

Target for Fermilab-based Demonstrator

Michael Hedges

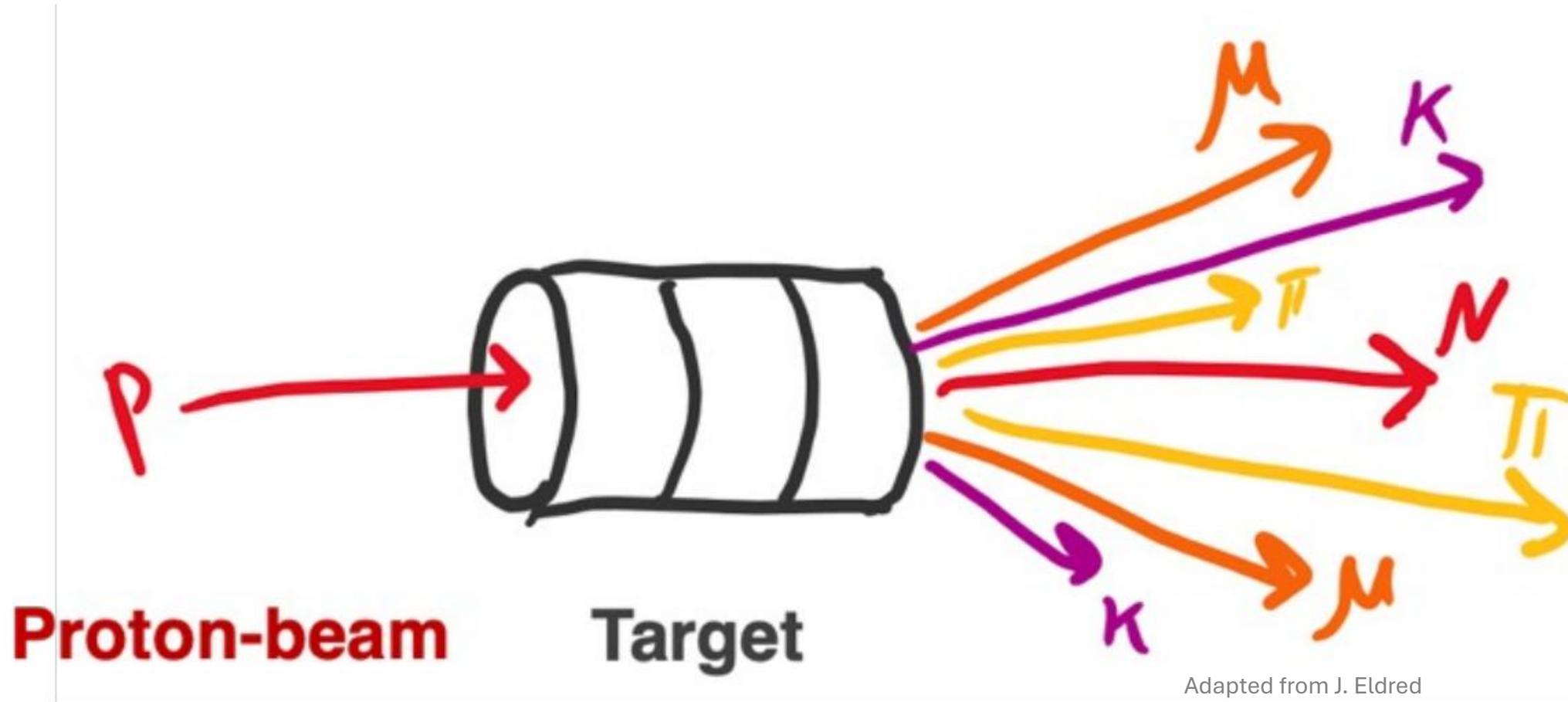
Considerations

- Intensity of “useful” secondaries always drives target design
 - Likely 200 MeV/c momentum muons
 - “moderate intensity” of something like $1e4$ to $1e8$ (!) muons / “cycle”
 - Instantaneous intensity depends on cooling cell, instrumentation, etc
 - Cycle length and frequency also depends on above (will not be constant power 24/7)
- 800 MeV (KE) protons or 8 GeV onsite (not sure yet...)

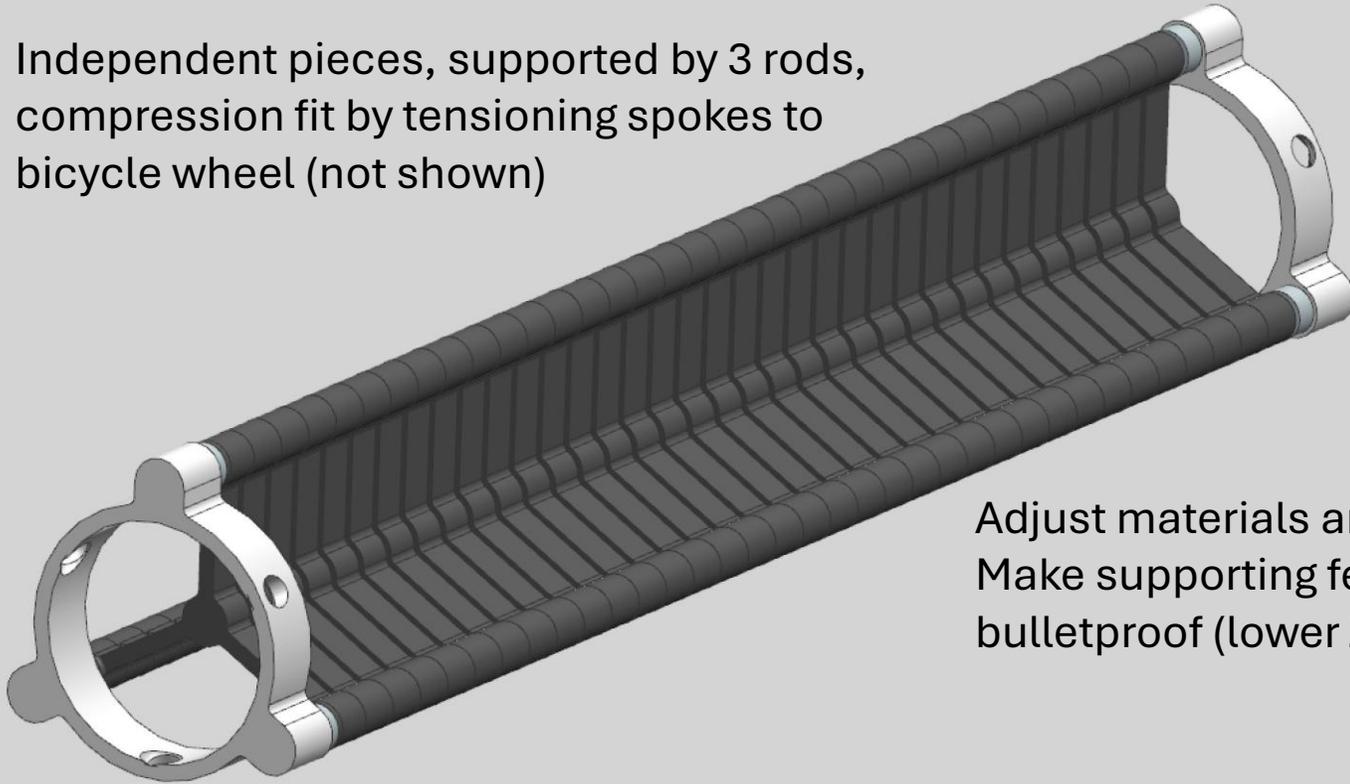
Considerations

- Intensity of “useful” secondaries always drive target design
 - Likely 200 MeV/c momentum muons
 - “moderate intensity” of something like $1e4$ to $1e8$ (!) muons / “cycle”
 - Instantaneous intensity depends on cooling cell, instrumentation, etc
 - Cycle length and frequency also depends on above (will not be constant power 24/7)
- 800 MeV (KE) protons or 8 GeV onsite (not sure yet...)
- Need a flexible, modular design that evolves with demonstrator needs!

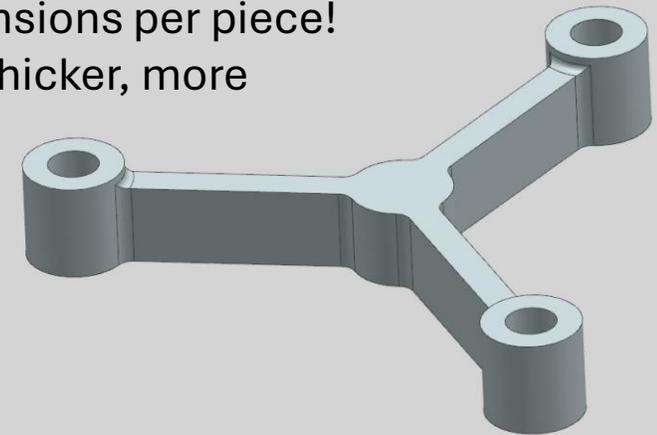
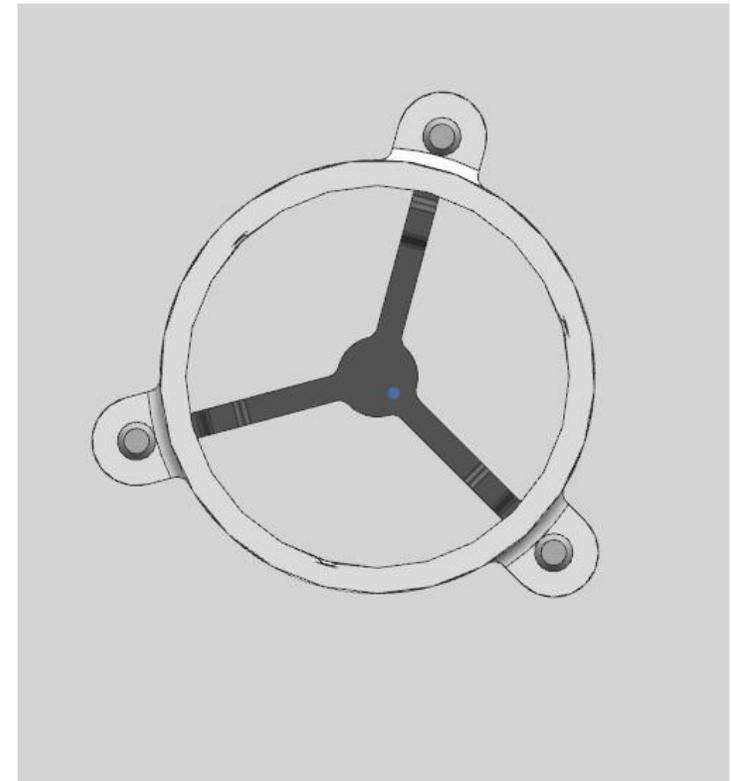
(most targets really are just this...)



