Cryopumps at the extremities of the beampipes: design and performance

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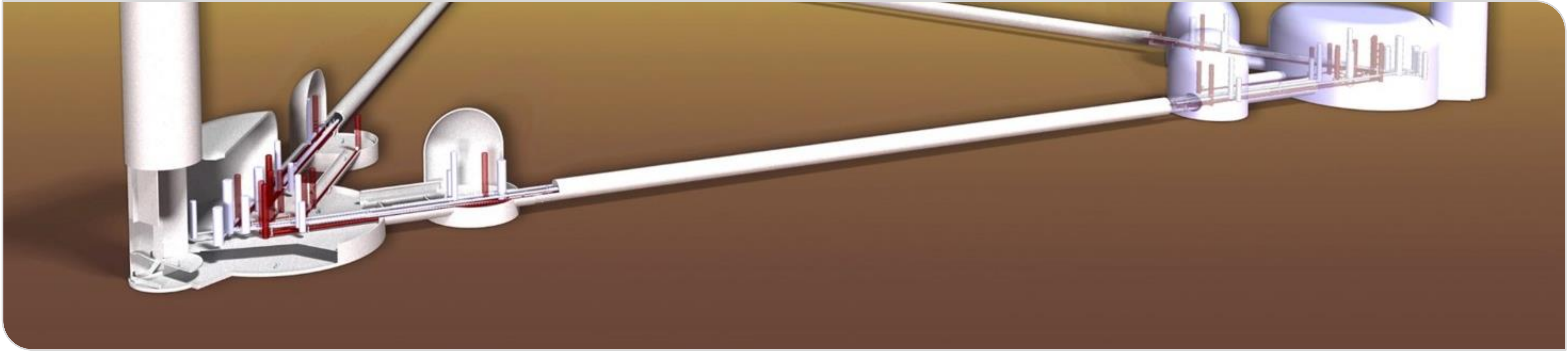
28 Mar 2023



Gas sources for ET-LF

Karlsruhe Institute of Technology

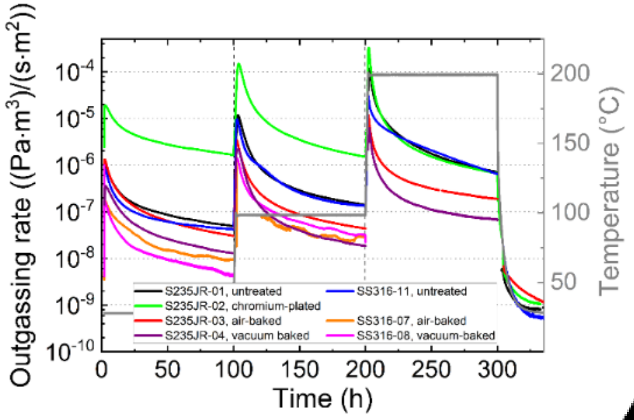
- Consideration of all gas sources and simplified geometry with TPMC model (in-house code ProVac3D)
- Disadvantagous L/D ratio → HPC (10,000 cores) required
- Find influences and sensitivities

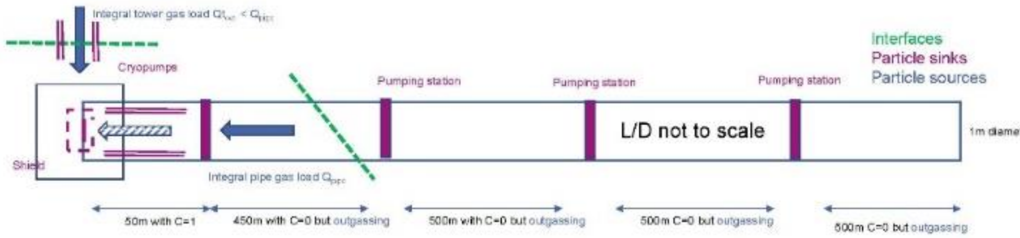
→Knowledge where effort is mostly needed

- First source – from 10 km long beam pipe
- Second source – from upper part of suspension tower
- Third source – from adjacent tower with much higher flow

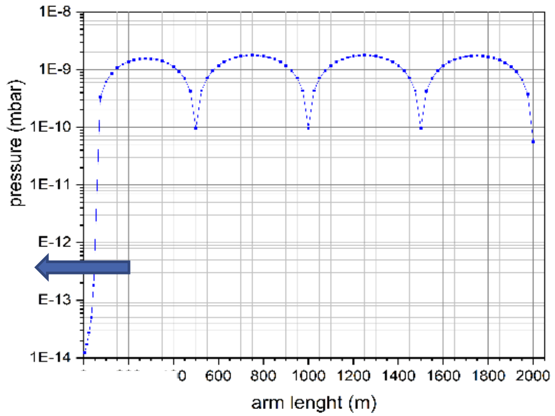
- All combined flows have to fulfill pressure and adsorption requirements

Sensitivity study to find the ´best´ solution

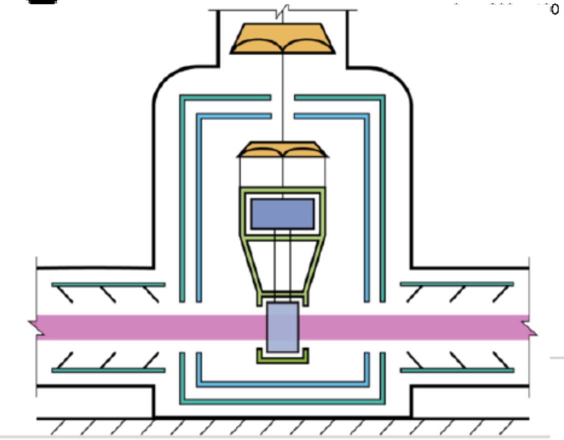




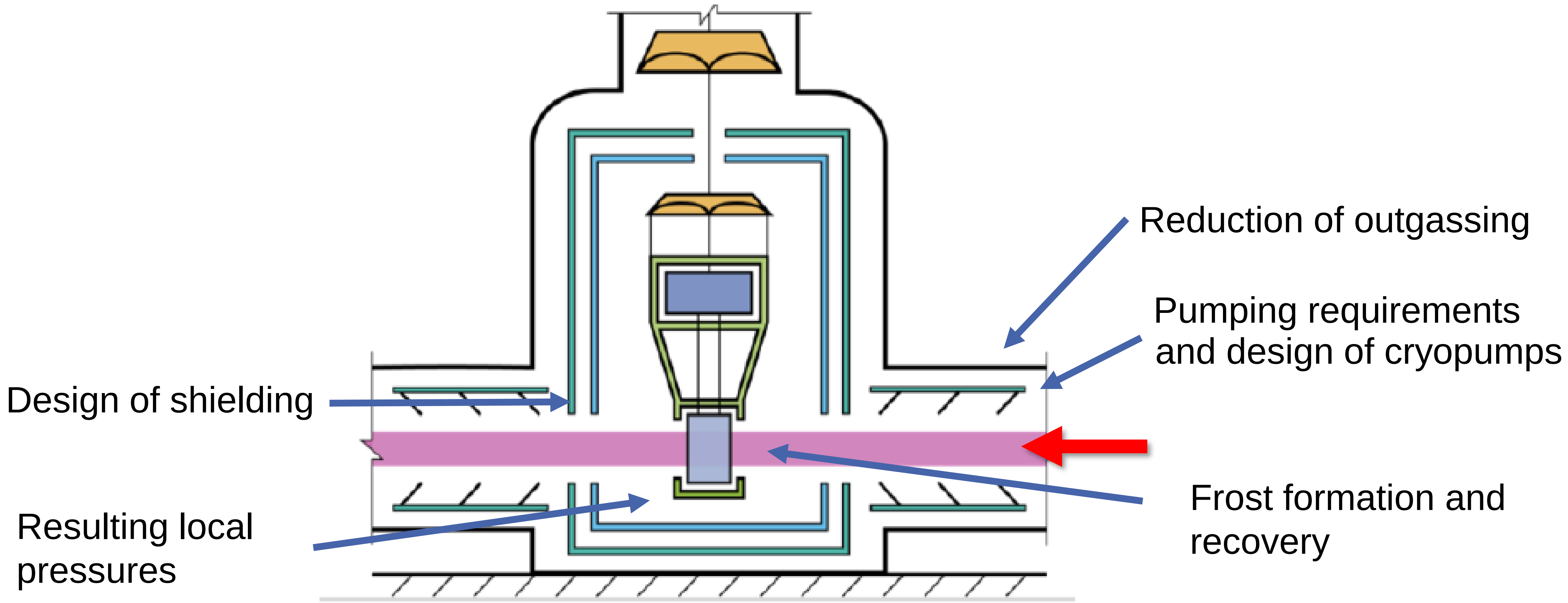
Output of this workflow:
Allocation of capture coefficients to each surface such that all design targets are achieved with measures that have been shown to have the highest impact.



