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GEANT4 Physics Evaluation with Testbeam Data of the ATLAS Hadronic End-Cap Calorimeter

LCG Physics Validation of LHC Simulations
CERN, 28-th of February, 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 8.1 + patch-02**
  - scan over the GEANT4 range cut with electrons
  - electron energy scans
  - charged pion energy scans
- Studies of physics lists with **alternative** standard **electromagnetic physics**
- Evaluation of hadronic physics lists with **Bertini** and **binary cascade** models

Evaluation of GEANT4 Version 8.1

- GEANT4 version 8.1 with patch-02
  - Release date: November 2006
  - Physics lists:
    - LHEP 4.1
    - QGSP 3.1

- Previous GEANT4 versions: from 5.0 to 8.0 (2003-2006)

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

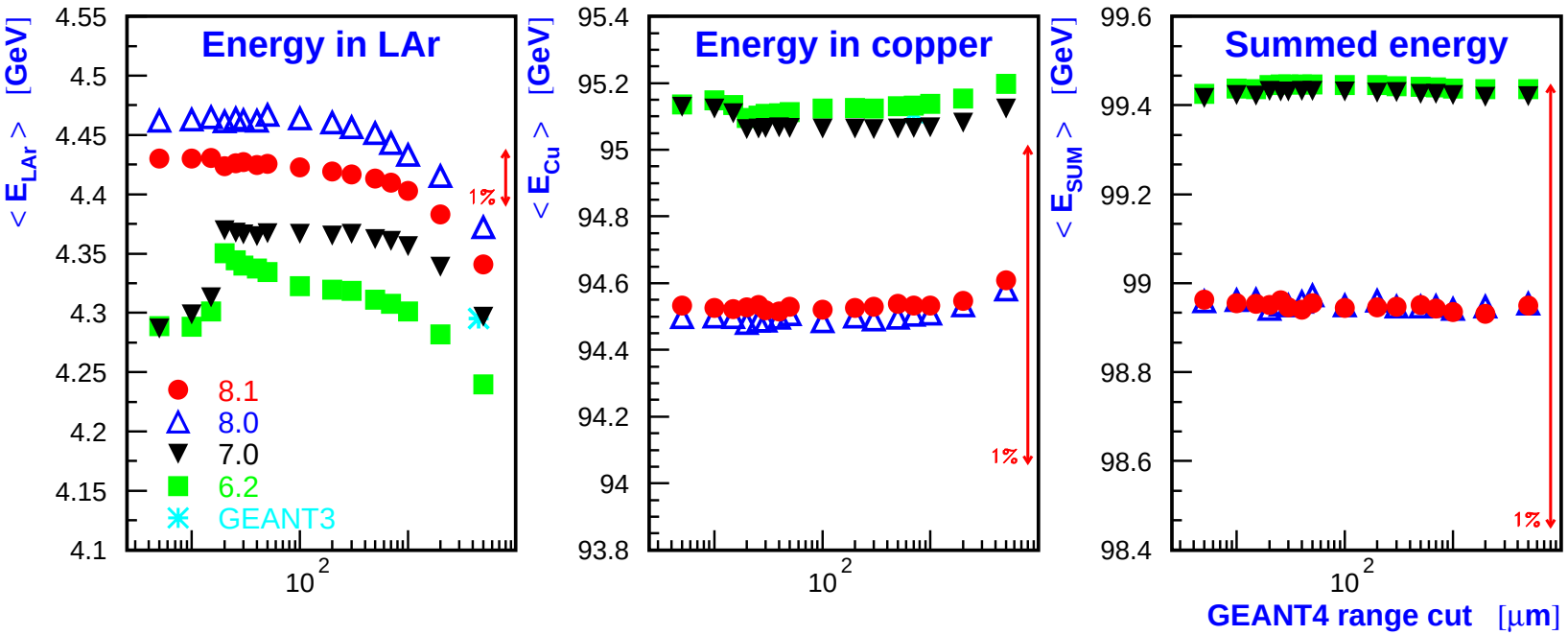
- HEC geometry: the same in all GEANT4 versions and very similar in GEANT3

Electrons: Scan over the Range Cut

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

Evaluation of GEANT4 version 8.1 / Scan over the range cut with electrons

Energy depositions in HEC



In versions 8:

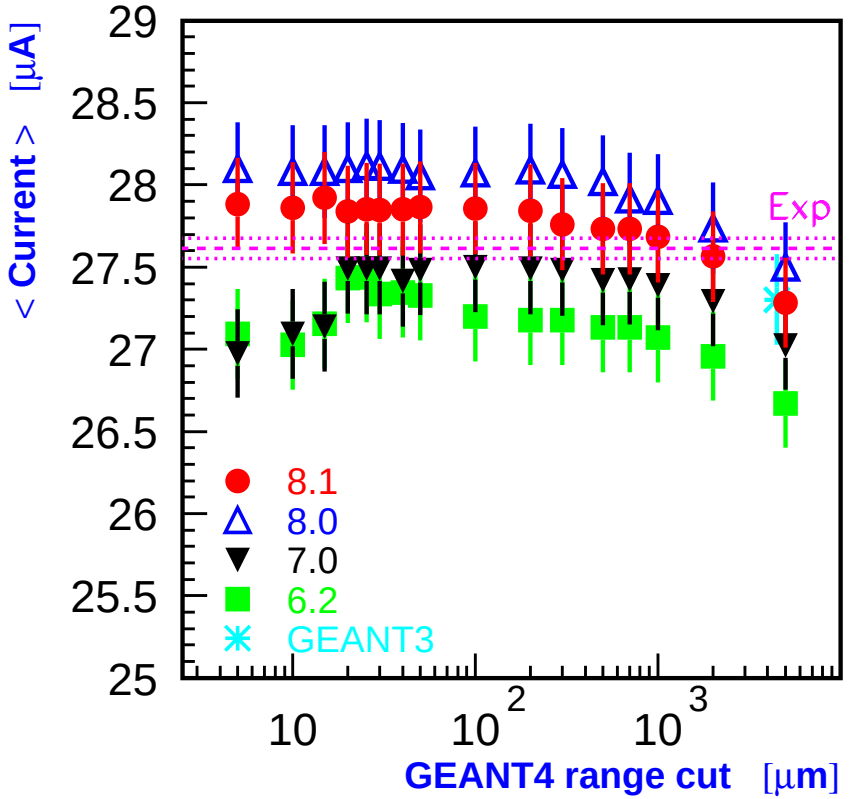
- broader plateau of the visible energy in LAr as a function of the range cut
- increase of the visible energy
- decrease of the total deposited energy

Result of the significant upgrade of the Multiple Scattering in GEANT4

Evaluation of GEANT4 version 8.1 / Scan over the range cut with electrons

Signal in one cell

- Cell with the maximal average signal
- Visible energy ⇒ 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



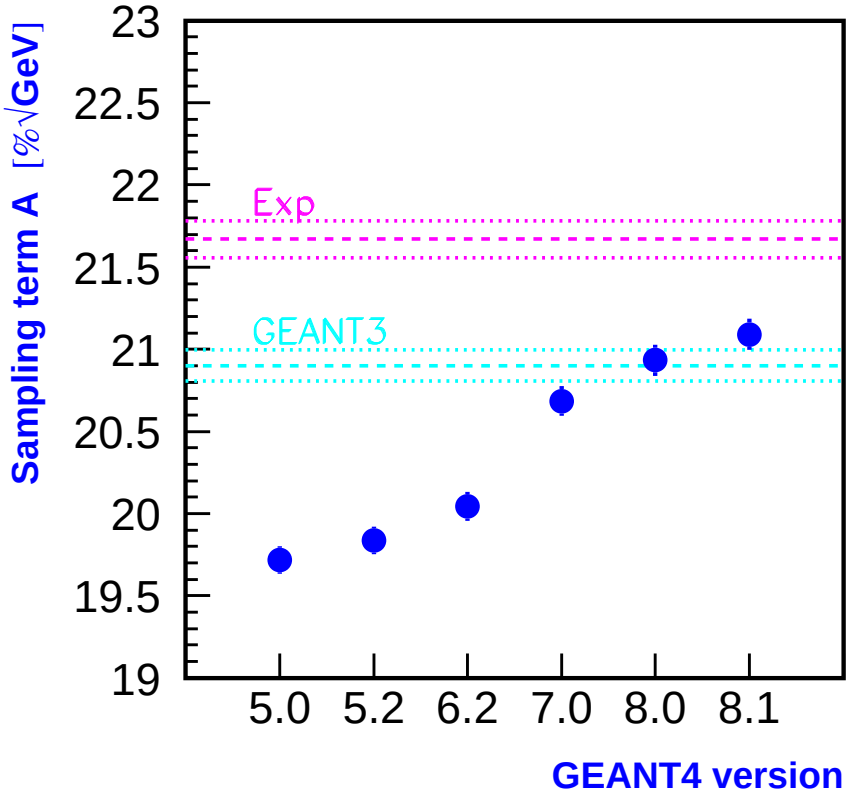
Electrons: Energy Scan

- Beam energies: 6 - 147.8 GeV
- GEANT4 range cut: 20 μm
- Physics list: LHEP
- 5000 events per beam energy

- Energy reconstruction:
  - following experimental procedure
  - cluster of the fix size
  - Gaussian fit: E_0 and σ

