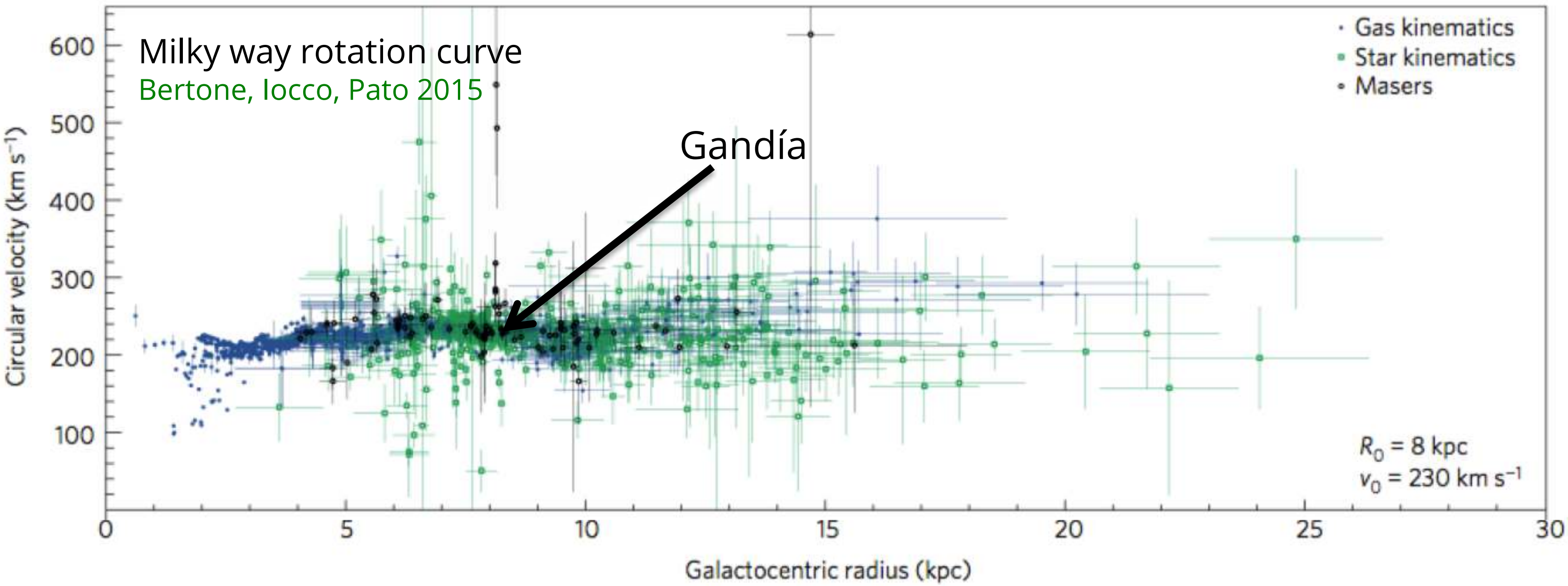
Low mass dark matter searches in SuperCDMS and characterisation of the Migdal effect

DAVID G. CERDEÑO
ELÍAS LÓPEZ-ASAMAR

There is Dark Matter here and now!

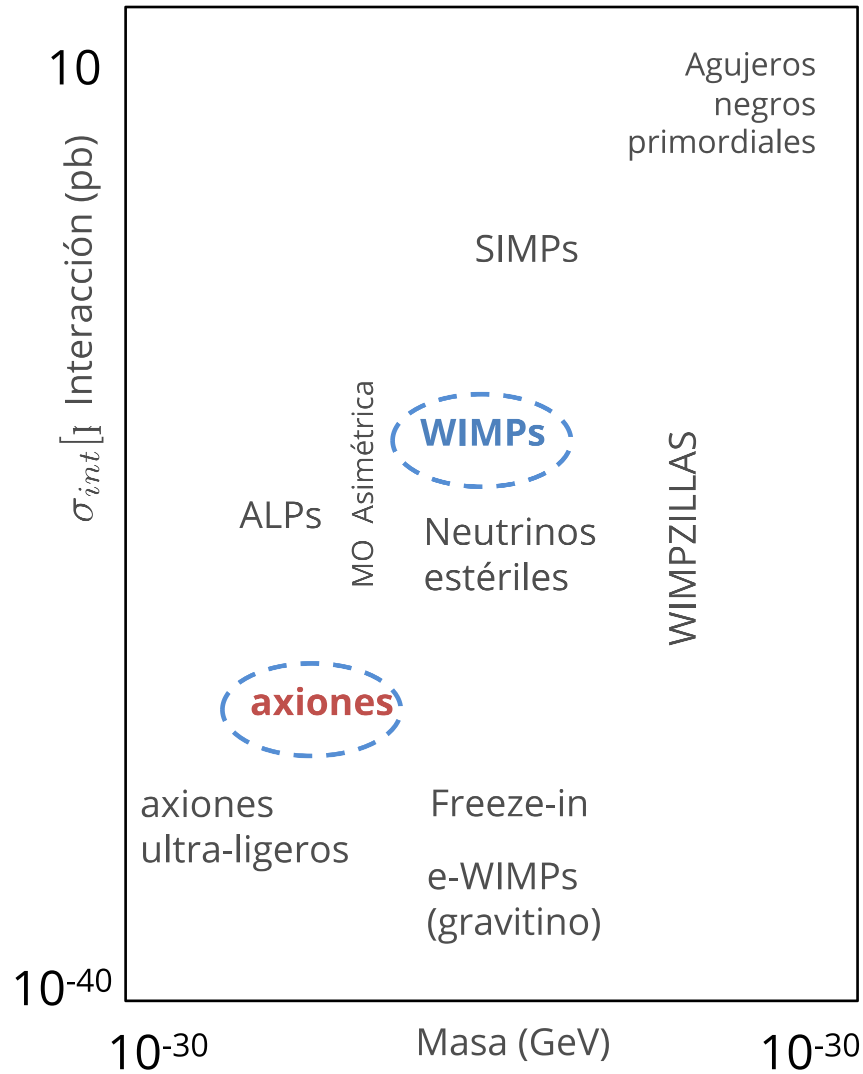


Every second, **20 picograms** of dark matter cross this room

There are multiple ways to ”solve” the Dark Matter problema, and these solutions imply different cosmological histories

- **Thermal decoupling**: **WIMPs**
- **Out of equilibrium production (FIMPs and other eWIMPs)**
- **Axions**
- **Primordial BHs**

What is the particle model for DM?

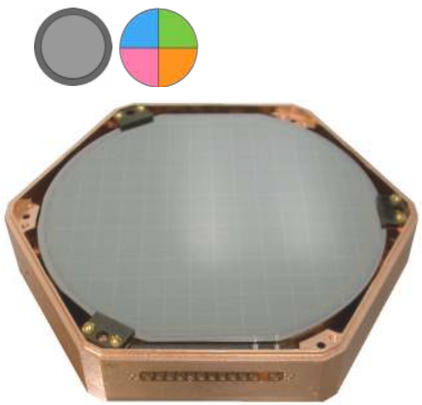


2009 | 2011 | 2015 | 2024

CDMS II — SuperCDMS Soudan — SuperCDMS SNOLAB

4.6 kg Ge (19 x 240 g)
1.2 kg Si (11 x 106g)

3” diameter
1 cm height



9.0 kg Ge (15 x 600g)

3” diameter
2.5 cm height

25.2 kg Ge (18 x 1.4 kg)
3.6 kg Si (6 x 0.6 kg)

4” diameter
3.3 cm height

SuperCDMS SNOLAB

The new experiment is being installed at SNOLAB at about 2 km depth (6000 mwe). Includes more active volume, improved detectors and specific detectors for light MO.

Two materials are included: germanium and silicon.

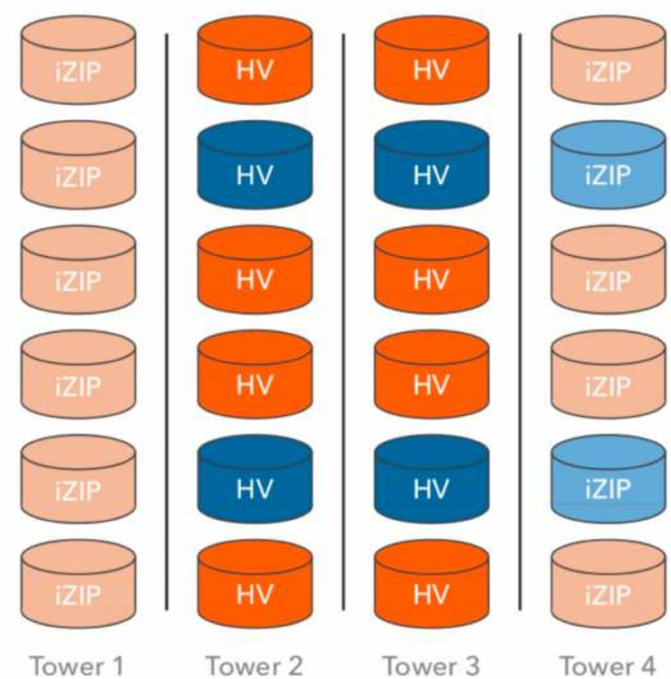
iZIP: Ionisation + Phonons

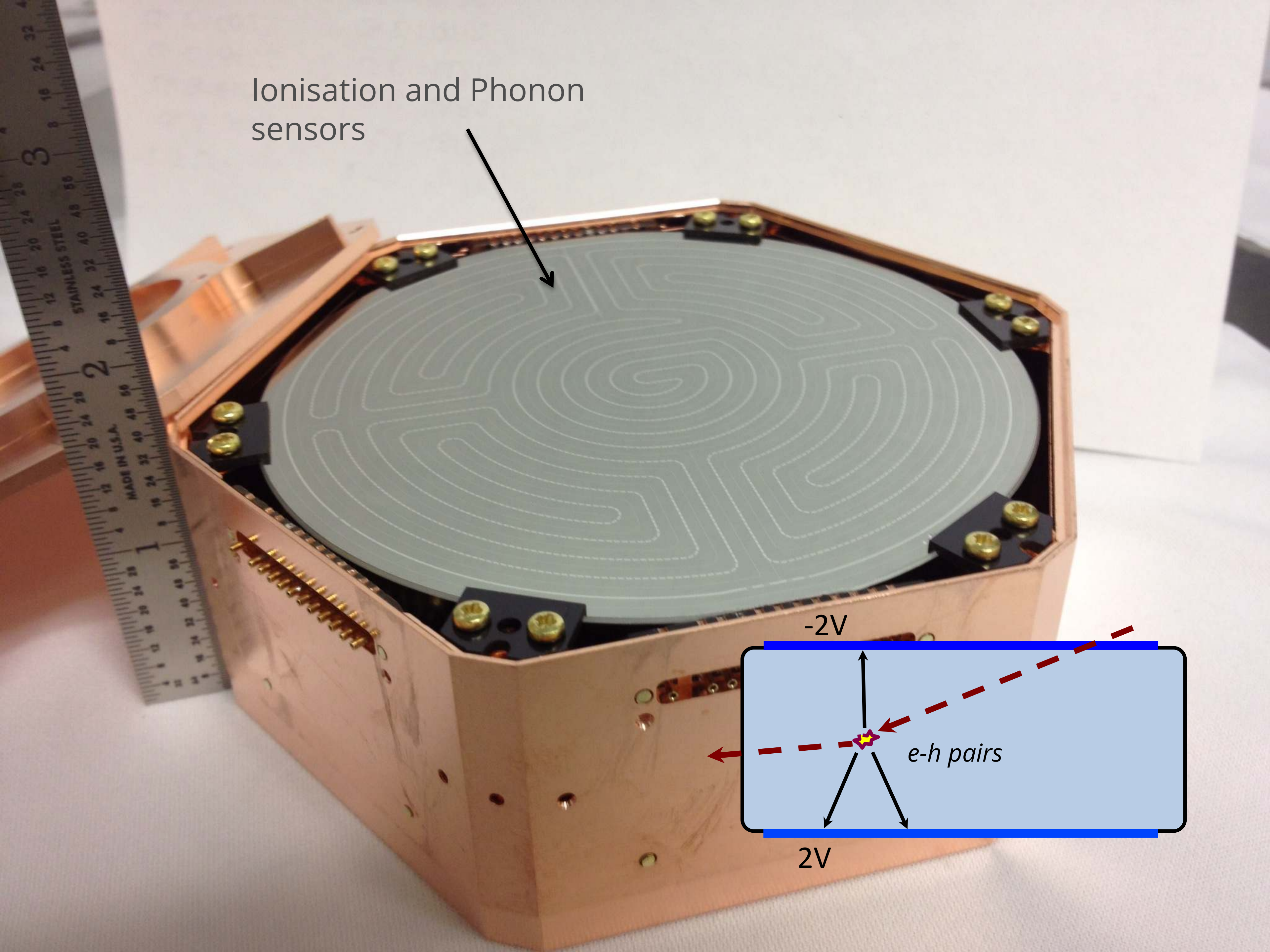
Discrimination of nuclear recoils (NR) and electronic recoils (ER) of $1/10^5$

