The Canfranc Axion Detection Experiment

CADEx

Alicia Gómez, on behalf of the CADEx Collaboration

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CENTRO DE ASTROBIOLOGÍA · CAB
ASOCIADO AL NASA ASTROBIOLOGY PROGRAM
CSIC
EXCELENCIA MARÍA DE MAEZTU

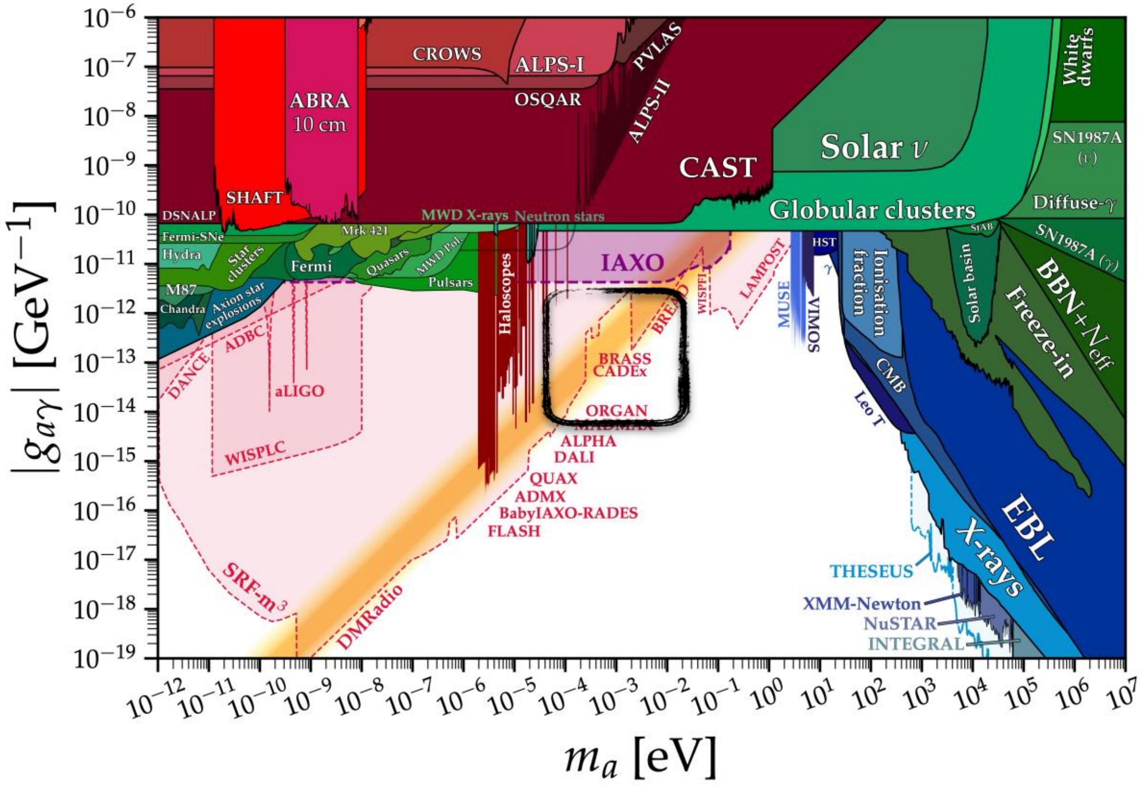
MINISTERIO DE CIENCIA E INNOVACIÓN
Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
AGENCIA ESTATAL DE INVESTIGACIÓN

Primera Reunión Presencial De Planes Complementarios de Astrofísica y Altas Energías

Motivation

- *Inverse Primakoff effect: axion-photon conversion in strong magnetic fields.*
- *Photon frequency ∝ axion mass.*
- *Detection traditionally based on haloscopes and heterodyne receivers.*
  - Standard quantum limit for heterodyne detectors at 100 GHz: 2.5 K
  - Very slow search for wide ranges

Looking for axions in the mm/submm/Far- IR desert



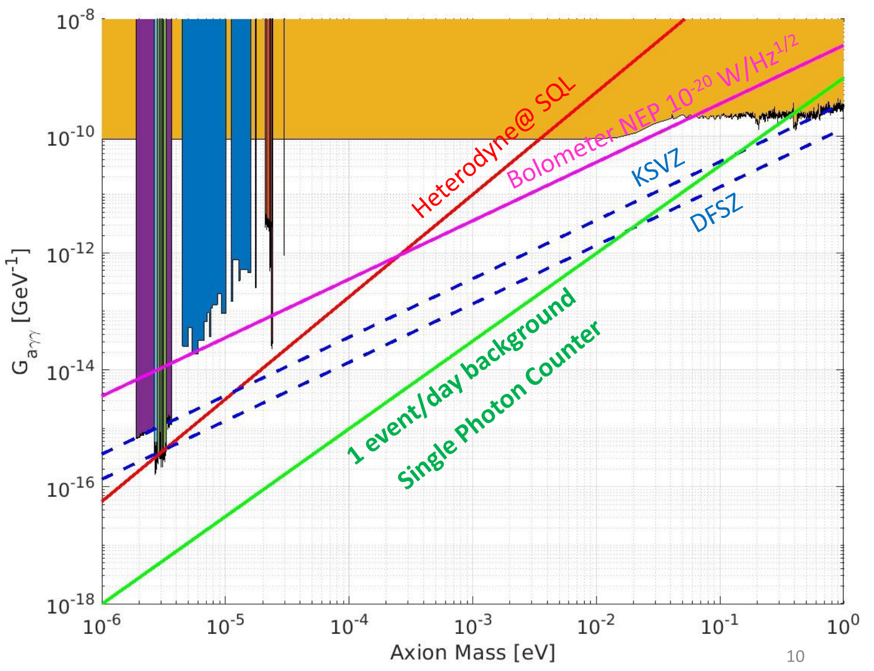
The challenging THz desert

Detection system

- Use of direct directors with state-of-the-art sensitivities.
- But… Sensitive to cosmic rays, so underground lab needed.

