

# Acceleration Techniques For Direct Use of CAD-Based Geometries In Fusion Neutronics Analysis

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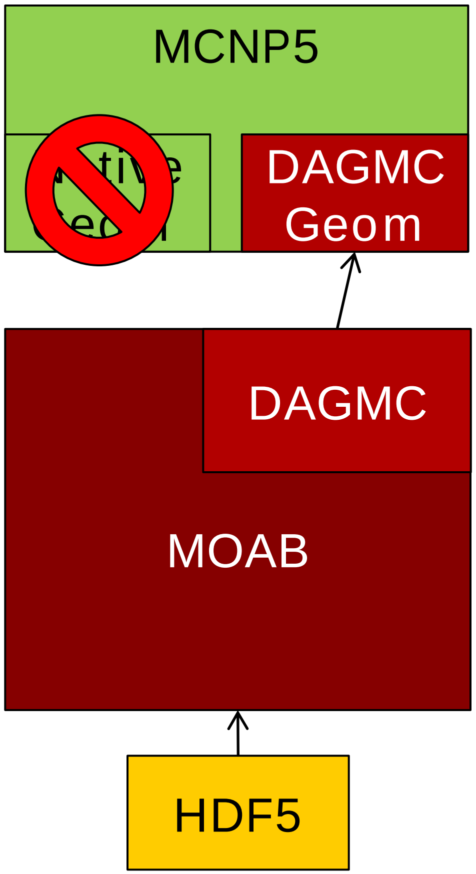
# Overview

- Background
- Implementation
- Workflow and Related Tools
- Acceleration Techniques
- Benchmarking
- Applications

# Three Motivations for CAD-Based Monte Carlo Tools

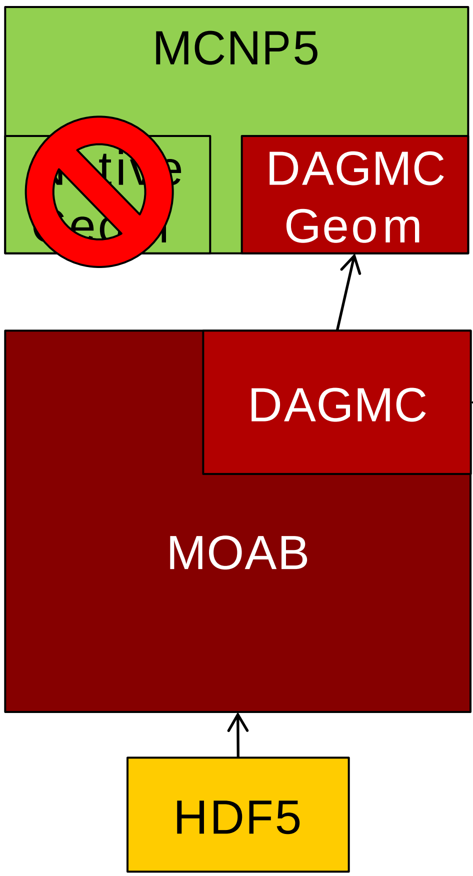
- Faster
  - Reduce human effort
  - **Provide common domain for coupling to other analyses**
- Cheaper
  - Reduce human effort
- Better
  - Avoid human error in conversion
  - **Include higher-order surface descriptions in analysis**

# DAGMC
## Direct Accelerated Geometry Monte Carlo

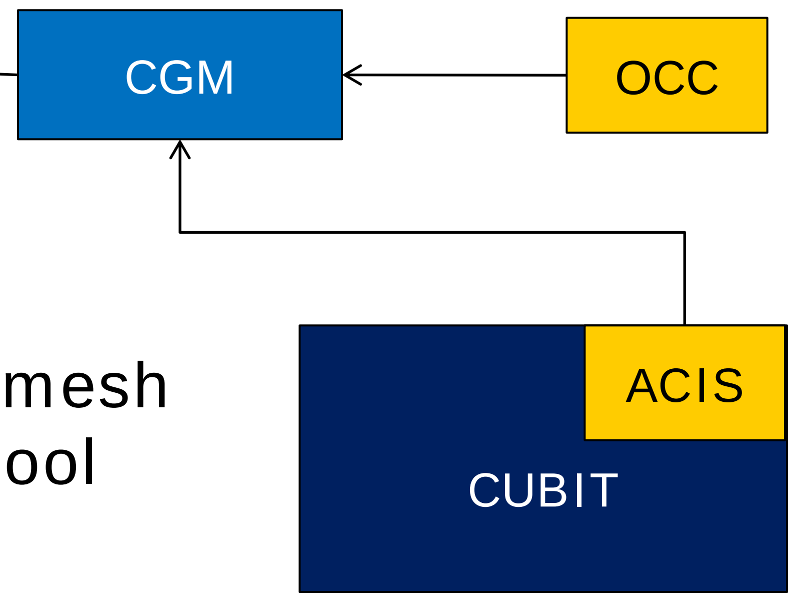



- MOAB
  - Mesh-Oriented dAtaBase (ITAPS)
  - Acceleration techniques based on mesh/geometry concepts
  - Native file format based on HDF5

# DAGMC
## Direct Accelerated Geometry Monte Carlo




- Read solid model geometries with Common Geometry Module (ITAPS)
  - Implement once for generic CGM
  - Variety of underlying solid modeling engines




- CUBIT solid modeling & mesh generation tool (Sandia)

# Workflow Includes a Variety of New Tools and Skills

Generate CAD Geometry

Annotate CAD Geometry

Prepare Input File

Standard CAD software tools are used to define the solid model.

Models are exported to a standard geometric-model file format supported by Common Geometry Module (CGM).

DAG-MCNP5

Read Model and Initialize Search Tree

Perform Random Walks

Report Tally Results

# Workflow Includes a Variety of New Tools and Skills

Generate CAD Geometry

Annotate CAD Geometry

Prepare Input File

Allocate materials and densities

Define boundary conditions

Define tally locations

*Imprint & Merge*

(Currently use CUBIT mesh generation tool for this step)

DAG-MCNP5

Read Model and Initialize Search Tree

Perform Random Walks

Report Tally Results

# Workflow Includes a Variety of New Tools and Skills

Generate CAD Geometry

Annotate CAD Geometry

Prepare Input File

Skip cell definitions

Skip surface definitions

Provide data cards
- Material definitions
- Tally modifiers
- Source definition
- etc...