Translates the physics requirements into engineering requirements
→ Temperatures, fluxes and to be pumped amounts



Beam pipe gas source **towards cryogenic mirror**

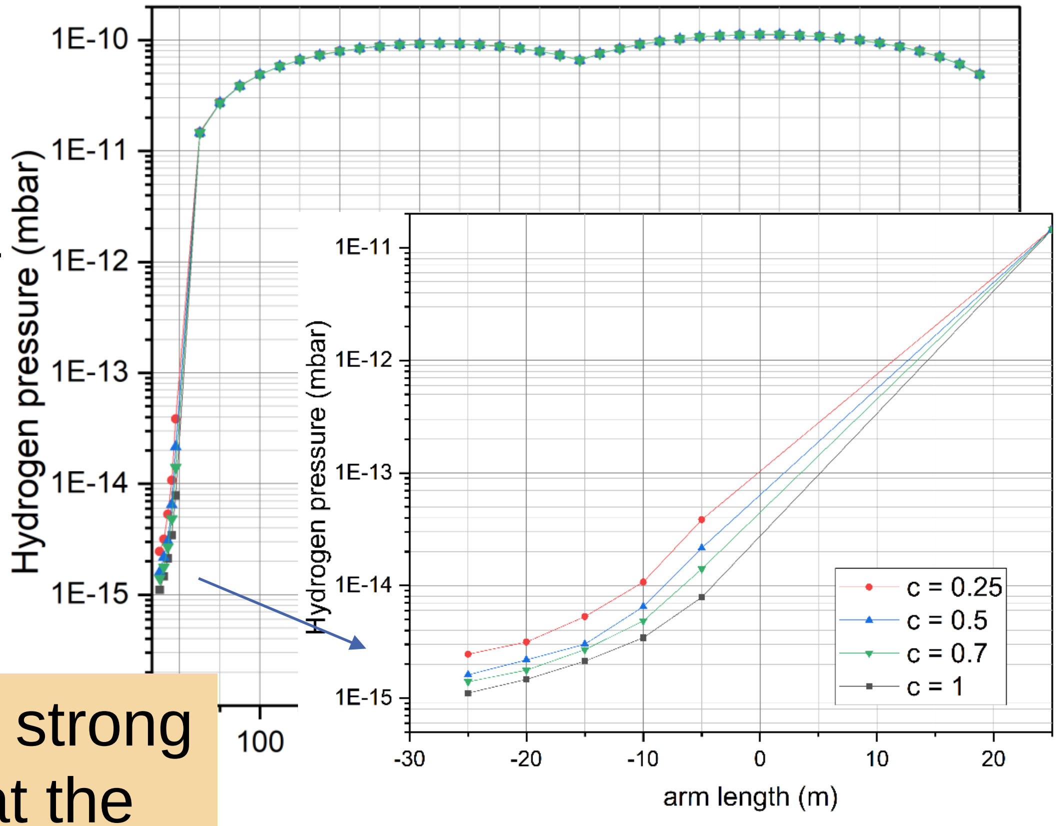


Differentiation between hydrogen and water (I)

- Step 1: **Hydrogen pressure profile** (neglecting water flow rate towards cryogenic mirror)
- Assumptions:
  - Total outgassing is 50/50 H_2/H_2O
  - Outgassing of $2.5 \cdot 10^{-11}$ Pa $m^3/(s\ m^2)$ each
  - Warm pumping station with 5 m^3/s every 500 m
  - Cryopump with **30 m** length, sticking coefficient for H_2 varied (0.25…1)

→ Reduction of pumping speed flattens the curve (but needs low outgassing!)

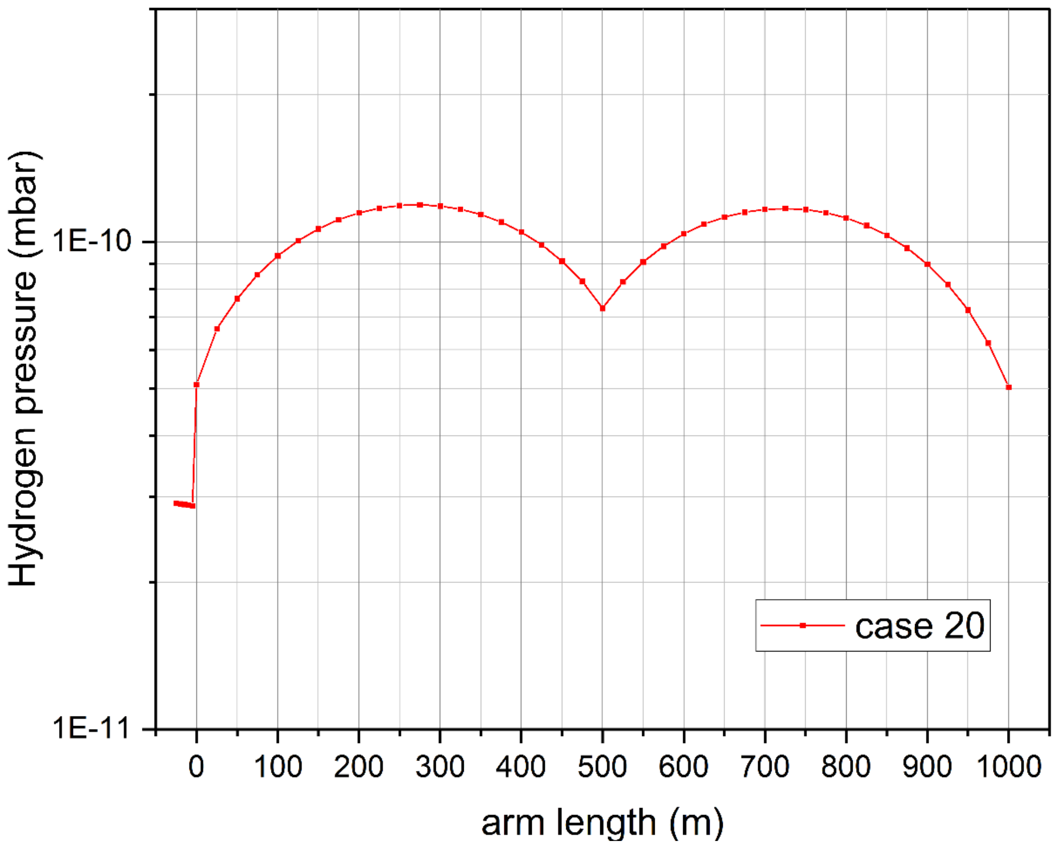
→ Cryopump for hydrogen may not be needed



<u>Finding:</u> There is no need for a strong hydrogen pumping cryopump at the beampipe side of the cryostat.

