Neutronics Study on SNS Targets

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Target Simulation Workshop

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- Target modeling
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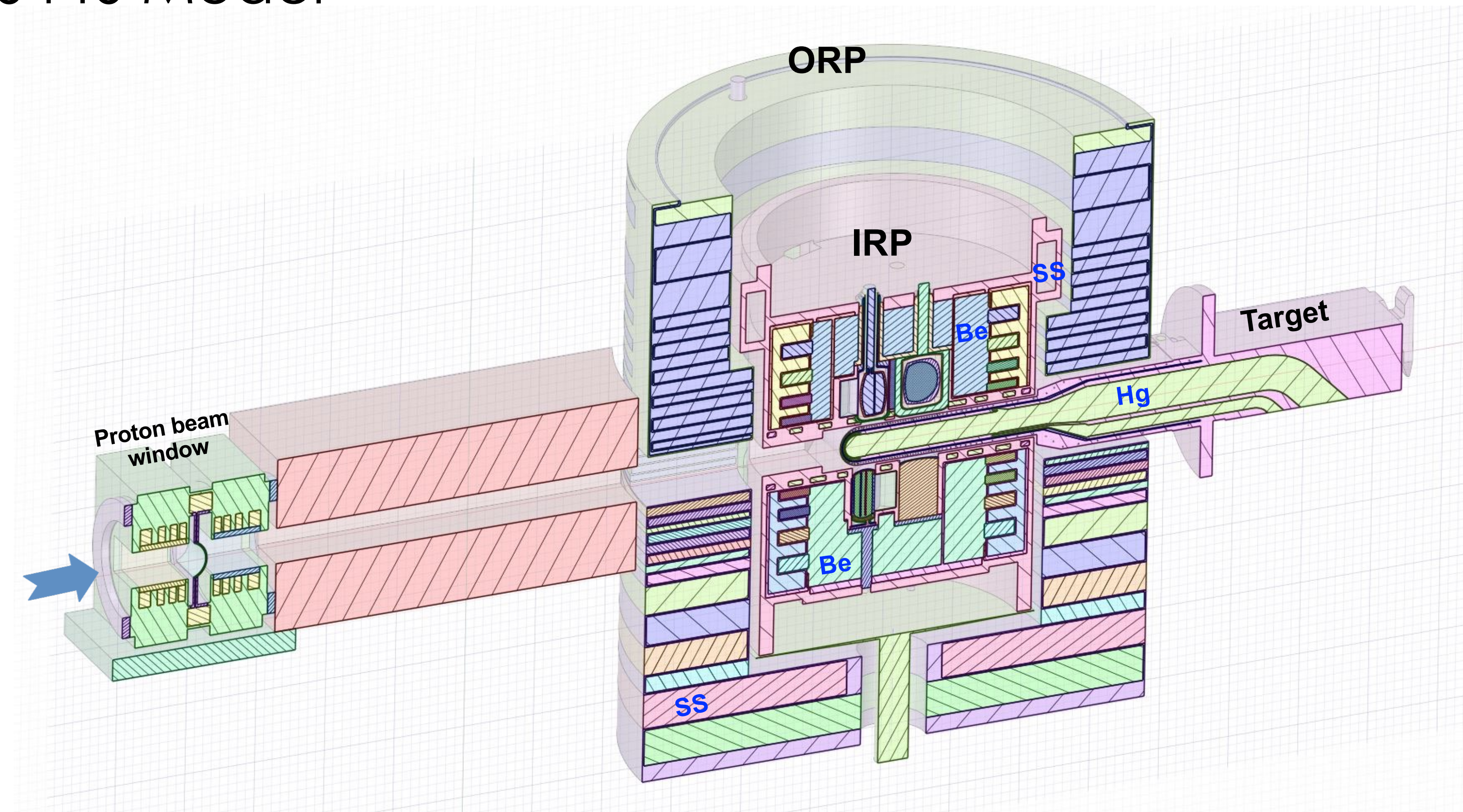
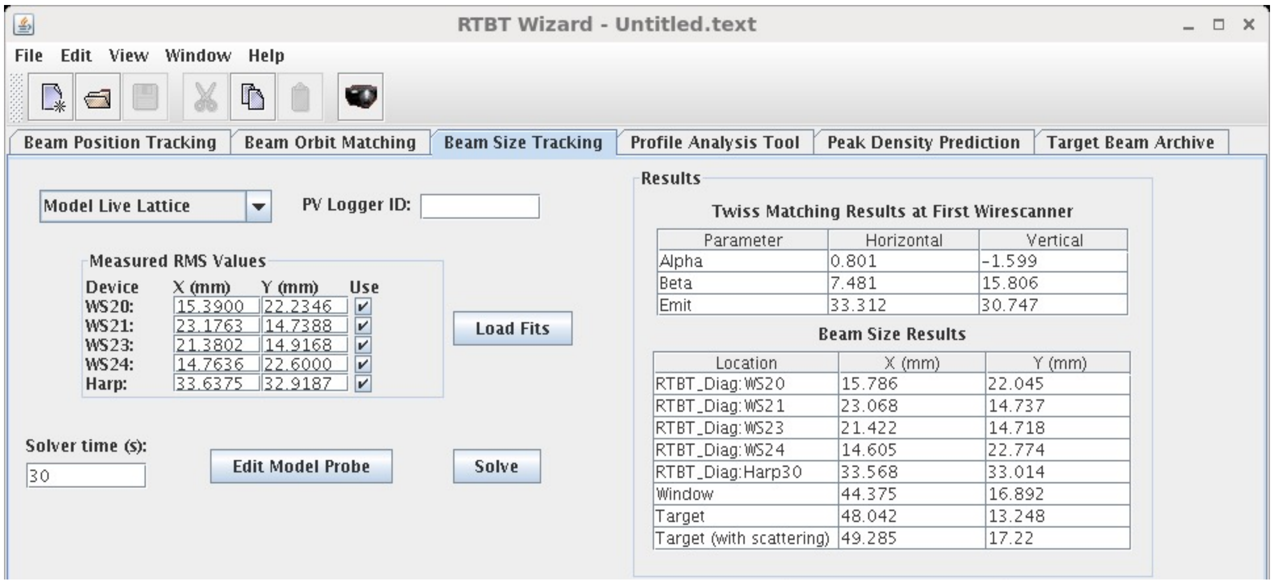
SNS FTS Model



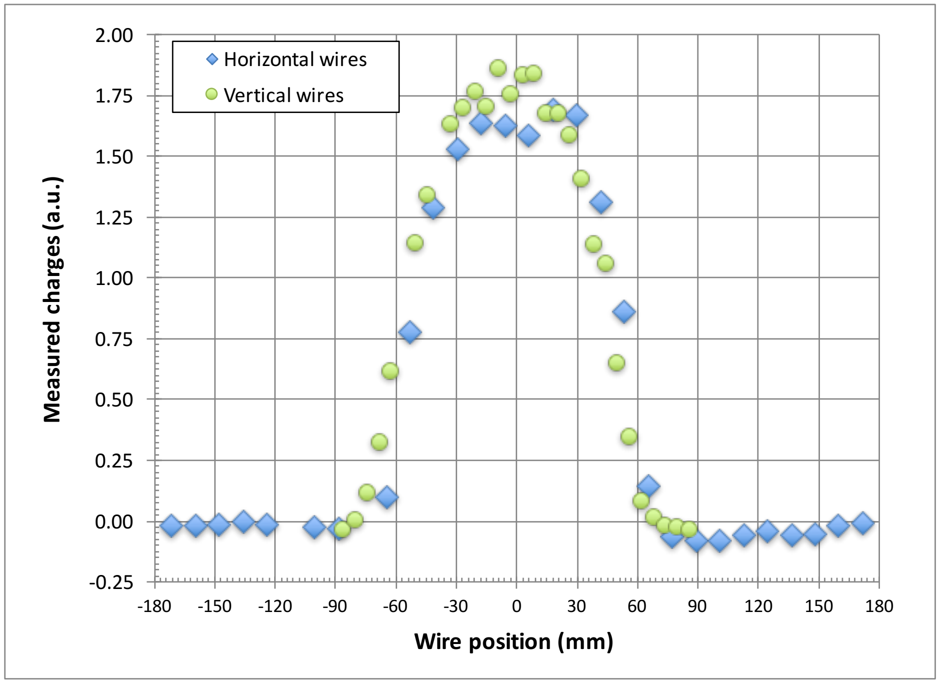
Constructing beam profile at the PBW

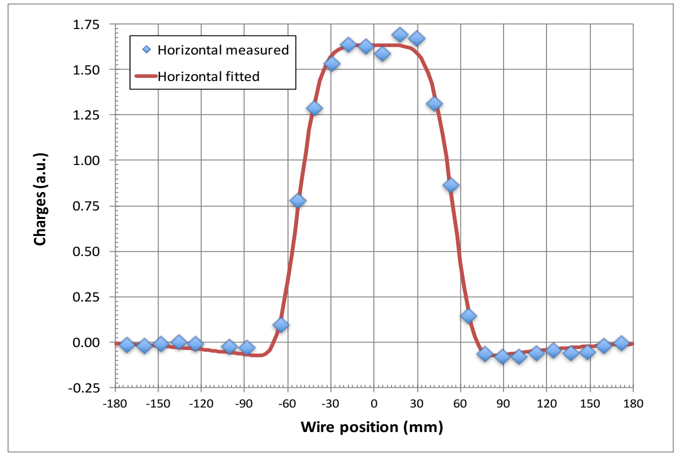
- There are four sets of magnets upstream of the harp, all of which are measured by wire scannings. The beam passing after the harp are generally free drifting
- Based on the measurements, accelerator physicists can predict the beam size (RMS) at the proton beam window and the target

