Expression of Interest
to the
Laboratorio Subterráneo de Canfranc (LSC)

The Canfranc Axion Detection Experiment (CADEx)

CADEx Collaboration

Outline

CADEx team & expertise

The nature of Dark Matter. Axions

Searches for the Axion. Status

The proposal. CADEx

Need of the Laboratorio Subterraneo de Cranfranc

Request to the LSC. Dilution Cryostat

Request to the LSC. Schedule &support

Conclusions

CADEx team & expertise

Wide range of expertise built up in RADES: 13 institutions and 33 researches and engineers

Science

- Instituto de Ciencias del Cosmos de la Universidad de Barcelona
- 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

- Observatorio de Yebes (IGN)

Detectors. KIDs (added to RADES)

- Centro de Astrobiología (CSIC-INTA)
- Universidad de Cantabria
- Instituto de Física de Cantabria (CSIC-UC)
- Instituto Madrileño de Estudios Avanzados en Nanociencia
- Instituto de Ciencias del Cosmos de la Universidad de Barcelona

Calibration & data reduction

- Instituto de Ciencias del Cosmos de la Universidad de Barcelona
- Donostia International Physics Center
- Laboratorio Subterráneo de Canfranc
- Instituto de Física de Cantabria (CSIC-UC)

The nature of Dark Matter. Axions

Axions:

- Motivated to solve the strong CP problem (SM)
- Address long standing problems in the SM
- Consistent with the observational astrophysical and cosmological constraints
- **The most promising dark matter candidate**

Two axion models KSVZ and DFSZ : axion mass and photon coupling strength

Wide range of possible mass. Need of systematic blind searches

Searches for the Axion. Status

Axion-photon conversion in strong magnetic fields

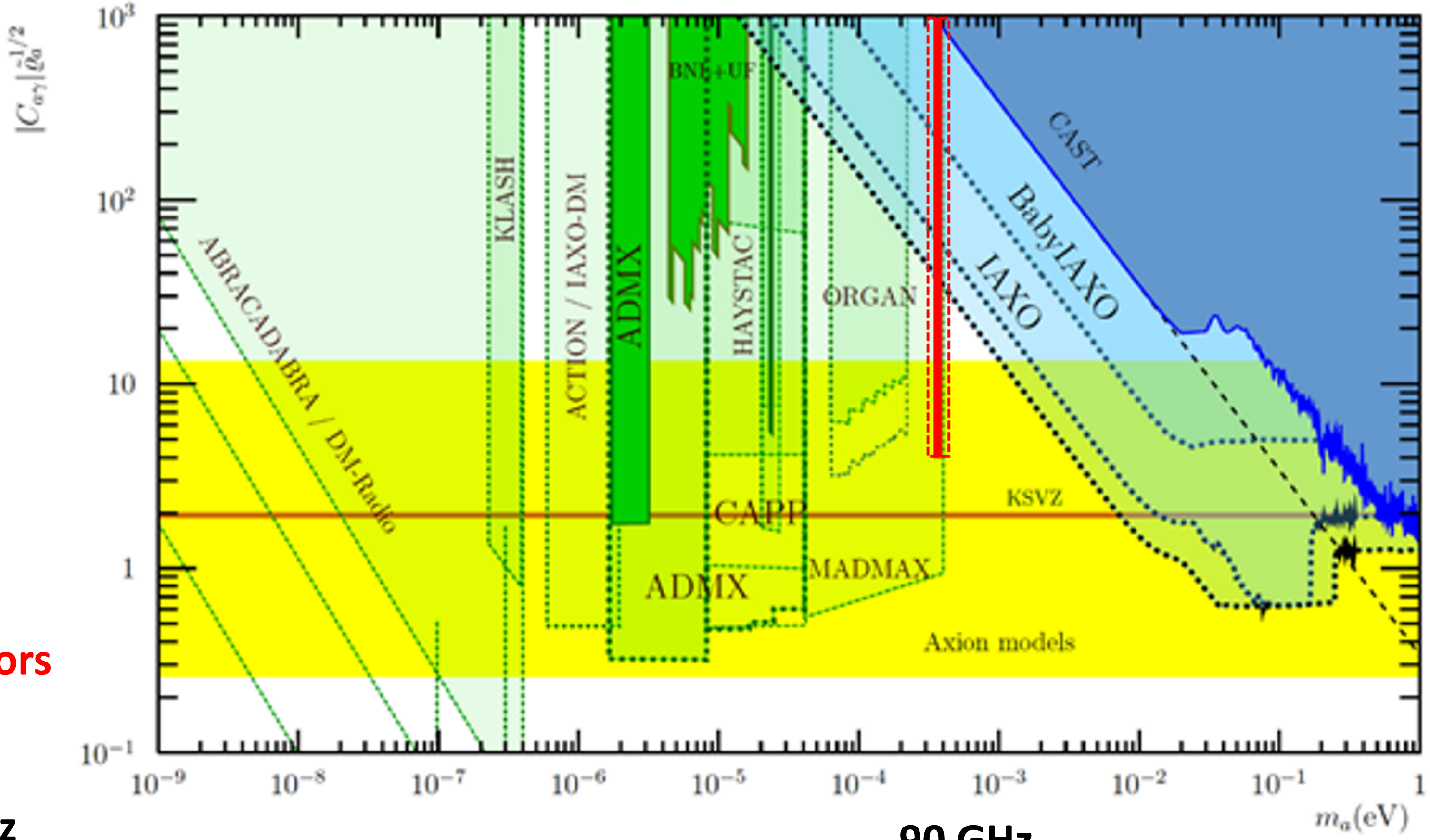
- Inverse Primakoff effect
- Frequency of the photon: $\nu \propto$ mass
- Very narrow line width : $\Delta\nu = \nu x10^{-6}$
- Detection needs cavities (haloscopes)
- Needs very high sensitivity detectors
- Use heterodyne receivers

