Design of Cavities from UPCT and IFIC-CSIC-UV Groups

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FLASH TDR Meeting

May 15th, 2024

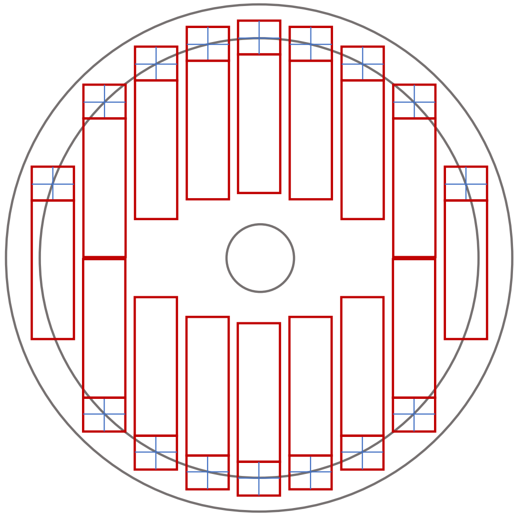
OUTLINE

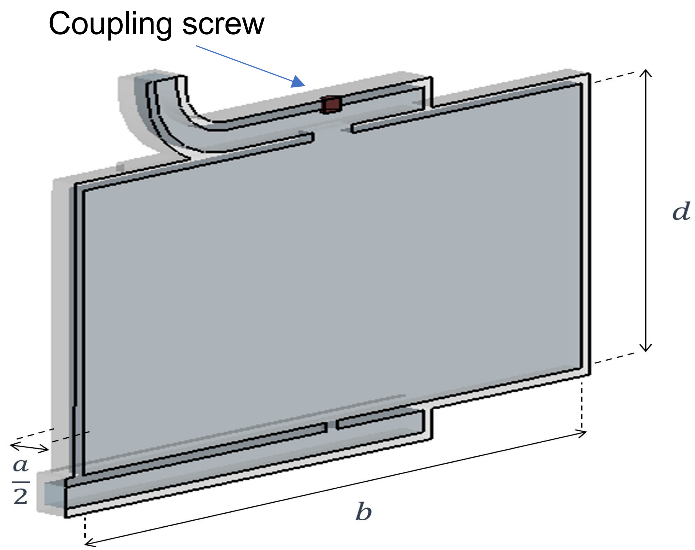
- **Cavities in CADEx (80 – 110 GHz)**
  - Large (tall and long) cavities
  - Tuning
  - Coupling
- **Cavities in HF – RADES (8 – 10 GHz)**
  - Multicavities
  - Superconductors
  - Tuning
- **Cavities in LF – RADES (250 – 450 MHz)**
  - Experiment concept
  - Scaled-down cavity
  - Measurements at KIT
- **Cavities for GWs**

CADEx

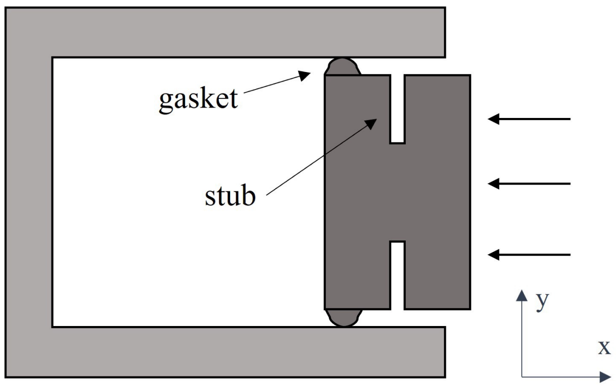
80 – 110 GHz
Solenoid magnet at LSC (Canfranc)
Multiple large rectangular cavities: TM_{110}
Waveguide-cavity coupling (iris)
Quasi-optical coherent sum
Detector: KID

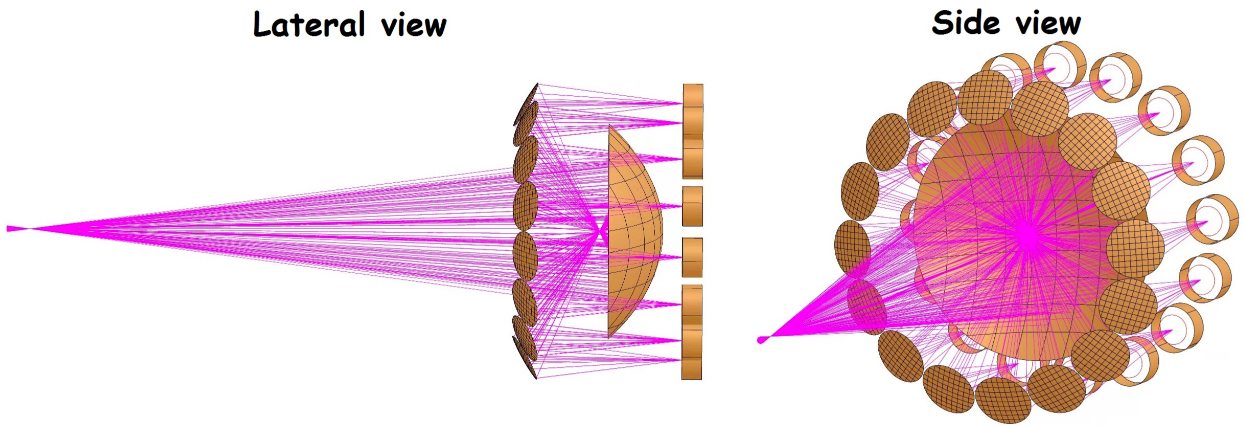
JCAP11(2022)044





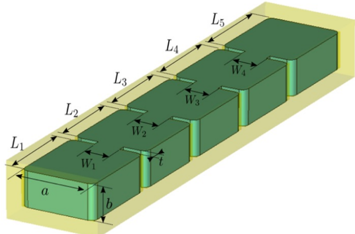
Tuning

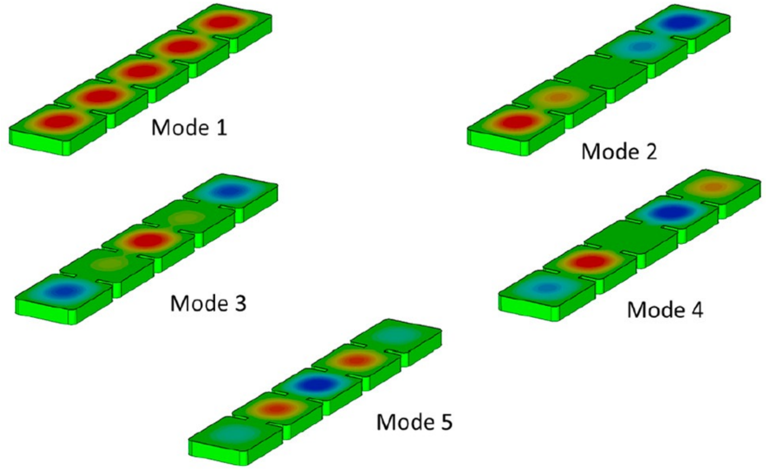




HF – RADES: MULTI-CAVITIES (I)

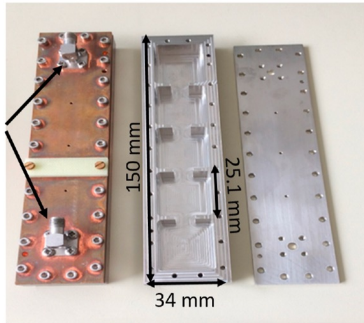
8 – 10 GHz
Dipole magnet (CAST, SM18 at CERN)
Rectangular multi-cavities: $TE_{101}^{+++\cdots}$
Read-out chain: LNA + DAQ





