COLD Lab activity report

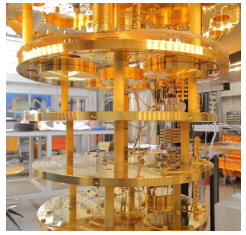
Claudio Gatti

65th LNF Scientific Committee – May 2023

COLD - Cryogenic Laboratory for Detectors

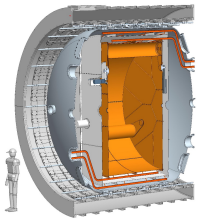
- Axion Experiments
- Superconducting Quantum Devices
- Superconducting Cavities
- Magnetic Measurements

EXPERIMENTS



QUAX – QUest for AXions

Search for galactic axions with Sikivie's Haloscopes at 10 GHz (Ongoing experiments at LNL and LNF).



(K)FLASH

Search for galactic axions with a Sikivie's Haloscope at 100 MHz (Design Study).

Networking Projects

CA21106 - COSMIC WISPers in the Dark Universe: Theory, astrophysics and experiments (CosmicWISPers)

PNRR Projects

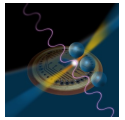
ICSC National Center of HPC Big Data and Quantum Computing

NQSTI National Quantum Science and Technology Institute

Superconducting Devices

Qub-IT Quantum Sensing with superconducting qubits (Second year)

DART WARS (Detector Array Readout with Travelling Wave AmplifieRS)
Development of wide band quantum amplifiers for multi-channel detector readout (last year)



SIMP (Single Microwave Photon detectors)
Development of single-microwave photon detector (Completed)

Supergalax FET H2020 Project
SC-qubits array photon-detector for axion experiments (Last year)

SQMS USA DOE Project
Superconducting Quantum Materials and Systems (0ngoing)

Resilience Grant Giovani CSNV Magnetic field resilient microwave single photon detector based on van der Waals Josephson junctions (First year)

SAMARA Superconducting materials for cavities and haloscopes (Second year)

outline

FLASH

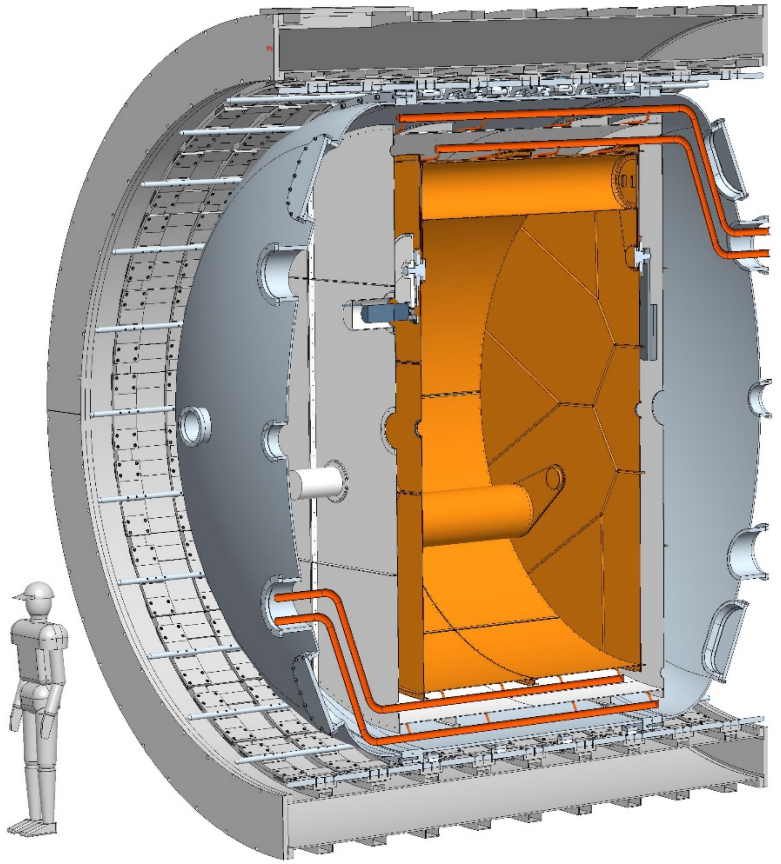
QUAX

Quantum Sensors

PNRR

FLASH
Finuda magnet for Light Axion SearcH

Galactic axion search at 100 MHz (0.5-1.5 μeV)



Flash paper almost ready

Article

FLASH

Firstname Lastname [1,†,‡], Firstname Lastname [2,‡] and Firstname Lastname [2,*]

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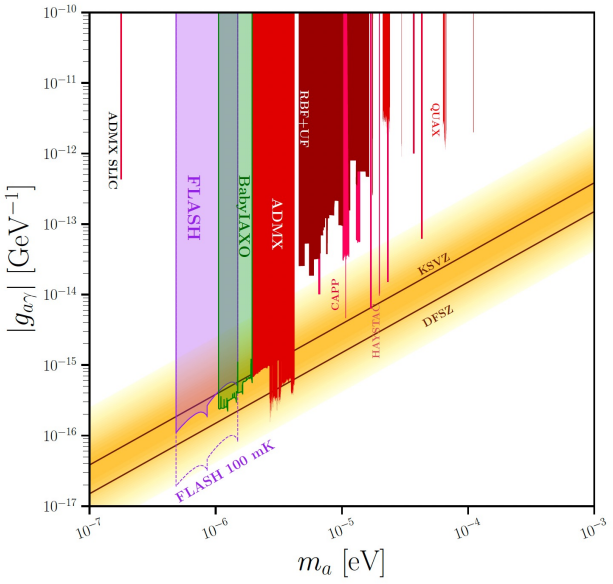
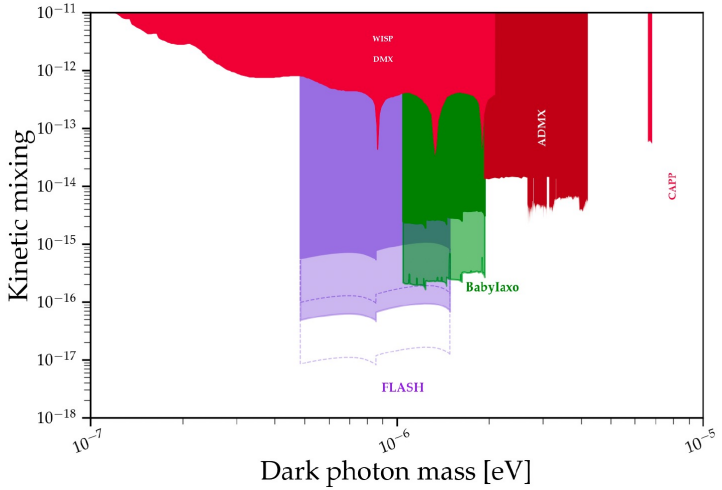
† Current address: Affiliation 3.
‡ These authors contributed equally to this work.

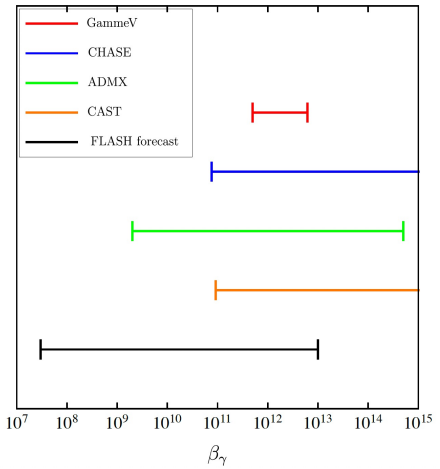
Abstract: We present a proposal for new experiment, the FINUDA magnet for Light Axion SearcH (FLASH), a large resonant-cavity haloscope in a high static magnetic-field which is planned to probe new physics in the form of a dark-matter axion, hidden photons, and high frequency gravitational waves (GWs). In more details, FLASH will search for dark matter axions in the mass range $0.3 - 1\,\mu$eV, thus filling the mass gap between the ranges covered by ADMX and DMRadio/ABRACADABRA. The mass range overlaps with the Very High Frequency (VHF) range of the radio wave spectrum and allows for a search in GWs in the range $\omega_{\rm GW} = (100 - 300)\,$MHz. A dedicated Microstrip SQUID operating at ultra-cryogenic temperatures will amplify the signal. The experiment will use the cryogenic plant and magnet of the FINUDA experiment at the Frascati National Laboratories of INFN near Rome. The works needed to put the plant back into operation are currently underway. We present the setup of the experiment and the sensitivity forecasts for the detection of axions, hidden photons, and GWs with FLASH.

