Direct Dark Matter search with solid state detectors

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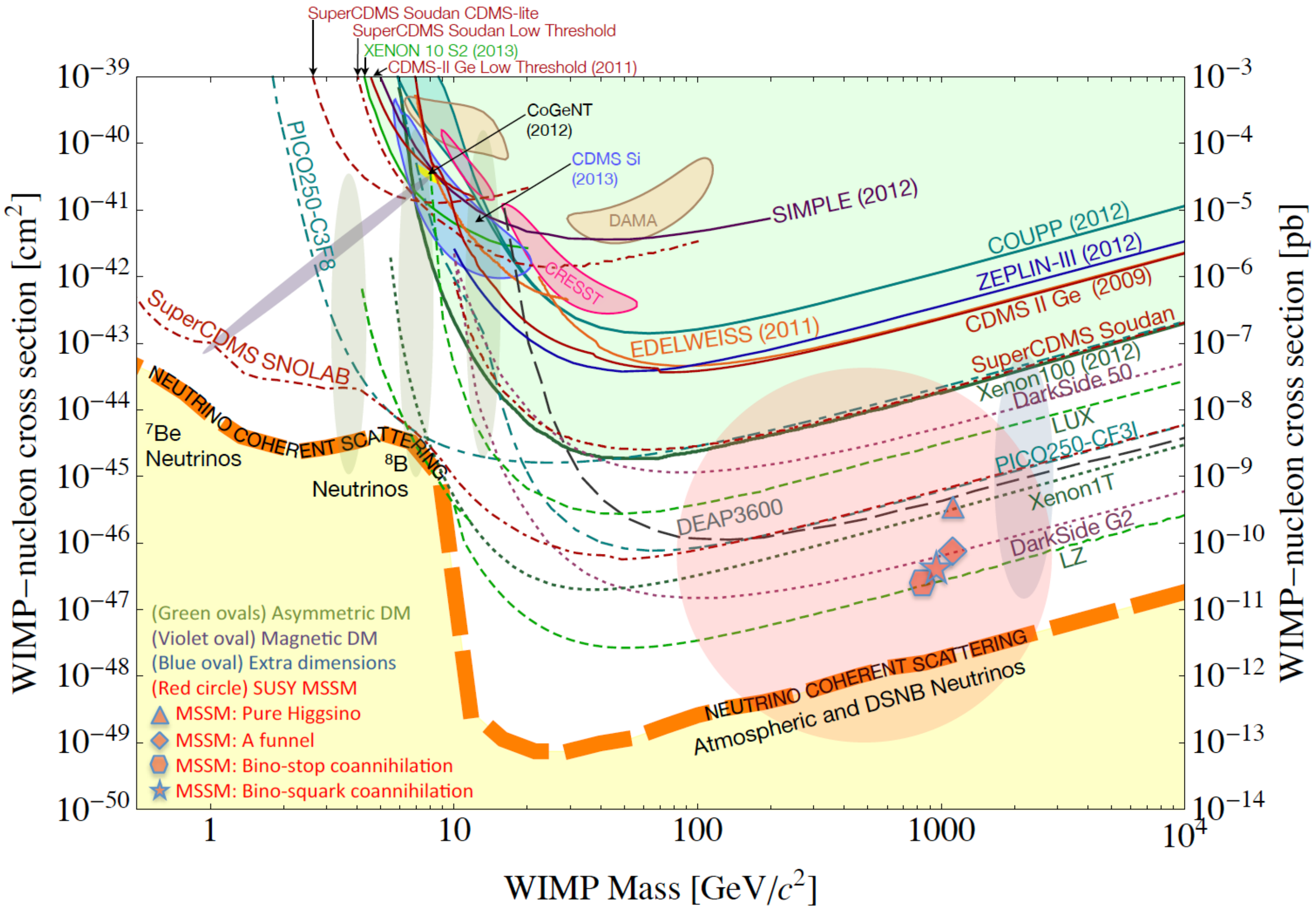
Les Rencontres de Physique de la Vallée d'Aoste

La Thuile, 3-9 March 2024

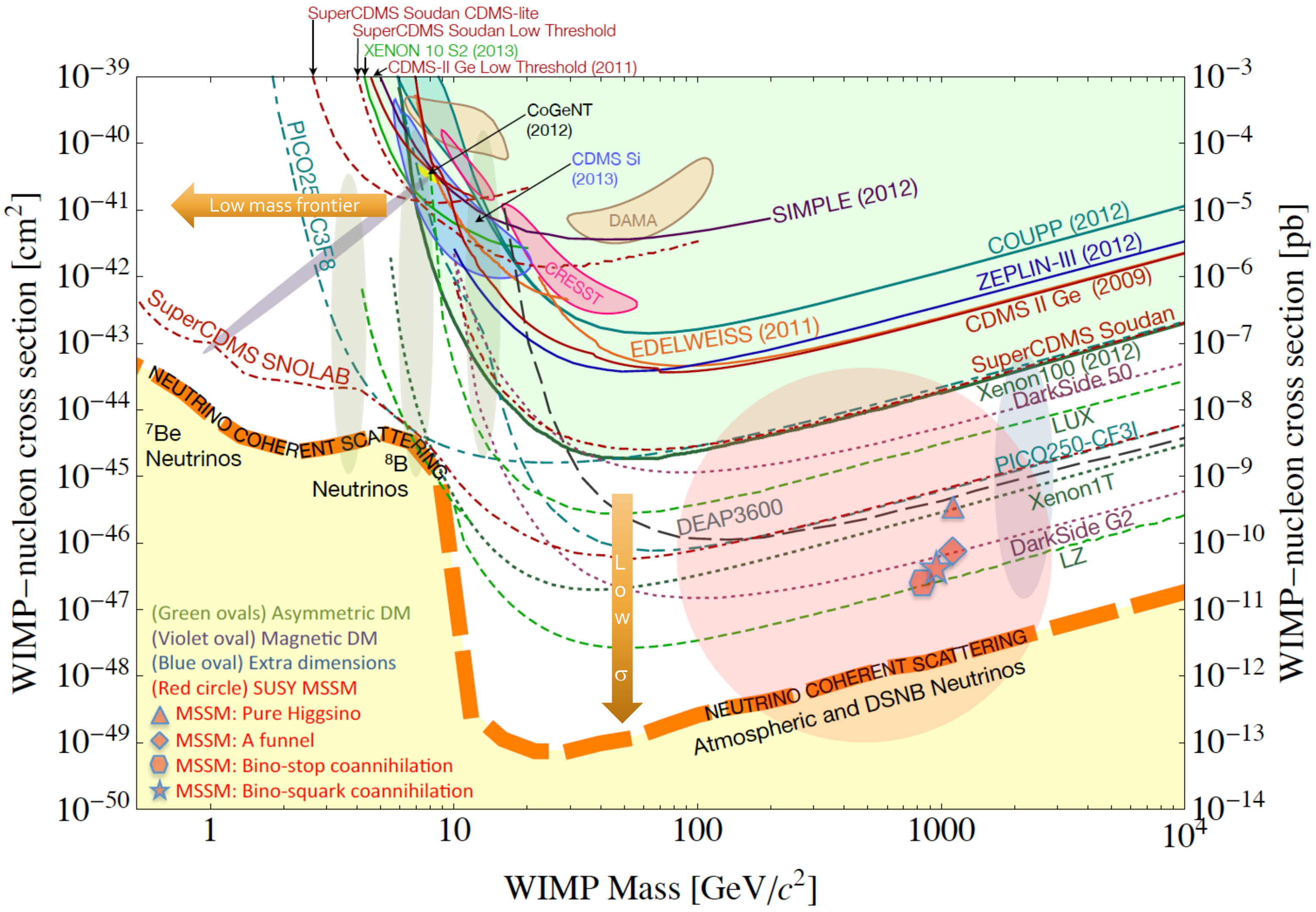
OUTLINE

- ✓ Direct DARK MATTER search panorama
- ✓ DARK MATTER candidates
- ✓ Technologies and methods
  - ✓ NaI-based experiment family
  - ✓ Low mass frontier
  - ✓ Very low mass frontier
- ✓ Conclusions

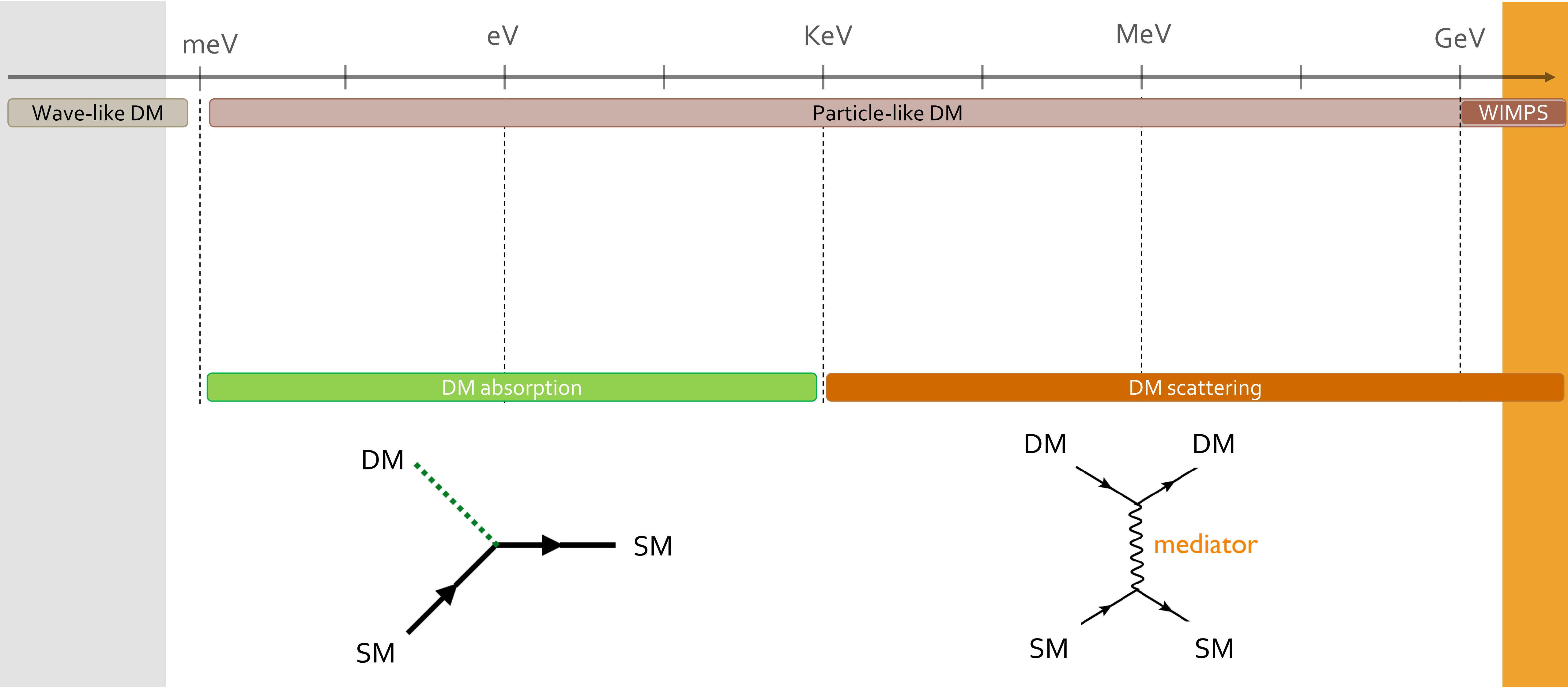
Direct DARK MATTER search - Panorama



Direct DARK MATTER search - Panorama

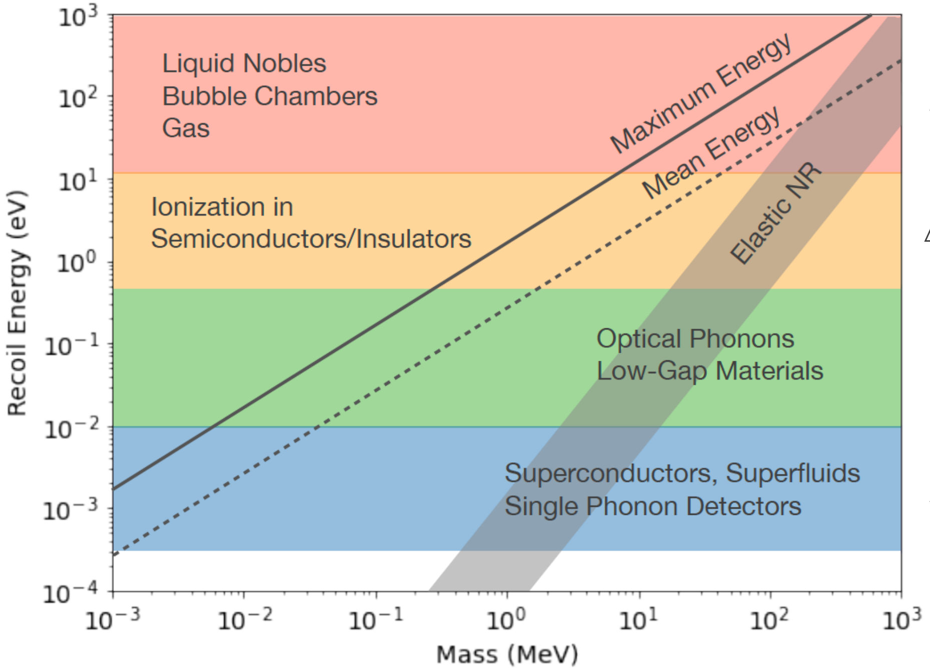


DARK MATTER candidates and detection strategies



DARK MATTER candidates and detection strategies

arXiv:2203.08297v2



ΔE = 10 eV (Xe, Ar, He)

ΔE = 1 eV (Si, Ge, GaAs, diamond)

ΔE = 10-100 meV (GaAs, sapphire, Dirac materials)

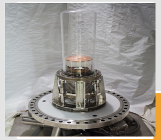
ΔE = 1 meV (superfluid, superconductors)

Elastic DM-nucleus scattering: $E_{NR} < 5\ \text{eV}\left(\frac{m_\chi}{100\ \text{MeV}}\right)^2\left(\frac{130\ \text{GeV}}{M_N}\right)$

Inelastic scattering (transfer of a large fraction of DM kinetic energy):

- DM scattering with bound electrons
- DM scattering with nuclei through the Migdal effect
- DM-target scattering that produces a collective excitation (phonons)

Direct Dark Matter search: methods and technologies



Superheated liquids

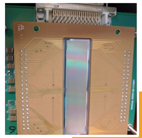
- PICO

Noble Liquids TPC

- LUX
- LZ
- Xenon
- PandaX
- DEAP
- DS-20k
- DARWIN
- ...

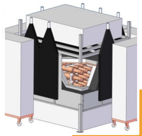
Cryogenic Bolometers

- CRESST
- CDMS/ SuperCDMS
- EDELWEISS
- COSINUS
- ...



Ionization detectors

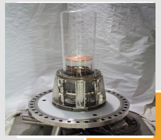
- CDEX
- NEWS-G
- TREX-DM
- DAMIC
- SENSEI
- OSCURA
- ...



