GEANT4 Physics Validation
with ATLAS HEC Testbeam Data

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- 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

- New round of GEANT4 simulations: version **8.0** + patch-**01**

- Simulated/analysed samples:
  - scan over the GEANT4 range cut with electrons
  - electron energy scans
  - charged pion energy scans

Simulation Packages

- ## GEANT4

Version	**5.2p02**	**6.2p02**[1]	**7.0p01**	**8.0p01**
Physics lists	LHEP 3.6	LHEP 3.7	LHEP 3.7	LHEP 4.0
	QGSP 2.7	QGSP 2.8	QGSP 2.8	QGSP 3.0
Packaging library	PACK 2.3	PACK 2.4	PACK 2.4	PACK 5.0
Release date	October 2003	October 2004	February 2005	February 2006

- ## GEANT3

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

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

[1] A.E. Kiryunin et al., NIM A560 (2006) 278-290
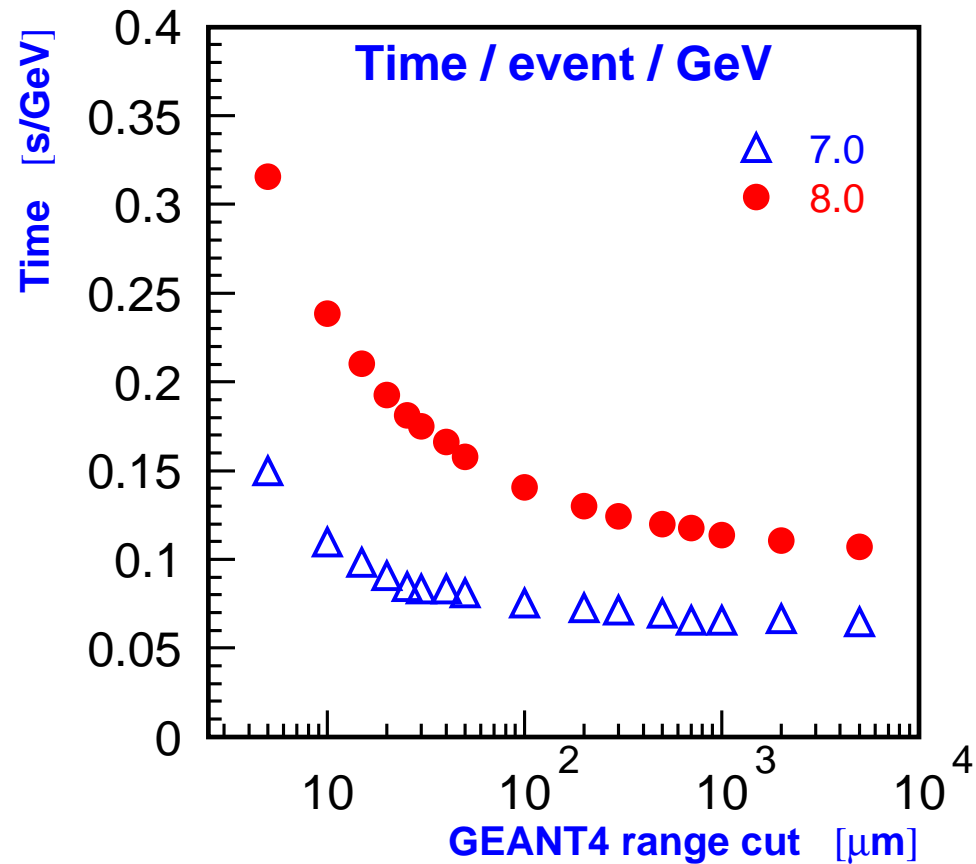
Electrons: Scan over the Range Cut

- 100 GeV electrons

- GEANT4 range cut: 5 μm - 5 mm

- Physics list: LHEP

- 5000 events per cut

- Analysis:
  - time of simulations
  - mean energy depositions in LAr gaps and copper plates
  - signal in the most loaded cell
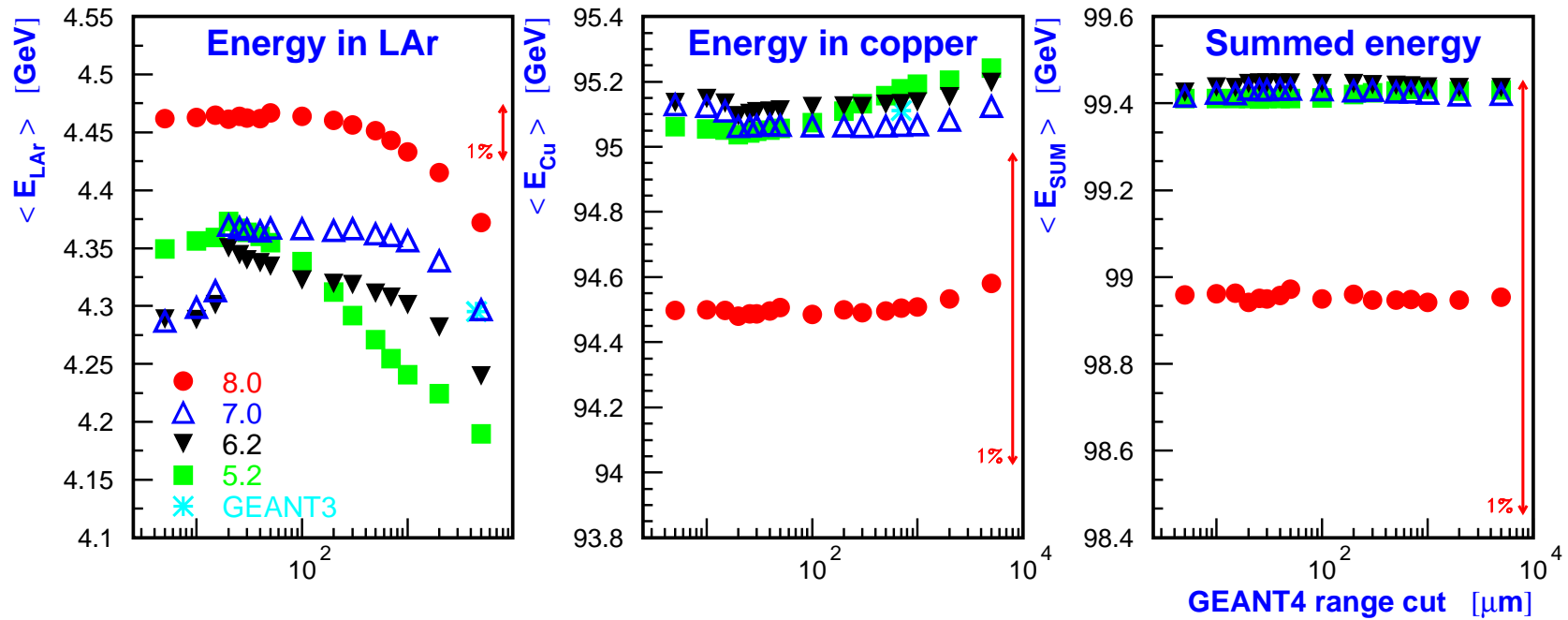 - energy resolution

