First results from the Geant4 ATLAS HEC test beam simulation

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Geant4 validation using ATLAS HEC beam tests

- Project: validate Geant4 using data 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.**

   ✔ A first version was released last week.

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

   ✔ First (preliminary) data available.

3. **Include the application in the geant-val validation testing suite.** ✎ To be done.

ATLAS LAr SW - Our starting point

- ATLAS provided a simulation package used for LAr calorimeter simulations.
  Available on gitlab [link].
  Not integrated in ATHENA, but many points in common.

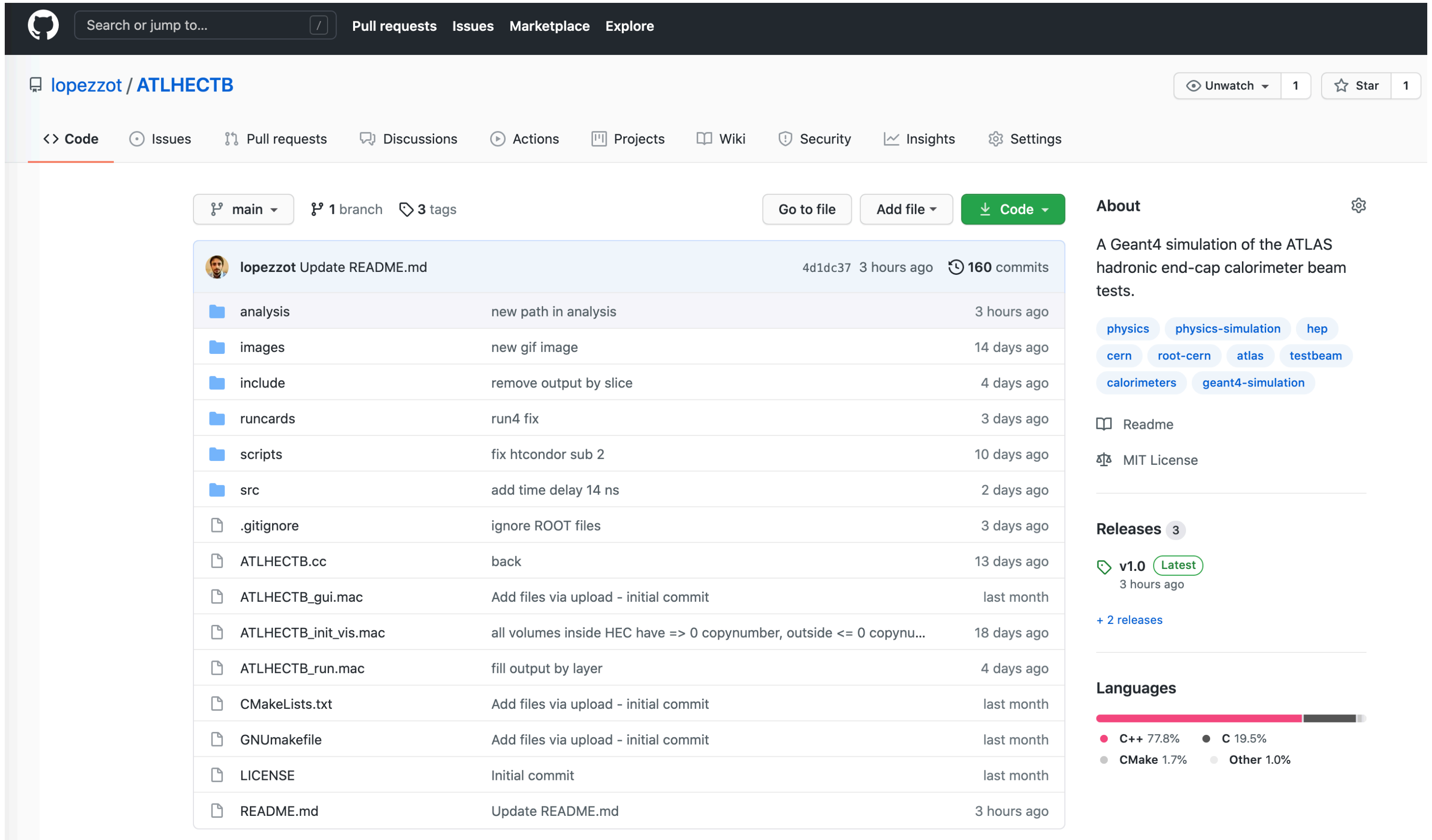
- Main changes while porting to a Geant4 standalone application:

1. Eliminate geometry parameters extraction from ATLAS MySQL Geo DB. ✓
2. Eliminate any env variable dependency but Geant4 (ROOT, …). ✓
3. Ensure multi-threading as the Geant4 standard (G4RunManagerMT, G4analysis). ✓
4. Migrate from make to cmake. ✓

ATLHECTB

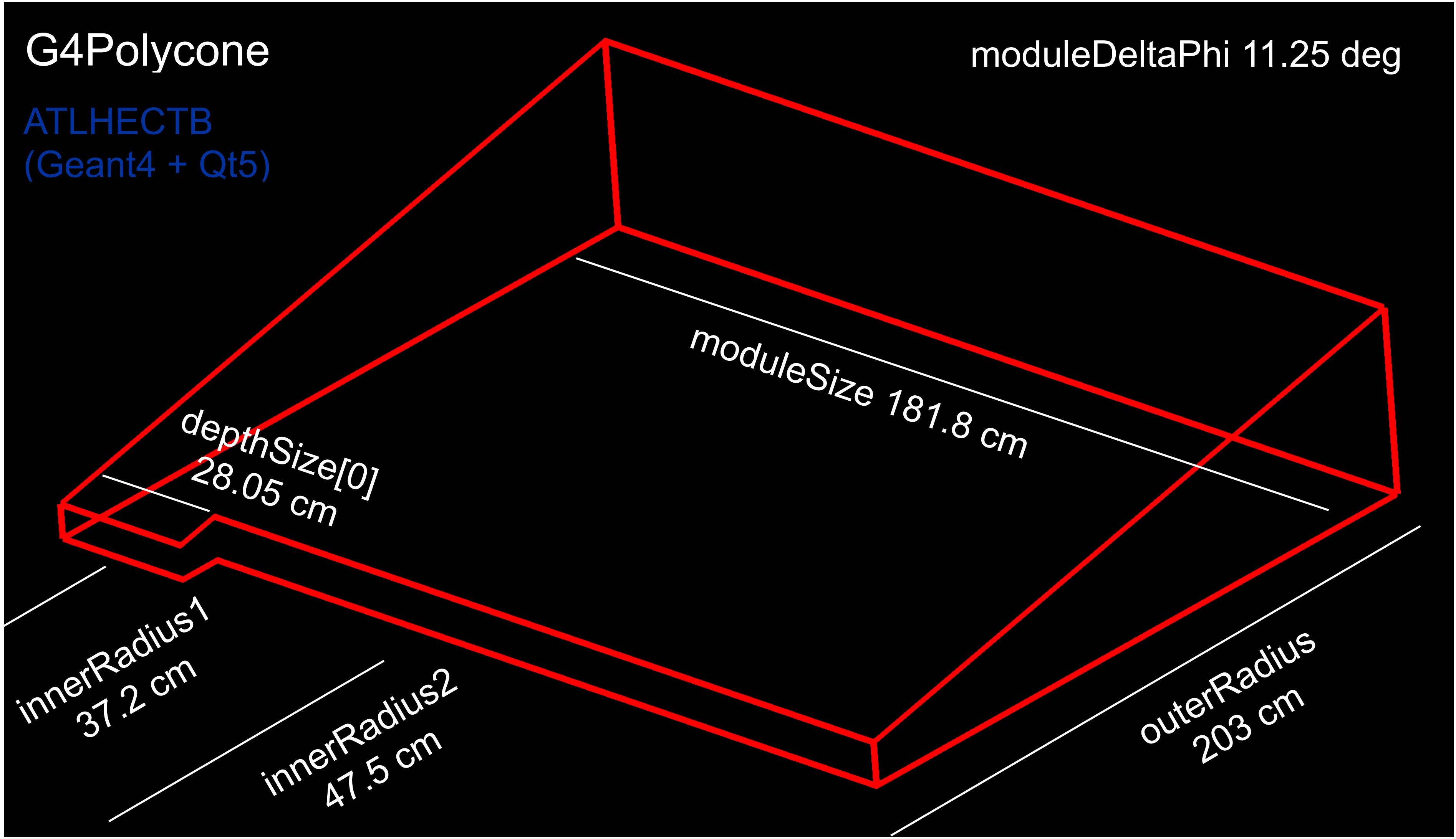
A Geant4 simulation of the ATLAS hadronic end-cap calorimeter beam tests.

- 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 v1.0.

