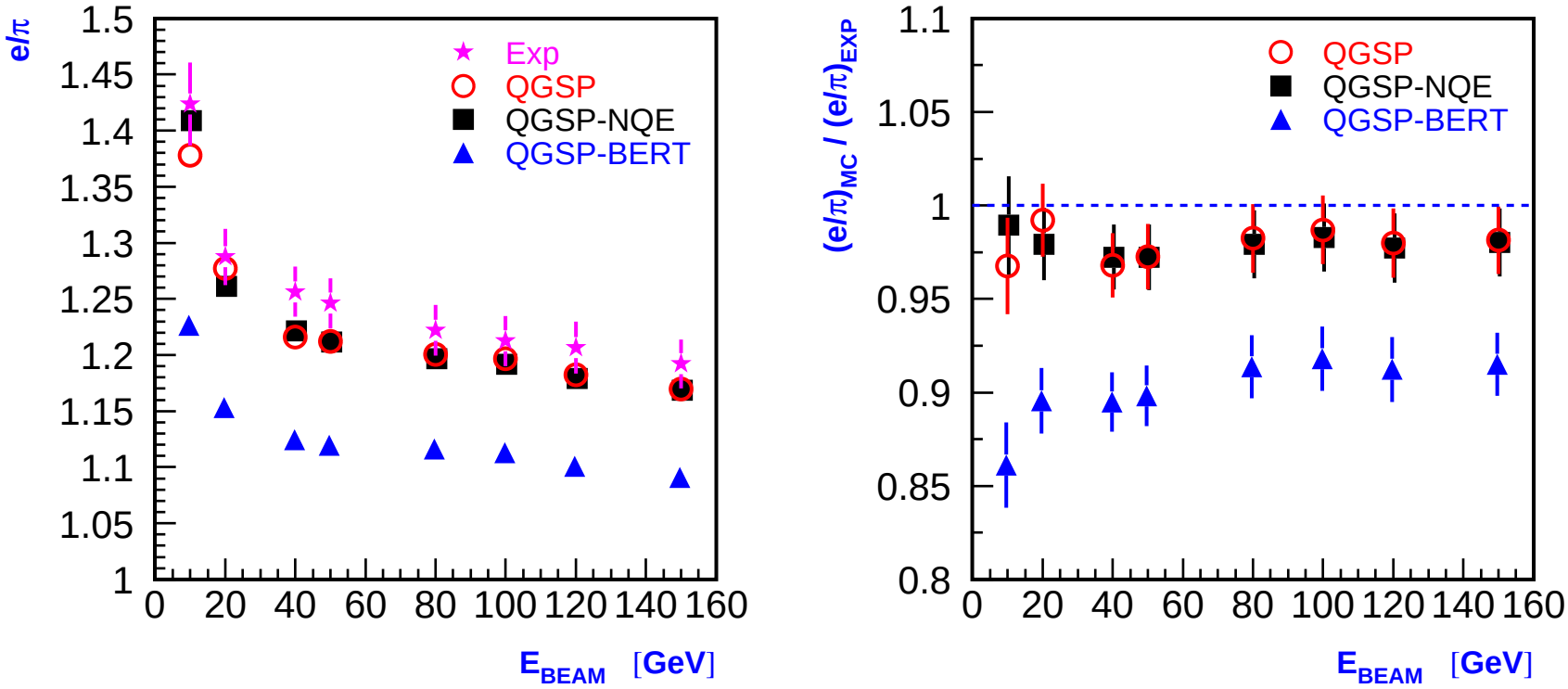
QGSP: in version 9.0 description of the resolution is improved w.r.t. version 8.2.

QGSP-NQE: close to QGSP.

QGSP-BERT: in version 9.0 disagreement with experimental data is larger than in version 8.1.