Range cut scan with electrons

Time of simulations

- Batch farm at MPI

- 2 processor computers
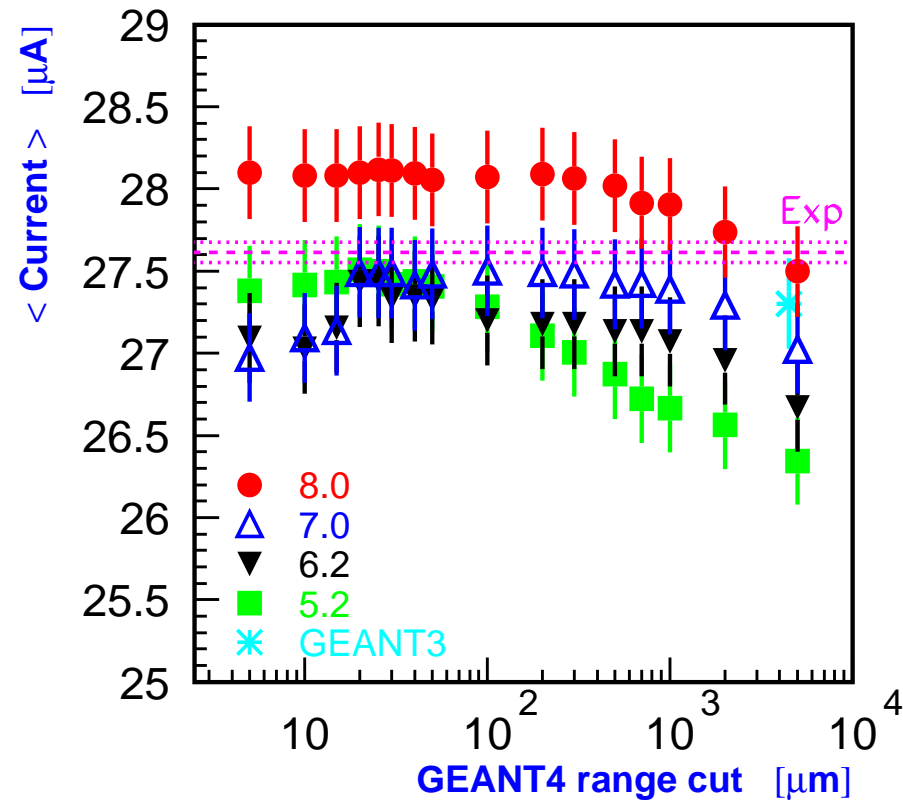
- 1533 MHz

Range cut scan with electrons

Energy depositions in HEC

Range cut scan with electrons

Signal in one cell

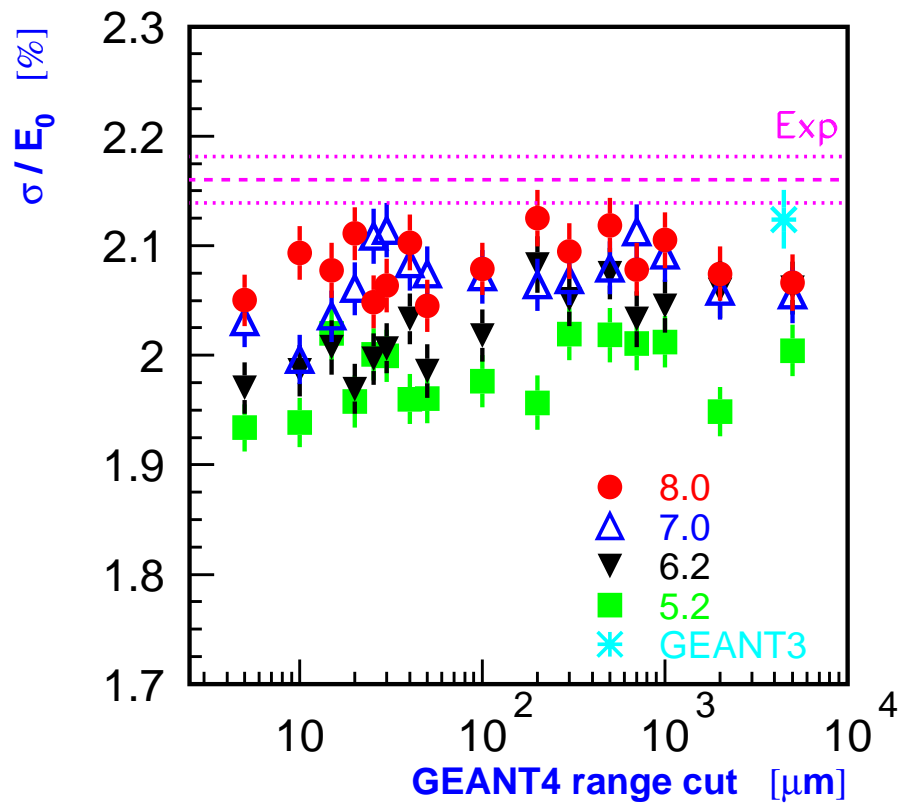- Cell with the maximal average signal

- Experiment (averaging over 11 runs): mean$\pm$RMS

- Visible energy $\Rightarrow$ Current

- Conversion factor (from detailed modeling of the HEC electronic chain): 7.135 μA/GeV with an uncertainty of ±1 %

Range cut scan with electrons

Energy resolution

- Energy reconstruction:

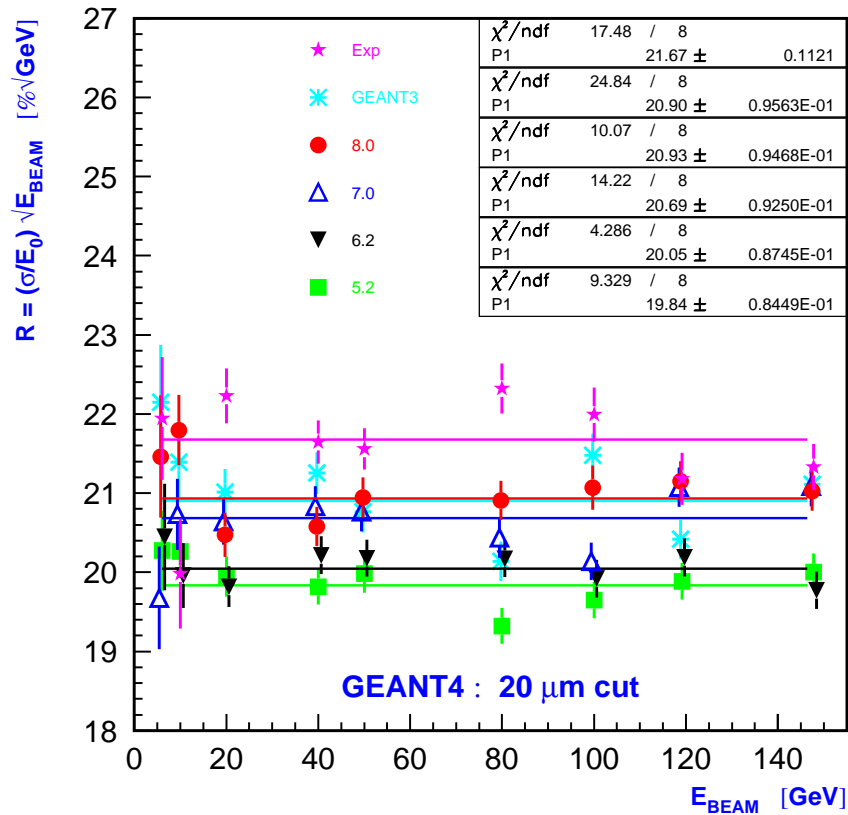 - cluster of the fixed size
  - Gaussian fit: E_0 and σ

Electrons: Energy Scans

- Beam energies: 6 - 147.8 GeV

- GEANT4 range cuts: 20, 50, 100, 200, 500 and 1000 μm

- Physics list: LHEP

- 5000 events per beam energy and per cut

Energy scans with electrons

## Energy resolution: $\sigma/E_0 = P1/\sqrt{E_{BEAM}}$
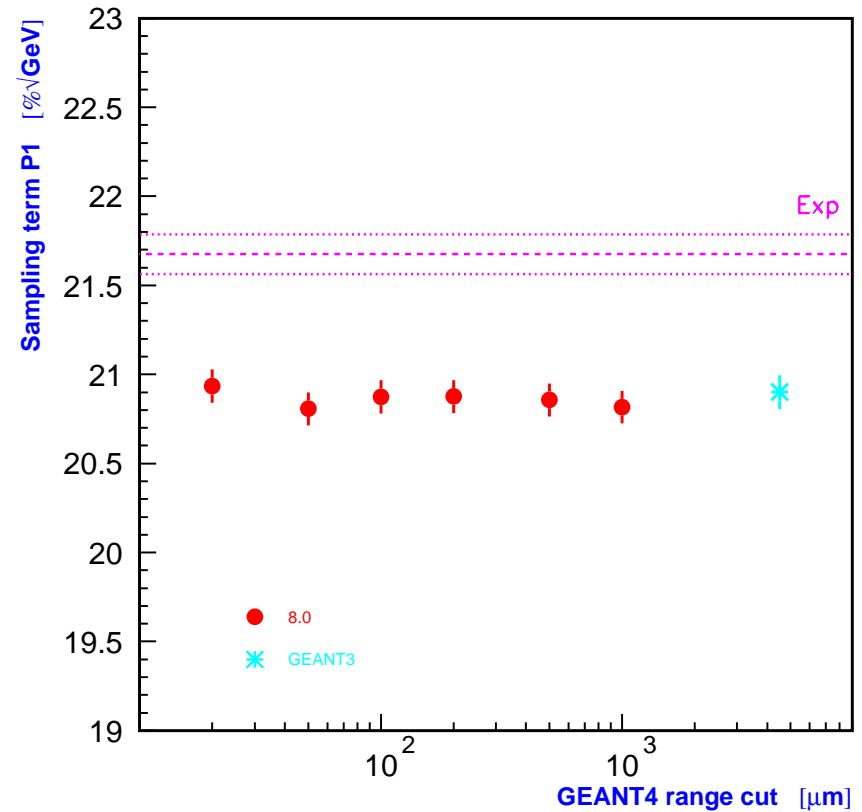
Charged pions: Energy Scans

- Beam energies: 10 - 200 GeV

- GEANT4 range cuts:
  20, 100 and 1000 μm

- Physics lists: LHEP and QGSP

- 5000 events per beam energy, cut
  and physics list

- Energy reconstruction:
  – cluster of the fixed size
  – Gaussian fit: E_0 and σ

