Workshop on EU Underground Laboratories

Superconducting sensors in ultra-low background environments for quantum computing

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Superconducting sensors in ultra low background enviroments:

Two types:

- **Particle detectors**: Transition Edge Sensors (TES) and Kinetic Induction Detectors (KIDS)
- **Superconducting qbits**

Two type of devices for experiments with common requirements due to its superconducting nature:

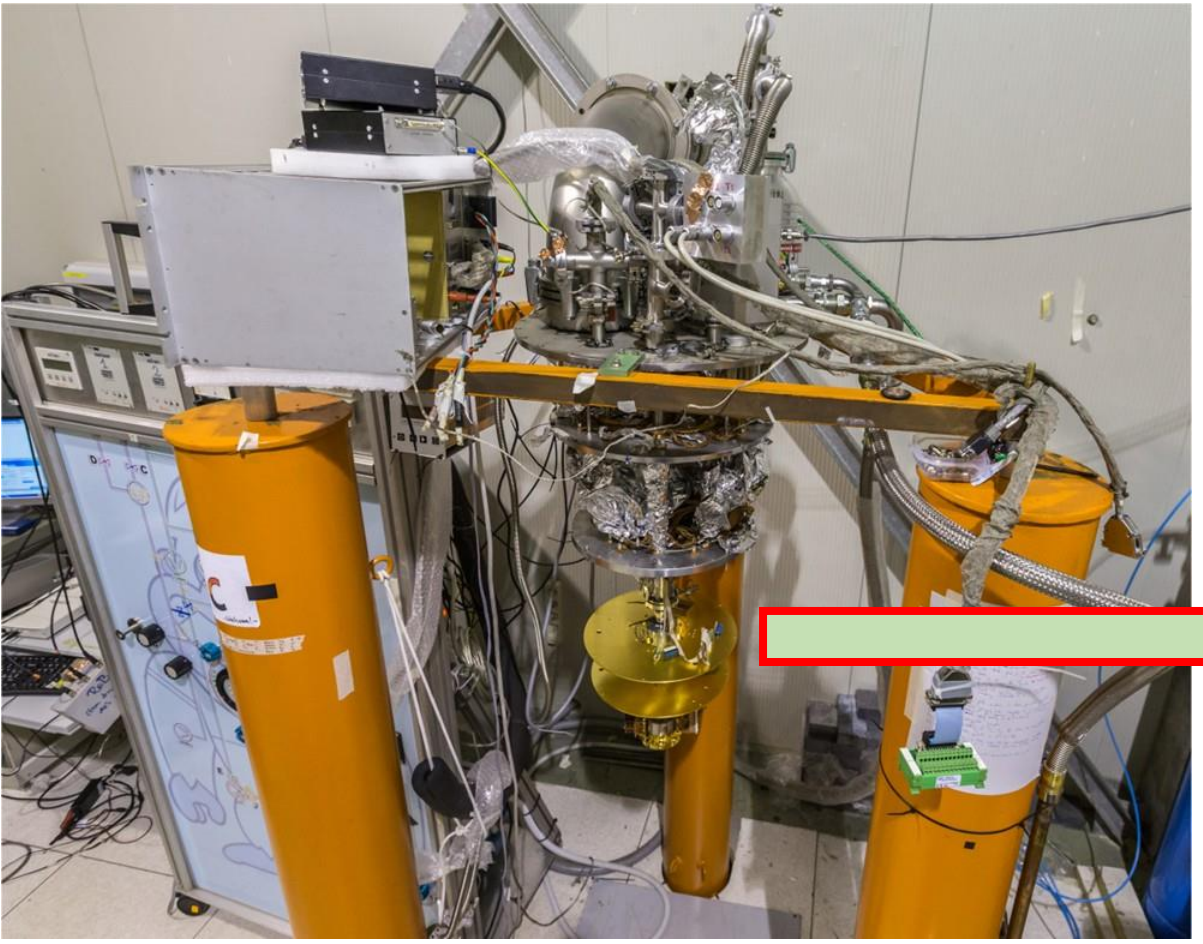
- Low temperature (~K to mK)
- Magnetic fields (~μT)