DAG-MCNP5

Read Model and Initialize Search Tree

Perform Random Walks

Report Tally Results

# Workflow Includes a Variety of New Tools and Skills

Generate CAD Geometry

Annotate CAD Geometry

Prepare Input File

Generate *tree-based decomposition* of facets on model surfaces

**DAG-MCNP5**

- Read Model and Initialize Search Tree
- Perform Random Walks
- Report Tally Results

# Workflow Includes a Variety of New Tools and Skills

Generate CAD Geometry

Annotate CAD Geometry

Prepare Input File

Circumvent standard functions involved in ray-tracing, esp.

- ray-surface intersection
- point-in-volume determination
- neighboring cell determination

DAG-MCNP5

Read Model and Initialize Search Tree

Perform Random Walks

Report Tally Results

# The Need for Acceleration Techniques

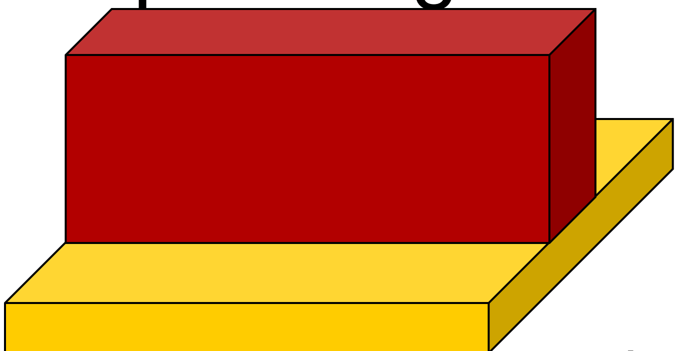
- Ray-tracing: fundamental operation of Monte Carlo transport
  - Ray-tracing on 2$^{nd}$ order analytic surfaces is efficient
  - Ray-tracing on arbitrary high-order surfaces requires high-order root finding
  - Also need to detect curves where surfaces meet
    - More complexity with high-order surfaces

# Accelerations

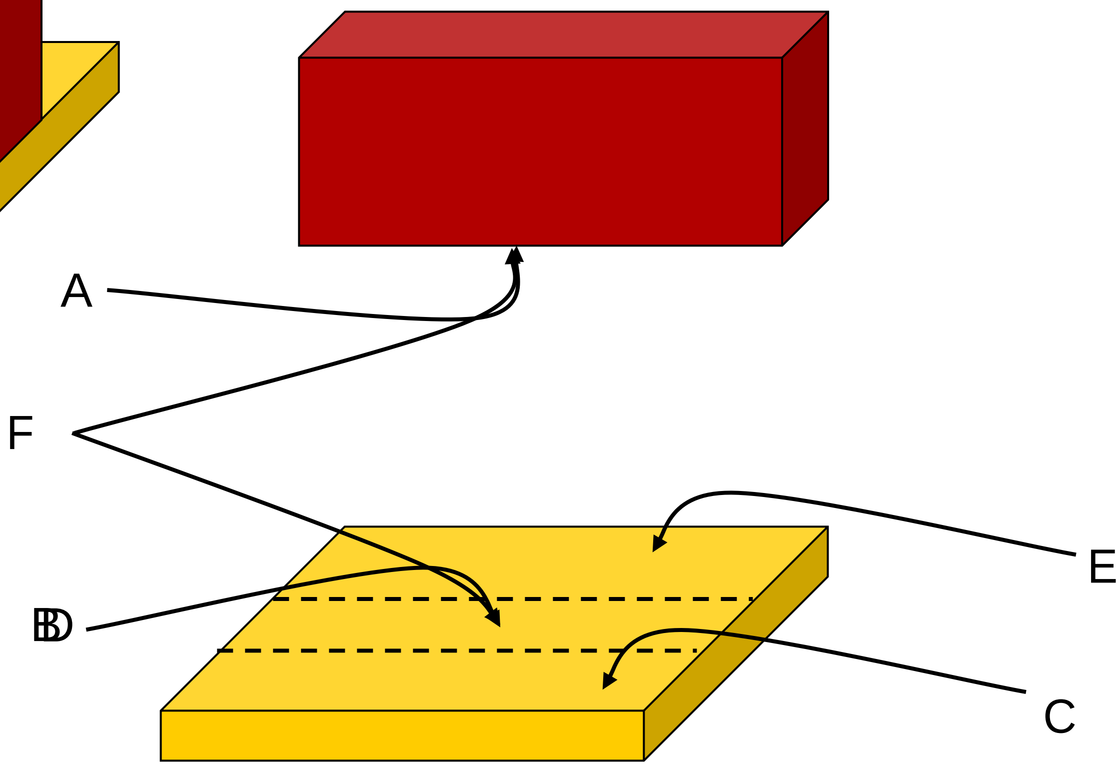
- Imprint & merge
  - Reduce complexity of determining neighboring regions in space
- Faceting
  - Reduce ray-tracing to always be on (planar) facets, but
    - introduce approximations
    - millions of individual facets
- Oriented Bounding Box Tree
  - Accelerate search of millions of surfaces
  - Reduce number of surface tests