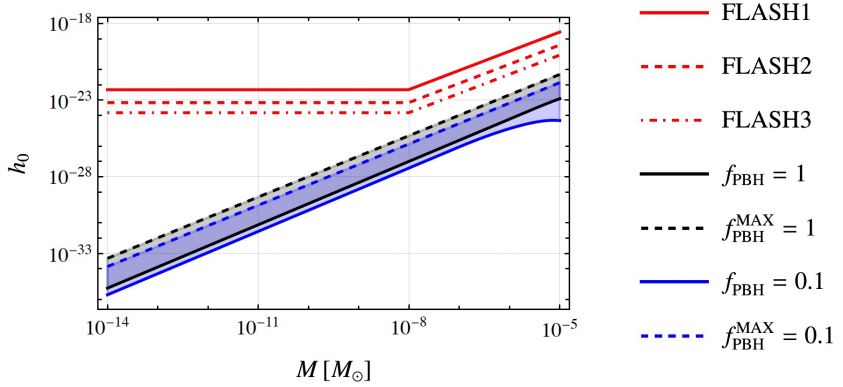
In collaboration with LNF theory group and L Visinelli, M Zantedeschi and M Giannotti.

FLASH Sensitivity to Axions, DP, HFGW and Chameleons





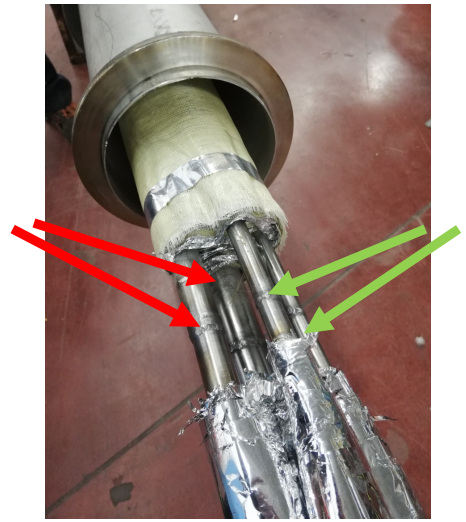




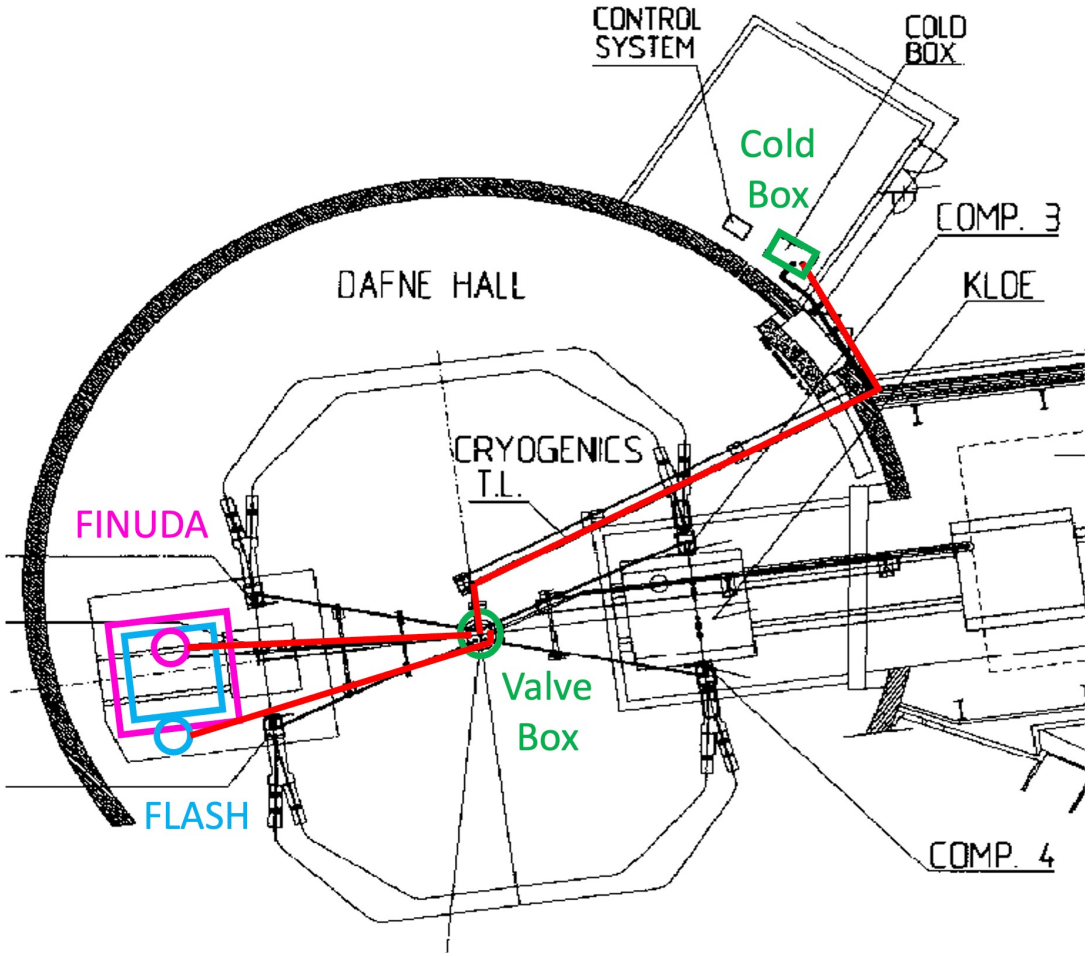
FINUDA Transfer Line reconnection

- FINUDA was supplied with liquid/gaseous Helium from the cryogenic Valve Box using a cryogenic transfer line which was dimensioned to reach the FINUDA position in the 2nd DAFNE interaction region. FINUDA was moved 5 meter apart.
- At the end of February the Helium transfer line from the cryogenic plant to FINUDA was modified. The old line was cut and a brand new section, about 5 meter long, was inserted, to reach the magnet position far from DAFNE.