Independent pieces, supported by 3 rods,
compression fit by tensioning spokes to
bicycle wheel (not shown)



Adjust materials and dimensions per piece!
Make supporting features thicker, more
bulletproof (lower Z)



Mu2e Target

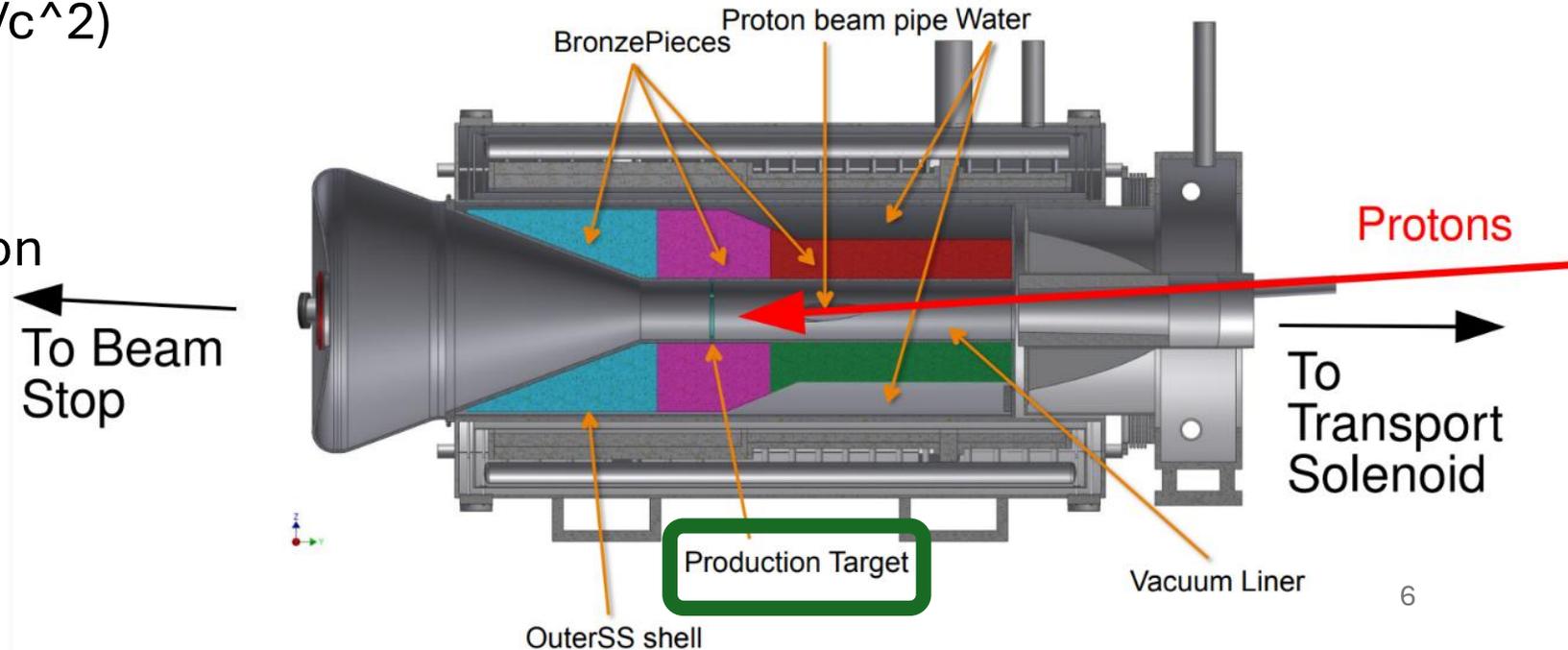


- Compact, radiatively cooled (vacuum) in 4.5 T solenoid
 - $1e20$ POT / yr @ 8 kW ($8 \text{ GeV}/c^2$)
 - Replace once / yr
 - Two Booster batches / 1.4 s
 - About $350 \text{ MeV}/c^2$ per proton

(PRELIMINARY STUDIES)

Solution-Annealed Inconel 718

2/25/2026



Why Inconel?

Acta Materialia 231 (2022) 117889



Contents lists available at [ScienceDirect](#)

Acta Materialia

journal homepage: www.elsevier.com/locate/actamat



Observations of radiation-enhanced ductility in irradiated Inconel 718: Tensile properties, deformation behavior, and microstructure[☆]



Materials Science & Engineering A 929 (2025) 148111

David A. McClintock^{a,*}, Maxim N. Gussev^b, Cody Campbell^c, Keyou Mao^d, Timothy G. Lach^d, Wei Lu^a, Jordan A. Hachtel^e, Kinga A. Unocic^e



Contents lists available at [ScienceDirect](#)

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea



^a Neutron Technologies Division, Oak Ridge National Laboratory, P.O. Box 2008, M.S. 6476, Oak Ridge, TN 37831, USA
^b Nuclear Energy and Fuel Cycle Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
^c BWX Technologies Inc., Lynchburg, VA 24504, USA
^d Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
^e Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

Microstructure, stored energy, and stability of H/He-filled nanocavities in low temperature irradiated Inconel 718[☆]



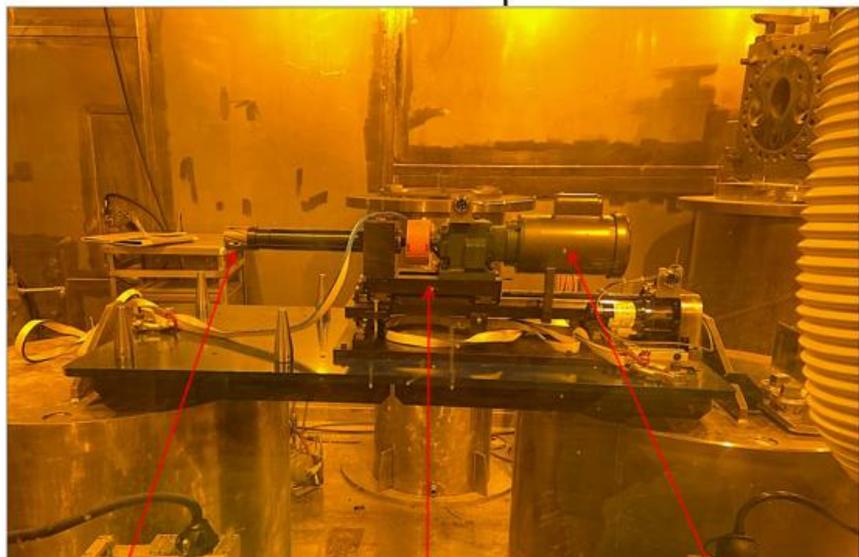
Timothy G. Lach^{a,*}, Kinga A. Unocic^{b,c}, Maxim N. Gussev^d, Amy J. Godfrey^a, Weicheng Zhong^a, Hsin Wang^a, Wei Lu^e, Elvis E. Dominguez-Ontiveros^e, David A. McClintock^e

^a Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37831, USA
^b Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, TN, 37831, USA
^c Currently: Department of Materials Science and Engineering, North Carolina State University, Raleigh, NC, 27695, USA
^d Nuclear Energy and Fuel Cycle Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37831, USA
^e Neutron Technologies Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37831, USA

Proton beam windows are sampled using a custom device

- PIE samples (~58 mm diameter) are cut from window using an annular cutter
- Samples have been removed from three PBWs to date:
 - PBW-4 (Inconel 718, 9.7 dpa, 1833 appm He, 7211 appm H)
 - PBW-6 (Al 6061-T6, ~4 dpa, ~2000 appm He) (D. McClintock: IWSMT-16 (2024))
 - PBW-7 (Inconel 718, ~15 dpa)

PBW Sampler



Annular Cutter

Translating Carriage

Electric Motor

Sampler with PBW Assembly



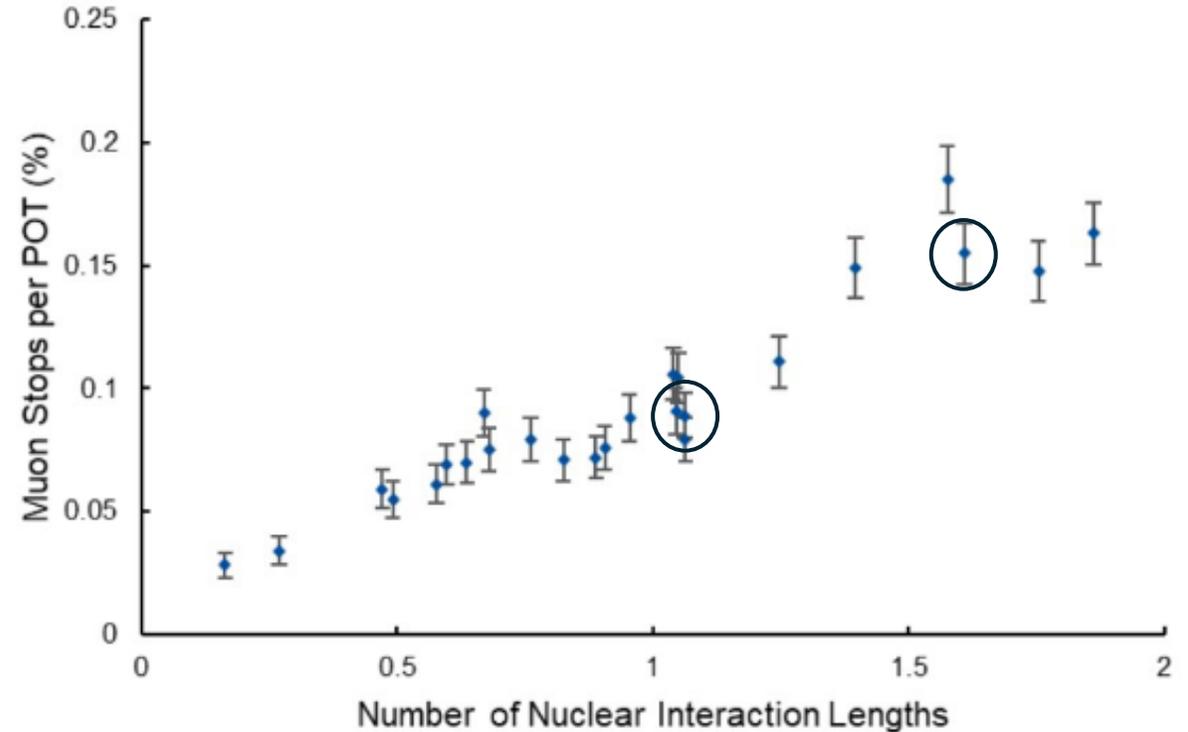
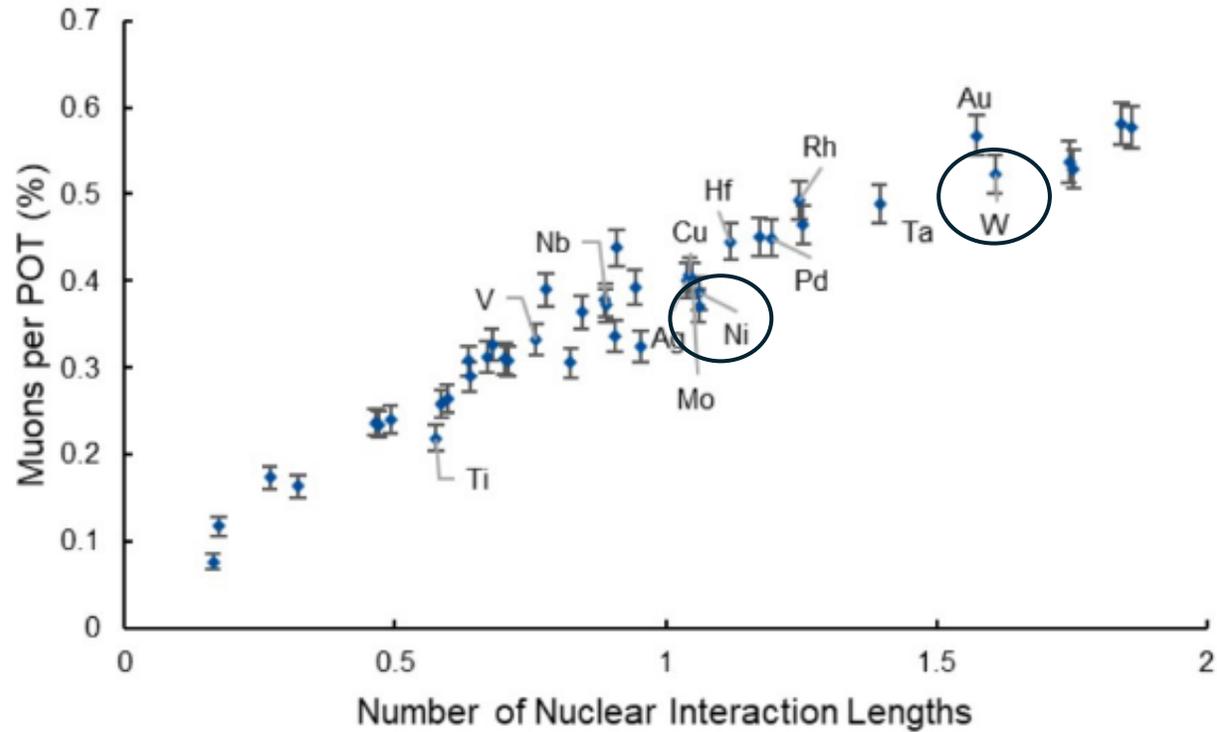
Alignment Pins

