GEANT4 Physics Evaluation with HEC Testbeam Data

A. Kiryunin and P. Strizenec

- Beam tests of serial HEC modules in 2000-2001
- GEANT4 version 9.2 (released in December 2008)
- Different physics lists:
  - **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 ∼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 ∼10 GeV
  - **FTF-BIC**
    - with binary cascade model for nucleon induced reactions below 3 GeV

Simulation, Reconstruction, Analysis

- Stand-alone package for simulations of the HEC testbeam
- Simulated samples:
  - energy scans with charged pions (10-200 GeV)
  - energy scans with electrons (6-147.8 GeV)
- GEANT4 range cut = 30 μm
- 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

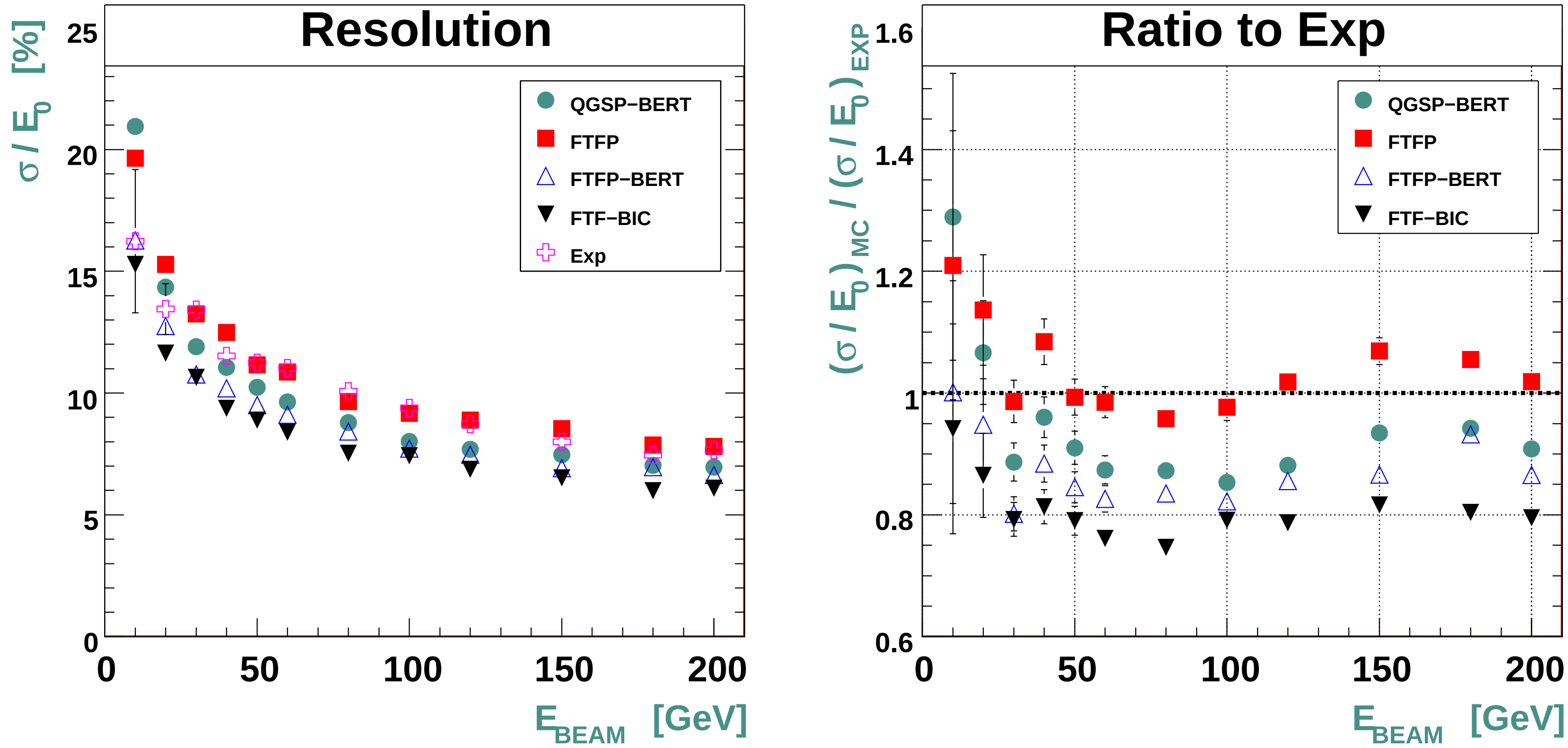
- Fast readout of calorimeter signals:

  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

- Energy reconstruction:
  - following experimental procedure
  - EM-scale calibration
  - cluster of the fix size
  - Gaussian fit: E_0 and σ
- Analysed parameters:
  - energy resolution (σ/E_0)
  - calorimeter response to charged pions, defined as a ratio of energies in pion and electron clusters (π/e)
  - shape of hadronic showers

Pion energy resolution



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

Pion energy resolution:
Two-term parametrization

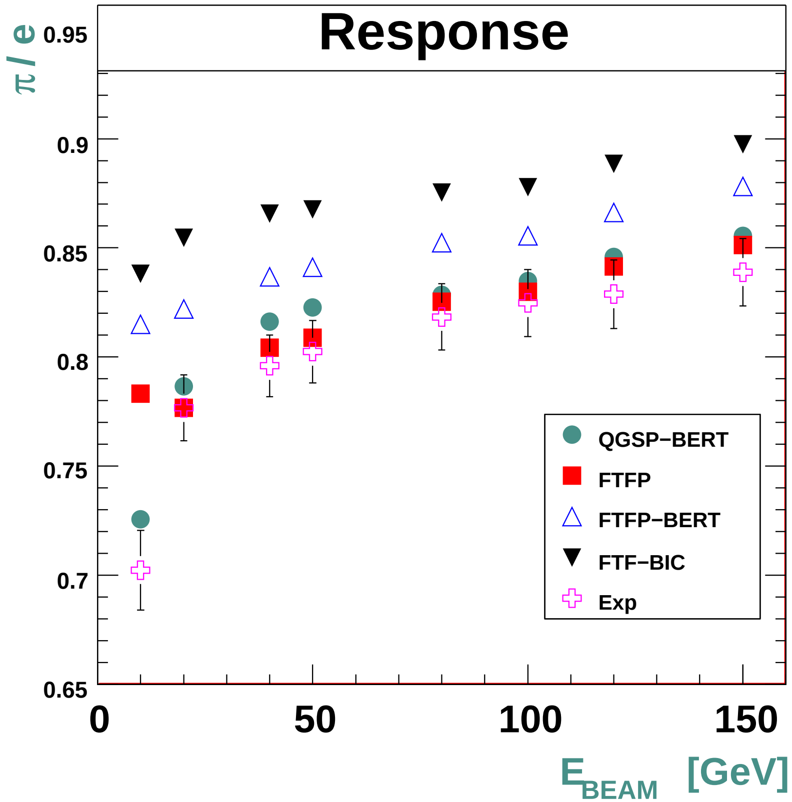
- $\sigma/E_0 = A/\sqrt{E_{BEAM}} \oplus B$
- Experimental values:
  $A = 69 \pm 1\ \%\sqrt{GeV}$, $B = 5.8 \pm 0.1\ \%$

