Topical Discussion T3:
Pumping system, valves sectorization and bakeout

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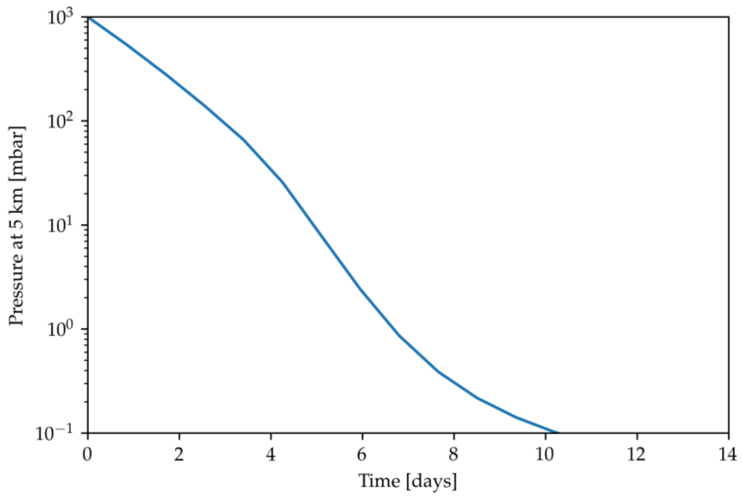
What's on the menu today….

- **Passing thorough a possible layout to trigger discussion**
- **Valves and sectorization**
- **Bake-out and insulation system**
- **Gauges and RGA**
  - *Possible Agilent Presentation*
- **Coffee break (30')**
- **Pumping system for H_2, CO, CO_2 and CH_4**
  - Roughing and turbo molecular pumping
  - Final pumping system
    - *SAES Presentation*
    - *Agilent Presentation*
- **Tower Vacuum** *(If time allow)*
- **Wrap-up**

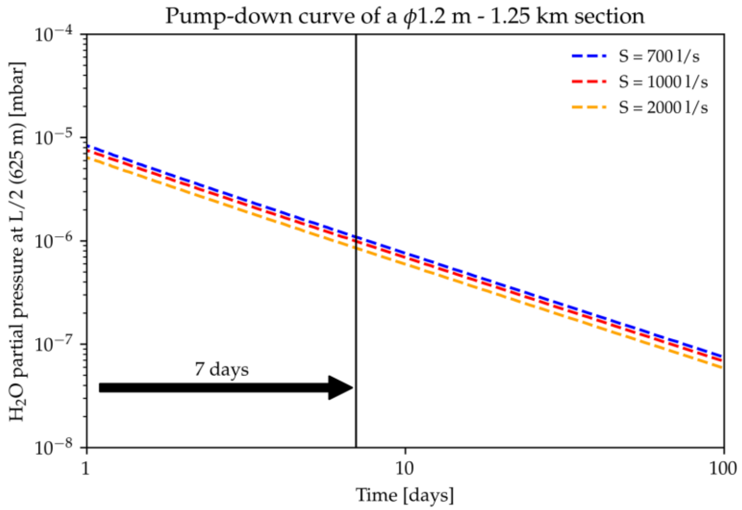
Simplified overview of pumping stages

P_{ET} (H_2O) = $2 \cdot 10^{-11}$ mbar

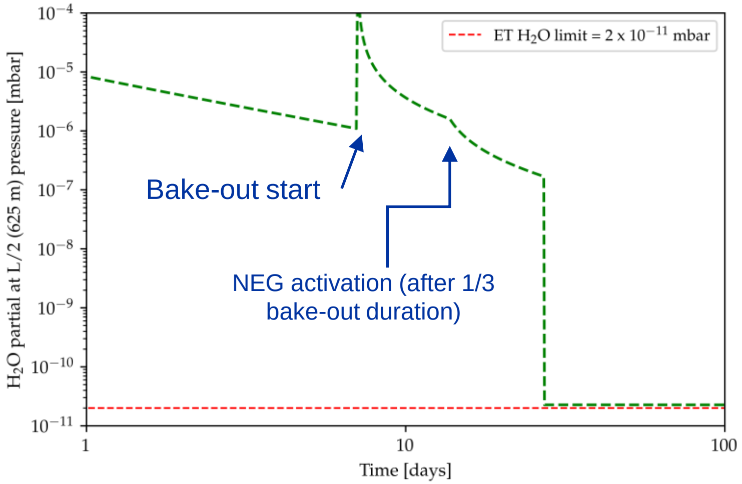
1 – Rough pumping



2 – Intermediate pumping



3 Bakeout & Steady state



8-10 days

5-7 days

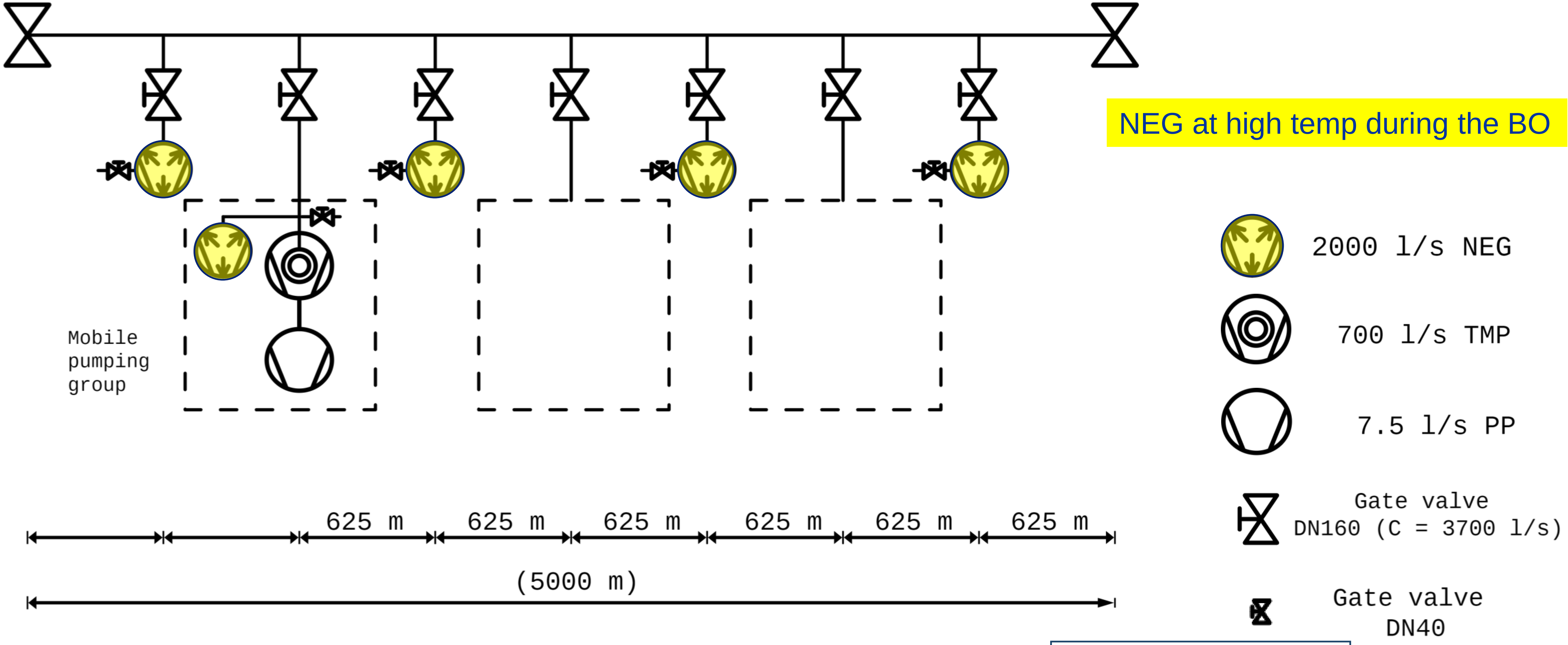
20 days

About 5-6 weeks to fully commission 5km of beam pipes -> Furter optimization, mainly on the bakeout (P(H_2O) requirements, bakeout temperature, insulation thickness) could even reduce the time to ≈ 4 weeks (?)

Close to one year to commission all the vacuum system: Which parallel activities could be allowed in the tunnel?