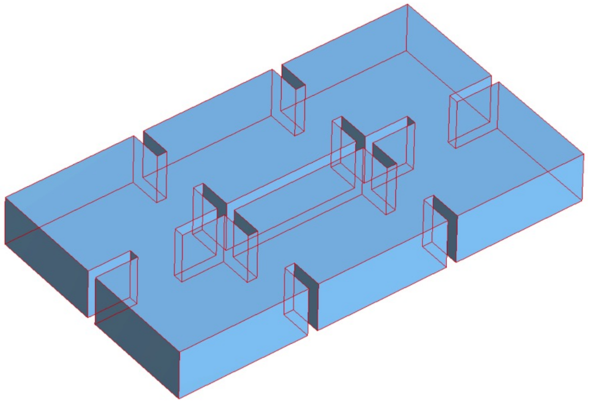
1D 5-cells multi-cavity

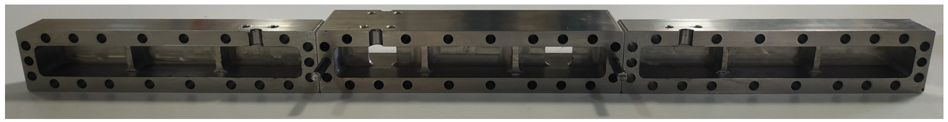
Universe 2022, 8, 5

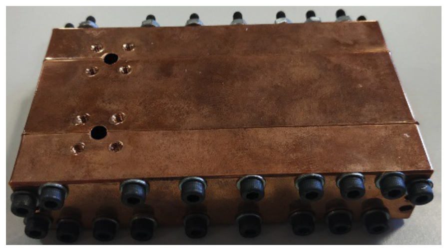


2D 6-cells multi-cavity

JHEP08(2023)098





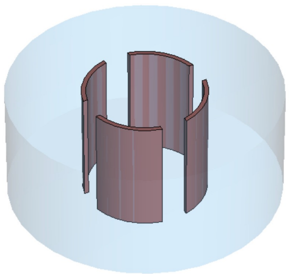


HF – RADES: MULTI-CAVITIES (II)

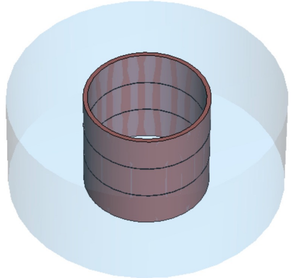
Cylindrical multi-cavities

JHEP11(2023)159

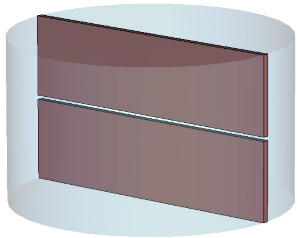
1D



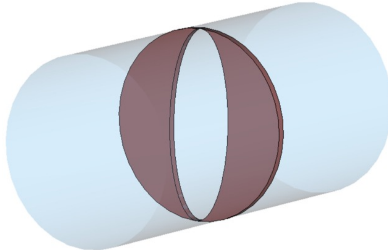
ρ inductive



ρ capacitive

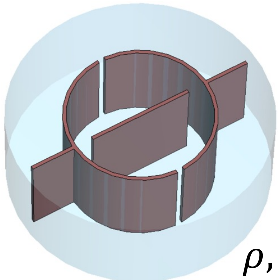


φ capacitive

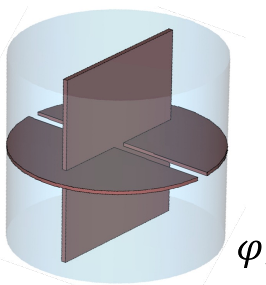


z

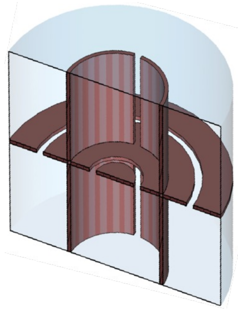
2D



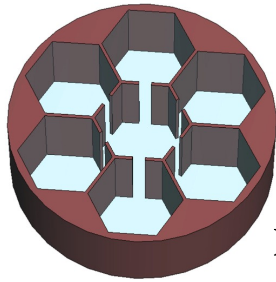
ρ, φ



φ, z

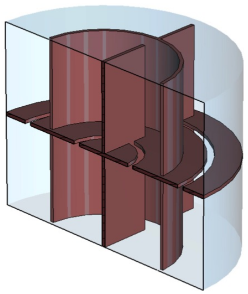


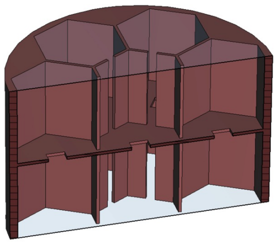
ρ, z



Hexagonal, ρ, φ

3D

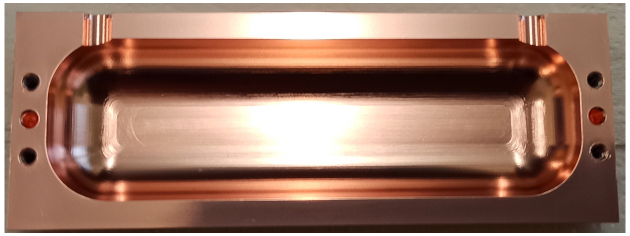


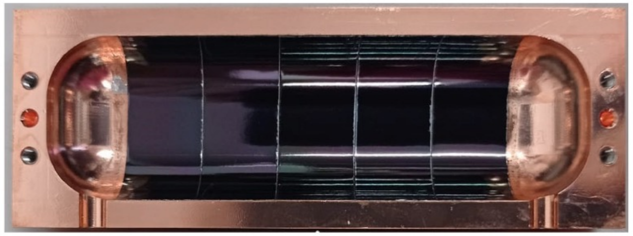


+ Just one external coupling mechanism
- Increase in volume limited by mode clustering
- Complex tuning mechanisms (in general)

HF – RADES: SUPERCONDUCTORS AND TUNING

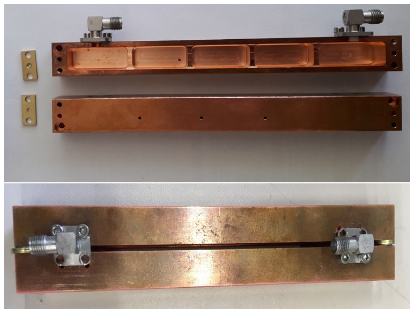
REBCO





IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 32, NO. 4, JUNE 2022

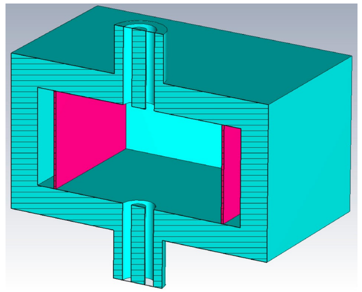
Mechanical tuning



arXiv:2312.13109v1 [physics.ins-det]
20 Dec 2023

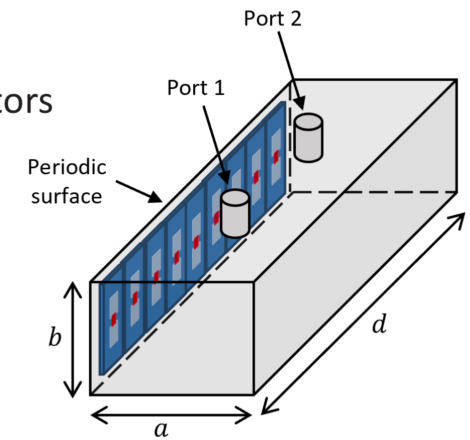
Non-mechanical (EM) tuning:

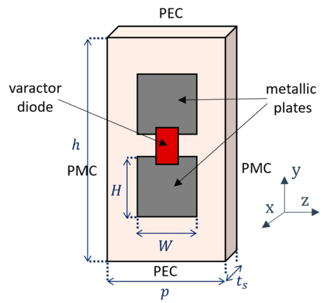
Ferroelectrics ($KTaO_3$)