Charged pion energy scans

Ratio e/π for GEANT4 version 9.0

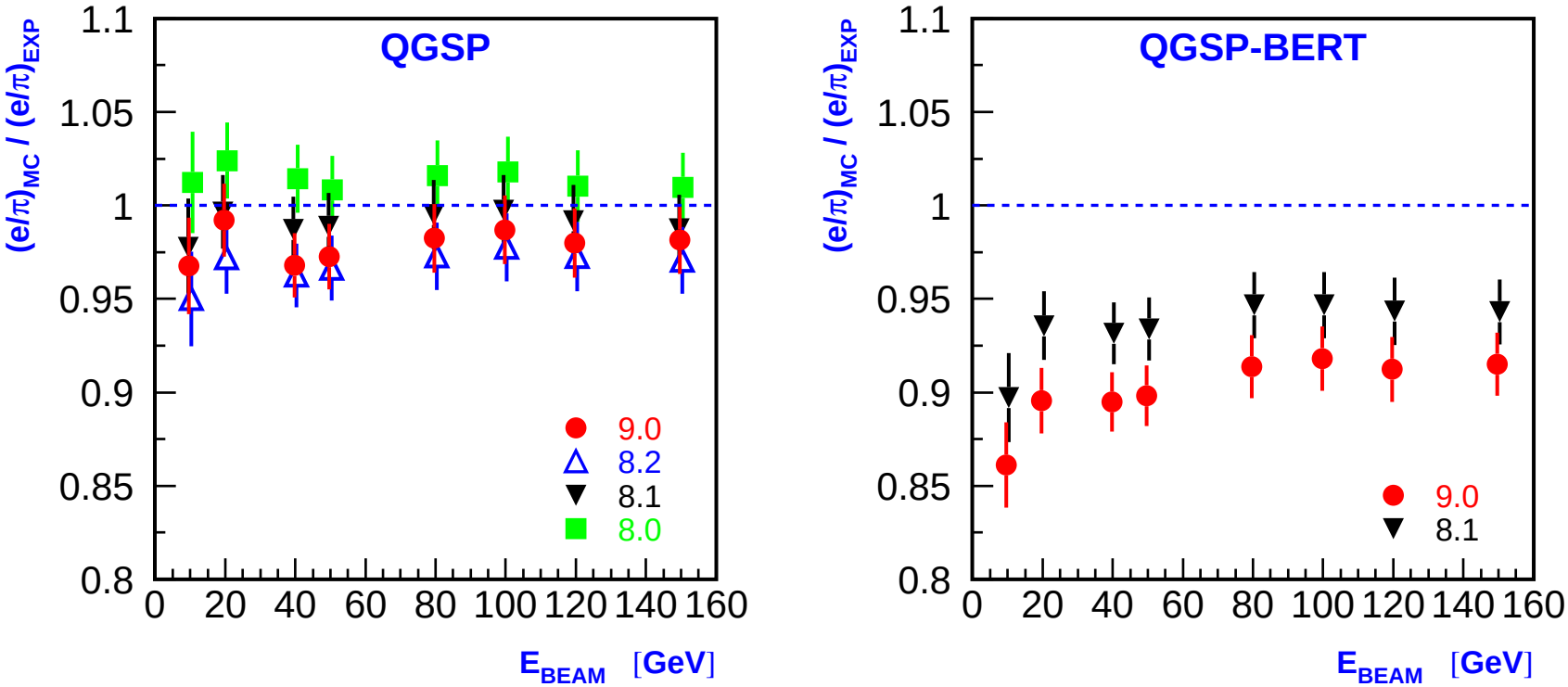


QGSP and **QGSP-NQE** describe e/π-ratio rather well.

QGSP-BERT predicts too small values of e/π w.r.t. experimental ones.