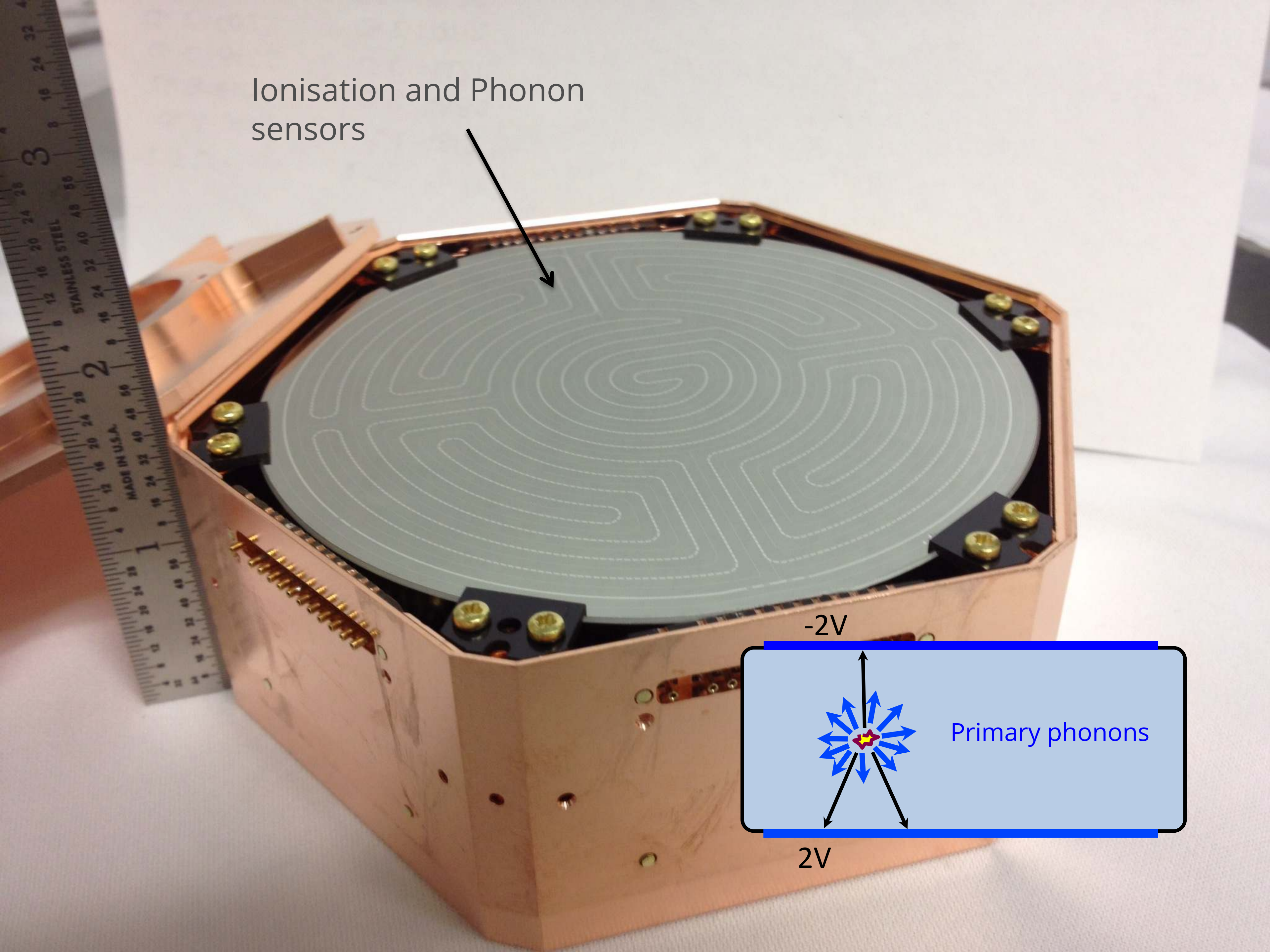
HV: Phonons (High Voltage)

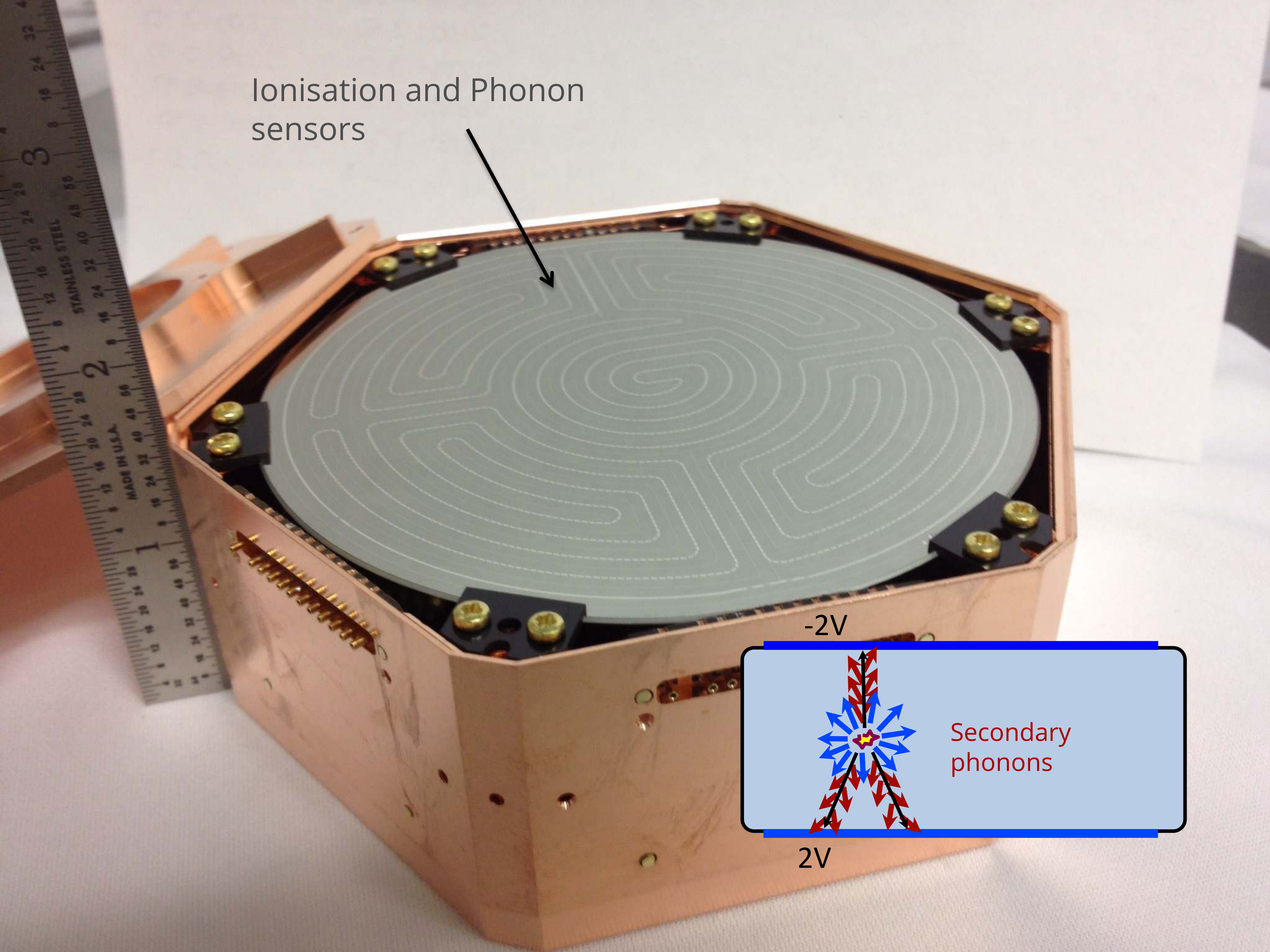
They amplify the signal by applying high voltage. Increases sensitivity to light MO (at the cost of sacrificing discrimination)

4 torres de cristales de germanio (1.4 kg) y silicio (0.6 kg)




Ionisation and Phonon sensors
-2V
e-h pairs
2V

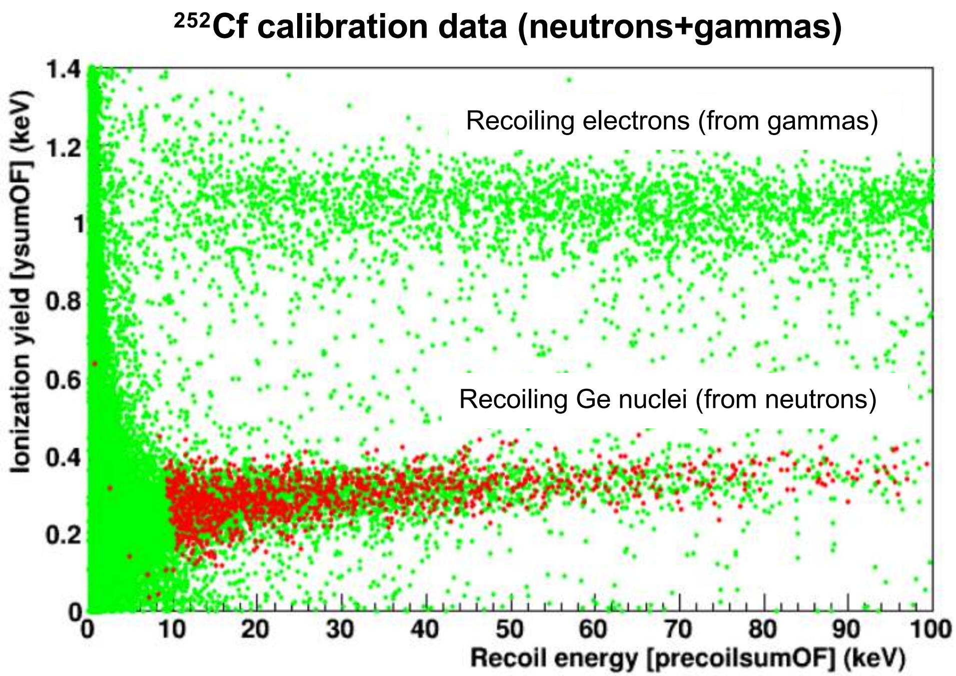

Ionisation and Phonon sensors
-2V
Primary phonons
2V


Ionisation and Phonon
sensors
-2V
Secondary
phonons
2V

Ionization yield (Y): fraction of deposited energy used to produce charge, depends on type of recoiling particle (suppressed for nuclei)