- Analysis:

  – response E_0/E_{BEAM}

  – energy resolution

  – fraction of energies in HEC
    longitudinal layers
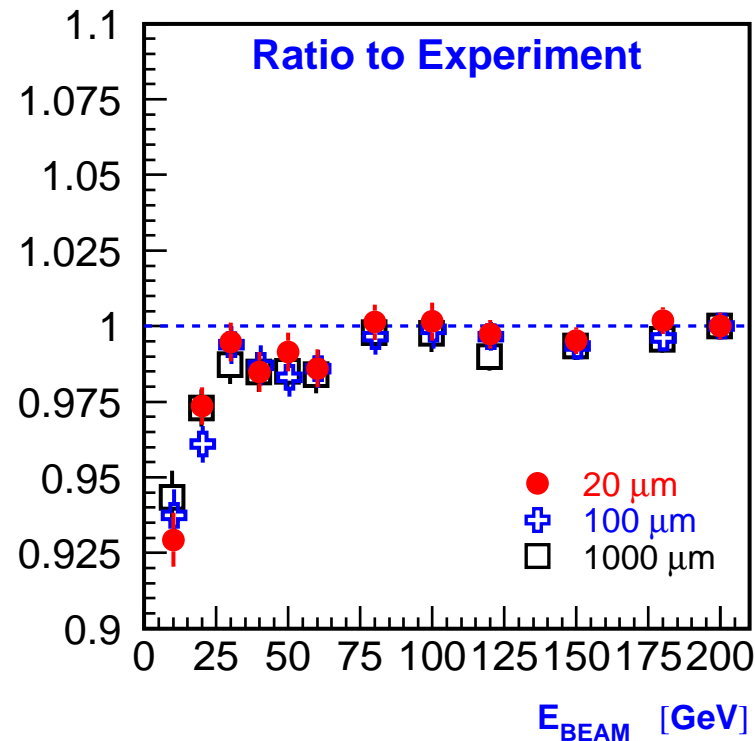
  – ratio e/π
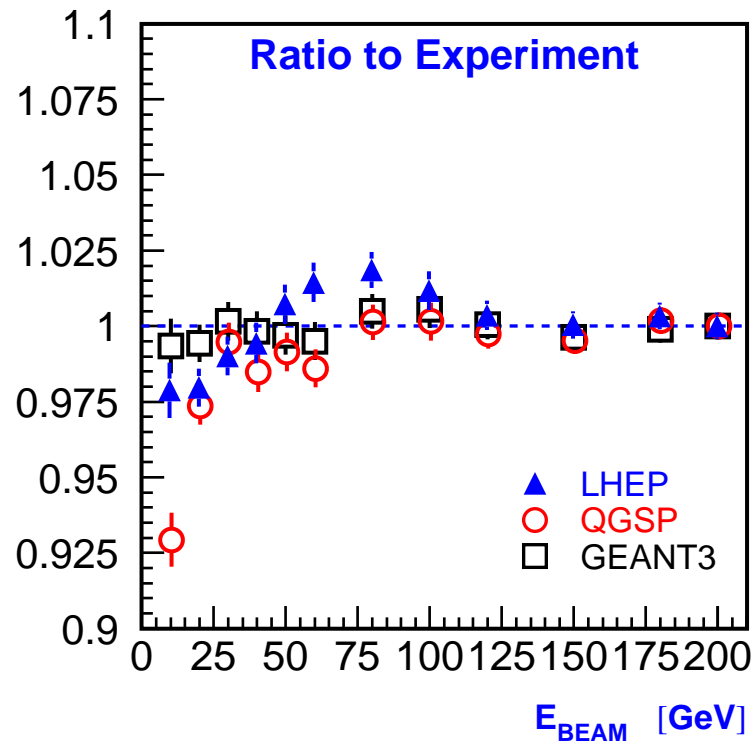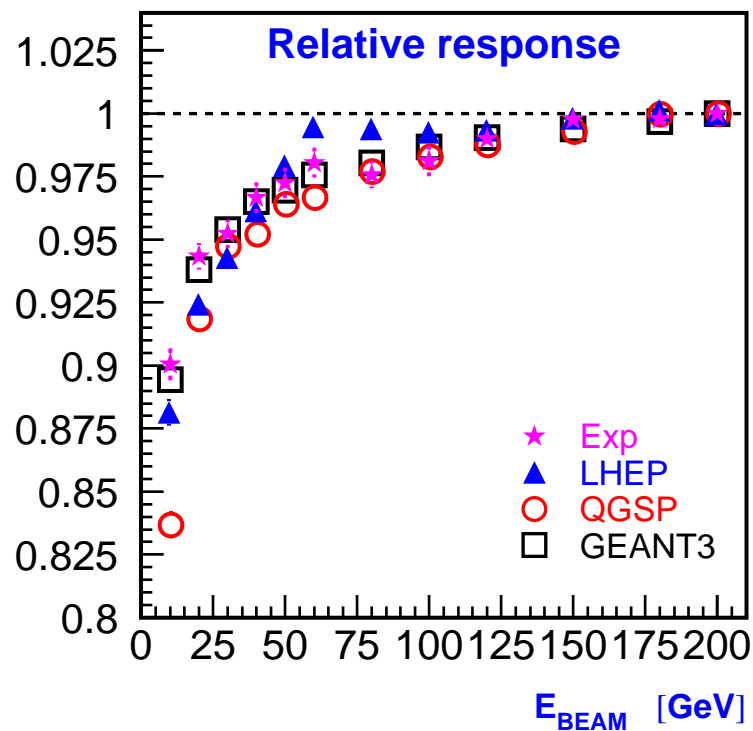
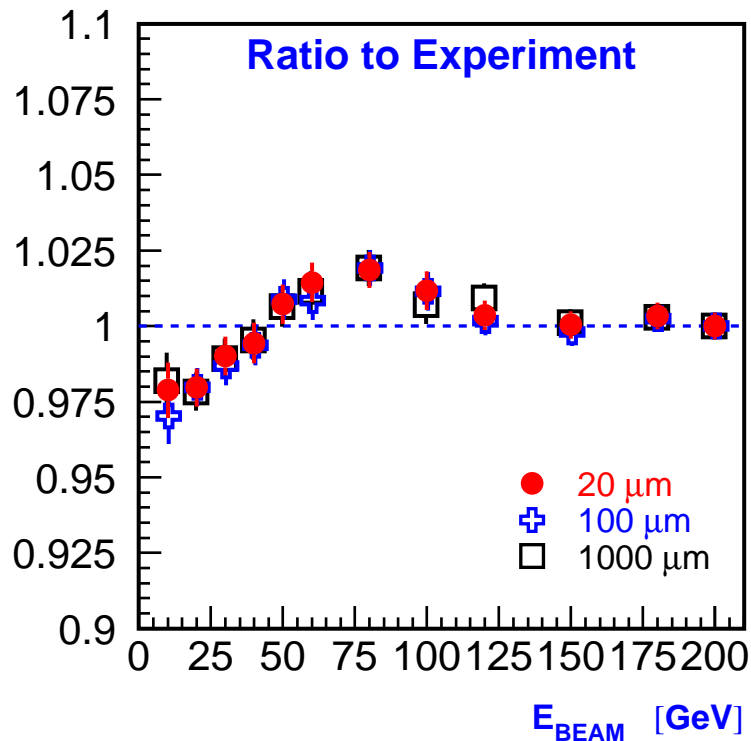**Energy scans with pions**

Relative response

GEANT4 version 8.0, 20 μm cut

Energy scans with pions

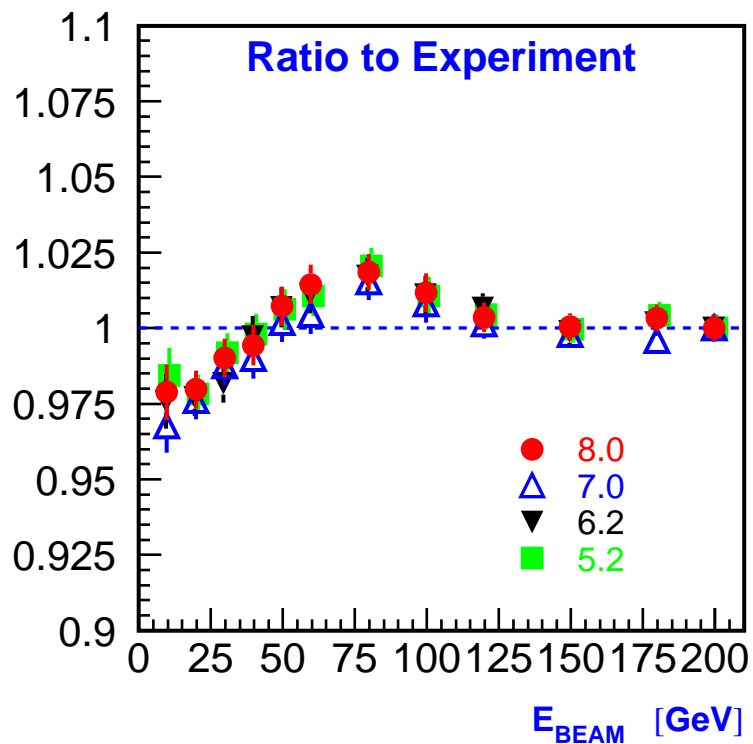# Relative response: ratio to experimental data

