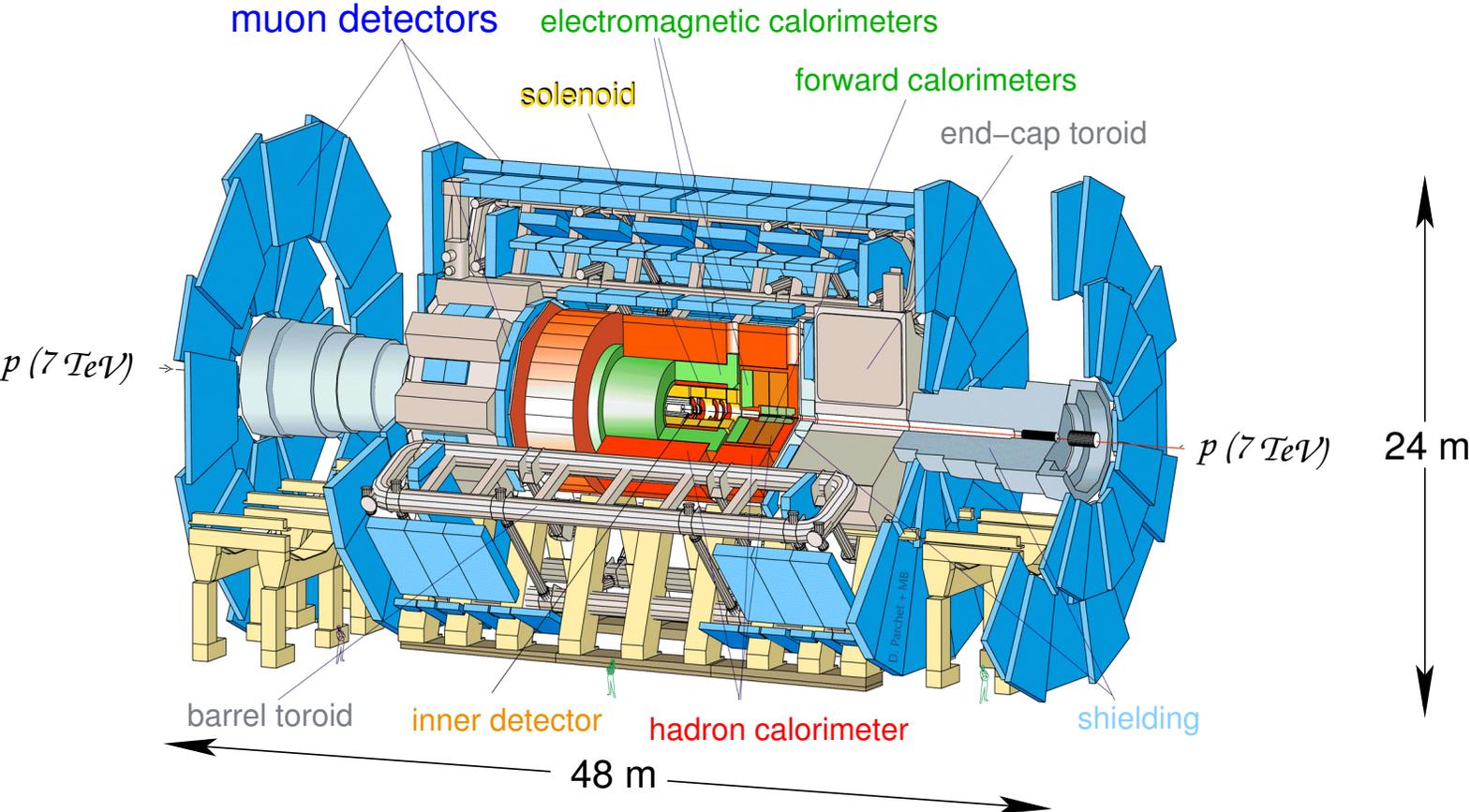


Hadronic Shower Validation Experience for the ATLAS End-Cap Calorimeter

D. Salihagić (MPI Munich)

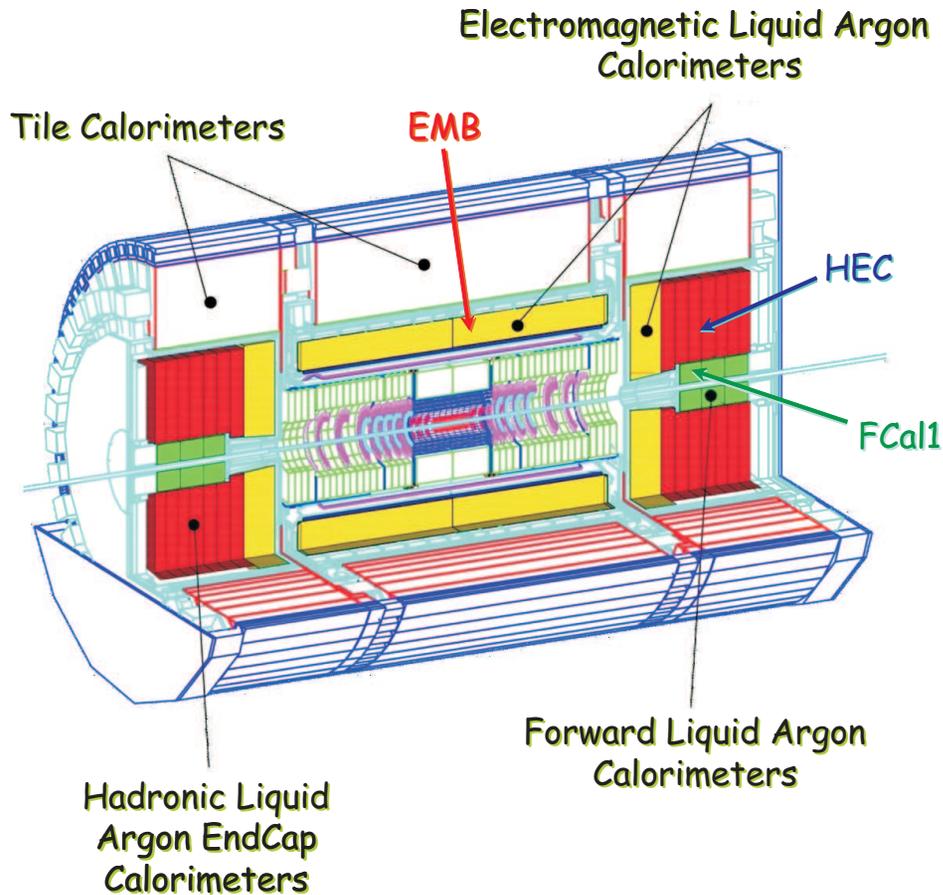
on behalf of the ATLAS LAr collaboration





