New EMEC description with Geant4 solids

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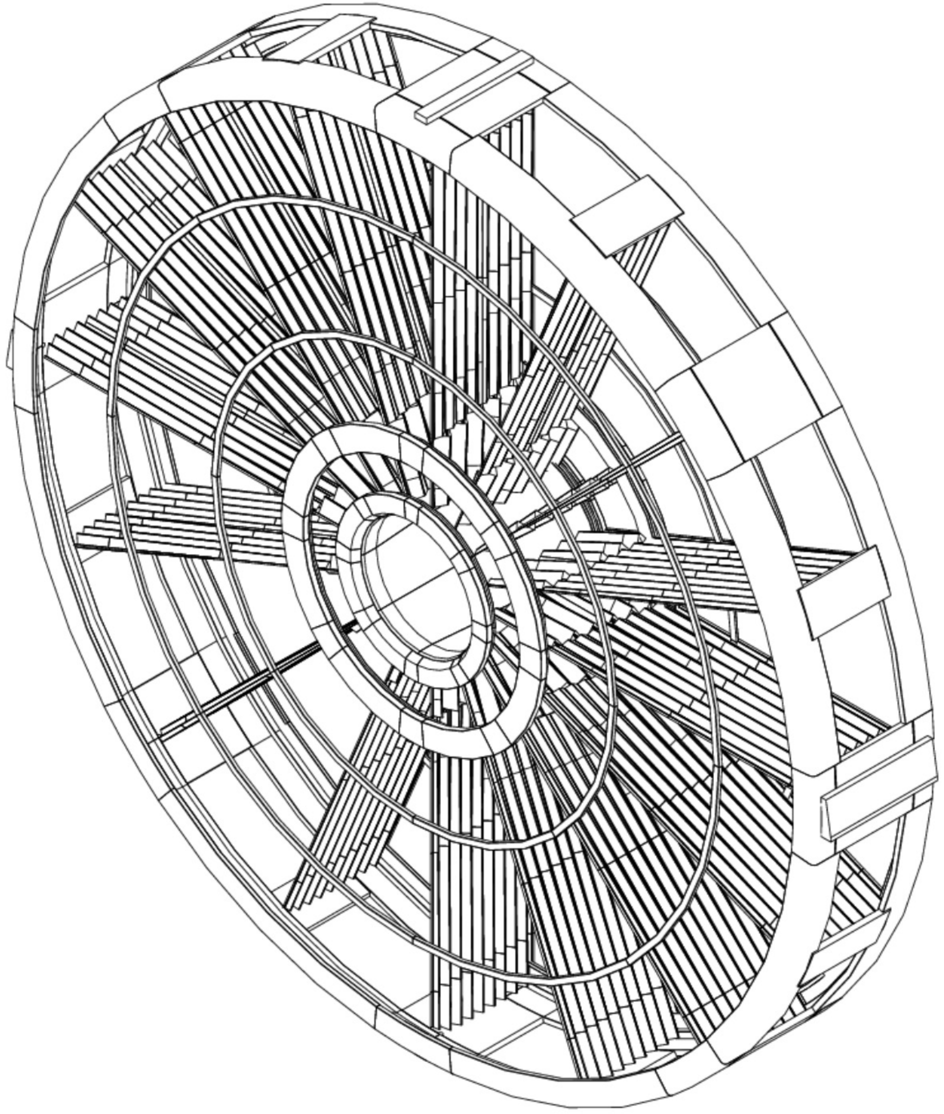


Prehistory. Geant3

Geometry description of the ATLAS Electromagnetic Endcap calorimeter (EMEC) has a long story. EMEC absorbers and electrodes have a complicated accordion-like shape with twisted surfaces.

In Geant3 there was a solid GTRA (General Trapezoid) with a potentially convenient for EMEC shape, unfortunately its implementation was imperfect:

Users should avoid to use this shape as much as possible, and if they have to do so, they should make sure that the faces are really planes. If this is not the case, the result of the transport is unpredictable.
(GEANT – Detector Description and Simulation tool, p.113)

So, EMEC absorbers and electrodes in the Geant3 version of simulation were described as sets of mini-pieces of ordinary shapes.

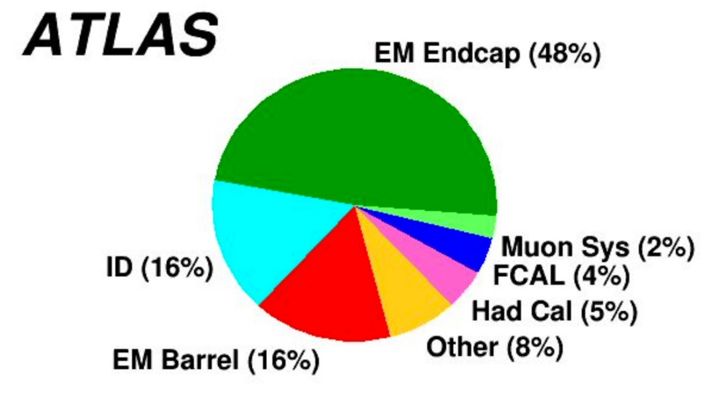
Prehistory. Geant4

In 2001, it was decided to rely on the Custom solid implemented by for the Geant4 version of the ATLAS simulation. The main reasons for the decision were:

- Absence of “twisted trapezoid” shape in Geant4 at that time
- Non ideal stacking of ”elementary pieces” in Geant3

The Custom solid can very accurately describe the shape of EMEC absorbers and electrodes, but it also has several serious drawbacks.

