VSC Seminar: Sub-monolayer adsorption isotherms and gas propagation of H_2 and He in cryogenic copper tubes

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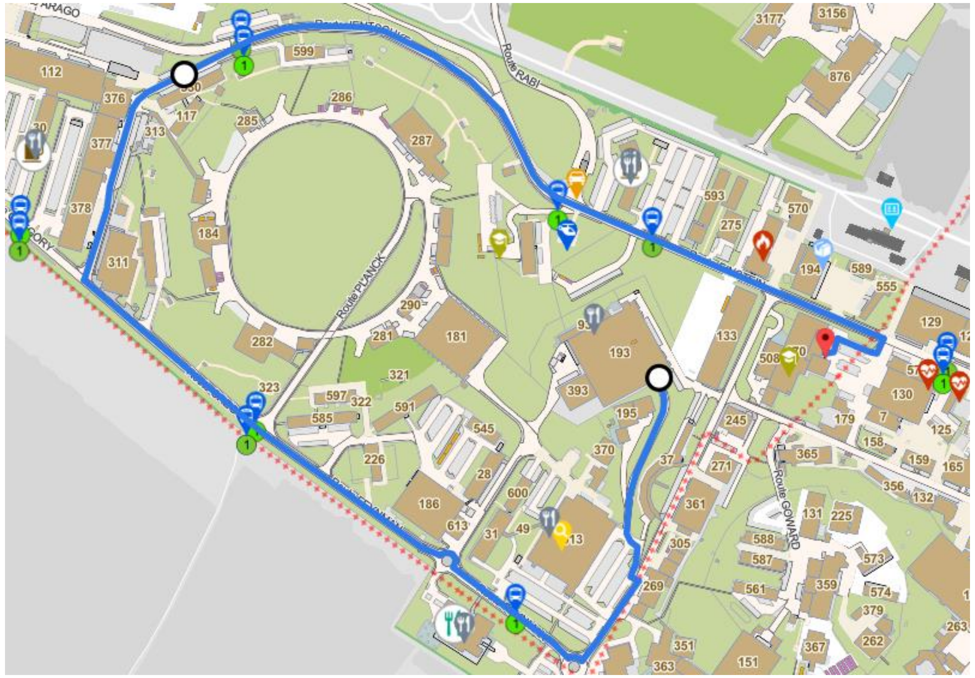
Motivation

antiProton Unstable Matter Annihilation

VSC is involved in the vacuum and cryogenics layout of the new antimatter experiment PUMA.

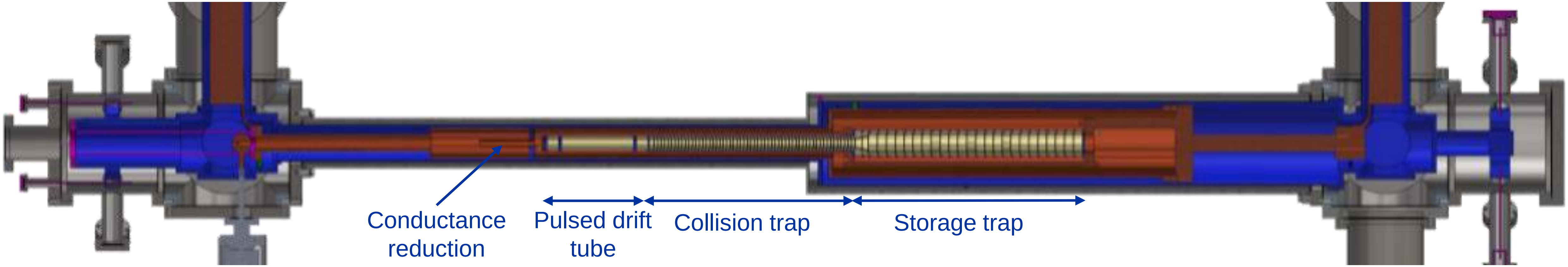
- PUMA aims to study neutron skins and halos of short-lived nuclei by observing annihilations of antiprotons with the outermost part of these nuclei.
- For that, they need to store and transport 1 billon antiprotons from ELENA to ISOLDE.



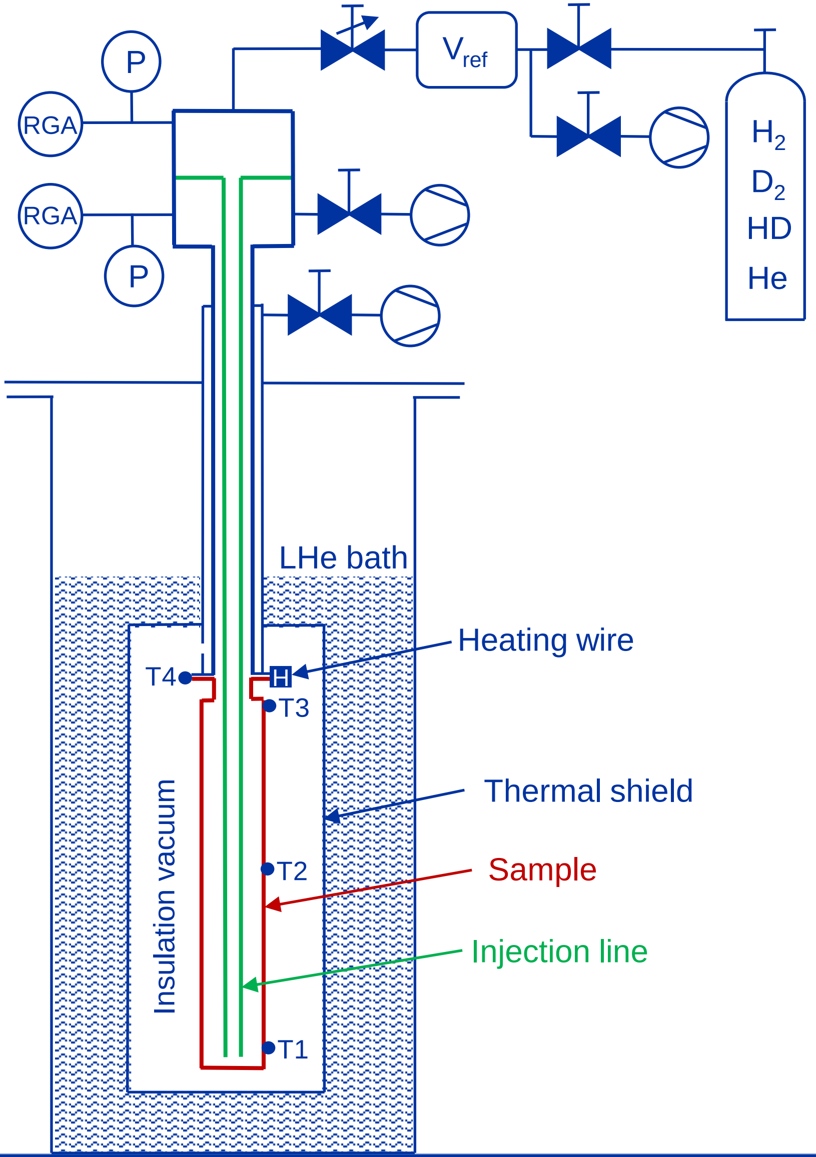
For further information, please refer to Jose A. Ferreira's seminar talk on the 23rd Nov 2021.

Motivation

- Adsorption isotherms relating pressure, temperature and coverage p = f (T, θ) as input for simulations in the design phase of cryogenic vacuum systems
- Current isotherm data for He and H_2 only goes down to pressures of 1E-11 mbar
- PUMA requirements: Storing antiprotons > 30 days → Antiproton lifetime > 200 days → Pressure ~ 10^{-17} mbar at 4.2 K in the storage trap
- Surface temperature 4.2 K → relevant gases are H_2 and He