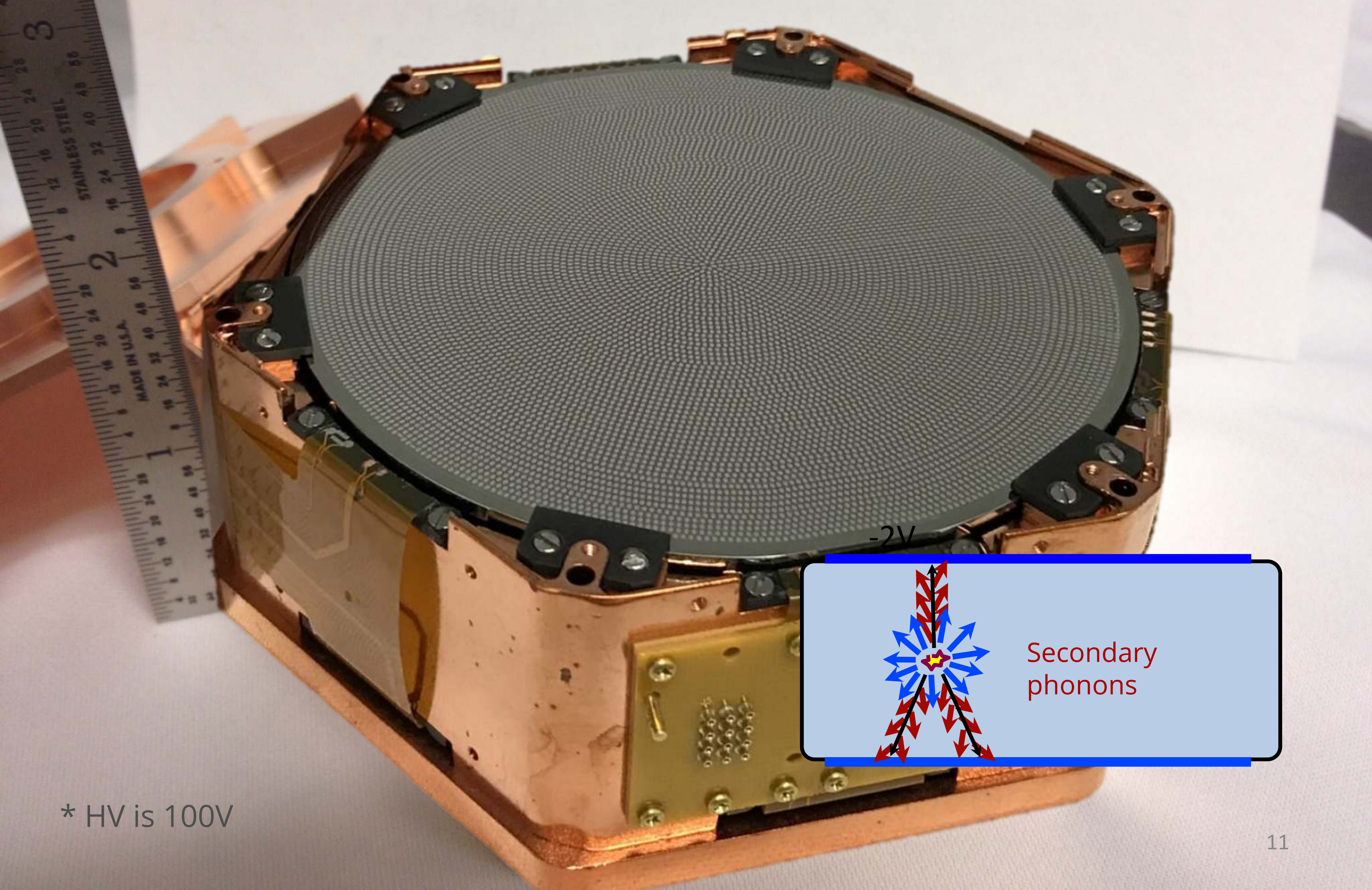
iZIP detectors: measure both Nq and EP to determine recoil energy (ER) and Y

Feature **particle discrimination**, but threshold on ER is limited by measurement of Nq




HIGH
AC/DC
VOLTAGE

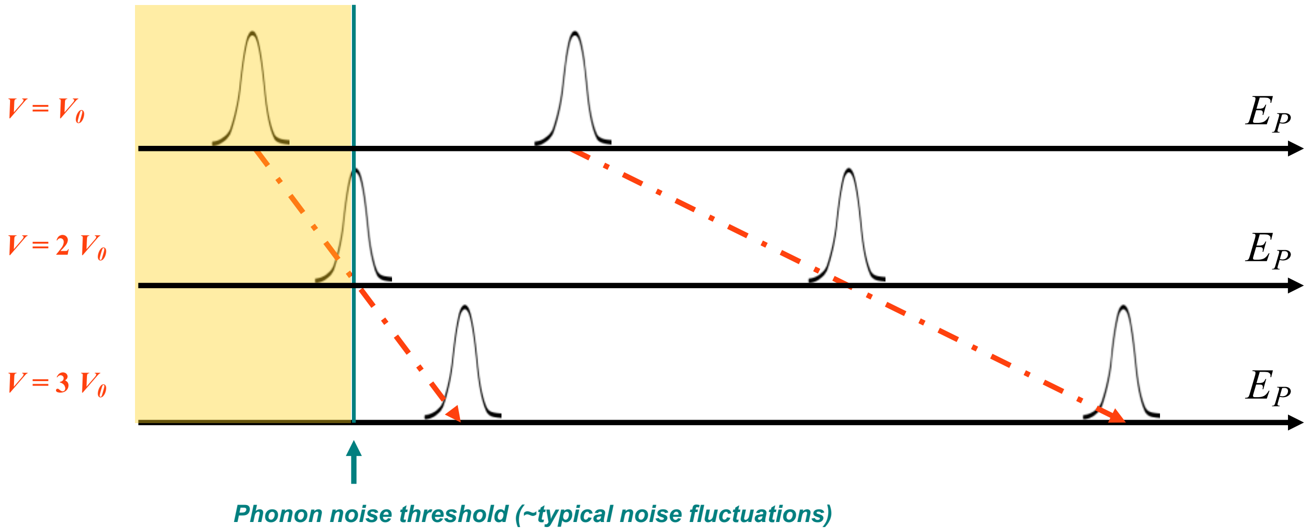
High Voltage (HV) Detector*



* HV is 100V

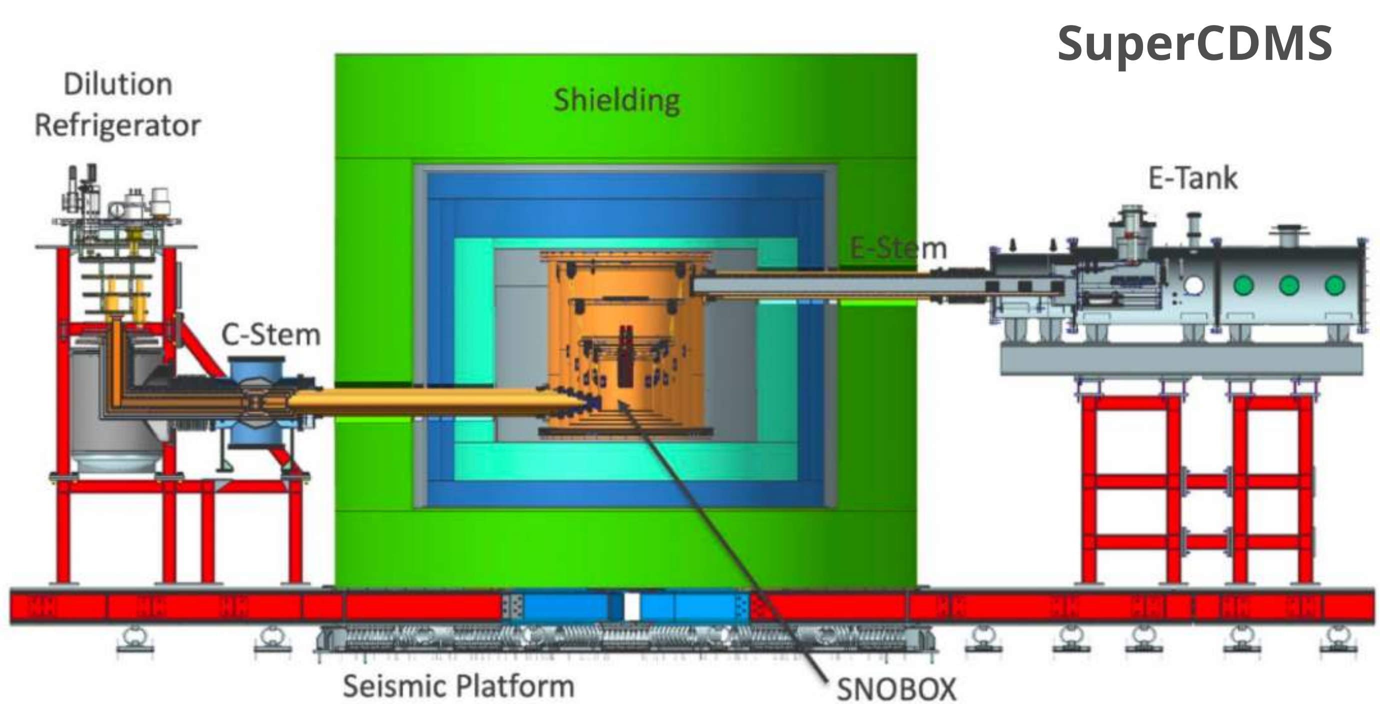
Neganov-Trofimov-Luke (NTL) amplification: phonon energy is increased if external voltage (V) is applied, $\Delta E_P \sim V E_R$

HV detectors: apply high voltage to induce NTL amplification, and measure EP only
Therefore, threshold on ER is effectively decreased



SuperCDMS SNOLAB

- Base of the shielding installed.
- Dilution refrigerator installed (10 mK reached this year)
- 2 detector towers in SNOLAB (2 more expected during 2023)
- Comisioning expected autumn 2024



