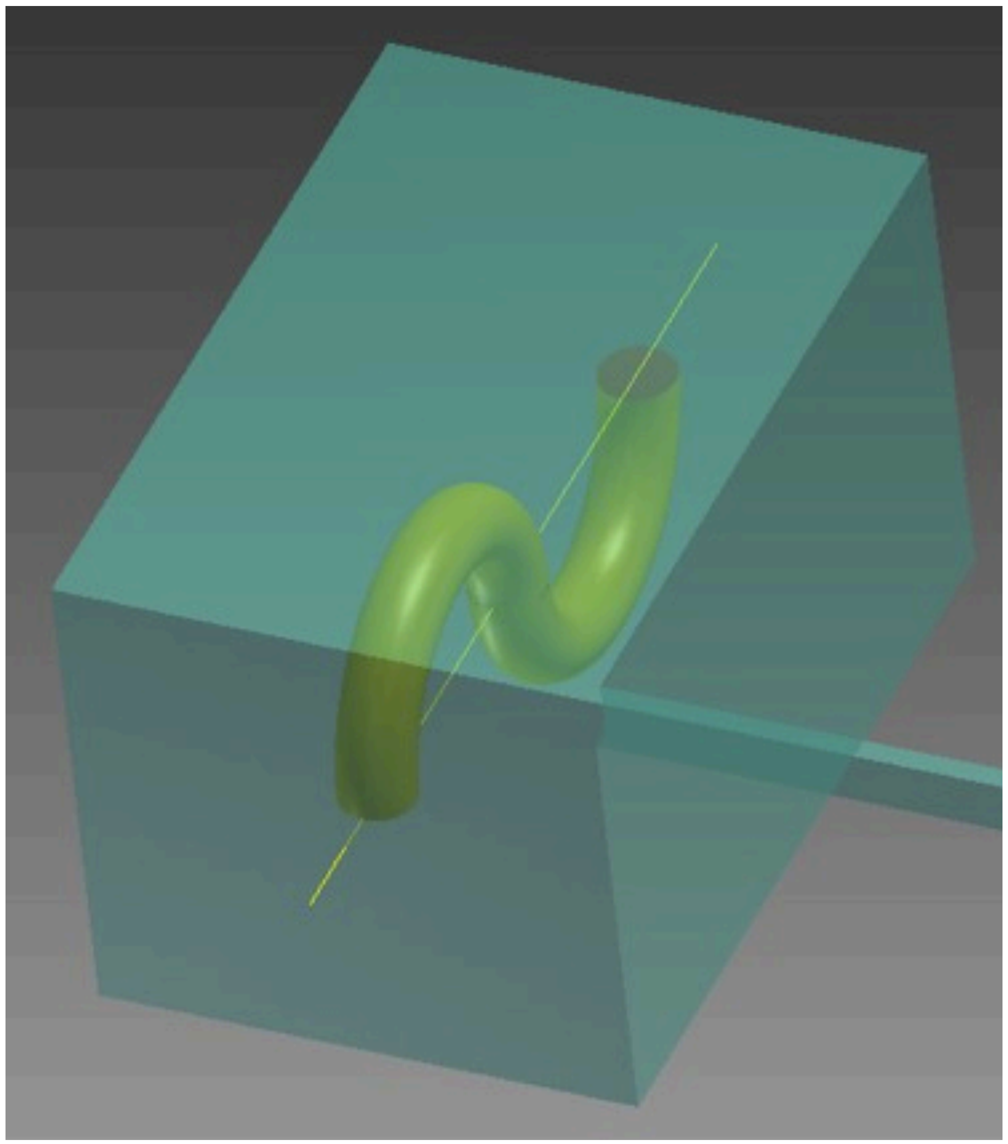
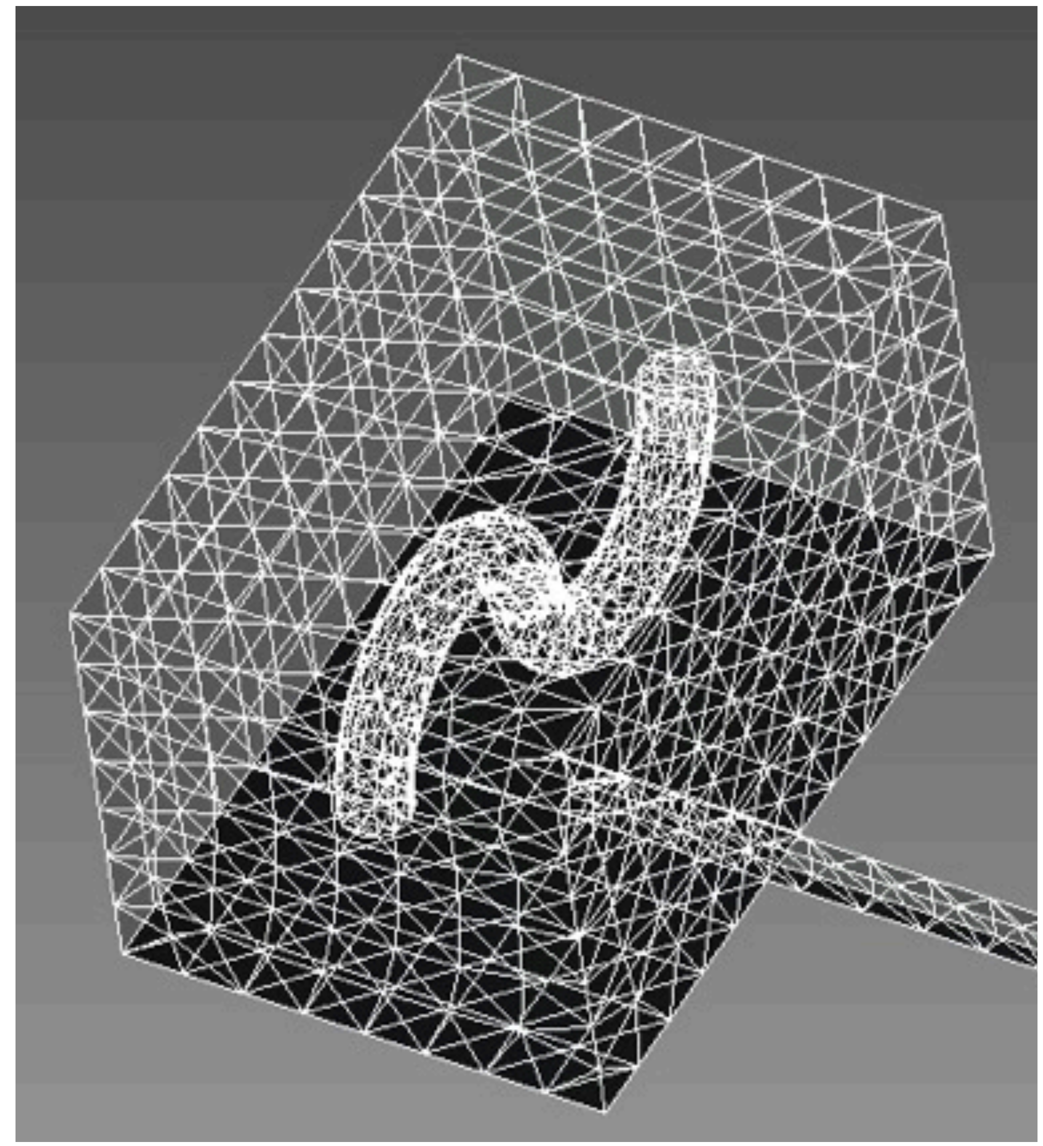
Simulation-aided optimization of detector design using portable representation of 3D objects





