

# Neutronics Study on SNS Targets

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Target Simulation Workshop

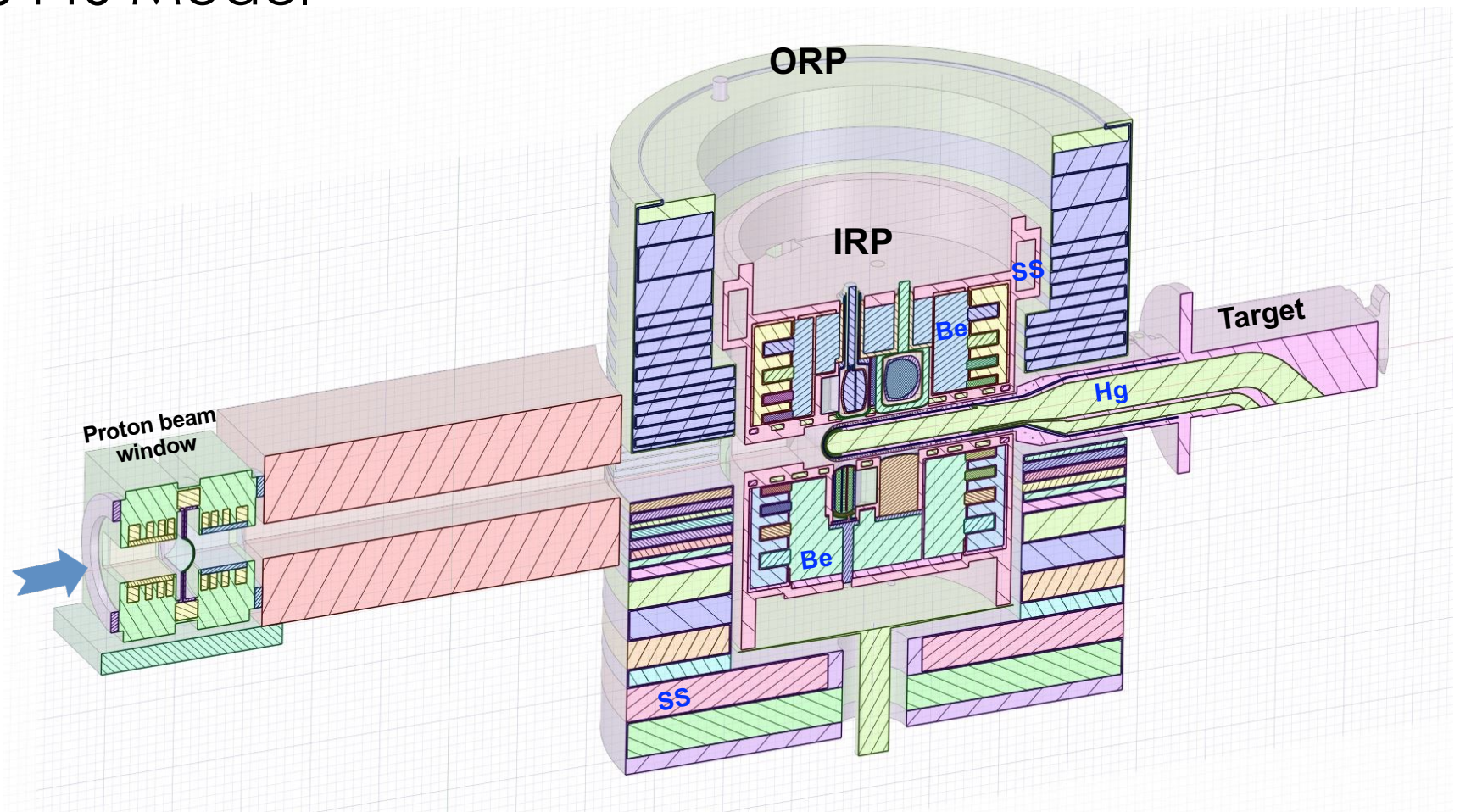
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# Contents

- Constructing source terms at the Target
- Target modeling
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- Calculation method and results
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# SNS FTS Model



# Constructing beam profile at the PBW

- There are four sets of magnets upstream of the harp, all of which are measured by wire scanings. The beam passing after the harp are generally free drifting
- Based on the measurements, accelerator physicists can predict the beam size (RMS) at the proton beam window and the target

The screenshot shows the RTBT Wizard software interface. The main window is titled "RTBT Wizard - Untitled.text". It has a menu bar (File, Edit, View, Window, Help) and a toolbar with icons for file operations and simulation. The interface is divided into several tabs: "Beam Position Tracking", "Beam Orbit Matching", "Beam Size Tracking" (which is the active tab), "Profile Analysis Tool", "Peak Density Prediction", and "Target Beam Archive".

Under the "Beam Size Tracking" tab, there is a section for "Model Live Lattice" with a dropdown menu and a "PV Logger ID" field. Below this is a table of "Measured RMS Values" for various devices, including WS20, WS21, WS23, WS24, and Harp, with columns for X (mm), Y (mm), and a "Use" checkbox. A "Load Fits" button is next to the table.

At the bottom left, there is a "Solver time (s):" field with the value "30" and buttons for "Edit Model Probe" and "Solve".

On the right side, there is a "Results" section. It contains two tables:

**Twiss Matching Results at First Wirescanner**

Parameter	Horizontal	Vertical
Alpha	0.801	-1.599
Beta	7.481	15.806
Emit	33.312	30.747

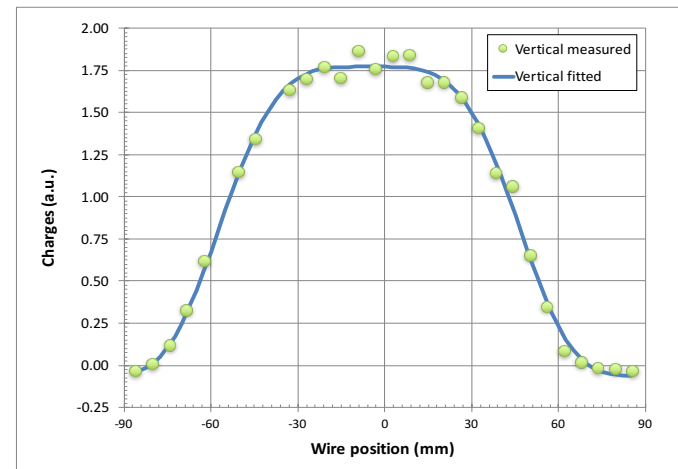
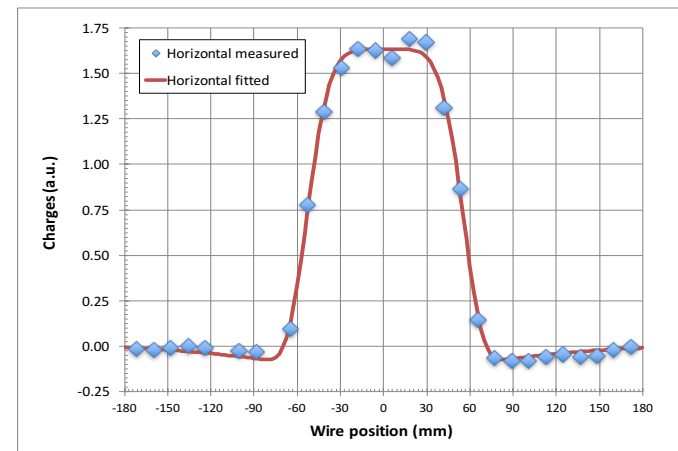
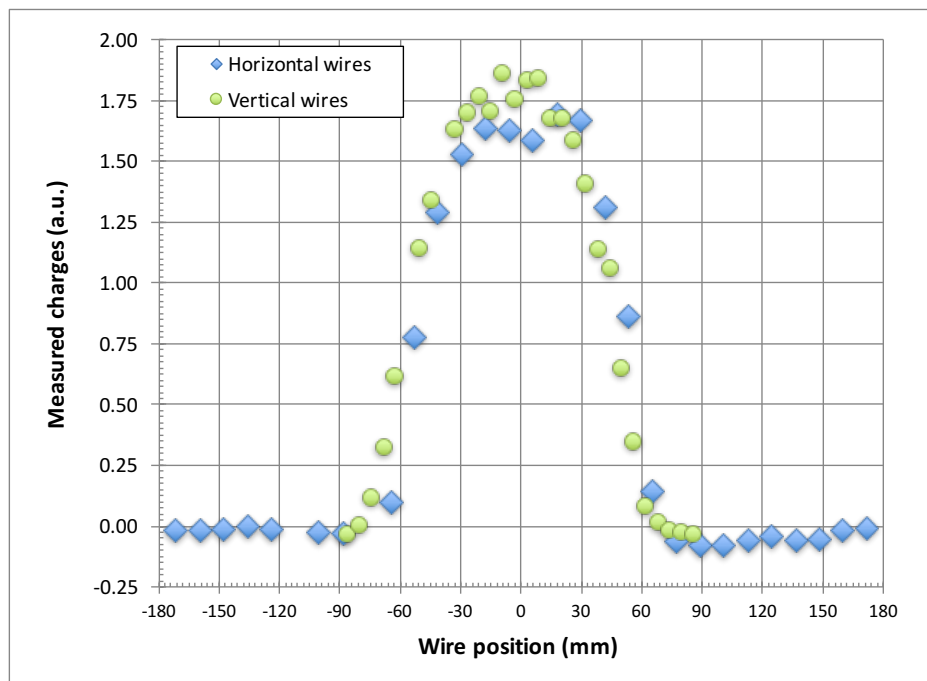
**Beam Size Results**