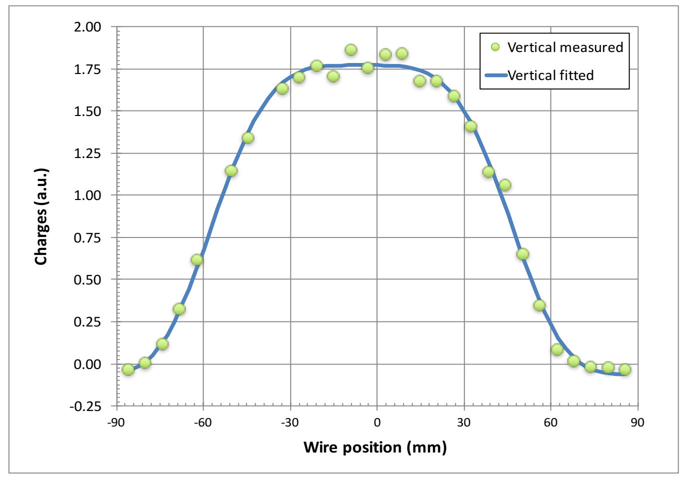


Beam profiles at the Harp

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



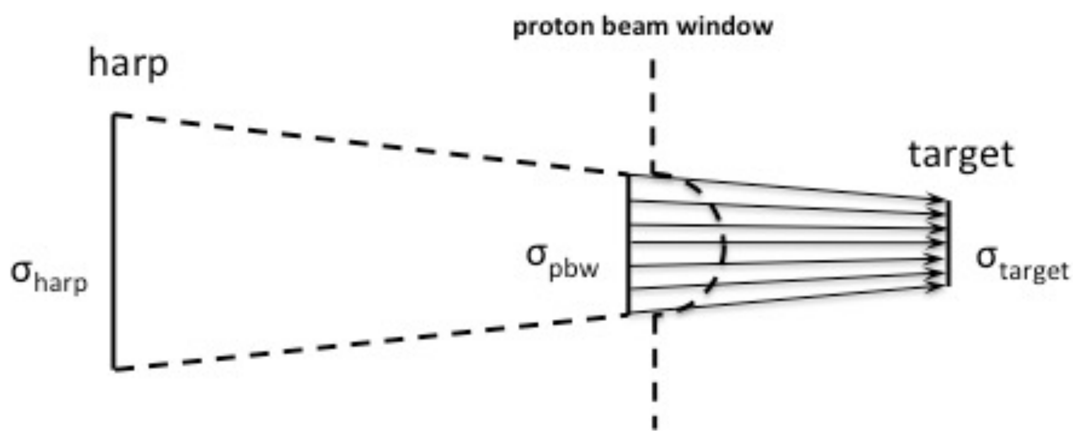




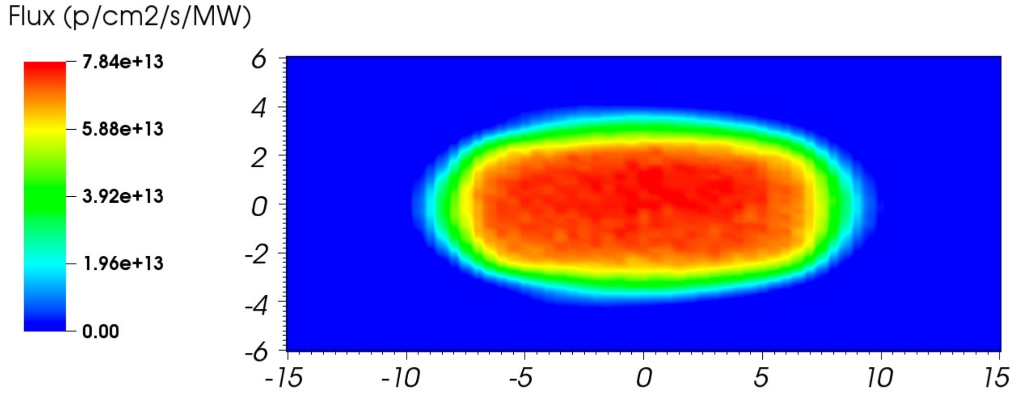
Constructing beam profile at the PBW

- Scaling the harp measured beam profile to the proton beam window by $\frac{(\sigma_h \sigma_v)_{pbw}}{(\sigma_h \sigma_v)_{harp}}$

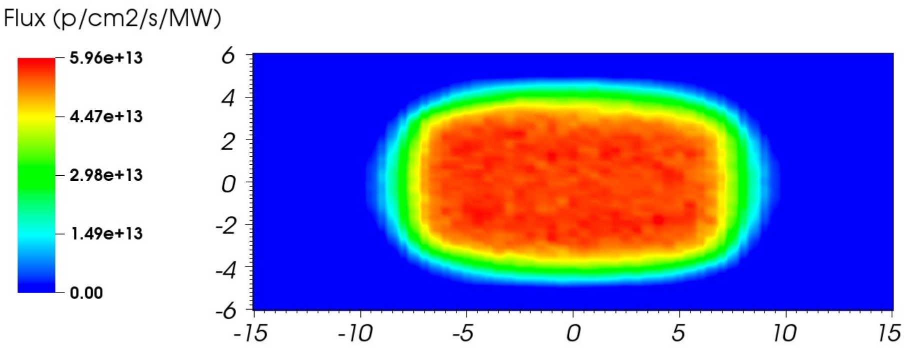
- The direction of each pixel at the proton beam window is pointing to its corresponding pixel at the target, which is scaled by $\frac{(\sigma_h \sigma_v)_{target}}{(\sigma_h \sigma_v)_{harp}}$



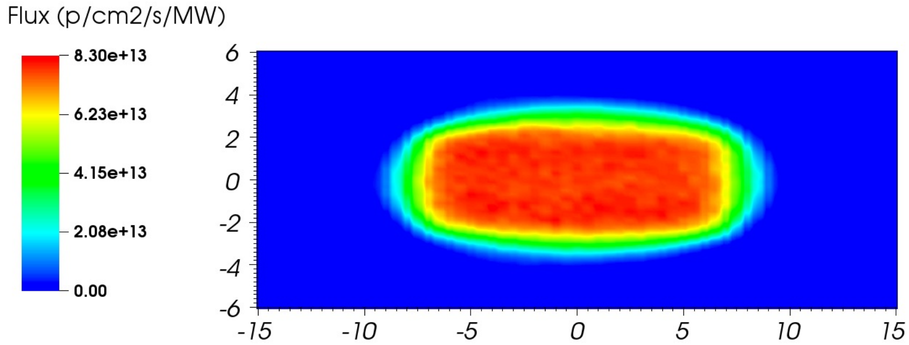
Beam profiles at the PBW



Case J (Nominal)

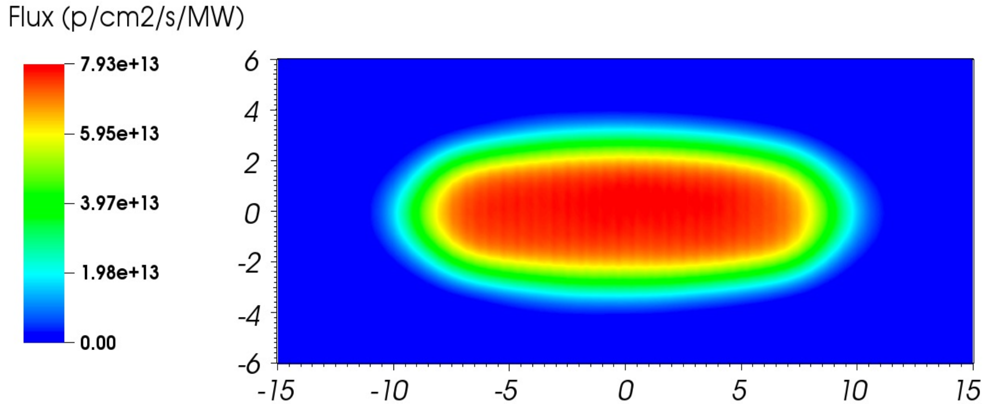


Case E (Underfocused)