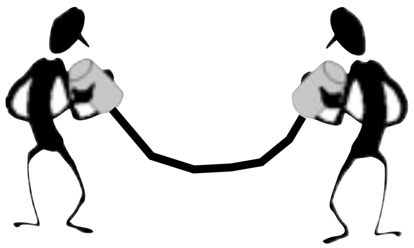
May 16-21, 2013, Beijing, China

http://acat2013.ihep.ac.cn

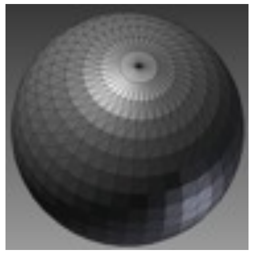
Jan Balewski

LNS Laboratory for Nuclear Science

Outline

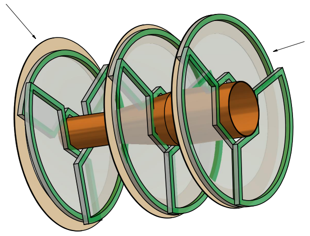


•Describe traditional approach



•Contrast STL-based approach
- STL pros
- STL cons

•'plumbing' : CADMesh, VMs



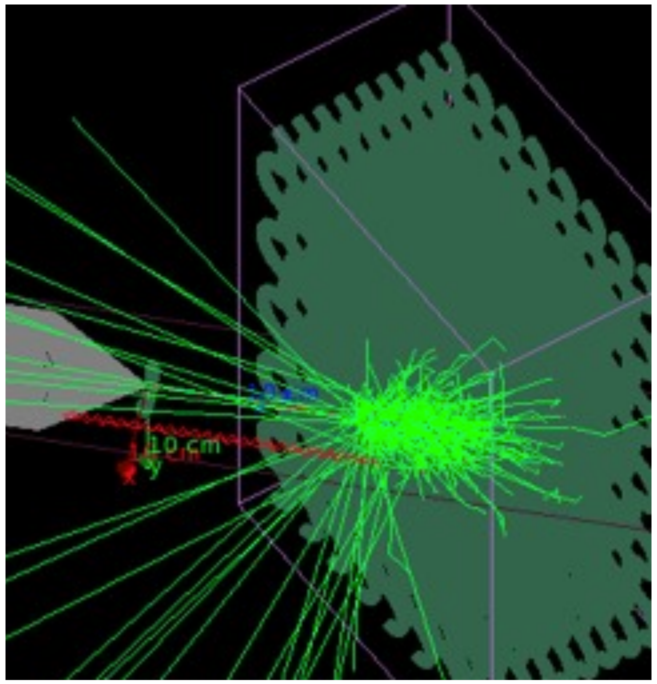
•Example: DarkLight detector design

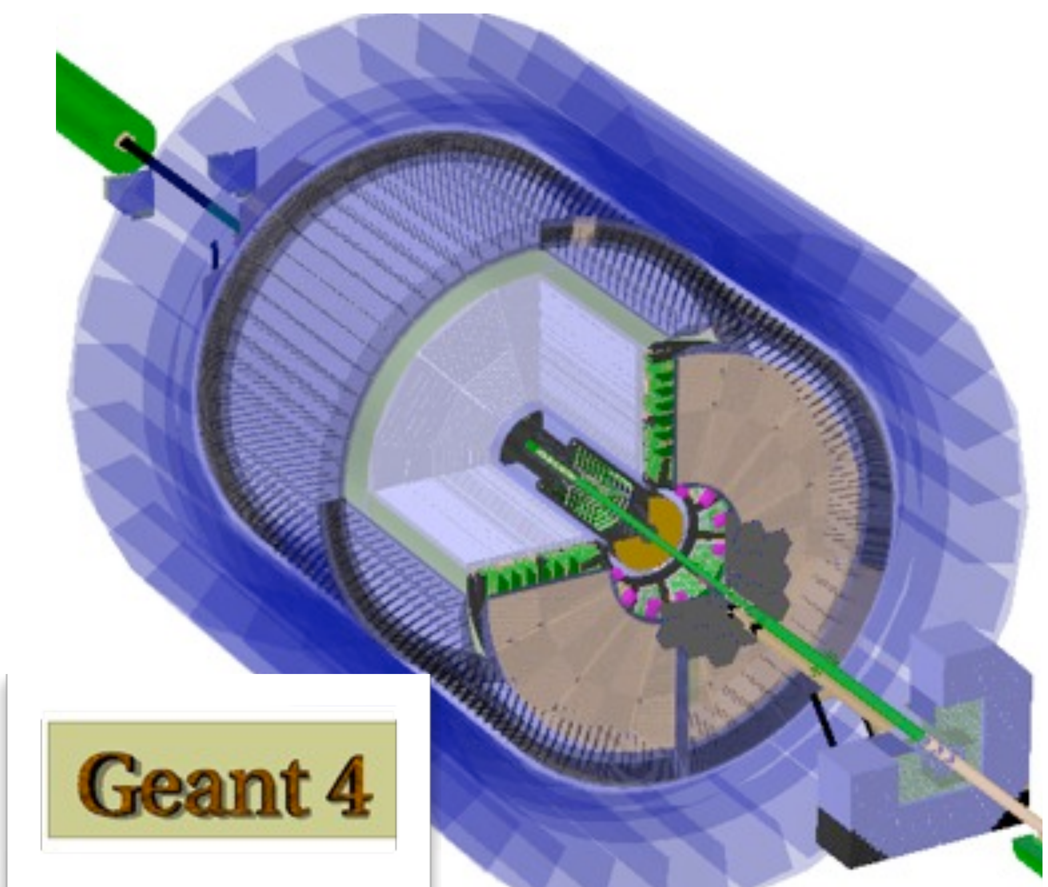
•Conclusions

Typical 2-prong detector design process

Physicists

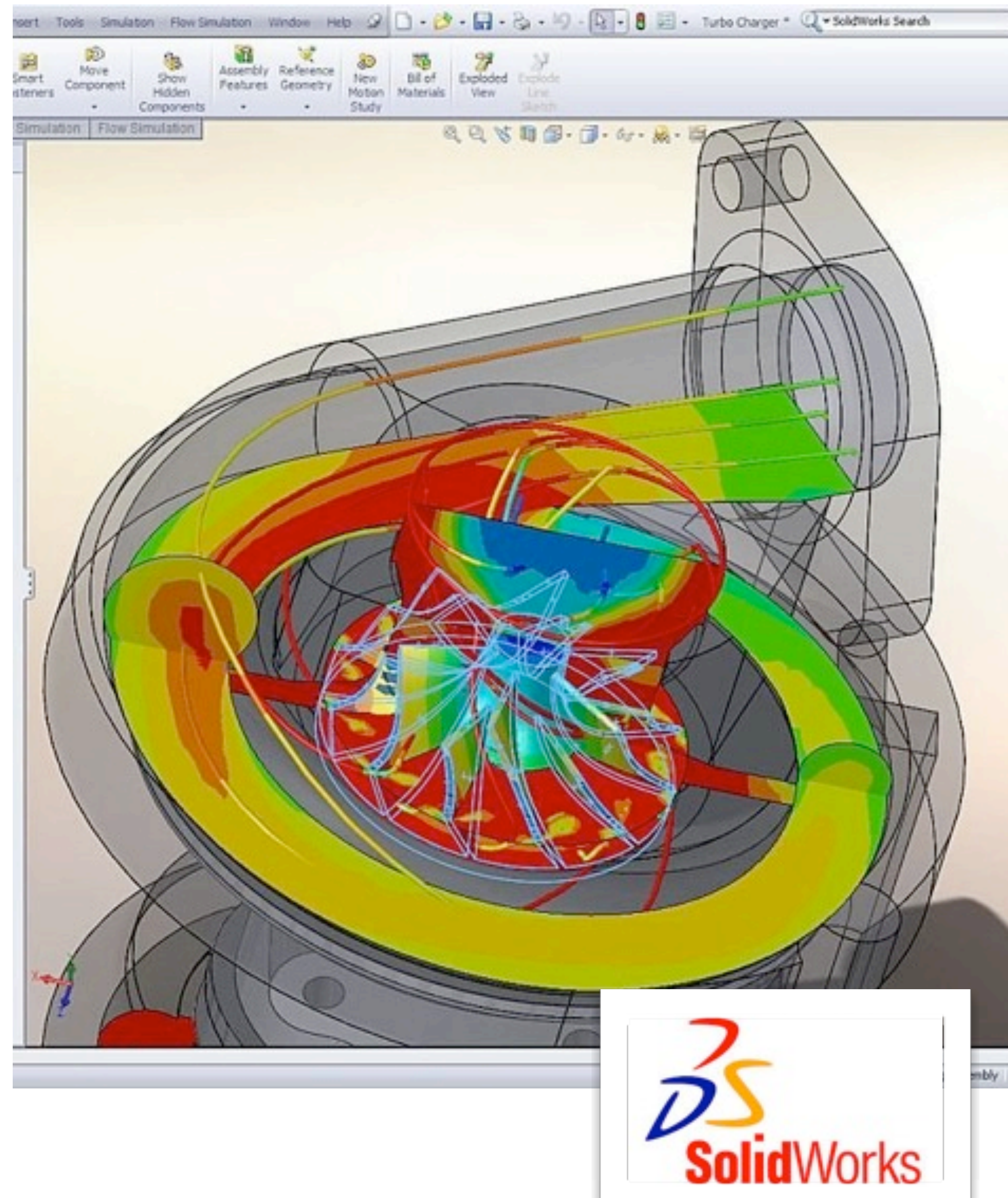
Geant model



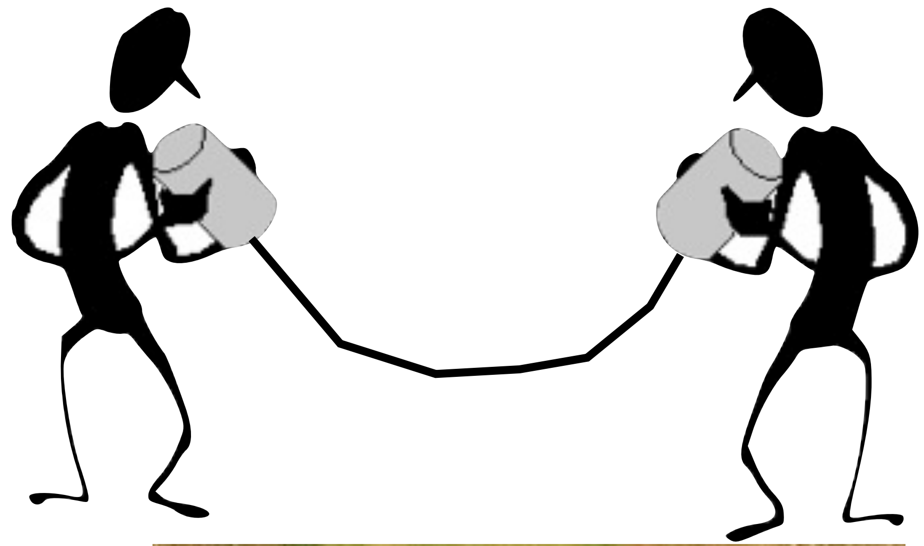


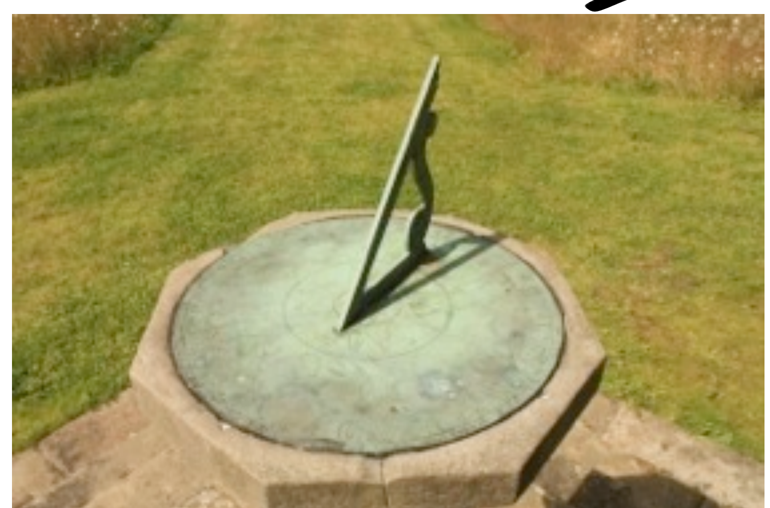
Engineers

CAD model



Typical detector design process ... takes time





Physicists

bring idea

•purpose of experiment
•key components
•preferred technology
•space constraints

• simulated response
→changed requirements

• high cost
→changed requirements

Engineers

bring technical knowledge

• detailed construction plan
• realistic material budget
• realistic price tag

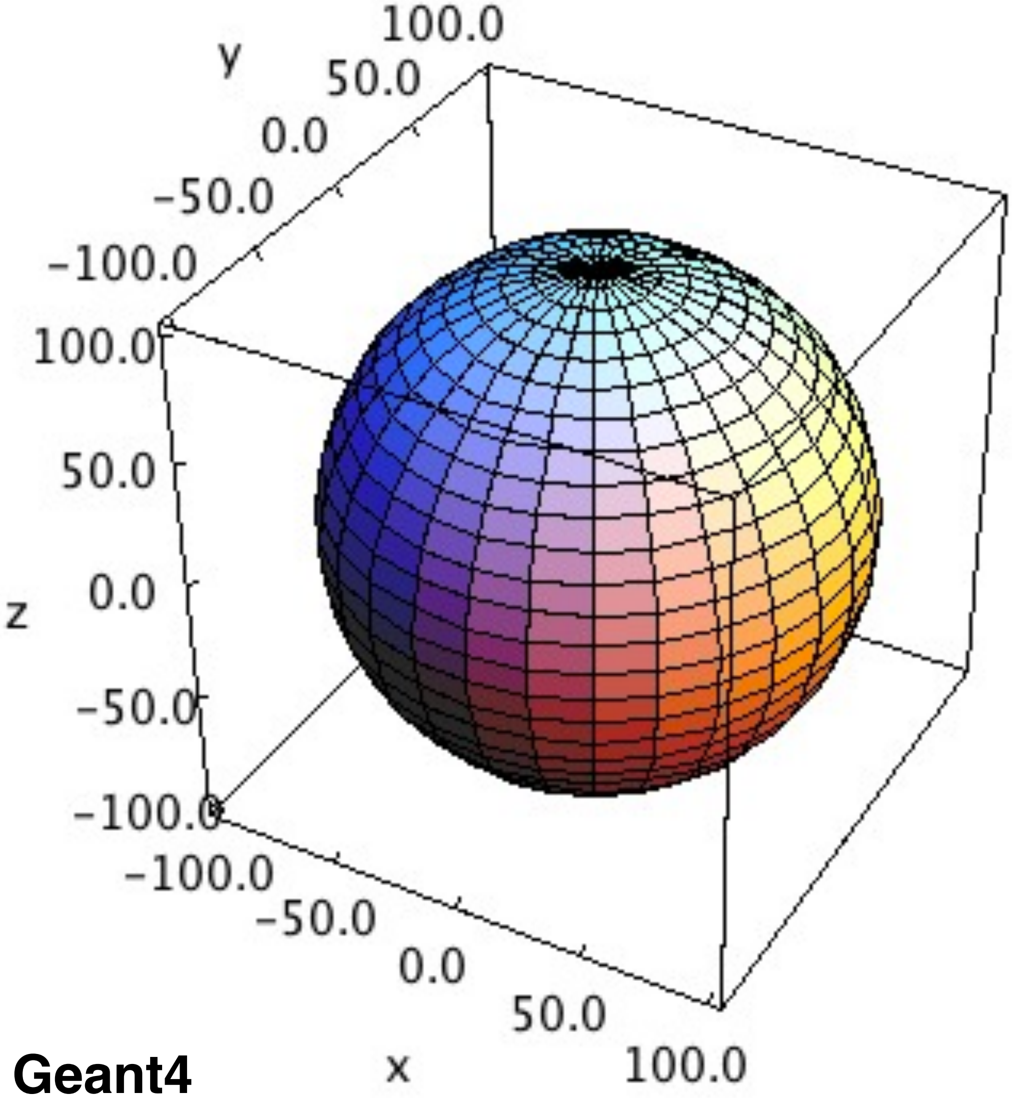
• revised design & price tag

• revised design & price tag

days, weeks, months,...

Geant4 representations of solids

Constructive Solid Geometry (CSG)

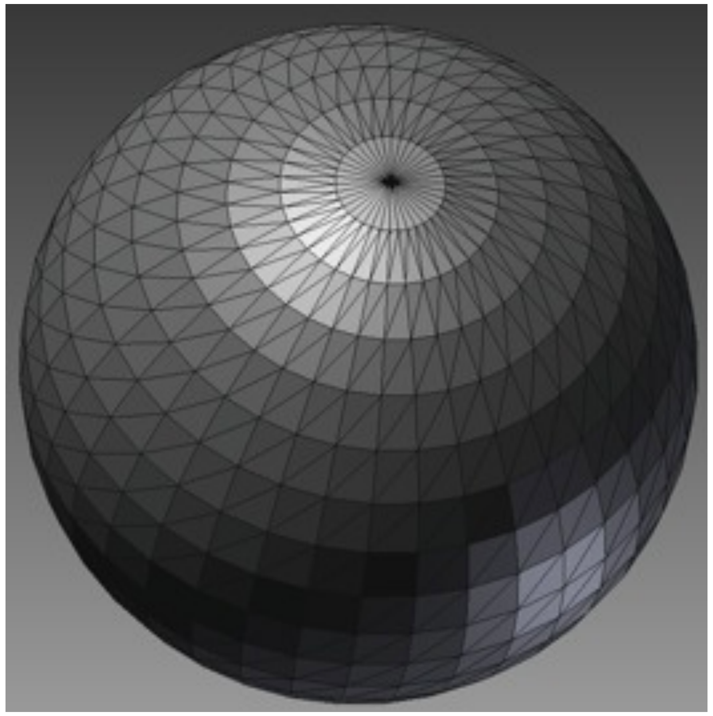


Geant4

To build a **full solid sphere** use:

```
G4VSolid *
G4Orb(const G4String& pName,
              G4double pRmax)
```

Boundary Represented Solids (BREPs)



SolidWorks

AutoCAD

CAD ⇒Standard Tessellation Language (STL)

Geant4: to import sphere in **STL format** use:

```
CADMesh * mesh = new CADMesh("mySpehre.stl", "STL",...)
G4VSolid  * mySolid = mesh->TessellatedMesh();
```

Streamlined sharing of detector design

Geant 4

SolidWorks

Physicists ⟷ Engineers

exchange geometry using
Standard Tessellation Language (STL)

`G4TessellatedSolid` shapes.

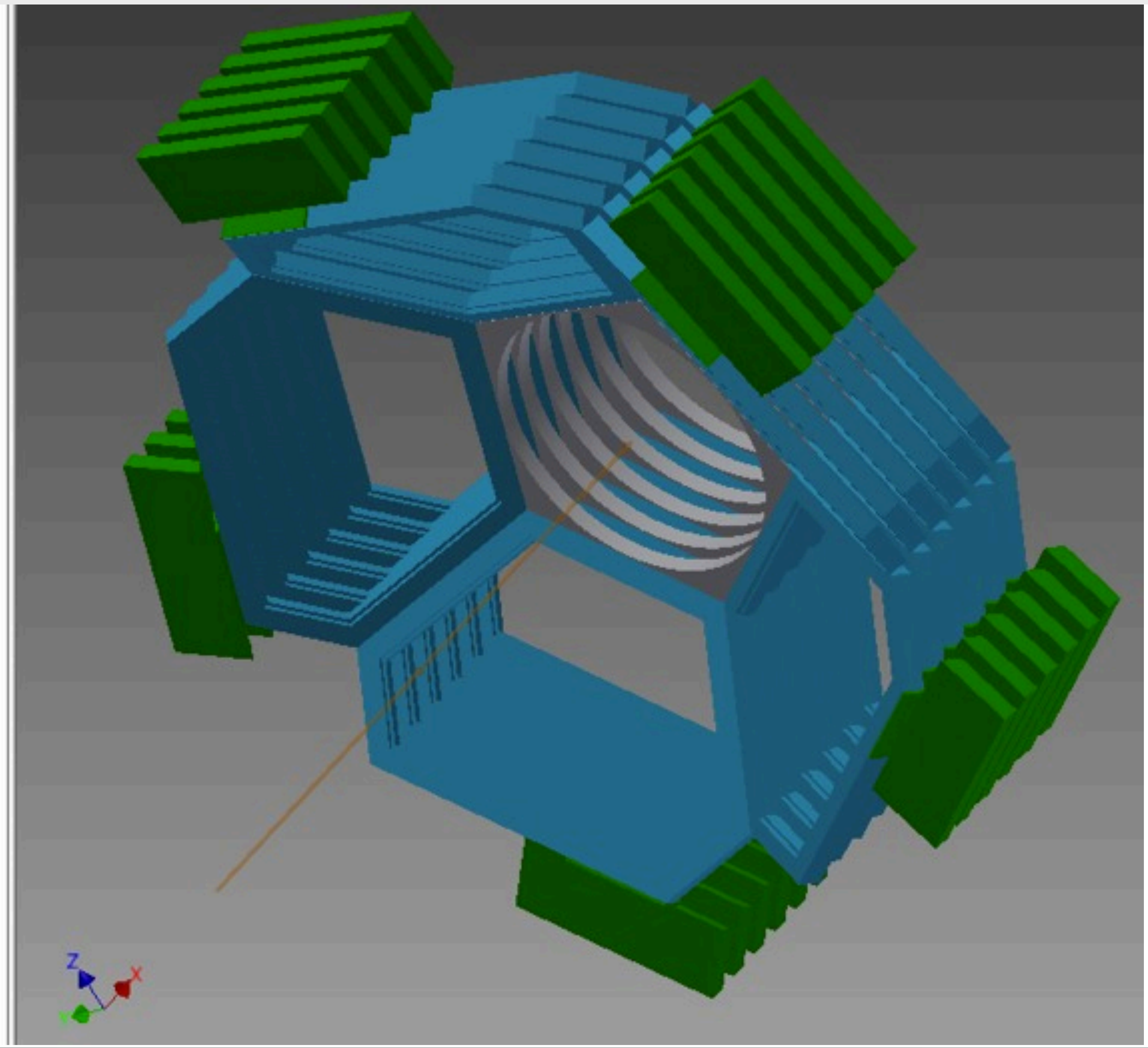
Other tools which can be used to generate meshes to be then imported in Geant4 as tessellated solids are:

- STL2GDML - A free STL to GDML conversion tool.
- SALOME - Open-source software allowing to import STEP/BREP/IGES/STEP/ACIS formats, mesh them and export to STL.
- ESABASE2 - Space environment analysis CAD, basic modules free for academic non-commercial use. Can import STEP files and export to GDML shapes or complete geometries.
- CADMesh - Tool based on the VCG Library to read STL files and import in Geant4.
- Cogenda - Commercial TCAD software for generation of 3D meshes through the module `Gds2Mesh` and final export to GDML.