Location	X (mm)	Y (mm)
RTBT_Diag:WS20	15.786	22.045
RTBT_Diag:WS21	23.068	14.737
RTBT_Diag:WS23	21.422	14.718
RTBT_Diag:WS24	14.605	22.774
RTBT_Diag:Harp30	33.568	33.014
Window	44.375	16.892
Target	48.042	13.248
Target (with scattering)	49.285	17.22



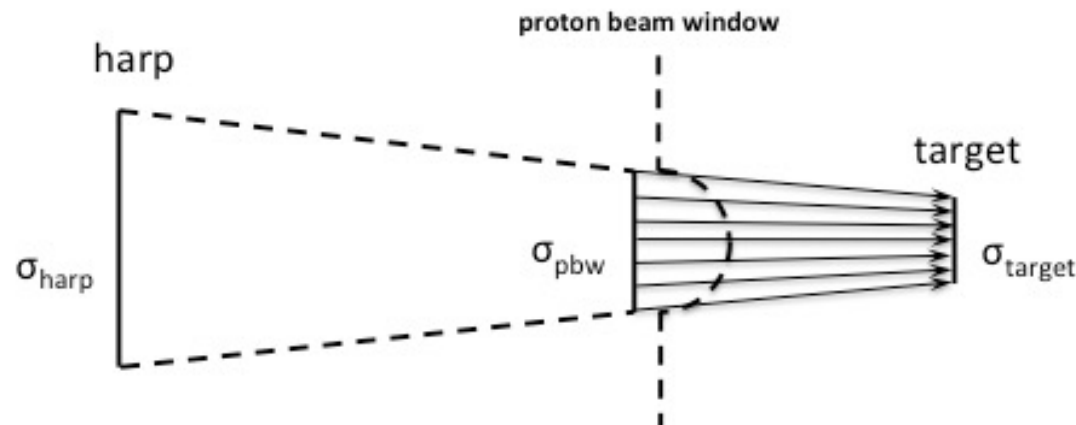
# Beam profiles at the Harp

- Three sets of wires at the harp (23.1 (h) x 42.2 (w) cm<sup>2</sup>)
  - Horizontal, vertical and diagonal
  - 7.912 m upstream of the target



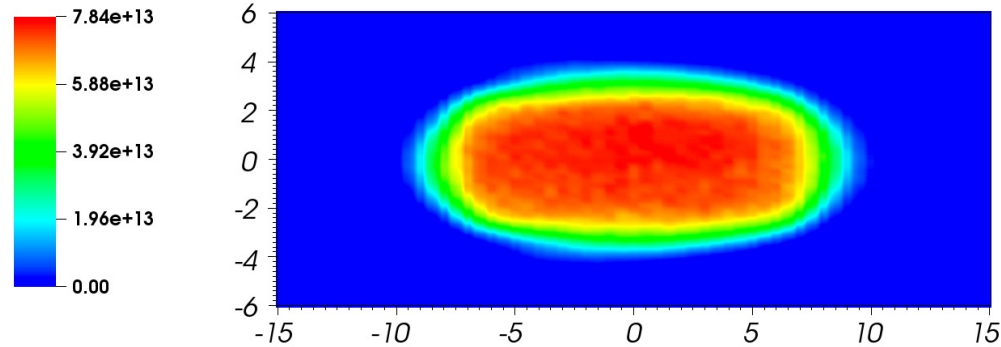
# Constructing beam profile at the PBW

- Scaling the harp measured beam profile to the proton beam window by  $\frac{(\sigma_h \sigma_v)_{pbw}}{(\sigma_h \sigma_v)_{harp}}$
- The direction of each pixel at the proton beam window is pointing to its corresponding pixel at the target, which is scaled by  $\frac{(\sigma_h \sigma_v)_{target}}{(\sigma_h \sigma_v)_{harp}}$



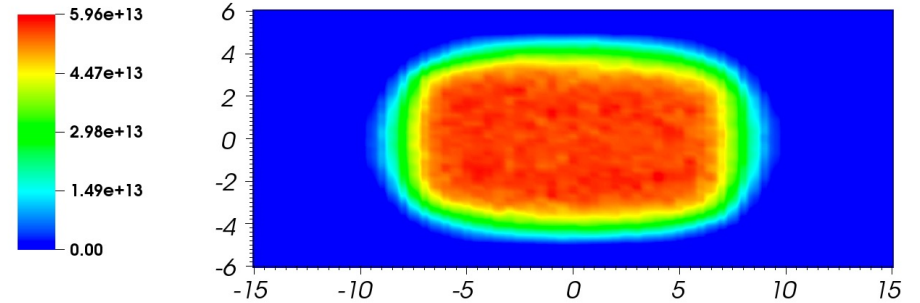
# Beam profiles at the PBW

Flux (p/cm<sup>2</sup>/s/MW)



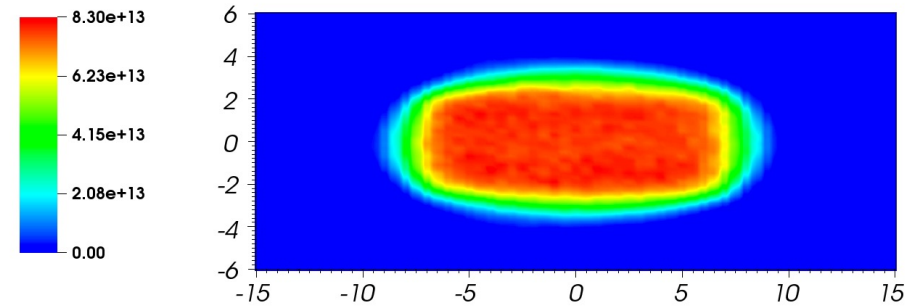
Case J (Nominal)

Flux (p/cm<sup>2</sup>/s/MW)



Case E (Underfocused)

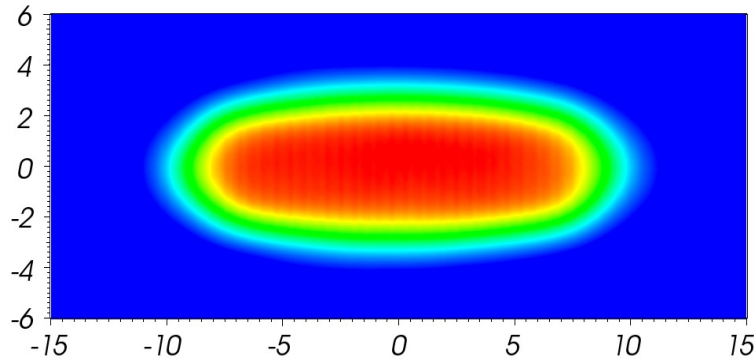
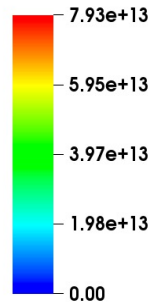
Flux (p/cm<sup>2</sup>/s/MW)



Case B (Overfocused)

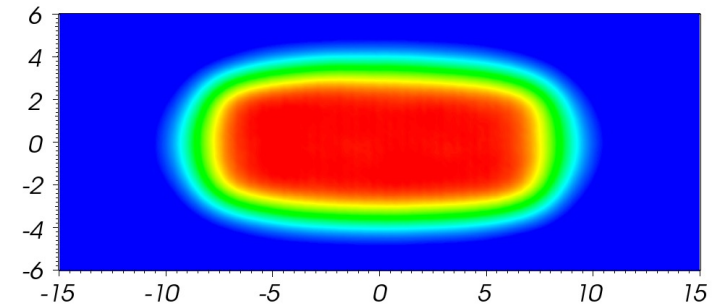
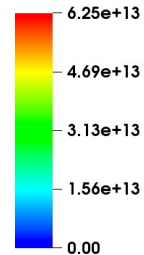
# Incident proton beam profiles on target

Flux (p/cm<sup>2</sup>/s/MW)



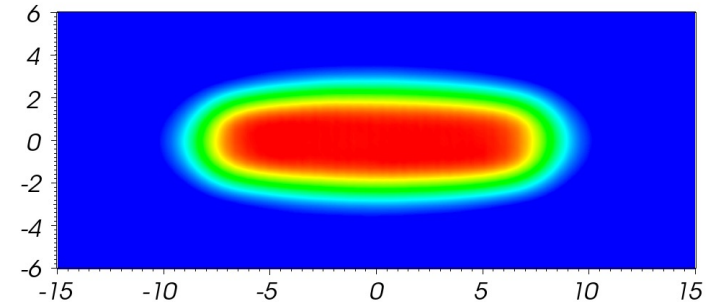
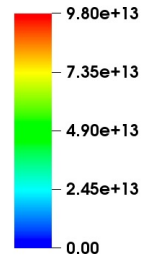
Case J (Nominal)