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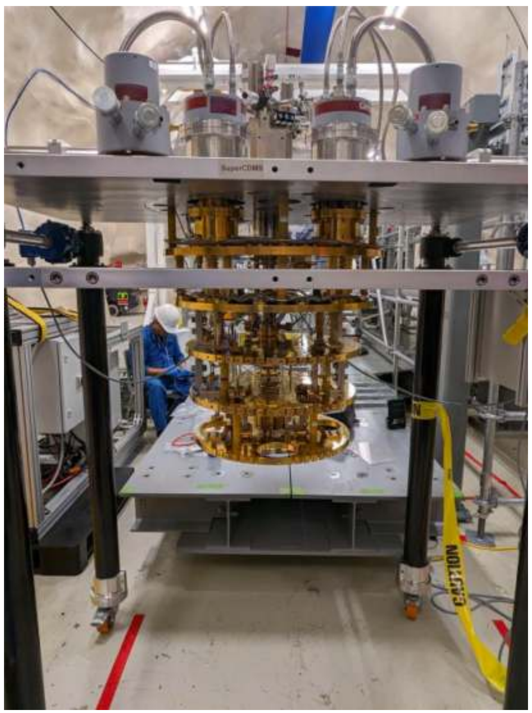
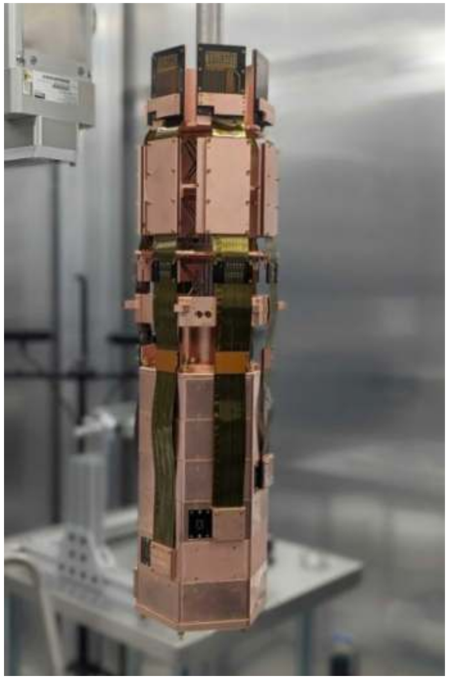
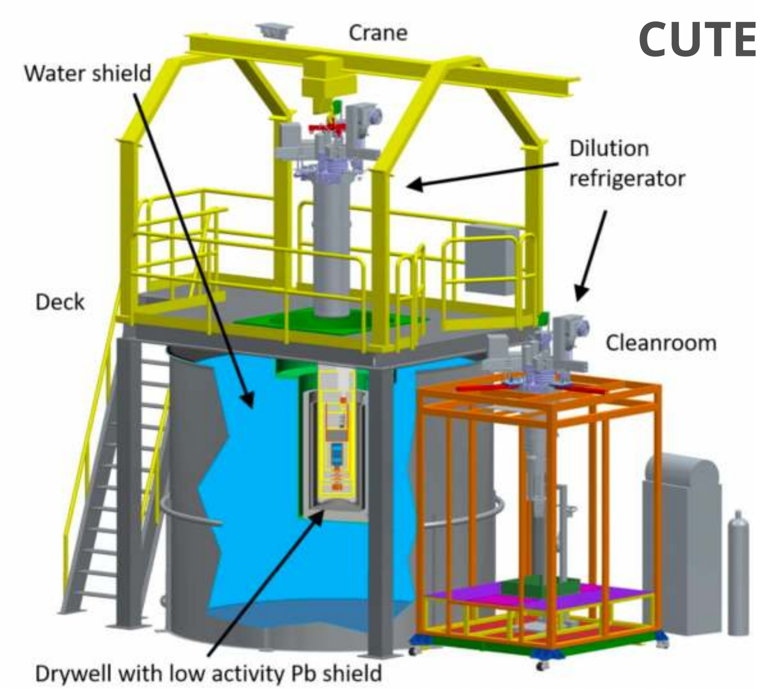


Elías López-Asamar y David Alonso during base shielding installation (May 2023)

We plan to test a first towe in **CUTE** (a test facility at SNOLAB).
First science analysis expected with data collected Nov 2023

We are currently testing a HV tower (that is cold since this week)



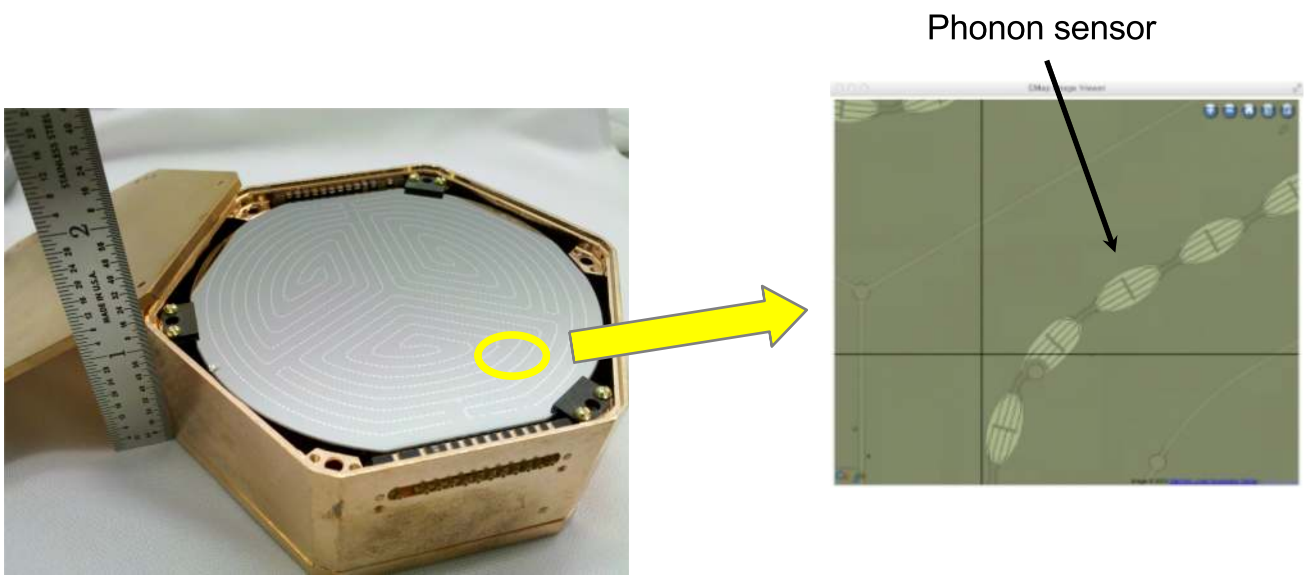


Analysis of phonon channel data

The UAM group is involved in the upcoming detector tests at CUTE
In particular, will contribute to analysis of phonon channel data:

- Characterization of transition-edge sensors (R. López Noé, ELA)
- Measurement of phonon collection efficiency (M. de los Ríos)

This work is considered as a starting point to involve the UAM group in the early science analyses with detector test data

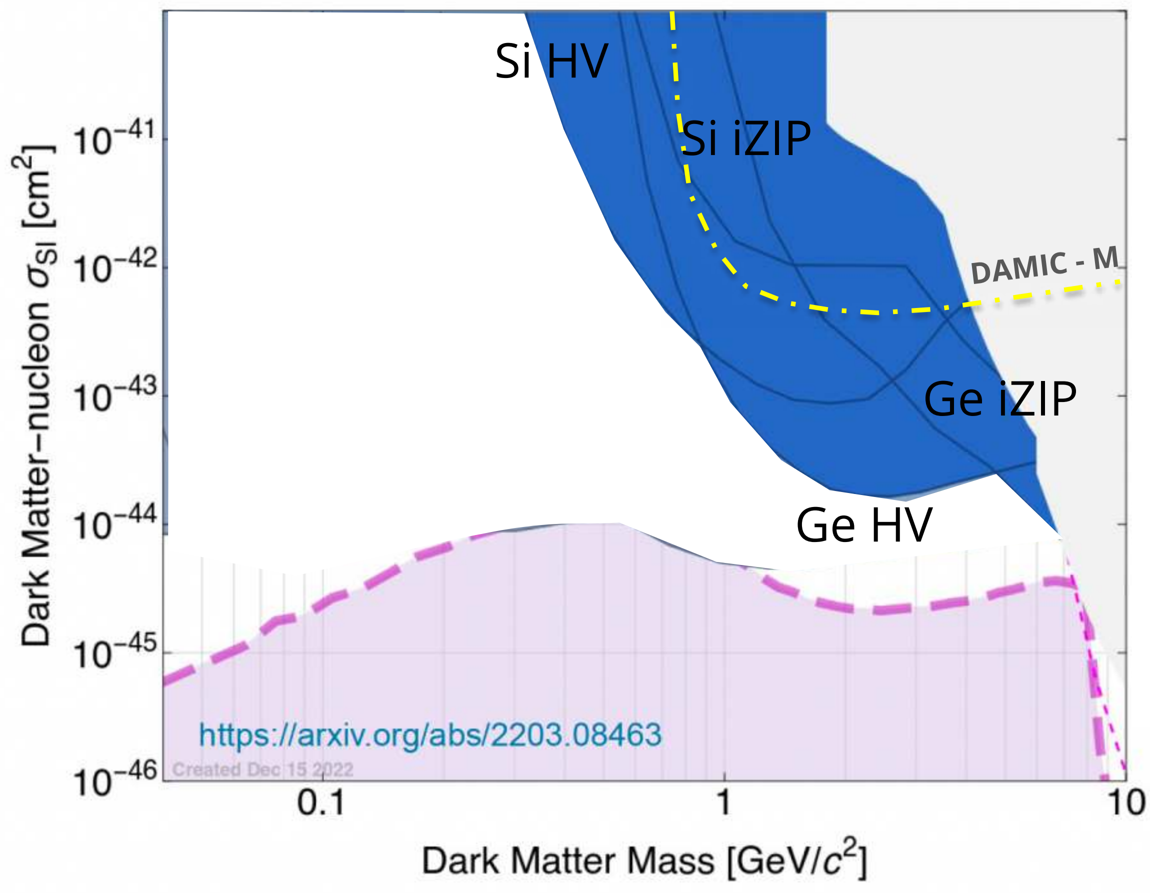


SuperCDMS projected sensitivity (nuclear recoils)

SuperCDMS will explore new regions with low-mass DM, with excellent sensitivity below 1 GeV.

Ge and Si targets explore complementary areas

Sensitivity improvement in Effective Theories



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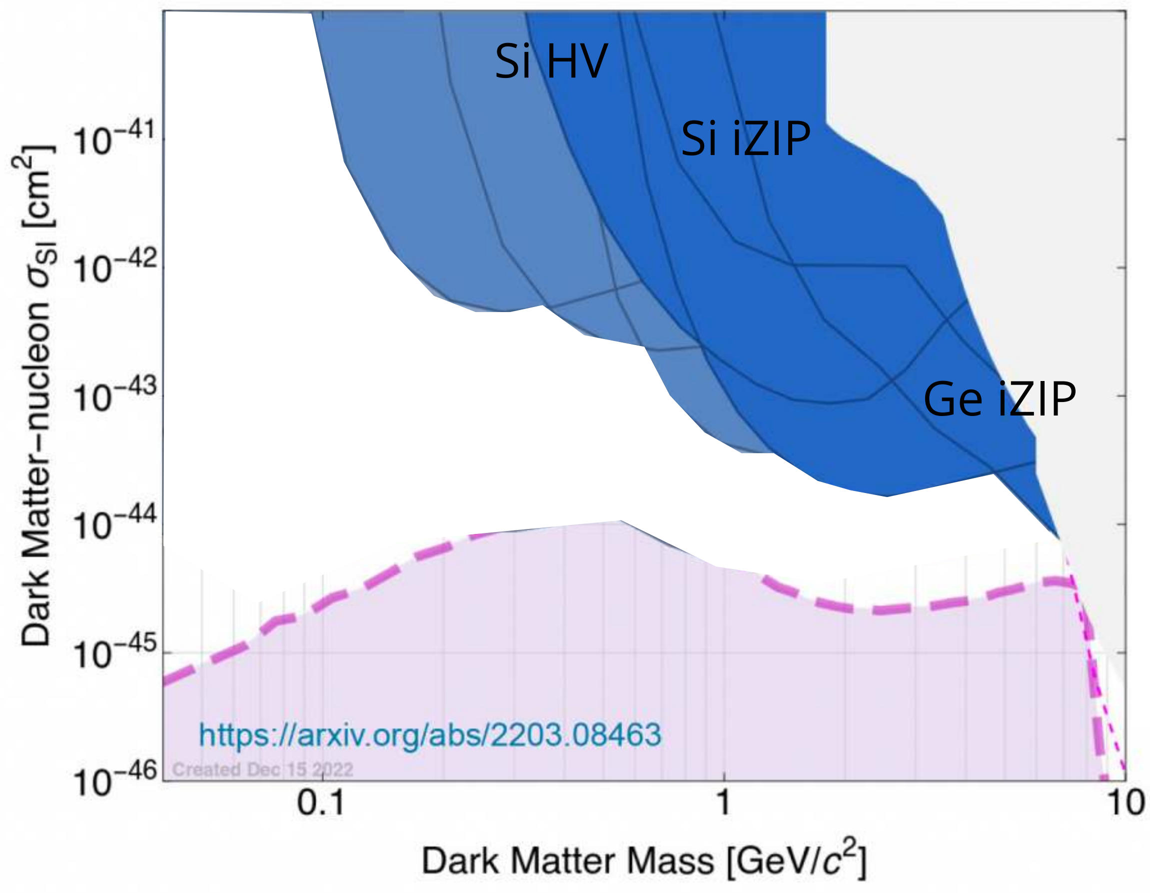
The cryostat is set to include more detector towers at a later stage, and improvements in background noise are expected



