EINSTEIN TELESCOPE

ET Vacuum: what next

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e⁻CLOUD'22

GWD Vac'22

25 September 2022 to 1 October 2022

Italy, La Biodola Bay, Isola d'Elba

Why Vacuum for ET

The laser path of ET has to be kept under High Vacuum (HV) and Ultra- High-Vacuum (UHV) for several reasons:

- reduce the noise due to vacuum fluctuations along the beam path to an acceptable level
- isolate test masses and other optical elements from acoustic noise
- reduce mechanical losses to reduce thermal noise contribution due to residual gas
- contribute to preserve the cleanliness of optical elements.

Requirements for ET U.H. Vacuum pipe lines

120 kilometres of **HUV vacuum pipes**
ET Project Office and CERN responsibility!

CERN is asking the ET collaboration: what are the requirements?

The reference numbers are derived under two assumptions:

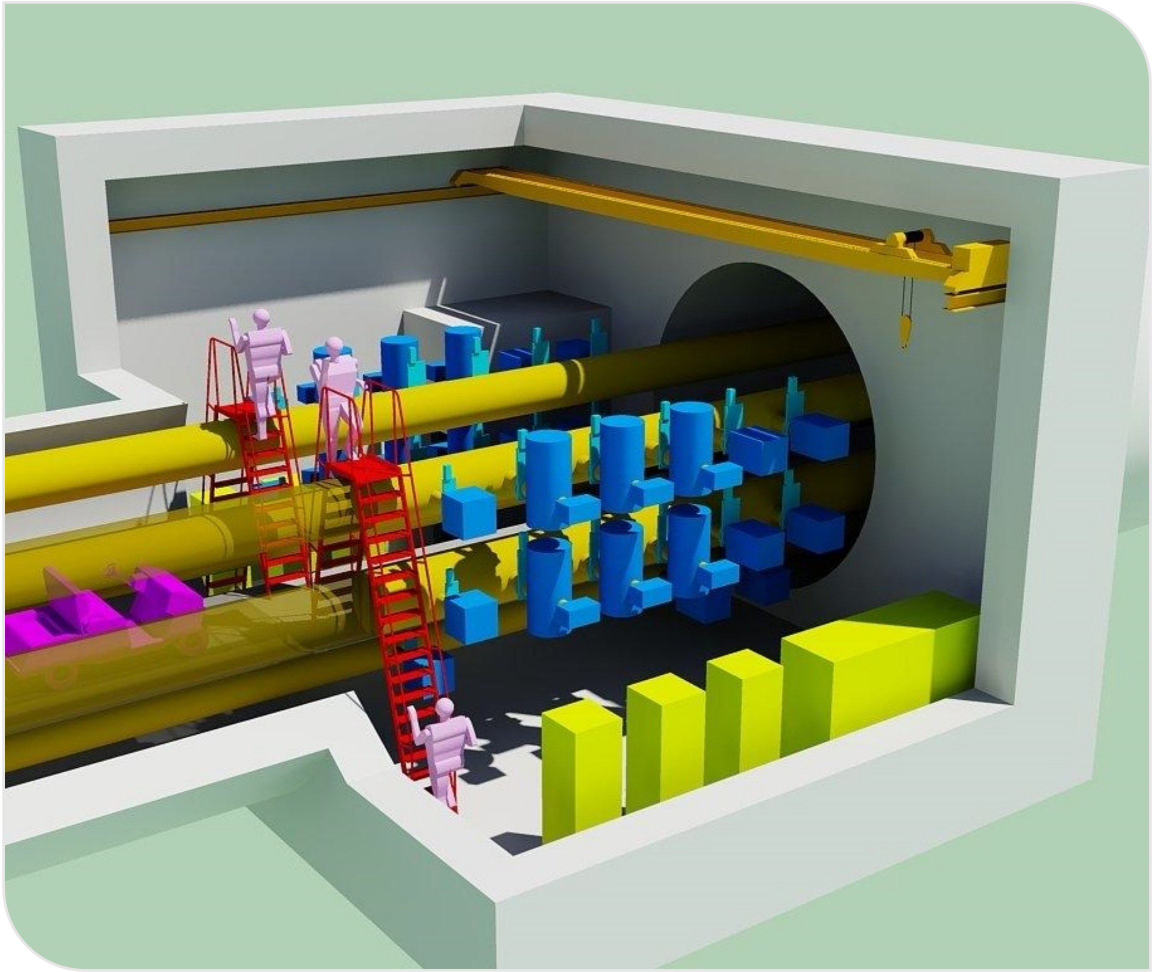
1) The long term goal of ET is summarised by the corresponding sensitivity curve (Do we agree on the use of ET-D ??)

1) The safety factor, i.e. how much the spectral noise curve due to the residual gas must be smaller that the ET sensitivity curve (Do we agree on a factor 10 ?)

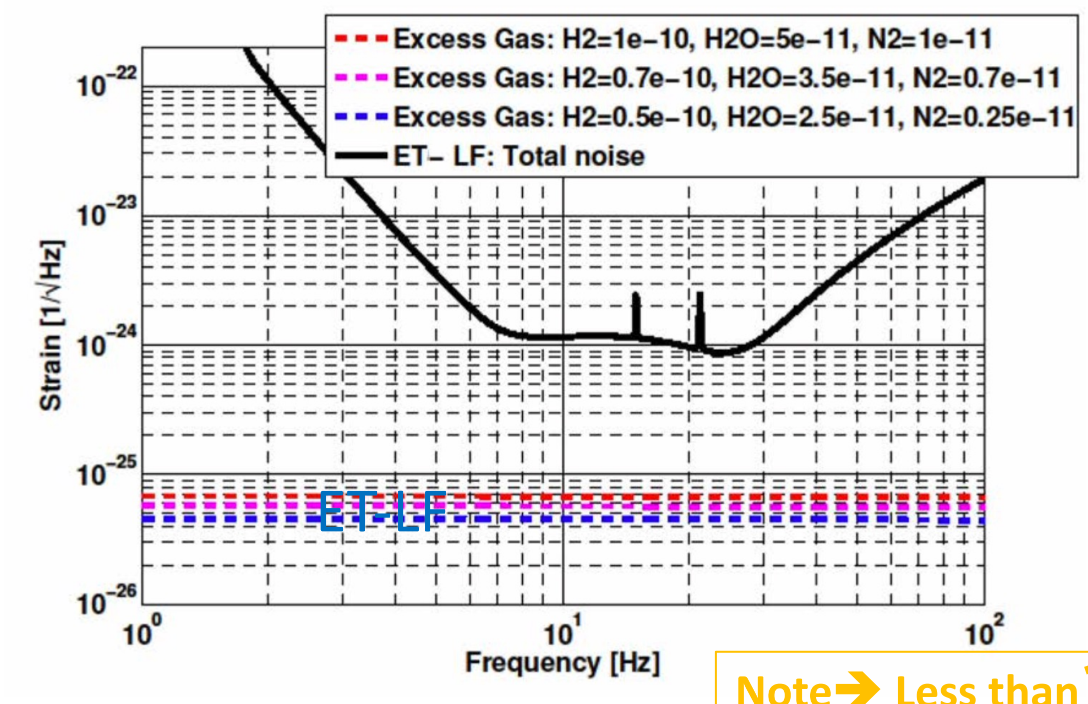
Vacuum requirements (current values)

