Test Infrastructure and Accelerator Research Area

Development of compact spallation sources

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Project objectives
EU Context

TIARA :Test Infrastructure and Accelerator Research Area
Preparatory Phase

http://www.eu-tiara.eu/

- The main objective of TIARA is the integration of national and international accelerator R&D infrastructures into a single distributed European accelerator R&D facility with the goal of developing and strengthening state-of-the-art research, competitiveness and innovation in a sustainable way in the field of accelerator Science and Technologies in Europe
- CEA, CRNS (F) CERN, PSI (CH), DESY, GSI (D), SFTC (UK), UU (SE), IFJ (PL), CIEMAT (ES), INFN (IT)
- 9 Work packages in all related to accelerators

Project objectives
EU Context

Team Members

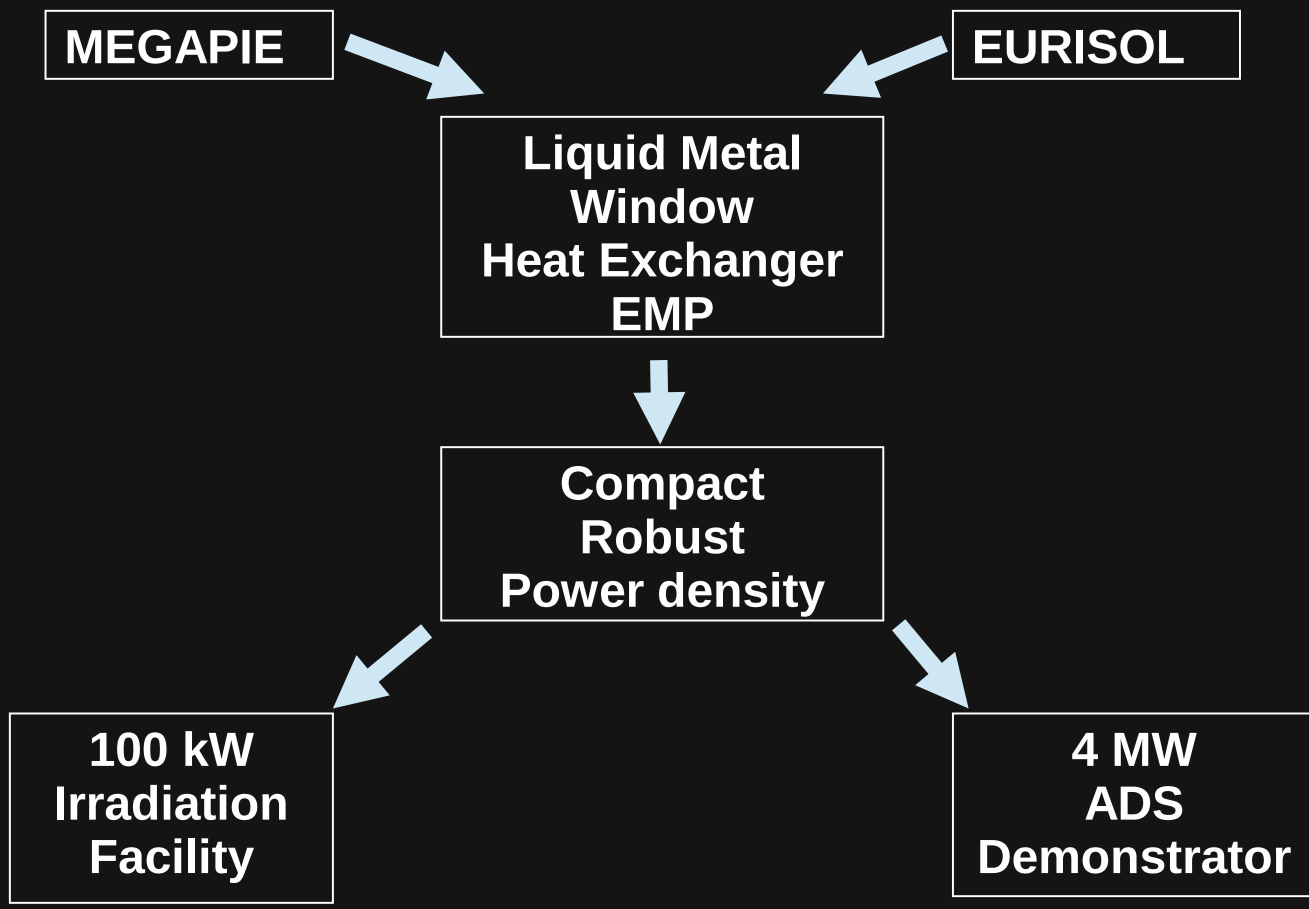
Roy Aleksan	CEA	EU Tiara Project leader
Sebastien Bousson	CNRS	EU Tiara WP9 Work-package leader
Yacine Kadi	CERN, SKKU	EU Tiara WP9 .1 Local coordinator
Masoud Behzad	SKKU	Target CFD
Yoann Fusco	CERN	Design & analysis
Raul Luis	ITN	Neutronic calculation
Yuri Romanets	ITN	Neutronic modeling
Karel Samec	CERN	Engineering responsible

Project objectives
Local Context

Purposes of a LM spallation source:

- Neutron sources are used in laboratories
  - SINQ - Villigen Switzerland,
  - JSNS –Hokkaido Japan,
  - SNS - Oakridge USA
- Further installations are planned (ESS in Lund SE, MYRRHA in BE)
  - Life sciences / Material sciences / Particle physics
- Industrial applications are possible:
  - power from Thorium / spent Uranium / ADS
  - Isotope production for medical purposes
  - Irradiation facility for nuclear materials

Project objectives
From prior experience to applications



100 kW Irradiation Facility

Design process
Specification

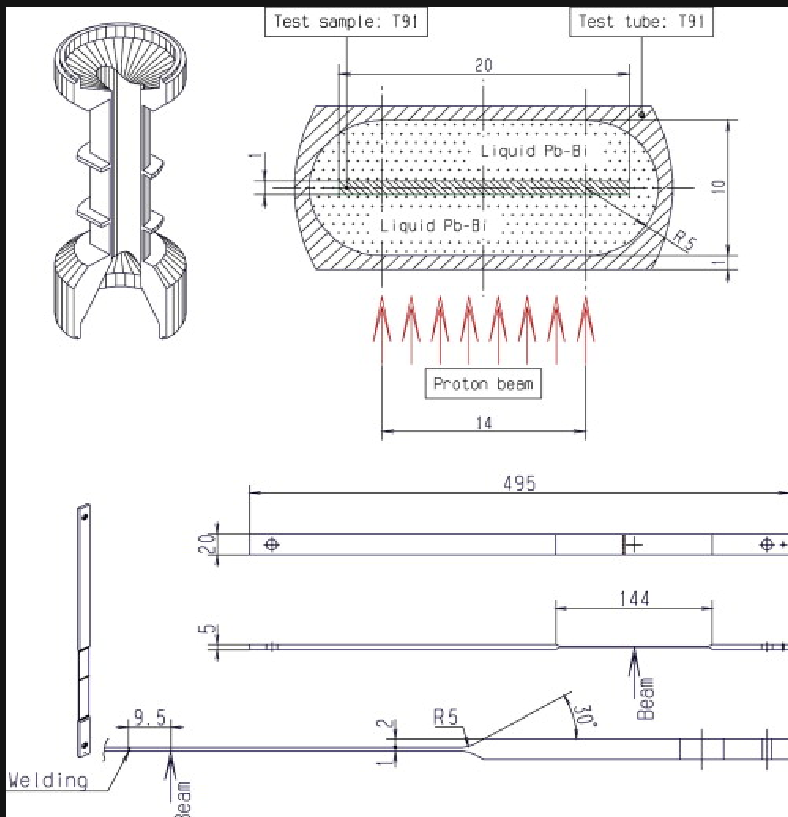
- Specification to test materials under:
  - At least 10 Dpa per year
  - up to 600°C
  - up to 500 Mpa (static or cyclical)
  - Liquid metal corrosion
- Facility must be usable “anywhere”
- Integrated safety barriers, no need for dedicated zone

Design process
Essential parameters

Characteristic	Value	Unit
Primary Circuit Lead inventory	11	L
Secondary Circuit Gallium inventory	4.5	L
Max / min primary temperature	550 / 380	°C
Max / min secondary temperature	120 / 75	°C
Beam Power	100	kW
Beam Energy	200 - 600	MeV
Peak current density	30	μA / cm2
Min proton / neutron damage	10	Dpa / y
Max window stress	<100	MPa
Neutron flux density	$>10^{13}$	n/cm^2s

Design process
prior experience

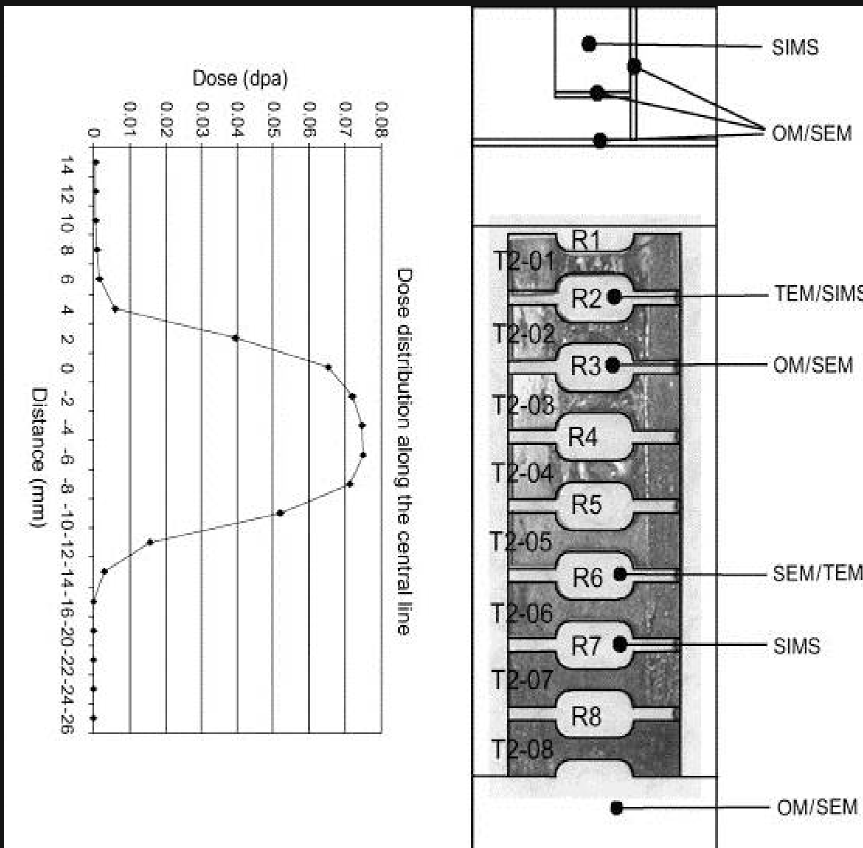
- Accelerator-based facility, like LISOR

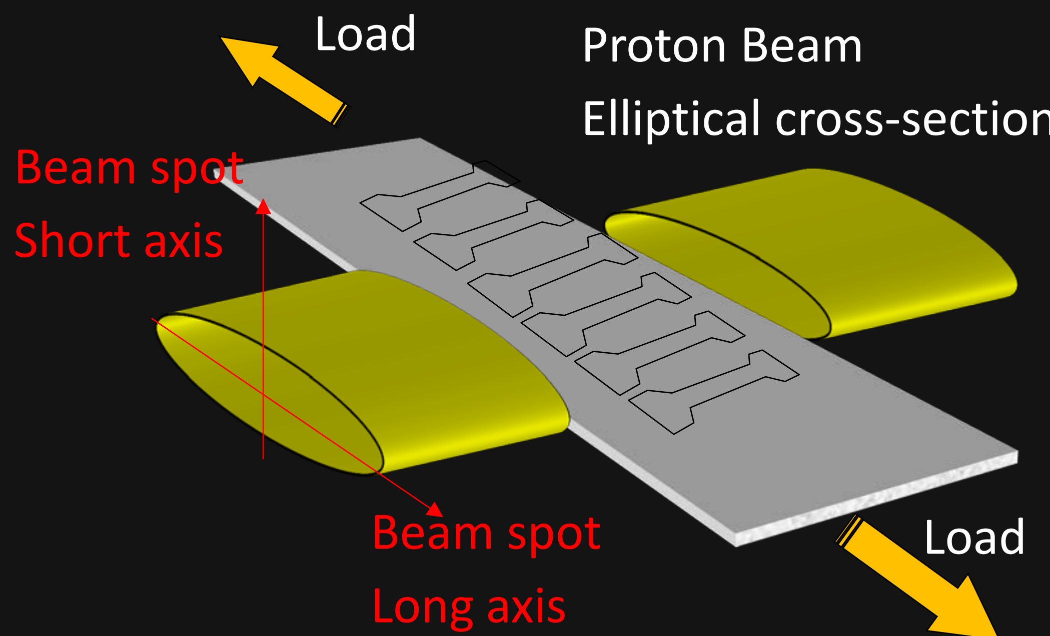


- …but more samples, like BR2 (reactor)

Design process
prior experience

- Micro-samples as in LISOR



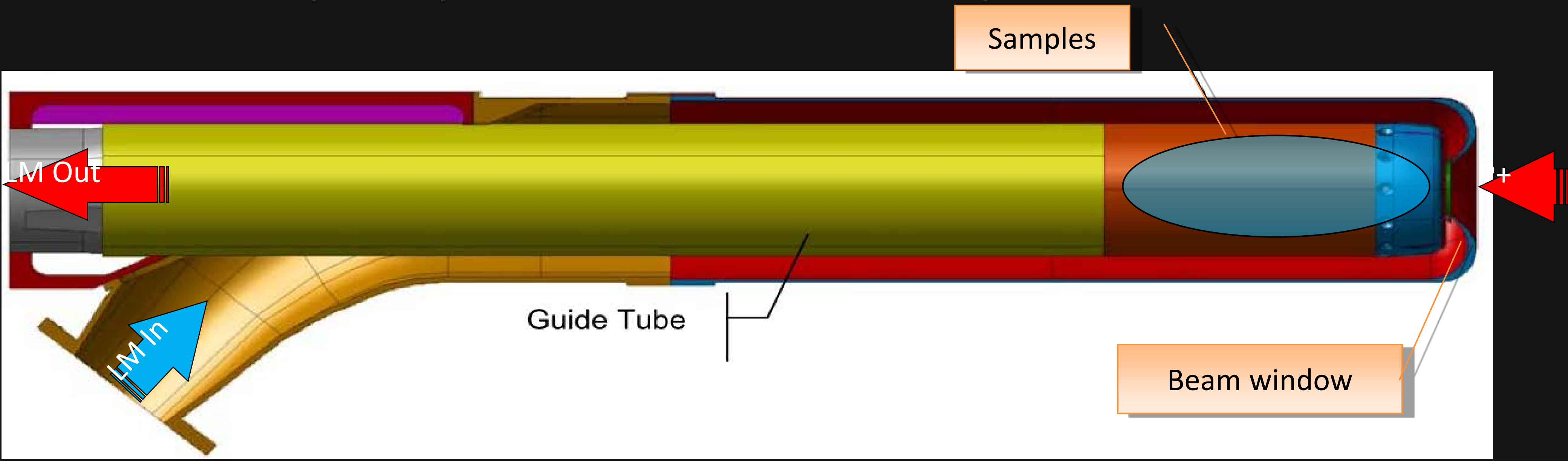


- …but more consistent doses with constant beam

- (elliptical beam section for homogenous pattern)

Design process
prior experience

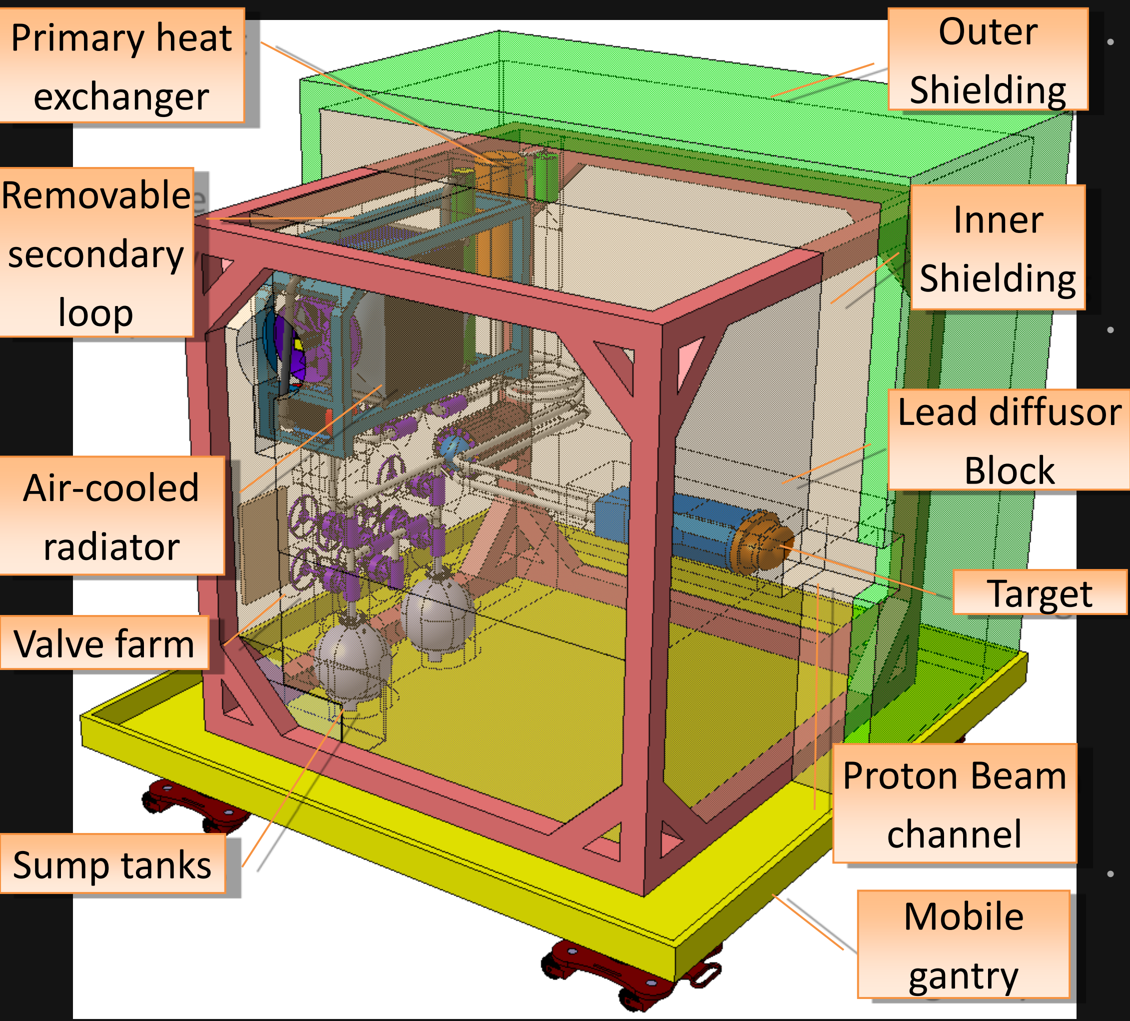
Compact liquid metal neutron source design from Eurisol



Conical beam window adapted to high power density

Ample room for samples in high flux regions

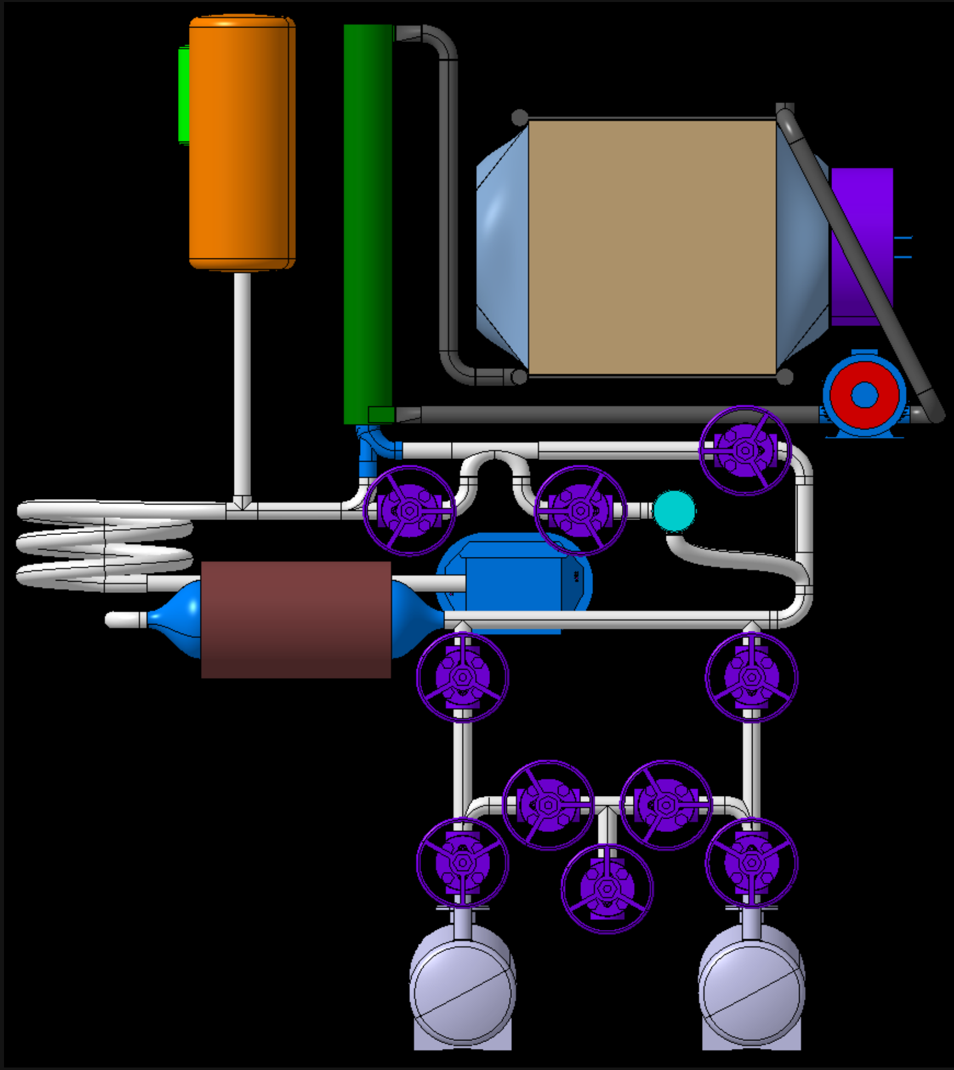
Design process
Overall Concept



- Entire facility fits within a transportable structure, containing the irradiation area, all ancillaries, barriers and shielding.
- In the center of the facility rests the neutron spallation source where the material samples are positioned for testing. The spallation source contains liquid lead which when hit by a proton beam emits neutrons thus leading to DPA build-up in samples from neutrons and protons
- A primary loop interfaces with a secondary loop containing gallium which then evacuates the heat to an air-cooled heat exchanger.

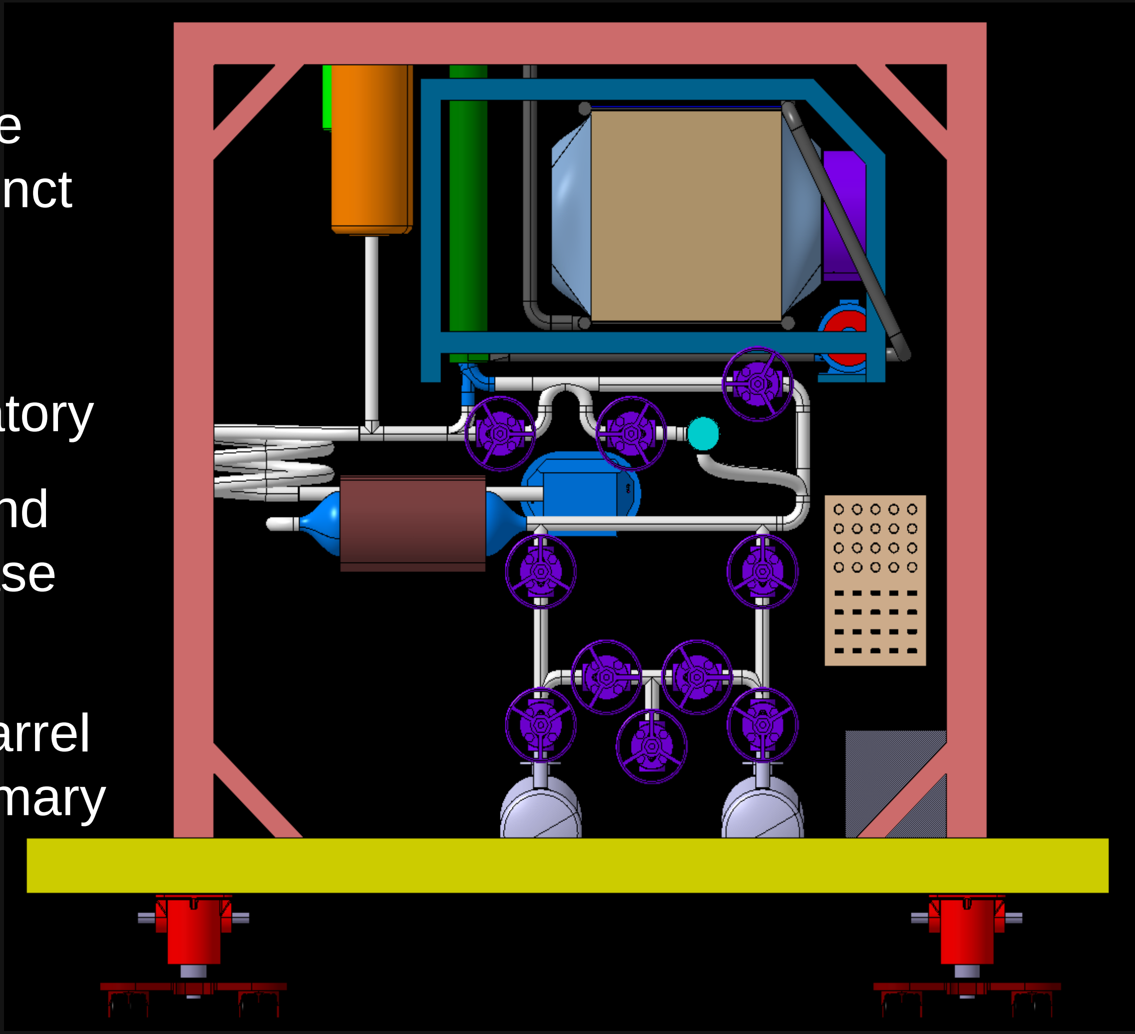
Design process
Primary Loop Design

- Design ensures:
- Drainage: full redundancy and external evacuation.
- On-line Filtering on bypass line.
- Large pressurizer able to also collect spallation gases.
- Detachable primary/secondary HEX interface.
- HEX bypass for thermal control.
- All control valves manual/pneumatic.

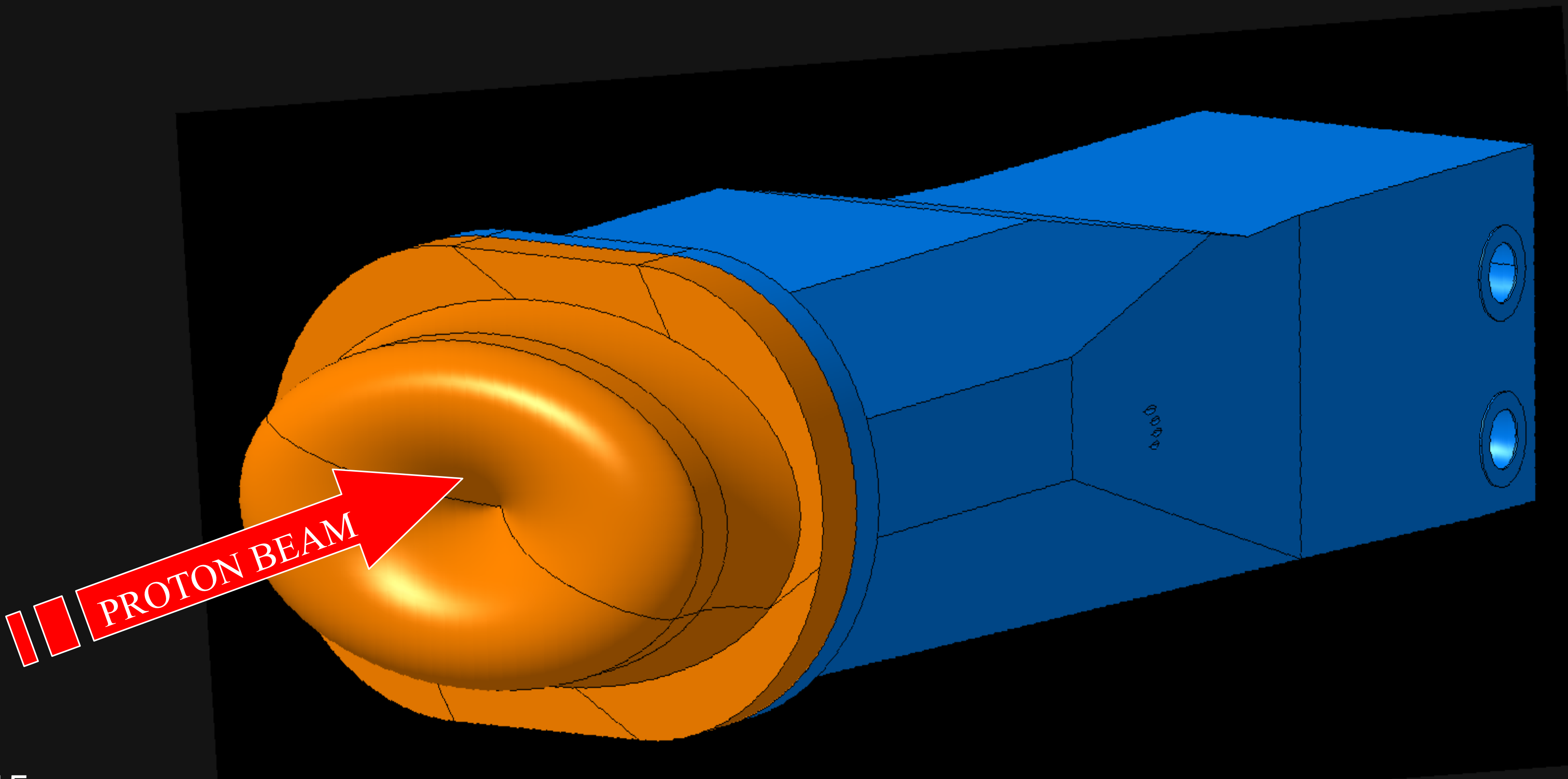


Design process
Secondary Loop Design

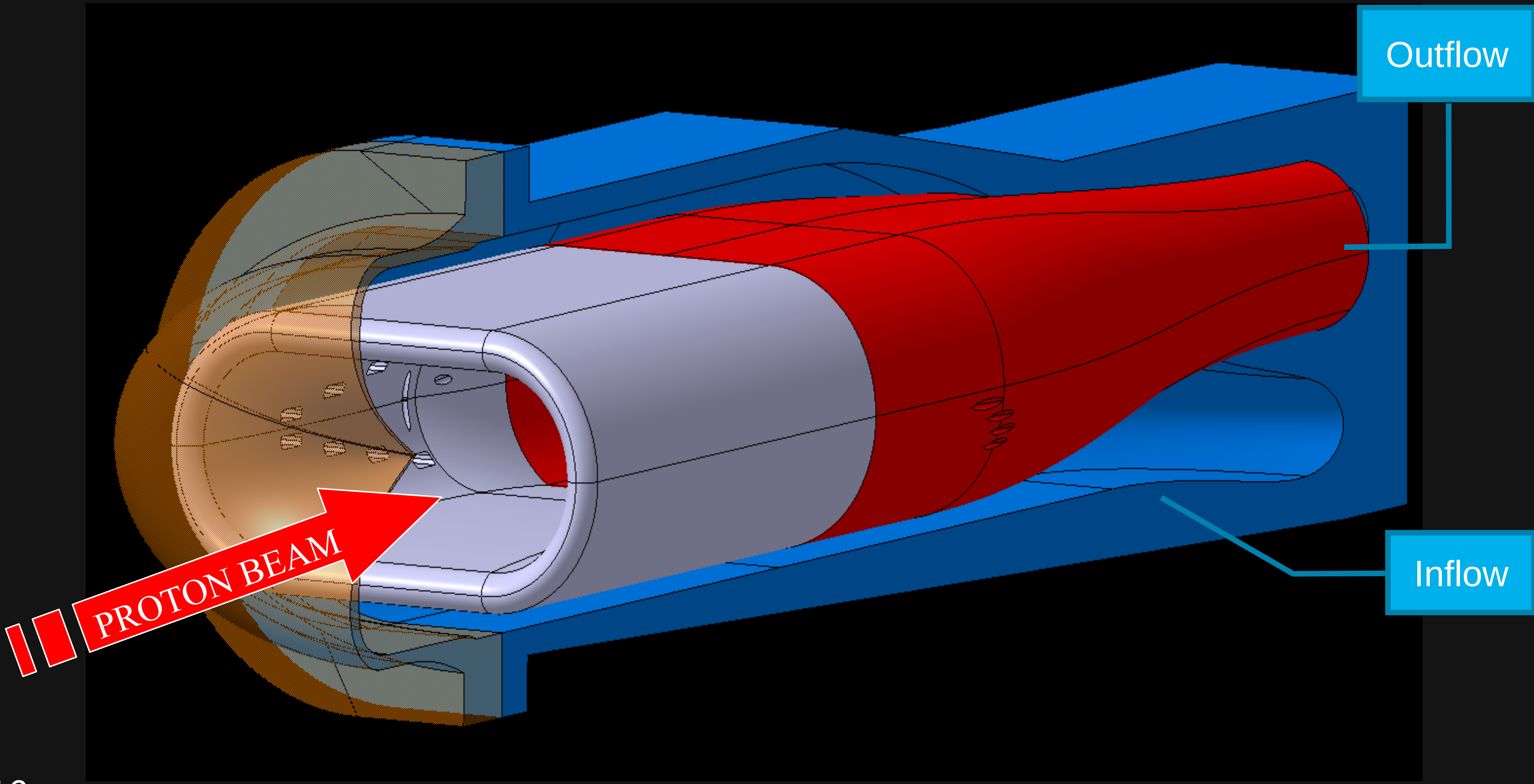
- Secondary loop fits inside a detachable truss located inside the primary truss, from which it is distinct
- Heat evacuation by air heat exchanger using forced heat convection to dump heat to laboratory
- Pump using permanent magnet and conventional motor (diversity + ease of maintenance)
- Interface with primary limited to barrel of heat exchanger sliding over primary pin