PBW Assembly

PBW-6 After Sampling



Effect of production with target material



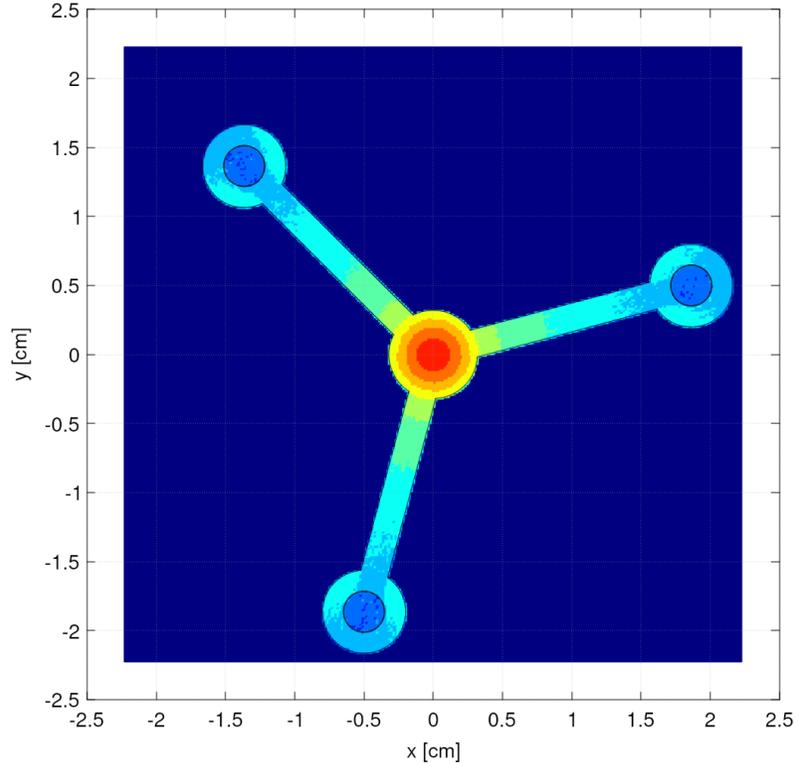
FLUKA

TUNGSTEN

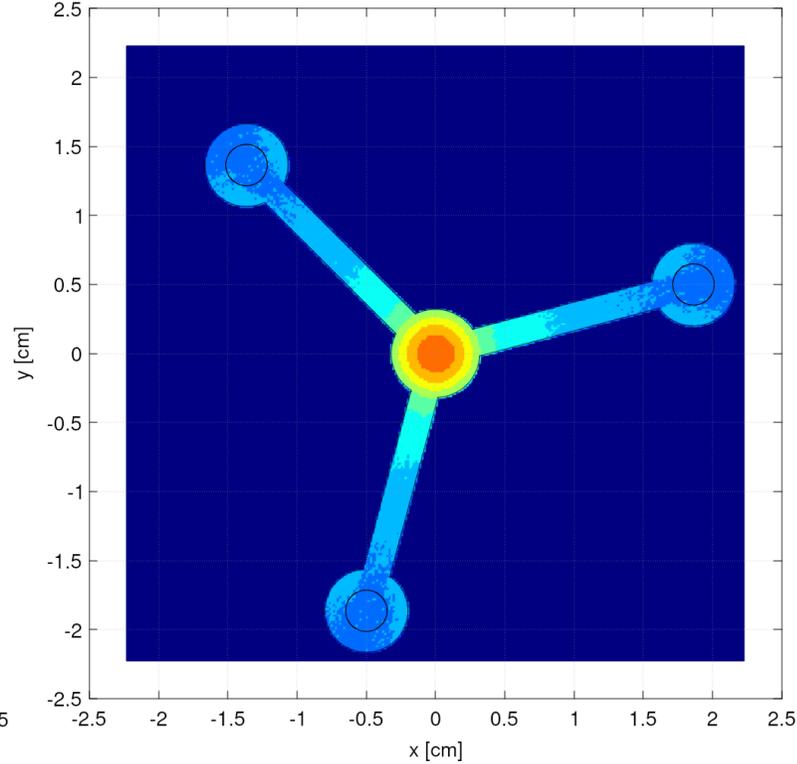
INCONEL-718

HAYMAN 2 (W)

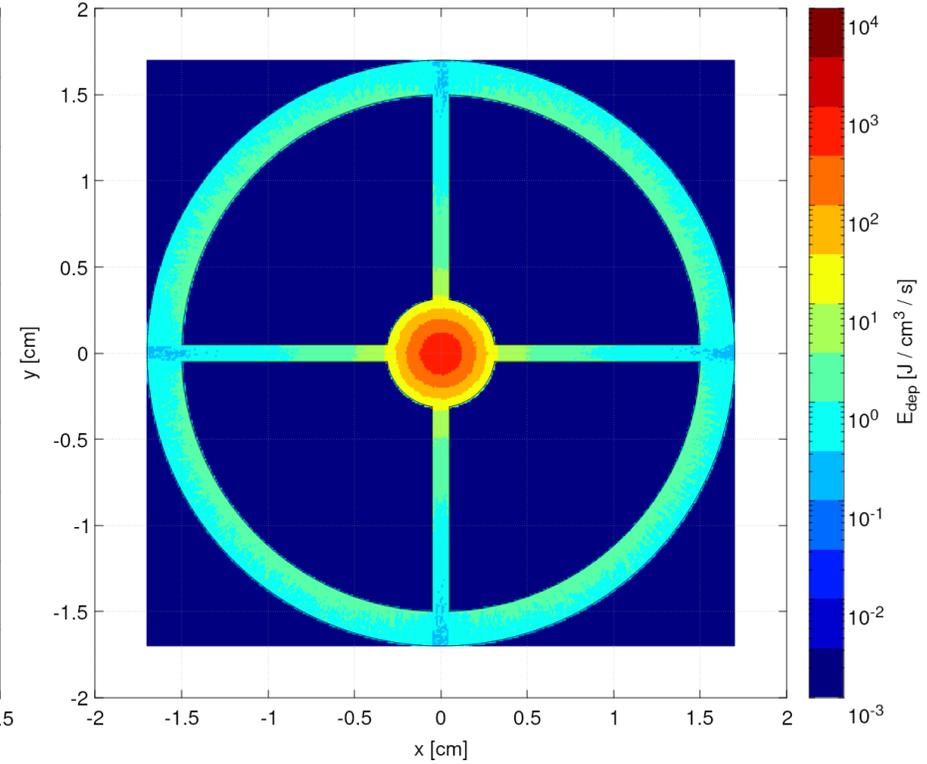
Energy Deposition in 1st TUNGSTEN Target Plate (Z = 0.000-0.033 cm)



Energy Deposition in 1st Target Plate (Z = 0.000-0.033 cm)

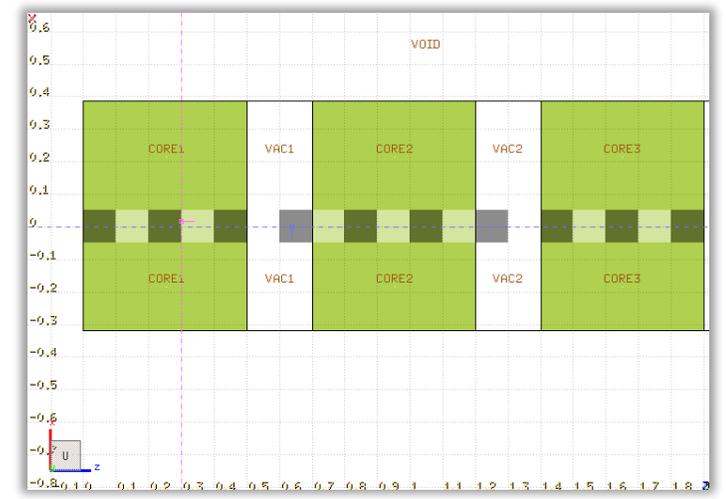
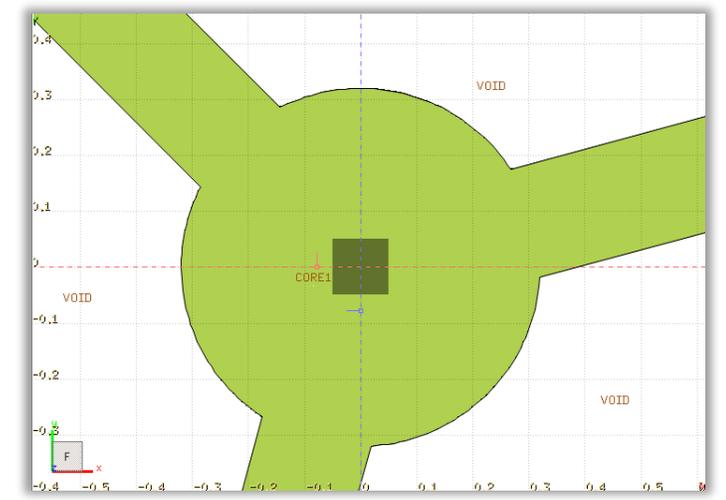
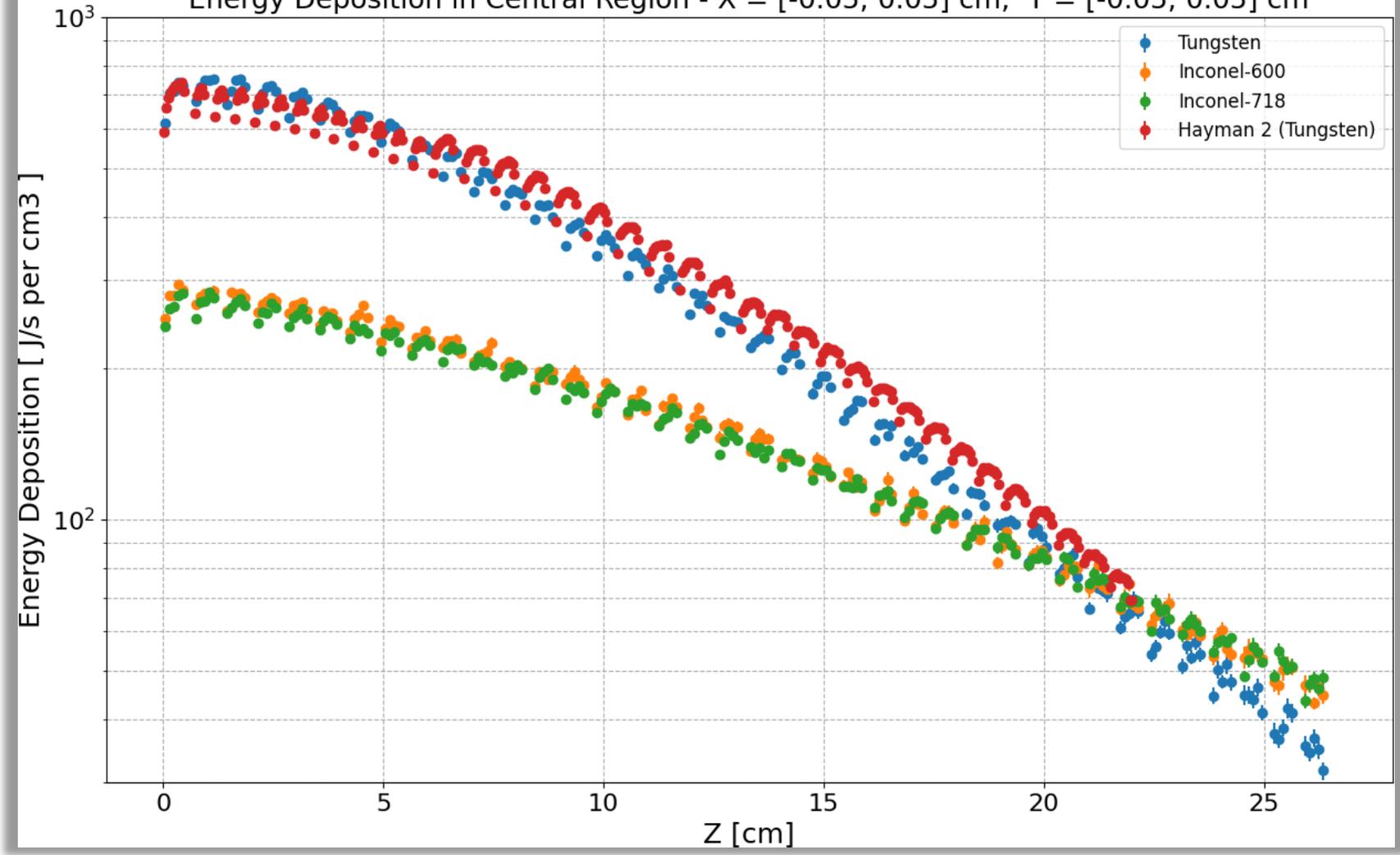