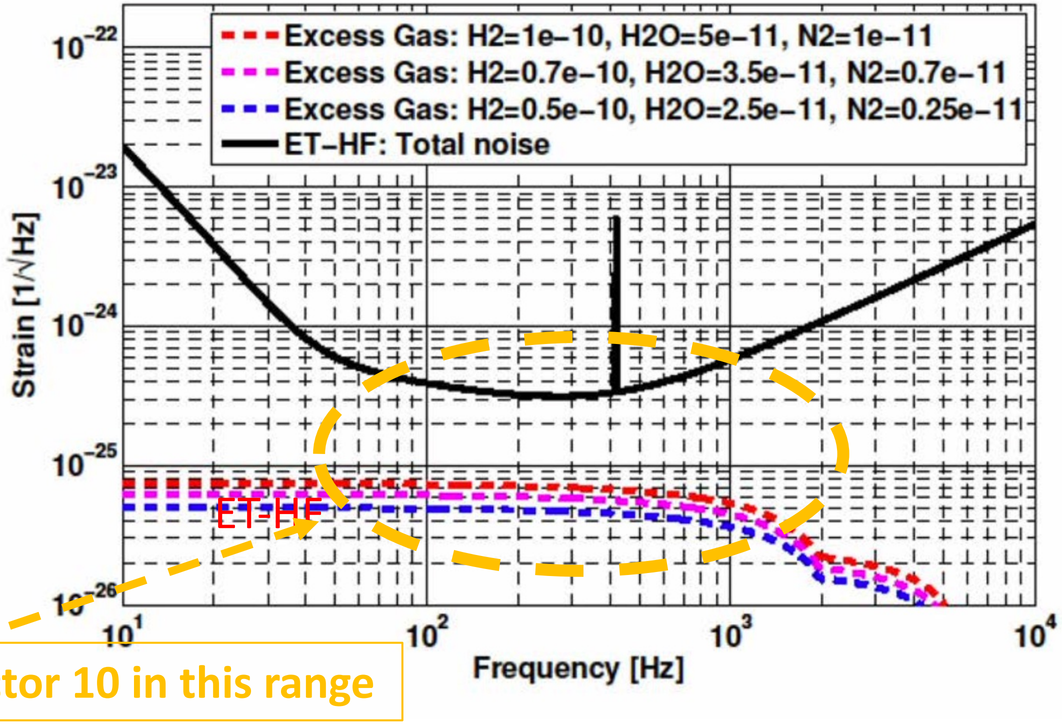
see the toady talk of C. Day

- Beam pipe vacuum
  - **Total residual pressure ~ 10^{-10} mbar (LF), 10^{-11} mbar (HF)**
  - Partial pressure of hydrocarbons (> 100 amu) ~ 10^{-14} mbar
  - Partial pressure of water ~ 10^{-12} mbar
- Separation between towers (HV) and arms (UHV) by differential pumping or cryotraps
- LF-design target: reduction of inflows (beam pipe, upper tower, adjacent tower) + acceptable flow of sticky gases



Plots reported on the Updated ET Conceptual Design - 2020





Note➔ Less than a factor 10 in this range

- *Total residual pressure ranging around 1 x10^{-10} mbar, corresponding to a noise level below 1x10^{-25} $Hz^{-1/2}$*
- *Hydrocarbon partial pressure shall be at the level of 10^{-14} mbar*

My two cents➔ We should check again the consistency of these statements before GSSI meeting .

The Vacuum of the ET Towers

Vacuum Towers are large chambers **not baked**

- Crucial part of the GW set-up vented

↓

Contamination

- Mirrors, Optics are located inside towers

↓

Outgassing budget table of the tower/area of interest.

- Calculating the outgassing contributions for different gases

ET-ISB responsibility: Tower Vacuum

- The work package includes the definition of the specifications, the R&D program for material qualifications and handling procedures, the design and the cost evaluation of the various vacuum chambers hosting the super attenuator, i.e. the upper part of the cryostat for the LF interferometer and the entire tower for the HF interferometer including the vacuum chamber hosting the payload. The design of the auxiliary towers is also part of this WP.
  - Viewports, vacuum pumps for the towers, valves, gauges, mass spectrometer and vacuum leak detectors should be included in the design and the cost evaluation.

