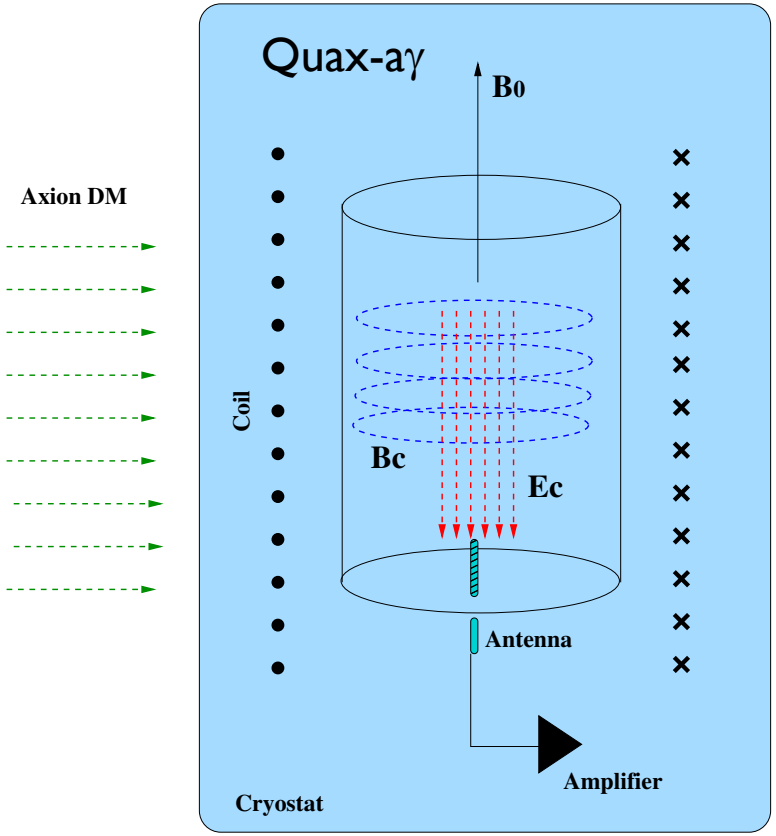
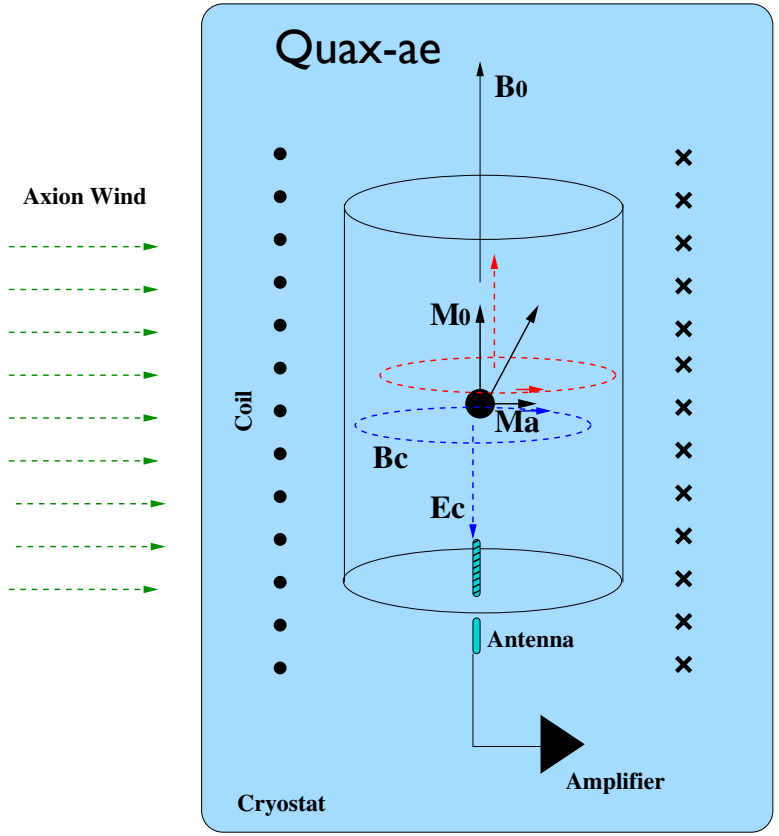
QUAX

CLAUDIO GATTI

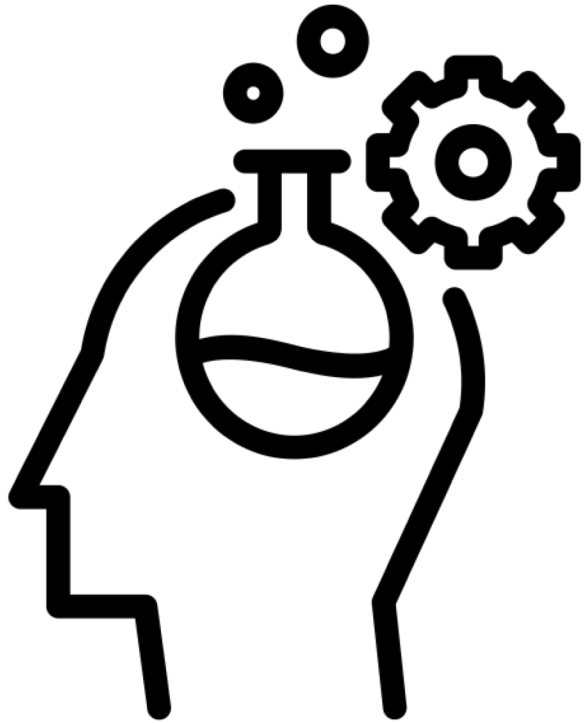
QUAX: Quest for Axions

$$\mathcal{L} = i\frac{g_d}{2} a \left(\bar{N}\sigma_{\mu\nu}\gamma^5 N\right) F^{\mu\nu} + i\frac{g_{aNN}}{2m_N}\partial_\mu a \left(\bar{N}\gamma^\mu\gamma^5 N\right) + i\frac{g_{aee}}{2m_e}\partial_\mu a \left(\bar{e}\gamma^\mu\gamma^5 e\right) + g_{a\gamma\gamma} aE\cdot B$$





QUAX R&D 2018-2020



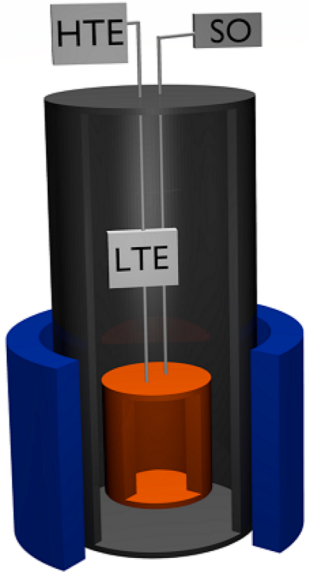
Created by Chameleon Design from Noun Project