DOI: 10.1109/ACCESS.2023.3260783

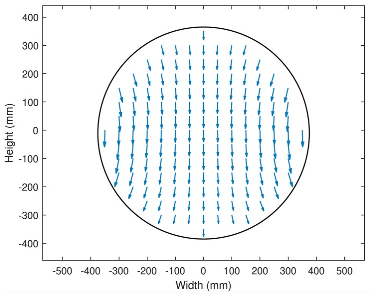
High Q varactors

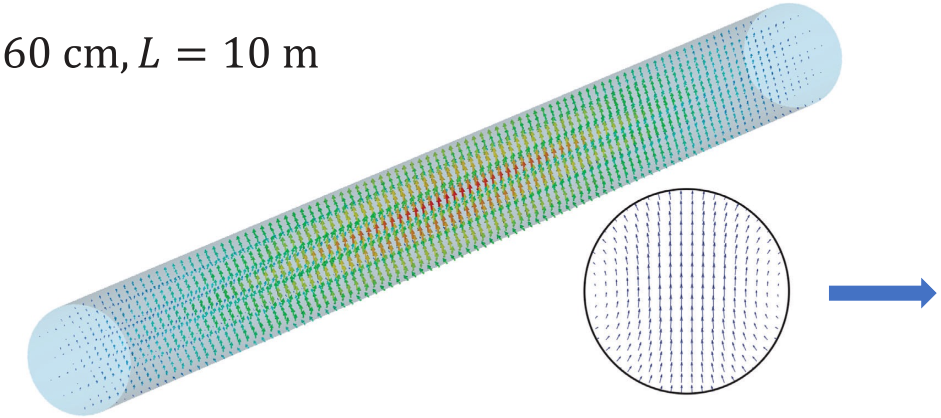




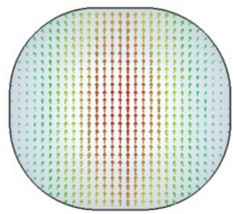
BABYIAXO – RADES. CONCEPT

BabyIAXO magnet bore: $\phi = 60 \text{ cm}, L = 10 \text{ m}$
Quasi-dipole magnet
Magnetic field in one bore





Mode TE$_{111}$ provides the best C for BabyIAXO $\vec{B}_e$



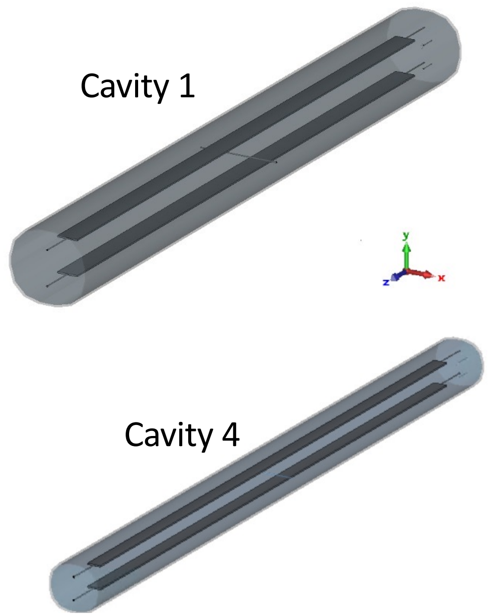
Target: 250 – 450 MHz

Scaling final design for different axion masses in the range of $m_a \in [1.05 - 1.94]$ μeV (253 – 469 MHz)

