Virgo Vacuum System

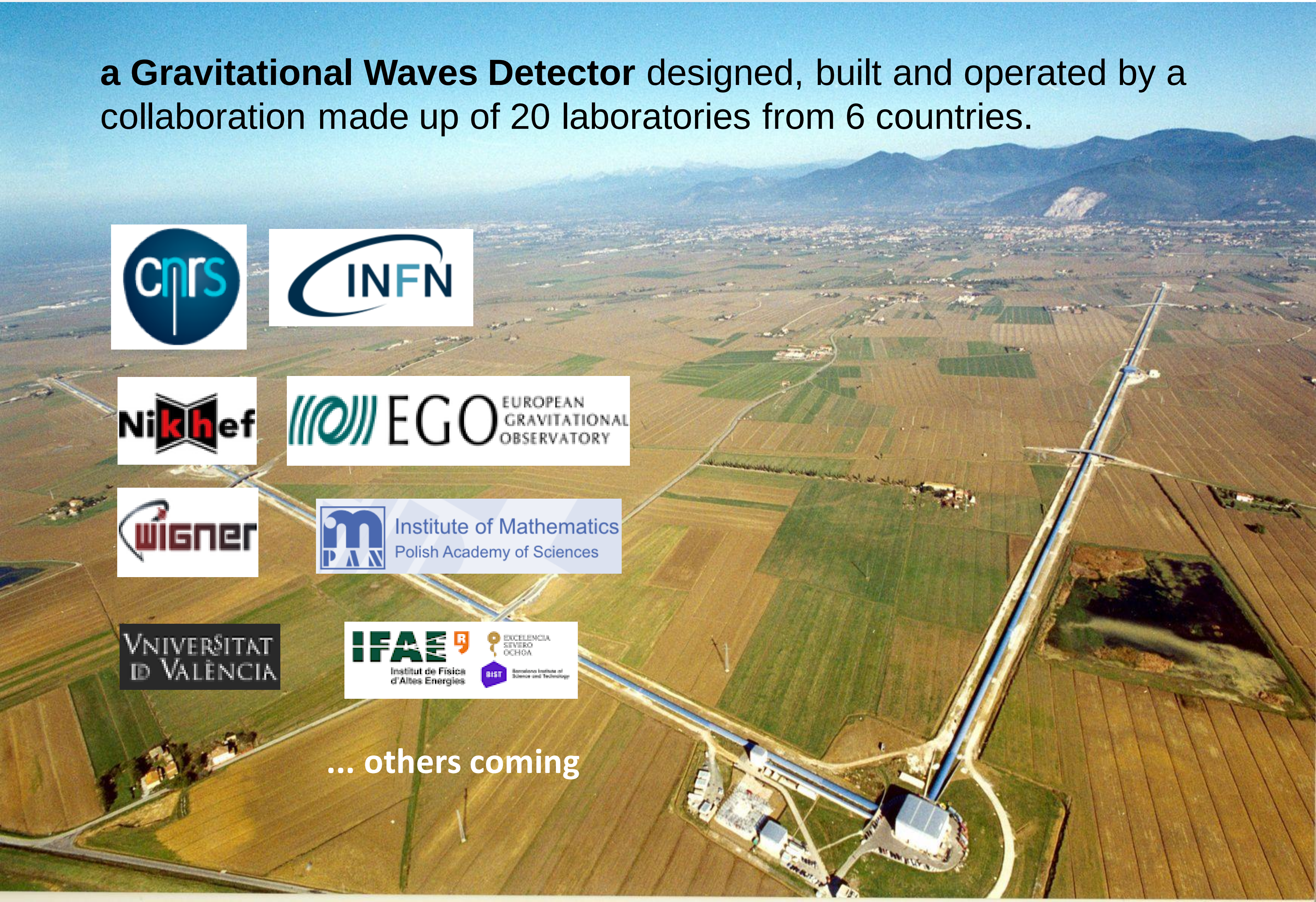
INFN LASA - Jun 13, 2024

A. Pasqualetti on behalf of the team that realized and operates the Virgo Vacuum System

EGO - Virgo Collaboration

VIRGO experiment

a Gravitational Waves Detector designed, built and operated by a collaboration made up of 20 laboratories from 6 countries.



... others coming

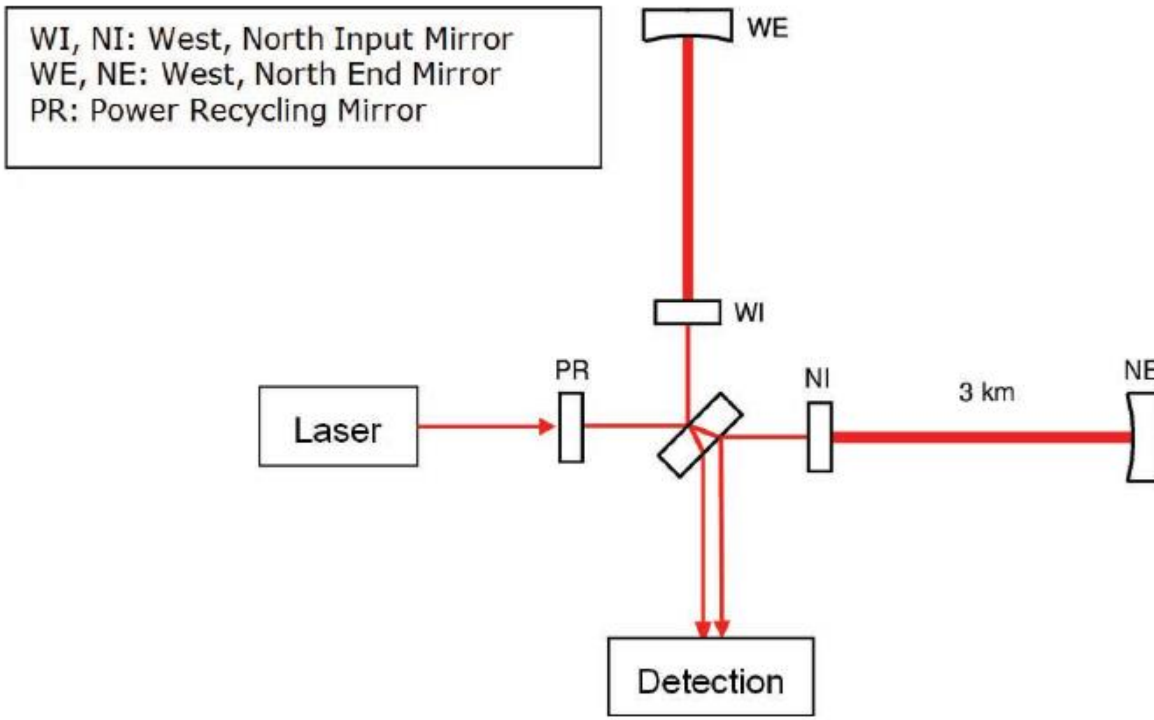
VIRGO experiment

Gli interessati sono invitati a visitare il sito

SUMMARY

- Virgo Vacuum System
  - Overview
  - Part. Pressure Requirements
  - Chambers
  - Pumping systems
  - Materials compatibility
  - ‘Cryotraps’
  - Selected Experiences
- Prospettiva per ET
  - Key figures: layout, size, vacuum levels

Interferometro laser Rivelatore GW

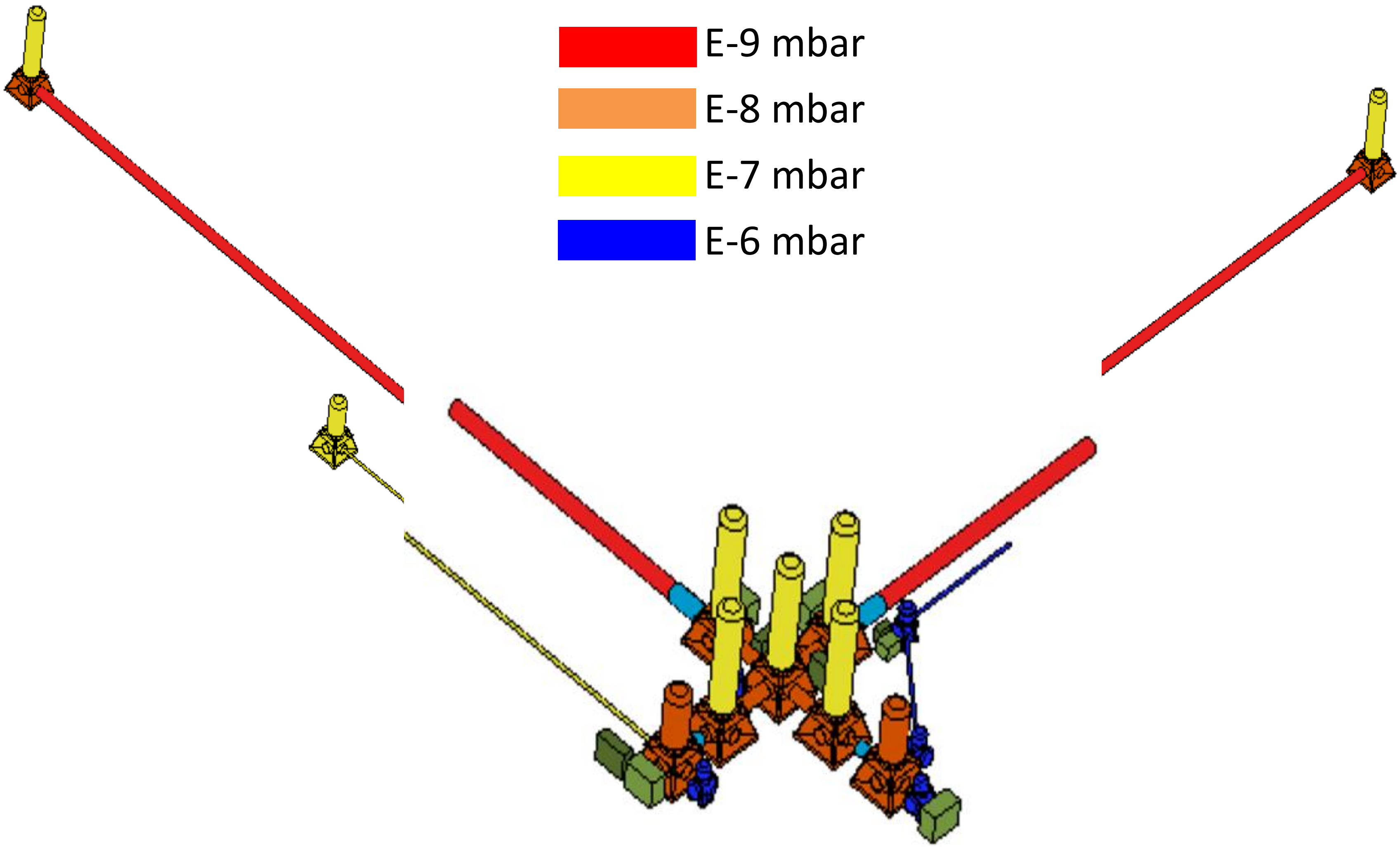


Fonte: Virgo WEB

Le parti sensibili dell'interferometro, inclusi gli specchi principali, i sistemi meccanici e il fascio laser, sono mantenute sotto vuoto per ridurre vari disturbi a livelli accettabili.

VACUUM LAYOUT

- 2 x 3 km UHV arms
- Large chambers and cryogenics at extremities



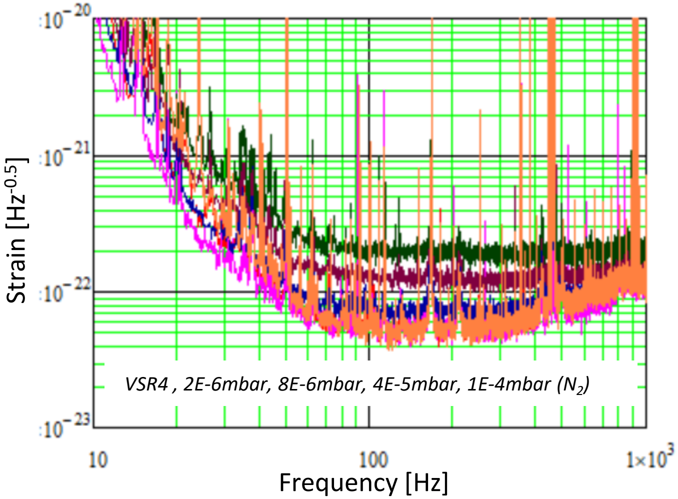
Partial Pressure limits

3 km UHV tubes: **low E-9 mbar** (H_2 dominant) to lower the statistical fluctuation of the optical path (fluctuaction of residual gas density)

Towers: shall operate down to **low E-8 mbar** (TMs ones) **unbaked** . Molecules hitting the mirrors produce the so-called ‘gas damping‘ effect *[Cavalleri et al. (2009). Gas damping force noise on a macroscopic test body in an infinite gas reservoir]*

Mirror contamination: **Low-volatile molecules < 1E-13 mbar** (‘one-monolayer’ conventional approach). The build-up of deposits on optical surfaces can increase ‘absorption and scattering’. *[S. Tanioka et al. Optical loss study of molecular layer for a cryogenic interferometric gravitational-wave detector, Phys. Rev. D 102 (2020)]*

Raising the pressure in the 3 km tubes



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

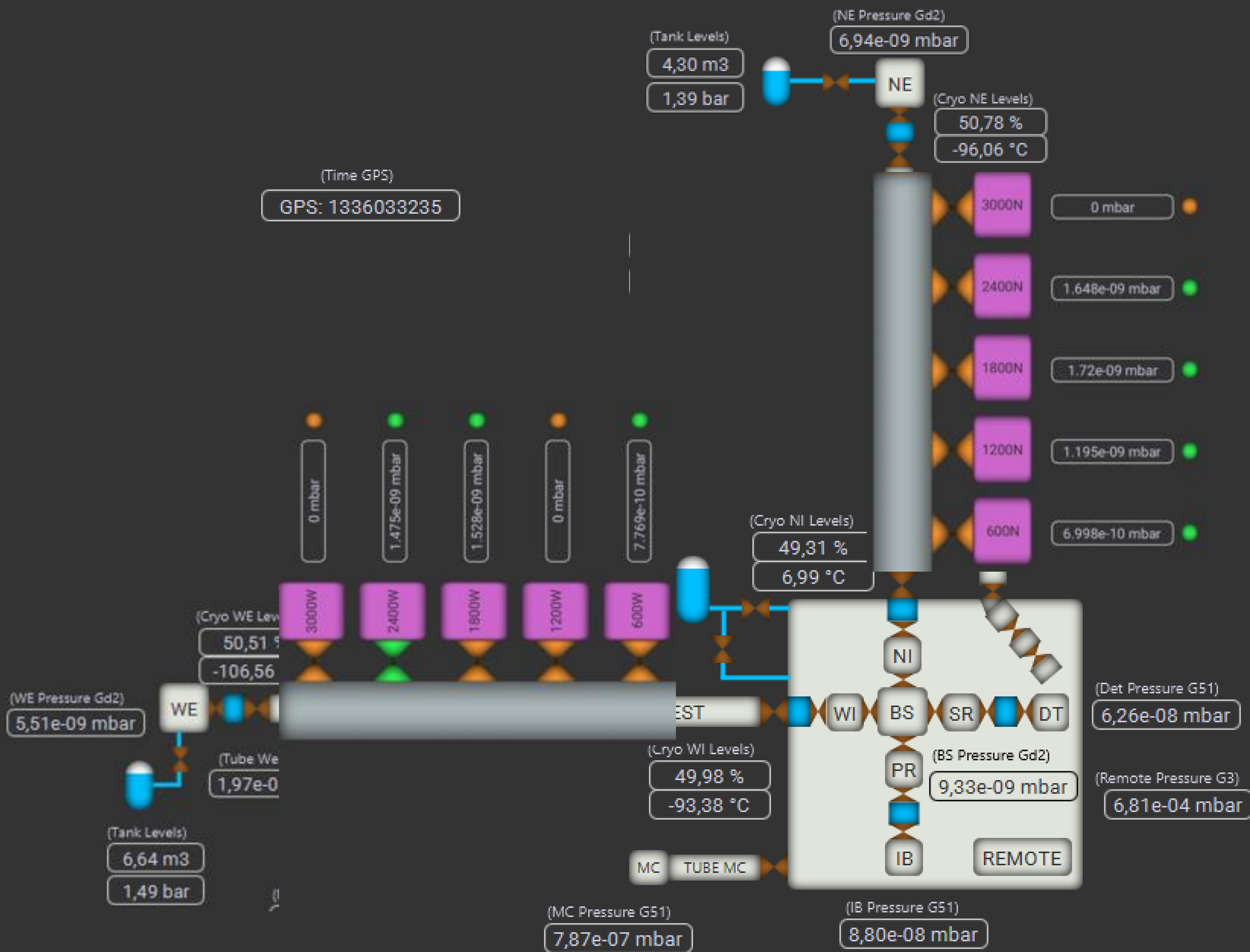
Example, common species wrt N_2 at same pressure: $CO \approx x\ 1.1$, $CH_4 \approx x\ 1.2$, $CO_2 \approx x\ 1.8$, $\sim(\sqrt[4]{m_i} * \alpha_i)/(\sqrt[4]{m_{N_2}} * \alpha_{N_2})$

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

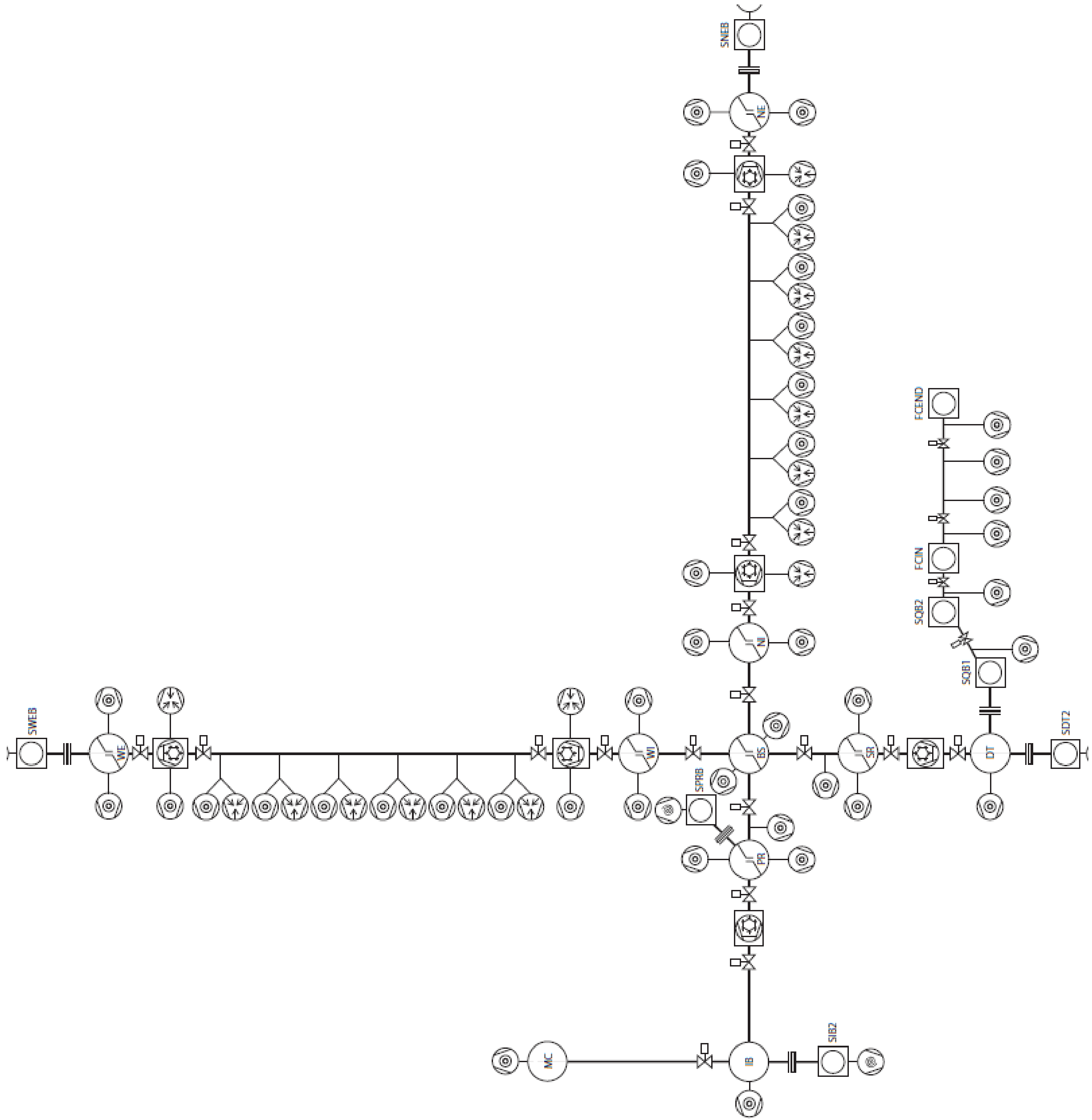
[1] G. Cella et al., Residual pressure noise evaluation, 2008

M. Zucker, S.Whitcomb, Measurement of Optical Path Fluctuations due to Residual Gas in the LIGO 40 Meter Interferometer LIGO Project internal document

