CADEX: a new haloscope axion search from 330 to 460 μeV at the Canfranc Underground Laboratory (LSC)

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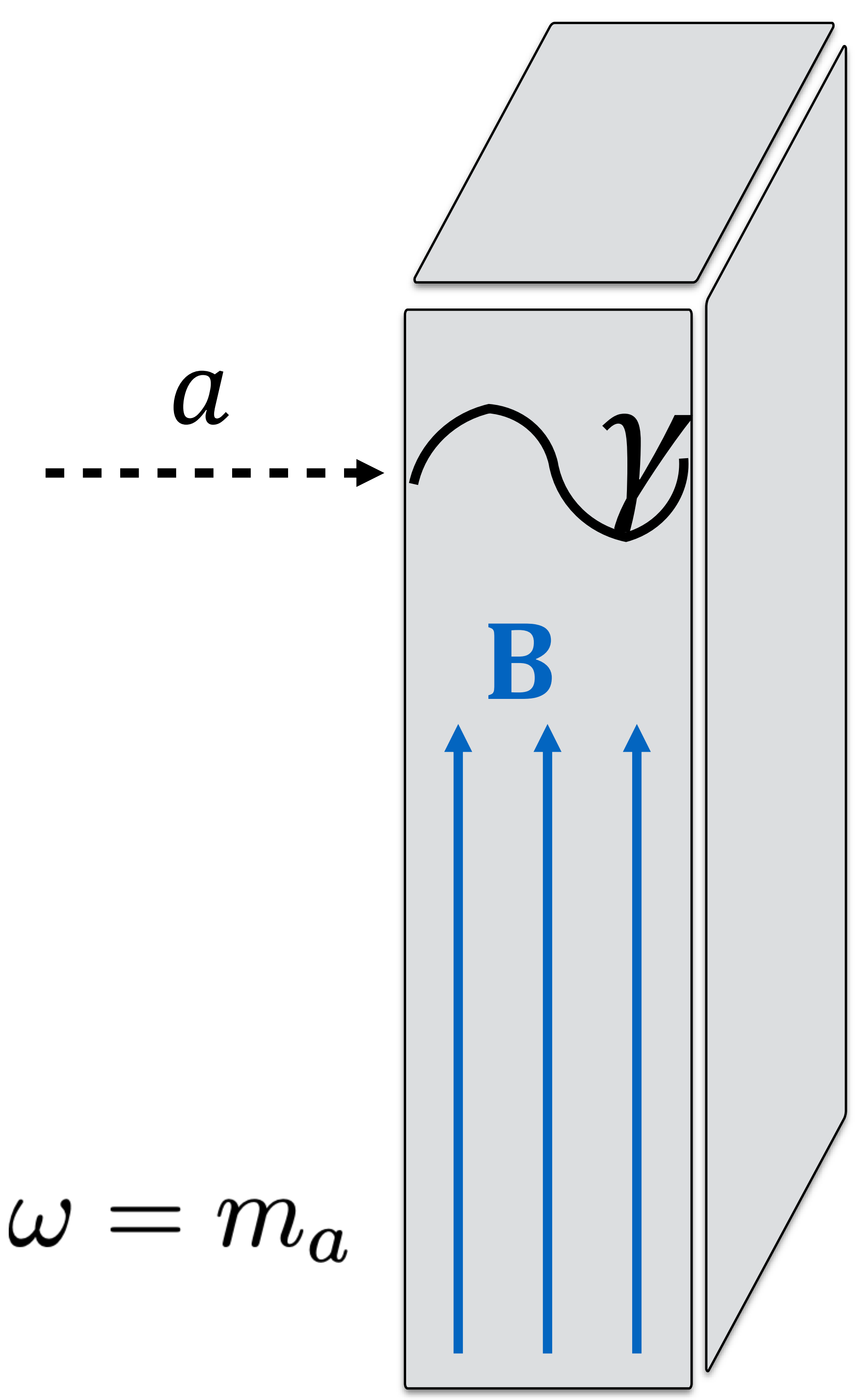
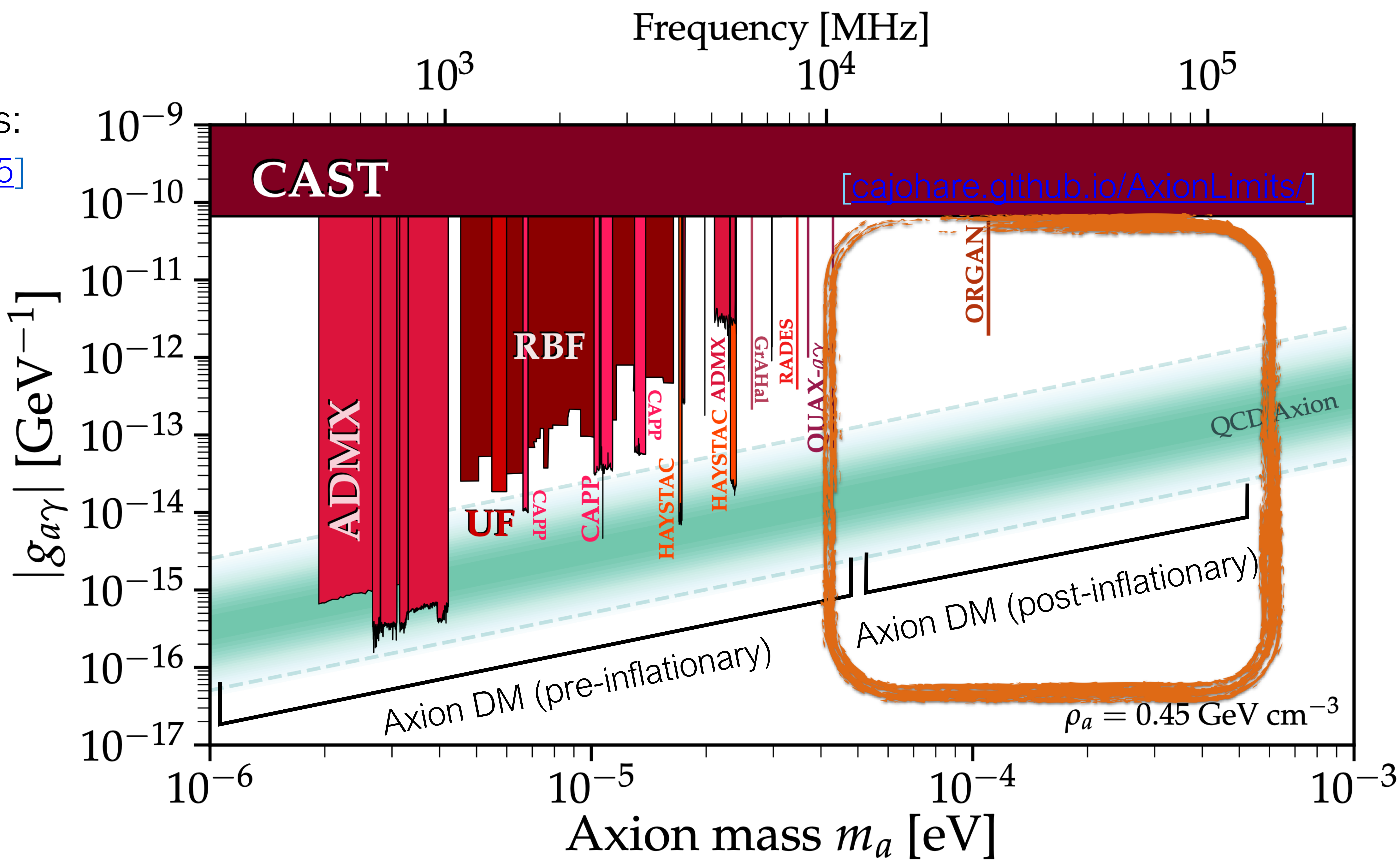
The QCD Axion

Axions, a, are light pseudo-scalar particles proposed to solve the Strong CP problem of QCD, and natural cold Dark Matter candidates!

The window 20 to 200 GHz is difficult but theoretically interesting (e.g. Saikawa+ 2024), and few experiments can explore it.