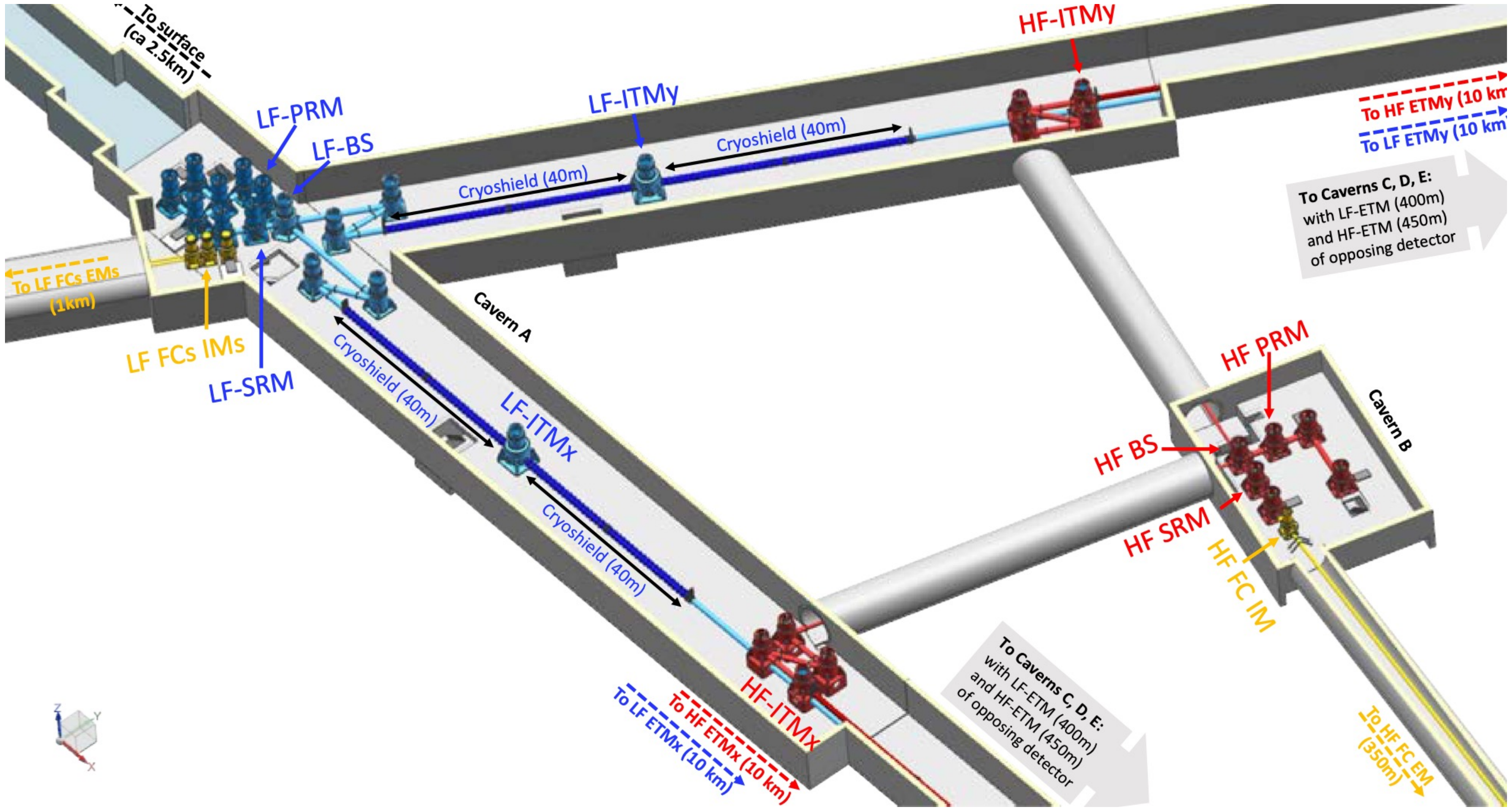
The proposed solutions must be in agreement with those of the other WPs concerning

- Infrastructure
- Optical layout of the interferometer
- Suspension system
- TCS system
- Light scattering reduction
- Interferometer local control
- Safety plan for the caverns

ET VACUUM Towers

- Ten's of vertical vacuum towers hosting the optical elements
  - ➢ ET-LF tower basements ➔cryostat, ET-HF basements ➔ UHV chamber
- Absolute cleanness: any residual particles of dust along the light path and near the monolithic suspensions ➔ let us make an effort in translate this requarement in a quantitative language➔ define a method to check the cleanness➔

XX residual particles/m^2 ??? XX residual particles/m^3 ???



Defining the vacuum requirements for the towers

Preparing the data base, crucial tool to evaluete the otgassing budget

https://apps.et-gw.eu/et_outgassing_db/
(need a gitlab.et-gw.eu account)

The Data base:

- Outgassing of materials

- Outgassing of assemblies (full objects e.g. coils)

- For each element inserted in the tower: quantity, exposed surfaces and material

- Pumping system installed on the chamber, speed for the various gases

- Non accepted materials

From the today talk of J. Gargiulo

Outgassing Database tool

Available at (need a gitlab.et-gw.eu account):

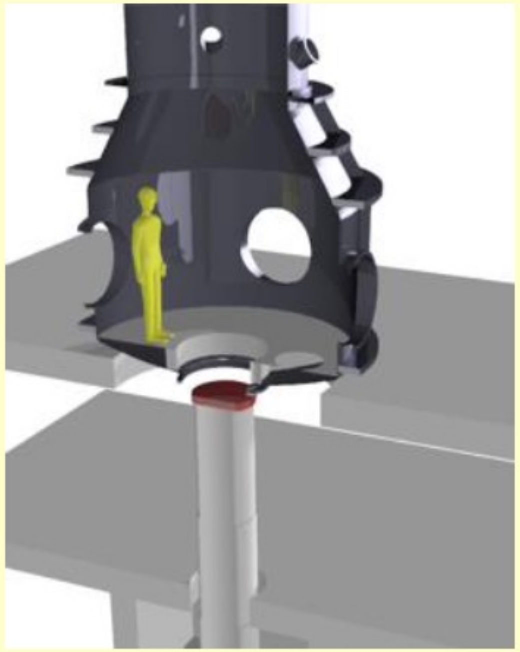
https://apps.et-gw.eu/et_outgassing_db/

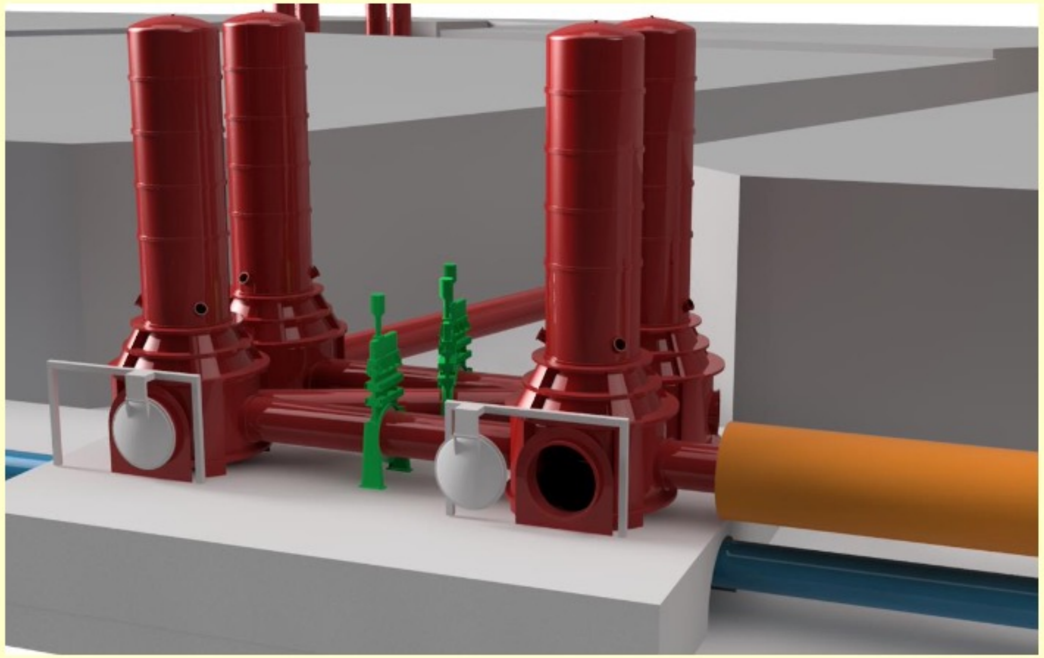
	Component				Optical measurements		Vacuum measurements															
	Item	Manufacturer	Main material	History	Optical check	Optical losses (ppm)	Test procedure	mbar-l/s							Q_HC (peaks N>44) (m/z)	Preparation (highlight)	Pre-baking			Notes	Installation scenario	Reference
								Q_H2O @24h	Q_H20 @100H	Q_H20 @1000H	Q_H2	Q_N2+OTHERS @24h	Q_N2+OTHERS @100h	Q_HC (level>44)			Done?	Temperature (°C)	Hours			
	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 Instrumente 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: 10.1116/6.000065
	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: 10.1116/6.000065
	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: 10.1116/6.000065
	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: 10.1116/6.000065