Cryopump for H_2 needed?

- 30 m cryopump at 10 km beam pipe only 80 K [for water & Co] but with no H_2 pumping capacity.
- Hydrogen pumped only by last warm pump station (added at warm end of cryopump)
- Resulting H_2 pressure at mirror ~$3 \cdot 10^{-11}$ mbar



Finding: Indeed, there is no need for a strong hydrogen pumping cryopump at the beampipe side of the cryostat.

Differentiation between hydrogen and water (II)

- Step 2: **Water flow rate towards cryogenic mirror** (neglecting hydrogen pressure profile)
- Assumptions:
  - Total outgassing is 50/50 H_2/H_2O
  - Outgassing of $2.5 \cdot 10^{-11}$ Pa $m^3/(s\ m^2)$ each
  - Warm pump stations with 5 m^3/s every 500 m
  - Cryopump with different lengths, sticking coefficient for H_2O (c=1)
- Low flow towards the cryogenic mirror can be achieved with cryopump

→Shorter cryopump might be sufficient to have acceptable time until water monolayer build-up

Finding: The cryopump at the beampipe side of the cryostat can be operated at 80 K (only water pump, but this very effectively.)

#	Outgassing rate (Pa m³/(s m²)	Length of cryopump (m)	Flow towards mirror (Pa m³/s)
23	2.50E-11	5	**2.5E-10**
22	2.50E-11	10	**1.2E-10**
21	2.50E-11	20	**5.5E-11**
17	2.50E-11	30	**3.1E-11**
18	2.50E-11	50	**1.6E-11**
19	2.50E-11	70	**1.1E-11**

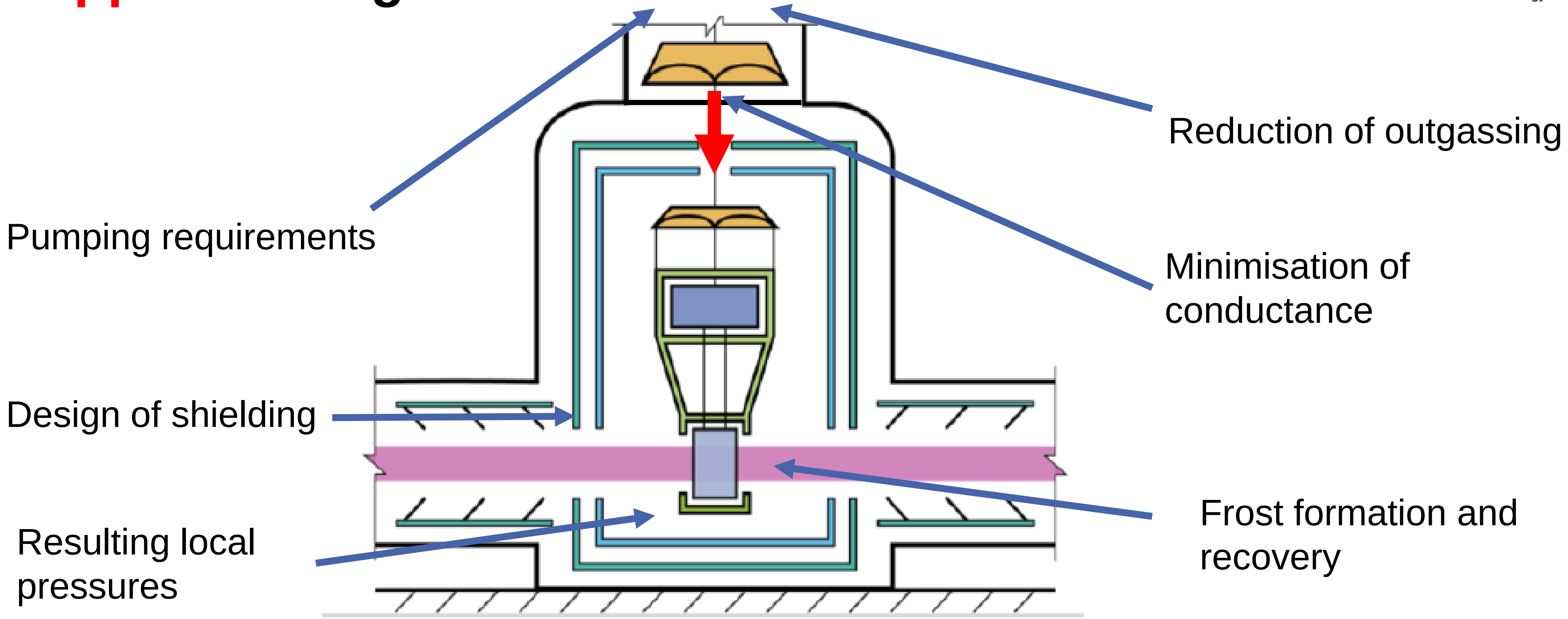
Results

- Stronger pumping to compensate higher outgassing in beam pipe is not helpful.

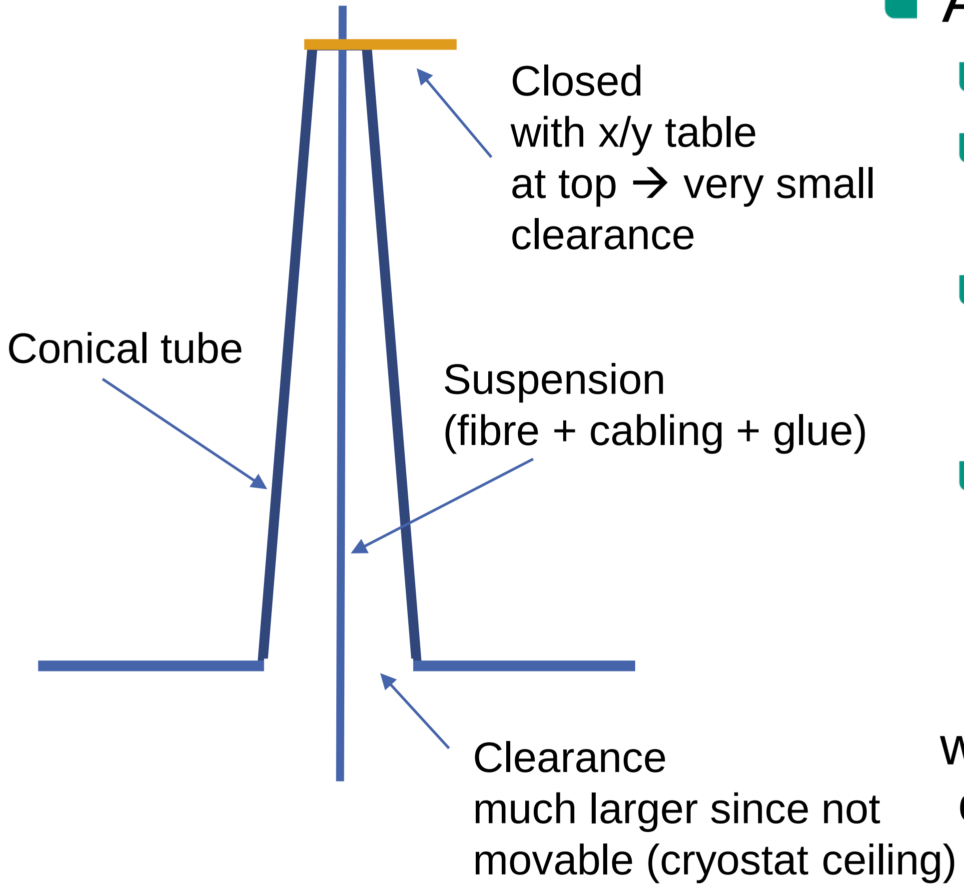
→ Required beam pipe conditions have to be established by low outgassing rates, not by stronger pumping.