Microwave cavity or "**Haloscope**" Searches: [2003.02206, 2105.04565]





[Pre-inflationary axion abundance: e.g. 1810.07192, 2003.01100]

[Post-inflationary axion abundance: e.g. 1412.0789, 1906.00967,2007.04990]

Motivation for CADEx:

Novel detection system for 330-460 μeV range (W-band):
Haloscope + Kinetic Inductance Detectors (KIDs)

Axion-photon conversion power:

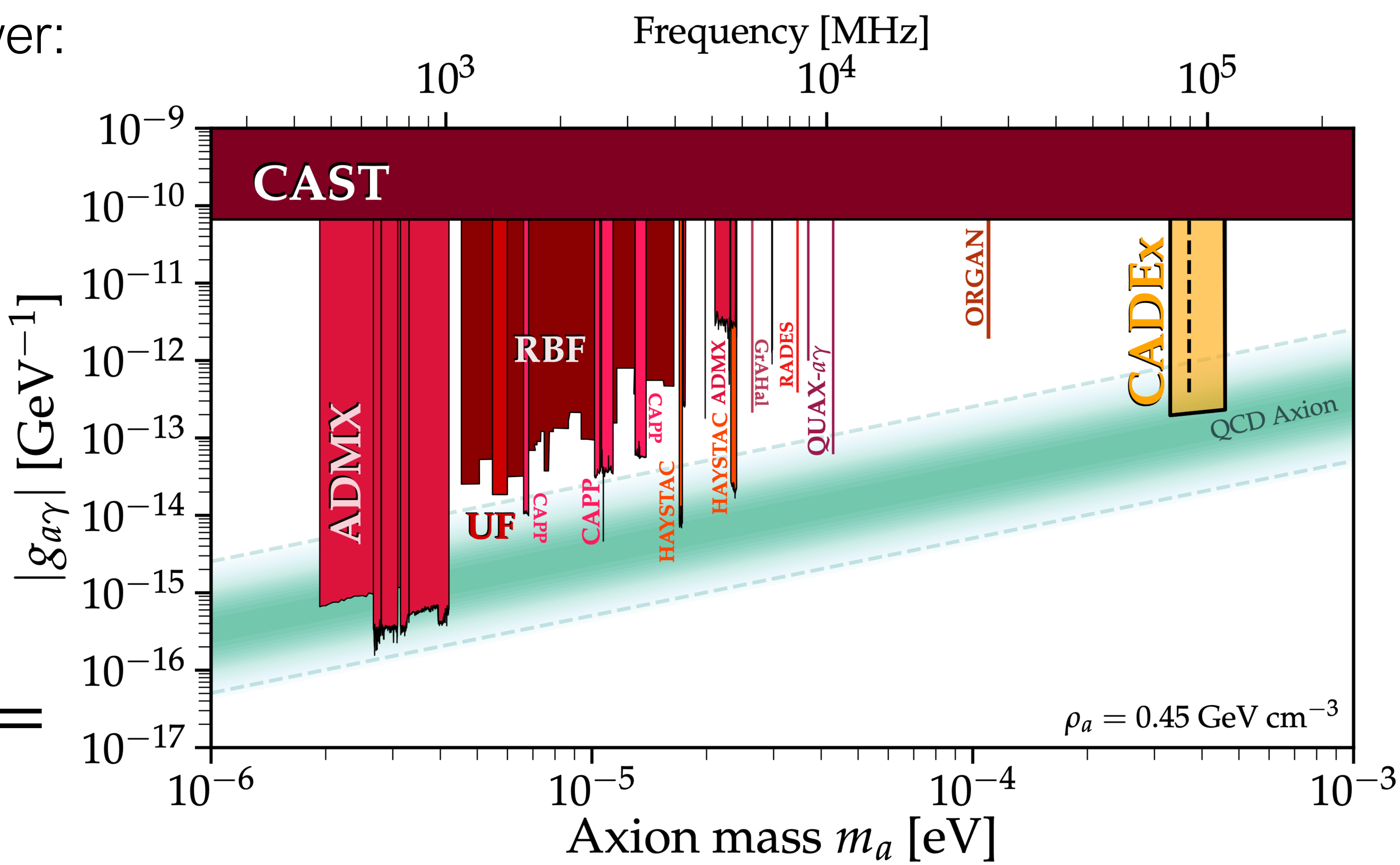
$$P_d \propto g_{a\gamma}^2 \frac{\rho_a}{m_a} B^2 V Q_0$$

Estimate 5σ sensitivity:

Magnetic field: $B = 8\mathrm{T}$

Total cavity volume: $V = 0.2\mathrm{L}$

Cavity quality factor: $Q_0 = 2 \times 10^4$



- - - - - - 3 month exposure with NEP = $10^{-19}\ \mathrm{W}/\sqrt{\mathrm{Hz}}$

——— 8 year scan with NEP = $3 \times 10^{-20}\ \mathrm{W}/\sqrt{\mathrm{Hz}}$

CADEx Collaboration

The Canfranc Axion Detection Experiment (CADEx): search for axions at 90 GHz with Kinetic Inductance Detectors

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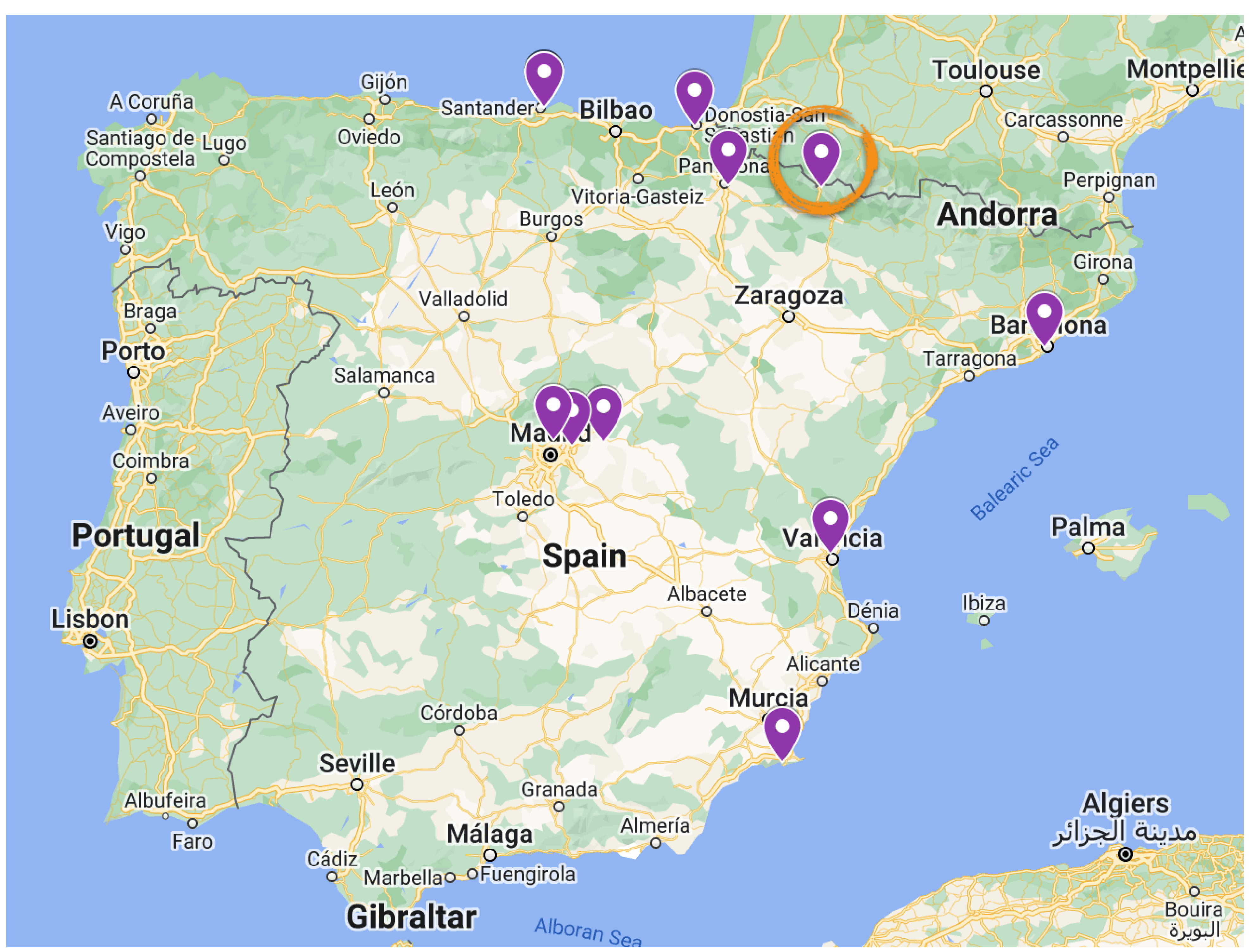
[JCAP 11 (2022) 044, arXiv:2206.02980]



Open collaboration

Science
- Instituto de Ciencias del Cosmos (UB)
- Donostia International Physics Center
- Laboratorio Subterráneo de Canfranc
- Instituto de Física de Cantabria (CSIC-UC)