Haloscopes:

- High frequency resonant cavities.
  - Need technological demonstration.



Detection system must be:

- Spectroscopic to detect the expected narrow spectral feature.
- Polarimetric to detect the expected linear polarization.

CADEx can be considered as a technological platform

The CADEx Collaboration

CADEx: a novel and challenging experiment to search for dark matter axions in the range

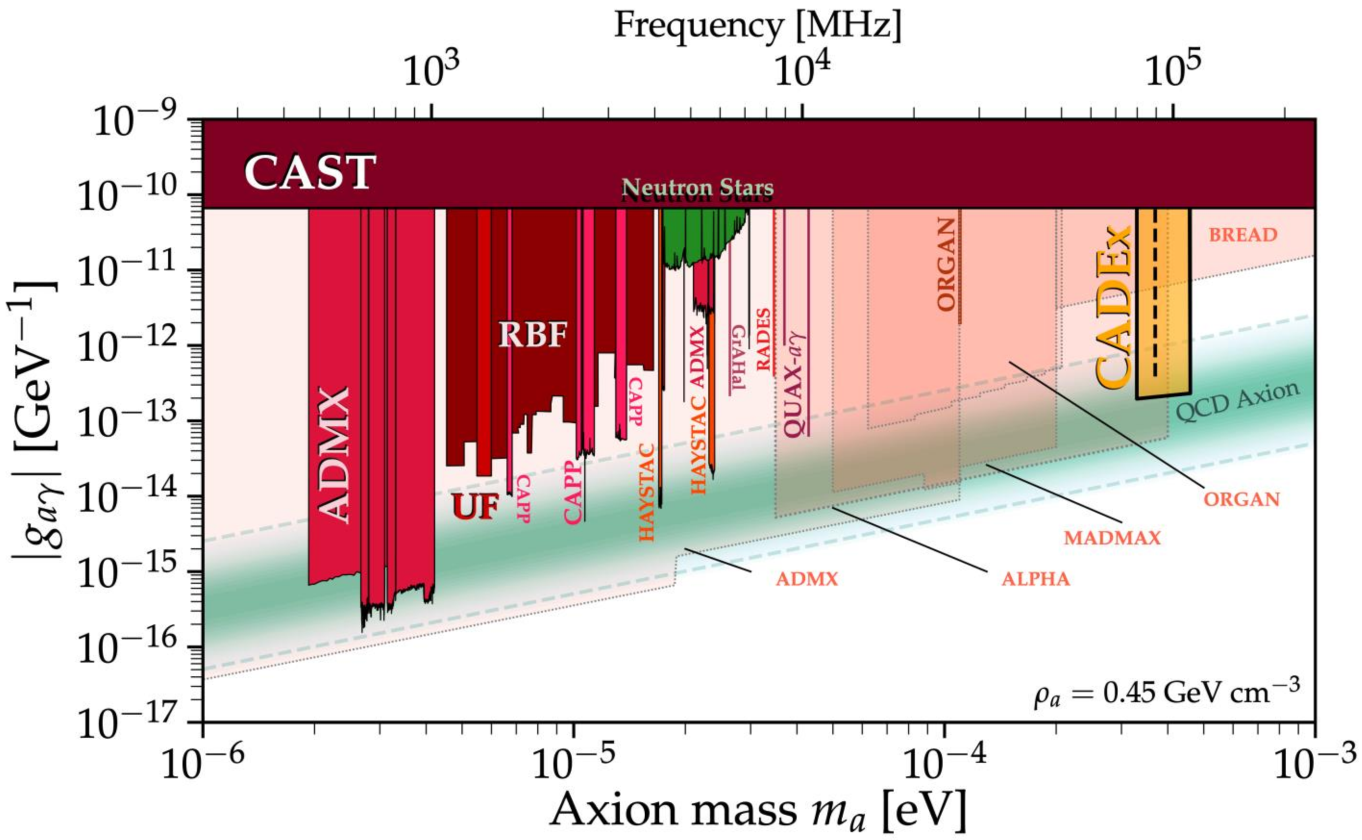
330–460 μeV (W-band → 86–110 GHz). Also sensitive to dark photons.

Novel detection system:
Haloscope + KIDs

Estimate 5σ sensitivity assuming:

Magnetic field: $B = 8\text{T}$
Total cavity volume: $V = 0.2\text{L}$
Cavity quality factor: $Q_0 = 2 \times 10^4$

- - - - - - 3 month exposure with NEP = $10^{-19}\ \text{W}/\sqrt{\text{Hz}}$
——— 8 year scan with NEP = $3 \times 10^{-20}\ \text{W}/\sqrt{\text{Hz}}$



The CADEx Collaboration

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

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

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More than 30 people from 11 institutions