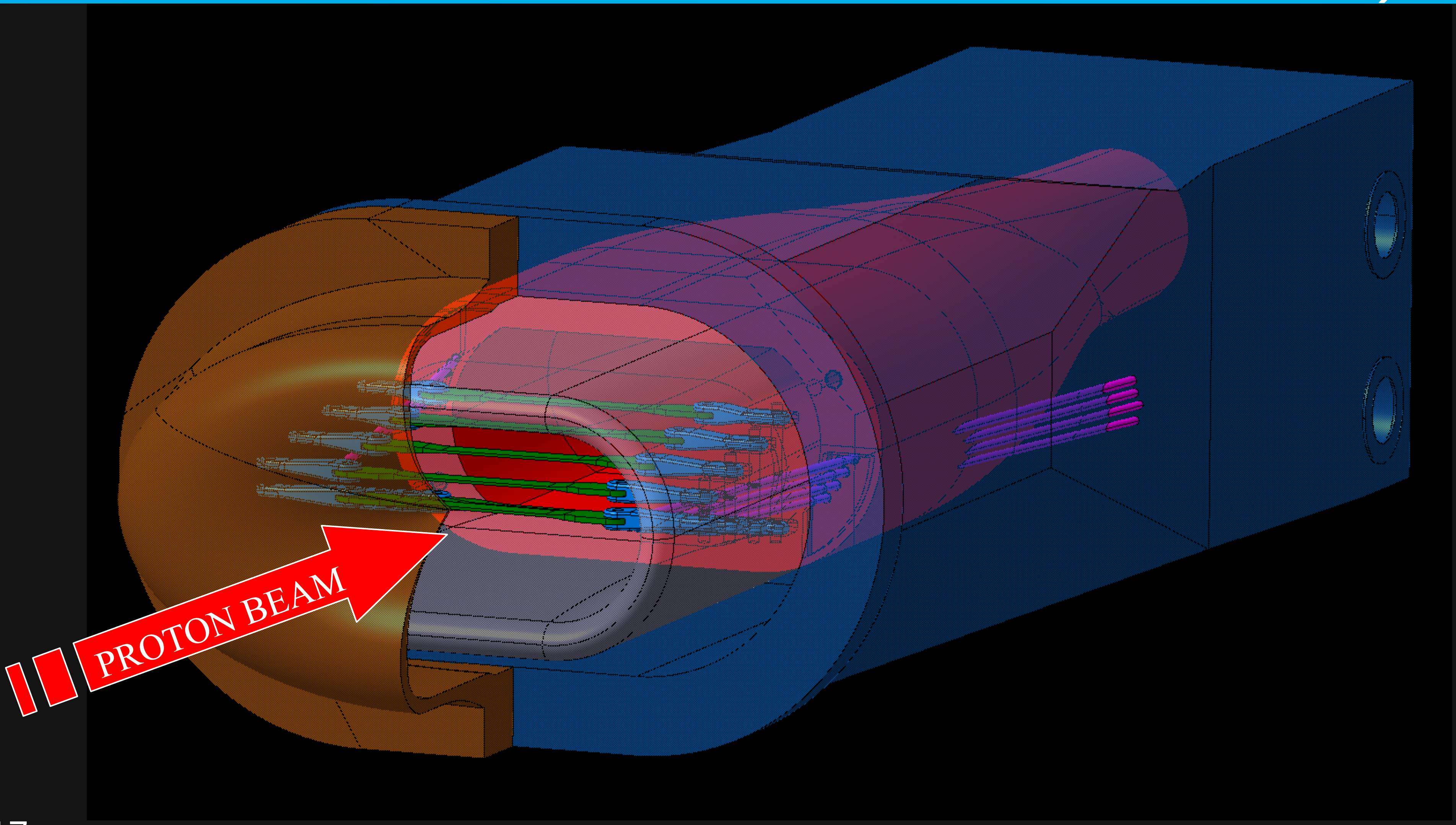
Design process
Tiara Target station concept



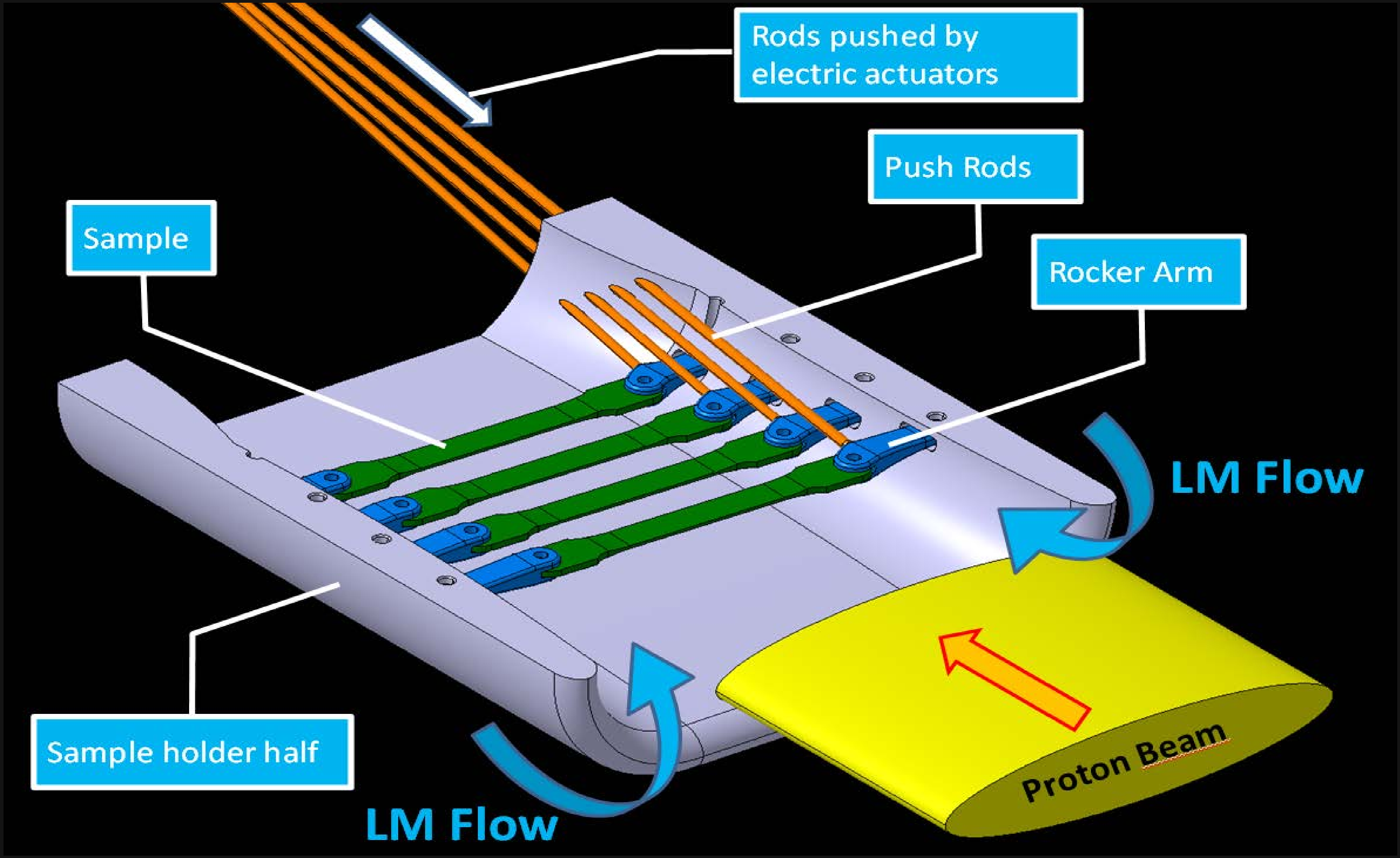
Design process
Target station concept



Design process
Placement of samples in target



Design process
Loading of samples in target



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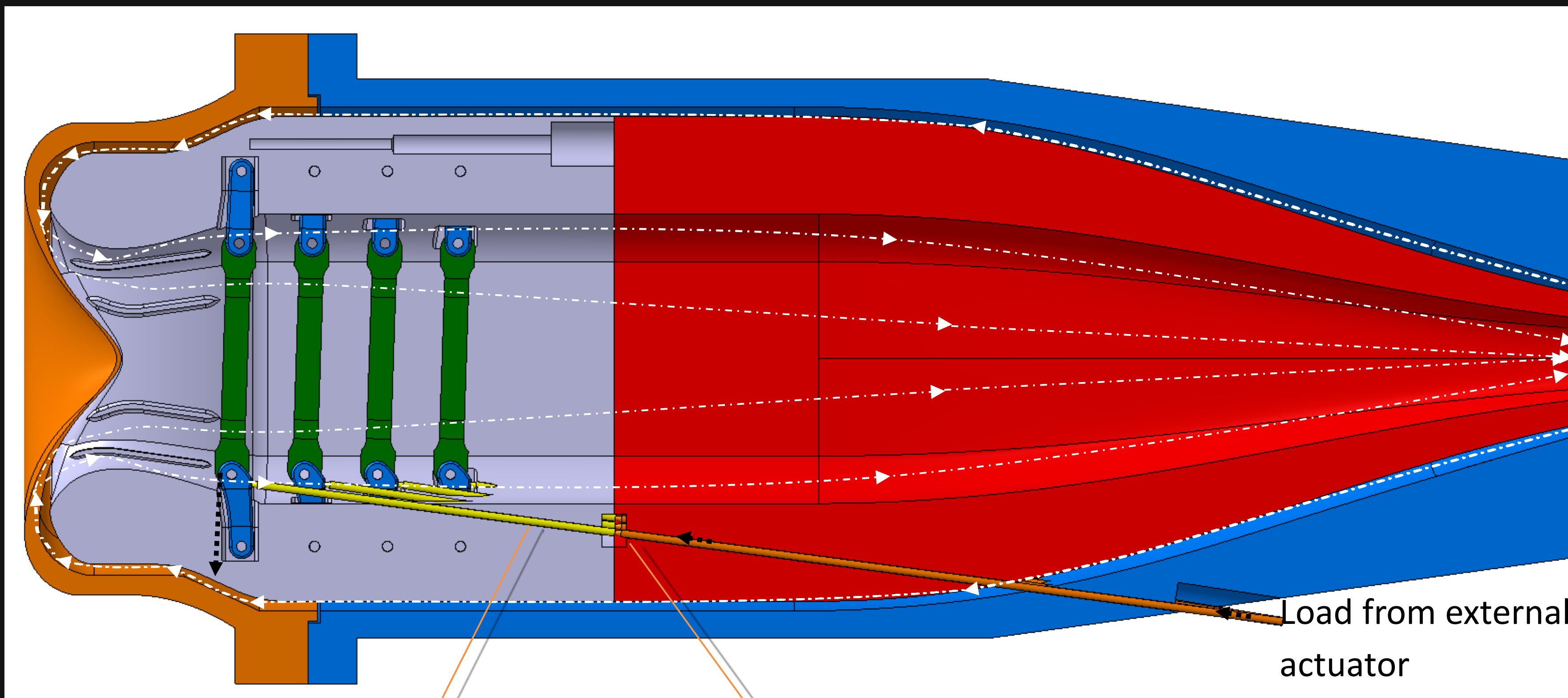
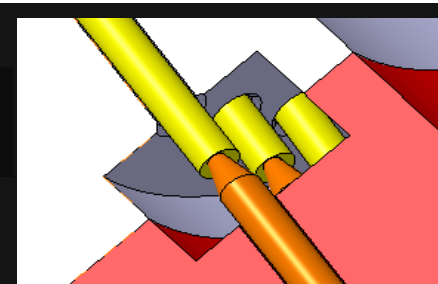
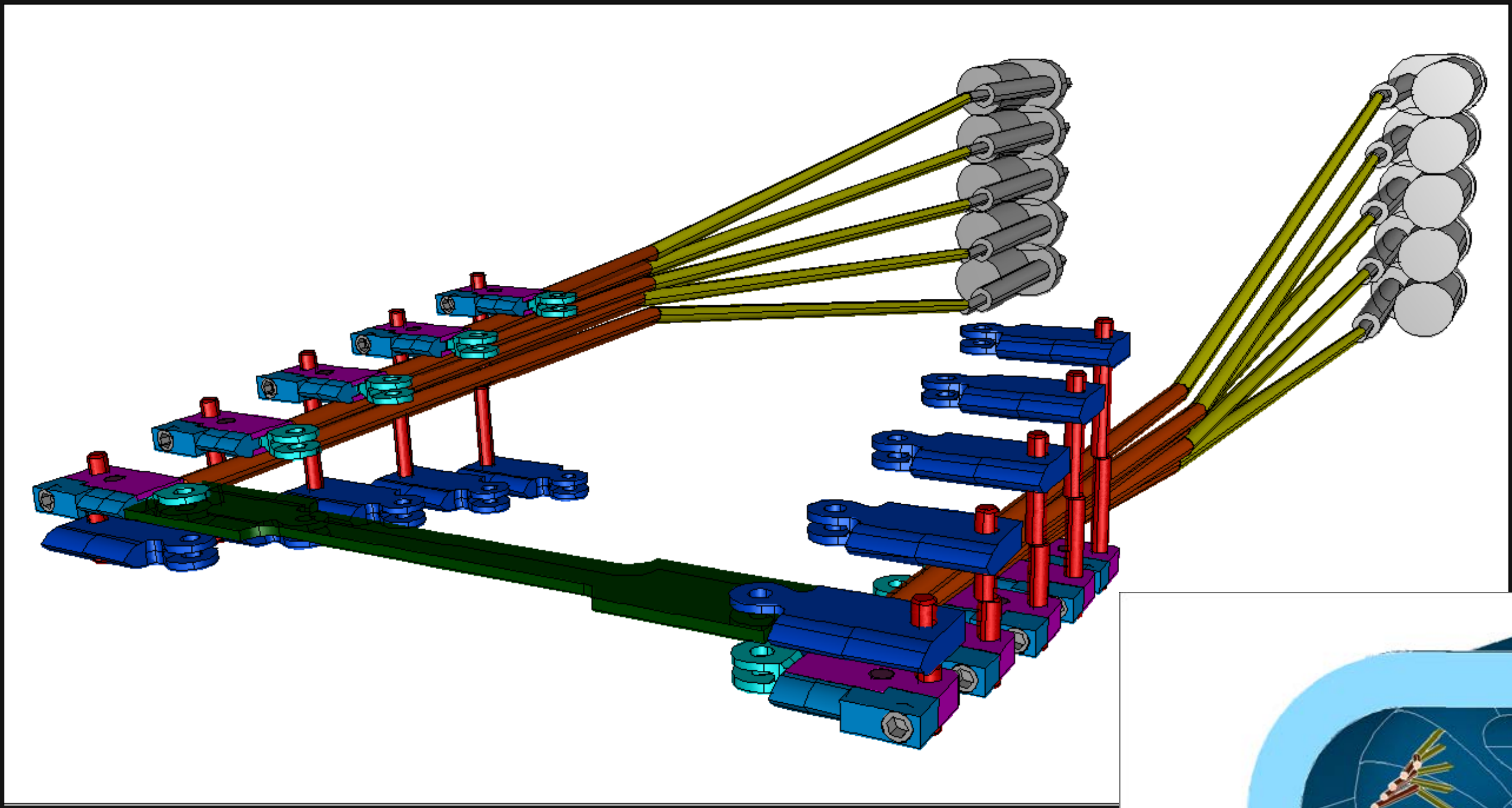
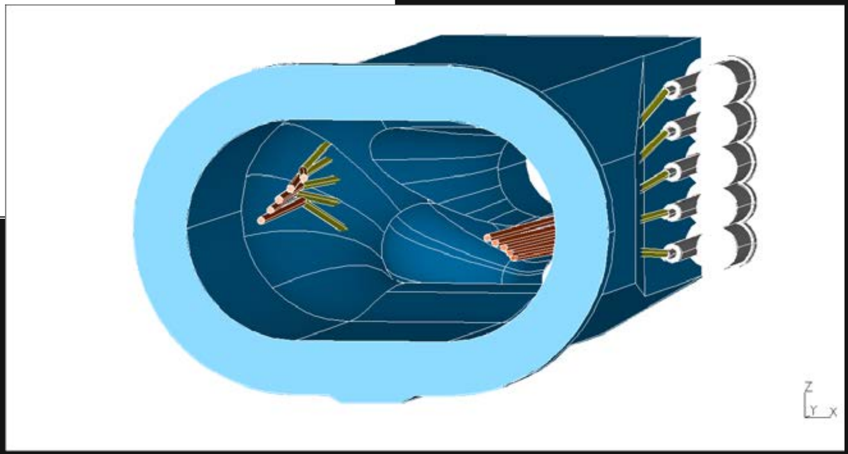




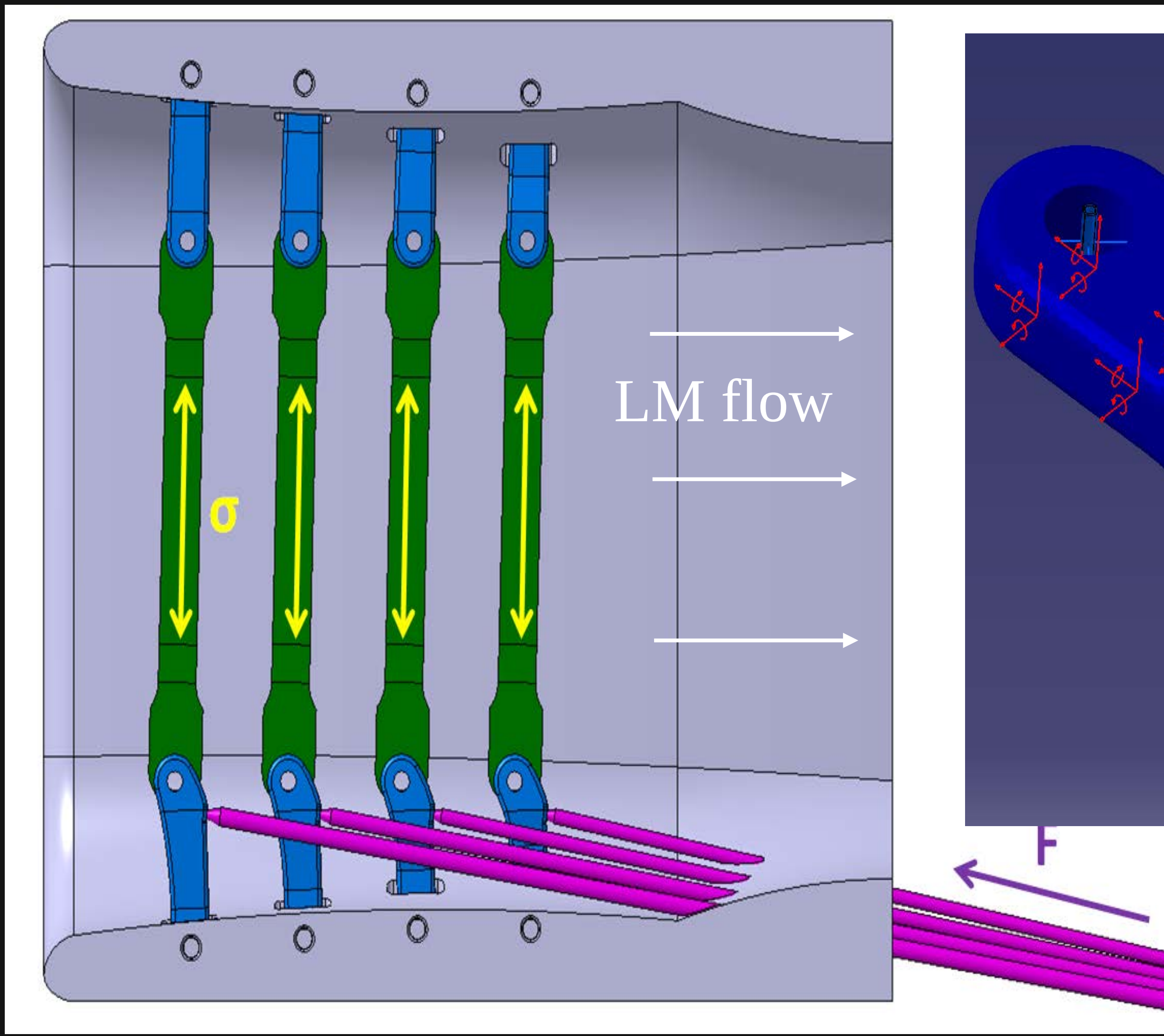
Design process
Loading of samples in target

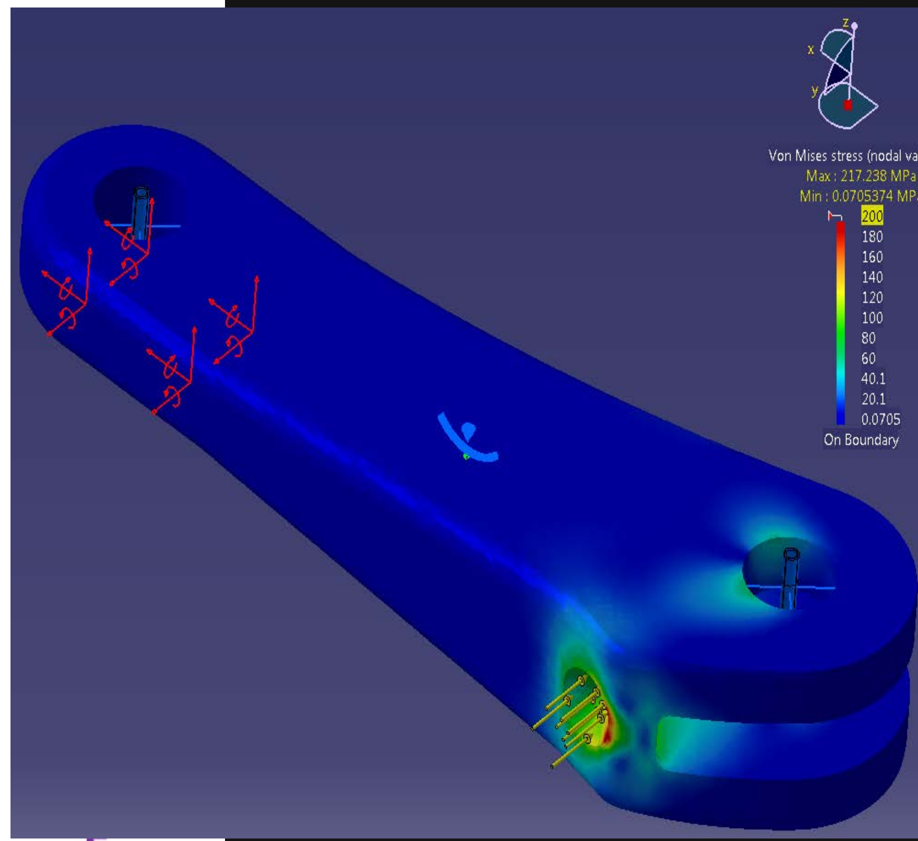


Detachable pushrods at sample holder Interface



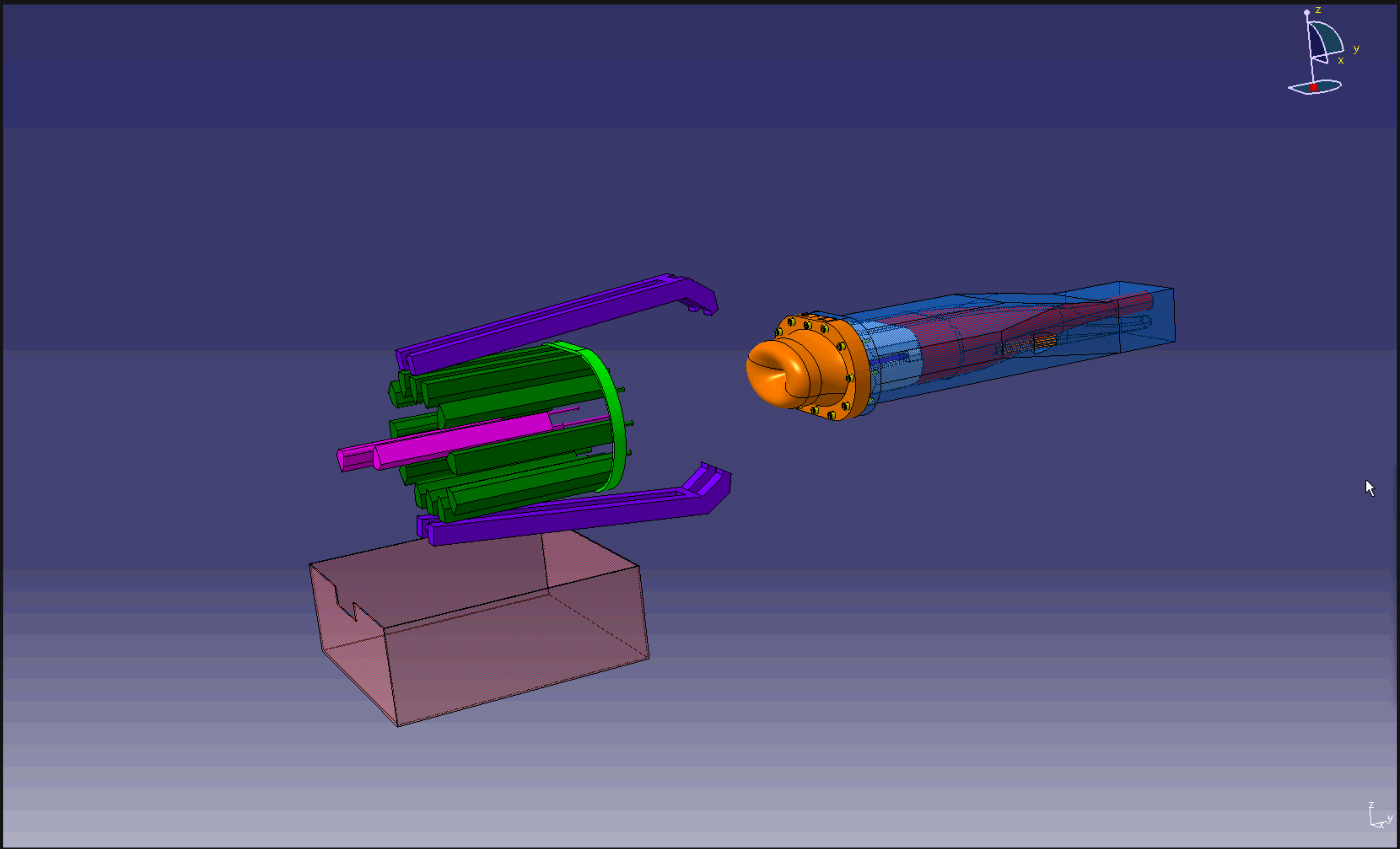
Design process
Loading of samples in target



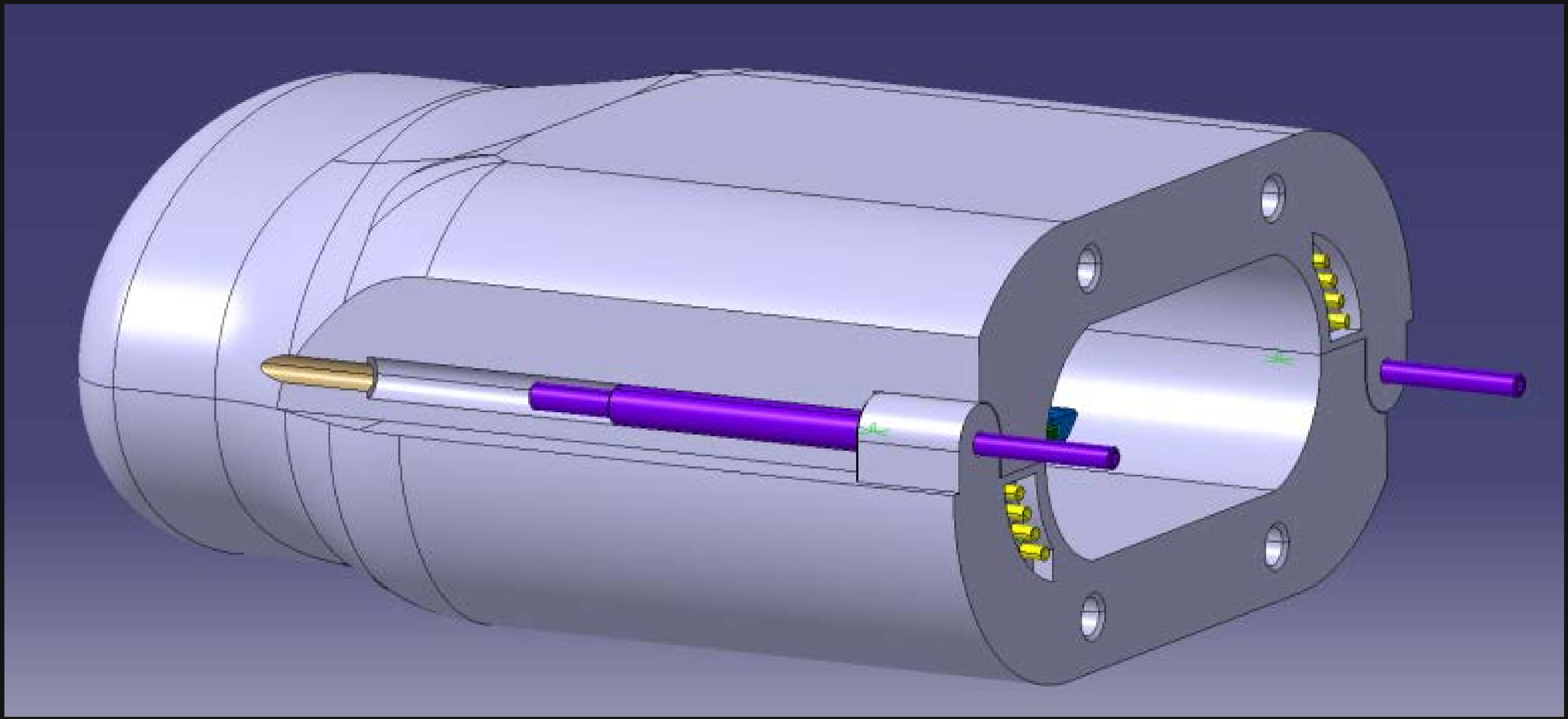


Stress analysis on sample loading mechanism

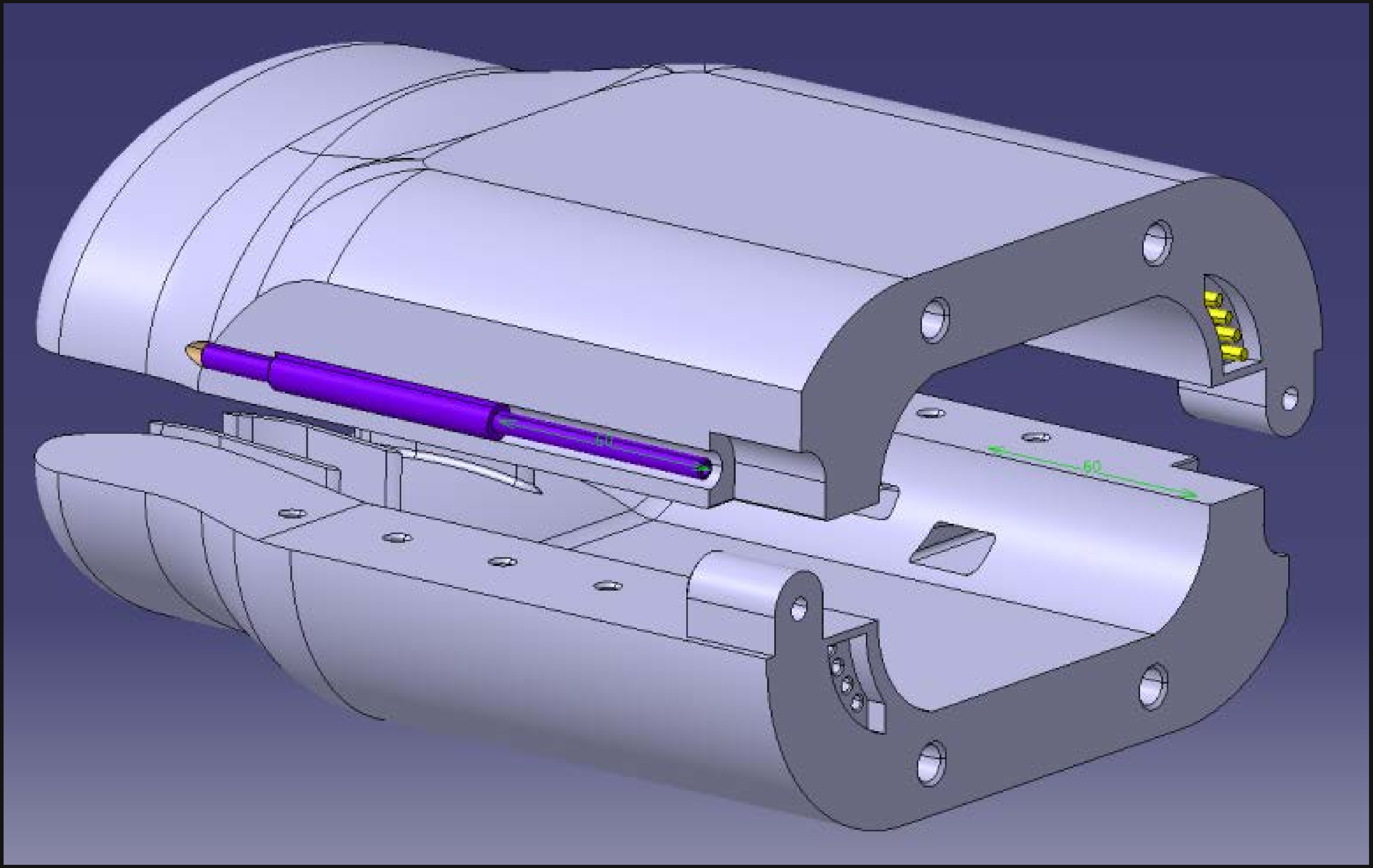
Specific design innovations
Robotic maintenance