- Analysed variable:
  - energy resolution

$$\sigma/E_0 = A/\sqrt{E_{BEAM}}$$

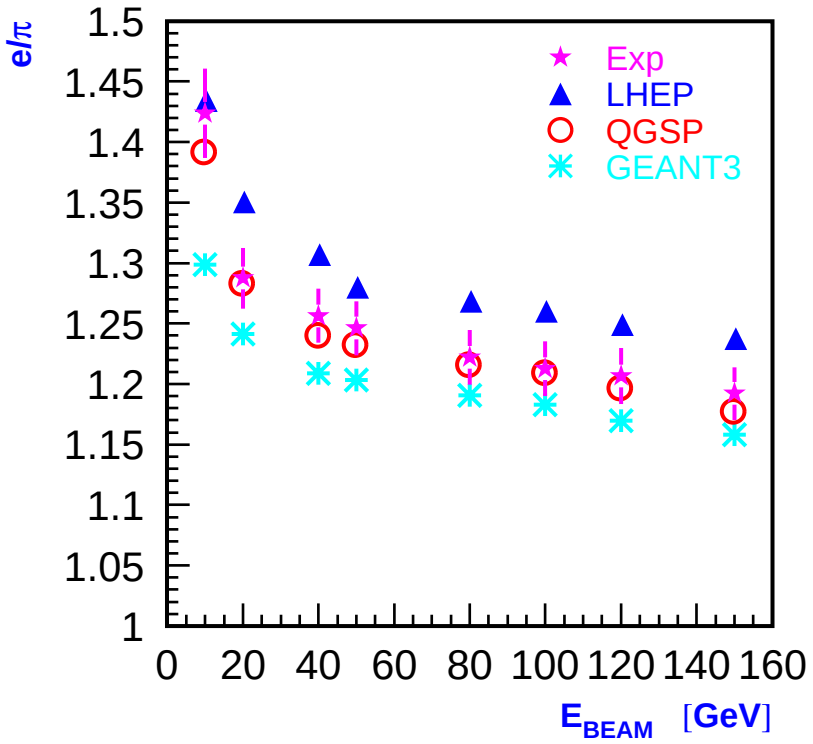


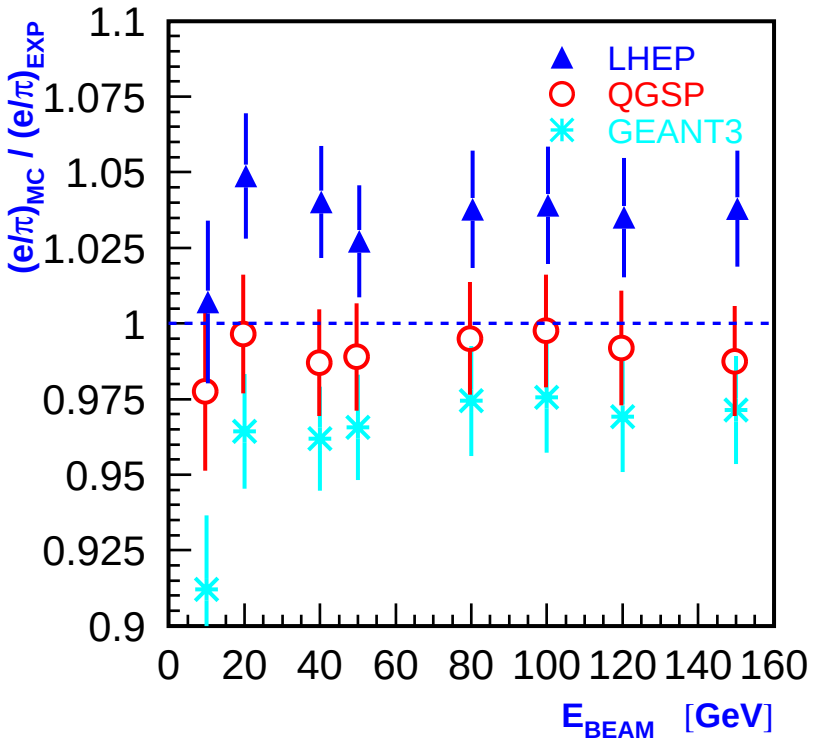
Charged Pions: Energy Scans

- Beam energies: 10 - 200 GeV
- GEANT4 range cut: 20 μm
- Physics lists: LHEP and QGSP
- 5000 events per beam energy and physics list
- Energy reconstruction:
  - similar as for electrons
- Analysed variables:
  - ratio e/π (ratio of energies in electron and pion clusters)
  - energy resolution
  - fraction of energies in HEC longitudinal layers

Evaluation of GEANT4 version 8.1 / Charged pion energy scans

Ratio e/π for GEANT4 version 8.1





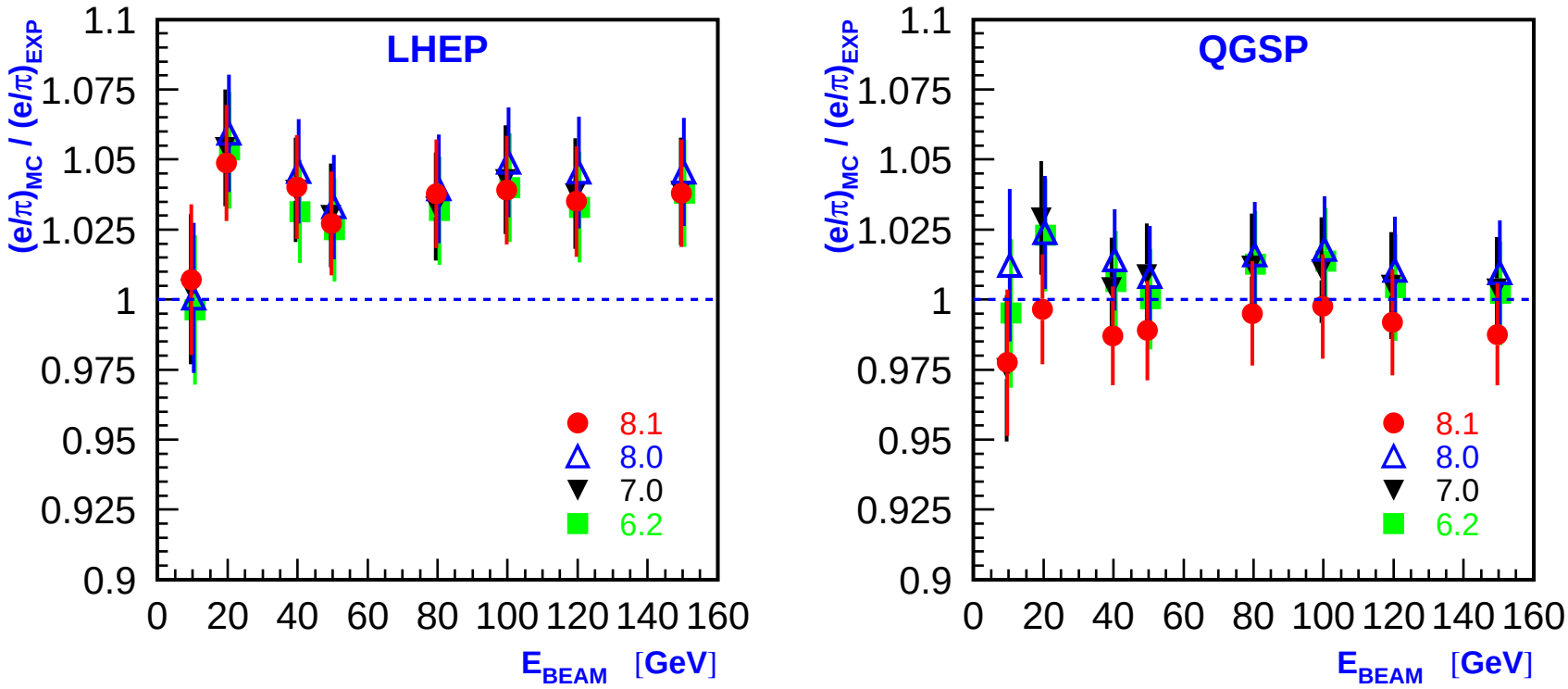
QGSP describes experimental values of e/π well

LHEP predicts larger values of e/π

GEANT3 is systematically lower

Evaluation of GEANT4 version 8.1 / Charged pion energy scans

Ratio e/π for different GEANT4 versions



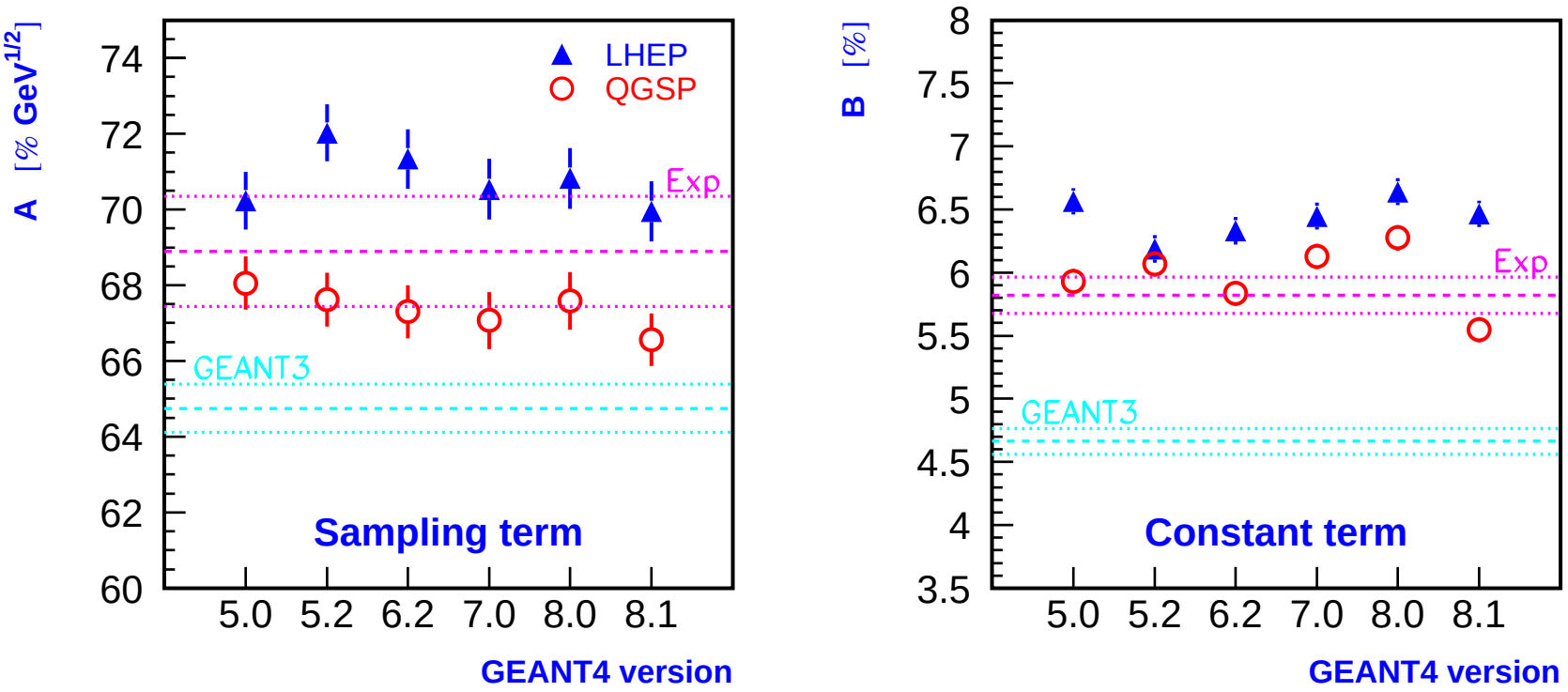
LHEP: no difference for e/π-ratio between GEANT4 versions

