MAX-PLANCK-INSTITUT
FÜR PHYSIK

STATUS OF THE RADES-MPP ACTIVITIES IN HALOSCOPE EXPERIMENTS

Dr. Jose María García Barceló

2nd General Meeting of COST Action COSMIC WISPers (CA21106) – 3rd Sep/2024

ERC-STG802836

European Research Council
Established by the European Commission

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  - UPCT/UV - Cartagena/Valencia subgroup
  - UJG-M - Mainz subgroup

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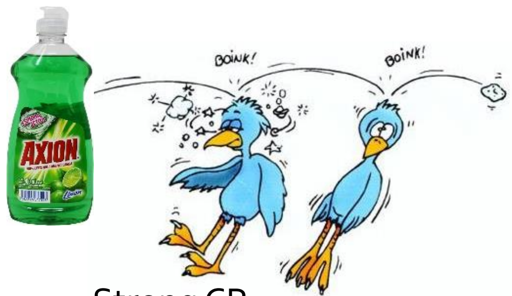
History of the RADES collaboration

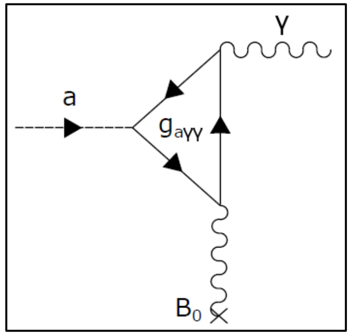
Motivation and goal



Strong CP problem

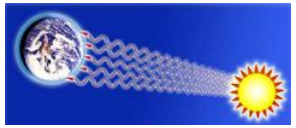
Dark matter composition

- **Axions** elegantly solve 2 problems from one
- Cold Dark Matter between 1-1000 μeV.
- Weak EM interaction. However, potential detection by the **axion-photon coupling**.

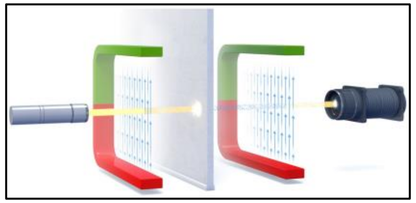


- Types of detectors:

Haloscopes

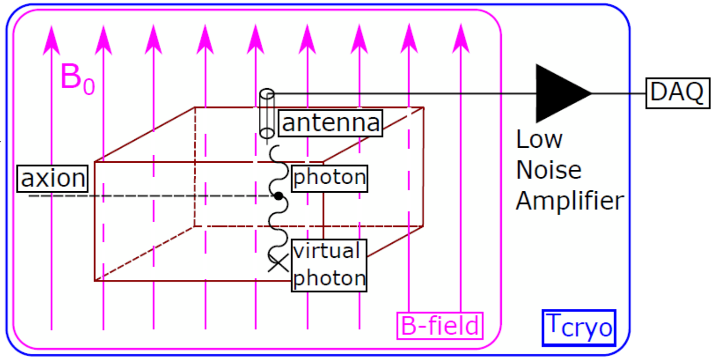


Helioscopes



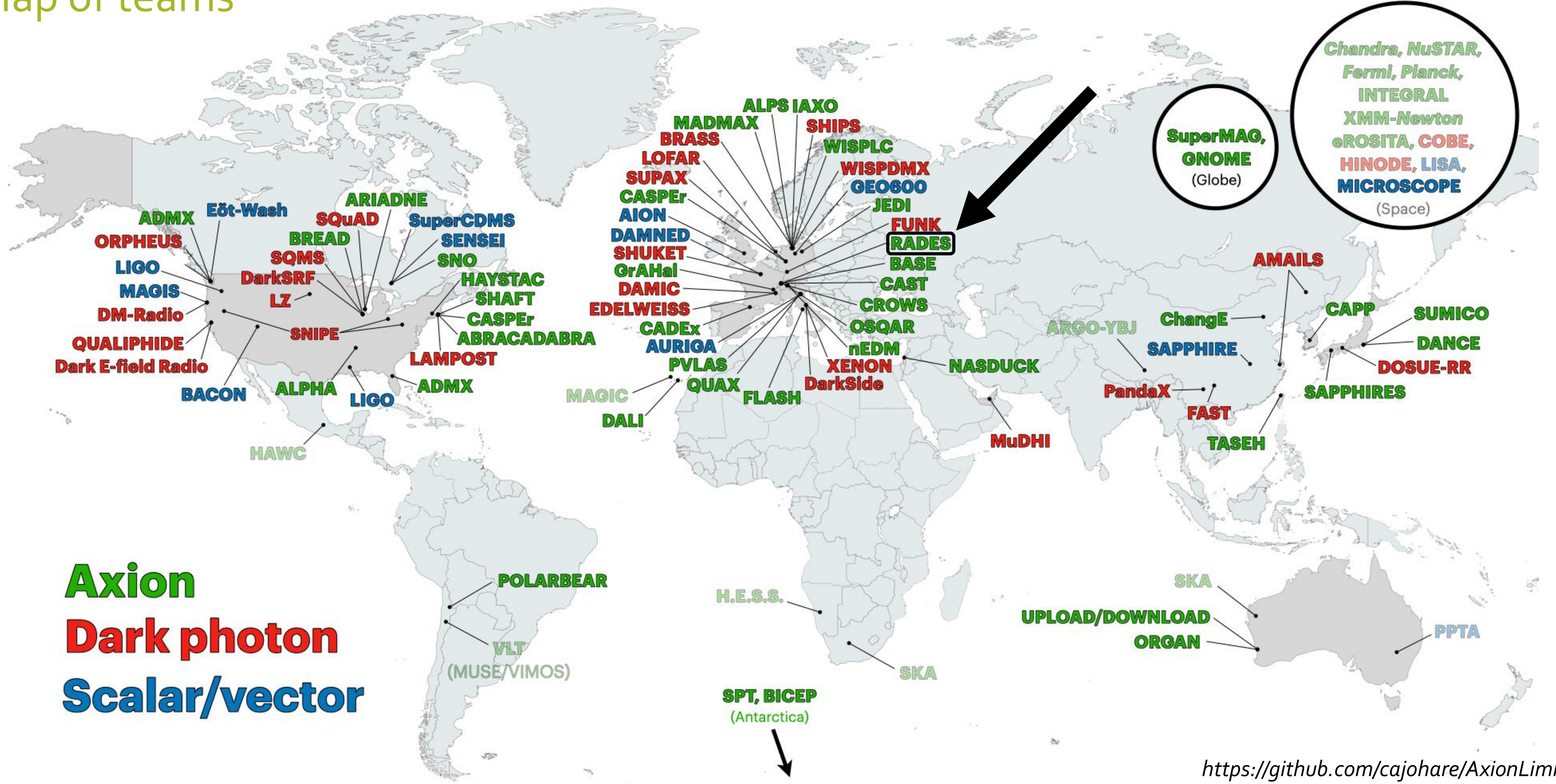
Light Shining Walls

- Conversion concept: inverse Primakoff effect
- **Haloscope** technology: **microwave cavity** immersed in a high static magnetic field for boosting the axion-photon conversion.



History of the RADES collaboration

Map of teams



https://github.com/cajohare/AxionLimits

History of the RADES collaboration

RADES team

~30 people from different institutes around the world

Universidad Zaragoza 1542 · JG|U · A! Aalto University School of Science · CERN · MAX-PLANCK-INSTITUT FÜR PHYSIK · UNIVERSITAT DE BARCELONA · ICMAB INSTITUT DE CIÈNCIA DE MATERIALS DE BARCELONA EXCELENCIA SEVERO OCHOA · Universidad Politécnica de Cartagena · KIT Karlsruher Institut für Technologie · IFIC INSTITUT DE FÍSICA CORPUSCULAR · CSIC · VNIVERSITAT DE VALÈNCIA · LPENS LABORATOIRE DE PHYSIQUE DE L'ÉCOLE NORMALE SUPÉRIEURE

...

