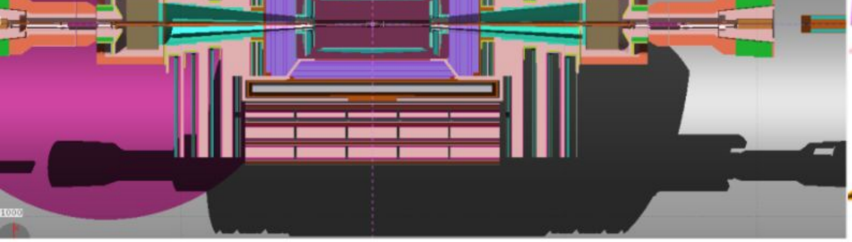
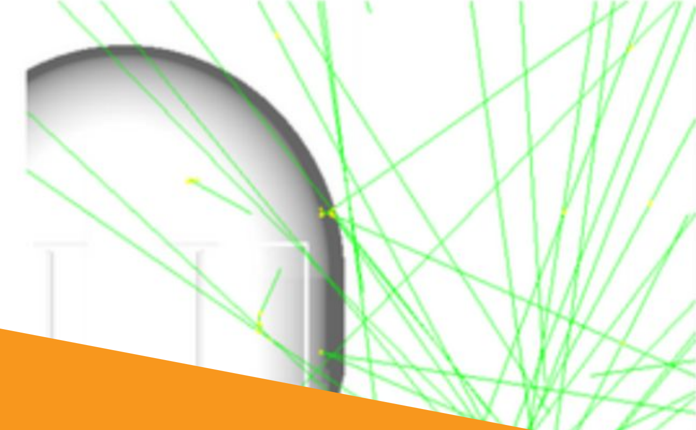
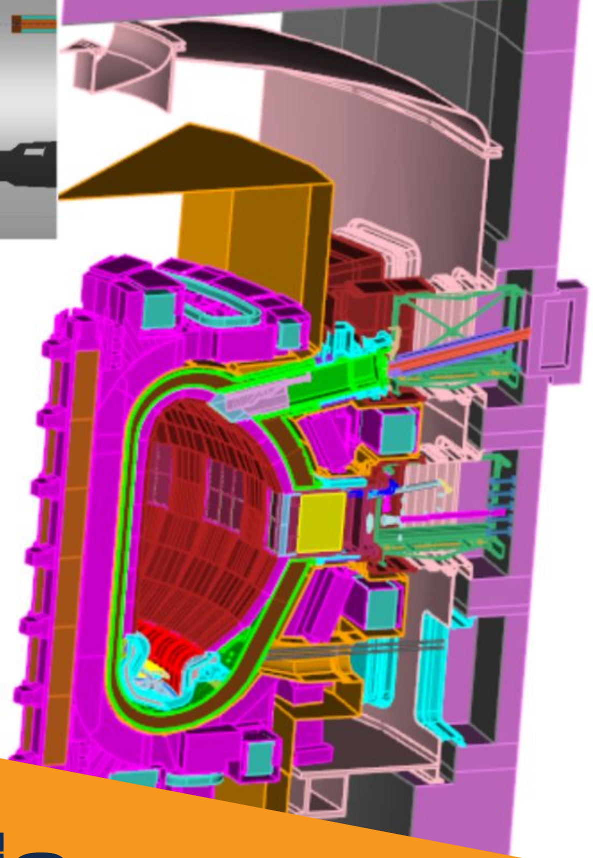
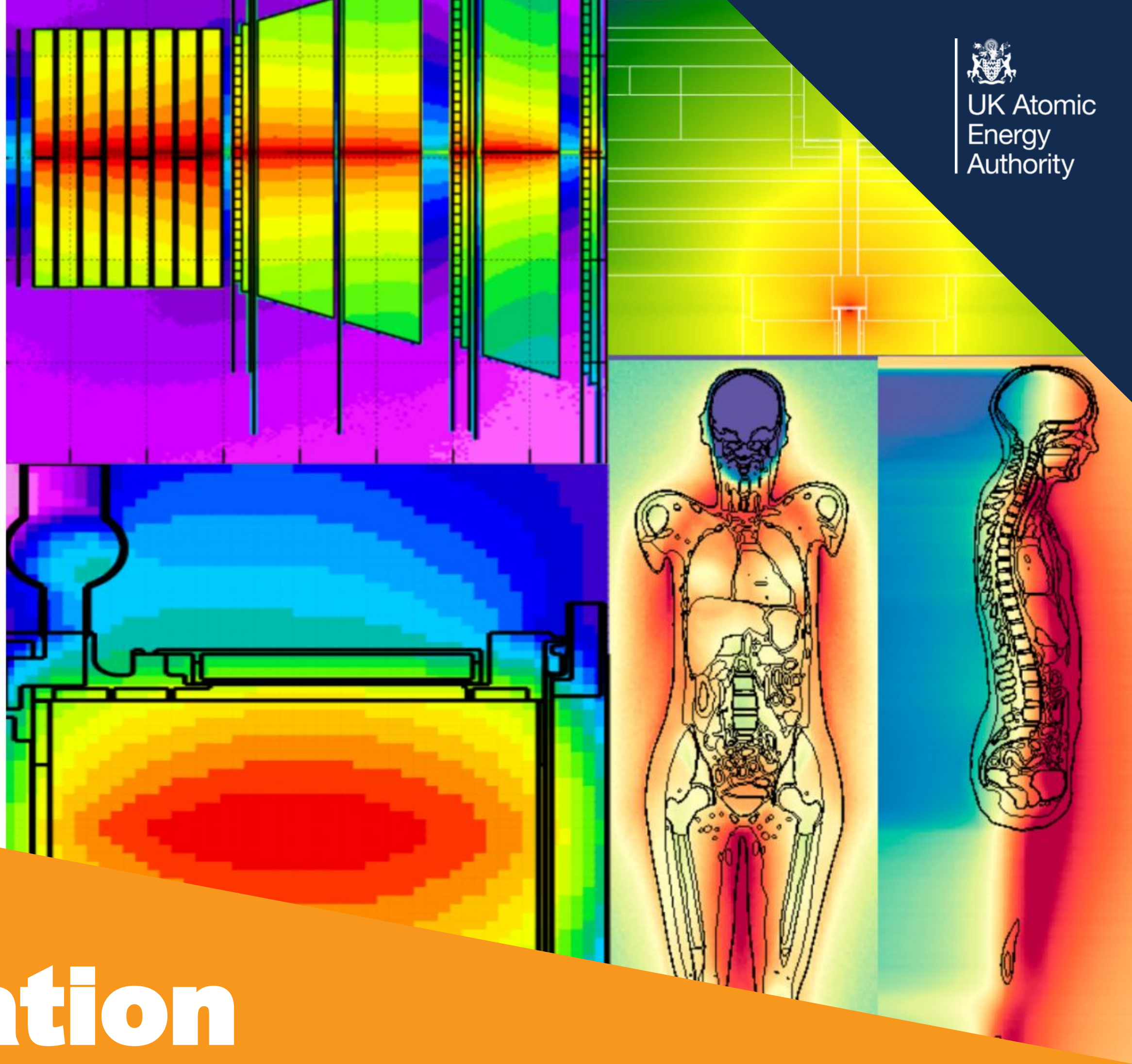

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Andrew Davis

CAD/Mesh Based Radiation Transport

Culham Centre for Fusion Energy

European Commission

Energy

Contract for the Operation of the JET Facilities Co-Funded by Euratom
This work was funded by the RCUK Energy Programme [Grant number EP/P012450/1]

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Contents

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- Introduction
    - Monte Carlo Analysis, What is DAGMC, Users, Theory
- Fusion Examples
    - MCNP5 and MCNP6 Examples
- Fission Example
    - Space Reactor
- High Energy Physics Examples
    - nTOF, Space Radiation
- Non Traditional Examples
    - Mesh based models

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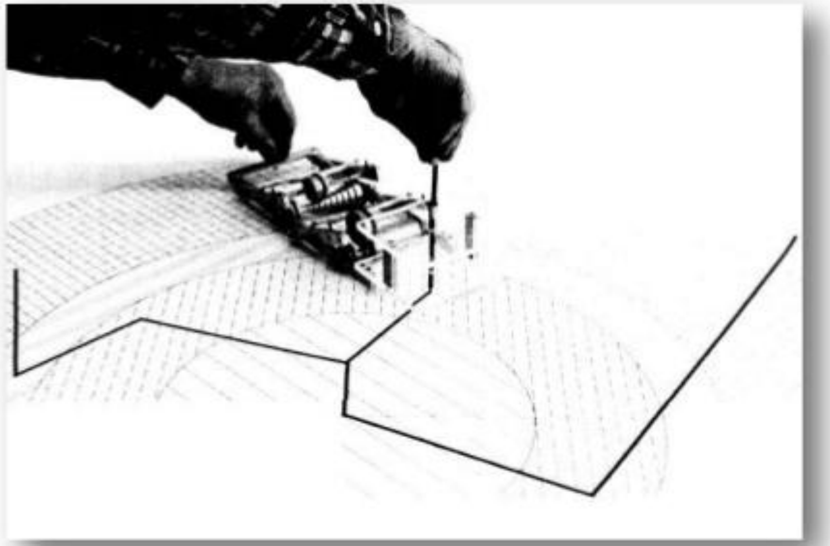
Monte Carlo Analysis

- Monte Carlo analysis was born in the Manhattan Project
- Von Neumann, Metropolis, and Fermi
- We define materials in regions of model, these regions have interaction probabilities, random numbers used to sample
- Traditionally we define regions using combinations of quadratic surfaces united with boolean operations

Let's Apply a Monte Carlo Simulation Tool



The Monte Carlo trolley, or FERMIAC, was invented by Enrico Fermi and constructed by Percy King. The drums on the trolley were set according to the material being traversed and a random choice between fast and slow neutrons.

Another random digit was used to determine the direction of motion, and a third was selected to give the distance to the next collision. The trolley was then operated by moving it across a two dimensional scale drawing of the nuclear device or reactor assembly being studied.

The trolley drew a path as it rolled, stopping for changes in drum settings whenever a material boundary was crossed. This infant computer was used for about two years to determine, among other things, the change in neutron population with time in numerous types of nuclear systems.

33

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CAD Based Workflows

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- CAD is desirable as a source of geometry for Monte Carlo calculations for several reasons
  - Allows very complex models to be represented (fidelity,accuracy)
  - Produced for manufacturing purposes (provenance)
  - User friendly, easier to fix and modify than CSG (effort)
  - Faster analysis turn around (efficiency)
- CAD model integrity - “cleanliness”
- Several routes for use:
  - Translation - MCAM, McCAD, FastRAD, CATIA-GDML
  - Directly - DAGMC
  - Hybrid - OiNK

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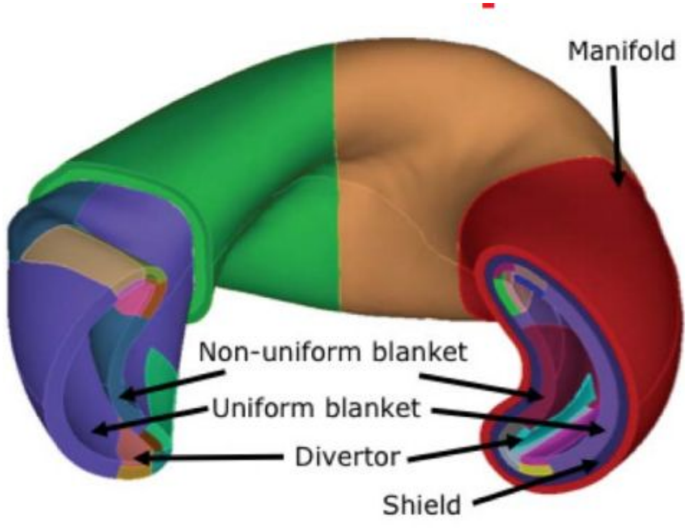
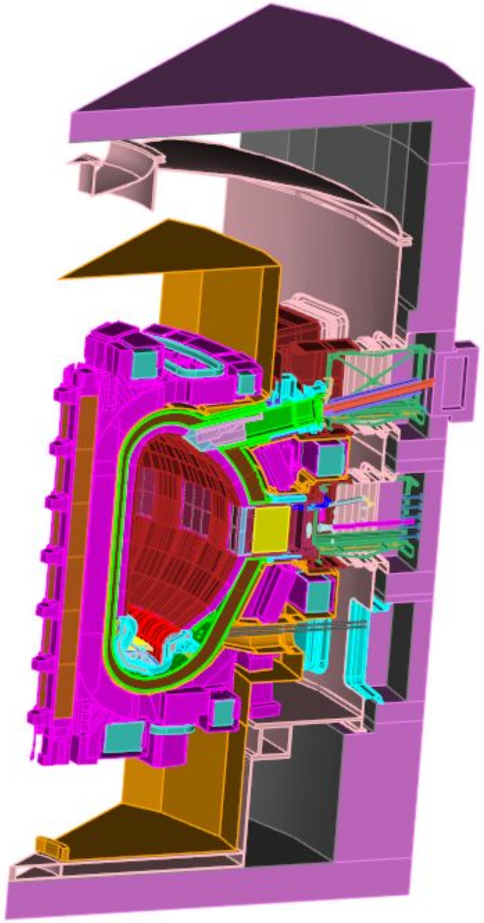
CAD Based Workflows

- Automation (including translation) provides:
  - Reduced human effort
  - Increased quality assurance
  - Direct geometry use provides **richer surface** representation
  - Facilitates coupling to other analysis types through common geon





What is DAGMC?

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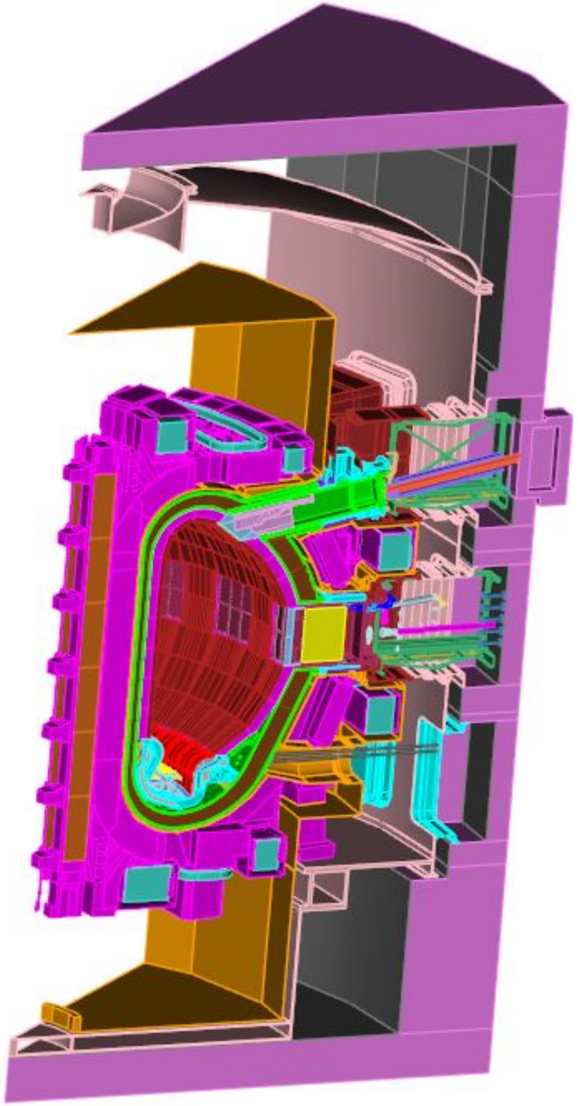
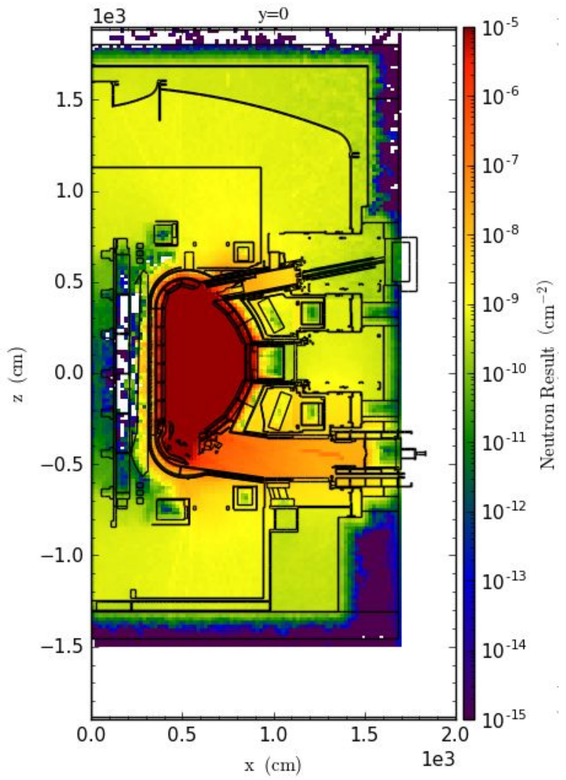
- DAGMC (http://svalinn.github.io/DAGMC) is an open source toolkit that allows a user to transport particles on CAD based geometries
- Developed by the Computational Nuclear Energy Research Group (CNERG - http://cnerg.github.io/) at the University of Wisconsin-Madison (and since I’m at UKAEA now) and UKAEA
- Its purpose is to enable particle transport on very detailed and complex geometries, by having a core geometry library which can be plugged into any Monte Carlo code





