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Studies of the Time Structure
of Hadronic Showers in GEANT4
for the ATLAS HEC

LCG Physics Validation for LHC Simulations
CERN, 27-th of February, 2008

- **Update** of results, presented at the *LCG Physics Validation for LHC Simulations* meeting on the 30-th of January 2008:
<http://indico.cern.ch/conferenceDisplay.py?confId=25466>
- **New**: studies of the QGSP-BERT-HP physics list

Simulations

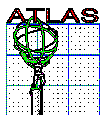
- GEANT4 version 9.0 (without patch), released in June 2007
- Hadronic physics lists:
 - **QGSP** 3.3
 - **QGSP-BERT** 3.3
(Bertini cascade model)
 - **QGSP-BERT-HP** 2.3
(high precision neutron model)
- GEANT4 range cut = 30 μm
- Usage of **Birks' law** (to describe saturation of the response in liquid argon for particles with large dE/dx):

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

$$A = 1$$

$$c = 0.0045 \text{ g}/(\text{MeV cm}^2)$$

$$\rho = 1.396 \text{ g}/\text{cm}^3$$

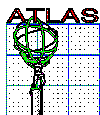


Simulations

- Stand-alone package for simulations of beam tests of HEC serial modules
 - energy depositions in LAr and absorbers in 1 ns bins
- Simulated samples:
 - electron energy scans (6 – 147.8 GeV)
 - charged pion energy scans (10 – 200 GeV)
- Simulations were done at the Garching computer centre

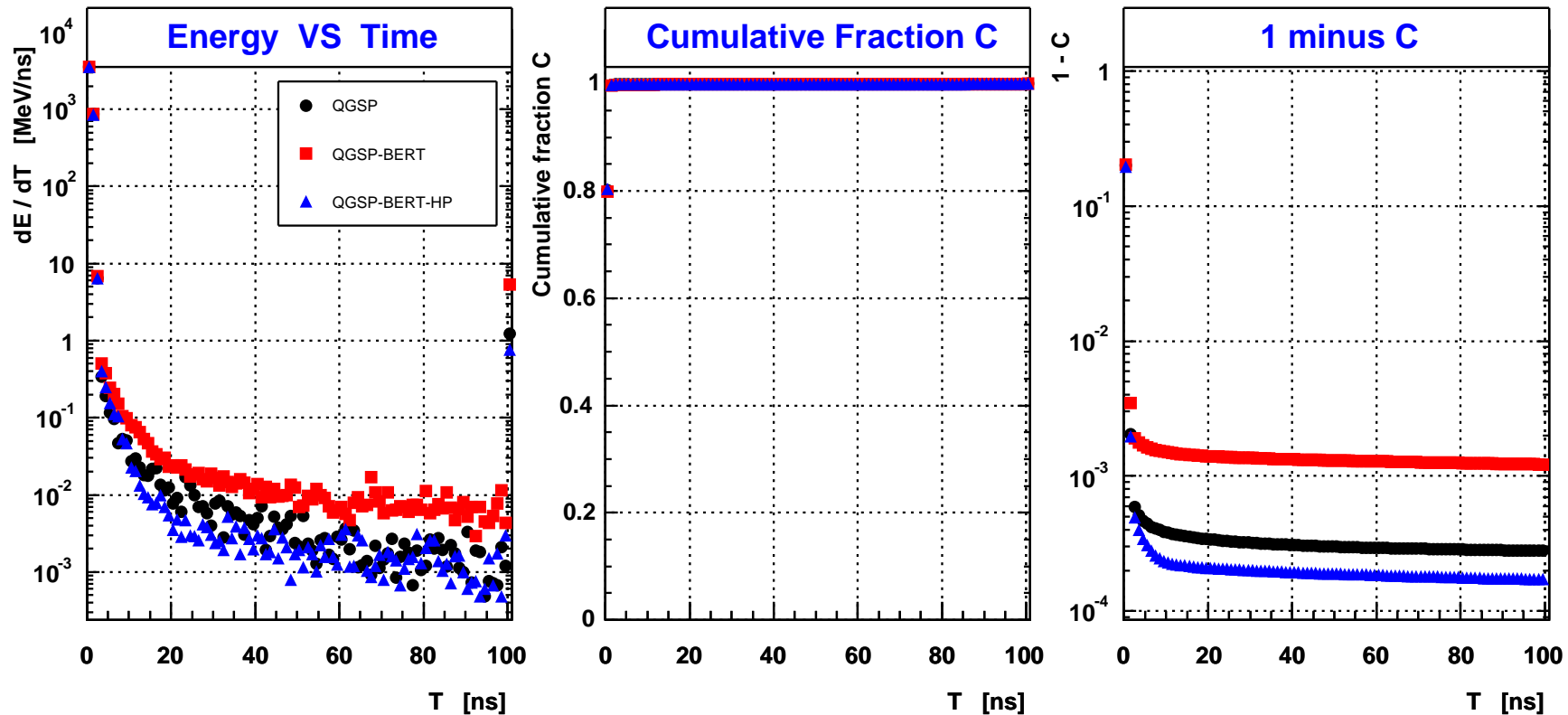
- Ratio of simulation times:

	π^- / e^-	
QGSP	0.7	
QGSP-BERT	1.2	
QGSP-BERT-HP	3.2	
	e^-	π^-
QGSP-BERT / QGSP	1.0	1.7
QGSP-BERT-HP / QGSP	1.1	4.9



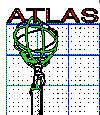
Time Profiles

100 GeV electrons (Birks' law OFF)



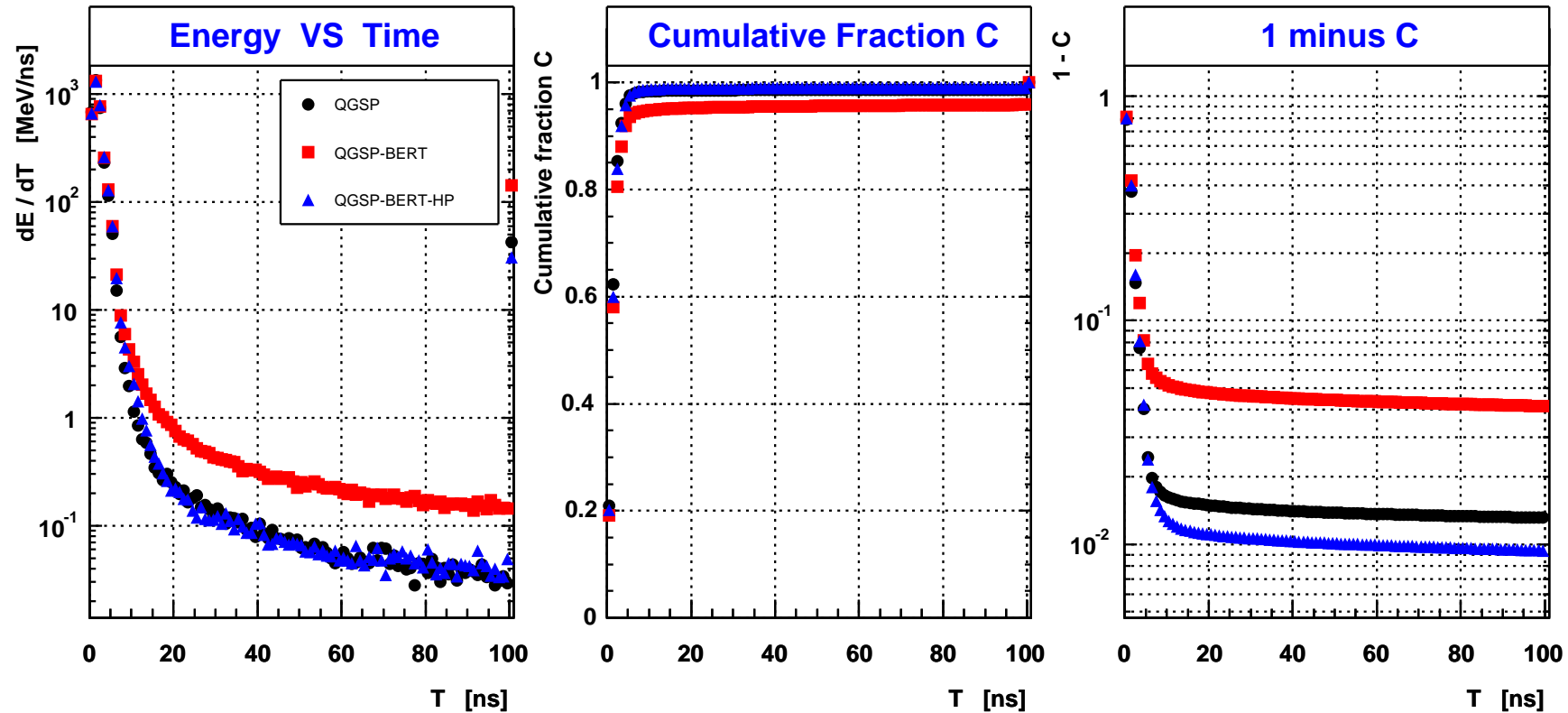
QGSP-BERT predicts slower showers than **QGSP** and **QGSP-BERT-HP**.

