Target Flow Rate Simulations

- LH2-only cell flow and density loss
- LH2+He mix predictions
- Unrastered beam incident
- Summary

Silviu Covrig Dusa, Halls A/C

NPS Collaboration Meeting

17 Jul 2024

NPS Target Data

- Tables 4.1 and 4.2 from Hall C Target Configuration Sep 2023 – TGT-RPT-23-001.Rev:0 (Dave Meekins) https://logbooks.jlab.org/entry/4172378
- Beam entrance windows are about 0.13 mm, beam exit windows are about 0.185 mm (~0.17%RL)
- The Al dummies are about 0.7%RL (each)

Target	Entrance (mm)	Exit (mm)	Length (mm)	Material
Loop 1 (10 cm)	0.130 ± 0.012	0.188 ± 0.013 Tip 0.184 ± 0.017 wall	100 ± 0.26	AL 7075
Loop 2 (10 cm)	0.150 ± 0.011	0.191± 0.019 Tip 0.219 ± 0.018 wall	100 ± 0.26	AL 7075
Loop 3 (10 cm)	0.116 ± 0.0086	0.184 ± 0.021 Tip 0.14 ± 0.023 wall	100 ± 0.26	AL 7075

Target	Thickness Total (g/cm^2)	Material
10 cm Dummy Upstream	0.1703 ± 0.0002	Al 7075
10 cm Dummy Downstream	0.1677 ± 0.0002	Al 7075

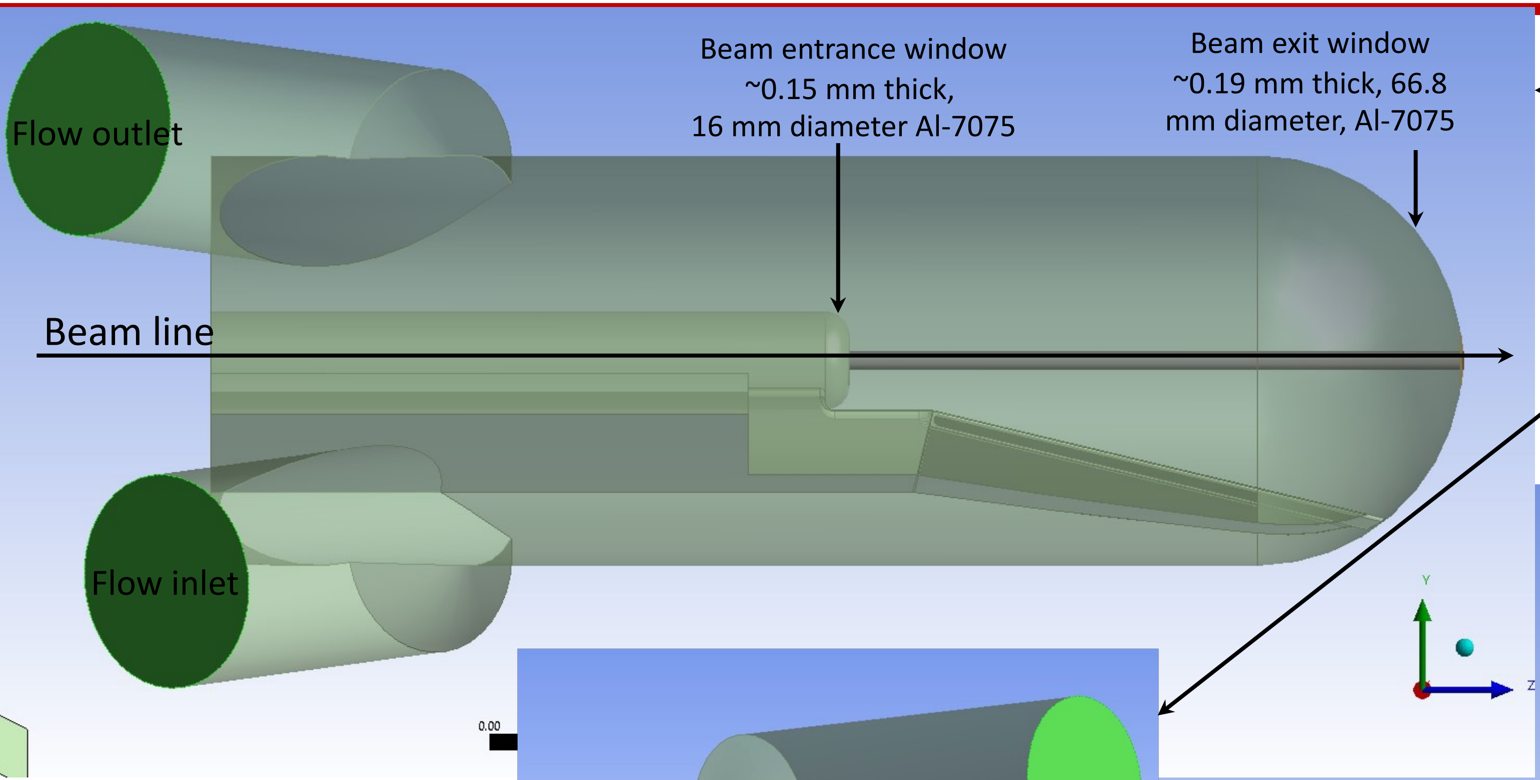
- Table from Jlab Alignment and Survey Group: C2085 (Chris Gould) https://logbooks.jlab.org/entry/4175297 →
- The misalignment in both x and y is less than 0.5 mm

Below are the results of the Hall C target survey carried out 5/12/23. Coordinates are beam following and relative to the ideal Hall C target center. A negative X is beam right, a positive Y is up and a negative Z is upstream. Angles are given in right hand rule. Values are in mm and degrees.