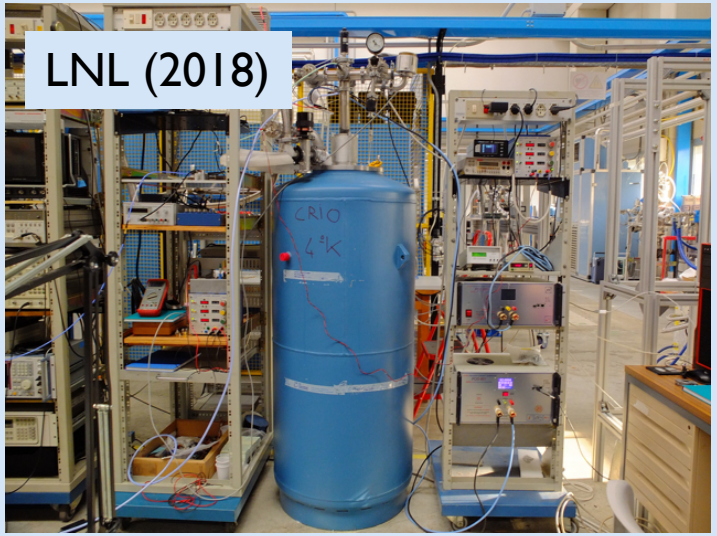
QUAX R&D 2018-2020

R&D goals:

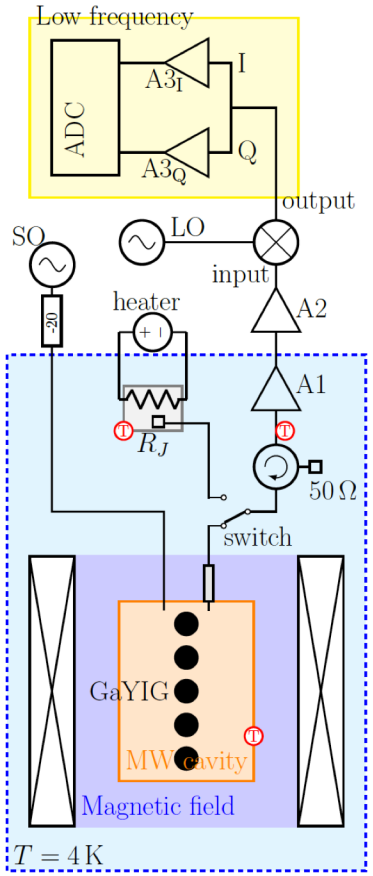
- High-Q resonant cavities operating in intense B field
- Low loss magnetic material for axion-electron detection
- Low noise cryogenic amplifiers and/or microwave photon detectors

Sezioni INFN
Padova (Resp Naz)
LNL
LNF
TIFPA FBK
Salerno



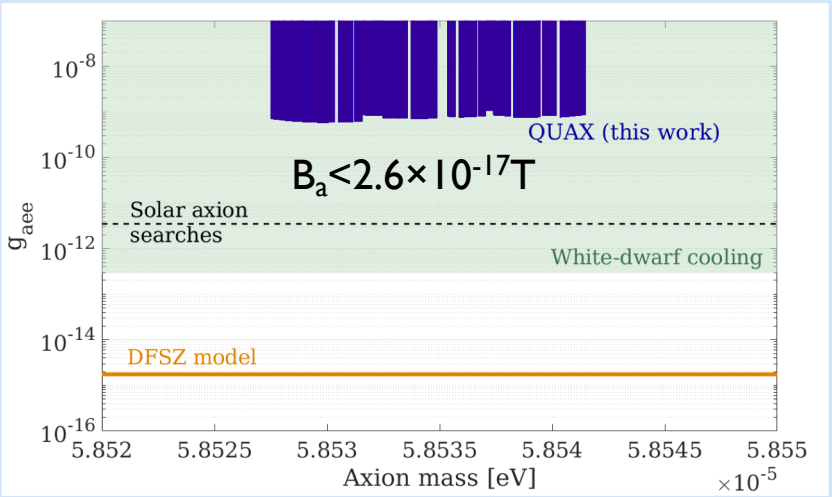


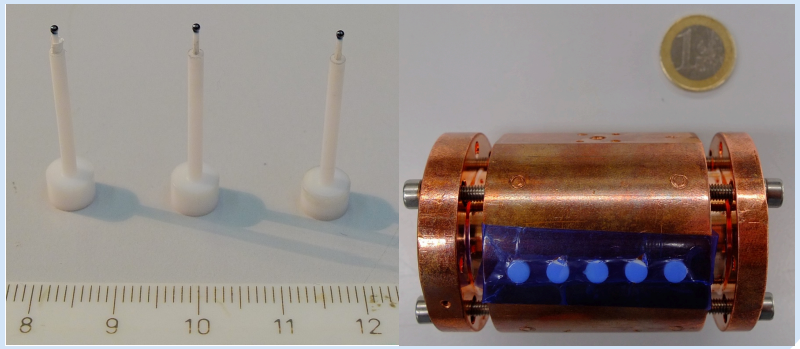
QUAX-ae result with Ferromagnetic Axion Haloscope at m_a = 58μeV



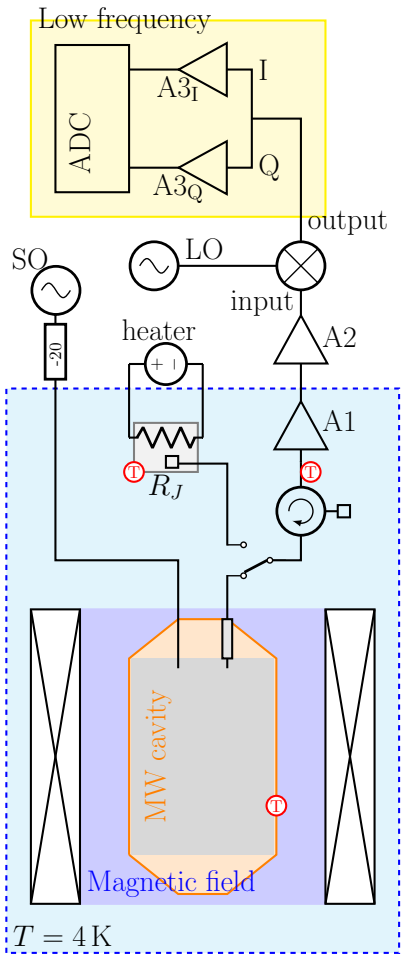
Experimental Setup	
B [T]	0.5
N. of GaYIG Sphere (diameter =1 mm)	5
n_s [spin/m^3]	2.1×10^{28}
τ_{min} [μs]	0.11
Frequency [GHz]	13.98
Cu-cavity Q (mode TM110)	50,000
T_{cavity} [K]	5.0
T amplifier [K] (HEMT)	11