Advantages of STL over G4-native (CSG)

- no 'logical disassembly' into TBox, TTube, etc. of complex, real life shapes
- portability between Geant4 projects (similar to GDML)
- STL fidelity (accuracy) can be changed while exporting from CAD

Example of a non-planar multi-layer detector assembled in CAD



(subjective)

Advantages of CAD over Geant4-native detector design

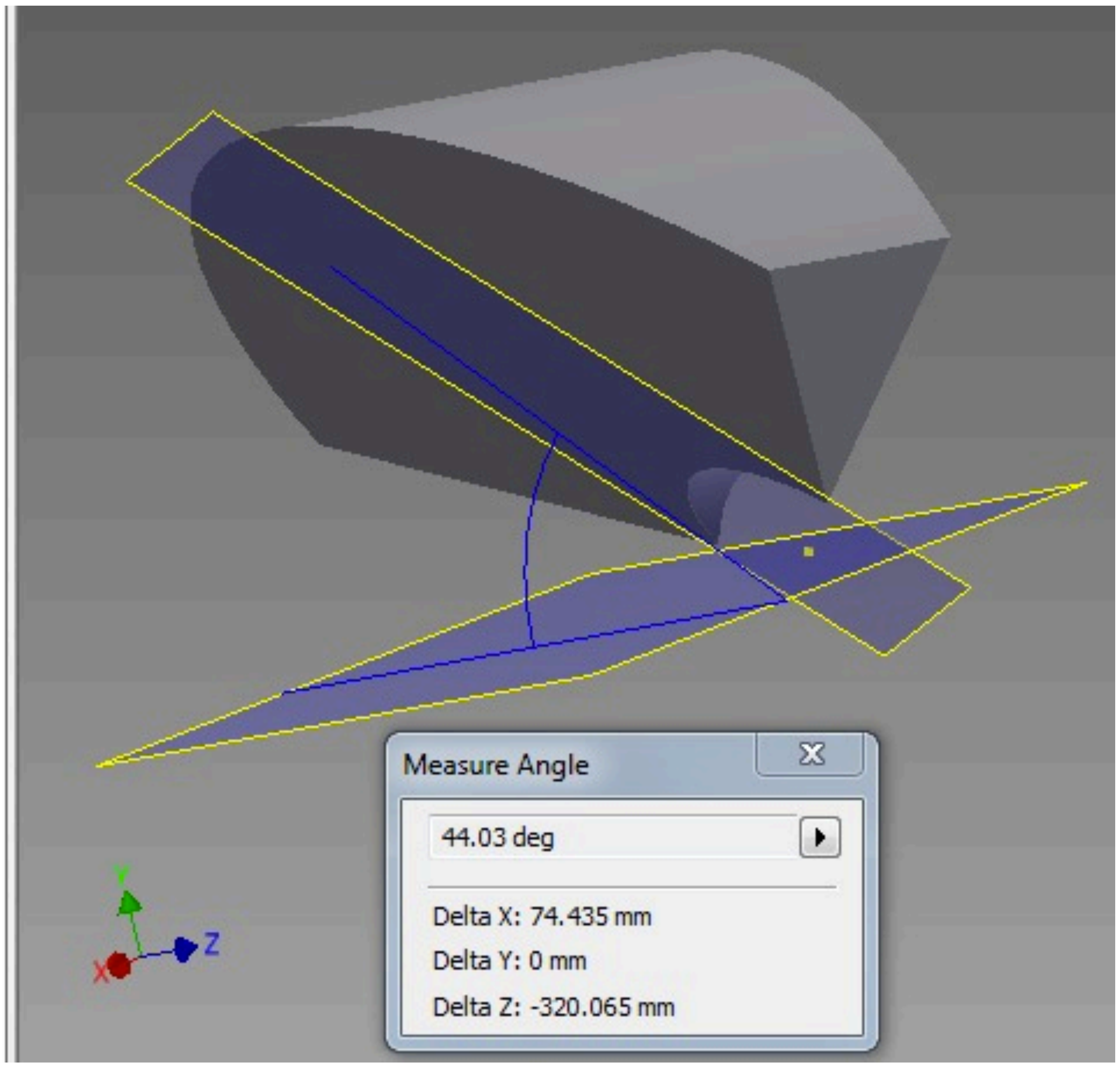
- intuitive assembly in 3D of non-trivial volumes and their alignments

- high quality graphics and animations - important for public relations

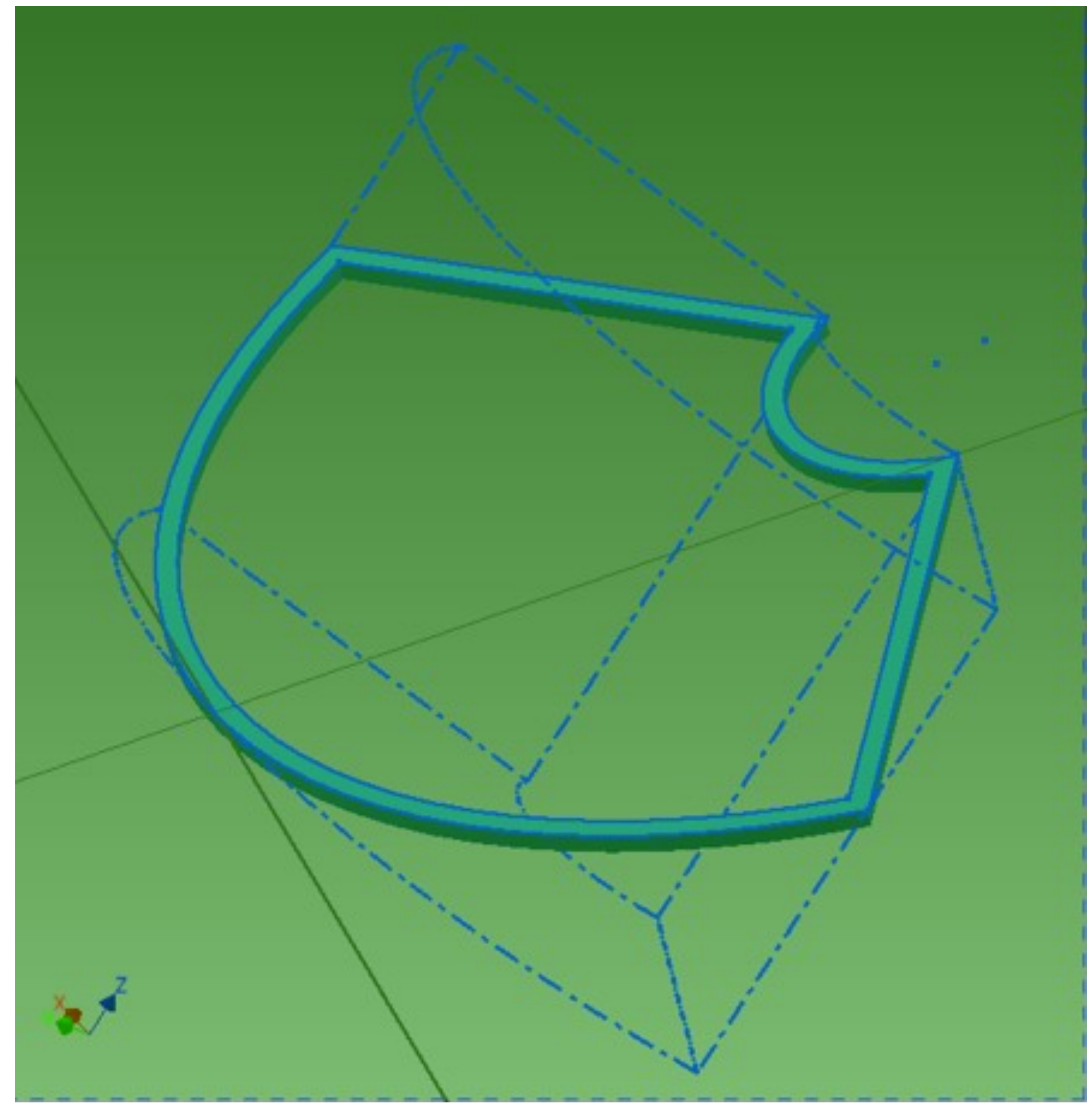
Design a non-trivial 3D volume

Requirement:
design GEM detector (1) made out of frames, (2) placed it at an angle to the beam, (3) fitting it in to a tube

a) Slice a cylinder with the plane inclined to the beam

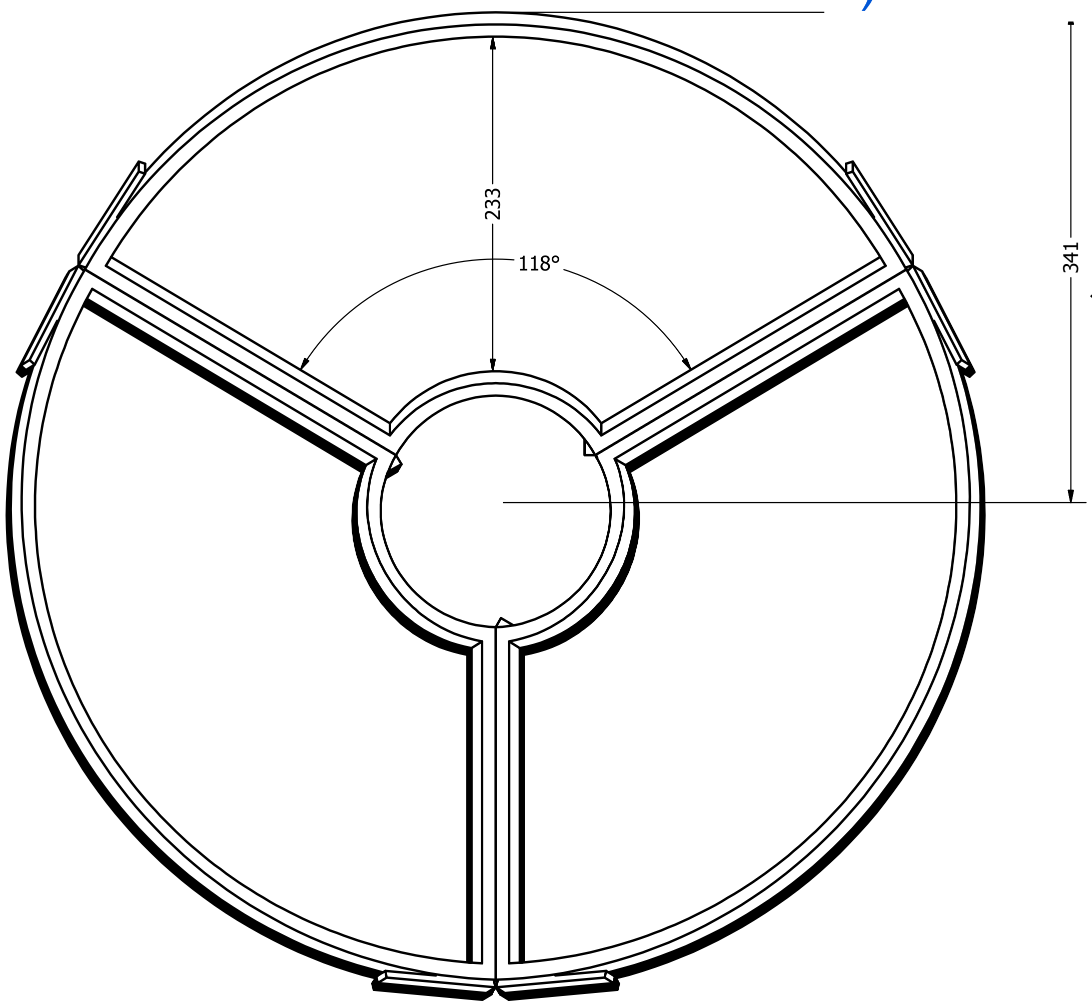


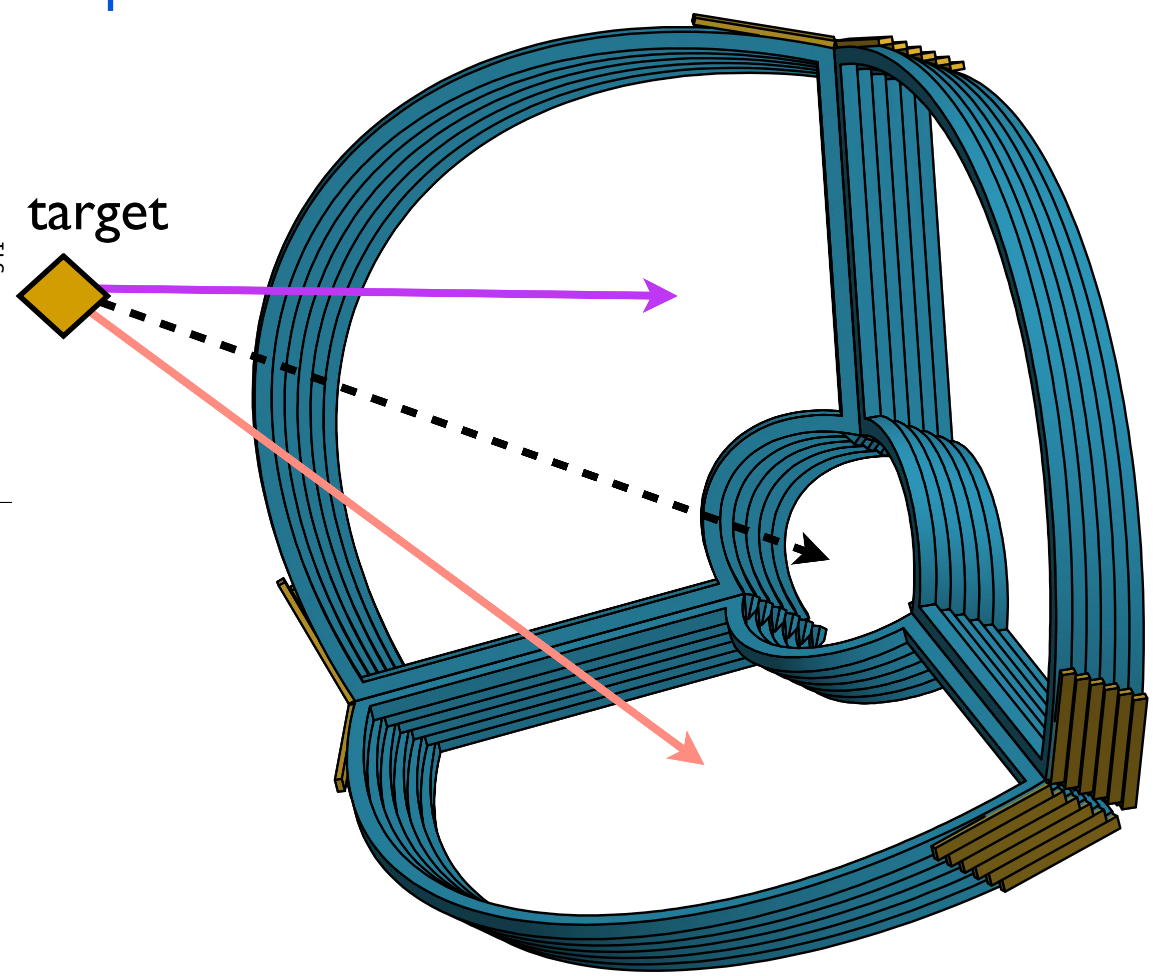
b) define one GEM frame (green)