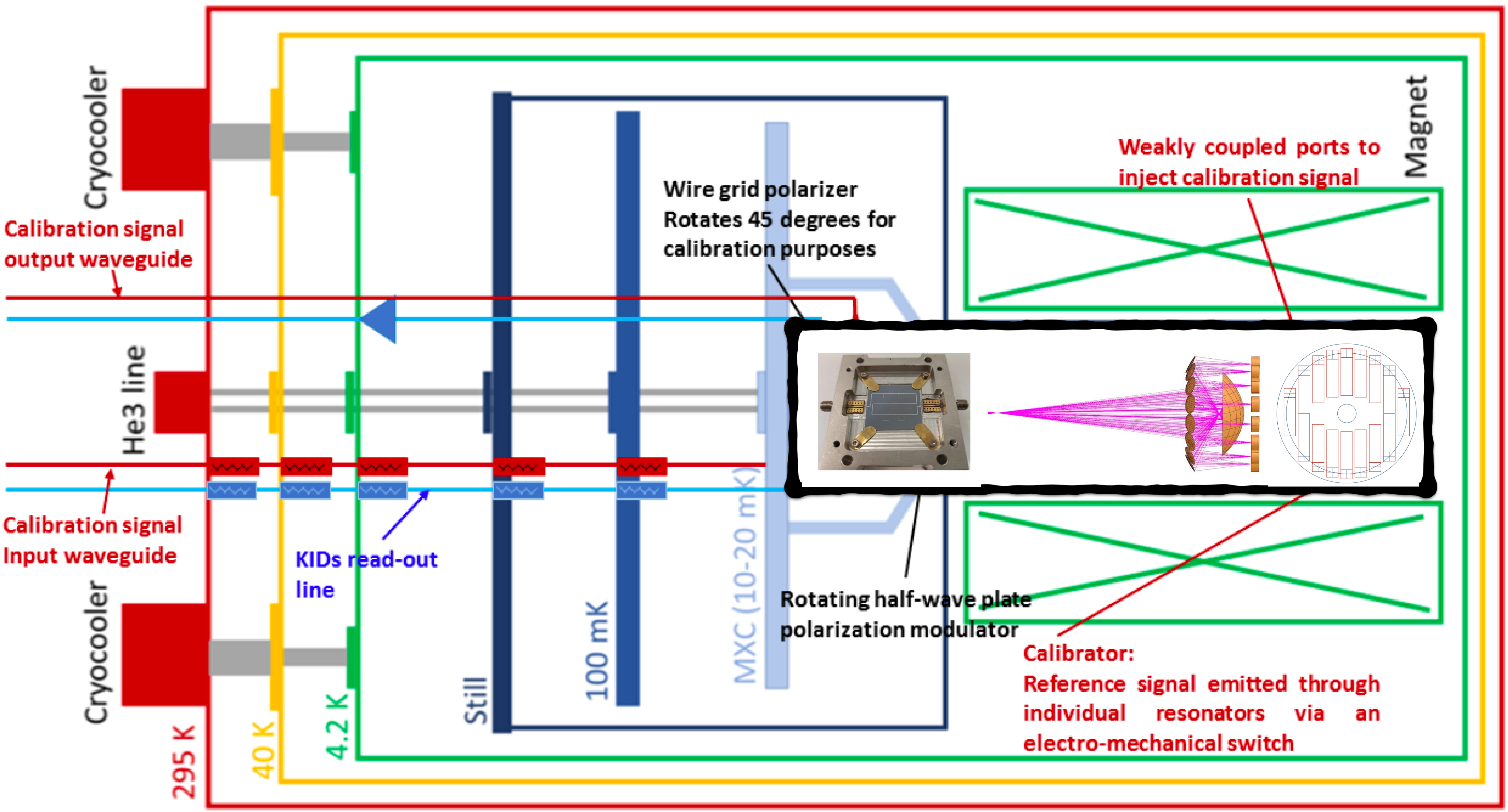
Haloscope
- Universidad Politécnica de Cartagena
- Instituto de Física Corpuscular (Universidad de Valencia, CSIC)

Optics
- Universidad Pública de Navarra
- Anteral S.L.

Detectors: Heterodyne & KIDs
- Observatorio de Yebes (IGN)
- Centro de Astrobiología (CSIC-INTA)
- Universidad de Cantabria
- Instituto de Física de Cantabria (CSIC-UC)
- Instituto Madrileño de Estudios Avanzados en Nanociencia

Calibration & data reduction
- Instituto de Ciencias del Cosmos (UB)
- Donostia International Physics Center
- Laboratorio Subterráneo de Canfranc
- Instituto de Física de Cantabria (CSIC-UC)
- Centro de Astrobiología (CSIC-INTA)

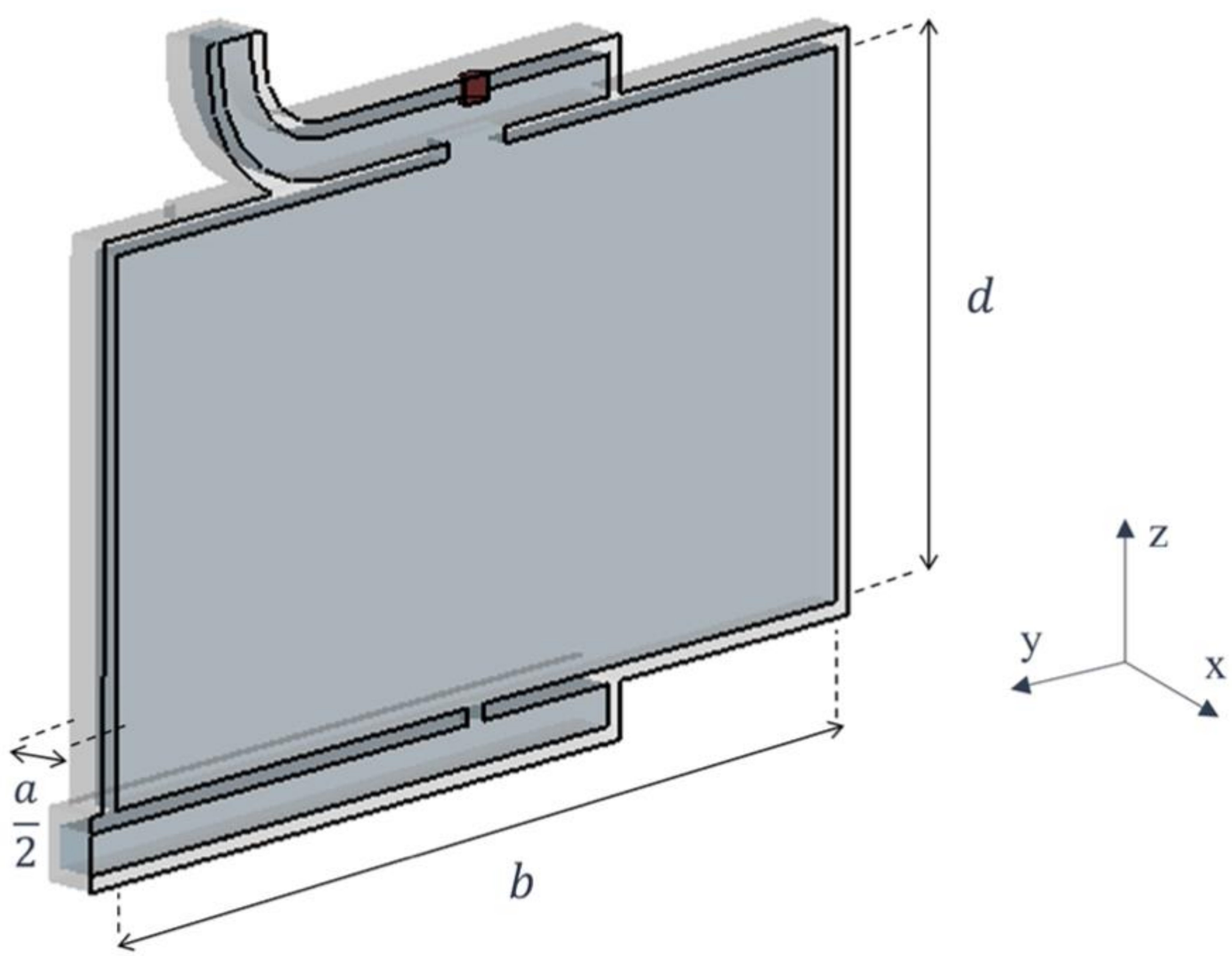
CADEx Conceptual Design



Immerse haloscope array in high static magnetic field of B = 8-10 T

Aim to **discriminate polarized axion-photon conversion signal** from unpolarized background.

Haloscope



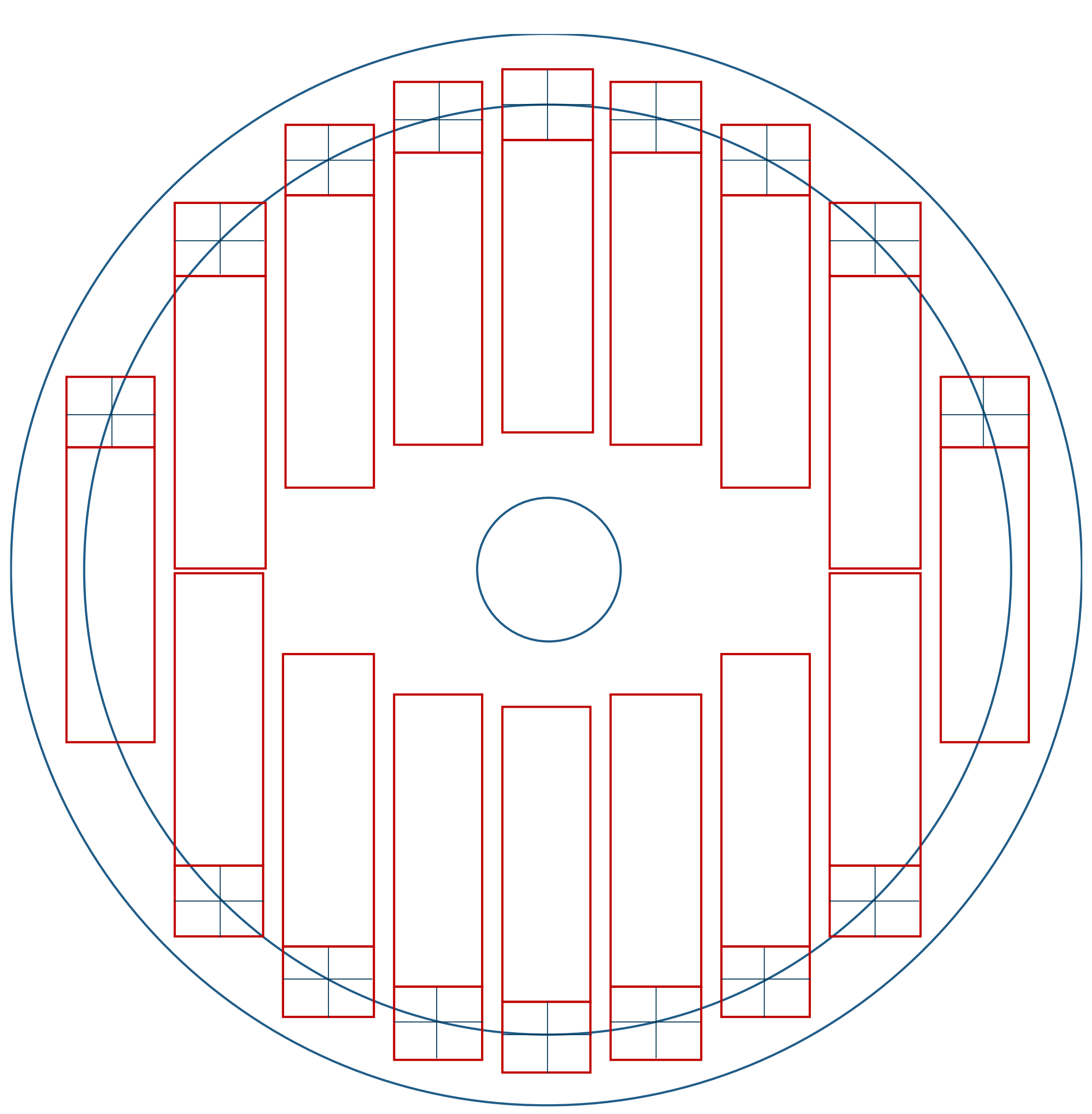
TM_{110} mode resonant frequency: $$f_r = \frac{c}{2}\sqrt{\frac{1}{a^2} + \frac{1}{b^2}}$$

