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

LCG Physics Validation of LHC Simulations
CERN, 25-th of July, 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 8.2 + patch-01**
  - scan over the GEANT4 range cut with electrons
  - electron energy scan
  - charged pion energy scan
- Studies of the influence of response saturation in liquid argon: **Birks' law**

Evaluation of GEANT4 Version 8.2

Simulation Packages

- GEANT4

Version	**7.0p01**	**8.0p01**	**8.1p02**	**8.2p01**
Physics lists	LHEP 3.7 QGSP 2.8	LHEP 4.0 QGSP 3.0	LHEP 4.1 QGSP 3.1	LHEP 4.2 QGSP 3.2
Packaging library	PACK 2.4	PACK 5.0	PACK 5.1	PACK 5.1
Release date	February 2005	February 2006	November 2006	February 2007

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

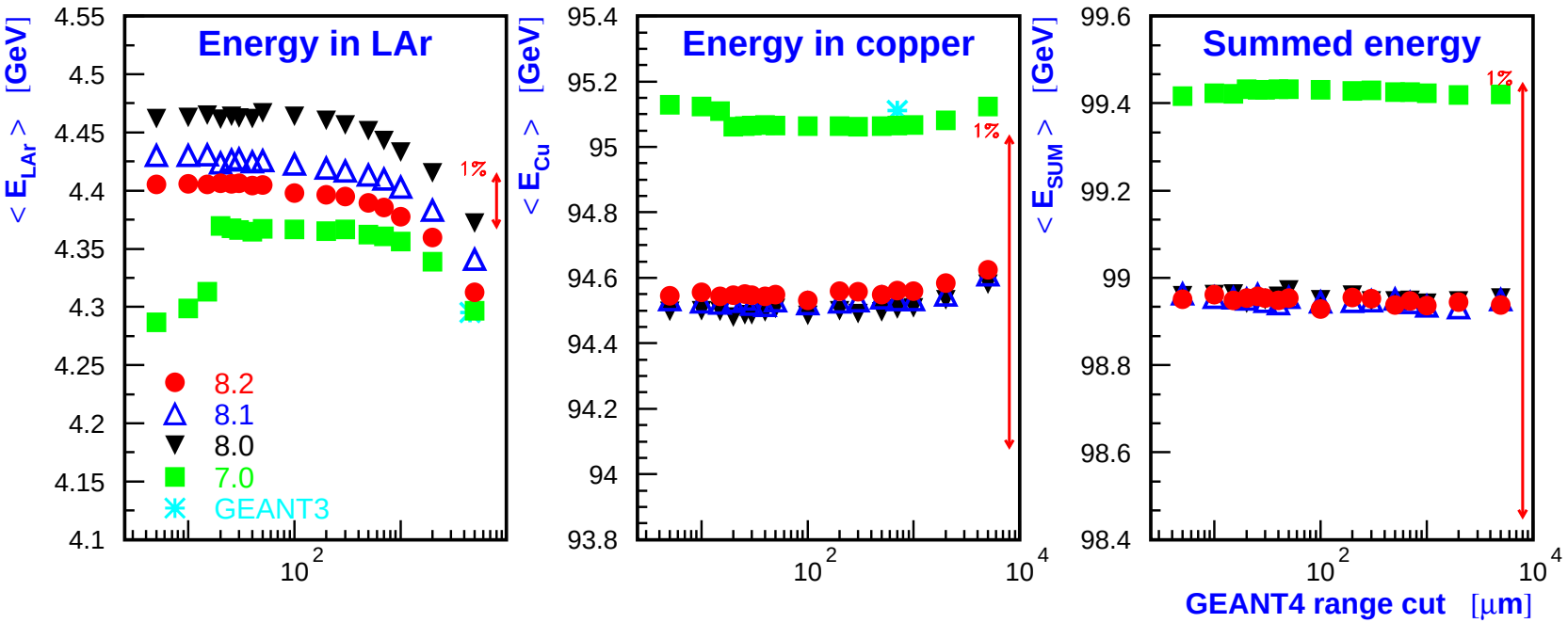
- HEC geometry: the same in all GEANT4 versions and very similar in GEANT3

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 8.2 / Scan over the range cut with electrons

Energy depositions in HEC



In **8**-th versions of GEANT4 (w.r.t. version **7.0**):

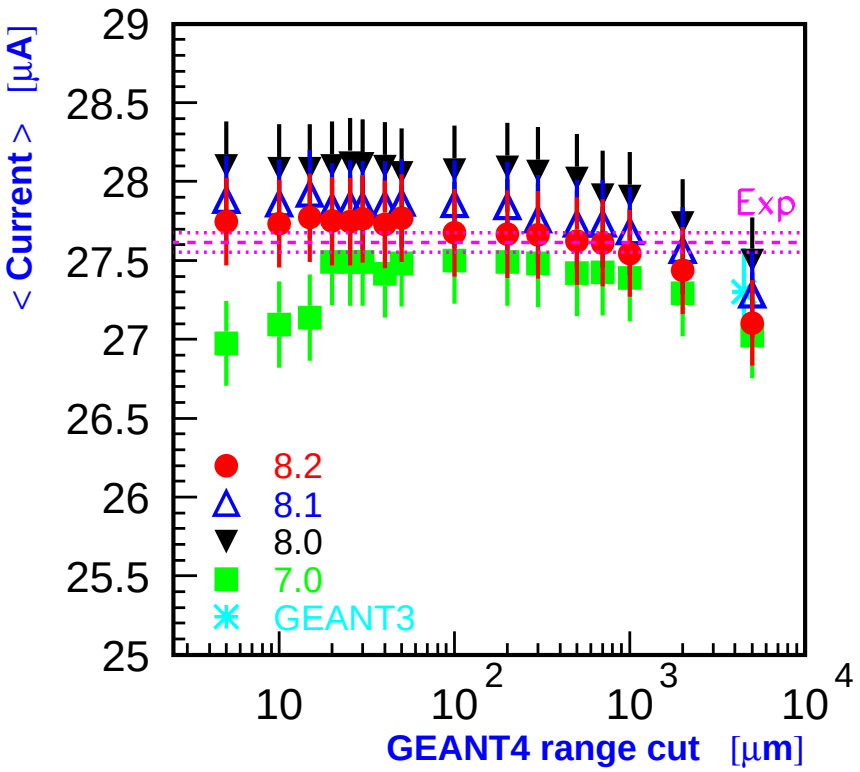
- broader plateau of the visible energy in LAr as a function of the range cut
- increase of the visible energy
- decrease of the total deposited energy