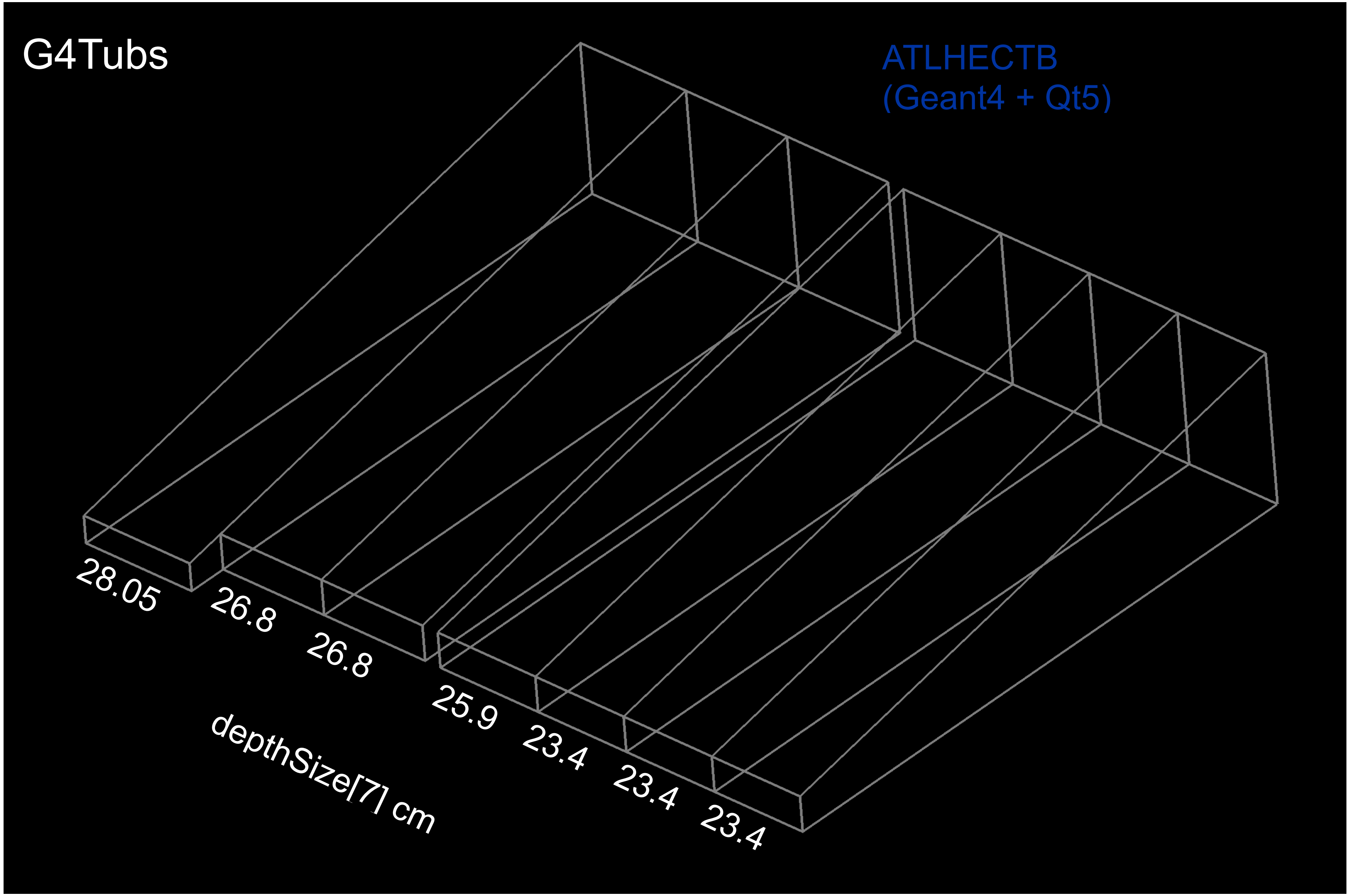


ATLHECTB geometries

- **The HEC geometry is based on a key object called "module". A module is described by a G4Polycone.**

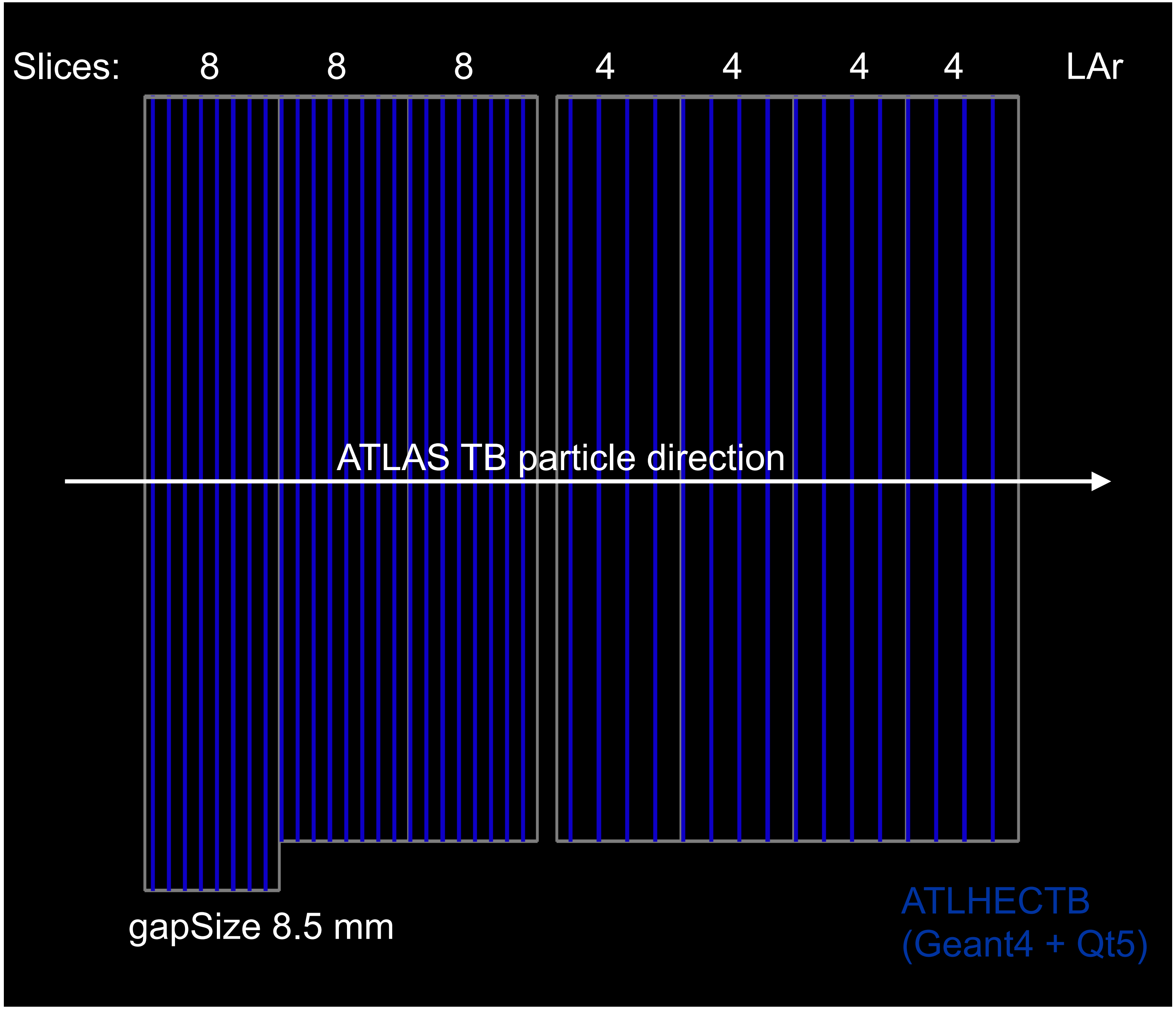


- **Each module is divided in 7 "depths" objects with different sizes.**
  Each depth is a G4Tubs.

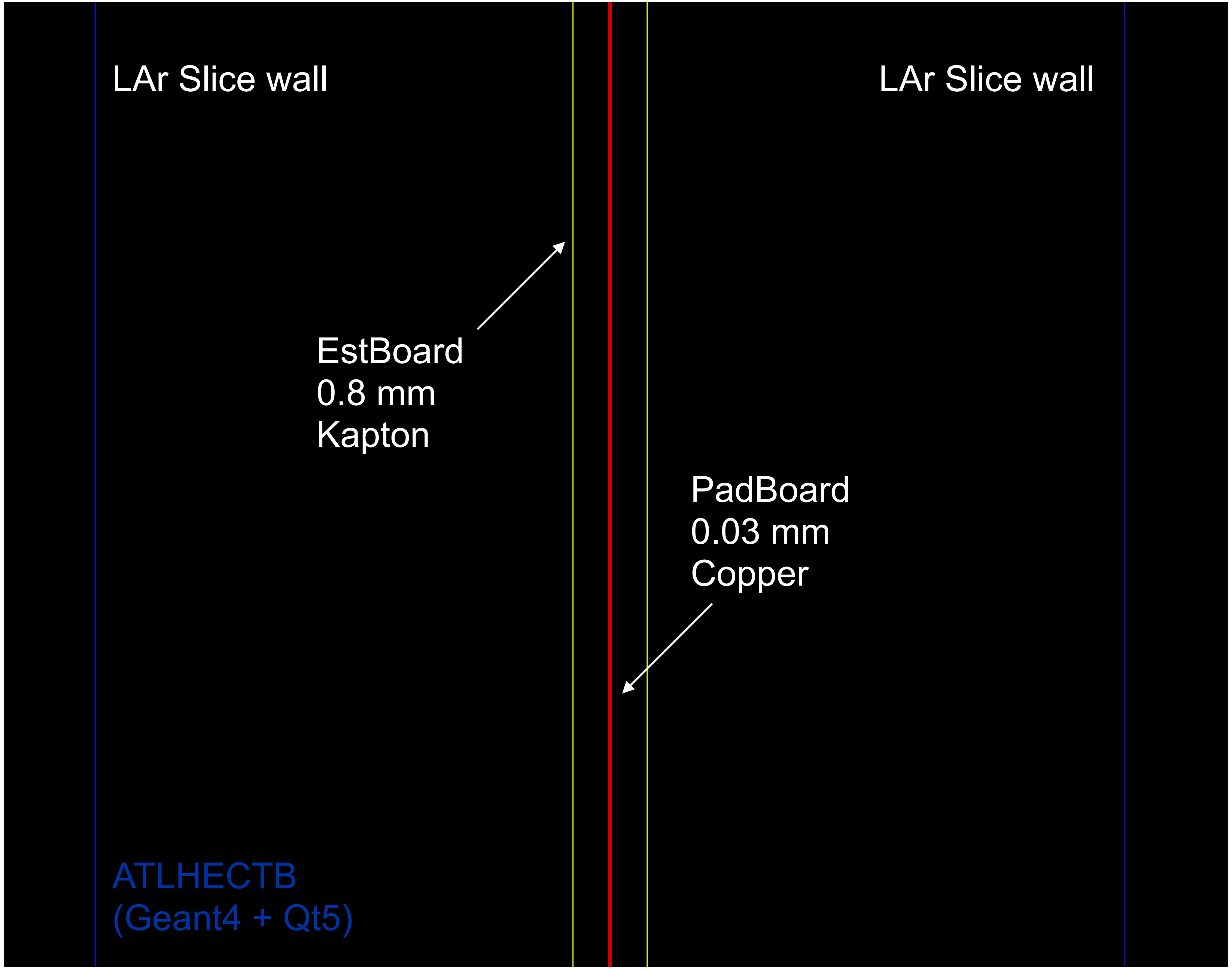


- The first three depths are filled with 8 LAr slices each. The remaining four depths are filled with 4 LAr slices each.