1st RADES collaboration meeting in 2019 at UNIZAR

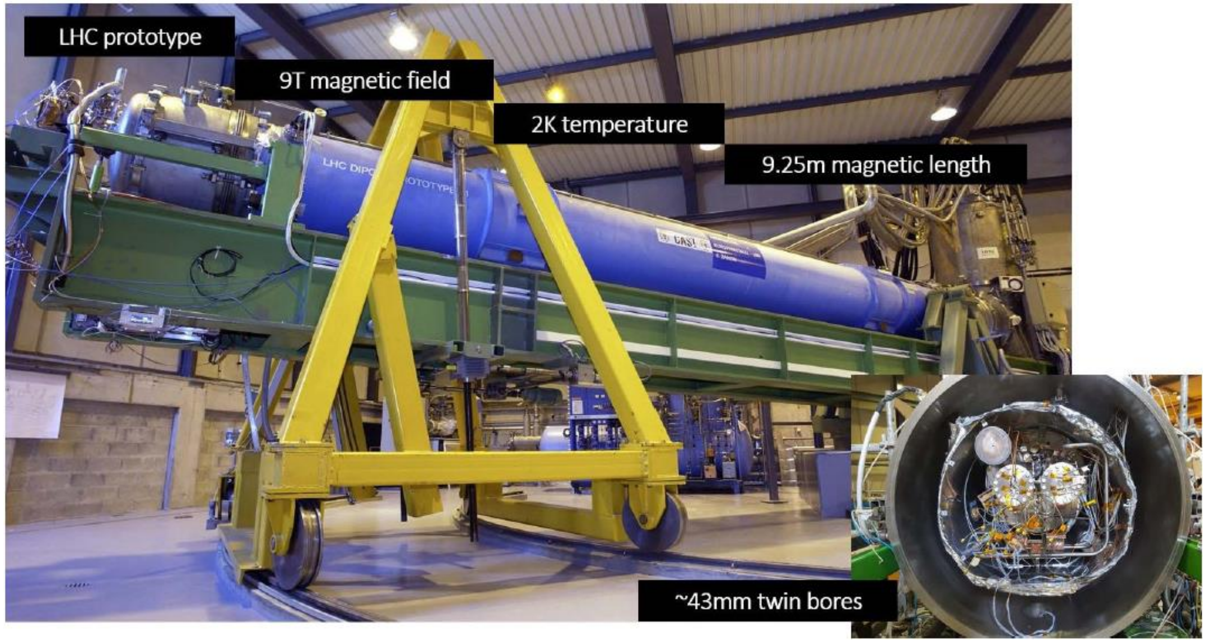
2nd RADES collaboration meeting in 2024 at MPP

Next RADES collab. meeting → February/2025 in Valencia

History of the RADES collaboration

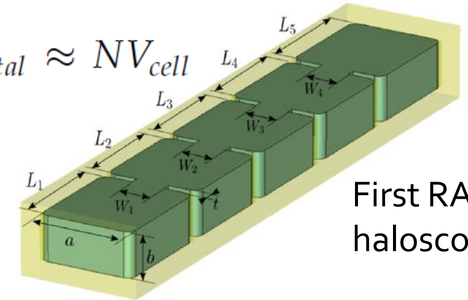
RADES origins

- The RADES (Relic Axion Detection Exploratory Setup) team originated in 2016 within the framework of the CAST (CERN Axion Solar Telescope) experiment, for the search for dark matter axions with haloscopes.



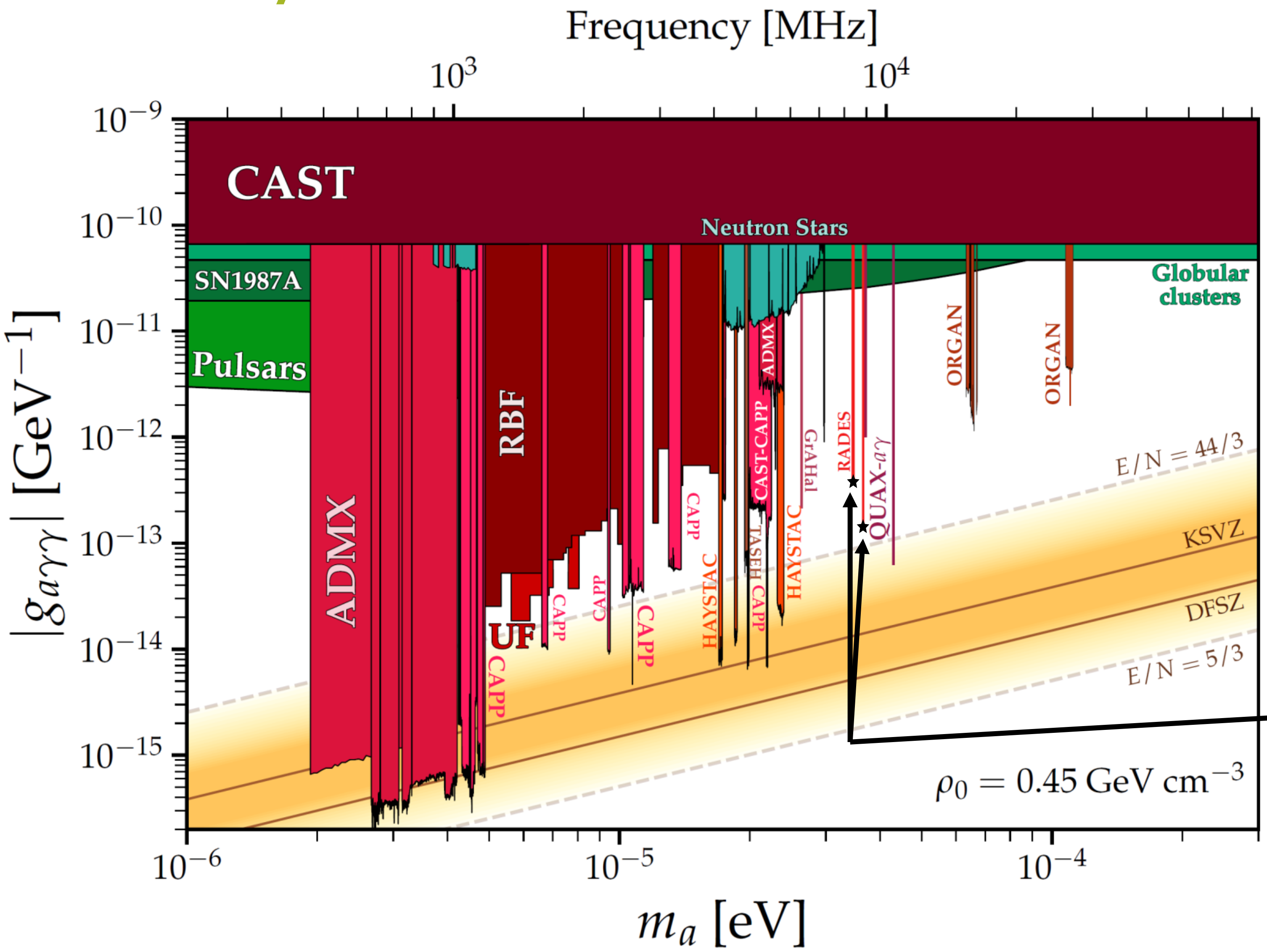
The first haloscope designs were based on the multi-cavity concept:

$$V_{total} \approx N V_{cell}$$



First RADES haloscope (2018)