The main one is the CPU consumption. As it follows from the diagram of CPU fraction in different subdetectors, almost half of CPU time for 50 ttbar events was spent in the EM Endcap calorimeter.



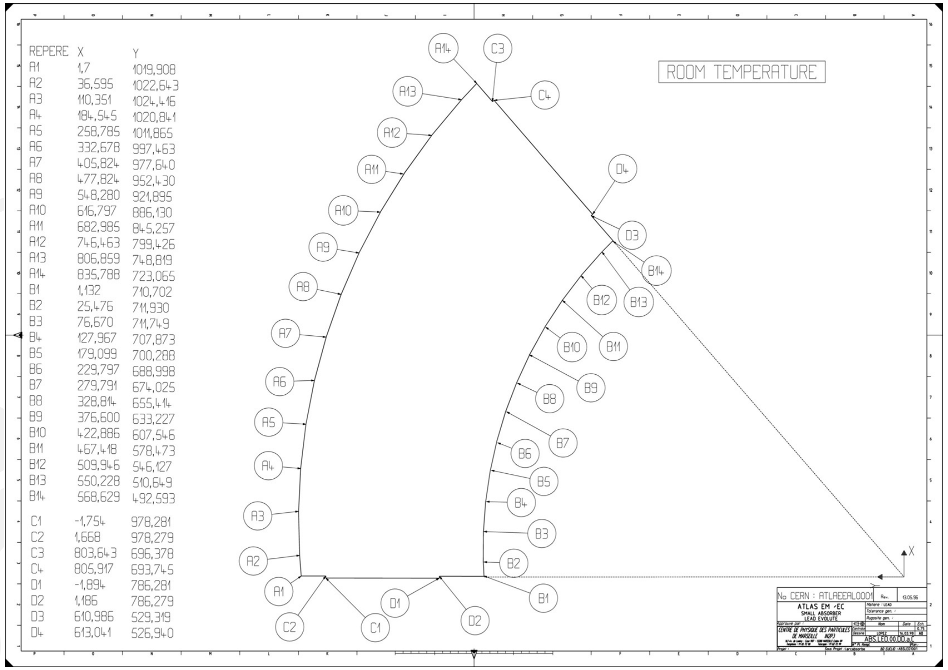
Subdetector CPU fraction for 50 ttbar events
MC16 Candidate Release

Another disadvantage of the Custom solid is that it can not be dumped into GDML. This does not allow to provide full ATLAS geometry to external teams (Geant4, Adept, Celeritas) for testing their developments.

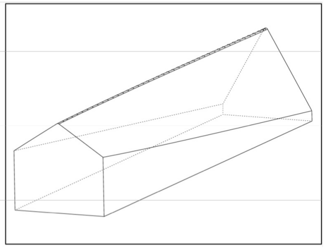
Therefore, there always been interest in describing the EMEC geometry using Geant4 solids. The current project is not new, it is a continuation of previous efforts.

Selecting solid for describing absorber

- In 2005 (Geant4 7.0.0) G4TwistedTrap was added to the Geant4 collection of solids.
- Current implementation of G4GenericTrap, adopted from Root TGeoArb8, appeared there in 2010 (Geant4 9.4.0)
- To understand which of these two solids is suitable for describing the EMEC Accordion geometry, let's look at how the absorbers were formed. The absorbers were made from flat plates by deforming them in a press machine using a special knife to obtain the desired profile.
- The top part of the knife consists of two curved surfaces, but all its edges are straight lines.
- Similar property has G4GenericTrap, not G4TwistedTrap



Plate

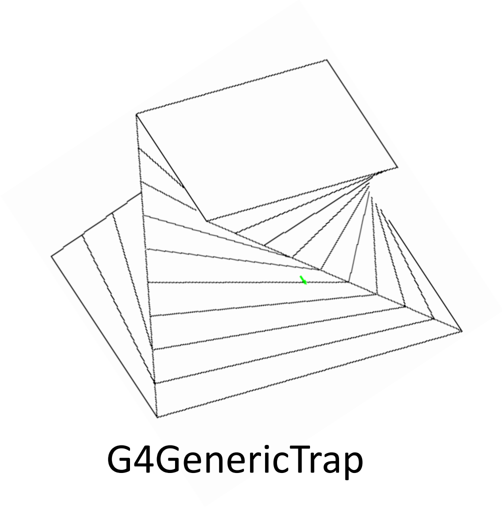


Knife

Absorber

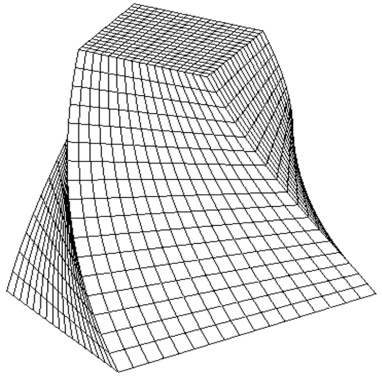
G4GenericTrap vs G4TwistedTrap

- The lateral surfaces of G4GenericTrap are 2nd order surfaces, namely hyperbolic paraboloids. The points of intersection of a line with a hyperbolic paraboloid can be found as the roots of a quadratic equation.



