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Validation of GEANT4 Version 9.2 with HEC Testbeam Data

LAr week: Software and Data Preparation session

CERN, 26-th of May, 2009

Introduction

- Beam tests of serial HEC modules in 2000-2001
- Stand-alone code for GEANT4 based simulations of the HEC testbeam
- New round of GEANT4 simulations: version 9.2
  - electron energy scans
  - charged pion energy scans

- Comparison of different physics list for GEANT4 version 9.2
  - **QGSP-BERT**
    - quark-gluon-string (QGS) model for interactions
    - pre-equilibrium decay model for the fragmentation
    - Bertini cascade code for modeling particle-nuclear interactions below $\sim$10 GeV
  - **FTFP**
    - similar to QGSP, but with FRITIOF string model instead of QGS one
  - **FTFP-BERT**
    - with Bertini cascade code for modeling particle-nuclear interactions below $\sim$10 GeV
  - **FTF-BIC**
    - with binary cascade model for nucleon induced reactions below 3 GeV

- Comparison of GEANT4 versions 9.2 and 9.0 for the QGSP-BERT physics list

Simulations

GEANT4

GEANT4 version	Release date	Packaging library	Physics list
9.0	June 2007	PACK 5.3	**QGSP-BERT** 3.3
9.2	December 2008	PACK 5.4	**QGSP-BERT** 3.3 **FTFP** 4.4 **FTFP-BERT** 1.0 **FTF-BIC** 1.1

- GEANT4 range cut = 30 μm

Detector effects

- Saturation of the response in liquid argon for particles with large dE/dx:

  usage of Birks' law

$$\Delta E' = \Delta E \frac{A}{1 + \frac{c}{\rho}\frac{\Delta E}{\Delta x}}$$

  $A = 1$

  $c = 0.0045$ g/(MeV cm^2)

  $\rho = 1.396$ g/cm^3

- Fast readout of calorimeter signals:

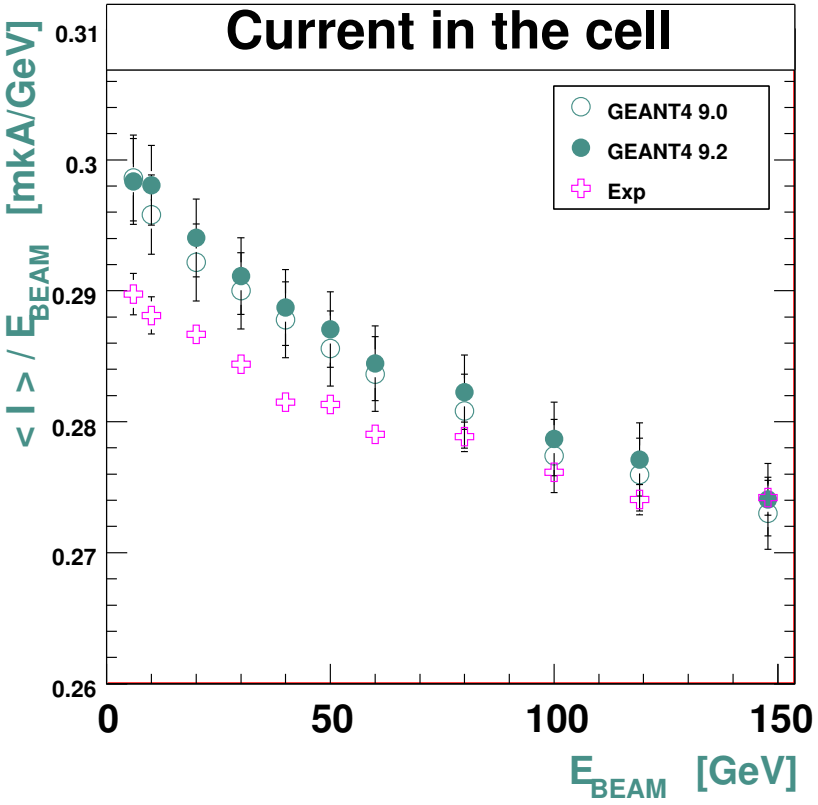
  detailed modelling of signal measurements (by convolution of time profiles with shaping functions)

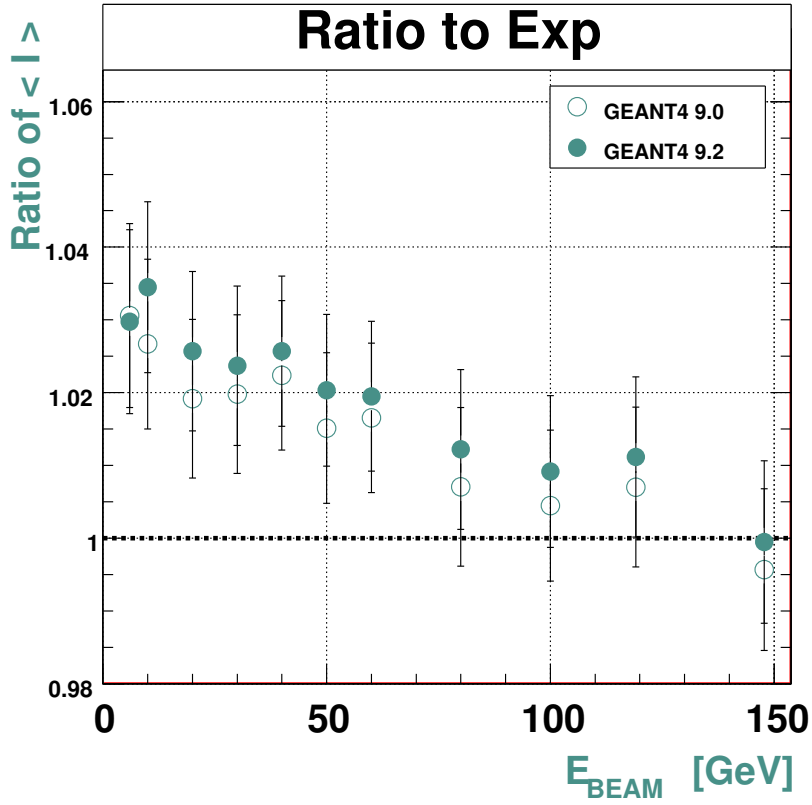
  Effectively this procedure means the integration of time profiles of shower development over a few tens of nanoseconds

