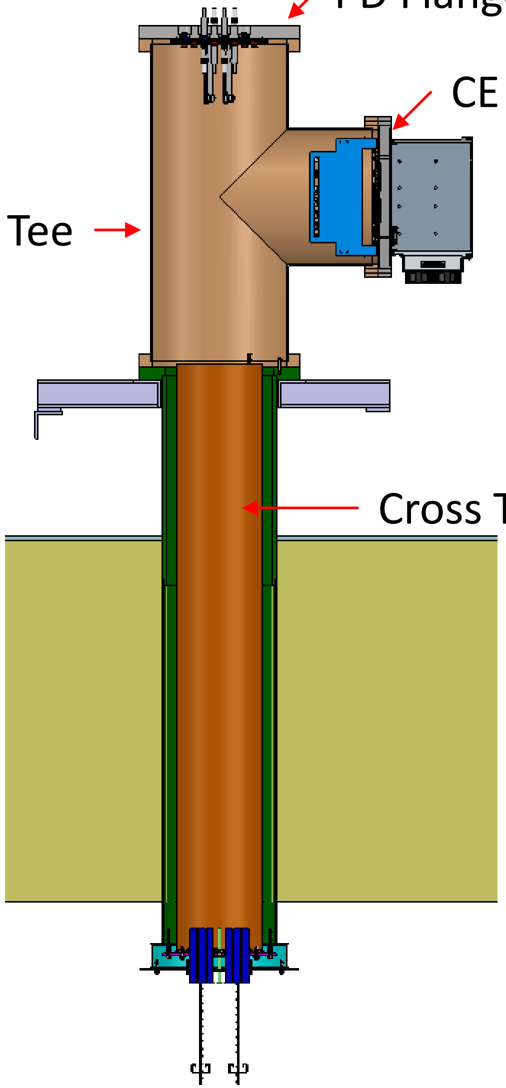
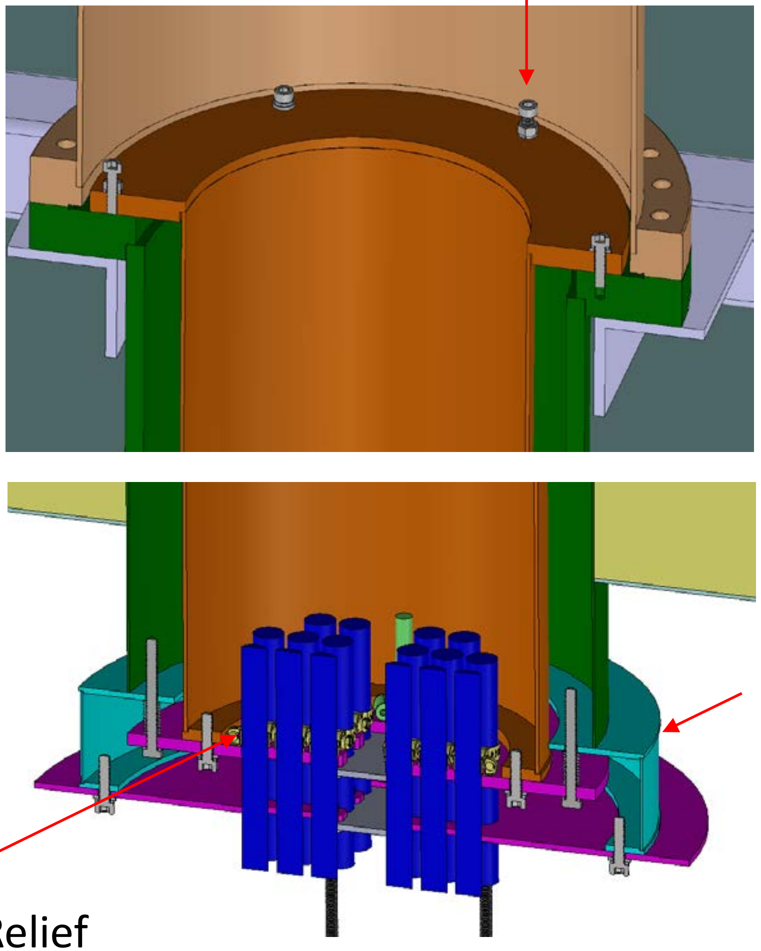
Feedthrough Provisions for Argon Purity