Certain decrease of the visible energy: by 1% and 0.5% for **8.0** → **8.1** → **8.2**

Evaluation of GEANT4 version 8.2 / Scan over the range cut with electrons

Signal in one cell

- Cell with the maximal average signal (most loaded cell)
- Visible energy $\Rightarrow$ 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
- Version **8.2** shows the best agreement with experimental values



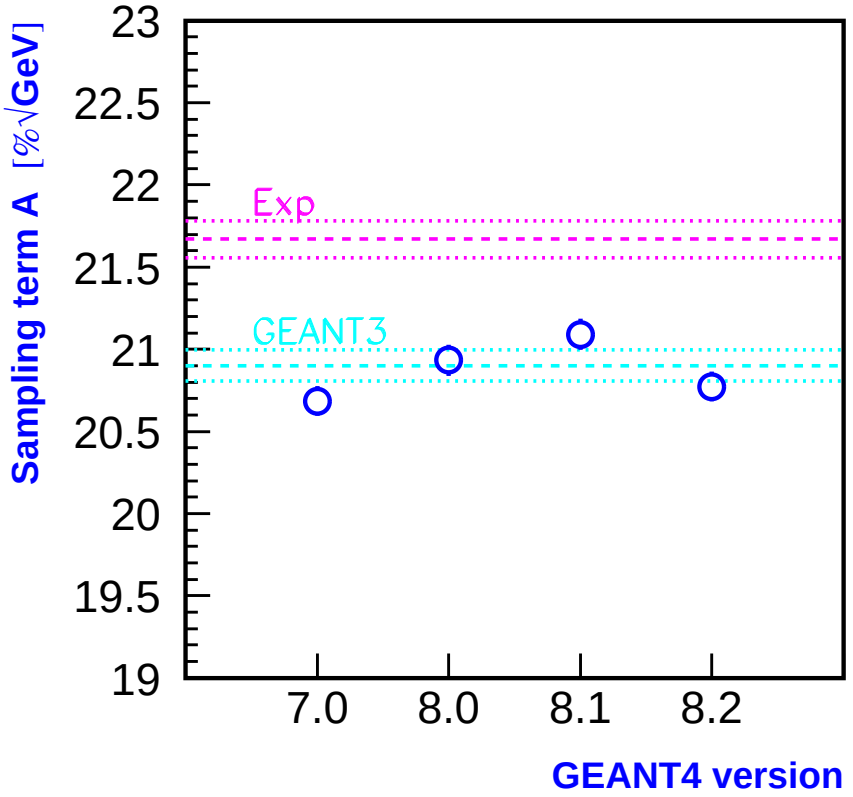
Electrons: Energy Scan

- 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

