



PAOLA PUPPO – INFN ROMA

VACUUM FLUCTUATIONS AT  
NANOSCALE AND GRAVITATION:  
THEORY AND EXPERIMENTS

APRIL 28<sup>TH</sup>-MAY 3<sup>RD</sup> 2019 – OROSEI  
(SARDINIA), ITALY

# THE ARCHIMEDES EXPERIMENT

- INFN sezione di Napoli – Laboratorio Fisica della Gravitazione Univ. Federico II
- INFN sezione di Roma1 – Univ. La Sapienza Roma
- INO sezione di Napoli
- Université de Aix-Marseille Centre de Physique Théorique de Luminy  
Institut Universitaire de France
- EGO European Gravitational Observatory - Italy

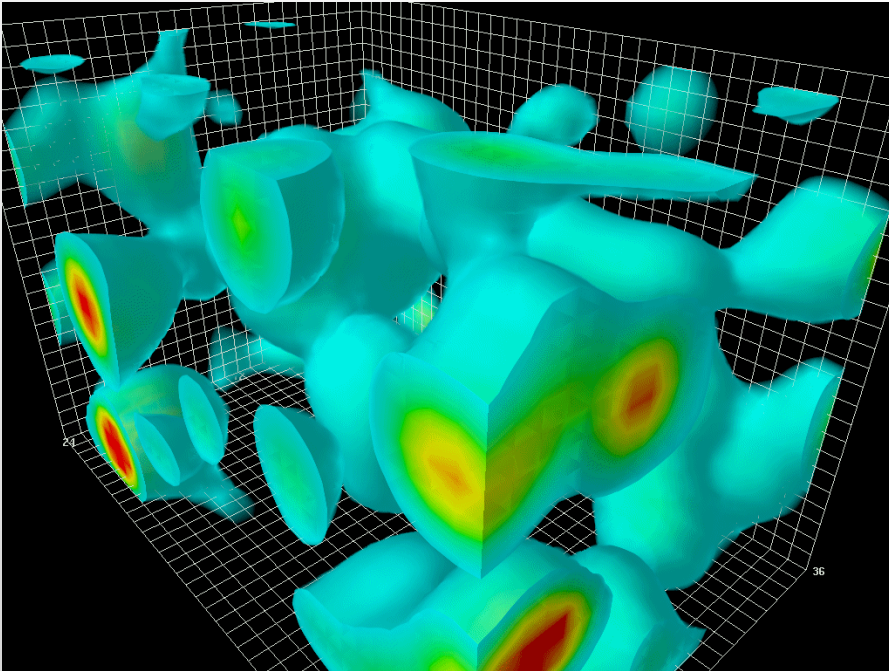
ARCHIMEDES IS SINCE 2018 AN EXPERIMENT FUNDED BY INFN

# SCIENTIFIC MOTIVATIONS AND GOAL OF THE EXPERIMENT

**DOES VACUUM FLUCTUATIONS INTERACT WITH GRAVITY?**

**DOES THE VACUUM STRESS GRAVITATES?**

**DOES VACUUM WEIGHS?**



The theoretical understanding and experimental evidences are still not completely satisfactory

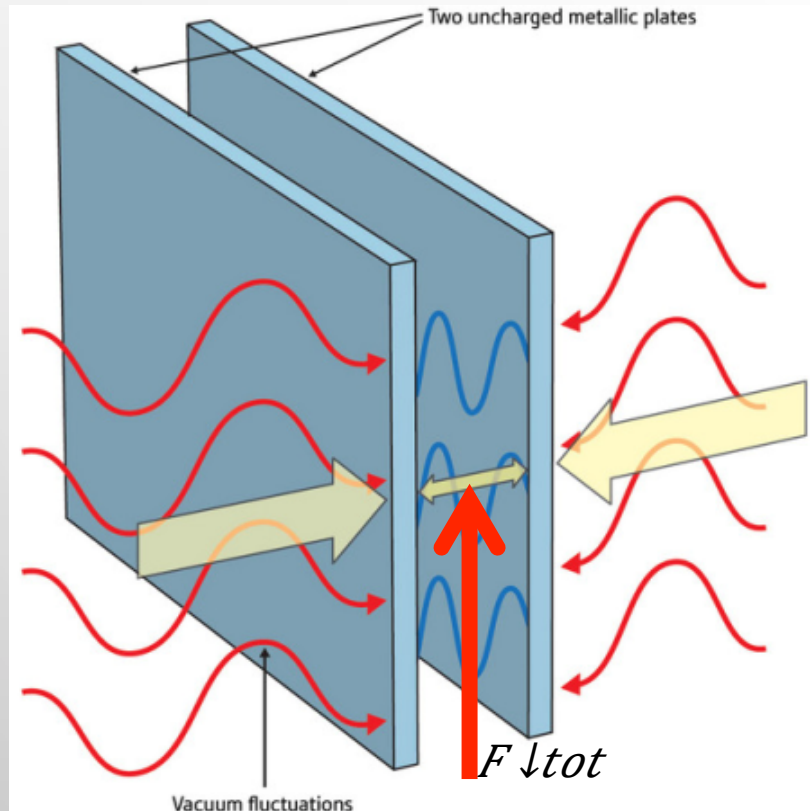
$$\sum \frac{1}{2} \hbar \omega \quad \longrightarrow \quad \infty$$



# THE VACUUM WEIGHT

The Casimir effect is one of the macroscopic manifestations of vacuum fluctuations.

If the vacuum «weighs» then there is a force, directed upward, equal to the weight of the modes expelled from the cavity. In analogy with the Archimedes force.



$$F_{tot} = -\frac{dE_c}{dC}$$

$E_c$ : Casimir Energy

# HOW TO MEASURE THE VACUUM WEIGHT?

THE IDEA IS TO

**MODULATE THE VACUUM ENERGY OF A RIGID CASIMIR CAVITY**

BY CHANGING THE REFLECTIVITY OF THE PLATES WITH TIME

Use **high  $T_c$  layered superconductors** (like YBCO) as natural multi Casimir-cavities.

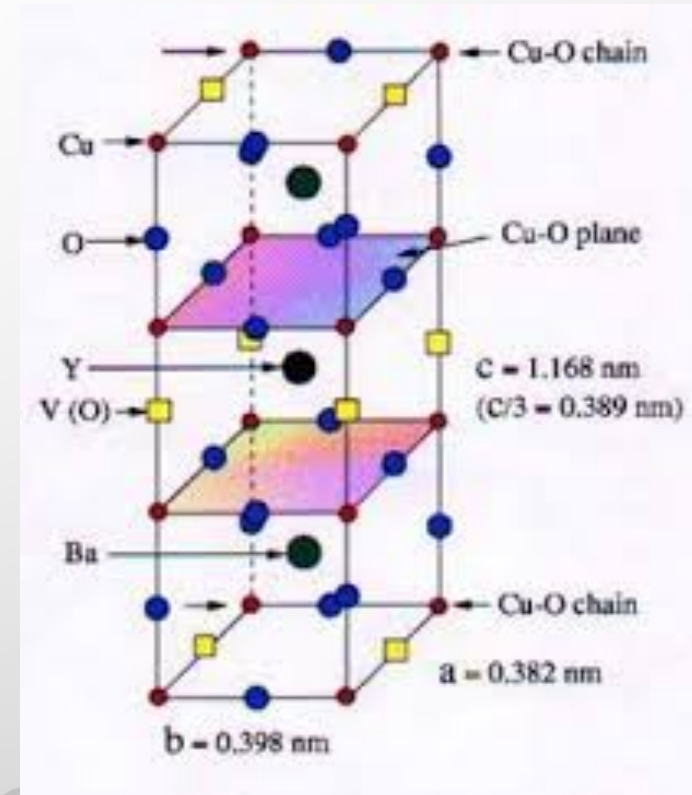
The planes have high trasmittivity also in the superconducting state, plasmonic modes are expected to give the highest contribution, the multilayer effect could enhance the radiation part like a sort of 'in multilayer coating mirrors' (see L. Rosa presentation of Monday 29th)

Profit of the fact that in normal state the plane that will become superconducting is a very poor conductor.

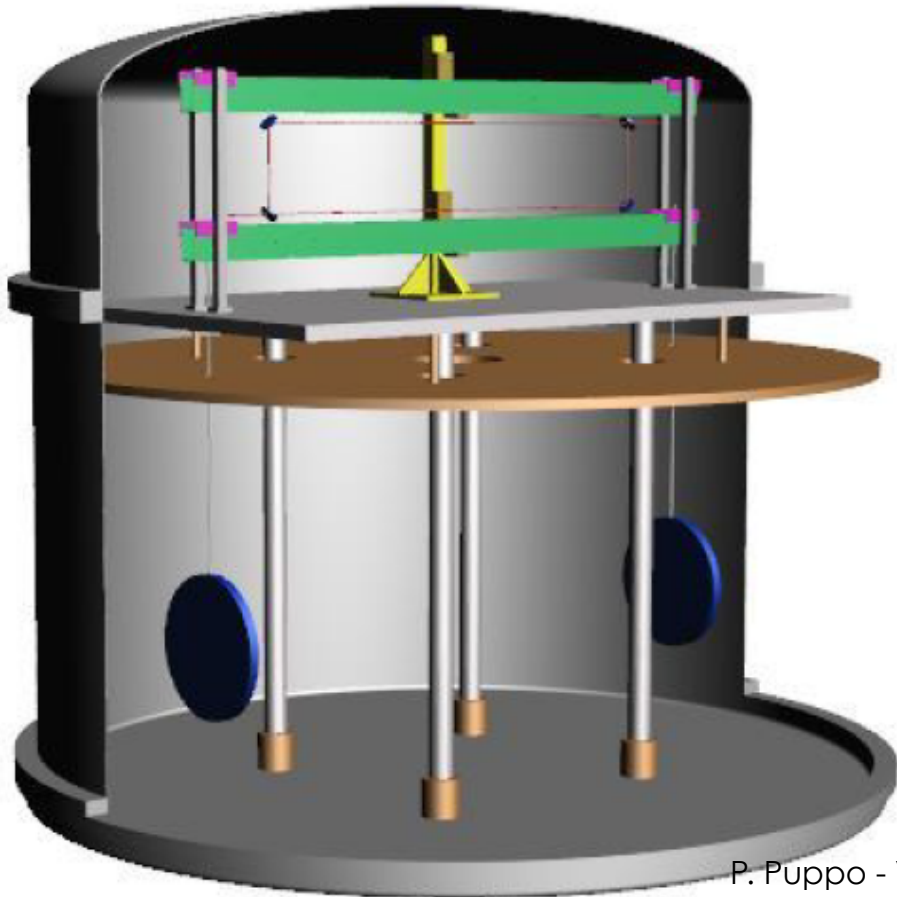
→ high variation of Casimir energy at the transition