- Beam pipe vacuum strongly decoupled from cryostat vacuum.
- Hydrogen pumping not needed in the cryopump at the beampipe side of the cryostat.
- Water is well manageable by a 80 K cryopump.

Upper tower gas source

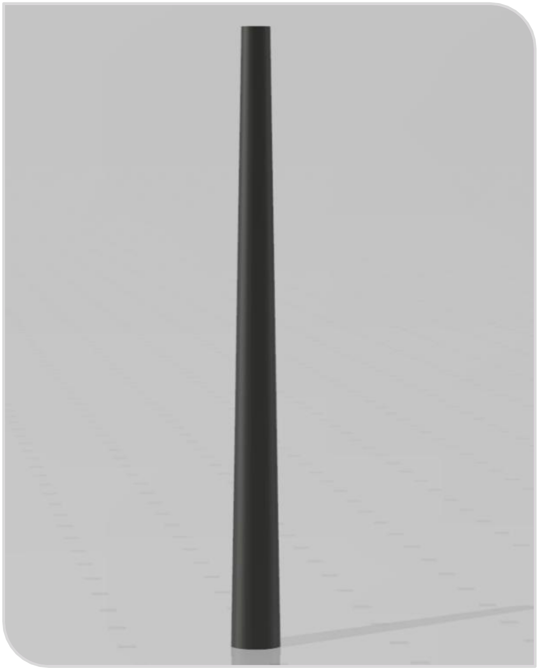


Conductance minimisation – cone solution



- Assumptions
  - Suspension diameter: 12 mm
  - Clearance at bottom: 6 mm
  - Tube length:
    300 mm, 500 mm, 800 mm
    or 1000 mm
  - Clearance at top:
    1 mm or 0.5 mm

with x/y table moving the smaller opening with the position of the suspension cable



Calculated gas flows from tower to mirror

	Radius suspension	Radius opening	Radius opening 2	Clearance	Orifice/tube length	Transmission surface	Transmission probability	Conductance	Gas flow to mirror
	r_i	r_o	r_{o2}	dr	l	A	P	C	Q
	(mm)					(m²)		(m³/s)	(Pa m³/s)
orifice	6	12		6	0.5	3.39E-04	0.95	1.41E-01	**1.41E-06**
	6	7		1	0.5	4.08E-05	0.80	1.43E-02	**1.43E-07**
	6	6.5		0.5	0.5	1.96E-05	0.70	6.03E-03	**6.03E-08**
tube	6	12		6	300	3.39E-04	0.055	8.19E-03	**8.19E-08**
	6	12		6	500	3.39E-04	0.035	5.21E-03	**5.21E-08**
	6	12		6	800	3.39E-04	0.025	3.72E-03	**3.72E-08**
	6	12		6	1000	3.39E-04	0.020	2.97E-03	**2.97E-08**
cone	6	7	12	1	300	4.08E-05	0.067	1.21E-03	**1.21E-08**
	6	6.5	12	0.5	300	1.96E-05	0.070	6.01E-04	**6.01E-09**
	6	6.5	12	0.5	500	1.96E-05	0.043	3.70E-04	**3.70E-09**
	6	6.5	12	0.5	800	1.96E-05	0.028	2.37E-04	**2.37E-09**
	6	6.5	12	0.5	1000	1.96E-05	0.022	1.91E-04	**1.91E-09**

Results

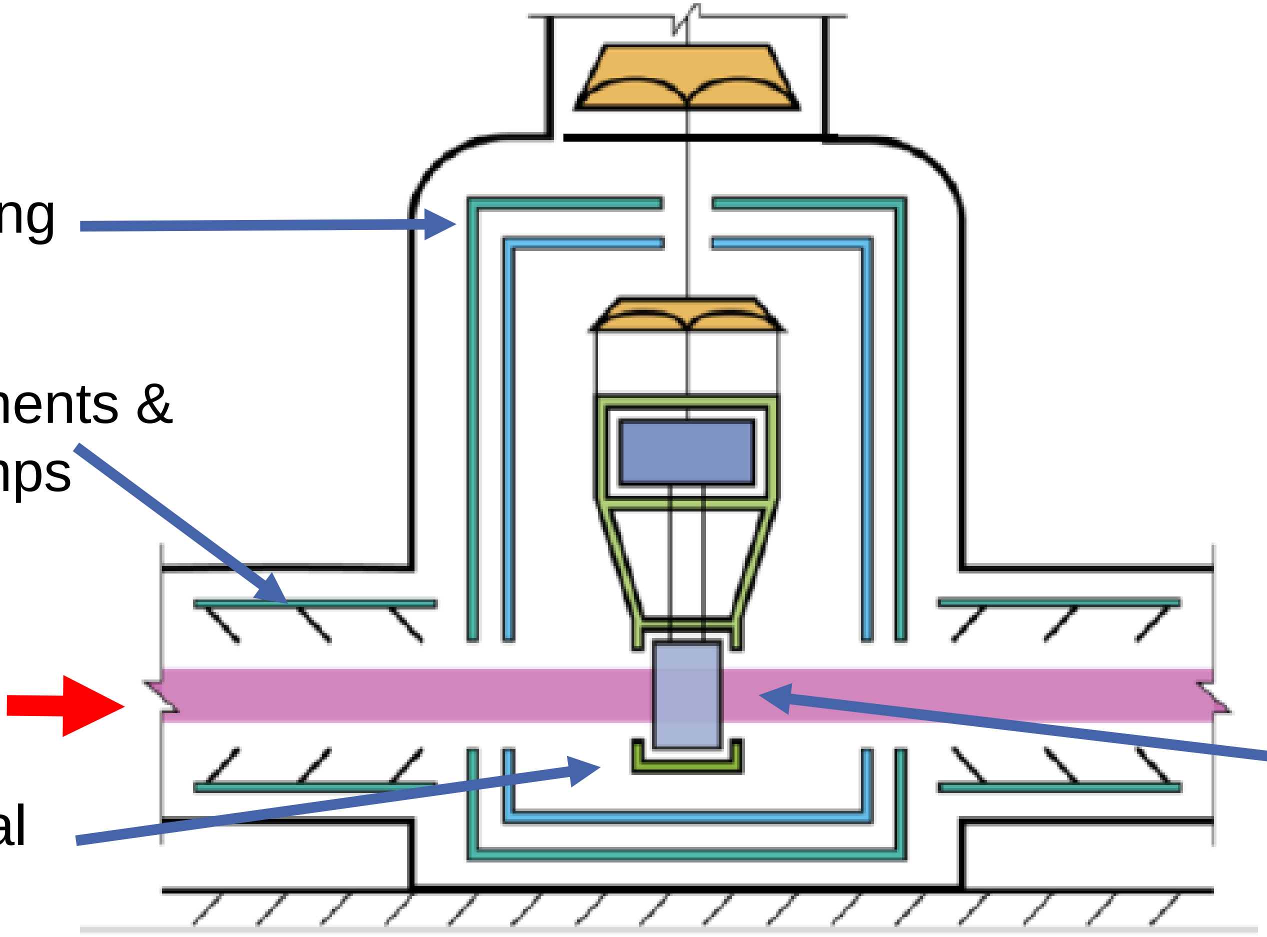
- Some geometric solution of tower isolation is needed (tube)
- Extra pressure reduction by factor ~10 in tower is advisable (by additional means to reduce outgassing and/or increase pumping speed, most probably cryopumping).
- High uncertainties in outgassing composition and tower pressure
- Implementation of baffles possible
- Assumed value for further simulations: **$2 \cdot 10^{-9}$ Pa·m³/s**