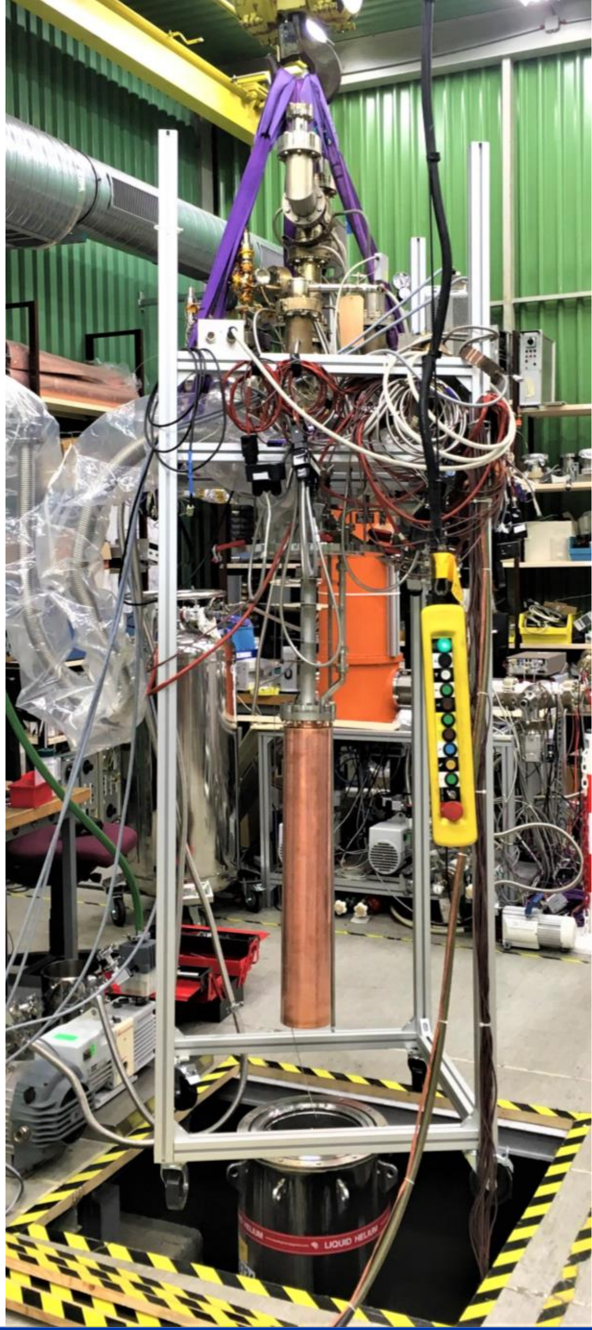


Setup (modification from CISTM)



Option 1: **Isosteres**
(pressure over temperature scans at a constant coverage) by varying the heating current and insulation vacuum pressure
→ several isosteres can be used
find the fit parameters of adsorption isotherm models

Option 2: **Gas propagation**
at constant sample temperature with a continuous injection
→ can be used to **test the isotherm parameters in simulations** and reproduce the gas propagation

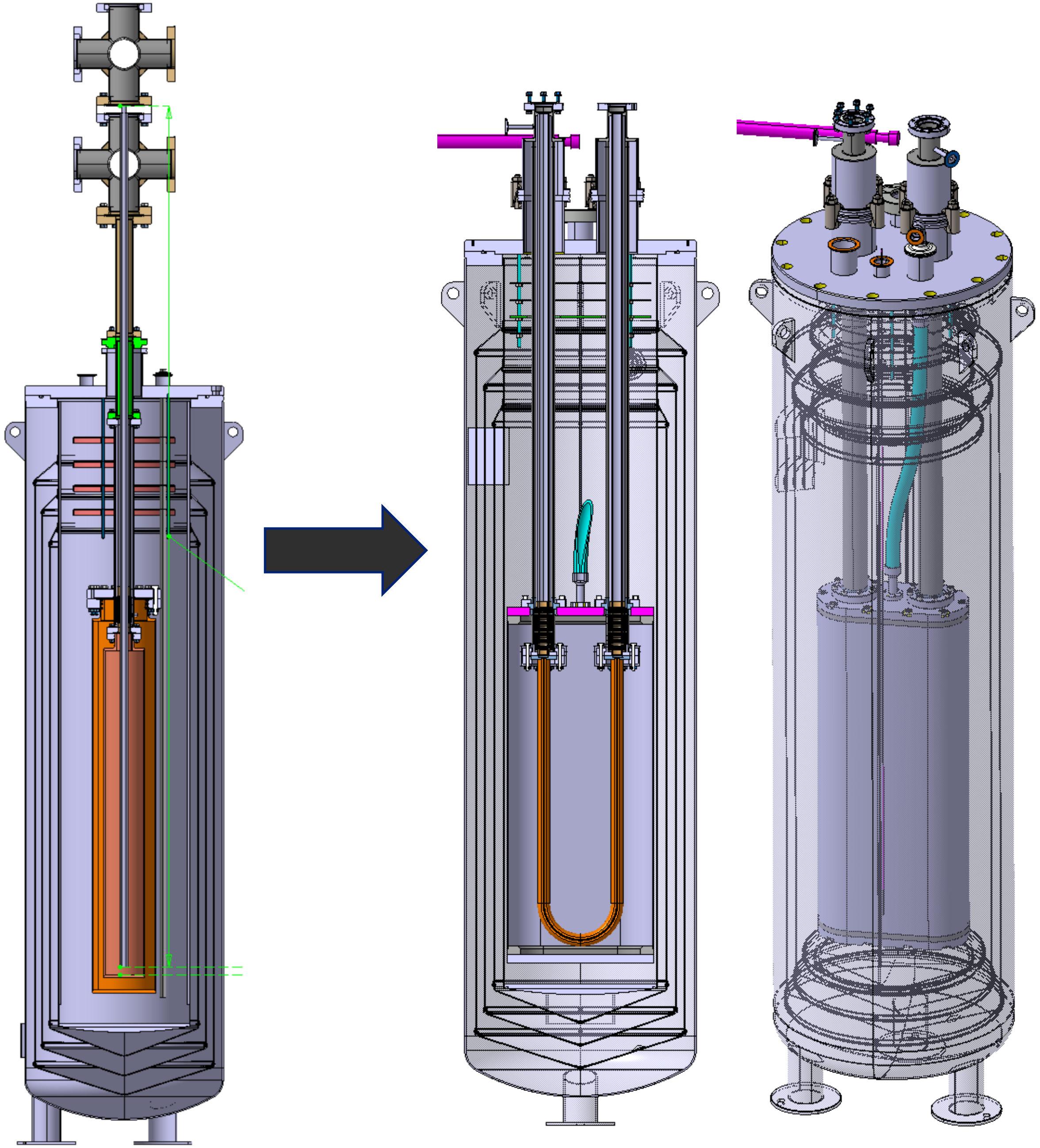


Setup – future upgrade

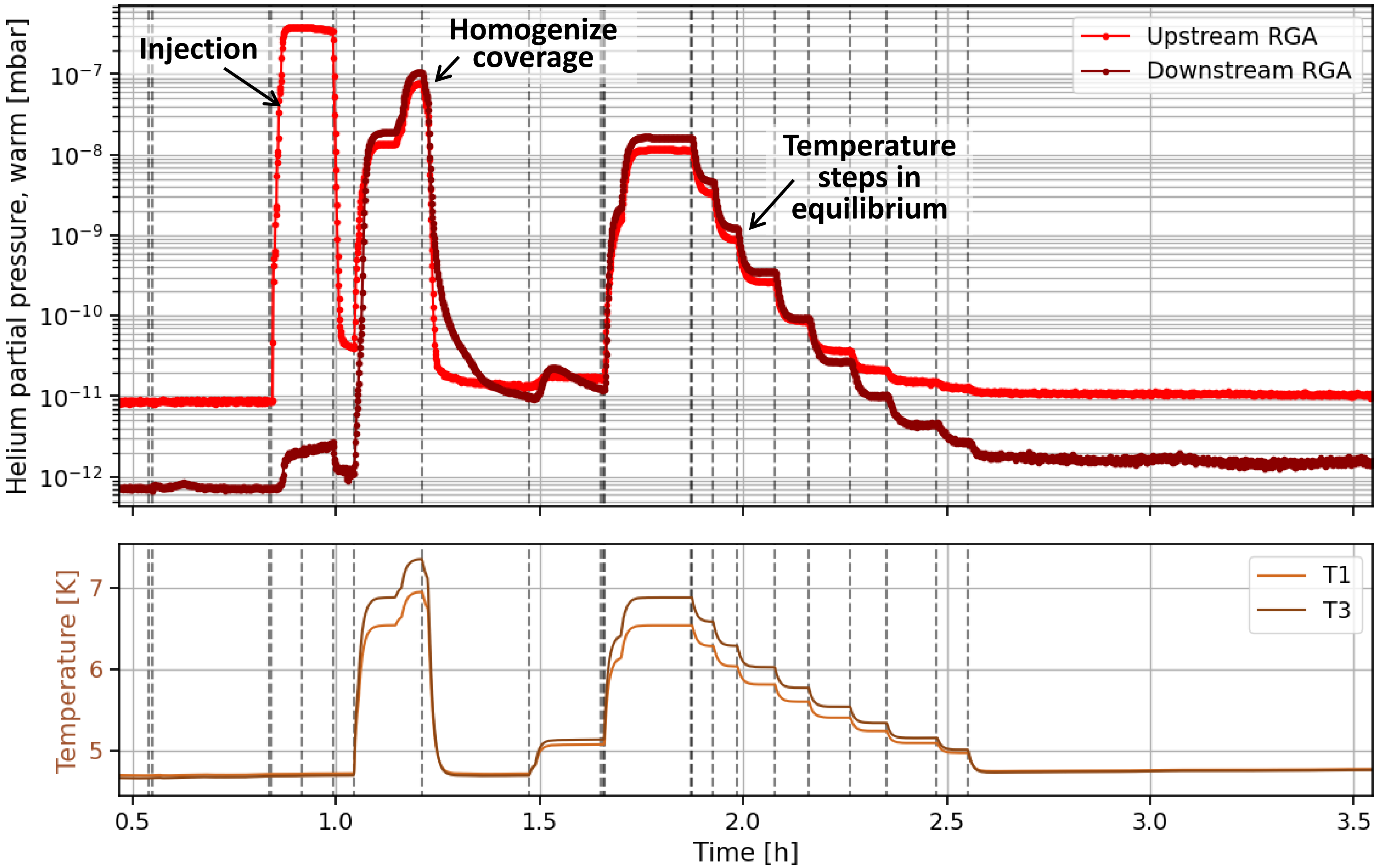
- Specialized setup for propagation measurements
  (U-shaped sample)

