Sectorisation, pumping system, commissioning and operation of ET beampipes

Carlo Scarcia on behalf of CERN TE/VSC

28/03/2023

Summary

- Assumptions
- Sectorization
- Commissioning:
  - Rough pumping
  - HV pumping
  - UHV pumping at RT
- Bake-out: insulation and operational aspects
- Pressure monitoring:
  - Air leak: impact on total pressure
- Vacuum system cost assessment (hardware only)
- Final considerations

Assumptions

- The **beampipe internal diameter** is here assumed to be of **1.2 m.**
- **Material** properties (vacuum outgassing, electrical and thermal)**: Mild steel.**
- **Water outgassing rate simulation** done using a **quasi-equilibrium (1D)** models (**Kanazawa hyp.**) based on **Temkin isotherm.**
- **Compact** and **evenly distributed pumping groups.**
- **Gate valves** to **separate the tube** from the **pumping group.**
- **Pumping speeds** used are **nominal** (**no conductance limited by the gate valve**).
- **UHV pumping** only with **capture pumps** (**no noise, low power needed**).

Sectorization

Sectorization

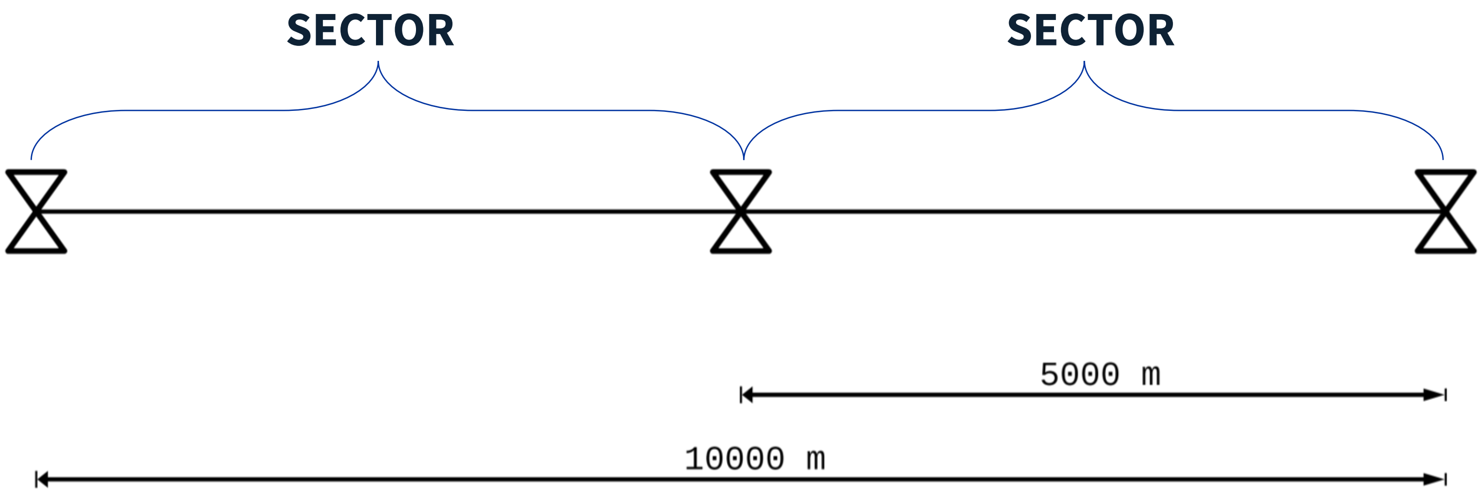
0 — 10 km

	$x \leq 2.5$ km	$2.5 < x \leq 5$ km	$x > 5$ km
Downtime due to ordinary maintenance (pump or gauge exchange, etc.)	=	=	=
Bake-out	++	+	-
Installation and **commissioning**	++	+	-
Downtime due to major failure (detrimental size leak, etc.)	++	+	--
Cost (components, alcoves, controls, etc.)	--	-	+

Sectorization

For this scenario, we chose to have a balanced option between cost and system flexibility. Therefore, we foreseen the use of one **sector gate valve (DN1250) every 5 km**.

Note: to be checked the possibility of reduced aperture for the middle sector valve



Courtesy of VAT

150 x 270 x 25 cm
2500 kg

Commissioning

Commissioning of the vacuum system

- Rough pumping (from atmospheric pressure to 10^{-1} mbar)
- HV pumping (from HV to UHV range)
- UHV pumping at RT

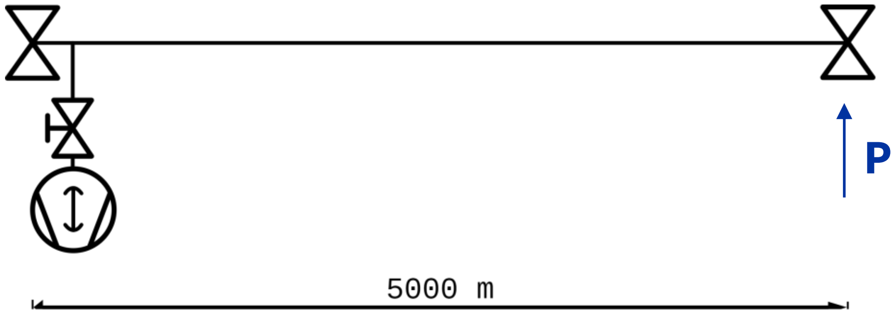
Rough pumping

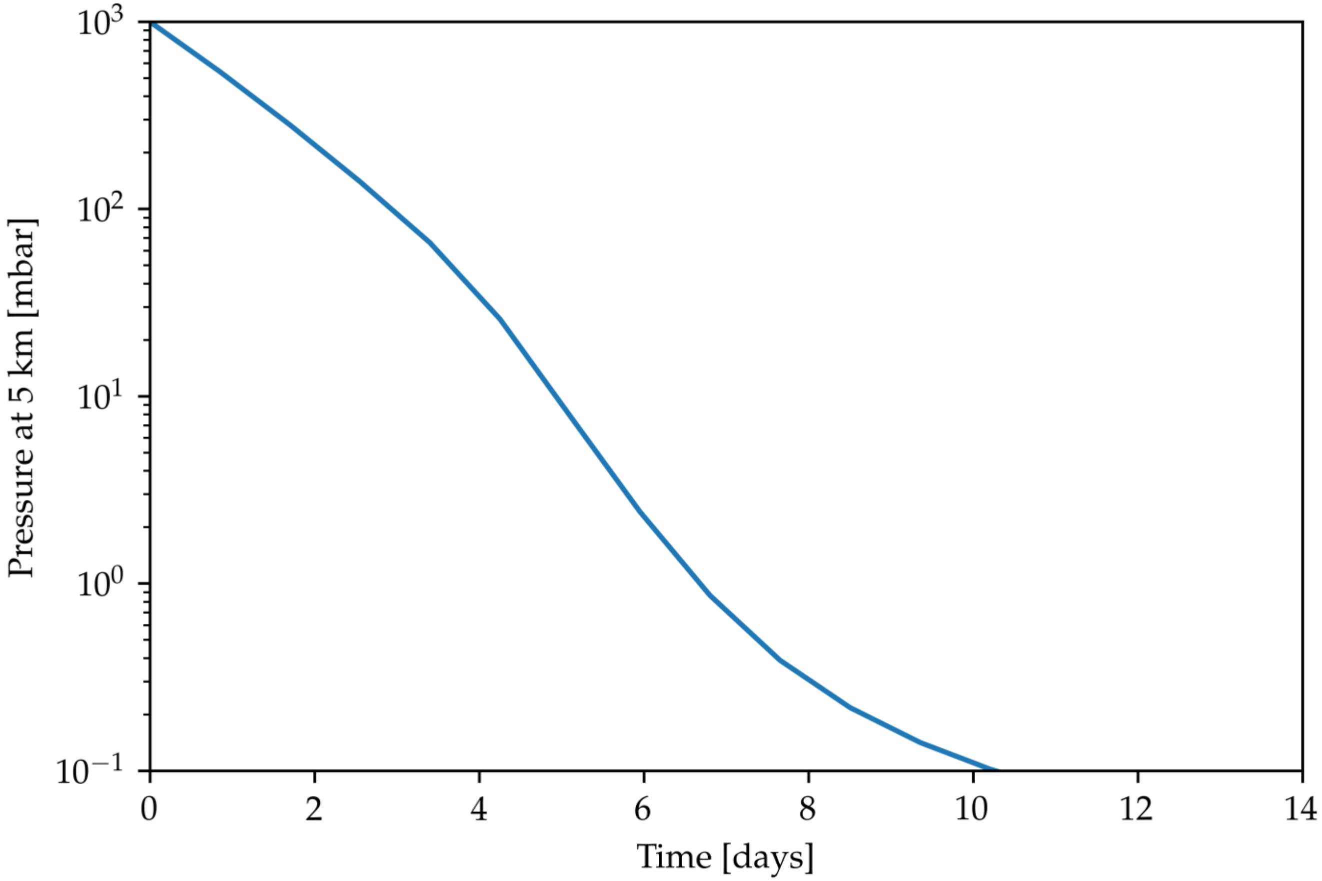
(from atmospheric pressure to 10^{-1} mbar)

Rough pumping: pump-down curve

Instrumented rough pumping group:

- Nominal pumping speed = **1000 $m^3 h^{-1}$**
    - Ultimate pressure = **1×10^{-2} mbar**
- **Target pressure = 1×10^{-1} mbar**
    - x 10 higher to reduce any back streaming of gas
    - Low enough for TMPs starting



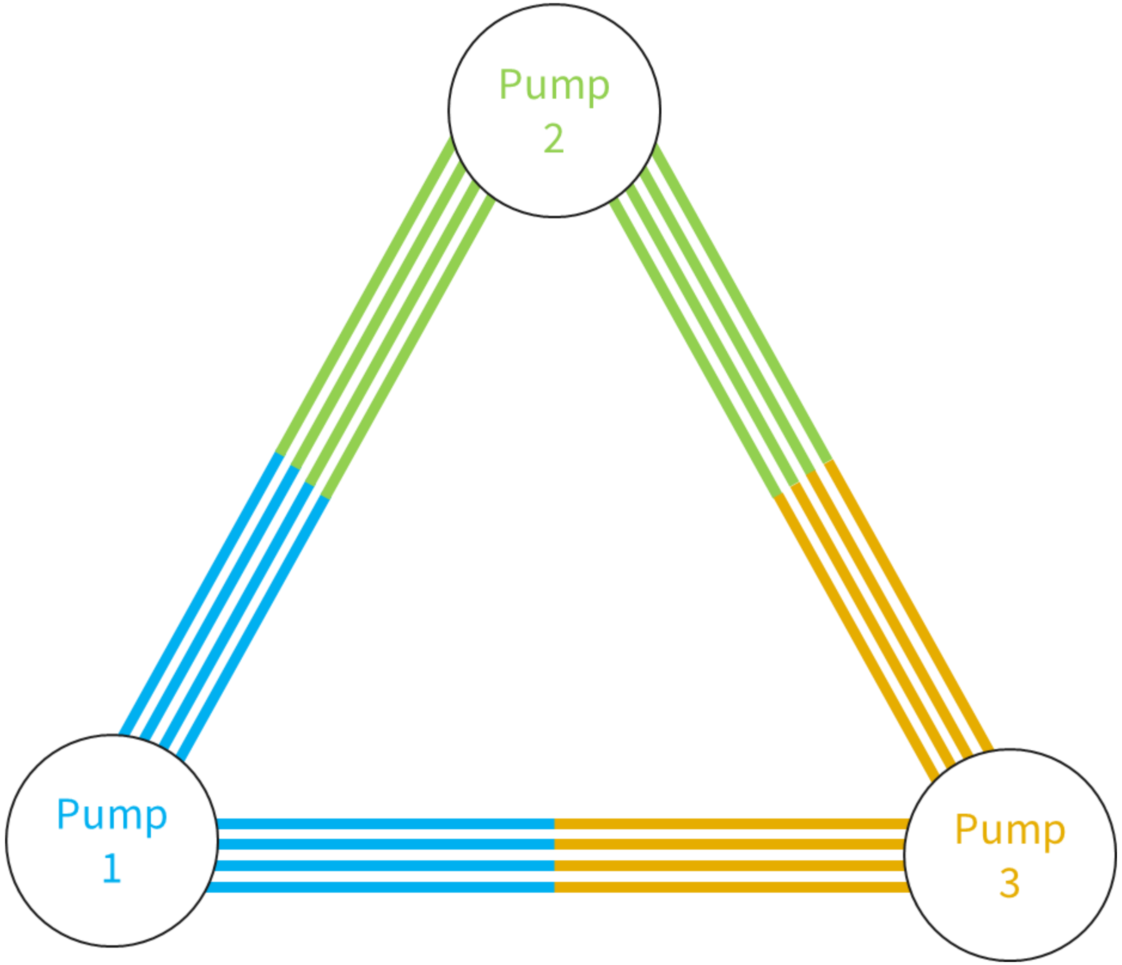


→ **Target pressure** reached in ~**10 days**

Rough pumping: optimization

In view of their weight (>350 kg), these pumping groups cannot be easily transported along the arm length.

Can be deployed to all 8 - 5km long sector sharing the same vertex.



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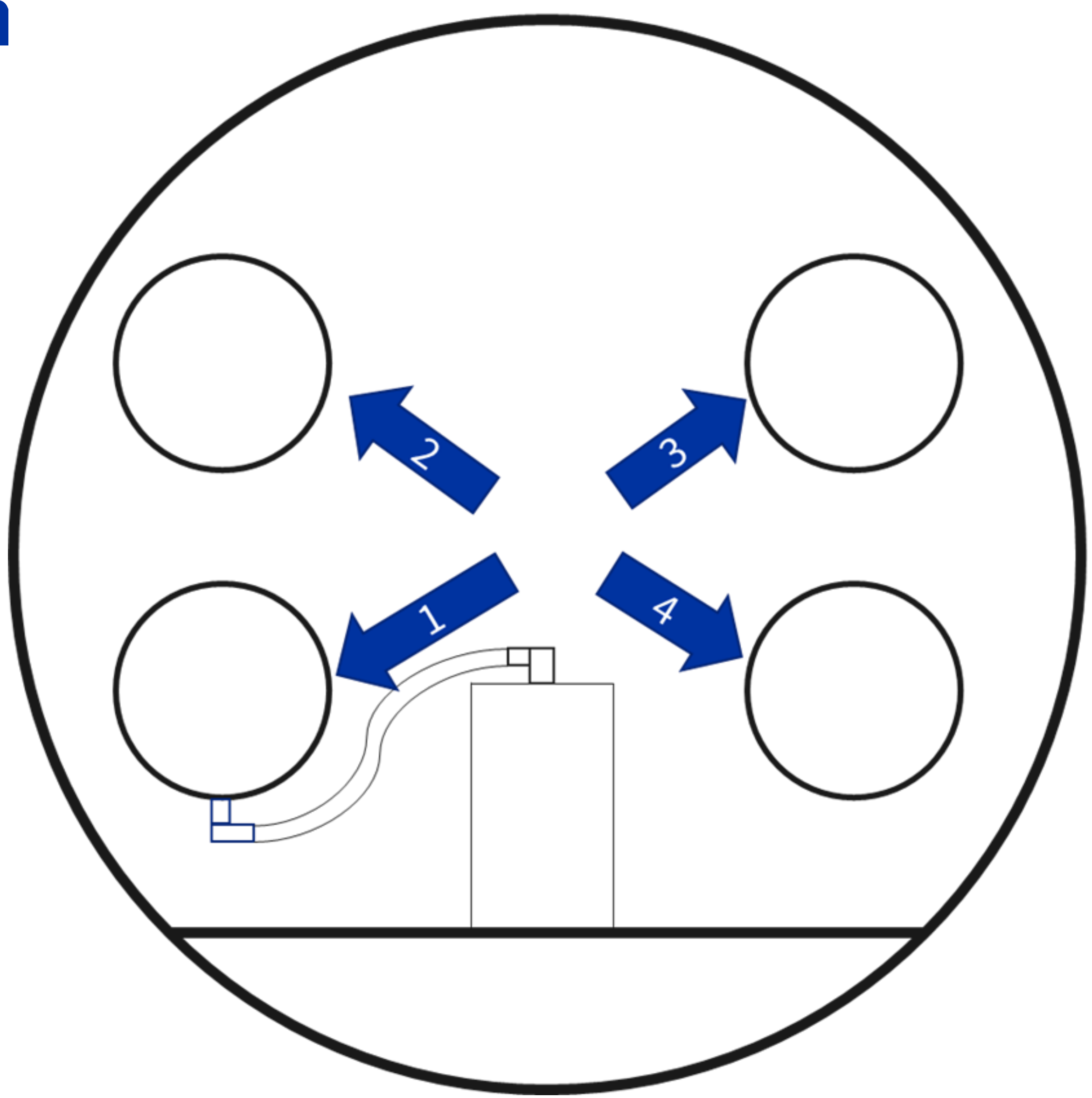


