Preliminary results from the ATLLArBarrel test

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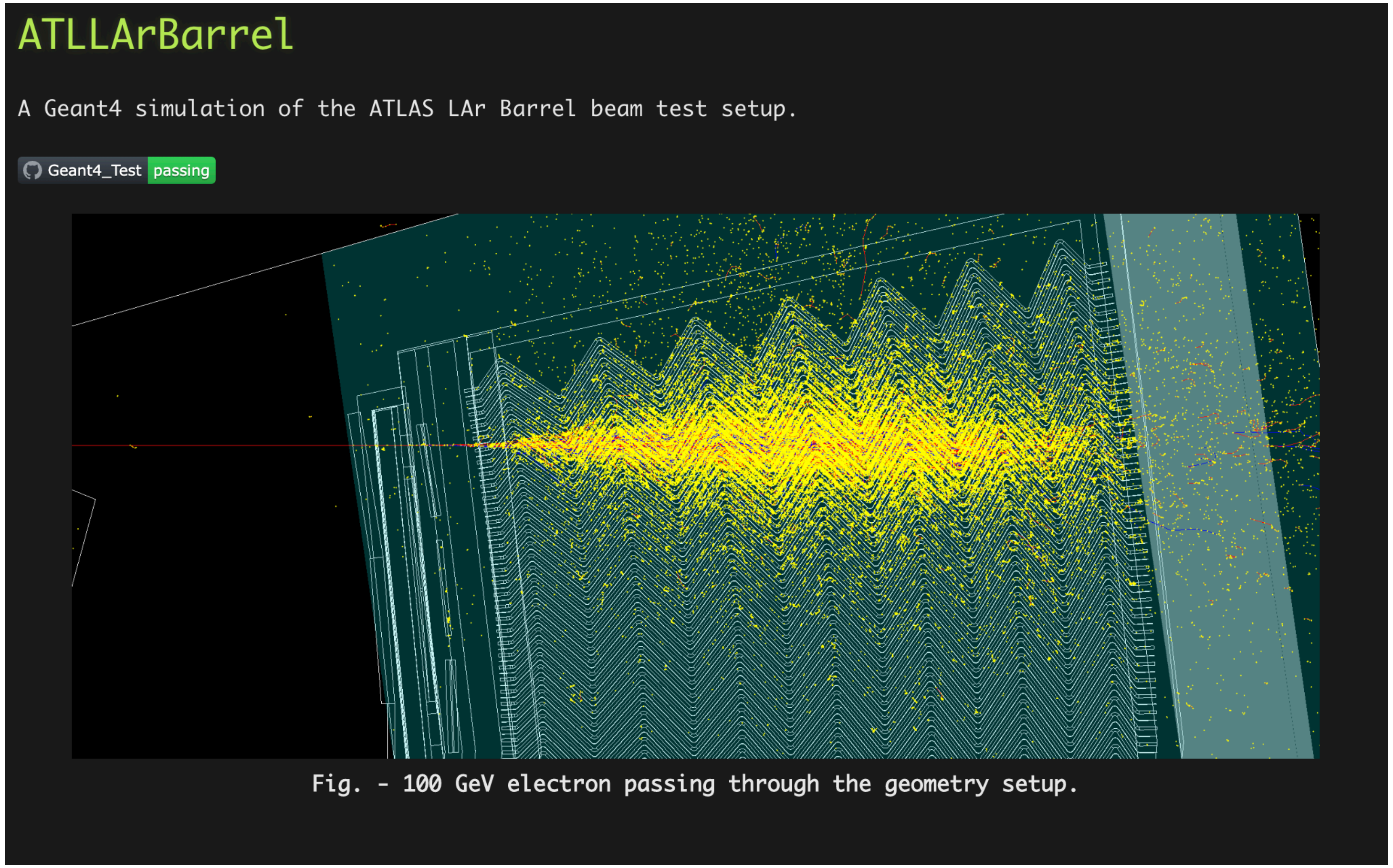
About a Geant4 ATLAS LAr barrel test

- A JIRA ticket to *create realistic setup for testing of EM showers in ATLAS EM-Barrel geometry* is open on GEANT4-SIM JIRA
- The ATLAS LAr test-beam setup is the ideal framework to accomplish it
- However, as far as I know, ATLAS is no longer using/validating the simulation of the LAr barrel test-beam → little expertise preservation
- A standalone Geant4 test can only target:
  - Geant4 version control and
  - physics list comparison (EMZ, EMY, …)
- Most EM-shower generation happens in the LAr barrel geometry → we have to speed up the simulation mostly there

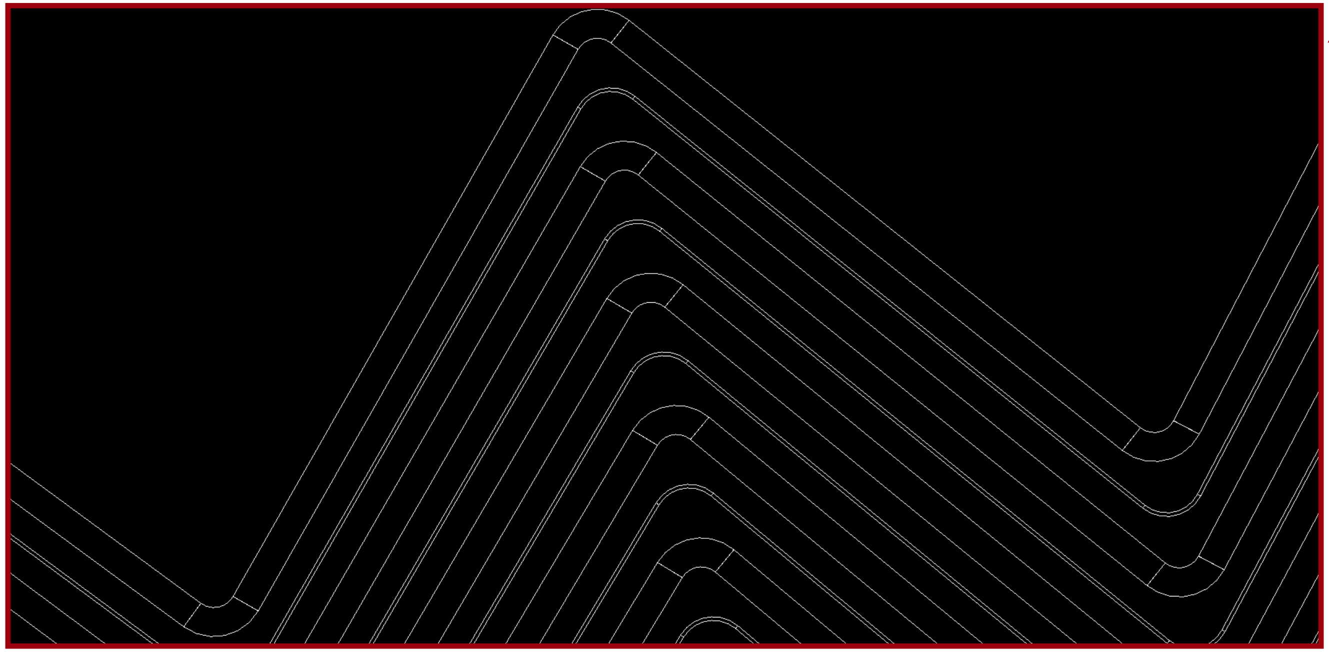
ATLLArBarrel

- Github repo now in pre-release v0.3
- Contains a realistic G4Solid-based geometry and a simplified sensitive detector implementation (more in the following)
- Added G4HepEm related files as optional library compiled with
  - -DWITH_G4HepEm=ON
  - -DWITH_G4HepEmTracking=ON
- Tested with VecGeom with scalar backend
- Results in the following are preliminary and obtained with v0.3 (tag 0.3_1)

