Results from the Geant4 ATLAS HEC test-beam simulation

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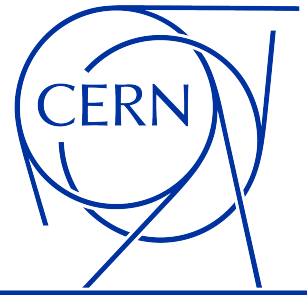
Simulation bi-weekly meeting
13/7/2021



Geant4 validation using ATLAS HEC beam tests

- **Project: validate Geant4 using results from the ATLAS Hadronic End-cap Calorimeter (HEC) test-beam data. Started in May 2021.**

- **Three main tasks identified:**

1. **Porting the ATLAS HEC simulation into a new standalone Geant4 application.**

2. **Perform Geant4 validation against HEC TB data and Geant4 regression testing.**

3. **Include the application in the geant-val validation testing suite.**

Geant4 validation using ATLAS HEC beam tests

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- **Three main tasks identified:**

1. Porting the ATLAS HEC simulation into a new standalone Geant4 application.

Currently at v1.1

2. Perform Geant4 validation against HEC TB data and Geant4 regression testing.

Today's topic.

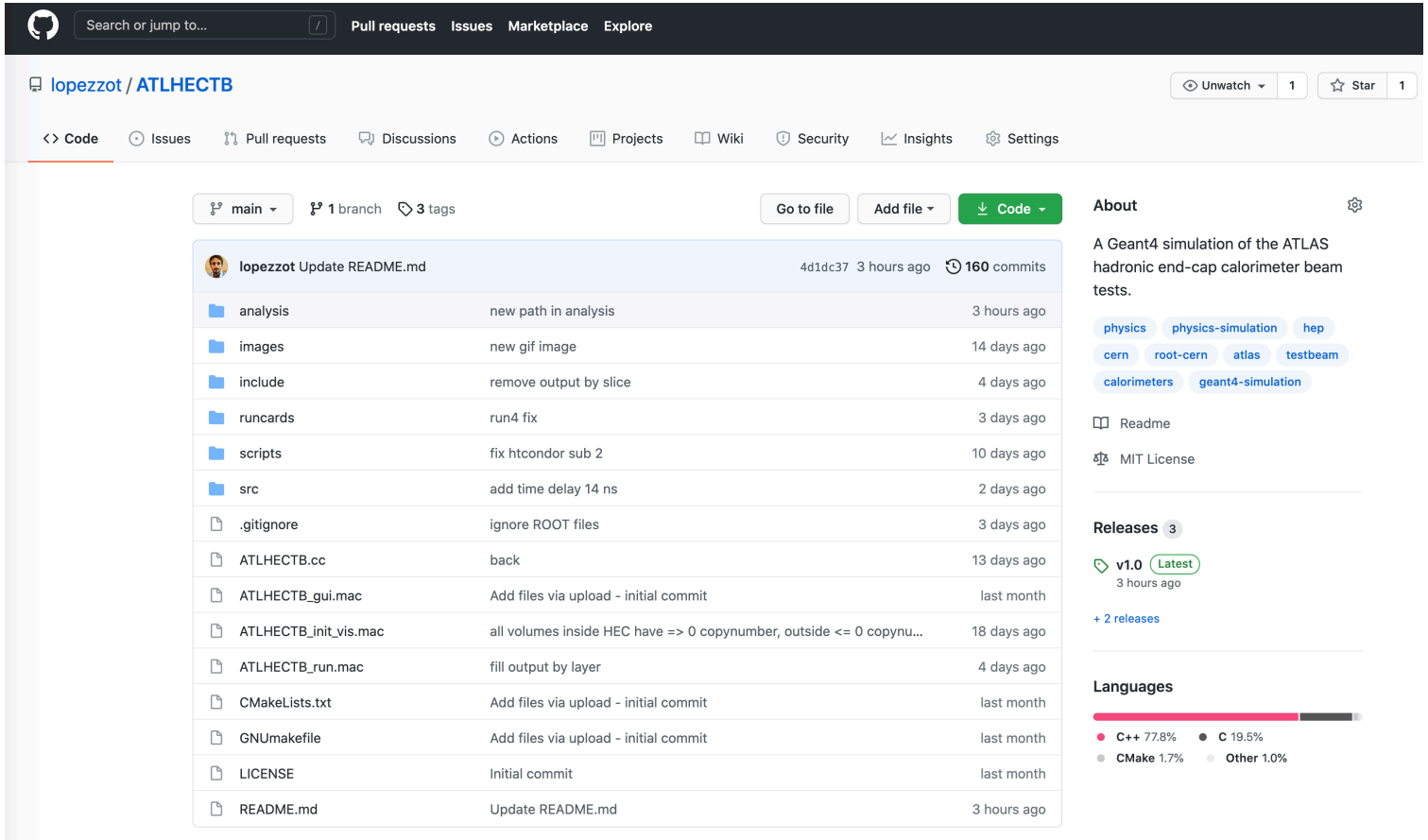
3. Include the application in the geant-val validation testing suite.

To be done.

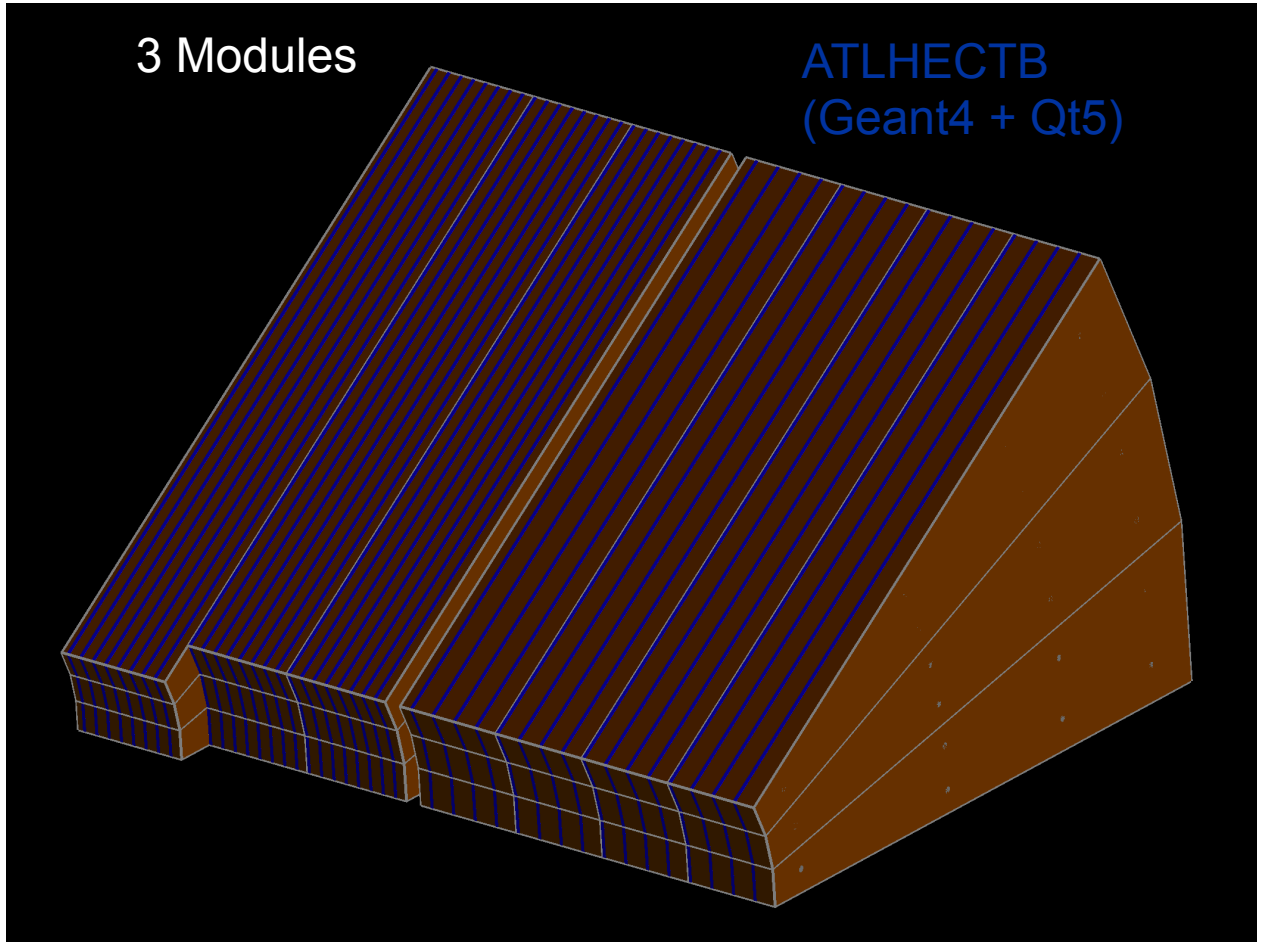
ATLHECTB

A Geant4 simulation of the ATLAS hadronic end-cap calorimeter beam tests.

