The QUAX Experiment

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1 Search for galactic axions with with the LNF Haloscope

In July 2022 we performed a first test run of the LNF Haloscope. The Haloscope was assembled inside a Leiden CF-CS110-1000 of Leiden Cryogenics with a base temperature of 8 mK. It hosts a superconducting magnet, a QDE 9T 100mm compensated with PSW made by American Magnetics (AMI) (Fig. 1). The magnet has a conduction cooled bucking coil and a compensation coil, and it was delivered with a copper plate, to be mounted to the 4K-stage of our dilution refrigerator. New radiation screens have also been bought from Leiden Cryogenics to host the magnet in the cryostat. A resonant cavity was mounted on a cold finger thermally connected to the mixing chamber plate, and positioned at the center of the superconducting magnet once the cryostat is closed (Fig. 2).

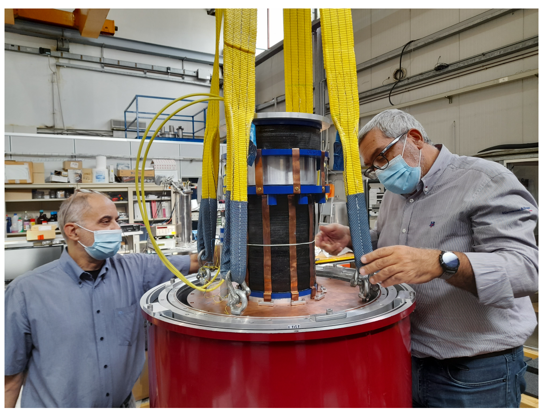

Figure 1: Insertion of the superconducting magnet in the dilution refrigerator.

The cavity was designed, simulated and fabricated at LNF and chemically polished at LNL. It is a cylindrical OFHC copper-cavity with fundamental mode at 8.5 GHz for dark matter axion searches with masses of about 35 μeV. The cavity has about 1 cm radius and 25 cm length. We characterized the cavity modes at room and cryogenic temperatures during a test run for axion searches. At cryogenic temperatures, we observed an unloaded quality factor $Q_0 = 100,000$ compatible with a surface resistace of about 5 mΩ as expected for cryogenic copper at 8 GHz.

The radiofrequency (RF) measurement setup is shown in Fig. 5. The cavity has two ports. The upper port, critically coupled, is used to extract the signal and direct it to the amplification stage on the RF line 5 through a double junction circulator (Quinstar QCY-G0801202). The lower port, undercoupled, is used for calibration purposes and was terminated to 50 Ω at 10 mK during the measurement by means of a switch (Radiall R577443005). The RF lines 1 and 4 were used for system calibration. Signal amplification is provided by a HEMT amplifier (LNF-LNC4-16B)

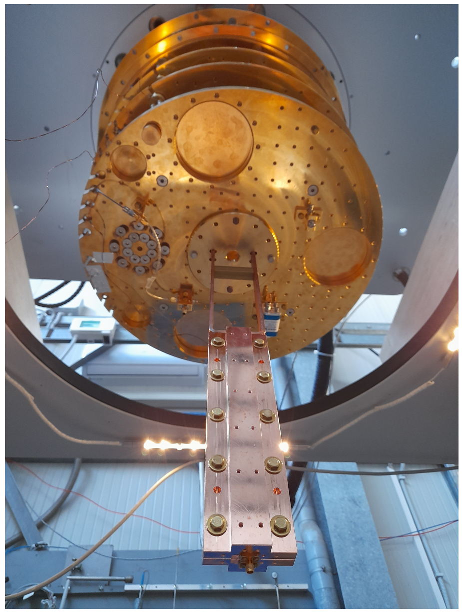

Figure 2: OFHC resonant cavity mounted on the coldest plate of the refrigerator.

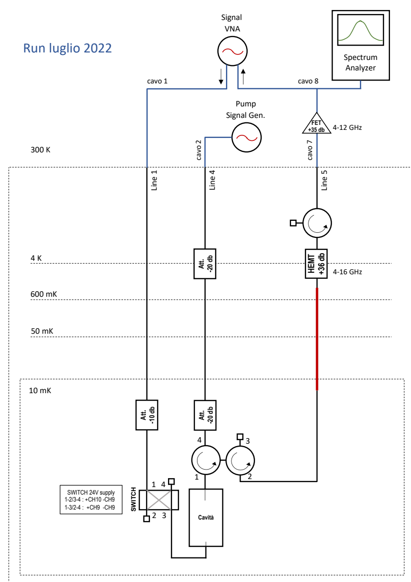

Figure 3: Radiofrequency measurement setup

at 4 K and a room-temperature low-noise FET (L3 HARRIS LNA-30-04001200-15-10P) providing in total about 70 dB of amplification. The signal was downconverted with an IQ mixer (Marki MMIQ-0520H) and both I and Q are further amplified with a low noise amplifiers (SR560) and acquired with and ADC board (NI6336) with 1 MHz sampling.