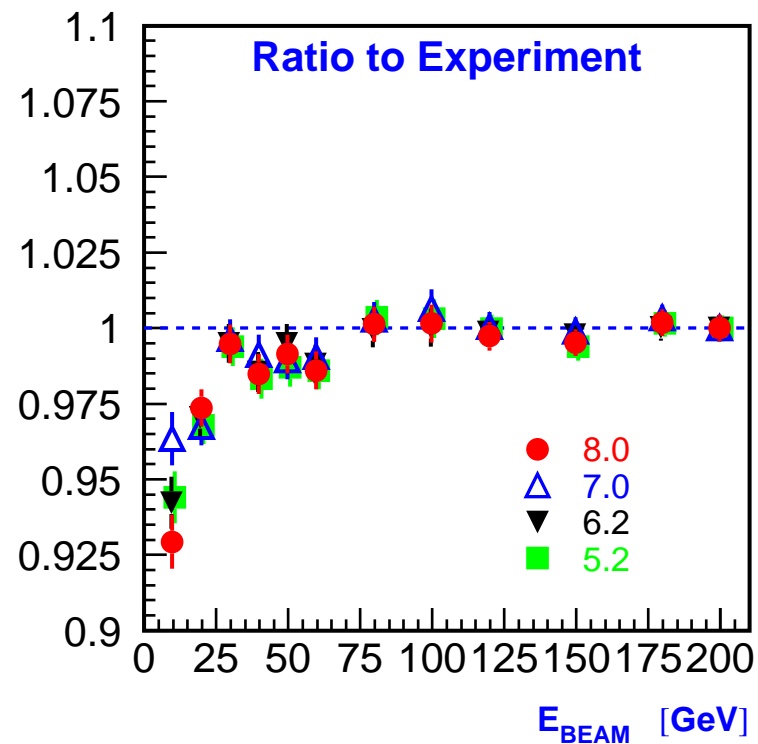GEANT4 version 8.0, LHEP   GEANT4 version 8.0, QGSP

Energy scans with pions

Relative response: ratio to experimental data
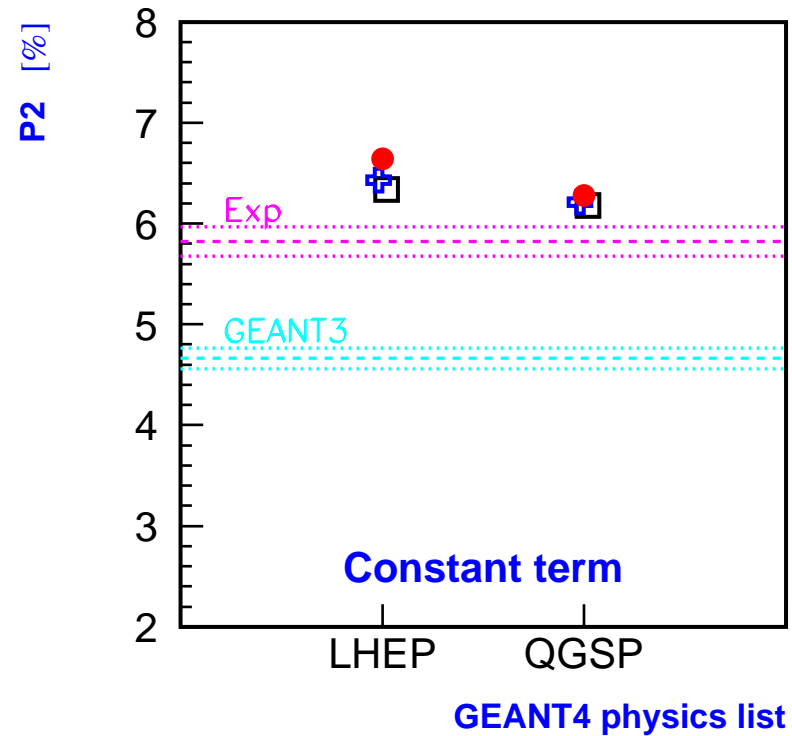

LHEP, 20 μm cut

QGSP, 20 μm cut
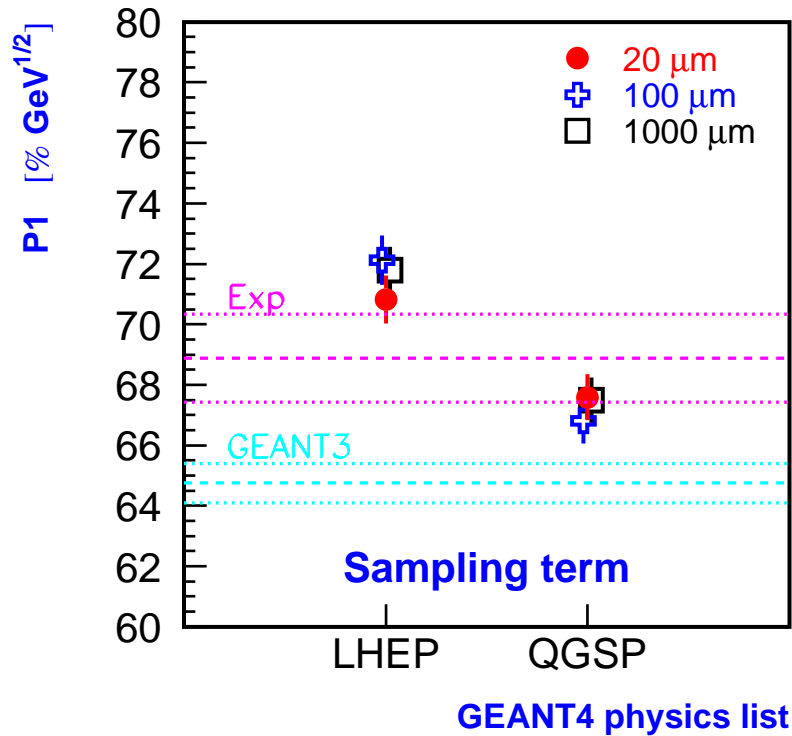
Energy scans with pions

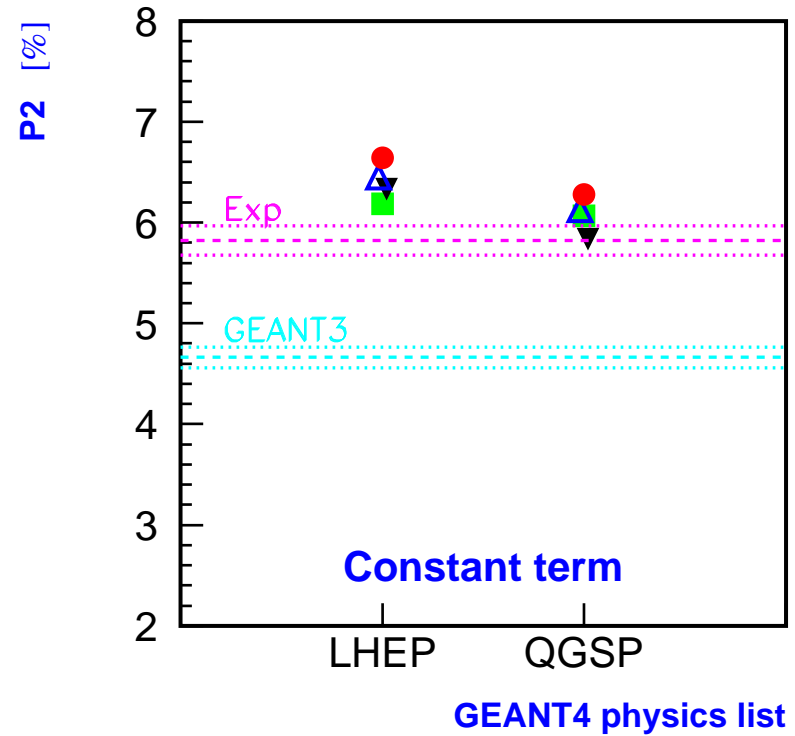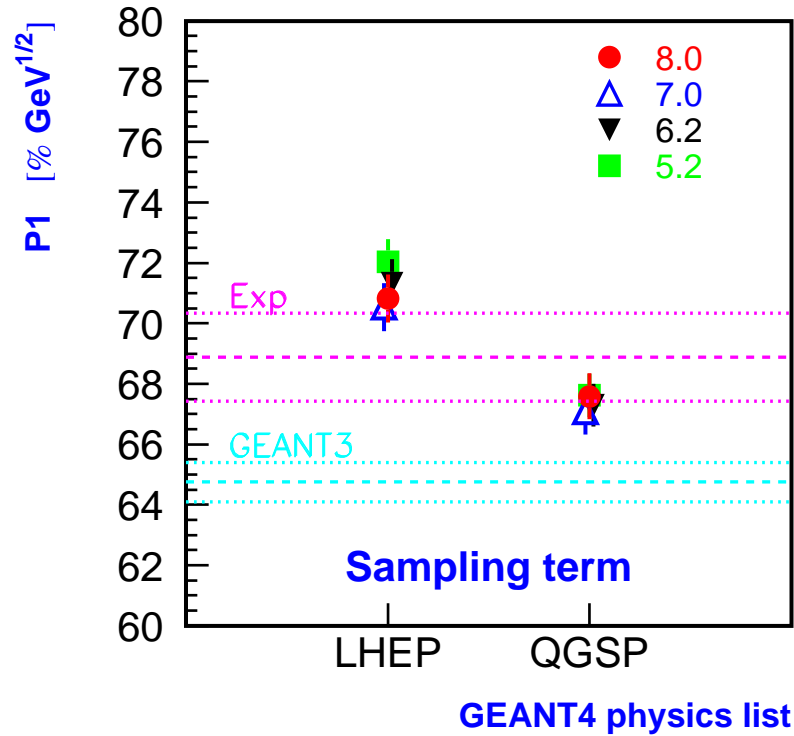## Energy resolution: $\sigma/E_0 = P1/\sqrt{E_{BEAM}} \oplus P2$