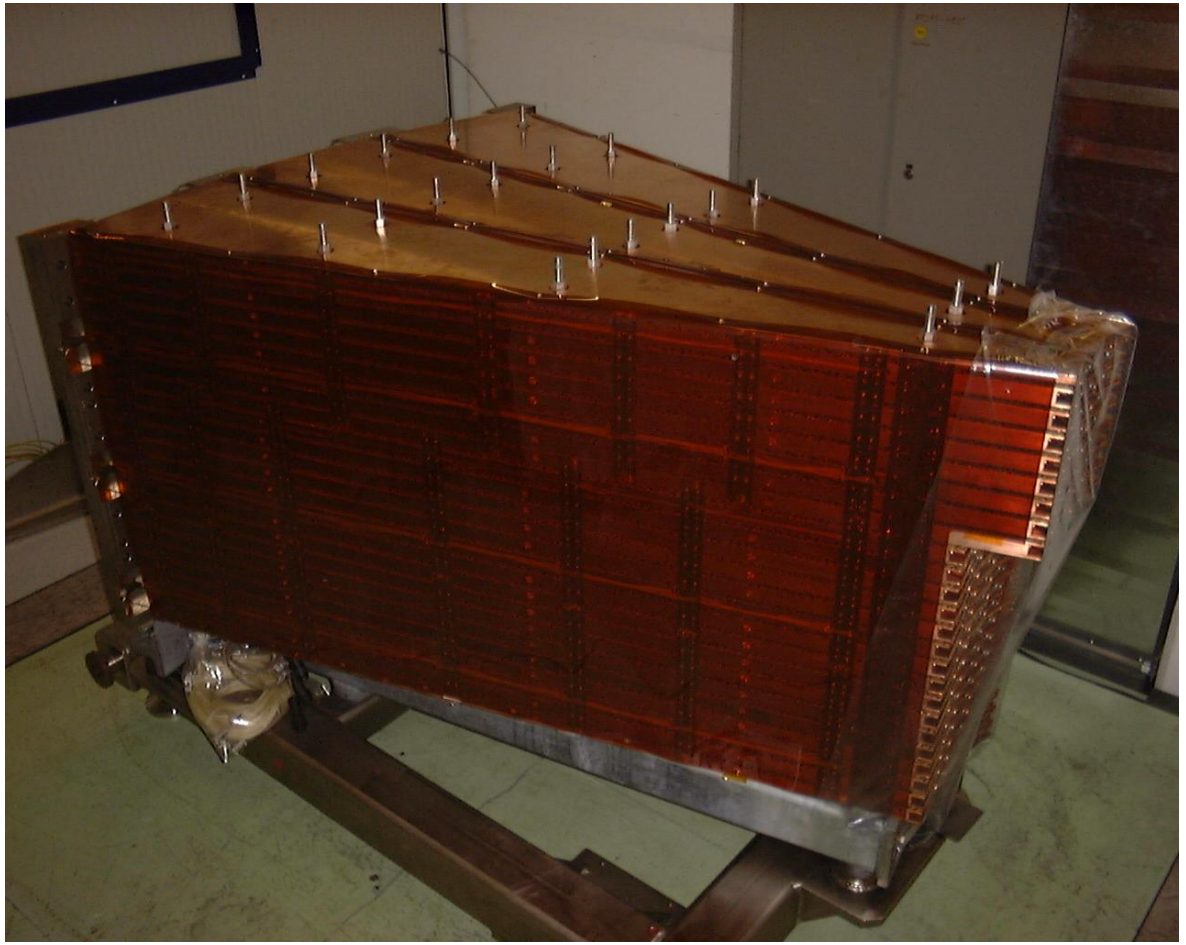
- **Code and geometry presented at the the meeting on June 15th [link].**
- **github [link].**
- **v1.0 released on 14/6/2021.**
- **850k events (e^-, π^-) events produced with HTCondor with no crashes and no warnings.**
- **Documentation available in README.md.**
- **All results in the following obtained with ATLHECTB v1.1**

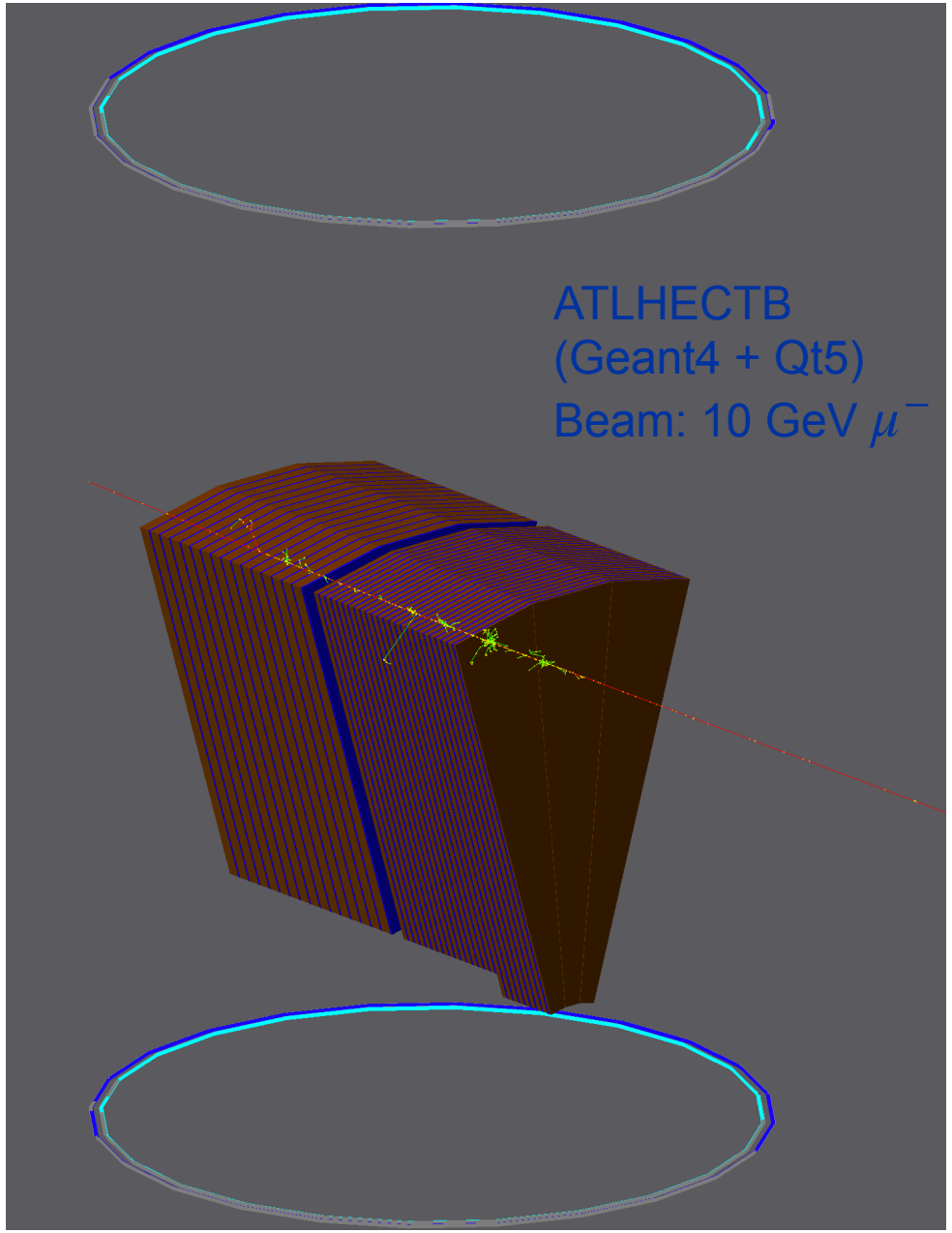


Default ATLHECTB geometry.