G4GenericTrap

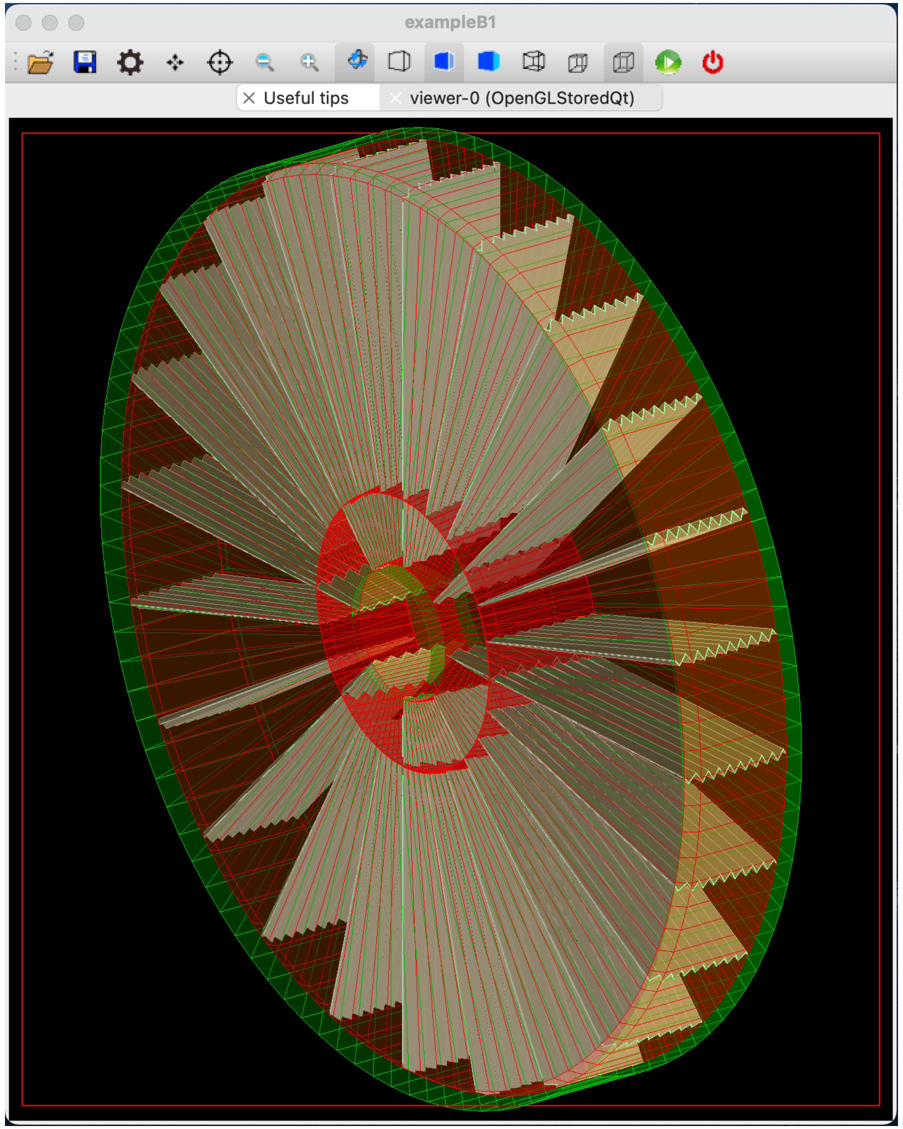
- The lateral surfaces of G4TwistedTrap are helicoids. The lateral edges are not straight, and, in addition, there is no analytical solution of the line-helicoid intersection problem, the intersection points are calculated iteratively, which makes G4TwistedTrap much slower than G4GenericTrap.



