CFD Simulation of Target Cell and Gas Supply System

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April 8th, 2026

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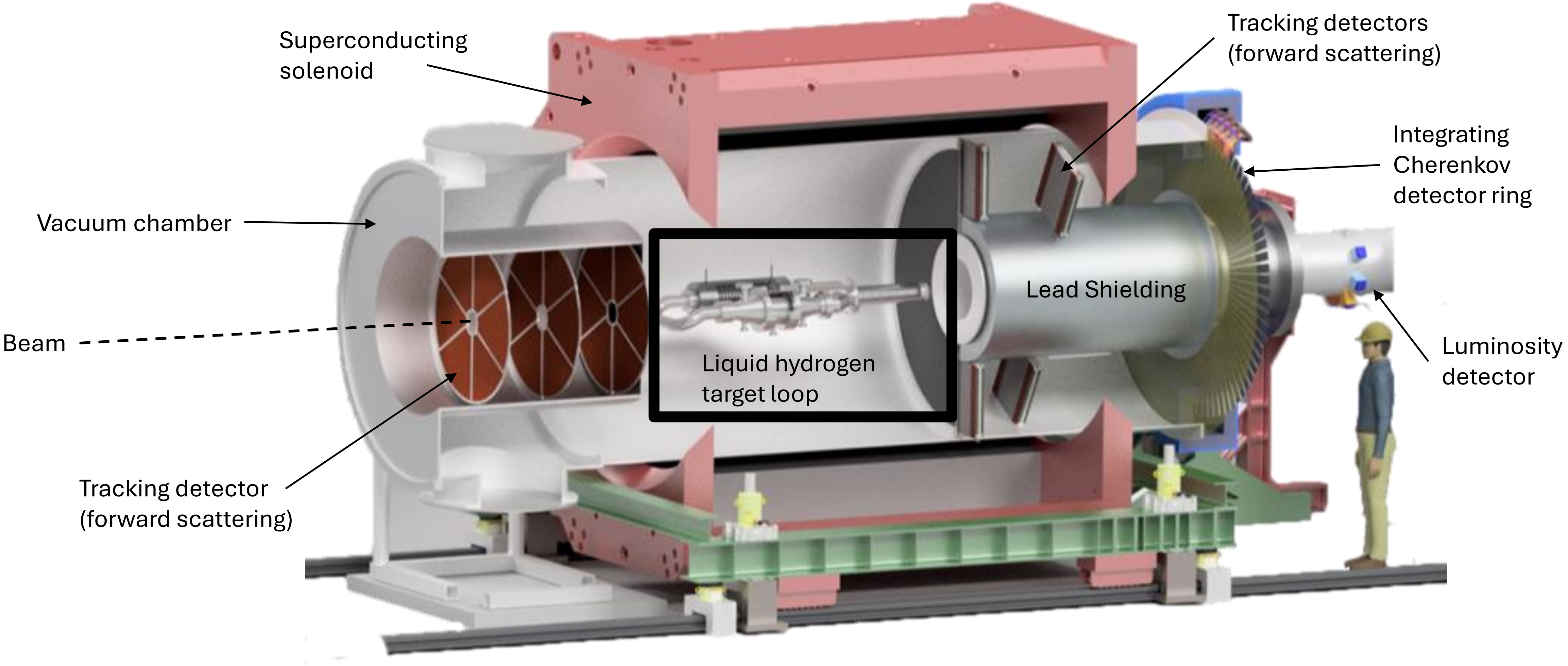
Experimental setup



The liquid hydrogen target loop

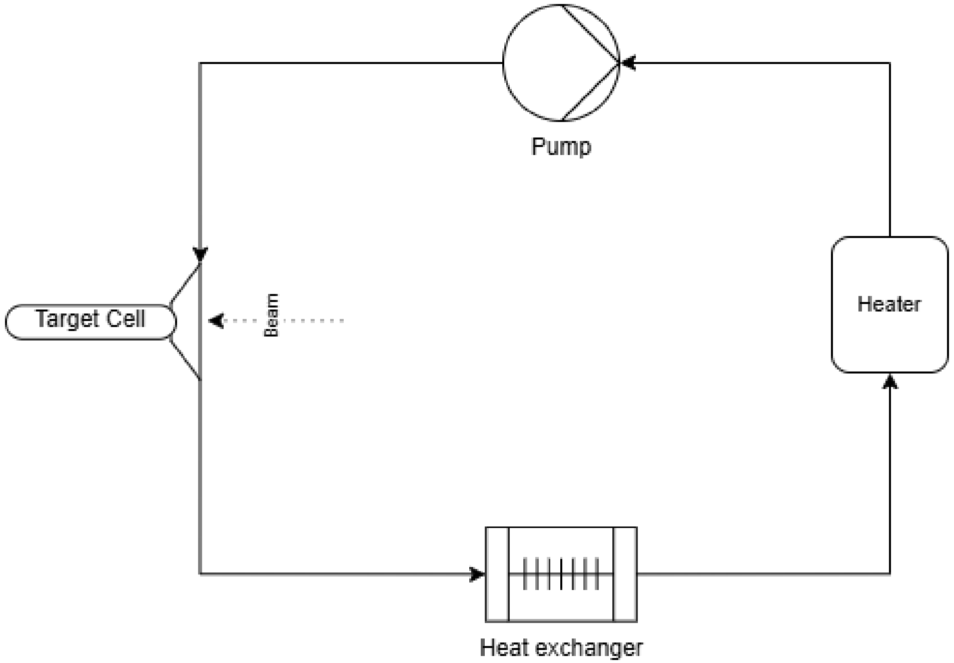


Fig: Loop flow diagram

Design requirements

- accommodate full azimuthal angle
- polar angle range between 25º to 45º
- 3135W of heat deposited in target cell by the beam
- Systematic effects affecting A^{PV} uncertainty –
  - Density reduction, $\Delta\rho/\rho$ – A static decrease in target density caused by beam-induced heating within the illuminated volume.
  - Density fluctuation, $\delta\rho/\rho$ – Time-dependent variations in density occurring over the beam's helicity periods.

Target cell specifications

Pressure/temperature	2.4bar / 20K
Cell length	60cm
Mass flow rate	< 2kg/s
lH2 pump head	< 0.1bar
Beam area on target	25mm^2
Heat deposited	3.1kW
Target thickness	4.3g/cm^2
lH2 $\Delta\rho/\rho$	<2%
lH2 $\delta\rho/\rho$ at 1 kHz	<10ppm