Picture from ATLAS HEC test beam (2000/2001). [link]





- **In the test beam configuration three modules are immersed in the cryostat.**
- **Beam particles pass through module 2 at 90° with respect to the HEC surface.**
- **Results in the following obtained with this beam setup.**

ATLHECTB signal computation

- Recombination of ions in LAr is dealt with a law inspired by the Birks Law for light emitting elements:

$$\Delta E' = \frac{\Delta E \cdot A}{1 + (k/E_f)(1/\rho)(\Delta E/\Delta x)}$$

$E_f = 10$ kV/cm - electric field in LAr gaps

$\rho = 1.396$ g/cm^3 - LAr density

$E_{min} = 1.51$ MeVcm^2/g - LAr minimal energy losses

$k = 0.0486$ kV/cm g/MeVcm^2 - Birks Law parameter

$A = 1 + (k/E_f) \cdot E_{min}$ - Birks Law parameter

- **Same parameterization adopted in ATHENA.**
- **Each ionizing energy deposit in LAr $(\Delta E, \Delta x)$ is used as input for $\Delta E'$ calculation.**
- **No electronic noise or signal smearing included so far.**

ATLHECTB event data model

- **The HEC Module readout channels define a granularity of**

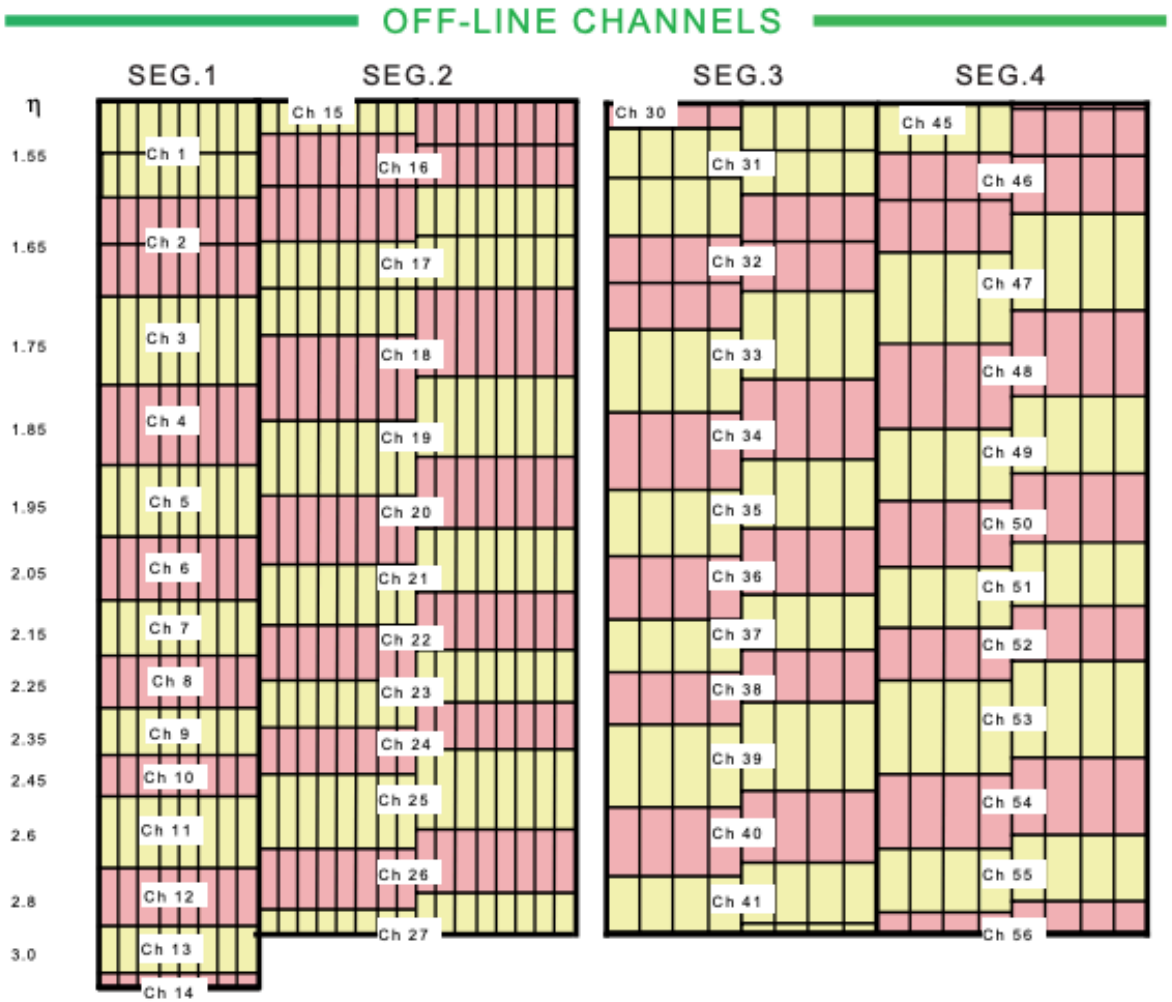
$$\Delta\eta \times \Delta\phi = 0.1 \times 0.1 \text{ for } |\eta| < 2.5$$
$$\Delta\eta \times \Delta\phi = 0.2 \times 0.2 \text{ for } |\eta| > 2.5$$

Table 1: Parameters of HEC longitudinal layers

Layer	Wheel	Number of LAr gaps	Layer length [cm]	Layer length [λ_{int}]	Number of channels per module
1	HEC1	8	28.05	1.45	24
2	HEC1	16	53.60	2.75	23
3	HEC2	8	53.35	2.87	21
4	HEC2	8	46.80	2.66	20

- **88 channels per module.**
  88 channels x 3 modules in the TB configuration.

Found at [Link]