weight ~ 7000 tons; ~ 2000 physicists in ~ 150 labs and 34 countries

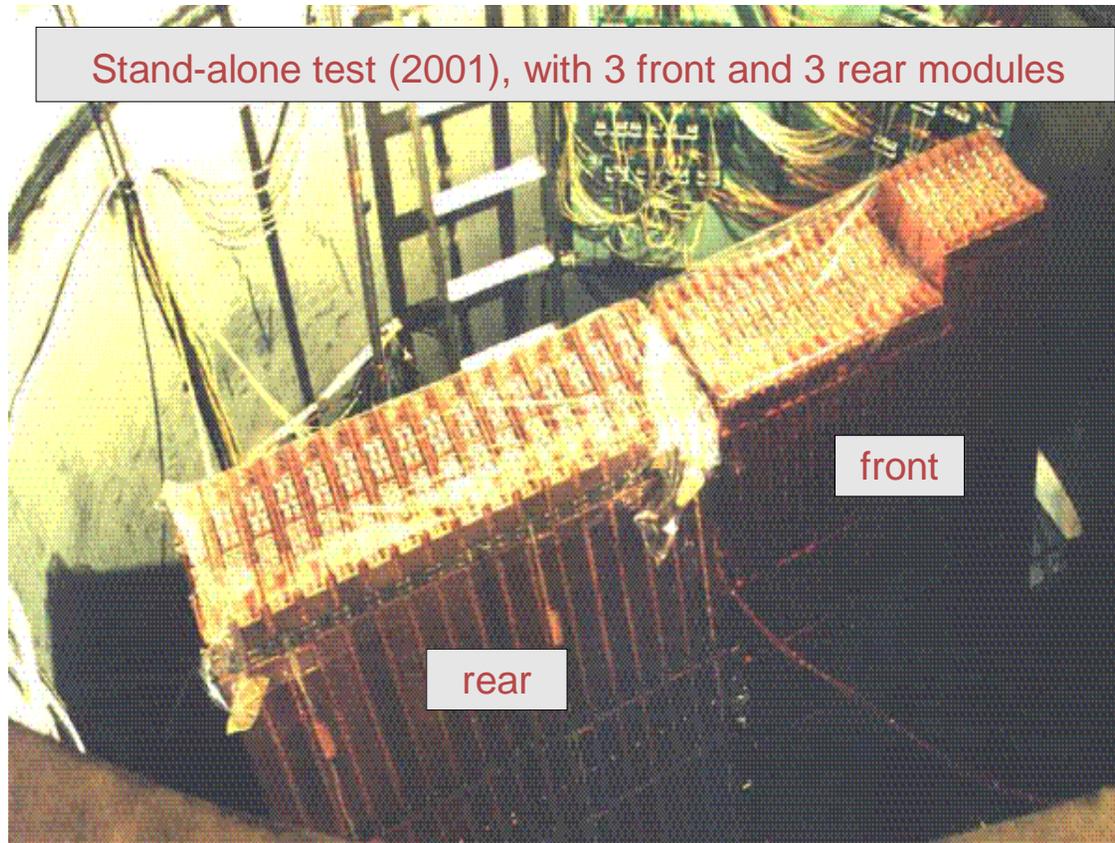




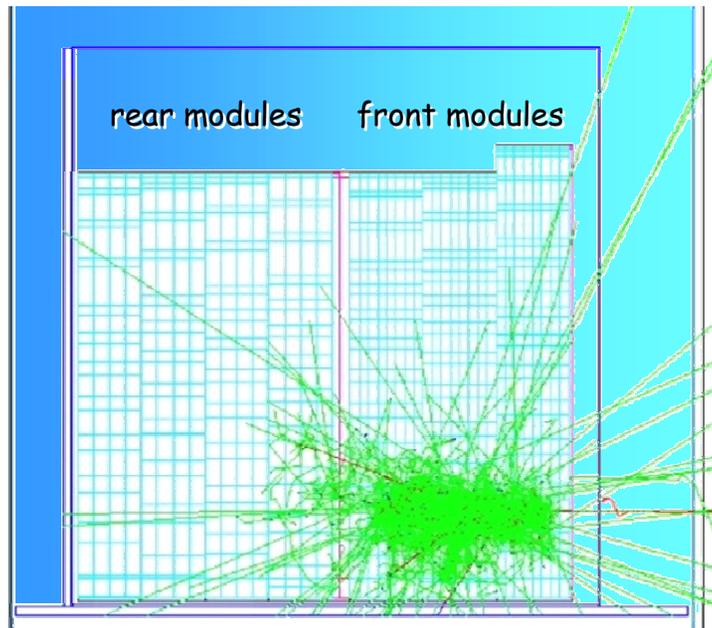
- Hadronic Tile Calorimeter; Fe/scintillator; $|\eta| < 1.7$; $\sim 8\lambda$; $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
- Hadronic End Cap Calorimeter; Cu/LAr parallel plate; $1.5 < |\eta| < 3.2$; $\sim 10\lambda$; $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ ($1.5 < |\eta| < 2.5$), $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ ($2.5 < |\eta| < 3.2$)
- Forward End Cap Calorimeter; Cu/tungsten tubular electrodes; $3.2 < |\eta| < 4.9$; $\geq 10\lambda$ $\Delta\eta \times \Delta\phi \sim 0.2 \times 0.2$, non-projective!



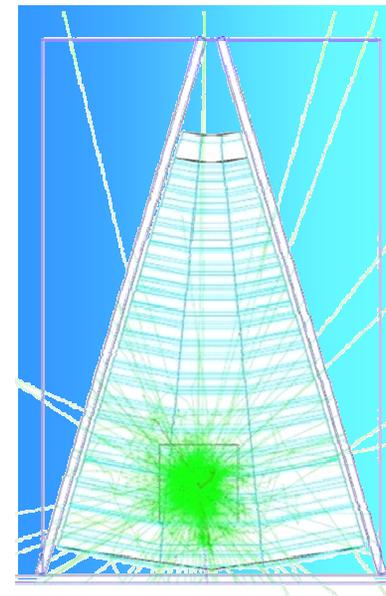
- ATLAS hadronic end-cap calorimeter (HEC)
 - liquid argon (LAr) sampling calorimeter with parallel copper absorber plates
 - beam tests of serial modules in 2000-2001



- Stand-alone code for GEANT4 based simulations of the HEC testbeam (include beam line, leakage detectors, pencil beam)



side view



front view

- Latest round of GEANT4 simulations: version **8.0** + patch-**01**
- Simulated/analysed sample:
 - focus on charged pion response simulation to understand evolution of hadronic shower models in GEANT4, also electrons and muons simulation available

Simulation Packages

- **GEANT4**

Version	5.2p02	6.2p02 ¹⁾	7.0p01	8.0p01
Physics lists	LHEP 3.6 QGSP 2.7	LHEP 3.7 QGSP 2.8	LHEP 3.7 QGSP 2.8	LHEP 4.0 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 all GEANT4 and very similar in GEANT3

¹⁾ A.E. Kiryunin et al., NIM A560 (2006) 278-290



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
- data: 20000 events per beam energy
- Energy reconstruction in electromagnetic scale:
 - cluster of the fixed size, $R \sim 30$ cm

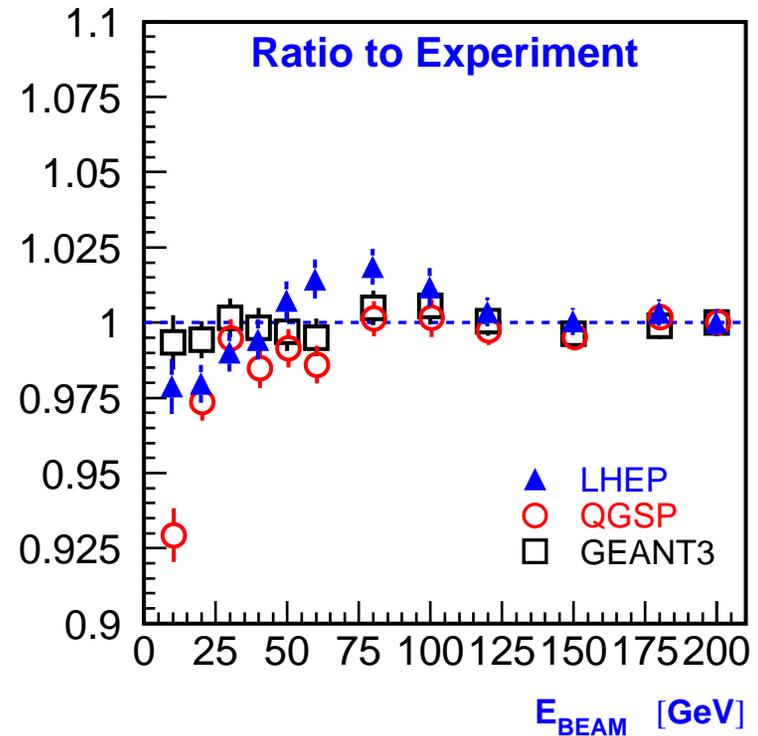
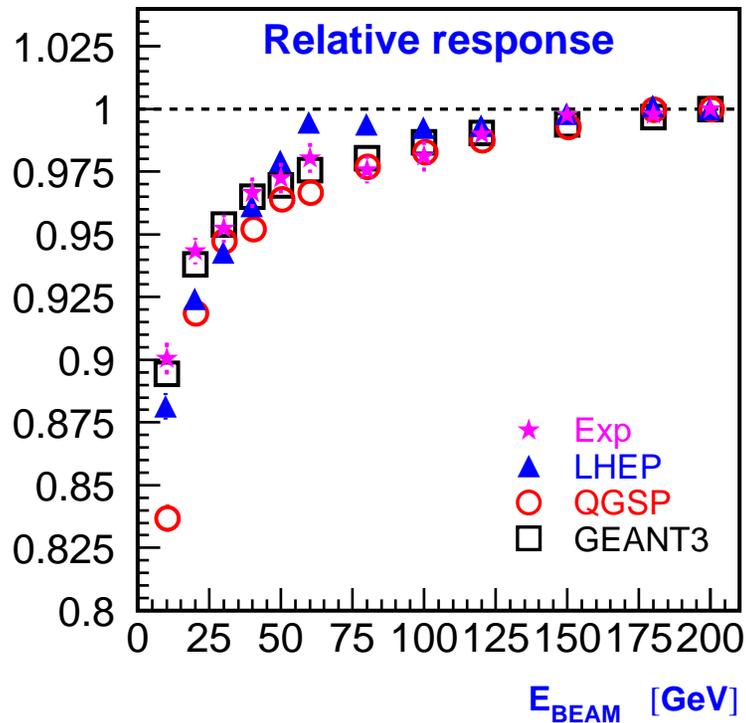


- noise was subtracted from resolution of experimental data
- Gaussian fit: E_0 and σ

- Analysis:
 - response E_0/E_{BEAM} , normalized at 200 GeV
 - energy resolution
 - fraction of energies in HEC longitudinal layers
 - ratio e/π



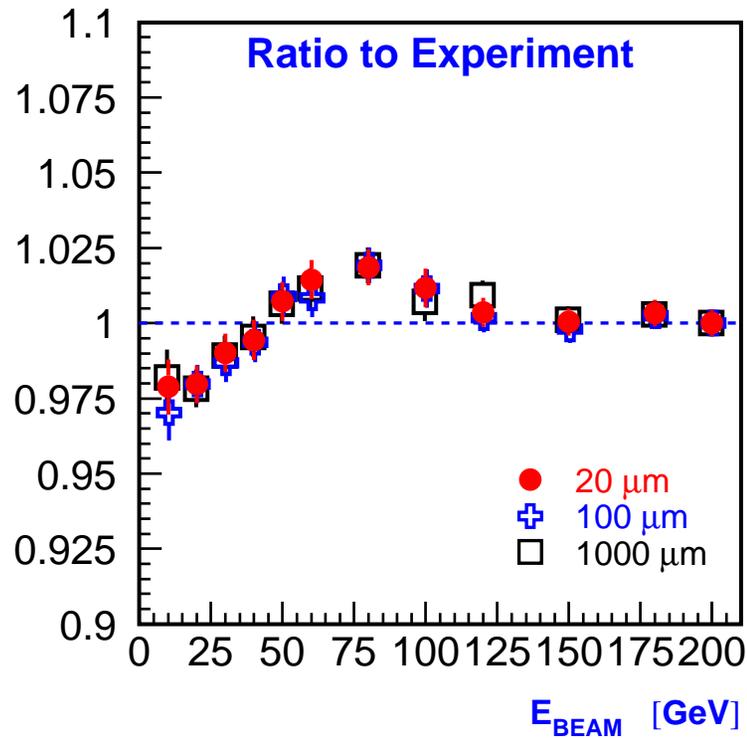
Relative response, GEANT4 v.8.0, 20 μm cut