QGSP: some changes in version 8.1, but still in good agreement

Evaluation of GEANT4 version 8.1 / Charged pion energy scans

Energy resolution for different GEANT4 versions

$$\sigma/E_0 = A/\sqrt{E_{BEAM}} \oplus B$$



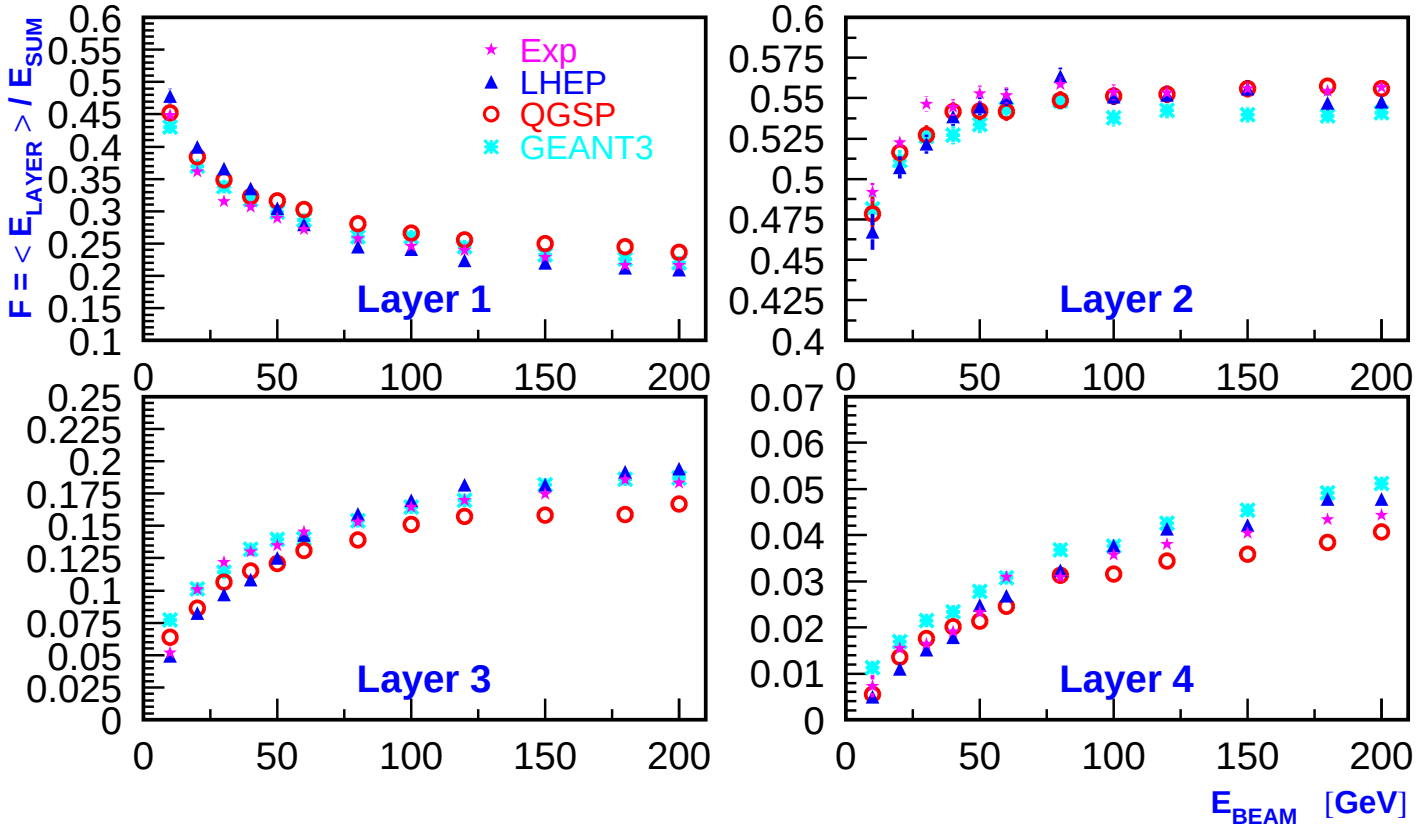
GEANT4 describes the resolution quite well (where QGSP is somewhat better)