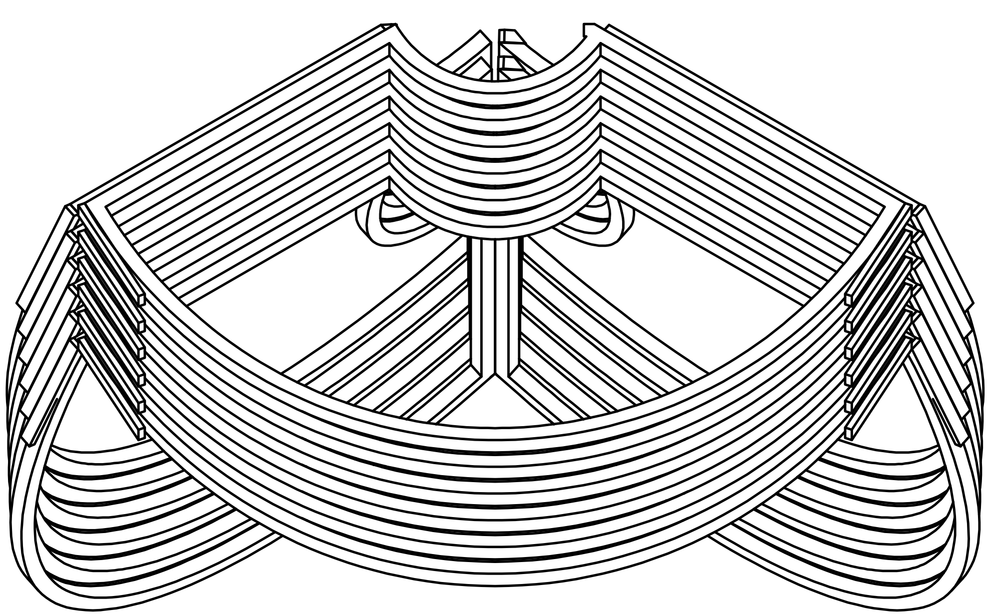


Assemble a non-trivial volume

c) assemble 6 ‘planes’ of GEMs







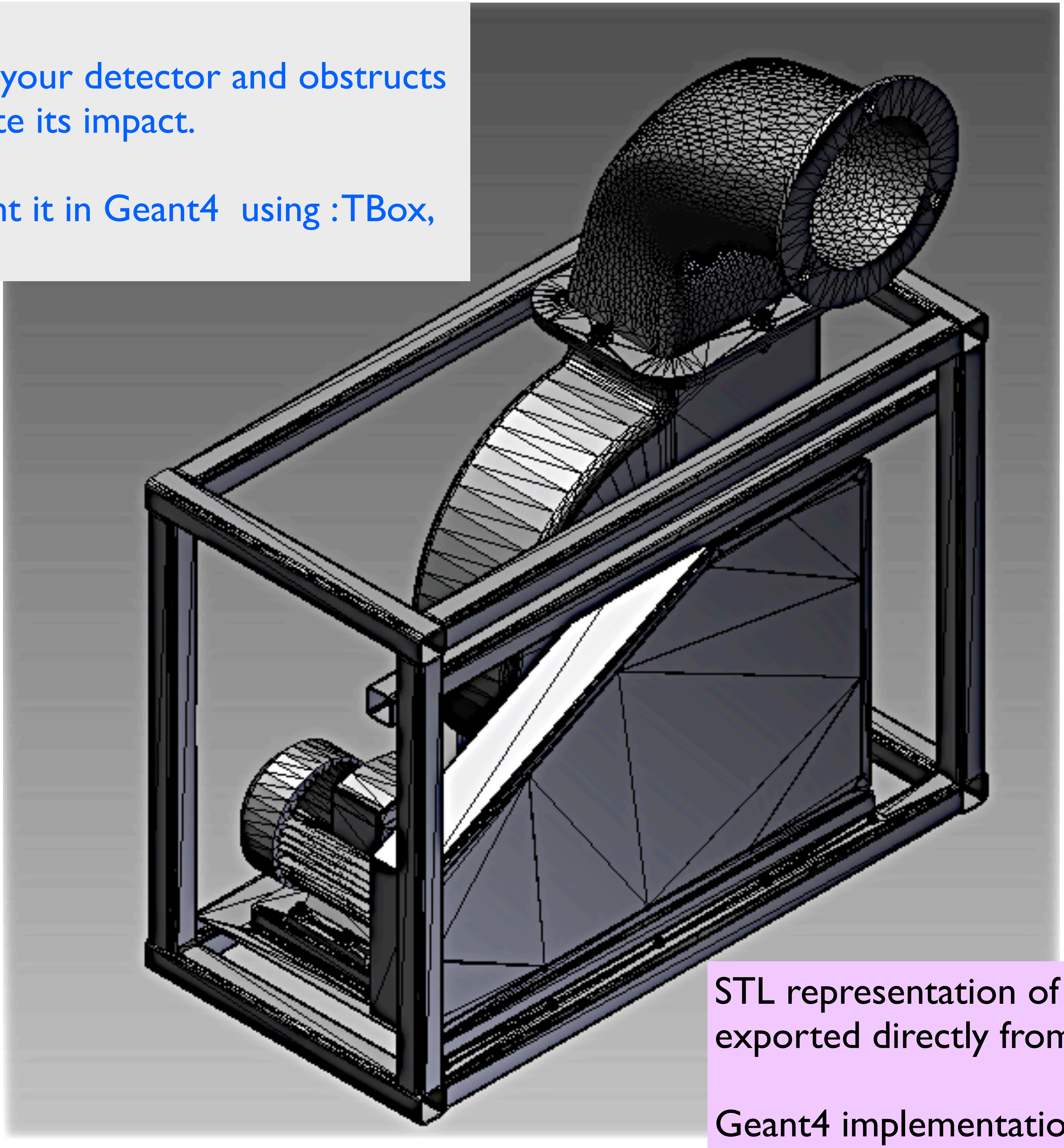
d) export GEM frame to Geant4 and re-assemble
e) run Geant4 simulations
f) conclude: acceptance for coincidence is bad
g) drop this design

Total time spent : 1 week

Complex object as STL package

Requirement:
this blower sits in front of your detector and obstructs measured particles. Simulate its impact.

How would you implement it in Geant4 using : TBox, TTube, ..., etc ?



STL representation of the blower exported directly from CAD

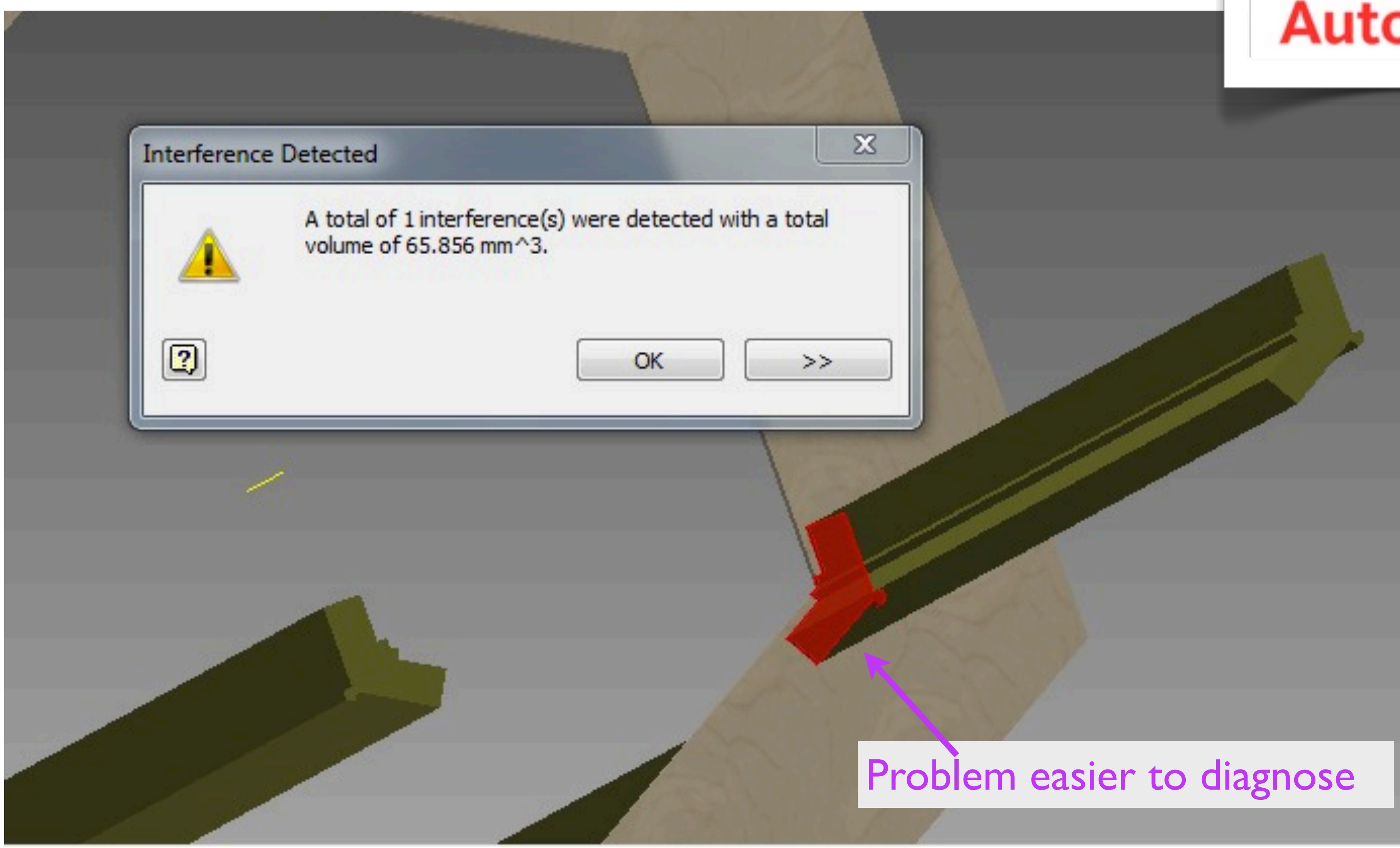
Geant4 implementation time : ~ hour

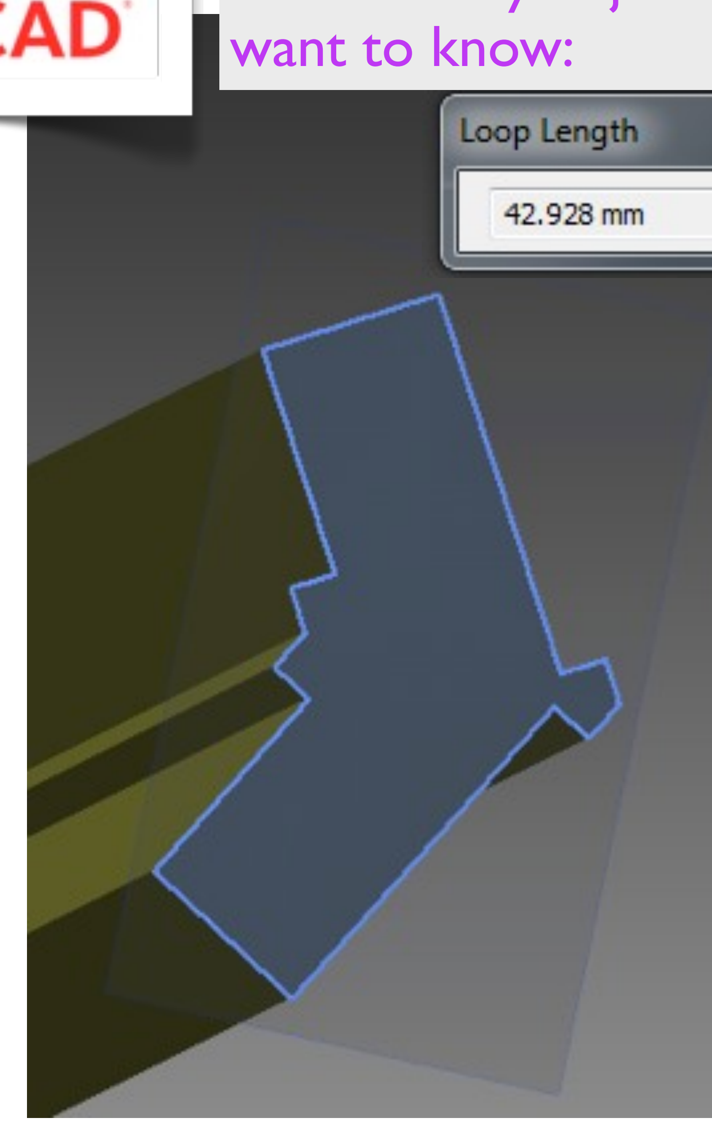
Volumes conflict detection, inspection

Checking overlaps for volume TpcSens15 ...
*** G4Exception : GeomVol1002
issued by : G4PVPlacement::CheckOverlaps()
Overlap with volume already placed !
Overlap is detected for volume TpcSens15
with TpcSens14 volume's
local point (-116.344,198.404,441.614), overlapping by at least: 2 mm
*** This is just a warning message. ***