History of the RADES collaboration



$f \approx \frac{m_a c^2}{h}$

RADES
(~8.38 + ~8.84 GHz)

https://github.com/cajohare/AxionLimits

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Axion data taking campaigns

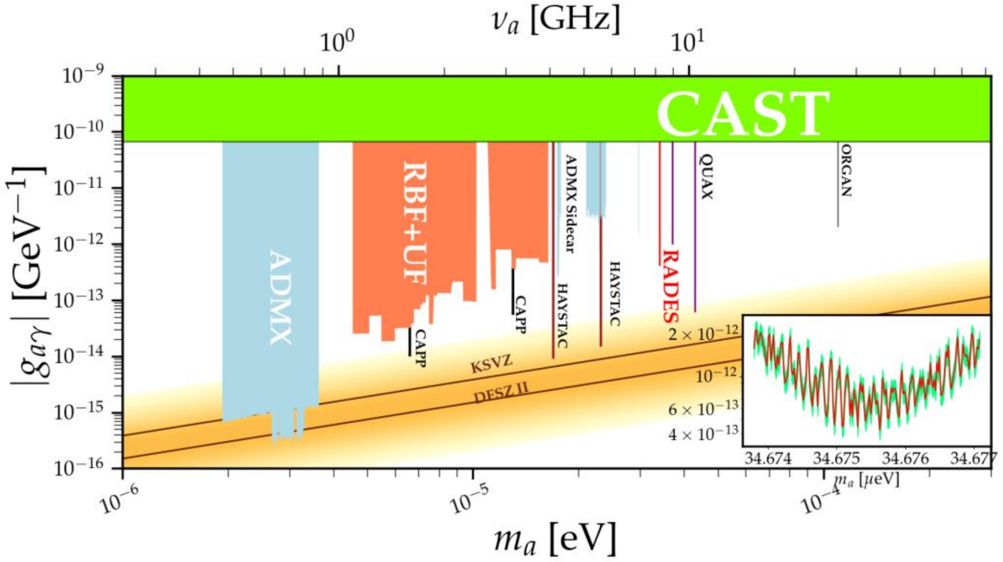
- 2 done + 1 in preparation

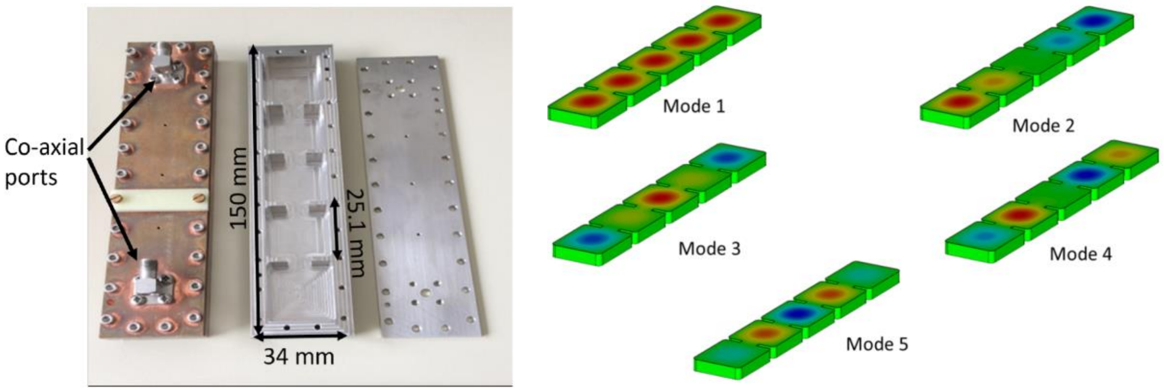
- 2018 at CAST (CERN) with a multicavity
- 2021 at SM18 (CERN) with a HTS cavity
- 2024 at SM18 (CERN) with a HTS cavity

Axion data taking campaigns

2018 at CAST (CERN) with a multicavity

- CAST magnet (9T + 1.9 K)
- Multicavity at 8.38 GHz
- Results (limits) published in: https://doi.org/10.1007/JHEP10(2021)075





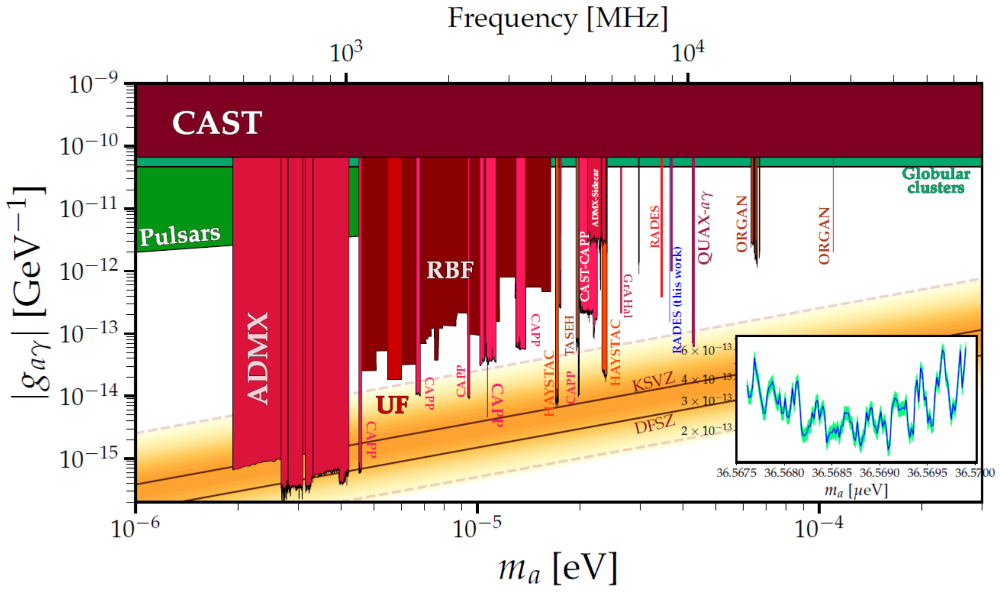
Axion data taking campaigns

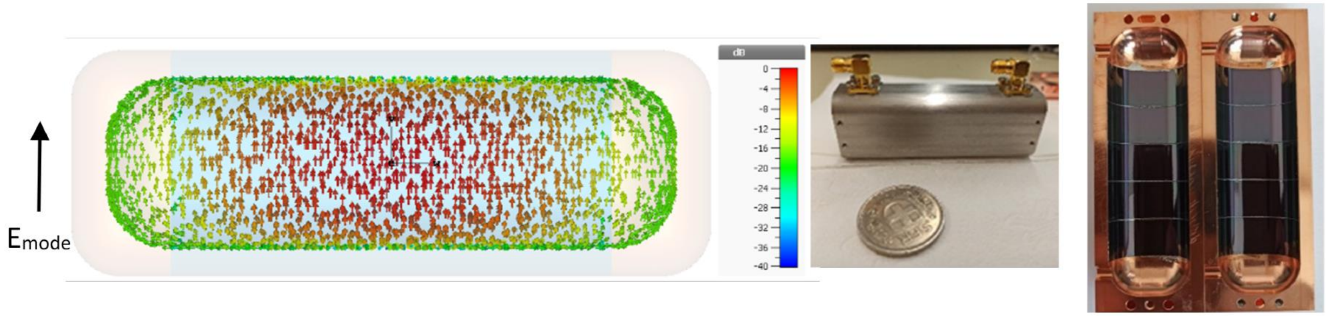
2021 at SM18 (CERN) with a HTS cavity

- CAST stopped so we explored other activities: ARIES TNA
- SM18 magnet (11.7 T + 1.9 K)
- Single cavity with HTS tapes (↑Q_0) at 8.84 GHz

(small effective tuning through helium pressure change)

- Results (limits) published in: https://arxiv.org/abs/2403.07790





Axion data taking campaigns

2024 at SM18 (CERN) with a HTS cavity

- New window to take axion data at the SM18 magnet (11.7 T + 1.9 K) in November/2024
- Single cavity with HTS tapes (↑Q_0)

