QUANTUM TECHNOLOGIES

in DRD5

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Quantum sensing

Use of a quantum system, quantum properties or quantum phenomena to perform a measurement of a physical quantity.
High sensitivity and precision.

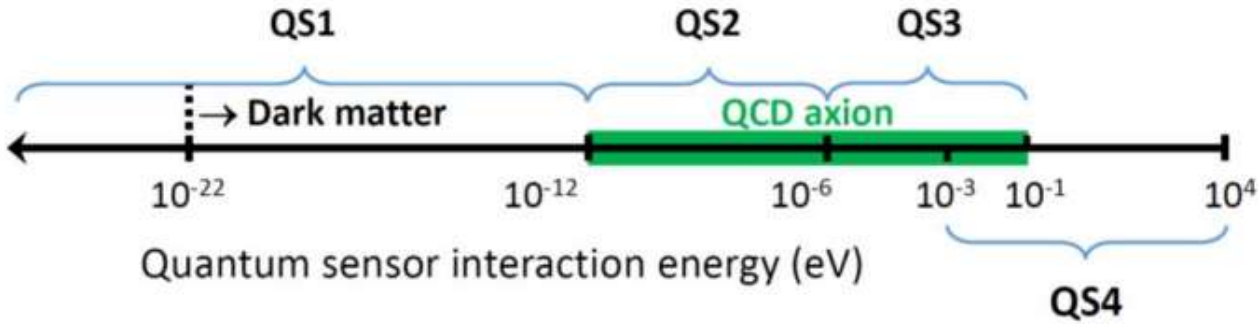
Rev. Mod. Phys. 89, 035002 (2017)

Quantum Sensors and HEP Science

- Ultralight wavelike dark matter (generalized axions, hidden photons, scalars)
- Scattering / absorption of dark matter particles
- Electric dipole moment measurements (electron, nuclear, neutron)
- Gravitational waves
- Dark energy
- Violations of fundamental symmetries
- New forces and particles

IF1: **Quantum Sensors Snowmass Instrumentation Frontier Kickoff Workshop** (2020)
by Cecil, Irwin, Maruyama, Pyle

Quantum Sensors by Interaction Energy



Dark Matter Energy Range

- **QS1 (0 eV - 1 peV) - wavelike interactions**
  - Atomic & molecular spectroscopy, atom interferometers and mechanical sensors, clocks, atomic magnetometers, spins, quantum defects in solids
- **QS2 (1 peV - 1 microeV) - wavelike interactions**
  - Nuclear, electronic, and other spins, electromagnetic quantum sensors, optical cavities, quantum defects in solids
- **QS3 (1 microeV - 0.1 eV) – wave-like interactions**
  - Superconducting qubits / sensors, spins, Rydberg atoms, quantum defects in solids
- **QS4 (1 meV - 10 keV) - particle-like interactions**
  - Low threshhold phonon and charge detectors, quantum defects in solids, single-photon counters (SNSPD, APD, ...) - interface to IF2: Photon detectors, depending on application

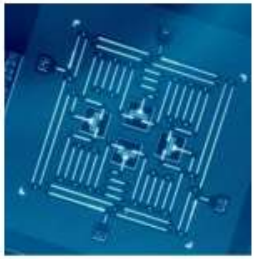
IF1: **Quantum Sensors Snowmass Instrumentation Frontier Kickoff Workshop** (2020) by Cecil, Irwin, Maruyama, Pyle

