Karlsruhe Institute of Technology

Windowless liquid metal target for ESS

A. Class, J.Fetzer, S. Gordeev, U. Fischer, M. Majerle, B. Weinhorst, M. Daubner, R. Stieglitz, P. Vladimirov, A.Möslang at KIT,
L. Massidda at CRS4

IKET, INR, IMF1

4th High Power Targetry Workshop
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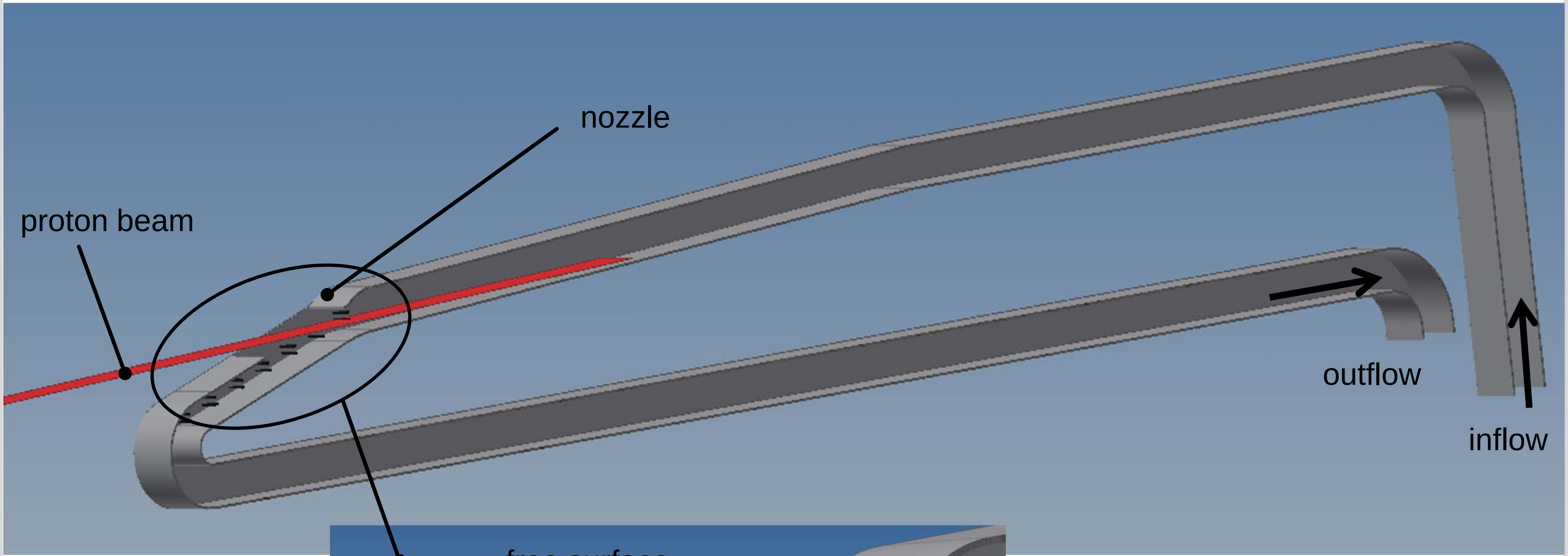
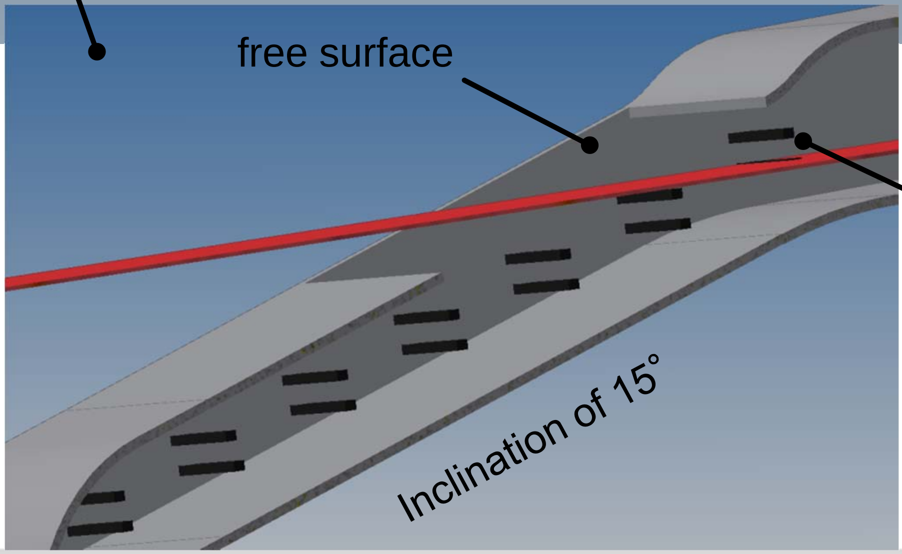
Outline