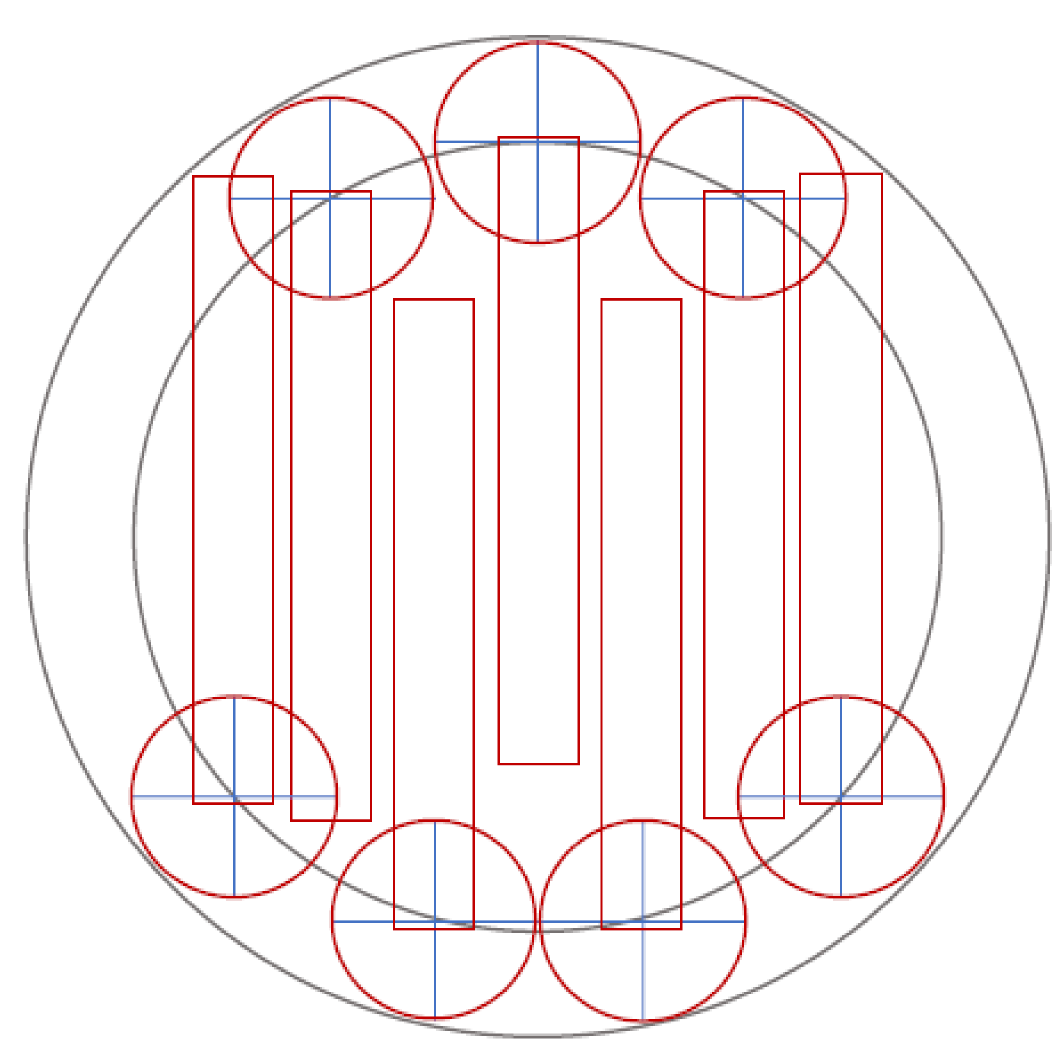
Example: $a \approx 1.7\mathrm{mm}$ and $b = 40a$ gives resonance frequency $f_r = 90\mathrm{GHz}$

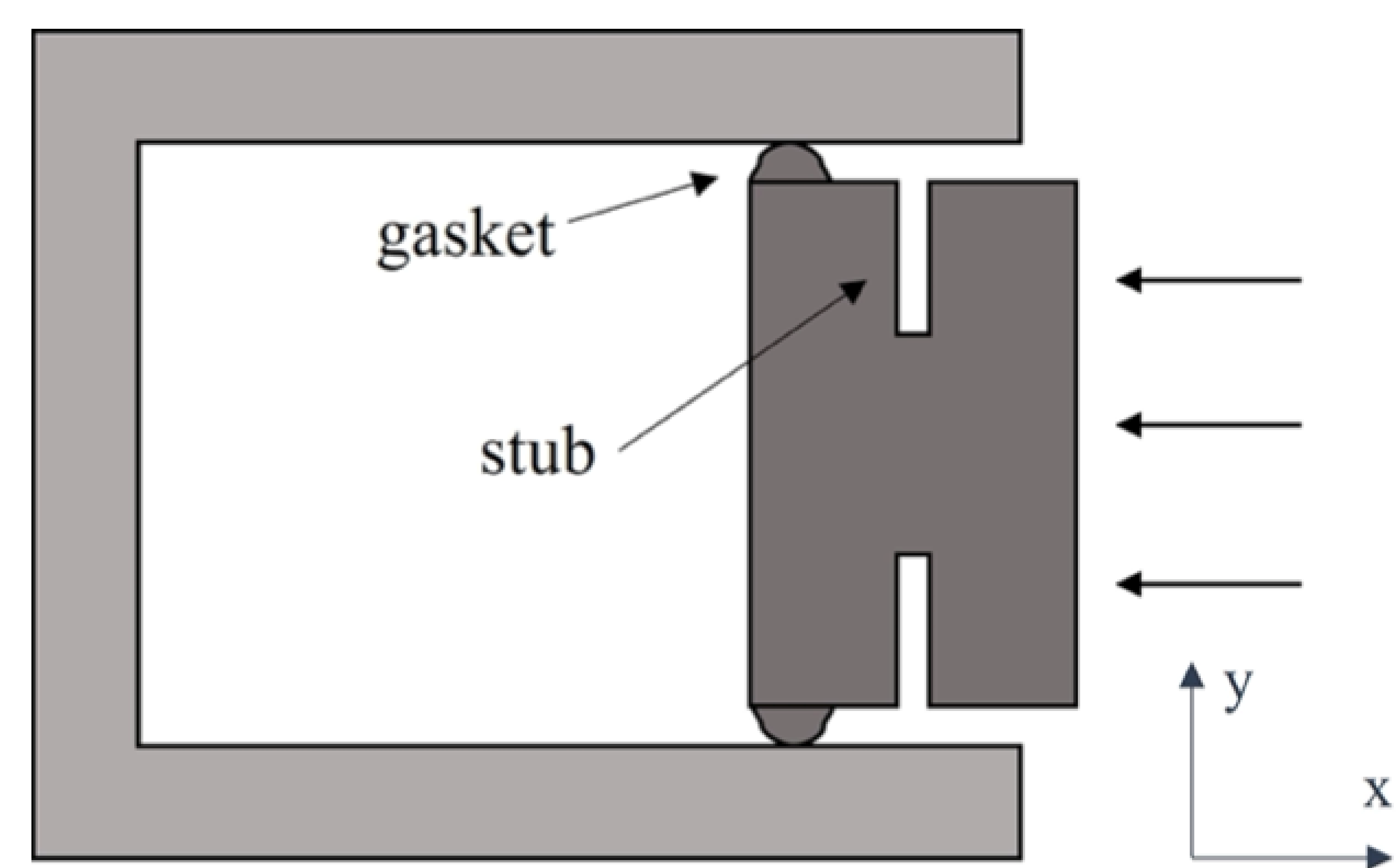
Need to scan over resonant frequency of haloscope cavity.