Table: All design parameters for target cell

Target cell

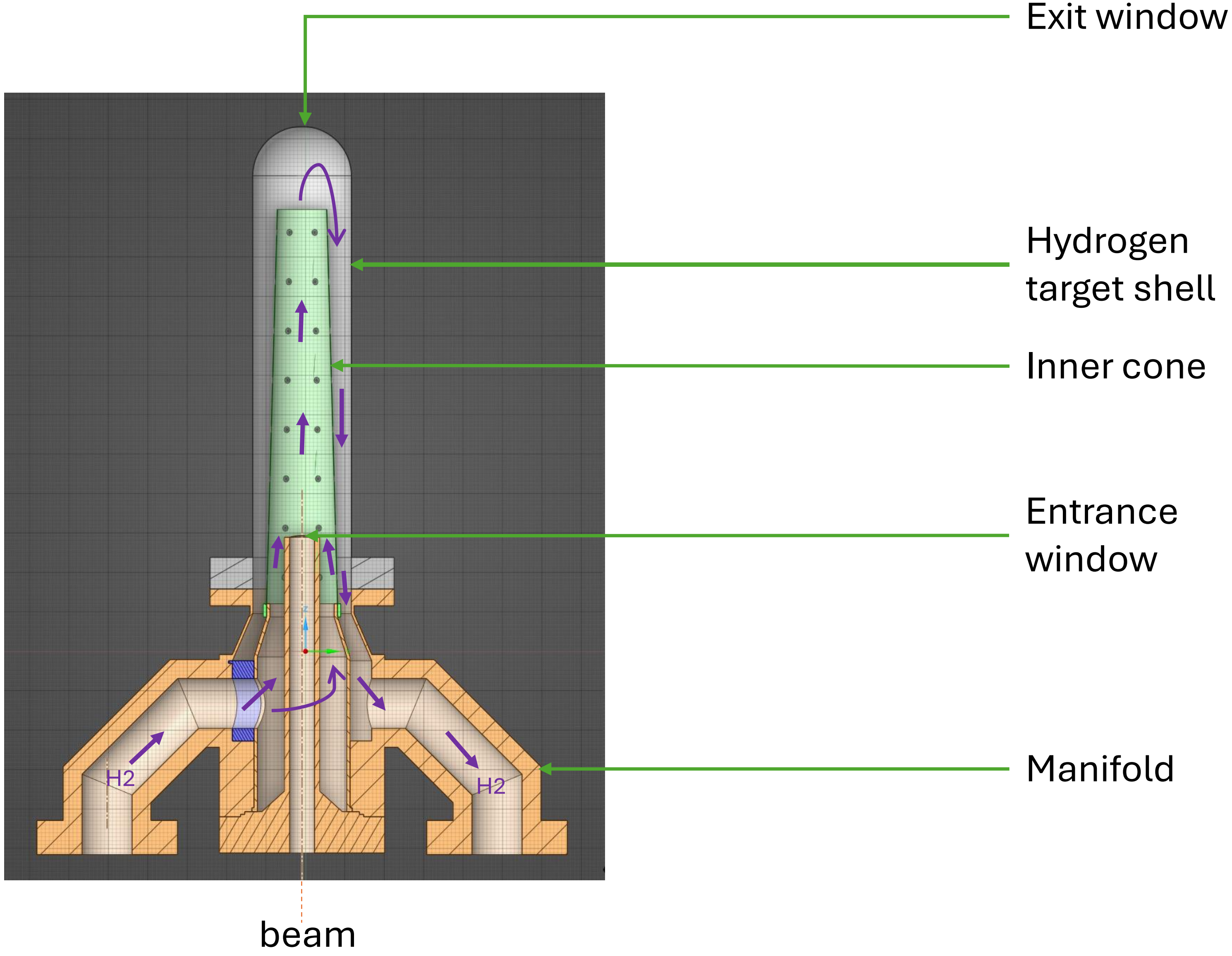


Fig: Target cell with manifold

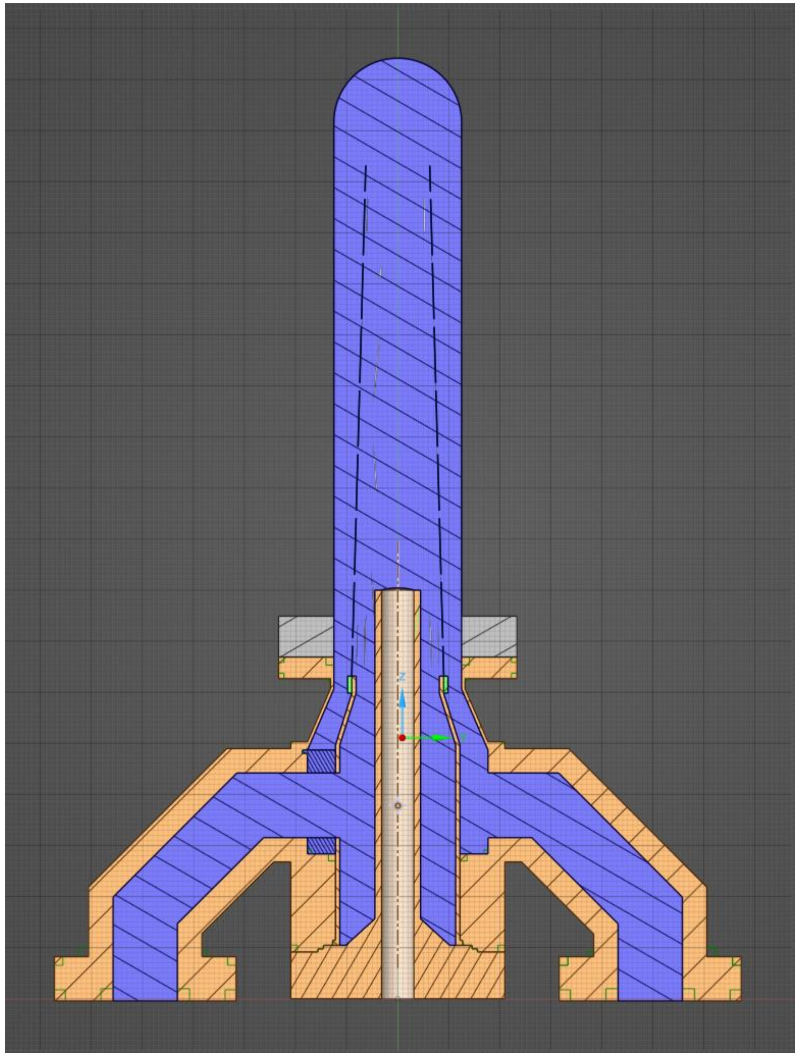


Fig: Target cell
During operation

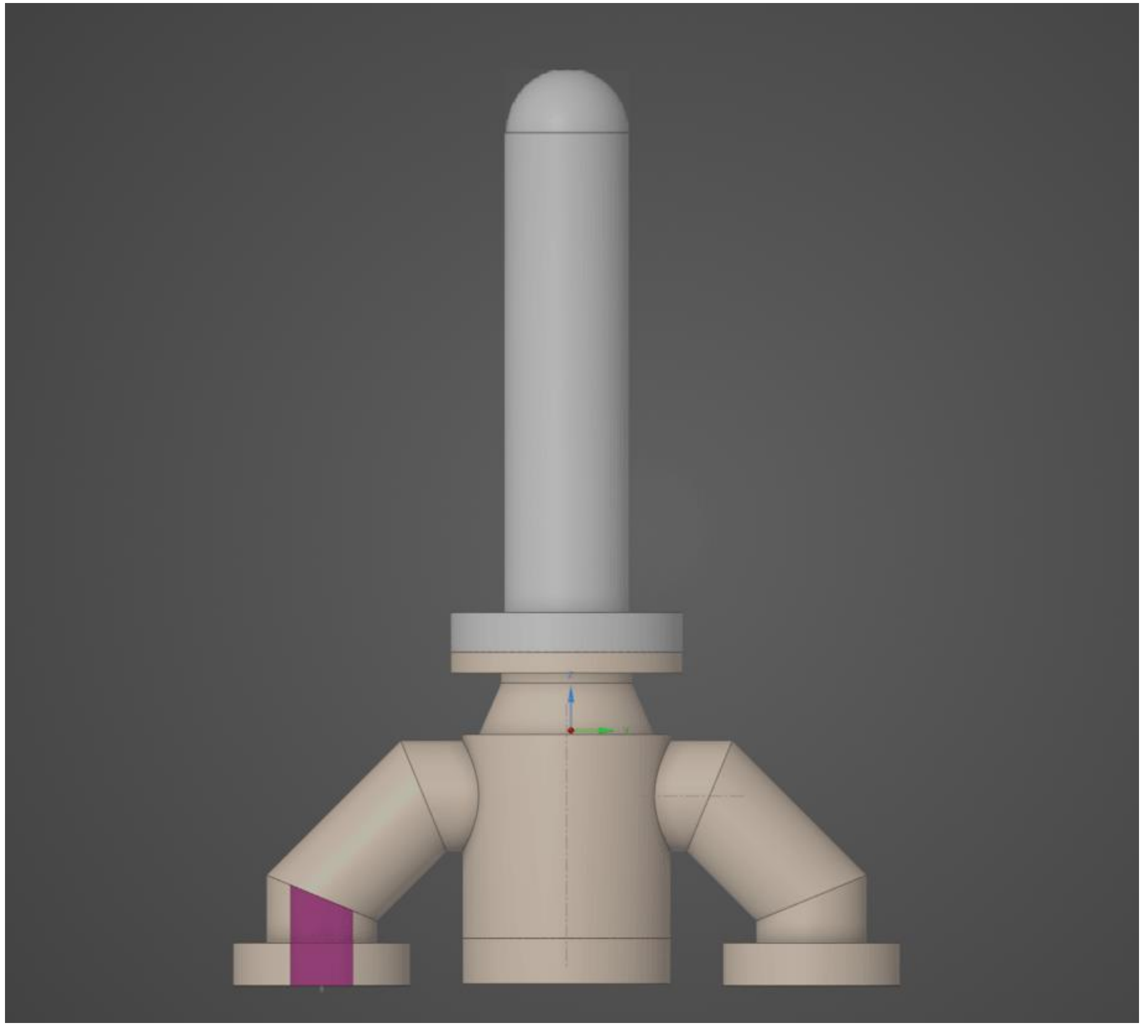
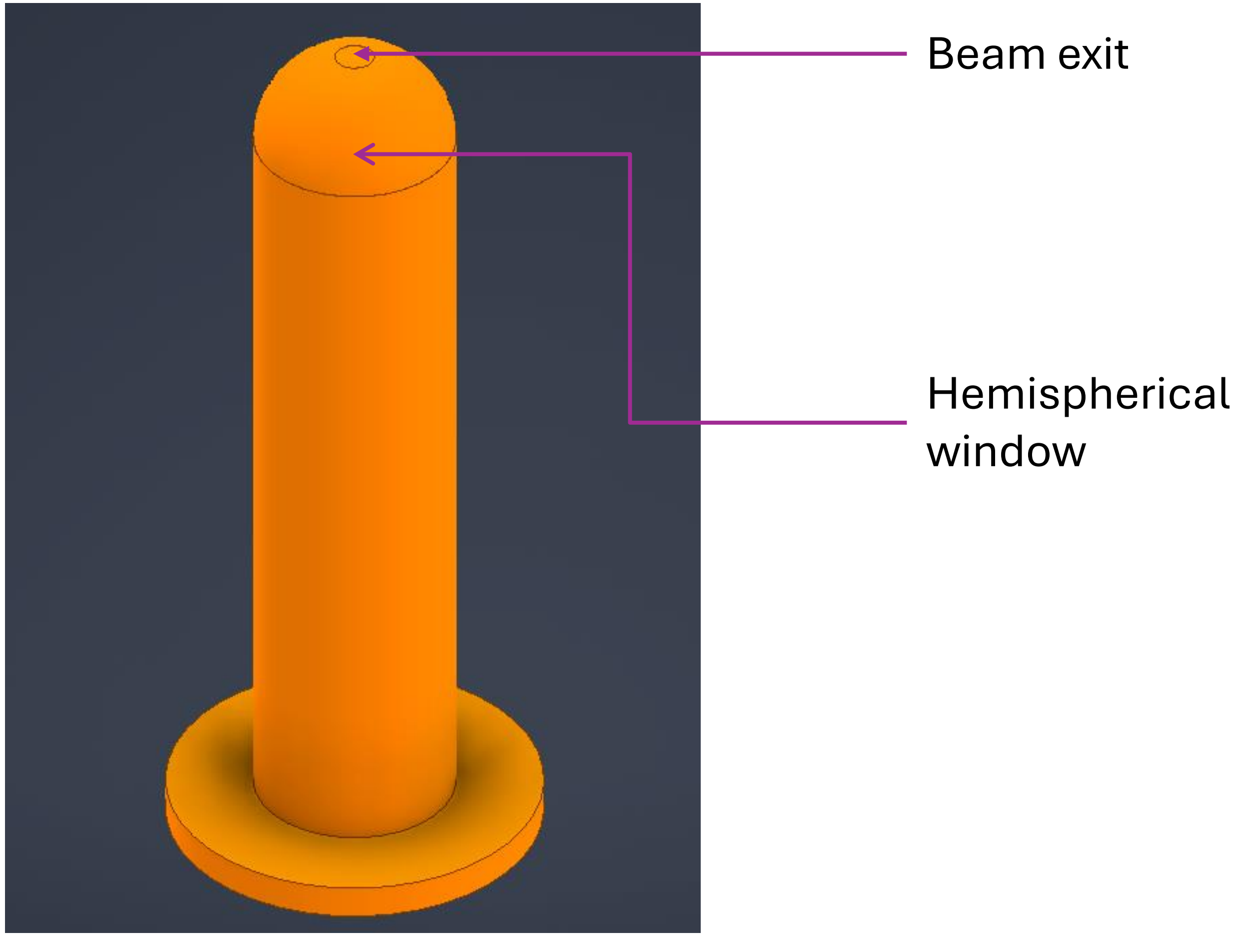
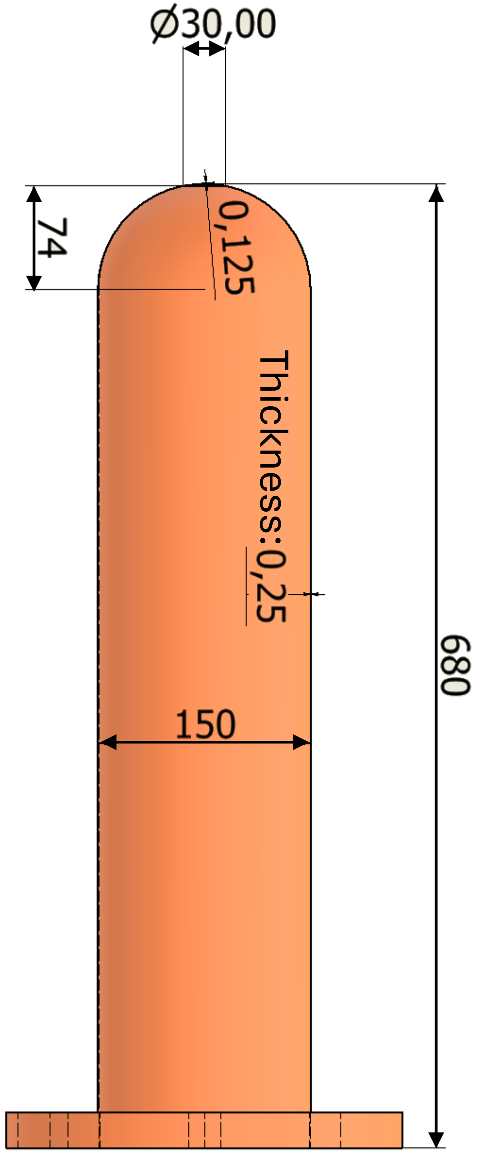


