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Prevention of Residual Gas Condensation on Cryogenic Inertial Confinement Fusion Targets using a Warm Thin-Film Window

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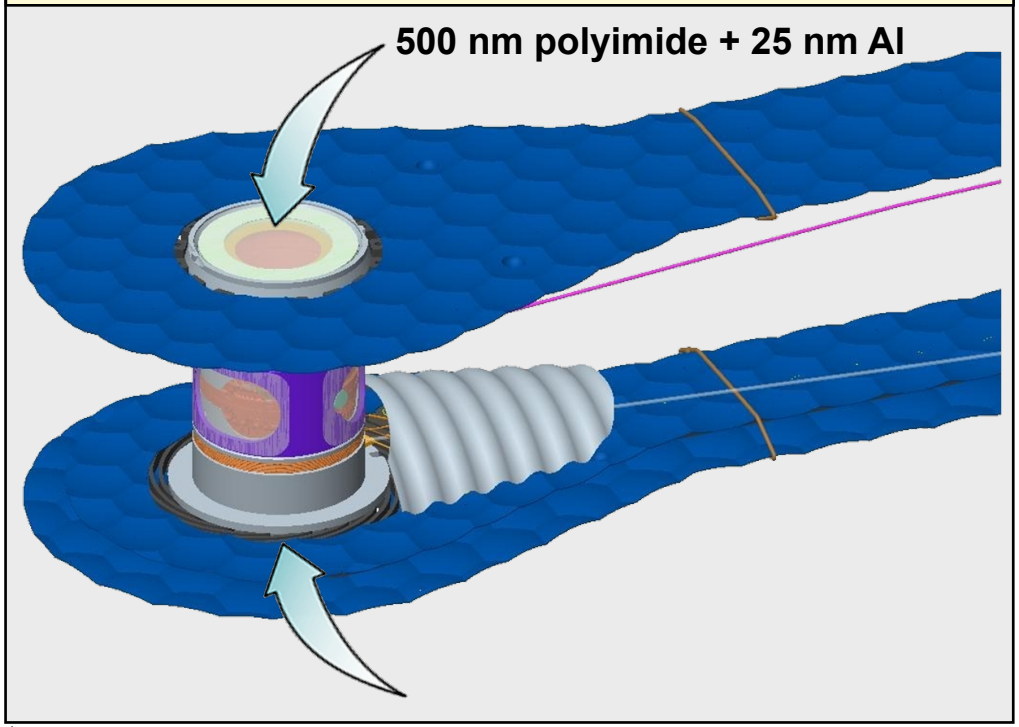
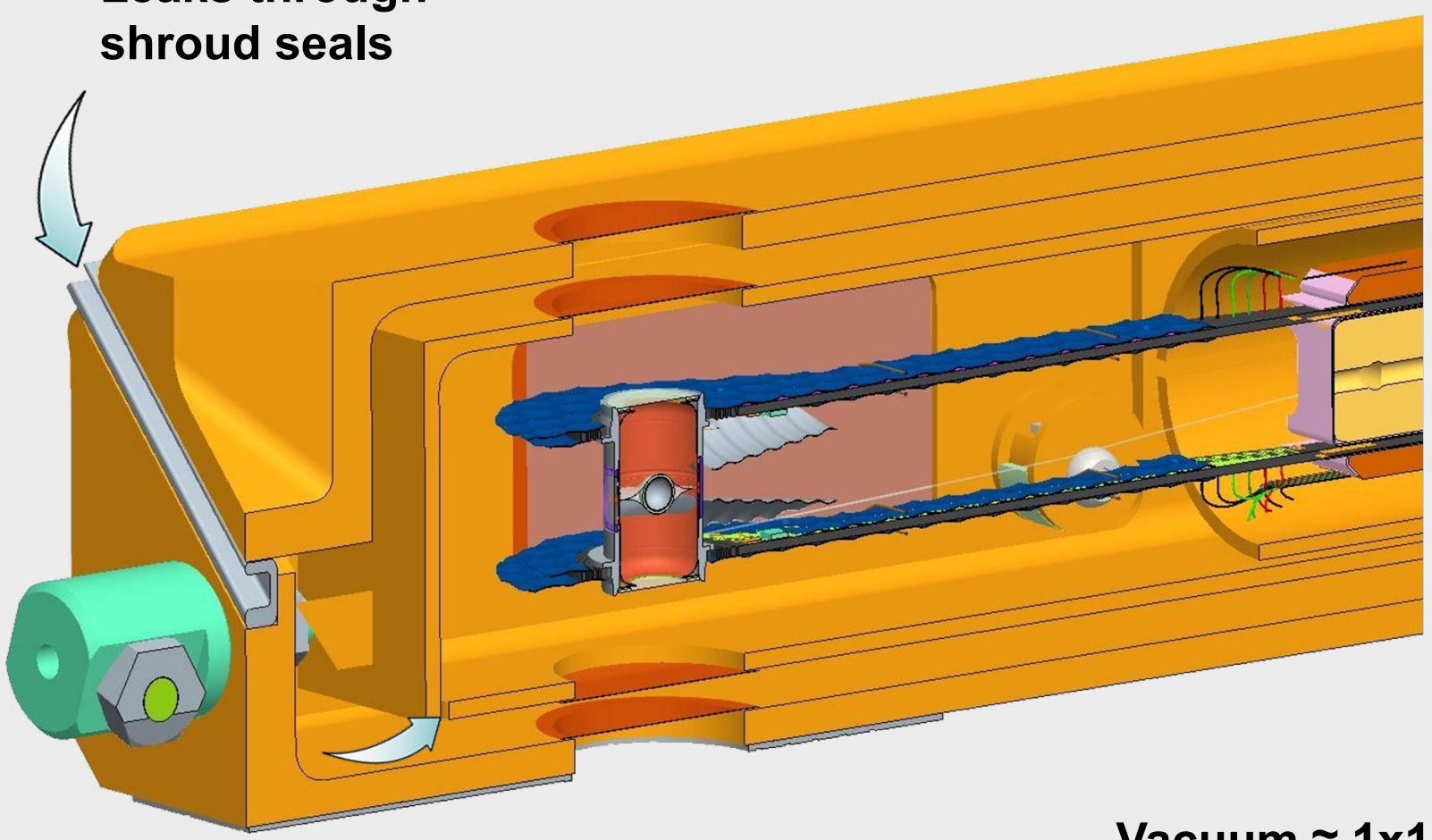
Ignition targets have thin windows to contain cold (<19K) hohlraum gas and keep out IR radiation at the 2 LEH ports

Laser entrance hole (LEH) windows



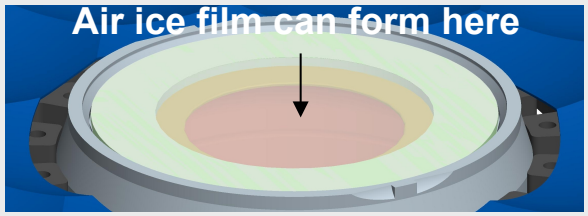
Full target assembly

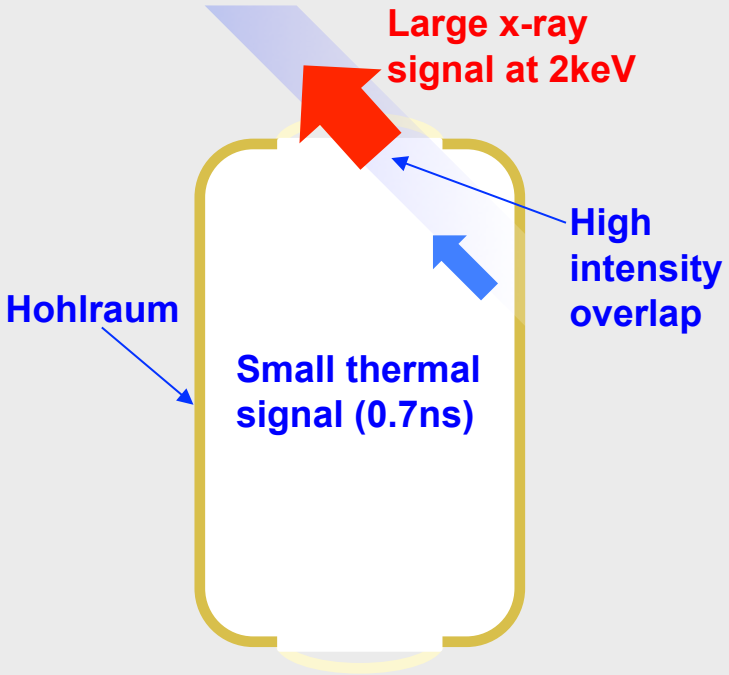
The target deployment system provides some isolation from the vacuum chamber but residual air still leaks in



LEH windows are cooled to < 19K by the hohlraum gas so residual air condensation can affect NIF experiments