Scintillation detectors

- DAMA
- ANAIS
- COSINE
- SABRE
- PICOLON
- DM-ICE

Direct Dark Matter search: methods and technologies



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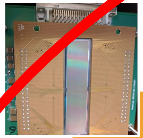

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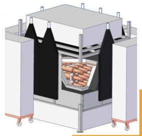

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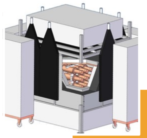
NaI-based experiment family



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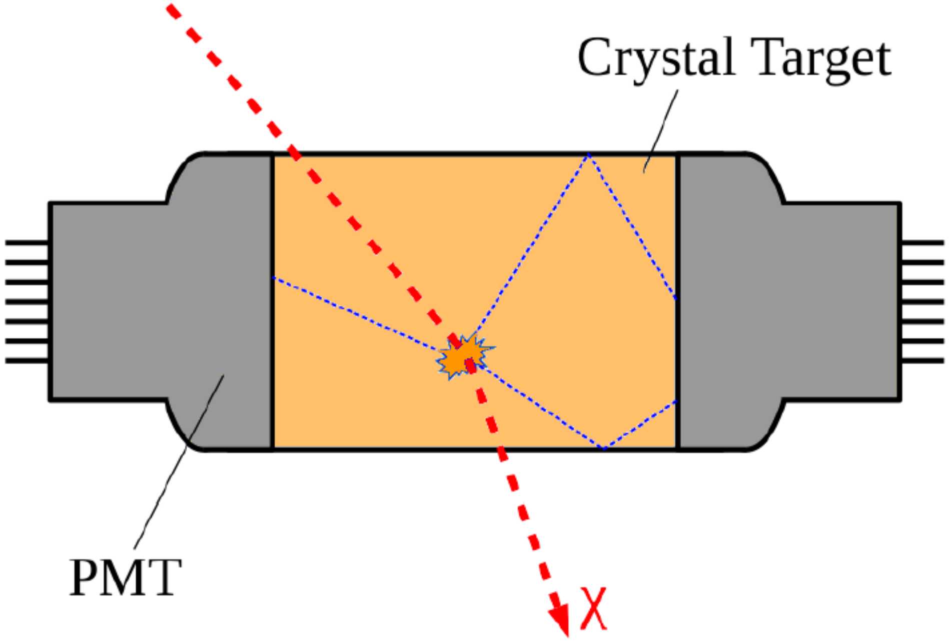
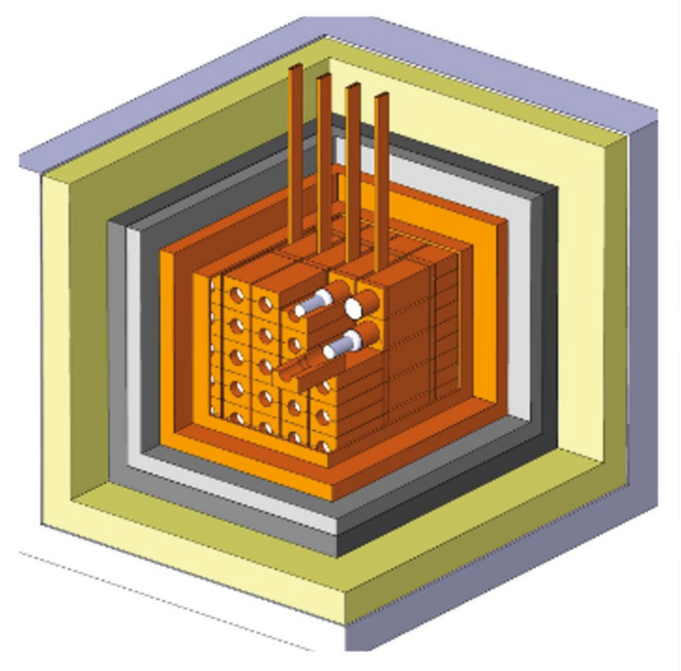
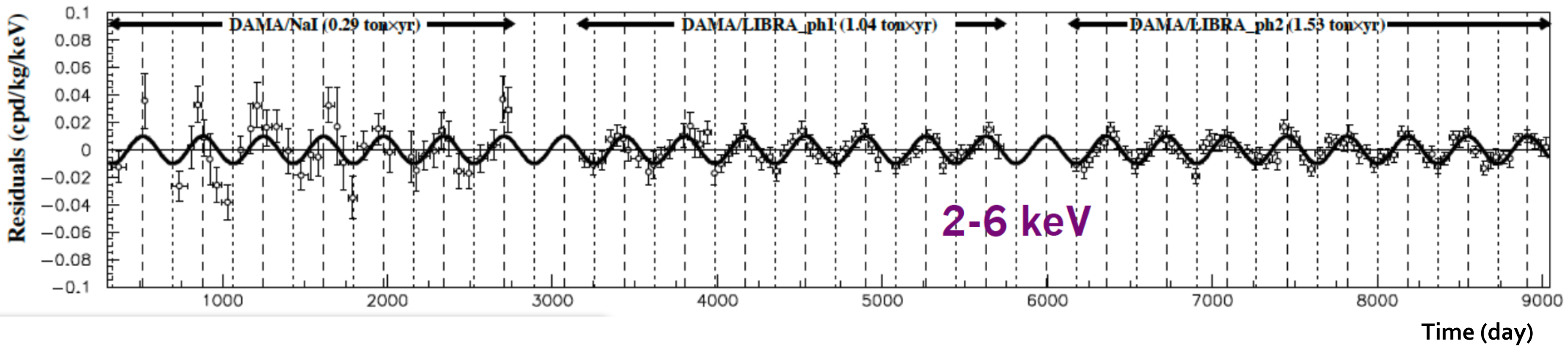


NaI-based experiment family - DAMA



- DAMA/LIBRA » 250 kg NaI(Tl) (Large sodium Iodide Bulk for RAre processes)
- 232Th, 238U and 40K at level of 10-12 g/g
- Threshold = 0.5 keV
- 22 years of data taking, 2.89 ton x year exposure
- 13.7 σ C.L.



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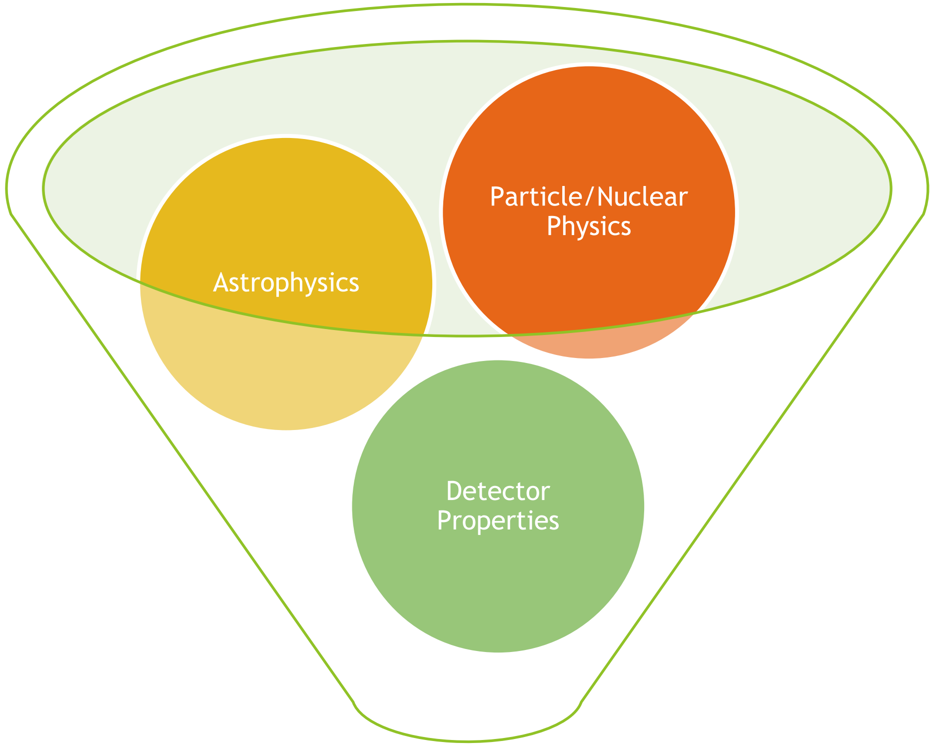
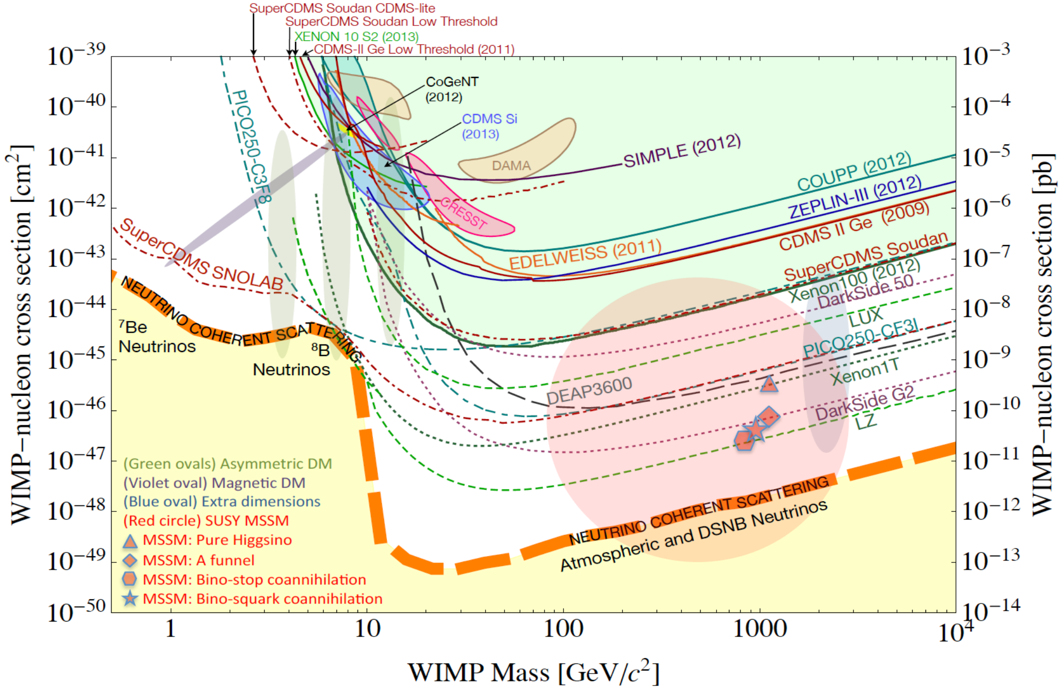


$$\frac{dR}{dE_r} = N_N \frac{\rho_0}{m_\chi} \int_{v_{min}}^{v_{max}} d\vec{v}\, f(\vec{v}) v \frac{d\sigma}{dE_r}$$



Astroparticle Physics European Consortium (APPEC) Recommendation:

"The long-standing claim from DAMA/LIBRA [...] needs to be independently verified using the same target material."

NaI-based experiment family – ANAIS/COSINE/SABRE

- 9 NaI(Tl) crystals (112.5 kg) @ **CANFRANC (Spain)**
- 2017 → today: 643.48 kg×y @ August 8, 2023
- Phys. Rev. Lett. 123, 031301 (2019); J. Phys. Conf. Ser. 1468**,** 012014 (2020); 3 y: Phys. Rev. D 103, 102005 (2021)
- Sensitivity improved with machine-learning techniques:
  incompatible with DAMA/LIBRA at 3.9(2.8) σ for [1-6]([2-6])keV

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- No conclusive results yet (consistent with both DAMA and zero modulation)

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- SABRE goal is to search for annual modulation with two nearly identical NaI(Tl) detectors in the Northern (**LNGS-Italy**) and Southern Hemispheres (**Stawell – Australia**)
- Crystals current result @LNGS: ~1 cpd/kg/keV background (goal 0.5 cpd/kg/keV)
- SABRE-South full detector deployment by end of 2024, SABRE-North new underground site outfitting by 2024
- SABRE expected to exclude/confirm annual modulation in 3-5 years of operation

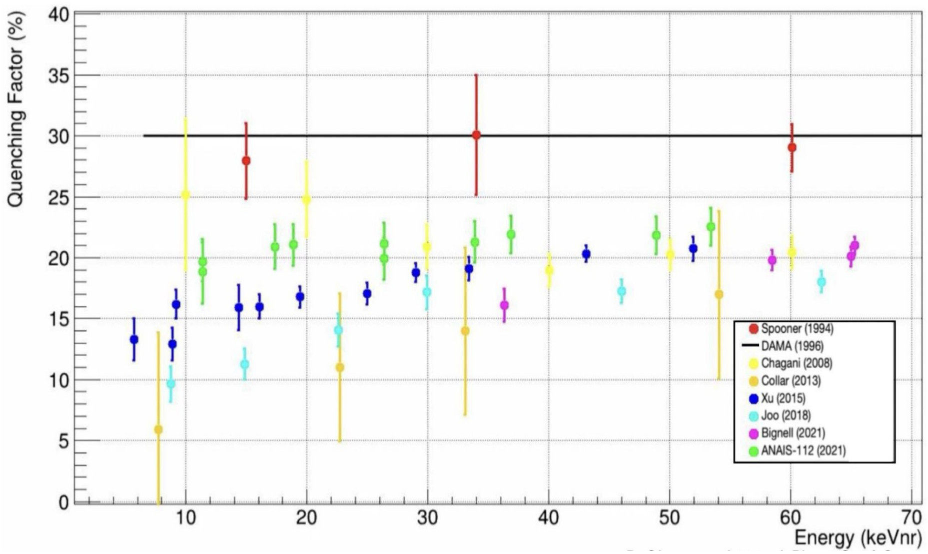
NaI-based experiment family – QFs

Quencing factor values set the energy scale

$$QF(E) = \frac{L_{NR}(E)}{L_{ER}(E)}$$

DAMA: Na 30%, I 9%

D. Cintas et al 2021 J. Phys.: Conf. Ser. 2156 012065



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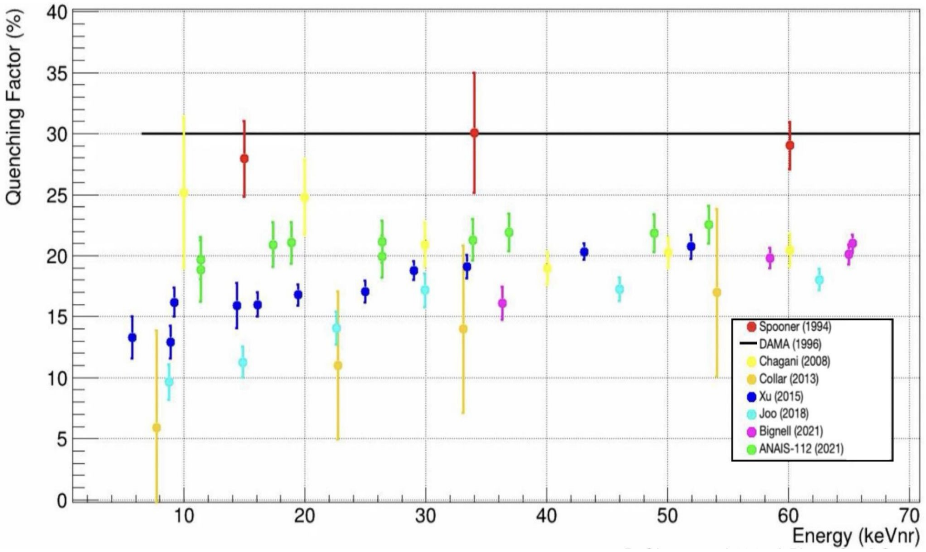
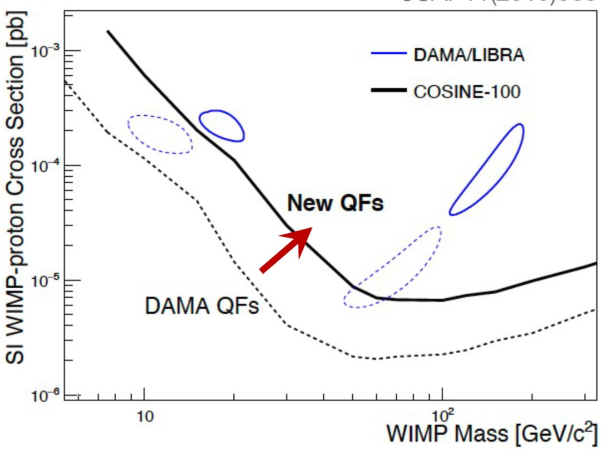


JCAP11(2019)008



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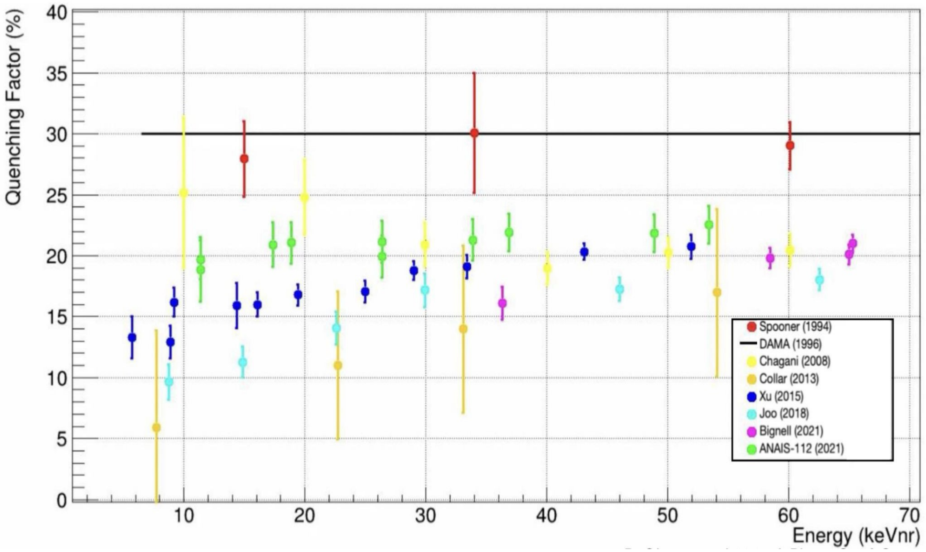
- Energy dependence?
- Systematic uncertainties deriving from different measurement:
  - ❑ Procedure?
  - ❑ Non-linearity?
  - ❑ Tl concentration dependence?
  - ❑ Impurities?
- …

D. Cintas et al 2021 J. Phys.: Conf. Ser. 2156 012065



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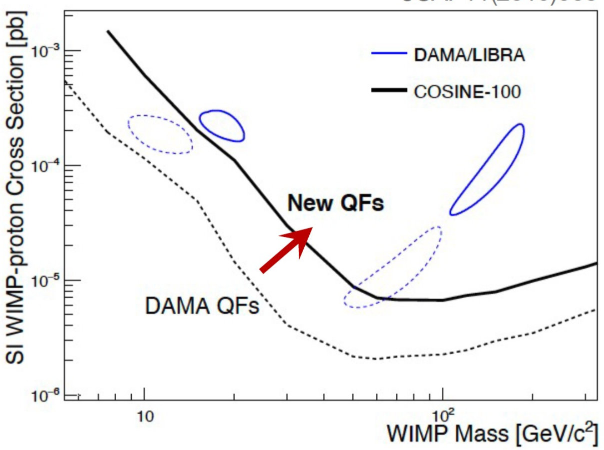
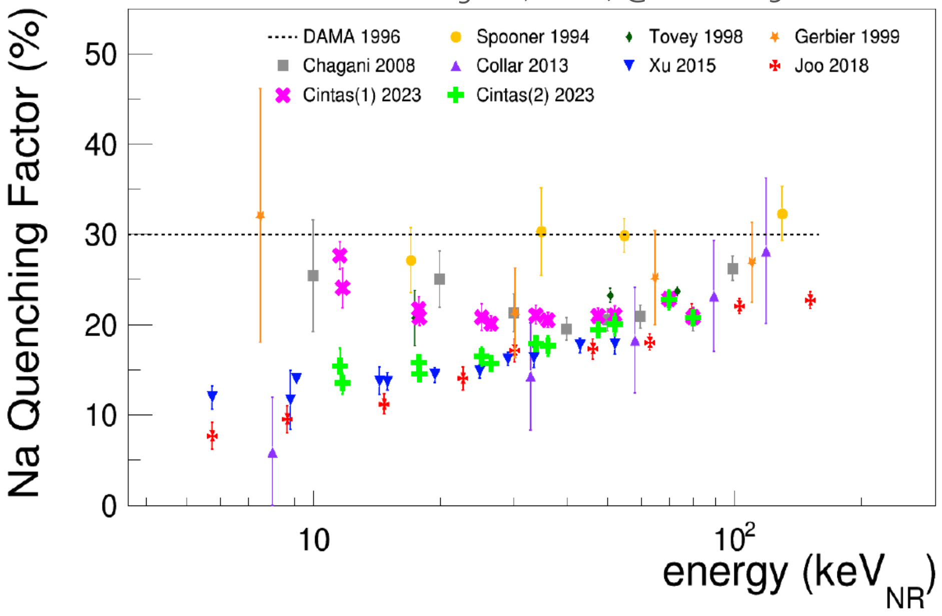