**Expected upward force  $10^{-16}$  N**

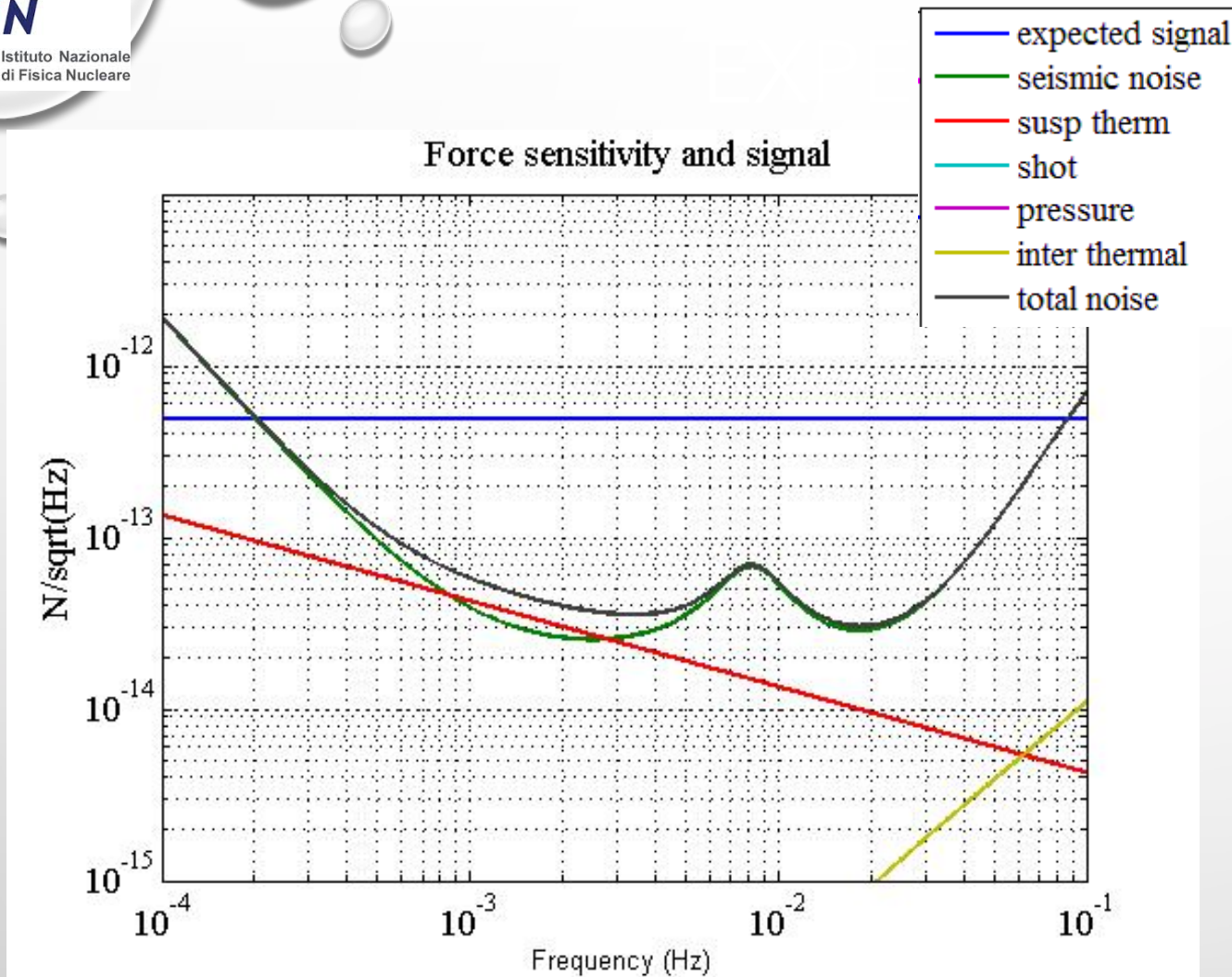
(\*)Negative weight of the condensation energy



# THE MEASUREMENT STRATEGY



- High Sensitivity Balance: arm center of mass and suspension point must be well positioned (within 4mm)
- Temperature modulation around  $T_c$
- Quiet environment: low human activity (Newtonian noise) and low seismic noise
- Interferometric Readout



- High Sensitivity Balance
- Temperature modulation around  $T_c$
- Seismically quiet place for the experiment site

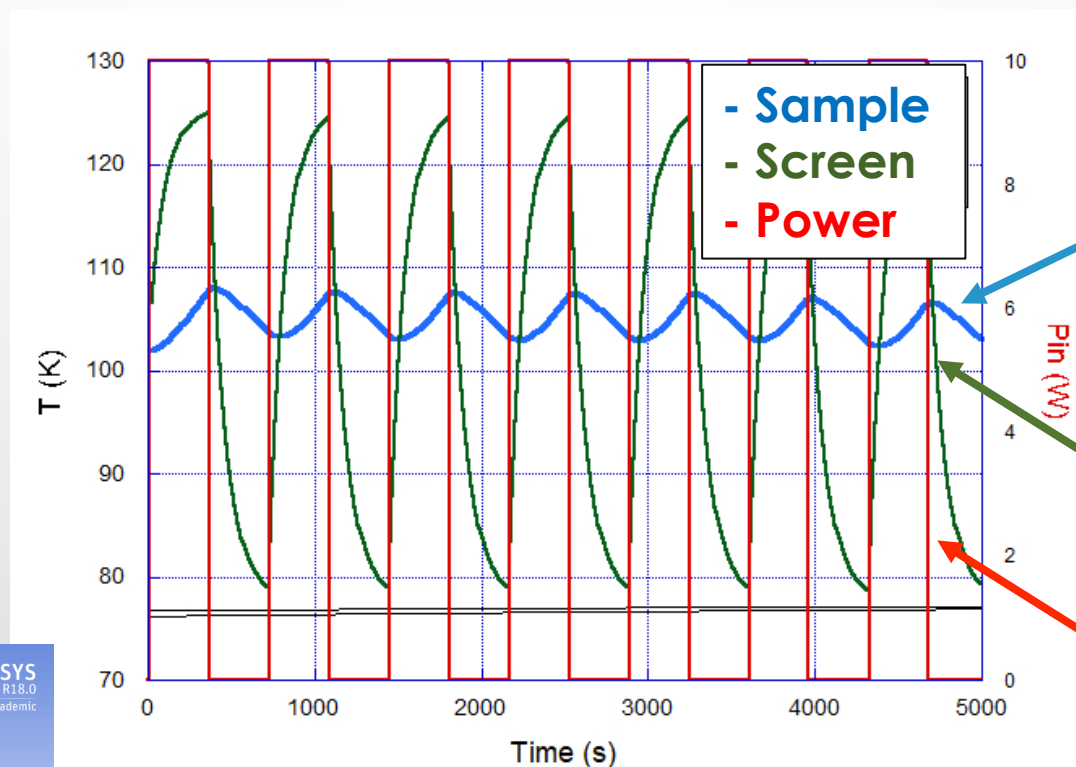
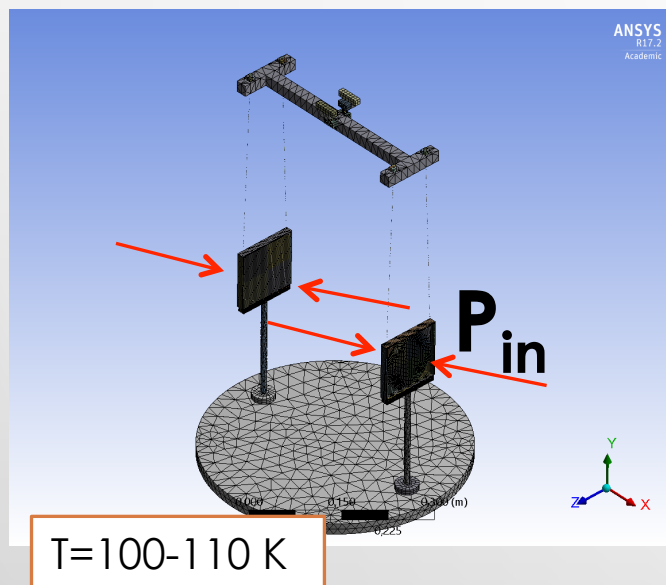
This sensitivity is for 1 months of integration time ( $10^6$  s)

Limited by : thermal noise and seismic noise



# Thermal modulation

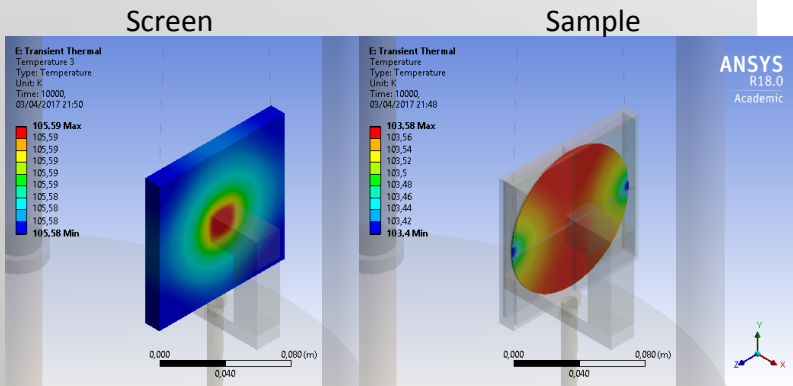
- The thermal modulation must be done by radiative exchange between the sample and a screen which surrounds it.
- The frequency modulation and their amplitude around  $T_c$  depend on the thermal properties of the materials
- A finite element study is important for the geometry definition and the material choice.