- Factor 100 increased sensitivity for hydrogen

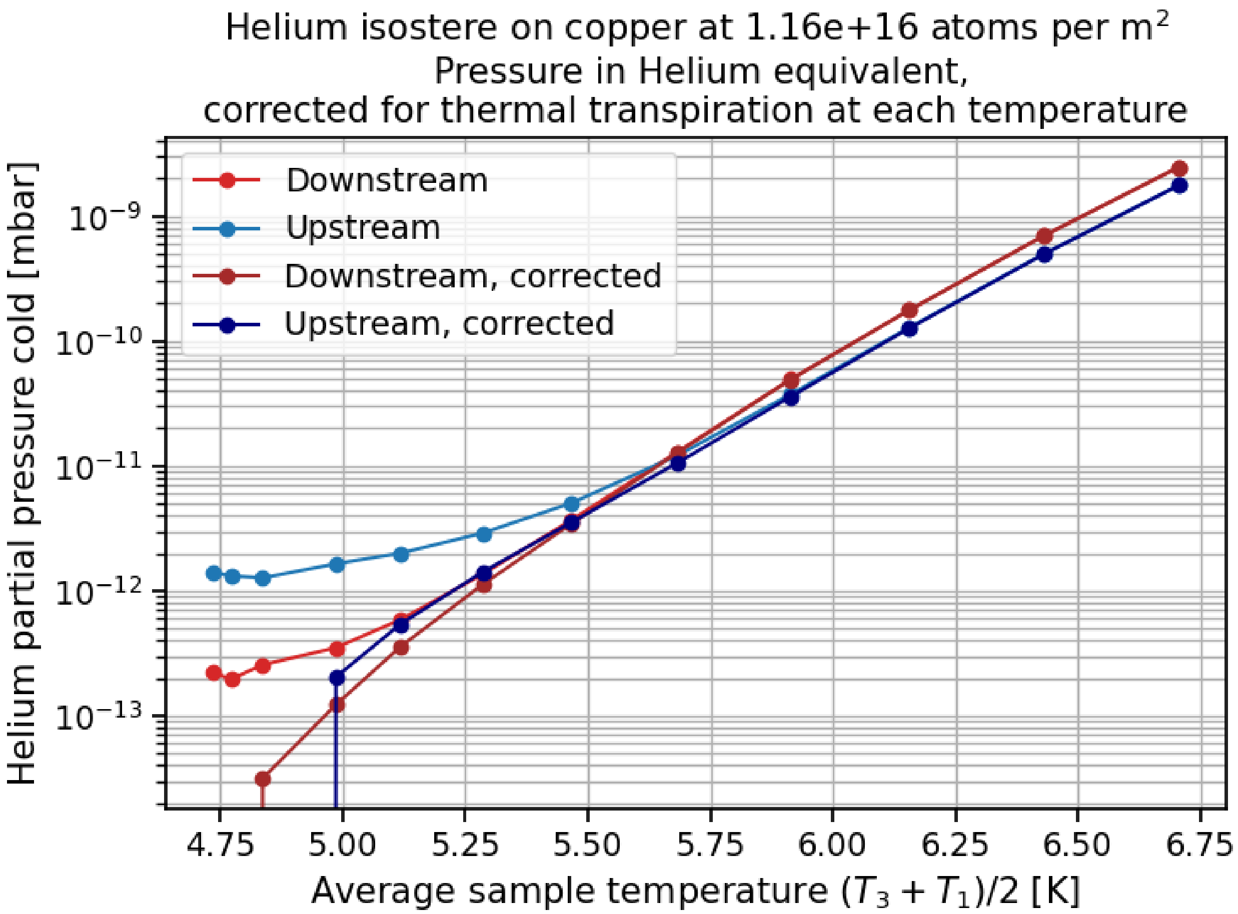
→ Manufacturing of parts ready by the end of this year

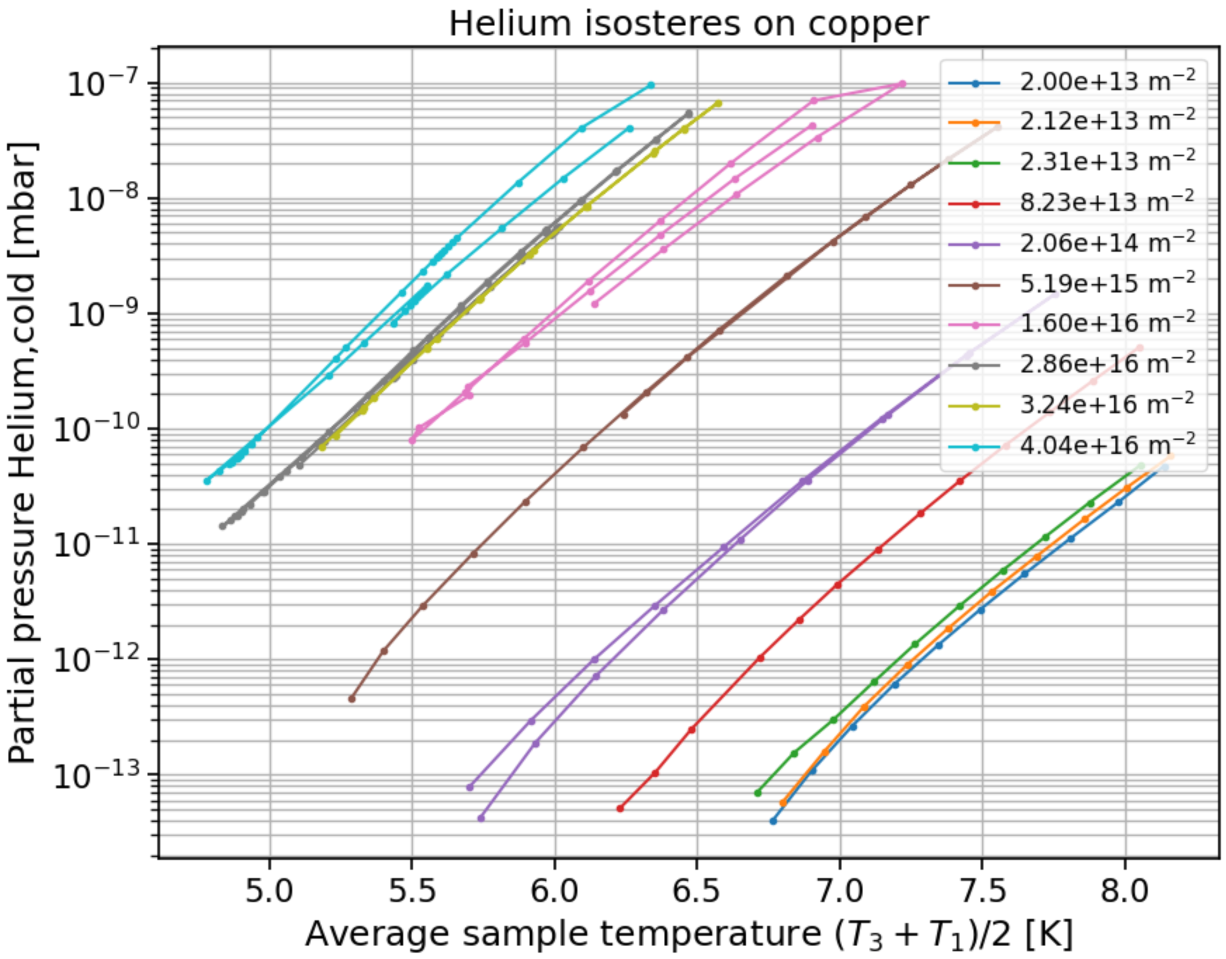


Typical helium isostere measurement



Helium isosteres





→ Measurements down to $\mathbf{1 \cdot 10^{-14}}$ **mbar** (cold) possible

Fitting helium isosteres

Best theory candidate to describe sub-monolayer adsorption isotherms:

Dubinin-Radushkevich-Kaganer (DRK) model

$$p(T) = p_{sat}(T) \cdot e^{-\frac{T_0}{T}\cdot\sqrt{-\ln\Theta}}, \text{with } \Theta = \frac{S}{S_m}$$