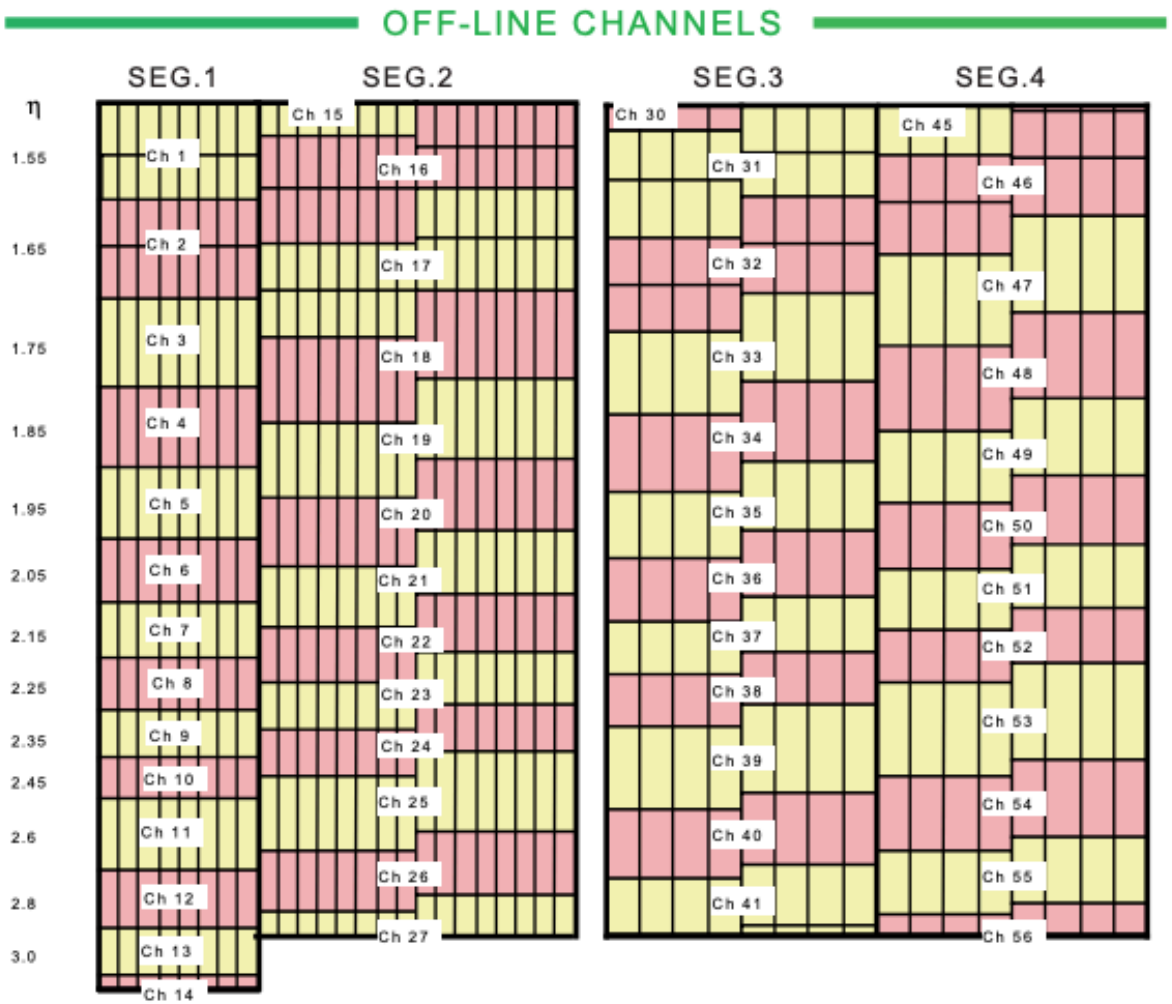


ATLHECTB channels selection

- e^- events are reconstructed from the 7 channels with, on average, the highest signal.
  The 7 channel are selected once and kept for every event at every beam energy.

- π^- events are reconstructed starting from the channels that, on average, have a signal greater than 2.1 MeV (15 nA) at 180 GeV.
  50 channels were selected and kept fixed at every event at every beam energy.

Found at [Link]

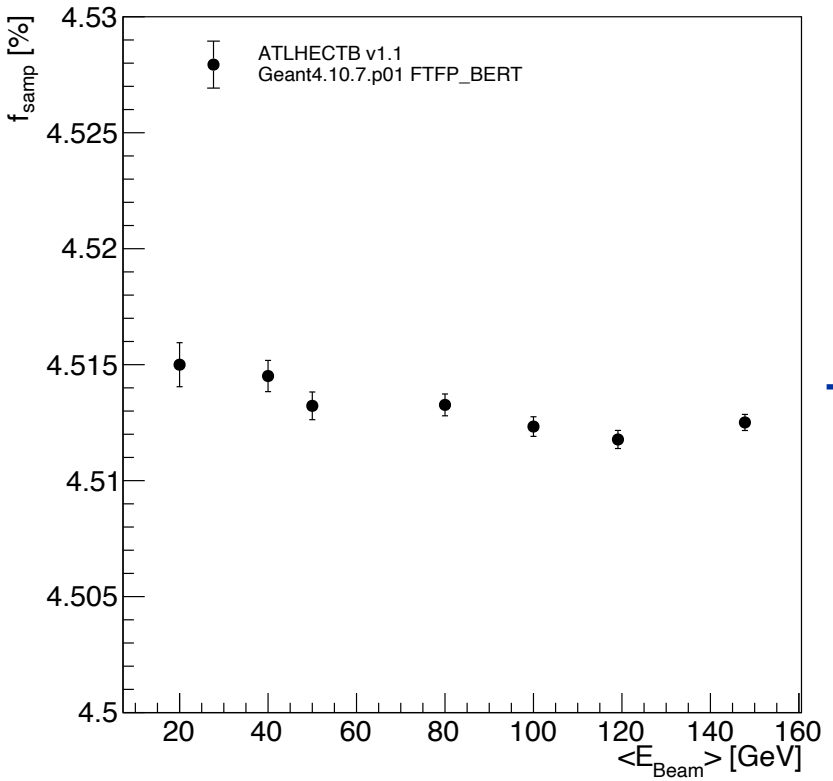


e^- results and comparison with ATLAS

Very encouraging agreement between ATLHECTB and ATLAS SW.

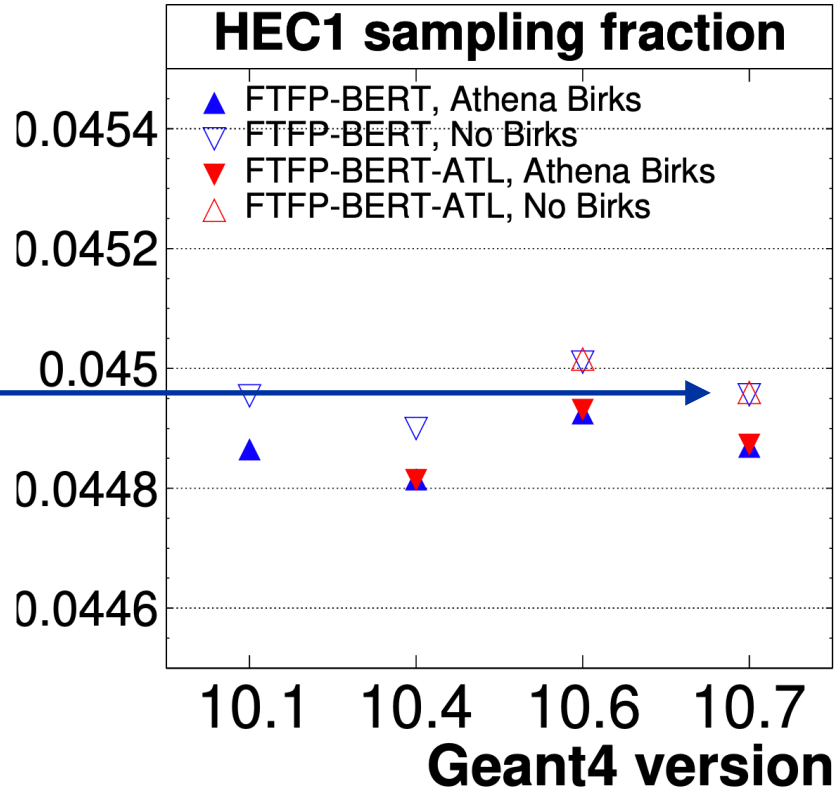
ATLHECTB

Sampling fraction estimated as energy deposited in calo divided by total visibile energy.