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

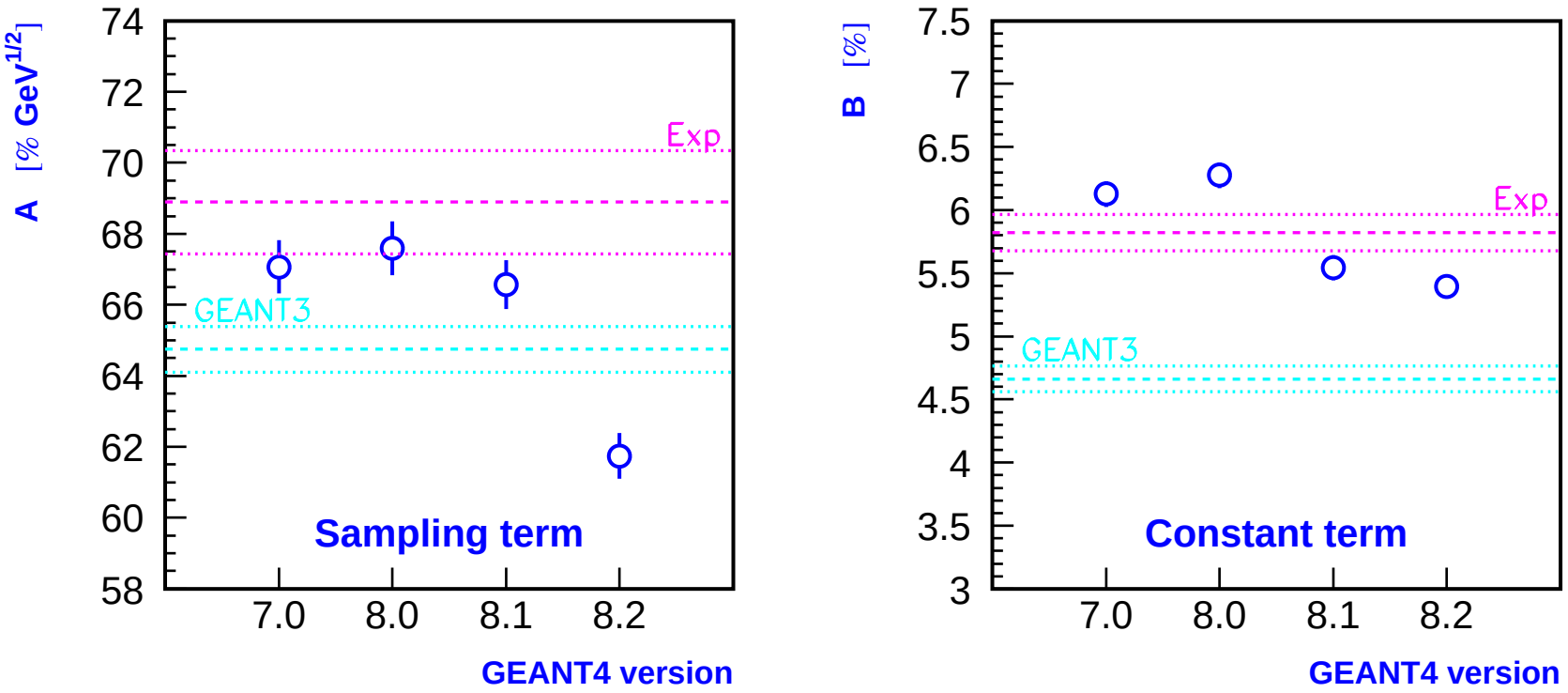


Charged Pions: Energy Scans

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

Pion energy resolution

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

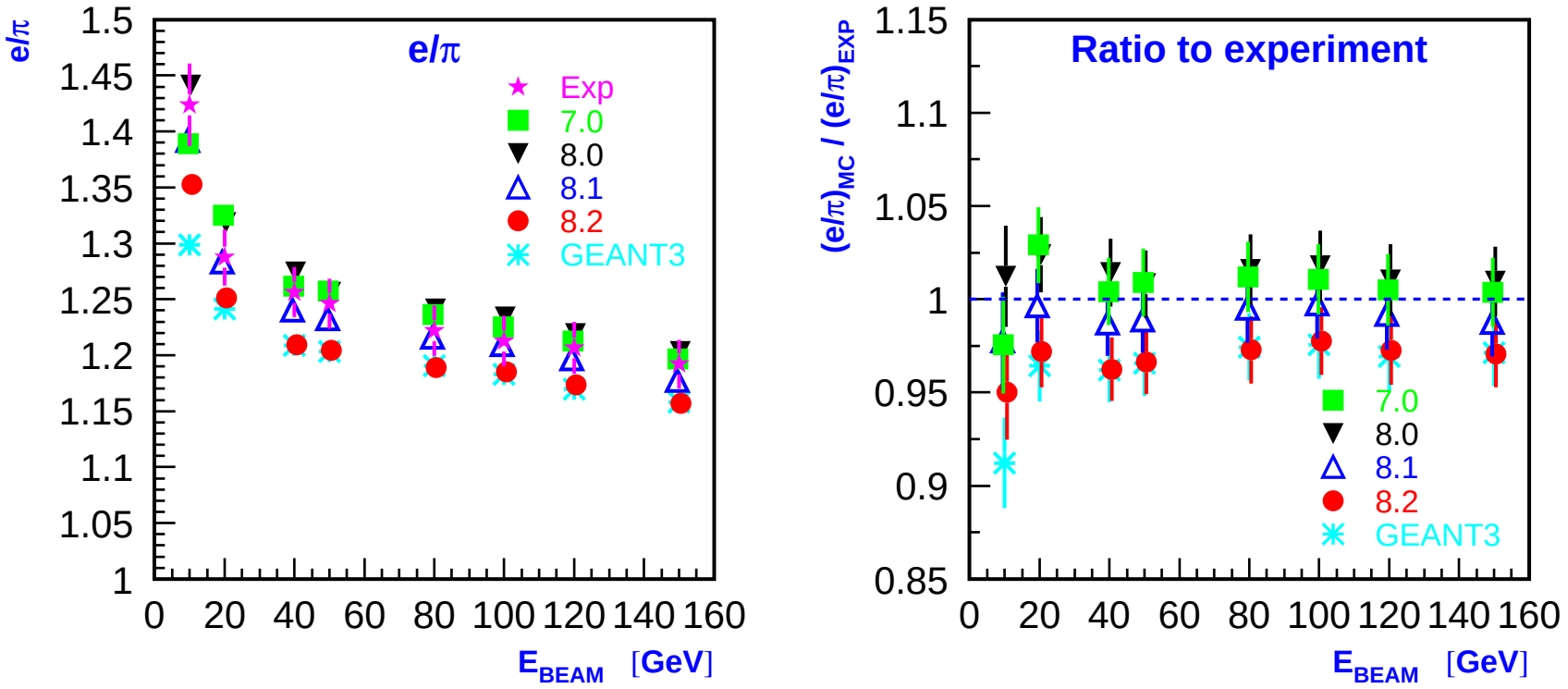


Version **8.2** predicts too low values of the energy resolution

Evaluation of GEANT4 version 8.2 / Charged pion energy scans

Ratio e/π

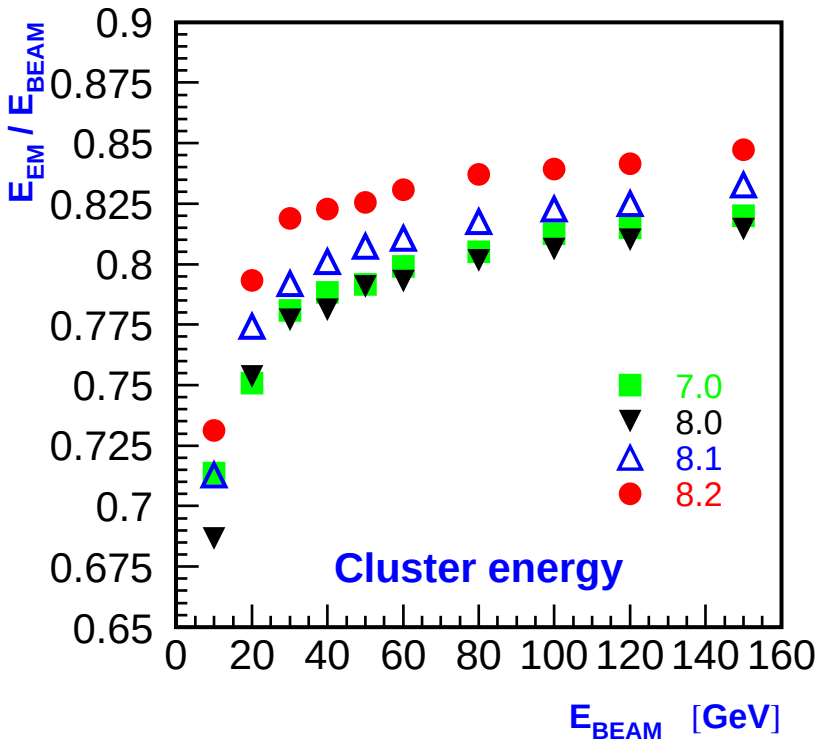
(ratio of energies in electron and pion clusters)