NaI-based experiment family – QFs

Tamara Pardo Yanguas (ANAIS) @ TAUP2023



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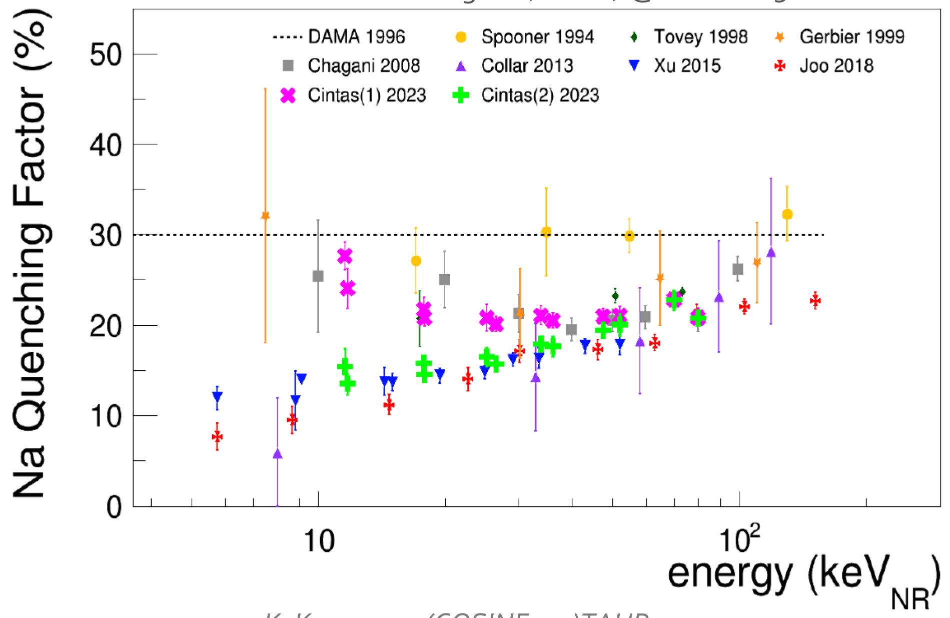
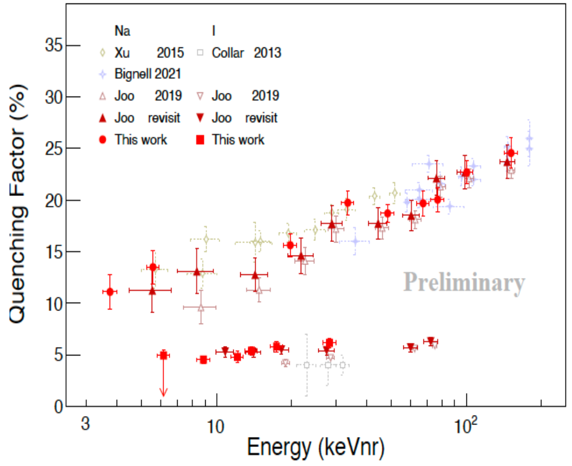
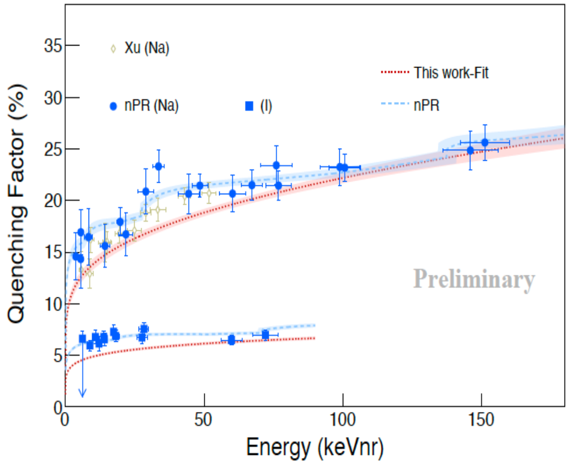


K. Kyungwon (COSINE100)TAUP2024





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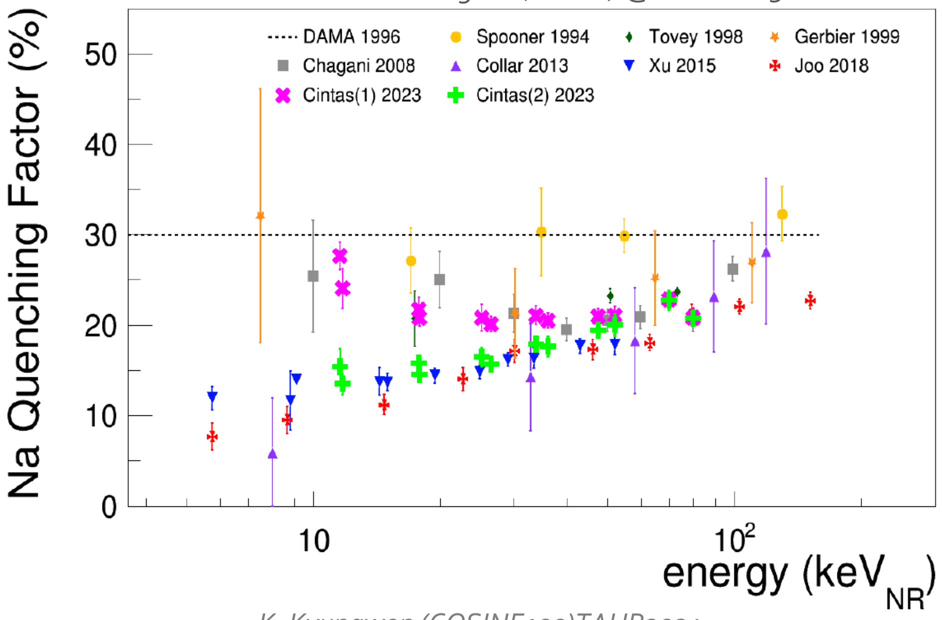
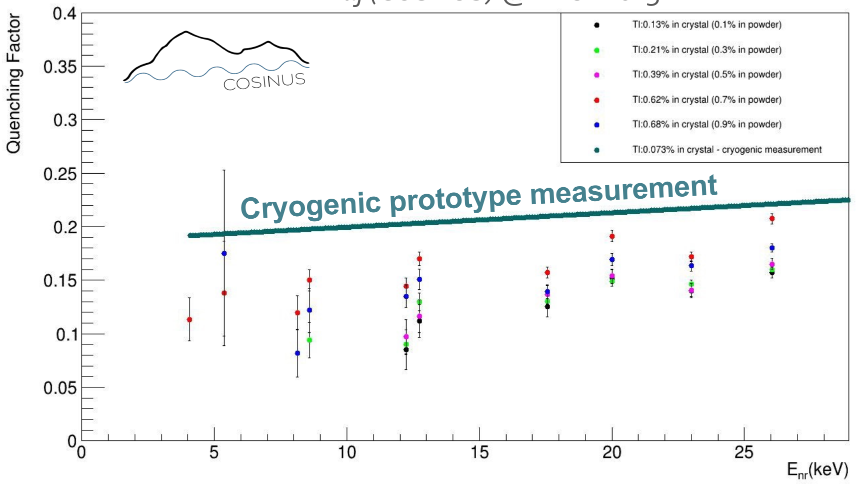
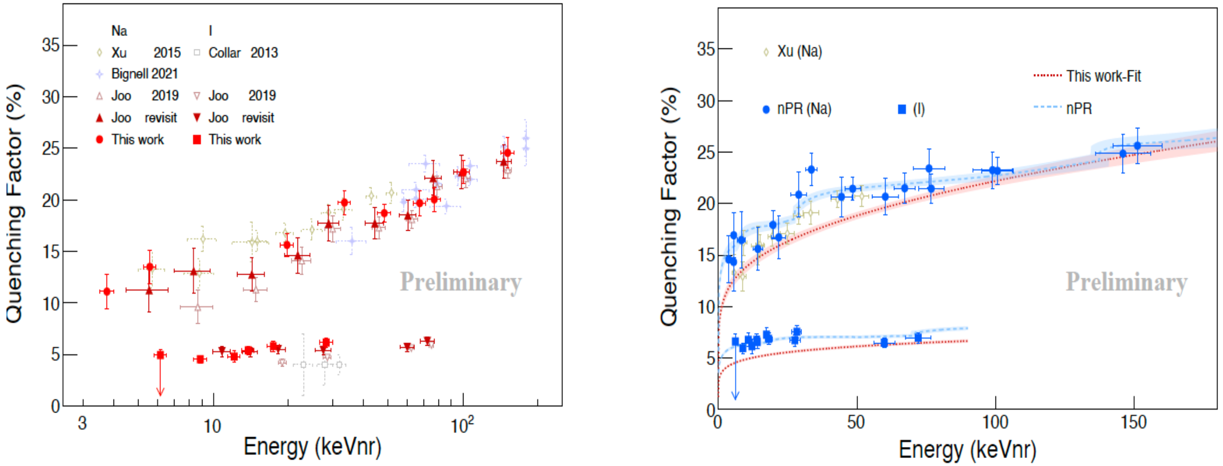
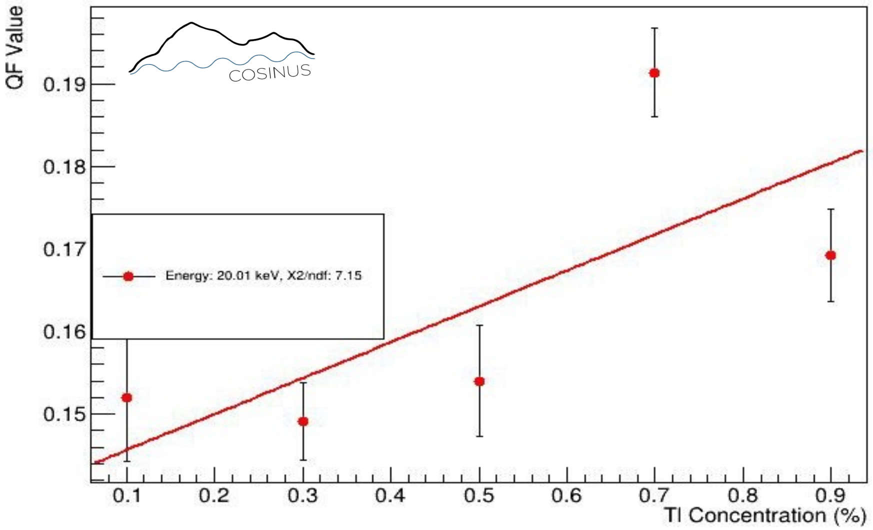


R. Maji(COSNUS) @ TAUP2023



K. Kyungwon (COSINE100)TAUP2024

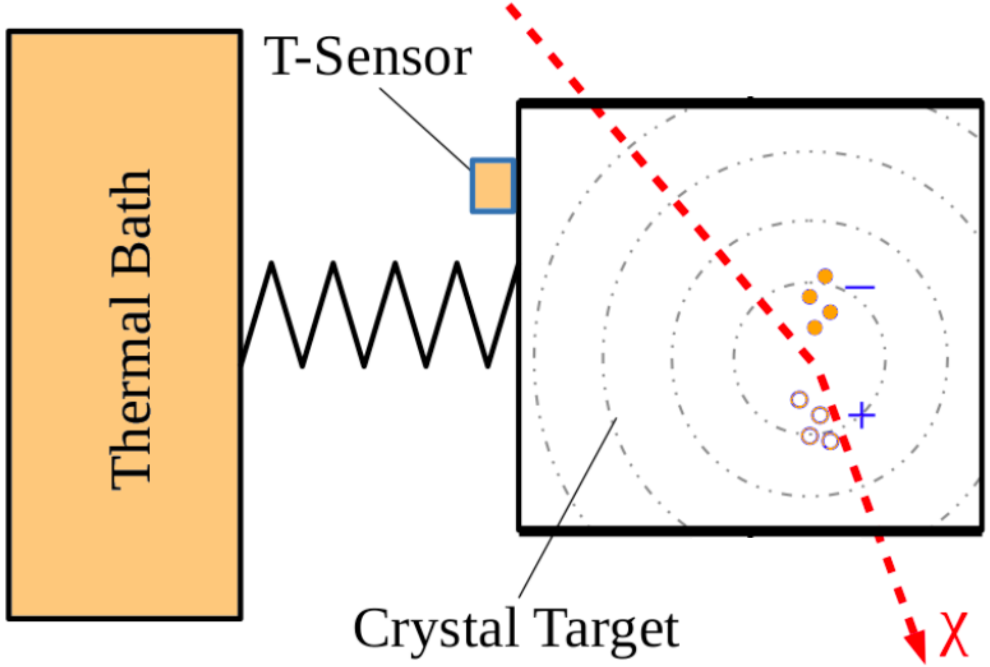




Cryogenic Bolometers

Cryogenic Bolometers

- CRESST
- CDMS/ SuperCDMS
- EDELWEISS
- COSINUS
- …



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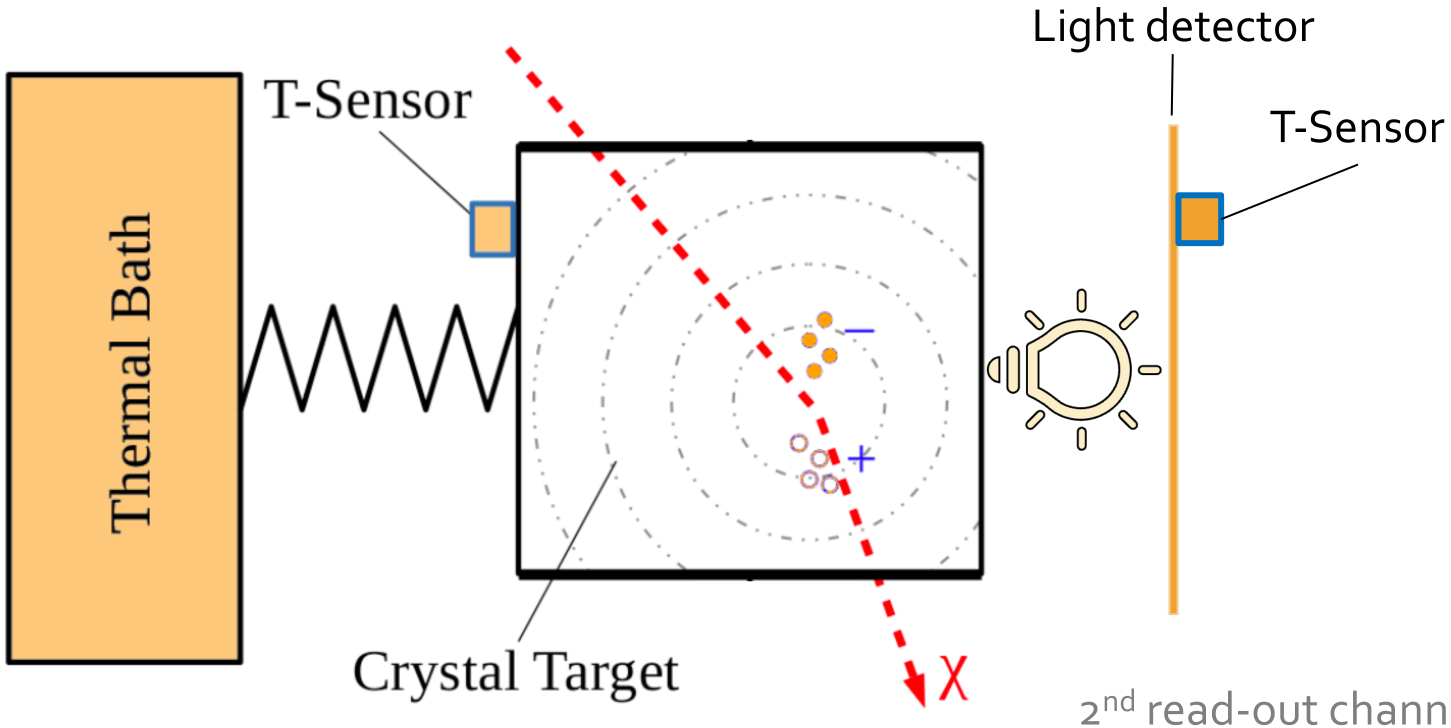