Fig: Target cell
Animation of the liquid hydrogen flow

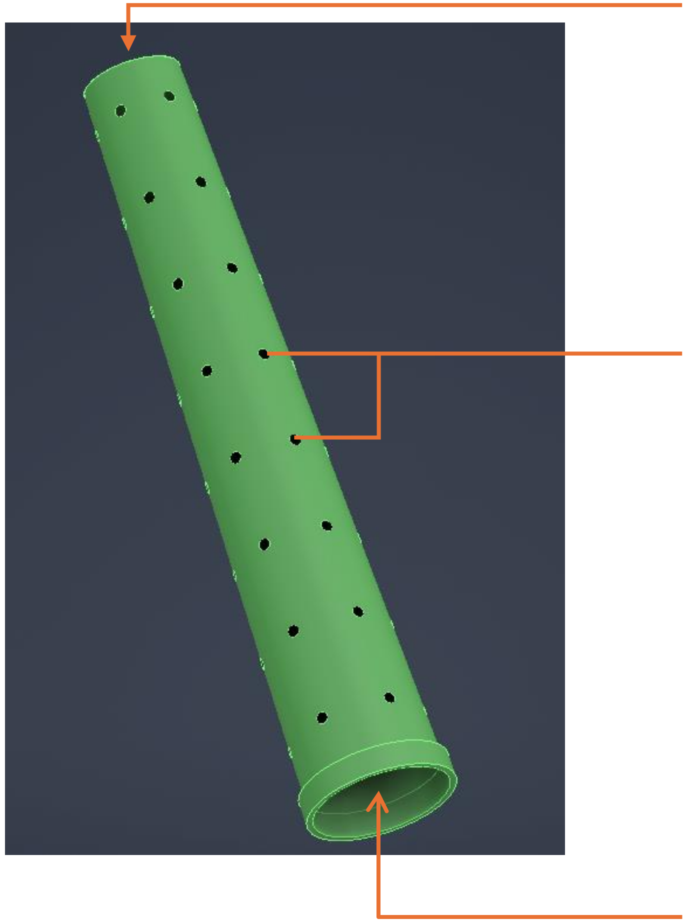
Hydrogen target shell

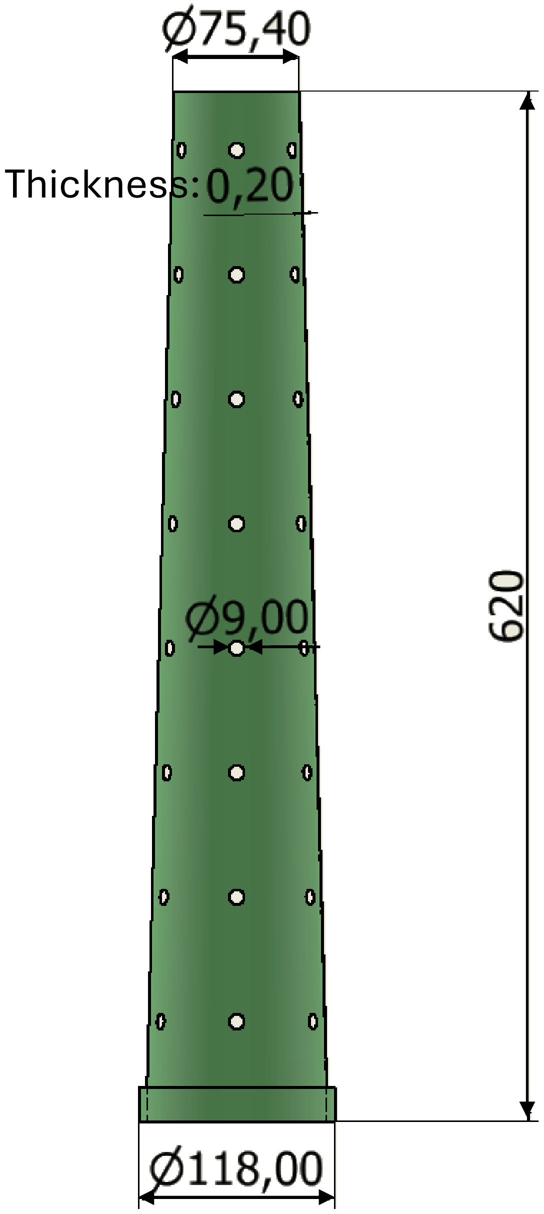




(in mm)

