
Vacuum
&
Cryogenics
Fulvio Ricci
Spienza University of Rome

Vacuum and Cryogenic for ET

- We have to develop a UHV vacuum system, never built in the past and supposed to last for several decades, compliant with cryostats, whose design must be adequate to respect cryogenic payload requirements.

- R&D on both vacuum systems and cryogenics is needed to drive strategic choices of the whole project

Projects on the same topic in the last 5 years

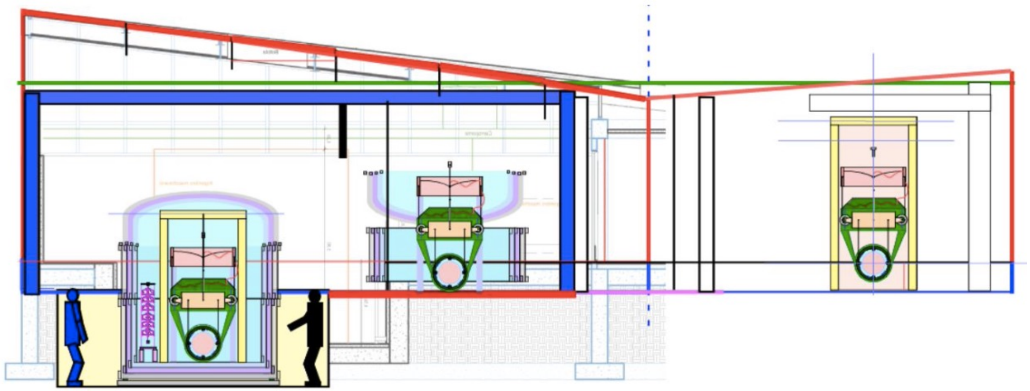
LATINO Laboratory in Advanced Technologies for INnOvation is a project co-funded by INFN and Regione LAZIO for the construction of technological facilities, useful both for Research Institutes and Industry, in four different application fields: Radiofrequency, Vacuum-Heat Treatments, Magnets and Mechanical Integration. The “Vacuum-Heat Treatments” section concerns two different apparatus: a system for outgassing measurements and a furnace for brazing and material heat treatments.

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

ARC (Amaldi Research Center) Excellence project the department of Physics of the Sapienza university, devoted to the search of Gravitational Waves, is involved with its cryolab L5 created and supported thanks to the synergy of university and INFN funds, will be available to host the facilities conceived to carry on studies of the material properties at cryogenic temperature and qualify the medium size cryogenic prototypes developed for ET. ARC project is mainly meant to build a laboratory building from scratch and covers the basic cost of a prototype cooling system. ARC will last until Dec 2022.

SAPIENZA
UNIVERSITÀ DI ROMA

CENTRO AMALDI




ICONISMUS III.
Pag. 39.
Fig. II
Vacuum
Fig. III

The need an ultra-high vacuum system in ET

- *Reduce the phase noise due to residual gas density fluctuations along the beam path to an acceptable level*
- *Isolate test masses and other optical elements from acoustic noise*
- *Reduce test mass motion excitation due to residual gas fluctuations*
- *Reduce friction losses in the mirror suspensions ➔ suspension thermal noise*
- *Contribute to thermal isolation of test masses and of their support structures*
- *Contribute to preserve the cleanliness of optical elements*

The motivation

- Find ways to significantly reduce the costs ~ 120 km of UHV beam tubes
- Initial ET approach estimated that the vacuum cost is the second higest cost among the ET subsystem (after civil construction)
- Explore use of low carbon steel rather than stainless steel
- No *in situ* high temperature bakeout to remove water qHydrophobic surface treatments

Constraints on Vacuum Interaction

- Dual requirements of minimizing system cost while maintaining the stringent vacuum requirements for the long beam tubes.

The primary requirement is to limit the column density of the residual gas (average pressure over the length of the tube)

$$h^2(f) = \frac{4(2\pi\alpha)^2}{L^2 v_0} \int_0^L e^{-\frac{2\pi f w(z)}{v_0}} \frac{\rho(z)dz}{w(z)}$$

$$v_0 = \sqrt{\frac{2kT}{m}}$$

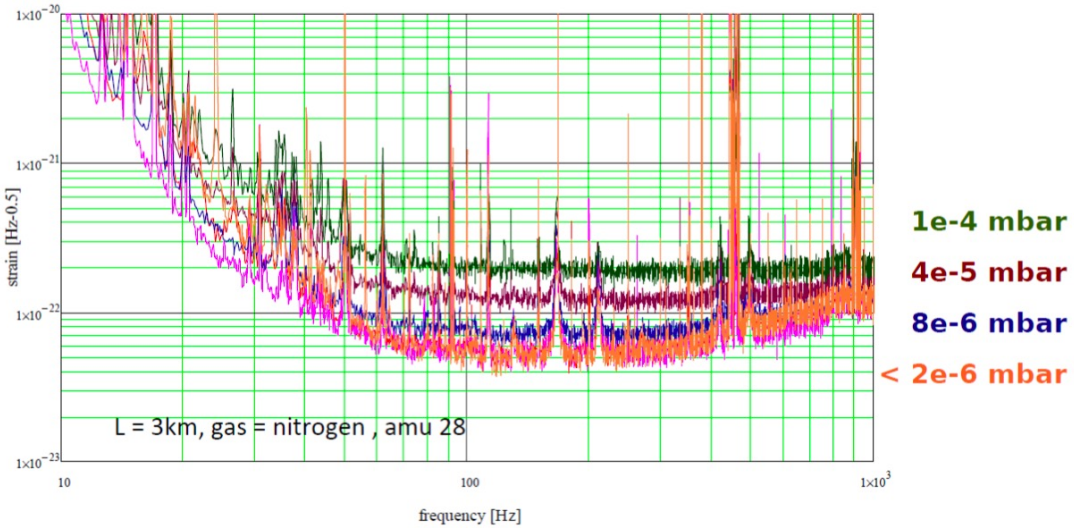
ρ = particle density $\#/cm^3$ at z; α = optical polarizability, cm^3

v_0 = thermal velocity, cm/sec; k = Boltzmann constant

T = temperature, K; m = molecule mass, gm

L = arm length, cm; w(z) = optical beam radius at z, cm

f = frequency of gravitational wave, Hz; h(f) = GW strain, $1/\sqrt{Hz}$



Fluctuations of the refractive index of residual gas limits sensitivity Virgo case

Virgo requirements

Gas species	Pressure [mbar]	Noise [$\sqrt{Hz}$]
Hydrogen	1×10^{-9}	9.7×10^{-26}
Water	1.5×10^{-10}	2.5×10^{-25}
Air	5×10^{-10}	5.6×10^{-25}
Hydrocarbons	1×10^{-13}	2.9×10^{-26}
Total	1.7×10^{-9}	6.2×10^{-25}

➔ *Einstein Telescope* ➔

Scale an order of magnitude from the Virgo Table!