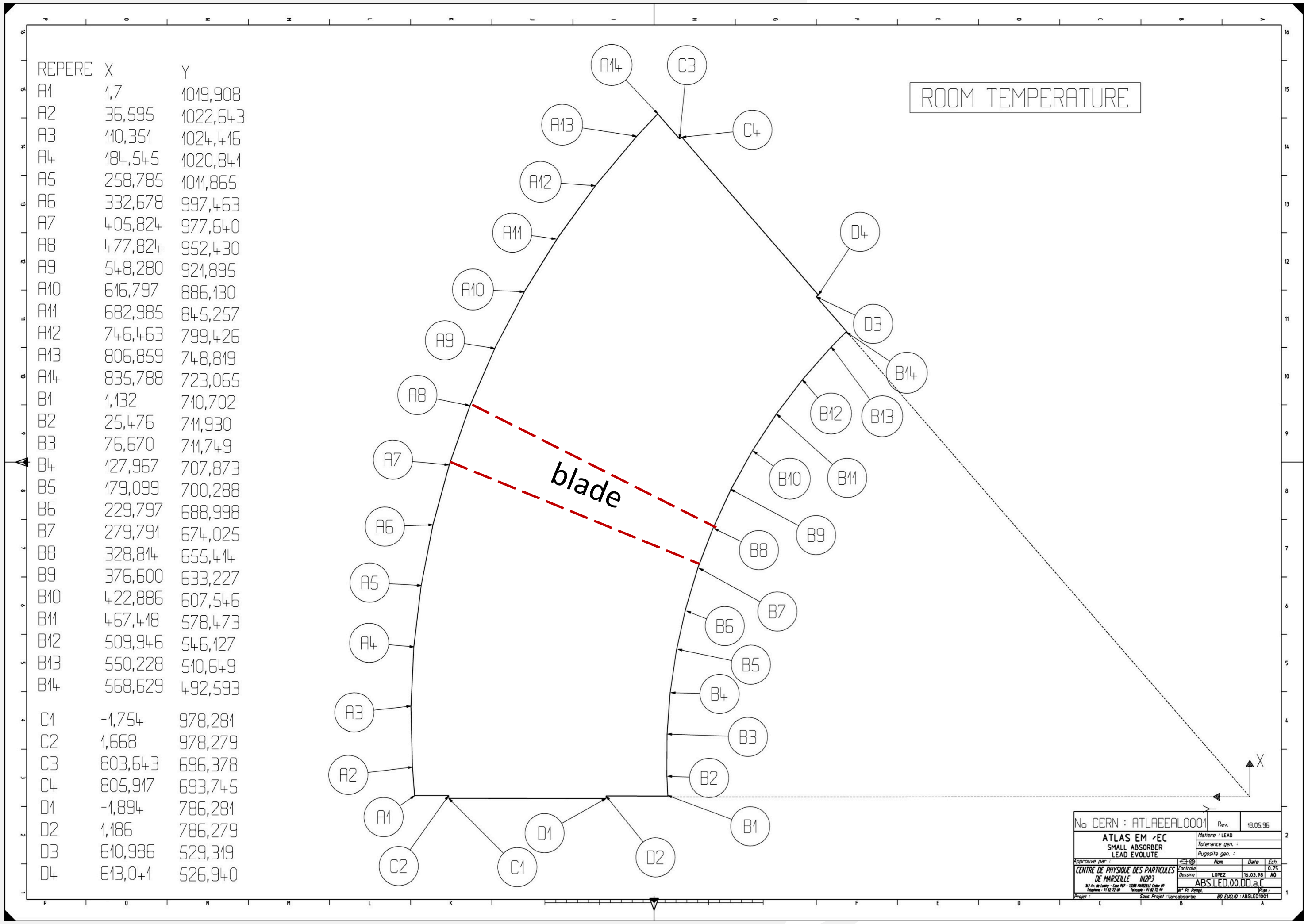
G4TwistedTrap

Current implementation of EMEC Accordion structure

- For the construction of absorbers and electrodes inside the Inner and Outer wheels it was implemented a C++ class.
- At present time it uses G4GenericTrap, later it will be migrated to GeoGenericTrap
- The structures can be built with or without subdivision of the wheels into slices. More options foreseen in the future.
- The implementation is based on data taken from the technical drawing of the lead plates for the Inner and Outer wheel absorbers (see next two slides)
- Definitions of materials have been taken from C++ code for HEC Test Beam simulation. A possibility to change the materials is provided.
- It was checked that the volume of the absorbers corresponds to the volume of original plates.

