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# Importing and Exporting Tesselated Volumes

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# Geant4 Geometry “Primitives”

- Geant4 provides a very rich library of basic geometrical shapes, often referred to as “primitives”, plus the ability to define complex compound geometries via boolean operations.
- Often analytic, or at least attempts to optimize the calculation of “inside” or distance to boundary.
- Parameterizations also available.
- GDML provides geometry IO

# So Why Tesselations?

- Input to Geant4
  - To support complex geometries from CAD with minimal human intervention.
  - To support irregular shapes, e.g. biological phantoms
  - Useful in applications where access to the geometry is not needed for sensitive detector definitions or further event reconstruction
    - e.g. dose or flux calculations using scoring meshes
- Output from Geant4
  - Solving partial differential equations
    - e.g. see John's space applications talk yesterday
    - FEA analysis for geometries defined in code
  - Rapid prototyping and additive manufacturing
- Round-tripping for debugging and performance analyses.

# CAD to Geant4 I

- Often requested from user community, despite recognized limitations of:
  - difficulty accessing proprietary formats
  - mismatch between level of detail, approaches to parent-child relationships, material definitions
  - performance issues
- Most existing solutions target recognized interchange formats such as STEP and IGES, but even these can have problems
  - complicated file format, usually not open source
  - possible loss of hierarchy or material association
  - little or no mapping to primitives

# CAD to Geant4 II

- Solutions tend to target a mesh description using G4TessellatedSolid using either G4TriangularFacet or G4QuadrangularFacet.
- Performance issues arise when comparing analytic calculations to loops over possibly very many facets per volume.

