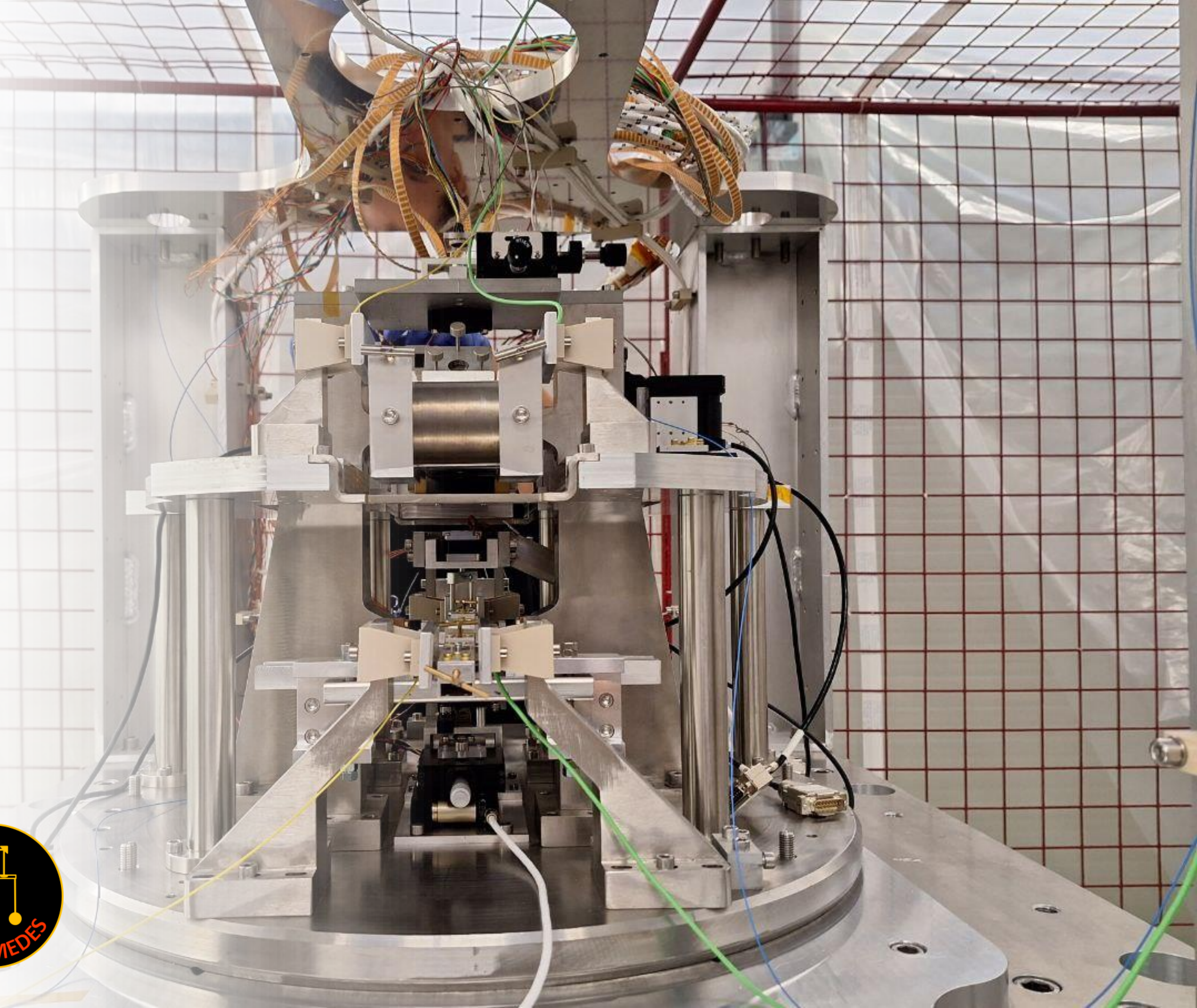
Archimedes Experiment
the Weight of Quantum Vacuum

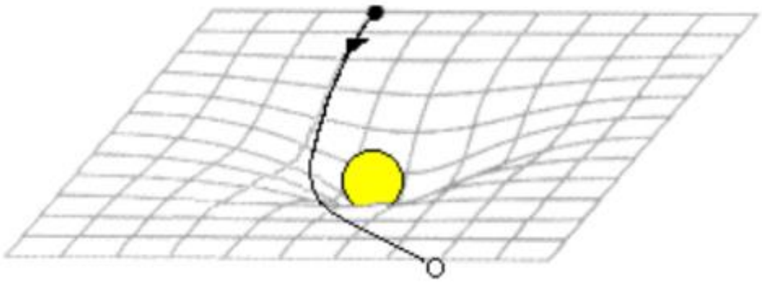
Marina Esposito, PhD Student
University of Naples ‘Federico II’
marina.esposito@na.infn.it

On behalf of Archimedes Collaboration



Coupling between Gravity and EM field

➢Gravity on massive objects also depends on their stress state



➢Gravity also applies to non-massive fields (like the e.m. field)

➢While quantum electrodynamics (QED) in curved spacetimes is established, its coupling with gravity remains a topic of debate

➢**Extreme case:** virtual photons field in equilibrium with weak gravitational field; this is the regime in Archimedes experiment