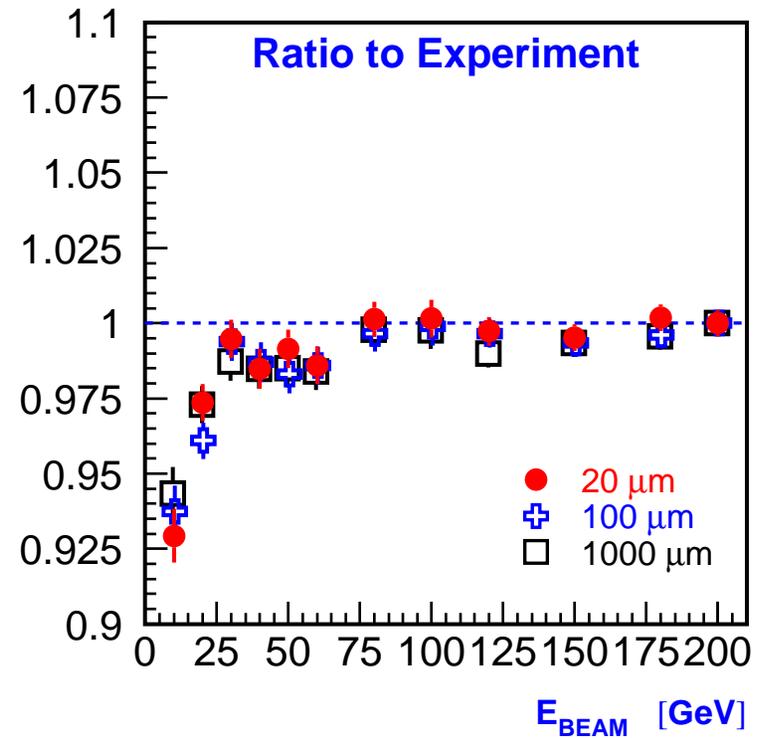
The GEANT3 - closest to data; within errors LHEP and QGSP - consistent as well



GEANT4 version 8.0, LHEP



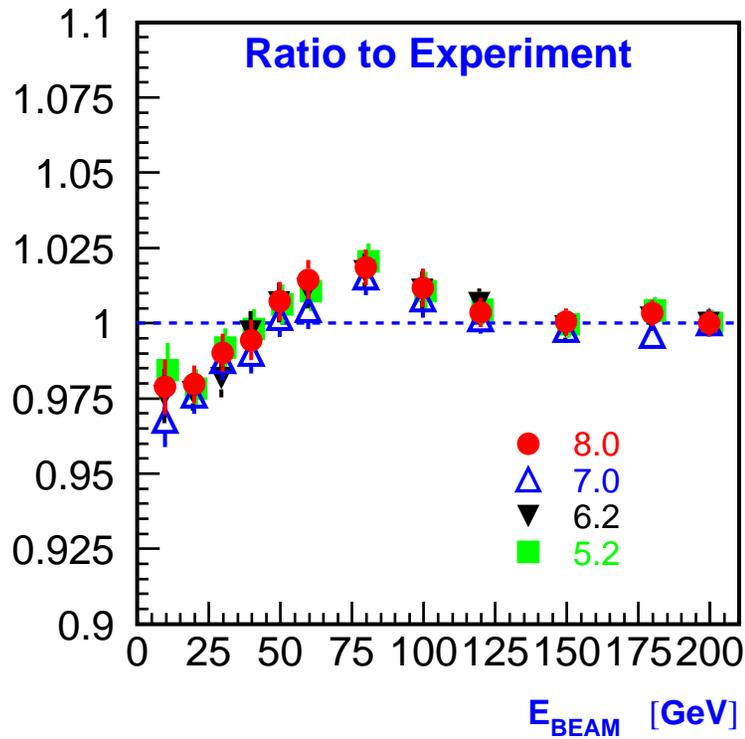
GEANT4 version 8.0, QGSP



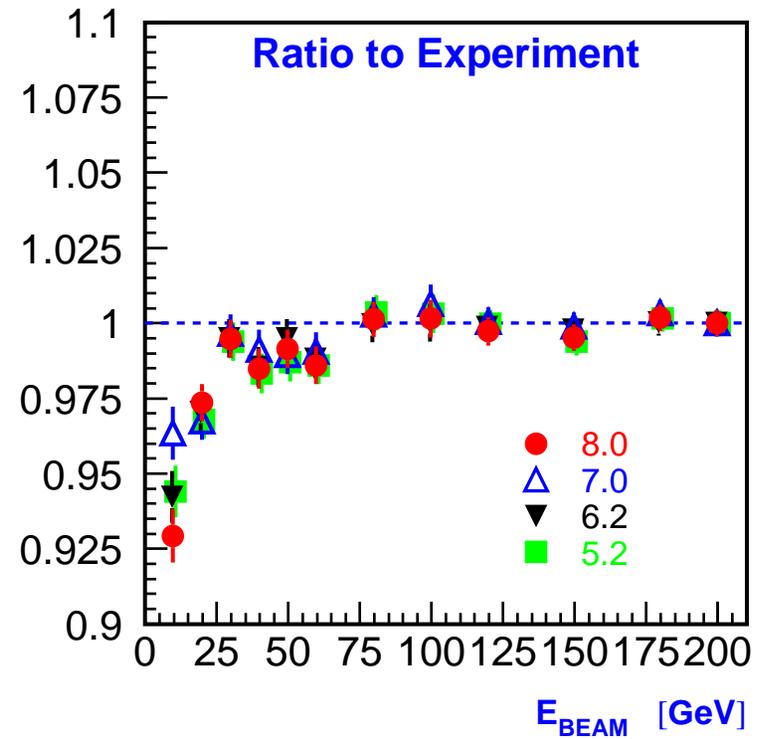
No dependences on range cuts



LHEP, 20 μm cut



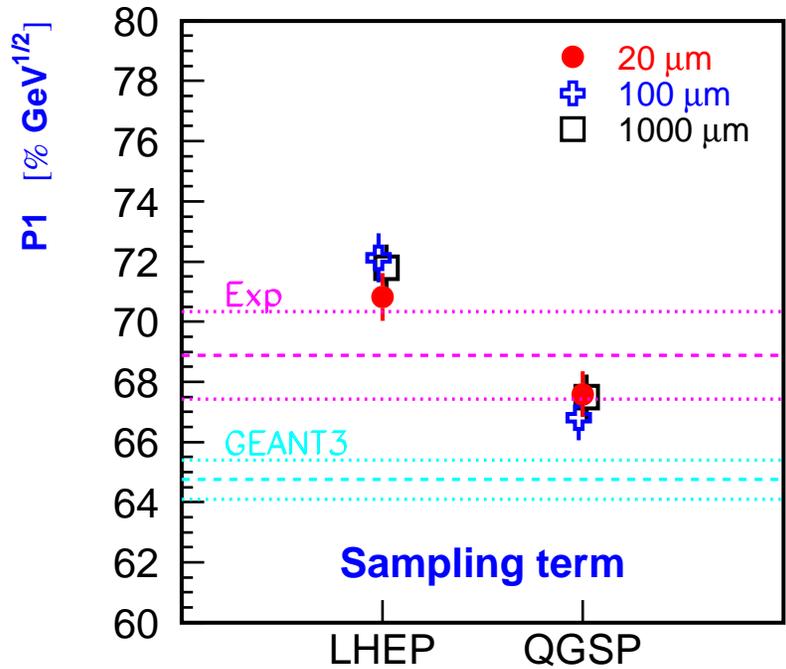
QGSP, 20 μm cut



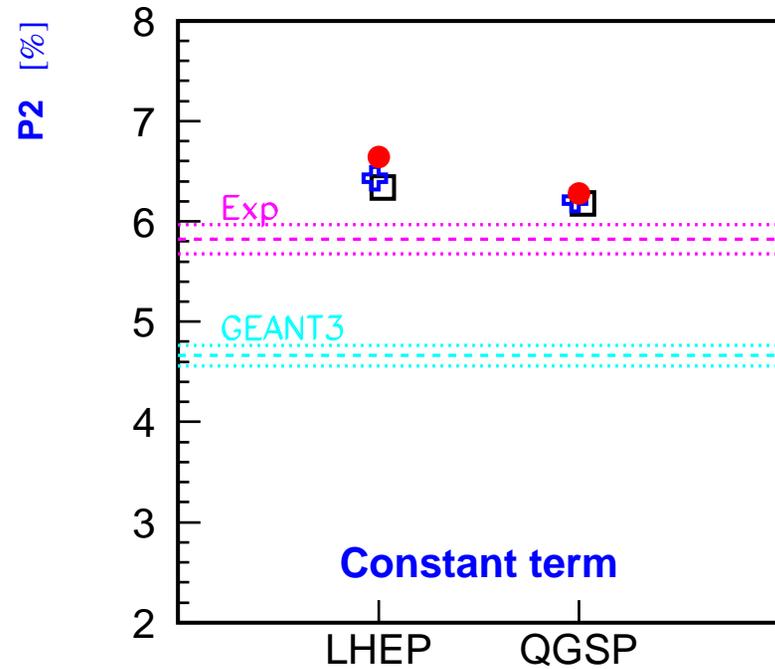
No changes between different GEANT4 versions