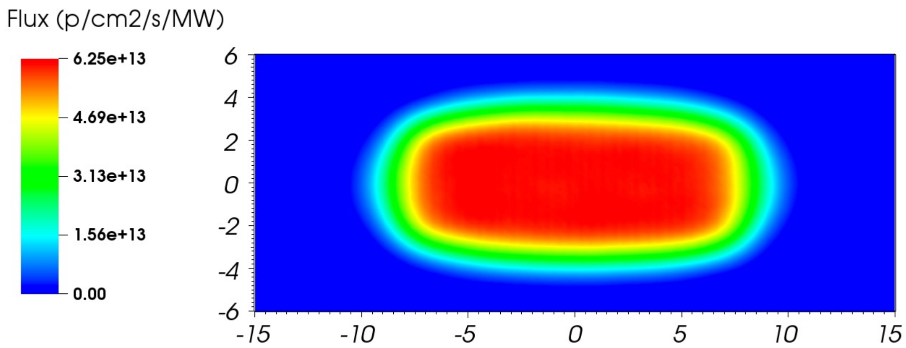


Case B (Overfocused)

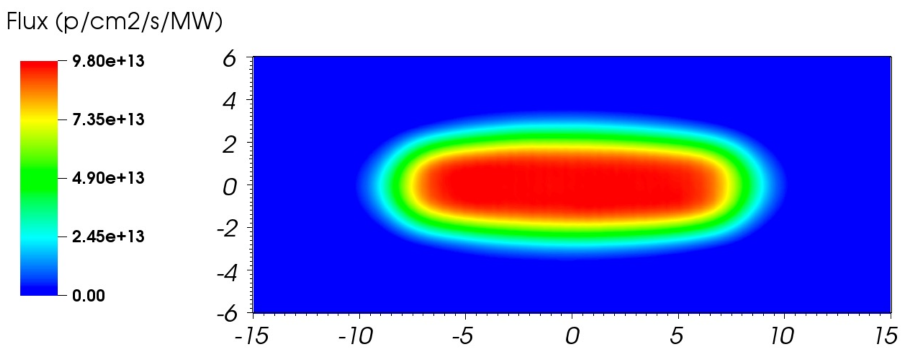
Incident proton beam profiles on target



Case J (Nominal)



Case E (Underfocused)

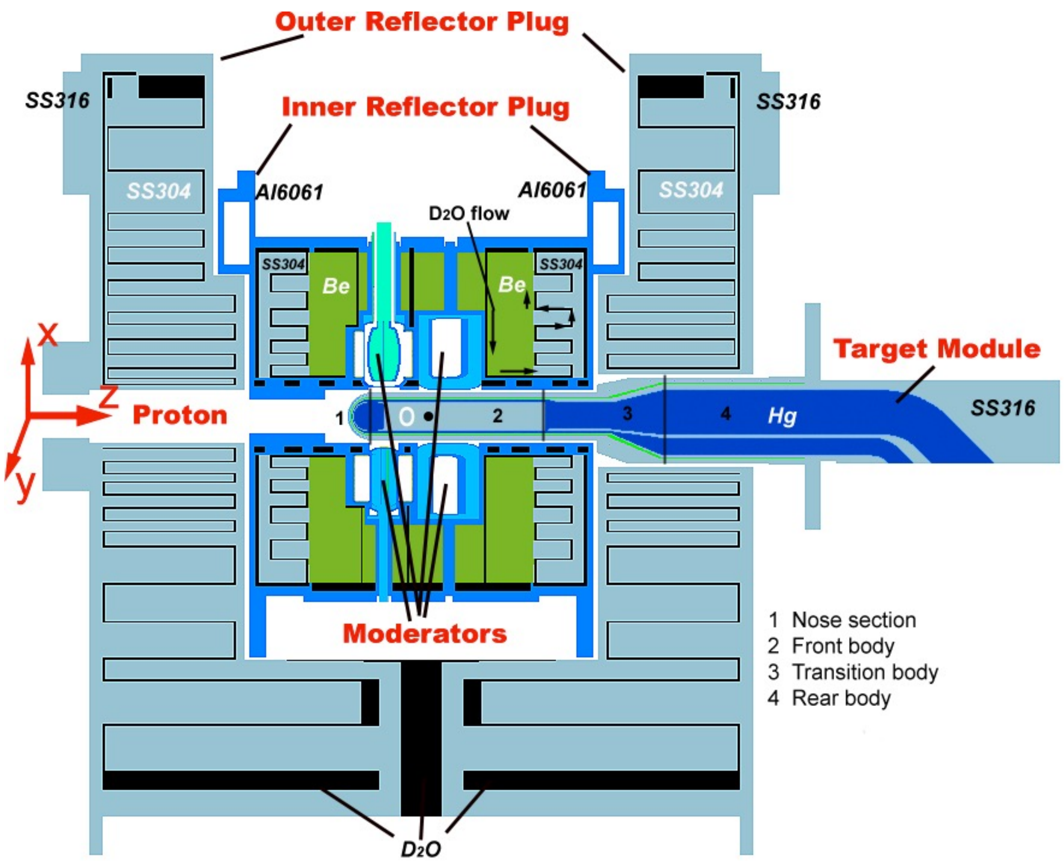


Case B (Overfocused)

Target Modeling at SNS

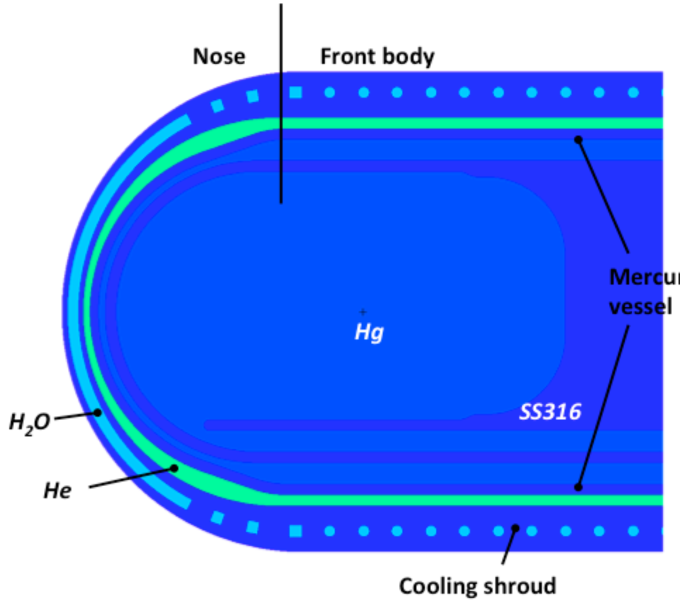
- Conventional modeling uses code provided surface/body definitions to manually construct geometry model
- Challenge to supporting engineering design
  - Complicated design model
  - High accuracy requirement for neutronic information
  - Short response time waiting for neutronic information

Traditional Neutronics model – TMR

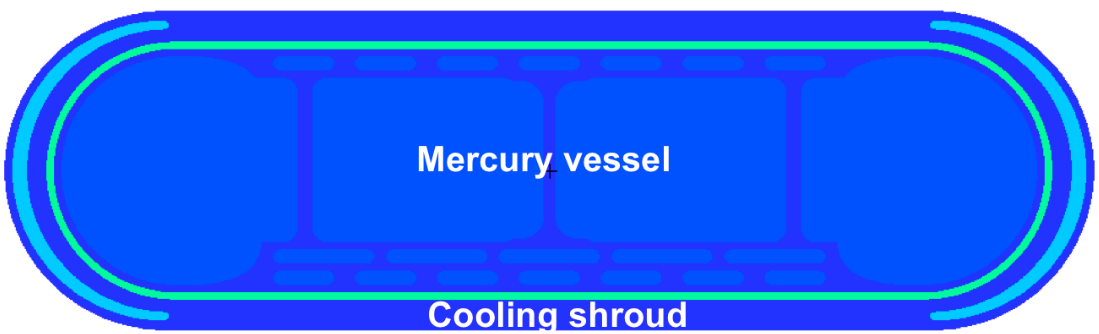


- Mercury vessel (SS316)
  - Nose section
  - Front body
  - Transition body
  - Rear body
- Inner reflector plug
  - Al-6061 structure (D=0.99 m, H=1.22 m)
  - Be reflector (D=0.64 m, H=0.95 m)
  - SS304 shielding blocks
  - Four moderators
- Outer reflector plug
  - SS316 structure (D=1.91 m, H=2.3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

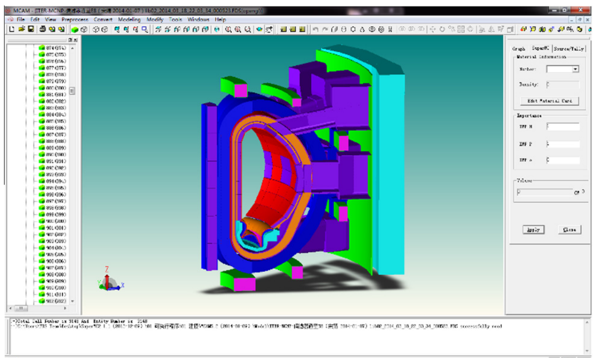


Fig. 3. ITER model conversion in SuperMC.