Charged pion energy scans

Ratio e/π
for different GEANT4 versions



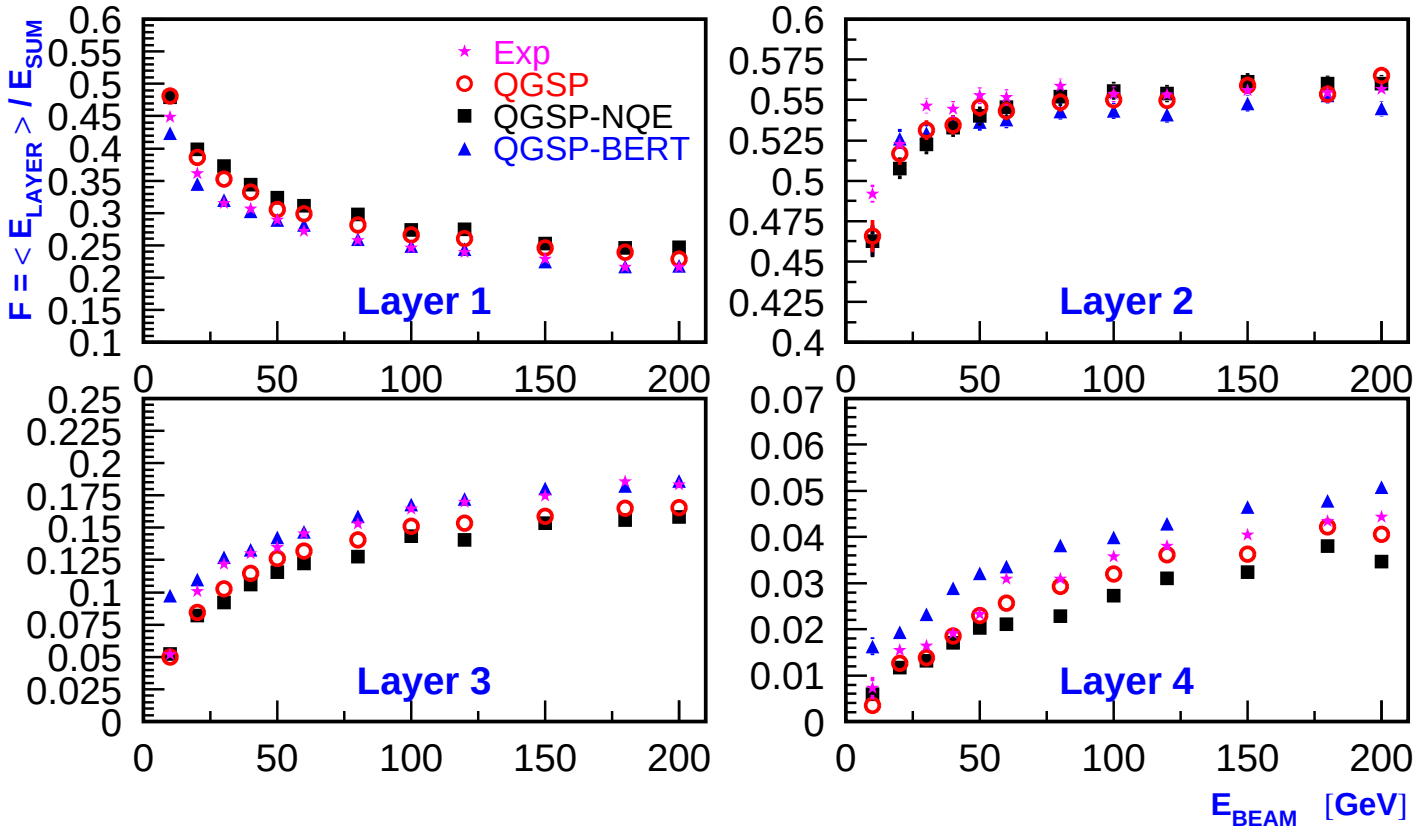
QGSP: changes of e/π-ratio are at a few percent level between GEANT4 versions.

QGSP-BERT: in version 9.0 disagreement with experimental data is larger than in version 8.1.