	X	Y	Z
CARBON_HOLE	-0.48	-0.20	
LOOP1	-0.24	0.31	-103.57
LOOP2	-0.23	0.24	-103.57
LOOP3	-0.45	0.30	-103.57
LOOP2_REP	-0.45	0.19	-103.57

Rx(Pitch)	Ry(Yaw)
90.2007	0.0358

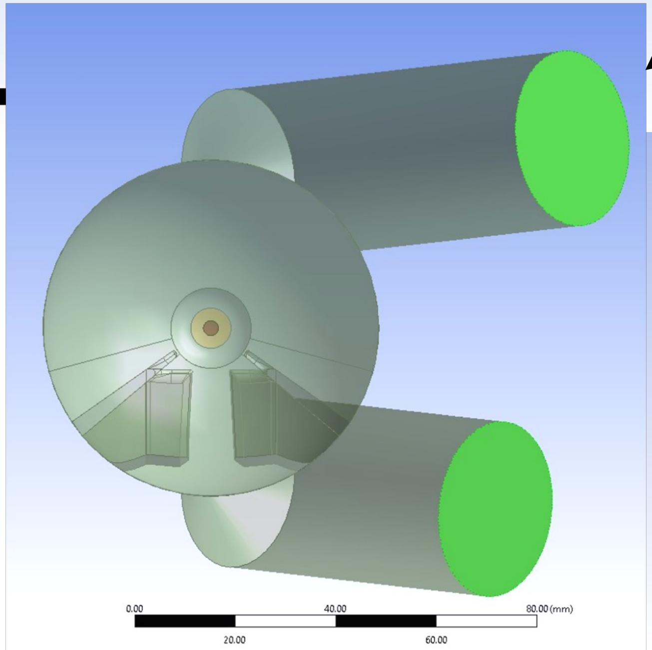
Cell Geometry

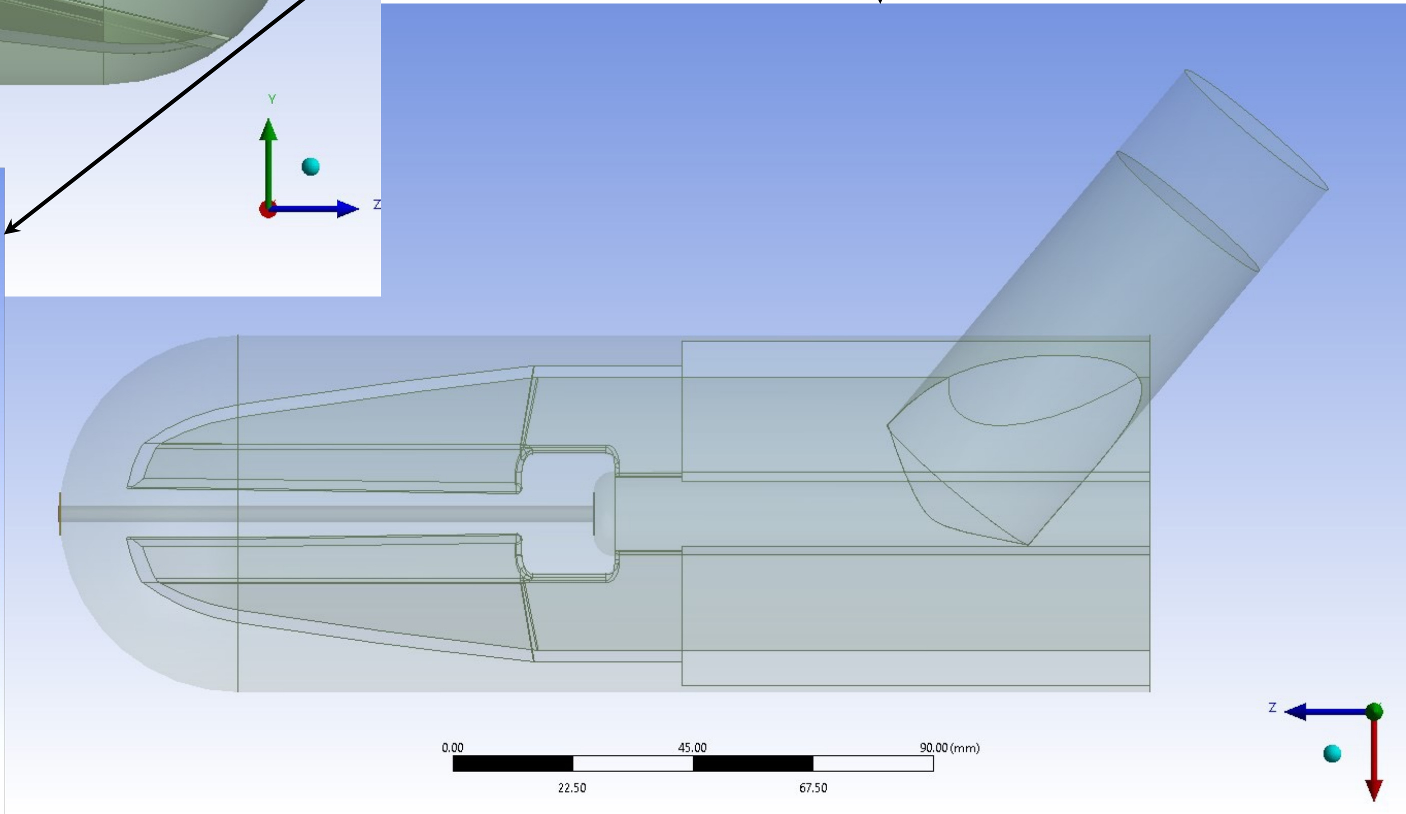


Side view

Beam view

Flow view



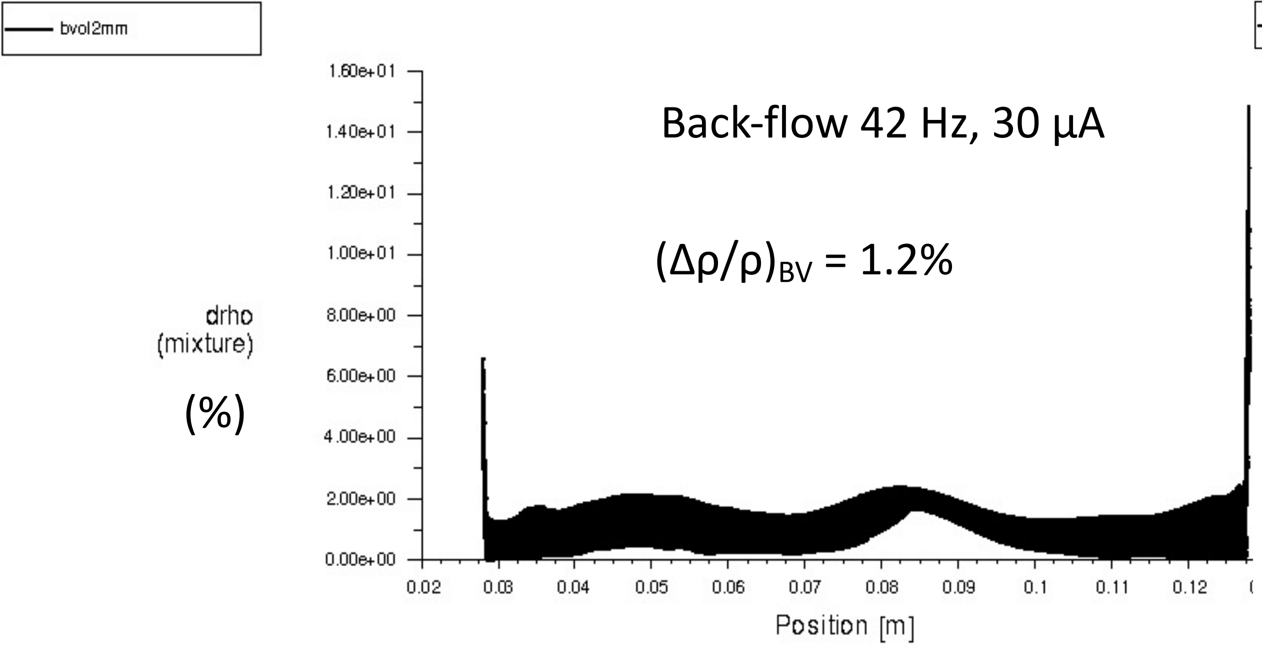


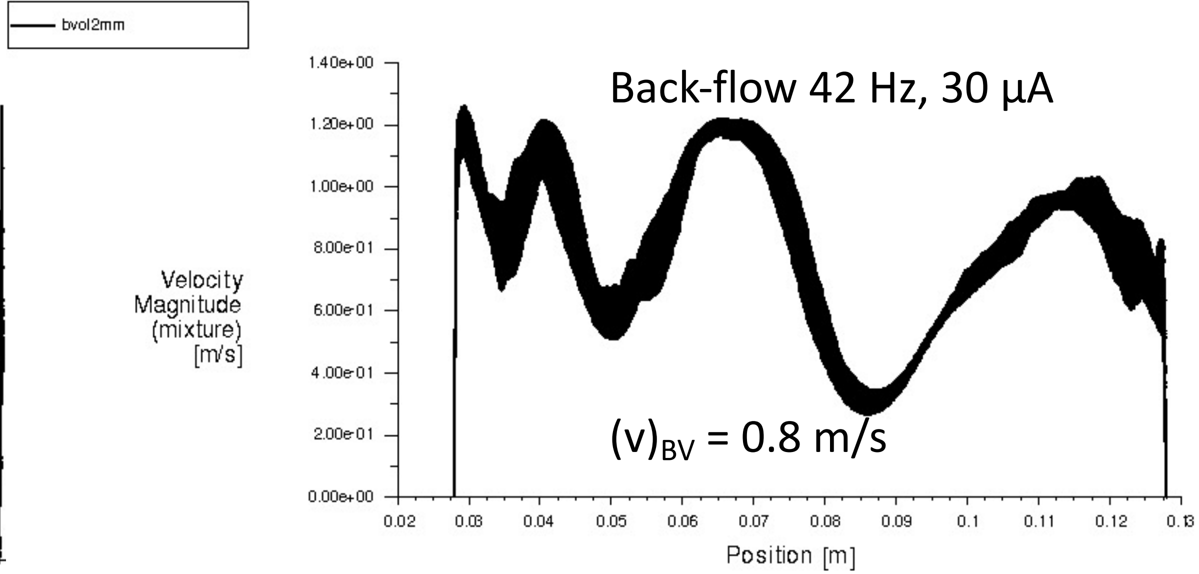
Cell acceptance

- 15.74° to y-
- 90° to y+
- +/- 90° in x

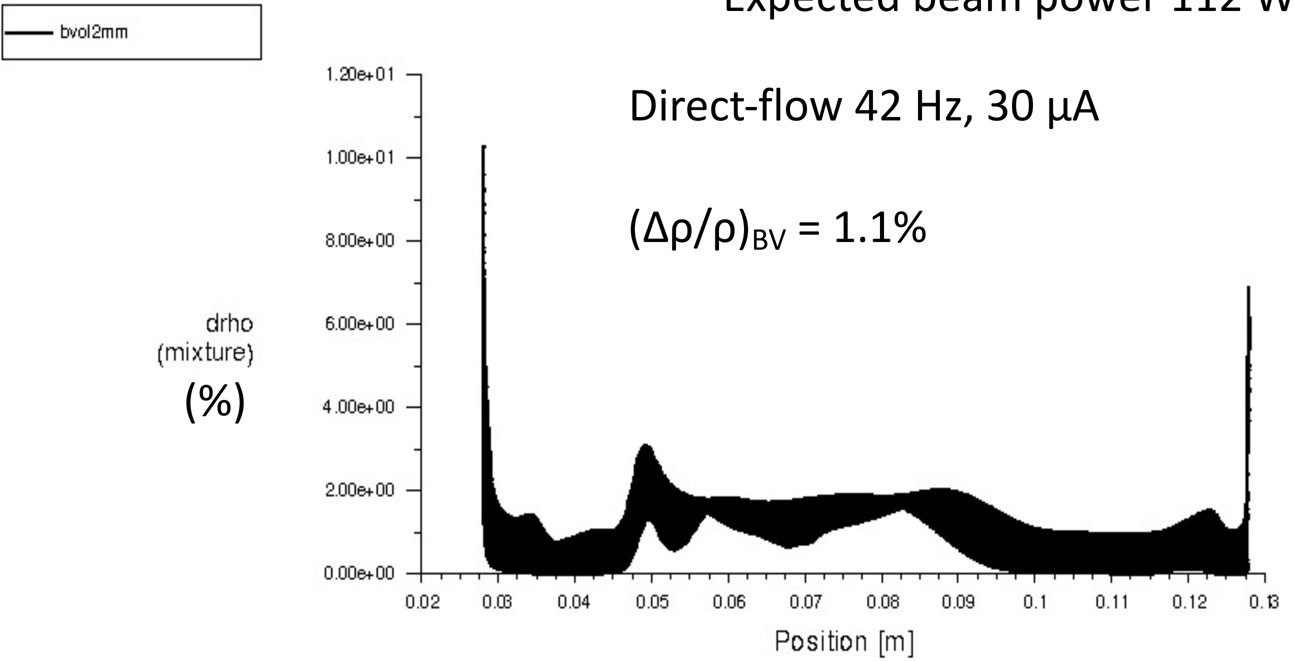
LH2 CFD simulations

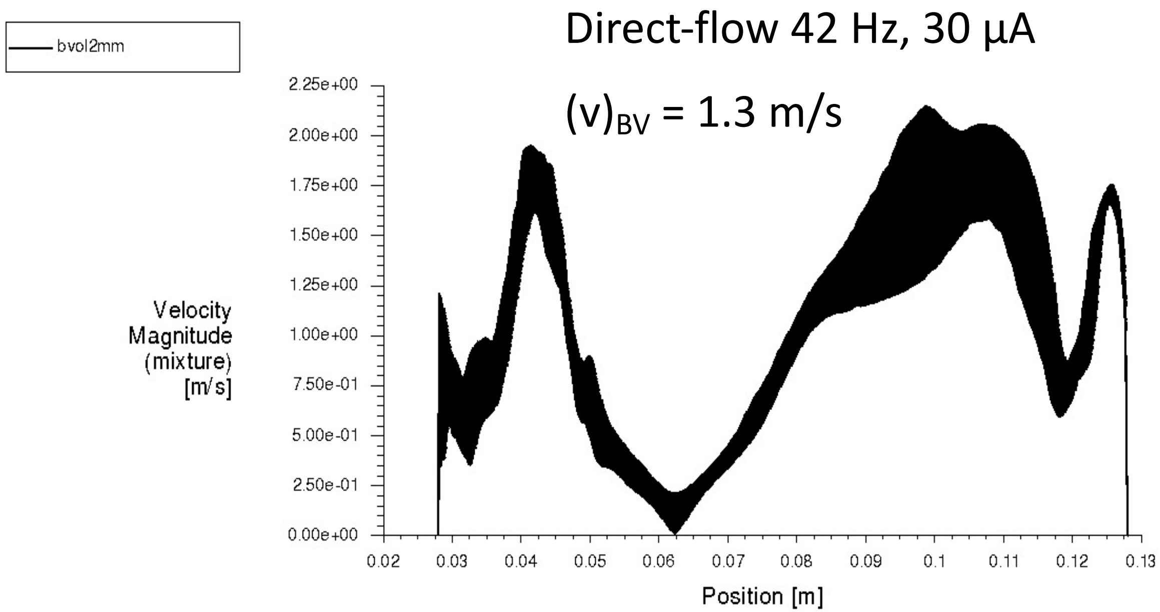
- CFD simulations conditions for LH2-only