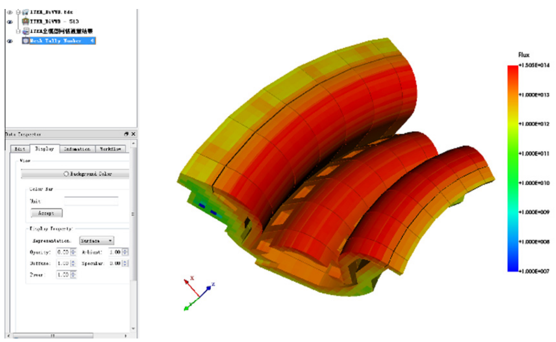
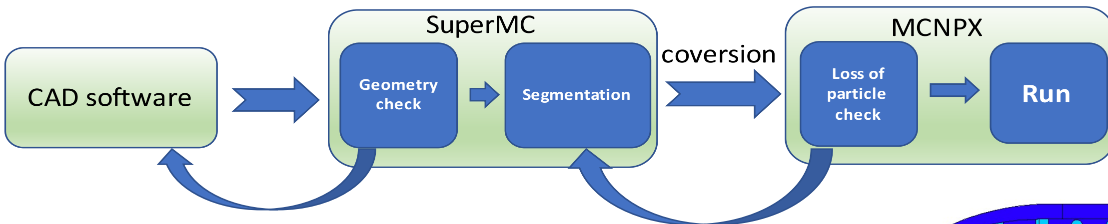


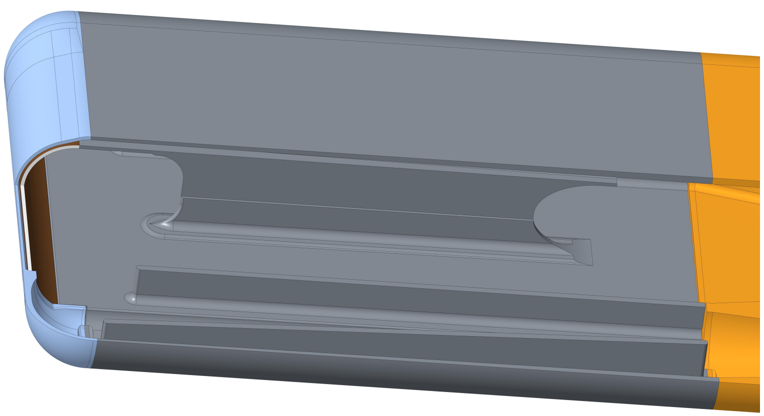
Fig. 6. Visualization of neutron flux distribution in divertor cassettes.

* Y. Wu et al.. Annals of Nuclear Energy, 2015, 82:161-168.

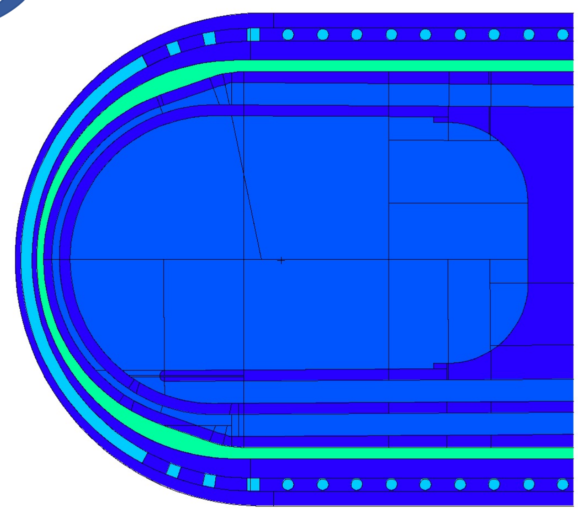
High-fidelity Modeling at SNS - *SuperMC*

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





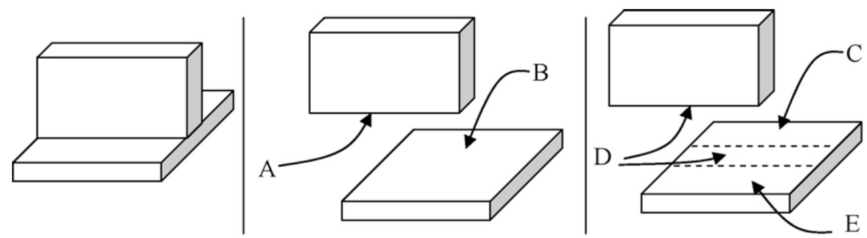
Blue target in CAD model



SuperMC converted MCNP model

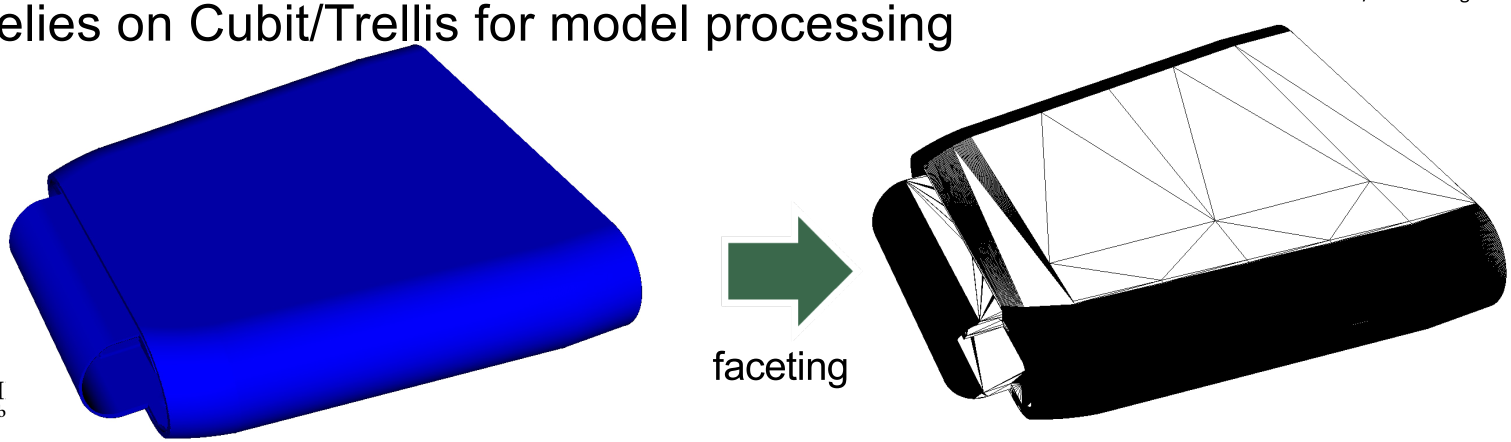
DAGMC (Direct Accelerated Geometry Monte Carlo)

- 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



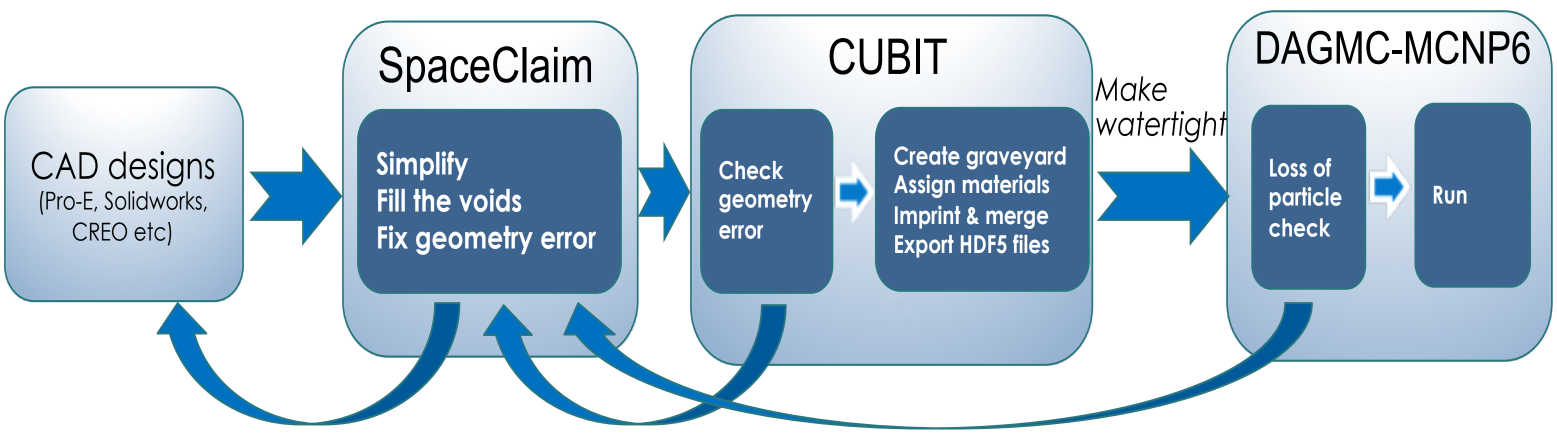
* P.P.H. Wilson et al. / Fusion Engineering and Design *85 (2010) 1759–1765*