EPJC (2018) 78:703

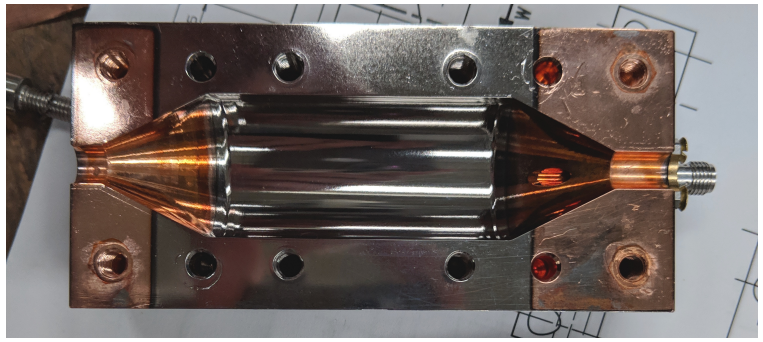




QUAX-aγ Result with Superconductive Resonant Cavity at m_a = 37.5 μeV



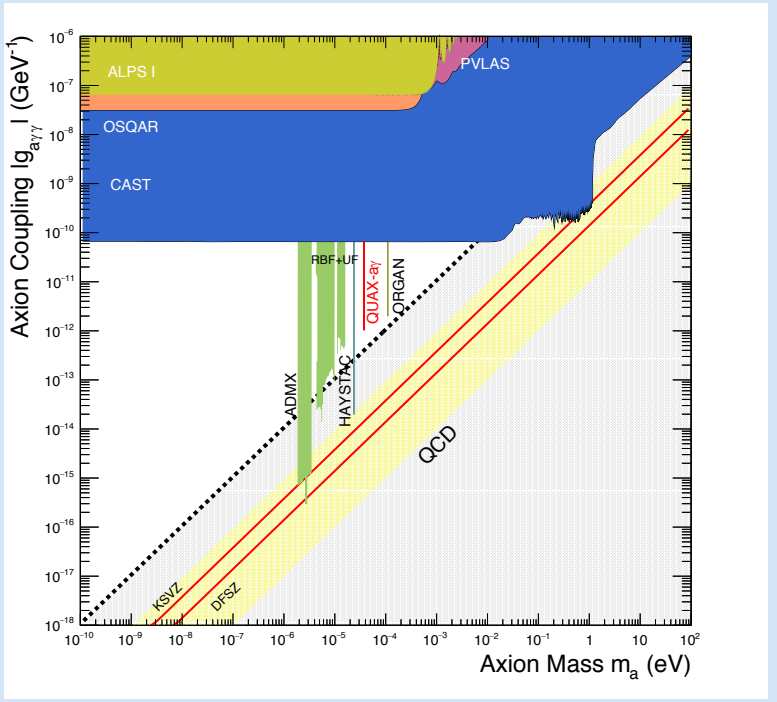
Experimental Setup	
B [T]	2
Frequency [GHz]	9
NbTi cavity Q (mode TM010)	400,000
T_{cavity} [K]	5.0
T amplifier [K] (HEMT)	11



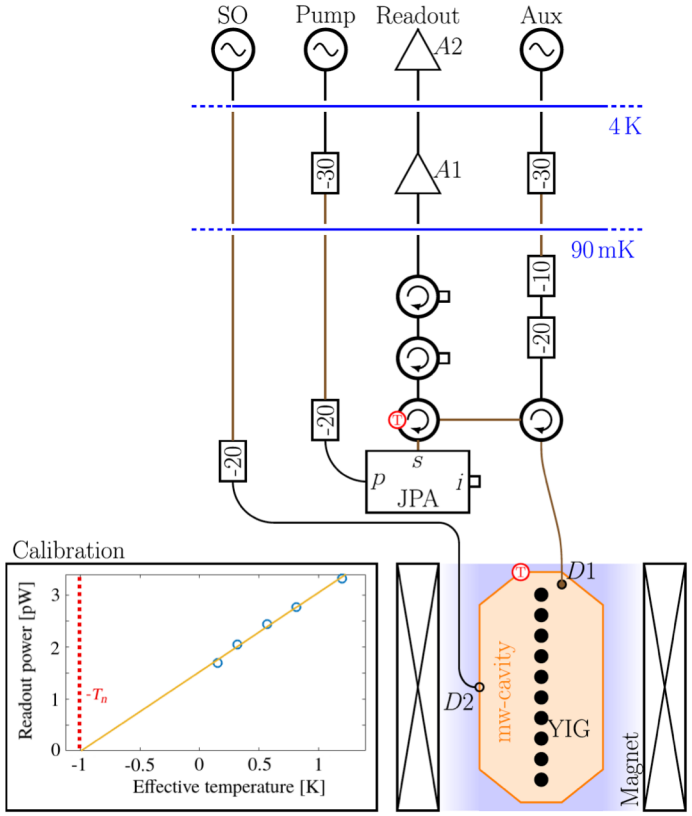
IEEE TRANS. APP. SUPERCOND. 29, 5 (2019)

Phys. Rev. D **99**, 101101(R) (2019)

$$g_{a\gamma\gamma} < 1.03 \times 10^{-12}\,\mathrm{GeV}^{-1}$$

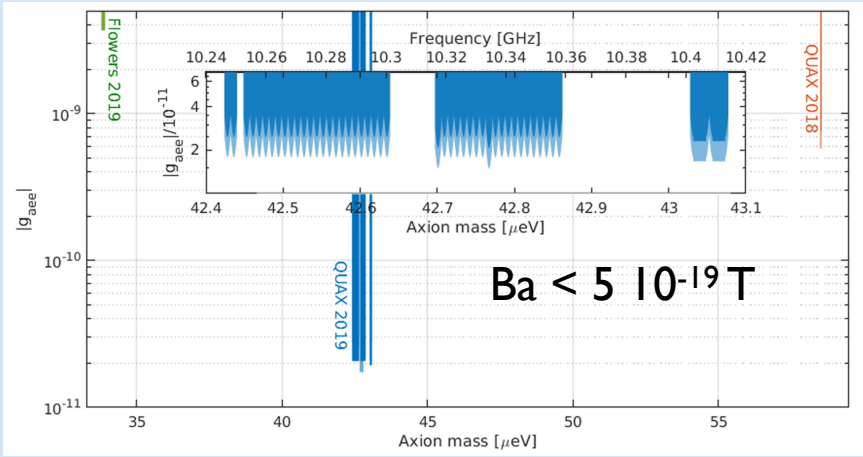


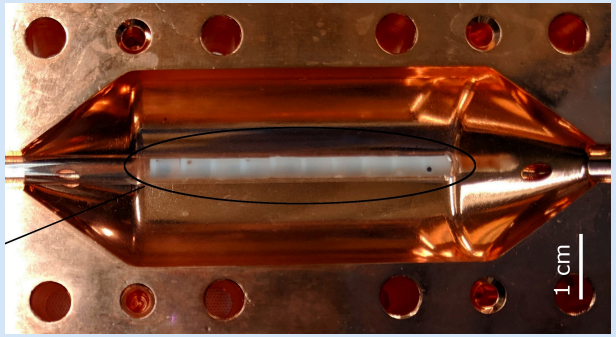
QUAX-ae with Quantum-Limited Ferromagnetic Haloscope