HV pumping
(from HV to UHV range)

HV pumping: vacuum layout

Assumption:

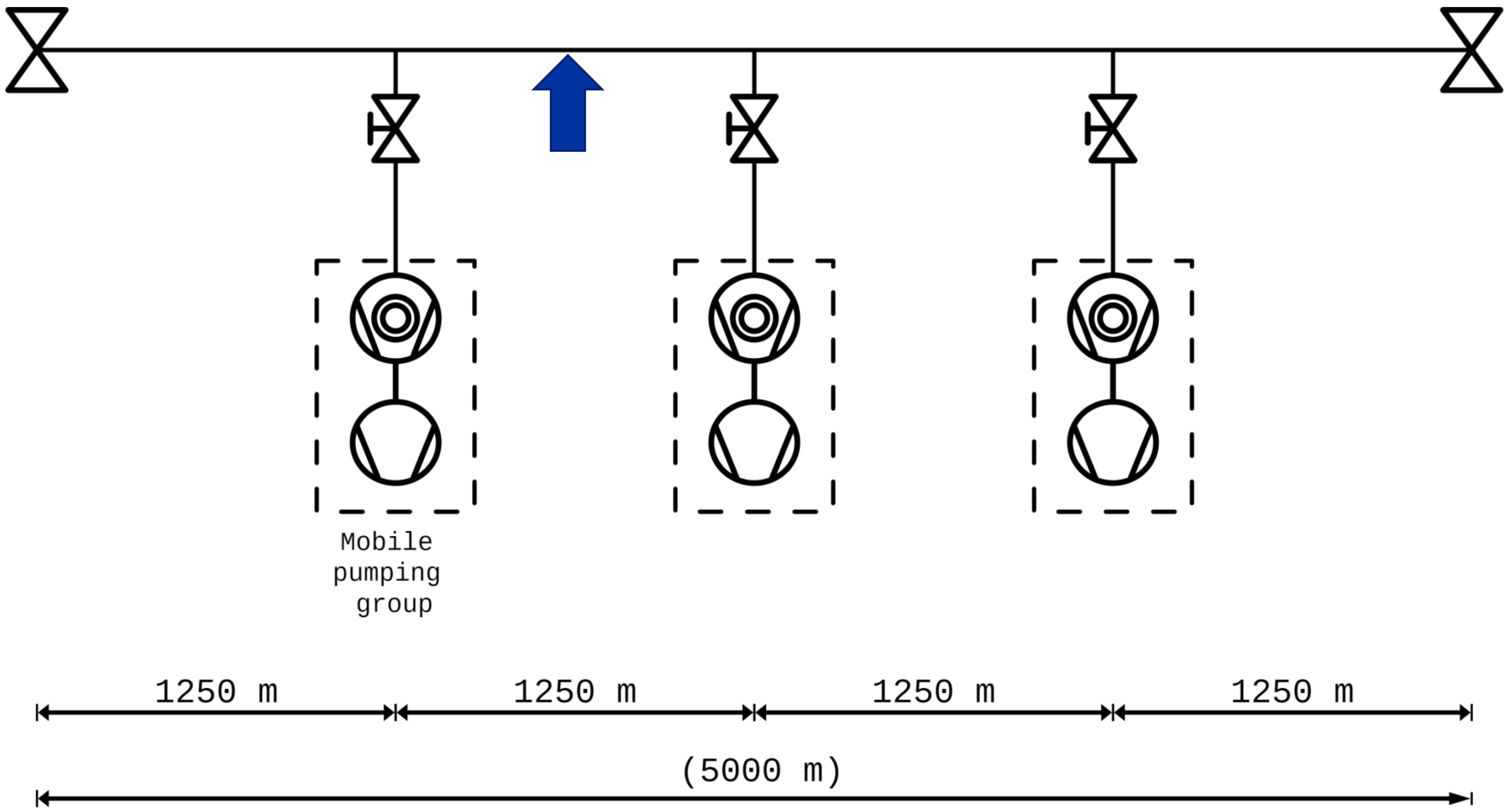
- **Mobile pumping groups (Turbomolecular pump + primary pump).**

  → At UHV range, they will be substituted with capture pumps.

- **Gate valves** to **separate the tube** from the mobile **pumping group.** (preferably electropneumatic).
- **Pumps evenly distributed.**

HV pumping: vacuum layout

After a set of iterations, an optimal solution could be:



HV pumping: optimal turbomolecular pumps

What is the impact of the TMP pumping speed on the pump-down time?

TMP pumping before bake-out starts: 7 days

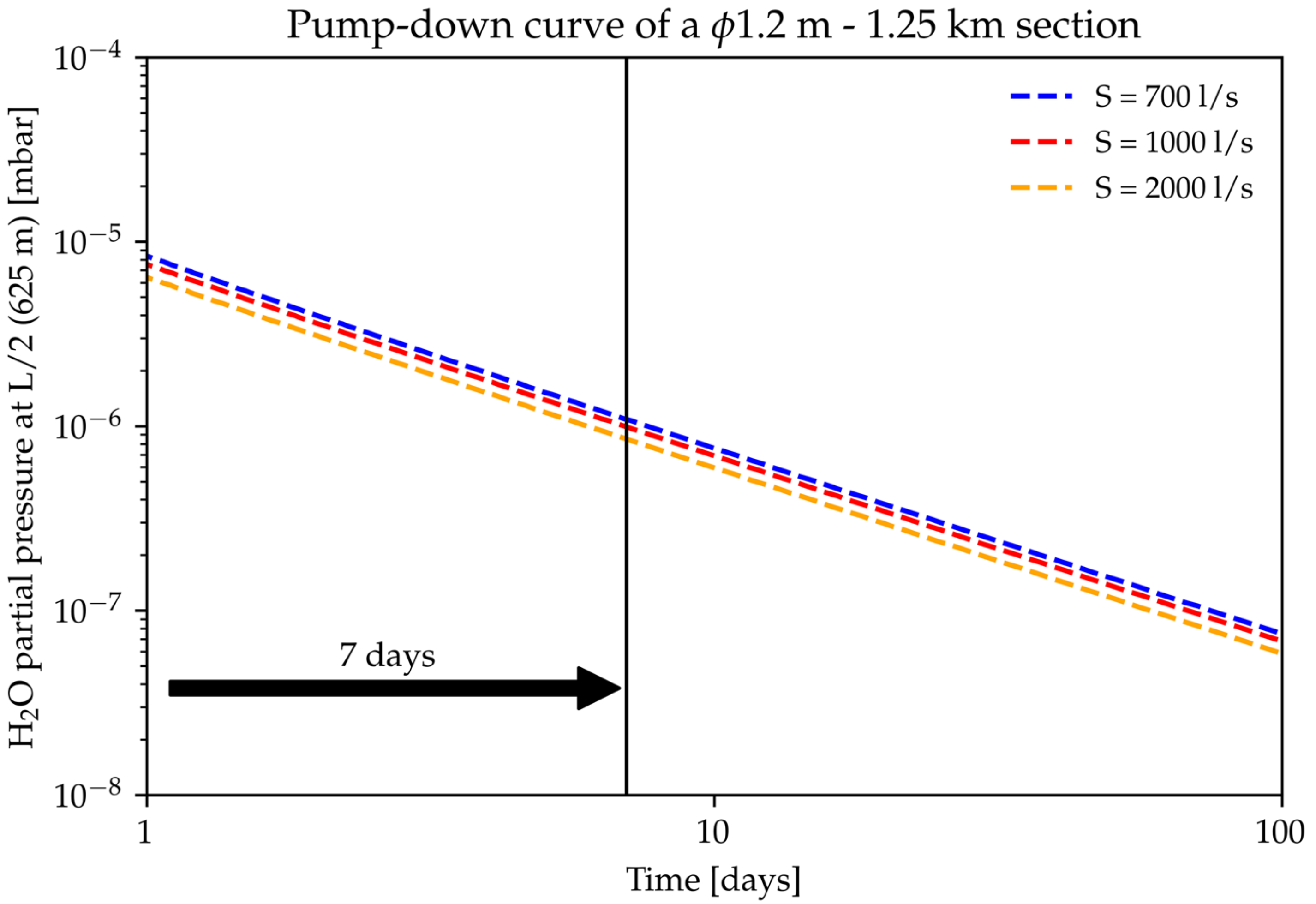
No clear advantage shown for going > 700 l s^{-1}.

At most the gain in pressure is of ~25% (for S = 2000 l s^{-1})

→ 700 l s^{-1} pump represent the optimal solution

700 l s^{-1} TMPs:

- Off the shelf product
- Air cooled
- Compact solution (with fittings)



From HV to UHV pumping: bake-out

Bake-out strategy must take in account several constraints on:

- ventilation system
- power consumption
- increase of temperature in the tunnel

Assumptions:

Bake-out **temperature :**	**Less than 100°C**
Bake-out **duration:**	**max 30 days**

Bake-out performance can be enhanced by increasing the local pumping speed

↳ **NEG pumps**

HV pumping: NEG pump distribution

Parameters:

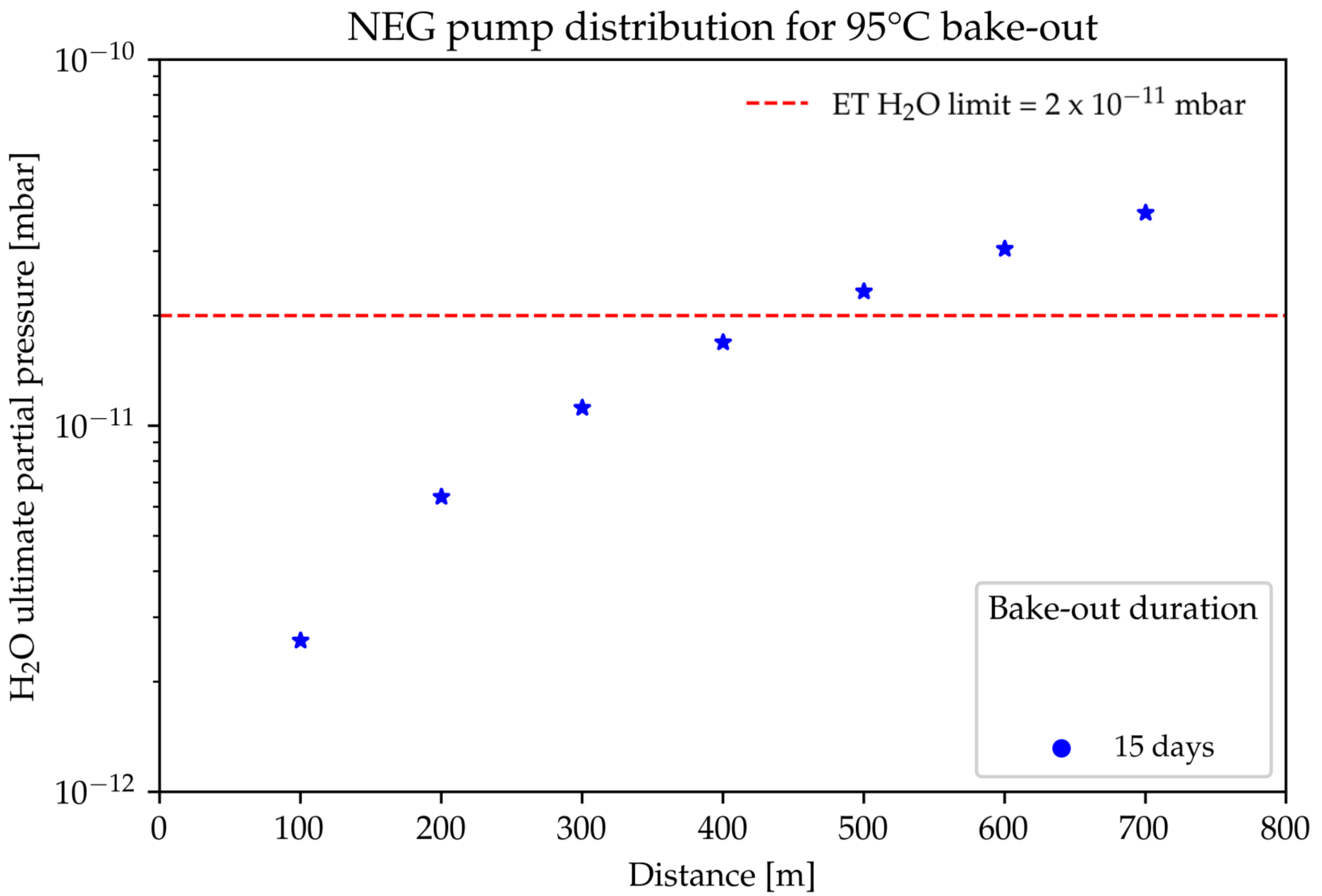
D = 1.2 m

L = 1250 m (distance between two turbos)

TMP pump-down duration: **7 days**

S_{TURBO} = 700 ls^{-1}

S_{NEG} = 1500 ls^{-1} (H_2O)



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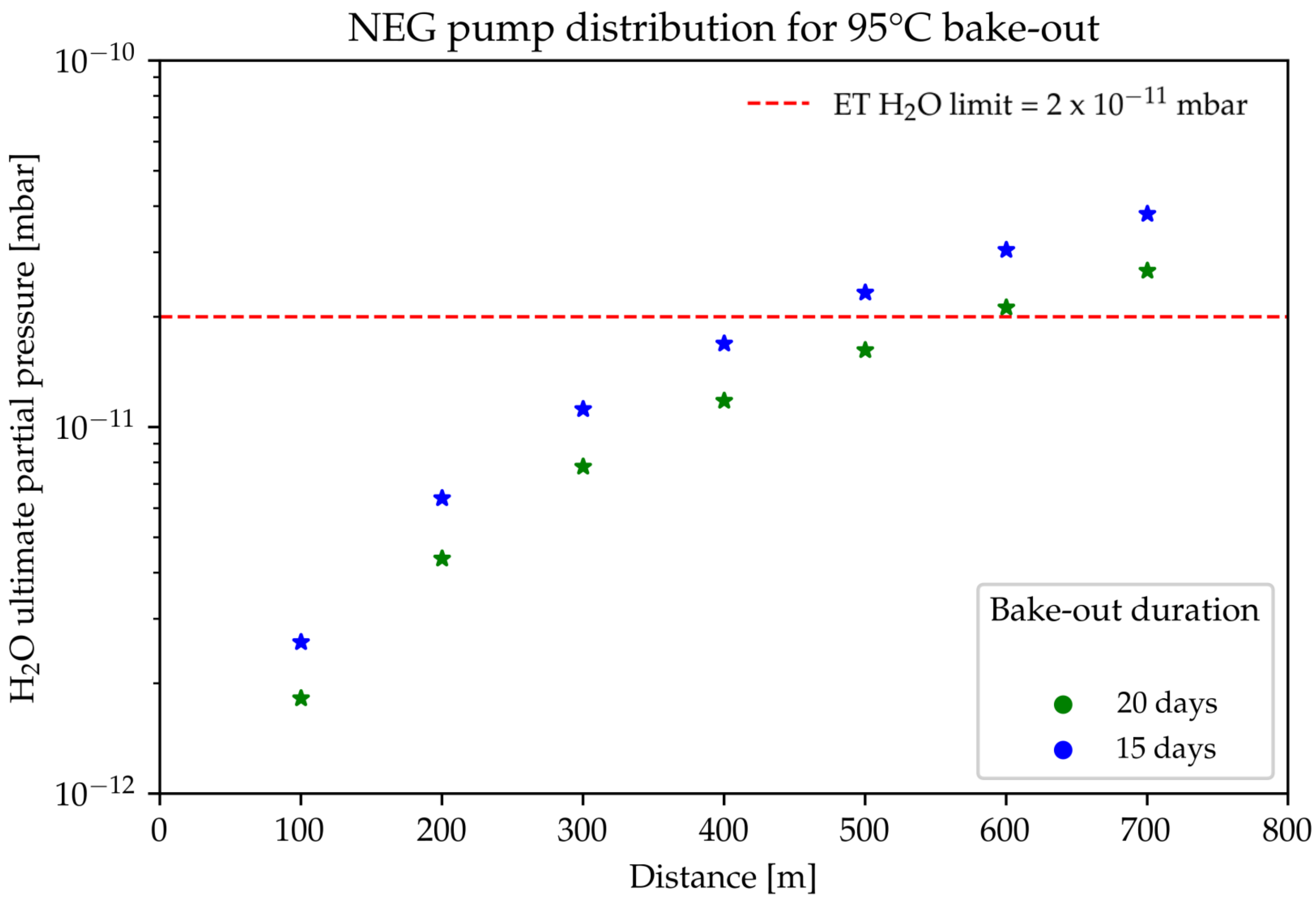