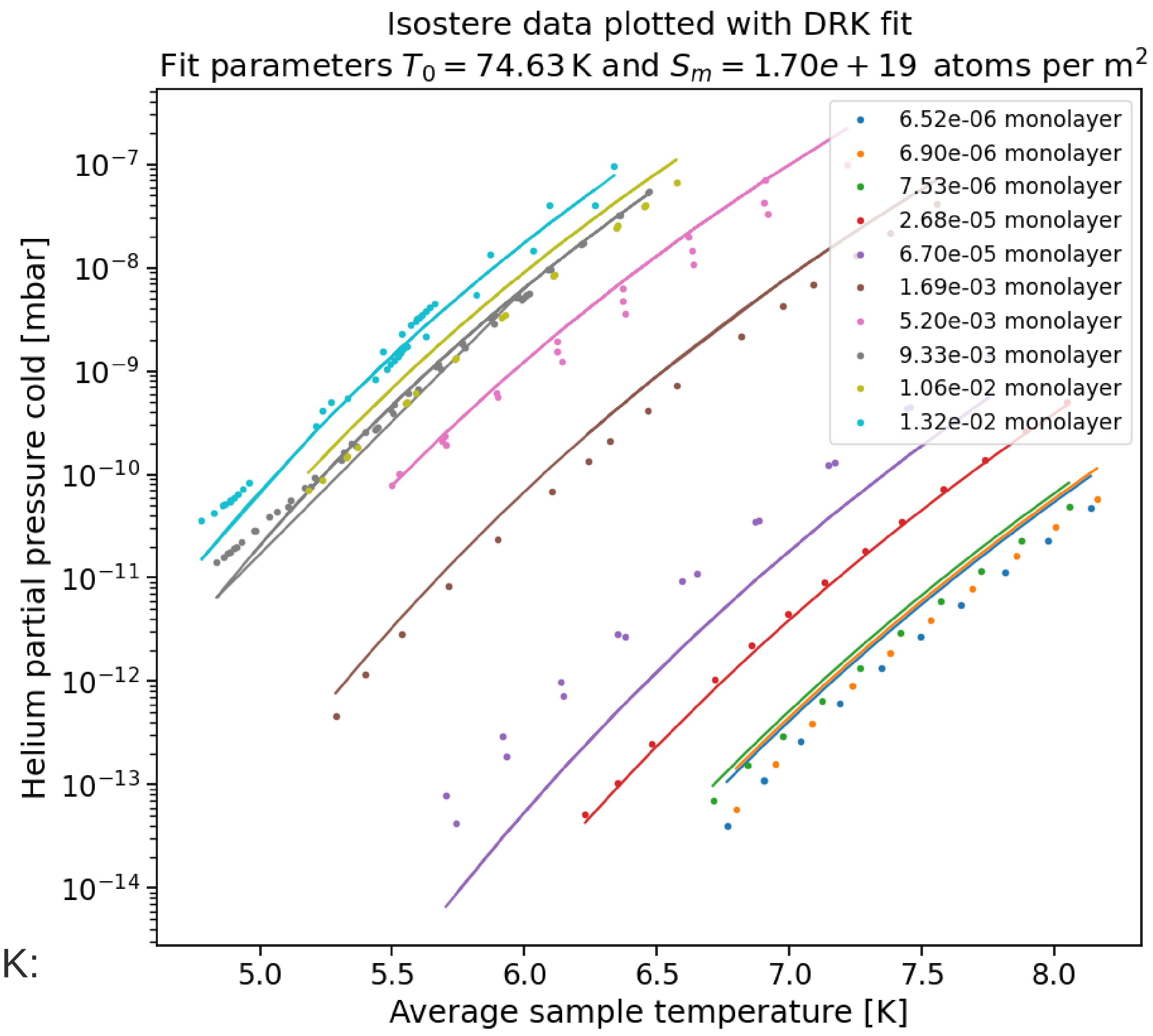
with fit parameters T_0 (binding energy) and S_m (monolayer capacity).

Fit equation: $\ln\left(\frac{p}{p_{sat}(T)}\right) = -\frac{T_0}{T} \cdot \sqrt{-\ln\left(\frac{S}{S_m}\right)}$

→ Fit values for helium work well across all data sets and many orders of magnitude:

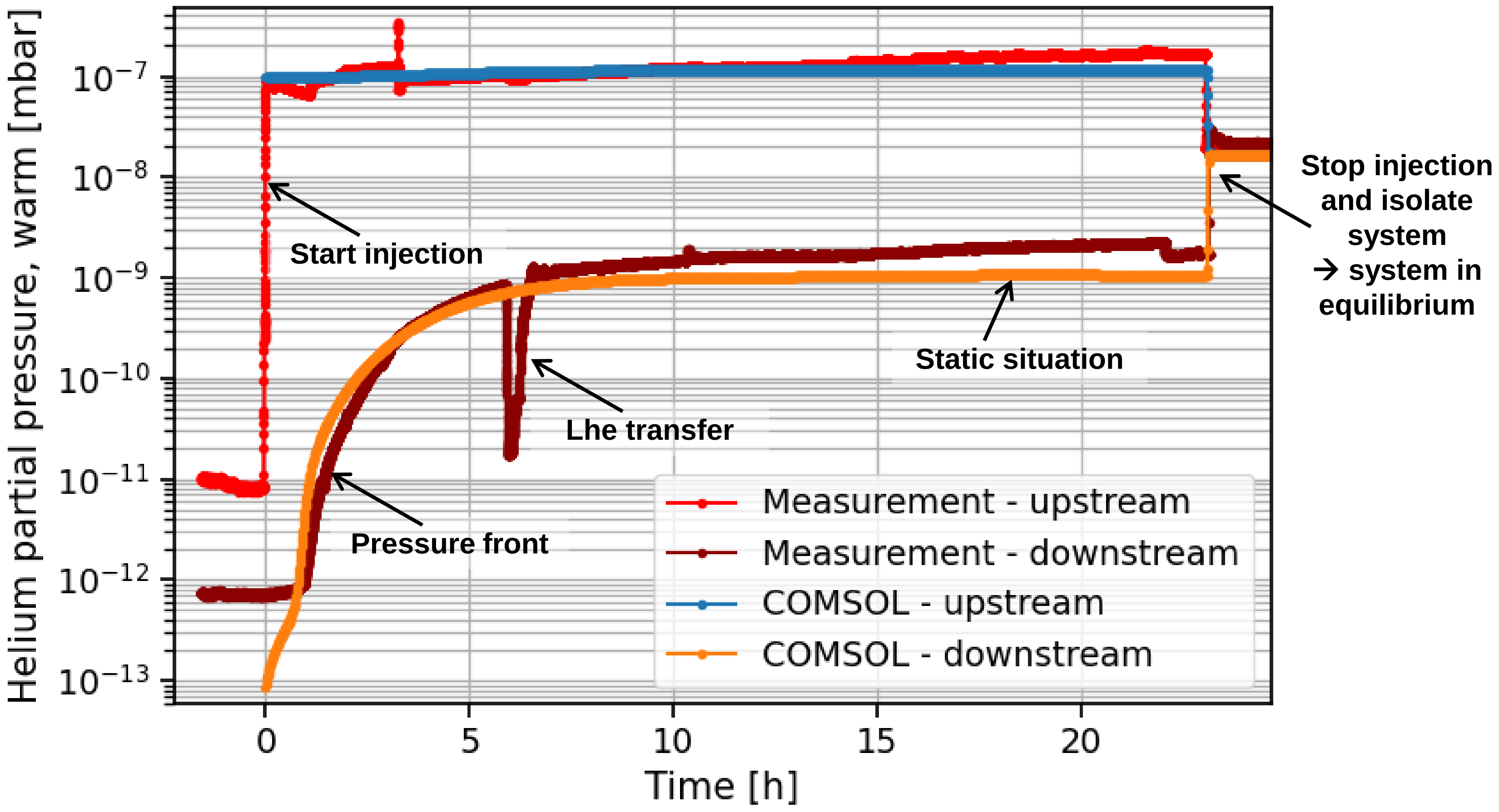
$$T_0 = 74.6\ \mathrm{K} \text{ and } S_m = 1.70 \cdot 10^{19}\ \mathrm{m}^{-2}$$

