

The Canfranc Axion Detection Experiment



Alicia Gómez, on behalf of the CADEX Collaboration

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CENTRO DE ASTROBIOLOGÍA · CAB
ASOCIADO AL NASA ASTROBIOLOGY PROGRAM



Motivation

CADEx: a novel and challenging experiment to search for dark matter axions in the range 330–460 μeV (W-band \rightarrow 86–110 GHz). Also sensitive to dark photons.

Novel detection system:
Haloscope + KIDs

Estimate 5σ sensitivity assuming:

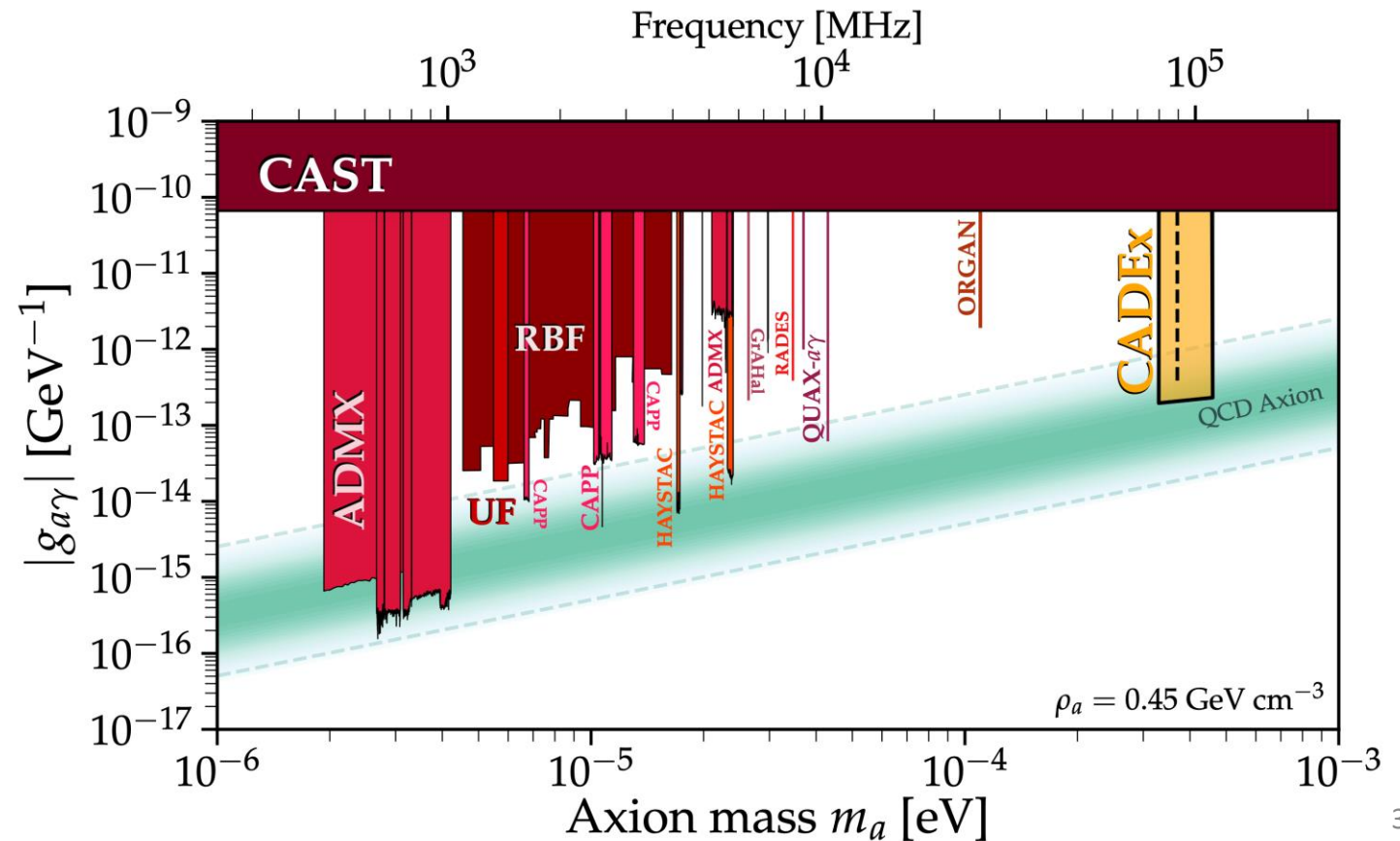
Magnetic field: $B = 8\text{T}$

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

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

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

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



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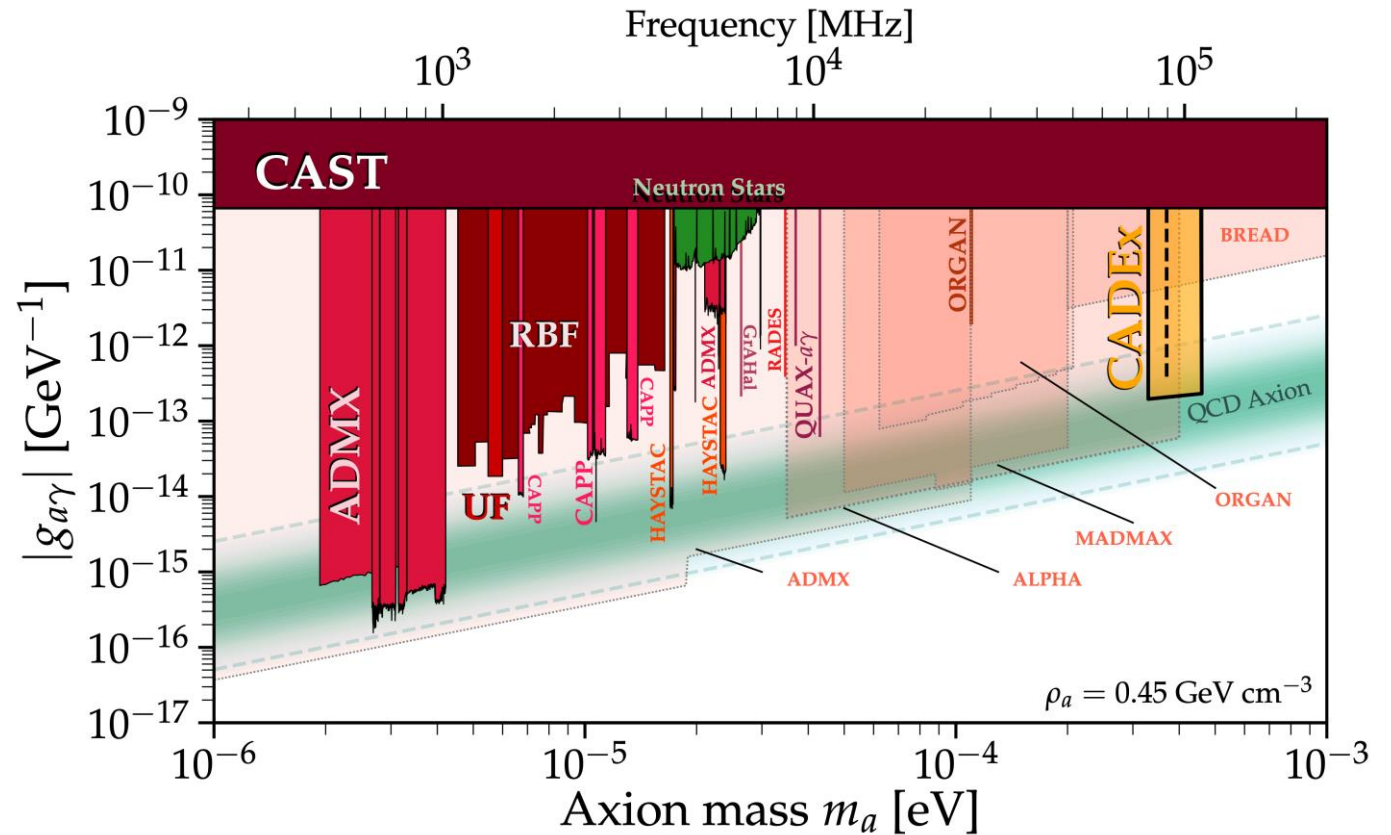
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The challenging THz desert