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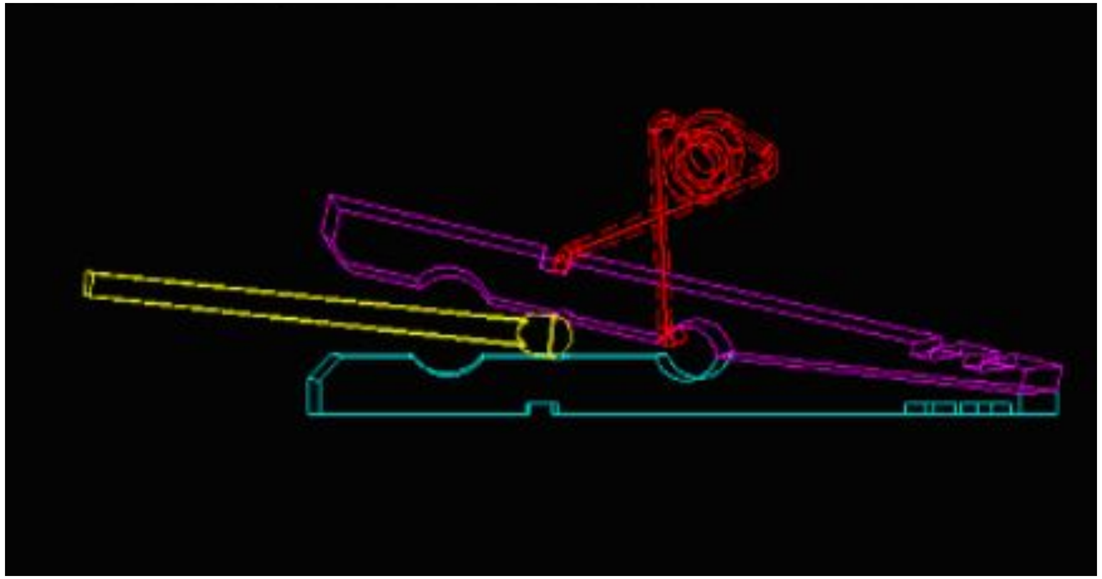
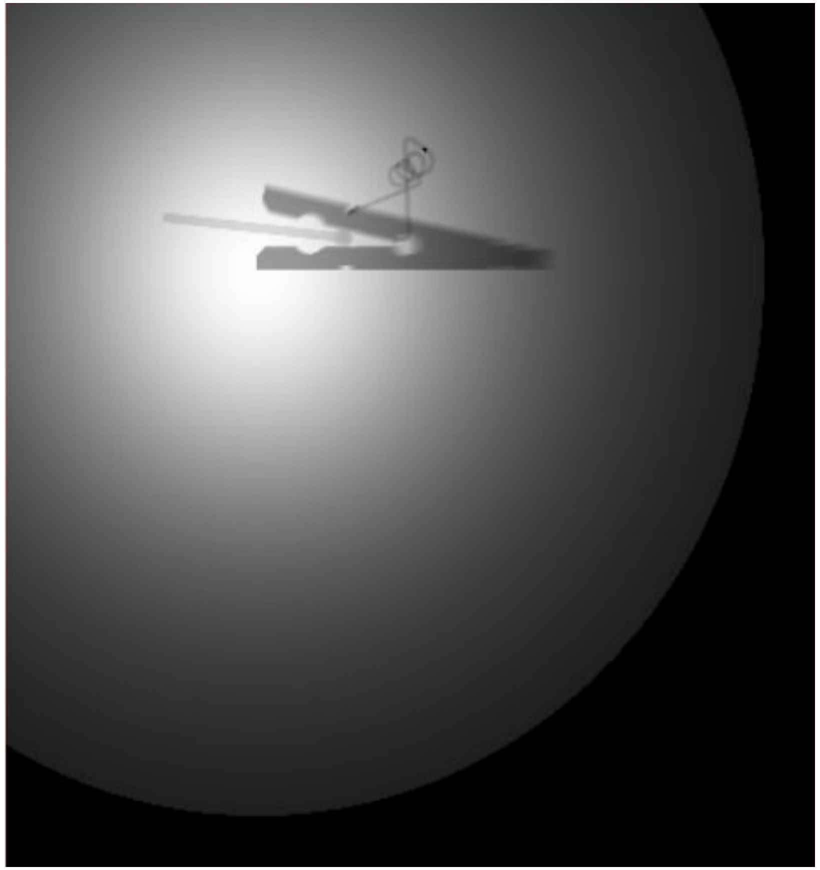
What is DAGMC?

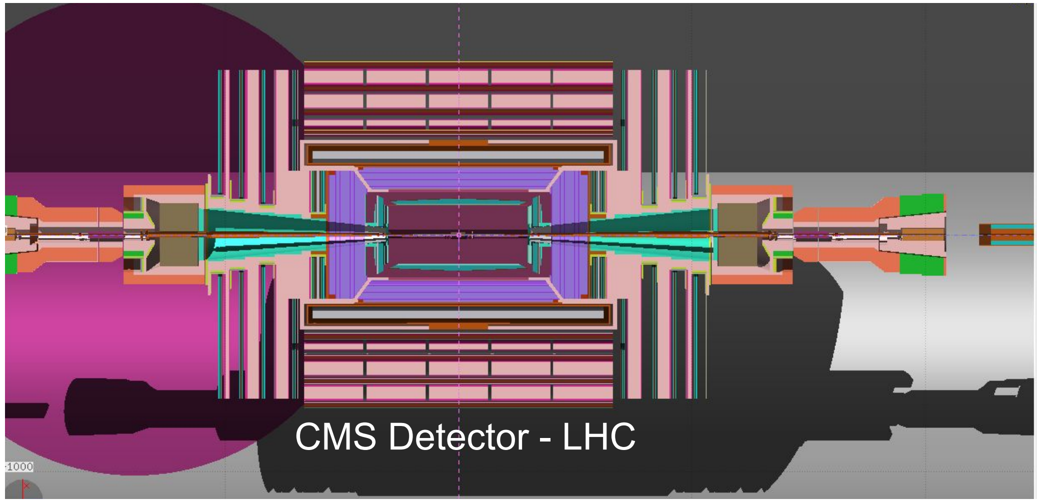
- Direct Accelerated Geometry Monte Carlo (DAGMC) started in 2001 (proof of principle by 2004) integrated directly into MCNP/X and tied directly into a CAD engine



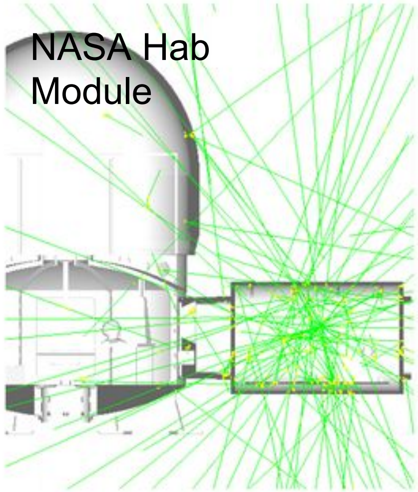


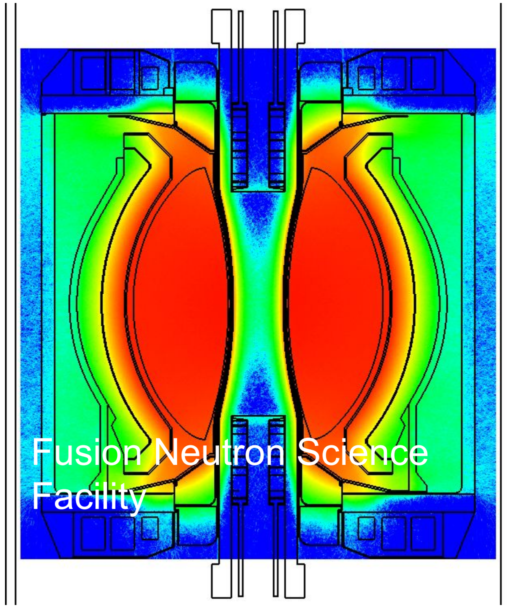
Example use, Clothes peg defined in CAD with spiral winding in clasp, Right MCNP/X radiograph

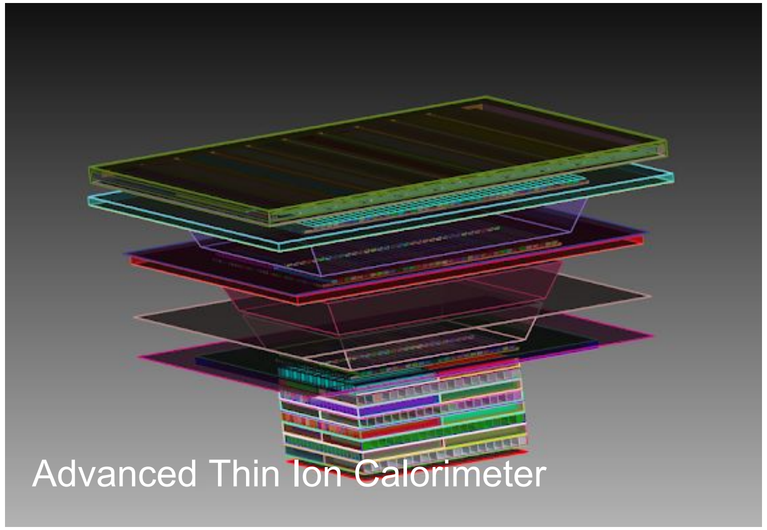
Examples of DAGMC Use


CMS Detector - LHC

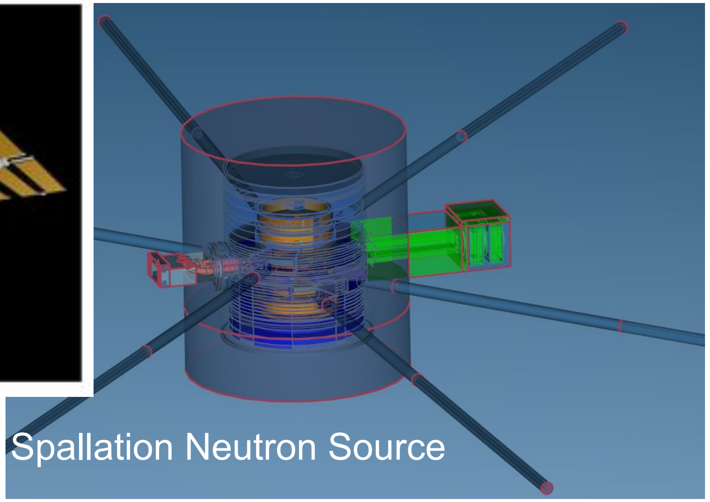

ATR


NASA Hab Module


Fusion Neutron Science Facility

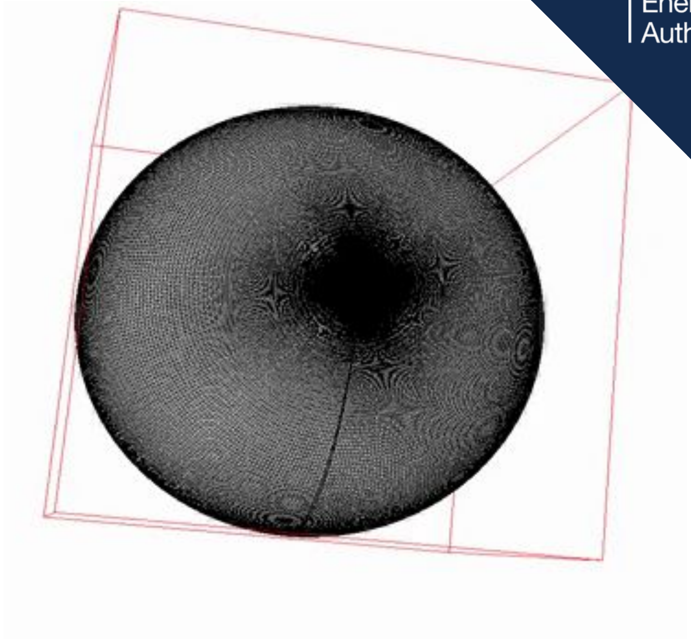

Advanced Thin Ion Calorimeter

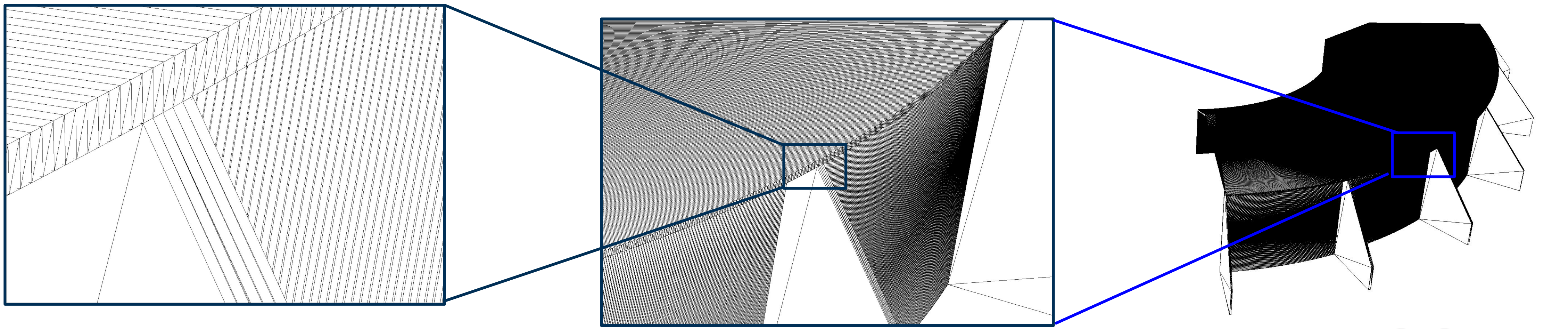

ISS


Spallation Neutron Source

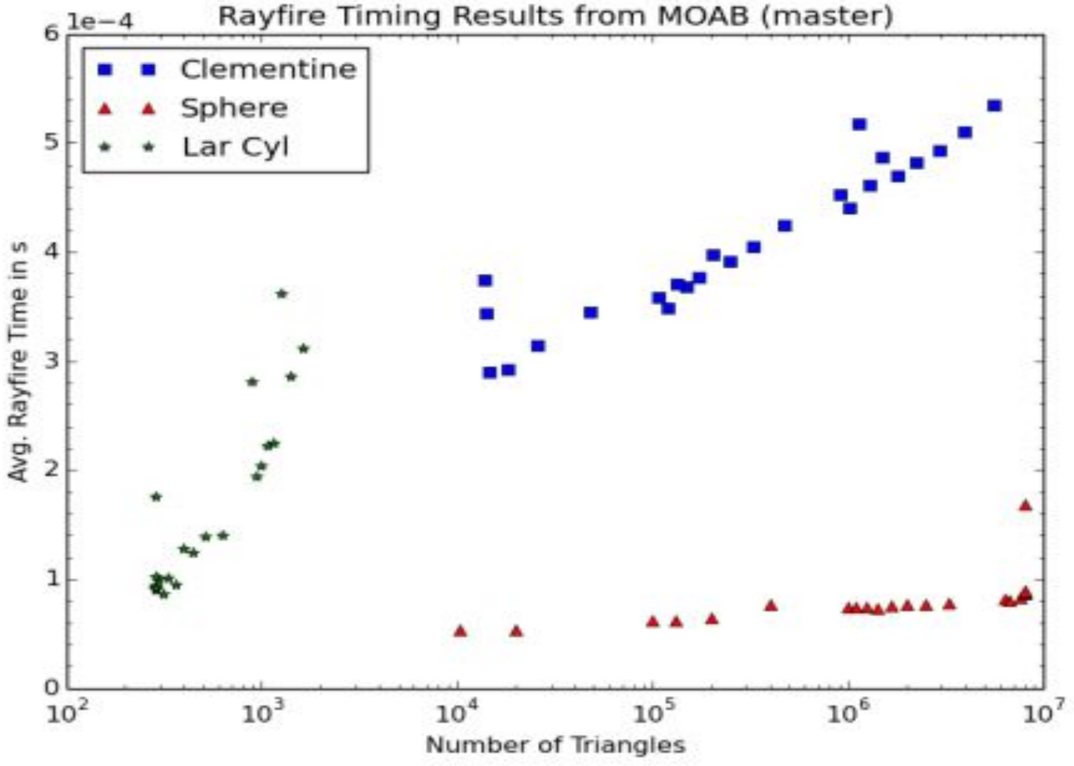
DAGMC Faceting

- Reduces ray tracing to always be on planar facets
  - introduces approximation
  - millions of facets
- Axis aligned bounding box often larger than needed
  - Oriented boxes make for smaller boxes
  - OBB on facets allow for finer granularity boxes