Late energy depositions (after a few tens of nanoseconds) are at the level $\leq 10^{-3}$.



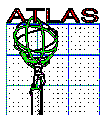
Time profiles

100 GeV charged pions (Birks' law OFF)



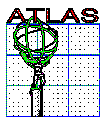
QGSP-BERT predicts slower showers than **QGSP** and **QGSP-BERT-HP**.

Late energy depositions (after a few tens of nanoseconds) are at the percent level.



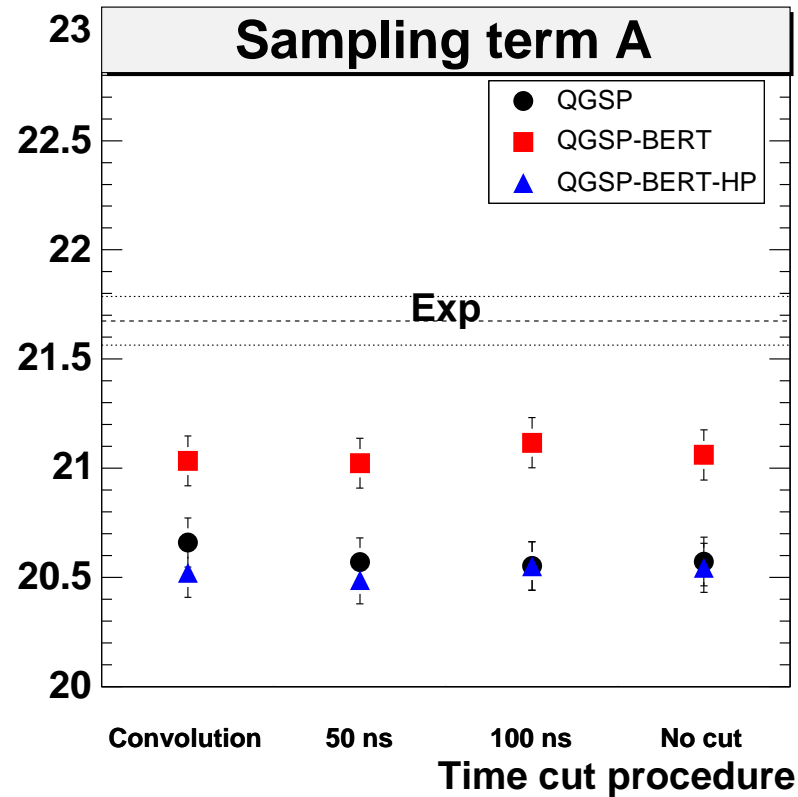
Reconstruction and Analysis

- Measurement of calorimeter signals (time cut procedures):
 - no time cut
 - integration of time profiles up to $T = 100$ ns
 - integration of time profiles up to $T = 50$ ns
 - convolution of time profiles with shaping functions and amplitude measurement at the position of the maximum of a shaping function
- Energy reconstruction:
 - following experimental procedure
 - EM-scale calibration
 - cluster of the fix size
 - Gaussian fit: E_0 and σ
- Analysed variables:
 - Energy resolution σ/E_0 for electrons and charged pions
 - Ratio e/π ratio of energies in electron and pion clusters
 - Fraction of energies in HEC longitudinal layers for charged pions (not shown today)