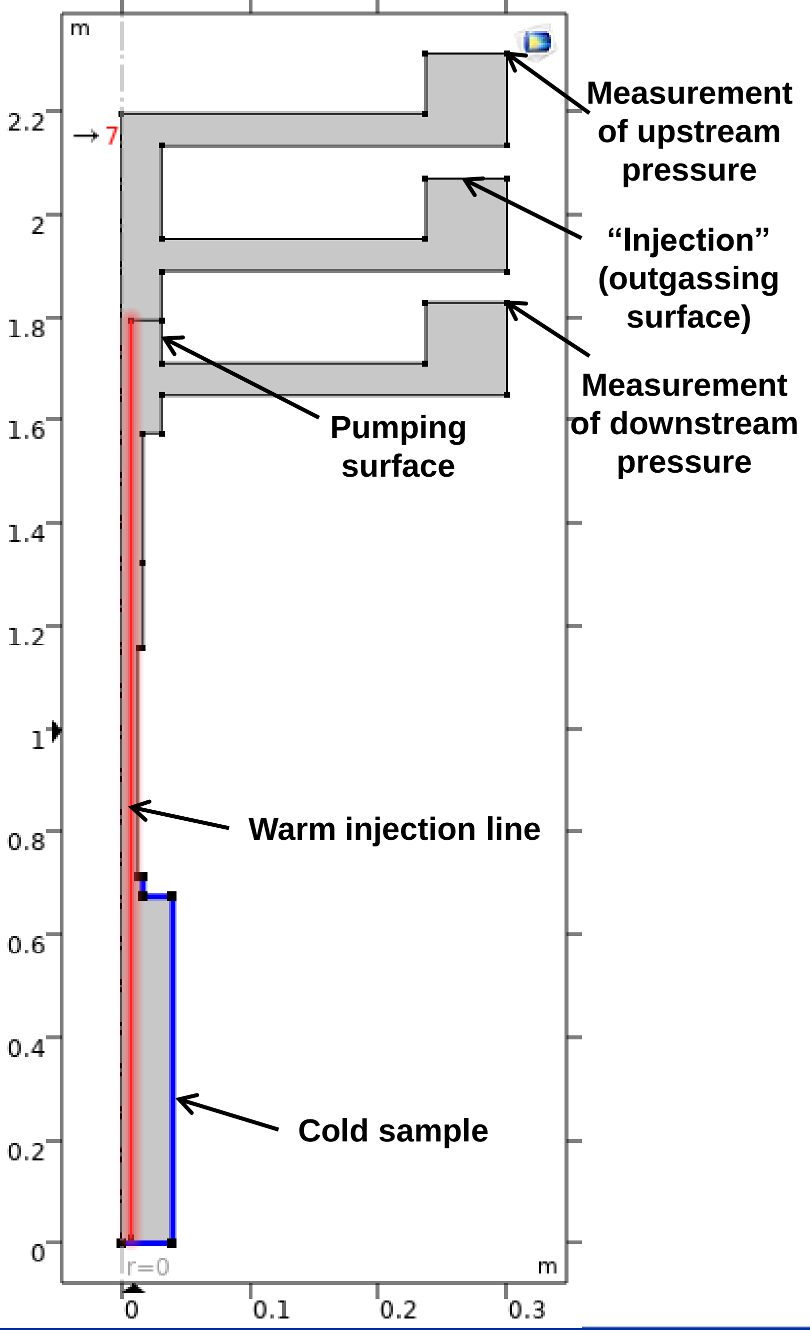
→ **Comparison** with values found by E. Wallén (CERN) for He on Cu plated stainless steel at 4.2K: $T_{0,Wallen} = 67.2$ K and $S_{m,Wallen} = 1.72 \cdot 10^{19}\ \mathrm{m}^{-2}$



Helium propagation at 6 K

Isotherm fit values from isostere measurements used in COMSOL simulation of the helium propagation measurement





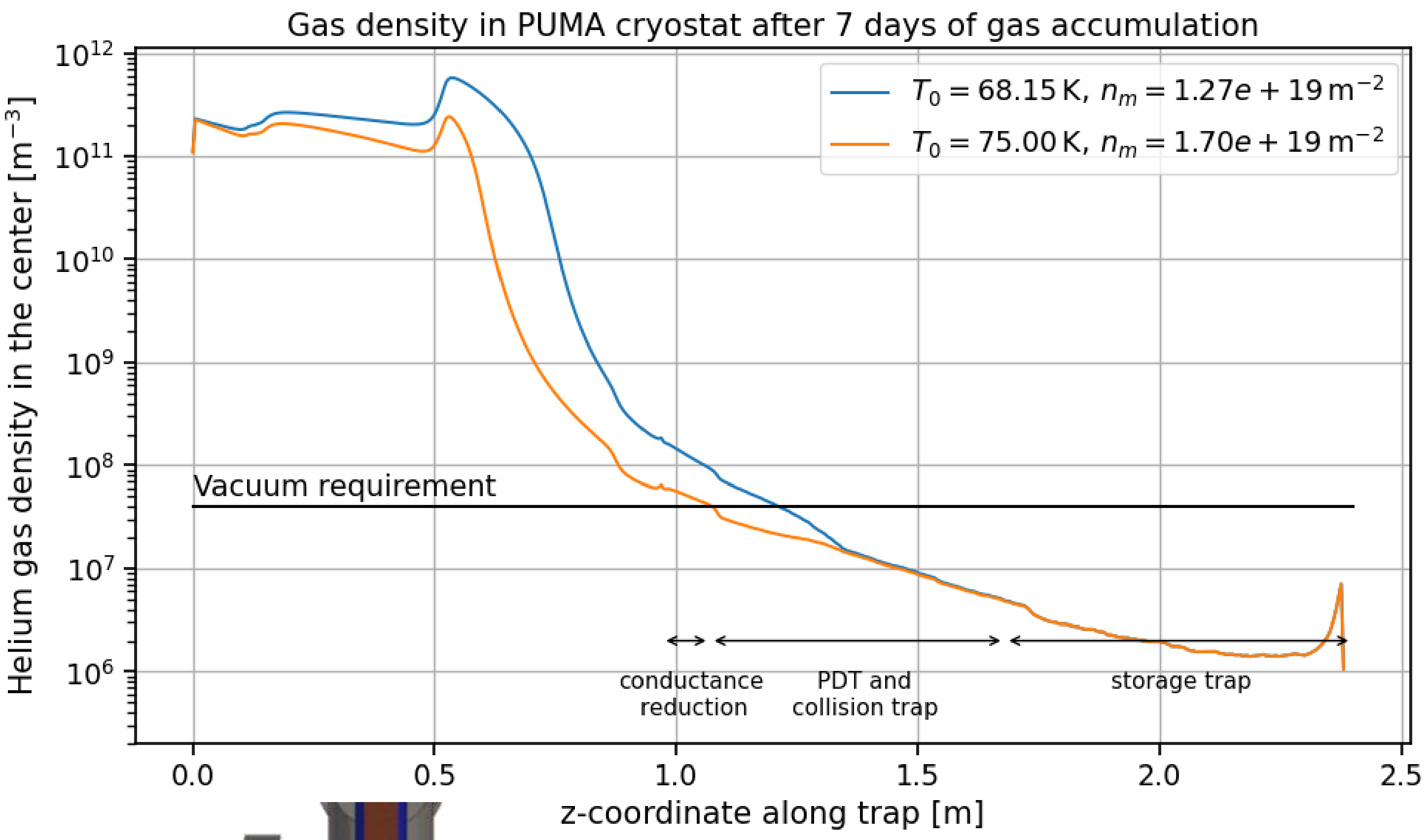
→ **Simulation and measurement agree well with each other!**