- It relies on Cubit/Trellis for model processing



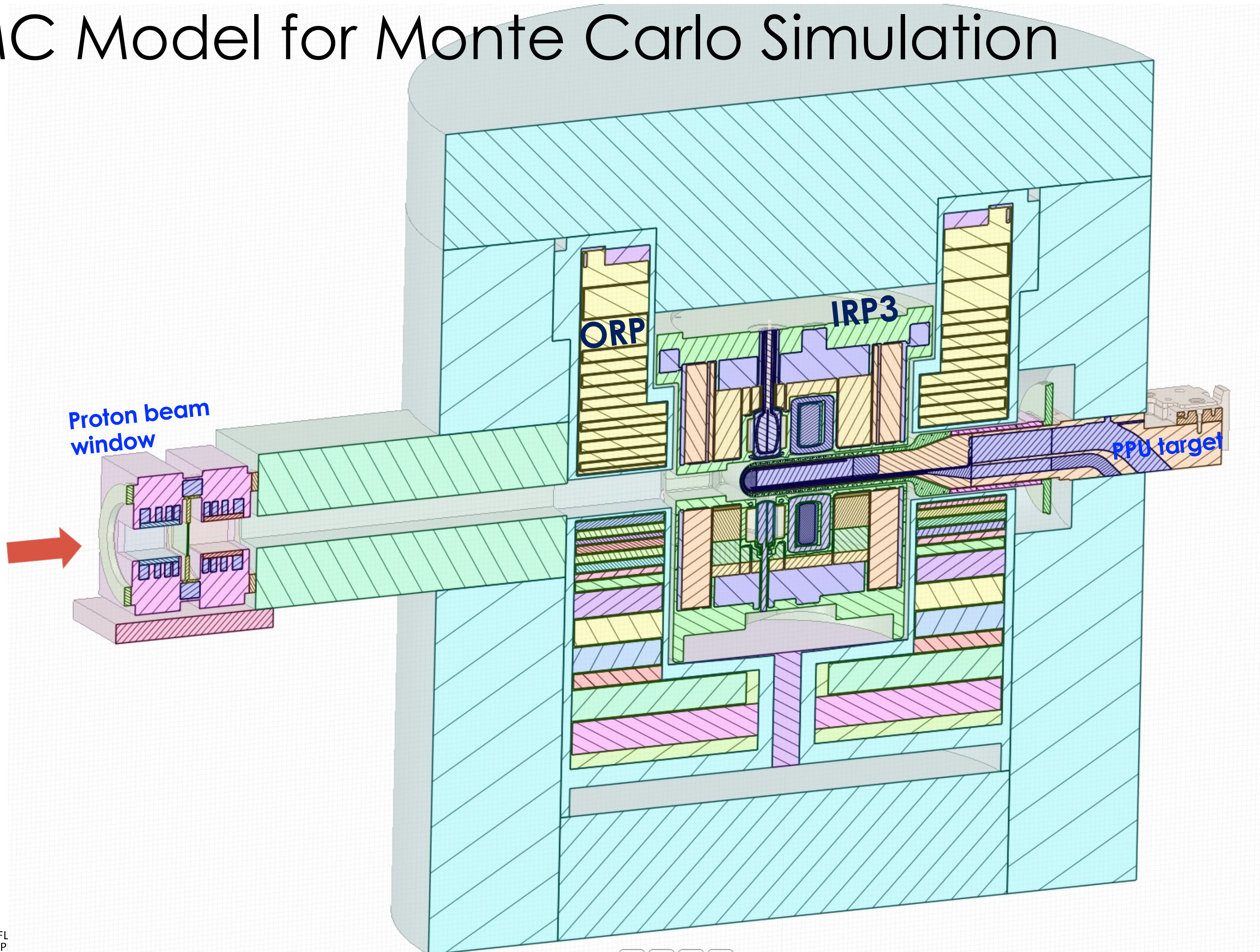
High-fidelity Modeling at SNS

- 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

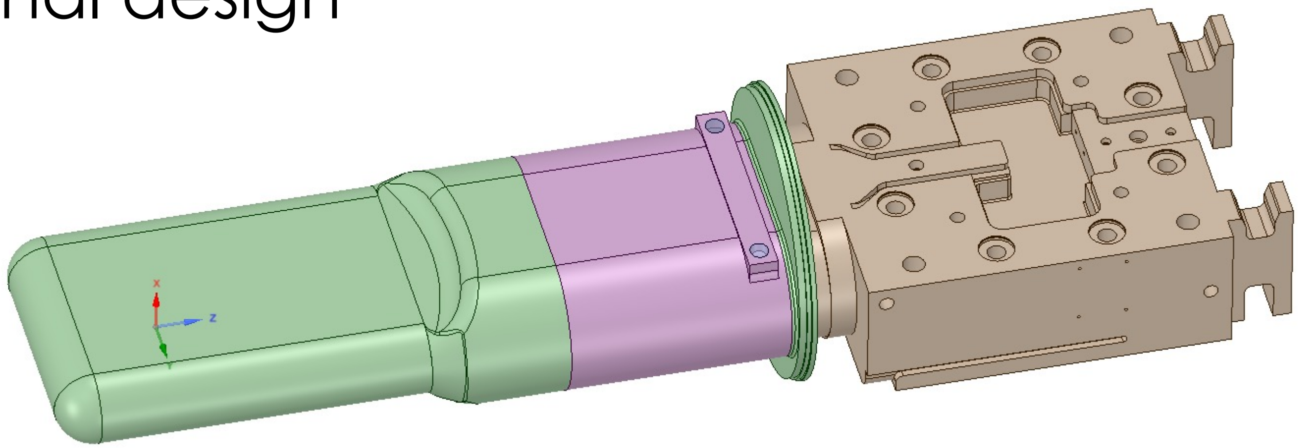


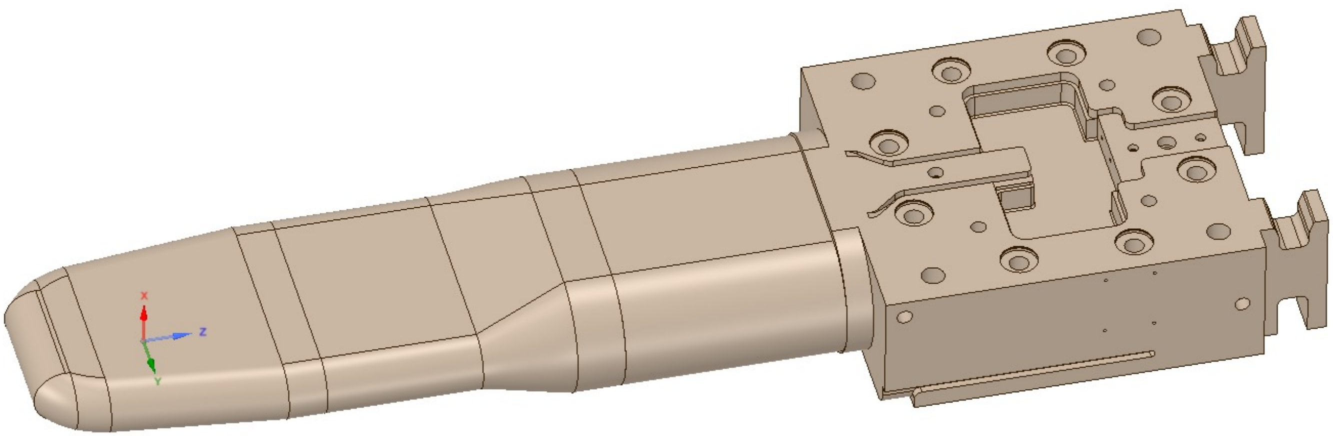
Flow-chart of CAD model preparation for a DAGMC-MCNP6 run