Sample T amplitude 8K

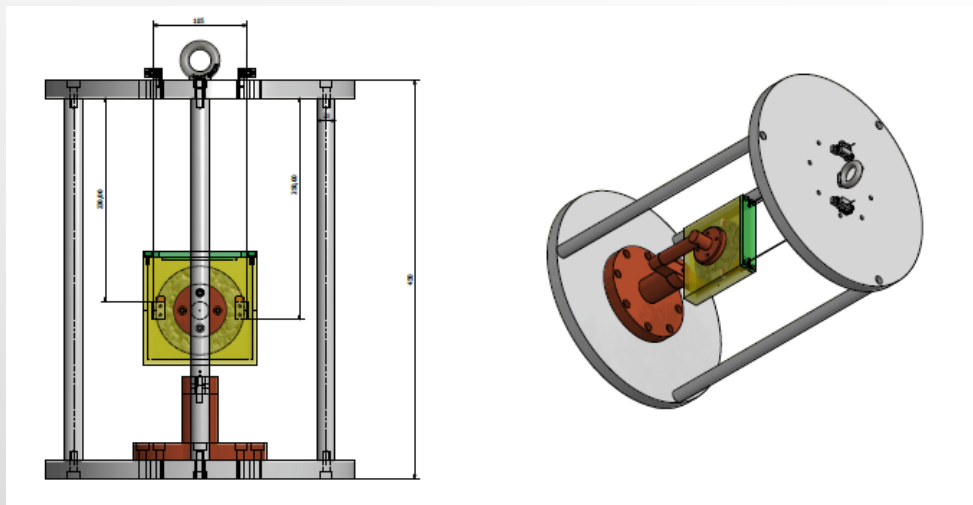
Screen T Amplitude 40K

Max Input Power 10W





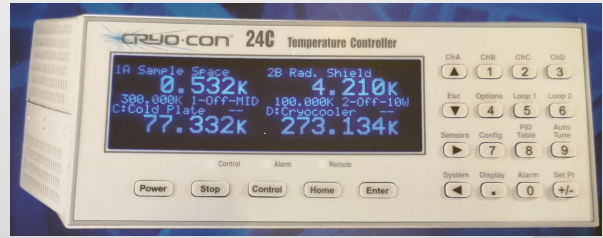
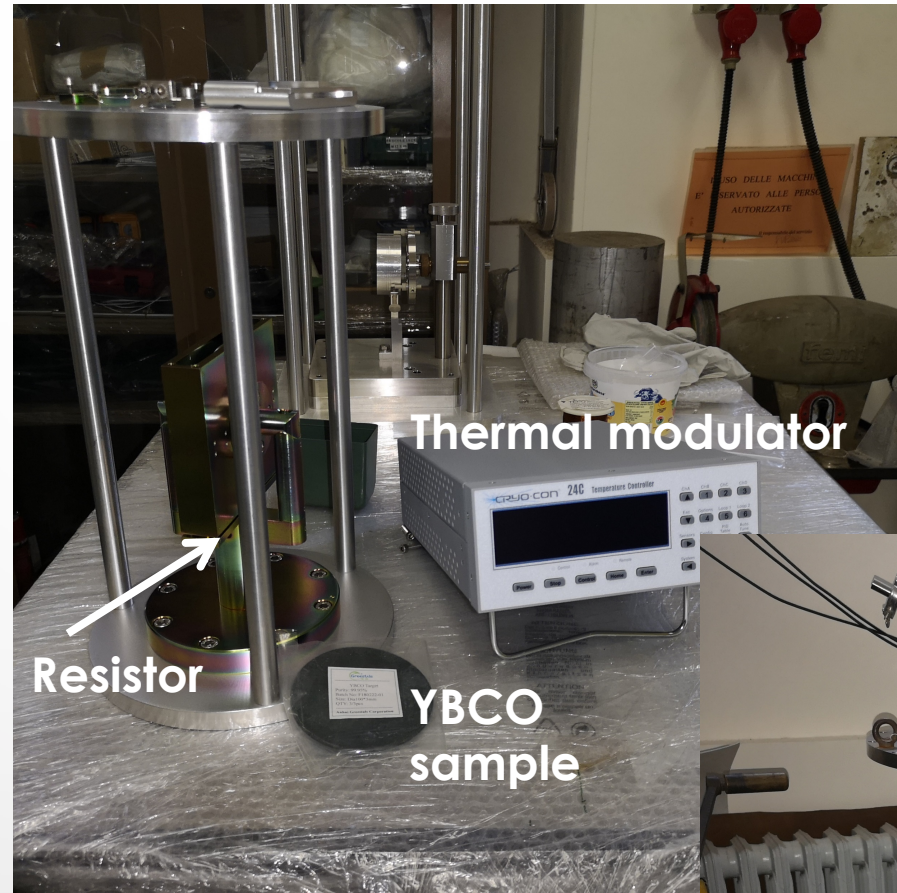
# Thermal Modulation Tests



Thermal modulation system is tested in a small vacuum chamber in Rome Laboratory.

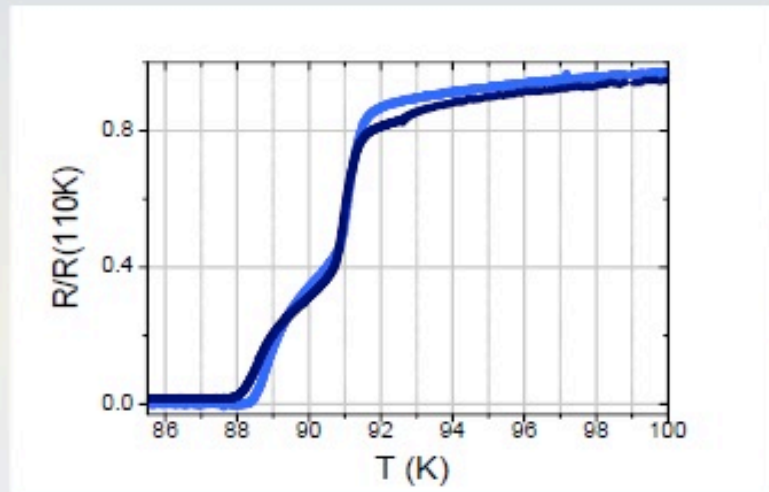
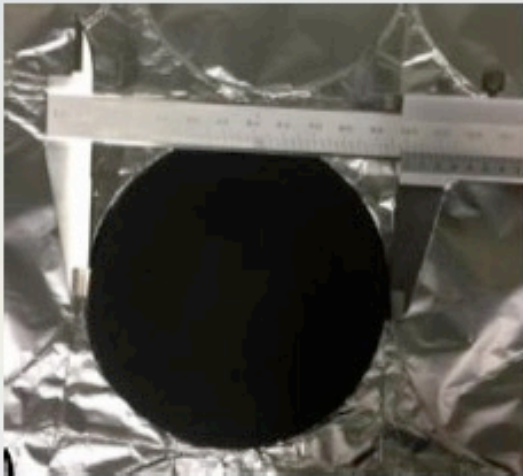
YbCO diam. 100mm thickness 3mm

As a test of the method, a resistance (max. 20 W) will be used to heat the screen



# Large diameter superconductor discs

- Large YBCO discs are produced (CAN Superconductors)
- Tests on custom samples with diameter 10 cm, thickness 3 mm
- Sufficient uniformity
- Transition width too large
- Further investigation are being done with other samples.