- Consider mild steel alloys and Al in addition to SS, detailing surface treatment, coatings, and material transitions
- Quantify TiN, DLC, a-Si, Fe3O4 coating effectiveness for H_20 adsorption, scale and particulate, welding interference, and optical characterization
- Strength a collaboration as first with al the competent INFN groups to carry on outgassing studies

- Explore carbon and alloy steels as the material for the beam tubes rather than stainless steel:
  - ➢ *Firmly establish the reported low outgassing rate of hydrogen for these materials*
  - ➢ *Identify surface processing, alloying, and coatings to reduce the environmental corrosion on the exterior surface*
  - ➢ *Perform a test of a section commercial tube under UHV conditions*
    Test welding techniques for leak free welds, especially for coated tubes
    Identify steel mills capable of (custom) producing tubing on scale needed for ET

An alternative choice to be explored

Chongdo Park and Taekyun Ha
Pohang Accelerator Laboratory, 80 Jigok-Ro 127 Beon-Gil, Pohang, Gyeongbuk 37673, Korea ,
Boklae Choa
Korea Research Institute of Standards and Science, 267 Gajeong-Ro, Yuseong-Gu, Daejeon 34113, Korea

TABLE III. Total outgassing rates measured using throughput method during pump-down at room temperature. $q_i = q_0\, t_h^{-a}$ where i is time [h]. Values are N_2 equivalents of which the main component is water. All sample chambers were subjected to *in situ* bakeout for 48 h at 150 °C and subsequent N_2 gas exposure for 5 h before the measurements.

		Outgassing rate q_i ($\mathrm{Pa\,m^3\,s^{-1}\,m^{-2}}$)				
Material	Sample no.	q_1	q_{10}	q_{24}	$q_0\, t_h^{-a}$ or a_h (10–40 h)	Remarks
D3752	1	4.5×10^{-7}	4.3×10^{-8}	1.7×10^{-8}	$5.0 \times 10^{-7}\, t^{-1.05}$	After degas (850 °C, 12 h)
		1.2×10^{-6}	9.9×10^{-8}	4.0×10^{-8}	$9.7 \times 10^{-7}\, t^{-1.00}$	After machining by 2 mm and finished using honing
		4.6×10^{-7}	3.9×10^{-8}	1.8×10^{-8}	$3.3 \times 10^{-7}\, t^{-0.91}$	After degas (850 °C, 12 h)
D3507	3	1.0×10^{-5}	7.1×10^{-7}	2.9×10^{-7}	$6.6 \times 10^{-6}\, t^{-0.98}$	
		9.5×10^{-7}	7.1×10^{-8}	3.0×10^{-8}	$6.6 \times 10^{-7}\, t^{-0.97}$	After degas (850 °C, 12 h)
D3562	4	8.7×10^{-7}	8.2×10^{-8}	3.7×10^{-8}	$6.7 \times 10^{-7}\, t^{-0.92}$	After degas (850 °C, 12 h)
	5	-	9.4×10^{-7}	3.7×10^{-7}	$1.1 \times 10^{-5}\, t^{-1.08}$	
		7.2×10^{-7}	6.3×10^{-8}	2.8×10^{-8}	$5.5 \times 10^{-7}\, t^{-0.94}$	After degas (850 °C, 12 h)
STS304	6	3.4×10^{-7}	3.0×10^{-8}	1.6×10^{-8}	$3.0 \times 10^{-7}\, t^{-0.95}$	
Mild steel	—	5.6×10^{-4}	1.8×10^{-5}			Ref. 31
Mild steel	—	2.7×10^{-3}	2.7×10^{-4}	4.0×10^{-5}		Ref. 11
Mild steel	—	6.7×10^{-4}	6.7×10^{-5}		$a_{10} = 1$	Ref. 2
Mild steel	—		2.5×10^{-6}	5.3×10^{-7} (100 h)		Ref. 32
Mild steel	—		1.6×10^{-8}			Ref. 32
S15C	—	—	$\sim 2.6 \times 10^{-6}$	—		Degassed, 400 °C, 15 h Ref. 3 300 °C, 3 h bake + air vent + (1∼38 h) exposure