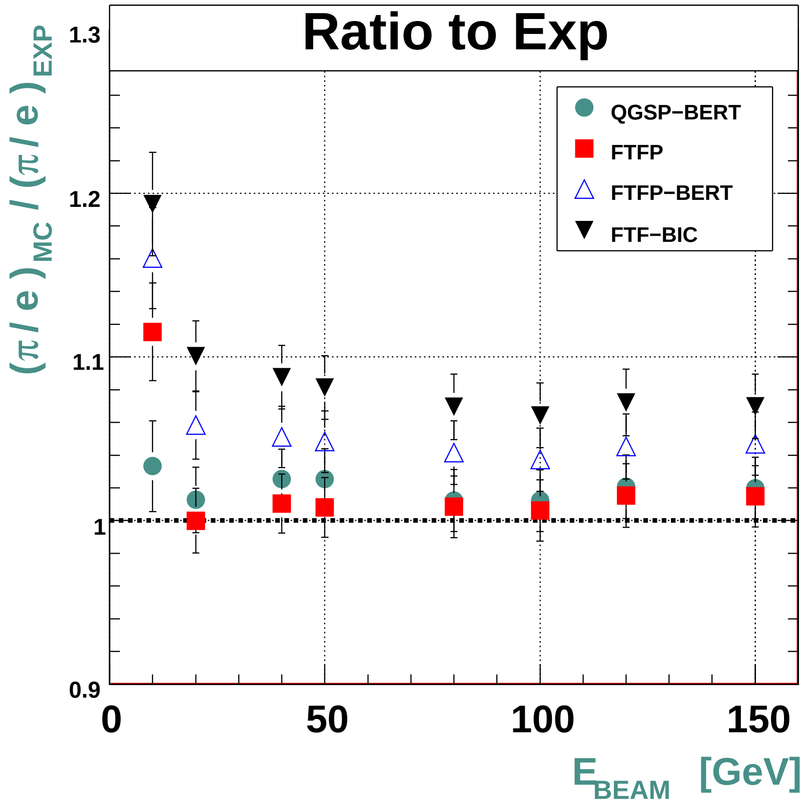
- MC predictions:

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

- Sampling term A 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 B

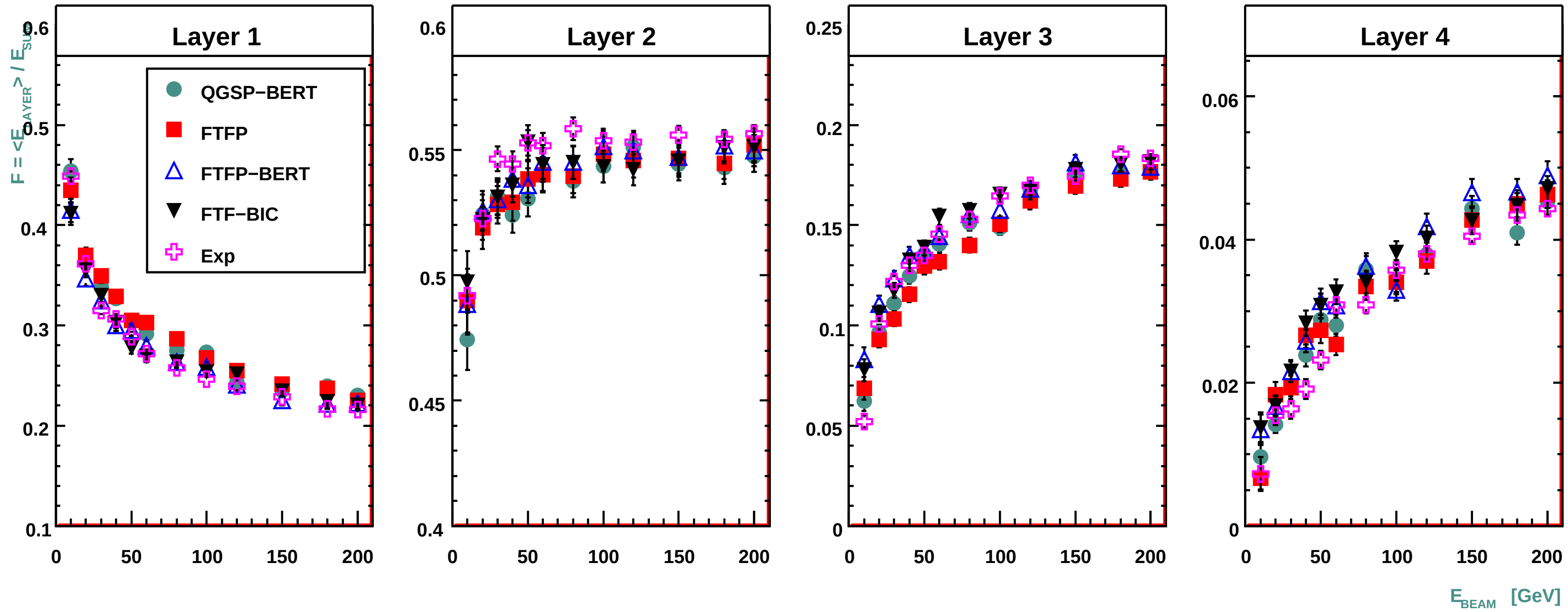
Pion response





- **FTFP** gives the best description of the pion response, *except the lowest beam energy*
- **FTF-BIC** and **FTFP-BERT** predict too high response to charged pions