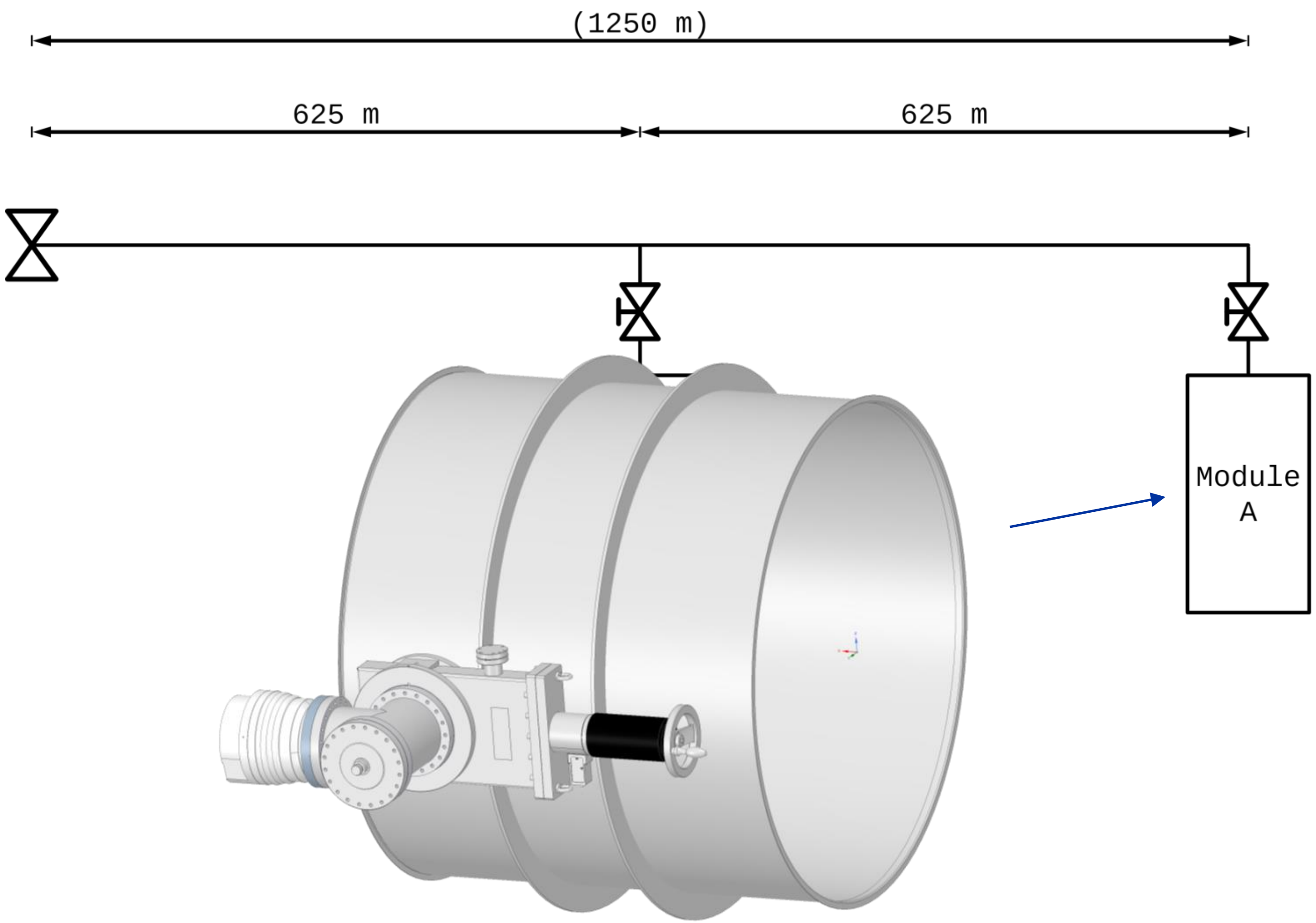
From C.Scarcia presentation

HV pumping: Mobile group to be used during the bakeout cycle



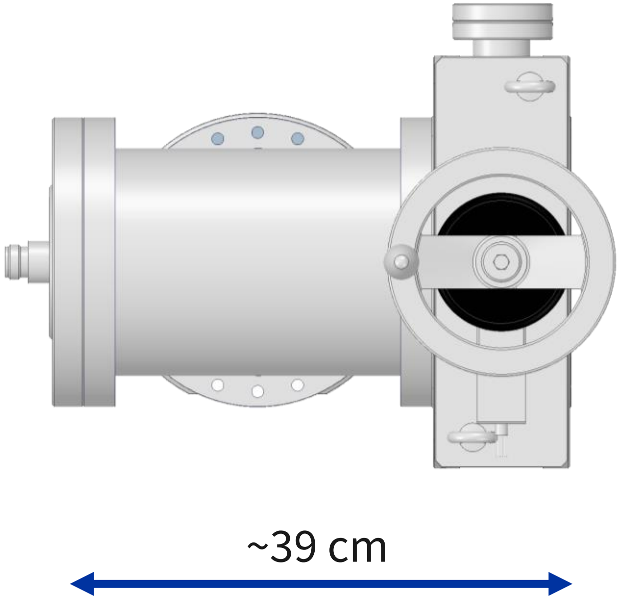
From C.Scarcia presentation

HV pumping: vacuum layout



Module A (mobile):