2nd read-out channel: **light**

Cryogenic Bolometers

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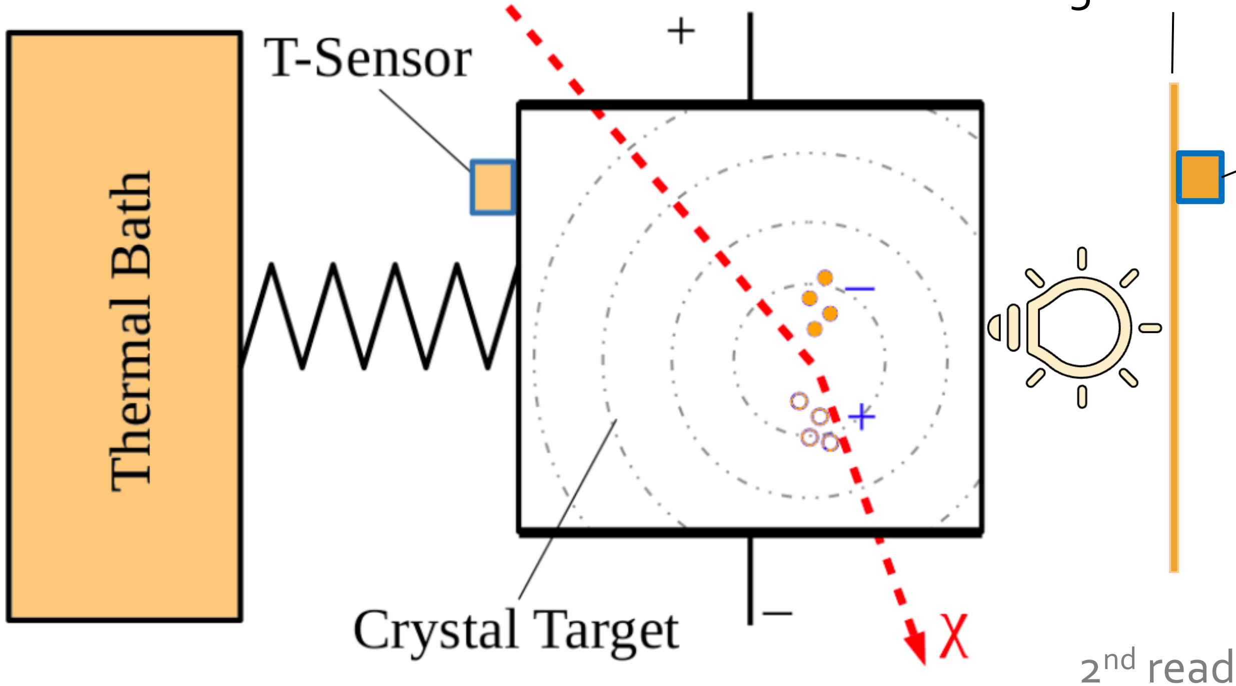

2nd read-out channel: **light** or **charge**

Cryogenic Bolometers

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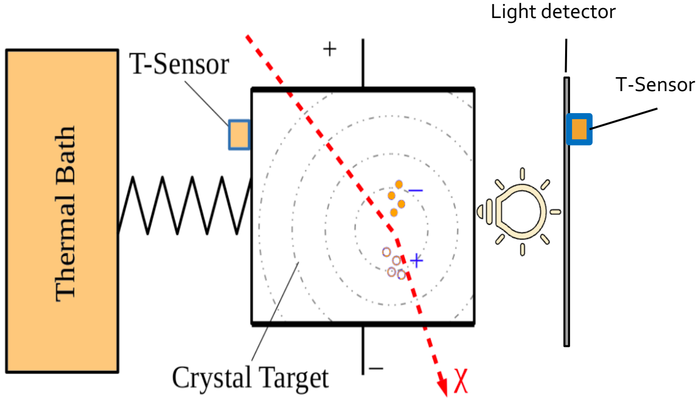
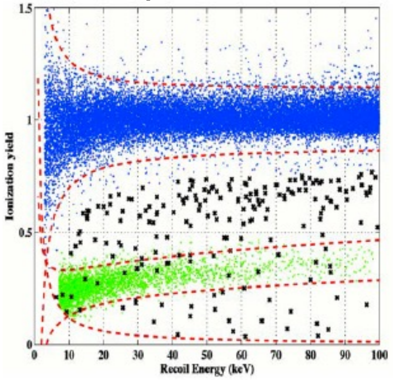
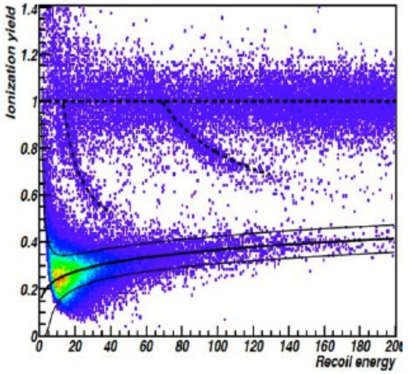


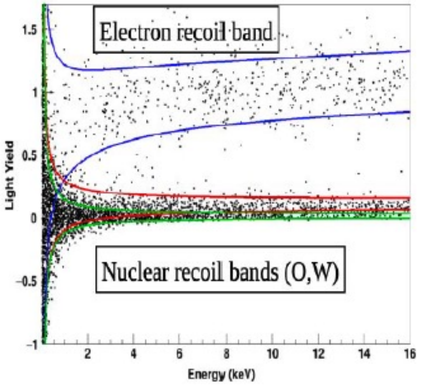
SuperCDMS



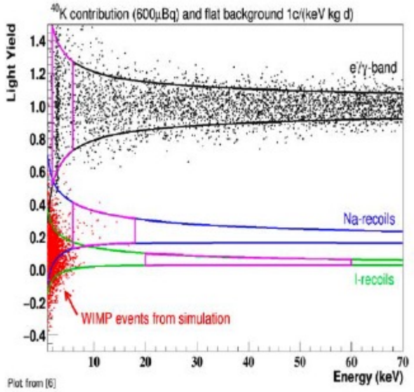
EDELWEISS



CRESST



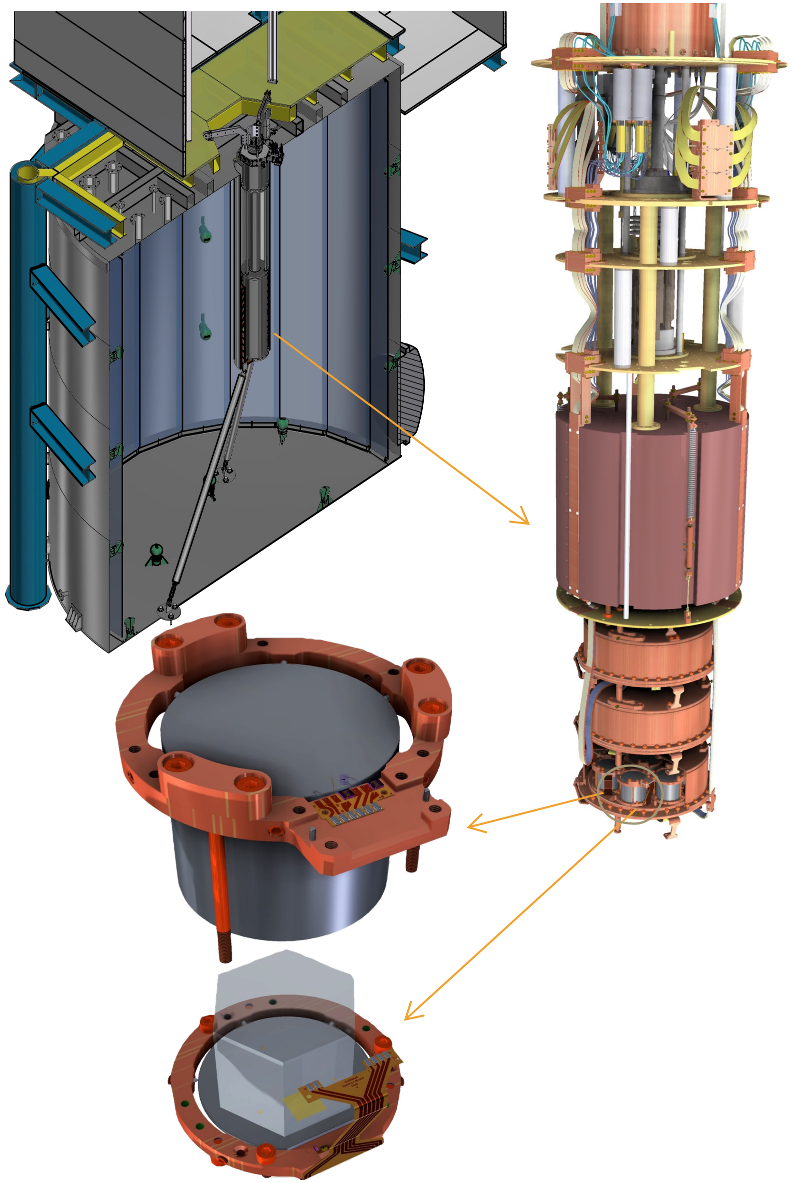
COSINUS



Charge/Heat

Light/Heat

NaI-based experiment family – COSINUS



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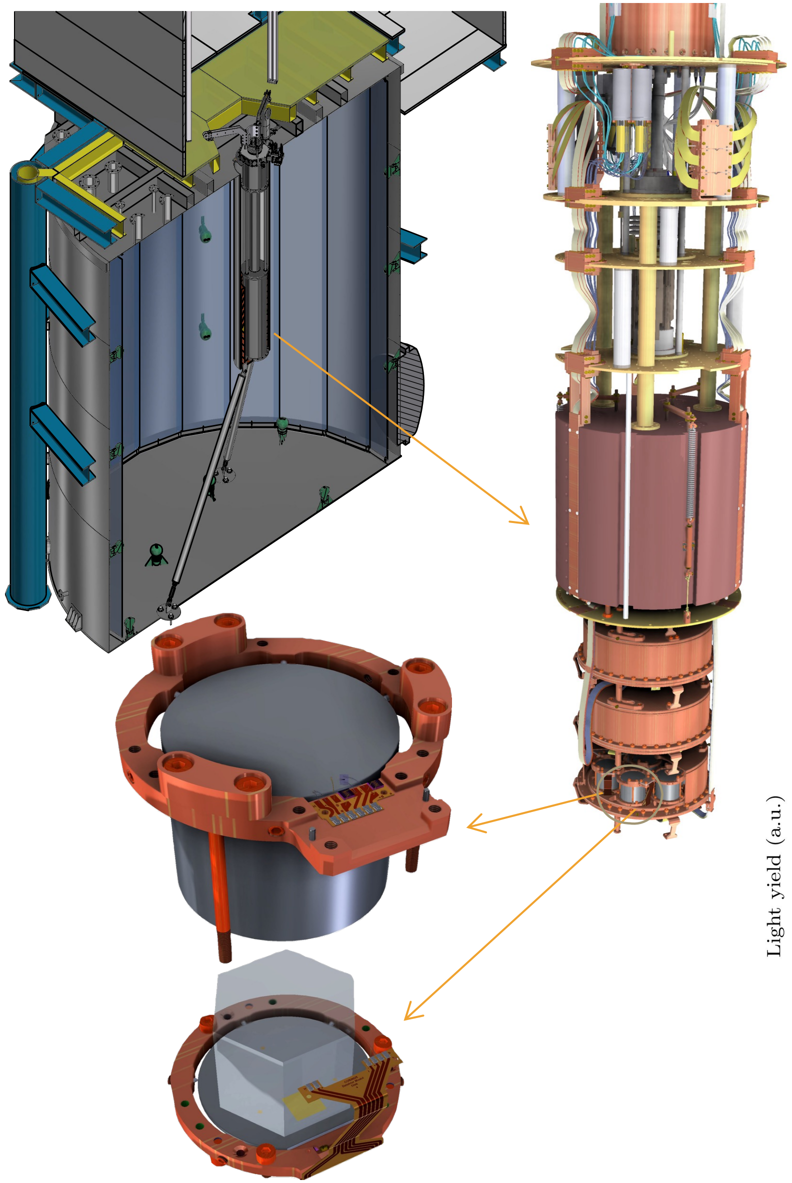
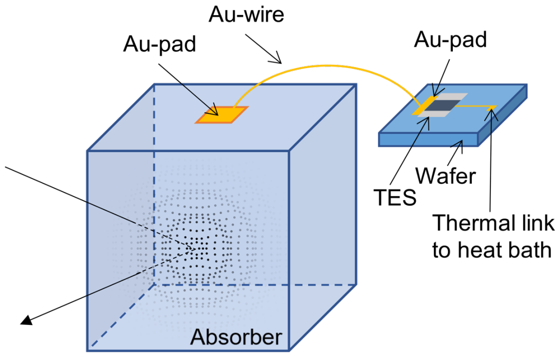
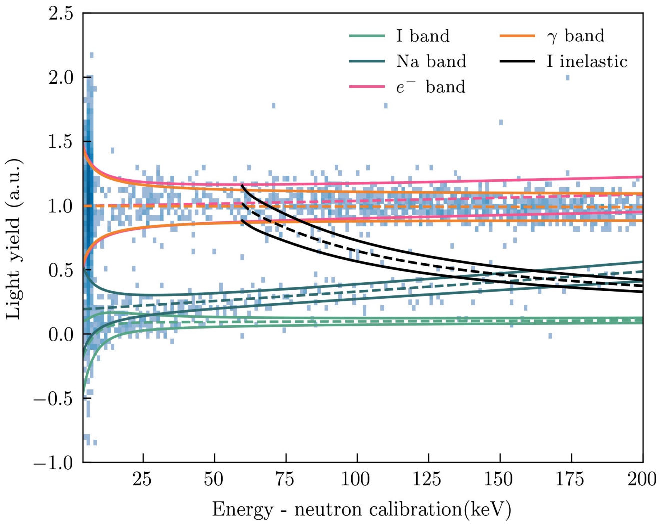
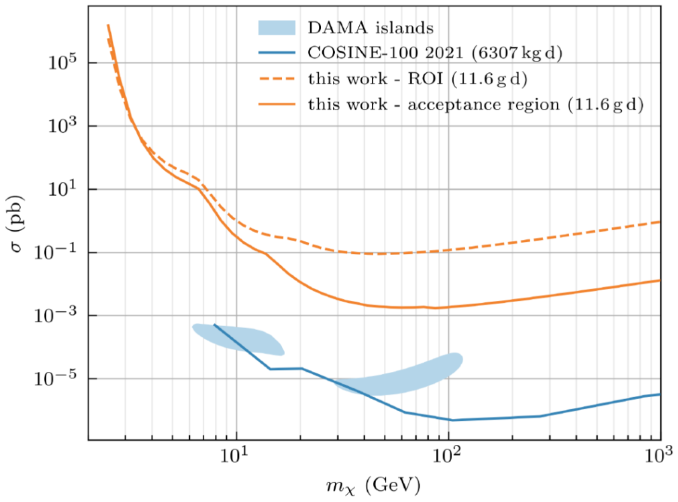


First experimental remoTES implementation:
Nucl.Instrum.Meth.A 1045 (2023) 167532







https://arxiv.org/pdf/2307.11139.pdf

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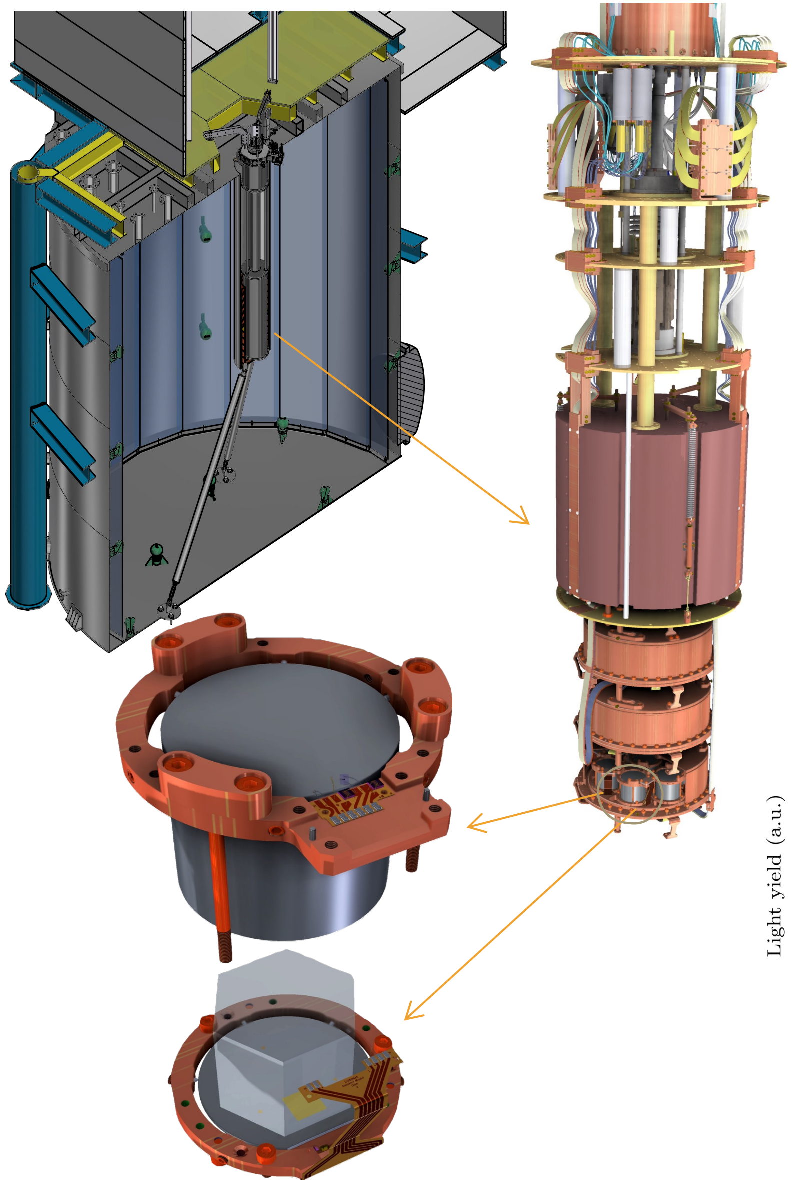