Detection system

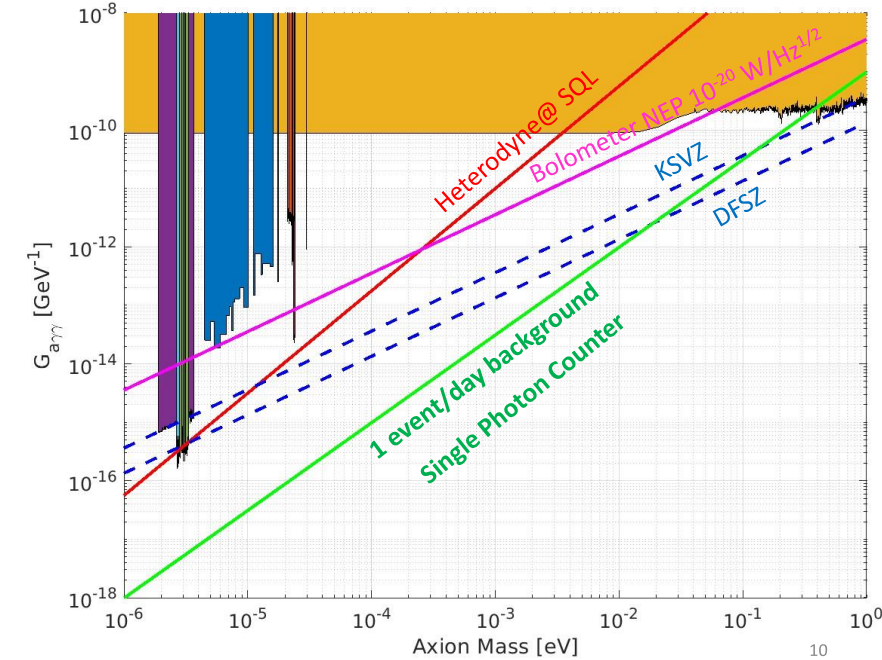
- Use of direct detectors with **state-of-the-art sensitivities**.
- But... **Sensitive to cosmic rays**, so underground lab needed.

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 team



[JCAP 11 (2022) 044, [arXiv:2206.02980](https://arxiv.org/abs/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