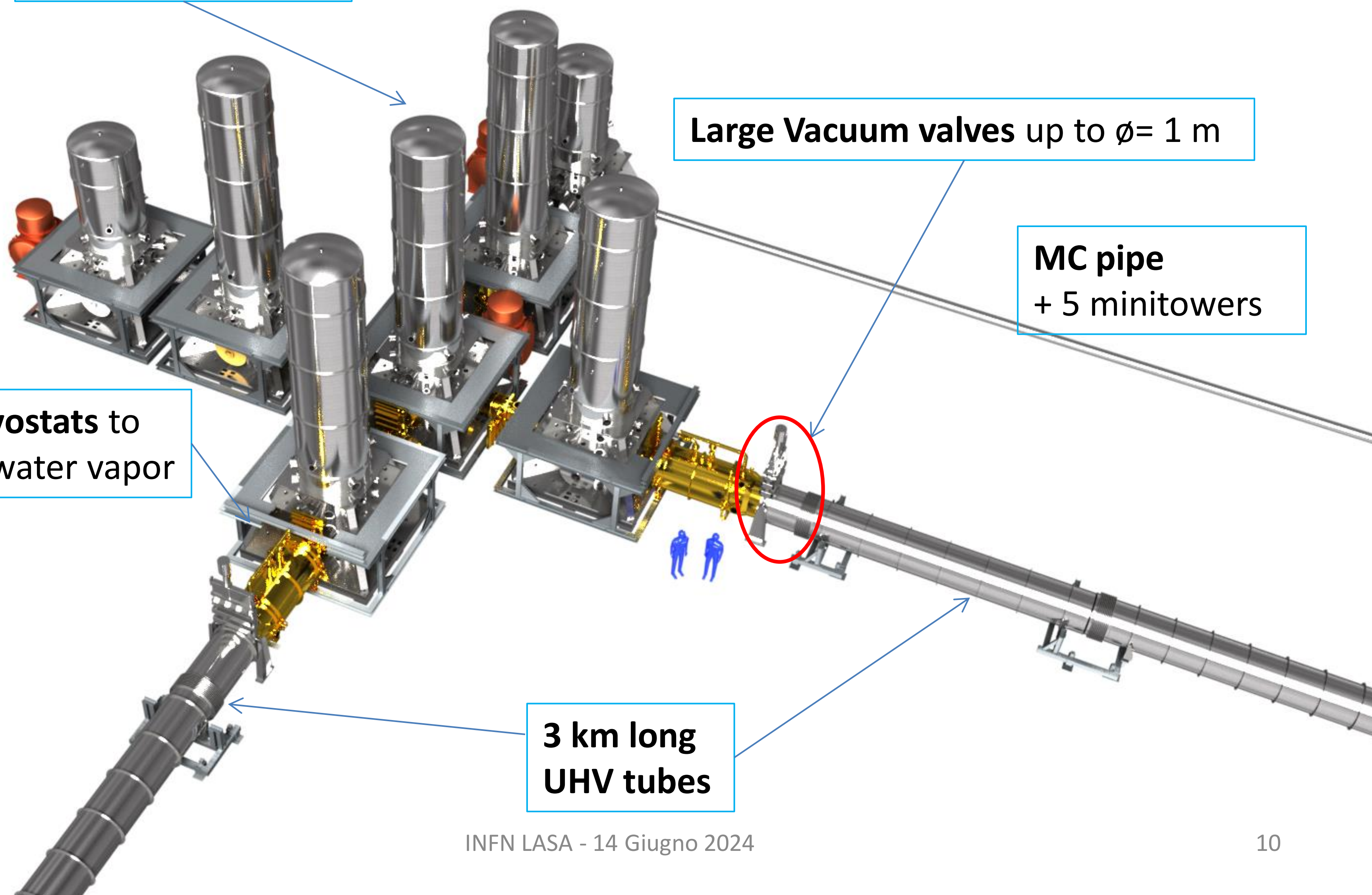
VACUUM SNAPSHOT



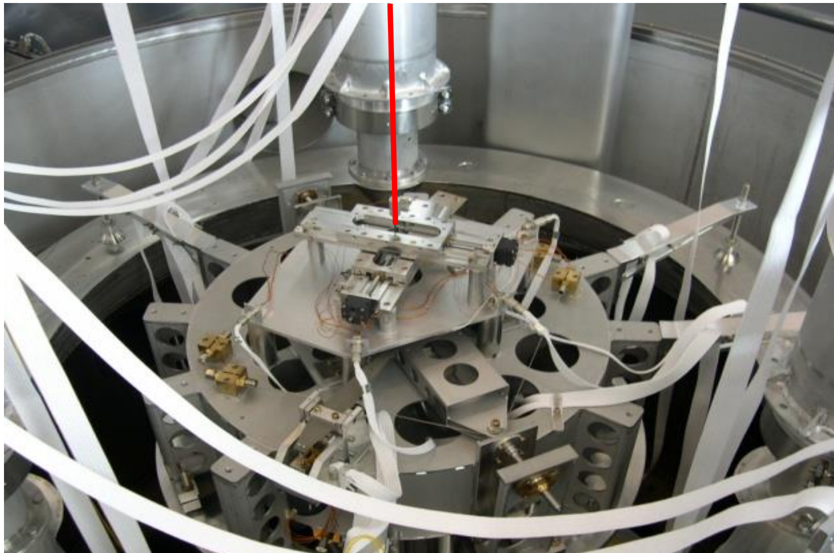
VACUUM SCHEMATIC

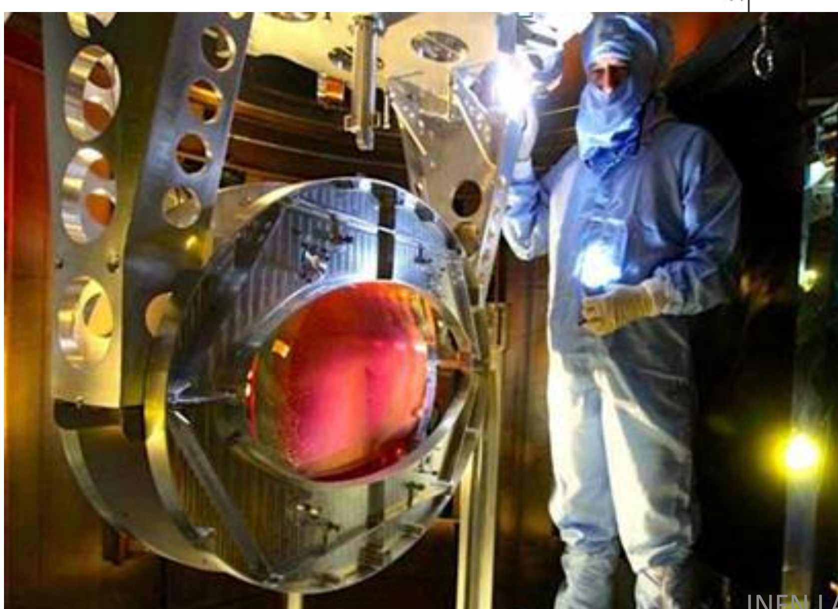


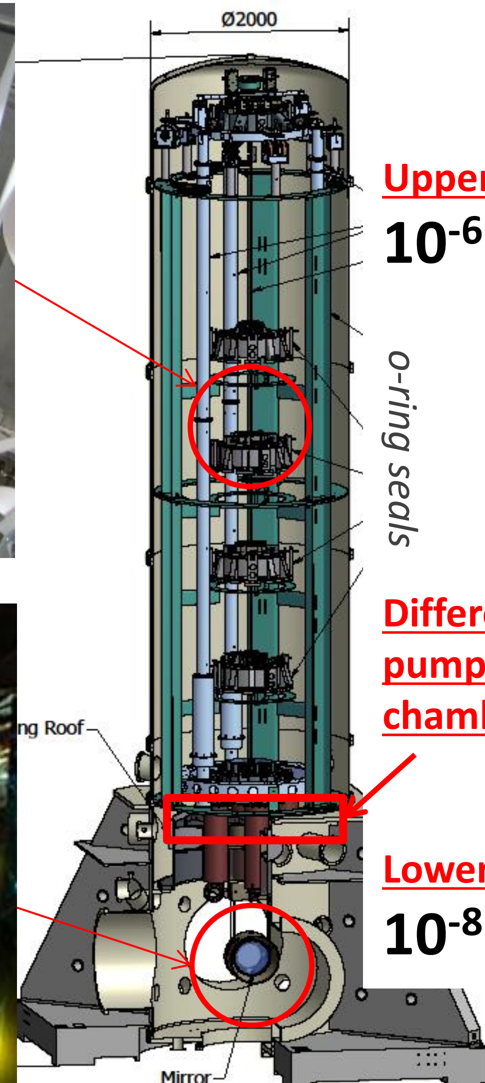
VACUUM CHAMBERS



TOWERS: two (three) vacuum levels







Upper Part

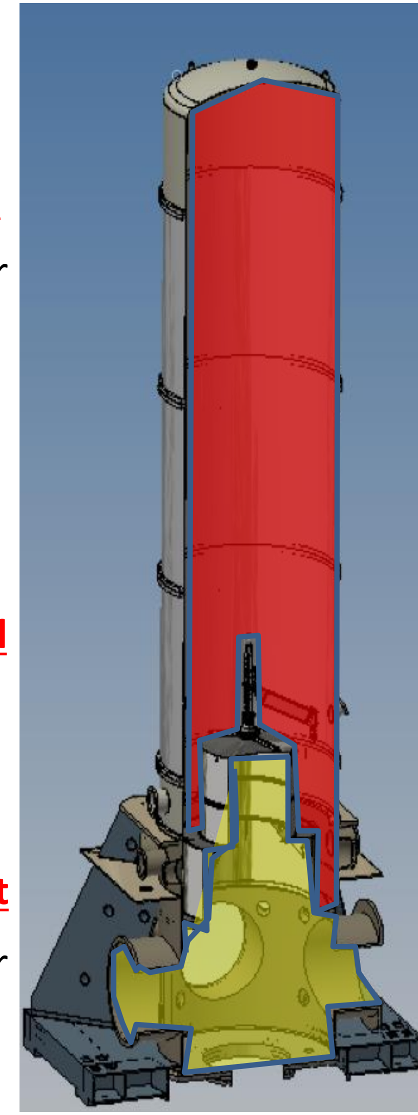
10^{-6} mbar

o-ring seals

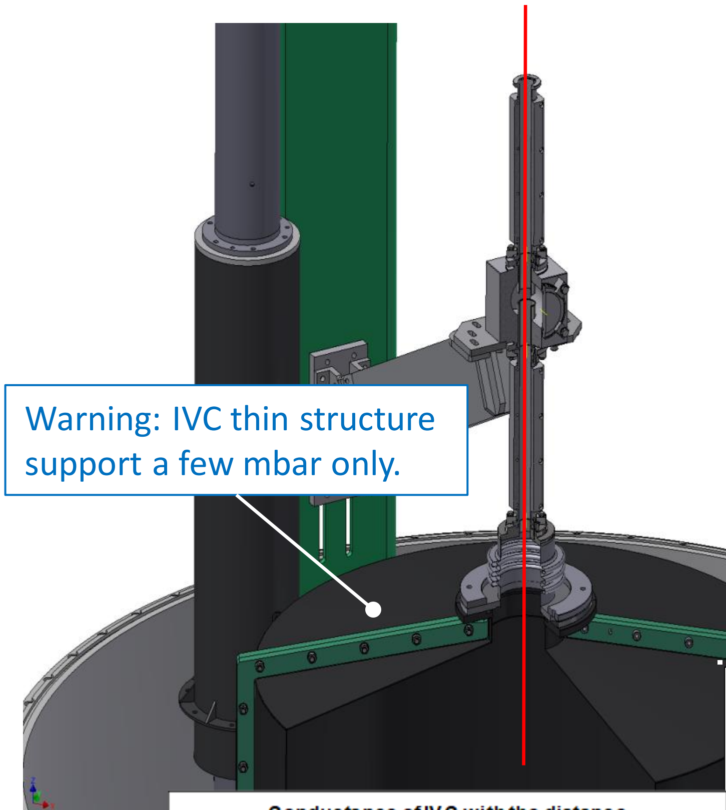
Differential pumping chamber

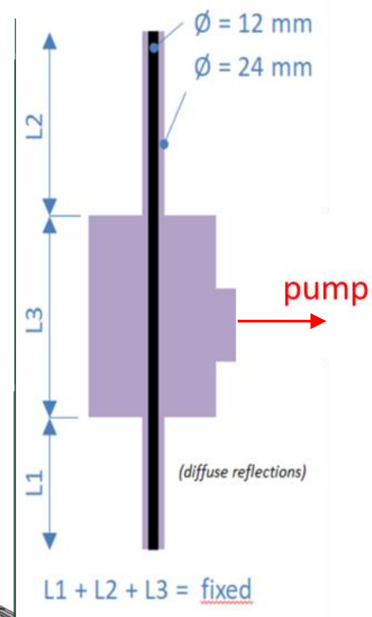
Lower part

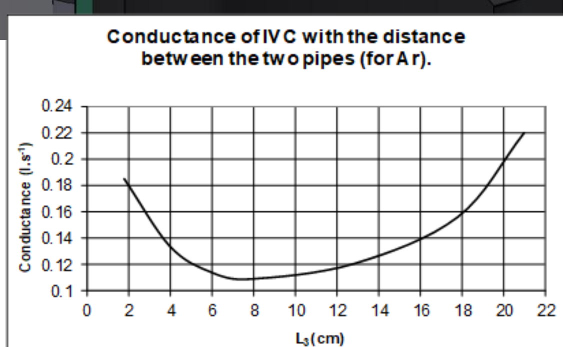
10^{-8} mbar

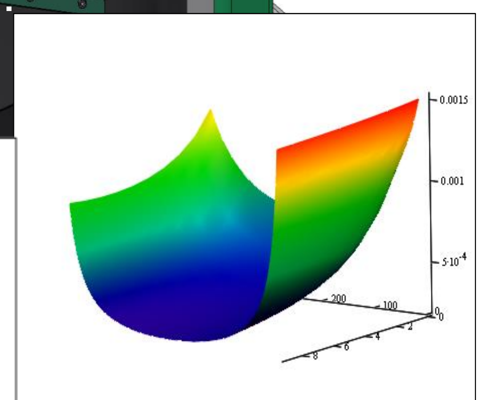


IVC







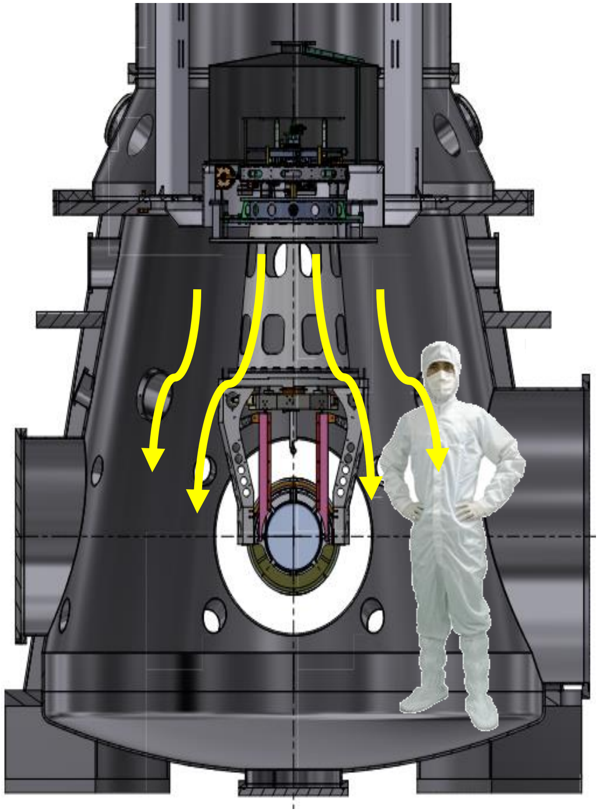


Allows the suspension wire passing through in a small pipe with a few mm of clearance.
Possible pumping with external ion pump (not used).

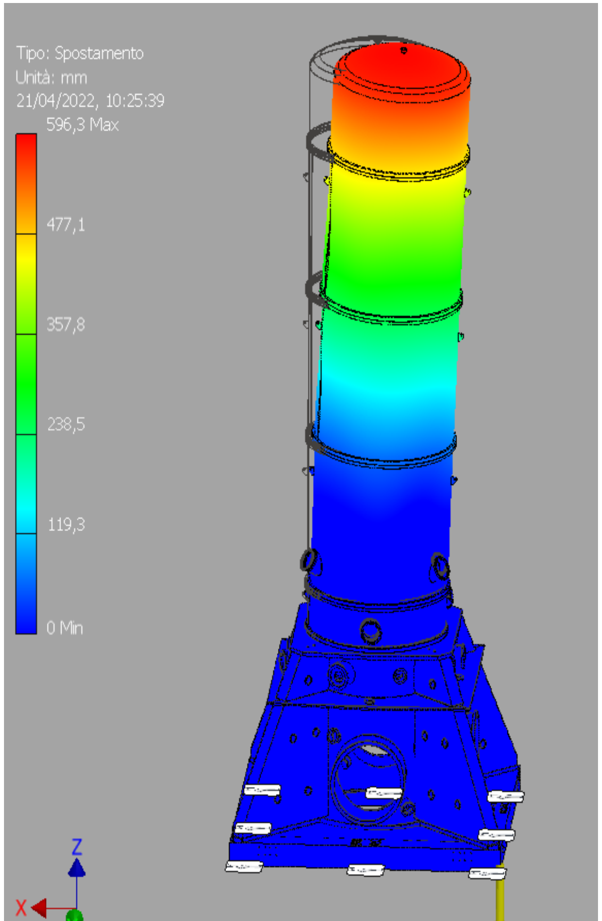
Equivalent ‘conductance’ evaluated from 1.5 l/s to 0.1 l/s N2 if pumping.
Field tests: bypass effects in some towers increase Ceq up to 4-5 l/s.

TOWERS: mechanical features

- Ø = 2m, up to 11m high, > 20 ton;
- House complex mechanics (chambers frequencies > 15 Hz, within seismic-attenuator range);
- When in air, they works as a cleanroom: allow clean and 'easy' access of personnel to work close to inner optics;



Credits F.Bianchi



Credits G.Capoccia

Flanges and seals

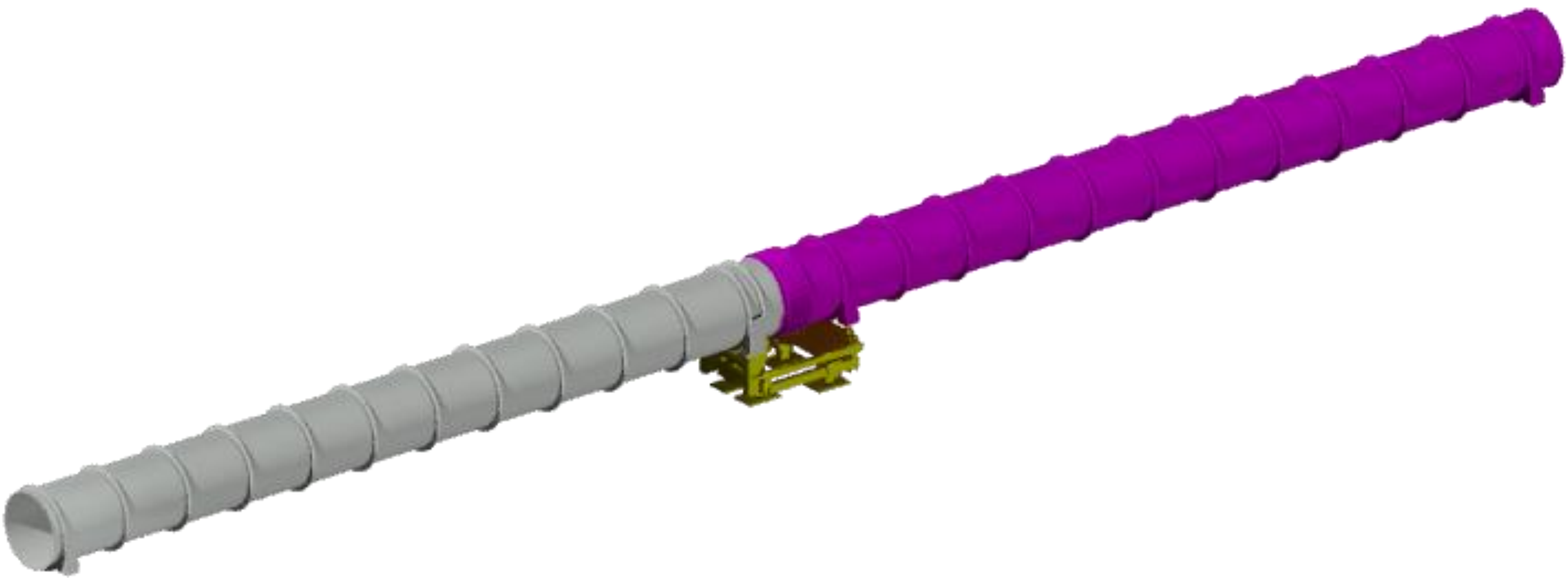
- Helicoflex® for not-accessed flanges, 20+ years 'welded-like' lifetime.
- Double o-ring (*any experience? e.g. wrt residual water permeation*)
- Single o-ring (upper parts)

3 km UHV TUBES

- 24000 m^2 walls!
- They contain "only" optical baffles and the laser beam

TUBE DESIGN: THE MODULE

- Prefabricated modules 15 m long, joined by welding ;
- Raw material 304L , plain walls 4 mm thick + stiffeners every 1.2 m;
- Bellows to allow heating up to 160°C (80 kgf/mm);
- Flanges: only a few on 3 km for pumps and gauges;

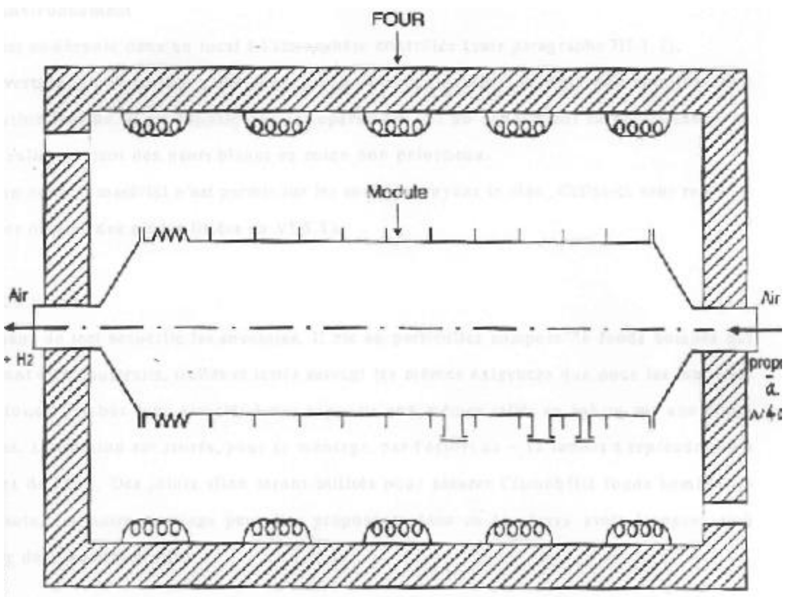


AIR-BAKE OUT

Base material conditioning was required to meet vacuum goals (24000 m^2 walls).

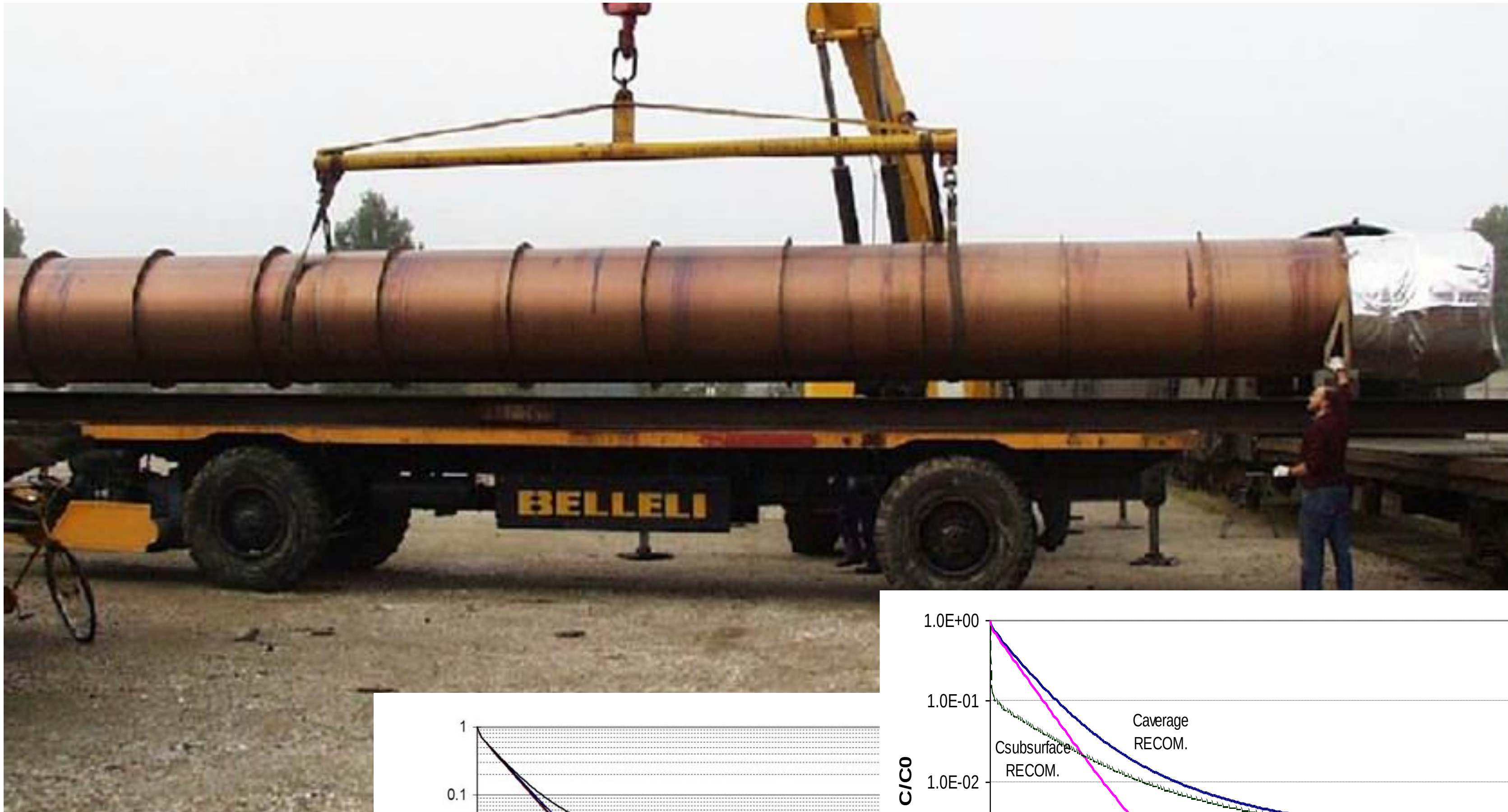
heating at ~ **400°C in air** involved a ''simple'' oven and reduced the hydrogen outgassing by a factor ~ 100; our result: **$q(H_2) \leq$ 3E-14 $mbar.l.s^{-1}cm^{-2}$ @ 20°C**