Science

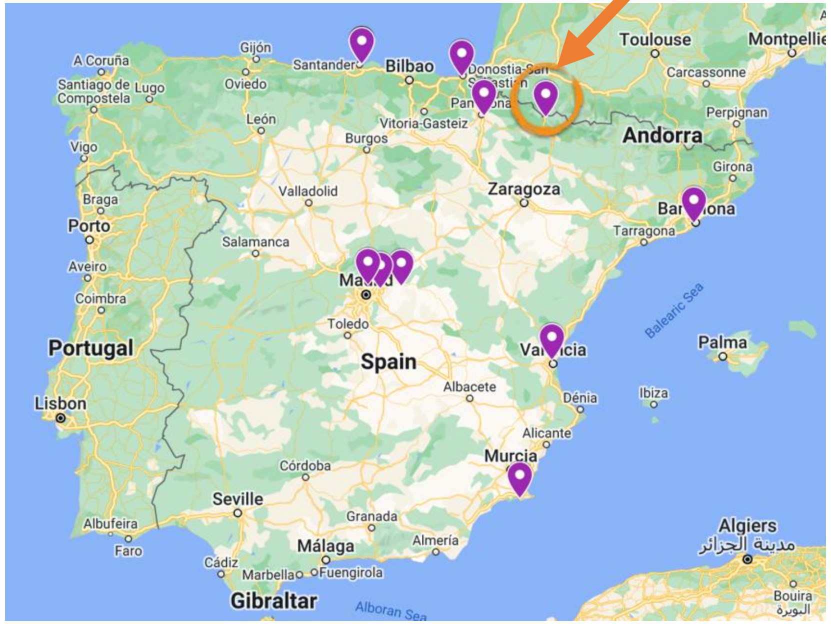
Optics

Haloscopes

Cryogenics

Detectors

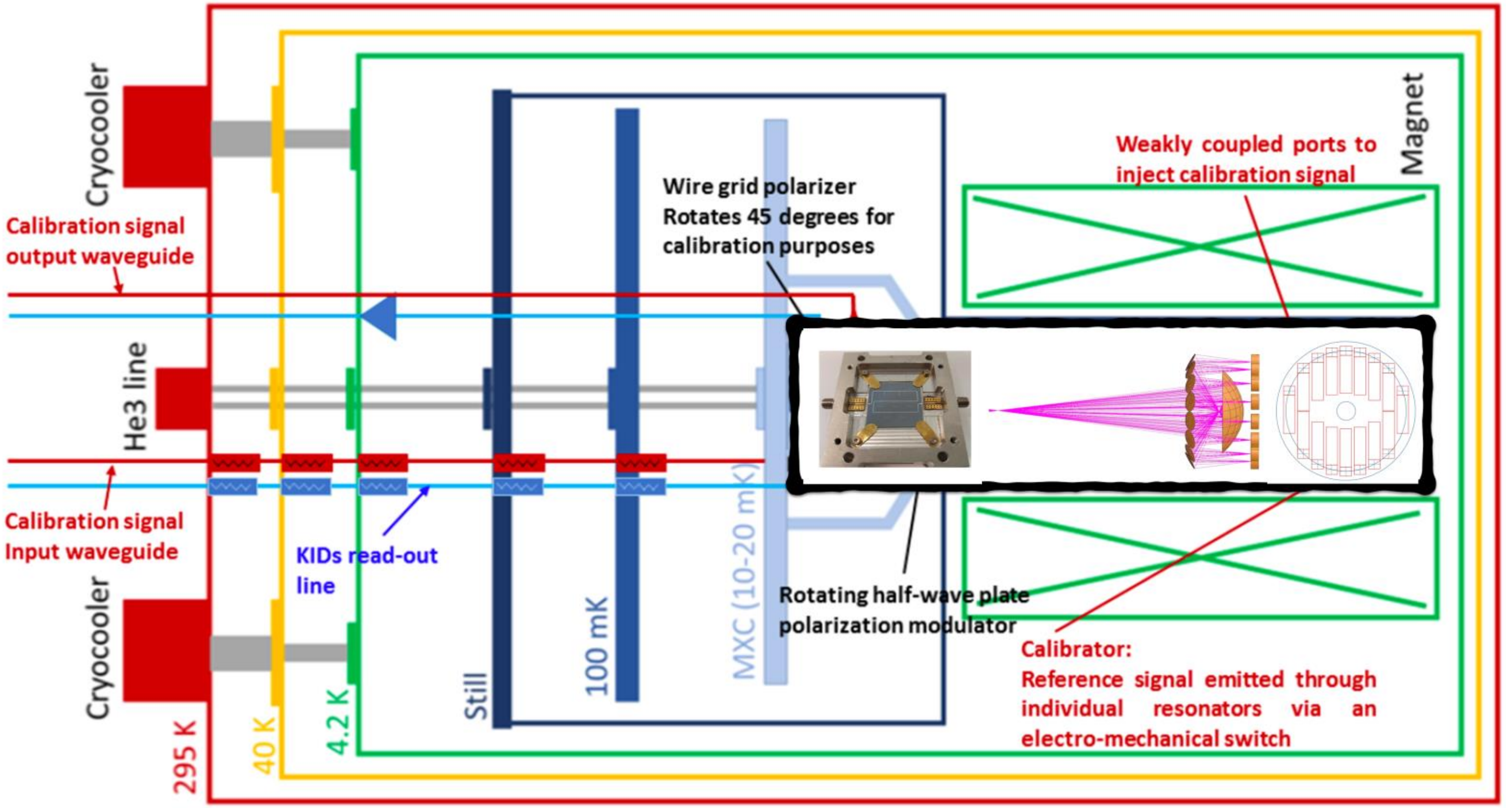
Data Reduction



CADEx Conceptual Design

- Immerse **haloscope** array in high static **B = 8-10 T**.
- Aim to discriminate the **polarized** axion-photon conversion signal from the unpolarized background.
- Detection system based on **Kinetic Inductance Detectors**.
- Cryogenic background at **T = 100 mK**.