  - LH2 at cell inlet at 19 K, 25 psia, mass flow according to the pump frequency, frequencies accounted for 42 Hz, 48 Hz and 58 Hz (LH2 pump efficiency considered 80-100%)
  - Both direct and back-flow through the cell have been simulated
  - Beam current was 30 µA, beam power was accounted for both in the 2x2x100 mm^3 beam illuminated volume in the cell and in the Al windows 2x2x0.15 mm^3
  - Conduction and convection accounted for
  - 2-phase flow accounted for anywhere in the volume where the LH2 reaches saturation at 25 psia, 22.312 K, H2 properties accounting for T-dependence 15-300 K and phase transition. Al-7075 properties accounting for T-dependence
- CFD simulation conditions for He-LH2 mixture (only 48 Hz pump frequency simulated, direct flow)
  - For LH2 the conditions are the same as above, $\dot{m} = 0.12\frac{kg}{s}, \dot{V} = 1.66\frac{l}{s}$
  - For He, properties have been corrected for T-dependence, volume flow at inlet to cell 37% of total volume flow $\dot{m} = 0.0043\frac{kg}{s}, \dot{V} = 0.976\frac{l}{s}$
  - In this model there are three phases that are calculated and tracked through the geometry: LH2, GH2 and He
  - At cell inlet the fluids are at 25 psia and 19 K
  - The beam current is 30 µA, raster is 2x2 mm^2





Expected beam power 112 W = 107 W (LH2) + 5 W (Al windows)