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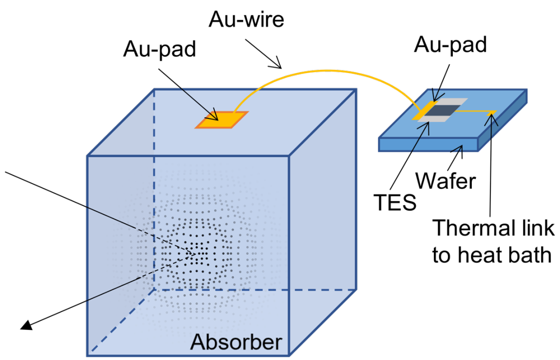
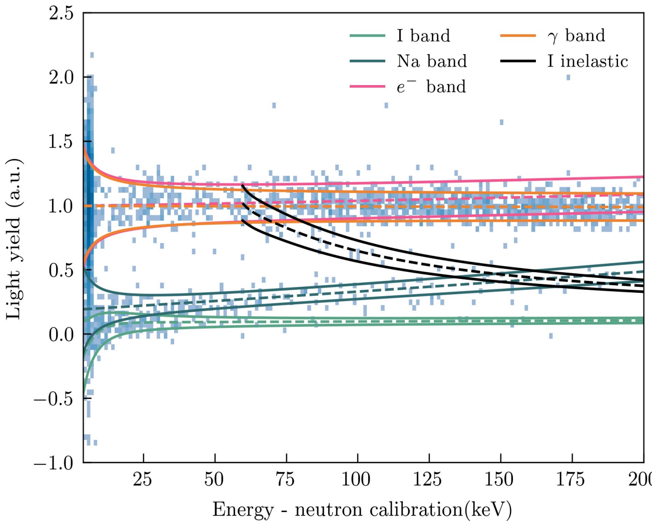




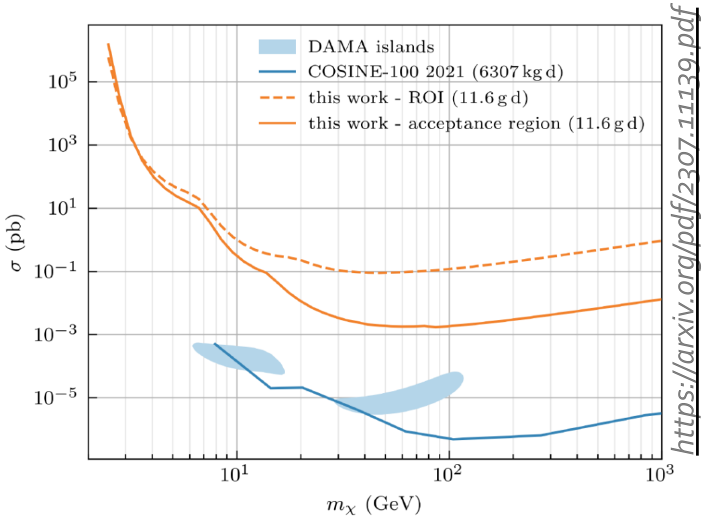
COSINUS 1π (2024-2027)

Probing any DM-nuclei interactions

compatible with DAMA/ LIBRA signal

- 100 kg days excluding any falling recoil spectra
- 1000 kg days excluding any arbitrary spectrum

COSINUS 2π (>2027): Investigating annually modulating signals

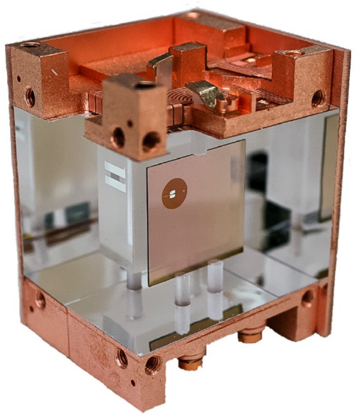


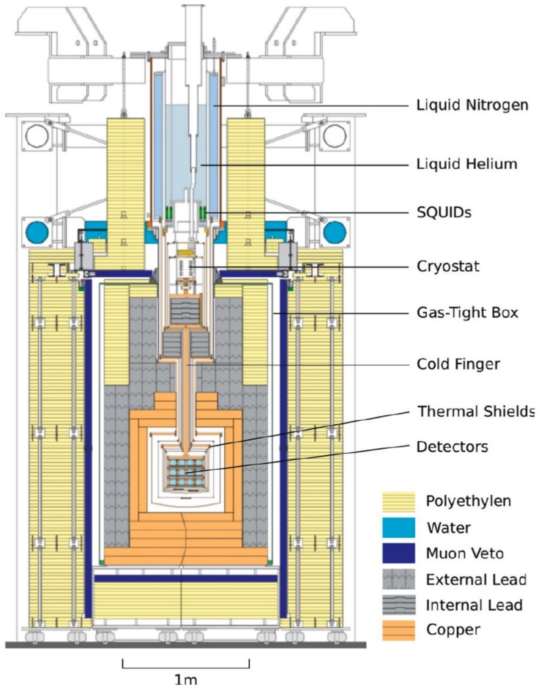
Felix Kahlhoefer et al JCAP05(2018)074

https://arxiv.org/pdf/2307.11139.pdf

Cryogenic bolometers - CRESST

- *Target: various crystal materials:*
  $CaWO_4$, Al_2O_3, $LiAlO_2$, Si
- *Sensor: W-TES at 15 mK*
- *Energy calibration with X-rays*
- *Energy threshold of O(10 eV)*





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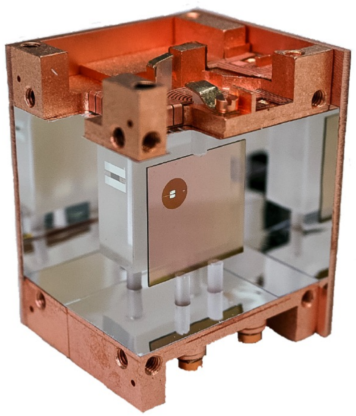
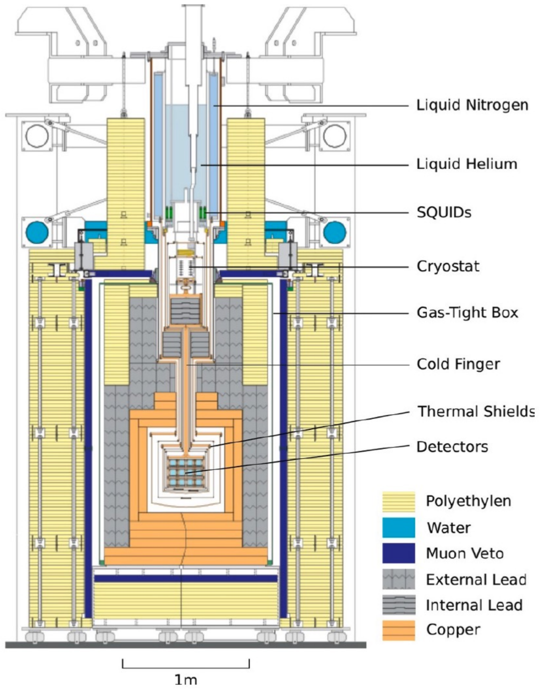




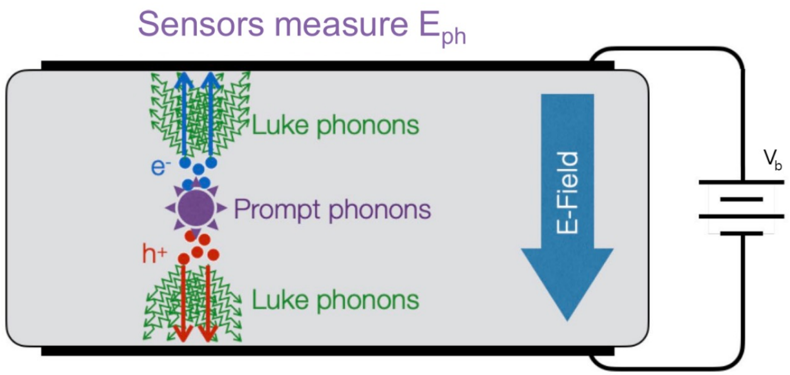
Detector A - $CaWO_4$:
23.6 g
exposure: 5.698 kgd
Eth= 30.1 eV_{NR}

Al_2O_3 wafer detector:
0.6 g
exposure: 0.14 kgd
Eth= 6.7 eV_{NR}

$LiAlO_2$ detector:
10.5 g
exposure: 1.161 kgd
Eth= 83.6 eV_{NR}

Si wafer detector:
0.35 g
exposure: 55.06 gd
Eth= 10.0 eV_{NR}

Cryogenic bolometers –SuperCDMS

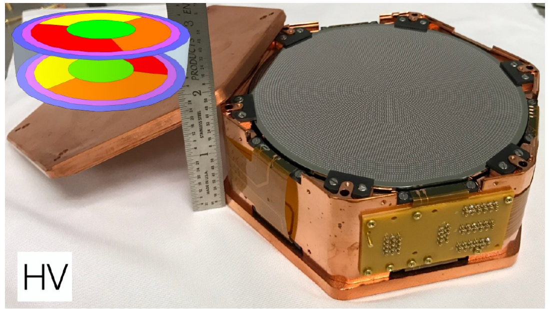


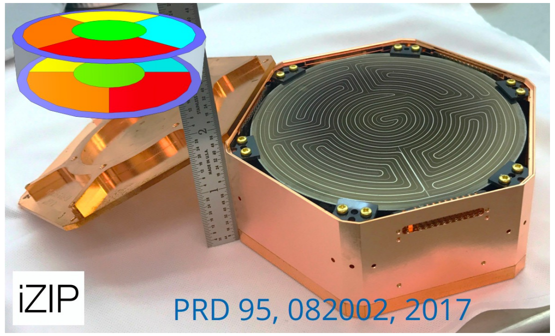
HV detector *→ low threshold*

- *Drifting charge carriers (e–/h+) across a potential (V_b) generates a large number of Luke phonons (NTL effect)*
- *Trade-off: no NR/ER discrimination*
- $E_t = E_r + (N_{eh} \times e\, Vb)$
- $E_{th} \sim 60\ eV_{nr}$

iZIP detector *→ low background*

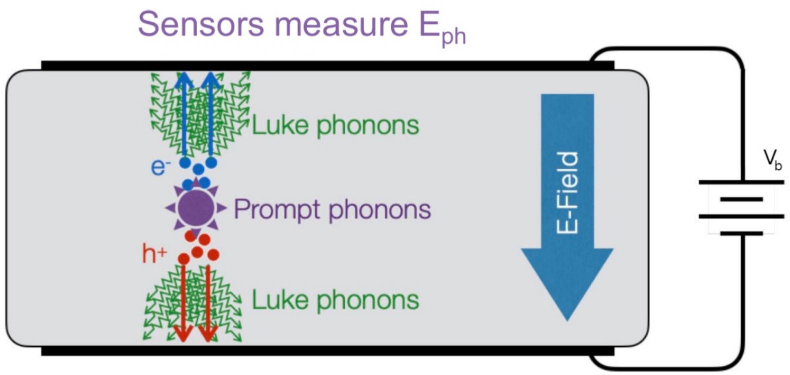
- *Interleaved Z-sensitive Ionization and Phonon detector*
- *Prompt phonon and ionization signals allow for NR/ER event discrimination*
- $E_{th} \sim 150\ eV_{nr}$





PRD 95, 082002, 2017

Cryogenic bolometers –SuperCDMS



SuperCDMS@SNOLAB
Initial payload: 24 detectors:
- ✓ *iZIP towers: 10 Ge + 2 Si crystals*
- ✓ *HV towers: 8 Ge + 4 Si crystals*

HV detector *→ low threshold*
- *Drifting charge carriers (e–/h+) across a potential (V_b) generates a large number of Luke phonons (NTL effect)*
- *Trade-off: no NR/ER discrimination*
- $E_t = E_r + (N_{eh} \times e\,Vb)$
- $E_{th} \sim 60\ eV_{nr}$

iZIP detector *→ low background*
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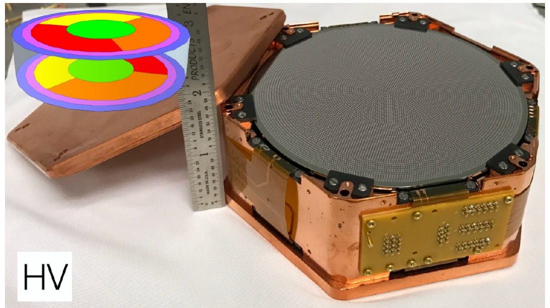
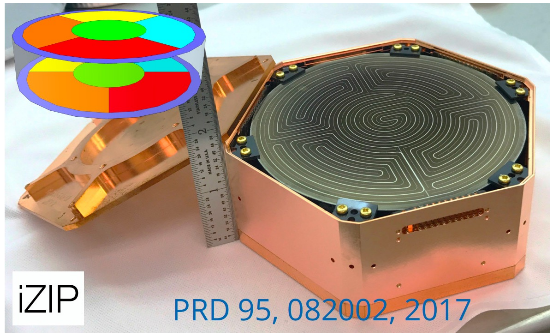
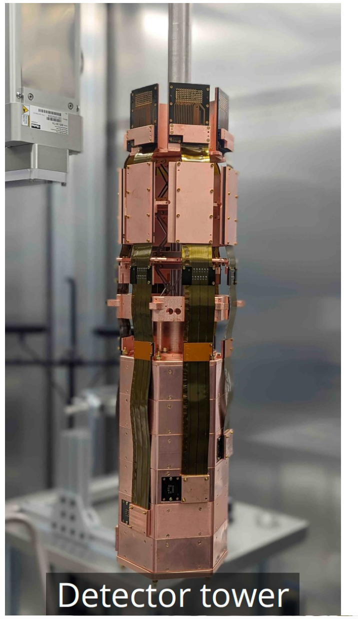
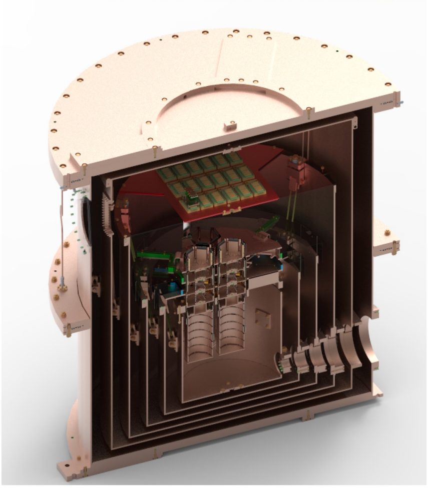
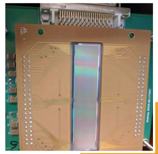