Energy resolution: $\sigma/E_0 = P1/\sqrt{E_{BEAM}} \oplus P2$; GEANT4 v.8.0



GEANT4 physics list

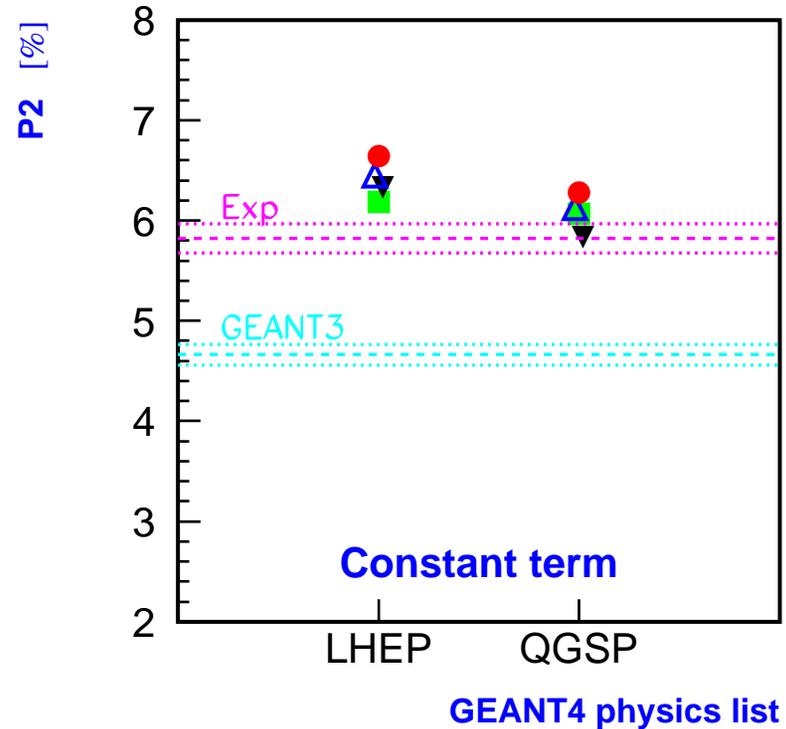
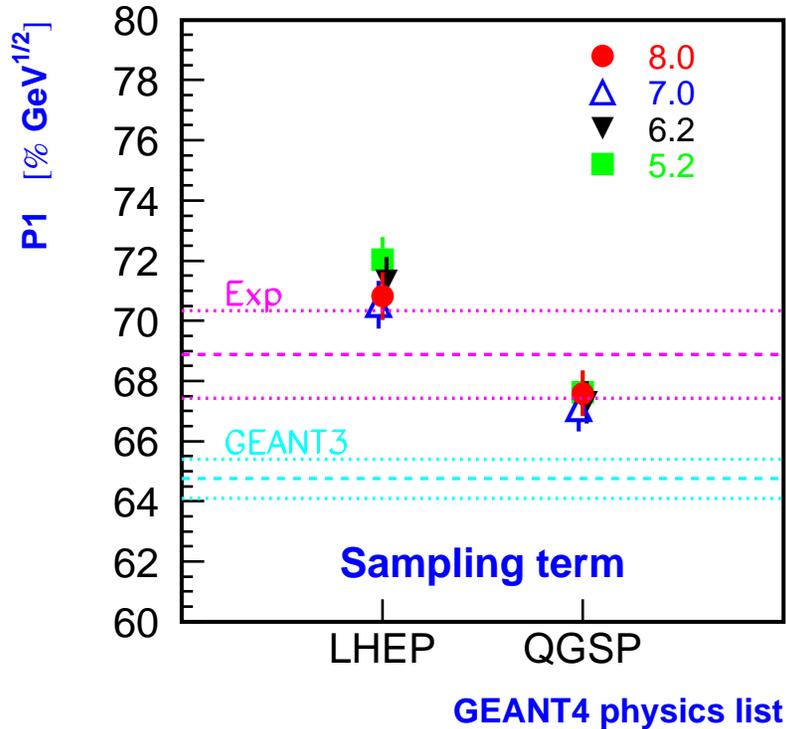


GEANT4 physics list

GEANT3 - systematically too good; LHEP and QGSP - quite well (QGSP - somewhat better); No cut dependences



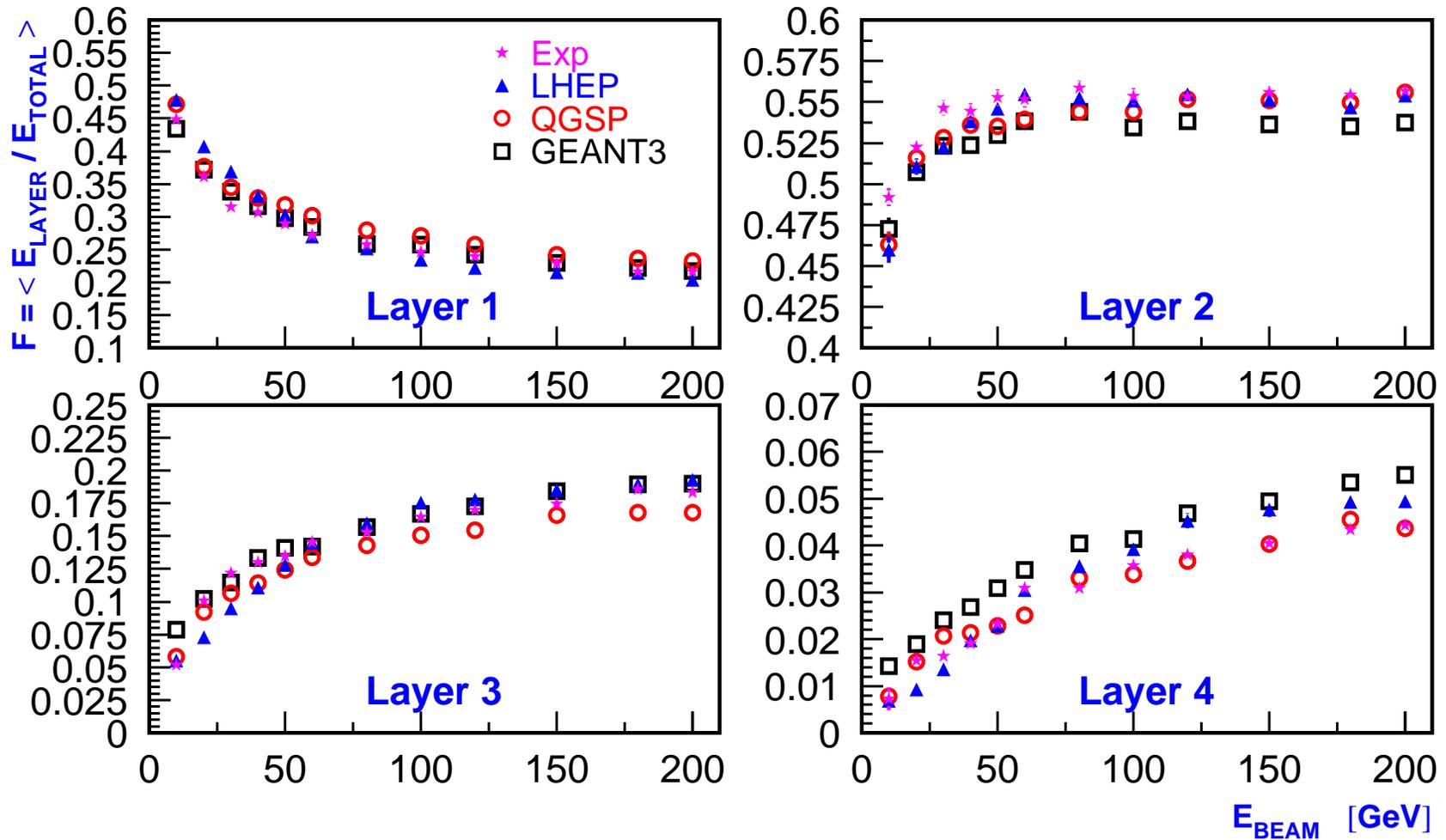
Energy resolution: $\sigma/E_0 = P1/\sqrt{E_{BEAM}} \oplus P2$, 20 μm cut



