The TOPAS Tool for Particle Simulation

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SLAC National Accelerator Laboratory
and
TOPAS MC Inc (a California Non-Profit Organization)

15th Geant4 Space Users Workshop
Pasadena, December 2023

Monday (Jan/10/2011

09:30 - 10:00 Registration
10:00 - 10:15 Opening addresses (
10:15 - 10:30 Tutorial Introductior
- Tutorial structure
- Lecturer introduction

10:30 - 11:00 User Documents anc
- Installation Guide
- Application developers manual
- Novice examples in Geant4 distr
- LXR source code browser
- HyperNews

11:00 - 11:30 Break

11:30 - 12:30 Kernel I (M.Asai) (p
- General introduction
- Global structure of Geant4
- Run, event, track, step, trajecto
- User classes

12:30 - 14:00 Lunch Break

14:00 - 14:30 User Interface I (M.
- Syntax of UI command
- Interactive mode / batch mode
- G4UIterminal class

14:30 - 15:00 Visualization I (J.Per
- Introduction to Visualization
- Quick Looks at Seven Visualizati
- Basic Visualization Commands

15:00 - 15:30 User Documents anc
- Toolkit developers manual
- Physics reference manual
- Extended and advanced exampl

15:30 - 16:00 Break

16:00 - 18:00 Hands-on I (J.Perl)
- Complete Geant4 installation if
  - -- Step-by-step installation gui
  - -- OpenGL HepRApp DAWN
- Execute a few novice examples t
- Troubleshooting: Installation an

Tuesday (Jan/11/2011)

09:00 - 09:20 Material Definition (S.Ince
- Defining Materials
- NIST Material database

09:20 - 10:00 Geometry I (M.Asai) (ppt,
- Introduction
- G4VUserDetectorConstruction class
- Solid
- Logical volume
- Region

10:00 - 10:30 Visualization II (J.Perl) (pp
- Basic Visualization Commands

10:30 - 11:00 Break

11:00 - 11:45 Physics I (D.Wright) (pdf)
- Introduction
- G4VUserPhysicsList class
- Modular physics list
- Packaged physics lists

11:45 - 12:30 Geometry II (M.Asai) (ppt,
- Placement volume
- Parametrized volume
- Replicated volume
- Divided volume
- Touchable
- Geometry checking tools

12:30 - 14:00 Break

14:00 - 14:45 Physics II (D.Wright) (pdf)
- Overview
- Processes
- Production thresholds

14:45 - 15:10 Physics III (S.Incerti) (pdf
- Cuts per region
- Decay
- Optical

15:10 - 15:30 Primary Particle (T.Koi) (p
- G4VUserPrimaryGeneratorAction class
- G4ParticleGun
- General particle source

15:30 - 16:00 Break

16:00 - 18:00 Hands-on II (T.Koi)
- Material and geometry implementation
- Visualization of geometry
- Shoot primaries
- Minimal (EM) physics list

Wednesday (Jan/12/2011)

09:00 - 09:30 EM Physics I (S.Incerti) (pd
- EM standard overview
- Multiple scattering

09:30 - 10:00 Scoring I (M.Asai) (ppt,pdf)
- Introduction to sensitivity
- Command-based scoring
- Define scorers in the tacking geometry

10:00 - 10:30 EM Physics II (S.Incerti) (p
- Low-E EM overview

10:30 - 11:00 Break

11:00 - 11:30 Visualization III (J.Perl) (pp
- Advanced Visualization

11:30 - 12:00 User Interface II (M.Asai) (
- Define user commands

12:00 - 12:30 Geometry III (J.Perl) (pdf)
- GDML interface
- CAD interface

12:30 - 14:00 Break

14:00 - 14:50 Hadronic Physics I (D.Wrigh
- Overview
- Elastic process
- Precompound/de-exitation models
- Cascade models
- Parameterized models

14:50 - 15:30 Hadronic Physics II (T.Koi) (
- Neutron physics
- Ion physics
- Radioactive decay

15:30 - 16:00 Break

16:00 - 18:00 Hands-on III (S.Incerti)
- Define scorers
- Output results

Thursday (Jan/13/2011)

09:00 - 09:40 Hadronic Physics III (D.Wright) (pdf)
- String models
- CHIPS / electro-nuclear models
- Capture / fission / isotope-production models

09:40 - 10:20 Scoring II (M.Asai) (ppt,pdf)
- Sensitive detector
- Hits

10:20 - 10:30 Analysis (J.Perl) (ppt,pdf)
- Analyze scored results

10:30 - 11:00 Break

11:00 - 11:30 Geometry IV (M.Asai) (ppt,pdf)
- Magnetic field
- Nested parametrization
- Reflected volume, Assembly volume
- Geometry optimization

11:30 - 12:30 Hands-on IV (T.Koi)
- Storing hits

12:30 - 14:00 Break

14:00 - 14:30 Kernel II (M.Asai) (ppt,pdf)
- User limits
- User information classes
- Stack management

14:30 - 15:00 Which Physics List to Use (D.Wright) (pdf)
- Choosing appropriate Physics List
- Validation

15:00 - 15:30 Event Biasing (J.Perl) (pdf)
- Overview
- Geometrical biasing
- Physics biasing
- Bremsstrahlung splitting

15:30 - 16:00 Break

16:00 - 16:40 Kernel III (M.Asai) (ppt,pdf)
- Parallel geometry
- Moving objects
- Shower parametrization
- Speeding up the application

16:40 - 18:00 Hands-on V (J.Perl)
- Alternate physics lists
- Event biasing by Bremsstrahlung splitting
-

Friday (Jan/14/2

09:00 - 11:50 Parallel session

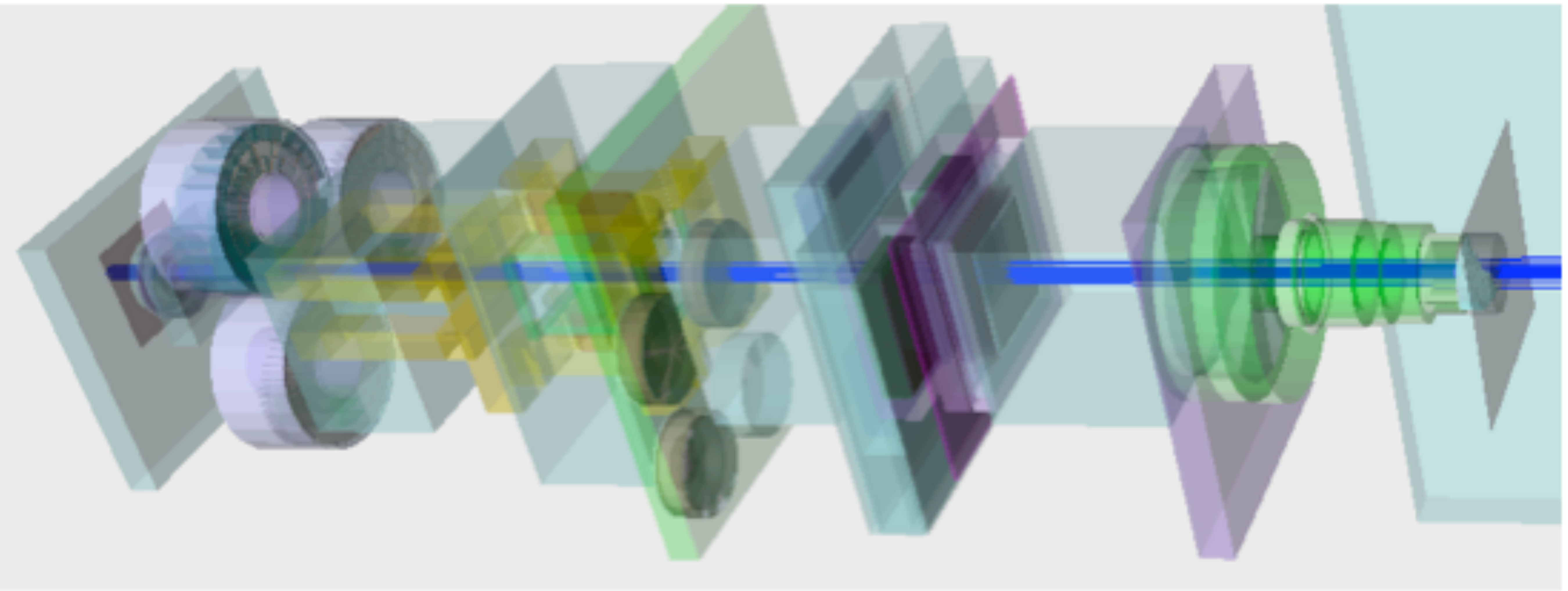
High Energy	Medical Physics	DNA Damage

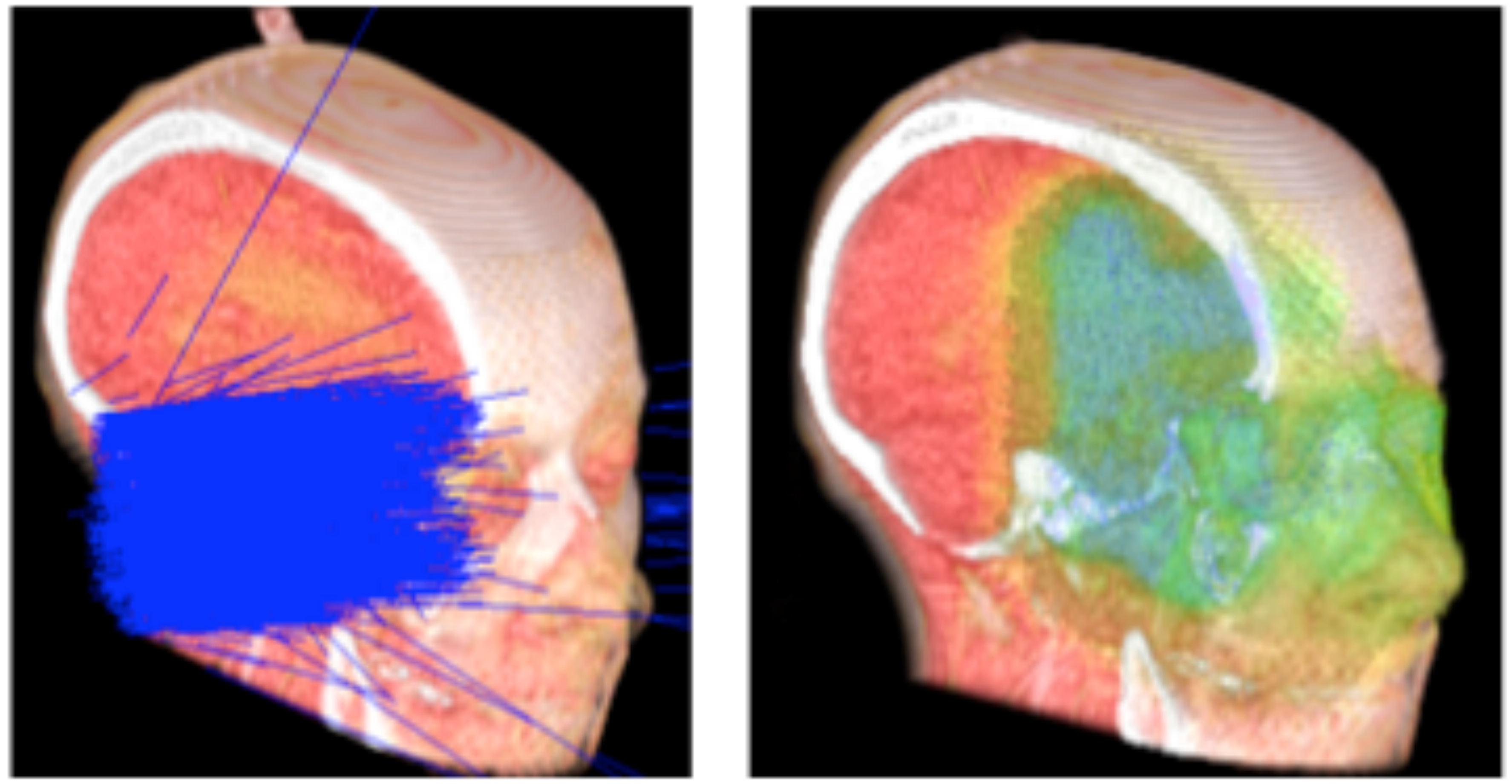
11:50 - 12:10 How to Upgrade Your Geant4 Release (J.Perl) (ppt,pdf)
- Major versus minor releases
- What to look for in the release notes
- How to upgrade

12:10 - 12:20 Closing remarks (M.Asai) (ppt,pdf)
12:20 - 12:30 Concluding Remarks (local organizer)
12:30 Adjourn

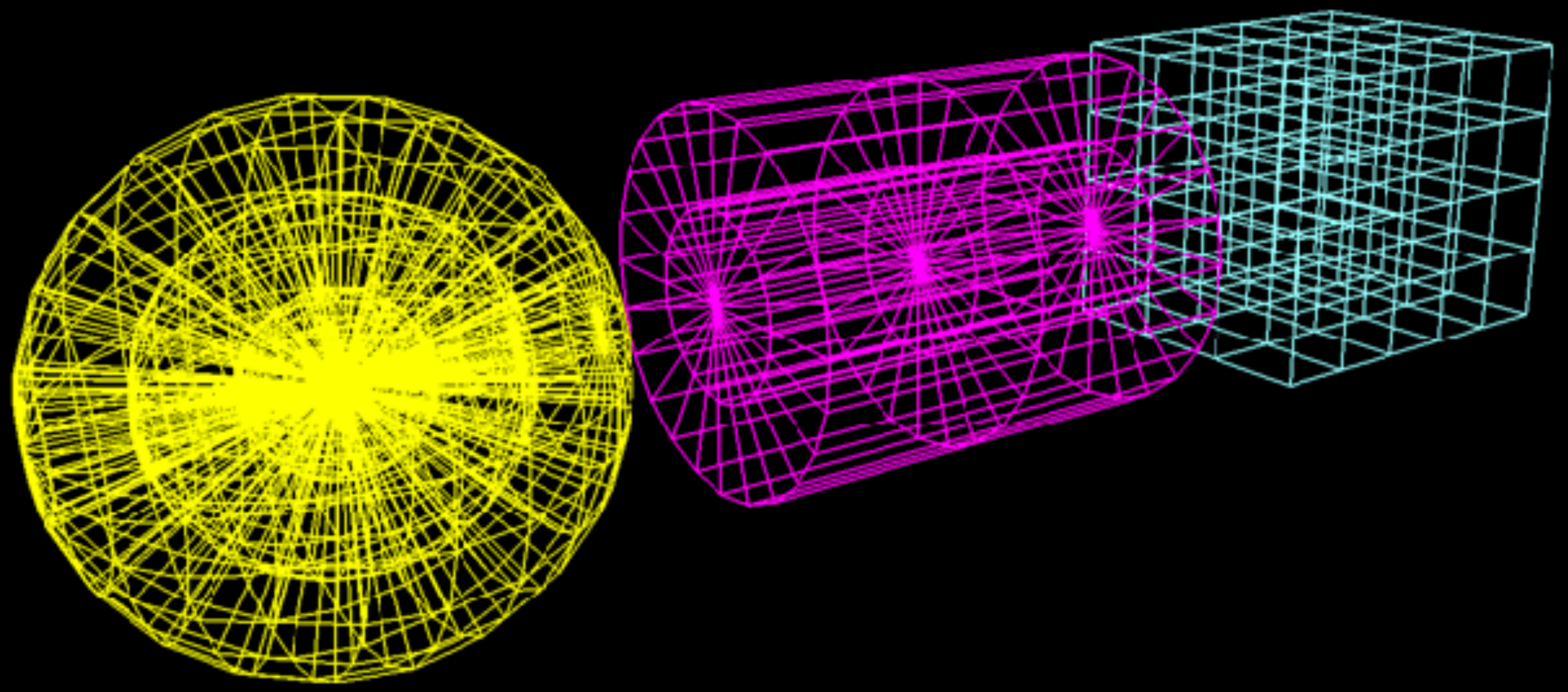
Single, Integrated, Pre-Built Application