Geant 4

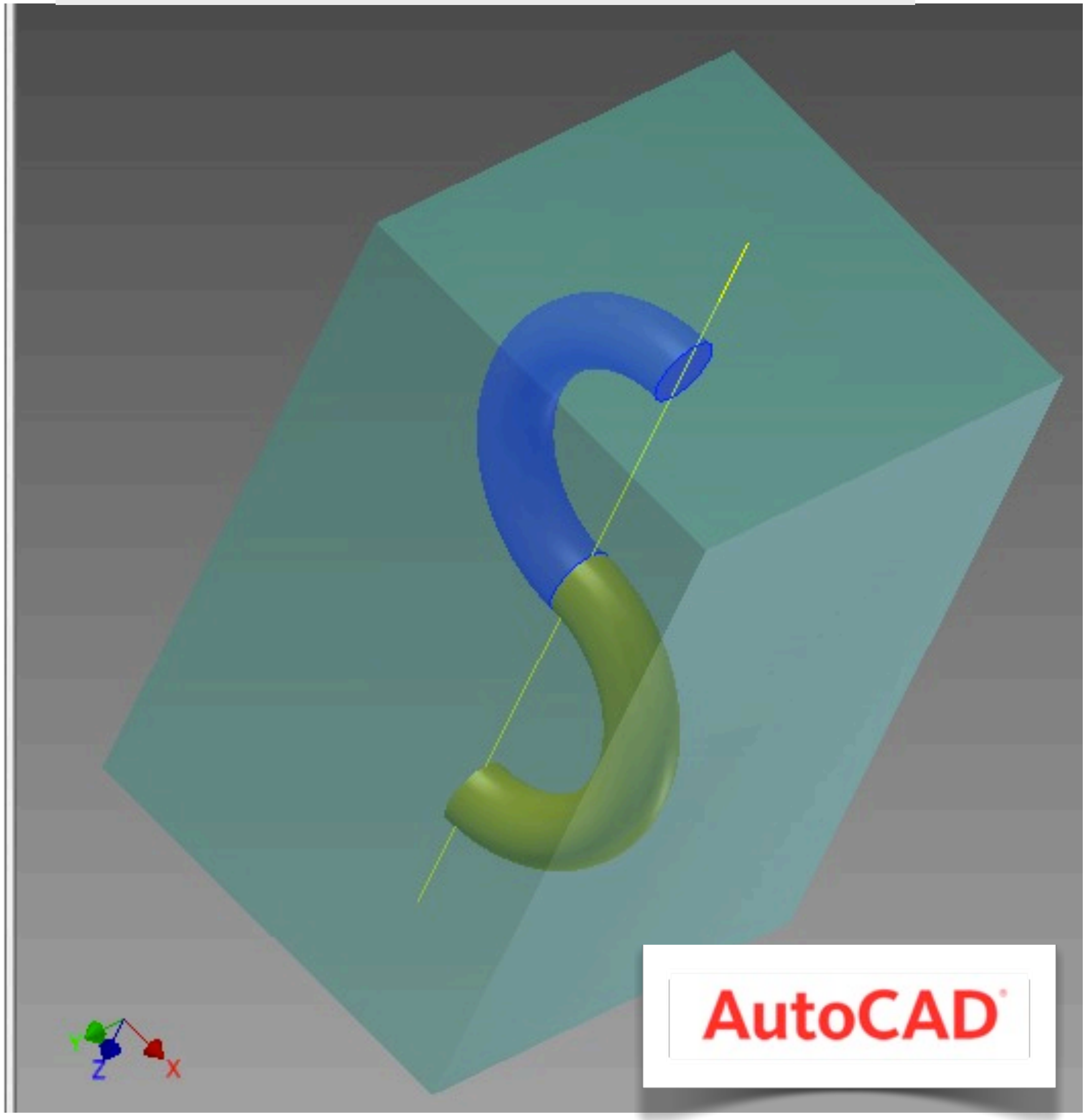
AutoCAD





Limitations of STL geometry model

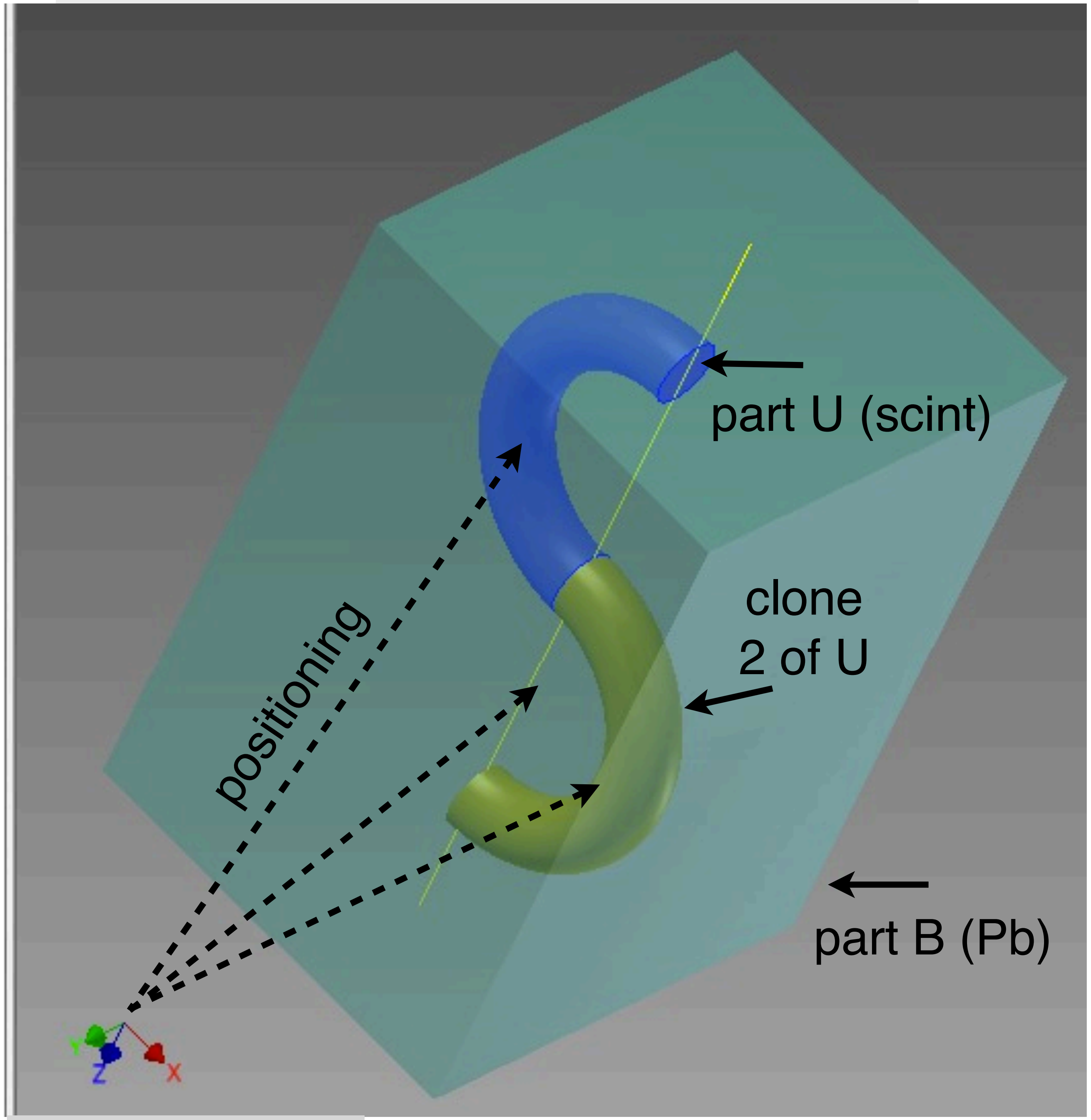
EMCAL: S-shape scintillator in Pb-block
3 parts positioned in space



- no sub-volumes (parts)
- positioning ~lost
- material type ~lost
- fidelity has its price (simulation time)
- add gaps between parts to reduce risk of volume conflicts at lower fidelity

Exporting complex structure as 'parts'

EMCAL: S-shape scintillator in Pb-block
3 parts positioned in space



abs. ref frame

Many approaches ...

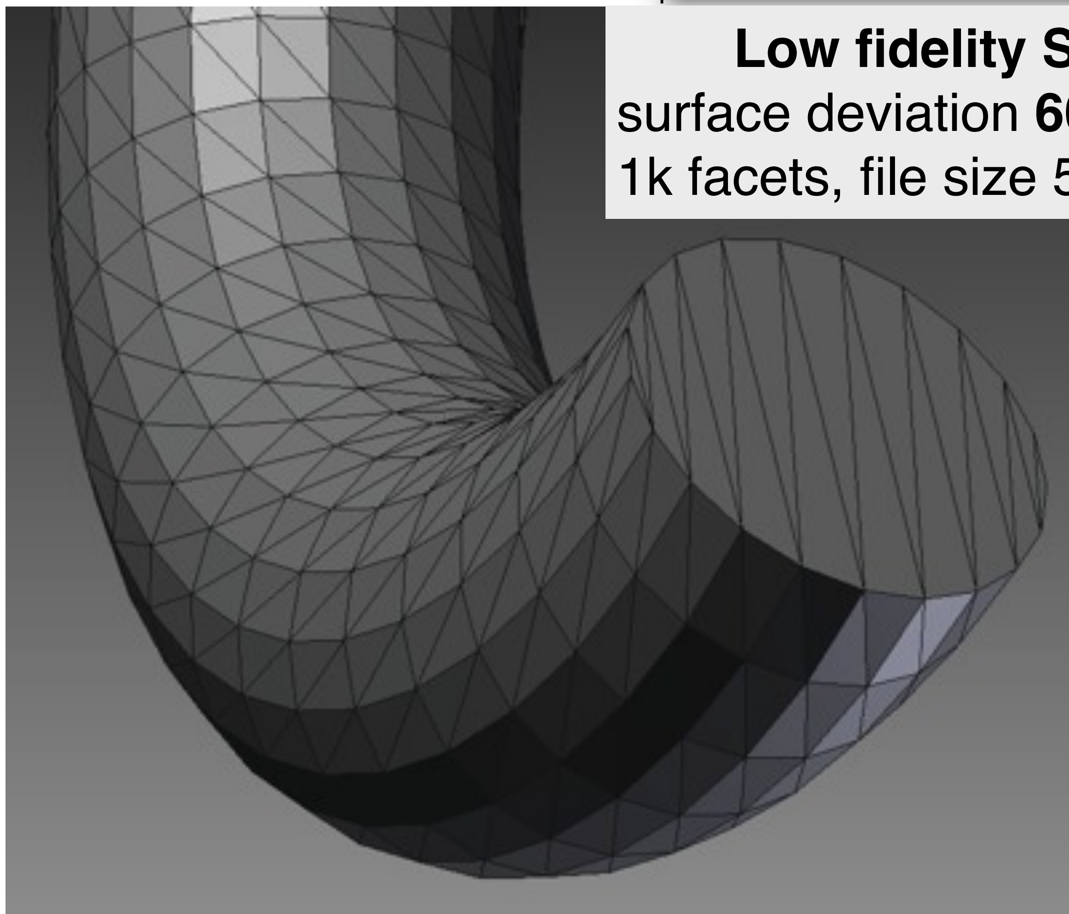
in CAD

- export as STL single copies of U, B parts in the parts local ref frames

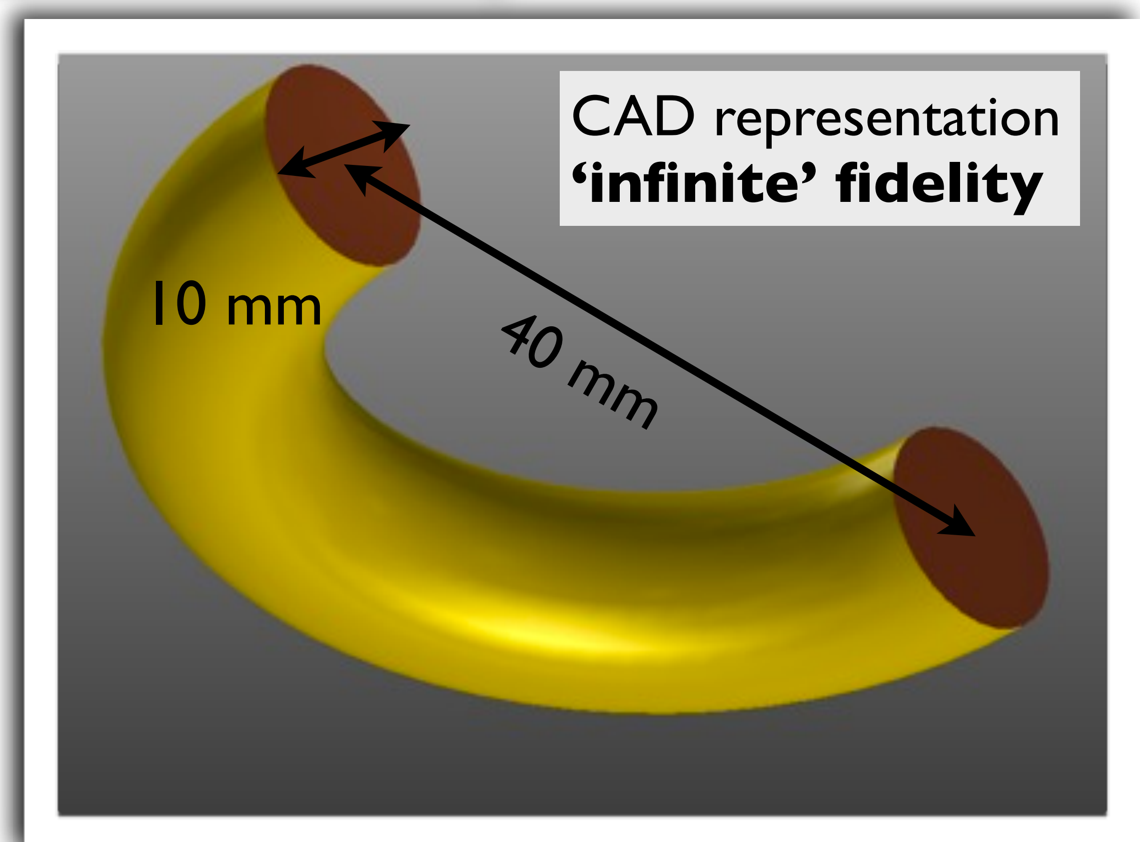
in Geant4

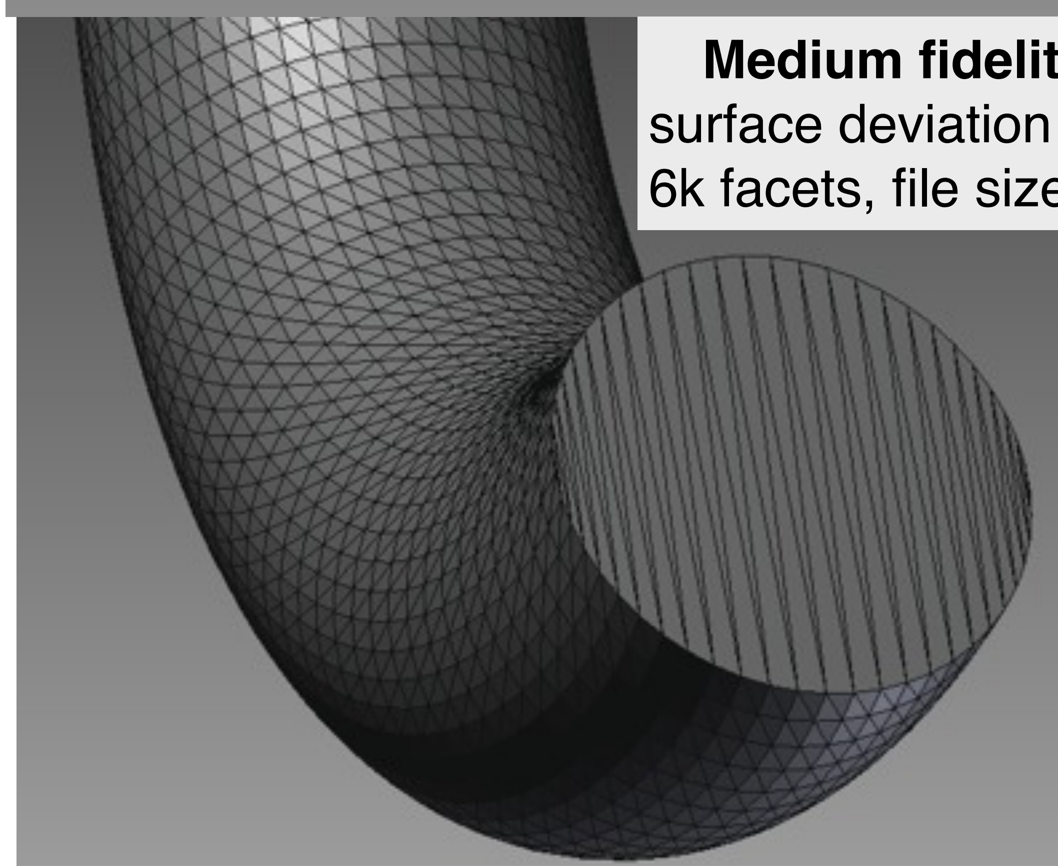
- re-assign materials to parts
- re-position parts in MARS (6 dof)
- clone part U2