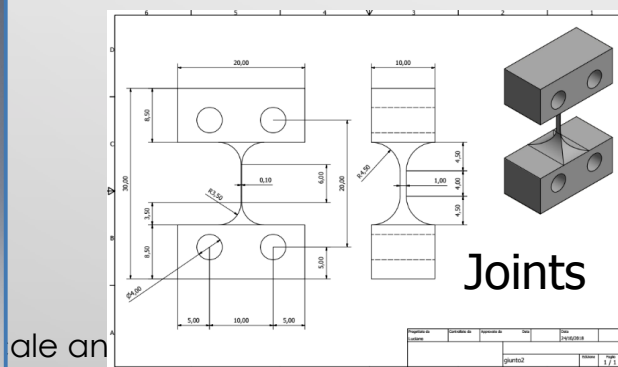
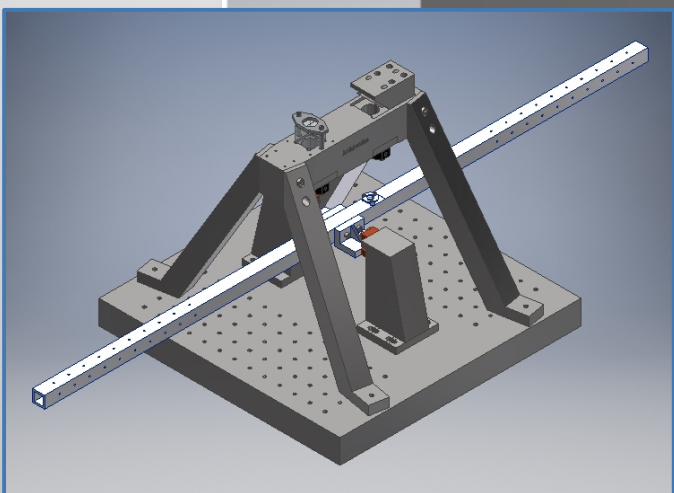
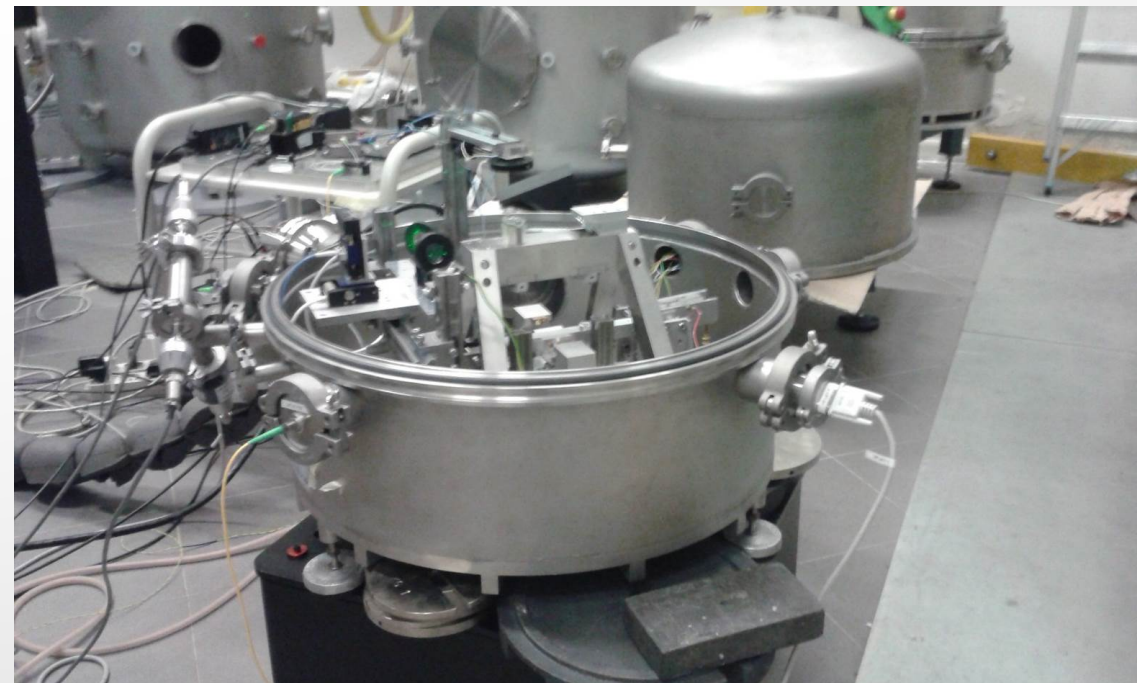
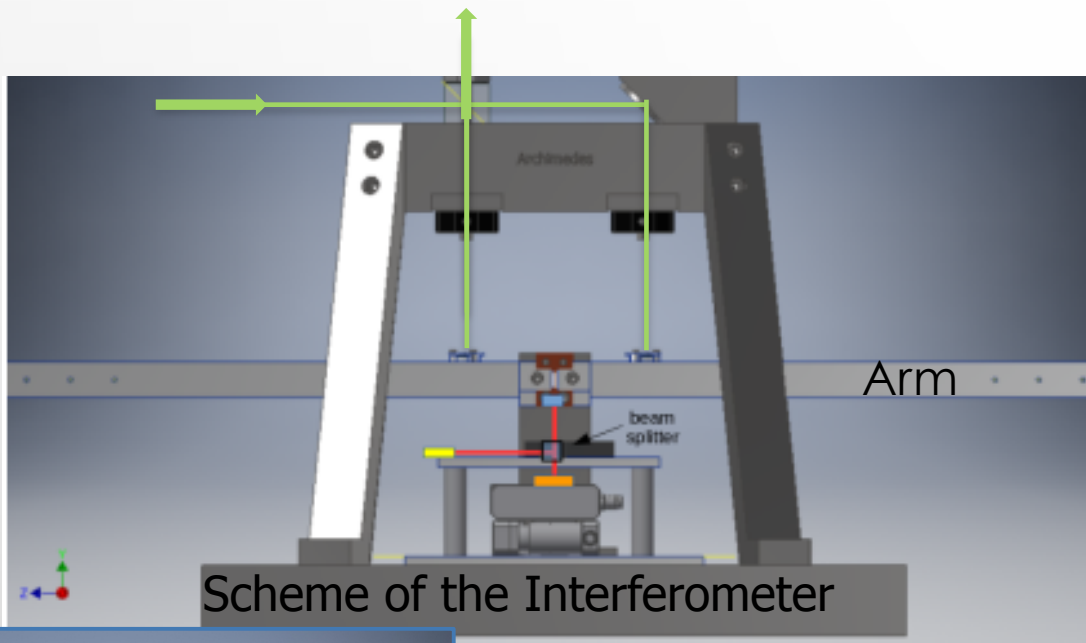




# THE BALANCE

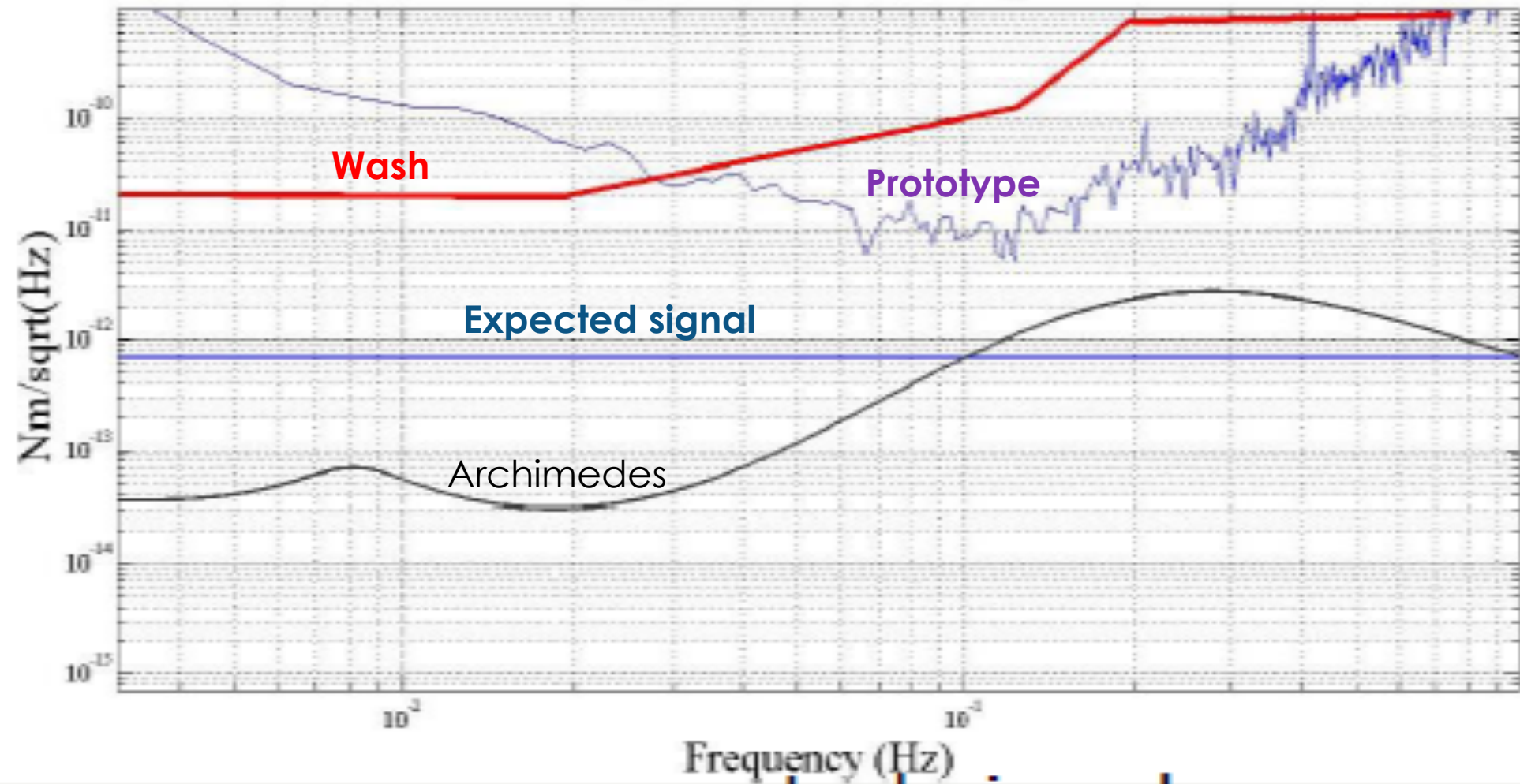
THE BALANCE IS SUSPENDED WITH VERY SOFT FLEXURAL JOINTS

