QUAX Activity Report 2024

D. Alesini, D. Babusci, M. Beatrici (Tecn.), A. Calanca (Tecn.),
A. D'Elia (AR), D. Di Gioacchino, C. Gatti (Resp.), A. Iungo (Tecn.)
S. Lauciani (Tecn.), C. Ligi, G. Maccarrone, D. Moricciani, G. Papalino (Tecn.),
A. Rettaroli (AR), S. Tocci (TD), G. Vidali (Laur.)

1 QUAX activity

The QUAX activity is carried out in the COLD laboratory of LNF.

Data analysis

During the beginning of 2024, the analysis of the data acquired in December 2023 with the new QUAX haloscope at LNF was finalized. The final plot of the 6 MHz axion search is shown in Fig. 1. The refined excluded value of the axion-photon coupling constant is estimated to be $g_{a\gamma\gamma}^{\rm CL} < 0.882 \times 10^{-13}$ GeV^{-1} at 90% C.L. Moreover, a detailed analysis of the thermal noise, changing among the different frequencies, has been performed to characterize the spectral shapes.

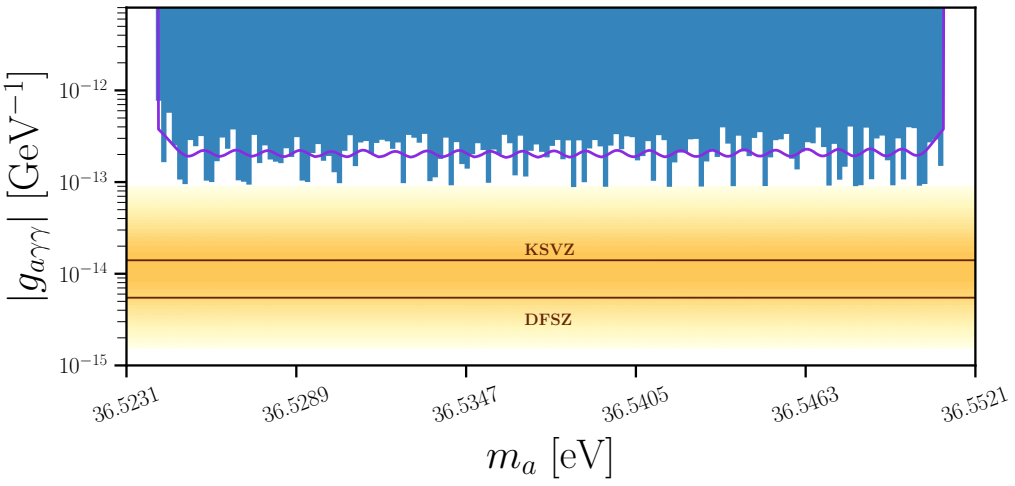

Figure 1: *Exclusion plot of $g_{a\gamma\gamma}$ at 90% CL, in the 6 MHz frequency span.*

Tuningn system

Then, a series of improvements to the resonant cavity and tuning system have been made (refer to Fig. 2), in view of the next science run:

- a new tuning rod was manifactured, with general improvements to the manufacturing process of it and its supports,
- the thermal coupling between the rod and the cavity was improved by substituting one of the PEEK supports with a copper support; this also allows to reduce the dielectric losses of the electric field,
- the positioning of the rod was improved by reducing the space between the rod and the cavity endcaps and by reducing the space between the rod and the cavity sidewall,
- new electromagnetic simulations including the new tuning desing were performed.

After the new rod was manifactured by the mechanical workshop, the whole tuning system (including the motion imparted by two piezo motors) was tested at room temperature. The movements work smoothly, and the quality factor measured at room temperature is about $Q_0 = 16000$ at $f_0 = 8.768$ GHz, matching the electromagnetic simulation results.