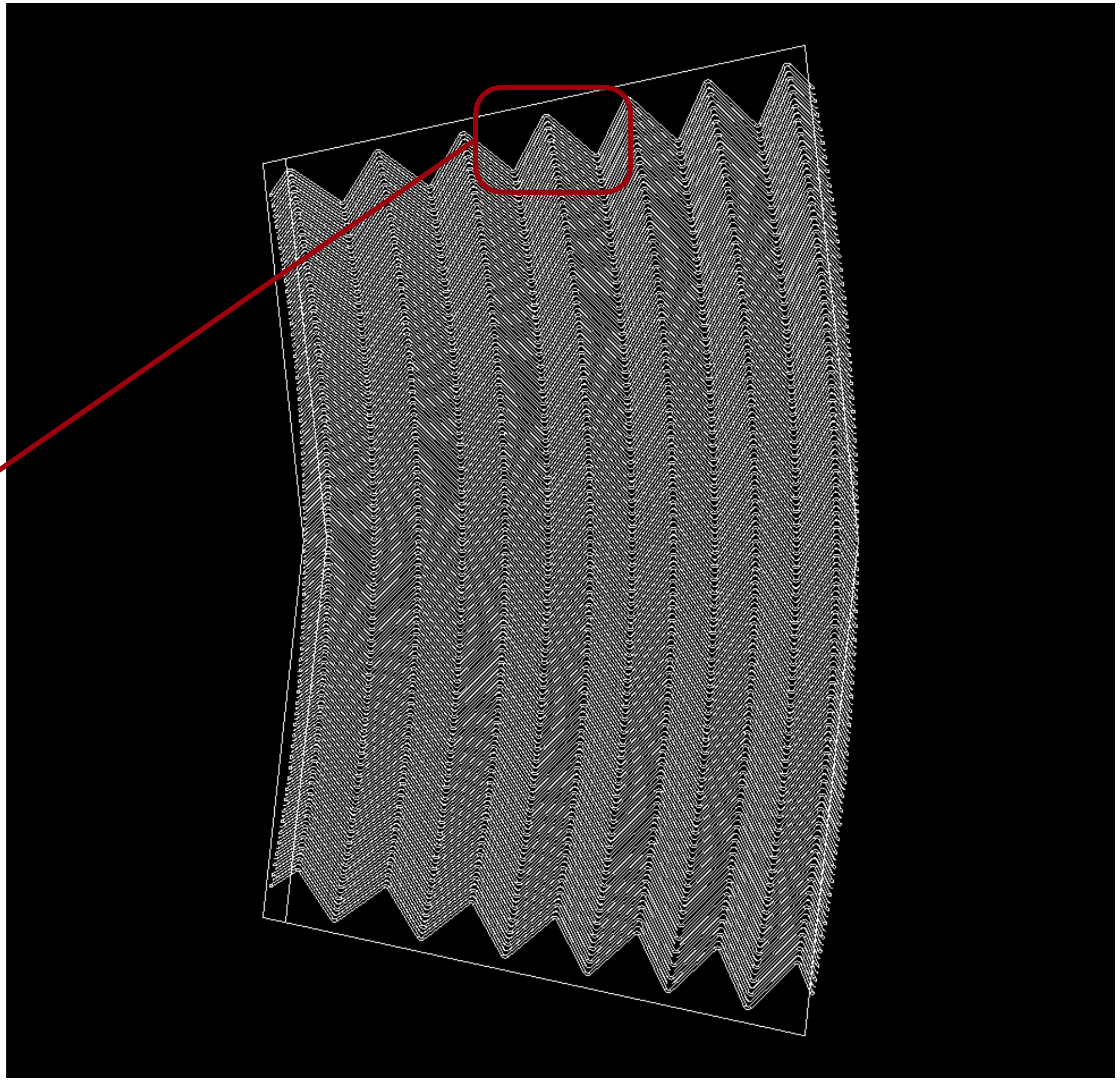


Test beam geometry (1/4)

- Geometry is an adaptation of the ATLAS LAr original code
  - we isolated the LAr barrel test-beam volumes (by G. Unal *et al.*),
  - hardcoded numbers from the ATLAS DDD, and
  - added few optimizations (e.g. use G4Box instead of G4Trap if parameters allow)

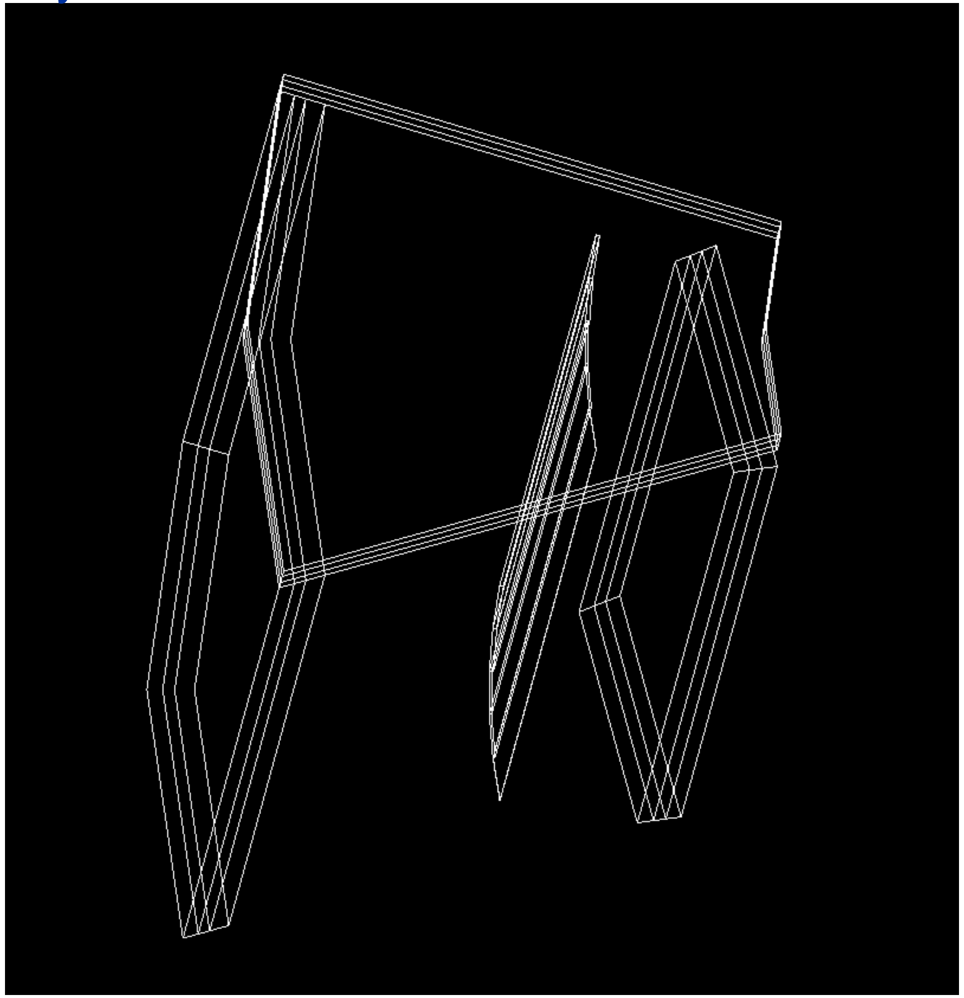


EMB::STAC

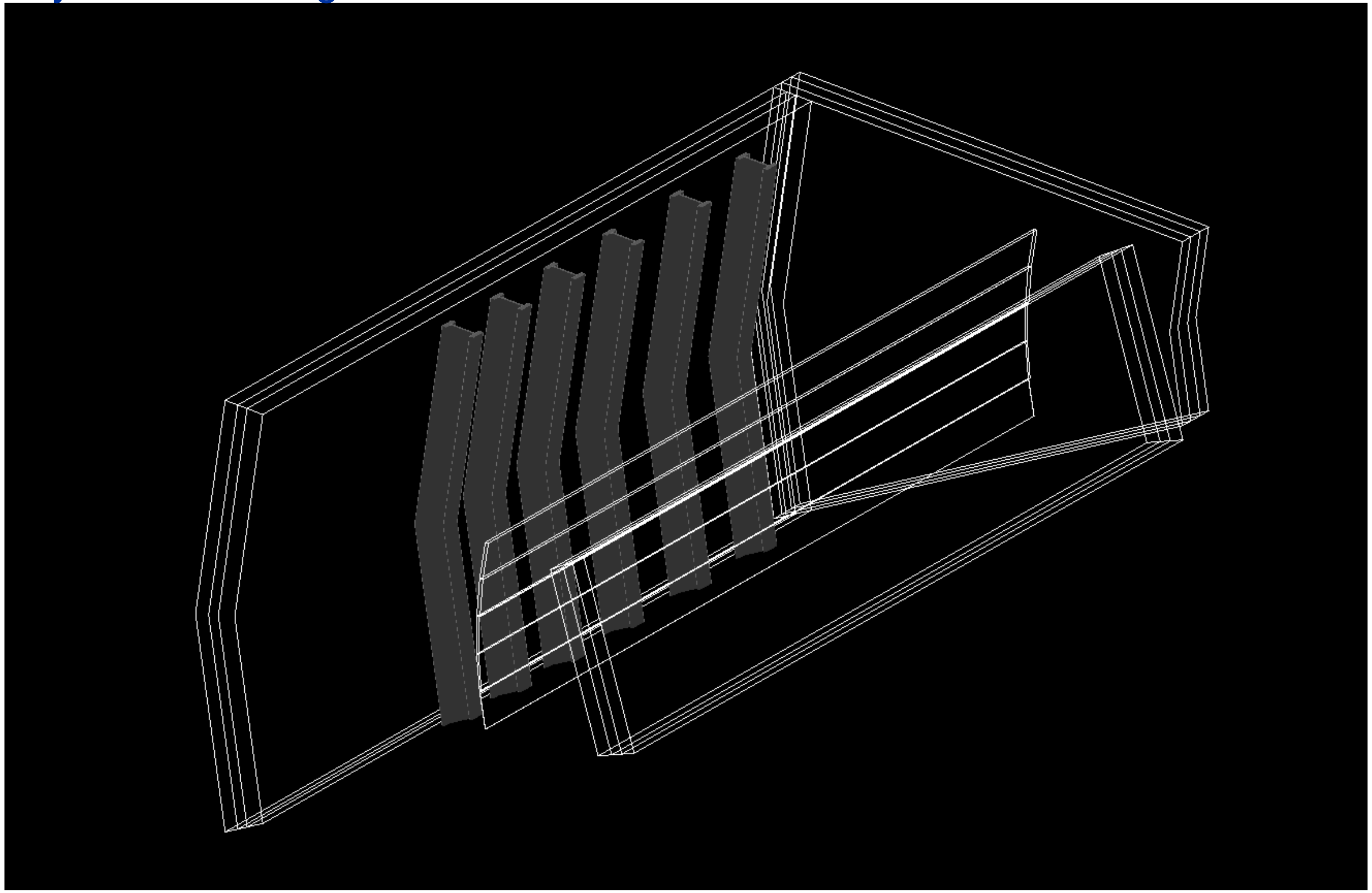


Test beam geometry (2/4)