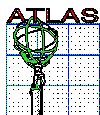
Analysis

Electron energy resolution

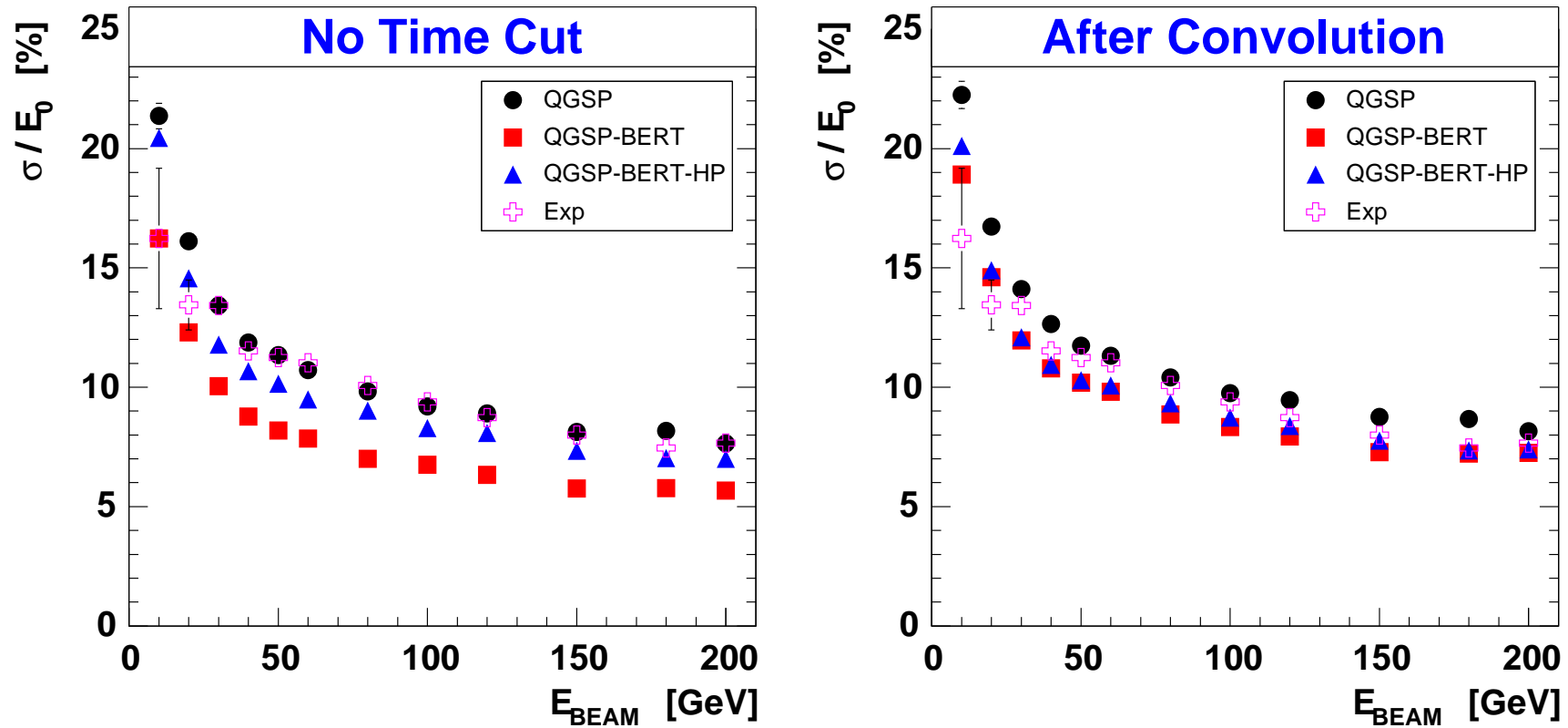


- One-term parametrization:

$$\sigma / E_0 = A / \sqrt{E_{BEAM}}$$
- No dependence on the time cut procedure
- **QGSP-BERT** closer to experiment than **QGSP** or **QGSP-BERT-HP** (why?)



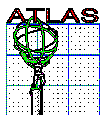
Pion energy resolution



Time cuts strongly influence energy resolution:

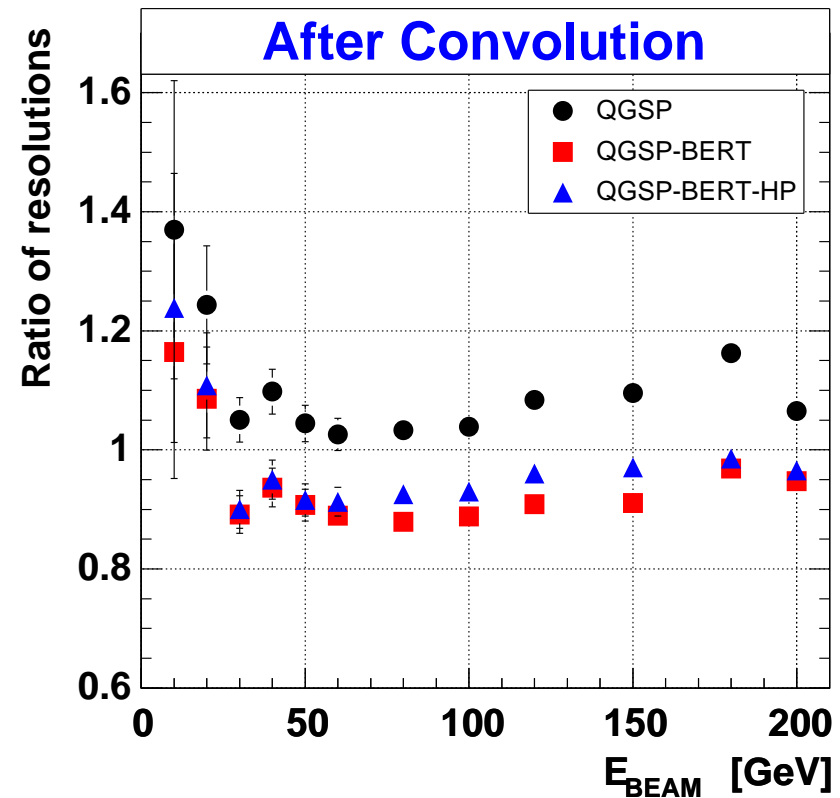
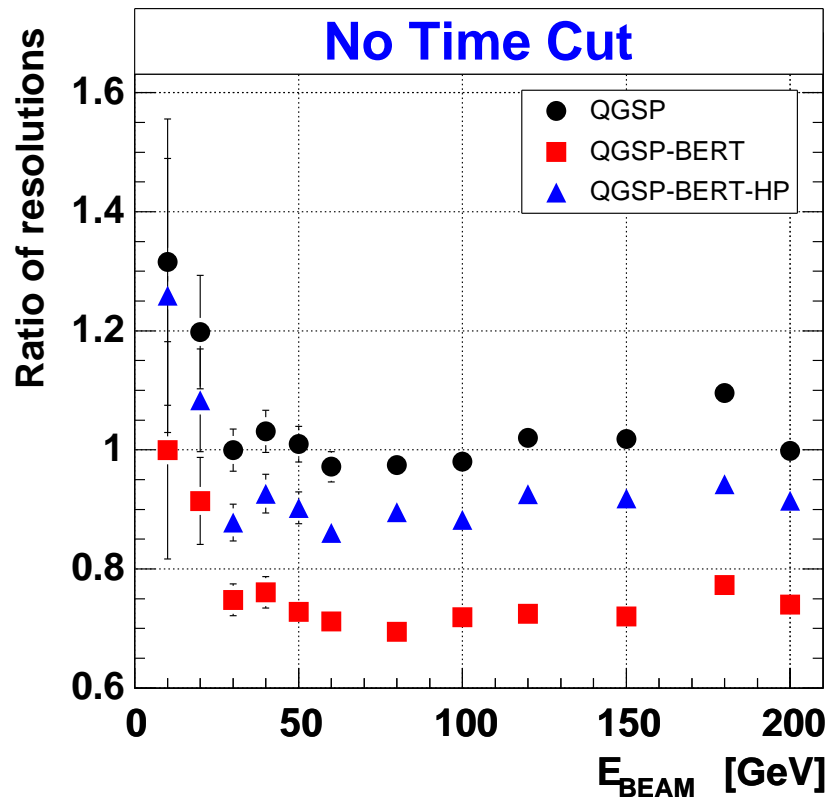
QGSP-BERT — 10-30 % relative increase,

QGSP and **QGSP-BERT-HP** — relative increase by ~ 5 %.



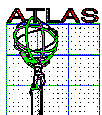
Analysis

Pion energy resolution: Ratio to experiment



QGSP describes well energy resolution below $E_{BEAM} \simeq 100$ GeV.

