Search for sub-GeV dark matter – SuperCDMS and MIGDAL

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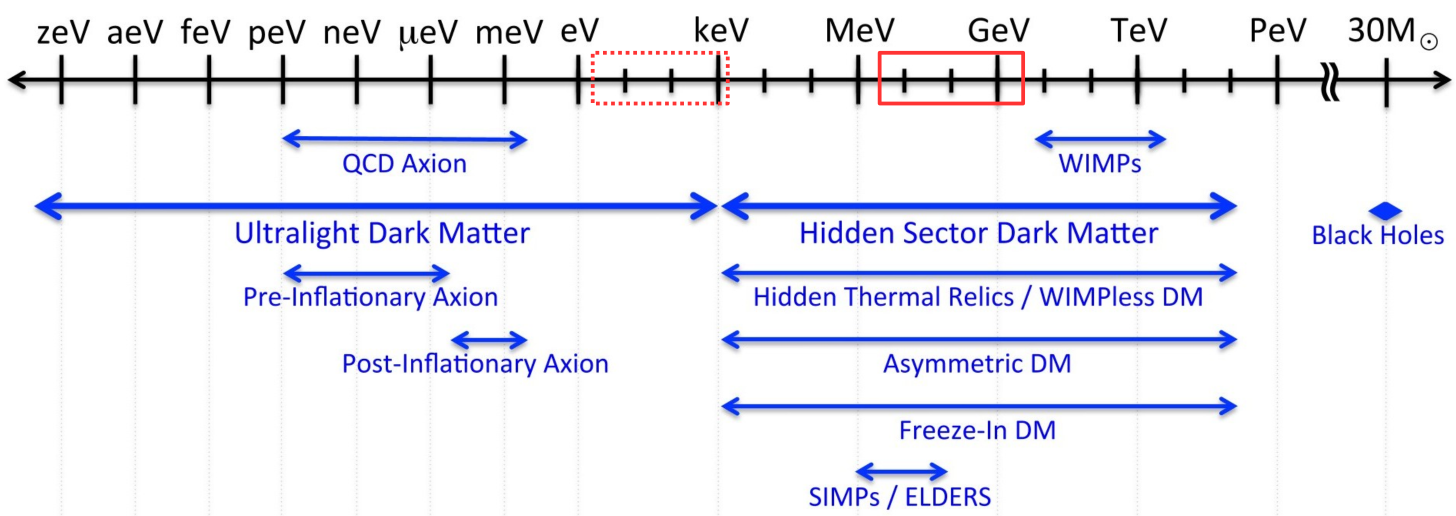
Introduction

Observations have strongly constrained the WIMP hypothesis

Sub-GeV candidates are still allowed in several models that assume new interactions (hidden sector freeze-out, freeze-in, etc) to explain the DM abundance in the universe

In this context, Universidad Autónoma de Madrid (UAM) contributes to SuperCDMS and MIGDAL

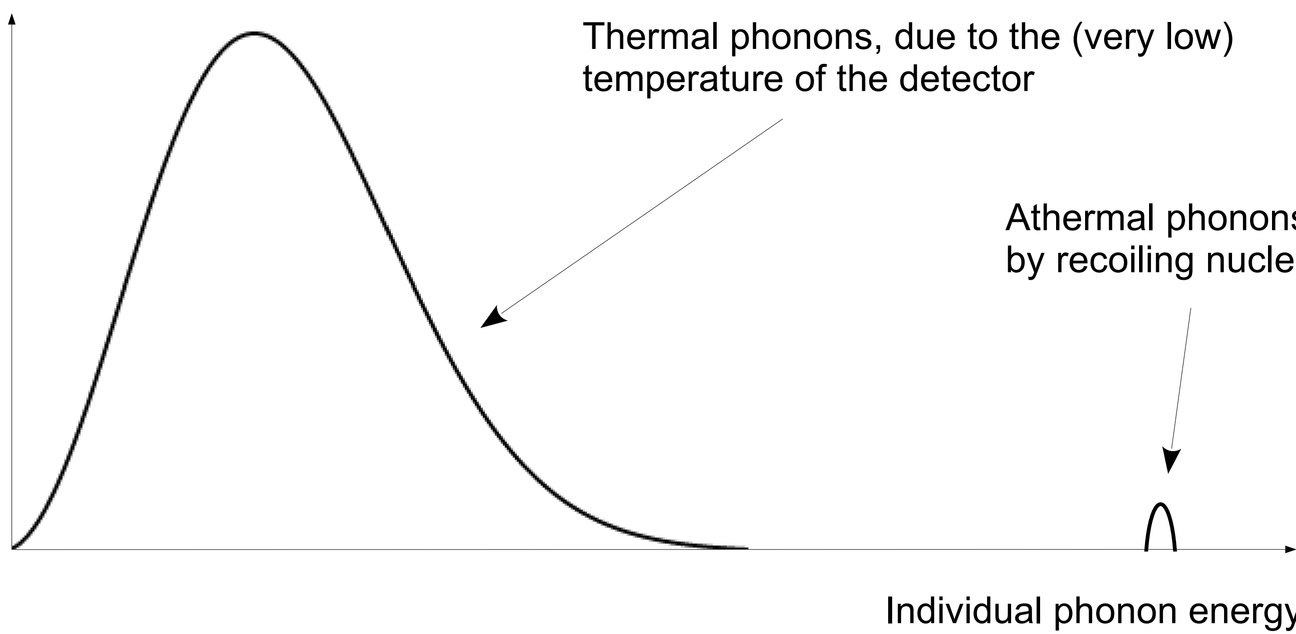


SuperCDMS

The SuperCDMS detectors

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

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

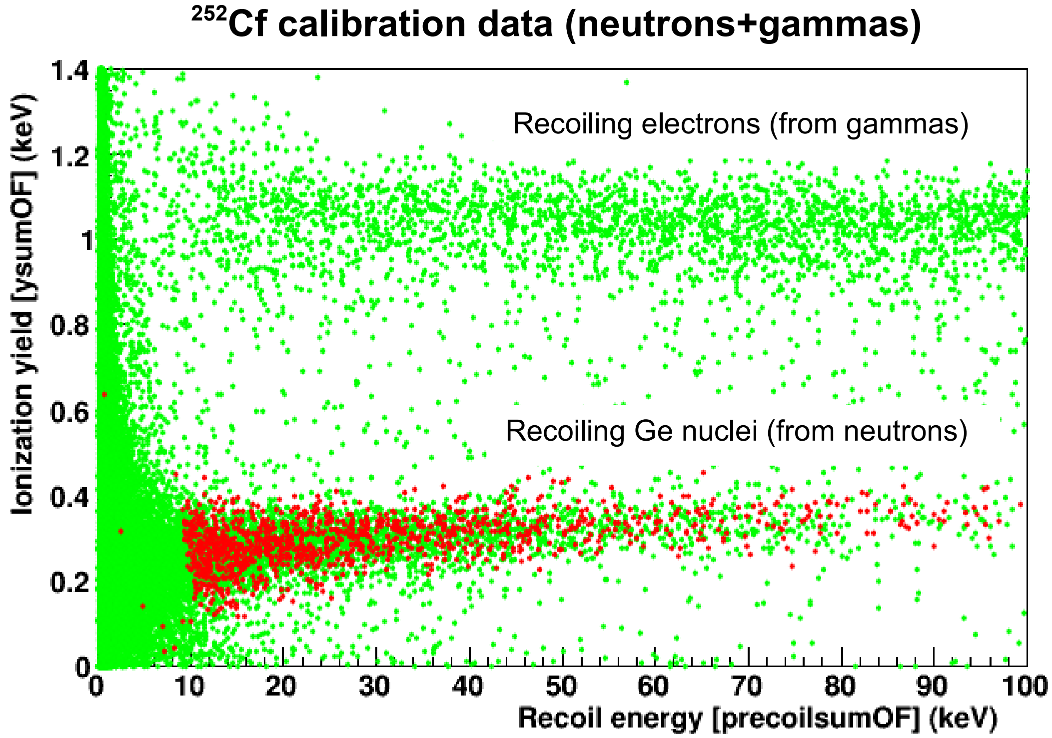


The SuperCDMS detectors

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

<u>iZIP detectors</u>: measure both N_q and E_P to determine recoil energy (E_R) and Y

Feature particle discrimination, but threshold on E_R is limited by measurement of N_q

