QUAX

QUaerere Axion

Detection of **cosmological axions** through their **coupling to photons**

Sezioni/Centri INFN partecipanti

- Laboratori Nazionali di Frascati (LNF)
- Laboratori Nazionali di Legnaro (LNL)
- Sezione di Padova (PD)
- Sezione di Napoli, Gruppo Collegato di Salerno (SA)
- Trento Institute for Fundamental Physics and Applications (TIFPA)

Personale afferente 2023 in totale 9,5 FTE

Personale afferente 2023 al TIFPA 0,5 FTE

P. Falferi 30%, R. Mezzena 20%

Durata esperimento 3 (R&D) +3 anni (data taking) (2021-2026)

Finanziamento QUAX totale (k€)

	2021	2022	2023
Richieste	435	530	250
Assegnazioni	343	429	302

Finanziamento QUAX TIFPA (k€)

	2021	2022	2023
Richieste	9	9	10
Assegnazioni	7	7	9

Responsabile nazionale

Giovanni Carugno (PD)

Responsabili locali

Giuseppe Ruoso (LNL)

Claudio Gatti (LNF)

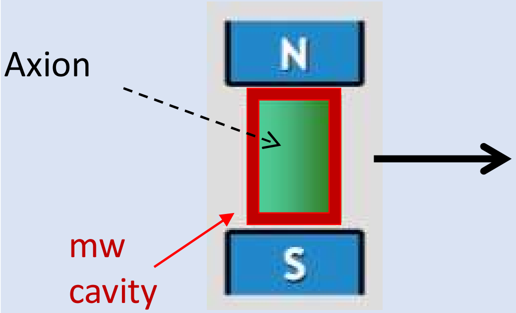
Umberto Gambardella (SA)

Paolo Falferi (TIFPA)

QUAX – QUaerere AXion

The axion is a hypothetical particle introduced to solve the so-called strong CP problem.
It is a neutral, very light (1 μeV < m < 10 meV) particle having negligible interaction with the ordinary matter.
It is an interesting candidate as a main component of dark matter.

- **Photon coupling: Due to the motion of the solar system in the galaxy, Dark Matter axions** are converted into **rf photons** inside a **resonant cavity** immersed in a **strong magnetic field** (inverse Primakoff effect)

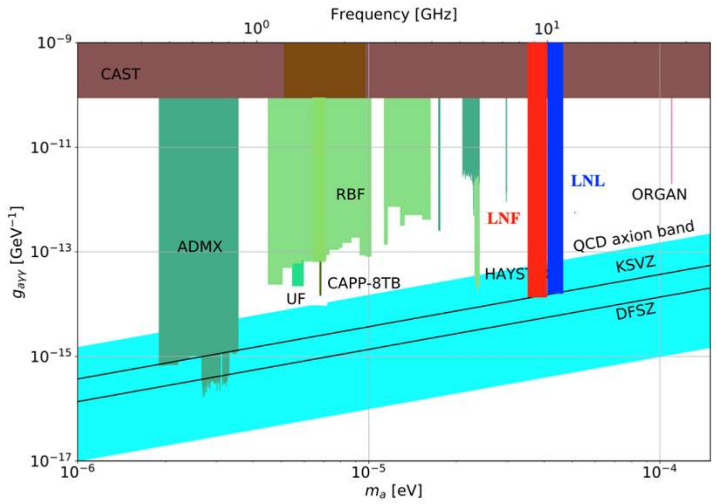


Expected rf power

$$P_a = 1.85 \times 10^{-25}\,\mathrm{W}\left(\frac{V}{0.0361}\right)\left(\frac{B}{2\,\mathrm{T}}\right)^2\left(\frac{g_\gamma}{-0.97}\right)^2 \times \left(\frac{C}{0.589}\right)\left(\frac{\rho_a}{0.45\,\mathrm{GeV\,cm^{-3}}}\right)\left(\frac{\nu_c}{9.067\,\mathrm{GHz}}\right)\left(\frac{Q_L}{201000}\right)$$

QUAX HALOSCOPES (@LNL @LNF)