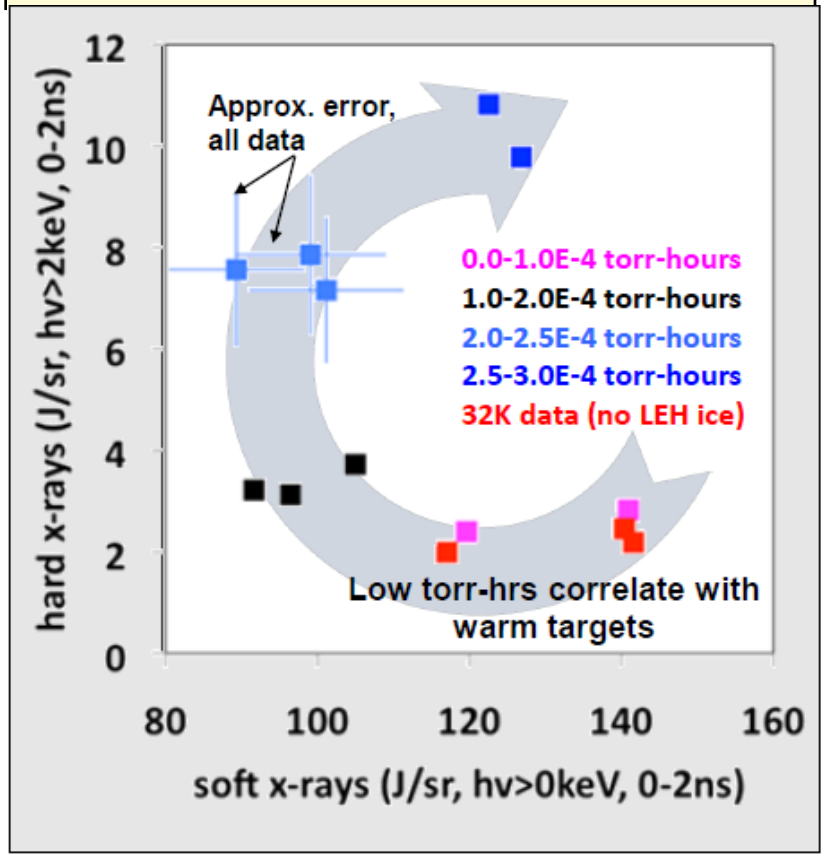
LEH air-ice effects





At > 2μm of LEH ice the laser stalls at the LEH

X-ray ratios scale with torr-hrs



- Laser must burn through the LEH window at t_0
- LEH T depends on the time to burn-through
- Condensate at window increases the LEH T
- Hard x-rays are a signature of the higher T plasma

To achieve an ice accumulation rate of < 1 nm/hr needed for THD targets, we must lower the pressure to < 2×10^{-9} torr - this is impractical

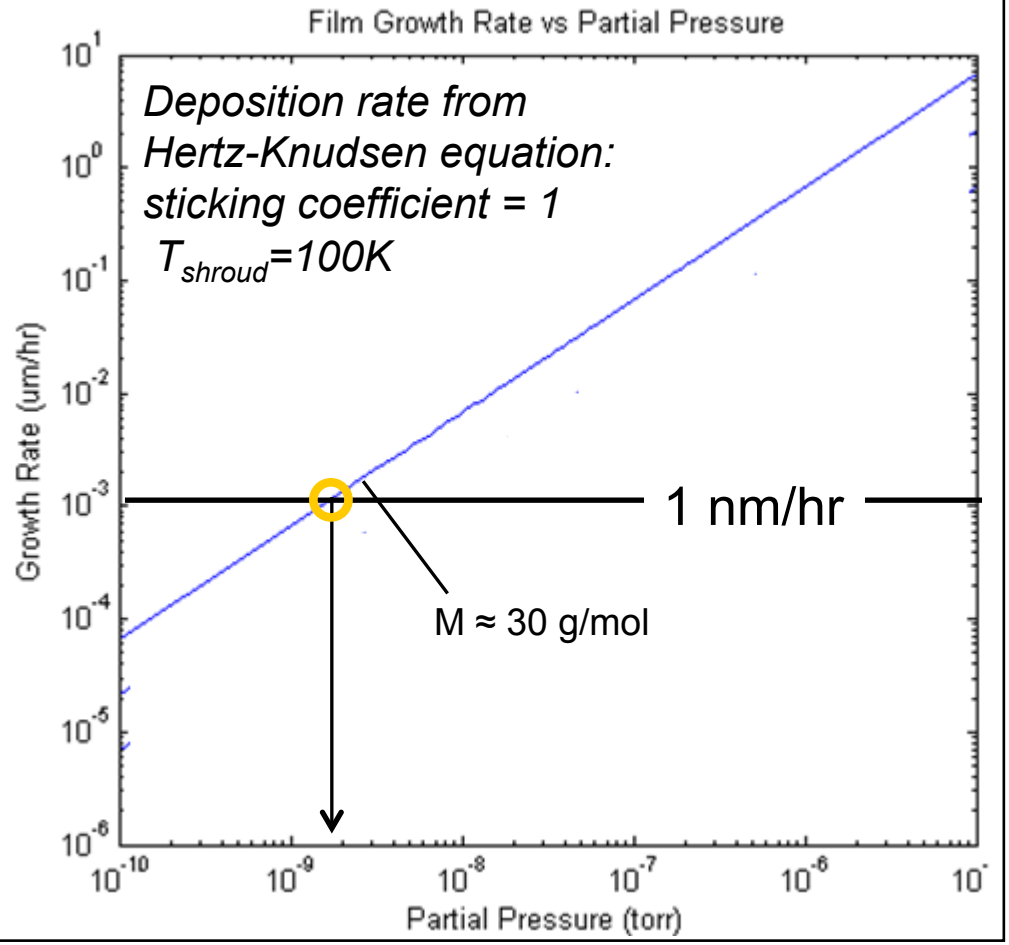
Hertz-Knudsen equation[1]

$$\frac{dh_i}{dt} \propto \frac{M_i^{1/2}}{\rho_i}\left(\frac{s\,p_i}{T_{shroud}^{1/2}} - \frac{p_i^*}{T_{LEH}^{1/2}}\right)$$

$$i = N_2, O_2, H_2O, \ldots$$

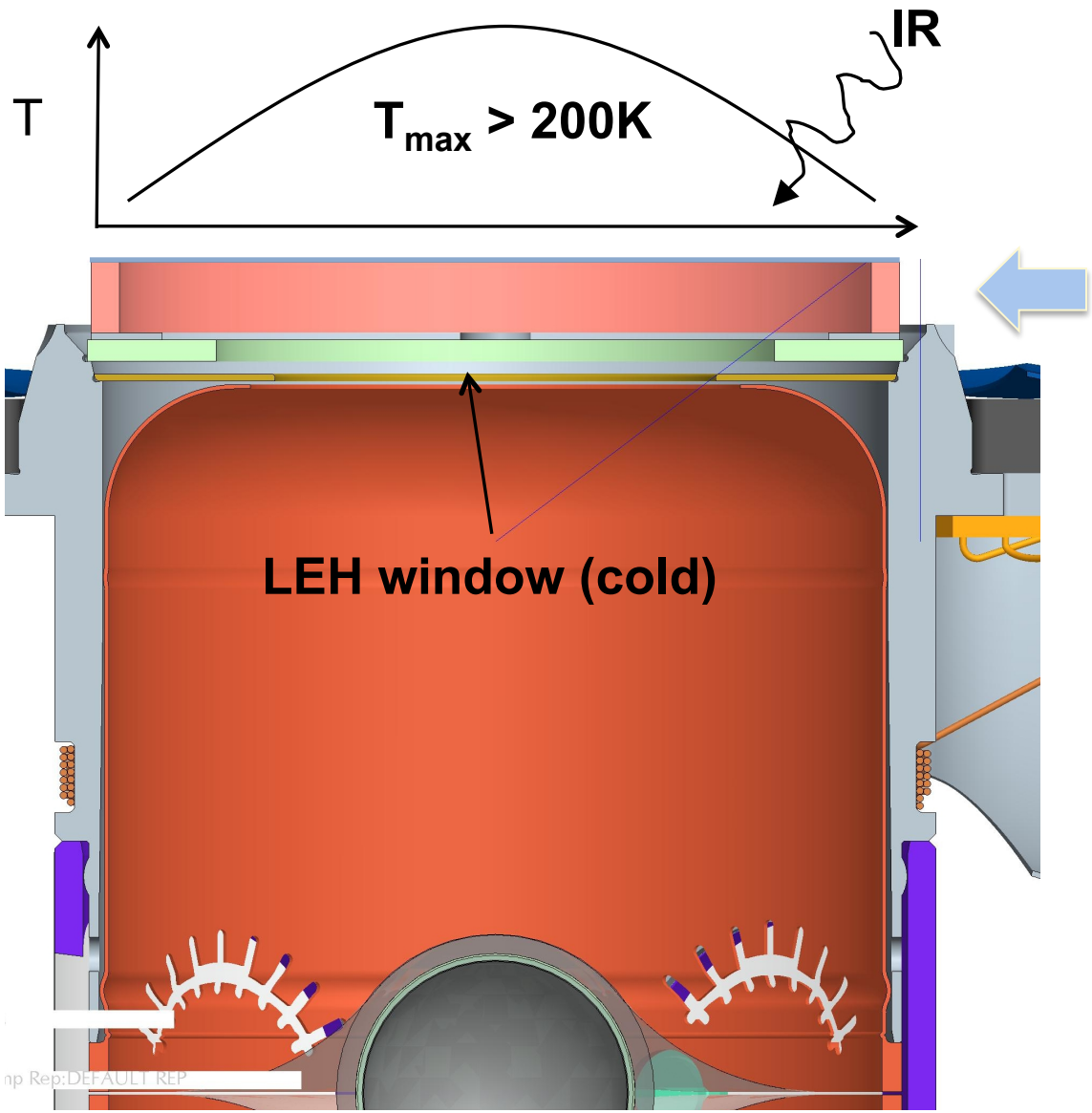
h = film thickness
ρ = solid density
T = temperature
s = sticking coefficient
p = partial pressure
p^* = saturated vapor pressure
M = molecular weight