Observatorio de Yebes
Infraestructura Científica
y Técnica Singular



Innovative Antenna and Terahertz Imaging Technologies



INSTITUT DE FÍSICA
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Science

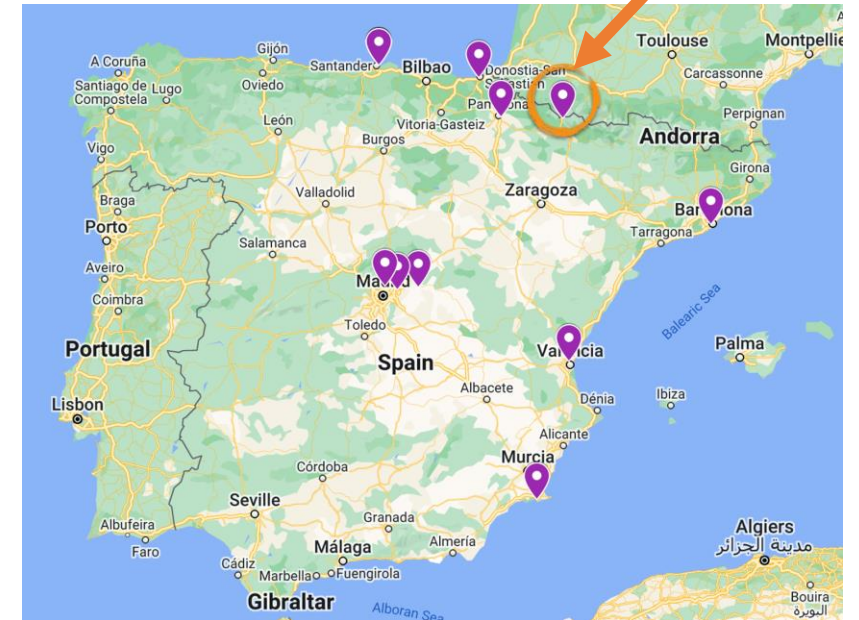
Optics

Haloscope

Cryogenics

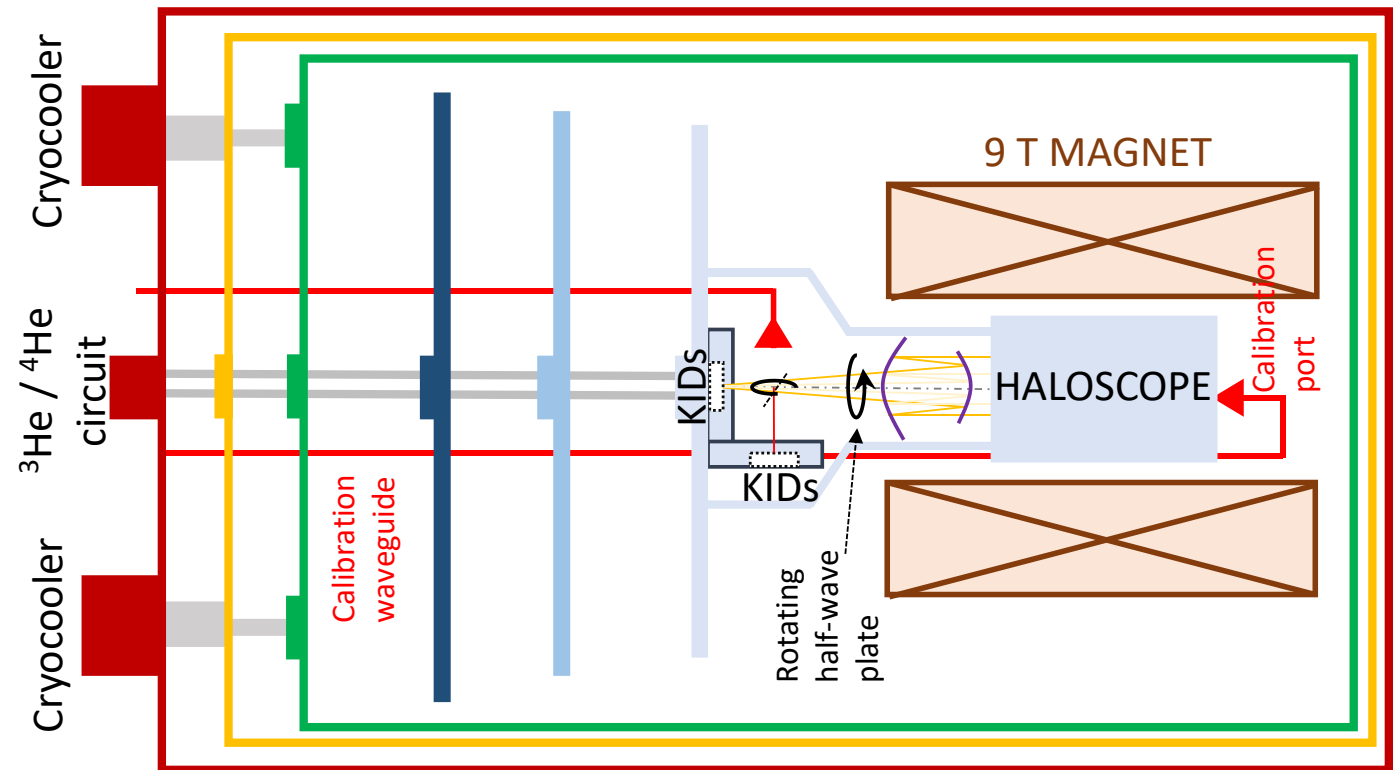
Detectors

Data Reduction



- 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

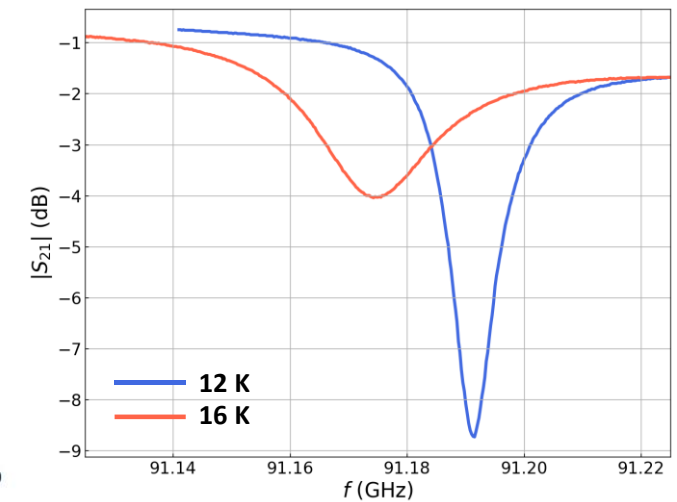
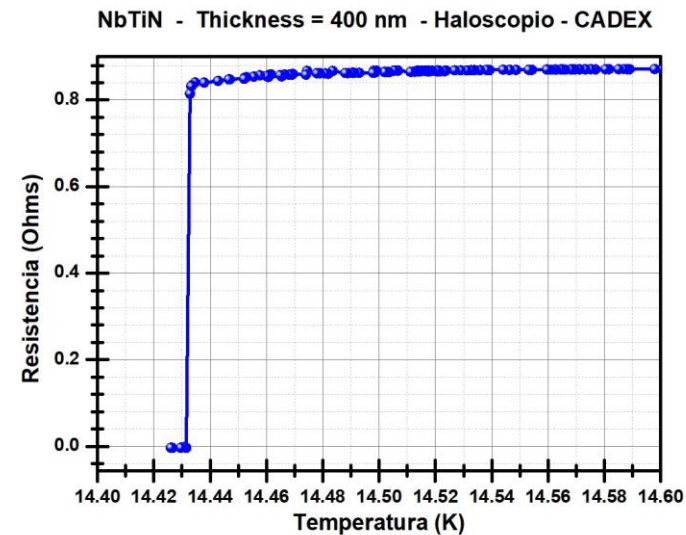
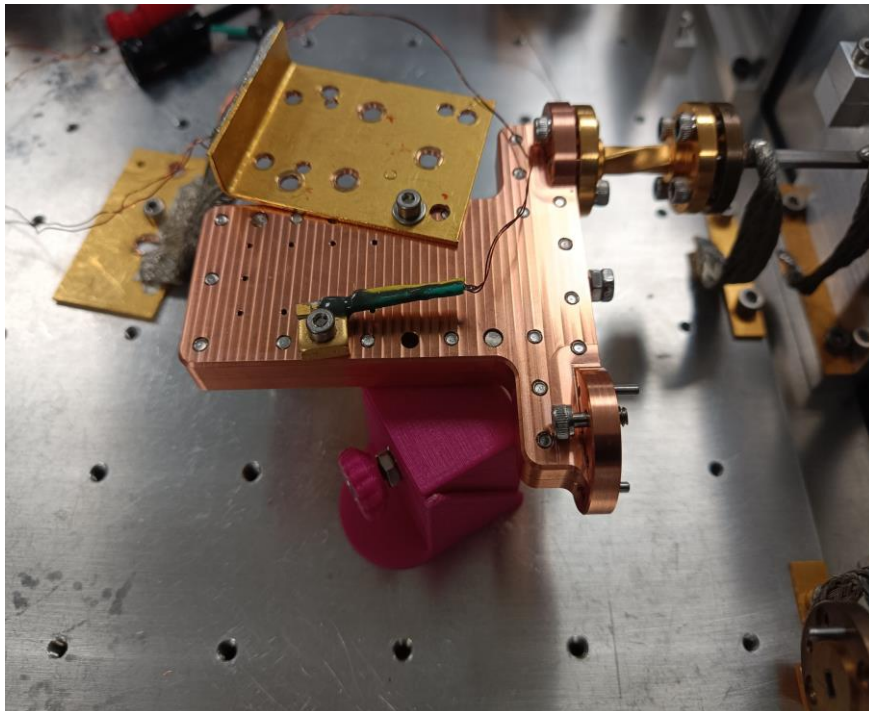
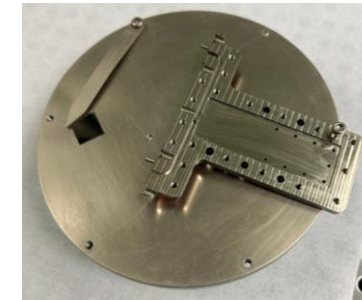
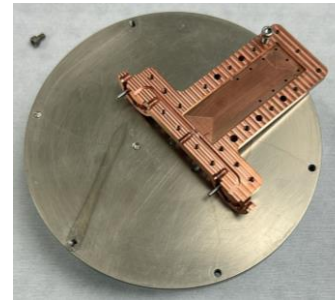
➤ Pushing 3D Cavities to the **W-band** covered by a **NbTiN** 400 nm film.