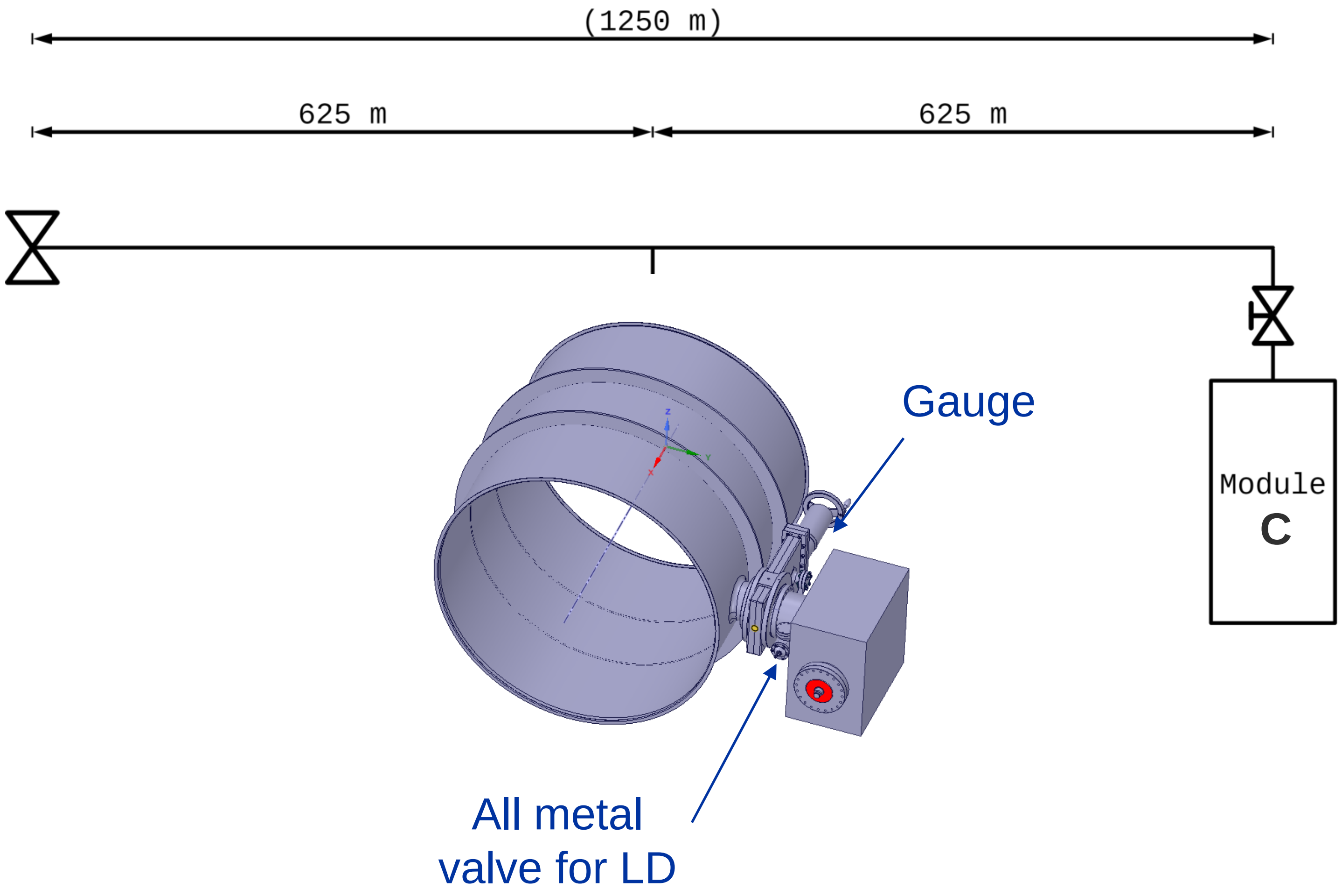
2000 ls^{-1} NEG + 700 ls^{-1} TMP



NEG at high temp during the BO

From C.Scarcia presentation

HV pumping: vacuum layout



Module C

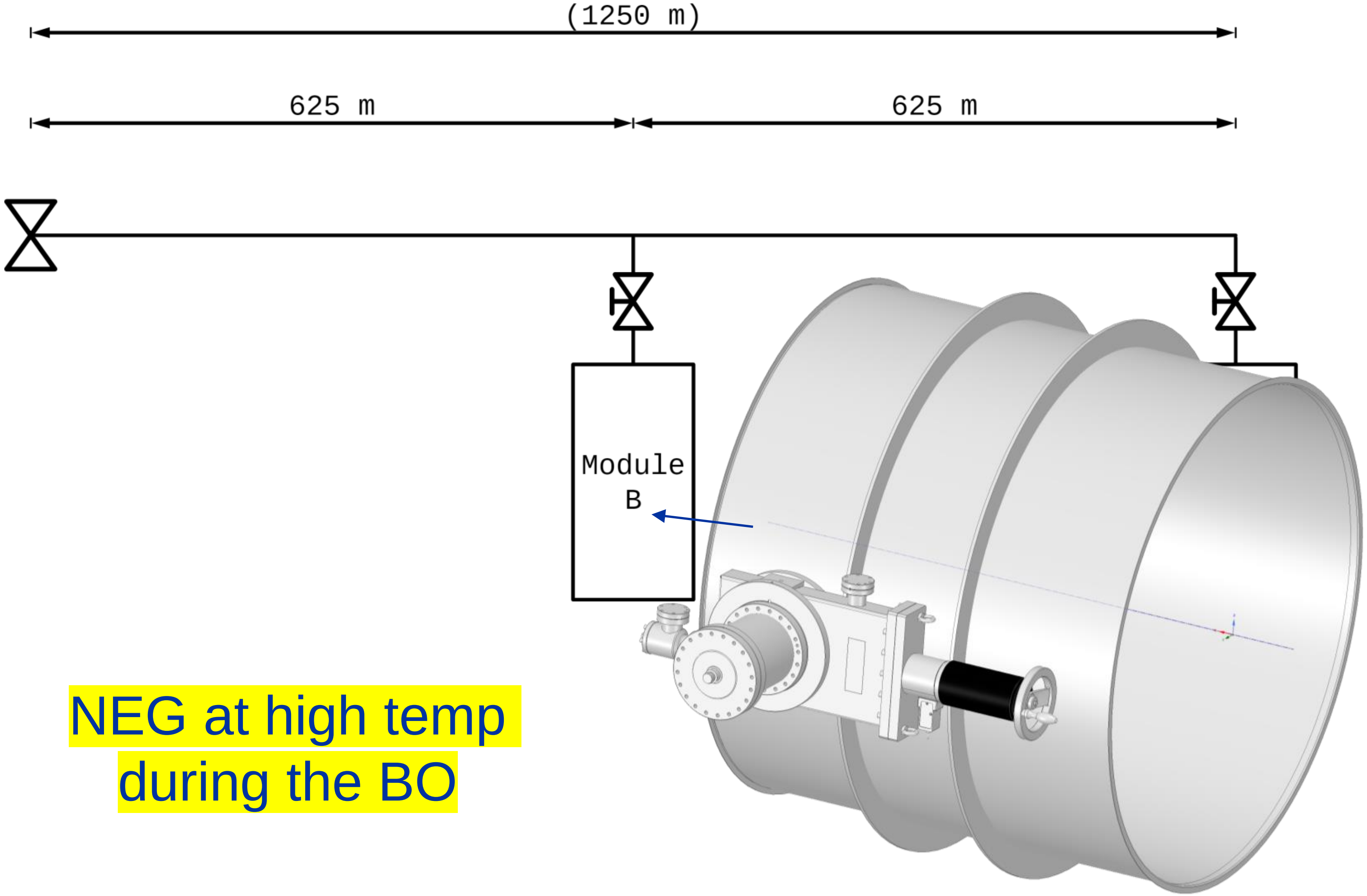
Will replace the module A mobile turbo

2000 ls^{-1} NEG + 500 ls^{-1} Ion Pump

Final configuration after bakeout

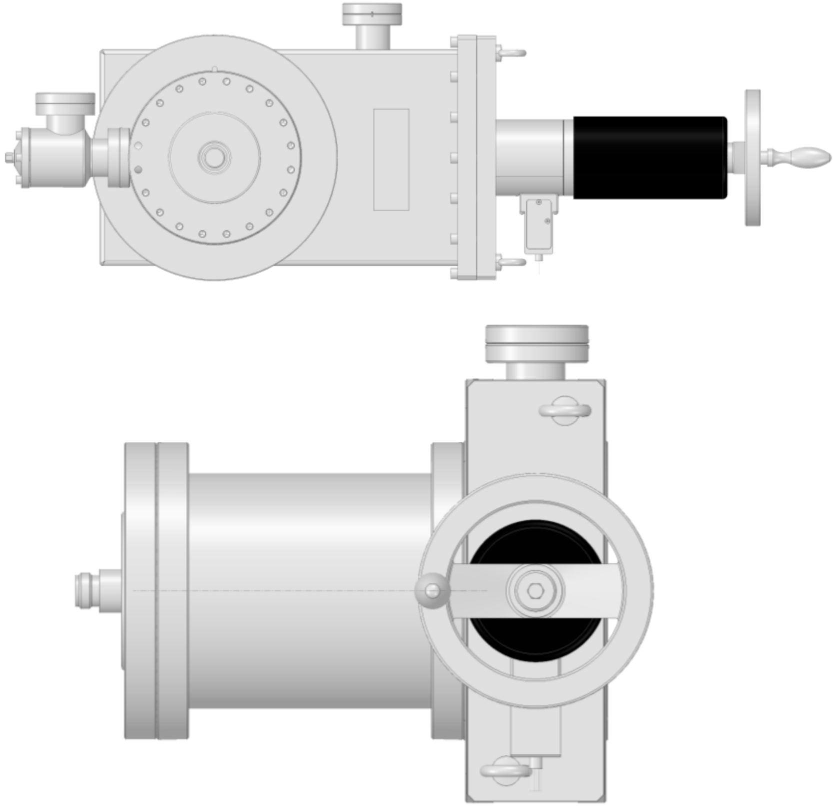
From C.Scarcia presentation

HV pumping: vacuum layout



Module B:

2000 ls^{-1} NEG

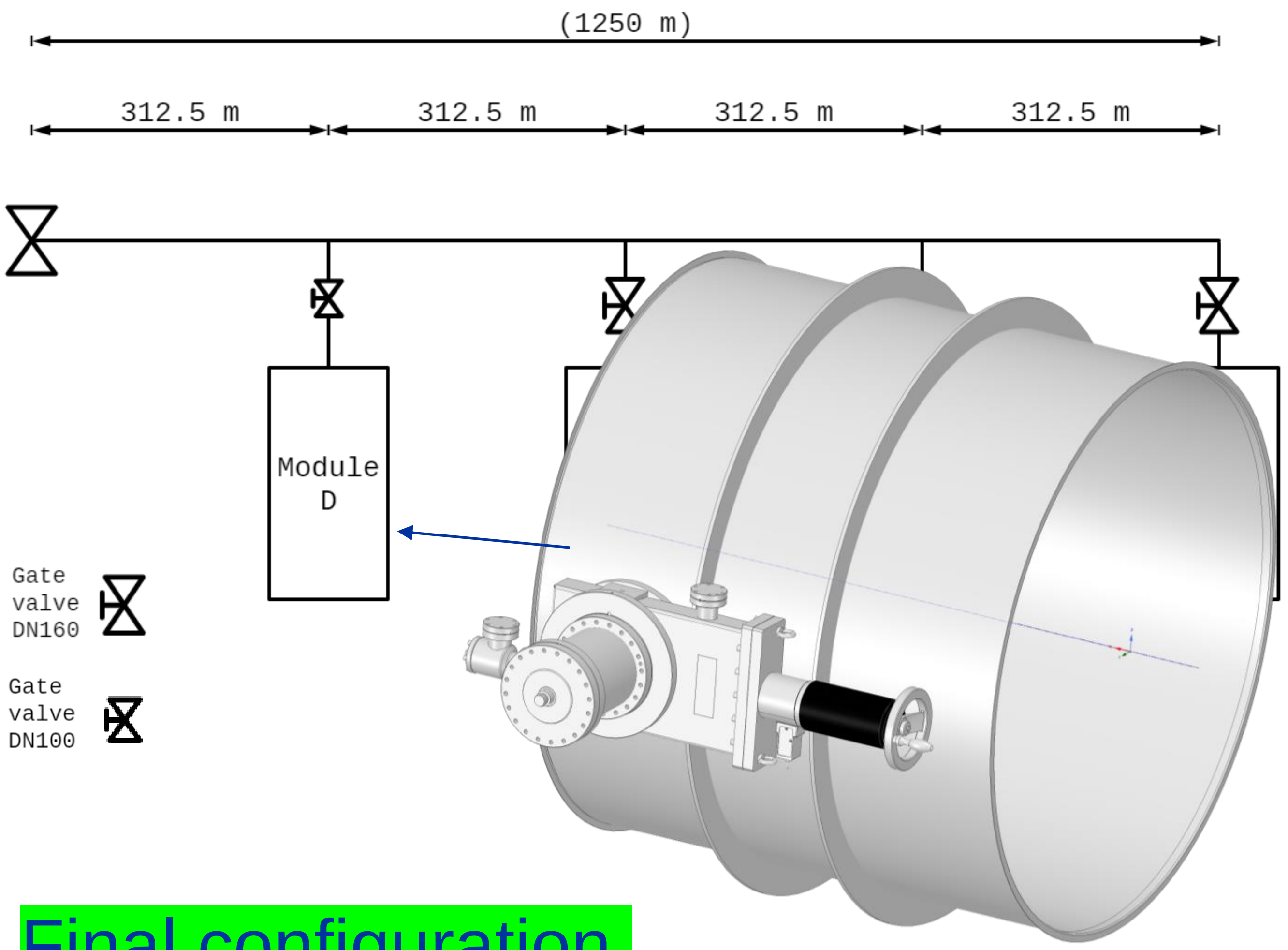


~39 cm

From C.Scarcia presentation

NEG at high temp during the BO

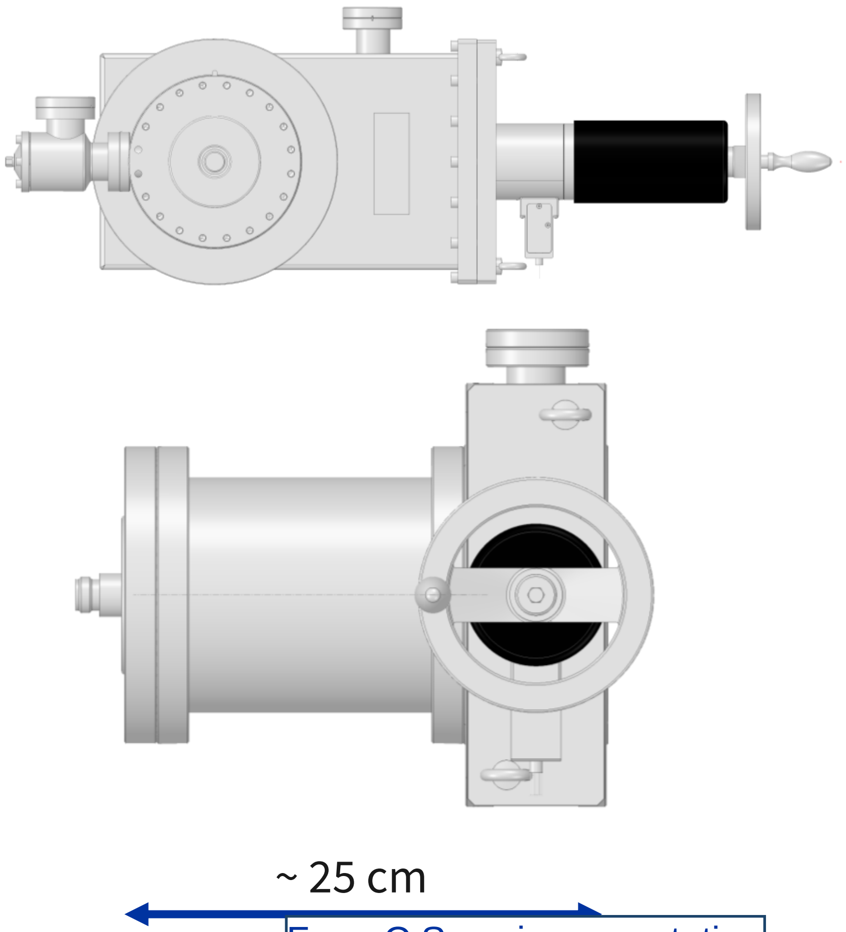
UHV pumping at RT: vacuum layout



Final configuration after bakeout

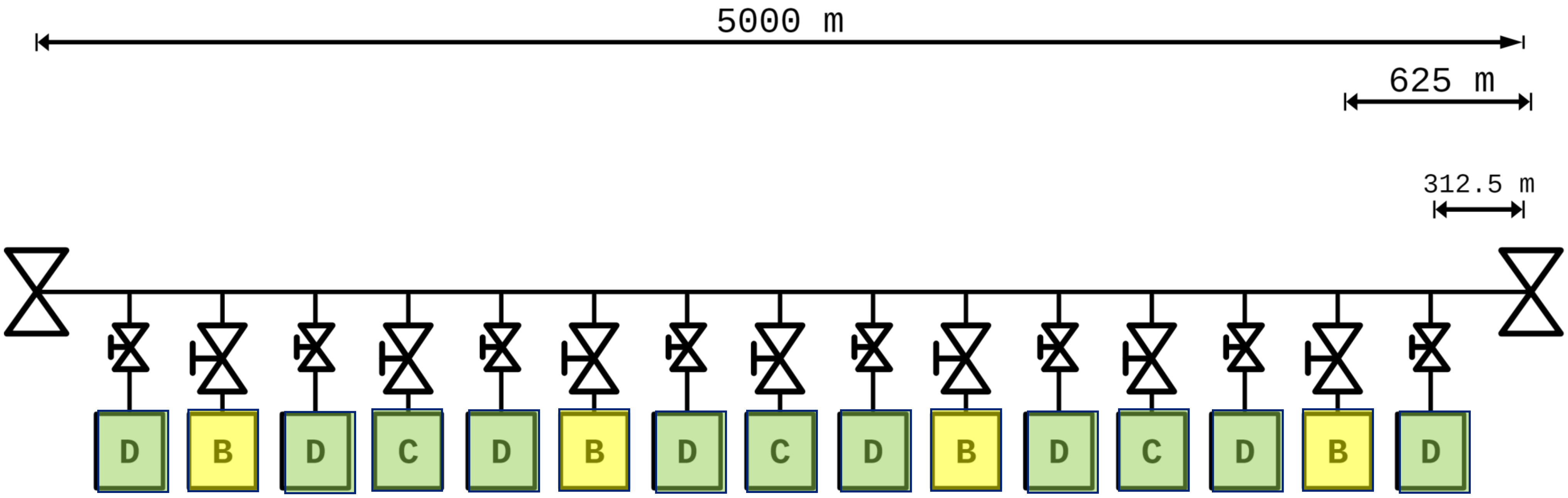
Module D:

1000 ls^{-1} NEG or similar



From C.Scarcia presentation

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)

Working @ RT

Working @ High temperature

From C.Scarcia presentation

Thinking about pumping port layout

Which are the elements to be considered when discussing the pumping stations ‘spacing’ ?

Average pressure wrt pump speed & spacing + :

1. **Pump efficiency reduction scenarios (maintenance, failures + 'forbidden' pipe ventings...)**
2. **Optimal use of dedicated civil infrastructure, if special ‘tunnel’ requirements are needed: minimize number of pumping station areas ?**
3. **Flexibility ? (changes in the ITF operation scenario over 50 years, small leaks, not uniform outg. rate)**
4. ***At a next stage, gas load from Towers/Cryogenic Sections (HF ≠ LF)***
5. ***Overall cost (pumps + civil infrastructure + ...)***
6. **...?**

Valves and sectorization

Sectorization

0 — 10 km

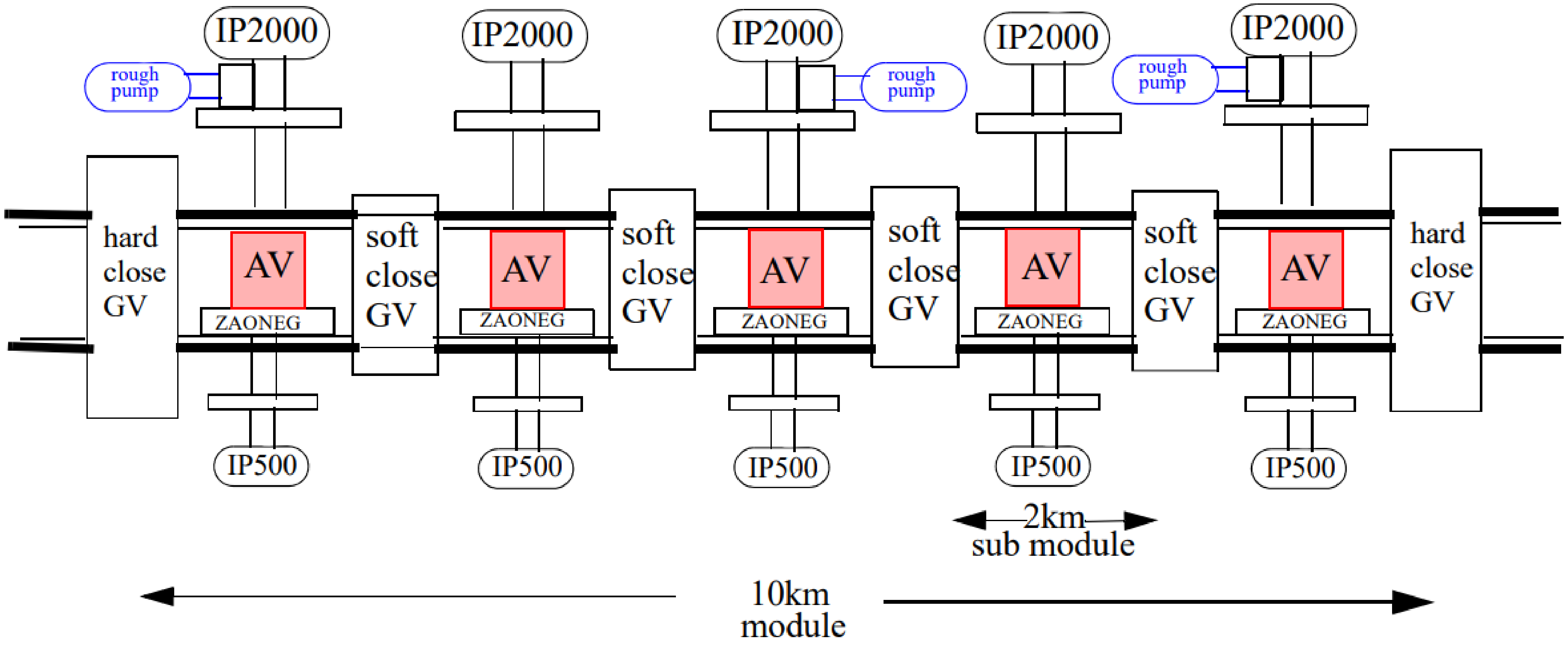
	$x \leq 2.5$ km	$2.5 < x \leq 5$ km	$x > 5$ km
Bake-out	=	=	=
Downtime due to ordinary maintenance (leak <10^{-7}, etc.)	=	=	=
Downtime due to major failure (leak ~mbar, etc.)	++	+	-
Installation and **commissioning**	++	+	--
Cost (components, alcoves, controls, etc.)	--	-	+

From C.Scarcia presentation

Sectorization

- What could be the optimal sectorization length?
- Can we have gate sector valves of reduced diameter: For example, from 1250mm to 1000mm
    - DN1000 valves 'practical': installation + environment
- By installing the gate sector valve horizontally, could we reduce the cost of drilling of upper part of the tunnel
- Where the mechanism of the gate sector valve at the extremities should be installed? On the side of the tower or of the beam pipe?
- If we are using gate valve for the final pumping system, can we use viton valve? What is the pre-treatments to reduce their outgassing?
    - Seen the ET low demanding ultimate pressure a detailed study of the outgassing rate of each valve should be done
- From experience a baked (250C x 24h)all metal DN100 valve has an H_2 outgassing rate in the low 10^{-9} mbar . A viton should be in the 10^{-8} mbar range. Process to reduce viton outgassing could be easily done, but need to be implemented and defined precisely.
- Pseudo valves (custom design): old ideas, development may be long, compatibility with present plans?
- Venting system: N_2? Underground safety constraints?