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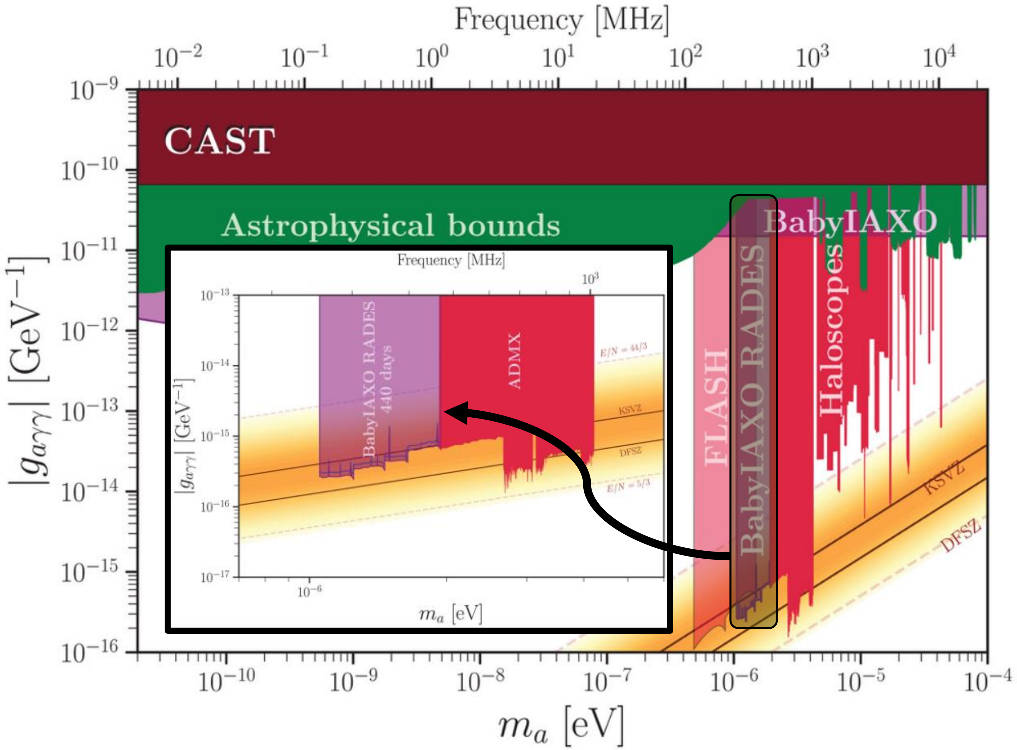
Future plans in BabyIAXO

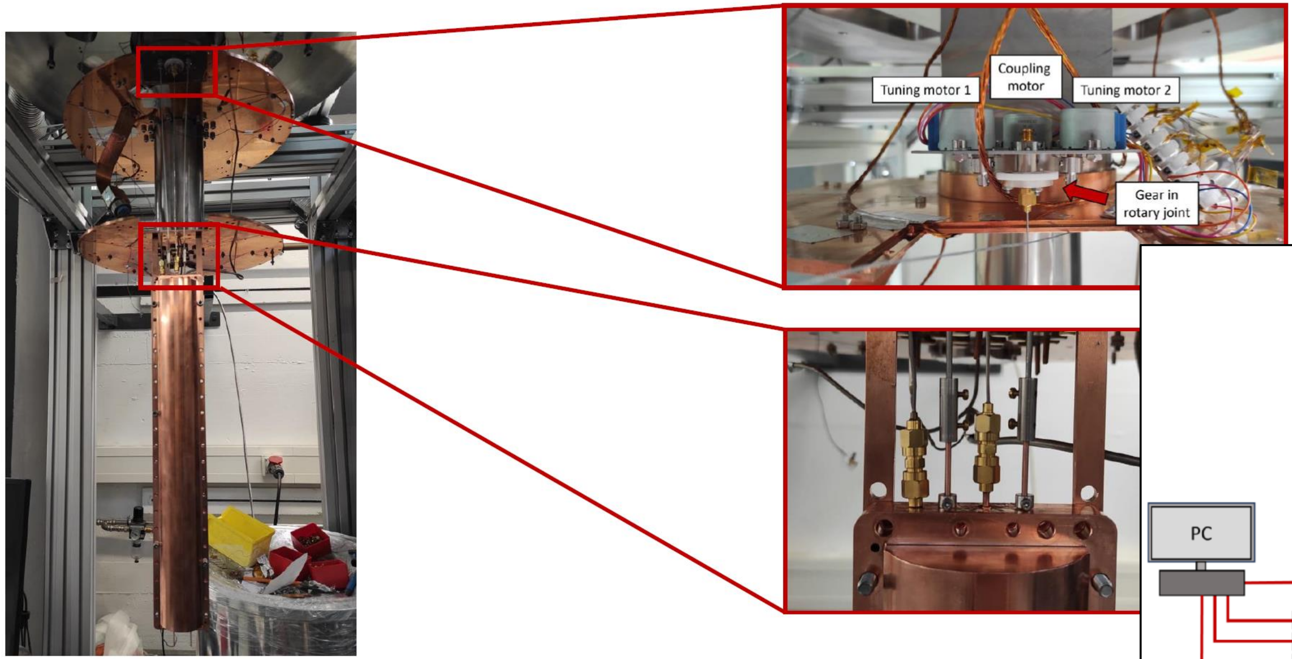
- The BabyIAXO experiment, at DESY (Hamburg, Germany), is an intermediate step to explore further possible improvements to the final IAXO telescope. Helioscopes and haloscopes could be installed.
- B = ~2.5T
- Dimensions: Ø = 60 cm, and L = 10 m.

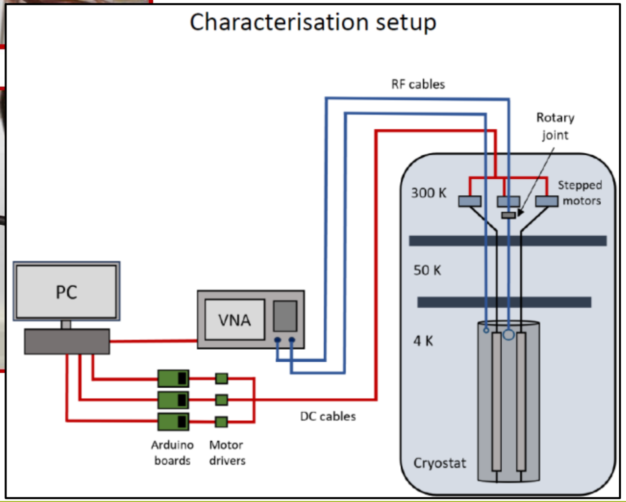
Future plans in BabyIAXO

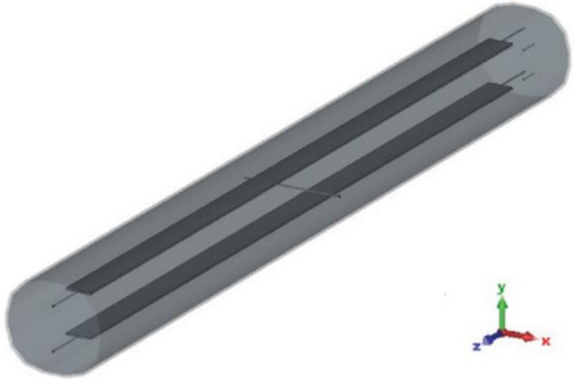
- RADES recently suggested (in [Ann.Phys. 535, 12]) the use of low-frequency (around [250-470] MHz) axion haloscope configurations (four 5-meter-long cavities) appropriate for operation within the BabyIAXO magnet.