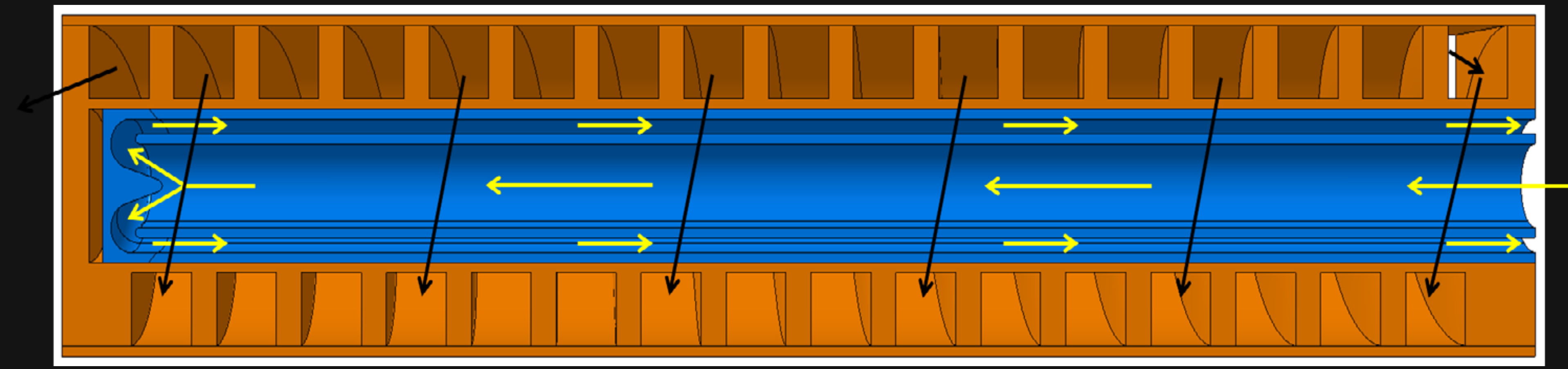
Specific design innovations
Opening of samples holder



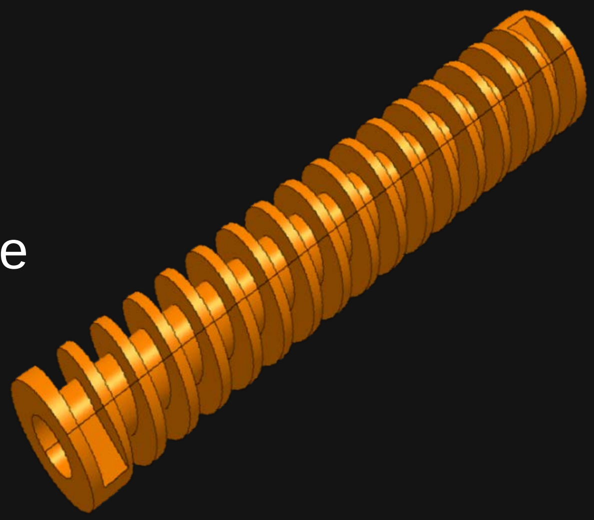
Specific design innovations
Opening of samples holder



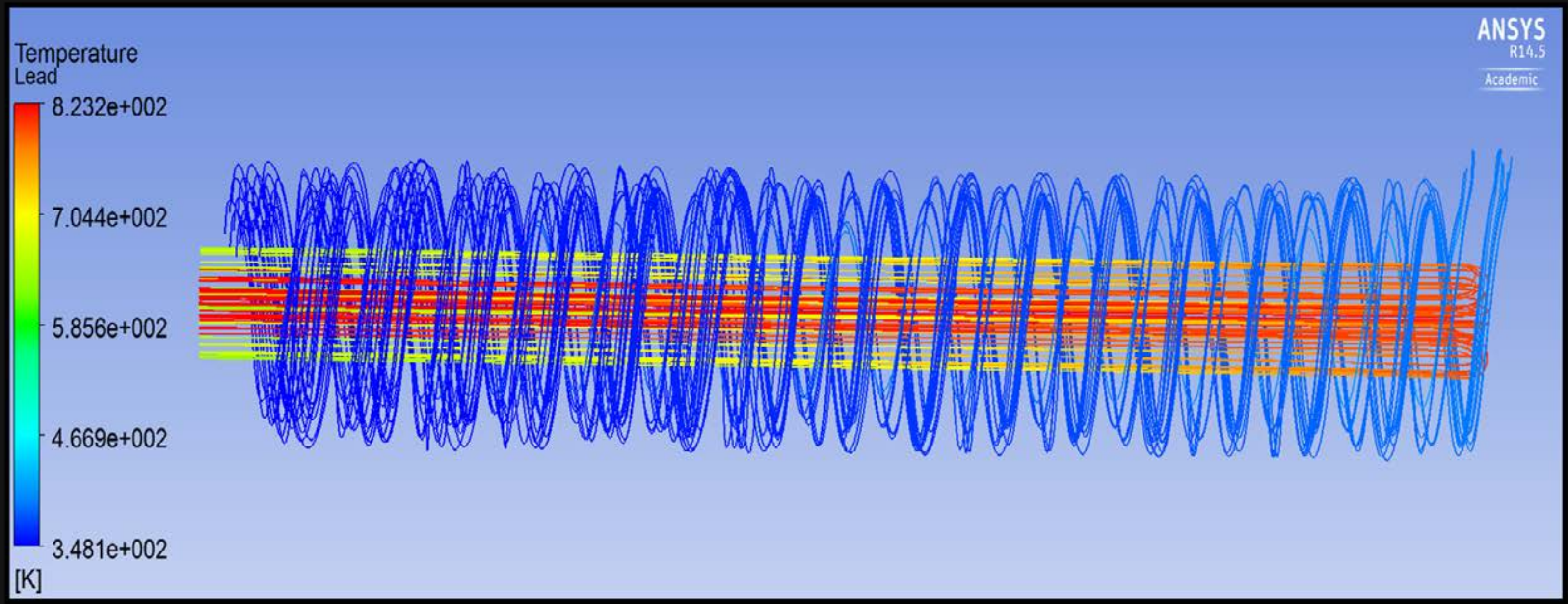
Design process
Two-piece separable Heat EXchanger



- A primary fluid circulating in a central tube (blue) is located inside a hollow cylinder forming a spiral flow containing the secondary fluid (orange)
- The inner primary pin can easily be extracted from the secondary cylinder, thus ensuring the two fluids are kept separate (no leak-through) and can be sent for maintenance in different zones



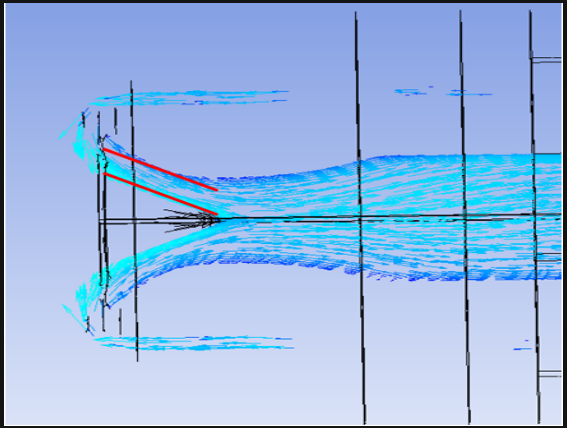
Design analysis
CFD Analysis of Heat Exchanger

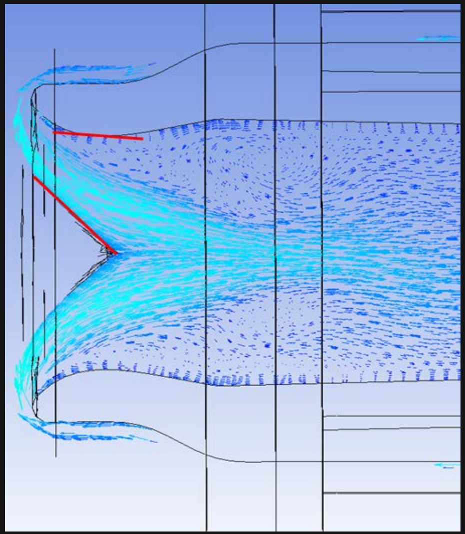


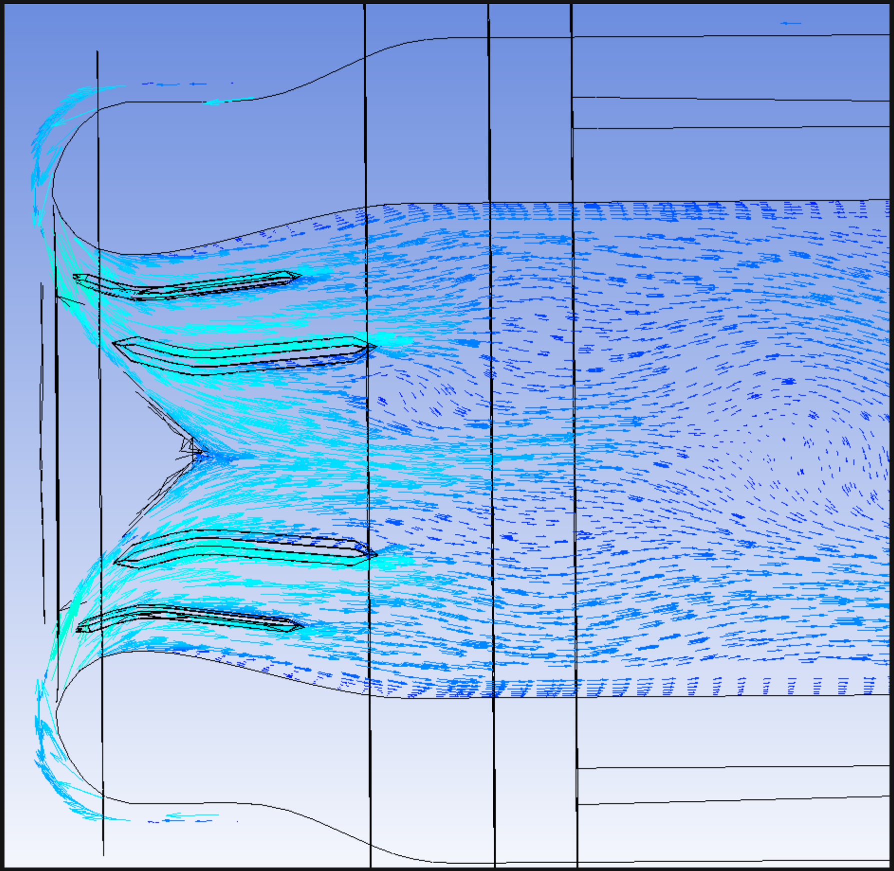
- The primary hotter fluid reverses at the end of the central pin and exits from the same side
- The secondary fluid travels in a spiral around the primary container and is in contact with it through a double-wall which serves as an extra barrier but does degrade the performance
- The design is nevertheless able to evacuate 100 kW in a very compact design

Design Analysis
CFD Analysis of Target

- Numerous iterations were necessary to improve flow conditions after the reversal in the beam window…

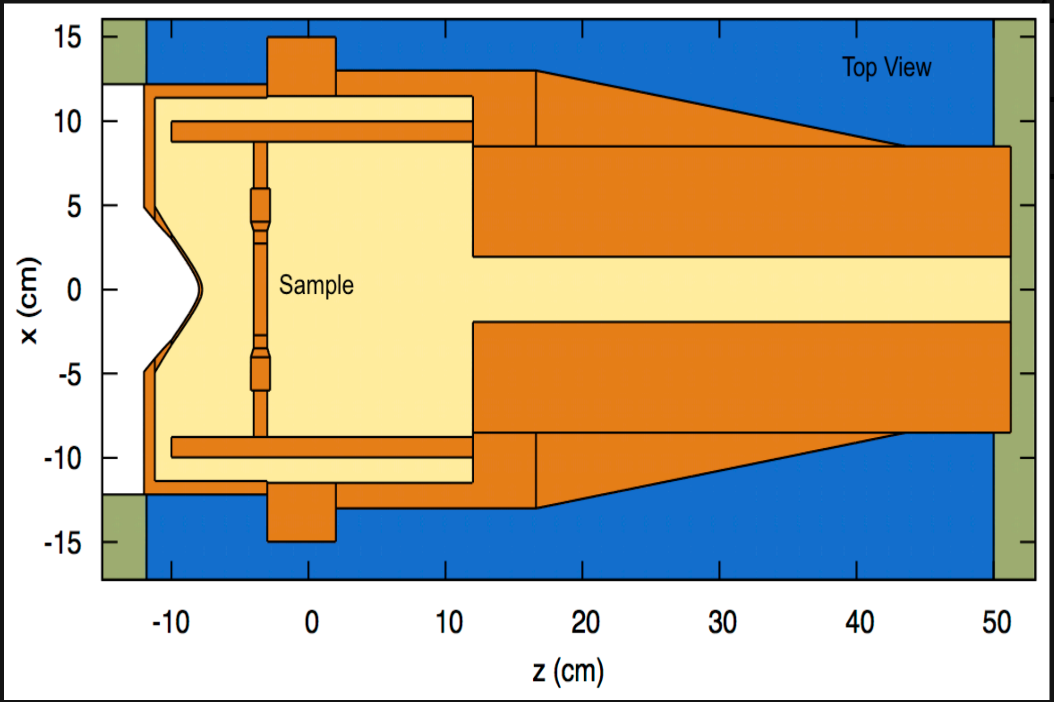


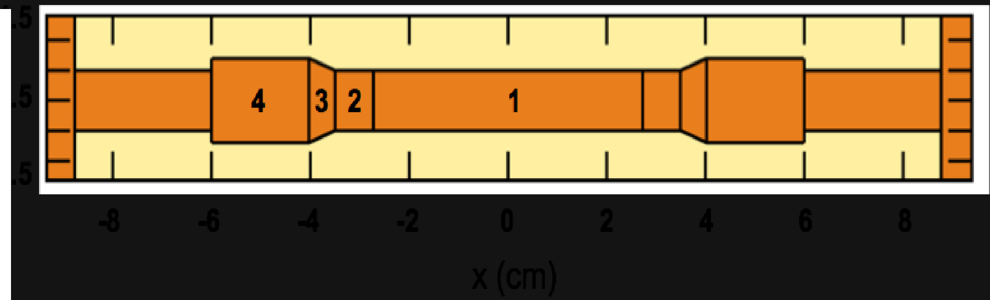


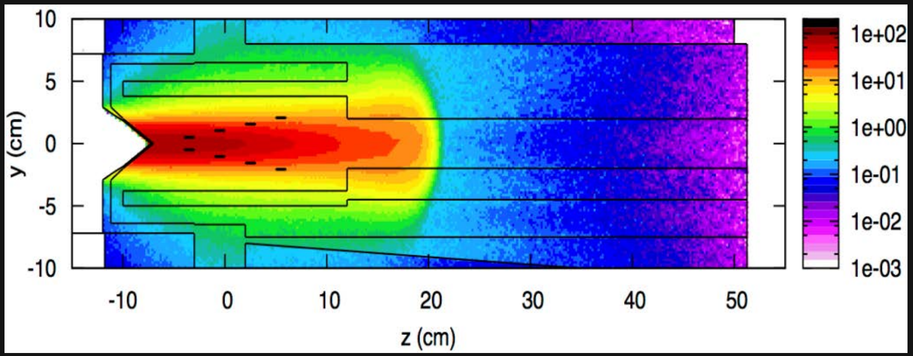


Design Analysis
Neutronics analysis in target

- Very detailed model allowing great depth of investigation into every aspect of the design.

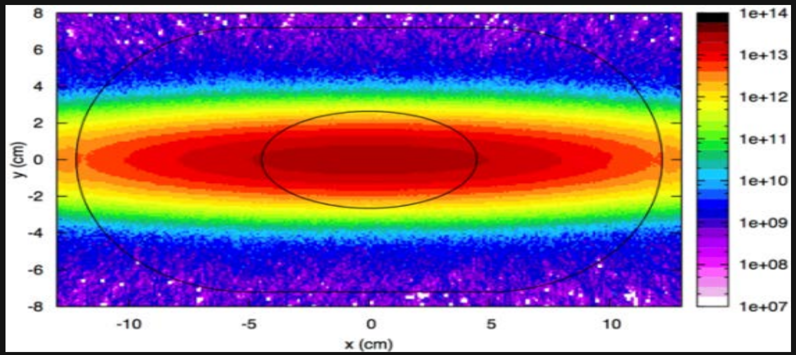




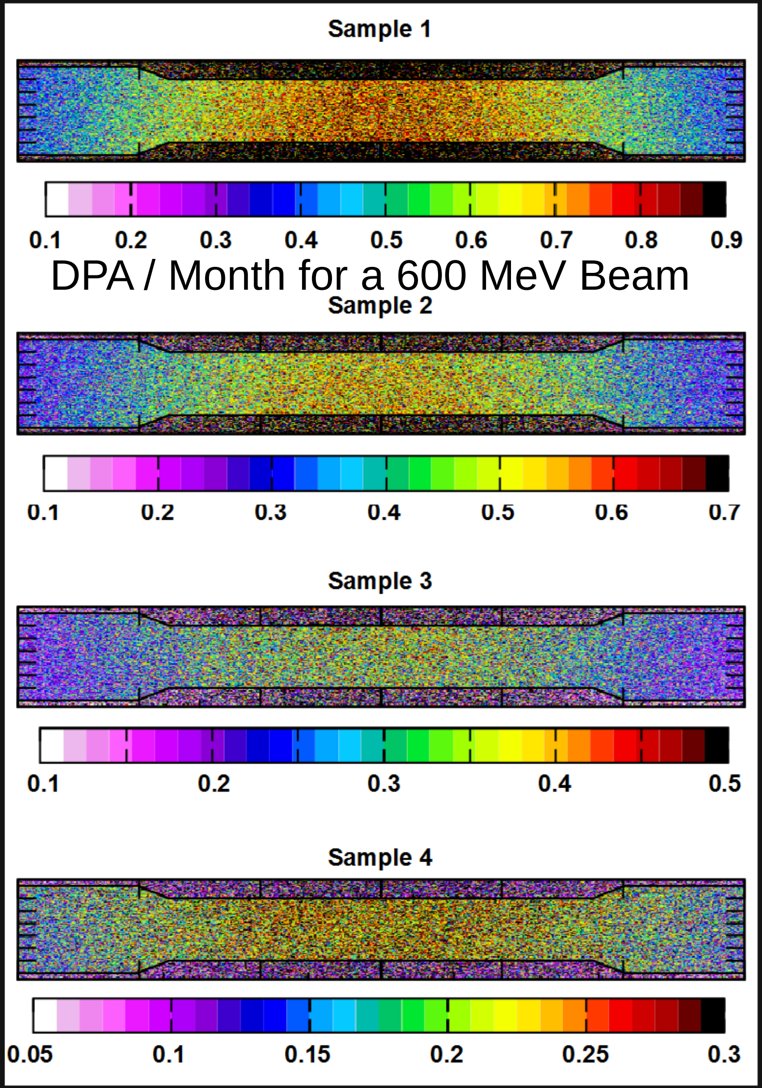


Design Analysis
Sample Neutronics / Beam sigma 1:6

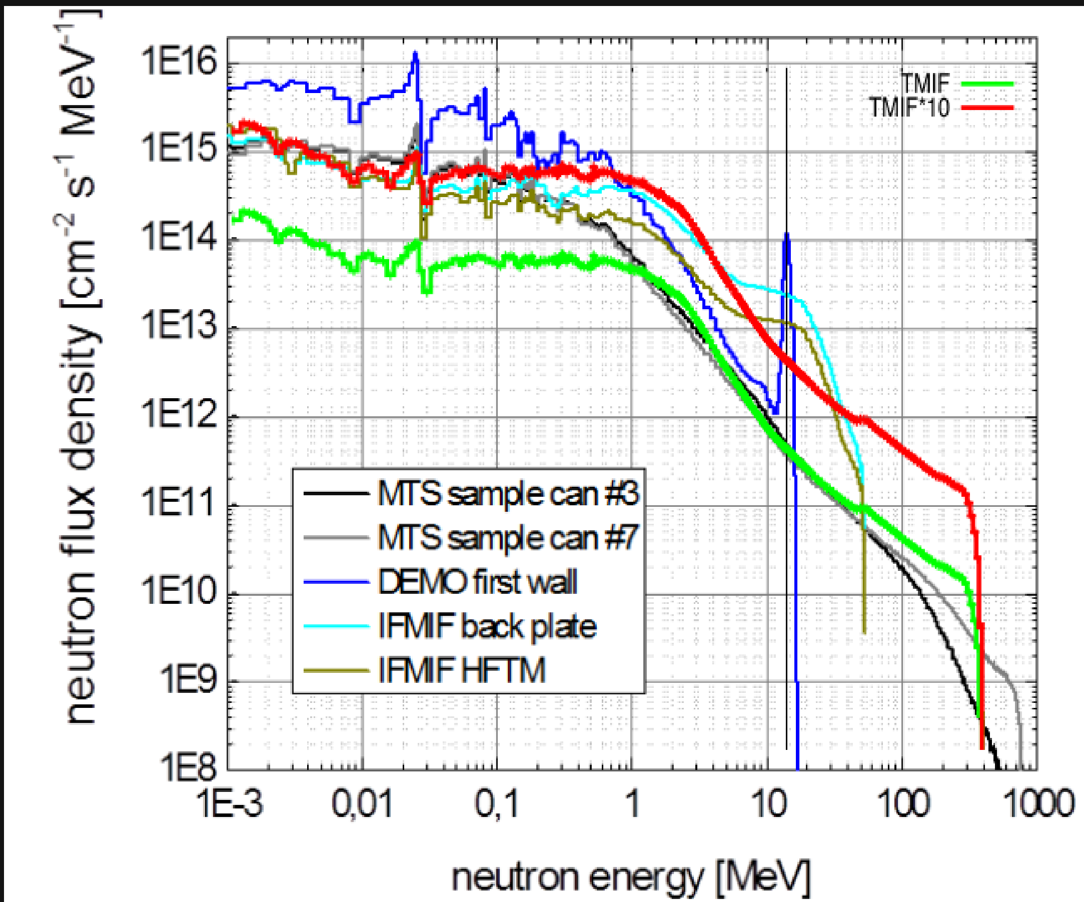
- DPA values up to 0.73 DPA/month ~ 9 DPA/year
- Relative contribution from protons and neutrons depends on the position of the sample
- Variation of 20% from tip to centre



Sample	DPA/month	Protons	Neutrons
1	0.73 (0.4%)	44.3%	55.5%
2	0.50 (0.5%)	34.9%	63.8%
3	0.34 (0.5%)	25.9%	73.2%
4	0.24 (0.6%)	20.0%	79.1%



Neutronics Analysis
Sample Analysis – Beam reduced to 1:1.7



	DPA per year (stat. uncertainty < 1%)		
Beam Spot	s_X : 6 cm s_Y : 1 cm	s_X : 1.7 cm s_Y : 1 cm	
Sample N°	600 MeV 166 µA	400 MeV 250 µA	200 MeV 500 µA
1	8.8	23.0	25.7
2	6.0	13.9	1.7
3	4.1	8.3	1.0
4	2.9	5.0	0.6

- DPA values increased over 10/yr.
- Relative contribution from protons and neutrons depends on the position of the sample

Neutronics Analysis
Sample Analysis – Beam reduced to 1:1.7

Sample	Beam	DPA/year (stat. uncertainty)	Contribution from protons	Contribution from neutrons
1	s_X : 6 cm s_Y : 1 cm 600 MeV	8.76 (0.4%)	44.3%	55.5%
2		6.00 (0.5%)	34.9%	63.8%
3		4.08 (0.5%)	25.9%	73.2%
4		2.88 (0.6%)	20.0%	79.1%
1	s_X : 1.7 cm s_Y : 1 cm 400 MeV	22.92 (0.1%)	58.1%	40.6%
2		13.92 (0.3%)	49.8%	49.2%
3		8.40 (0.3%)	44.5%	54.5%
4		4.92 (0.4%)	45.1%	54.0%

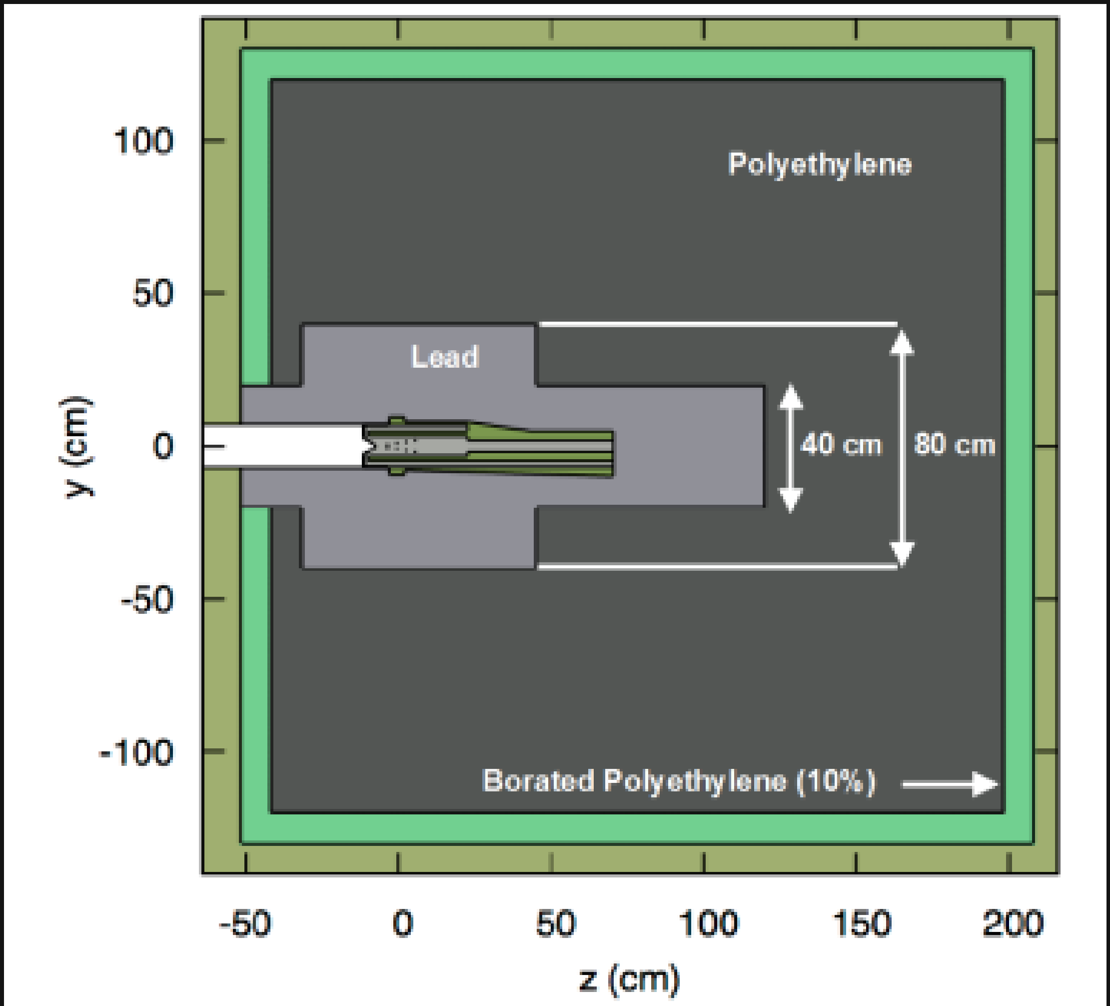
- Tightening the beam influences relative contribution from protons and neutrons

Neutronics Analysis
Sample Analysis – Gas production

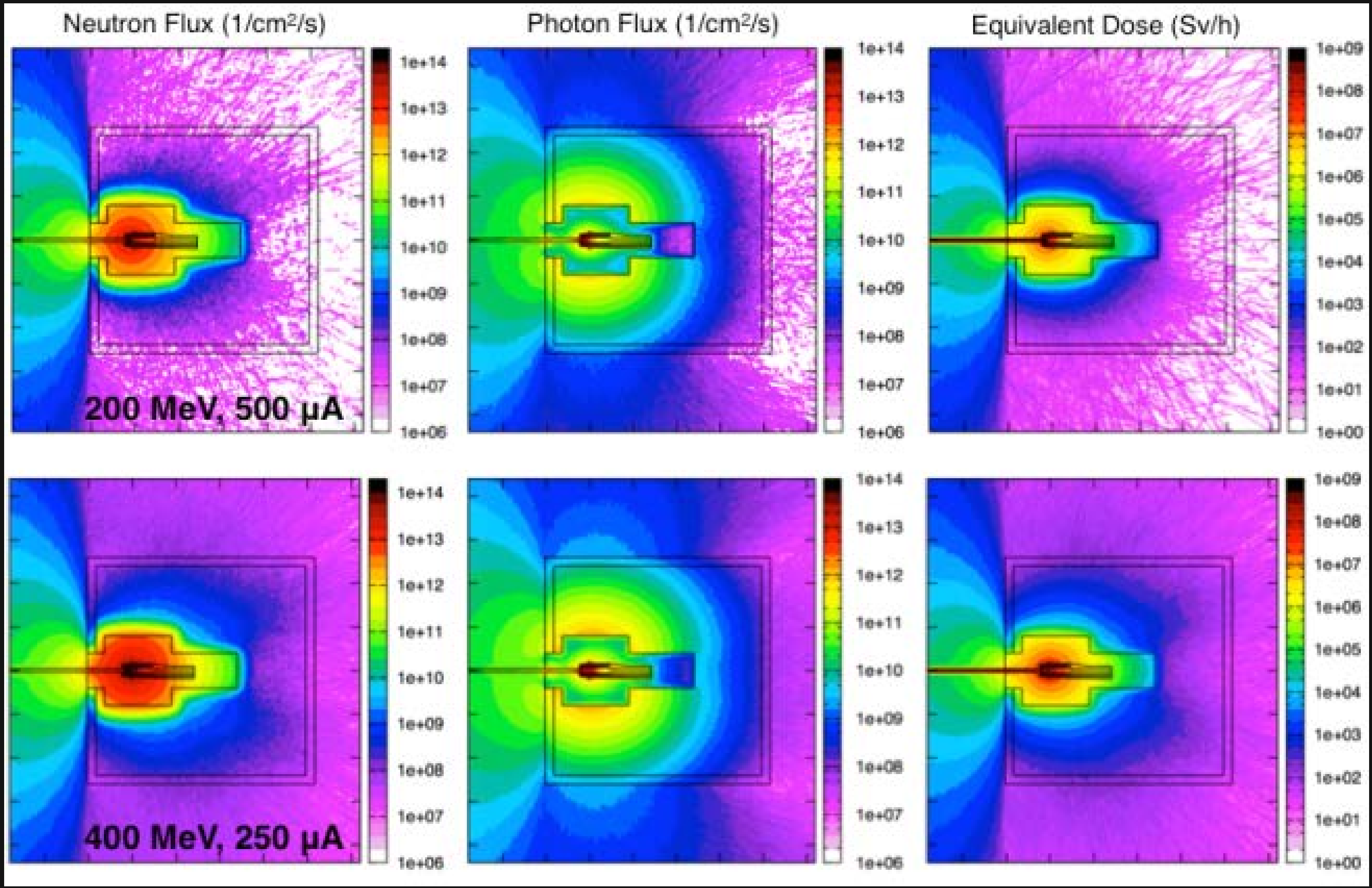
	Wide Beam		Narrow Beam	
	nuclei/cm3/s	appm (1 yr.)	nuclei/cm3/s	appm (1 yr.)
Sample 1				
Total H	2,33E+12	226	5,71E+12	553
Total He	3,84E+11	148	1,19E+12	457
Sample 2				
Total H	1,34E+12	130	3,20E+12	310
Total He	2,06E+11	79	4,89E+11	188
Sample 3				
Total H	8,55E+11	83	1,80E+12	175
Total He	1,07E+11	41	2,38E+11	92
Sample 4				
Total H	1,50E+12	145	3,35E+12	324
Total He	4,13E+10	16	9,59E+10	37

Neutronics Analysis
Shielding Analysis

- Shielding dimensioning studies are complete.
- A mix of polyethylene and borated polyethylene with a lead neutron diffusor around the target has yielded the best results.