Flux (p/cm<sup>2</sup>/s/MW)



Case E (Underfocused)

Flux (p/cm<sup>2</sup>/s/MW)



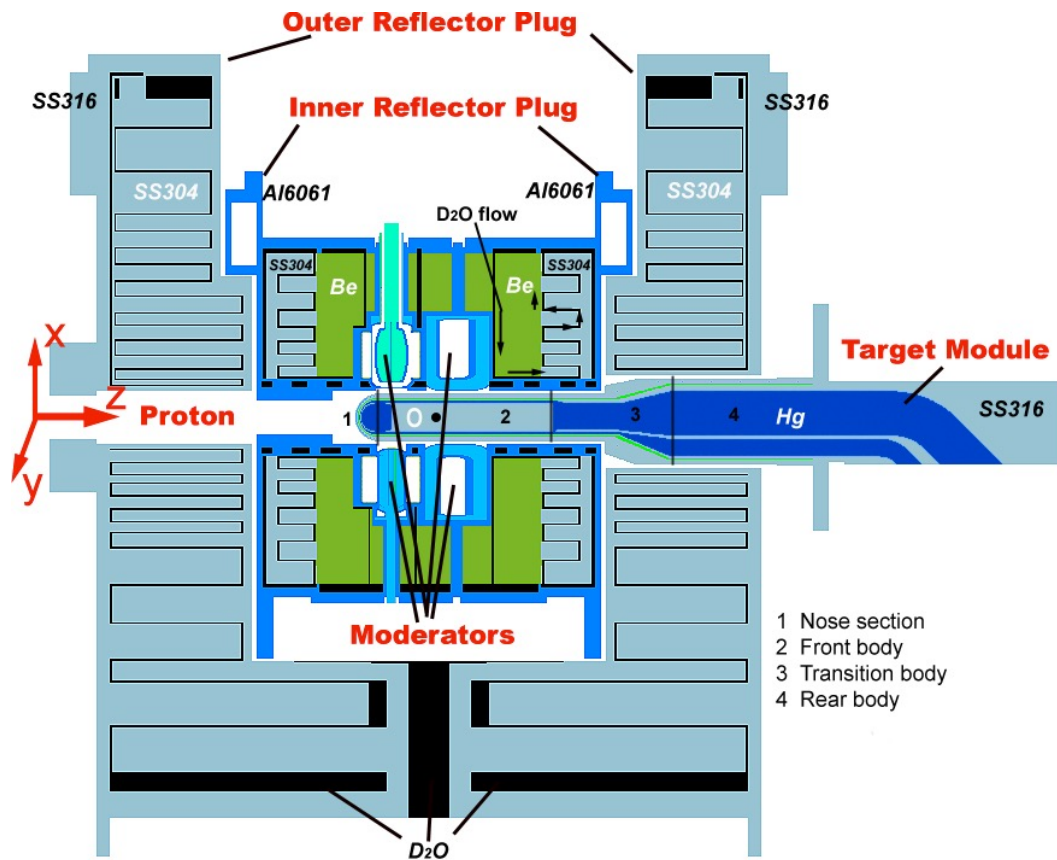
Case B (Overfocused)



# Target Modeling at SNS

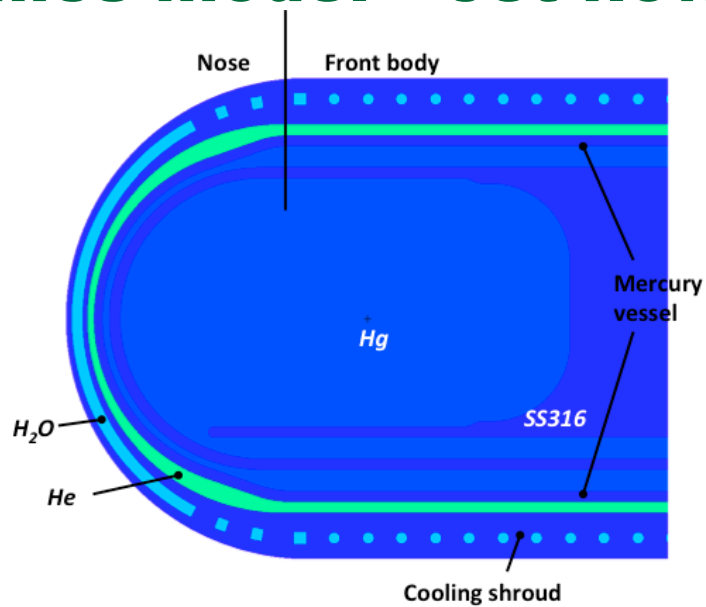
- Conventional modeling uses code provided surface/body definitions to manually construct geometry model
- Challenge to supporting engineering design
  - Complicated design model
  - High accuracy requirement for neutronic information
  - Short response time waiting for neutronic information

# Traditional Neutronics model – TMR

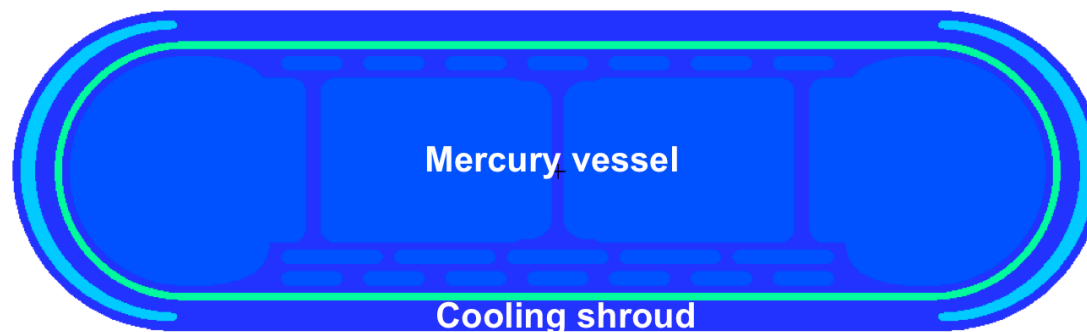


- Mercury vessel (SS316)
  - Nose section
  - Front body
  - Transition body
  - Rear body
- Inner reflector plug
  - Al-6061 structure (D=0.99 m, H=1.22 m)
  - Be reflector (D=0.64 m, H=0.95 m)
  - SS304 shielding blocks
  - Four moderators
- Outer reflector plug
  - SS316 structure (D=1.91 m, H=2.3 m)
  - SS304 shielding blocks

# Neutronics model – Jet-flow target



Elevation view



Transverse view

# High-fidelity Modeling at SNS

- High-fidelity modeling
  - Converts a CAD model automatically into an input file for the Monte Carlo simulation: ***SuperMC & McCAD***
  - Directly run a CAD model in a Monte Carlo simulation: ***DAGMC***
- Both methods were tested at SNS and we opted for DAGMC



# High-fidelity Modeling at SNS - SuperMC

- SuperMC
  - Developed by Y. Wu's team, Institute of Nuclear Energy Safety Technology, Chinese Academy of Science  
(<http://www.fds.org.cn/en/software/SuperMC.asp>)
  - CAD converter and inverter, supports MCNP, TRIPOLI, FLUKA & GEANT4
  - Limited transport capability for running directly a CAD model
  - Hybrid with deterministic transport method like TORT, and coupled with other engineering software for thermal-hydraulic and structural analysis
  - Visualization of the results
  - All are supported in its own GUI

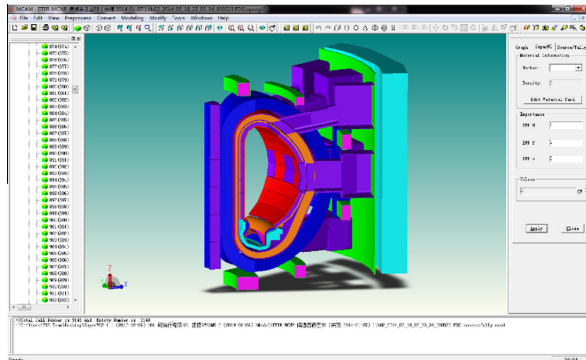


Fig. 3. ITER model conversion in SuperMC.