- Preliminary version (10 times smaller, 50 cm in length):







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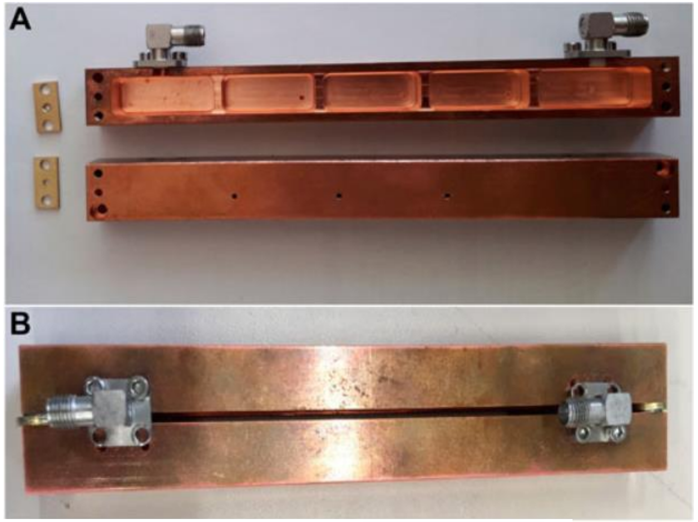
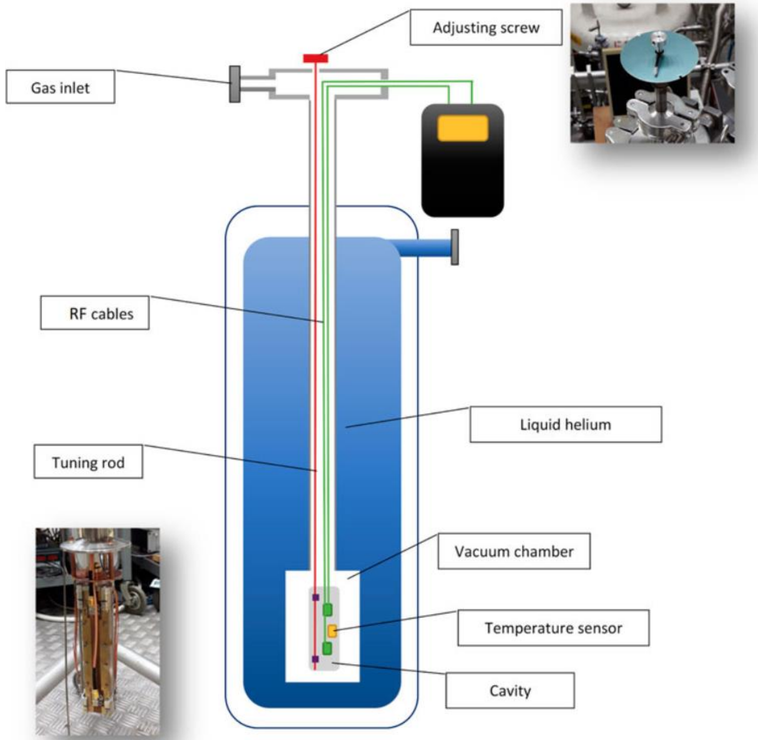
Other R&D activities - Tuning

- Throughout the years of the RADES research, different frequency tuning mechanisms have been explored: ferroelectric, ferromagnetic, vertical cut, rotating plates, helium bath pressure variation, etc.

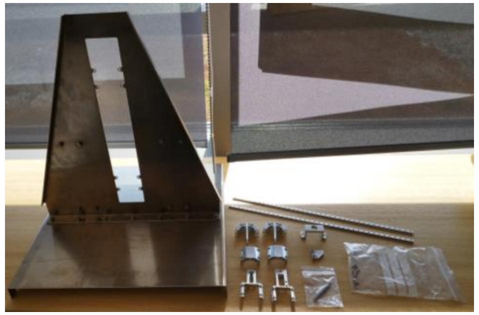
- The two most explored concepts have been ferroelectric (still without experimental results) and vertical cut tuning. For the latter, an investigation has been carried out in one of the RADES cavities of 5 sub-cavities with a longitudinal cut. The tuning here is based on the controlled opening between the two parts of the haloscope housing in order to modify the width and thus the operating frequency (see *Front. Phys. 12:1372846*).

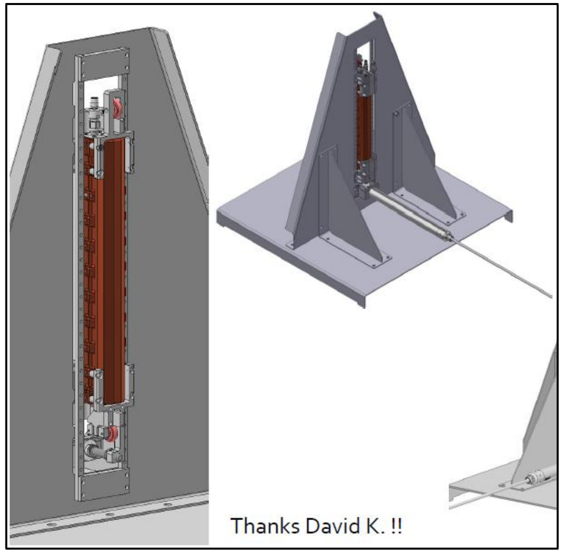


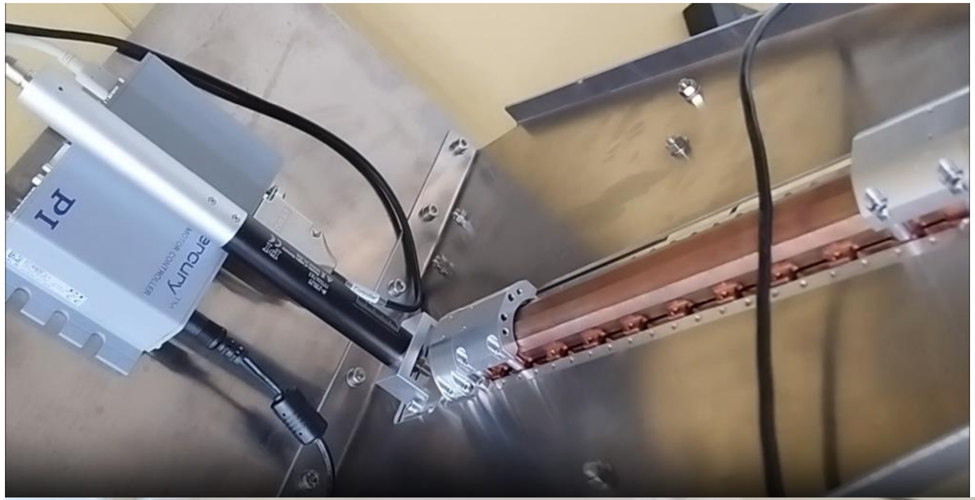


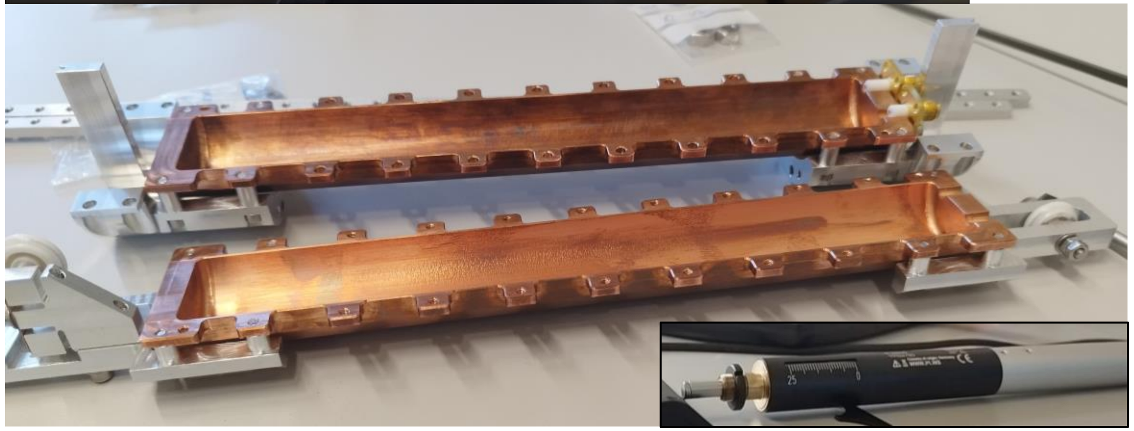
Other R&D activities - Tuning

- At the MPP (Munich, Germany) we are also exploring this concept for a single cylindrical cavity. 4K and 10 mK tests are foreseen.