Inner Cone/ Conical Flow Diverter





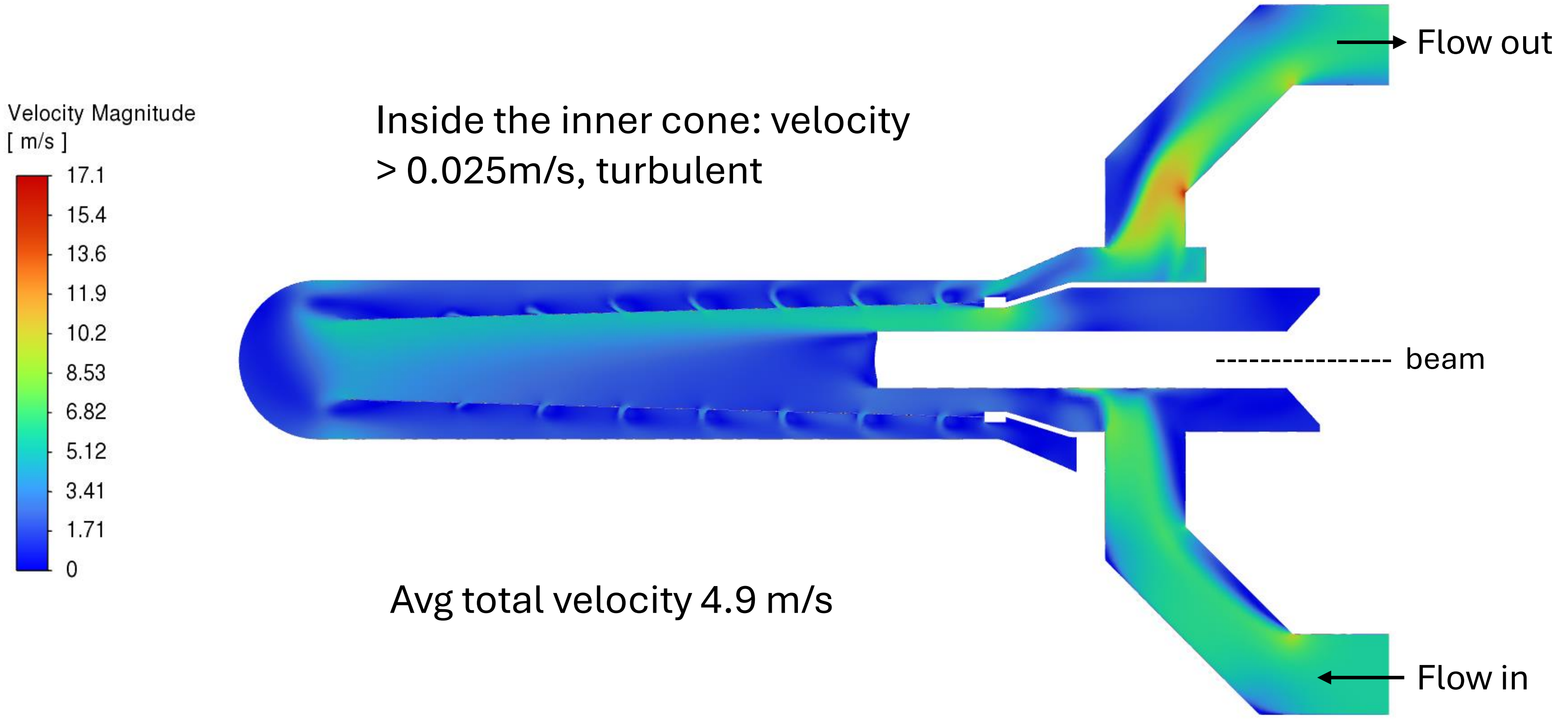
(in mm)

CFD simulation of target cell

- Target cell with its manifold
- Steady state simulation
- 20K liquid H2
- Mass flow 1.9 kg/s
- Turbulence using K-epsilon viscous model
- 5x5mm rastered beam depositing 3.1kW