Fidelity of tessellation

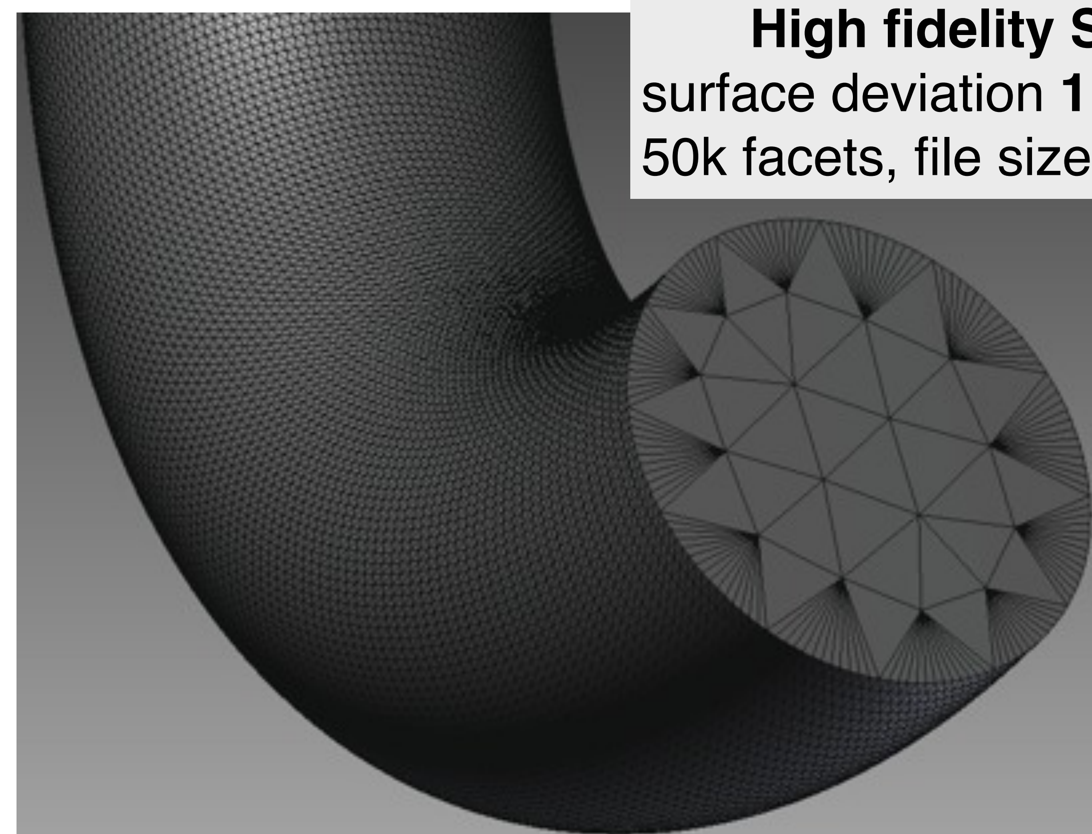


Low fidelity STL
surface deviation **60 µm**
1k facets, file size 51 kB



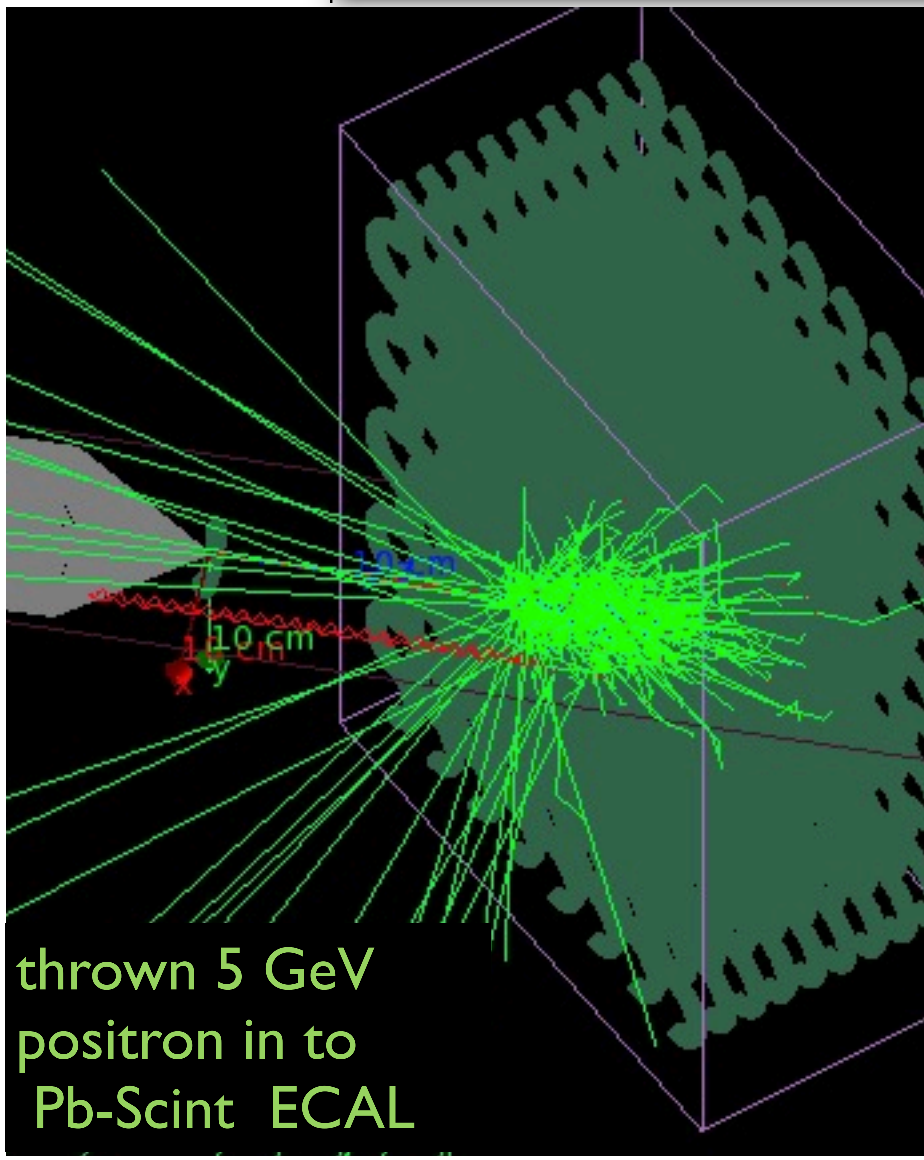


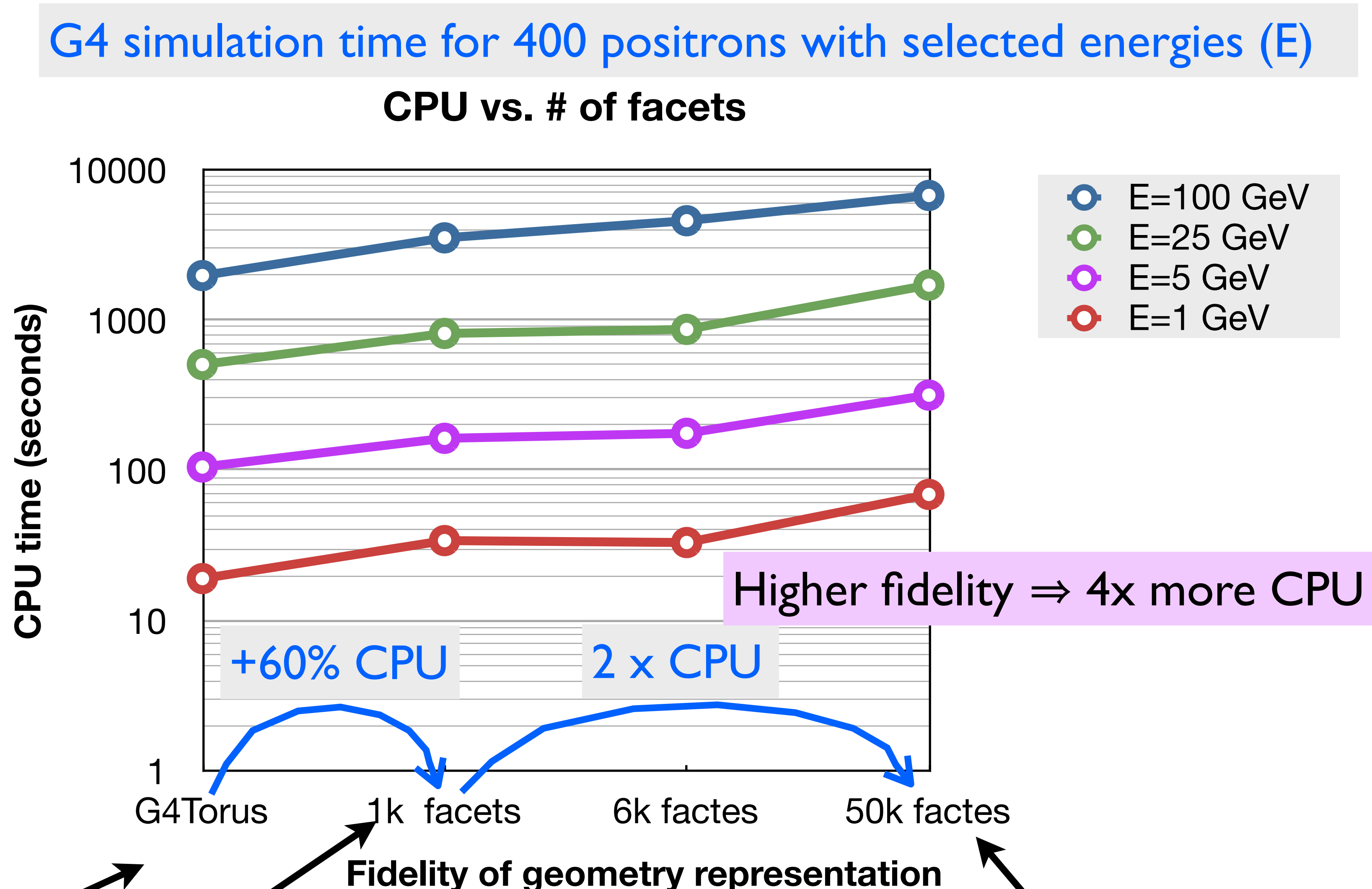
Medium fidelity STL
surface deviation **9 µm**
6k facets, file size 320 kB

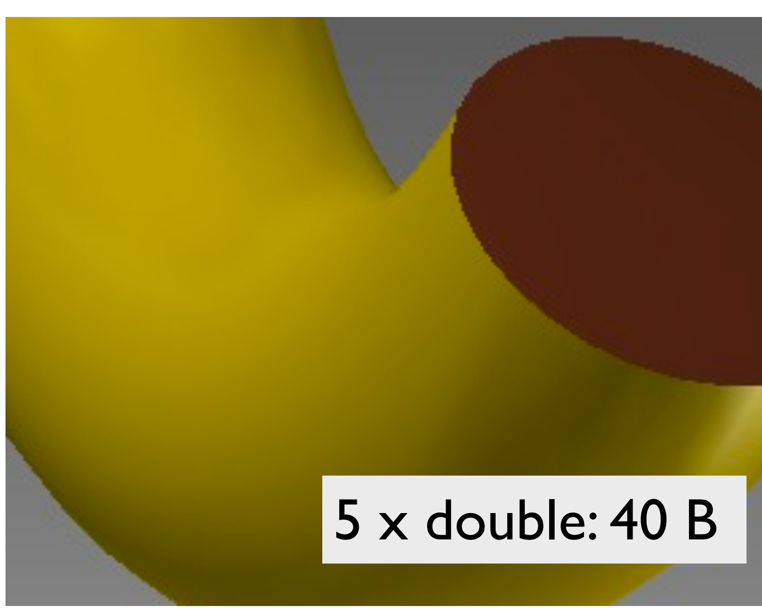


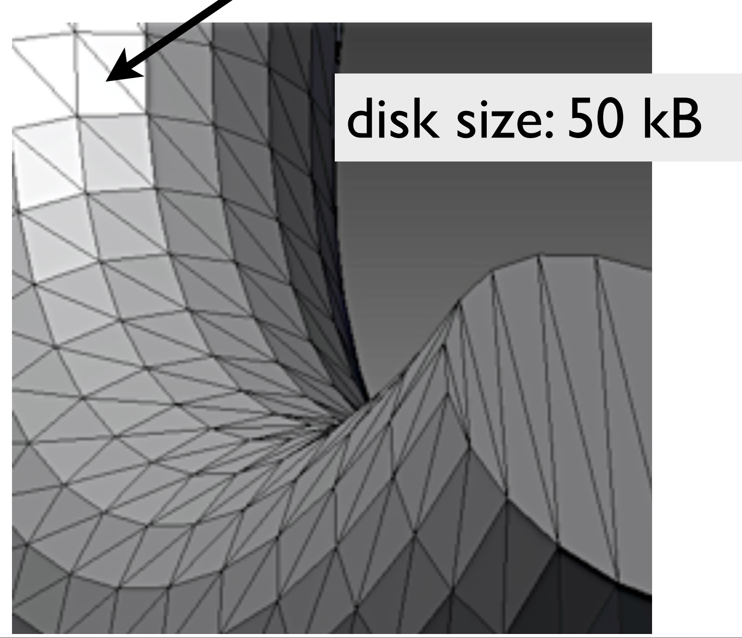
High fidelity STL
surface deviation **1 µm**
50k facets, file size 2.5 MB