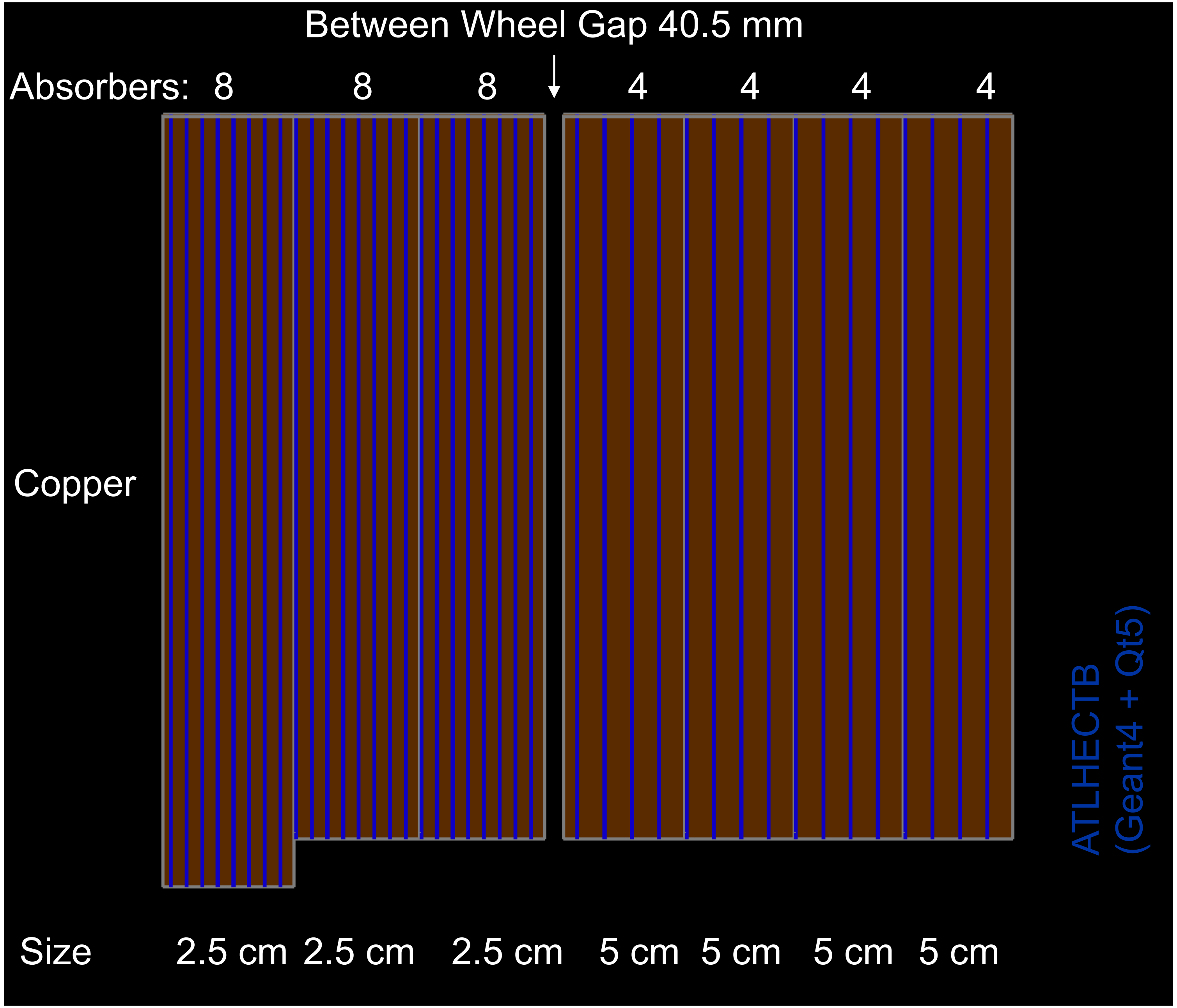
- Each LAr slice is a 8.5-mm-thick G4Tubs.



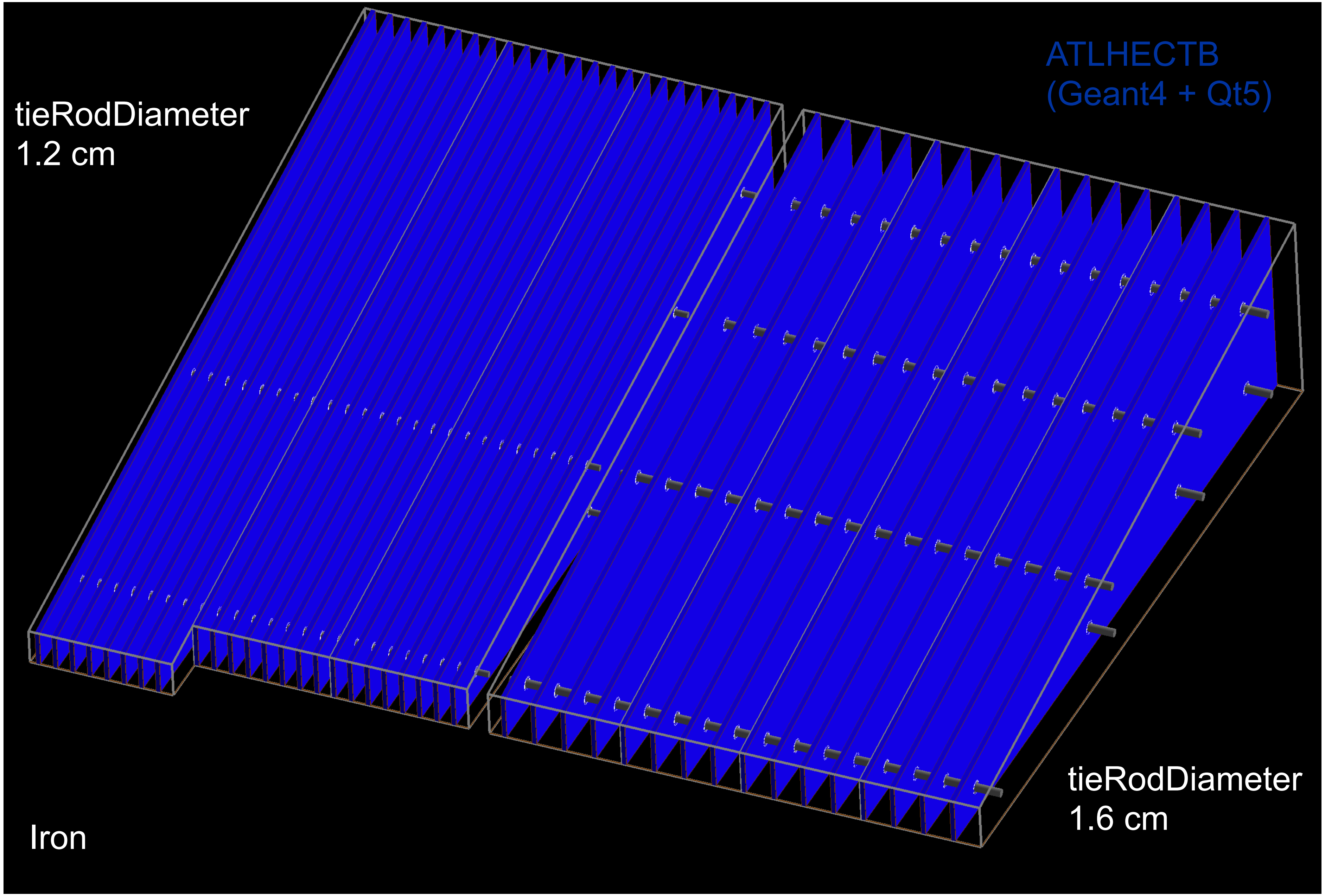
- Each slice is filled with a **0.8-mm-thick external board** (Kapton).
- Each external board is filled with a **0.03-mm-thick copper readout board**.
- Each board is a G4Tubs.
- HEC signal is created by capacity coupled induced signals on copper by free charge in LAr. Details given later.