Thanks David K. !!

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Other R&D activities - Single-photon technologies

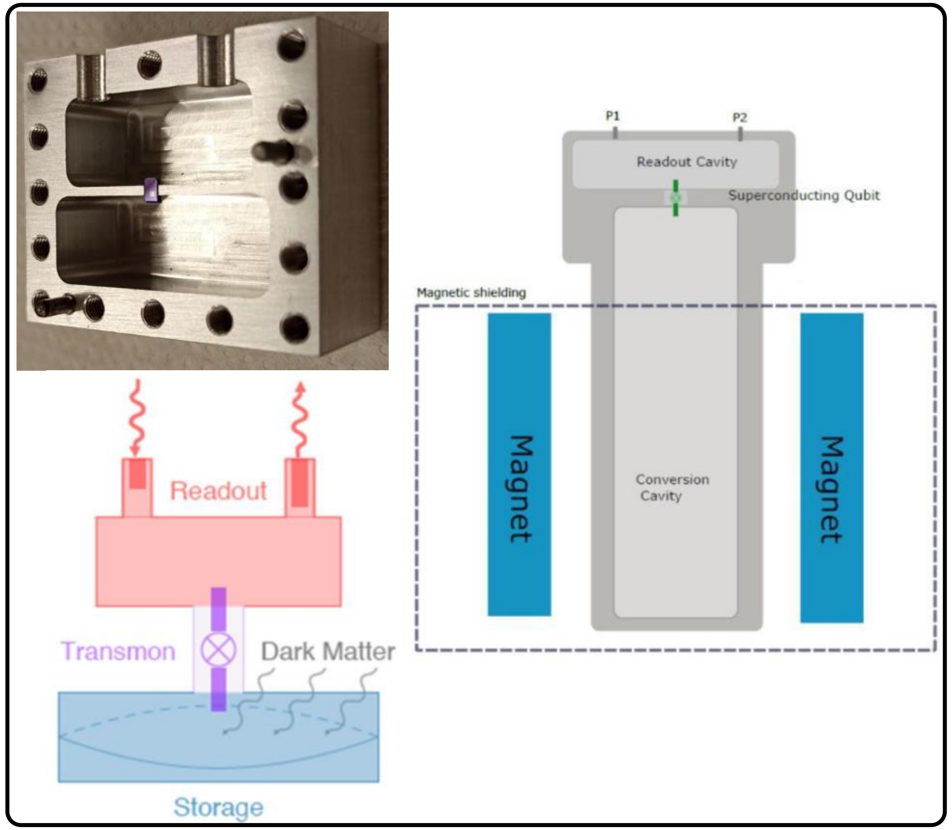
- Haloscope sensitivity is determined by the detector's noise: $T_{sys} = T_{phys} + T_{sen}$

- Lowering T_{phys} by cooling down the experiment will only increase sensitivity if T_{sen} is also decreased, so we need:

  - Quantum-limited amplification
  - Single-photon detectors (to overcome standard quantum limits).

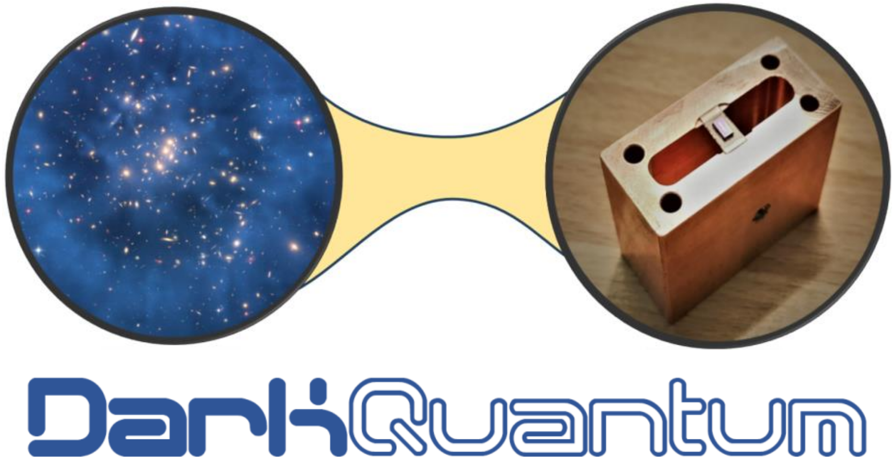
Other R&D activities - Single-photon technologies

- Explored quantum technologies:
  - Superconducting QuBits (transmons)
  - Nano-TES (Transition Edge Sensor)



Other R&D activities - Single-photon technologies

- As part of DarkQuantum project (ERC Synergy Grants 2023), we plan to develop a qubit-based QSPC and overcome all challenges for implementation in RADES.



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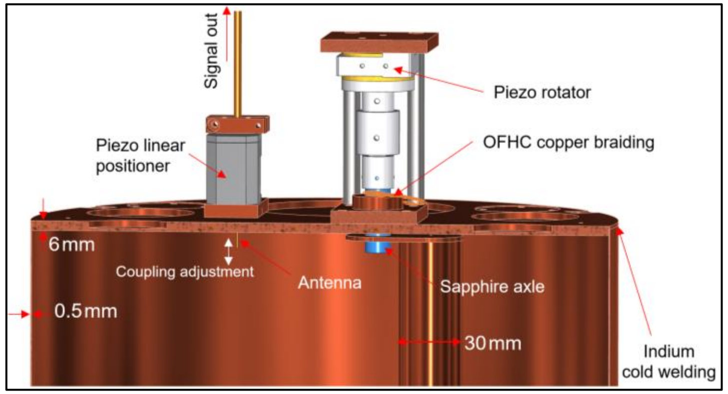
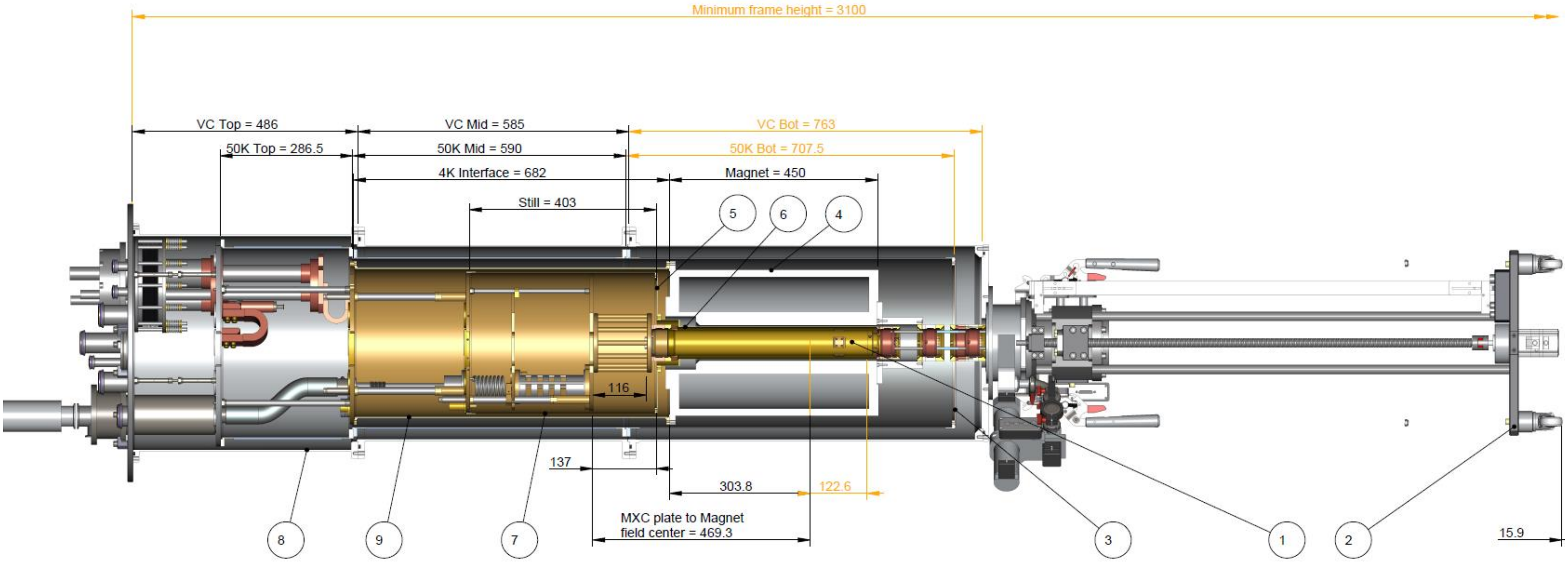
Other R&D activities - MPP-Munich subgroup

- Cylindrical cavity with a frequency tuning system based on the vertical cut concept.
- System for the coaxial cable to be inserted more or less to adjust the beta coupling of the system. Similar to CAPP cavities.
- We are going to manufacture a new cavity version with oxygen-free copper material (↑σ, ↑Q0).
- Installation of the LD-250 Bluefors dilfridge system (arrives on October/2024).
- Nano-TES studies.
- Preparing data taking protocol for SM18 axion data taking in November/2024.