Tool for Particle Simulation





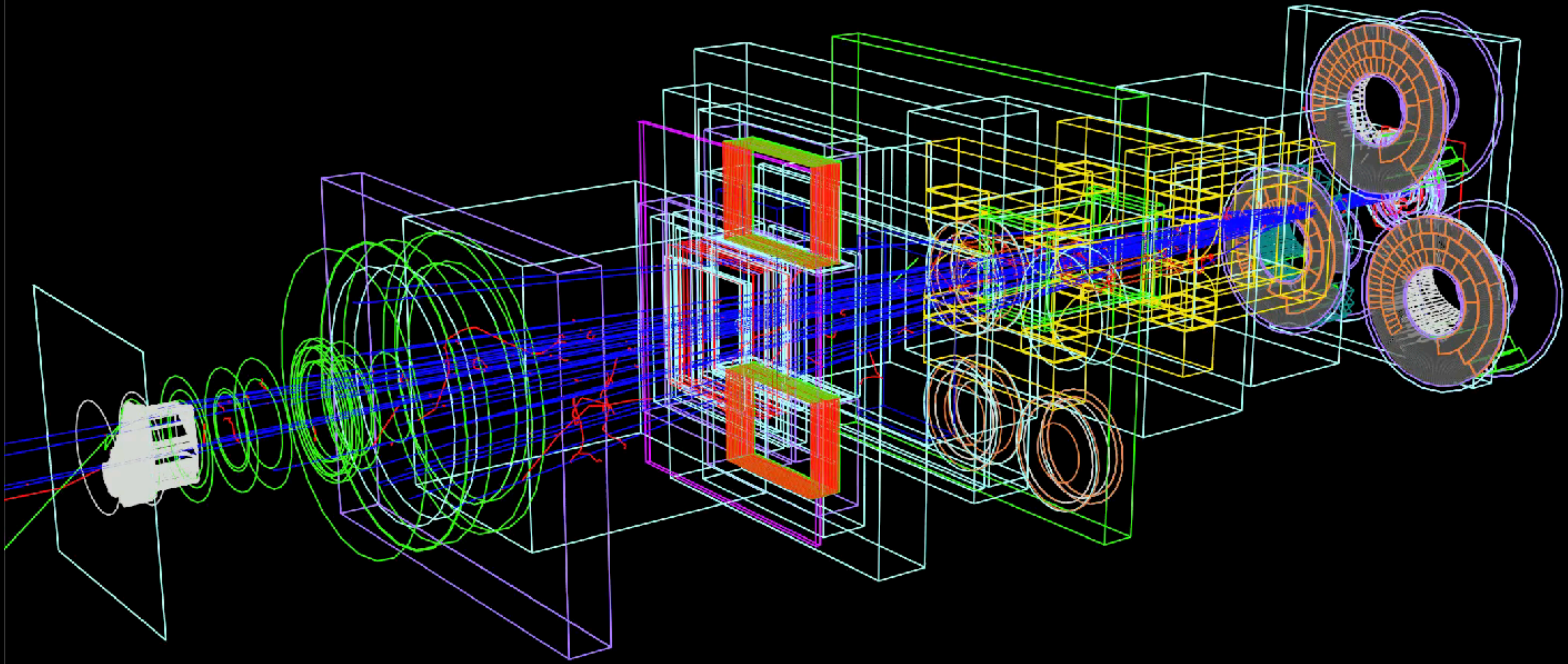
Score Energy, Dose,
Fluence, RBE, ToF, etc.
to various formats:
csv, binary, nTuple,
phase space, DICOM,
DVH, TCP, NTCP



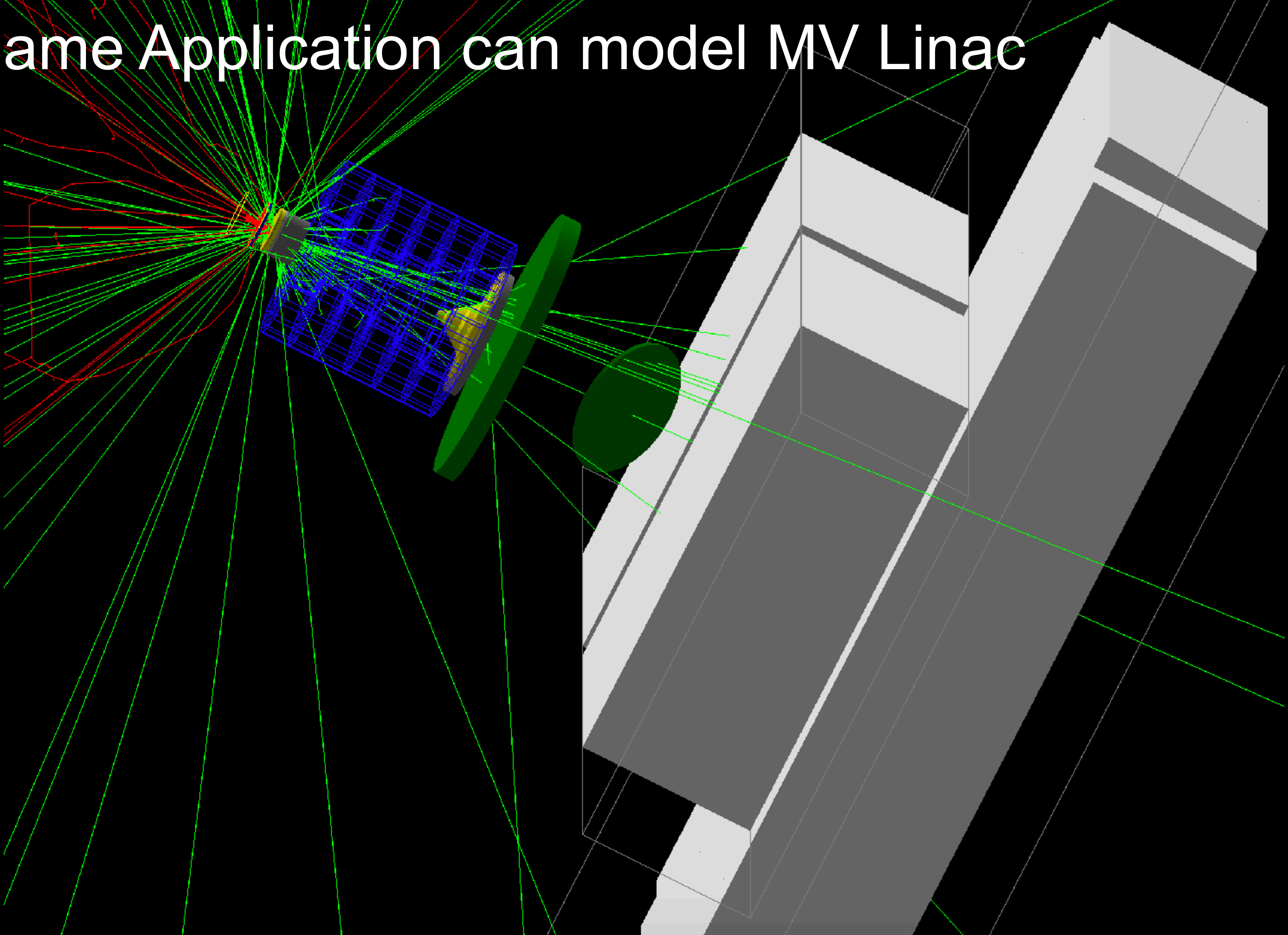
4-Dimensional

2605 Users at
646 Institutions in
68 Countries

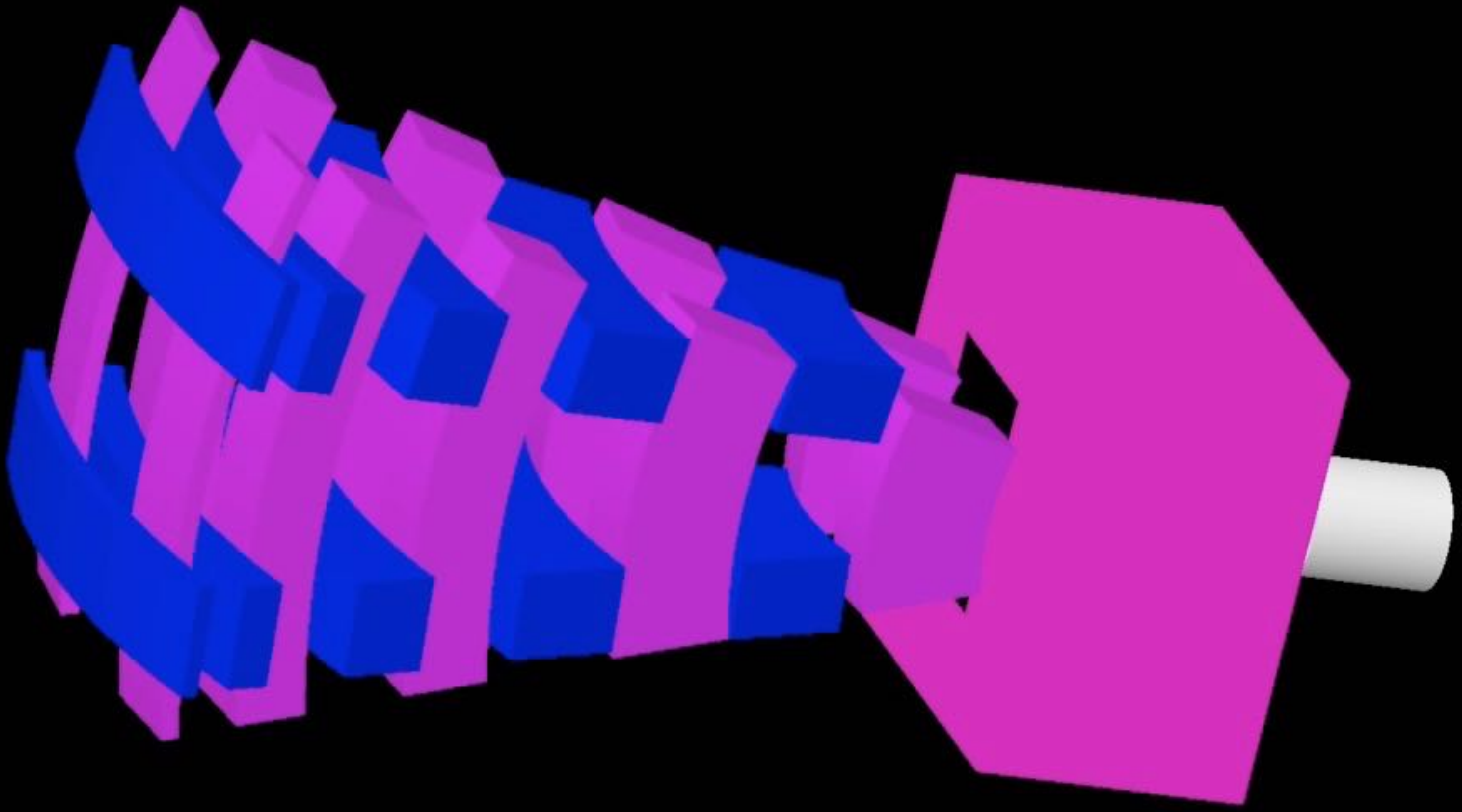
Users can build complex and precise models, such as this Proton Therapy system



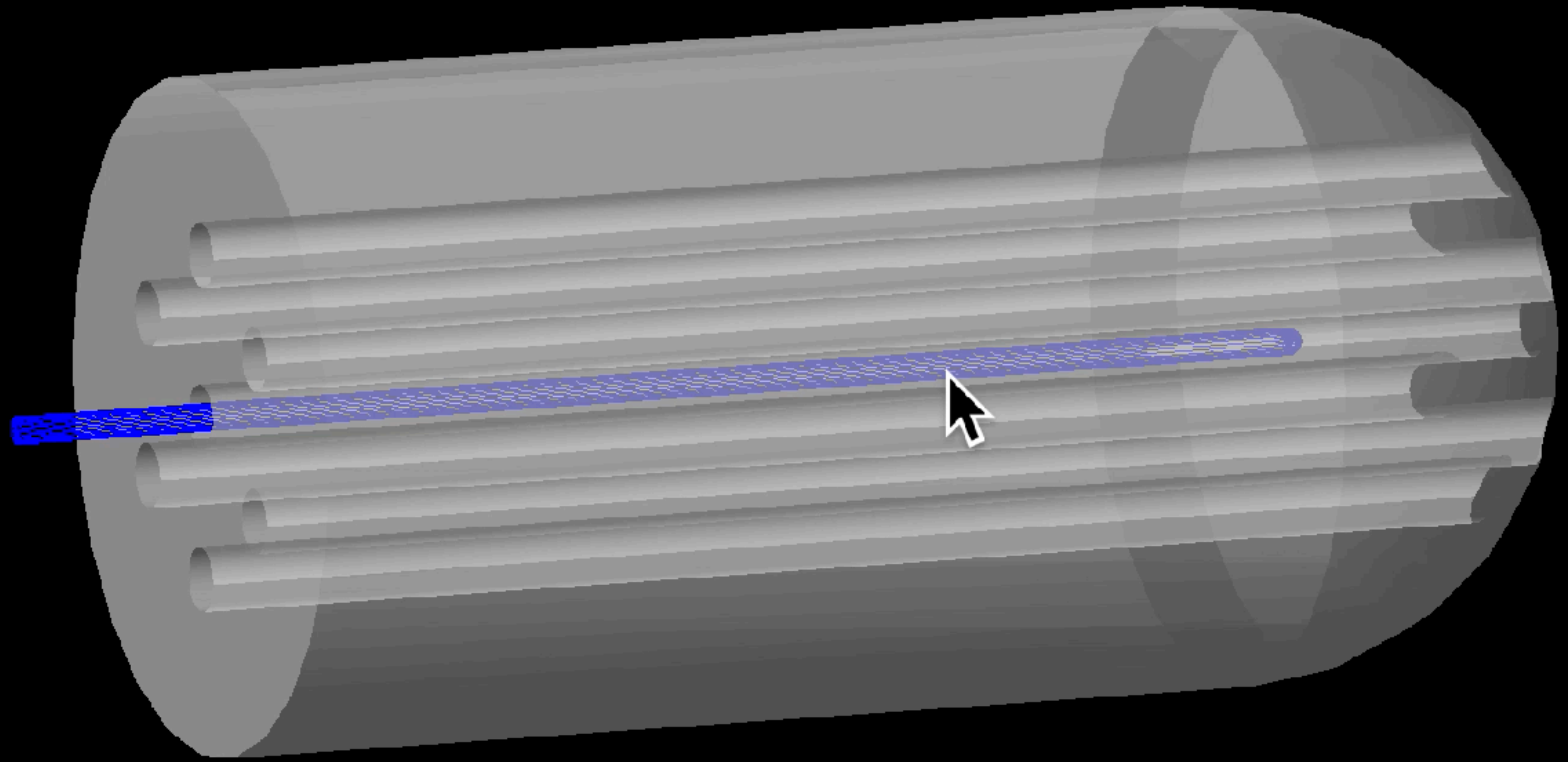
Same Application can model MV Linac



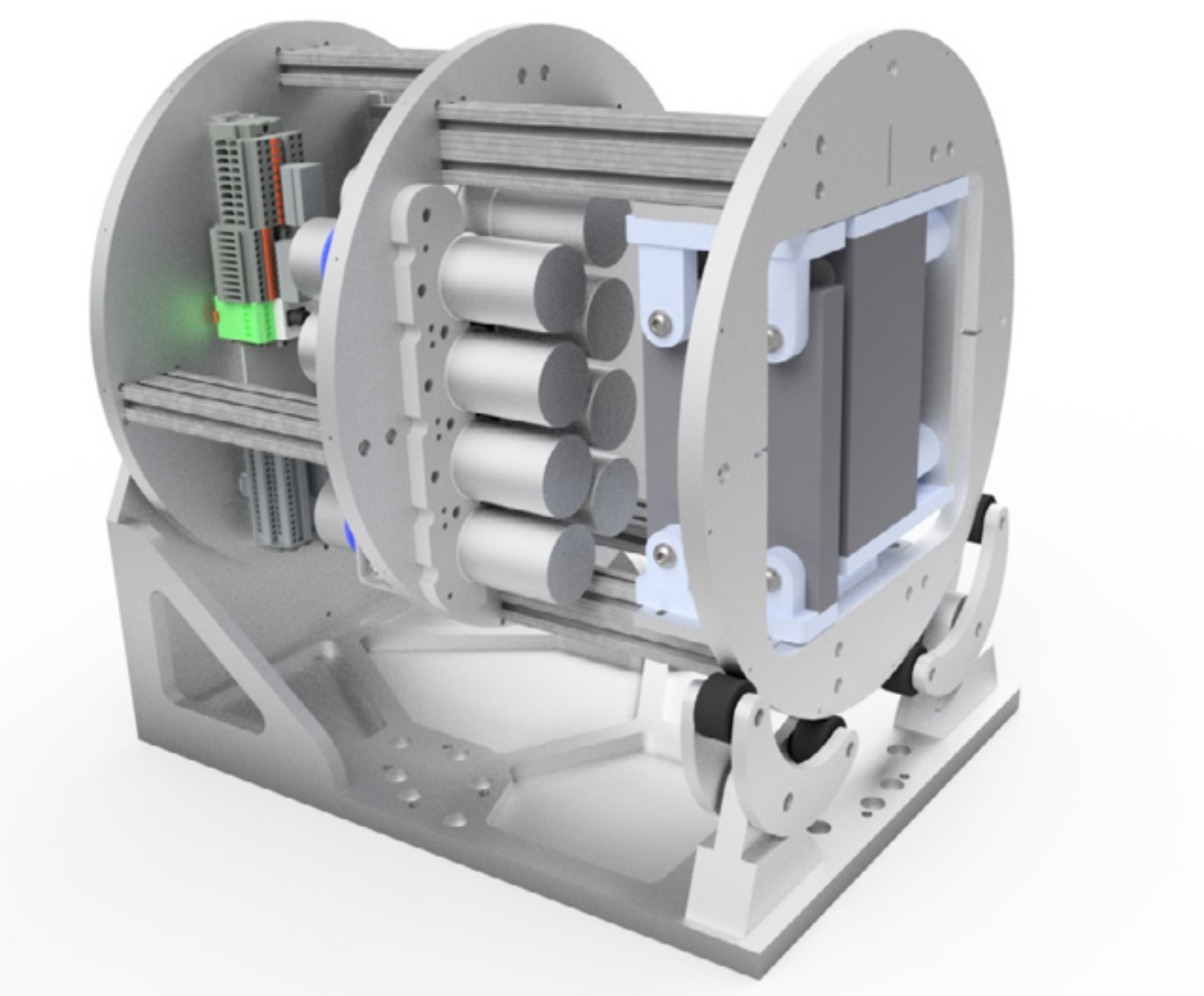
Cobalt Therapy System



HDR Brachytherapy



Prompt Gamma Range Verification



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TOPAS: an innovative proton Monte Carlo platform for research and clinical applications