ProtoDUNE & DUNE

CFD Study of ProtoDUNE Signal Feedthrough

ProtoDUNE Cross Tube Cable (CTC) Support





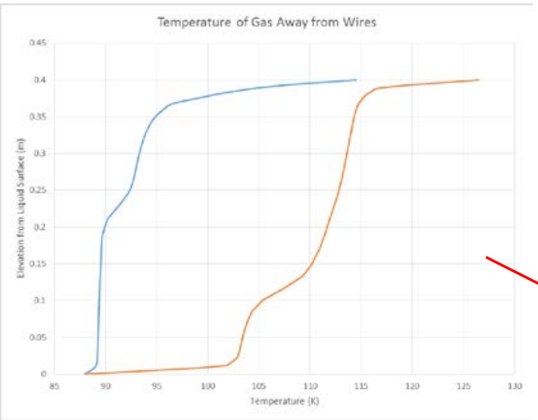
CFD Model of Signal Feedthrough Chimney

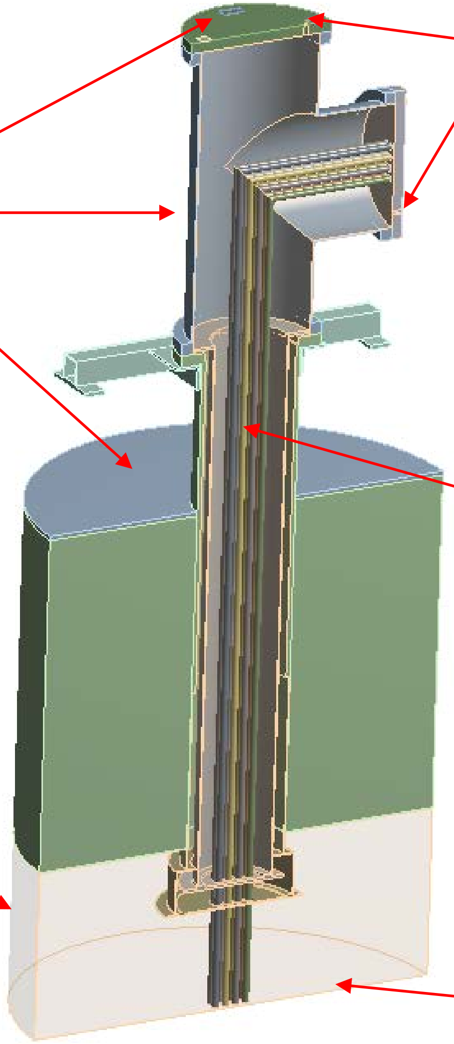
Outer surfaces
6 W/m^2-K @ 293 K

Gas outlet:
0.35 g/s

Liquid Surface Boil Off Flux of ProtoDUNE: 21 g/s from Liquid Model (see Ref)