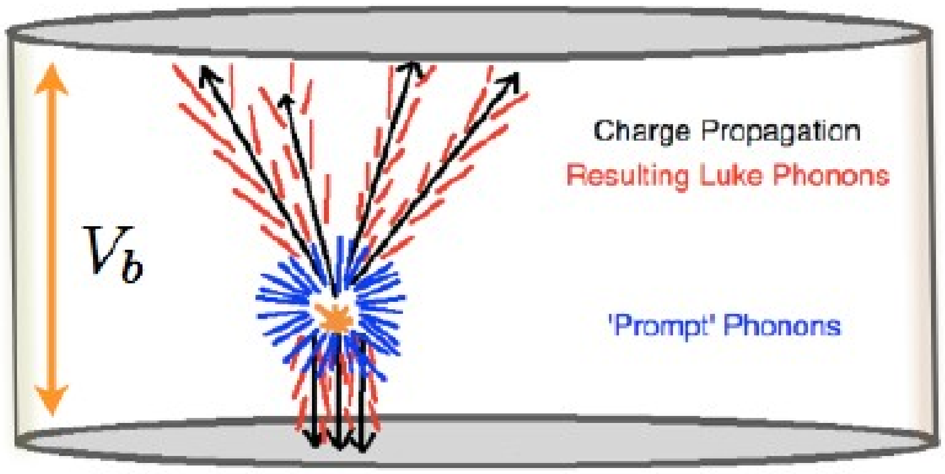


The SuperCDMS detectors

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 E_P only

Therefore, threshold on E_R is effectively decreased



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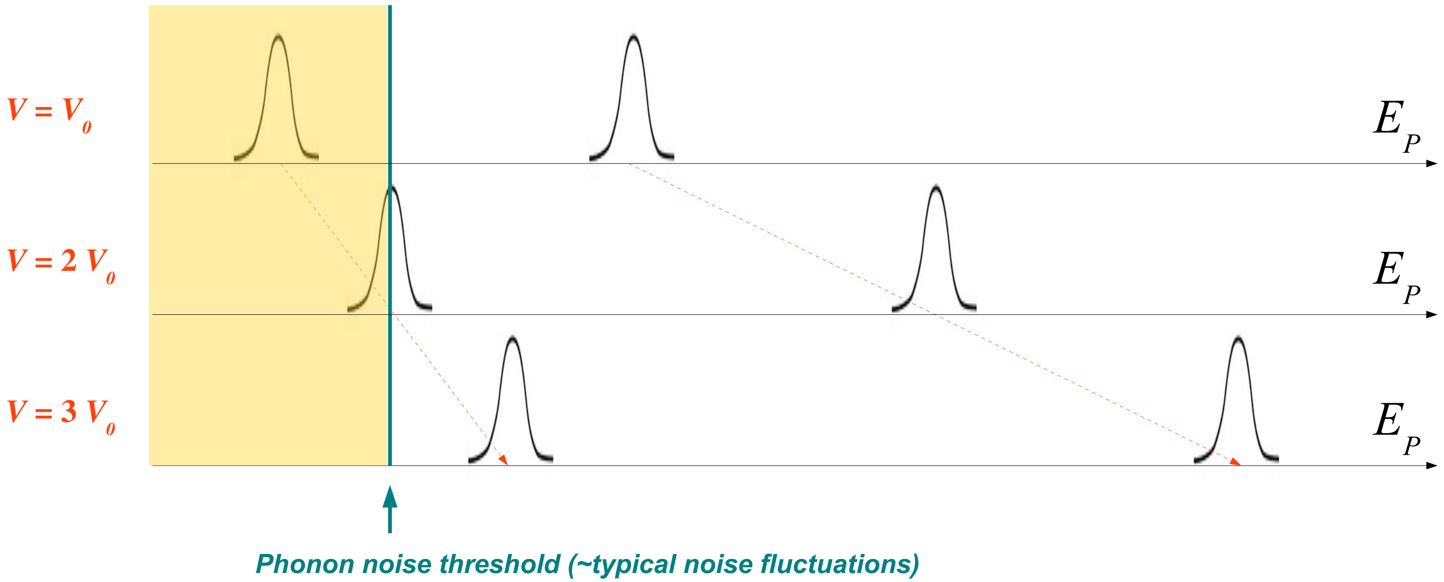


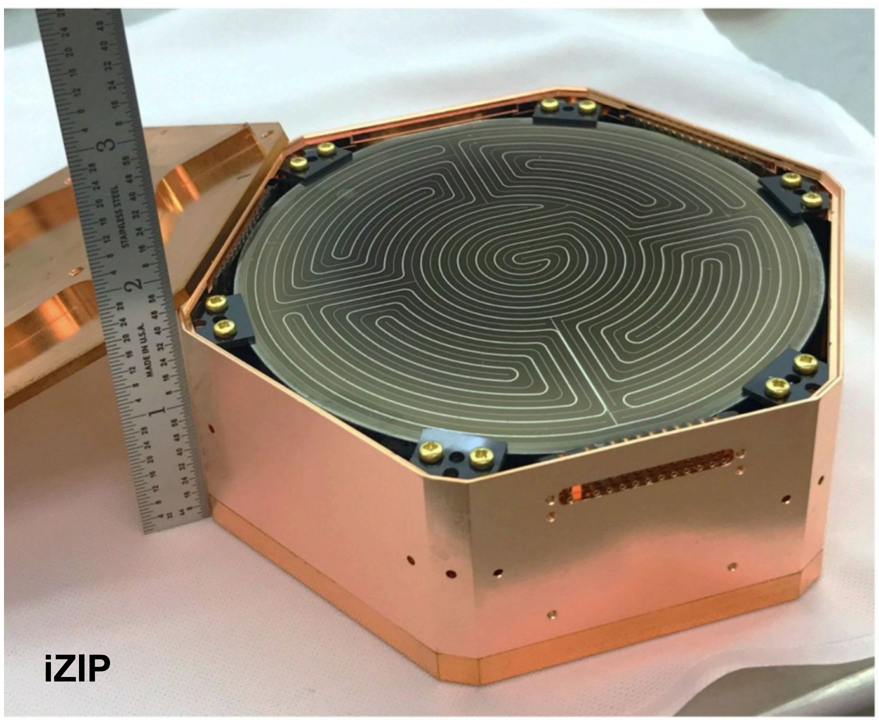
SuperCDMS SNOLAB

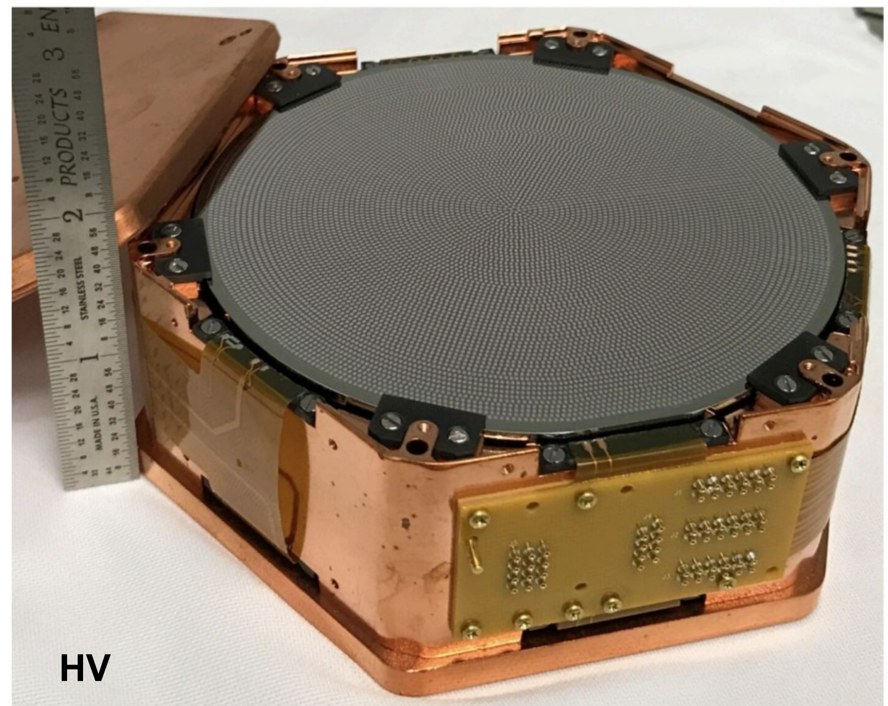
4 arrays (towers) of instrumented Si and Ge crystals (0.6 and 1.4 kg respectively)

Cryogenics: cryocooler+dilution refrigerator

Shielding: high-density polyethylene+Pb

Experiment site: SNOLAB, Canada (6000 m. w. e. overburden)