New concepts and technologies can open new windows into dark sector physics

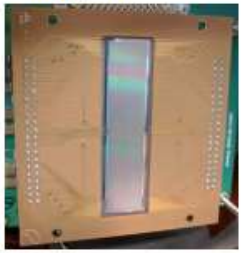
Atomic clocks

SRF Cavity

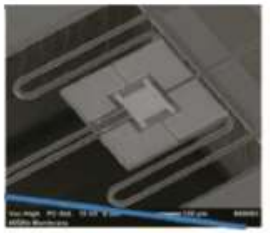
Qubits



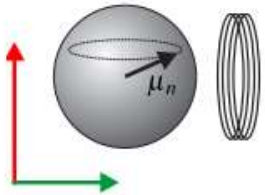
Skipper CCD



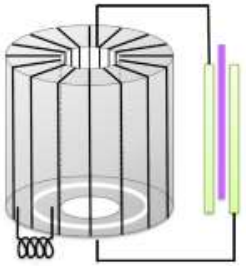
TES



NMR

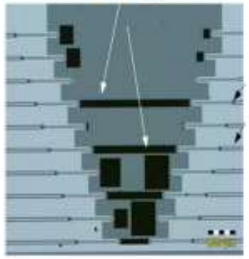


LC Resonators

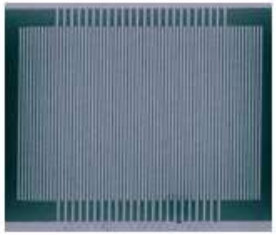


Metamaterials

KIDs



SNSPDs



Emerging Concepts in Dark Matter Detection Tongyan Lin, UCSD **Snowmass 2021** - P5 Town Hall (2023)

QTEP – Quantum Technologies Platform. Instrumento PTI del CSIC.

PTI - Plataformas Temáticas Interdisciplinares

Launched in 2018

T10. Información compleja y digital. Ch.3 *Quantum Computing* (2021)

Información compleja y digital | Desafios 2030 CSIC

QS4DM. Quantum Sensors for Dark Matter Searches

Proyecto Nacional del Plan de Recuperación

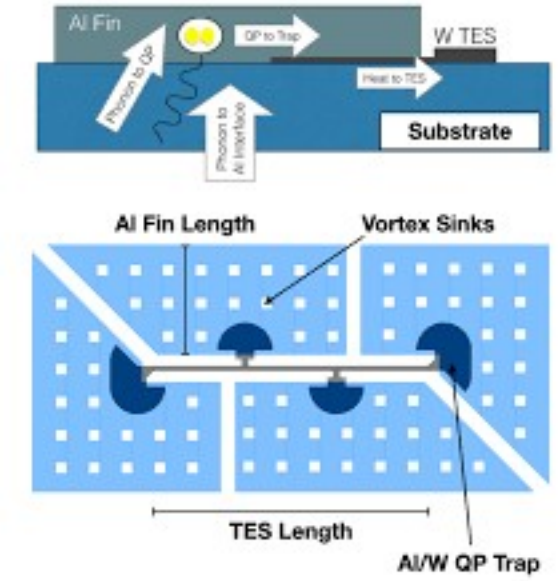
'*Aplicaciones de las Tecnologías Cuánticas a la Industria*'

T9. Entender los componentes básicos del Universo (2021)

Entender los componentes básicos del universo | Desafios 2030 CSIC

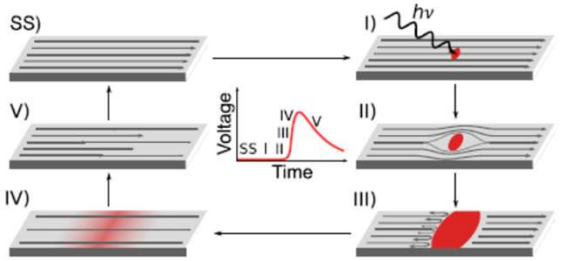
QS4DM. Quantum Sensors for Dark Matter Searches

- **Athermal Phonon Sensor (Threshold ~ 100meV)**
- **SNSPD**
- **Dark Matter Ghost Imaging (Skipper CCD, TimePix4)**