GAr temperature in ullage





Water mass flux from Teflon cable insulation

87.93 K @ LAr/GAr interface

Reference: ProtoDUNE Ullage Space CFD Model, Erik Voirin

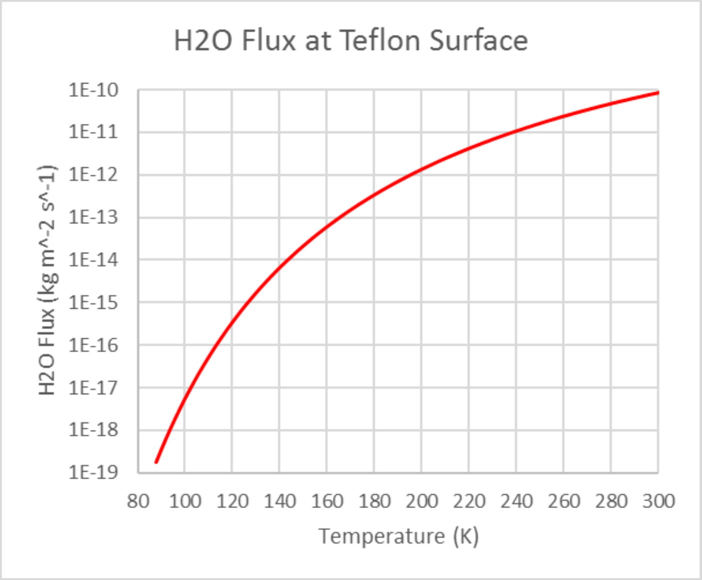
Water release of Teflon wire insulation

H2O mass flux at Teflon surface

$$H2O_{SurfaceFlux}(t_{ins}, Temp, t) := \left| \left(\phi_{waterMax} \cdot \sqrt{\frac{D_o \cdot e^{\frac{-U}{k_b \cdot Temp}}}{\pi \cdot t}} \right) \text{ if } t \le \frac{(t_{ins})^2}{2\pi \cdot D_o \cdot e^{\frac{-U}{k_b \cdot (Temp)}}} \right.$$

Where:

- "$H2O_{SurfaceFlux}$" - is a function of thickness, temperature, and time
- "t" - is time after placed in dry atmosphere, starting fully saturated in (seconds)
- "Temp" - is Teflon temperature in (Kelvin)
- "U" - is the activation energy which is estimated at (0.43eV)
- "k_b"- is the Boltzmann constant ($1.381*10^{-23}$ $m^2*kg/K*s^2$)
- "$\varphi_{waterMax}$" is the saturated concentration of water in Teflon (216 grams/m^3)
- "t_{ins}" is the thickness of the material, drying on one side, other side adiabadic
- "D_{12}(Temp) " is the temperature dependant diffusion coefficient
- "D_o" is estimated at (0.73694 cm^2/sec) for Teflon



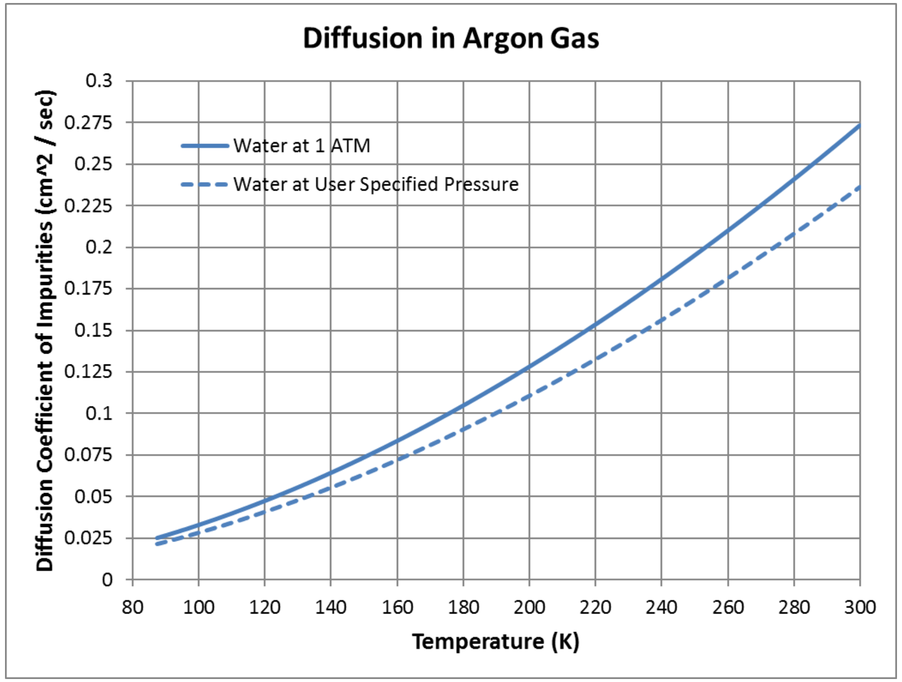
Assume after 100 days drying

H2O_Flux = 0.216*sqrt(2.715e-12*exp(-4988[K]/T)) [kg m^-2 s^-1]

Reference: Mass Transport of Water in Teflon Down to Cryogenic Temperatures; a Transient Numerical Analysis, Erik Voirin