Main chamber: Access

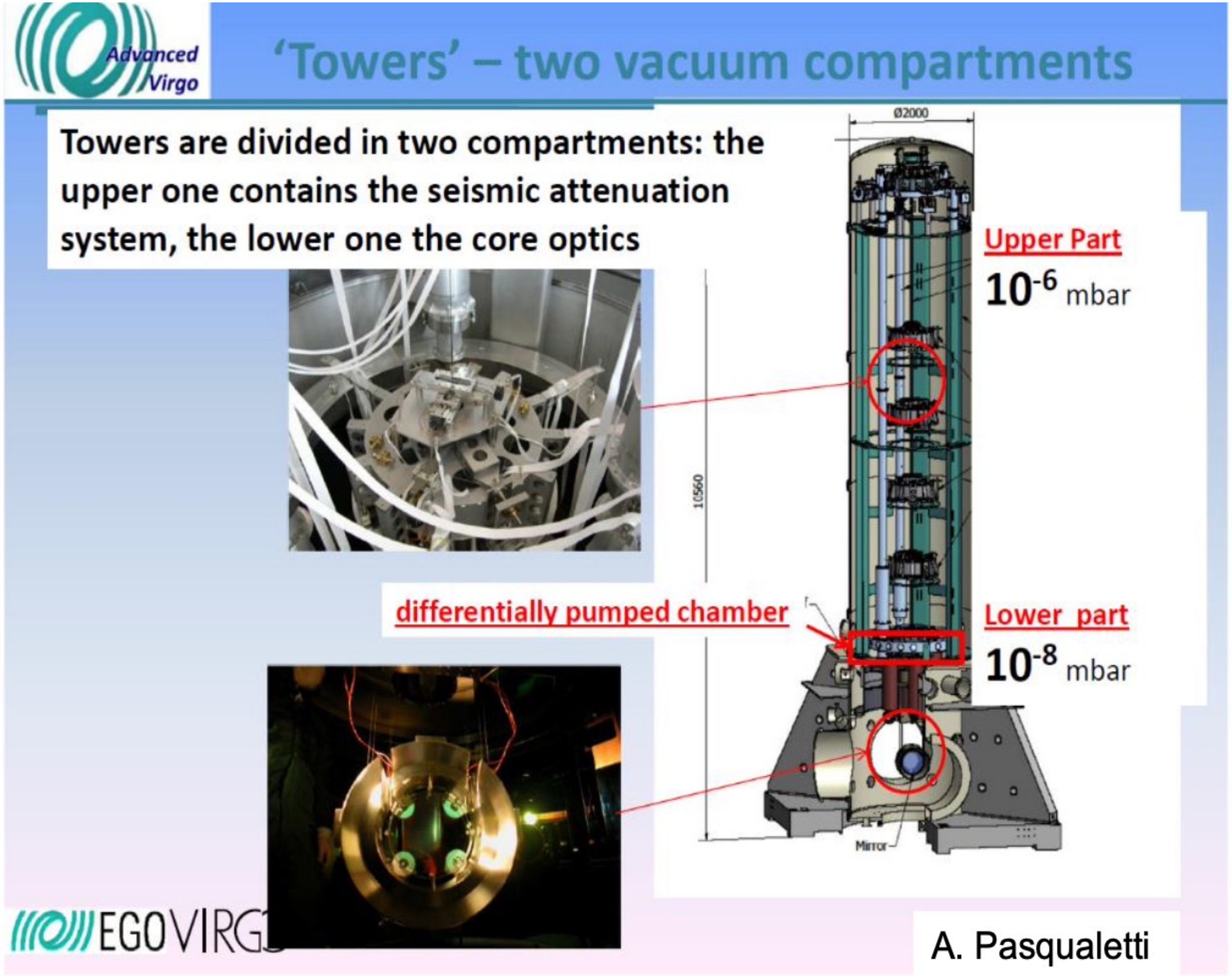
From the today talk of A. Pasqualetti

- **Remaks:**
  - Bottom access: seems not possible for all the Towers (ESFRI configuration, due to superposed vacuum tubes. *Rotation of 'tubes' possible?*)
  - Lateral access: seems not possible for all the Towers as well (due to room constraints inside the central hall)





The LF tower



- Cryostat access from below: 1.2 m aperture; tower height 20 m

- Influence of the upper part of the tower needs to be considered
- Virgo: Pressure reduction of factor 100 by differential pumping

For ET-LF:
- Reduction of outgassing rate of upper tower
- Conductance(s) should be as small as possible
- Increase of pumping speed

- Do we need to set a crtyotrap between upper and lower part of the tower?

The HF tower

- shorter superattenuator

➔ then shorter tower (10 m ?)

- Pressure reduction of factor 100 by differential pumping between upper and lower part as in Virgo