The haloscope was not yet in its final configuration. There was no tuning mechanism for the cavity and no preamplification stage at 10 mK. Moreover, the refrigerator had at that time a single Sumitomo pulse tube SRP-182B2S of 1.5 W at 4 K that was not enough to sustain the additional thermal load caused by the presence and operation of the 9 T superconducting magnet. We then operated the magnet at 2.5 T. The actual configuration was however enough to perform a preliminary test.

We determined through calibrations the noise temperature and the total amplification. During the ramp of the magnet we observed an anomalous heating of the cavity that increased its temperature up to 200 mK, due perhaps to induced currents. The HEMT amplifiers also showed an higher noise temperature of about 8 K. We collected data for 2 hours at the fixed frequency of about 8.5 GHz corrisponding to an axion mass of about 35 μeV, and were able to set a limit on the axion photon coupling $g_{a\gamma\gamma} < 3.3 \times 10^{-13}\mathrm{GeV}^{-1}$ a factor about 30 above the KSVZ limit that we expect to reach in the final configuration with 9 T field, a quantum amplifier such as a JPA or TWPA and a Nb3Sn, NbTi or YBCO resonant cavity.

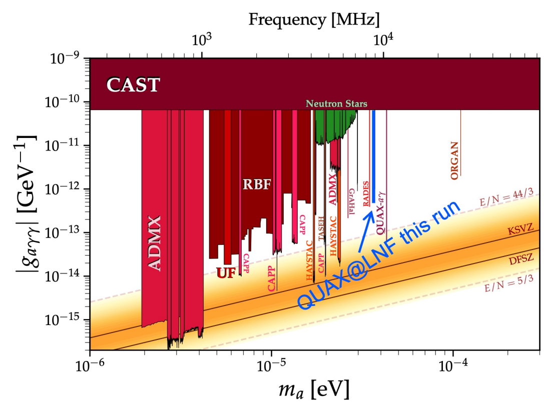

Figure 4: Sensitivity

2 Search for galactic axions with a high-Q dielectric cavity with LNL Haloscope

The haloscope of the QUAX-$a\gamma$ experiment at LNL, composed of an high-Q resonant cavity immersed in a 8 T magnet and cooled to $\sim$ 4.5 K was operated to search for galactic axions with mass $m_a \simeq 42.8$ μeV, not accessible to other running experiments. The design of the cavity with hollow dielectric cylinders concentrically inserted in a OFHC Cu cavity, allowed us to maintain a loaded quality-factor Q $\sim$ 300000 during the measurements in presence of magnetic field. Through the cavity tuning mechanism it was possible to modulate the resonance frequency of the haloscope in the region $10.35337 - 10.35345$ GHz and thus acquire different dataset at different resonance frequencies. Acquiring each dataset for about 50 minutes, combining them and correcting for the axion's signal estimation-efficiency we set a limit on the axion-photon coupling $g_{a\gamma\gamma} < 0.731\times10^{-13}$ GeV^{-1} with the confidence level set at 90% (Fig. 5).The results are published on Physical Review D [1].

3 List of Conference Talks by LNF Authors in Year 2022

1. C. Gatti, "Search for Axion Dark Matter," Vulcano Workshop, Isola d'Elba September 2022.

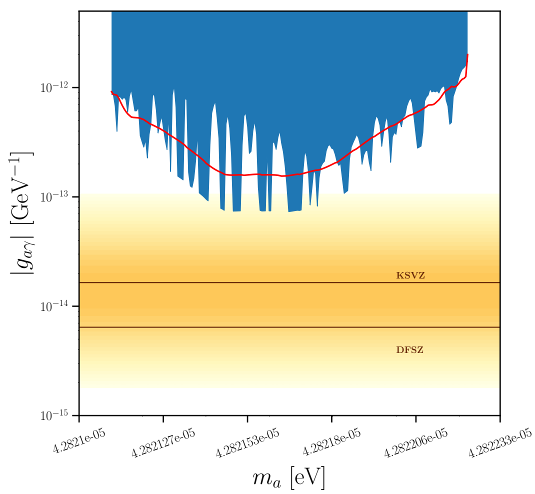

Figure 5: The 90% single-sided C.L. upper limit for the axion coupling constant $g_{a\gamma\gamma}$ as a function of the axion mass. The red solid curve represents the expected limit in the case of no signal. The yellow region indicates the QCD axion model band.

2. C. Gatti, "Review of axion program at LNF and LNL," FIPs 2022 CERN October 2022.

4 Publications

- D. Alesini *et al.*,"Search for Galactic axions with a high-Q dielectric cavity," Phys. Rev. D **106** (2022) no.5, 052007 doi:10.1103/PhysRevD.106.052007 [arXiv:2208.12670 [hep-ex]].

Acknowledgement

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References

1. D. Alesini, D. Babusci, C. Braggio, G. Carugno, N. Crescini, D. D'Agostino, A. D'Elia, D. Di Gioacchino, R. Di Vora and P. Falferi, *et al.*,"Search for Galactic axions with a high-Q dielectric cavity," Phys. Rev. D **106** (2022) no.5, 052007 doi:10.1103/PhysRevD.106.052007 [arXiv:2208.12670 [hep-ex]].