Velocity contour

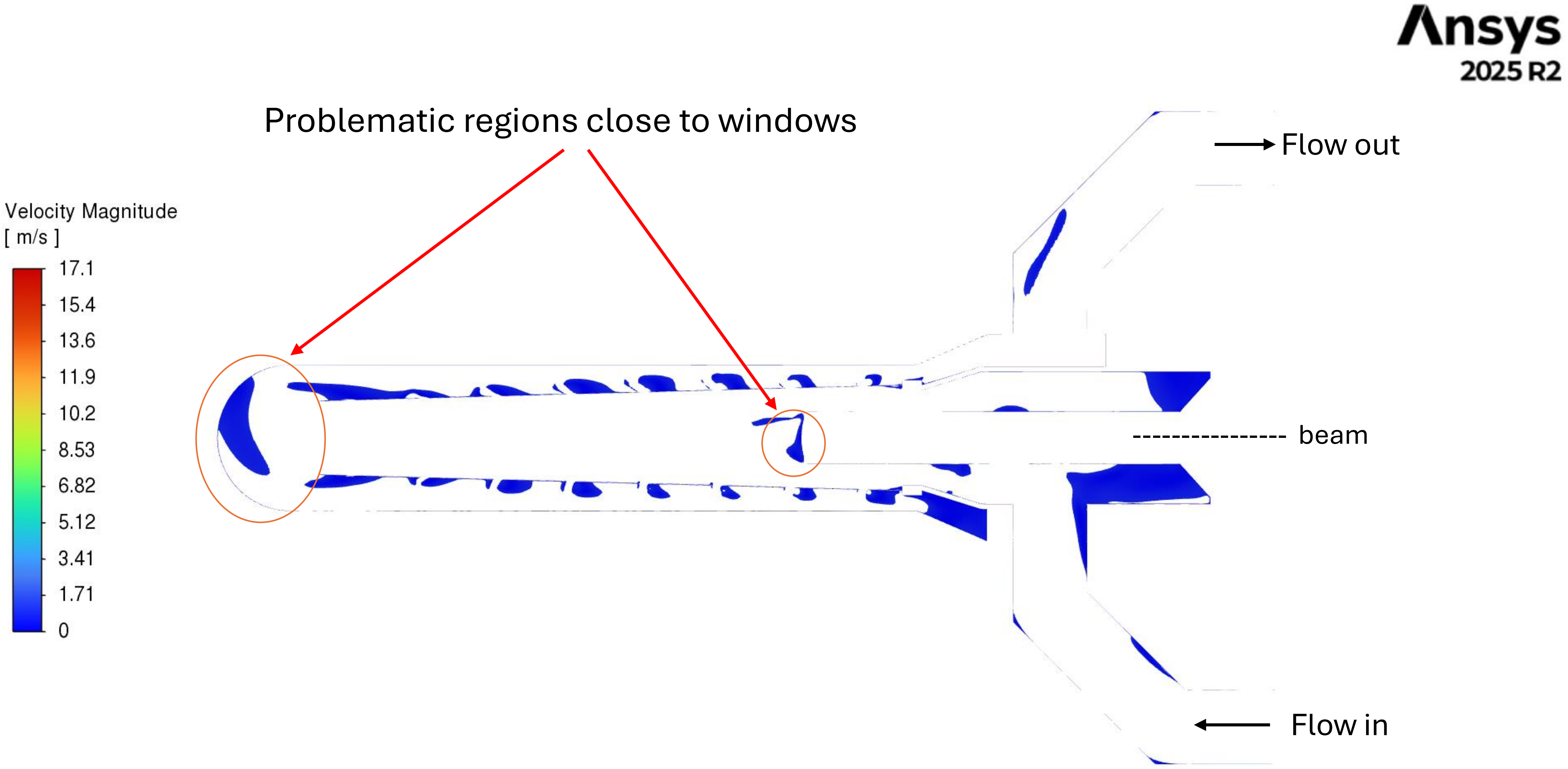
Ansys
2025 R2



Inside the inner cone: velocity > 0.025m/s, turbulent

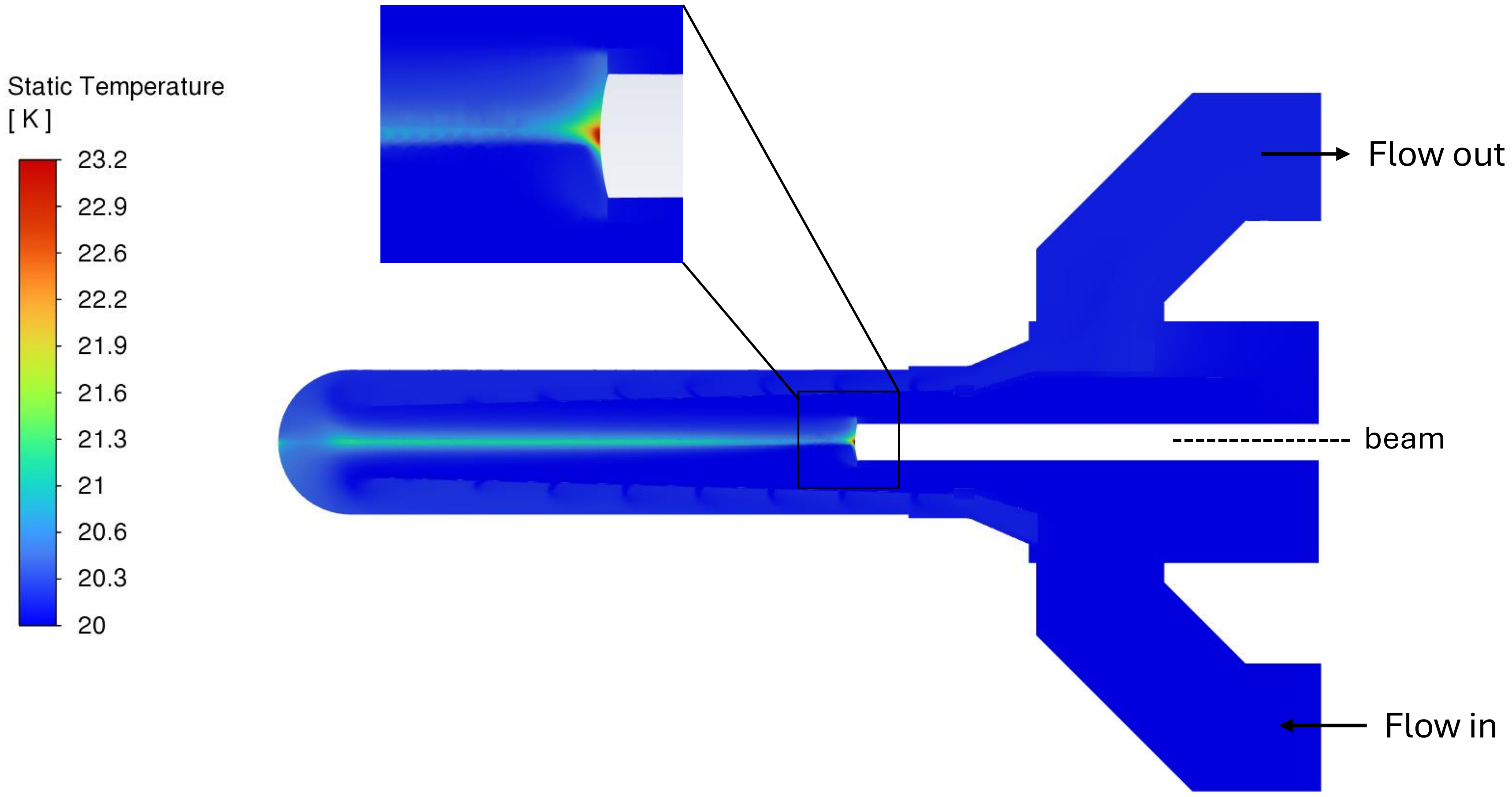
Avg total velocity 4.9 m/s

Low velocity regions with < 1m/s



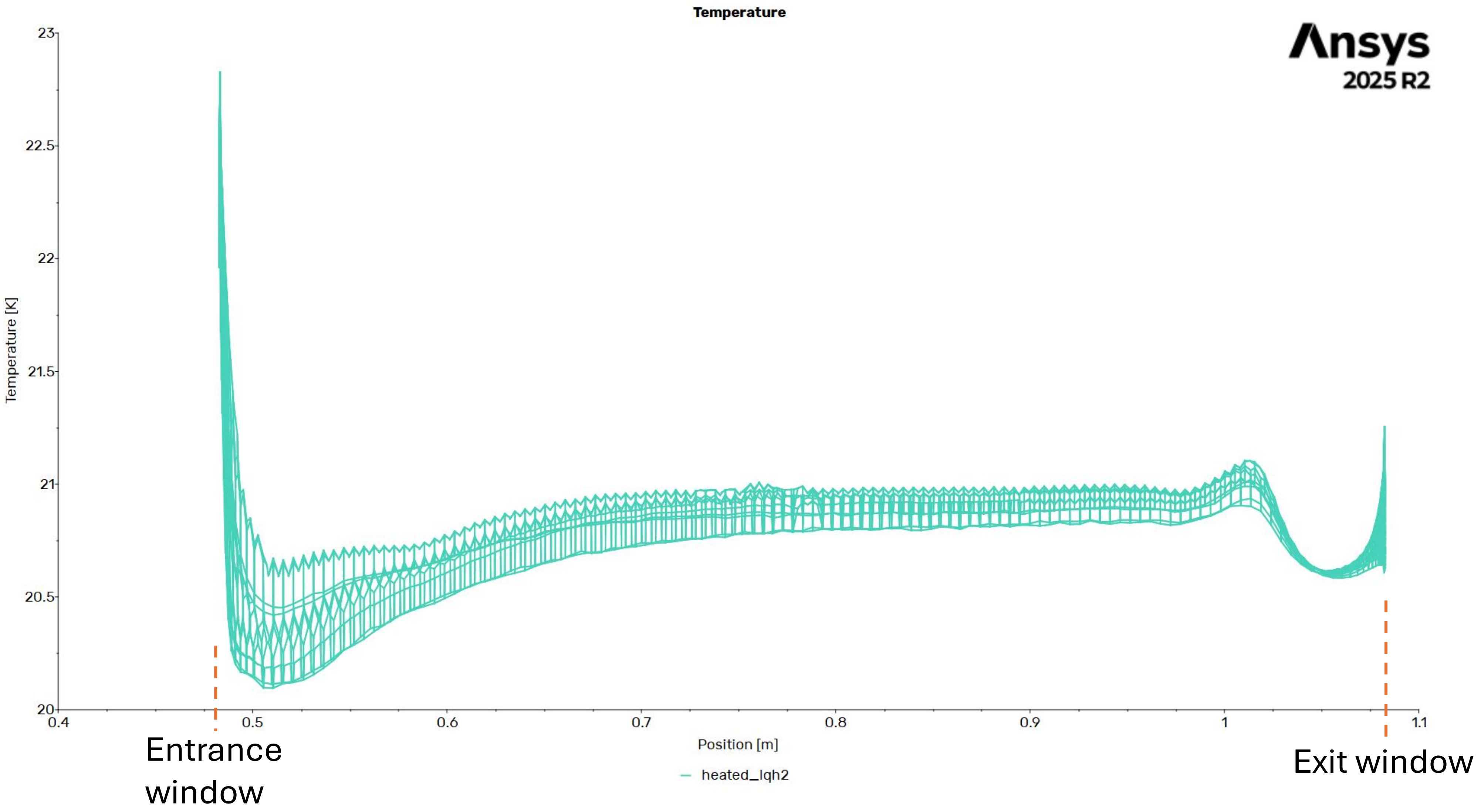
Temperature contour

Ansys 2025 R2



lq H2 is expected to boil at 23.2K

Temperature variation at the beam



Gas supply and safety

Parts

- Active gas cabinet
- Gas Panel
- Supply lines
- Exhaust lines

Operation

- Commencing – Vacuum in supply lines, inerting the exhaust lines, hydrogen supplied to the loop and cooled
- During the experiment – lq H2 in the loop, exhaust lines in place
- After the experiment – lq H2 slowly boils and returns to tank via check valve

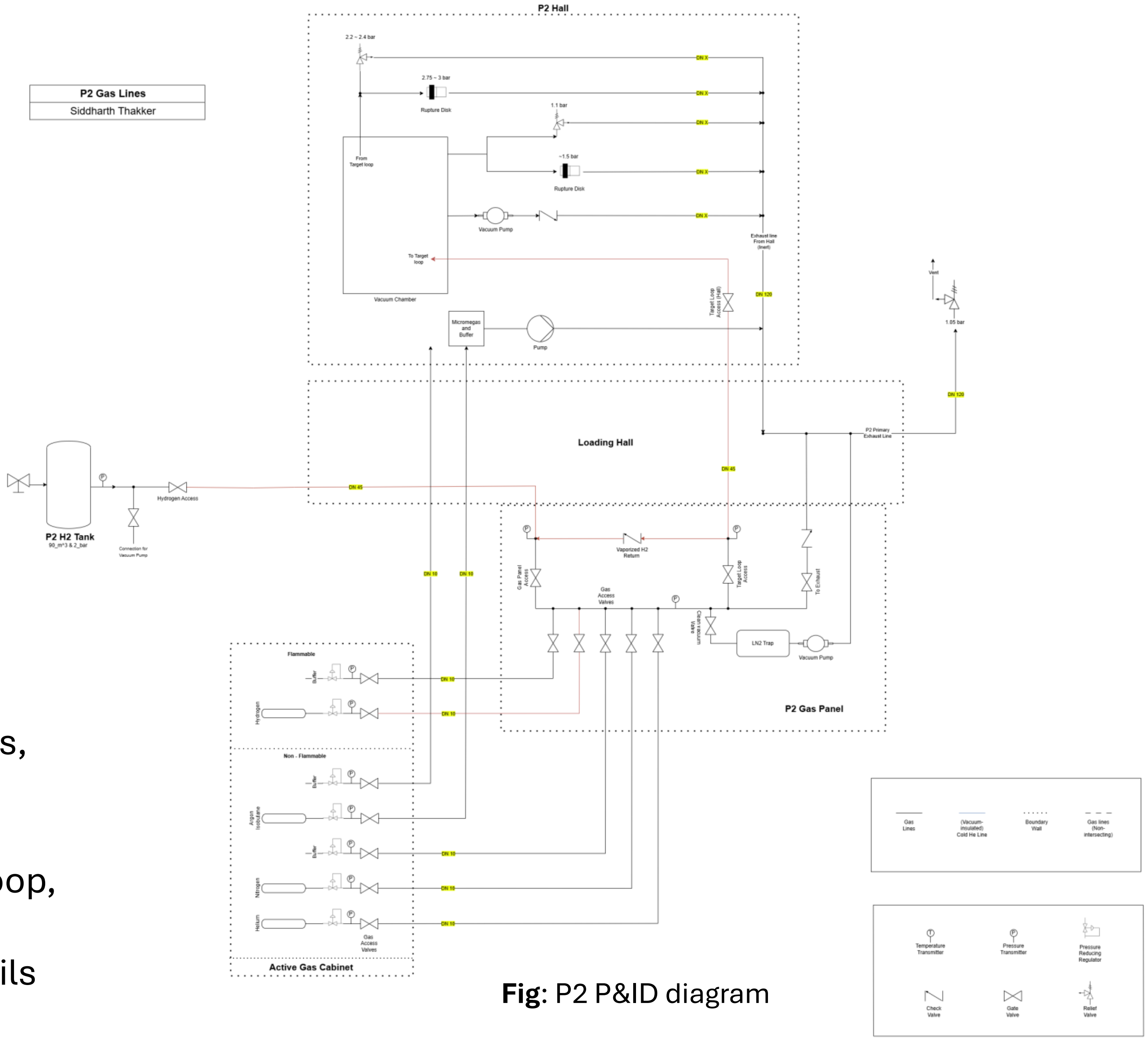
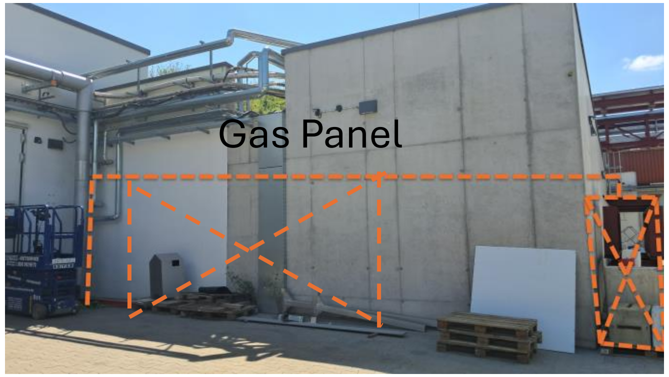