DAGMC Model for Monte Carlo Simulation

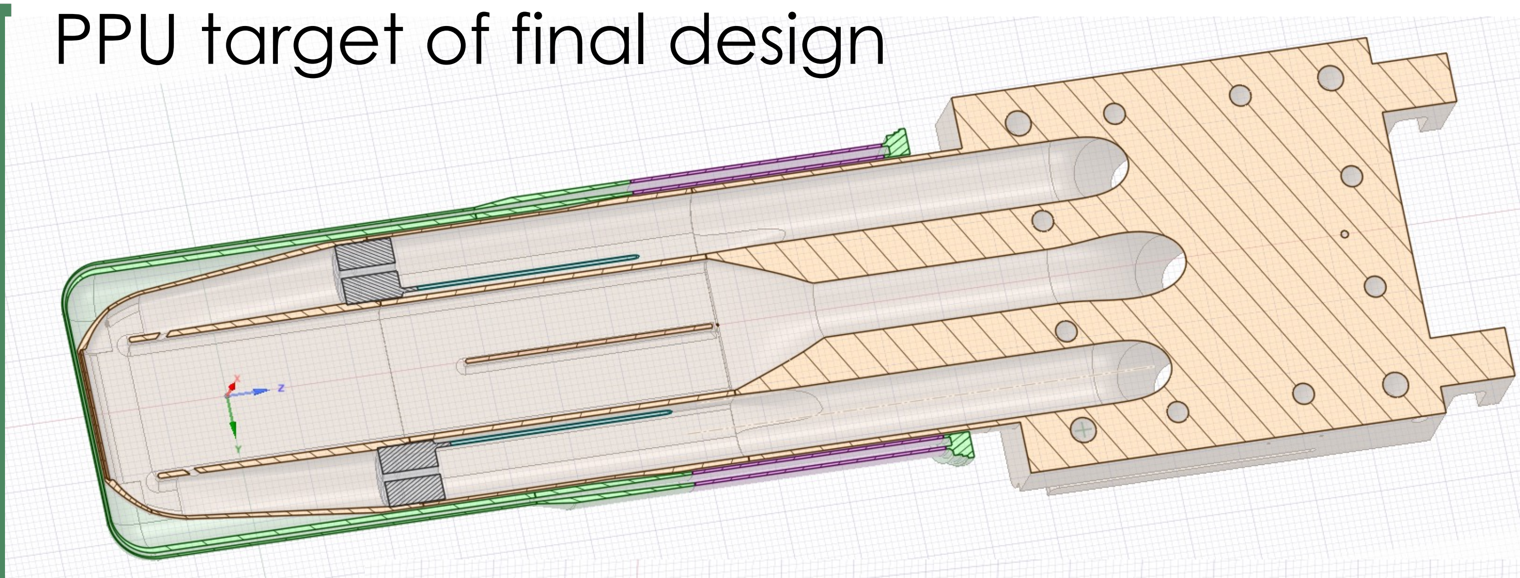


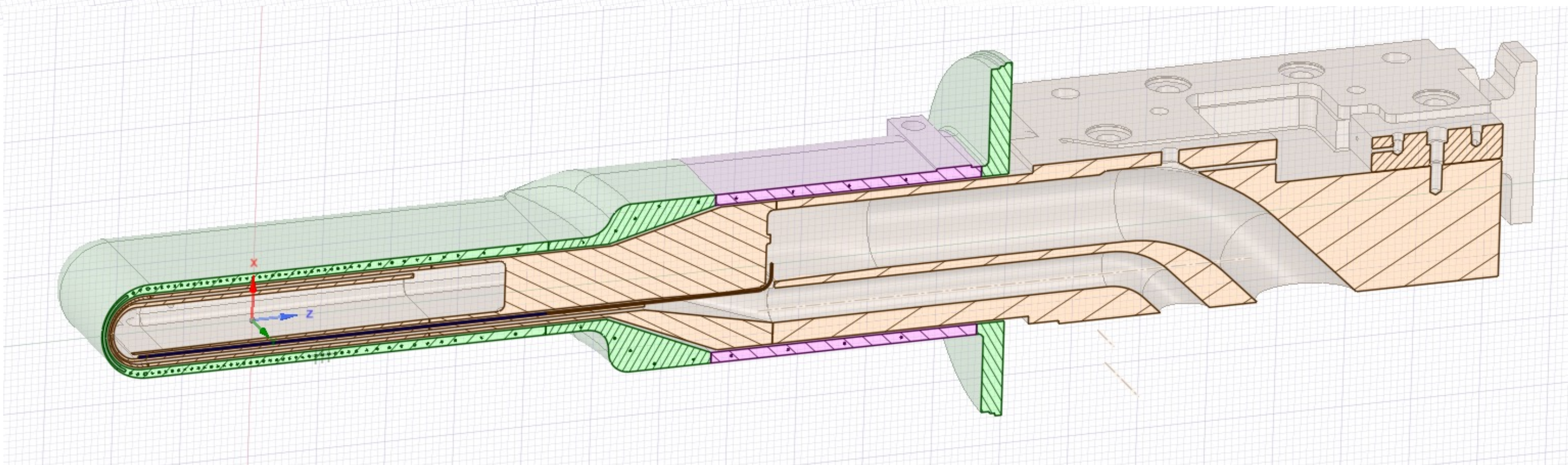
PPU target of final design



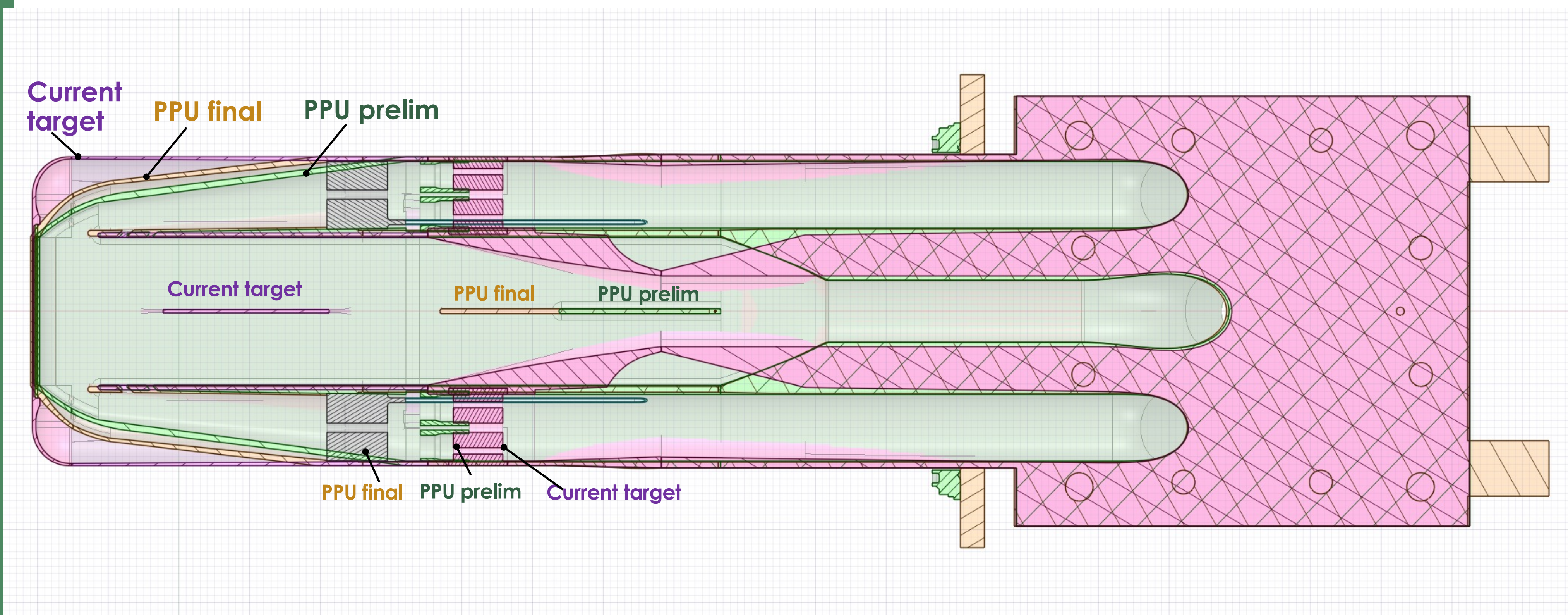


PPU target of final design

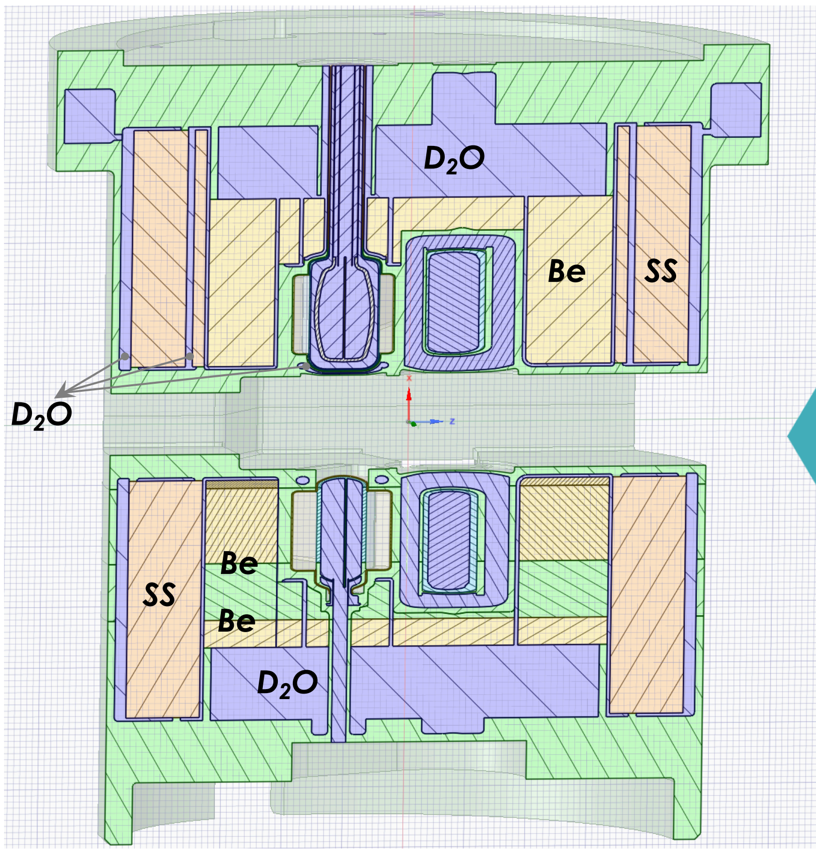




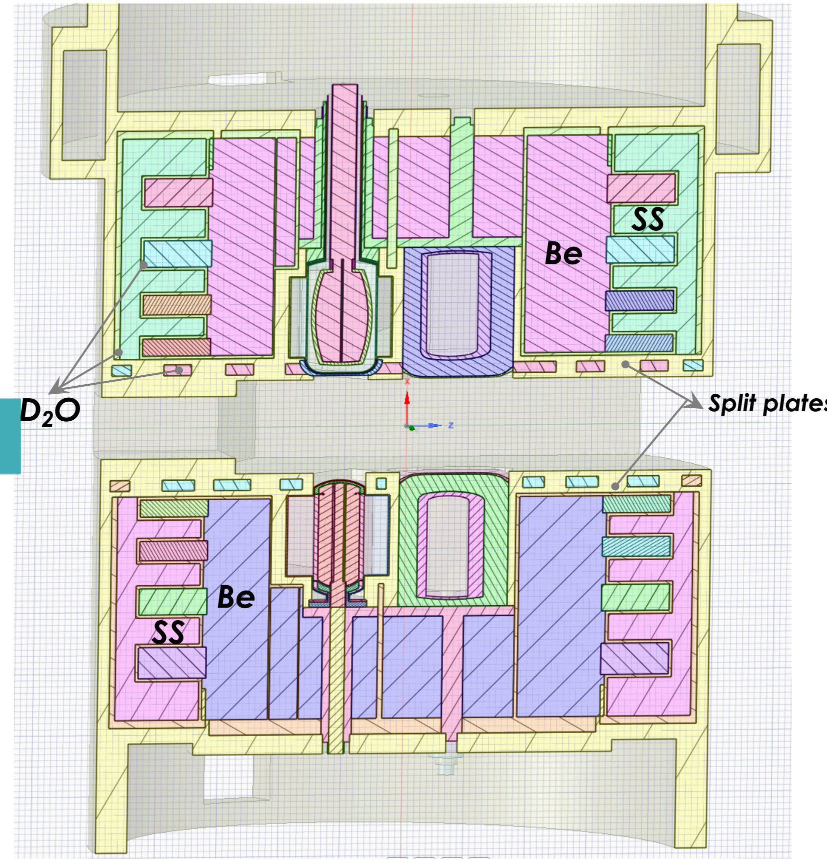
Target design comparisons



DAGMC Modeling *-Change of IRPs*