Ice accumulation rates



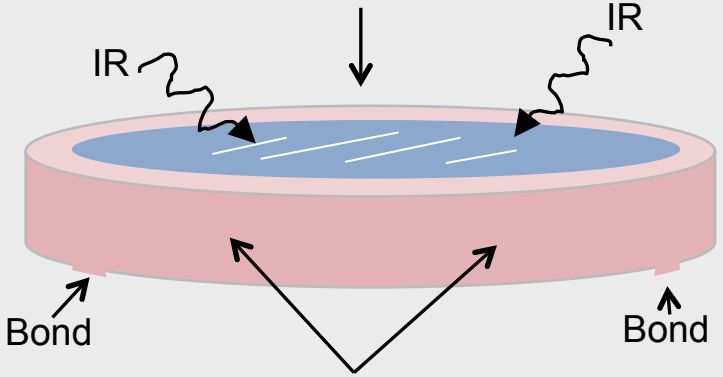
1. P. Rahimi and C. A. Ward, "Kinetics of Evaporation: Statistical Rate Approach," *Int. J. of Thermodynamics*, **Vol. 8**, (no1), pp. 1-14, (2005)

To eliminate LEH ice, the idea was to use a second warmer film that encloses each of the LEH windows- like a 'storm' window



Warm window concept

1. 150 nm polyimide/carbon film absorbs ambient IR and heats up above air condensation temperature

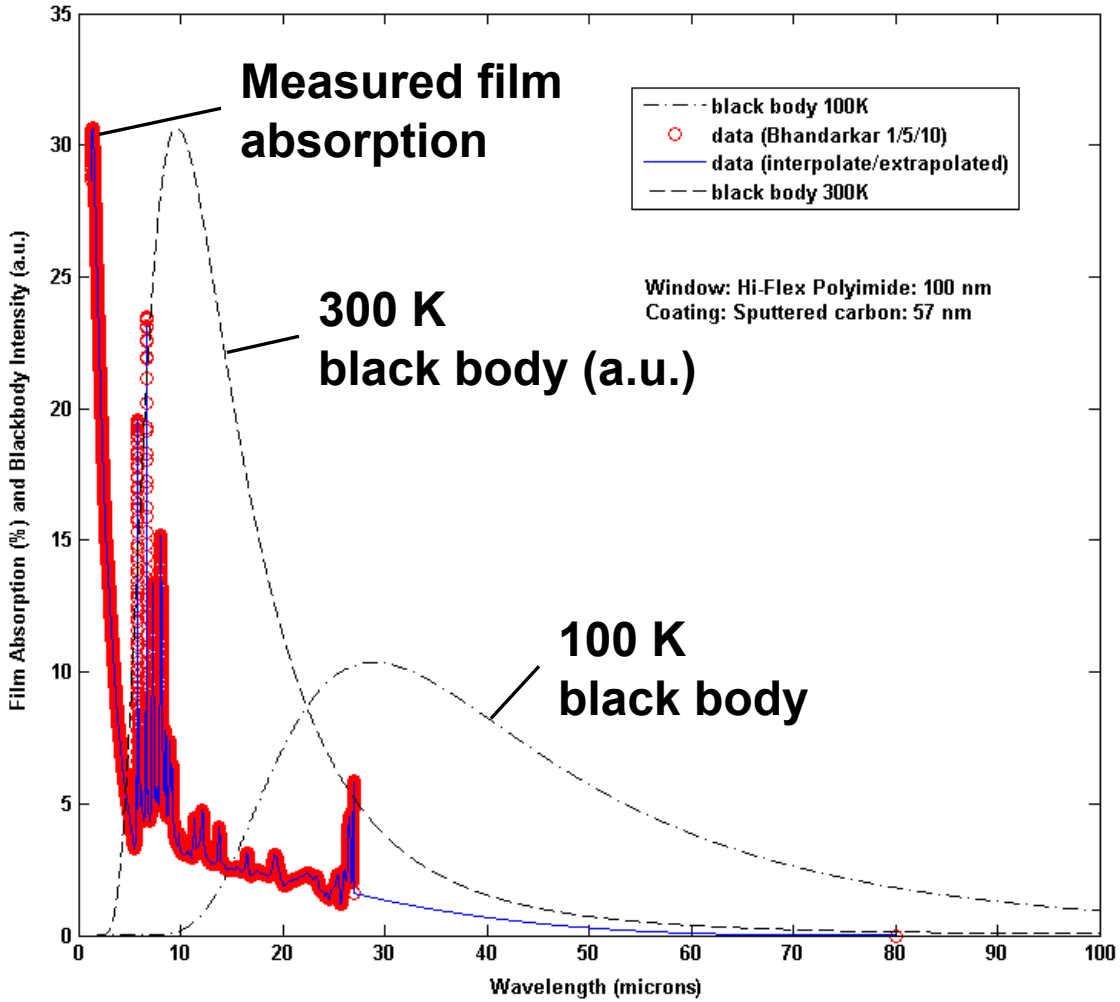


2. Polystyrene ring supports the window film and blocks gas flow to the inner LEH window at its base

3. The ring bonds have minimal cross-section and so thermally isolate the window assembly from the underlying cold surface

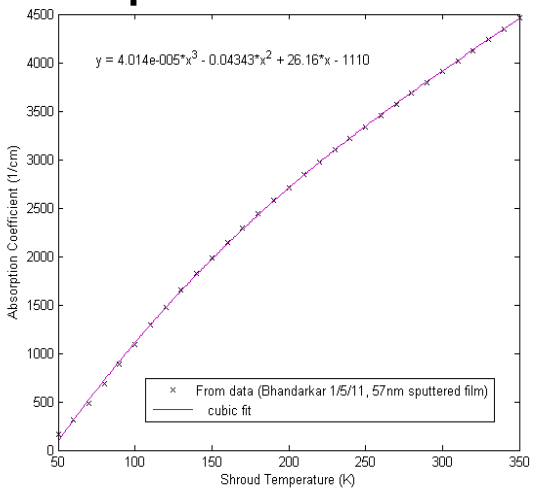
Warm window performance is better at shorter wavelengths – due to higher IR flux and absorption