J **Perl**, J Shin, J Schümann, B Faddegon… - Medical …, 2012 - Wiley Online Library

… We built and tested the **TOPAS** code. We have shown that the **TOPAS** parameter system … data and demonstrate the capabilities of **TOPAS** in simulating beam delivery in 3D and 4D. …

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BRACHYTHERAPY

Brachytherapy 21 (2022) 229–237

Comparison of novel shielded nasopharynx applicator designs for intracavitary brachytherapy

Benjamin Insley[1,6,*], Ken Goldberg[2], Luc Beaulieu[3], Yunzhi Ma[4], Stephen McKinley[2], I-Chow Hsu[5], J. Adam Cunha[5]

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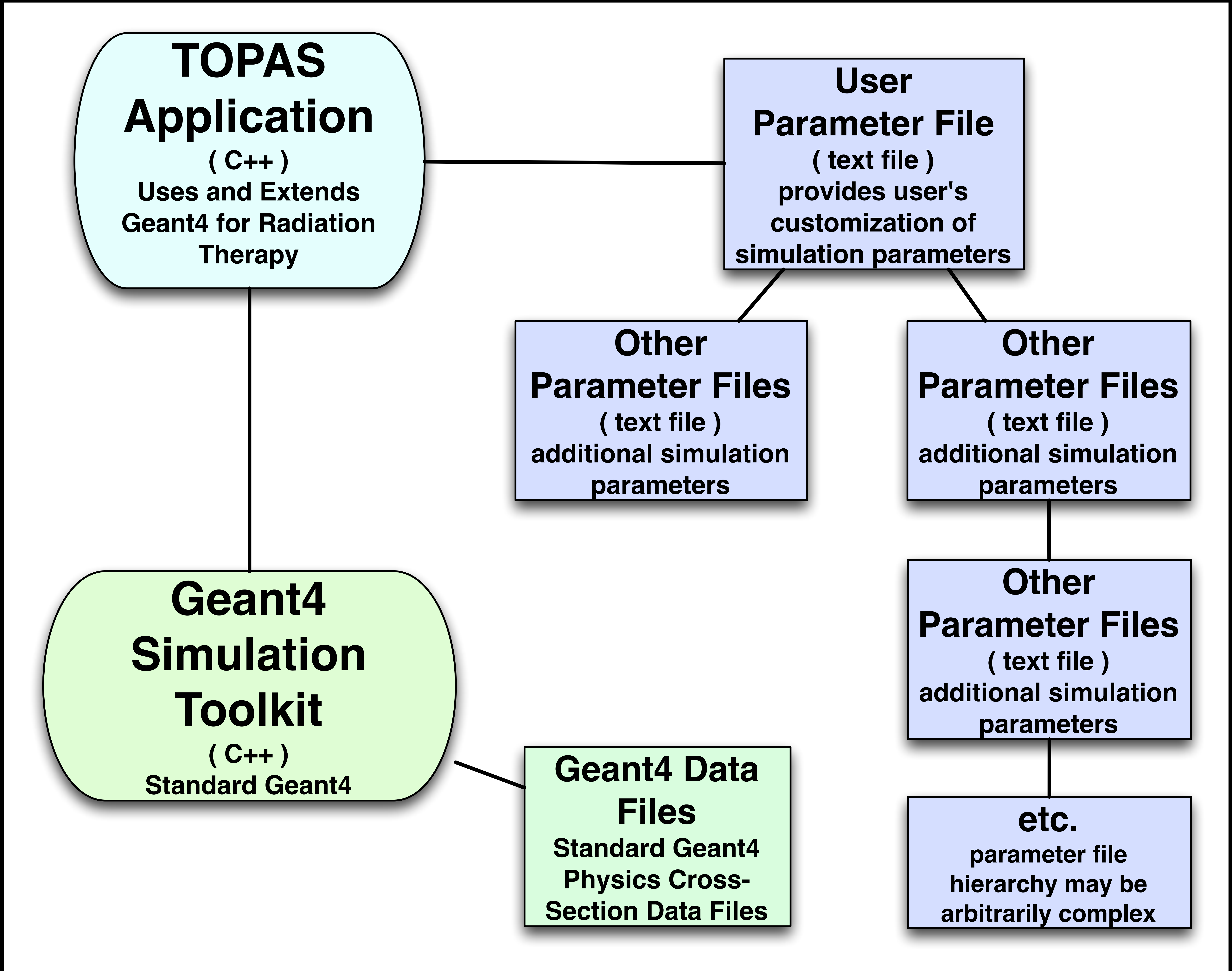
[2] *Industrial Engineering and Operations Research, University of California, Berkeley, CA*
[3] *Department of Physics, Université Laval, Quebec, Canada*
[4] *CHU de Quebec - Université Laval Research Center, Axe Oncologie, Quebec, Canada*
[5] *Department of Radiation Oncology, University of California, San Francisco, CA*

ABSTRACT

PURPOSE: Nasopharyngeal brachytherapy is limited in part by the radiotolerance of nearby organs like the soft palate. This study explores several novel shielding designs for an intracavitary applicator to significantly reduce soft palate dose while adhering to the constraints of standard treatment procedure.

METHODS: The Monte Carlo code TOPAS is used to characterize each prototype under typical high-dose-rate treatment conditions. Mucosal surface dose maps are collected to evaluate the

Geant4 Inside



Unified, Pre-built, Ready-to-Go

Exact same single application shared by thousands of users

- X-Ray
- Proton
- Ion
- Brachytherapy
- Imaging
- Radiation Biology
- Free to use for any area of research
- Has also been used in Materials Science and Archaeology

Model any kind of apparatus,
or take a model someone else shared
and modify it in ways the original creator
never anticipated

Without C++

A Geant4 Application Reimagined

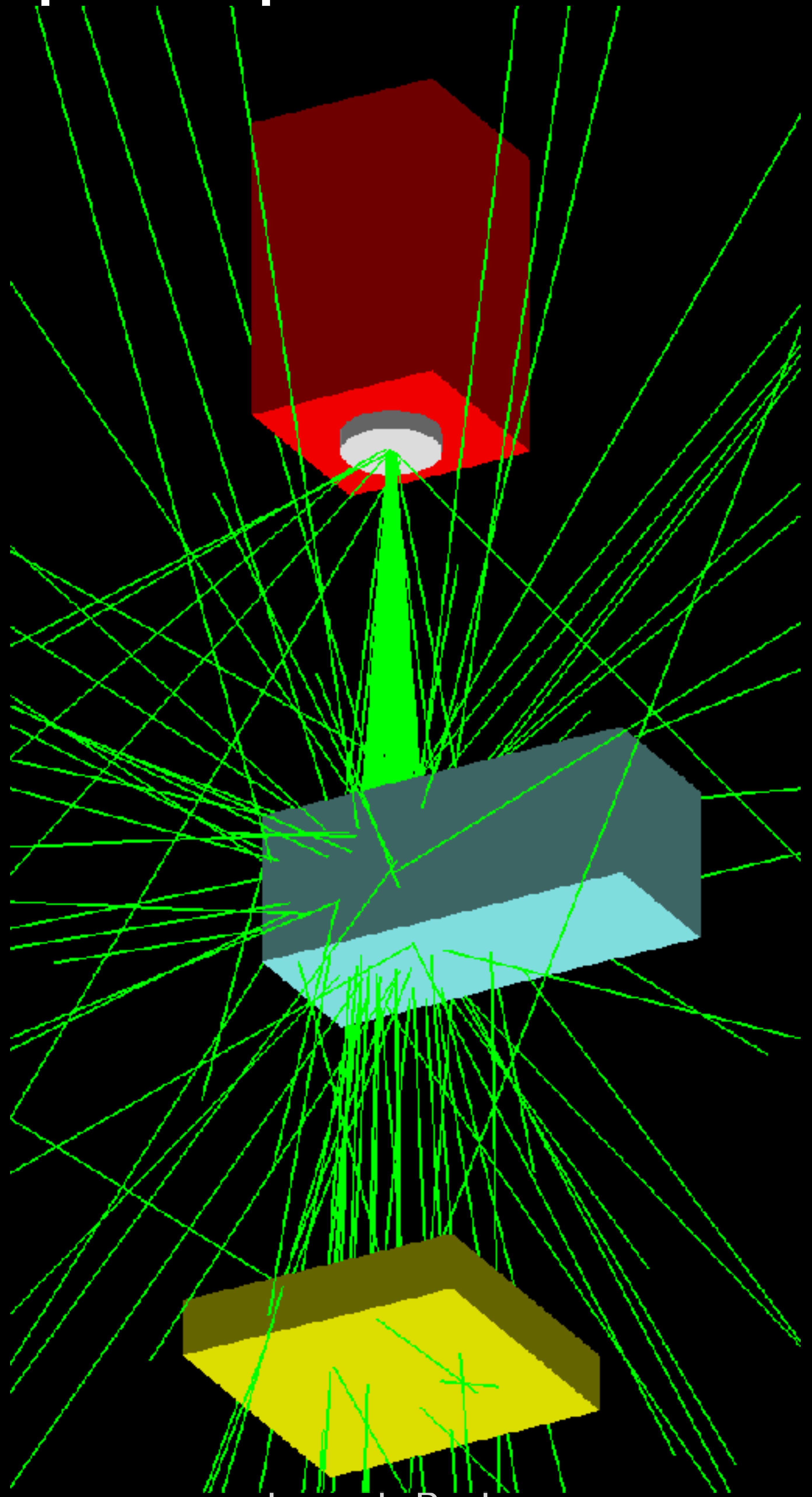
- Unconstrained by HEP paradigms
- Significant architectural differences from other Geant4 applications
- A tribute to Geant4's fundamental OO design

Custom Designed Control System

- Line order shouldn't matter
- Case shouldn't matter
- Make it easy to add to or modify someone else's setup
- So...
- Not C++
- Not Geant4 Macro Files
- Not XML

TOPAS Parameter Control System: Up to speed in 2 Hours

```
s:Ge/XRaySystem/Type      = "Group"
s:Ge/XRaySystem/Parent    = "World"
d:Ge/XRaySystem/RotZ.     = 90. deg
d:Ge/XRaySystem/TransX = 0. cm

s:Ge/XRayExitWindow/Type      = "TsCylinder"
s:Ge/XRayExitWindow/Parent    = "XRaySystem"
s:Ge/XRayExitWindow/Material = "G4_Ti"
d:Ge/XRayExitWindow/RMax     = 5. mm
d:Ge/XRayExitWindow/HLZ       = 0.05 mm

s:So/LinacBeam/Type = "Beam"
s:So/LinacBeam/Component = "XrayExitWindow"
s:So/LinacBeam/BeamParticle = "gamma"
d:So/LinacBeam/BeamEnergy = 6. MeV
u:So/LinacBeam/BeamEnergySpread = 0.2
s:So/LinacBeam/BeamPositionDistribution = "Gaussian"
s:So/Demo/BeamPositionCutoffShape = "Ellipse"
```



Parameter Math

You can do some simple math directly in the parameter file:

```
d:Ge/Compensator/ZTrans = Ge/Aperture/DistalEdge +
                          Ge/Compensator/HLZ mm
```

The TOPAS Parameter Control System: Designed for Collaboration

OneBoxRotate.txt

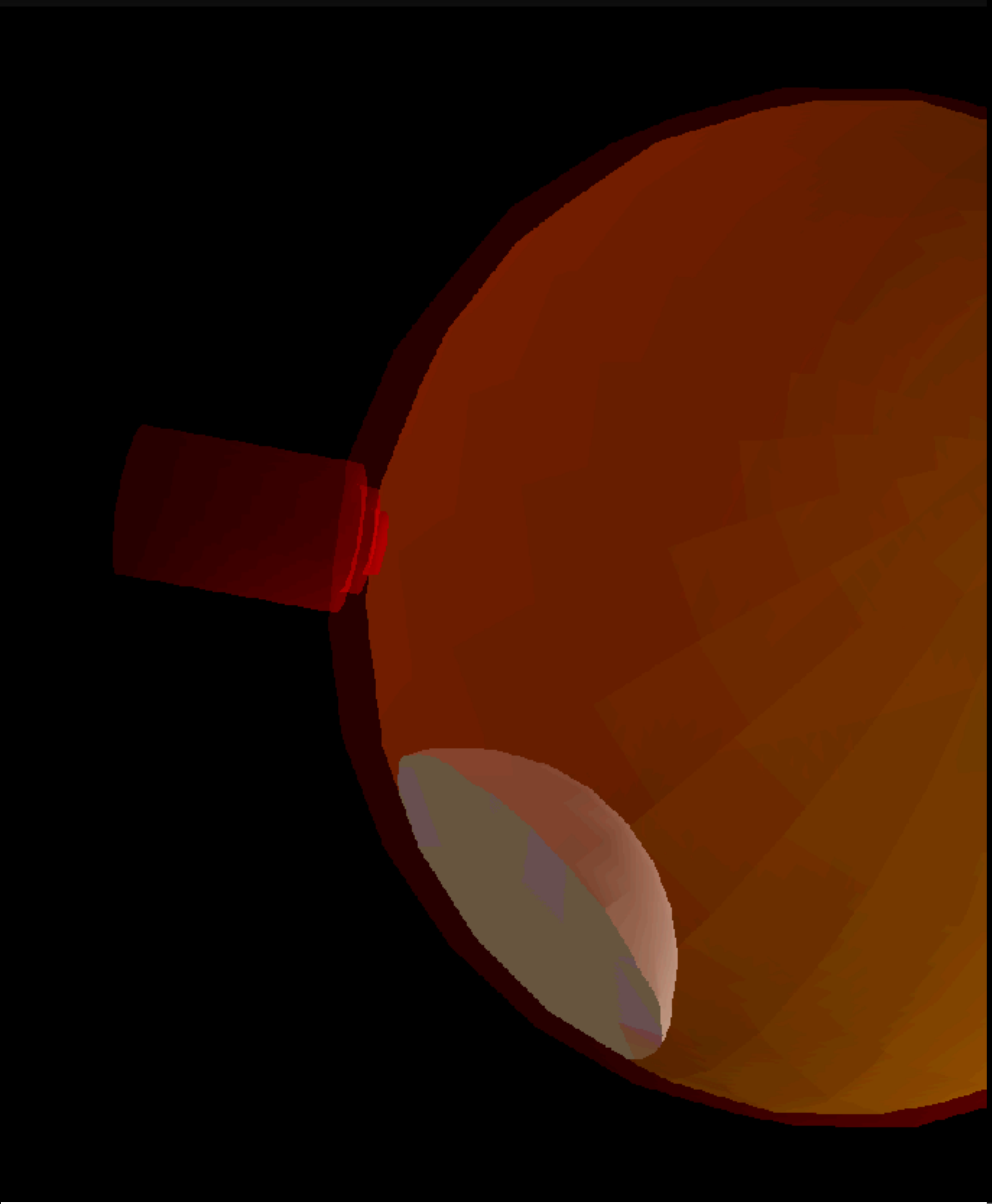
```
# Demonstrates use of includeFile.
# Overrides the RotX value from OneBox.txt

includeFile = OneBox.txt

d:Ge/MyBox/RotX = 45. deg
```