# Accelerating the Neighboring Cell Determination

- Imprinting



- Merging
- Each surface in max. 2 cells

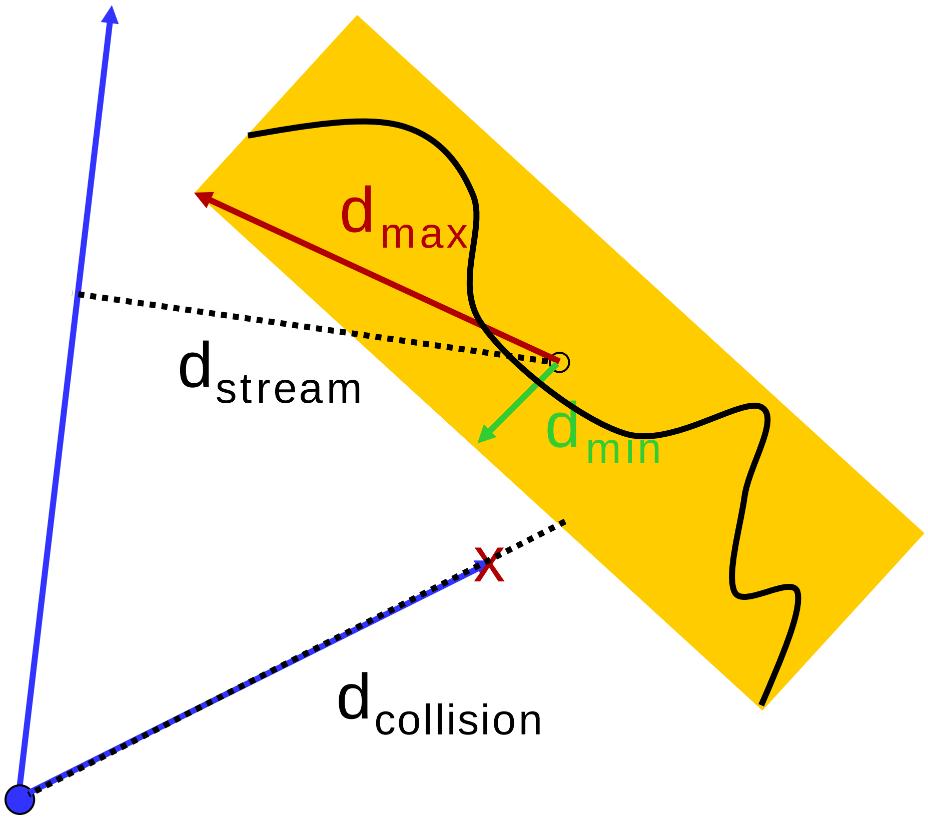


# Avoiding the Explicit Calculation of the "Complement"

- CAD-based solid models do not typically represent non-solid regions
  - e.g. voids, coolants
- Explicit calculation
  - Boolean operations in CAD (or CUBIT)
  - Often computationally expensive
- Implicit determination
  - Volume bounded by surfaces with only 1 cell following imprint & merge

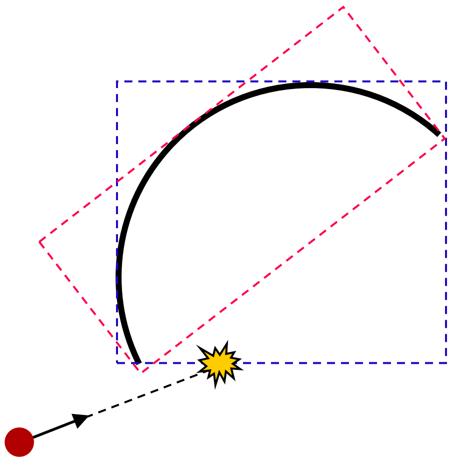
# Accelerate Testing of Each Bounding Box

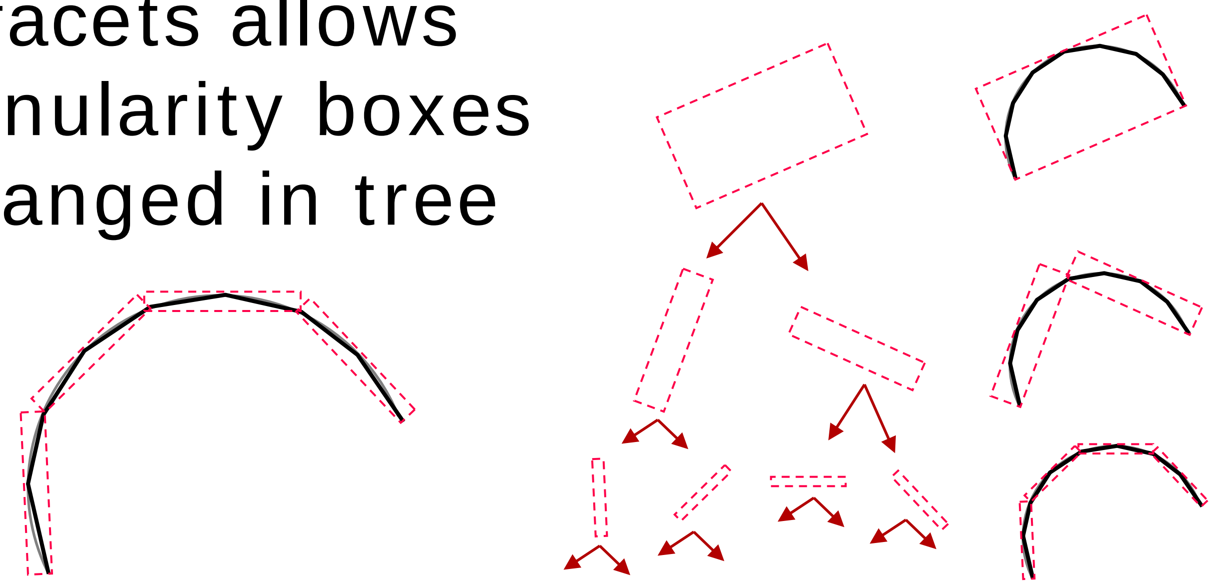
- Simple (inexpensive) bounding box test
  - Streaming distance to closest approach
  - Collision distance to closest approach



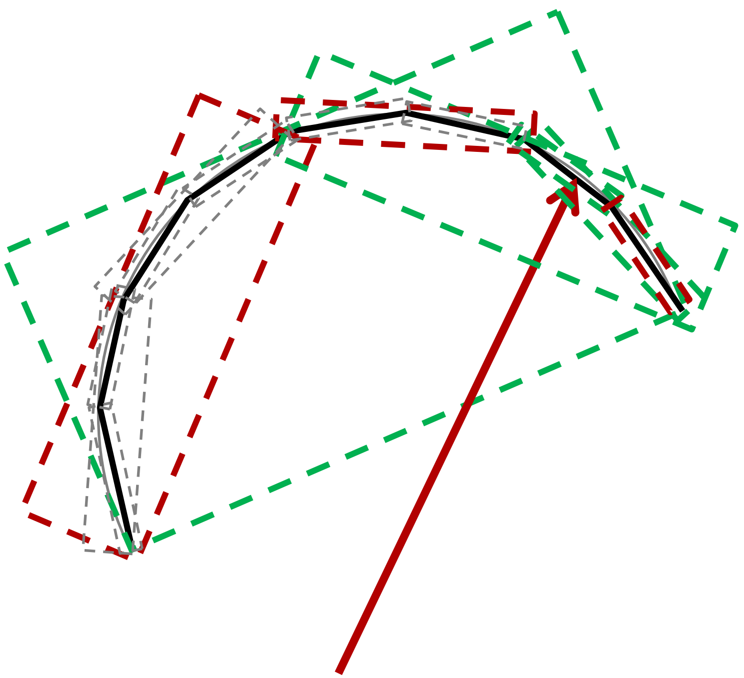
# Oriented Bounding Box on Facets as Nodes in a Tree