Warm window film IR absorption

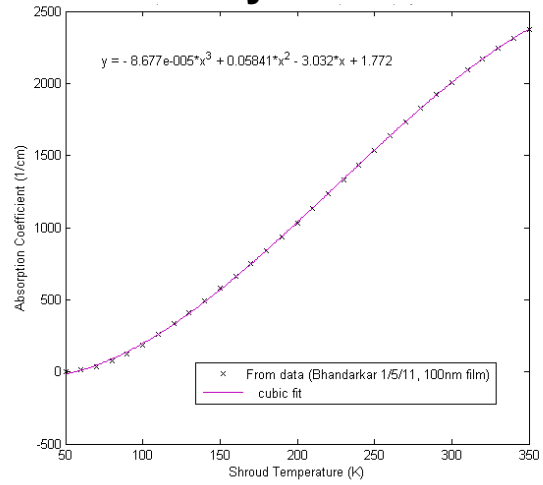


Absorption coefficients

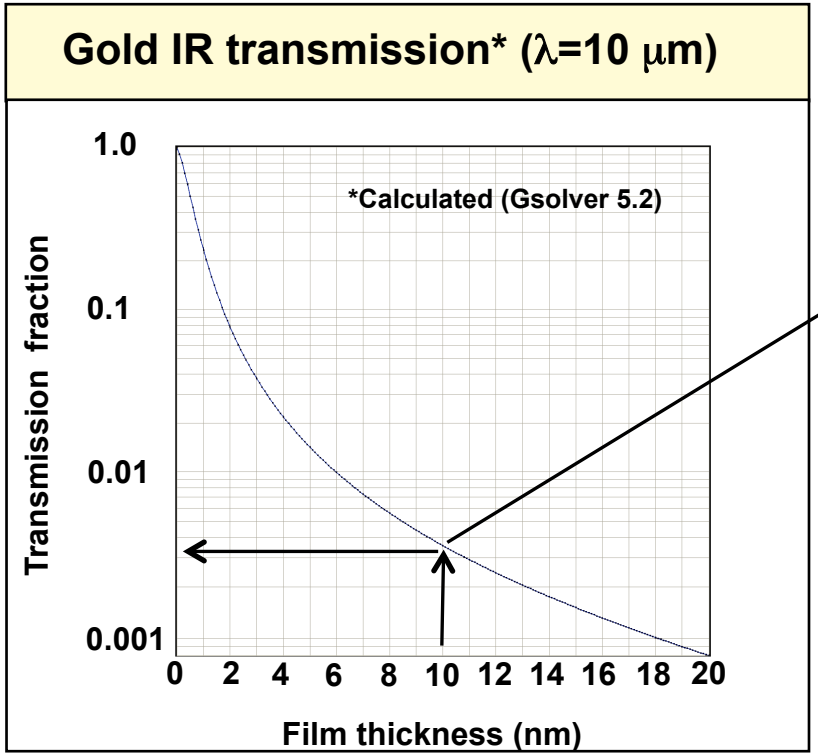
Sputtered Carbon



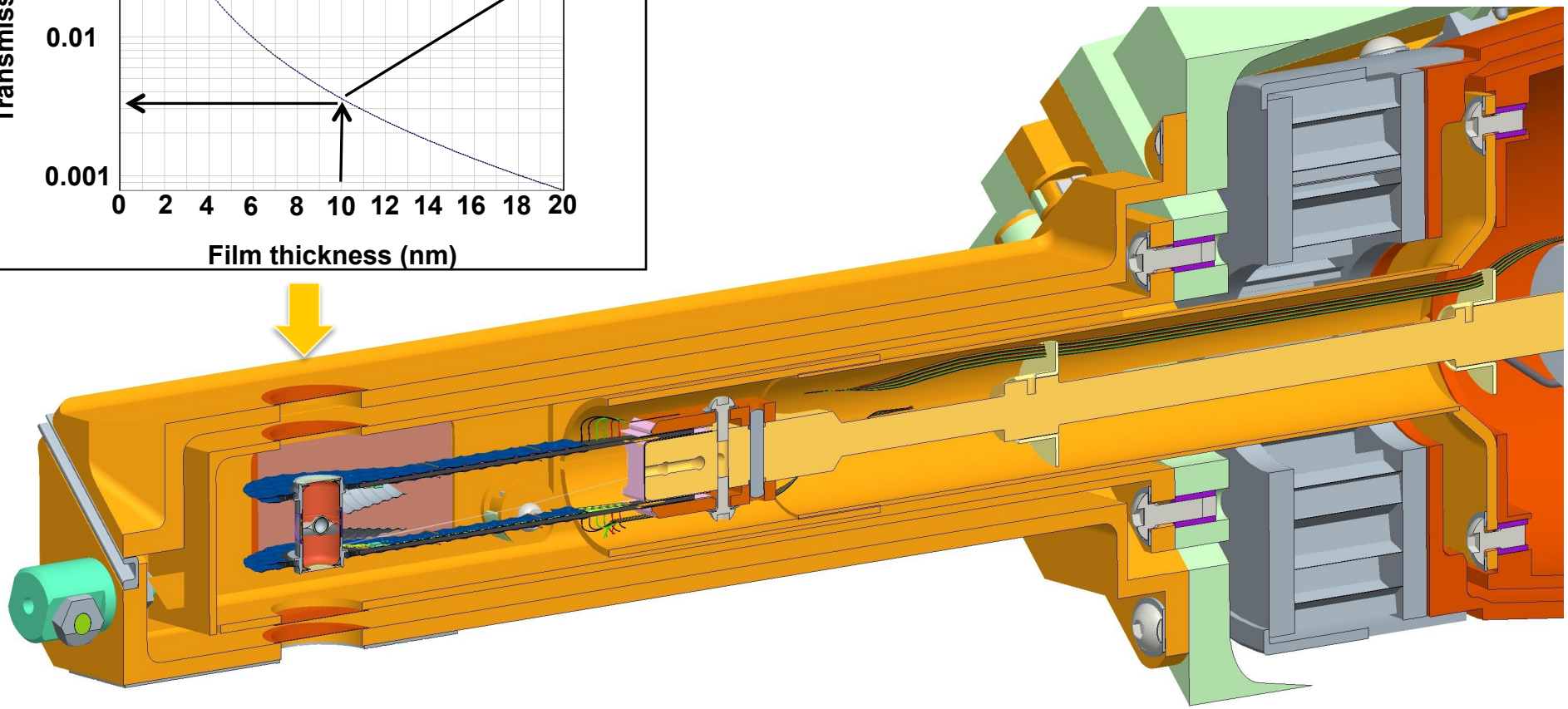
Polyimide



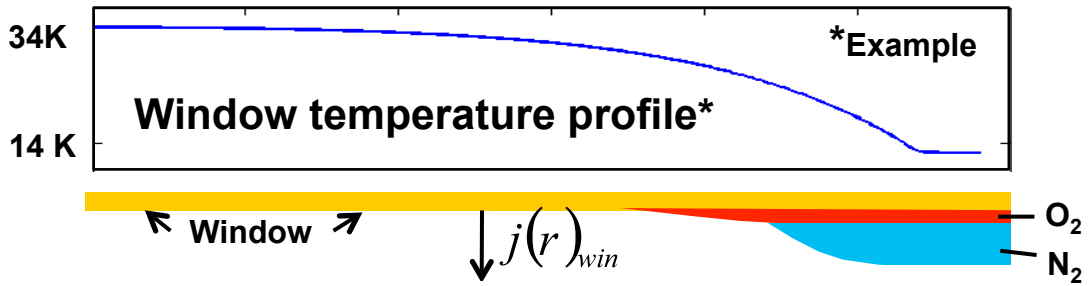
By tailoring shroud window coatings, we control 300K IR flux onto the warm window to optimize performance