Electrons: Energy Scans

- Beam energies: 6 - 147.8 GeV
- 5000 events per beam energy and physics list
- Energy reconstruction:
  - following experimental procedure
  - cluster of the fix size
  - Gaussian fit: E_0 and σ
- Analysed variables:
  - Energy resolution σ/E_0
  - Current in a channel with the maximal average signal (most loaded cell)
    - visible energy $\Rightarrow$ current
    - conversion factor (from detailed modelling of the HEC electronic chain): **7.135 μA/GeV** with an uncertainty of **$\pm$1 %**

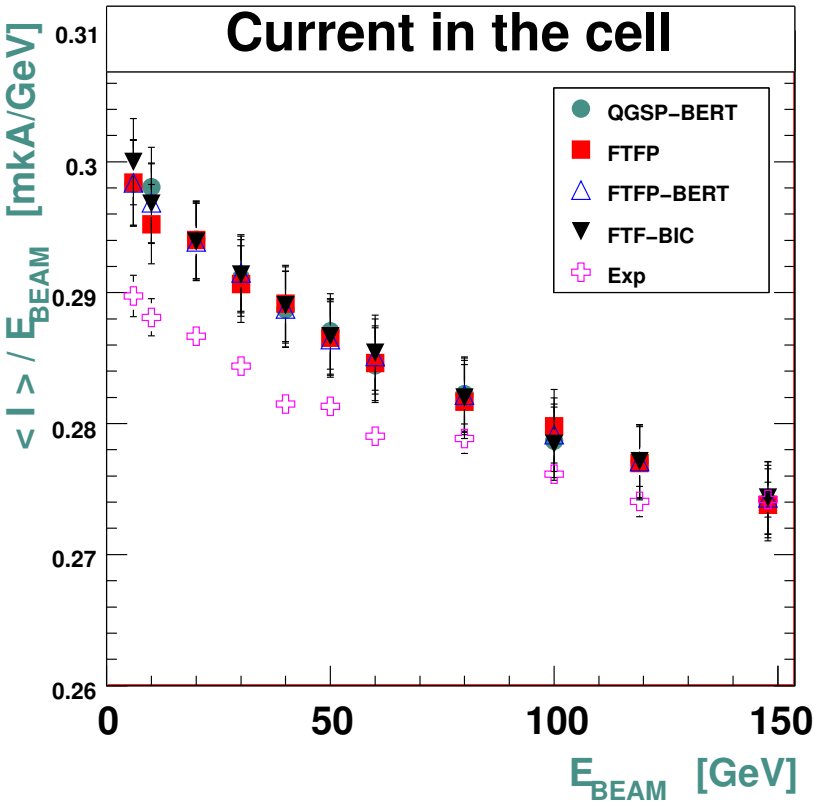
Signal in the most loaded cell: for QGSP-BERT

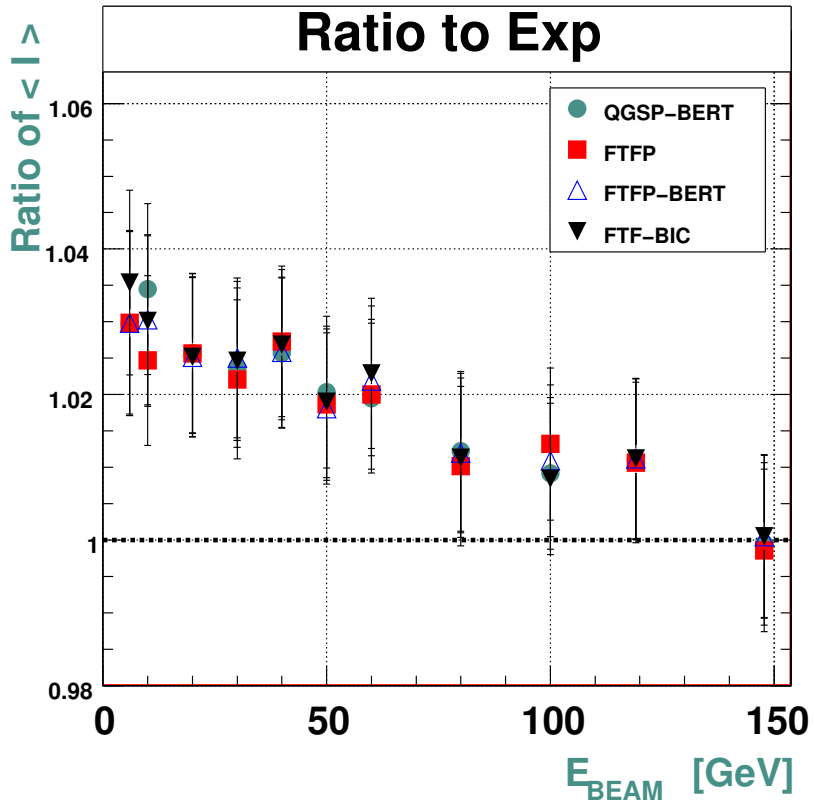




- Moderate agreement with experimental data
- 0.5 % increase of signal for GEANT4 version 9.2

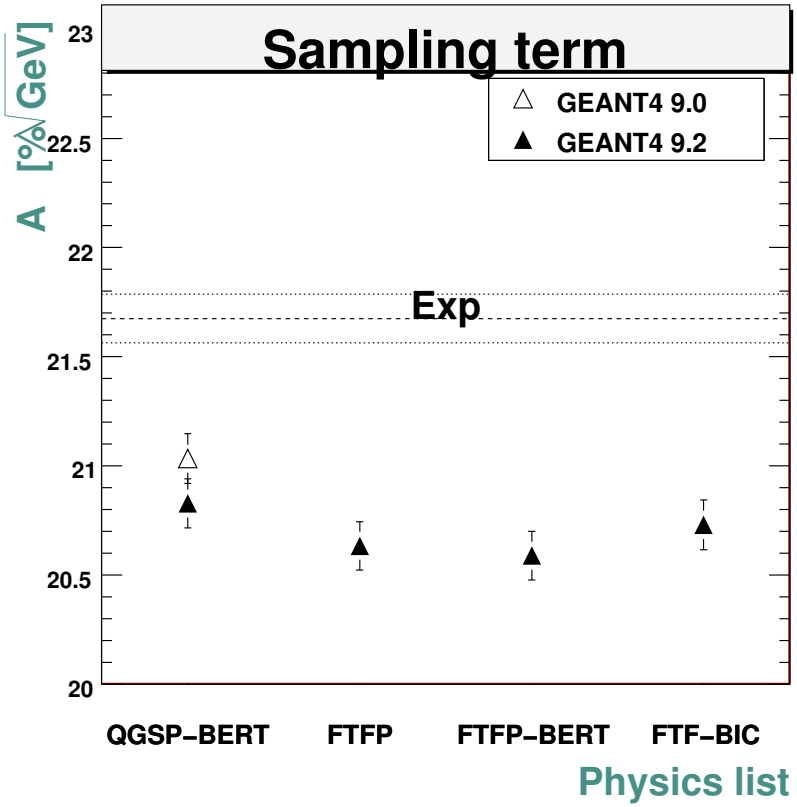
Signal in the most loaded cell: for GEANT4 version 9.2