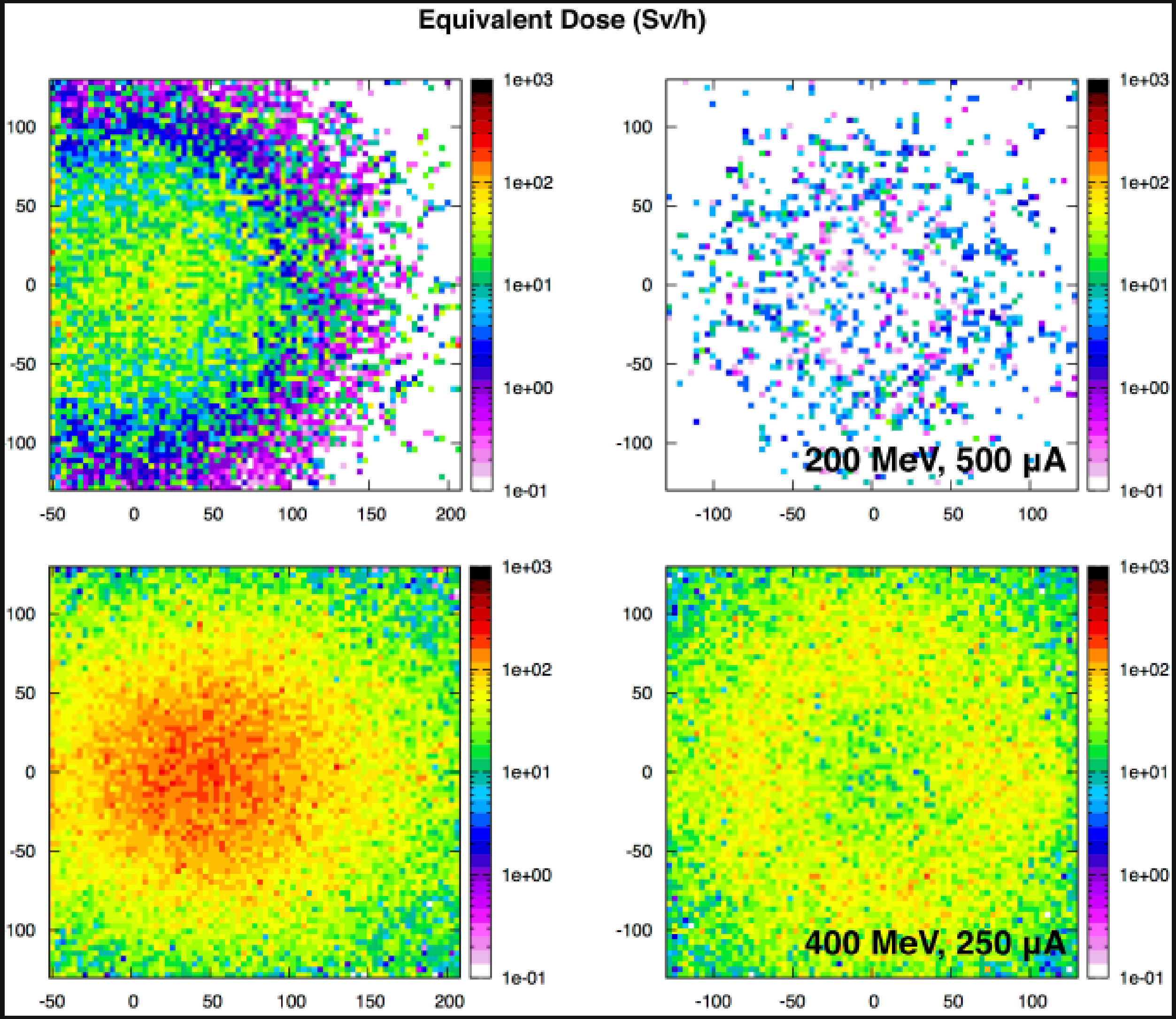


Neutronics Analysis
Shielding Studies



Neutronics Analysis
Shielding Studies

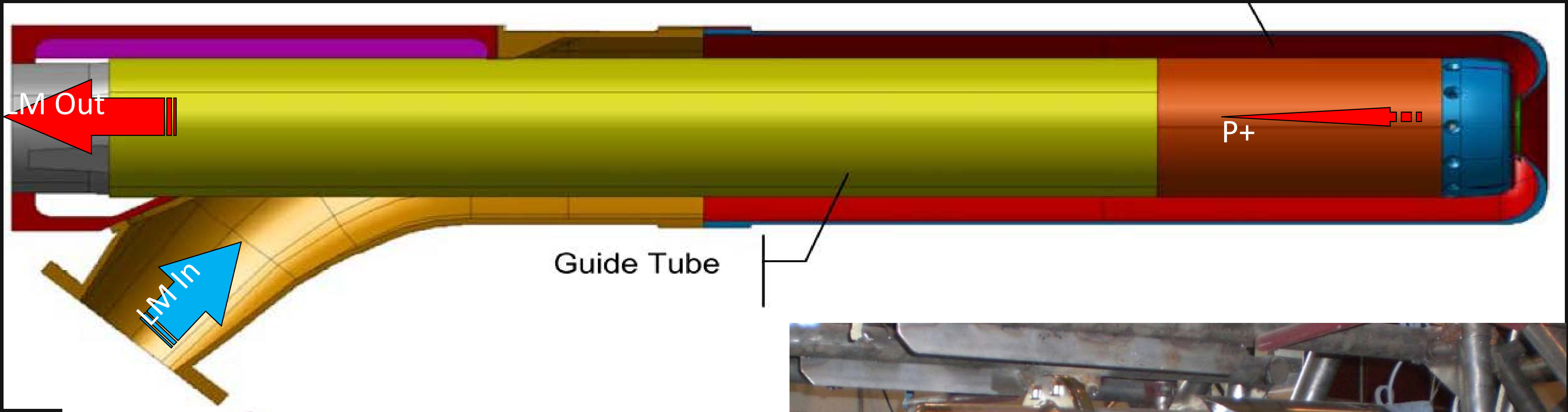
- Ambient equivalent dose rates (Sv/h) after the shielding, in 1 cm slices of air, for
- 200 MeV (top)
- 400 MeV (bottom)
- Beam σ = 1.7 cm / 1.0 cm
- Left side – lateral side of the TMIF facility.
- Right side back end of the T-MIF facility.

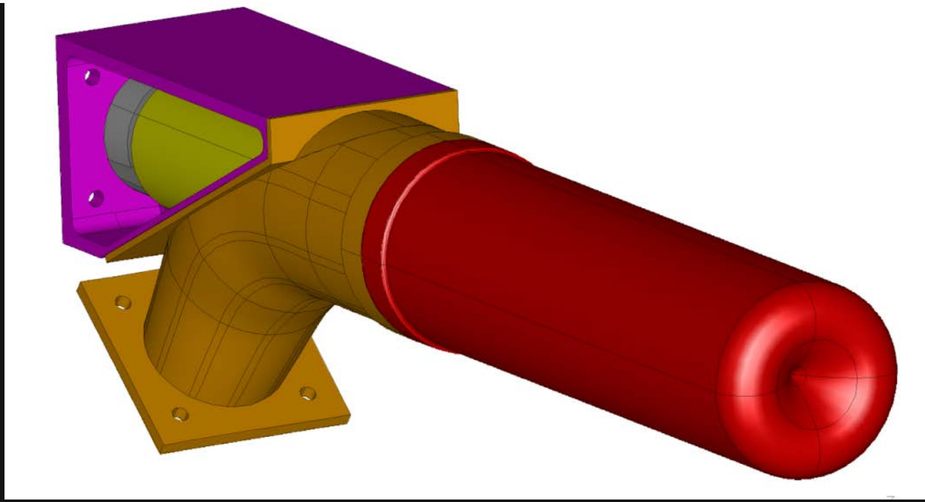


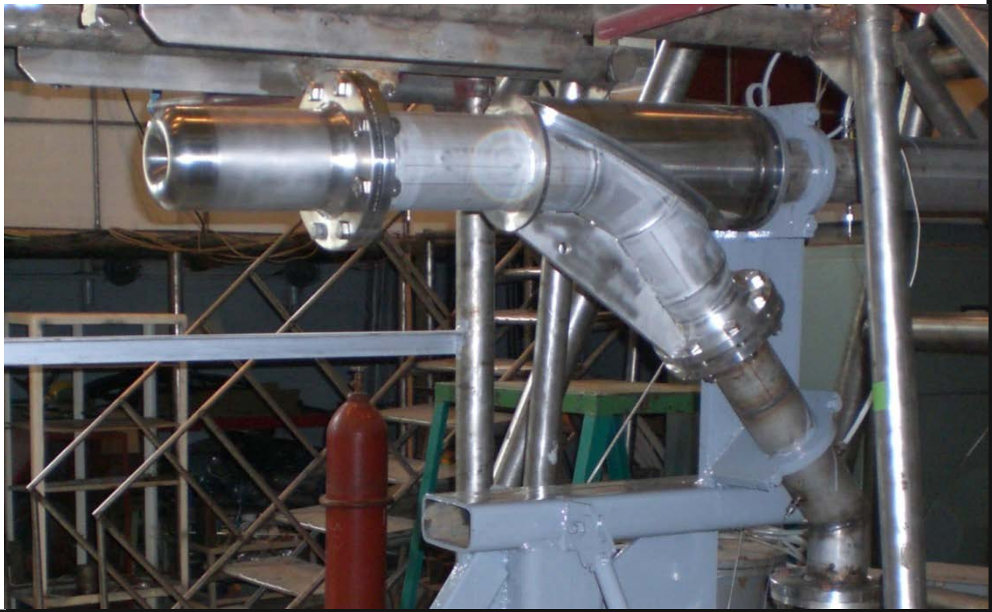
4 MW ADS Demonstrator

Design process
prior experience

Compact liquid metal neutron source design from Eurisol

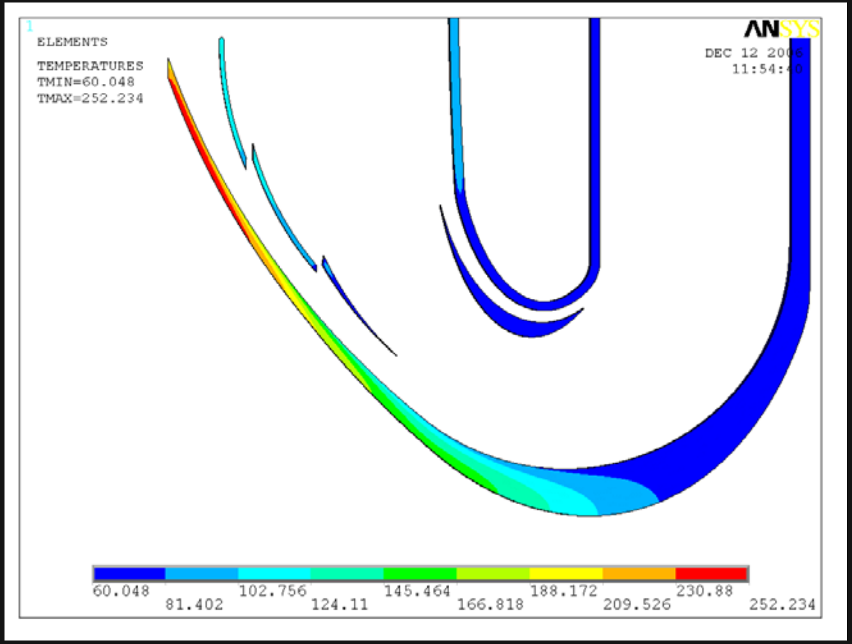


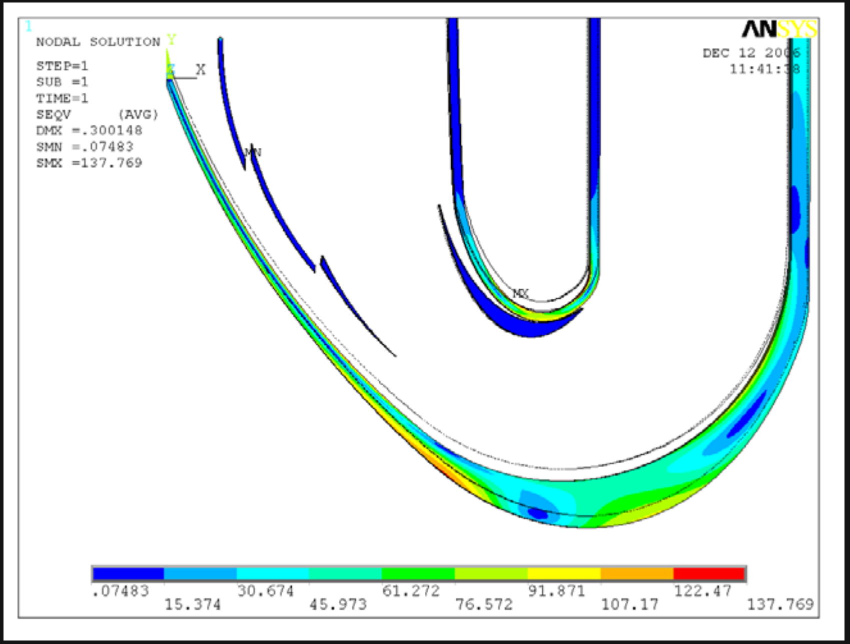




Proposed design of a high-power spallation source for ADS

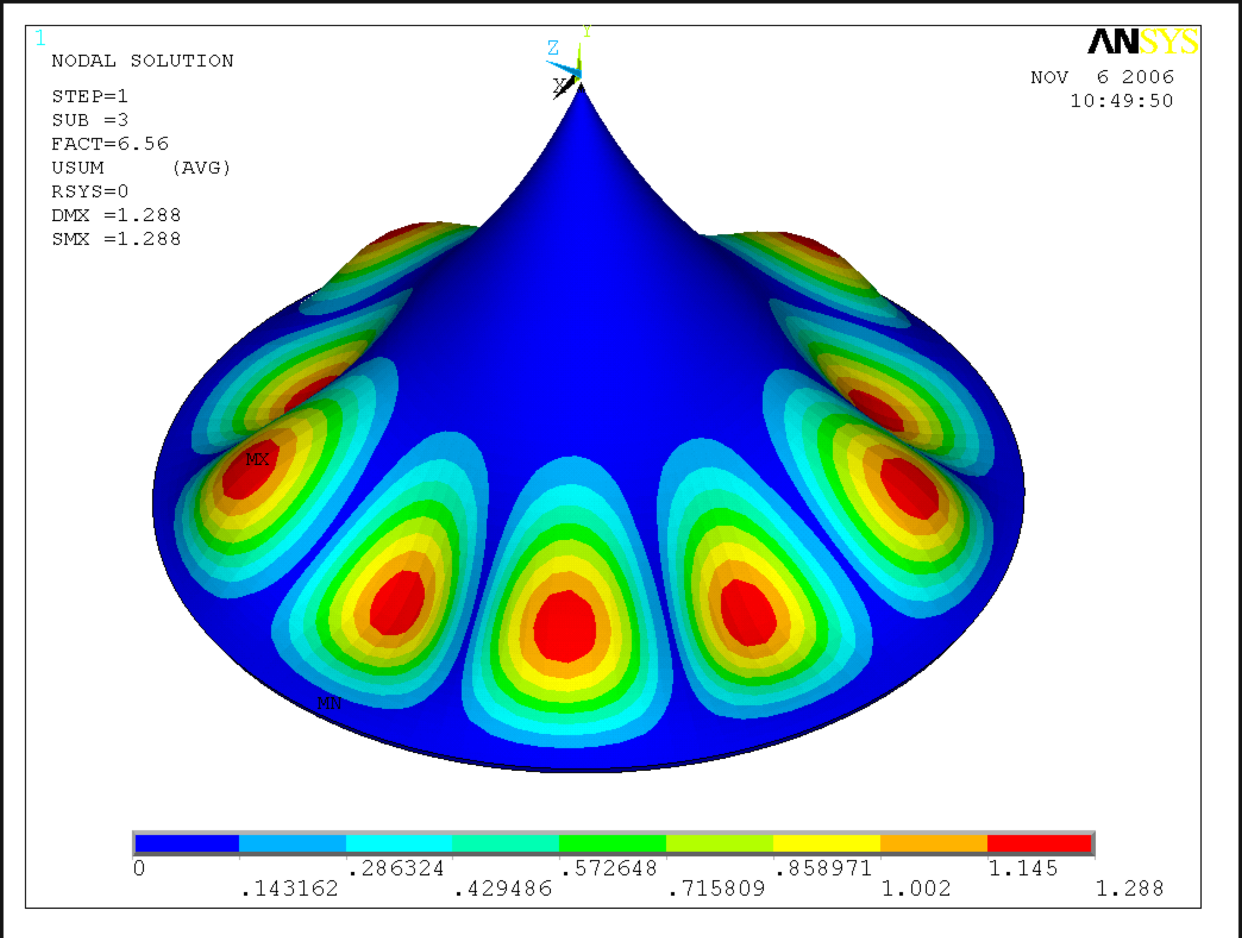
- The thin-gauge low-stress concave conical window of EURISOL is used as a base for the design
- FEM Results for a 4 MW / 1 GeV / Sigma 15mm beam
- Max DeltaT = 190°C Max stress = 137 MPa



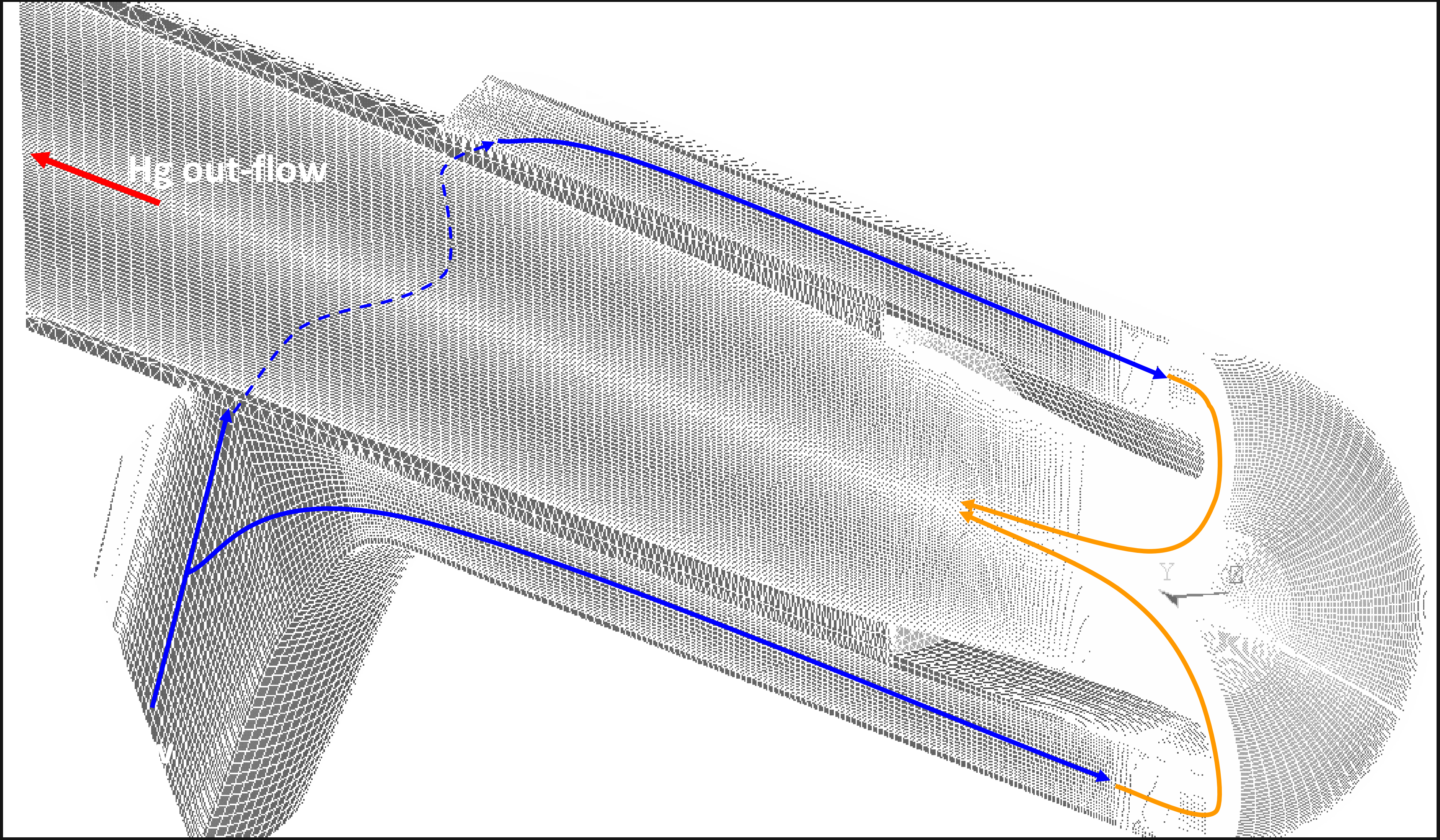


Design of the window target
3D Stress Analysis for checking buckling

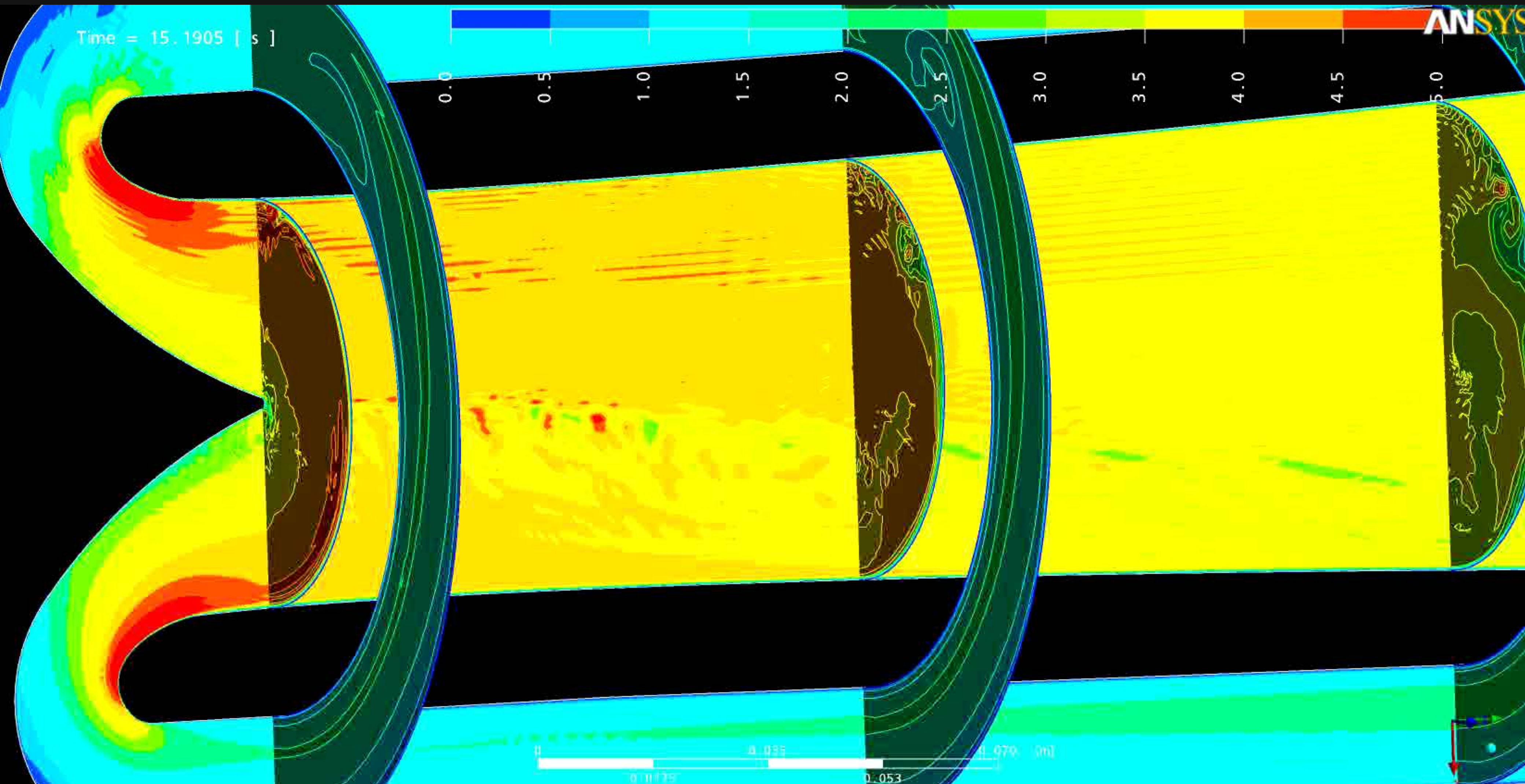
- Previously optimised section, in 3D,
- uniform internal pressure 40 Bar
- Safety factor of 6



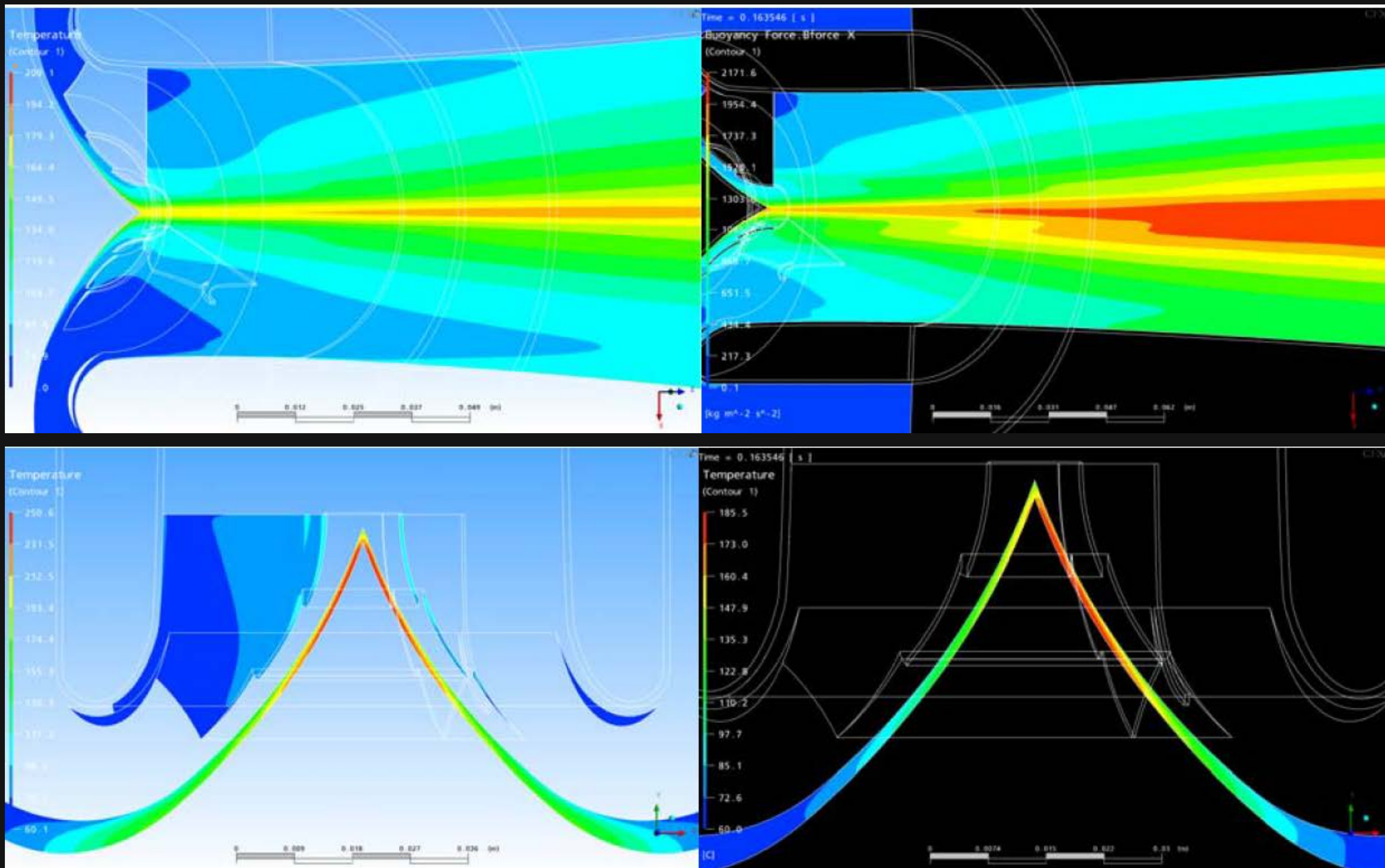
Design of the window target
3D CFD Analysis



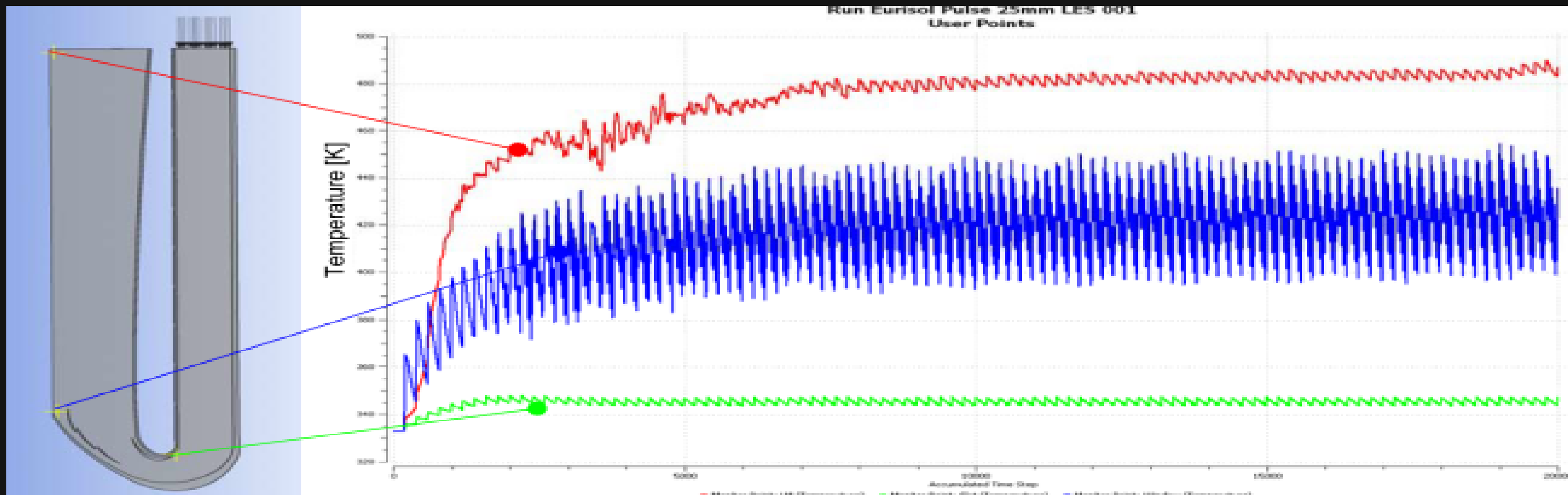
Design of the window target
CFD Analysis

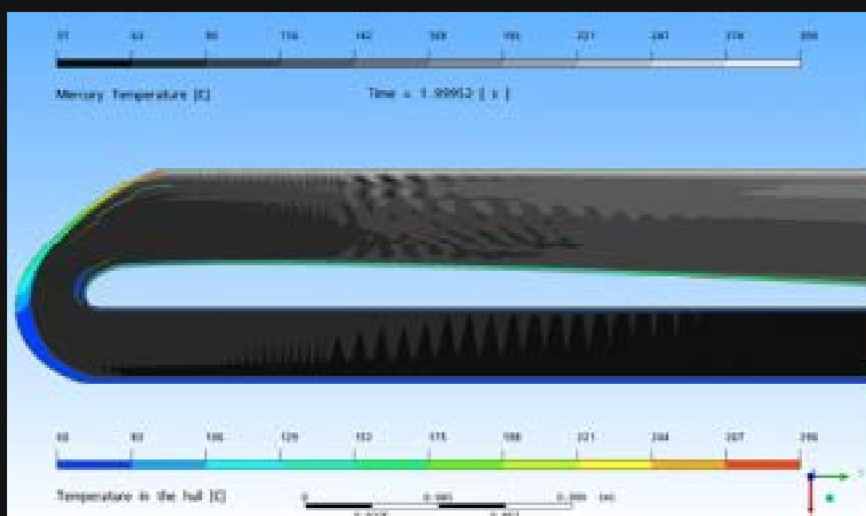


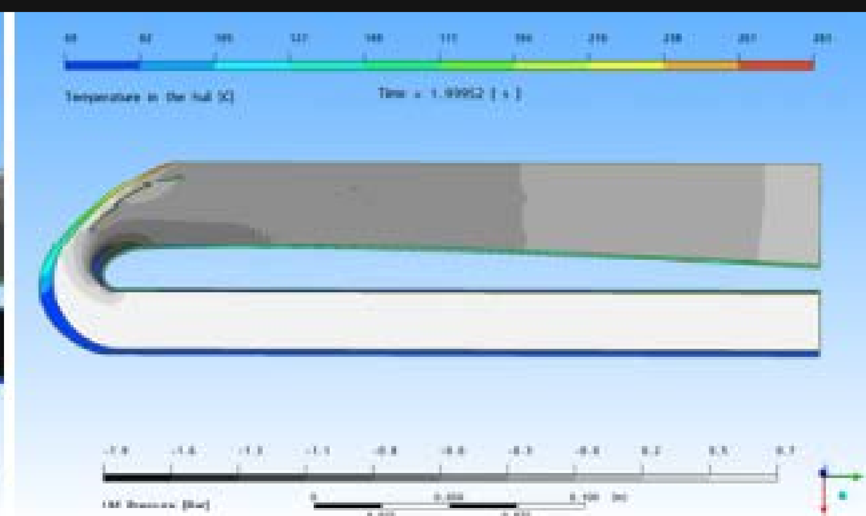
Design of the window target
CFD Analysis with beam



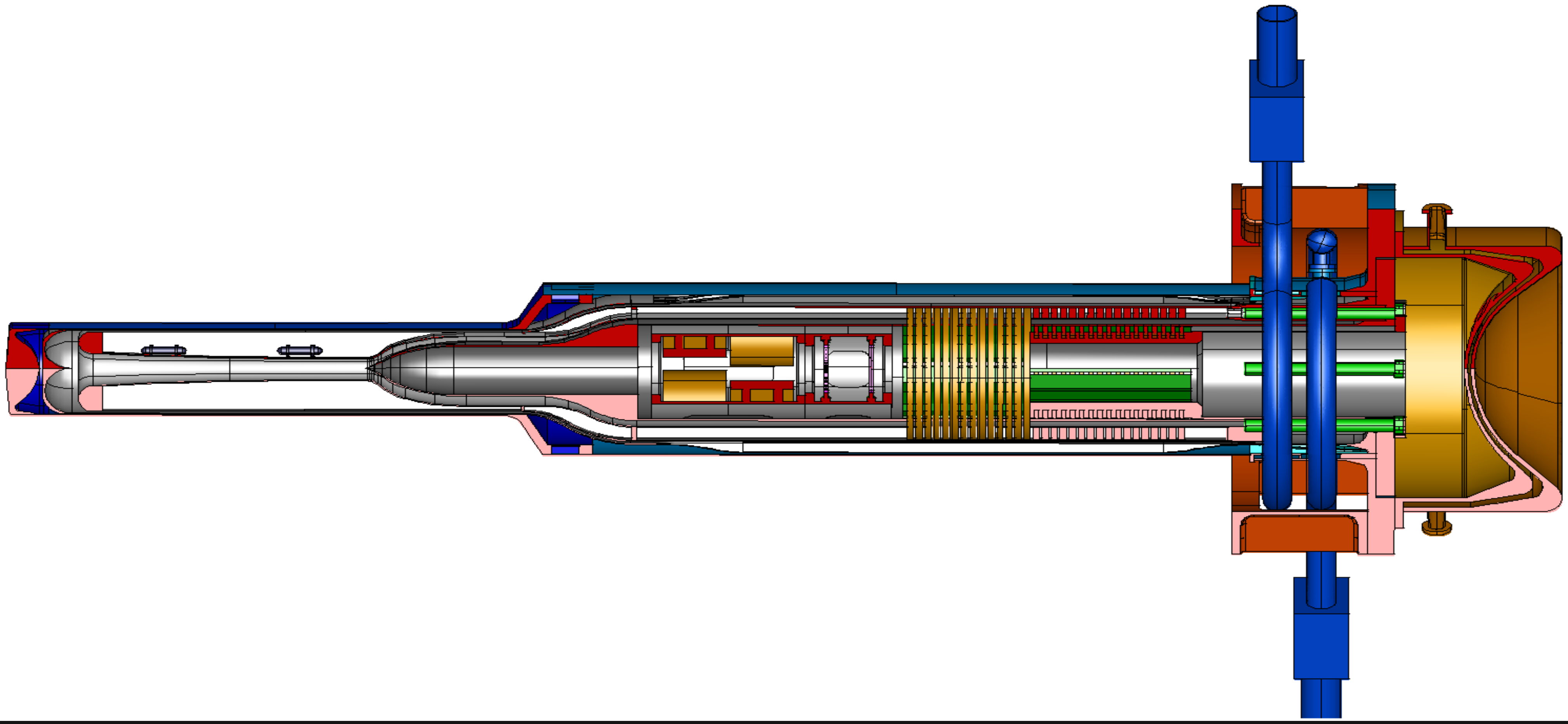
Design of the window target
CFD Analysis with pulsed beam