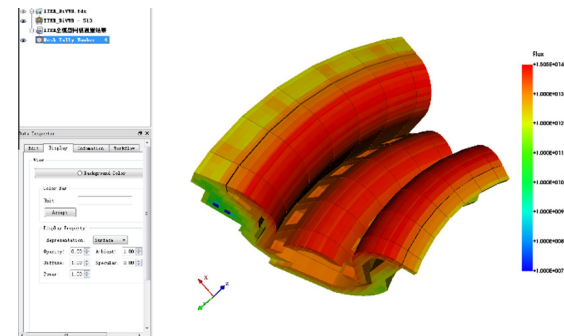
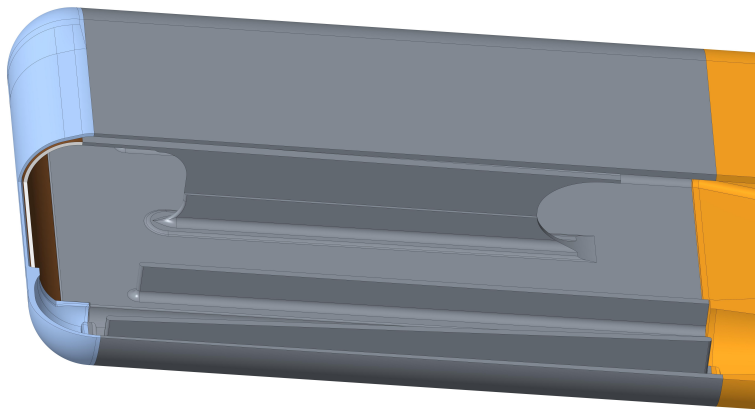
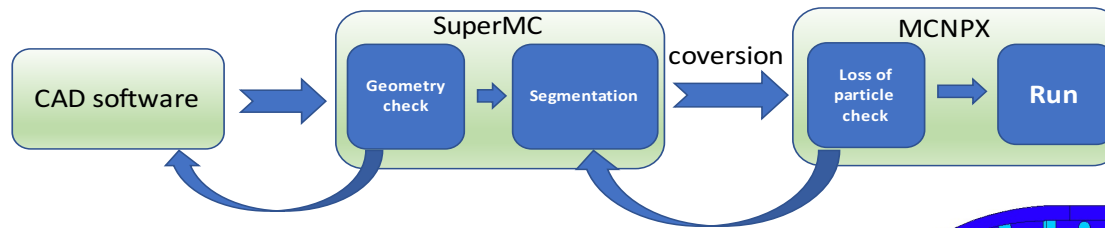


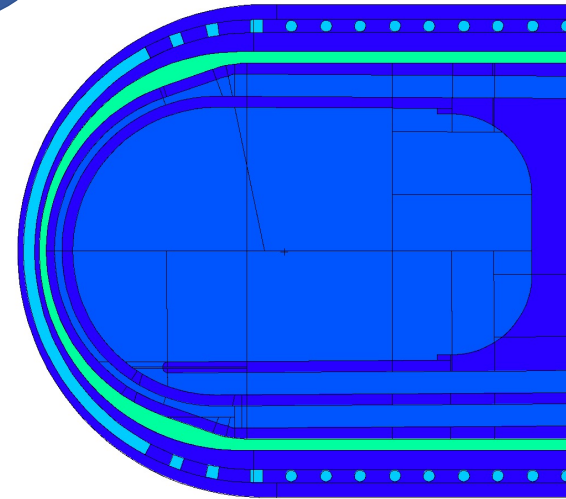
Fig. 6. Visualization of neutron flux distribution in divertor cassettes.

# High-fidelity Modeling at SNS - *SuperMC*

- Hurdles in using SuperMC
  - Not able to deal with spline surfaces
  - Logic not perfect in writing cell descriptions



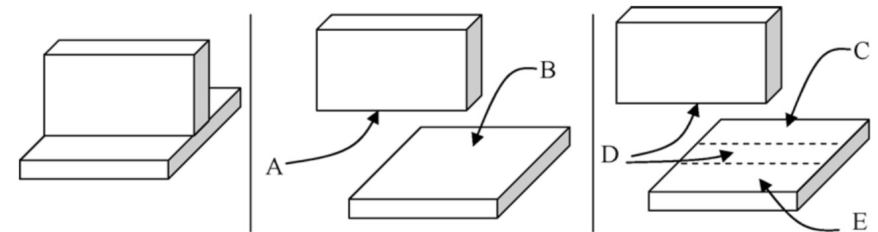
Blue target in CAD model



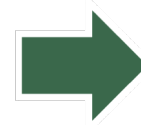
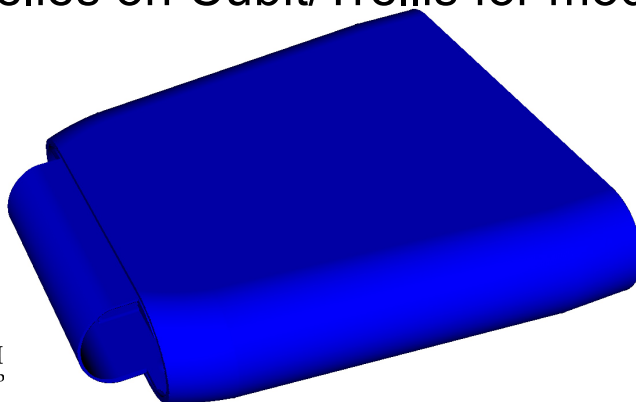
SuperMC converted MCNP model

# DAGMC (Direct Accelerated Geometry Monte Carlo)

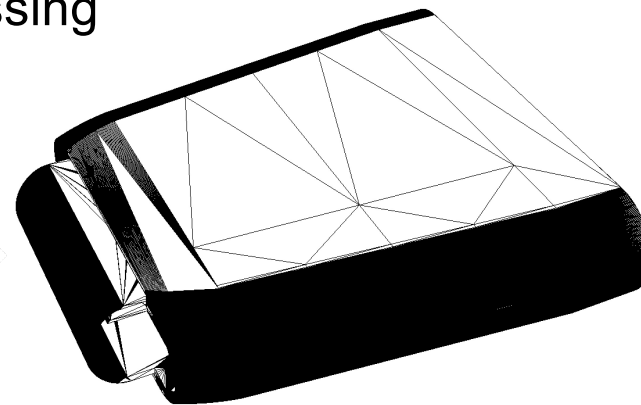
- Developed by Prof. P. Wilson's team, Univ. of Wisconsin-Madison  
<http://svalinn.github.io/DAGMC/index.html>
- Supports MCNP6 (sponsored by SNS), MCNP5, FLUKA, & OpenMC
- Demonstration implementation for Shift, Tripoli & GEANT4
- Acceleration techniques
  - Imprint/merge
  - Surface faceting
  - Oriented bounding box & bounding box tree
- It relies on Cubit/Trellis for model processing



\* P.P.H. Wilson et al. / Fusion Engineering and Design 85 (2010) 1759–1765



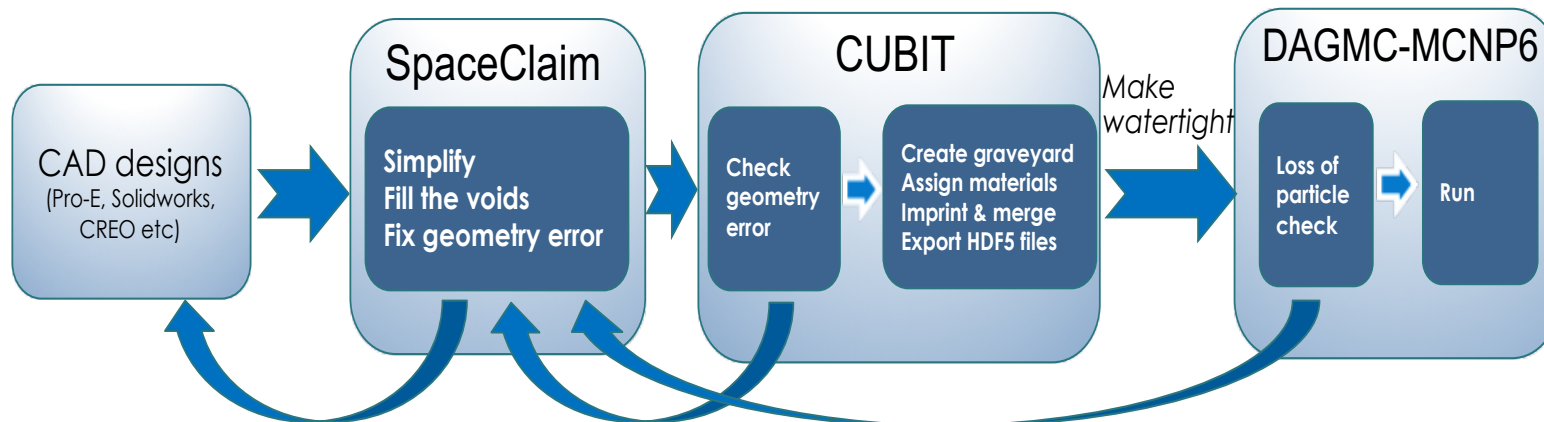
faceting



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# High-fidelity Modeling at SNS