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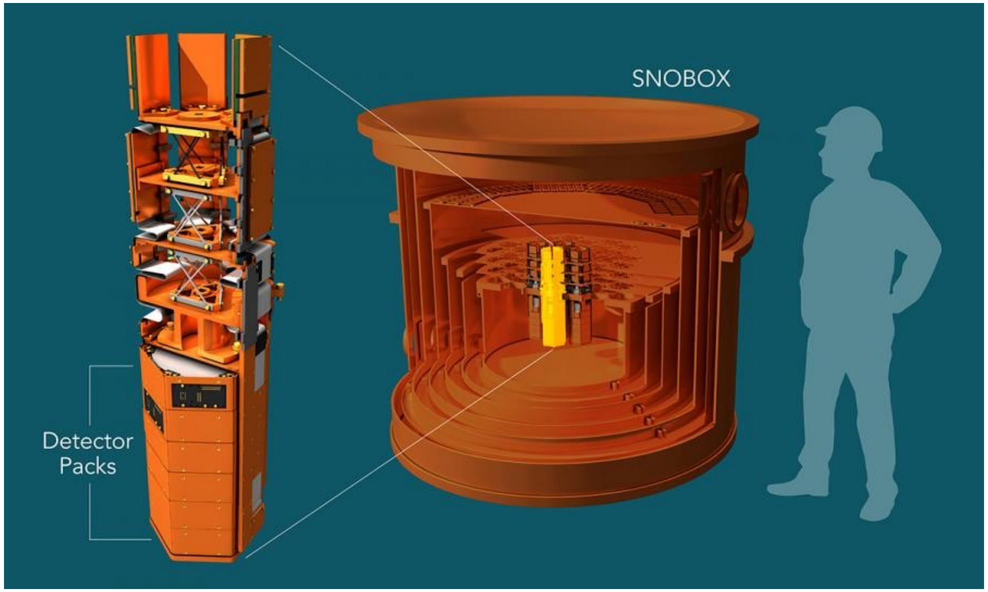

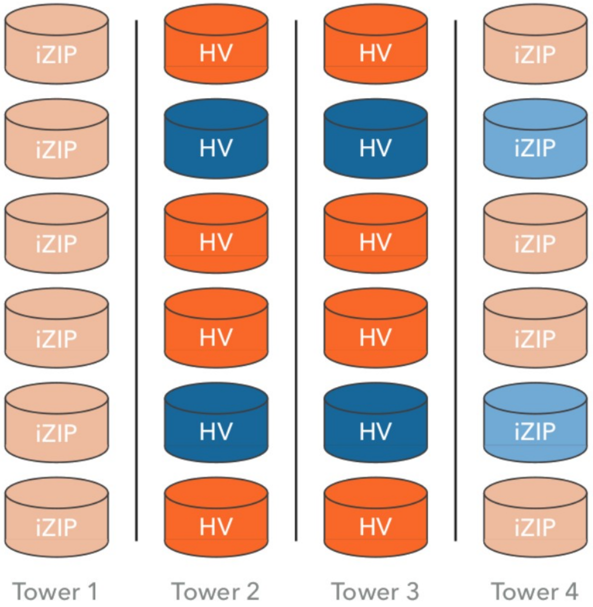

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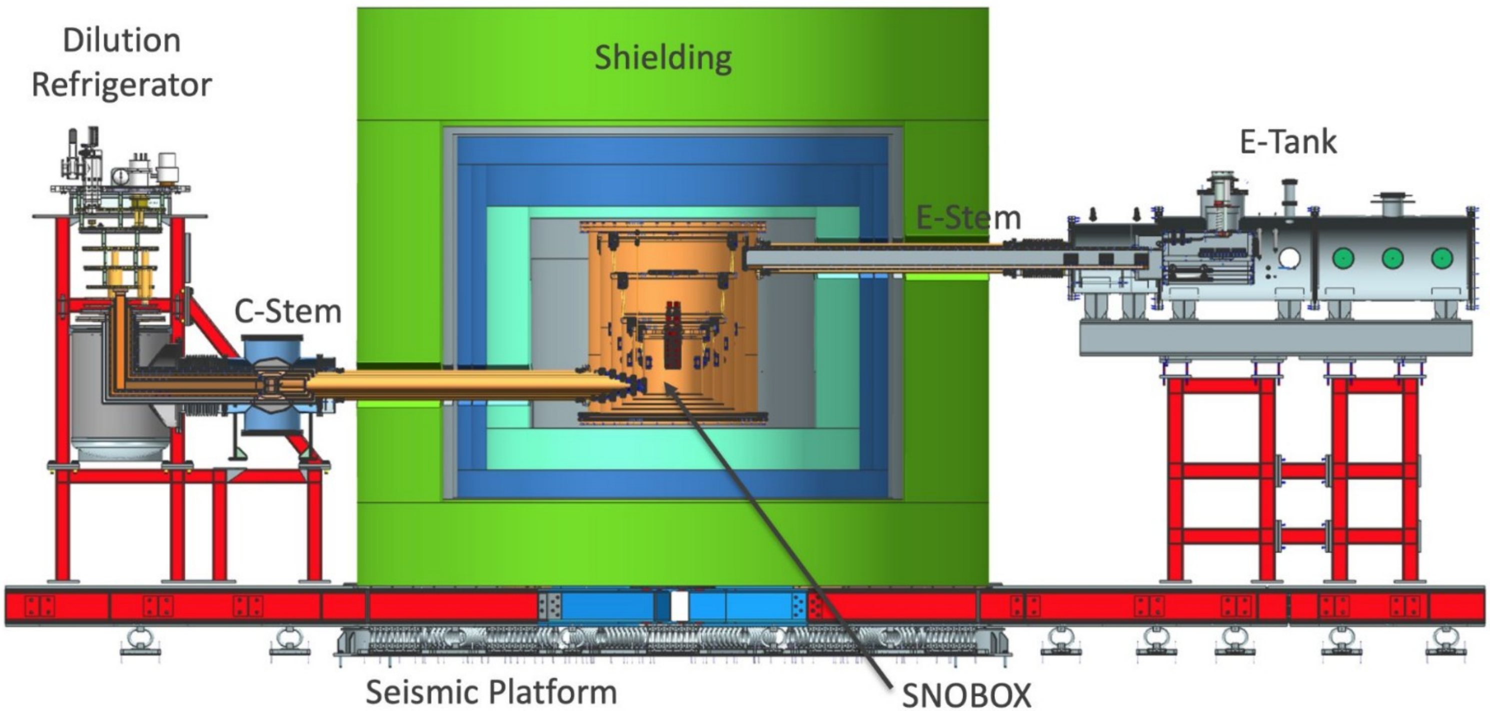


Status and plans

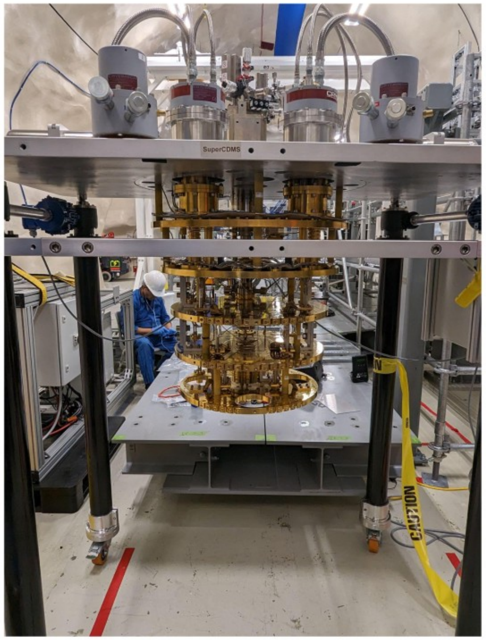
Base shielding completed

Dilution refrigerator already underground, reached 10 mK earlier this year

2 detector towers arrived at SNOLAB in May, other 2 expected later this year

Planning to start testing towers at CUTE in late October, opportunity for early science

Commissioning scheduled for late 2024



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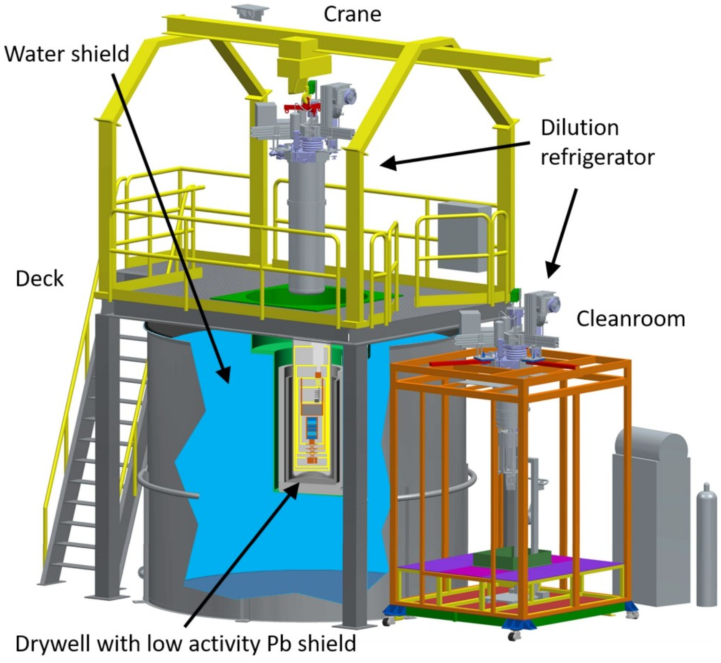