Experimental Proof: Weighing the Quantum Vacuum

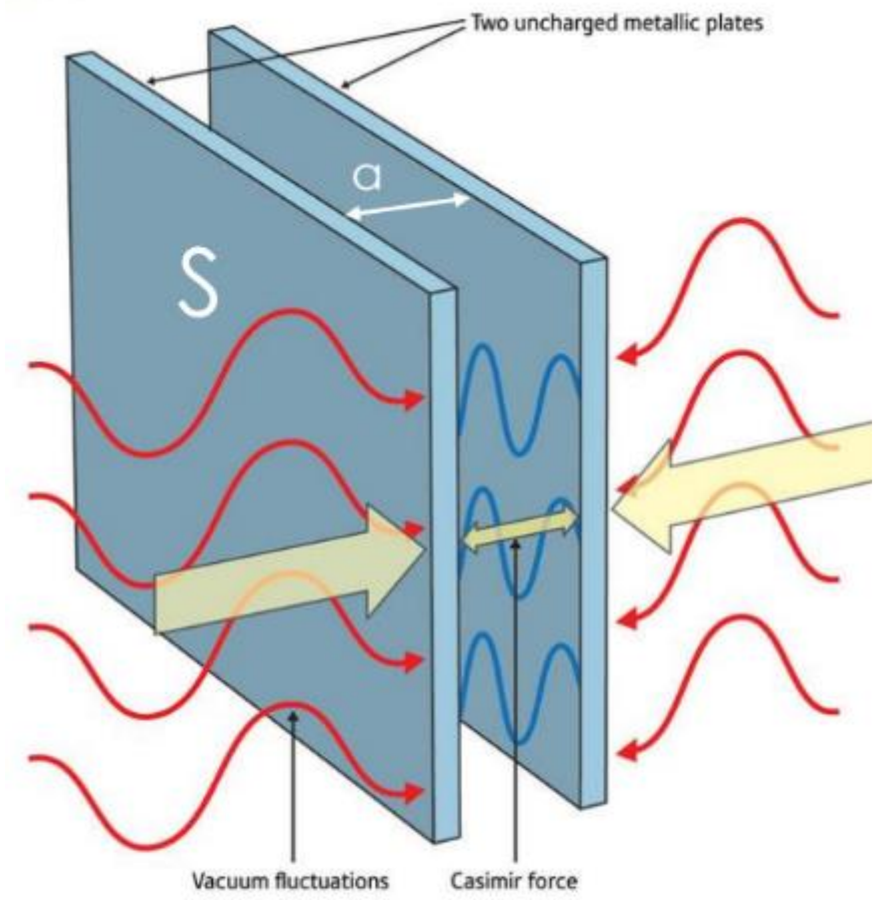
- Massive samples (+ their internal energy) are suspended to a balance;

- These samples contain a big amount of vacuum energy;

- The internal quantum vacuum energy of samples is modulated;

If quantum vacuum gravitates, the weight changes and the weight variation is detected in real time with the balance

Storing Vacuum Energy



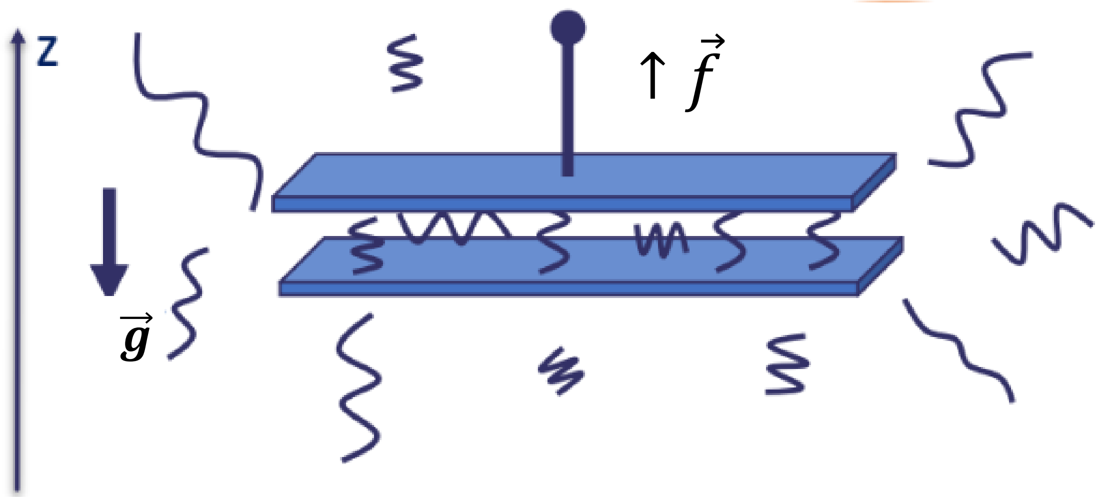
Vacuum Energy confined using Casimir effect (1948), also the most direct proofs of vacuum fluctuations

$$E_{reflective\ plates} - E_{empty} \equiv \varepsilon_{Cas} = -\frac{\pi^2}{720}\frac{\hbar c}{a^3}L^2$$ negative energy

$$\frac{1}{L^2}F(a) = -\left(\frac{1}{L^2}\right)\frac{\partial}{\partial a}E_C(a) = -\frac{\pi^2\hbar c}{240a^4}$$ *Casimir Force*

typically $a \sim 1\ \mu m$, $\mathrm{S} \sim 1\mathrm{cm} \times 1\ \mathrm{mm} \rightarrow \mathcal{E}_{cas} \sim 10\ \mathrm{nJ}$, $F_{cas} \sim 10^{-7}\ \mathrm{N}$