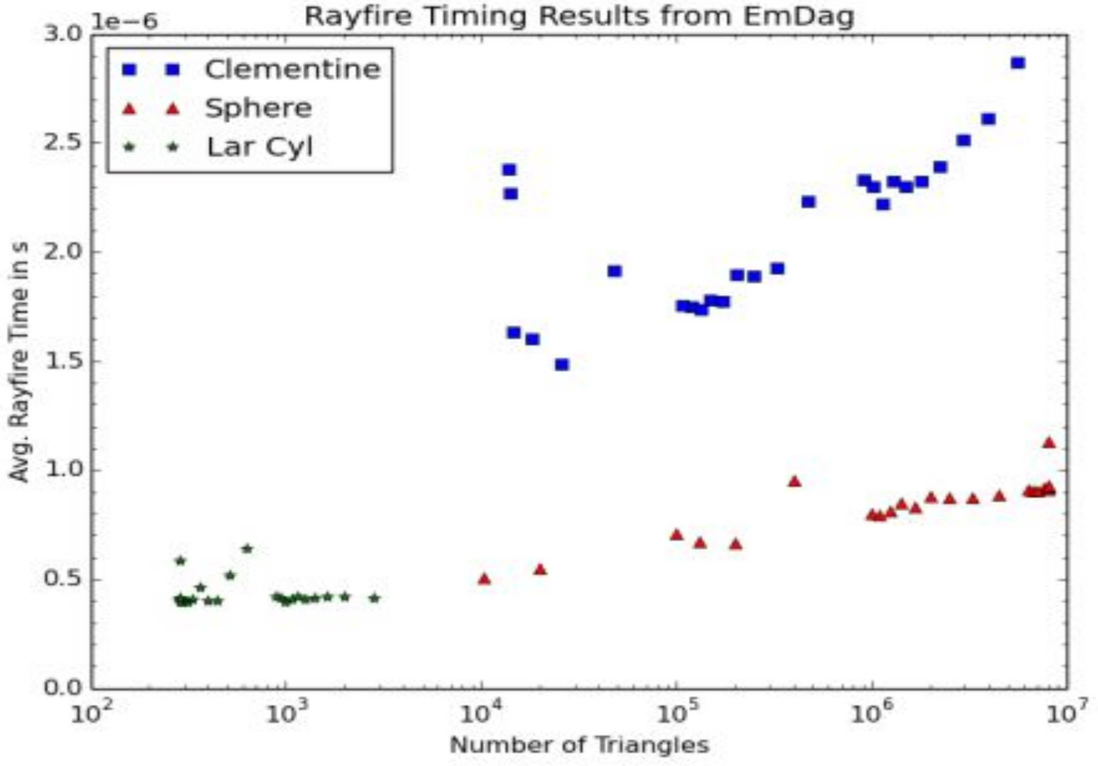




DAGMC Bounding Volume Hierarchy



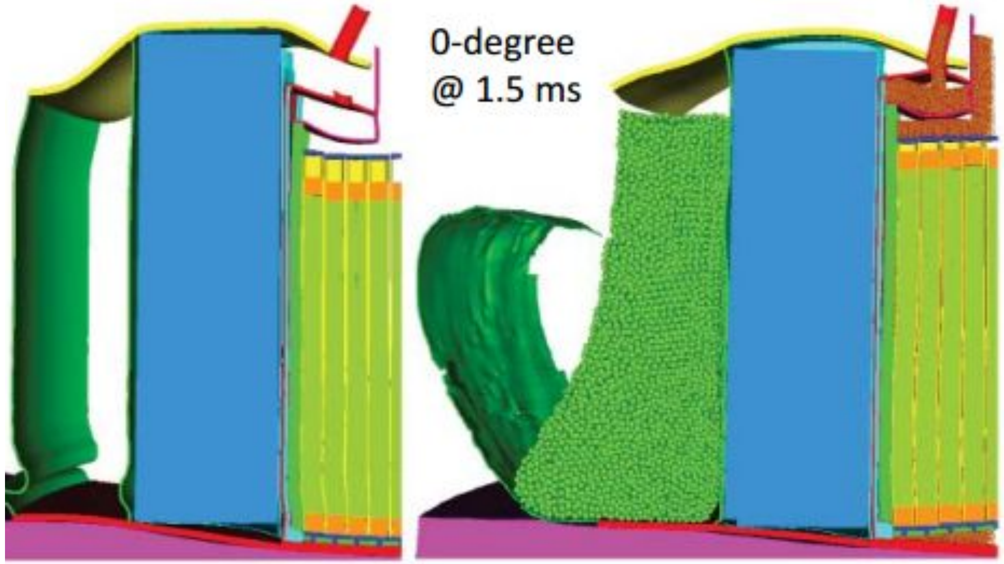
MOAB OBBs

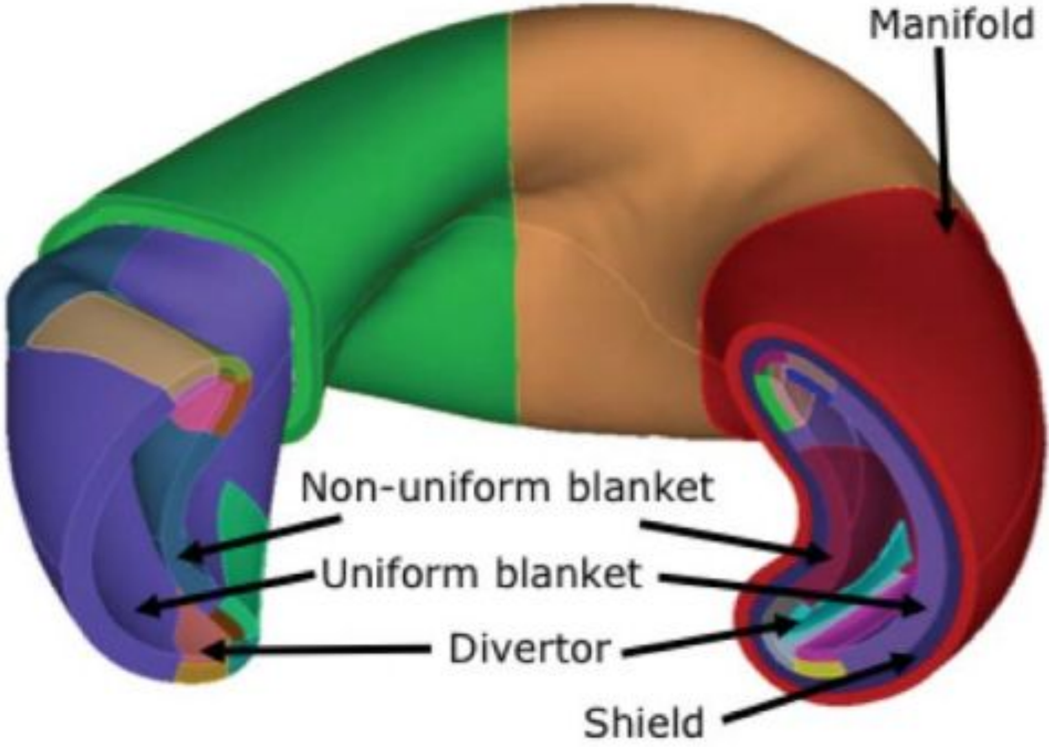


Embree AABB

DAGMC Advantages

- Richer surface description
  - Stellarator only possible to model in DAGMC - Andre Haussler (KIT)
- Implicit Complement
  - Complex negative space geometry not needed to be defined
- All volumes implicitly derived from triangle surface representation





- Tighter coupling to other physics
  - Facet based model can be deformed due to external input

Working with FE Mesh

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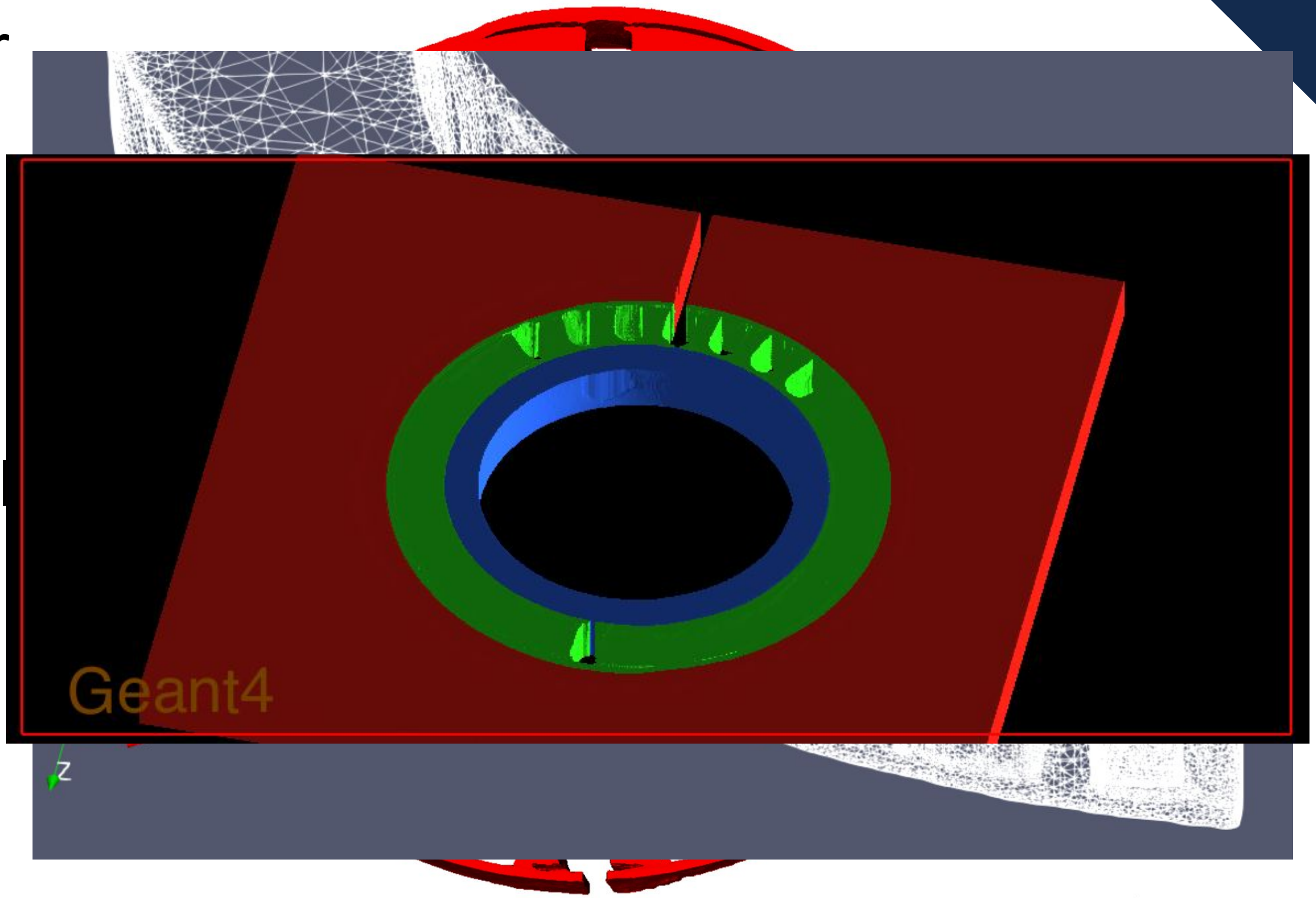
- Finite Element mesh is usually the product of CAD meshed geometry for engineering analysis : not ideal for radiation transport
    - Many additional wasteful boundary crossings
    - Limited precision text format
- Instead go through procedure optimal for radiation transport
    - For each material region
    - Skin the volumes
    - Create surface based entities
    - Transport



Extract the mesh belonging to a given material

Skin the mesh (generates surface mesh)

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DAGMC - Integration

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FLUKA

MCNP6

MCNP5

GEANT4

Tripoli4

Shift

Complete and Available

OpenMC

In Progress

EGSnrc

PHITS

Particle and Heavy Ion Transport code System

Serpent2

Proposed

13

Penelope

Mercury

MARS

Not Currently Planned

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DagSolid + Geant4 = DAGGeant4

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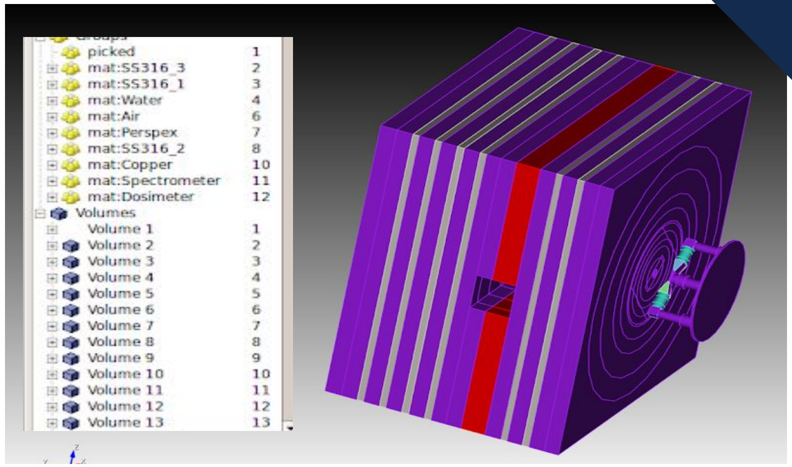
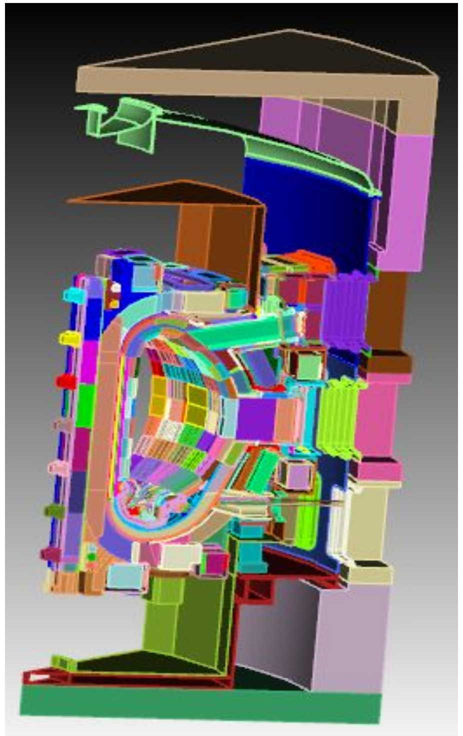
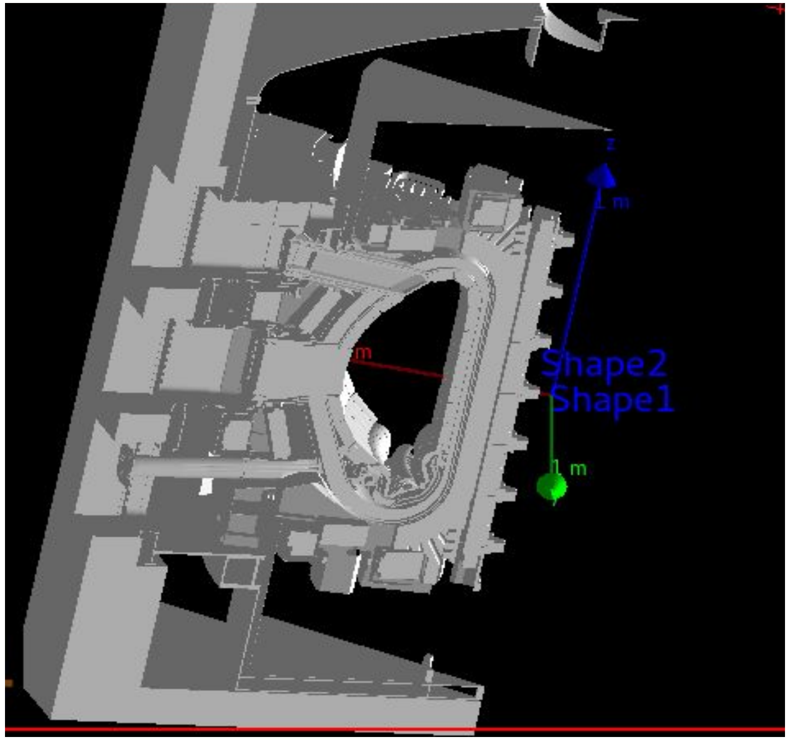
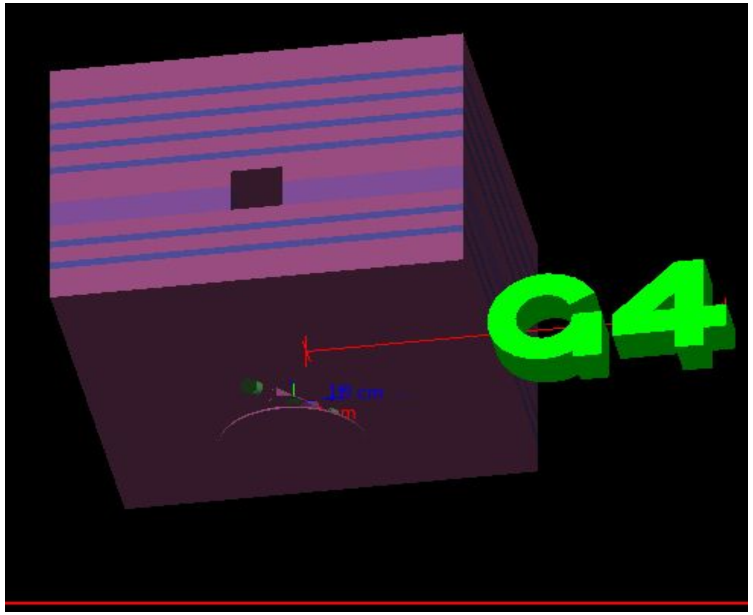