Diffusion Coefficient of Water in Argon Gas

$$\text{Diffusion}_{12}(T) = \frac{1.86\cdot 10^{-3}\cdot T^{\frac{3}{2}}\cdot\sqrt{\dfrac{\frac{kg}{kmol}}{M_1}+\dfrac{\frac{kg}{kmol}}{M_2}}}{\dfrac{P}{atm}\cdot\left[\dfrac{1}{2}\left(\sigma_1+\sigma_2\right)\right]^2\cdot\dfrac{\left[2.6693\cdot 10^{-6}\cdot\left(\dfrac{M_{Ar}}{\frac{kg}{kmol}}\cdot T\right)\right]^{\frac{1}{2}}}{\dfrac{\mu_{Ar}(T)}{Pa\cdot s}\cdot\left(\dfrac{\sigma_{Ar}}{Angstrom}\right)^2}}$$

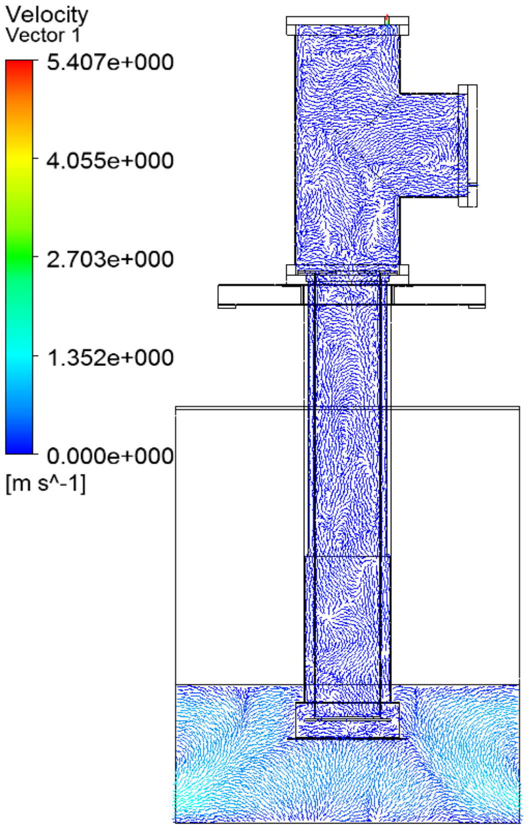


The curve can be fitted as

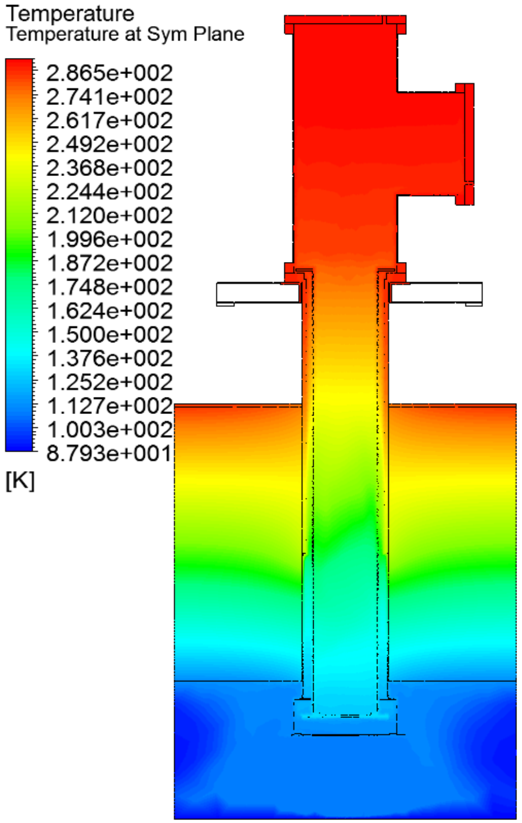
H2O_Diff = 0.275 [cm^2 s^-1] * (T/300[K])^1.9*(1 [atm] /Pressure)