CUTE

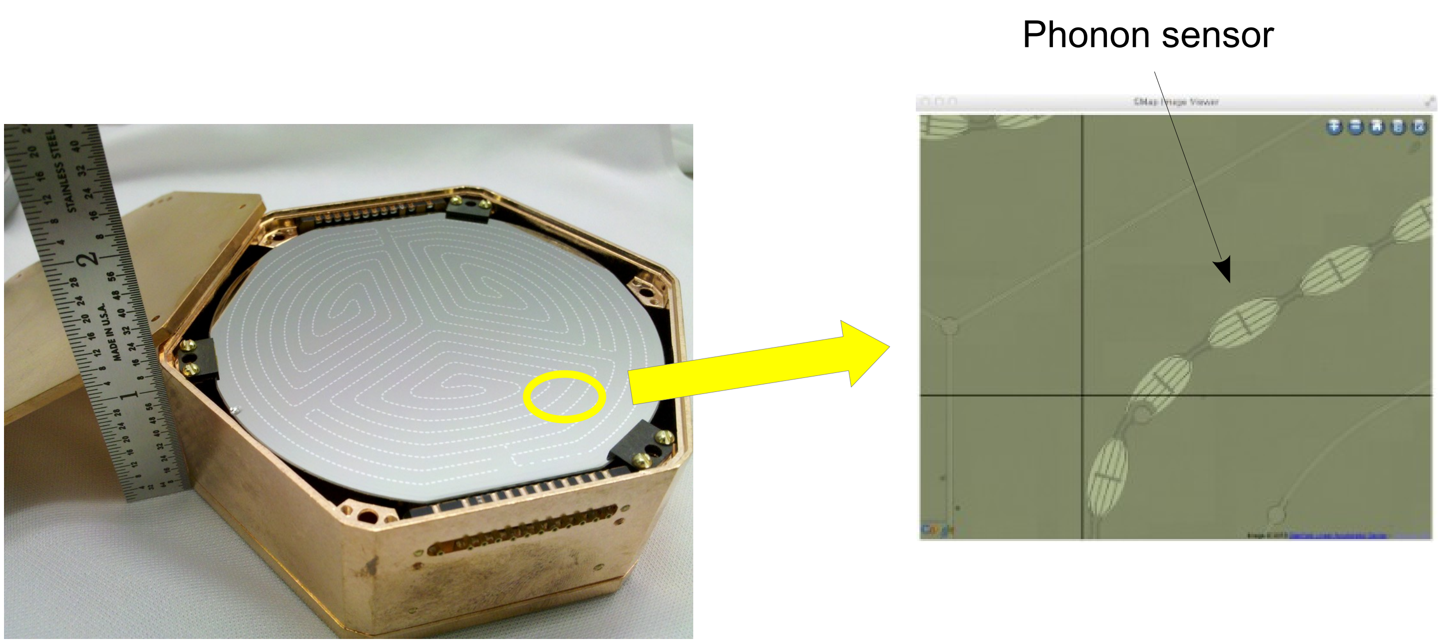
Analysis of phonon channel data

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



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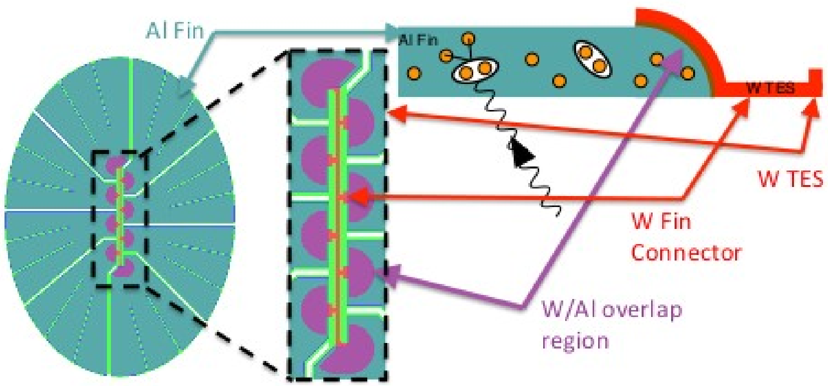
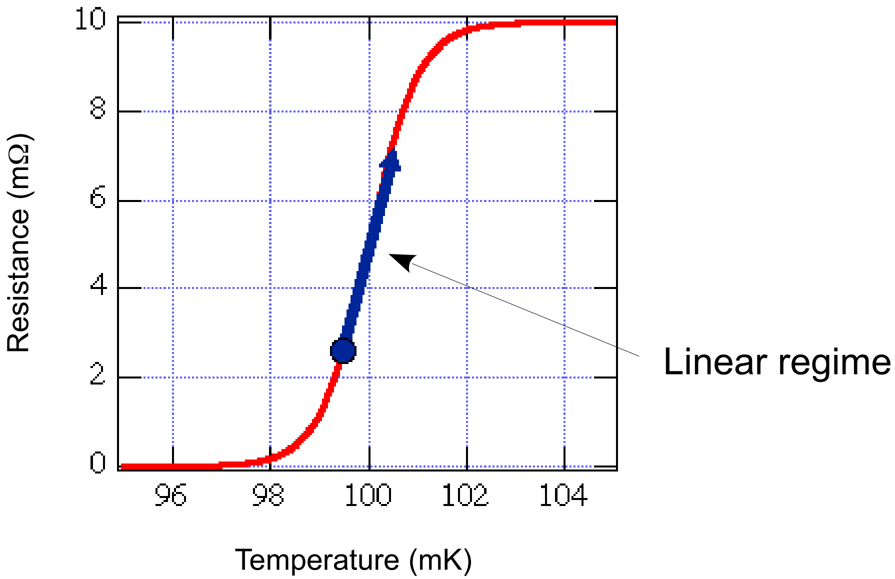


Al fin+TES

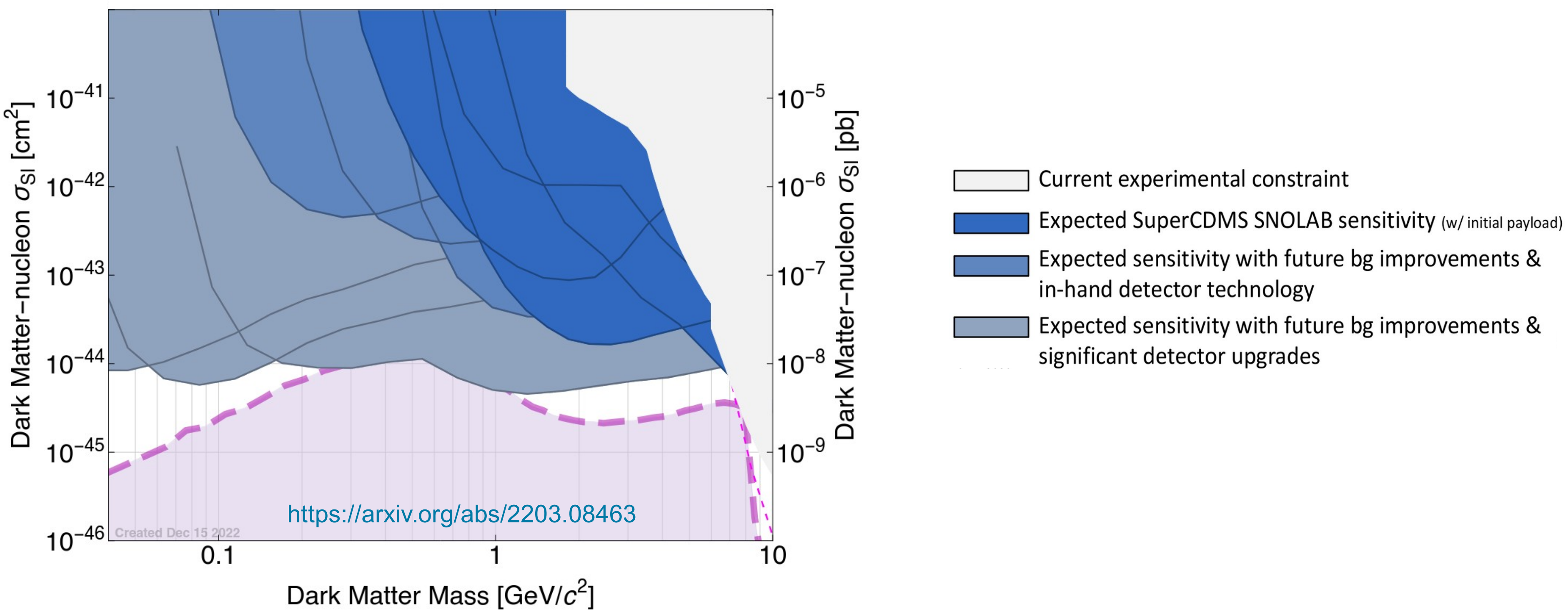


Projected sensitivity – nuclear recoils

SuperCDMS SNOLAB will be sensitive to dark matter down to ~400 MeV, well into the sub-GeV regime, and will approach the neutrino floor