ATLAS LAr Simulation Group

Sampling fraction estimation. [link]



e^- results and comparison with ATLAS

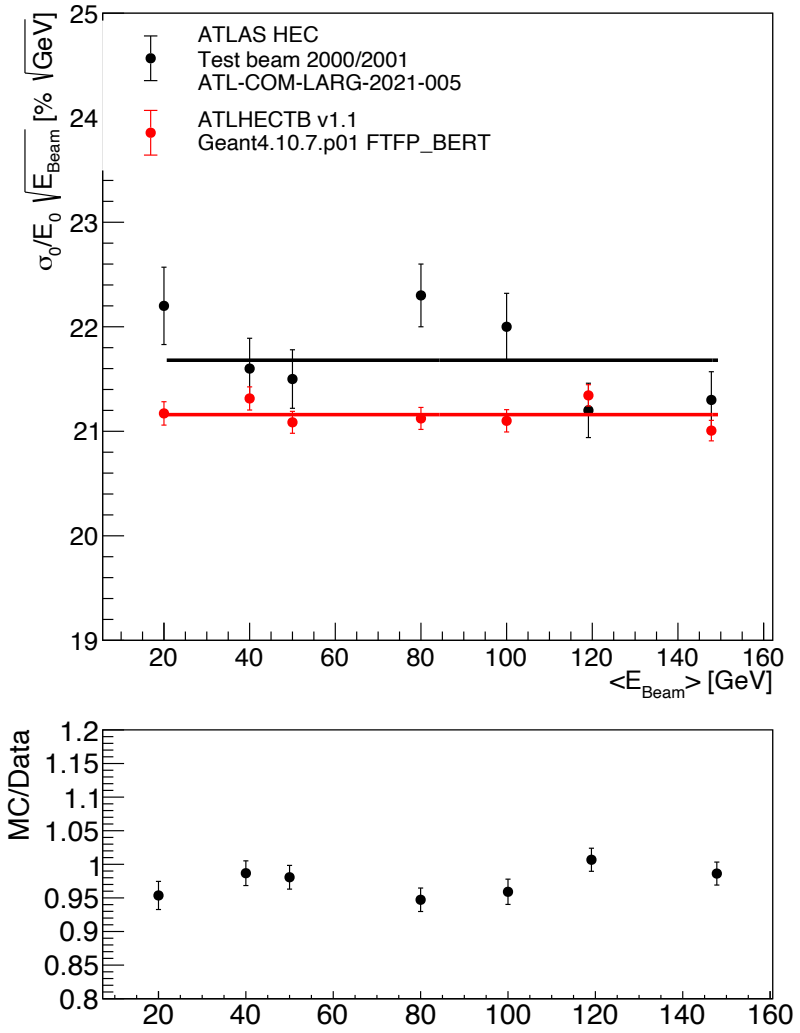
- The calorimeter response to electrons was found to be constant and used as a gauge to reconstruct beam energies.
  A gaussian fit was performed over energy distributions and used for energy resolution measurements.

- Can be directly compared to TB results (ATL-COM-LARG-2021-005) as ATLAS quotes

  [link] $\sigma_0 = \sqrt{\sigma_E^2 - \sigma_{noise}^2}$

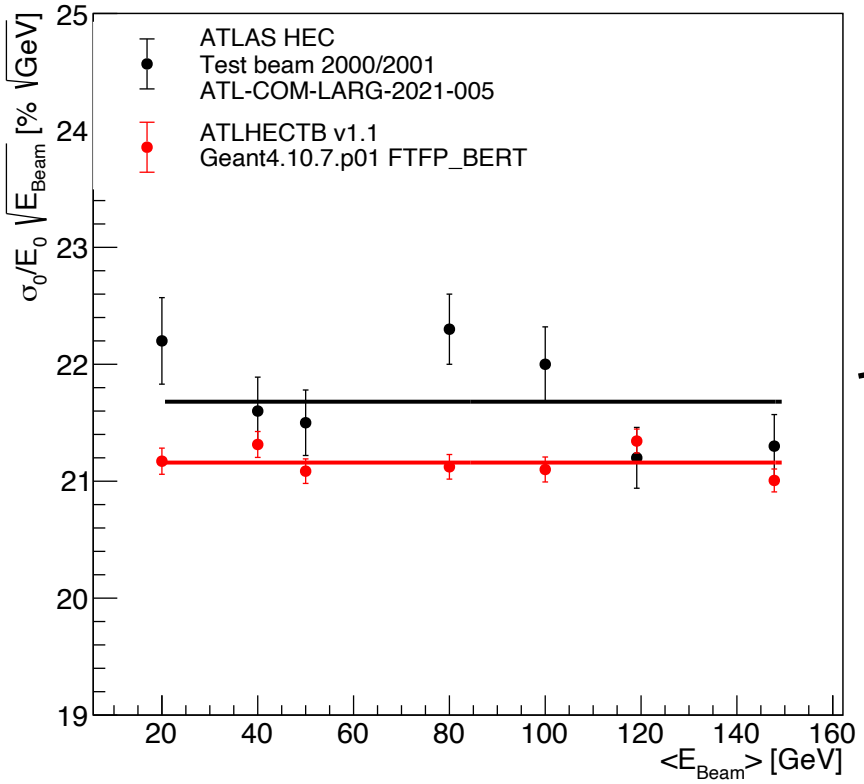
- **ATLAS HEC TB 2000/2001**:
  $A = 21.71 \pm 0.11\,\% \sqrt{GeV}$