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

$$a \approx 1.7 \text{ mm}$$

$$b = 40a$$

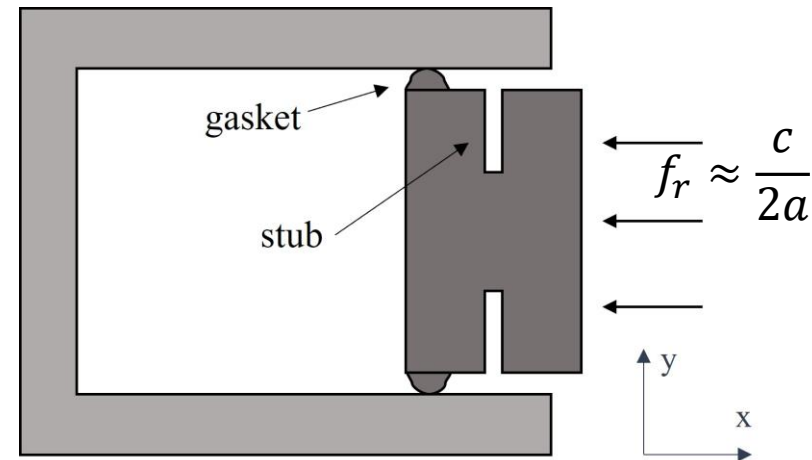
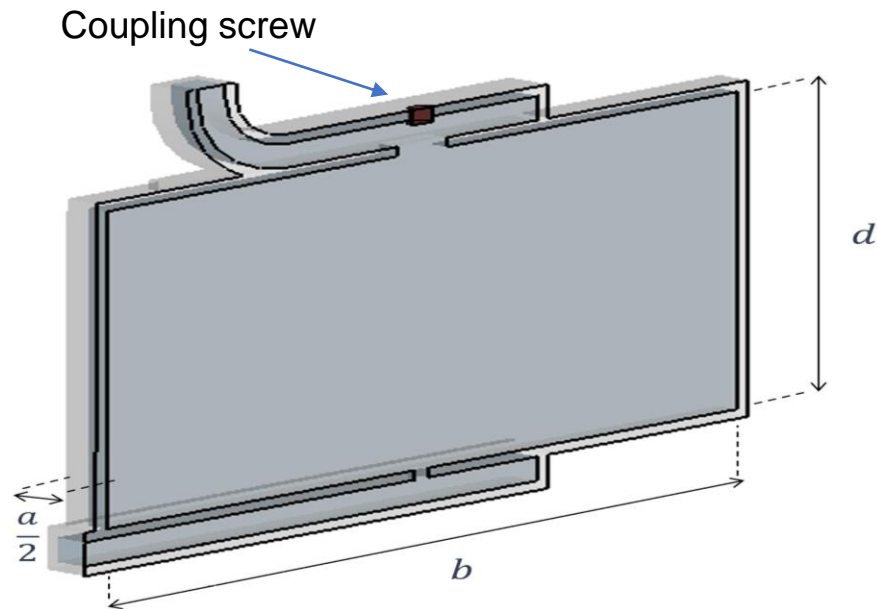
$$f_r = 90 \text{ GHz}$$



$Q_i (16 \text{ K}) = 7420.69$

$Q_i (11 \text{ K}) = 88150.73$

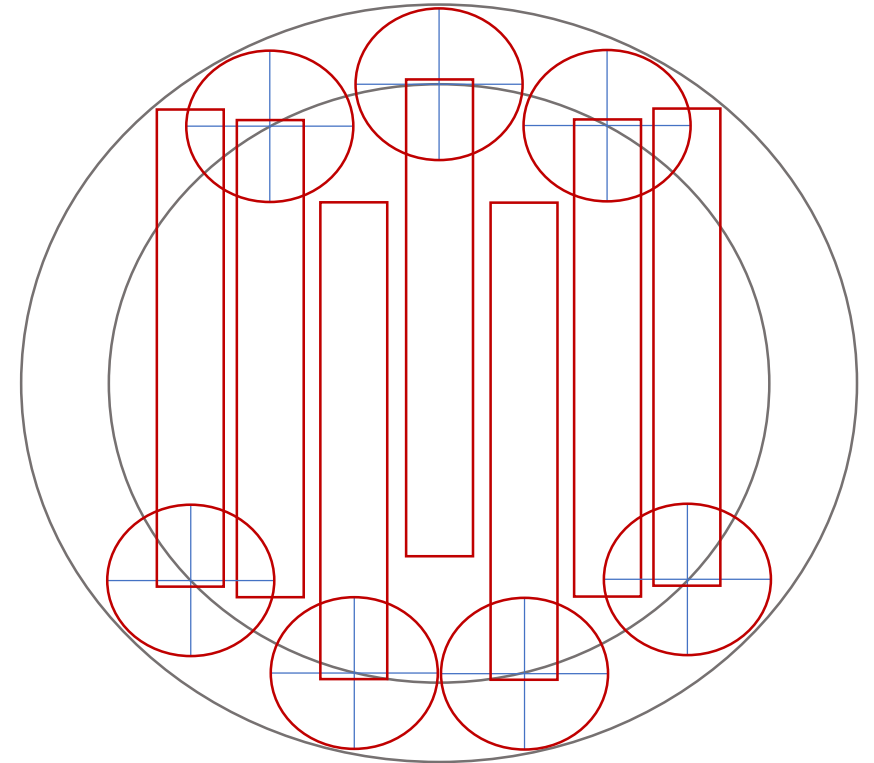
- Pushing 3D Cavities to the **W-band** while maintaining very **high quality factor** (Q).
- Develop **tunable cavities** to scan frequency range $f_r \in [86,111]$ GHz and tune Q.