Predictions for the PUMA geometry - Helium

- Inlet pressure max. $1 \cdot 10^{-11}$ mbar during measurements at ISOLDE

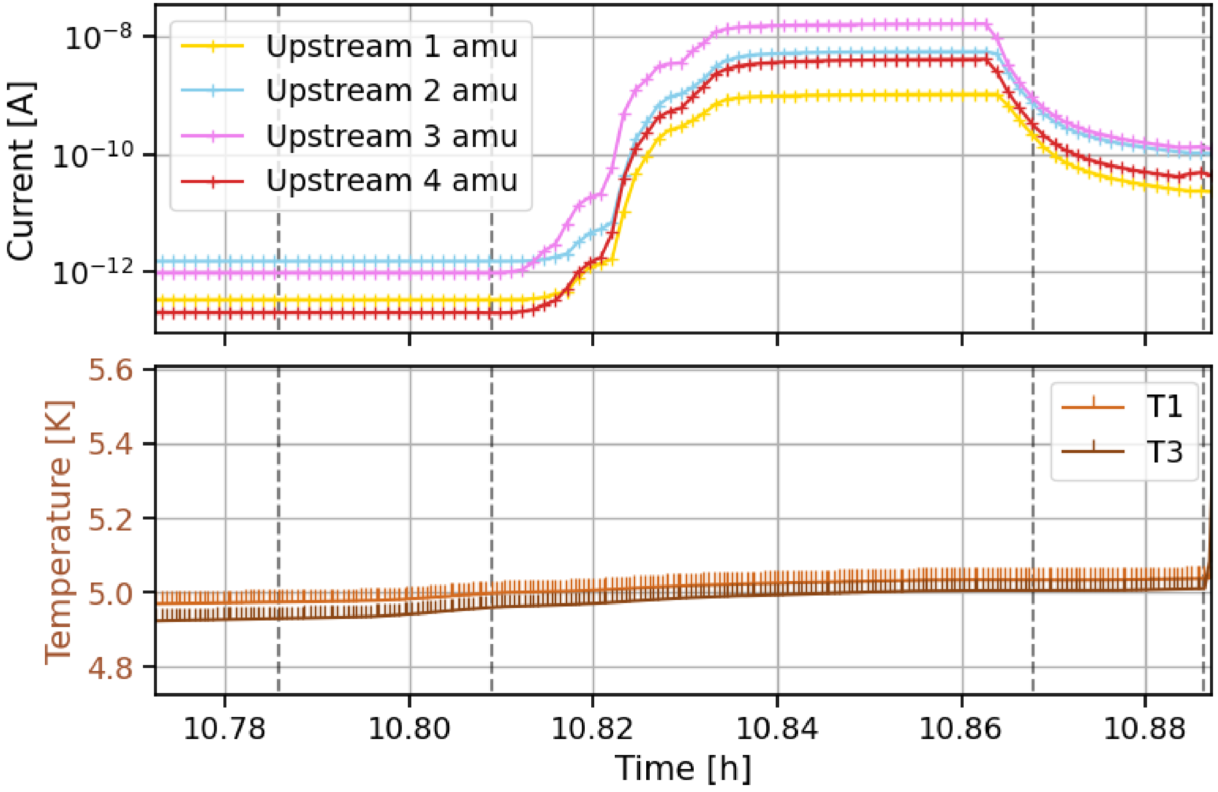
- Vacuum limit for helium to ensure sufficient experimental time: $n < 4 \cdot 10^{7}$ helium atoms per m^3

→ **Gas densities in the collision and storage trap are low enough** with the new isotherm values even **after 7 days** of exposure to $1 \cdot 10^{-11}$ mbar helium at the inlet

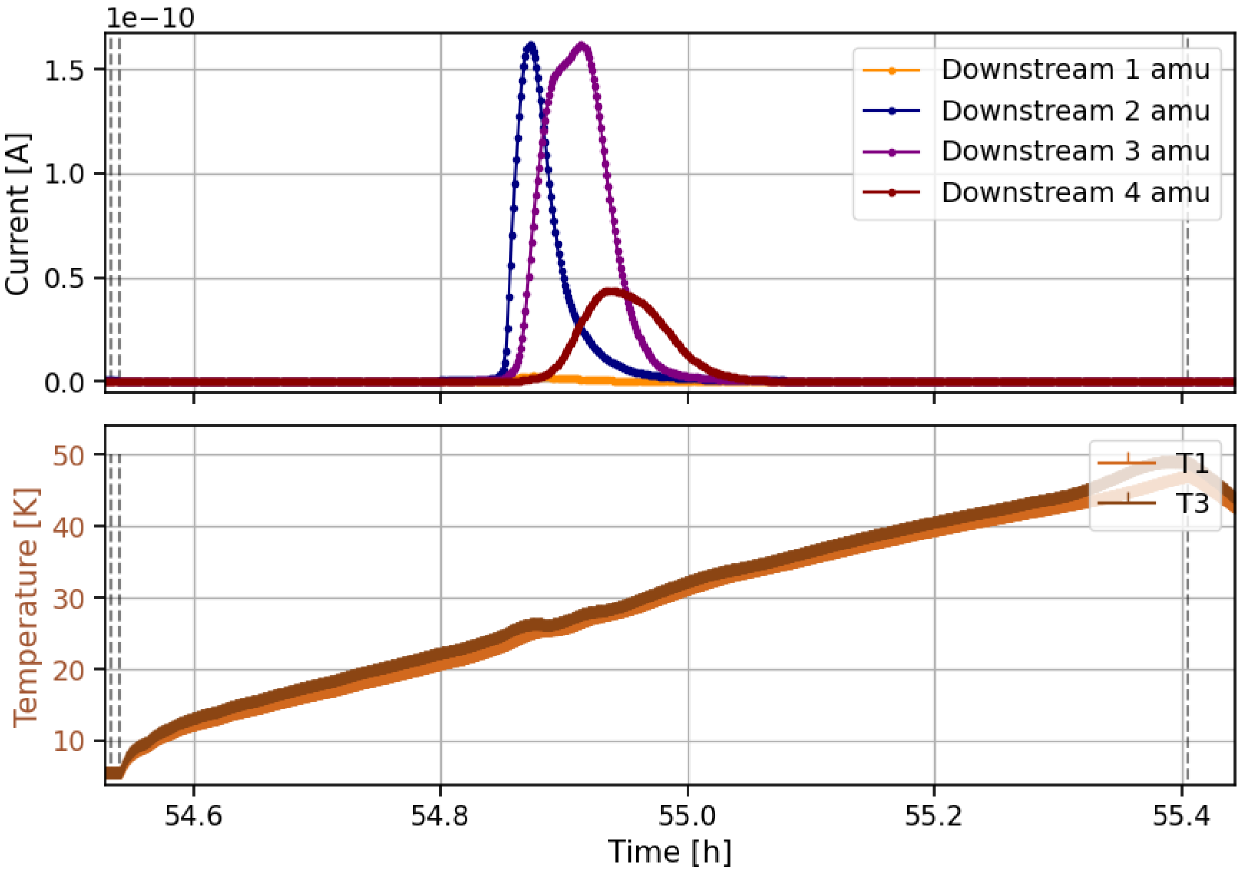


Conversion of hydrogen isotope HD into H_2 and D_2

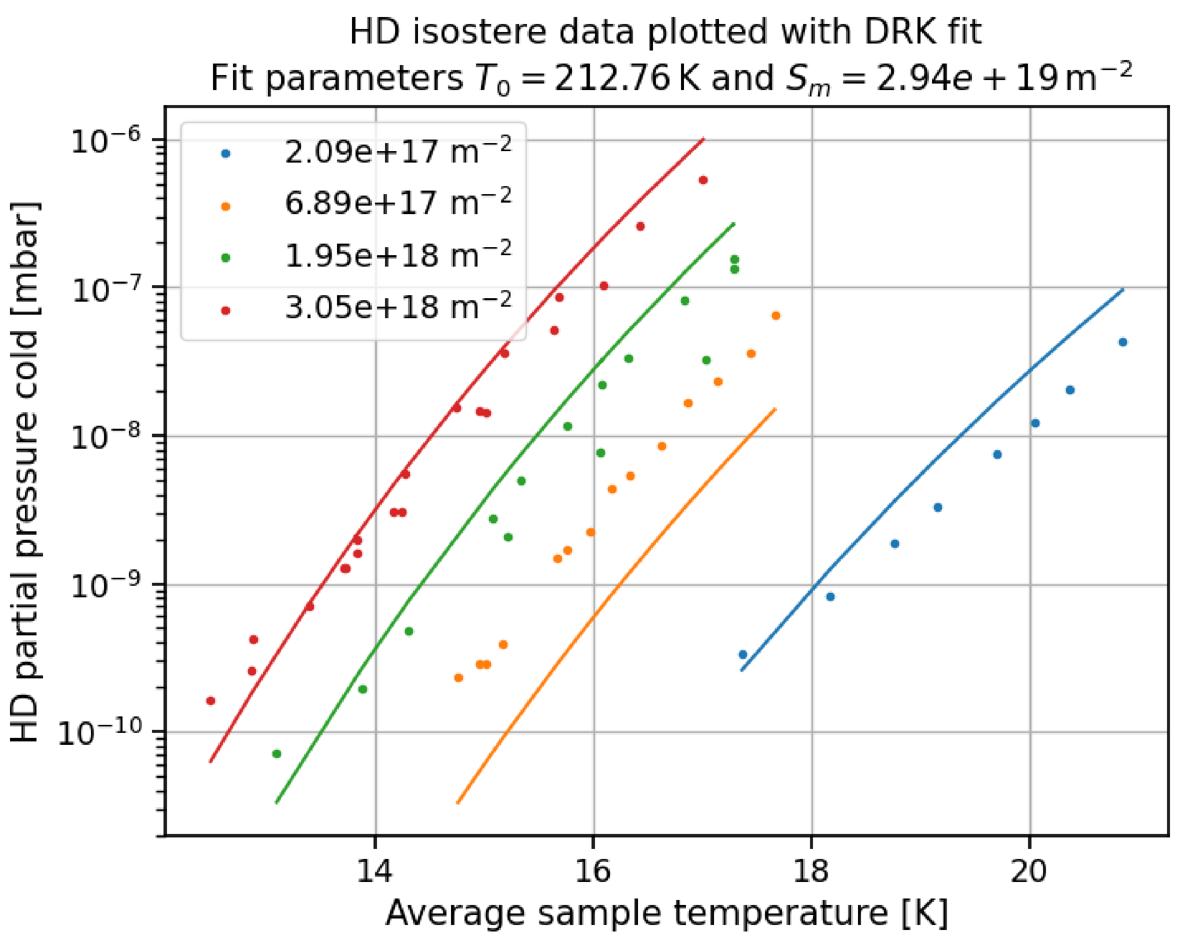
Injection of $1 \cdot 10^{18}$ HD molecules per m² into closed, cold system → high signals for masses 2 and 4 visible during injection of HD (mass 3)