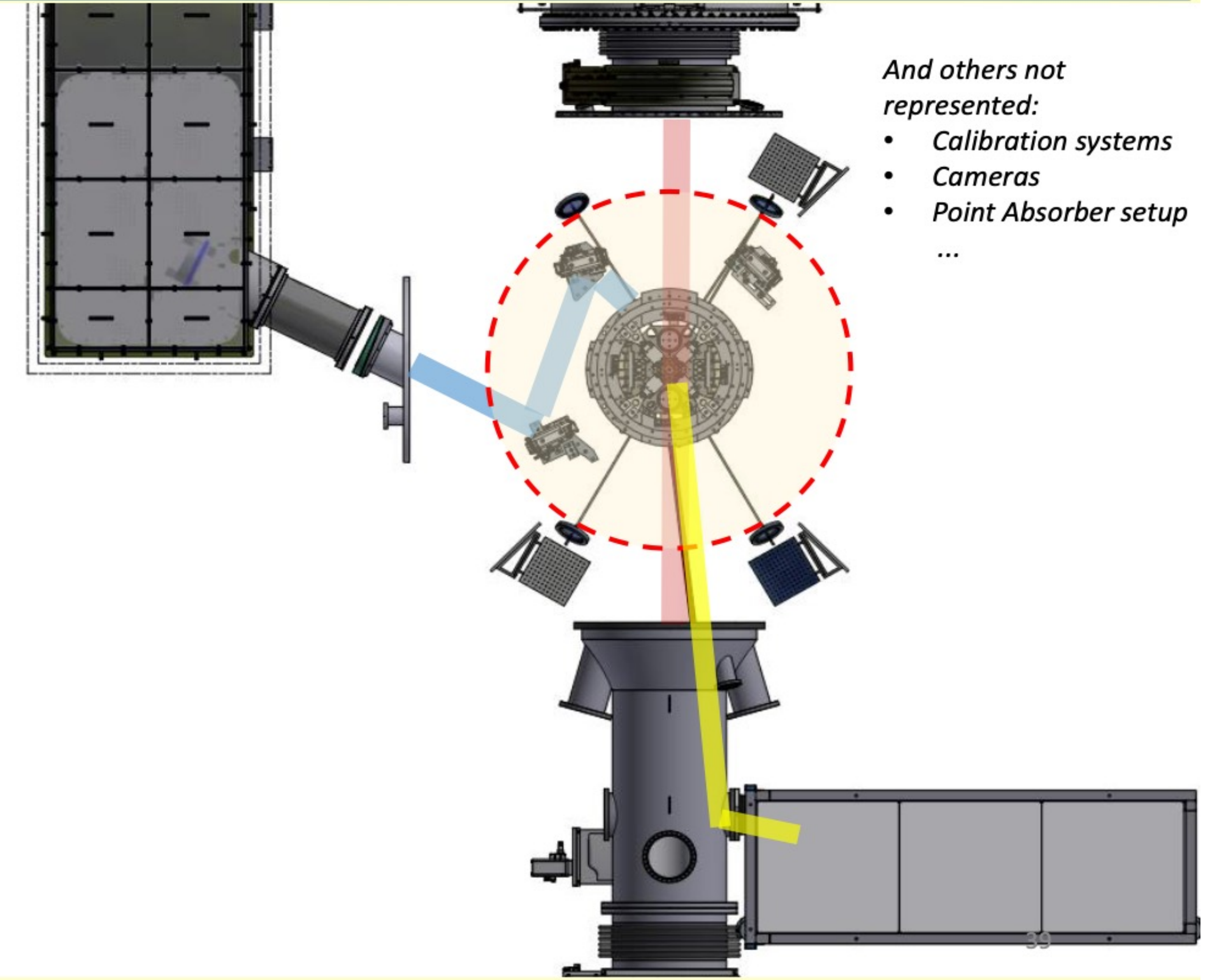
- <u>Lateral access as in LIGO Case</u>
- Clean rooms to be installed on the lateral side of the cameras
- Influence of the upper part of the tower needs to be considered

A crucial topic to be discussed with the Optics WP: interface between the TM towers and auxiliary towers - I

from the today talk of A. Pasqualetti

Optics 'service'

- **Determination of chambers apertures and of space needs adjacent to towers**
  - Main beam size and position, height to floor, wanted chambers apertures
  - Stray-light baffling strategy and wanted chambers apertures (affect links, main valves…)
  - Optical benches guess sizes and positions – In-vacuum and external ones
  - Estimated types, size and number of viewports. Features of the viewports to be defined as well, related to safety.



And others not represented:

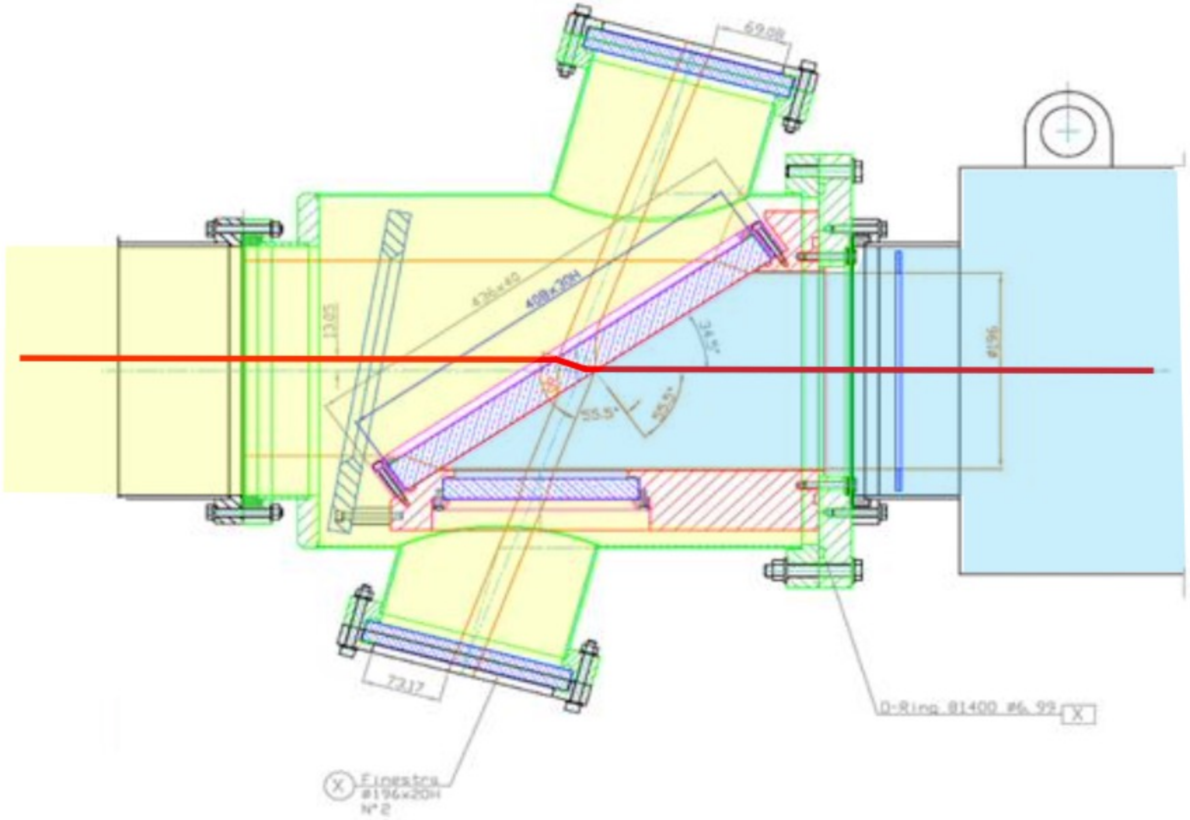
- *Calibration systems*
- *Cameras*
- *Point Absorber setup*

…

Interface between the TM towers and auxiliary towers - II
from the today talk of A. Pasqualetti

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

high vacuum side



Rough vacuum side

ET-ISB responsibility: **Cryopumps**

This includes the development of design tools, the qualification of materials and handling procedures, the simulation of the vacuum conditions and the design of the cryostat with thermal shields and cryopumps. Transportation constraints, assembly procedure and special tools should also be studied. In addition, the WP includes the selection of the superinsulation material and the temperature control.