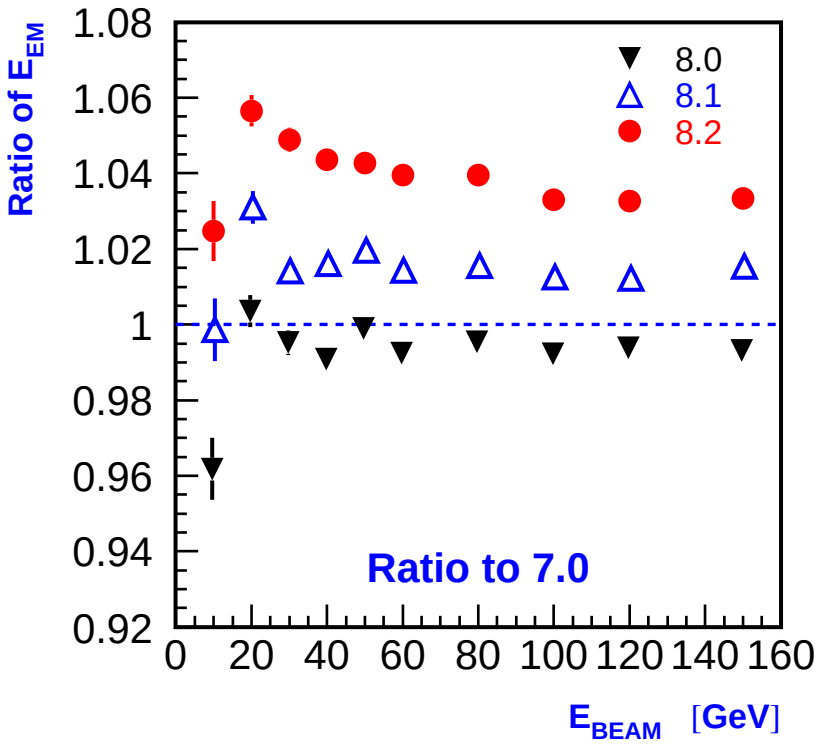


Version **8.2** predicts smaller values of e/π than experimental ones

Energy at EM-scale in pion clusters

(EM-scale returns the total deposited energy for electrons)

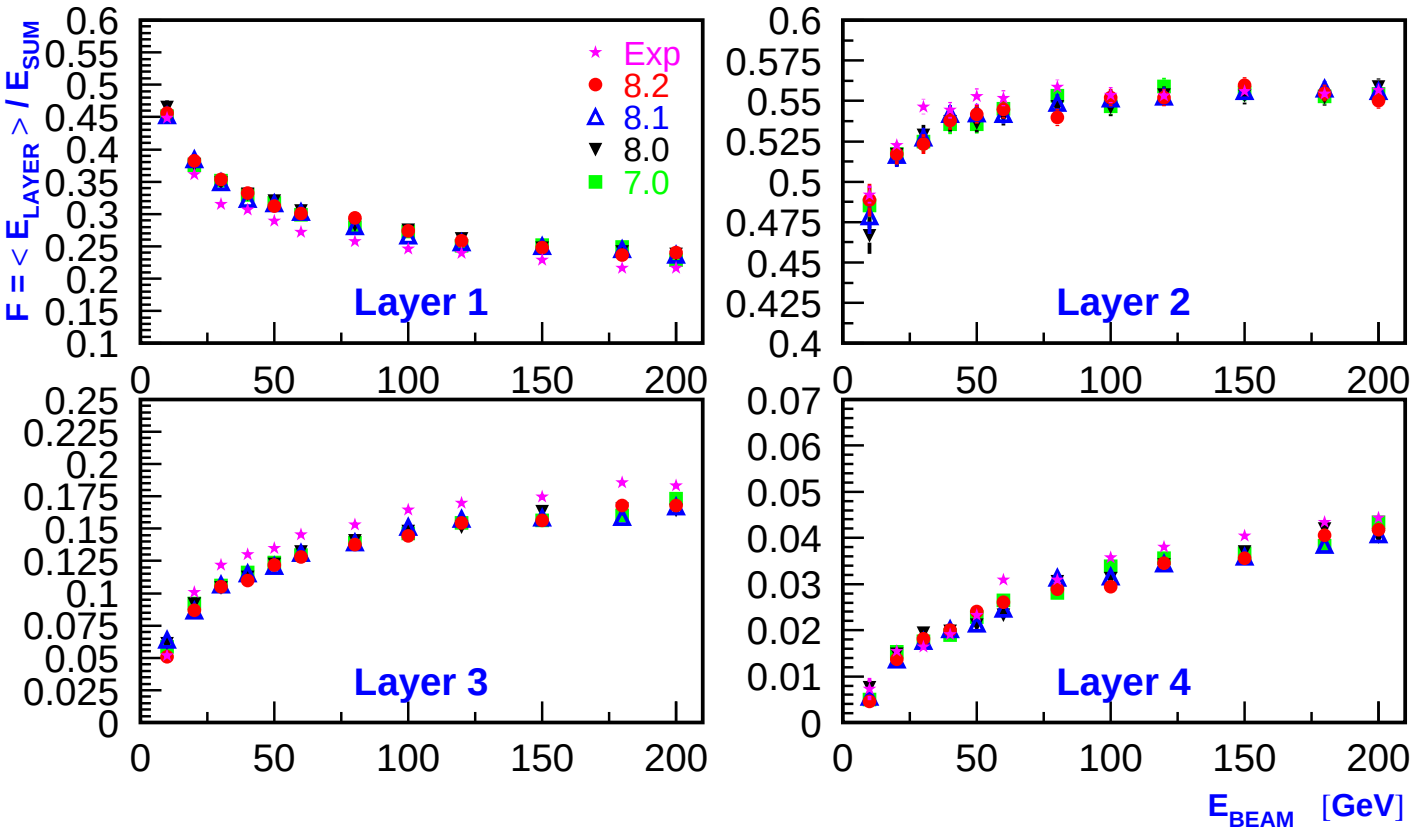




Increase of the energy in pion clusters in version **8.2** by 3-5% w.r.t. version **7.0**