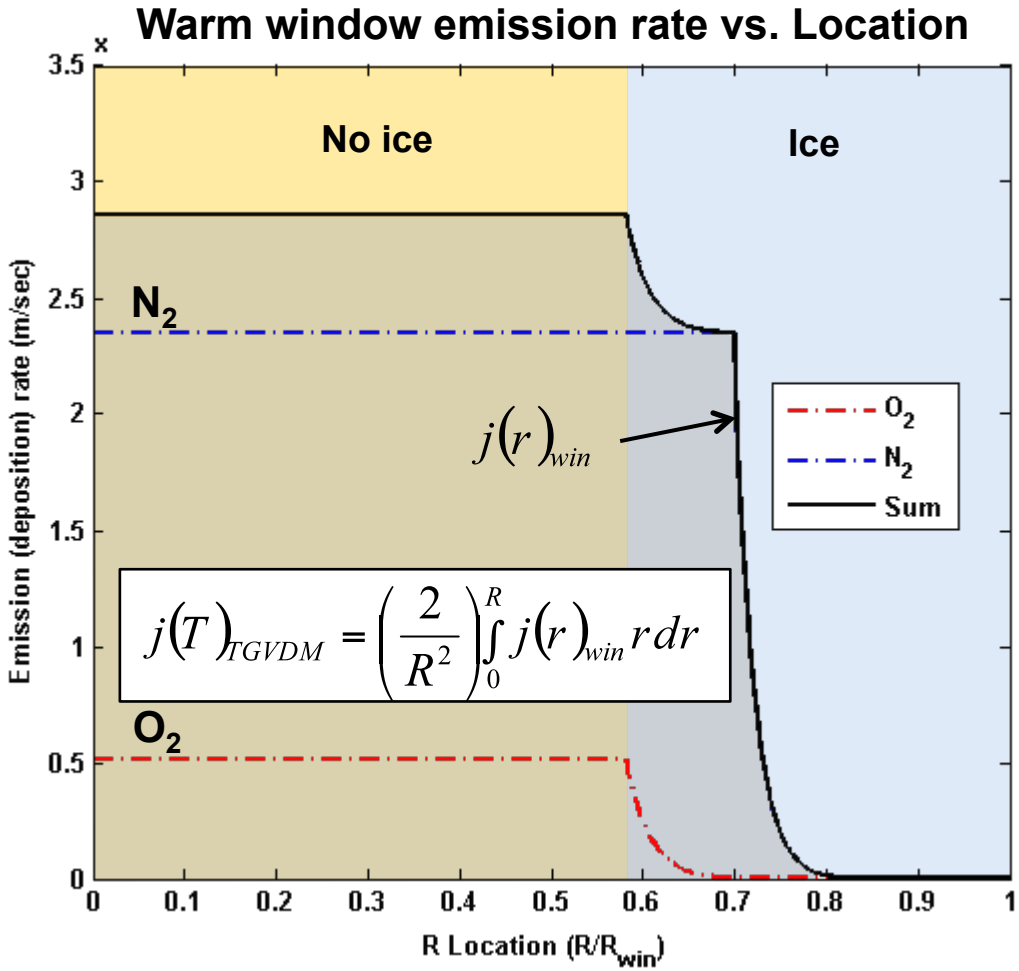


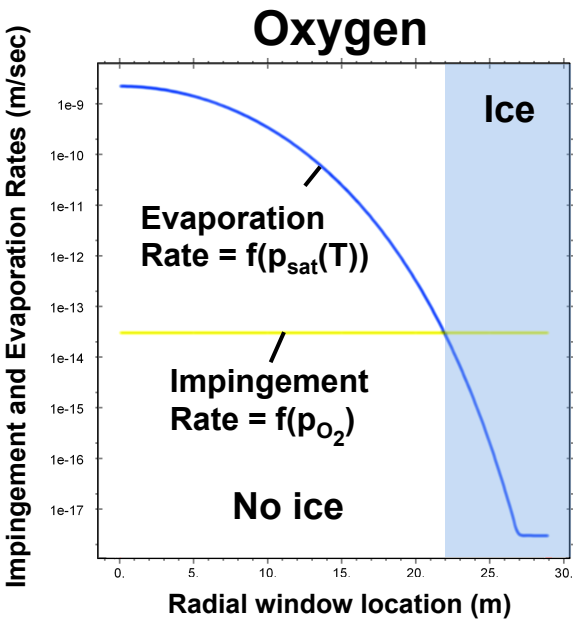
Optimum for layered targets is T ≈ 0.3%

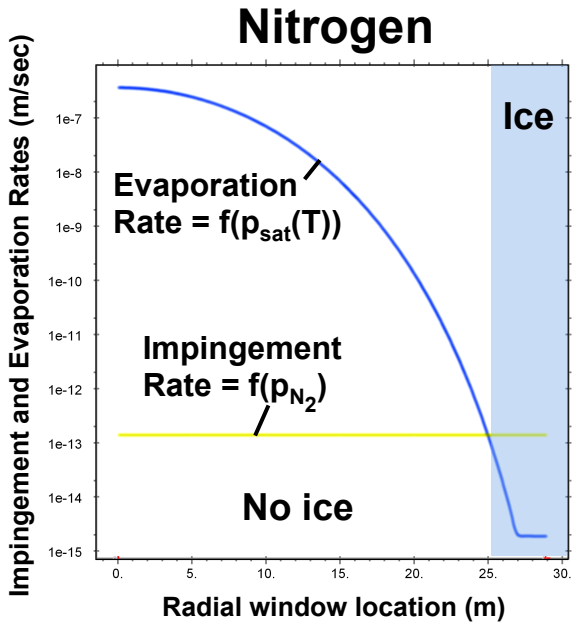


TGVDM response was modeled as gas emission from the window surface via a Hertz-Knudsen mechanism

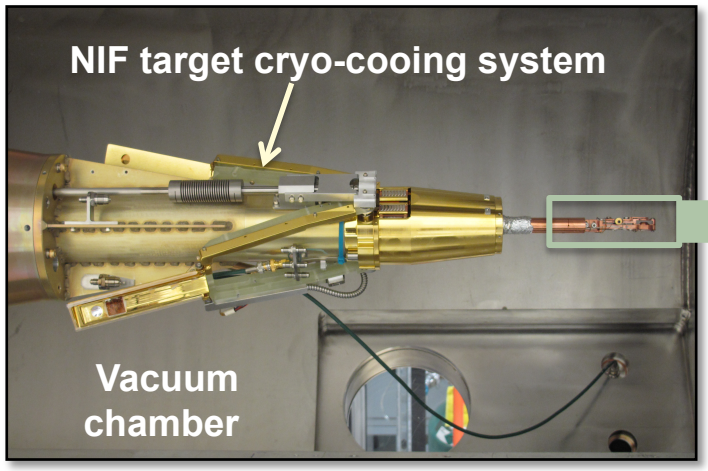


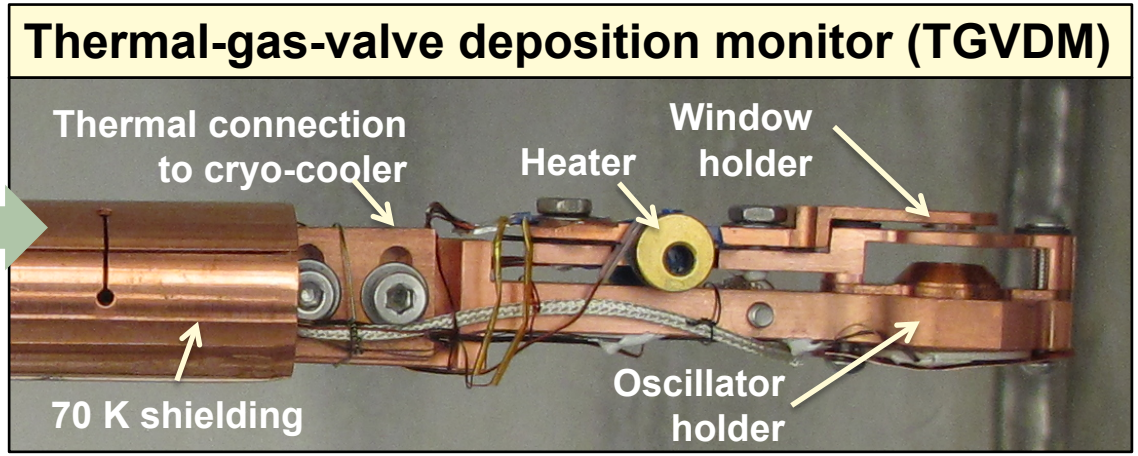


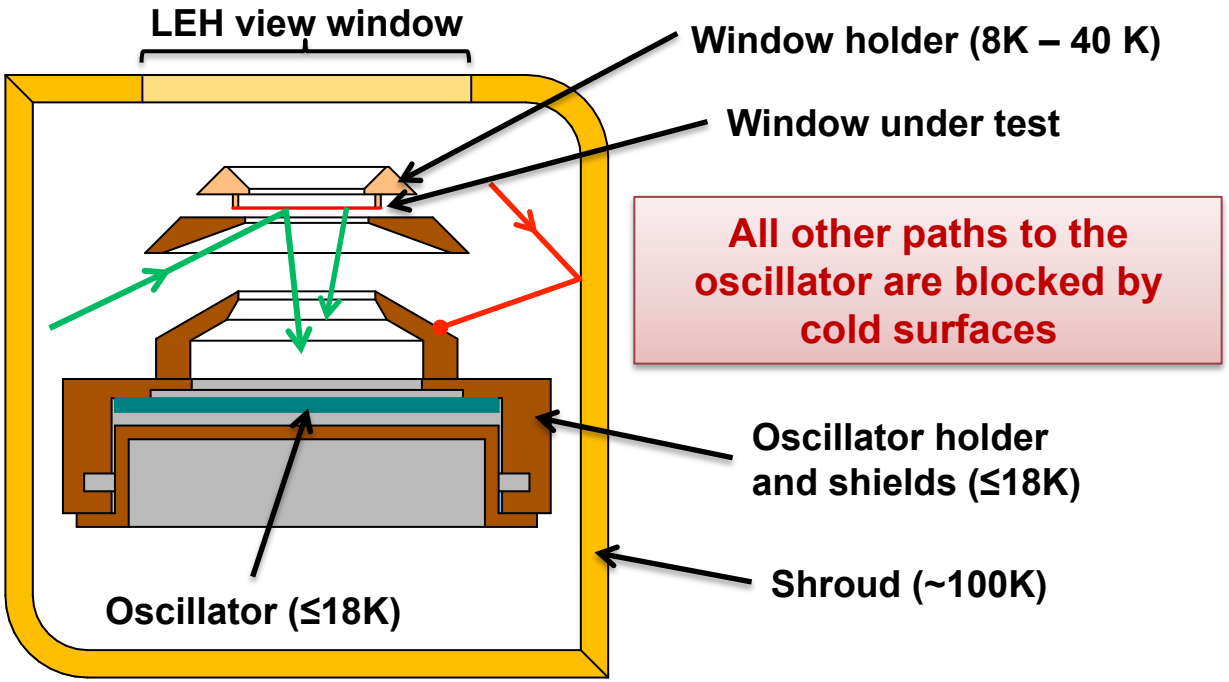




To verify thermal performance we built a system to measure gas particles reflected from a warm window