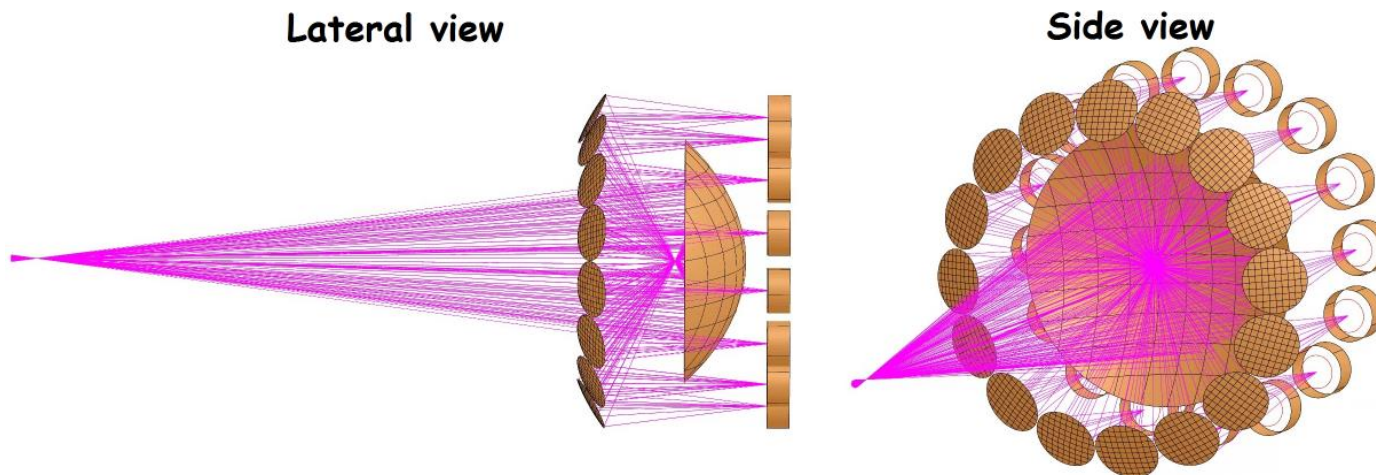
- Pushing 3D Cavities to the **W-band** while maintaining very **high quality factor** (Q).
- Develop **tunable cavities** to scan frequency range $f_r \in [86,111]$ GHz and tune Q.
- Need to **maximize volume** to increase the sensitivity.

Detected axion-photon conversion power P :

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

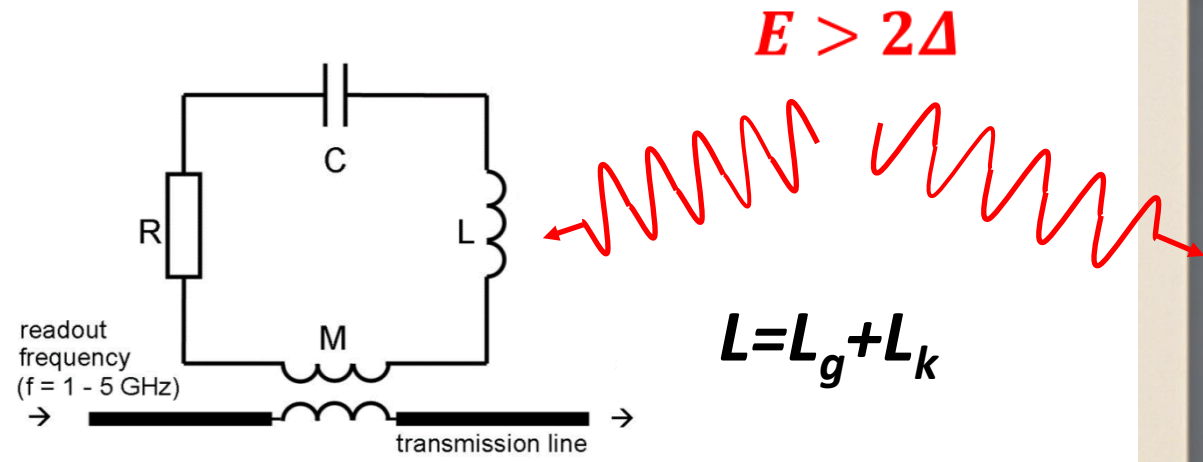


- Quasi-optical system based on 16 horn antennas apertures focus signal going out from the haloscope to the detection system.
- Polarization needs to be preserved.
- To be fitted in the 100 mK space within the cryogenic system.
- Filters are mandatory to diminish out-of-band background signal.