Shape of hadronic showers:
Fraction of energy in HEC longitudinal layers

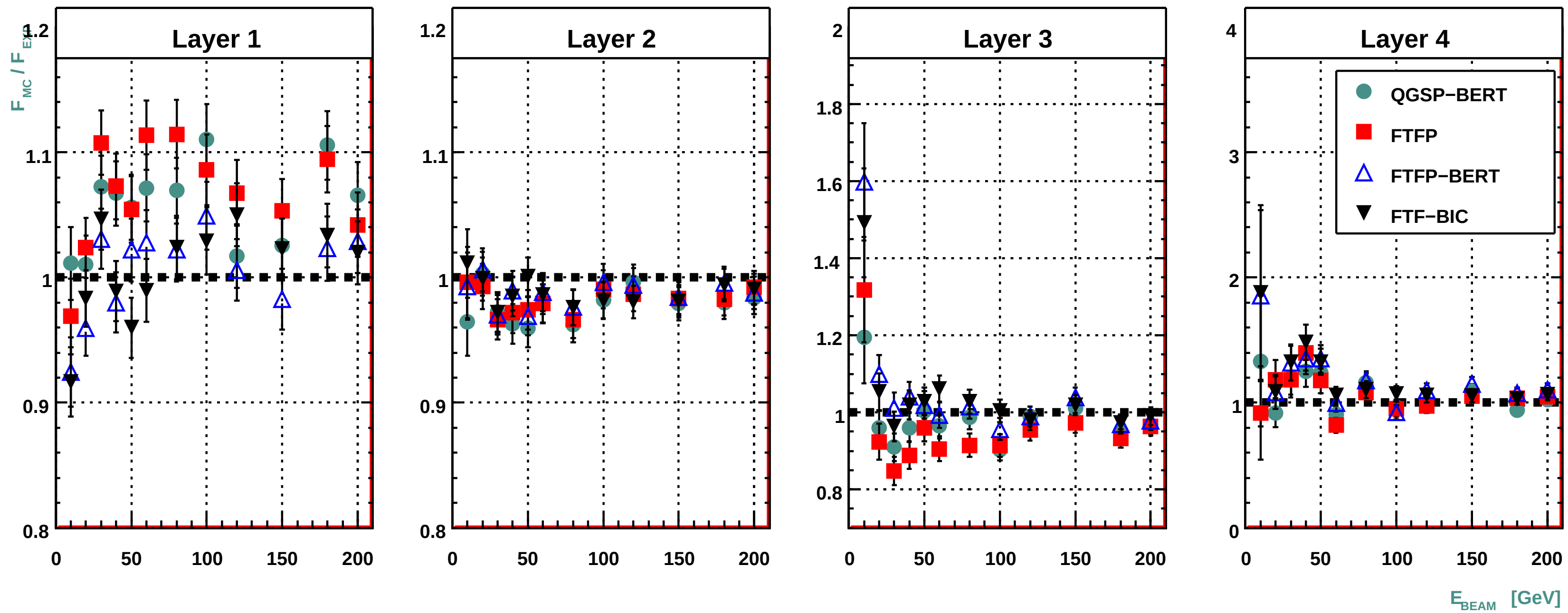


Four HEC longitudinal layers: 8/16/8/8 LAr gaps, 1.5/2.9/3.0/2.8 λ

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

Shape of hadronic showers

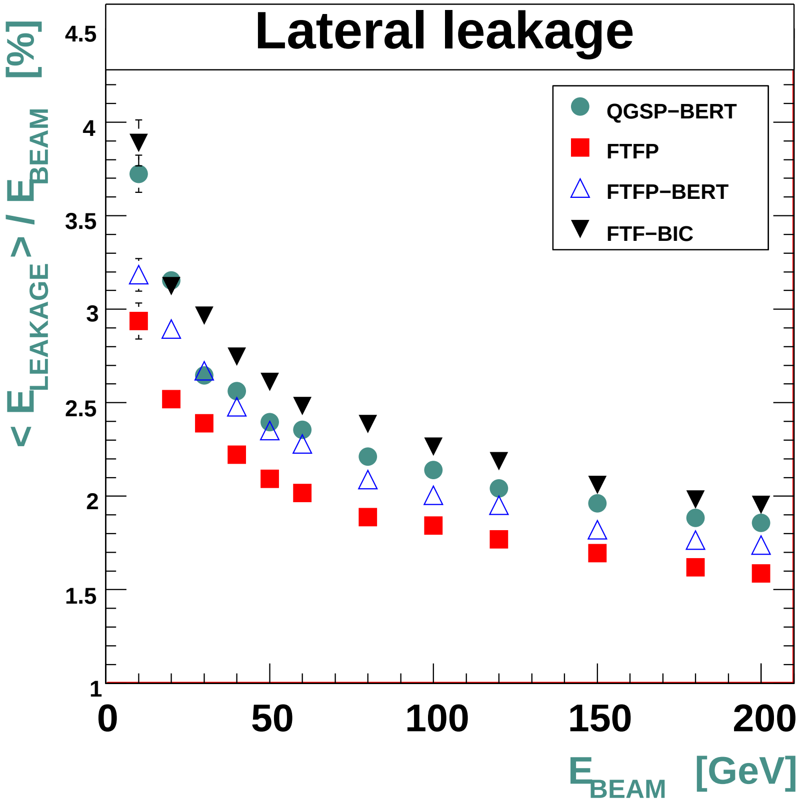
Fraction of energy in HEC longitudinal layers: Ratio to experiment



- 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)

Shape of hadronic showers:
Lateral energy leakage

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



- **FTFP**: the smallest lateral leakage
- **FTF-BIC**: the largest lateral leakage

Summary of the Comparison of MC Predictions and Experimental Results

- Ratio between simulated and experimental data as a function of the beam energy E_{BEAM}
- Maximal and minimal values of this dependence ⇒

Deviation of MC predictions from experimental results [in %]

Physics list	Resolution[1]		Response[2]		Fraction of energy in layers[2]					
					Layer 1		Layer 2		Layer 3	
QGSP-BERT	-15	-4	$+1$	$+3$	$+1$	$+11$	-4	0	-10	$+1$
FTFP	-4	$+8$	0	$+2$	$+2$	$+11$	-3	-1	-15	-3
FTFP-BERT	-20	-7	$+4$	$+6$	-4	$+5$	-3	$+1$	-4	$+10$
FTF-BIC	-25	-18	$+6$	$+10$	-4	$+5$	-3	0	-4	$+6$

[1] Data with $E_{BEAM} \geq 30$ GeV are used: Errors of the resolution are too large at smaller beam energies.

[2] Data with $E_{BEAM} = 10$ GeV are not used: Studied physics lists have problems to describe those parameters at this beam energy.

Conclusions

New round of GEANT4 based simulations with version 9.2 was carried out for the HEC stand-alone testbeam. Four different physics lists, namely: QGSP-BERT, FTFP, FTFP-BERT and FTF-BIC — were used for GEANT4 simulations. Comparison with experimental results was done.

None of these physics lists can describe the whole set of studied HEC performance parameters:

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