- Design
- Moduls
- Simulations
- Pros & Cons

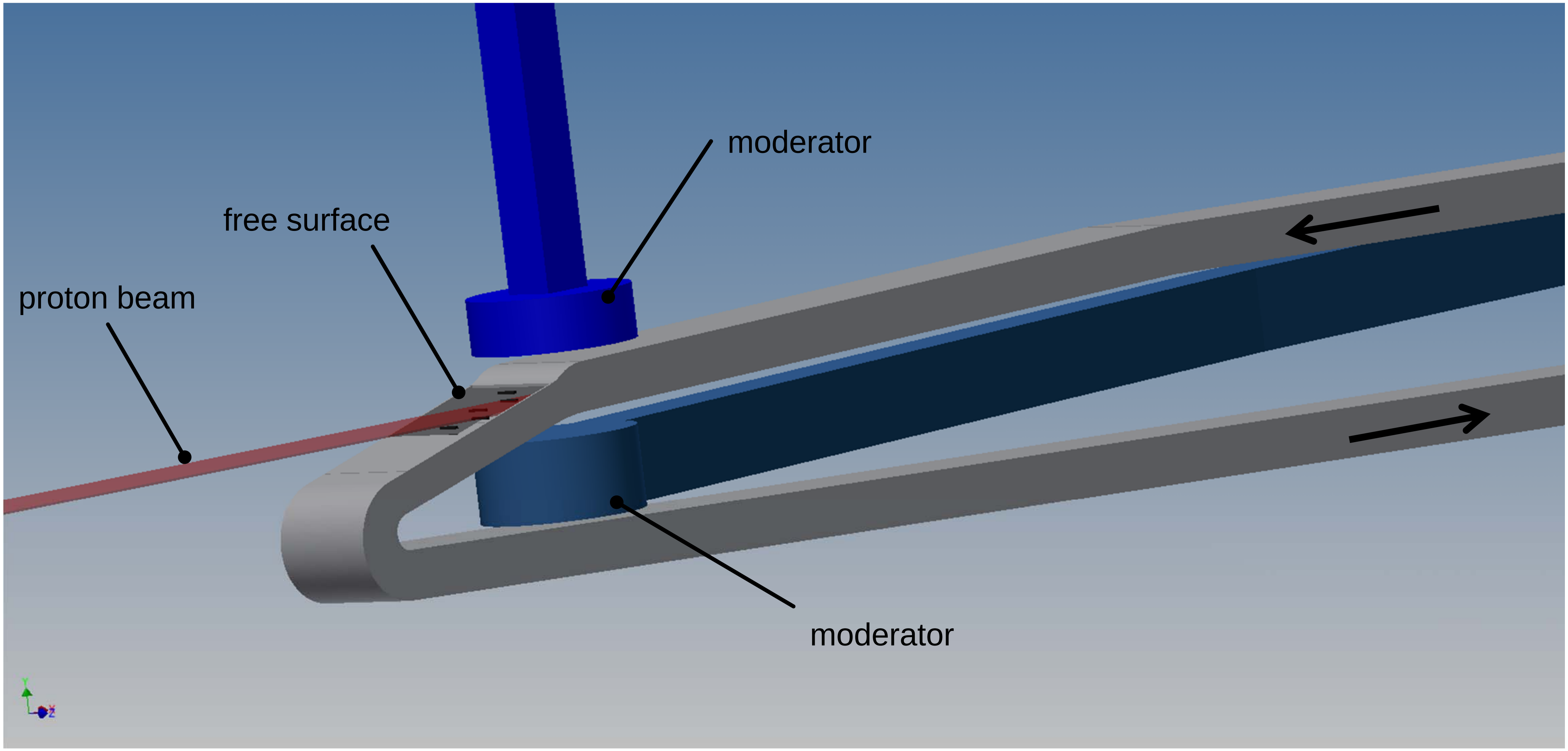
Windowless target module