A Rigid Casimir Cavity in the Gravitational Field



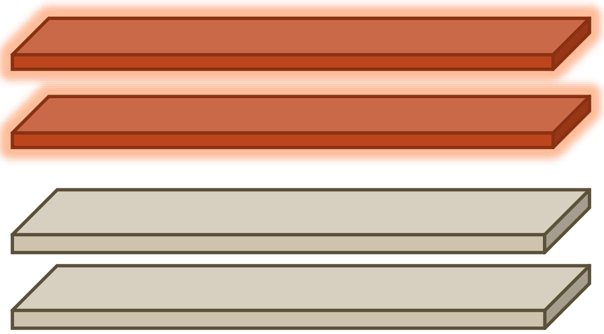
$$\vec{f} = \frac{|\varepsilon_{Cas}|}{c^2}\vec{g}$$

$\rightarrow \vec{f}$ is the weight of the cavity in the framework of GR, it depends on the vacuum energy inside the Casimir cavity

For a single Casimir cavity with $S \approx 1\, dm^2$ and $a \approx 1\, \mu m$, the signal force intensity would be $|\vec{F}| \simeq 4 \cdot 10^{-28}\ N$

[G.Bimonte, E. Calloni, G. Esposito, L. Rosa - Phys. Rev D 76:025008 (2007)]

Modulating Vacuum Energy with Superconductors

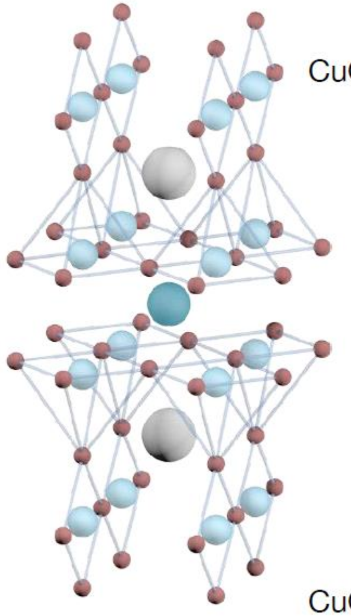


> Cavities with tunable reflectivity

> Modulate the samples temperature (and superconductivity) → modulate reflectivity → "amount of vacuum" modulated, and possibly the total weight

HTS (like YBCO) are natural multi-layered Casimir cavities. For a disk-shaped YBCO with R = 5 cm, thickness 5 mm the force exerted by the gravitational field is:

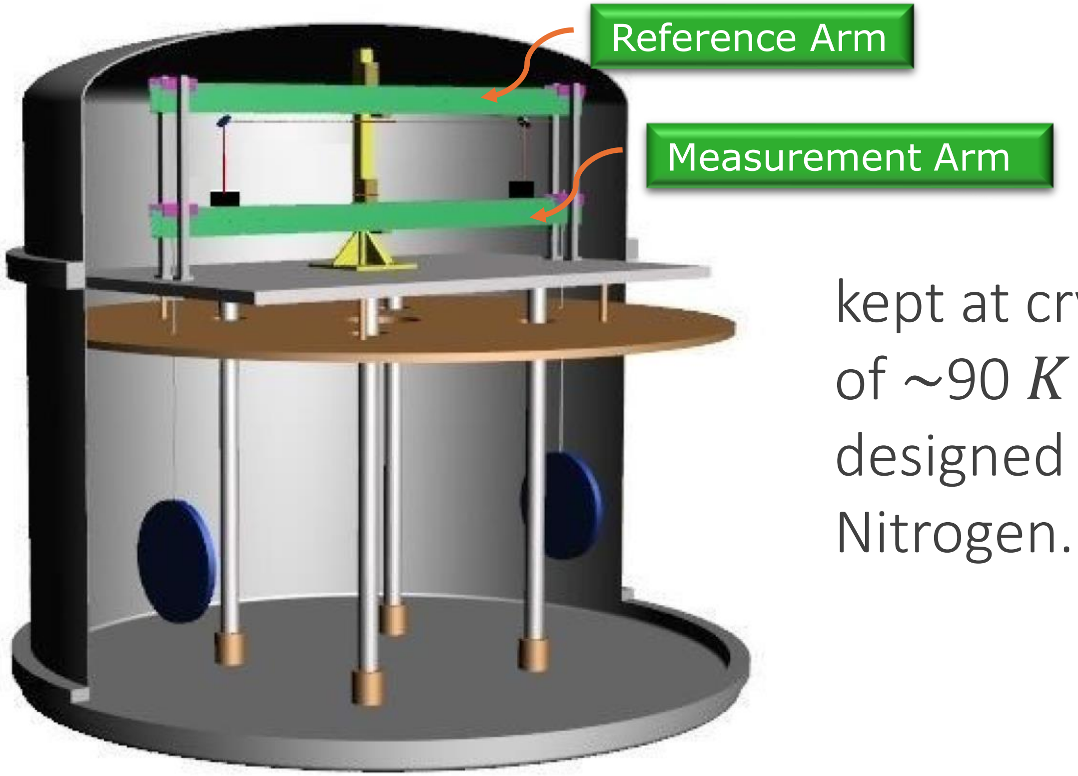
$$\left|\vec{F}\right| \approx 5 \times 10^{-16}\, N$$