TES, QET de W, Al, Nb…
Sapphire, SiC…

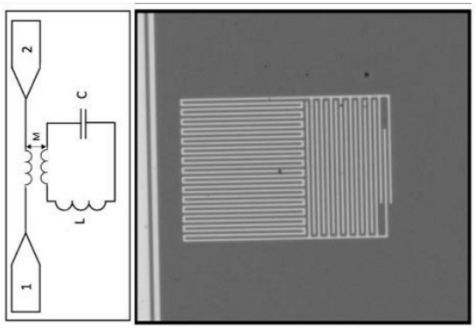
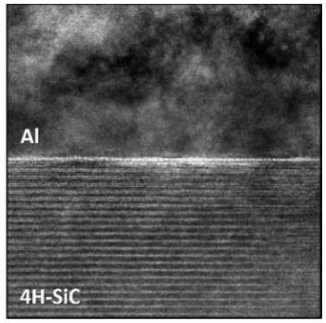
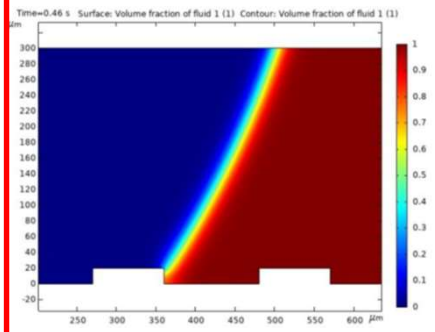
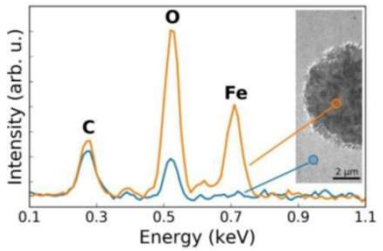
Design and characterization of a phonon-mediated cryogenic particle detector with an eV-scale threshold and 100 keV-scale dynamic range (2021) R. Ren *et al.* Phys. Rev. D 104, 032010 https://journals.aps.org/prd/abstract/10.1103/PhysRevD.104.032010



SNSPD, nanoTES…
Superconducting alloys

Superconducting nanowire single-photon detectors (…) APL 118, 190502 (2021) https://doi.org/10.1063/5.0045990

Fabrication and Integration of Emerging Electronic Devices and Nanomaterials

1. Baseline Technology for Fabrication of Superconducting Devices and Circuits	2. Explorative Hybrid Devices based on 2D Materials and Superconductors	3. Miniaturization of Devices for Unconventional Applications	4. *Micro-Nano Fabrication of Emerging Devices. Magnetoionics*
			
QUANTUM TECHNOLOGIES		*HARSH Appl.*	*Emerging TIC*
TRL 1 - 5		TRL 1 - 7	TRL 1 - 4

Centre Nacional de Microelectrònica IMB

ICRQ. Interaction of Cosmic Radiation with Qubits

Proyecto Plan Estatal (Set. 2022). FPN Area

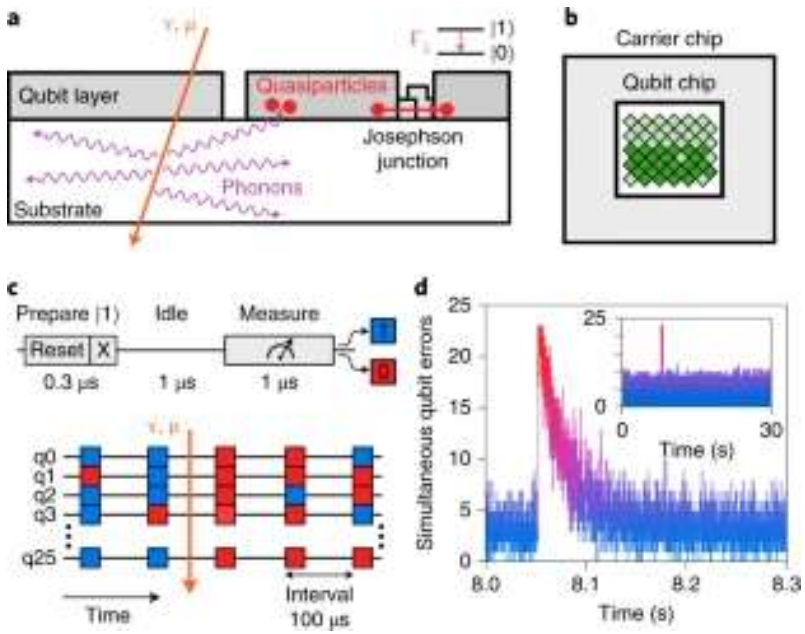
Institut de Física d'Altes Energies

Centre Nacional de Microelectrònica IMB

LSC Laboratorio Subterráneo Canfranc

- **Understanding Effects of Cosmic Radiation in Qubit Decoherence**
- **Apply to Quantum Sensing in HEP**