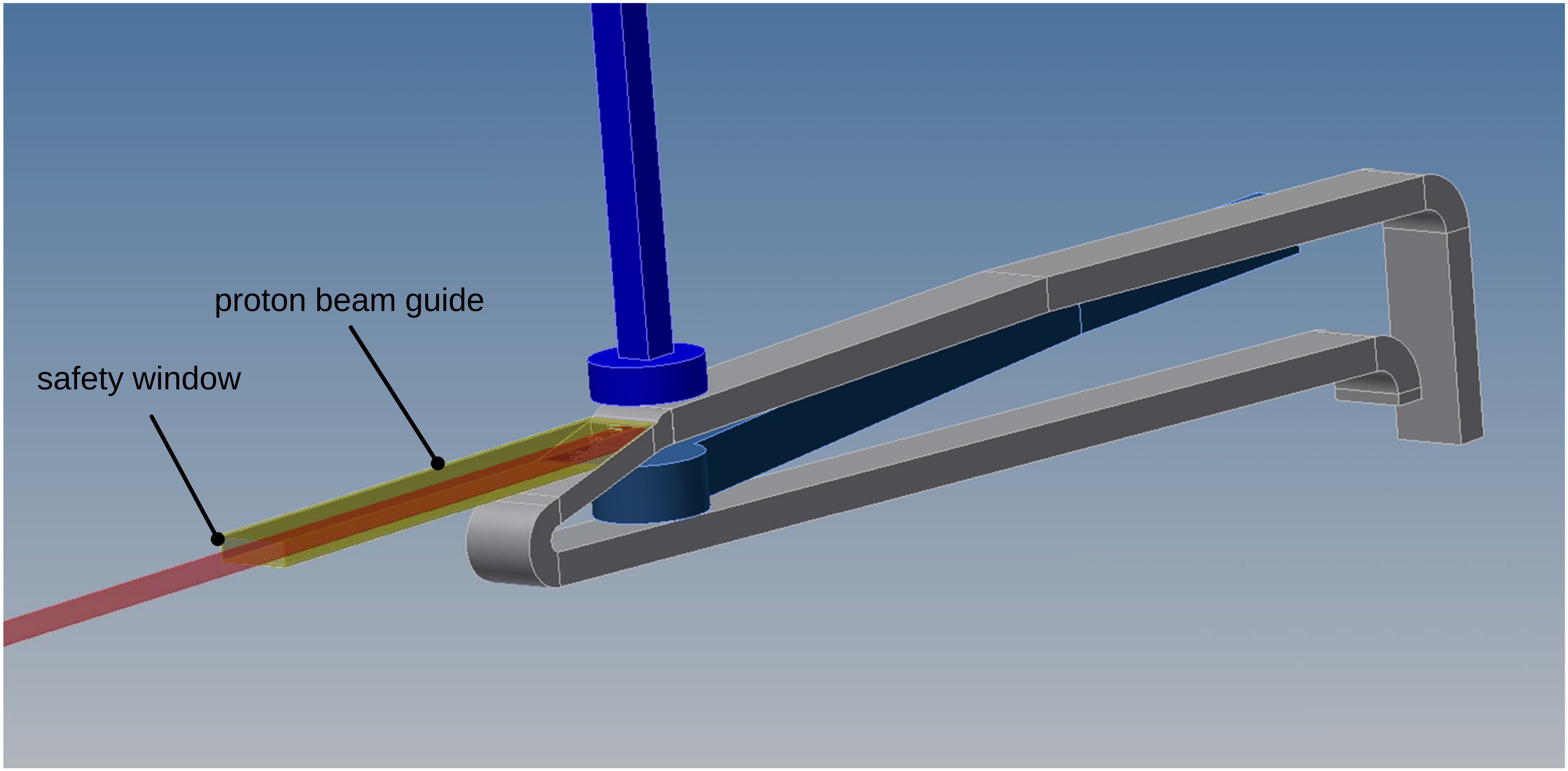


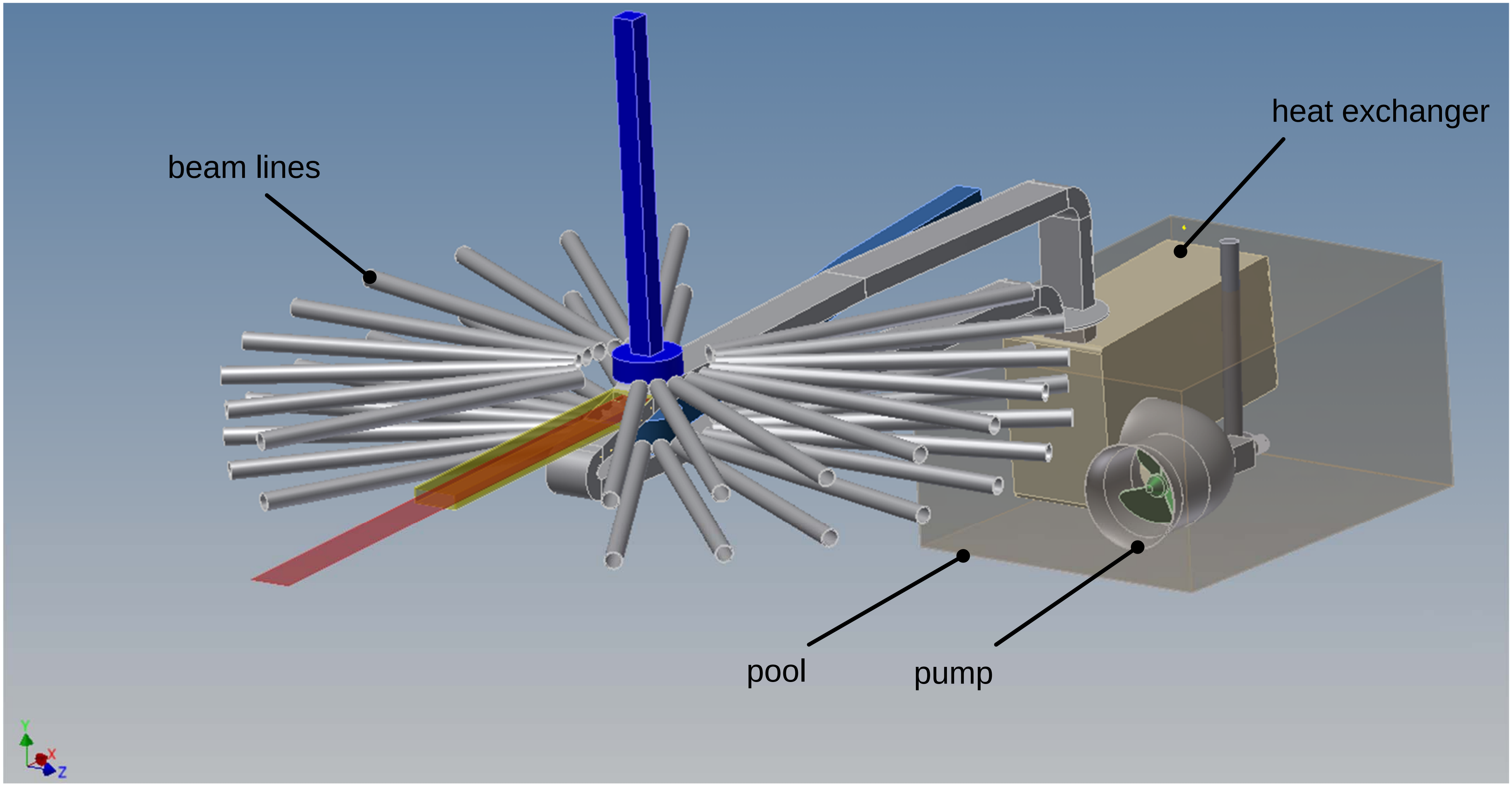
flow obstacles:

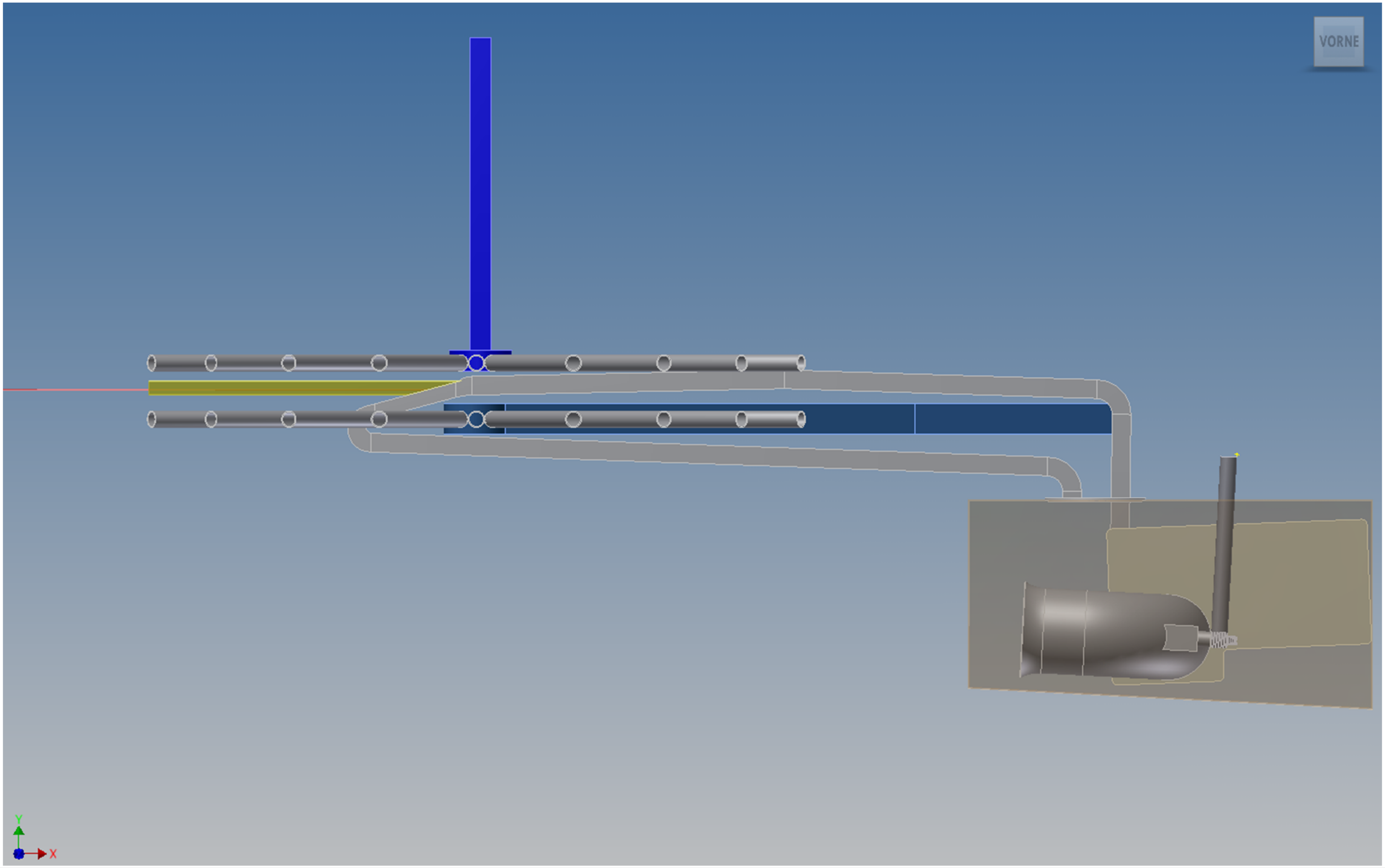
- flow conditioning for free surface stability
- limit the lateral bypass flow and total flowrate
- dispersion of pressure waves

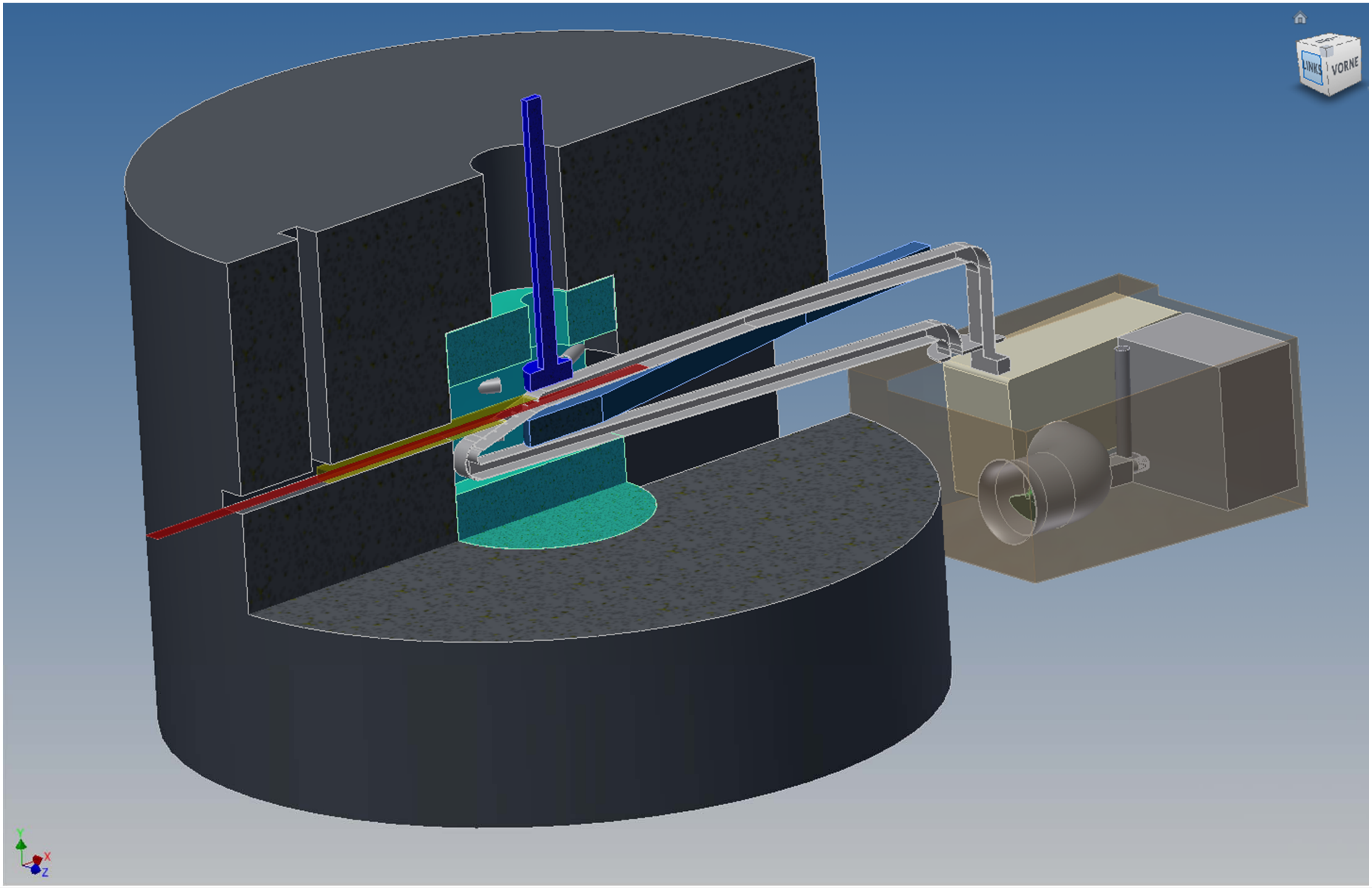


moderator
free surface
proton beam
moderator


proton beam guide
safety window


beam lines
heat exchanger
pool
pump


VORNE
Y
X


LINKS
VORNE

Modular concept

- pool
- 3 separate replaceable modules
  - pump module
  - heat exchanger module
  - target module
- containment