Different GEANT4 versions in agreement within errors

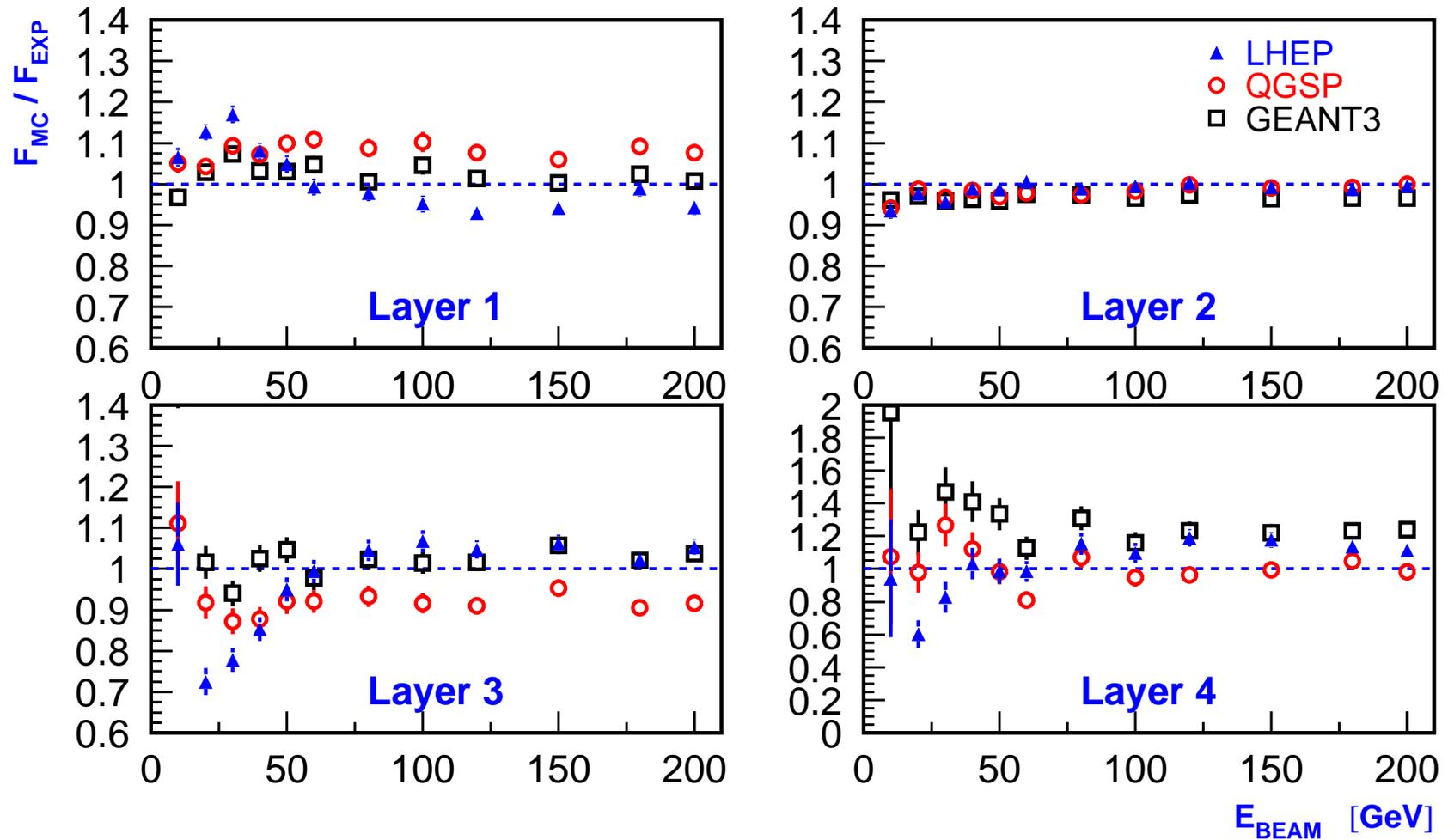


Fraction of energy in longitudinal layers, GEANT4 v.8.0, 20 μm cut



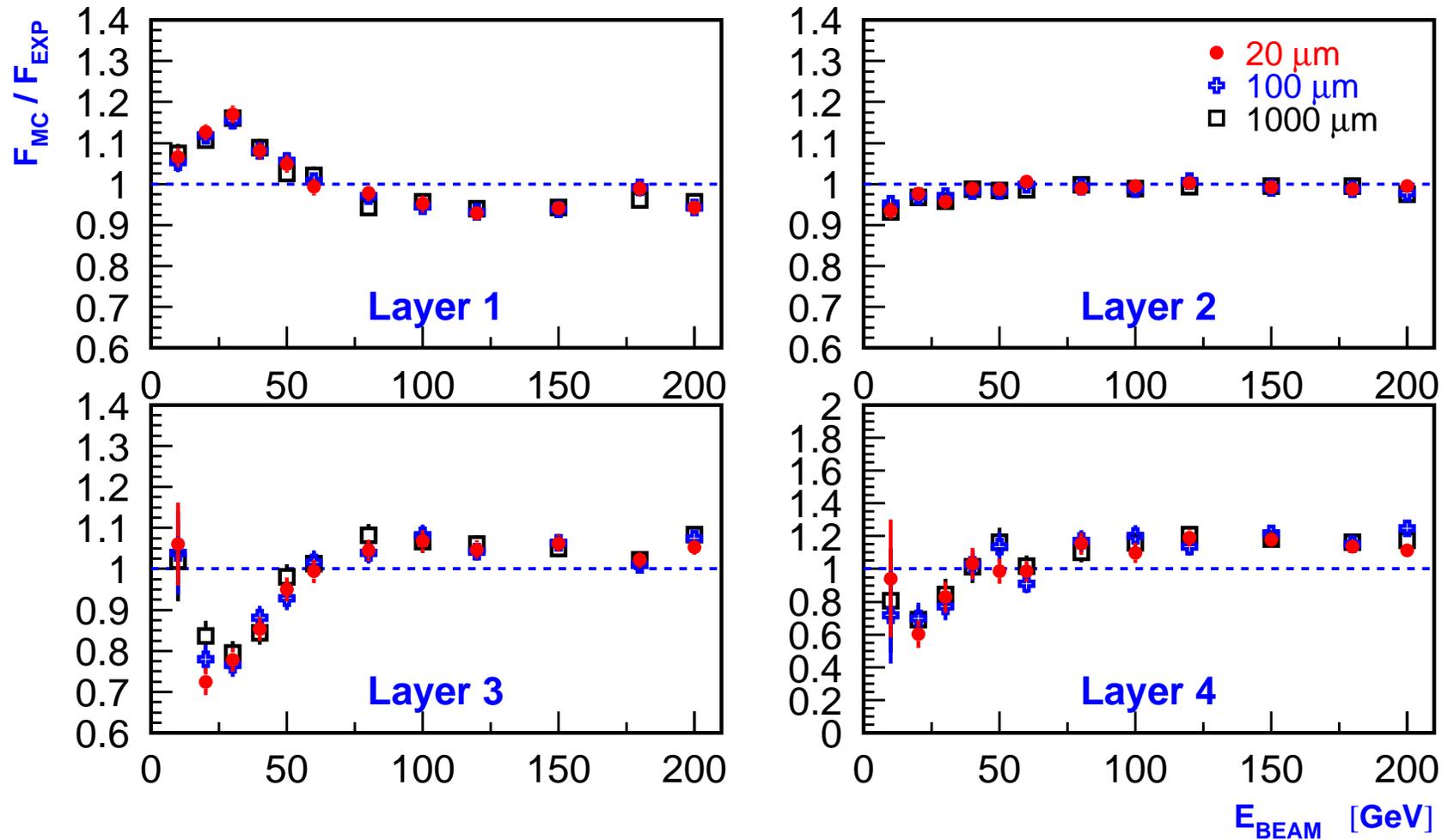
Half of the signal in layer 2

Fraction of energy in layers: GEANT4 v.8.0, 20 μm cut



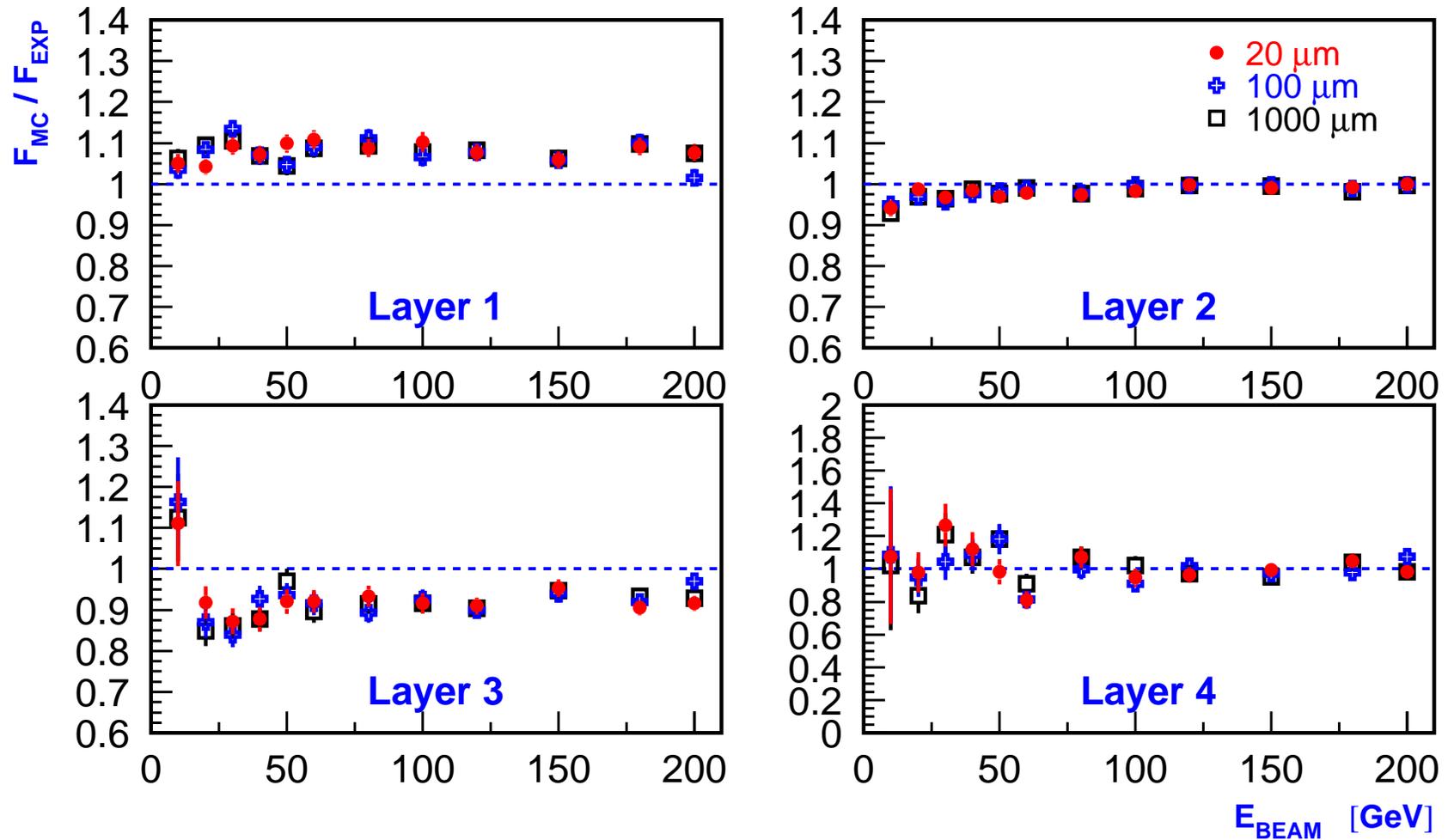
GEANT3 - good; QGSP - early; LHEP - energy dependent