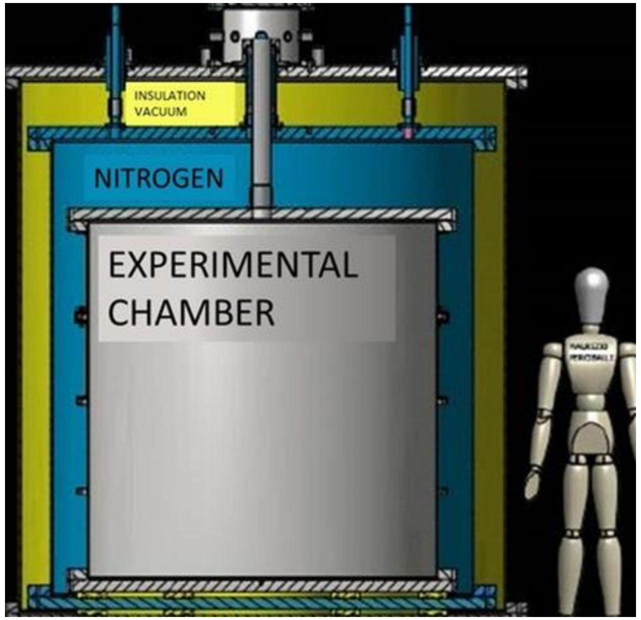
Rosa, L., et al. "Casimir energy for two and three superconducting coupled cavities: Numerical calculations." The European Physical Journal Plus 132 (2017): 1-12.

The Archimedes Experiment

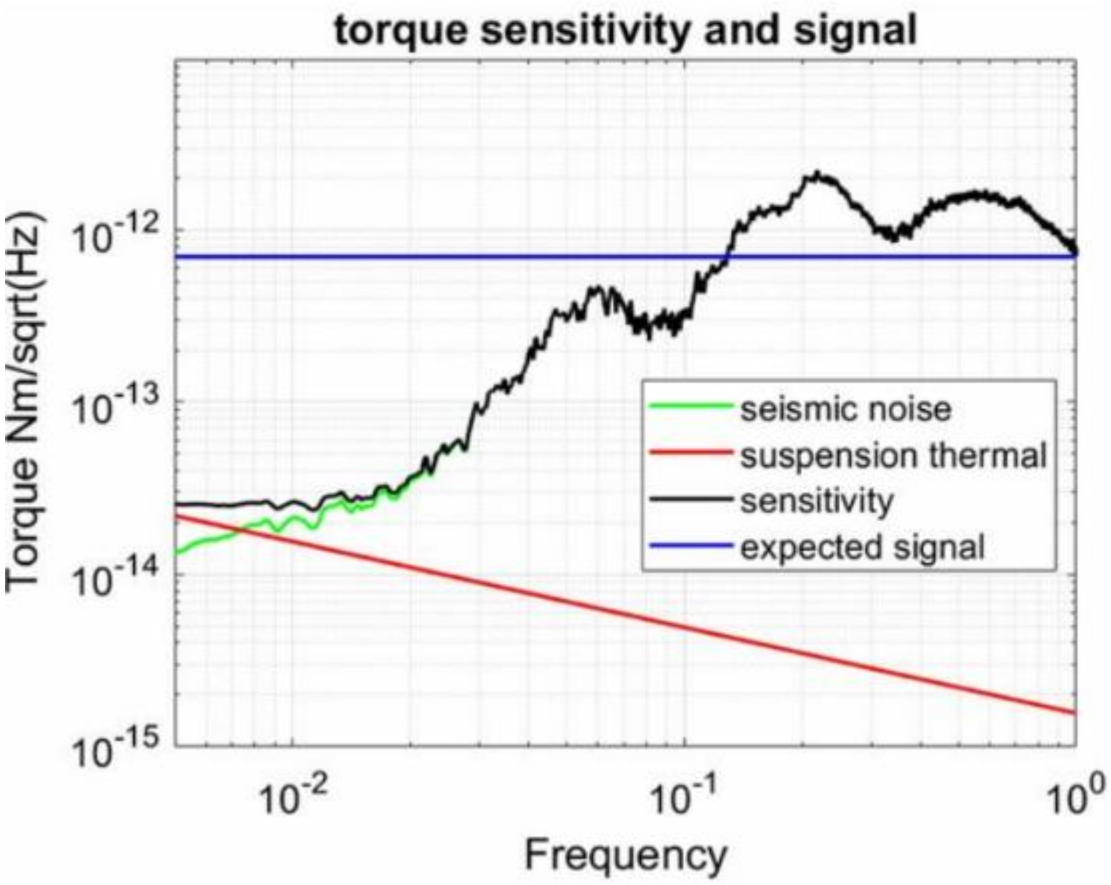
Extremely sensitive balance. It consists of a measurement arm that will suspend two superconductive samples.



kept at cryogenic temperature of $\sim 90\ K$ thanks to a suitably designed cryostat filled with liquid Nitrogen.