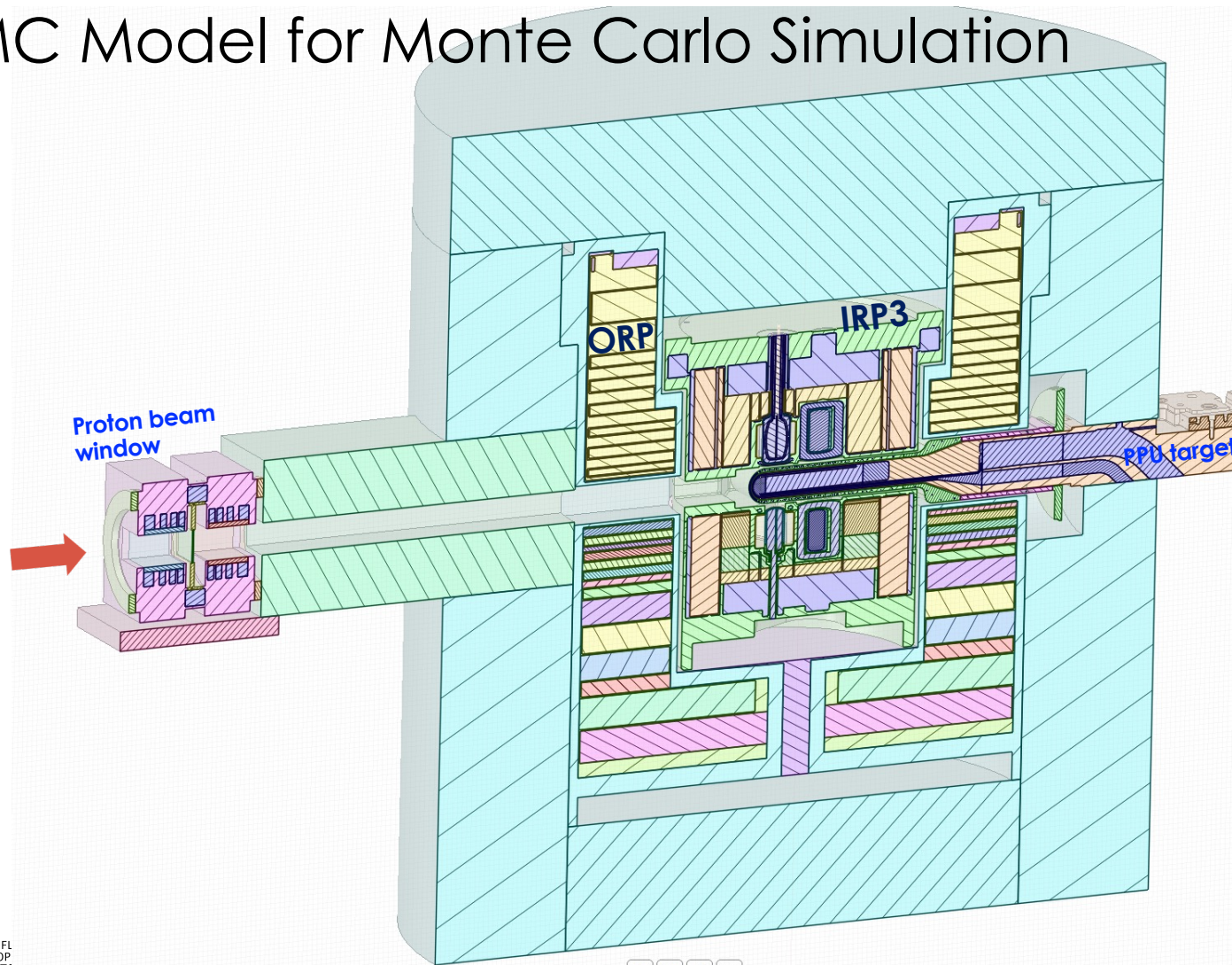
- A native CAD model is usually not suited for DAGMC-MCNP6
  - Loose definition of geometry in CAD vs. water-tight requirement in MC
  - Gaps
  - Overlaps
  - Small details not necessarily needed
  - Fluid space not defined
- CAD model must be fixed and checked before DAGMC-MCNP6 run



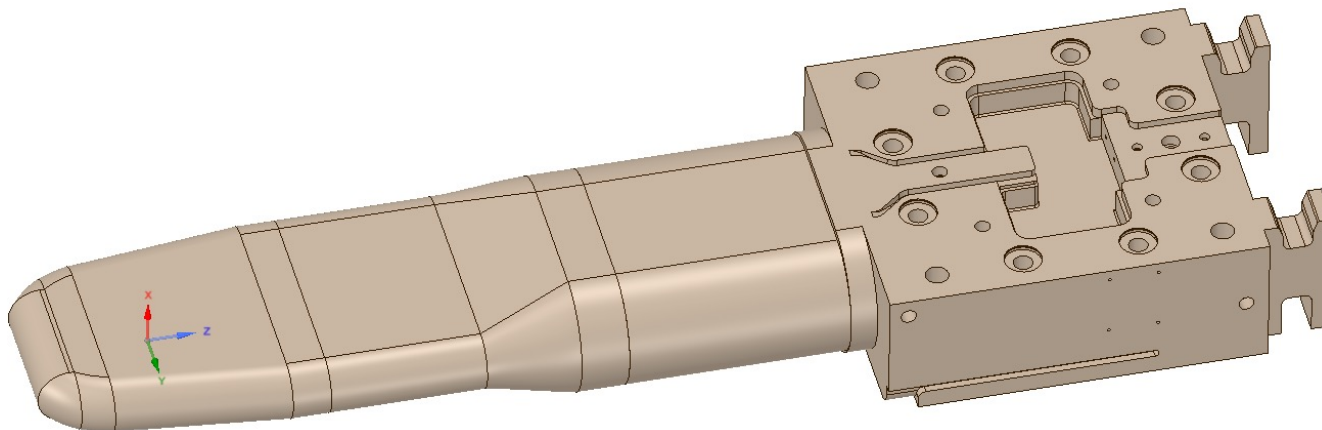
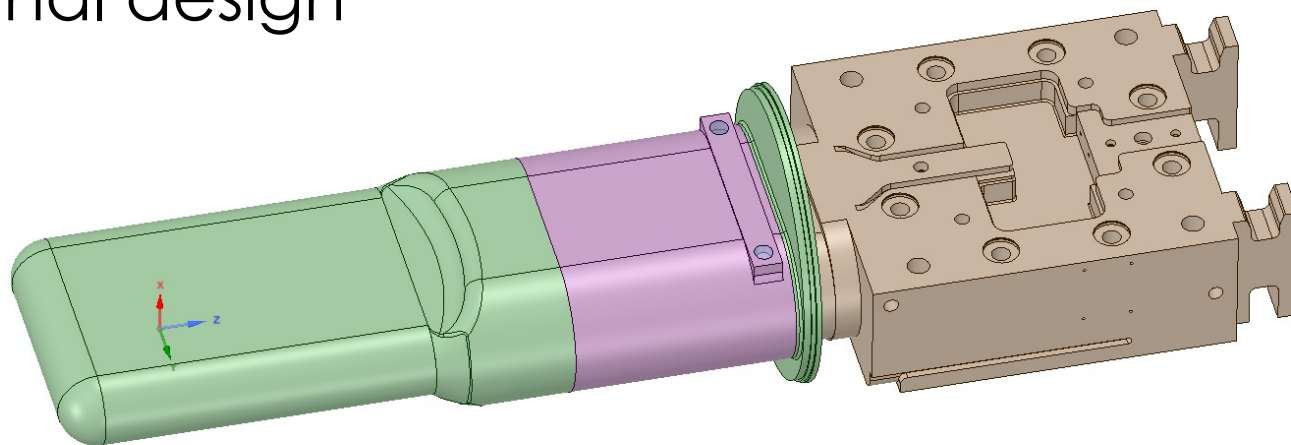
Flow-chart of CAD model preparation for a DAGMC-MCNP6 run



