Axion search with RADES

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AXIONS

Axions are a well-motivated extension of SM, being hypothetical pseudoscalar particles that could elegantly solve 2 problems from one:

- Strong CP problem of QCD
- Account for the dark matter (DM) content of the universe

Firstly, proposed by Peccei and Quinn in 1977 (and independently demonstrated by Weinberg and Wilczek) to solve the strong CP problem.

$$\mathcal{L} = ... + \frac{\bar{\theta} g^2}{16\pi^2} G^a_{\mu\nu} \tilde{G}^{a\mu\nu} + ...$$

$\bar{\theta} \in [-\pi, +\pi]$

Calculated upper limit: ~10^{-10} rad

P-Q mechanism gives to $\bar{\theta}$ a dynamical behaviour (being zero in the early universe) introducing an axion field.

At low energies axions couple to photons with the effective Lagrangian:

$$\mathcal{L}_{a\gamma} = g_{a\gamma\gamma}(\mathbf{E} \cdot \mathbf{B})a$$

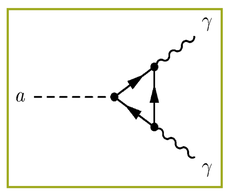

Fig. 1 Axion-photon coupling.

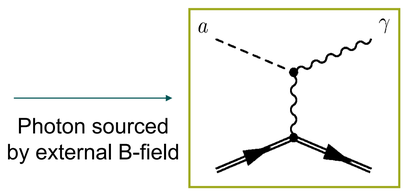

Fig. 2 Primakoff conversion.

$$m_a \in [1, 1000]\ \mu\text{eV}$$

Axion models: KSVZ and DFSZ

HALOSCOPE DETECTORS

Haloscopes are intended to enhance the power measured after the conversion of DM axions into photons

Signal power $\longrightarrow$ $P_s = \kappa g^2_{a\gamma} V B^2_e \mathcal{C}^2_m Q_m \frac{\rho_{DM}}{m_a}$

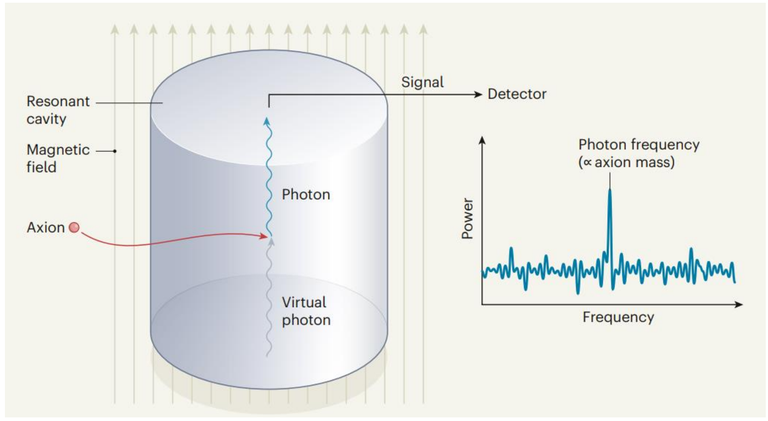

Fig. 3 Haloscope schematic [1].

THE RADES COLLABORATION

Started as a haloscope experiment exploring the use of multi cavity structures for bigger detection volumes at higher frequencies [2].

A first run inside of the CAST magnet served as a proof of principle and allowed us to extract exclusion limits for a mass of 34.67 μeV [3].