Technological challenges

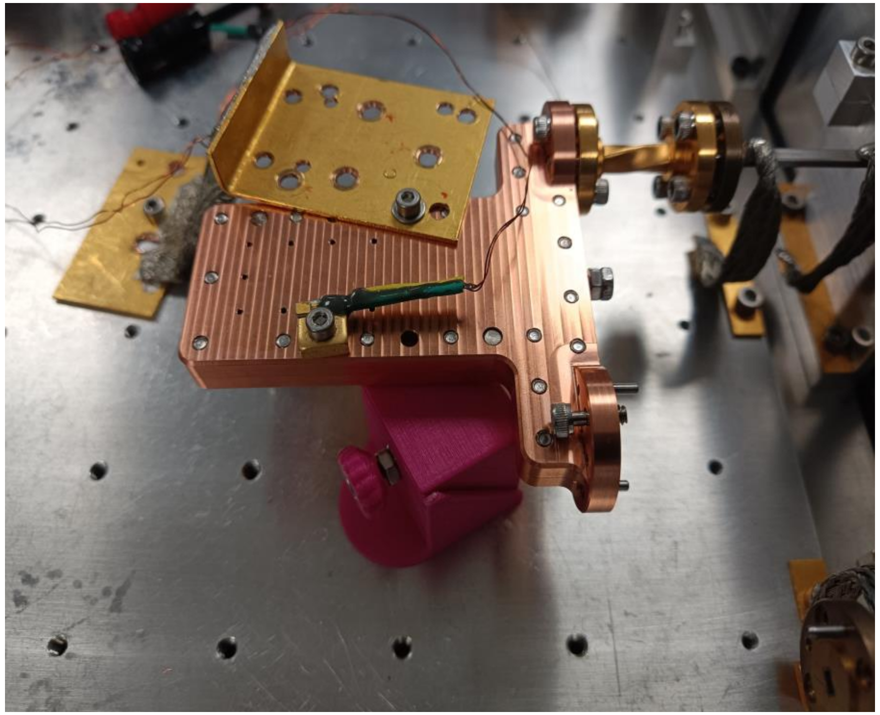


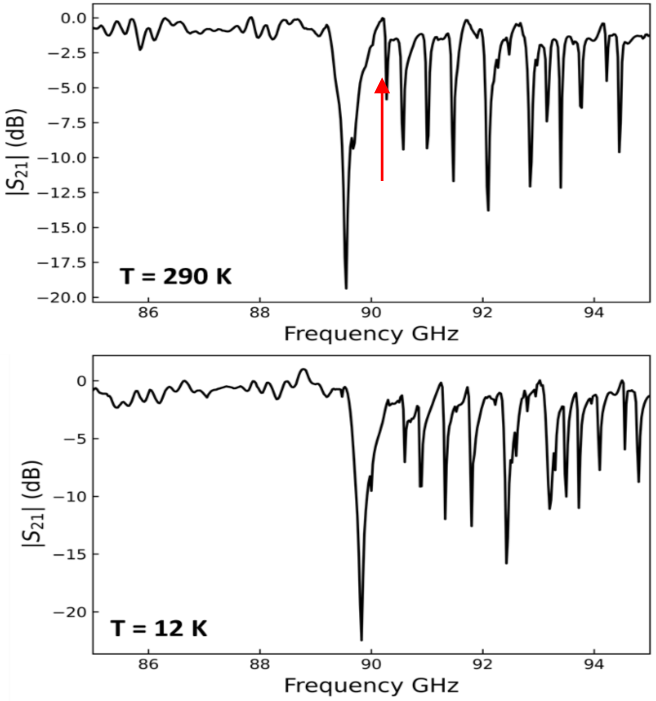
CADEx status: Haloscope

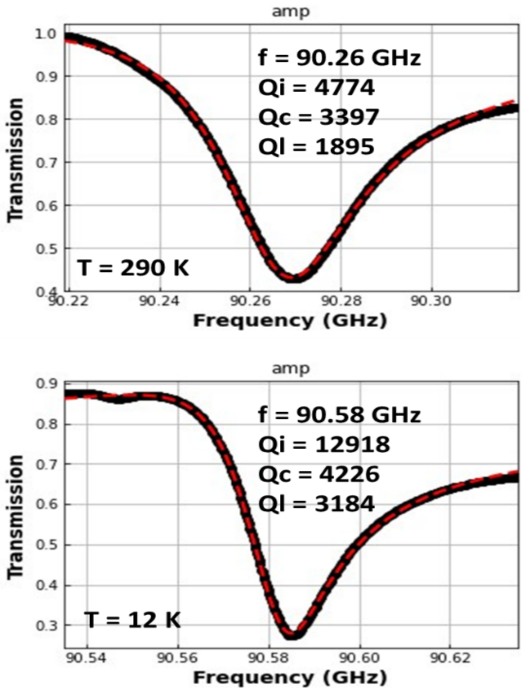
- Pushing 3D Cavities to the **W-band** while maintaining very **high quality factor** (Q).

$$f_r = \frac{c}{2}\sqrt{\frac{1}{a^2} + \frac{1}{b^2}}$$

Dimensions $a \approx 1.7$ mm and $b = 40a$ gives a resonance frequency of $f_r = 90\text{GHz}$