Potential to further constrain the sub-GeV regime with future upgrades

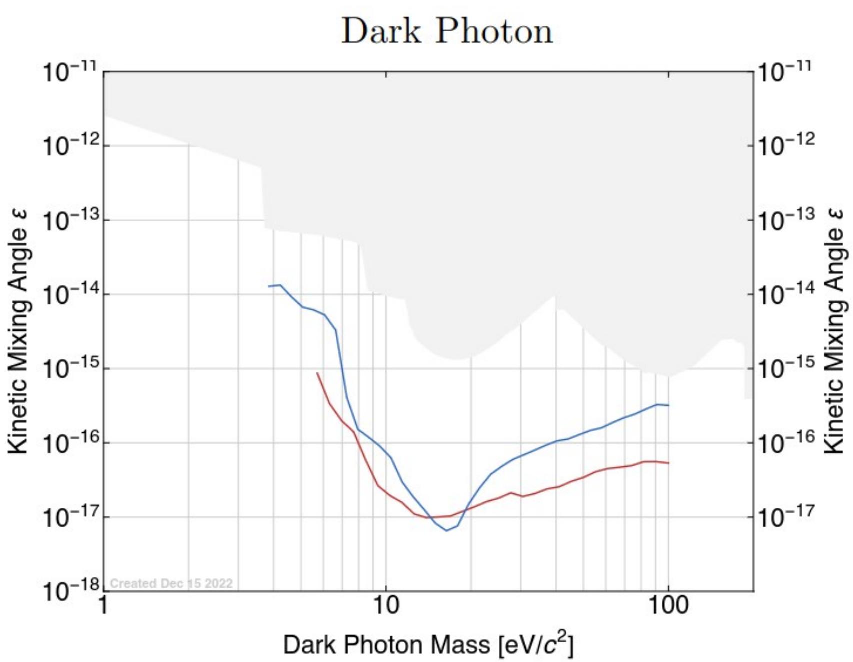
Besides, the UAM group has started to study the sensitivity of SuperCDMS SNOLAB to sub-GeV DM assuming the Migdal effect (D. Alonso González, D. Cerdeño, ELA)

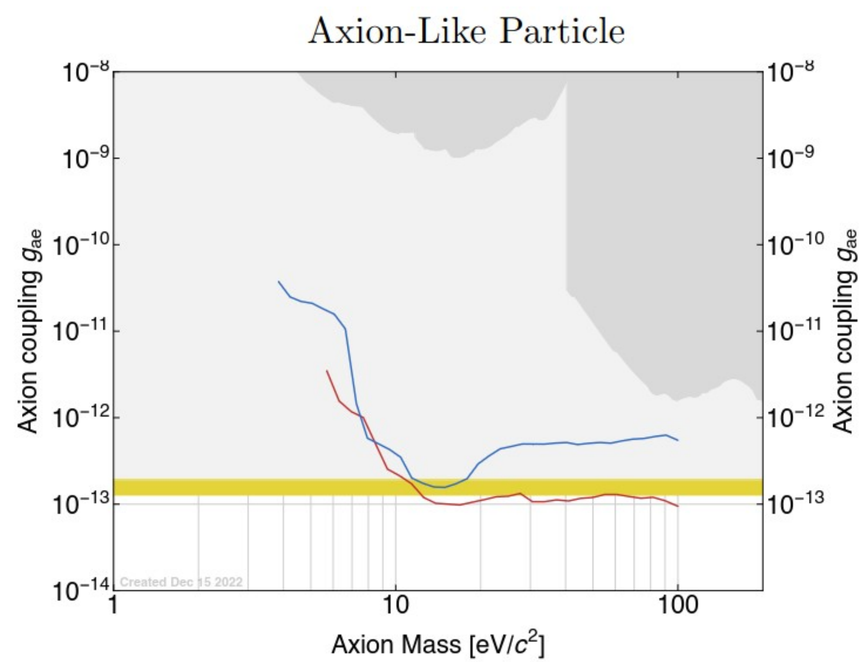


Projected sensitivity – electron recoils

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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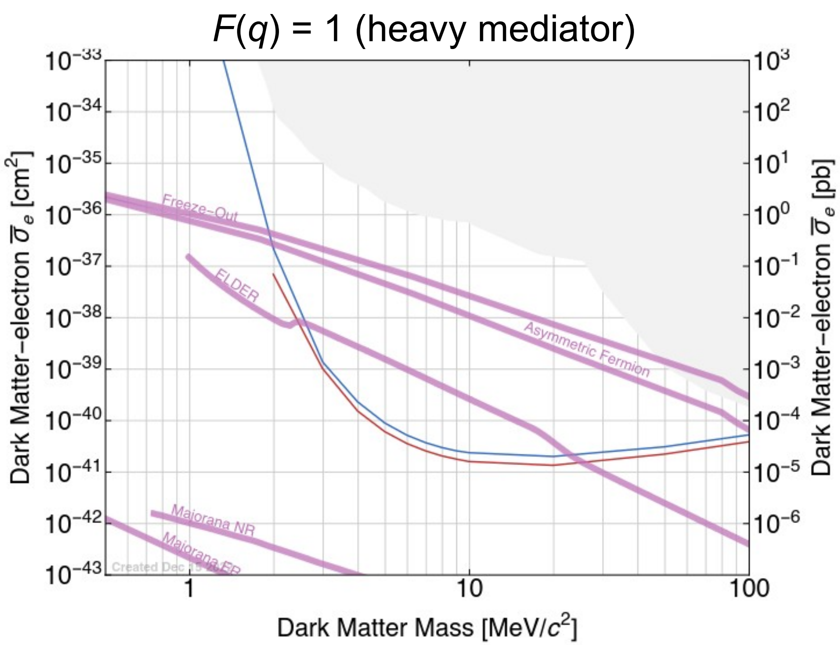

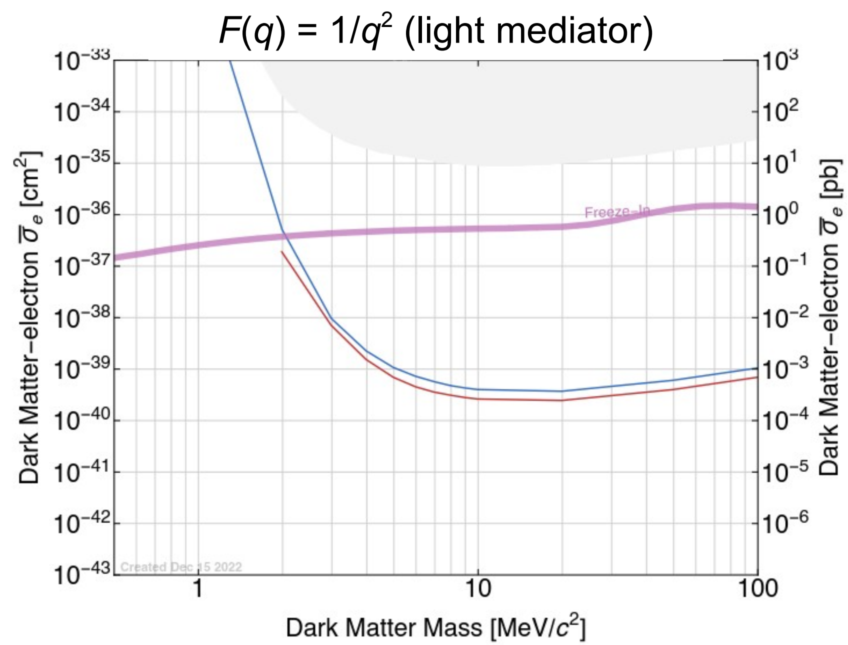

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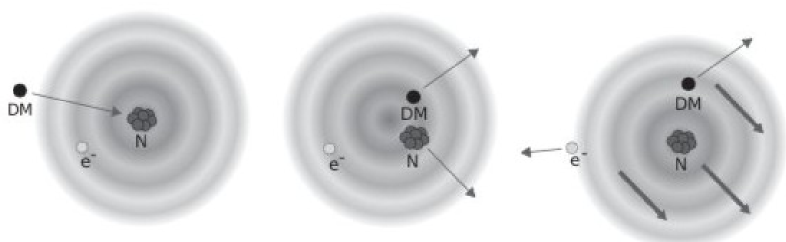
MIGDAL