Charged pion energy scans

Fraction of energy in HEC longitudinal layers

for GEANT4 version 9.0



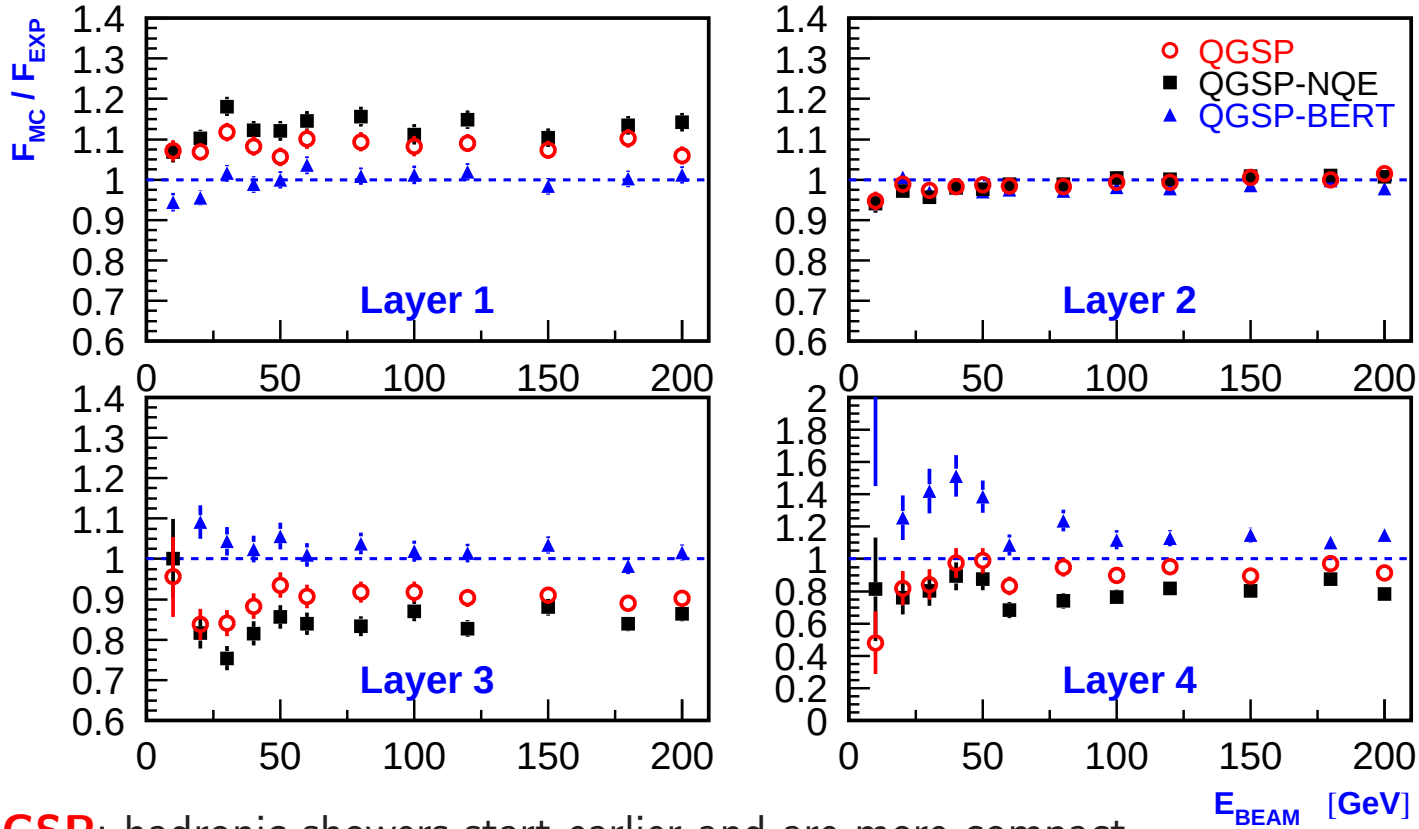
Four HEC longitudinal layers: 8/16/8/8 LAr gaps, 1.5/2.9/3.0/2.8 λ

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

Charged pion energy scans

Fraction of energy in longitudinal layers: Ratio to experiment

for GEANT4 version 9.0



QGSP: hadronic showers start earlier and are more compact.

QGSP-NQE: worse than QGSP.