No difference between studied physics lists

Electron energy resolution



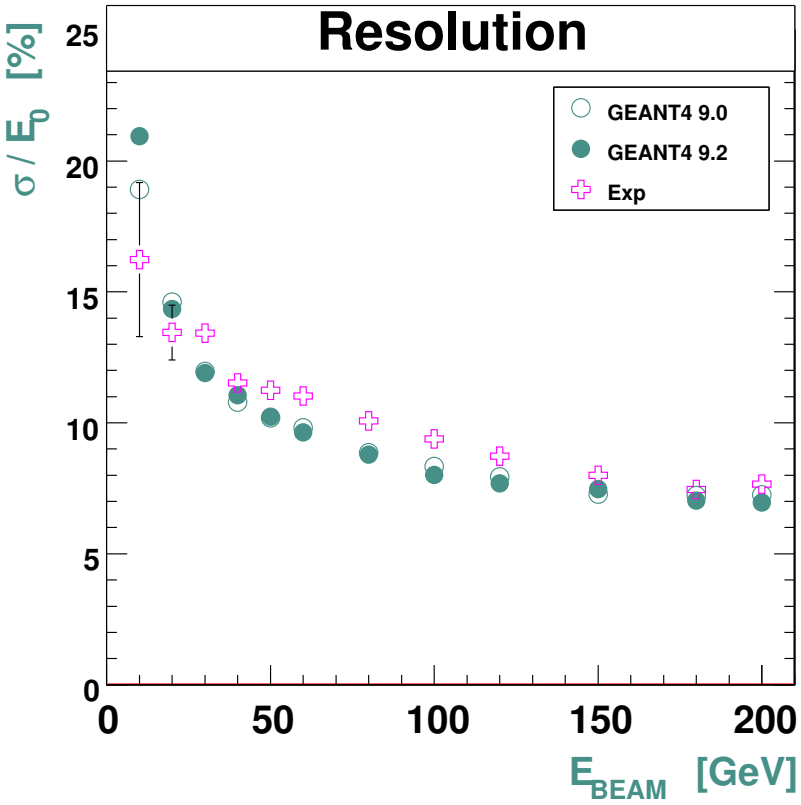
- One-term parametrization: $\sigma/E_0 = A/\sqrt{E_{BEAM}}$
- MC predictions are still too optimistic
- There is small difference between physics lists

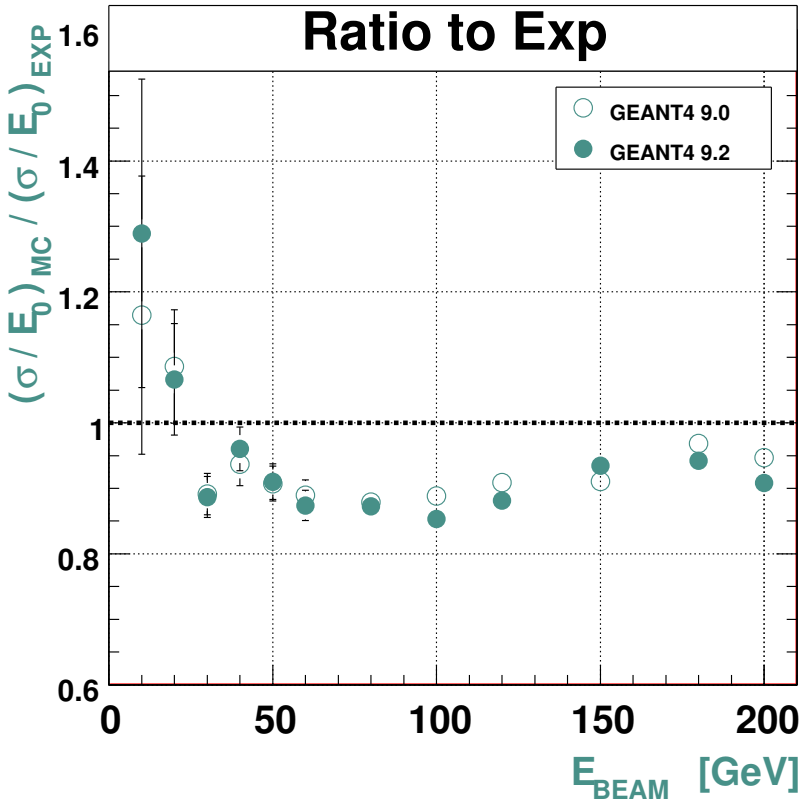
Charged Pions: Energy Scans

- Beam energies: 10 - 200 GeV
- 5000 events per beam energy and physics list
- Energy reconstruction:
  - similar as for electrons
- Analysed variables:
  - Energy resolution σ/E_0
  - Ratio e/π
    ratio of energies in electron and pion clusters
  - Shape of hadronic showers