- Implementation of single Geant4 executable
  - Takes models in UW^2
  - Including tallies & materials
  - Cartesian scoring meshes are output in MOAB mesh *h5m
  - Not optimized for any one application







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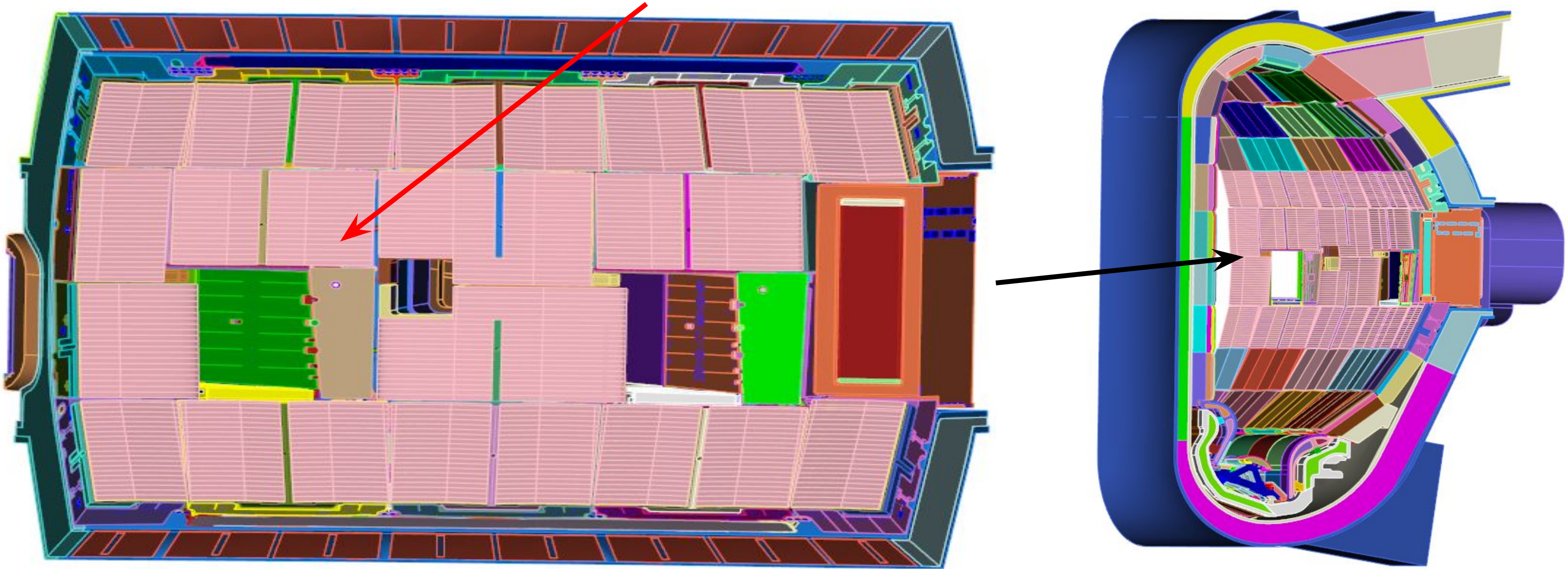
DAGMC Examples - ITER NBI Sector

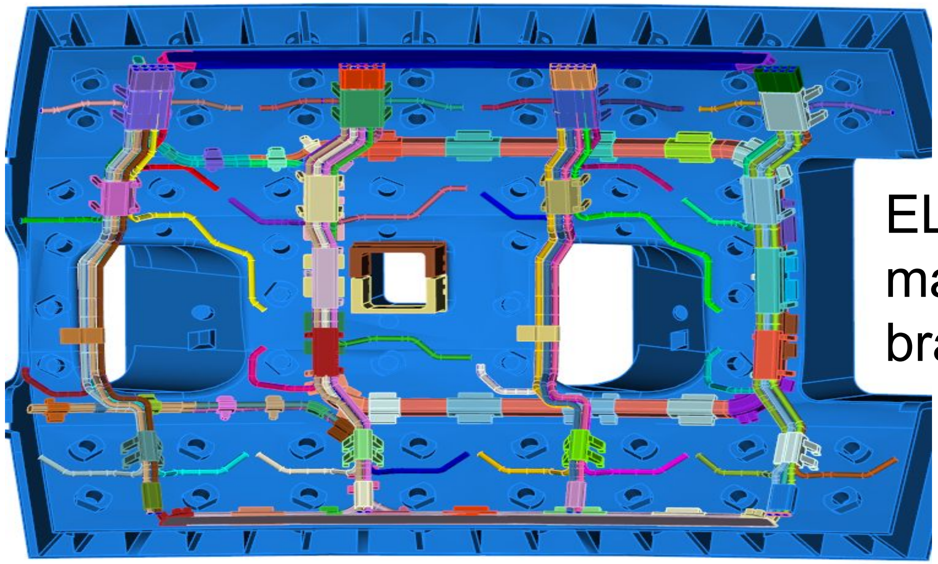
- A detailed, updated model of the NB port region was integrated into the BL-Lite model (40° model) - 2646 volumes, 72019 surfaces, 171361 curves



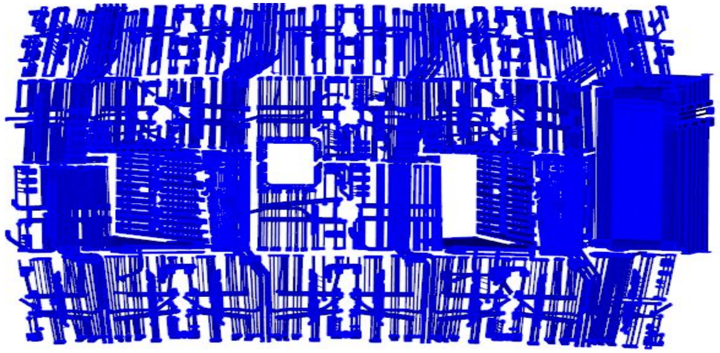
Calculations run using DAG-MCNP5 and FENDL-2.1 cross section library

DAGMC Examples - ITER NBI Sector

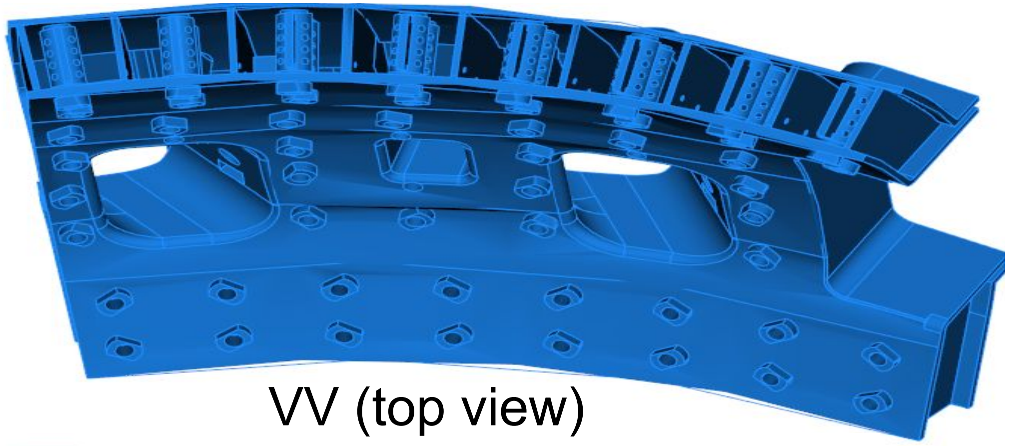
- A lot of detail in the BM13-16 region:



ELM coils, manifolds, brackets



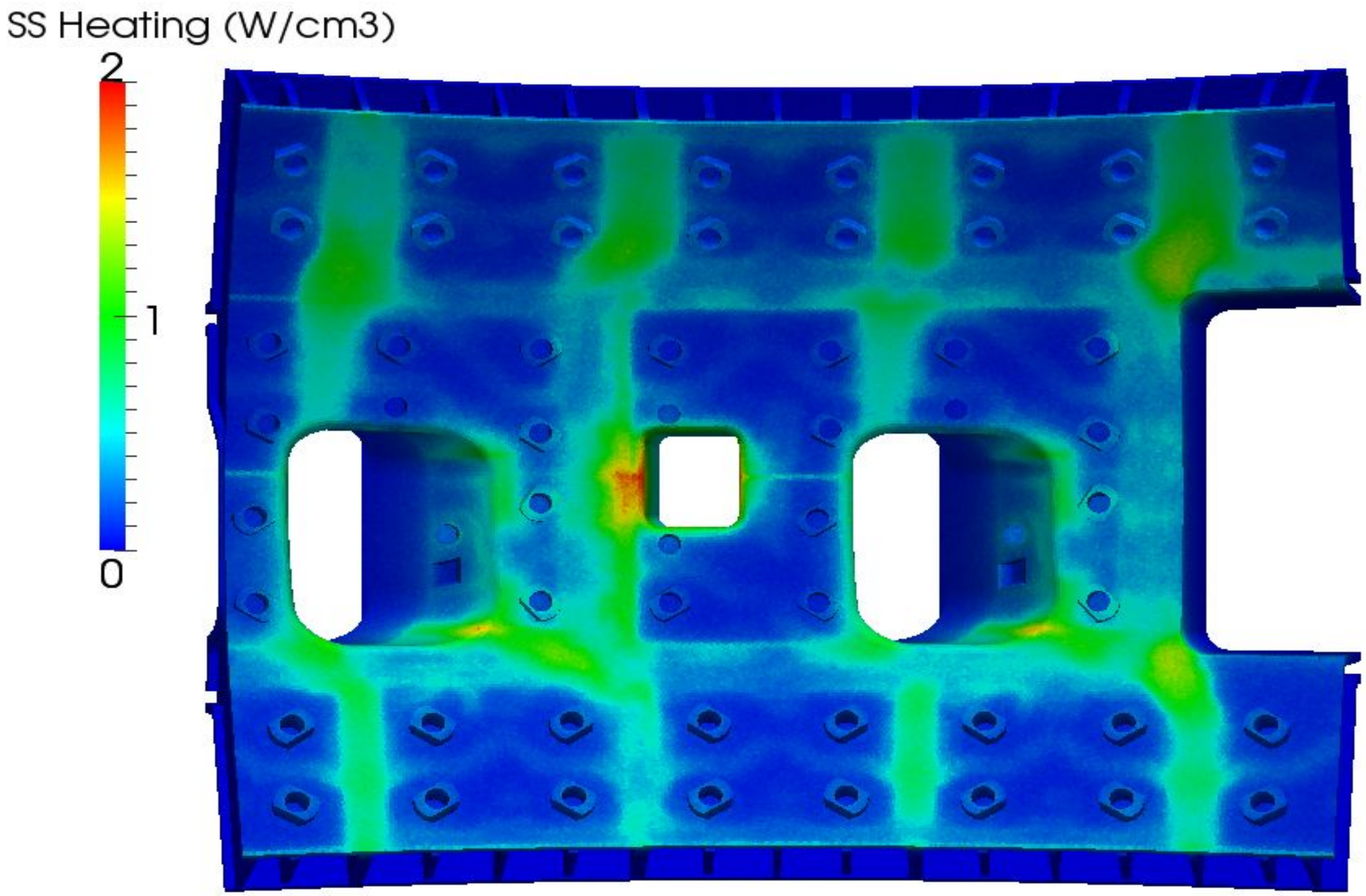
Water coolant channels

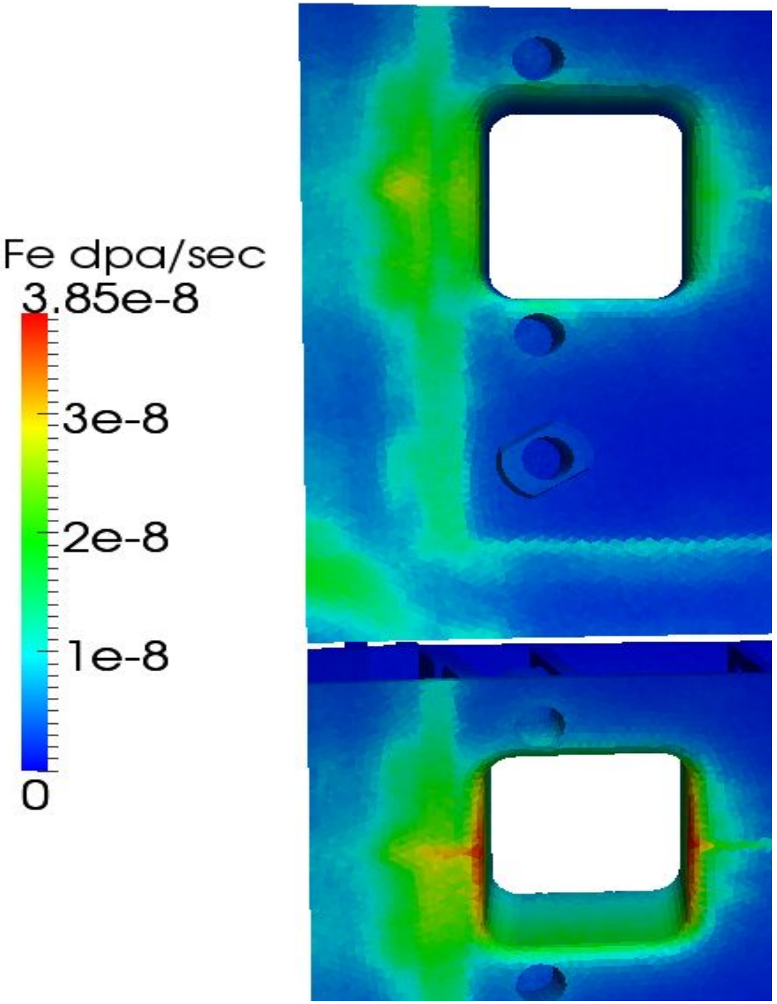


VV (top view)

SB (rear view)