Fraction of energy in layers: GEANT4 v.8.0, LHEP



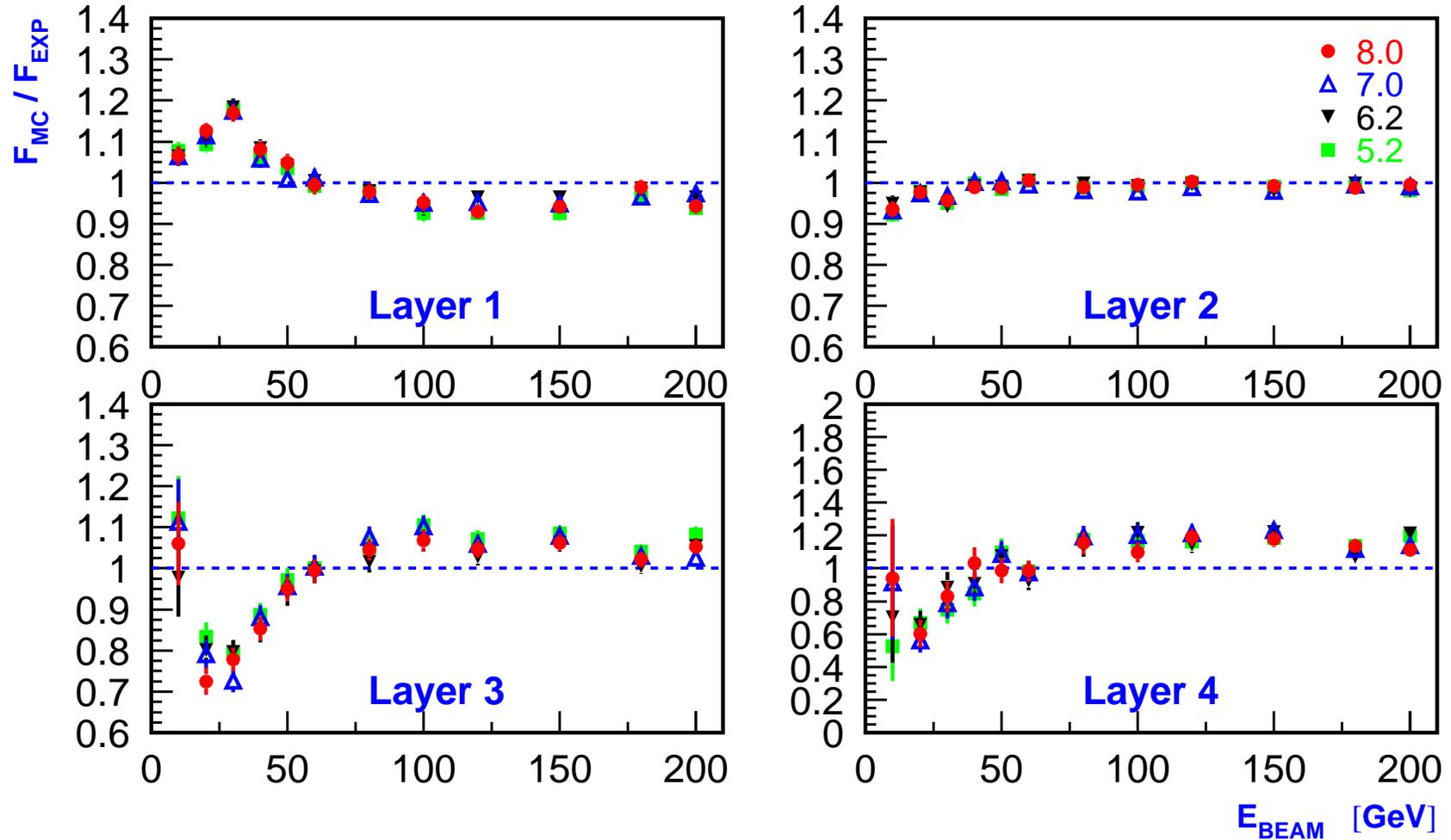
No range cut dependences

Fraction of energy in layers: GEANT4 v.8.0, QGSP



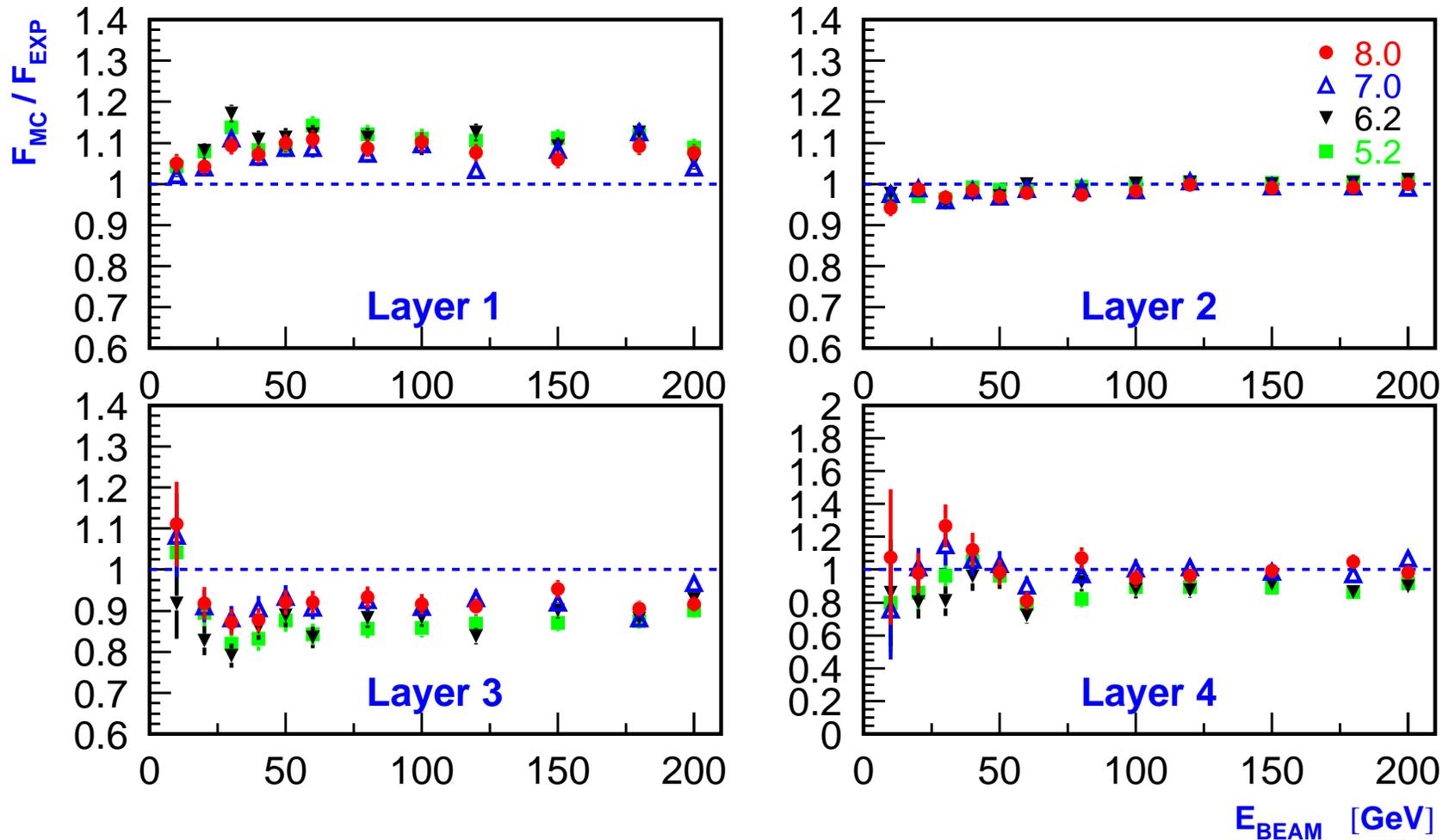
No range cut dependences

Fraction of energy in layers: LHEP, 20 μm cut



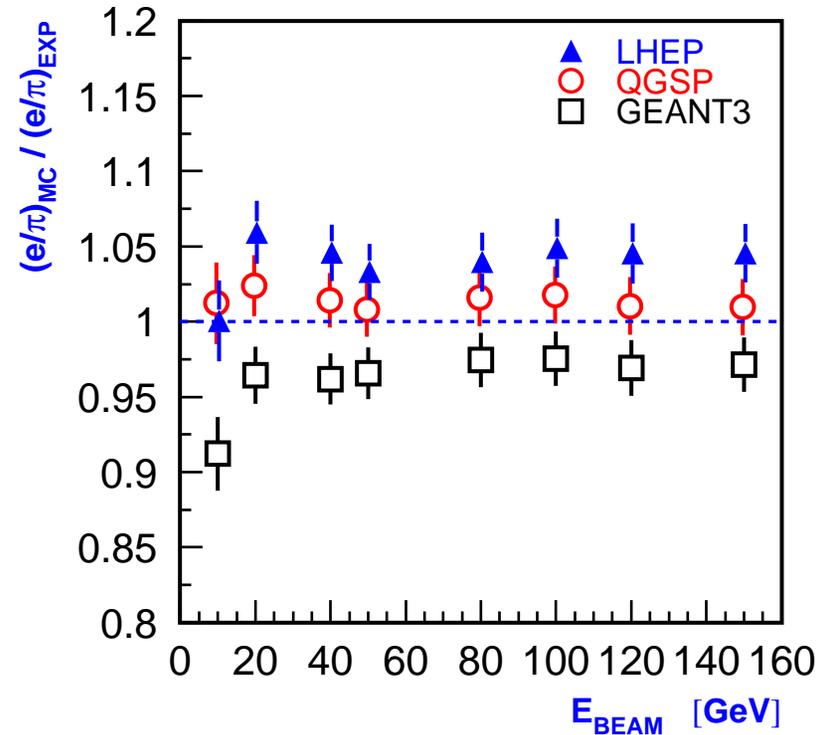
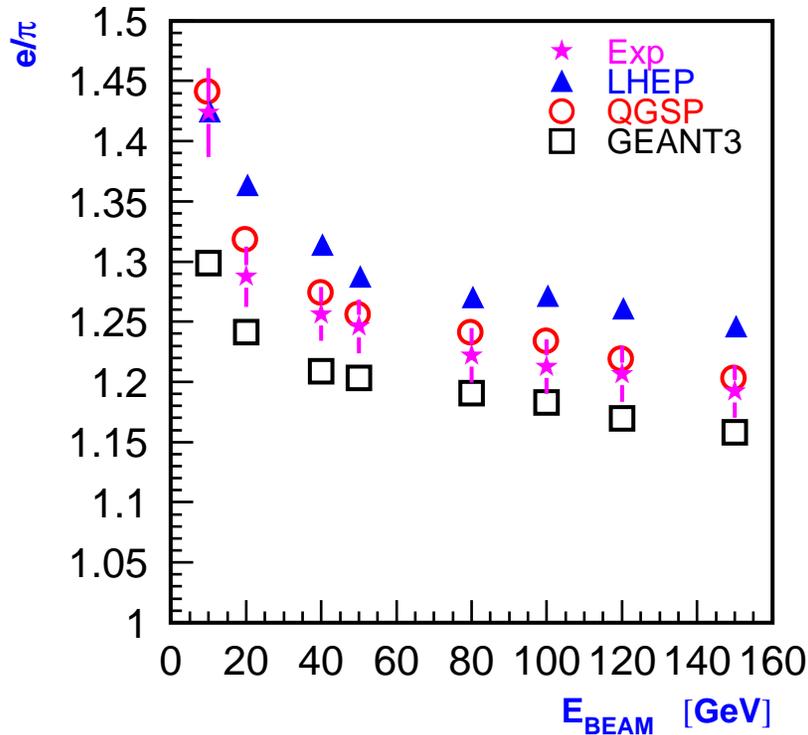
No differences between GEANT4 versions