The industrial specification was: $q(H_2)$ = 5E-14 - NOT CONTRACTUAL -



- <u>Applied to finished modules</u>
- Electrical oven, 'sealed' modules
- 410°C +20/-10 , plateau 72h
- Hot air purge 8 m^3h^{-1}
- 5 days long cycle
- H content raw mat. ≤ 2 ppm wt - CONTRACTUAL -

Past results about ‘air bake-out’



Air bake-out to reduce hydrogen outgassing from stainless

M. Bernardini, S. Braccini, R. De Salvo, A. Di Virgilio, A. Gaddi, A. Gennai, G. G
A. Giazotto, G. Losurdo, H. B. Pan, A. Pasqualetti,[a] D. Passuello, P. Popolizio,
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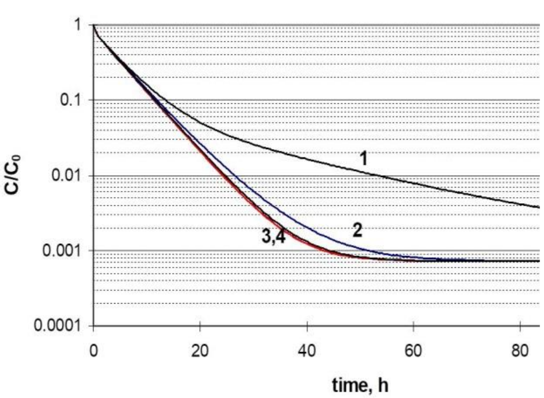
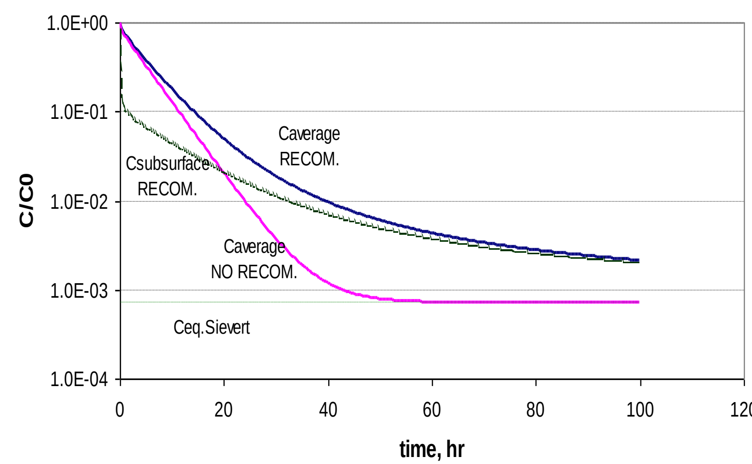
(Received 29 May 1997; accepted 19 September 1997)

Hydrogen outgassing is the most significant factor limiting the attainment of outgassing r
10^{-12} mbar l s^{-1} cm^{-2} in stainless steel vacuum systems. This limit turns out to be cruc
large vacuum systems, like the VIRGO vacuum tubes (2 tubes 1.2 m diam, 3000 m length
the raw material at 400 °C in air was suggested as a money saving alternative to th
vacuum heating at 950 °C. We report the results of hydrogen content analysis performed o
steel samples submitted to different treatments, and also the measurement performed on a
tube (1.2-m-diam, 48-m-long). We concluded that air bake-out drives out most of the
absorbed in the bulk stainless steel, while the presence of an oxide layer does not
hydrogen outgassing. © 1998 American Vacuum Society. [S0734-2101(98)02601-3]





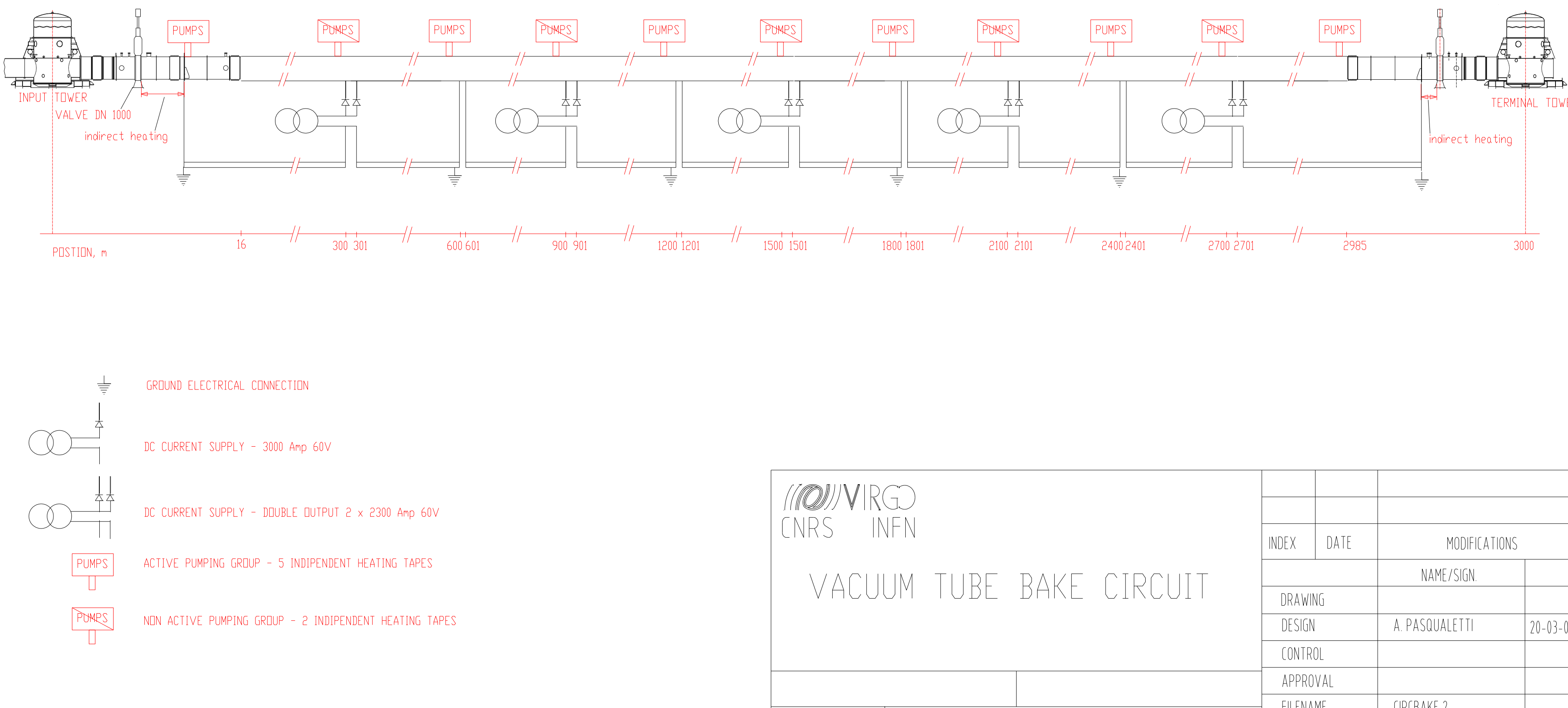
FAT tube modules

- RGA test in factory (non contrattuale TBC) ma che ha aiutato a correggere il processo (risciacquo) ed controllare qualità dei moduli.

TUBES: BAKE-OUT in situ

- Chamber at 150°C uniform and at a controlled rate (~1 week for SAT stage)
- 1 Mwatt to heat one tube (15 cm thick thermal insulation)
- Joule effect: 2000 A flowing through tube walls
- diesel generators: ~ 10^5 litres of fuel to bake one tube

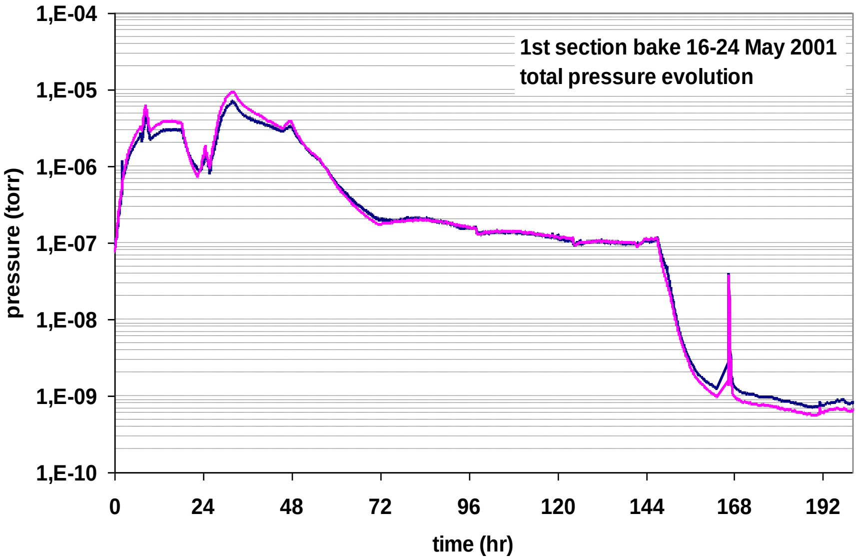
***Normally to be performed just one time*.**



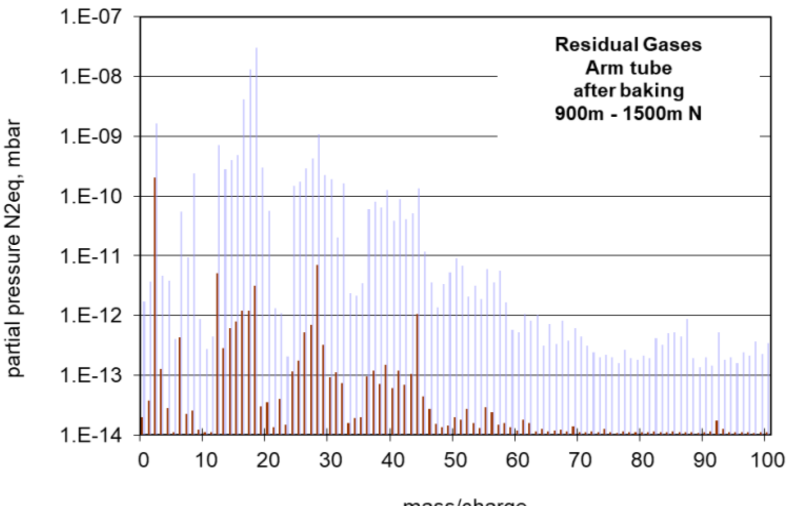
SOME DATA of BAKED TUBES

- H$_2$ outgassing , our findings

Module0 test: **= 3E-14**
Tube sections (check) **≈ 1E-14**
Pisa/LAL prototypes **< 1E-14**
[$\text{mbar.l.s}^{-1}\text{cm}^{2}$ @20°C]

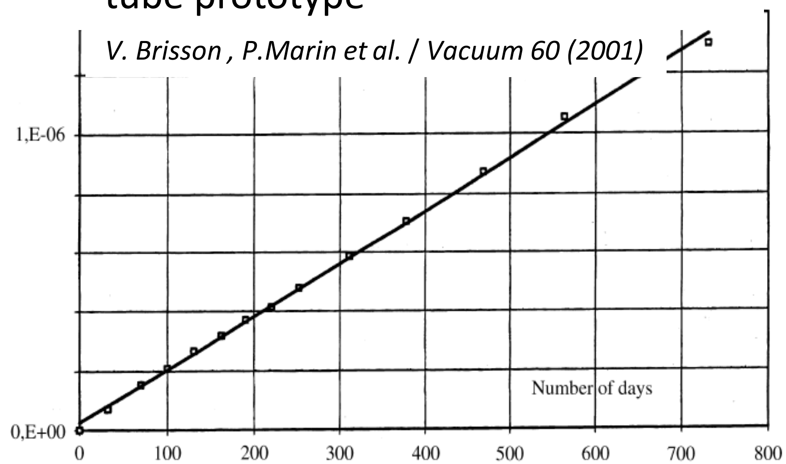


Typical RGA on 'tube' after bake-out



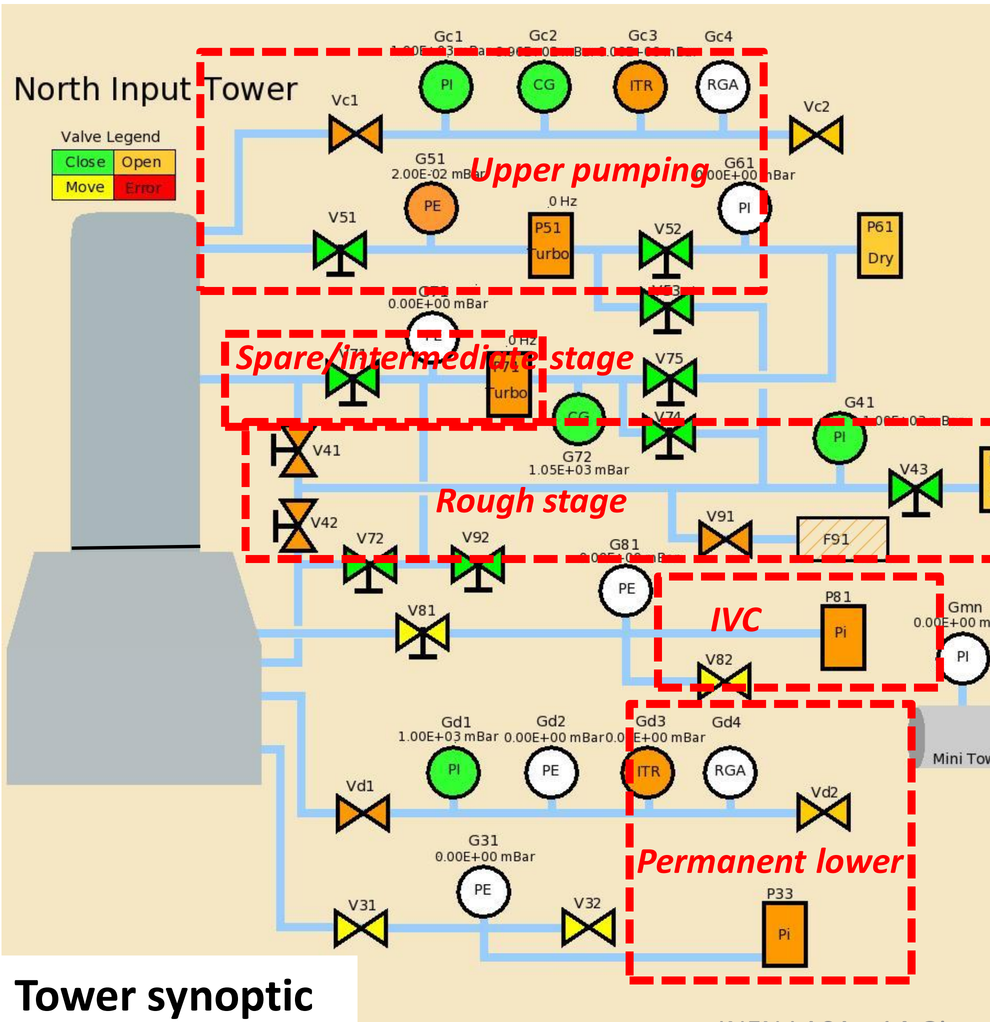
Accumulated gas over 2+ years on a 'tube prototype'

V. Brisson , P.Marin et al. / Vacuum 60 (2001)



PUMPING SYSTEM

Main requirements: oil free pumps against contamination risk, low acoustic / seismic / magnetic emissions , long maintenance intervals to preserve duty cycle.

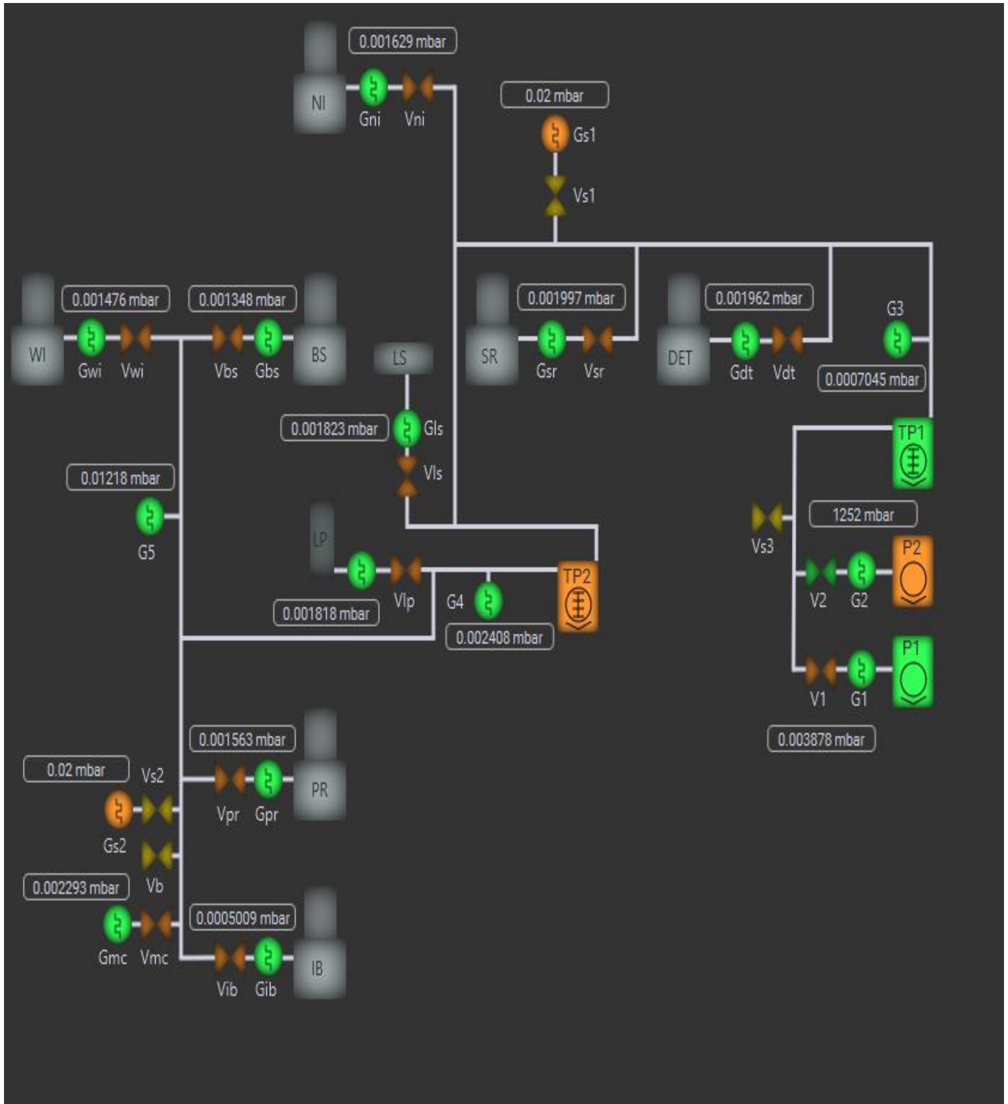


Tower synoptic

Statistic (not updated)

22	Roughing/backing dry pumps
21	Turbo-molecular pumps
25	Ion pumps
20	Residual gas analyzers
221	Angle valves
111	Gate valves
4	Large valves ø=1000 mm
153	Gauges

Remote backing pumps



A more recent upgrade: Turbo-molecular pumps permanently running on each tower upper compartment (typical size 1000 l/s) are backed remotely to limit acoustic/seismic disturbances (or discontinuously , this not optimal for hydrogen)

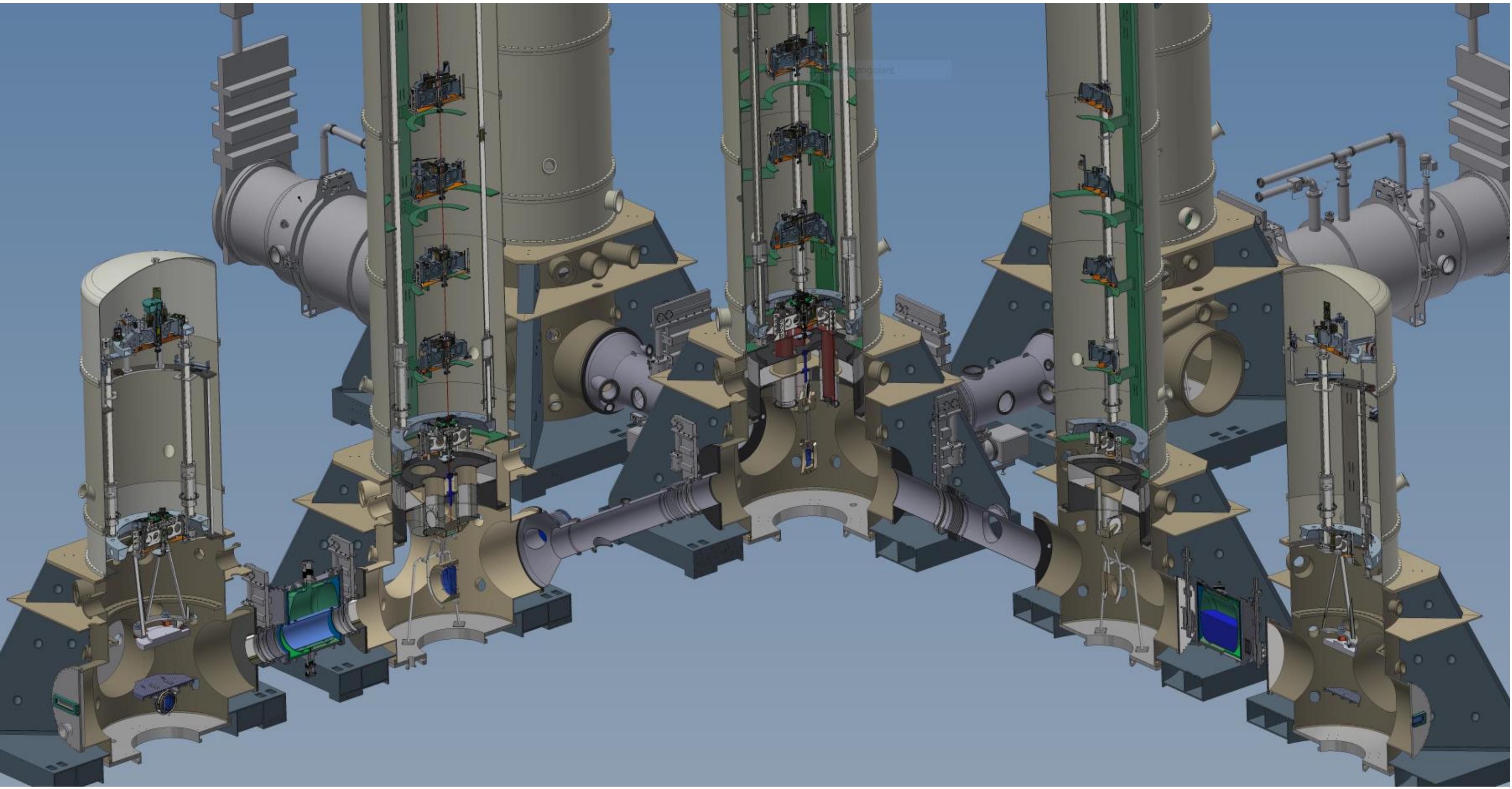
CONTROL SYSTEM HW & SW

- Local or remote operation
- Logic of operation is managed by a PLC
- Interlocks by Supervisor SW

• Data fully integrated in Virgo DAQ (5000 channels @ 1 Hz , < 0.1 % of the total)

by LAL team

Main optics and critical systems concentrated in this area. The challenge is to limit environmental emissions such as mechanical, acoustic, and magnetic vibrations. Turbo-molecular pumps: bellows and separate base, shielding of the cable. Not ideal choice. Alternatives? Ion pumps? Dispersed charges… Cryogenics? Noise … NEG? High load… All of them are present, in different positions.