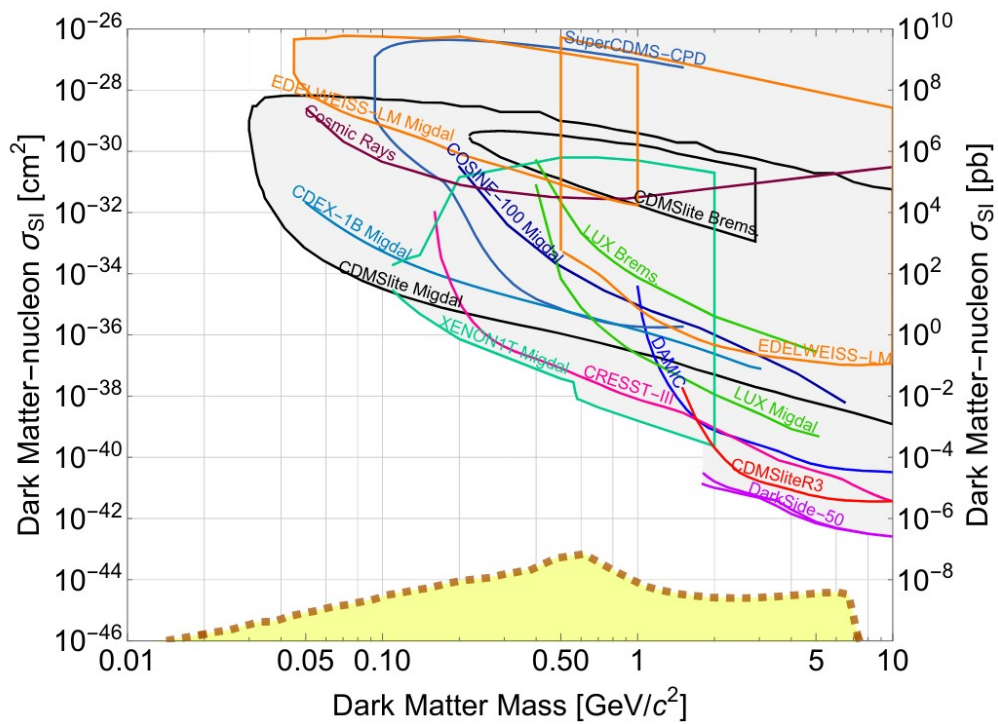
Migdal effect

Migdal effect refers to the emission of an atomic electron (ionization) when the nucleus is perturbed

Prediction from atomic physics, that has not been confirmed experimentally yet

Confirmation would imply that existing experiments are also sensitive to sub-GeV DM particles: inelastic process with recoiling electron in the final state





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)

The MIGDAL experiment:
Measuring a rare atomic process to help the search for dark matter

H. M. Araújo[a], S. N. Balashov[b], J. E. Borg[a], F. M. Brunbauer[c], C. Cazzaniga[d], C. D. Frost[d], F. Garcia[e], A. C. Kaboth[f,b], M. Kastriotou[d], I. Katsioulas[g], A. Khazov[b], H. Kraus[h], V. A. Kudryavtsev[i], S. Lilley[d], A. Lindote[j], D. Loomba[k], M. I. Lopes[j], E. Lopez Asamar[j], P. Luna Dapica[d], P. A. Majewski[b,*], T. Marley[a,b], C. McCabe[l], A. F. Mills[k], M. Nakhostin[a,b], T. Neep[g], F. Neves[j], K. Nikolopoulos[g], E. Oliveri[c], L. Ropelewski[c], V. N. Solovov[j], T. J. Sumner[a], J. Tarrant[m], R. Turnley[d], M. G. D. van der Grinten[b], R. Veenhof[c,n]

[a]Department of Physics, Imperial College London, UK
[b]Particle Physics Department, STFC Rutherford Appleton Laboratory, UK
[c]CERN – European Organization for Nuclear Research, Geneva, Switzerland
[d]ISIS Neutron and Muon Beams, STFC Rutherford Appleton Laboratory, UK
[e]Helsinki Institute of Physics, University of Helsinki, Finland
[f]Department of Physics, Royal Holloway University of London, UK
[g]School of Physics and Astronomy, University of Birmingham, UK
[h]Department of Physics, University of Oxford, UK
[i]Department of Physics & Astronomy, University of Sheffield, UK
[j]LIP–Coimbra & Department of Physics, University of Coimbra, Portugal
[k]Department of Physics & Astronomy, University of New Mexico, USA
[l]Department of Physics, King's College London, UK
[m]Technology Department, STFC Rutherford Appleton Laboratory, UK
[n]National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Russia

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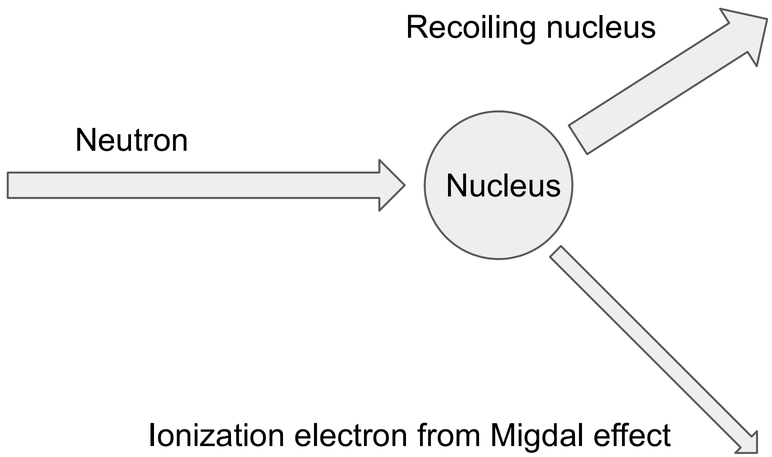
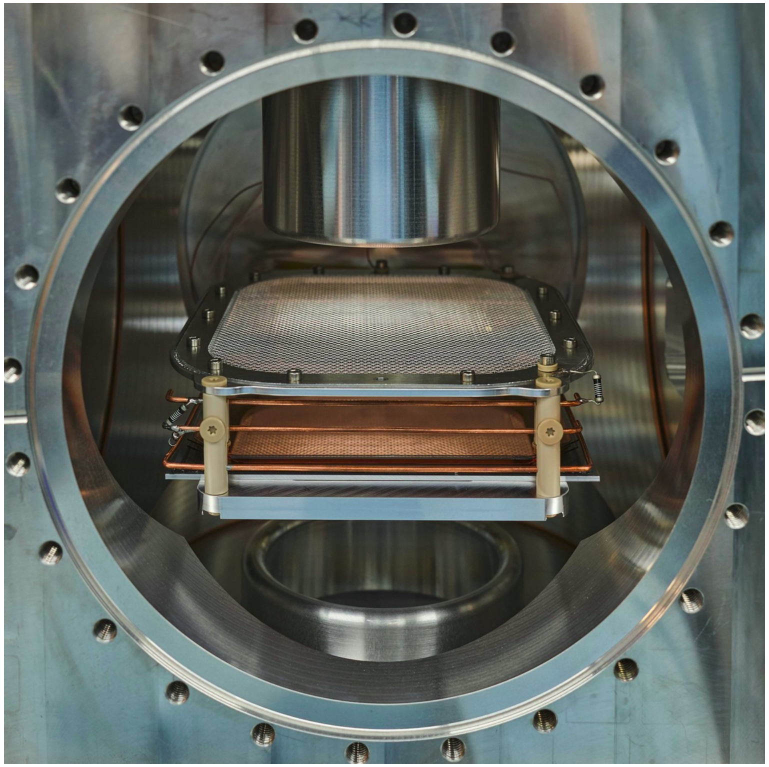