Some changes in the resolution between GEANT4 versions

GEANT3 predicts a too good energy resolution

Evaluation of GEANT4 version 8.1 / Charged pion energy scans

Fraction of energy in longitudinal layers for GEANT4 version 8.1

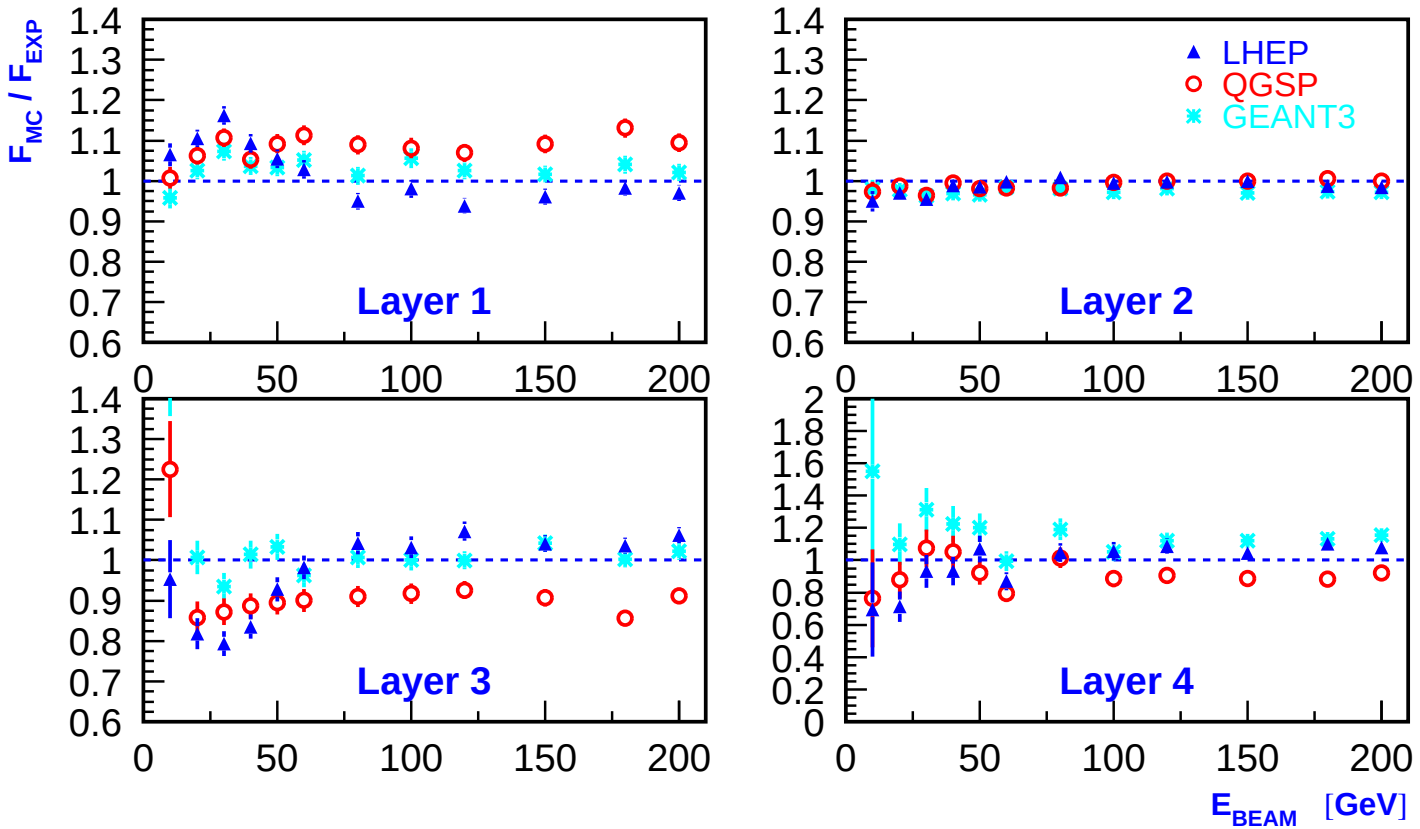


Four HEC longitudinal layers: 8/16/8/8 LAr gaps, 1.5/2.9/3.0/2.8 λ

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

Evaluation of GEANT4 version 8.1 / Charged pion energy scans

Fraction of energy in longitudinal layers for GEANT4 version 8.1

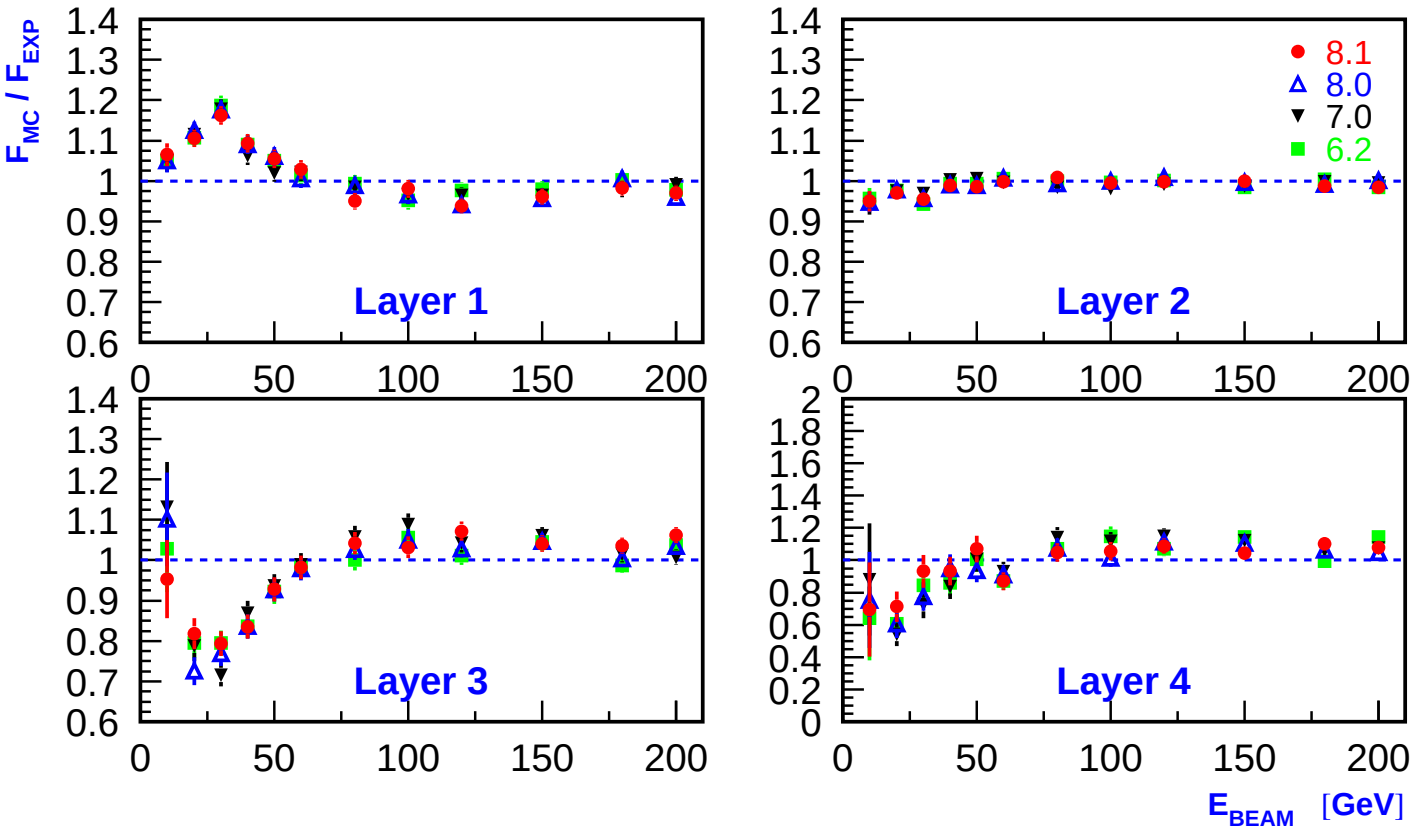


Fraction of energy in the second layer – well described by three simulation codes

- GEANT3 describes longitudinal profiles better than GEANT4
- QGSP hadronic showers start earlier and are more compact
- LHEP different trends at different beam energies

Evaluation of GEANT4 version 8.1 / Charged pion energy scans

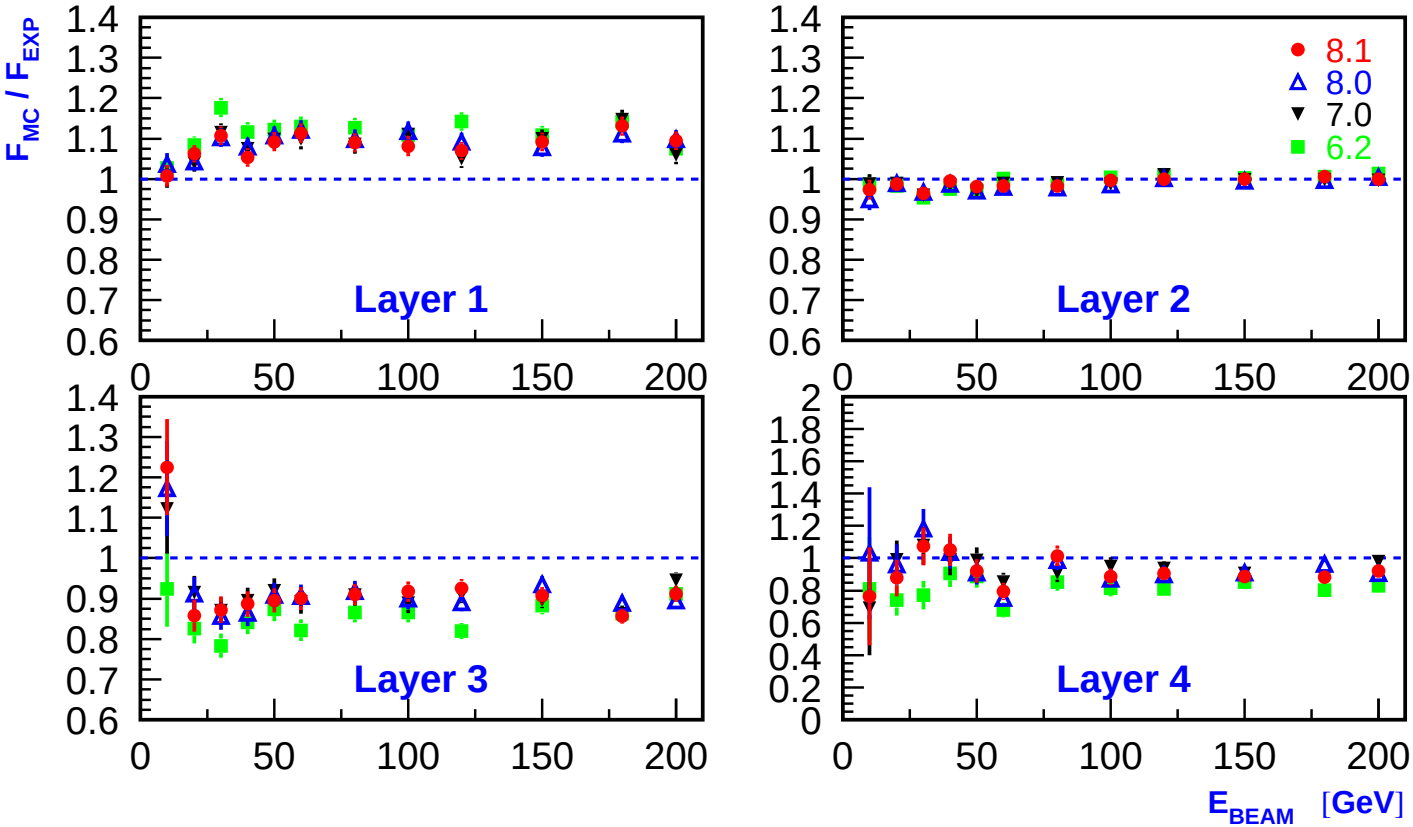
Fraction of energy in layers for different versions: LHEP



LHEP: No difference between GEANT4 versions

Evaluation of GEANT4 version 8.1 / Charged pion energy scans

Fraction of energy in layers for different versions: QGSP



QGSP: Certain improvement between GEANT4 versions **6.2** and **7.0**

Conclusions on Version 8.1p02

New round of GEANT4 based simulations with version 8.1p02 was carried out for the HEC stand-alone testbeam. Comparison with experimental results and results of previous simulations is done.