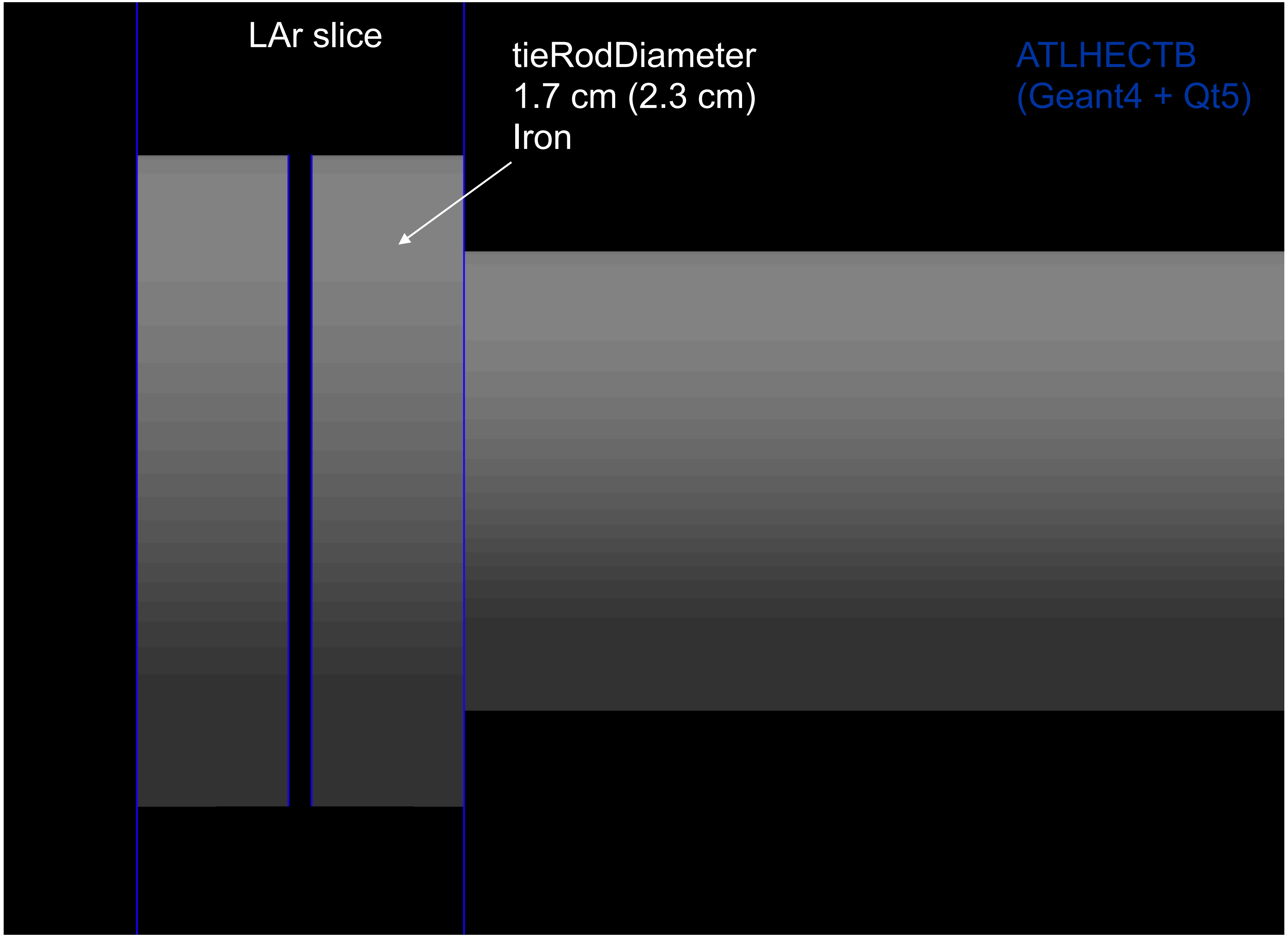
- **The first three depths are filled with 8 2.5-cm-thick copper absorbers. The remaining four depths are filled with 4 5-cm-thick copper absorbers.**
- **Each absorber is a G4Tubs.**
- **Sampling fraction (for *mips*) is twice higher in the last four depths.**



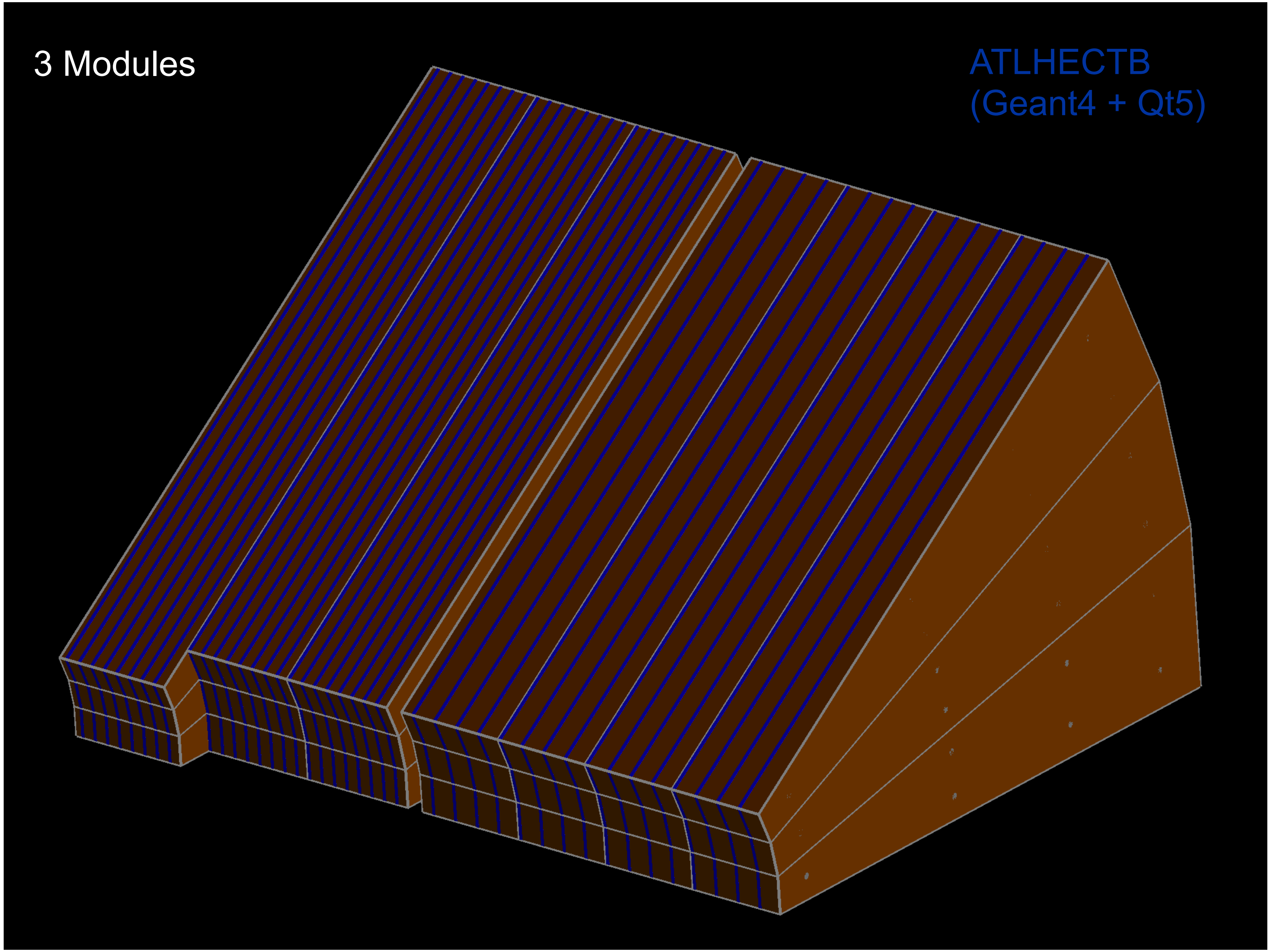
- **Absorbers are pulled together with 7 iron tie rods per module.**
- **Each tie rod is a G4Tubs.**



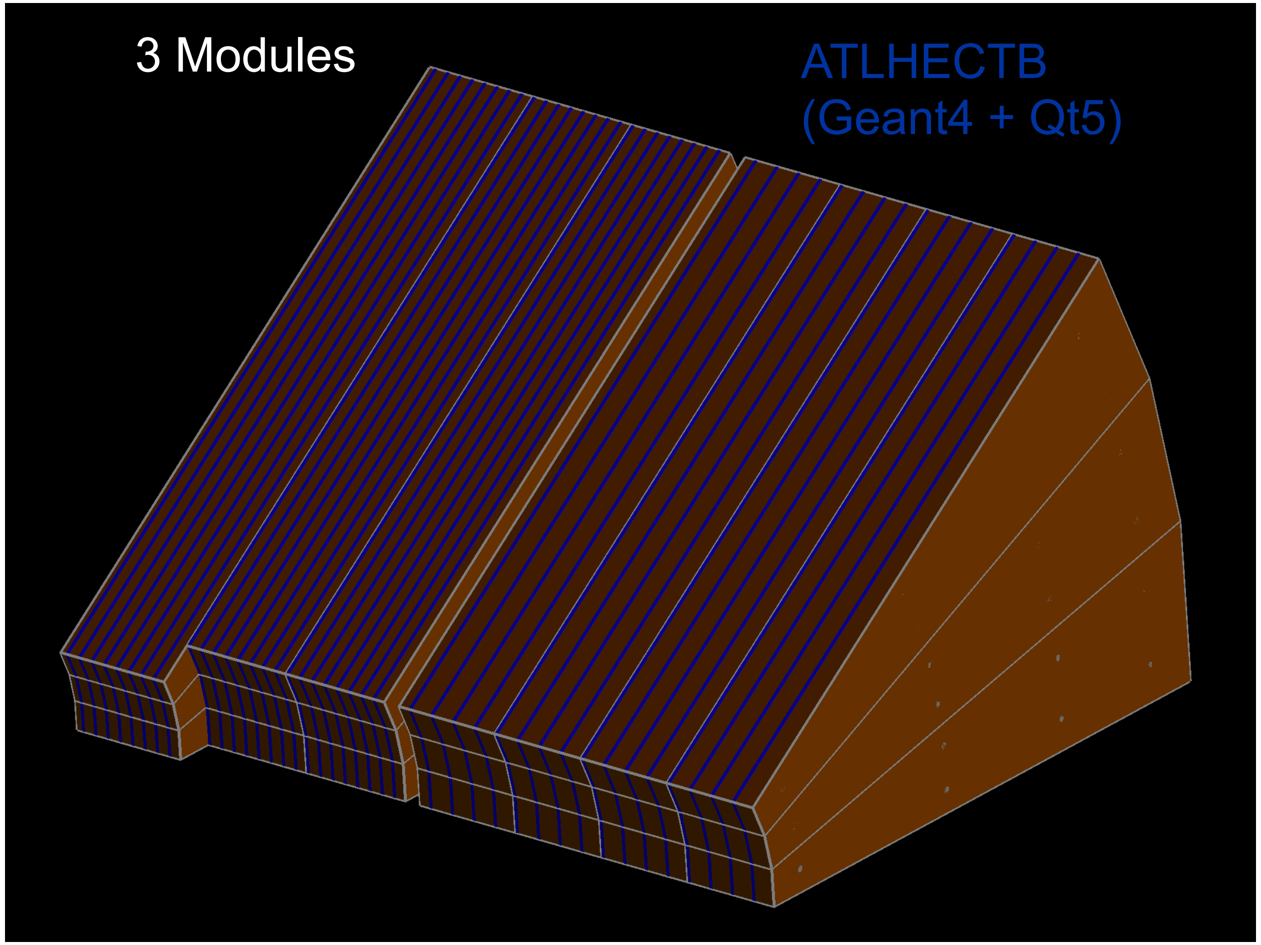
- **Tie rods extend within the LAr slices with diameters of 1.7 cm (first three depths) and 2.3 cm (remaining four depths).**