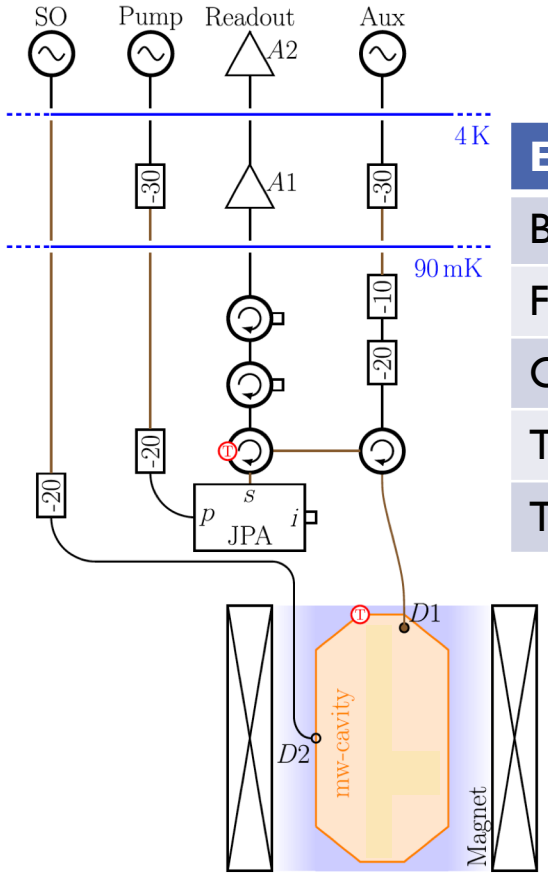
Experimental Setup	
B [T]	0.5
N. of GaYIG Sphere (diameter =2.1 mm)	10
n_s [spin/m^3]	2.1×10^{28}
τ_{min} [μs]	0.1
Frequency [GHz]	10.7
Cu-cavity Q (mode TM110)	50,000
T_{cavity} [mK]	90
T amplifier [K] (JPA)	0.5-1

Phys. Rev. Lett. **124**, 171801 (2020)



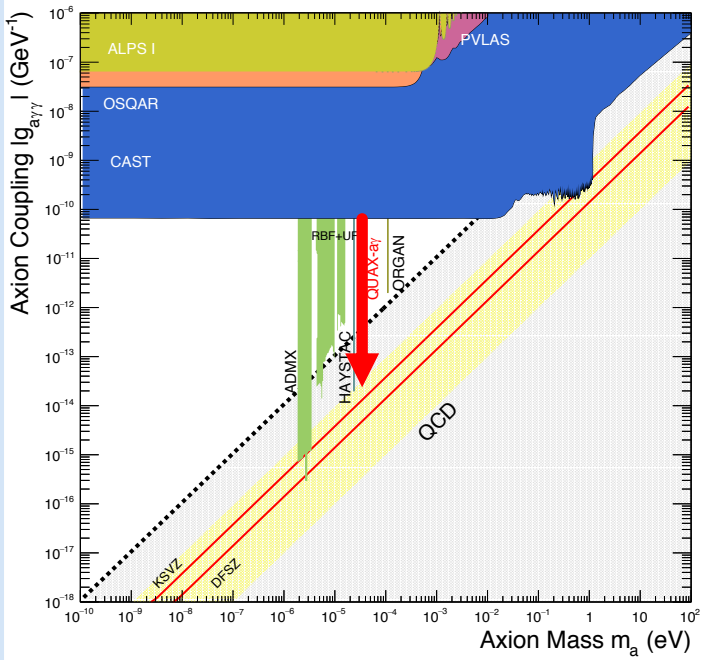


QUAX-aγ in 2020 Reached the Sensitivity to QCD Axions



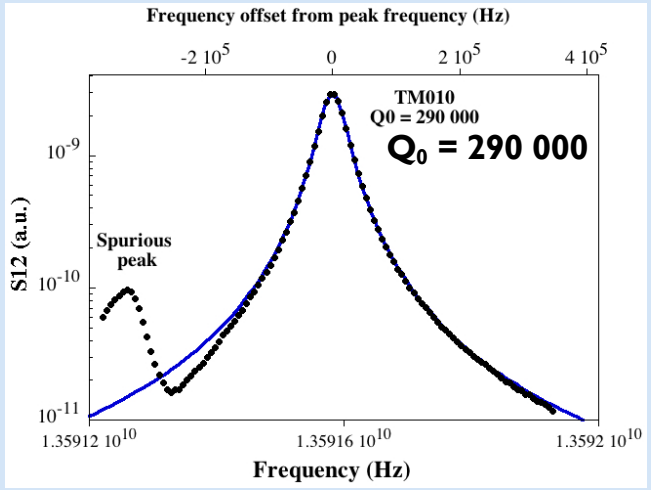
Experimental Setup	
B [T]	8
Frequency [GHz]	10.4
Cu cavity Q (mode TM010)	76,000
T_{cavity} [mK]	90
T amplifier [K] (JPA)	0.5-1

