Low-Frequency Axion Searches with Near-Quantum-Limited SQUID Amplifiers:

Toward a RADES experiment in BabyIAXO

Dr. Jose María García Barceló (CAPA/UNIZAR)

RADES & DarkQuantum project

Identification of Dark Matter 2026 (IDM2026) – Zaragoza (Spain) – 2 June/2026

RADES

Universidad Zaragoza 1474

DarkQuantum

European Research Council
Established by the European Commission

CAPA Centro de Astropartículas y Física de Altas Energías Universidad Zaragoza

IAXO

Universidad Zaragoza 1474

The Axion & Dark Matter Frontier

Strong CP Problem

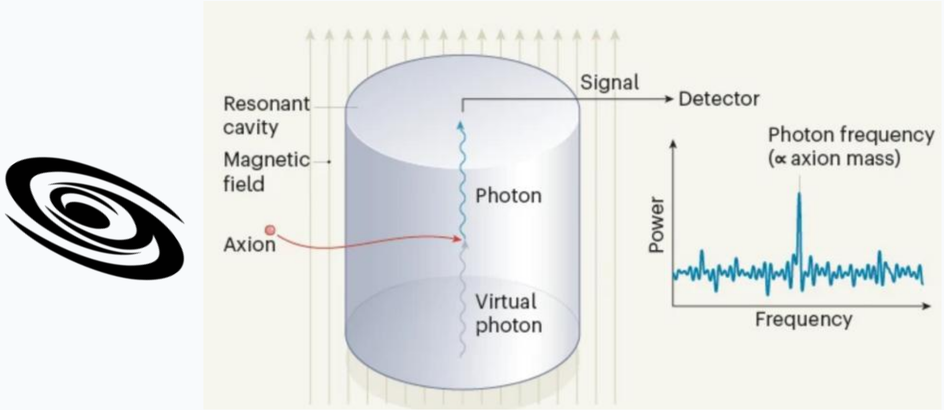
A puzzling symmetry in QCD: Why does the strong interaction preserve Charge-Parity (CP) conservation to such high accuracy?

The Peccei-Quinn Mechanism: Introduces a global U(1) symmetry which dynamically relaxes the QCD θ-parameter to zero, predicting the Axion.

Dark Matter Candidate

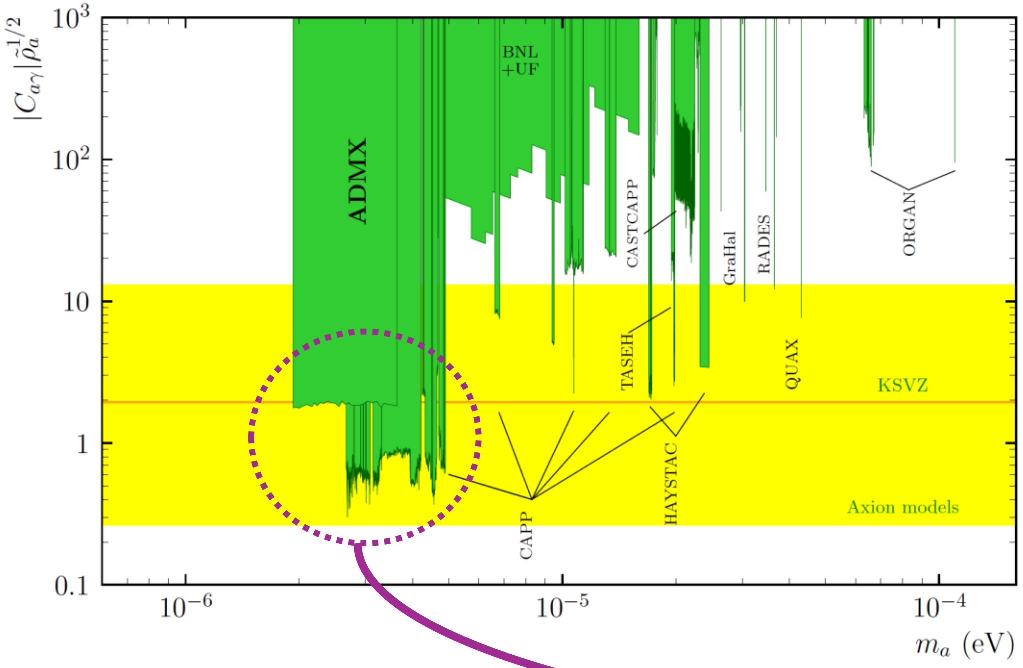
Axions behave as a cold, collisionless fluid, produced abundantly in the early universe, fulfilling all parameters for the unaccounted cosmological Dark Matter.