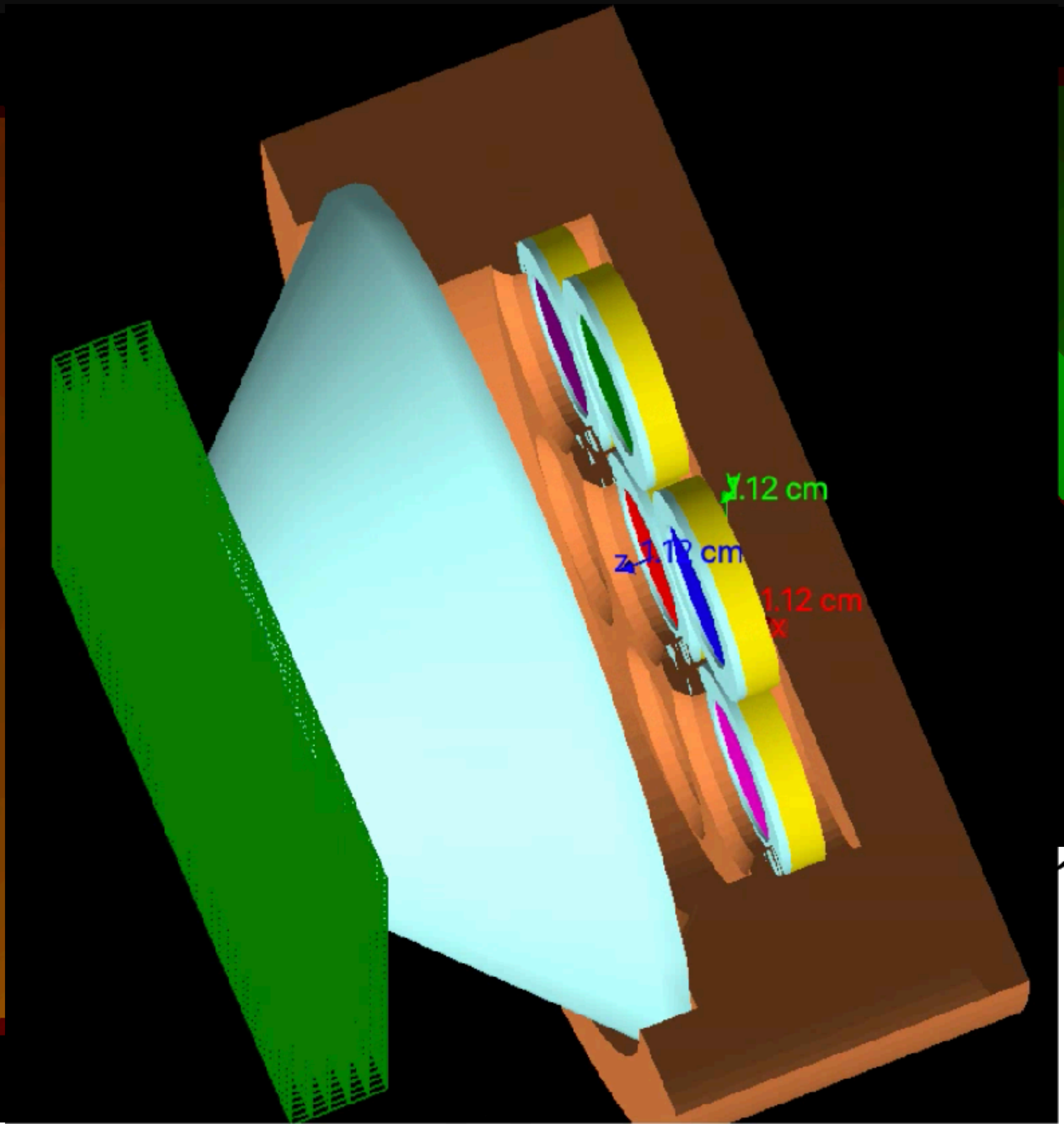
OneBox.txt

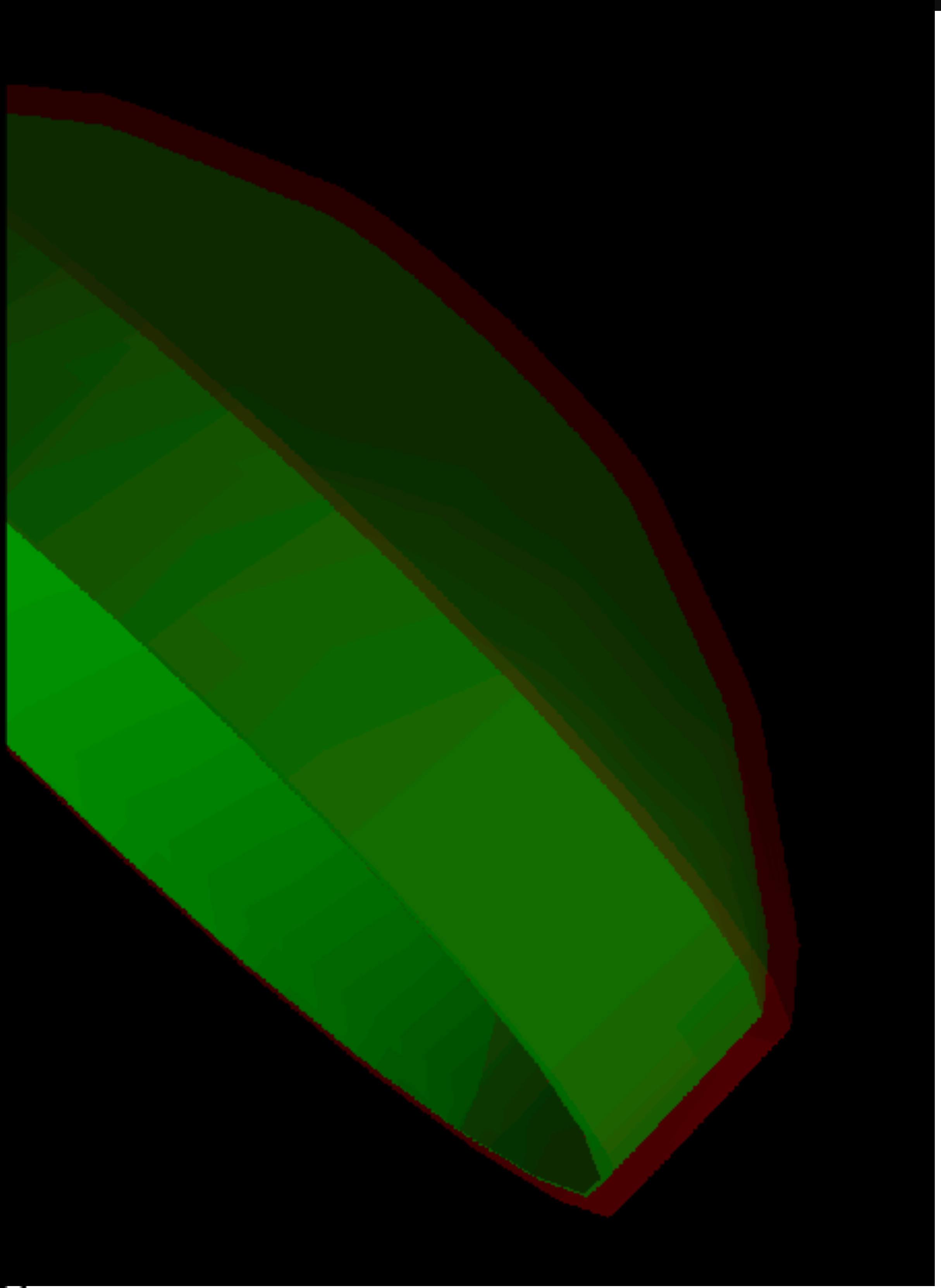
```
# Simplest TOPAS example.
# A box in a beam with EM physics.

s:Ge/MyBox/Type     = "TsBox"
s:Ge/MyBox/Material = "Air"
s:Ge/MyBox/Parent   = "World"
d:Ge/MyBox/HLX      = 2.5 m
d:Ge/MyBox/HLY      = 2. m
d:Ge/MyBox/HLZ      = 1. m
d:Ge/MyBox/TransX   = 2. m
d:Ge/MyBox/TransY   = 0. m
d:Ge/MyBox/TransZ   = 0. m
d:Ge/MyBox/RotX     = 0. deg
d:Ge/MyBox/RotY     = 0. deg
d:Ge/MyBox/RotZ     = 0. deg

sv:Ph/Default/Modules = 1 "g4em-
standard_opt0"

s:Gr/ViewA/Type             = "OpenGL"
i:Gr/ViewA/WindowSizeX      = 1024
i:Gr/ViewA/WindowSizeY      = 768
b:Gr/ViewA/IncludeAxes      = "True"
d:Gr/ViewA/Theta            = 55 deg
d:Gr/ViewA/Phi              = 20 deg
s:Gr/ViewA/Projection       = "Perspective"
d:Gr/ViewA/PerspectiveAngle = 30 deg
u:Gr/ViewA/Zoom             = 2.

b:Ts/PauseBeforeQuit = "True"
```

Geometry: Not the standard Geant4 paradigm

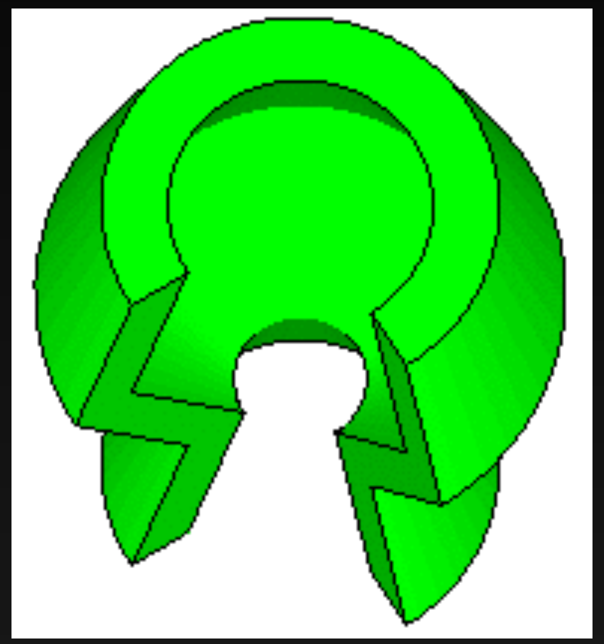
We work at a level above solids, LVol and PVol