Energy Deposition - (Z = 0.00-0.05 cm)

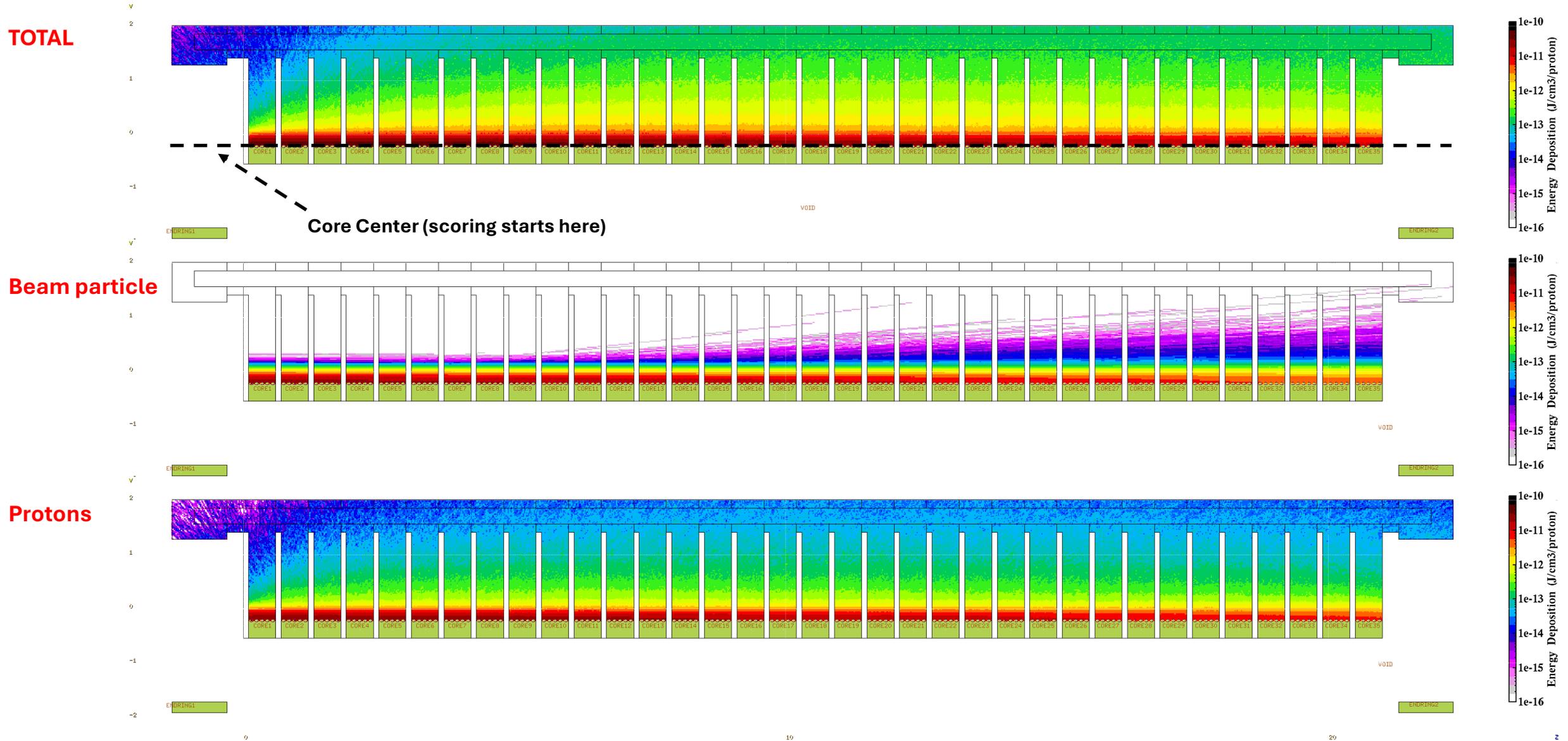


NB: support rods (blue “eyes”) are graphite here, has been fixed to Inconel718

Energy Deposition in Central Region - X = [-0.05; 0.05] cm, Y = [-0.05; 0.05] cm

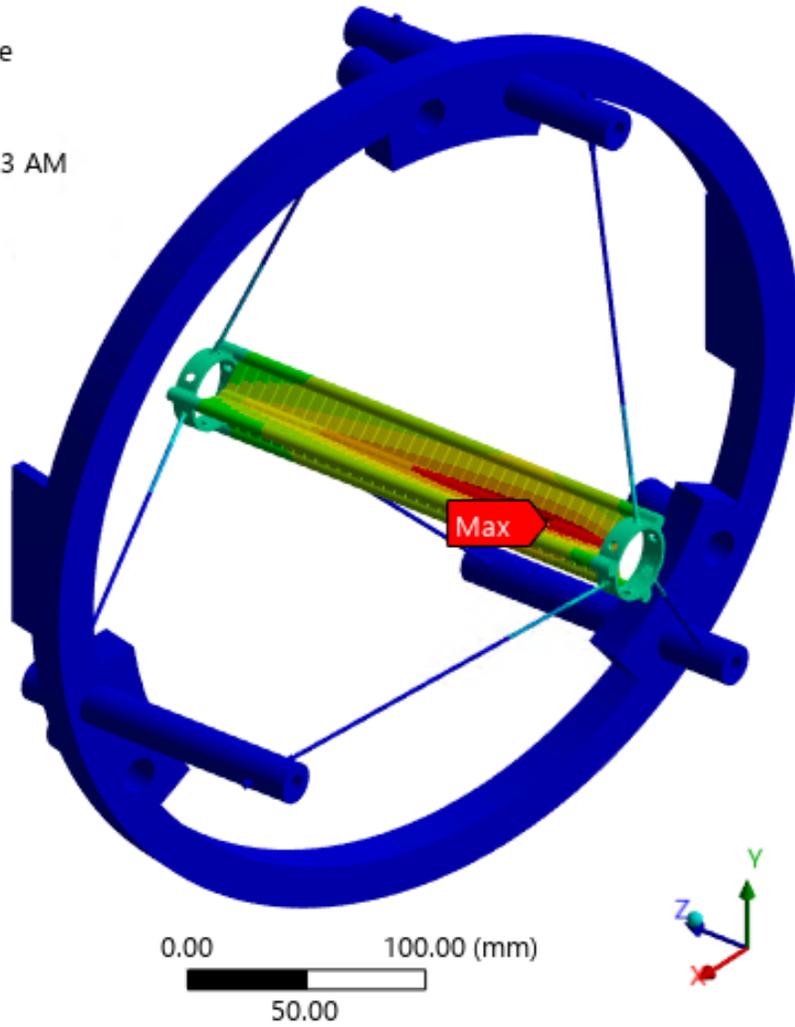
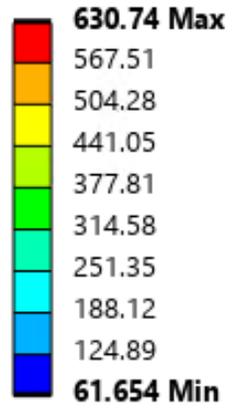


Energy Deposition Contributions by Particle Type (TOTAL vs. Beam Particle vs. Protons)



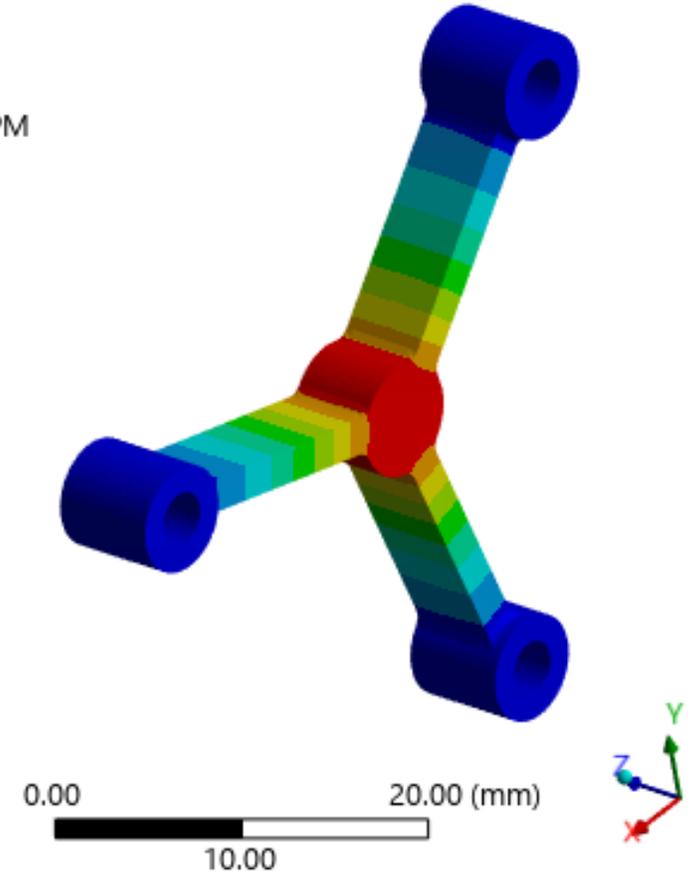
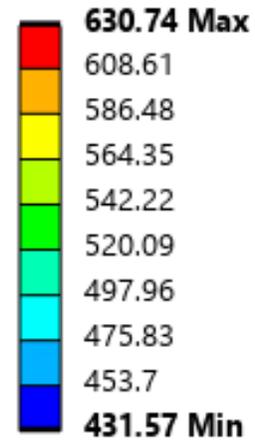
AW: Stickman Inconel718, steady-state FEA