Haloscope Technique: Resonant detection relies on conversion of galactic dark matter axions into microwave photons within high-field magnets.

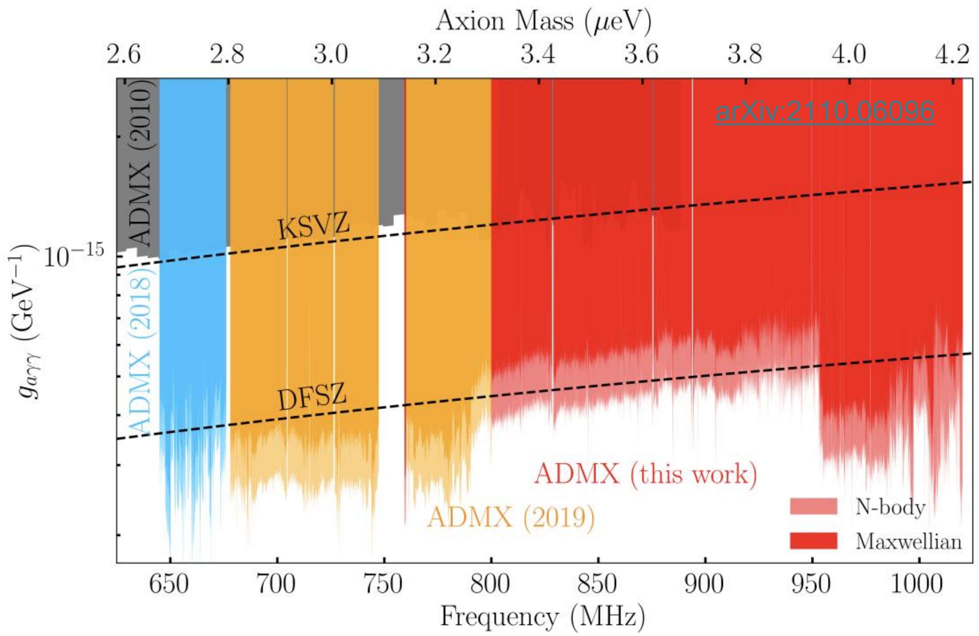


Haloscope experiments → ADMX, HAYSTAC, CAPP, QUAX, MADMAX, RADES, ...

Haloscope current results at low frequencies



Many years of R&D by AMDX @ U. Washington, progressively exploring the few μeV region → What about lower masses?



The DarkQuantum Framework

RADES Collaboration

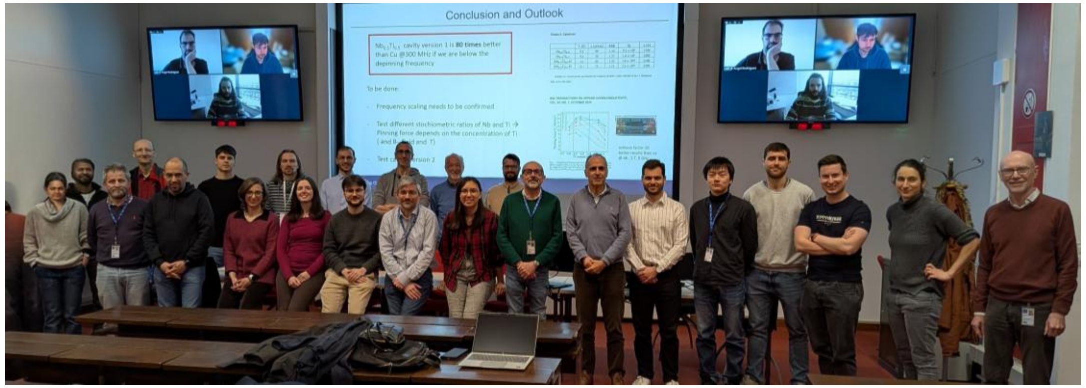
Developing advanced RF-resonant microwave cavities designed specifically for galactic dark matter axion detection.