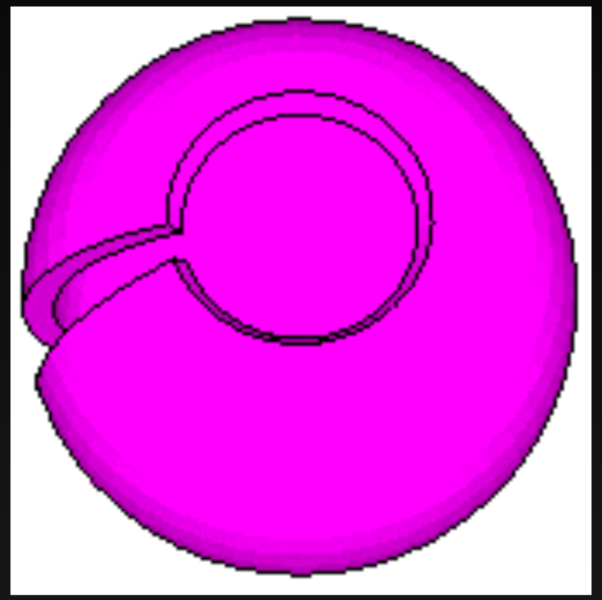


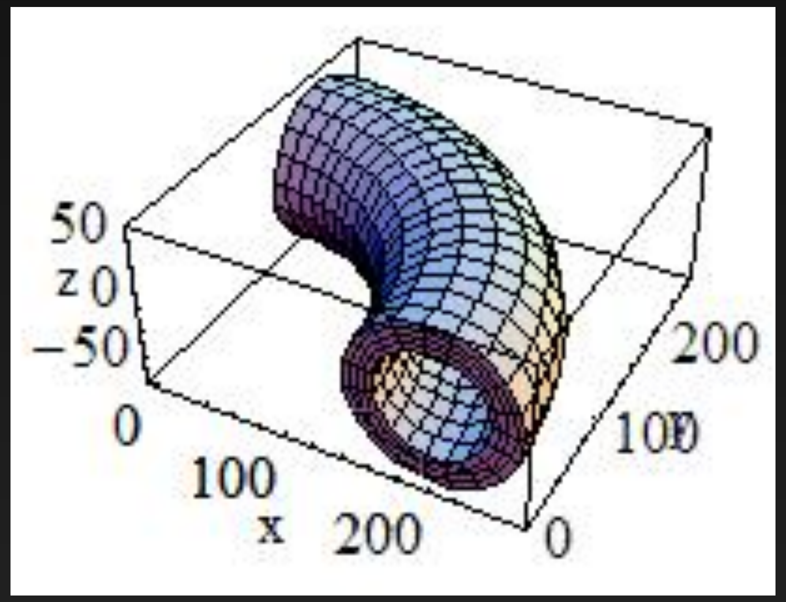


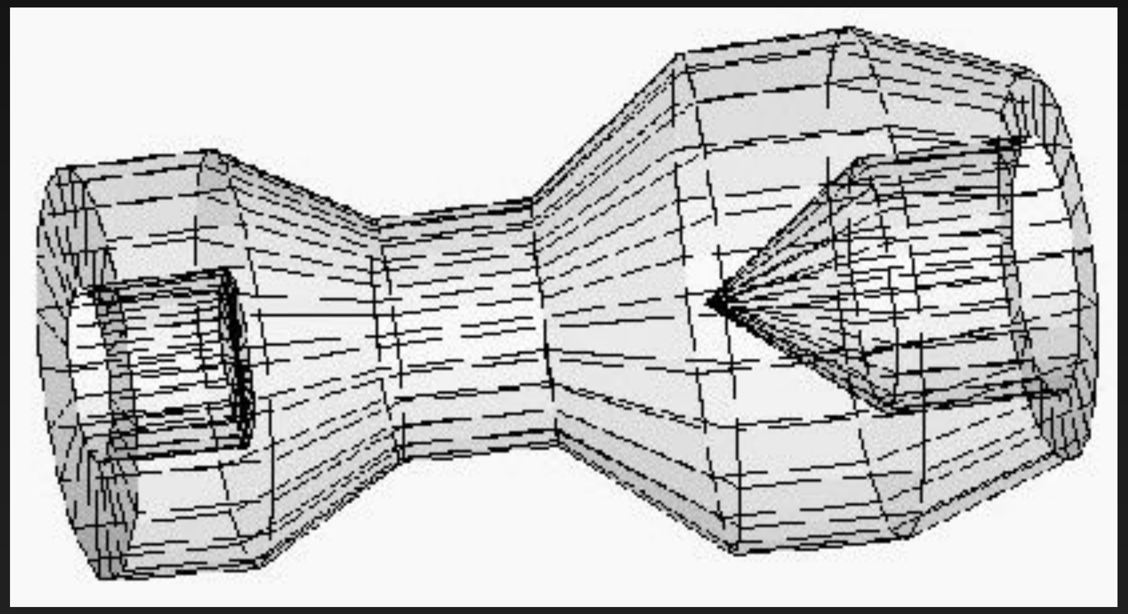


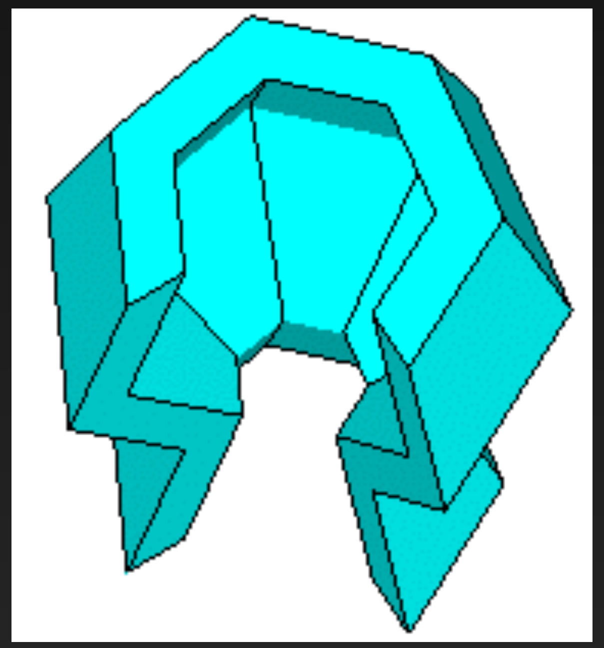
Wide Selection of Geometry Components

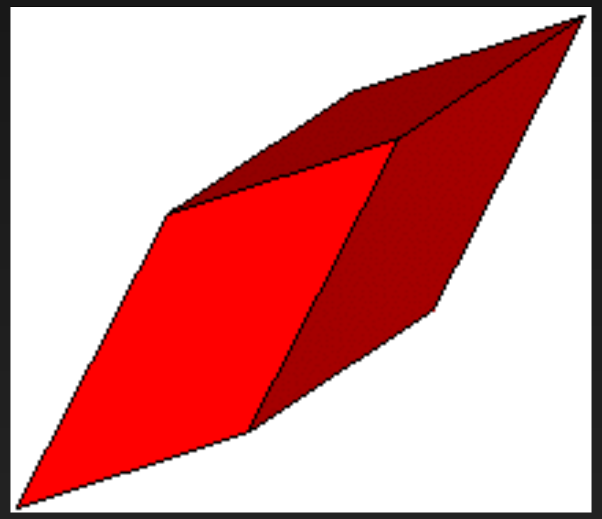


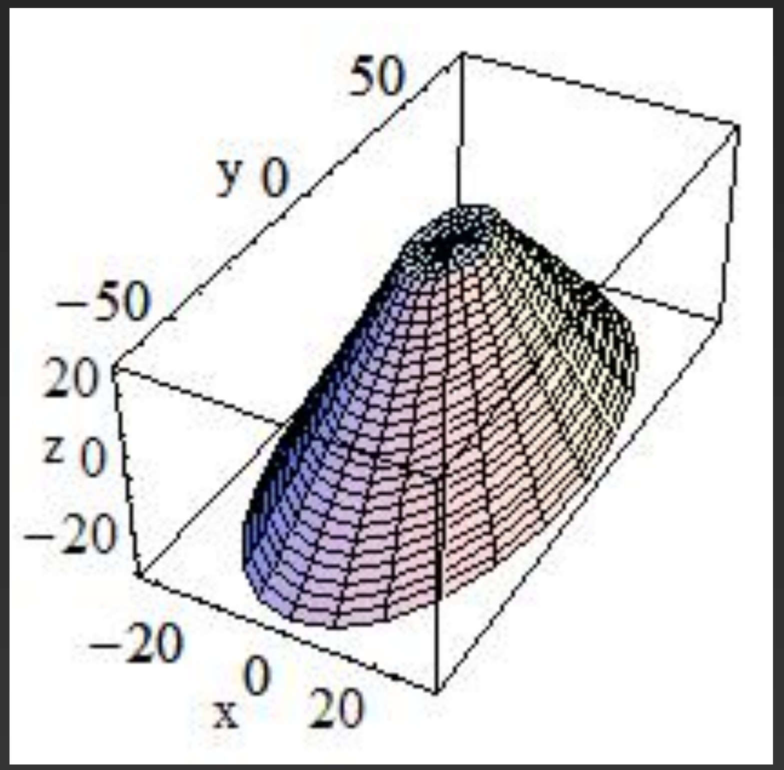


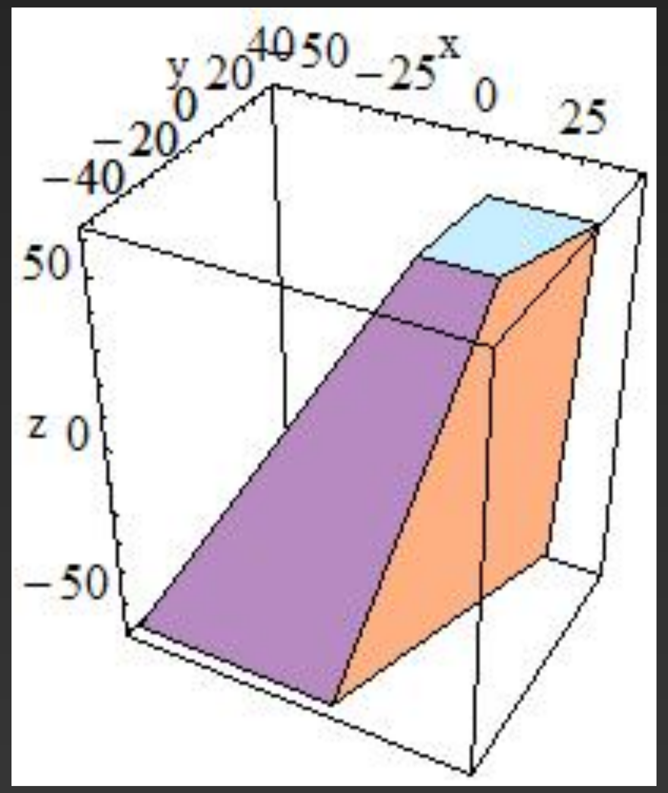


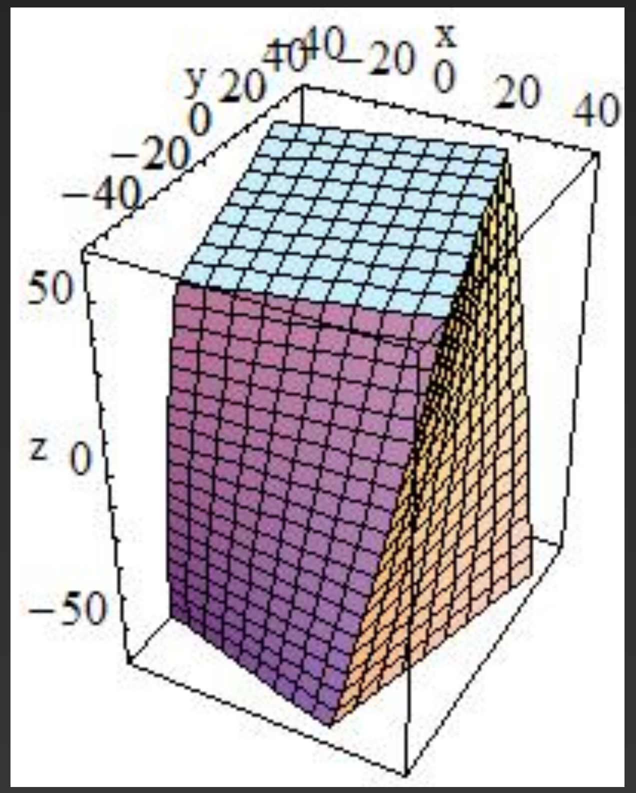


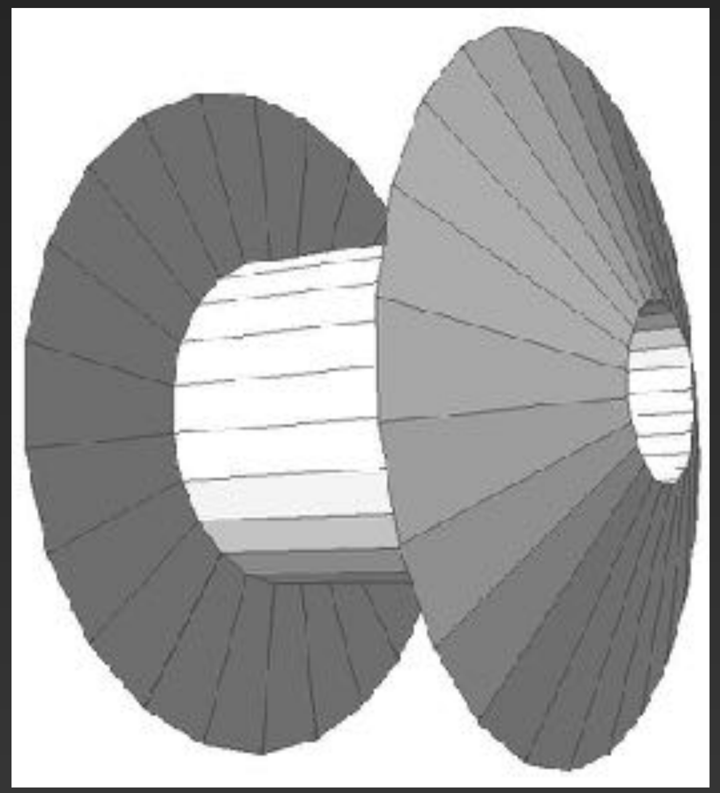




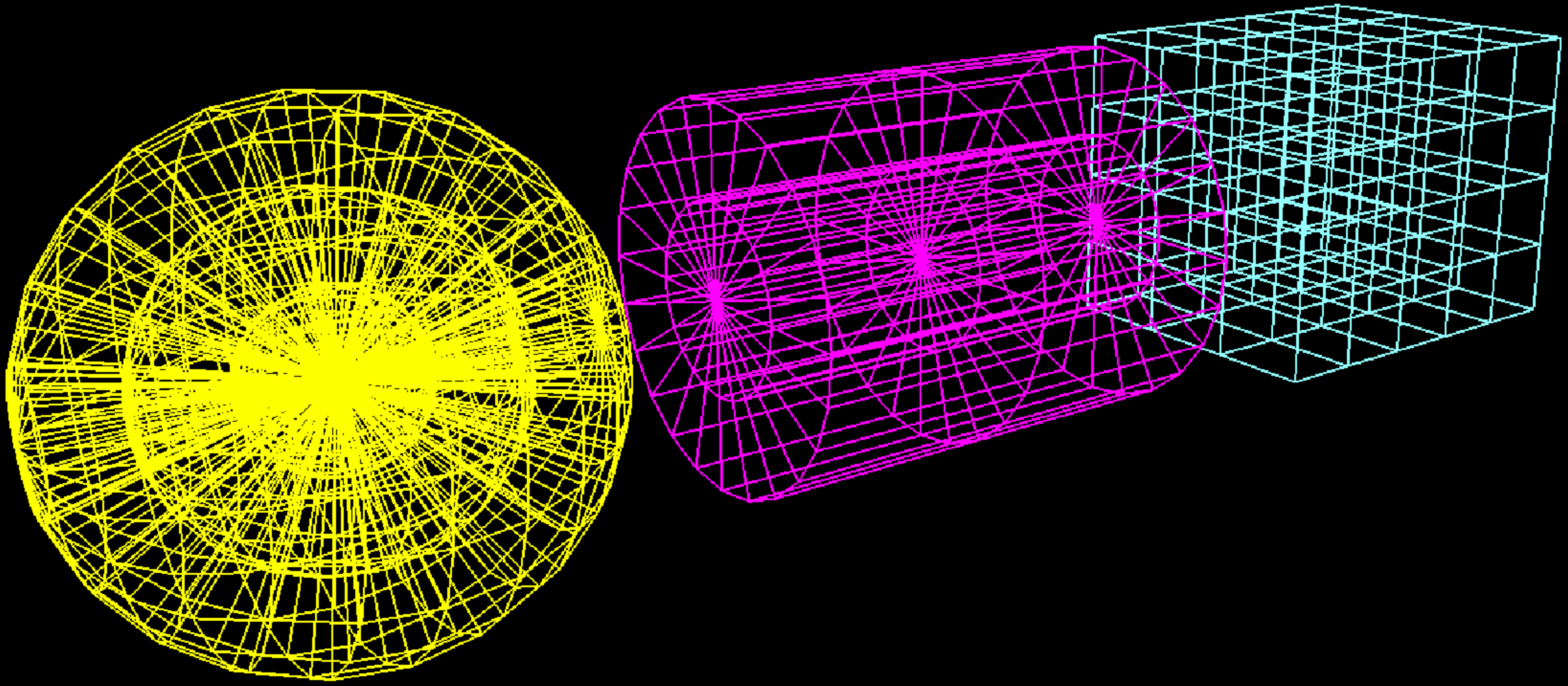






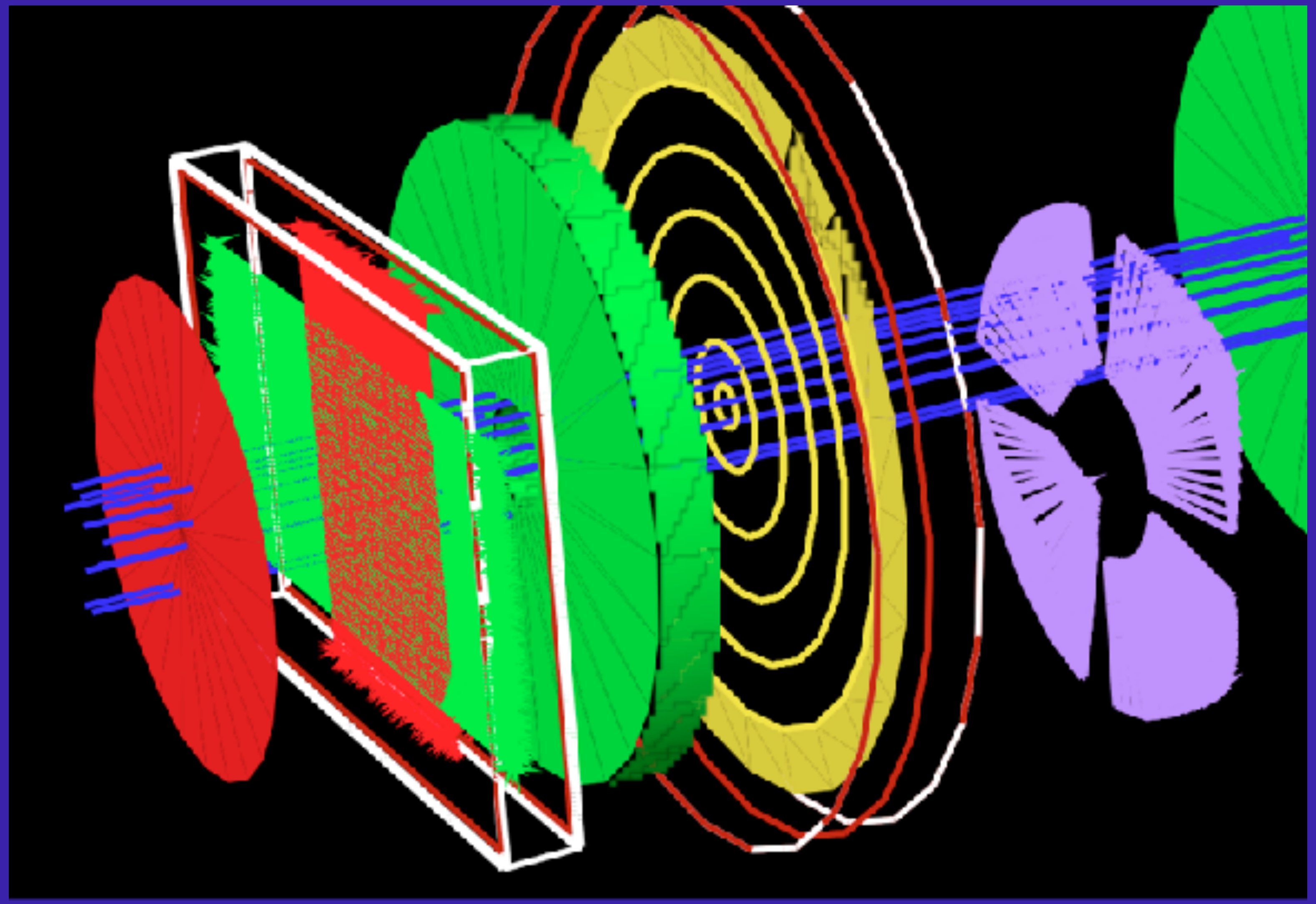


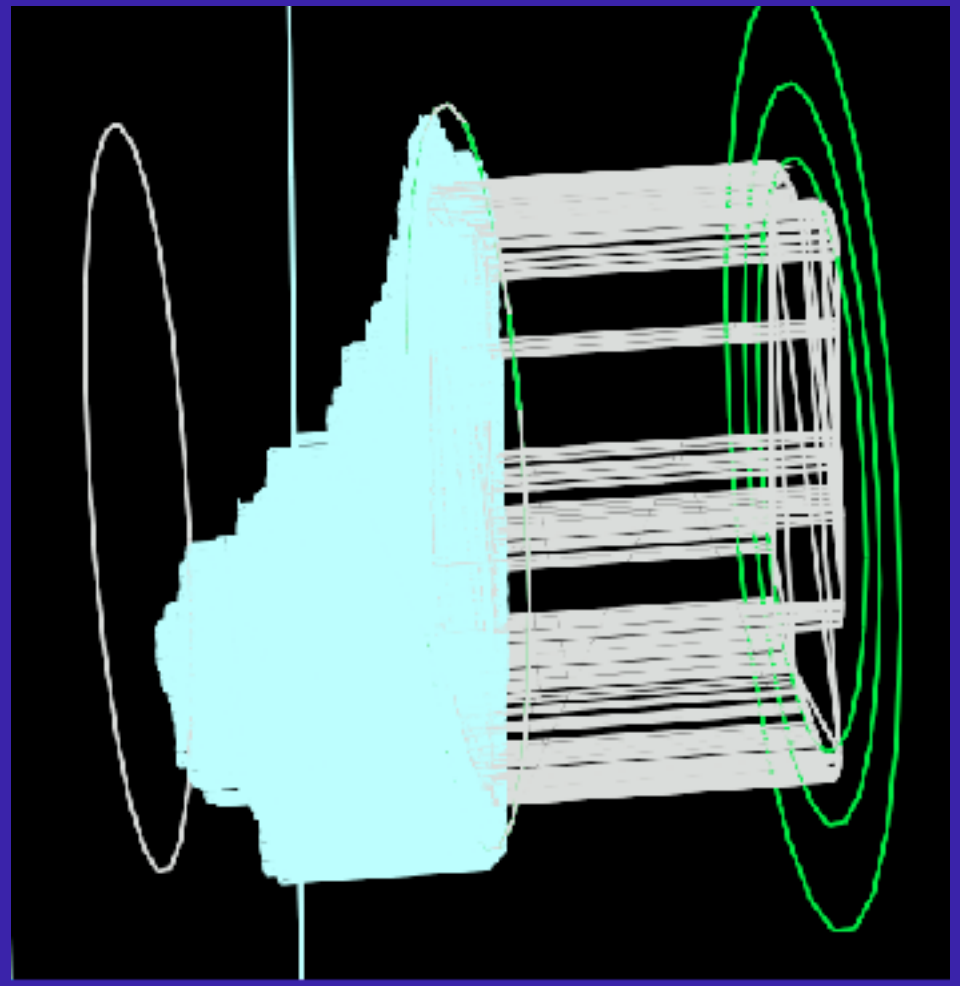
Dividable Geometry Components



Complex TOPAS Geometry Components

Compensator
Aperture
Range Modulator Wheel
Propeller
Wire Chamber
Jaws
Multi-Leaf Collimator
EyeModel
EyePlaque
CAD Part
Group
Patient