Fig: P2 P&ID diagram

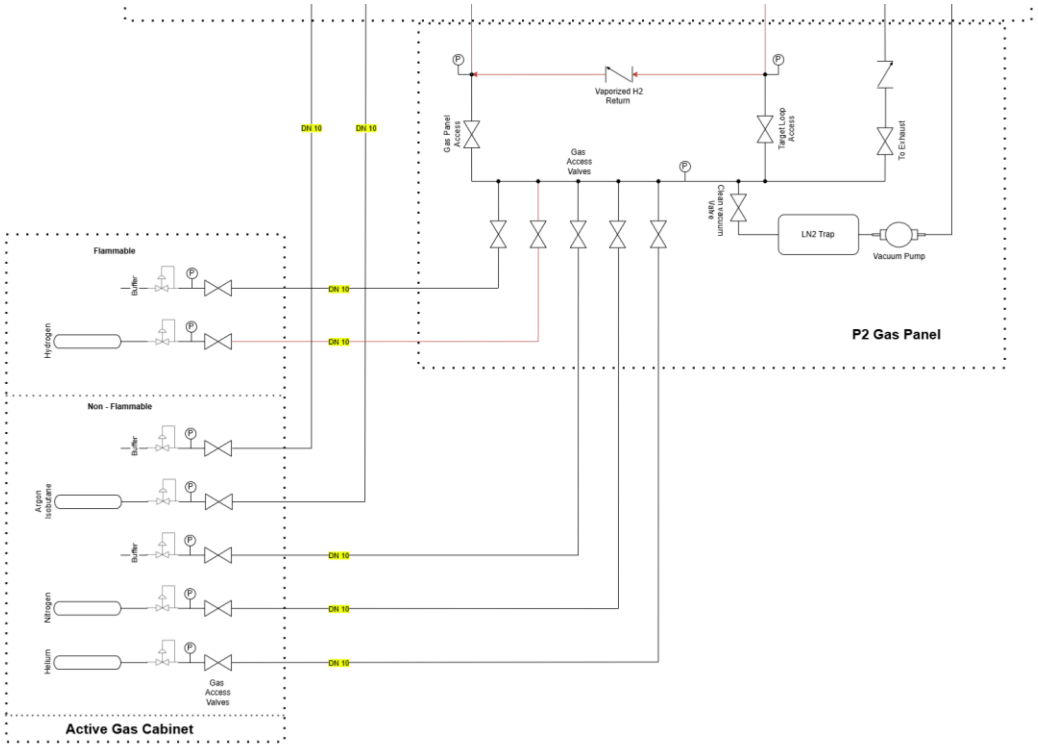
Active Gas Cabinet: Bottle connections of

- Hydrogen
- Helium – to test leaks
- Nitrogen – to provide an inert environment in the exhaust line
- Argon isobutane



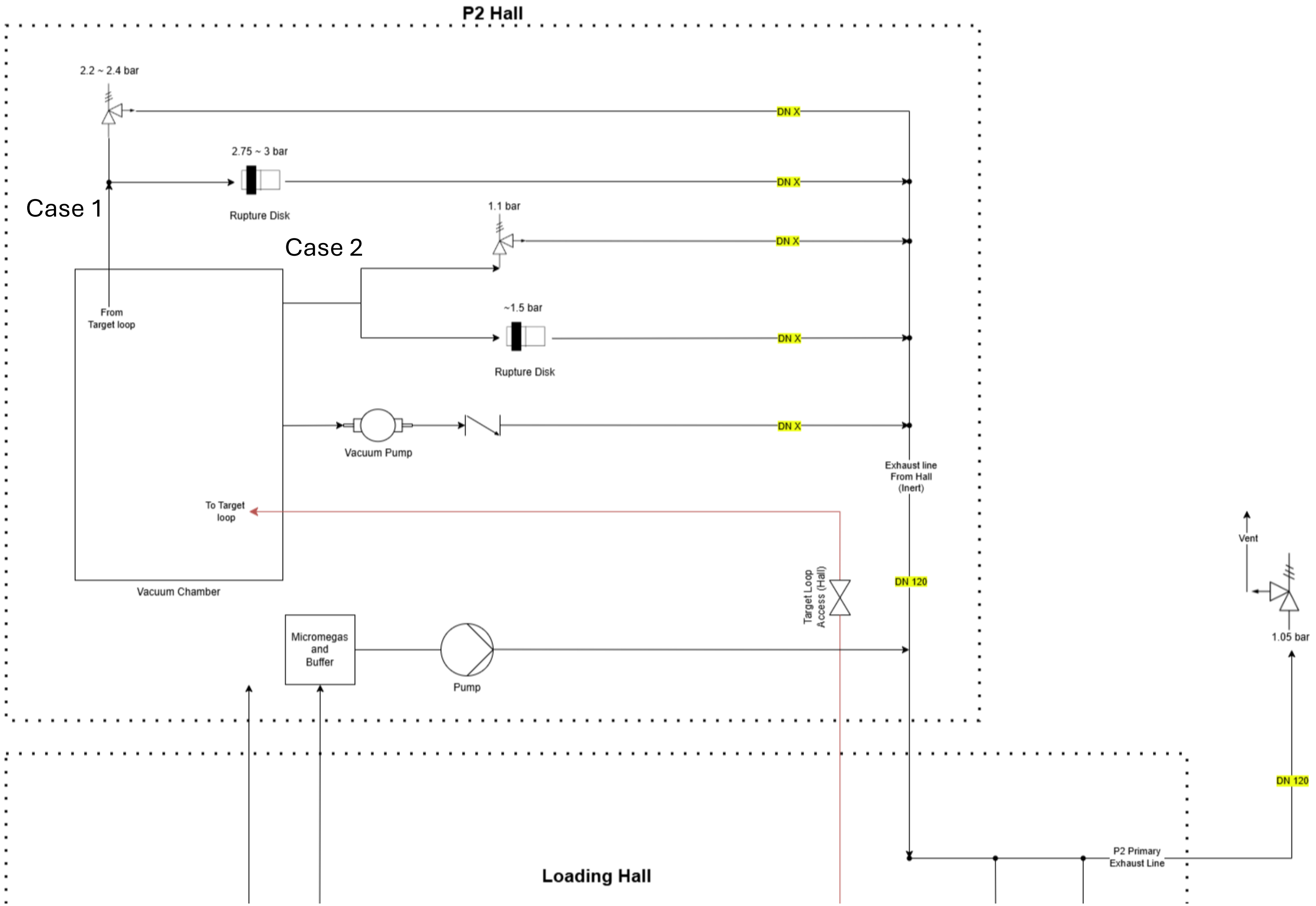
Gas Panel

- The gas panel is the main control station
- Connections to/from AGC, hydrogen tank, Target loop and exhaust lines
- Vacuum pump venting out to exhaust lines through LN2 trap



Exhaust and emergency relief

- A primary exhaust line, where all other lines connect
- Exhaust for vacuum chamber
- Emergency case 1 – high pressure in the gas lines
- Emergency case 2 – Explosion of the target cell