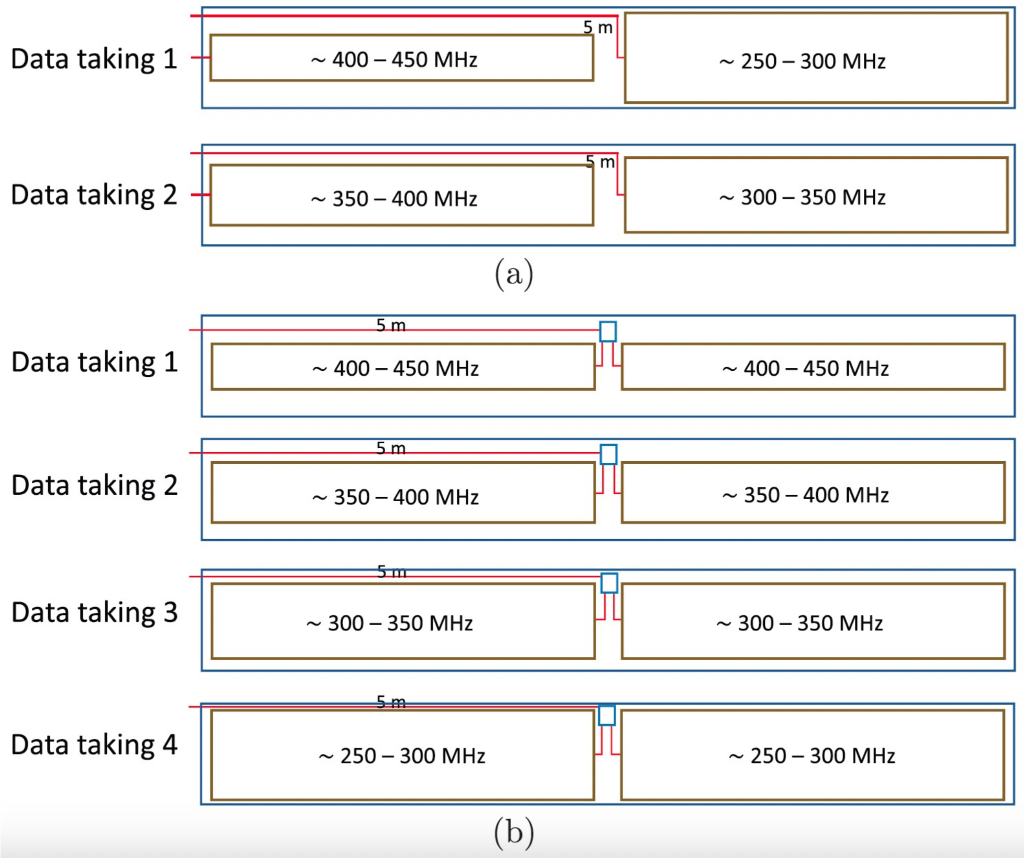
All cavities: 5 meters long

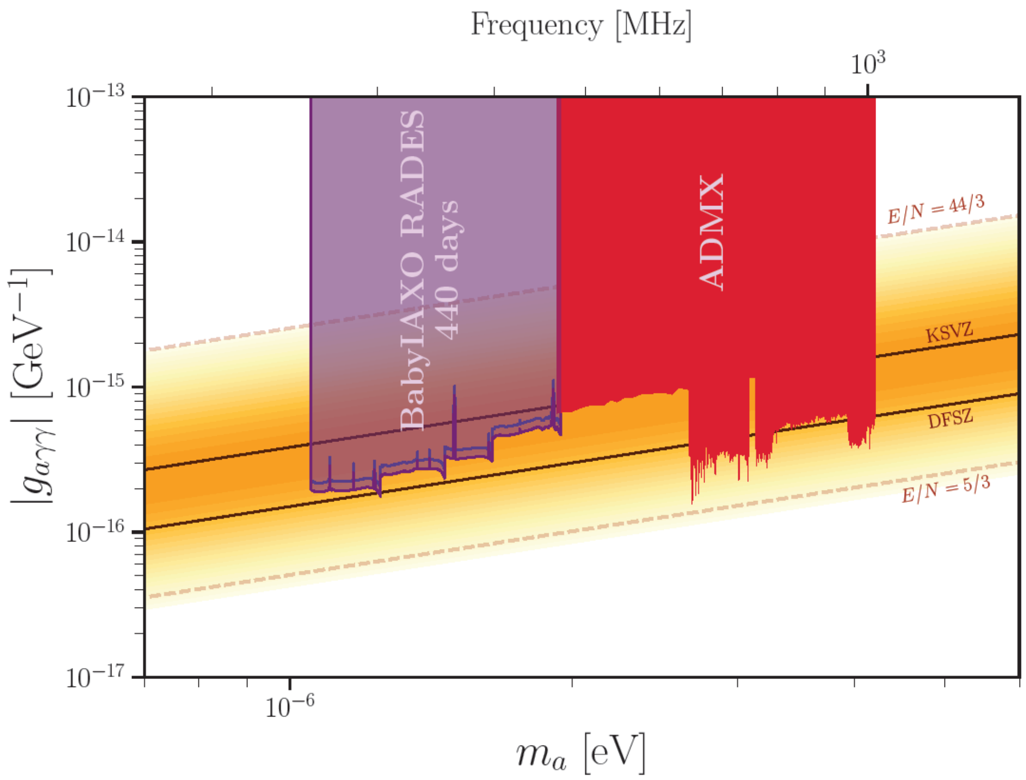
Ann. Phys. (Berlin) 2023, 2300326

Cavity 1: ø = 56 cm (253 – 300 MHz)
Cavity 2: ø = 49 cm (300 – 352 MHz)
Cavity 3: ø = 43 cm (351 – 395 MHz)
Cavity 4: ø = 35 cm (392 – 469 MHz)



BABYIAXO – RADES. CONCEPT & PROSPECTS



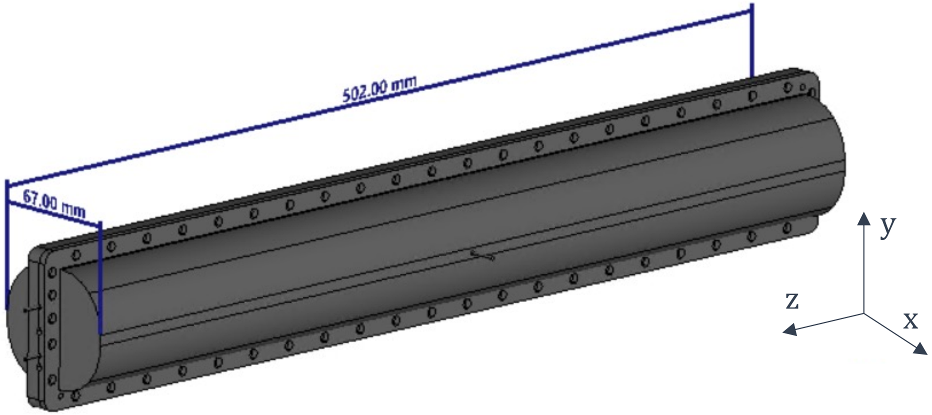


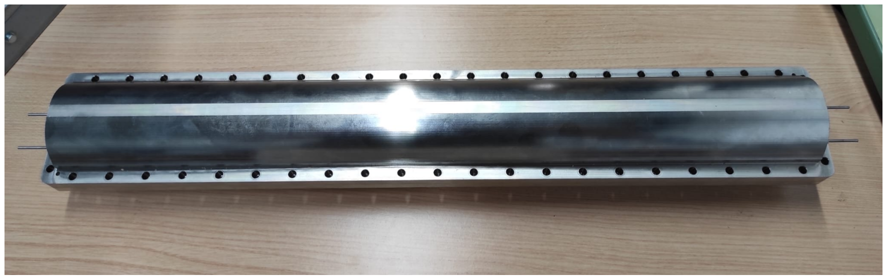
BABYIAXO – RADES. SCALED-DOWN CAVITY

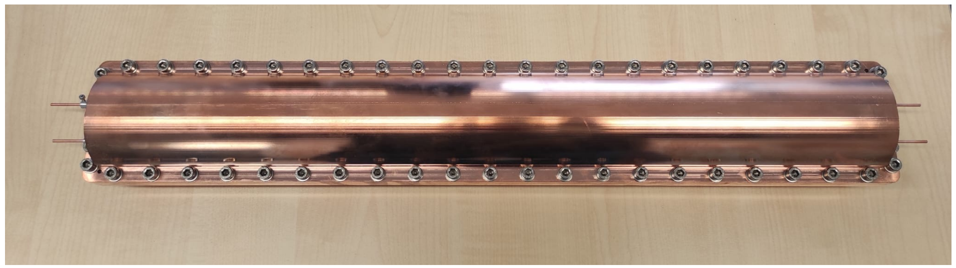
Scaled-down version (x10 times)

Tuning range: 2.5 – 3 GHz

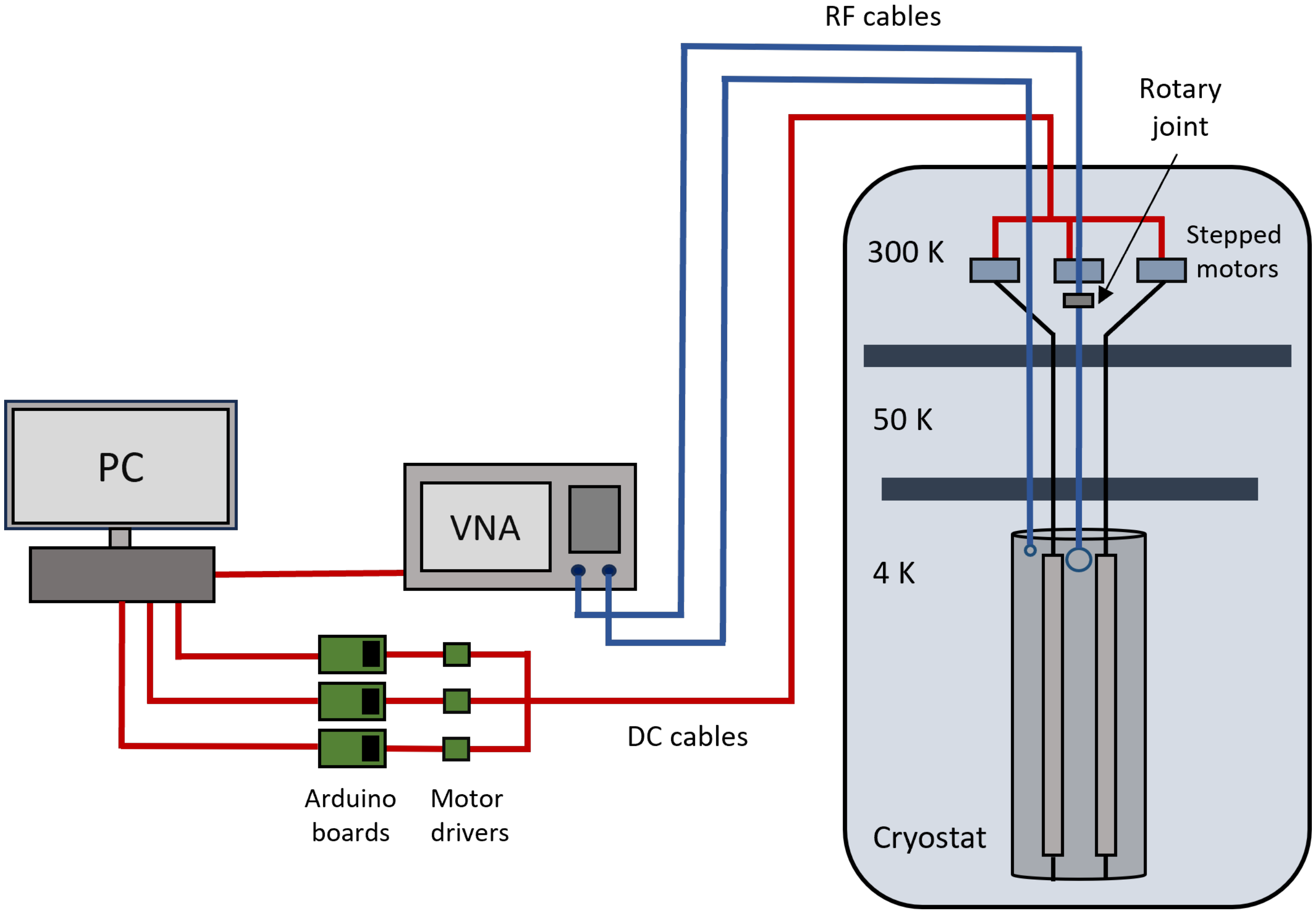
Body: stainless steel.
Cover: copper plating.