Precision Measurement: Expected Torque Sensitivity



$|\vec{F}| \simeq 5 \cdot 10^{-16}\, N$

$|\vec{\tau}| = |\vec{F}| \cdot 0.7\, m \simeq 3.5 \cdot 10^{-16}\, N \cdot m$

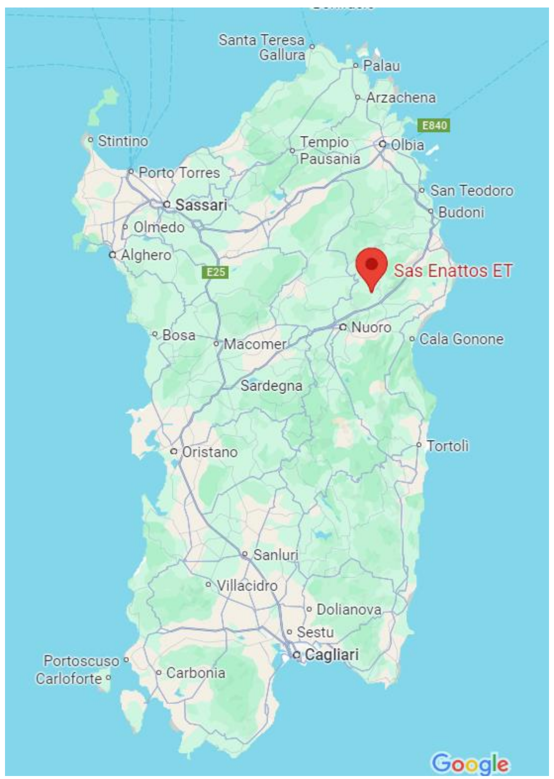
Integration time: $10^6\, s$ (~ 2 weeks)

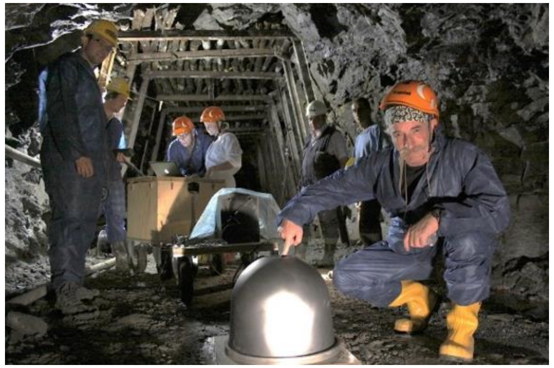
Spectral Torque Signal:

$$\tau_s = 3.5 \cdot 10^{-13}\ \frac{N \cdot m}{\sqrt{Hz}}$$

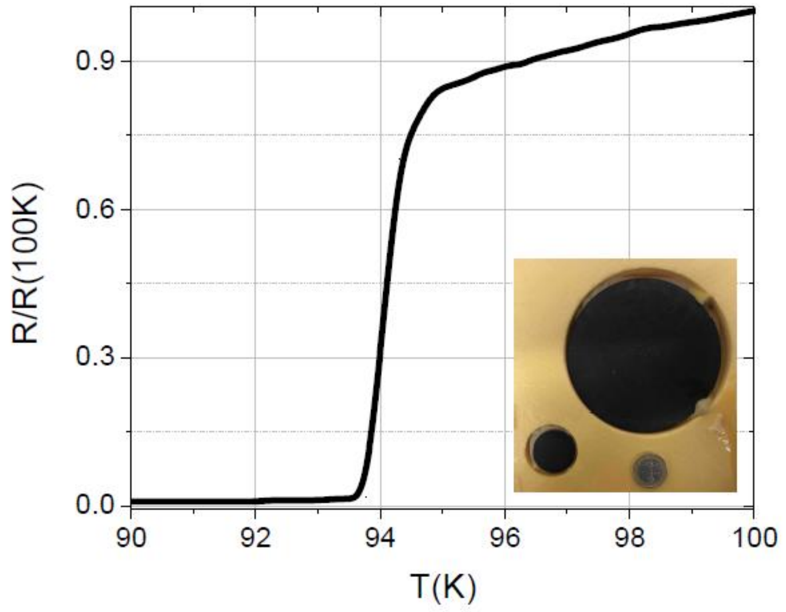
Optimal Conditions:

Low Noise Site





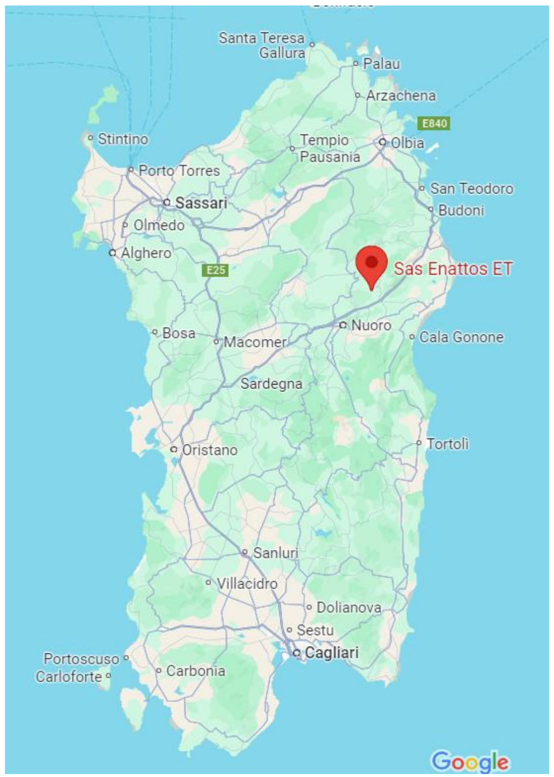
High Signal Samples

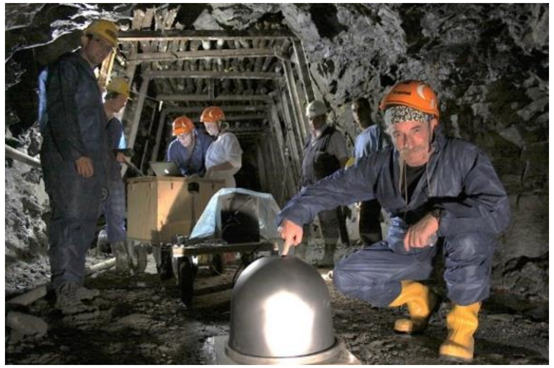


- Tests with various cuprates;