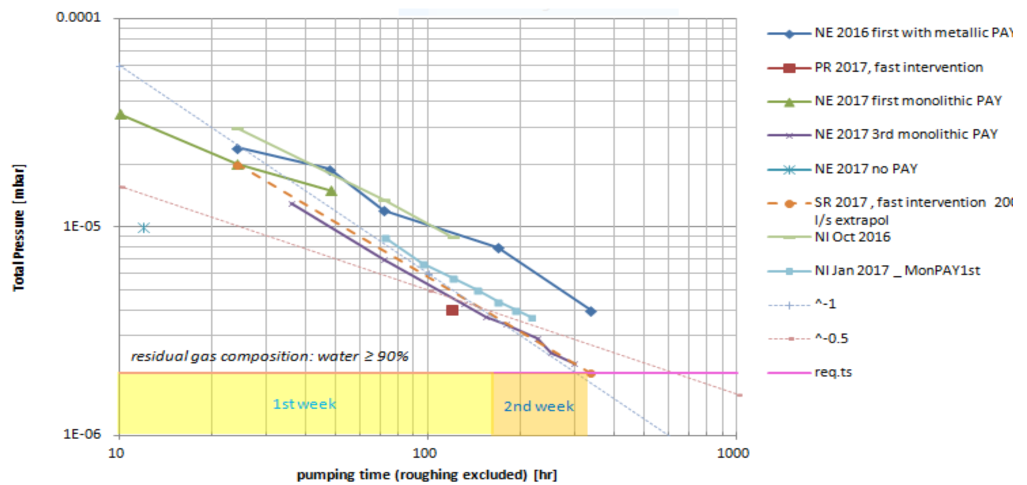


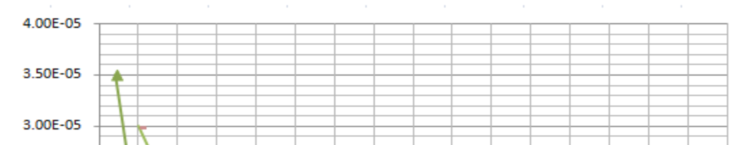
LIVELLO DI VUOTO DELLE TORRI

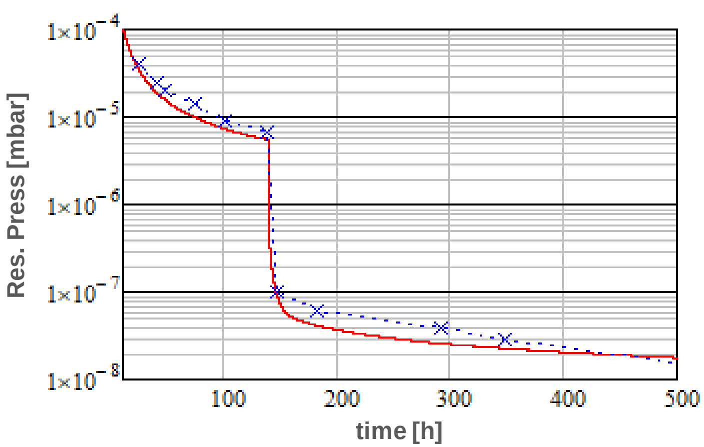
The gas load is largely due to the added inner materials!

Increasing along detector upgrades (from V -> V+ -> AdV -> AdV+) while aiming to improve the vacuum in the tubes…

Beyond the 'steady state' level, the recovery time is also important for the duty cycle.



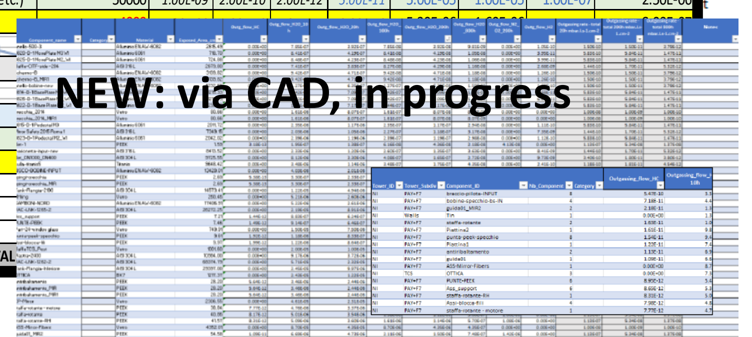




OLD: xls table

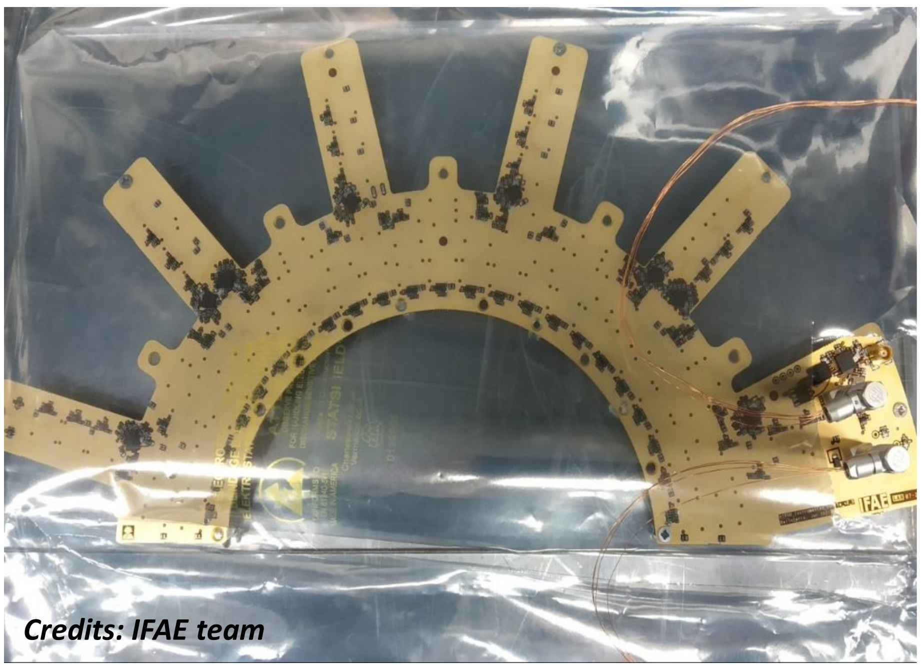
For 1 base tower	-->								
Material	Surface (cm2) Hyp	q100h	q1000h	qH2	qN2 100h	Q100H	Q1000H	QH2	N2 and al. 100H
Walls (AISI 304L)	400000	4.00E-11	2.00E-12	1.00E-12		1.60E-05	8.00E-07	4.00E-07	
Alu - AW_6082	100000	3.00E-11	3.00E-12	4.00E-14		3.00E-06	3.00E-07	4.00E-09	
Glass	15000	2.00E-09	2.00E-10	TBC	TBC	3.00E-05	3.00E-06		
Kapton (cables...) - METER	500	9.00E-09	2.00E-10	1.00E-09	2.00E-09	4.50E-06	1.00E-07	5.00E-07	1.00E-06
Other materials (StSt, Titanium, Rame, PTFE, etc.)	50000	1.00E-09	2.00E-10	2.00E-12	5.00E-11	5.00E-05	1.00E-05	1.00E-07	2.50E-06
Macor (thick polymer material)									
Estimate 2022									
Ideal Case									
Allowable leak (double Oring) - AREA M2									
"Extra" materials - Margin									
PEEK (thick)									
Total - non Ideal only									
All - Total									
Taking into account the unknown "TBC" - TOTAL									

NEW: via CAD, in progress



IN-VACUUM COMPONENTS

In-tower components are checked for vacuum compatibility to obtain a sufficiently low overall outgassing (i.e. of water vapor, air species, hydrogen). Partial pressure of potentially contaminating species are to be kept under control as well.



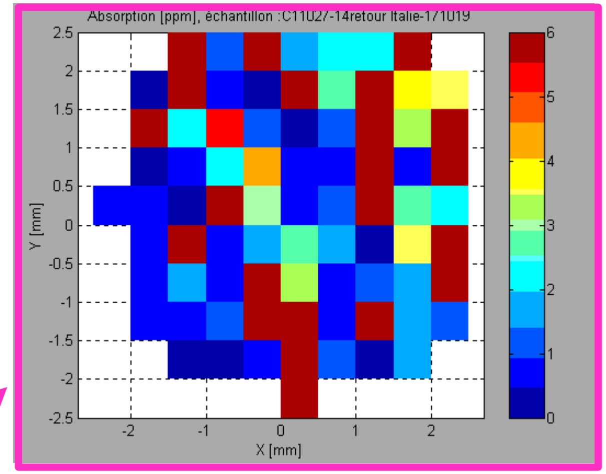
Credits: IFAE team

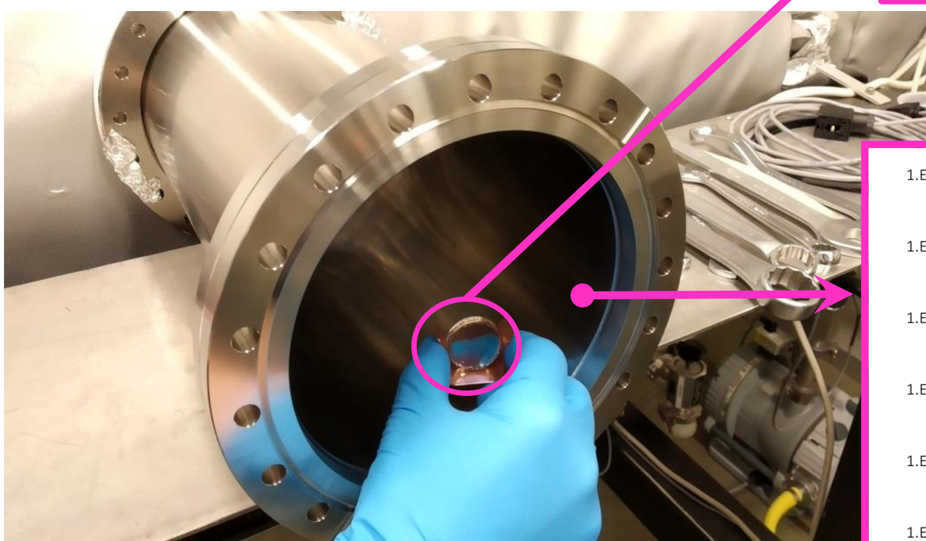
IN-VACUUM CONTAMINATION CONTROL

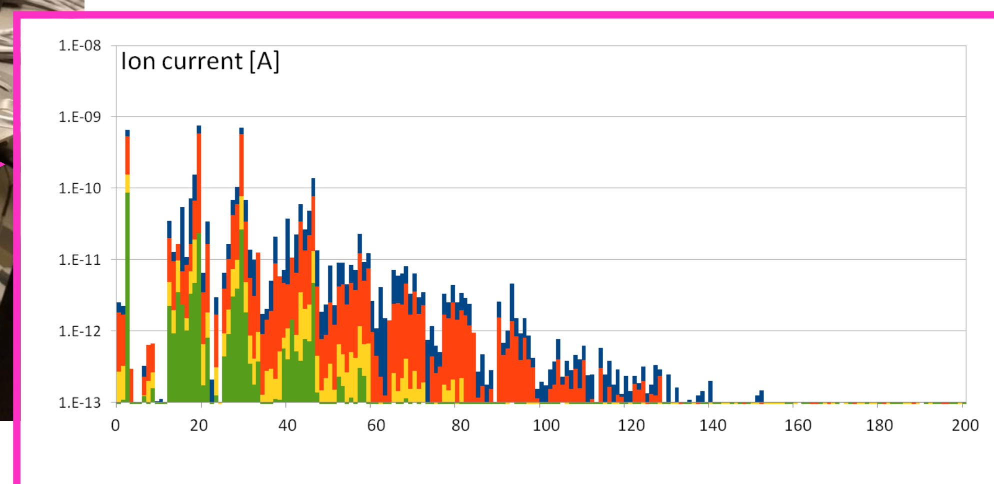
Deposition of low-volatile species = crucial risk for Virgo optics.

we qualify materials checking the:

1. residual gas analysis
2. optical losses on dedicated samples

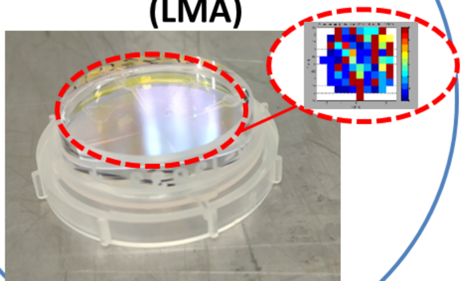






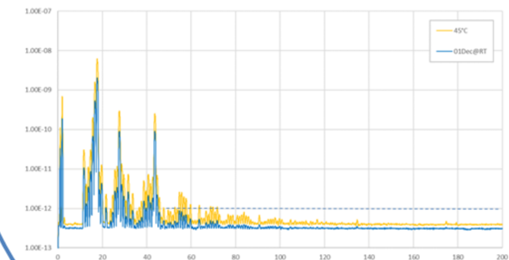
IN-VACUUM CONTAMINATION CONTROL

OPTICAL LOSSES MEASUREMENTS (LMA)

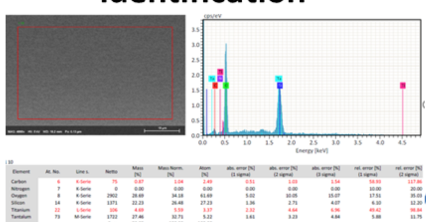


No clear correlation between the detected contaminant level in the gas and the measured optical losses

RESIDUAL GAS ANALYSIS



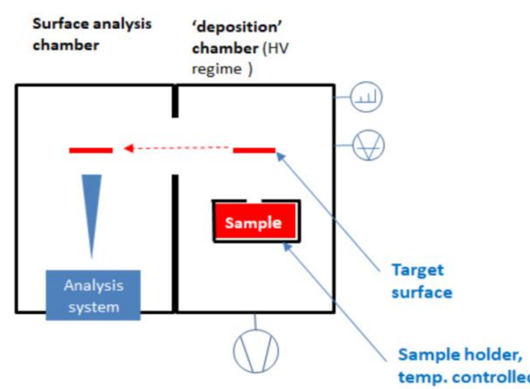
SEM for GROSS contamination identification



MISSING

1. **Identification of deposited species**
2. **Quantification of deposited film**

?



Trials with XPS thanks to E.Placidi [J. Vac. Sci. Technol. B 42, 034003 (2024)]

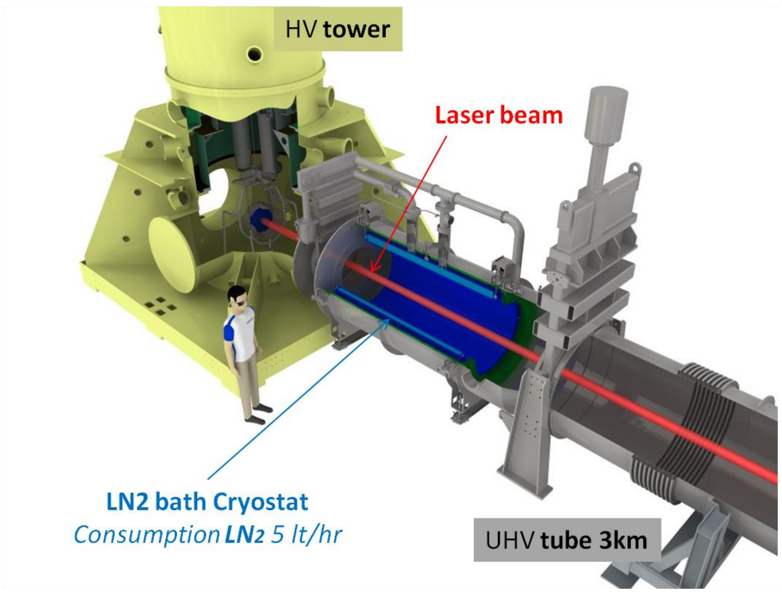
TUBE PUMPING STATIONS

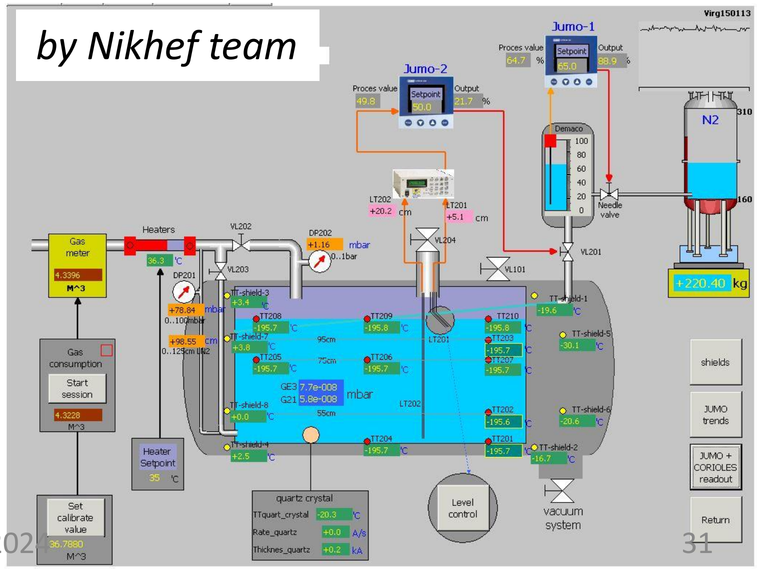
Every 600 m, taking advantage of the 'enormous' conductance compared to typical ducts in other applications

- Turbomolecular pump 1000 ls^{-1} for the intermediate phase
- TSP/IP pumps 2000 ls^{-1} H_2 for the permanent phase
- Valves: “Viton” for the gates (‘evacuated’ to limit permeation)
- spares @ 300m
- requires a ‘clean’ and protected area, UPS mains and network.

CRYOGENIC PUMPS & EQUIPMENT

Installed between 'unbaked towers' and 'baked tubes' *(added in a second stage)*
LN2 consumption 2000 l/day from 3 'horizontal tanks, 50 m^3 total capacity. Refill operations affect the scientific duty cycle.

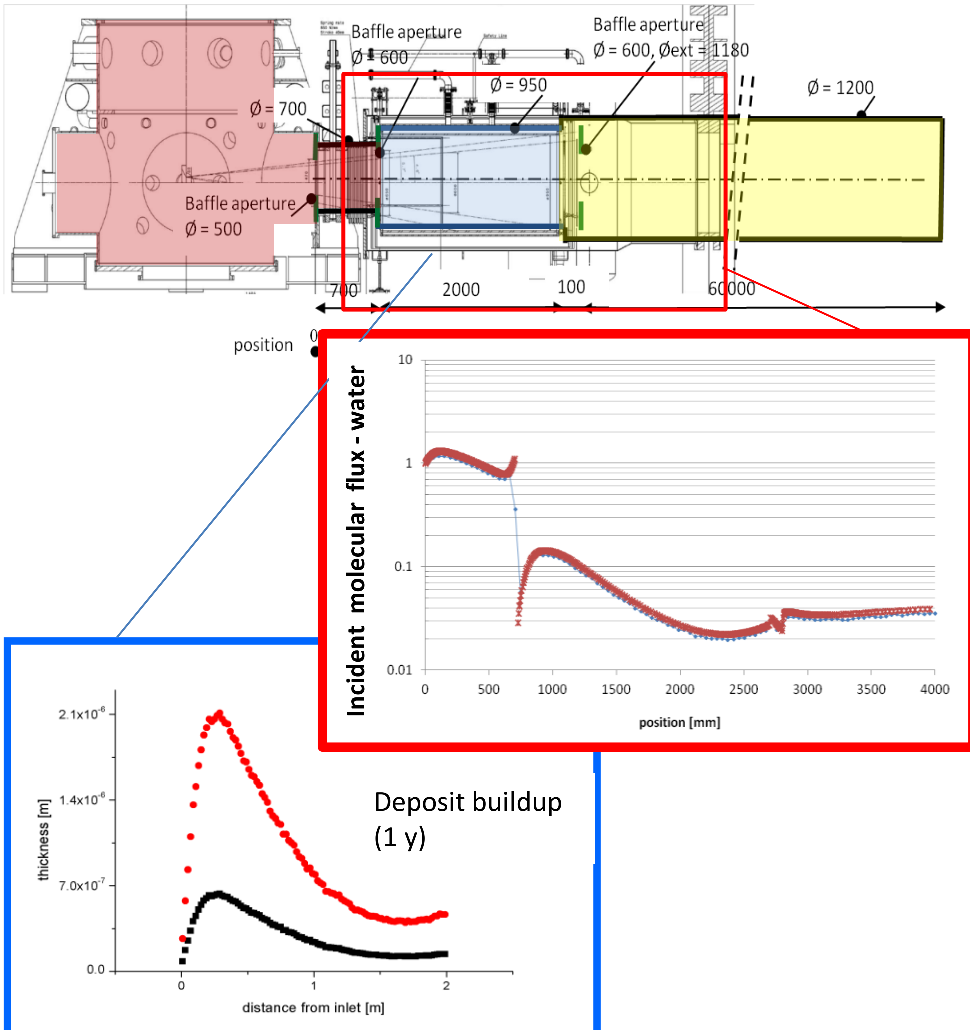


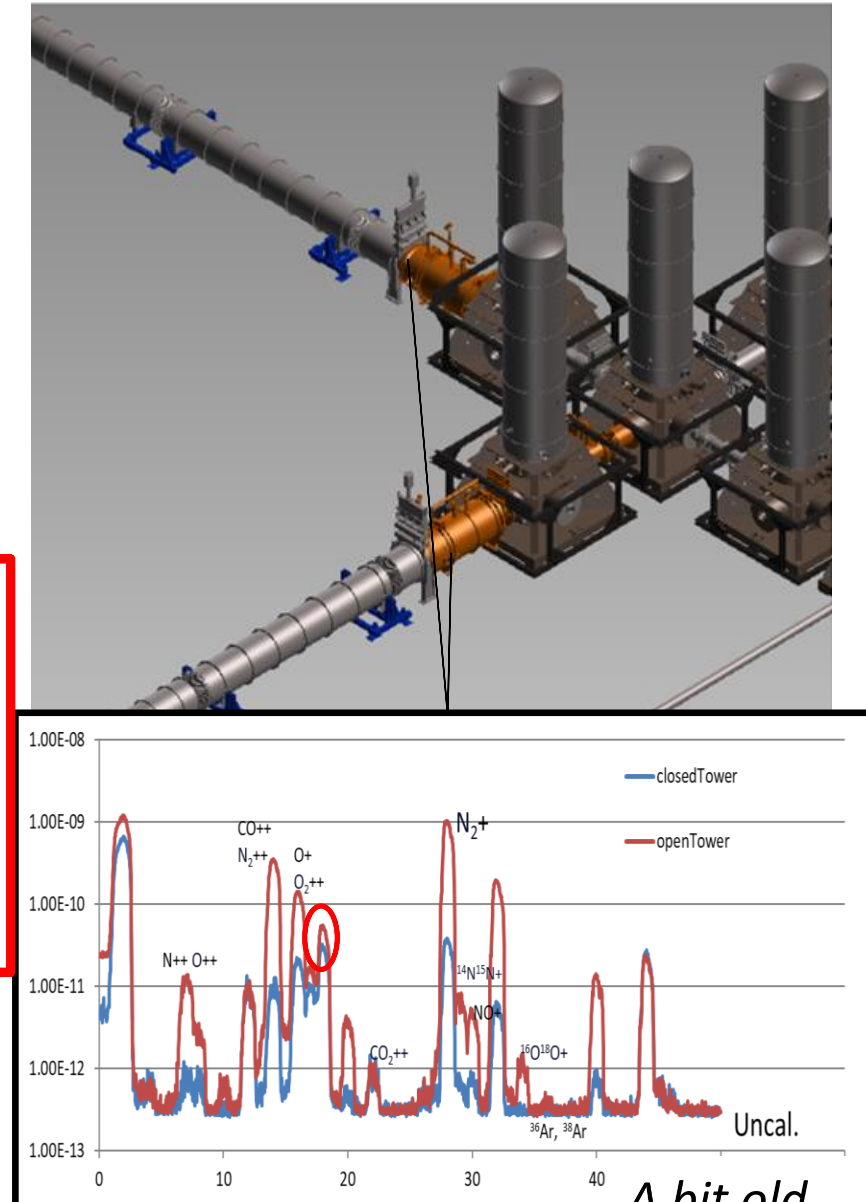


Function is to pump water vapor coming from towers

CRYOGENIC PUMPS & EQUIPMENT

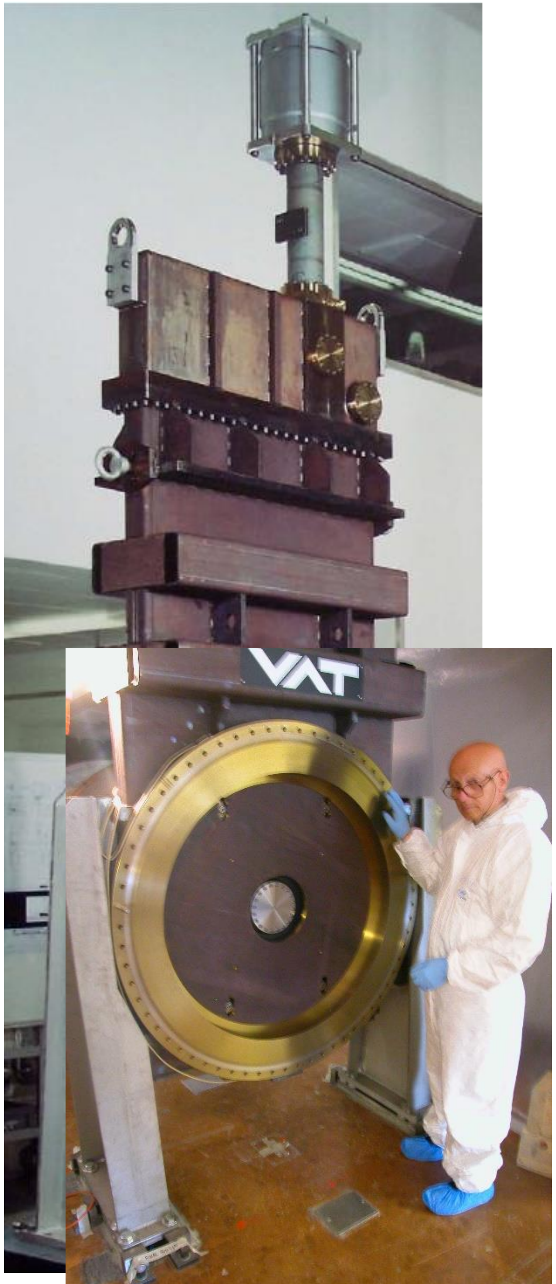
a 2m long cylindrical section cooled at 77K pumping the water vapor coming from 'towers' chambers *(originally used by LIGO)*.