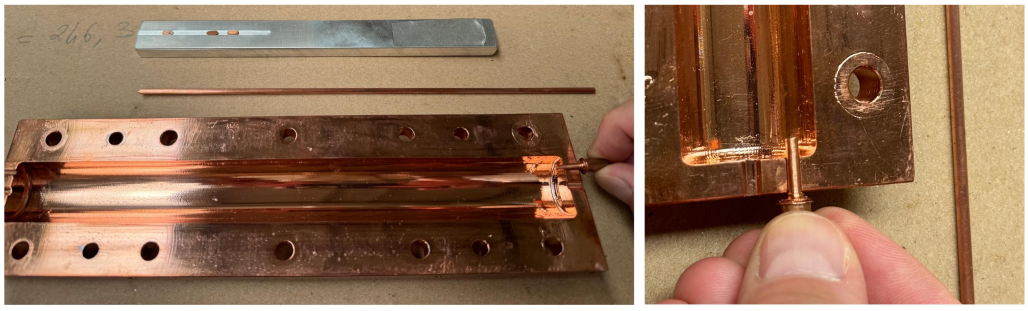

Figure 2: *Pictures of the new rod and supports.*

Josephson Parametric Amplifier

Low-noise amplification is essential when reading a signal from a haloscope. In this regard, Josephson Parametric Amplifiers (JPAs) can provide the lowest possible amount of noise, namely they can operate at the Standard Quantum Limit. This noise temperature is $T_{\mathrm{SQL}} = \hbar\omega/k_B$, which at 8.8 GHz equals 420 mK. We characterized a JPA that we had from NIST, which will be added to the amplification chain to improve the noise performance in the next future. The characterization

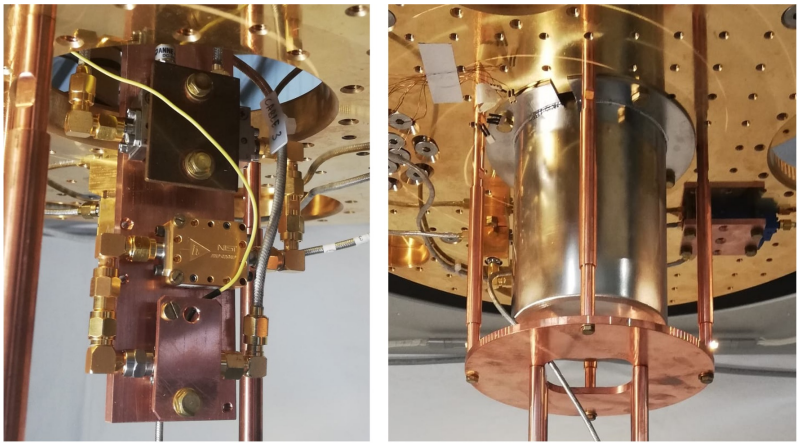

Figure 3: *Pictures of the JPA and the magnetic shield.*

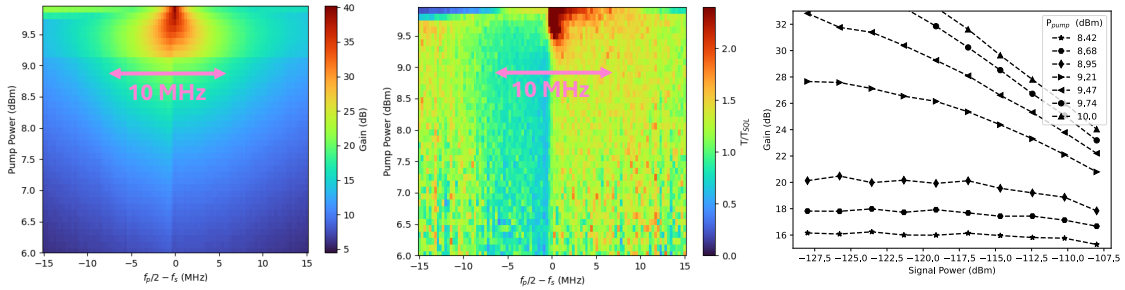

Figure 4: *Left) Gain map. Center) Noise temperature map. Right) Compression point at different pump values.*

was performed in our dilution refrigerator, and a picture of the JPA mounted on the cold finger can be seen in Fig. 3, together with the Aluminum+muMetal shield to protect the JPA from magnetic fields.