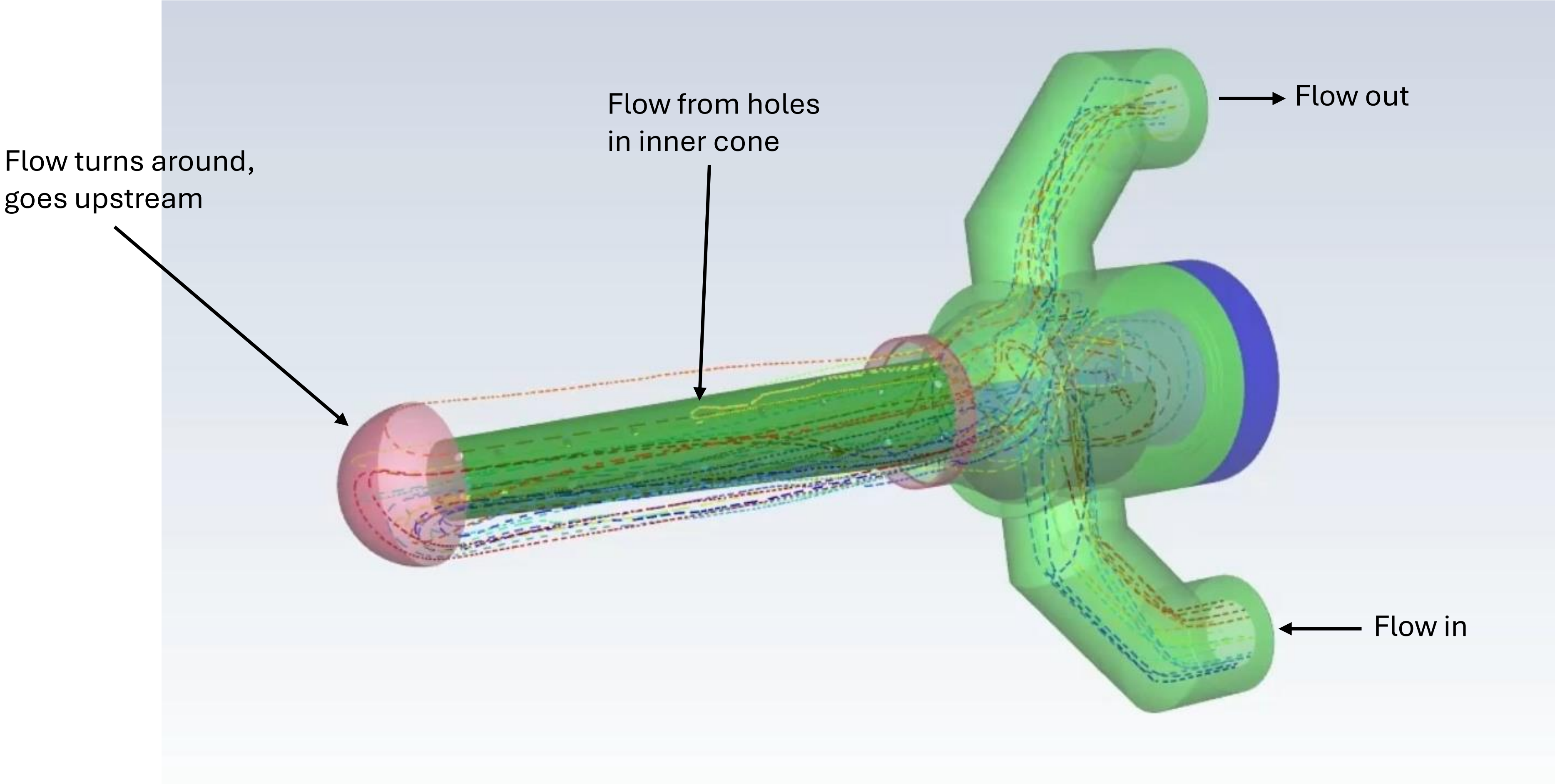
Summary and next steps

- Lq H2 target cell design
- CFD simulation of the target cell
- Problem identification in the geometry
- Gas supply and safety
- Next steps
  - Advancing simulation with added multiphase and transient state
  - Extraction of required values of density fluctuation and reduction
  - Modification in the geometry to satisfy all requirements