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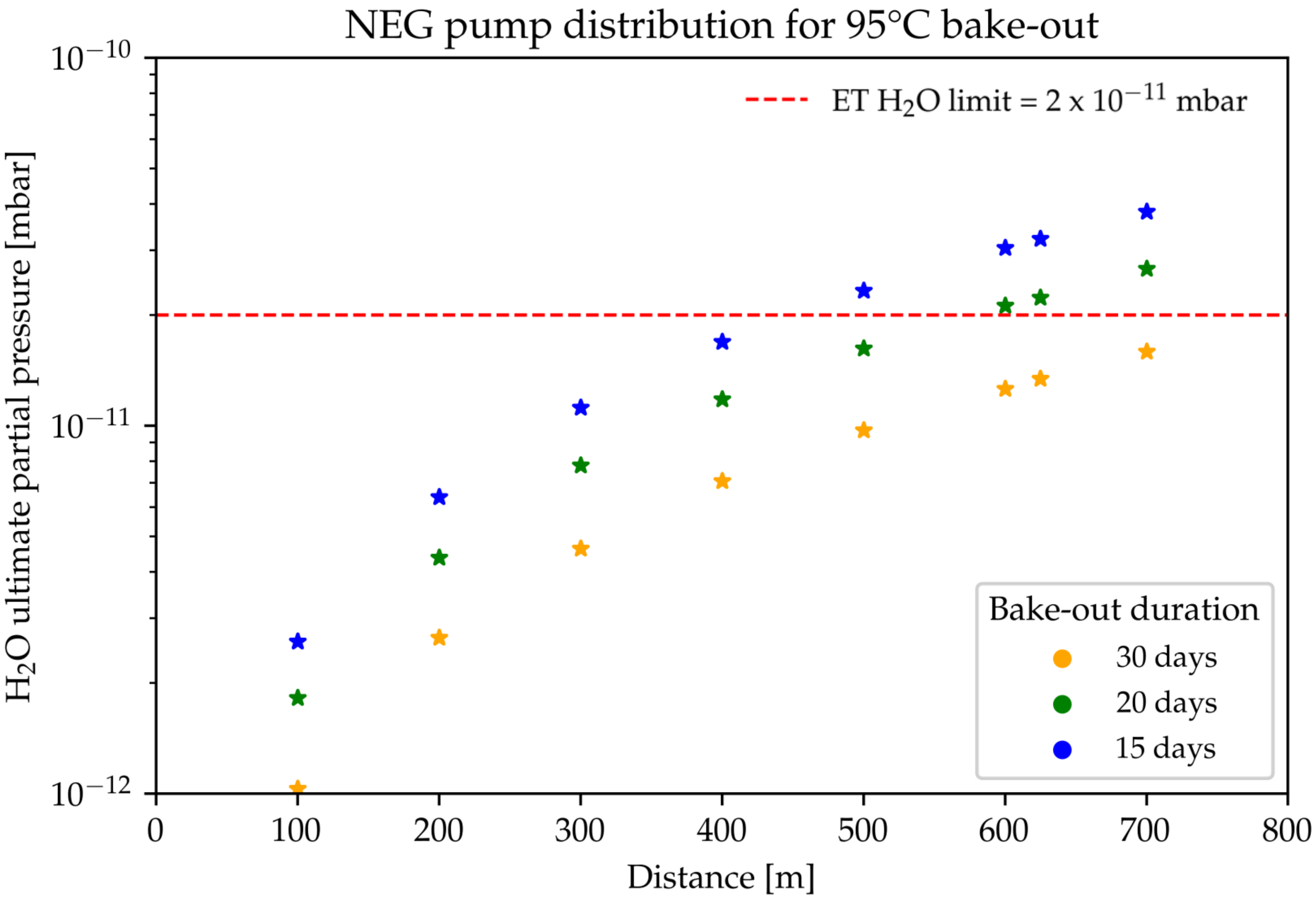

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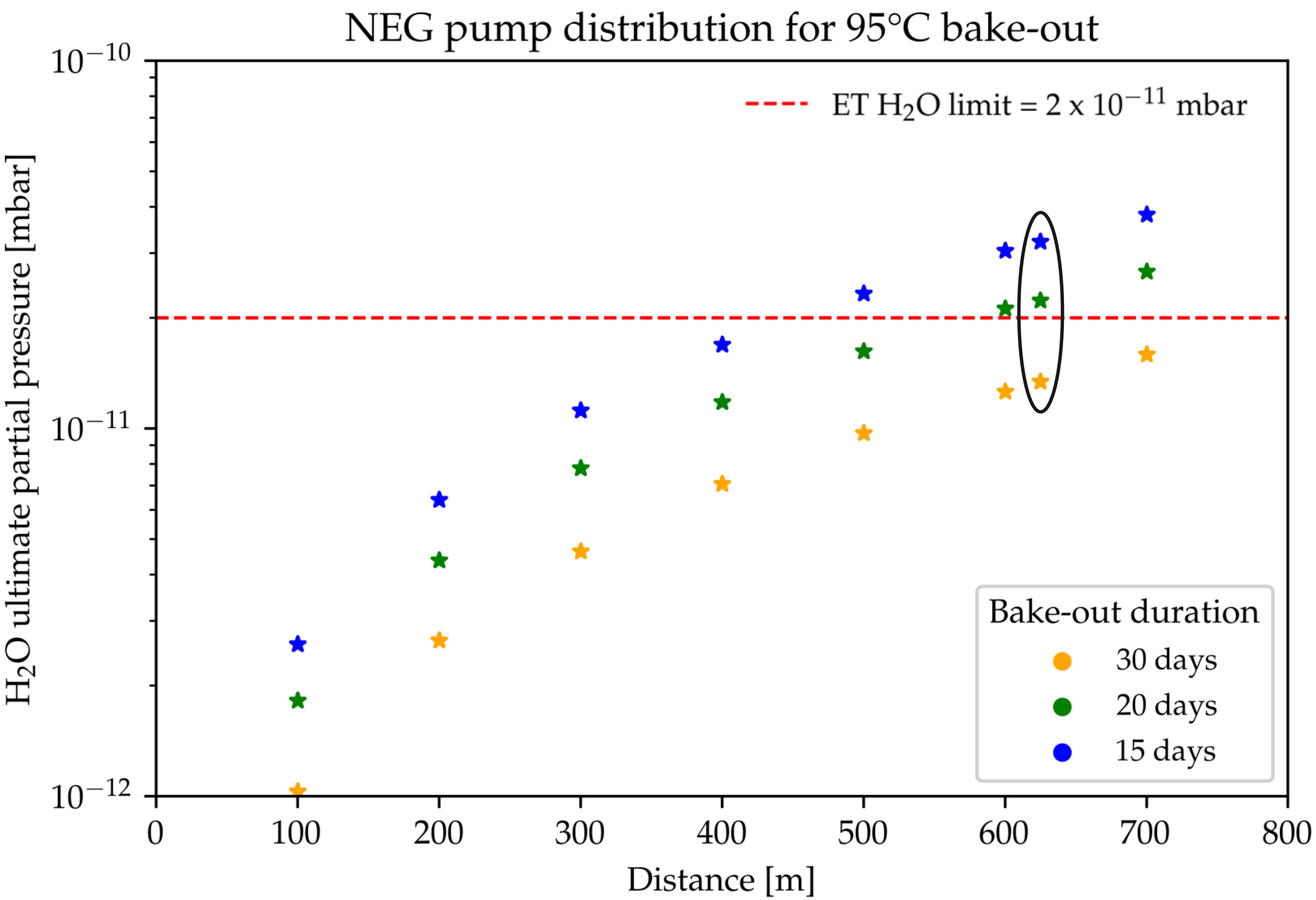
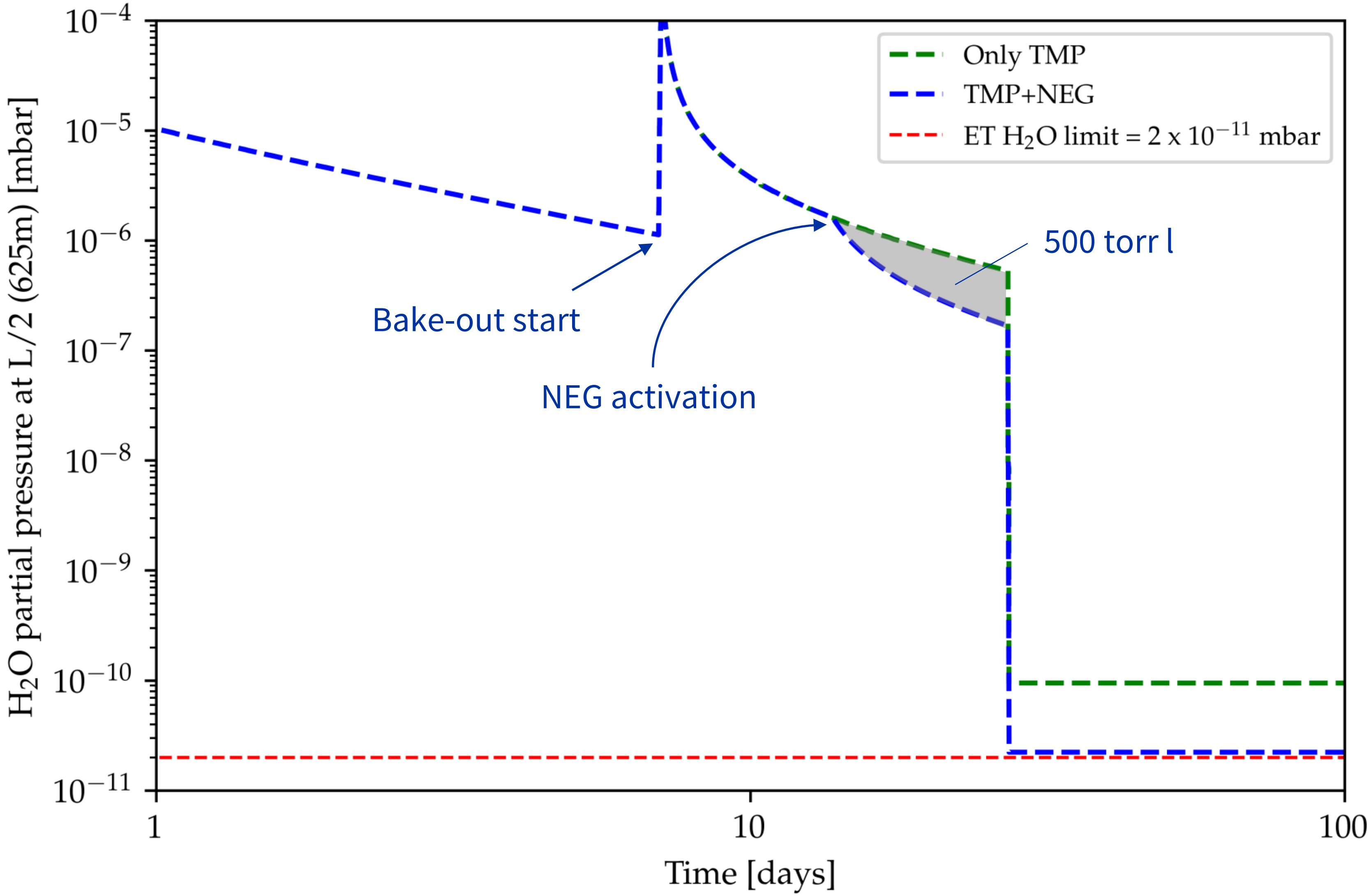
One NEG pump every 625 m to assist the bake-out cycle



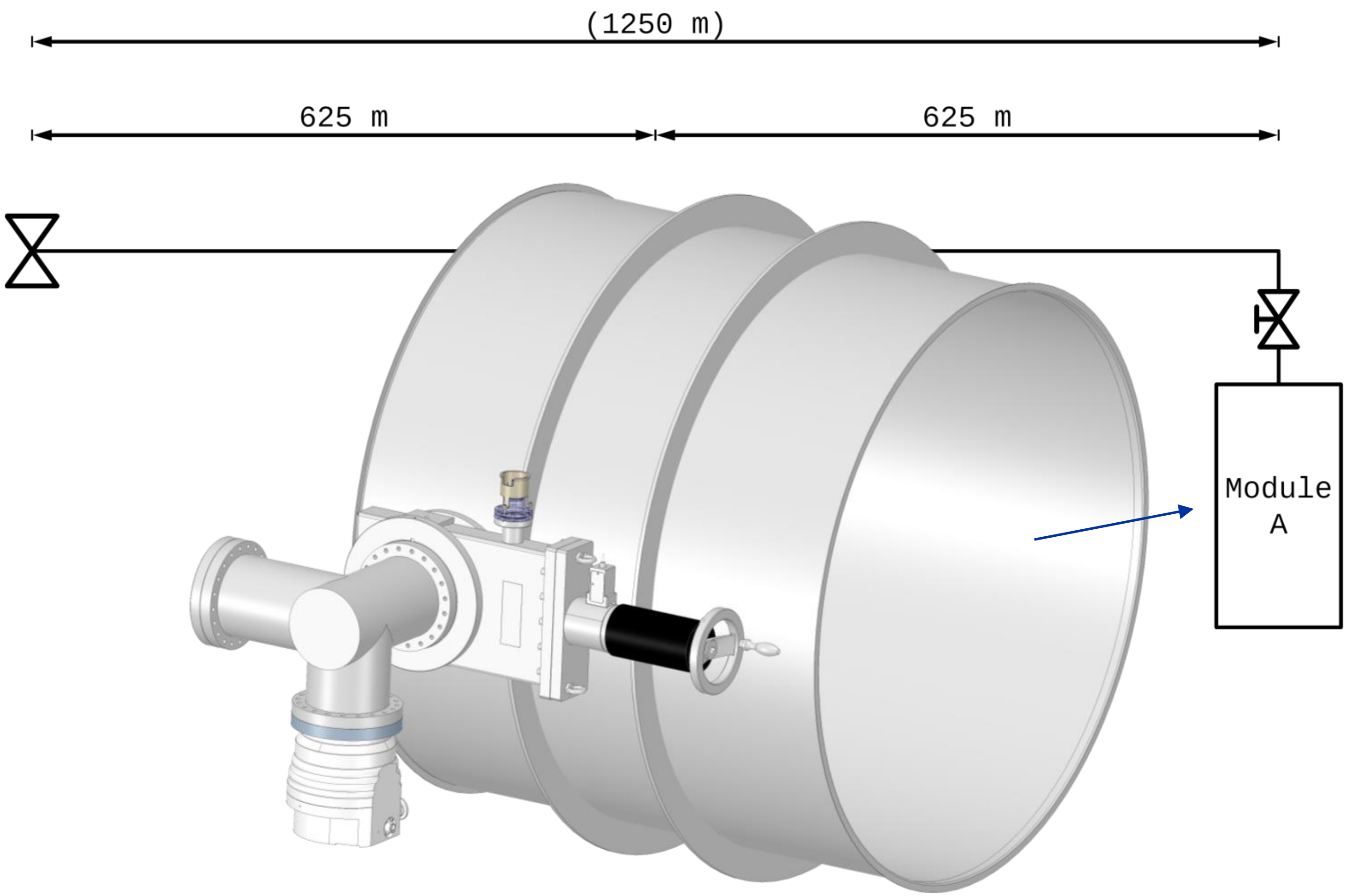
HV pumping: ultimate pressure after bake-out