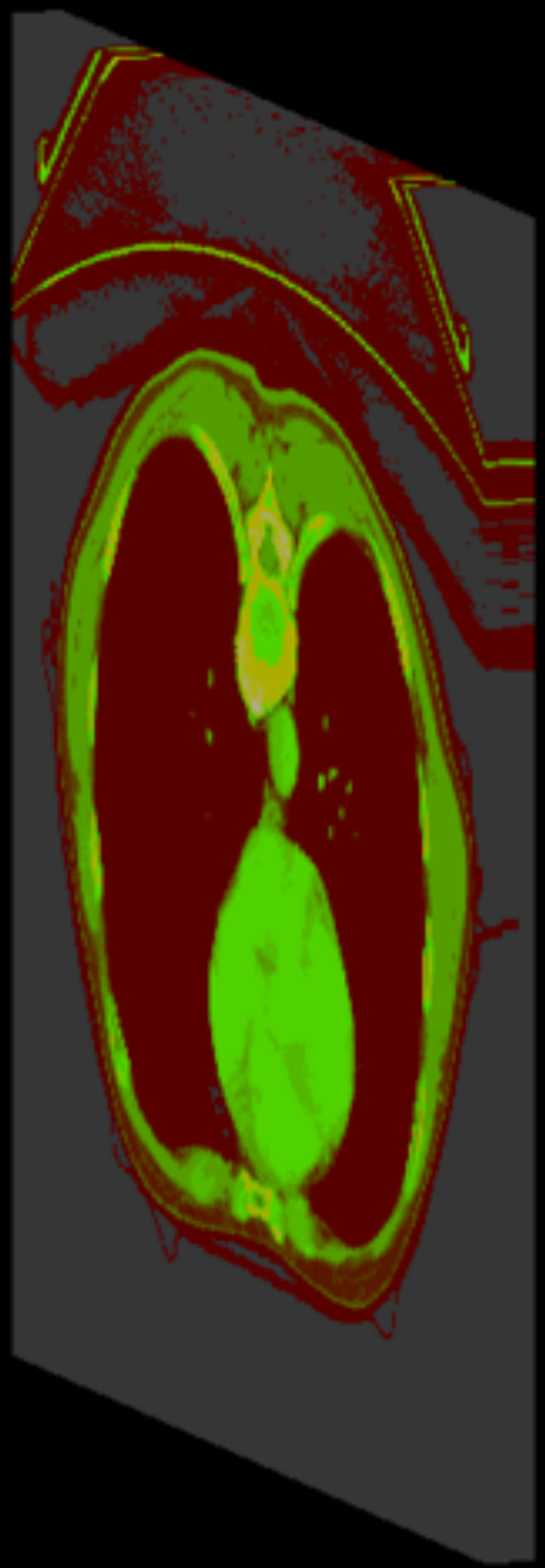




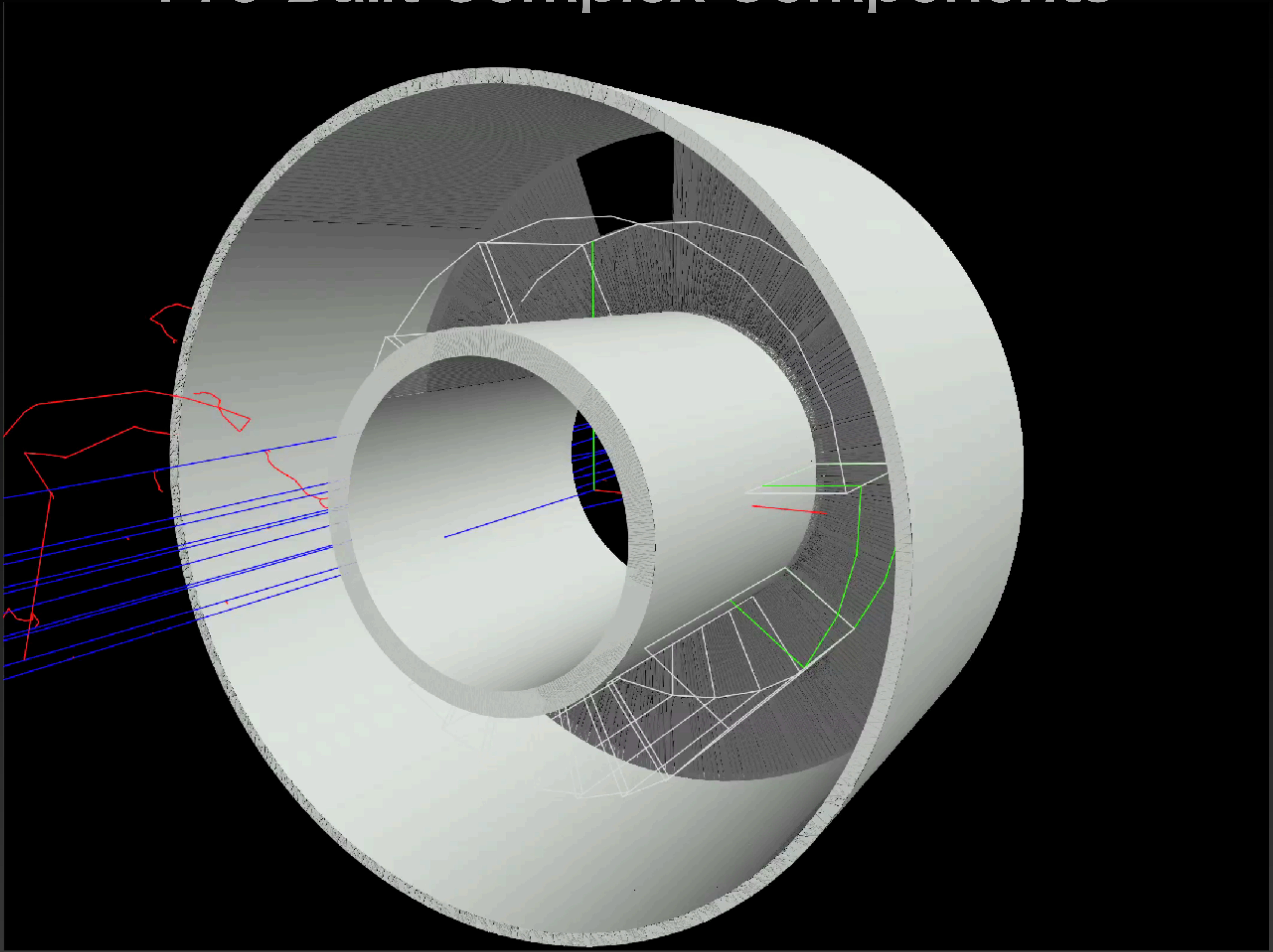
The Group Component

Patient is a kind of Component

DICOM including RTStruct



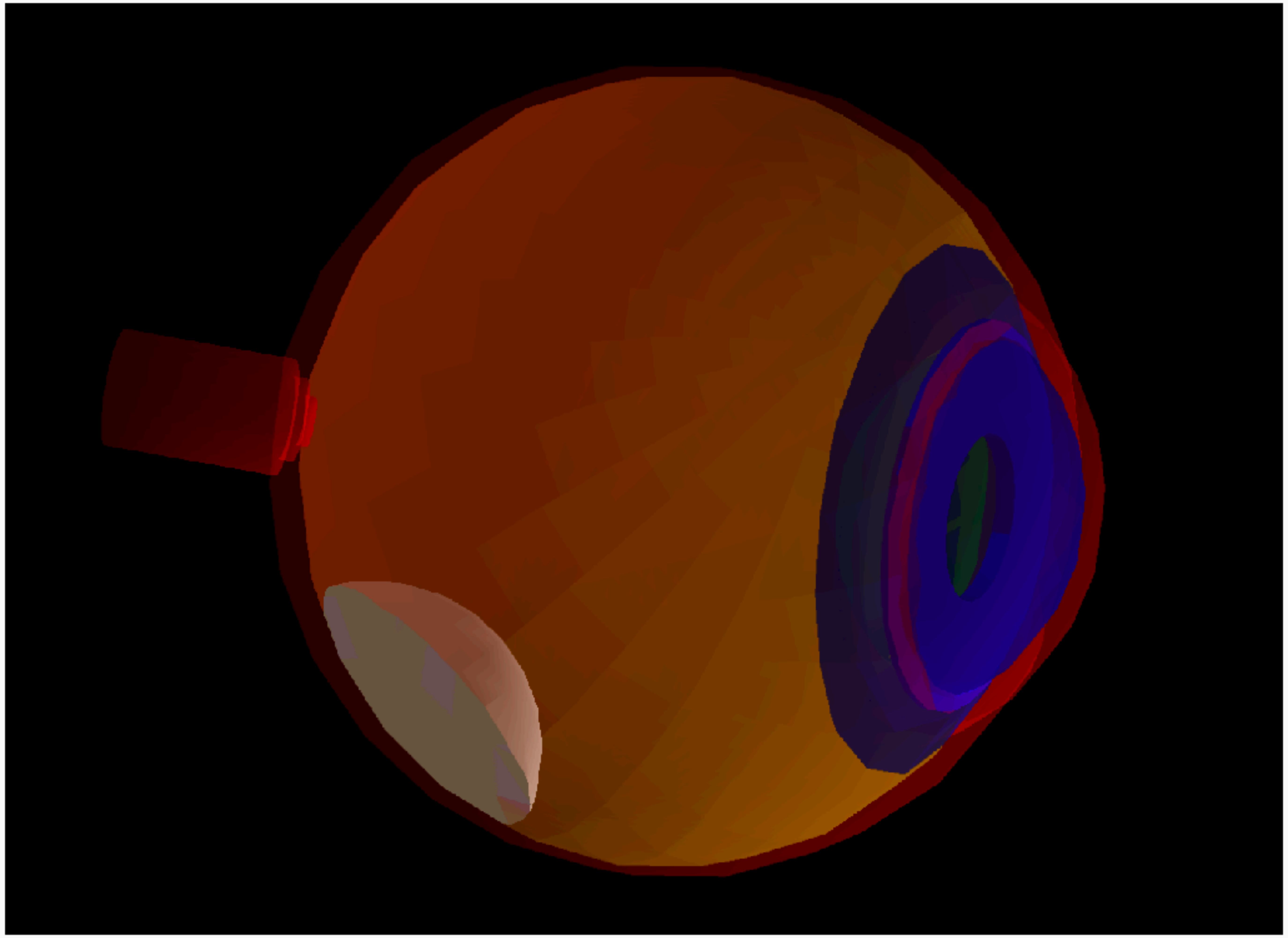
Pre-Built Complex Components



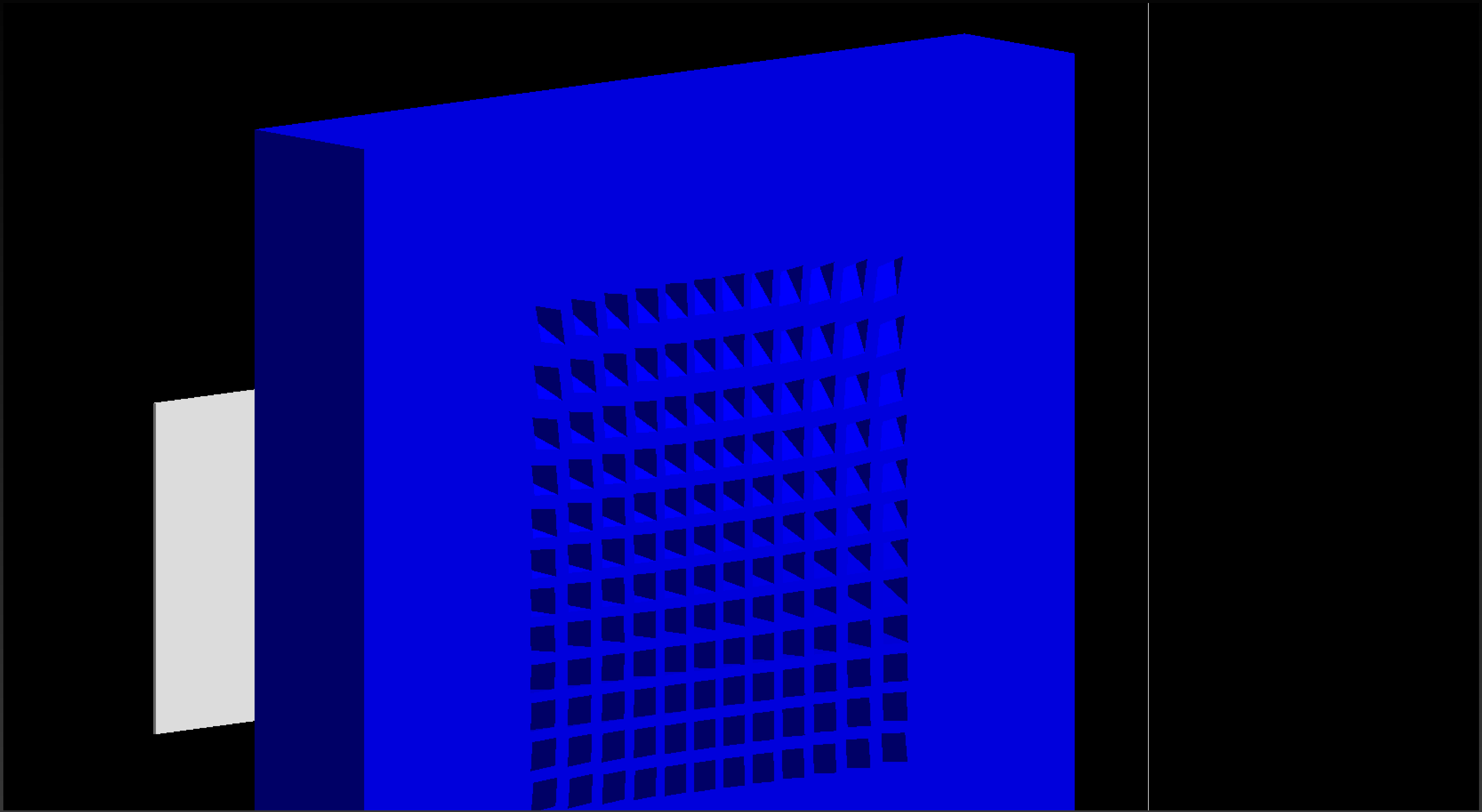
Pre-Built Complex Components

Eye Model

The TsEye component provides a configurable model of the human eye.



Complex Collimator



These Geometry Components are the Only place TOPAS keeps geometrical information

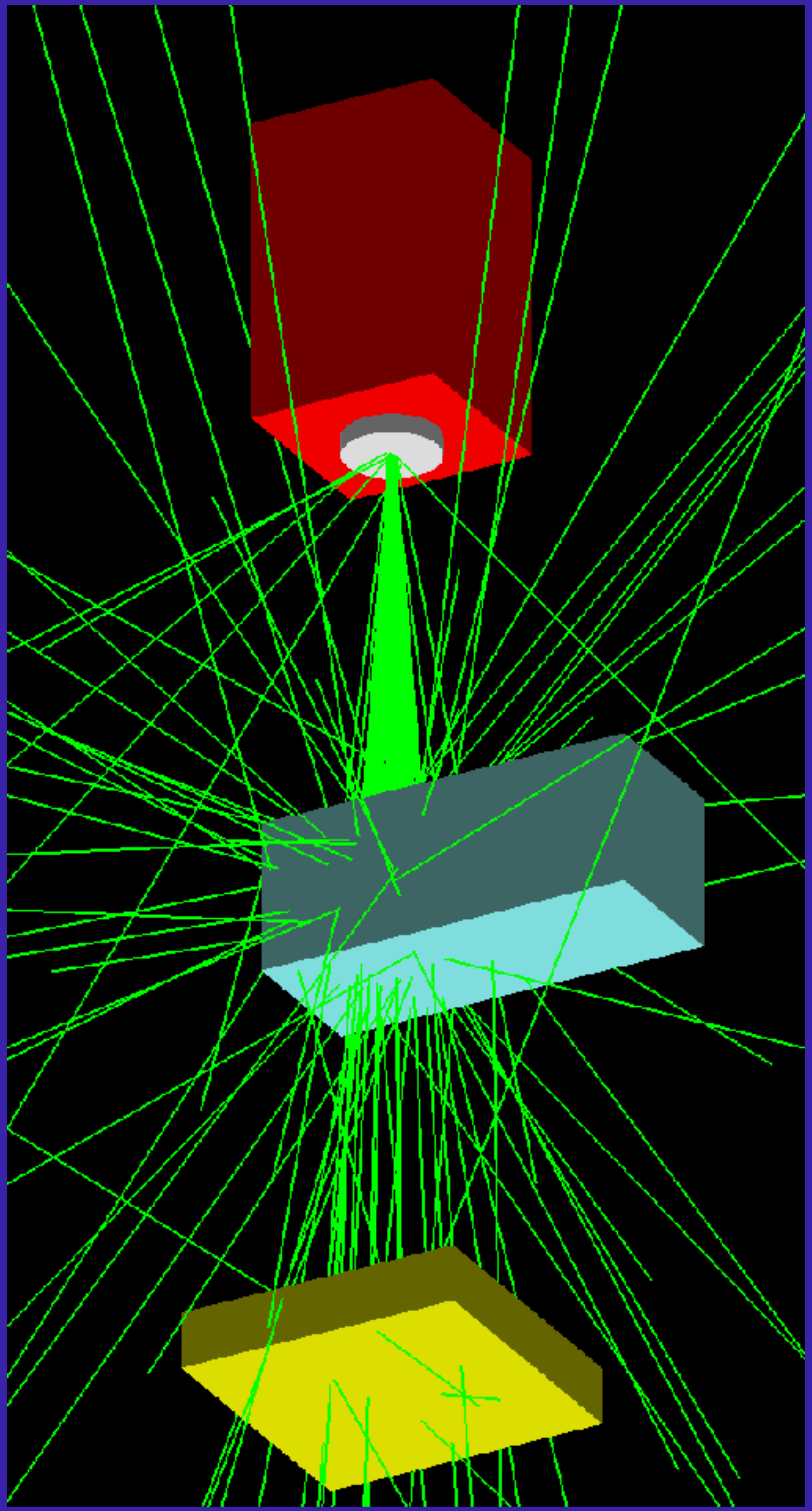
- Particle sources starting positions
- Scorers sensitive volumes
- Variance Reduction Technique boundaries
- Field extents

Geometry Component defines where a Particle Source Begins and how it is Directed

s:Ge/XRayExitWindow/Type = "TsCylinder"
s:Ge/XRayExitWindow/Parent = "XRaySystem"
s:Ge/XRayExitWindow/Material = "G4_Ti"
d:Ge/XRayExitWindow/RMax = 5. mm
d:Ge/XRayExitWindow/HLZ = 0.05 mm