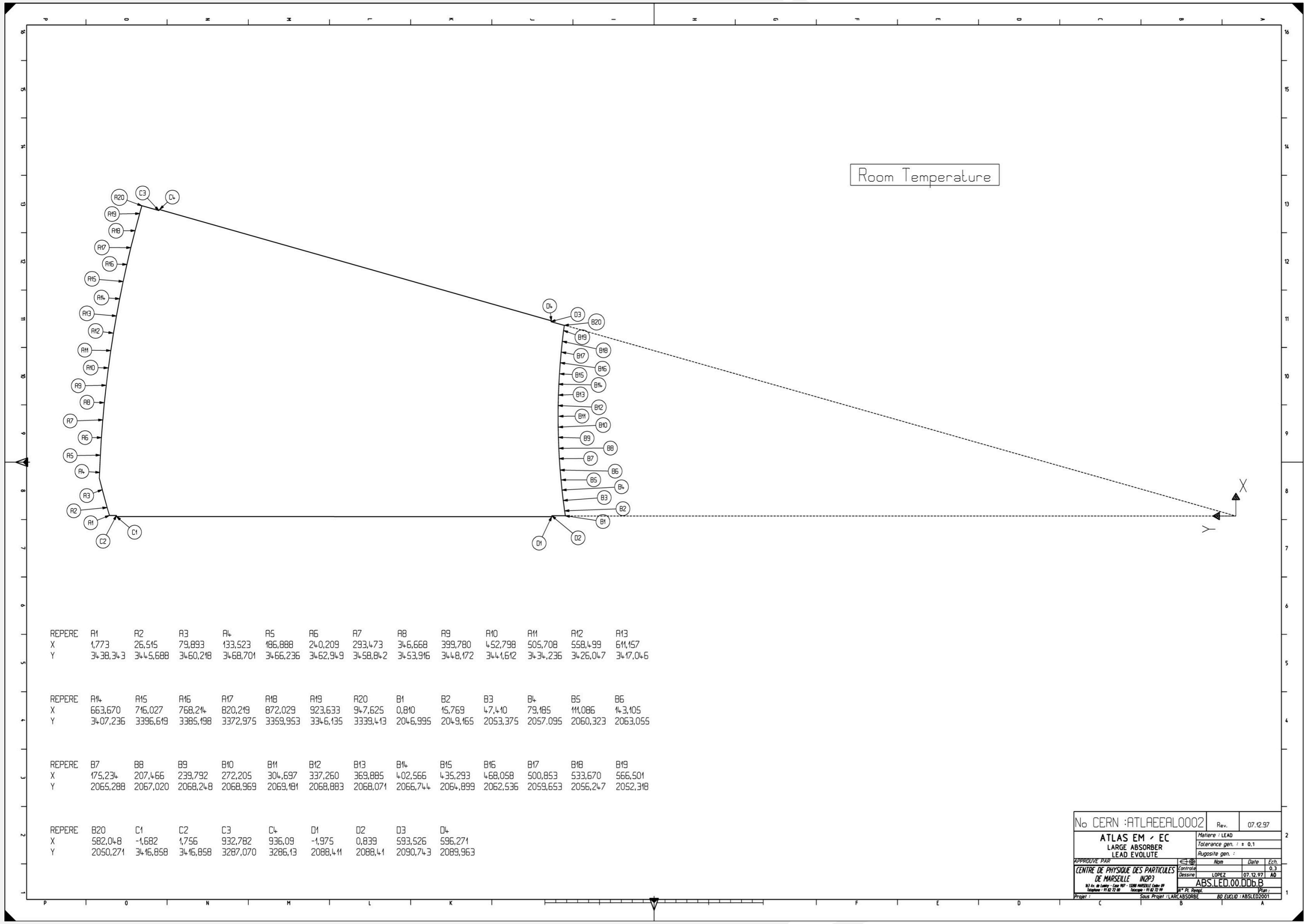


Inner Wheel contruction



- The Inner Wheel contains 256 Absorbers and 256 Electrodes
- The plate can be divided into *blades* by connecting corresponding points (red lines):
  - 11 half-wave blades
  - 2 quarter-wave blades
  - 2 lips for connection with the longitudinal bars (C-D points)
- Profiled blades are described as G4GenericTrap solids
- The Inner Wheel can be splitted into **15 slices**, each slice contains blades of the same type, in total 512 physical volumes per slice

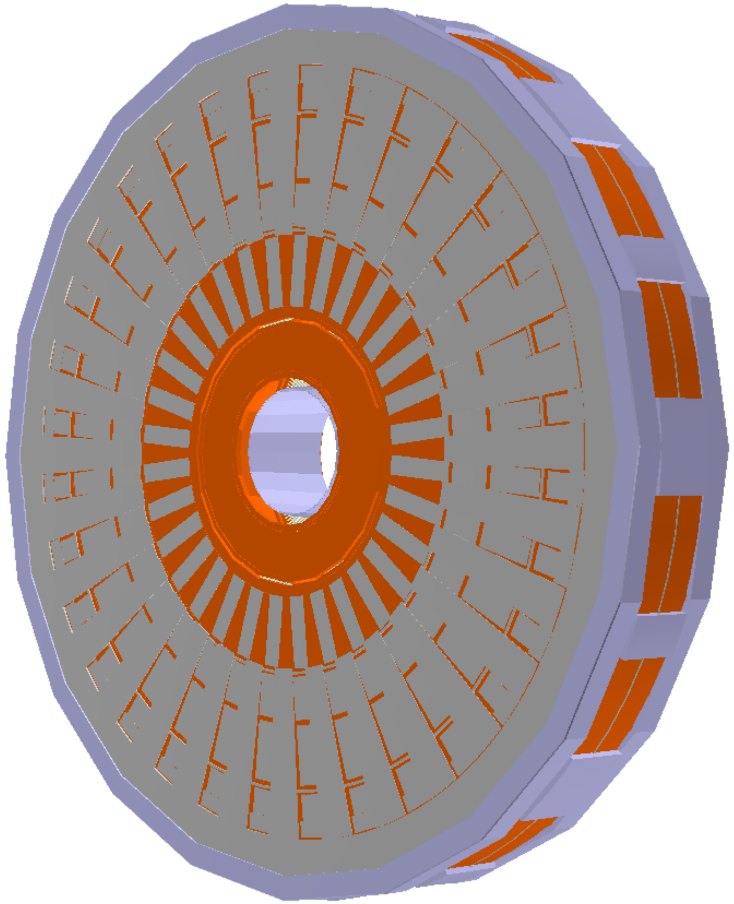
Outer Wheel construction



- The Outer Wheel contains 768 Absorbers and 768 Electrodes
- The plate can be divided into the following *blades*:
  - 17 half-wave blades
  - 2 quarter-wave blades
  - 2 lips for connection with the longitudinal bars
- The Outer Wheel can be splitted into **21 slices**, in total 1536 physical volumes per slice