Charged pion energy scans

Pion energy resolution: for QGSP-BERT

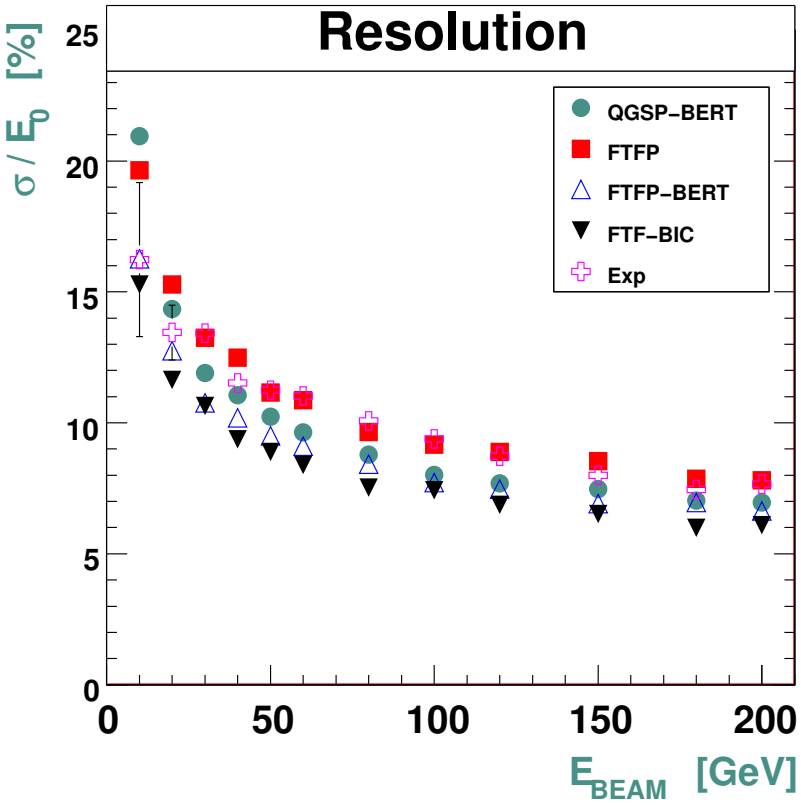


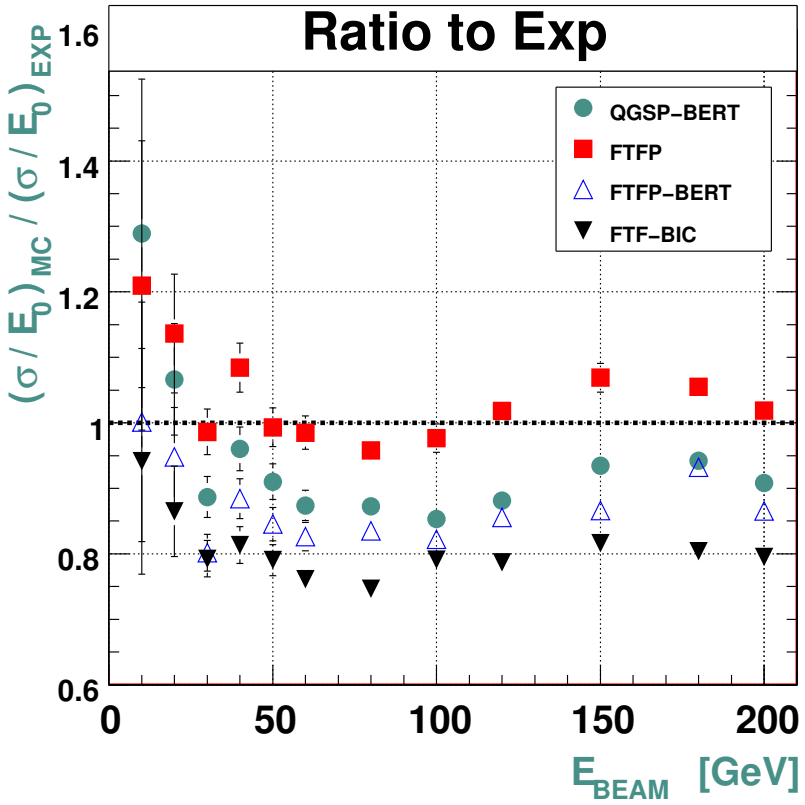


No significant difference between GEANT4 versions

Charged pion energy scans

Pion energy resolution: for GEANT4 version 9.2





- **FTFP** is the closest to experimental values of the energy resolution
- **FTF-BIC** demonstrates the worst behaviour

Pion energy resolution: Two-term parametrization

- $\sigma/E_0 = A/\sqrt{E_{BEAM}} \oplus B$
- Experimental values:
  $A = 69 \pm 1\ \%\sqrt{GeV}$, $B = 5.8 \pm 0.1\ \%$

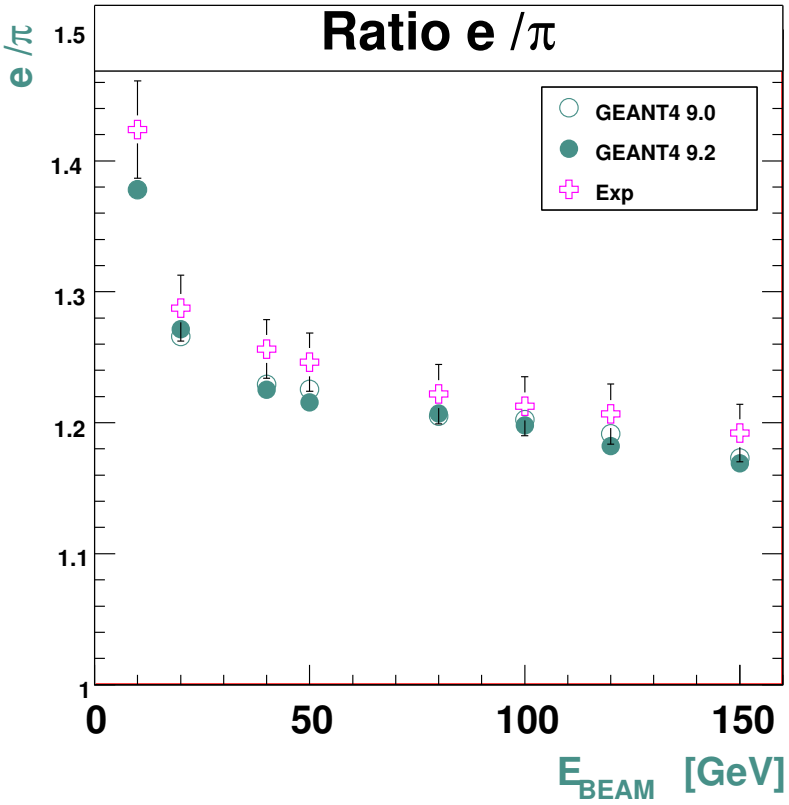
- MC predictions:

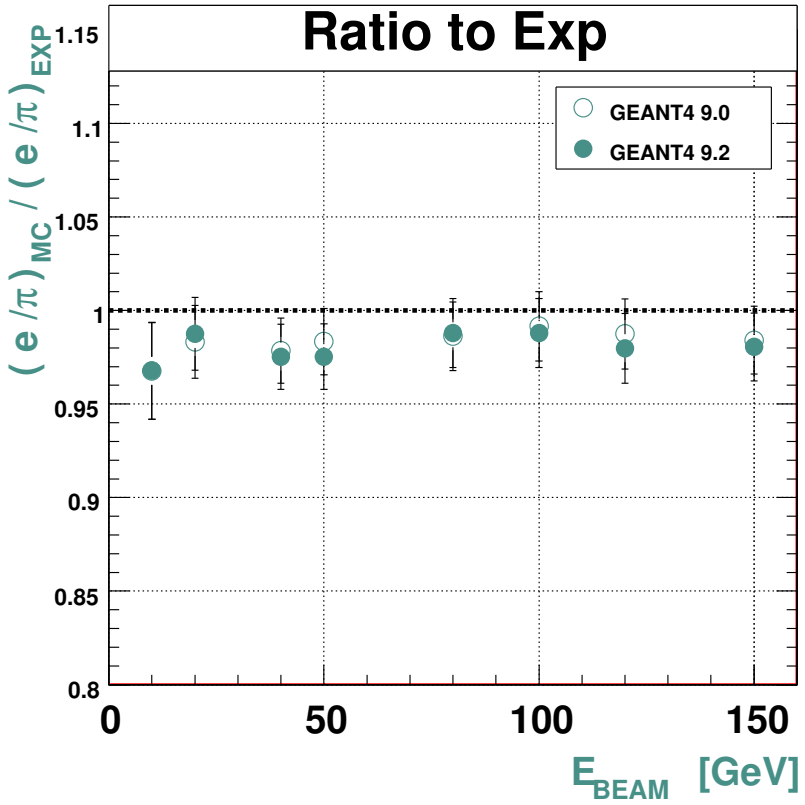
GEANT4 version	Physics list	Terms of energy resolution	
		$A[\%\sqrt{GeV}]$	B [%]
9.0	**QGSP-BERT**	58.6 $\pm$ 0.7	5.83 $\pm$ 0.09
9.2	**QGSP-BERT**	60.2 $\pm$ 0.7	5.48 $\pm$ 0.09
	FTFP	63.3 $\pm$ 0.8	6.61 $\pm$ 0.10
	FTFP-BERT	51.5 $\pm$ 0.7	5.76 $\pm$ 0.08
	FTF-BIC	49.5 $\pm$ 0.6	5.09 $\pm$ 0.08

- Sampling term of the energy resolution is better described by **FTFP**
- Physics lists with the Bertini cascade model (**QGSP-BERT** and **FTFP-BERT**) give better predictions of the constant term

Charged pion energy scans

Ratio e/π: for QGSP-BERT

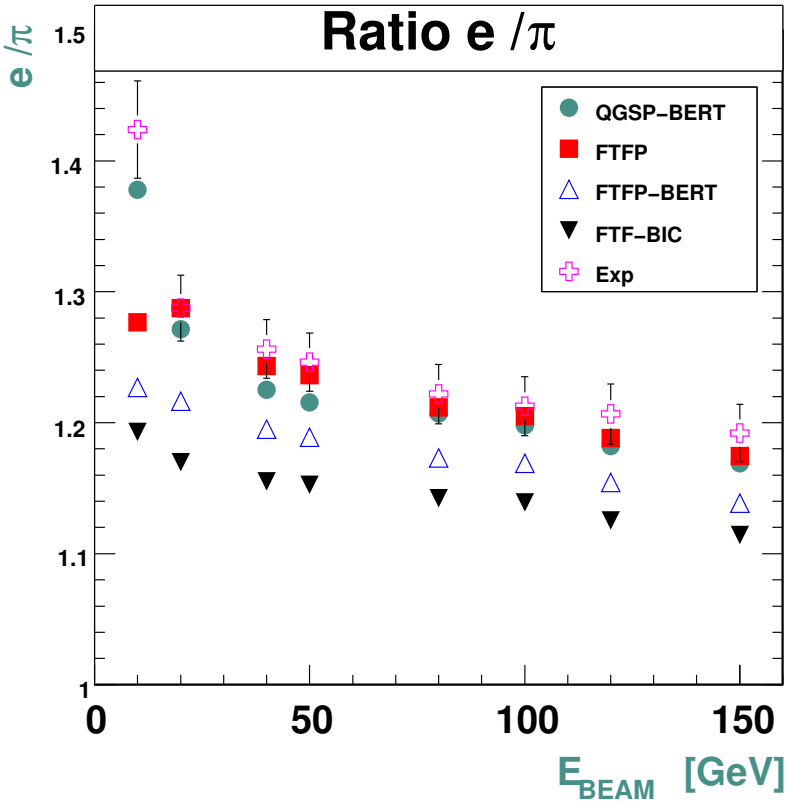


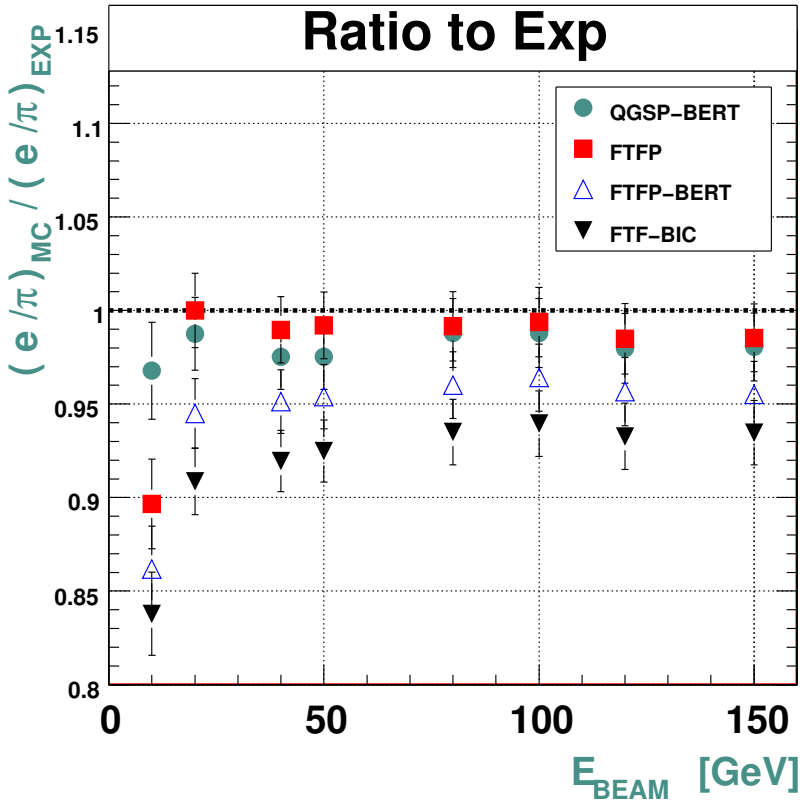


No significant difference between GEANT4 versions

Charged pion energy scans

Ratio e/π: for GEANT4 version 9.2





- **FTFP** gives the best description of the ratio e/π (except the lowest beam energy)
- **FTFP-BERT** and **FTF-BIC** predict rather small values of e/π-ratio