GEANT4 version 8.0

Energy scans with pions

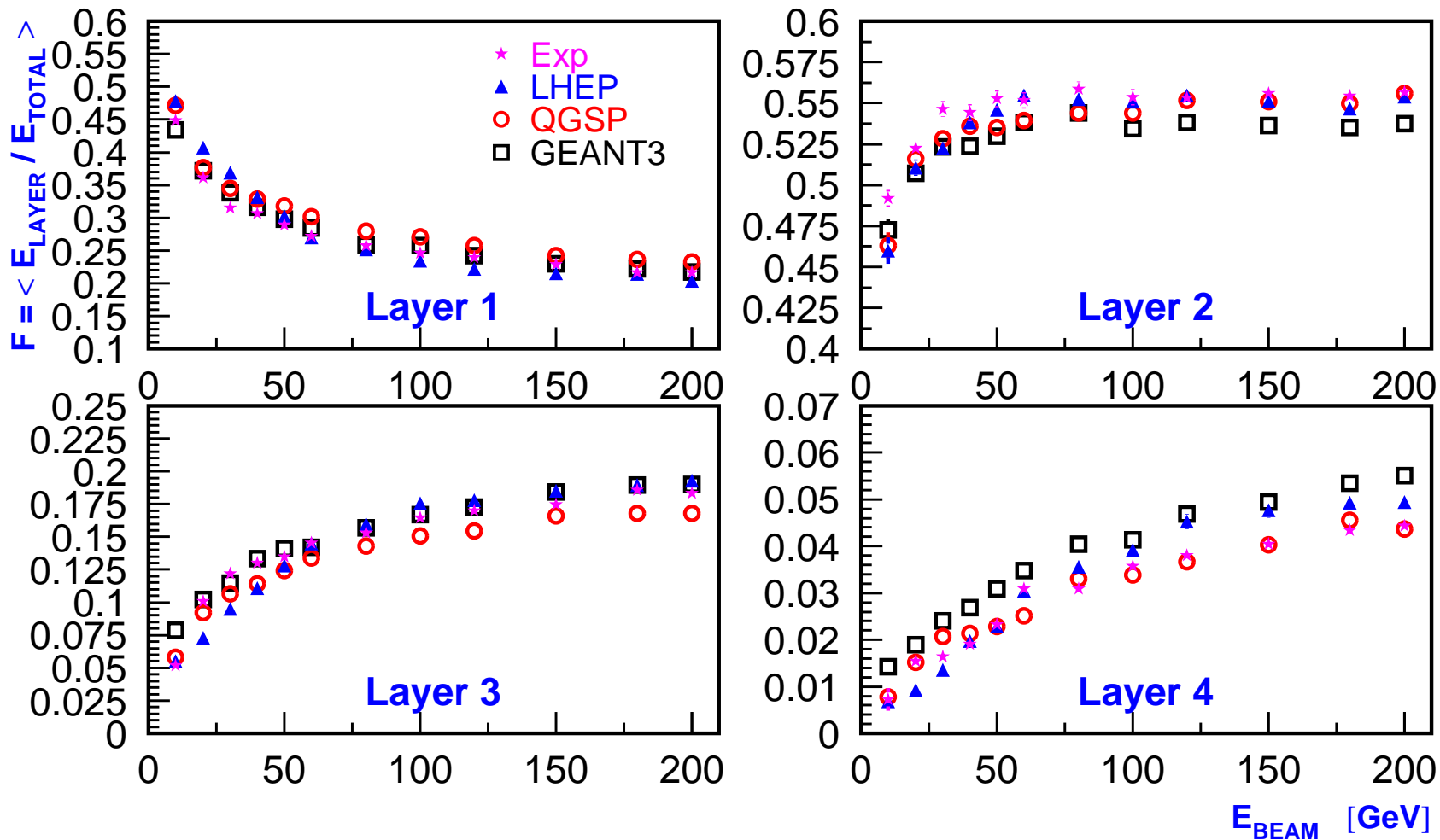**Energy resolution:** $\sigma/E_0 = P1/\sqrt{E_{BEAM}} \oplus P2$