  ATLHECTB v1.1 FTFPBERT:
  $A = 21.16 \pm 0.04\,\% \sqrt{GeV}$

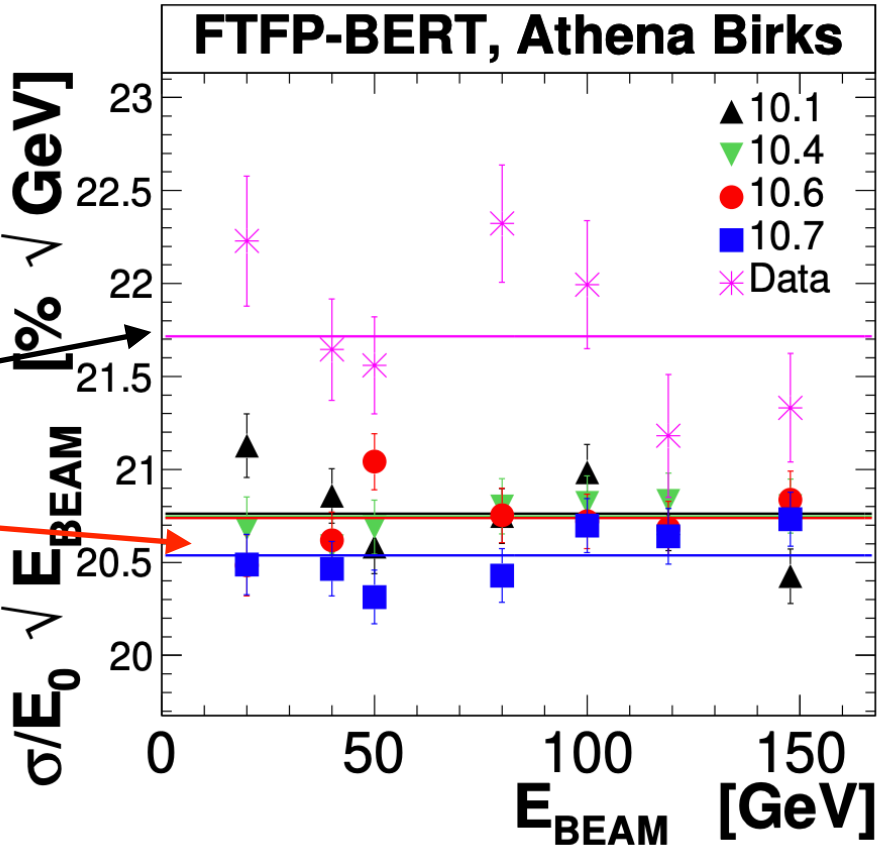


e^- results and comparison with ATLAS

ATLHECTB v1.1
FTFP_BERT
e^- energy resolution

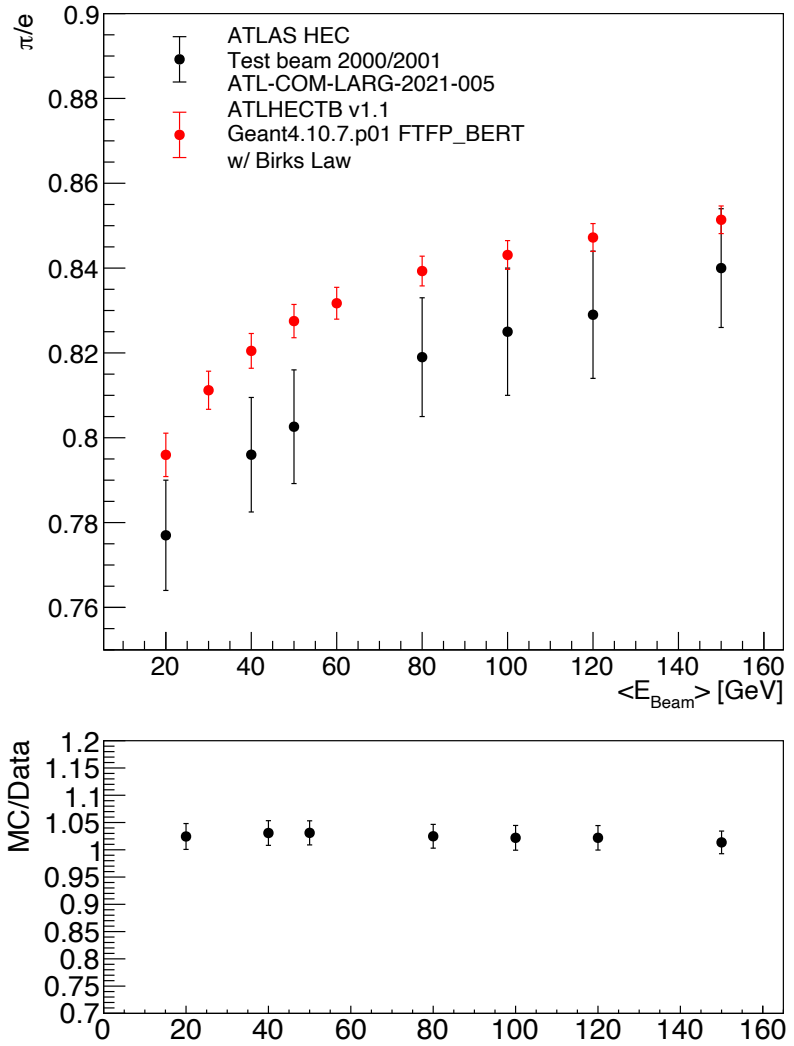


ATLAS LAr Simulation
e^- energy resolution (preliminary)
[link]



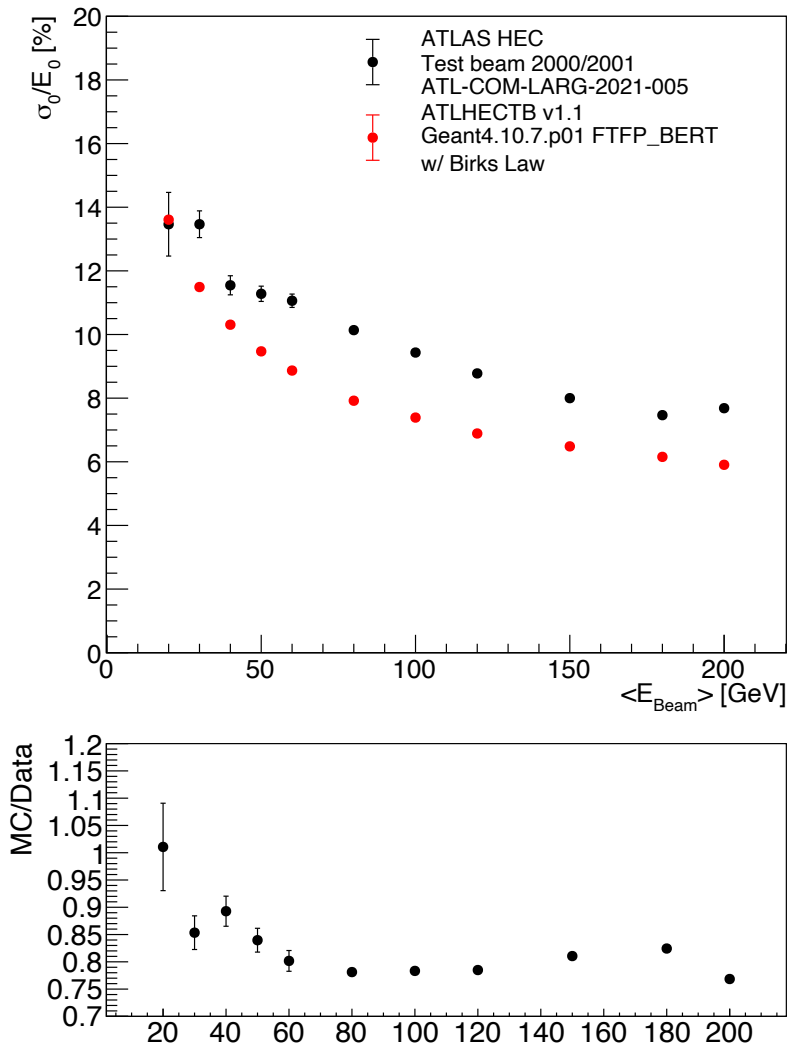
π^- results and comparison with ATLAS

- π/e is obtained from the ratio of the average π reconstructed energy, using the em-response, and the corresponding average e^- reconstructed energy.
- In the energy range 20-150 GeV, ATLHECTB, using geant4.10.7.p01 FTFP_BERT, is within $5\ \%$ agreement with test-beam data.



π^- results and comparison with ATLAS

- π^- energy resolution is obtained from a gaussian fit to the (asymmetric) energy distribution.
- In the energy range 20-200 GeV, ATLHECTB, using geant4.10.7.p01 FTFP_BERT, is ~20 % off w.r.t test-beam data.