- **Isotherm: Temkin**
- **TMP pump-down** duration: **7 days**
- **Bake-out** = **95°C, 20 days**
- **Neg activation: after 1/3 of bake-out duration**

→ **H_2O ultimate P ≈ 2×10^{-11} mbar**

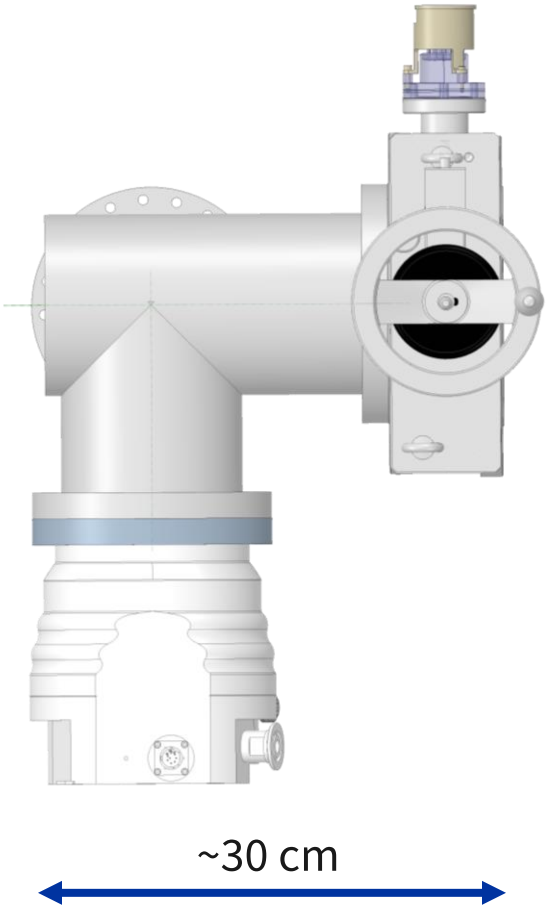


HV pumping: vacuum layout



Module A (mobile):

2000 ls^{-1} (H_2) NEG + 700 ls^{-1} TMP



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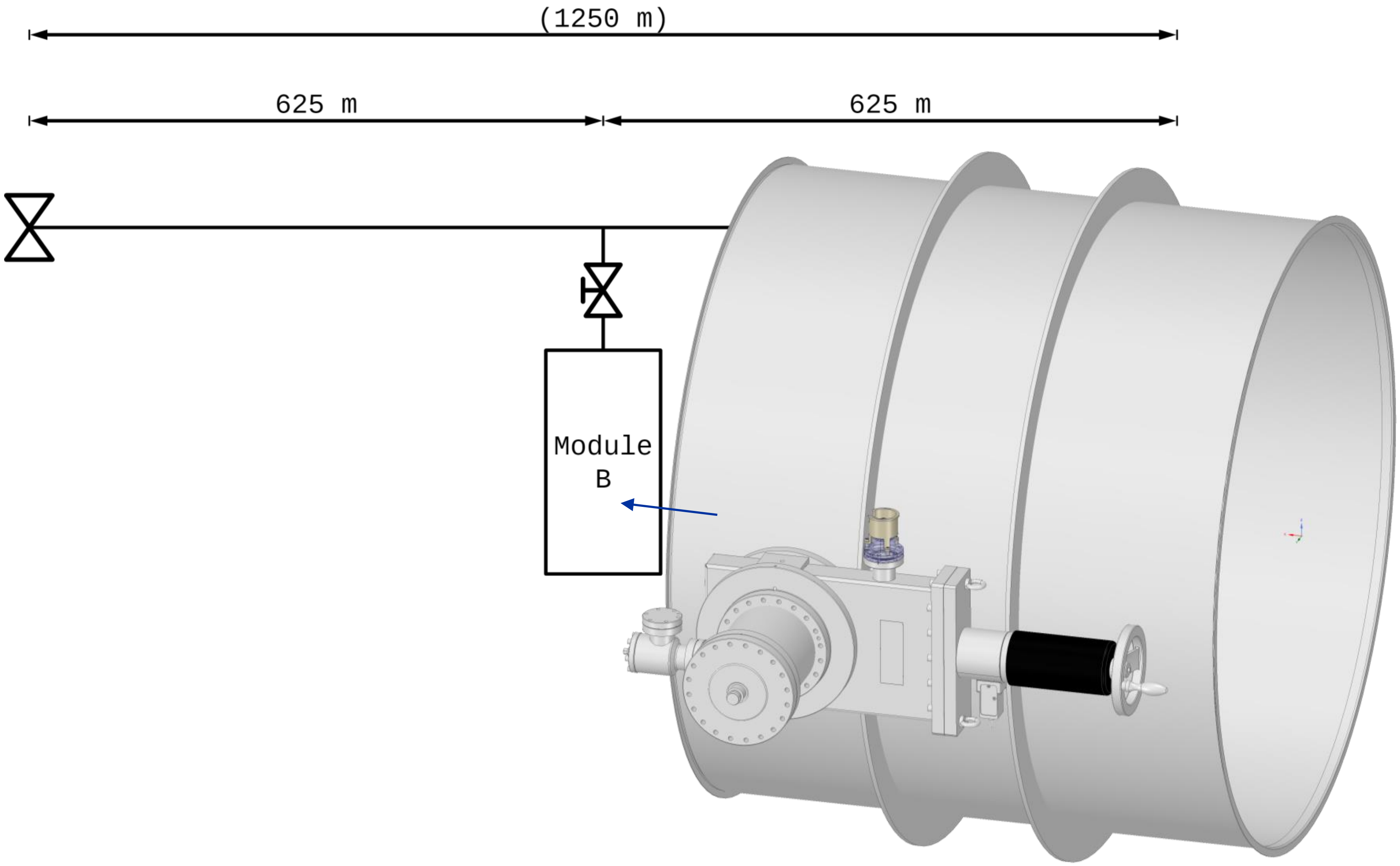
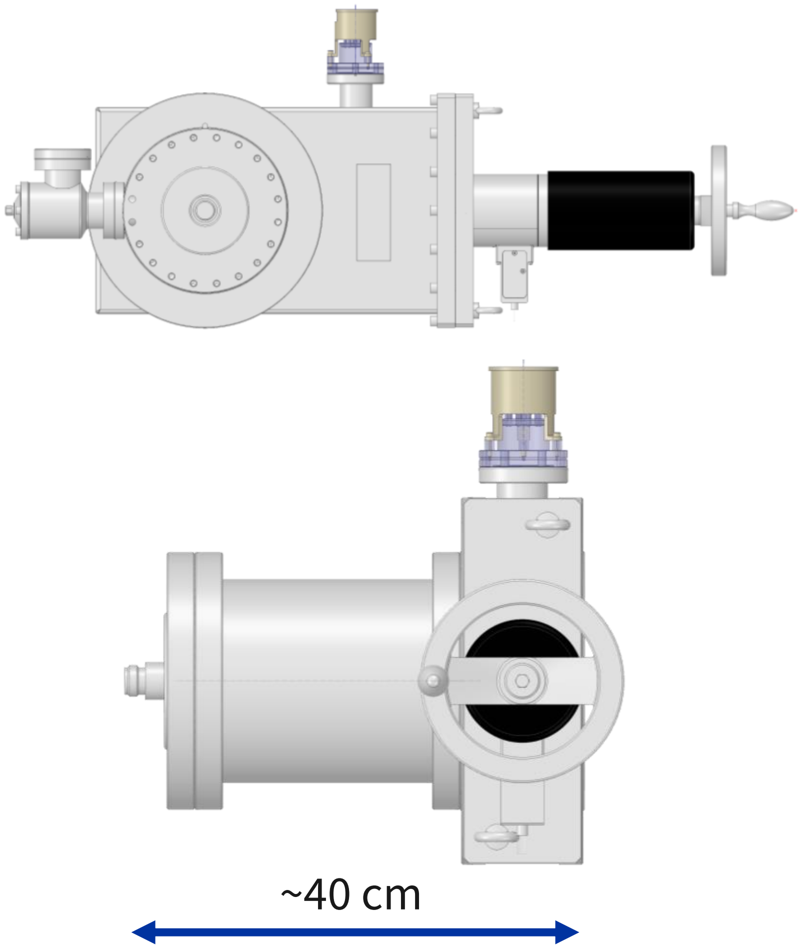


Module B:

2000 ls^{-1} (H_2) NEG



UHV pumping at RT

(H_2, CH_4, CO and CO_2)

UHV pumping at RT: pressure requirements

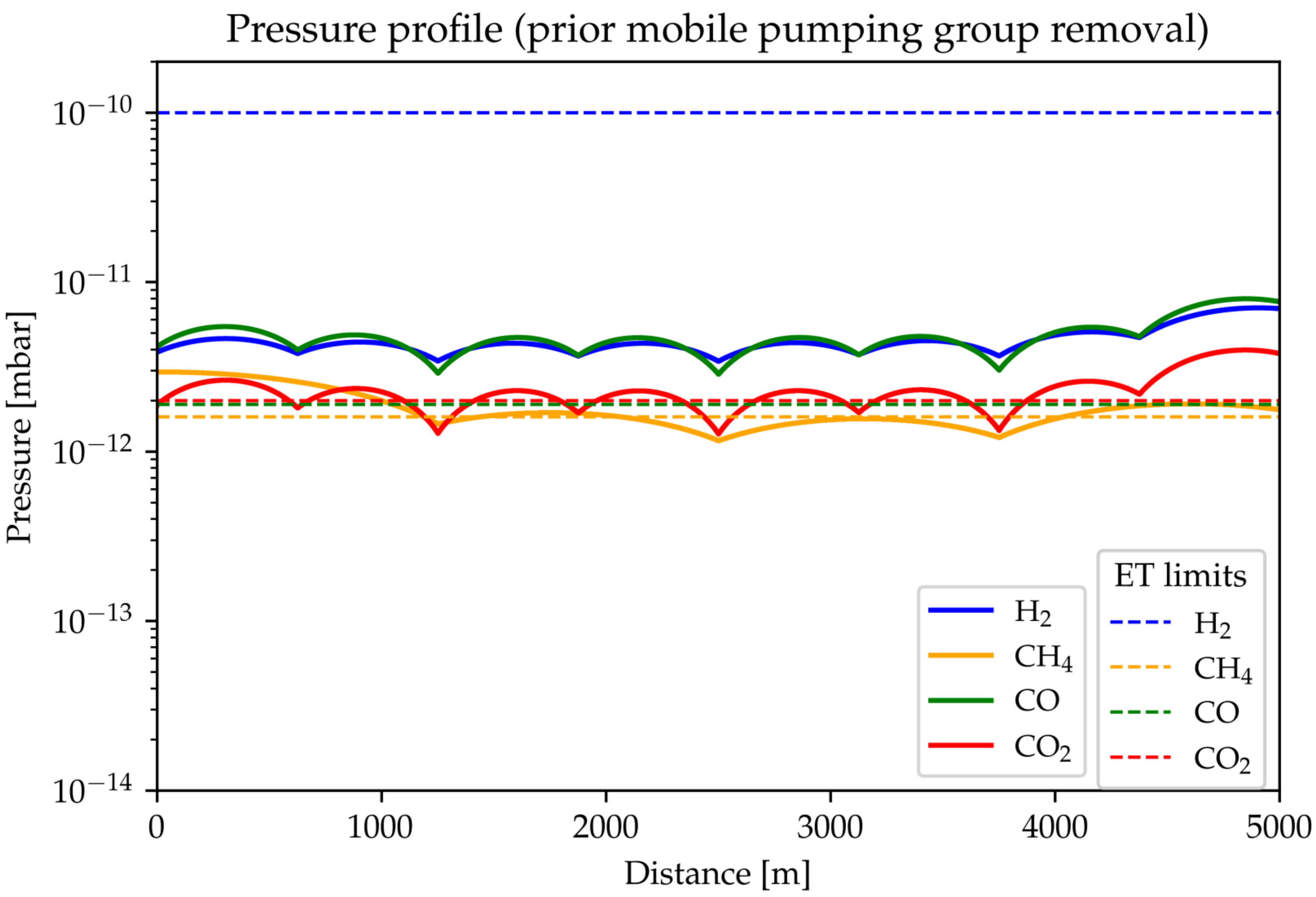
Very strong pressure requirements from physics (both for LF and HF line):

Gas	Goal P_{ET} [mbar]
H_2	1×10^{-10}
CH_4	1.6×10^{-12}
CO	1.9×10^{-12}
CO_2	2×10^{-12}

UHV pumping at RT: pressure profile post bake-out

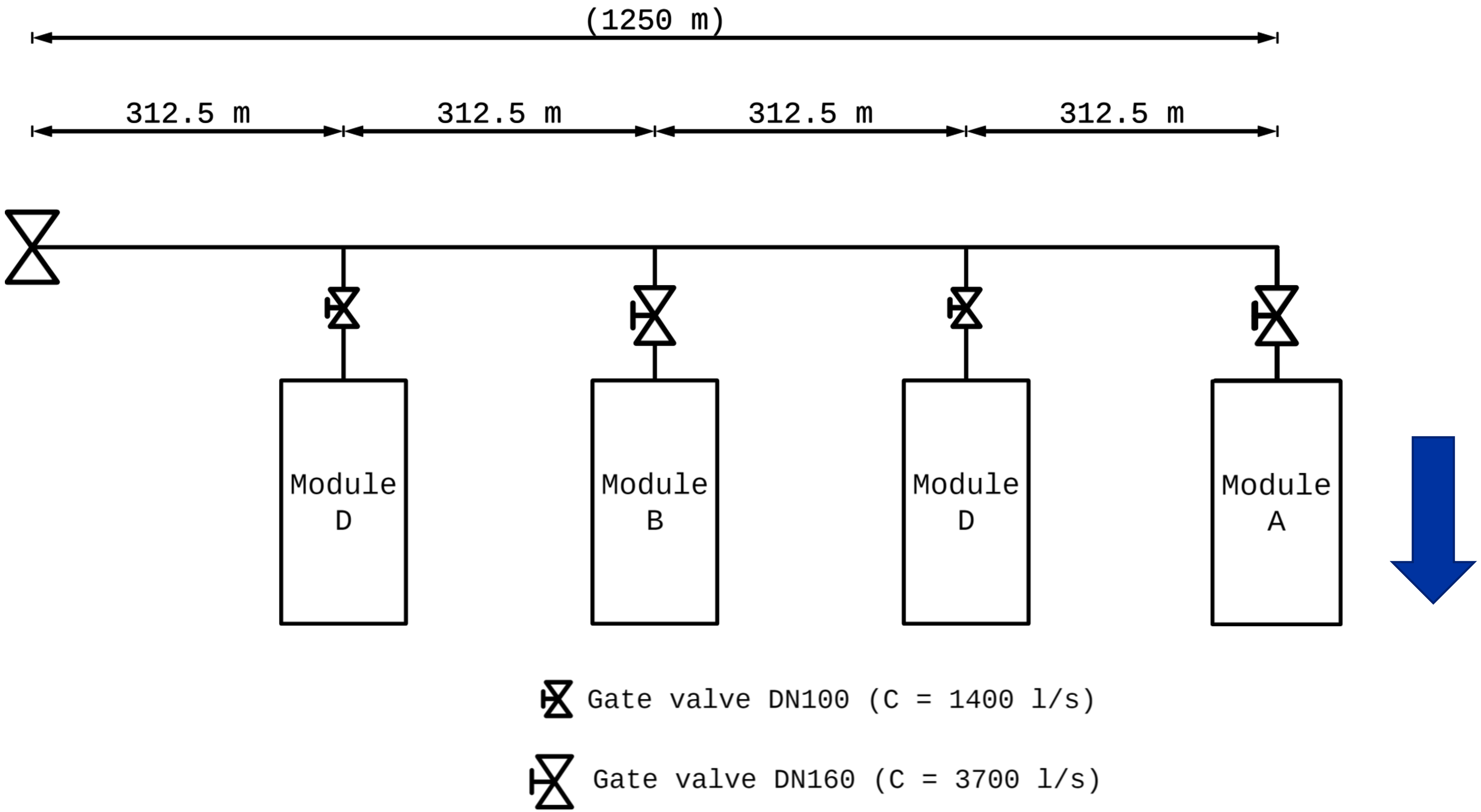
If we rely only on the pumps from HV pumping layout, we cannot meet the requirement.