Fraction of energy in layers: QGSP, 20 μm cut



Some improvement between versions 6.2 and 7.0

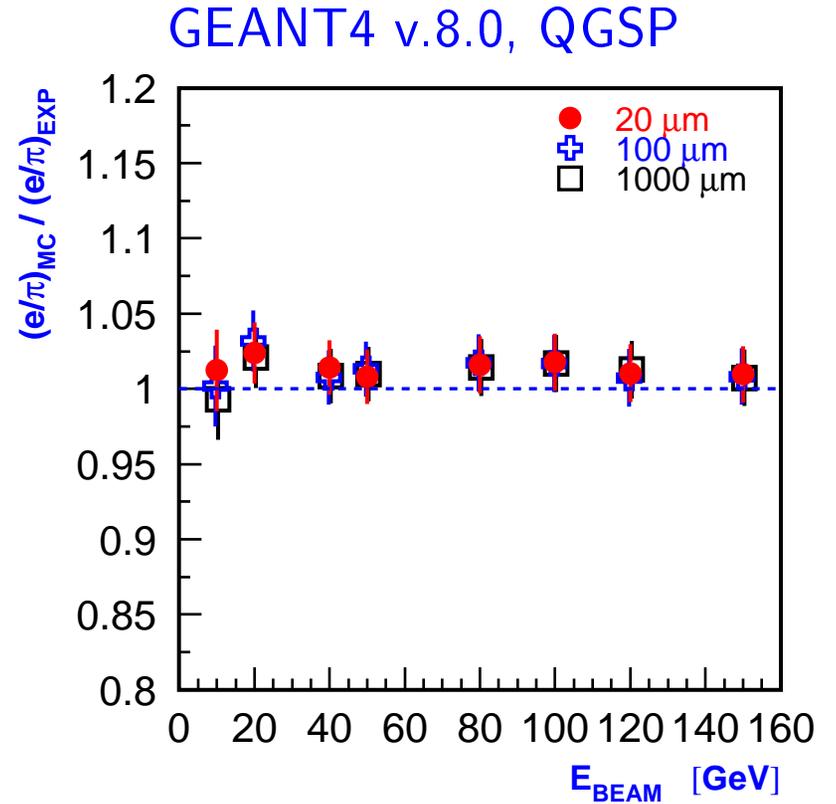
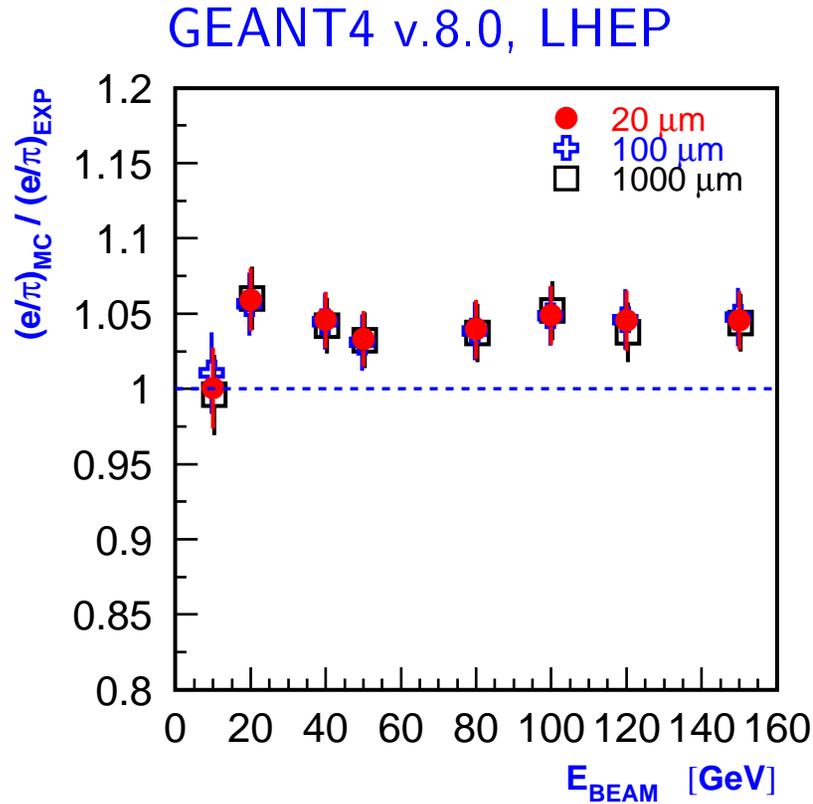
Ratio e/π ; GEANT4 v.8.0, 20 μm cut



QGSP - very well; LHEP - larger values; GEANT3 - systematically lower



e/π : ratio to experimental data

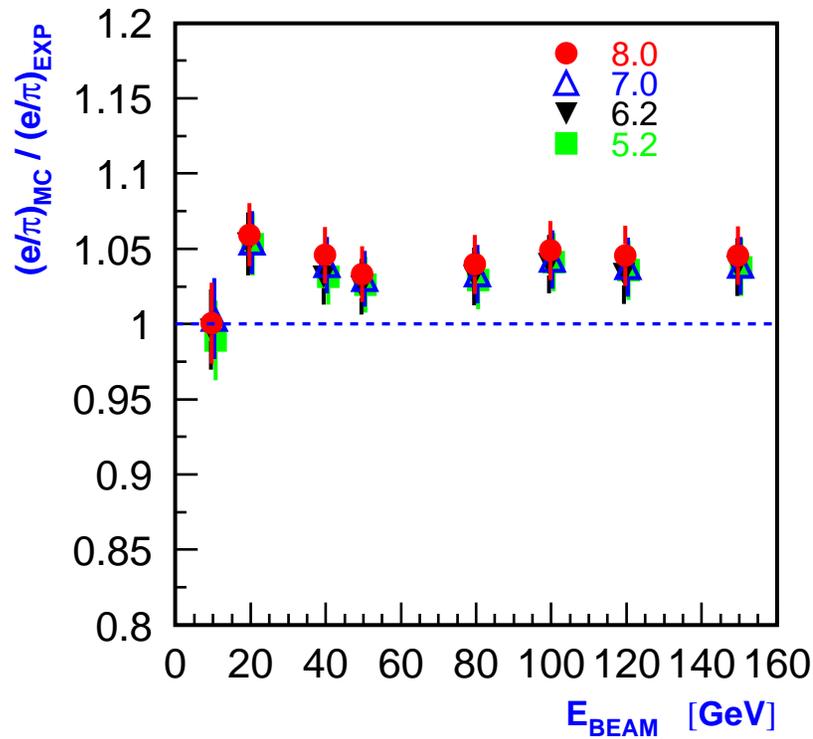


No range cut dependences

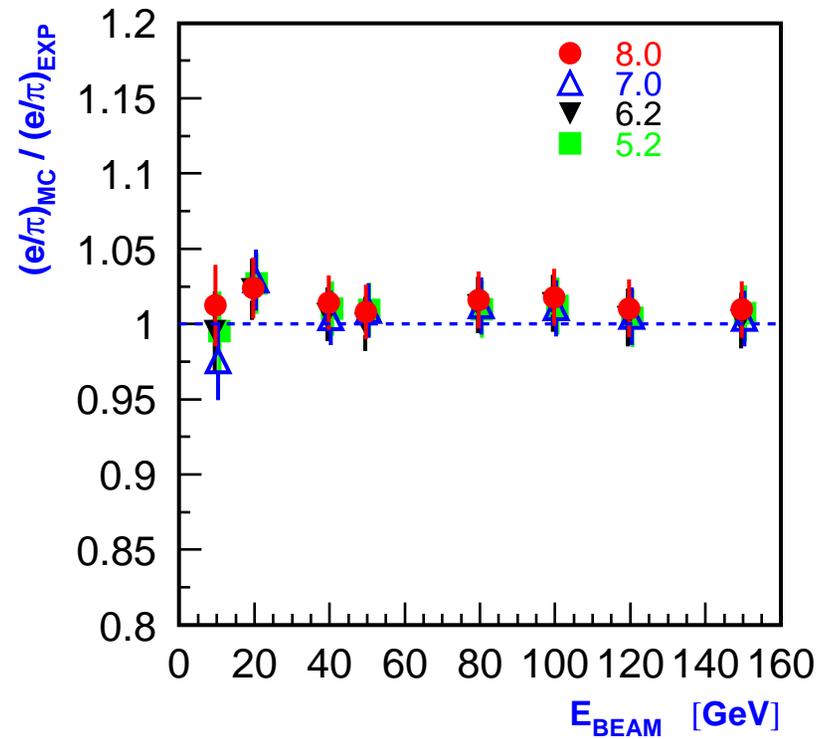


e/π : ratio to experimental data

LHEP, 20 μm cut



QGSP, 20 μm cut



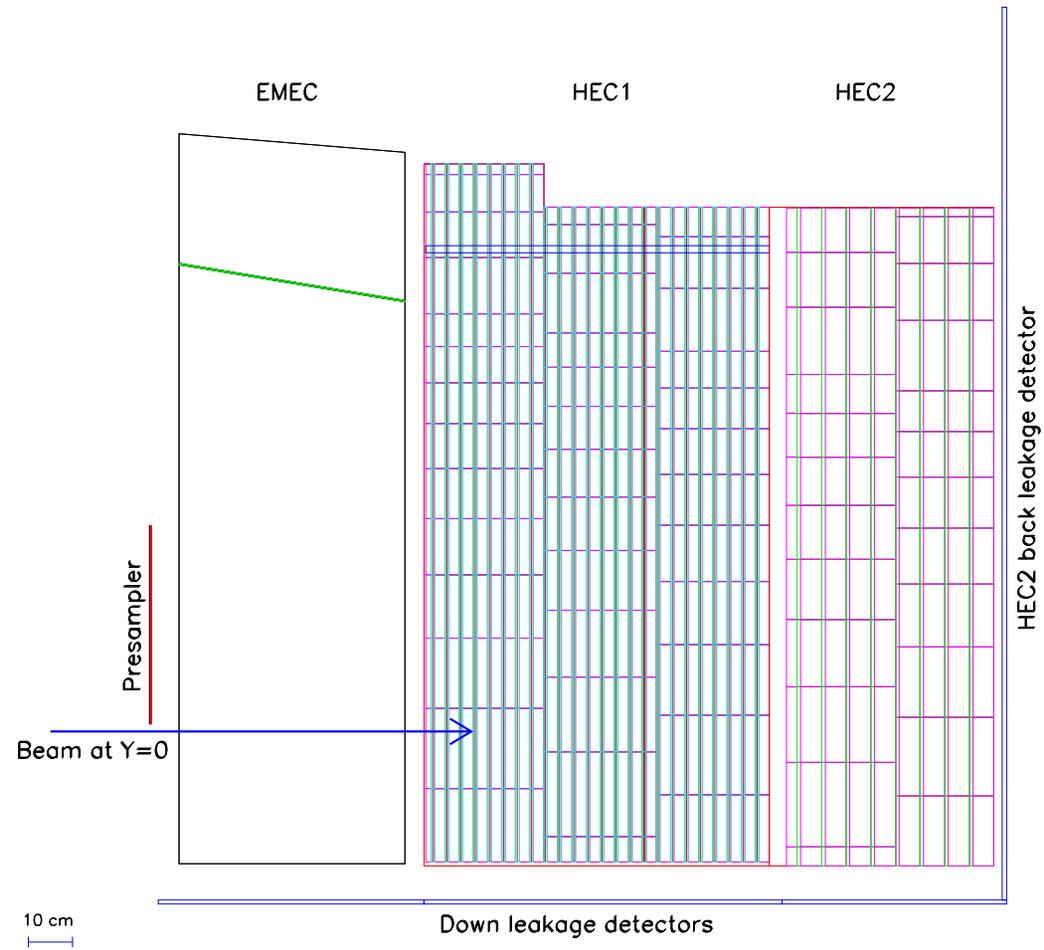
No differences between GEANT4 versions



Combined EMEC+HEC Data versus MC

- GEANT3 v.3.21:
 - GCALOR
 - 100 keV track and 1 MeV production threshold
- GEANT4 v.5.0.p1
 - LHEP v.3.3 & QGSP v.2.3
 - 700 μm range cut
- reconstruction:
 - noise generated for Monte Carlo
 - electromagnetic scale
 - cluster algorithm