Finding: Pumping in upper tower and conductance minimisation assumed

Adjacent tower gas source

Design of shielding

Pumping requirements & design of cryopumps



Resulting local pressures

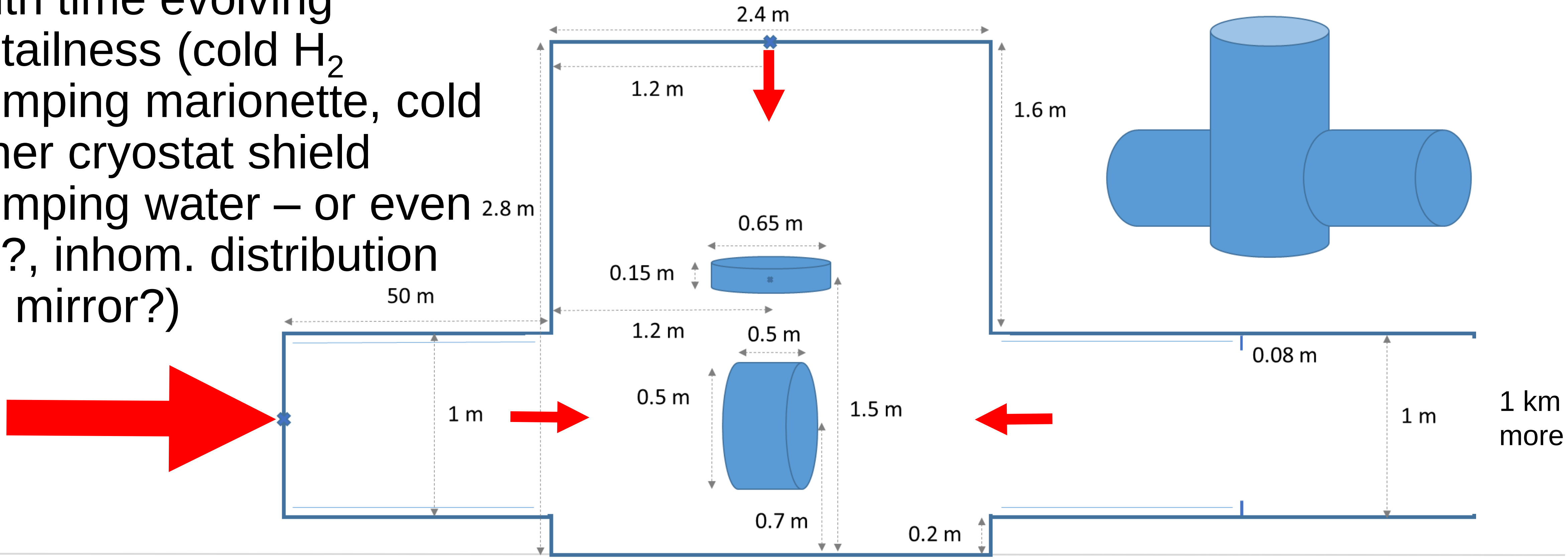
Frost formation and recovery

Details of third gas source

- Source from adjacent warm tower/optics
- Separated by only 50 m from cryogenic mirror
- Releasing high gas flow with 10^{-7} Pa m^3/s for H_2 and 10^{-6} Pa m^3/s for water
- Much higher flows as from other two sources
- Cryopump section needed to handle H_2 flow
- Low temperature cryopump section seems indispensable (3.7 K or 10 K with some dust-free sorbent (R&D))
- Water trapping with longer 80 K section

Complete model established

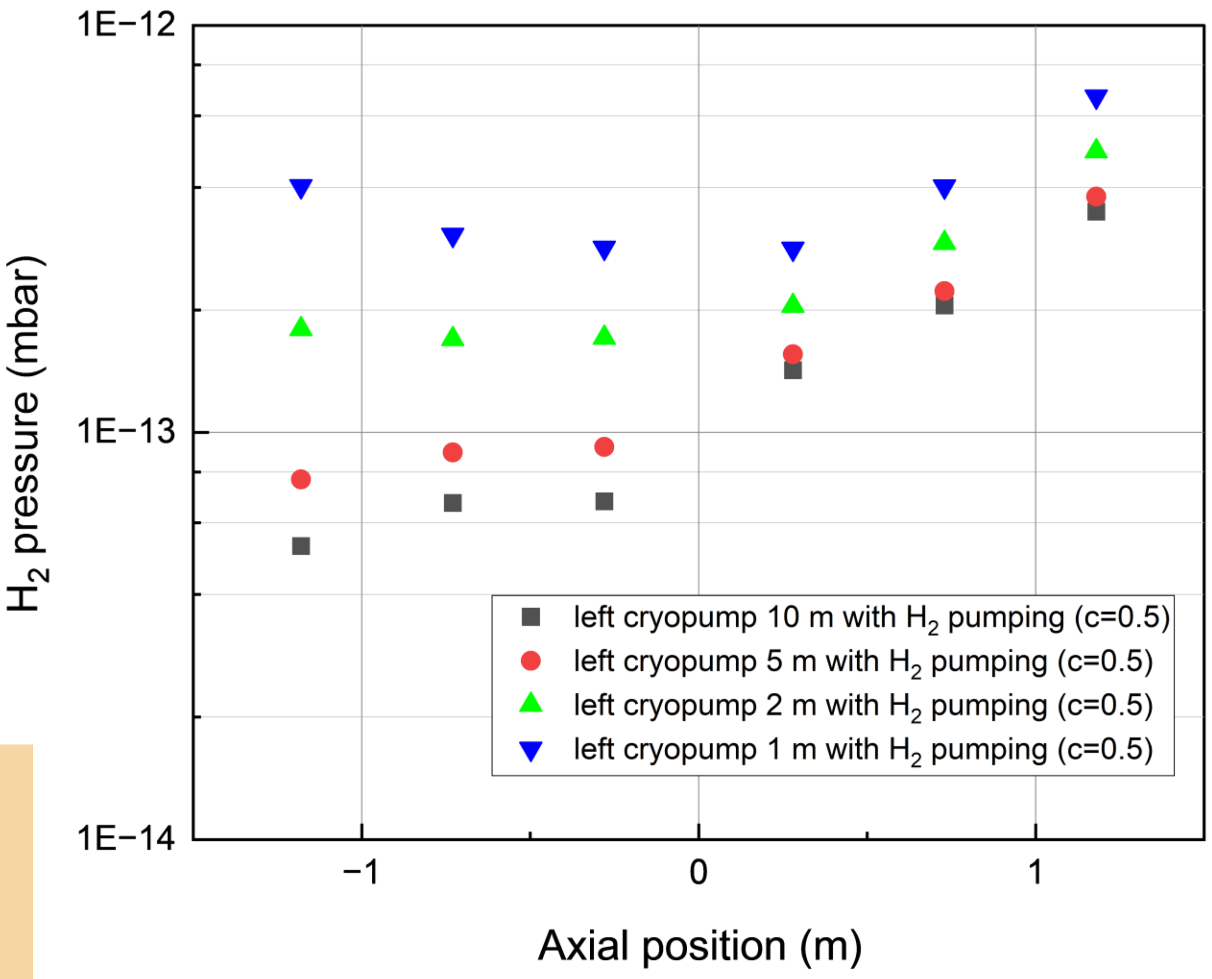
- Three sources implemented
- With time evolving detailness (cold H_2 pumping marionette, cold inner cryostat shield pumping water – or even H_2?, inhom. distribution on mirror?)