Cryostat

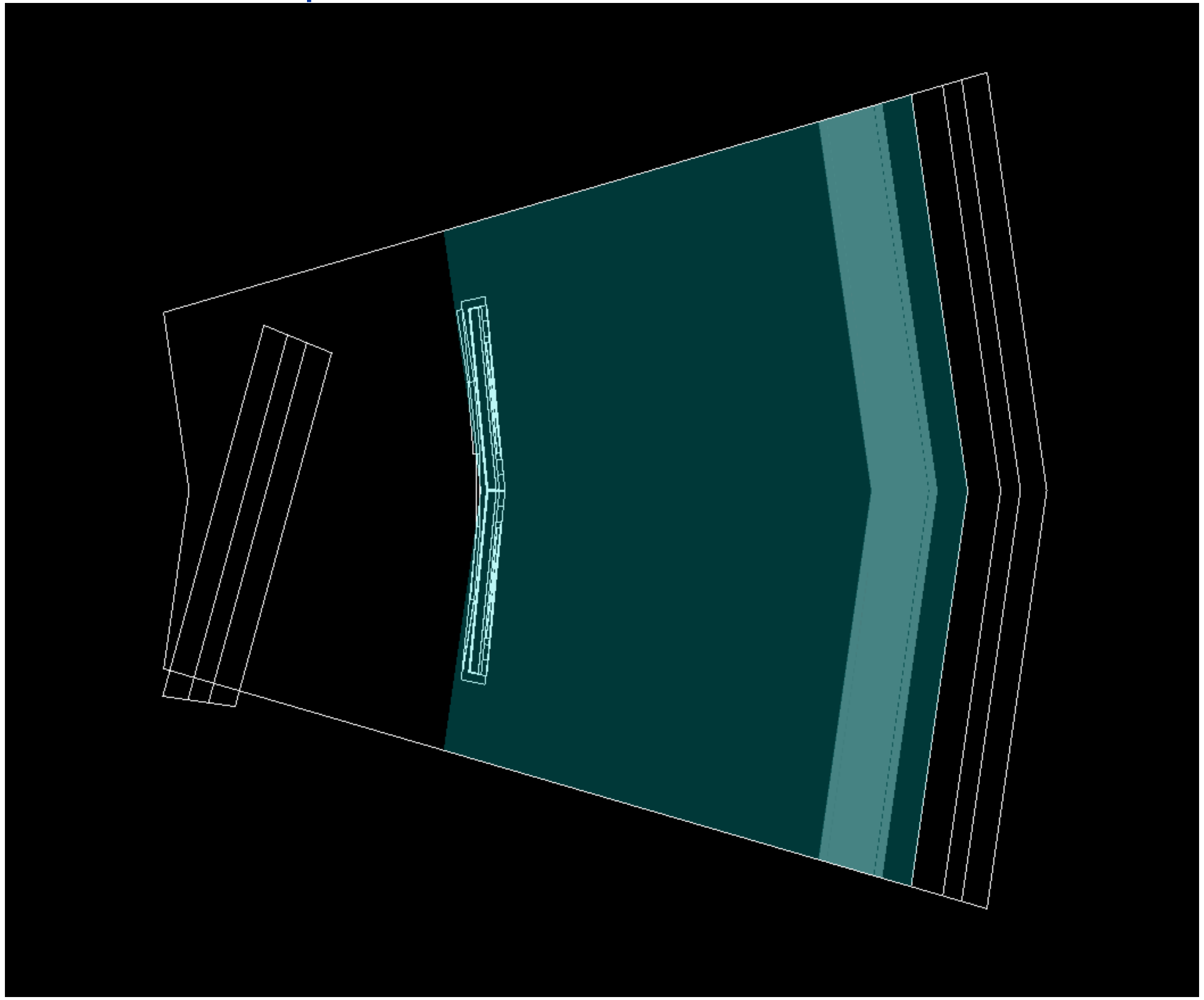


Cryostat + 6 Rings

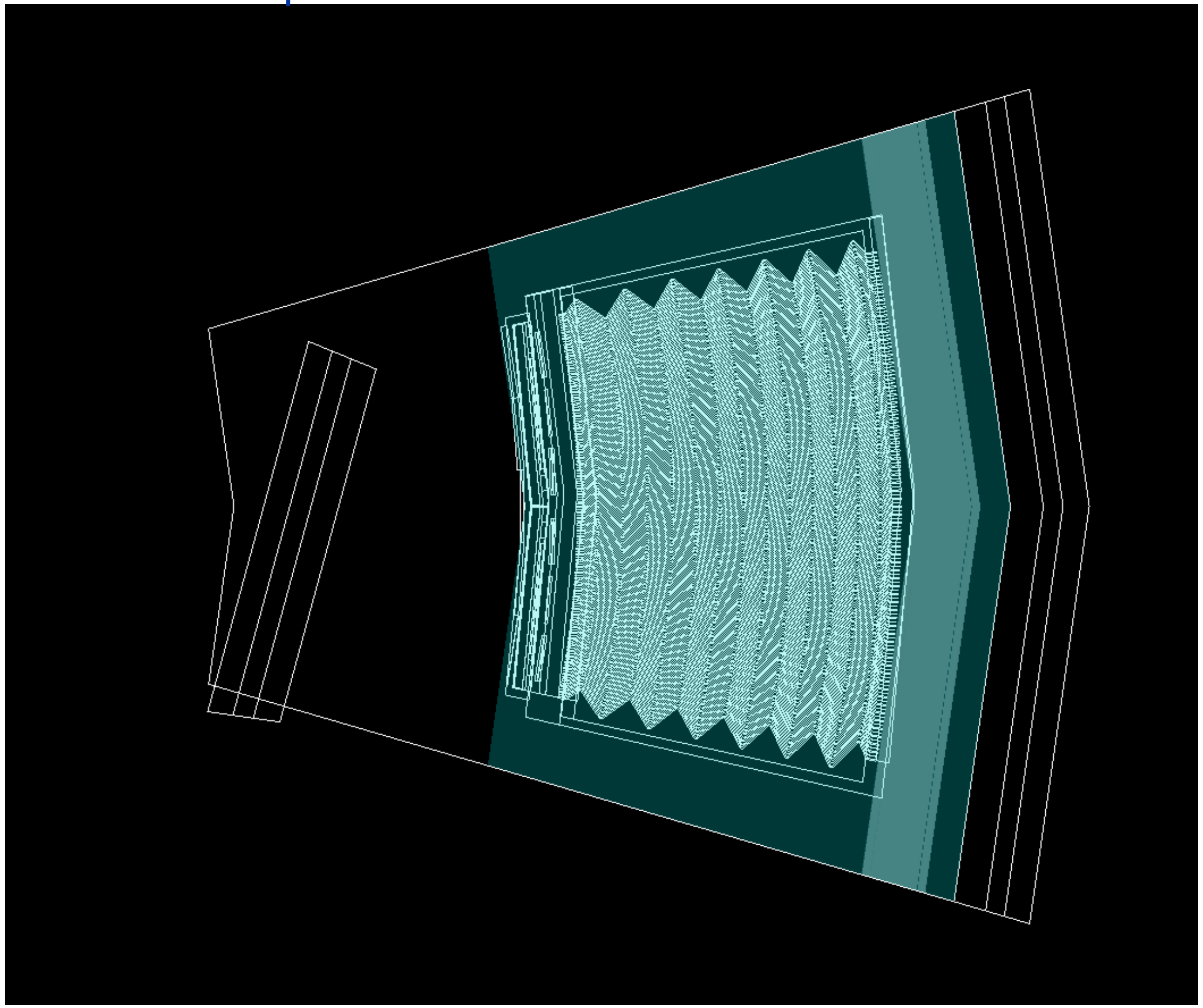


Test beam geometry (3/4)

LAr + Presampler



LAr +Presampler + EMB::STAC



Test beam geometry (4/4)

- The ATLAS LAr barrel geometry consists of two half-barrels ($z < 0$ and $z > 0$)
- Each half-barrel is divided in 16 modules replicated around the beam axis
- The test-beam geometry has one half-barrel ($z > 0$) and one module