Maximize volume to increase the sensitivity
Parallelized haloscope of 7/16 cavities

Develop **tunable cavities** to scan frequency range $f_r \in [86{,}111]\mathrm{GHz}$

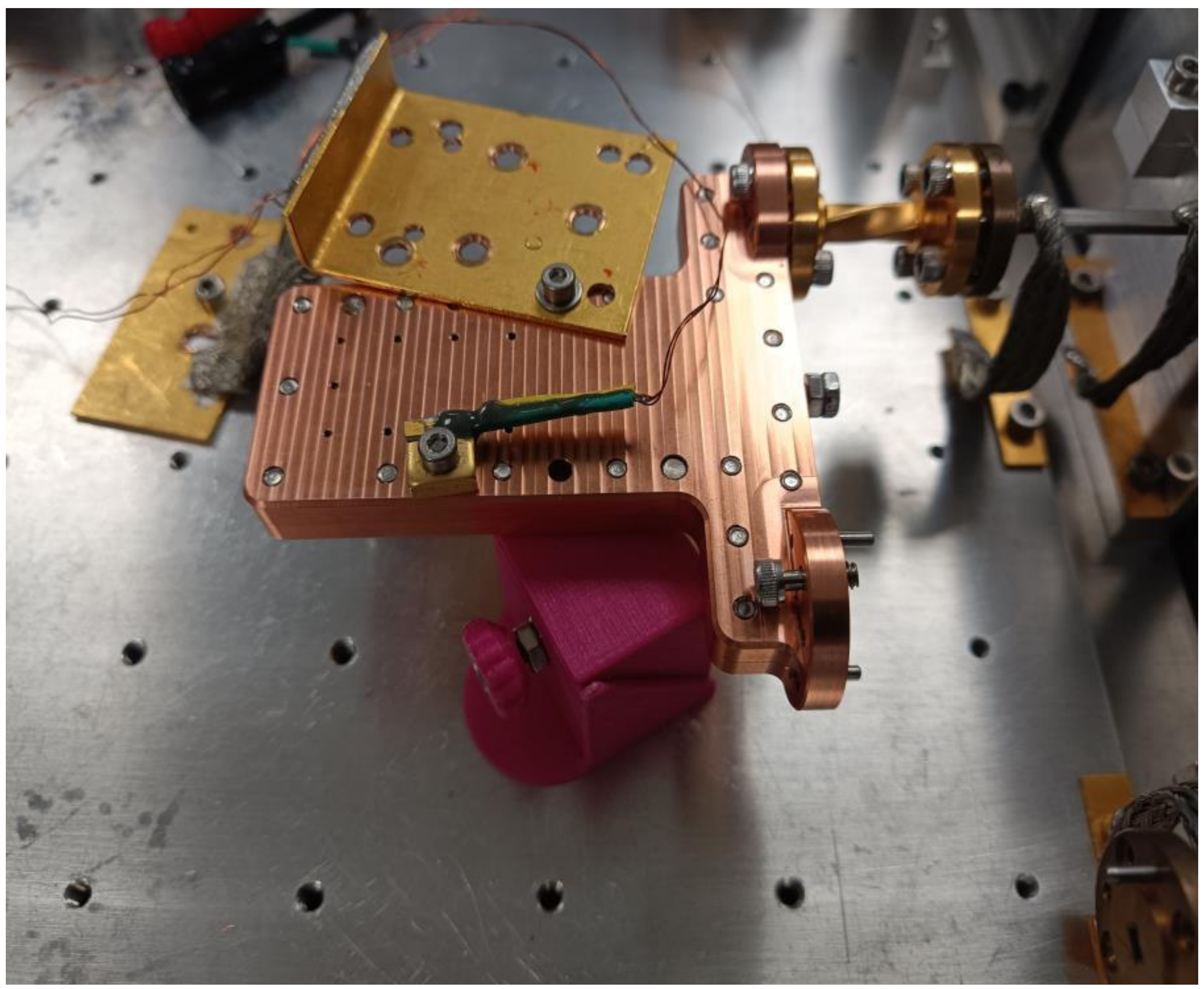


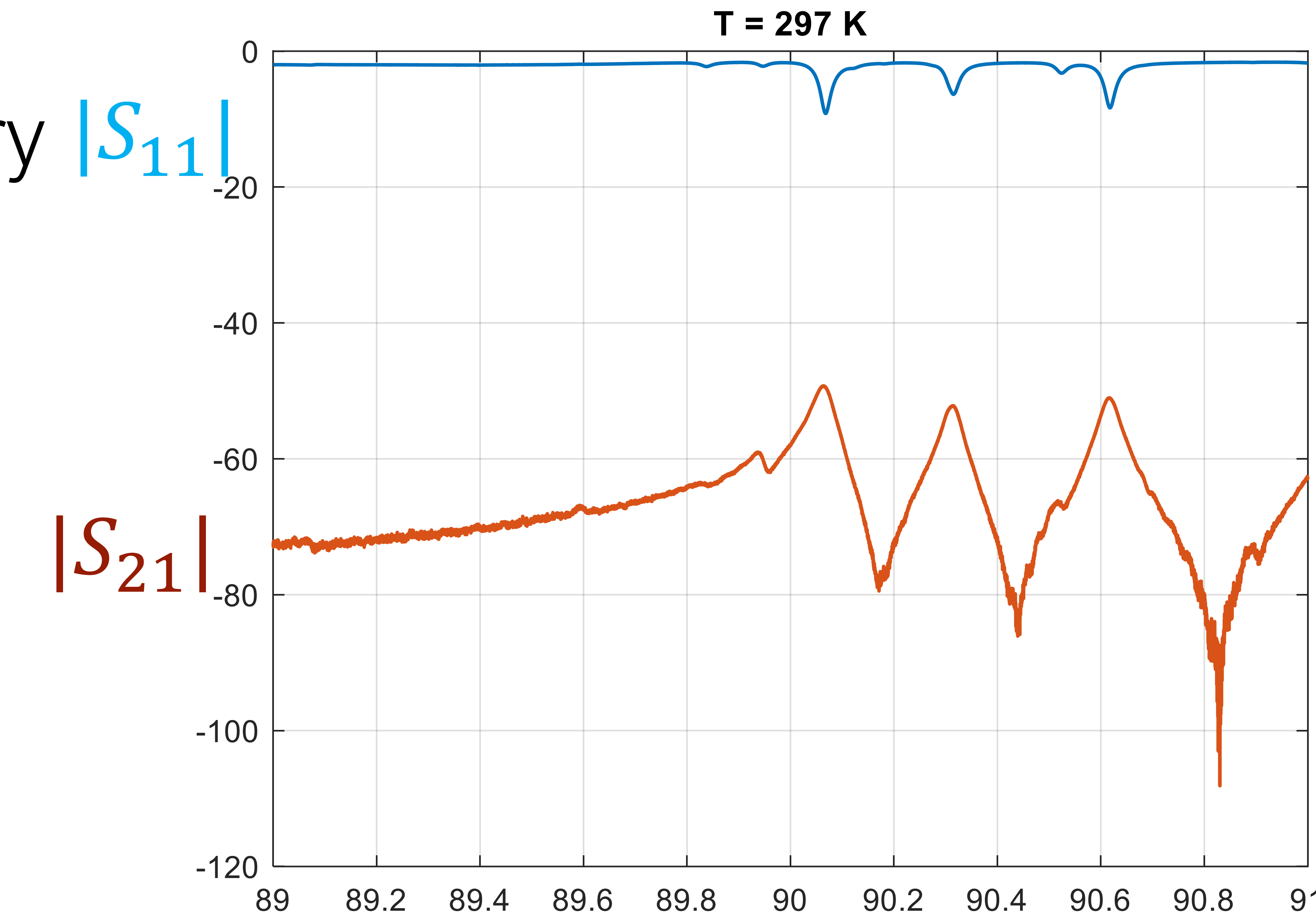


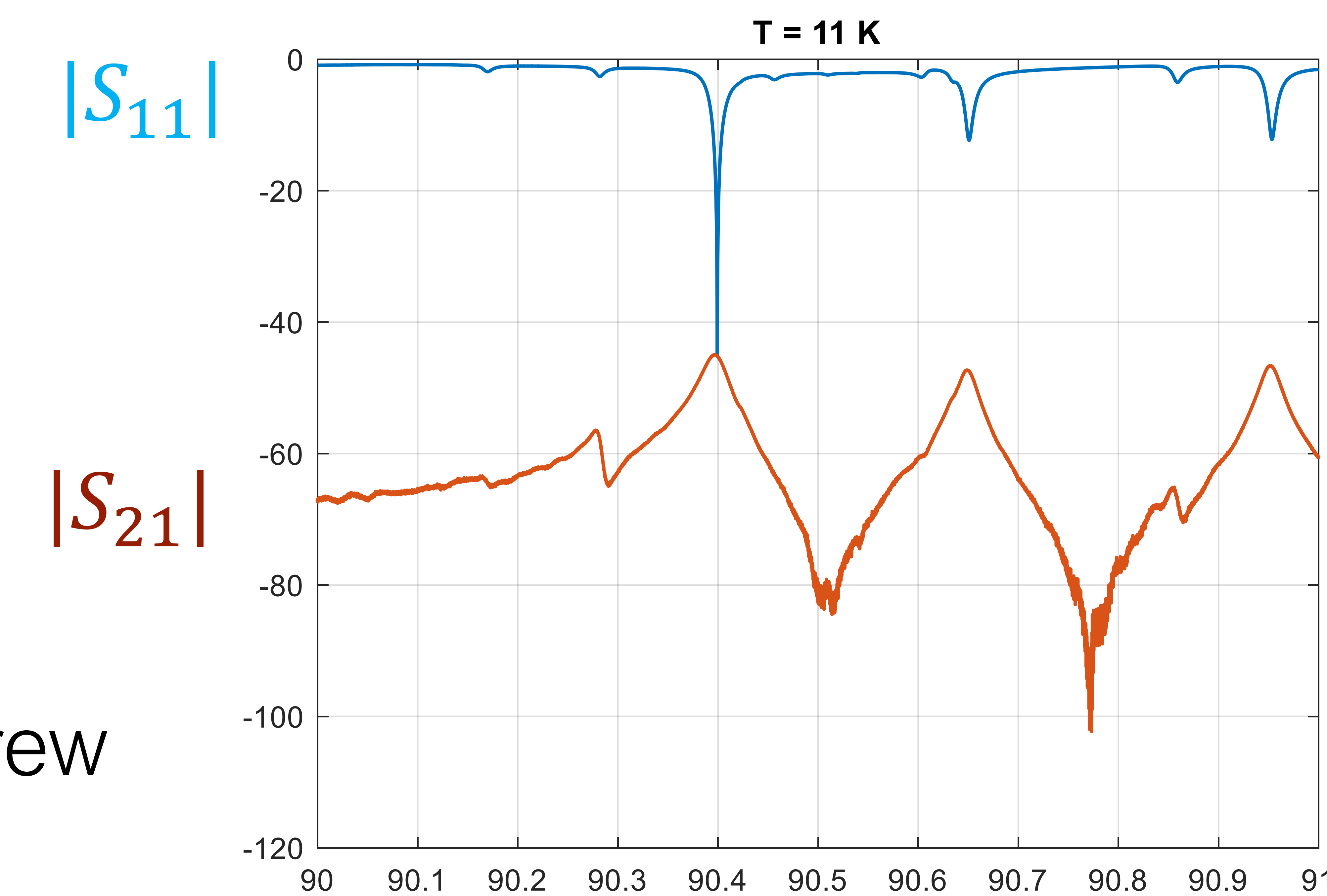


CADEx haloscope characterization

2 cavities designed & fabricated (UPCT, UPN).
Characterization of one of them (UPN & OY)
Cryogenic measurements at Yebes Observatory