No significant changes w.r.t. the previous version 8.0 are observed. Main conclusions stay the same:

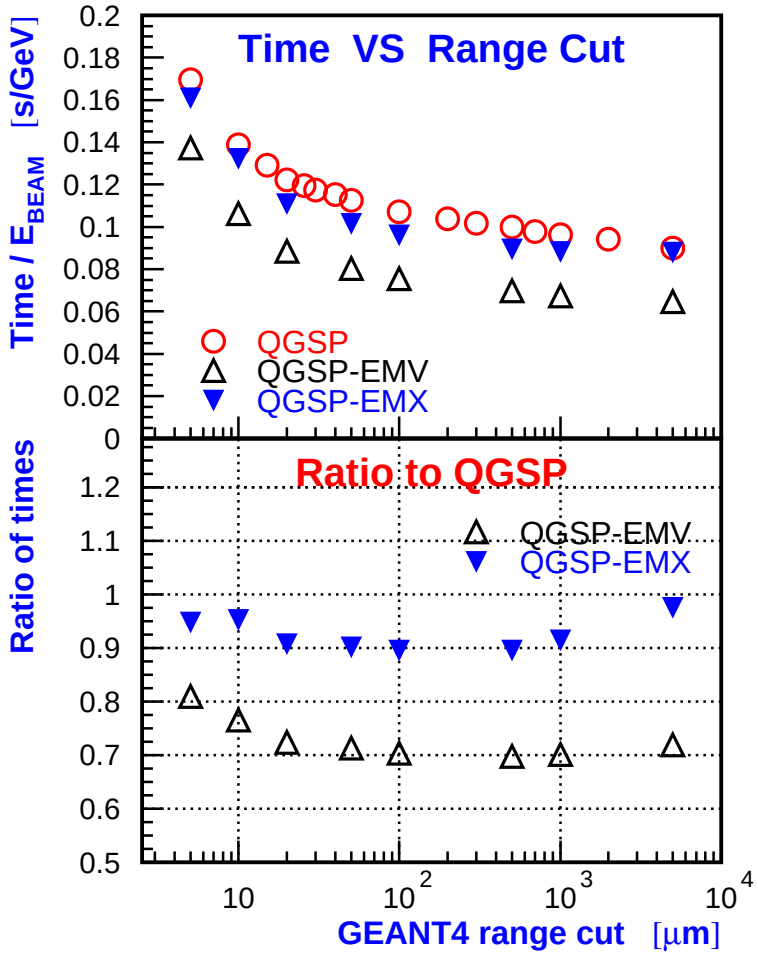
- GEANT4 is a mature product
- In particular, a good description of the pion energy resolution and the ratio e/π is obtained
- From two studied hadronic physics lists of GEANT4 (LHEP and QGSP) the second one shows better overall agreement with experimental data
- The main open question is shapes of hadronic showers

Studies of Physics Lists with Alternative EM Physics

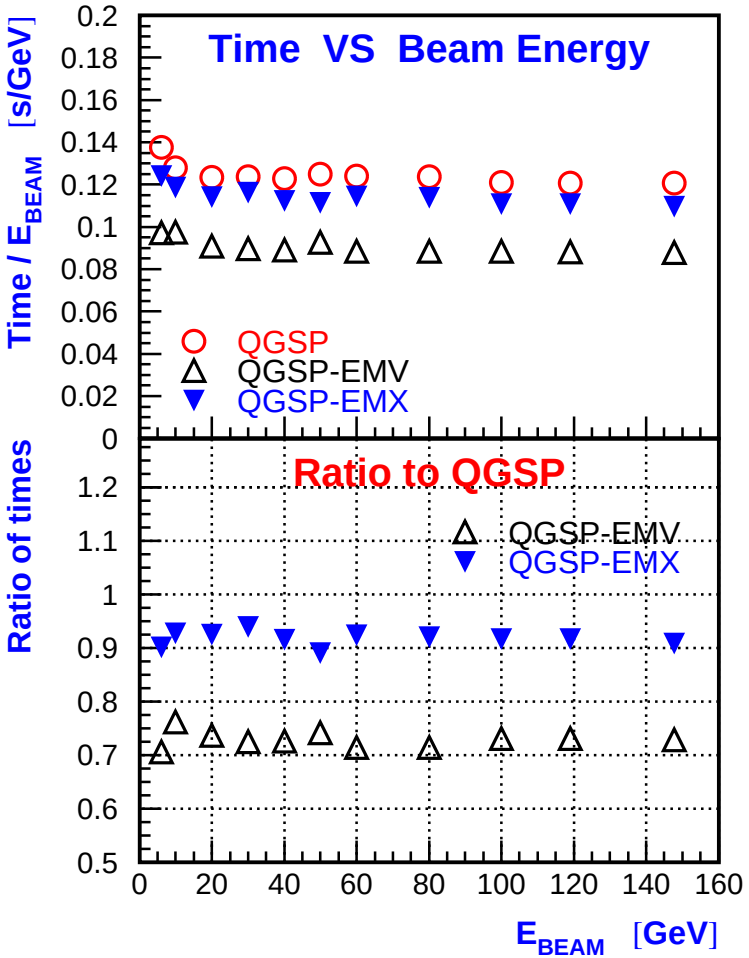
- "Experimental" physics lists, providing an alternative standard electromagnetic physics
- Reversion to physics and to speed as in GEANT4 version 7
- Two studied lists:
  - QGSP-EMV 3.1 (uses EM physics v71)
  - QGSP-EMX 3.1 (uses EM physics v72)
- Simulations:
  - version 8.1p02
  - scans with electrons: range cut, beam energy
  - standard reconstruction and analysing procedures

Studies of physics lists with alternative EM physics

Time of simulations



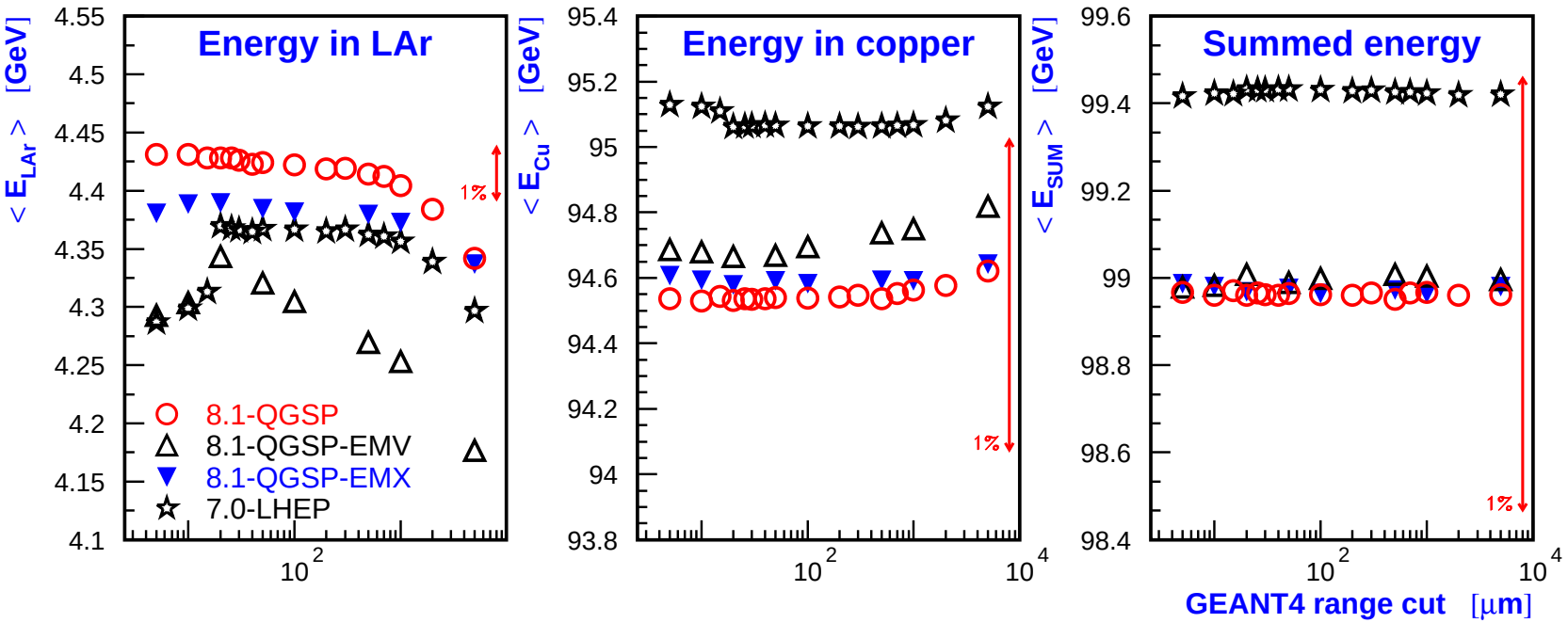
100 GeV electrons



Electrons, 20 μm cut

Studies of physics lists with alternative EM physics

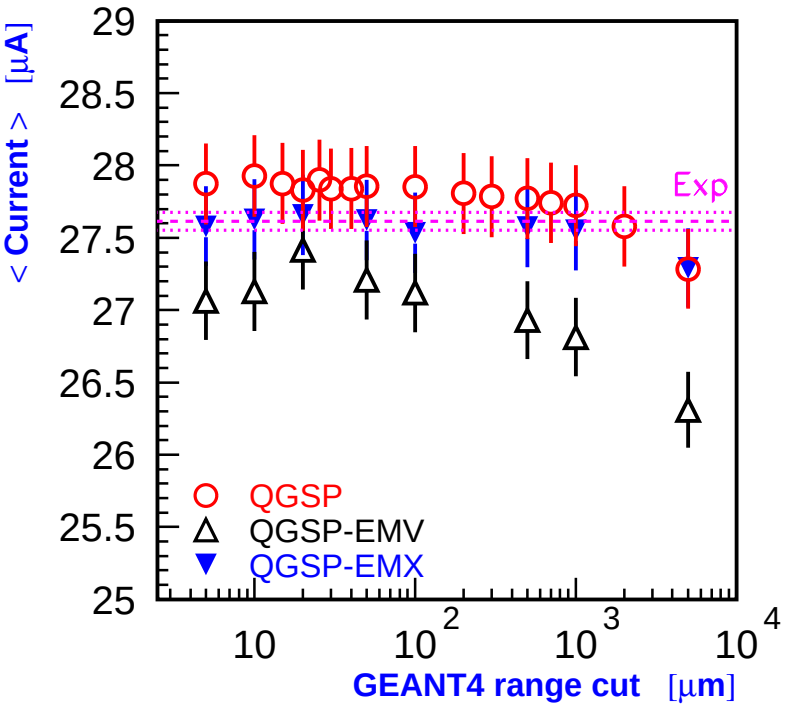
Energy depositions in HEC



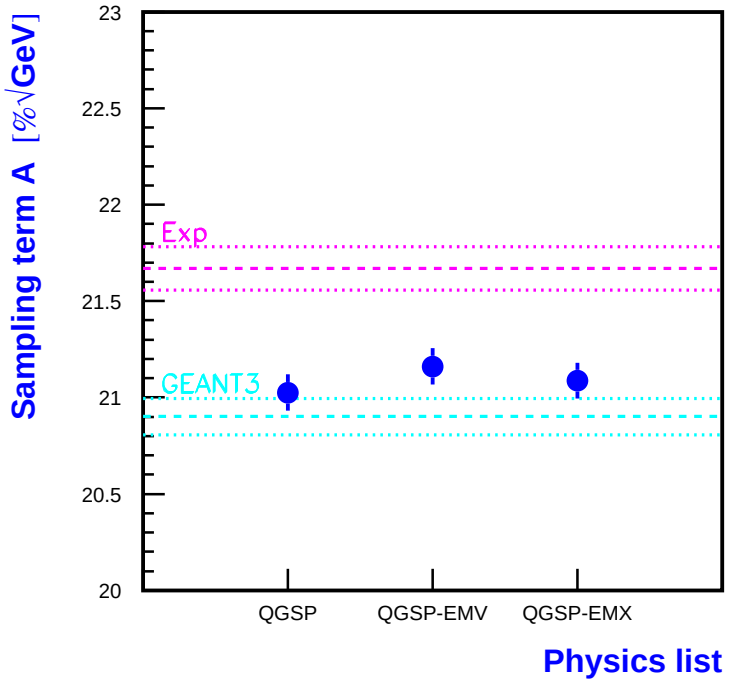
QGSP-EMV: again (as in earlier GEANT4 versions) there is strong dependence of the energy in LAr on the range cut