Basic 10 Km Module Schematic for Vers. B design (R. Weiss)



- Annulus or soft sealing valves/shutters

Credit: R. Weiss, MIT,2023

Bake-out and insulation system

Bake-out: Insulation

Mineral wool

EPDM

Phenolic/Polyurethane foam

Aerogel

Price →

← Thermal conductivity

From C.Scarcia presentation

Bake-out: Insulation thickness

Assuming:

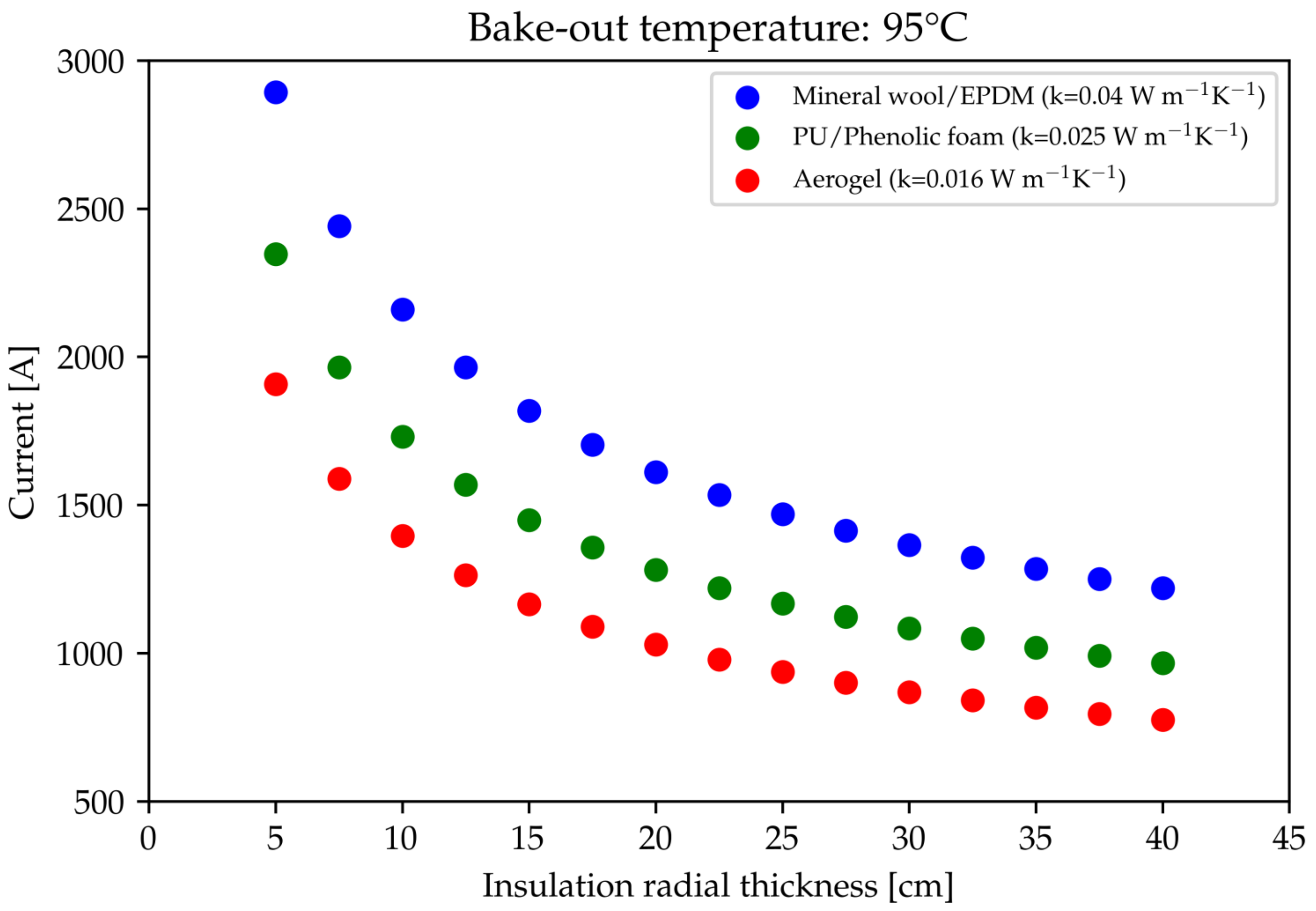
- h_{air} = 5 W m^{-2} K^{-1} (calm air, free convection)
- t_{tube} = 3 mm

For 15 cm of insulation (2G like):

Q [W m^{-1}] ≈ 81, 72 , 35

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

I^* [A] ≈ 1820, 1450, 1165

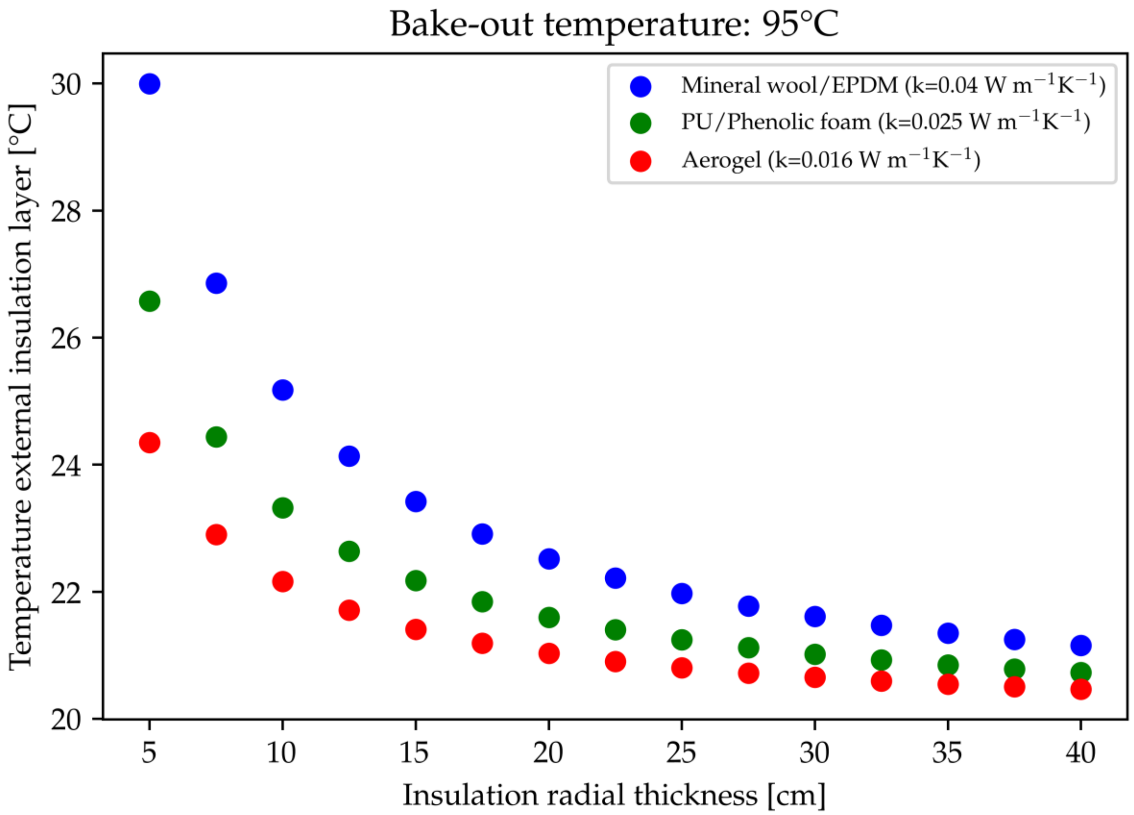


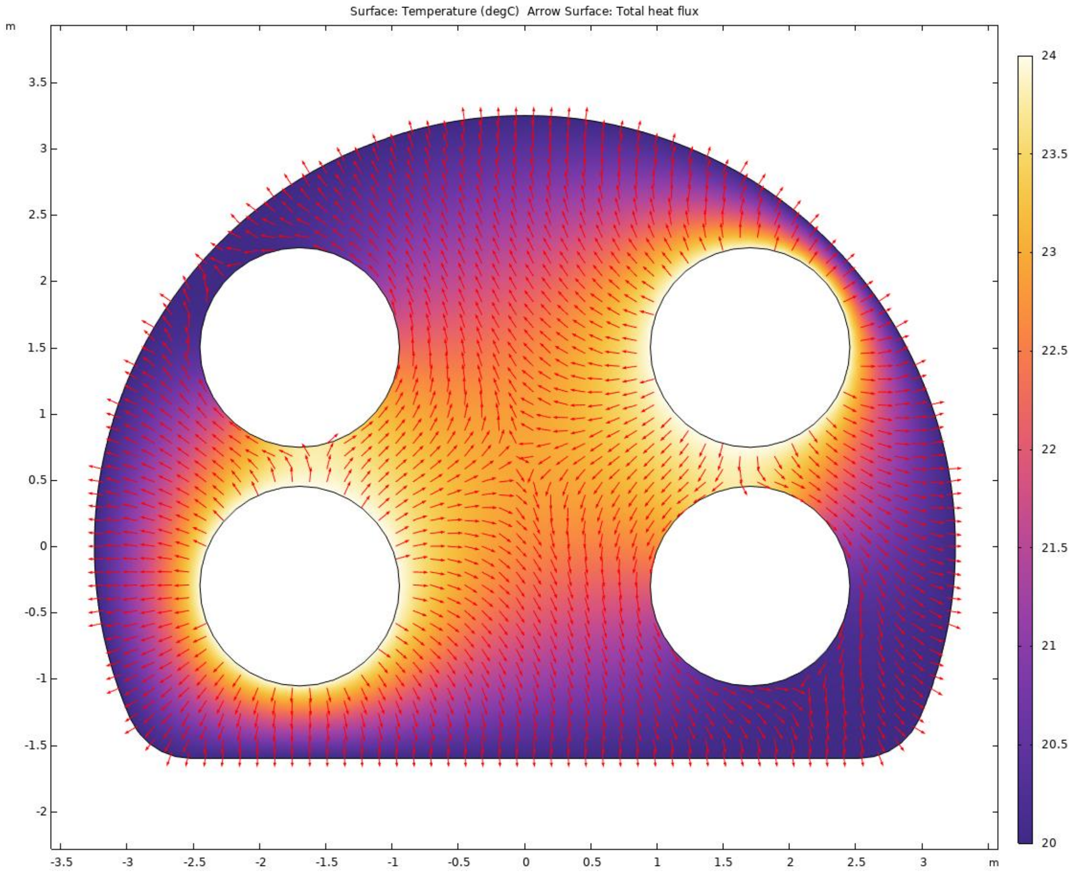
*Only thermal power loss is considered

**2.77×10^{-7} ohm m @ 95°C

From C.Scarcia presentation

Bake-out: cavern temperature





Heat to be exhausted during bakeout: HVAC not necessary? experiences of real cases?