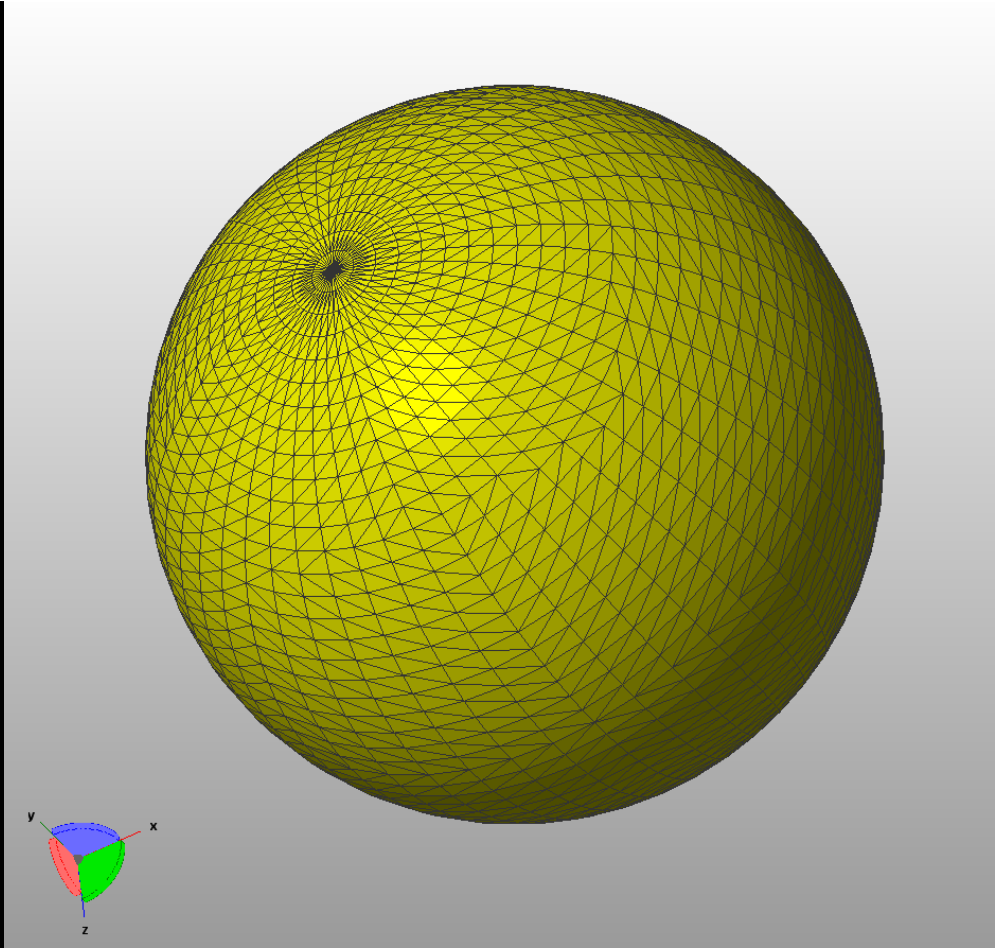
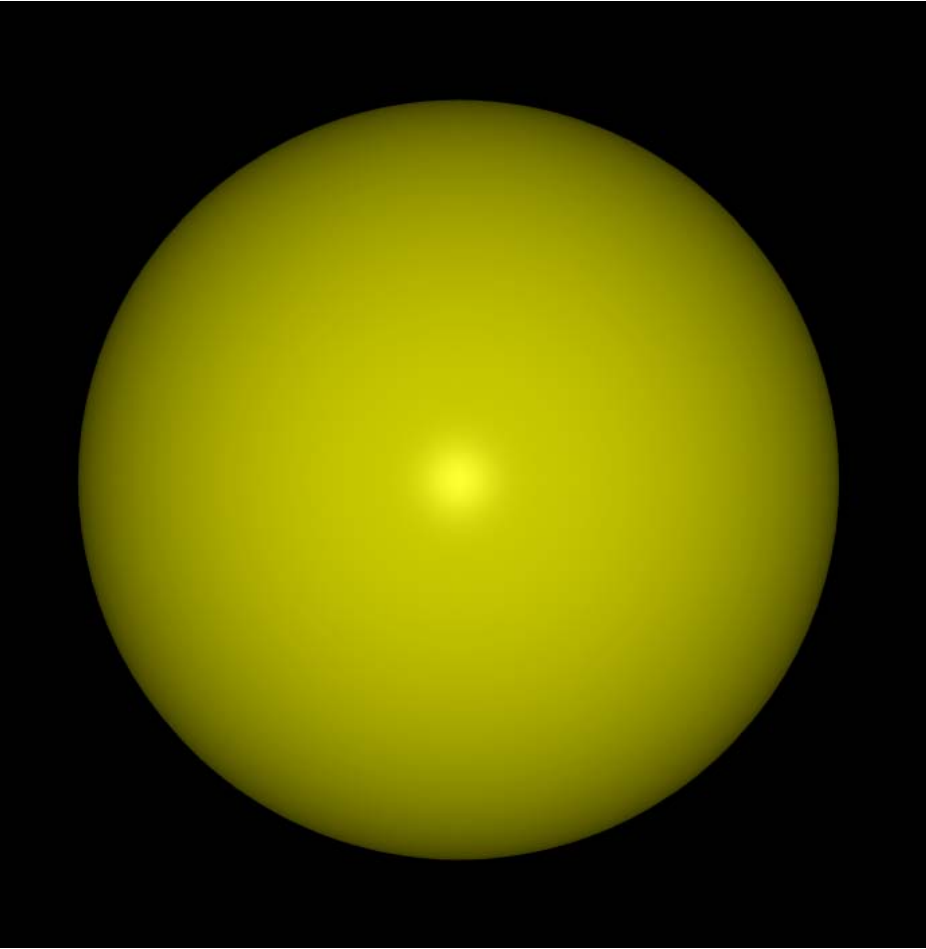
- e.g. Sphere isInside