- Axis-aligned bounding box often larger than necessary
- *Oriented* bounding box makes smaller boxes
- OBB on facets allows finer-granularity boxes to be arranged in tree





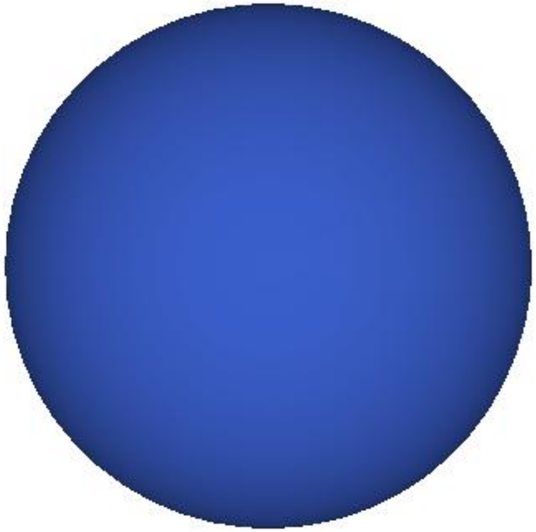
# Tree Traversal Could Have $O(\log_2(n))$ Bounding Box Tests



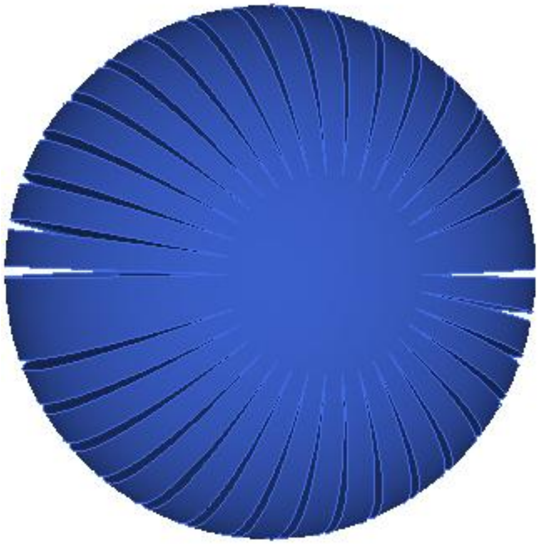
- Distance limit should guarantee improved performance
- Tree root for each cell/volume
  - Accelerate ray-tracing in implicit complement