Reference: Diffusion Coefficients of Water and Oxygen in Argon, Erik Voirin

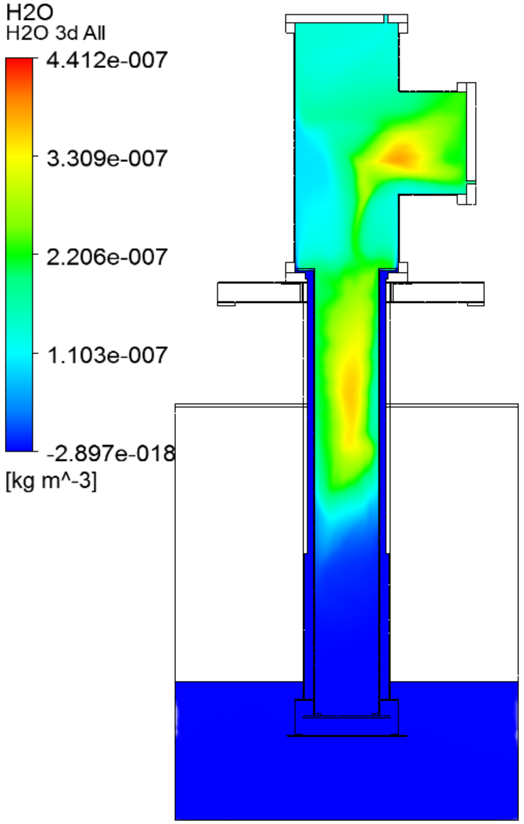
Results: Gas Flow, Temperature and Moisture Diffusion