→ HIGH FREQUENCY NOISE LOWERED AND HENCE LOCKING ON THE INTERFEROMETER IS POSSIBLE

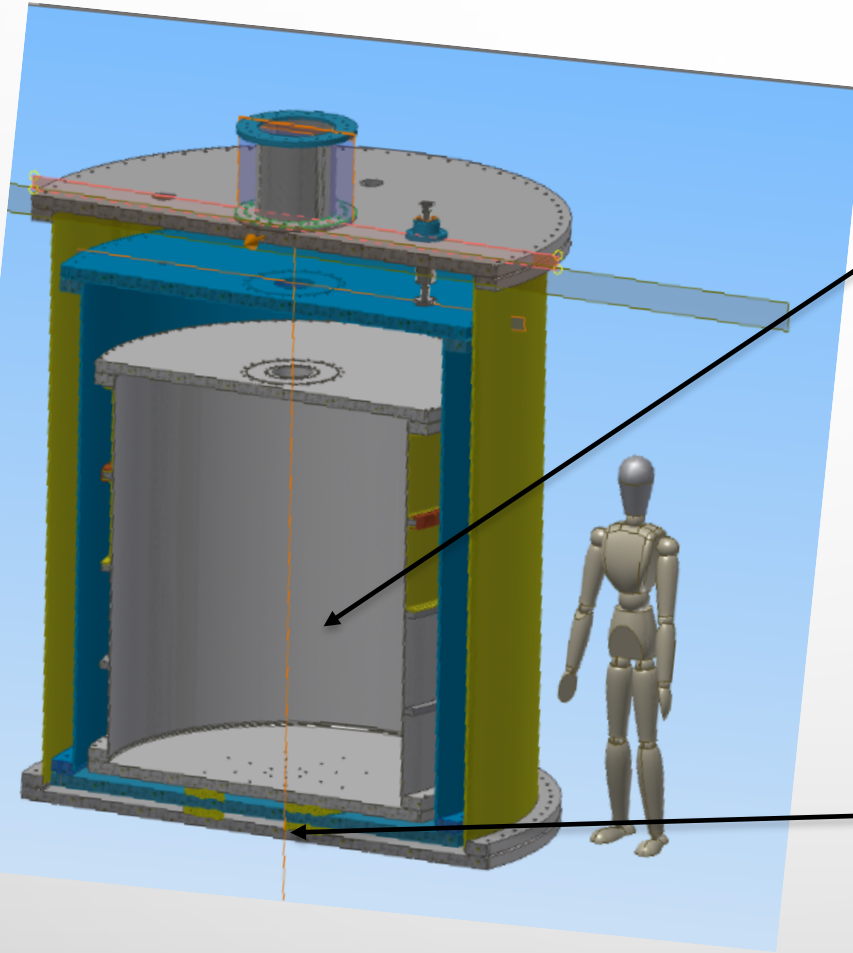


- Total arm length: 1 m
- Base dimensions: 40 cm x 40 cm
- Total height : ~35 cm (~15 cm only the balance)
- More details in the talk of L. Errico on Friday

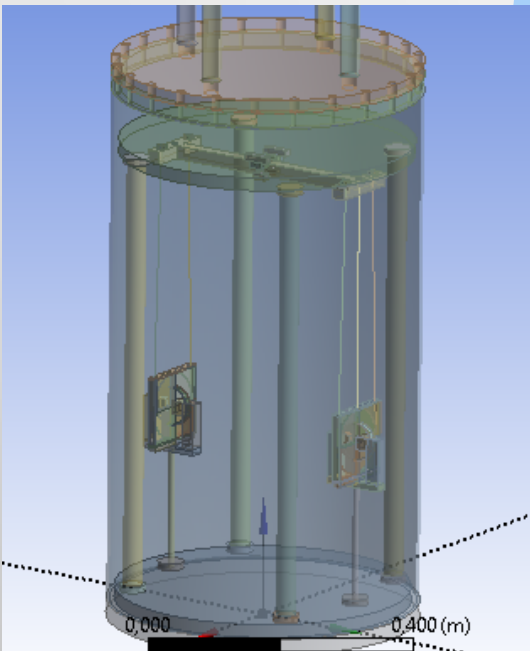
## Torque sensitivities and signal



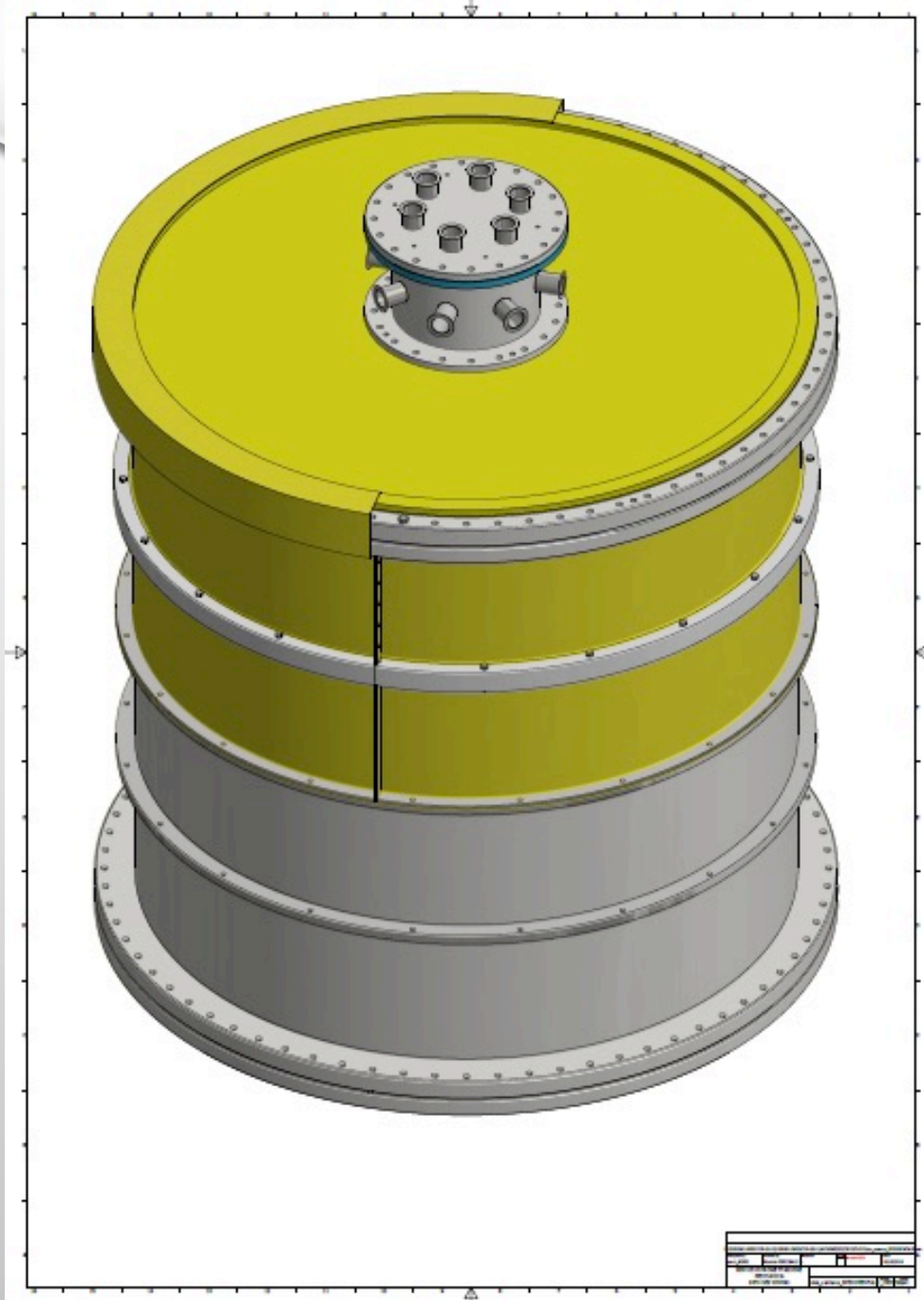
# DESIGN AND REALIZATION OF THE CRYOSTAT



- BIG CRYOSTAT FOR THE EXPERIMENTAL APPARATUS (3M DIAMETER, 3.5 M HEIGHT)
- THE INNERMOST CHAMBER OF THE CRYOSTAT WILL HOUSE THE ARCHIMEDES EXPERIMENT
- IT WILL BE COVERED BY 4000 L OF NITROGEN
- WITH THERMAL INPUT OF ABOUT  $2\text{W/M}^2$  5 MONTHS EVAPORATION TIME.
- EQUIPPED WITH A HEATER (KW) PLACED AT THE BOTTOM OF THE EXPERIMENTAL CHAMBER AND IN A BATH IN THE CRYOGENIC LIQUID







## Phase I

2019: as a first step the inner vacuum chamber will be built and then the experimental system composed by the balance and the thermal modulation system will be tested in it.

**The whole cryostat will be ready by the end of 2020.**

# NEED A QUIET SITE!

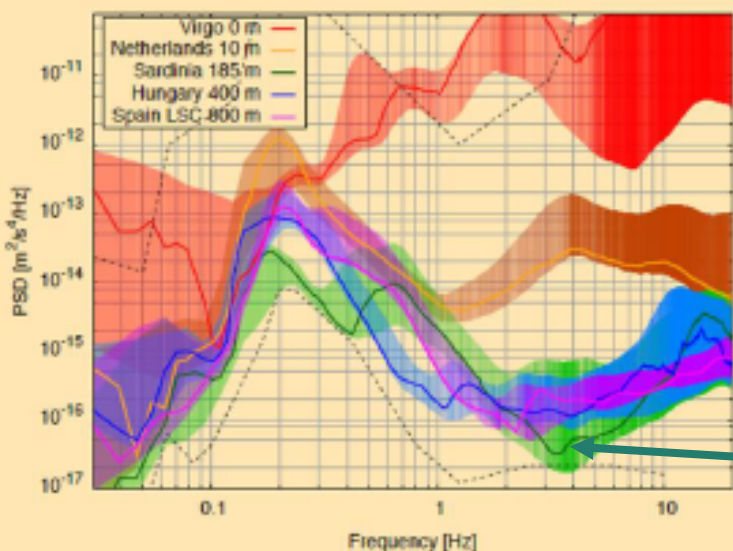
## NO SEISMIC – NO ANTHROPIC NOISE



Former metal mine at SOS –  
ENATTOS, Lula (Nu) Sardinia  
521m above sea level  
**SARGRAV LAB –**  
110m underground



Horizontal spectral motion at various sites



One of the candidate sites for third  
generation GW interferometers like ET.