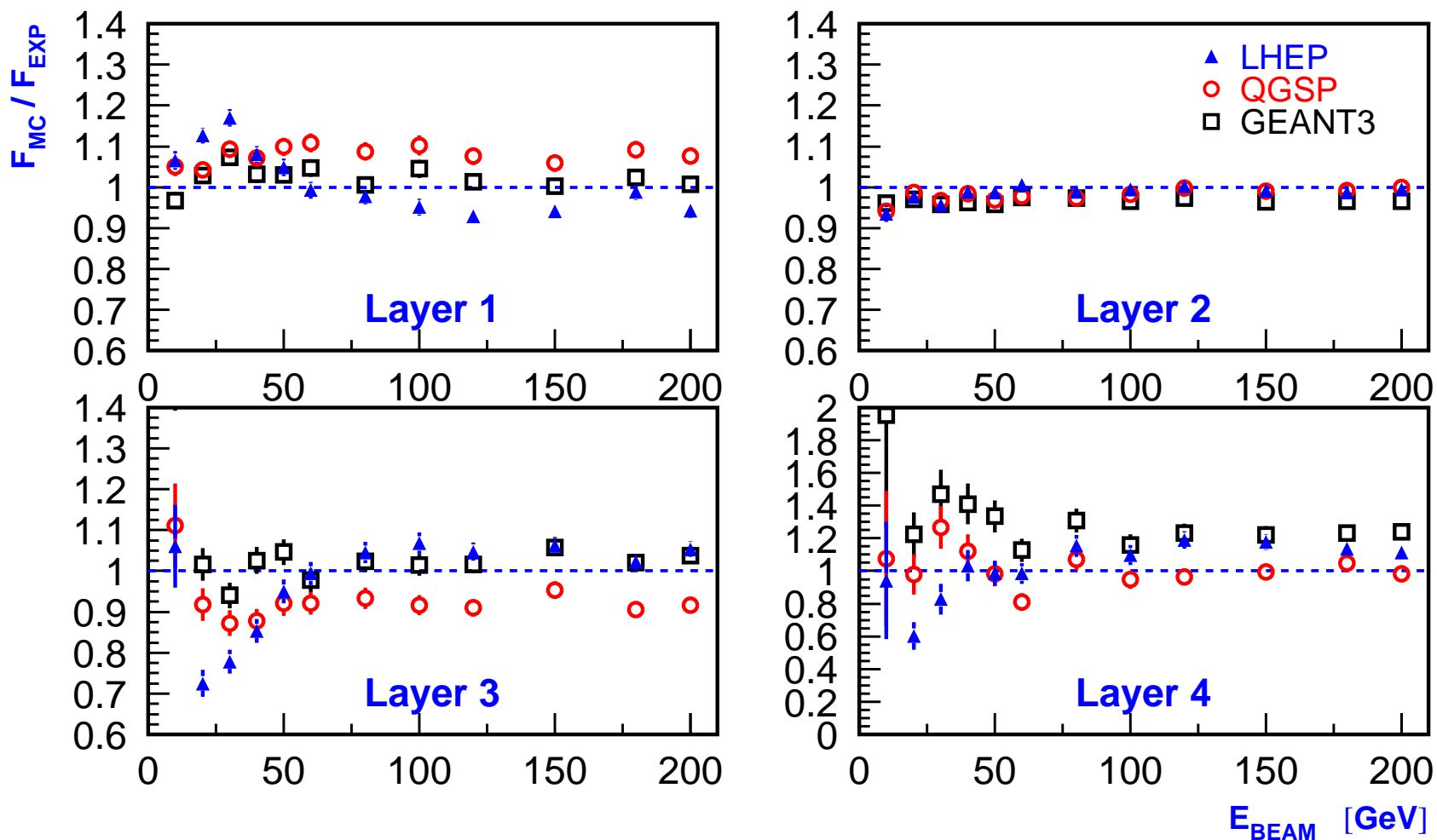$20\ \mu$m cut

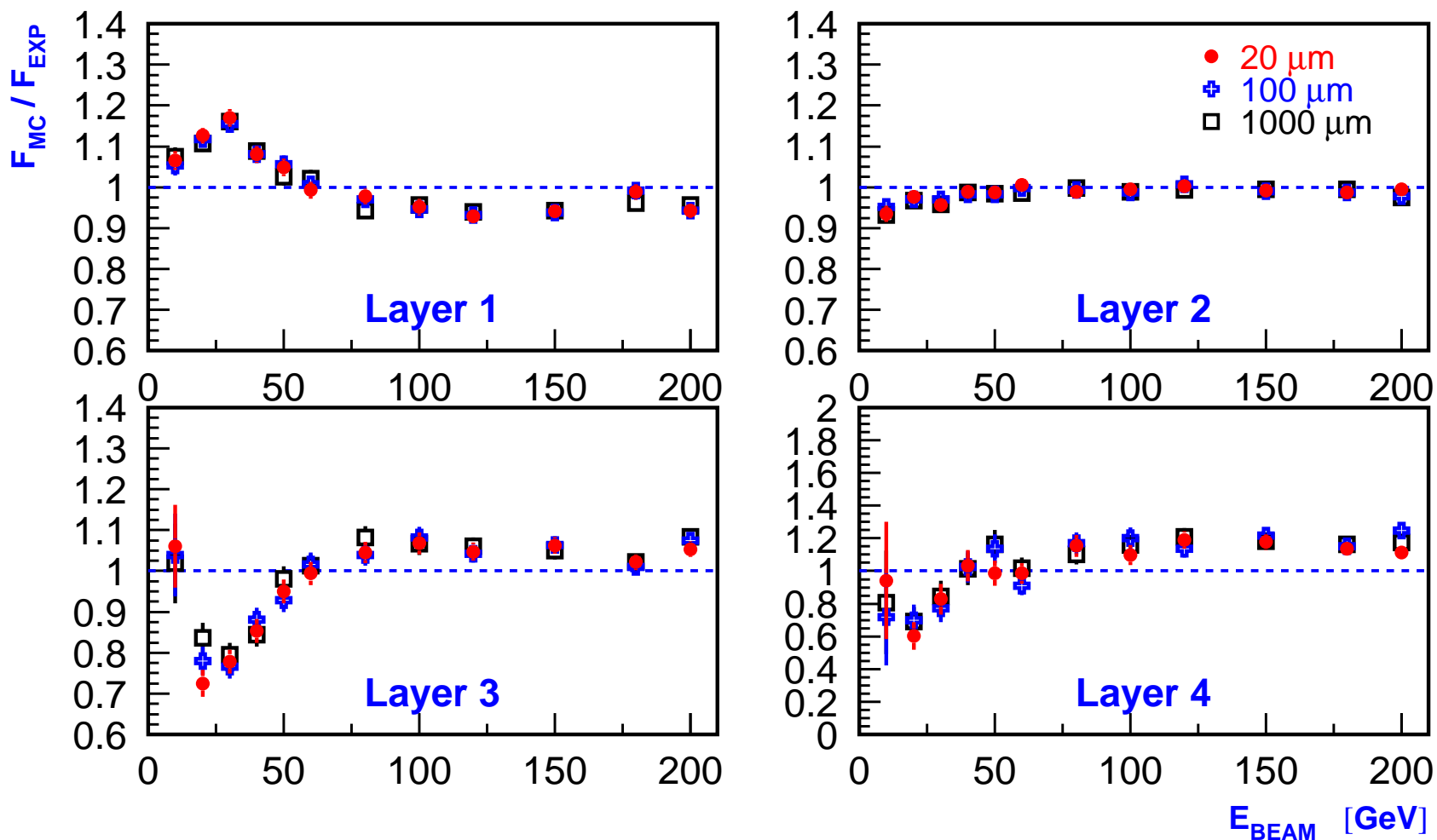**Energy scans with pions**

Fraction of energy in longitudinal layers

GEANT4 version 8.0, 20 μm cut

Energy scans with pions

Fraction of energy in layers: ratio to experimental data

GEANT4 version 8.0, 20 μm cut

Fraction of energy in layers: ratio to experimental data

GEANT4 version 8.0, LHEP

Energy scans with pions