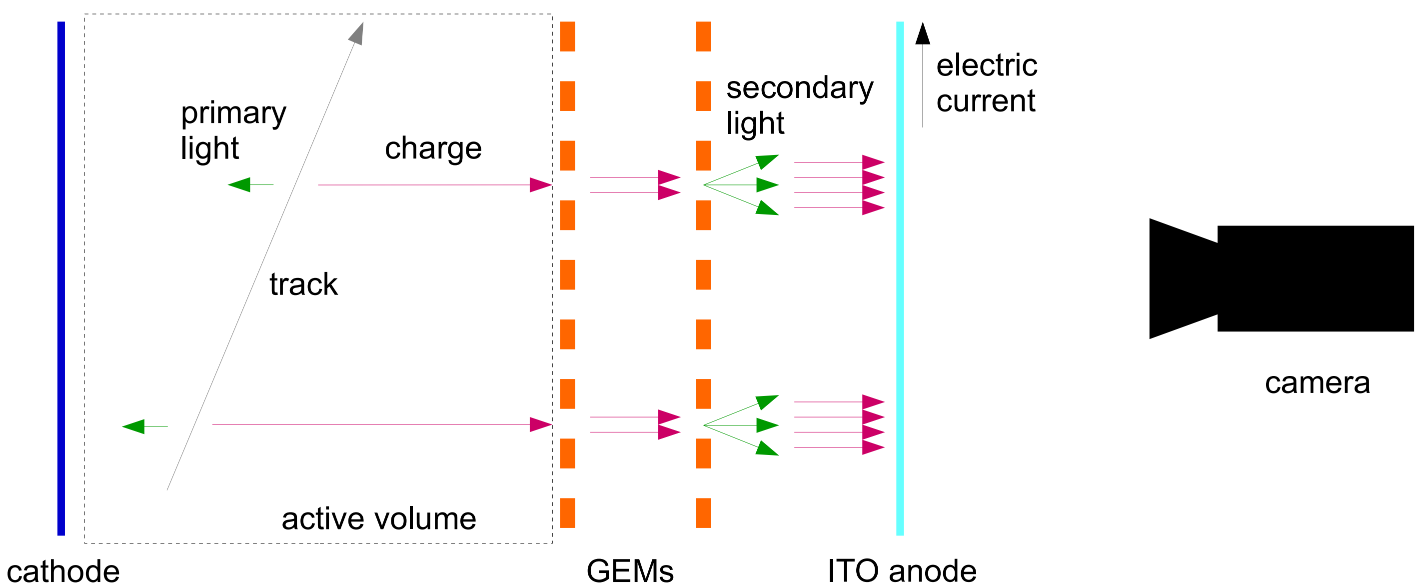
Optical TPC

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 <u>CMOS camera</u>: 2D projection
- Timing of charge collected at transparent <u>anode</u> (indium-tin-oxide): depth information



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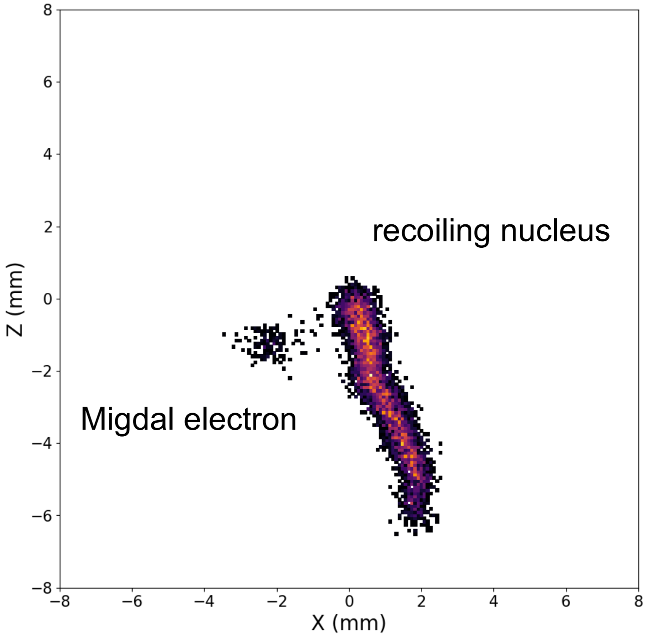
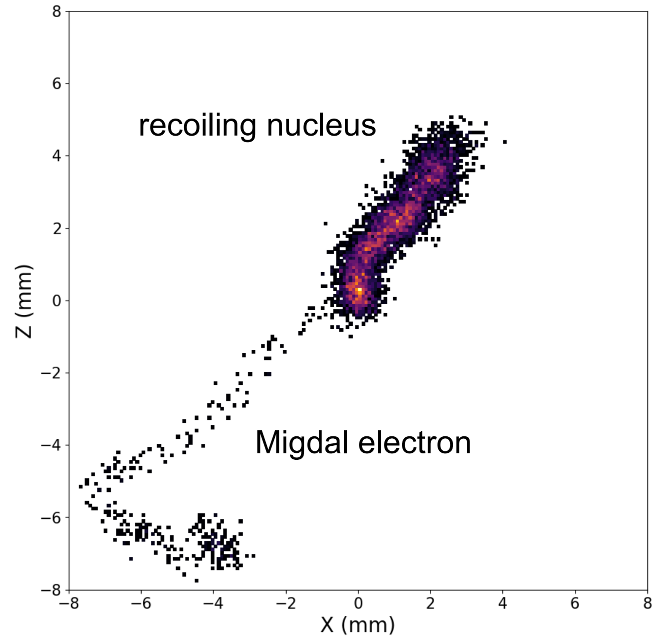




Status and plans

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

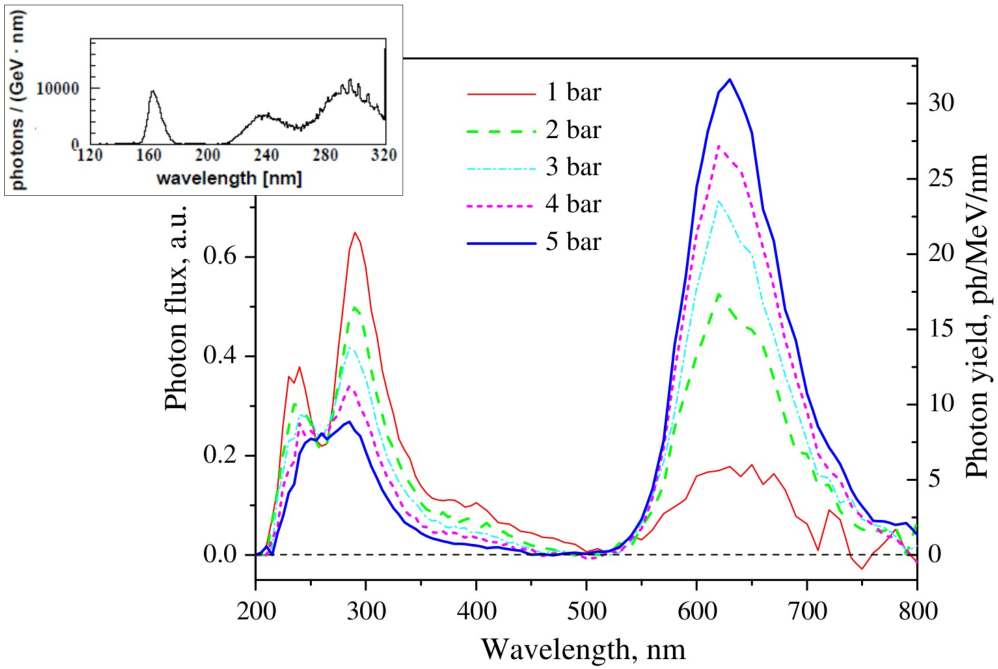
Such detector is being developed by the UAM group, at Laboratorio de Altas Energías, and is funded by a “Planes Complementarios con CCAA” project (150,000 EUR)

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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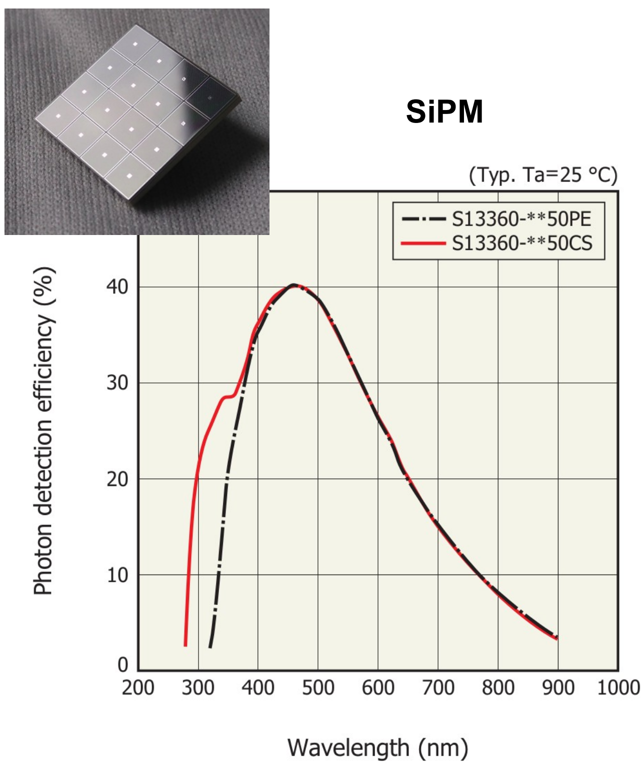