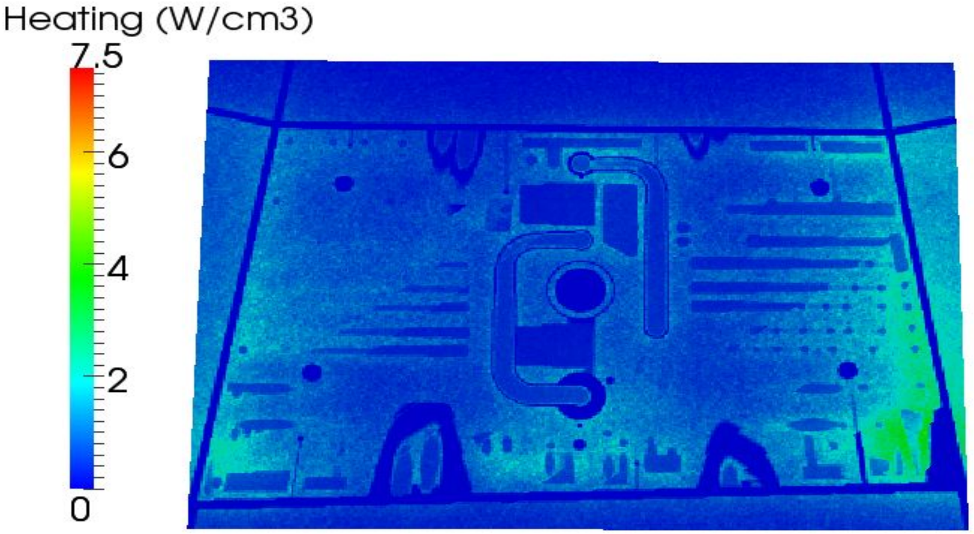
DAGMC Examples - ITER NBI Sector



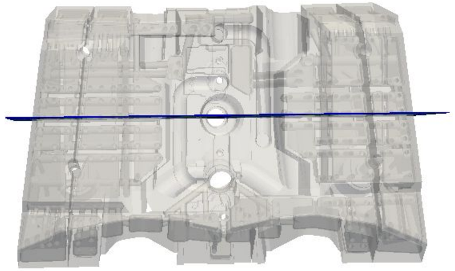


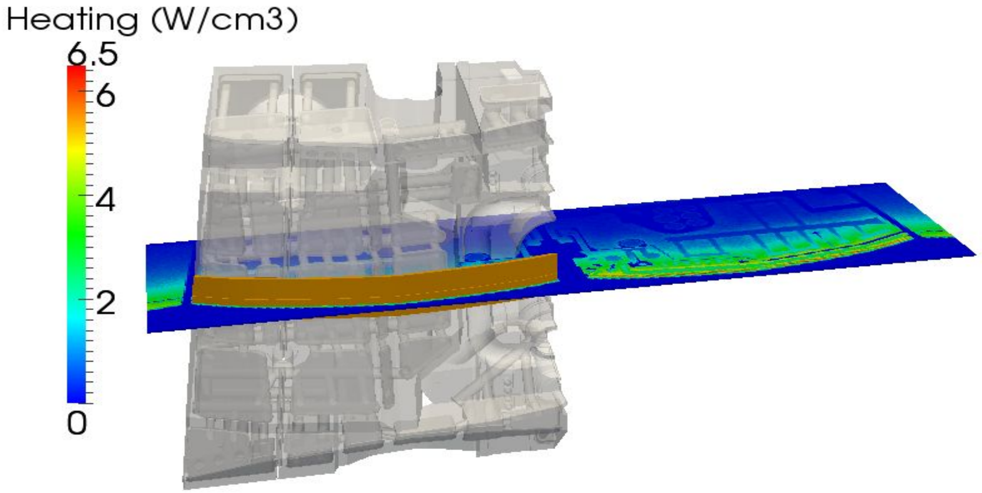
ITER lifetime is 0.54 FPY (1.7e7 sec) so 2.94e-8 dpa/sec corresponds to 0.5 dp

Detailed Blanket Module Heating

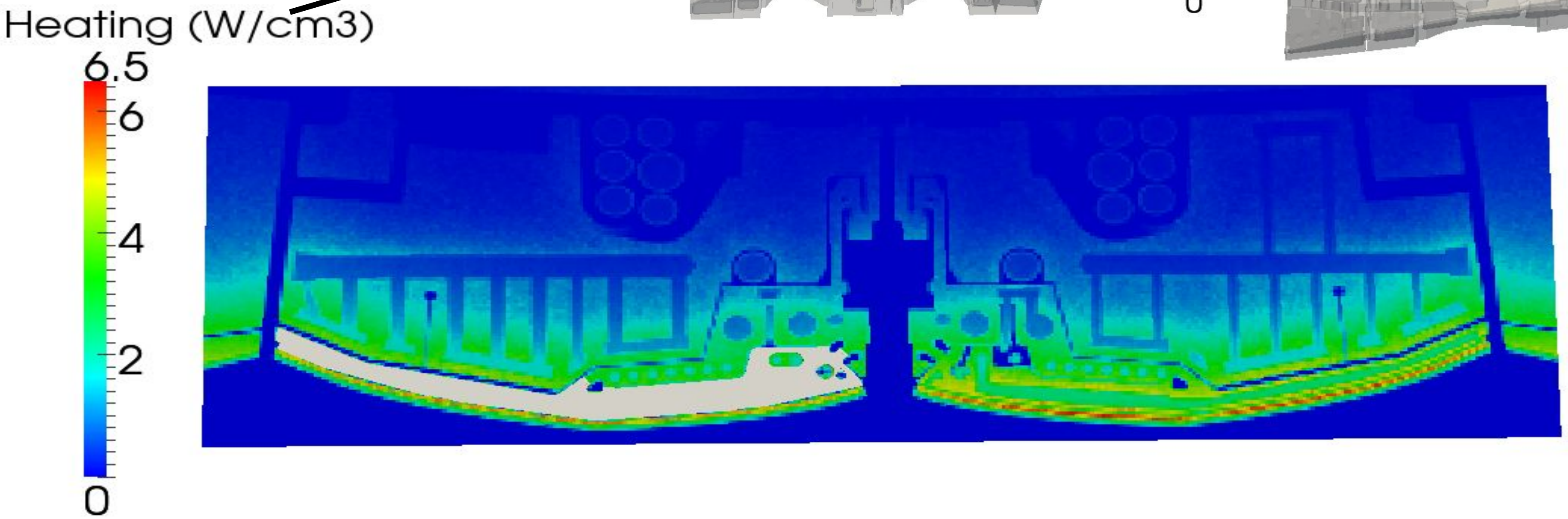


- Entire BM08 model covered with a rectangular (non-conformal) mesh tally



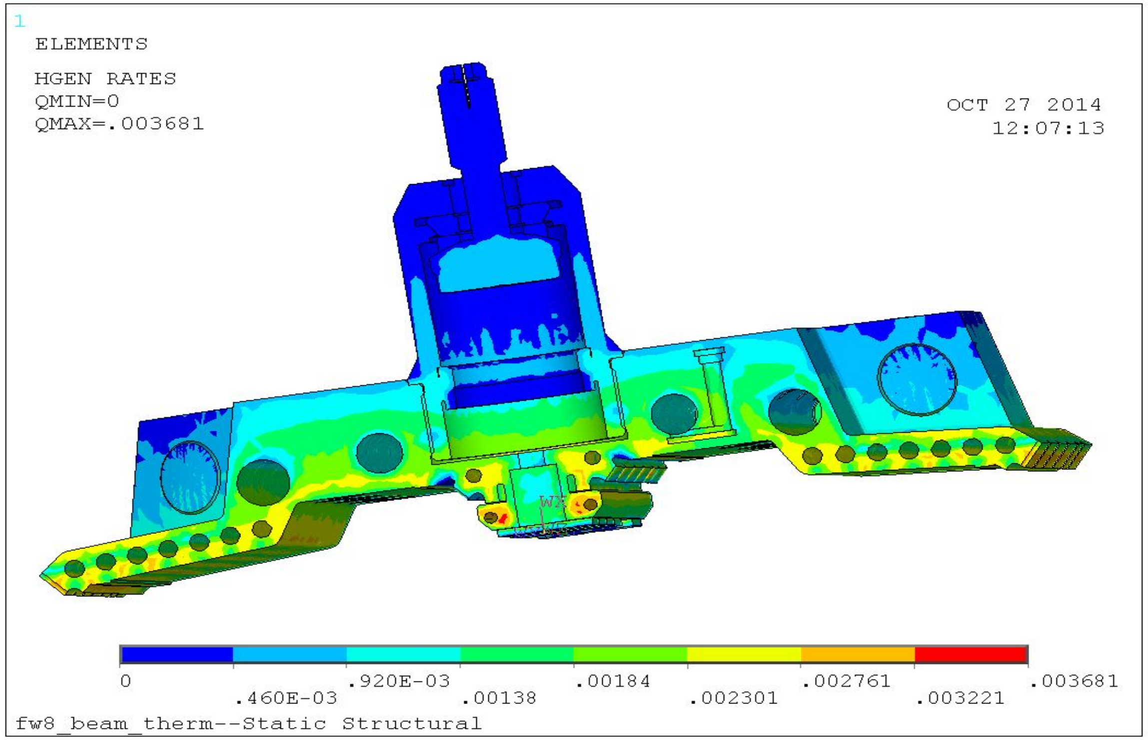


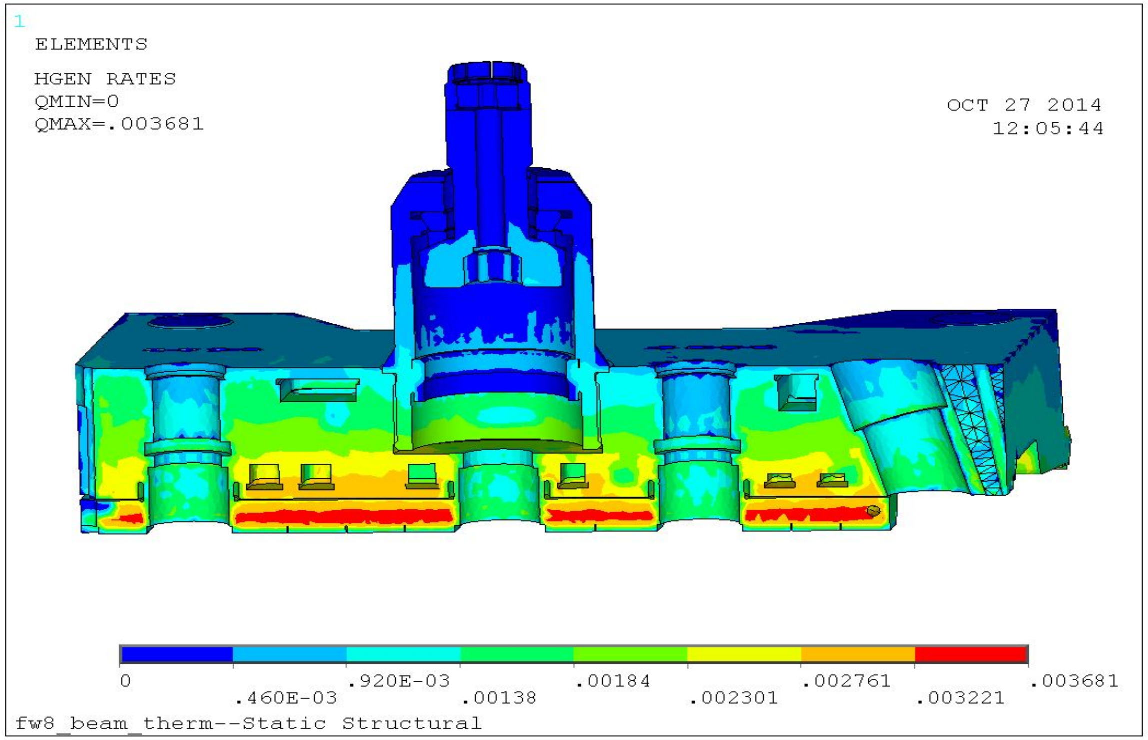
Slice through mid-plane



Detailed Blanket Module Heating

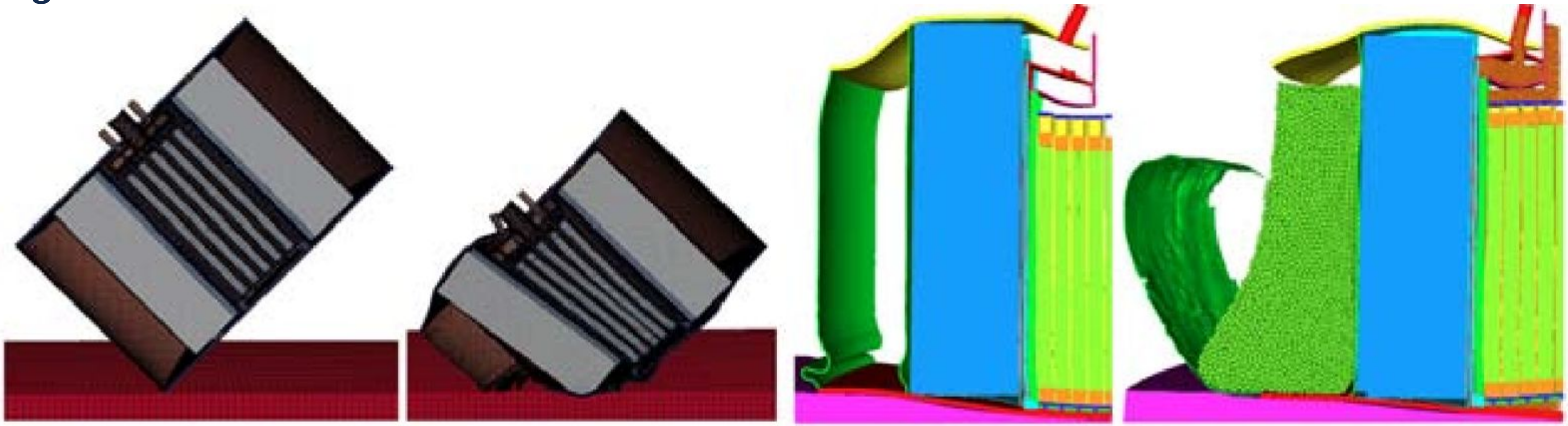
- The IO requested nuclear heating mapped onto an ANSYS mesh of the BM08 beam with units of W/mm^3
- The nuclear heating generated with the Cartesian mesh was used for this mapping:





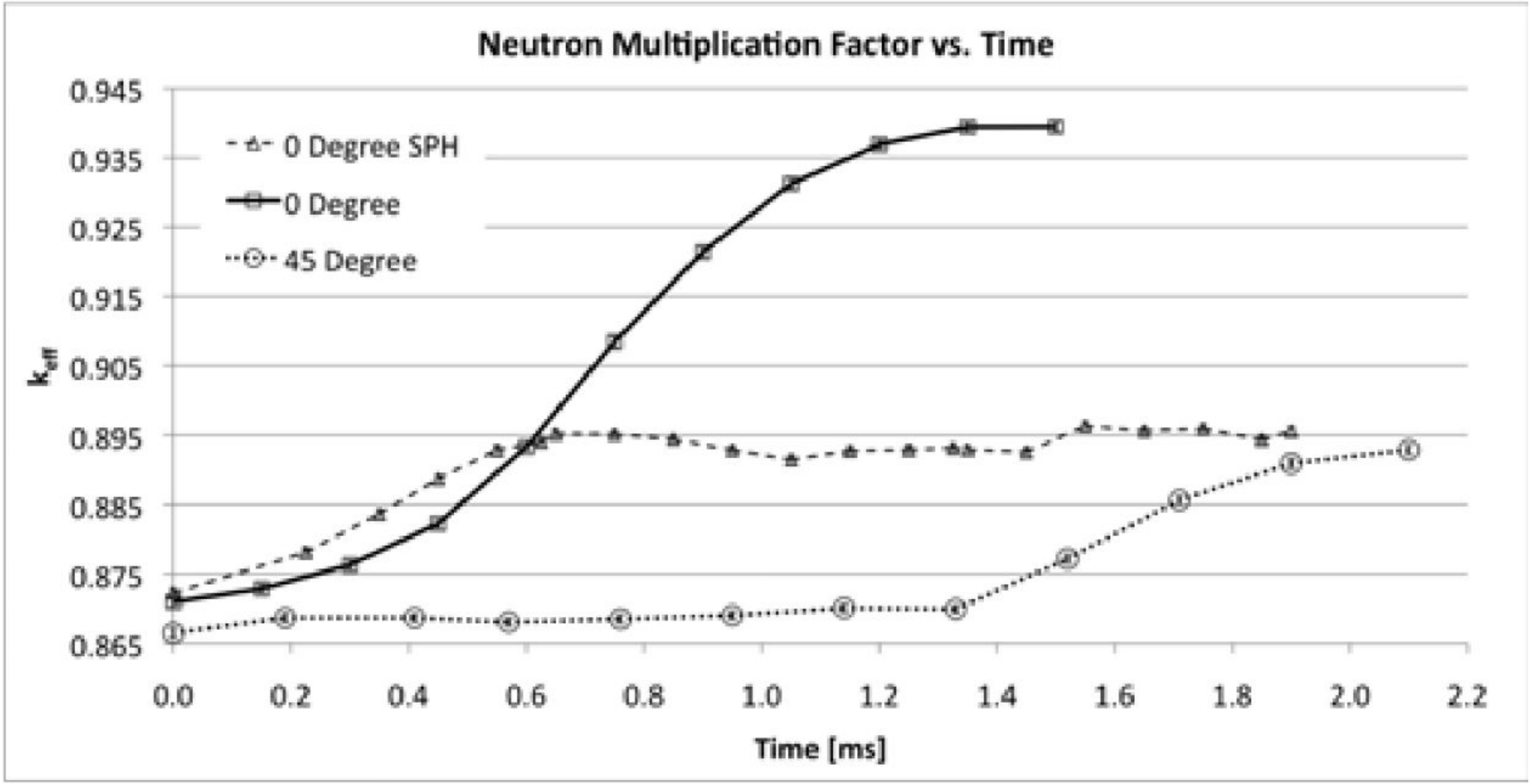
SNL Space Reactor

- CAD geometry of the SNL Space reactor was was meshed, structural mechanics of the FE mesh used to determine deformation of the geometry when the reactor was dropped ‘during launch conditions’
- Need to determine the k_{eff} of the system under various failure modes, drop angles