# DAGMC Model for Monte Carlo Simulation

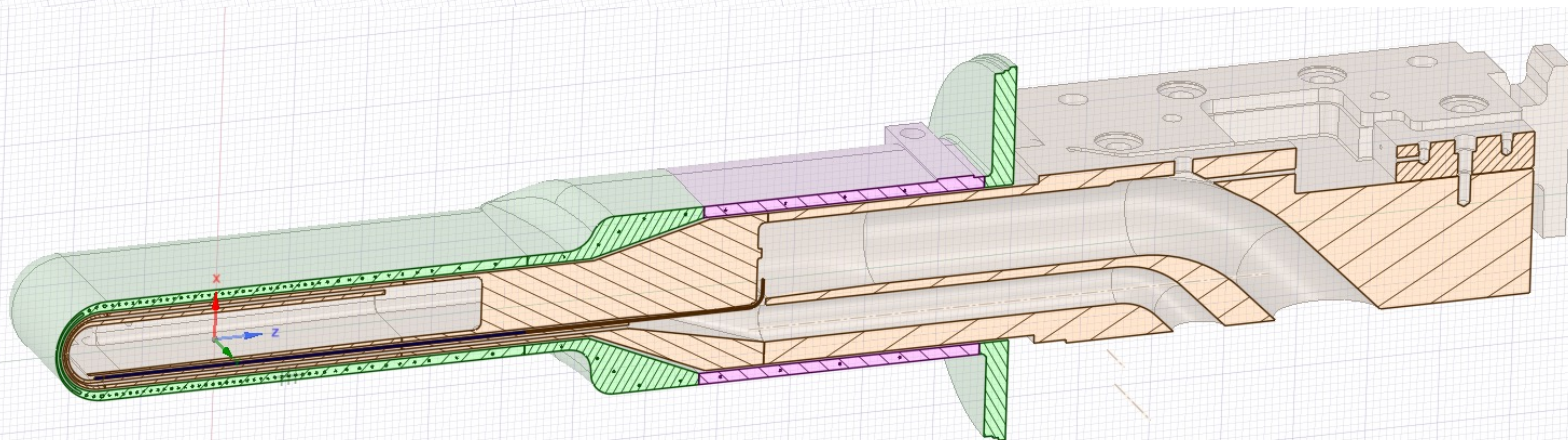
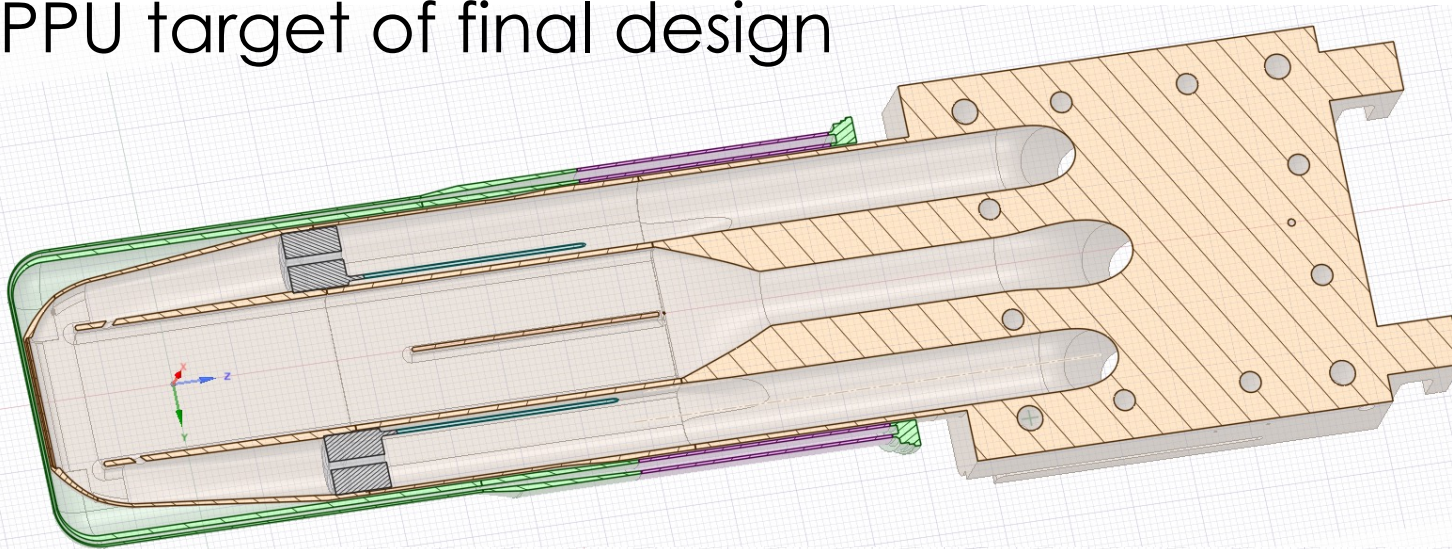