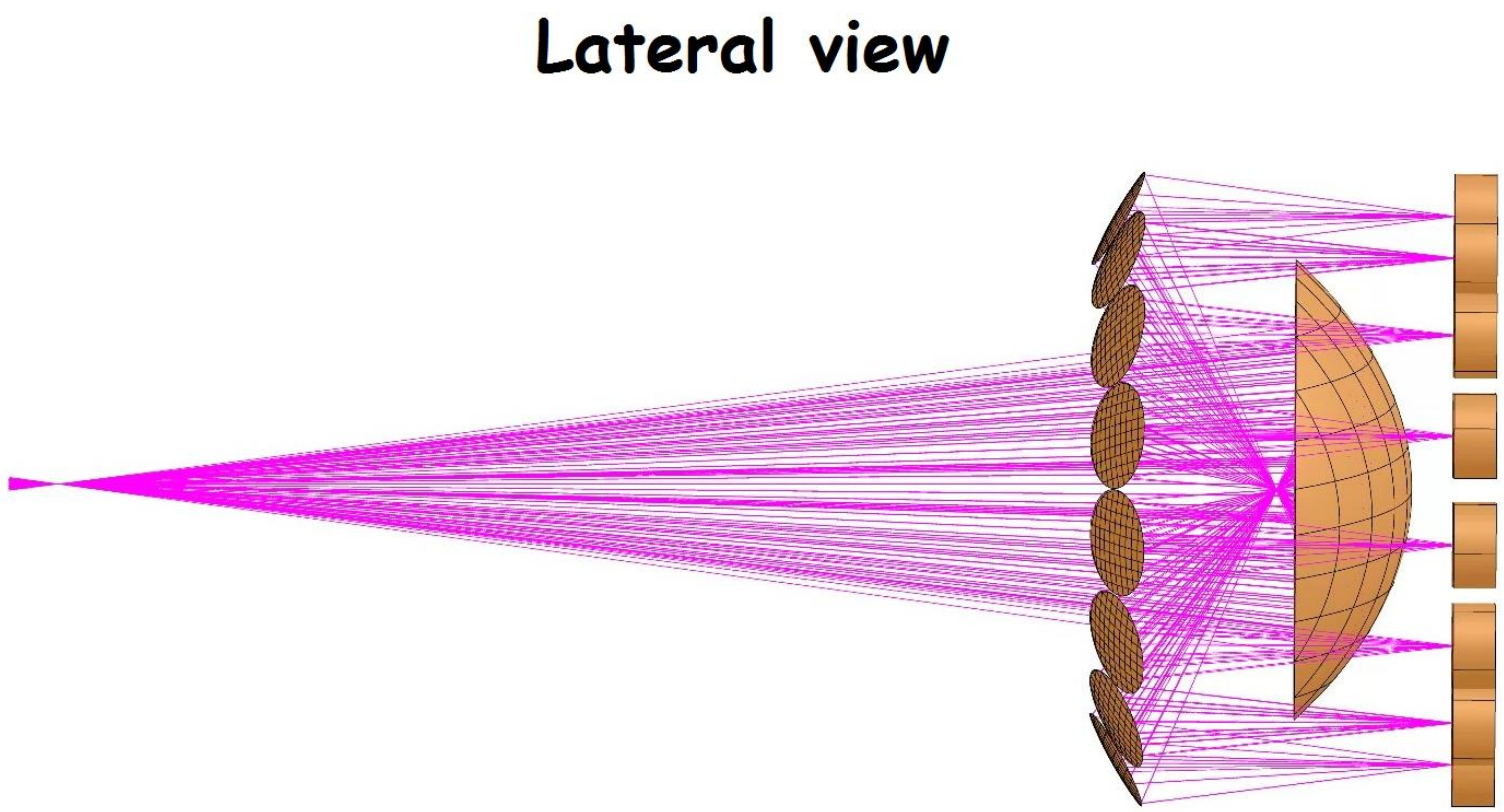


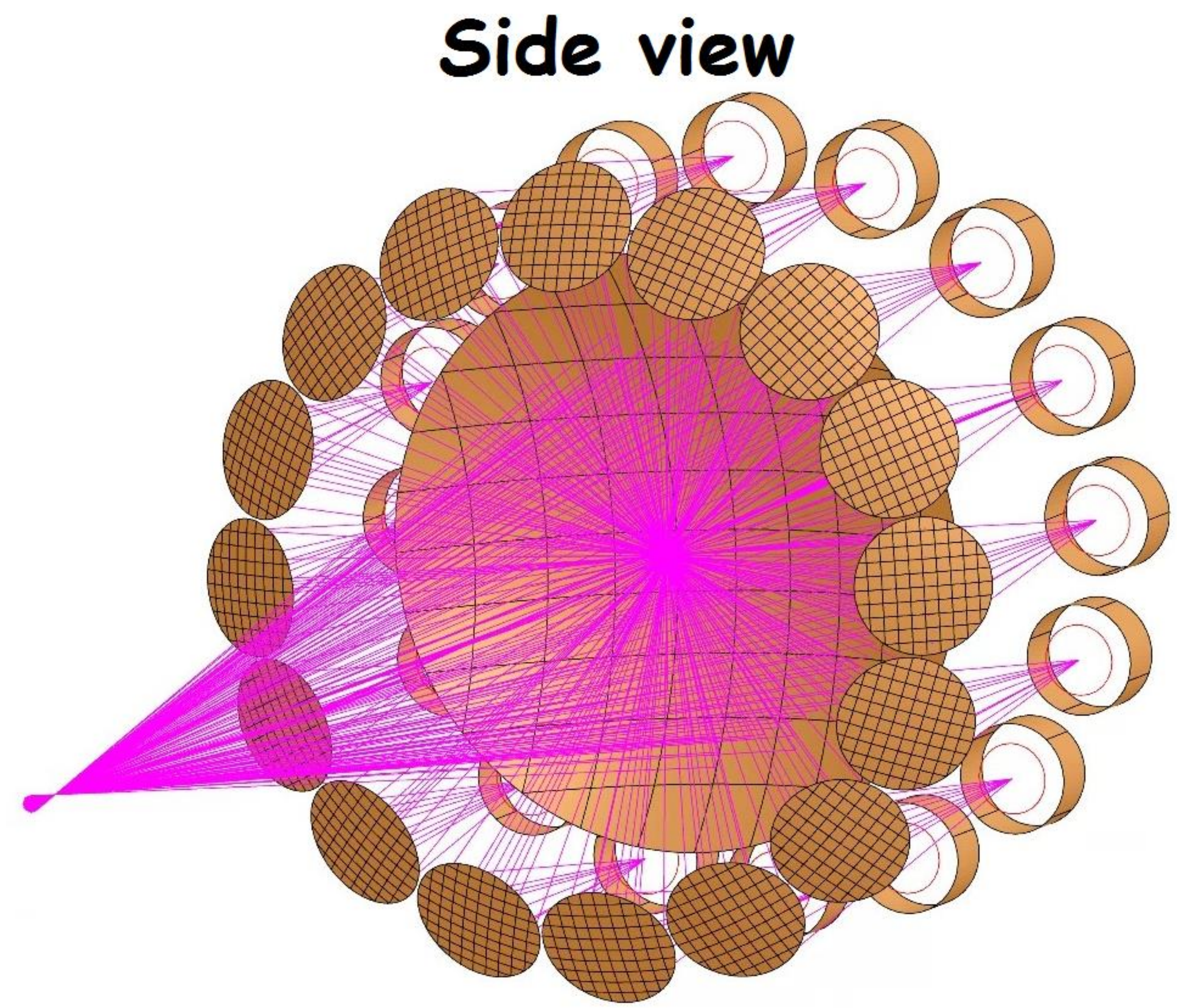


Change coupling axion mode with the moving screw
Q factor of 10^4

Optical system

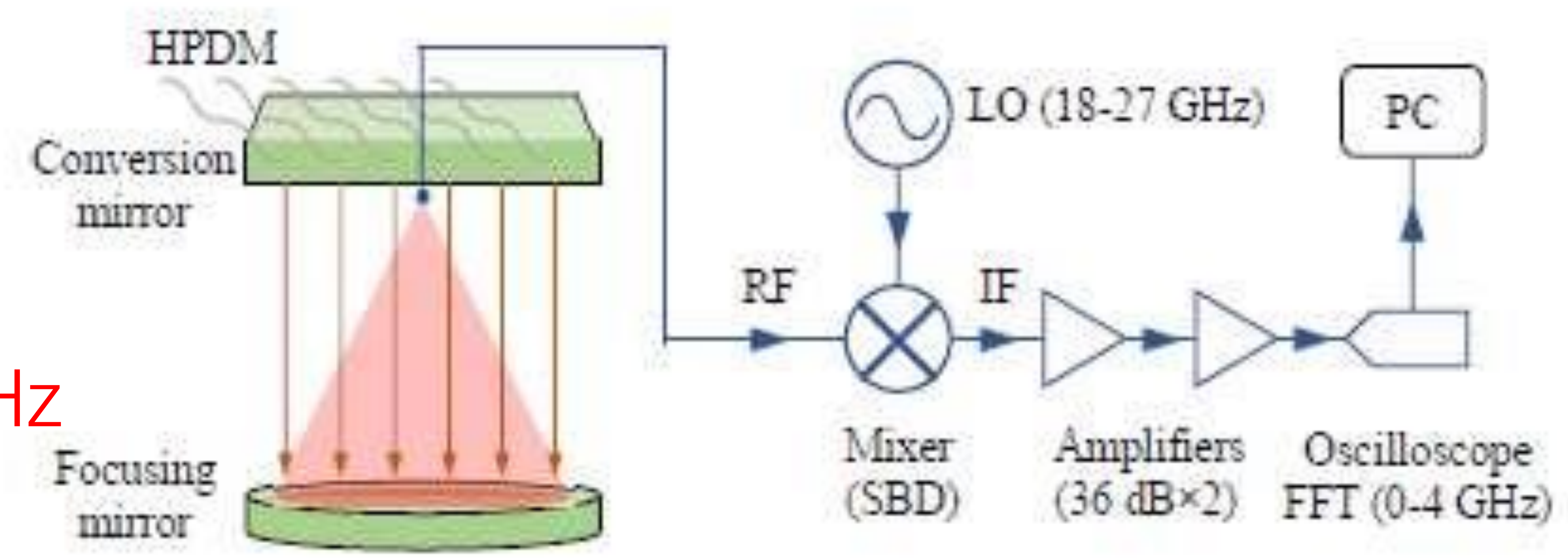
Increase the $\boldsymbol{Volumen}$ by stacking several cavities and sum signals coherently





Heterodyne detection

- Excellent for measuring narrow spectralfeatures.
- Limited by Standard Quantum Limit (SQL)
- State of the art 25 K ➔ 10xSQL at 100 GHz

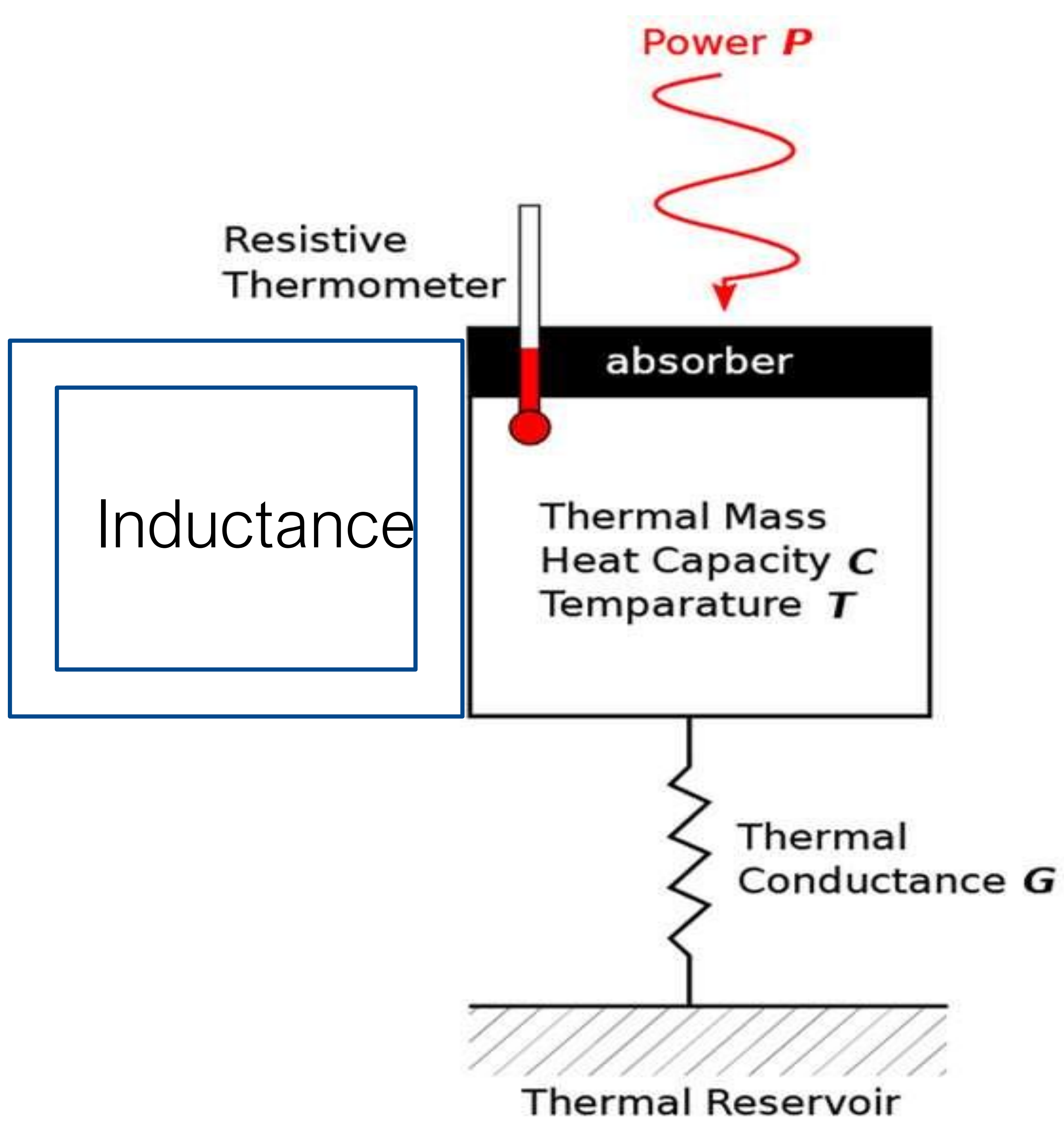


Bolometer /Direct

- Broadband. No frequency resolution
- Not limited by Standard Quantum Limit.
- Detection of 10^{-25} W KSVZ axion signal