Performance measurement environment

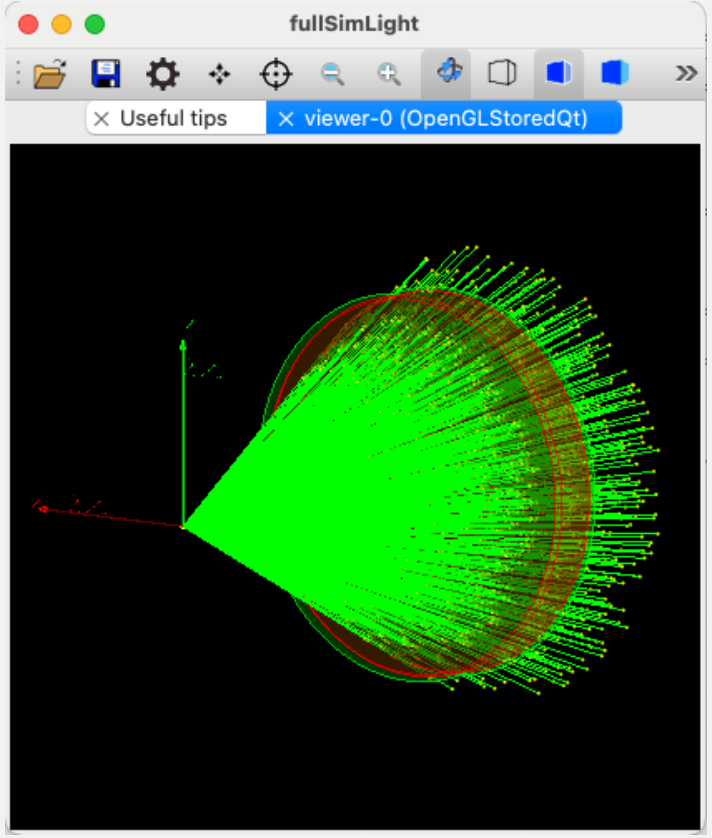
- The CPU consumption of various EMEC implementations was measured using a modified (personal) version of FullSimLight
- To have a suitable environment the following features have been added to FullSimLight:
  - Visualization mode for visual control on the setup, the measurements themselves were performed with visualization turned off
  - The particle gun that shoots particles within a cone, to ensure that all primary particles cross EMEC
  - EMEC_mother.db, containing the Custom solid, was used as the source of geometry with a possibility to replace the Custom solid with the new implementation based on G4GenericTrap

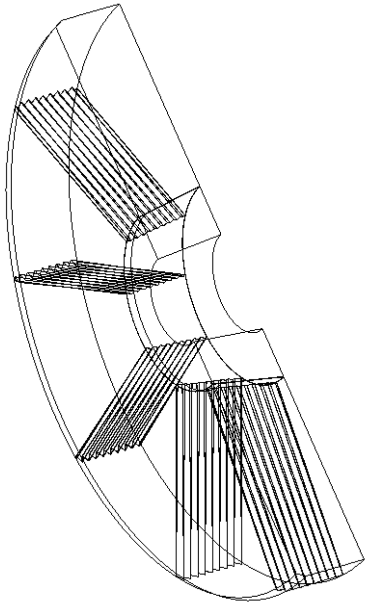
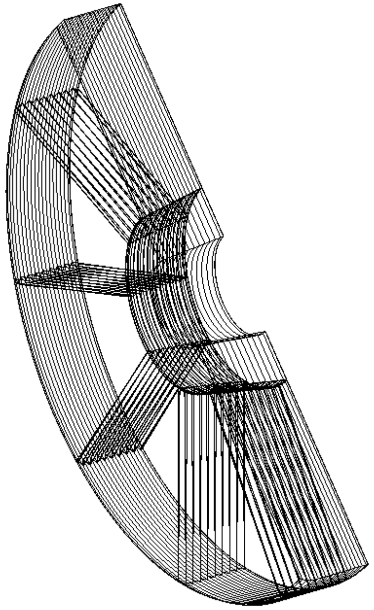