$T_{\text{bake-out}}$: 95°C

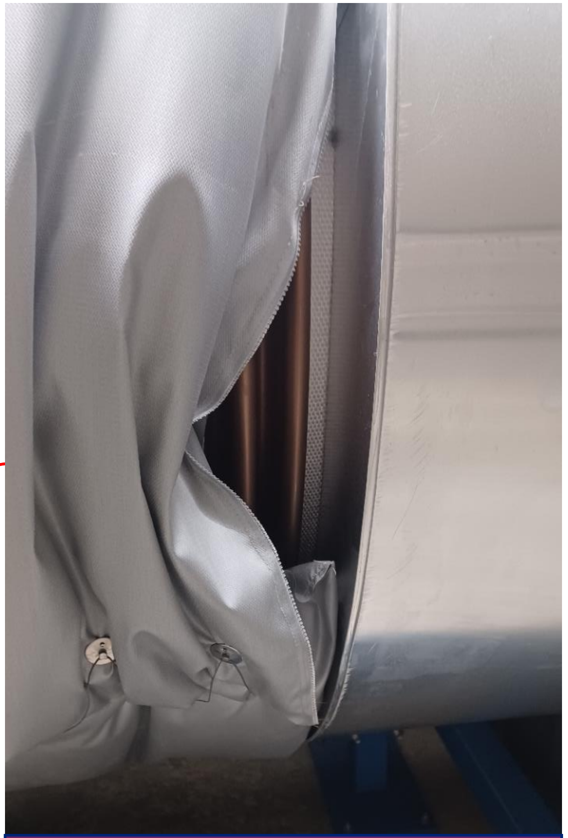
$T_{\text{center of cavern}}$: 23°C

From C.Scarcia presentation

Bake-out via ‘Joule effect’

Some details

I. Electrical isolation of beampipe stands &



II. more heat generated in thinner sections (top/bottom unequal)

Bake-out via ‘direct Joule effect’

Some details

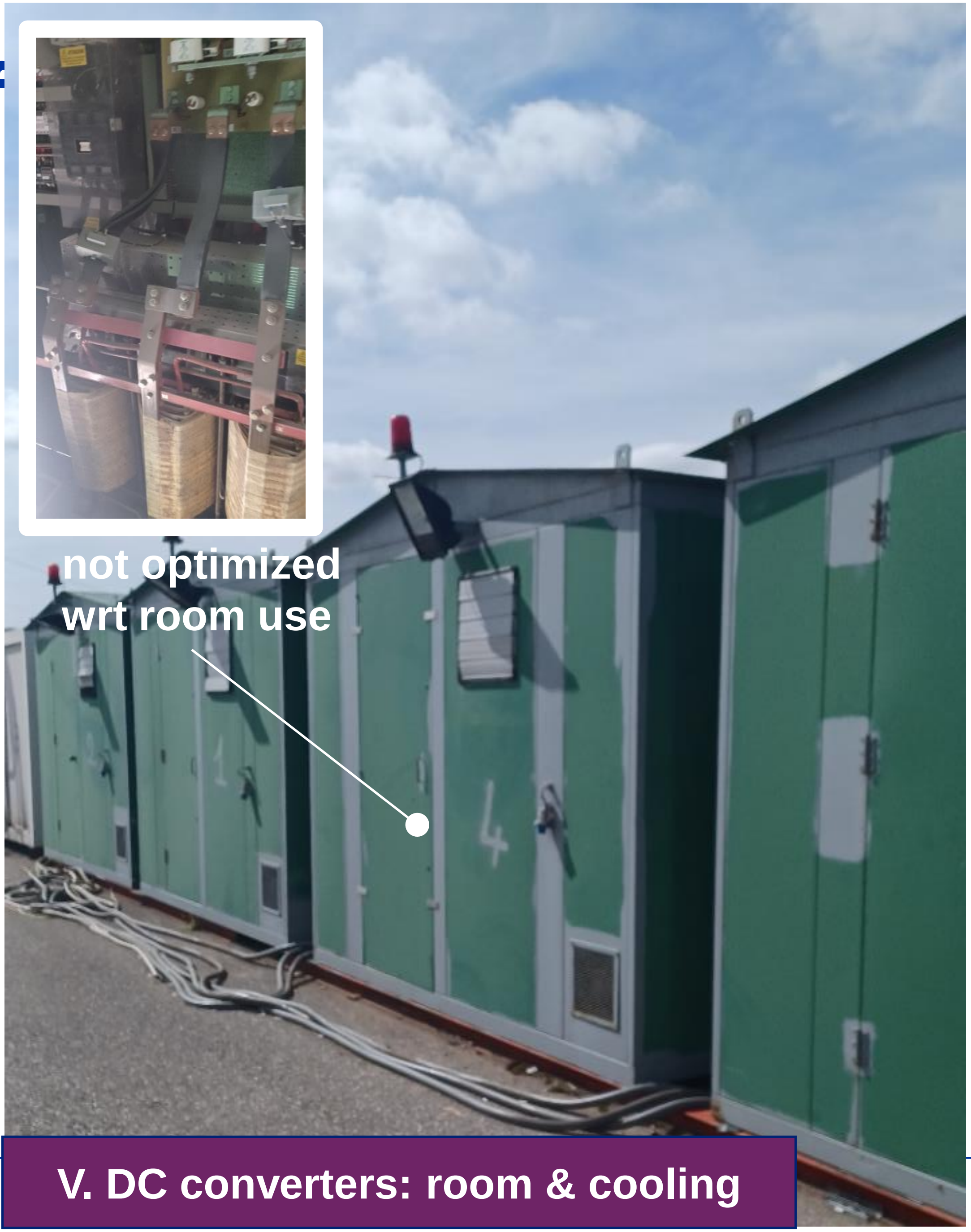
III. Pumping stations @ ≈ 0 V

to be designed on purpose

Bake-out via ‘direct Joule ef

Some details II

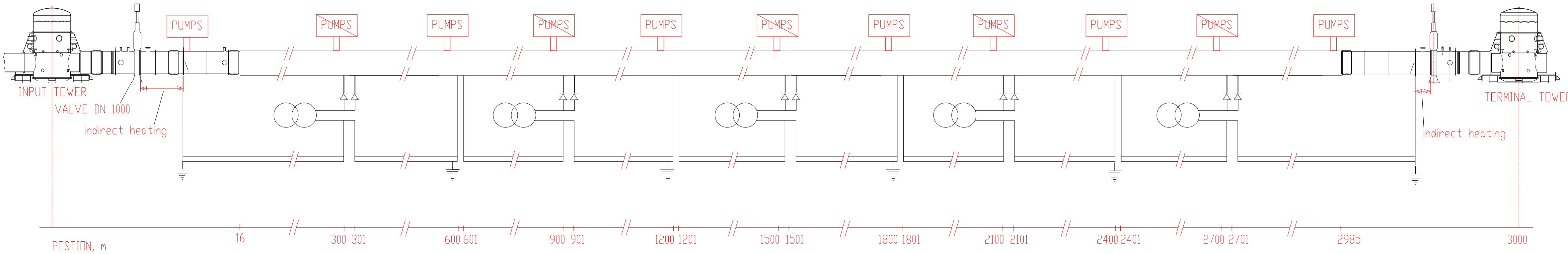
IV. Return conductor



V. DC converters: room & cooling

Bake-out via ‘Joule effect’