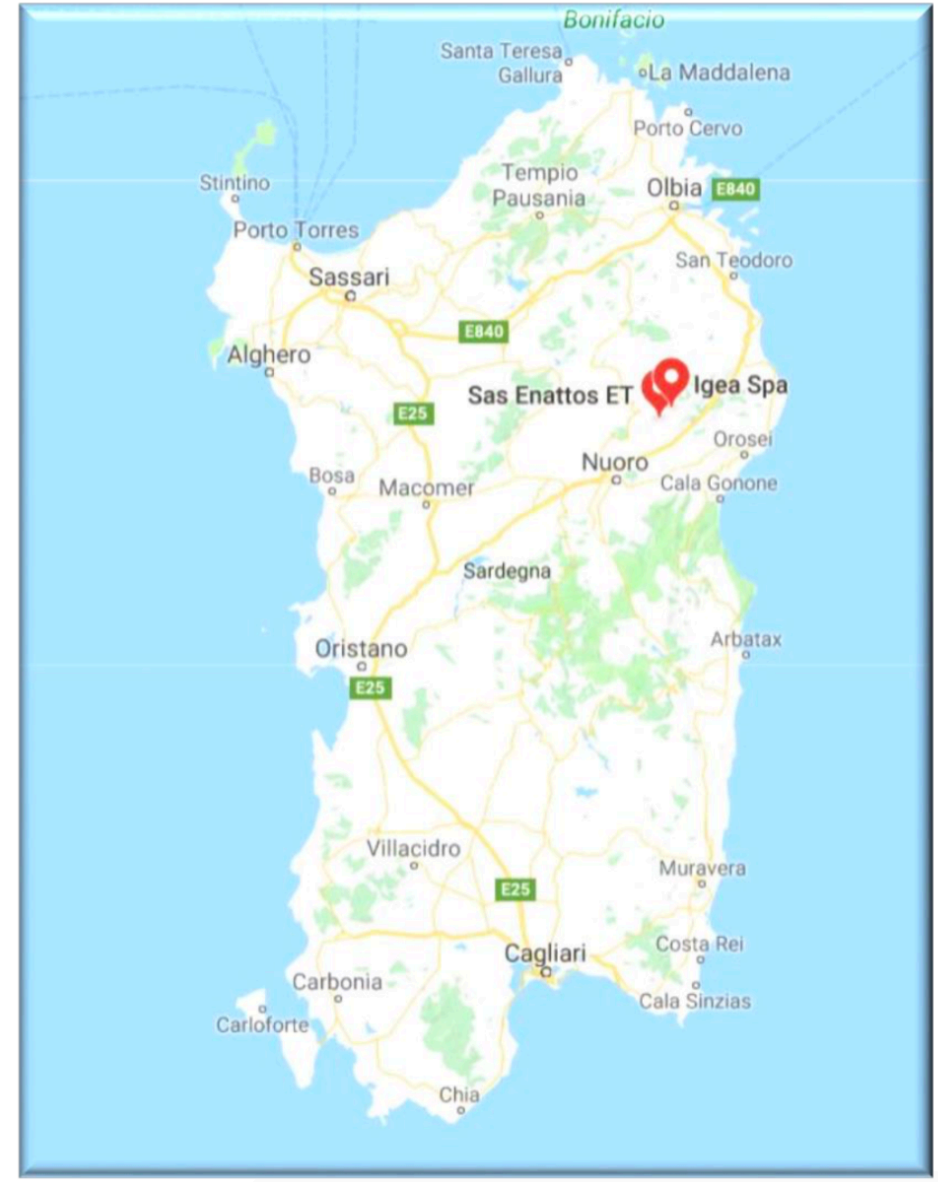
Seismic Measurements  
By Virgo and ET collaborations

**SOS ENATTOS**



# HISTORICAL HINTS

- ❑ MINING EXPLOITATION OF THE AREA STARTED MORE THEN 2000 YEARS AGO
- ❑ FROM 1996 THE MINE INFRASTRUCTURE IS MAINTAINED BY IGEA S.P.A
- ❑ SINCE 2010 SEVERAL UNDERGROUND MEASUREMENT CAMPAIGNS HAVE BEEN CARRIED OUT TO CHARACTERIZE THE SITE IN TERMS OF ENVIRONMENTAL NOISE
- ❑ IN 2017 WAS CHOSEN AS THE SITE FOR SAR-GRAV LABORATORY HOSTING HIGH PRECISION GRAVITATIONAL EXPERIMENTS OPERATING IN UNDERGROUND SITE
- ❑ IN 2018 WAS SELECTED AS ONE OF THE CANDIDATES SITE TO HOST THE FUTURE EINSTEIN TELESCOPE

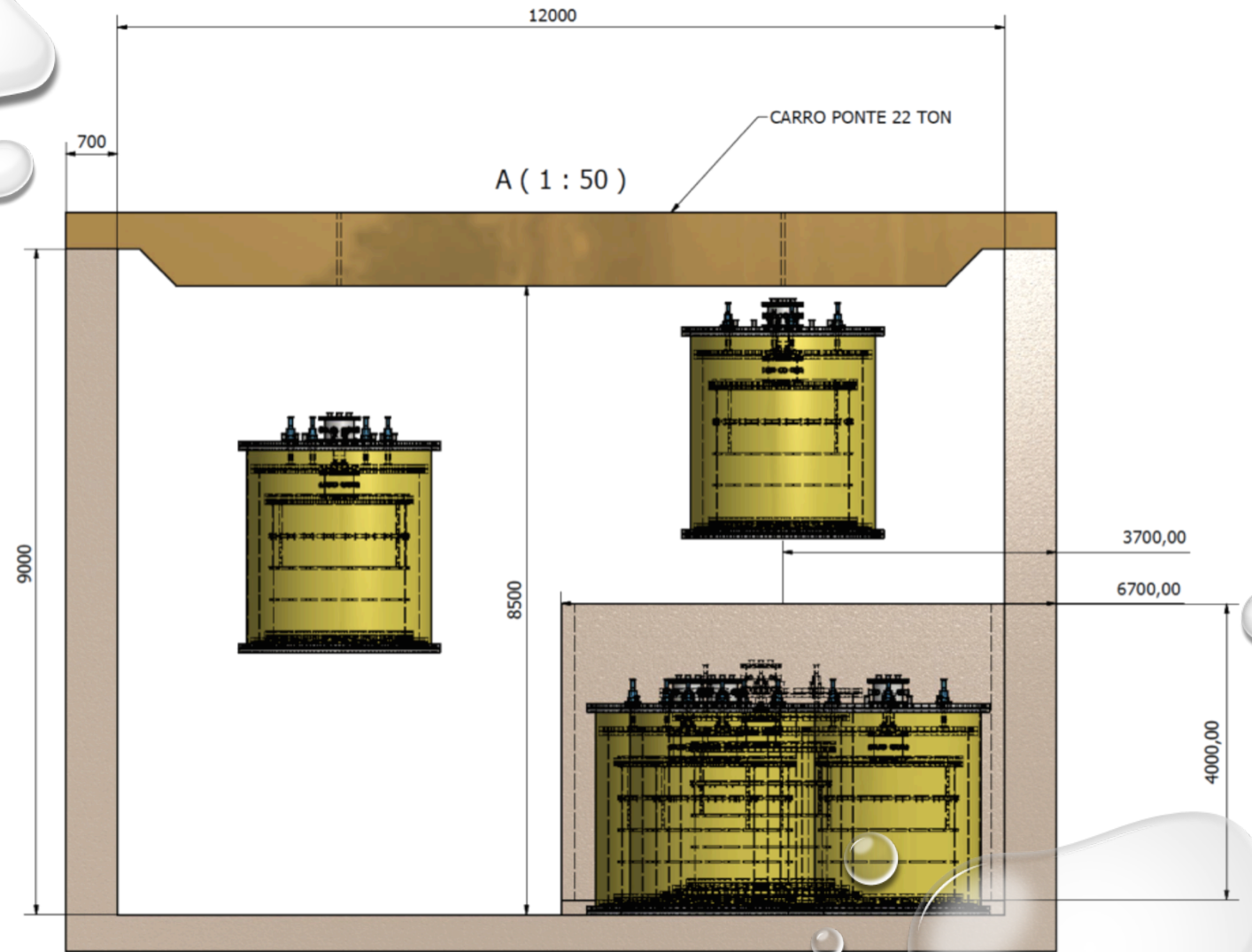
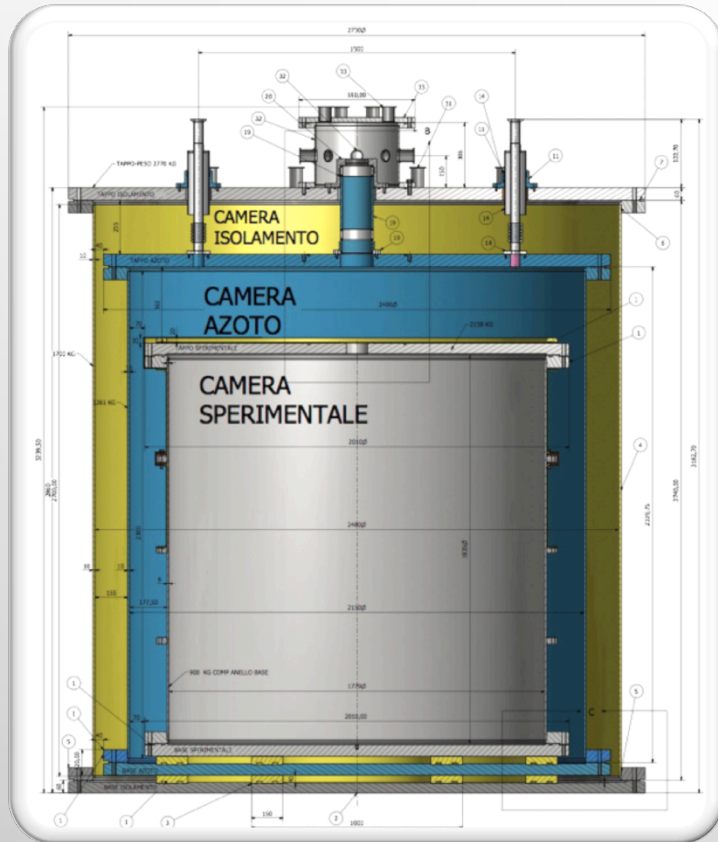