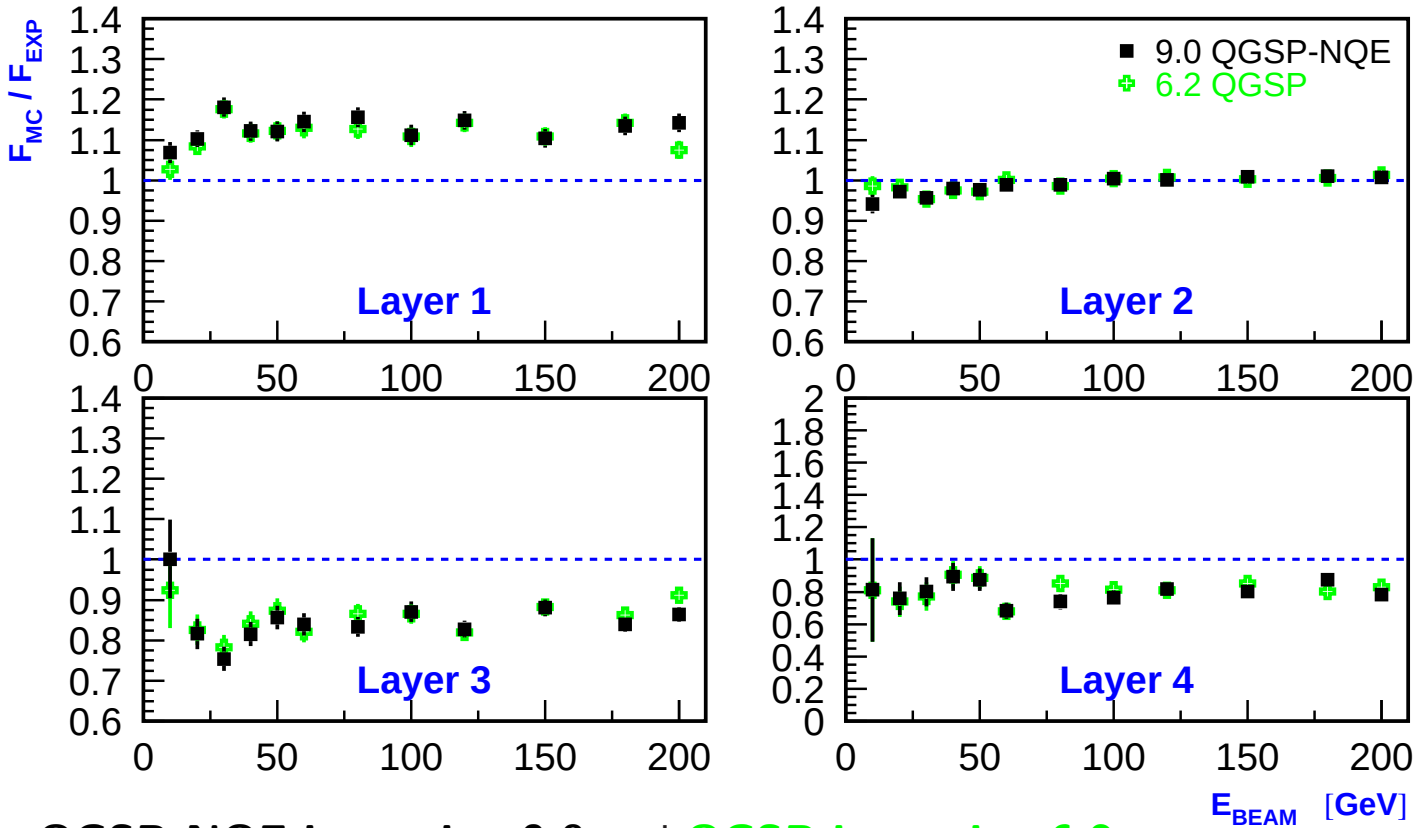
QGSP-BERT: good description of shower profiles.

Some differences between GEANT4 versions

- Since version 7.0:
  4% reduction of Cu-π^+/π^- cross-section
- Since version 8.3:
  this reduction is taken out
- Since version 8.3:
  QGSP* based physics lists contain quasi-elastic channel
- Since version 8.3:
  for backward compatibility QGSP*NQE lists are provided