Evaluation of GEANT4 version 8.2 / Charged pion energy scans

Fraction of energy in longitudinal layers

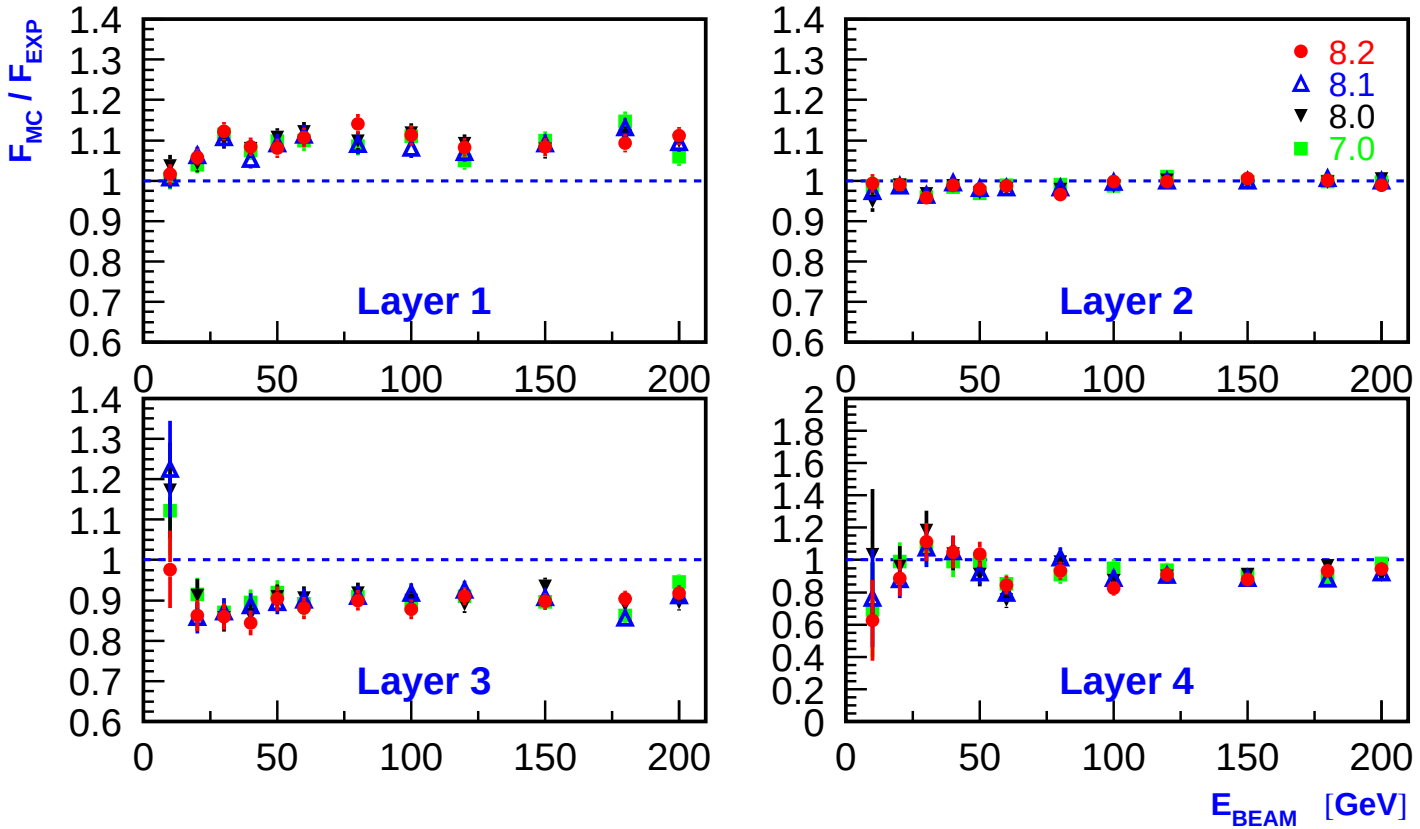


Four HEC longitudinal layers: 8/16/8/8 LAr gaps, 1.5/2.9/3.0/2.8 λ

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

Evaluation of GEANT4 version 8.2 / Charged pion energy scans

Fraction of energy in longitudinal layers: Ratio to experiment

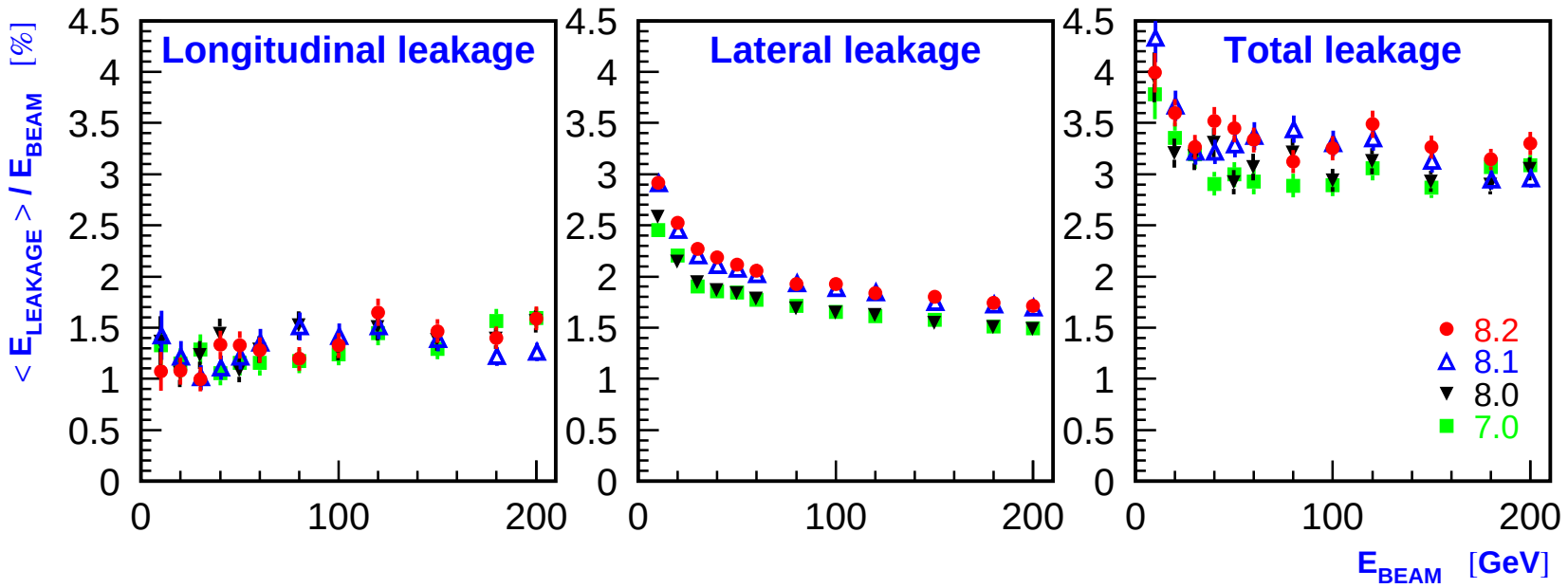


GEANT4 (QGSP): hadronic showers start earlier and are more compact.

No difference between GEANT4 versions.

Energy leakage from HEC modules

(sum of kinetic energies of all particles stopped in "leakage" detectors)



Increase of the lateral leakage in versions **8.1** and **8.2** w.r.t. previous versions, i.e. increase of the transverse size of hadronic showers.

Conclusions on Version 8.2