Gas flow in chimney



Temperature

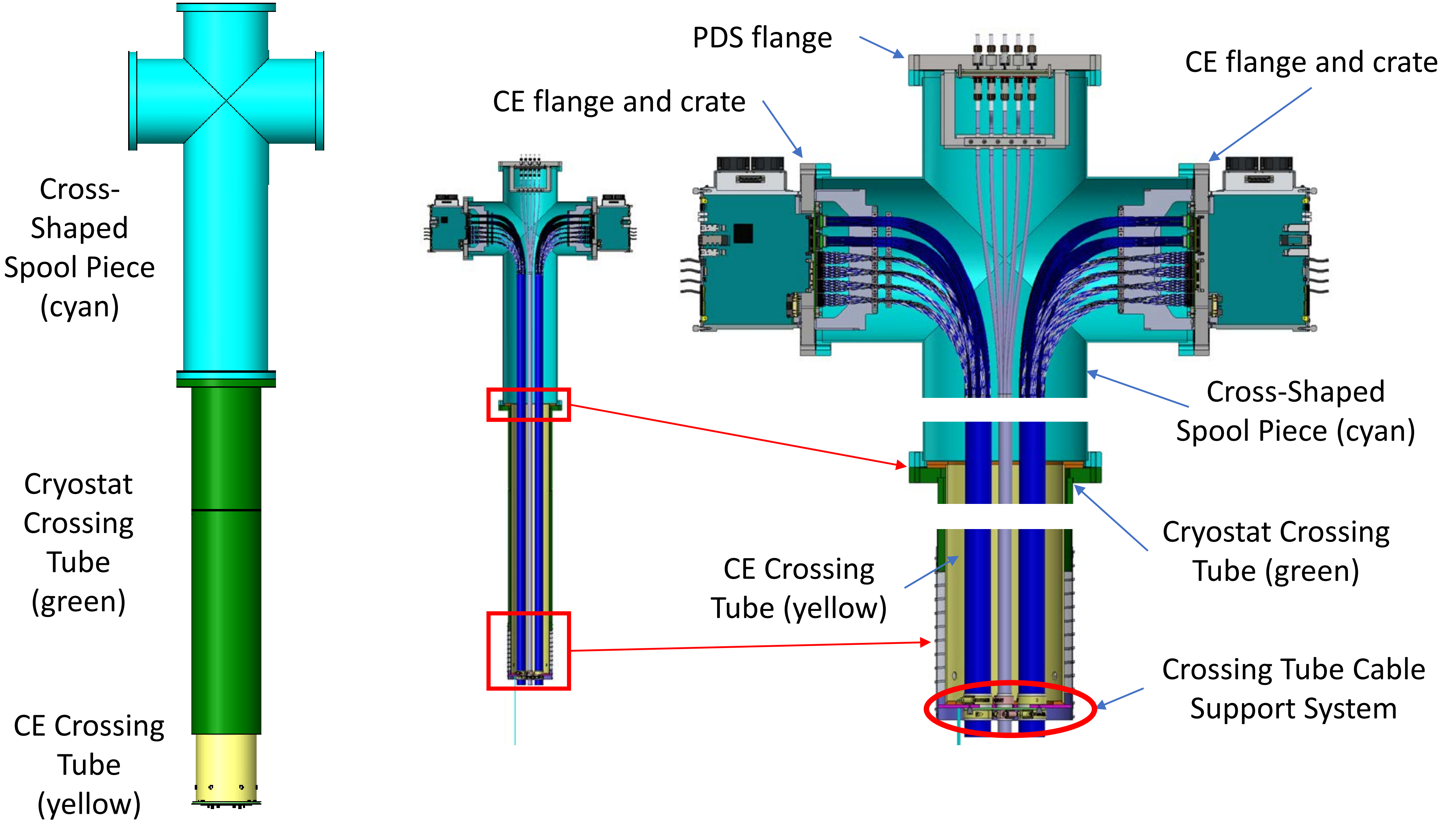


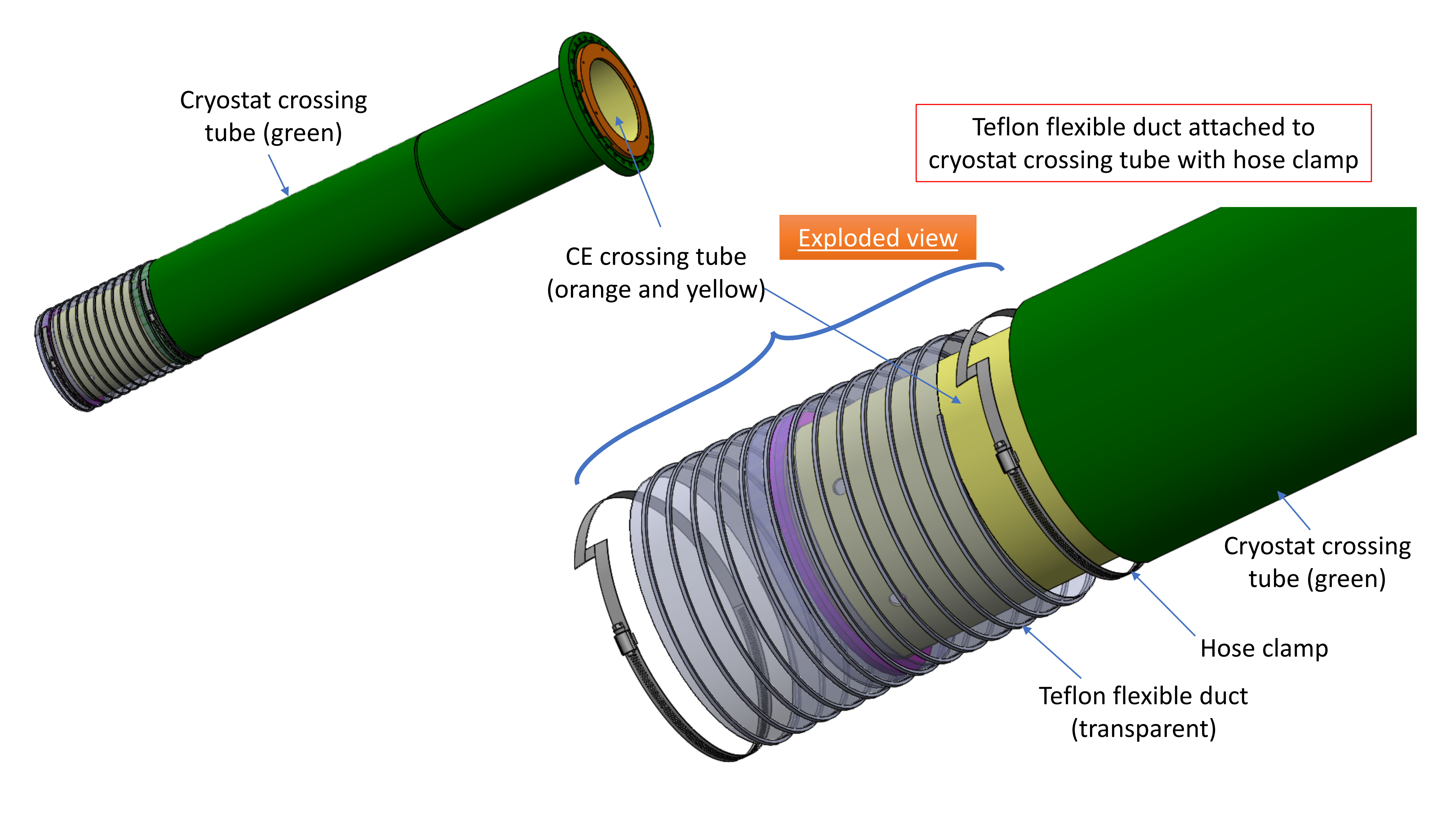
Moisture Diffusion

Moisture diffused into ullage ~ 9×10^{-16} g/sec

DUNE Signal Feedthrough

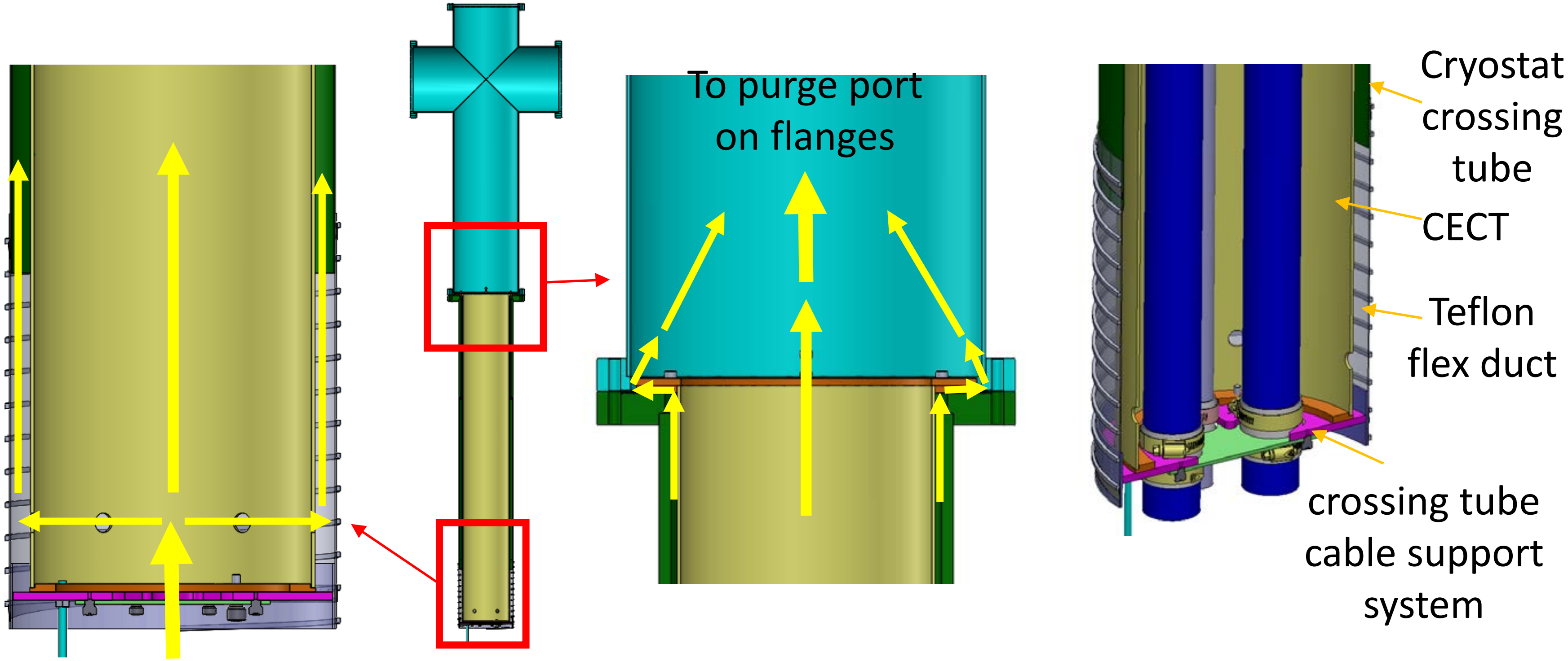
Cryostat Signal Penetration




Cryostat crossing tube (green)
CE crossing tube (orange and yellow)
Teflon flexible duct attached to cryostat crossing tube with hose clamp
Exploded view
Cryostat crossing tube (green)
Hose clamp
Teflon flexible duct (transparent)