Temperature
Type: Temperature
Unit: °C
Time: 1 s
8/19/2025 10:49:23 AM



AW: Stickman Inconel718, steady-state FEA

Temperature 2
Type: Temperature
Unit: °C
Time: 1 s
8/19/2025 12:10:57 PM



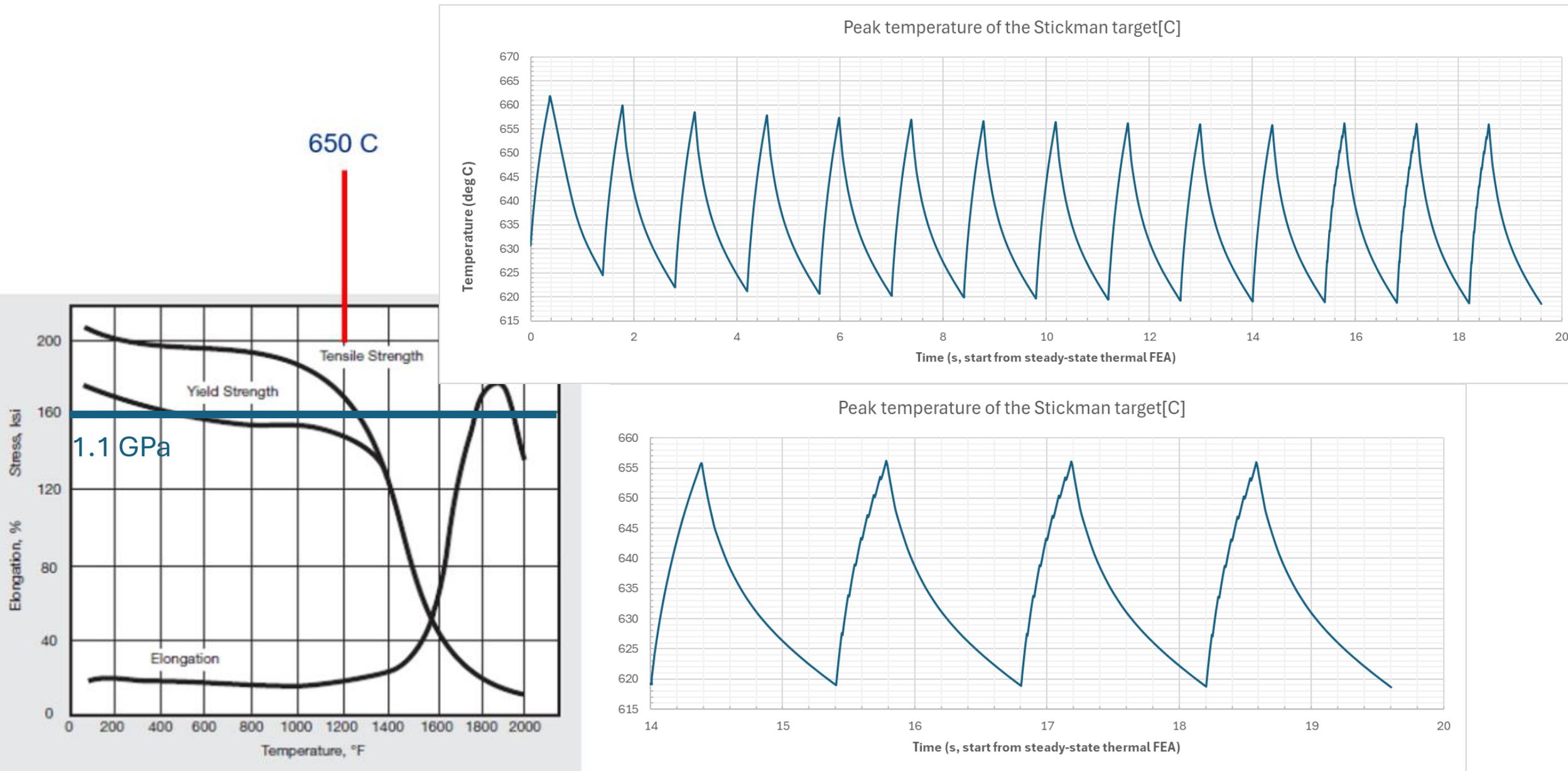


Figure 1. High-temperature properties of ½-in. diameter hot-rolled, annealed (1800°F/1 hr) and aged (1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours) bar.

BD: 1 core, 8 spills, from steady-state, refined mesh

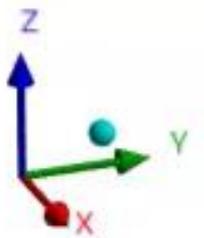
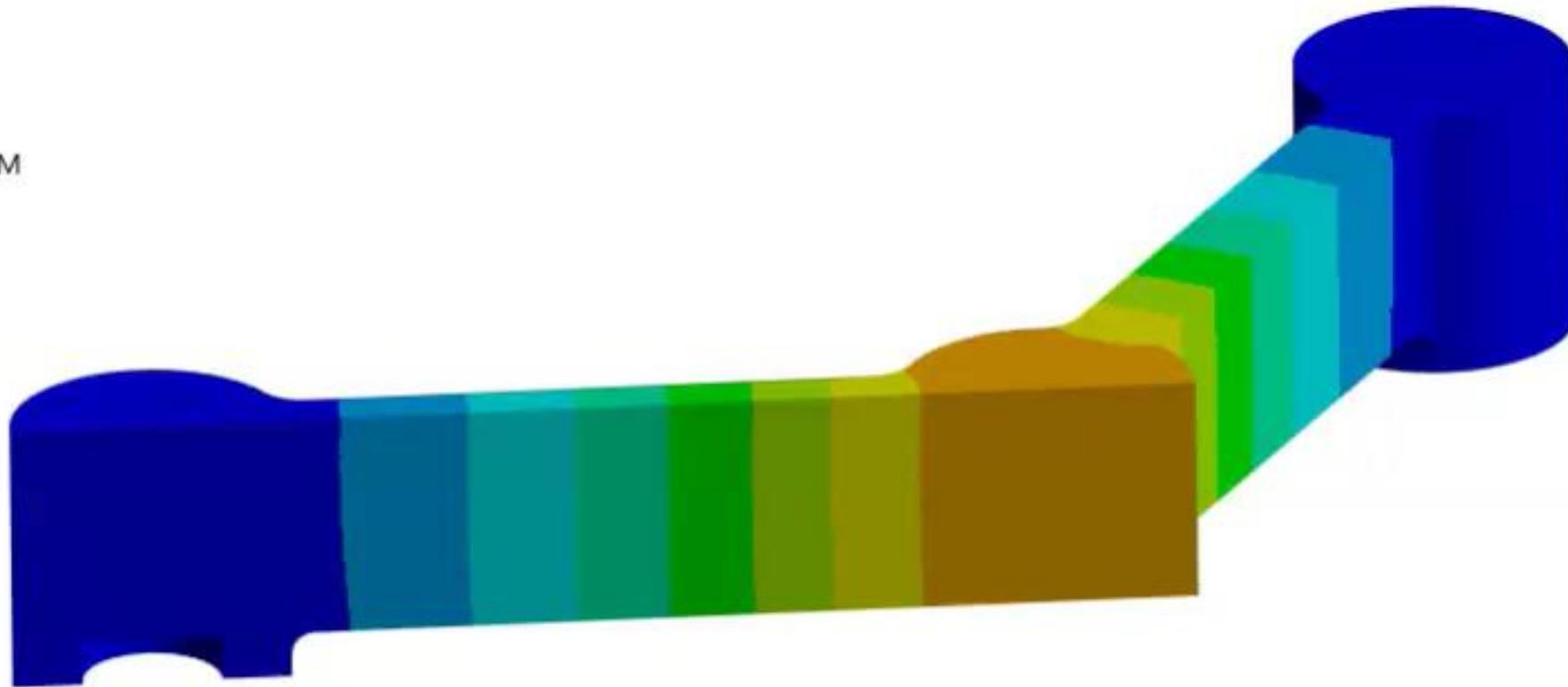
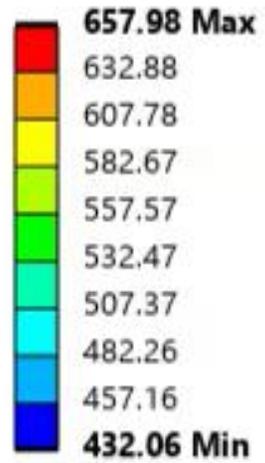
Temperature 8

Type: Temperature

Unit: °C

Time: 0.379 s

8/11/2025 10:41:26 PM



BD: 1 core#6, 8 spills, from steady-state, refined mesh

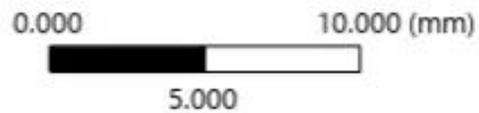
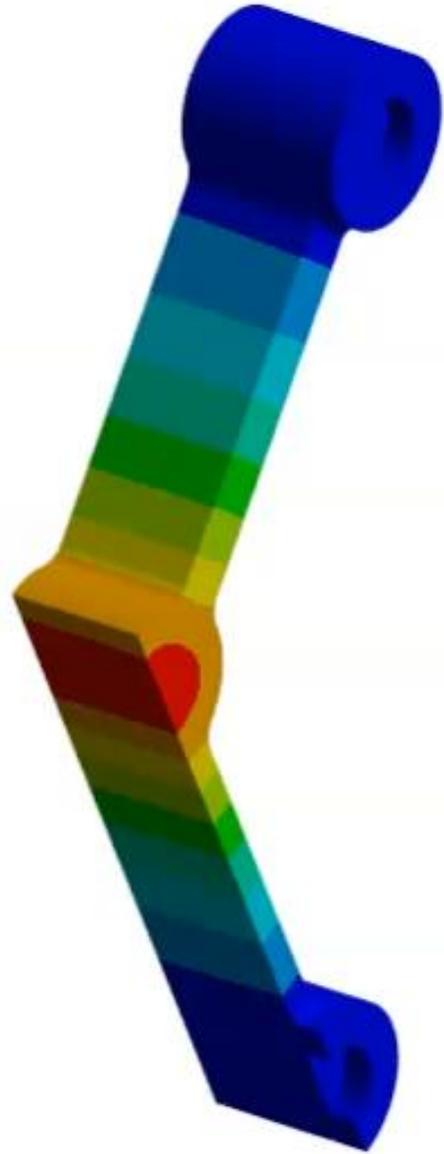
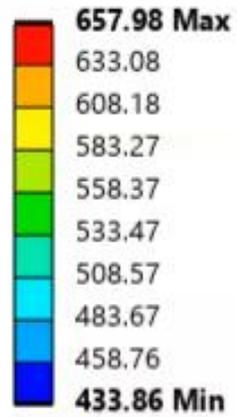
Temperature 8

Type: Temperature

Unit: °C

Time: 0.3799 s

8/16/2025 6:36:50 PM



BE: no gravity, pure thermal, no bars

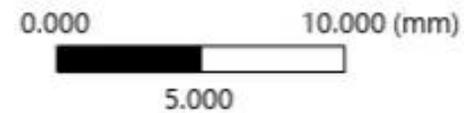
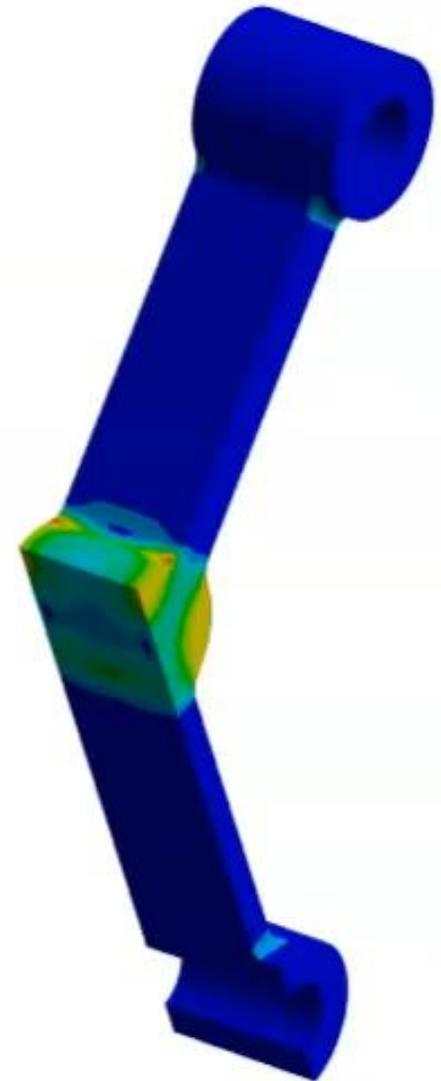
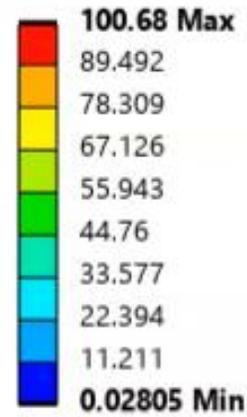
Equivalent Stress