Moreover, when mobile pumping groups are removed, we need to pump CH_4 and to lower CO and CO_2 pressures.



UHV pumping at RT: vacuum layout

Keeping symmetry:



UHV pumping at RT: vacuum layout

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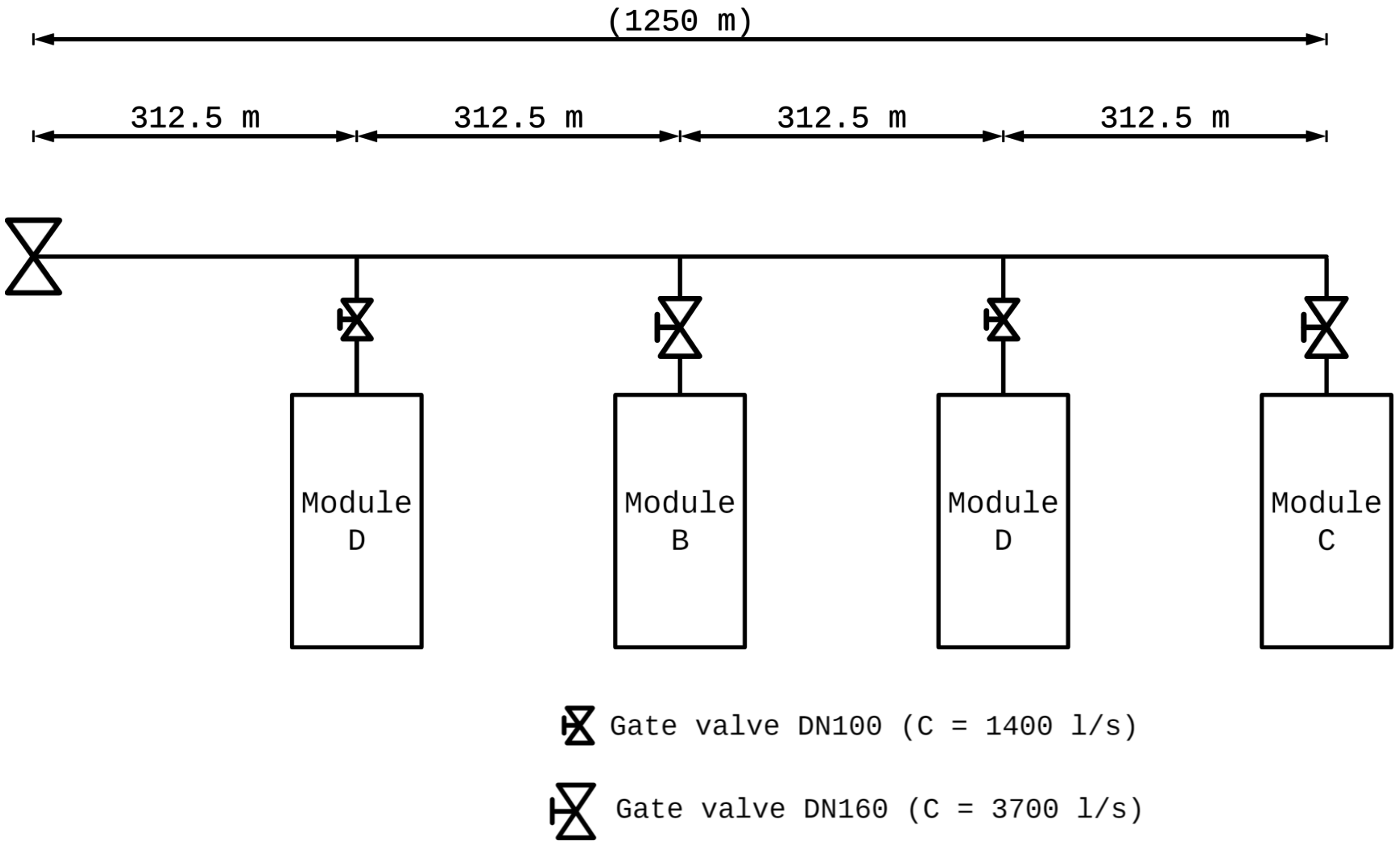
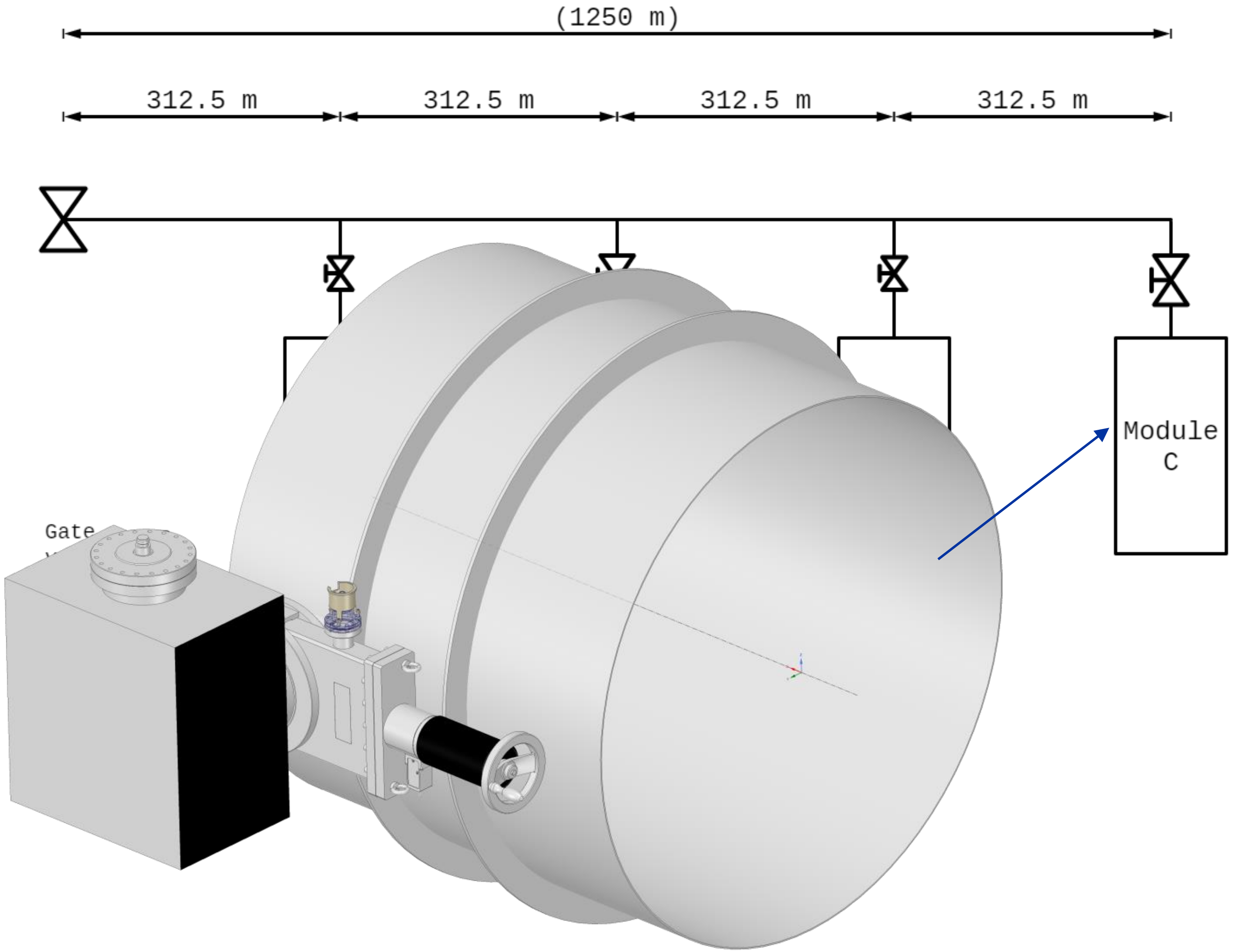
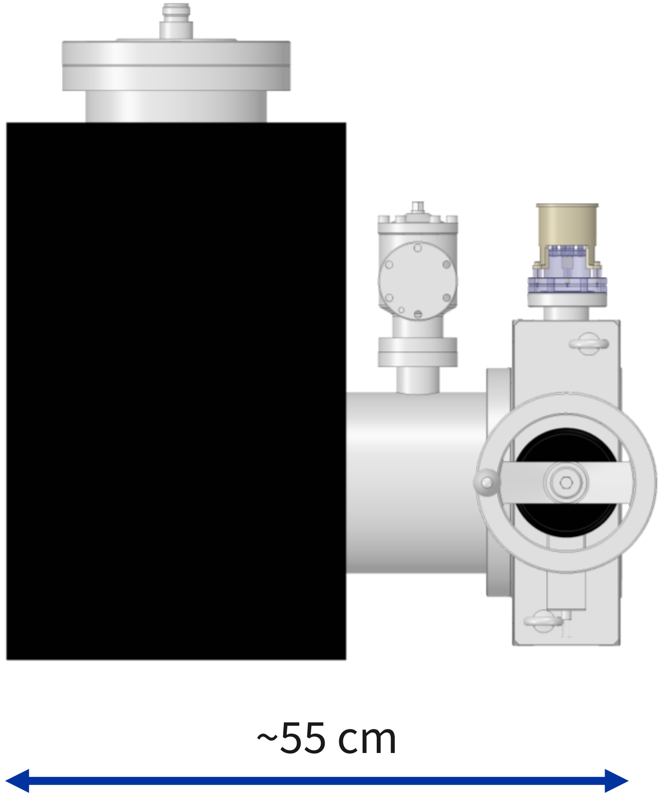


UHV pumping at RT: vacuum layout

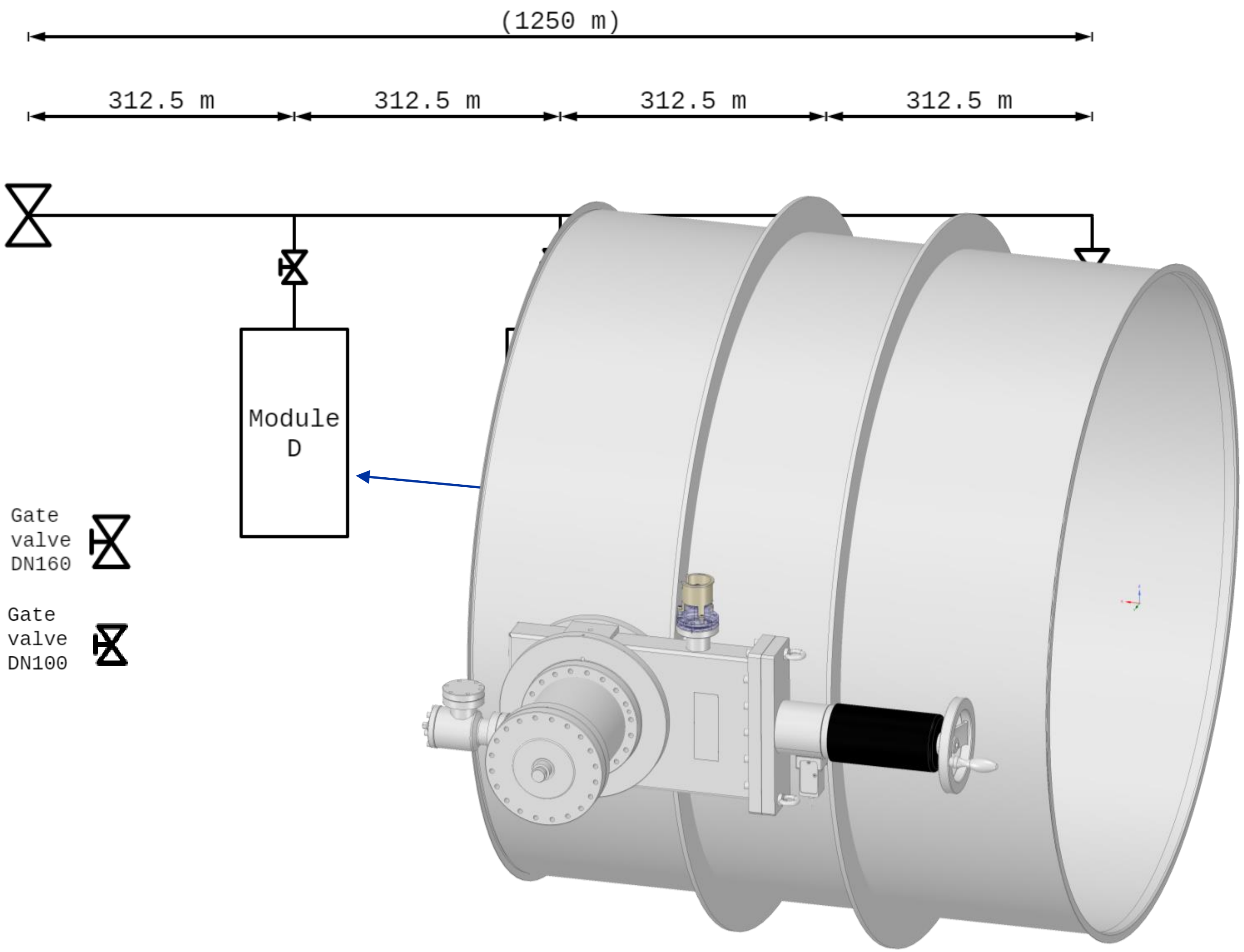


Module C:

2000 ls^{-1} (H_2) NEG + 500 ls^{-1} IP

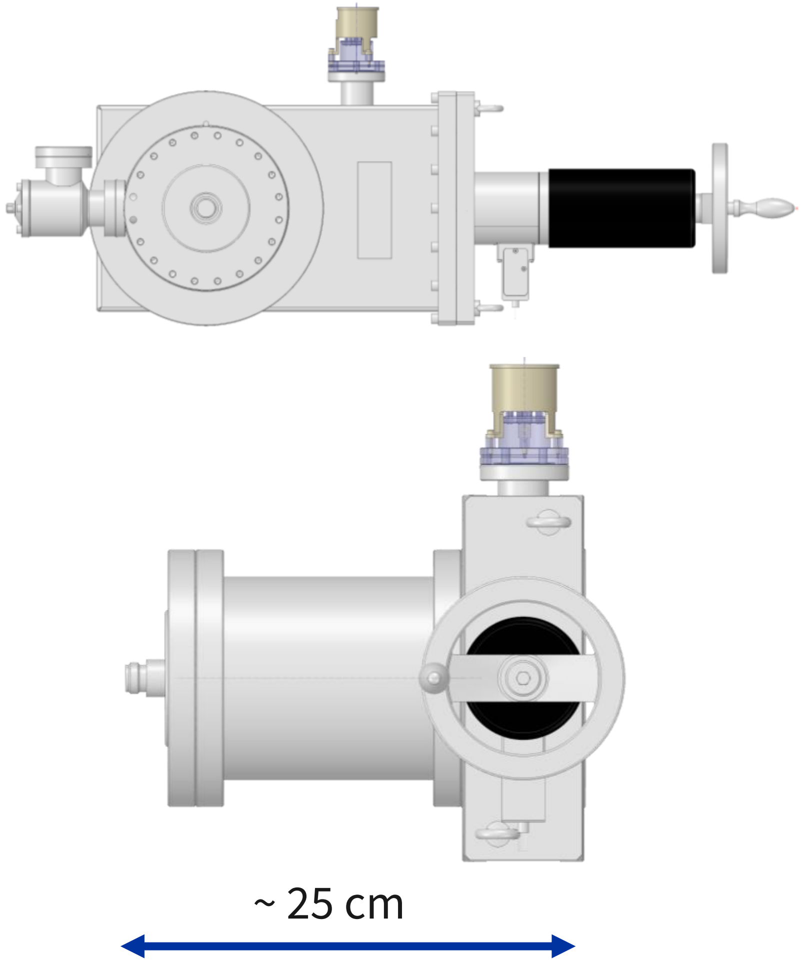


UHV pumping at RT: vacuum layout

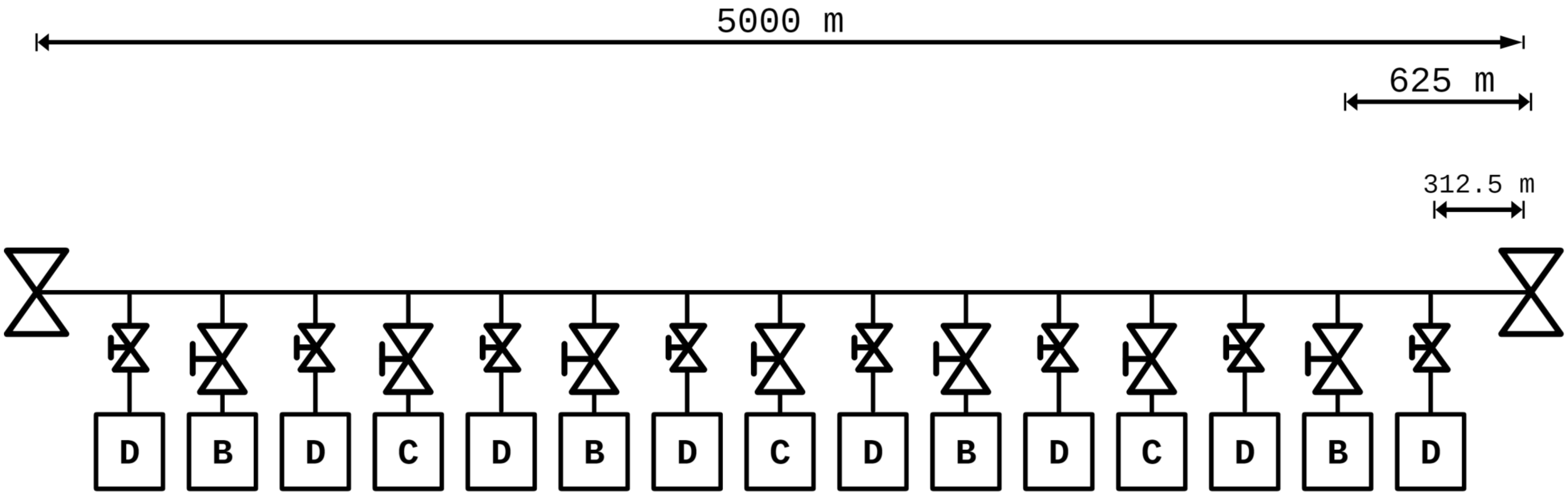


Module D:

1000 ls^{-1} (H_2) NEG



UHV pumping at RT: vacuum layout



From intermediate phase → B 2000 l/s NEG

D 1000 l/s NEG

C 2000 l/s NEG + 500 l/s IP

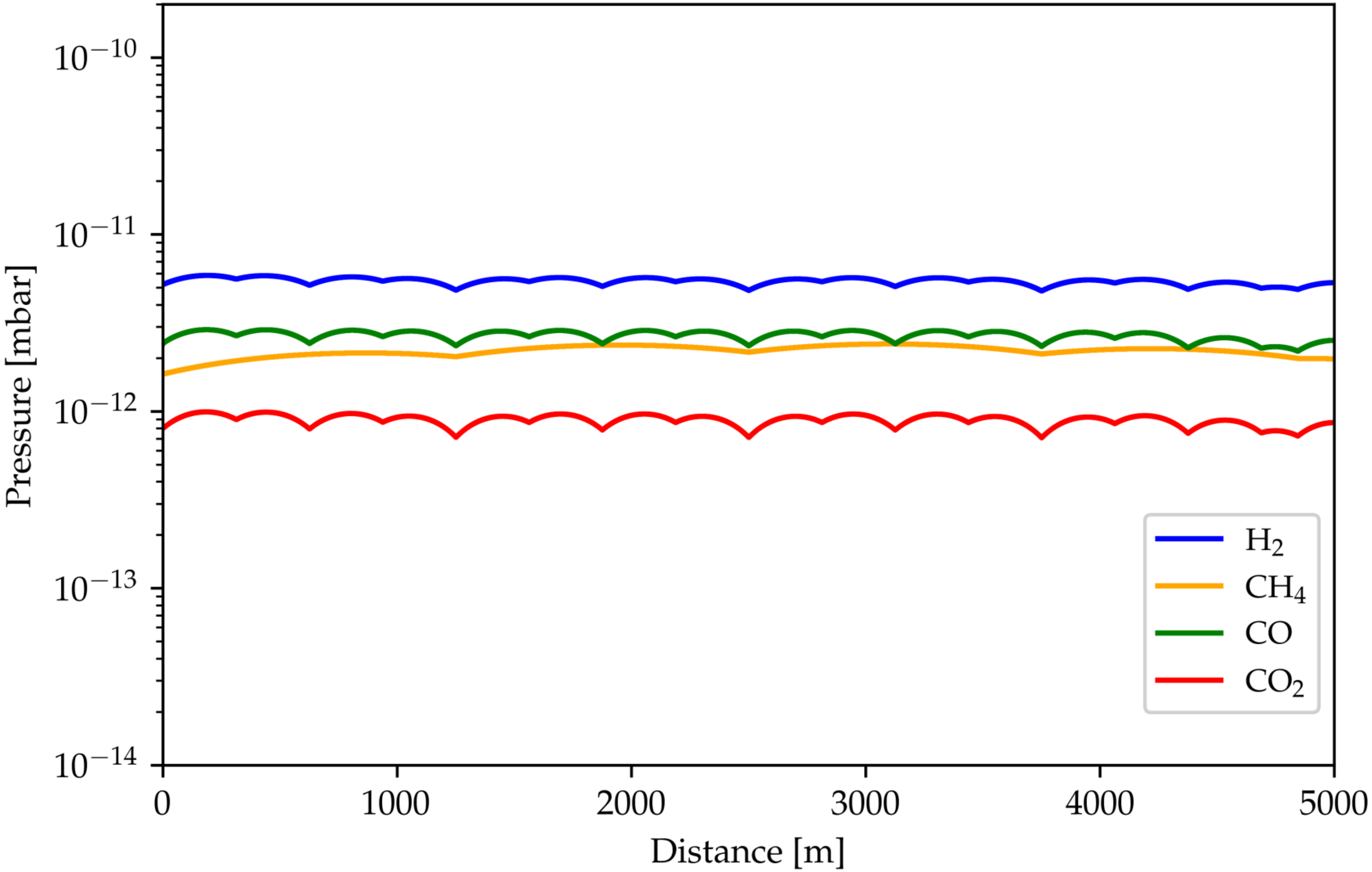
Gate valve DN100 (C = 1400 l/s)

Gate valve DN160 (C = 3700 l/s)

UHV pumping at RT: ultimate pressures

Gas	Pressure from sim. [mbar]
H_2	6×10^{-12}
CH_4	2.5×10^{-12} *
CO	3×10^{-12} *
CO_2	1×10^{-12} *

- **Upper limit (measurement background limited)**

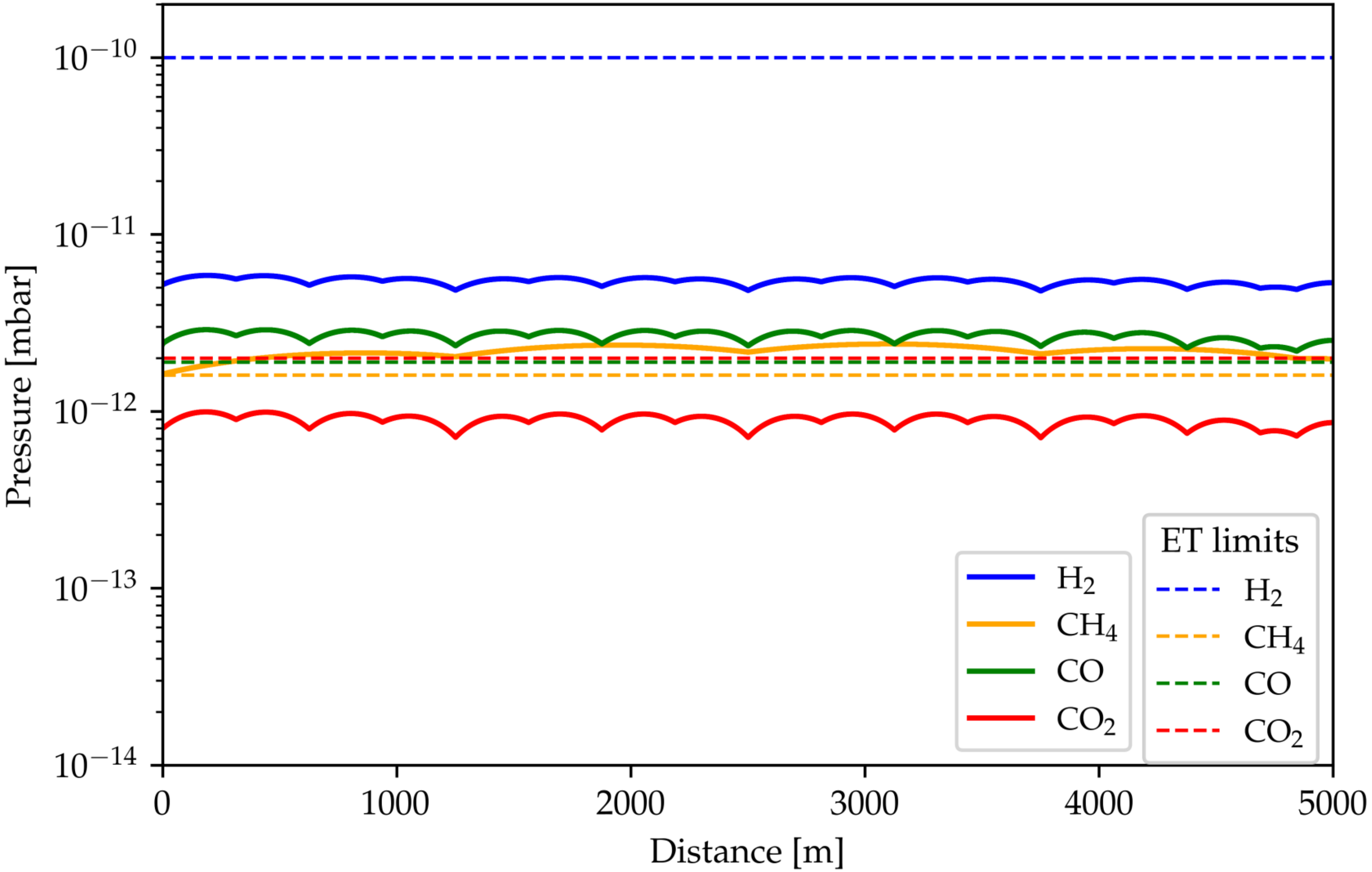


- Distance 0 m = Pressure are going to be much lower due to cryogenics
- Distance 5000 m = DN1250 GV outgassing contribution not considered (a special module is in study to cope with it)
- **Gate valves DN150/DN100 needs extra care, their outgassing rate could be harmful!**

UHV pumping at RT: ultimate pressures

Gas	Pressure from sim. [mbar]	
H_2	6×10^{-12}	✓
CH_4	2.5×10^{-12} *	≈
CO	3×10^{-12} *	≈
CO_2	1×10^{-12} *	✓

- **Upper limit (measurement background limited)**



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Bake-out: insulation and operational aspects

Bake-out: Insulation

Low temperature bake-out, opens also to more options for insulation

Mineral wool

EPDM

Phenolic/Polyurethane foam

Aerogel

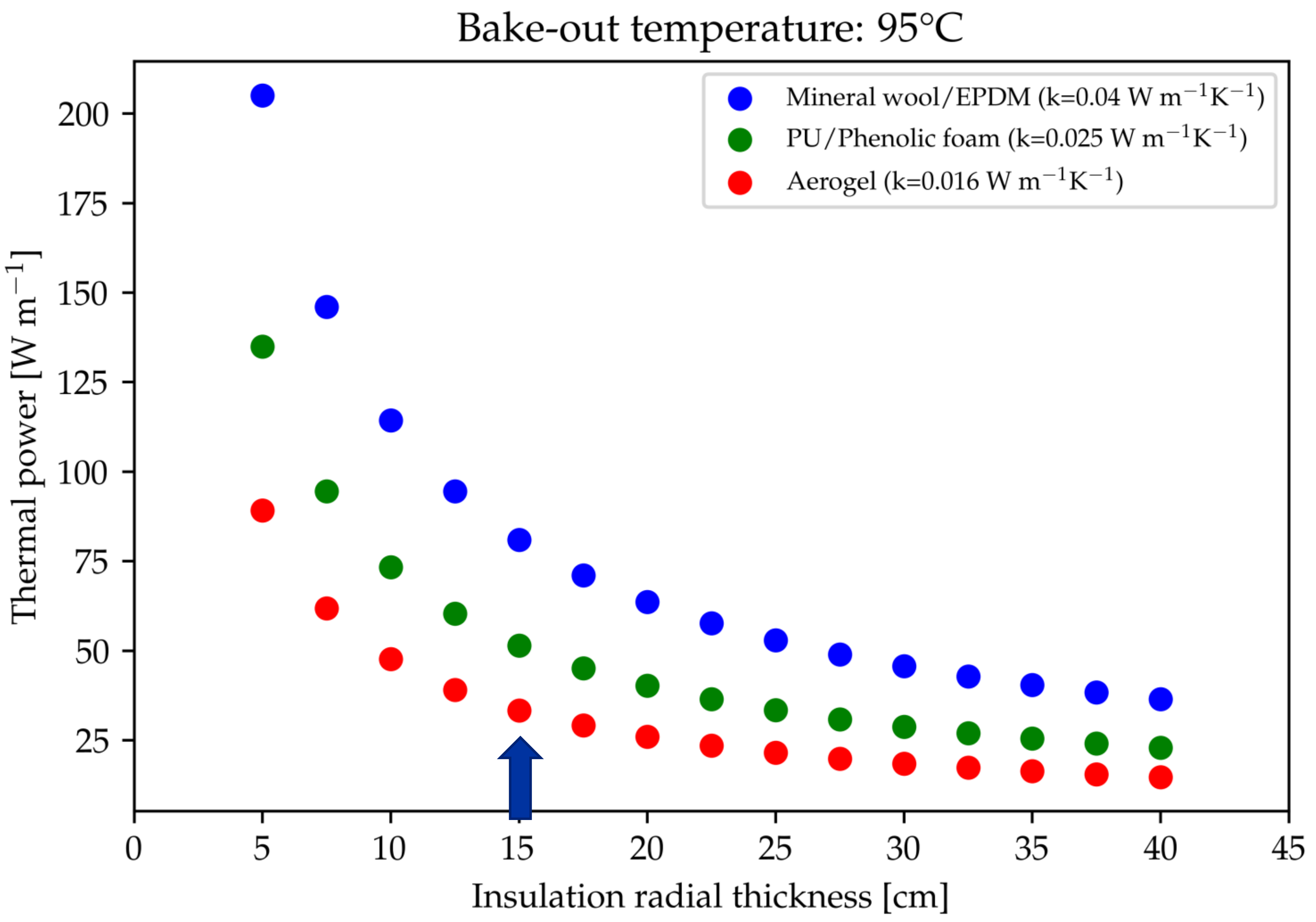
Bake-out: Insulation thickness

Assuming:

- h_{air} = 5 W m^{-2} K^{-1} (calm air, free convection)
- t_{tube} = 3 mm

For 15 cm of insulation (2G like):

Q [W m^{-1}] ≈ 81, 72 , 35



*Only thermal power loss is considered

**2.77×10^{-7} ohm m @ 95°C

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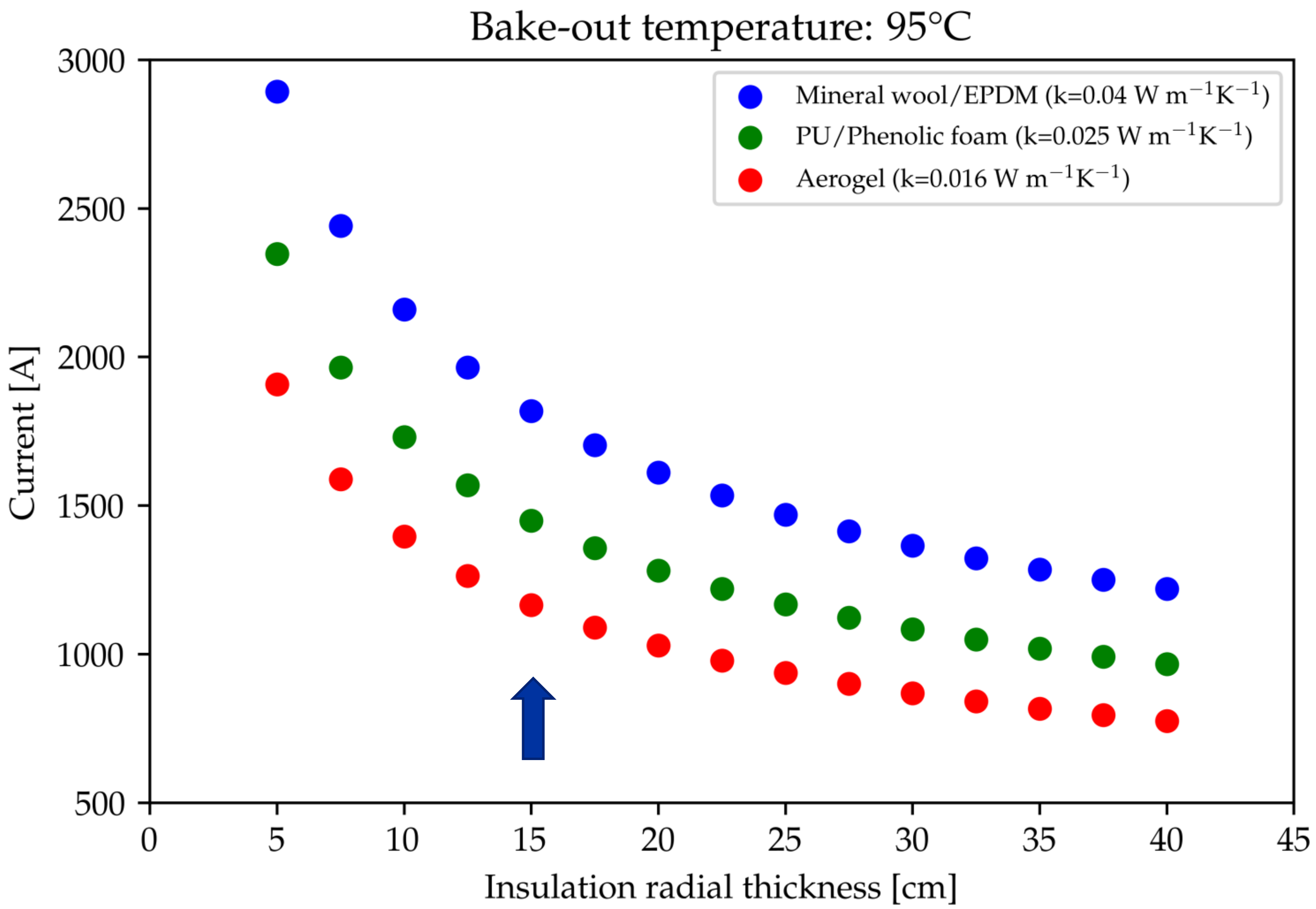
Assuming mild steel electrical resistivity** to be ~30% of the SS one:

I* [A] ≈ 1820, 1450, 1165



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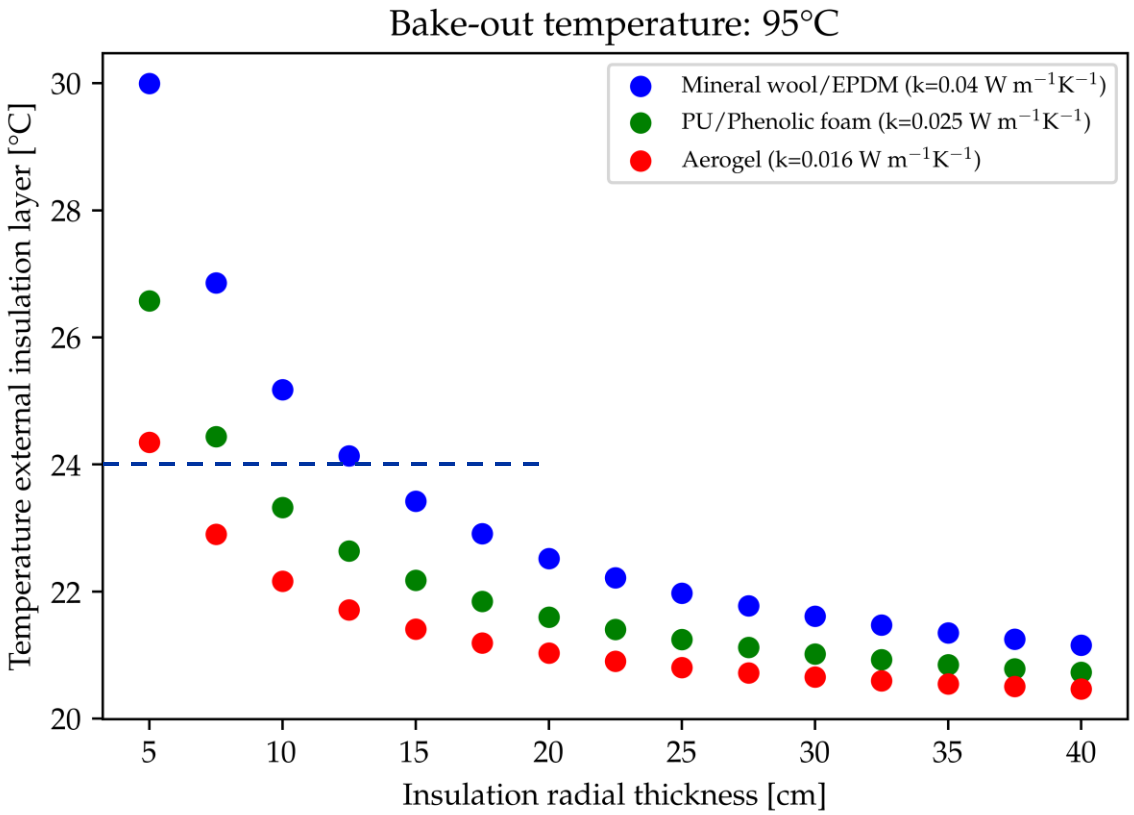
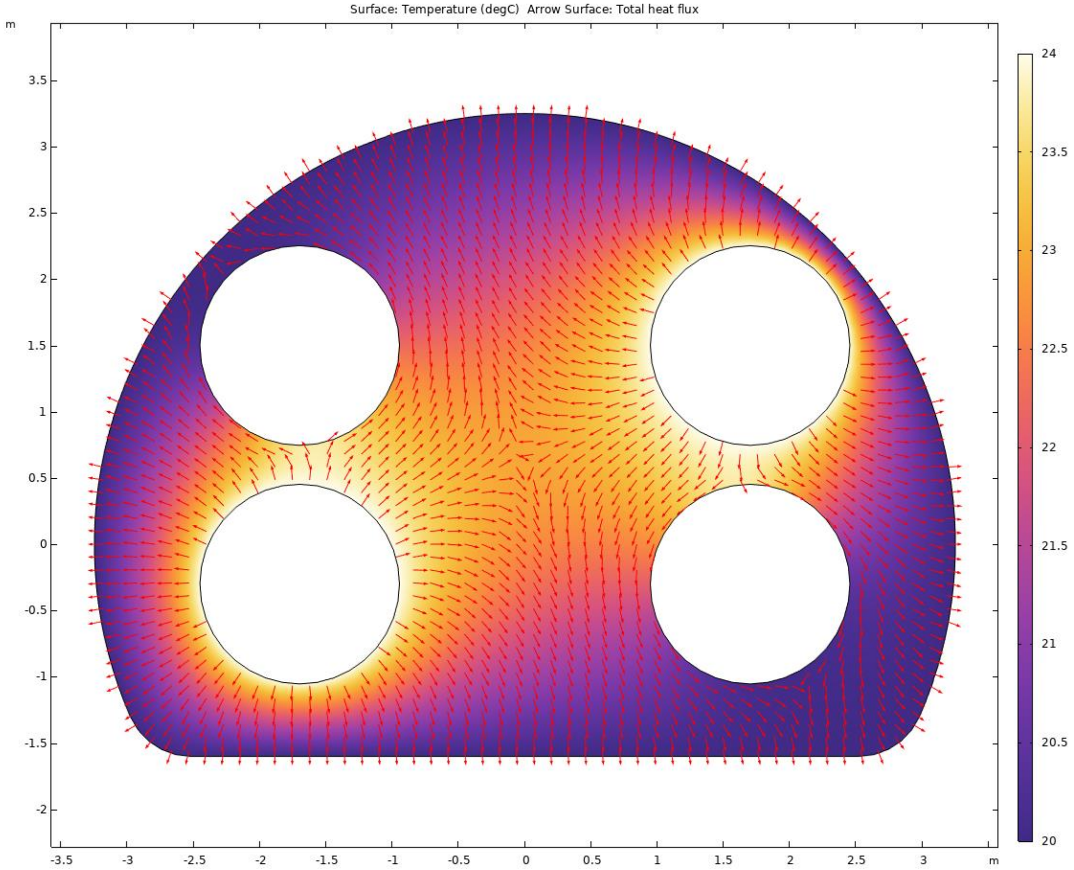
Bake-out: cavern temperature





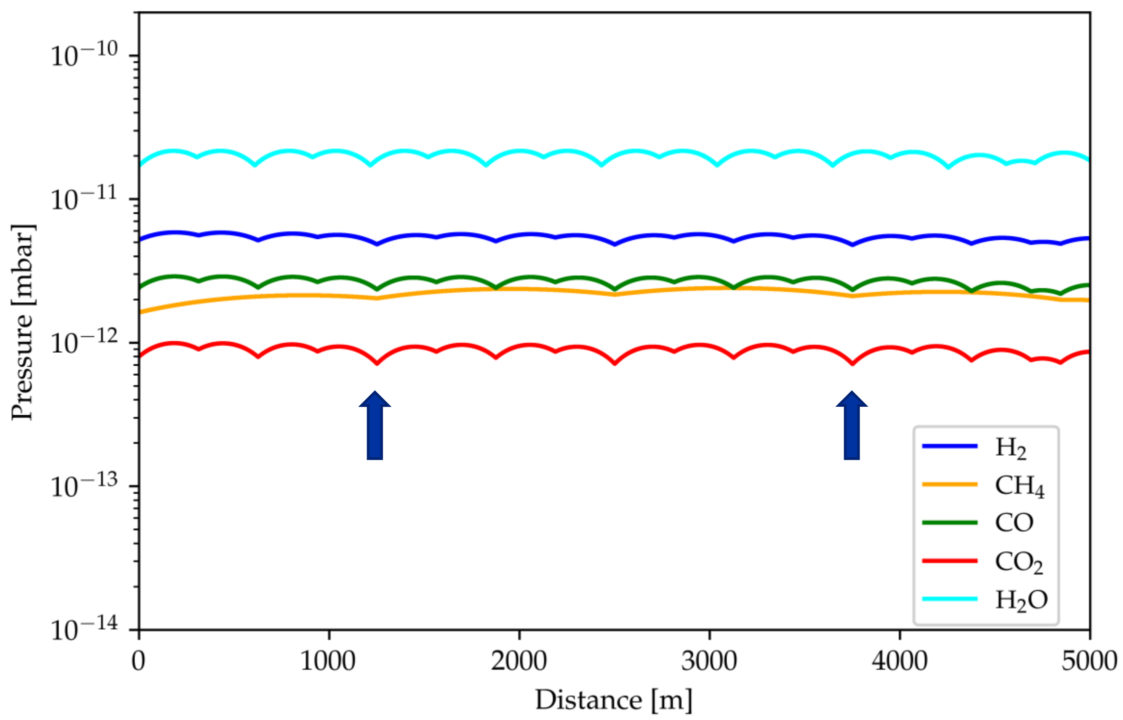
$T_{bake\text{-}out}$: 95°C, $T_{surf,\ ins.}$: 24°C (max)