Charged pion energy scans

Fraction of energy in longitudinal layers: Ratio to experiment



QGSP-NQE in version 9.0 and **QGSP in version 6.2**

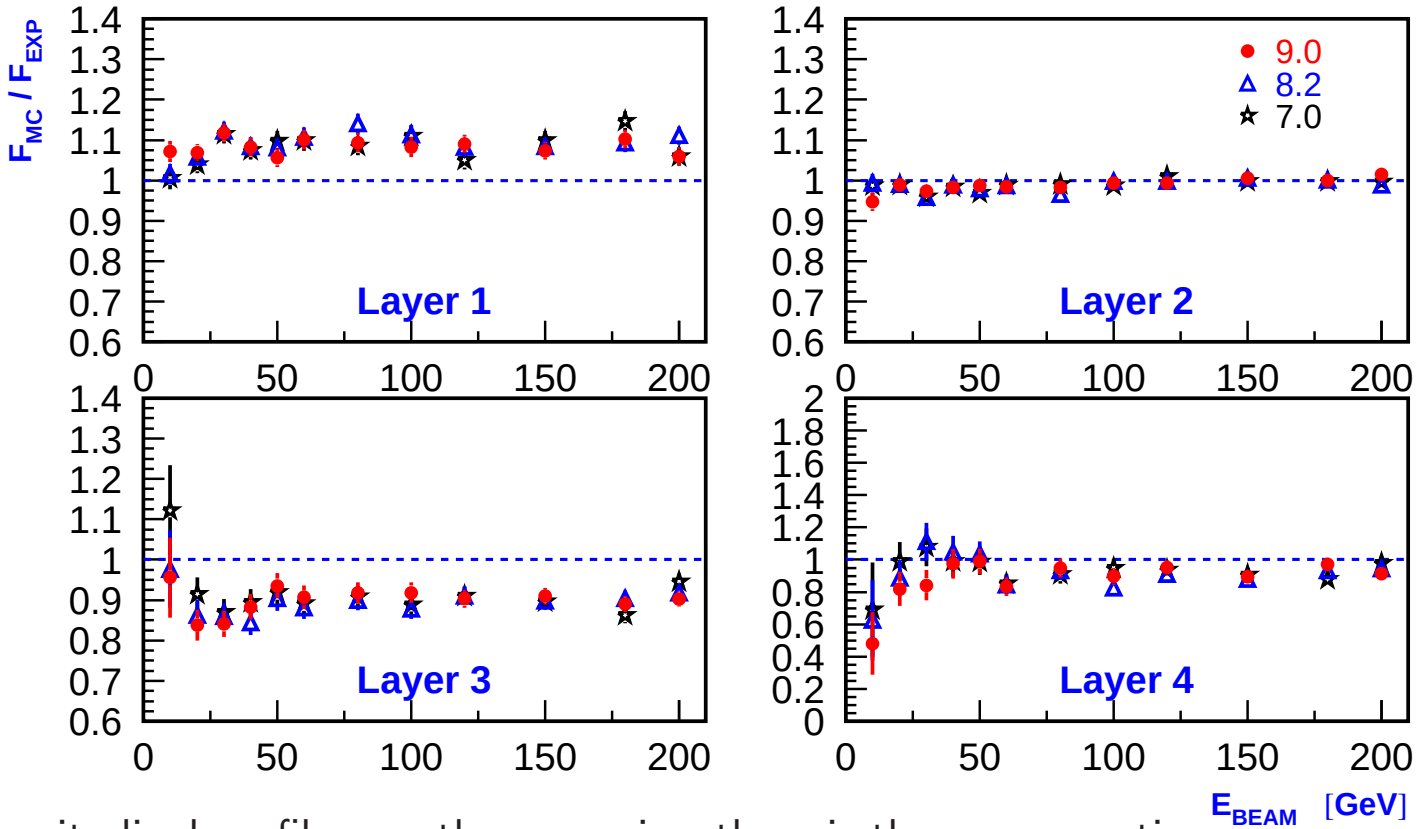
(no quasi-elastic channel and correct Cu-π^+/π^- cross-section):