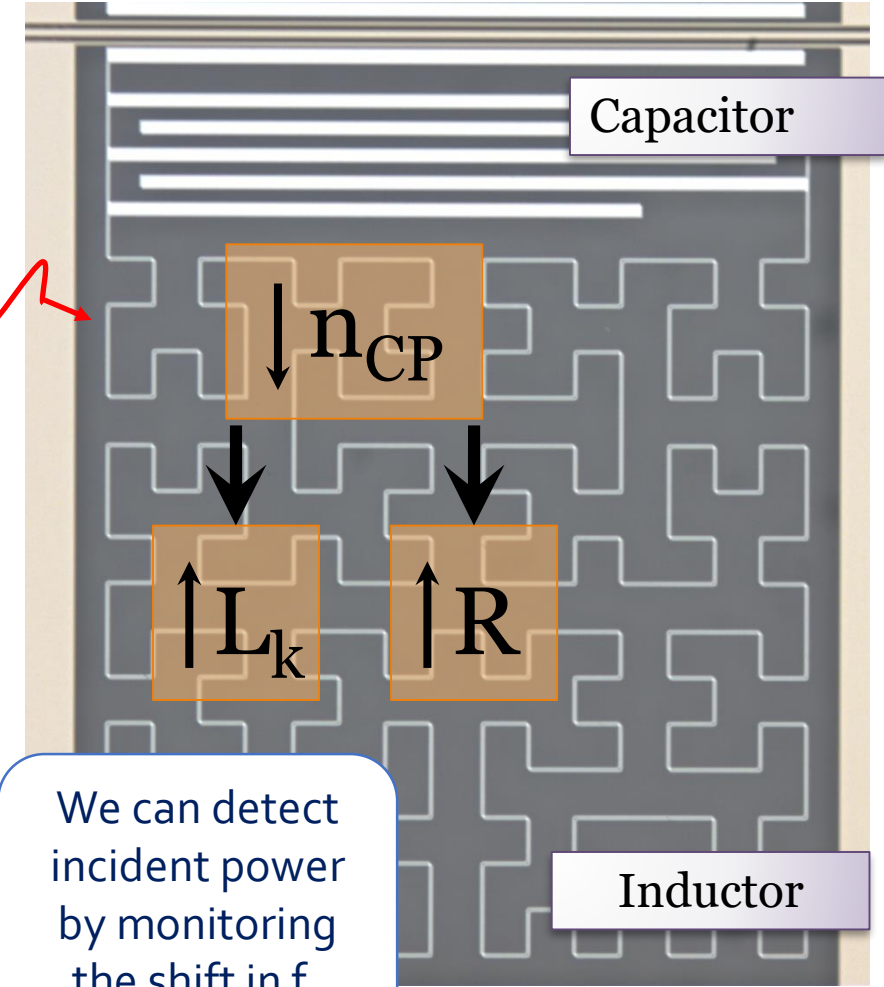
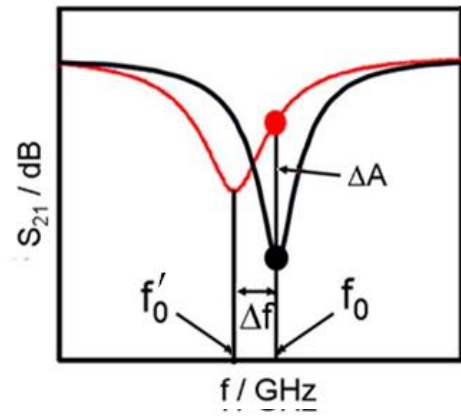
CADEx status: Kinetic Inductance Detectors

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



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

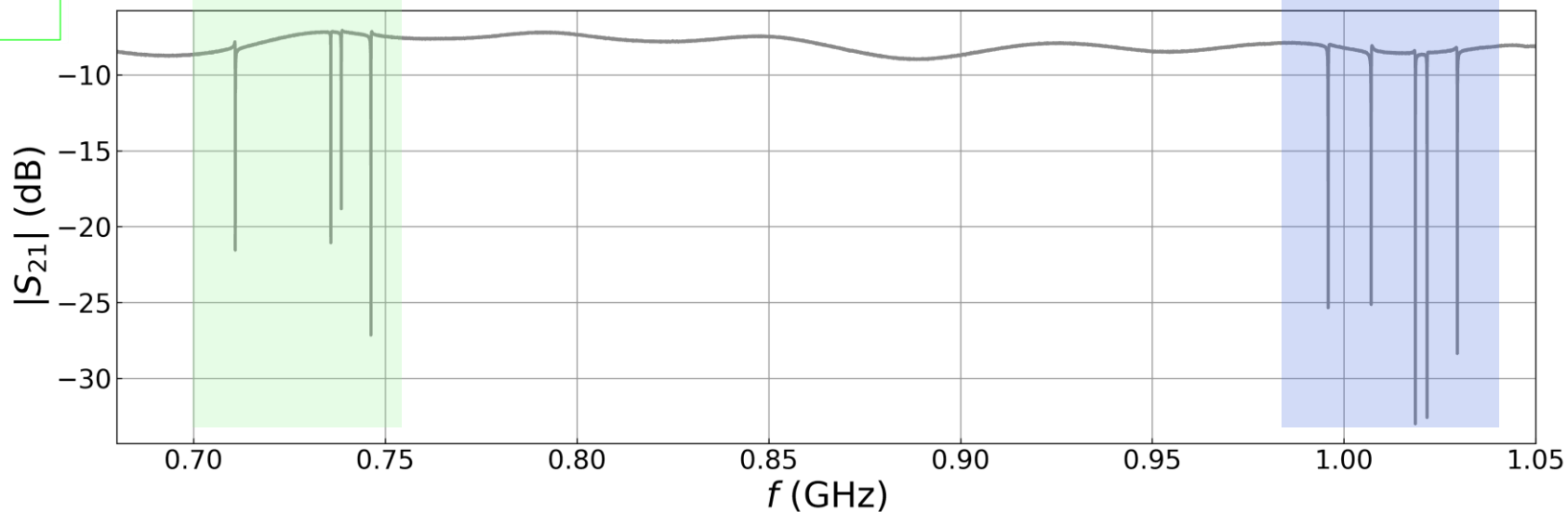
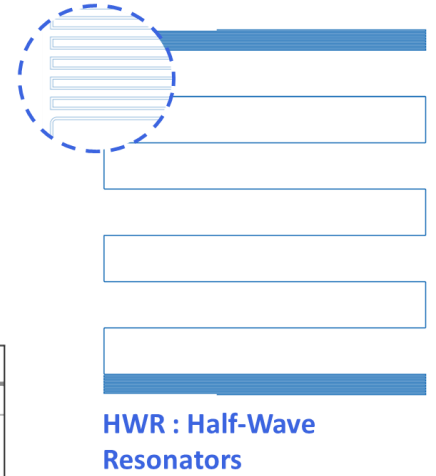
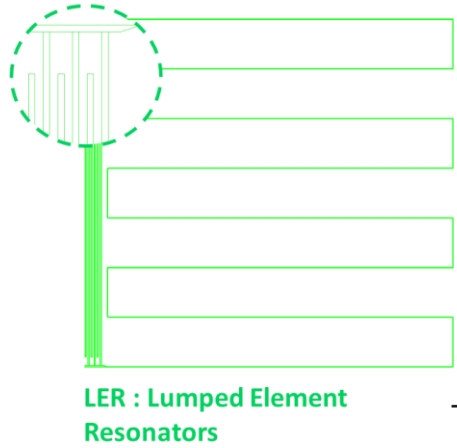
$$f' = \frac{1}{\sqrt{L'C}}$$



We can detect incident power by monitoring the shift in f_0 .