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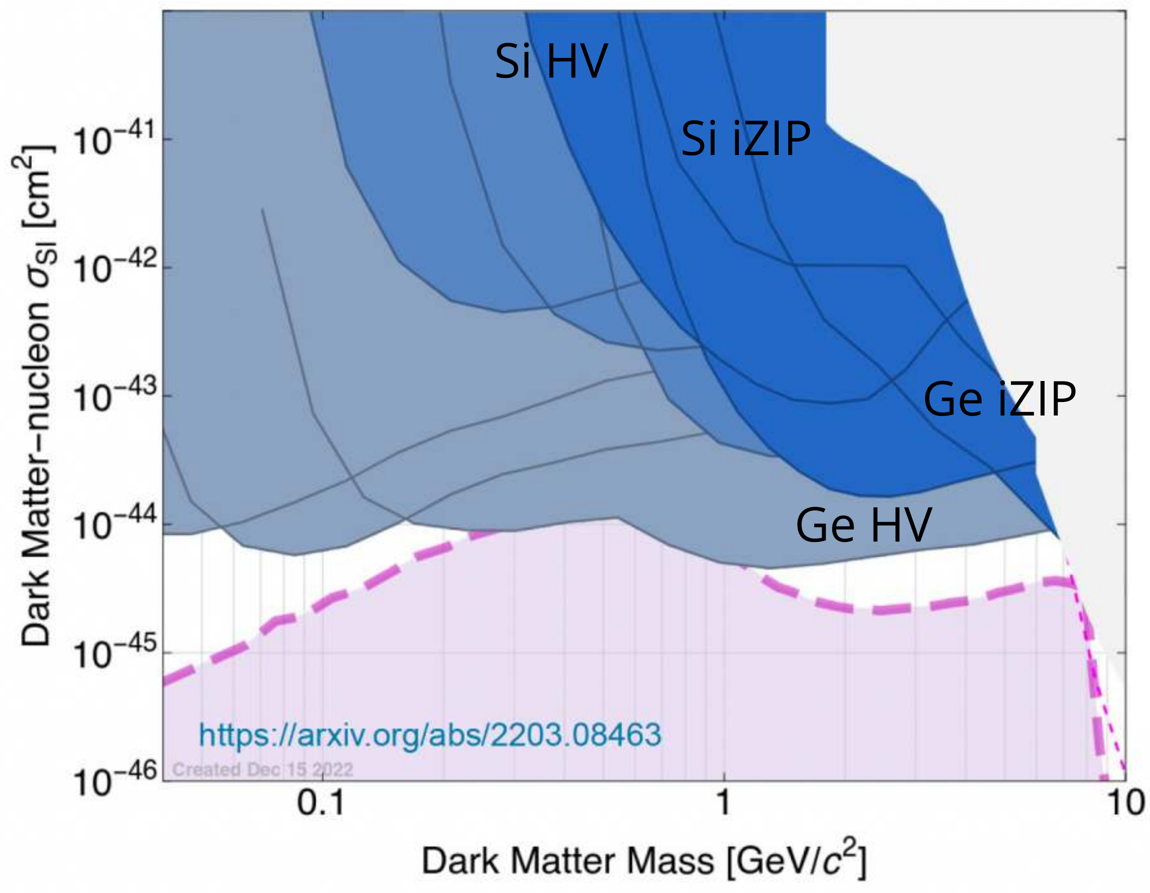
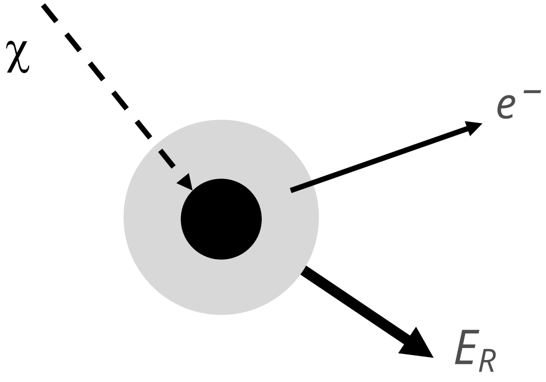
Close to the "*neutrino floor*" it will allow to study new neutrino physics



The Migdal effect (and its use in direct DM detection)

To correctly interpret the experimental data, it is essential to know the detector signal. The low-energy region is extremely important because it is where the DM signal is expected to be dominant.



The Migdal effect consists of the ionization (or excitation) of an atom as a result of a collision with the nucleus.

Migdal 1939; Feinberg 1941

This produces energy deposition (ionization) above the detection threshold of the experiment (higher than that of an elastic nuclear recoil).

Bernabei et al. 2007; Ibe et al. 2017; Dolan et al. 2017

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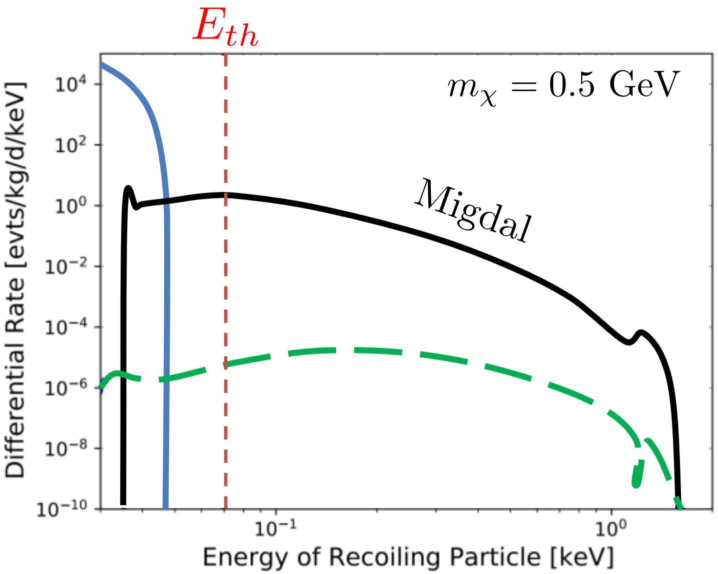

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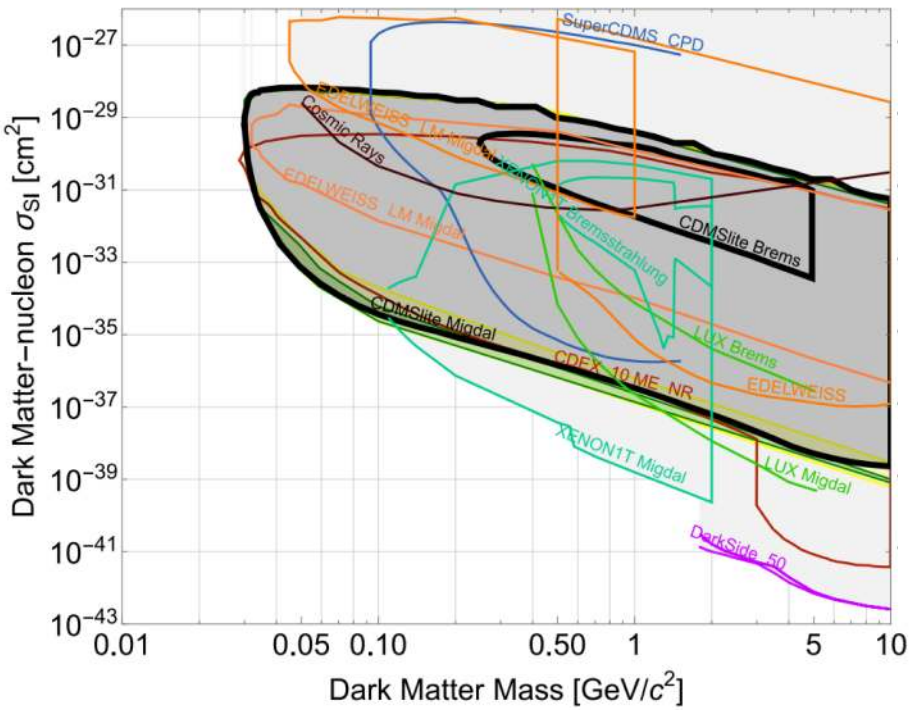
It makes signals that were thought to be undetectable (e.g., light dark matter) observable.

It is not new physics, but this effect **has not been measured**

It substantially improves the sensitivity to low-mass DM **without modifying the detectors**



The main collaborations have re-analysed their data using the Migdal effect.