# PPU target of final design

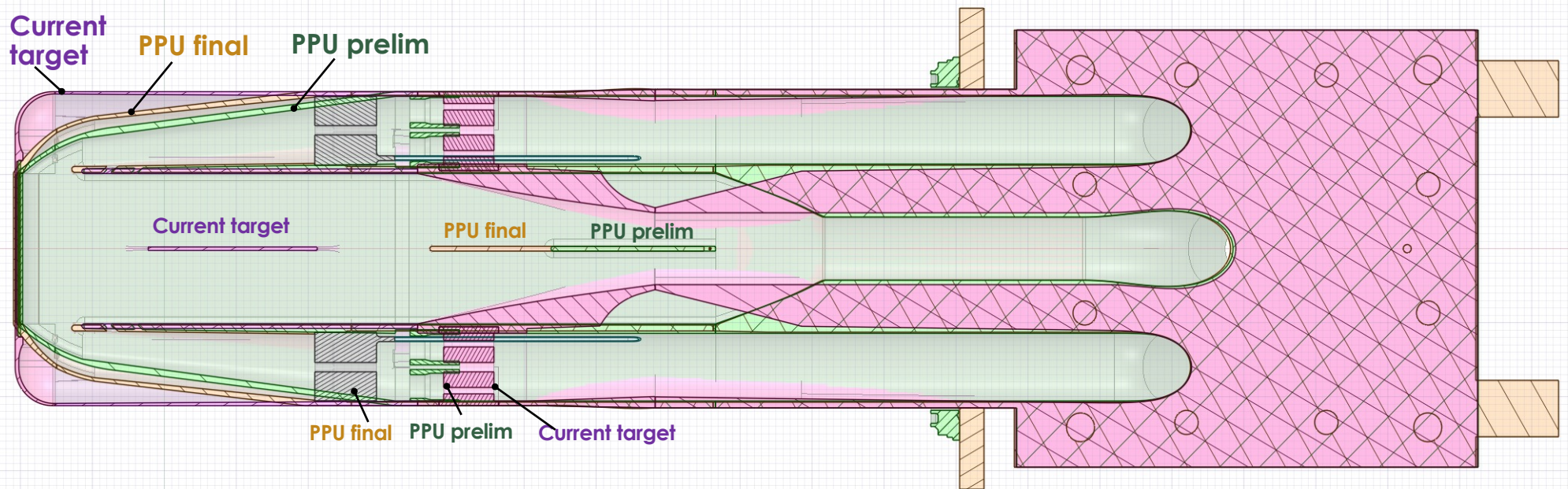




# PPU target of final design

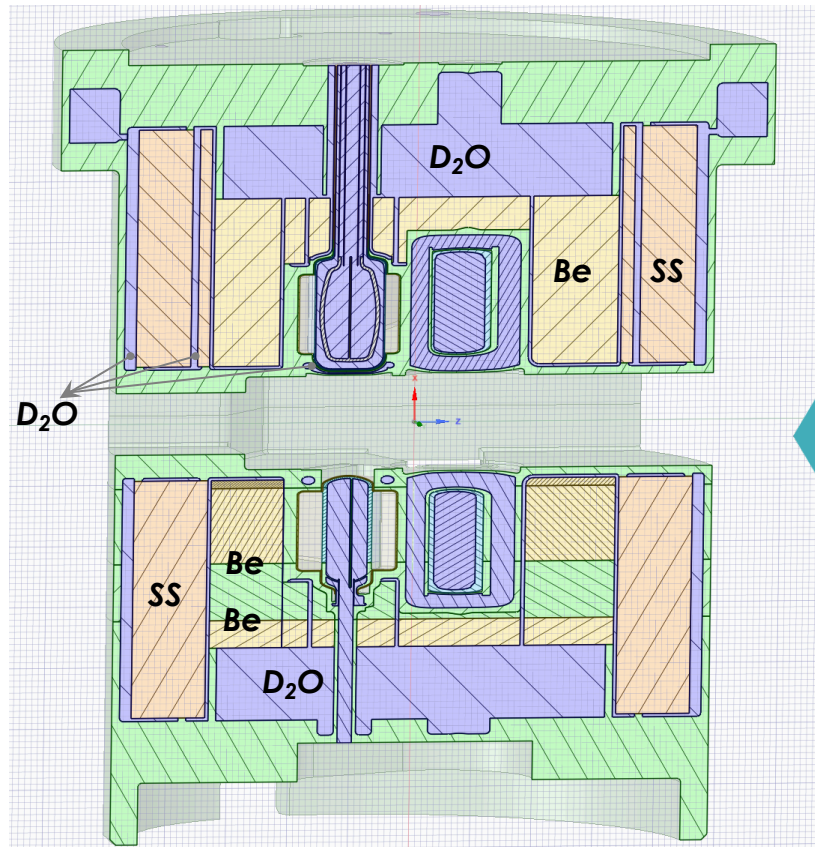


# Target design comparisons

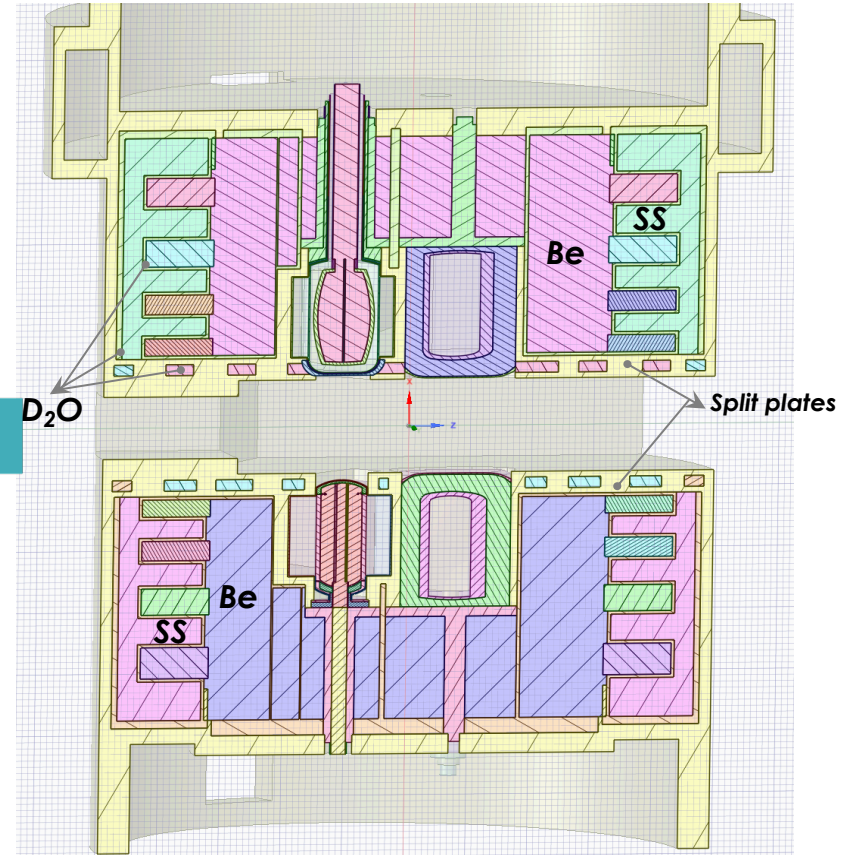




# DAGMC Modeling - *Change of IRPs*



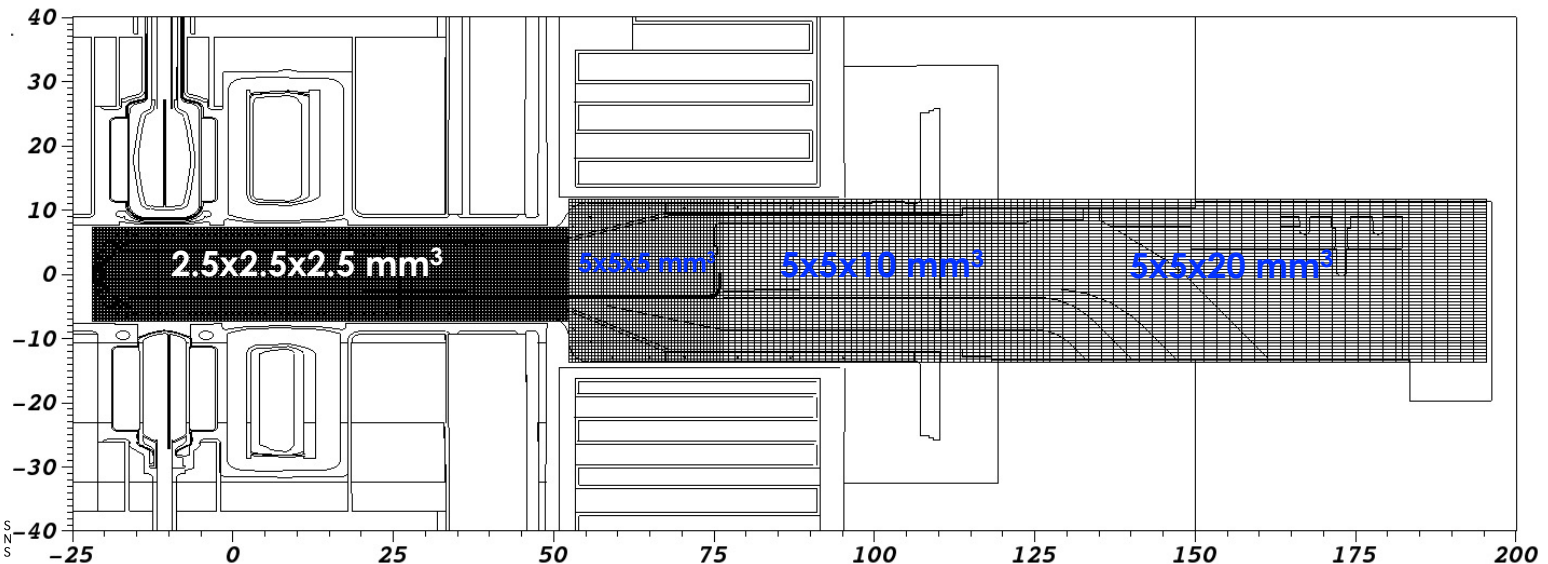
IRP 3



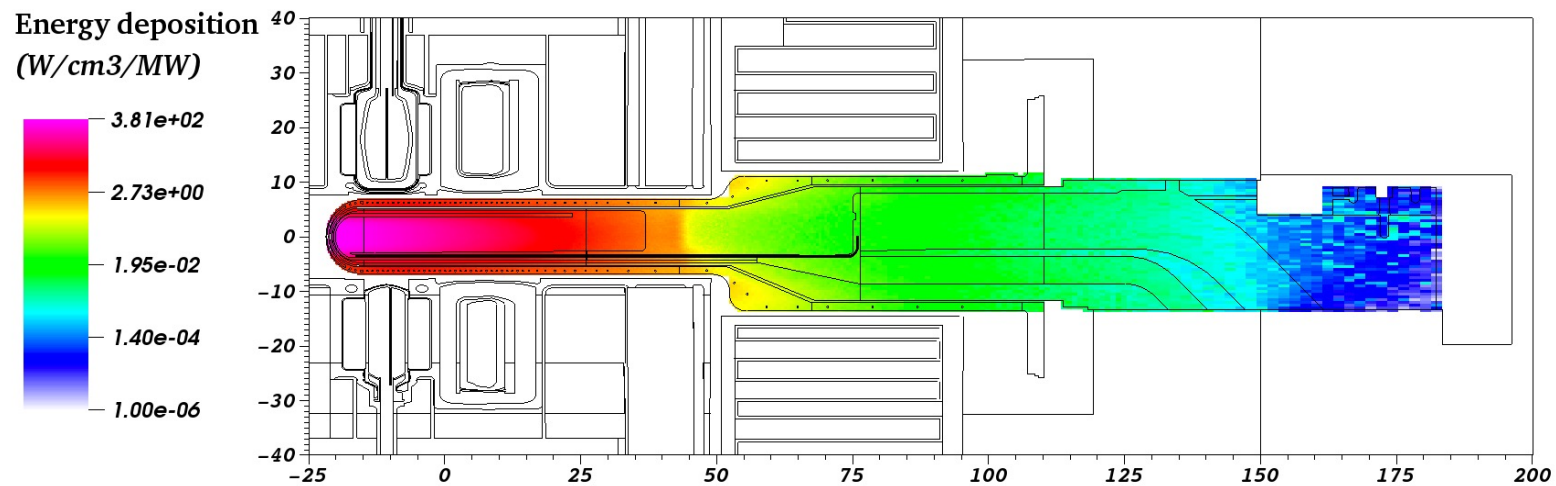
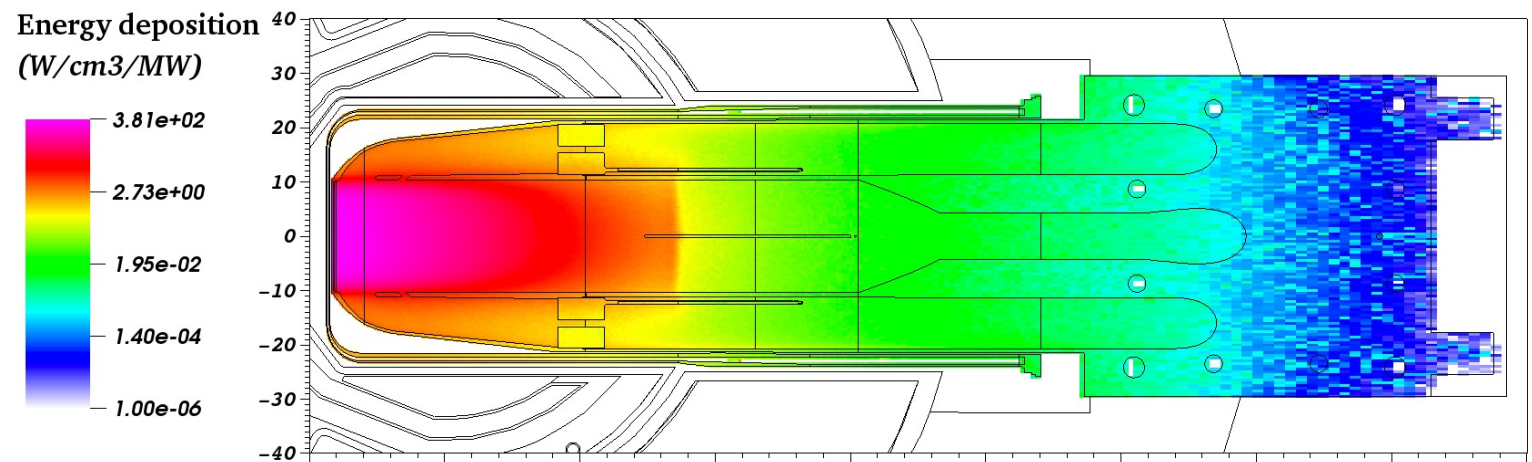
IRP 1 or 2