Superconducting Devices and Circuits
Aluminum JJs



McEwen, *et al.* **Resolving catastrophic error bursts from cosmic rays in large arrays of superconducting qubits.** *Nat. Phys.* **18**, 107–111 (2022). https://doi.org/10.1038/s41567-021-01432-8

IMB-IFAE Co-supervised PhD – Starting in April 2023

NESQQ. Nanofabrication Enhanced Superconducting Qubit Quality

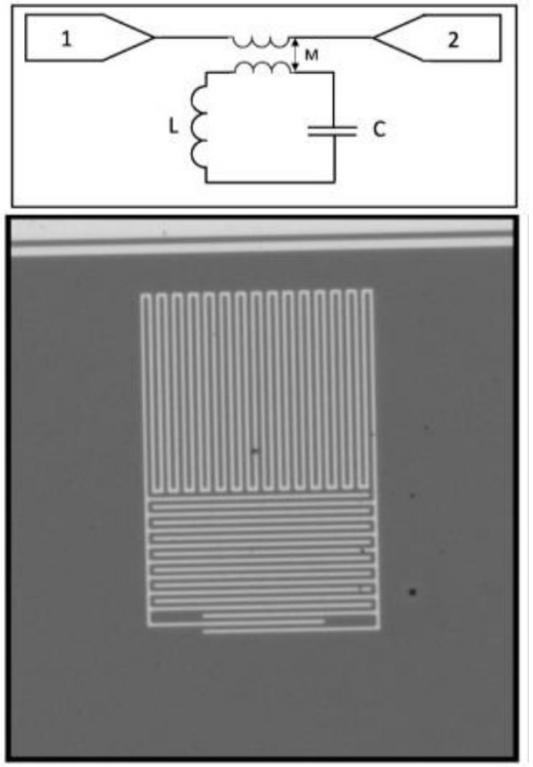
Fondos Recuperación CCAA

Superconducting Devices and Circuits

Institut de Física d'Altes Energies

Centre Nacional de Microelectrònica IMB

- **Resilience and Mitigation of Qubit decoherence on chip**
- **Improvements based on micro/nanofabrication & new materials developments**



Manuscripts in prep - NitrAl for Superconducting Applications; Penetration Depth in Al thin films

HYBQTECH. Proyecto Convocatoria TED

Universidad Autónoma de Madrid

eman ta zabal zazu

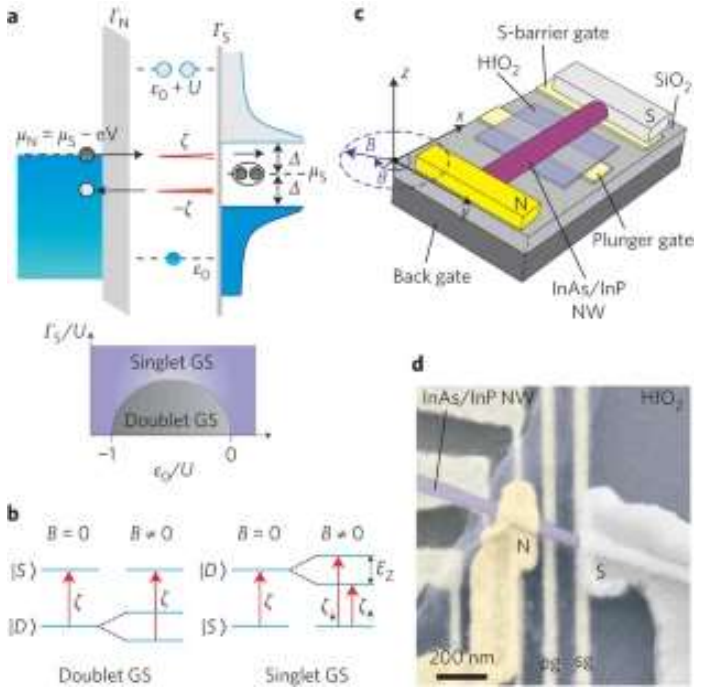
UPV EHU

Centre Nacional de Microelectrònica IMB

CSIC Consejo Superior de Investigaciones Científicas

- **New Physics on Shiba Qubits, for Q Computing**

Nanowire - Thin Films
Semiconductor-Superconductor



Lee, E. *et al.* **Spin-resolved Andreev levels and parity crossings in hybrid superconductor–semiconductor nanostructures**. *Nature Nanotech* **9**, 79–84 (2014). https://www.nature.com/articles/nnano.2013.267

IGOR GARCÍA IRASTORZA

Quantum sensors for the detection of axions in RADES

Physics driver: searches for axion dark matter (5.3.3.1 of the ECFA Roadmap)

Technological challenge:

Detect a tiny MW signal of fixed (but unknown) frequency, out of a large an strong B field.