Very slow search for wide ranges of energy
Most searches below 12 GHz (50 μeV)

Only MADMAX plans to reach up to 100 GHz
But the search will concentrate < 40 GHz
Strongly constraint by the detector sensitivity

Standard quantum limit for heterodyne detectors
At 100 GHz : 2.5 K

Sensitivity searches for axion-photon > 100 GHz
Need to use direct detectors



90 GHz

I.G. Irastorza and J. Redondo., Prog. Part. Nucl. Phys., 2018, 102, 89-159.

The Canfranc Axion Detection Experient (CADEX)

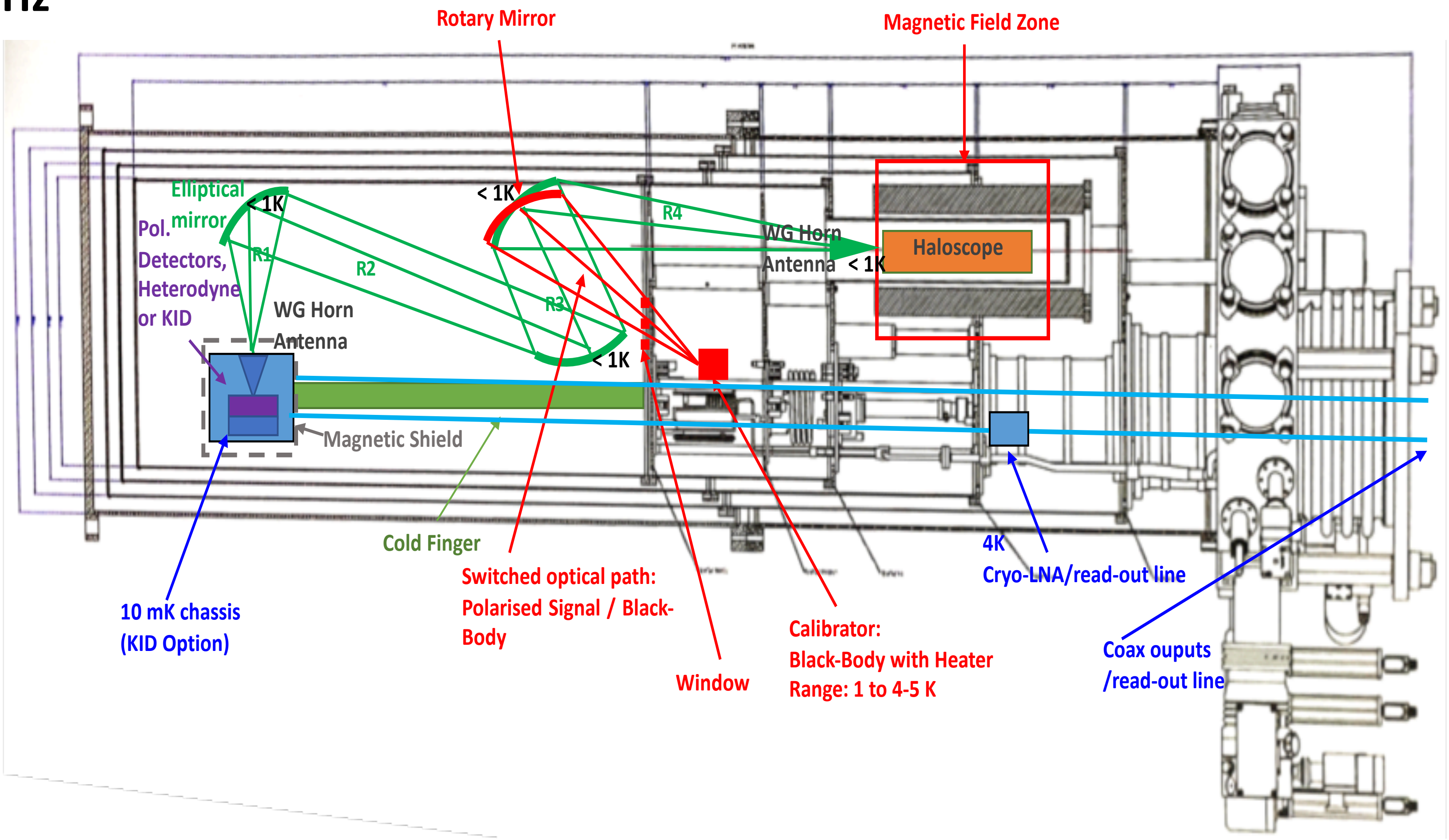
Search for axions with mass 330-460 μeV
Axion-photon frequencies 86- 111 GHz