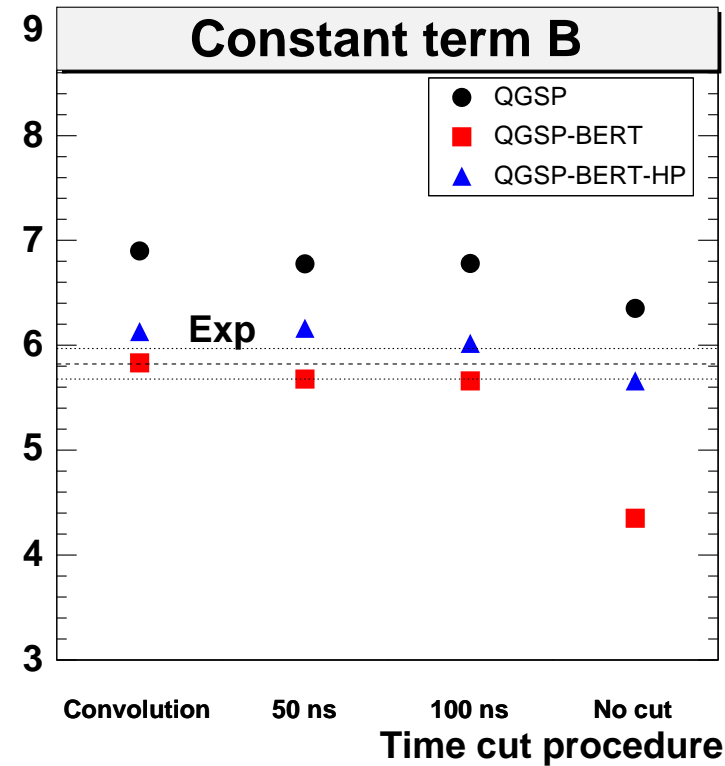
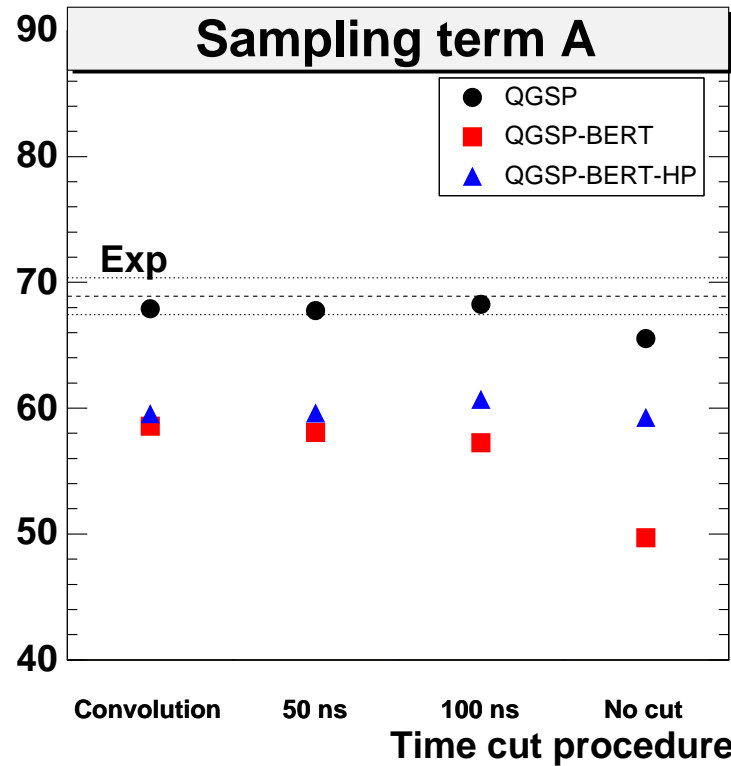
At high beam energies: **QGSP-BERT-HP** and **QGSP-BERT** are closer to experimental values than **QGSP**, when time cuts are applied.



Analysis

Pion energy resolution: Two-term parametrization

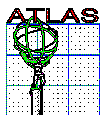
$$\sigma / E_0 = A / \sqrt{E_{BEAM}} \oplus B$$



After applying time cuts:

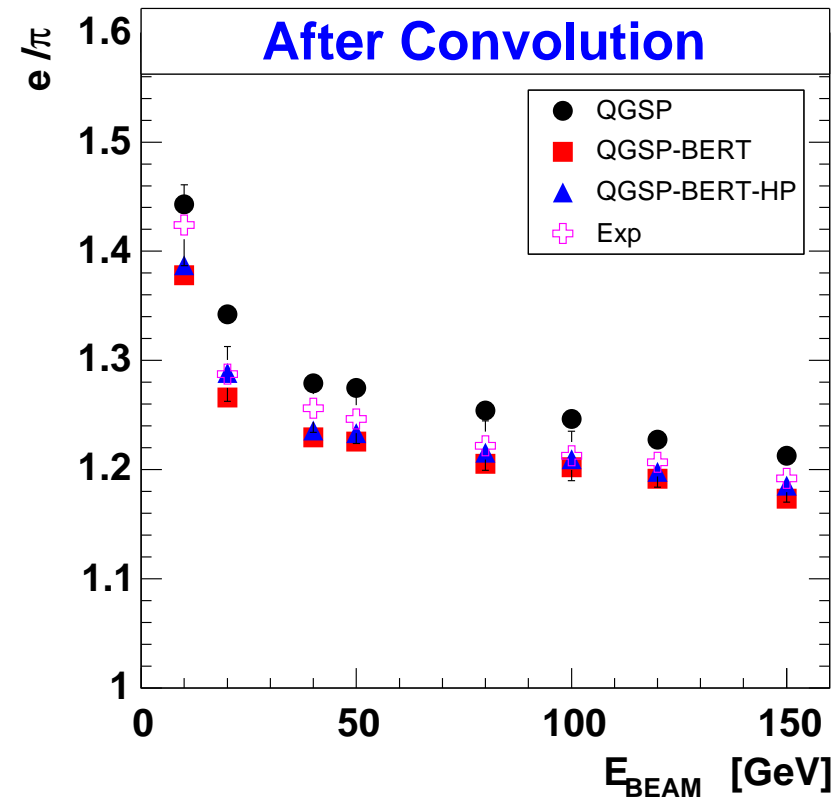
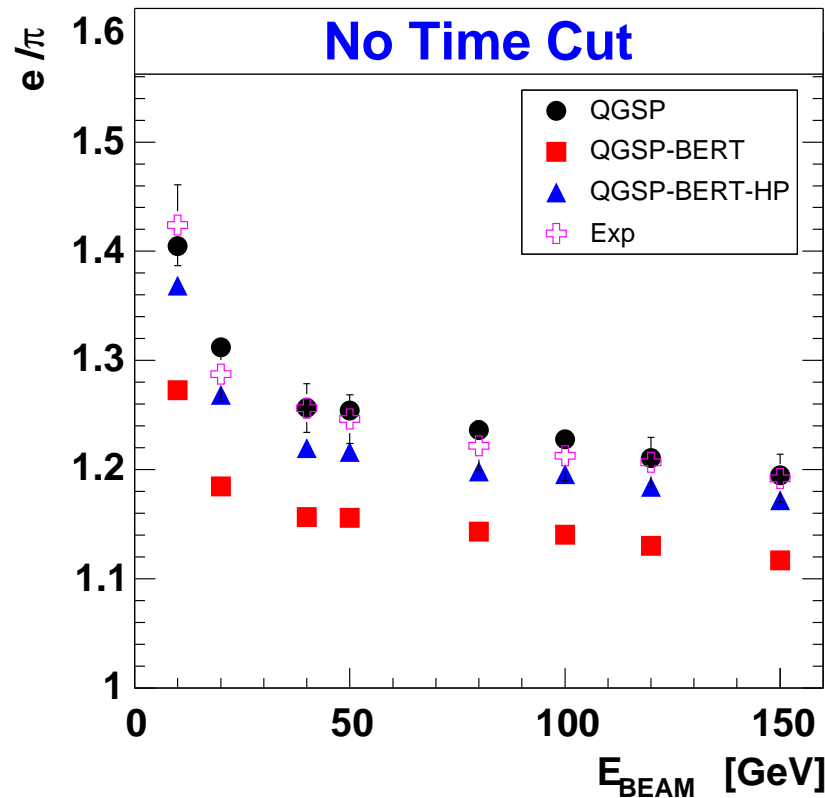
sampling term is described by **QGSP**,

constant term is described by **QGSP-BERT** and **QGSP-BERT-HP**.