New round of GEANT4 based simulations with version 8.2p01 was carried out for the HEC stand-alone testbeam. Comparison with experimental results and results of previous simulations is done.

- Certain changes w.r.t. previous versions are observed for the QGSP physics list:
  - pion energy resolution becomes smaller and lower than experimental values
  - increase of the energy in pion clusters leads to systematically low values of e/π-ratio
- Fractions of energy in HEC layers stay unchanged

Studies of the Influence of Birks' Law

- Saturation of the response for particles with large dE/dx
- Phenomenological description by Birks' law:

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

- Simulation of the response in liquid argon for the HEC:

  $A = 1$

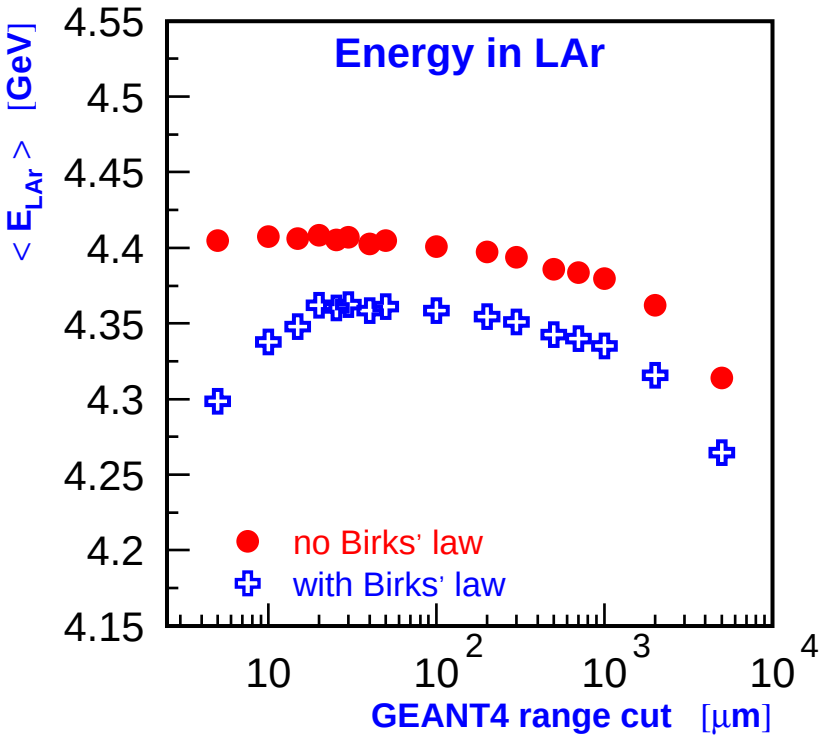
  $c = 0.0045$ g/(MeV cm^2)