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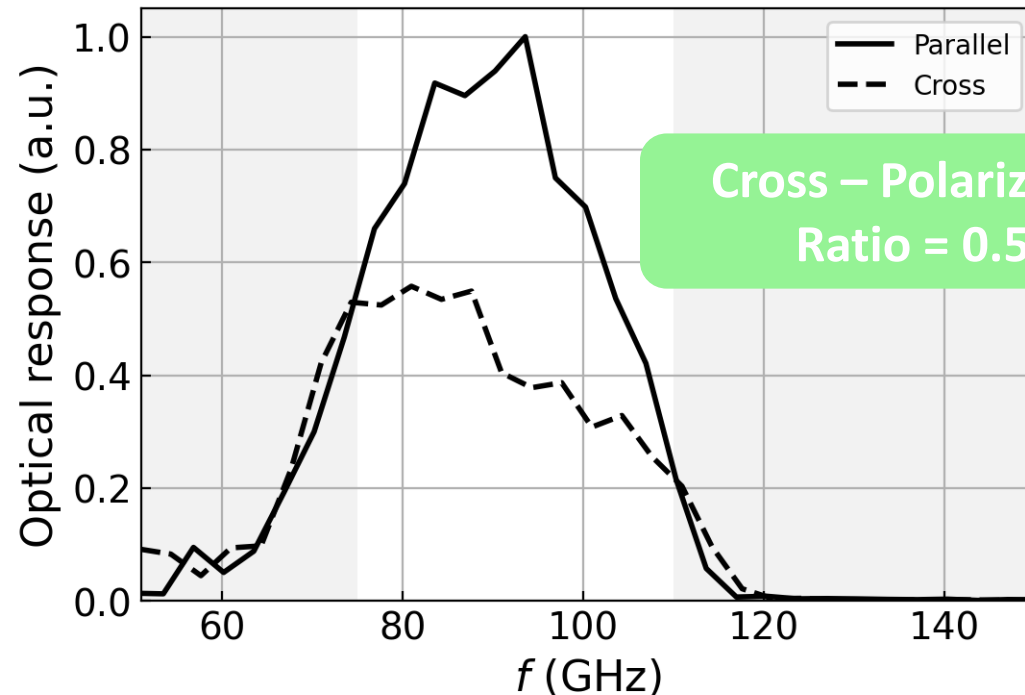
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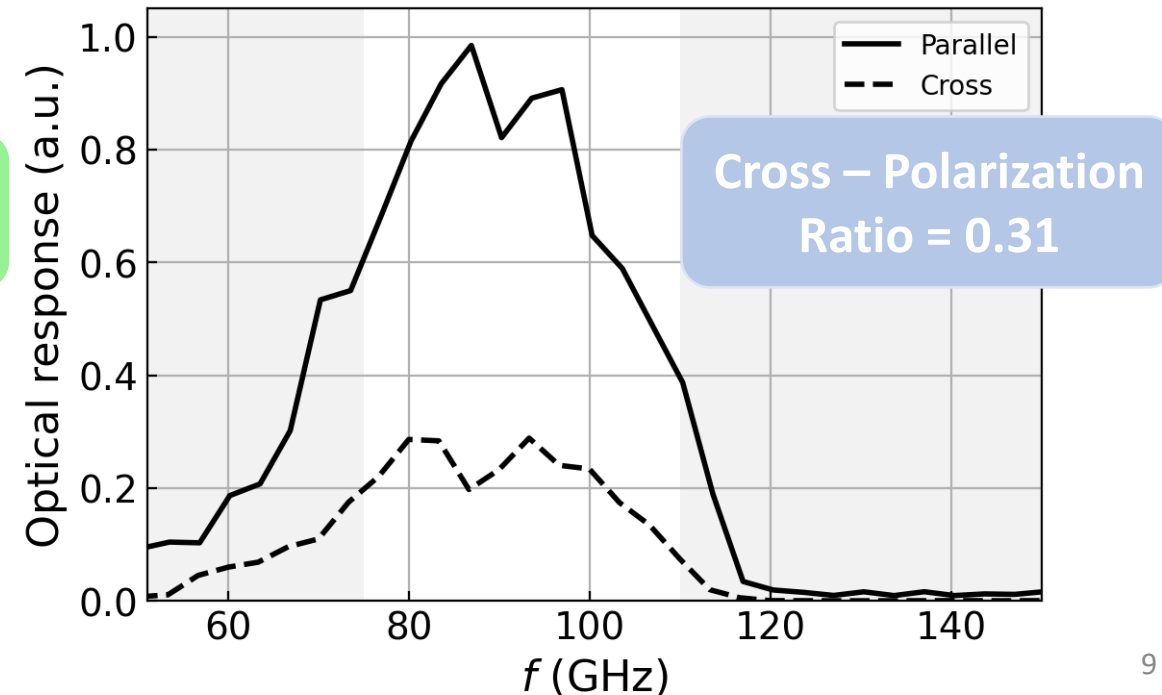
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LER – averaged signal