ERC Synergy Grant

The DarkQuantum initiative drives the integration of breakthrough superconducting quantum technologies into haloscopes at high and low frequencies.

Quantum Integration

Combining superconducting cavities with ultra-low noise linear quantum sensors to surpass traditional standard quantum limits.

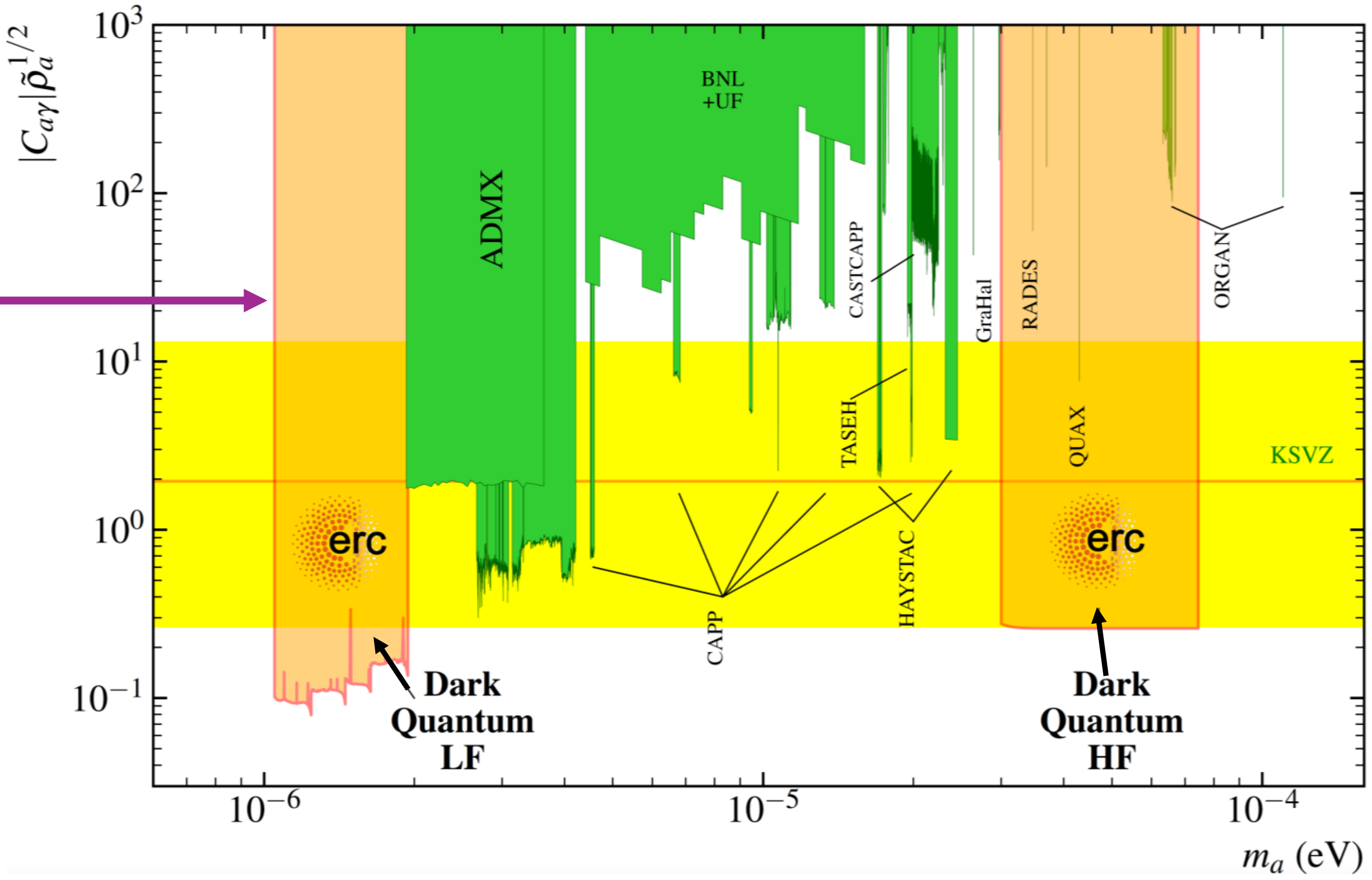


5th RADES – DQLF (Dark Quantum Low Frequency) meeting @ CERN

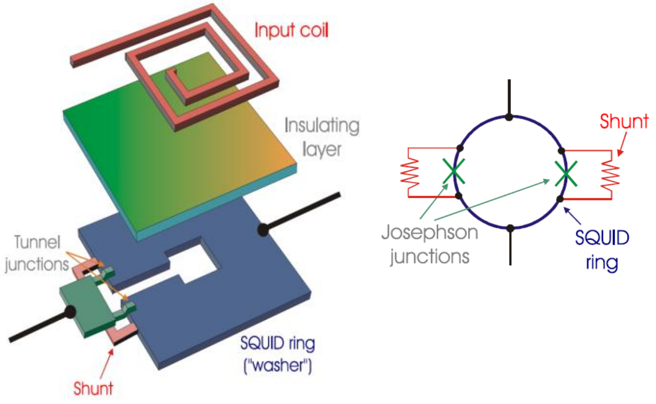
Low-Frequency Target (1–2 μeV)

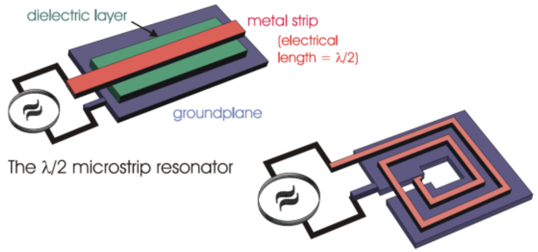