Studies of physics lists with alternative EM physics

Signal in one cell



Energy resolution



Conclusions on Physics Lists with Alternative EM Physics

Two lists, providing an alternative standard electromagnetic physics, have been studied with version 8.1p02.

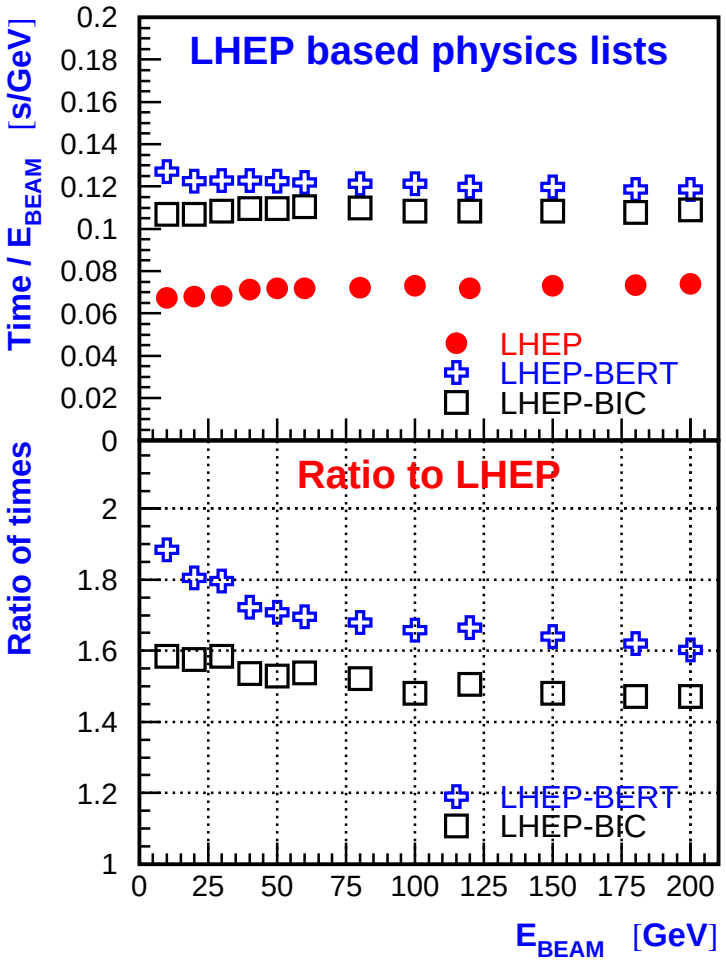
- QGSP-EMV is ∼30 % faster than the standard QGSP physics list, but it brings back old problems (strong dependence of signals in LAr on the range cut)
- QGSP-EMX is rather close to the standard QGSP physics list

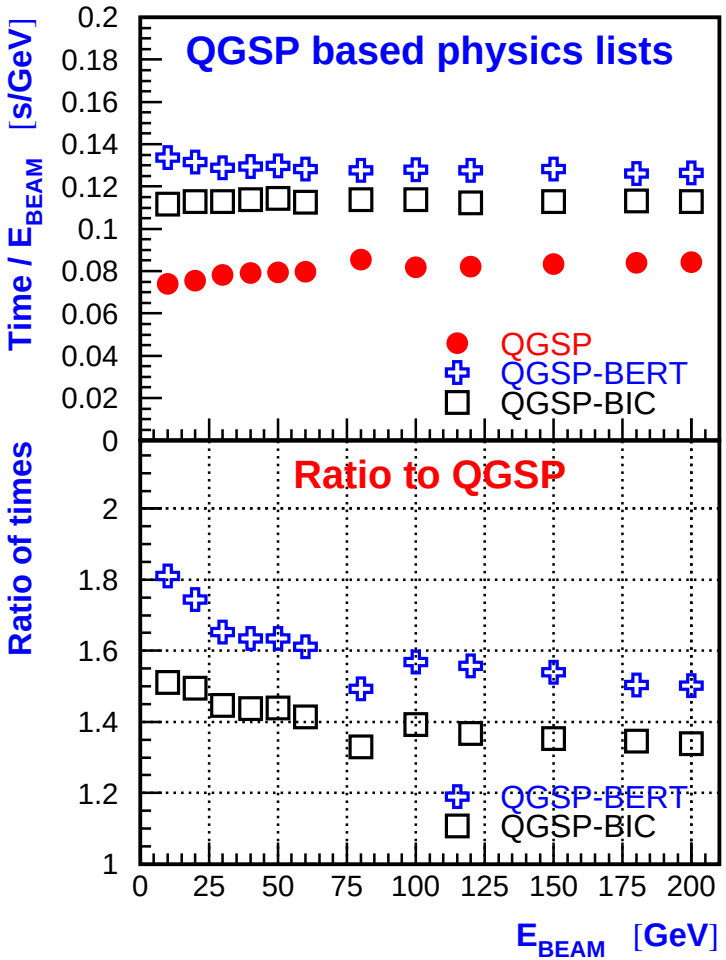
Evaluation of Physics Lists with Cascade Models

- Physics lists LHEP-BERT 3.1, QGSP-BERT 3.1:
  use a Bertini cascade code for modeling inelastic interactions of pions and nucleons below 3 GeV
- Physics lists LHEP-BIC 3.1, QGSP-BIC 3.1:
  use a binary cascade code for modeling inelastic interactions of pions and nucleons below 3 GeV
- Comparison with standard (STND) physics lists:
  LHEP 4.1 and QGSP 3.1
- Simulations:
  - version 8.1p02
  - 20 μm range cut
  - energy scan with charged pions
  - 5000 events per beam energy and physics list