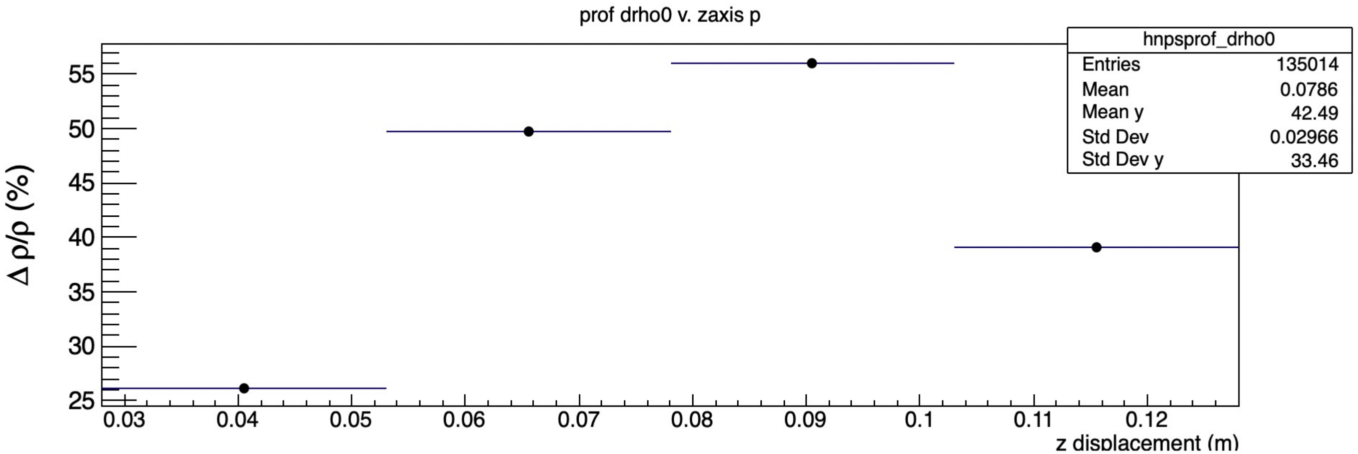


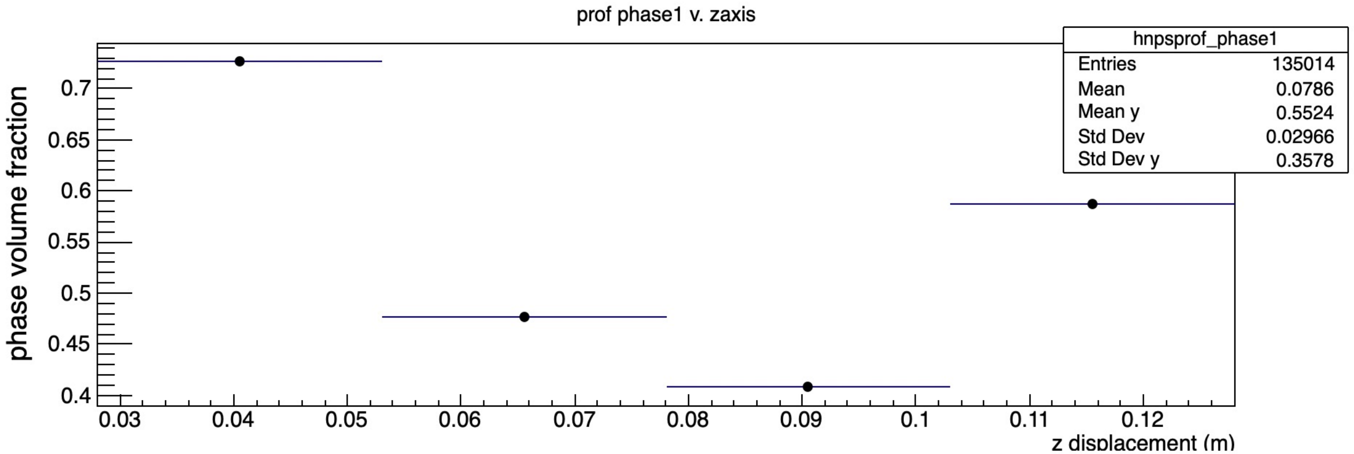
LH2-only CFD Results

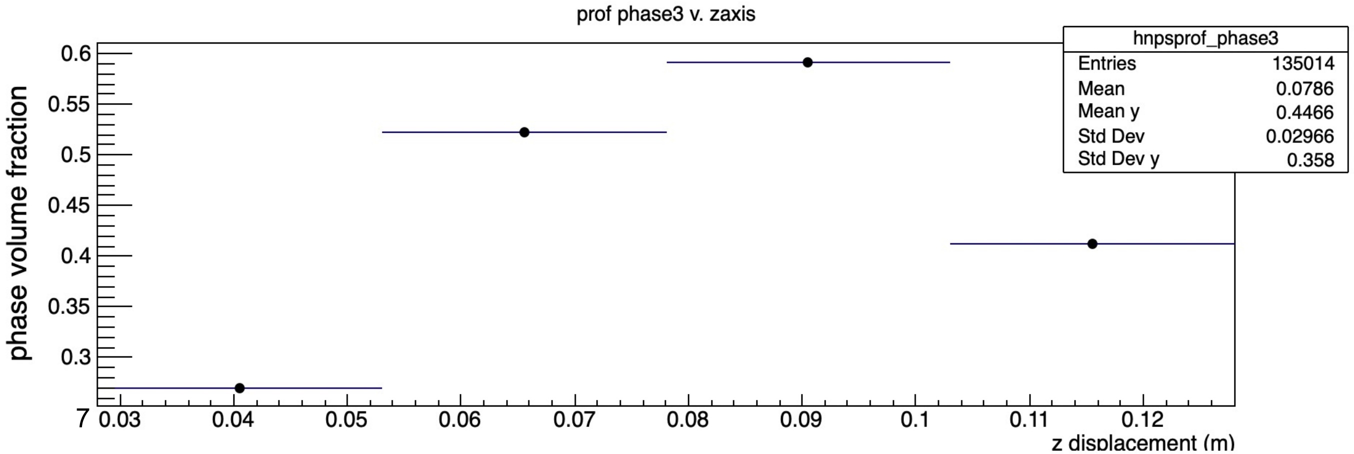
- The flow through the cell is unstable below 40 Hz at 80% LH2 pump frequency (this value to be adjusted upwards at lower pump efficiencies
- Direct-flow (DF) through the cell makes for 50-60% higher flow average velocity in the beam volume than back-flow (BF)
- DF at 58 Hz means 22% less density loss than BF. At 48 Hz and 42 Hz there is no noticeable difference in density loss between DF and BF. This means that the average LH2 density loss is dominated by the bulk effects. BF shows worse boiling at the cell windows regardless of pump frequency
- Overall there is no significant LH2 density loss asymmetry in the cell along the beam line for both DF and BF. For BF the downstream half of the cell seems worse than the same region for DF, but still less than ~2% density loss
- If the LH2 pump efficiency is better than 80%, we cannot explain the target cell thickness loss in the second half of the cell with LH2-only
- A LH2 pump efficiency less than 50% or a flow constrictor/blockage in the cell, could explain the cell thickness loss in the downstream half of it