Free surface requires operation pressure near vapor pressure

Inside of containment leak tightness not required for improved remote handling and maintenance

Pool

- lead bismuth eutectic
- permanently in liquid state
- LBE inventory is major (activated) mass of target
- dimensioned for potential future upgrades
- designed for long lifetime
- modules attached to pool with bayonet-fixings large tolerances
- connection to target should be remote handled for quick target replacement
- beam guide prevents migration of LBE

Pump module

- impeller pump
- flow rate of 15-50 m^3/h
- impeller is submerged in pool
- impeller housing is part of the pump module
- installed at heat exchanger low pressure side
- set of gears transfers motors momentum to impeller

- alternative: electro-magnetic pump

Heat exchanger module

- 5 MW heat removal capacity (upgrade to 15 MW)
- heat transfer on liquid metal side is very efficient
- possibly water spray evaporation cooling
- alternatively helical pin heat exchangers employed in MEGAPIE with increased number of cooling pins and oil coolant

Target module

- beam does not directly hit any solid structures
- stable supercritical free surface flow entering subcritical flow in U-bend (hydraulic jump)
- nozzle for flow conditioning and elimination of cavitation
- open channel with15° inclination results in small relatively uniform heating
- operational for “beam on” if LBE level reaches top wall (heated thermocouple provides signal)
- successive beam pulses interact with “fresh” fluid
- optional dispersion of the shockwave by obstacles
- splashing with speed < 0.6 m/s & height <2 cm estimated by CRS4
- small channel height allows for optimal moderator position ~ +- 60 mm from neutron flux maximum
- low corrosion/erosion with T91/ 316LN
- window option possible with good cooling & low mechanical stresses
- 5MW with large margin for upgrade option

Containment

- safety barrier for activated material (LBE, polonium...)
- target & pool installed in double-wall containment
- gap filled with cover-gas which is monitored
- small wall thickness (Jülich idea of layers of tubes can be employed)
- low mechanical stresses
- below ambient pressure inside containment
- “cold” traps (200° C) near any free surfaces & safety window
- proton beam enters containment through a double safety window (heat pipe minimizes needed pressure, liquid inventory and thermal stresses)
- proton beam guide prohibits direct interaction of LBE with safety window
- target connection plug should be remote handled (PSI inflatable seal?)
- (optional window adds additional safety barrier)

Simulations: Thermohydraulics

Calculation conditions:

Proton beam energy deposition:
(M.Majerle, 2010)

Average jet velocity:
1-2 m/s (30-60 m3/h)

Inlet temperature: 200˚ C

Boundary conditions:

-Adiabatic walls;

-symmetry in Z-direction

-no slip at walls

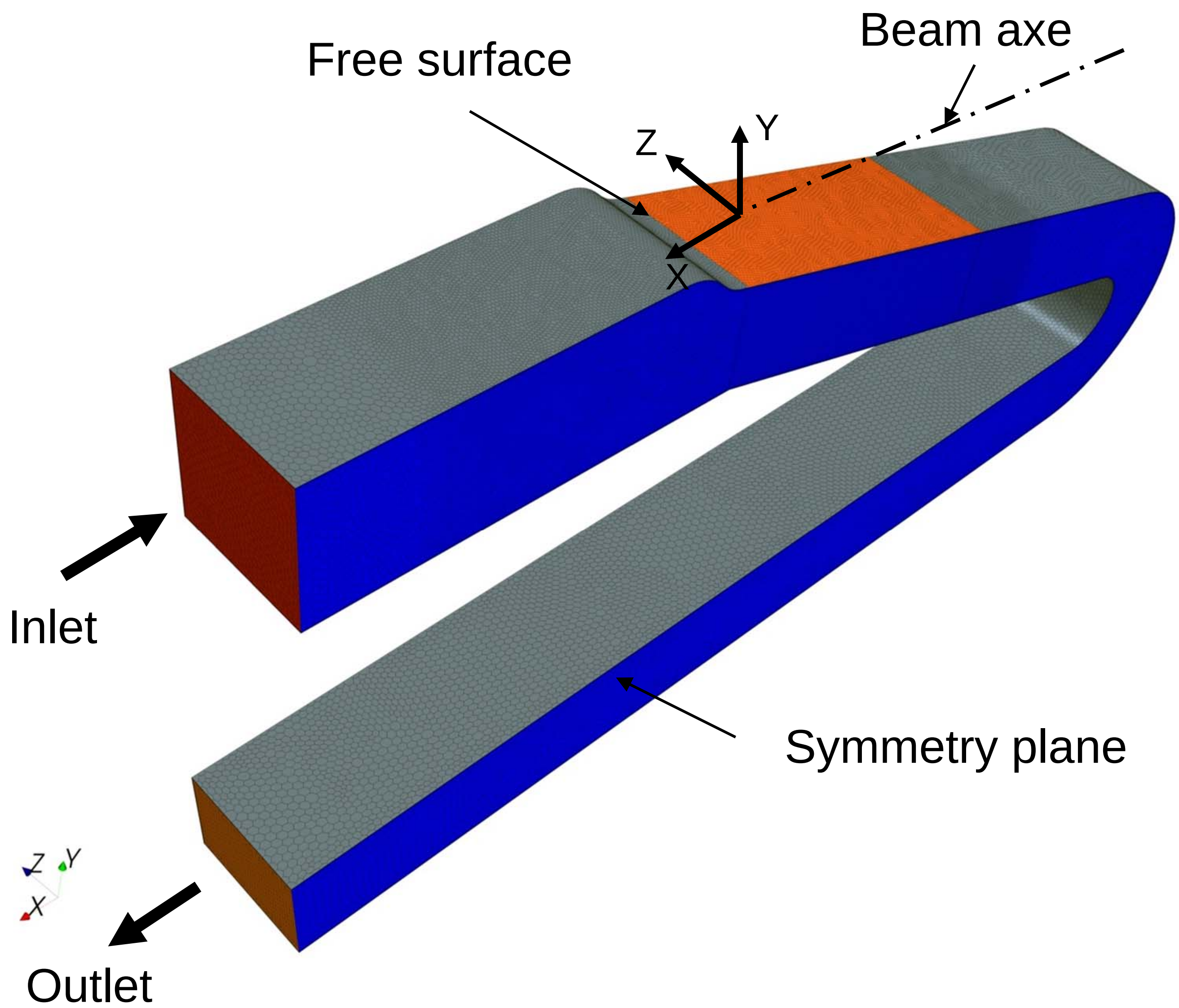
-free surface

Fluid properties:

LBE, $(\nu,\sigma,\rho,\lambda) = f(T)$

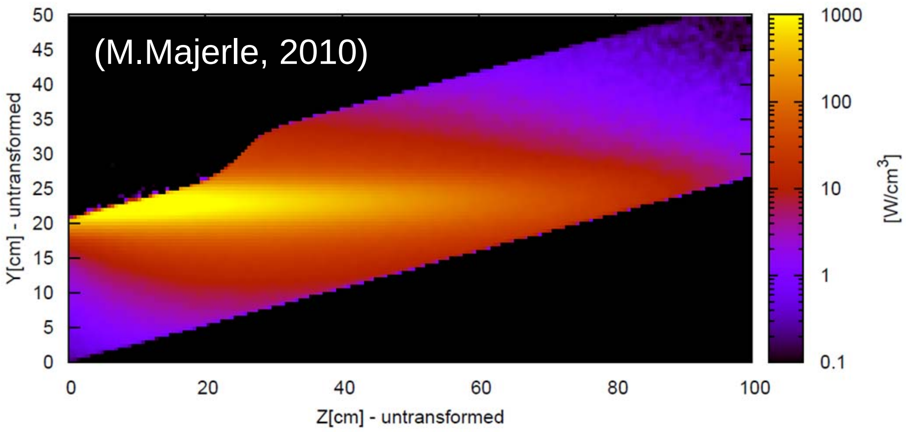
Calculation model:

K-ε High Reynolds number TM;
Volume of Fluid (VOF) Method;
Transient

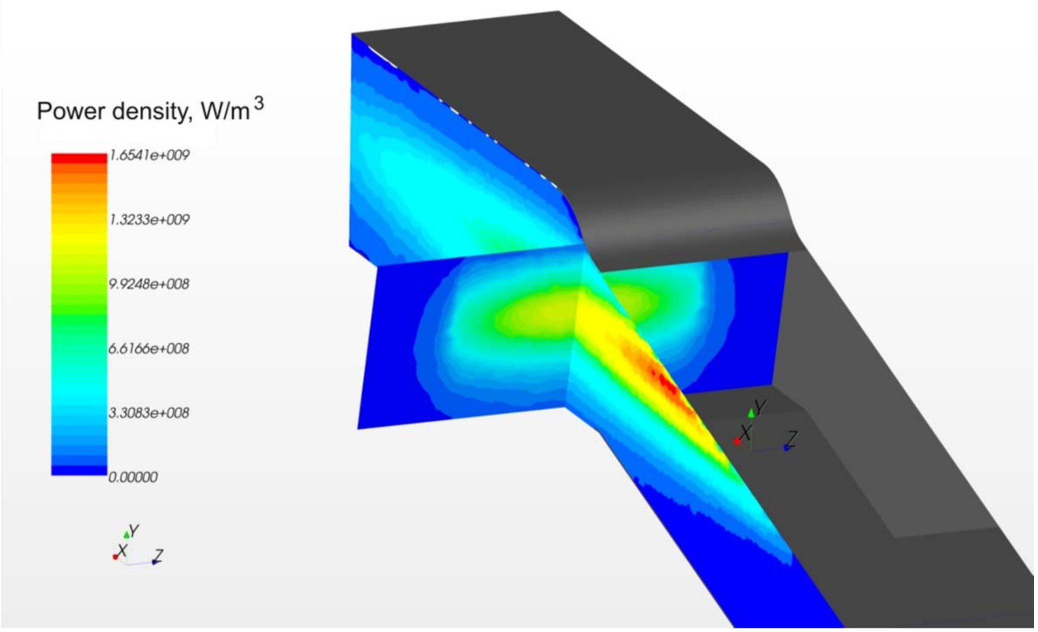


Heating power density distribution in LBE

Heating power density distribution (MCNPX)