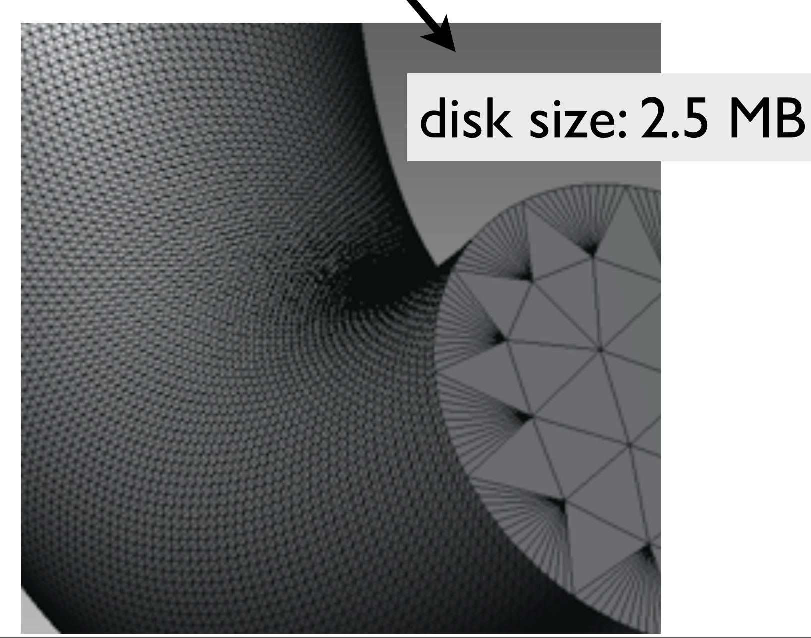
Fidelity of tessellation vs. CPU cost





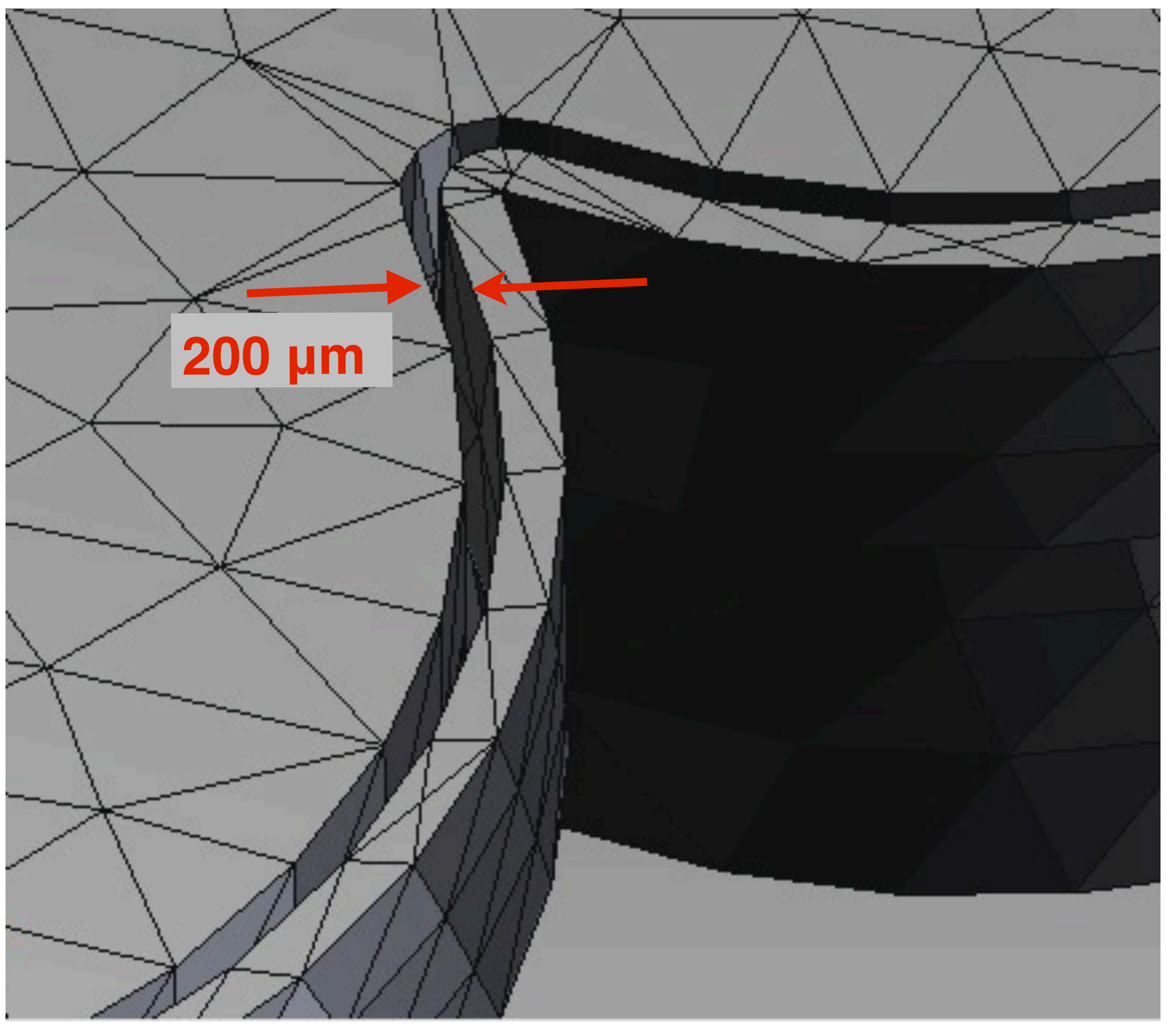


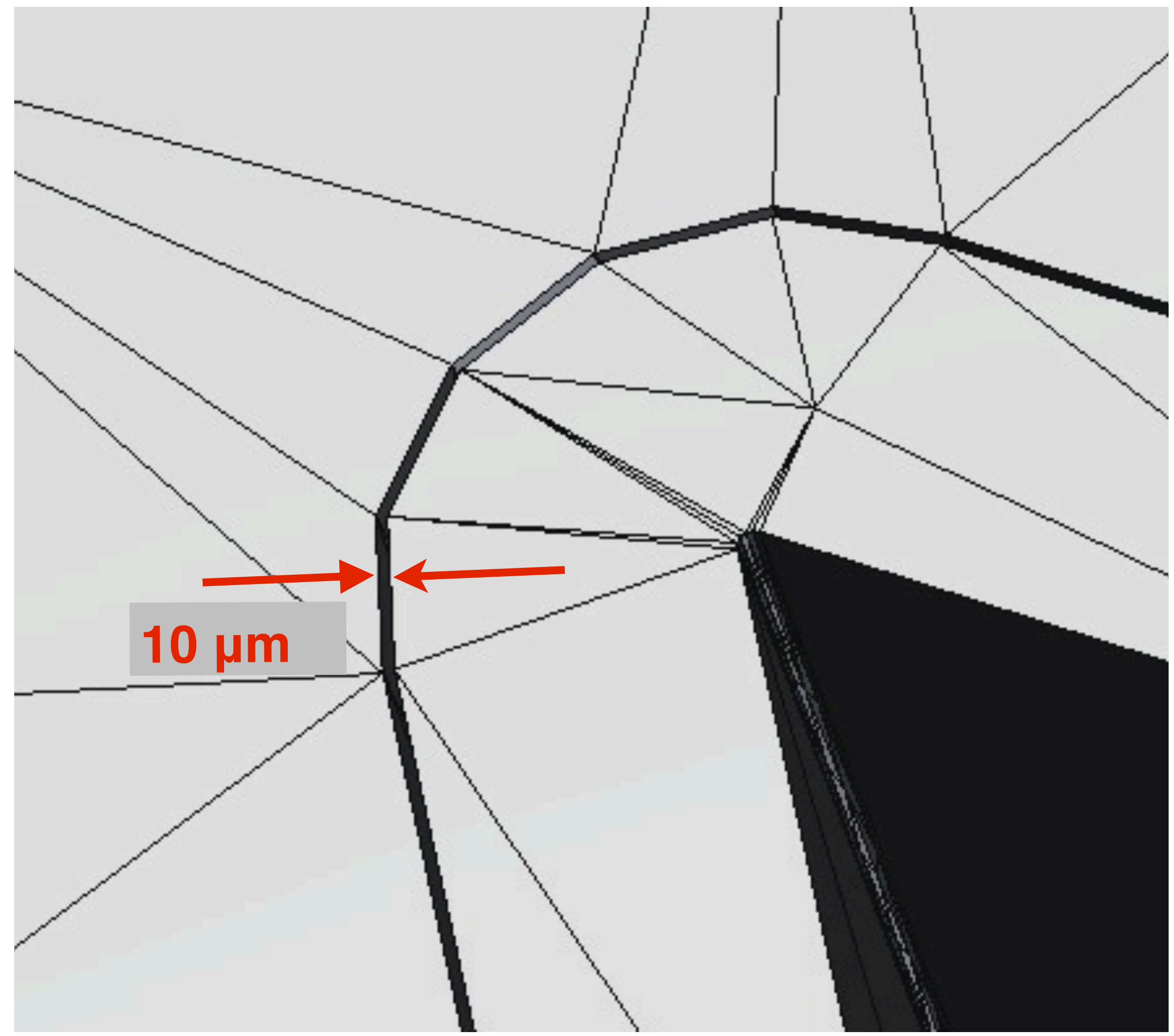




Separation between parts

Low fidelity STL
Fixed: surface deviation **90 μm**
Varied: separation gap between 2 parts





For rounded surfaces exported to STL with low fidelity and for narrow gaps between parts

- **clearance between parts may shrink, be non-uniform**
- **parts may eventually collide**

Geant4+STL: software configuration

Start: empty SL5.8 VM

Install base (compile locally):

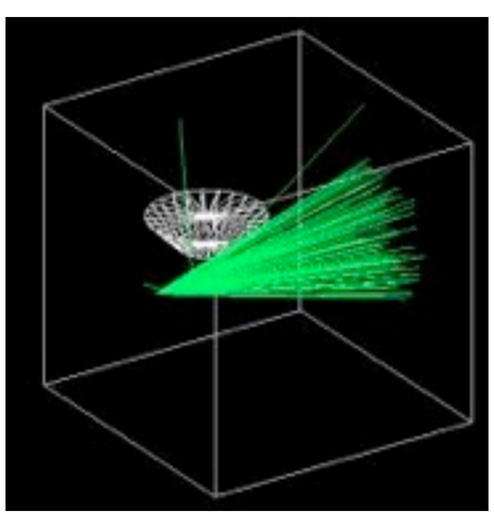
- **CERN root , ver 5.34.04**
- **Geant 4.9.6.p01**

Add components needed for STL

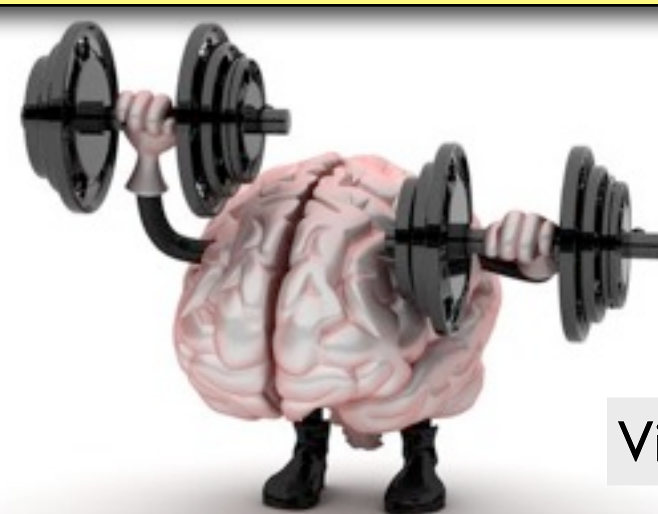
- **ASSIMP for reading various CAD file formats**
  - http://sourceforge.net/projects/assimp/files/assimp-3.0
  - minor code fixes
- **CADMesh parsing STL to Geant4**
  - http://cadmesh.googlecode.com/files/cadmesh-v0.9.tar.bz2
- **Test STL (example provided)**
  - ./build/cadmesh_example