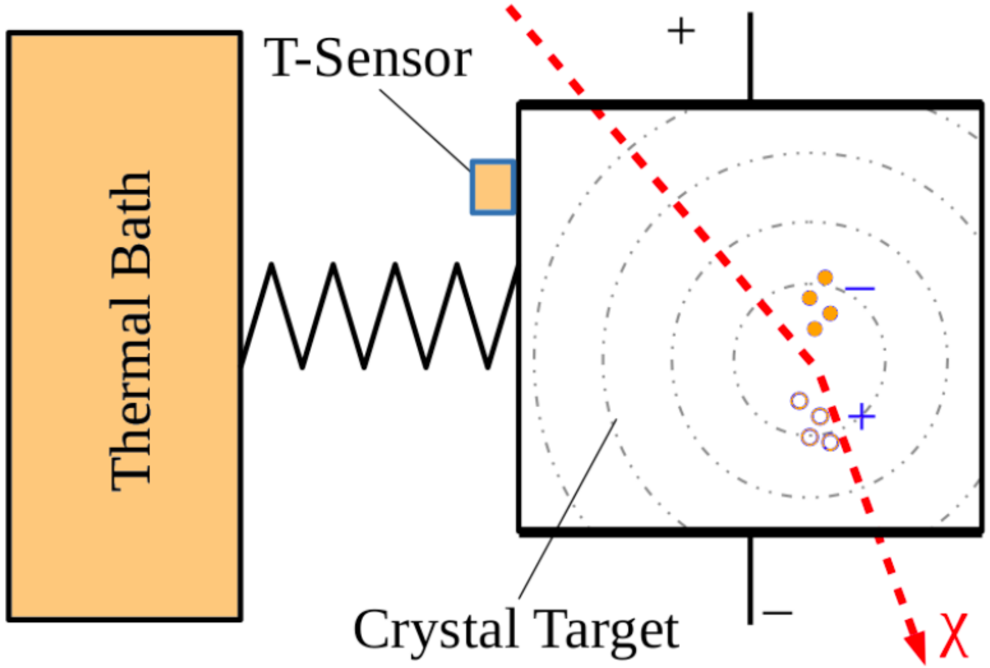


Ionization detectors

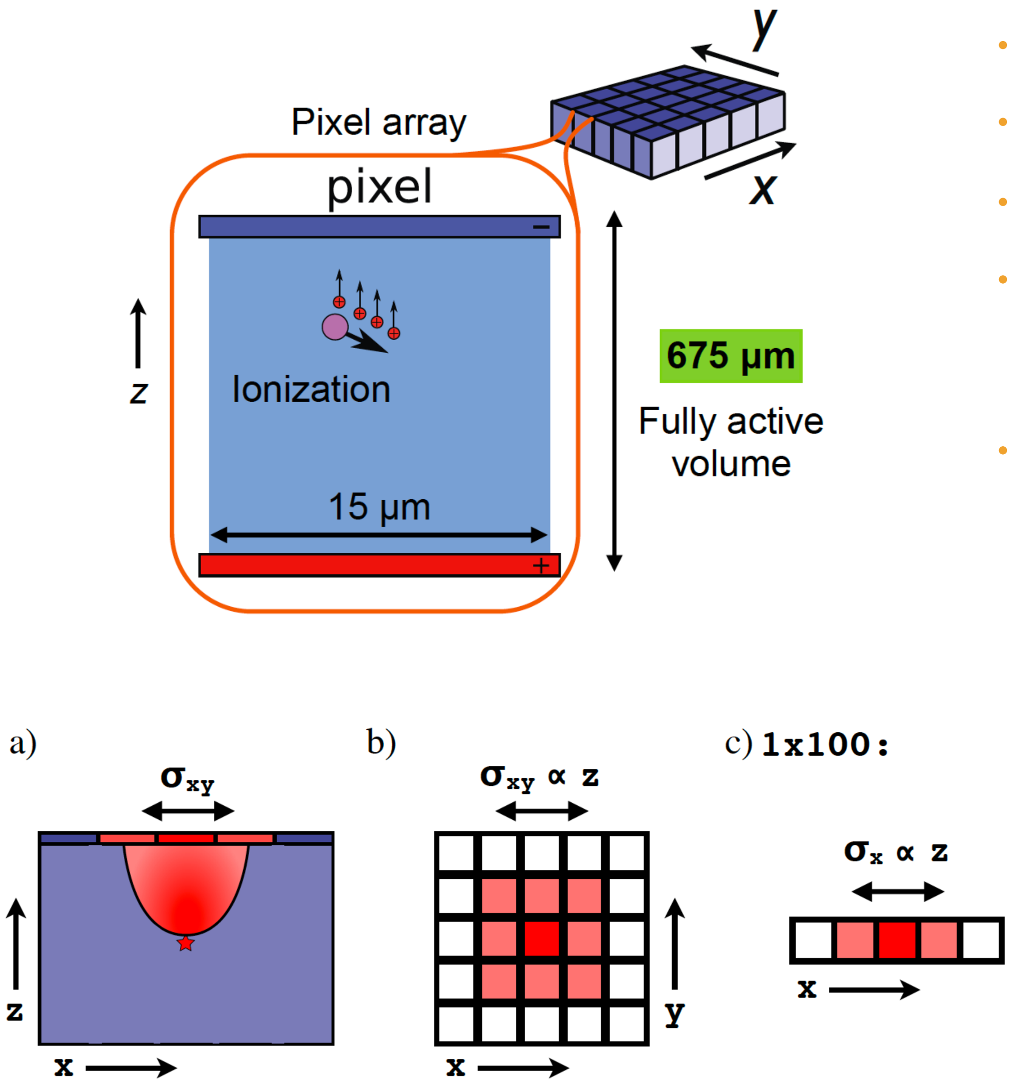


Ionization detectors

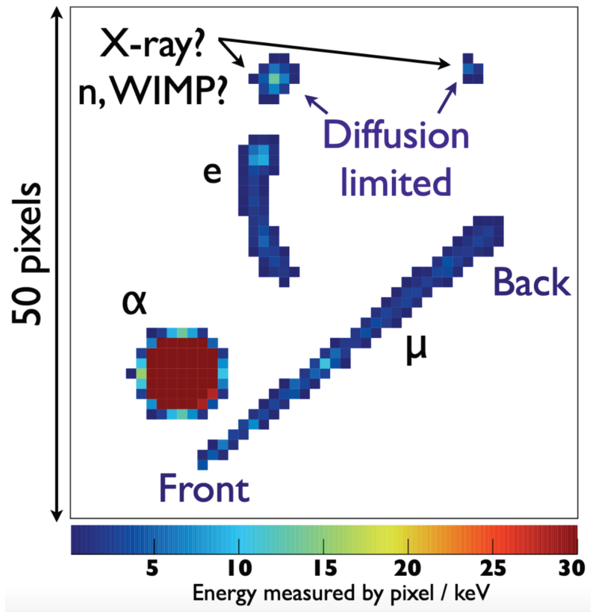
- CDEX
- ~~NEWS-G~~
- ~~TREX-DM~~
- DAMIC
- SENSEI
- OSCURA



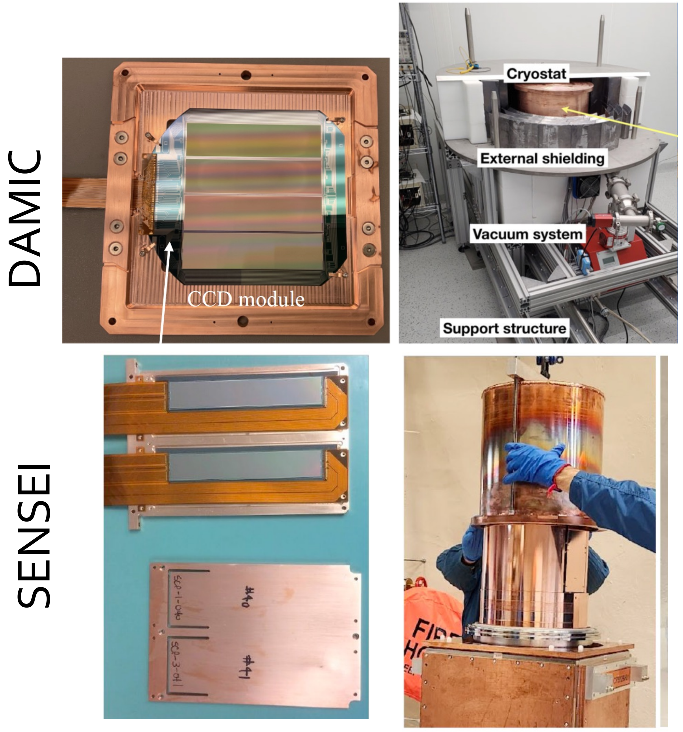
Charge Coupled Devices

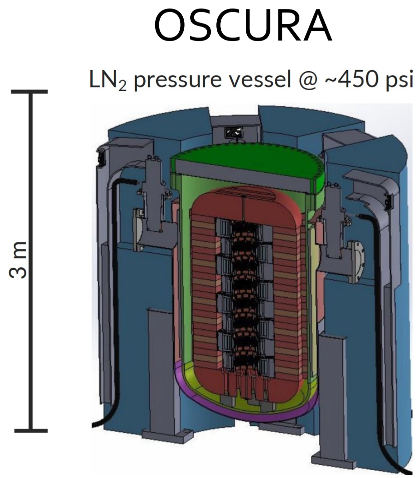


- Operated @ O(100 k)
- 3D reconstruction of the interaction location
- Identification of particle type via cluster pattern
- *Skipper* CCD: Skipper read out consists in performing N uncorrelated measurements of the same pixel → *sub-electron readout noise*
- O(20) eV_{ee}



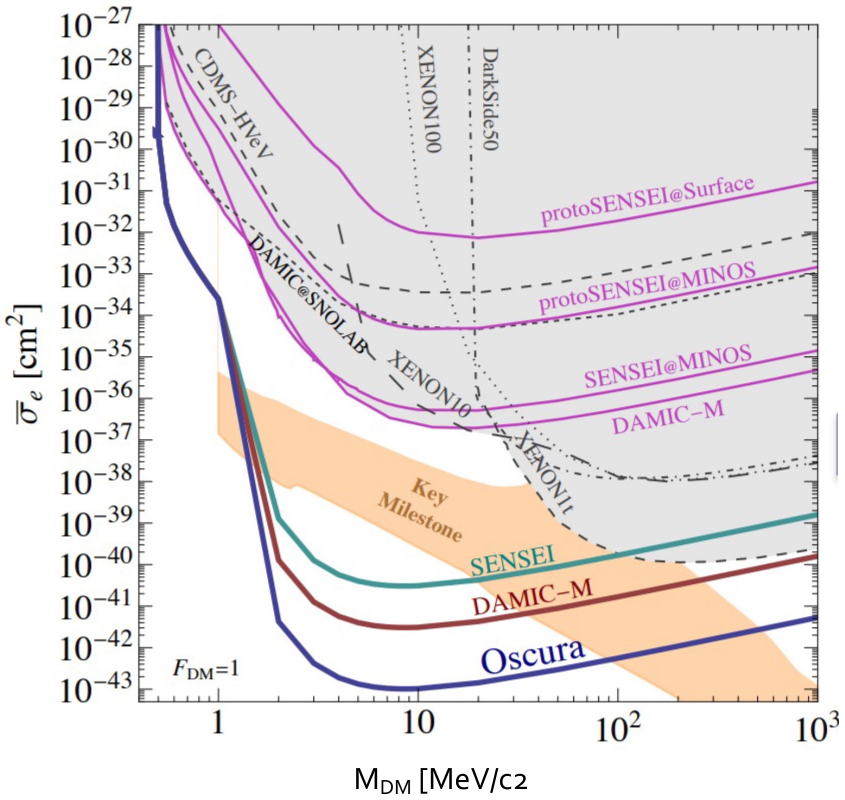
Ionization detectors – DAMIC/SENSEI/OSCURA





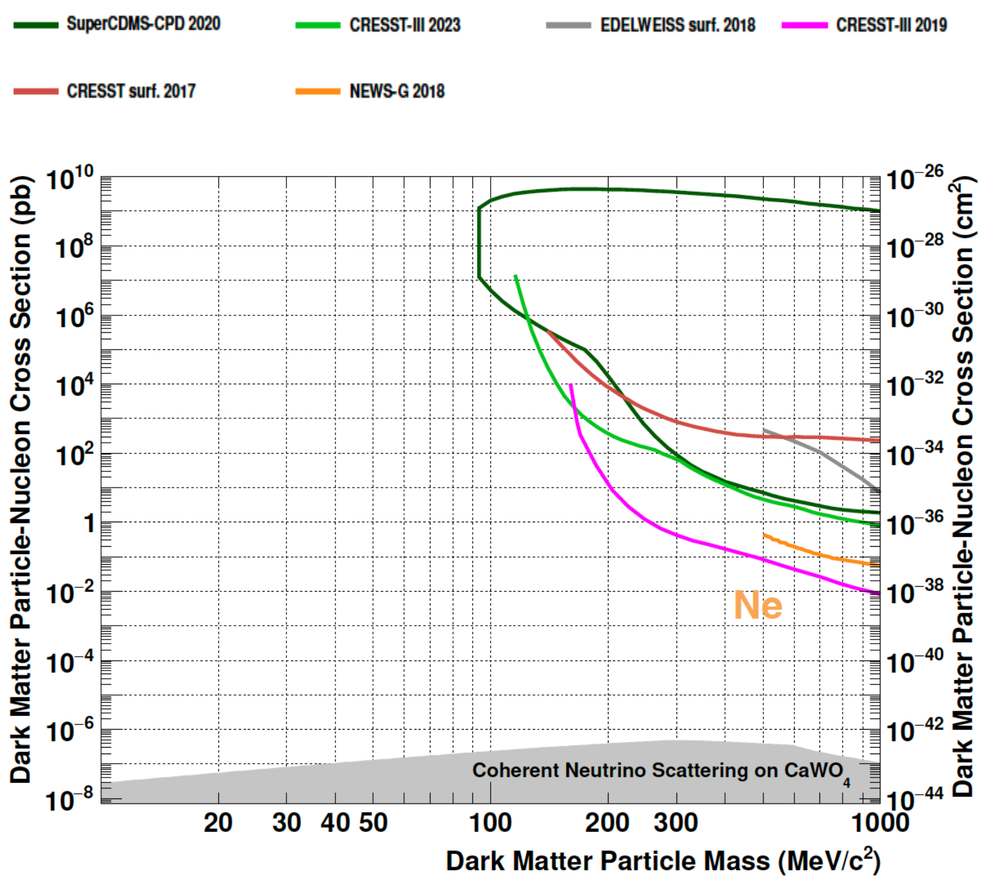
OSCURA goals:
- 30 kg y
- 10^{-2} dru
- Commissioning 2028
- Operation 2029

Experiment	Mass [kg]	#CCDs	Radiation bkgd [dru]	Instrumental bkgd [e-/pix/day]	Commissioning
SENSEI @ MINOS	~0.002	1	3400	1.6×10^{-4}	late-2019
DAMIC @ SNOLAB	~0.02	2	5	$\sim 3 \times 10^{-3}$	late-2021
DAMIC-M LBC	~0.02	2	~10	3×10^{-3}	late-2021
SENSEI-100	~0.1	50	10 (goal)		mid-2022
DAMIC-M	~1	200	0.1 (goal)		~2023
OSCURA	~10	20,000	0.01 (goal)	1×10^{-6} (goal)	~2028