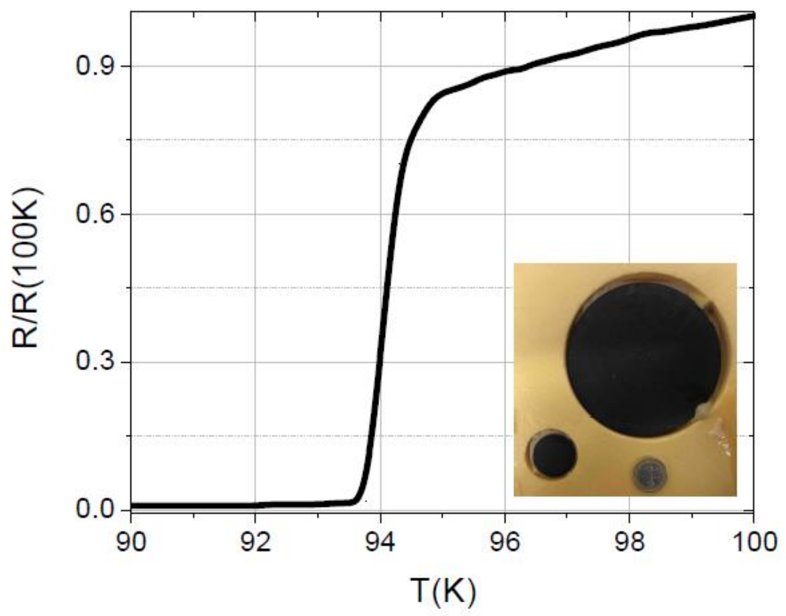
Optimal Conditions:

Low Noise Site





High Signal Samples



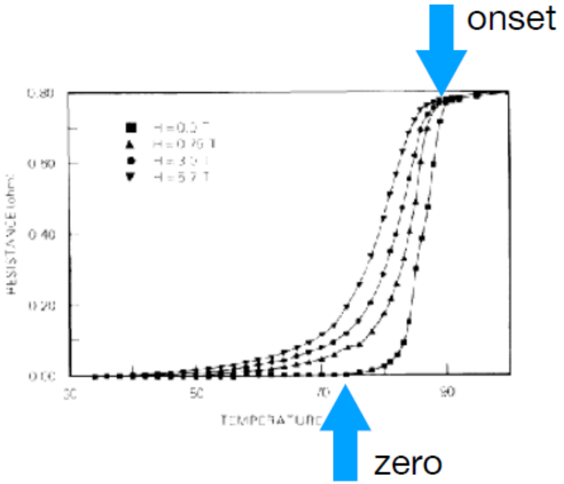
- Tests with various cuprates;
- PhD project is in this framework;

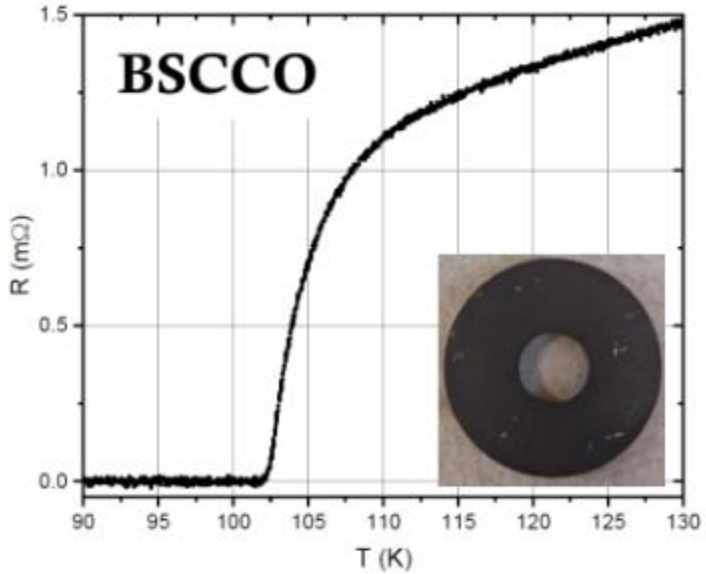
About the samples…

(1) an HTS sample of "large" mass (in the order of hundreds of grams)

(2) narrow transition: $\Delta T = T_{C_{onset}} - T_{C_{zero}} = 1\ K$ (ideally)