# SAR-GRAV CONSORTIUM

- SAR-GRAV IS A CONSORTIUM AMONG INFN, UNIVERSITY OF SASSARI, REGIONE SARDEGNA, IGEA SPA, INGV FOR THE CONSTRUCTION AT SOS ENATTOS OF AN UNDERGROUND LAB TO HOST GRAVITATIONAL EXPERIMENTS
- ✓ THE FIRST APPROVED EXPERIMENT IS ARCHIMEDES EXPERIMENT AND FOR WHICH IS ON-GOING THE DESIGN PHASE BASED ON SCIENTIFIC APPARATUS



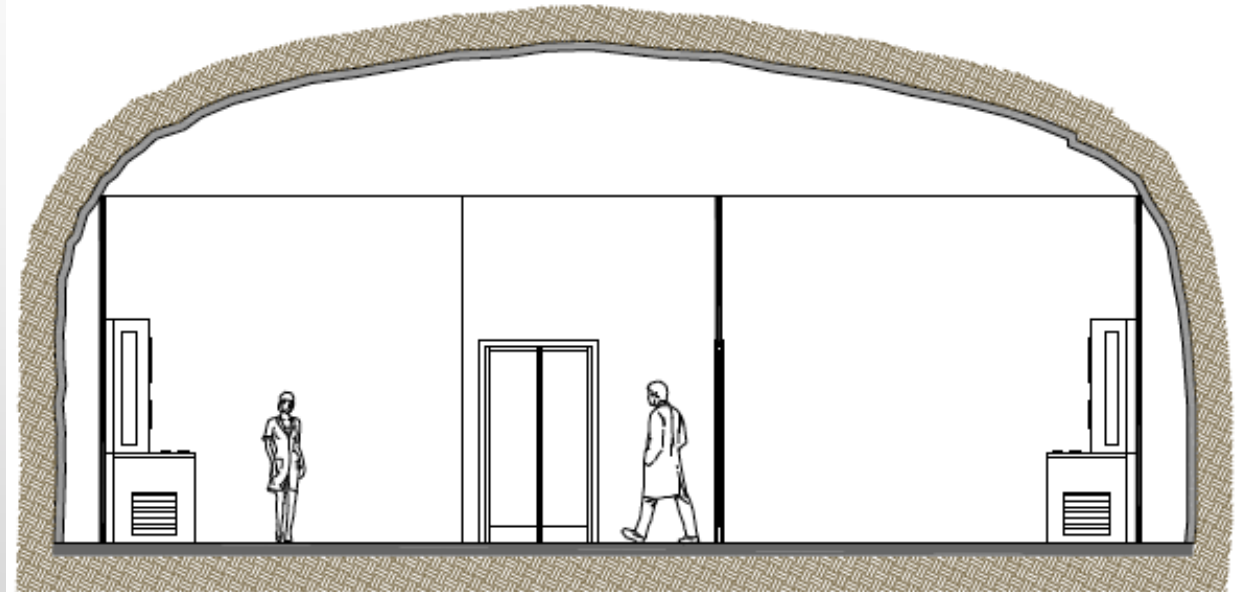
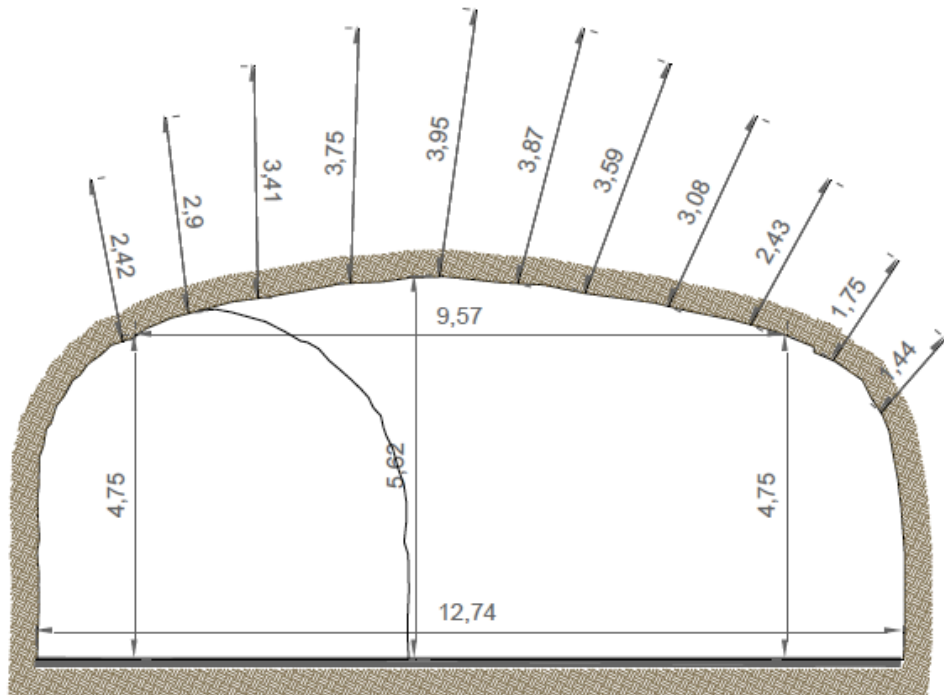
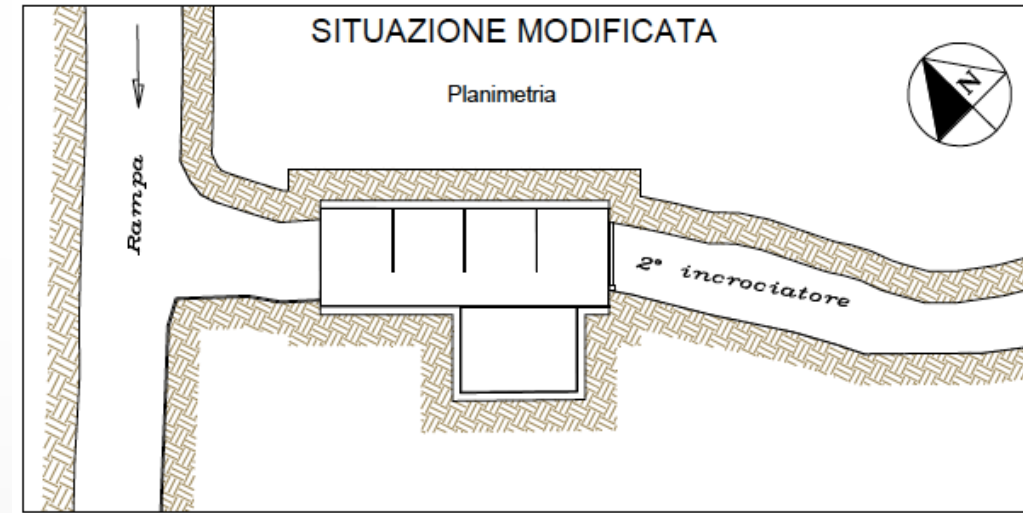
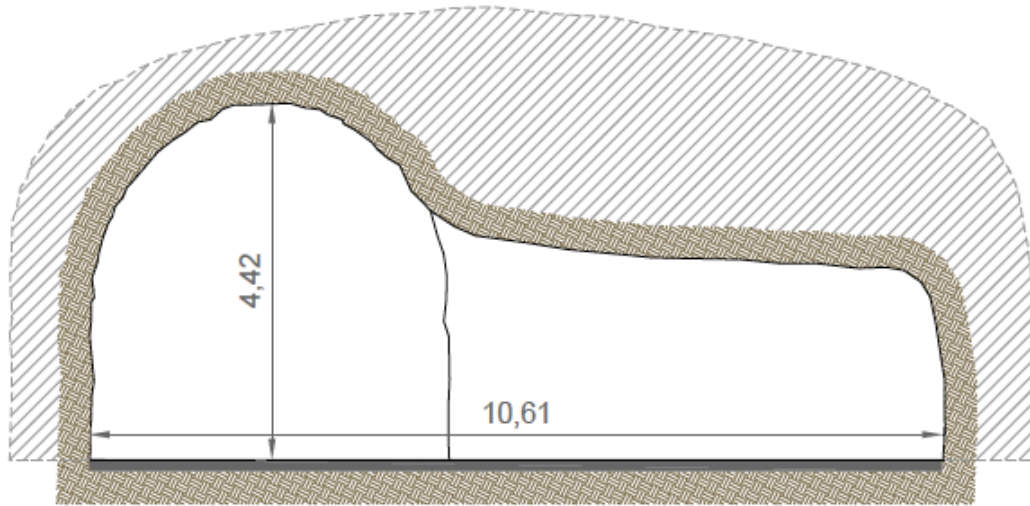
The production of the inner vacuum chamber has started. Ready for the end of 2019