Type: Equivalent (von-Mises) Stress

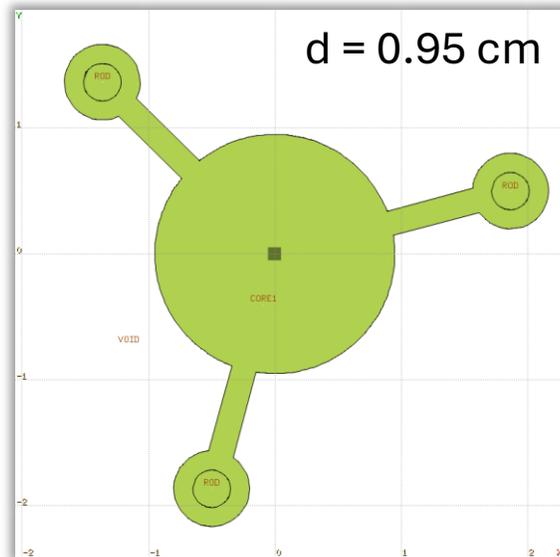
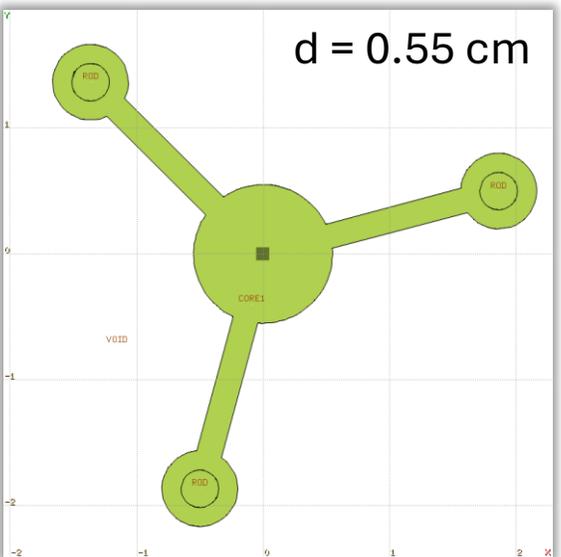
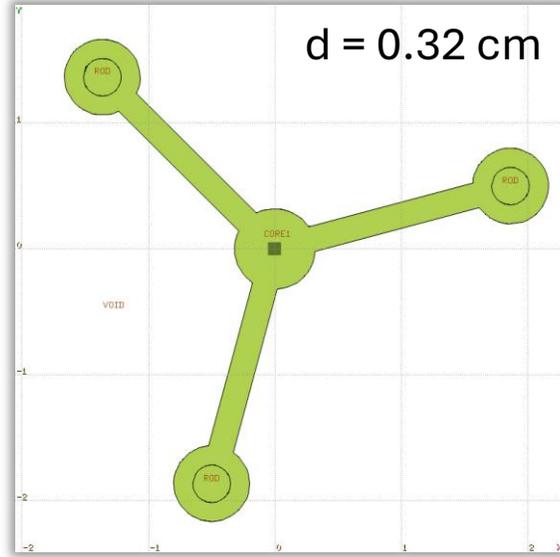
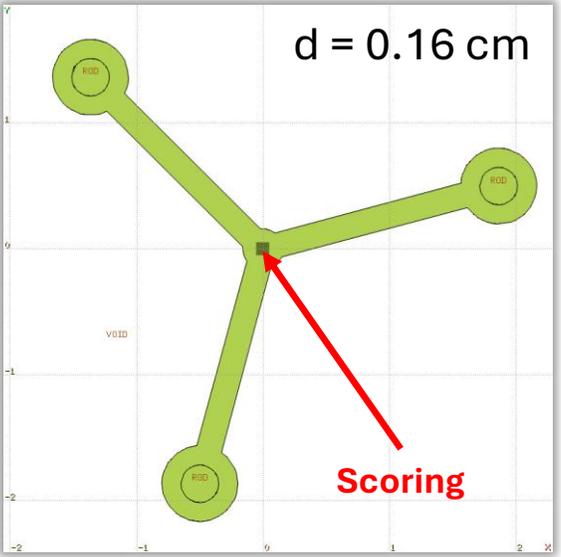
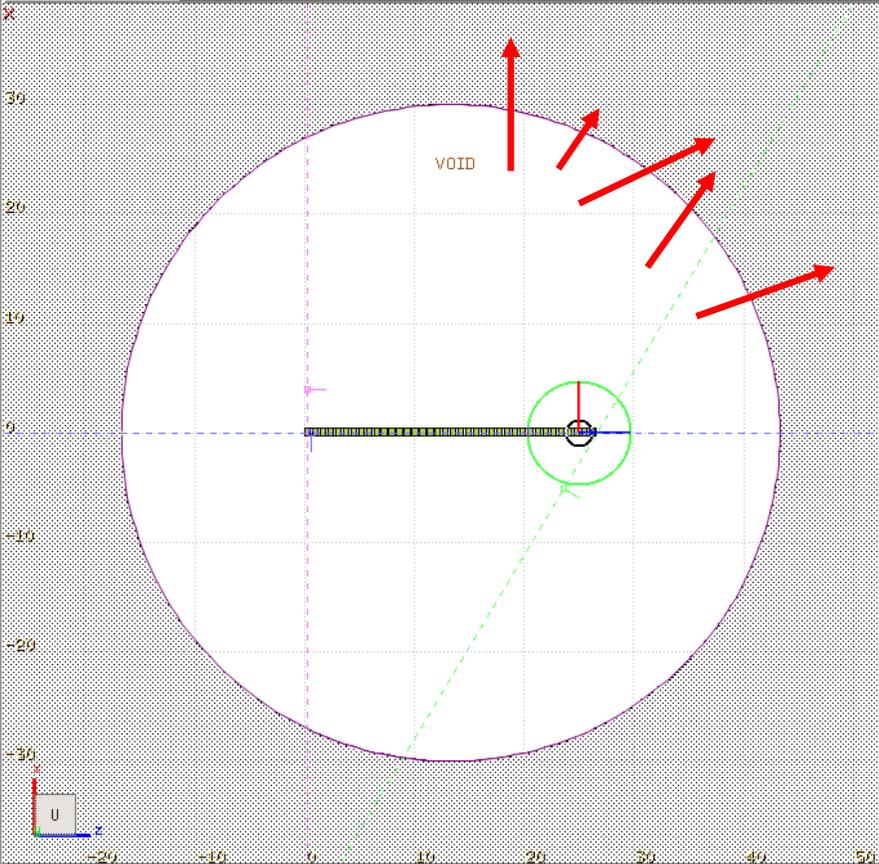
Unit: MPa

Time: 0.3799 s

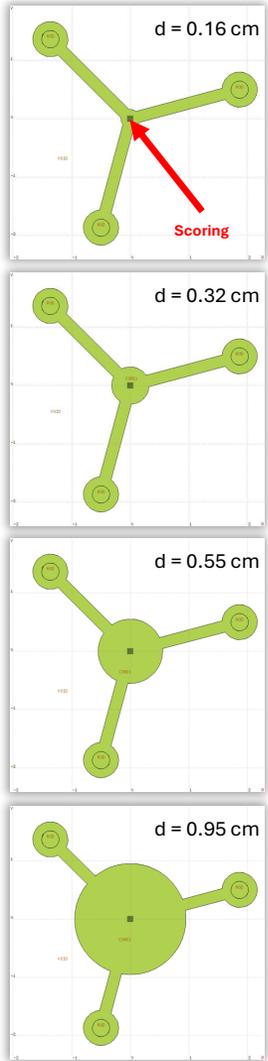
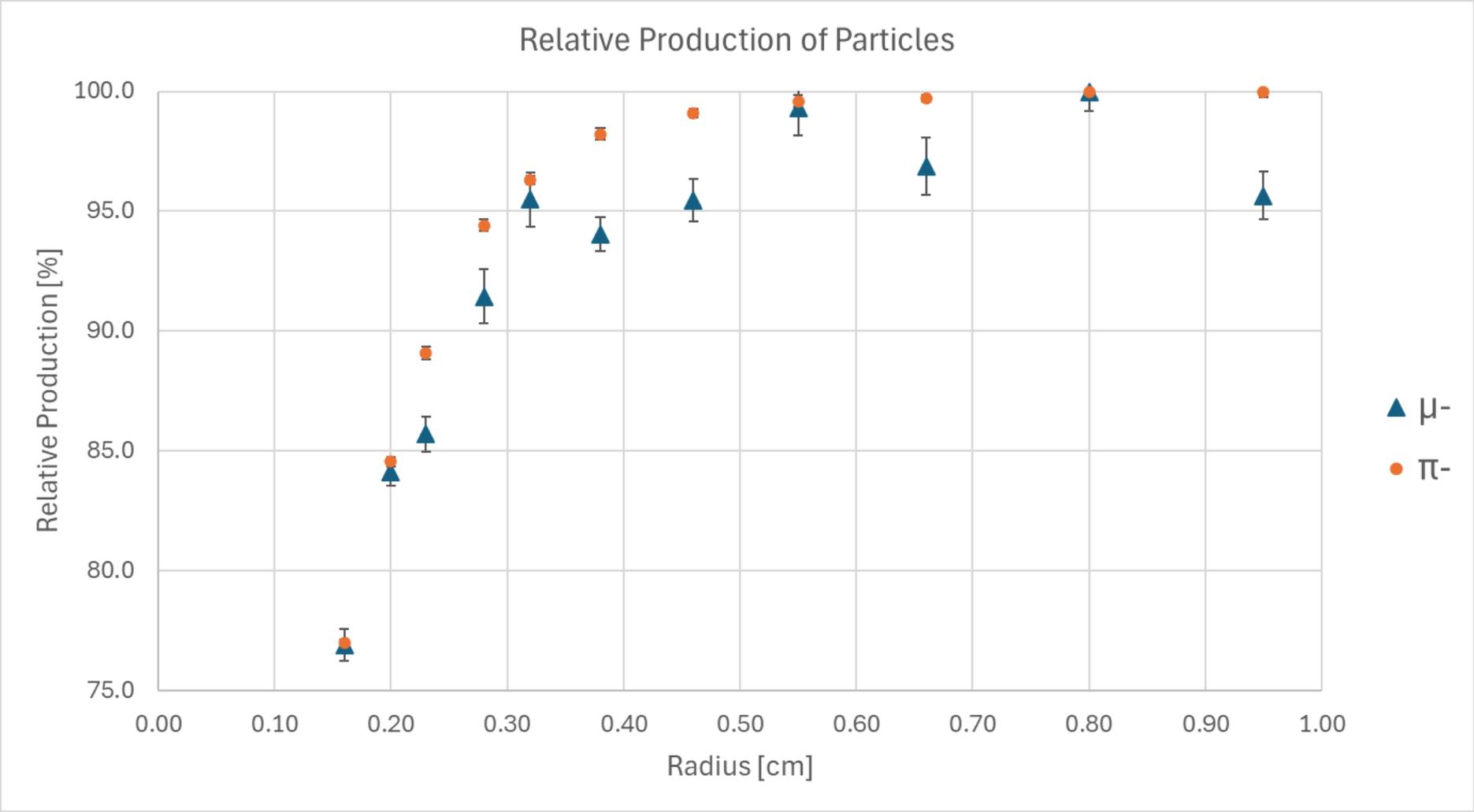
8/16/2025 10:23:02 PM