70K send/return lines



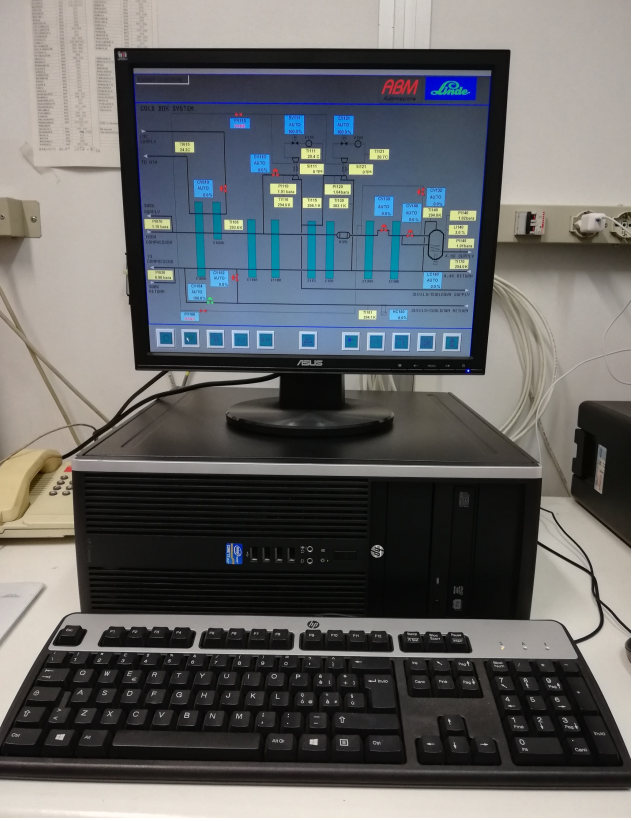
4.5K send/return lines



C. Ligi

FINUDA TL reconnection

C. Ligi



Cryogenic plant

- The cryogenic plant is almost ready to start.
- The compressor is ready but we must clean the cooling water circuit before to start it
- The cold box is ready, the PLC has been checked. Safety batteries replaced.
- The spectrometer for Helium purity works - Pyrolizer needs to be checked for working.
- Need to check the compressed air circuit in the cryoplant needed
- Safety valves for FINUDA and cryogenic plant have been mainteined
- Water cooling for the FINUDA power supply has been restored

C. Ligi

Control of Magnet Power Supply

- The current control system is based on National Instrument hardware and software
- The power supply control hardware consists of:
  - Two PXI national instrument crates
  - 1 Pxi controller NI 8175 with windows XP e Labview 5
  - 2 NI 8835 MXI – 3 optical fiber connection board (not used)
  - 1 PXI GPIB
  - 1 PXI NI 6527 Digital I/O
  - 1 PXI NI 6704 Analog Out
  - 1 PXI NI 8320 RS-232
  - 1 NI 6031° Multifunction I/O
  - Rack with PID and signal conditioning board
- Software developed in labview 5. We have the source code
- All hardware and software are outdated
- All needed hardware, even if obsolete, is supported in the new version of Labview.

Control of Magnet Power Supply

Actions to take during next Dafne stop:

- Replacing the two crate connections with a single crate with controller
- Installing a more recent version of the operating system on the controller that supports newer versions of Labview

Actions in progress:

- Upgrade of the control software
- We are checking the connections between the acquisition boards and the conditioning boards with an analysis of the electrical diagrams in our possession

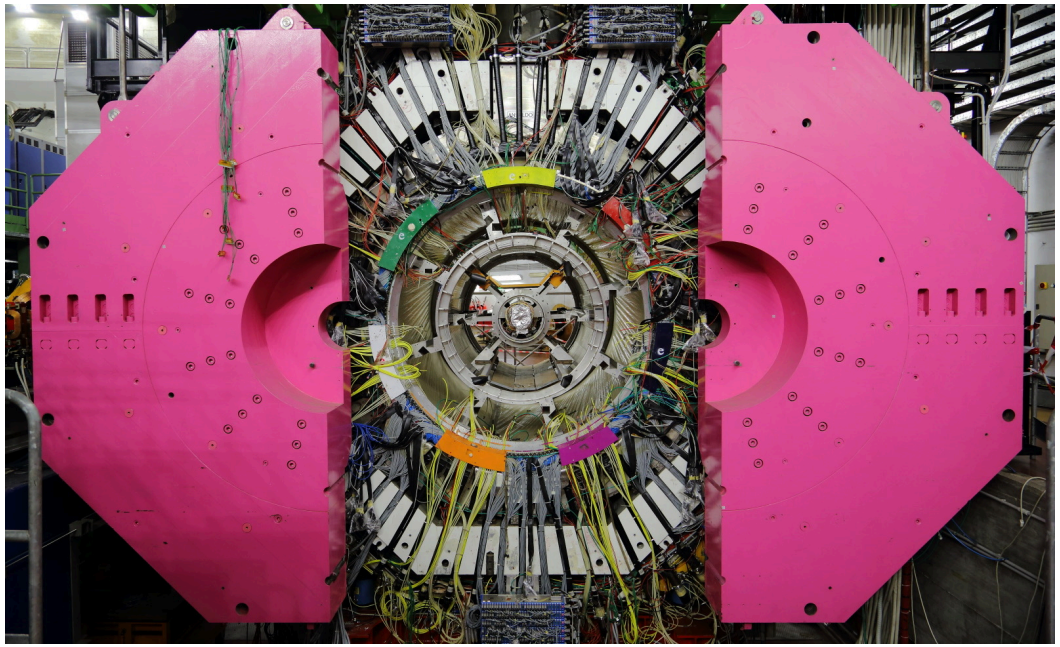
These actions should allow us to operate the power supply for the magnet test

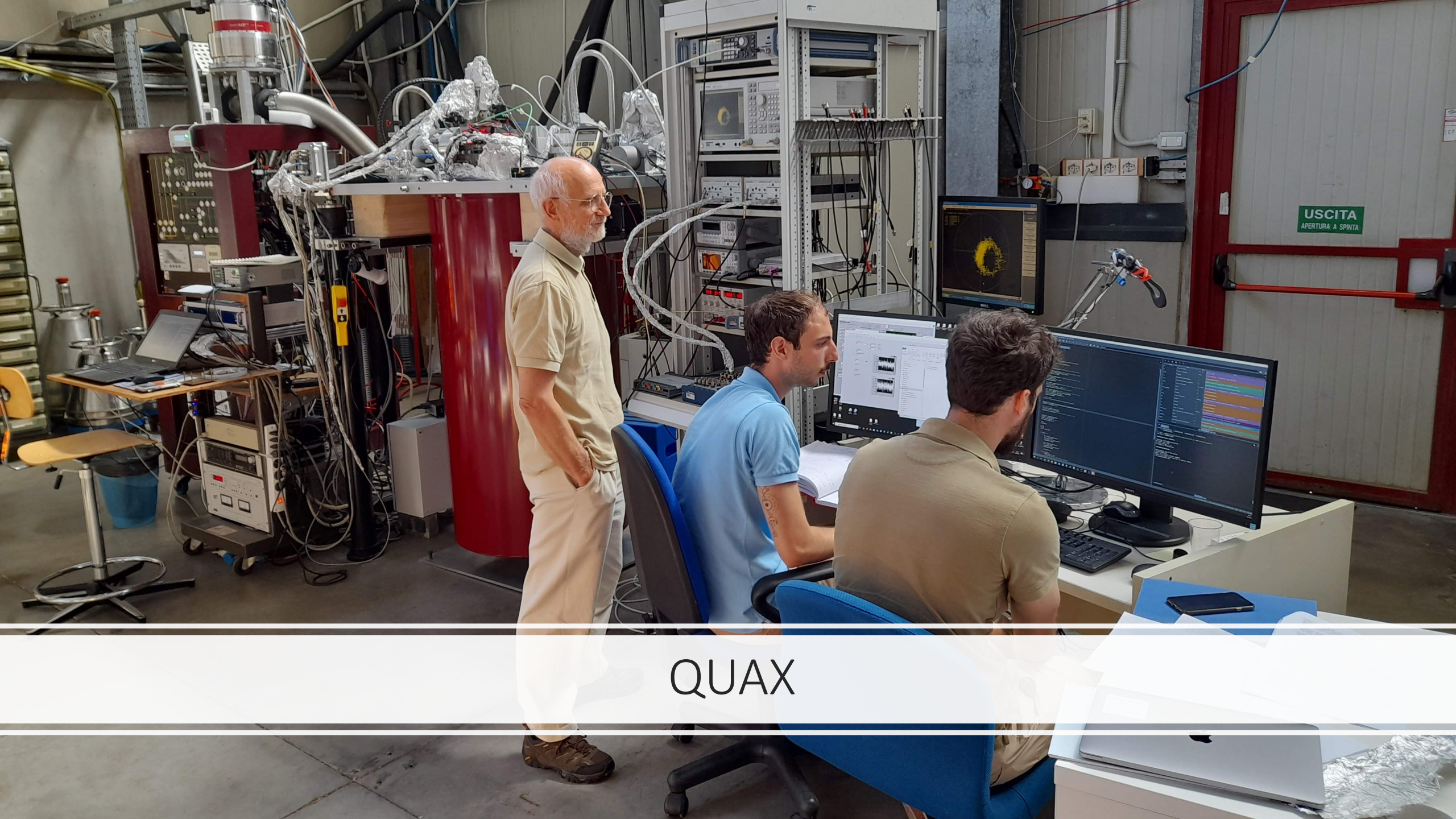
An update of the hardware and software is needed for the experiment