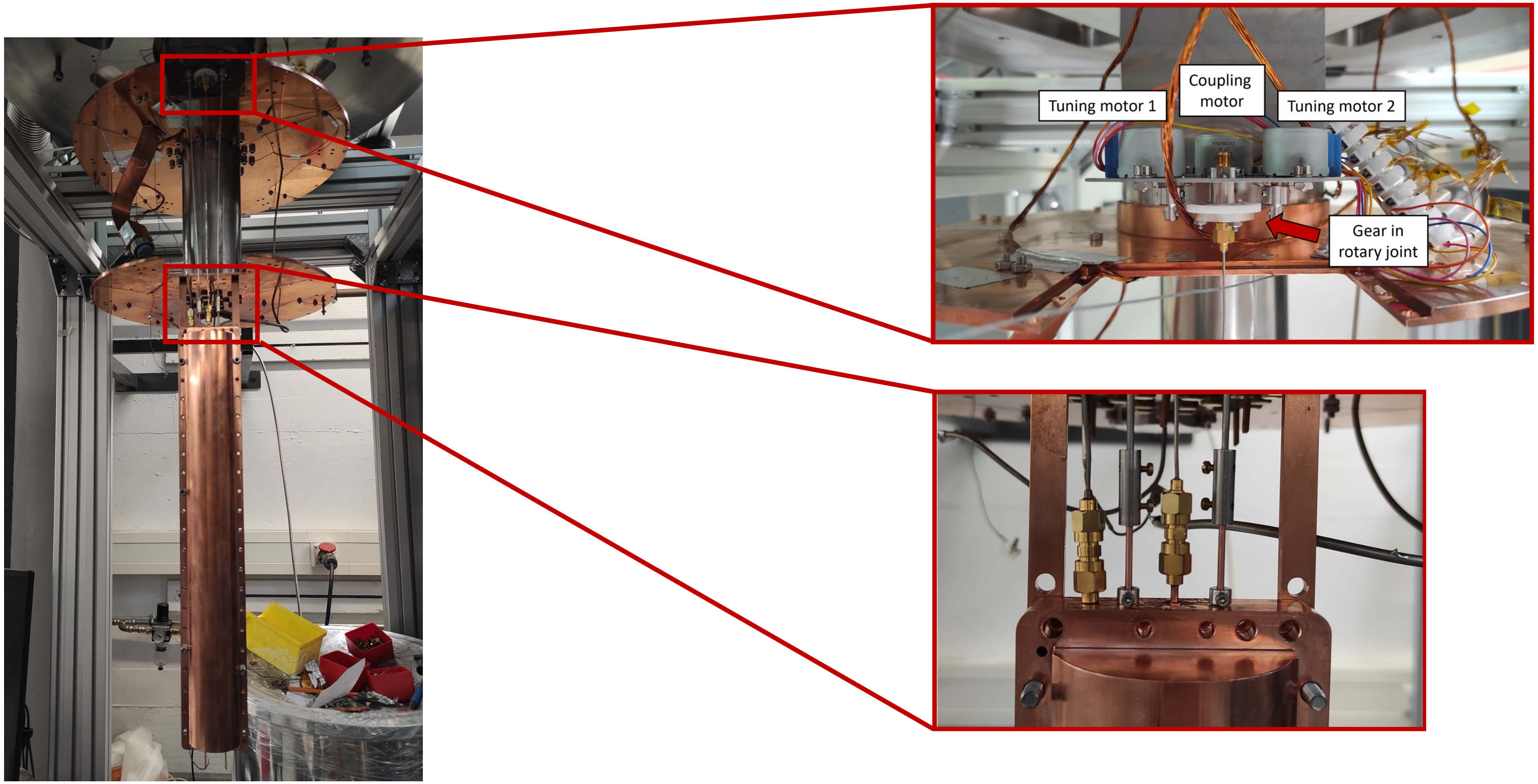




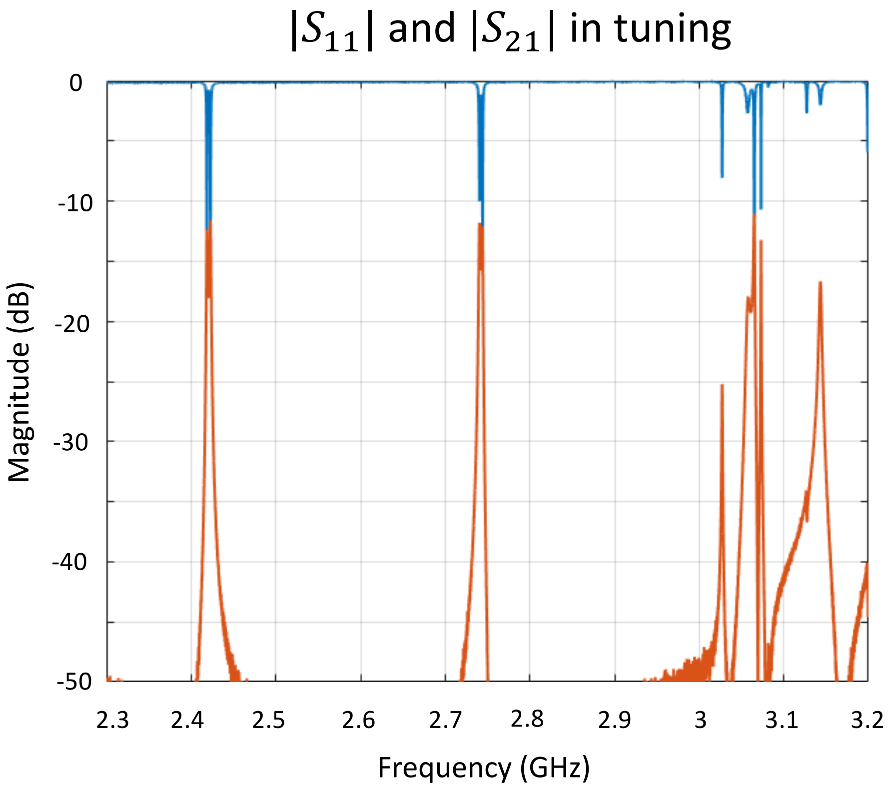
BABYIAXO – RADES. MEASUREMENTS AT KIT (I)