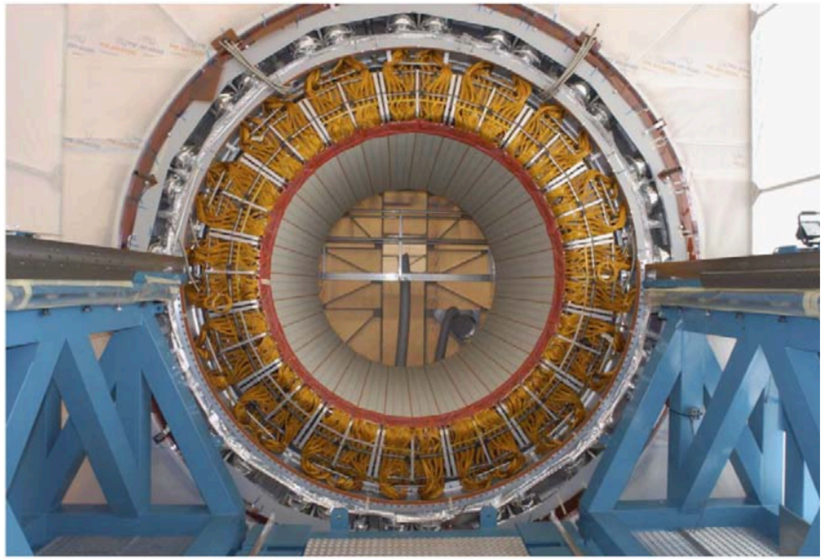
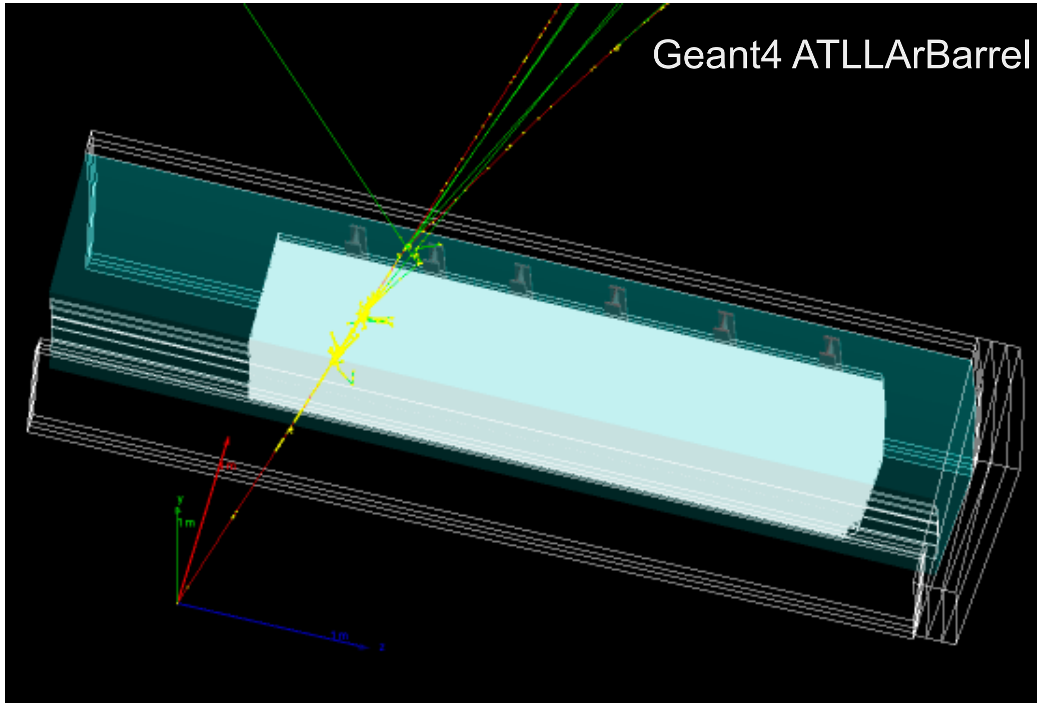


Fig. 1. First half barrel inserted inside the ATLAS cryostat.

Fig. 29. The first two modules are joined together.



ATLAS pictures from paper

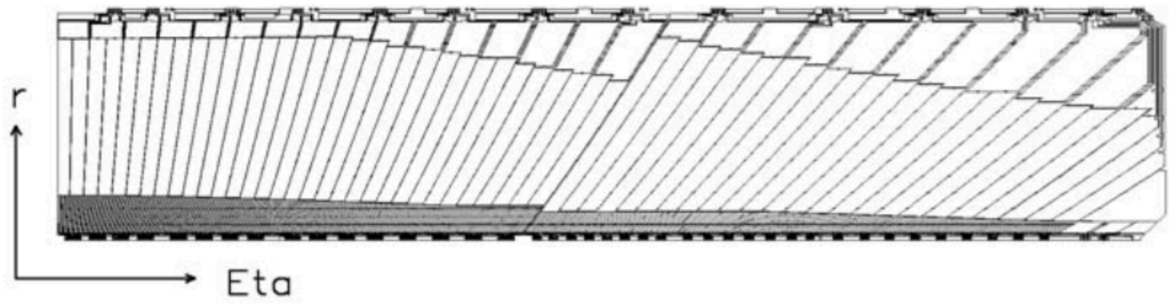
Readout structure

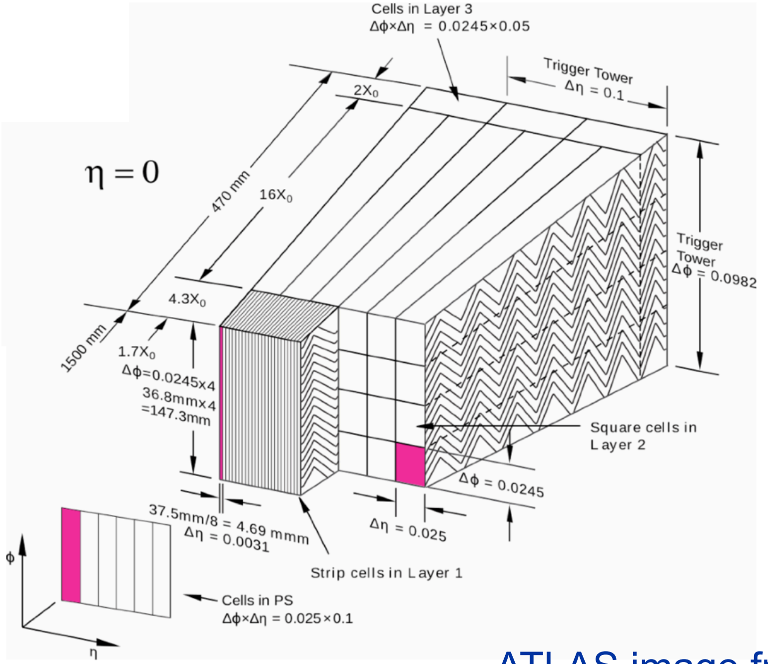
ATLLArBarrel_0.3 implements a simplified readout cells (hits) structure as follows:

- It preallocates a fixed number of hits in three hit collections: *front-section hits*, *middle-section hits* and *back-section hits*
- At each step in LAr it calculates (using global coordinates) the corresponding calorimeter section (*front*, *middle* or *back*)
- Using $\Delta\eta$ and $\Delta\phi$ of the hit section, it retrieves the proper hit in the selected hit collection

NOTE:This is a simplification w.r.t. the ATLAS approach that still uses global coordinates but retrieves a more detailed hit structure
(see for instance slide 22).

ATLAS image from paper





ATLAS image from slides

Signal treatment (1/2)

- ATLLArBarrel_0.3 introduces the Birks non linearity correction for electric charge ionization in LAr:
  - Imported as in the ATHENA LArG4BirksLaw class
    - $K = k_{birk}/E_f$, $E_f = 10$ kV/cm, $k_{birk} = 0.05832$
    - $LAr_{density} = 1.396$ g/cm^3

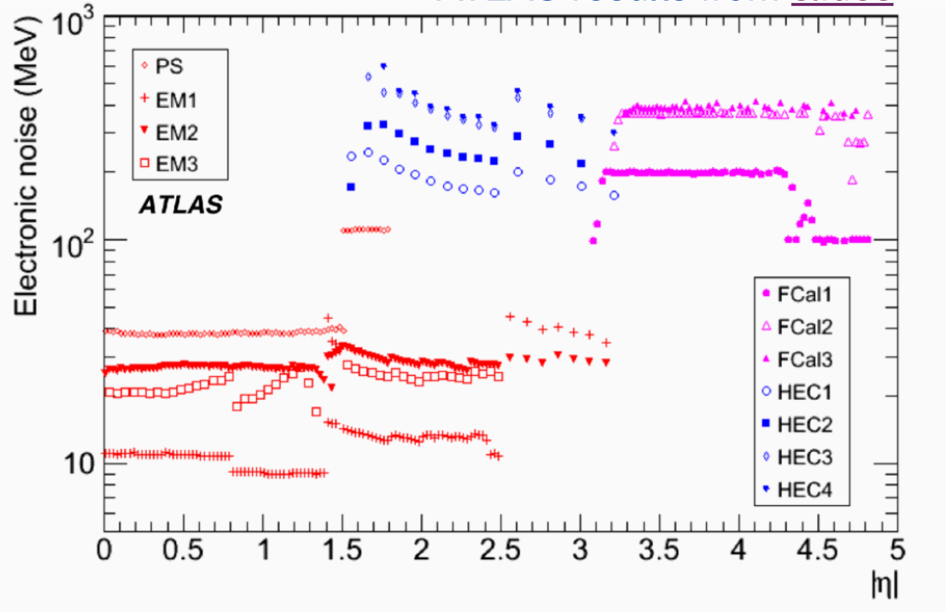
$$\partial E' = \partial E \frac{1 + K1.51}{1 + K\frac{\partial E}{\partial x}(1/LAr_{density})}$$

Birks corrected

from Geant4

- Per each hit (readout cell) we consider a electronic noise equivalent of 20 MeV:
  - seems to not be far from reality, but we have to crosscheck it with ATLAS

ATLAS results from slides



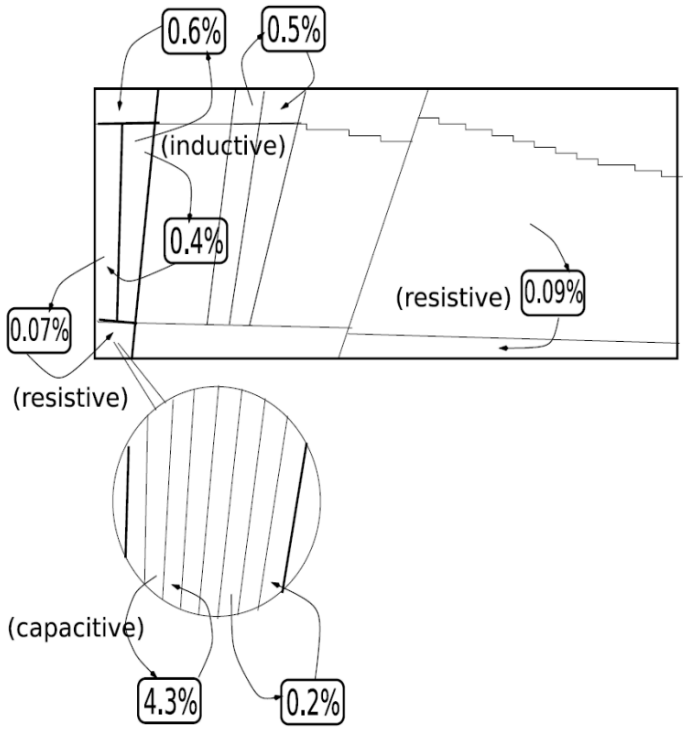
Signal treatment (2/2)