Open challenges being addressed:

(mostly DRDT 5.2 of the ECFA roadmap)

More specifically, we aim at developing/applying:

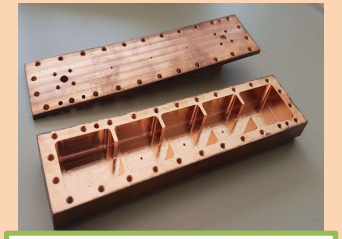
1. **Linear amplification of small microwave signals with quantum-limited sensitivity**
2. **Sensors with single photon counting capability at frequencies of ~10 GHz, based on novel superconducting qubit designs (transmons)**
3. **Implementation in real setups (B-resiliency, non-thermal noise, tuning,…)**

RADES

- **Exploratory project emerged at a later stage of CAST life: use of "helioscope" magnets for "haloscope" searches**
- **Creation of "axion haloscope" community in Europe.**
- **Also design + prototyping of setup to be hosted in the BabyIAXO magnet**

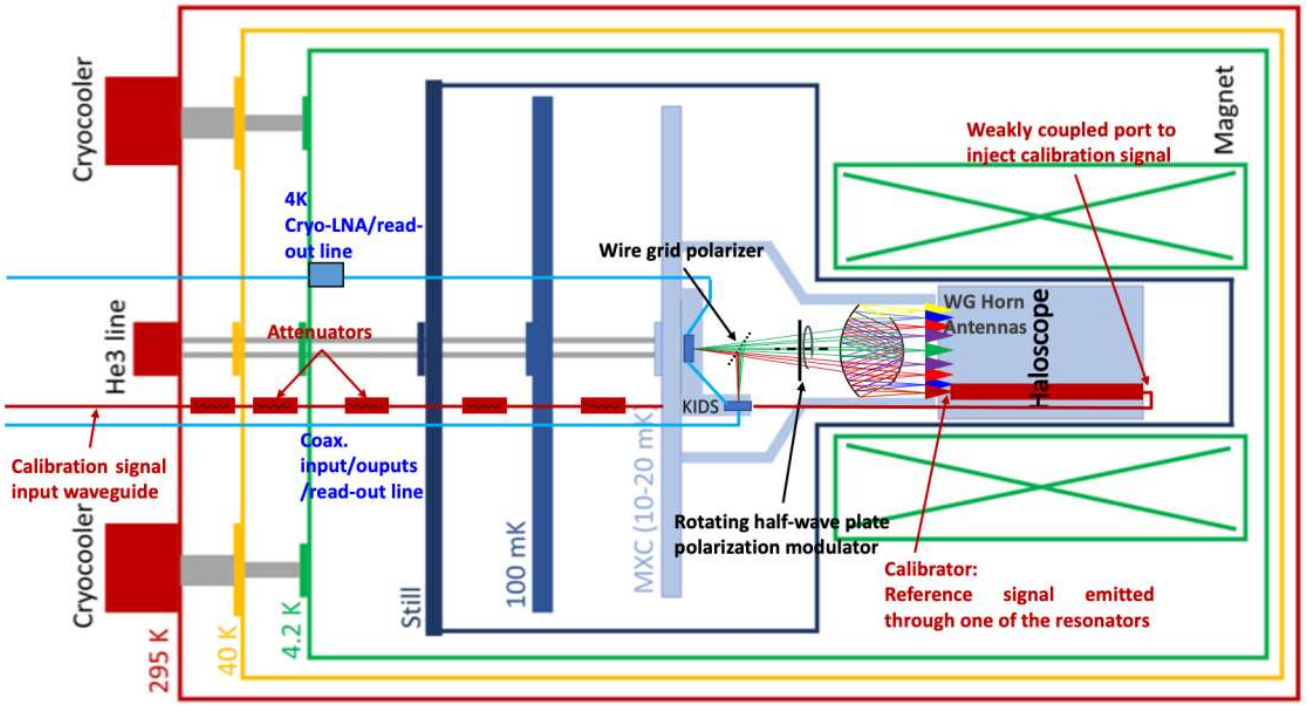
- **Spanish groups active: CAPA/Zaragoza, ICCUB, UPCT/Cartagena, ITA/Zaragoza**