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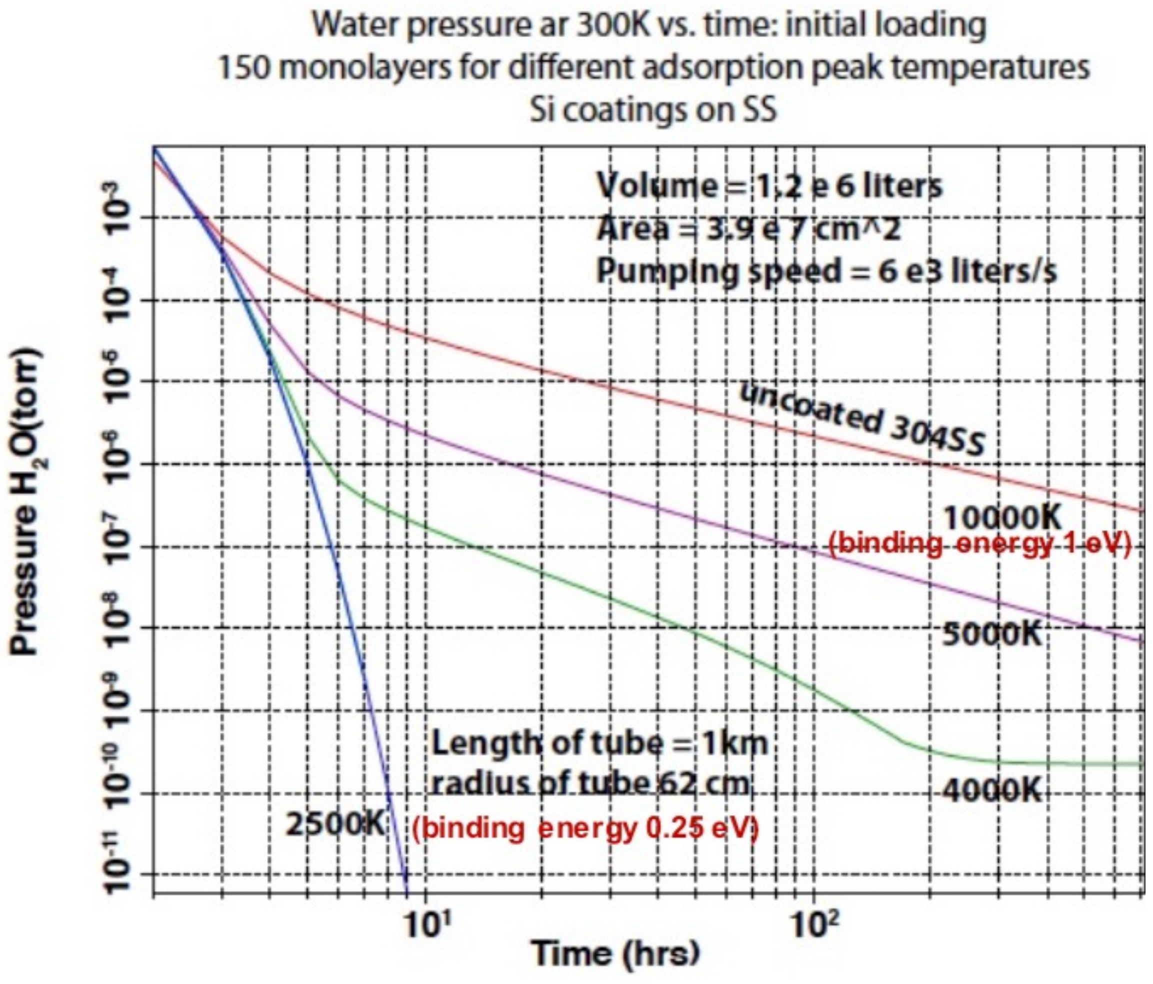
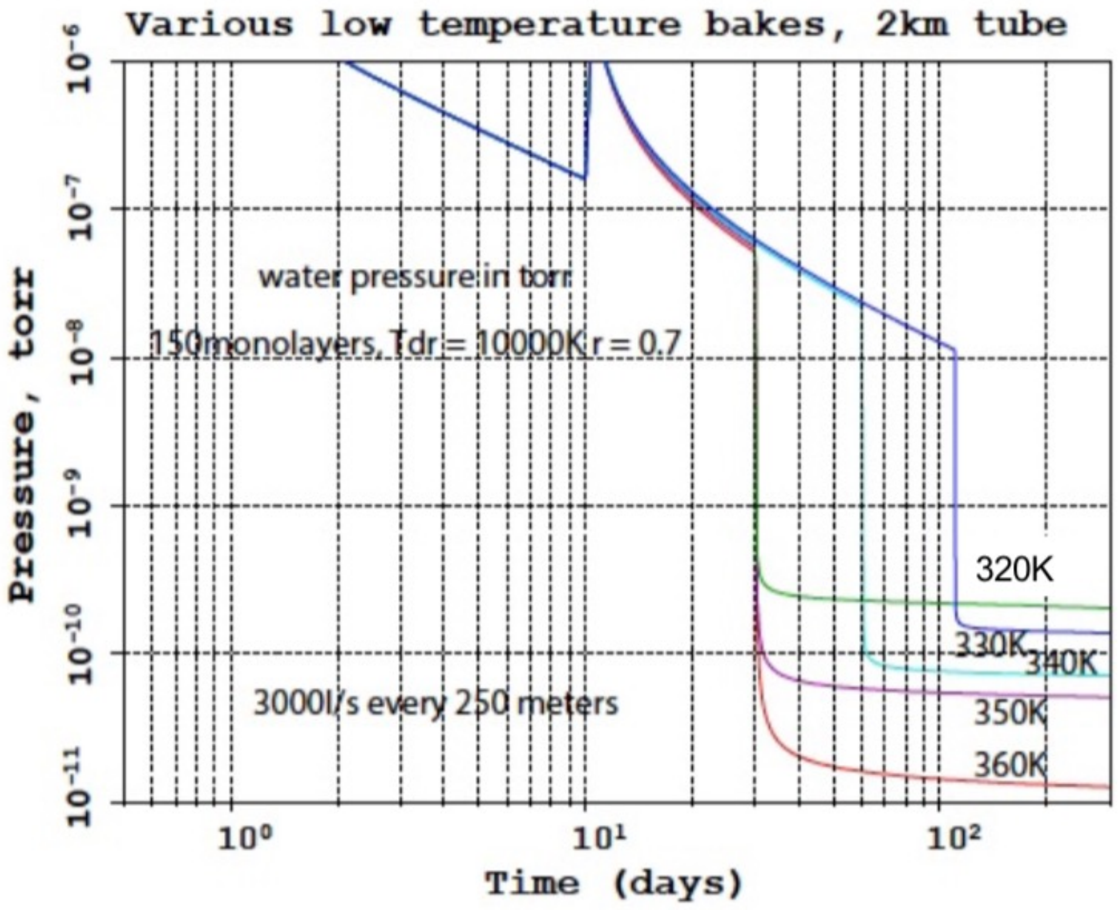
- Develop techniques to eliminate the need for a high temperature bakeout to outgas water:

  - ➢ *Identify coatings to be applied to the inner surface of the steel and potential steel alloy modifications to reduce the adsorbed water and thereby the outgassing rate*
  - ➢ *Test silicon-based, other hydrophobic coatings and potential steel alloy modifications to reduce water adsorption and subsequent outgassing (ref: fig next page)*
  - ➢ *Test low temperature long-duration bakes to reduce the water outgassing*
  - ➢ *Investigate ultra-dry gas refill to avoid reintroduction of water on outgassed surfaces during a venting*
  - ➢ *Develop a moving external heater with dry flush gas technique to remove water from a tube*

A couple of plots to highlight the problem





Preliminary studies for ET Vacuum

Materials:

- Outgassing rate studies
- Corrosion

Backing:

- Need for high temperature bakeout
- Surface coatings vs. mobile backout systems

New Pumping systems:

- Evaluation of the use of adsorption pumping system

Tube Geometry:

- Interface with towers
- Interface with cryostat

Logistic issues:

- Tube unit transport
- Underground installation

Prototypes of vacuum tube to be tested n the next years *(as we did for Virgo)*

Then, solution choice.


Cryogenics

Cryo and Vac

Cryotraps for UHV of ET HF as we have already in Virgo

Cryotraps for UHV of ET-LF that have to stop the thermal radiation impinging on the mirror from the km beam pipeline

Traps to be simulated and designed.

Brutal estimation of the trap length 10s of meters

Main studies for ET Cryogenics

Mirror Cryostat:

- Input radiation shielding without Multi Layers Insulation
- Vibration control in Cryostat Design
- Cooling down and warming up procedures

Mirror Cooling:

- Low vibration Pulse Tubes refrigeration lines
- High conductivity soft thermal links (Al6N)
- Surface coatings for optimal radiation absorption
- Surface coatings for optimal radiation absorption
- Mirror contamination control
- Superfluid Helium cooling techniques for payload