Evaluation of physics lists with cascade models

Time of simulations

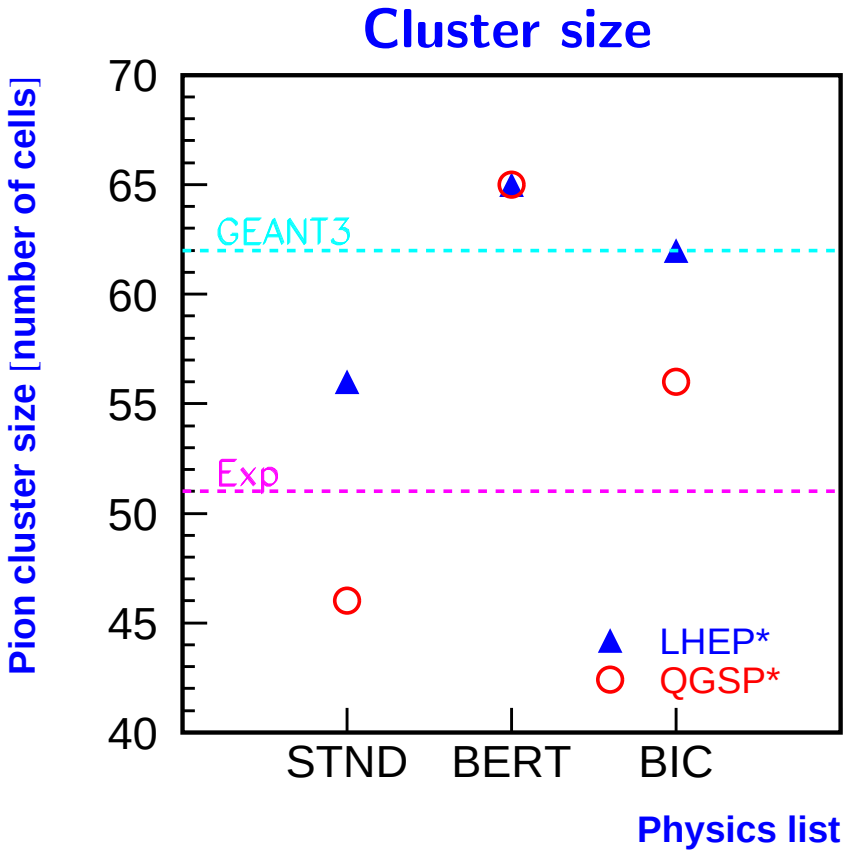




Evaluation of physics lists with cascade models

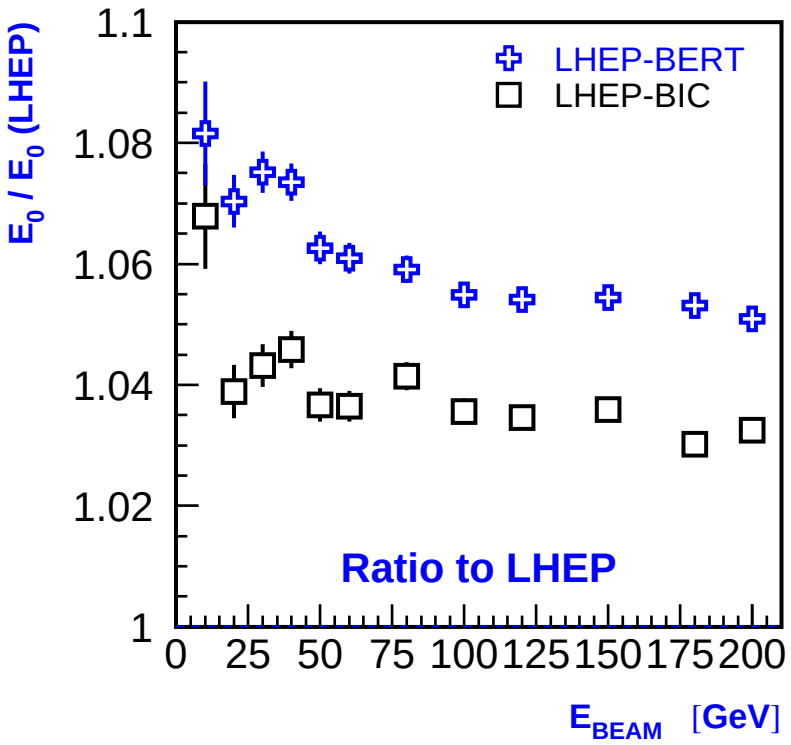
- Energy reconstruction:
  - following experimental procedure
  - cluster of the fix size
  - Gaussian fit: E_0 and σ

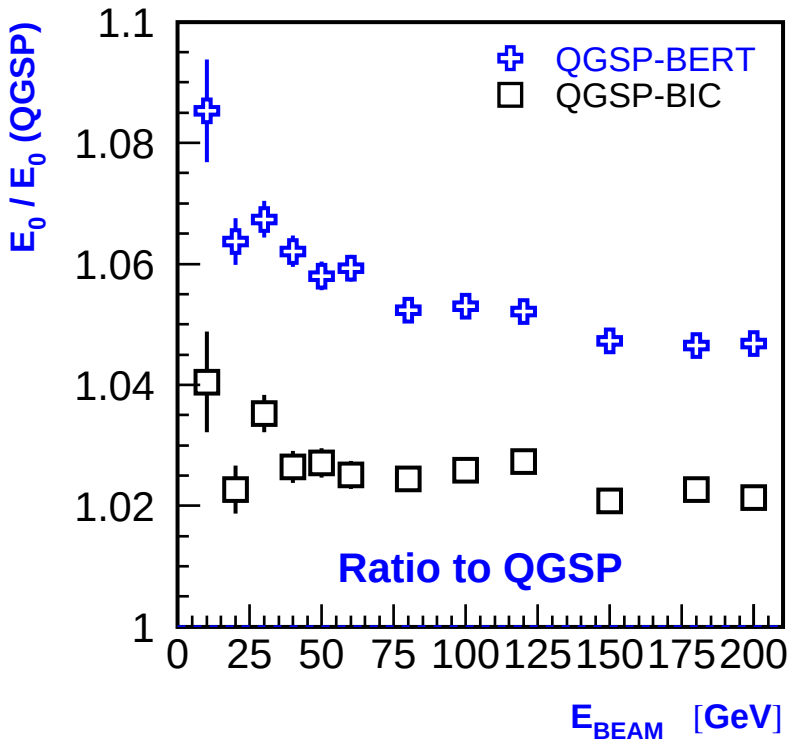
- Analysed variables:
  - cluster size
  - reconstructed energy E_0
  - ratio e/π
  - energy resolution σ/E_0
  - fraction of energies in HEC longitudinal layers



Lists with cascade models predict larger pion clusters than standard lists

Energy in a cluster: comparison with standard lists

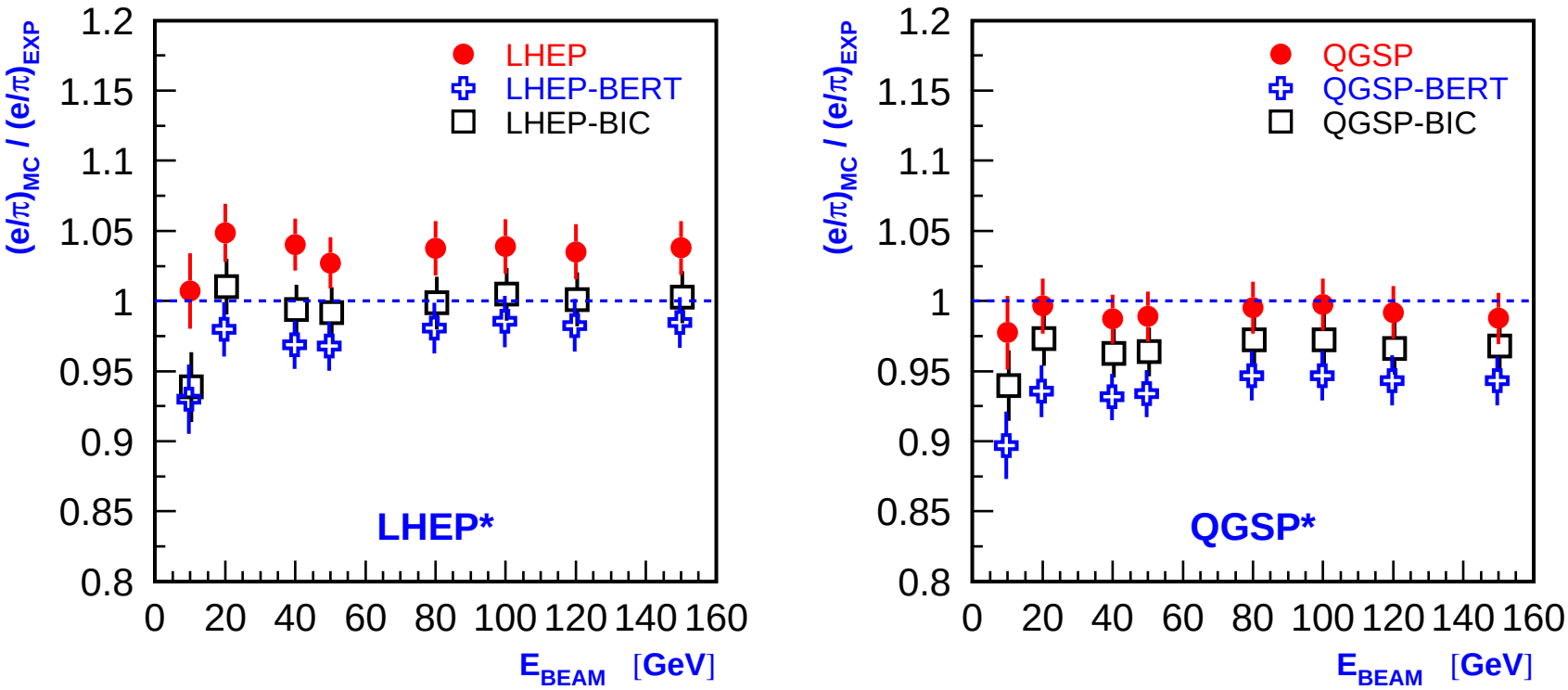




Lists with cascade models predict a few per cent more energy than standard lists

Evaluation of physics lists with cascade models

Ratio e/π: comparison with experiment



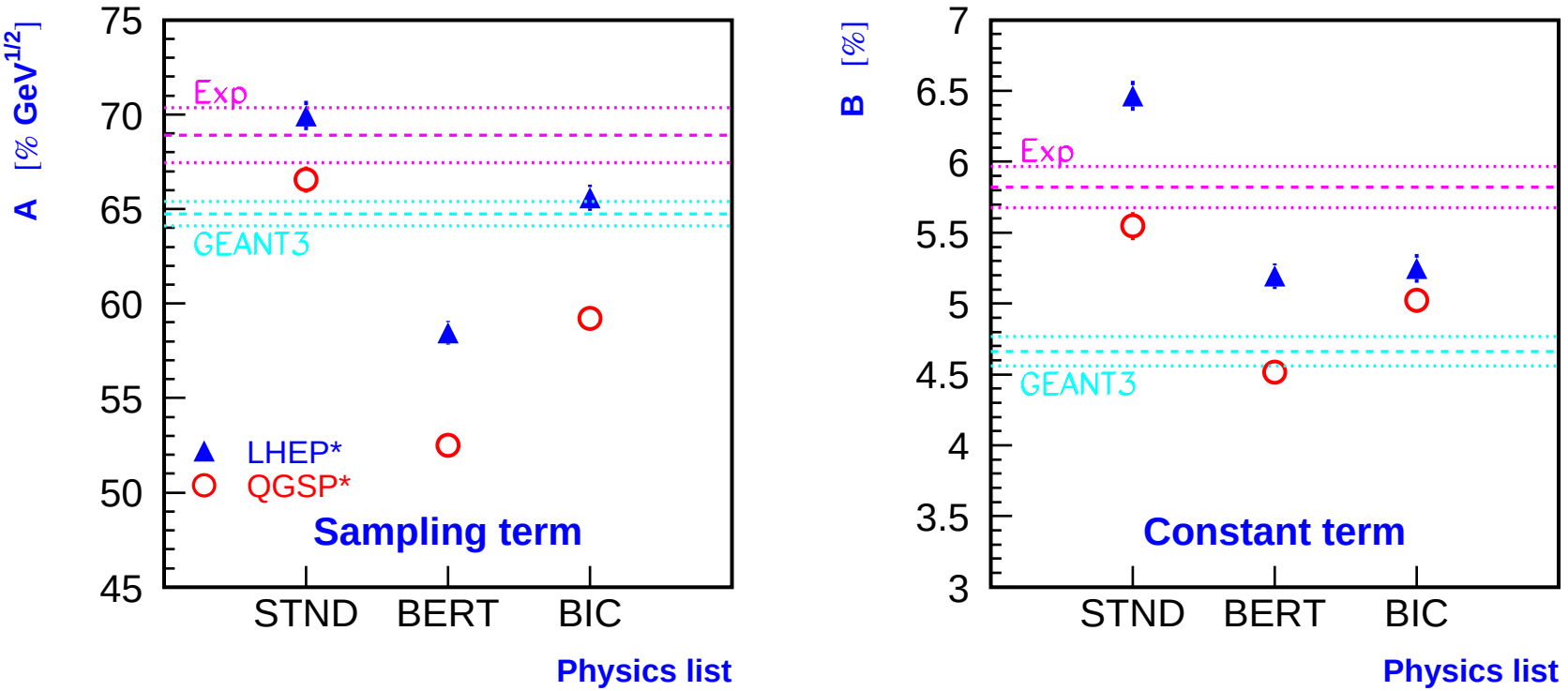
Lists with cascade models predict lower values of the e/π than standard lists