LH2-He Mixture Model

- Profile plots:
  - Top: Fluid density loss in beam volume in the cell, 4 bins along the beam axis
  - Middle: LH2 volume fraction in the beam volume in the cell, 4 bins along the beam axis
  - Bottom: He volume fraction in the beam volume in the cell, 4 bins along the beam axis
- There is a significant cell thickness loss in the beam volume at 30 μA with a He-LH2 mixture in the cell (loop): about 35-40%
- LH2 seems to flow well at the cell windows, better at the upstream window than the downstream one, while He seems to flow mostly through the middle of the cell, skewed downstream
- These predictions seem to mimic the data from the NPS detector and the estimates of beam power loss in the cell
- These are time-dependent CFD simulations, which seem stable over a full turnover of the fluid in the loop

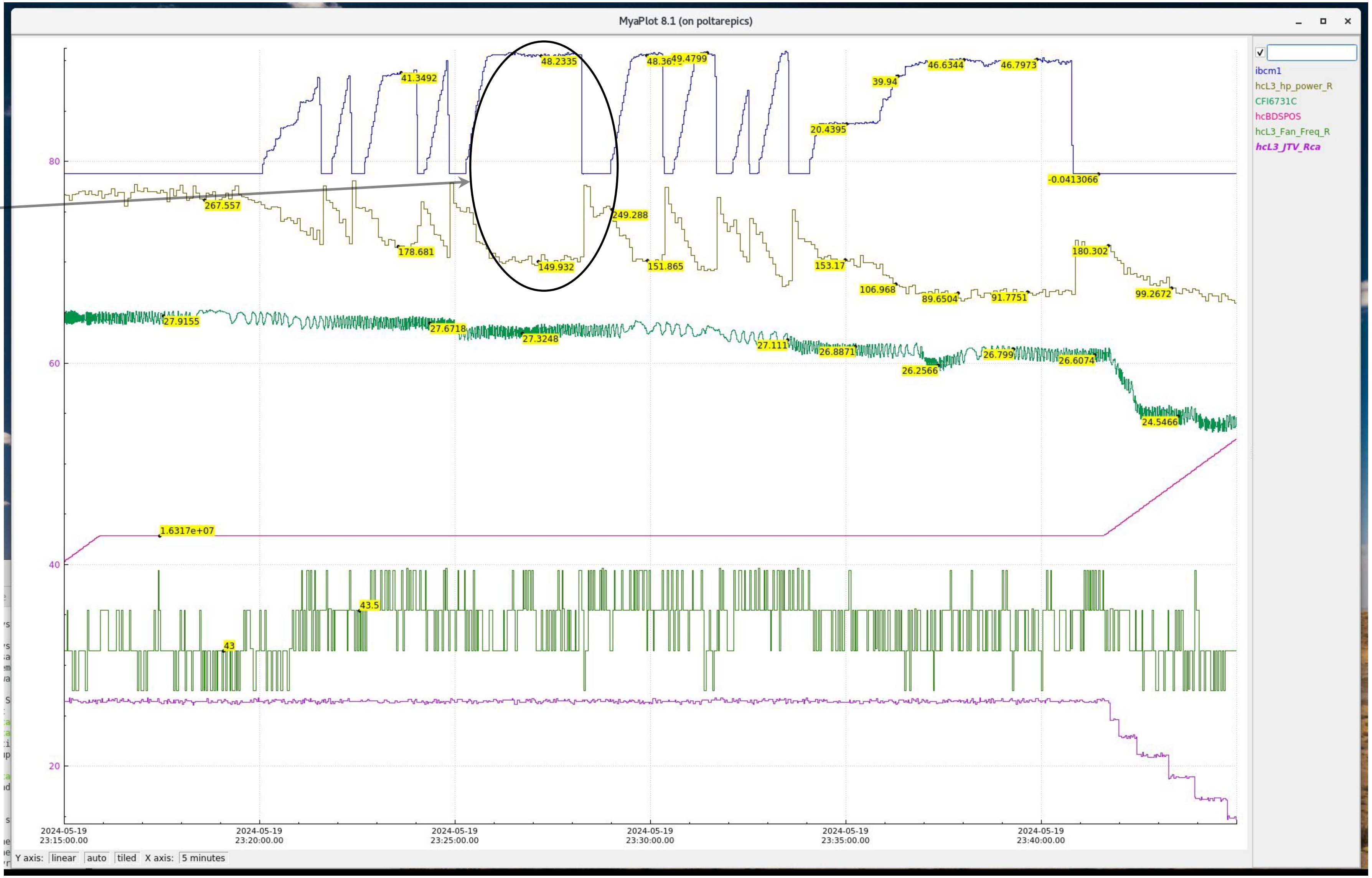






Beam Test on 19-May-2024

- At a beam current of 48.2 μA, the beam power in LH2 and Al windows would be expected to be 182 W
- The HPH decreases about 117.6 W from zero beam to 48.2 μA (267.55 W to 149.93 W)
- Accounting for the 15 K coolant flow drift of 0.6 g/s over this period, may add about 10 W to the HPH