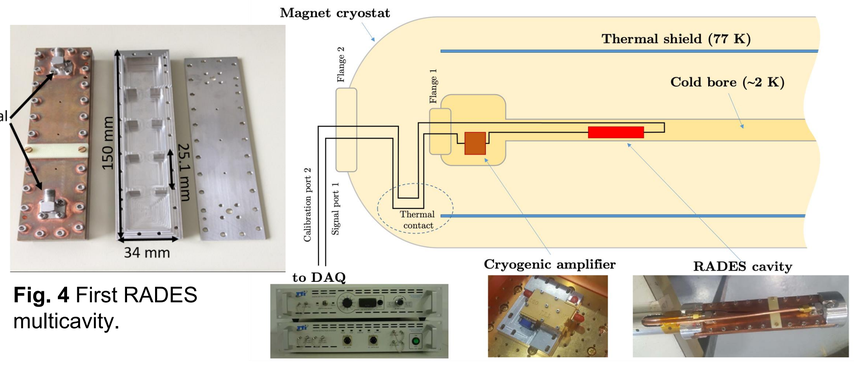

Fig. 4 First RADES multicavity.

Fig. 5 CAST- RADES setup schematic.

Currently we are more than 30 collaborators from more than 10 different institutions working on cutting-edge technologies for high-frequency axion searches.
Working on topics ranging from phenomenology to quantum sensing, cryogenics and others.

Fig. 6 RADES Collaboration Meeting (Valencia 2025).

SETUP AT MPP IN MUNICH

In 2022, a new research group was established at MPP, and it has been involved in axion detection efforts, including the development and construction (in OFHC copper) of a mechanically tunable 9 GHz resonant cylindrical cavity, which is now operating inside of a dilfridge at 10 mK and, in the following months, under a 12 T magnetic field [4].

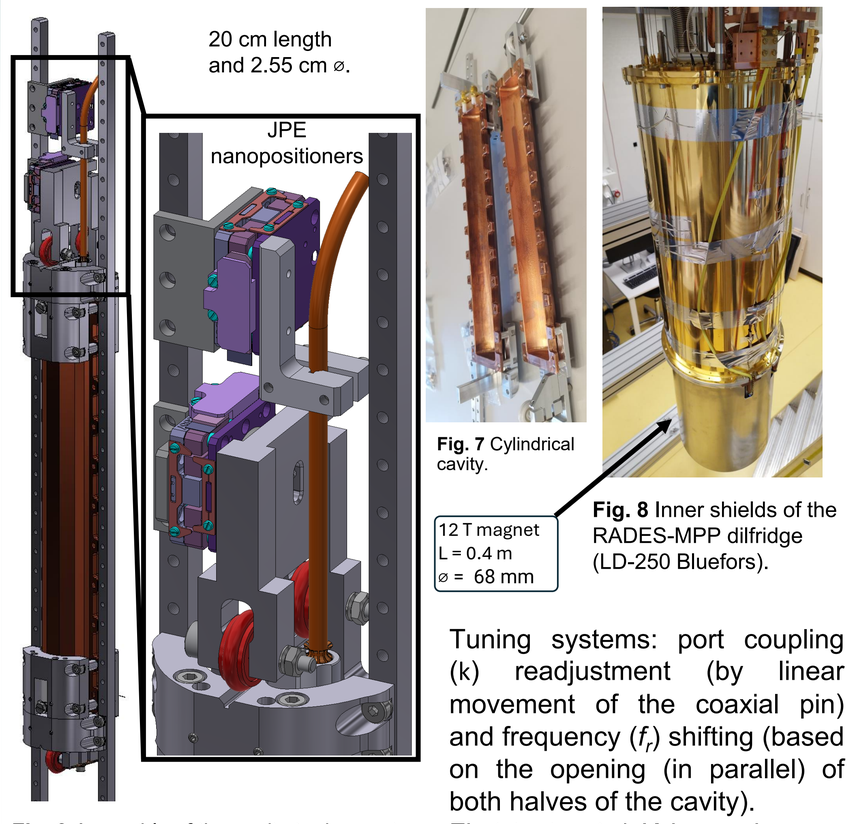

Fig. 9 Assembly of the cavity tuning system.

Fig. 7 Cylindrical cavity.

Fig. 8 Inner shields of the RADES-MPP dilfridge (LD-250 Bluefors).

Quantum-limited amplifier to be implemented in this setup.