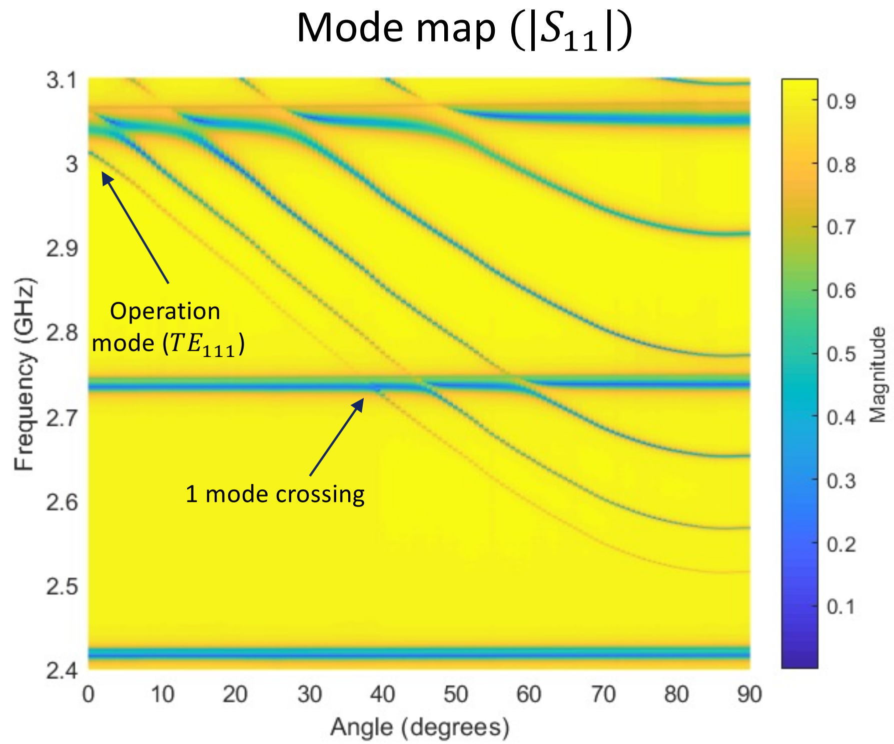


BABYIAXO – RADES. MEASUREMENTS AT KIT (II)



BABYIAXO – RADES. MEASUREMENTS AT KIT (III)

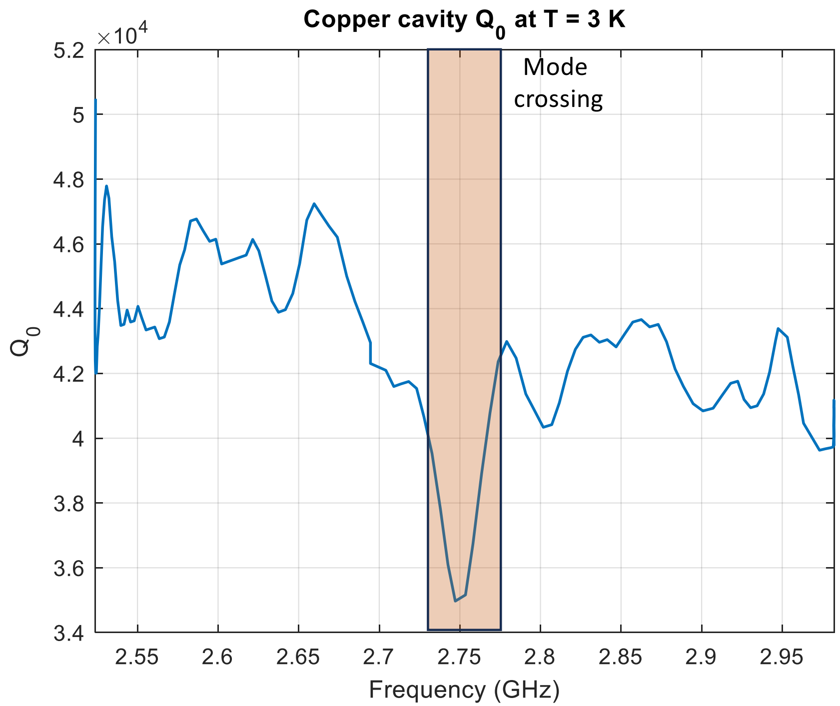


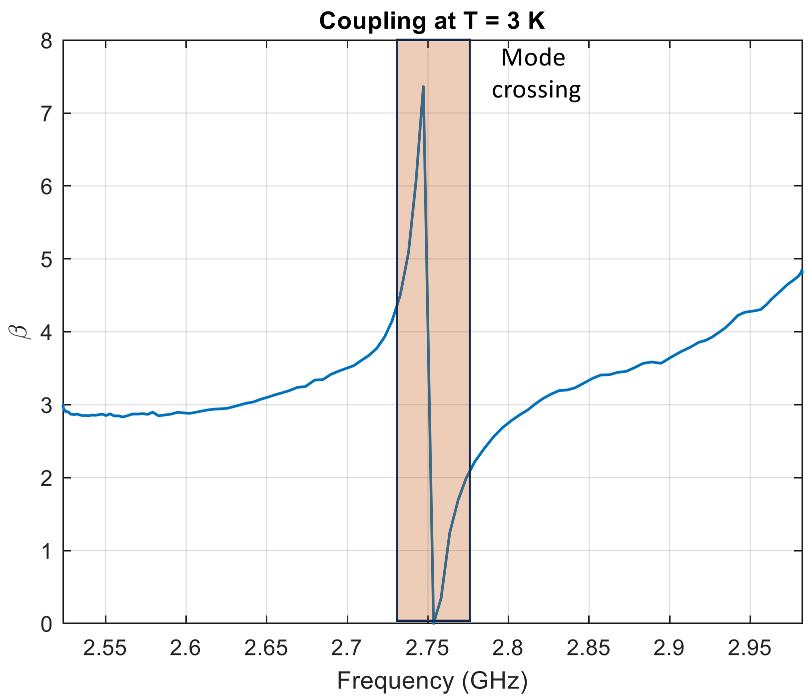


BABYIAXO – RADES. MEASUREMENTS AT KIT (IV)

Simulated $Q_0 \sim 5 \cdot 10^4$ (T≈ 3 K)

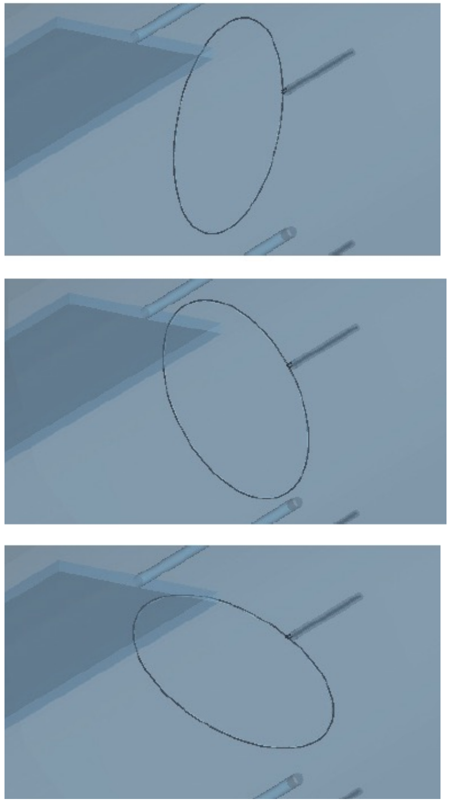
We reach $\beta > 2$ in the whole range (needed $\beta = 2$)

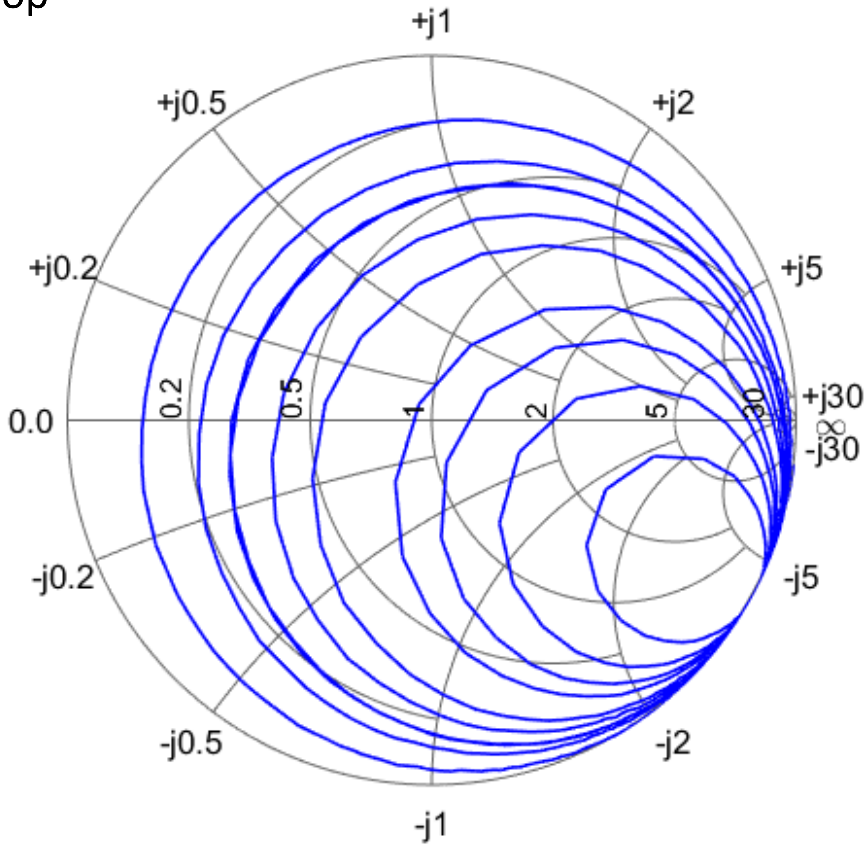




BABYIAXO – RADES. MEASUREMENTS AT KIT (V)