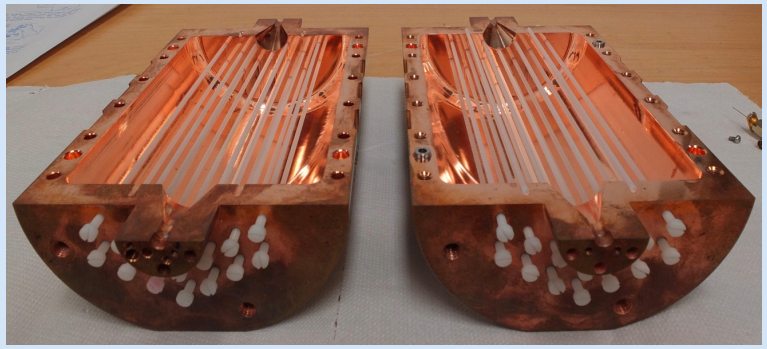
Paper in preparation



High Q Dielectric Cavities

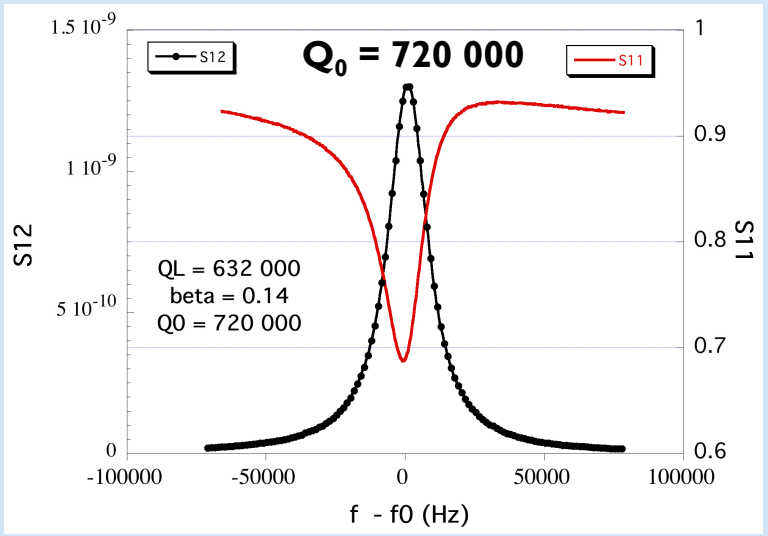
High quality factor photonic cavity





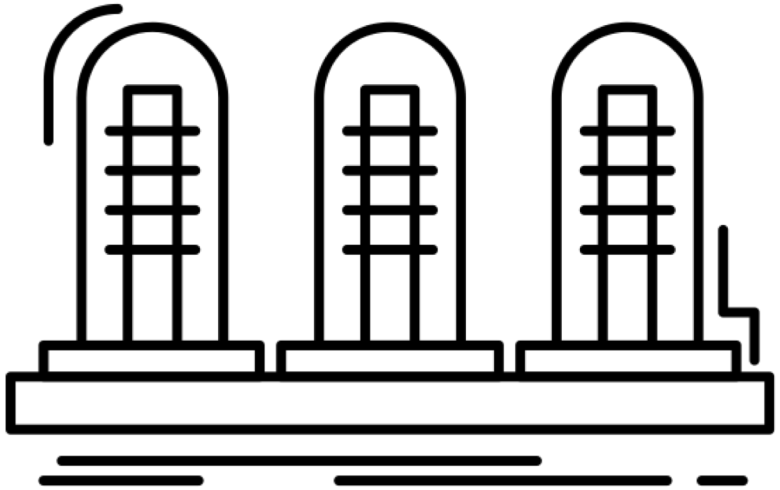
Submitted to Rev Sci Instr

High quality factor photonic resonator with hollow dielectric cylinders



Submitted to Nucl Instr Met

SIGNAL AMPLIFICATION



Created by Flatart from Noun Project

TWJPA

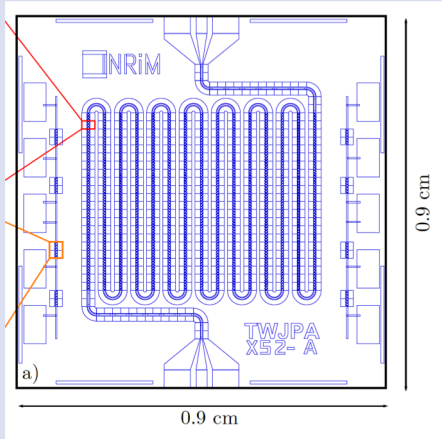
Travelling Wave Josephson Parametric Amplifier fabricated at INRIM:

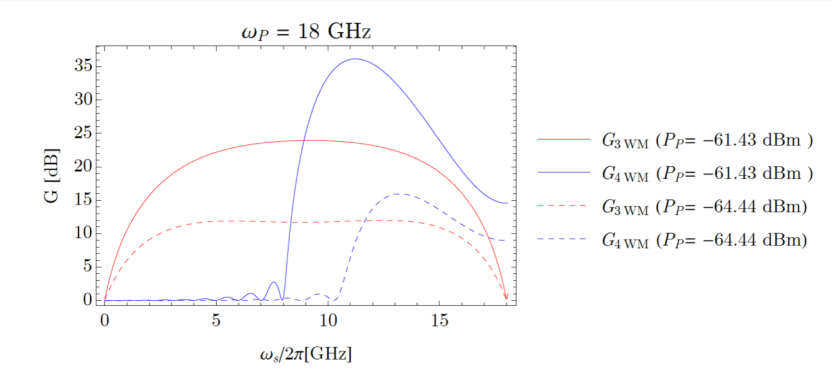
- Broadband (2-3 GHz)
- High gain (>20 dB)

INRiM
ISTITUTO NAZIONALE
DI RICERCA METROLOGICA

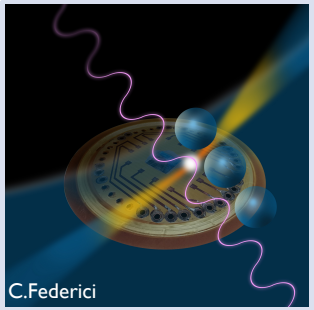
HaraWave

A TWJPA ia a two-port superconducting device consisting in a coplanar waveguide in which is embedded a repetition of hundreds of elementary cells. These cells are made of an RF-SQUID and a geometrical inductor capacitively coupled to ground.





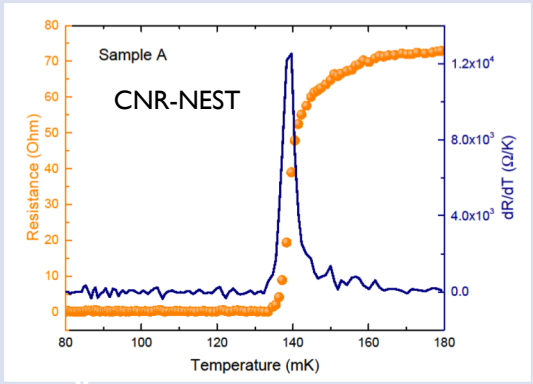
SIMP (CSN V)

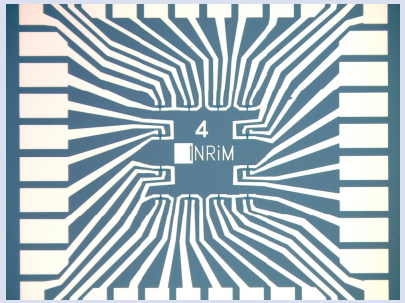


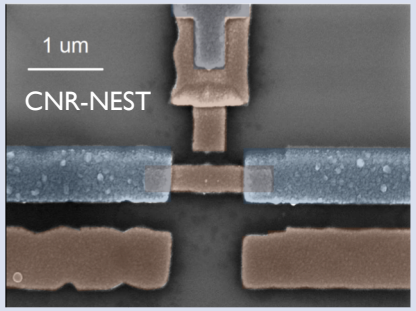
Units
LNF (Resp Naz)
INFN Pi
INFN Sa
TIFPA-FBK
CNR Nano NEST
CNR IFN
INRIM

Objective: develop devices sensitive to single microwave photons in the range 10-100 GHz. Two different technologies: Josephson Junctions; Nanowire-TES.