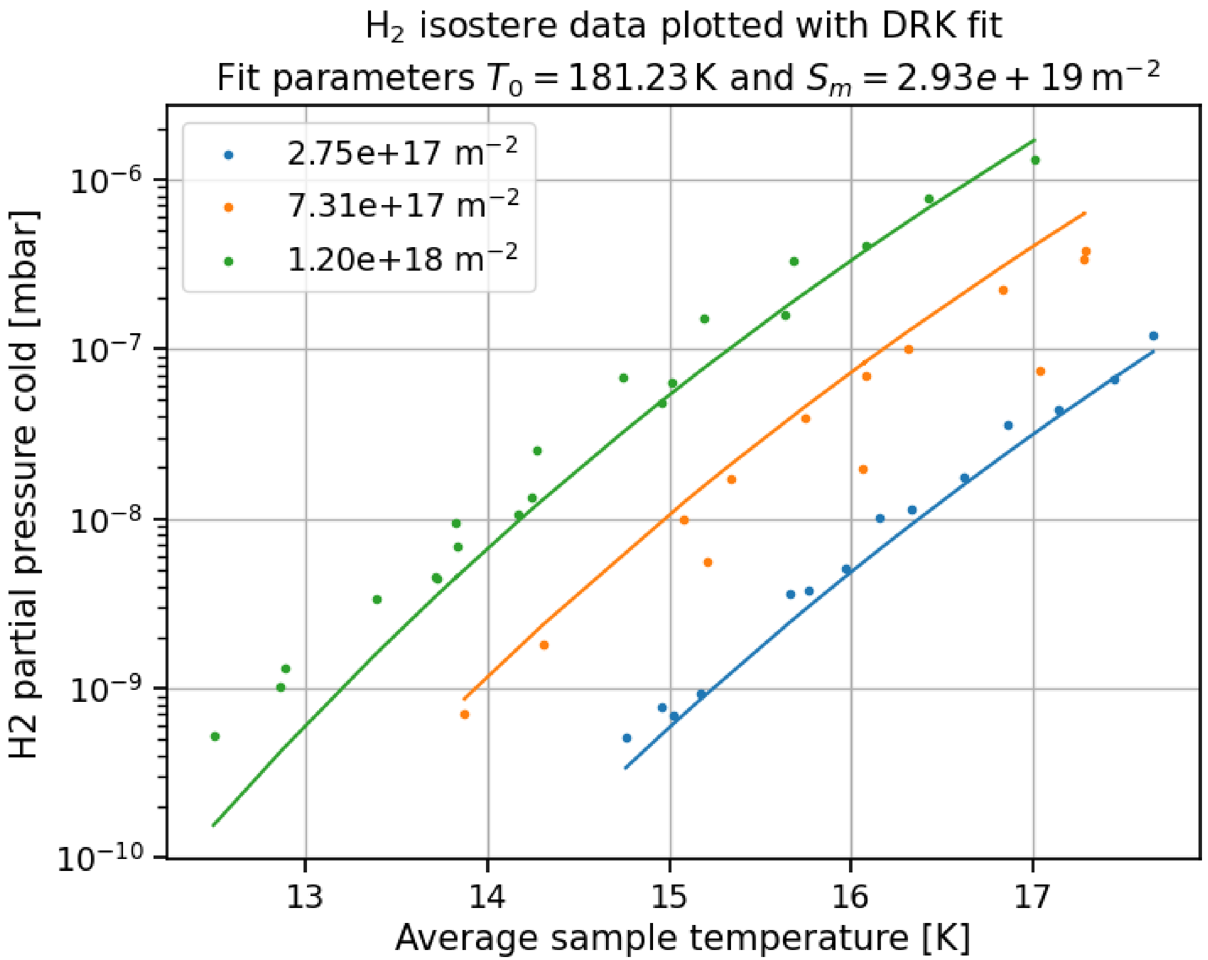


"TDS" after isostere measurement → Clear, distinct peaks at slightly different temperatures on masses 2, 3 and 4