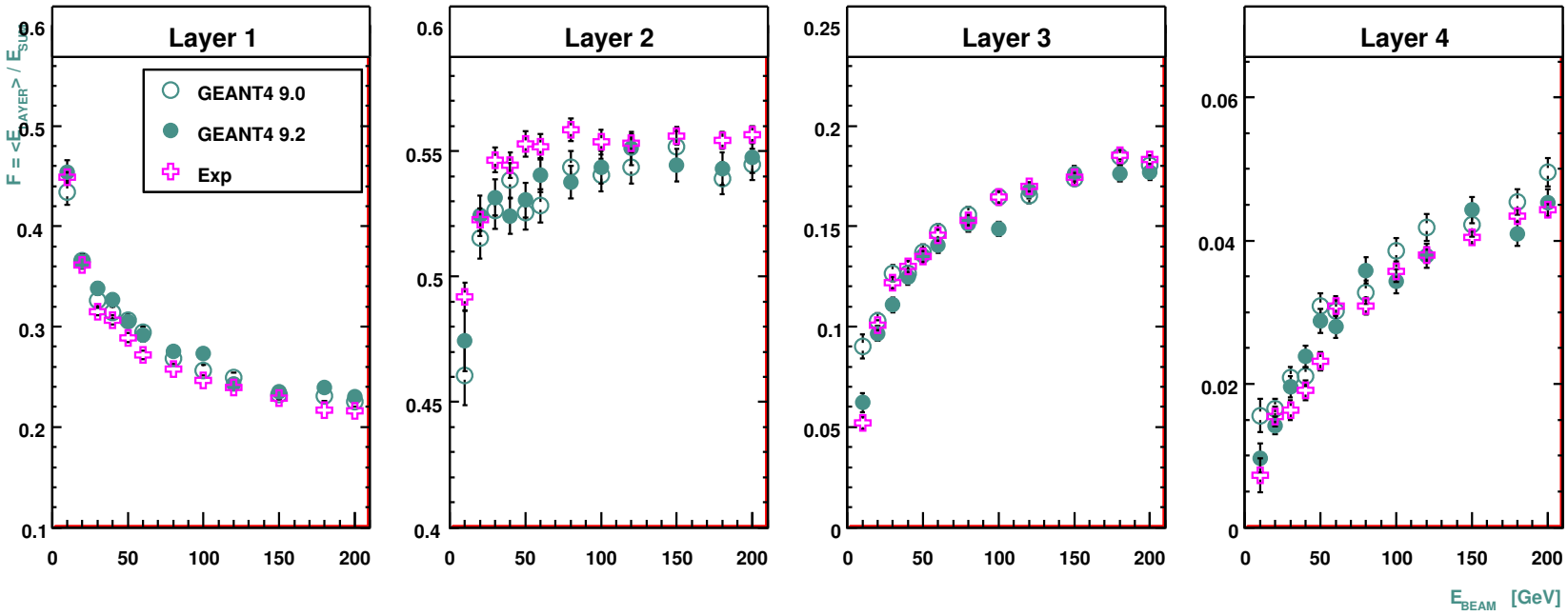
Shape of hadronic showers

- Fraction of energy in HEC longitudinal layers:
  - four layers, consisting of 8/16/8/8 LAr gaps (thickness 1.5/2.9/3.0/2.8 λ)
  - fraction of energy
    $F =< E_{LAYER} > / E_{SUM}$, where $E_{SUM} = \Sigma < E_{LAYER} >$

- Energy leakage from HEC modules:
  - virtual "leakage" detectors surrounded calorimeter modules
  - leakage energy = sum of kinetic energies of all particles stopped in "leakage" detectors