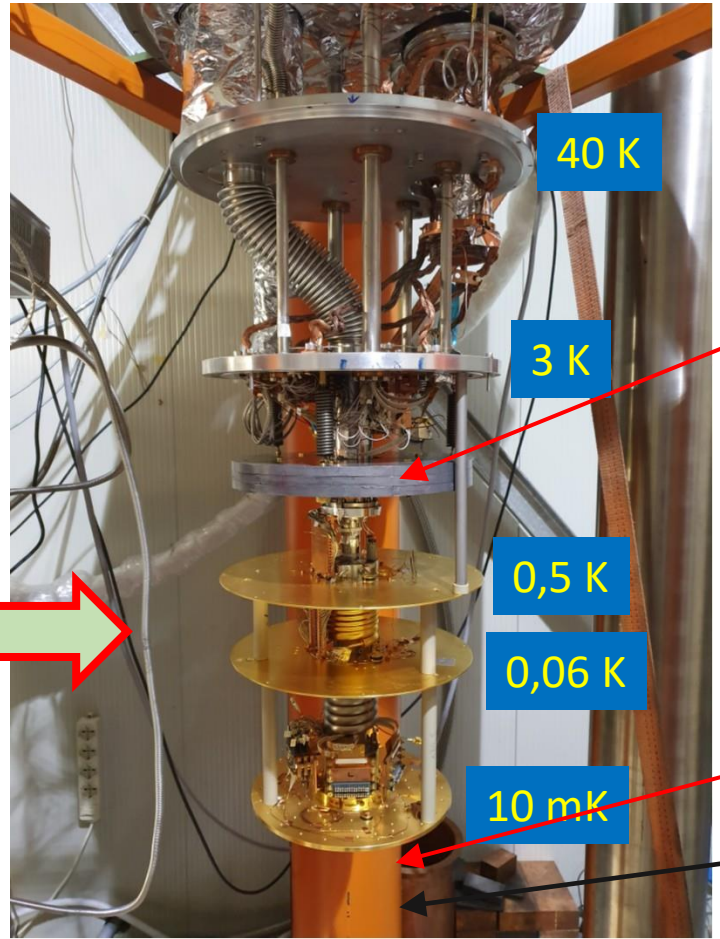
The use of TES and KIDS is widely applied, with its own challenges, in low background enviroments, however qbits require specific equipment to communicate with them not available in general outside specialised facilities.

We have very cool facilities

The IETI facility at LNGS:

It is a dry (Pulse Tube based) $^3He/^4He$ dilution unit located in the Hall C of LNGS. The cryostat is characterized by an extremely low vibration level due to Pulse Tube decoupling and a custom-made 3-stage mechanical decoupling system between cold plates and detectors. System is accessible for external users.





3 cm Internal LEAD

Additional 3 cm Lead @10 mK

Exp volume
Dia=25 cm h=16 cm

The IETI facility at LNGS:

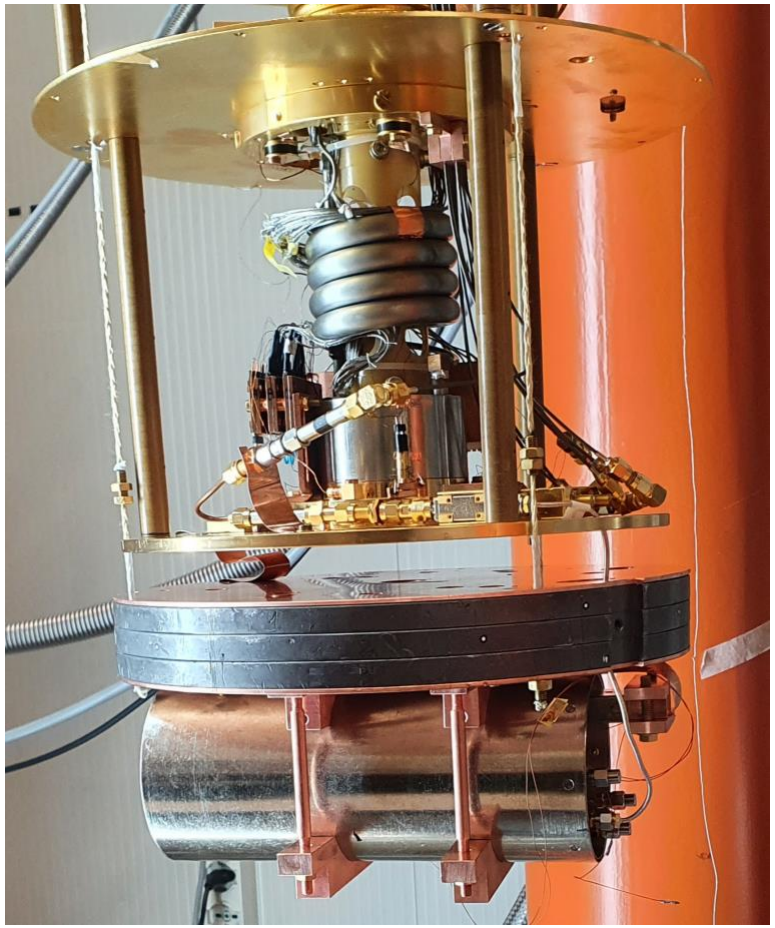
The cryostat is equipped with an *internal* lead shielding of **3 cm** below the 3 K Flange and **3 cm** of Lead below the Mixing Chamber (MXC). This lead is also integral part of the three-fold mechanical decoupling system.
The outside shielding can be made with **10 cm** of lead surrounding the main 300 K vacuum chamber. This shielding, even if relatively small compared to the standard low-radioactivity cryostats belonging to experiment like CUORE and/or CRESST is sufficient to run even large bolometers (few hundreds of grams) w/o affecting the performances of Energy resolution induced by pile-up.

The IETI cryostat is presently equipped with different readout lines:
- 12 electronic Channels equipped with low noise voltage preamplifiers (2 nV/√Hz) (**R&D** for CUPID experiment);
- 3 Magnicon SQUIDS (**R&D** for Cosinus Experiment).
- 8 low attenuation SMA Coax cables from 300 K to 3K + 8 NbTi Superconductive Coax from 3K to MC (**R&D** Demetra/SQMS for Resonators/Qubit applications)
- **48** additional twisted superconductive wires from Room Temperature (RT) to MC.
- A ^{60}Co crystal for absolute thermometry calibration.
- A Noise Thermometer will be available for fall 2022