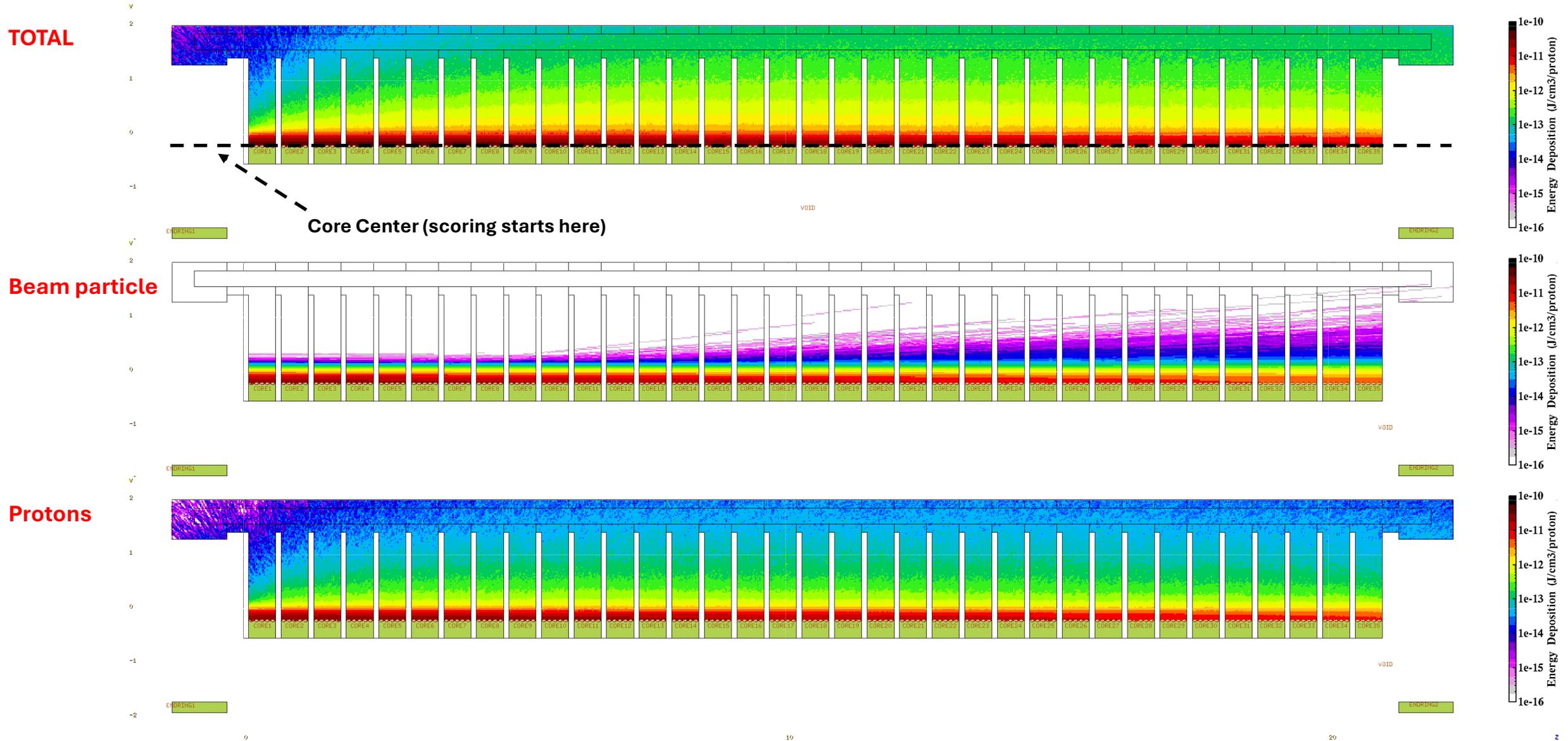
Comparison of π^- and μ^- Production vs. Core Diameter of the Stickman Target (Inconel-718)

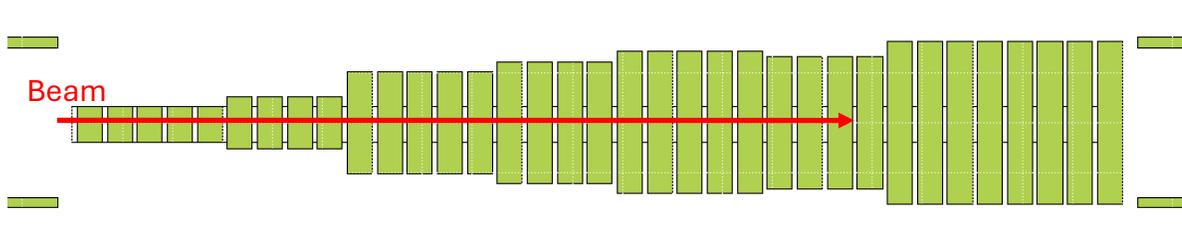


Comparison of π^- and μ^- Production vs. Core Diameter of the Stickman Target (Inconel-718)

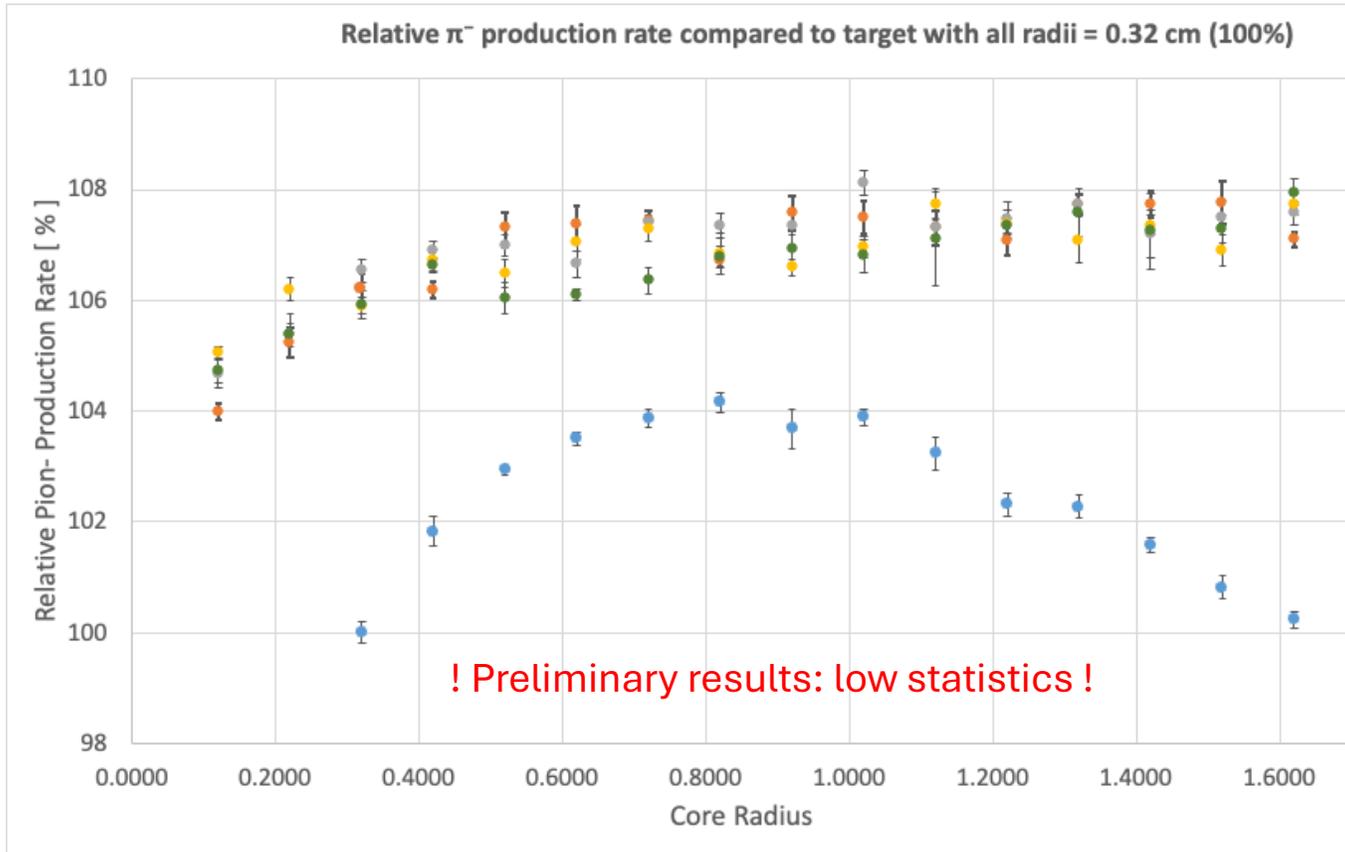


Energy Deposition Contributions by Particle Type (TOTAL vs. Beam Particle vs. Protons)





- Target divided into 8 sections:
 - 1-5, 6-9, 10-14, 15-18, 19-23, 24-27, 28-31, 32-35.
- Used R_2S1 – R_2S4 as starting radii.
- Varied each section's radius in 16 steps => 8 x 16 = 128 simulations.
- **Final shape => 8 unique radii, practical for manufacturing**



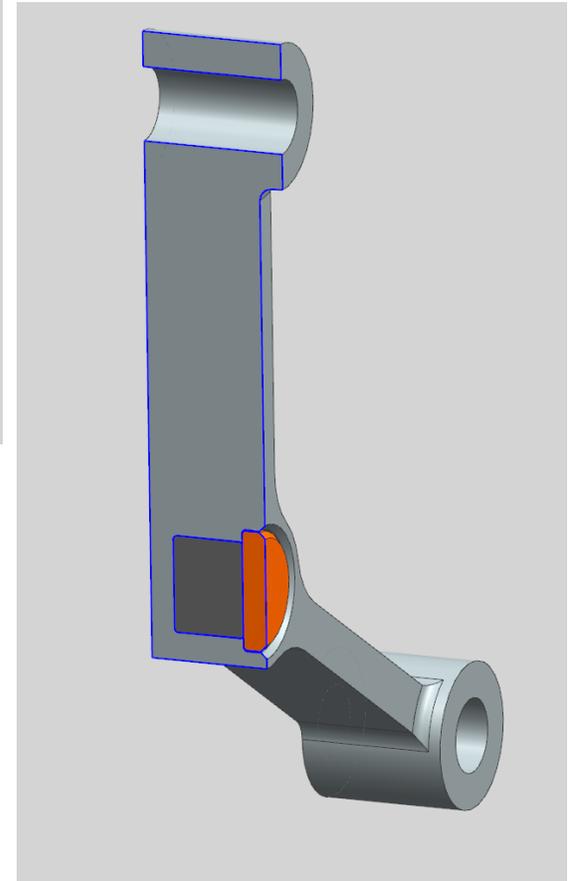
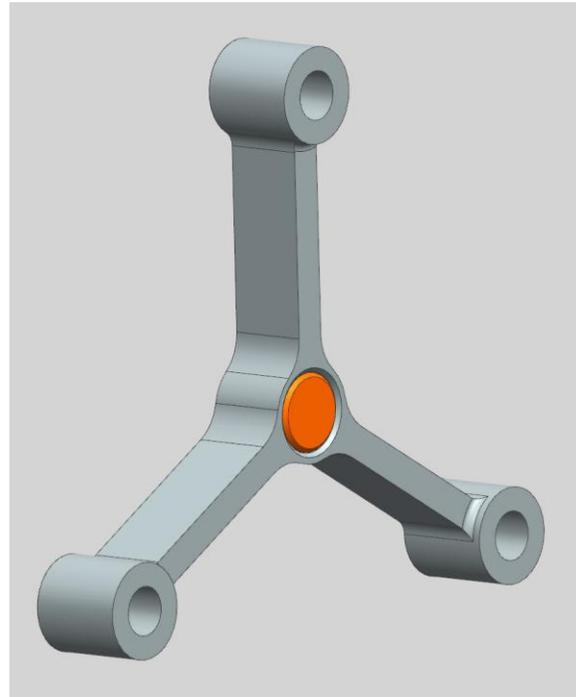
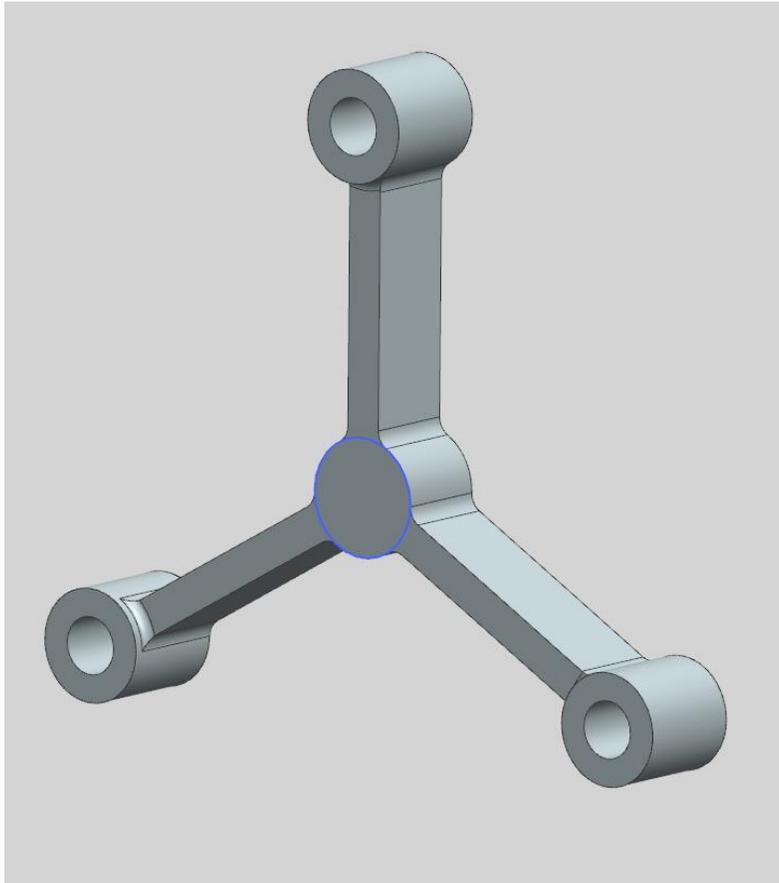
Pion- MAX	R_3S5	Pion- MAX	R_3S6
[%]	[cm]	[%]	[cm]
107.73	1.42	107.73	1.32