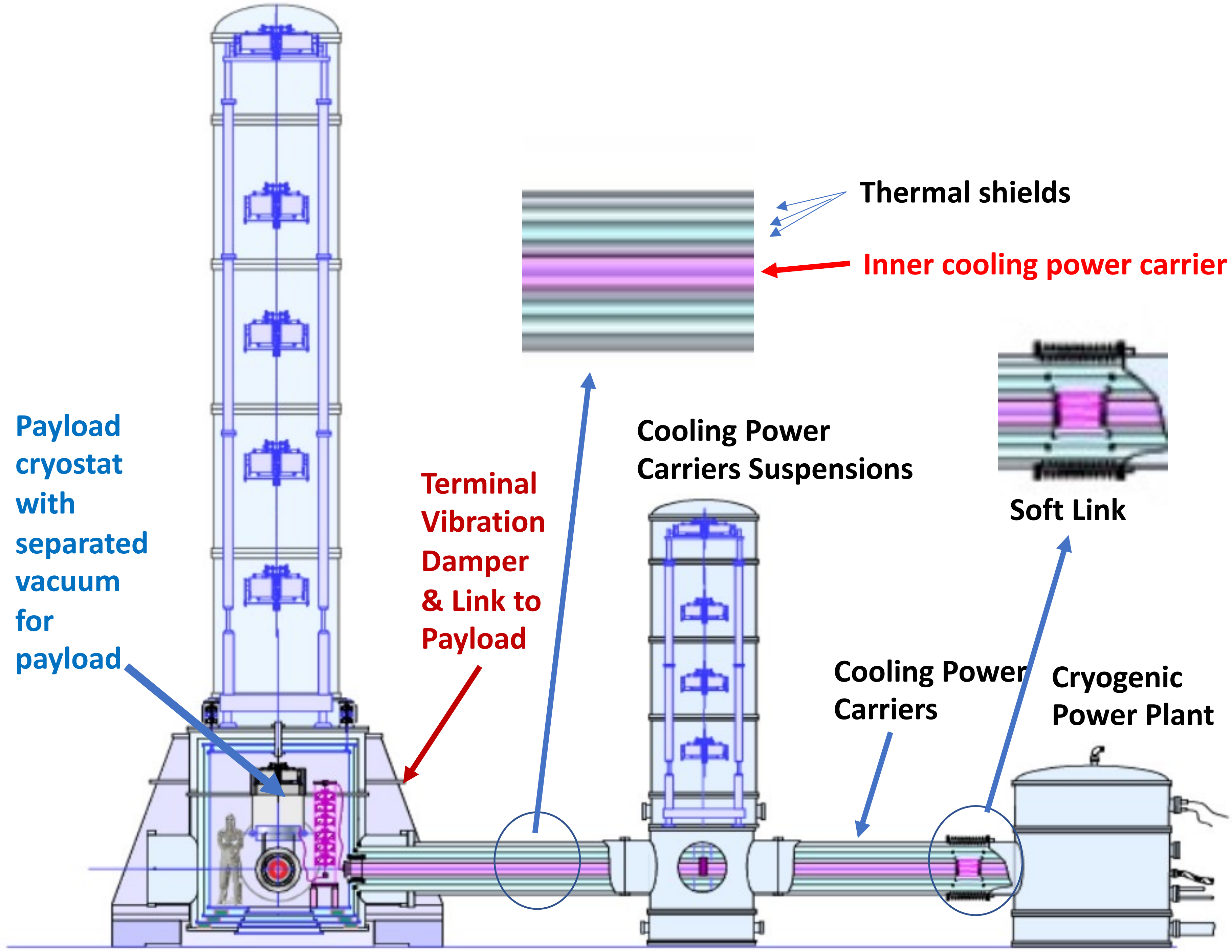
Mirror Control: Superconducting Techniques for mirror sensing and actuation

Prototype of LF-Payload ready and under test in 3 years.

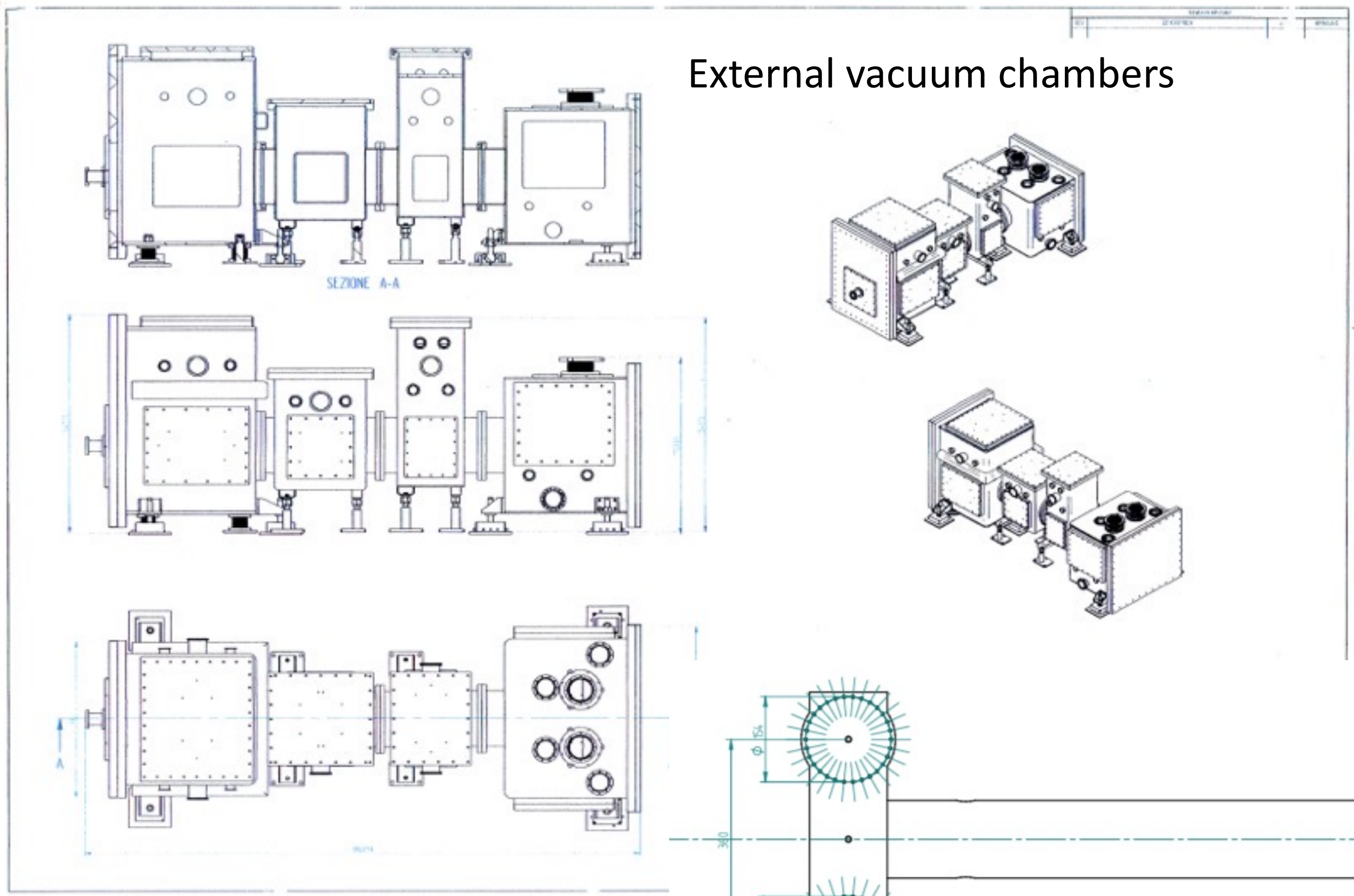
Cryostat protype to be designed in colaboration with KIT

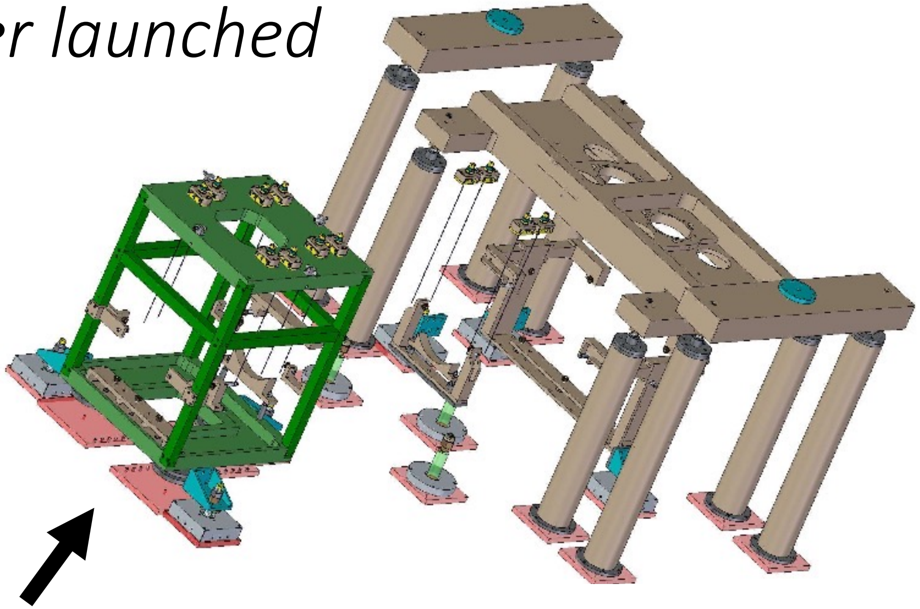
Installation in the new lab of he Amaldi center @ Sapienza university