Other R&D activities - MPP-Munich subgroup

- LD-250 Bluefors dilfridge system



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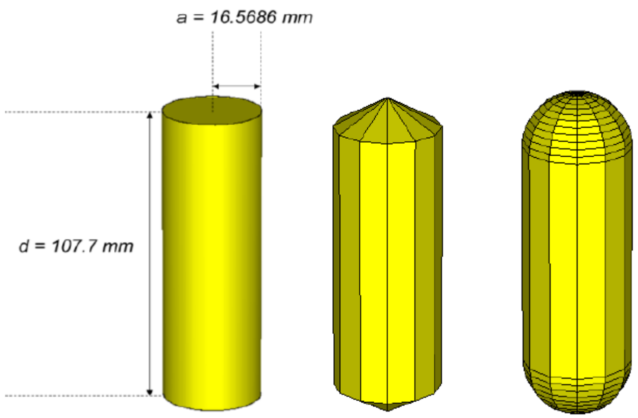
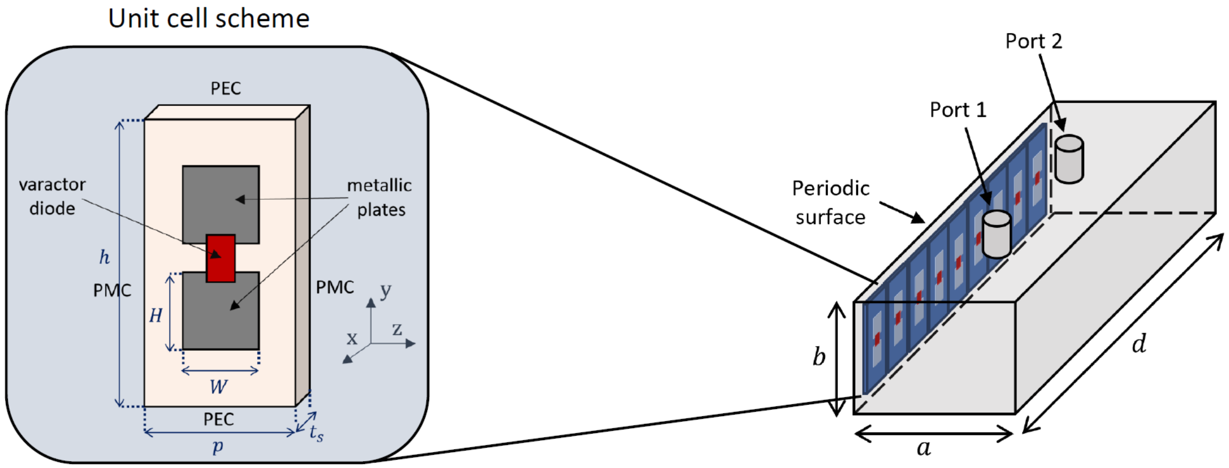
Other R&D activities - UPCT/UV - Cartagena/Valencia subgroup

- BabyIAXO haloscopes
- HTS cavities
- Electrical tuning with periodic surfaces based on varactor diodes.
- Ferroelectric and metamaterial studies.
- Other cavity designs to increase V and Qo

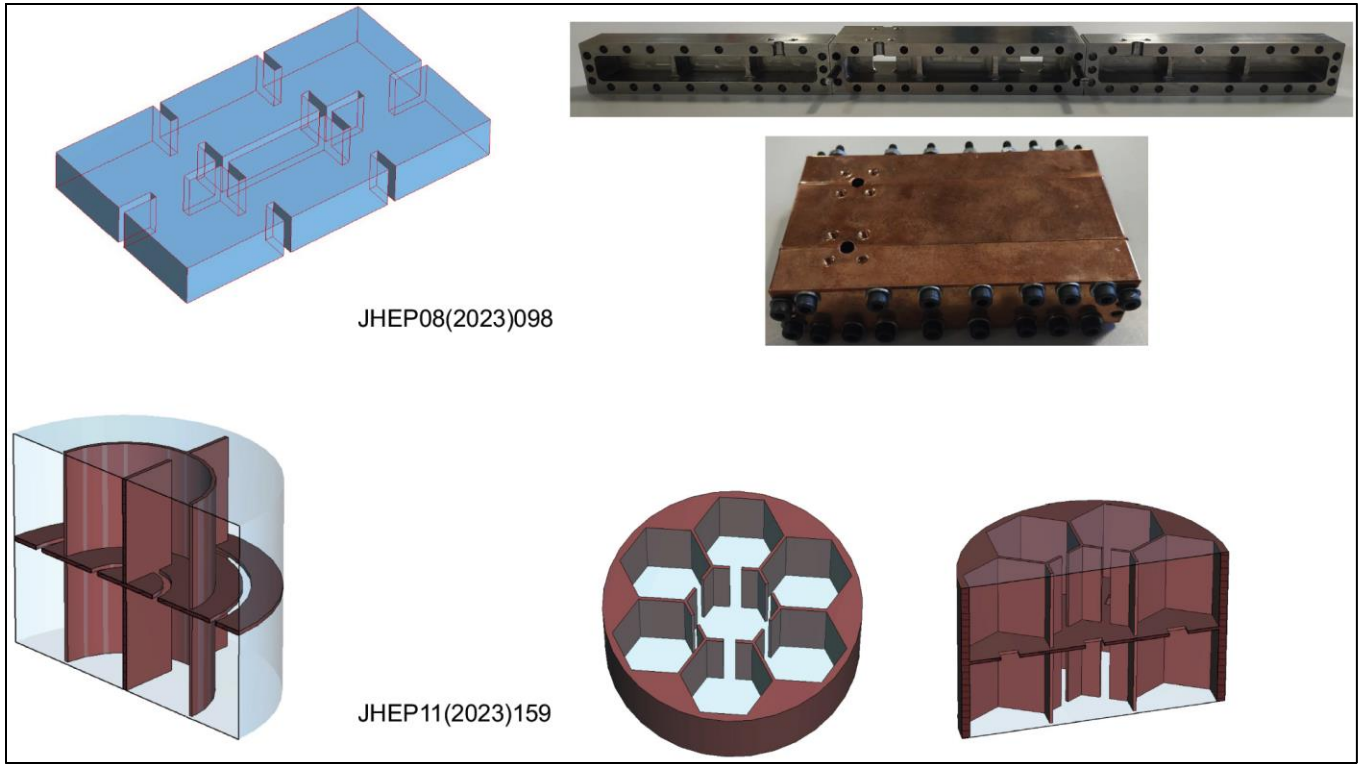




Study of tuning in a 8 GHz (for TE101) cavity

Other R&D activities - UPCT/UV - Cartagena/Valencia subgroup

- ➢ Rectangular and cylindrical 1D, 2D, and 3D multicavities →



Other R&D activities - UPCT/UV - Cartagena/Valencia subgroup

- Cavity for the detection of GWs at microwave frequencies.