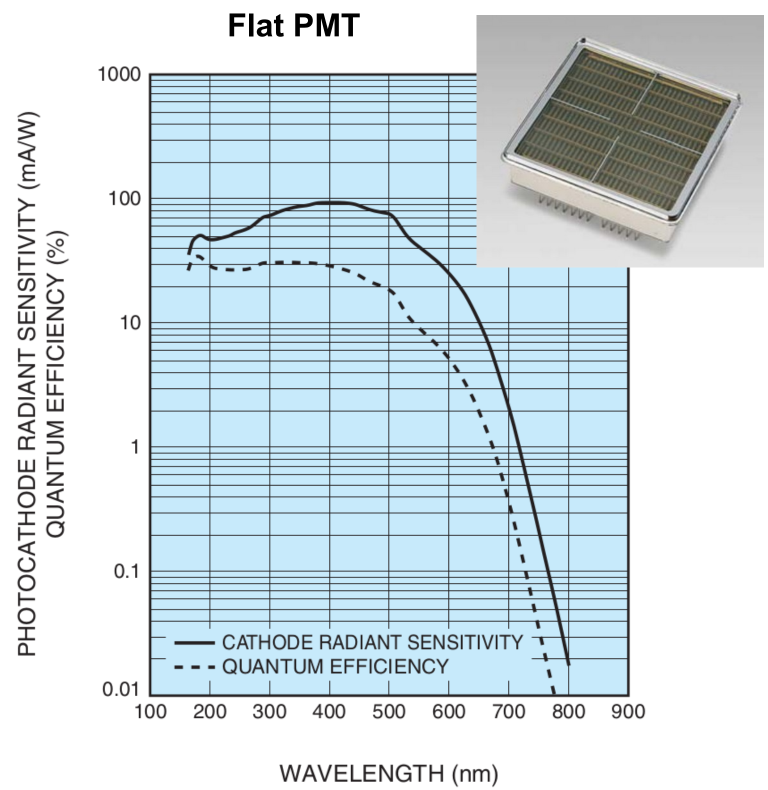

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Currently we are about start testing the different sensor samples, in order to determine the most appropriate choice for our detector

Big thanks to the CIEMAT neutrino group for their help in designing the electronics

Conclusions

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

Commissioning is scheduled for late 2024, but detector tests will occur at CUTE later this year

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

MIGDAL is an R&D experiment to confirm the Migdal effect using a neutron beam and an optical TPC

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

Backup slides

Projected sensitivity – electron recoils

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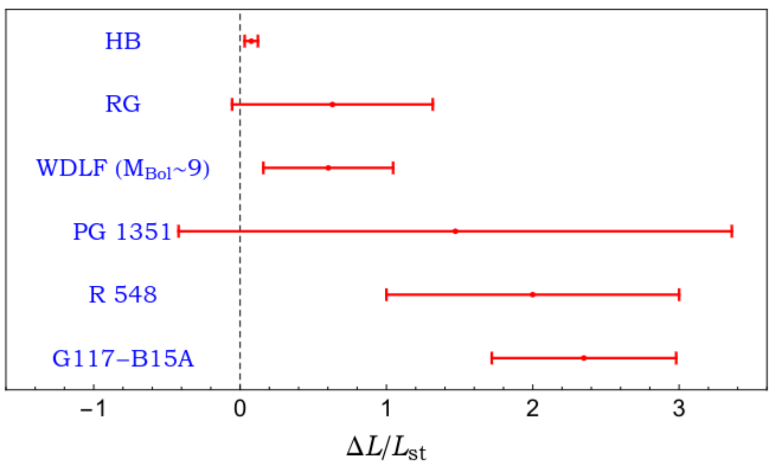


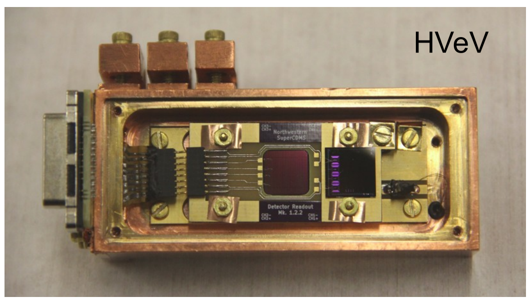
https://arxiv.org/abs/1512.08108

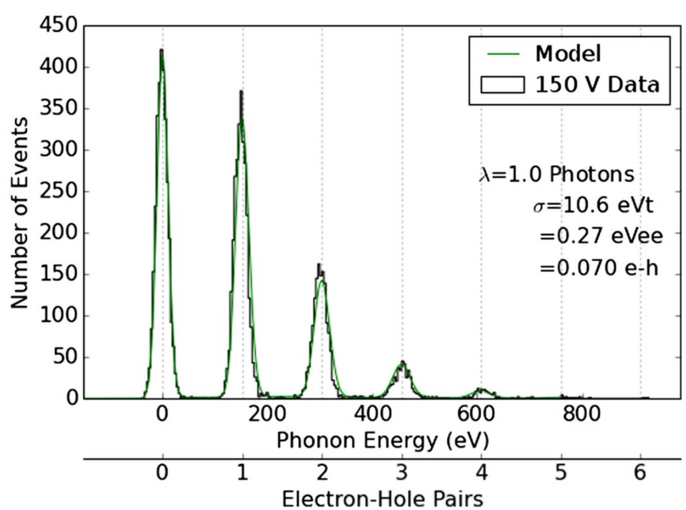
Figure 1. Missing energy loss, ΔL, normalized over a reference luminosity, L_{st}, for different stellar systems. The plot includes only stars for which an analysis with confidence levels was provided: the three white dwarf variables G117-B15A [4], R548 [6] and PG 1351+489 [7]; an example from the central region of the WDLF ($M_{Bol} \sim 9$) [8, 9]; red giants [11, 12]; and HB stars [13]. For RG and HB stars, the reference luminosity is taken to be the core average energy loss. The errors are derived from the $1\,\sigma$ uncertainties provided in the original literature.

Detector R&D

SuperCDMS is also conducting R&D to achieve sensitivity to lower energy recoils:

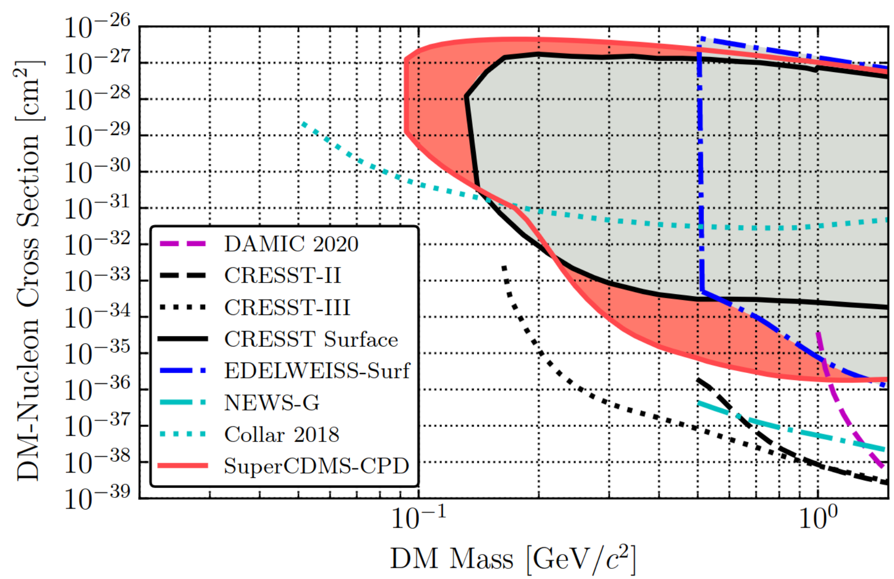
- HVeV: gram-scale Si, able to detect single ionization electrons through NTL effect
- Cryogenic photo-detector (CDP): 10 g Si, high-sensitivity phonon detector (σ_E ~ 4 eV)





Phys. Rev. Lett 121, 051301 (2018)

DM exclusion limits from CPD



Phys. Rev. Lett. 127, 061801 (2021)