LUX 2019, Xenon 2019, SuperCDMS 2023, DAMIC

It allows us to explore **unexplored regions** in the MeV range**.**

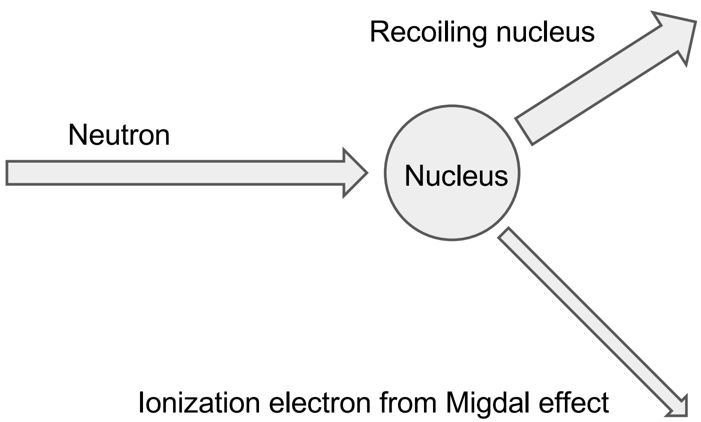
It is not only crucial to extract exclusion limits, but also (more importantly) to **correctly determine the MO parameters in case of detection.**

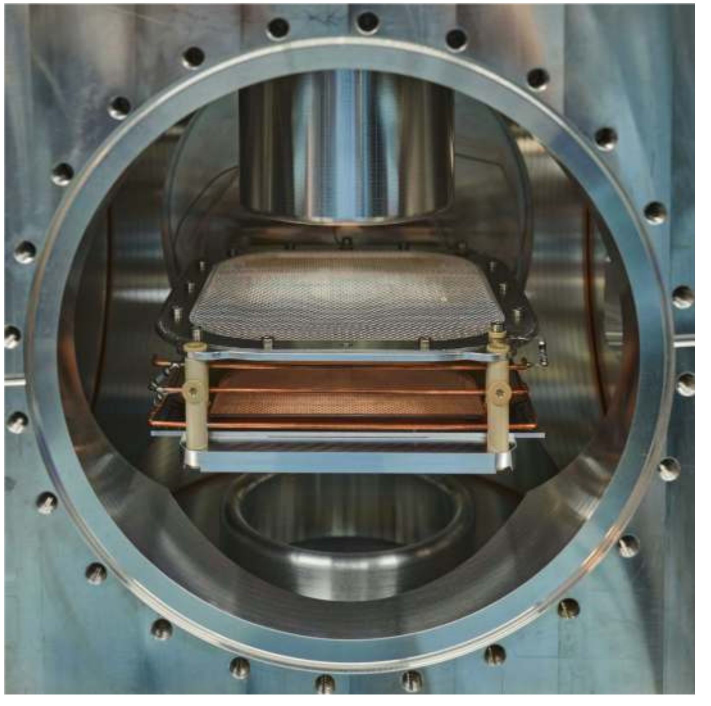
To do this, the Migdal effect **must be detected** and the response **characterized in materials used for direct detection experiments.**

The MIGDAL experiment

The MIGDAL Collaboration is developing an experiment at RAL (UK) to confirm experimentally the Migdal effect

Concept: use neutrons to induce the Migdal effect in a tracking chamber, then detect both the recoiling nucleus and the ionization electron (~10 keV)

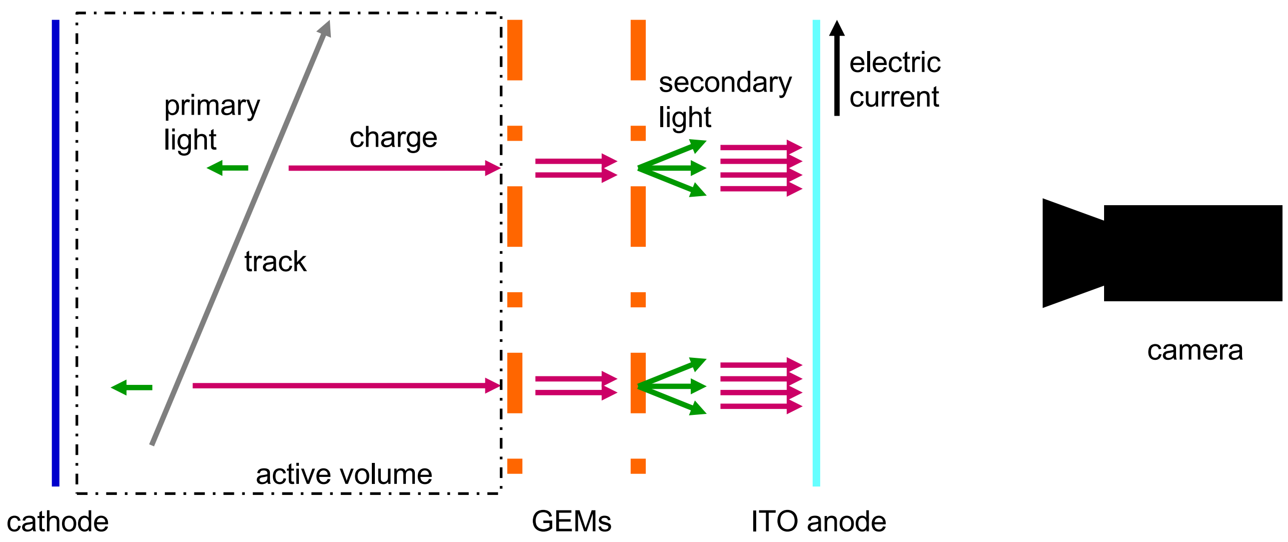




Optical TPC

Target: CF_4 at low pressure (50 torr) ⇒ Migdal electron track length is ~ 1 cm
Mixtures of CF_4 and noble gases (He, Ar, Xe) will be considered in the future
Optical TPC is instrumented to obtain 3D information of particle tracks:

- Secondary scintillation light imaged by CMOS camera: 2D projection
- Timing of charge collected at transparent anode (indium-tin-oxide): depth information



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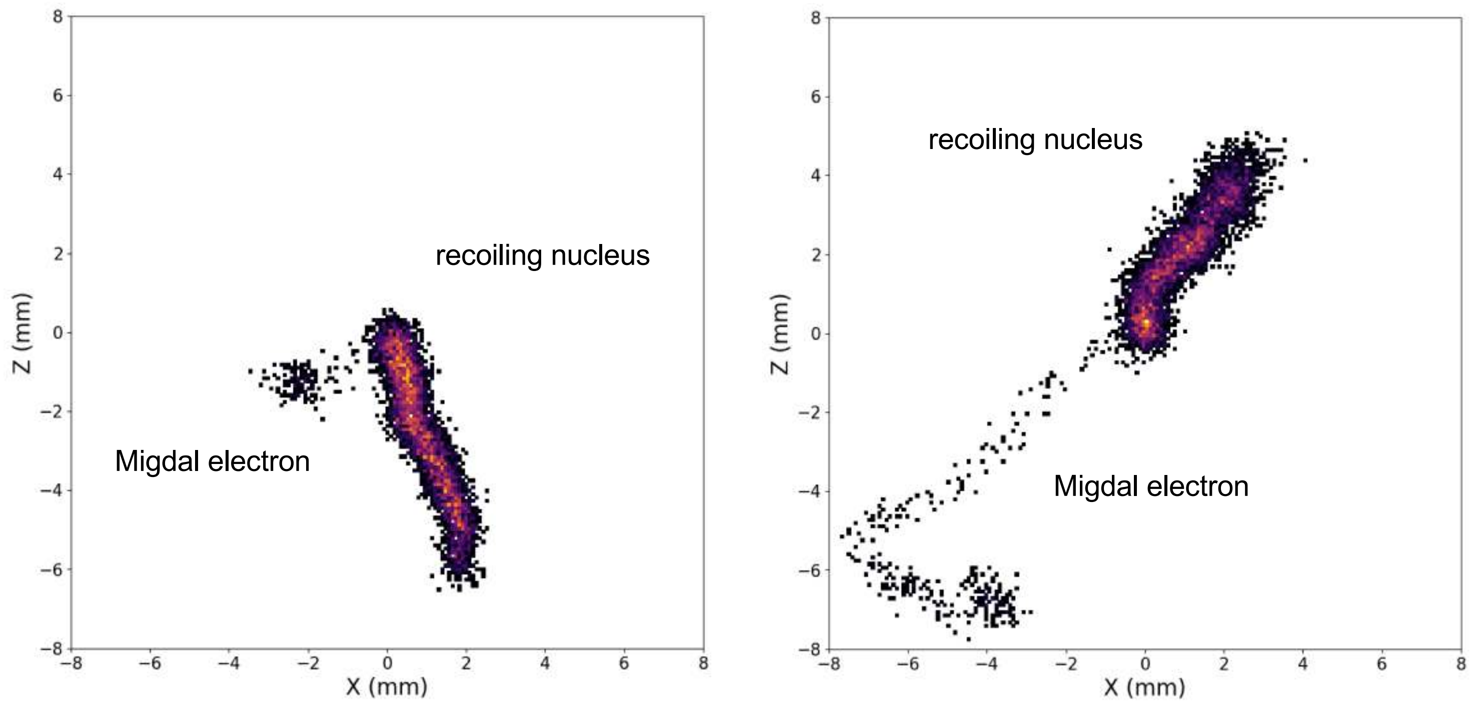


Status and plans

The MIGDAL experiment is currently being commissioned

Expecting first science run with D-D neutrons in the next months, sufficient statistics should be collected with few days of data-taking

The experiment will be upgraded with a detector to improve the measurement of the primary scintillation light

Such detector is being developed by the UAM group at the Astroparticle Laboratory for Elusives Searches (ASTROLABES)

Funding:
- Tecnologías Avanzadas para la Exploración del Universo y sus Componentes (TAU-CM)

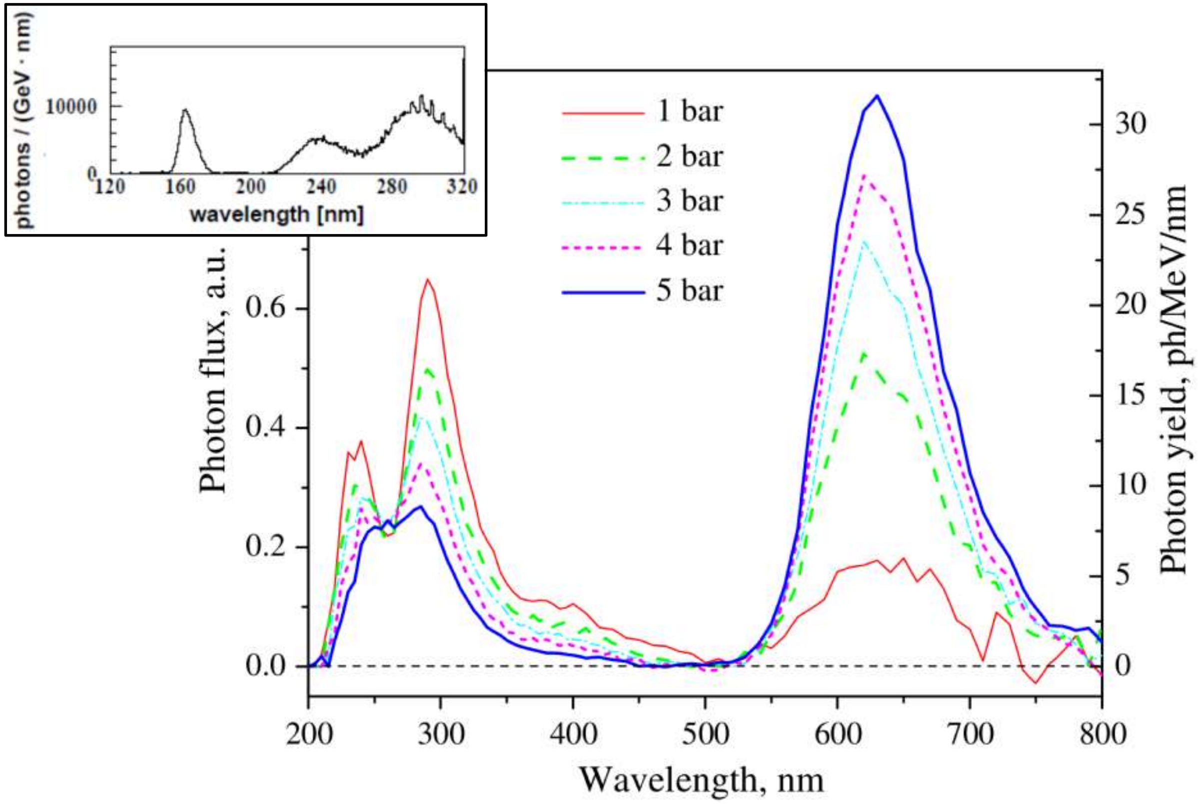
- ASTROLABES: CNS2022-135702

Primary scintillation light detector

Such detector is required to:

- Lower the trigger threshold, to approach the regime of interest for DM searches
- Reject backgrounds from pairs of tracks not occurring in coincidence