# ARCHIMEDES UNDERGROUND LAB



# Archimedes underground lab: first design

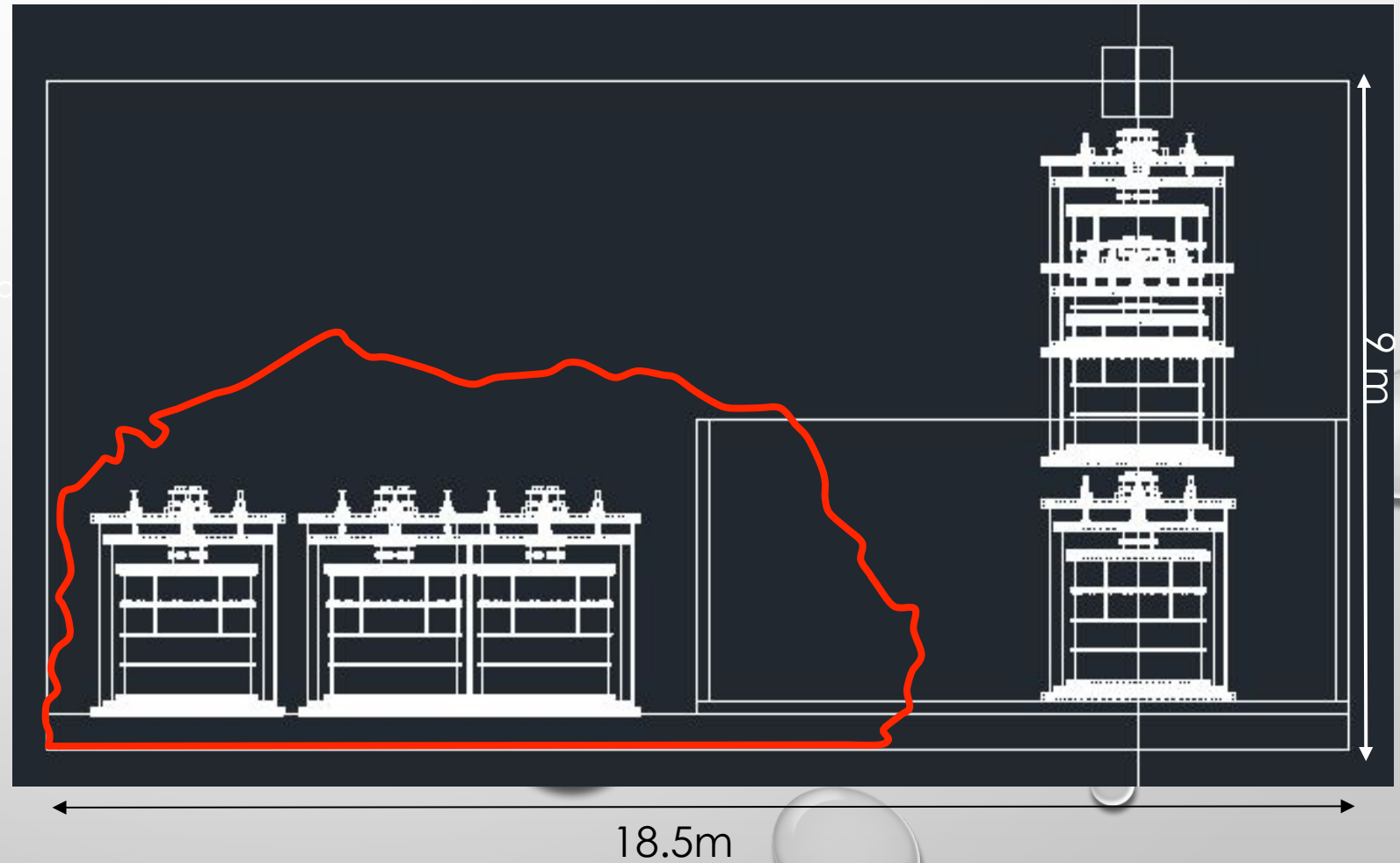
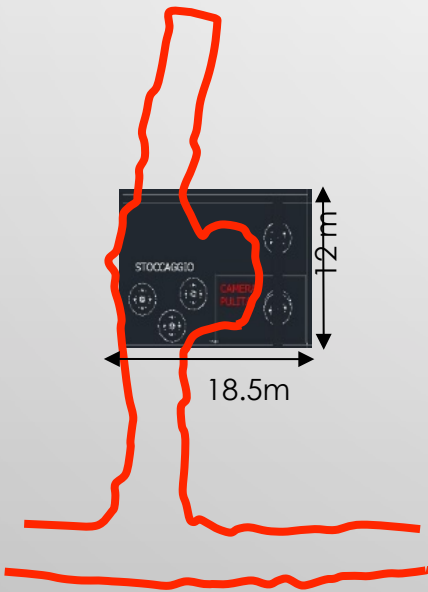


From Technical report Nov. 2017



**IGEA SPA**  
INTERVENTI GEO AMBIENTALI

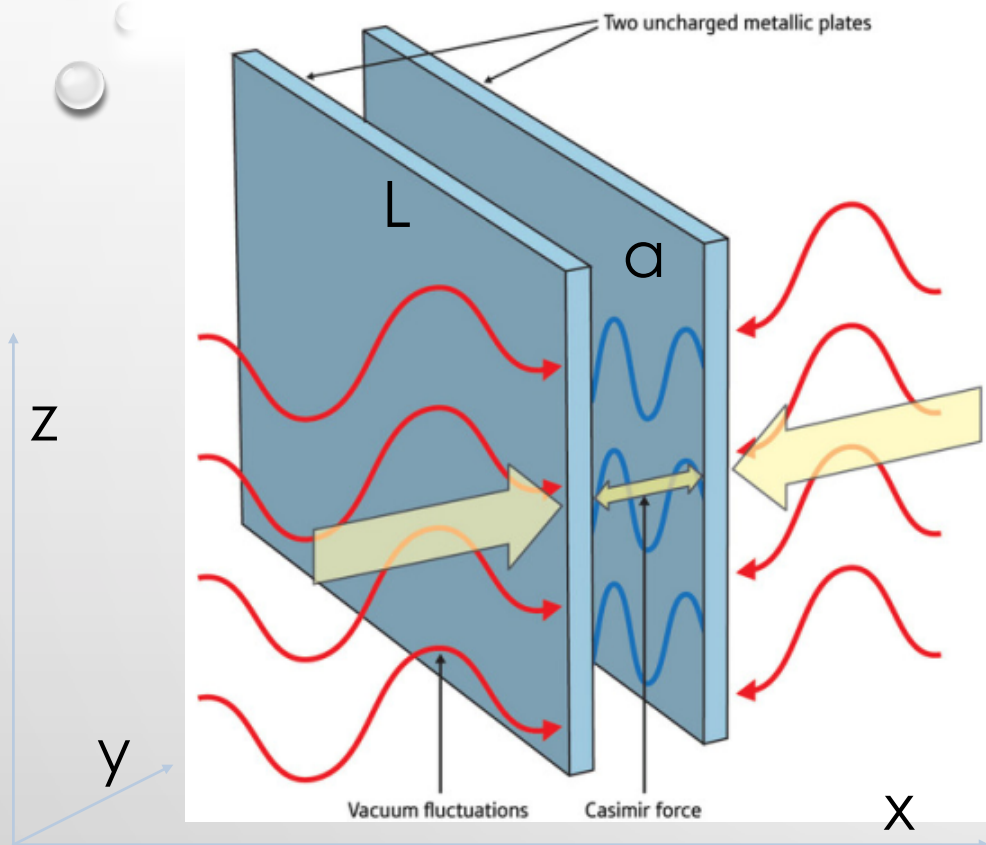
# Archimedes underground lab: future configuration



# CONCLUSIONS

- ARCHIMEDES IS AN EXPERIMENT CONCEIVED TO SHED LIGHT ON THE INTERACTION BETWEEN THE GRAVITATIONAL FIELD AND THE VACUUM FLUCTUATIONS
- IT WILL BE INSTALLED IN ONE OF THE QUIETEST PLACES IN EUROPE WHICH IS ALSO A CANDIDATE SITE FOR ET
- PRELIMINARY TEST ARE BEING CARRIED ON IN ROME (THERMAL MODULATION) AND NEAPLES (BALANCE)
- THE FIRST TESTS ON SITE SHOULD START BY THE END OF THIS YEAR IN A DEDICATED EXPERIMENTAL VACUUM CHAMBER
- THE COMPLETE CRYOSTAT WILL BE READY BY THE END OF 2020
- THE DEDICATED LABORATORY SAR-GRAV IS BEING BUILT AT SOS-ENATTOS (LULA)

**The Casimir effect** is derived considering the zero point e.m. energy contained in a casimir cavity, i.e. in the volume defined by two perfectly reflecting parallel plates



If the plates are perfectly reflecting, the modes that can oscillate must have discrete wavenumbers on horizontal axes  $k_y = n\pi/a$  while all values are allowed for  $k_x$  e  $k_z$

$$E = \sum \frac{1}{2} \hbar \omega$$

$$E(a) = \frac{hcL}{2} \sum_{n=-\infty}^{n=\infty} \int \frac{d^2 k}{(2\pi)^2} \sqrt{k^2 + (n\pi/a)^2} \quad \xrightarrow{\quad} \quad \infty$$



The Casimir Energy is the change in energy when the plates are at distance “a” with respect to the plates having  $a \rightarrow \infty$

$$E_C = E(a) - E(\infty)$$

$$E_C = -\frac{\pi^2 L^2 \hbar c}{720 a^3}$$

CASIMIR ENERGY

$$P_C = \frac{1}{L^2} \frac{\partial E_C}{\partial a} = -\frac{\pi^2 \hbar c}{240 a^4} = \mathbf{1.3 \text{ mN/m}^2} \text{ @ } \mathbf{a = 1 \mu m}$$

CASIMIR PRESSURE

First prediction: Casimir 1948

First measure (force): Sparnay 1956

Presently tested (force) with an accuracy of 0.5% (Mohideen: 2005)