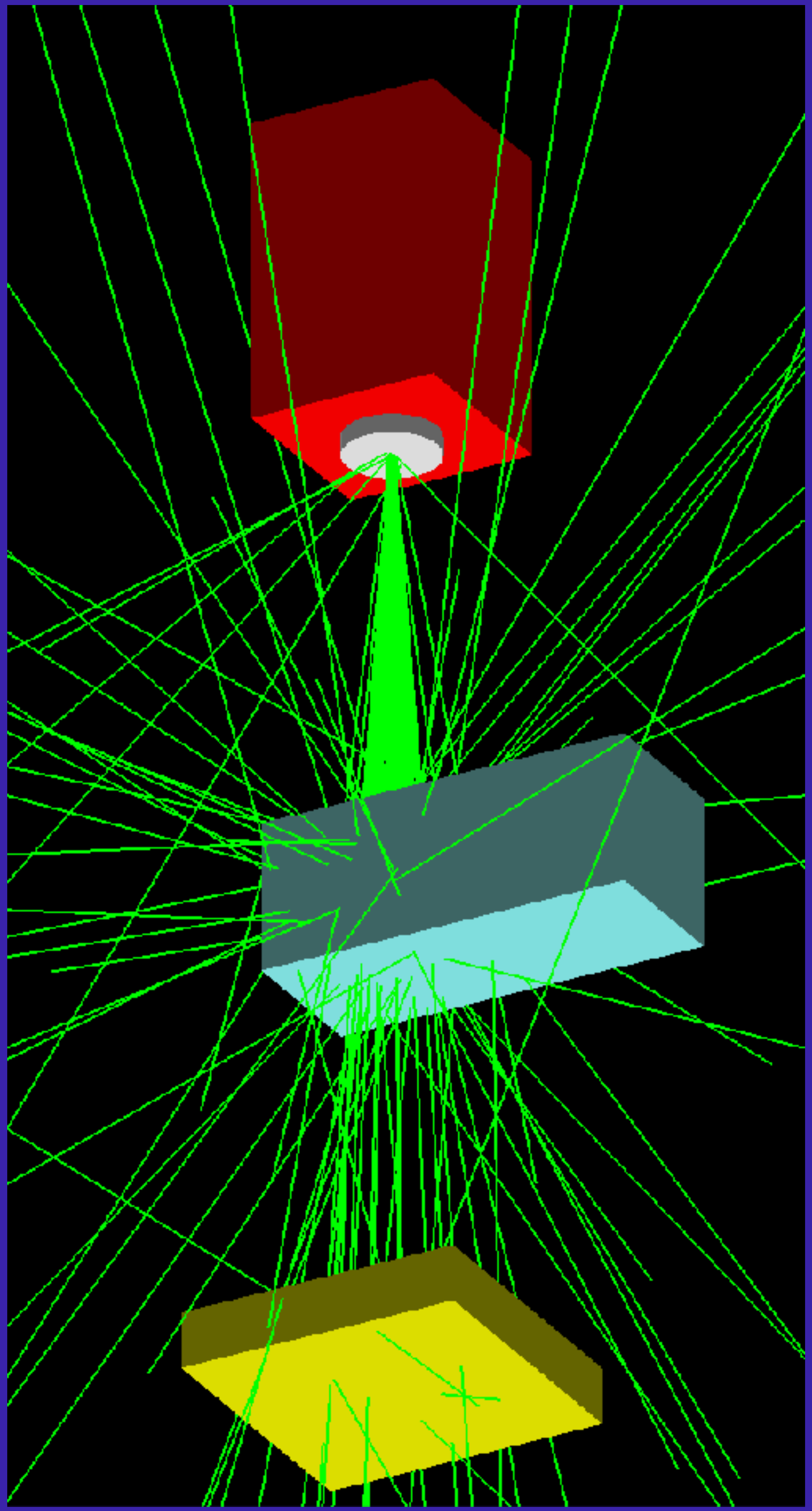
s:So/LinacBeam/Type = "Beam"
s:So/LinacBeam/Component = "XrayExitWindow"

To Rotate the Beam, adjust:
d:Ge/XRaySystem/RotX
d:Ge/XRaySystem/RotY
d:Ge/XRaySystem/RotZ
d:Ge/XRaySystem/TransX
d:Ge/XRaySystem/TransY
d:Ge/XRaySystem/TransZ



Geometry Component defines where a Scorer will be Sensitive

```
s:Ge/Phantom/Type      = "TsBox"
s:Ge/Phantom/Parent    = "World"
s:Ge/Phantom/Material = "G4_WATER"
d:Ge/Phantom/HLX       = 10.0 cm
d:Ge/Phantom/HLY       = 10.0 cm
d:Ge/Phantom/HLZ       = 20.0 cm

s:Sc/MyScorer/Quantity = "DoseToMedium"
s:Sc/MyScorer/Component = "Phantom"

s:Sc/Scorer2/Quantity = "SurfaceTrackCount"
s:Sc/Scorer2/Surface = "Phantom/ZPlusSurface"
```



Geometry Component defines where a Magnetic or Electric Field will be created

```
s:Ge/SomeComponent/Type          = "TsBox"
s:Ge/SomeComponent/Parent        = "Nozzle"
s:Ge/SomeComponent/Material      = "G4_AIR"
d:Ge/SomeComponent/HLX           = 10 cm
d:Ge/SomeComponent/HLY           = 10 cm
d:Ge/SomeComponent/HLZ           = 20 cm
s:Ge/SomeComponent/Field = "DipoleMagnet"
u:Ge/SomeComponent/MagneticFieldDirectionX    = 0.0
u:Ge/SomeComponent/MagneticFieldDirectionY    = 1.0
u:Ge/SomeComponent/MagneticFieldDirectionZ    = 0.0
d:Ge/SomeComponent/MagneticFieldStrength      = 3.0 tesla
```

Particle Sources

Specialized for Medical Physics

- Beam
- Emittance (parameterized in Twiss space)
- Isotropic
- Volumetric - Brachytherapy
- Distributed - Nuclear Medicine
- Environment
- Phase Space
- No GPS

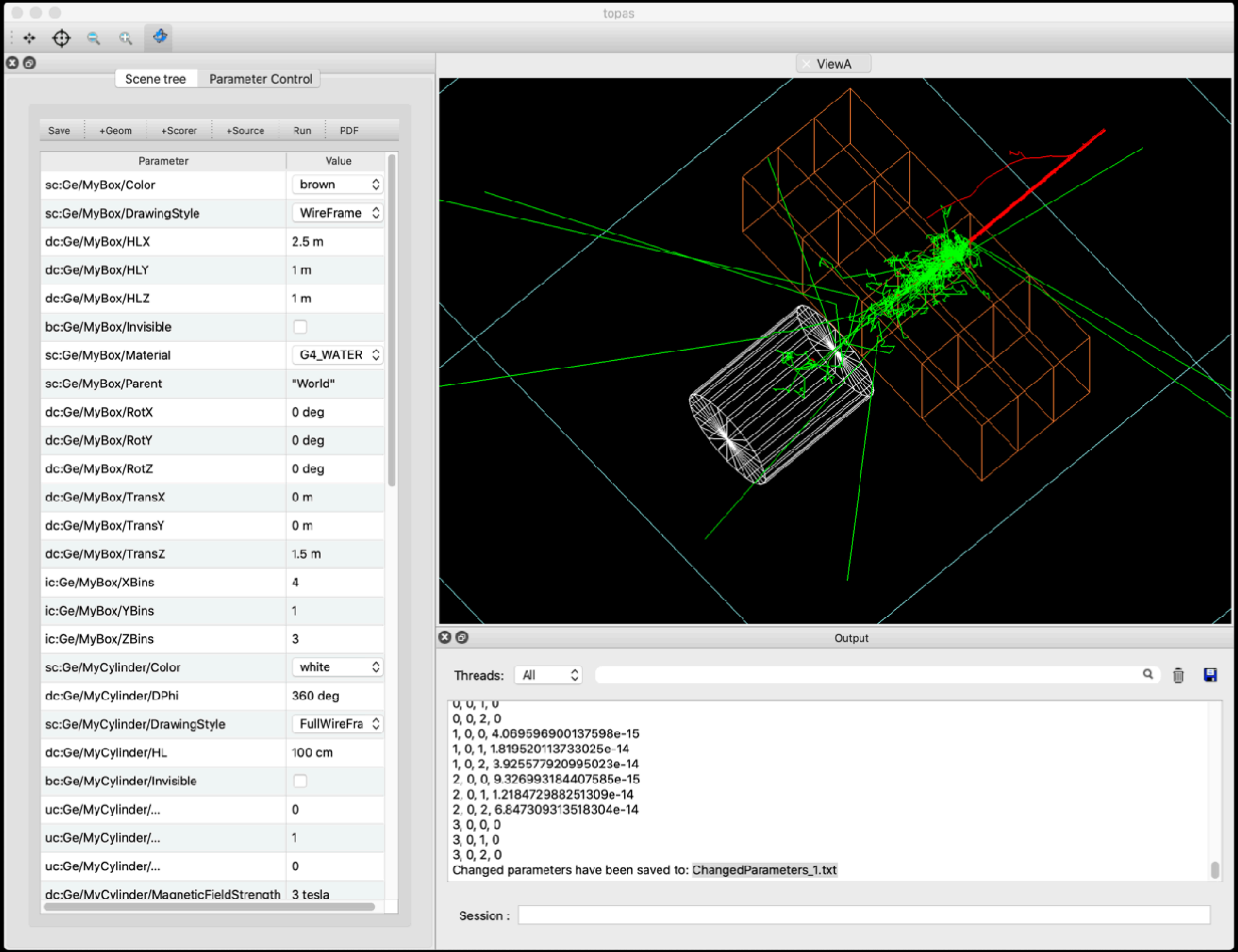
Scoring: Not the standard Geant4 paradigm

- Based on G4MultifunctionalDetector, but everything else replaced
- Not the Geant4 command-based scoring system
- All geometry is deferred to the Geometry Component
- Every Scorer works with Every Geometry Component
- Many different reporting options
- Binning by energy, time, motion...
- Statistics calculated on a running basis, history by history

Filtering: Not the standard Geant4 paradigm

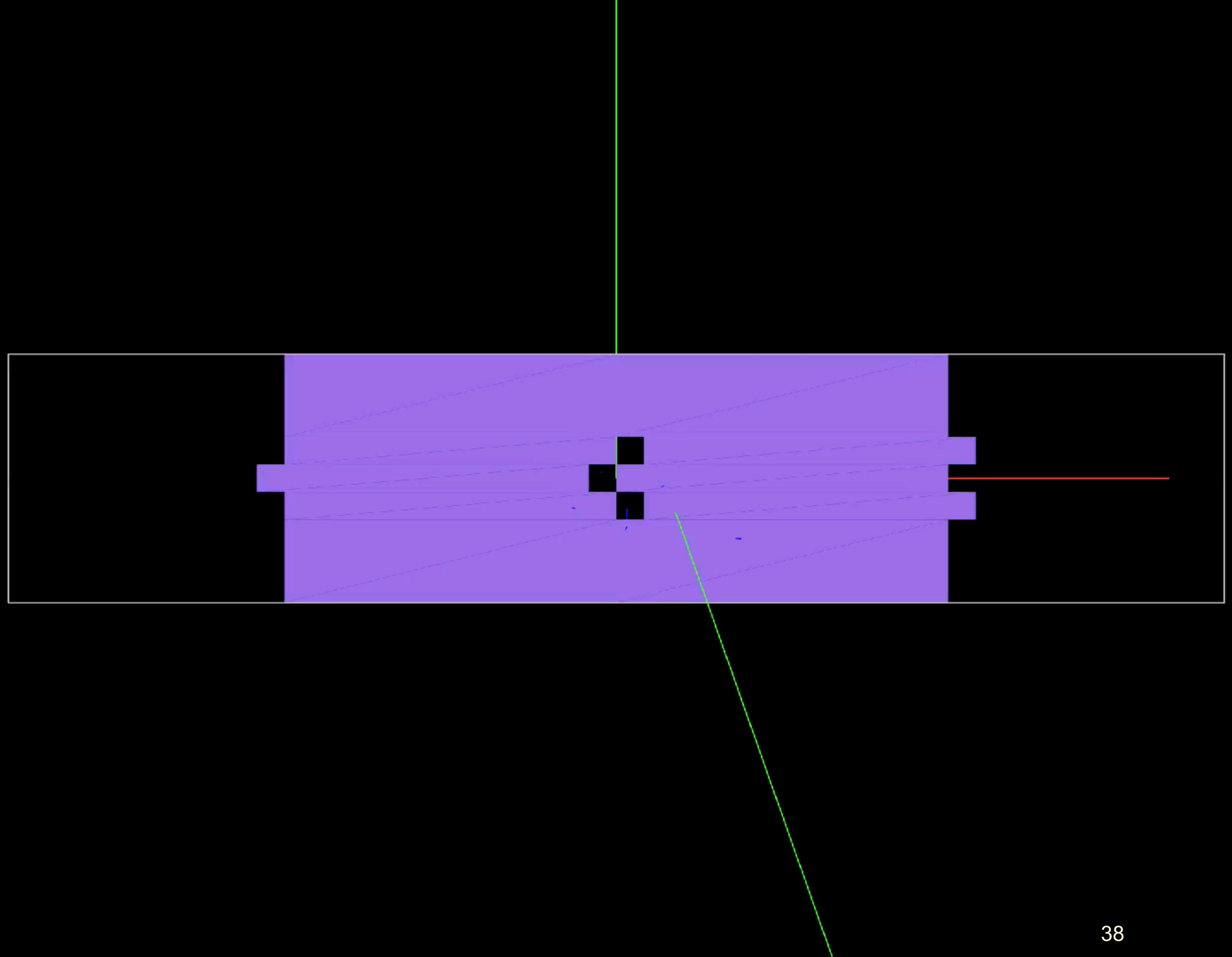
- Filters can be chained
- Every filter supports every scorer
- Filters apply to Particle Sources as well as to Scorers