Closing System of the Magnet Iron-Endcaps

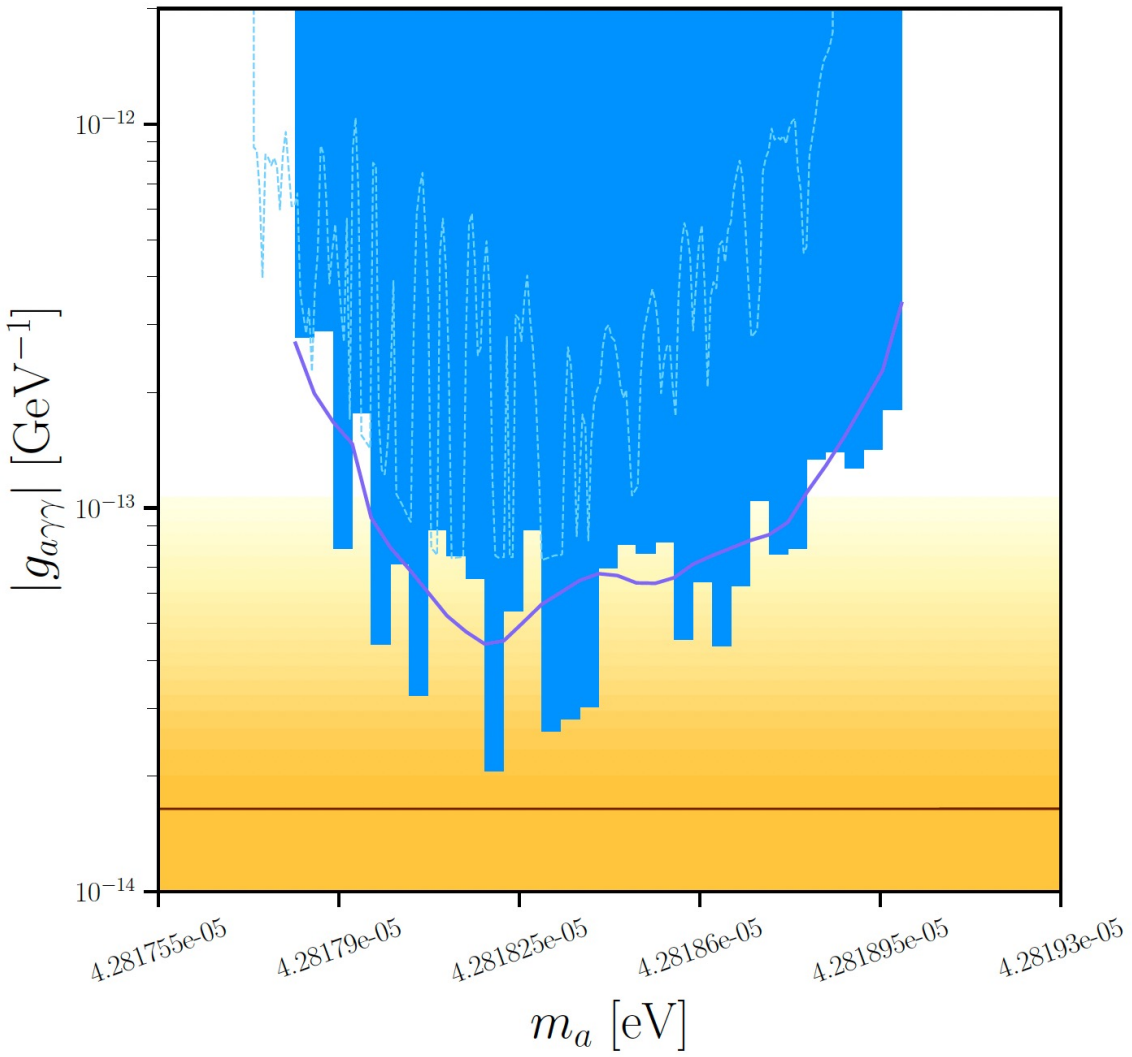
- Safety courses activated for the personnel concerned (work at height, work in confined spaces).
- The restoration works have been entrusted to an external company
- During the next DAFNE stop we plan dismount and replace, at least part of, the flex pipes of the hydraulic system.

ID	Task Mode	Task Name	Duration	Start	Finish
1		Project Start	0 days	Mon 07-11-2	Mon 07-11-2
2		**FINUDA Magnet Revamping**	**18 days**	**Mon 07-11-22**	**Wed 30-11-22**
3		PIT area cleaning	1 day	Mon 07-11-2	Mon 07-11-2
4		Scaffoldings and Lif	1 day	Tue 08-11-22	Tue 08-11-22
5		Cable arrangement	1 day	Wed 09-11-2	Wed 09-11-2
6		Flex pipes dismounting	1 day	Thu 10-11-22	Thu 10-11-22
7		Flex pipes Procurement	5 days	Fri 11-11-22	Thu 17-11-22
8		Flex pipe mounting	2 days	Fri 18-11-22	Mon 21-11-2
9		Air purging and tes	5 days	Tue 22-11-22	Mon 28-11-2
10		End cap closing	2 days	Tue 29-11-22	Wed 30-11-2
11		Electrical cabinet revamping	1 day	Mon 07-11-22	Mon 07-11-22
12		Vacuum pumping start	1 day	Tue 08-11-22	Tue 08-11-22
13		Project End	0 days	Wed 30-11-2	Wed 30-11-2