ERC-StG 2018 (B. Dobrich, CERN)

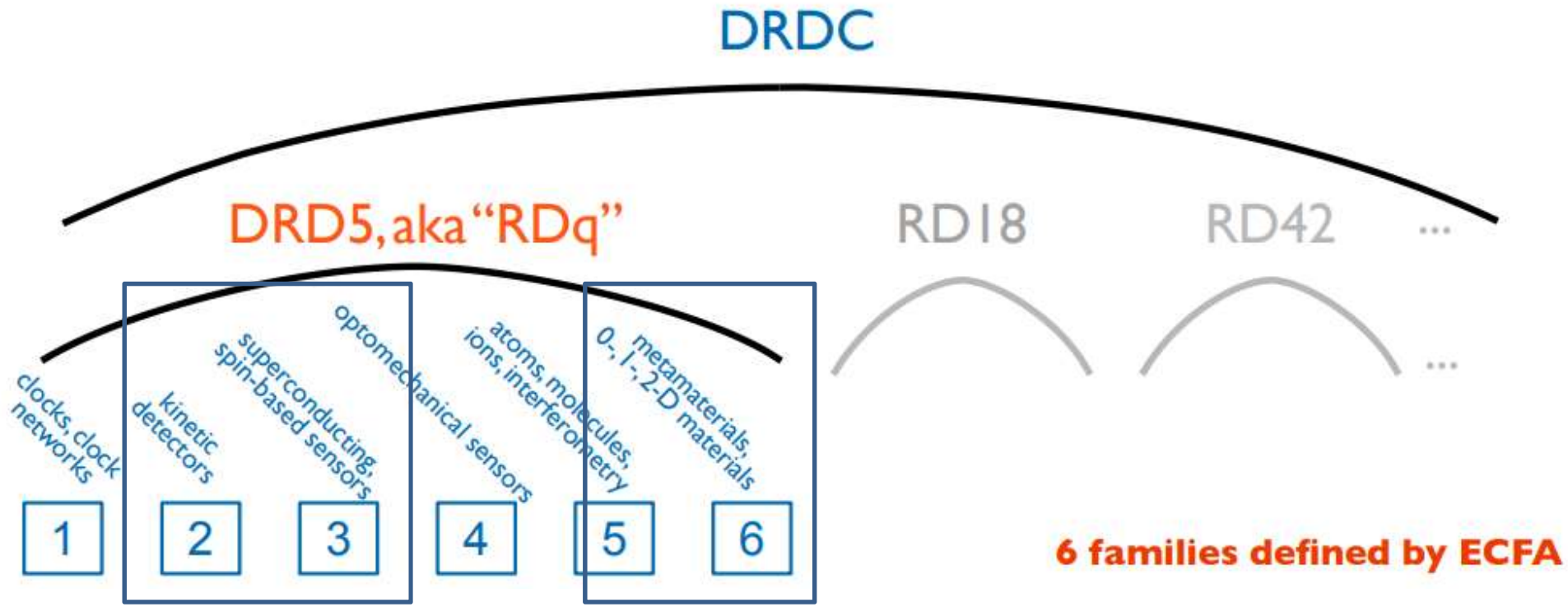


JCAP 05 (2018) 040
JHEP 07 (2020) 084
JHEP 21 (2020) 075
IEEE Trans. Appl. Supercond. 32 (2022) 45