A first characterization consisted in measuring the frequency tunability of the JPA with the bias current, and althought the measurement conditions were not optimal, we found a tunability of at least 30 MHz around 8.82 GHz. The frequency vs bias maps were repeated for different magnetic fields and we found that the JPA needed a further shielding, so we added another PbSn shield inside the Aluminum cylinder, and a Pb shield around the JPA case.

The gain and noise temperature were also characterized at $B = 0$ T. The gain and noise temperature maps (shown in Fig. 4) were made as a function of the pump power (y-axis) and the detuning between half the pump frequency and the signal frequency. The JPA shows a typical gain of about 20 dB over a bandwidth of $\sim$ 10 MHz. Correspondingly, in the same frequency range, the noise temperature attains to a range between T_{SQL} and $1.5 \times T_{\mathrm{SQL}}$, which is the expected noise. Subse-

quently, the compression point has been also characterized at different gain values (Fig. 4). −110 dBm is approximately the 1 dB compression point when the gain is 20 dB.

Automation

In view of the next data taking, we started to automatize the processes of calibration, data acquisition and successive offline analysis of data. To do so, we:

- started to create the frontend for all the instrumentation to be remotely and automatically governed;
- installed and configured MIDAS, the package that will manage data acquisition and the creation of a database;
- implemented the data analysis in a INFN Cloud environment to speed up the processing.

2 List of Conference Talks by LNF Authors in Year 2024

1. C. Gatti, *Cosmic WISPERs at LNF*, Working Group Meeting of COST Action COSMIC WISPers (CA21106), DESY - Hamburg (Germany) – Feb 2024
2. C. Gatti, *Search for Axion Dark Matter*, seminar at INFN Pisa, Pisa 20 March 2024
3. C. Gatti, *Axion searches at INFN*, MPP Colloquium, MPI Munich 9 April 2024
4. C. Gatti, *AXION Searches at INFN*, seminar at University of Milano Bicocca, 10 May 2024
5. C. Gatti, *FLASH: a proposal for a 100-300 MHz haloscope*, seminar at University of Liverpool, Liverpool 16 October 2024
6. C. Gatti, *Axions Searches at LNF*, seminar at Faculty of Physics, Sofia University 24 October 2024
7. C. Gatti, *AXION Searches at INFN*, invited talk at "CTPU-CKC Joint Focus Program: Let there be light (particles) Workshop", Institute for Basic Science (IBS) in Daejeon, Korea 2-6 December 2024 (https://indico.ibs.re.kr/event/715/)
8. A. Rettaroli, *Recents results of QUAX @ LNF*, Working Group Meeting of COST action Cosmic Whispers (CA21106), DESY - Hamburg (Germany) – Feb 2024

9. A. Rettaroli, *Recent results and future perspective in the search for axion dark matter with QUAX*, 19th Patras Workshop on Axions, WIMPs and WISPs, Patras (Greece) - Sept 2024

10. A. D'Elia, *Recent results and future perspective in the search for Axion dark matter at LNF*, Low Level Radio Frequency, Frascati (Italy) - Sept 2024

11. A. D'Elia, *Recent results and future perspective in the search for Axion dark matter at LNF*, IRN Terascale , Frascati (Italy) - 2024

3 Publications

- A. Rettaroli et al., *Search for axion dark matter with the QUAX–LNF tunable haloscope*, Phys. Rev. D **110**, 022008 (2024), DOI: 10.1103/PhysRevD.110.022008

- G. Marconato et al., *NbTi Thin Film SRF Cavities for Dark Matter Search*, IEEE Trans. Appl. Supercon. **34**, 1-6 (2024), DOI: 10.1109/TASC.2024.3416541