- State of the art NEP NEP ~$10^{-19} W/\sqrt{Hz}$.

Photon counting

- Beyond current capability
- Evolving fast driven by quantum science



CADEx uses Kinetic Inductance Detectors (KIDs)
Potential to break the SQL
Details next talk by Victor Rollano.

CADEx Timeline

CADEx accepted by Canfranc Underground Laboratory (LSC) under EoI-31-2021

Design and Demonstration phase (2 years)

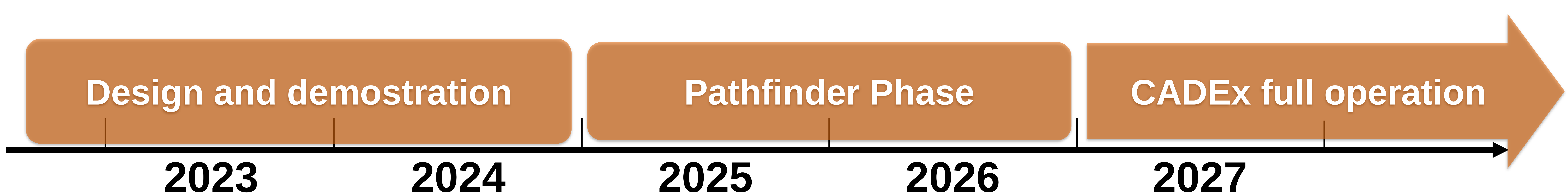
Cryostat acquisition (LSC & IFCA), installation and operation. Design and fabrication of cavities and KIDs . Demonstration of key technology (haloscope, detectors, etc.) in the lab.