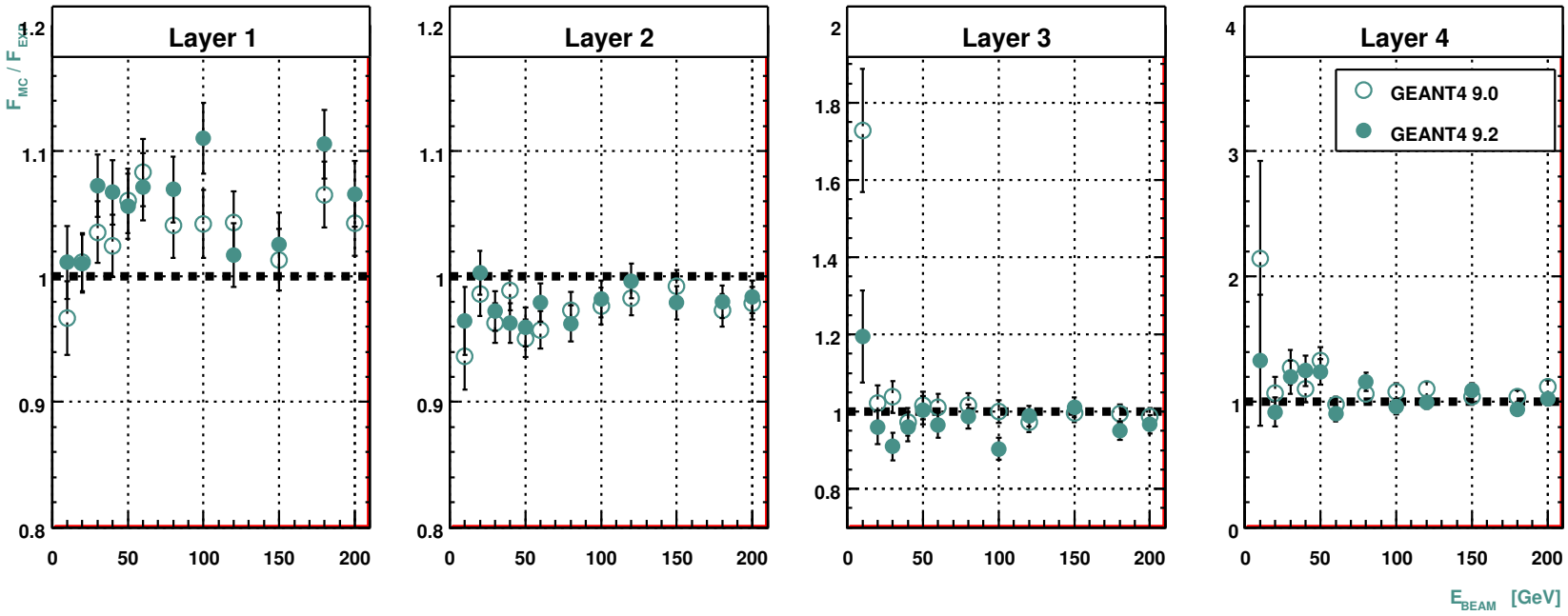
Charged pion energy scans

Fraction of energy in HEC longitudinal layers for QGSP-BERT



Charged pion energy scans

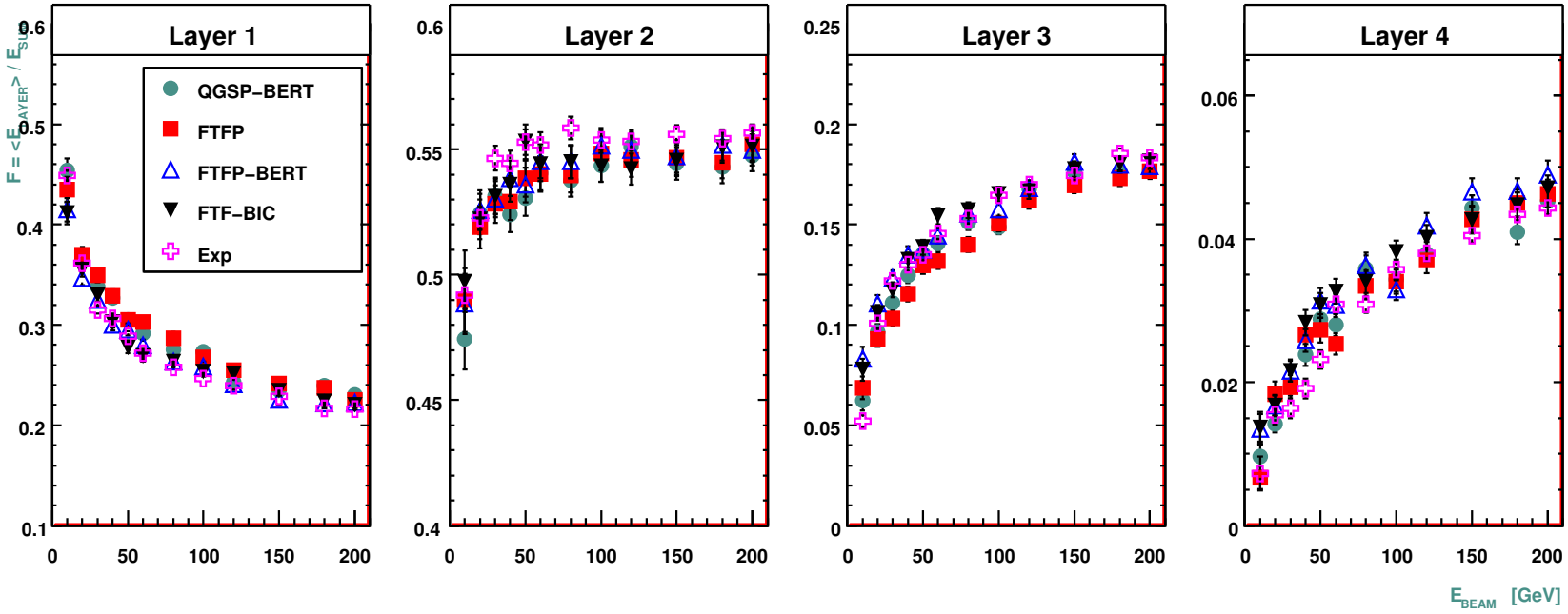
Fraction of energy in HEC longitudinal layers: Ratio to experiment for QGSP-BERT



- No significant difference between GEANT4 versions
- Certain improvement at 10 GeV in the last two layers