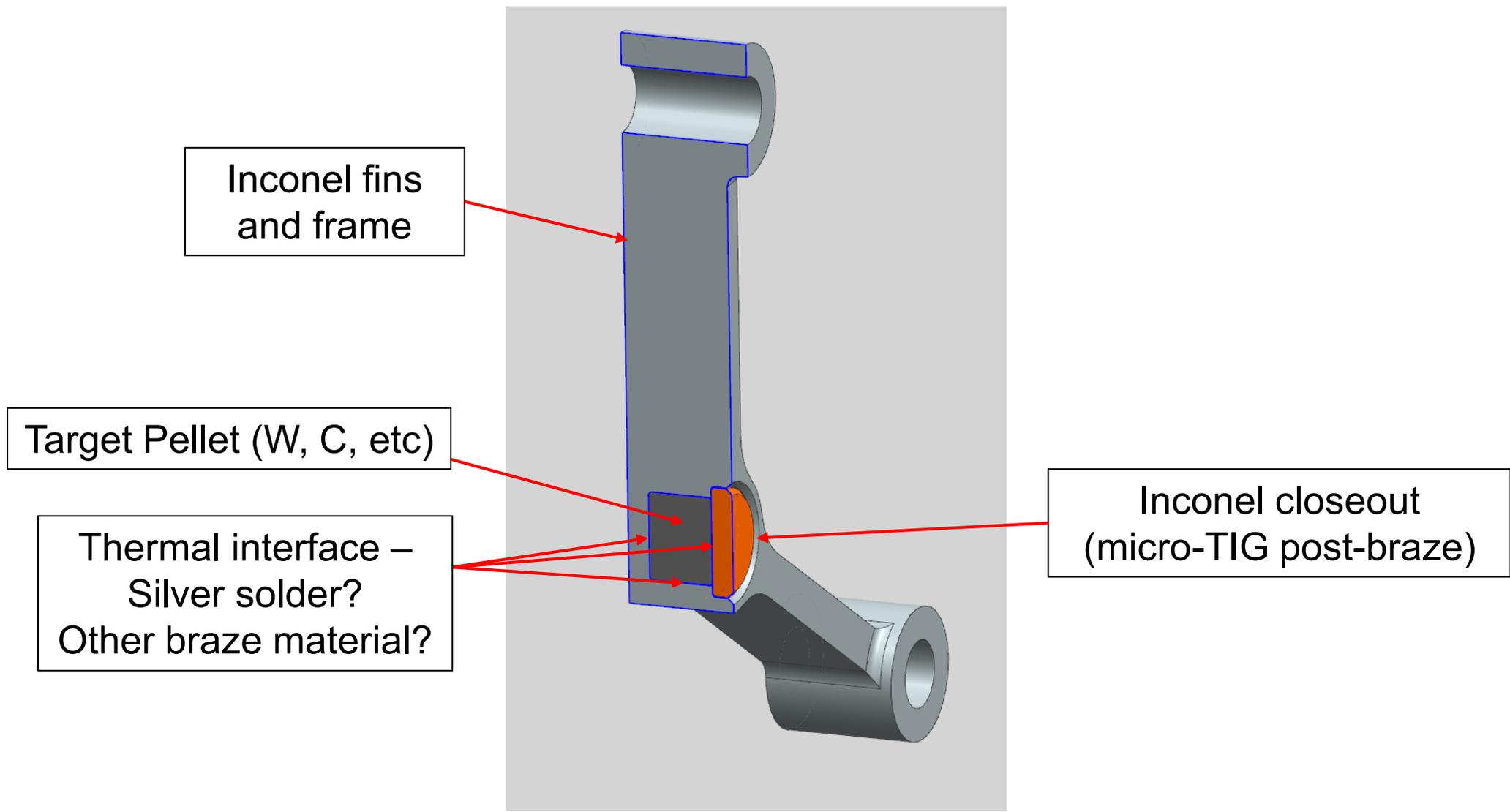
Pion- MAX	R_3S7	Pion- MAX	R_3S8
[%]	[cm]	[%]	[cm]
107.73	1.62	107.95	1.62

As discussed during the meeting, I will keep running Case 3 for better statistics; no further refinement is needed at this point.

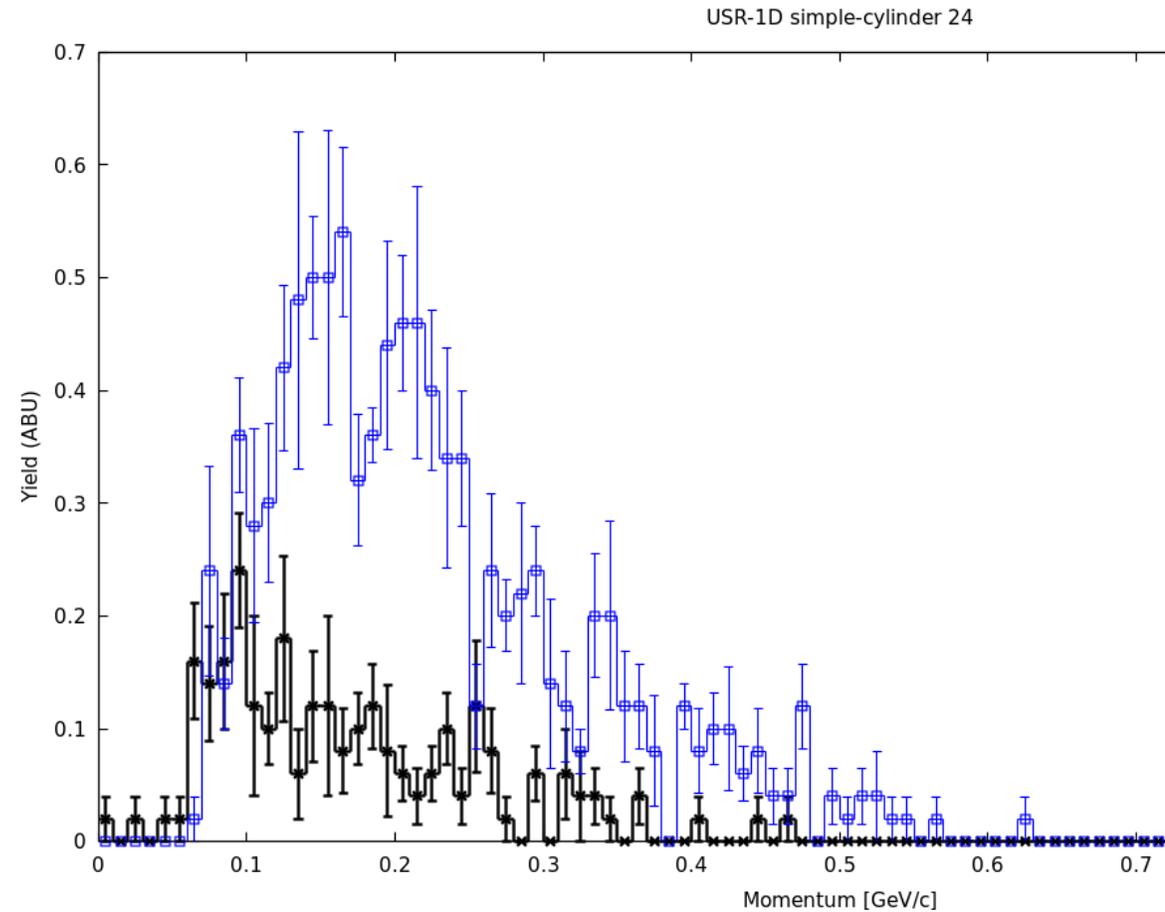
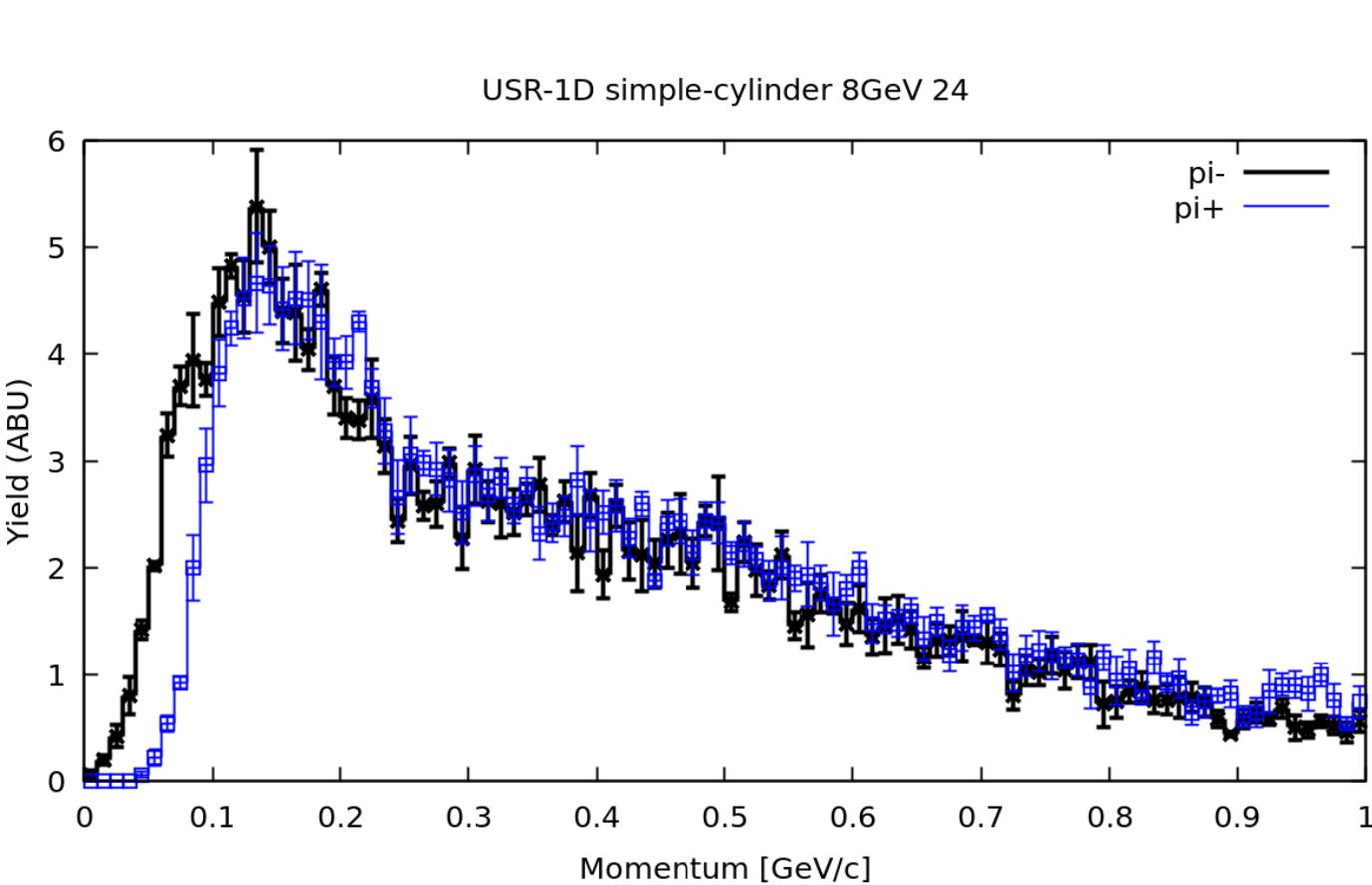
Gain: 7.65 ± 0.10%

Composite core Stickman





8 GeV \rightarrow 800 MeV? (no change in target)



Energy deposition (heat, stresses, etc WIP)