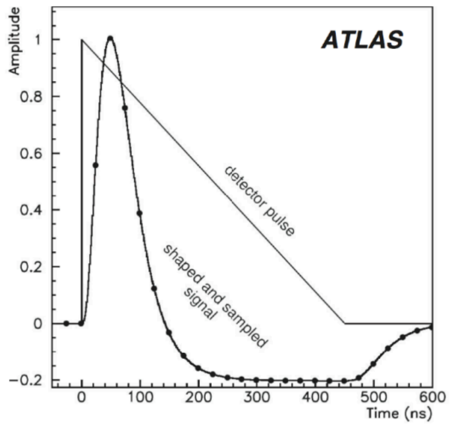
- No signal cross-talk is considered at the moment.
  Measuring the LAr barrel cross-talk is a rather complex task, mostly done with special calibration runs
  (see for instance slides).
  In the ATLAS simulation cross-talk is implemented by the LArPileUpTool after the detector simulation

- No signal digitization is considered at the moment.
  The detector output signal (detector pulse) can be simulated as the "convolution" of the deposited charge with the electric field among the accordion absorbers
  → ATLAS uses an electric field map in LAr to populate a current map (see for instance slide 25)

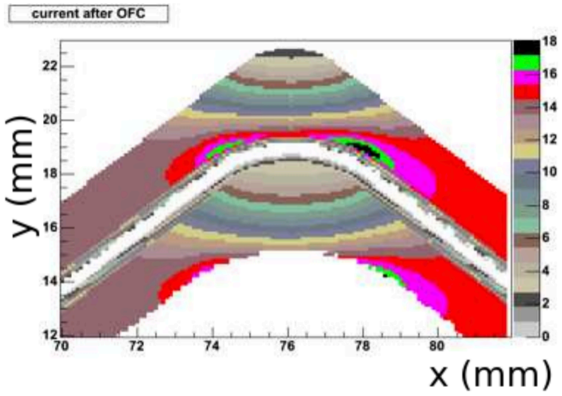
  - My feeling: this has little do it with Geant4. We should implement it only if we want to reproduce test-beam data. Otherwise, it might bring more cons than pros