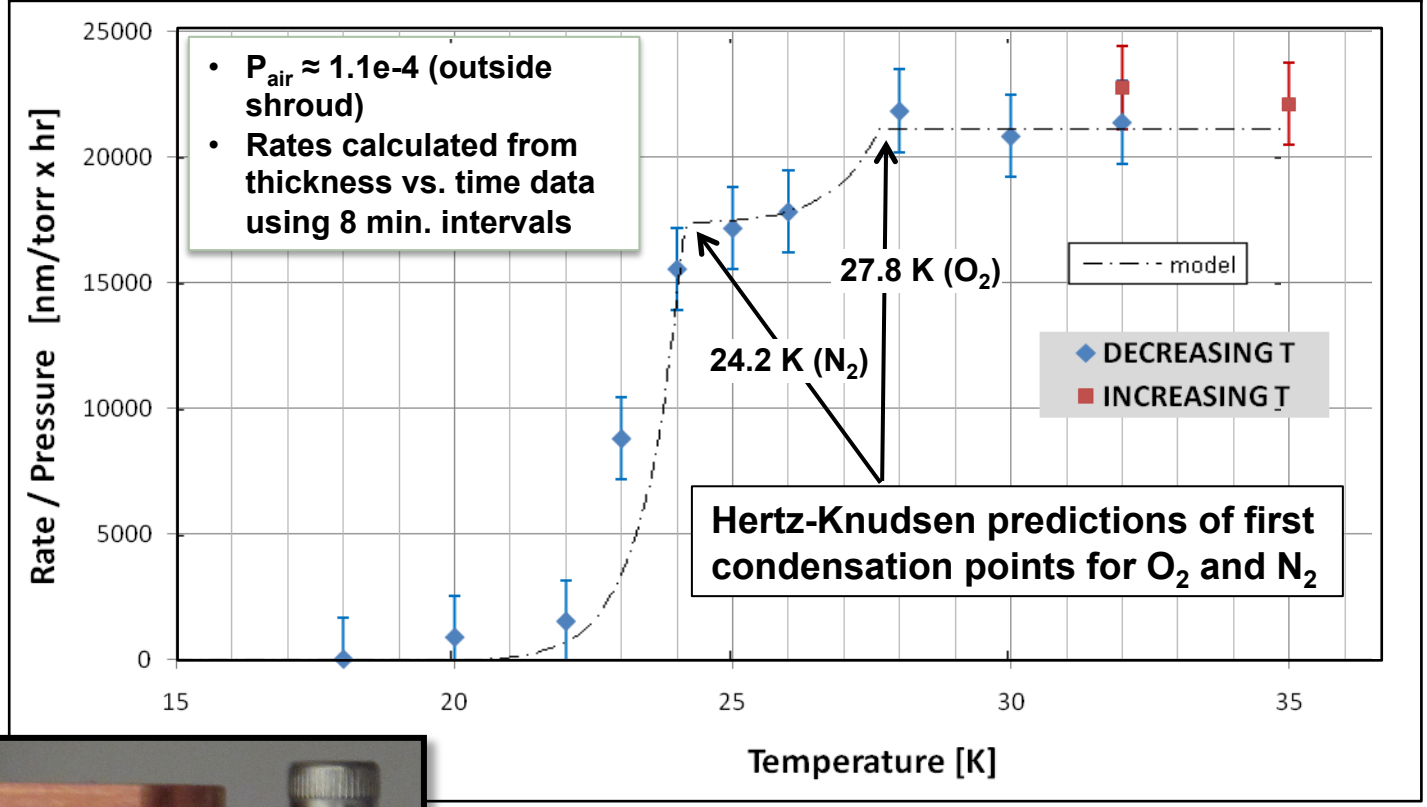


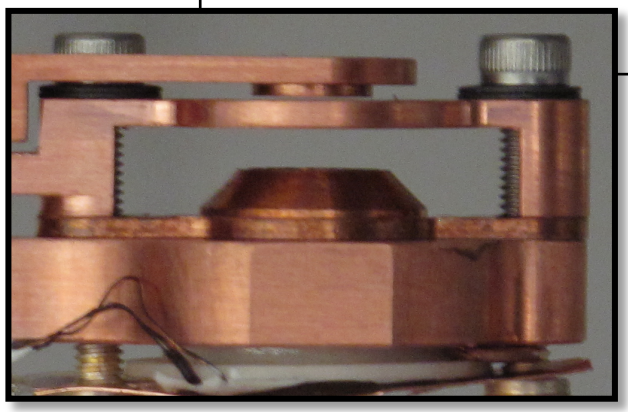
Molecules emitted from the TGVDM window may reach the oscillator

Modeling TGVDM response gives the temperature profile of the window

Initial TGVDM measurements with an isothermal copper window showed the expected behavior

Validation of isothermal TGVDM response



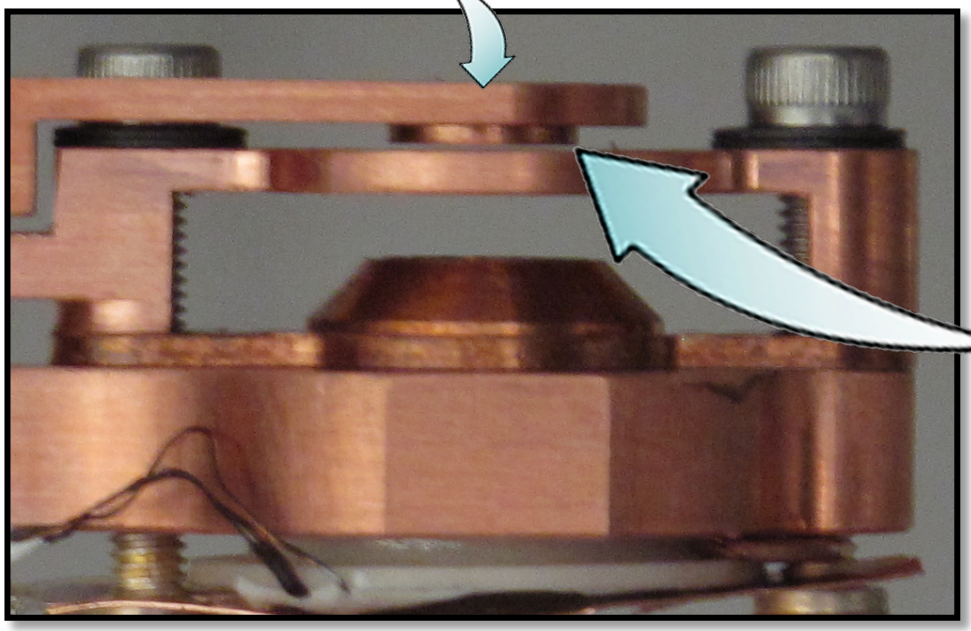


There is sufficient fidelity in the data to discern inflections from sequential O_2 and N_2 contributions to the TGVDM deposition rate

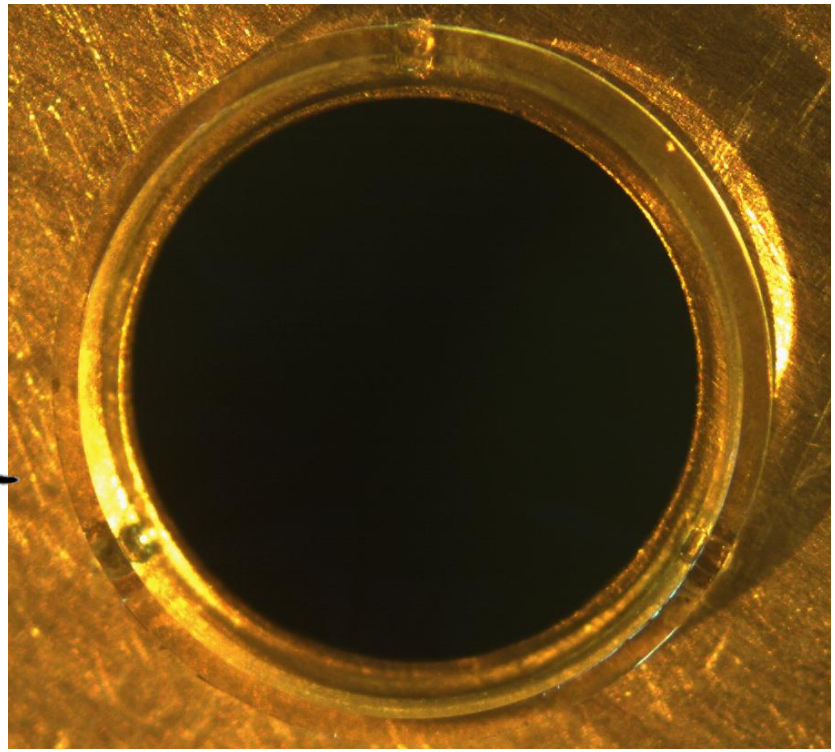
Warm window assemblies were bonded to the upper temperature-controlled TGVDM copper plate

Side view of TGVDM head

Temperature controlled window base (8K – 40K)



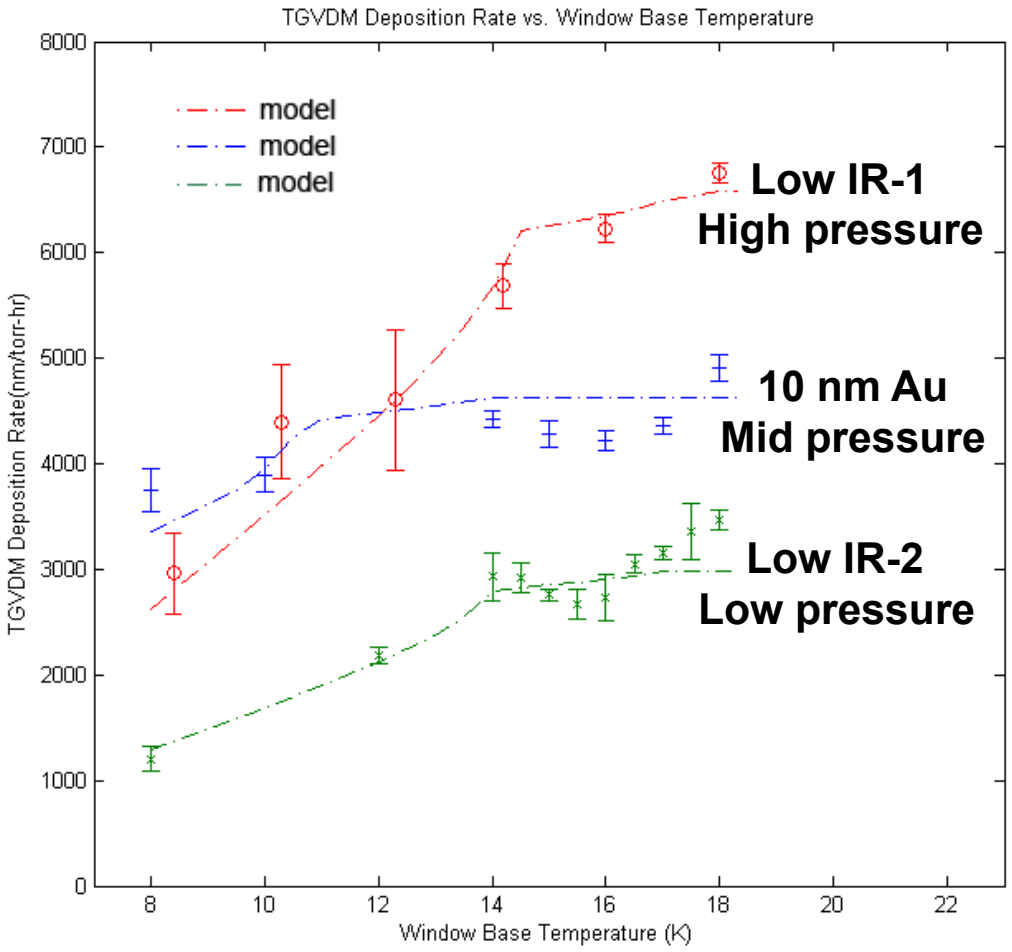
Warm window on copper TGVDM window base



Now, gas particles must be emitted from the warm window film surface in order to reach the quartz oscillator microbalance