Primitive

$r < r_{\text{sphere}}$

Faceted

for  $i=0$  to  $n\text{Facets}$   
check each facet



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# Non-CAD Geometry editors

- In addition to CAD programs, there are very many 3D modeling programs which provide the user with convenient graphical user interfaces to create solid models.
- Usually aimed at gaming or rendering but could be useful as a front end for a graphical geometry editor.
- Many output formats, including tessellations.
  - OFF, PLY, OBJ, etc.
- Plethora of open source or freeware projects

# STL: Lowest Common Denominator

- Thanks to the proliferation of rapid prototyping and additive manufacturing processes, the surface tessellation language (STL) format is the industrial standard for handling triangulated meshes and is ubiquitous as an export format for CAD and other 3D software.
- Format consists of a plain list of three dimensional corner point coordinates (vertex) and flat triangles (facet) with an associated normal vector.
- Both ASCII and binary formats supported.



# STL File Format

**solid** *name*

**facet normal**  $n_1$   $n_2$   $n_3$

**outer loop**

**vertex**  $v1_x$   $v1_y$   $v1_z$

**vertex**  $v2_x$   $v2_y$   $v2_z$

**vertex**  $v3_x$   $v3_y$   $v3_z$

**end loop**

**endsolid** *name*

repeated nFacet times

# STL shortcomings

- No topological information about the mesh.
- No guarantee of correctness
  - single facets, holes, overlaps, etc.
- No material or other attributes
- Format is verbose, making file sizes large and subject to error from roundoff precision
  - e.g. shared vertices are listed explicitly  $n$  times.
- Overlap problems can arise when combining STL files from different software packages, or exported with different tolerances.

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# ILC & lcdd

- ILC detector design required a fast and flexible full simulation and reconstruction environment to explore a large phase space of designs.
- Developed to liberate end users from C++ and Geant4
- Provide users with pre-compiled binaries on multiple platforms, define complete detector using lcdd, an extension of gdml.
- Target Geant4 primitives, provide many standard HEP subdetectors.
- Provides one single source of geometry for both simulation and reconstruction.
- Needed mechanism to incorporate complicated support or readout structures which were not necessarily needed in the reconstruction
  - Solution was to include raw gdml snippets into the lcdd

# STL to GDML

- Adopted a solution requiring no modifications to any Geant4 code by converting STL to GDML
- Convert STL facets directly to G4TriangularFacet and create G4TessellatedSolid.
- Assign material at creation time, e.g.  
> java StlToGdml model.stl model.gdml Aluminum
- Can either create world volume from bounding box to use standalone, or leave as individual volume to aggregate or incorporate into a common world volume later.
- Previous solution exists, see [talk](#) by F. Garcia at 2010 Space Users' Workshop, Seattle.

[http://www.solveering.com/products/products\\_stl2gdml.html](http://www.solveering.com/products/products_stl2gdml.html)

# “Topology from a Bucket of Facets”

- Previous solution works well for STL files containing one volume, but not often the case.
- Wrote code to identify topologically distinct elements in the file. Can either:
  - Split file into individual stl files
  - Create gdml file with many solids
- Problem arises when assigning materials.
  - Easiest solution is to have designer export separate STL files for volumes with same material.
- Writing code to assure that all models are closed manifolds is complicated.
- Assume that input STL file is valid.