	LNF	LNL
Magnetic field	9 T	14 T
Magnet length	40 cm	50 cm
Magnet inner diameter	9 cm	12 cm
Frequency range	8.5 - 10 GHz	9.5 - 11 GHz
Cavity type	Hybrid SC	Dielectric
Scanning type	Inserted rod	Mobile cylinder
Number of cavities	7	1
Cavity length	0.3 m	0.4 m
Cavity diameter	25.5 mm	58 mm
Cavity mode	TM010	pseudoTM030
Single volume	$1.5 \cdot 10^{-4}$ m^3	$1.5 \cdot 10^{-4}$ m^3
Total volume	7⊗0.15 liters	0.15 liters
Q_0	300 000	1 000 000
Single scan bandwidth	630 kHz	30 kHz
Axion power	$7 \otimes 1.2 \cdot 10^{-23}$ W	$0.99 \cdot 10^{-22}$ W
Preamplifier	TWJPA/INRIM	DJJAA/Grenoble
Operating temperature	30 mK	30 mK



Quax 2025 projection: 2 GHz scan to the KSVZ line

QUAX ACTIVITY IN 2024 @ LNL AND LNF

(End of the R&D in 2023, start of data taking in 2024)

LNL

- 2-3 months of data taking with 10.5 GHz, Cu/sapphire cavity at 8 T, Q=2x10^5, tuning 50 MHz, TWPA (N. Roch, Grenoble)
- Acquisition of a new magnet at 14 T, L=0.5 m, Phi=0.1 m
- Completion of automated dilution unit control system and radio frequency system data acquisition
- Development of Single Microwave Photon Detector (E. Florin, Paris)

LNF

- Data taking with 8.5 GHz Cu cavity at 9 T, Q=10^5, tuning 50 MHz, parametric amplification (TWPA (N. Roch) or wide band JPA (NIST))
- New dilution refrigerator (no magnet) for Quantum Technologies
- Development of superconducting cavities (e.g. Nb3Sn, Q=10^6 at 9T)

Activity at TIFPA in 2024

- Development of JPA (Josephson Parametric Amplifier) and TWPA (Traveling Wave Parametric Amplifier) within the GrV projects Qub-IT and Dart Wars
- Noise characterization of cryogenic amplifiers
- Calibration of thermometers down to 20 mK
- SQUID characterization of magnetic materials and shields down to 20 mK

TIFPA REQUESTS 2024 (Dotazioni)

Expenditures	Description	K€
Consumables	Cryospares, rf components, cryoperm shields, liquid helium	7
Missions	Experimenta Runs	3
	Totale	10

END

ATTIVITA’ @LNL

Test acquisizione dati

T_{MC} = 55 mK

LONG RUN:
2 weeks

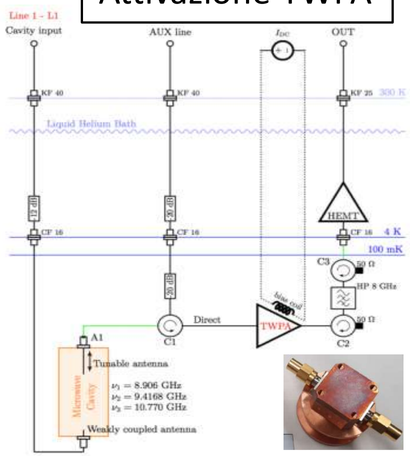
$P_{IVC} = 10^{-7}$ mbar

Dissipation @ 4K
1,2 W

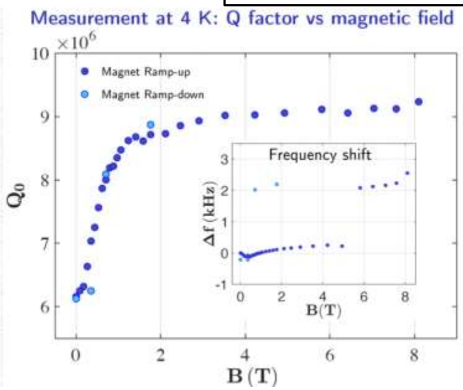
Magnet Charging
0,07 mA/s

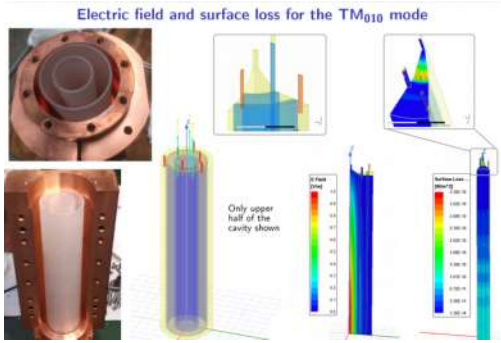
Magnetic Field
8 Tesla(2 days)