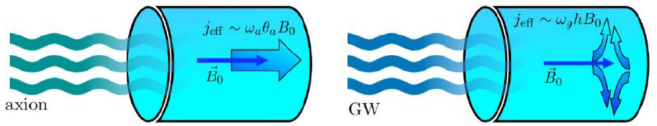
- Ideas and techniques developed for dark matter axions search be adapted to HF-GWs:

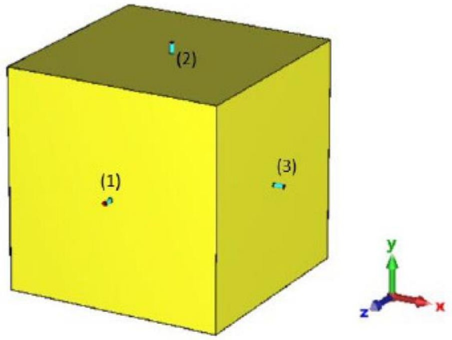
"Detecting high-frequency gravitational waves with microwave cavities",
Asher Berlin et al.,
Physical Review D,
105, 116011 (2022), pp 1-23

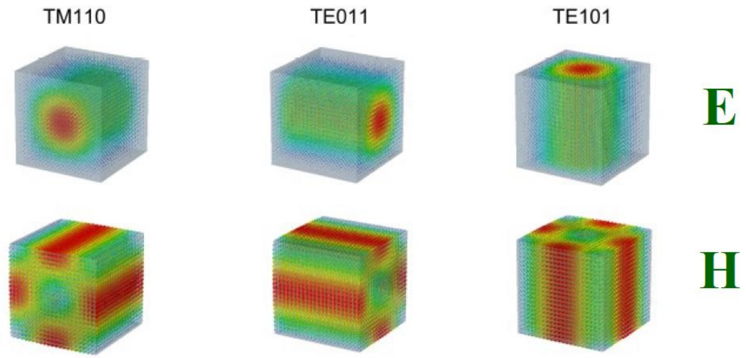
Detecting High-Frequency Gravitational Waves with Microwave Cavities

Asher Berlin,[1,2,3] Diego Blas,[4,5] Raffaele Tito D'Agnolo,[6] Sebastian A. R. Ellis,[7,6] Roni Harnik,[2,3] Yonatan Kahn,[8,9,3] and Jan Schütte-Engel[8,9,3]

See also Herman, Füzfa, Lehoucq, Clesse, 2012.12189







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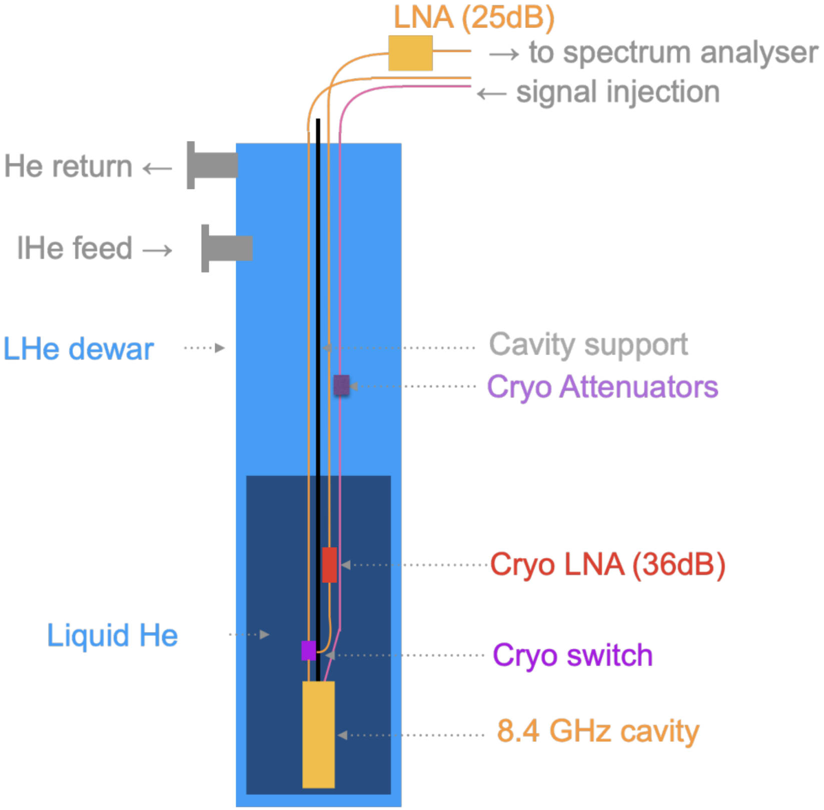
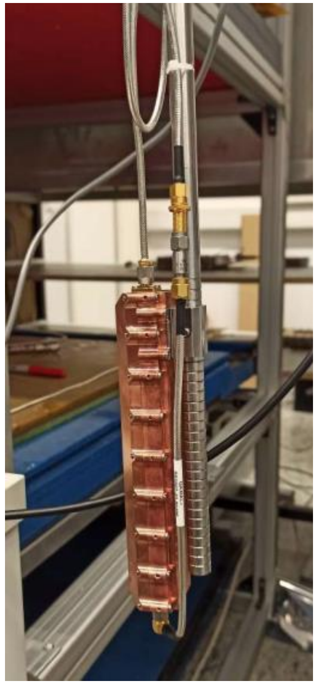
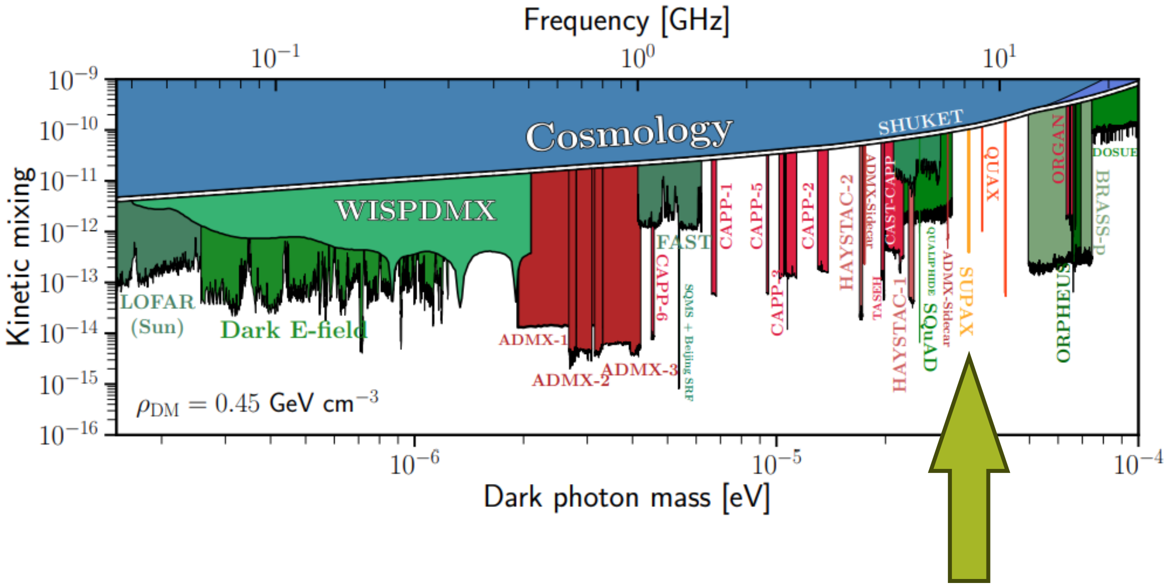
Other R&D activities - UJG-M - Mainz subgroup

- In Mainz (Germany), the SUPAX experiment is being carried out.
- First results of a new cavity-based haloscope searching for dark photons with masses around 34 μeV employing a 8.3 GHz copper cavity at 4K temperatures (see arXiv:2308.08337).







Thank you

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