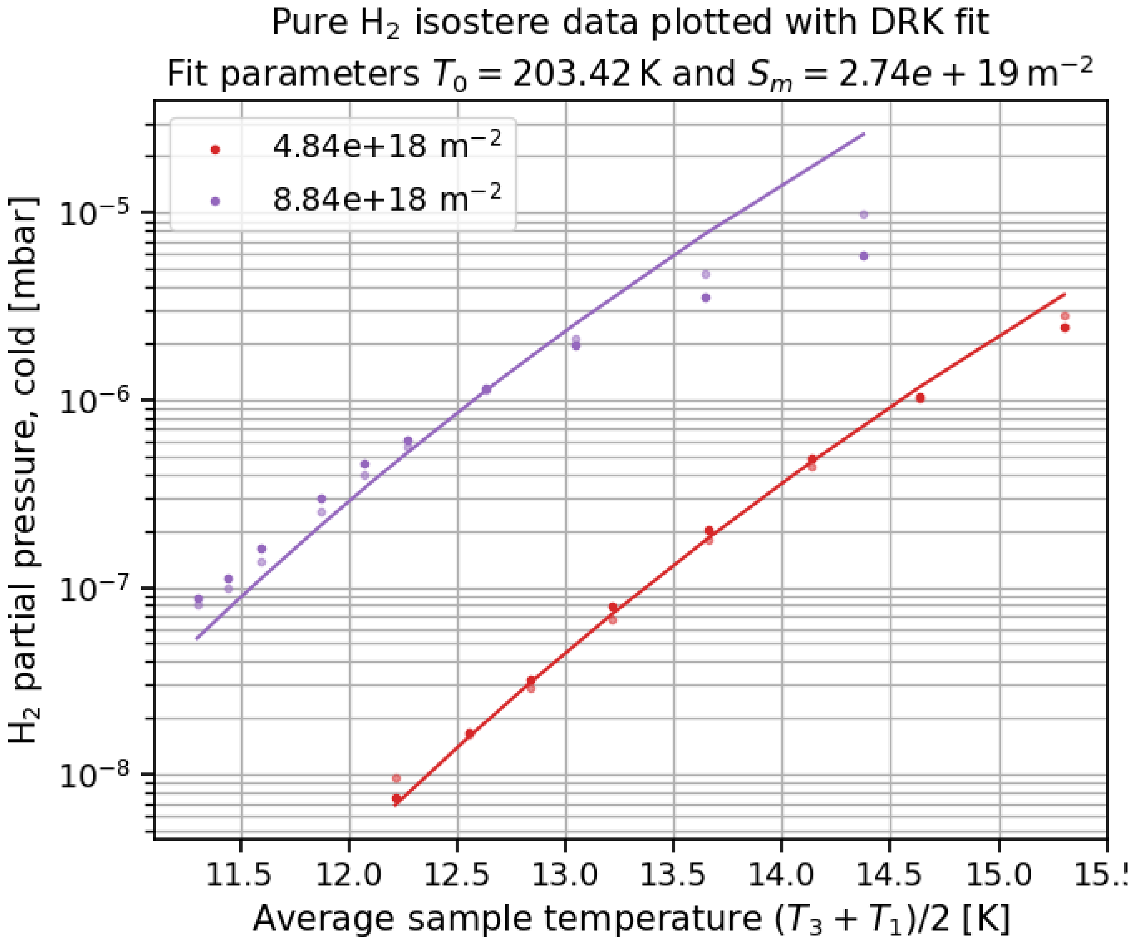


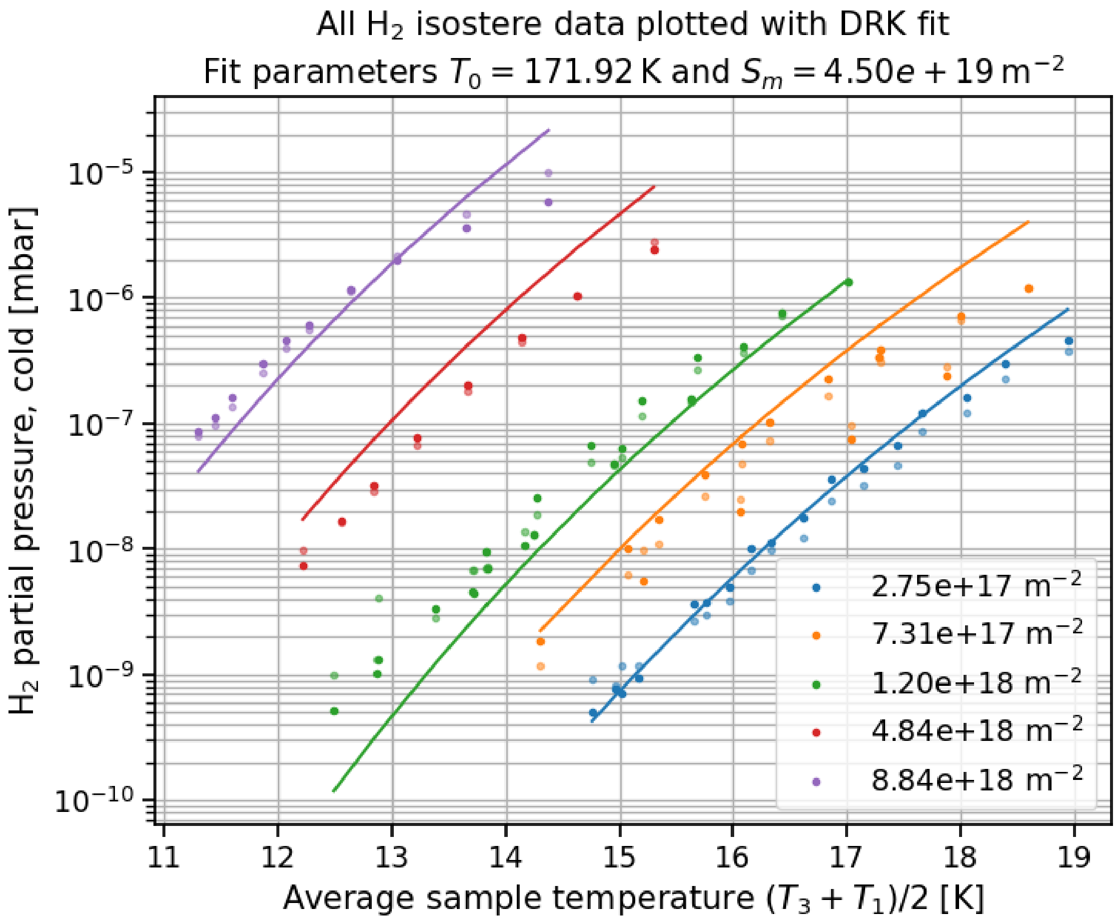
Joint H_2 and HD isosteres from HD injections





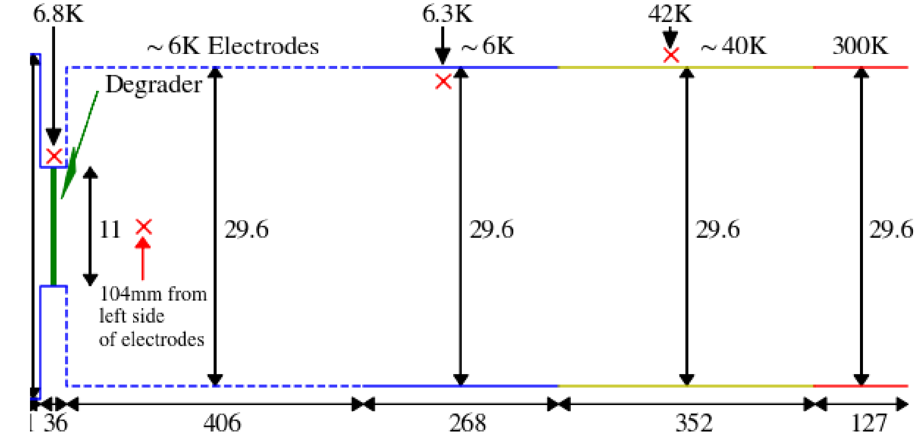
Pure H_2 injections and combination of all H_2 data

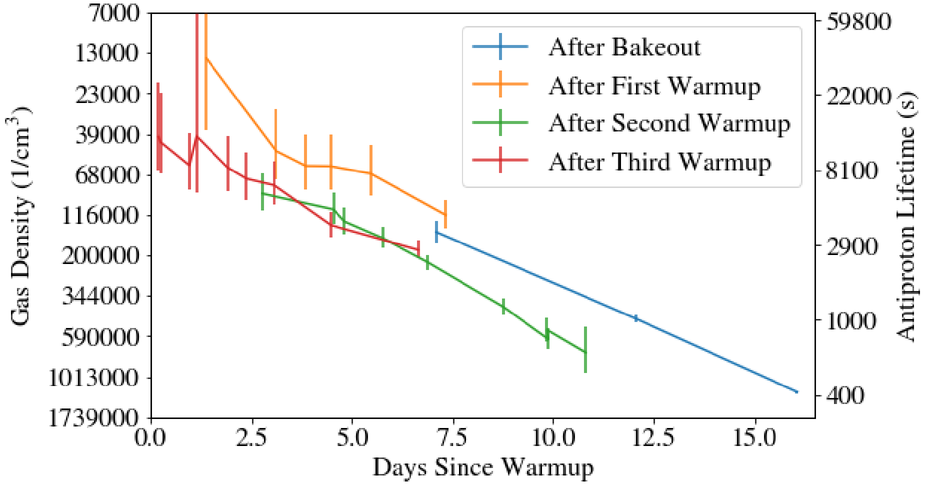




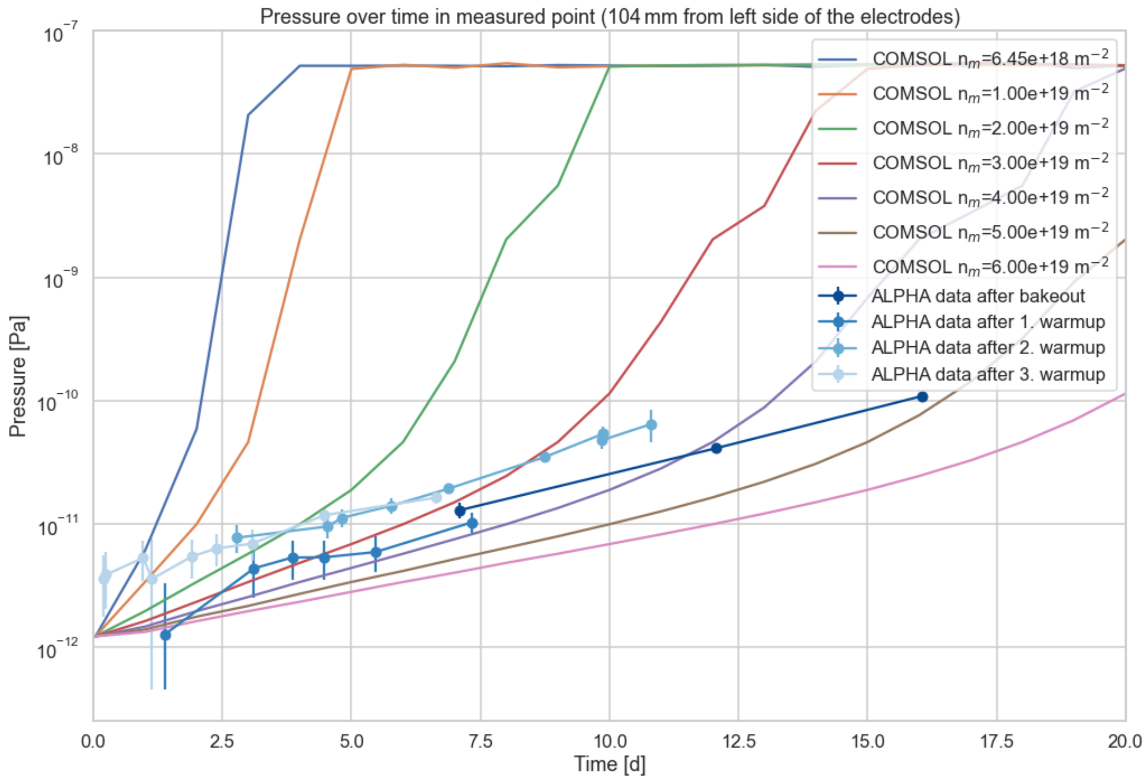
→ Combination of the two measurement methods might not be correct
→ Pure H_2 measurements still ongoing

Extracting H_2 isotherm data from $\bar{p}$ lifetime measurements in ALPHA with COMSOL simulations





Exemplary variation of the monolayer capacity with T_0=209K fixed



→ Vacuum in ALPHA is better than in simulations

→ Our isotherm assumptions for PUMA were conservative

Next steps

- Take more H_2 isostere data and find reliable fit values for the adsorption isotherm
- Verify H_2 isotherm with a pressure propagation measurement and COMSOL simulation
- Re-do some of the helium measurements with smaller temperature gradient

Conclusions

- Previous isotherm assumptions for the PUMA layout seem to have been conservative
- No anomalies or unknown effects could be found in the isotherm behavior of H_2 and He
- DRK model fits best for H_2 and He across many orders of magnitude

Thanks for your attention!