Hydrogen pressure near cryogenic mirror

- Consideration of all gas sources

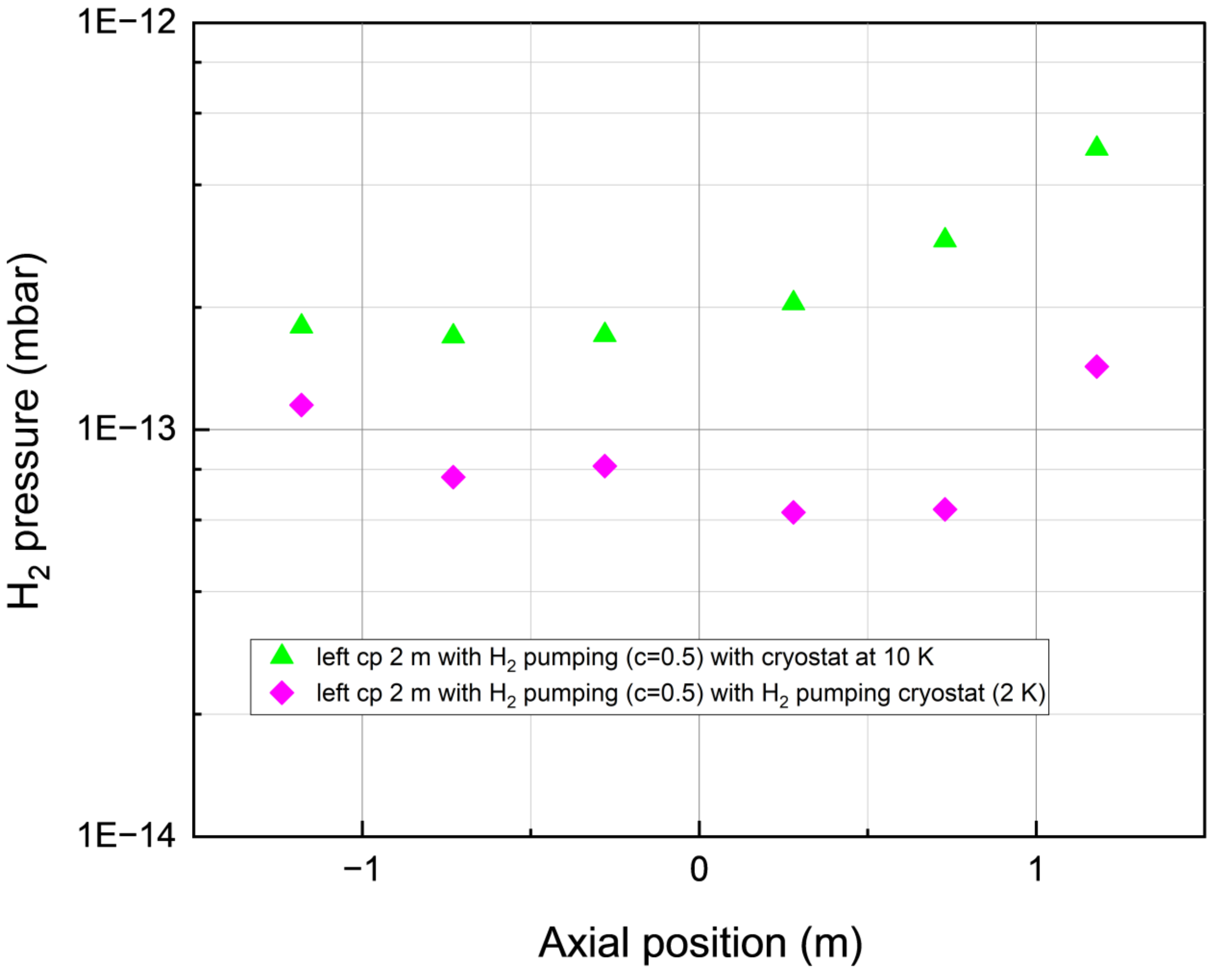
→ Short H_2 pumping at adjacent tower side is sufficient (still huge pumping speed)