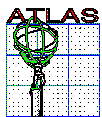
Analysis

Ratio e/π



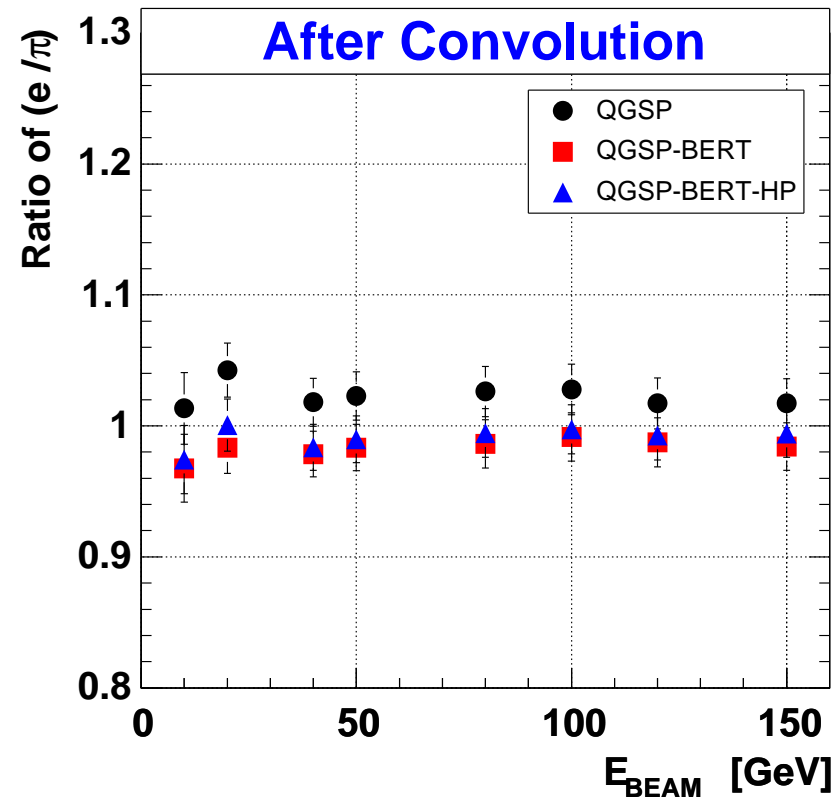
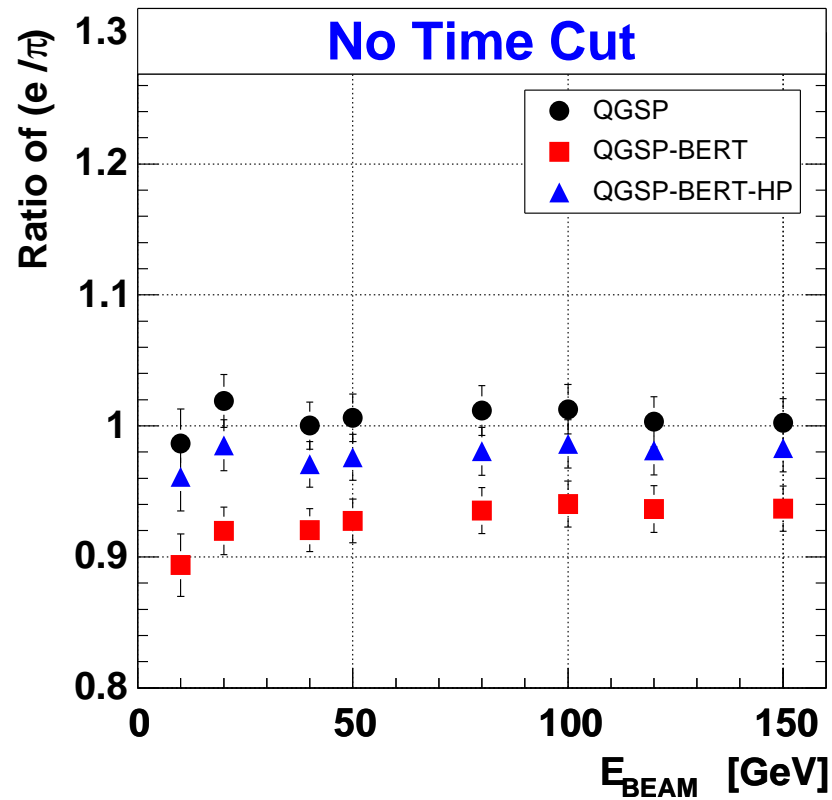
Time cuts strongly influence e/π -ratio for **QGSP-BERT**: 4-8 % increase.

For **QGSP** and **QGSP-BERT-HP** increase is smaller: 1-2 %.

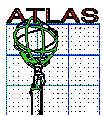


Analysis

e/π : Ratio to experiment



After applying time cuts: all three physics lists describe e/π ratio well.



Conclusions

Studies of the time structure of showers in GEANT4 for the ATLAS hadronic end-cap calorimeter were carried out. Three physics lists, namely: QGSP, QGSP-BERT and QGSP-BERT-HP — were investigated. Comparison with experimental results, obtained during beam test of HEC modules, was done.

- QGSP-BERT physics list predicts much slower hadronic showers than QGSP and QGSP-BERT-HP
- Usage of time cuts (following the experimental procedure of signal measurements in calorimeter cells) has influence on energy resolution and response for charged pions
- For QGSP-BERT this influence is much stronger than for QGSP and QGSP-BERT-HP
- After applying time cuts and with Birks' law switched ON: the better description of studied experimental parameters, in total, is given by **QGSP-BERT** and **QGSP-BERT-HP**
 - good description of longitudinal profiles of hadronic showers
 - agreement in e/π -ratio
 - rather close predictions of the resolution at high beam energies (i.e. of the constant term)