# GUI

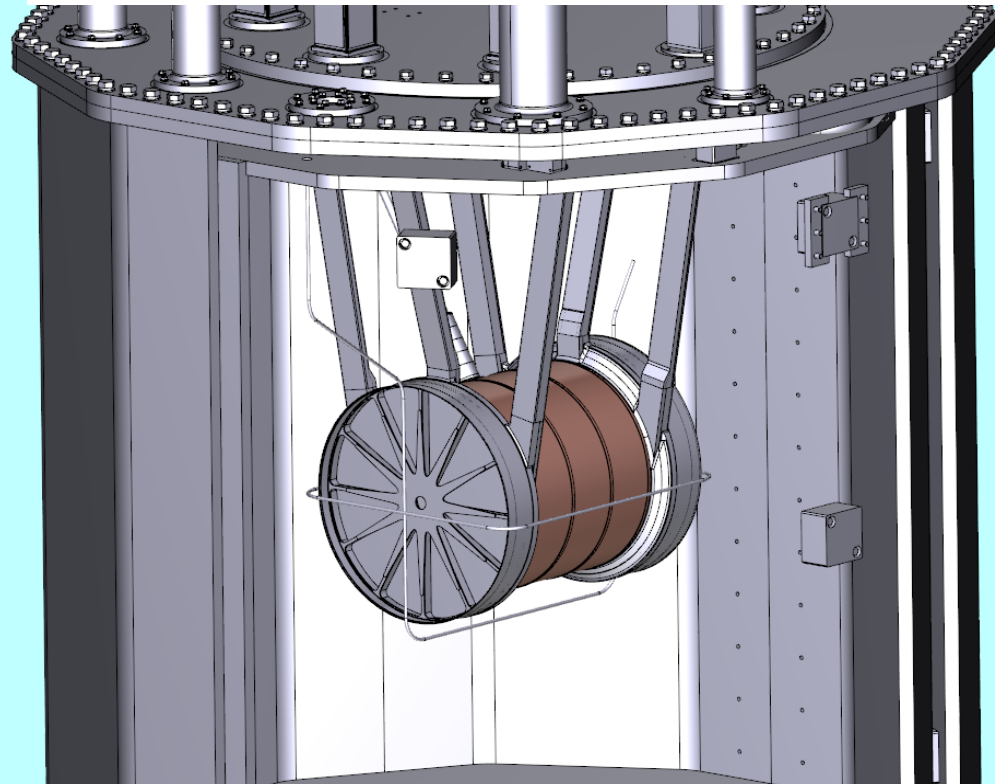
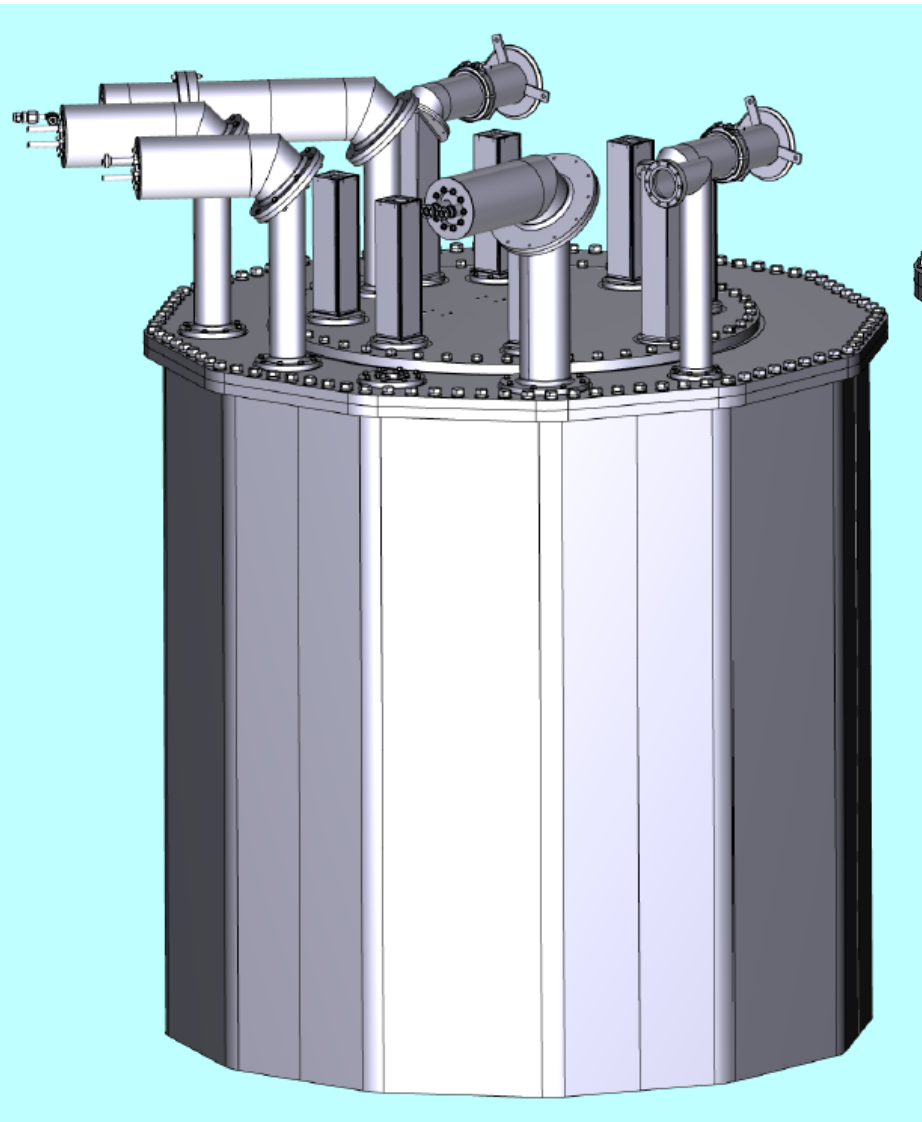
- Work in progress on GUI to aid translation process, allowing user to select volume and:
  - Delete unwanted volumes
  - Assign material
    - by name (prone to mistake, e.g. Aluminum vs Aluminium)
    - from drop-down list (predefined, e.g. NIST or G4\_\*)
    - from material editor
  - Create hierarchy and place volumes into it.
  - Associate sensitive detectors? ...
- Delighted to hear of work by Emmanuel Delage
  - using freeCAD framework + GDML import module