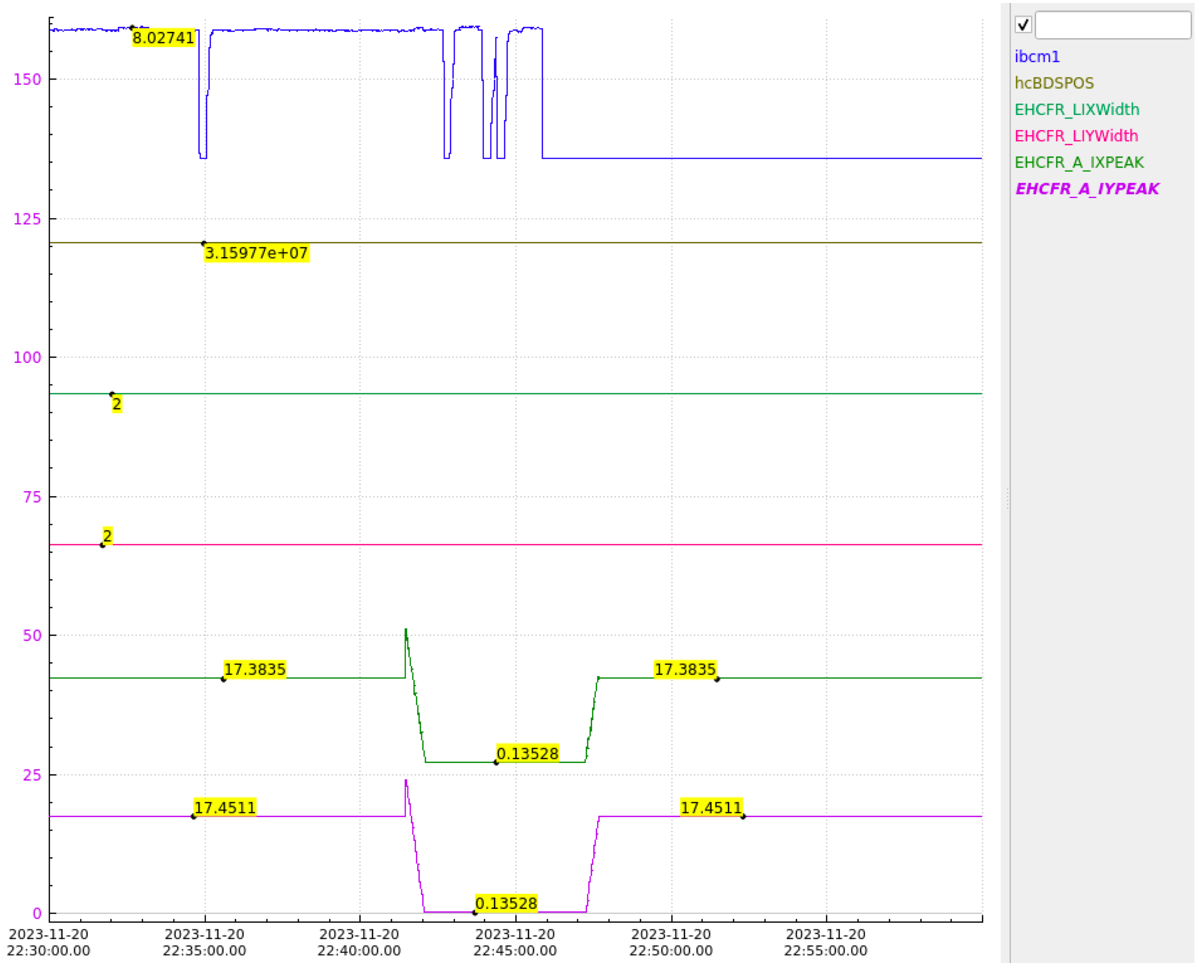


- The HPH senses that about 70% of the LH2 cell thickness is in beam at currents above 30 μA
- This is a global number, it does not say anything about where in the cell the thickness loss(if any) happens