Proposed design of a high-power spallation source for ADS



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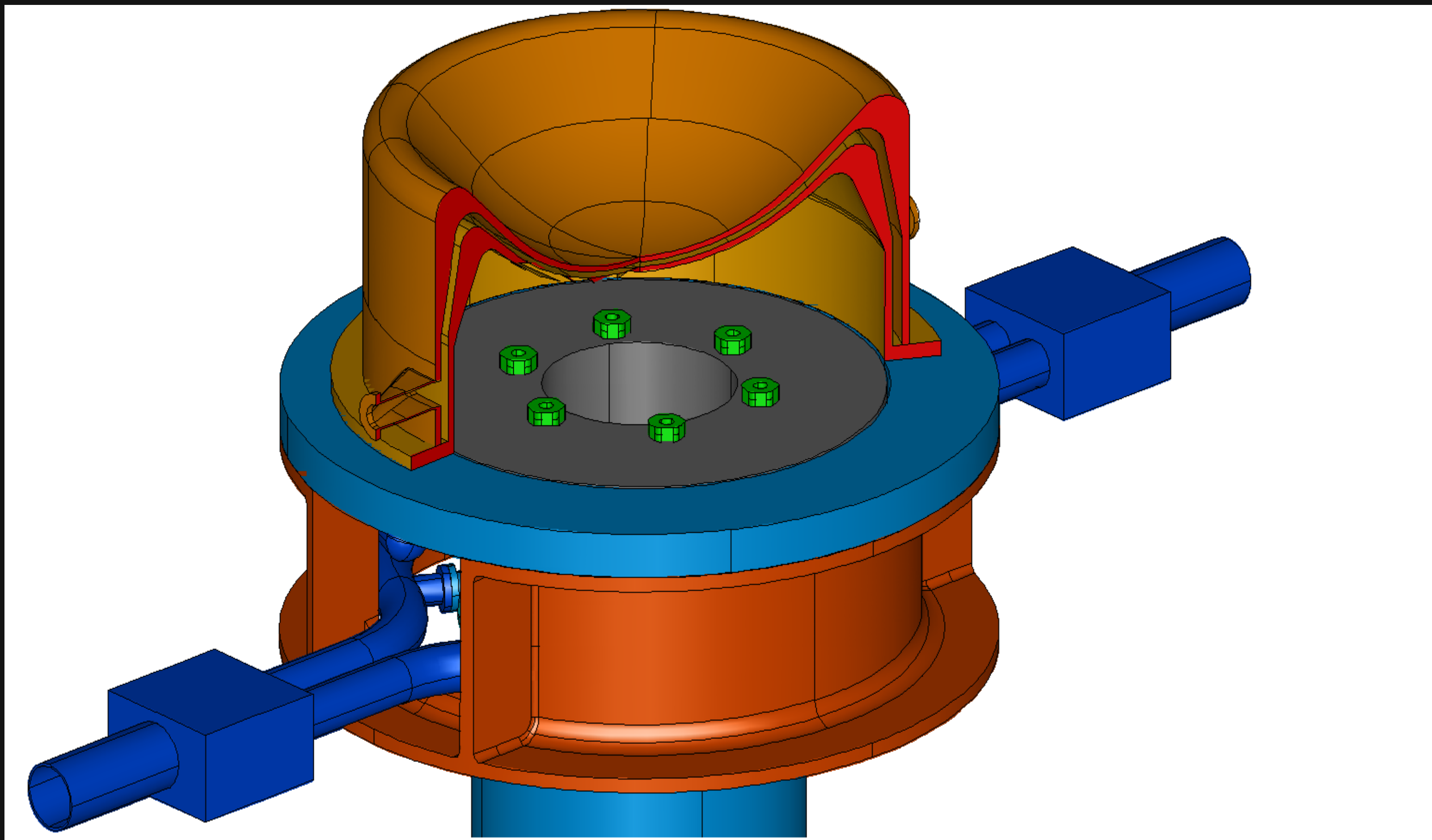
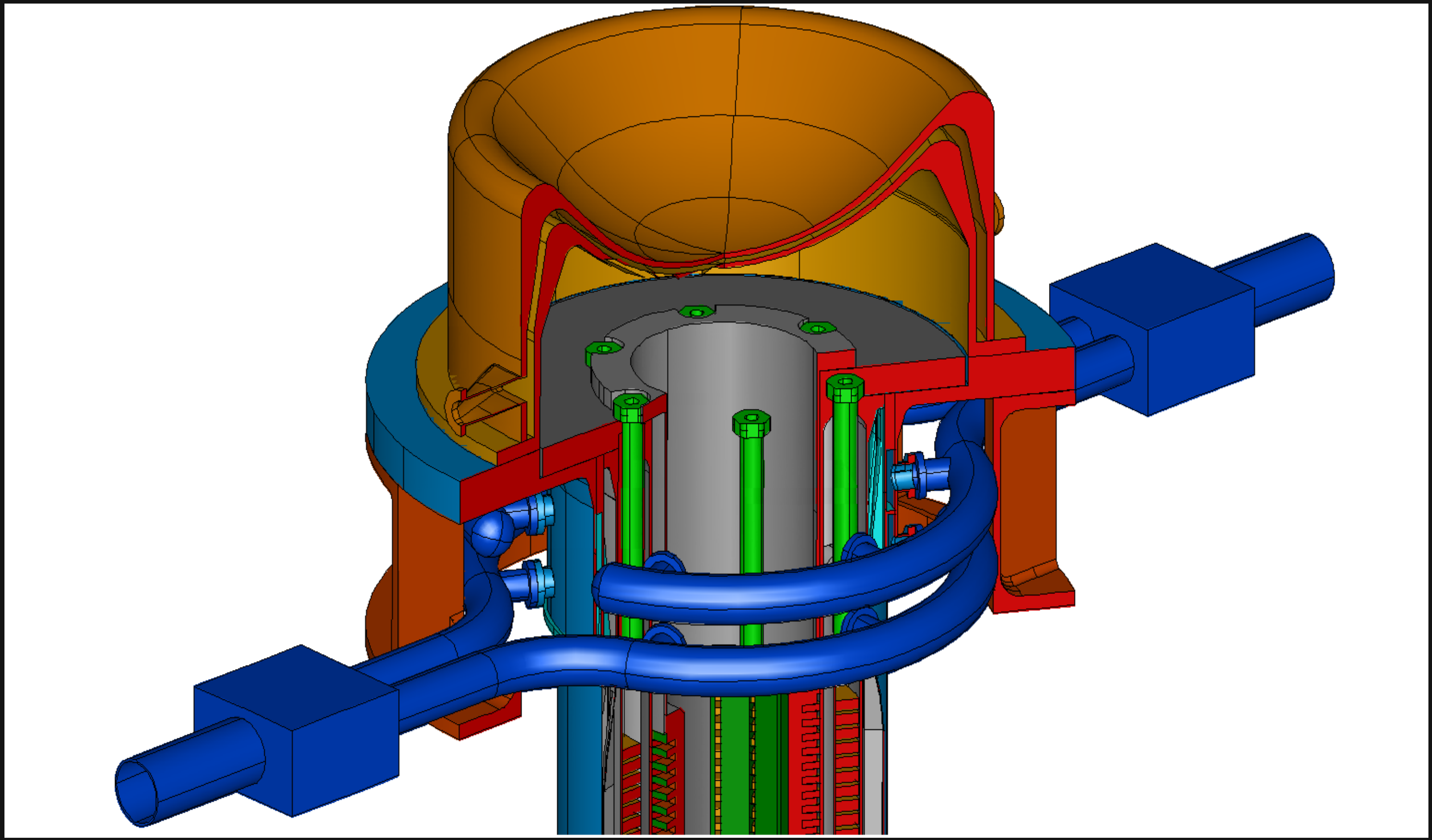


Proposed design of a high-power spallation source for ADS



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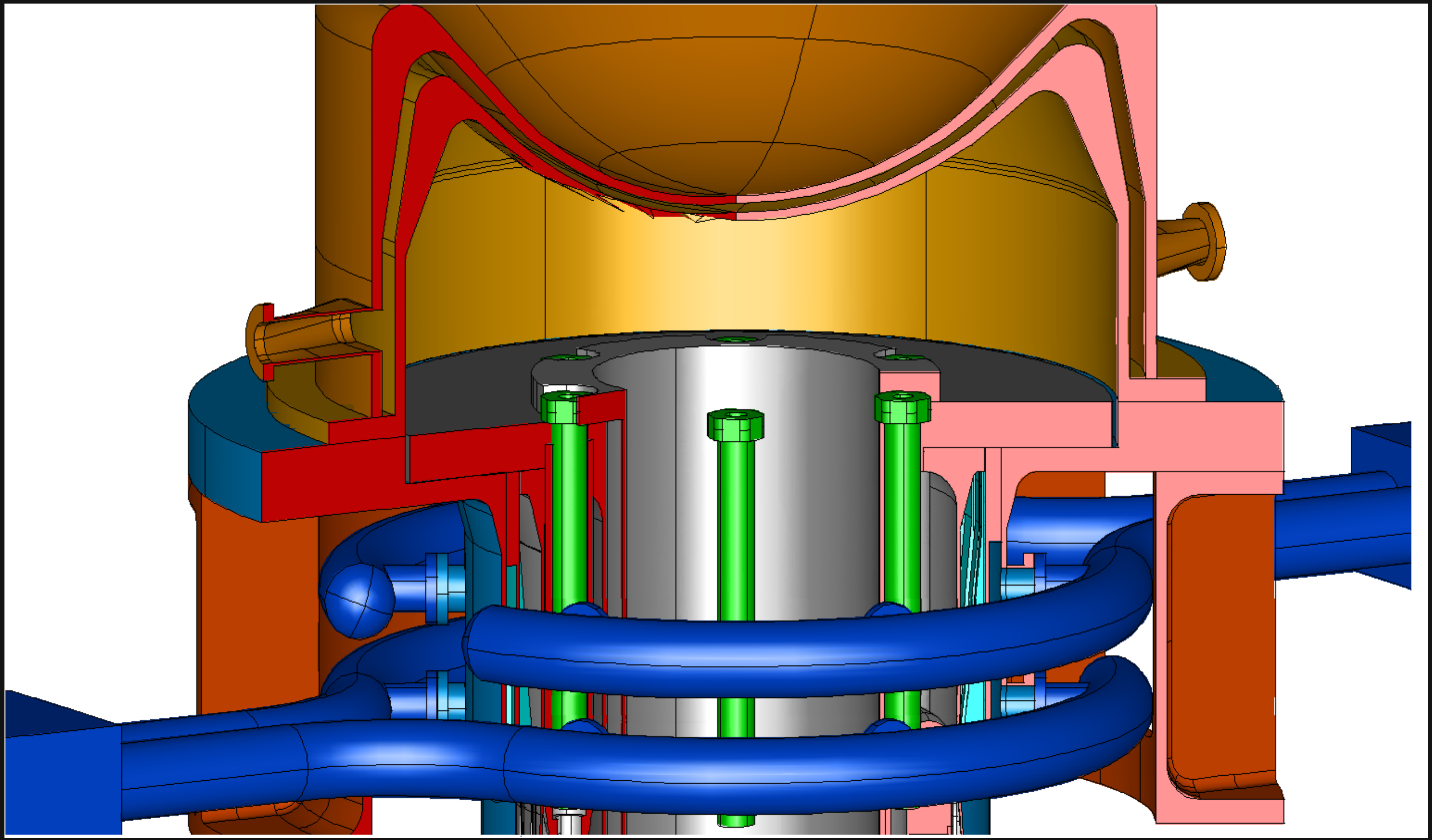

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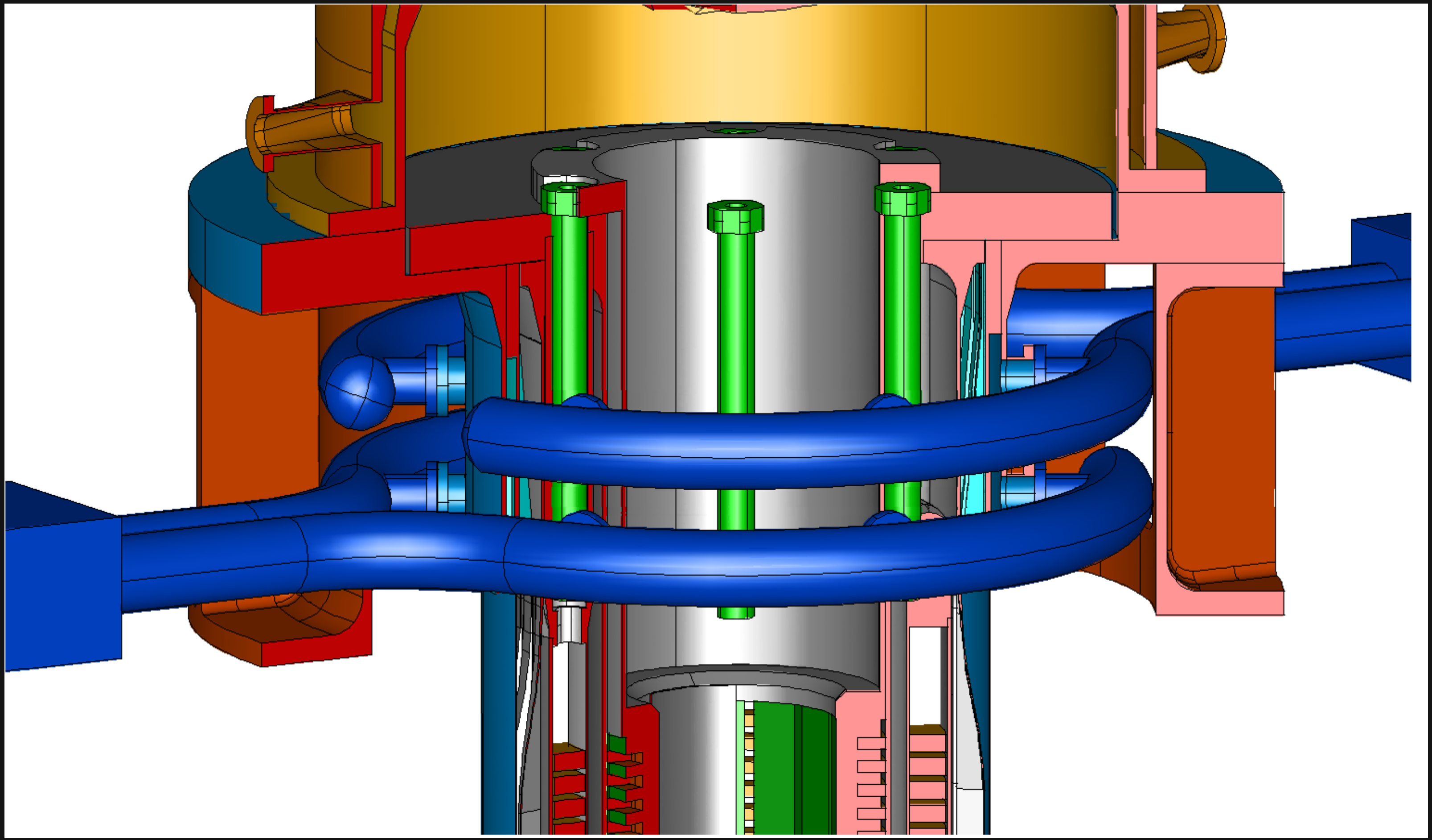

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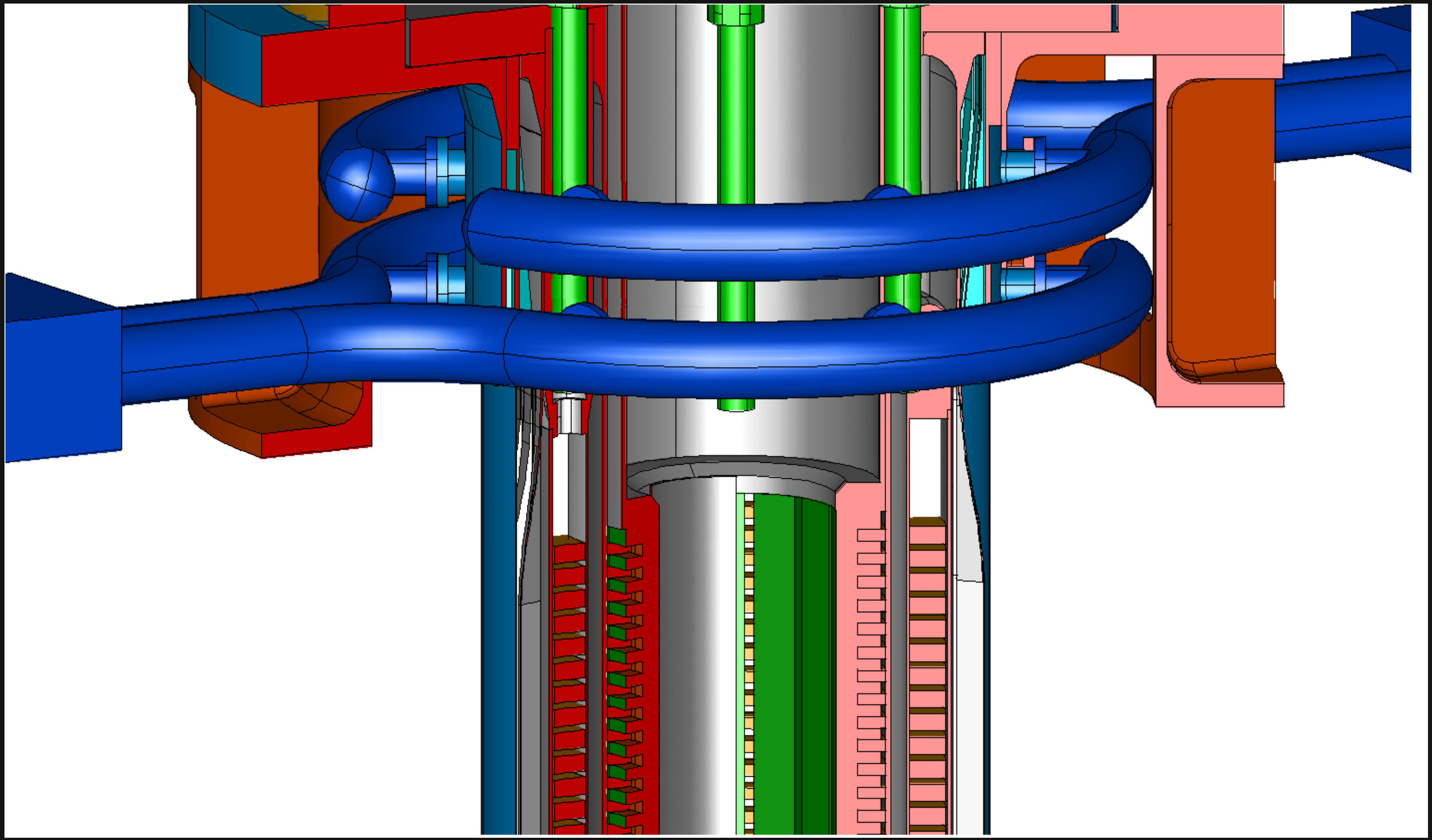

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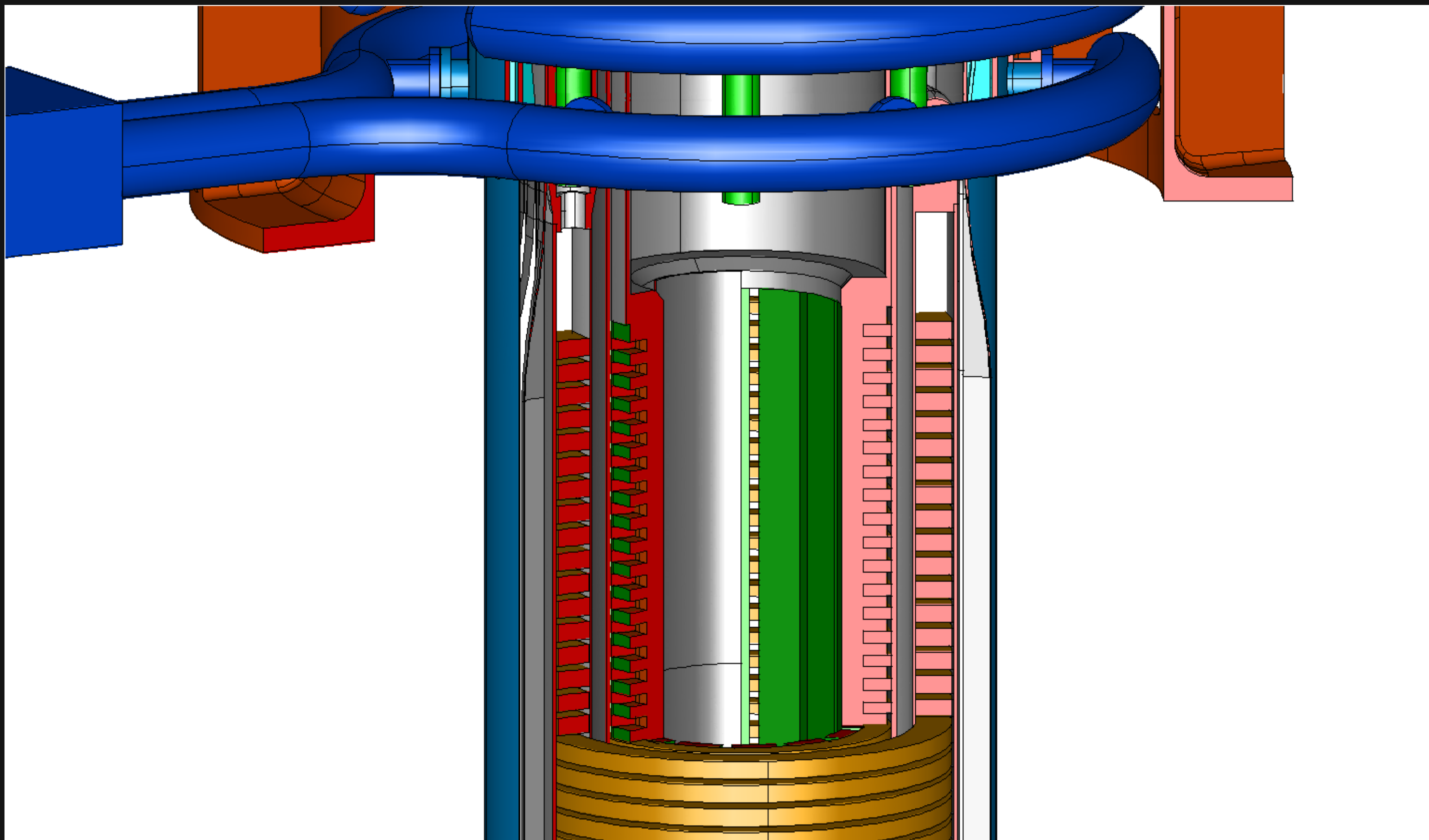

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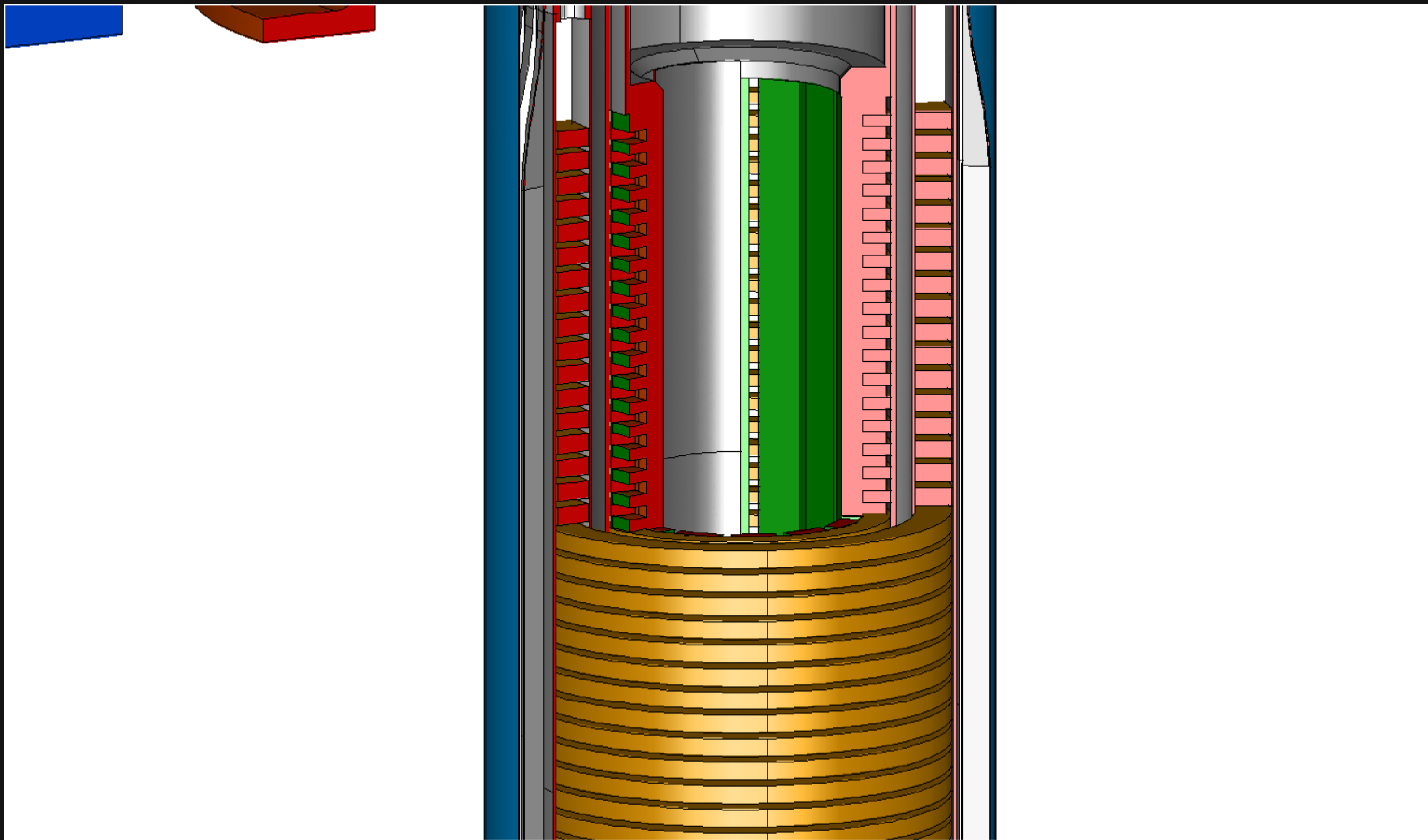

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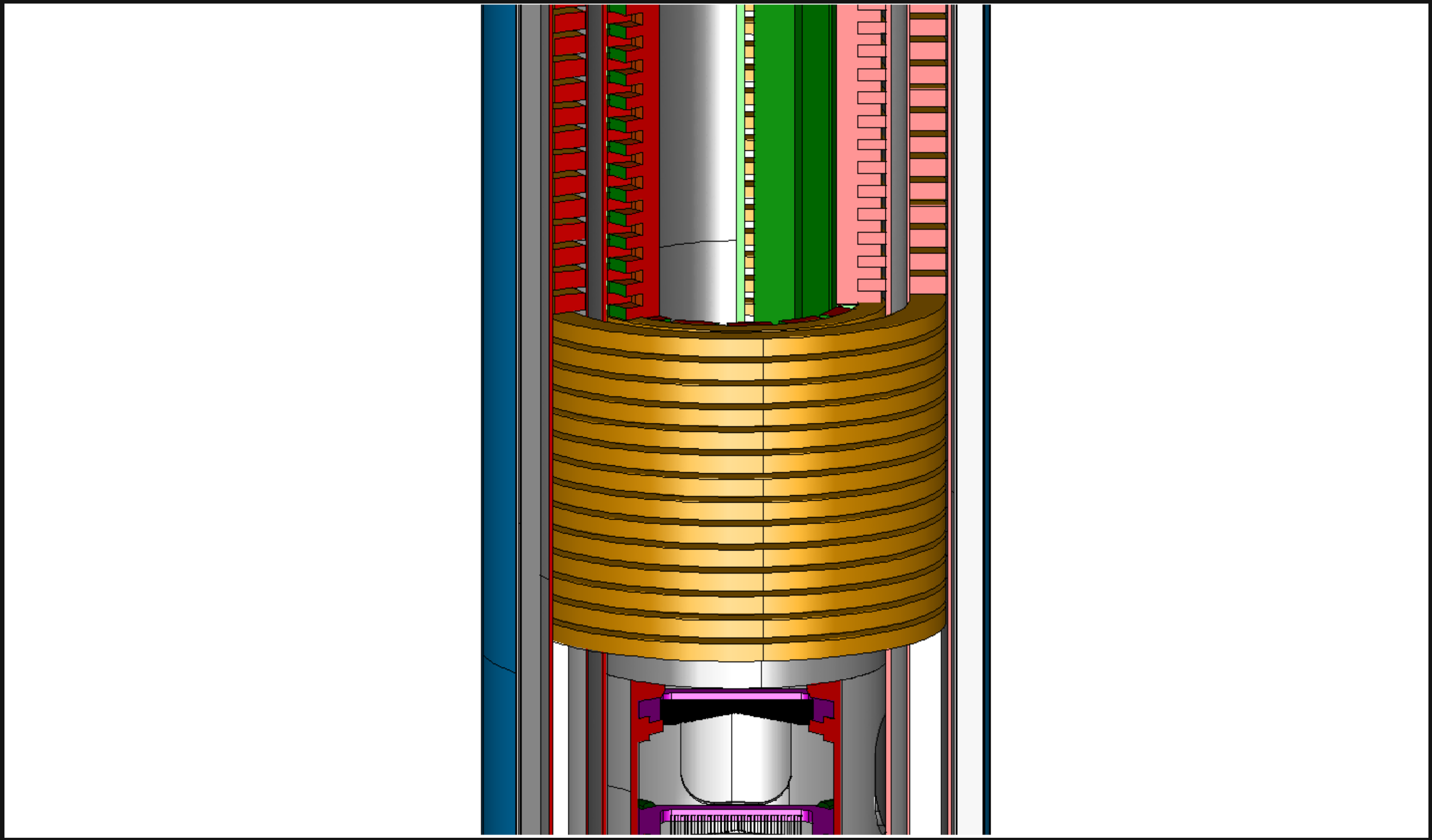

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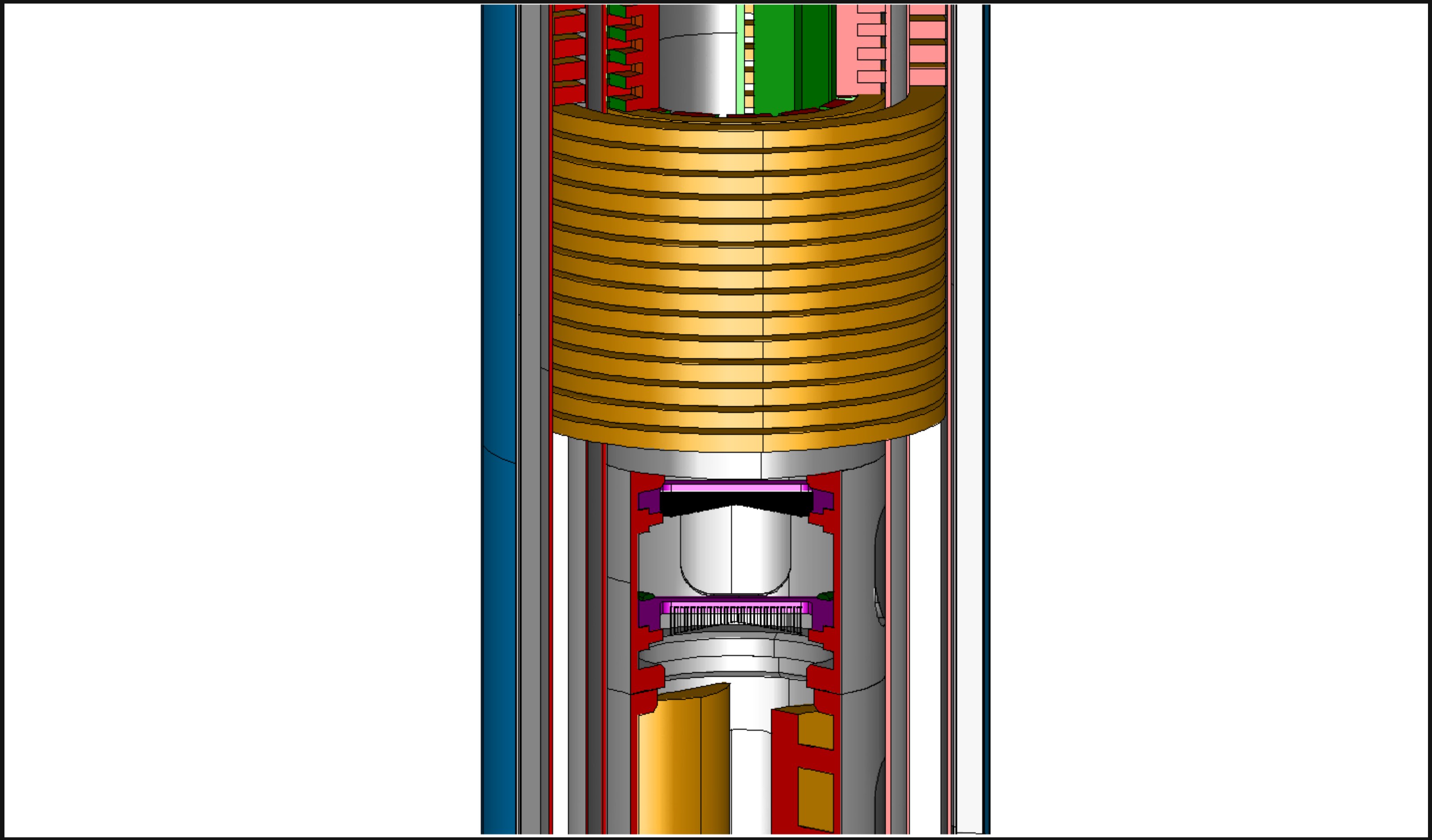