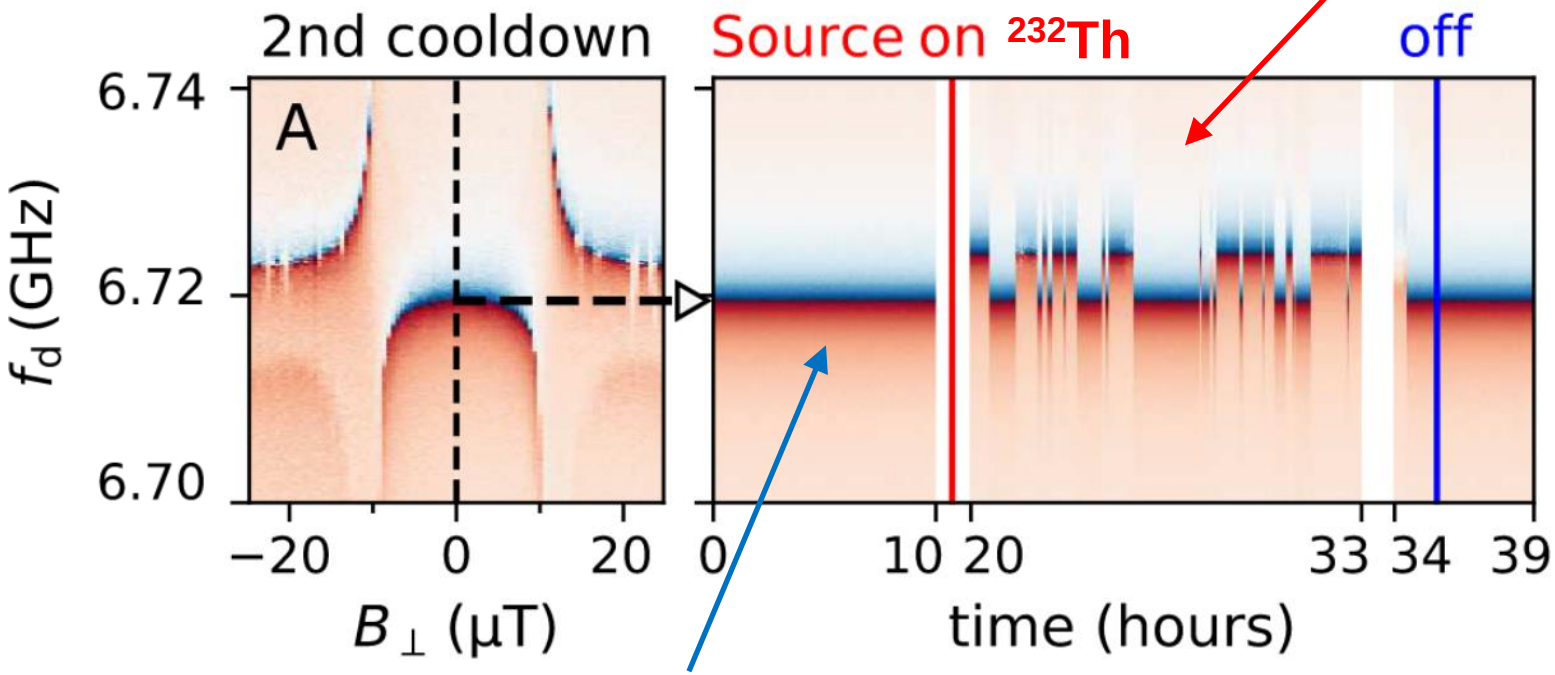
The IETI facility at LNGS:

In 2019 the FIRST pilot measurement was performed in the IETI cryostat in collaboration with KIT using a resonator
L. Cardani & al. *Reducing the impact of radioactivity on quantum circuits in a deep-underground facility,* **Nat. Comm. (2021)12:2733**

In December 2021 a new measurement was performed with a gradiometric Fluxonium Qubit



Fluxonium exposed to a ^{232}Th radioactive source which activates fluxon dynamics.



Large stability of the trapped flux on timescales of days.

D. Gusenkova,et al. *Operating in a deep underground facility improves the locking of gradiometric fluxonium qubits at the sweet spots,* Appl. Phys. Lett. **120**, 054001 (2022) https://doi.org/10.1063/5.0075909

Flux qbit preliminary work at LSC:

The LSC started to work on December 2021 with the group of Pol Forn-Diaz at IFAE in collaboration with CROSS to install and measure a qbit in their cryostat.

The experiment aims to analyse the influence of particle radiation in the entanglement time of flux qbits.

The coaxial lines and amplifiers were installed in the cryostat and currently is waiting for the qbit to be ready for installation.

This work has proven very useful for understanding the requirements of a qbit experiment.