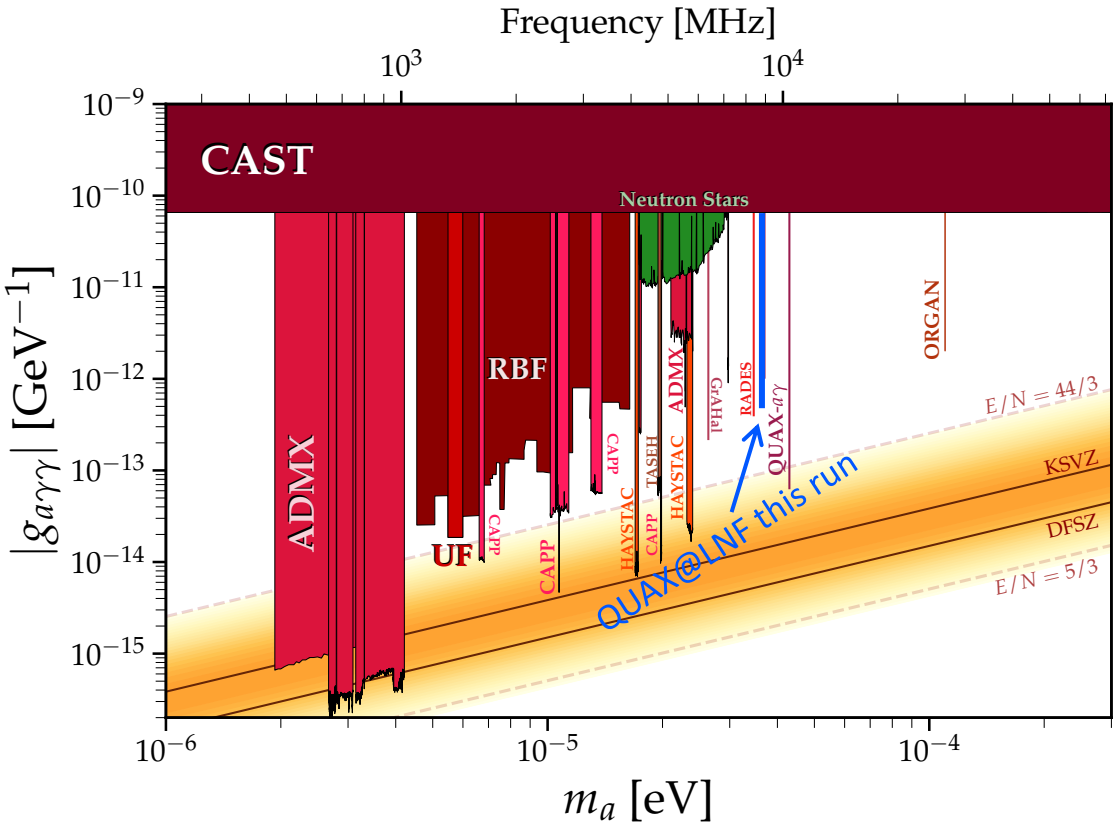
QUAX



arXiv:2304.07505v1

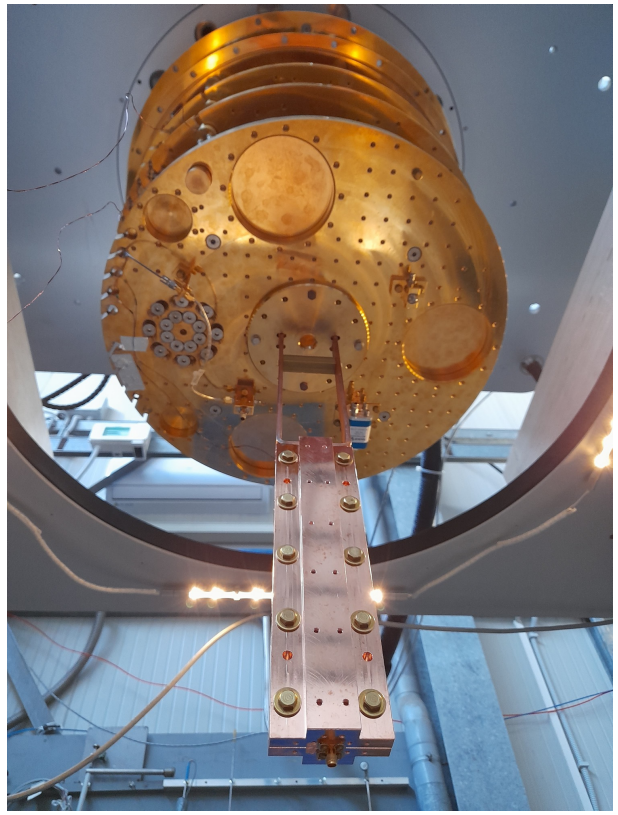
QUAX@LNL: Search for galactic axions with a traveling wave parametric amplifier

QUAX@LNF: First Test Run of LNF Haloscope in June 2022



$g^{KSVZ} = 1.35 \times 10^{-14}$ @ m_a=35 μeV

Frequency	8.5 GHz
Volume	0.14 L
Q_0	100,000
B	9 T
Tcavity	20 mK

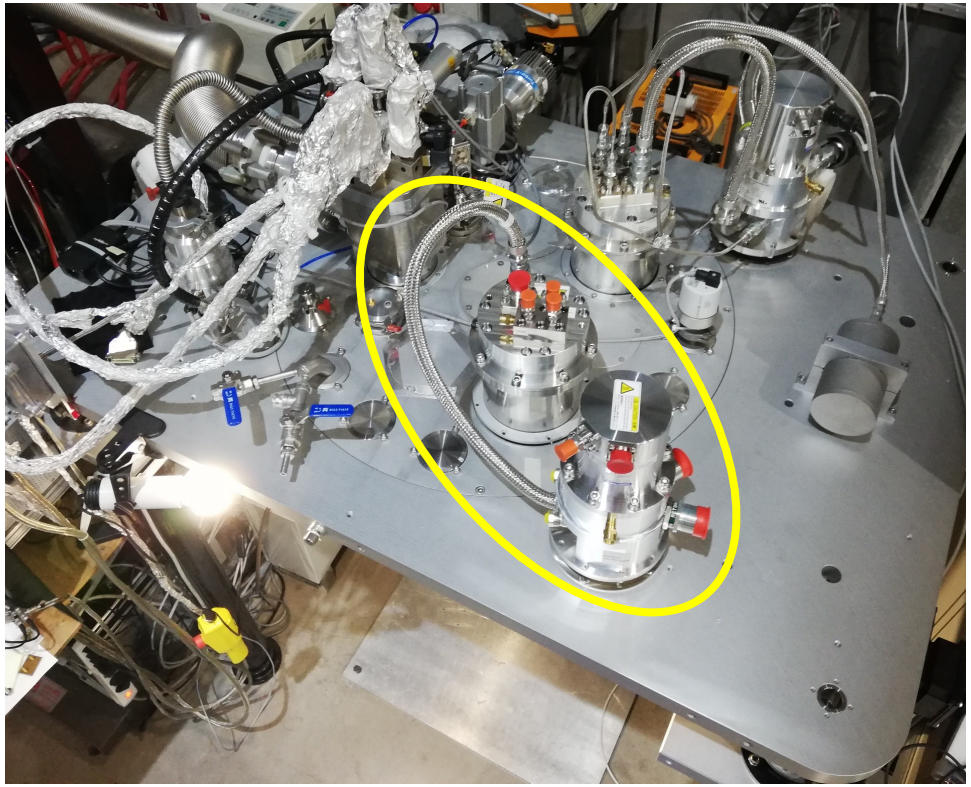


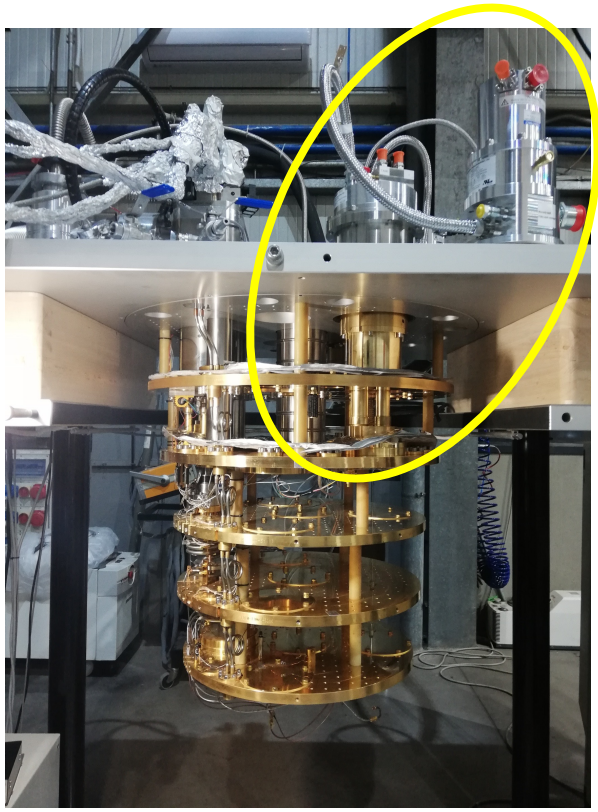
Gagg 90% cl	T_{noise}	Q	B(T)
3.3×10^{-13} (2h)	8 K (HEMT)	10^5 Cu Cavity	2.5
6.6×10^{-14}	3 K (HEMT)	10^5 Cu Cavity	9
2.5×10^{-14}	SQL (JPA)	10^5 Cu Cavity	9
DFSZ axions	SPD	2.5 10^5 SC Cavity	9