Pathfinder phase (2 years)

Development of first prototype of CADEx and installation in the LSC/IFCA/CAB facility in the first year (haloscope + KIDs + calibration). During the second year, the pathfinder experiment will be carried out.

Operation phase (8 years)

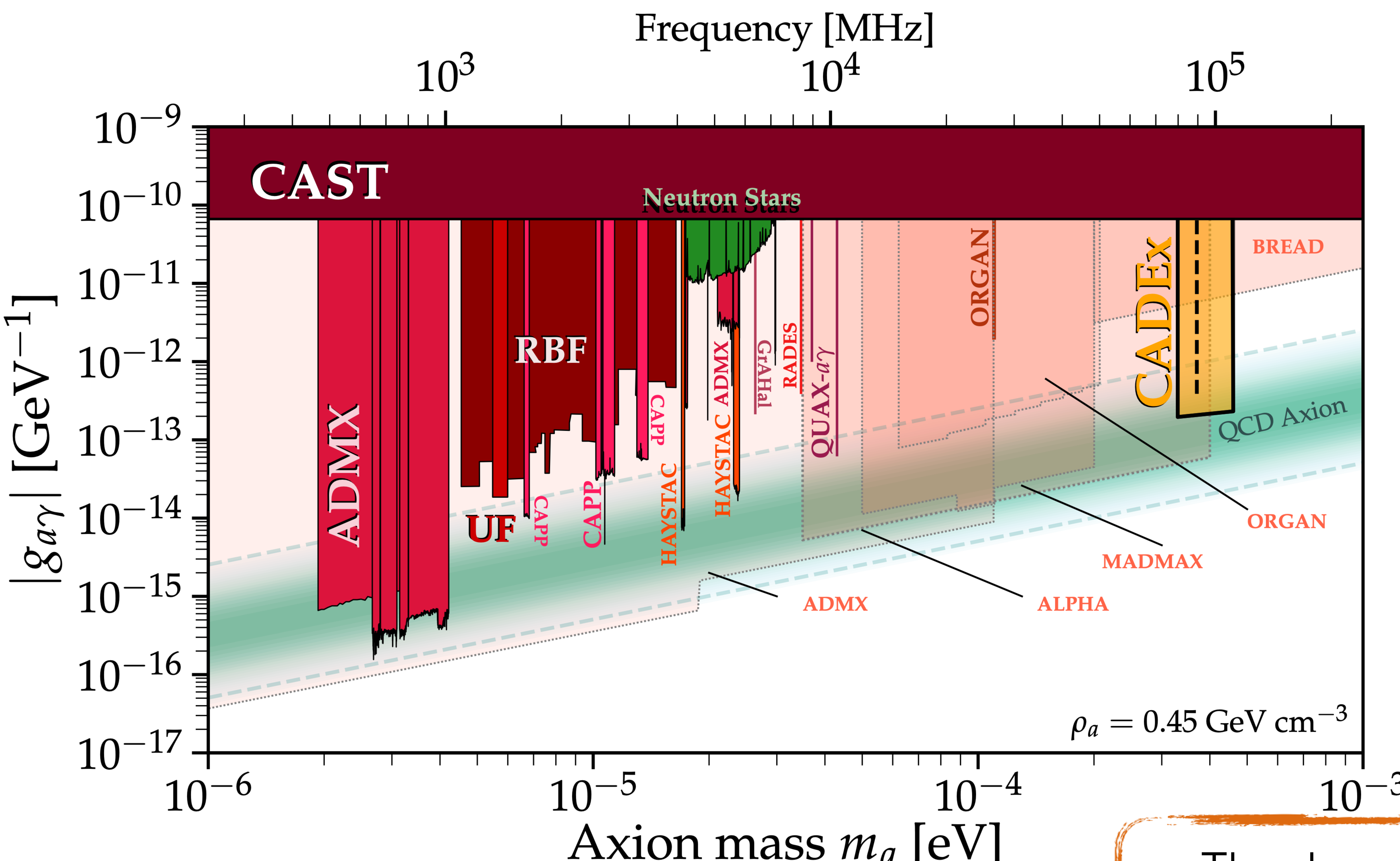
Upgrade the experiment to improve the sensitivity & efficient non-resonant waveguide haloscope. Installation & Commissioning. Full Operation to cover mass range $m_a \in [330,460]\mu\mathrm{eV}$



Outlook and Landscape

CaDEx

CADEx: a novel haloscope search for Dark Matter axions in the mass range 330–460 μeV (86–111 GHz)

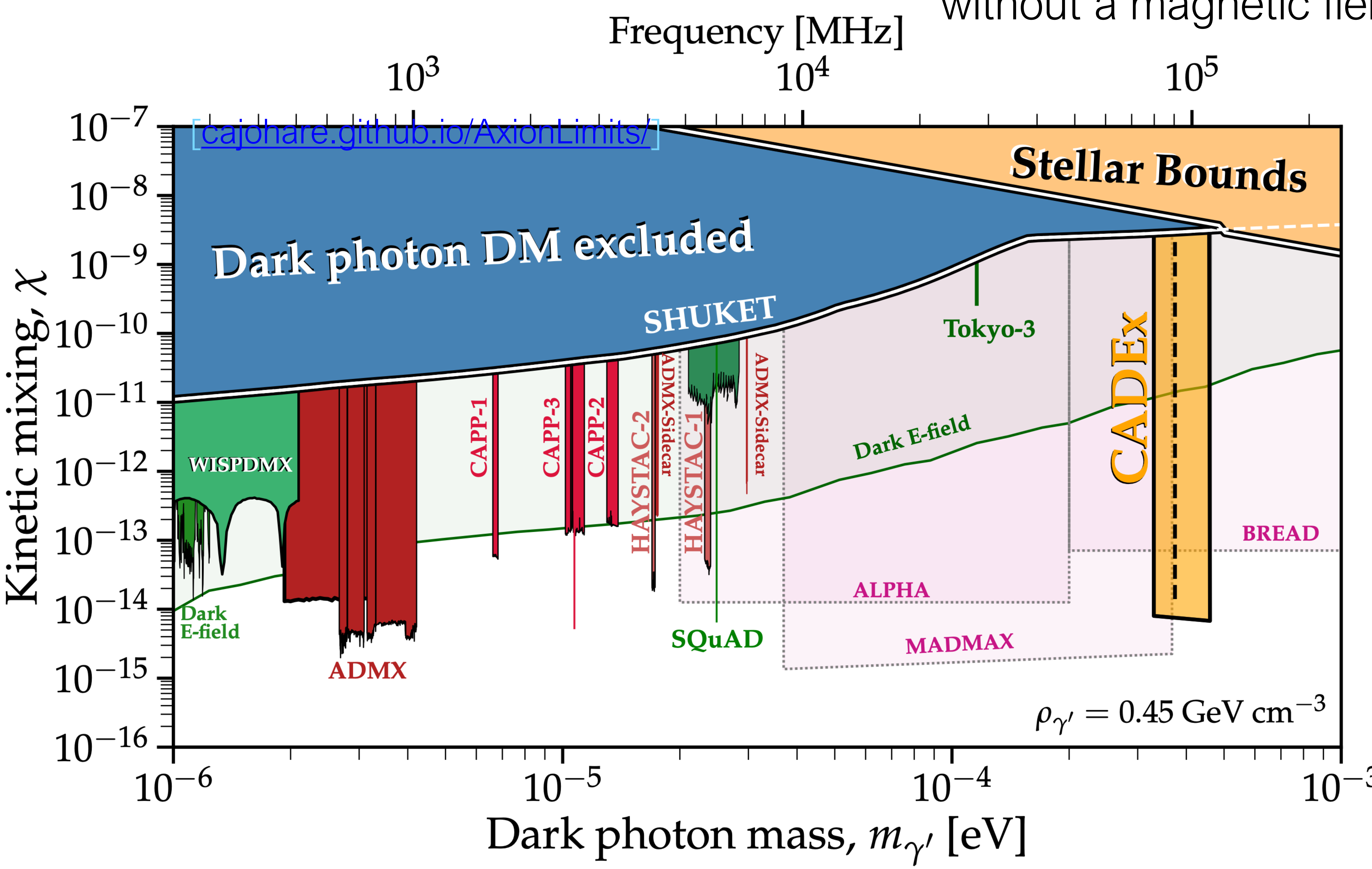


Thank you!

Dark Photon Sensitivity

$$g_{a\gamma} \to \frac{\chi m_{\gamma'} \sqrt{\cos^2 \theta_{\rm pol}}}{B}$$

CADEx is sensitive to conversion of photons to **Dark Photon γ'** even without a magnetic field



Other possibilities too:
e.g. GHz Gravitational Waves

- - - - - - 3 month exposure with NEP = $10^{-19} \mathrm{W}/\sqrt{\mathrm{Hz}}$

——— 8 year scan with NEP = $3 \times 10^{-20} \mathrm{W}/\sqrt{\mathrm{Hz}}$