Standard Xtalk ATLAS image from slides



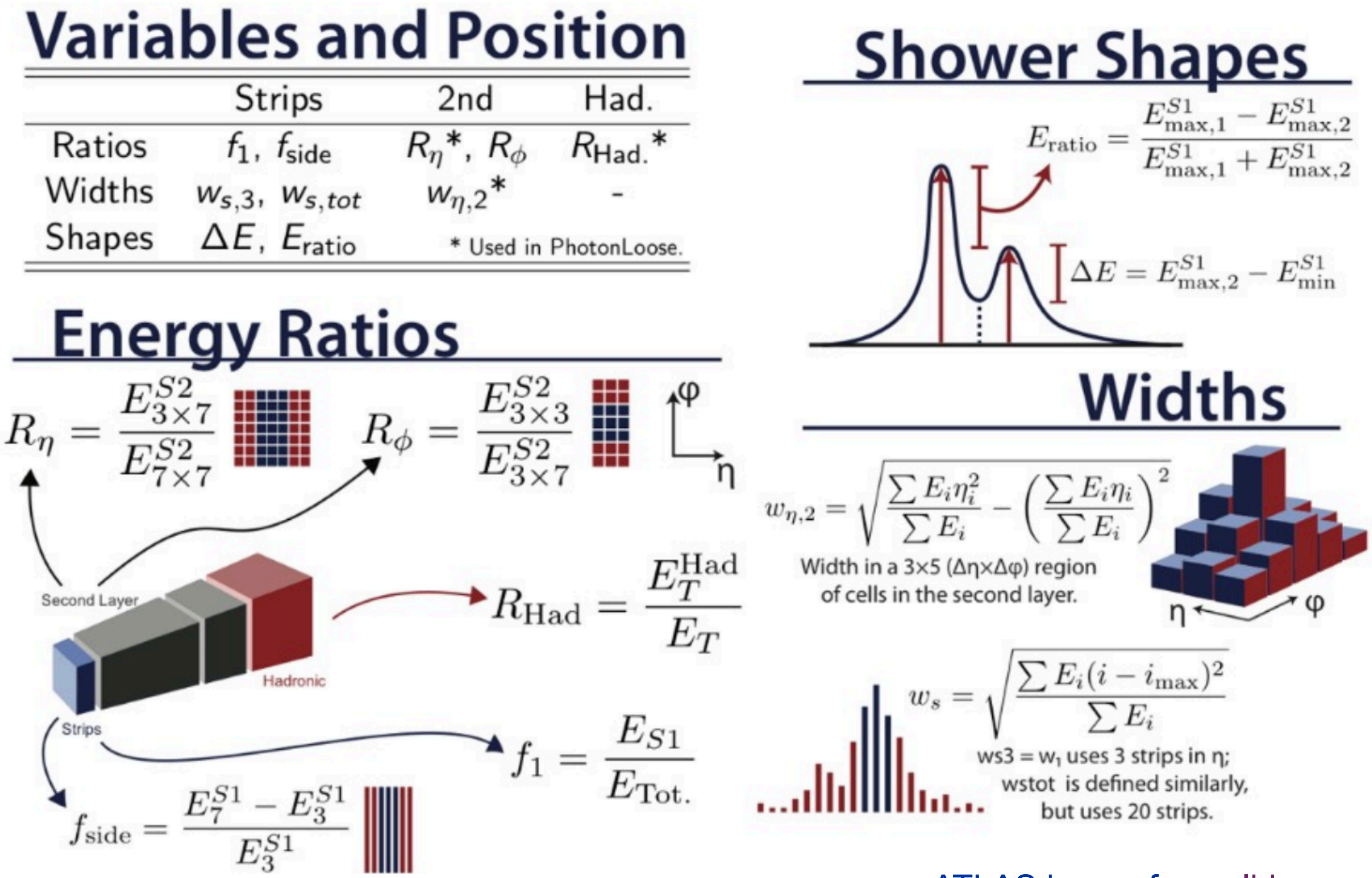


ATLAS image from slides



Physics variables

Table from ATLAS article



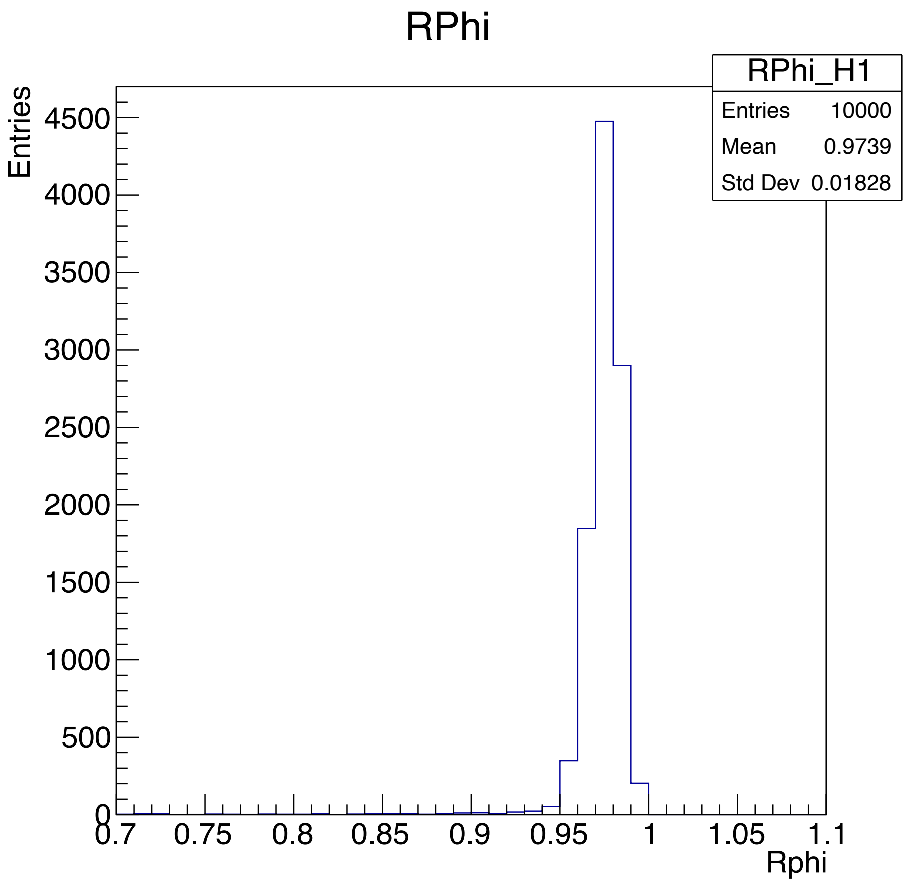
ATLAS image from slides

Hadronic leakage	Ratio of E_T in the first layer of the hadronic calorimeter to E_T of the EM cluster (used over the range $\|\eta\| < 0.8$ or $\|\eta\| > 1.37$)	R_{had1}
	Ratio of E_T in the hadronic calorimeter to E_T of the EM cluster (used over the range $0.8 < \|\eta\| < 1.37$)	R_{had}
Third layer of EM calorimeter	Ratio of the energy in the third layer to the total energy in the EM calorimeter. This variable is only used for $E_T < 80$ GeV, due to inefficiencies at high E_T, and is also removed from the LH for $\|\eta\| > 2.37$, where it is poorly modelled by the simulation.	f_3
Second layer of EM calorimeter	Lateral shower width, $\sqrt{(\Sigma E_i \eta_i^2)/(\Sigma E_i) - ((\Sigma E_i \eta_i)/(\Sigma E_i))^2}$, where E_i is the energy and η_i is the pseudorapidity of cell i and the sum is calculated within a window of 3×5 cells	$w_{\eta 2}$
	Ratio of the energy in 3×3 cells over the energy in 3×7 cells centred at the electron cluster position	R_ϕ
	Ratio of the energy in 3×7 cells over the energy in 7×7 cells centred at the electron cluster position	R_η
First layer of EM calorimeter	Shower width, $\sqrt{(\Sigma E_i (i - i_{max})^2)/(\Sigma E_i)}$, where i runs over all strips in a window of $\Delta\eta \times \Delta\phi \approx 0.0625 \times 0.2$, corresponding typically to 20 strips in η, and i_{max} is the index of the highest-energy strip, used for $E_T > 150$ GeV only	w_{stot}
	Ratio of the energy difference between the maximum energy deposit and the energy deposit in a secondary maximum in the cluster to the sum of these energies	E_{ratio}
	Ratio of the energy in the first layer to the total energy in the EM calorimeter	f_1

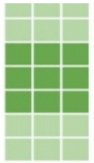
ATLAS results from Dongwon Kim's slides

R_ϕ (preliminary)

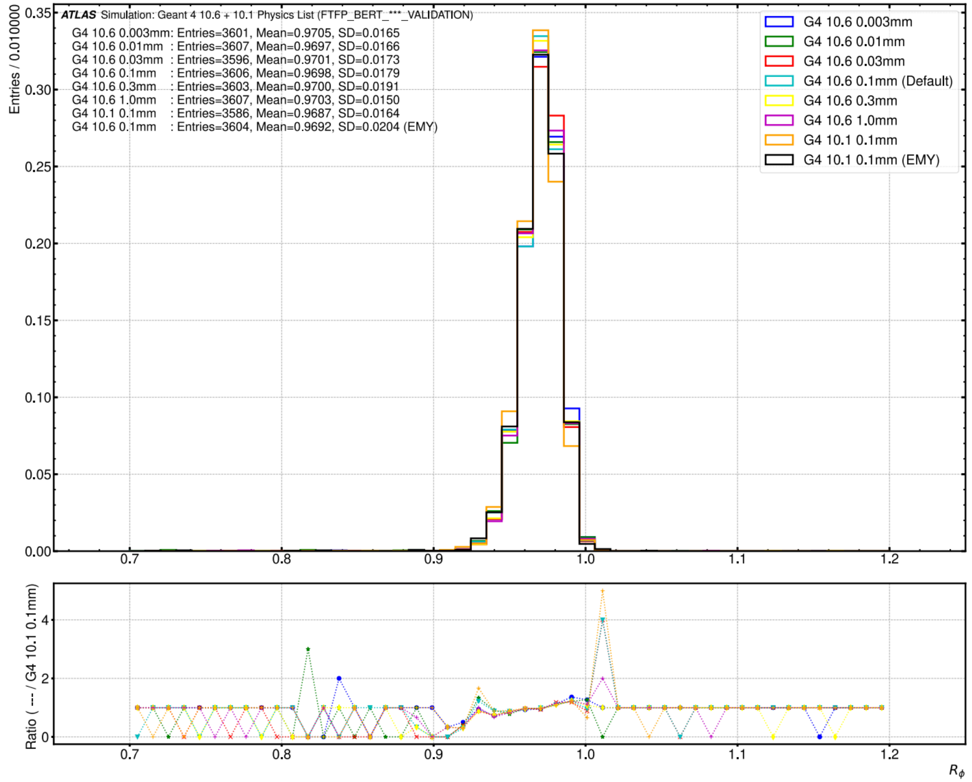
GEANT4-11.1 (FTFP_BERT, 0.1 mm range cut)
20 GeV γ
$0.2 < \eta < 0.25, 3.14 < \phi < 3.19$ (rad)



$R_\phi = E_{3x3}/E_{3x7}$



ATLAS
20 GeV γ (unconverted)
$0.2 < \eta < 0.25, \phi = ?$



ATLAS results from Dongwon Kim's slides

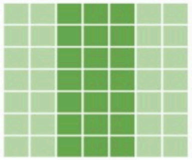
R_η (preliminary)

GEANT4-11.1 (FTFP_BERT, 0.1 mm range cut)

20 GeV γ

$0.2 < \eta < 0.25, 3.14 < \phi < 3.19$ (rad)

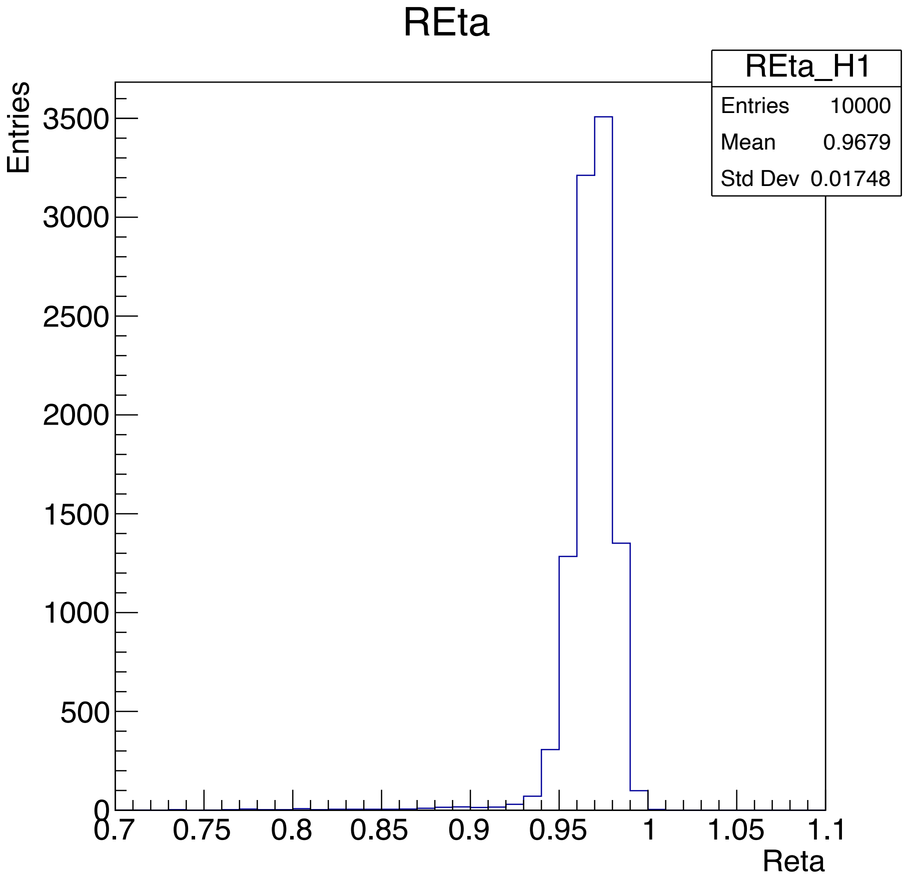
$R_\eta = E_{3x7}/E_{7x7}$

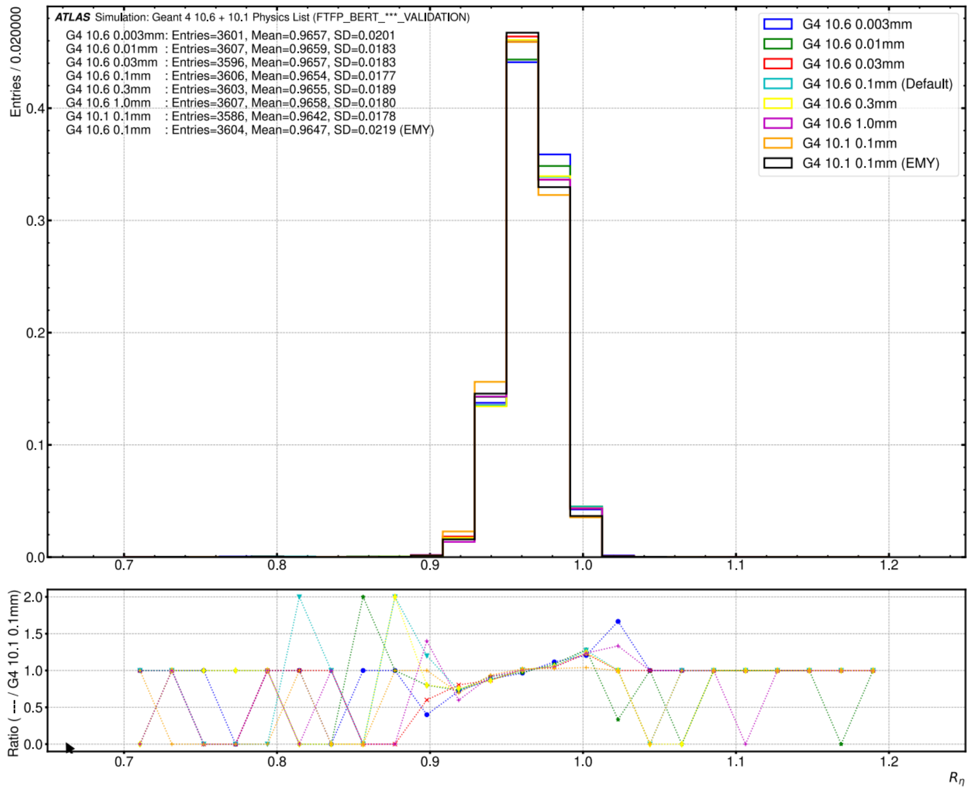


ATLAS

20 GeV γ (unconverted)

$0.2 < \eta < 0.25, \phi = ?$





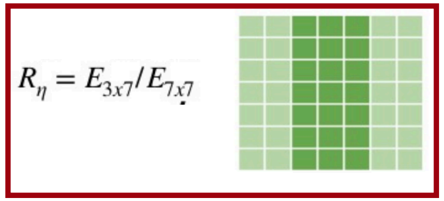
ATLAS results from Dongwon Kim's slides

R_η (preliminary)