1h data taking

Second Pulse Tube Arrival, Mounting and Operation on the 10 mK Cryostat

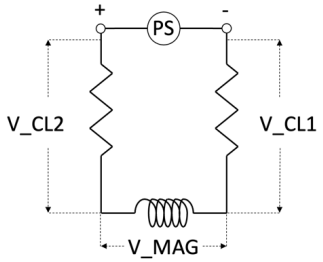
- A 1.5 W Pulse Tube refrigerator was procured and assembled on the COLD Lab cryostat with dilution refrigerator
- It is identycal to the one already mounted (Sumitomo SRP-182B2S) and works as a booster for the cooling capacity at 4 K and 50 K
- Dilution refrigerator operated succesfully with two pulse tubes since January 2023 with stable operation temperature on the 4K and 50 K plates.

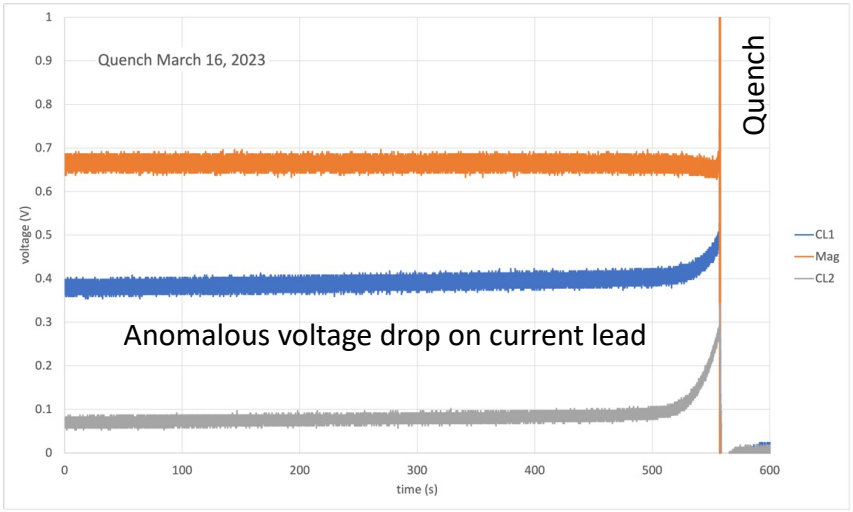




Quench of 9T, 100mm bore, SC magnet

Test #	Ramp Rate above 5T mA/sec (T/min)	Quench field (T)	magnet T just before quench (K)	magnet T just after quench (K)
1	23.1 (0.147)	6.27	4.6	28
2	7.9 (0.05)	6.08	4.3	22
3	3.14 (0.02)	5.98	4.2	21
4	1.57 (0.01)	5.94	4.1	23





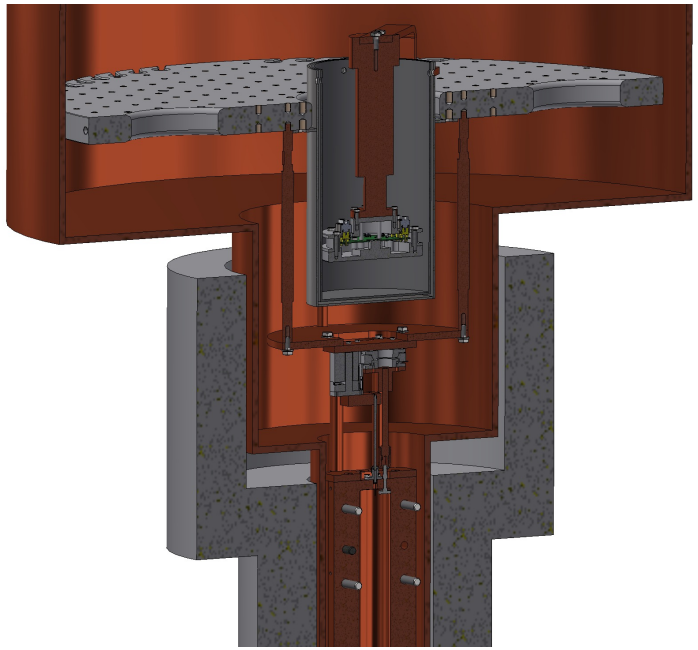
- Even with stable temperature at 4K the magnet quenches at 6 T (about 60 amps).
- Under suggestion of AMI, quench test has been repeated while measuring the voltage drop along the magnet and the magnet leads.
- Anomalous increase of the voltage drop on the current leads, up to 500 mV, before the quench.
- Melted plastic insulator found on the NbTi wires connecting at 4 K the HTC leads to the last stretch of copper leads reaching the magnet. Sent them back to Leiden Cryogenics. We received the repaired ones in April. New test next week.

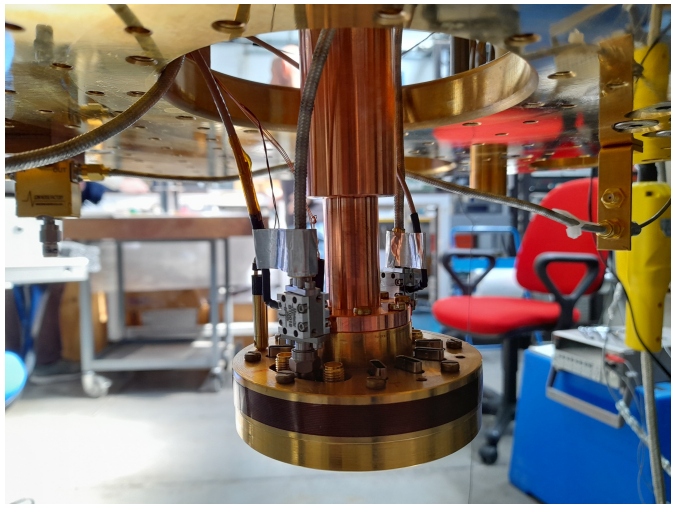
New magnetic field shield and support mechanics

- New Magnetic field shield composed of two concentric cylinders 1.5 mm CryoPhy and 1.5 mm Aluminum from Magnetic Shields UK.
- Support mechanics for shield, sample holder, cavity and piezo motors for tuning ready.
- Piezo motors arrived on May the 2nd.
- Nb3Sn cavity arrived from FNAL (SQMS) on February 2023, preparing for test in magnetic field.
- Getting ready for the first physics run

New B filed shield

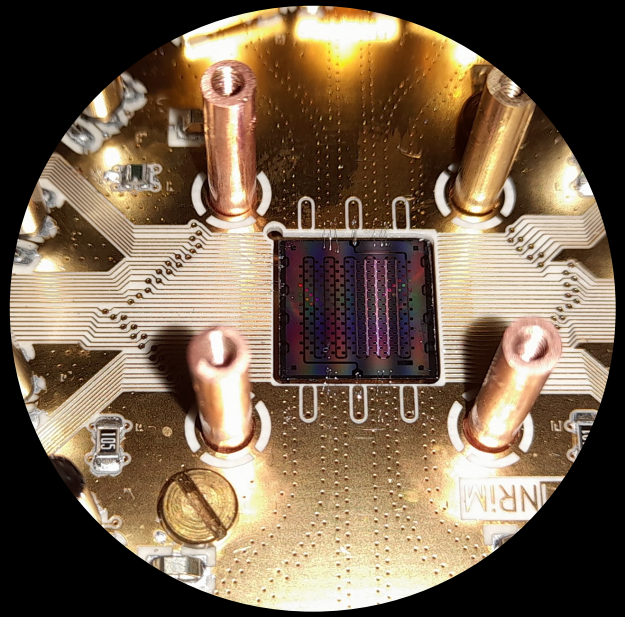
Support mechanics design (S. Lauciani)