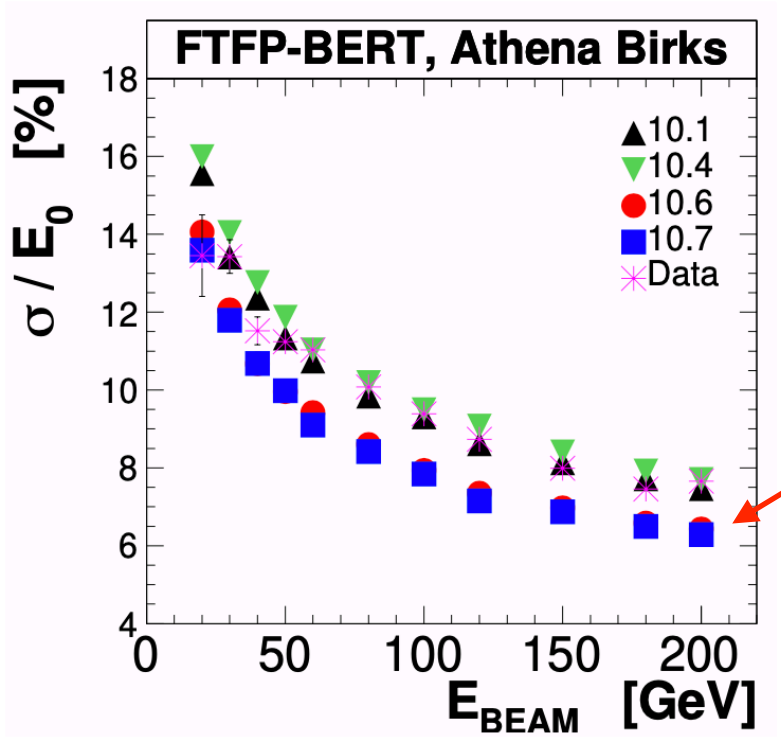


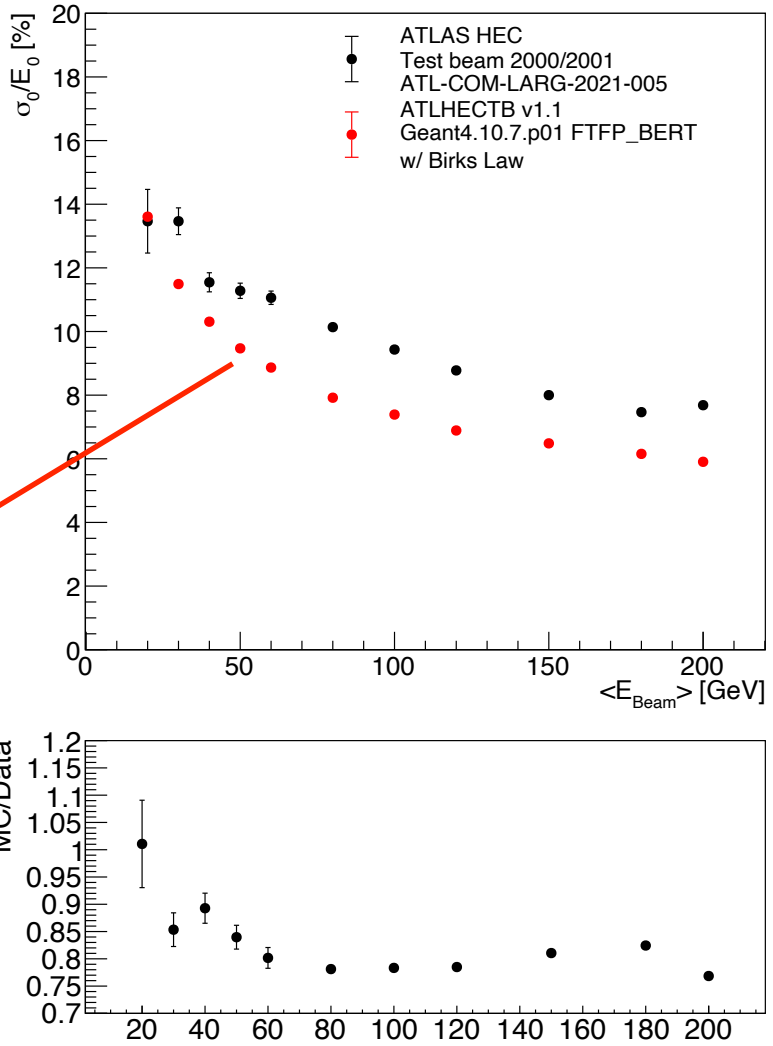
π^- results and comparison with ATLAS

- Same problem found with the ATLAS Simulation, linked to Geant4.10.7 version. Mostly recovered with previous versions.

ATLAS LAr Simulation Group

π^- energy resolution (preliminary) [link]





π^- results

- Fraction of energy in each layer
  $F_i = < E_i > / E_{sum}$, $E_{sum} = \Sigma < E_i >$
- F_i dependence on E_{beam} very well reproduced.

HEC longitudinal structure

HEC layer	Number of LAr gaps	HEC length [cm]	HEC length [λ_{int}]
1	8	28.05	1.45
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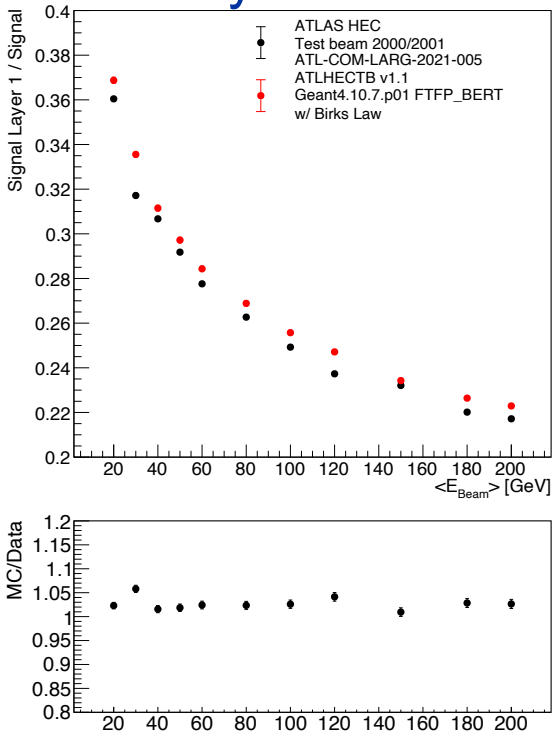
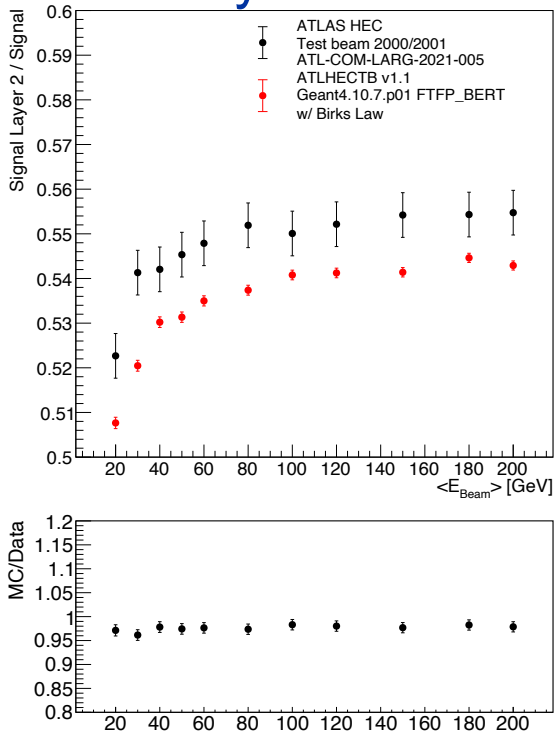
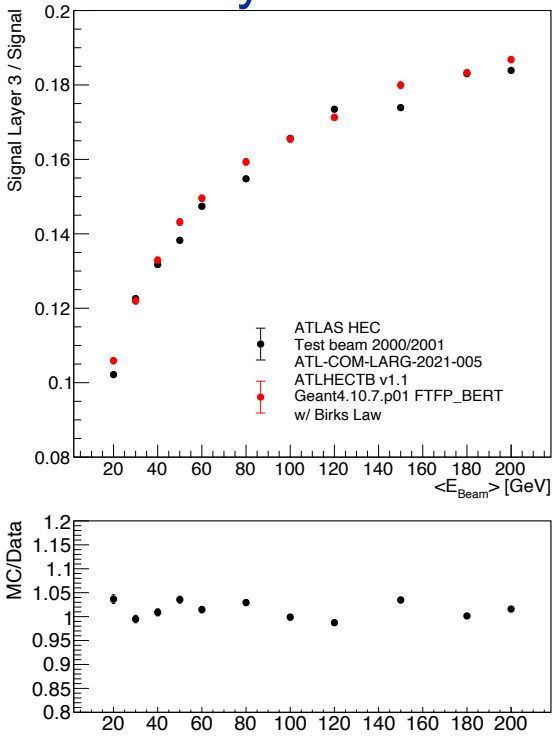
Layer 1