Attivazione TWPA



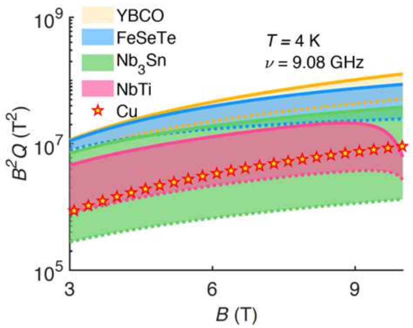
Cavità in rame con zaffiro – Q=9x10^6

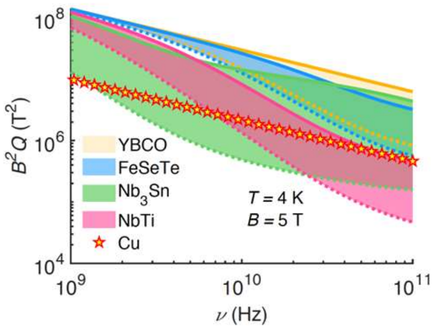




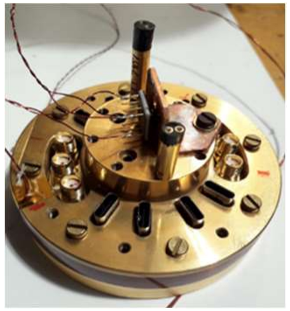
ATTIVITA' **@LNF**

Materiali per cavità

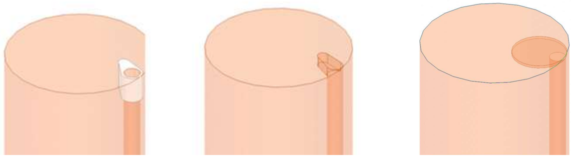




Amplificatori Quantum Limited



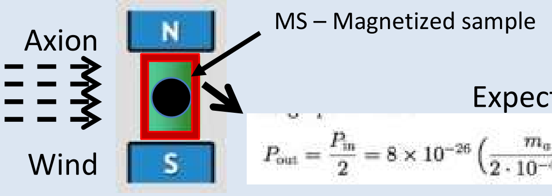
Tuning cavità



Schermi magnetici

R&D Activity

Electron coupling: the axion DM cloud acts as an **effective RF magnetic field** on electron spin exciting magnetic transitions in a magnetized sample and **producing rf photons**



Expected rf power

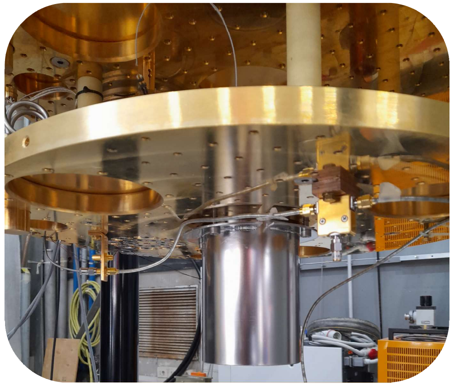
$$P_{out} = \frac{P_{in}}{2} = 8 \times 10^{-26} \left(\frac{m_a}{2 \cdot 10^{-4}\,\text{eV}}\right)^3 \left(\frac{V_s}{1\ \text{liter}}\right) \left(\frac{n_S}{10^{28}/\text{m}^3}\right) \left(\frac{\tau_{min}}{10^{-6}\,\text{s}}\right) \text{W},$$

LNF 2024

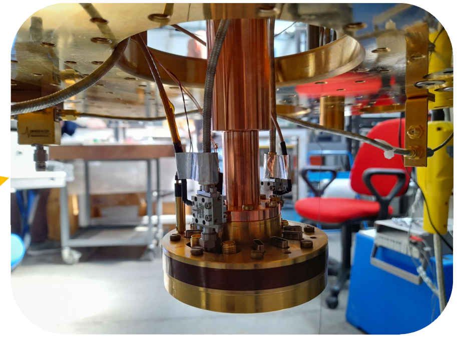
- Data taking con cavità in Cu, forse non cilindrica ma rettangolare, Q=10^5, 50 MHz tuning con barrette motorizzate inserite
- Amplificatore TWPA da Roch Grenoble o JPA 6-10 GHz da NIST (via progetto SQMS)
- Un nuovo refrigeratore senza magnete dedicato alle QT
- Sviluppo di nuove cavità: Nb_3Sn da Fermilab, Q=250000; NbTi sputtering su Cu (progetto SAMARA); in YBCO (da ENEA); Ferro-Selenio-Tellurio HTc elettrodeposizione su Cu (PRIN)