Assimp
Open Asset Import Library

cadmesh
A CAD file interface for GEANT4

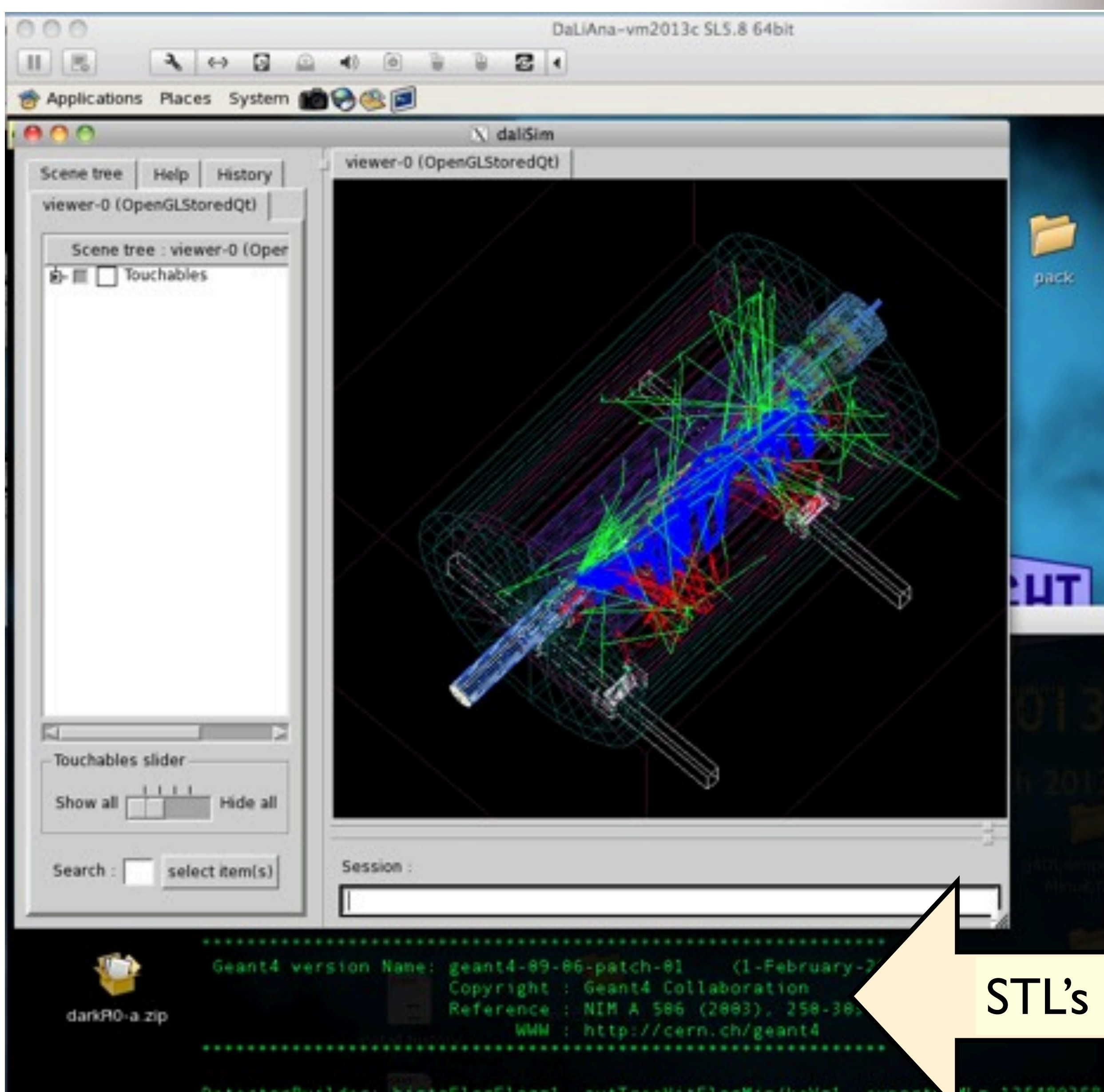


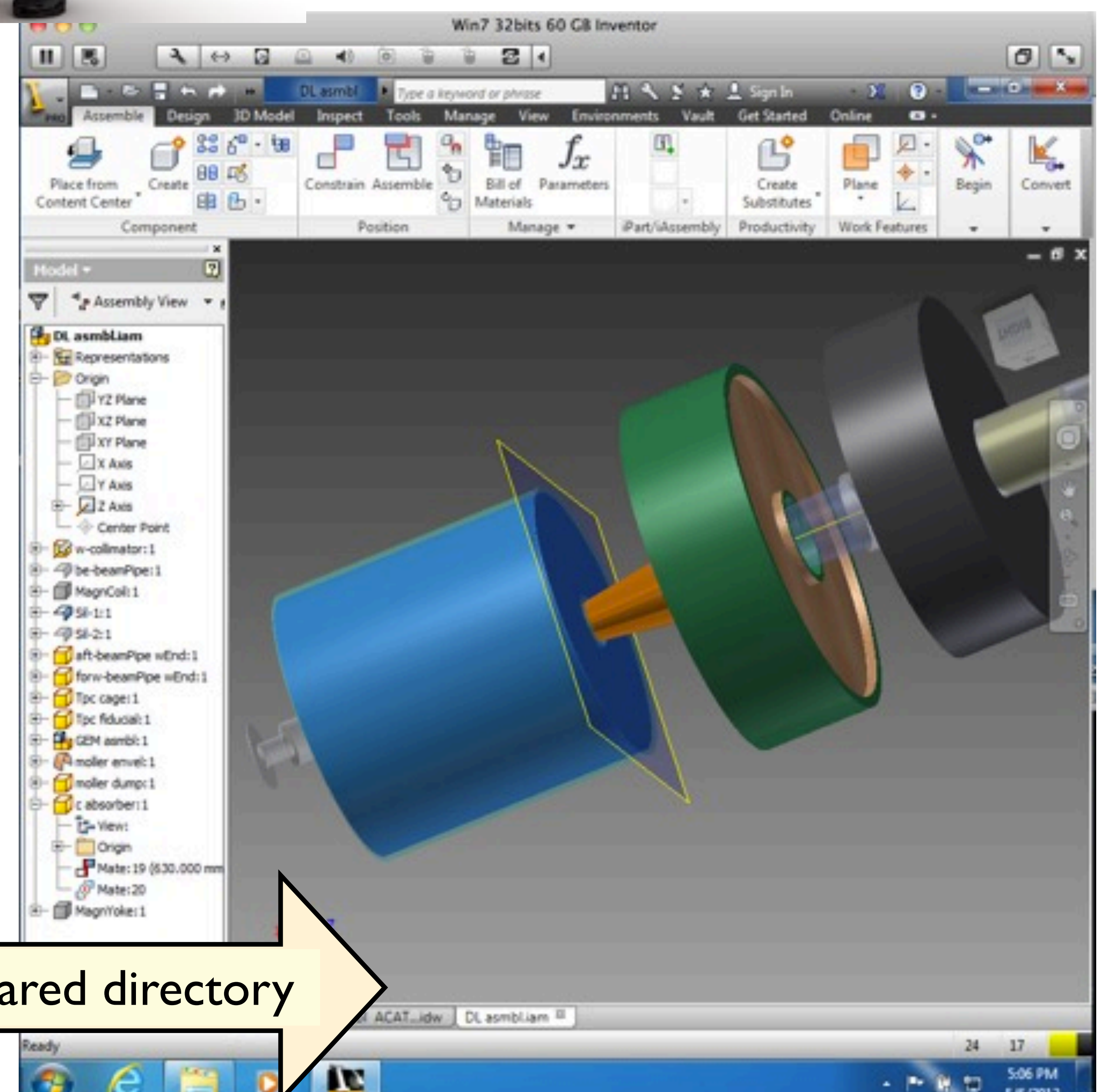
CAD+Geant4 on one laptop



Virtual Machine #1 : Linux/Geant4

Virtual Machine #2 : Windows/AutoCAD





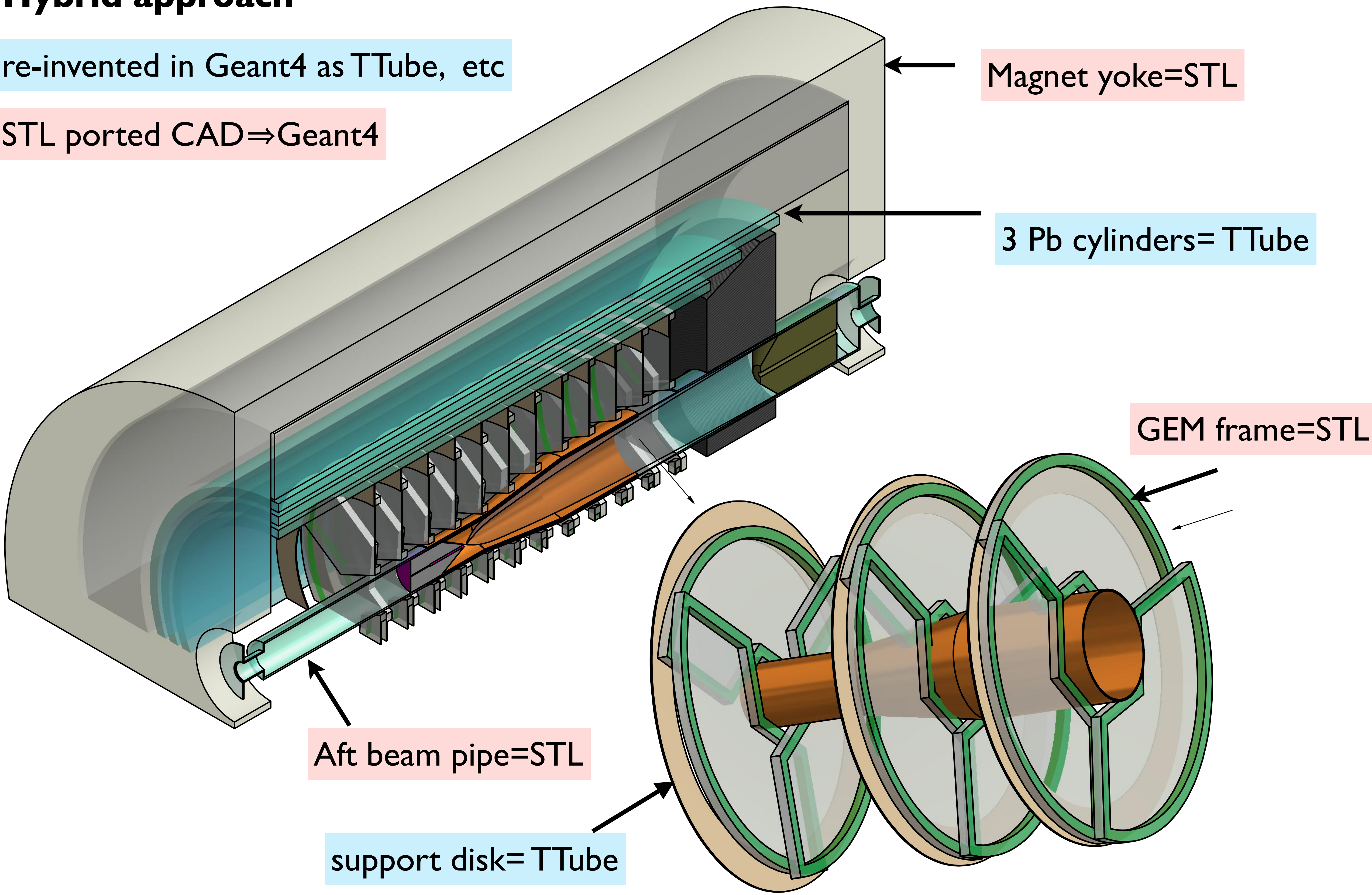
STL's in shared directory

Practical example: design of DarkLight detector

Hybrid approach

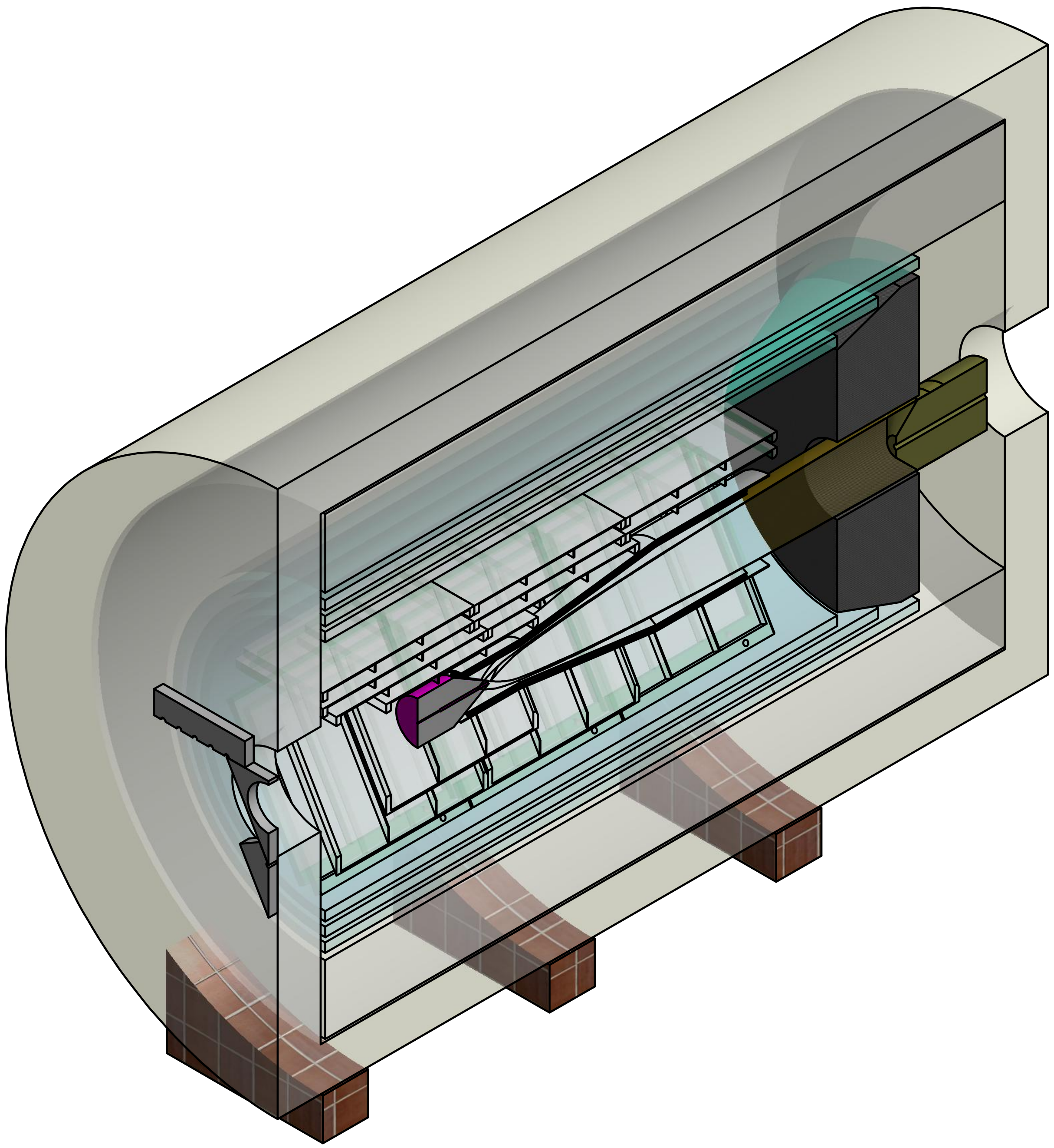
re-invented in Geant4 as TTube, etc

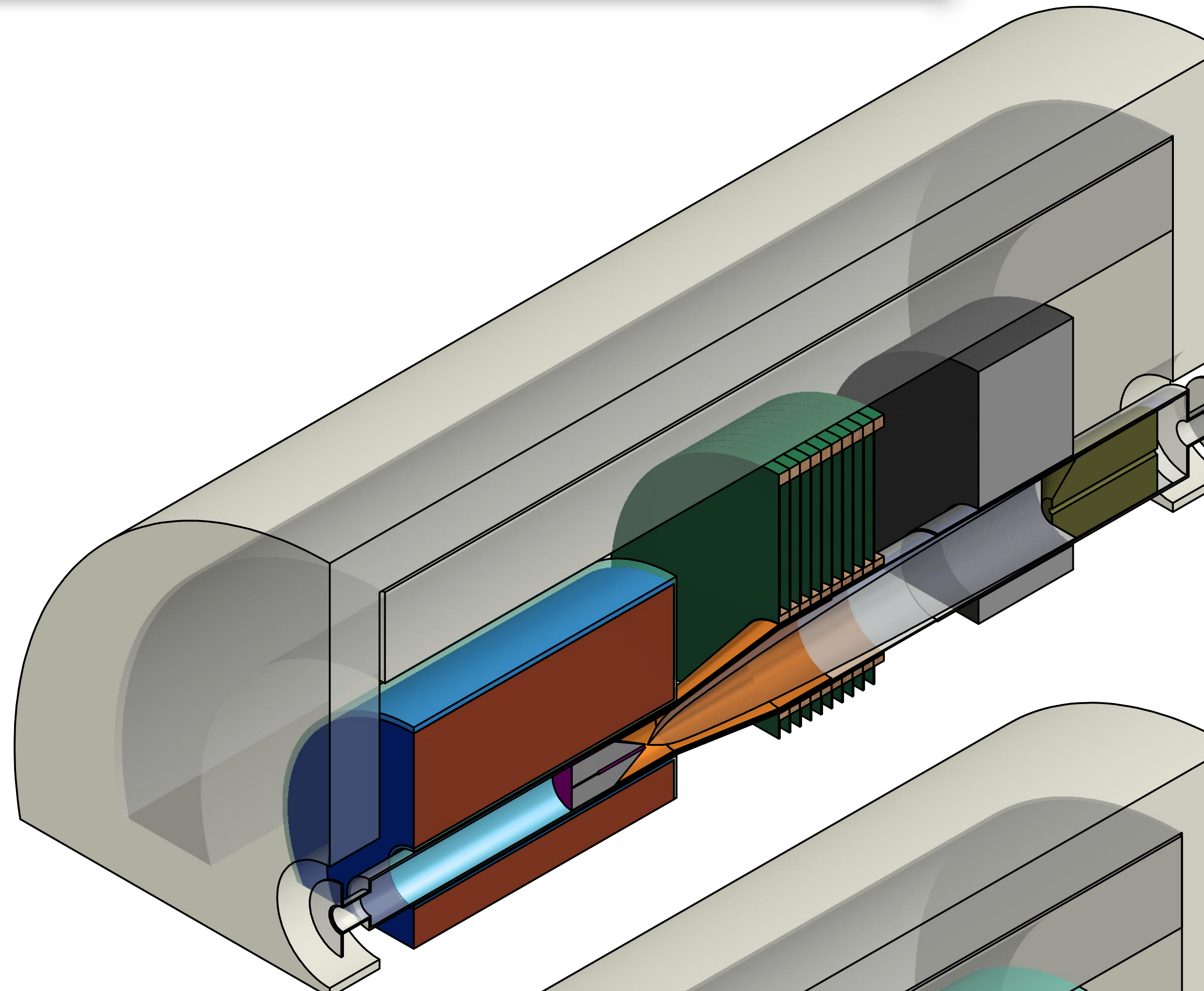
STL ported CAD⇒Geant4

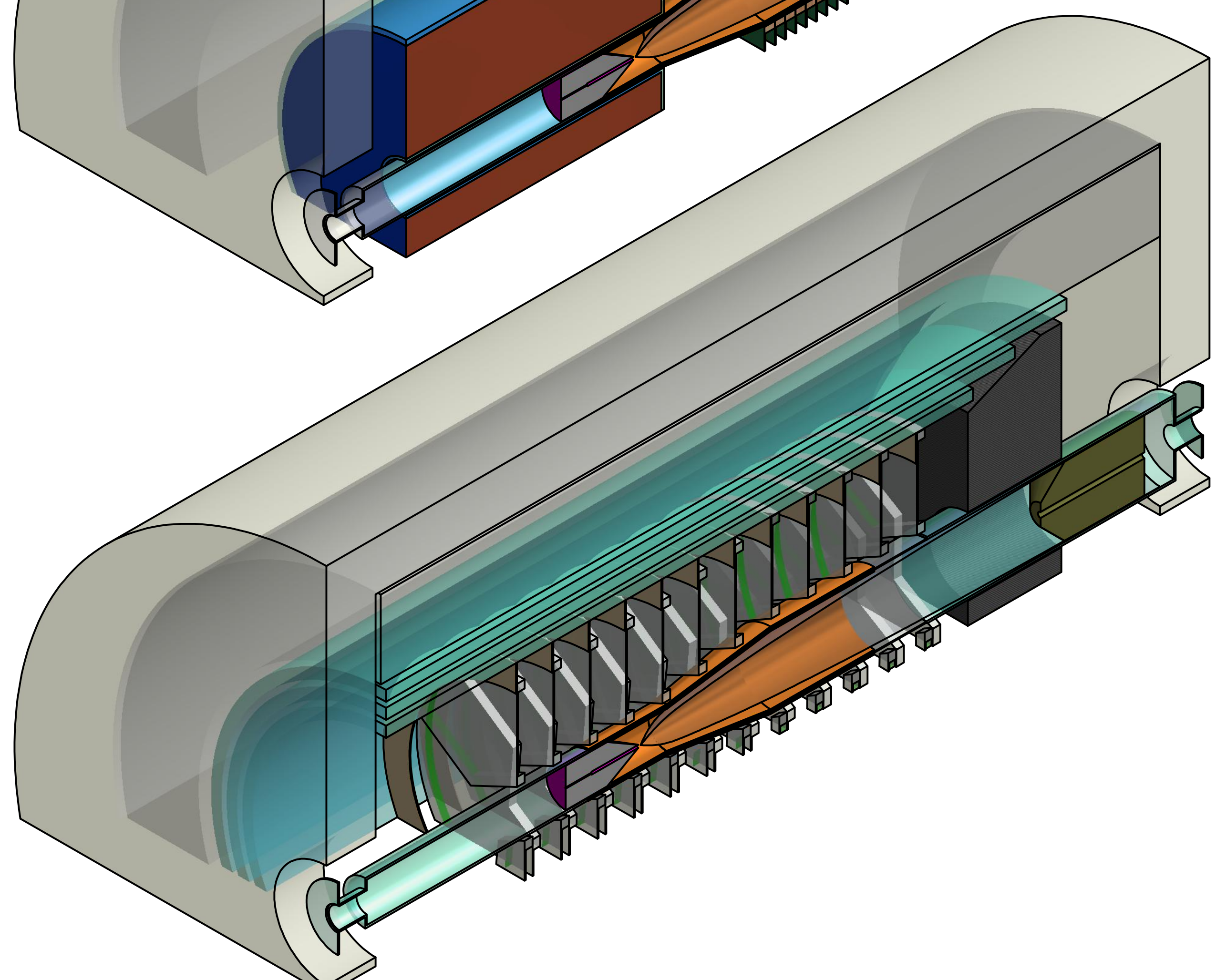


Evolution of DarkLight detector concept

Several detector models were designed in CAD and efficiency was simulated in Geant4.







Summary

- Tessellation Standard (STL) simplifies automatic translation of solids from CAD to Geant4 shortening time of design-to-simulation cycle

- CADMesh interface preserves shape of solids but position and material assignment needs to be redone in Geant4

- Hybrid approach combining STL definition for complex volumes with native Geant4 definitions for simple shapes works well

- Some practice is needed to apply this scheme for larger detector systems