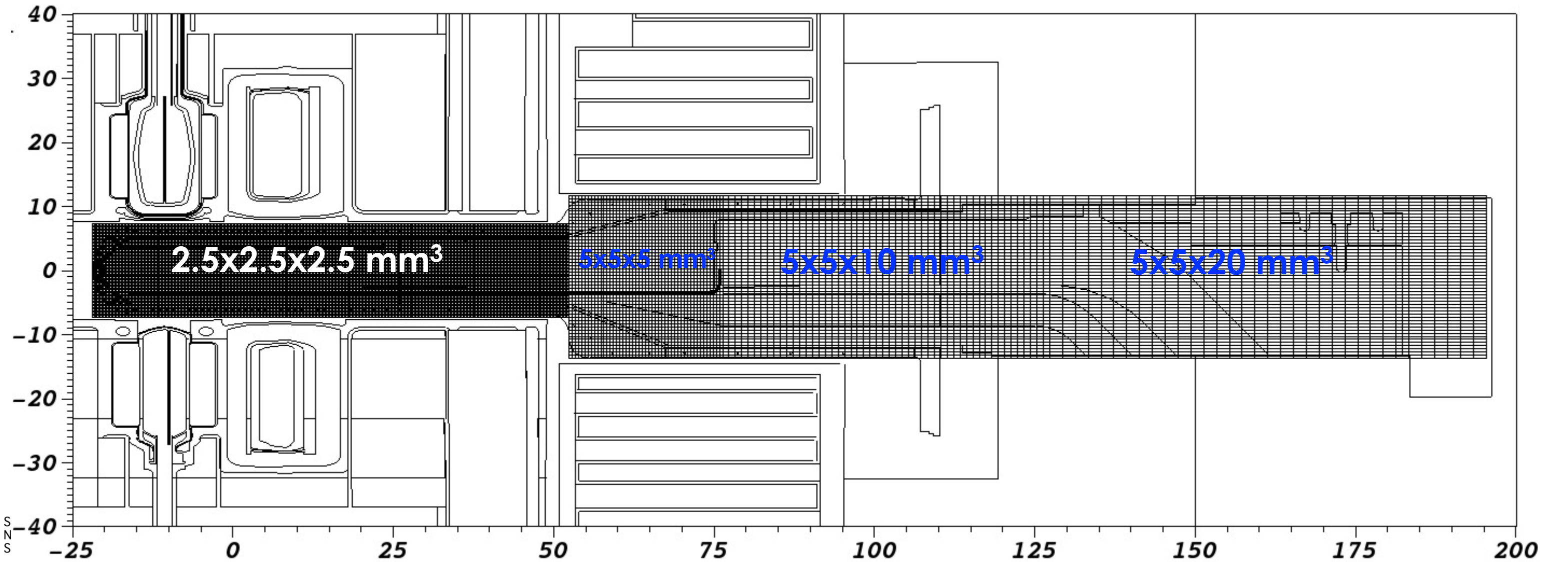
IRP 3



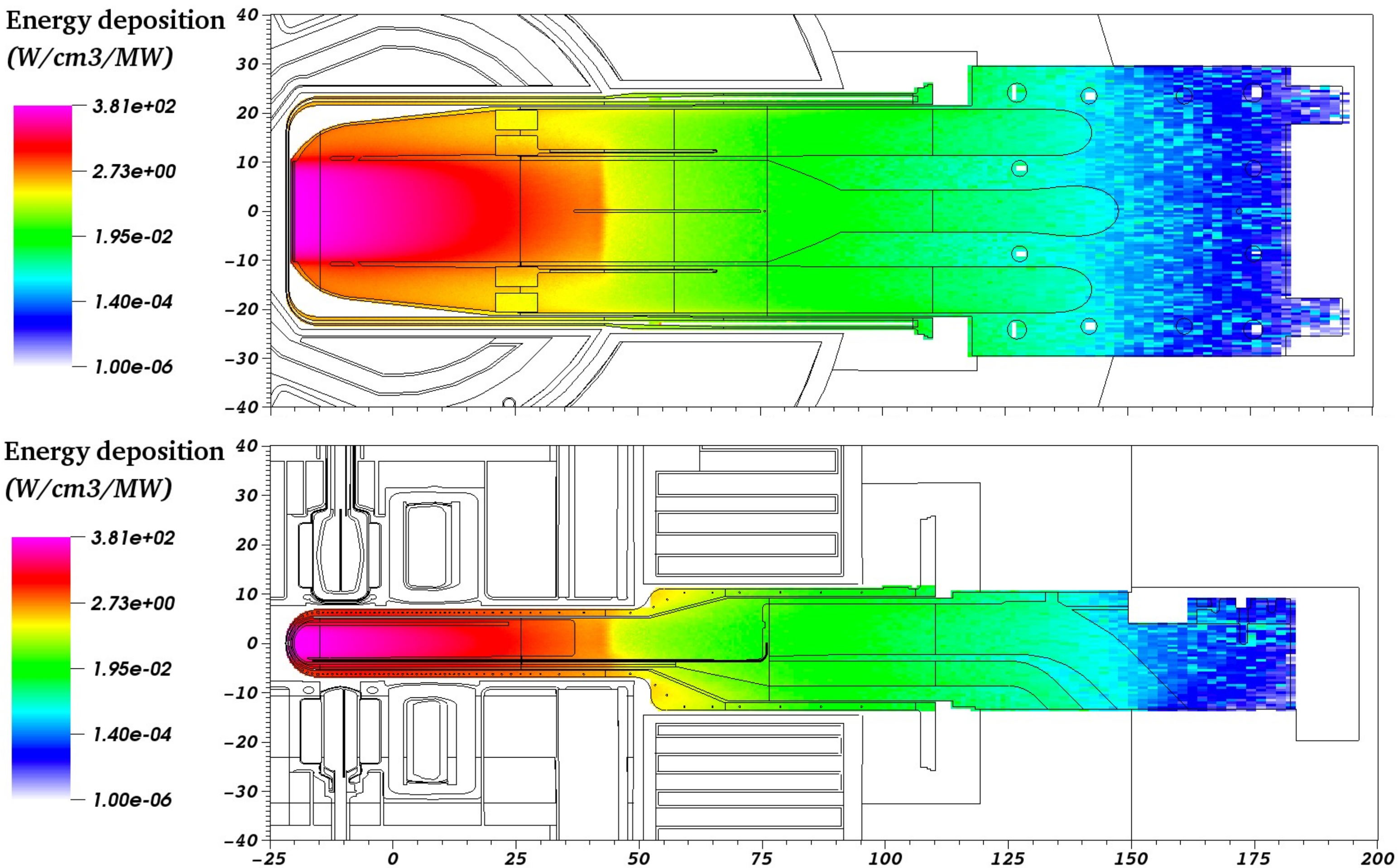
IRP 1 or 2

Calculation method

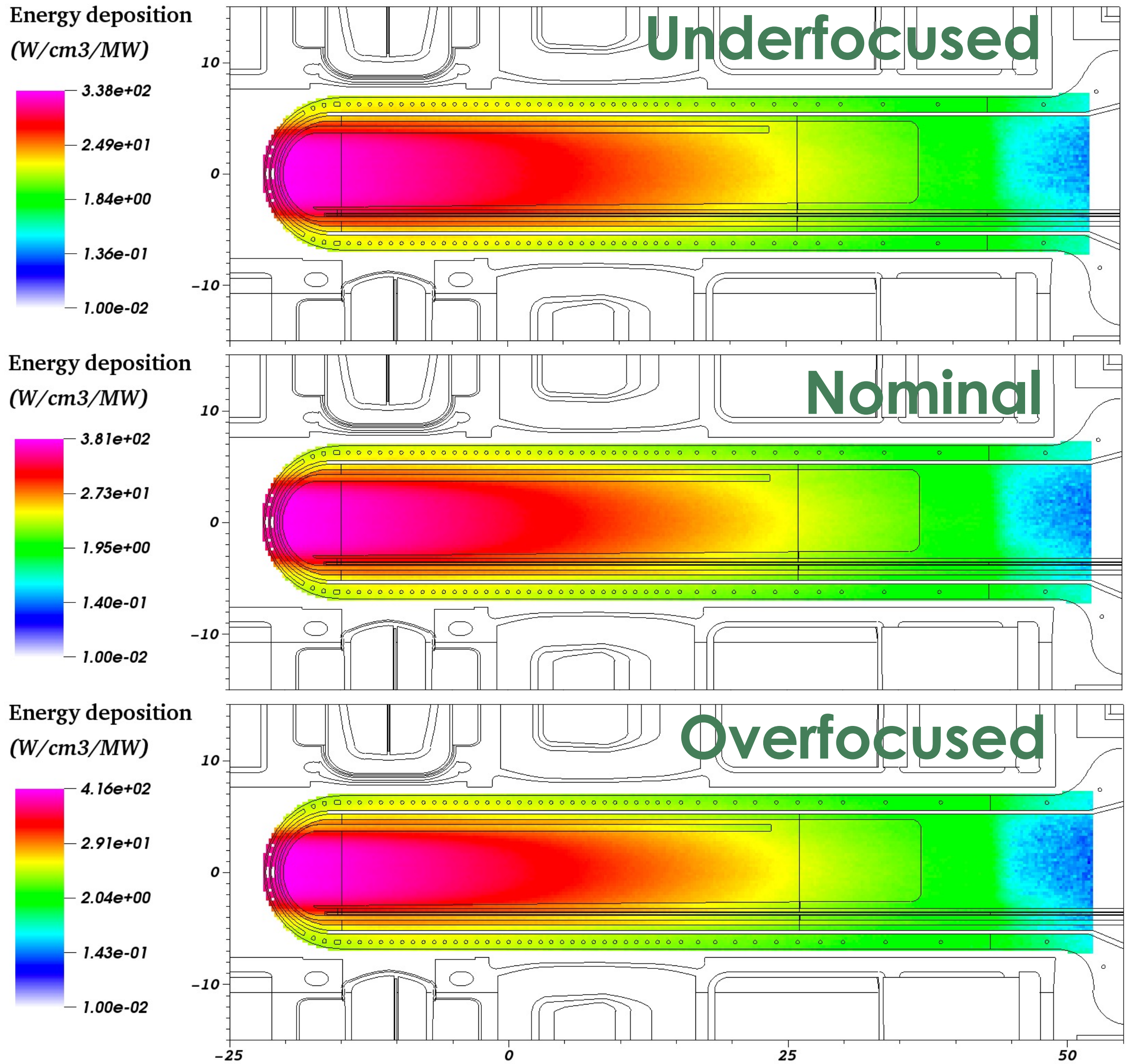
- Revised TMESH tally, which was modified by F. X. Gallmeier to allow tallying energy deposition, flux etc. for a specific material within a mesh element