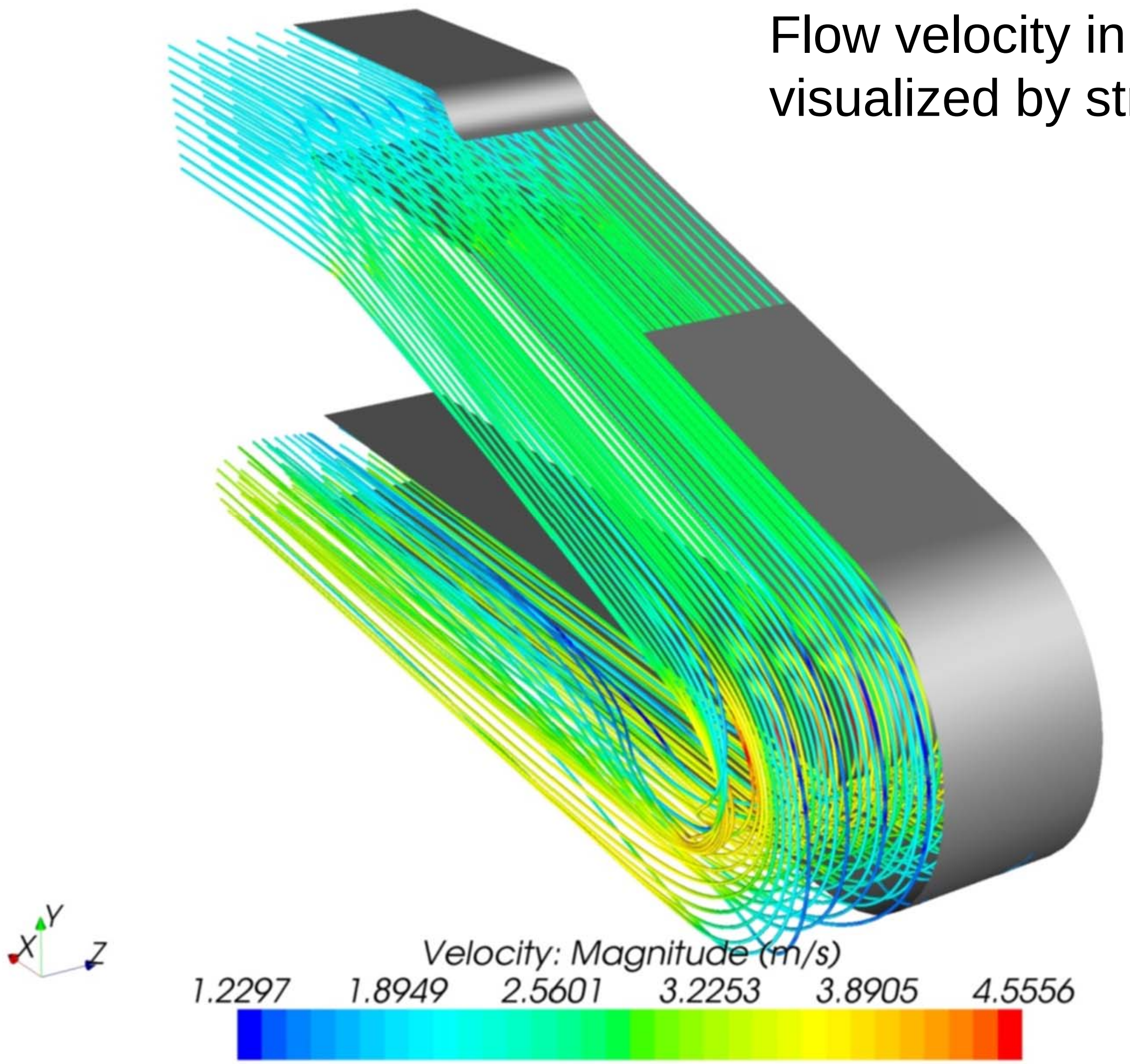


Heating power density distribution (Star CCM+)



Flow velocity distribution

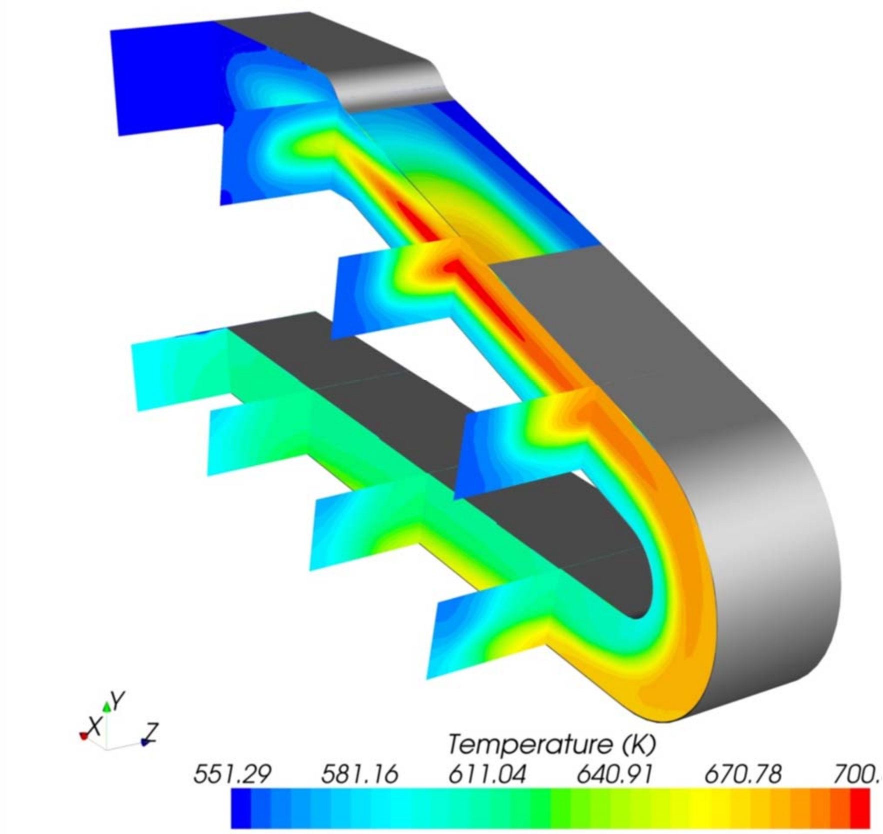
Flow velocity in the ESS LBE target visualized by stream lines (V=2m/s)