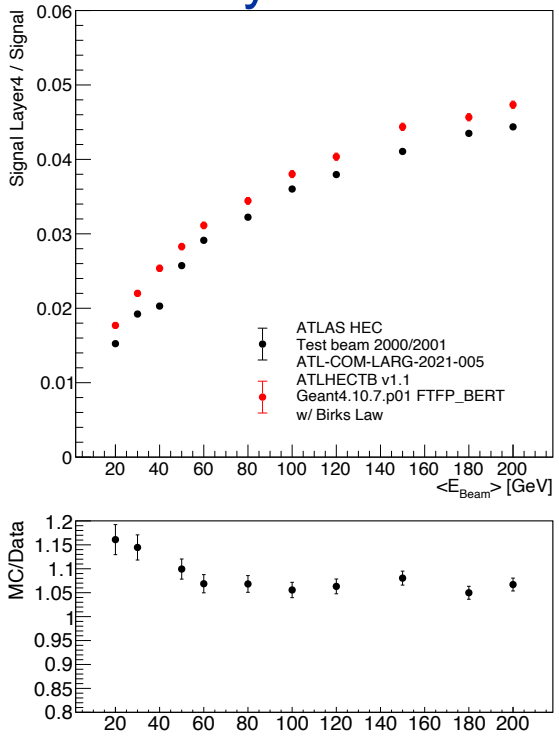
Layer 2



Layer 3

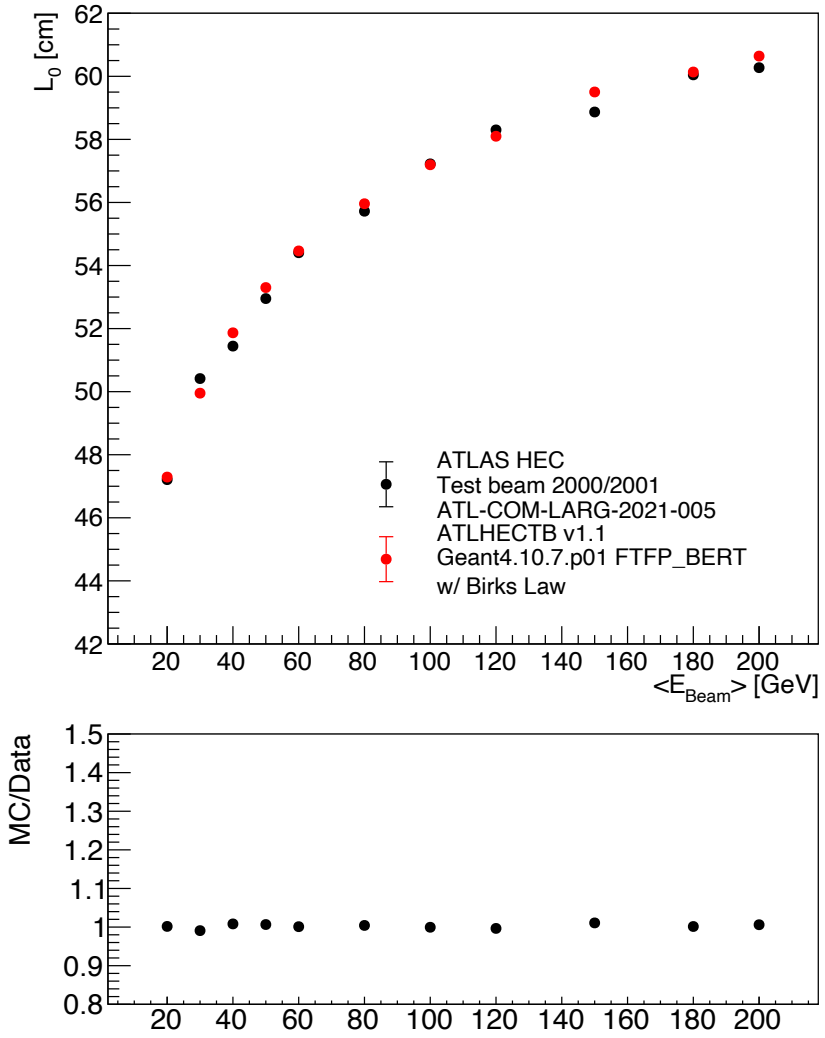


Layer 4



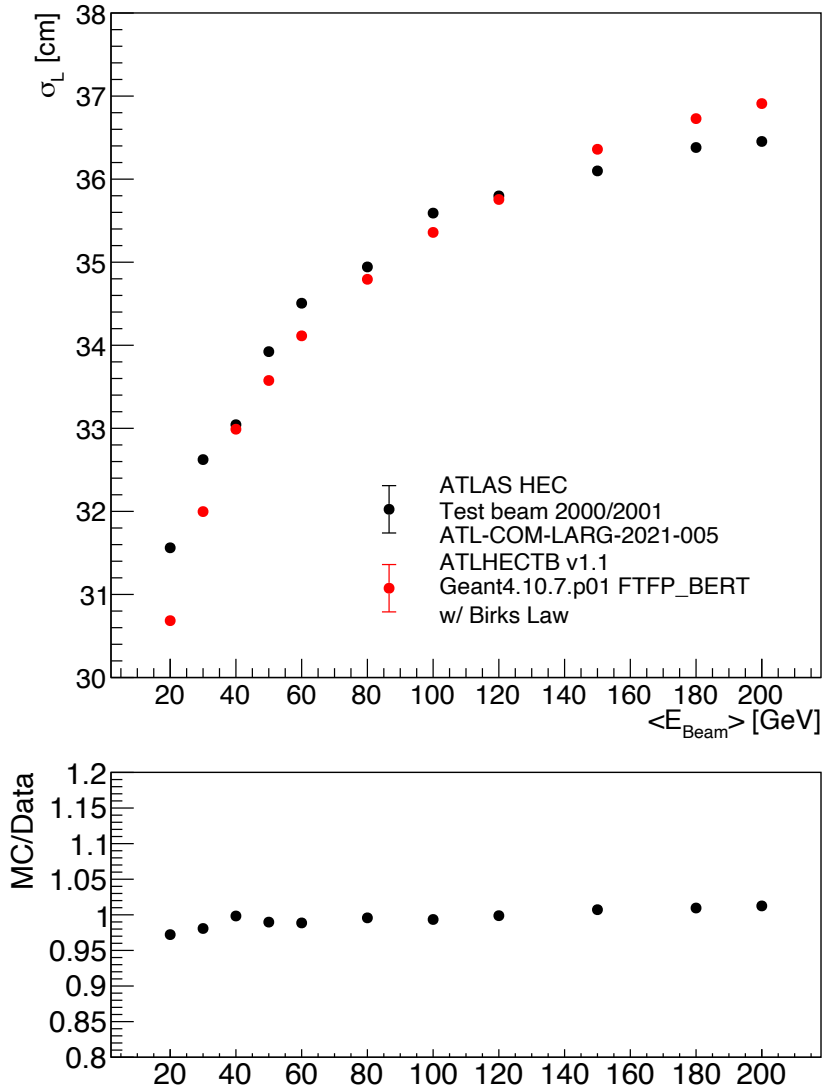
π^- results

- Hadronic showers longitudinal profiles
  extracted from the fraction of the energy in HEC layers, as a function of the layer longitudinal position.
- Mean: L_0 measurement of the hadronic shower (average) depth.
- Excellent description of hadronic shower depth, as a function of E_{Beam}, for nuclear interaction in copper.



π^- results

- Hadronic showers longitudinal profiles
  extracted from the fraction of the energy in HEC layers, as a function of the layer longitudinal position.
- RMS: σ_L measurement of the hadronic shower (average) longitudinal size.
- Good description of hadronic showers longitudinal size, as a function of E_{Beam},
  for nuclear interaction in copper.



Conclusions

- **A Geant4 validation program was recently started including ATLAS, Dual-readout and CALICE calorimeters.**
- **A standalone Geant4 ATLAS HEC simulation was written and is currently available.**
- **First results with e^- and π^- indicate good agreement with the ATLAS SW and ATLAS HEC 2000/2001 TB data.**

What next?

1. **Spot the origin of the (small) differences w.r.t ATLAS SW (Using FTFP_BERT and FTFP_BERT_ATL).**
2. **Adding ATLHECTB into geant-val.**

Backup material

Sanity check results

- **Performed some sanity checks to spot bugs.**

  E_{vis} **- total visible energy deposited in calo**

  E_{leak} **- total energy leaked (out of world leakage + energy in cryostat)**