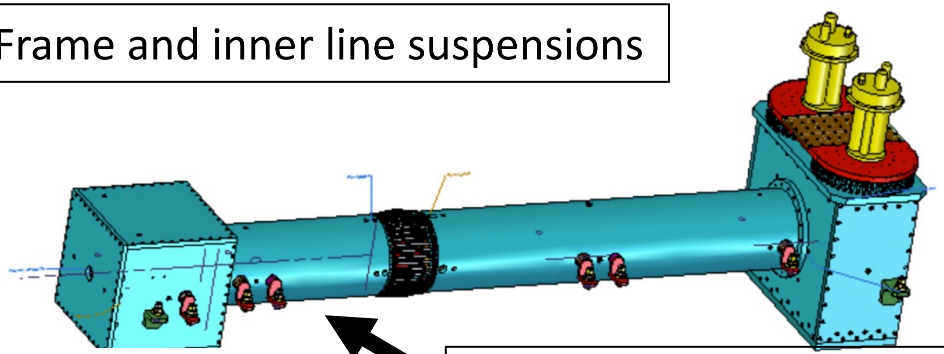
ET LF Scheme

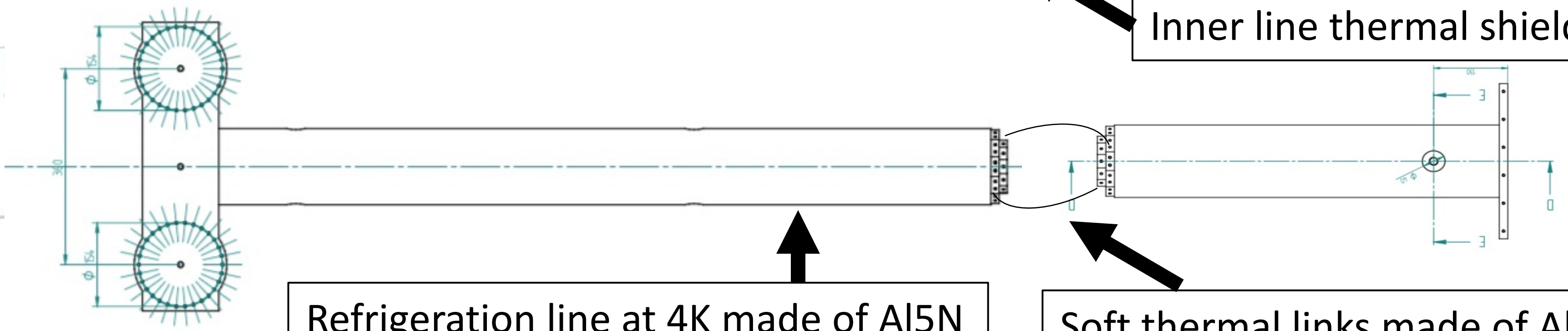

Thermal shields
Inner cooling power carrier
Soft Link
Cooling Power
Carriers Suspensions
Payload
cryostat
with
separated
vacuum
for
payload
Terminal
Vibration
Damper
& Link to
Payload
Cooling Power
Carriers
Cryogenic
Power Plant

ET refrigeration line designed: all the calls for tender launched on July





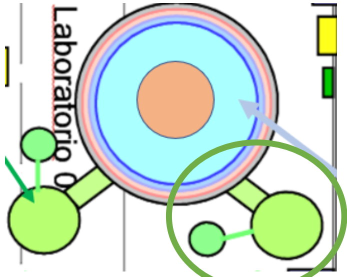


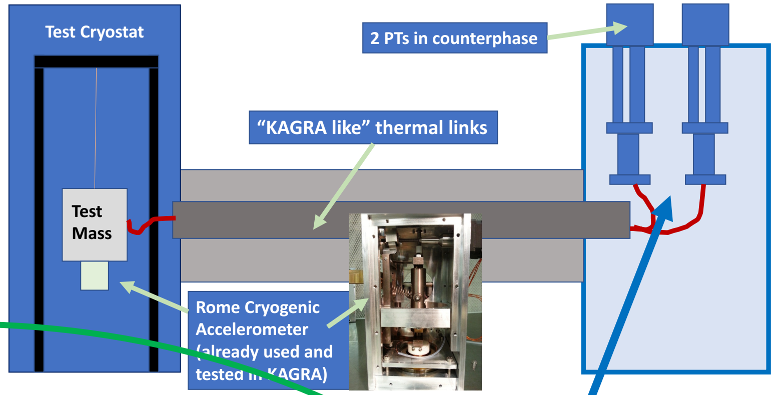


First phase: Pulse Tube Cooling Station *for ET LF-Payload Test Cryostat*

Cryogenic Test Chamber:

- Cooling efficiency,
- Residual vibrations,
- Sensing and actuators testing

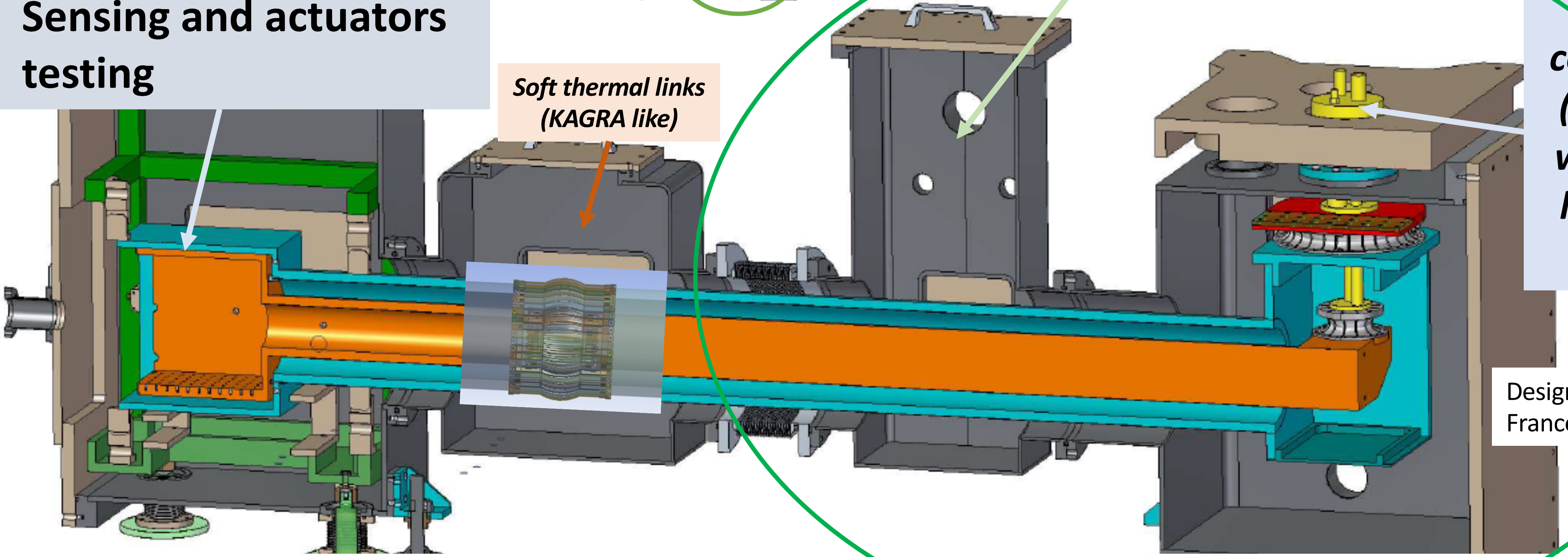




Cryogenic cooling lines suspensions (VIRGO like)