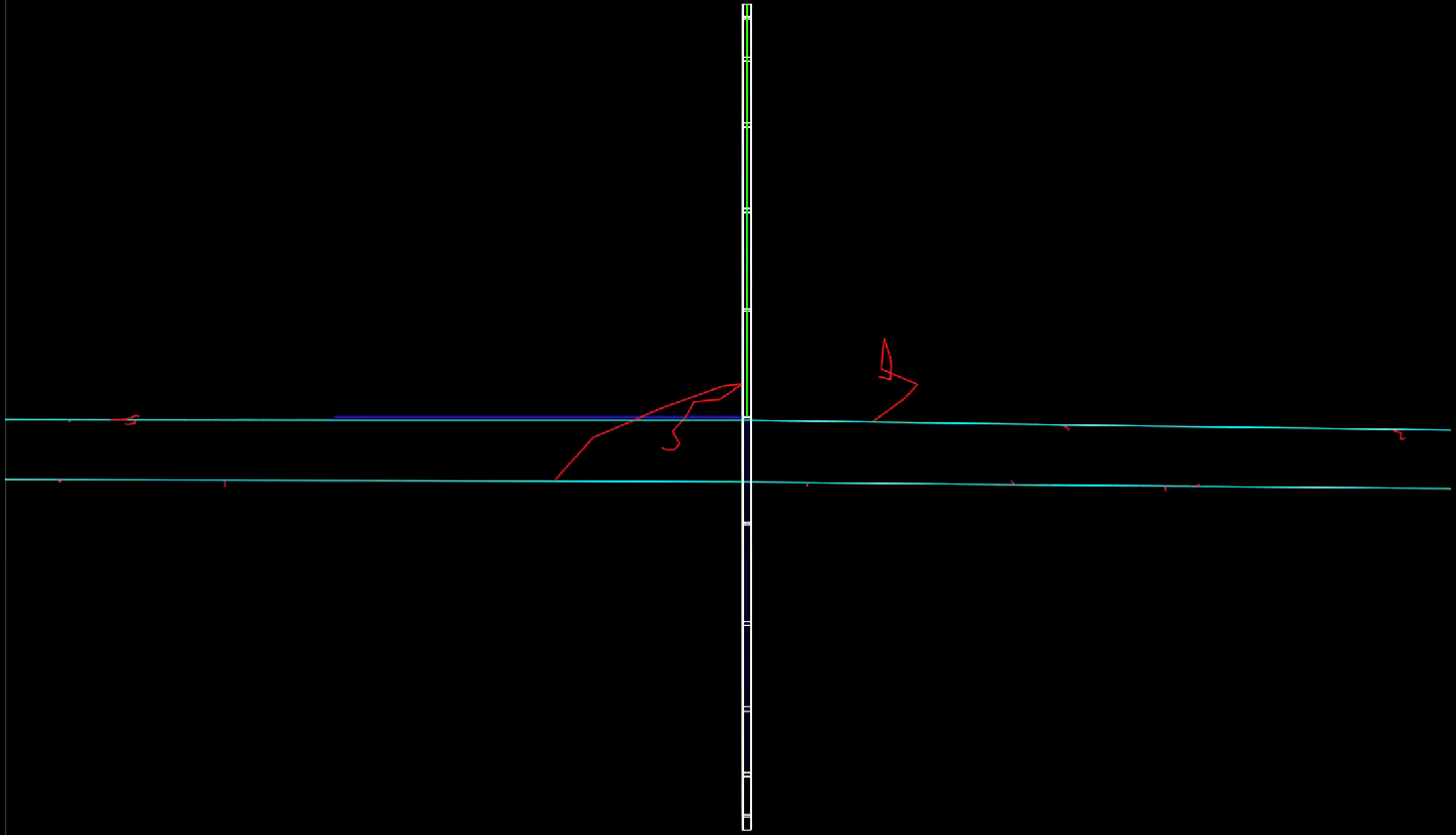
GUI for Rapid Prototyping

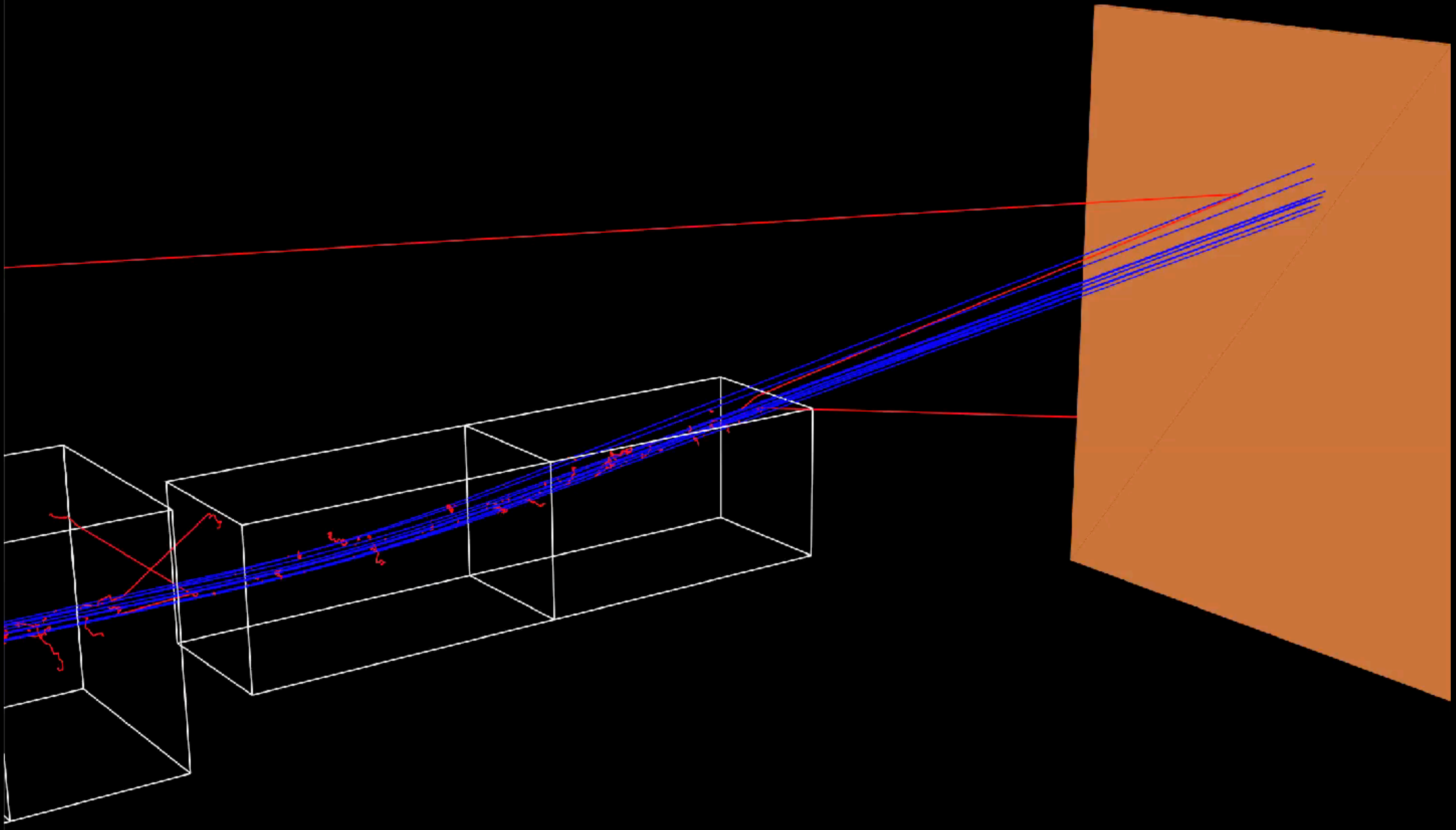


4D Everywhere

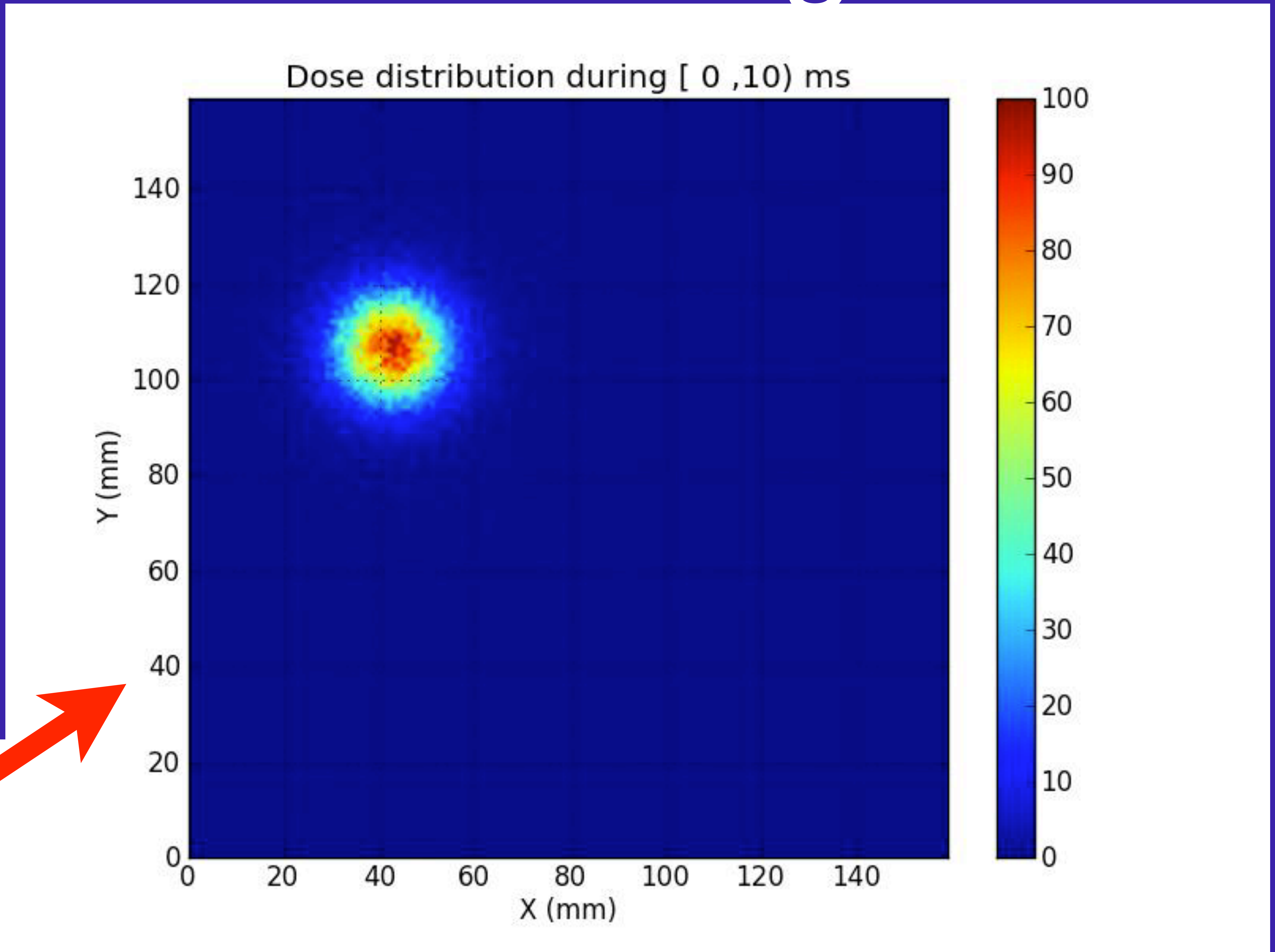
4D in motion
4D in component size
4D in magnetic and electric fields
4D in source position, characteristics and beam current
4D in VR, splitting planes, directional biasing, etc.
4D in scoring
4D in visualization

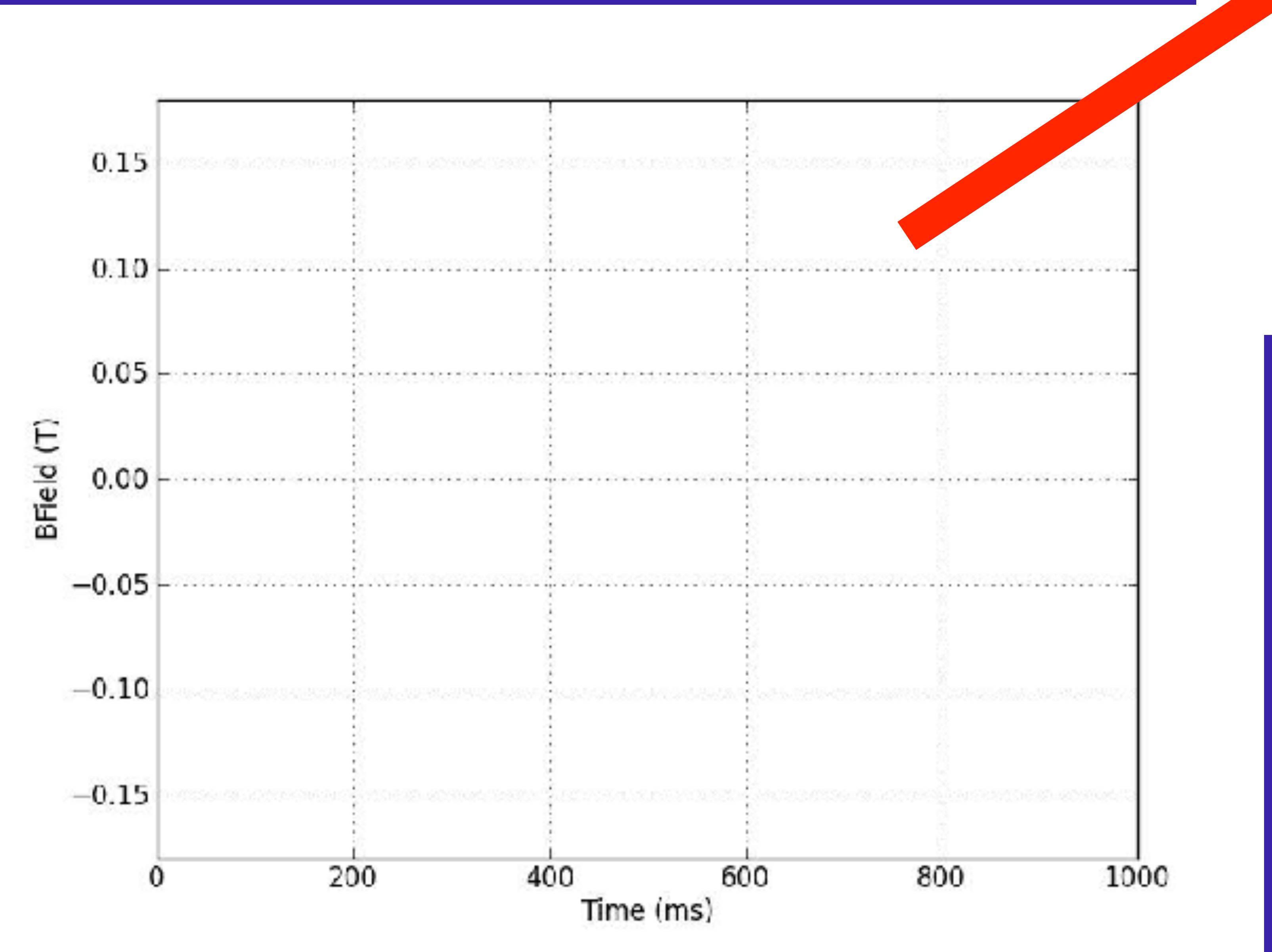






Simple Raster Scanning





Fully Multithreaded

TOPAS exploits the full Multithreaded capability of Geant4.
Our users can trivially adjust any TOPAS simulation to use dozens or even hundreds of threads on a single computing node.

Work is automatically distributed among the threads and results seamlessly collated.

Complex issues such as sharing a single phase space input file among multiple threads are handled without the user having to take any special action.

Just set a parameter:
i:Ts/NumberOfThreads = 8 # How many threads to use

i:Ts/NumberOfThreads = 0 # We'll ask your hardware what it's max is

i:Ts/NumberOfThreads = -2 # We'll use all but 2 threads

Designed for Portability and Integration

- Open Source using the most permissive license model

- Limited dependencies
- Runs on any common desktop, cluster or cloud
- Easily driven from scripts

Three Modes of User Engagement

- Standard Users
  Prebuilt executables, all user work is through parameter control files
- Extensions Developers
  Able to extend TOPAS by writing small amounts of C++
- Open Source Community
  Open Source Initiative MIT License

TOPAS Extensions System

Outlook

- Our current funding ran out May 2023
- Geant4.11 update was in progress when funding ended. Postponed until new funding.
- Plans for cloud interface.
- Plans for extension builder as a cloud service.

- New NIH proposal is currently waiting review.
- Fingers Crossed

Try it for yourself

- Easy to install
  - topasmc.org
  - Warning for this group: install expects a clean environment

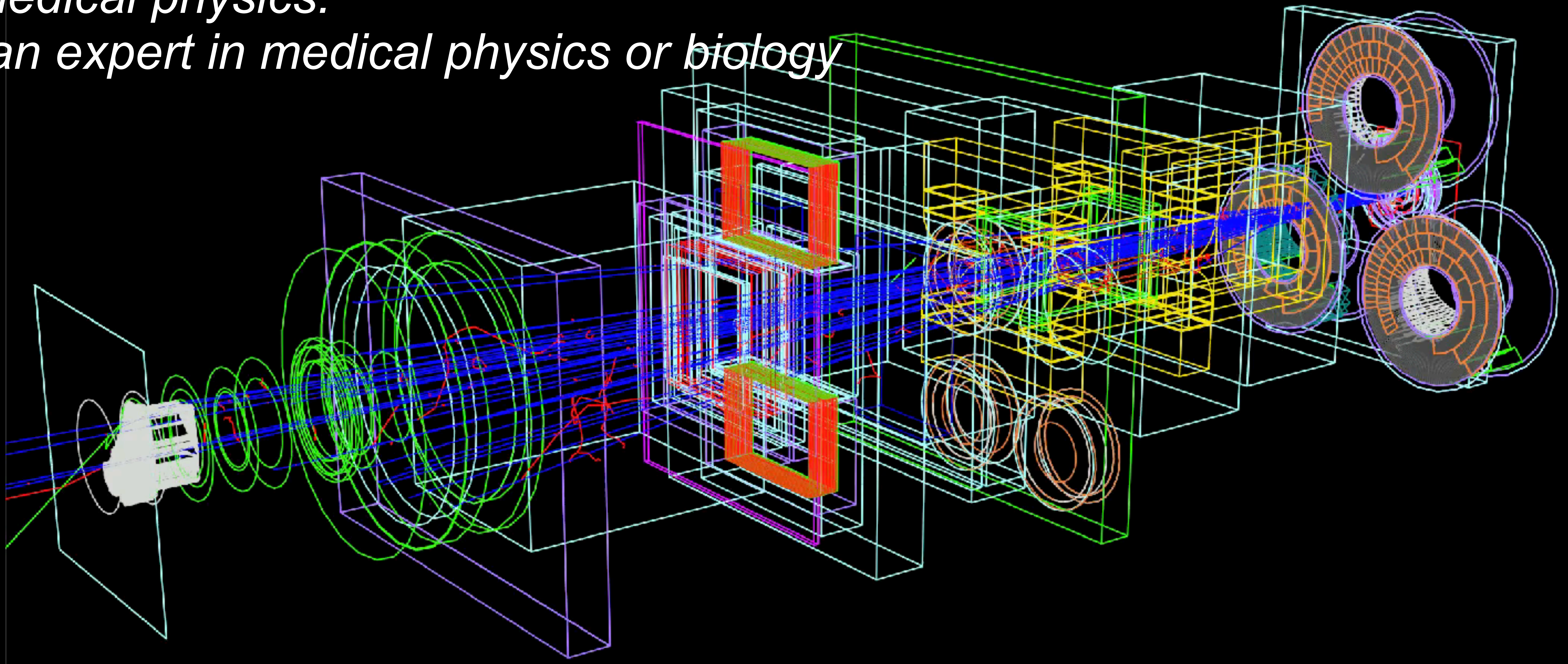
- Best way to start is to attend my Introduction to TOPAS zoom lecture
  - Lecture presented about once every 6 weeks
  - topasmc.org/registration
  - next is this Wednesday, Dec 13th, 9am Pacific

- Easy to delete if you don't like it

Tool for Particle Simulation

http://topasmc.org

To use Monte Carlo transport for radiation therapy research in the past, one had to be both an expert in Monte Carlo and an expert in medical physics.
With TOPAS, it is sufficient to be an expert in medical physics or biology



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