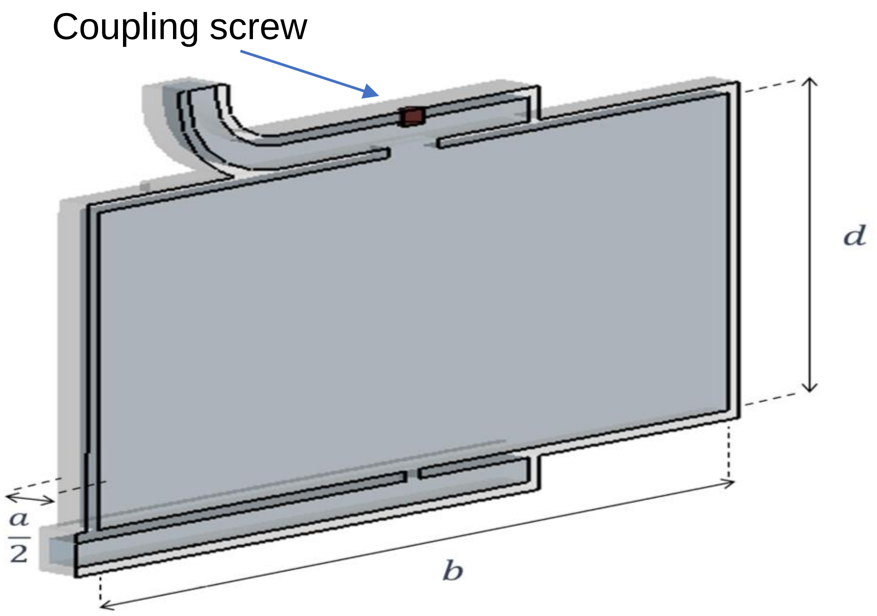


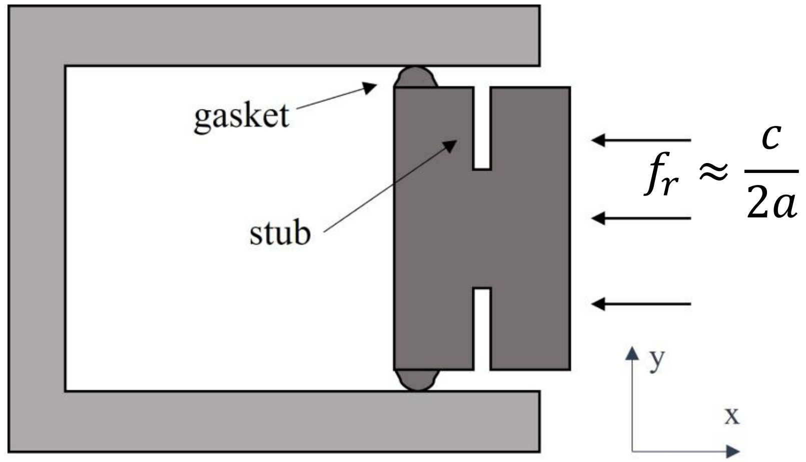




CADEx status: Haloscope

- Pushing 3D Cavities to the **W-band** while maintaining very **high quality factor** (Q).
- Develop **tunable cavities** to scan frequency range $f_r \in [86,111]$ GHz and tune Q.



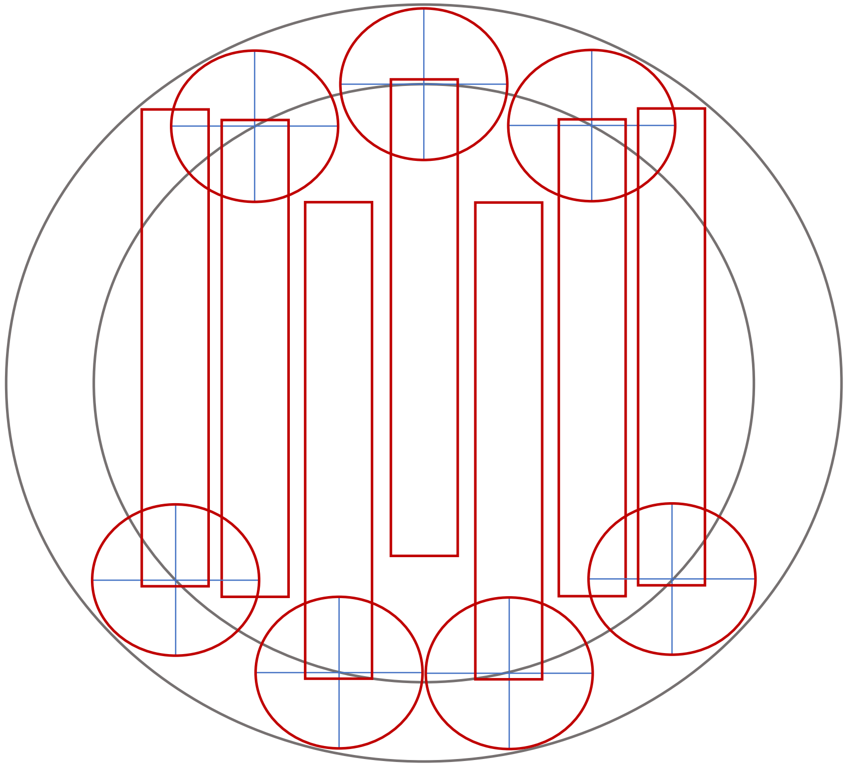


CADEx status: Haloscope

- Pushing 3D Cavities to the **W-band** while maintaining very **high quality factor** (Q).
- Develop **tunable cavities** to scan frequency range $f_r \in [86,111]$ GHz and tune Q.
- Need to **maximize volume** to increase the sensitivity.

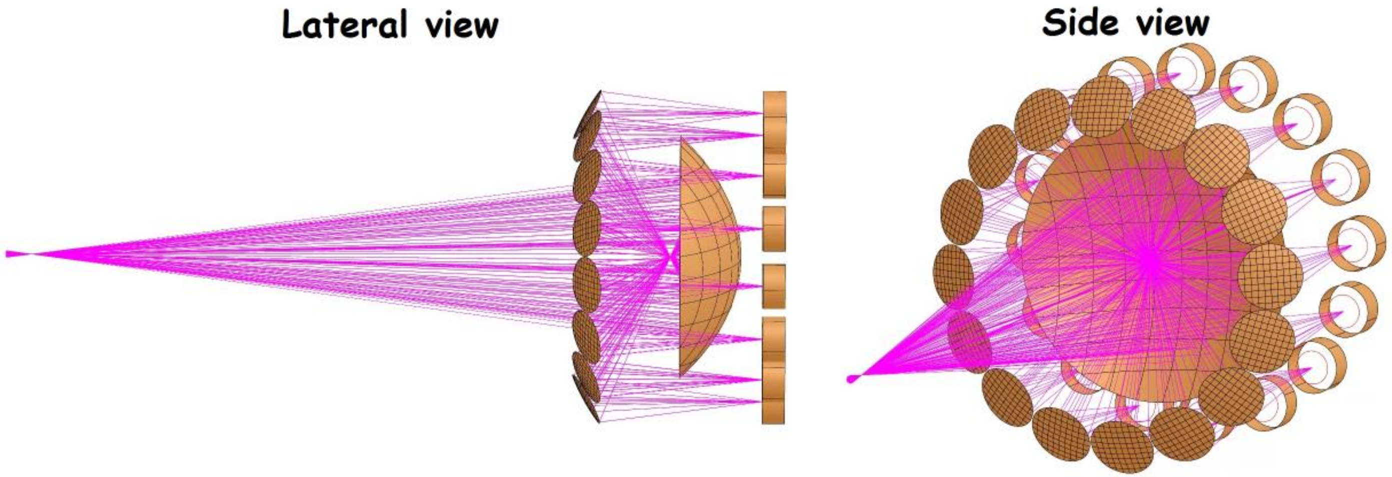
Detected axion-photon conversion power P:

$$P_d = \frac{\beta}{(1+\beta)^2} g_{a\gamma}^2 \frac{\rho_a}{m_a} B^2 C \boldsymbol{V} \boldsymbol{Q}$$



CADEx status: Optics

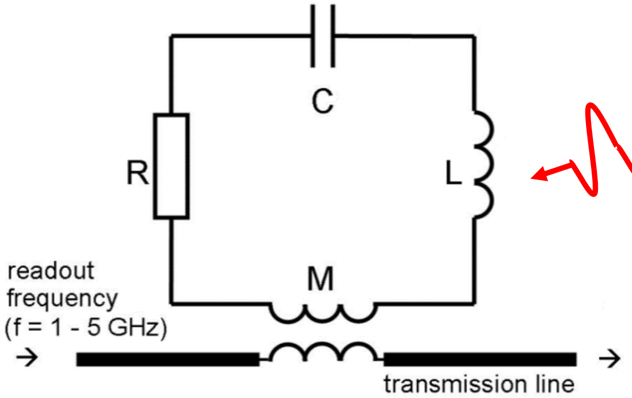
- Quasi-optical system based on 16 horn antennas apertures **focus signal** going out from the haloscope to the detection system.
- **Polarization** needs to be preserved.
- To be fitted in the 100 mK space within the cryogenic system.
- Filters are mandatory to diminish **out-of-band background signal**.



CADEx status: Kinetic Inductance Detectors

- Detection system based on superconducting **Kinetic Inductance Detectors**.