# Calculation method

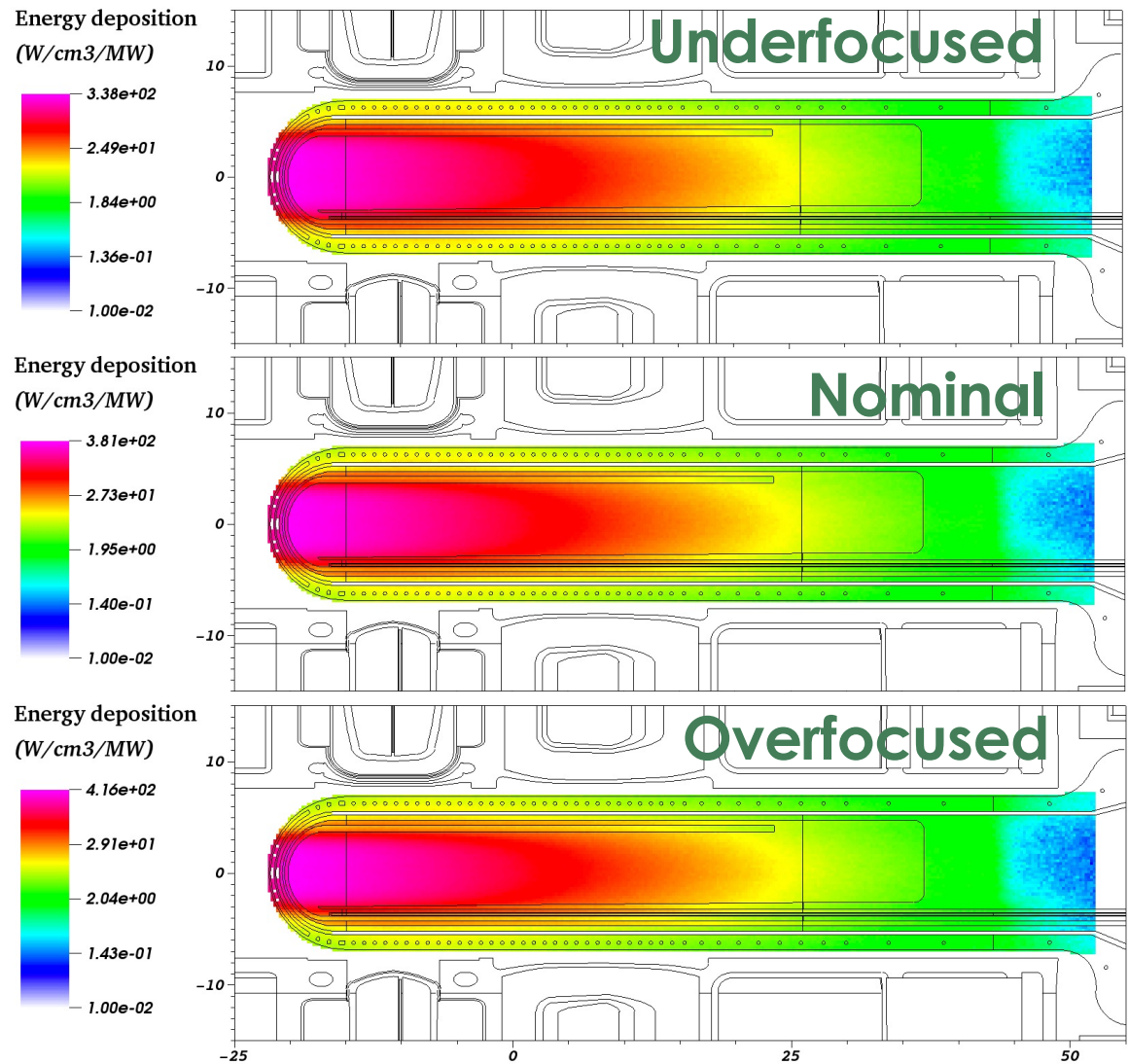
- Revised TMESH tally, which was modified by F. X. Gallmeier to allow tallying energy deposition, flux etc. for a specific material within a mesh element
- MCNPX/MCNP6 not able to calculate the volume of a specific material within a mesh element, therefore a statistical method of volume calculation has to be performed to correct the volume of that specific material. Assuming Material 1 is stainless steel
  - 1. "rmesh3 total mater 1" →  $E_{\text{dept}_{\text{nominal}}}$
  - 2. "rmesh1:n flux mater 1" →  $V_{\text{corr}}$
  - 3.  $E_{\text{dept}} = E_{\text{dept}_{\text{nominal}}} / V_{\text{corr}}$



# Energy deposition results - nominal

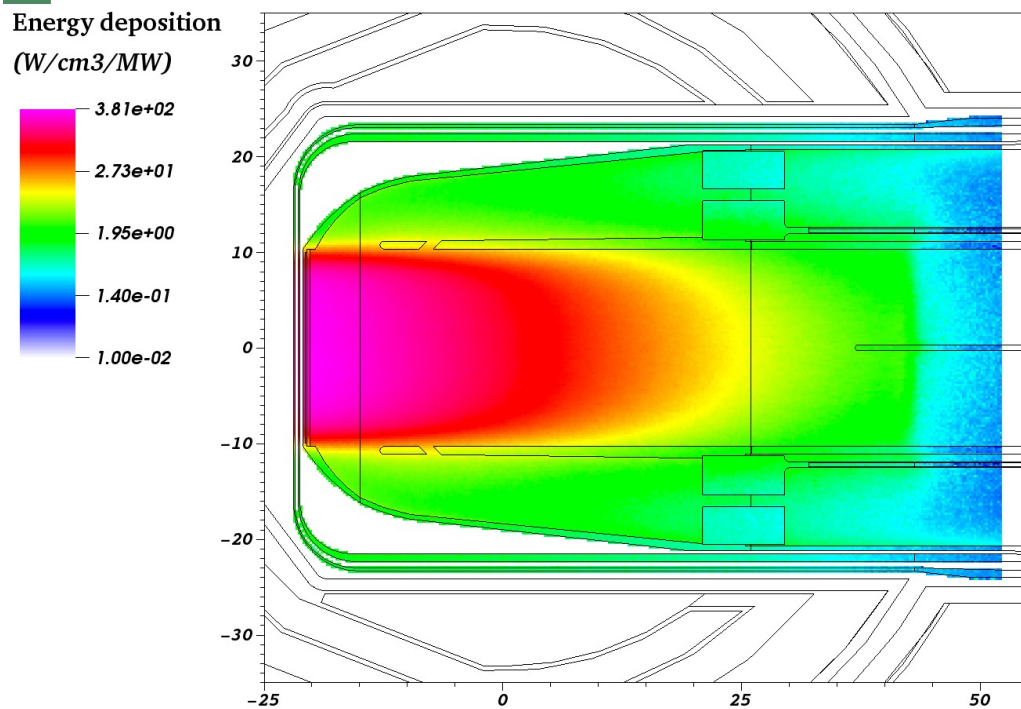


# Energy deposition results

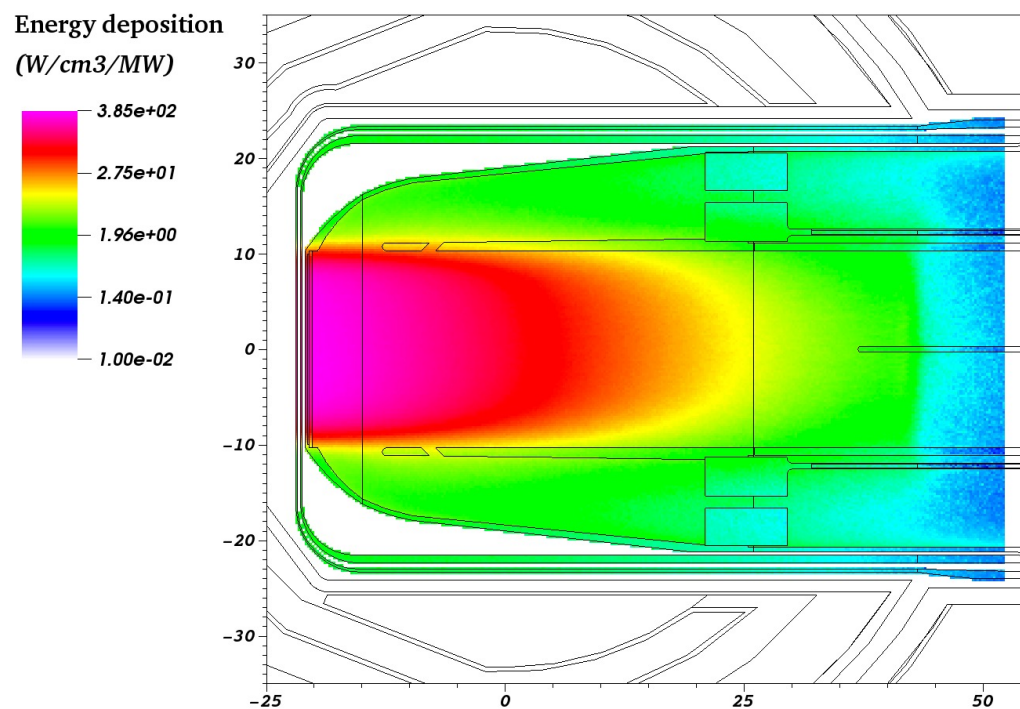




# Energy deposition results



Nominal



Nominal, 4 mm left

## Summary

- For the studying of SNS targets, the more realistic incident proton beam profiles were constructed from the harp measurement
- The traditional modeling of targets at SNS phased into high-fidelity modeling:
  - Greatly expands the ability of handling complicated geometry in modeling
  - Significantly improves the accuracy of the model
  - Reduce the response time to the engineering analysis requests
    - for the target modeling, it is reduced to be  $< 1$  week
- In future, high-fidelity modeling using unstructured mesh may expand our capability for the neutronics study