Soft thermal links (KAGRA like)

2 PTs in counterphase (CUORE like) with thermal links in Al5N and Al6N



Design by Antonio Marra, Franco Bronzini;

Call for tender started. Construction starting in June 2021.

Low temperature sensors and vibration control

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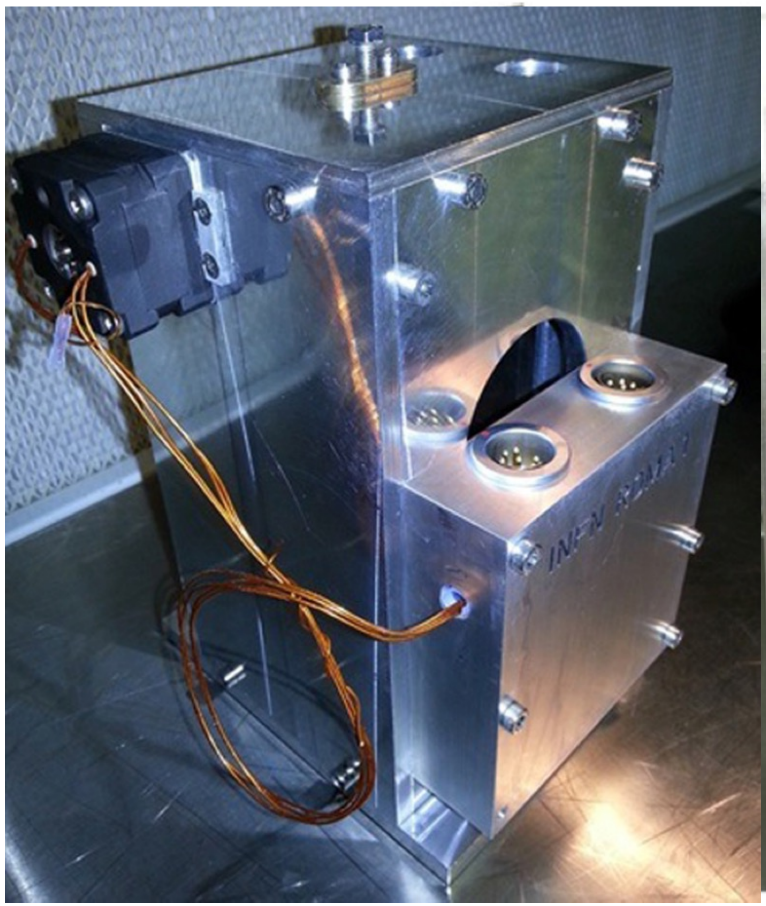
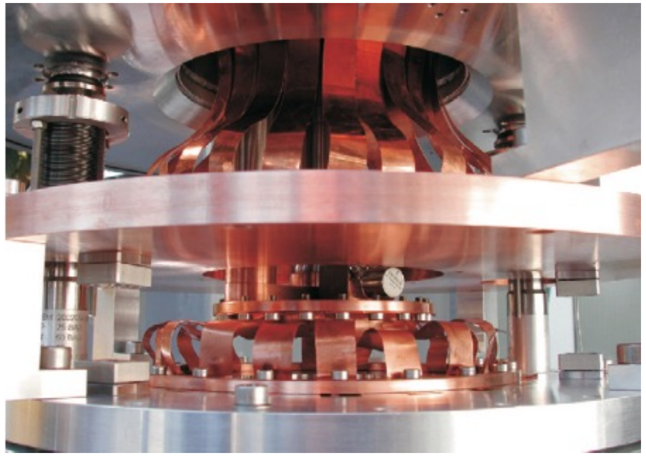
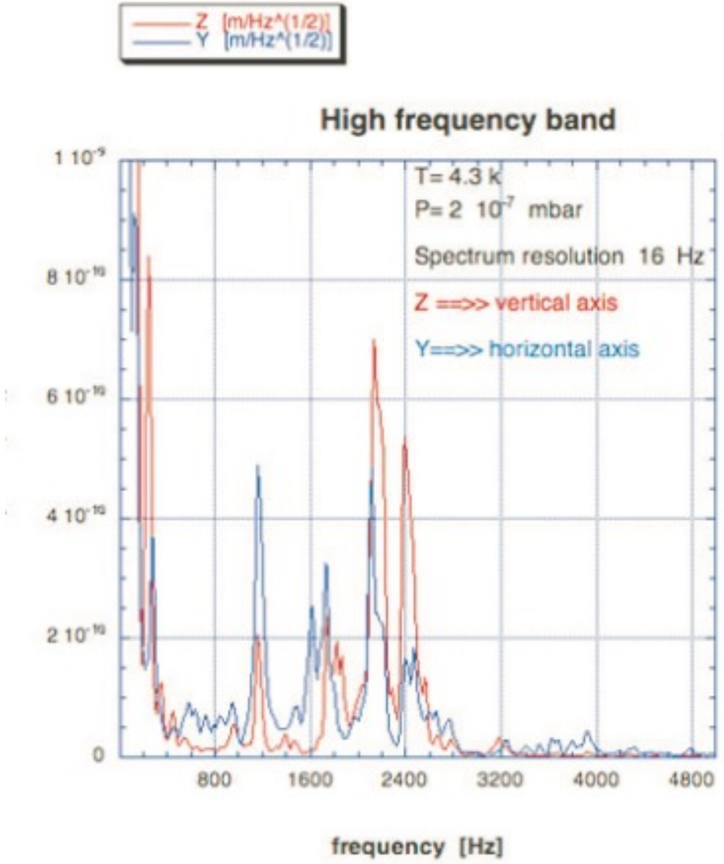


Cryogenic vertical accelerometer used to measure the vibration in the KAGRA Cryostat





Istituto Nazionale di Fisica Nucleare

Call CSN5 2021

VACRET

R&D on Vacuum and Cryogenics
for the Einstein Telescope

VAcuum/Cryogenics/ET

Call tecnologica in CSN5 dell'INFN. Perché?