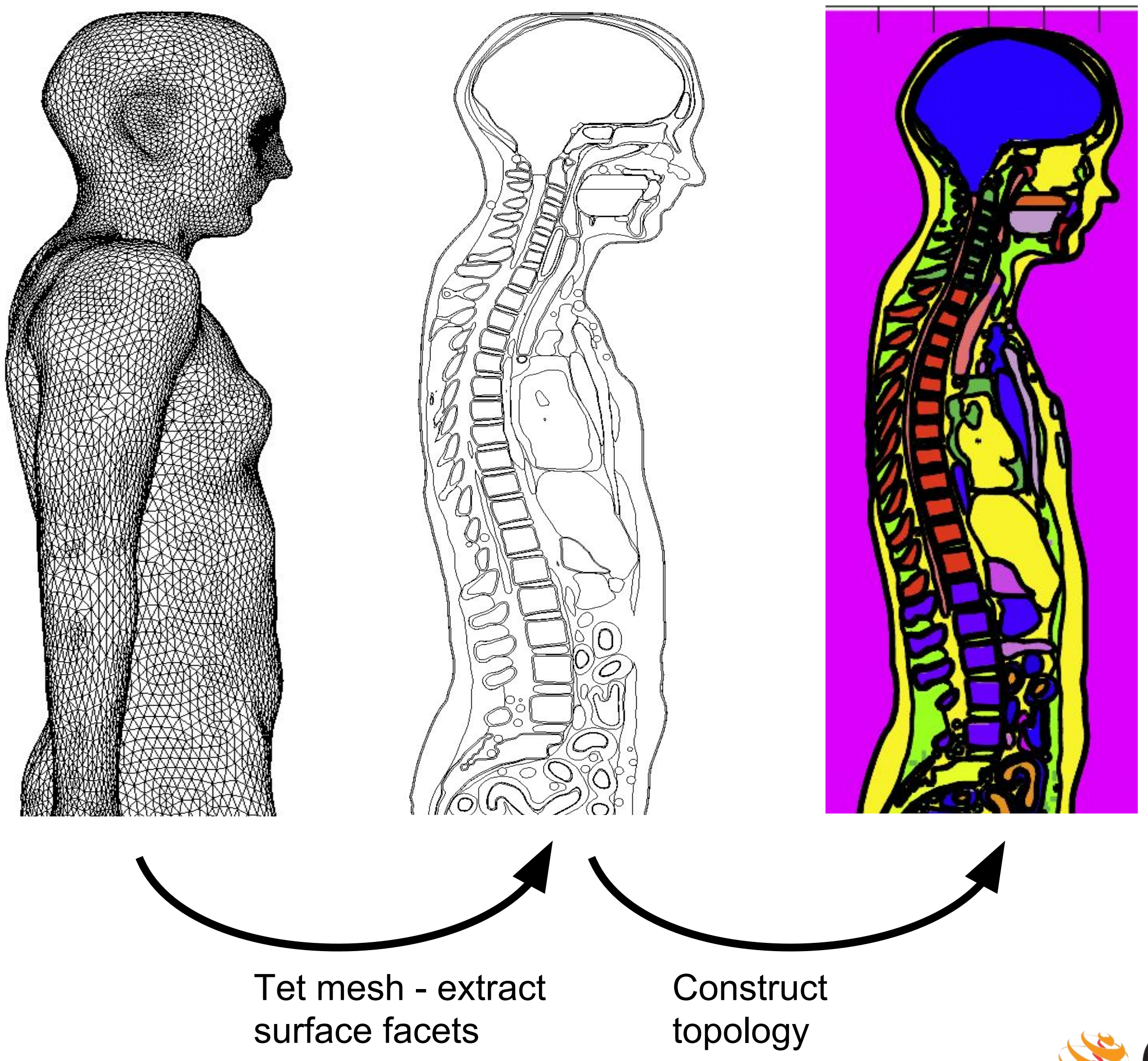
45-degree 0 ms | 45-degree 2.1 ms | 0-degree 1.5 ms | 0-degree SPH 1.5 ms

SNL Space Reactor



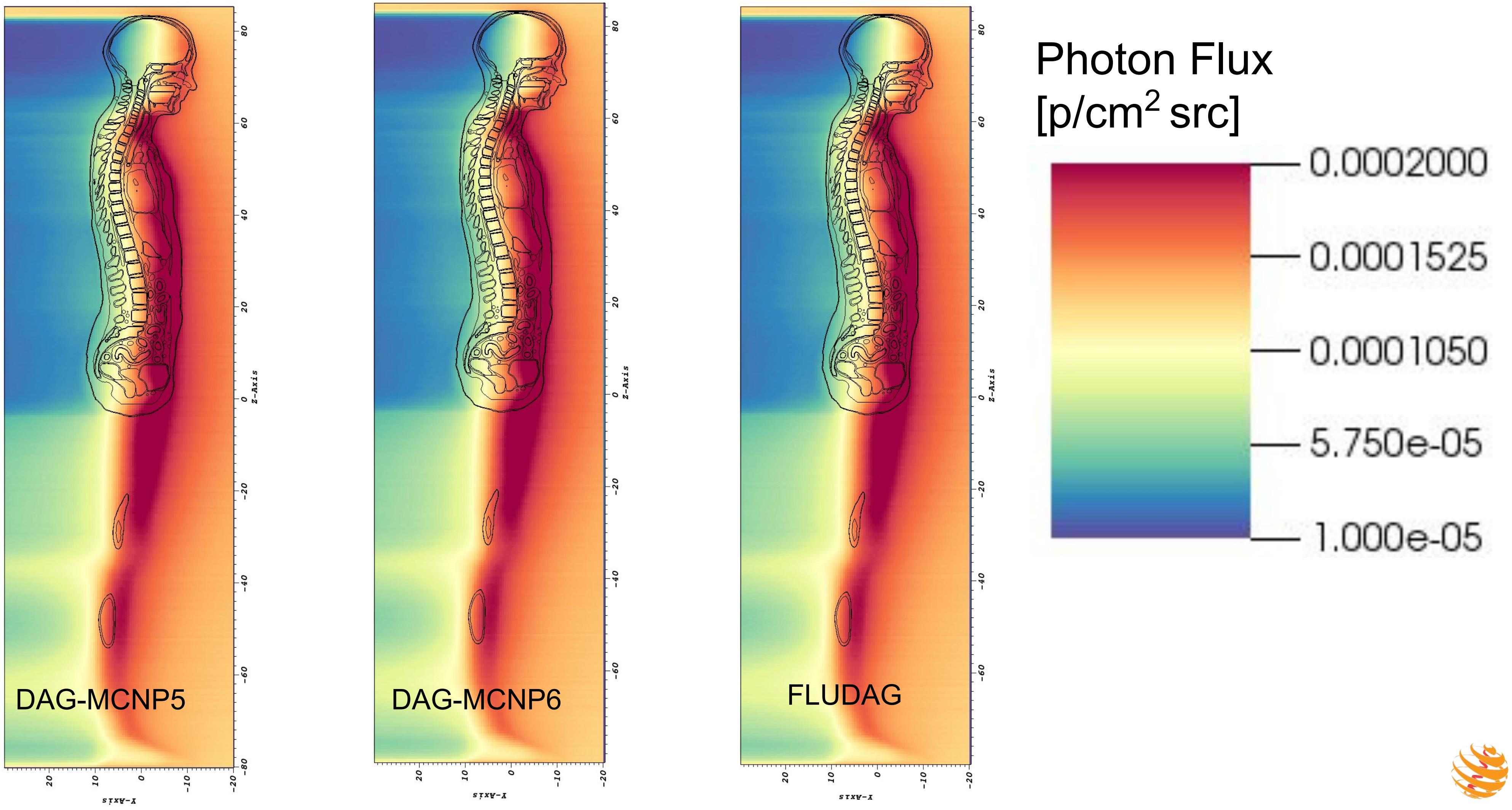
Human Mesh Phantom

- Adult female **M**esh-type ICRP **R**eference **C**omputational **P**hantom
- Created by HUREL @ Hanyang University
- 2.6 million triangular facets
- Tet mesh originally - extract surface triangles

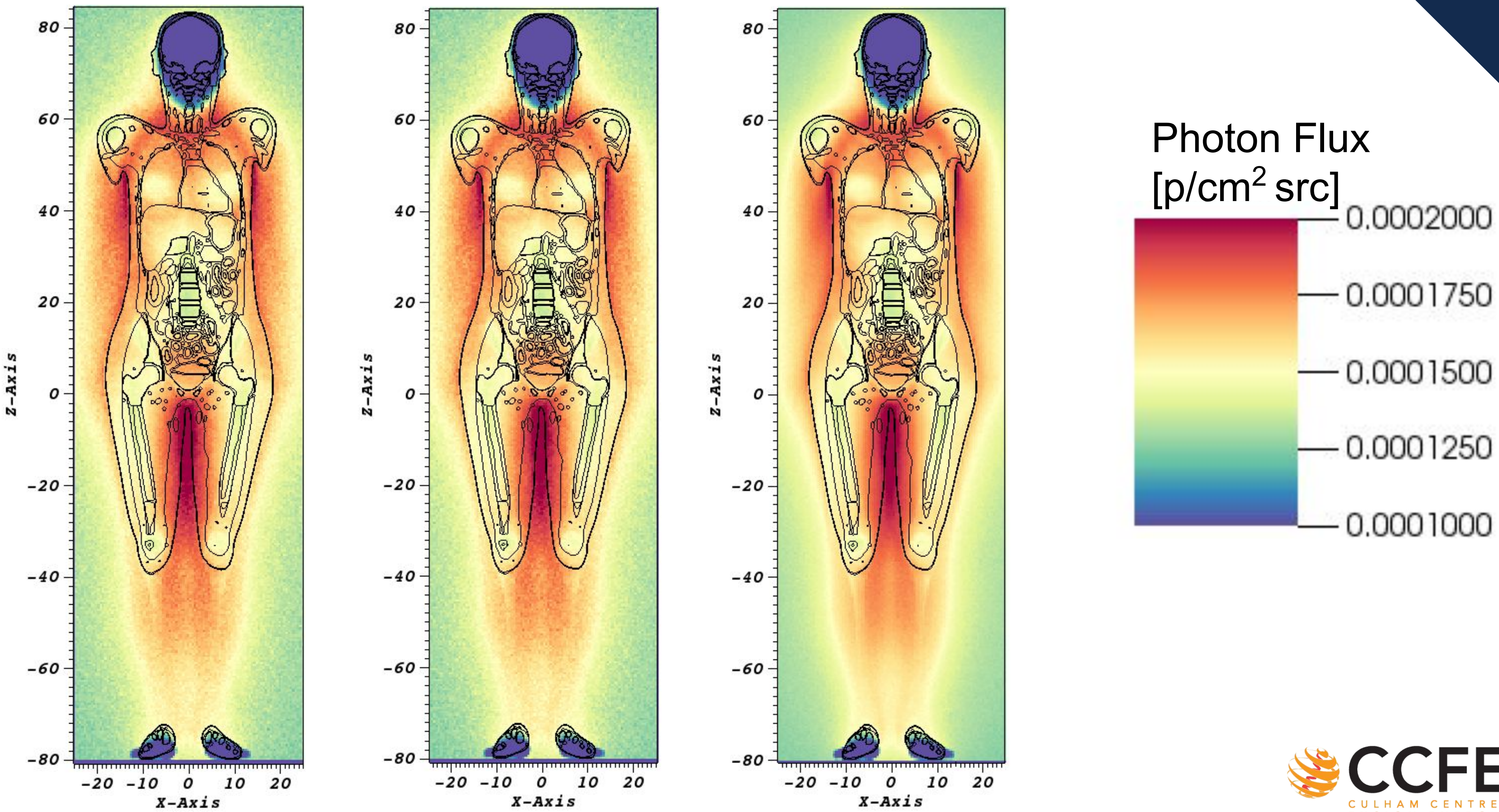


Human Mesh Phantom

Results: 0.1 MeV Photon Source



Human Mesh Phantom



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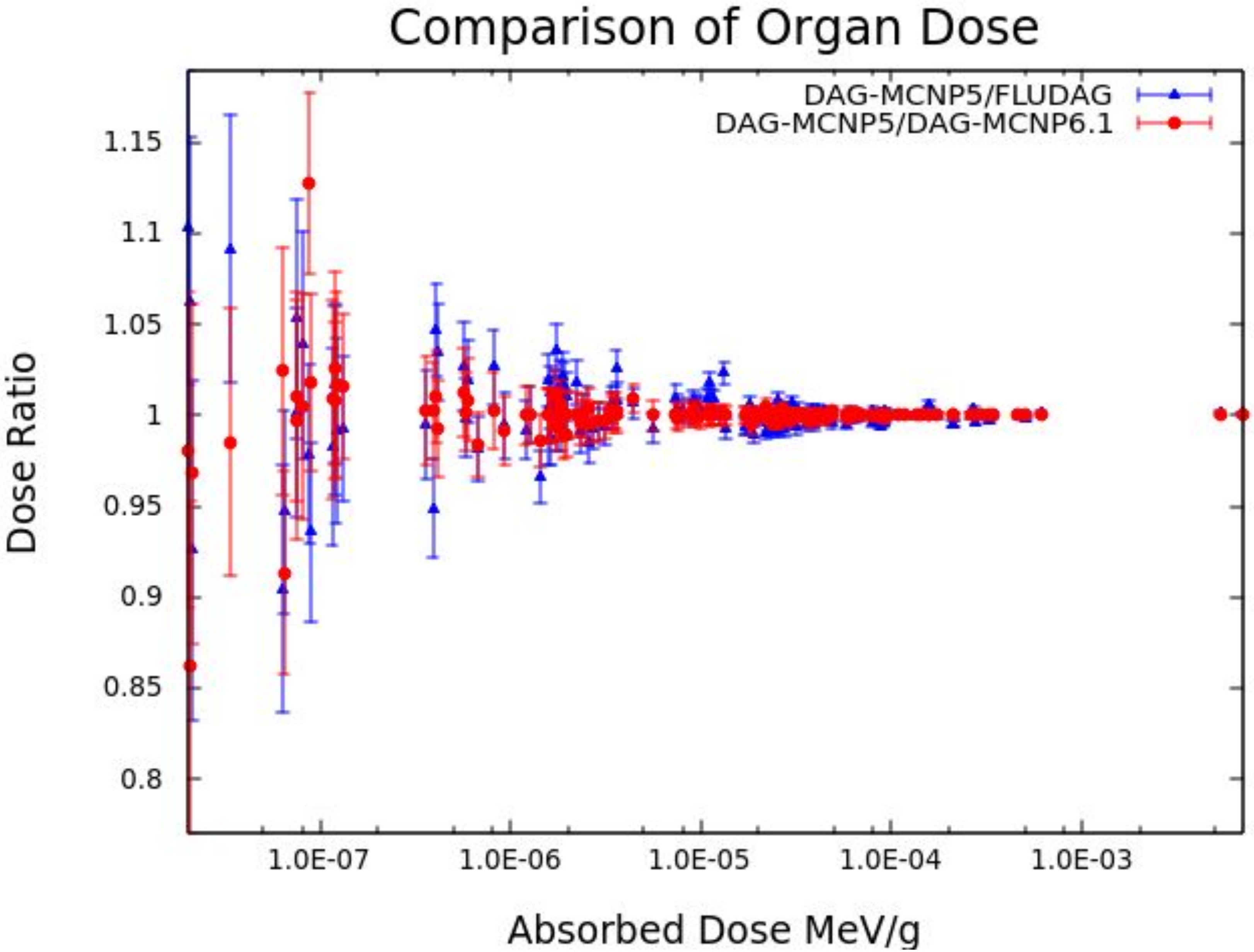
Human Mesh Phantom