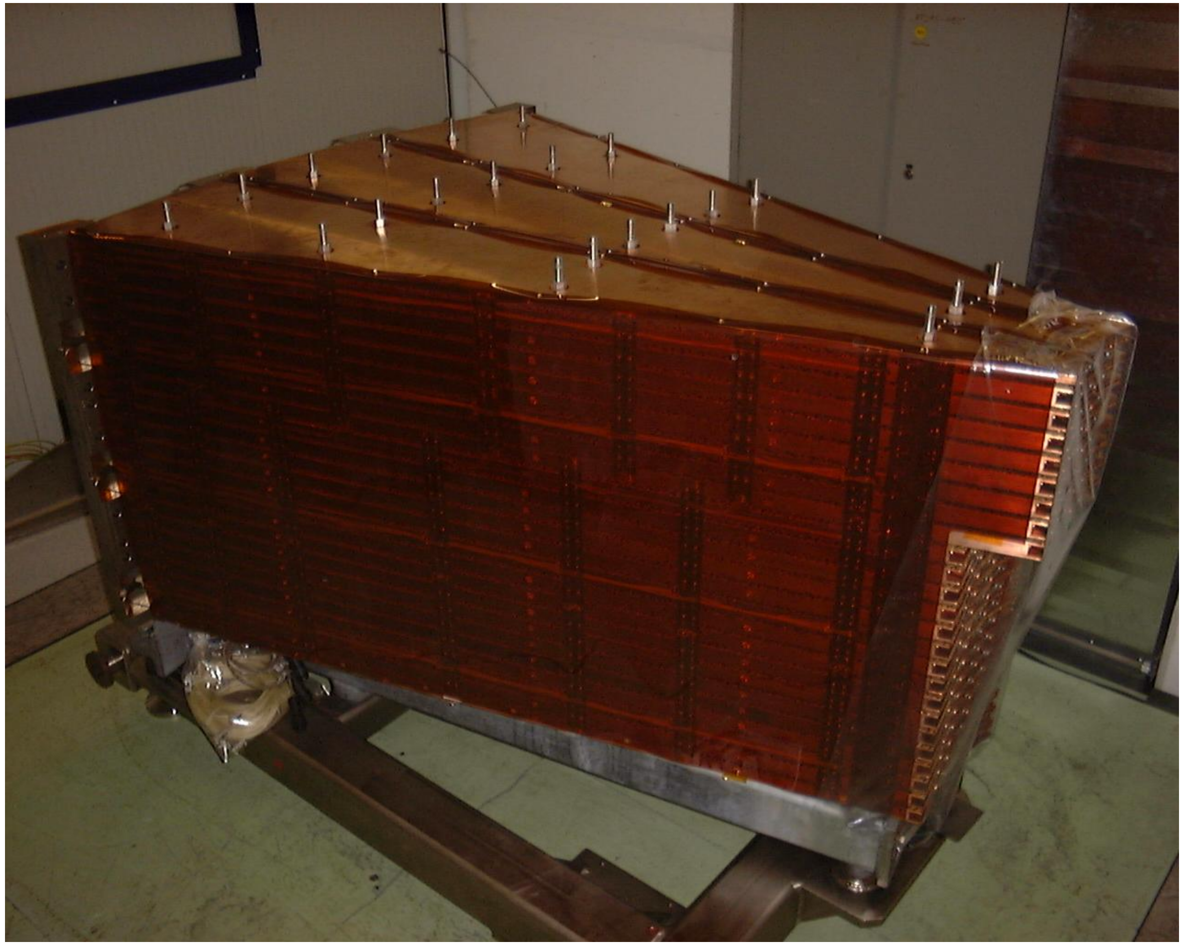
- **3 HEC Modules are used to recreate the HEC test beam Calorimeter.**

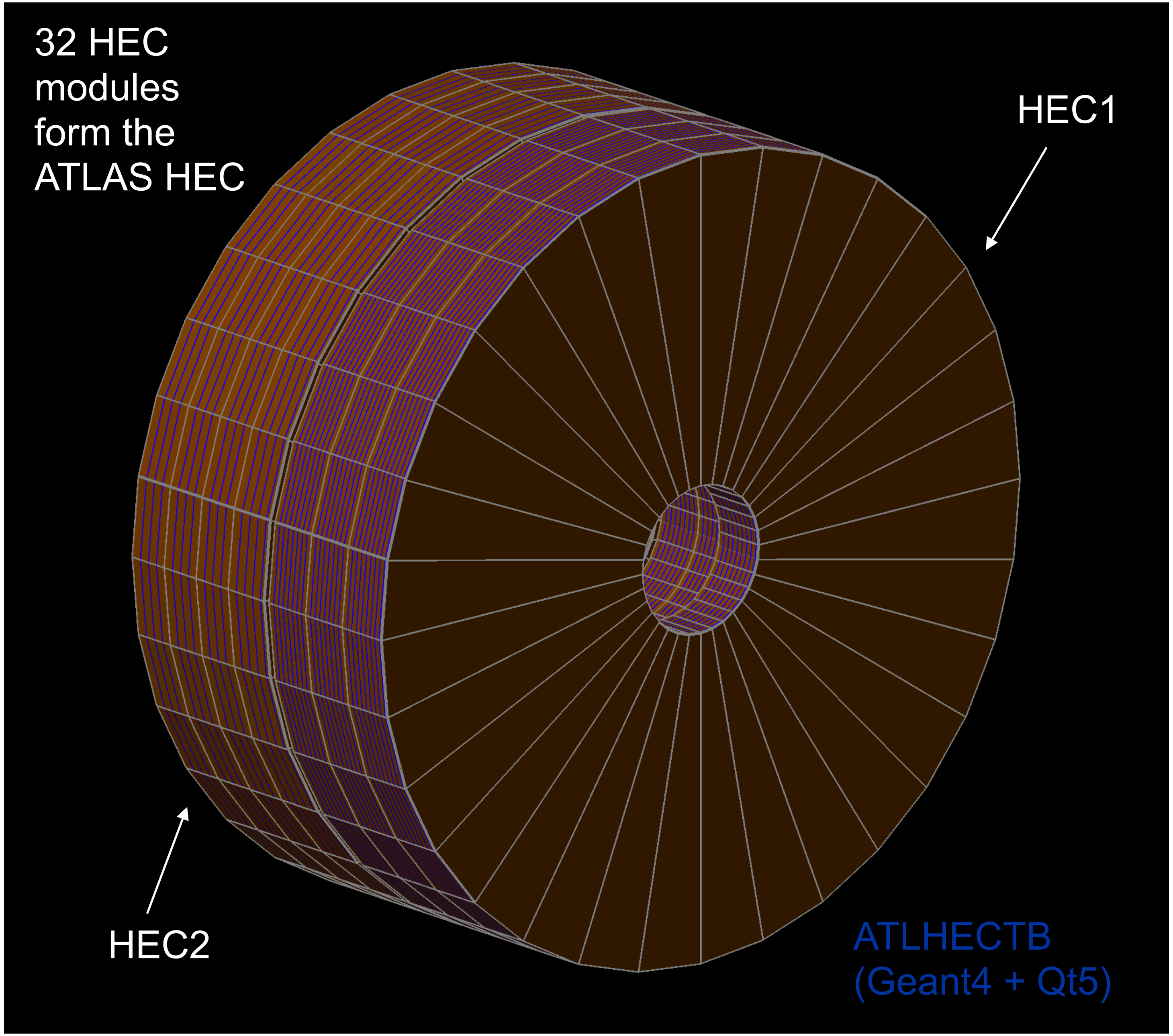


Default ATLHECTB geometry.