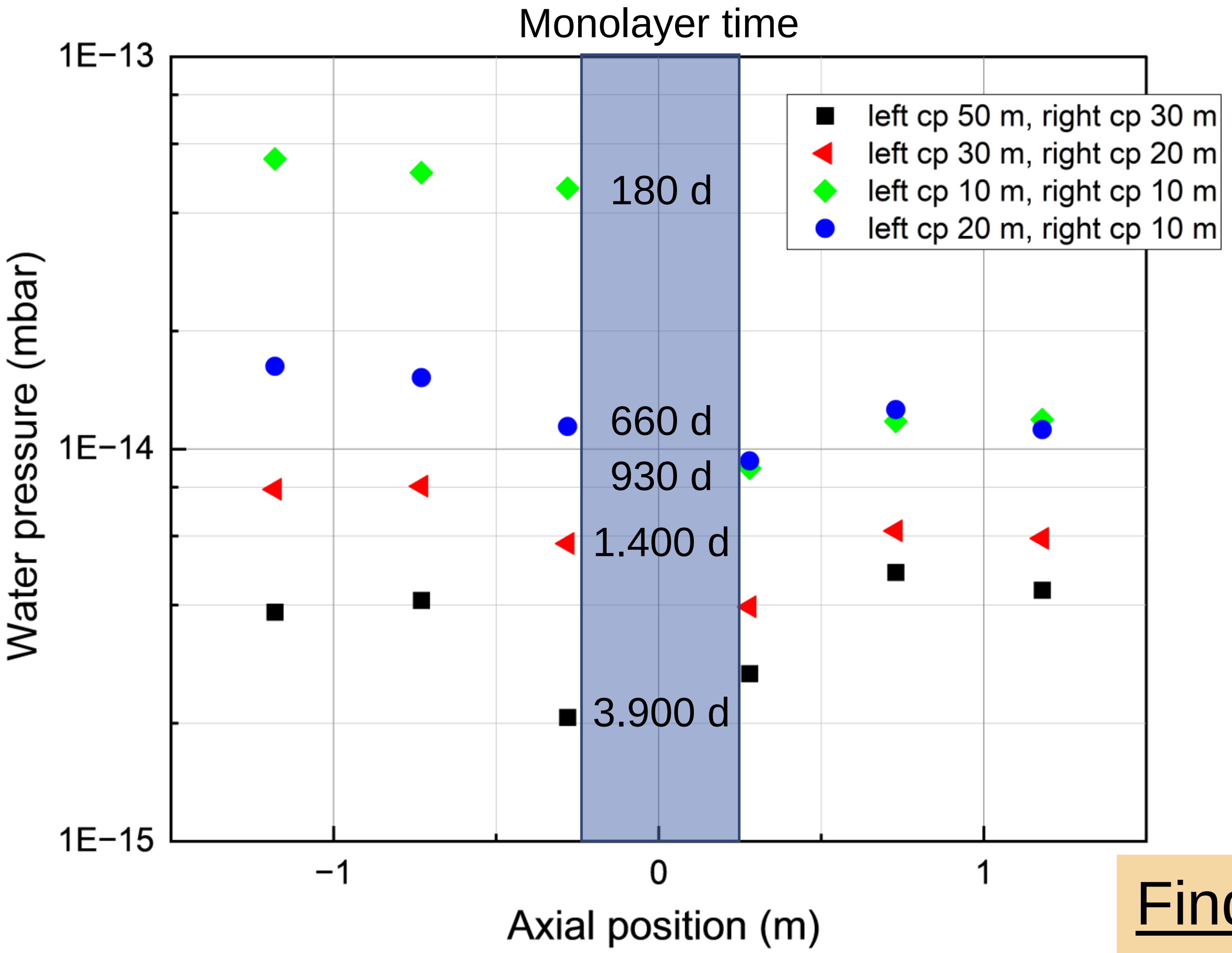
<u>Finding:</u> Short left cryopump section for H_2 needed, with 10 K and sorbent or 3.7 K without

Other pumping contributions

- Effect of additional hydrogen pumping by inner cryostat shield
- Water pumped by shield independent of temperature decision



Water pressure at cryogenic mirror and frost formation



- Consideration of all sources
- Water pumping at 80 K

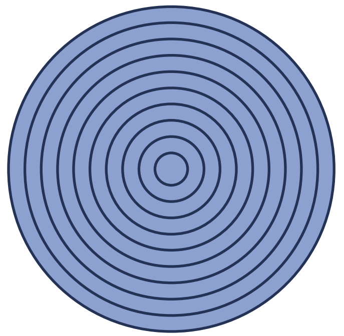
→20 m and 10 m seem sufficient

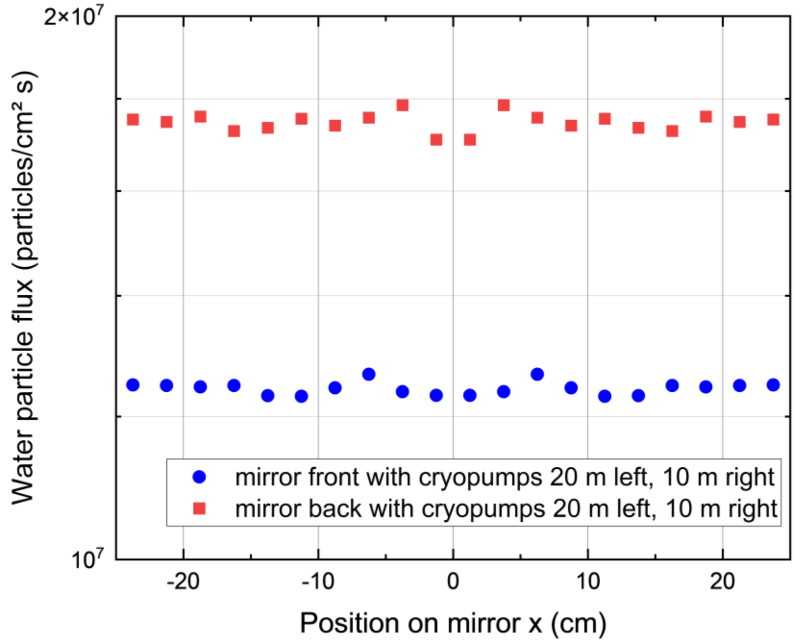
<u>Finding:</u> Frost on mirror drives more than pressure. Long ML times feasible.

Homogeneity of frost formation on mirror

- Inhomogeneity would result in lower acceptable time for ML formation (worst position drives the assessment)
- Implementation of segmented mirror in model and read out of particle impinging position

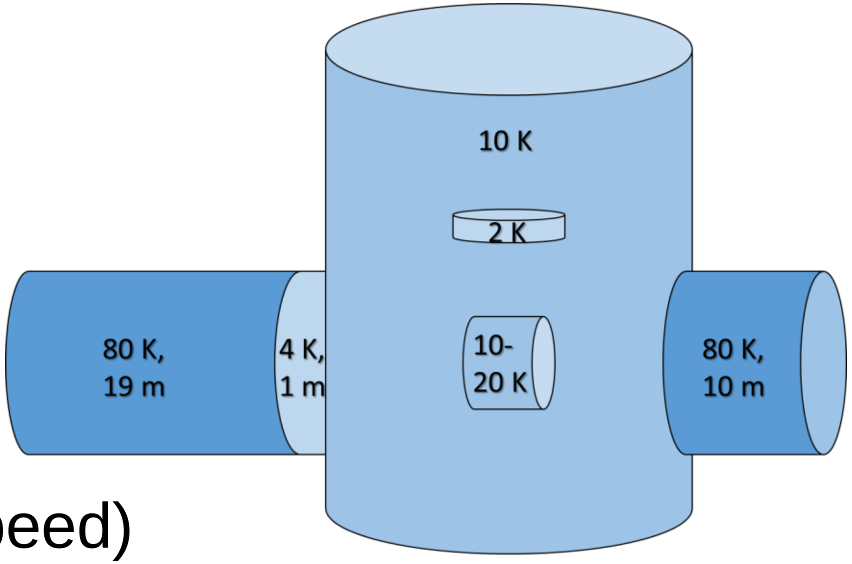
- Result: no significant inhomogeneity
- Plausible due to sticking of 1 for water at CP and so only direct flying water particles arrive on mirror from source 50 m away





<u>Finding:</u> Homogenous frost formation.