The future dilution cryostat at LSC:

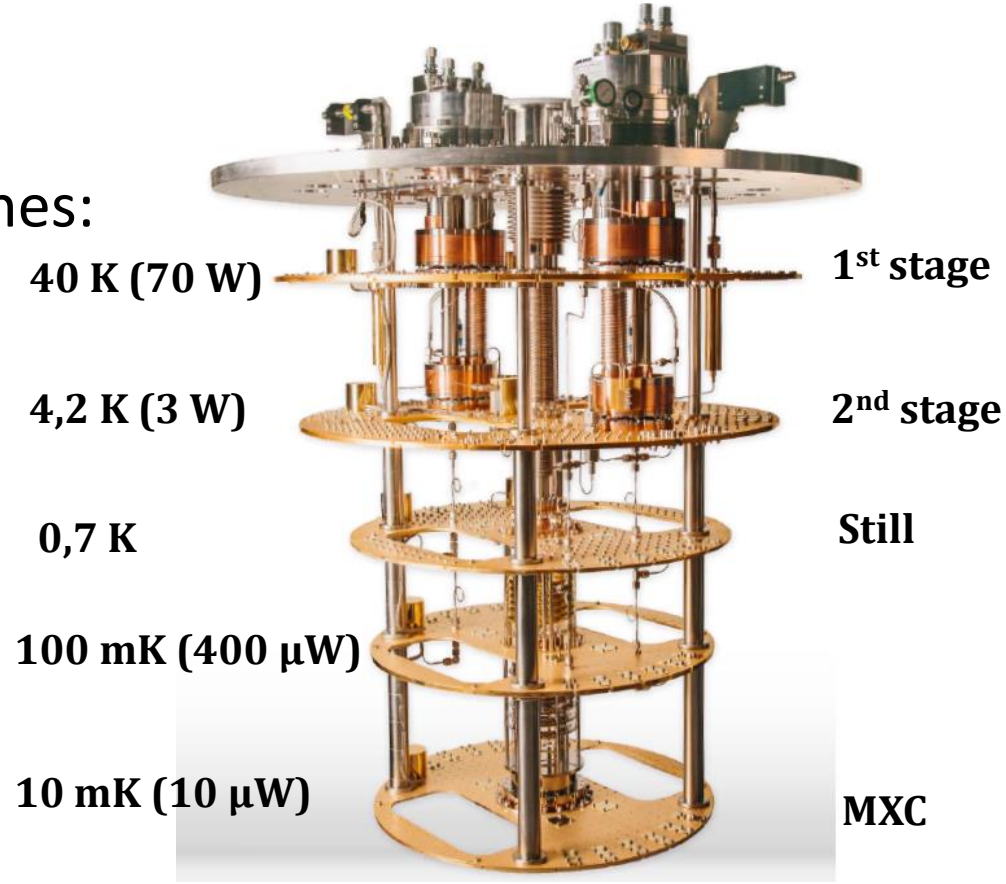
The LSC is in the process of purchasing a state-of-the-art dilution refrigerator with large experimental space (MXC of 500 mm)

It will have a low vibration system and the option to mount a lead shield below the MXC.

It is expected to include the following readout lines:

- 10-12 low attenuation coaxial lines CuNi+SC
- 24 twisted pair lines

It will include pre-installed 180 A current leads for incuding at a later stage of a wide bore (150 mm) high field magnet (10 – 14 T) compensated to mT at the MXC.