High Energy Physics Example

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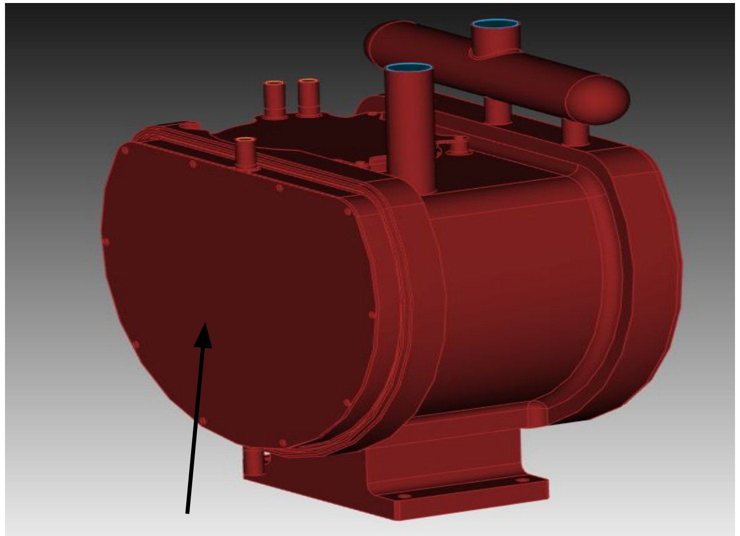
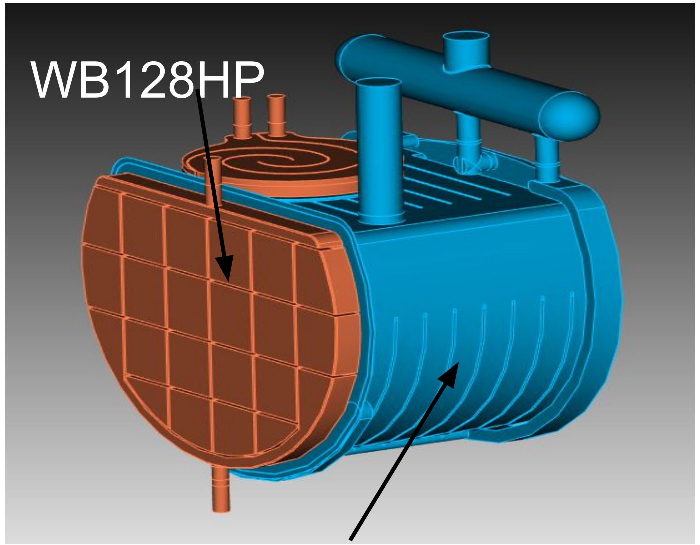
- 20 (ish) GeV proton beam onto a largely lead target
  - For a STEP file CAD was very clean :)
  - Needed some repairs in the spiral section
  - Model was rotated to the appropriate coordinate system and shifted



SS316LN



Water

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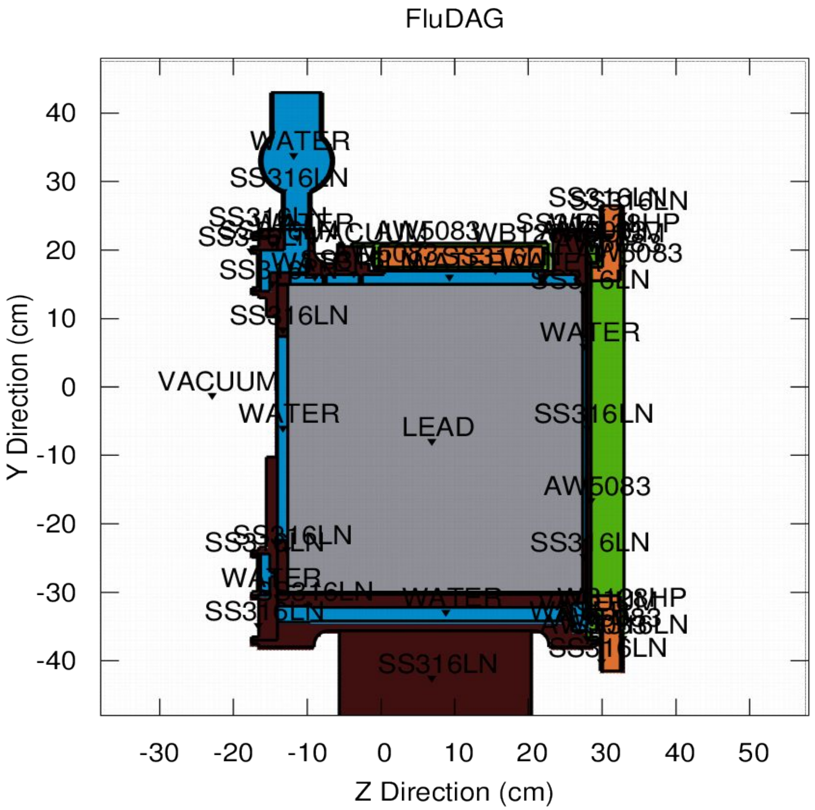
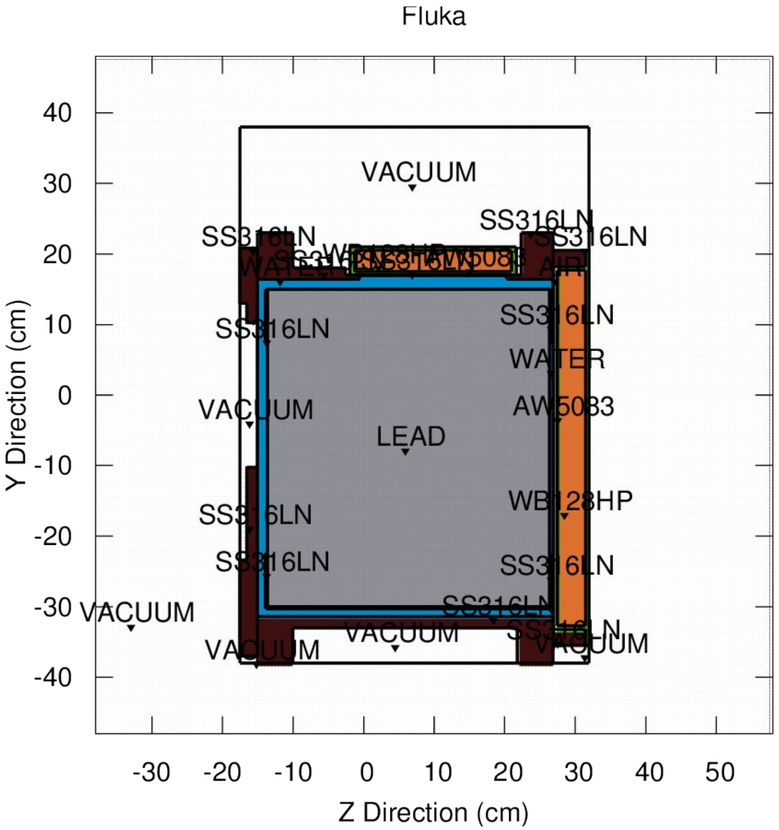
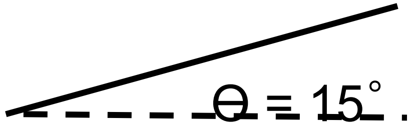
nTOF Geometry