Jefferson Lab

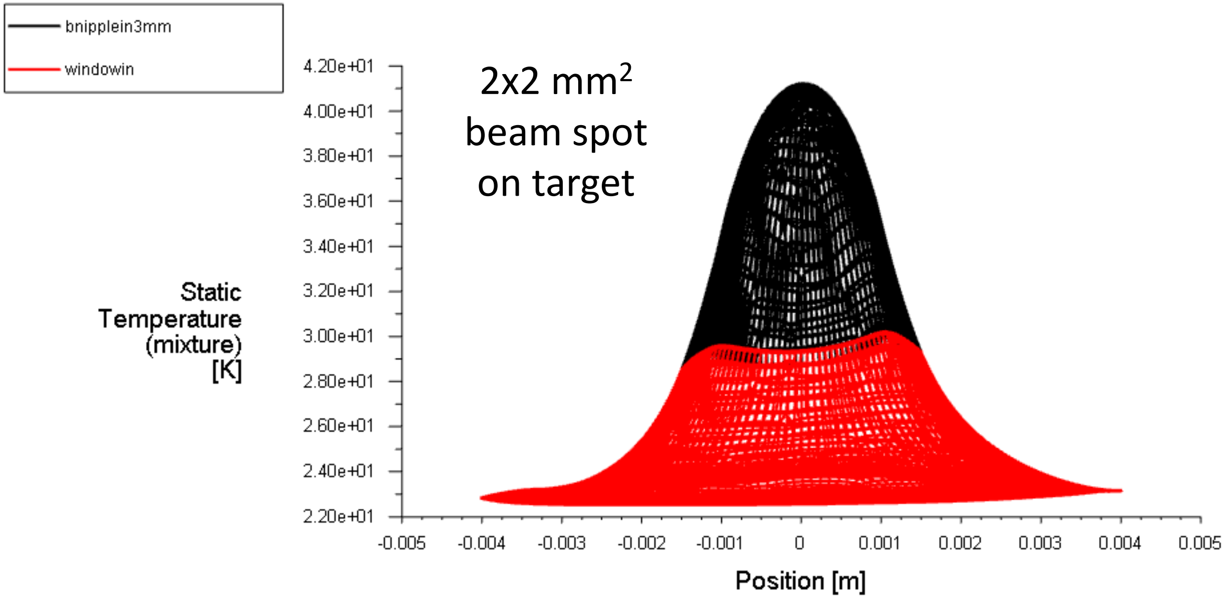
Unrastered Beam on Target

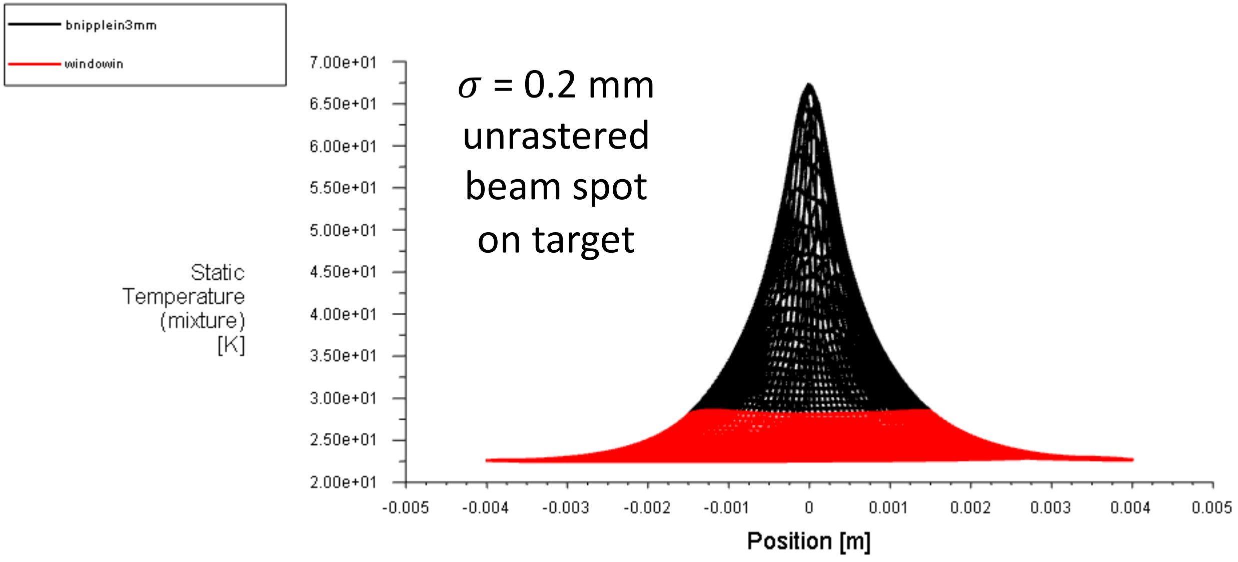
- On 20-Nov-2023 unrastered beam was put on the LD2 10 cm cell, from 22:42 to 22:47, about 5 min, with 3 beam trips
- We were very lucky that the beam current was only 8 μA. The beam power expected in LD2 is 32 W and 0.8 W in one Al window
- Thanks to Iuliia S. who noticed it and asked MCC to shut down the beam
- myaPlot on the right shows the beam current, the nominal beam raster setpoints in x and y, both 2 mm and the beam raster currents in the A pair of coils: X and Y. Notice that (like we train the TOs) beam raster setpoints being set do not mean that the raster is ON



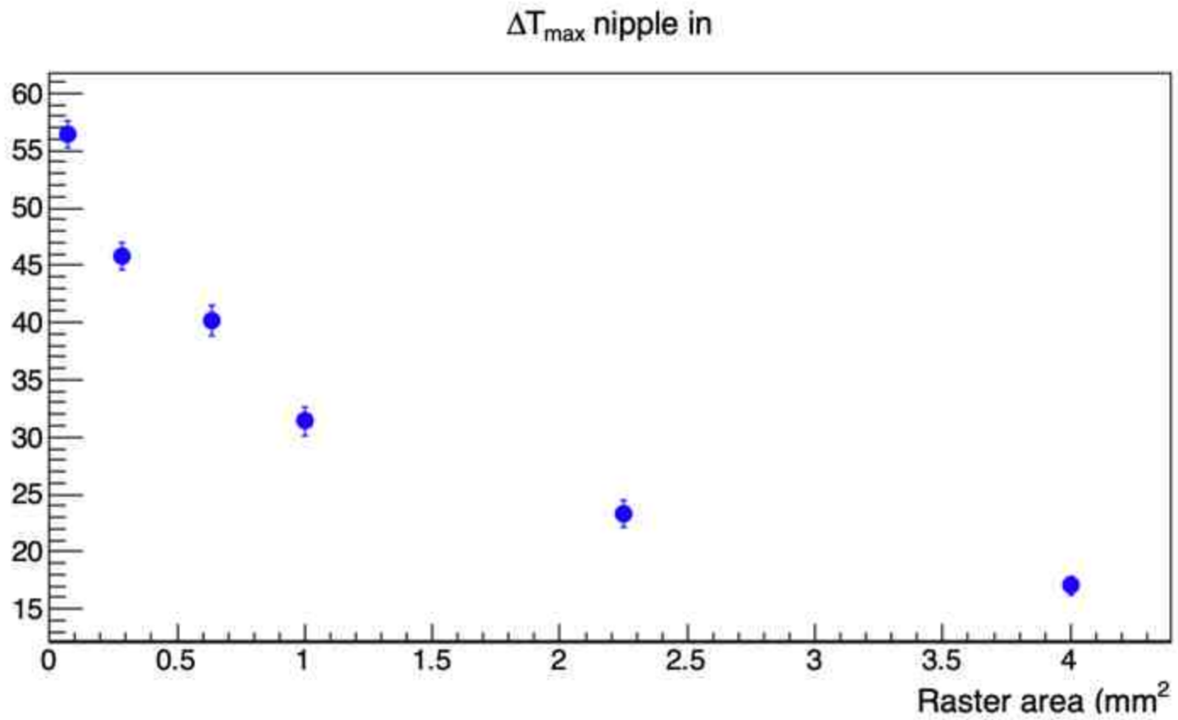
Jefferson Lab

Unrastered Beam on Target (II)





- Plots on the left show the temperature profiles in a cell window's beam nipple (Red extends to 4 mm radius, while black to 1.5 mm)
- Bottom right plot shows the maximum temperature in the cell upstream beam line window nipple v. beam area on target. The temperature rise is nonlinear with beam spot area at the same beam current!
- $\Delta T_{max}(0.2mm) \sim 2.4 * \Delta T_{max}(2mm)$
- Temperature gradient is 3x larger for unrastered beam 0.2 mm compared with rastered beam at 2 mm over the beam nipple



Summary

- Beam power deposition estimates in the LH2 cell with the HPH are short about 30% for beam currents in the range 30-50 μA
- CFD simulations of "regular" LH2 flow in the target loop do not explain the profile of target thickness loss along the beam line as measured by NPS and with the HPH estimates
- CFD simulations of a mixture of He-LH2 in the target loop seems to account for the profile of target thickness loss along the beam line and for the absolute value of it
- We seem to have dodged a bullet with the unrastered beam on the LD2 cell