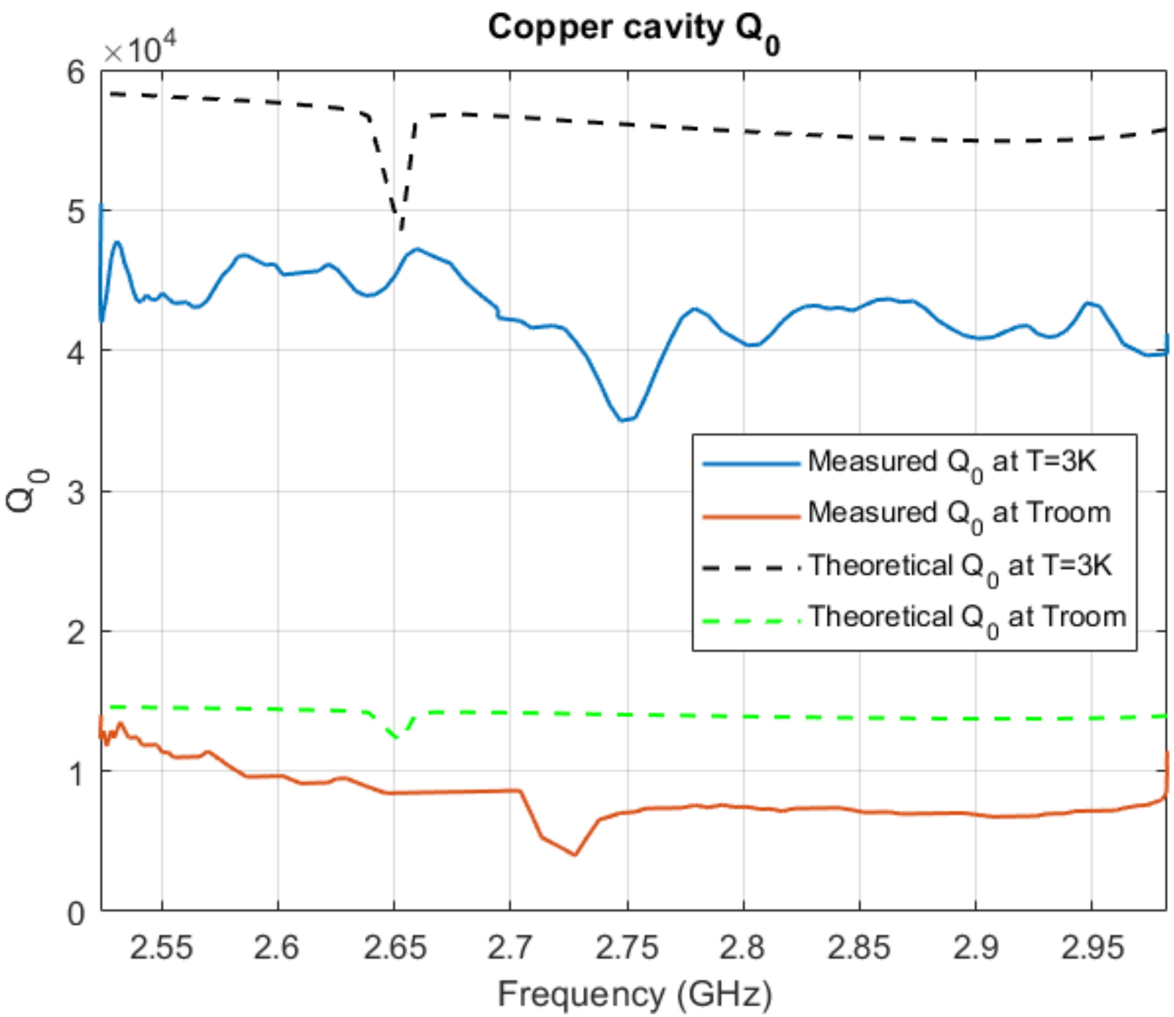
Change TE_{111} coupling by rotating the coupling loop





BABYIAXO – RADES. MEASUREMENTS AT KIT (VI)

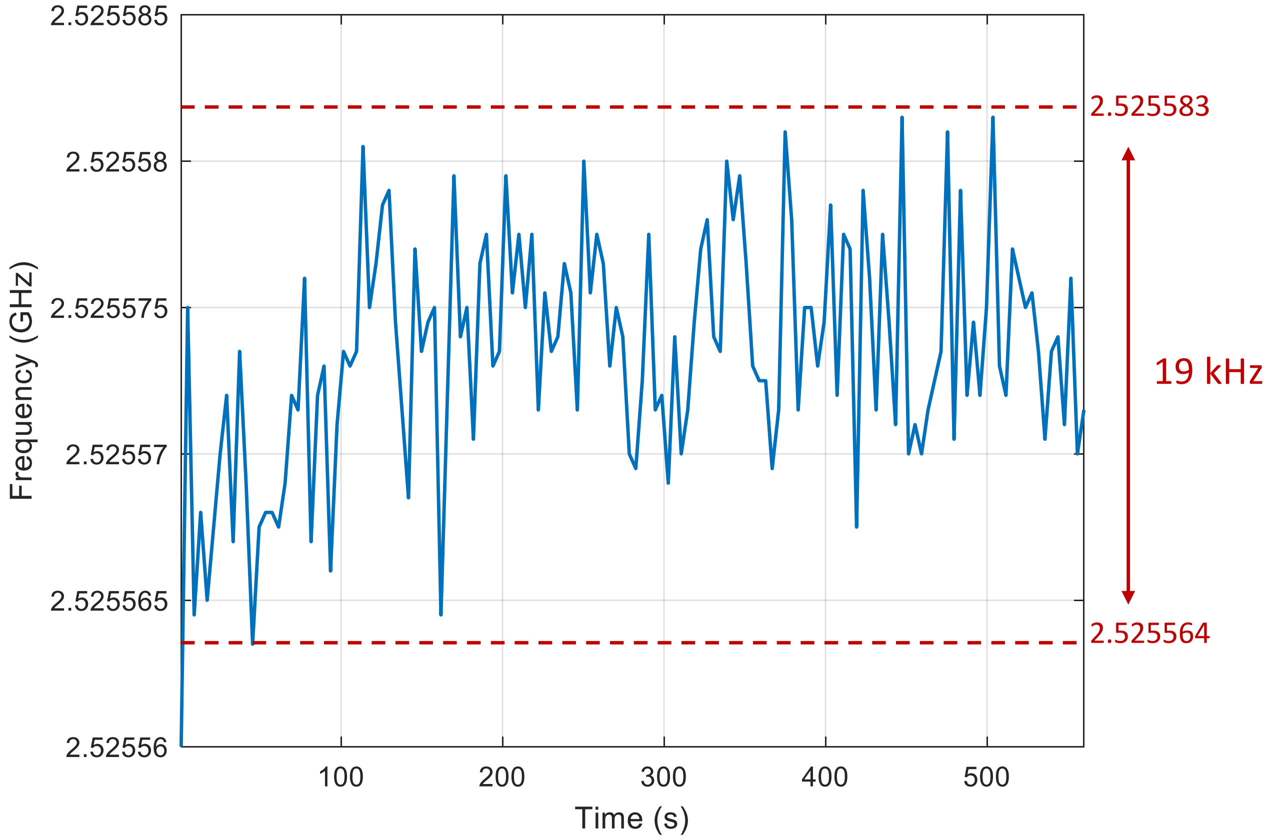
Theoretical $Q_0 \sim 5 \cdot 10^4$
(T≈ 3 K)