# OBB-Tree Traversal Performance Tested on 3 Geometries

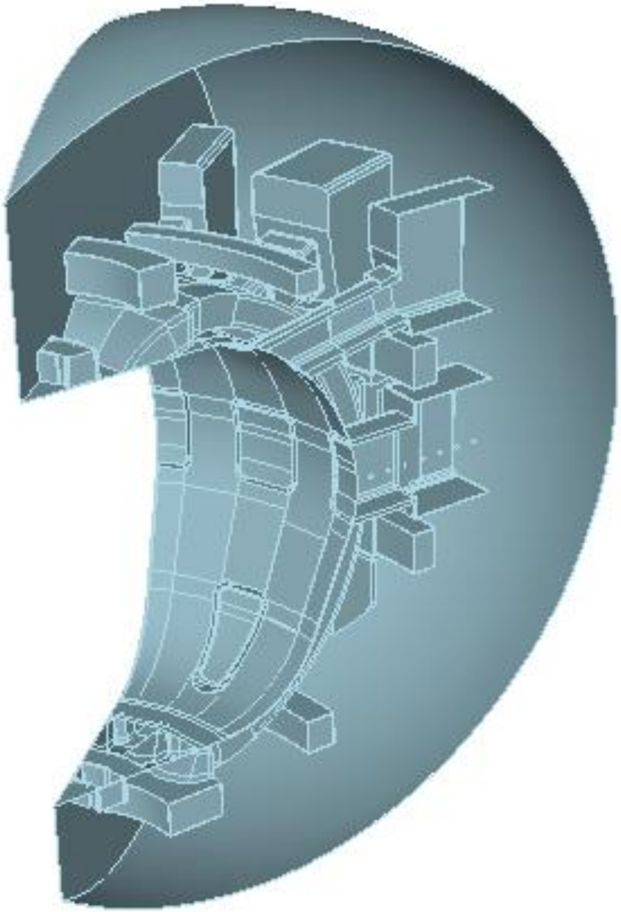
Sphere



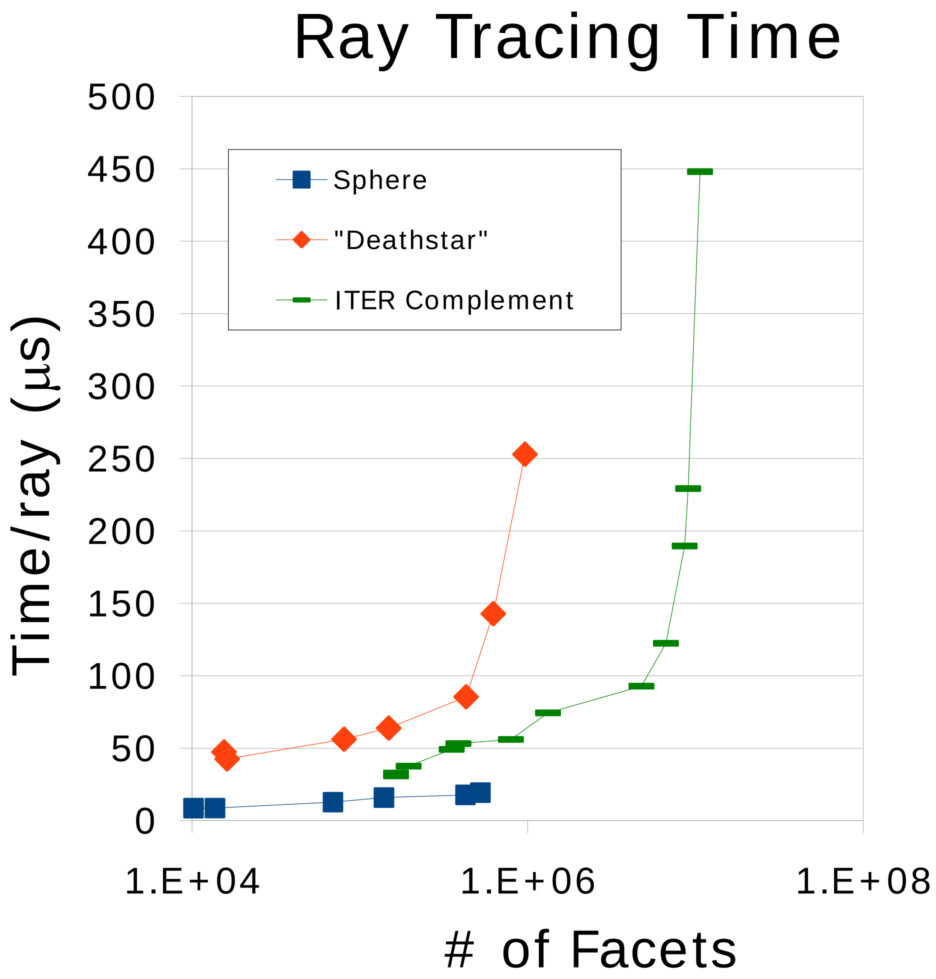
"Deathstar"

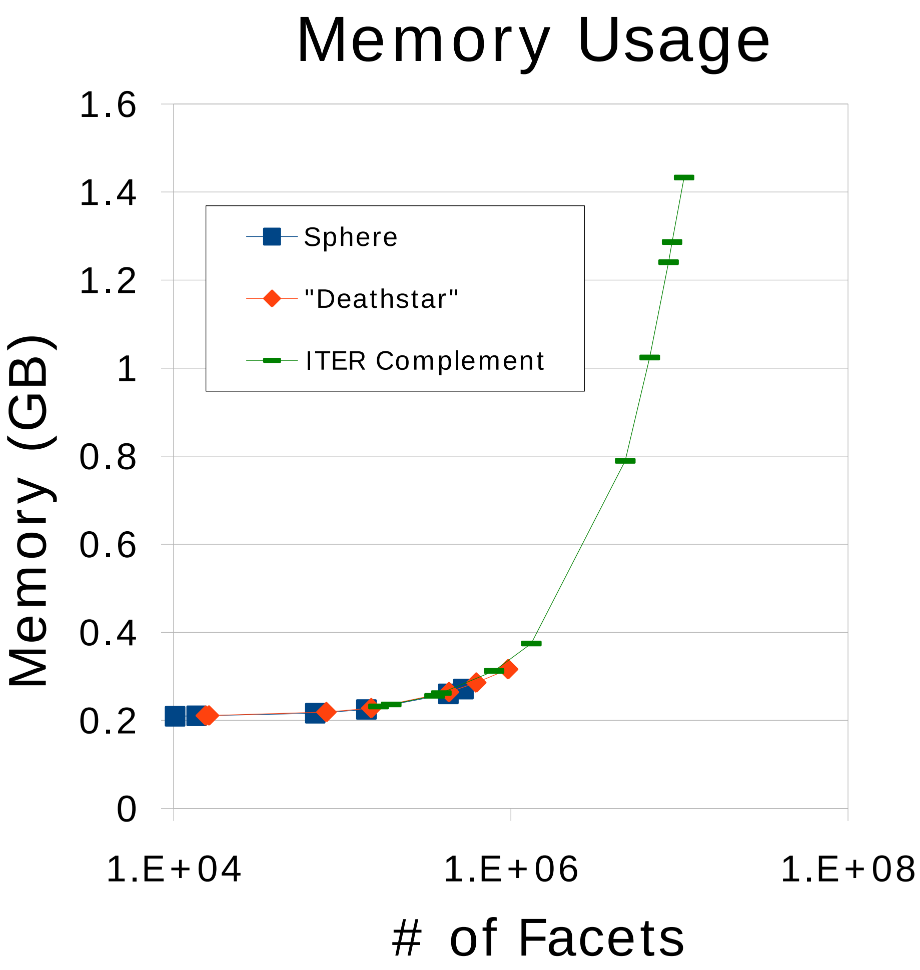


ITER Benchmark Complement



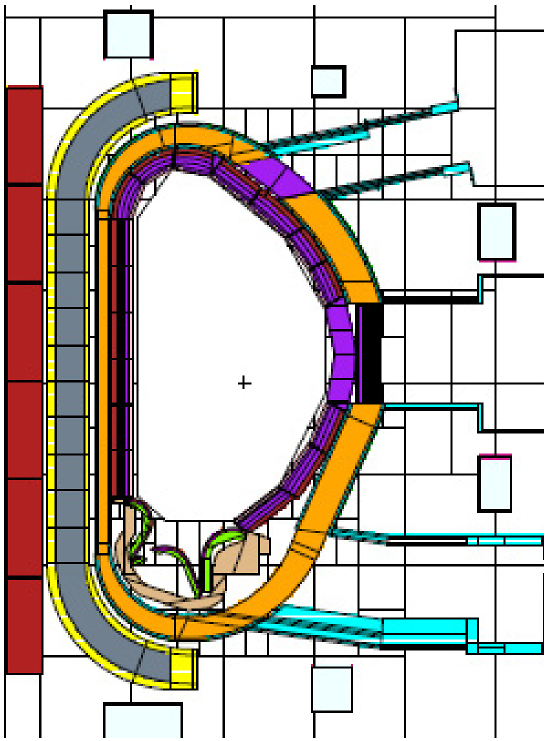
# OBB Tree Performance Not Scaling as Expected