(3) fast heat exchange



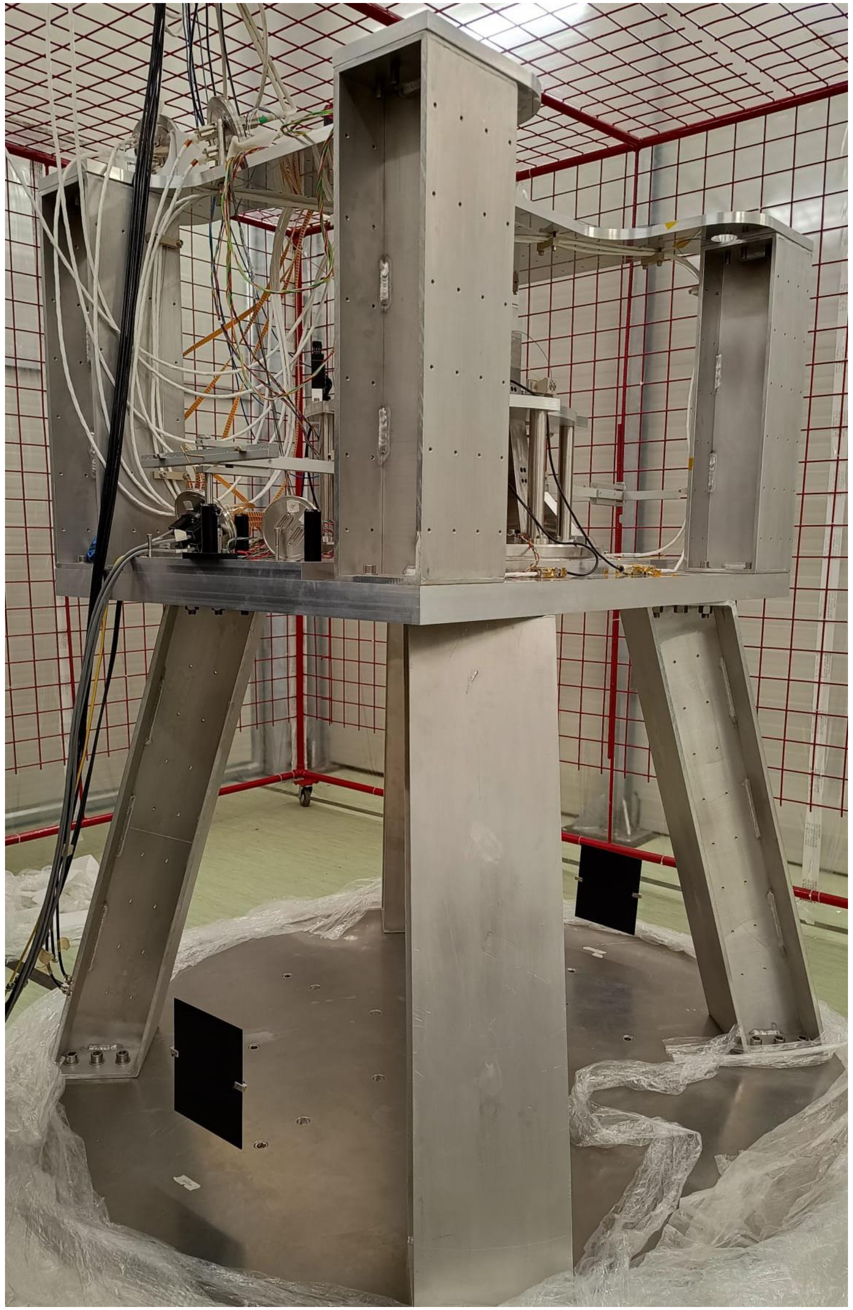


Experiment Progress: Current Status

- The experimental setup was designed, realized, assembled on site and largely tested;

- The cryostat has been realized and it is on its way to the site;

- In the meantime, possible use of this setup also for other fundamental physics measurements: *the weight of the heat*;



Thank you for you attention!

Some references

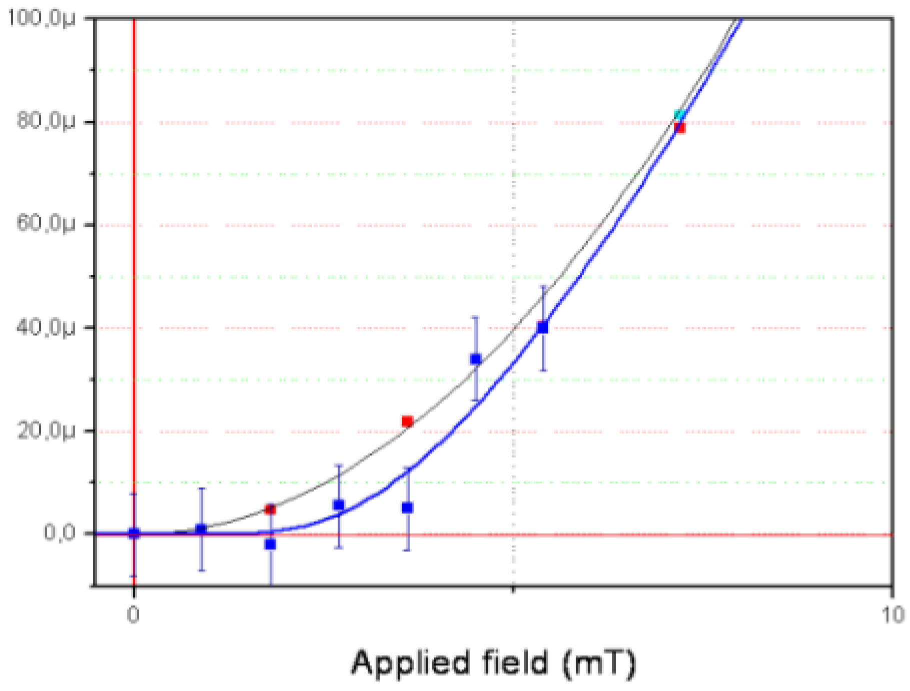
- E. Calloni. L. Di Fiore, G. Esposito, L. Milano, L. Rosa - Phys. Letters A, 297, 328-333, (2002)
- G. Bimonte, E Calloni, Di Fiore, G. Esposito, L. Milano, L. Rosa - CQG 21 647 (2004)
- G. Bimonte, E. Calloni , G. Esposito, L. Rosa - Phys. Rev D 74, 085011 (2006)
- G.Bimonte, E. Calloni, G. Esposito, L. Rosa - Phys. Rev D 76:025008 (2007)
- G. Bimonte, E. Calloni, L. Rosa - Phys. Rev D 77, 044026 (2008)
- A. Allocca G. Bimonte, E. Calloni, G. Esposito, U. Huebner, E. Il'ichev, L. Rosa, F. Tafuri., Jour. Of. Supercond. And Novel Magnetism. 25, 2557-2565 (2012)
- E. Calloni et al., Eur. Phys. J. Plus (2021) 136:335
- A. Allocca, E. Calloni, L. Errico et al, Eur. Phys. J. Plus (2021) 136: 1069
- A. Allocca et al, Eur. Phys. J. Plus 137, 826 (2022)
- Calloni, E. et al. Eur. Phys. J. Plus 139, 158 (2024)