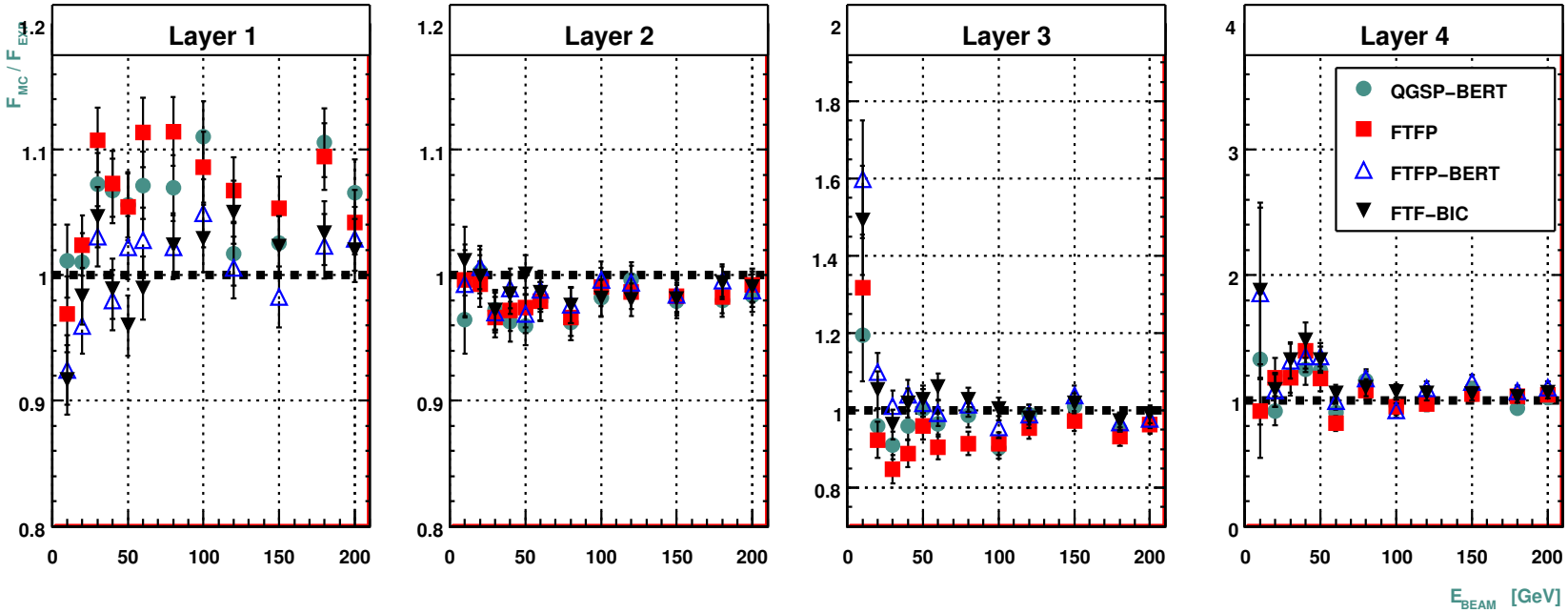
Charged pion energy scans

Fraction of energy in HEC longitudinal layers for GEANT4 version 9.2



Charged pion energy scans

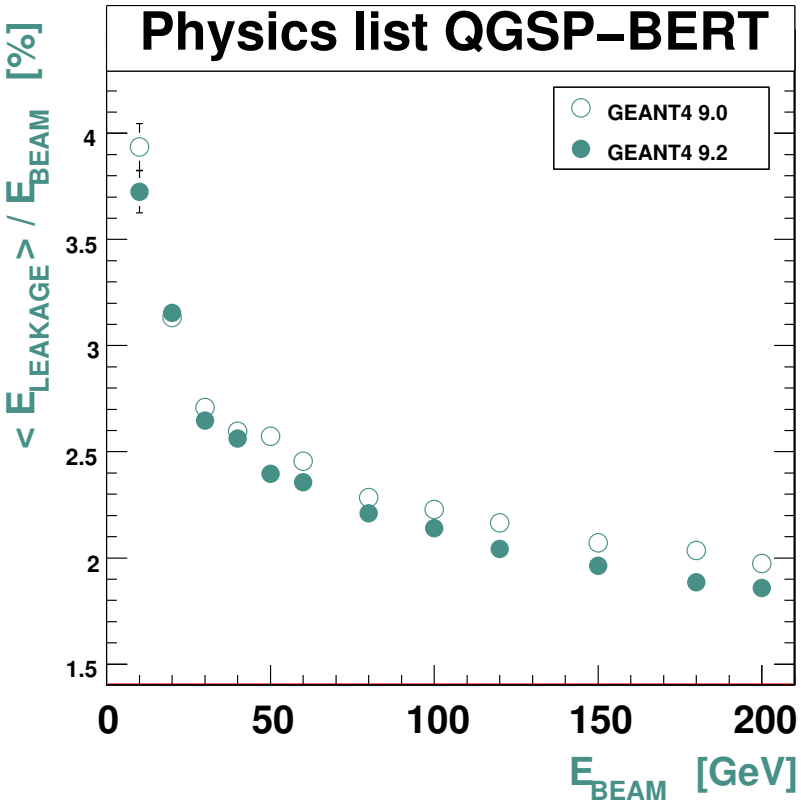
Fraction of energy in HEC longitudinal layers: Ratio to experiment for GEANT4 version 9.2

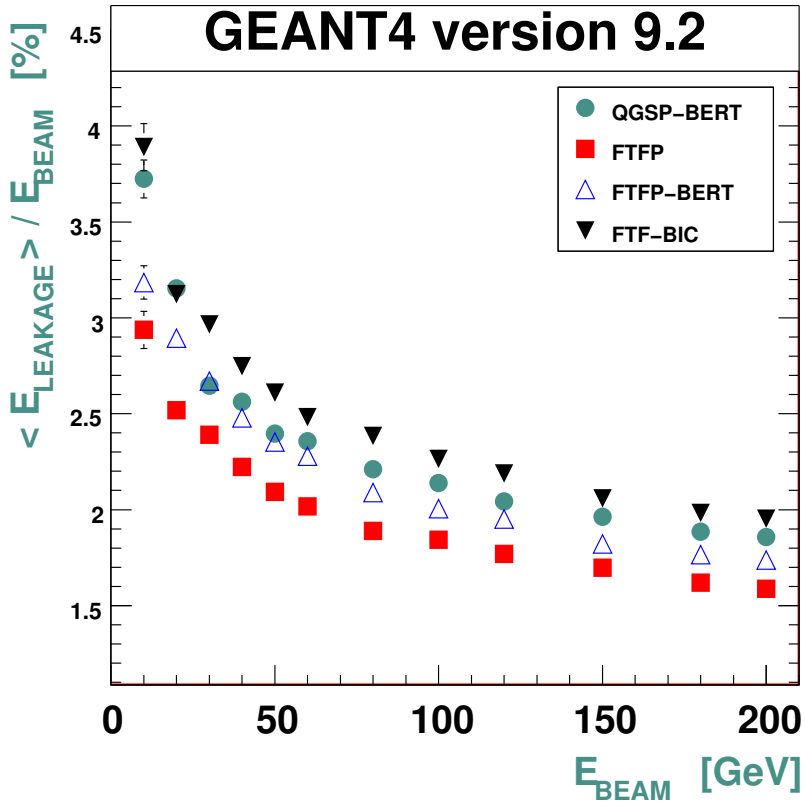


- Fraction of energy in the second (main) layer is described within a few percent by all physics lists
- **FTFP-BERT** and **FTF-BIC**: good description of shower profiles (except the lowest beam energy)
- **FTFP**: hadronic showers start earlier and are more compact (see layers 1 and 3)

Charged pion energy scans

Lateral energy leakage





- **QGSP-BERT**: smaller lateral leakage in GEANT4 version 9.2 than 9.0
- **FTFP**: the smallest lateral leakage
- **FTF-BIC**: the largest lateral leakage

Conclusions

New round of GEANT4 based simulations with version 9.2 was carried out for the HEC stand-alone testbeam.

Results obtained for the QGSP-BERT physics list were compared with corresponding results got with version 9.0 of GEANT4. No significant difference is observed between these versions.

Four different physics lists, namely: QGSP-BERT, FTFP, FTFP-BERT and FTF-BIC — were used for GEANT4 simulations with version 9.2. None of these physics lists can describe the whole set of studied HEC performance parameters:

- Ratio e/π is well predicted by FTFP and QGSP-BERT, while FTFP-BERT and FTF-BIC predict too high response to charged pions
- Sampling term of the energy resolution is better described by the FTFP physics list and the constant term — by the BERT-based physics lists
- FTFP-BERT and FTF-BIC give good description of longitudinal shower profiles, whereas FTFP predicts more compact hadronic showers