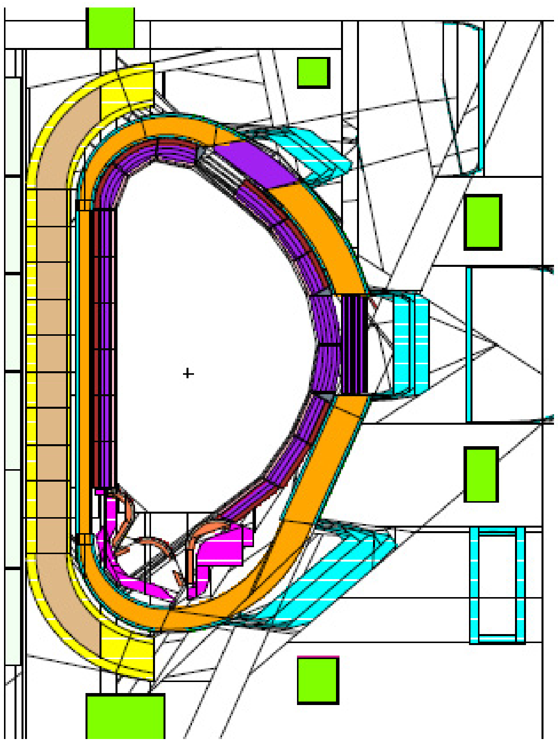



# Performance Compared Using Translated Models

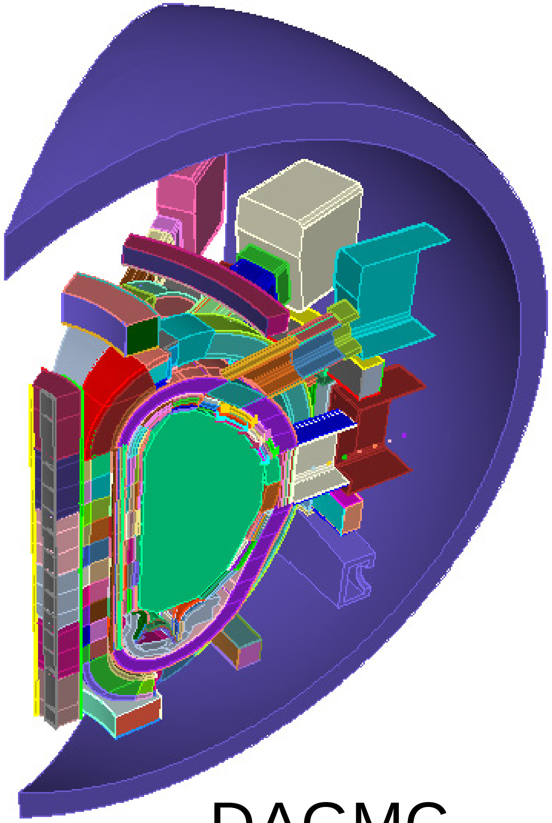
ITER Benchmark Model: >800 cells, ~10,000 surfaces



MCAM Translation



McCad Translation



DAGMC Solid Model

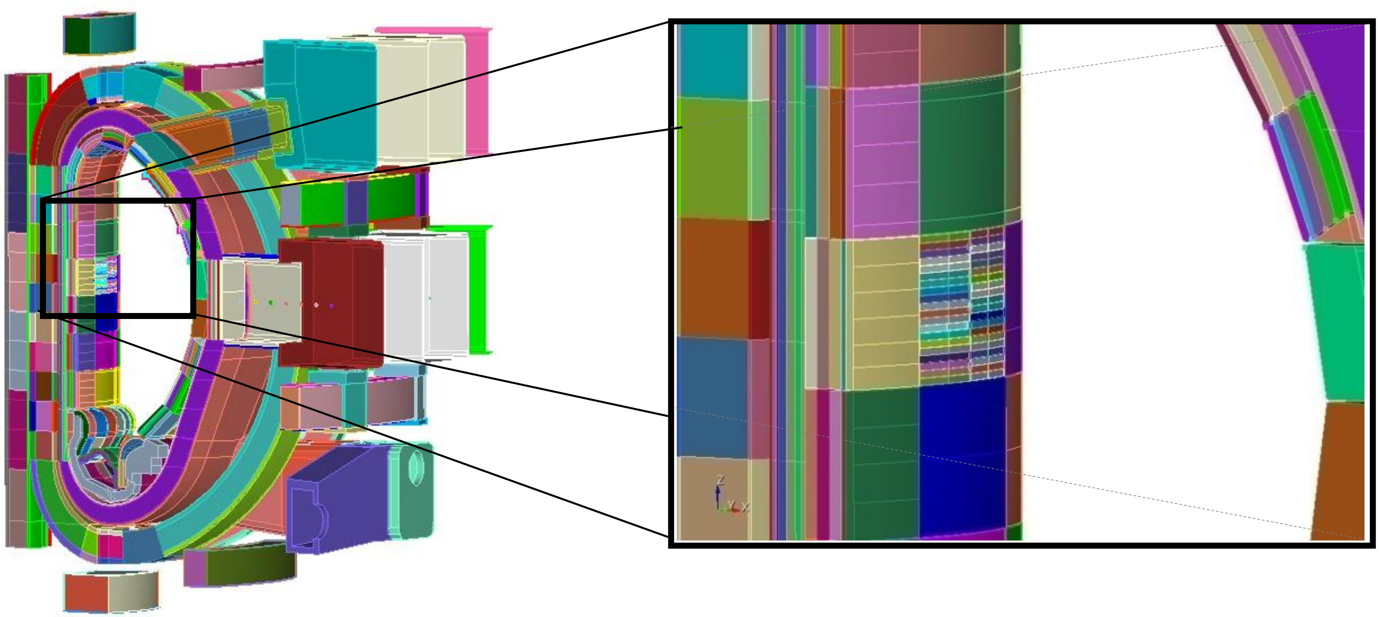
# Overall Performance Less than 3x Slower than Native Geometry