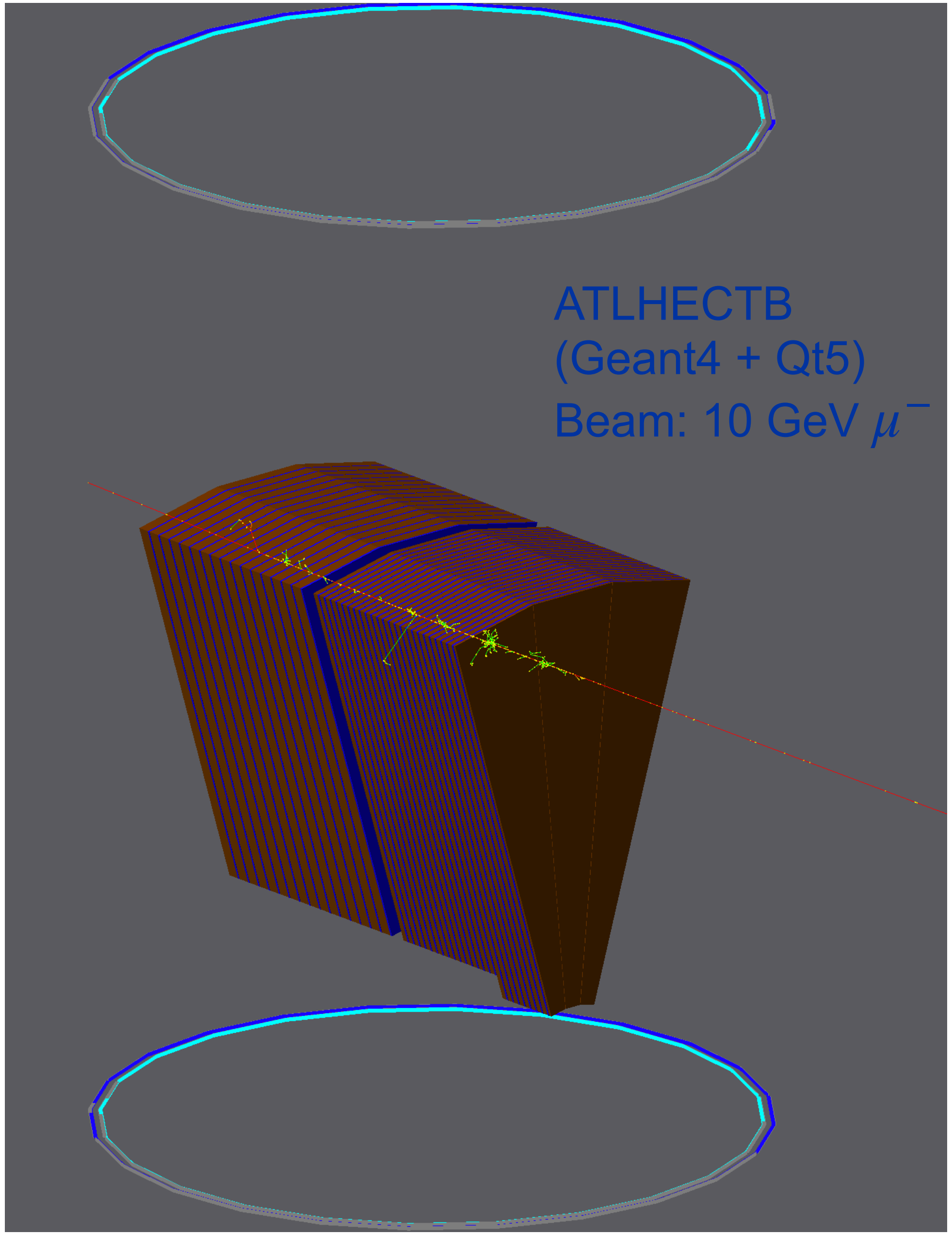


Picture from ATLAS HEC test beam (2000/2001). [link]





- **ATLHECTBDetectorConstruction.cc** implements a modular geometry that can reproduce up to the whole ATLAS HEC Detector.
- **ATLHECTBDetectorConstruction.cc** implements the geometry in ~10^3 lines of code.



- **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**

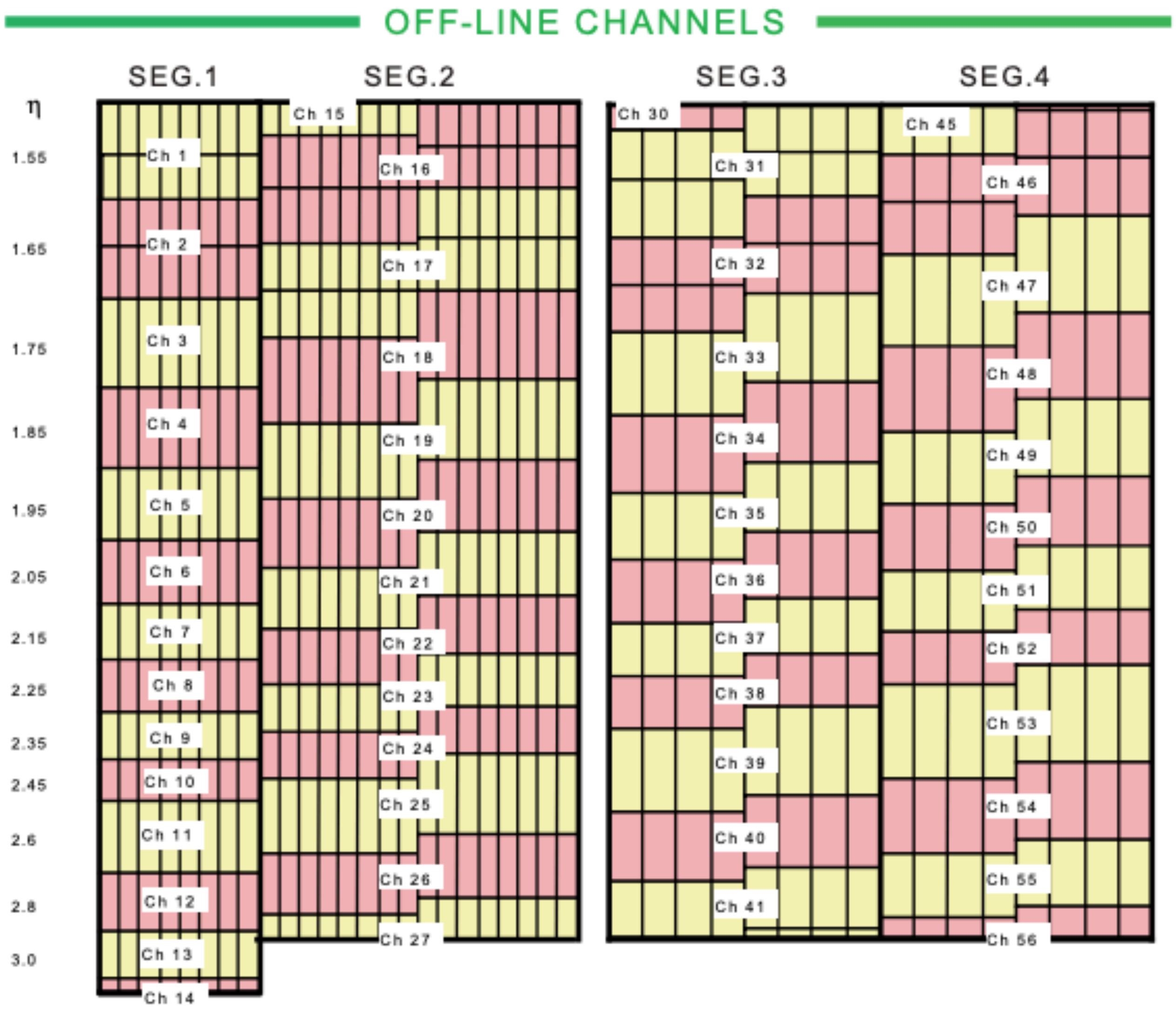
$$\Delta\eta \times \Delta\phi = 0.1 \times 0.1 \text{ for } |\eta| < 2.5$$
$$\Delta\eta \times \Delta\phi = 0.2 \times 0.2 \text{ for } |\eta| > 2.5$$

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 event data model

For each hit position the eta variable is calculated:

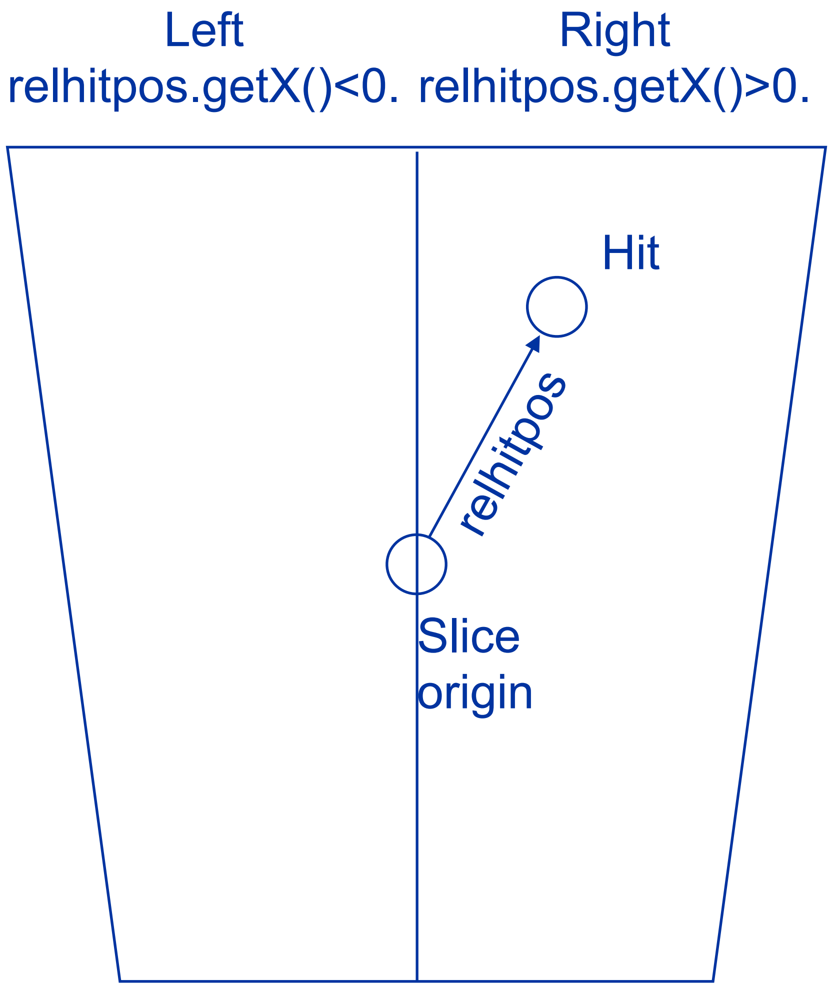
```
G4ThreeVector hitpos = step->GetPreStepPoint()->GetPosition();
hitpos.getEta();
```

If $|\eta| < 2.5$ need to distinguish left and right wrt slice axis.

```
G4ThreeVector sliceorigin = step->GetPreStepPoint()->GetTouchable()->GetHistory()->GetTopTransform().Inverse().TransformPoint(origin);
G4ThreeVector relhitpos = sliceorigin-hitpos;
```

A singleton (ATLHECTBSignalCalculator) gets eta, the hit relative position within the slice and the ionizing energy deposit.
It computes readout channel index and applies Birks Law.