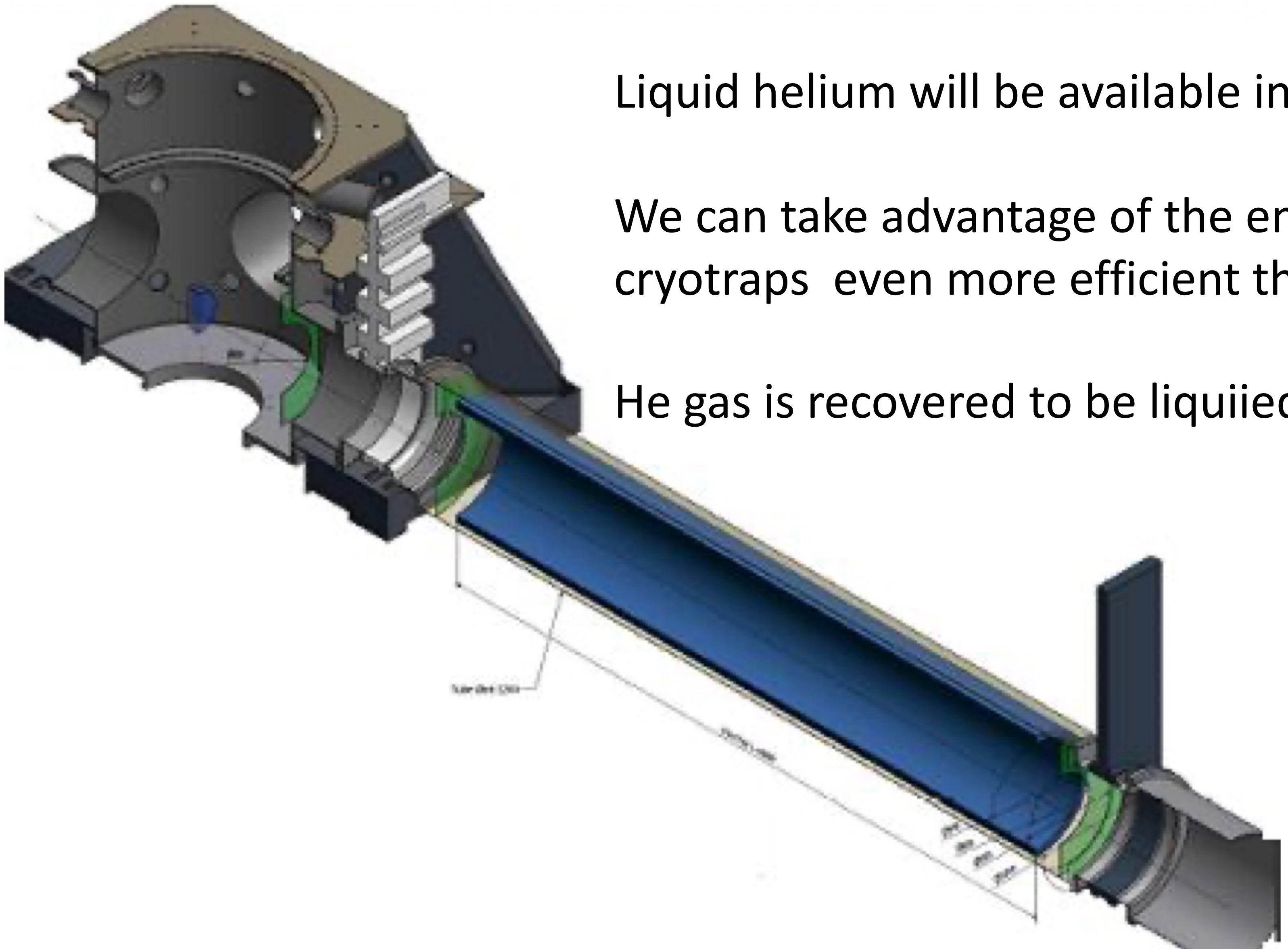
Interfaces with

- Tower Vacuum
- Pipe Arm Vacuum
- Cryogenic Infrastructure
- Detector Coolin

…and the other WPs concerning

- LF payload
- Suspensions
- Optical layout of the interferometer
- Light scattering reduction

He or Nitrogen CRYOPUMPS ?