A bit old ...

LARGE VACUUM VALVES



❖ **4 DN1000 Valves to isolate the ‘tubes’ from the ‘towers’**

- *Stainless steel body, air-baked*
- *Metal sealed(the only large flanged joint)*
- *Viton o-ring on the gate (single)*
- *Bakeable at 150°C*
- *Expensive*

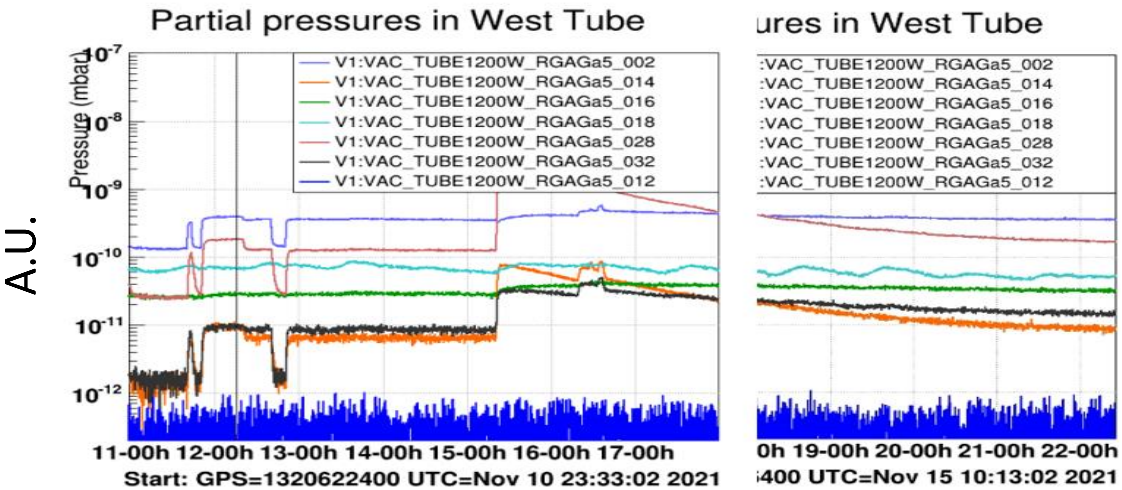
Outgassing data *(old, meas. in factory):*
< 5E-8 mbar.l.s^{-1} - stainless steel body, H_2
< 5E-7 mbar.l.s^{-1} - Viton® seal on the gate , baked;

❖ **7 DN650/400 Valves to isolate the ‘towers’ from each other**

Selected Experiences

Operation

- Frequent access to ‘towers’ during ‘Commissioning phases’ (not optimal for the TSPs).



- Super-quiet operation in ‘Observing phases’: long-time data taking with undisturbed vacuum along ≈ 1y , with maintenance breaks of 4 h / week.

‘3 km Tubes’ Venting

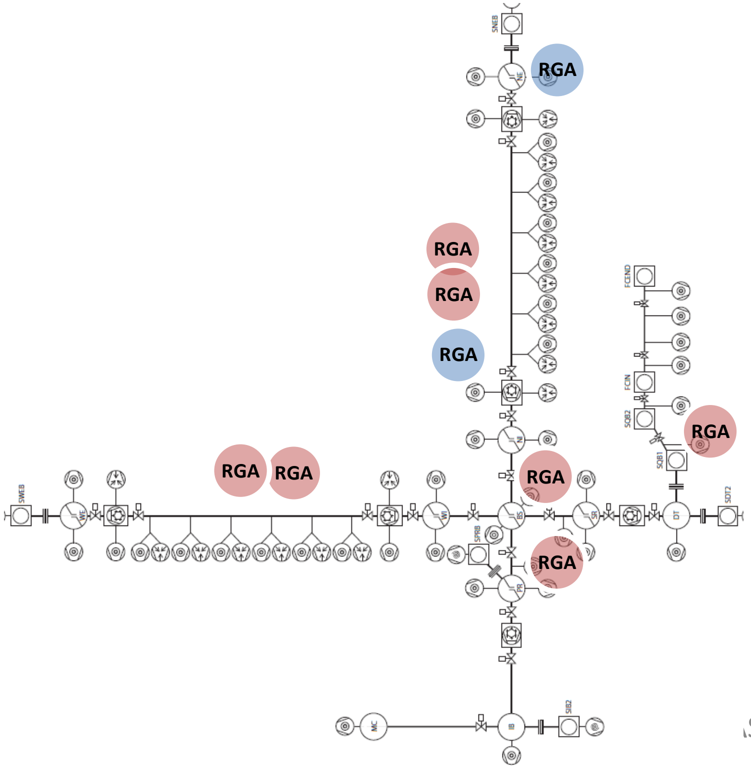
- **Recovery richiederebbe mesi di fermo ITF** La procedura di bake-out richiede l'interruzione delle operazioni per diversi mesi, complicando notevolmente il ripristino.

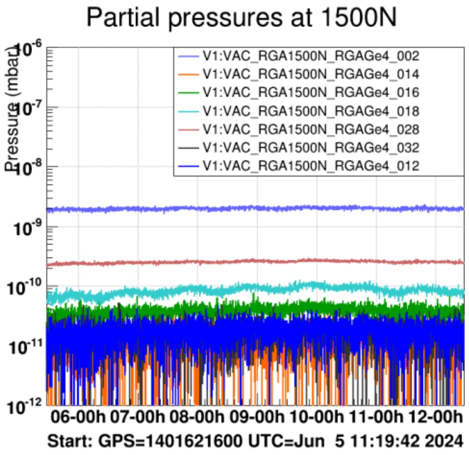
- **Massima attenzione a non compromettere il vuoto durante le operazioni e gli interventi in torre.** Per garantire la sicurezza e l'efficienza delle operazioni.

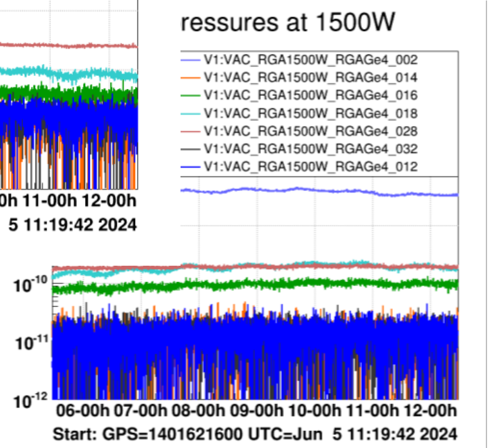
- **Impianto di venting con N2 (LN2): utile in caso di manutenzione straordinaria?**
  - L'uso di LN2 per il venting riduce la presenza di acqua, ma la percentuale esatta è sconosciuta.
  - È possibile quantificare il tempo di ripristino associato a questa procedura?

Monitoraggio del vuoto con RGA

- Several RGAs (old) normally OFF, used for maintenances (1 per tower + 1 per tube station)
- Some RGAs, ‘in pairs’, online 24/7 . Mostly in ‘Faraday mode’, 50 uma or 200 uma range. Installed close to pumps or ‘in the middle’.
- Long term stability? Aging ? Spurius peaks build-up ?





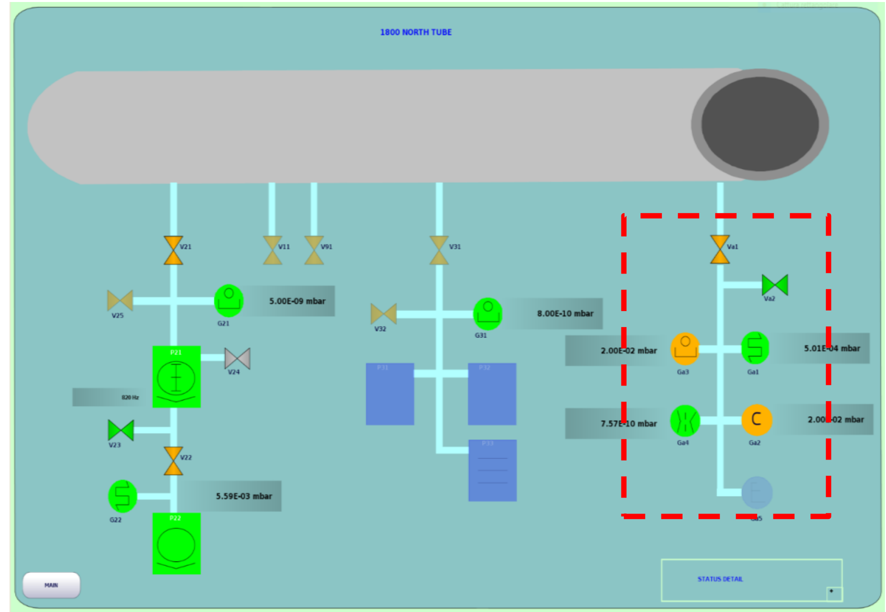


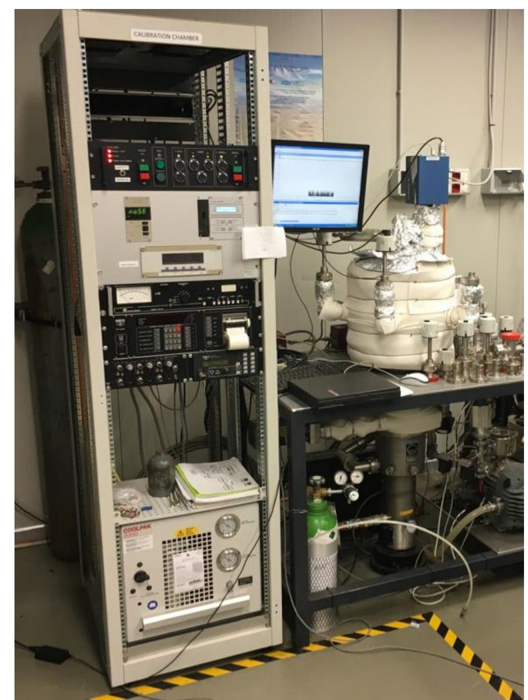
"Calibration" checks ?

Gauges are installed in a 'attached chamber' (with a gate valve). Pros: easy maintenance; Cons: possible influence on measurements (even if baked … …).

Gauges are initially 'checked' in lab, then left in-situ for years.

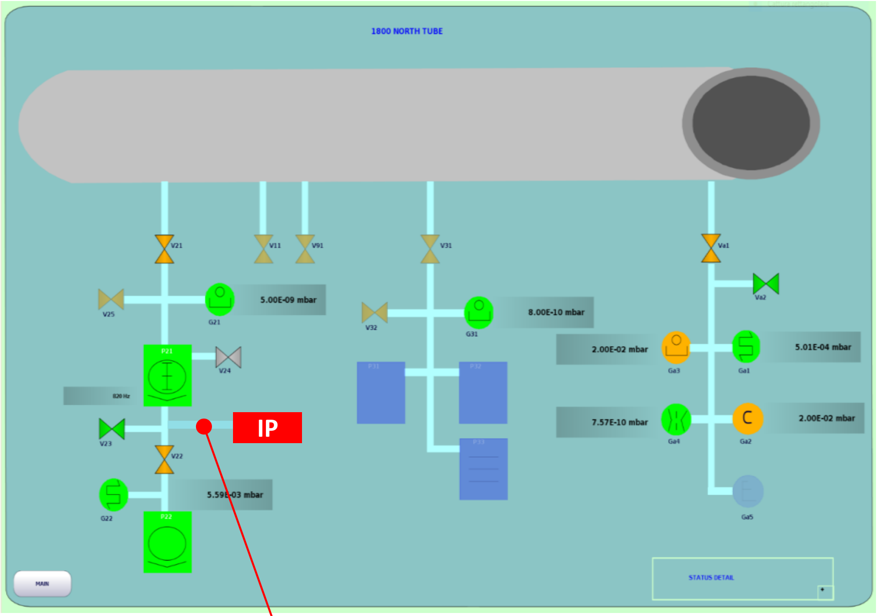
A possible 'check' in-situ: 1 point with a calibrated leak of N2 (H2) and a "known" speed at a relatively high pressure ?

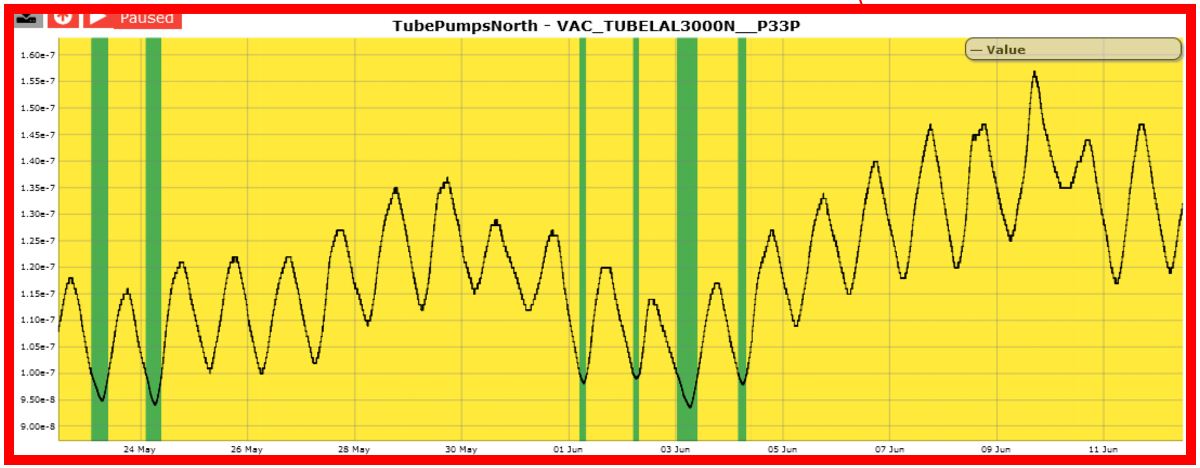




TUBE PUMPING STATIONS

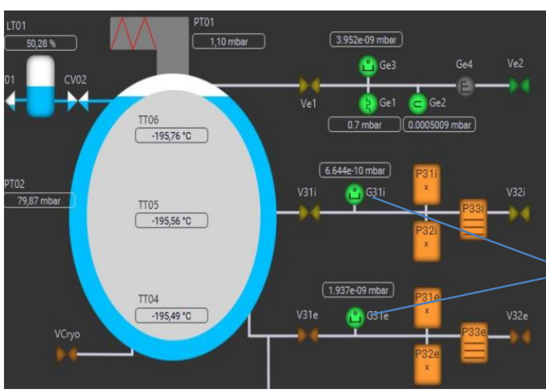
- Varie turbo-molecolari sono in funzione 24/7 anche sui tubi, specialmente vicino alle torri.
- Affidabilità delle backing pumps meccaniche e della loro manutenzione.
- Stiamo testando piccole pompe ioniche, che sembrano funzionare bene.
- Esperienze in merito?

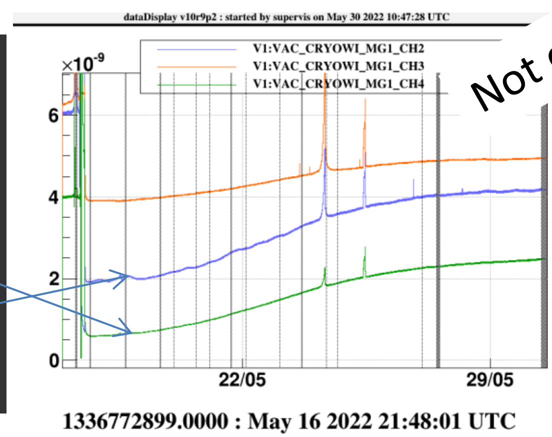




TSPs pumps

- 1 sublimation every 2 months or similar.
- Those near the towers saturate after a few days (all gas species) and are not used.
- The ones in the middle of the tube appear saturated with other species but still pump H2 (different sites?!).
- Unable to replicate this in the lab.
- Effects of gas release ?

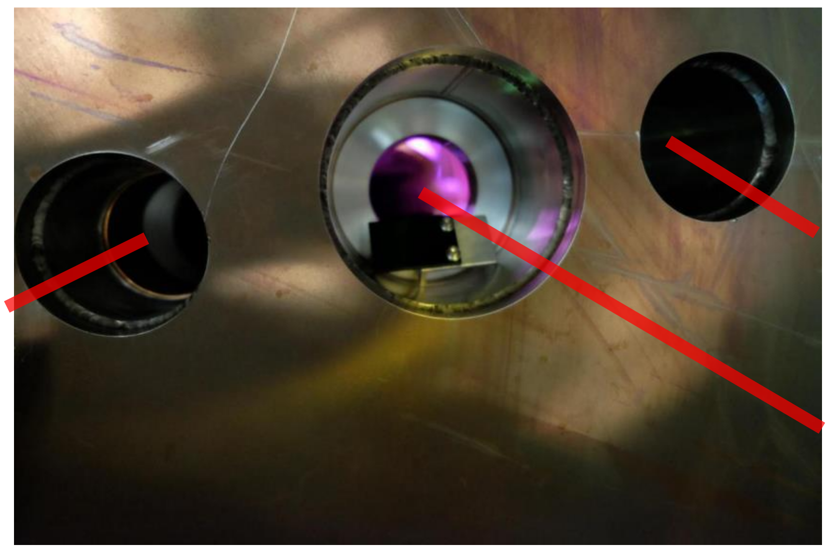


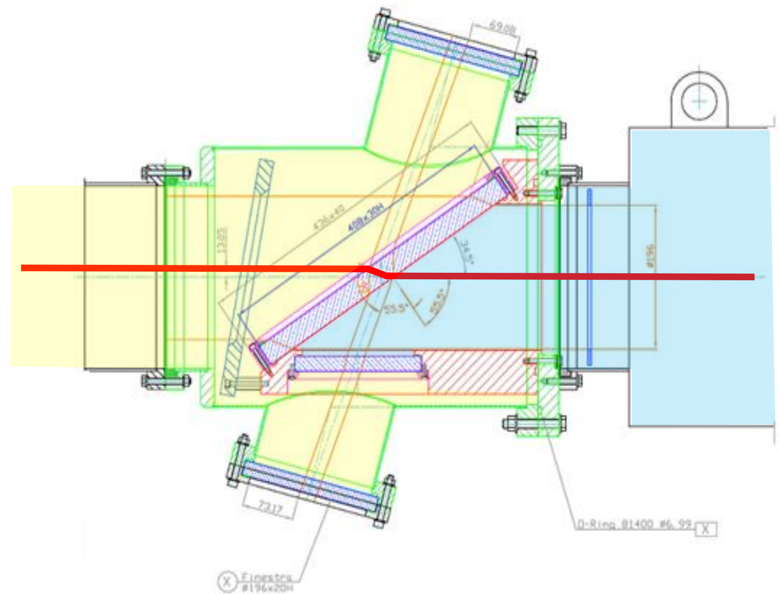


Not operated

'WINDOW' SEPARATIONS

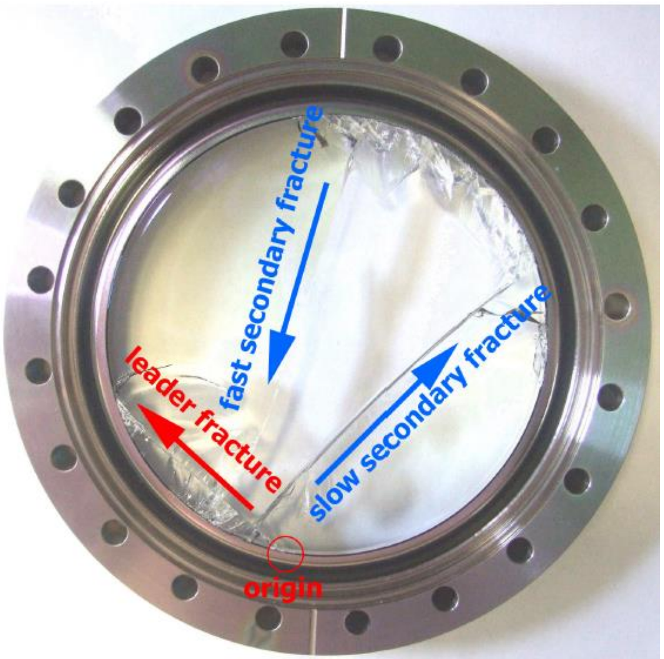
- Vacuum tight glass separation are in use to allow beam passage between chambers at different vacuum levels. May become limiting for the experiment (or for vacuum when removed). Not a valid solution for critical areas.

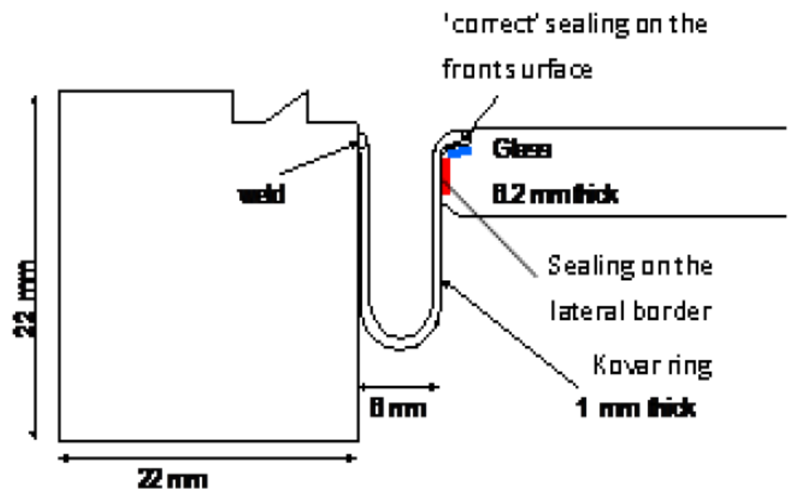




VIEWPORT RISKS

Order of 90 viewports needed, mostly standard ones. Dedicated policy against breaking risks in force. Further mitigation actions shall be implemented (external screen).