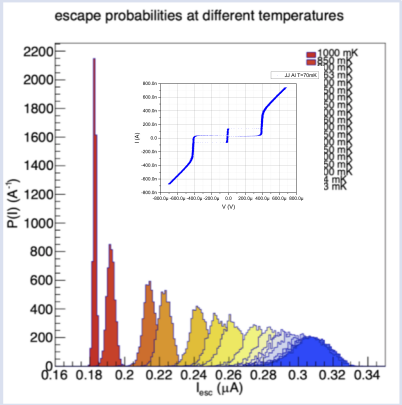
- Fabricated nanowire-TES with Tc about 130 mK (INRIM, CNR-NEST).
- Ongoing: SQUID readout; RF tests.

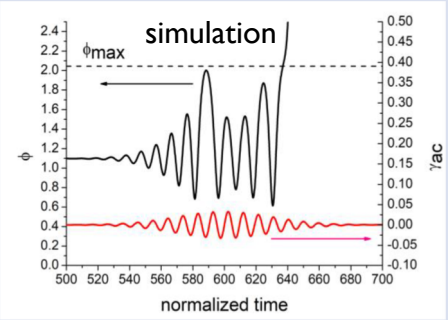


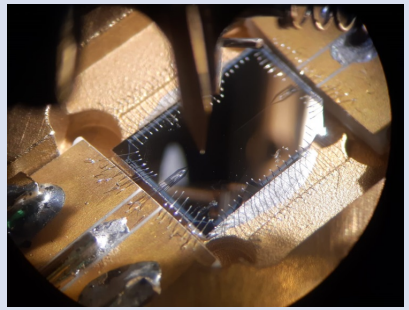




- JJ fabricated at CNR-IFN and fully characterized in DC at 40 mk.
- Device simulation
- RF tests ongoing







D Alesini et al Journal of Low Temperature Physics https://doi.org/10.1007/s10909-020-02381-x

D Alesini et al 2020 J. Phys.: Conf. Ser. 1559 012020

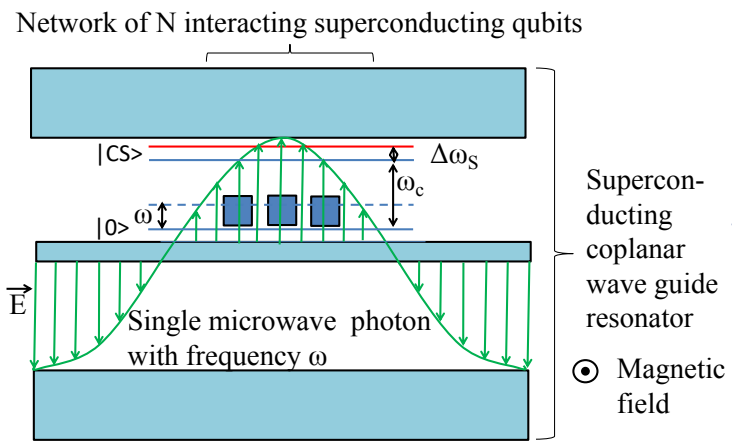
SUPERGALAX

C.Federici

FET OPEN SUPERGALAX
CNR (IT, PI, exp)
INRIM (IT, exp)
INFN (IT, axion exp)
KIT (DE, exp)
Leibniz IPHT (DE, exp)
RUB (DE theory)
LU (UK, theory)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 863313. Grant amount 2 456 232.50 Euro.

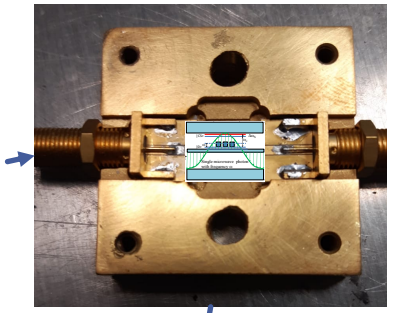
https://supergalax.eu

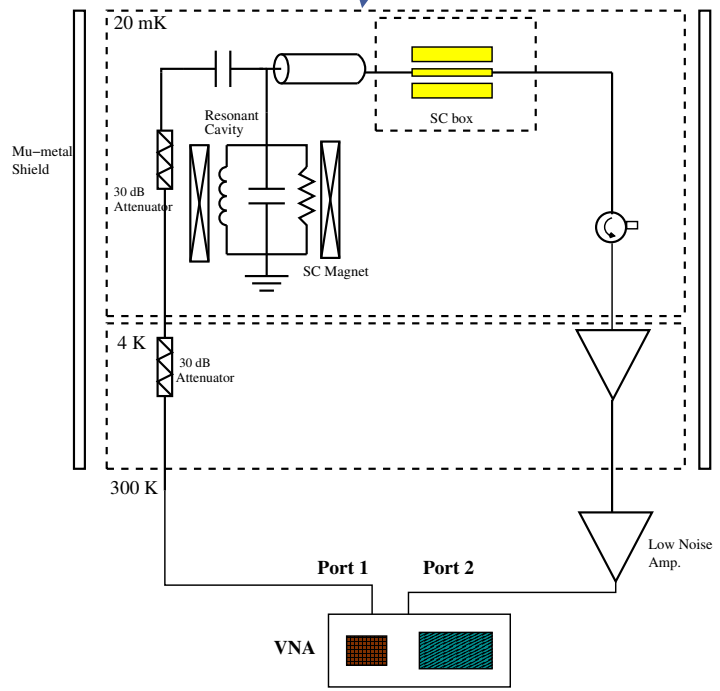


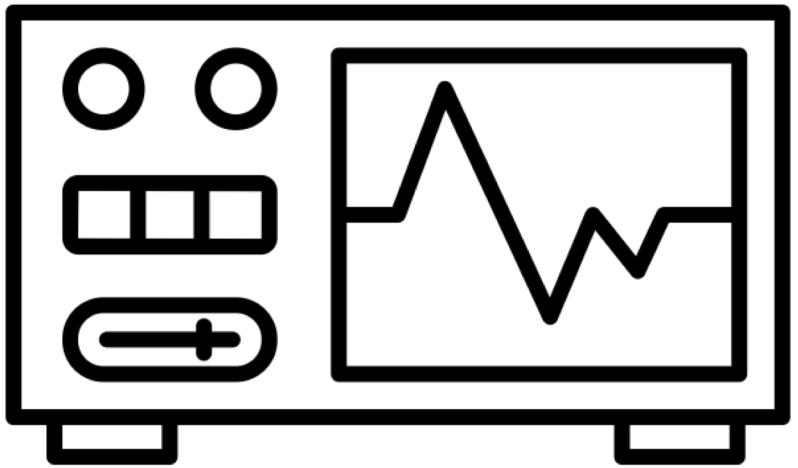
Objective: Develop a single microwave photon detector for axion search in QUAX experiment with an array of SC qubits.

In a device based on array of qubits signal noise is suppressed by √N.