Tuning systems: port coupling (k) readjustment (by linear movement of the coaxial pin) and frequency (f_r) shifting (based on the opening (in parallel) of both halves of the cavity).
First tests at 4 K have shown a good cavity performance in a frequency range of more than 600 MHz (> 6.5 % tuning).

FIRST RUN WITH HIGH-TEMPERATURE SUPERCONDUCTING (HTS) CAVITIES

In 2021 we performed a first data taking with a copper cavity coated with RebCo tapes in order to increase the quality factor (Q).

The cavity was installed inside a 11.7 T dipole magnet at the magnet testing facility at CERN.

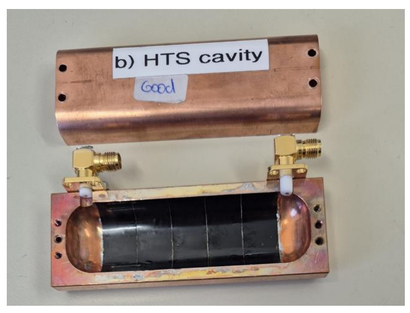

Fig. 10 Copper cavity taped with HTS.

Fig. 11 11.7 T magnet at CERN.

27h of data taking led to competitive results at higher masses [5].

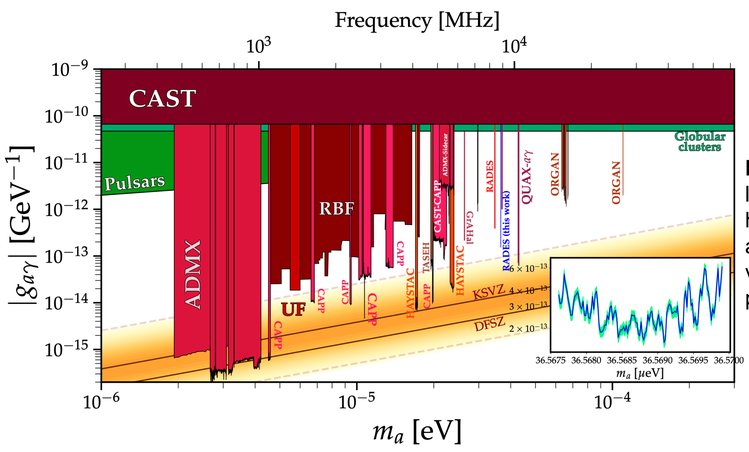

Fig. 12 Exclusion limits set by different haloscopes in the axion-photon coupling vs axion mass parameter space.

In Nov/2024 we did a 2nd run with an improved data taking system and a new HTS coated cavity, with a resonant frequency of 8.84 GHz.

A first look at the data indicates a successful run with a tuning (He pressure change) of around 40 MHz. Further analysis is ongoing.

QUANTUM SENSING

Quantum technology is being developed in the RADES experiment. The new sensor, designed as a single-photon detector, will significantly improve the sensitivity for detecting dark matter axions.

Transmon (superconducting qubit)

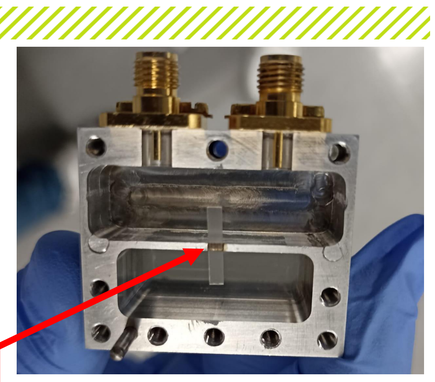

Fig. 13 Double cavity with transmon.

OUTLOOK

The RADES collaboration is advancing into the study of promising new technologies for high-frequency axion searches, including the implementation of qubits for single photon counting.

At the same time, different physic searches have been performed, the results of two have already been published. While the analysis of the last one is still under development.

Stay tuned for some upcoming results!

REFERENCES

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5. S. Ahyoune et al., RADES axion search results with a High-Temperature Superconducting cavity in an 11.7 T magnet, *JHEP* 04 (2025) 113 [arXiv:2403.07790]

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