Some details



VI. 60 V DC ‘limit’ (?) & safety aspects: possible impact on layout of bake-out pumping

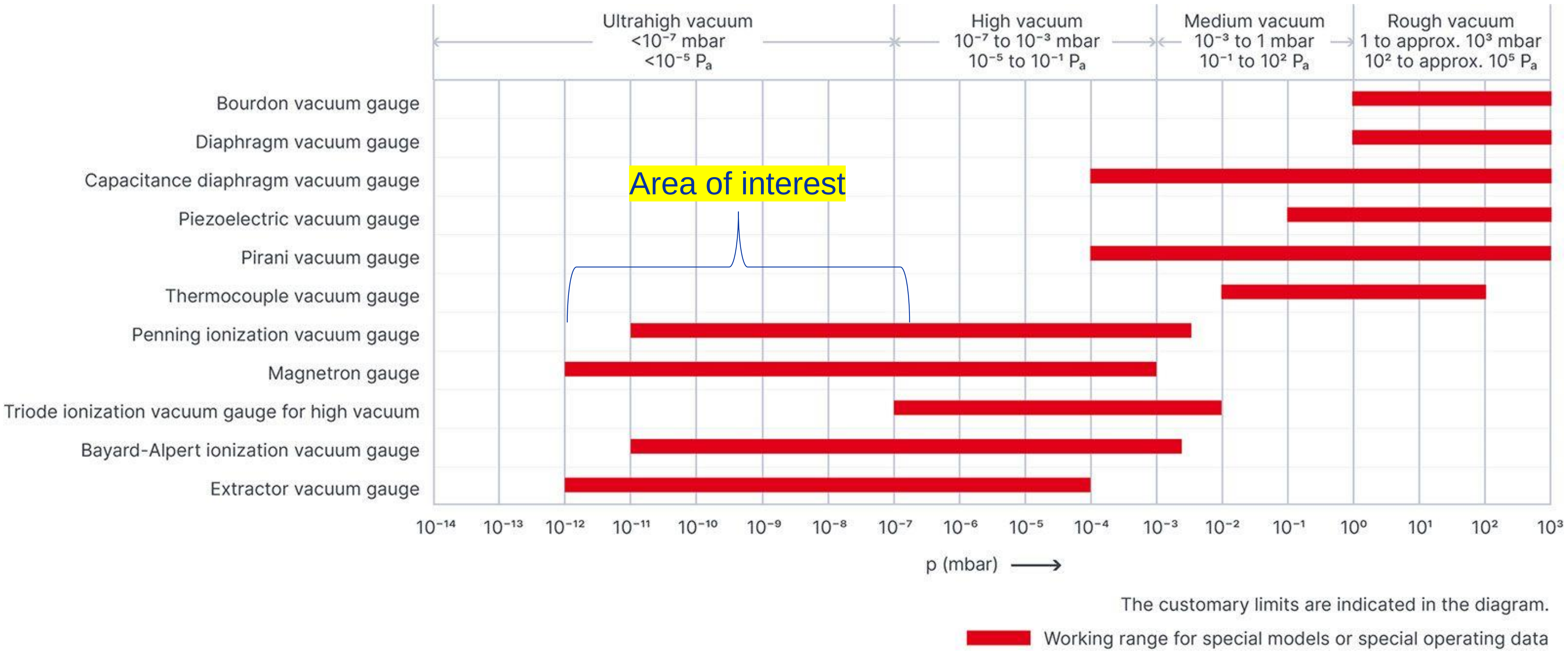
Insulation material & bakeout consideration

- Insulation: Easy to install and to de-install in case of leak
  - Is it worth looking at a solution with dismountable insulation system: Gain on cost of material but more labor cost.
- Are we searching an as much as possible dust free insulation?
  - Mineral wool or glass fibers or aerogel insulation (etc..) will produce a lot of dust in the tunnel: Coactivates? Blocking point?
- Is the support system taking in consideration the bakeout needs?

H_2O pressure requirements should be carefully defined because they could have an important impact on the bakeout temperature, insulation thickness and needed time for the bakeout

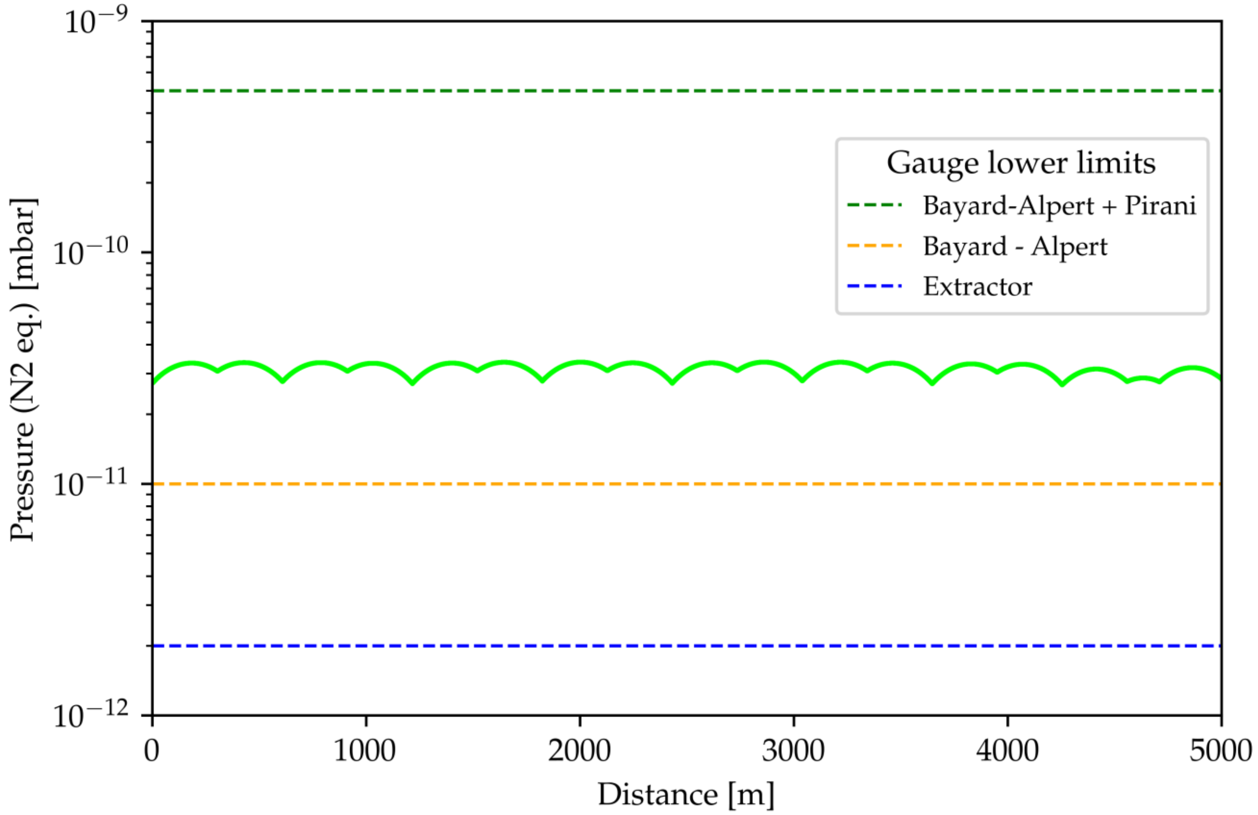
Control system:
Gauges and RGA

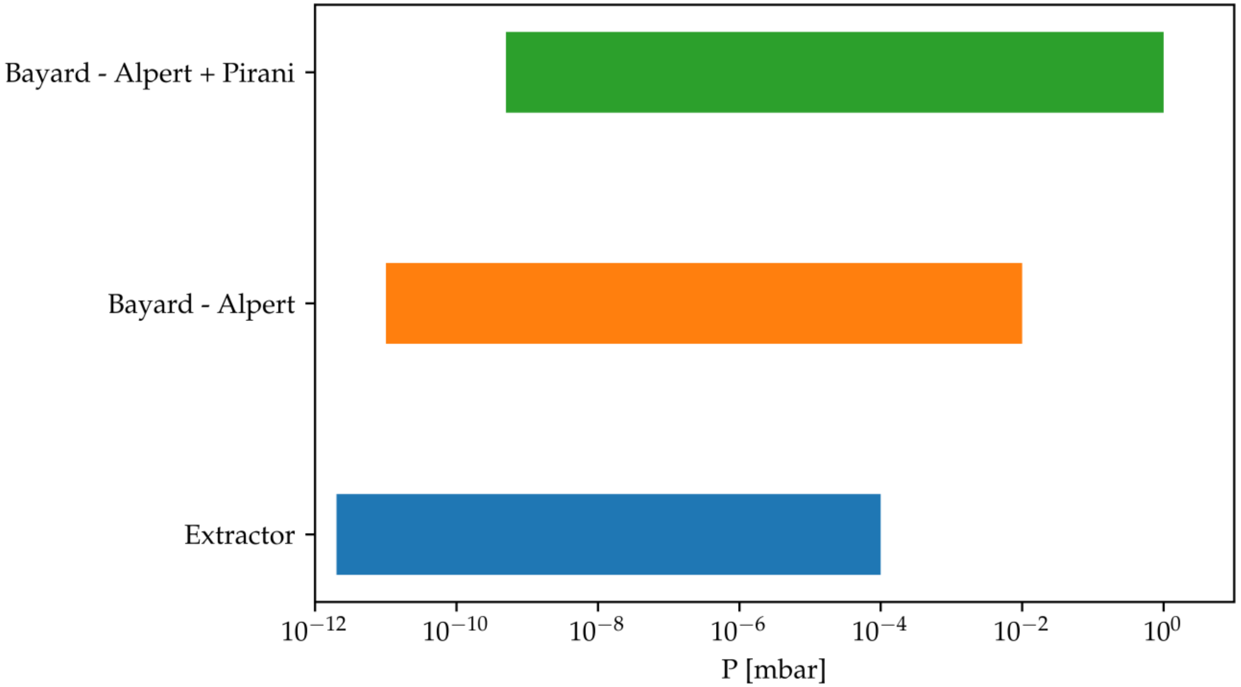
Which choice do we have for vacuum gauge?



FROM: https://diavac.co.jp/english/products/keisokuki/index.html

Pressure monitoring: total pressure profile vs. gauge limits





From C.Scarcia presentation

Roughing phase

- **Do we need gauges on the beam vacuum system to follow the roughing pumping?**
  - It would be better to have at least 3 gauges along the 5 km length to monitor the pressure profile
  - Could be integrated on the “Mobile module” to have a pressure reading every 1.2 km
    - We do not need anymore afterward
- **What is the resolution that we want to have?**

Intermediate phase & bakeout-phase

- Cold-cathode gauge could be easily damaged due to the high amount of degassed water because they will act as a “pump”
- Which other solution do we have?
- What is the resolution that we want to have during the bakeout cycle?
- Would be enough to use the gauge on the mobile system?