Targeting 200–500 MHz Frequencies

- **The Sub-GHz Window:** The DQLF program specifically targets the highly-motivated mass range of 1 to 2 μeV.
- **Volume Challenge:** Low frequencies require much larger haloscope resonators (~1 meter size) and big magnets.
- **Standard Amplification Bottleneck:** Traditional high-frequency amplification chains introduce prohibitive thermal noise.

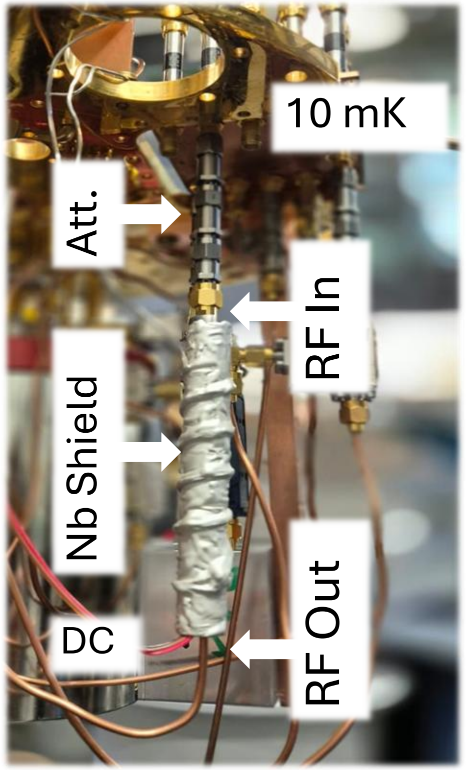


Quantum-Limited Linear Amplifiers (QLAD)





Microstrip SQUID amplifier (MSA)



MSA characterization (homogeneous gain at 280-360 MHz)