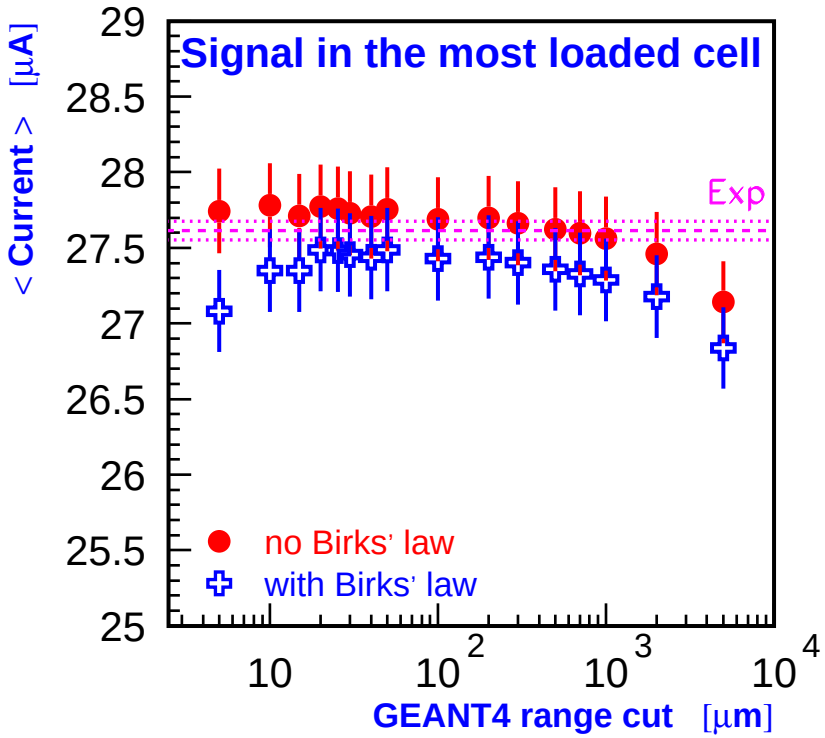
  $\rho = 1.396$ g/cm^3

- GEANT4 based simulations:
  - version – 8.2p01
  - physics list – QGSP 3.2
- Simulated samples:
  - scan over the range cut with 100 GeV electrons
  - electron energy scan with 20 μm range cut
  - charged pion energy scan with 20 μm range cut
- Standard analysis
- Presented variables – affected by Birks' law

Studies of the influence of Birks' law

100 GeV electrons: Scan over the range cut



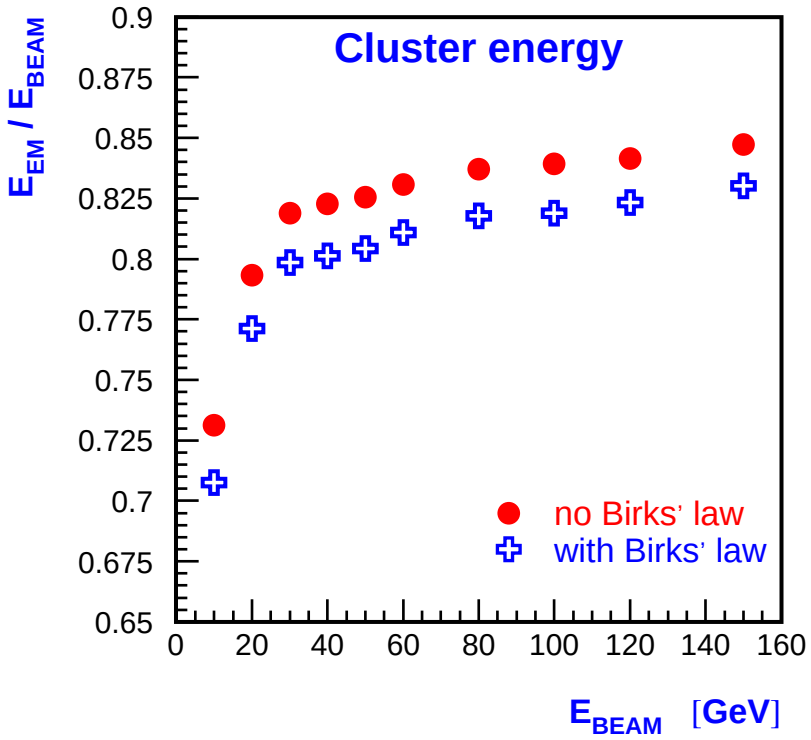


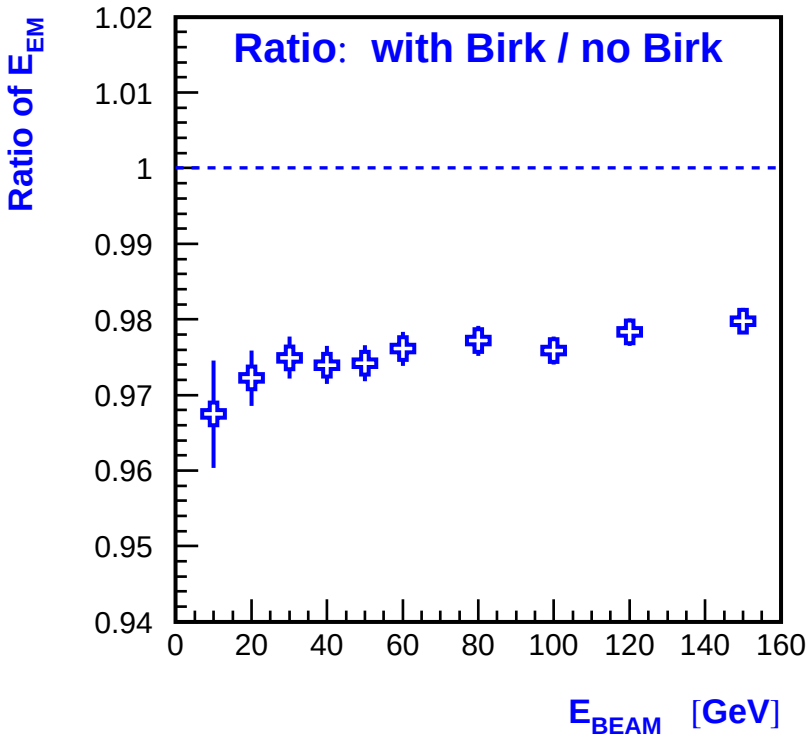
Above 20 μm range cut: decrease of the visible energy by 1%, when Birks' law is switched on. Below 20 μm reduction is larger.

MC predictions of signals in the most loaded cell are in good agreement with experimental values in the broad interval of range cuts.