Considering two sensor technologies: silicon photomultipliers, flat photomultiplier tubes



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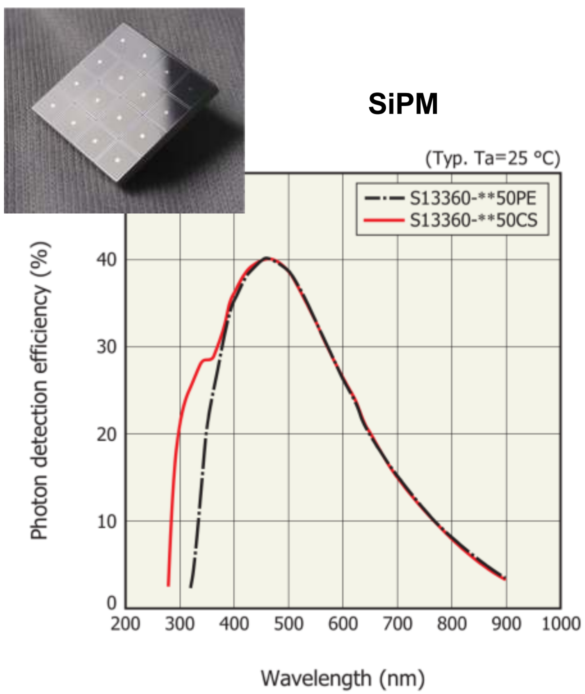
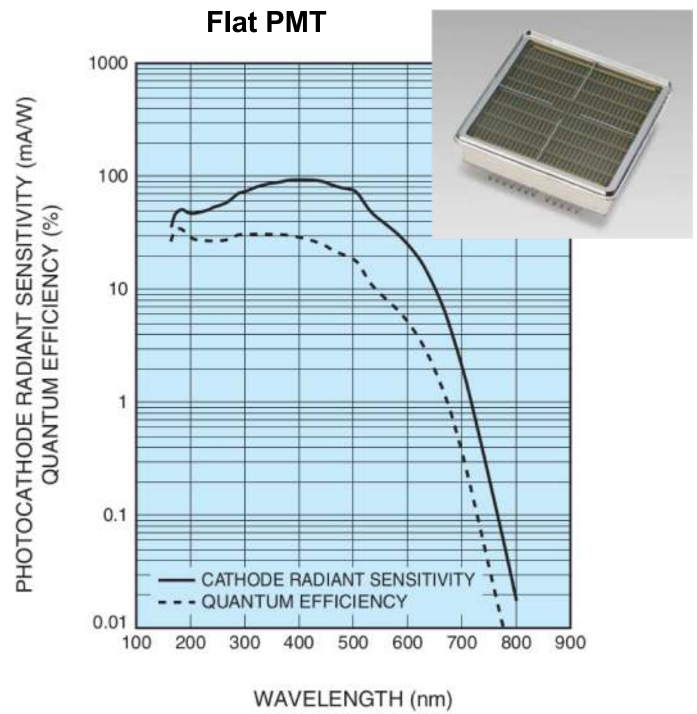
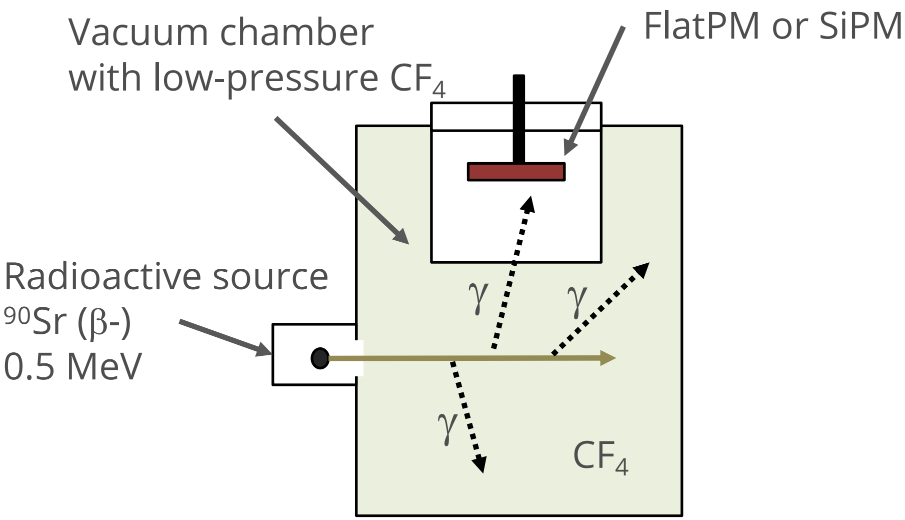
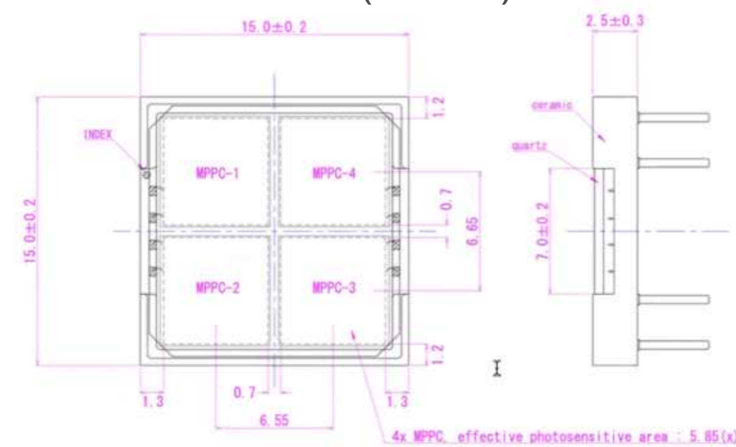


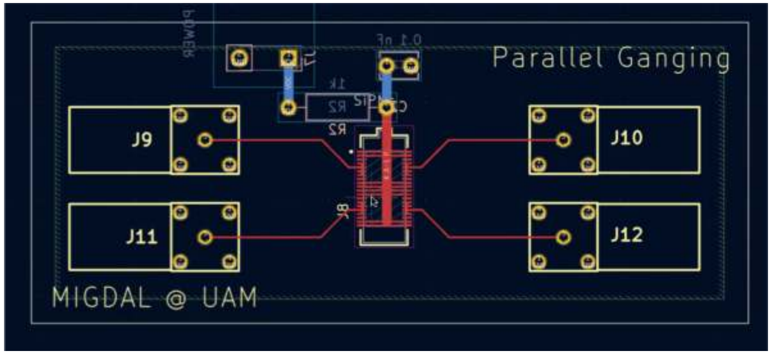


Experimental configuration in **ASTROLABES**



Bases (Flat PM)





Readout electronics

Workplan:

- PCB and bases fabrication (Oct 2023)
- Test FlatPM and SiPM (Dec 2023)
- Vacuum chamber setup (Mar 2024)
- Test CF4 (Jul 2024)
- Testo other gases (Sep 2024)

Conclusions

SuperCDMS SNOLAB will use semiconductor targets instrumented with phonon and charge sensors to search for dark matter down to ~400 MeV

- The UAM group is involved in the upcoming detector tests at CUTE, and is expecting to contribute to early science with such data

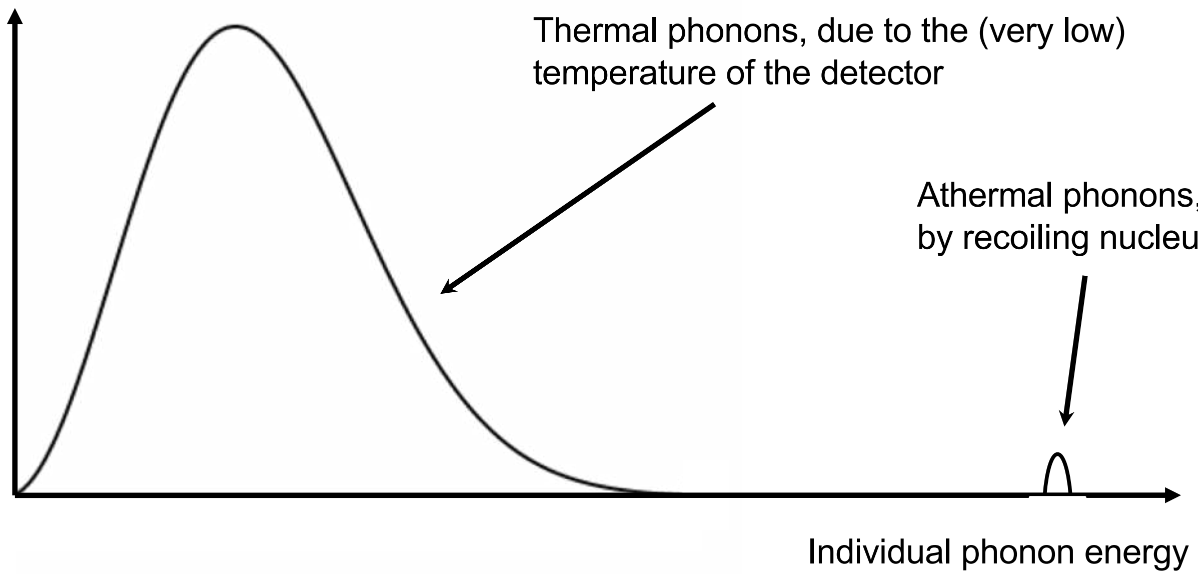
Besides, if the Migdal effect is confirmed, it would imply that existing experiments are also sensitive to sub-GeV dark matter

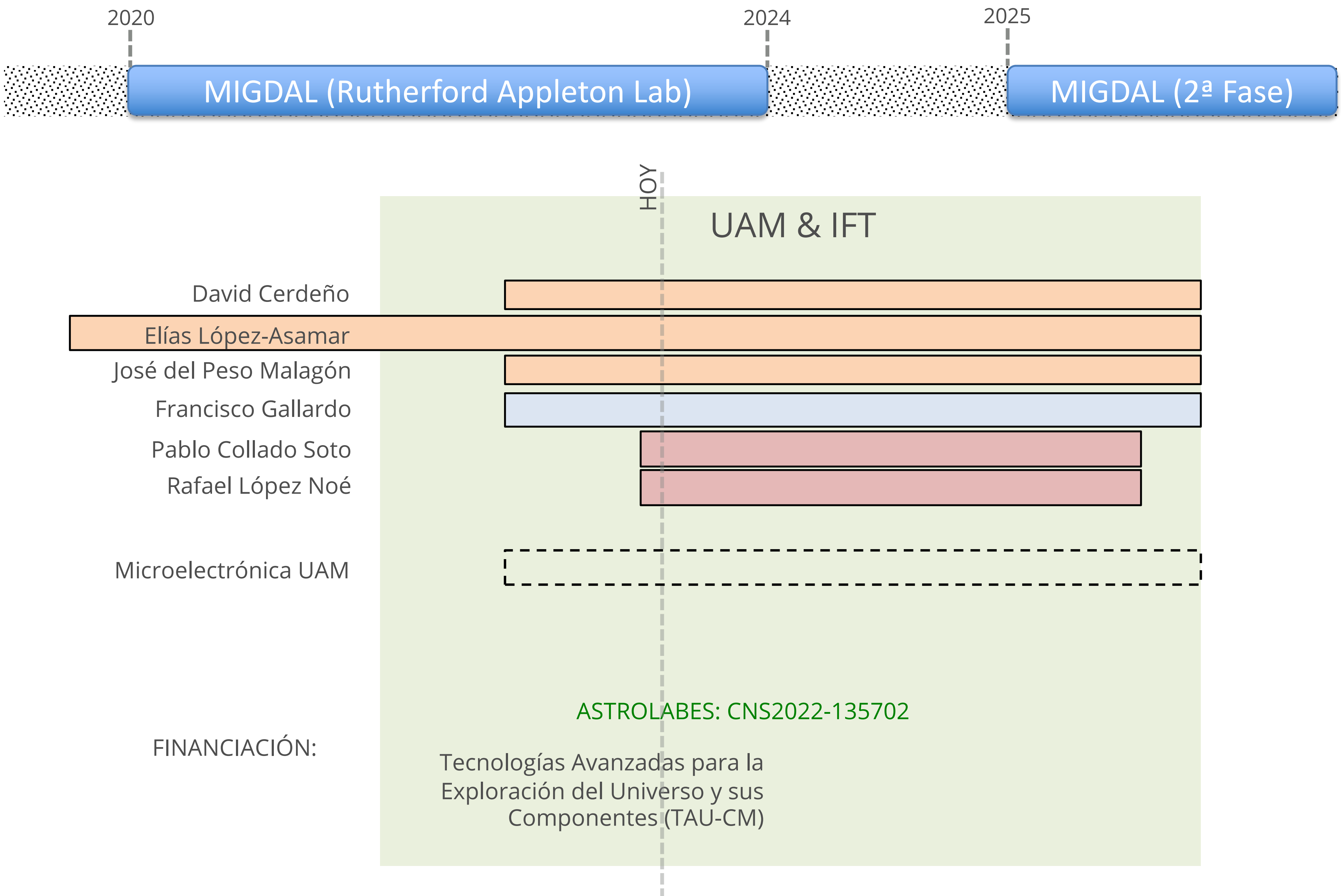
- The UAM group is developing a detector for the MIGDAL upgrade, aimed to improve the measurement of primary scintillation light