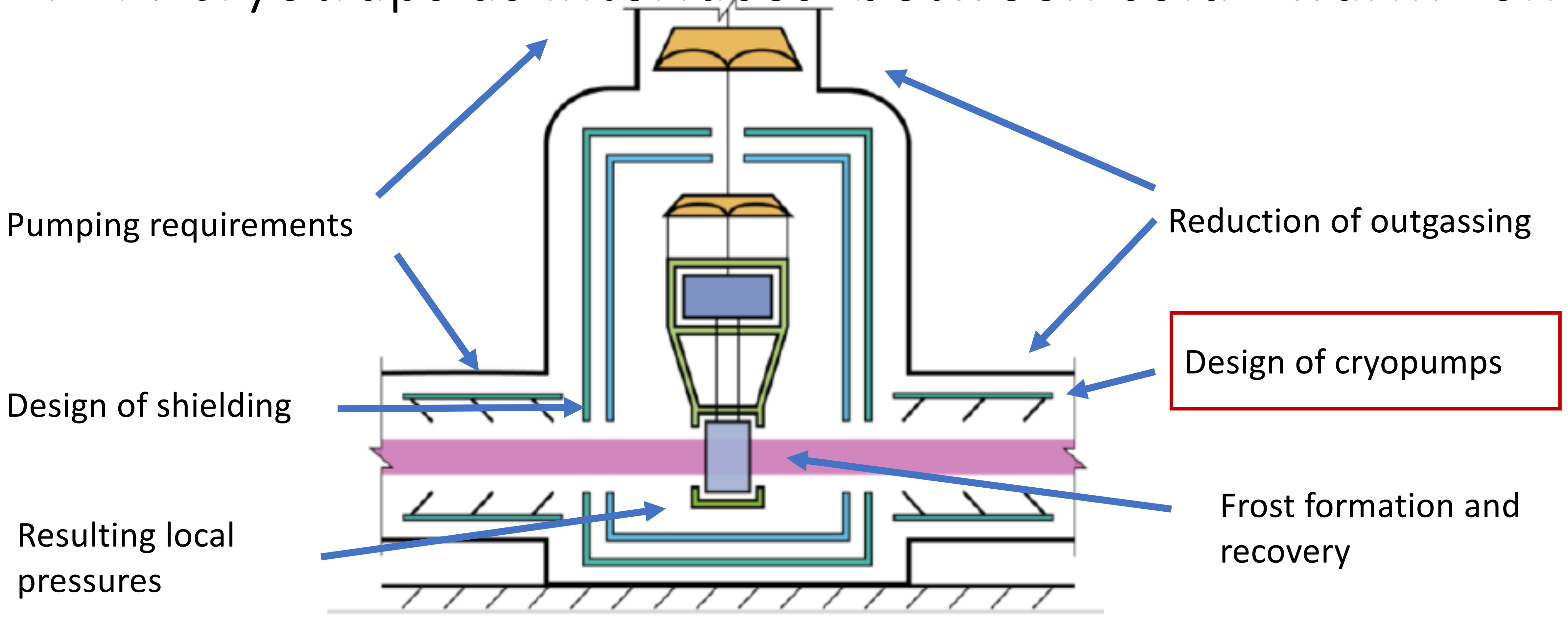


Liquid helium will be available in each vertex of the ET installation

We can take advantage of the entalpy of the cold He gas to design cryotraps even more efficient than nitrogen traps

He gas is recovered to be liquiied again in each vertex

ET-LF: Cryotraps as interfaces between cold –warm zones



Cryopumps

HF tower ➔ cryotraps limit the gas flow into the beam pipe arms

Vacuum requirements :

$$p_{\text{HF, Tower}} > p_{\text{Beam Pipe}}$$

H_2 ~ 1 × 10 $^{-10}$ mbar,

H_2O + others ~1 × 10 $^{-11}$ mbar

Relaxed requirement for vacuum in the HF towers ~1 × 10 $^{-9}$ mbar

The upper–lower interface of the ET towers

The suspension wire coming from the super-attenuator needs a few millimeter of clearance when passing through the flange connecting the cryostat to the rest of the tower

Advanced Virgo case: suspension fibre with 12 mm diameter in total and a ring of 6 mm around it as opening for alignment.

ET case: dimensions probably to be increased slightly, but large conductance makes difficult to maintain the vacuum requirement around the mirror

Science operation, a clearance ~ ±0.5 mm will likely be needed
Study under way: aperture wide during installation/alignment and narrow during operation.
Photo camera-like aperture combined with a x, y-positioning device that follows the suspension fibre + Cryopump added

First set of recommandations for the design

- Given the large number of towers in ET and the possibly long commissioning phases, having a rapid recovery of the vacuum to the required level will allow to not downgrade the ET duty cycle. Large and quiet pumping speed, such as that potentially provided by cryopumps, is a possible solution.

- If the tower vacuum shall be vented during normal LF cryostat operation, an excessive particle flow will enter the cryostat through the suspension conductance channel. This particle flow would condense on all cold surfaces, i.e. the optics, the thermal shields and the cryotraps, requiring complete regeneration of the cryostat vacuum including warm-up. Therefore, the suspension conductance channel must be closed completely in such scenario.

- Preferably, independent venting of the “tower vacuum” and the “cryostat vacuum” should be avoided.

- The lower bound time scale for interventions and/or vacuum recovery in the LF cryostats should be kept on the order of a month

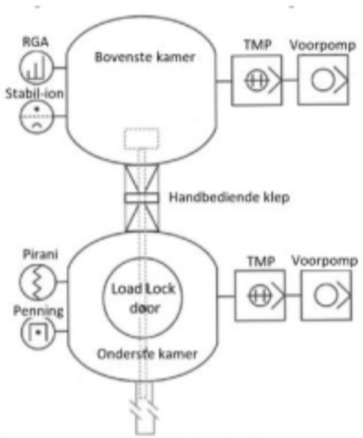
Mechanical,Thermal and E.M. simulations

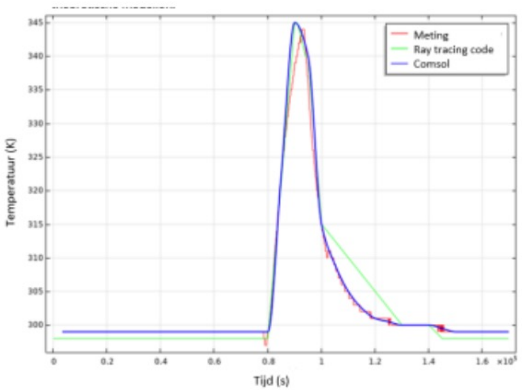
We should organise a group of experts devoted to the mechanical, thermal and e.m. simulation for the Vac&Cryo systems

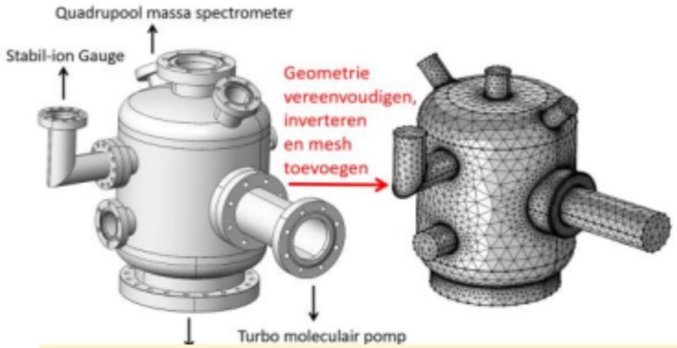
See the interesting talk of H.J. Bulten on ET pathfinder

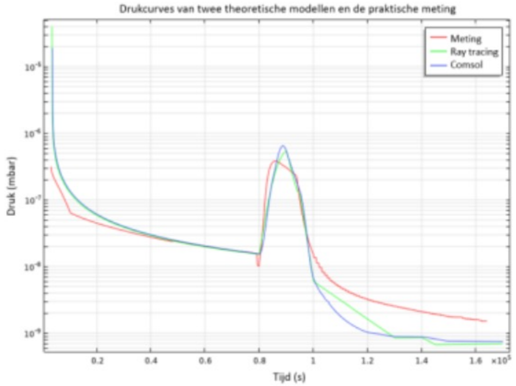
Vacuum simulations

- Coupled equations:
  - Impingement rate per surface. Particle flow between volumes. Surface-dependent adsorption and desorption.
- Initial tests: comparison for our outgas chamber with Molflow (CERN vacuum software) and COMSOL (molecular flow package) (minor thesis Vera Erends)
  - **Molflow**: the vacuum part is used as volume. Pumping speeds/impingement rates at different points in space can be calculated, effective pumping speeds for the full system can be obtained.
  - **Comsol**: we could program a time-dependent adsorption rate by tracking the outgassing history here and have an occupancy-dependent sticking probability. We subdivided the surface in small parts with different activation energies for water to simulate the Temkin isotherm.
  - **Our code**: the occupancy of the monolayer is tracked, and the hydrogen profile in the steel. Therefore we can simulate time-dependent and history-dependent adsorptions and desorptions, in contrast to Molflow and Comsol.
  - We can also easily introduce different models for e.g. surface coatings.