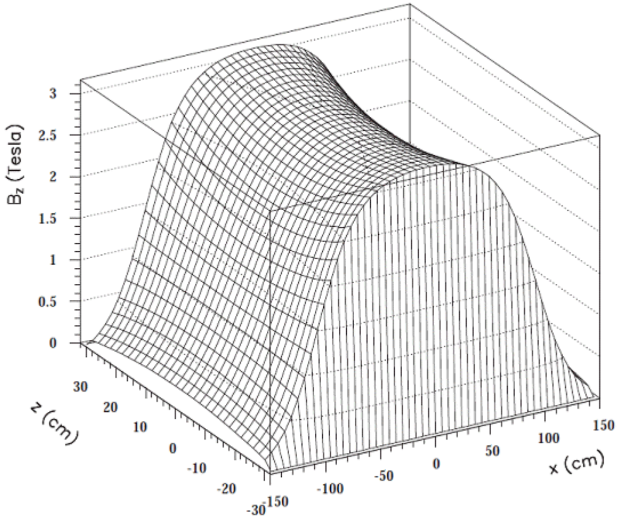
Implementing SQUID Technology

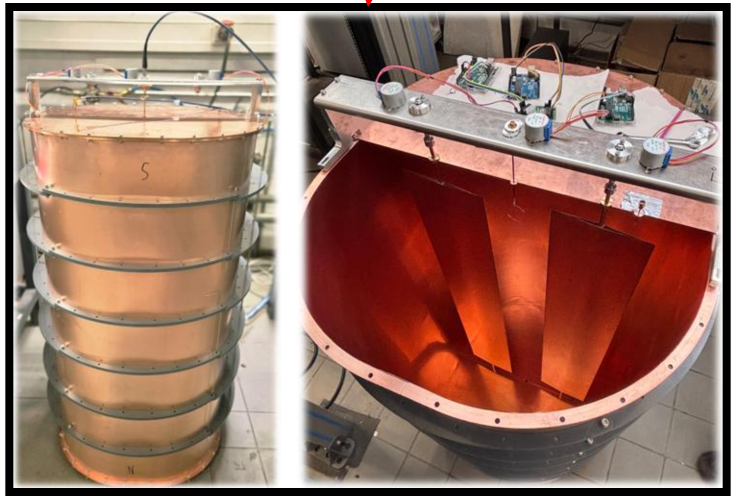
A cornerstone of the low-frequency setup is the SQUID-based amplification chain, minimizing additive detector noise towards the standard quantum limit

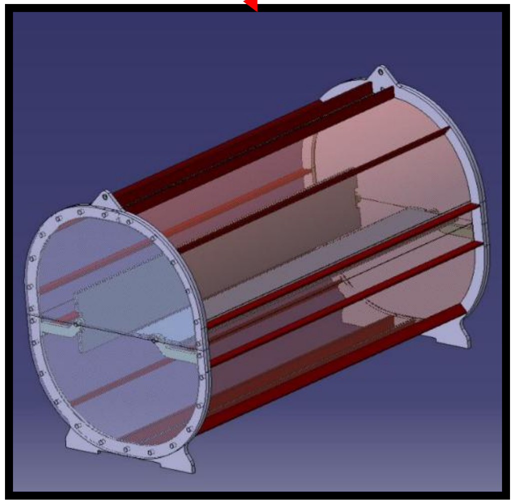
DQLF First-Gen Prototype

Establishing the Testbed

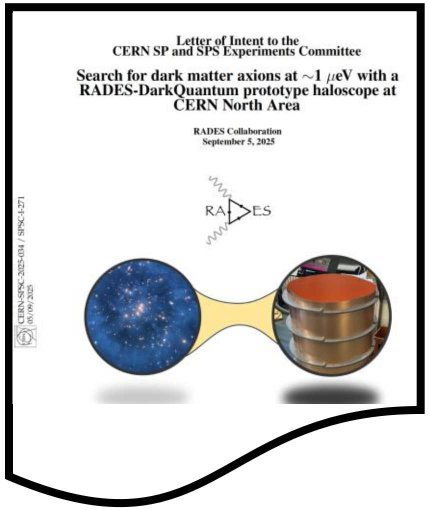
~1 Meter Resonant Cavity: Currently under construction to evaluate detection mechanics at sub-GHz frequencies. First prototype already built and tested at KIT. Second design effort ongoing at CERN.







Availability of suitable magnets at CERN North Area + Long-Shutdown-3 (LS3) a unique opportunity M1 magnet: 3T, 80-cm wide. Could already get physics from them: using M1 magnet at CERN North Area? Recent EoI to CERN SPSC submitted (sept-2025).