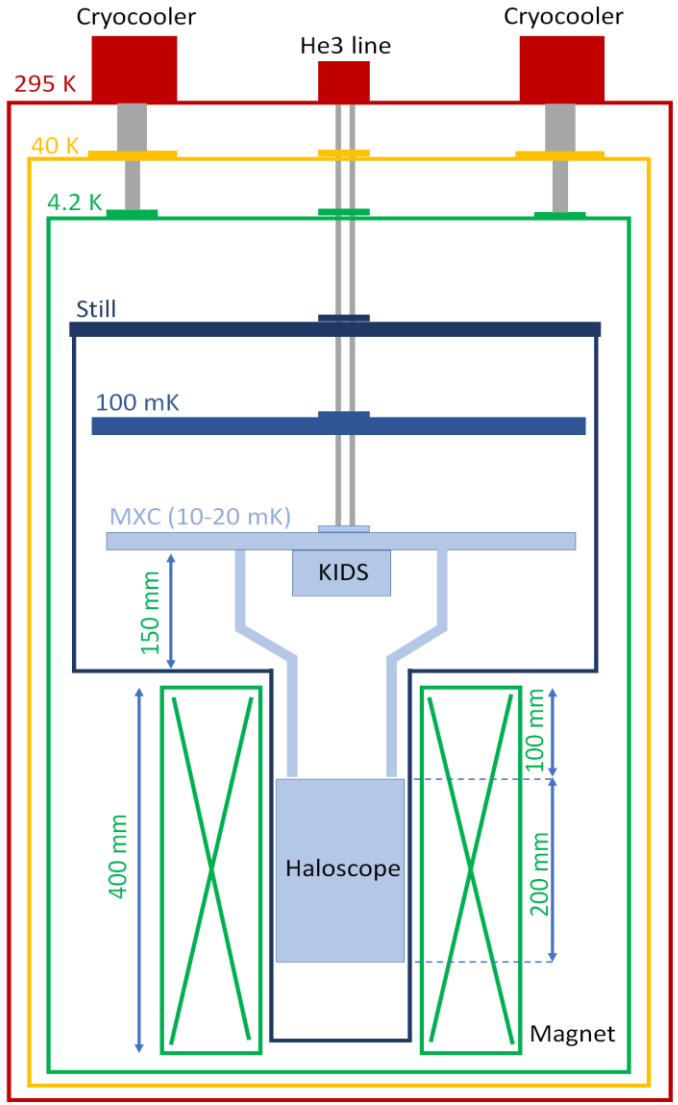
The future dilution cryostat at LSC:

The cryostat without the magnet will act as a platform for hosting qbit measurements.

Additionally it will host the Canfranc Axion Detector Experiment (CADEX)

The experiment will use a haloscope inside the high field magnet to produce the conversión of the axion into a photon via the Primakoff effect.

The photon detection is done using KIDS located at short distance for the magnet. This requires, on top of the magnet compensation, a bespoke magnetic shielding system with line of sight to the haloscope.



APOGEIA WP5.2

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Goals:

- To develop in conjuction with companies and research groups technologies related with superconducting devices.
- To upgrade the existing and future facilities at LSC and LNGS in order to become self-sufficient testing platforms for qbit companies and experimental groups.
- To design and test local magnetic shielding for superconducting detectors

People:

Table 3.1f: Summary of staff effort

	WPn	WPn+1	WPn+2	Total Person-Months per Participant
Participant Number/ Short Name	LSC	LSC		12(new) + 8(staff)
Participant Number/ Short Name		LNGS		4 (staff)
Total Person Months	12(new)	12(staff)		24 (12 new + 12 staff)

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Milestones:

Table 3.1c: List of Deliverables

Deliverable (number)	Deliverable name	Work package number	Short name of lead participant	Type	Dissemination level	Delivery date (in months)
3	Integration	WP5.2	LSC	R/DEM	PU	24
4	Purchasing	WP5.2	LNGS	R/DEM	PU	24
5	Testing	WP5.2	LSC	R/DEM	PU	36

Table 3.1d: List of milestones

Milestone number	Milestone name	Related work package(s)	Due date (in month)	Means of verification
1	Design of magnetic shielding	WP 5.2	12	simulation
2	Fabrication of shield and fixtures	WP 5.2	24	up and running
3	Testing of characterisation system	WP 5.2	36	publication

APOGEIA WP5.2

Budget:

Table 3.1h:‘Purchase costs’ items (travel and subsistence, equipment and other goods, works and services)

Participant Number/Short Name		
	Cost (€)	**Justification**
Personnel	252k	1FTE/year x 3 years (LSC)
Equipment	80k	Instrumentation and equipment needed in the cryostat (LNGS)
Other goods, works and services	30k	Manufacturing of components (LSC+LNGS)
Remaining purchase costs	30k	Consumables (LSC+LNGS)
Total	392k	

THANK YOU