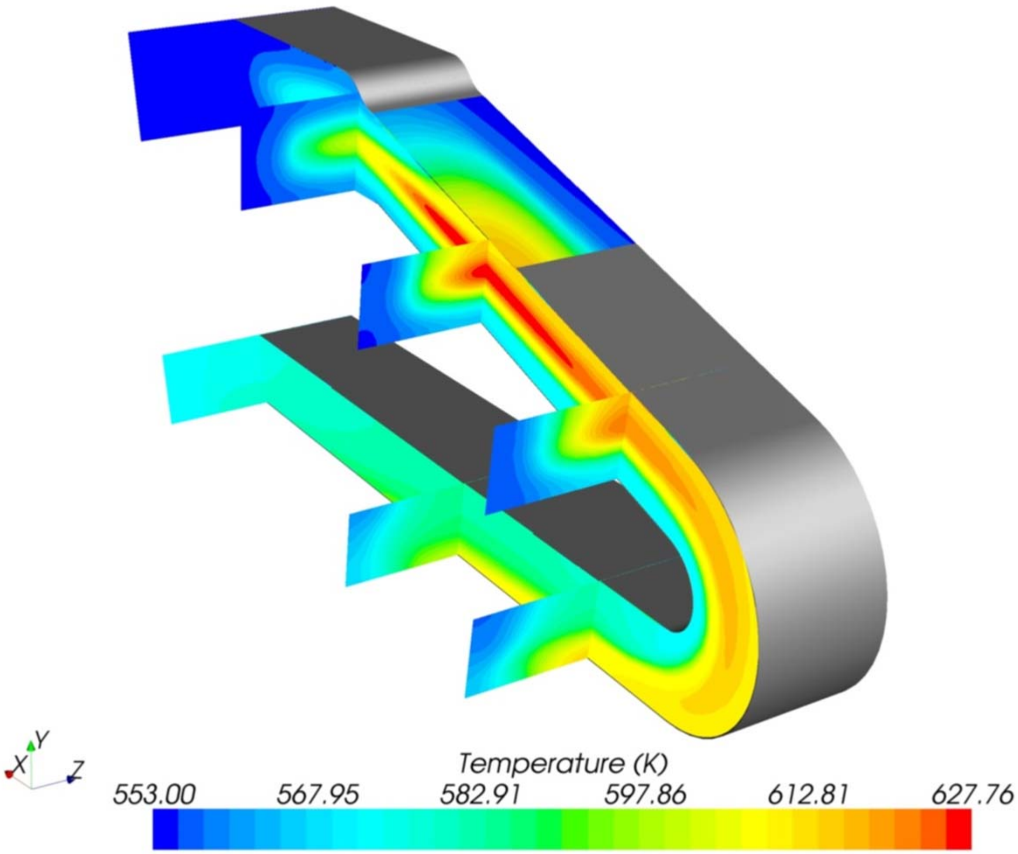
Temperature distribution

Flow velocity at the nozzle outlet

V=1m/s

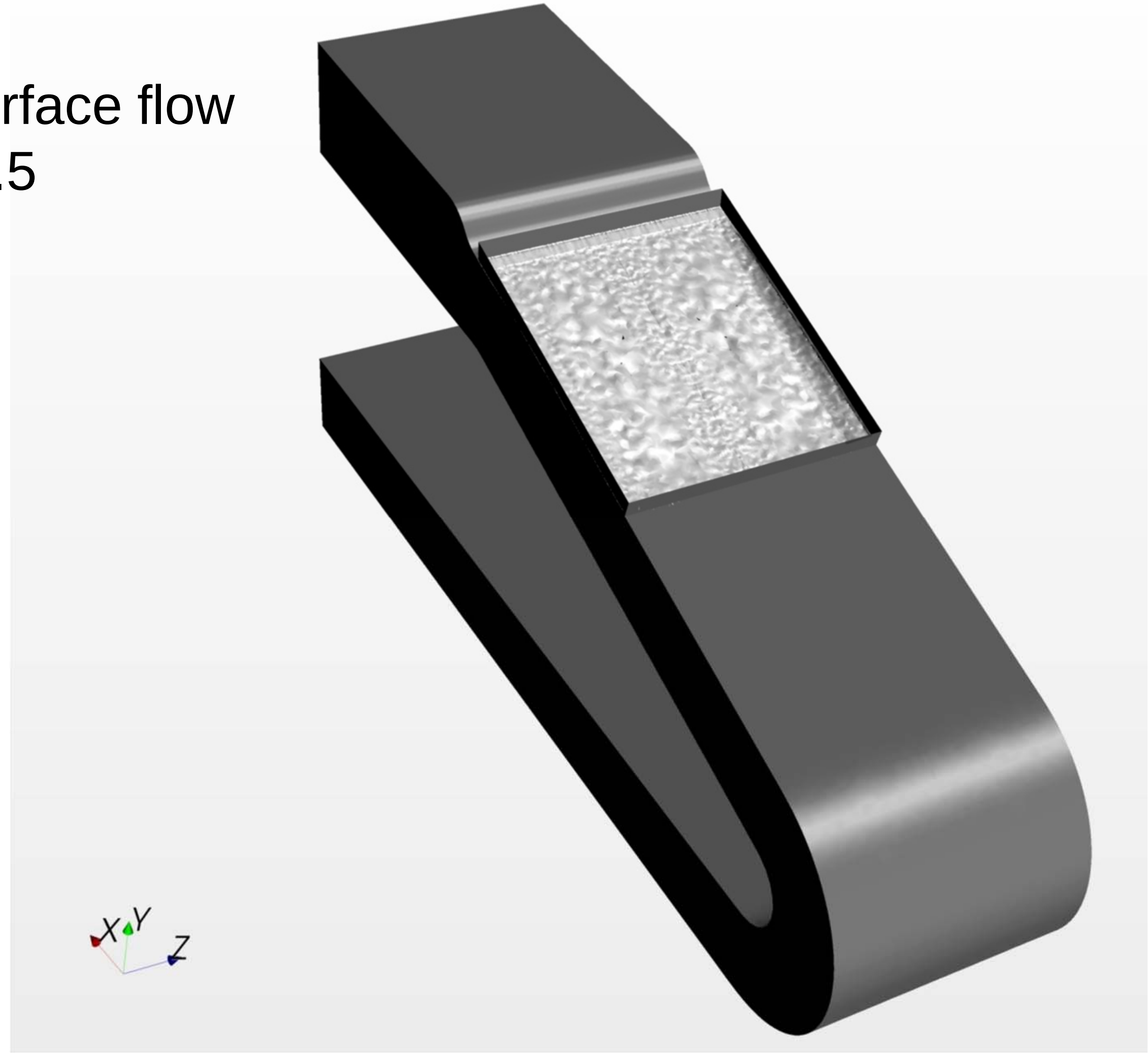


V=2m/s



Free surface

Instantaneous free-surface flow determined by VOF 0.5



Conclusions: thermohydraulics

- 15-50 m^3/h
- stable supercritical free surface
- nozzle design prevents cavitation
- channel walls stay at low temperature
- acceptable maximum temperature

PRO – CONS of WITA (WIndowlessTArget)

- long life system +
- modularity (replace just target module) +++
- no beam window, horizontal beam ++
- safety window and containment necessary –
- safety due to lower than ambient pressure inside containment ++
- removal of LBE vapor with “cold” traps (beam guide at 200° C) + –
- no flow guides needed for flow conditioning (low pressure drop) +
- low thermal and mechanical loads of walls ++
- target geometry is quiet complex –
- moderator can be located at optimal positions++
- relative large LBE inventory of pool, but very long operation –,++
- flexibility of pool geometry +
- dispersion of shock wave by obstacles, inclination (& bubbles) +
- possibility to install window using identical design +
- upgrade-ability to 15 MW ++