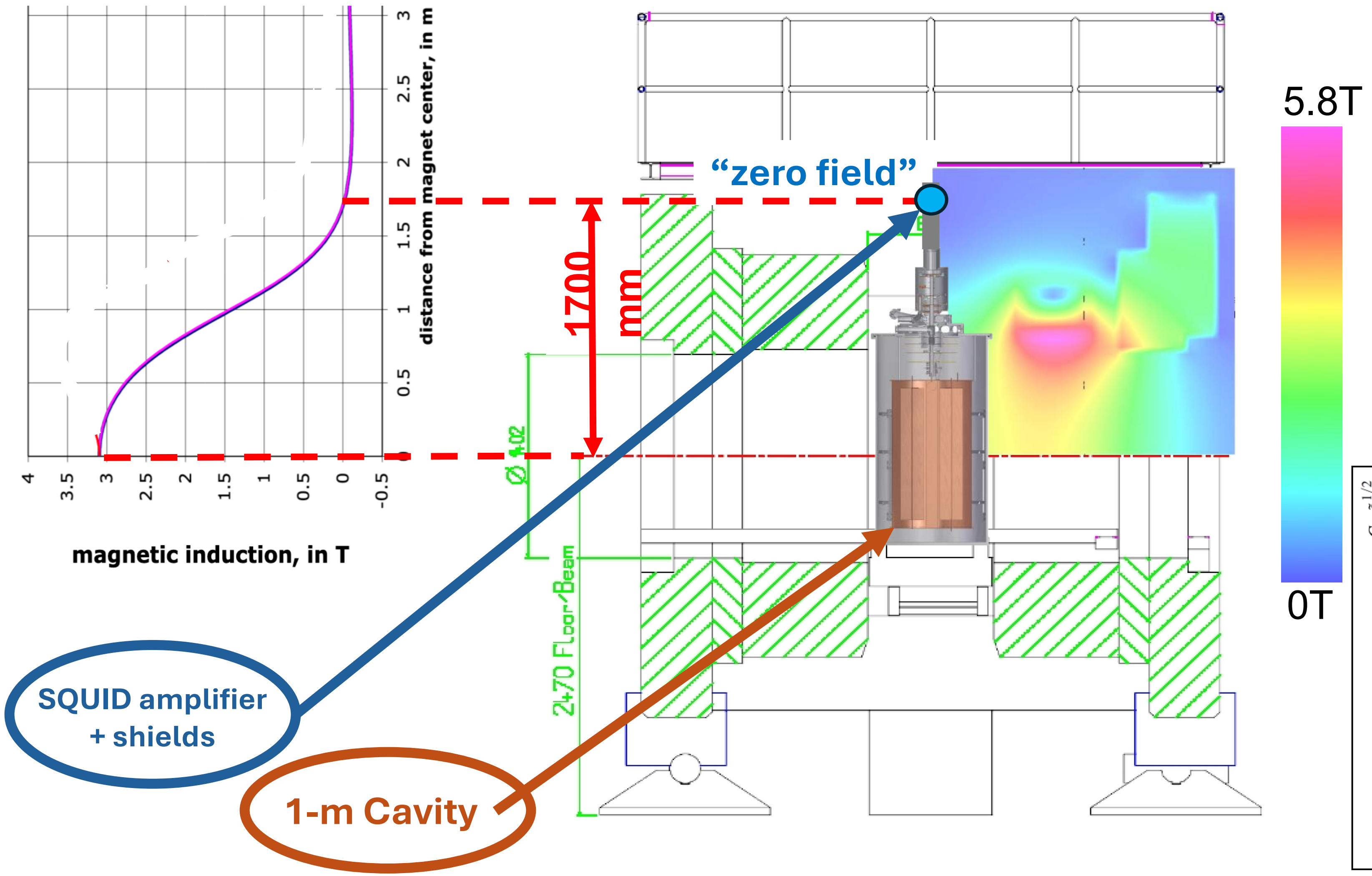

Letter of Intent to the CERN SP and SPS Experiments Committee

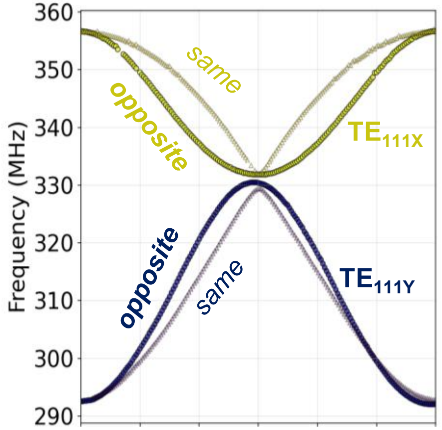
Search for dark matter axions at ~1 μeV with a RADES-DarkQuantum prototype haloscope at CERN North Area