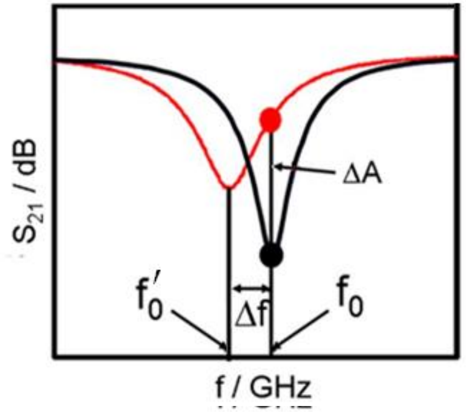
$E > 2\Delta$

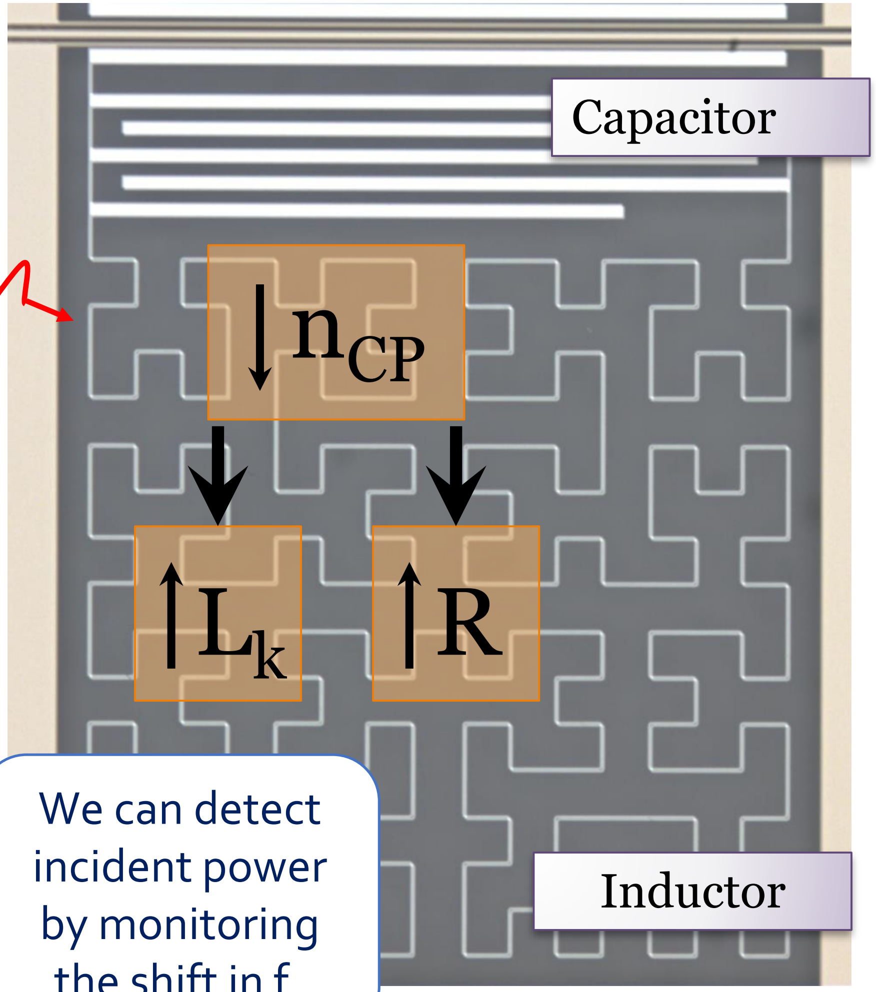


$L = L_g + L_k$

$$f_0 = \frac{1}{\sqrt{LC}}$$

$$f' = \frac{1}{\sqrt{L'C}}$$

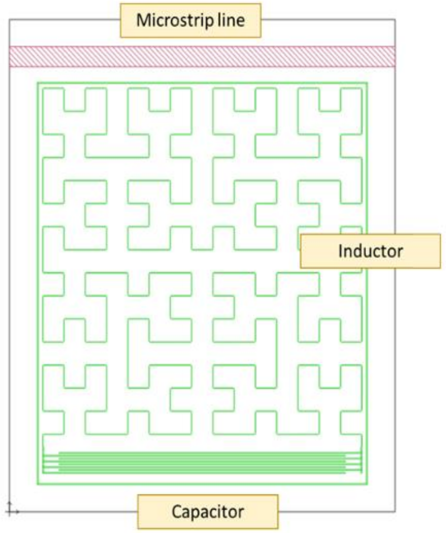


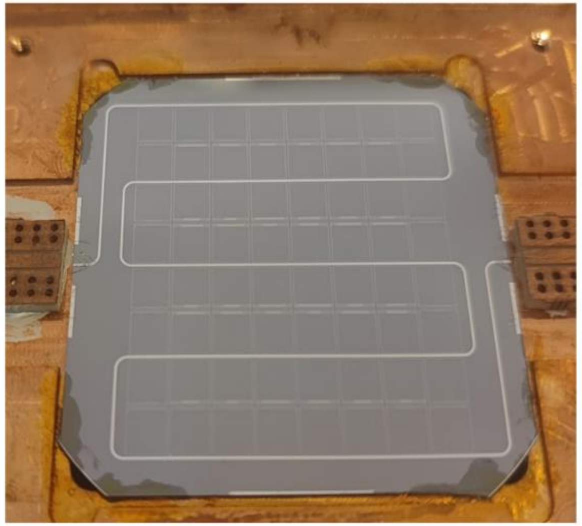


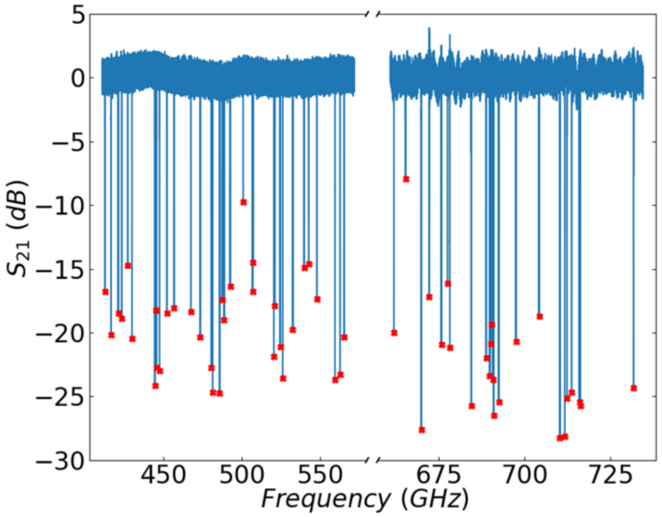
We can detect incident power by monitoring the shift in f_o

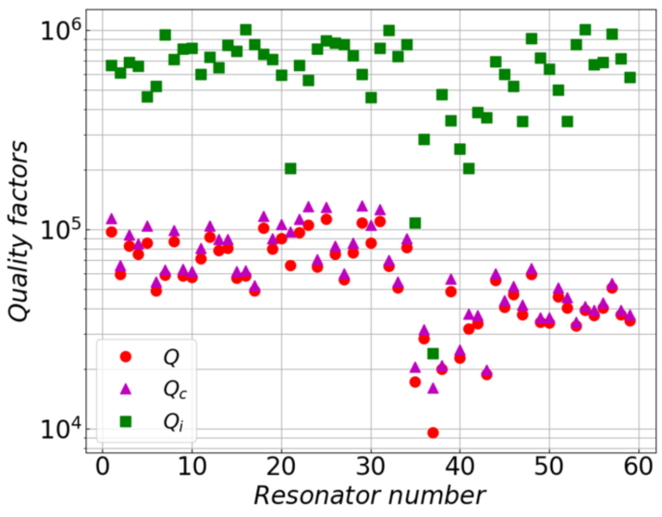
CADEx status: Kinetic Inductance Detectors

- ➢ Detection system based on superconducting **Kinetic Inductance Detectors**.
- ➢ A 64 LEKID camera based on **Ti/Al bilayer** has been developed and characterized.