BABYIAXO – RADES. MEASUREMENTS AT KIT (VII)

Frequency stability ≈ 40% of the bandwidth

Frequency of TE_{111}



BABYIAXO – RADES. NEXT STEPS

1. Automatic recoupling algorithm
2. Using the 2.5 – 3 GHz BabyIAXO cavity for dark photon search?
3. Manufacturing of 1 m long cavity (250 – 300 MHz)

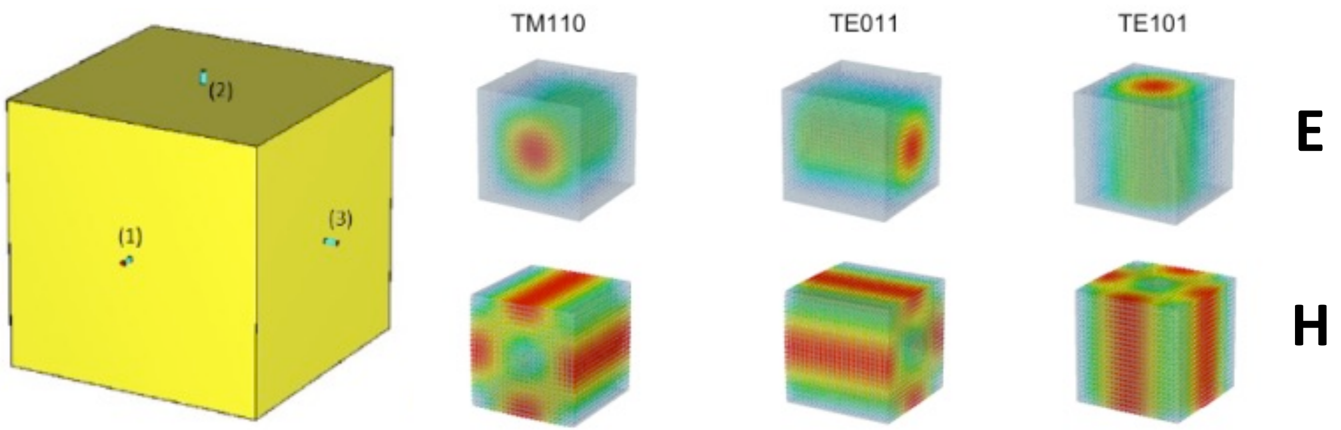
   Deciding material and thickness: only copper?, thermal conductivity, quench forces?

   Different fabrication technique?
4. Characterizing at T=3 K
5. Manufacturing of 5 m long cavity (250 – 300 MHz)
6. Characterizing at T=3 K

CAVITIES FOR GRAVITATIONAL WAVES (I)

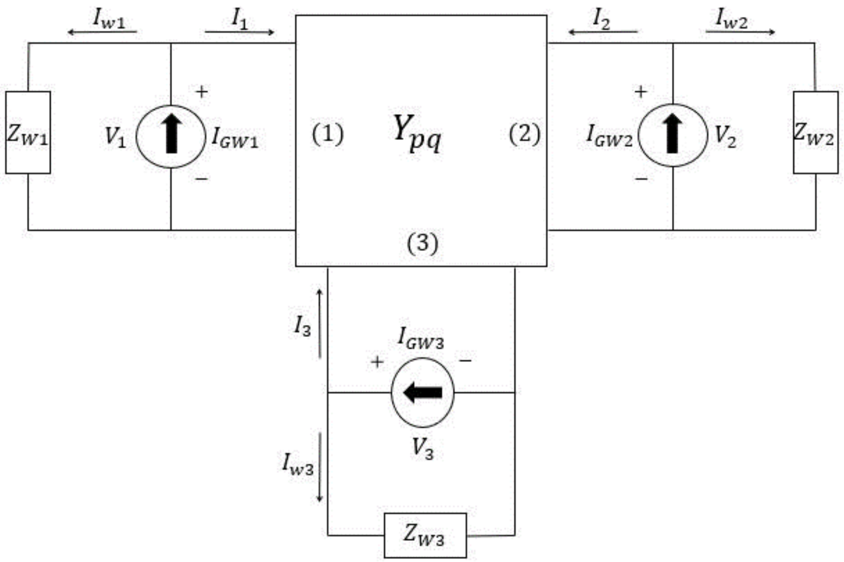
In collaboration with **Diego Blas**, Institut de Física d'Altes Energies (IFAE), Institució Catalana de Recerca i Estudis Avançats (ICREA)

- **Cubic resonator** with three degenerated modes that can be **independently** and **simultaneously** detected with three coaxial antennas placed in orthogonal directions.
- The homogeneous magnetostatic field *B* is oriented in the *Z* axis.
- Electric (up) and magnetic (down) field distributions of the three degenerate modes.



CAVITIES FOR GRAVITATIONAL WAVES (II)

- Application of the BI-RME 3D technique for the efficient and accurate electromagnetic analysis of the cavity excited by the GWs.

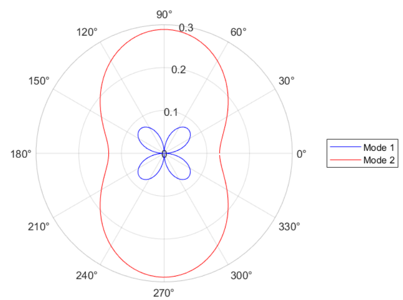


$$\begin{pmatrix} I_1 \\ I_2 \\ I_3 \end{pmatrix} = \begin{pmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{pmatrix} \cdot \begin{pmatrix} V_1 \\ V_2 \\ V_3 \end{pmatrix}$$

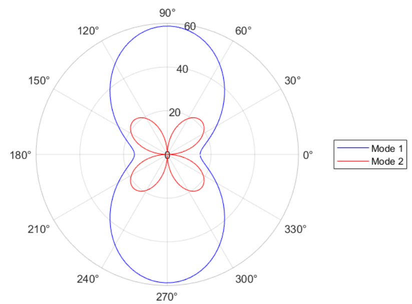
$$I_{GW_i} = \sum_{m=1}^{M} \frac{\kappa_m}{k^2 - \kappa_m^2} \underbrace{\left(\int_{S(i)} \vec{H}_m(\vec{r}) \cdot \vec{h}_1^{(i)}(\vec{r})\, dS \right)}_{COUPLING:CAV-PORT} \underbrace{\left(\int_V \vec{E}_m(\vec{r}\,') \cdot \vec{J}_{GW}(\vec{r}\,')\, dV' \right)}_{COUPLING:GW-CAV}$$

$$i \in \{1, 2, 3, ...P\}$$

- Application to:
  - Cubic, cylindrical and spherical cavities
  - BabyIAXO-RADES cavity



x polarization



+ polarization

COLLABORATION OF UPCT AND IFIC WITH FLASH

Two-level participation:

- Development of cavities for axion (& GW) detection
- Observers from RADES in FLASH (as commented at RADES steering committee)

FLASH is invited as observer to RADES meetings

Although different magnet type, both experiments can beneficiate each other.

Design of Cavities from UPCT and IFIC-CSIC-UV Groups

Thank you!

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