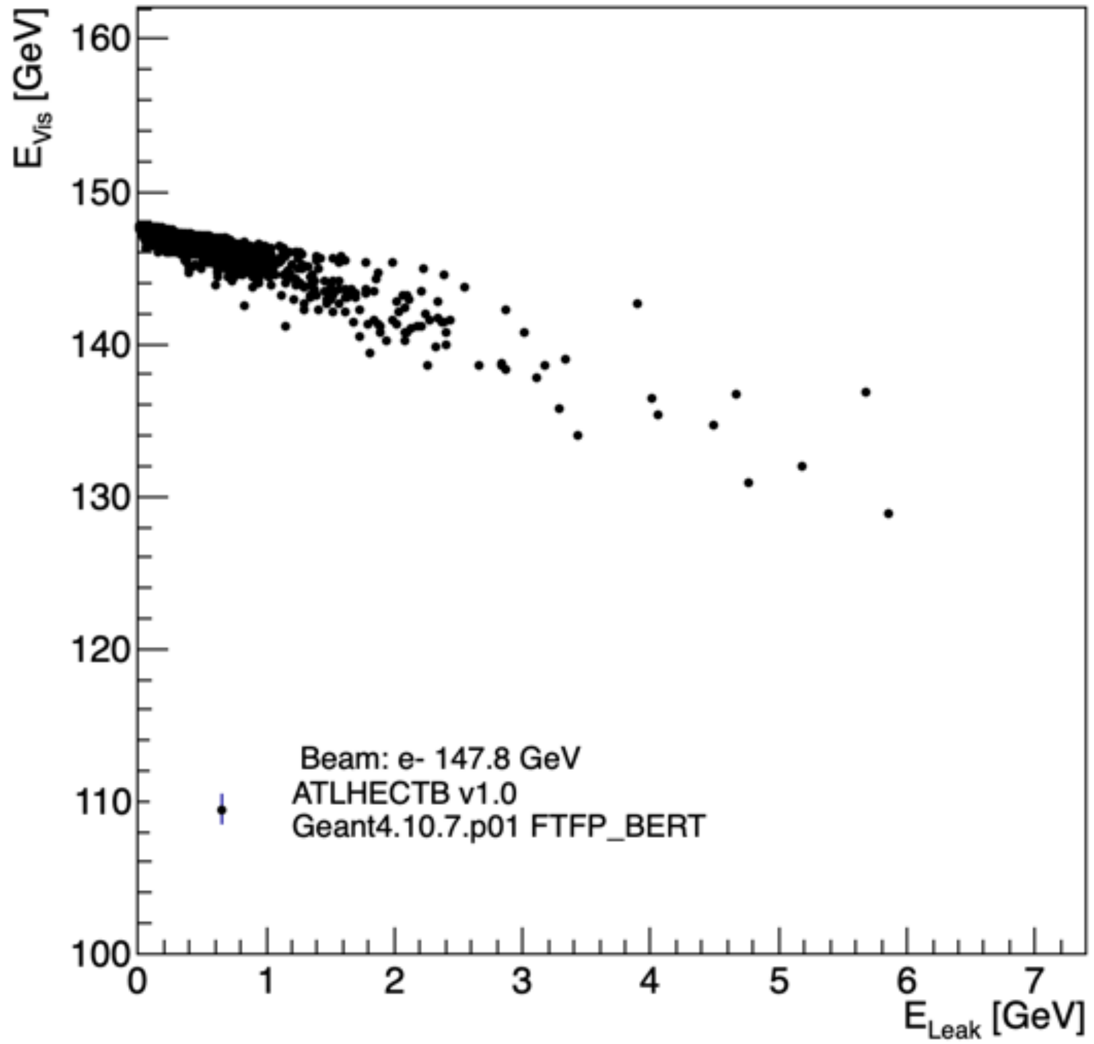
A time cut of 75 ns is considered for signal integration.



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)**

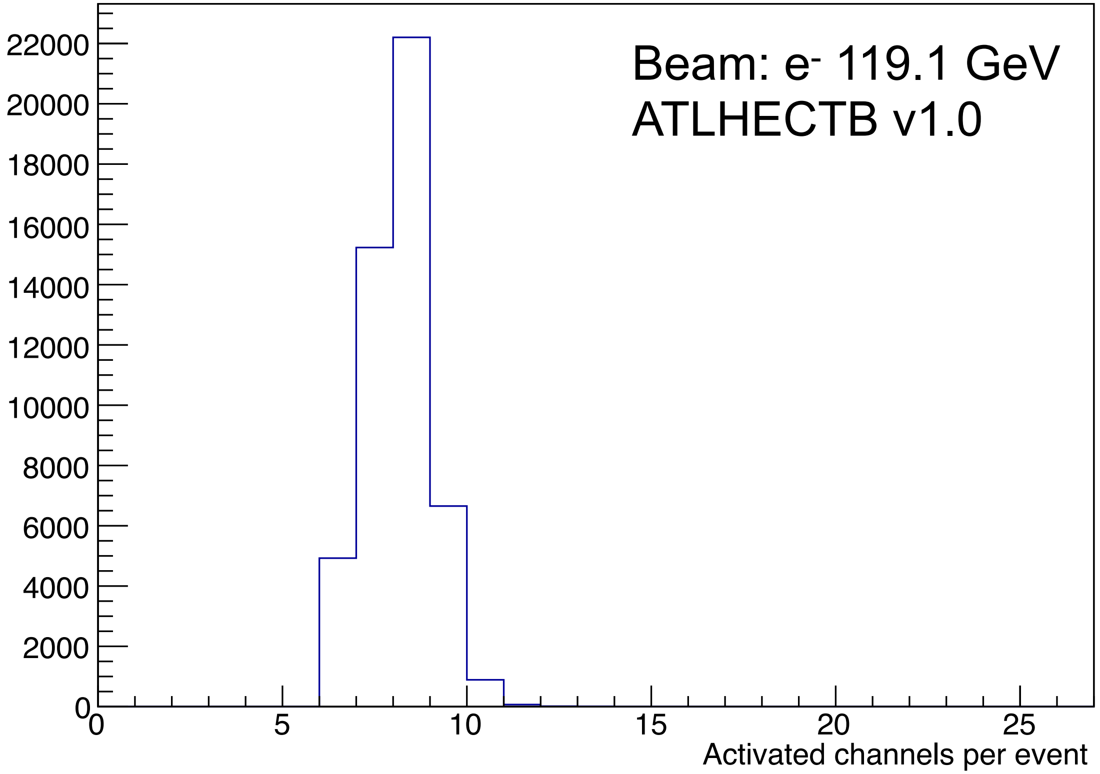


Sanity check results

- **According to a recent analysis of 2000/2001 test-beam data ATL-COM-LARG-2021-005 [link].**

  "The cluster reconstructed for electron energy measurements consists of seven cells: four of them are in the first HEC layer, three in the second layer."

  Similar number of channels per electron event is reproducible with ATLHECTB.

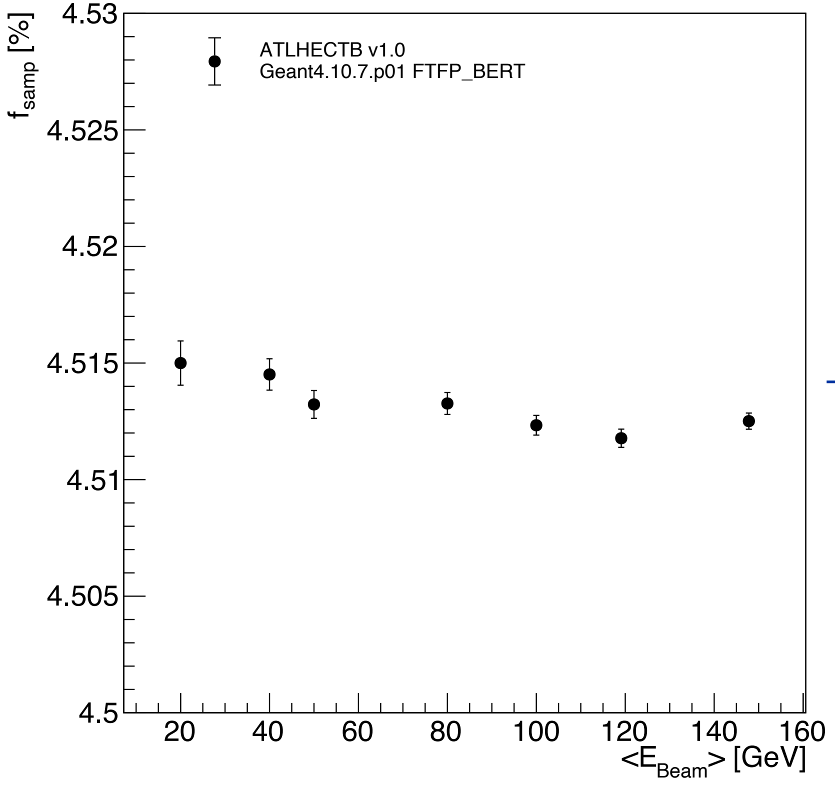


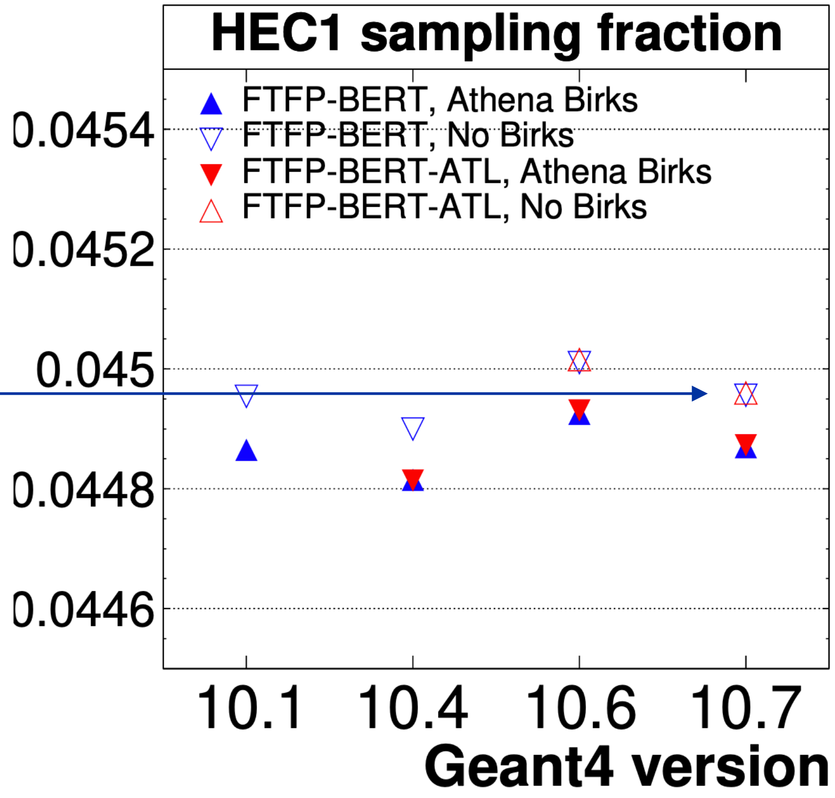
First e^- results and comparison with ATLAS

We studied the sampling fraction as the energy deposited in LAr divided by energy deposited in calo.