RADES Collaboration
September 5, 2025

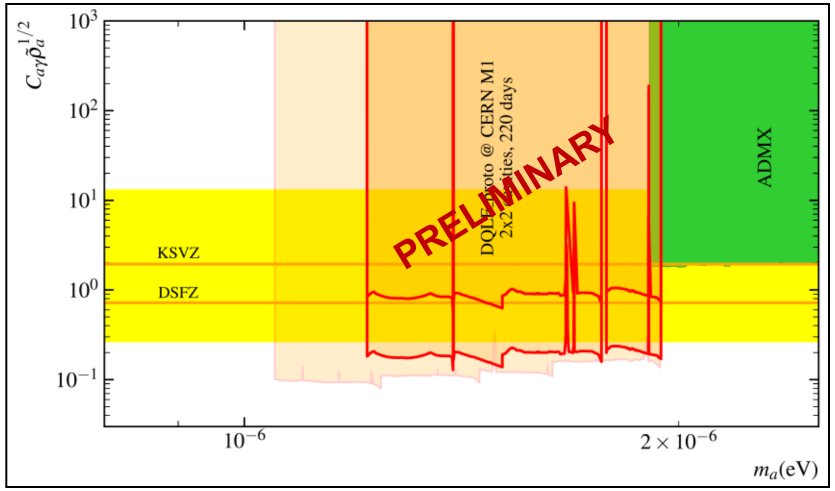
https://cds.cern.ch/record/2941908

Schematic of the setup in M1 magnet





Different results depending on the direction of tuning plates rotation



Roadmap Toward RADES-BabyIAXO experiment

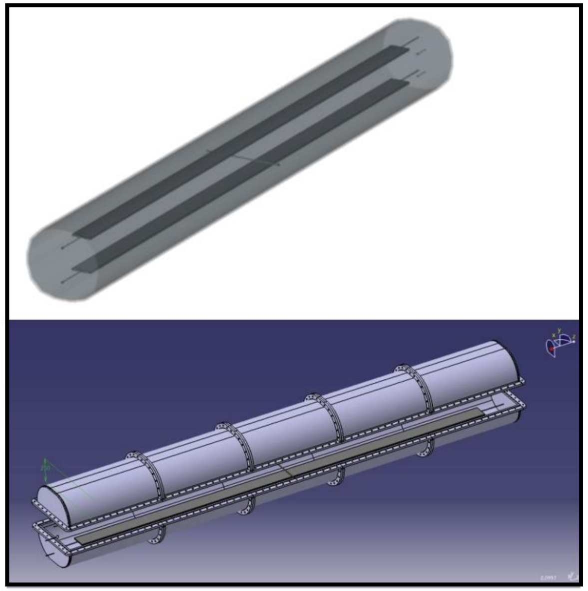
Scaling Up Detection Volume: Scaling physical cavity dimensions from the 1m prototype to 5m multi-haloscope arrays, matching BabyIAXO magnet sub-volumes.

RADES-LF @ BabyIAXO: very competitive prospects for 1-2 meV DM axion searches.

4 x 5m long cavities with tuning slabs.

DarkQuantum will push RADES-LF to SQL.

Standard axion DM paradigm could be fully tested in this range.




RESEARCH ARTICLE

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A Proposal for a Low-Frequency Axion Search in the 1–2 μ eV Range and Below with the BabyIAXO Magnet

Saiyd Ahyoune, Alejandro Álvarez Melcón, Sergio Arguedas Cuendis, Sergio Calatroni, Cristian Cogollos, Jack Devlin, Alejandro Díaz-Morcillo, David Díez-Ibáñez, Babette Döbrich, Javier Galindo, Juan Daniel Gallego, Jose María García-Barceló, Benito Gimeno, Jessica Golm, Yikun Gu, Louis Herwig, Igor Garcia Irastorza, Antonio Jose Lozano-Guerrero, Chloé Malbrunot, Jordi Miralda-Escudé, Juan Monzó-Cabrera, Pablo Navarro, Jose Ramón Navarro-Madrid, Javier Redondo, José Reina-Valero, Kristof Schmieden, Tim Schneemann, Marc Siodlaczek, Stefan Ulmer, and Walter Wuensch*