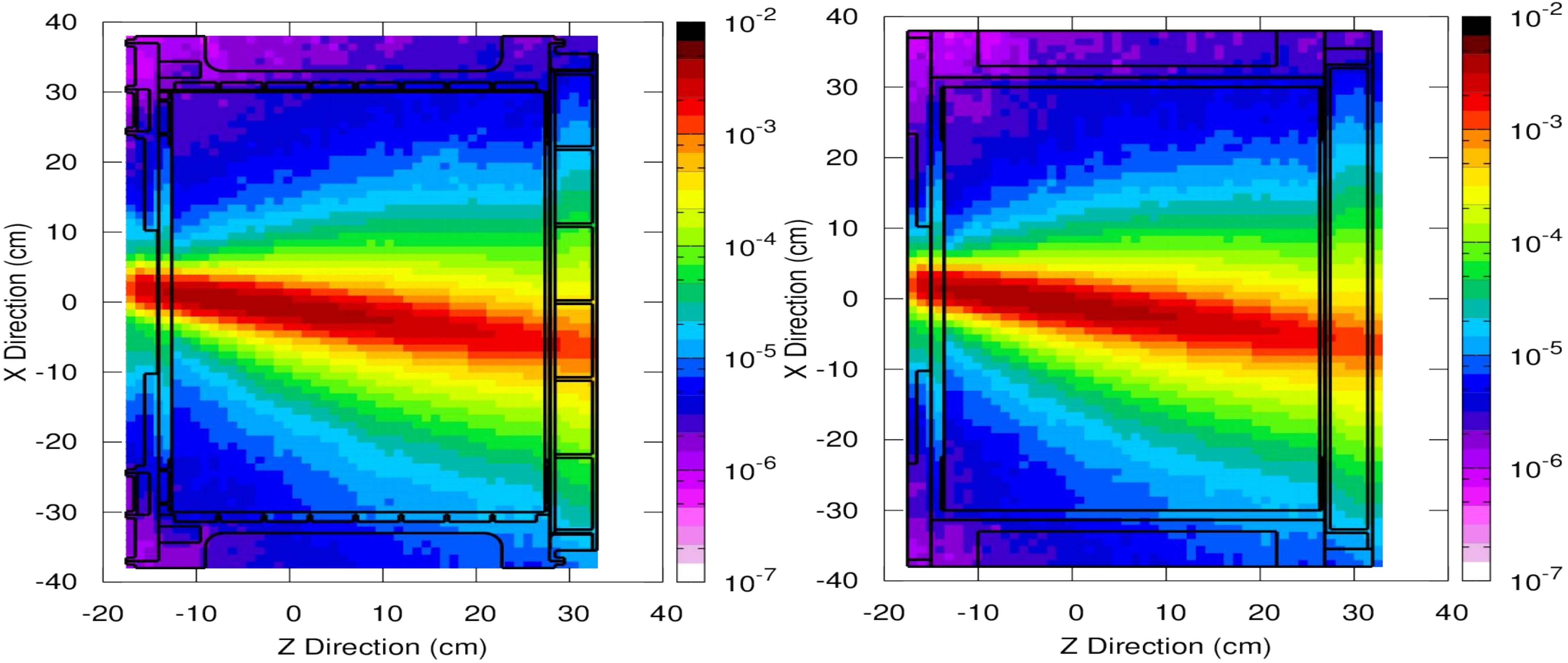




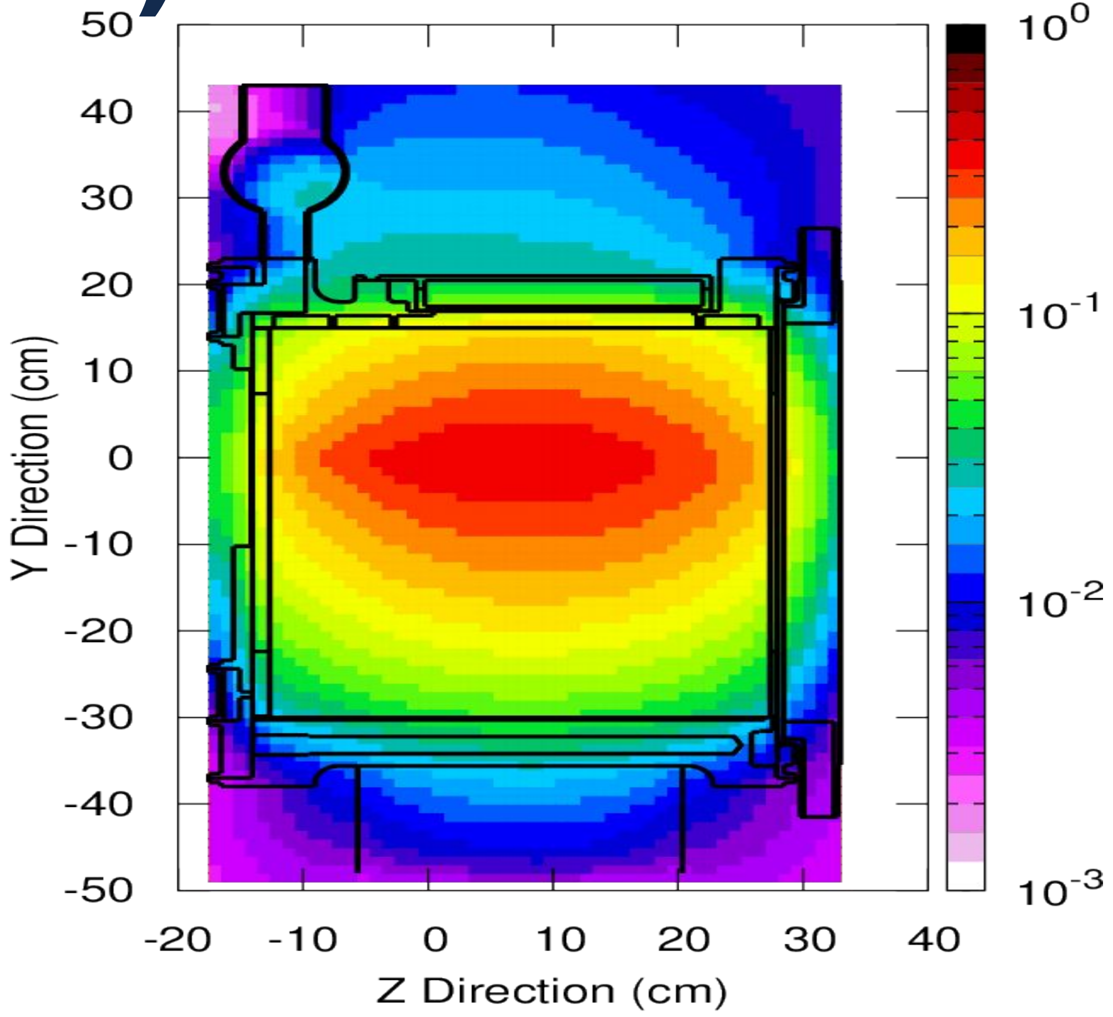


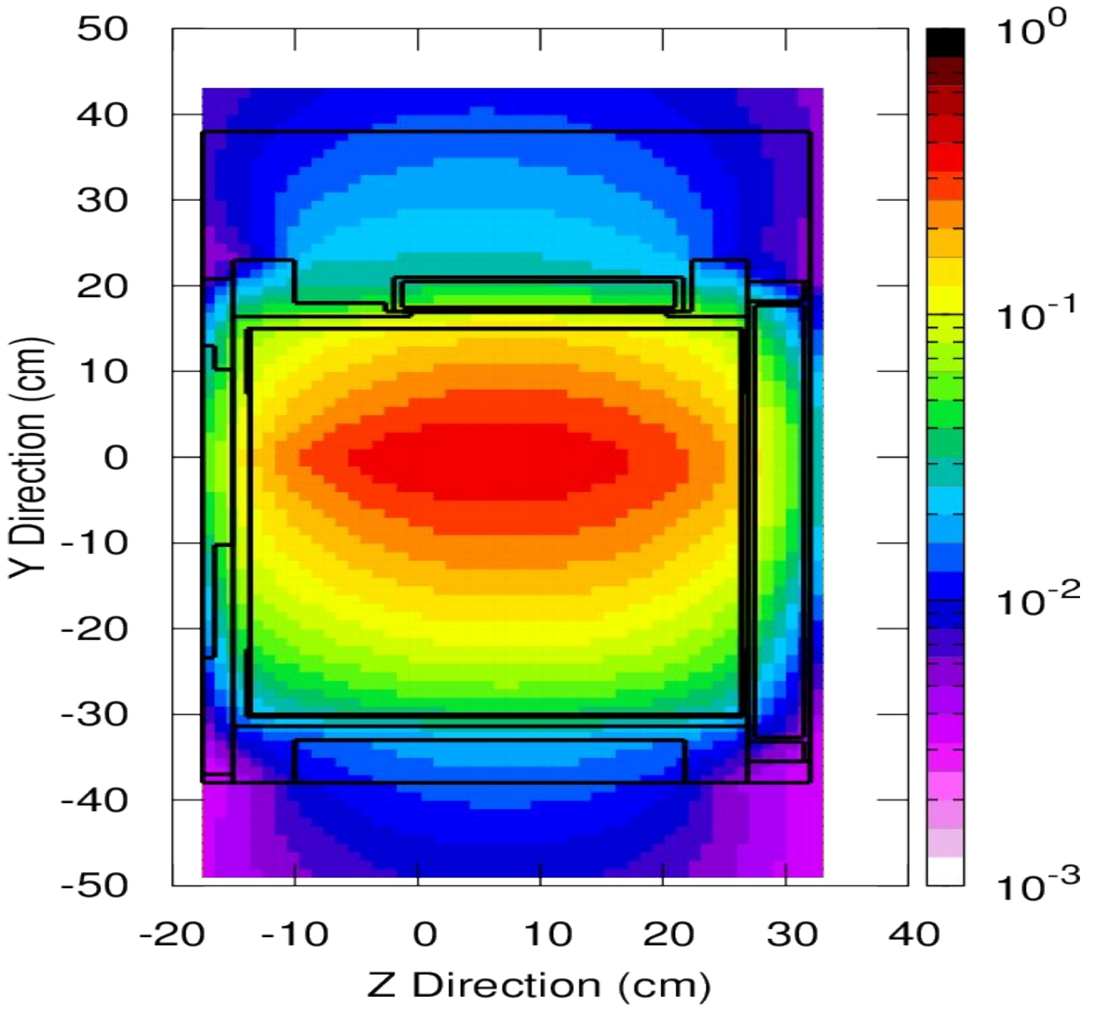
Slice through x=0

nTOF Comparisons - Proton Flux

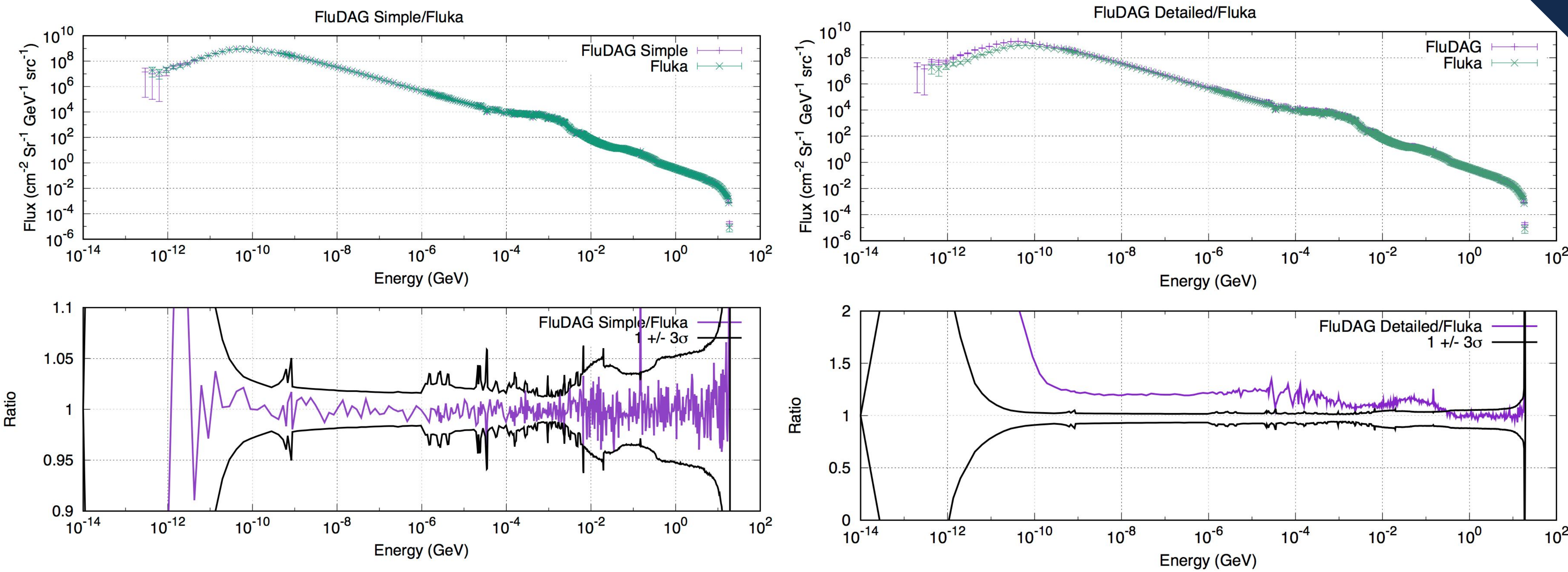


nTOF Comparisons - Neutron Flux (per src)

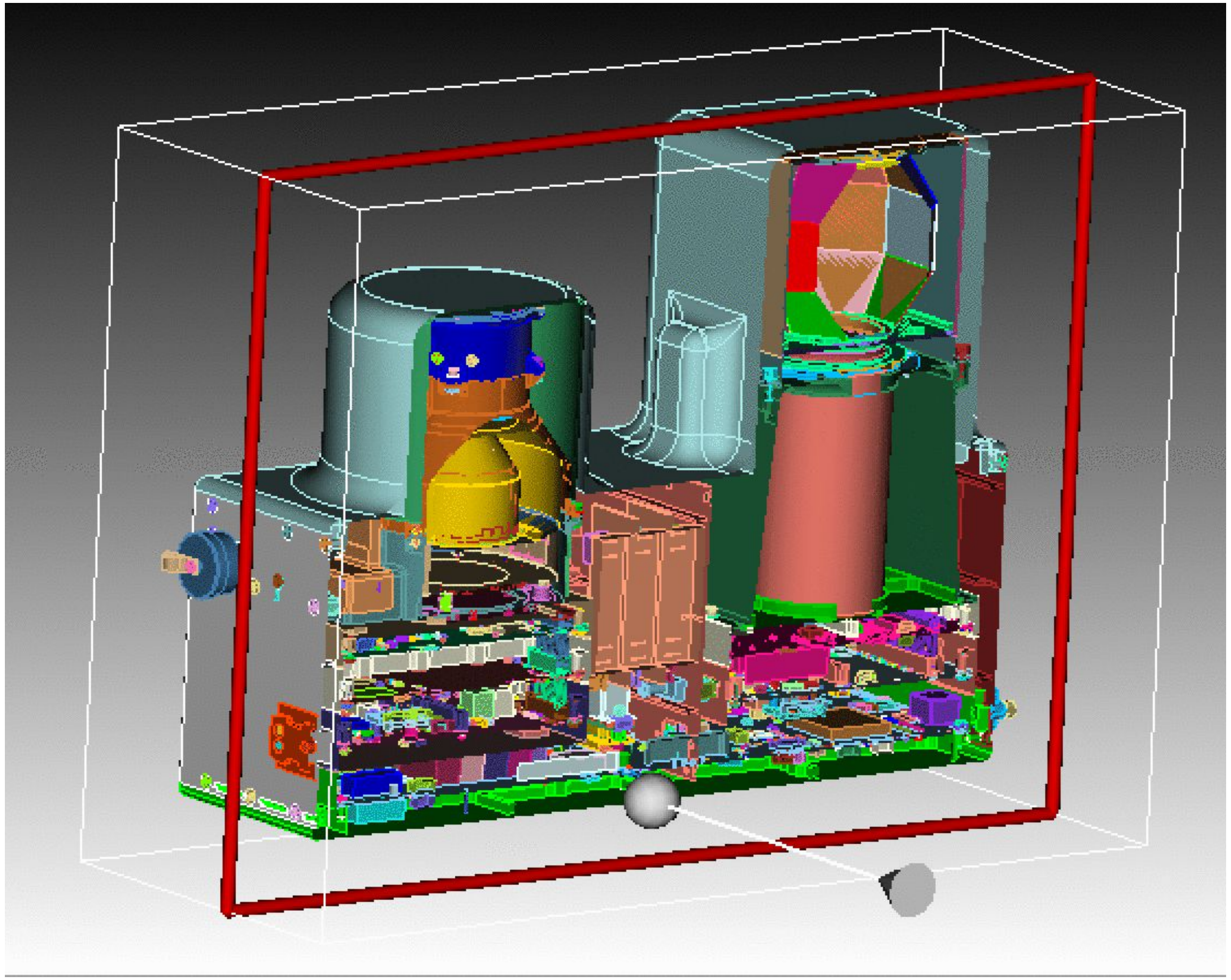


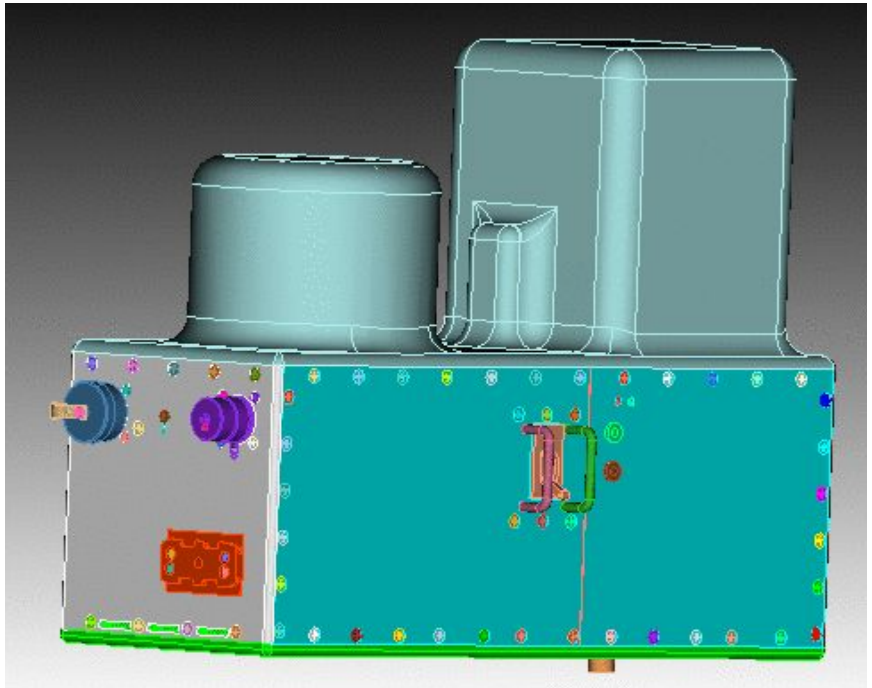


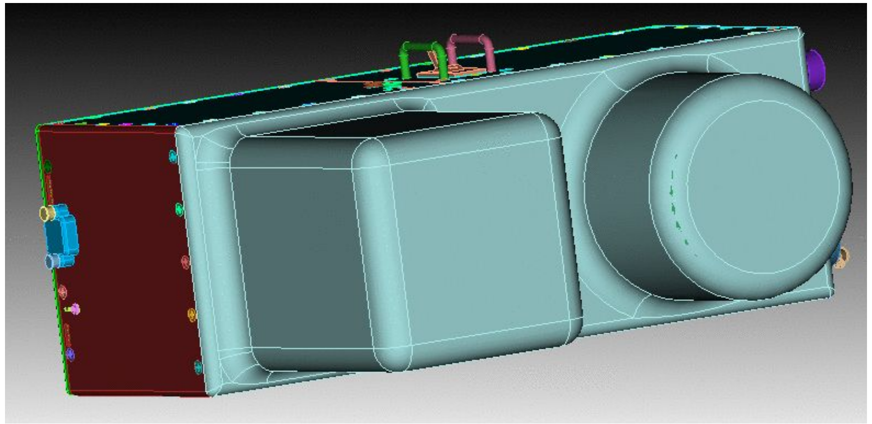
nTOF Comparisons - Neutron Spectrum



Space Radiation Example



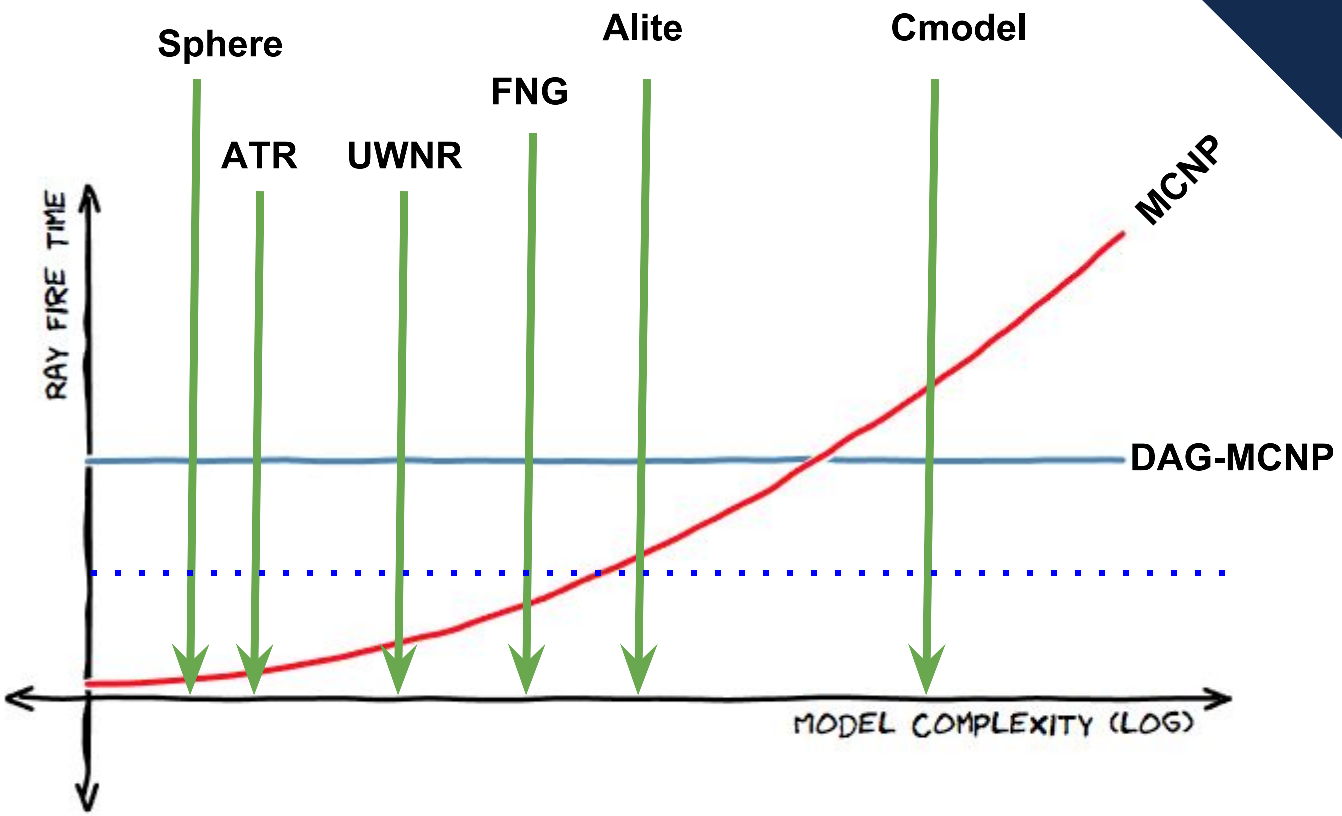




This work performed by SRAG - NASA

The Future

- DAGMC is approaching being a finished project
- Work in progress
  - DAGMC ‘parallel’ universe
  - Cubitless workflow
  - MC code integration(s)
  - Integration of DAGMC like workflow using NVidia OPTIX as ray fire engine
- CERN are interested in integration DAGMC directly into Geant4 as a prime geometry member
- Argonne National Lab want the san for OpenMC



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Advantages of DAGMC

- Faster model creation time
- Easier integration with existing CAD models
- MC Code independence
- Stresses the right part of the workflow (CAD)
- Simple coupling with other multiphysics analysis
- Represents the boundary of the volume only
    - no expensive extraneous boundary crossings

Questions

Any questions, sorry for all the slides :)

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https://github.com/svalinn/dagmc