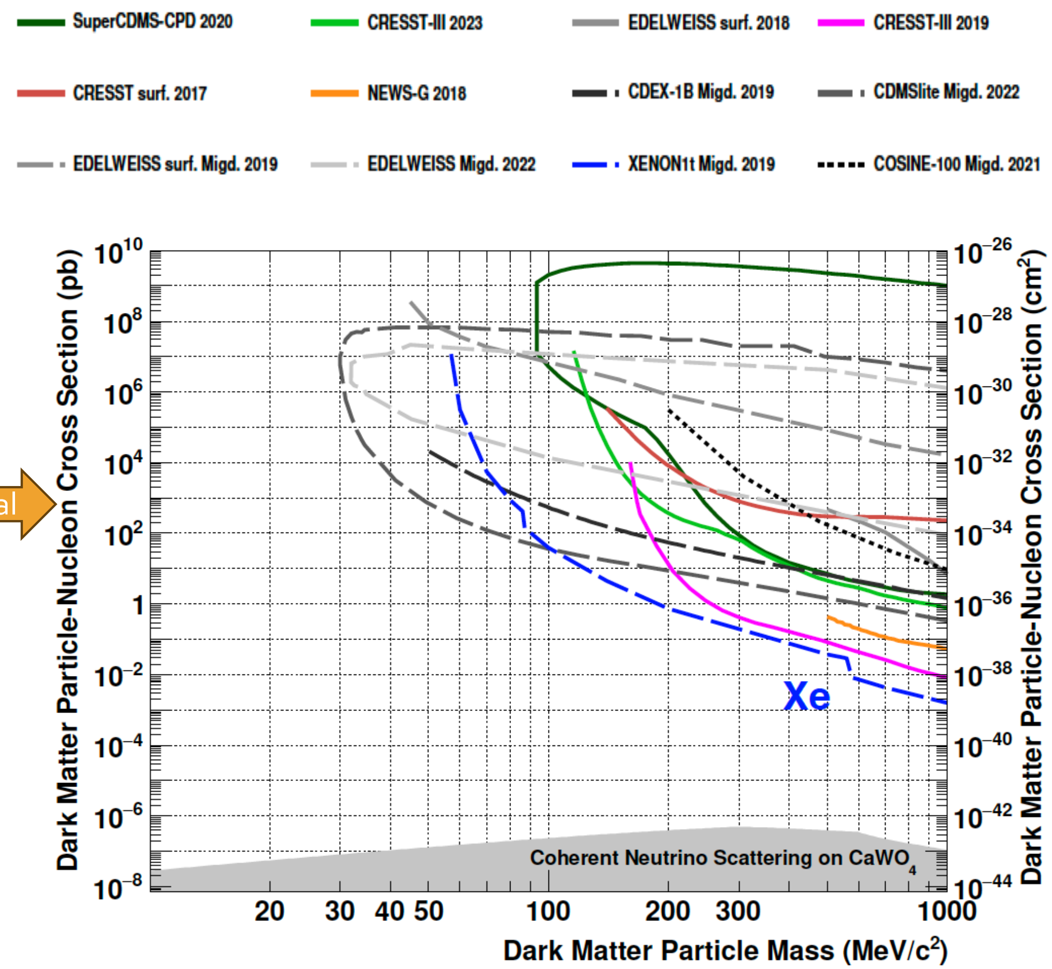


Saffold@TAUP2023

DM-nucleus scattering panorama

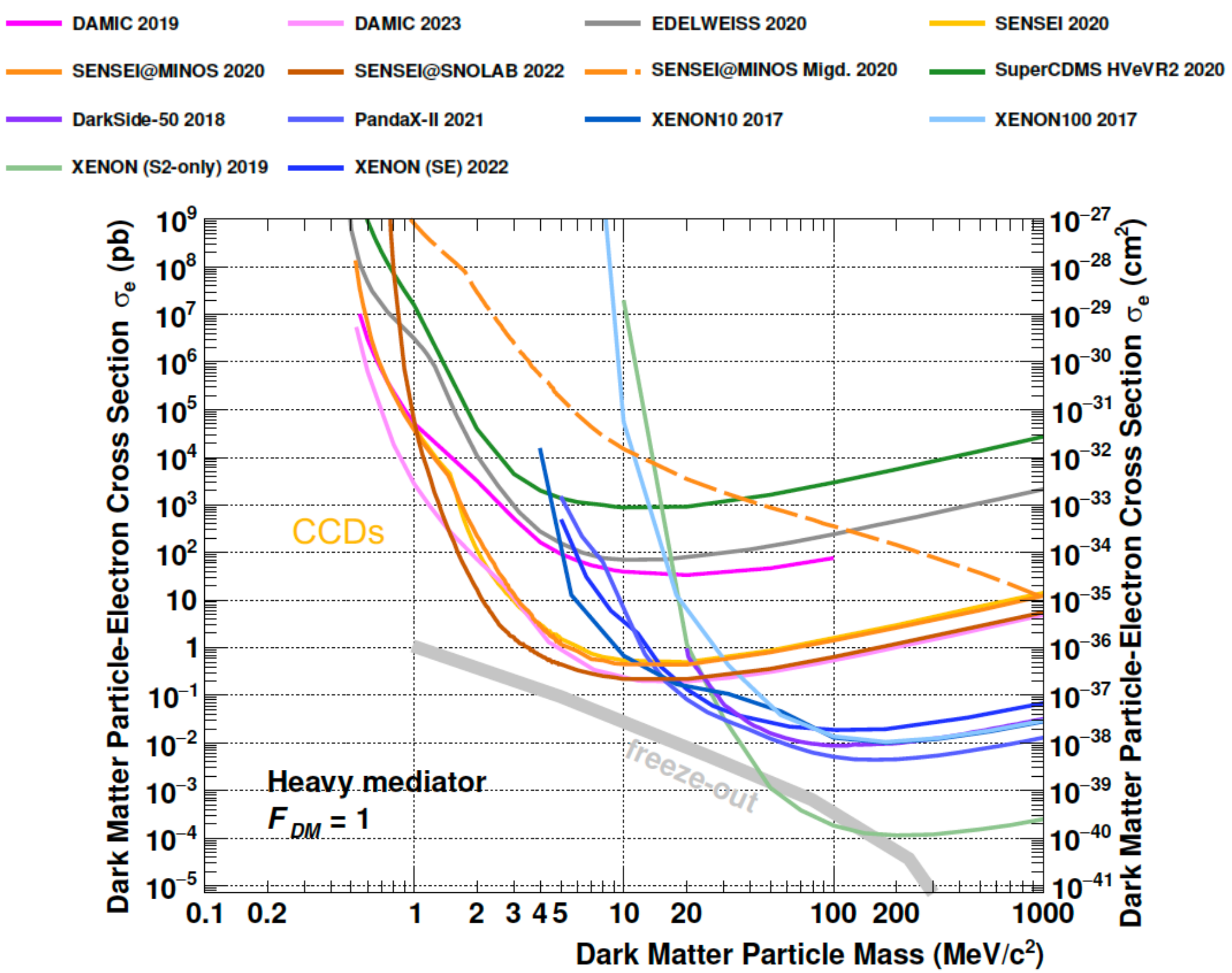


+ Migdal



K. SchaeffnerTAUP2023

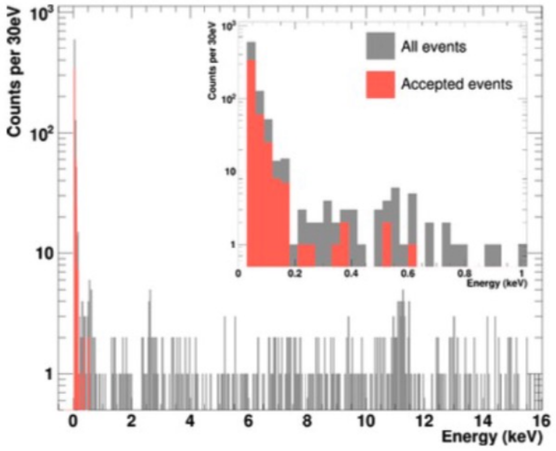
DM-electron scattering panorama



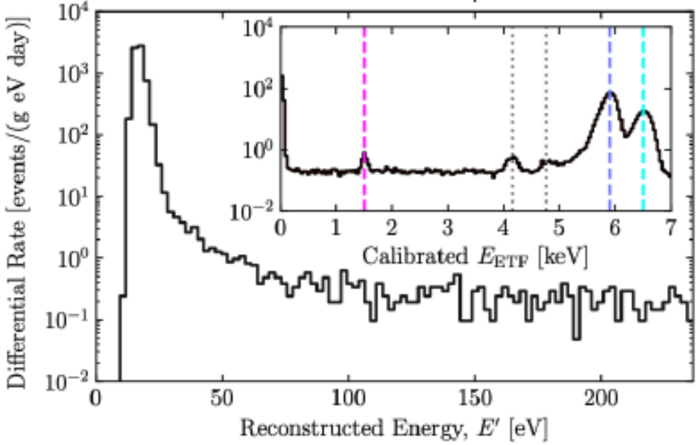
K. Schaeffner TAUP2023

The Low Energy Excess Problem

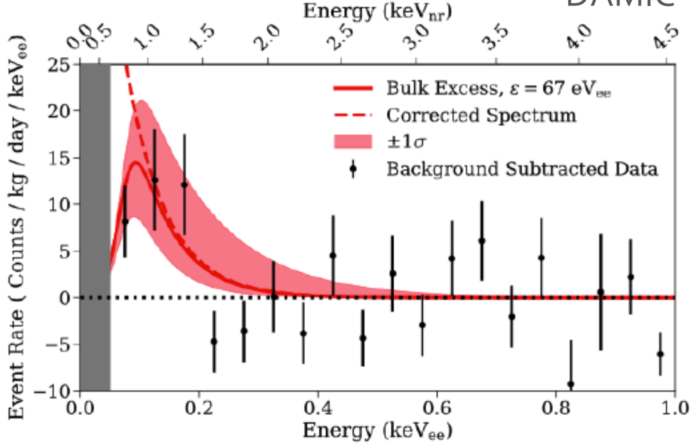
CRESST2019



SuperCDM 2021



DAMIC

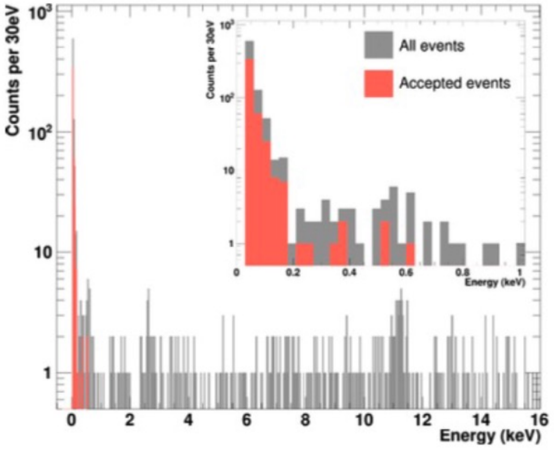


Observed in ALL type of experiment:

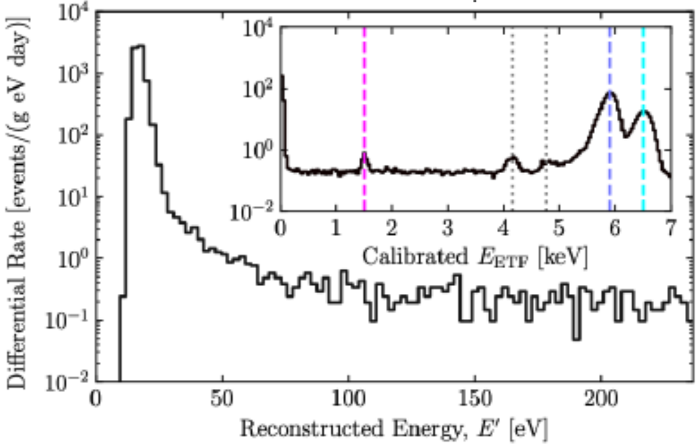
- *above ground and in underground laboratories.*
- *in cryogenic detectors and at room-temperature.*
- *for TESs, NTDs, QETs, (Skipper) CCDs.*
- *for different materials (Si, $CaWO_4$, Ge, Al_2O_3 ...).*
- *with significantly differing rates across detectors and experiments*

The Low Energy Excess Problem

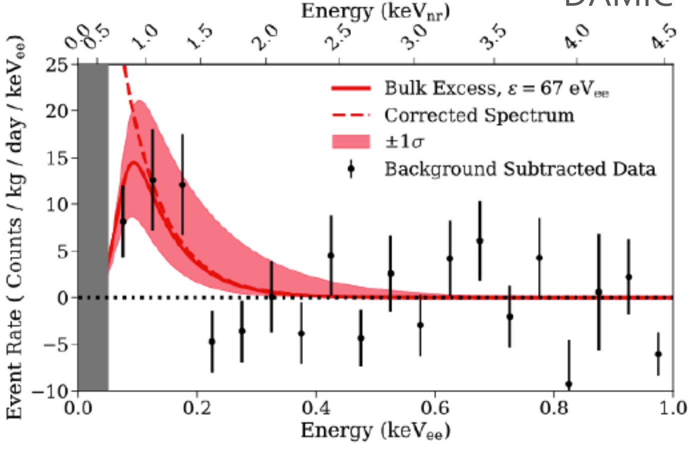
CRESST2019



SuperCDM 2021



DAMIC



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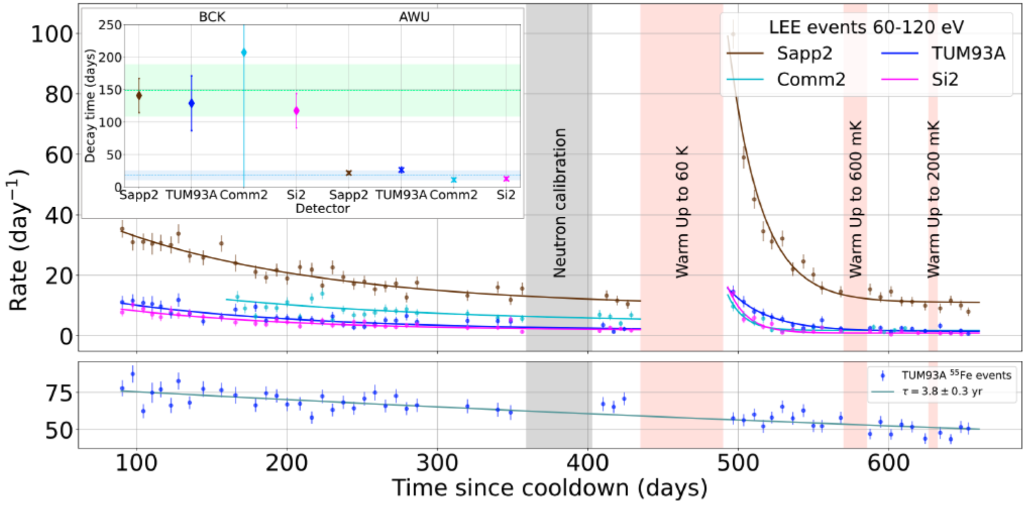
- *for different materials (Si, $CaWO_4$, Ge, Al_2O_3 ...).*
- *with significantly differing rates across detectors and experiments*

Is DM?

- *Excess rates do not scale with detector mass*
- *Excess rate decay with time*



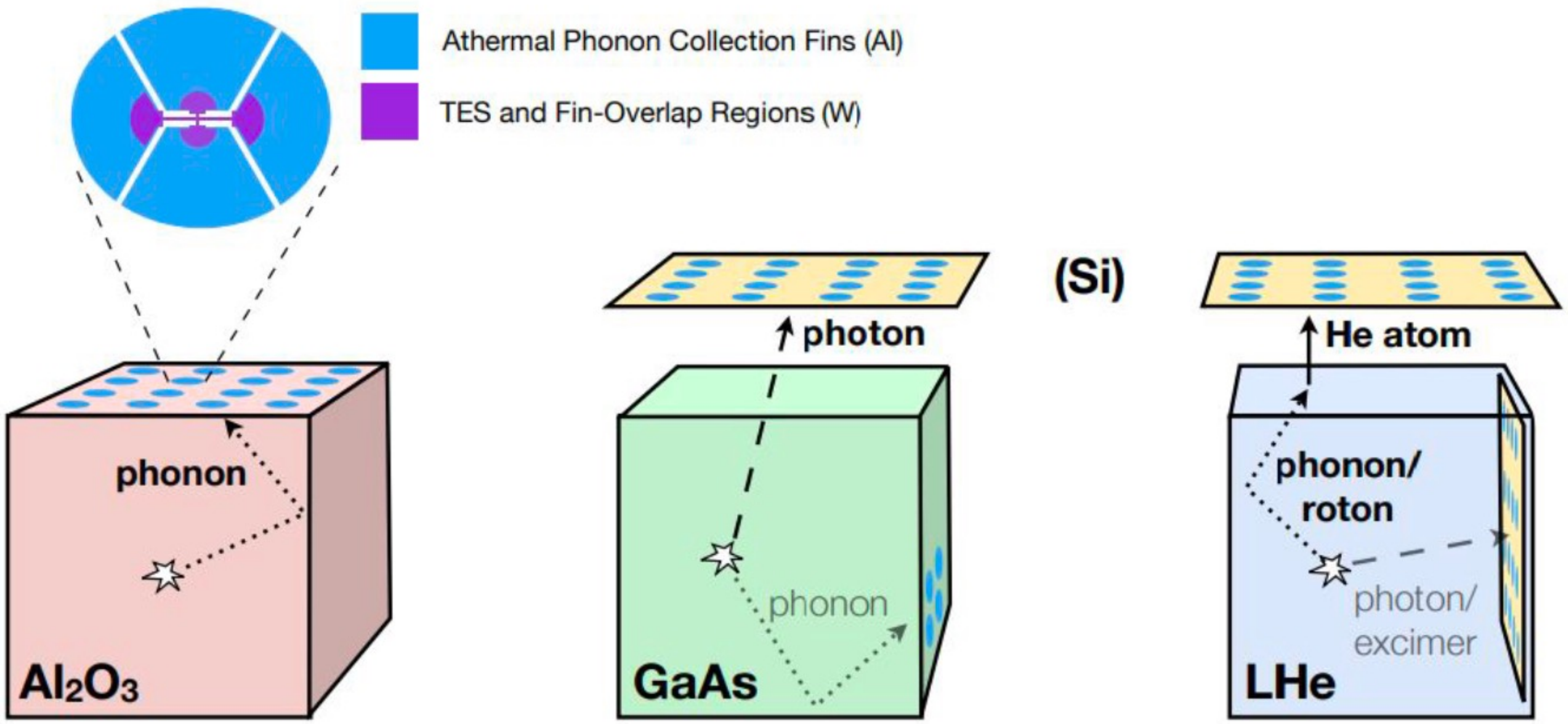
CRESST 2022, arXiv:2207.09375V2

Most favorite hypotesis:
STRESS from crystal, sensor or holding

CURRENT R&Ds for FUTURE VERY, VERY LOW MASS DM candidates

- TESSERACT
- SPLENDOR: narrow-gap semiconductors
- SPICE: polar crystals
- BULLKID
- DAREDEVIL (new!)
- MAGNETO-DM: magnetic sensors and diamonds
- Qubits
- Quantum devices
- Paleodetectors/Mineral detectors
- and many others…

TESSERACT



- TES read-out
- Zero-field→ no dark currents
- Target: SPICE (polar crystals), HERALD (superfluid He)
- Threshold goal O(100 meV)

DAREDEVIL

***DAREDEVIL**: **DAR**k matt**E**r **DEVI**ces for **L**ow energy detectors, a multi-target program for low mass DM search*

- $ZrTe_5$ (Dirac semimetal)
- CaAuAs (Weyl semimetal)
- Al (Superconductor)
- GaAs (Scintillator, polar crystal, small gap semiconductor)

Funded by the Research Italian Ministry (PRIN2022)

Institutions involved:

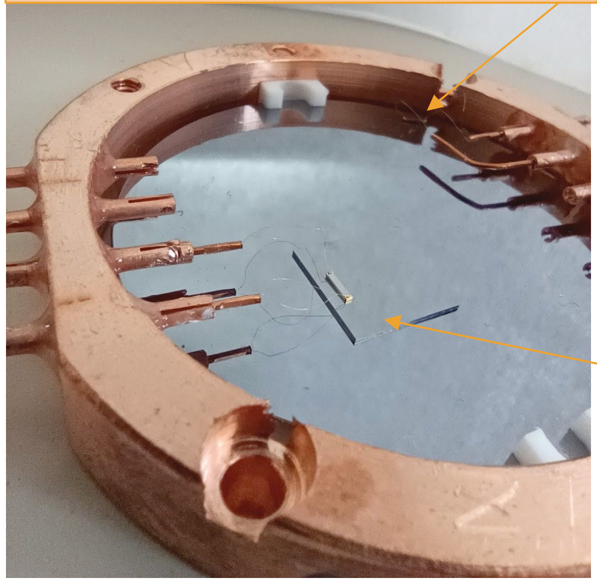
INRIM (Italian Institute for Metrology, sensor development)
CNR (Italian National Research Center, theoretical solid state studies)
LNGS, **GSSI**, **UnivAQ** --> (experimental astroparticle physics, theoretical and experimental solid state physics)
National Cheng Kung University of Taiwan and **Taiwan Semiconductor Manufacturing Company**