- MCNPX/MCNP6 not able to calculate the volume of a specific material within a mesh element, therefore a statistical method of volume calculation has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



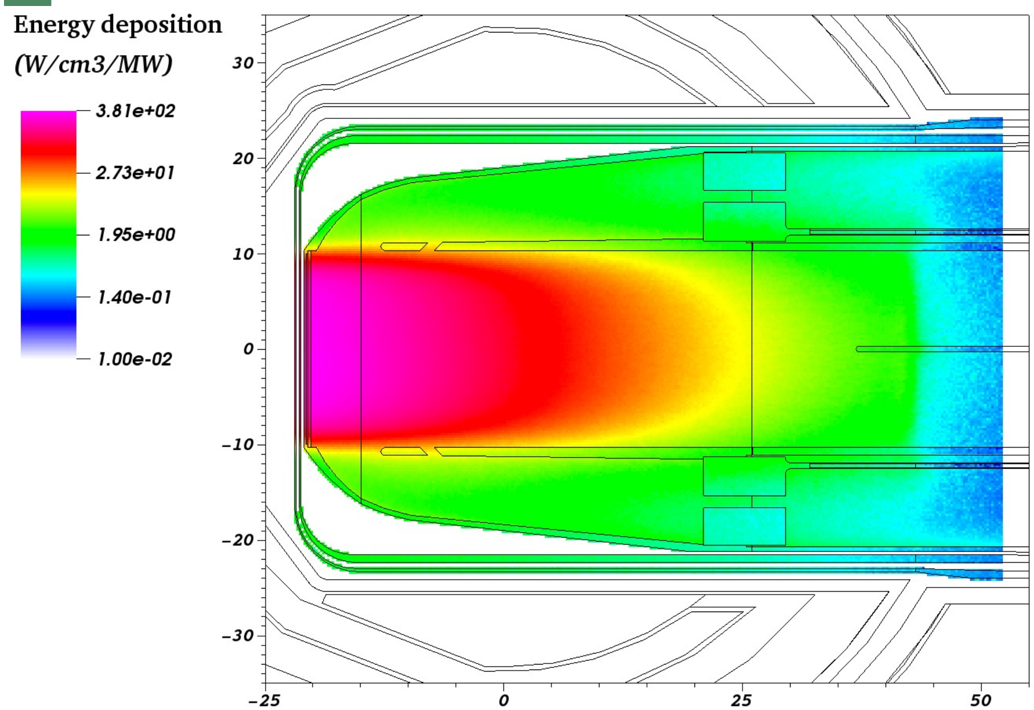
Energy deposition results - nominal



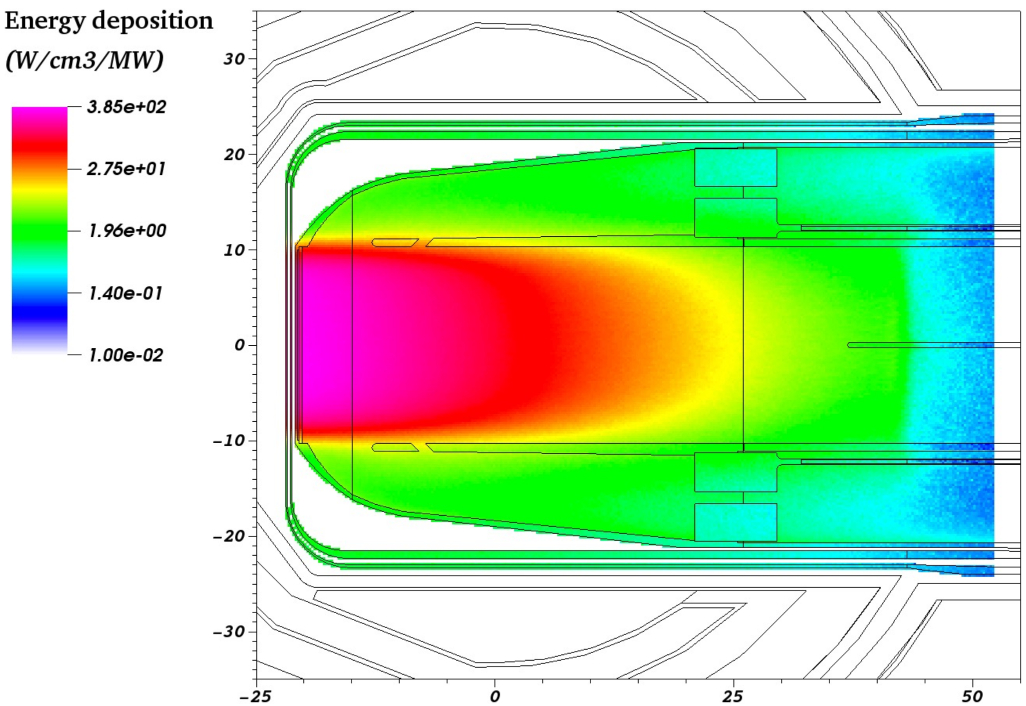
Energy deposition results



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