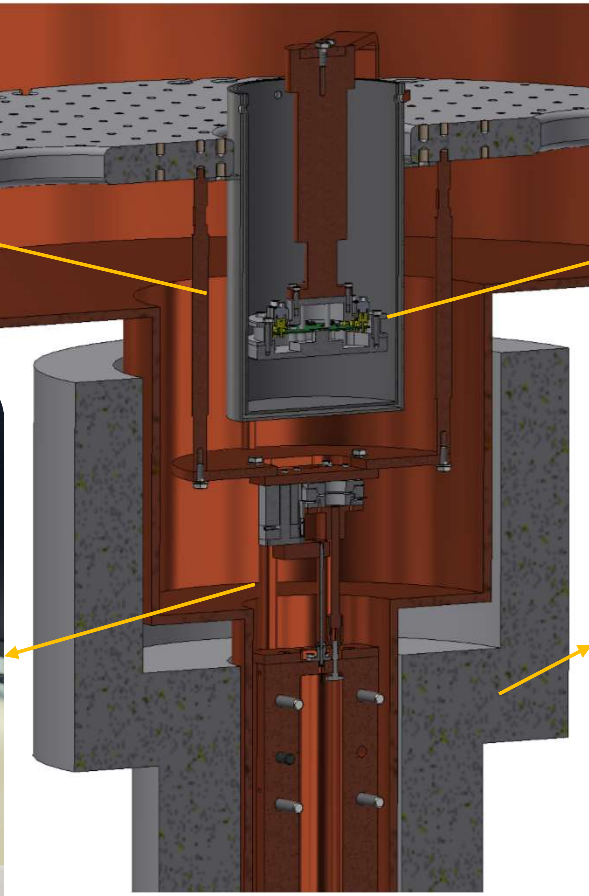
QUAX@LNF Commissioning

CryoPhi – Al magnetic shield

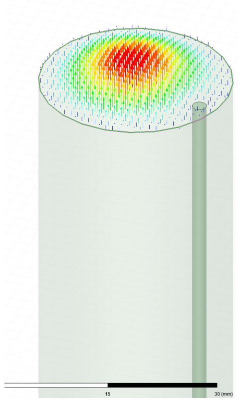


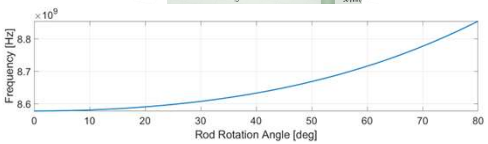
Sample holder for SC devices

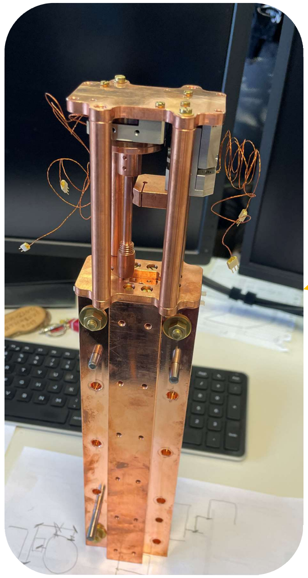




Cavity with tuning system



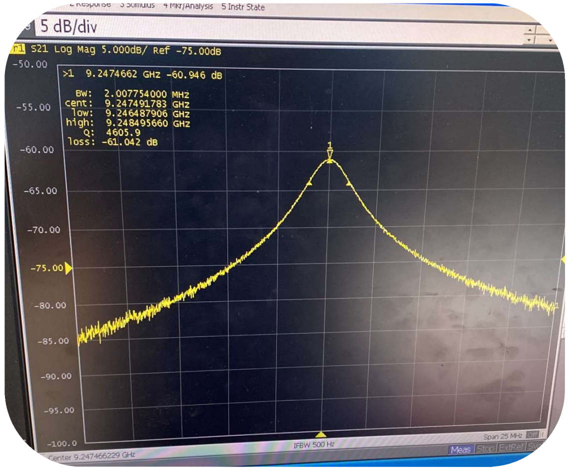




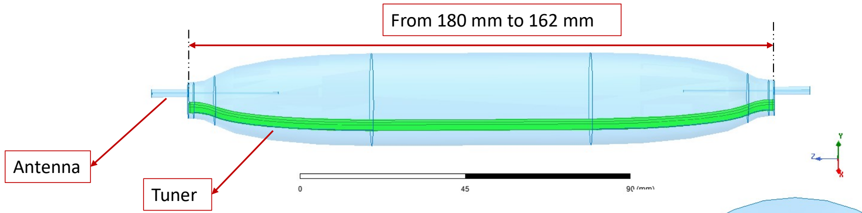
NbTi 9T magnet

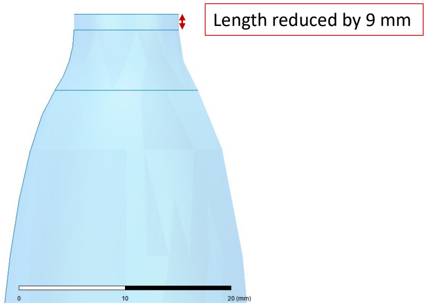
Superconductive Cavity: Nb_3Sn

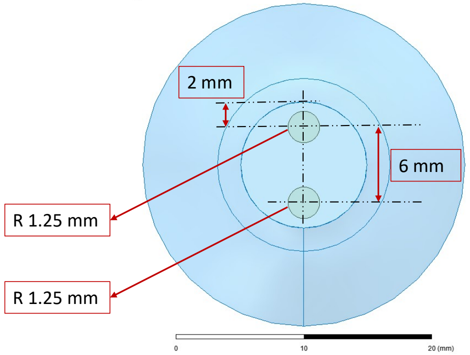
- Test in preparation at LNF

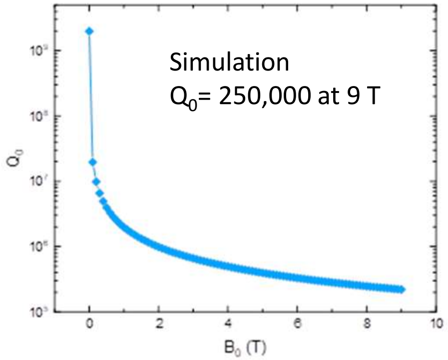


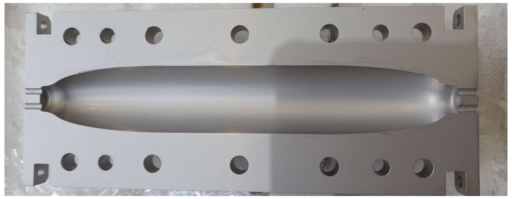