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# Mesh To GDML

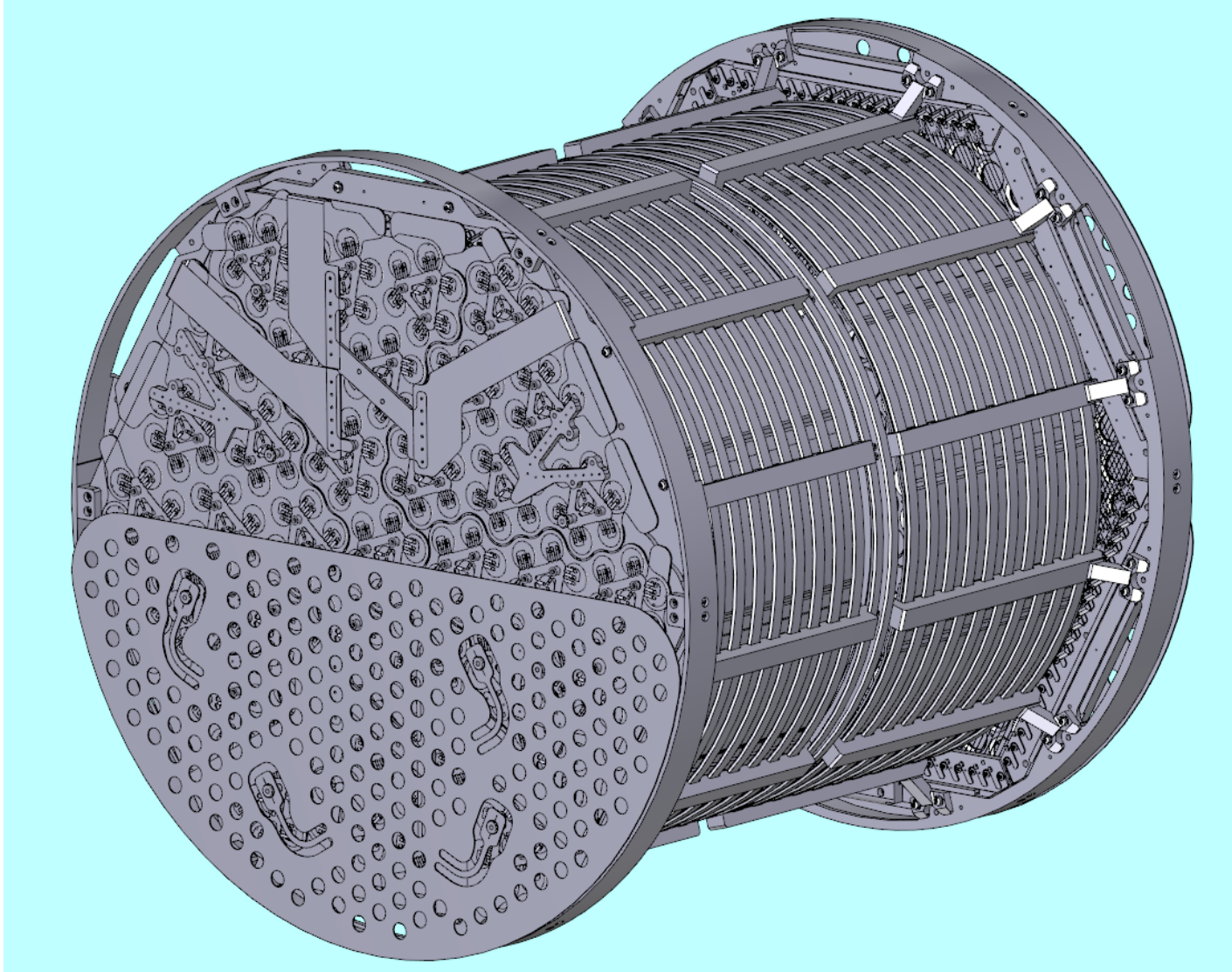
- Currently have code which parses a number of mesh file formats (STL, OFF, PLY, OBJ, ...), identifies disconnected volumes and creates GDML containing G4TessellatedSolid(s) with triangular facets.
- Tested on large CAD models for EXO and HPS.
  - Developed in SolidEdge, exported as STL
  - Correctly identifies separate elements from the collection of facets.
  - GDML incorporated into Icdd file and processed using slic Geant4 application.