Last week ATLAS LAr Simulation Group presented their sampling fraction results. [link]

Very encouraging agreement between ATLHECTB and ATLAS SW.





First 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 study.

- **Can be directly compared to 2021 ATLAS note ATL-COM-LARG-2021-005 as ATLAS quotes**

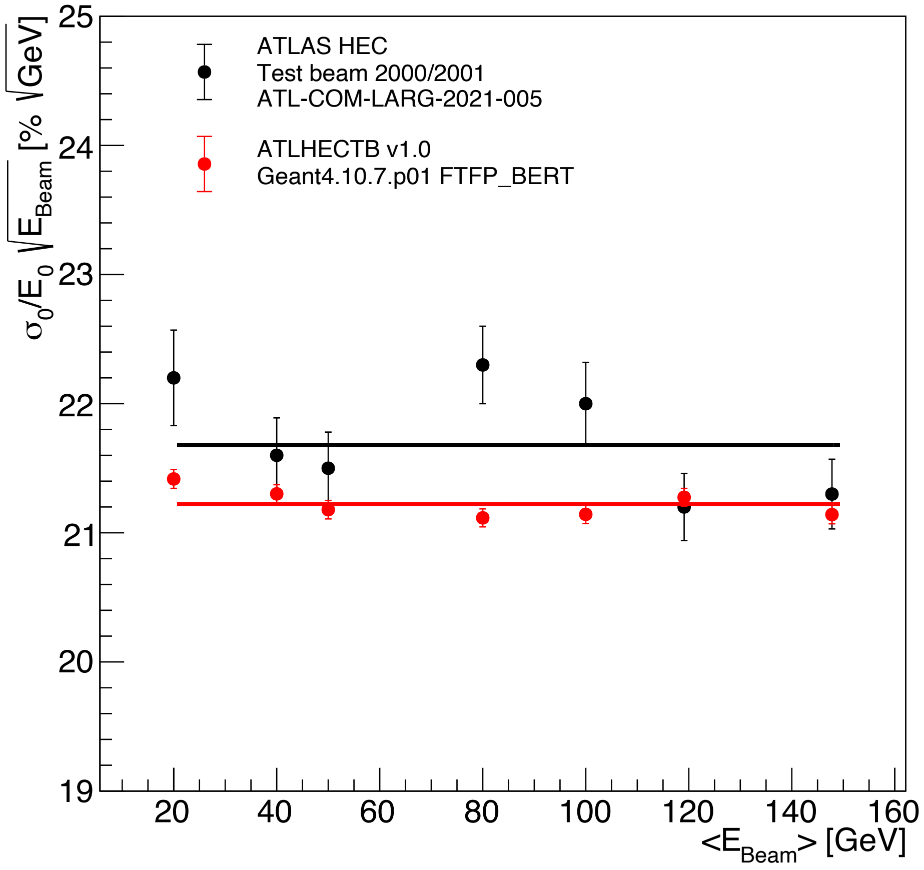
$$\sigma_0 = \sqrt{\sigma_E^2 - \sigma_{noise}^2}$$ **[link]**

- **ATLAS HEC TB 2000/2001**: **[link]**

$$A = 21.71 \pm 0.11\,\%\sqrt{GeV}$$

ATLHECTB v1.0 FTFPBERT:

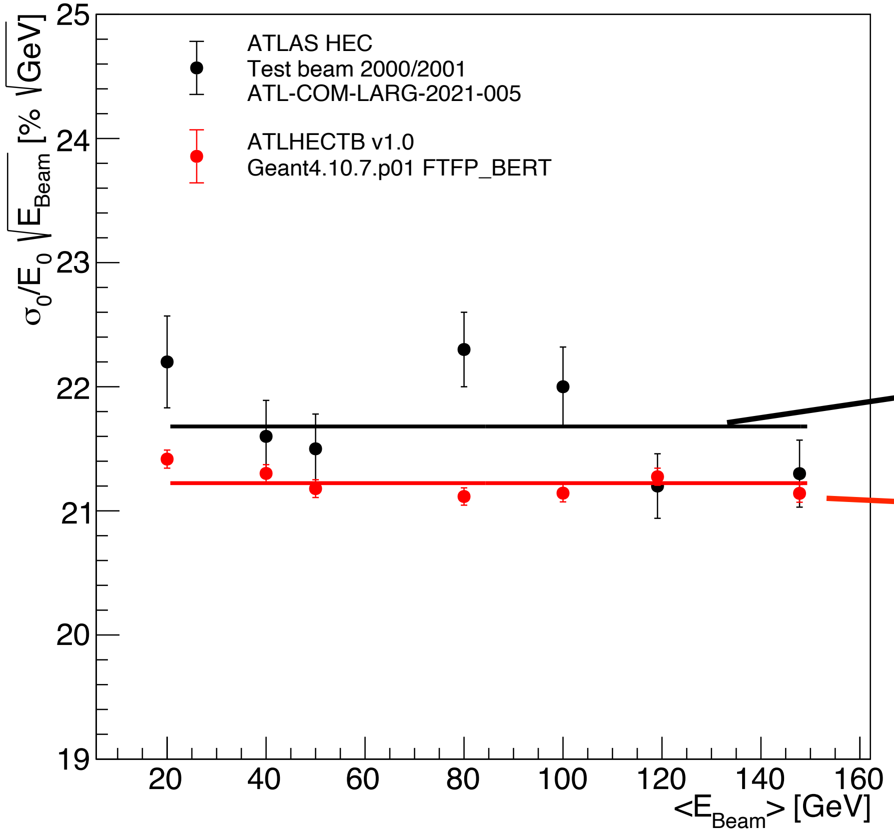
$$A = 21.22 \pm 0.03\,\%\sqrt{GeV}$$

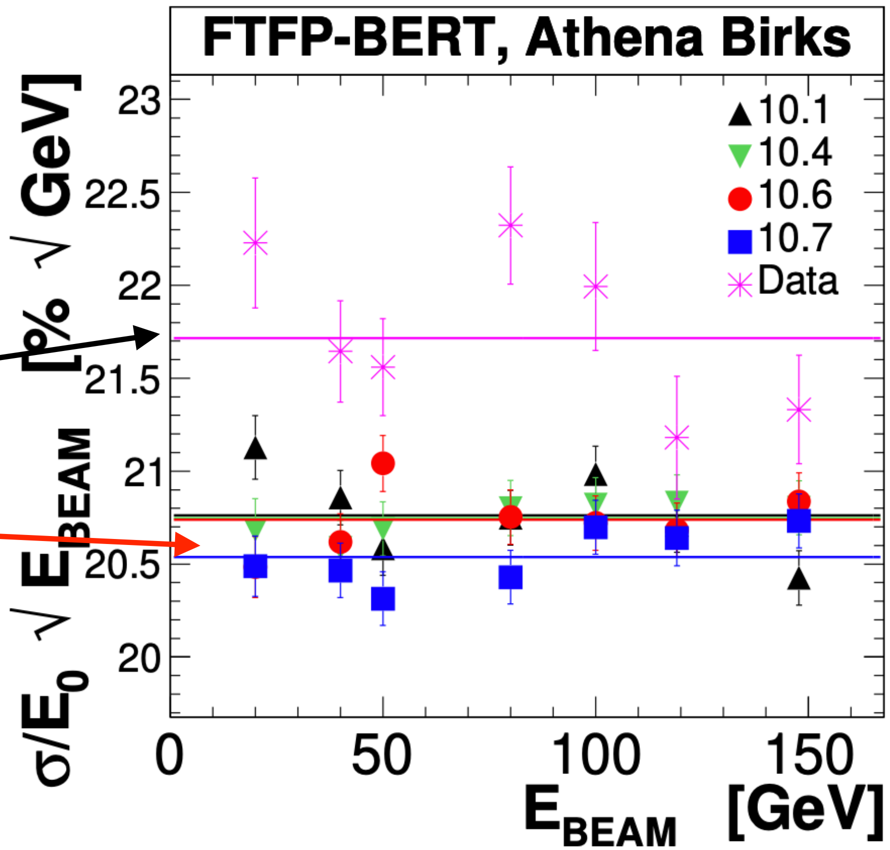


First e^- results and comparison with ATLAS

ATLHECTB v1.0
FTFP_BERT
energy resolution

Last week ATLAS LAr Simulation Group presented their energy resolution results. [link]





Conclusions

- **A standalone Geant4 ATLAS HEC simulation was written and is currently available for preliminary studies.**
- **Collaboration with ATLAS Colleagues was fruitful and efficient.**
- **First results with e^- indicate good agreement with the ATLAS SW and ATLAS HEC 2000/2001 TB data.**

Next steps:

- **Validate Geant4 on the ATLAS HEC π^- results. Where the fun begins** 🙂