La risposta alla call tecnologica ha tre scopi

1) Preparare il terreno in un campo dove il know-how INFN è specializzato

2) Interagire con altri esperimenti con caratteristiche simili (quasi tutti quelli facenti uso di grandi infrastrutture VAC-CRYO

3) Fornire soluzioni specifiche, sviluppate in modo agile, testate su piccola scala ma applicabili su grande scala

4) Utilizzare i risultati ottenuti nel quadro della grande collaborazione ET allargata agli altri partner internazionali

VAC: cosa è **dentro** e cosa è al **contorno**

- Il contenuto dei tubi da vuoto **non è oggetto** di VACRET, ne determina i requisiti da raggiungere

- Il metodo di assemblaggio e di back-out **sono** nel programma

- Il materiali, per la costruzione di tubi da vuoto **sono oggetto** del programma (corrosion di lungo termine, degassamento)

- Le superfici e il loro trattamento **sono oggetto** del programma

- L'operazione combinata di VAC e CRYO **è oggetto** di VACRET

CRYO: cosa è **dentro** e cosa è al **contorno**

- Il contenuto dei criostati **non è oggetto** di alcun task di sviluppo del progamma (esempio le test mass o i payload), ma pone severe condizioni

- La struttura dei criostati **è oggetto** del programma (esempio, gli schermi interni devono essere poco influenzati dalle vibrazioni esterne)

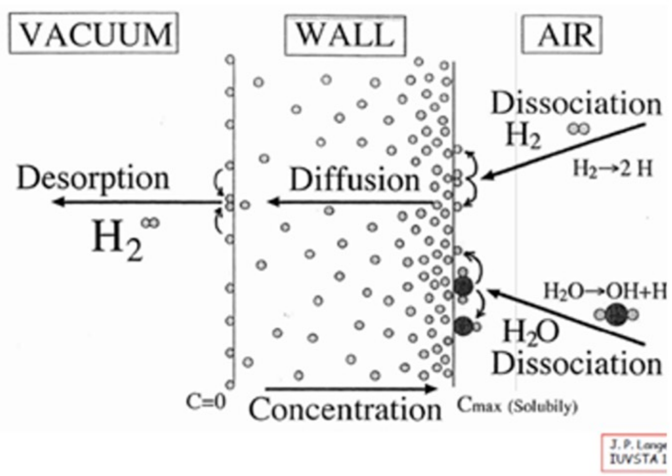
- Le superfici e i materiali del criostato **sono oggetto** del programma (esempio: superfici criogeniche che scambiano calore per radiazione o i materiali di superisolamento termico)

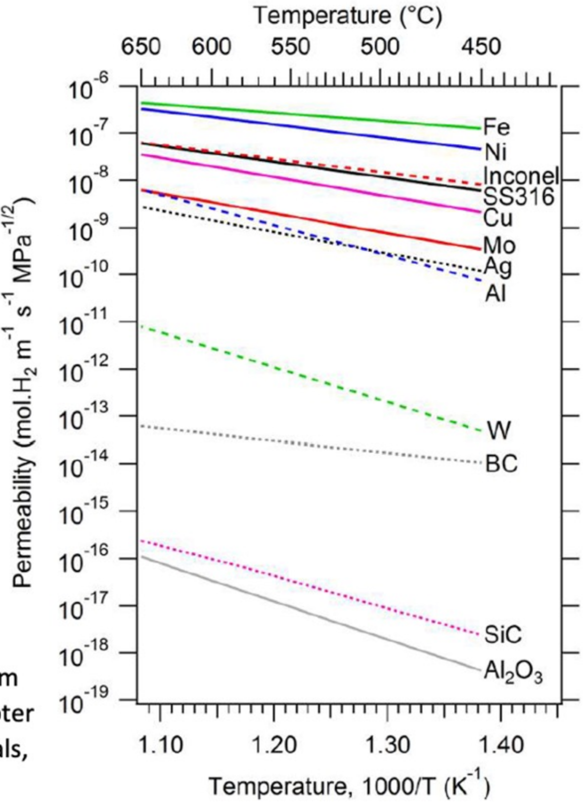
VACRET challenges (outgassing/bake-out)

Reducing the outgassing

1. Ex situ heating at high temperature in vacuum furnace (vacuum firing)
2. Passive coating also defined as Hydrogen Permeation Barrier (HPB)
3. Active coating (getter materials)

Below, Hydrogen permeability scheme
P. Michelato, Vacuum technology advanced lessons, December 12 - 14, 2016





Right, R.A. Causey, R.A. Karnesky, C. San Marchi, "Tritium Barriers and Tritium Diffusion in Fusion Reactors", Chapter in: R.J.M. Konings (Ed.) Comprehensive Nuclear Materials, Elsevier, Oxford, 2012, pp. 511-549.

Bake-out systems

Can we avoid in situ ?

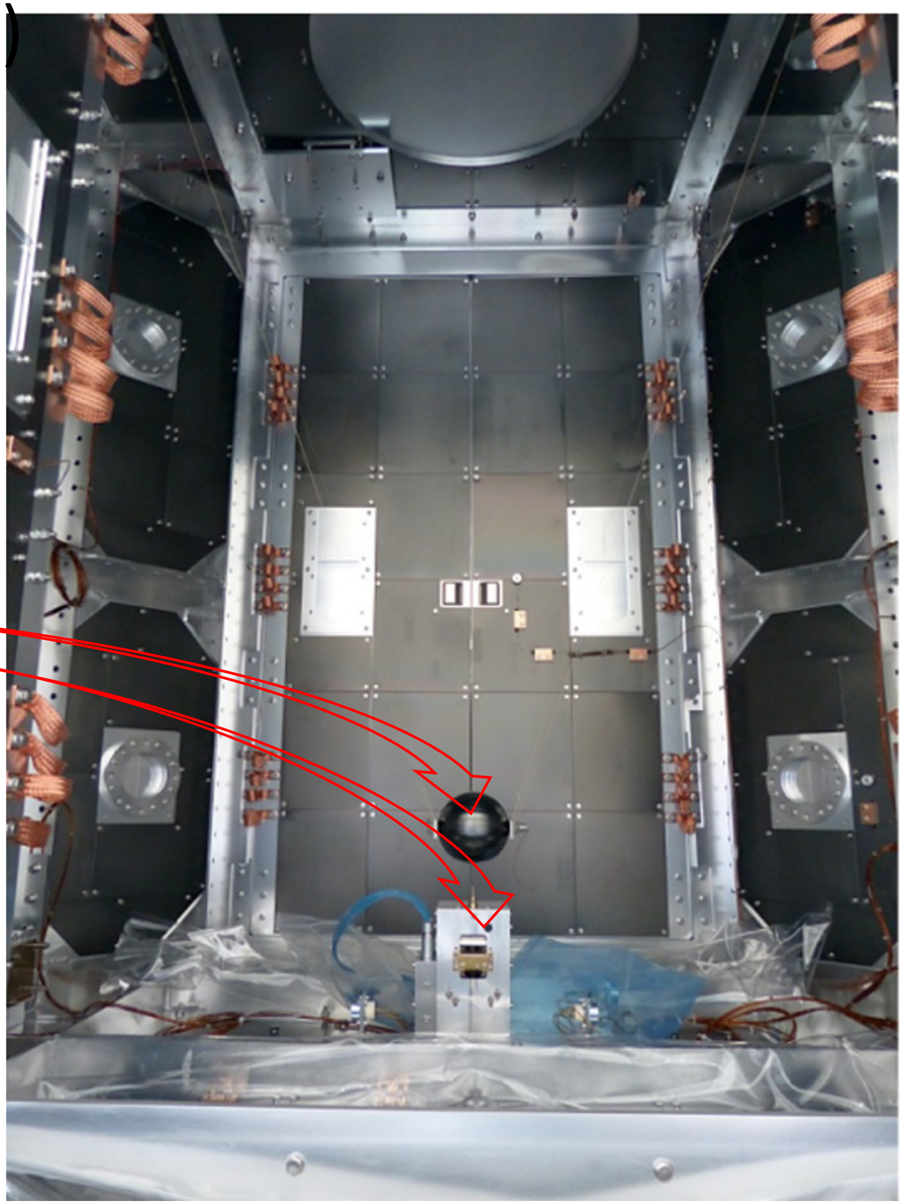
Can we envisage a cost effective technique ?