same longitudinal profiles of hadronic showers

Charged pion energy scans

Fraction of energy in longitudinal layers: Ratio to experiment

QGSP for different GEANT4 versions



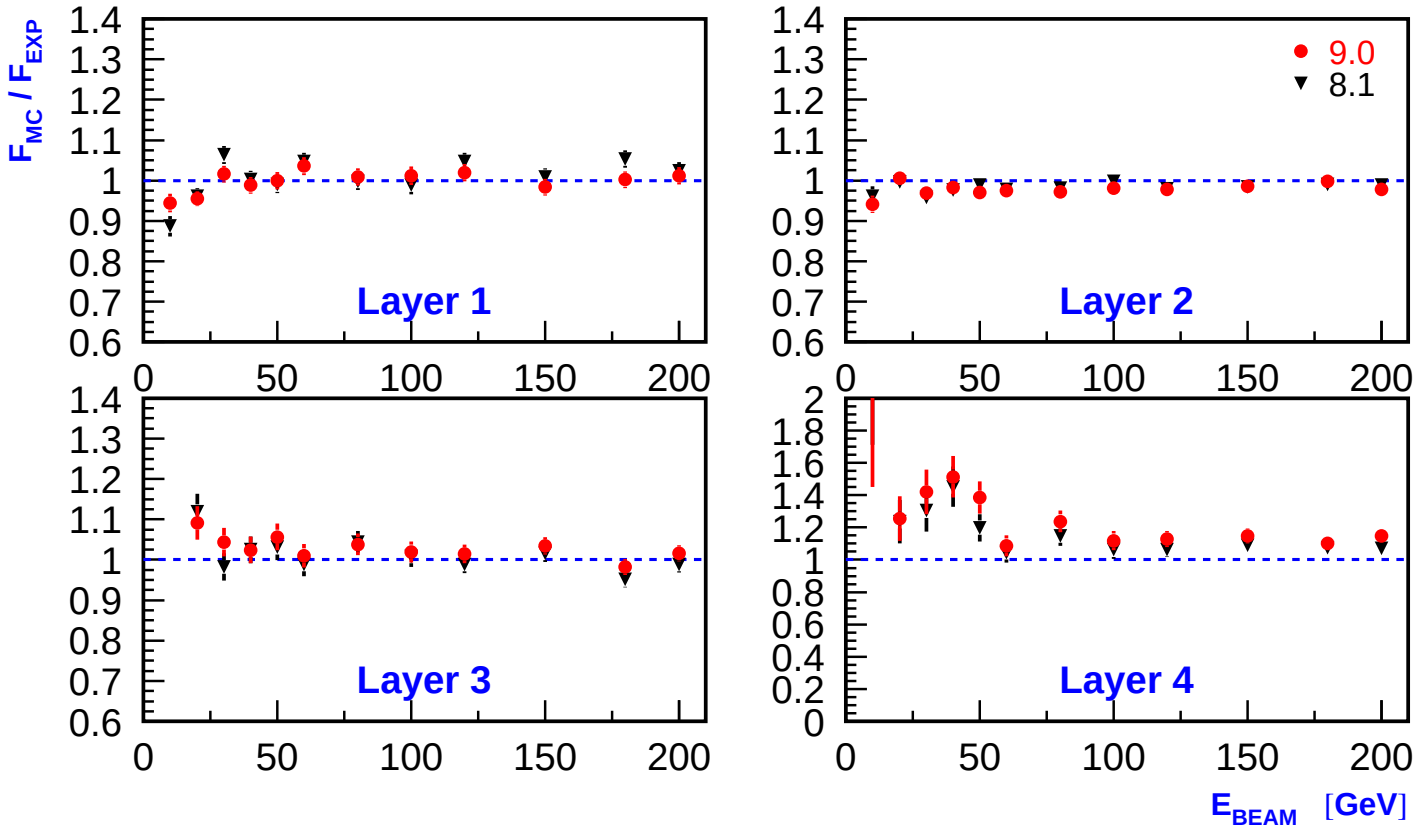
Longitudinal profiles are the same, i.e. there is the compensation:

- correct Cu-π^+/π^- cross-section $\longrightarrow$ worsening
- quasi-elastic model $\longrightarrow$ improvement

Charged pion energy scans

Fraction of energy in longitudinal layers: Ratio to experiment

QGSP-BERT for different GEANT4 versions



Good description of shower profiles (except low beam energies).

No difference between GEANT4 versions.

Conclusions

New round of GEANT4 based simulations with version 9.0 was carried out for the HEC stand-alone testbeam. Comparison with experimental results and results of previous simulations is done.

- Electron simulations:
  - predictions on EM-scale are in agreement with experimental data
  - electron energy resolution is still too optimistic
- QGSP hadronic physics list:
  - rather good predictions on e/π-ratio and pion energy resolution (problems appeared in version 8.2 are overcome)
  - problems in description of longitudinal shapes of hadronic showers
- Quasi-elastic model in QGSP:
  - no influence on pion energy resolution and e/π-ratio
  - small improvement of longitudinal profiles of hadronic showers
- Physics list QGSP-BERT with Bertini cascade model:
  - describes well longitudinal shapes of hadronic showers
  - predicts too low values of the pion energy resolution and too high values of the pion energy depositions