Studies of the influence of Birks' law

Energy at EM-scale in pion clusters

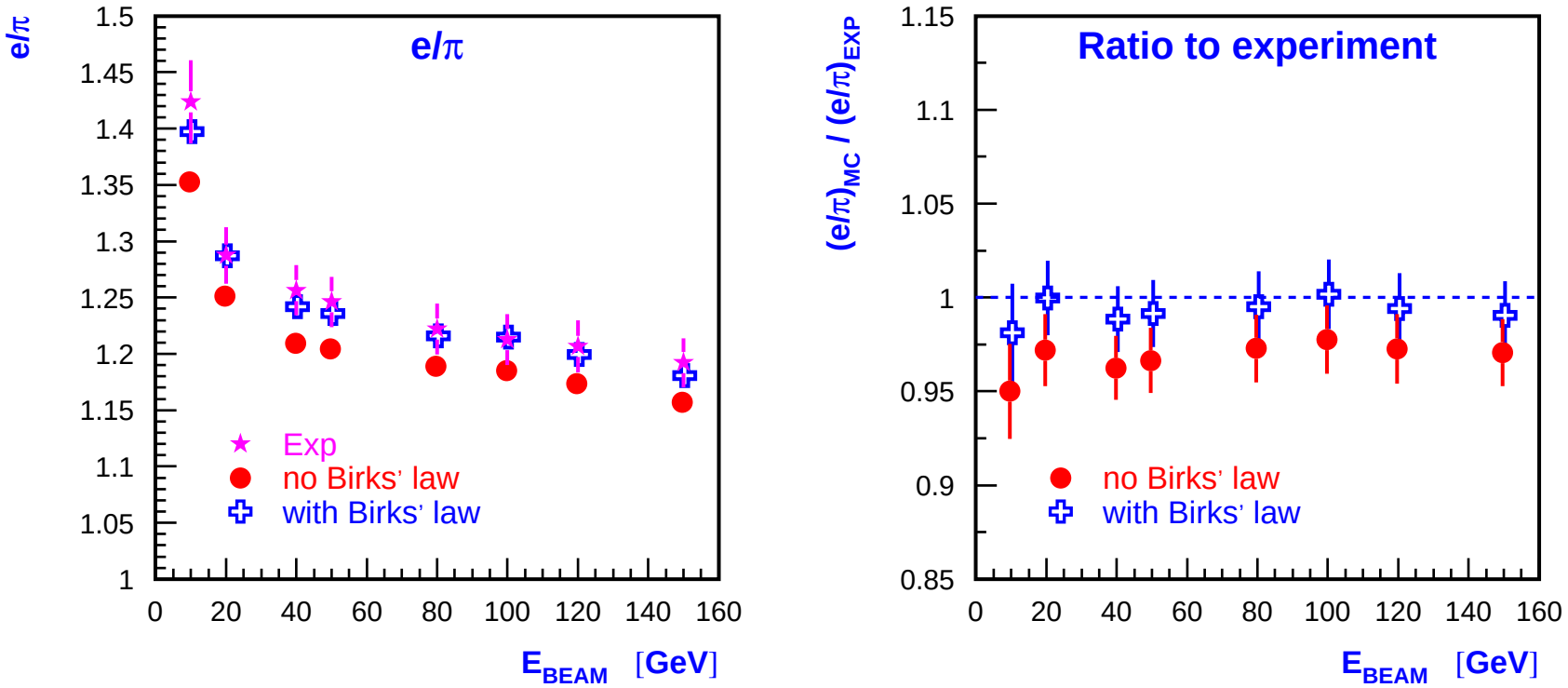




Decrease of the reconstructed energy in pion clusters by 2-3%, when Birks' law is included.

Studies of the influence of Birks' law

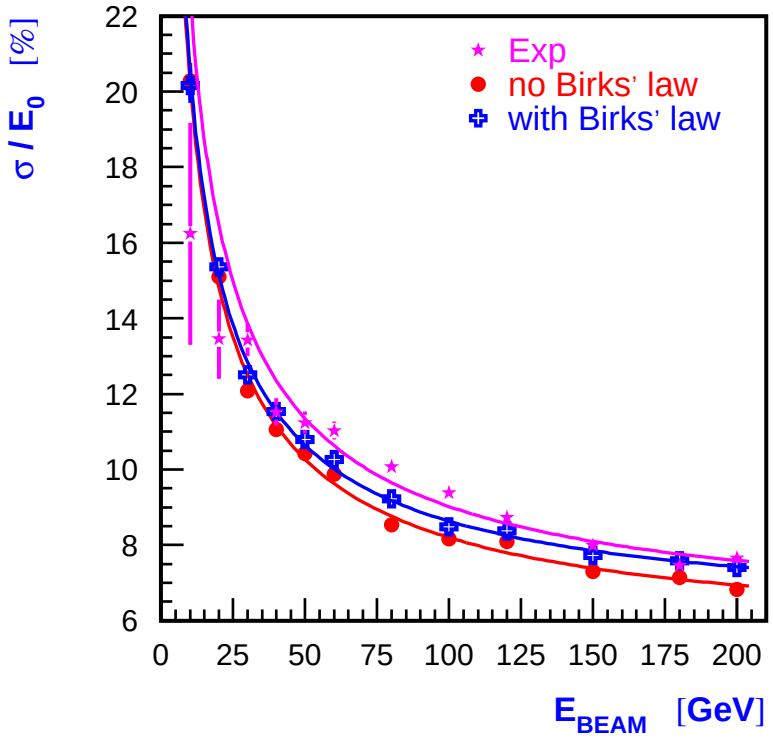
Ratio e/π



Experimental ratio e/π is described well, when Birks' law is taken into account.

Studies of the influence of Birks' law

Pion energy resolution



	A [% $\sqrt{GeV}$]	B [%]
Exp	69±1	5.8±0.1
no Birks' law	61.7±0.6	5.39±0.09
with Birks' law	62.2±0.7	5.98±0.09

Application of Birks' law improves description of the pion energy resolution (constant term)

Conclusions on Studies of the Birks' Law Influence

Attenuation of the response in liquid argon, as predicted by Birks' law, was implemented for GEANT4 based simulations of the HEC testbeam. Studies were carried out for version 8.2p01 and QGSP physics list. Comparison with experimental results and results of corresponding simulations without Birks' law is done.

Analysis shows that saturation of the response:

- describes well ratio e/π
- improves description of the pion energy resolution