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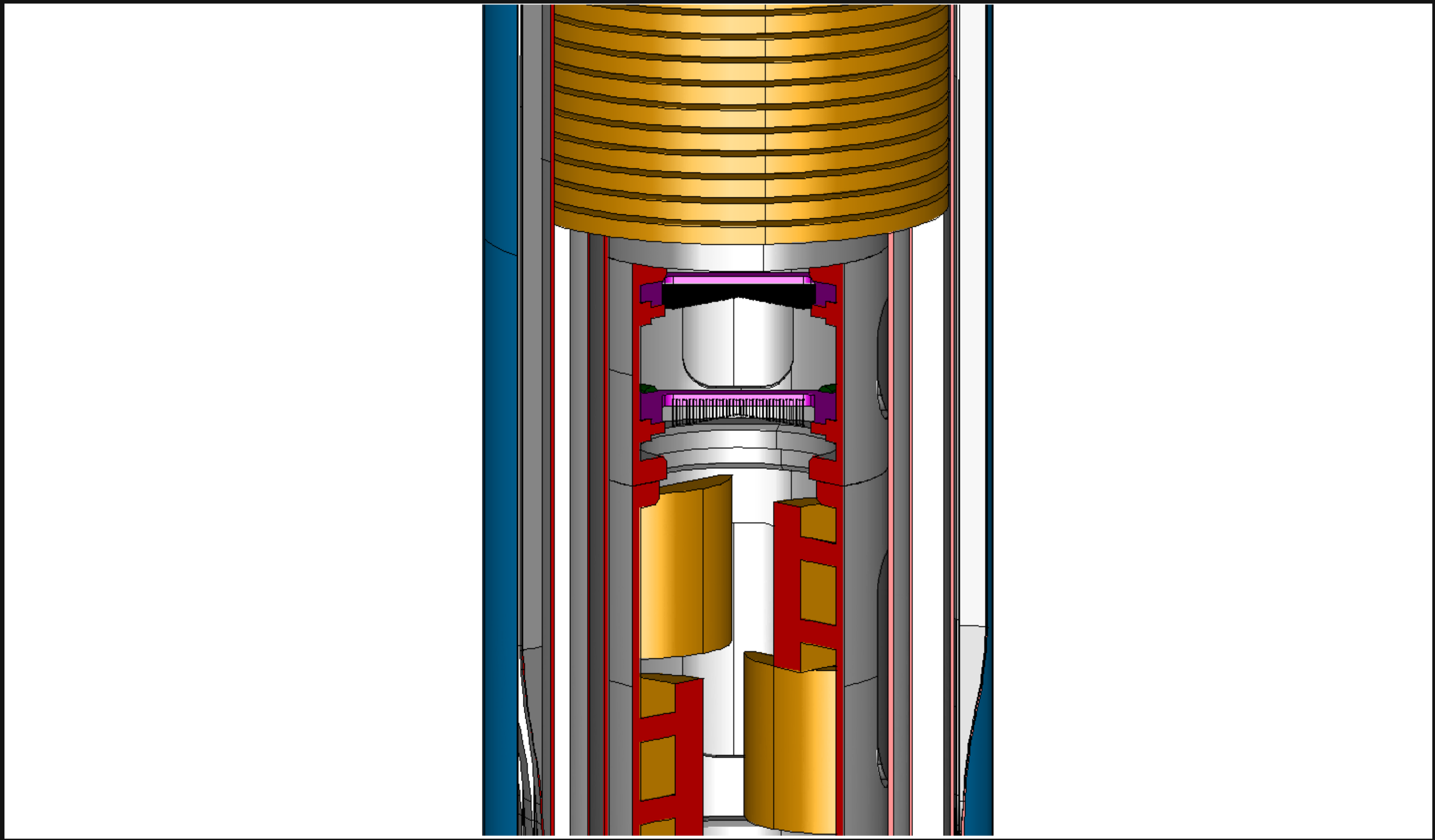

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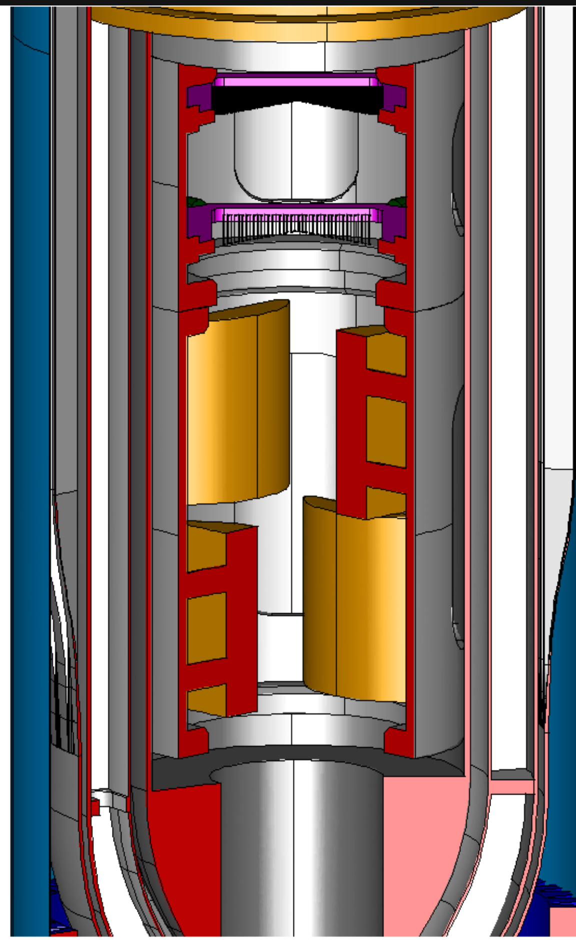

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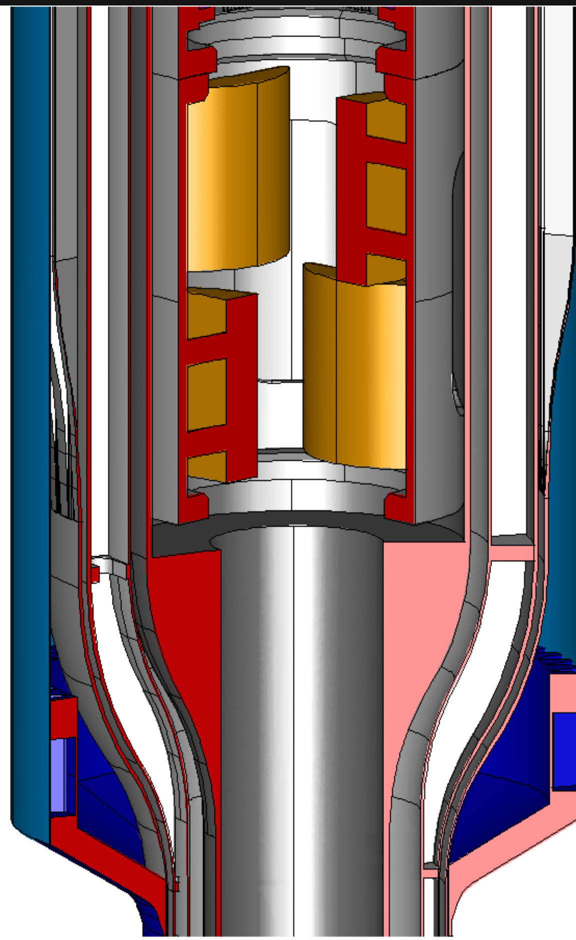

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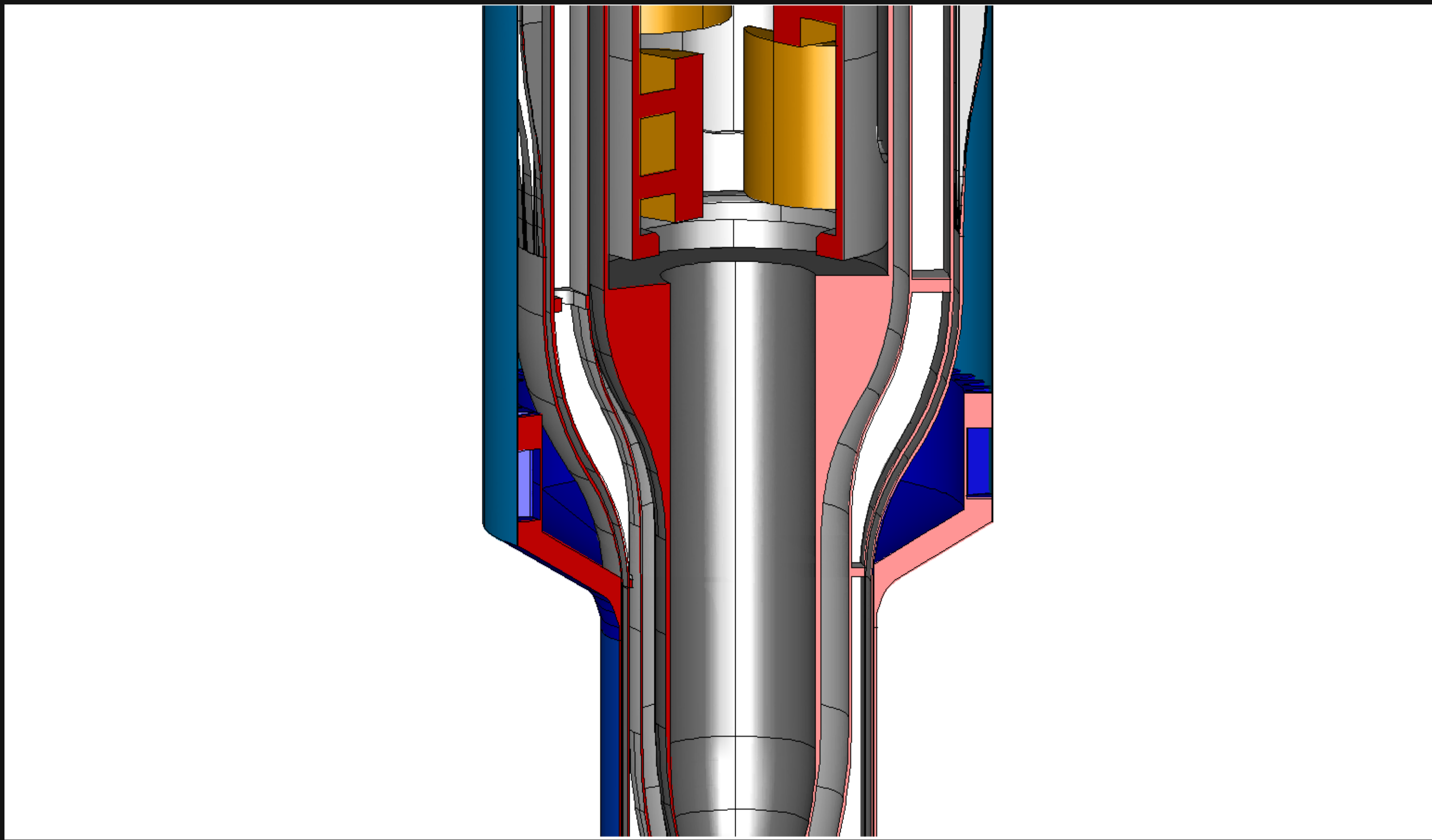

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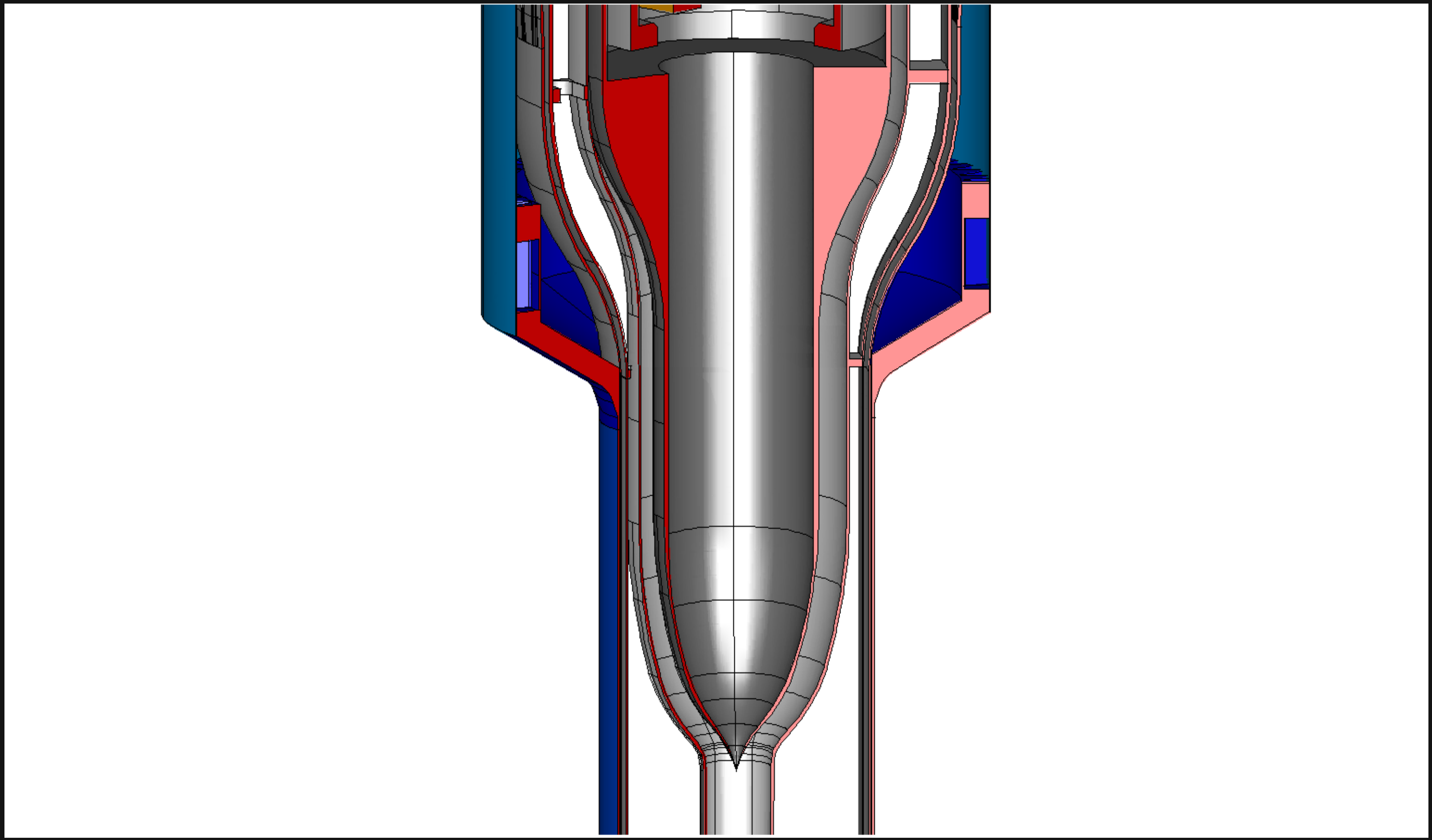

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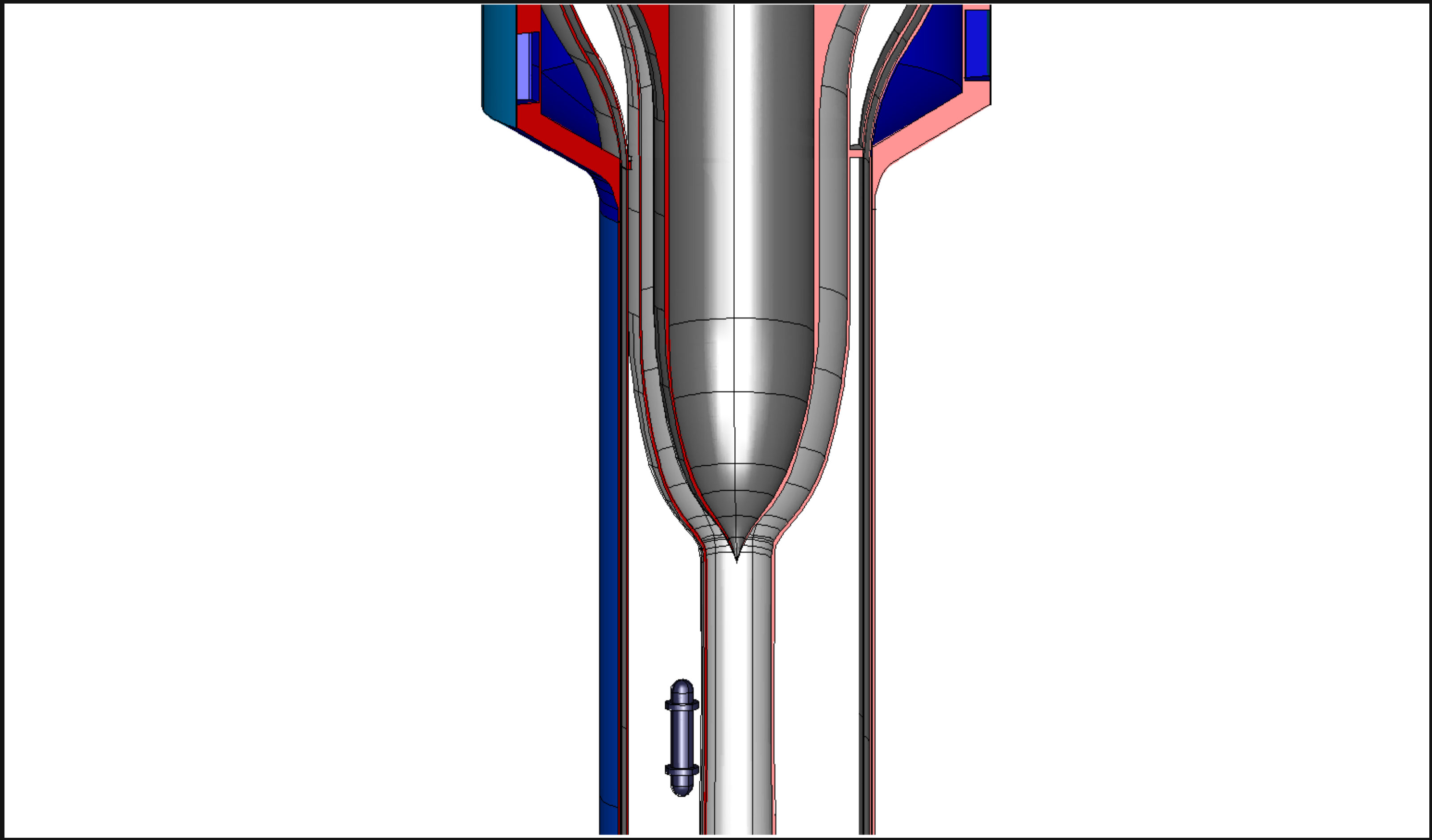

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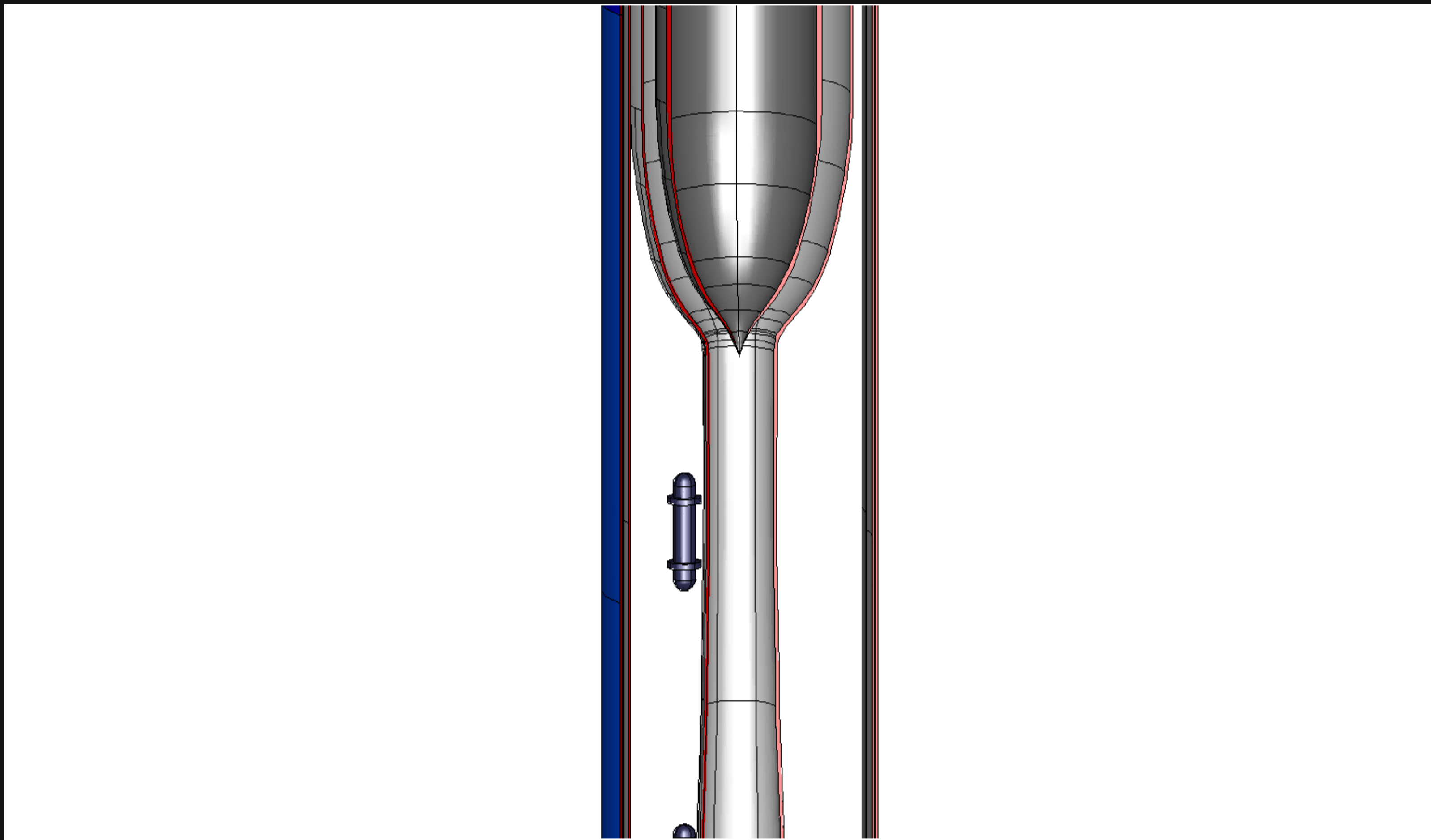

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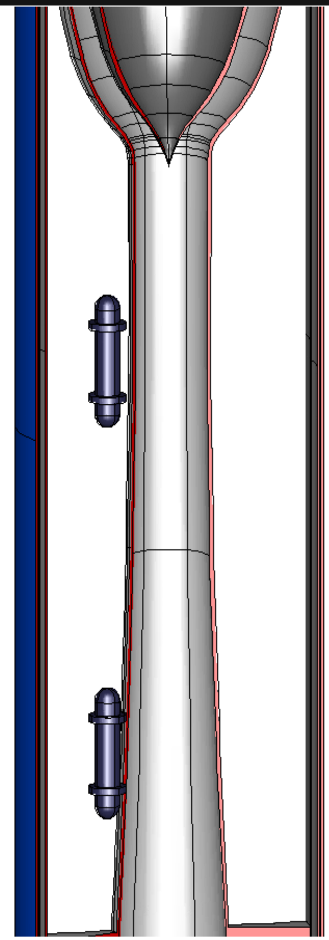

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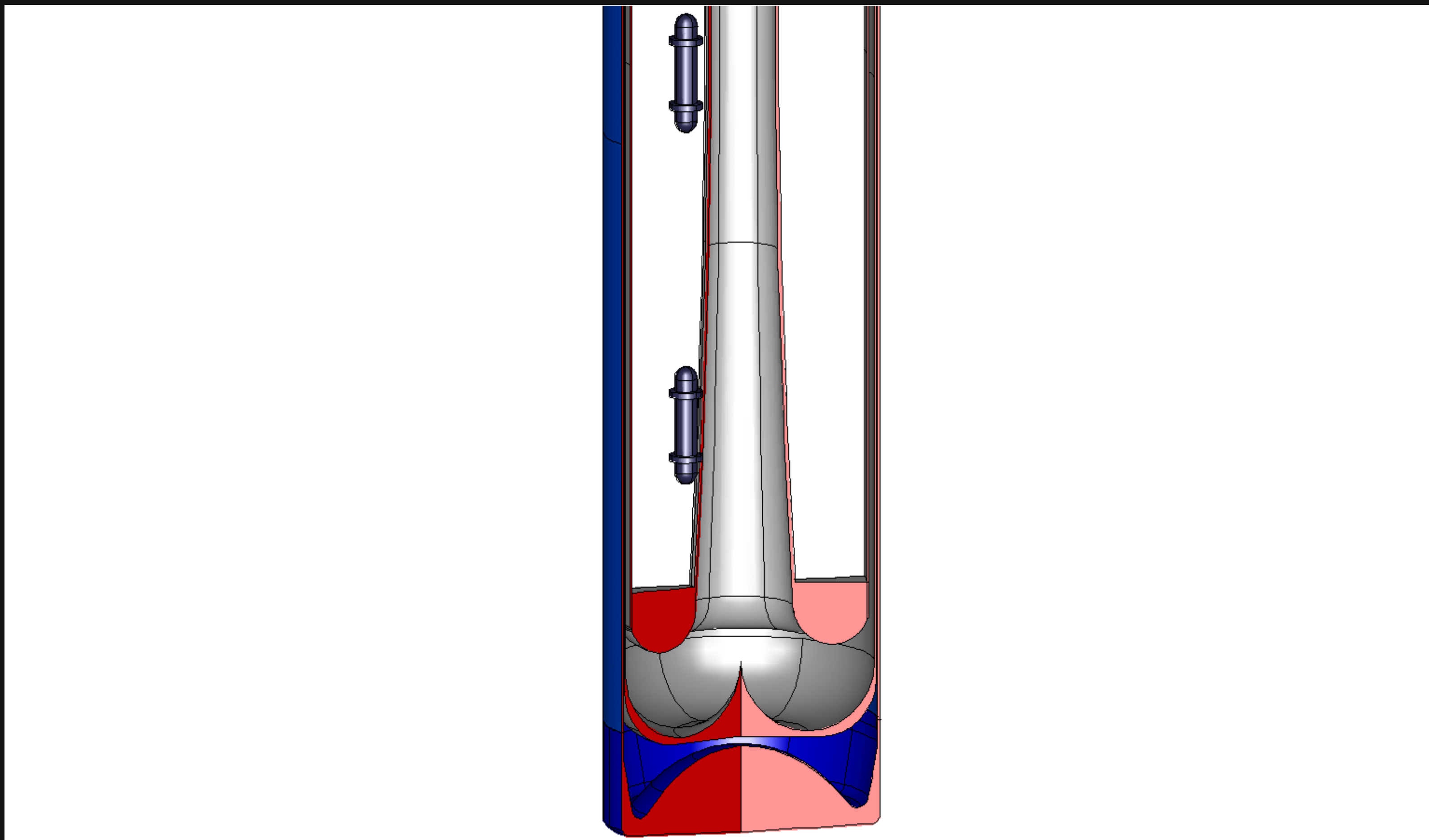

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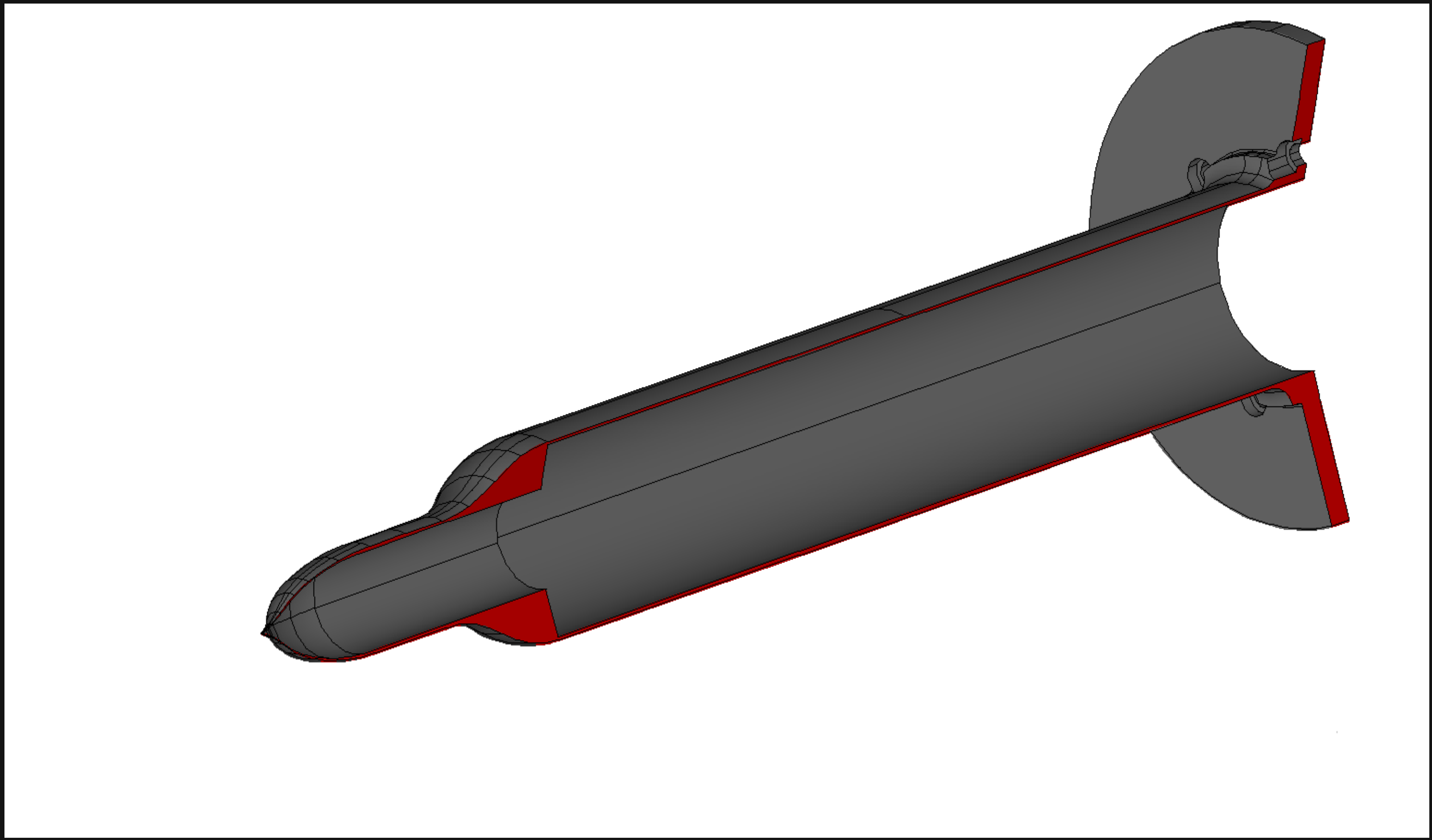

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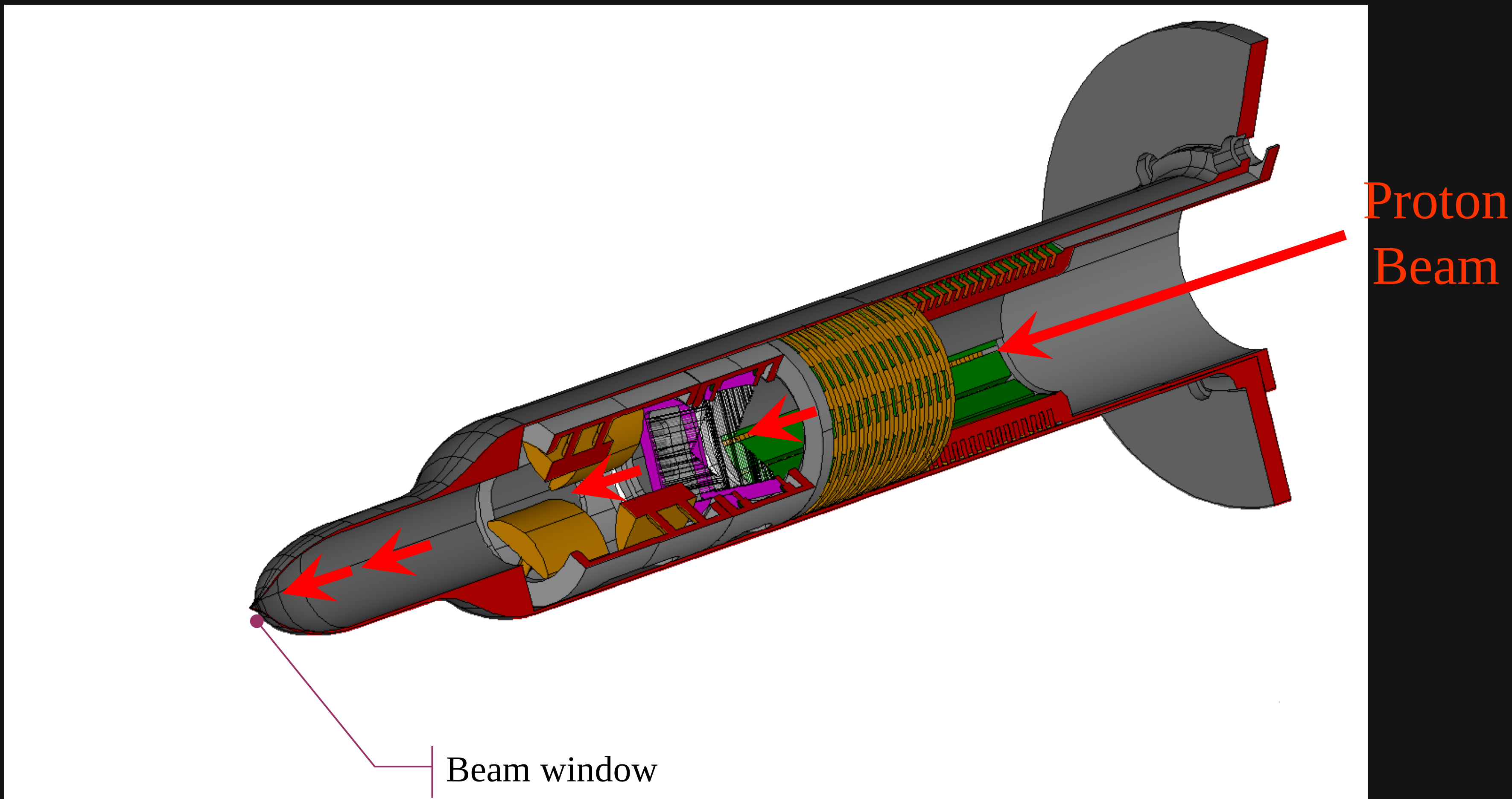