- Performance of translation approaches vary by 60%

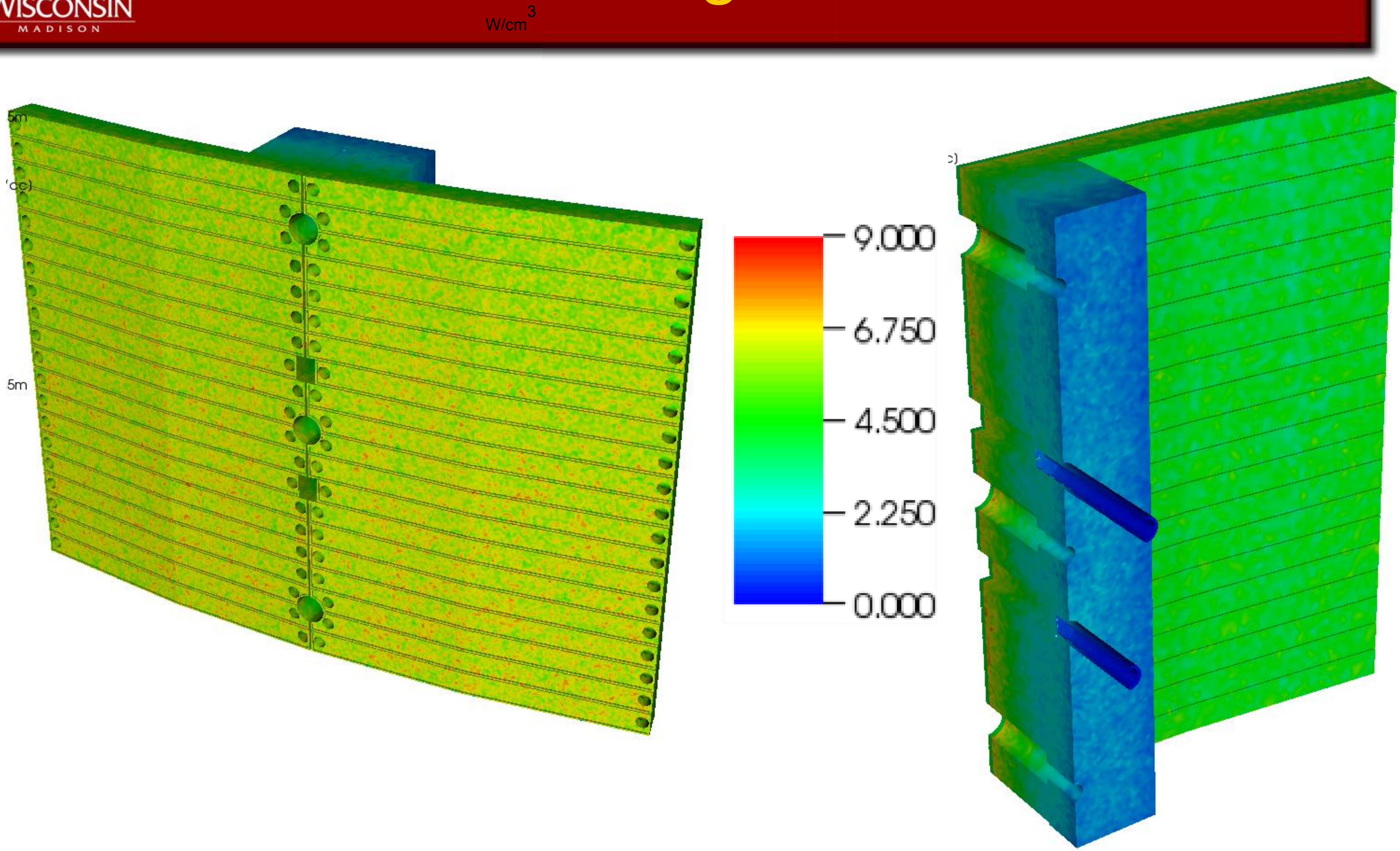
| Model | Number of Volumes | Number of Surfaces | **Relative CPU-Time** |
|---|---|---|---|
| MCAM translation | 4148 | 3192 | **1** |
| McCad translation | 6031 | 3800 | **1.63** |
| DAGMC | 802 | 9834 | **2.46** |

# Sample Application: First Wall & Shield Heating

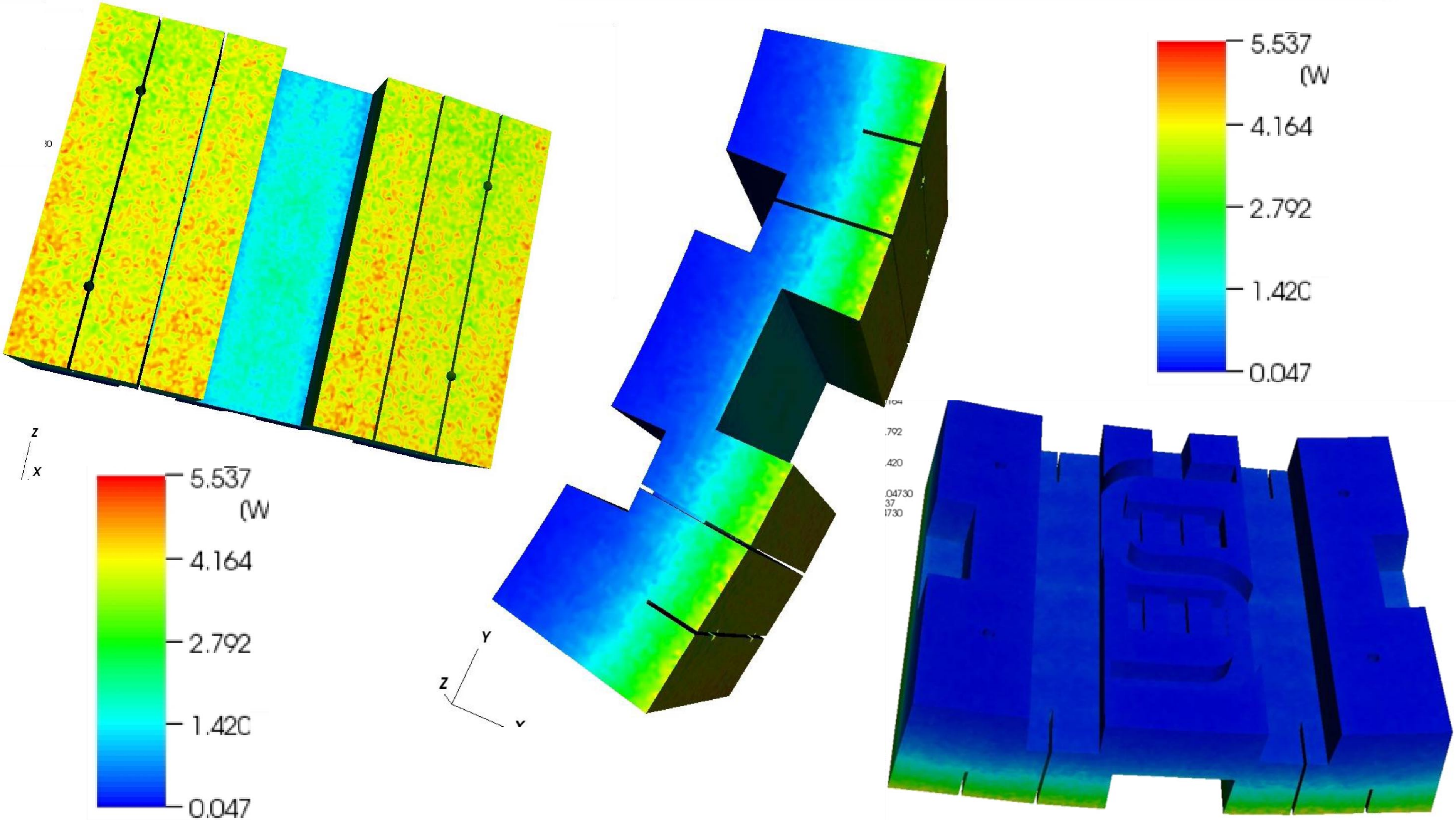
- Module 4 installed in full ITER model
- 500 M neutron histories (240 cpu-days)
- Cartesian mesh tallies
  - varying resolution (3mm – 10 mm) ~23 M voxels