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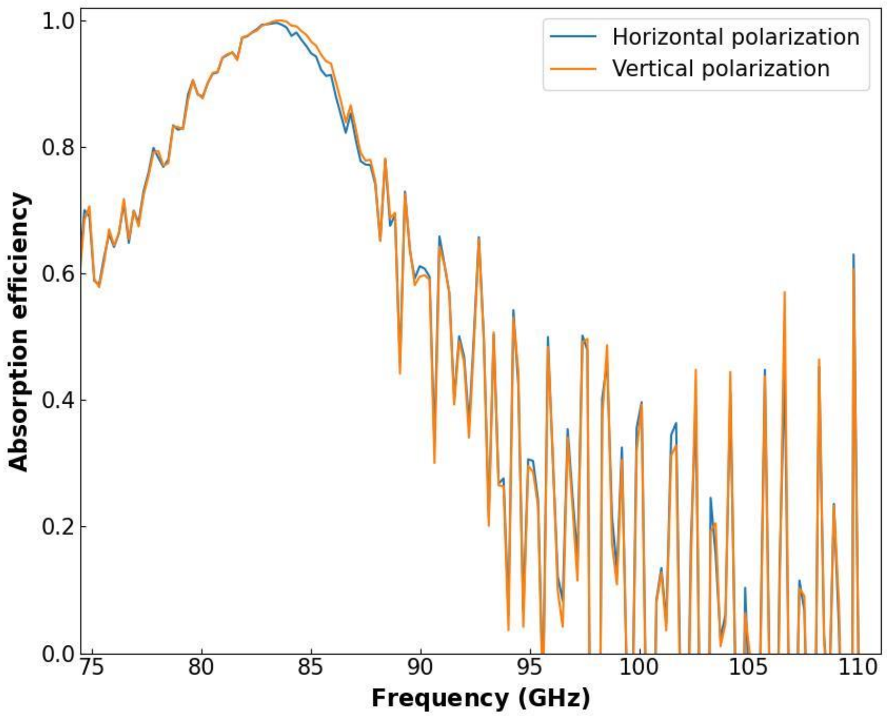
- Detection system based on superconducting **Kinetic Inductance Detectors**.
- A 64 LEKID camera based on **Ti/Al bilayer** has been developed and characterized.
- Room temperature quasi-optical **polarization characterization** demonstrated.



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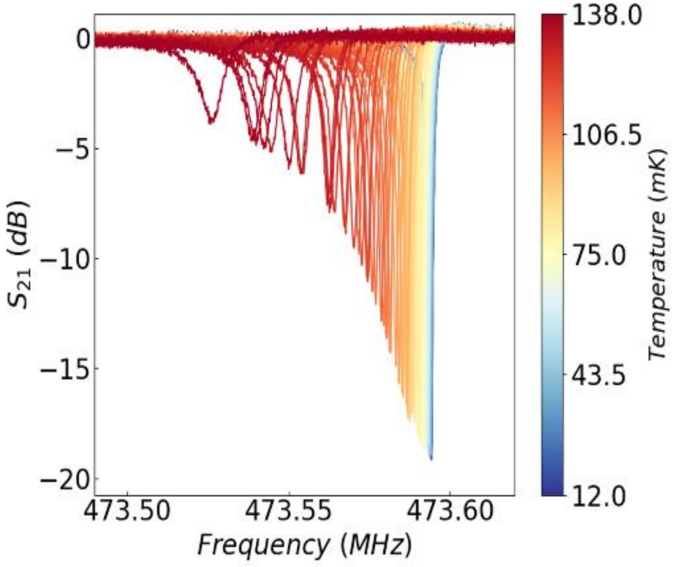

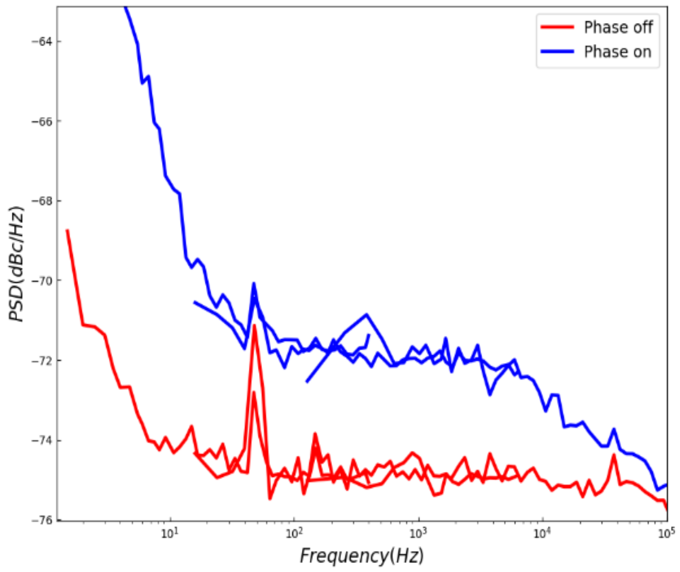

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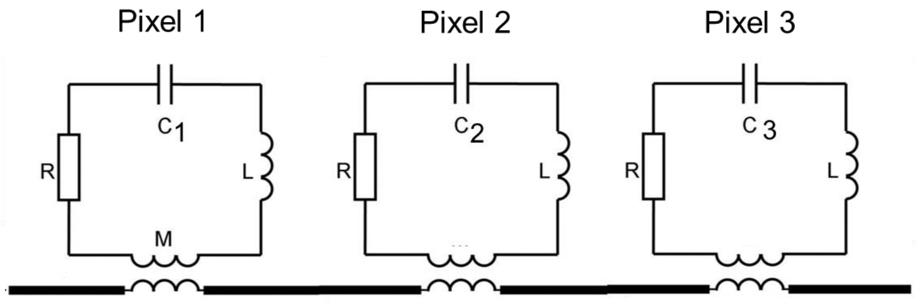
- KIDs **responsivity** and 1/f **noise characterization** ongoing.
- A contract for the fabrication of the **multipixel readout system** for KIDs is ongoing.

Readout line



Multiple KIDs read simultaneously

CADEx Timeline

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

- **Design and Demonstration Phase (2 years)**

  Cryostat acquisition, installation and operation.
  Full quasi-optical design.
  Demonstration of key technology (haloscope and detectors) in the lab.

- **Pathfinder Phase (2 years)**

  First prototype of the full CADEx system to be installed and tested in LSC facility. Optimization

- **Operation Phase (8 years)**

  Upgrade the experiment to improve the sensitivity & efficient non-resonant waveguide haloscope. Installation & Commissioning. Full Operation.

Thanks for your attention!!!

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