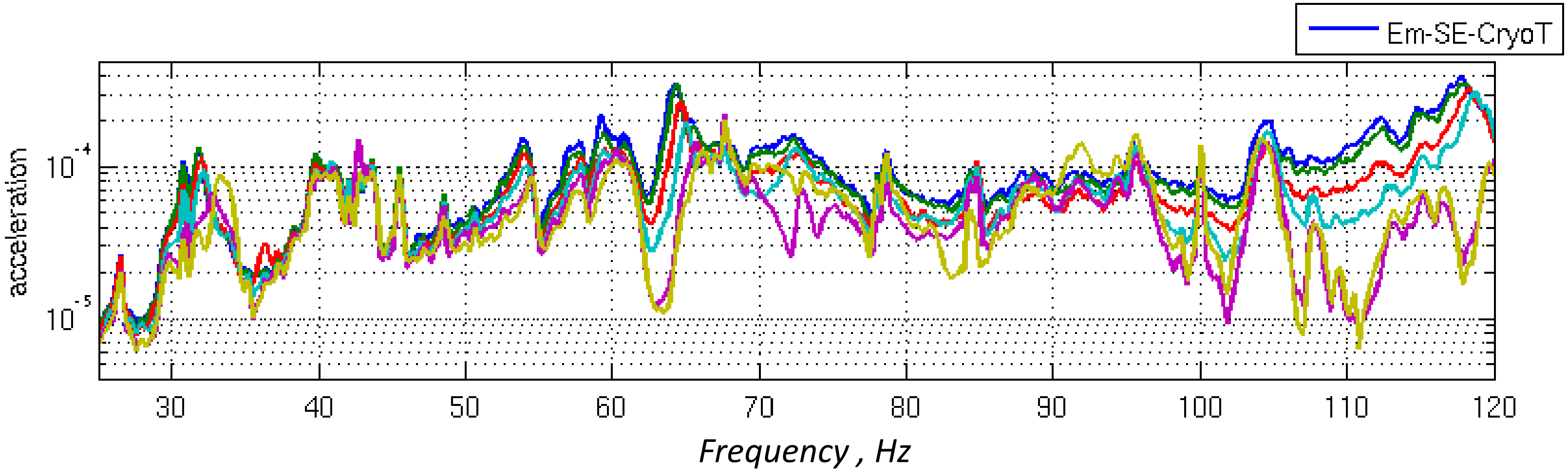
Breaking event of a viewport, 2008

Risk = defect + stress x time

Glass/KOVAR joint design was the origin of the stress (SSV)

LN2 BUBBLING

LN2 boiling inside cryostats is a possible source of noise (mechanical vibrations): *accurate design to avoid 'heat concentration spots' , seismic isolation of the cryostat, large walls opening.*

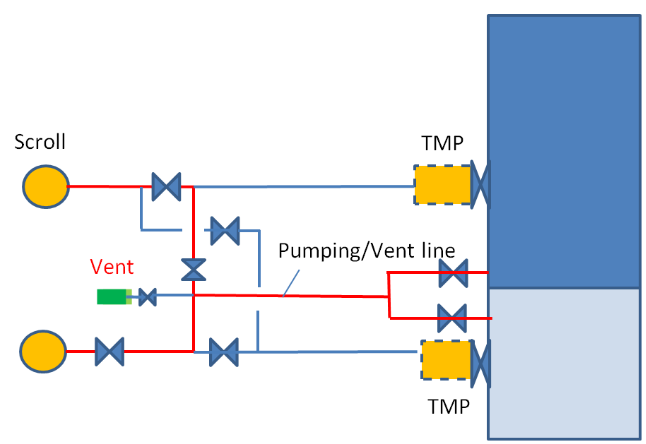


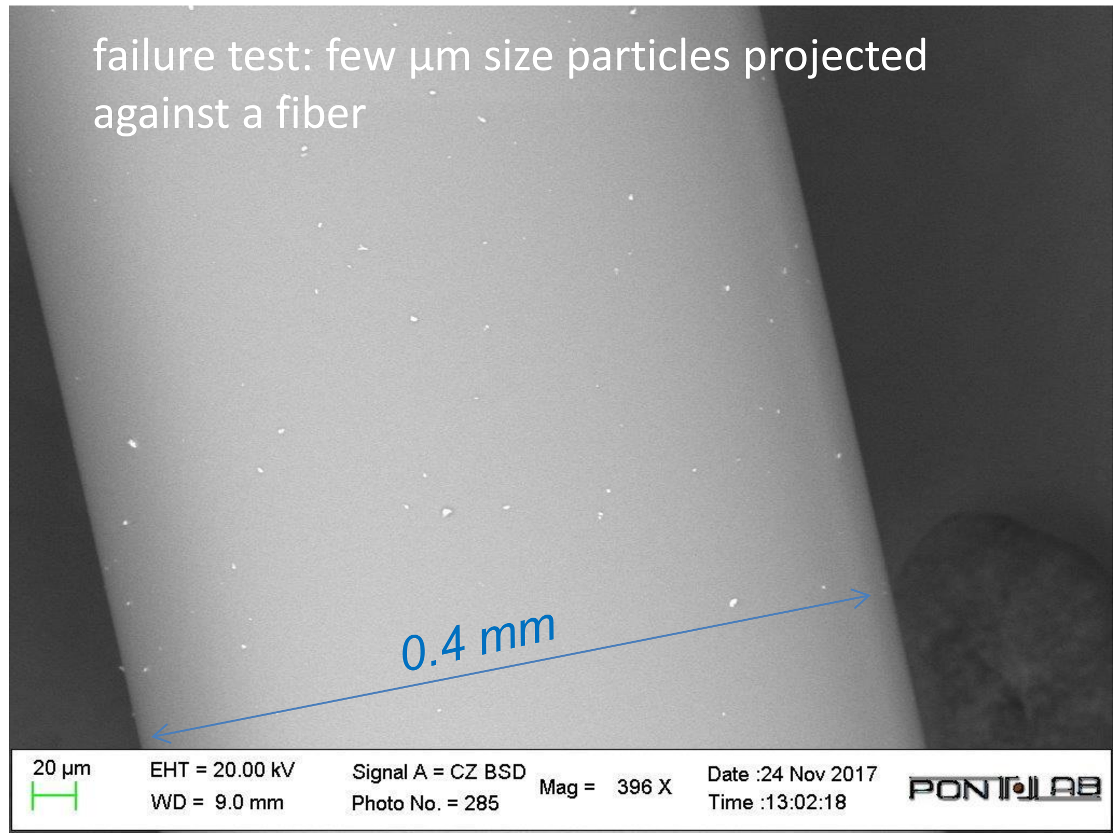
Increase of the seismic vibrations of cryostat walls due to LN2 bubbling

DUST PARTICLES vs QUARTZ FIBERS

Dust particles of a few µm and travelling at some m/s inside chambers has been recognized as the main cause of failure of quartz fibers

- Venting circuit re-designed
- Primary pumps (scroll type) replaced
- Guards added to fibers

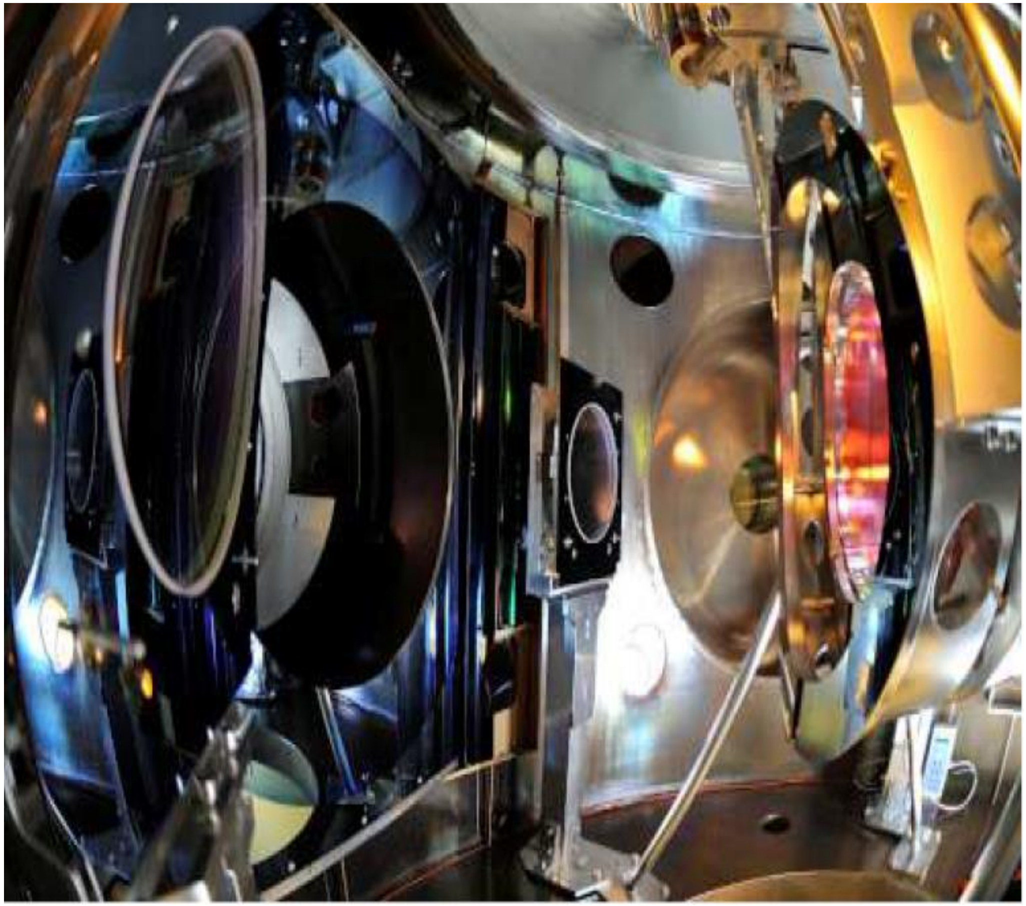


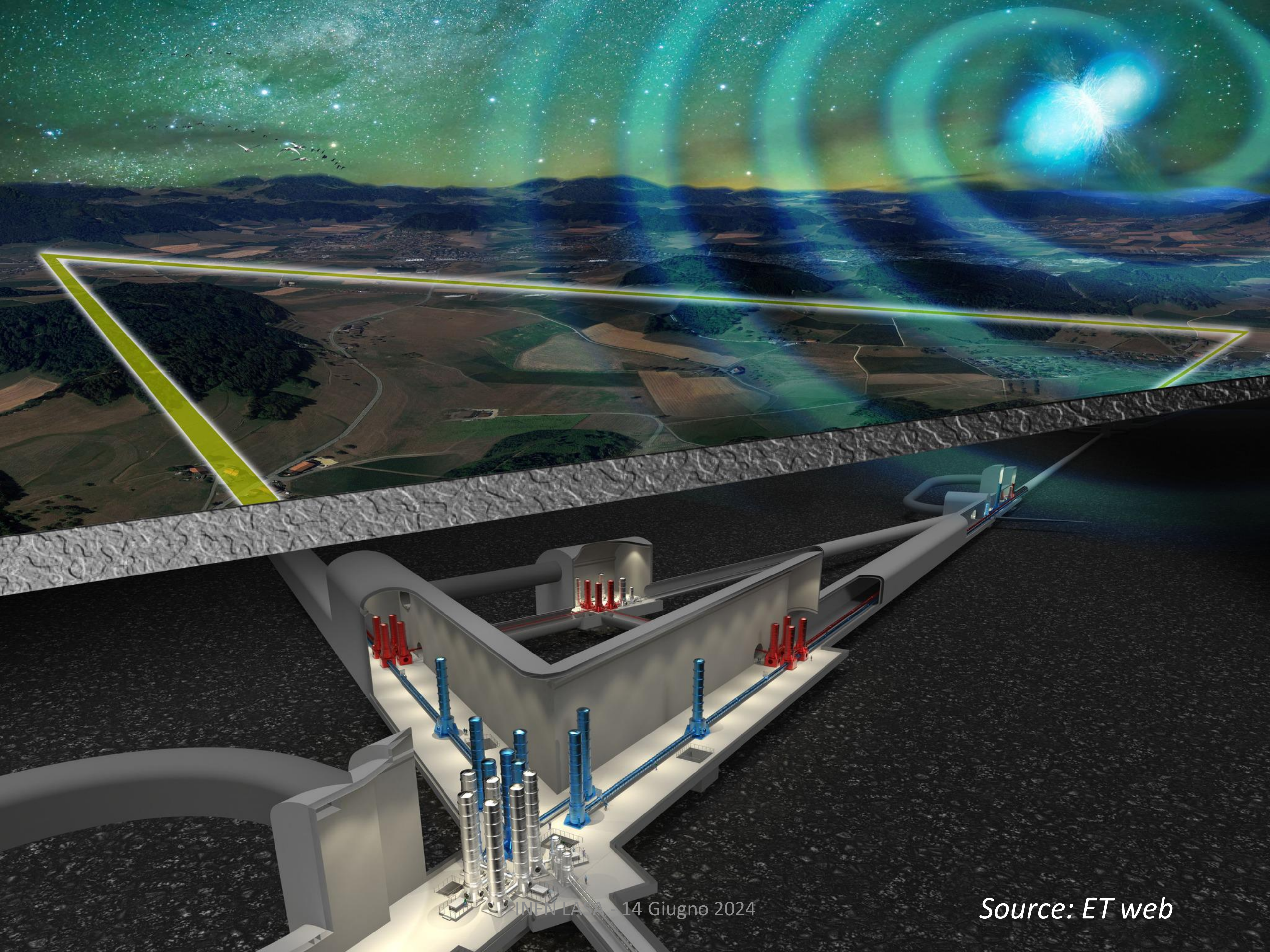


Electrostatic forces may play a role…

CHARGES ACCUMULATION

- Static charge can build-up on TMs after months of service under vacuum (in Virgo estimated at level of E-9 C) = neutralization device needed.





Source: ET web

ET PROJECT VACUUM SYSTEM

Six independent (nested) systems of 10 kilometer-scale

Huge **Pipes** (volume, length, surface) for the circulation of the laser beam: **world-largest UHV !**

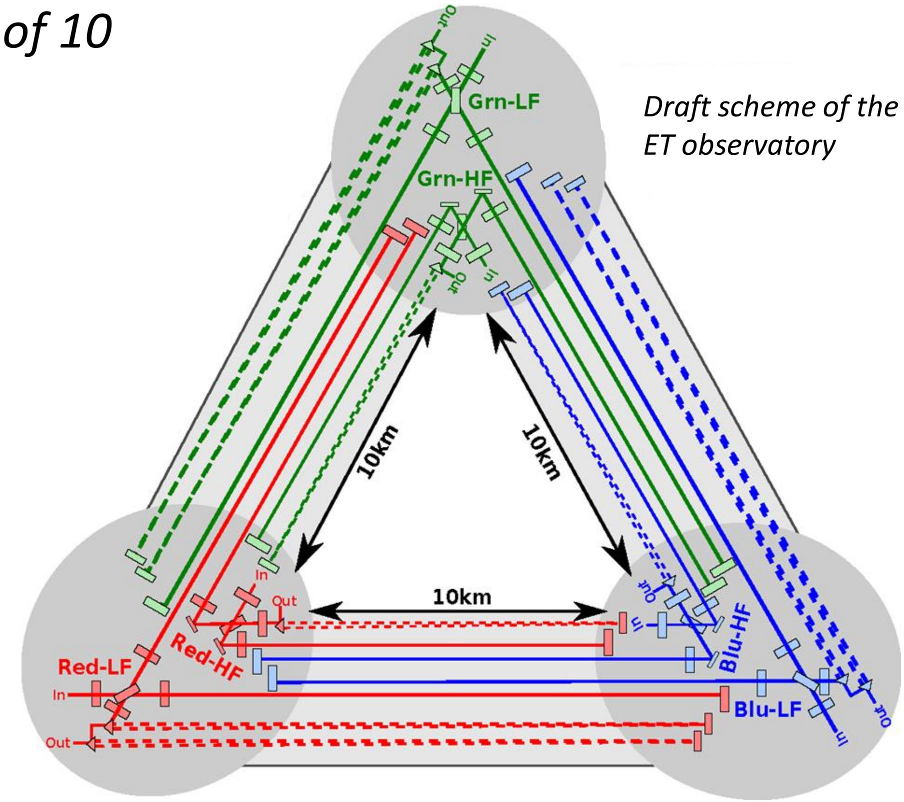
Towers chambers, hosting the scientific equipment.

Combined together by very large **cryogenic pumps**.

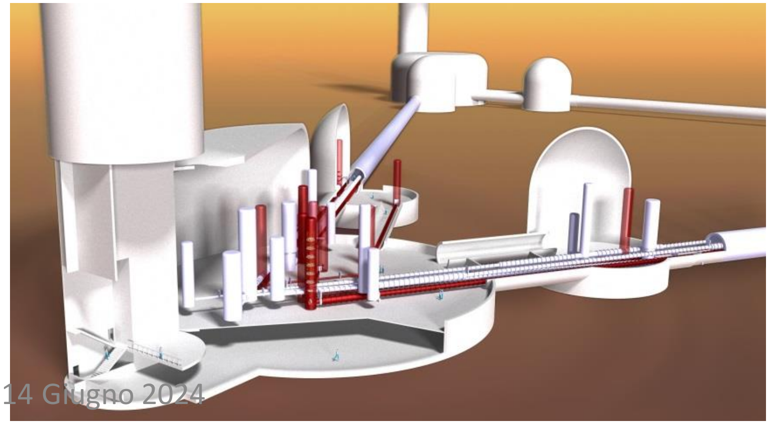
Cryostats *housing 10K mirrors and cryogenic payloads .*

To be realized **underground** (bake-out, installation, operation).

Size (Costs): a primary challenge.

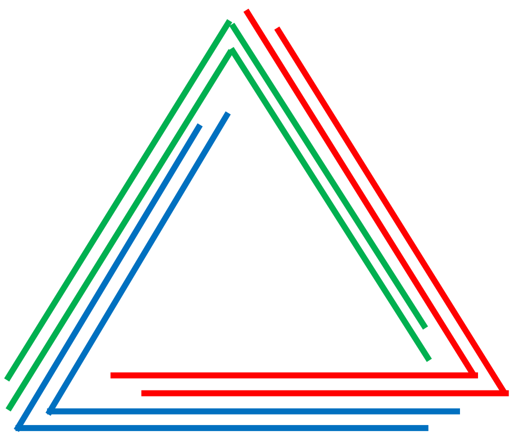


Draft scheme of the ET observatory



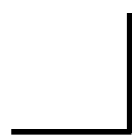
ET LAYOUT

- Two different layouts:



ET Conceptual Design
3 x (HF+LF)   10 km arms
(+ filter cavities)

***120+** km long UHV tubes*



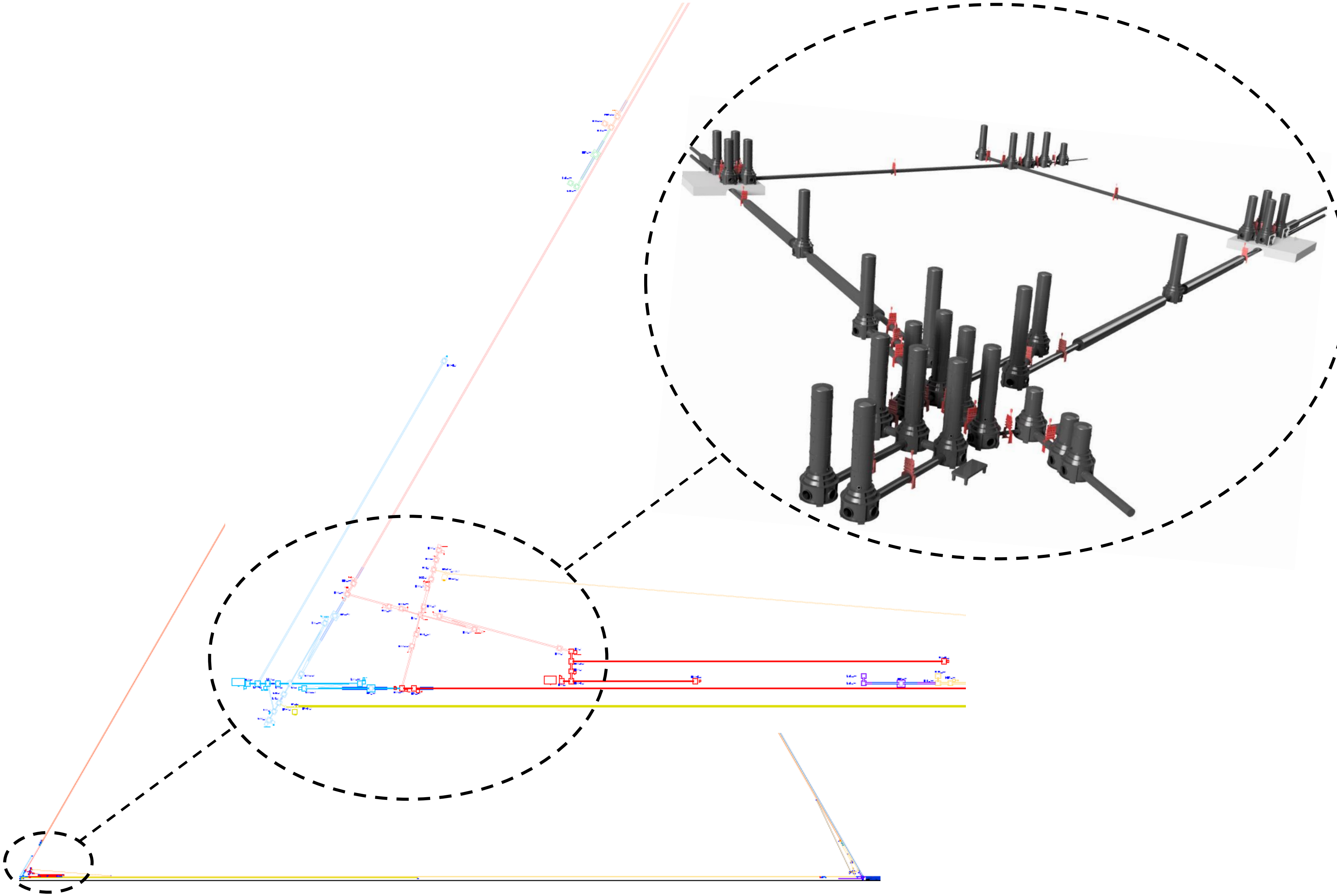
Virgo
3 km arms
(+ 300m FC)

***6** km long UHV tubes*

ET L_case
1 x (HF+LF) 15 km arms
(+ filter cavities)

***60+** km long UHV tubes*

ET PROJECT VACUUM SYSTEM



VACUUM CHALLENGES

- **Chambers realization costs**
- **Chambers realization schedule**
- **Vacuum Systems installation schedule**
- **Vacuum Systems performances**

Not to mention cryogenics:

Cryopumps *up to ≈ 30 m x Ø 1m at 4K or below*

EINSTEIN TELESCOPE

Outgassing database

Buildup & maintenance requires a <u>wide effort</u>

Possibly useful for the whole vacuum community

	Component: Item	Component: Manufacturer	Component: Main material	Component: History	Optical measurements: Optical check	Optical measurements: Optical losses (ppm)	Vacuum measurements: Test procedure	mbar-l/s: Q_H2O @24h	mbar-l/s: Q_H20 @100H	mbar-l/s: Q_H20 @1000H	mbar-l/s: Q_H2	mbar-l/s: Q_N2+OTHERS @24h	mbar-l/s: Q_N2+OTHERS @100h	mbar-l/s: Q_HC (level>44)	Q_HC (peaks N>44) (m/z)	Preparation (highlight)	Pre-baking: Done?	Pre-baking: Temperature (°C)	Pre-baking: Hours	Notes	Installation scenario	Reference
	Baffle PCB#10-21	IFAE	Pyralux AP		Absolute losses @LMA	0.50	throughtput method	1.03e-8	5.43e-9	1.94e-9			3.31e-11	5.00e-13		IPA cleaning	Yes	70	168	After pre-baking, one day in a clean room ISO5.	Mirror compartment	IMC Instrumented Baffle, Ref. IFAE-PCB#10-21
	Al EN AW-6061	N.A.	Al EN AW-6061		No		throughtput method	4.86e-10	1.17e-10	1.17e-11	5.50e-14					Factory Cleaning	No			Q_H2O : Q=Qo*t^-alpha, with Qo=4.2e-3(Pa L s-1 cm-2) and alpha=1	Lower compartment	NIST: DOI: 10.1116/6.0000657
	AISI 316L Vacuum Fired	N.A.	AISI 316L		No		throughtput method	8.64e-11	2.43e-11	3.21e-12	5.10e-14					Factory Cleaning	No			Vacuum fire process: 950°C for 24h Q_H2O : Q=Qo*t^-alpha, with Qo=3.30e-4(Pa L s-1 cm-2) and alpha=0.91	Lower compartment	NIST: DOI: 10.1116/6.0000657
	AISI 316L	N.A.	AISI 316L		No		throughtput method	1.20e-10	3.09e-11	3.48e-12	1.00e-12					Factory Cleaning	No			Q_H2 : conventional outgassing rate Q_H2O : Q=Qo*t^-alpha, with Qo=7.25e-4(Pa L s-1 cm-2) and alpha=0.95	Lower compartment	NIST: DOI: 10.1116/6.0000657
	AISI 304L	N.A.	AISI 304L		No		throughtput method	2.68e-10	4.19e-11	2.10e-12	1.00e-12					Factory Cleaning	No			Q_H2 : conventional outgassing rate Q_H2O : Q=Qo*t^-alpha, with Qo=7.00e-2(Pa L s-1 cm-2) and alpha=1.3	Lower compartment	NIST: DOI: 10.1116/6.0000657

<u>ET Outgassing database</u>: https://apps.et-gw.eu/et_outgassing_db/

Chambers realization

A new specification for GW vacuum chambers:

- limits for particle concentration on walls to be included for chambers realization
- A standard to refer -> ISO 14644-9:2022
- Need to define wanted limits and measurement tools

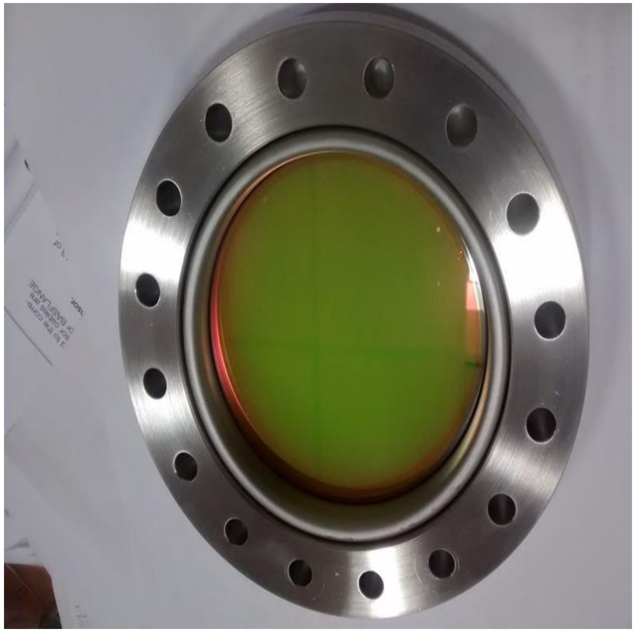
Solutions are to be found both to control the surfaces during the fabrication process and to monitor the tower chambers when in service

Thanks to contributions by LASA and DESY experts

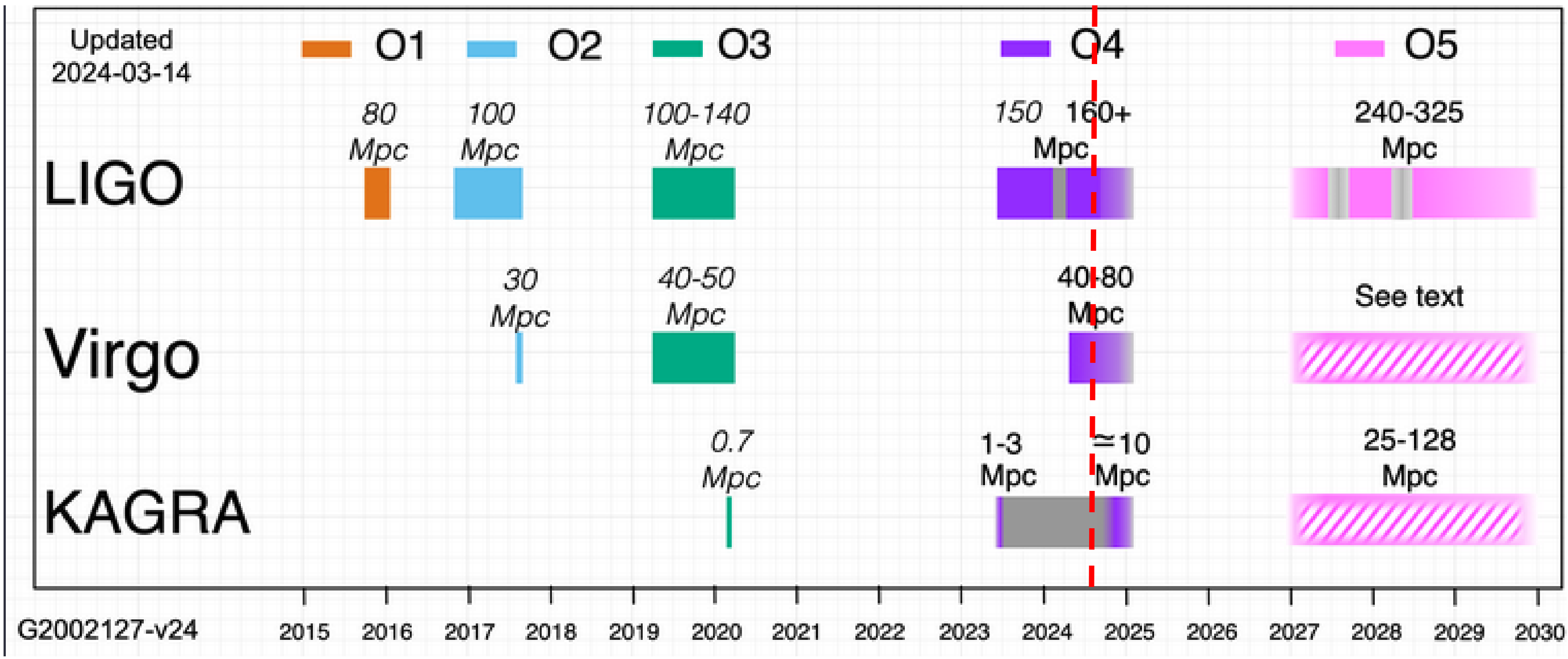
- Backup slides

Viewports

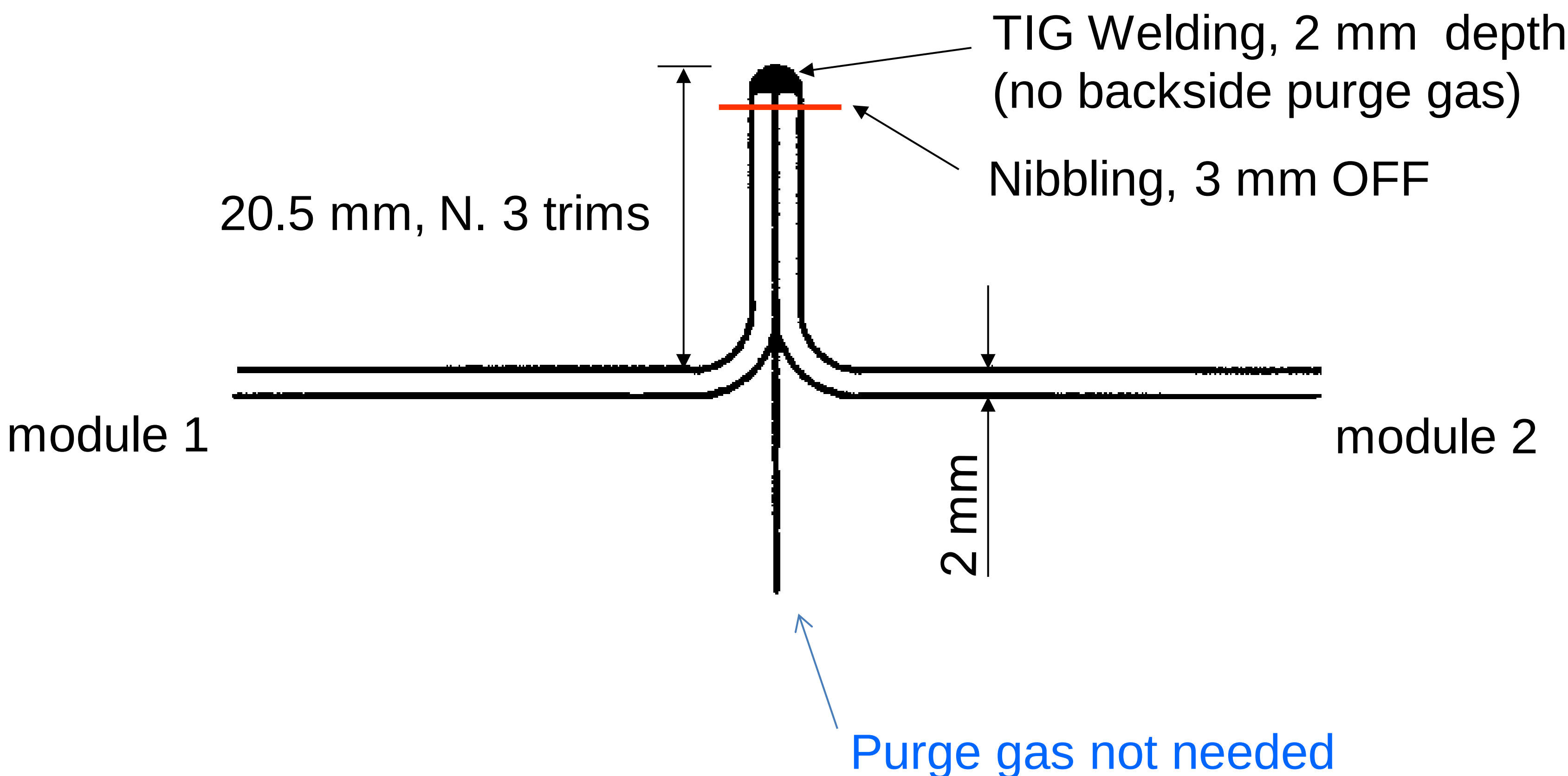
- Large number of viewports, e.g. 1000, large dimensions, of different base materials and possibly exposed to high power beams .
- Policy and solutions against breakage risks must be foreseen already during the design phase.
- *In addition, they are a possible source of disturbance for the ITF*



Current observing plans



TUBE MODULES JOINTS



The 'LIP' joint was a long discussed topic during the design phase

Detector Sensitivity

amplitude spectral density of the interferometer main signal (expressed in strain). The detector sensitivity improves as the curve is lowered . The best sensitivity achieved in the frequency range of 100 - 1000 Hz. The residual gas in the 3 km tubes and in the towers contributes minimally to the interferometer signal.

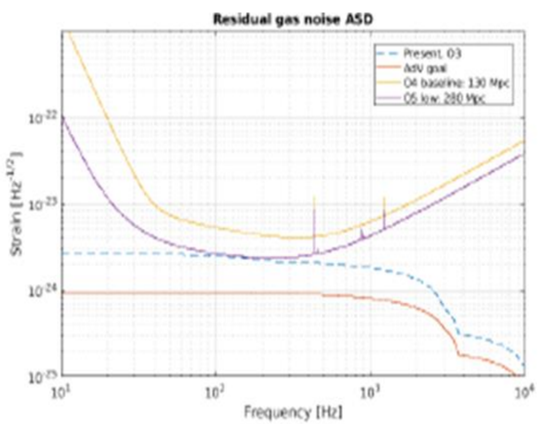


Fig. 1 Estimate of the noise due to the residual gas in the 3 km arms for the present configuration (O3). The AdV goal is added for comparison. The partial pressures in the computation are reported in tab.1.

Gas specie	Partial Pressure [mbar]	Noise [E-25 Hz-0.5]
Total	1E-8	26
H_2	2E-9	3
H_2O	3E-9	11
$N_2 + O_2$ + others	5E-9	19
Hydrocarbon 100 uma	1E-12	3
Hydrocarbon 300 uma	1E-12	10
PFPE lubricant	1E-12	10

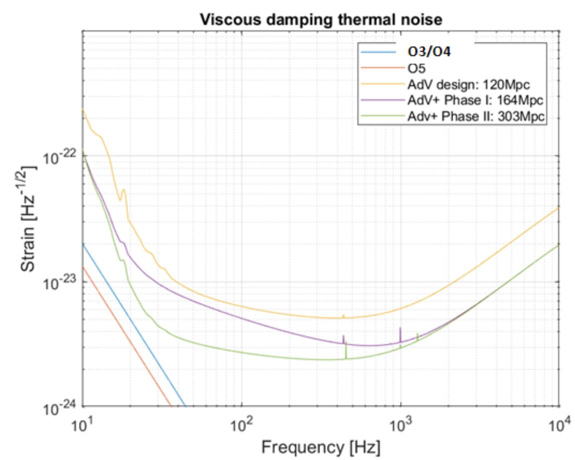
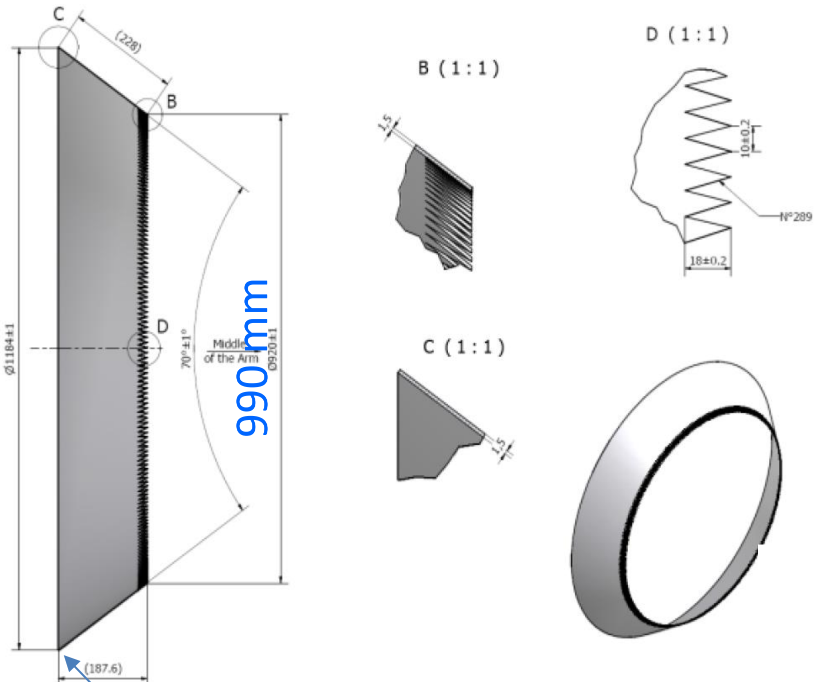


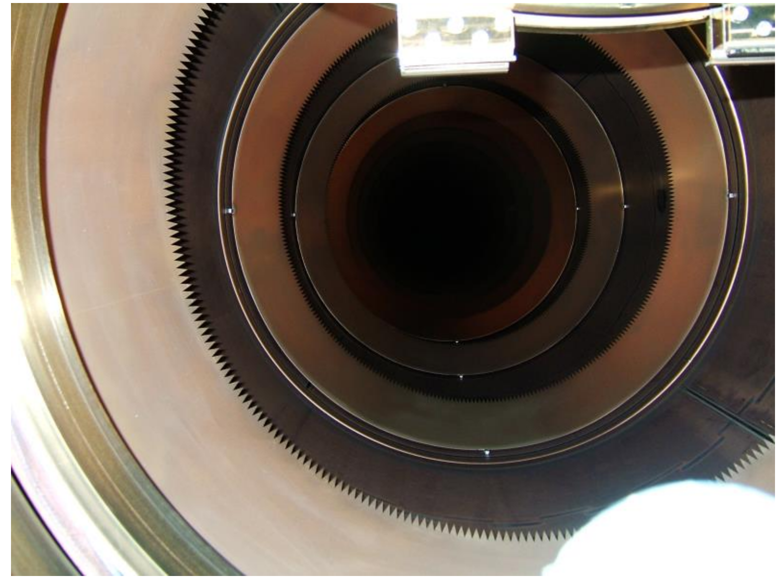
Fig.1 Strain equivalent noise amplitudes for the two considered scenarios, compared with some sensitivity predictions. The parameters used in the computation are reported in tab.1.

Case	Total pressure [mbar]	N2 Pressure [mbar]	H2O Pressure [mbar]	R ETM [m]	h ETM [m]	M ETM [kg]	R ITM [m]	h ITM [m]	M ITM [kg]
O3/O4	2E-8	1E-8	1E-8	0.175	0.2	50.2	0.175	0.2	50.2
O5	1E-8	5E-9	5E-9	0.25	0.2	80.0	0.175	0.2	50.2

ARM TUBE BAFFLES



Intalled by TIG welding

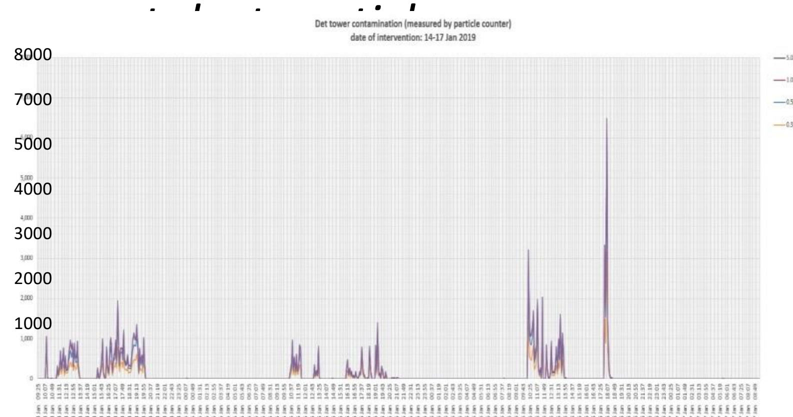


- made out by air-baked 304L
- > 100 baffles per arm
- make the modules non-interchangeable
- a few of different type at arms extremities

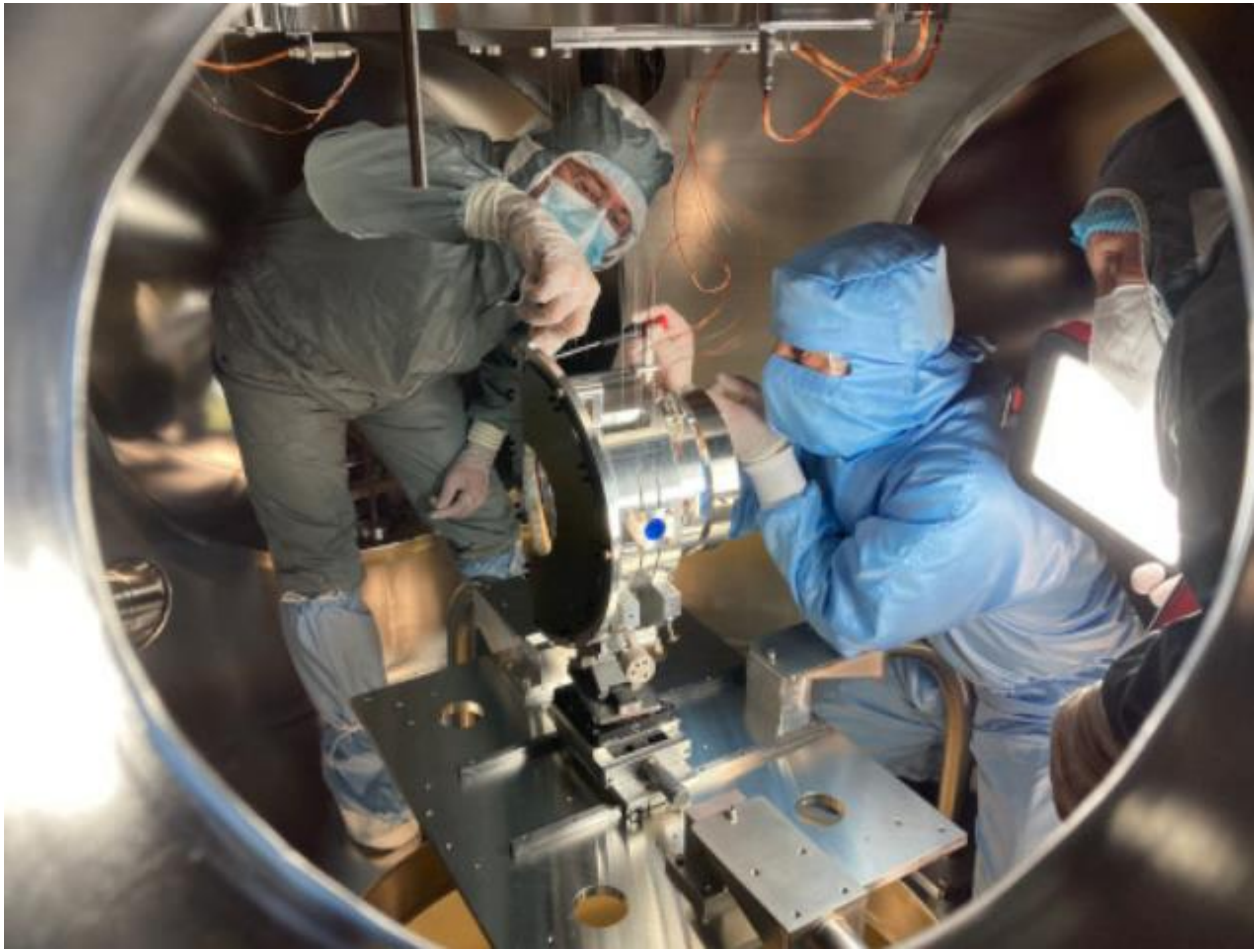
Cleanroom service

Credits: M.Perciballi

- *Towers lower compartments are a ‘classified’ environment for dust particles concentration (airborne)*
- *Flushed with HEPA filtered air and kept monitored*