# Nuclear Heating in M4 First Wall



# Nuclear Heating in M4 Shield



# DAG-MCNP5 Available For Use

- Requirements
  - Linux
  - Cubit 10.2 (Sandia National Laboratories)
  - MCNP5 source code (RSICC or NEA)
- Accompanying tools
  - MCNP->CAD converter
  - Mesh interpolation tools
- Coming developments
  - Conformal (body-fitted) mesh tallies
  - Coupling
    - Automated hybrid methods
    - Hi-fidelity activation/isotopics


# Questions?

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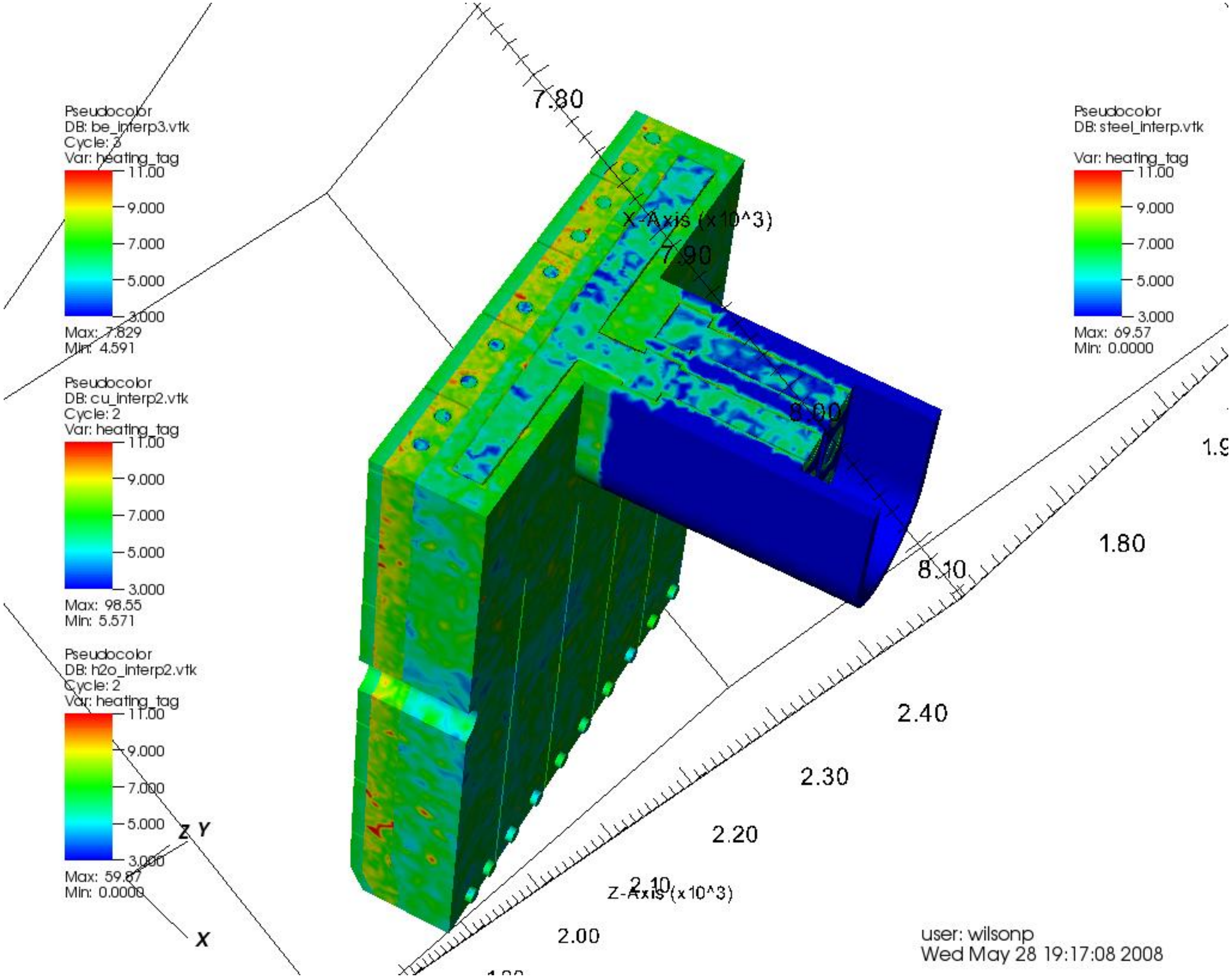
# Nuclear Heating
# Module 13 CFD Mesh



# Other Applications

- Space reactor analysis following large deformations
  - Mesh-based geometry is effectively the same as faceted representation
- ATR National User Facility experiment design
  - Allow experiment designers to more easily iterate

# Other MC codes

- UW development platform
  - MCNPX 2.6.x
  - MCNP5
- External groups
  - CEA: Tripoli-4
    - Implemented but not validated
  - MIT: Geant-4
    - Early development