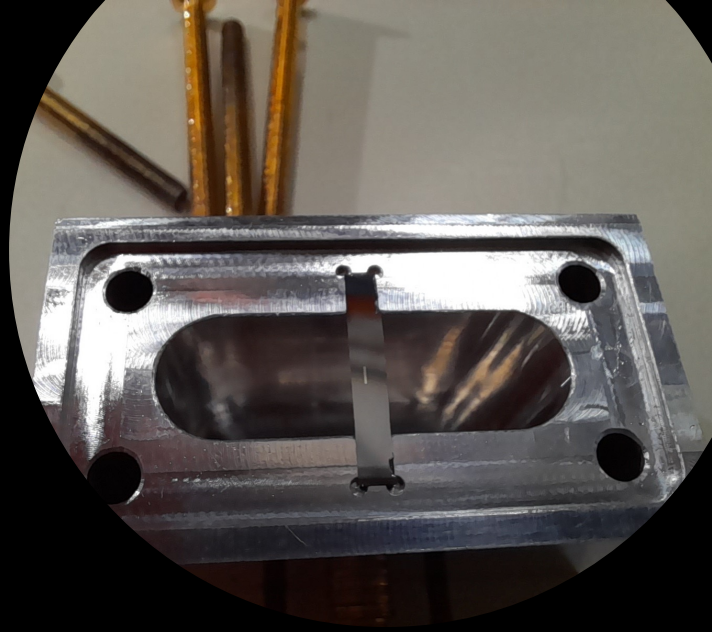


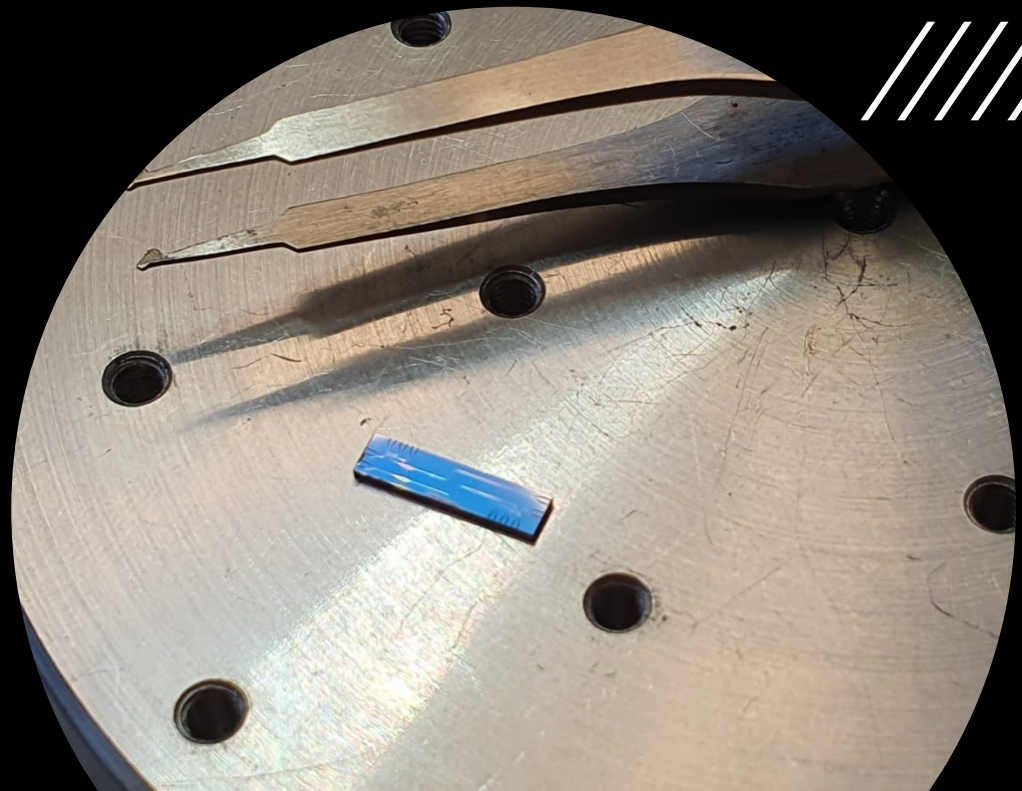


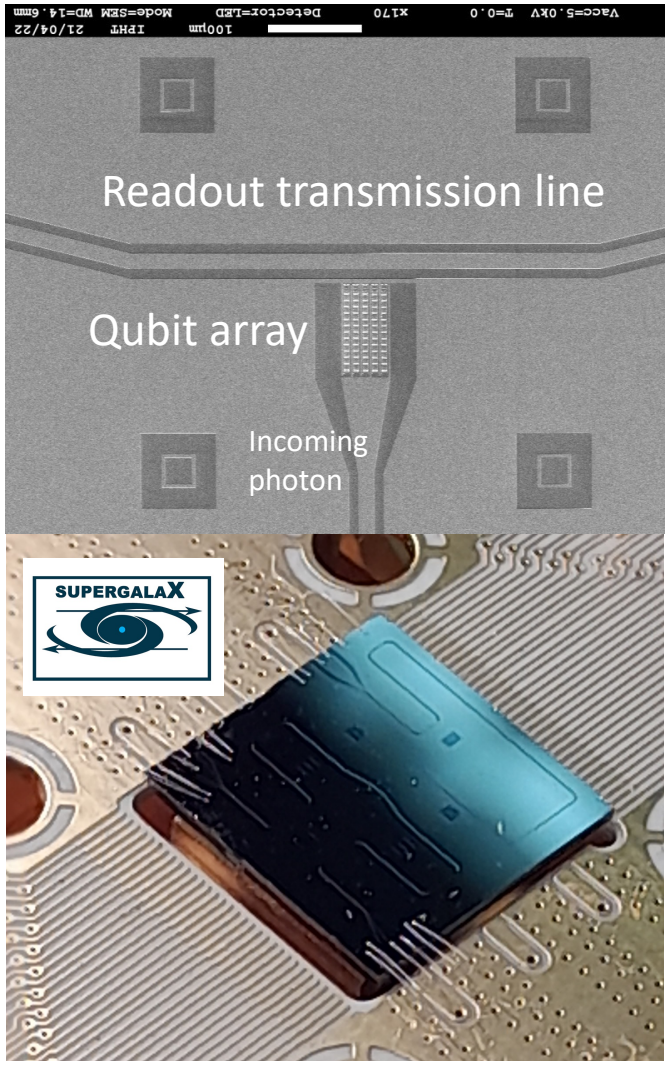
Sample holder muonted on the new cold finger