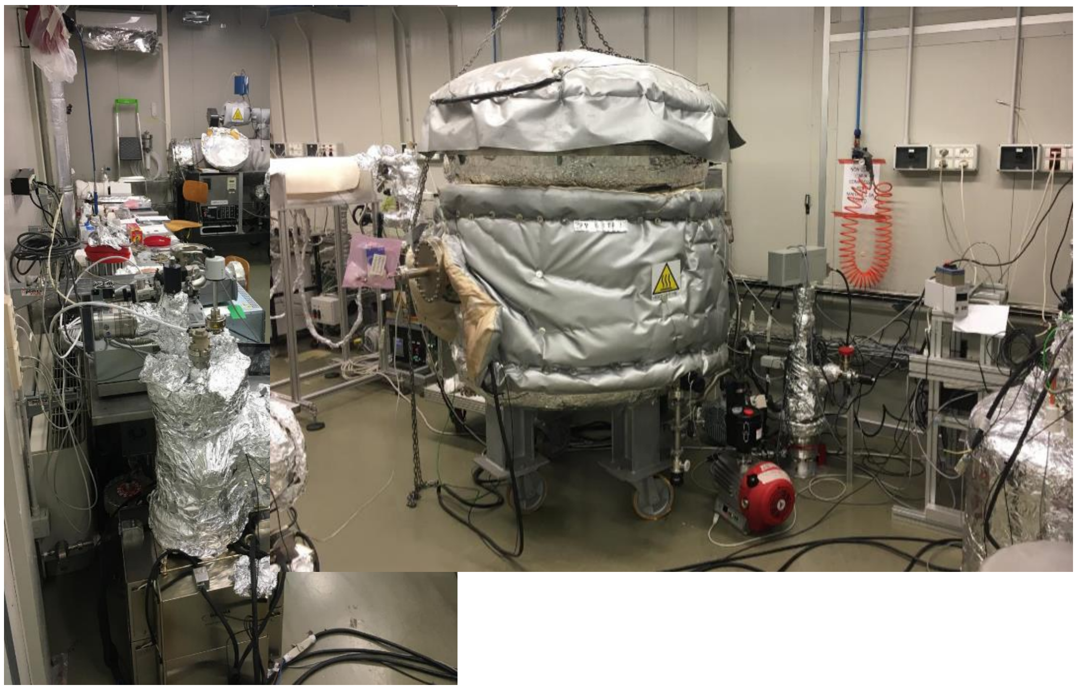


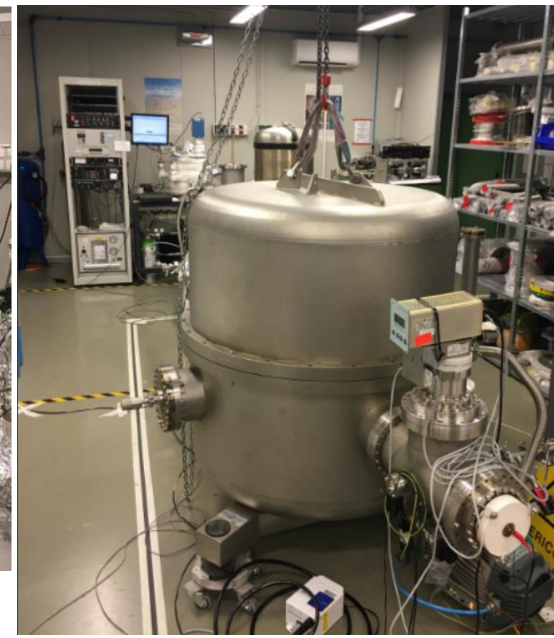
https://logbook.virgo-gw.eu/virgo/?r=444



IN-VACUUM COMPONENTS

- Pre-bake of non-metal components (sometimes of large size) for conditioning and cleaning step (motors, magnets, cablings, PEEK)





Known Leaks Register

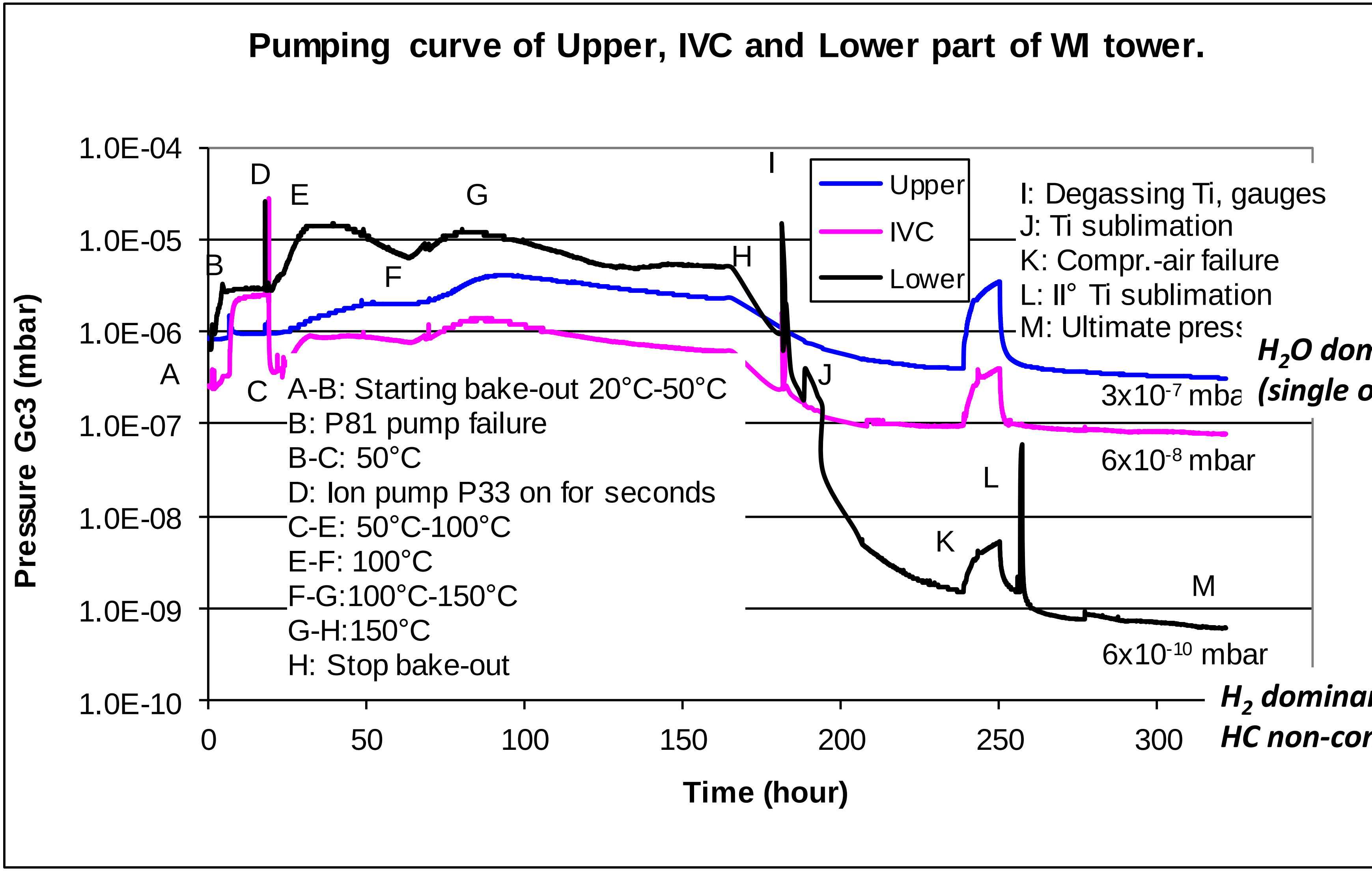
Id	LR (mbar.l/s)	position	detection date
Tower NE UP	5E-4	upper Virole (viton set?)	Dec 2017
Tower NE LP	2E-7	port DN62, position = DN1000_Southface_Wside_upper	Jan 2018
2700W	closed ?		2017
Tower MC	1E-5	first virole bottom joint	< 2017
Cryotrap WE	high	V31 - likely seal compressione set	2018
Cryotrap NE	high	V21 - likely seal compressione set	2018
Tower IB	1E-6?	inner box (Indium sealed, possibly becoming hot)	< 2017
Tower SR	?	P71 side bypass	< 2017
Tower WE	3E-6	joint above the technical ring (new o-ring)	Mar 2018
Tower BS	1E-6	DN250CF flange joint of new venting circuit, upper part	Mar 2018

PUMPING SYSTEM

General Requirements: cleanliness from HC, large throughput

Permanent service: mech. vibration free, pressure stability, and long maintenance interval

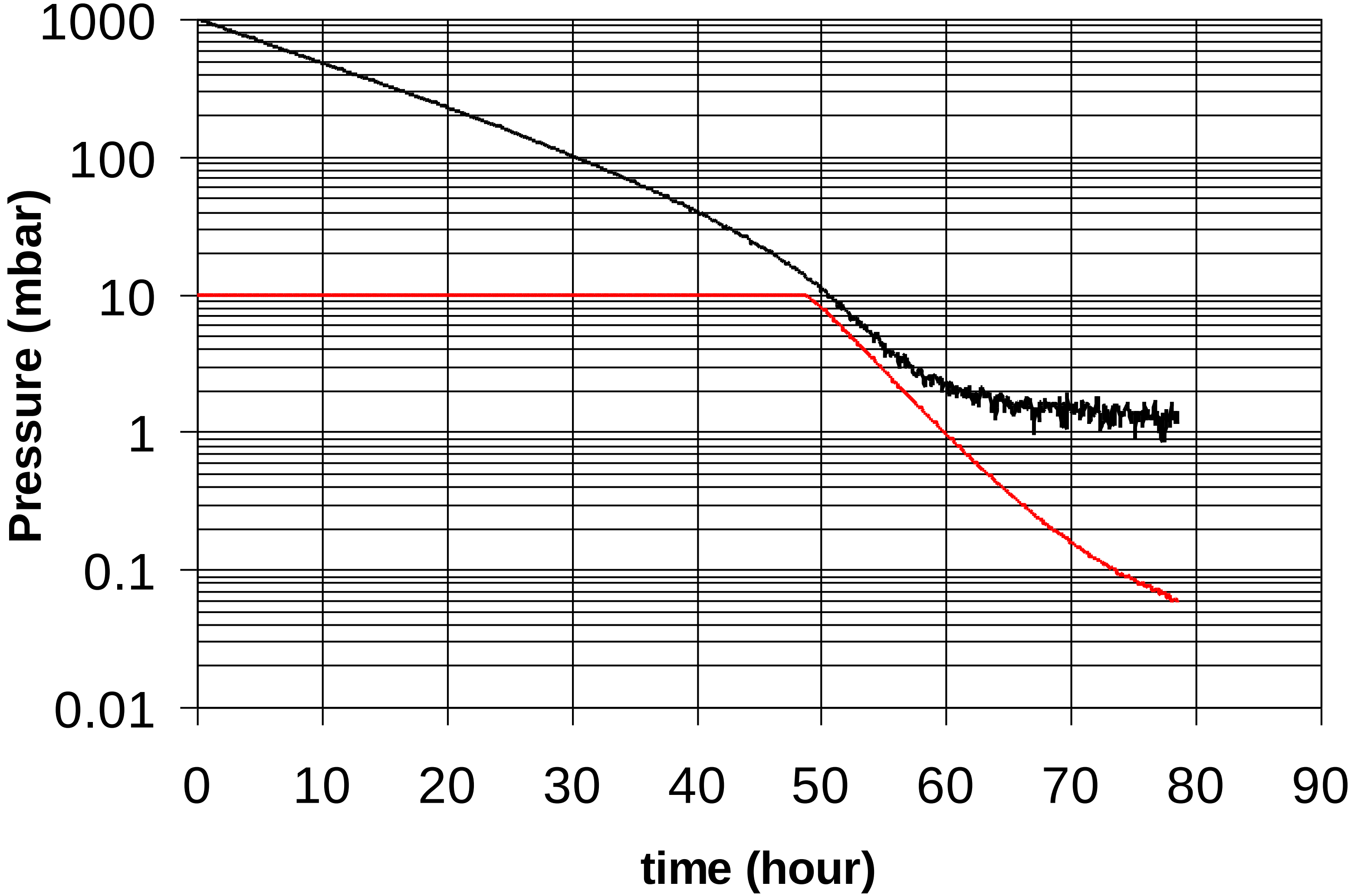
3 successive stages	*Vacuum level*	*Choices*
1. TRANSIENT viscous pumpdown)	1 atm to 0.1 mbar	Dry pumps system 80h for one tube, 24h for one tower
2. TRANSIENT "molecular" pumpdown & baking	0.1 mbar to 1E-7 mbar	Turbopump + scroll stage (gas is evacuated from chamber)
3. PERMANENT UHV	UHV	Titanium Getter Ion for noble gases… (gas is "trapped") A few regenerations/year
3. PERMANENT HV	HV	Magnetic turbopump + scroll stage 2 interventions/year



H_2O dominant (single o-ring)

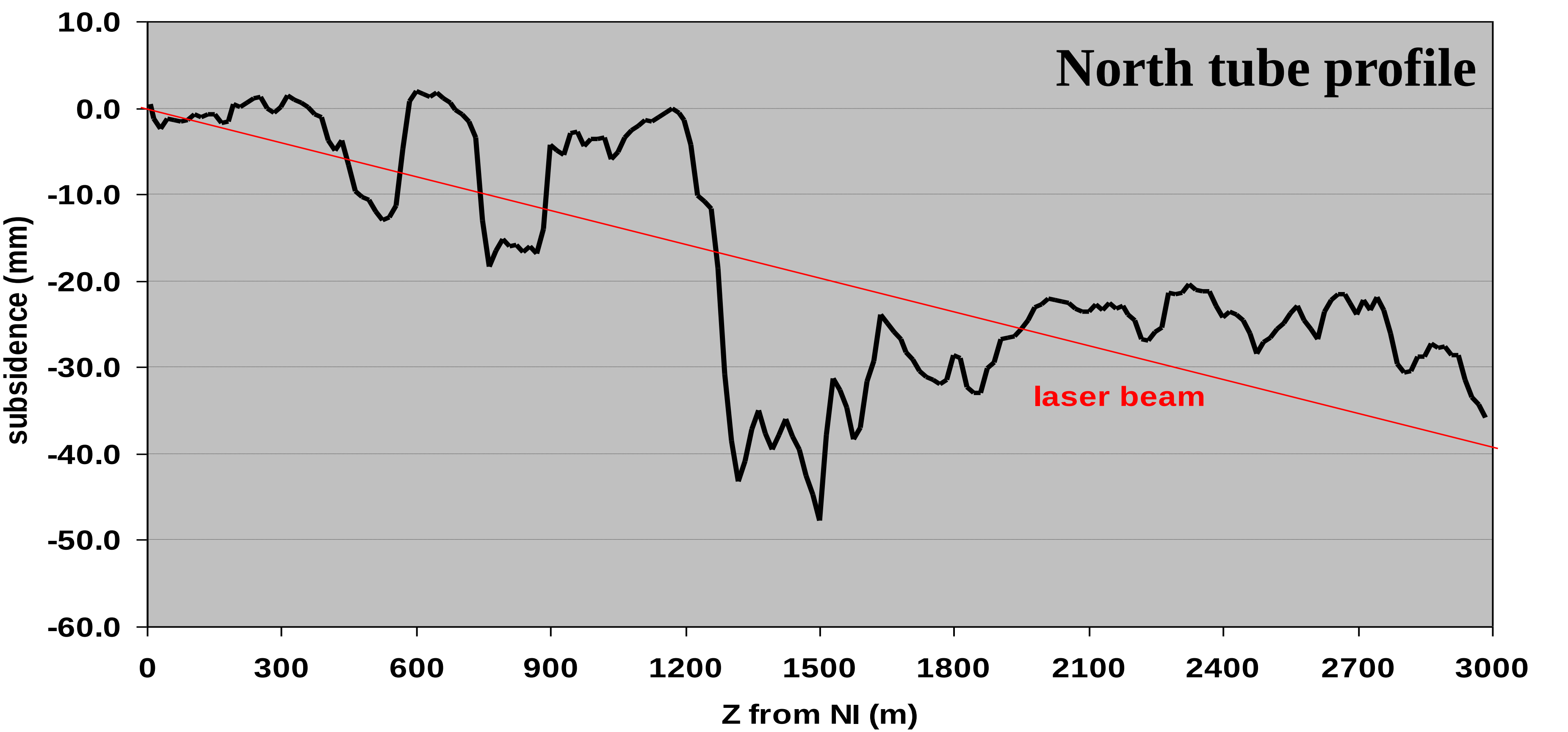
H_2 dominant HC non-compliant

3 km ROUGHING DOWN



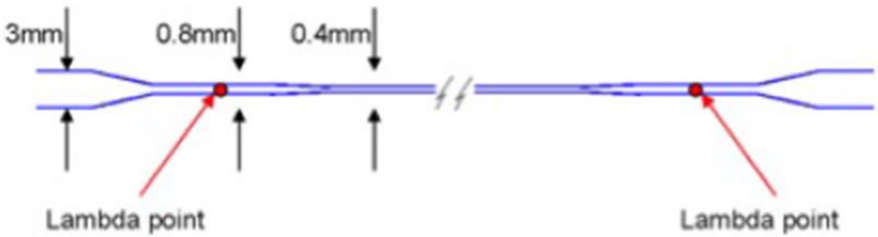
ACTUAL TUBE GEOMETRY

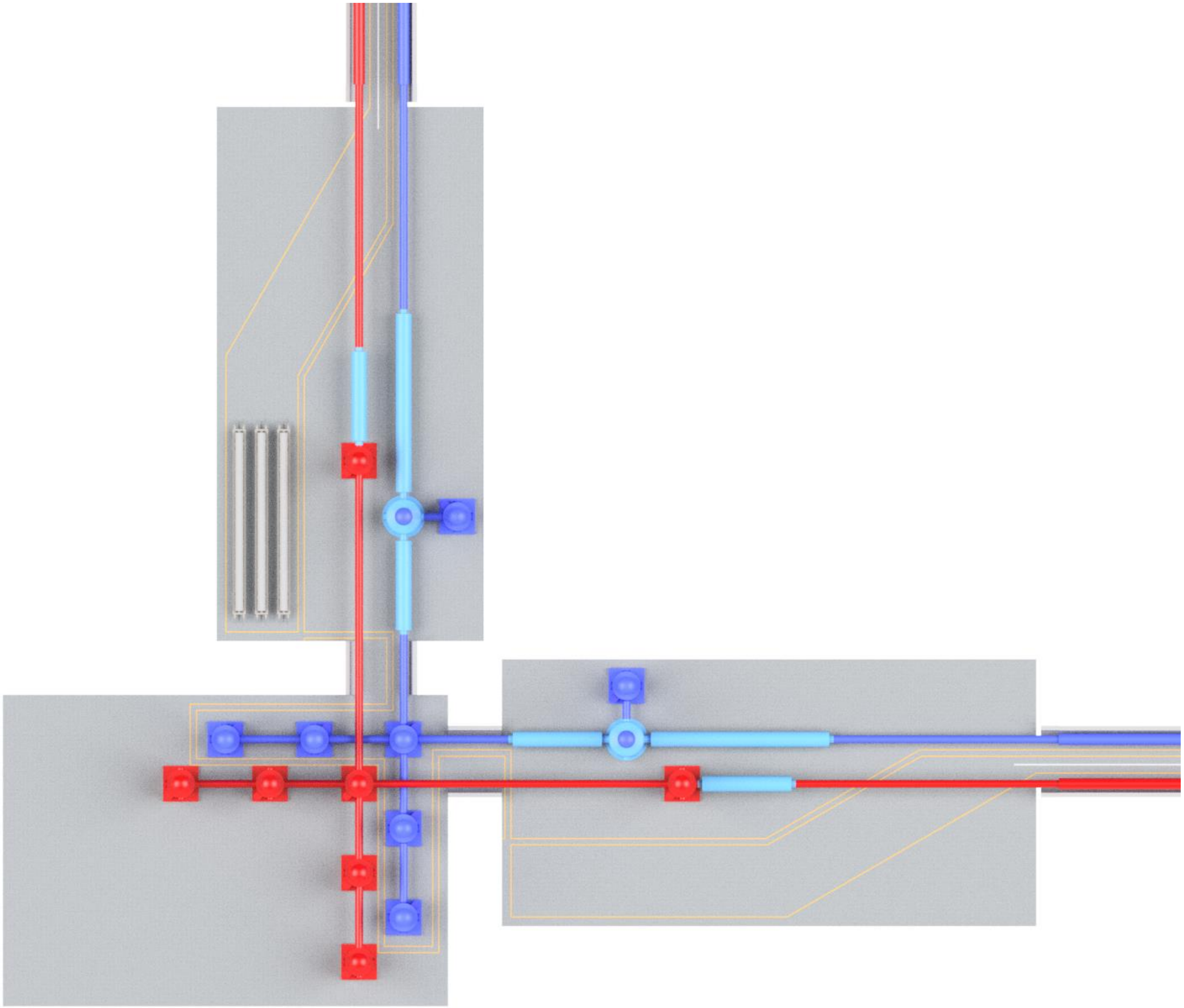
Due to GROUND SUBSIDENCE, tube foundations are sinking at a speed of the order of 1mm/month. Tubes are surveyed and periodically realigned to avoid mechanical stress.



DUST PARTICLES vs QUARTZ FIBERS

The last stage of seismic attenuator is realized with fibers made of fused silica (0.4 mm diameter).



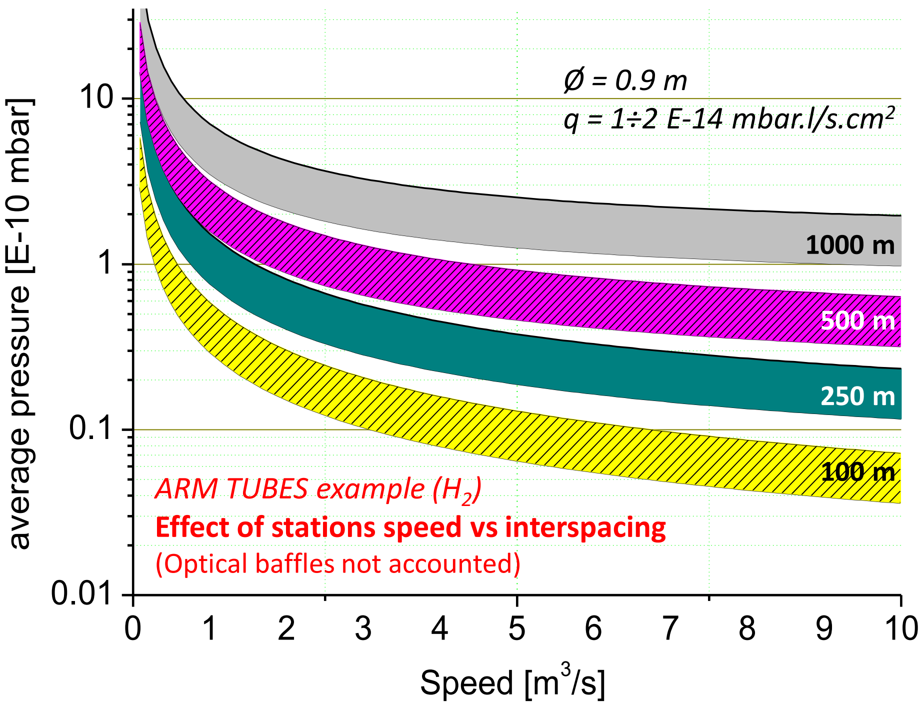


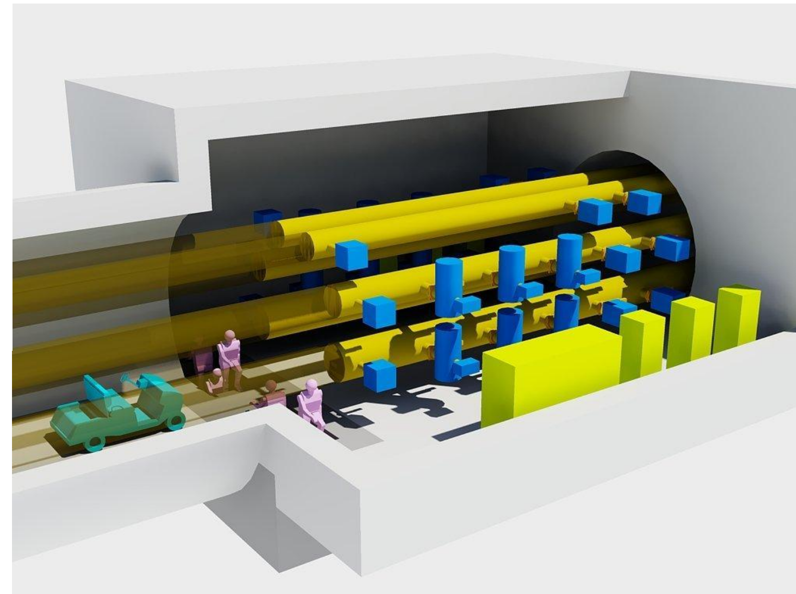
ET – Arm tubes: pumping stations

Concentrated pumping stations is the 2G solution. Enough?

Distributed pumping: is an option to be explored:

- **normally needed to push the vacuum limits.**
- **implementation in a 'big' GW pipe is to be studied.**





Design linked to civil infrastructure

Option 1: dedicated 'enlargements' @ 500 m (spares every 250 m)

Option 2: a larger tunnel (or a better arranged space and good environment) .

‘SQUEEZING’ VACUUM LINE

Recently added:

300 m long pipe, ø = 250 mm.

Residual pressure ≈ 10^{-6} mbar

Courtesy: NIKHEF team