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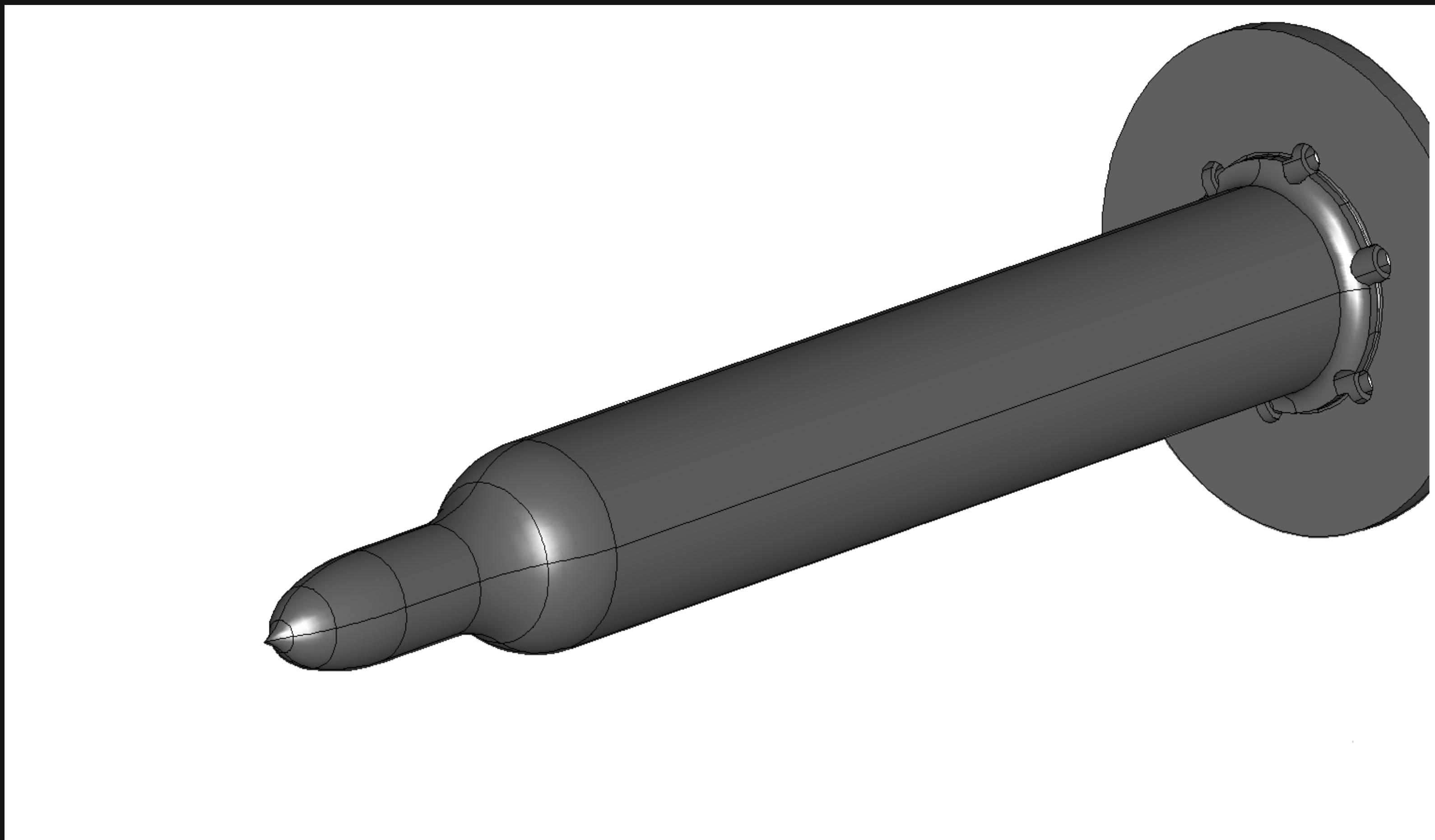

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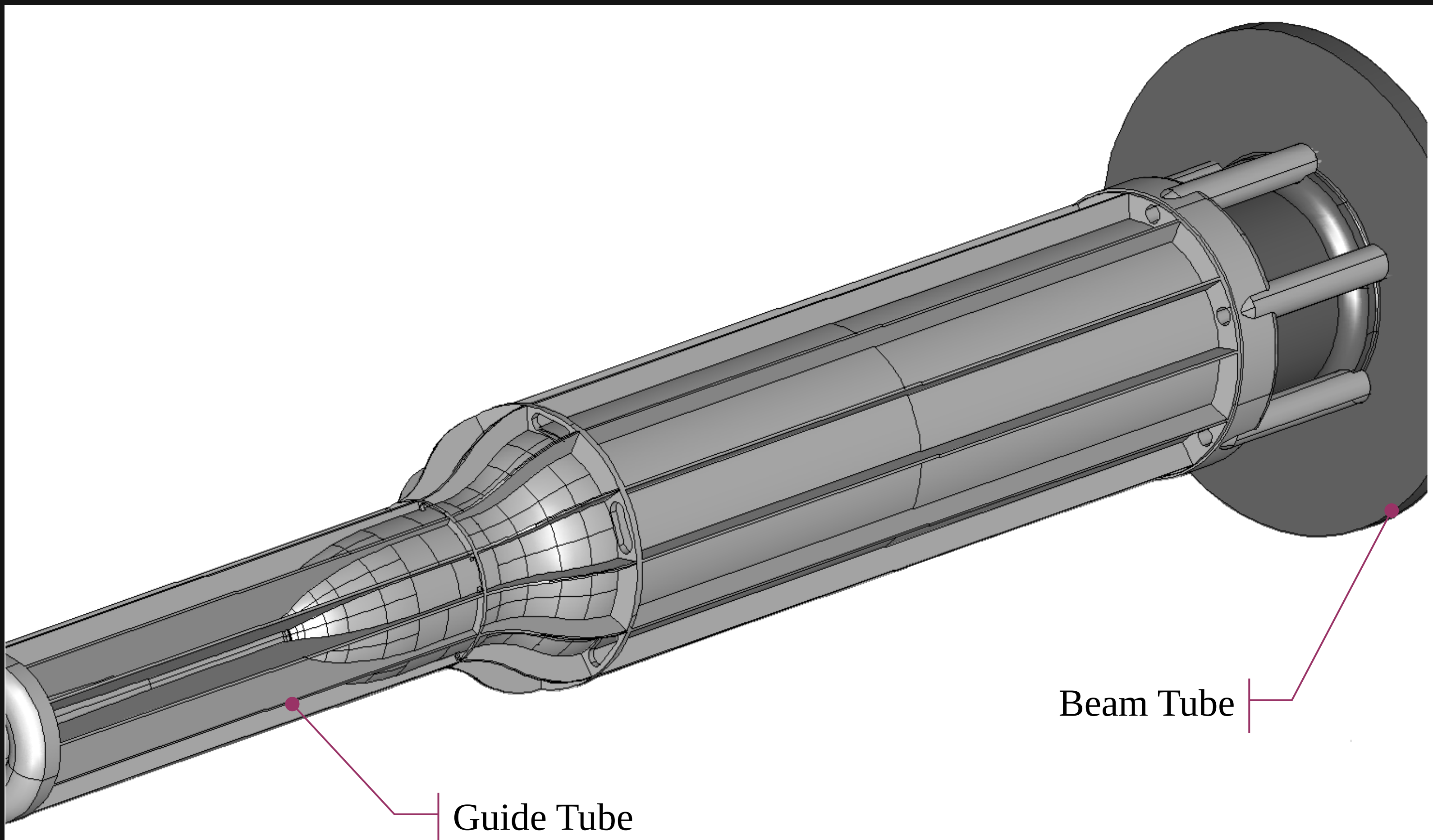

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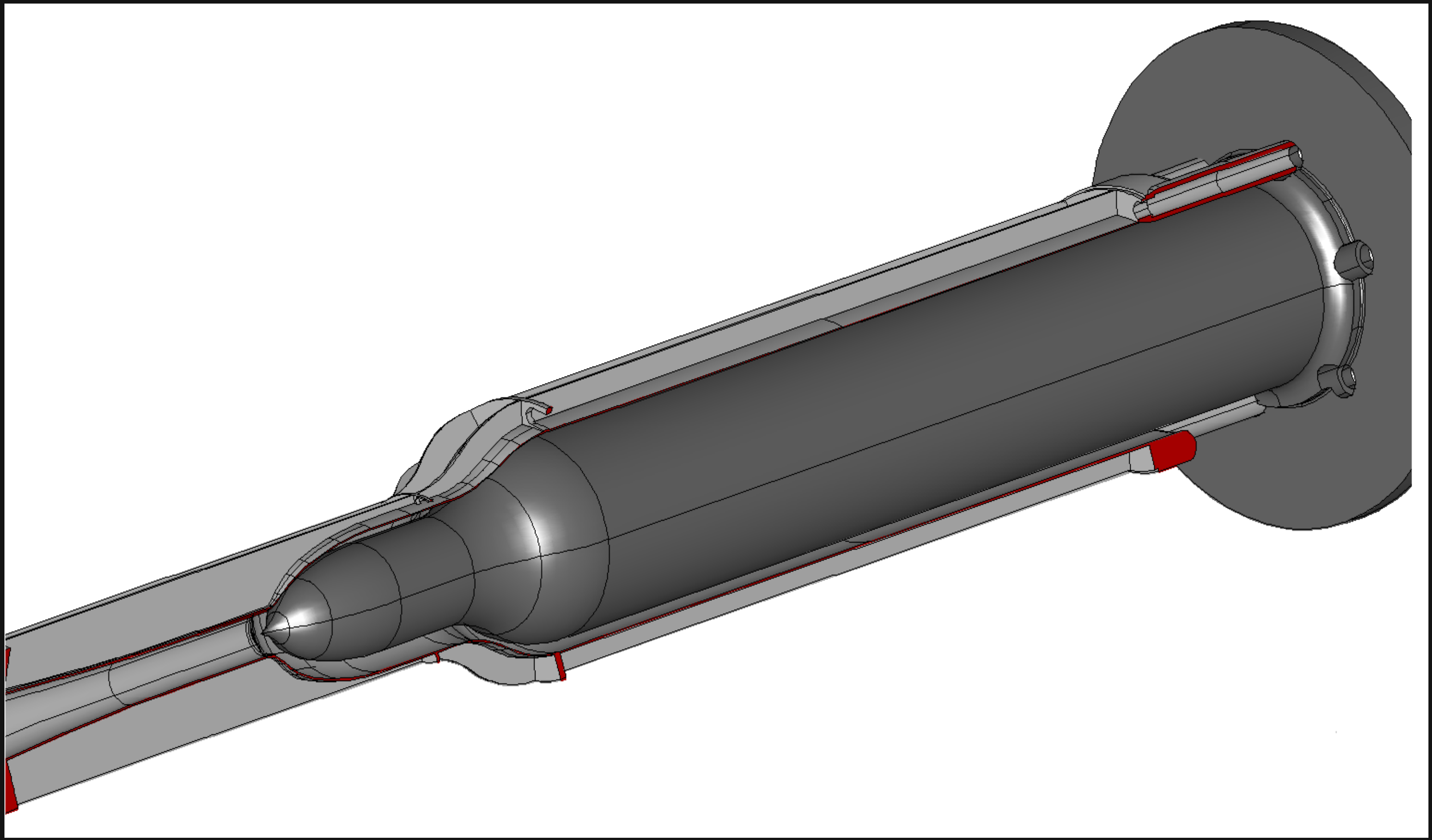

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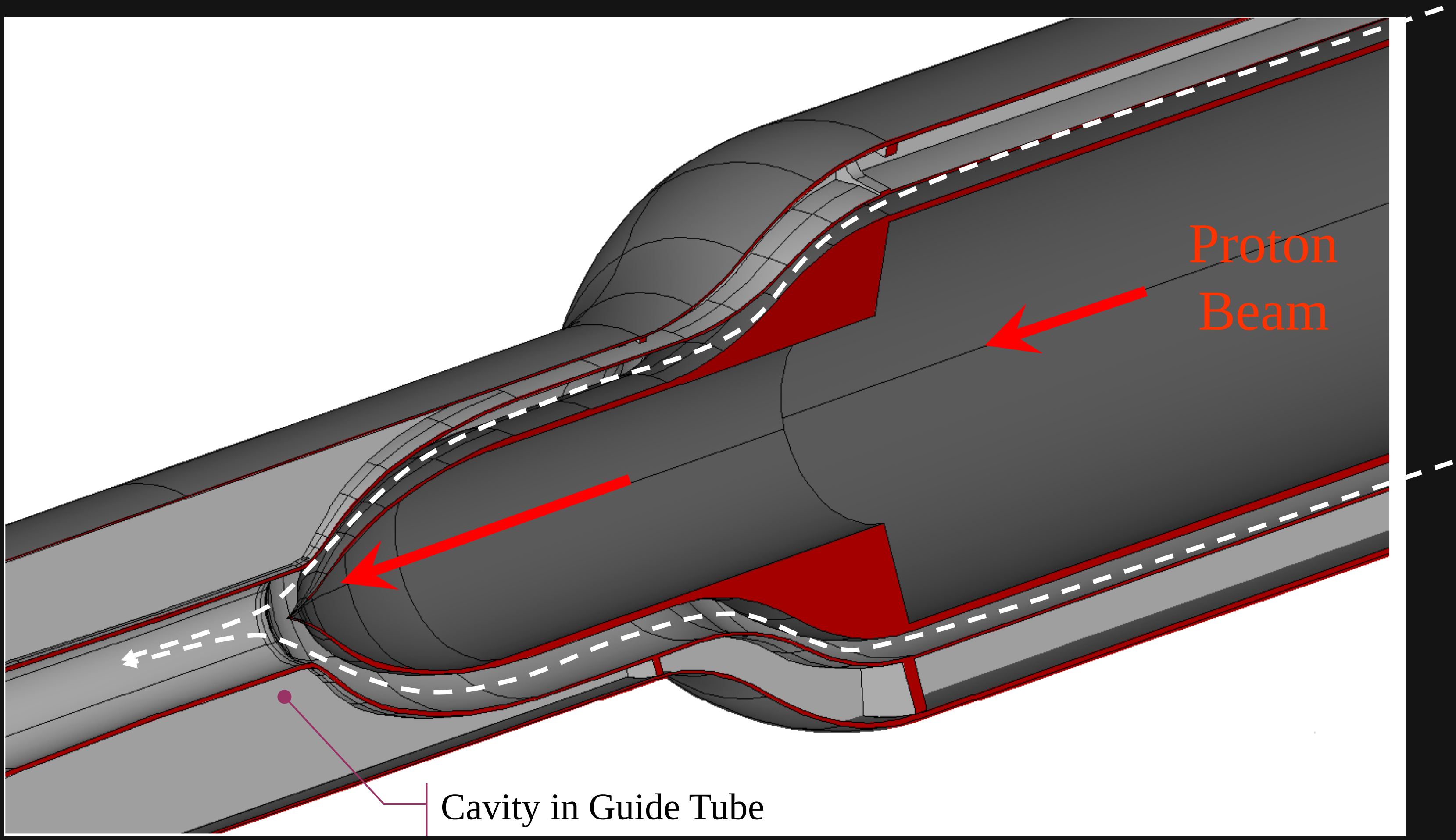

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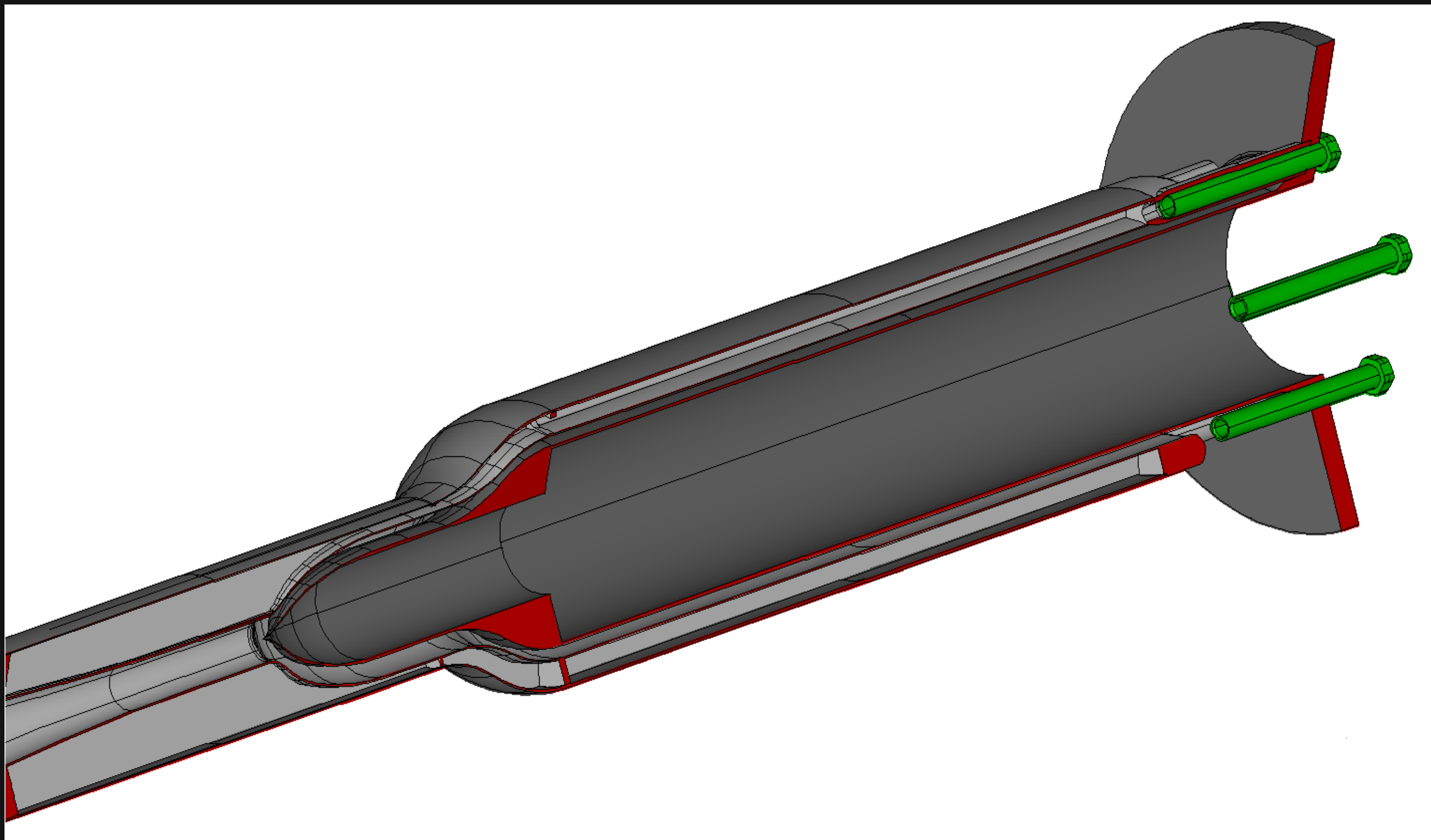
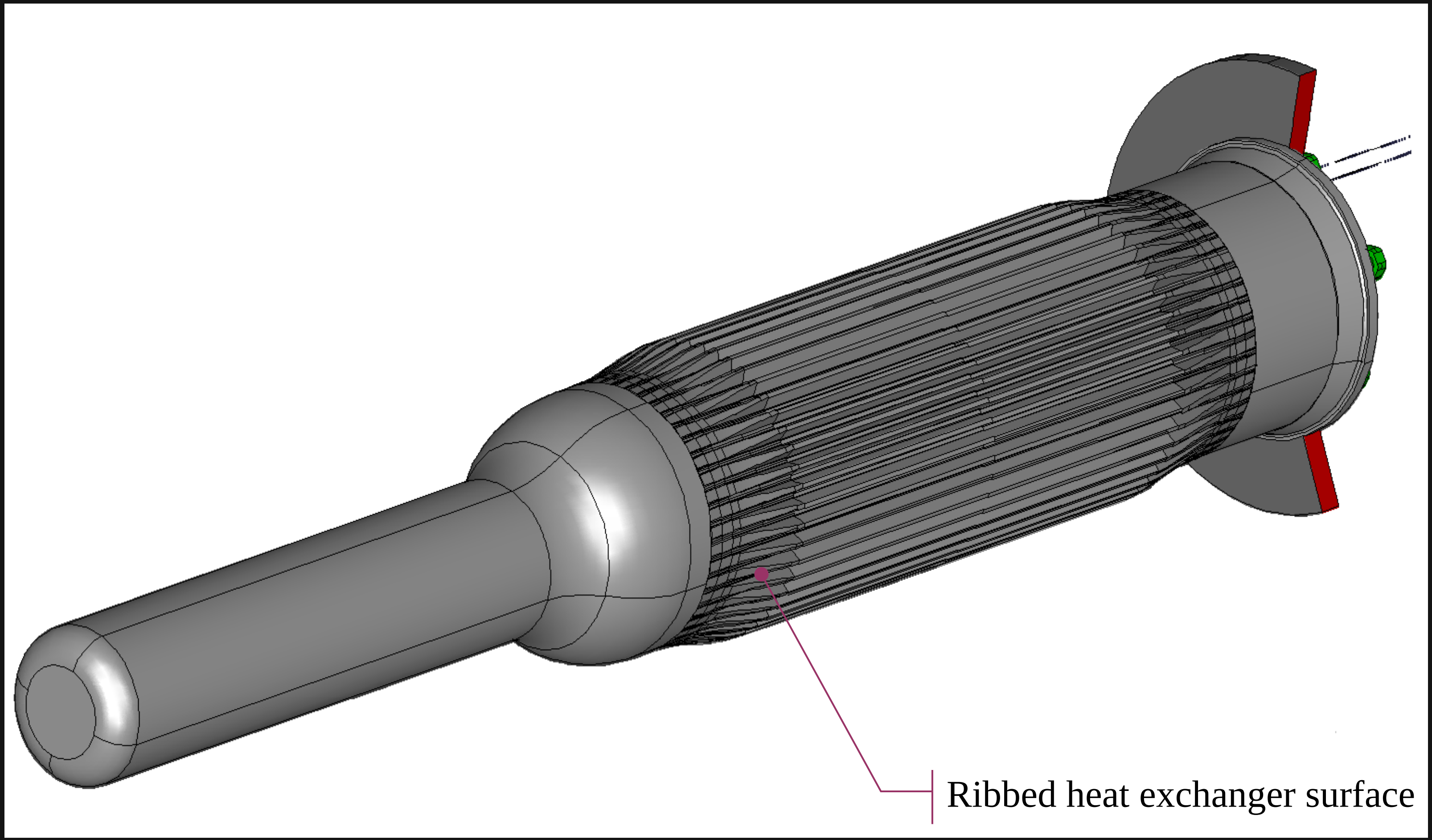
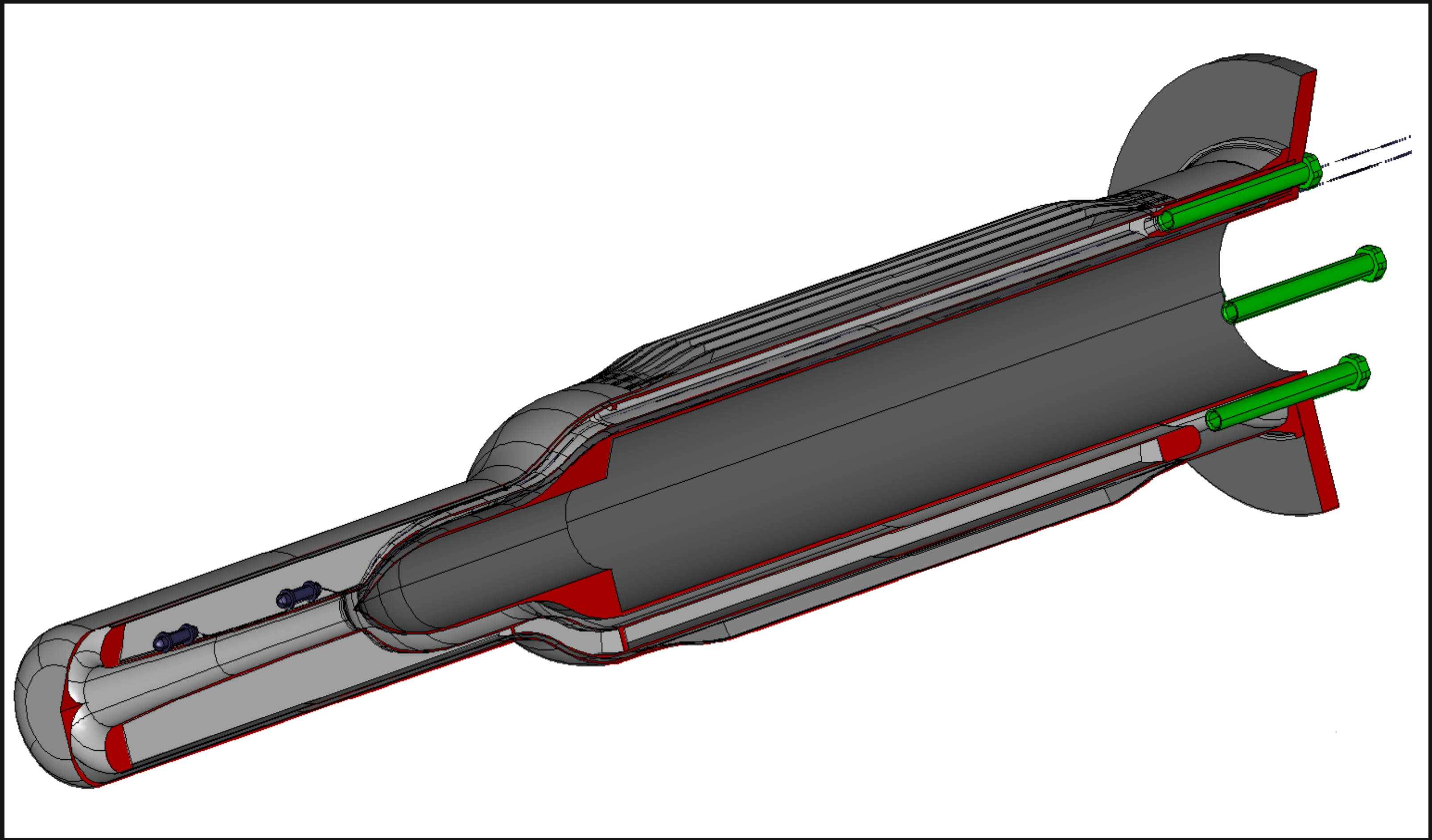