LHEP-BIC is in a good agreement with experiment

Evaluation of physics lists with cascade models

Energy resolution

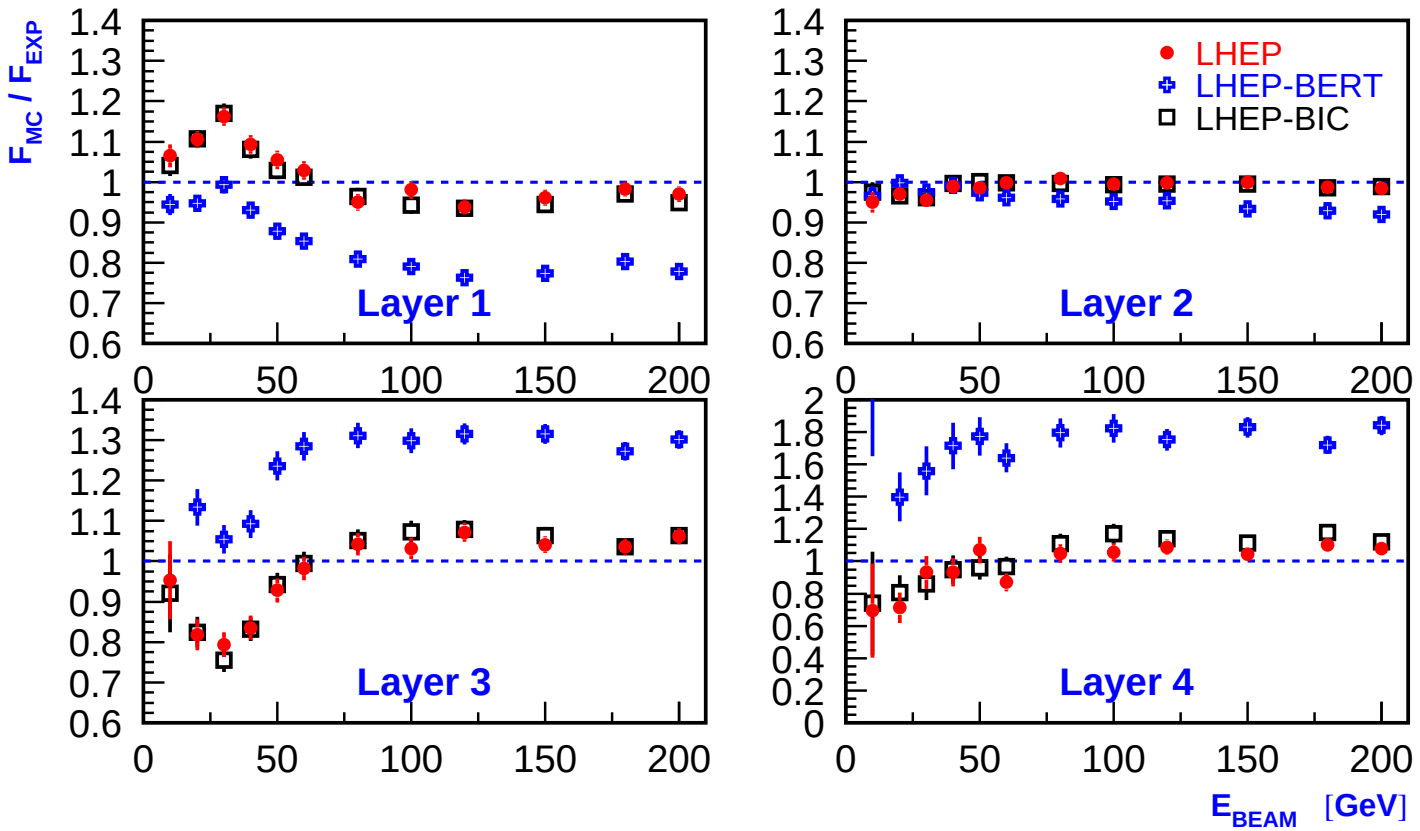
$$\sigma/E_0 = A/\sqrt{E_{BEAM}} \oplus B$$



Lists with cascade models predict too low values of the energy resolution

Evaluation of physics lists with cascade models

Fraction of energy in layers: LHEP based lists

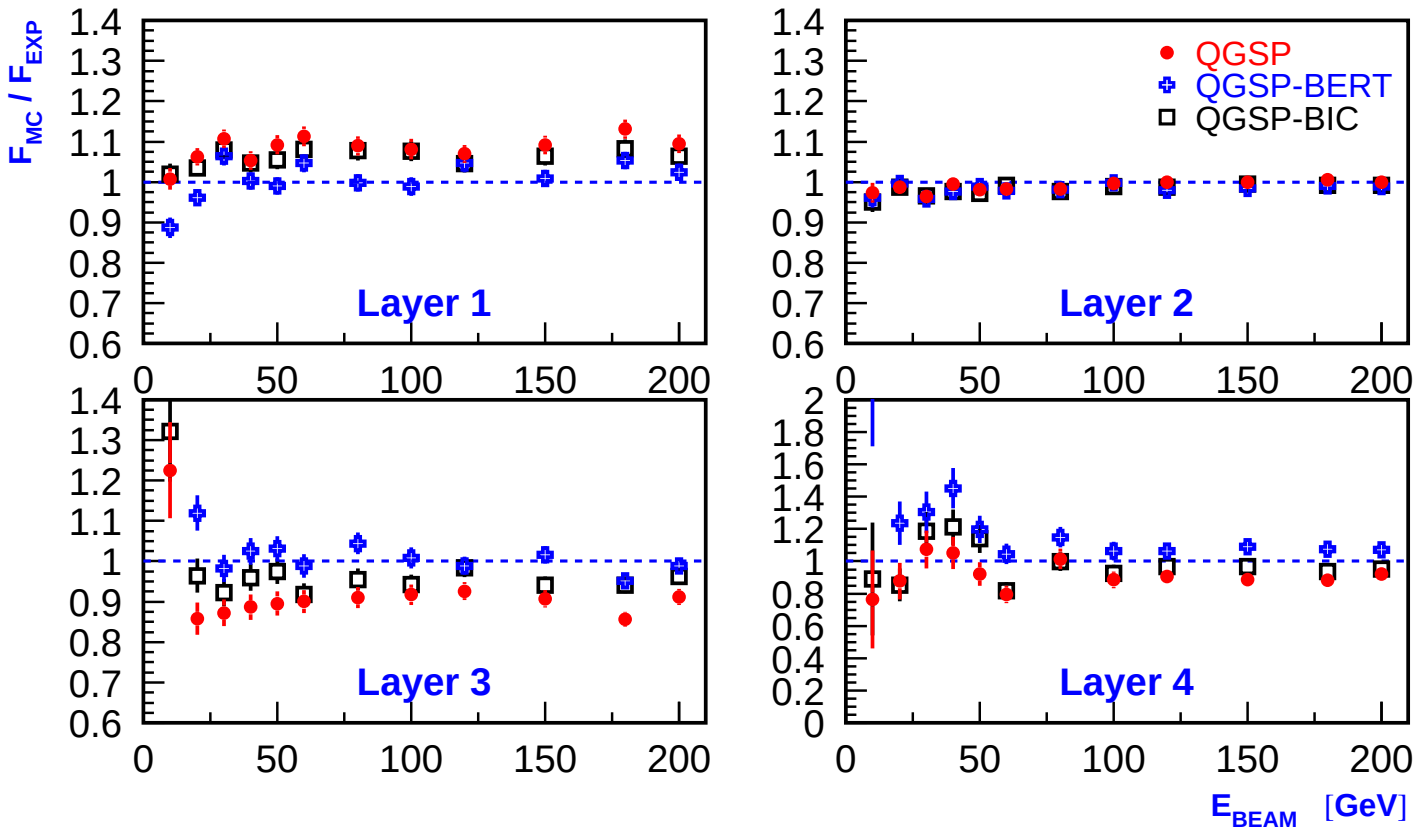


LHEP-BERT showers start too late

LHEP-BIC close to the standard LHEP

Evaluation of physics lists with cascade models

Fraction of energy in layers: QGSP based lists



QGSP-BERT good description of shower profiles (except low beam energies)

QGSP-BIC certain improvement w.r.t the standard QGSP

Conclusions on Physics Lists with Cascade Models

Physics lists LHEP-BERT, QGSP-BERT, LHEP-BIC, QGSP-BIC, exploiting Bertini and binary cascade codes for modeling inelastic interactions, have been evaluated.

- QGSP-based lists with cascade models improve description of shapes of hadronic showers
- Neither of those four physics lists can describe experimental results at the level achieved by the standard lists (QGSP and LHEP)
- Clear disagreement is in the description of the energy resolution for charged pions