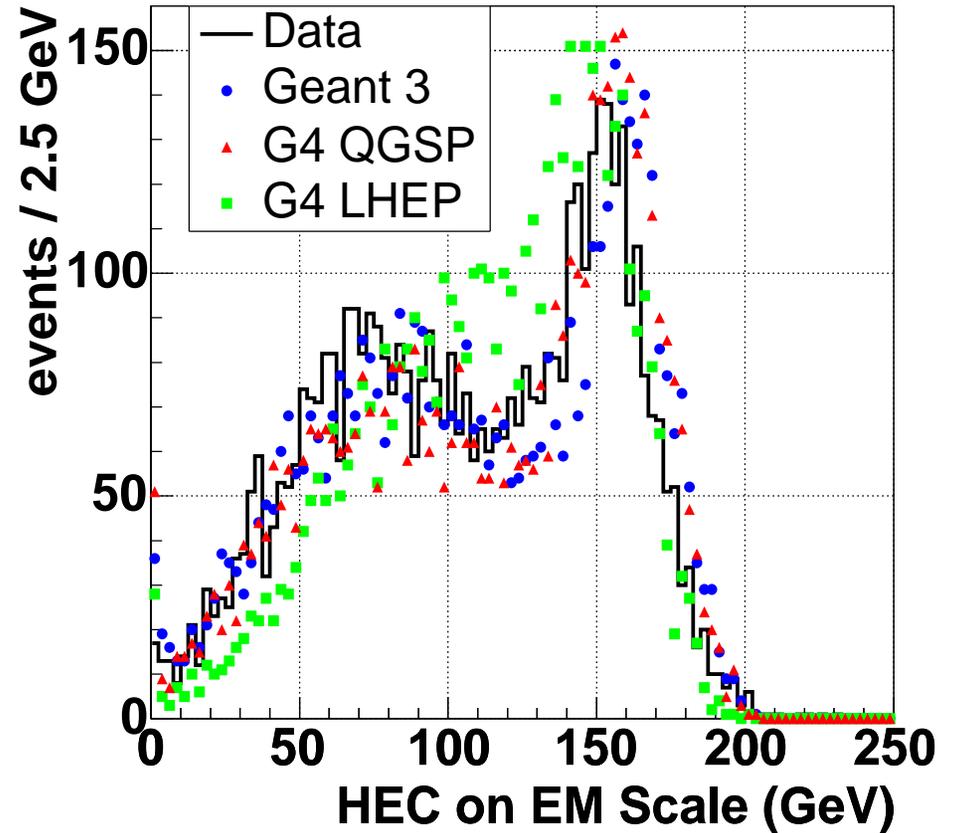
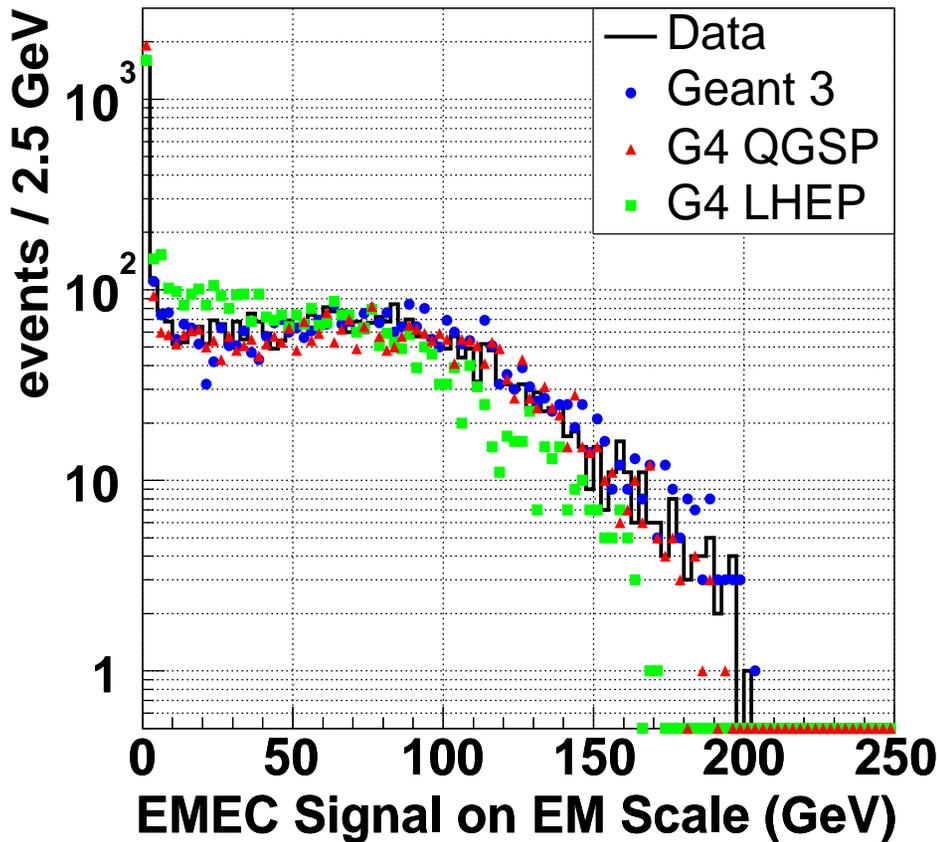




not so "young" version of GEANT4, but never the less:

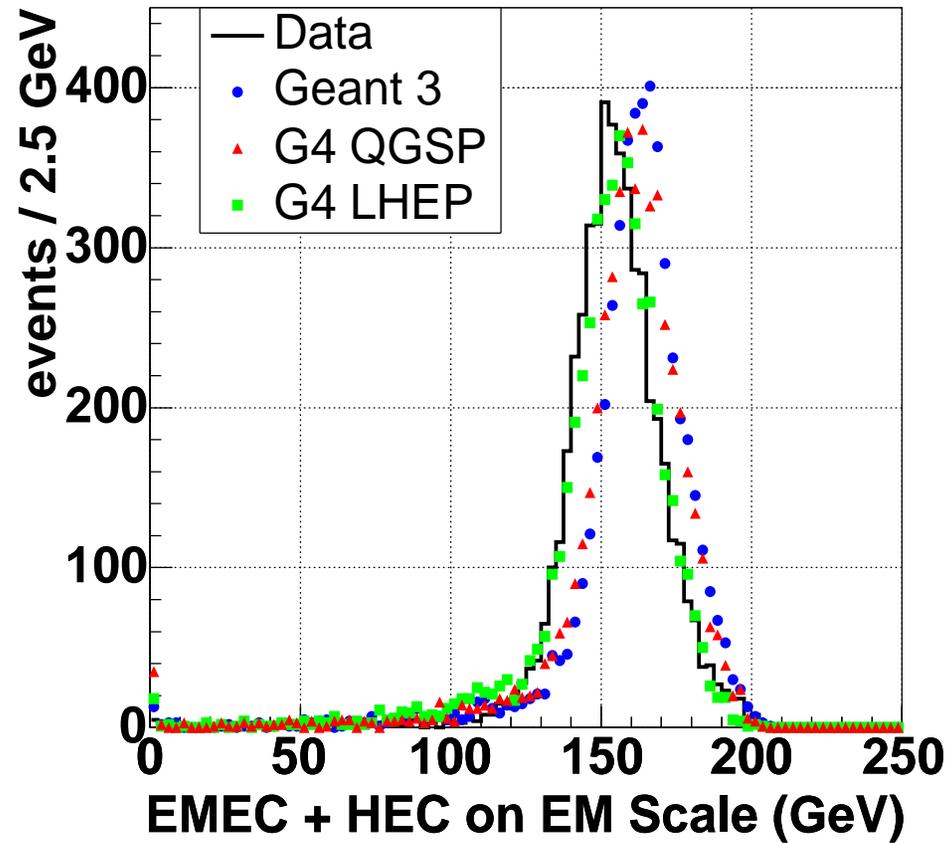


Response at electromagnetic scale (200 GeV pions)



Both GEANT3 and QGSP describe the EMEC and HEC data reasonably well but





LHEP yields the best agreement with data for the total signal.

Conclusions

- a long standing program for Geant4 hadronic shower model evolution validation has been established in ATLAS (A. Kiryunin et al., MPI)
- new releases and physics lists are systematically compared with experimental data as soon as they become available and reflect changes;
- in general it is observed that important hadronic signal characteristics like the e/π and energy dependence of the response in the non-compensating ATLAS calorimeters are reasonably well described
- some remaining problems are related to the description of the spatial shower spread



- it would certainly be interesting to include other shower models, mainly FLUKA, into the systematic studies, but one of the major requirements for this would be an implementation within the same geometry description framework
- hadron shower simulations for more complex regions of the ATLAS calorimeters like the EMEC/HEC/FCal transition, are in preparation now that reference pion testbeam data becomes available