EMEC

CPU time, 100K geantino events

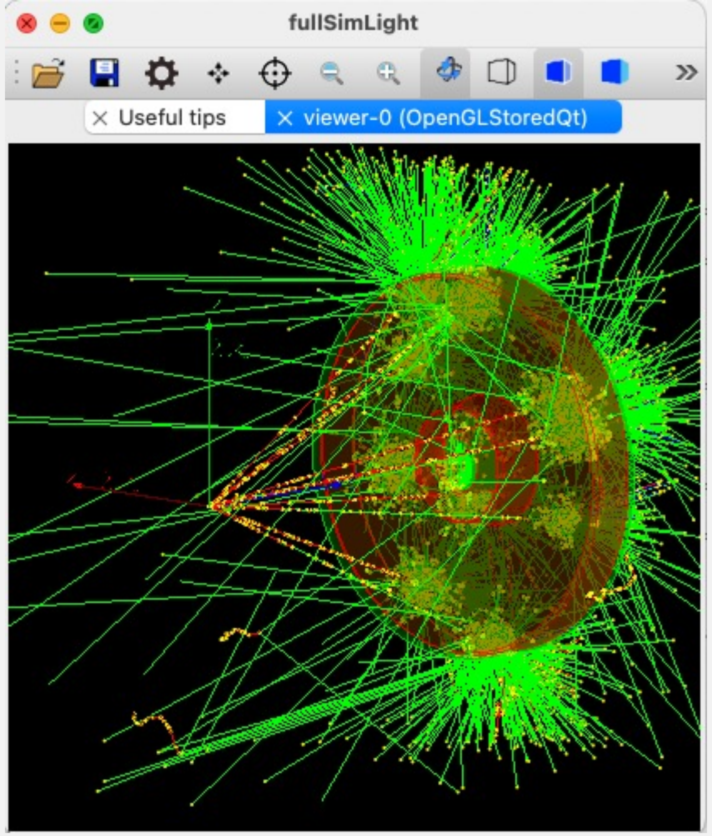
- The testing was performed for three different geometry settings (Custom solid, G4GenericTrap solids without and with division of the wheels into slices) by shooting a) geantino and b) 10 GeV electrons.
- Below is CPU time measured for 100K geantino events. Geantino is a virtual particle which is useful for testing pure transport through geometry. Geantino does not interact with matter, so there is no physics involved.



Custom solid	G4GenericTrap, no slices	G4GenericTrap, slices
107 s	36 s	30 s
		

CPU time, 200 e- 10 GeV events

- Benchmark test with 10 GeV electrons has shown very promising performance of the new description, CPU time improved by 2.5 times
- There was also observed an unexpected increase in number of secondary electrons by ~6%. A dedicated study has shown that small structural differences between the Custom solid and the description with G4GenericTrap cannot cause extra secondary electrons, and that the source of the issue is most likely in G4GenericTrap itself.



Custom solid	G4GenericTrap, no slices	G4GenericTrap, slices
100 s	51 s	42 s
Mean energy deposit per event = 9.938 +- 0.05315 [GeV] Mean track length (charged) per event = 2138 +- 252.1 [cm] Mean track length (neutral) per event = 2.774e+04 +- 6922 [cm] Number of steps (charged) per event = 6.495e+04 +- 3037 Number of steps (neutral) per event = 1.154e+05 +- 5550 Number of secondaries per event : Gammas = 4995 +- 97.5 Electrons = 9138 +- 114.9 Positrons = 504.4 +- 19.83	Mean energy deposit per event = 9.927 +- 0.09896 [GeV] Mean track length (charged) per event = 2063 +- 299.8 [cm] Mean track length (neutral) per event = 3.197e+04 +- 4966 [cm] Number of steps (charged) per event = 6.867e+04 +- 5078 Number of steps (neutral) per event = 1.066e+05 +- 6838 Number of secondaries per event : Gammas = 4921 +- 106.2 Electrons = 9775 +- 292.9 Positrons = 479.6 +- 17.92	Mean energy deposit per event = 9.898 +- 0.444 [GeV] Mean track length (charged) per event = 2056 +- 425.3 [cm] Mean track length (neutral) per event = 3.217e+04 +- 7400 [cm] Number of steps (charged) per event = 6.915e+04 +- 6241 Number of steps (neutral) per event = 1.085e+05 +- 1.04e+04 Number of secondaries per event : Gammas = 4907 +- 252.4 Electrons = 9776 +- 529 Positrons = 479.1 +- 31.03