$T_{center\ of\ cavern}$: 23°C

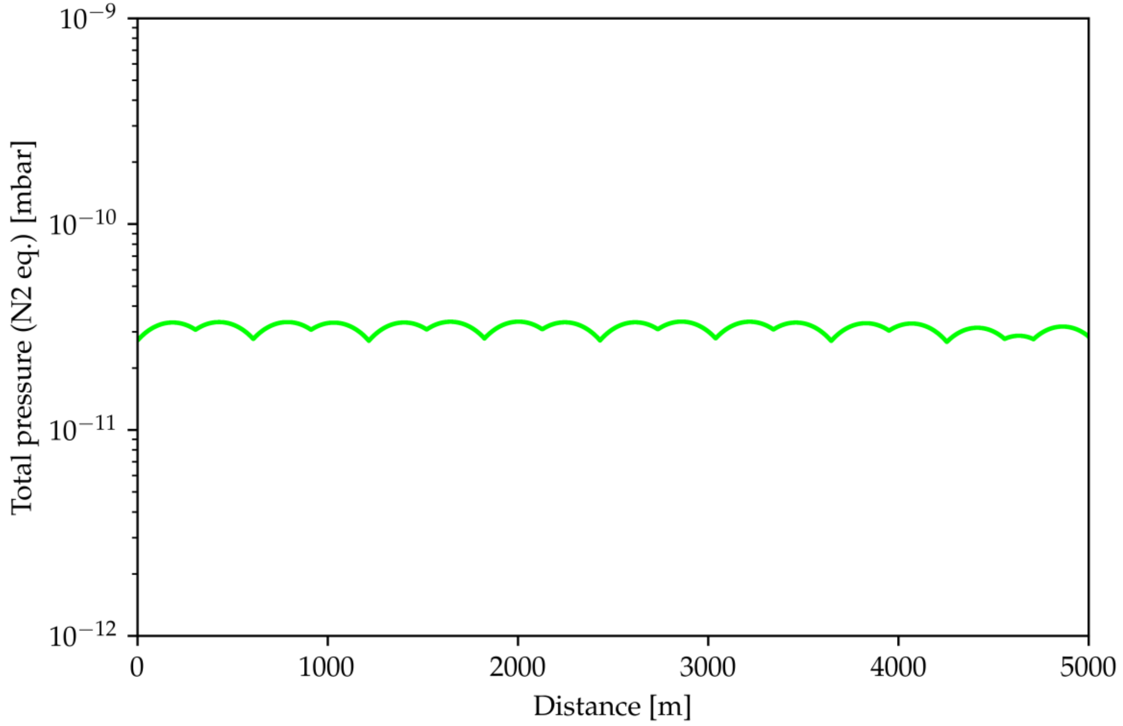
Pressure monitoring

Pressure monitoring: total pressure profile

How the partial pressures are

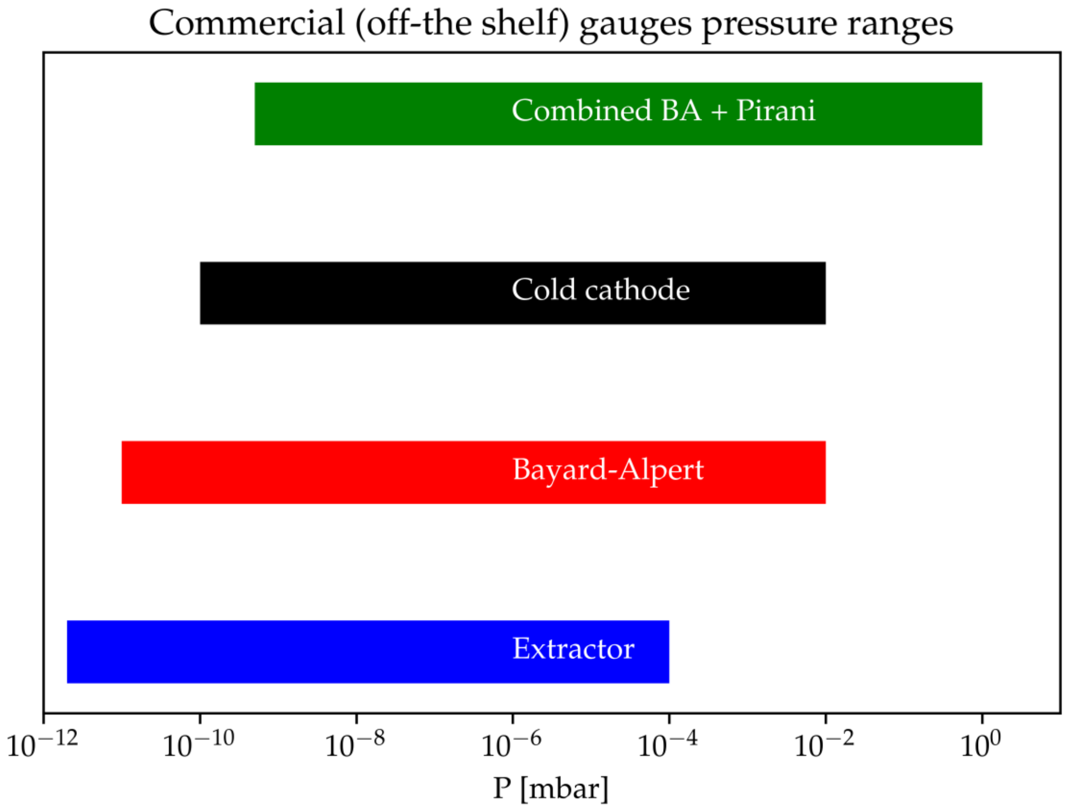


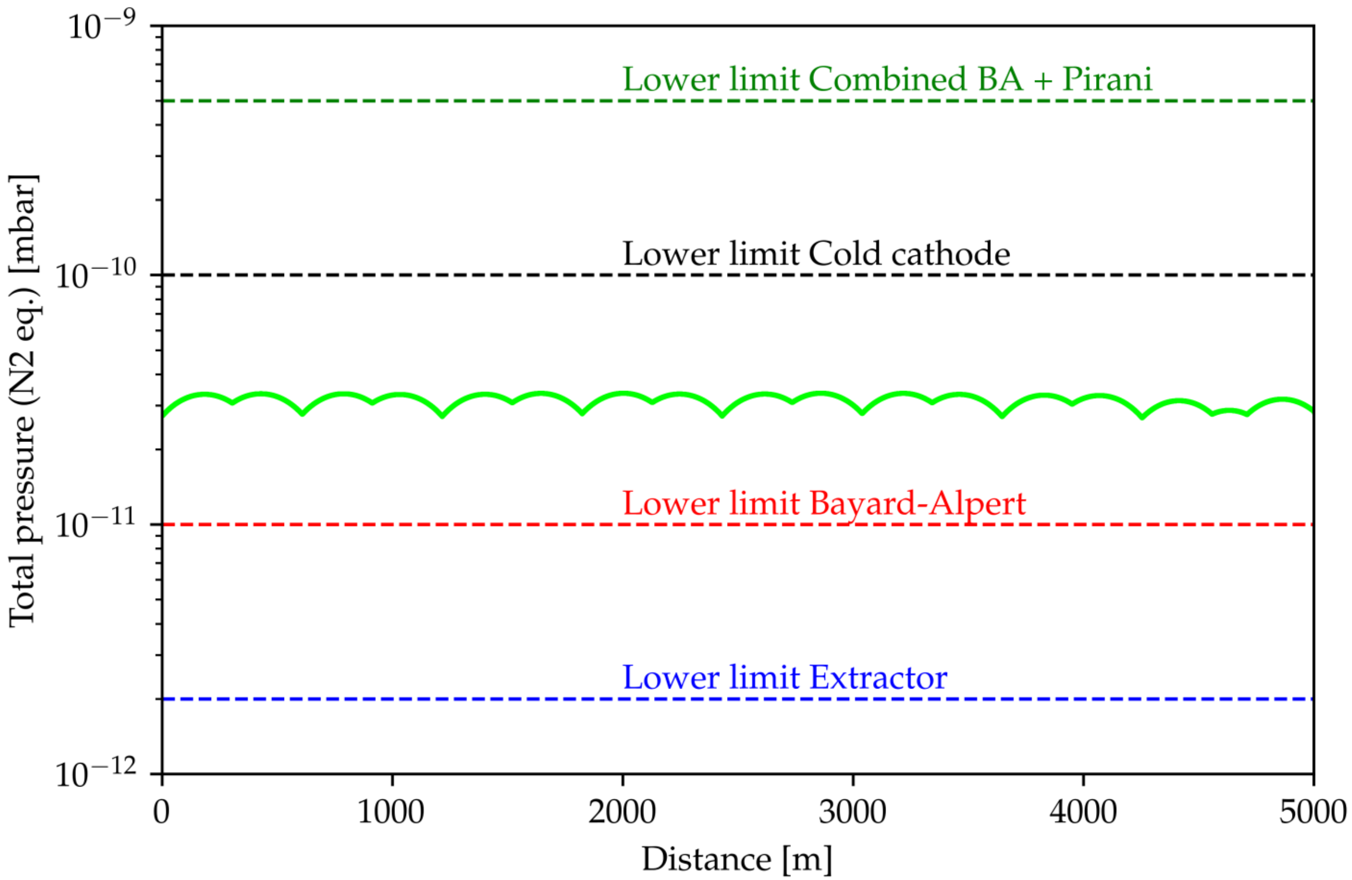
What the gauges show



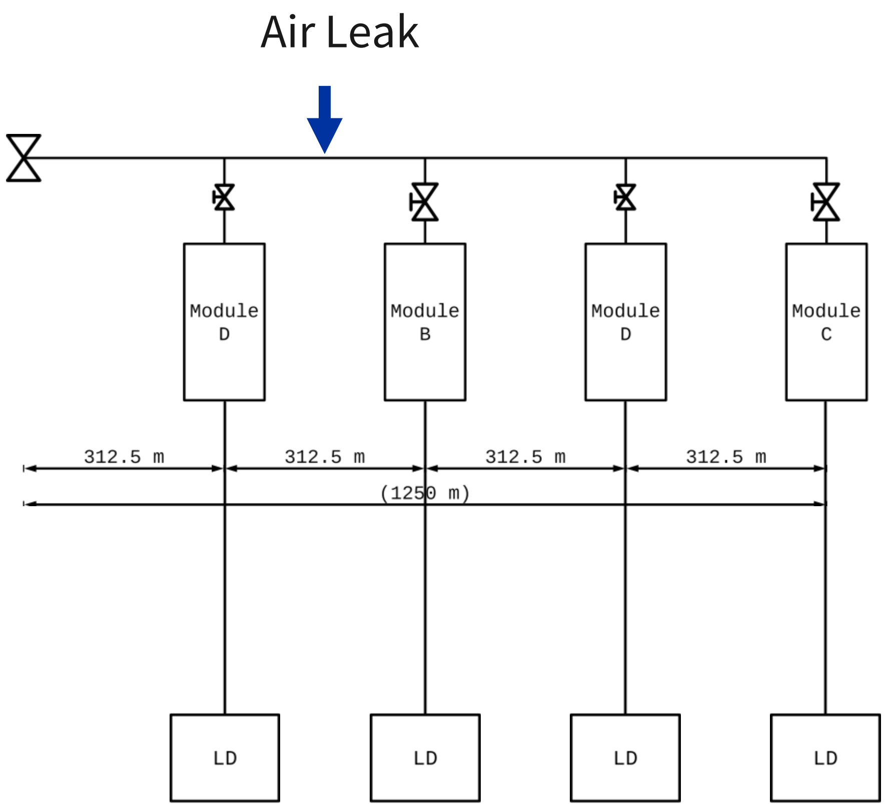
Possible RGAs position (min. 2 RGA/sector).
Allocation strategy under evaluation.

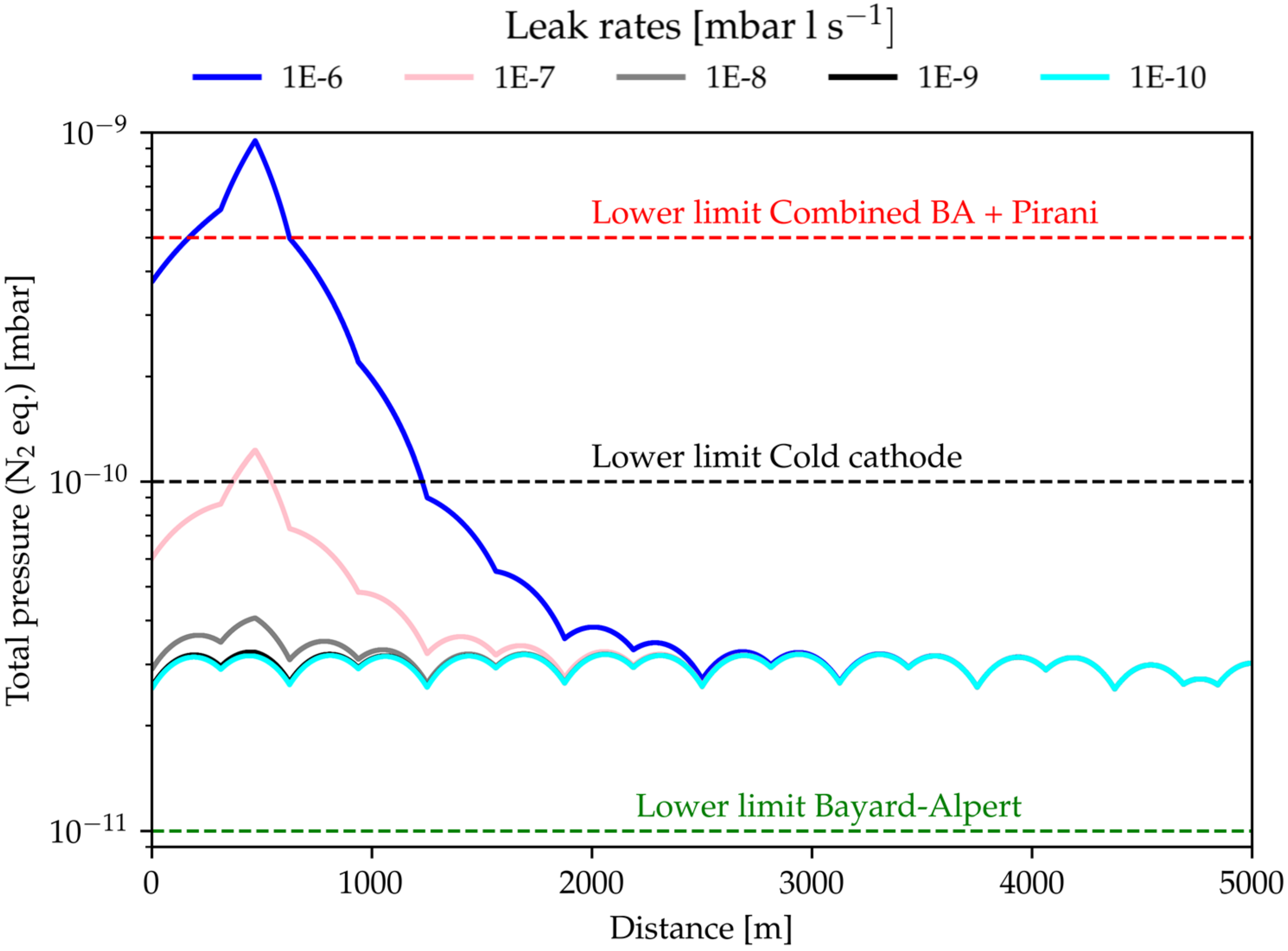
Pressure monitoring: total pressure profile vs. gauge limits





Air leak: impact on total pressure





Vacuum system cost assessment

Vacuum system cost assessment (hardware only)

Assuming market prices as of 2023, in absence of a specific contract:

Component	Quantity (+ spare)	Estimated cost [k€/unit]	Estimated ET total cost [k€]
Gate valve (DN1000 or) DN1250	36	200 - 250	**7200 – 9000**
Rough pumping group	3 (+3)	50	300
Mobile pumping group (TMP + PP, module A)	18 (+4)	50	1100
2000 ls^{-1} NEG (module A, B, C)	312 (+8)	15	**4800**
500 ls^{-1} Ion pump (module C)	72 (+8)	6.5	520
1000 ls^{-1} NEG (module D)	192 (+8)	5.5	1100
Gate valve DN150 (Viton - all metal)	168 (+8)	10 - 25	**1760 – 4400**
Gate valve DN100 (Viton - all metal)	192 (+8)	5 - 15	**1000 – 3000**
Angle valve DN40	360 (+10)	1	370
RGA	48-72 (+4)	10	520 - 760
Gauges (Bayard-Alpert)	360 + (10)	0.7	260
Leak detector	18 (+6)	15	360
Miscellaneous (bolts, gaskets, flanges)	-	-	500

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Miscellaneous (bolts, gaskets, flanges)	-		

Total cost: ~ 20 – 25 M€

Considerations

- Sector can be pumped from **1013 mbar to 10^{-11} mbar ≈ 6 weeks using compact products**.
- **NEG assisted - low temperature bake-out** represents a **viable solution** and **could** have a **positive impact** on **running and installation costs.**
- **Some insulation options (thin walled)** could **ease the installation** and **exploit the performances of the bake-out** while **keeping** the **cost under control.**
- **Pressure monitoring devices** needs to be **chosen carefully** to **balance** the need **of pressure reading, accidental phenomena, costs** and **controls.**
- The **costs** of the **vacuum system hardware could be reduced through further optimization** of **component selection and specific quotations/contracts.**
- **Any parameter change** (material, bake-out temperature, etc.) **can be easily applied since the model is parametric.**

Thank you for your attention!

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