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



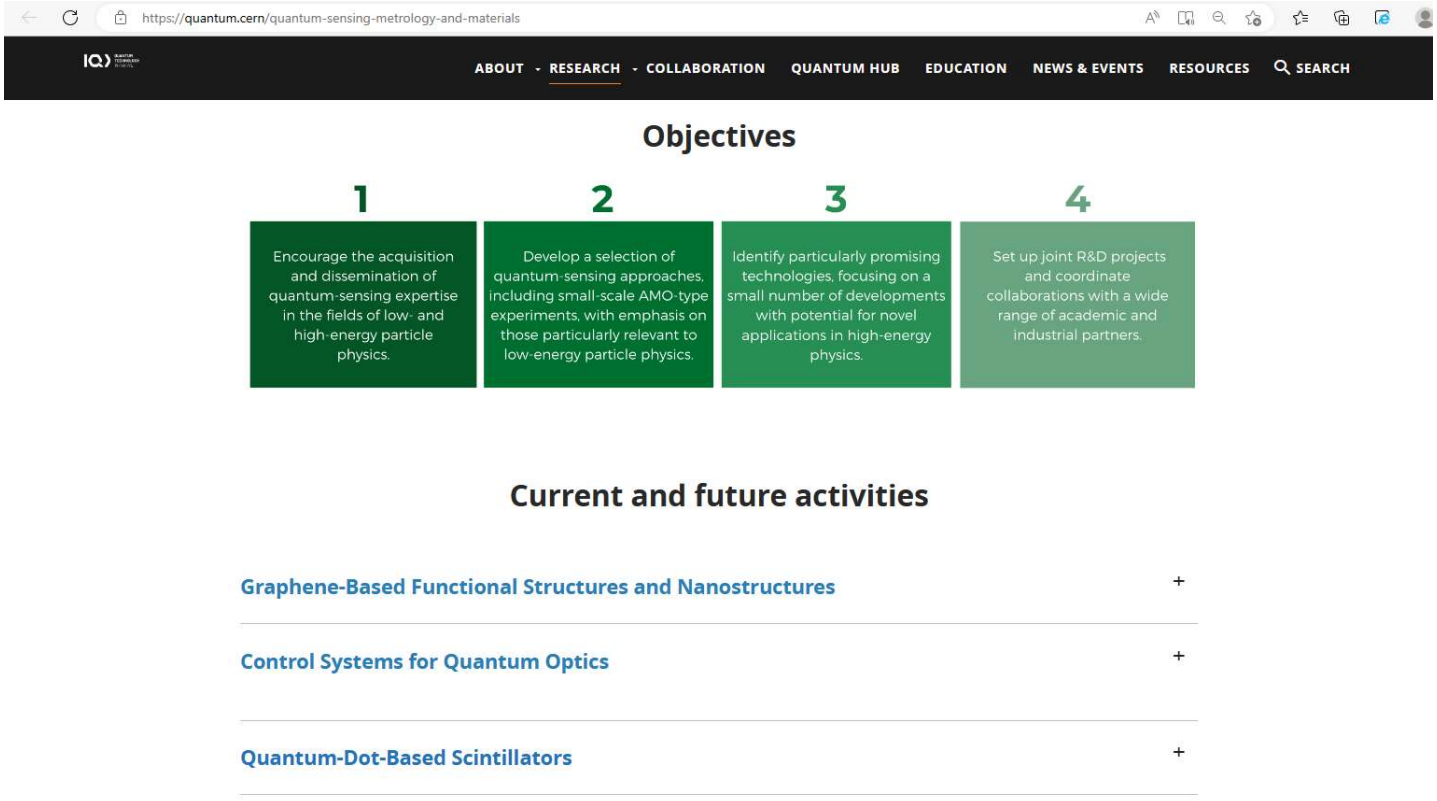
DRD5 – RDq. Implementation of the EFCA Roadmap



Additional Technology Platforms @ IMB-CNM-CSIC

- Graphene based.
  - Internal Collaboration. Graphene integrated on conventional detectors (Si & SiC)
  - IMB-BIST (IFAE-ICN2). Stand alone or integrated graphene transistors
- Potential collaborations - IMB-ICN2 on Graphene-TIs
- Previous device developments on CNTs FETs. Currently also NWs
- WBG materials for color centers (Quantum defects in solids)

- **To establish a working group on Quantum Sensing/Tech for FPN/HEP**
- **Proactively fit with CERN. Proposals and collabs within DRD5**
- **Survey opportunities within CERN QTI**



[Welcome | CERN QTI (quantum.cern)]