Innovation

- **Use polarization versus frequency**
- **Broadband detectors: breaks SQL**

CADEx:

- **Magnetic field + haloscope: < 0.1 K**
- **Optics : 1 K**
- **Detector system: mK**
- **Calibration system : blackbody 1-4 K**

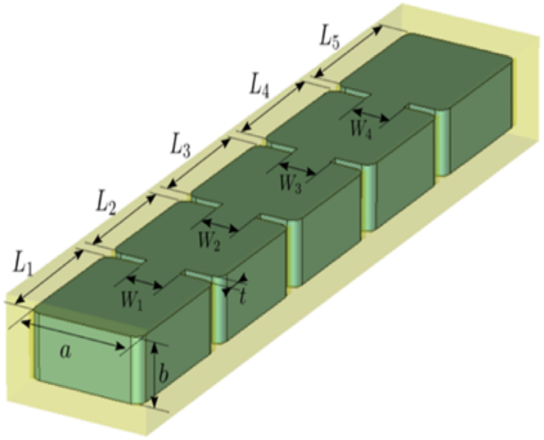


The Canfranc Axion Detection Experient (CADEX)

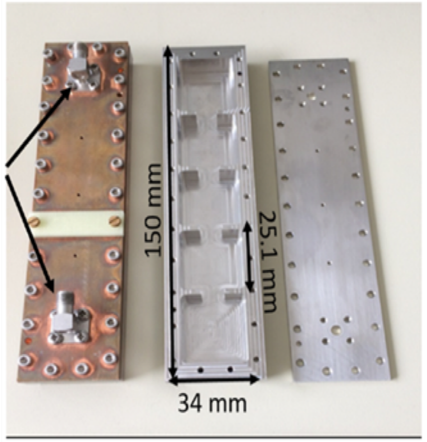
Magnetic field : 10 Tesla

Haloscope

- Based on RADES multi-cavity haloscope (8.4 GHz)
- Parallelized haloscope of N cavities
- Maximize volumes to increase the sensitivity



RADES



CADEX 3.4 mm

Optics

- Quasi-optical guiding system composed of mirrors and horn antennas.

Detector system

- Heterodyne receivers: HEMT amplifiers or SIS mixers+ HEMT amplifiers: Trec = 25-30 K
- Direct detectors: Kinetic Inductance Detectors (KIDs): NEP of $3.8 \cdot 10^{-19}$ W/√Hz

Calibration system

- Blackbody with temperature: 1-4 K

The Canfranc Axion Detection Experient (CADEX)