The SuperCDMS detectors

Concept: detect atomic nuclei that recoil after the interaction of DM particles with a <u>semiconductor</u> (Si, Ge) target

Energy deposited by recoiling nuclei is split into electron-hole pairs (<u>charge</u>, N_q) and athermal <u>phonons</u> (quanta of crystal lattice vibrations, E_P)

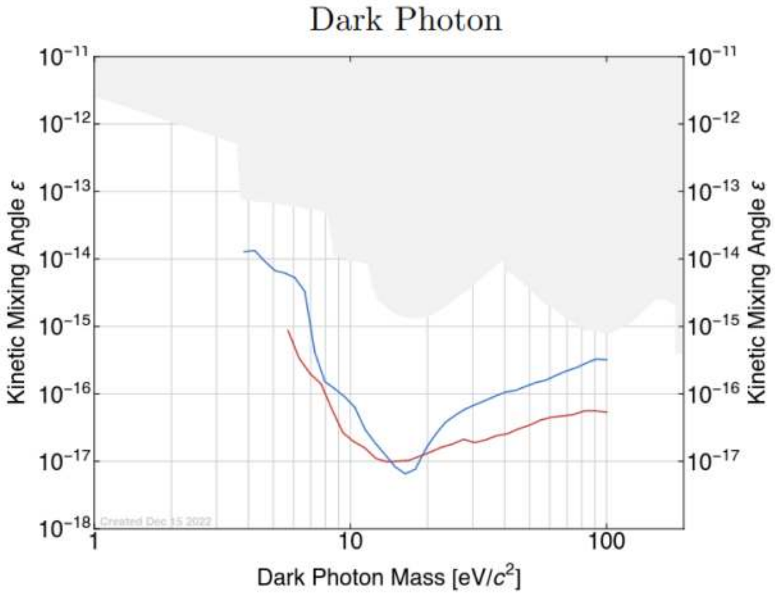


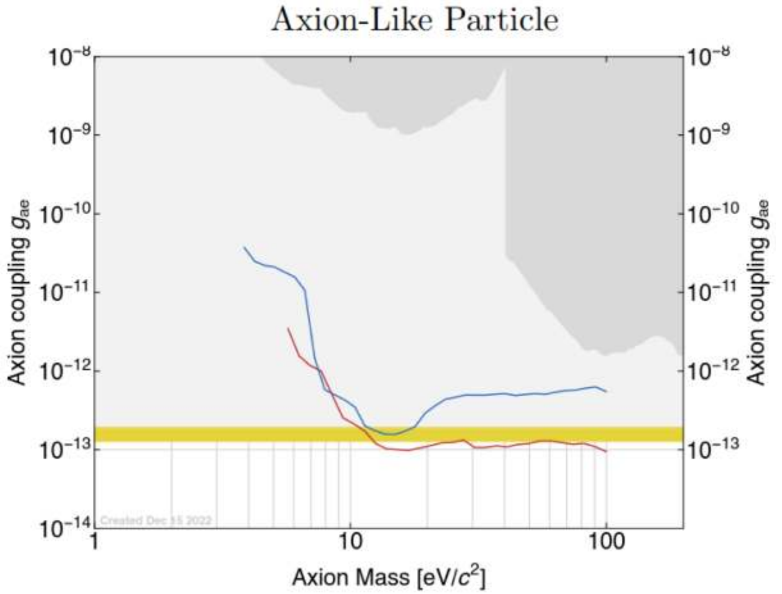

2020
2024
2025
MIGDAL (Rutherford Appleton Lab)
MIGDAL (2ª Fase)
HOY
UAM & IFT
David Cerdeño
Elías López-Asamar
José del Peso Malagón
Francisco Gallardo
Pablo Collado Soto
Rafael López Noé
Microelectrónica UAM
FINANCIACIÓN:
ASTROLABES: CNS2022-135702
Tecnologías Avanzadas para la Exploración del Universo y sus Componentes (TAU-CM)

Projected sensitivity – electron recoils

SuperCDMS SNOLAB will be also competitive to search for:

- Dark photon dark matter
- Axion-like particle dark matter
- Light dark matter mediated by dark photons





https://arxiv.org/abs/2203.08463

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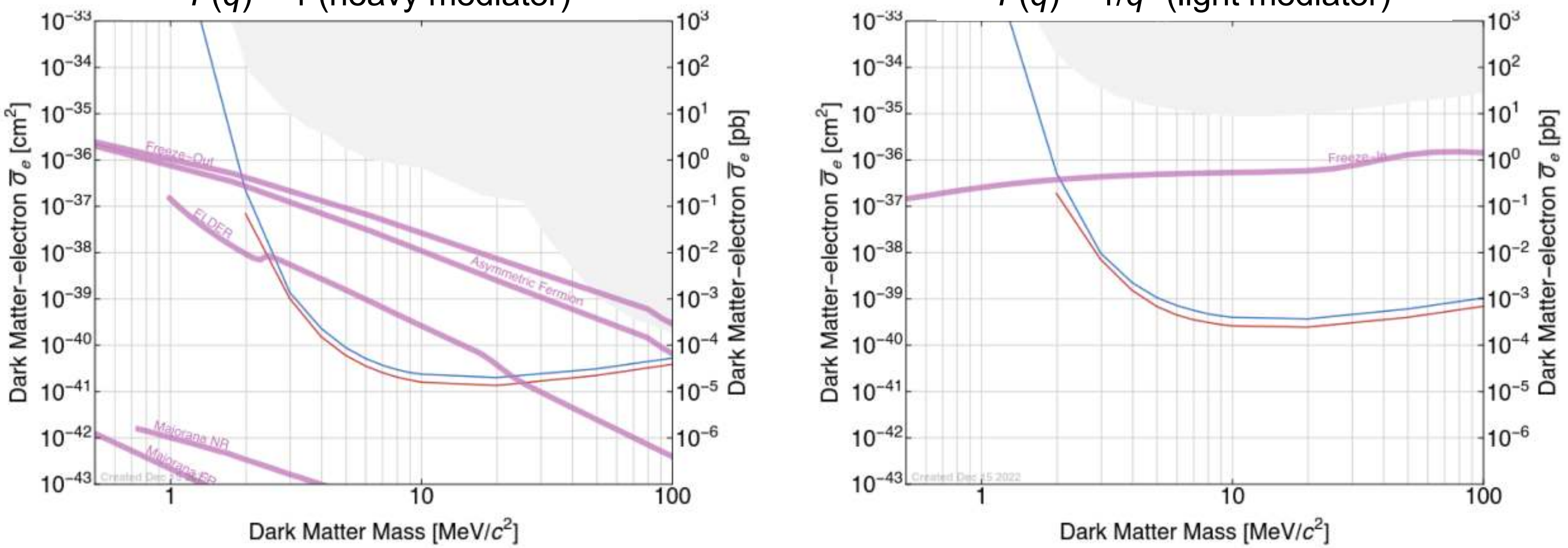
$F(q) = 1$ (heavy mediator) $F(q) = 1/q^2$ (light mediator)



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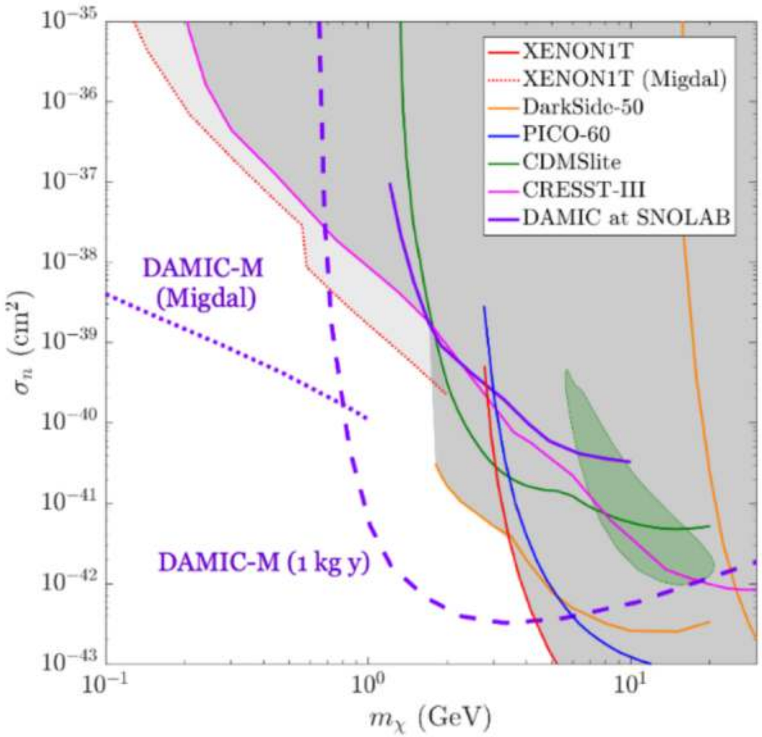

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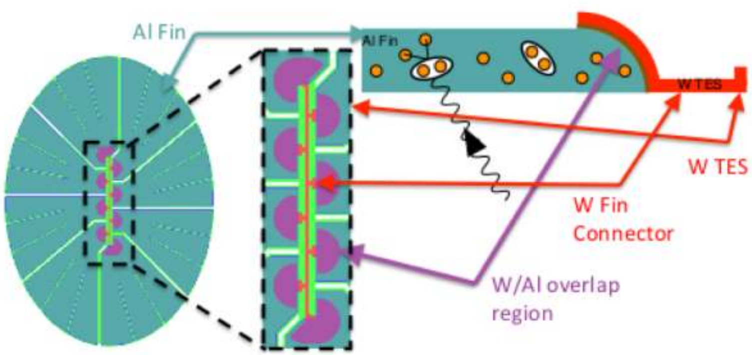

Al fin+TES