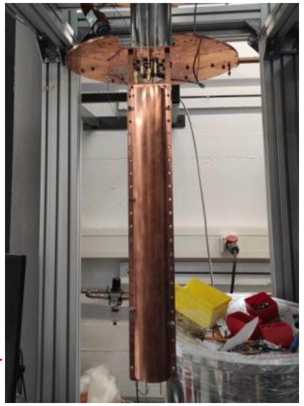
In the near future BabyIAXO will be the most powerful axion helioscope, relying on a custom-made magnet of two bores of 70 cm diameter and 10 m long, with a total available magnetic volume of more than 7 m^3. In this document, it proposes and describe the implementation of low-frequency axion haloscope setups suitable for operation inside the BabyIAXO magnet.

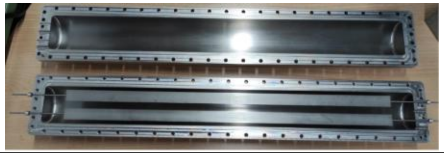
1. Introduction

Two of the most pressing issues of fundamental particle physics, the strong CP problem[1–3] and the identification of the nature of the Dark Matter (DM) of the Universe,[4] could be solved by the exis-

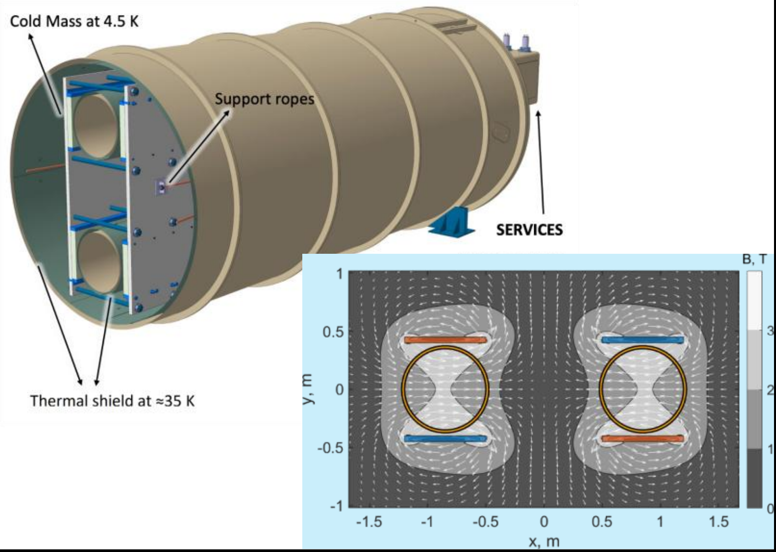
https://doi.org/10.1002/andp.202300326

- BabyIAXO: unprecedented magnetic volume to be available to axion community
- Ultra-cryogenics for unorthodox size and dimensions: challenging but possible.
- First 10x-scaled-down prototype cavity built and tested.





2 x 10-m long 70-cm diameter magnet bores



Acknowledgements

The work presented in this seminar is part of the work carried out in collaborations (IAXO & RADES), and funded by many agencies. But in particular I want to personally acknowledge support from:

- The European Union's Horizon 2020 research and innovation programme under the **European Research Council (ERC)** grant agreement ERC-2017-AdG788781 (**IAXO+**).
- The European Union's Horizon 2020 research and innovation programme under the **European Research Council (ERC)** grant agreement ERC-2023-SyG 101118911 (**DarkQuantum**).
- The Spanish **Agencia Estatal de Investigación (AEI)** under grant PID2019-108122GB-C31 funded by MCIN/AEI/10.13039/501100011033.
- The "**European Union NextGenerationEU/PRTR**" (Planes complementarios, Programa de Astrofísica y Física de Altas Energías), co-funded by Gobierno de Aragón

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Financiado por
la Unión Europea
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THANK YOU VERY MUCH

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