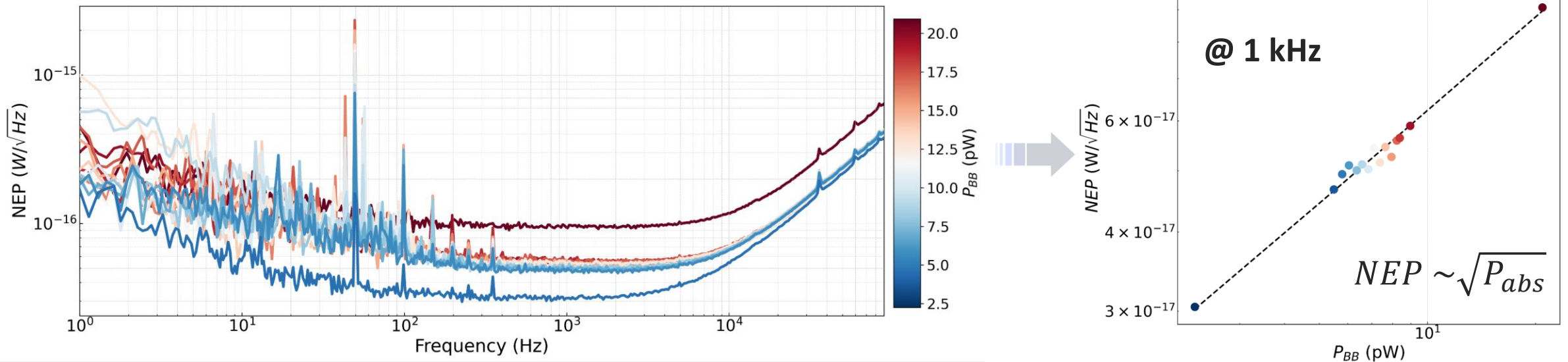


HWR – averaged signal



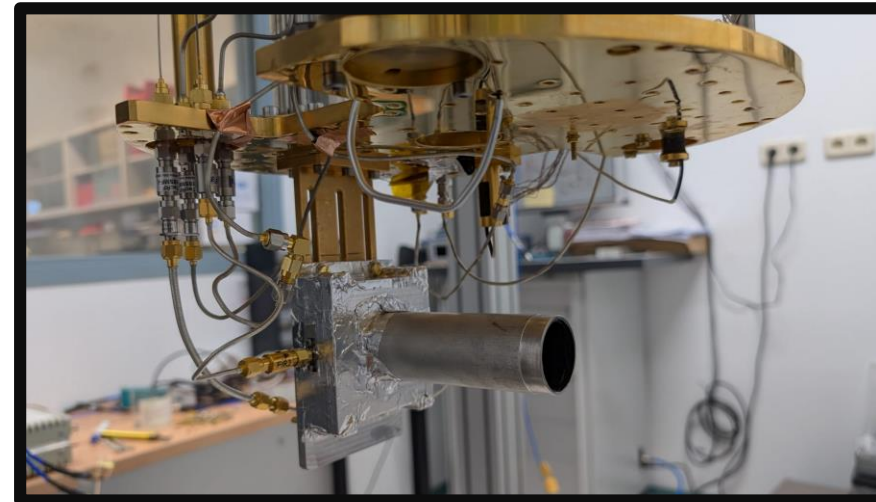
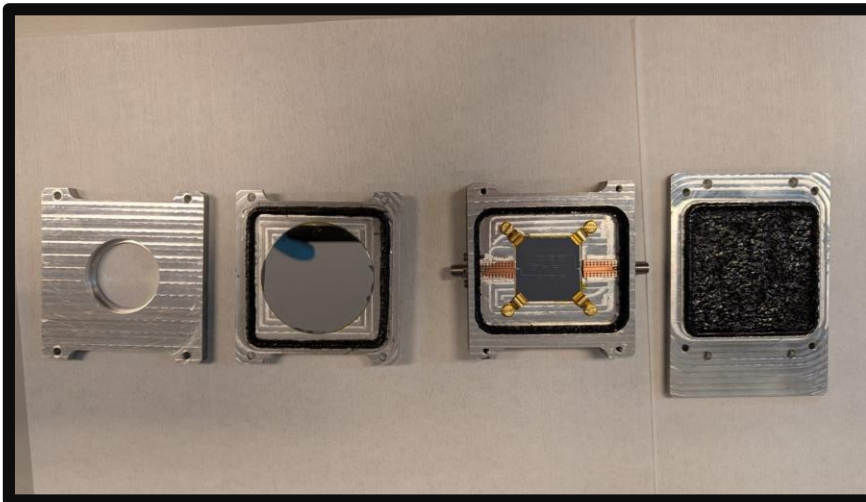
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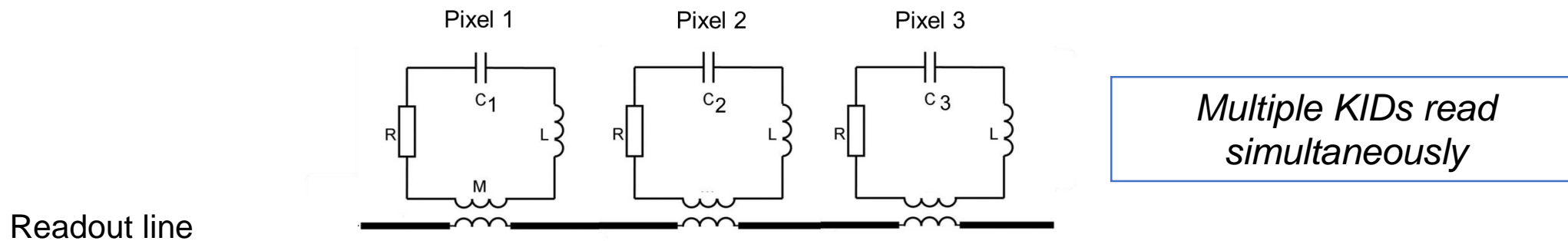


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- **Low background set-up** under tests.
- A contract for the acquisition of the **multipixel readout system** for KIDs is ongoing.



CADEX timeline

CADEX already accepted by Canfranc Underground Laboratory (LSC) under Eol-31-2021

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

Cryostat acquisition, installation and operation.

Full quasi-optical design.

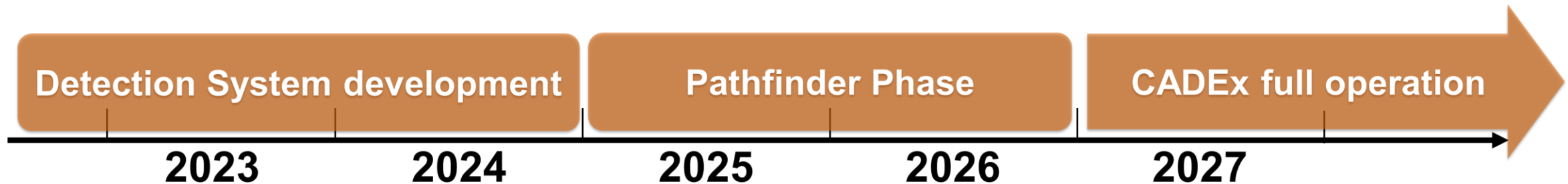
Demonstration of key technology (haloscope and detectors) in the lab.

➤ **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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Dark Matter 2025: From the Smallest to the Largest Scale