Casimir Cavity with type I superconductors

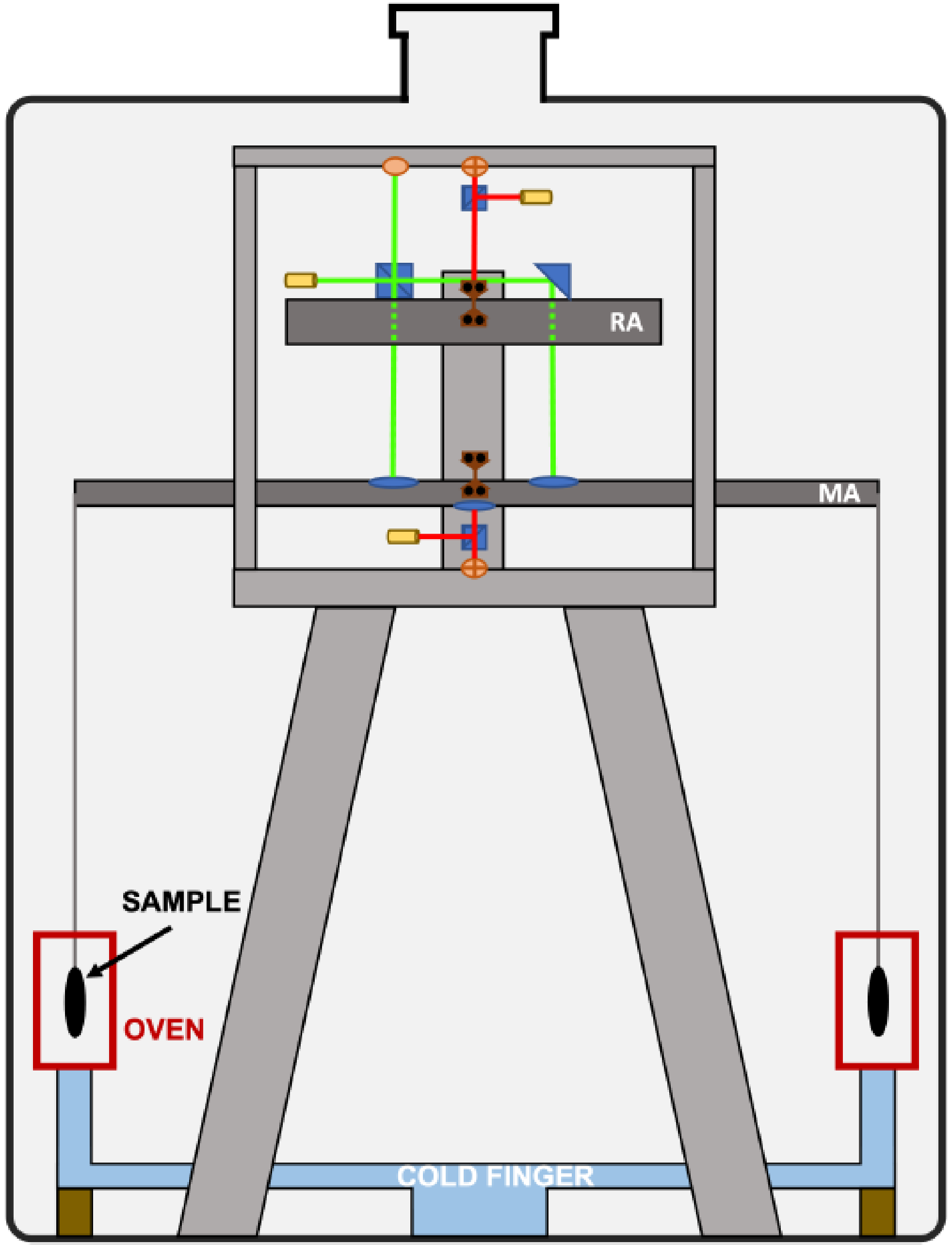
Condensation energy is very small so it can be expected that the variation of Casimir energy at the transition for a superconductor inside a cavity can be comparable with the total transition energy

$$\frac{\Delta\varepsilon_{cas}}{\varepsilon_{cas}} \simeq 10^{-6}$$

Data compatible with the theory and the region of energy of different behavior is the expected one



G. Bimonte et Al. - J. Phys. A: Math. Theor. 41 164023 (2008)
A. Allocca et Al. Jour. Of. Supercond. And Novel Magnetism. 25, 2557-2565 (2012)



Sketch of Archimedes Apparatus