9.08 GHz cavity : Variations











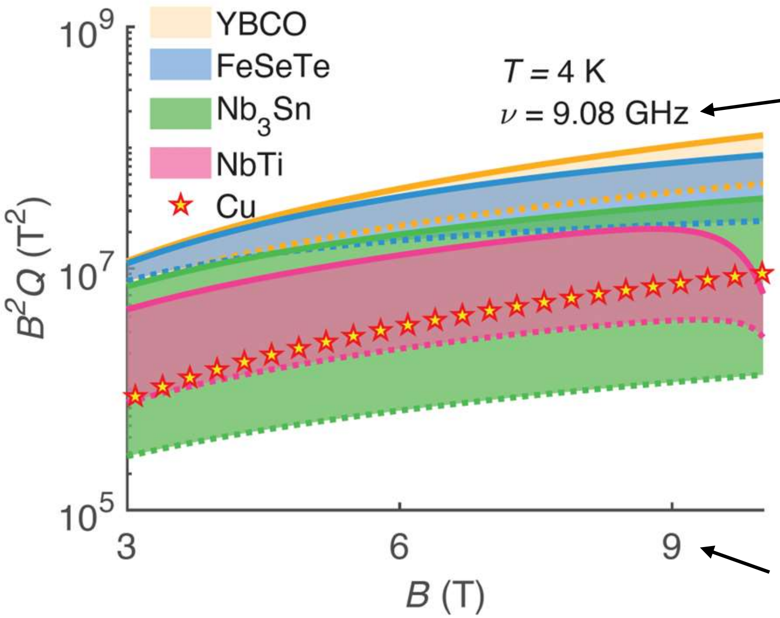
IRON MOON - PRIN

- 24 Months
- PI Nicola Pompeo, Ing. Dept. Roma Tre

IRON-based superconducting electropolished films at Microwaves fo the detection of axions
Goal: Superconducting cavity able to operate in strong magnetic field with high Q factor for axion searches.

FeSe vs YBCO
- FeSe performance comparable to YBCO
- FeSe has a simpler and more versatile deposition technique

Figure of merit for axion searches



Quax@LNF operation frequency

Quax@LNF field

Applied DC magnetic field