# EXO Example

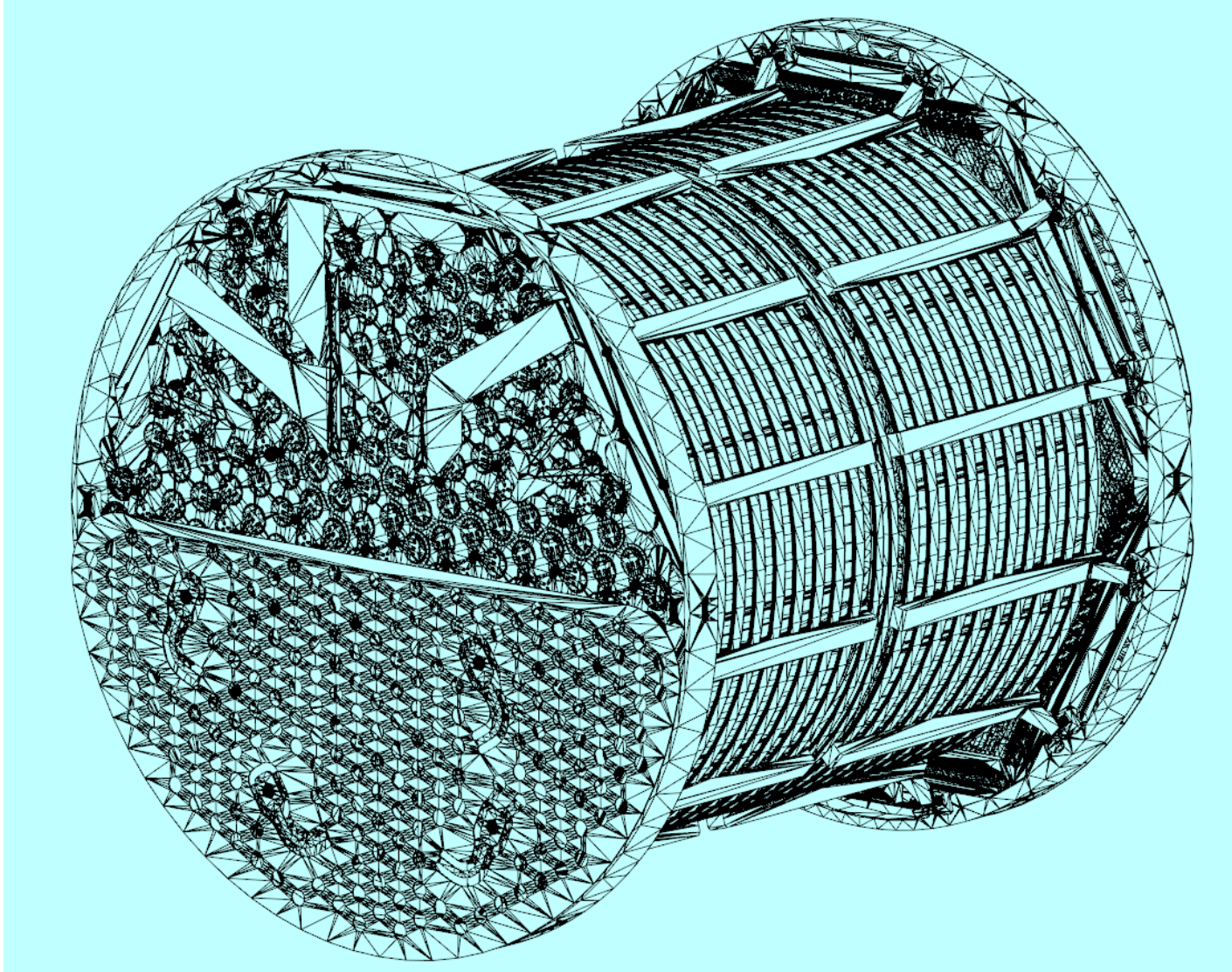




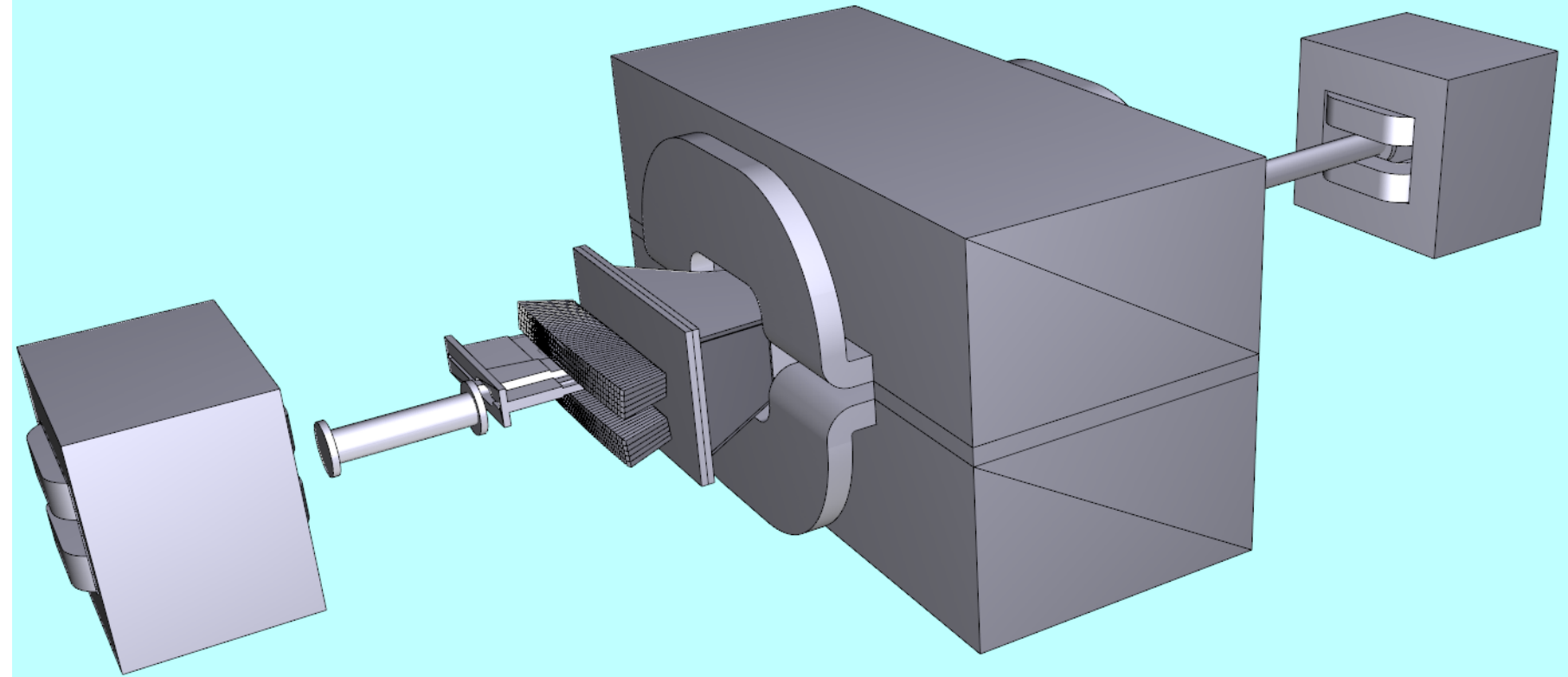
# EXO Example



# EXO Example



# HPS Example



# Exporting Meshes from Geant4

- Performance always an issue in simulations
- How to benchmark primitives versus faceted?
  - Develop module to take geometry developed using primitives and export as faceted solids.
  - Run simulations on “primitives” and “faceted” gdml to get comparison of identical geometries.
- Export code based on ASCII Tree
  - navigates full geometry to bottom “leaf” solid
    - solid.GetPolyhedron()
    - polyhedron.GetFacet(...)
    - transform local to global coordinates
    - split facet if quadrilateral
    - write facet and vertex info to STL file
    - other facet formats in the pipeline

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# Exporting Meshes from Geant4 II

- Needed for solving PDEs for charge accumulation or FEA.
- Can be used to “print” a 3D model of geometry
  - Rapid prototyping of parts
  - Comparison of modeled geometry to CAD geometry
  - Communication with colleagues
  - Useful for outreach
- Also provides path for embedding 3D models in PDF files
  - Comparison of modeled geometry to CAD geometry
  - Communication with colleagues
  - Useful for outreach

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# StlToPdf

- Side benefit is easy mapping on to file formats used in Acrobat's 3D PDF, U3D & PRC.
- Enables programmatic creation of pdf files containing rich 3D content, either standalone or embedded in a final document.
- Removes dependence on Acrobat or other commercial software.
  - > `java StlToPdf file.stl file.pdf`

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# Plans

- Finalize mesh export code, communicate with experts on optimization, perform code review, consider for inclusion in future release.
- Continue work on STL / GDML graphical editor to enable modification of geometry created from STL file
  - volume deletion, hierarchy creation, material association
- Any interest in 3D pdf creation from Geant geometries?

# File Format Future: STL → AMF

- ASTM F2915 defines a standard specification for Additive Manufacturing File Format (AMF)
- Takes STL format for vertices and facets and adds support for:
  - **<object>** Defines a volume associated with a material ID for printing.
  - **<material>** Optional element defines one or more materials for printing.
  - **<texture>** Optional element defines images or textures for color or texture mapping.
  - **<constellation>** Optional element provides hierarchy support.
  - **<metadata>** Optional element contains additional information
- Just recently approved (May, 2011) but expect CAD vendors to add support.
- Solves most of the problems associated with STL.