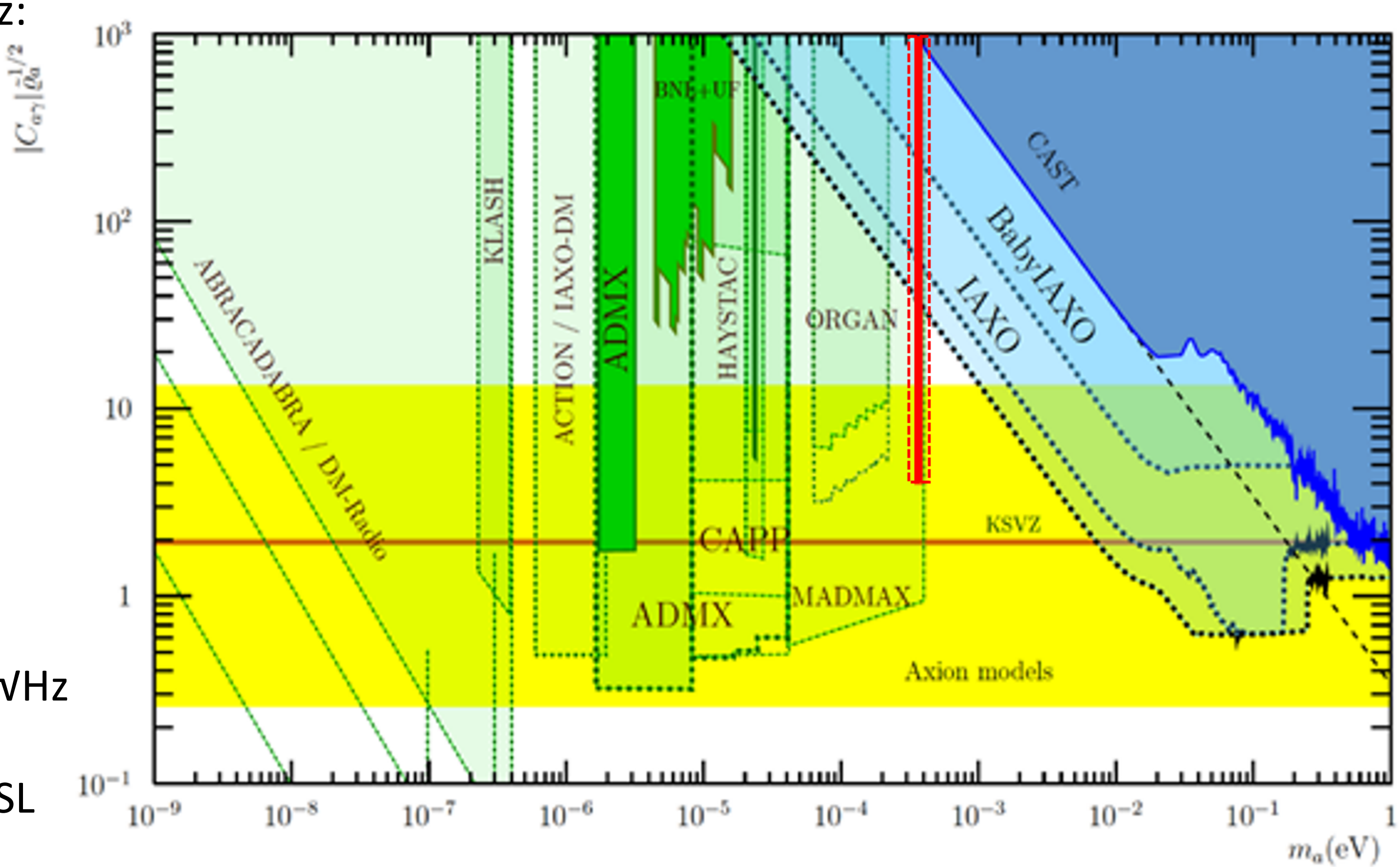
Expected sensitivity for CADEx baseline : 0.2 liter haloscope with magnetic field of 10 Tesla

- Heterodyne: T=25-30 K or KIDs: NEP $=10^{-19}$ W/√Hz:
  1 year integration will cover 9 MHz
  1 GHz will be prohibitive

- Near future improvements in sensitivity
  No improvement expected in heterodynes
  KIDs can reach NEP $=10^{-20}$ W/√Hz:
  10 years integration will cover 10 GHz

Long term improvements in sensitivity

- Explore broadband haloscopes
- Quantum Capacitance Detectors: NEP < 10^{-20} W/√Hz
- Single Photon Detectors : NEP < 10^{-20} W/√Hz
- Travelling Wave Parametric Amplifiers close to QSL