Conclusions



- Source 1: cryopump 80 K for water trapping sufficient
- 10 km beam pipe conditions via low outgassing (instead of high pumping speed)

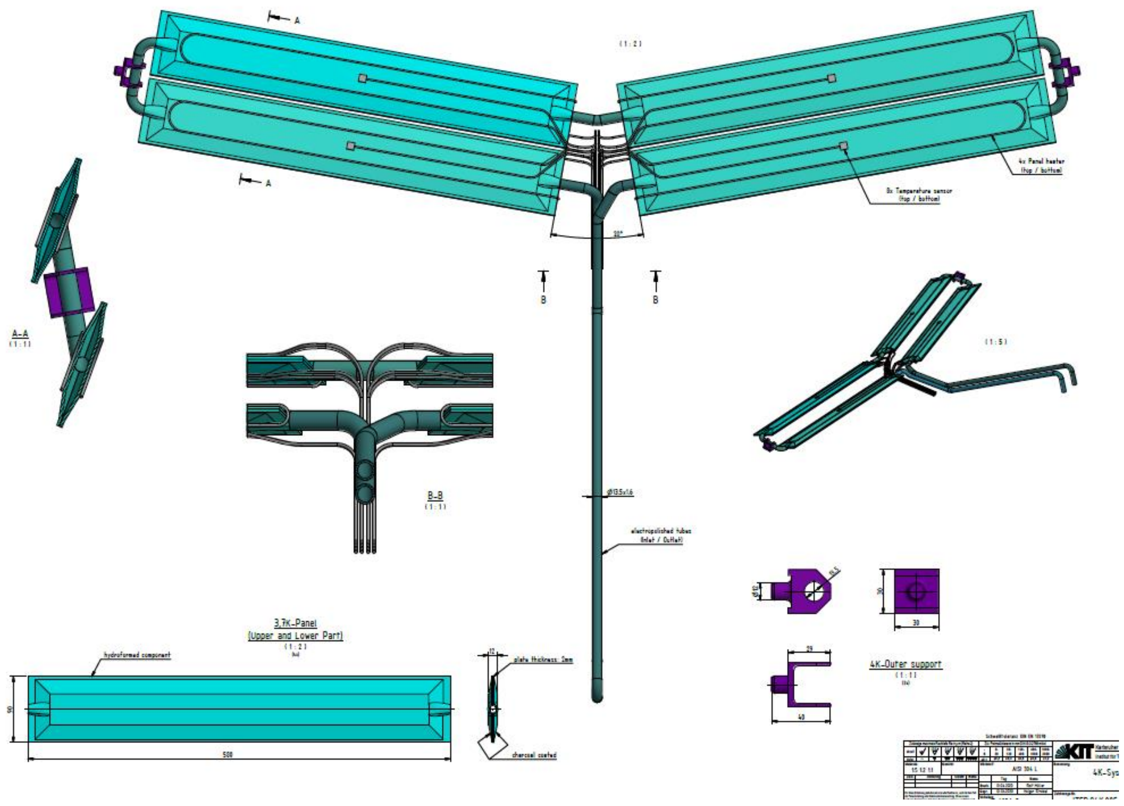
- Source 2: conductance minimisation plus (cryo)pumping in upper tower needed to reduce flow according needs
- More options will be studied (e.g. special water baffle upwards?)

- Source 3: cryopump section for hydrogen needed, additional to water pumping main section

→ Pressures around mirror: H_2: $3 \cdot 10^{-13}$ mbar, H_2O: $1 \cdot 10^{-14}$ mbar, water ice build-up ~2 years for 1 ML

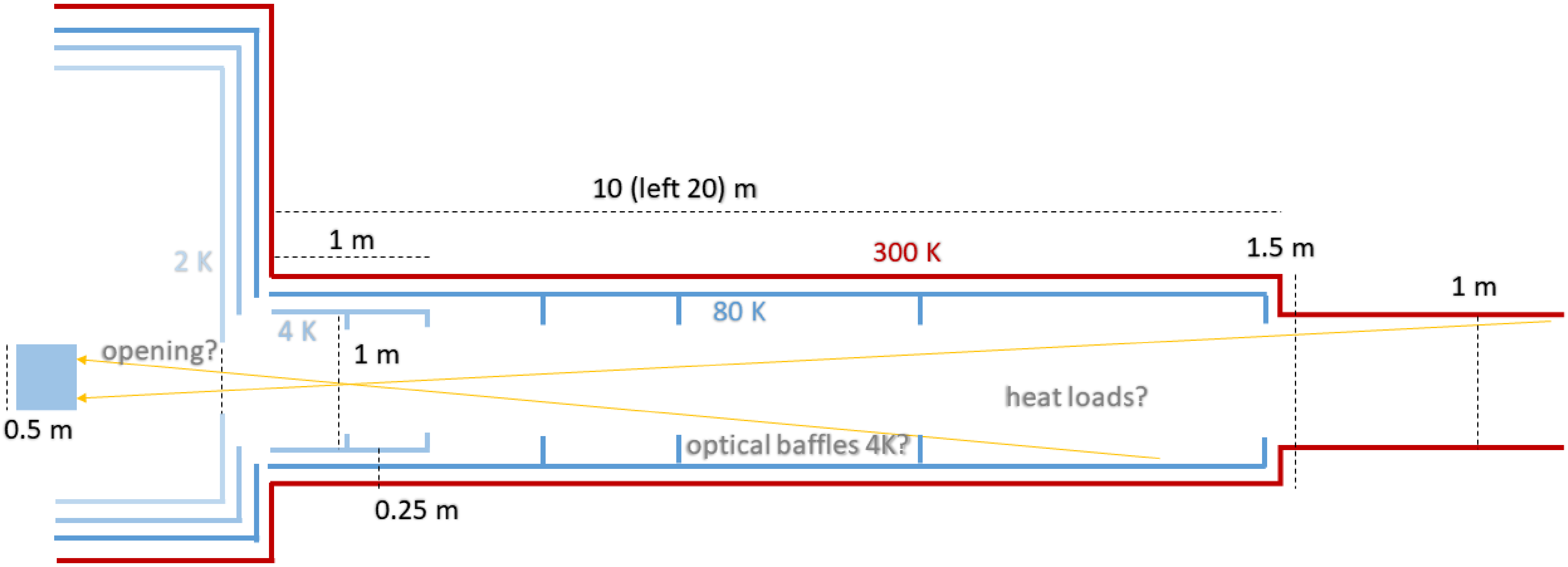
Next step: Cryopump design in tubes

- Cryopumps outside of free path in beampipe tubes of 1 (1.2) m diameter
- 0.25 m thickness needed (to be detailed and justified)
- 1.5 (1.7 m) + insulation diameter whereever a cryopump is contained
- 80 K shielding between cryopanels and backside (beam pipe wall)
- Hydroformed panels usually in fusion, here with reduced demands other options possible
- Shielding at ends of cryopump towards warm areas beside
- Modular system (panel and shield segments) → any length possible
- Cryogenic supply needs several in- and outlets for such long pumps
- Space and access demands for supply connections
- More detailed heat loads for cryoplant
- With developing concepts more precise heat loads on mirror
- With same code and modified model



Taylormade cryopump panels for fusion experiment

Heat load criticalities



Heat load criticalities need input

- Pump concept sound for vacuum requirements
- But heat loads towards mirror (and 2 K cryostat shield) from 80 K are excessive
- Solutions have to be found based on input needed from noise and beam optics experts
- How close can actively cooled CP components be positioned towards mirror?
- Cryostat shields closing partially the opening of the beam pipe to reduce thermal radiation load from 80 K and 300 K. To which extent acceptable for beam optics? 0.62 m or mirror Ø?
- What is the thermal budget on the mirror we can consume?
- Baffles additionally needed beside and inside CP
  → acceptable height? 10 K max and actively cooled acceptable regarding noise?