KAGRA solution, seems non-portable to large scale (must be evaluated)

The VAC-CRYO system VS its guests
(core elements of large detector are strongly affected)

Notice: UHV and cryogenic environment adopting thermal shields (involved in radiation cooling o of test masses) have very different overall requirements (even conflicting if the outgassing is considered)

Thermal emissivity and vibration studies

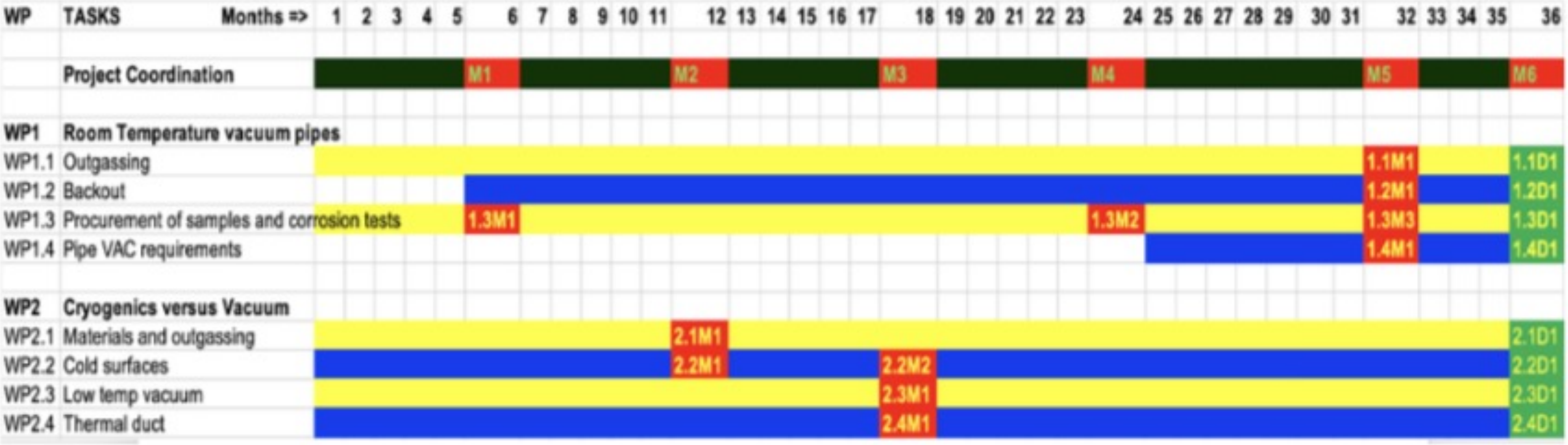


Nell’ambito di VACRET

- le proprietà superficiali potranno essere caratterizzate sia riguardo la componente VAC che quella CRYO.
- Il modello strutturale dei criostati verrà simulato per fornire le line guida

The group of laboratories and the planned activity

The project in a glance



Name PI= Principal Inv LR = Local Resp. WP = WP coord	Affiliation (Associate /Employee-Permanent/Temp)	Position	FTE (%)/year	Task engagement (if not specified all the tasks of the WP)
Ettore Majorana **PI**	INFN Roma (AP)	Professor	15	
Angelo Cruciani **LR,WP**	INFN Roma (EP)	Technologist	15	WP2.3, WP2.4
Mangano Valentina	INFN Roma (AT)	Contract	20	WP2.1, WP2.2, WP2.4
Naticchioni Luca	INFN Roma (EP)	Researcher	10	WP2.4
Rapagnani Piero	INFN Roma (AP)	Professor	10	WP2.1,WP2.3, WP2.4
Fulvio RIcci	INFN Roma (AP)	Professor	0	WP2.1, WP2.4
Aniello Grado **LR, WP**	INFN Napoli (AP)	Lead Research (INAF)	30	WP1
Valeria Sequino	INFN Napoli (AT)	Contract	20	WP1.1, WP1.2, WP1.3
Andrea Liedl **LR**	INFN LNF (ET)	Technologist	20	WP1, WP2.2
David Alesini	INFN LNF (EP)	Lead Technologist	10	WP1
Simone Bini	INFN LNF (EP)	Technologist	10	WP1
Fara Cioeta	INFN LNF (EP)	Technologist	10	WP1
Roberto Cimino	INFN LNF (EP)	Lead Researcher	10	WP1.1
Marco Angelucci	INFN LNF (ET)	Technologist	20	WP1
Luisa Spallino	INFN LNF (ET)	Contract	20	WP1.1
Giovanni Delle Monache	INFN LNF (EP)	Technologist	20	WP1
Luisa Sabbadini	INFN LNF (EP)	Technologist	10	WP1
Oscar Azzolini	INFN LNL ( )	Technologist	10	WP2.2, WP1.1
Paolo Favaron	INFN LNL (EP)	Lead Technologist	15	WP1.1, WP1.2, WP1.4
Giorgio Keppel **LR**	INFN LNL (EP)	First Technologist	10	WP2.2, WP1.1
Cristian Pira	INFN LNL (EP)	Technologist	10	WP2.2, WP1.1
Antonio D'Addabbo **LR**	INFN LNGS (EP)	Technologist	20	WP2.4
Miriam Olmi	INFN LNGS (EP)	Contract	20	WP2.4
Paolo Gorla	INFN LNGS (EP)	Researcher	10	WP2.4
Carlo Bucci	INFN LNGS (EP)	First Researcher	10	WP2.4

Financial requests

	Roma	Frascati	Legnaro	GranSasso	Napoli	GrandTotal
Personale	31	62	31	25	25	
Services			10			
Cons/Inv	20	36	30	30	20	
Miss	10	10	10	10	10	
Personale	31	31	31	25	25	
Services	0		8			
Cons/Inv	30	22	20	30	30	
Miss	12	12	10	10	12	
Personale	31	0	31	25	25	
Services						
Cons/Inv	24	22	20	30	30	
Miss	10	10	10	10	12	
Tot	199	205	211	195	189	999
FTEs						
FTE/y	0.7	1.3	0.55	0.6	0.5	
REQ-FTE_1	1	2	2	1	1	
REQ-FTE_2	1	1	1	1	1	
REQ-FTE_3	1	0	0	1	1	
Total PROJ F	**5.1**	**6.9**	**4.65**	**4.8**	**4.5**	
overall/y						
1st year	1.7	3.3	2.55	1.6	1.5	**10.65**
2nd year	1.7	2.3	2.55	1.6	1.5	**9.65**
3rd year	1.7	1.3	2.55	1.6	1.5	**8.65**

Thank you for the attention