A single model is able to describe all the warm window TGVM data

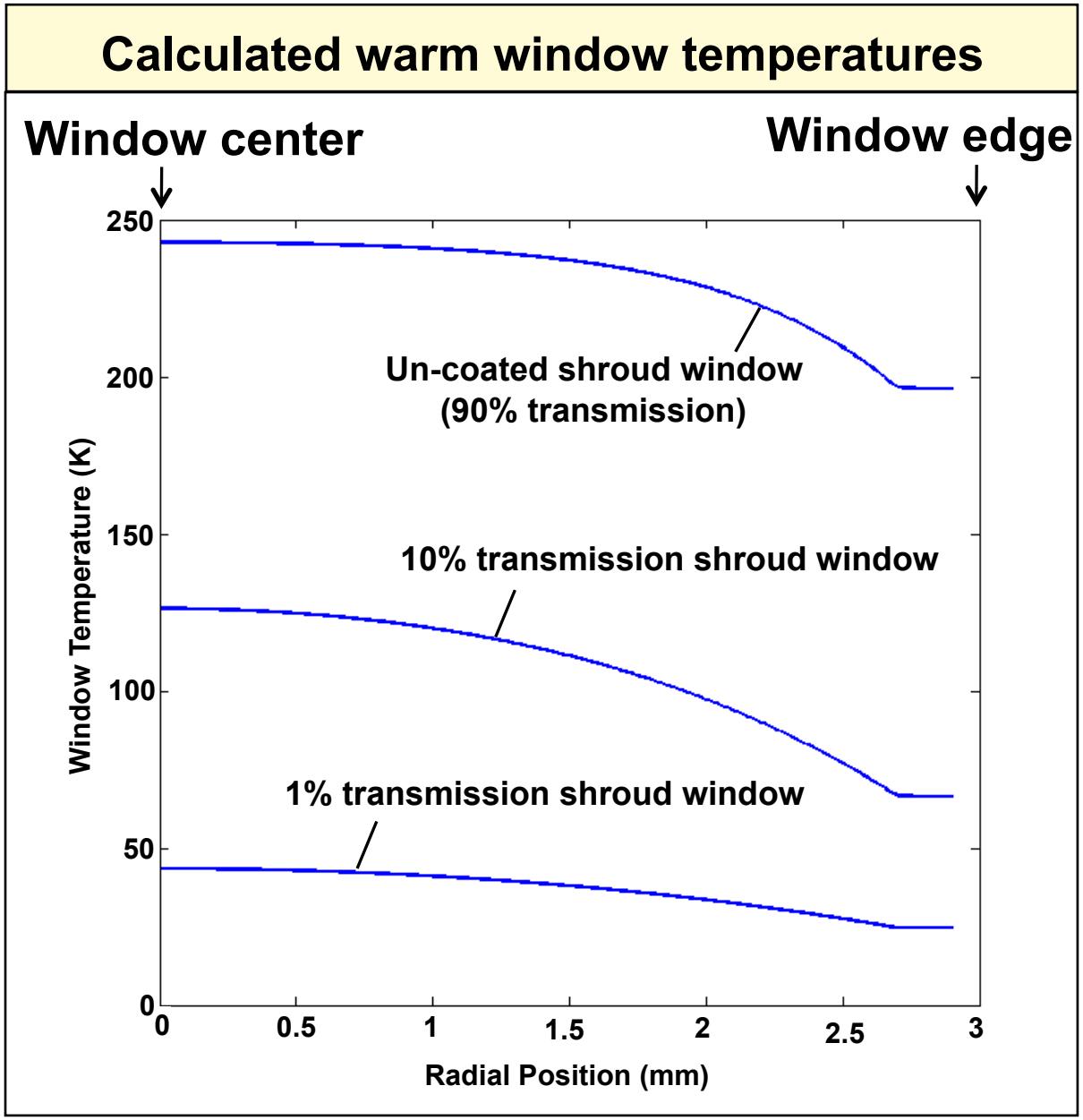
TGVDM data with best model



Best model characteristics

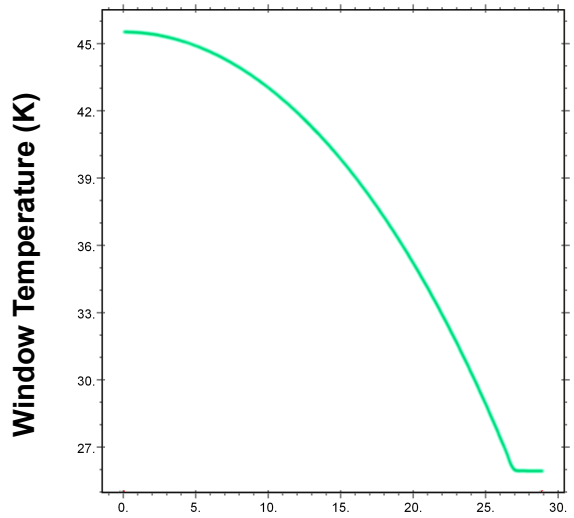
- IR coupling -> 10% lower than measured room temperature value
- k carbon film -> 2X higher than initial estimate from literature
- Support ring bond -> 7% smaller than original estimate based on design geometry

As expected, the model predicts warm window temperature will be a strong function of IR flux



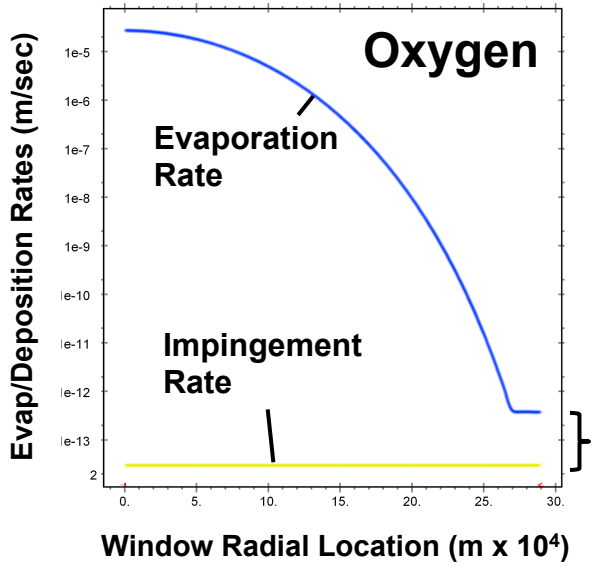
Now NIF cryogenic targets with warm windows have significant thermal margin against LEH condensation

NIF warm window model results



- 0.3% 300K IR leak
- T_{TMP} = 18K
- p_{ch} = 1x10^{-6} torr

← 26 K edge temperature



1.5 K equivalent margin in TMP temperature

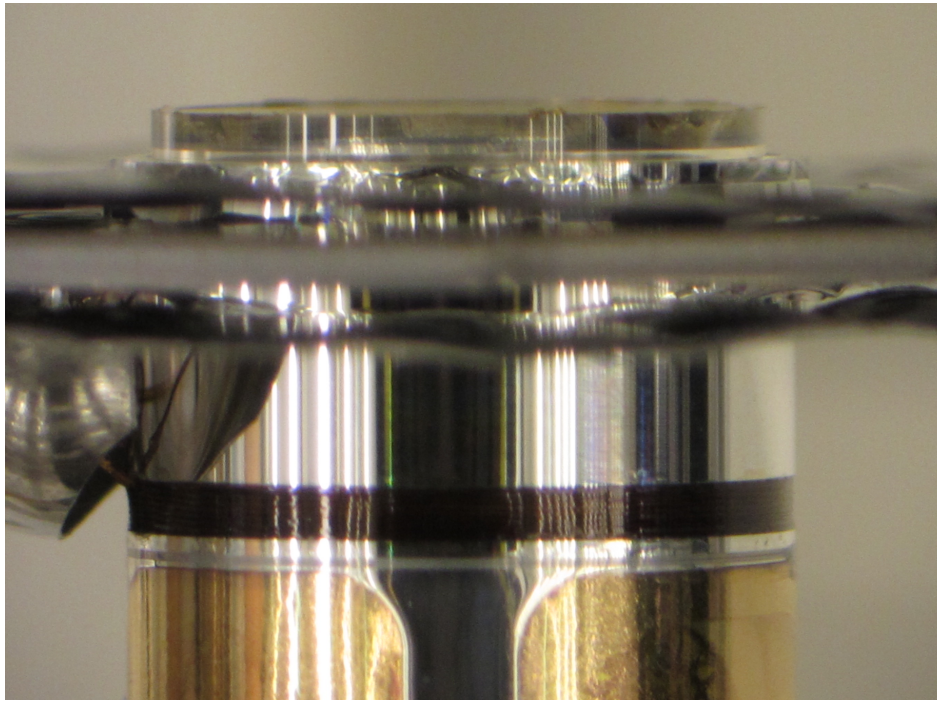
Chamber pressure margin (as TMP temperature)