Fraction of energy in layers: ratio to experimental data

GEANT4 version 8.0, QGSP

Energy scans with pions

Fraction of energy in layers: ratio to experimental data

LHEP, 20 μm cut

Energy scans with pions

Fraction of energy in layers: ratio to experimental data

QGSP, 20 μm cut
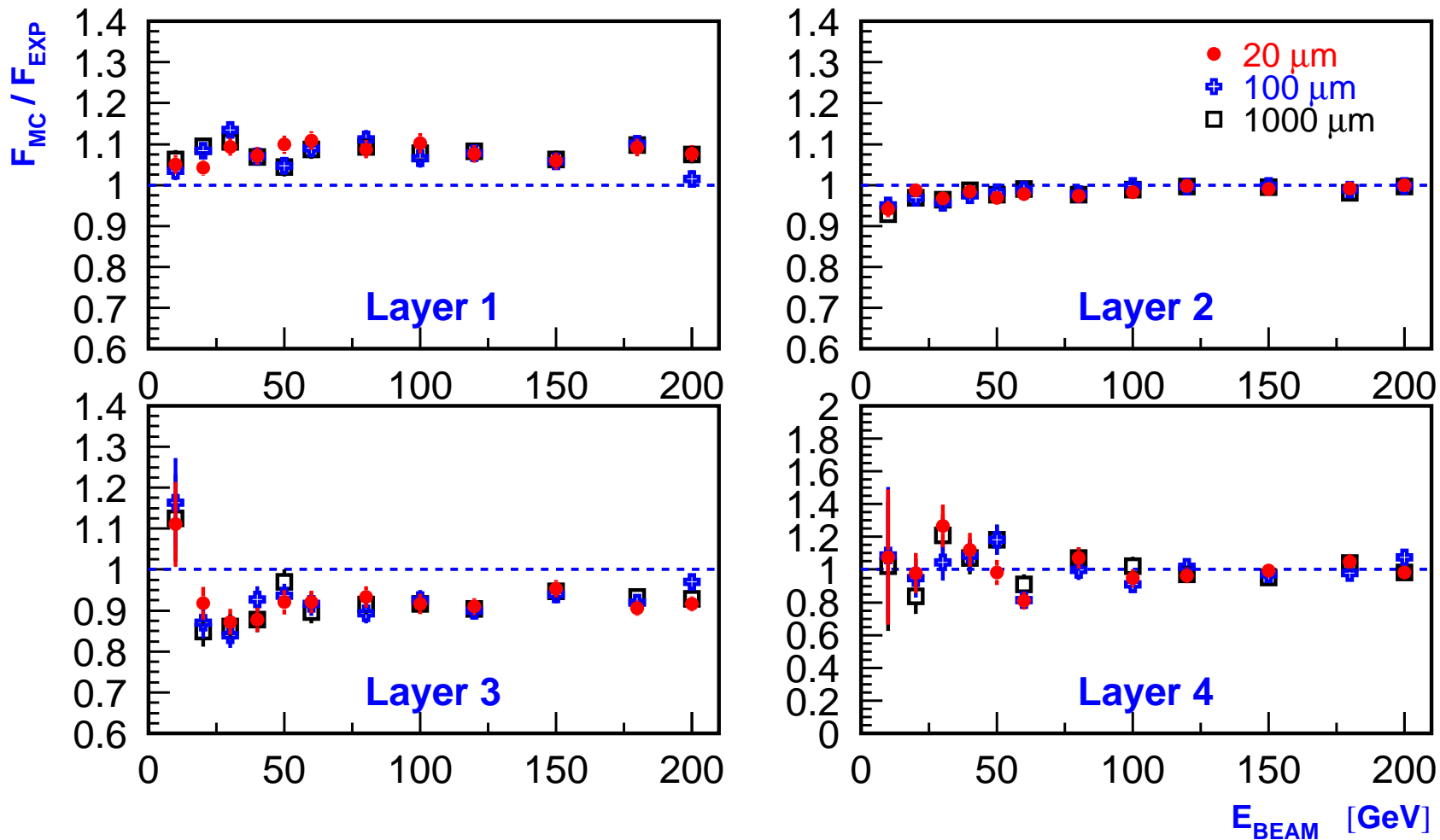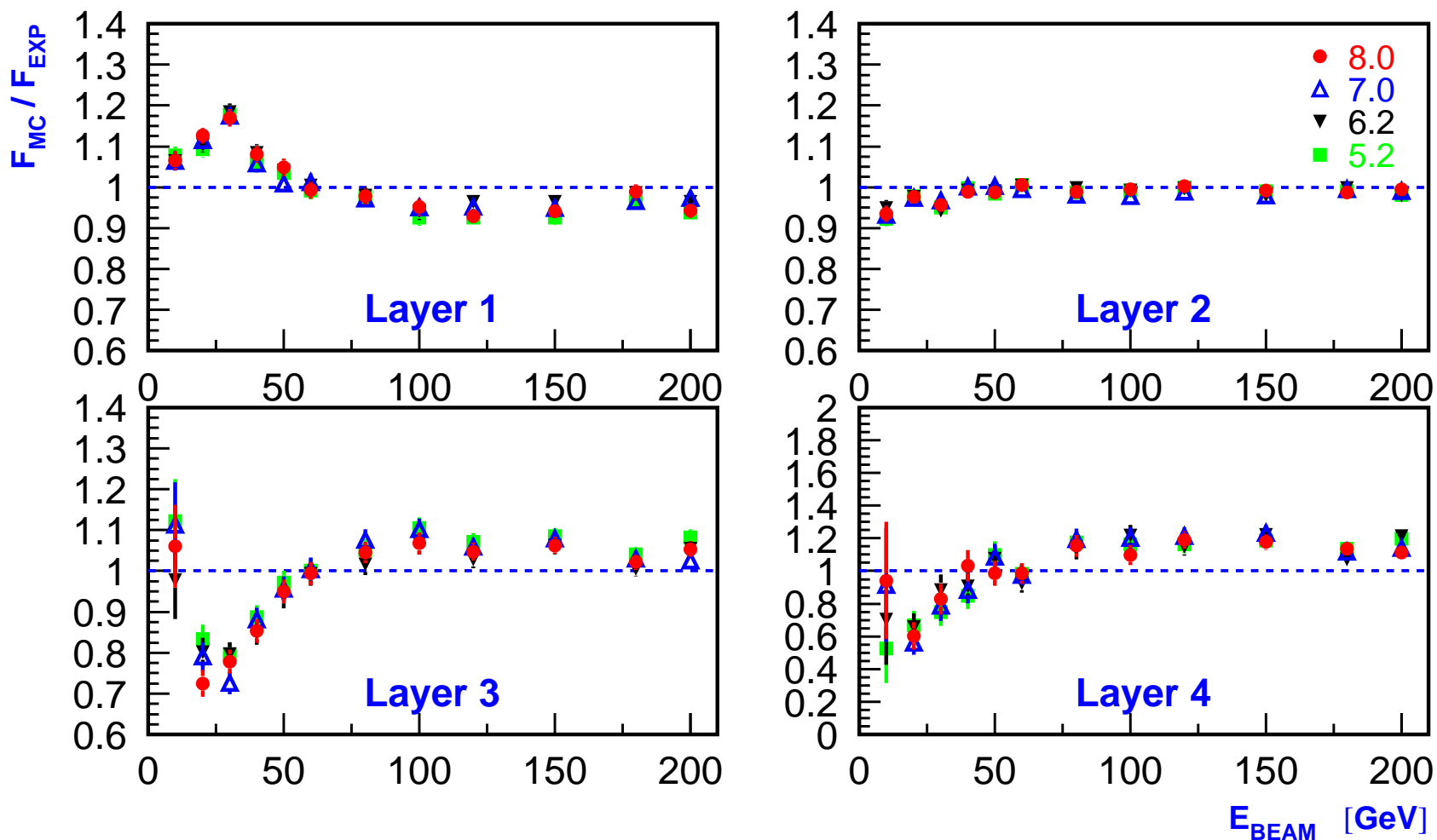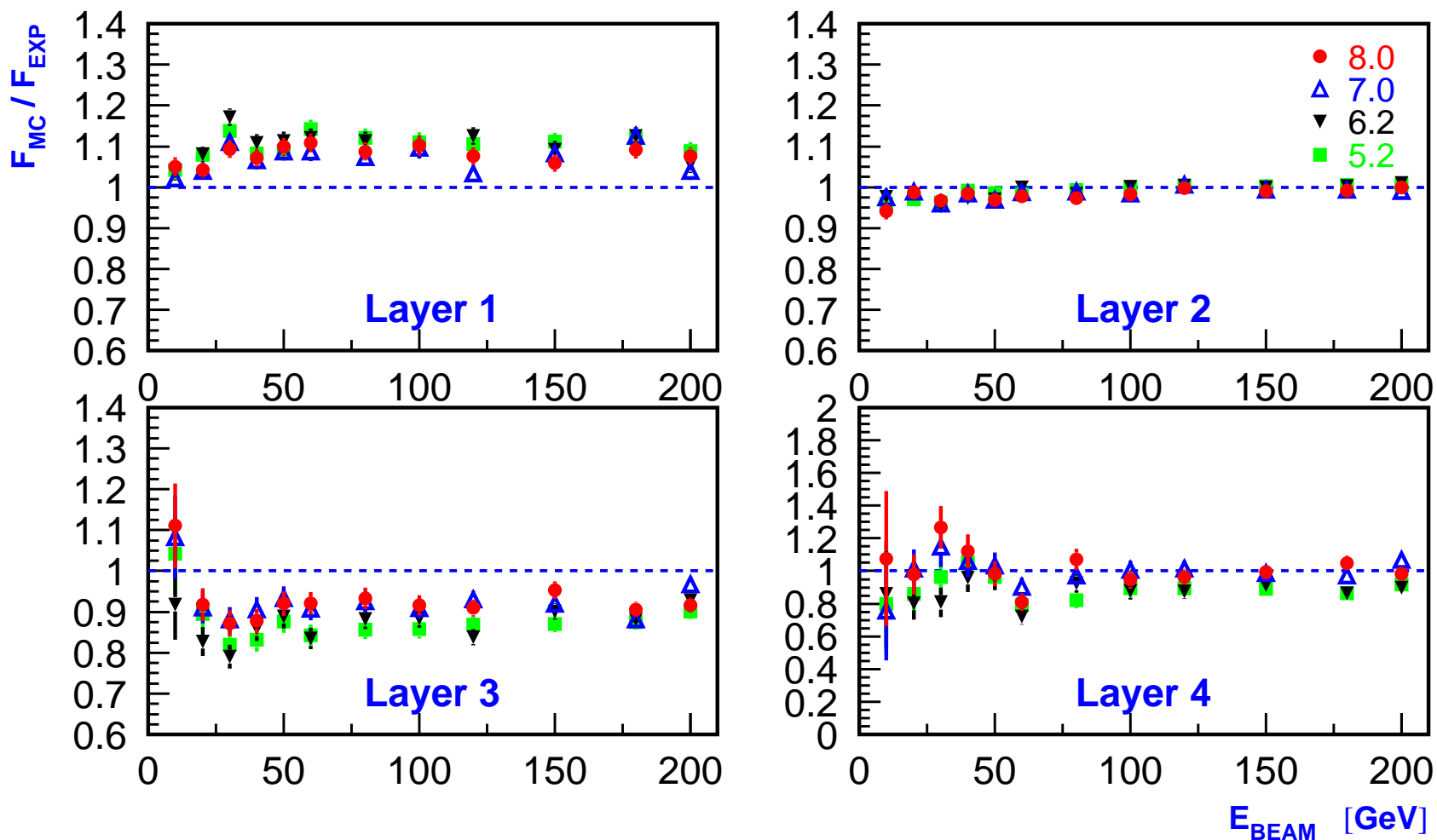
Energy scans with pions