Verification of our code for a simple testcase with Comsol and Molflow;
Vera Erends, Nevac Nov. 2021 https://nevac.nl/archief_pdf/pdf_208.pdf
https://www.comsol.com/blogs/simulating-the-pressure-in-an-ultrahigh-vacuum-system/

Vacuum: what next ? - I

- Outgassing budget tool build-up
- Iterations to get a preliminary mechanical design of tower vacuum chamber
- Raw material investigation even to reduce the magnetic effects: *material and thickness of the vacuum chambers, post processing, and perhaps thick coatings can be optimized to improve the magnetic shielding effect.*

Vacuum: what next ?   - II

- Pressure/outgassing rate/particle from a tower (lower compartment), second order estimations

- Pressure/outgassing rate/particle flow to the tower (upper compartment), second order estimations

- Preparation of a geometrical sketch of the interface as a basis for discussion and launch a design

- Organise meetings to discuss design options

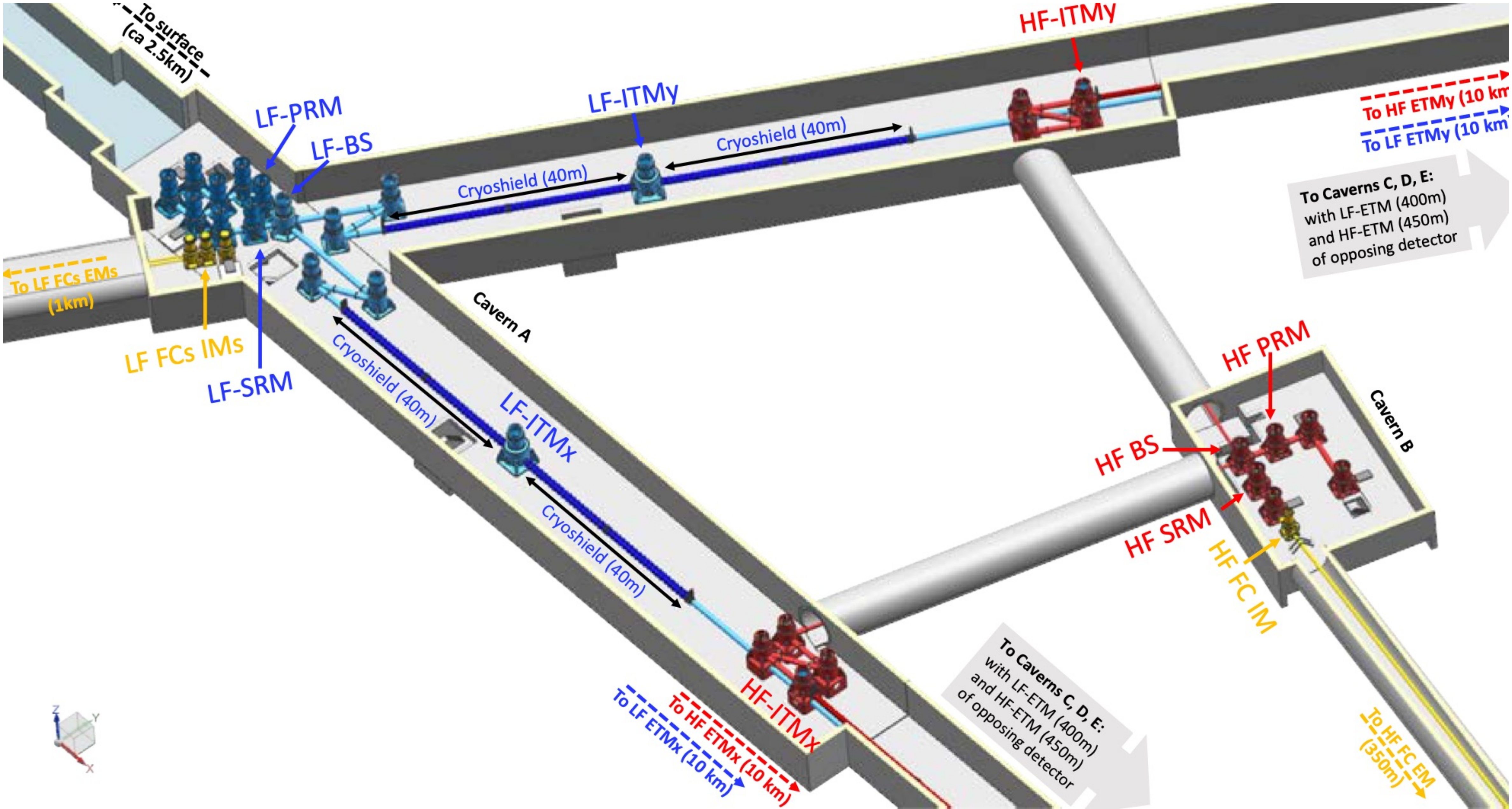
- Pumping speed (per main gas species) for HF and LF towers (up and lower parts)

Two final considerations

Impressive talk of G. SATTONNAY – S. BILGEN – B. MERCIER
MAVERICS team – IJCLab / IN2P3/ CNRS – Orsay - France

Welcome to the ET Vacumm& Cryo community for ET !

Finally:
let me thank the organisers of this very interesting meeting : see you in L'Aquila


To surface (ca 2.5km)
LF-PRM
LF-BS
LF-ITMy
Cryoshield (40m)
Cryoshield (40m)
HF-ITMy
To HF ETMy (10 km
To LF ETMy (10 km
To Caverns C, D, E:
with LF-ETM (400m)
and HF-ETM (450m)
of opposing detector
To LF FCs EMs (1km)
LF FCs IMs
LF-SRM
Cavern A
Cryoshield (40m)
LF-ITMx
Cryoshield (40m)
HF PRM
Cavern B
HF BS
HF SRM
HF FC IM
HF-ITMx
To LF ETMx (10 km)
To HF ETMx (10 km)
To Caverns C, D, E:
with LF-ETM (400m)
and HF-ETM (450m)
of opposing detector
To HF FC EM (350m)