Zagoskin et al., «Spatially resolved single photon detection with a quantum sensor array» SCIENTIFIC REPORTS | 3 : 3464 | DOI: 10.1038/srep03464



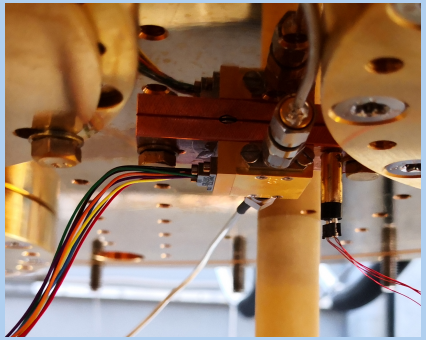




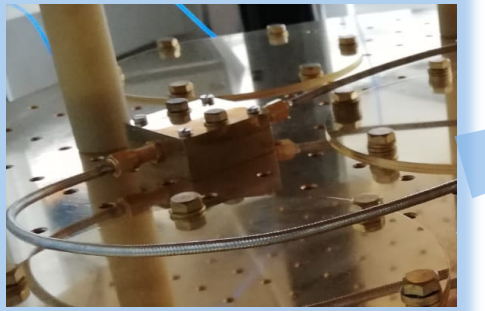
Created by Mohamed Mbarki from Noun Project

QUAX EXPERIMENT 2021-2025

QUAX@LNF

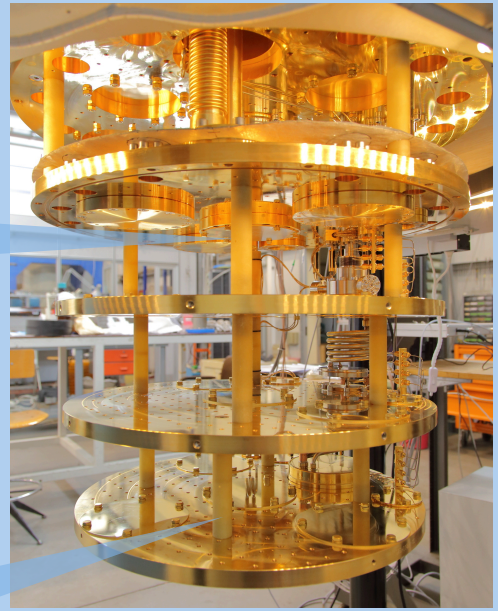


HEMT (6-20 GHz) 4K amplifier

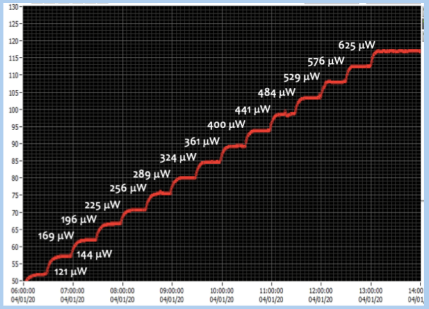


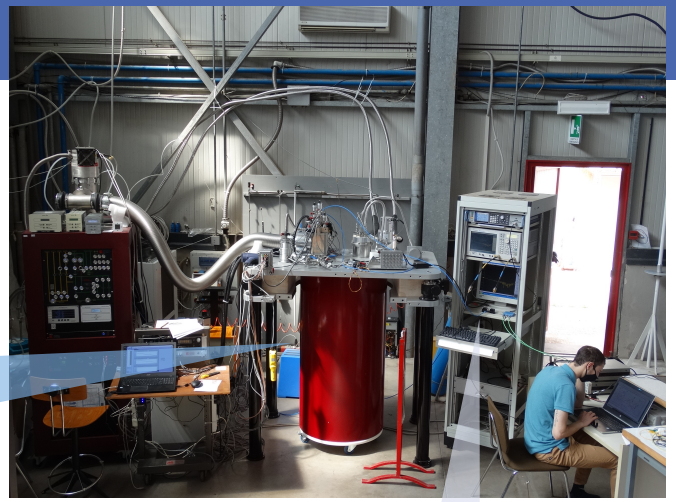
Sample holder for SC chip at 10 mK for single photon device or TWJPA

http://coldlab.lnf.infn.it

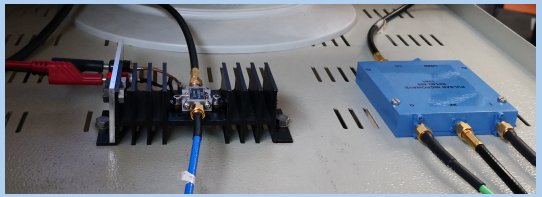


Characterization of dilution refrigerator (with not optimal pumping system, can be improved)



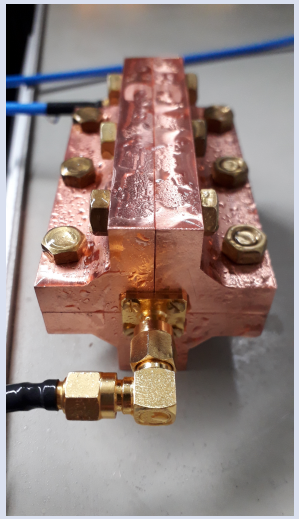


FET LNA 8-12 GHz and IQ-mixer (10-12 GHz)



DAQ

QUAX@LNF



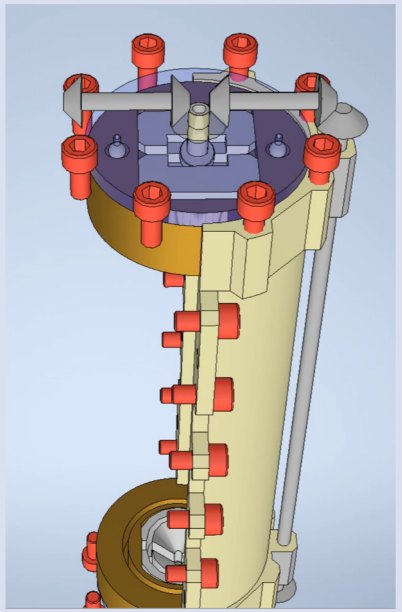
YBCO-Tape Cavity

17 GHz square cavity for YBCO-tape measurement

Q_{cu}^{77k}=20,000

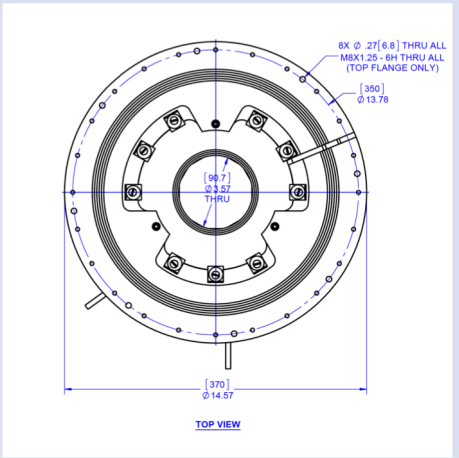
(IBS_CAPP measured Q=330,000 for a cavity with YBCO tabe in B field up to 8T at 7 GHz and 4 K arXiv:2002.08769)