Quantum Sensors

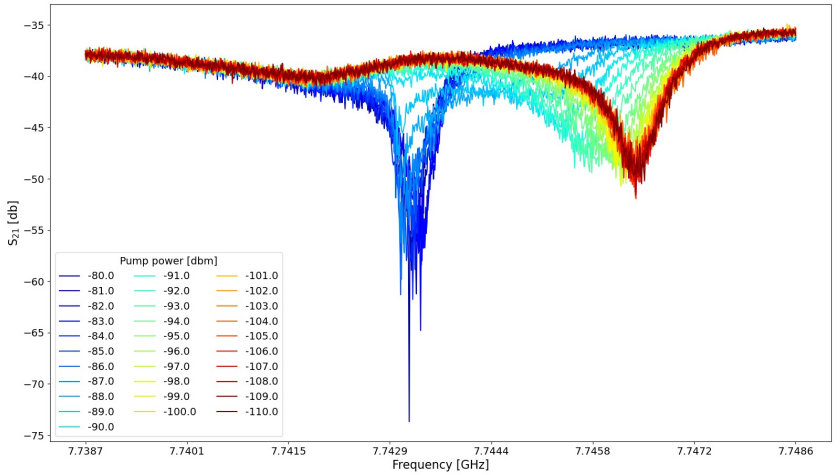






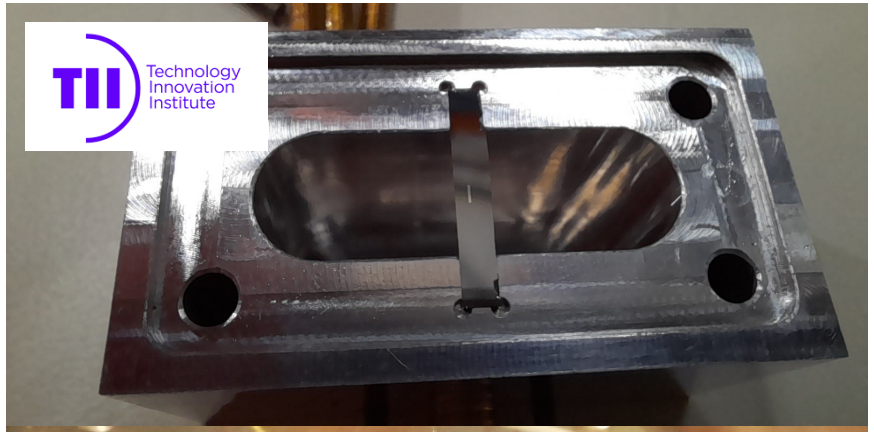


Coherent Quantum Network of Superconducting Qubits as a Highly Sensitive Detector of Microwave Photons

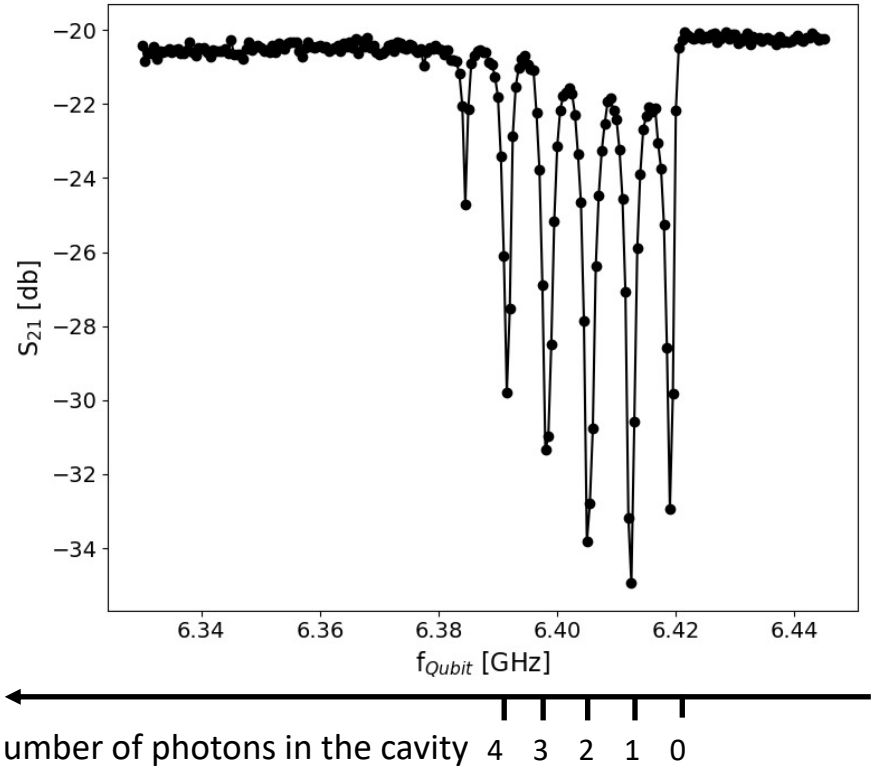


A substantial variation of the transmission properties was measured in a transistor-type detector based on 10 flux qubits when power was applied to the “base” terminal.

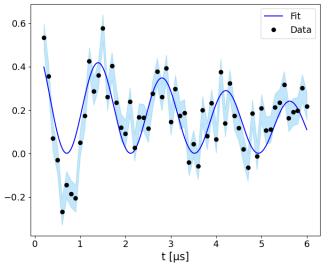
IEEE Transactions on Applied Superconductivity DOI 10.1109/TASC.2023.3263807



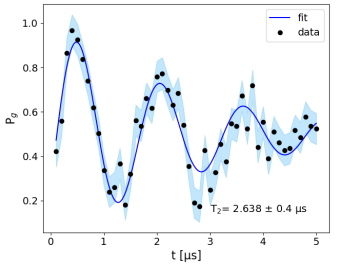
7 GHz Photon Counting in a 3D Resonator with a Superconducting Qubit



Rabi Oscillations



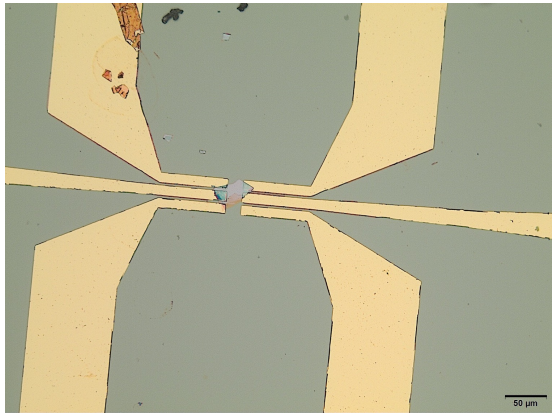
Ramsey Spectroscopy



3D qubit fabricated at the Technology Innovation Institute of Abu Dhabi

Magnetic field resilient JJ with van der Waals materials

(A. D'Elia INFN young researcher Grant)



- van der Waals (vdW) materials can be exfoliated down to monolayer thicknes
- New properties respect to the bulk counterpart.
- Exfoliated NbSe2 is an Ising superconductor able to withstand magnetic fields up to 30 T
- NbSe2 JJ can be used to assemble a magnetic-field resistant single-photon detector

Resilience

Recovery Plan (PNRR) Projects

ICSC National Center of HPC Big Data and Quantum Computing

NQSTI National Quantum Science and Technology Institute

- Development of the superconducting quantum computer hardware chain
- Design and test of superconducting qubits
- Design and test of parametric amplifiers
- Quantum Memories
- Generation of entangled photons with parametric amplifiers

1.5 M€ funding for COLD Lab

Instruments: new dilution refrigerator, new RF electronics, …

1 Research contract

1 Tecnician

1 Post Doc

In conclusion …

- FINUDA Magnet Test
  - Commissioning work have begun! Test expected within this year.
  - Many thanks to the Director, the divisions DA, DT and DR and their Services (Vacuum, Fluids, Electric and Electronics, Mechanics, Cryogenics, Saftey, Radiation and Protecion).
- QUAX
  - We forsee a QUAX@LNF scan of 10 MHz scan in fall at 8.5 GHz with a sensitivity at 5×KSVZ

As a general consideration, managing several projects in the lab is certainly complex but:

- Great synergy and overlap between projects
- We will upgrade the COLD lab cryogenic and electronic instrumentation.
- We can now pay for 3/4 postdocs, 1 technician and 1 researcher
- We have now 2 undergraduate students on quantum devices (Qubit/PNRR), 1 Erasmus student from Heidelberg, 1 more student will start this summer the thesis on QUAX@LNF.

https://agenda.infn.it/e/CosmicWispersKickOff

COSMIC WISPERS
CA21106