GEANT4-11.1 (FTFP_BERT, 0.1 mm range cut)

20 GeV γ

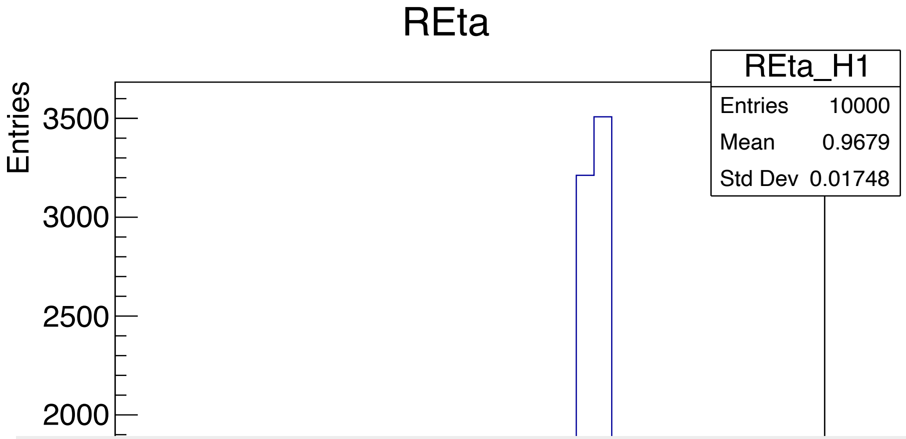
$0.2 < \eta < 0.25, 3.14 < \phi < 3.19$ (rad)

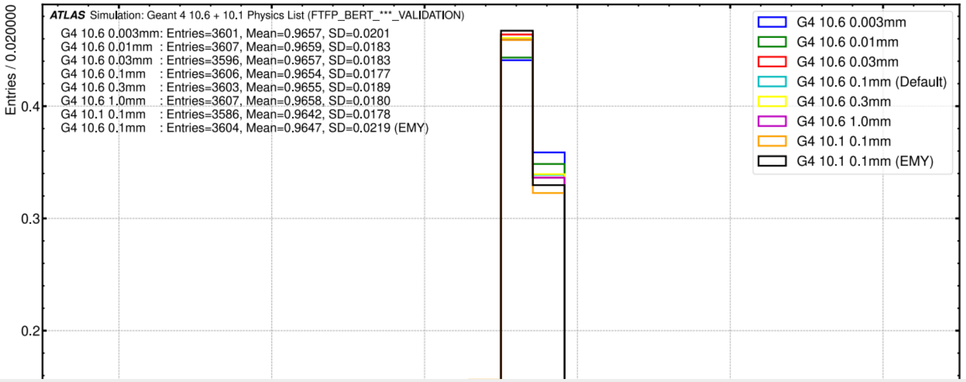


ATLAS

20 GeV γ (unconverted)

$0.2 < \eta < 0.25, \phi = ?$





- NOTE: Both R_ϕ and R_η are computed over a given cluster and depend on the cluster selection algorithm. My (simple) clusters are computed using the the mostly energetic cell (the seed cell), however ATLAS uses a way more complex algorithm, the topological clustering.

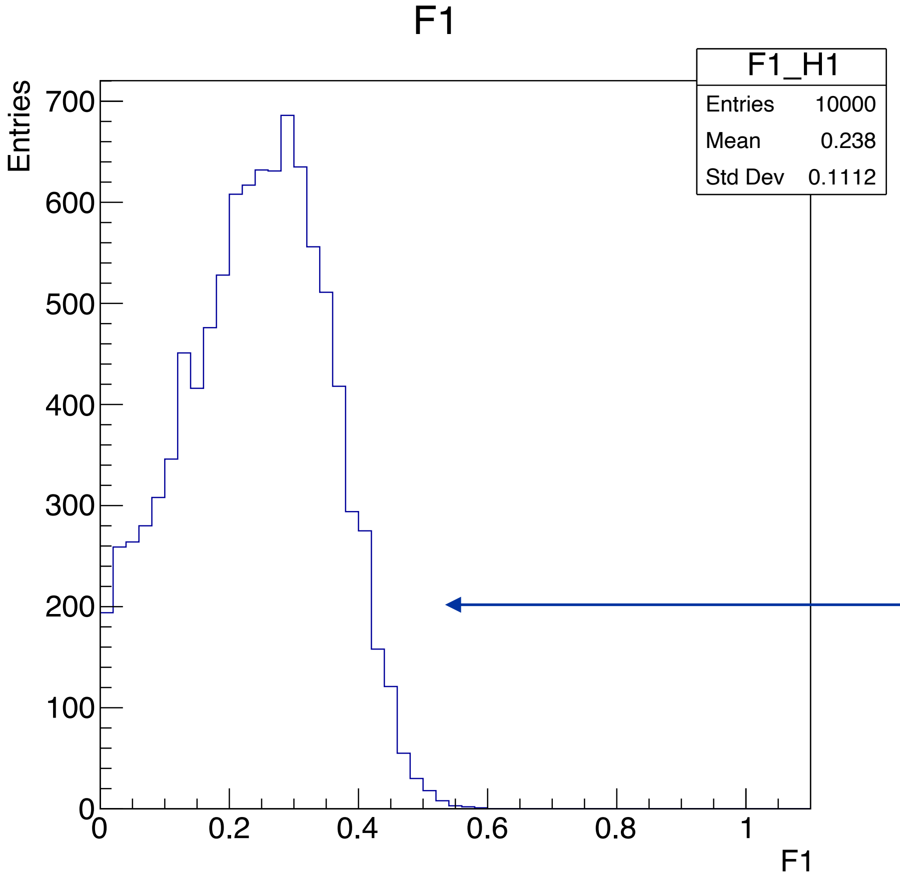
  → Good example of why we should validate Geant4 over test-beam data rather than experiments results

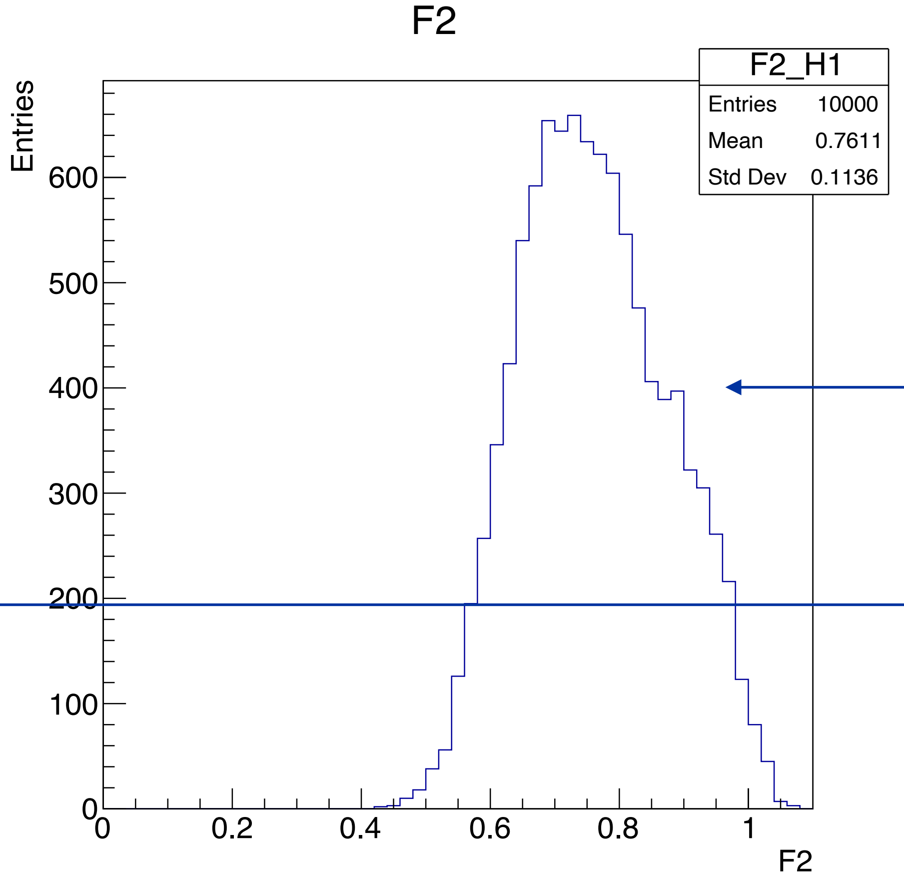
F_1 and F_2 (preliminary)