Gas Flow Path in the Cryostat Penetration

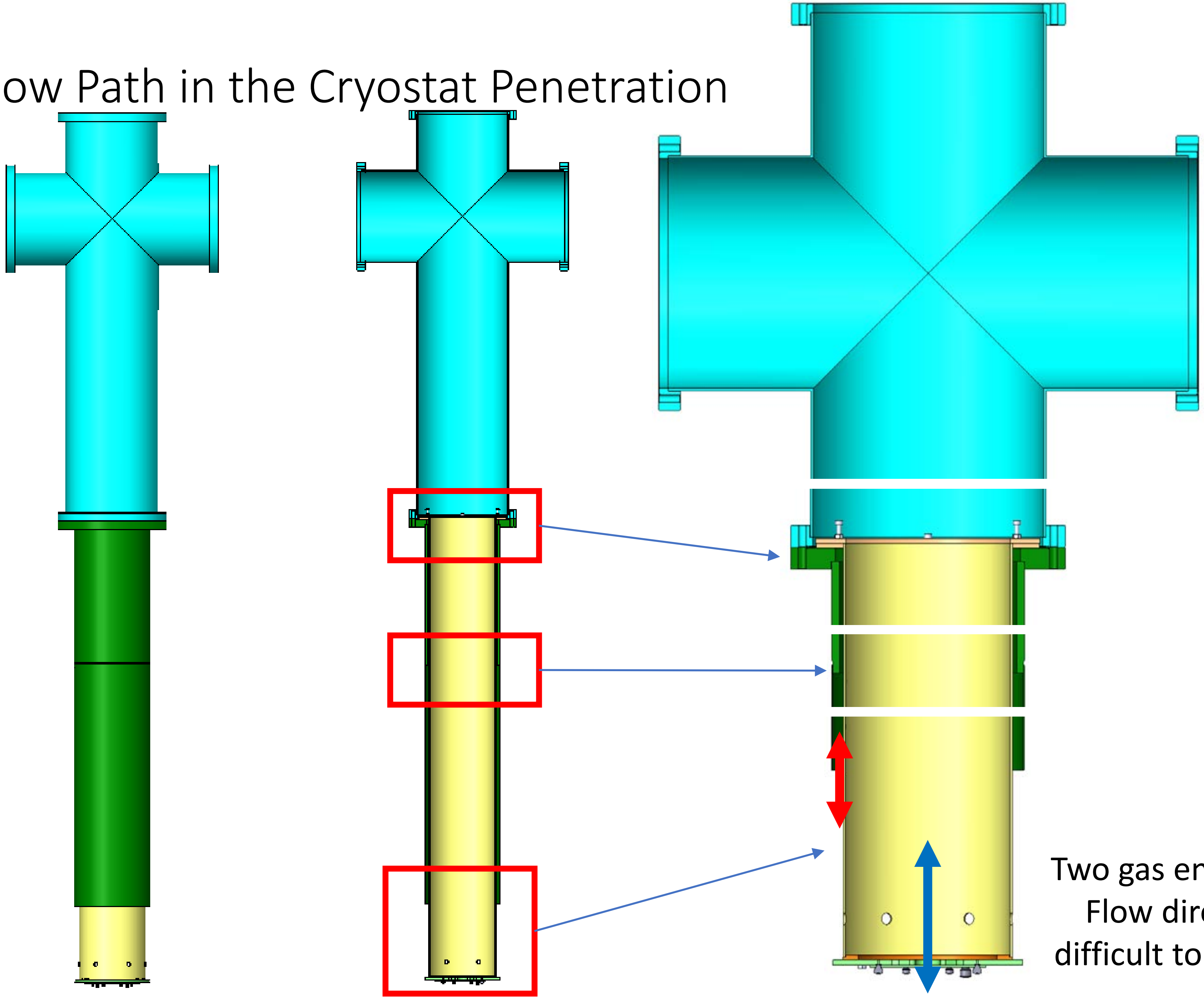
With Teflon Duct



The only entrance between penetration and ullage

Gas Flow Path in the Cryostat Penetration

Without Teflon Duct



Two gas entrances.
Flow direction
difficult to predict.

A simplified CFD (fluid volume only, no solid parts included)

Assumed Teflon duct is not installed. No thermal or gravity is considered in this simulation.

Although it shows all gas flows upwards, not sure if flow direction will change once include thermal and gravity in the CFD.