Proposed design of a high-power spallation source for ADS

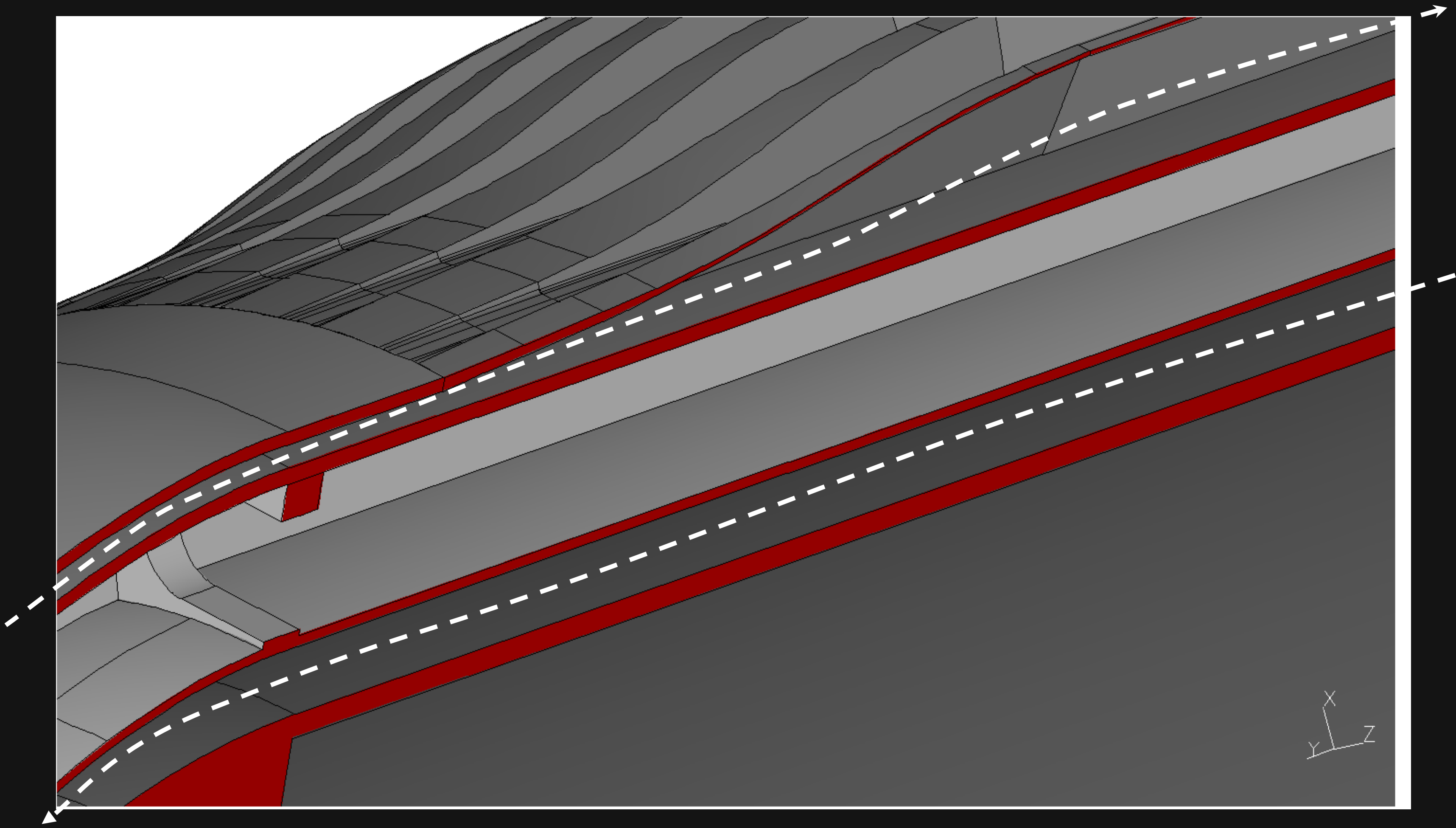


Outer shell of target

Proposed design of a high-power spallation source for ADS

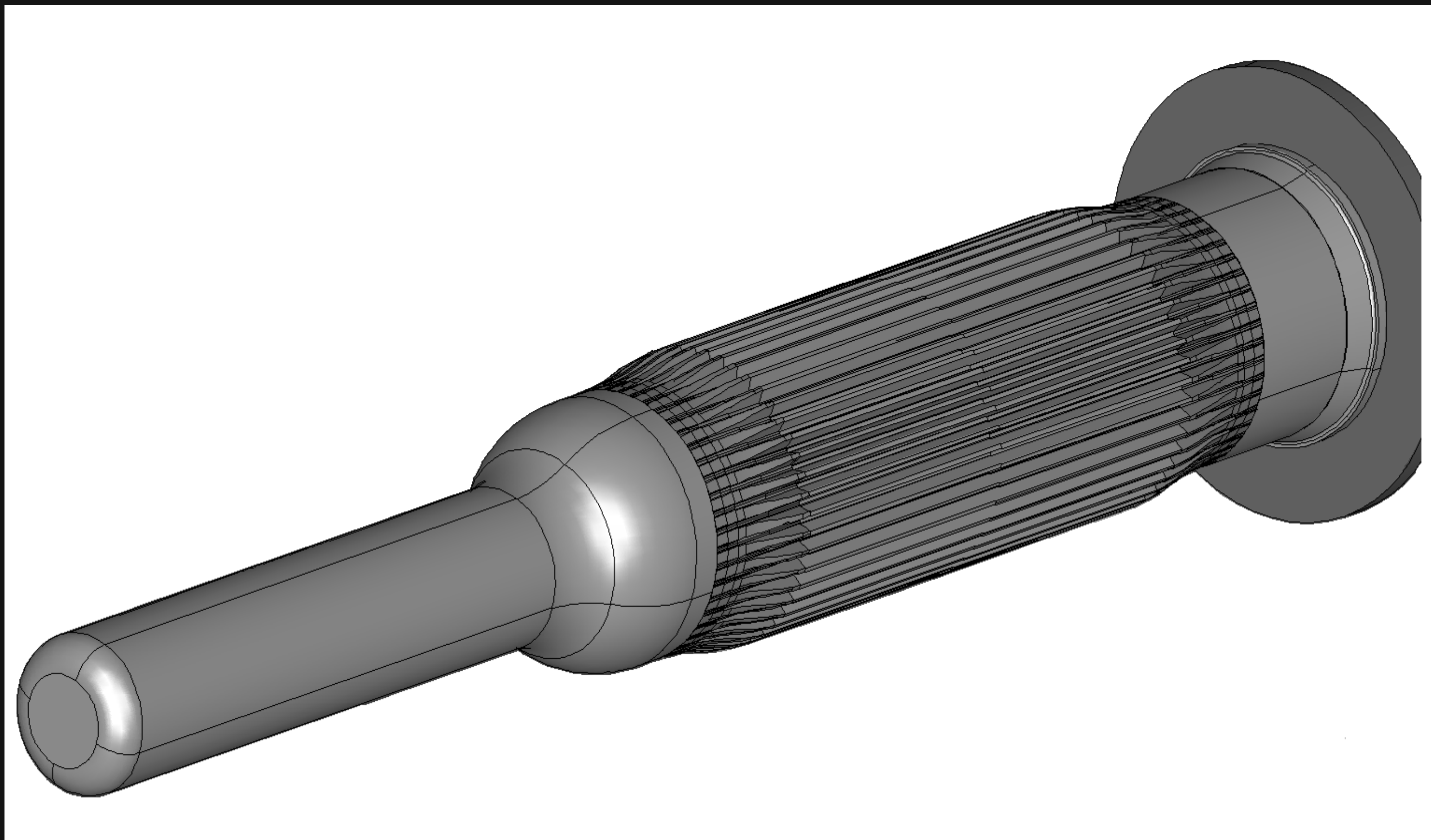


Proposed design of a high-power spallation source for ADS

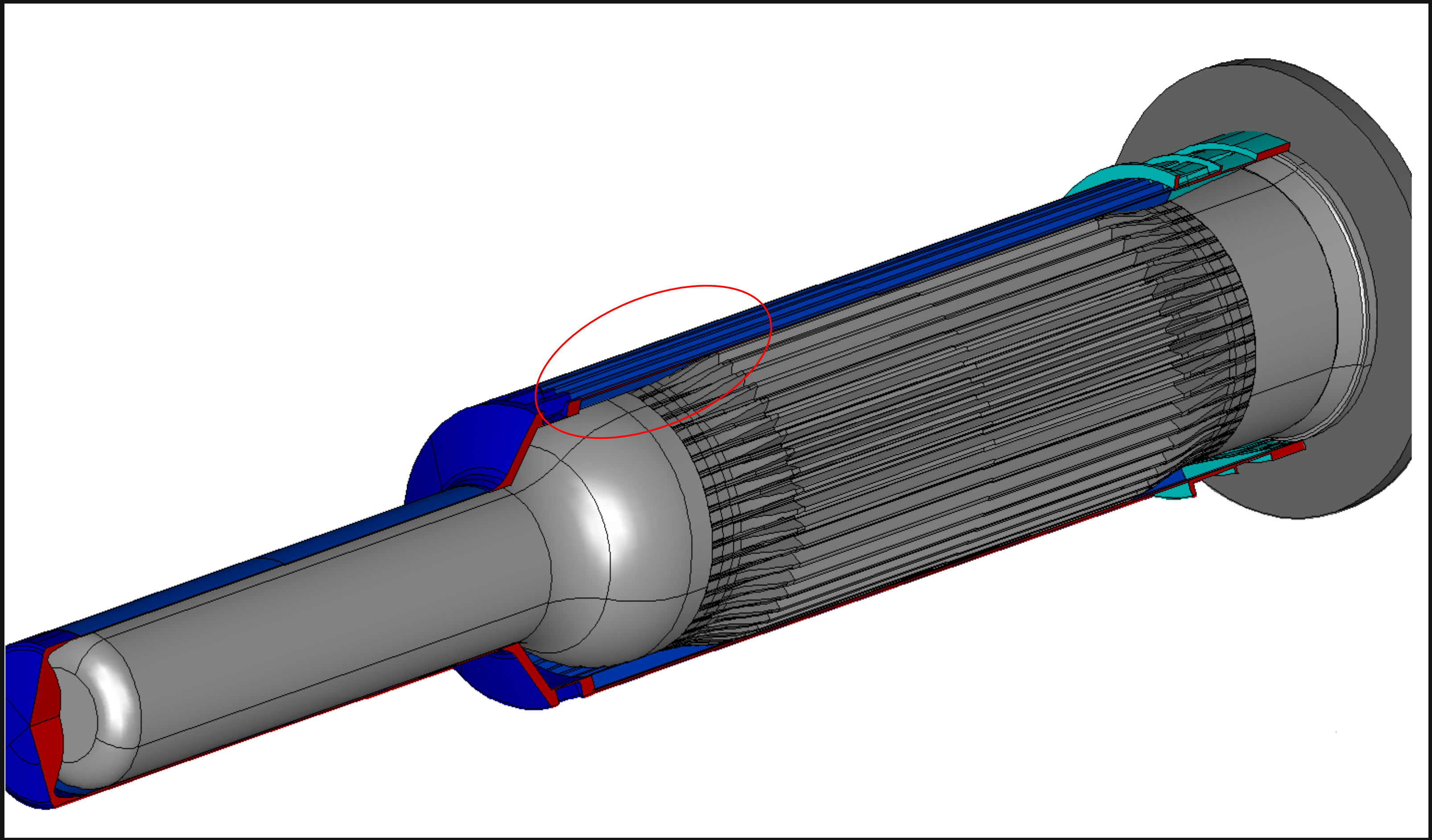


Liquid metal flow

Proposed design of a high-power spallation source for ADS

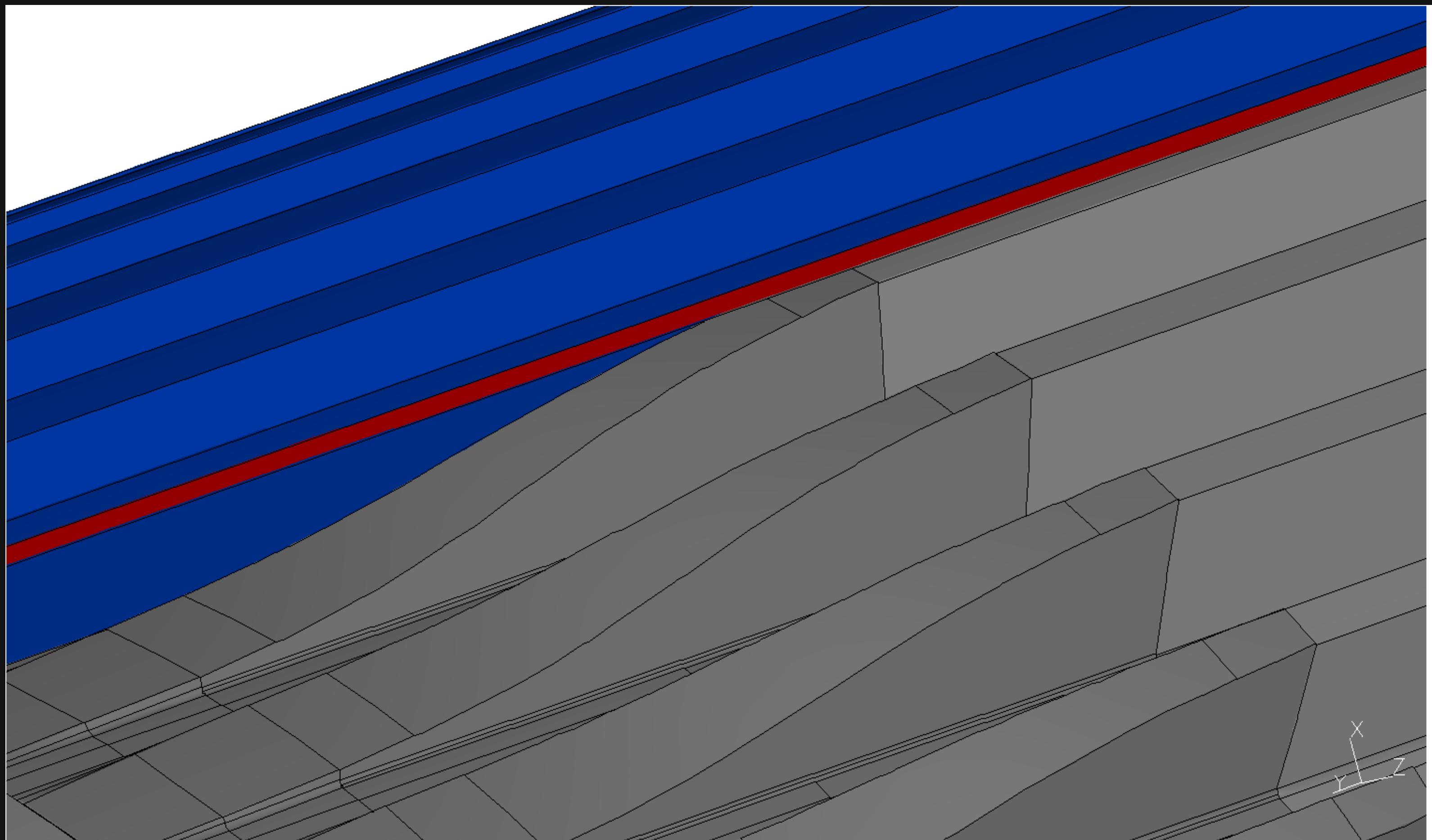


Proposed design of a high-power spallation source for ADS

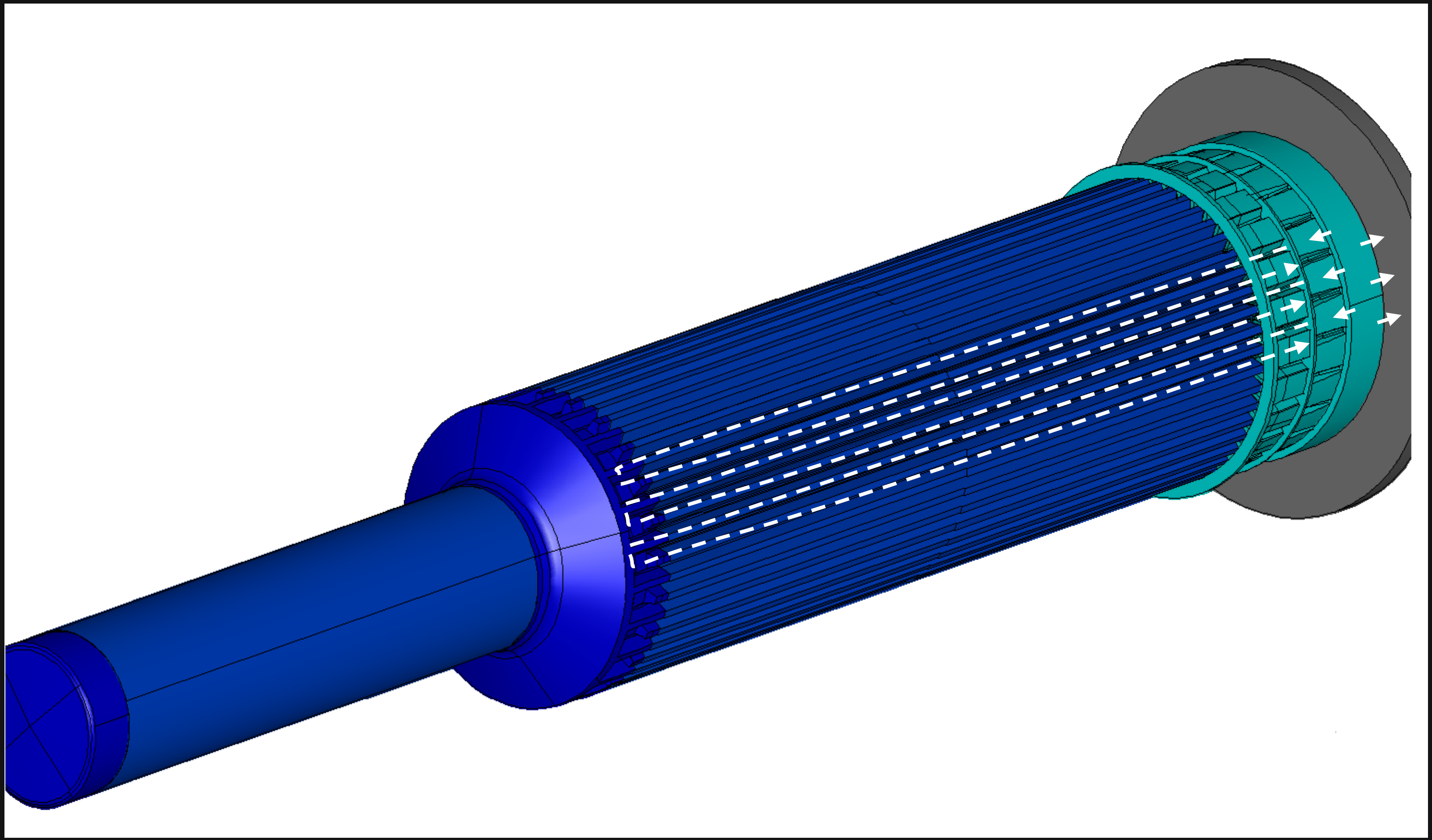


Outer containment serves as a heat exchanger

Proposed design of a high-power spallation source for ADS

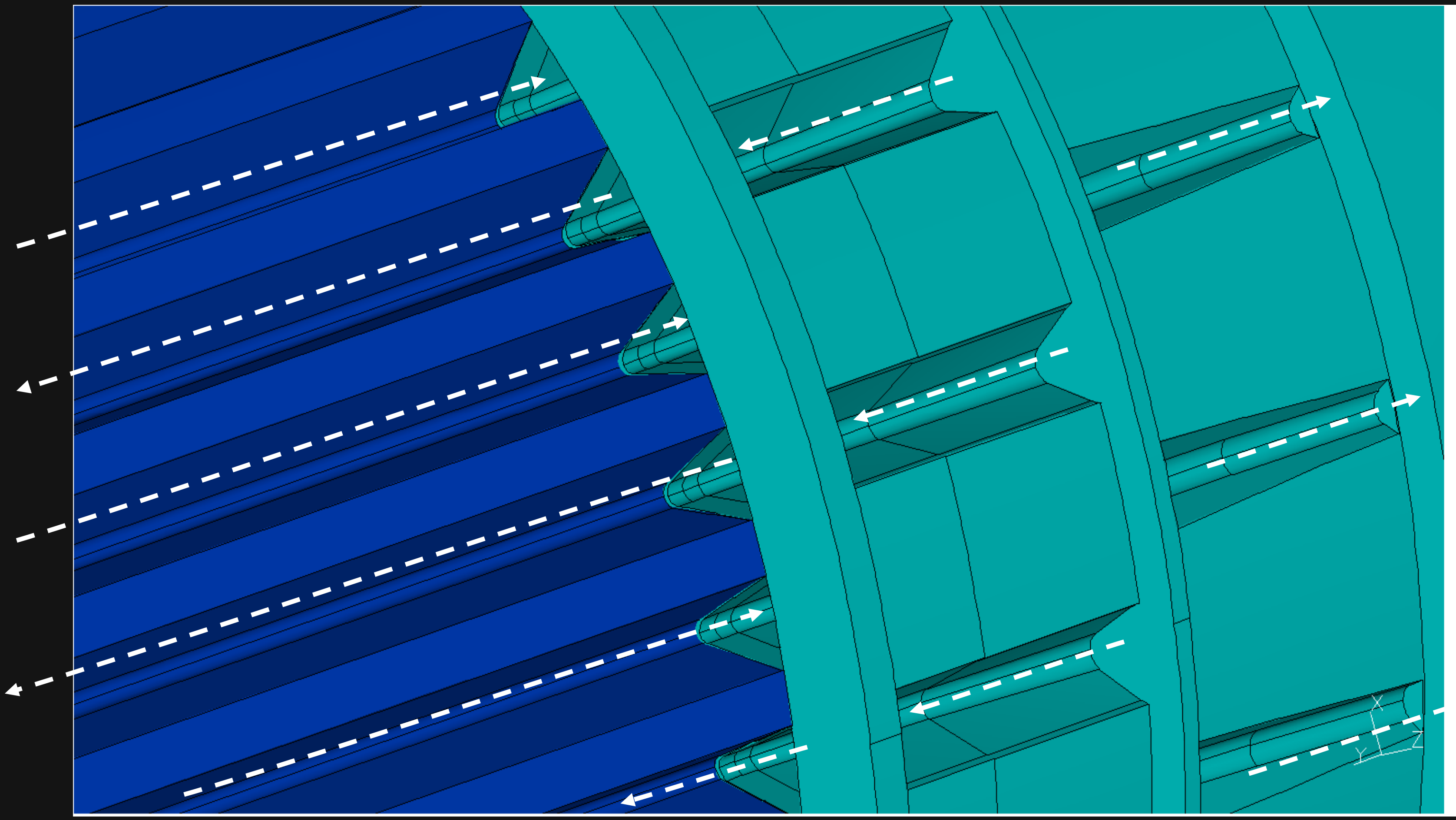


Proposed design of a high-power spallation source for ADS



Inner circulation of cooling fluid in external containment

Proposed design of a high-power spallation source for ADS



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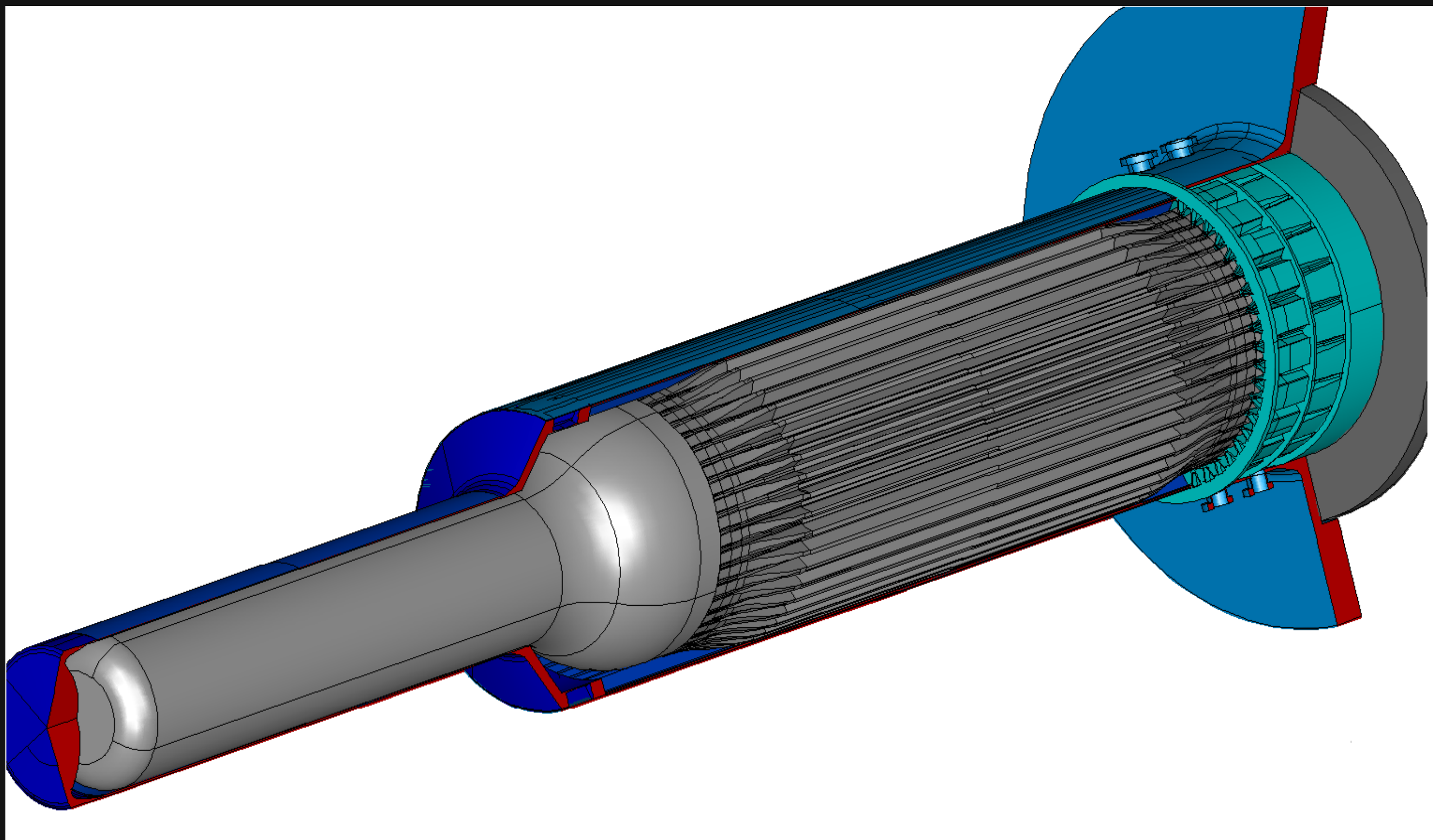

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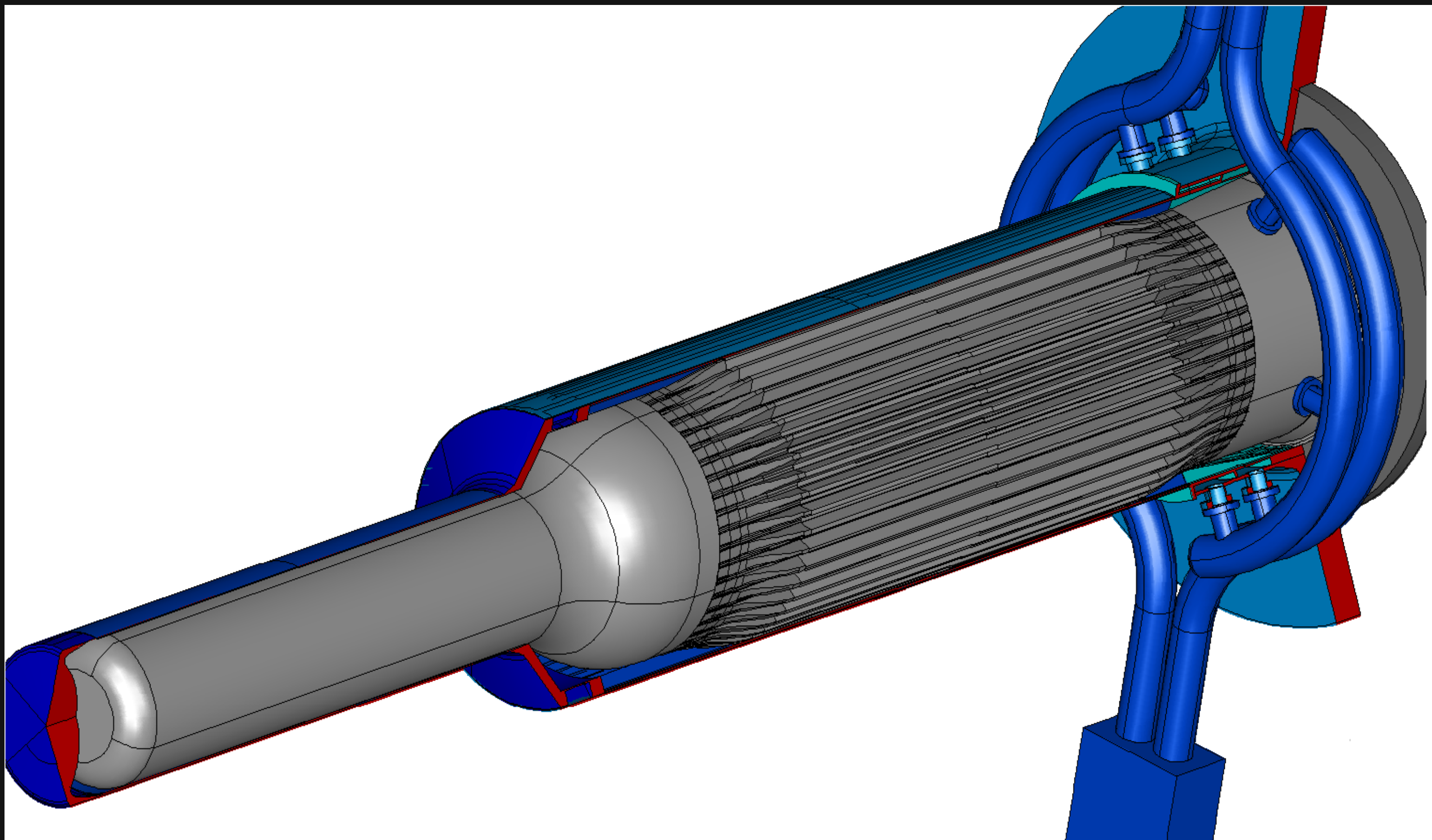
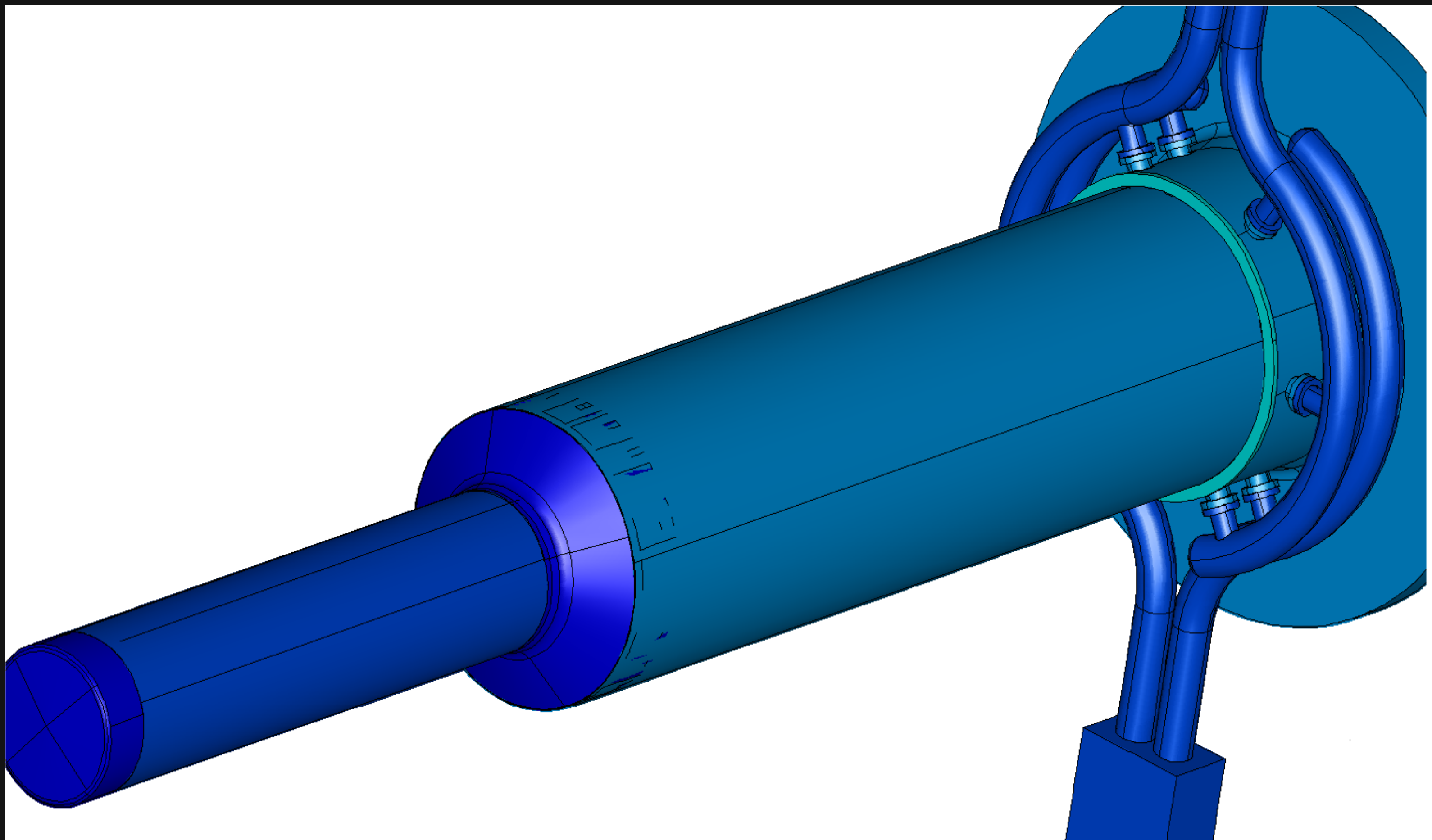


Proposed design of a high-power spallation source for ADS



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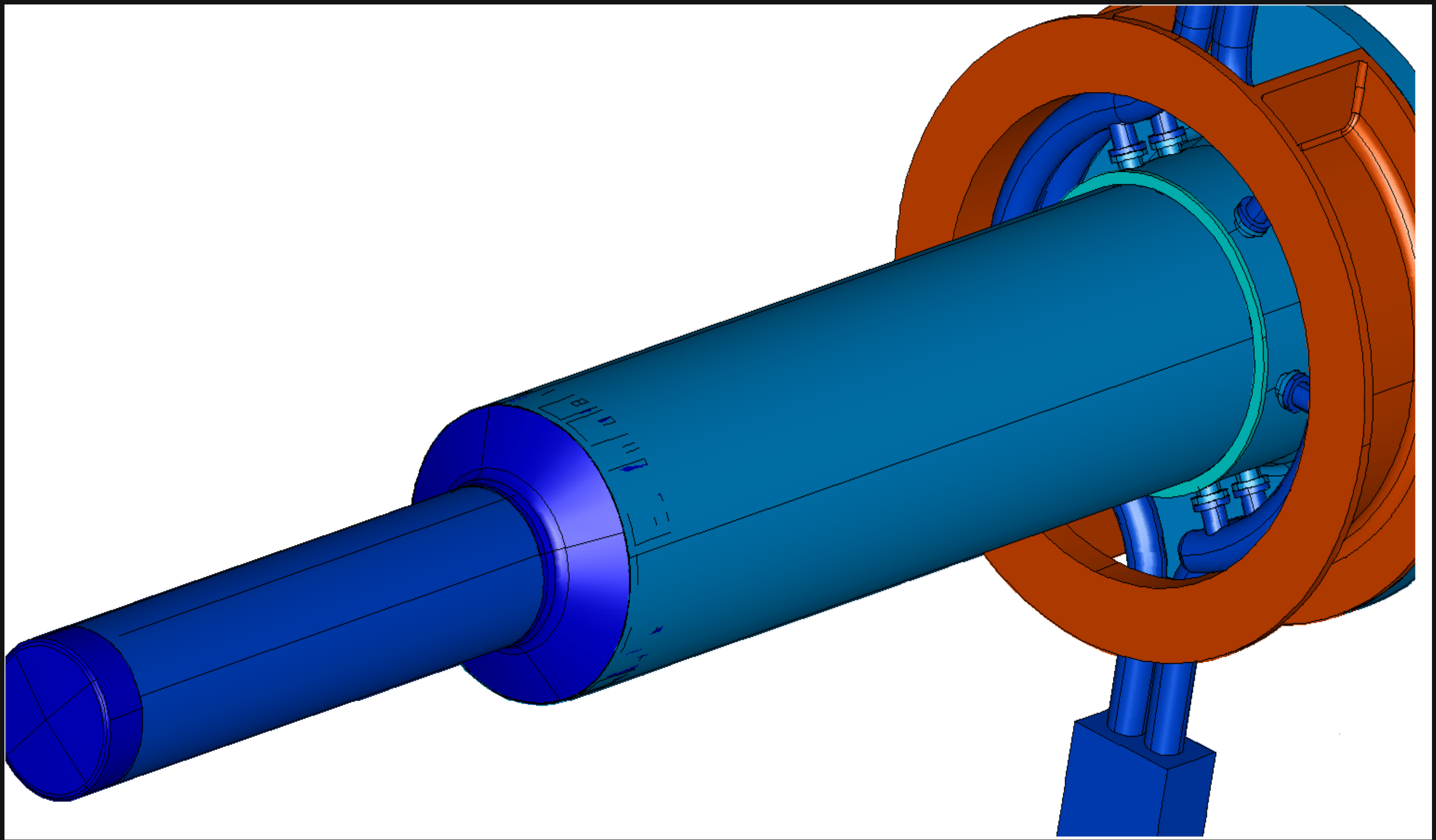

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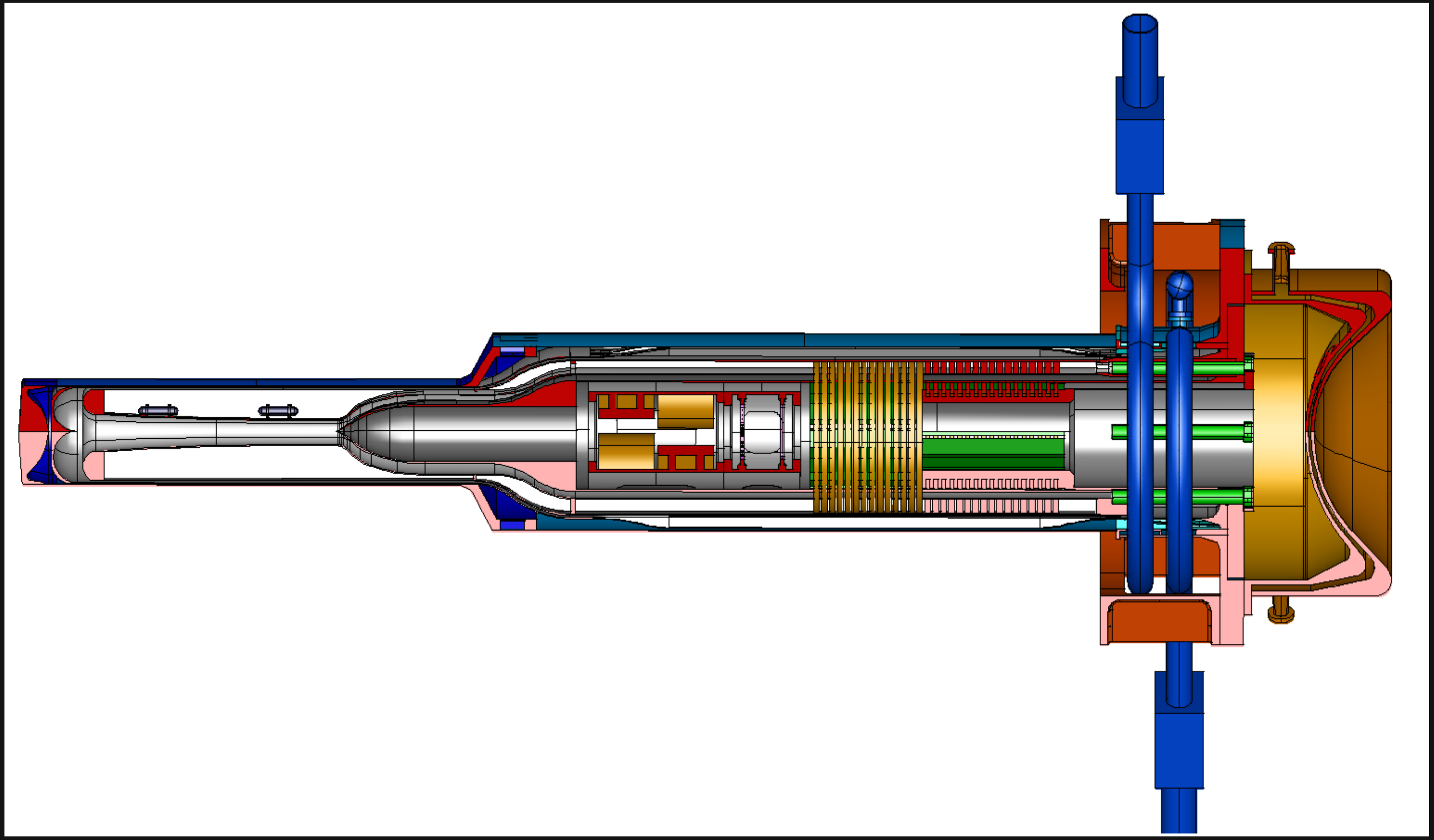

Concluding remarks
Spallation source development

- The most pressing difficulties in many of the new projects undertaken in high-power physics relate to achieving high irradiation doses, either for materials testing and/or new reactor concepts.

- Increasing the qualities of the spallation sources for the physics infrastructure of tomorrow is crucially dependent on improving the survivability of the components, their serviceability, their environmental impact.

- There is a rationale for liquid metal spallation sources to meet the needs for testing concepts under extreme conditions of irradiation, corrosion, temperature and stress.

Concluding remarks
Ressources & Publications

- The work has been sponsored by the EU-FP7 program and is available on the http://www.eu-tiara.eu/ website under WP9: TIHPAC R&D infrastructure

- The final design report comprises 150 pages of detailed information on the project and is available on-line at https://cds.cern.ch/record/1647578

- Publications are on-going and should include a “Special Topic” in the European Physical Journal in the coming year.