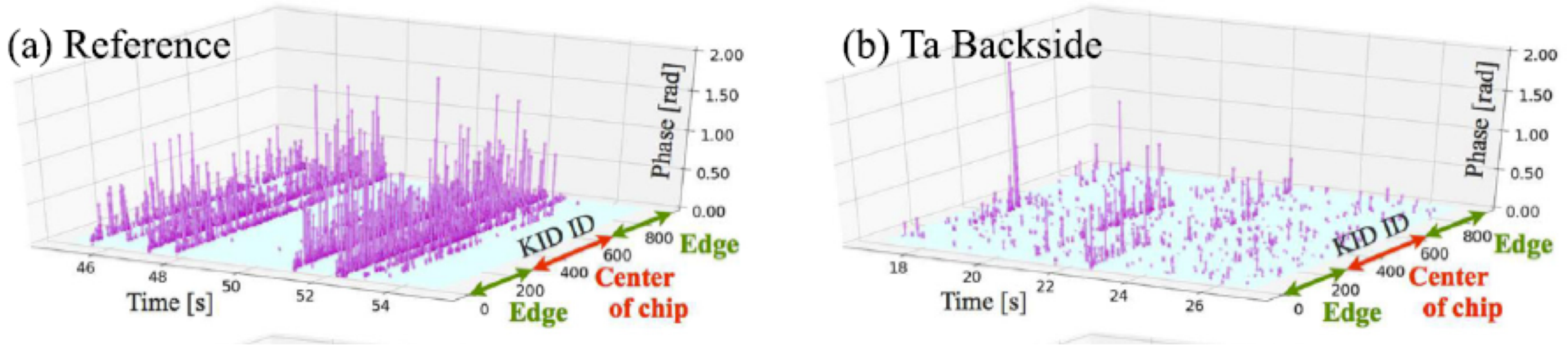


I.G. Irastorza and J. Redondo., Prog. Part. Nucl. Phys., 2018, 102, 89-159.

Need of the Laboratorio Subterraneo de Cranfranc

- **According to axion models: extremely low-level signal (10^{-24} - 10^{-22} W)**
- **Need to use superconducting detectors like KIDs operating at mK**
- **Superconducting detectors are sensitive to Cosmic rays (Cooper pair breaking)**

NEP of 3×10^{-19} W/√Hz



K. Karatsu et al, Appl. Phys. Lett. **114**, 032601 (2019)

- **CRs will introduce systematic effects due to measurements in two independent arrays (polarizations)**
- **Removing the effects of CRs tails (data editing) is extremely complicated for detectors with NEPs of < 10^{-20} W/√Hz to reach a sensitivity of 10^{-24} W**

LSC facility with a CR flux of 10^{-4} times that at the surface guarantees to reach signal levels of 10^{-24} W for NEPs of 10^{-20} W/√Hz

Request to the LSC. Dilution Cryostat

Ultimate sensitivity of CADEx requires a dilution cryostat with the following specifications:

- A magnetic field of 10 Tesla @ 4K
- A volume of $\Phi \geq 15$ cm and length ≥20 cm @ 0.1 K with uniform magnetic field to accommodate the haloscope.
- Plate @ few mK to accommodate the focal plane detectors
- Plate @ 1 K to accommodate the optics and the calibration source
- Magnetic shielding of the focal plane detectors

Request to the LSC. Schedule & support

Three different phases:

<u>1) Demonstration phase (2 years). Occasional use</u>

- Cryostat acquisition, installation and operation. Demonstration of key technology (haloscope, detectors, .) in lab.
- Need few weeks to test critical aspects involving the magnetic field (haloscope, **shielding**,..)

2) <u>Pathfinder phase (3 years). Dedicated use in the last year</u>

- First prototype of CADEx and installation in the LSC facility in the first 2 years (haloscpe + KIDs+calibration)
- Need few times a couple of weeks:
    - To test the functionality with the magnetic field
    - To install and commissioning the experiment.
- During the last year, the pathfinder experiment will be carried out.

3) <u>Operation phase (10 years). Dedicated use</u>

- Upgrade the experiment to improve the sensitivity & efficient non-resonant waveguide haloscope
- Installation & Commissioning
- Operation to cover 10 GHz

Support by the LSC staff for installation and running the experiment

Conclusions

We propose to use LSC facility to carry out CADEx

The lows CRs flux at LSC together with specified mK dilution cryostat will allow:

- **To lead the axion search in the 330-460 μeV mass range**
- **Provide relevant limits to the axion existence in the mass range between 330 and 366 μeV**
- **To implement a solid program for technology developments to improve the CADEx sensitivity**
- **Potential to easily expand to higher masses (frequencies)**