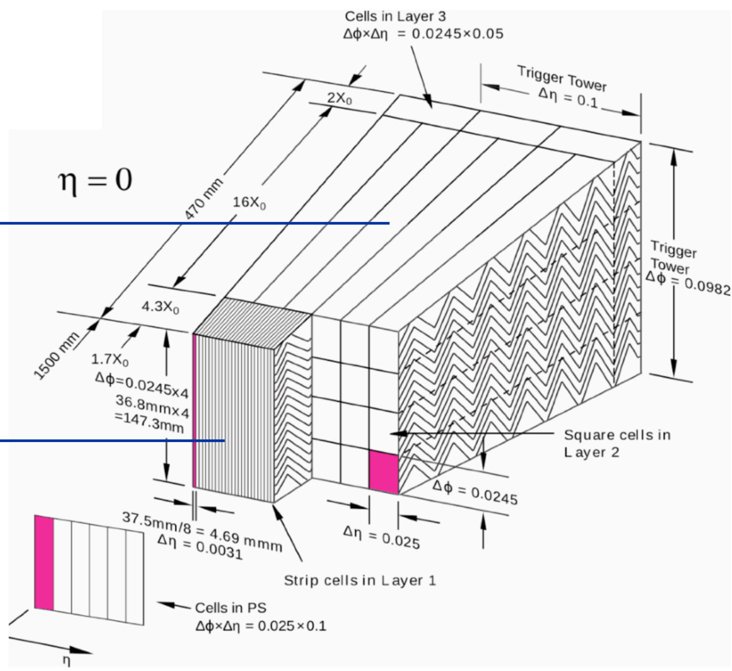
GEANT4-11.1 (FTFP_BERT, 0.1 mm range cut)

20 GeV γ

$0.2 < \eta < 0.25, 3.14 < \phi < 3.19$ (rad)

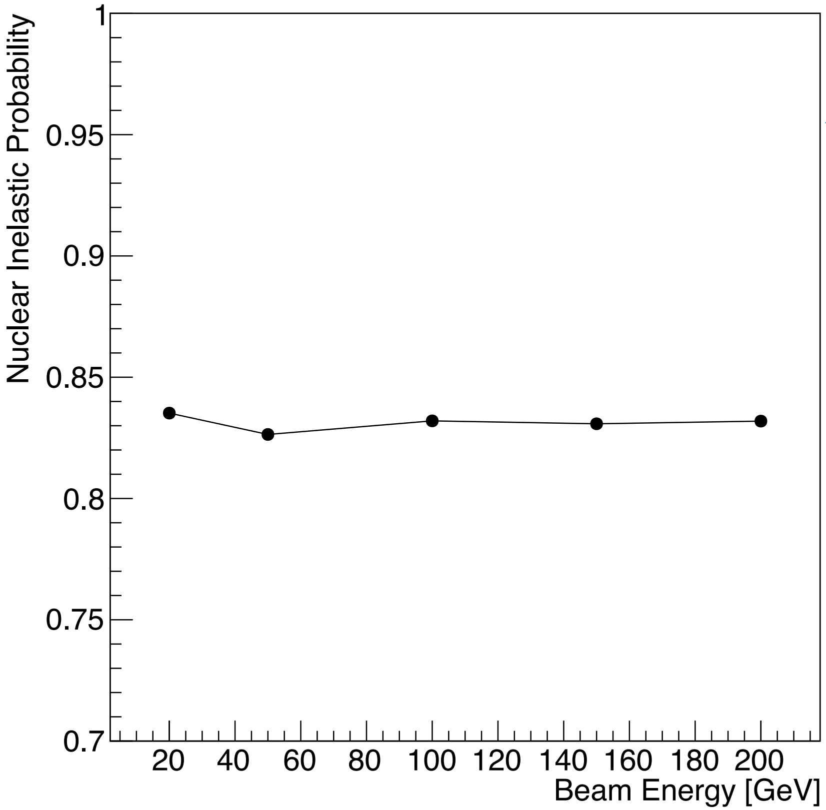






Hadron inelastic process probability (preliminary)

GEANT4-11.1 (FTFP_BERT)
π^- - 20, 50, 100, 150, 200 GeV
$0.2 < \eta < 0.25, 3.14 < \phi < 3.19$ (rad)



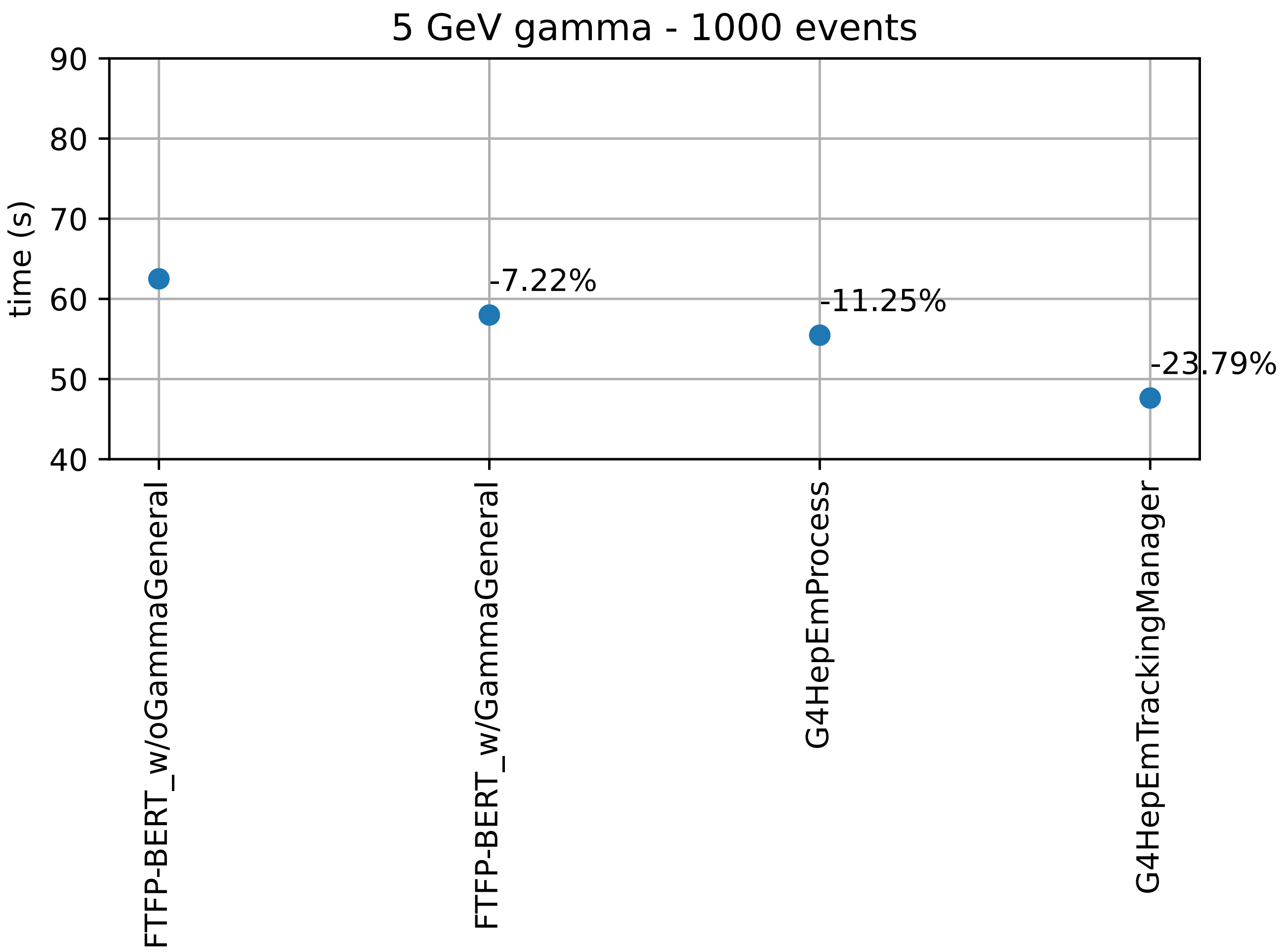
Take it directly from the MC truth

ATLLArBarrelTrackingAction.cc

```
void ATLLArBarrelTrackingAction::PostUserTrackingAction(const
G4Track* aTrack) {

    if(0!=aTrack->GetParentID())return;

     //Check it the primary particle had a nuclear breakup
     //(hadron inelastic process)
    //
    if(aTrack->GetStep()->GetPostStepPoint()

        ->GetProcessDefinedStep()->GetProcessSubType()==121) {

           //HadInElastic process
          fEventAction->SetHasHadronInteracted(true);
    }
}
```

Testing speedup solutions - G4HepEm (preliminary)

- Results from ATLLArBarrel_0.2 using 1000 events and 5 GeV γ:
  - Using Geant4-11.1
  - Time taken by `G4Timer` between `BeginOfRunAction` and `EndOfRunAction`.
  - CPU: Apple M1 Pro @3.2 GHz, using a single thread.
  - No SensitiveDetector, no hit, no SteppingAction, no EventAction.
  - NOTE:
    General process is not included in G4HepTrackingManager nor in G4HepEmProcess.



Conclusion

- We ported to a standalone Geant4/geant-val repo a simulation of the ATLAS LAr barrel calorimeter test-beam setup using the ATLAS legacy code
  - The geometry is realistic and slightly optimized (e.g. G4Trap → G4Box), does not involve GeoModel nor the ATLAS DDD
  - It includes a simplified SensitiveDetector with cell read-out structure, Birks Law, electronic noise and reconstruction
  - It does not include detector-specific features e.g. cell cross-talk, charge current computation in LAr (+ everything we might be forgetting)
  - Shower shape variables (R_ϕ, R_η) seem consistent with ATLAS results, however we are not comparing apples to apples

- My take: we can use this code to study the Geant4 performance on such detector as well as our speeding up solutions. In case we want to reproduce any ATLAS results we need instructions from ATLAS colleagues for detector-specific features implementation