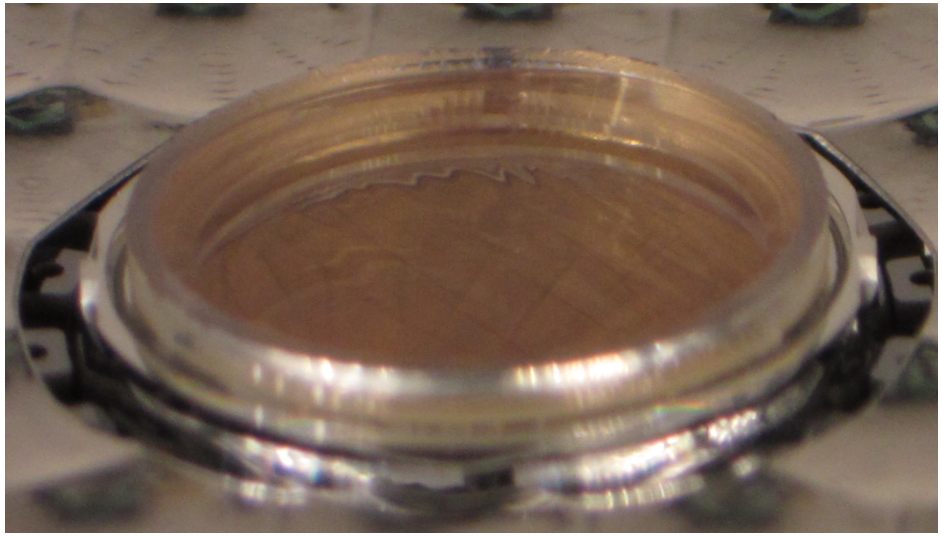
P_{ch} (torr)*	T_{ice} (O_2)	Margin
1x10^{-6}	24.5 (K)	+1.5 (K)
1x10^{-5}	26.0 (K)	0 (K)
1x10^{-4}	28.0 (K)	-2.0 (K)

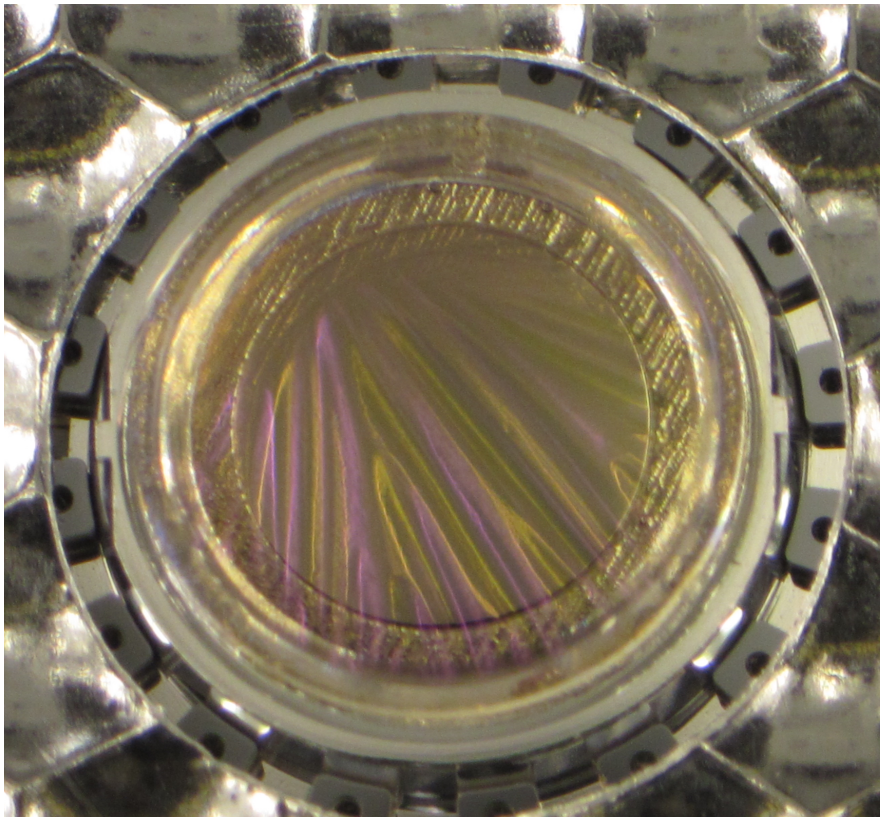
* Assumes 21% oxygen

The calibrated model predicts warm windows should remain ice-free at any chamber pressure below 1x10^{-5} torr

Warm windows have been deployed on multiple platforms including THD and DT layered targets

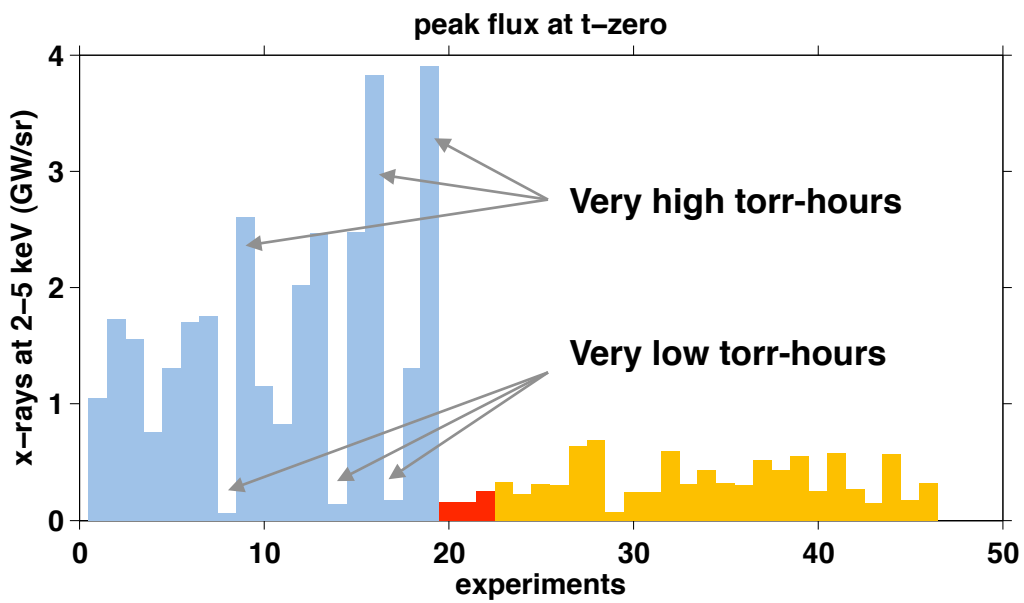




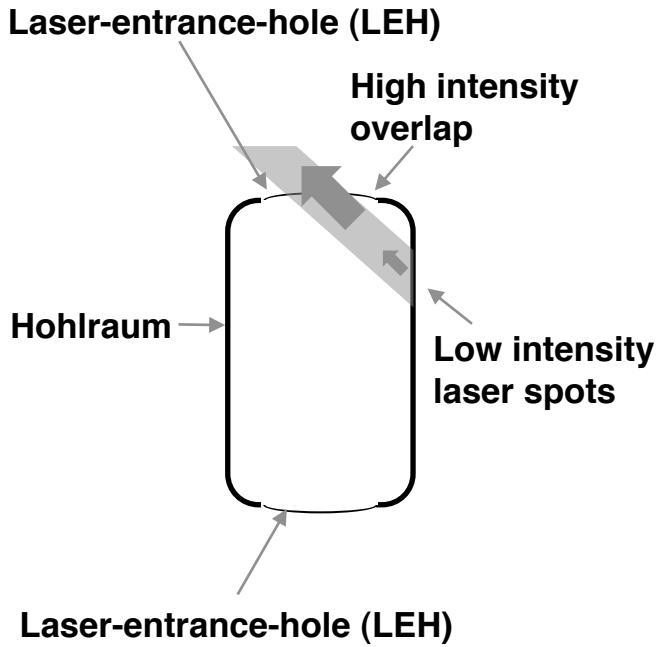


NIF X-ray spectrometer measurements confirm little or no LEH condensate with warm windows installed

History of LEH ice effects on NIF



Ice signature originates in LEH overlap region



Summary

- Condensation of vacuum chamber residual gases on the laser entrance hole (LEH) region of cryogenic ICF targets has been eliminated by adding a supplemental warm-window to the LEH closure assembly
- The warm window uses ambient IR energy to attain temperatures well above the condensation temperature of typical vacuum residual gases
- Thermal performance of the warm window has been verified by using the warm window as a gas valve for molecular flow into a crystal oscillator mass gauge
- The desired performance of warm windows on ICF targets has been verified by X-ray emission data taken on NIF