Steady state Operation

- **The required gauges should be able to have a precise pressure reading < $1 \cdot 10^{-10}$ mbar range**
    - Cold-cathode gauge are entering in a critical pressure range where they could easily go on a “sleep” mode
    - Bayard Alpert gauge would be a valid option and the pressure range could even < $1 \cdot 10^{-11}$ mbar , but they need local power, local controller and then connected to a PLC
    - Combined Bayard-Alpert & Pirani could be also used for the Roughing/Intermediate/Bake-out phase could be a valid option but they are limited to an ultimate pressure of $5 \cdot 10^{-10}$ mbar. They would need small controller and then the signal could be easily brought to a central PLC station

Steady state Operation: Do we need RGA?

- **What is the main reason on having a fix RGA on the vacuum system?**
  - Could be enough to have 2 RGA on a dedicated pumping port close to the gate valve?

Pumping system

Pressure requirements for ET

Pressure requirements for ET

Gas species	Outgassing rate	Pressure max	Noise LF	Noise HF
	$mbar\, l/s\, cm^2$	mbar	$1/\sqrt{Hz}$	$1/\sqrt{Hz}$
H_2	1.9×10^{-14}	1×10^{-10}	2.9×10^{-26}	2.4×10^{-26}
H_2O	2×10^{-15}	2×10^{-11}	2.9×10^{-26}	2.3×10^{-26}
N_2	2×10^{-17}	2×10^{-13}	3.7×10^{-27}	2.8×10^{-27}
CO_2	1.5×10^{-16}	2×10^{-12}	1.6×10^{-26}	1.2×10^{-26}
C_2H_4	1×10^{-17}	1×10^{-13}	6.3×10^{-27}	5×10^{-27}

Assuming a margin of 9 for ET-HF and 20 for ET-LF

- ET vacuum dimensions:
  - Diameter beam tubes: ~1m
  - Total Length vacuum system: 120 km

surface: 400.000 m^2
Volume: 100.000 m^3

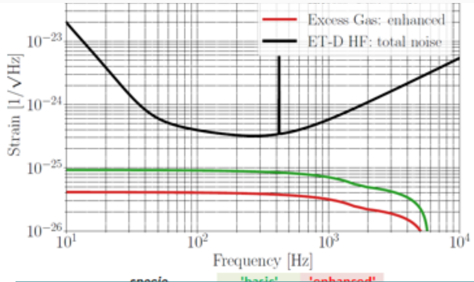
- Partial presssure:
  - H2 gas: 10^{-10} mbar
  - Water vapor: 5.10^{-11} mbar
  - Nitrogen: 10^{-11} mbar
  - Hydrocarbons: <10^{-14} mbar

IN
PE

T VACUUM LEVEL

nt we assume a factor 3 below the
factor ≈ 10 in terms of pressure).

ls from residual gas composition i.e.
l technologies. Here two simplified cases
th ET-D detectors : TBC wrt FACILITY



HF><LF?

Total	6E-10	1E-10

HF $H_2 \leq$ 5E-10 mbar, $H_2O + N_2 \leq$ 5E-11 mbar

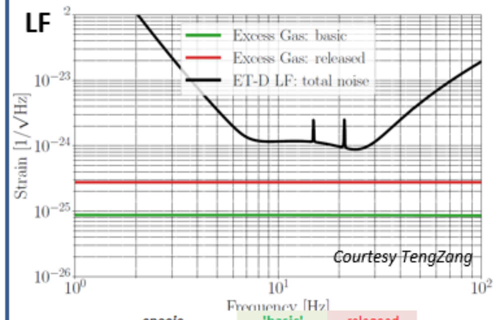
LF $H_2 \leq$ 5E-9 mbar, $H_2O + N_2 \leq$ 5E-10 mbar

In principle all present gas species are to be accounted [1]. *Noise level* $\propto \sim \sqrt{P_i} * \sqrt[4]{m_i} * \alpha_i$

Example, common species wrt N_2 at same pressure:
CO≈ x 1.1, CH_4≈ x 1.2, CO_2≈ x 1.8, $\sim(\sqrt[4]{m_i} * \alpha_i)/(\sqrt[4]{m_{N_2}} * \alpha_{N_2})$

Contamination of heavy organics ('Hydrocarbons') shall be required as very low: challenging.

LF



specie	'basic'	released
	PP, mbar	PP, mbar
H2	5E-10	5E-09
Others: H2O,...	5E-11	5E-10
HC (250)	1E-14	1E-14
Total	6E-10	6E-09

Are these average value of pressure along 10km? On which length can you accept to a have higher pressure? What is the limit?

Possible pumping system for H_2 and CH_4

Turbo molecular pump	Cryogenic pumps	Ion pumps	Sublimation pumps	NEG based pumps
			H_2	H_2
Maintenance	Maintenance	Weight	Low cost	No local controller and no power needs
Vibration	Vibration	Integration	If well designed: High pumping speed and high capacity	Activation cycle relatively short (30-60 min)
Single local power supply	Single local power supply	Single local power supply	Sublimation process very fats: few minutes	High capacity and possible custom made design
Control system: PLC	Control system: PLC	Control system: PLC	No local controller and could be easily remotely operated	
CH_4	CH_4	CH_4		

Outgassing vs Pumping

Example of outgassing rate per cm^2

Material	H_2	CH_4	CO	CO_2
SS (vacuum fired – Baked 24h@250C)	$1.0 \cdot 10^{-14}$	$2.0 \cdot 10^{-17}$	$3.5 \cdot 10^{-17}$	$2.0 \cdot 10^{-17}$
Mild steel (Baked @ <100C for 20d)	$7.5 \cdot 10^{-16}$	$< 1.0 \cdot 10^{-17}$	$< 1.0 \cdot 10^{-16}$	$< 5 \cdot 10^{-17}$

Outgassing vs Pumping

Example of total outgassing rate for 500m of tube diam.1.2m [mbar·l/s]

Material	H_2	CH_4	CO	CO_2
SS (vacuum fired – Baked 24h@250C)	$4 \cdot 10^{-7}$	$7.5 \cdot 10^{-10}$	$1.3 \cdot 10^{-9}$	$7.5 \cdot 10^{-10}$
Mild steel (Baked @ <100C for 20d)	$2.6 \cdot 10^{-8}$	$< 3.7 \cdot 10^{-10}$	$< 3.7 \cdot 10^{-9}$	$< 2 \cdot 10^{-9}$

Needed pumping speed [l/s]

Material	H_2	CH_4	CO	CO_2
SS (vacuum fired – Baked 24h@250C)	**≈ 4000**	**≈ 500**	≈ 700	≈ 400
Mild steel (Baked @ <100C for 20d)	**≈ 300**	**≈ 250**	**≈ 2000***	**≈ 1000***

- **What is the best pumps for these requirements?**

*Upper limit because calculated on the background of our measurement system

NEG cartridge based pumps
Some consideration & Open questions

- Custom made shape? What is the maximum pumping speed?
    - External vs Internal solution

- Capacity for different gases @ RT vs @ 200°C

- Is there any problem of dust or particles production during the activation cycle?

Pro and cons of different solution: Cost vs Performance

- Why and when using the ZAO?
- Why not capacitor?
- Why not the NEG Strip

Ion Pumps
Some consideration & Open questions

- CH4 Pumping: How efficient at this pressure level?
  - Internal vs external solution.

- Powder and particle production? Can they migrate in the beam tube?

- HV Feed through robustness? Can we drop the idea of the manual gate valve? Pro and cons

- How many ion pumps can be piloted with a single power supply? Power and cable needs? Ethernat or Profibus connection?

Vacuum system cost assessment (hardware only)

Total cost: ~ 20 – 25 m€

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

Component	Quantity (+ spare)	Estimated cost [k€/unit]	Estimated ET total cost [k€]	Consideration & saving
Gate valve DN1250	36	250	**9000**	**Important to push for a reduced aperture in the middle of the 5km (saving 1.8 M€)**
Rough pumping group	3 (+3)	50	300	-
Mobile pumping group (TMP + PP, module A)	18 (+4)	50	1100	-
2000 ls^{-1} NEG ZAO (module A, B, C)	312 (+8)	15	**4800**	**Fundamental for their high capacity during the bakeout process**
500 ls^{-1} Ion pump (module C)	72 (+8)	6.5	520	**Fundamental for CH_4 pumping**
1000 ls^{-1} NEG (module D)	192 (+8)	5.5	1100	**Could use "cheaper solution" like NEG strip or Ti sublimator: Saving (≈ 500k€)**
Gate valve DN150 (Viton - all metal)	168 (+8)	10 - 25	**1760 – 4400**	**Are they important to increase reliability on a long term? or do we want to take the risk?**
Gate valve DN100 (Viton - all metal)	192 (+8)	5 - 15	**1000 – 3000**	**Used for the fix pumping system at RT after the bakeout: Saving up to 3 M€**
Angle valve DN40	360 (+10)	1	370	**Fundamental for possible leak detection**
RGA (2 units per 5km)	48 (+4)	10	520	**Are they necessary? If limit 1 RGA per 5km: Saving 250 k€**
Gauges (Bayard-Alpert)	360 + (10)	0.7	260	-
Leak detector	18 (+6)	15	360	-
Miscellaneous (bolts, gaskets, flanges)	-	-	500	-