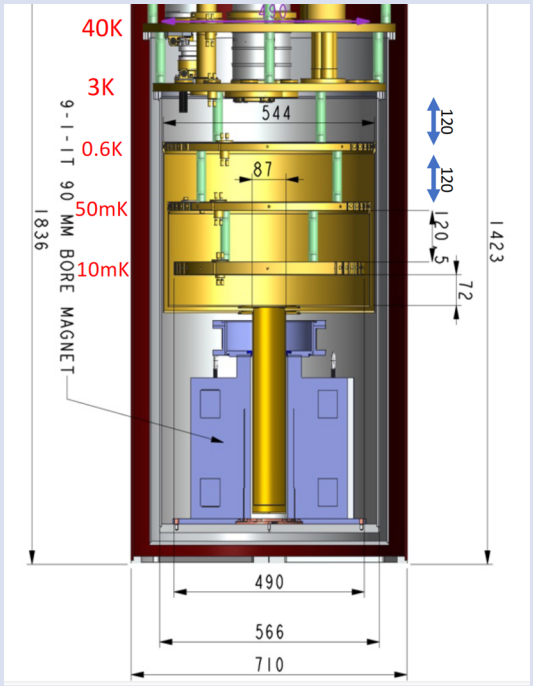
Design of tuning system for dielectric cavity (S. Lauciani)



New 9T magnet for dry dilution refrigerator:

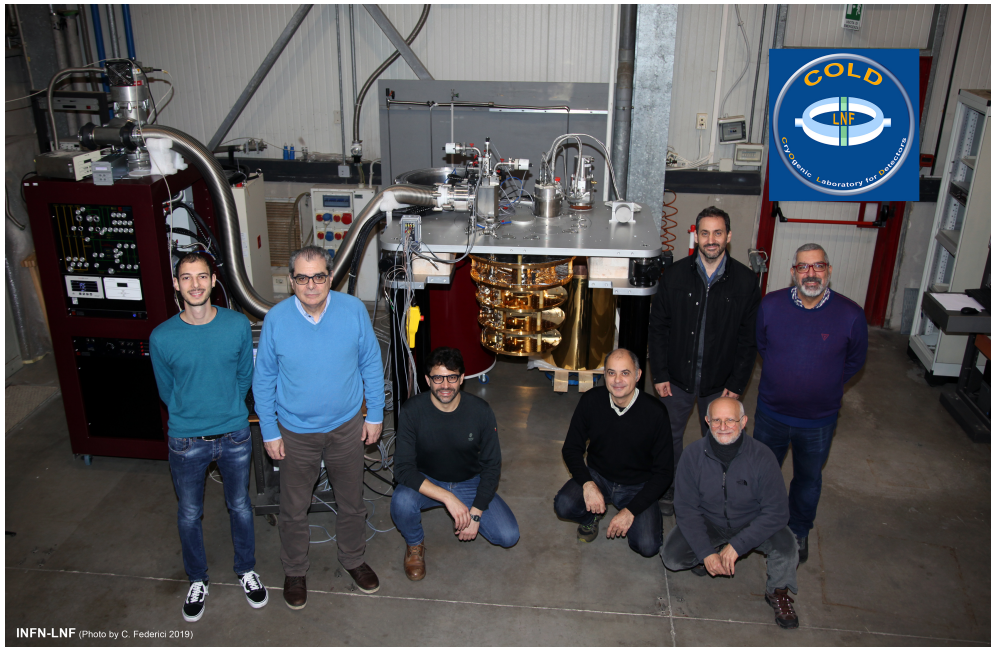
- length 40 cm
- Inner bore 9 cm

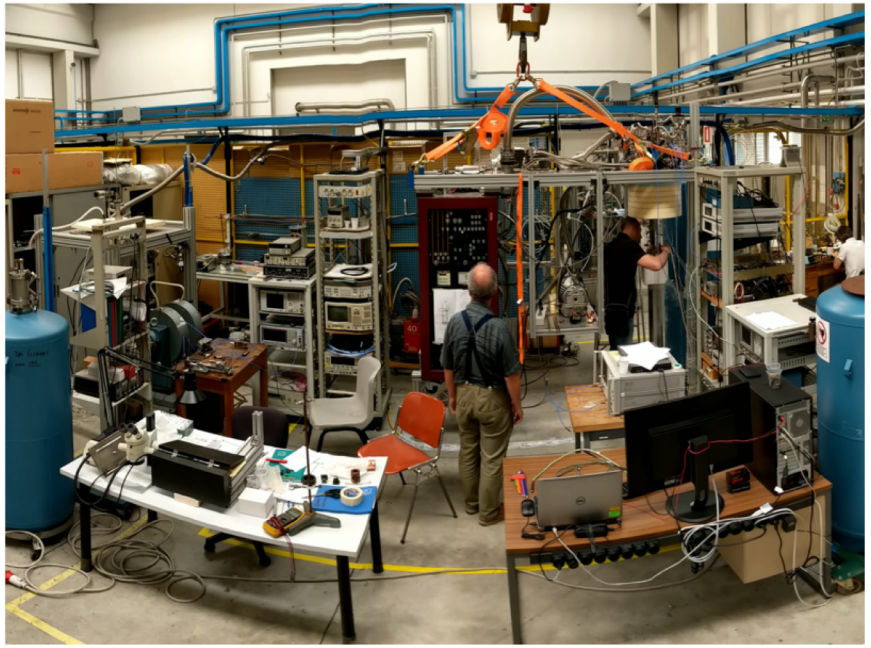




QUAX 2021-2025

	2021	2022	2023	2024	2025
Assembly of haloscopes at LNL and LNF					
Data Taking			1-2 GHz scan		





Conclusion

What happened in the last three years …

- QUAX had a rich R&D program leading to several publications on axion physics and superconductive and dielectric cavities.
- We reached the sensitivity to QCD-axion!
- We started an R&D on quantum limited amplifiers and single photon detectors (SIMP, SUPERGALAX, DART WARS?).
- Collaborations with CNR, INRIM, FBK and EU projects.
- LNF is going to be an experimental site of QUAX!!

Morevover:

COLD is a laboratory for radiofrequency in cryogenics, where we are testing quantum technologies such as superconducting qubits and Josephson metamaterials that may be the future tools for precision physics, dark-matter searches, analogue gravity on SC chips, quantum gravity, gravitational wave detection and more!

LNF 2021	FTE
C Gatti (PR, Loc Resp)	0.4 +0.2(supergalax)
D Di Gioacchino (R)	0.35 +0.15(supergalax)
C Ligi (T)	0.35 +0.5(supergalax)
D Alesini (DT)	0.1
G Maccarrone (PR)	0.3
D Babusci (PR)	0.3
D Moricciani (R)	0.5
A Rettaroli (PhD student)	0.6
Tot	2.9+0.5