Ratio e/π

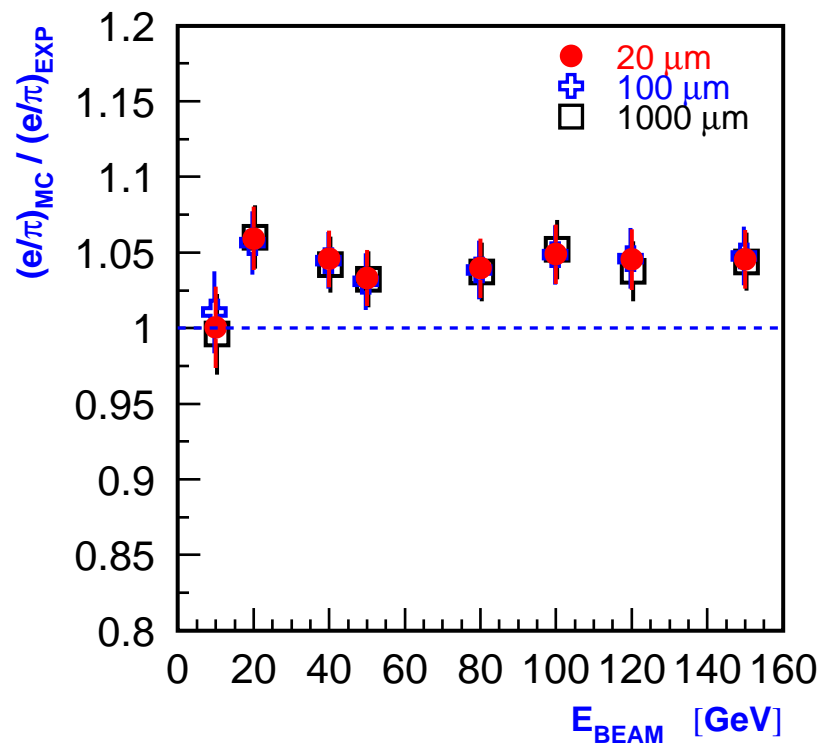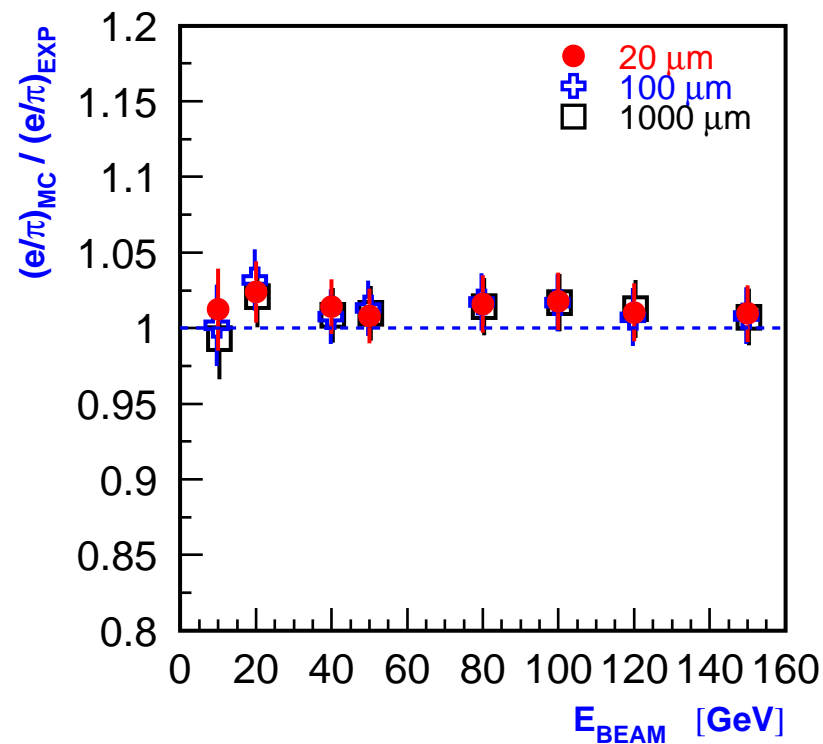GEANT4 version 8.0, 20 μm cut

Energy scans with pions

e/π: ratio to experimental data
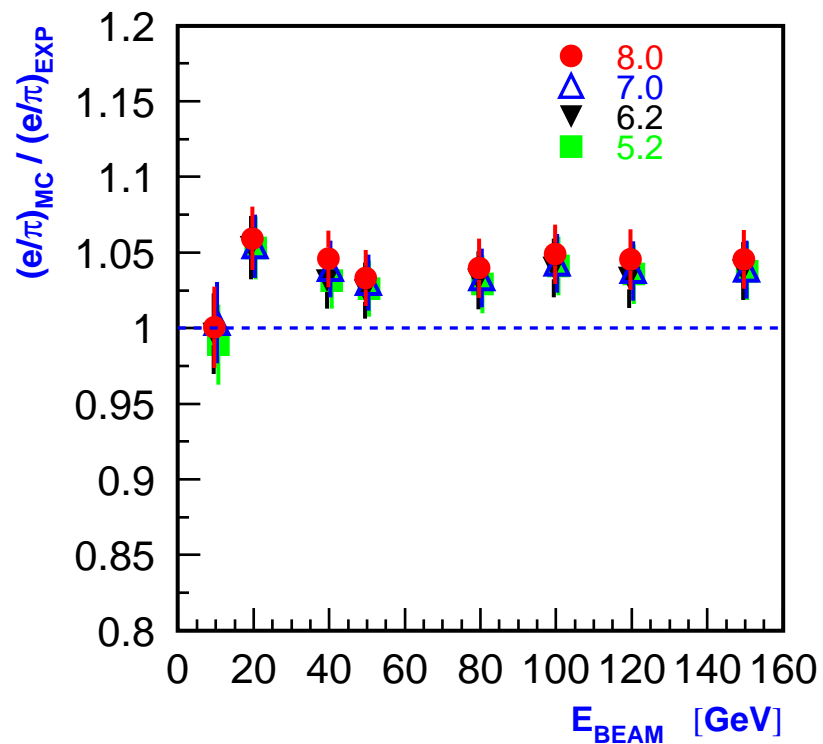

GEANT4 version 8.0, LHEP   GEANT4 version 8.0, QGSP
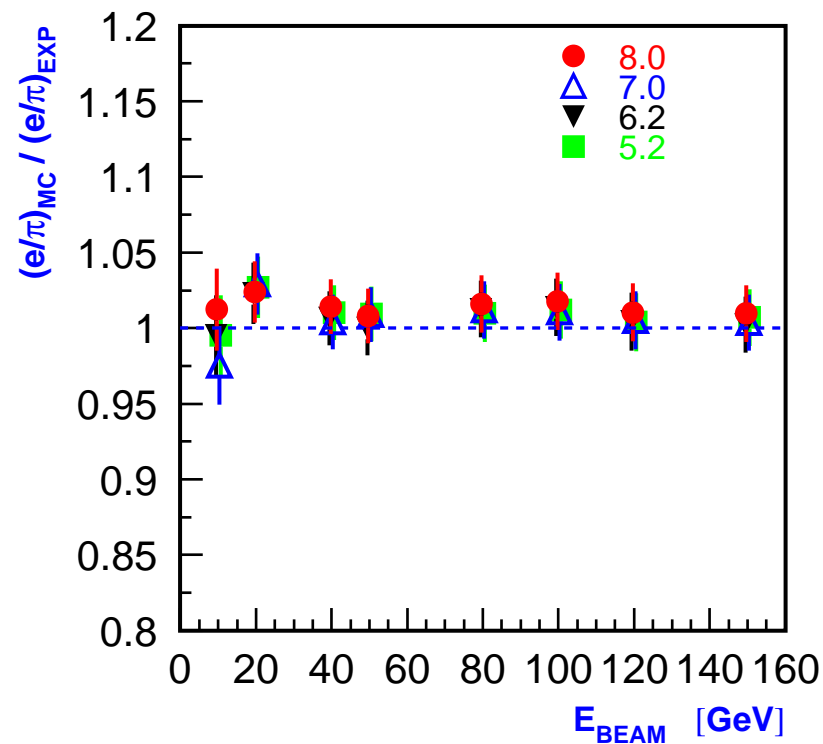
Energy scans with pions

e/π: ratio to experimental data

LHEP, 20 μm cut

QGSP, 20 μm cut

Conclusions

New round of GEANT4 based simulations with version **8.0p01** was carried out for the HEC stand-alone testbeam. Comparison with experimental results and results of previous simulations (GEANT4 versions **7.0p01**, **6.2p02** and **5.2p02**, GEANT3) is done.

Electrons (scan over the range cut, energy scans)

- Certain changes are observed in the new version:
  - broader plateau of the visible energy in LAr as a function of the range cut
  - increase of the visible energy (2-4 %)
  - increase of the energy resolution (σ and σ/E_0)
  - increase of the simulation time by factor $\sim$2 (w.r.t. version 7.0, at the same range cut)

- Main results:
  - Amount of energy depositions in LAr is still in agreement with experimental values
  - Energy resolution becomes closer to the experiment

Conclusions

Charged pions (energy scans)

- No significant changes are observed for the version 8.0p01 w.r.t. the previous GEANT4 versions

- Results obtained with different range cuts (20, 100 and 1000 μm) are very close

- Main conclusions:
  - QGSP describes well energy resolution, response and ratio e/π
  - LHEP is worse in the description of these parameters (but is at the level of GEANT3)
  - Both physics lists (QGSP and LHEP) meet problems to describe shapes of hadronic showers