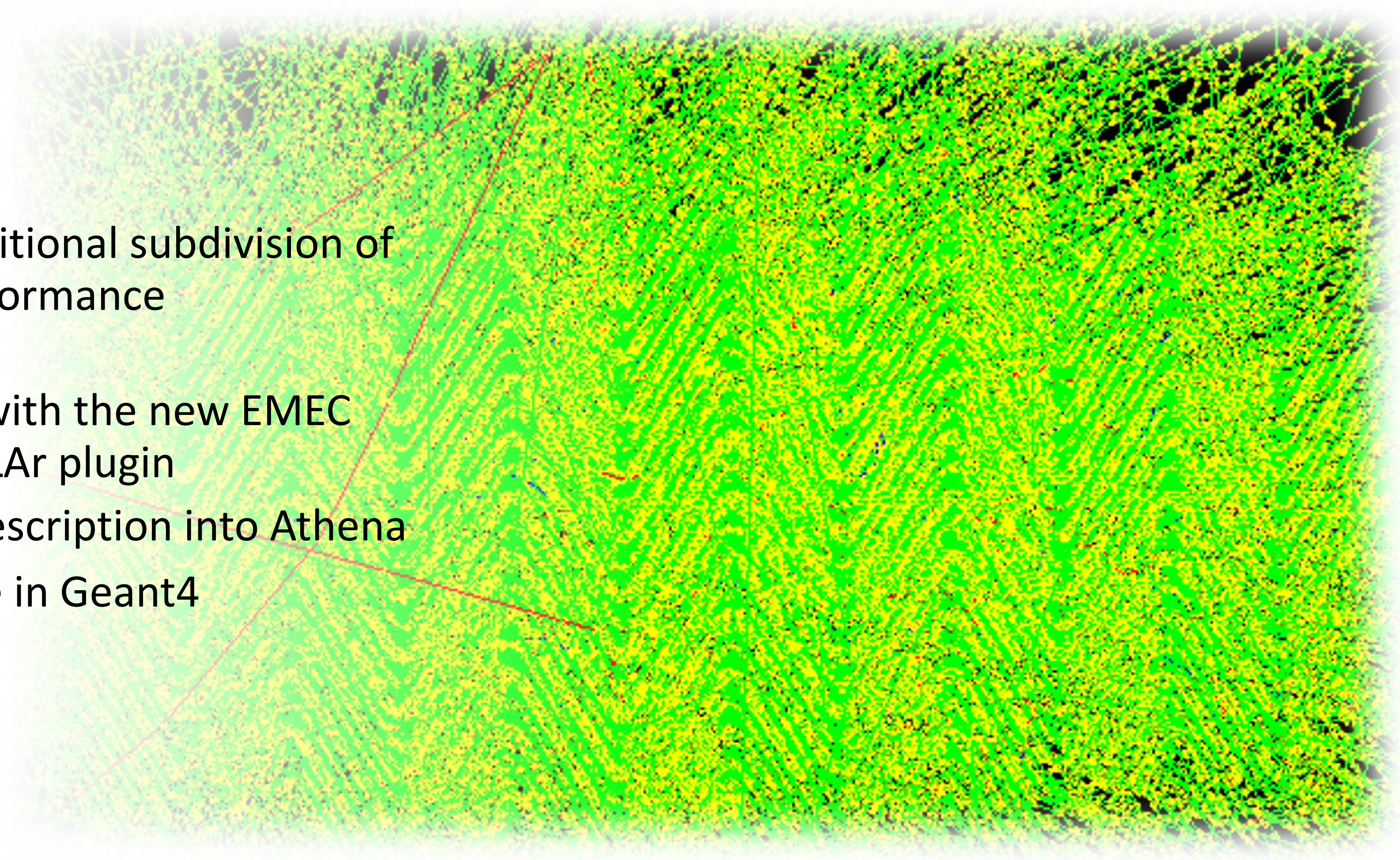
G4GenericTrap: overestimated safety distance

- A special test was implemented to located the problematic code. The test has shown that the safety distance returned by G4GenericTrap::DistanceToIn(p) and G4GenericTrap::DistanceToOut(p) is significantly overestimated in most of cases.
- Corresponding bug report was opened in the Geant4 problem report system.
- The *safety distance* of a point relative to a solid is the *radius of space around the point*, within which the point can move in any direction without crossing the boundaries of the solid. The safety distance may be underestimated, a zero safety distance is a legal return value.
- Setting safety distance to zero in G4GenericTrap normalizes the number of secondary electrons but increases the number of steps for charged particles and, consequently, the CPU time.
- The bug does not create problems for further development of the project, a revision of G4GenericTrap to improve its performance was a part of this project anyway.

	G4GenericTrap	DistanceToIn/Out(p) = 0
CPU	42 s	72 s
Mean energy deposit per event [GeV]	9.898 +- 0.444	9.935 +- 0.07721
Mean track length (charged) per event [cm]	2056 +- 425.3	2138 +- 395.5
Mean track length (neutral) per event [cm]	3.217e+04 +- 7400	2.837e+04 +- 9484
Number of steps (charged) per event	6.915e+04 +- 6241	2.58e+05 +- 5172
Number of steps (neutral) per event	1.085e+05 +- 10400	1.157e+05 +- 5873
Number of secondaries per event:		
Gammas	4907 +- 252.4	5021 +- 95.61
Electrons	9776 +- 529	9193 +- 121.8
Positrons	479.1 +- 31.03	503.5 +- 19.13

Further plans

- Implement options for additional subdivision of the wheels for further performance improvement
- Replace the Custom solid with the new EMEC description in the current LAr plugin
- Integrate the new EMEC description into Athena
- Revise G4GenericTrap code in Geant4



Shower inside EMEC

Conclusions

- Implemented a new C++ class for describing the EMEC Accordion structure:
  - At present time it uses G4GenericTrap, later it will be migrated to GeoGenericTrap
  - Geometry data taken from the technical drawings of the lead plates for the Inner and Outer Wheel Absorbers
  - A possibility to change the default materials is provided
  - Exists a possibility to divide the structure into slices, additional subdivision is under implementation
- New geometry description already demonstrates very promising CPU performance. More speed up is expected with further development.