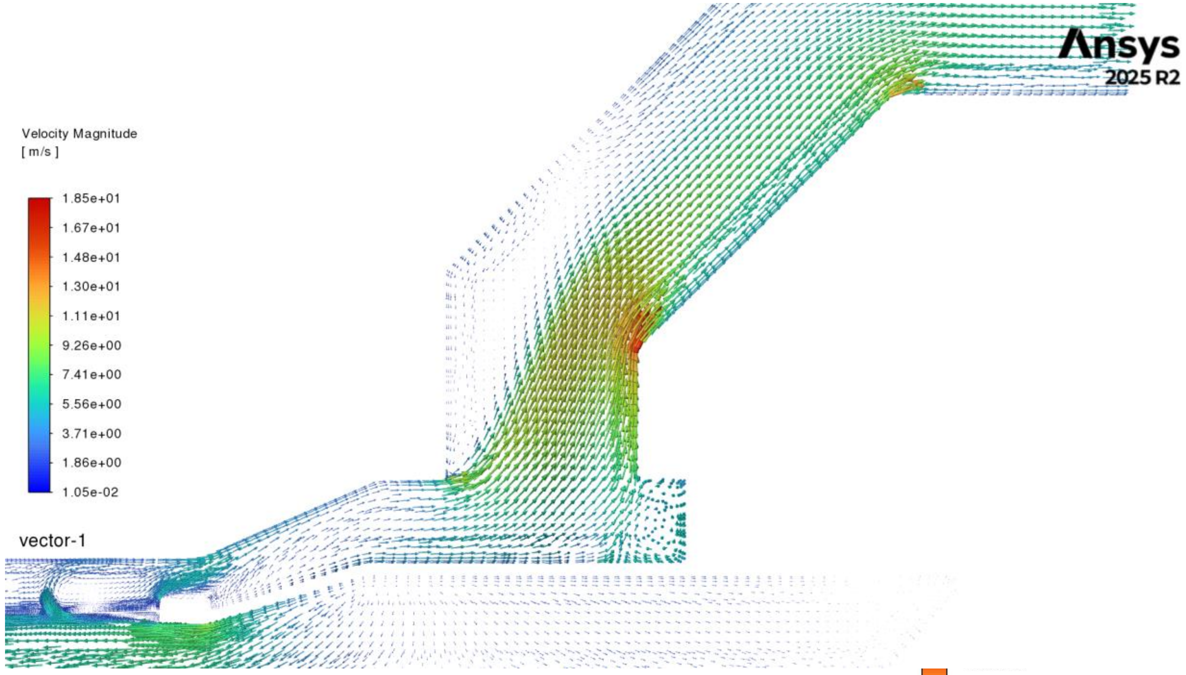
Thank you

Extra slides

Pathlines



Flow turns around,
goes upstream
Flow from holes
in inner cone
Flow out
Flow in


Velocity Magnitude
[m/s]
1.85e+01
1.67e+01
1.48e+01
1.30e+01
1.11e+01
9.26e+00
7.41e+00
5.56e+00
3.71e+00
1.86e+00
1.05e-02
vector-1
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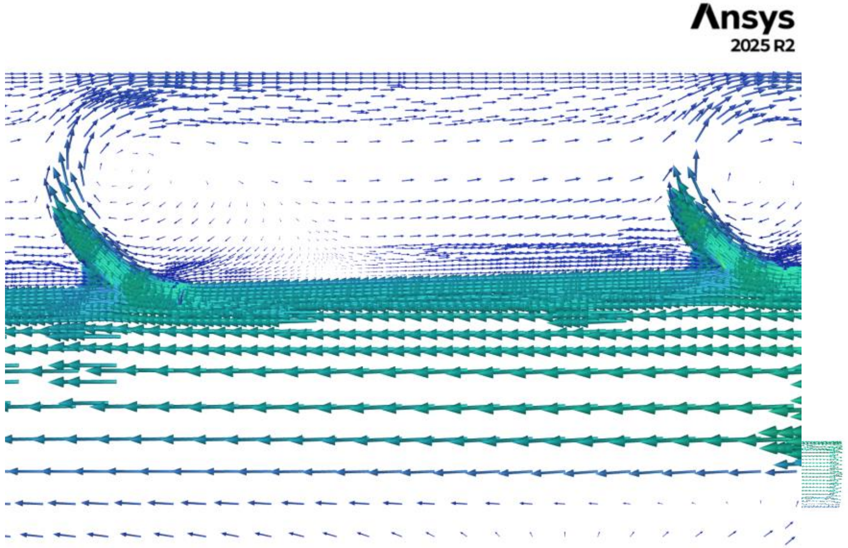
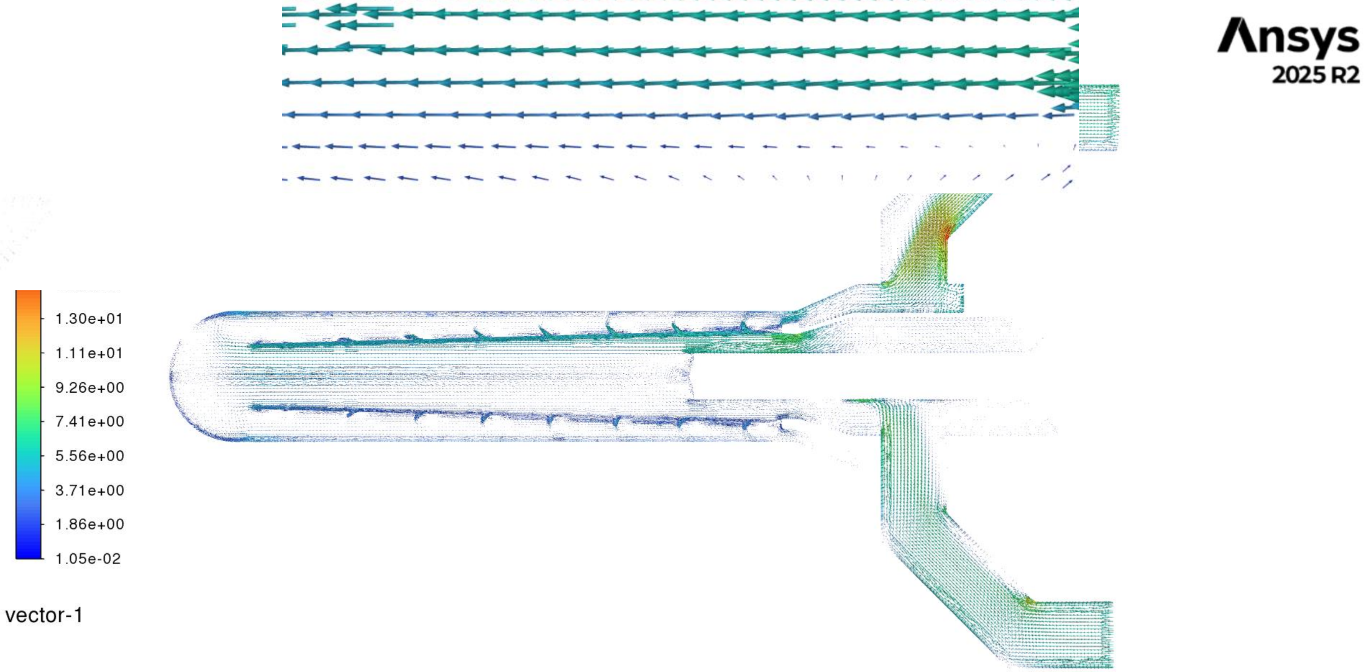

Ansys
2025 R2


Ansys
2025 R2
1.30e+01
1.11e+01
9.26e+00
7.41e+00
5.56e+00
3.71e+00
1.86e+00
1.05e-02
vector-1


Absolute Pressu
-re
[bar]
2.46
2.45
2.43
2.41
2.39
2.37
2.35
2.33
2.32
2.3
2.28
contour-1
Ansys
2025 R2

Heat exchanger

- Used to remove the heat load from the target loop using He gas coolant
- Will be modeled after the Qweak Counter flow heat exchanger with copper finned tube
- The mass flow needed can be calculated:

$$\dot{m} = P/\Delta H$$

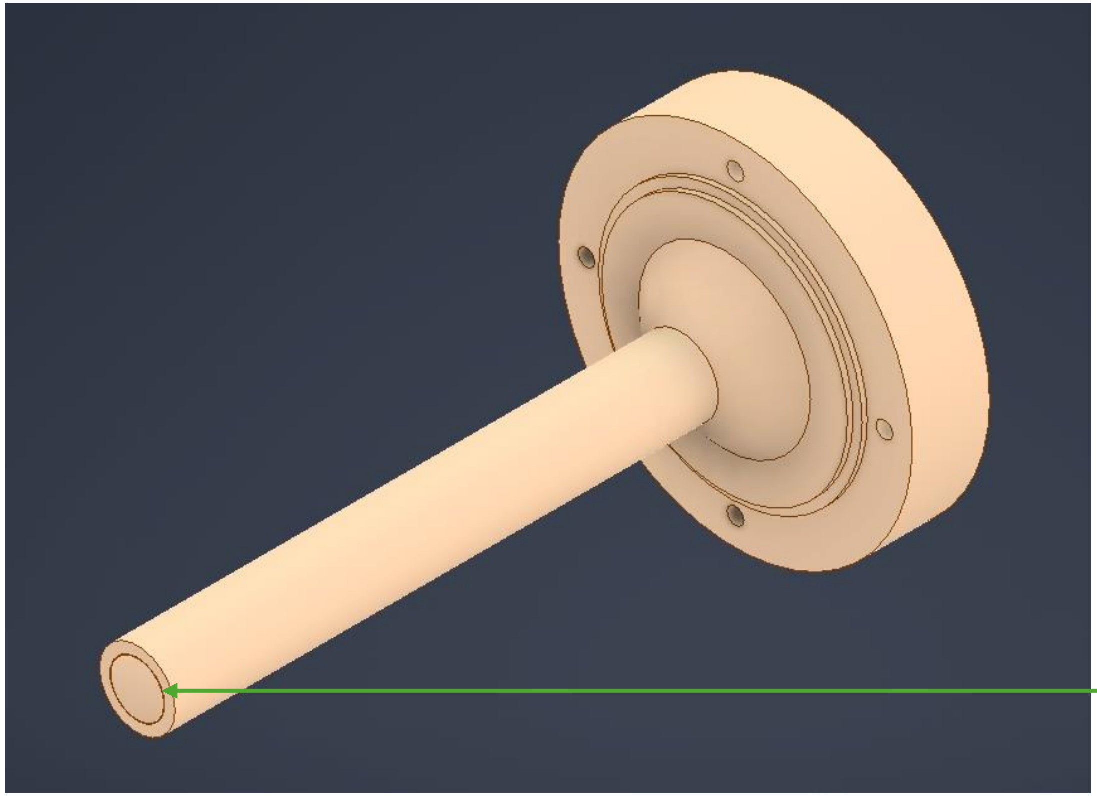
P is the total cooling power
ΔH is the He enthalpy bw He inlet and outlet

- For ex, He inlet – 10 atm and 14K, Outlet – 3 atm 20K, then 101g/s He flow is required
- The HX design will be assessed with CFD

High power heater (HPH)

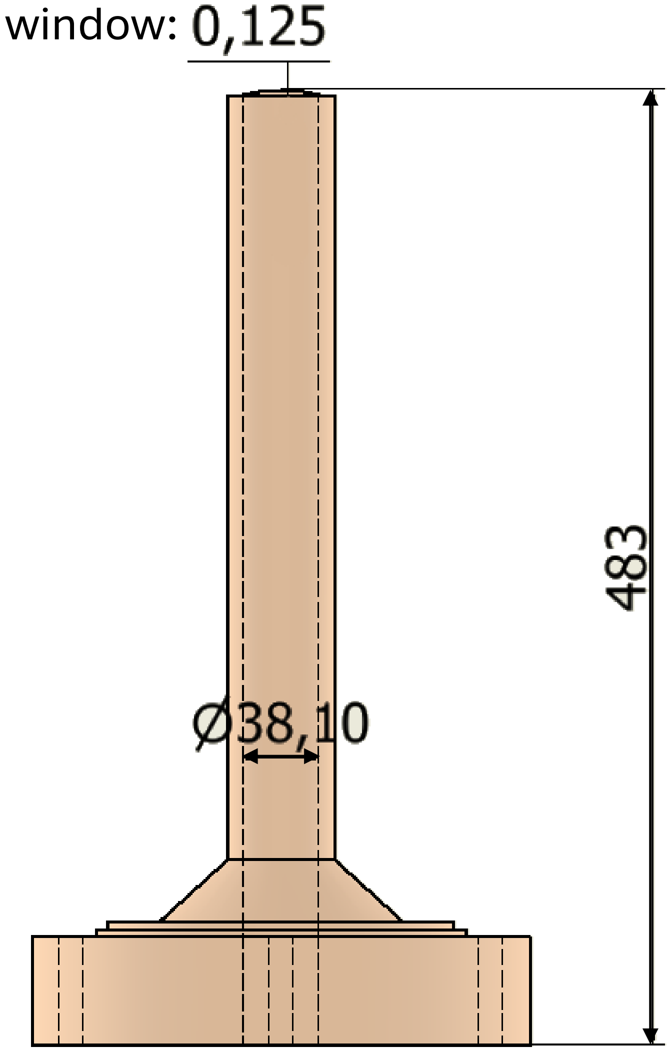
- Used to mitigate lH2 density variations and relaxation time when the beam trips
- HPH works in a feedback loop with the read-back of a temperature sensor in the Lq H2
- Ensures that the target is operated at constant heat load and regulate the temperature
- The qweak like heater is designed to have eight layers of Nichrome wire wrapped around crossed G10 boards.

Beam guide



Entrance window

Thickness at entrance window:



(in mm)