DAREDEVIL White Paper to appear soon

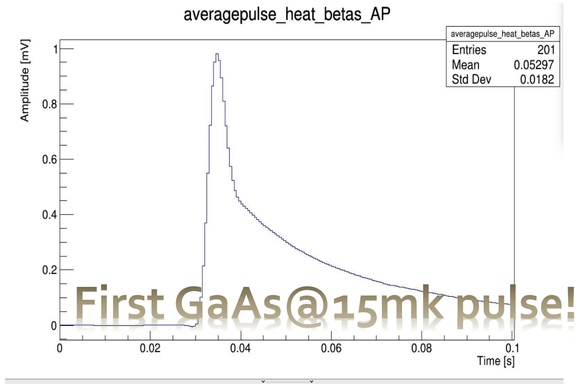
DAREDEVIL

Multi- channel detection:

- radiative - photons
- not radiative – phonons + NTL
- charge - electron/hole

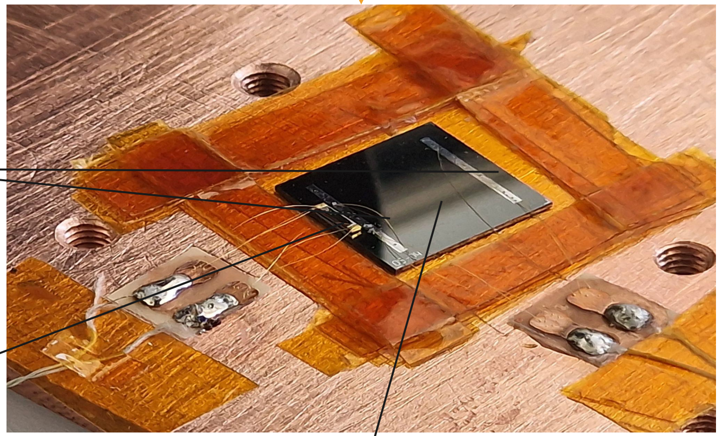


Phonon read out channerl: NTD sensor



Light read out channel: Mercury Cadmium Telluride (CdTeHg) layer sputtered on a Si substrate (stoichiometry tuned to achieve 0.2 eV gap suitable scintillation light from GaAs.

high voltage electrodes



NTD

surface where the CdTeHs is deposited

Conclusions

- We did not find DM (yet)
- … but trying to solve the DAMA puzzle
- New landscapes open:
  - ✓ Low mass and very low mass DM candidates well teorethical motivated
  - ✓ Solid state detectors play a crucial role
  - ✓ Explore new phace-space zones
  - ✓ More than one target needed to understand the nature of interaction
- Challenging search
  - ✓ QFs issue for NaI-based detecors
  - ✓ Low Energy Excess
  - ✓ New technologies to be developed
  - ✓ Mulitydisciplinarity! Solid state physicist are our new friends
  - ✓ Calibration
  - ✓ Backgroud
- A lot of fun…

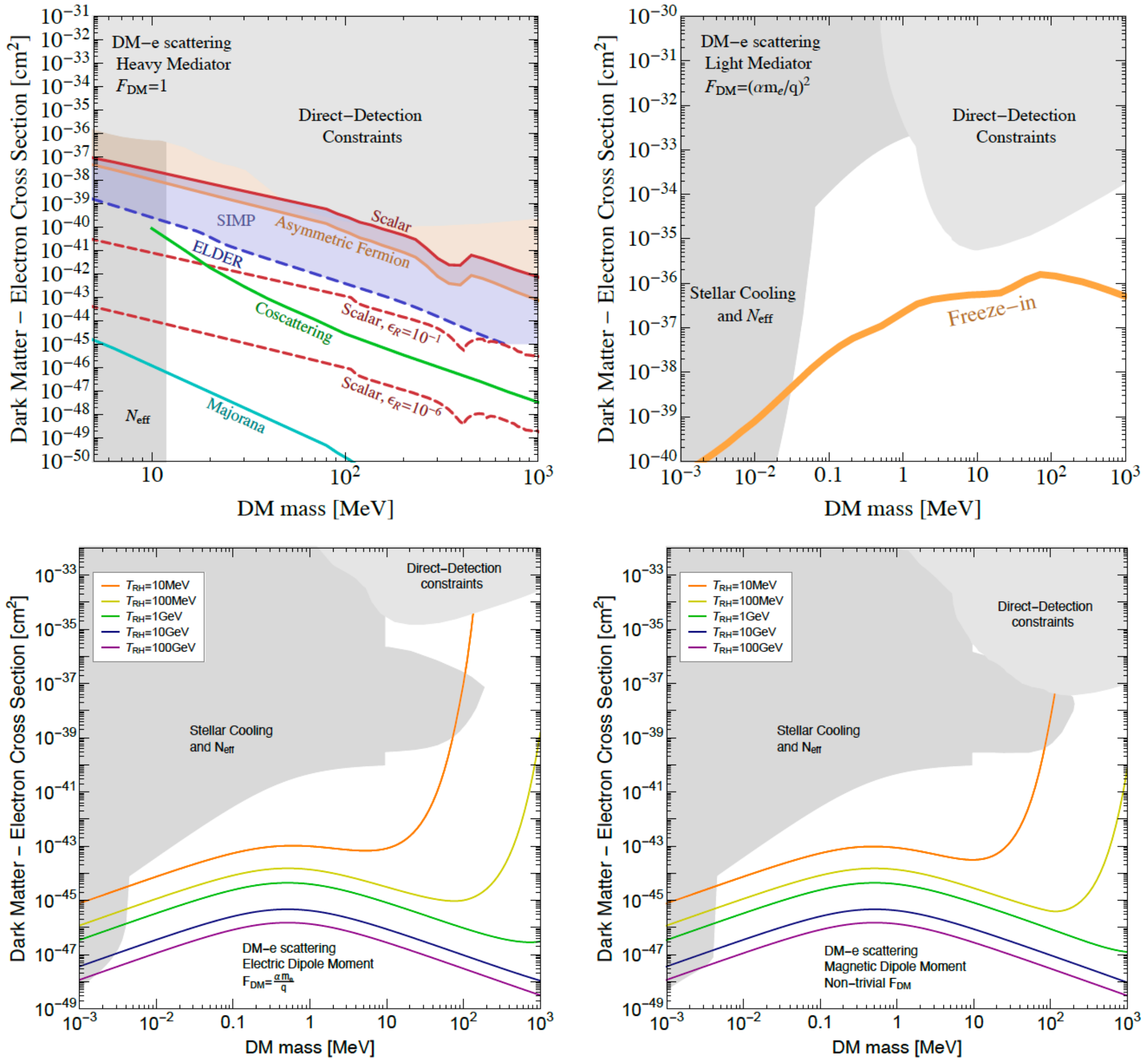
To knew more:

- Identification of Dark Matter (***IDM2024***) in L'Aquila (Italy), July 8-12 (www.idm2024.eu)
- **EXCESS2024 workshop**: La Sapienza University (Rome, Italy), July 6 (https://agenda.infn.it/event/39007/)

Thank you!

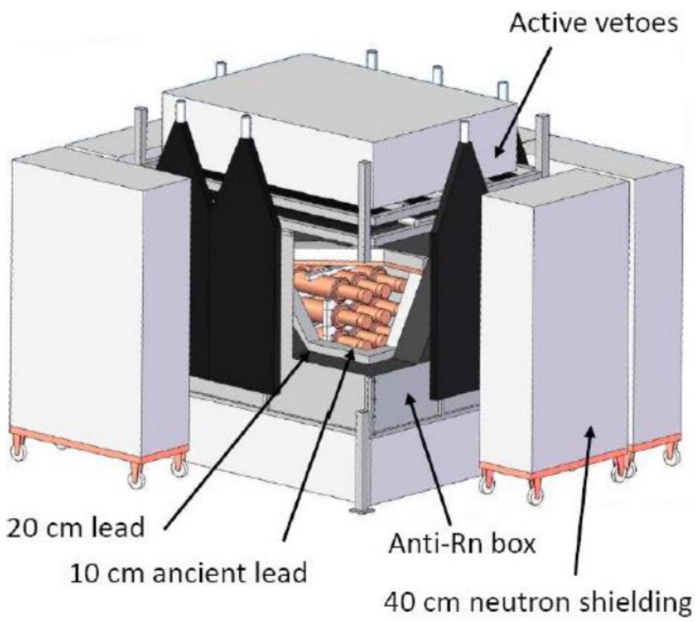
Light DM Theory landscape

arXiv:2203.08297v2

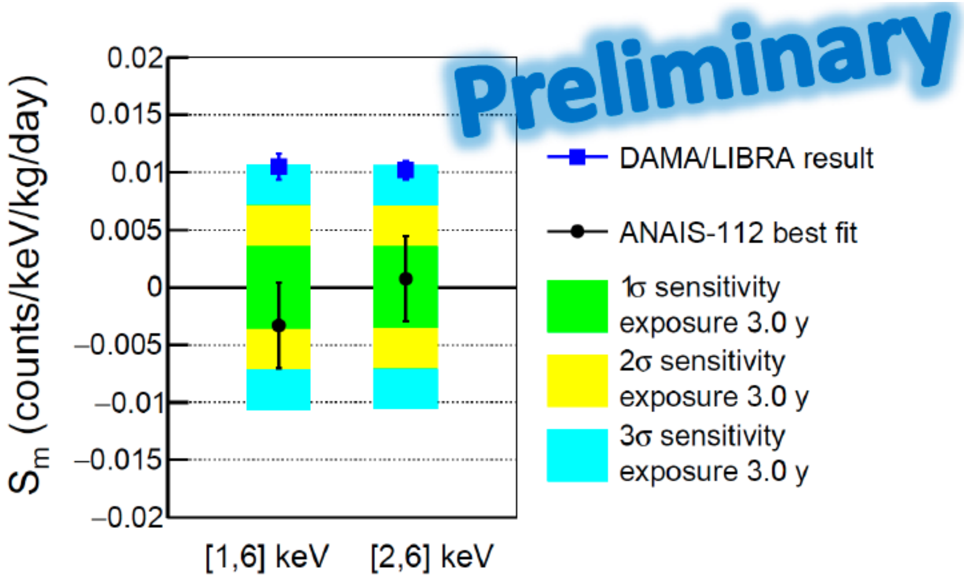


- *Specific target regions in the DM-electron cross section versus DM mass plane in which DM is produced with the observed relic abundance.*
- *For these benchmark models, DM interacts with both nuclei and electrons.*
- *When applicable, we show existing direct-detection bounds (light gray) and constraints from stellar cooling and the effective number of relativistic species (N_{eff}) (darker gray)*

NaI-based experiment family – ANAIS



- 9 NaI(Tl) crystals (112.5 kg) equipped with a **Mylar window CANFRANC (Spain)**
- **2017 → today: 643.48 kg×y @ August 8, 2023**
- Phys. Rev. Lett. 123, 031301 (2019); J. Phys. Conf. Ser. 1468, 012014 (2020); 3 y: Phys. Rev. D 103, 102005 (2021)
- Sensitivity improved with machine-learning techniques.

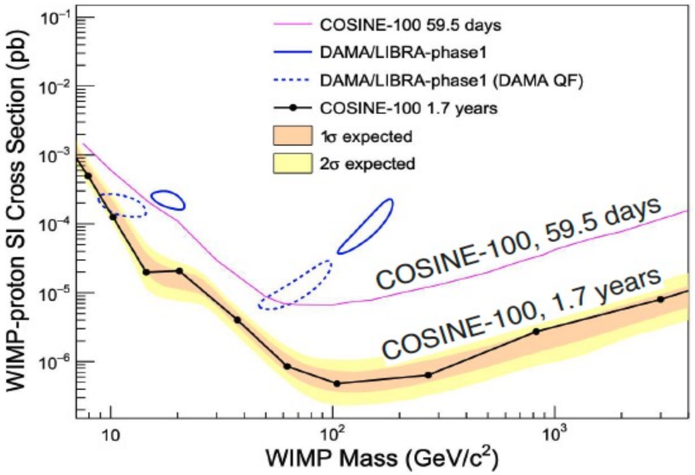


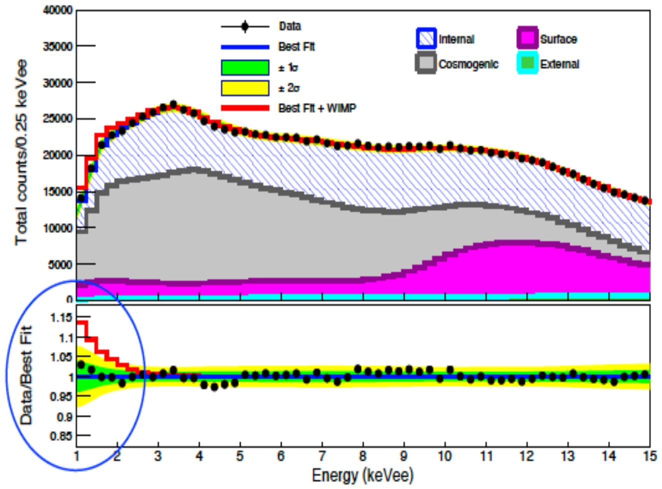
I. Coarasa, TAUP 2023

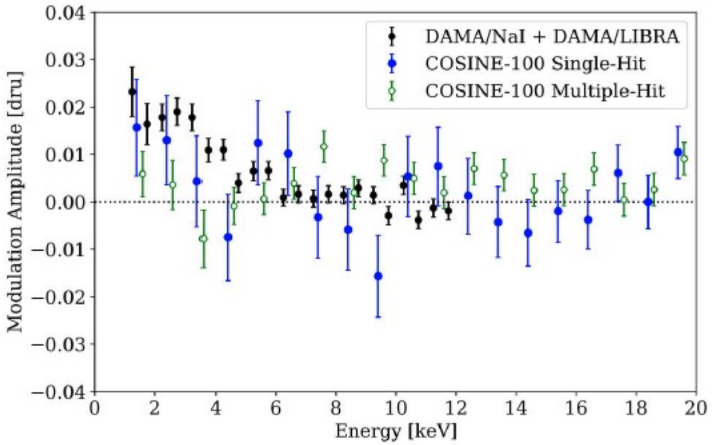
- Best fit modulation amplitudes **compatible with zero** at $\sim 1\sigma$
- Best fit **incompatible with DAMA/LIBRA** at 3.9(2.8) σ for [1-6]([2-6])keV
- **Sensitivity with 3 years data: 2.9 σ for [1-6] and [2-6] keV**
- **5 σ sensitivity at reachin late 2025**

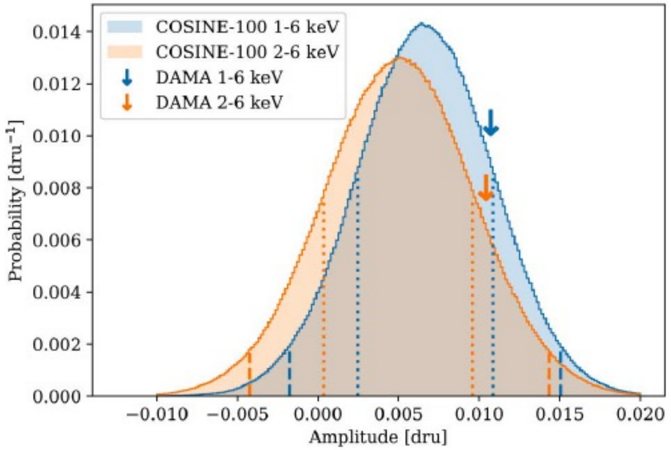
NaI-based experiment family –

- 106 NaI crystals Yang Yang lab (2016→2023). Now upgrade + moving to Yemilab
- Nature 564, 83 (2018), Sci Adv. 2021 Nov 12;7(46):eabk2699 , Phys. Rev. D. 106, 052005







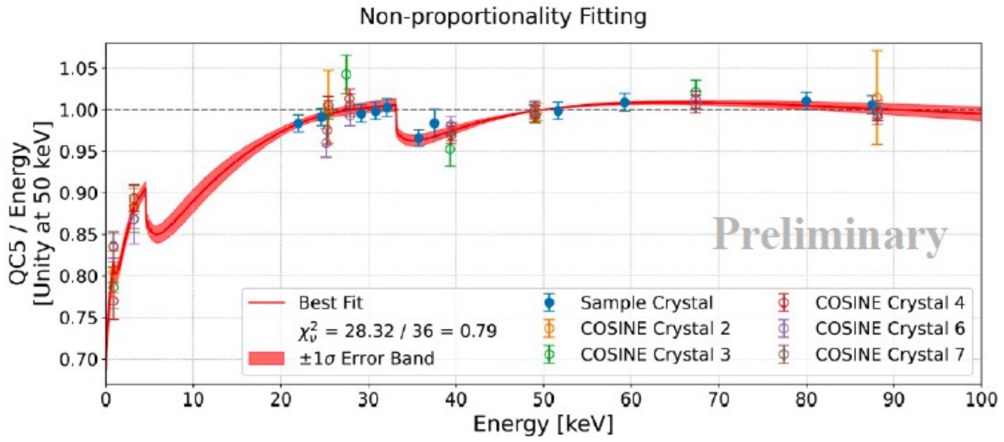


Hyun Su Lee, TAUP 2023

NaI-based experiment family – COSINE

Non-proportionality (nPR) in the light output

- Non-proportional behavior of scintillation detectors are well known phenomena
- Investigation of nPR in NaI(Tl): **X-ray and Gamma (not for electron)**
  - measurement using external radioactive source: ^{241}Am, ^{133}Ba, ^{109}Cd, and ^{137}Cs
  - internal radioactive in COSINE crystal: ^{210}Pb, ^{22}Na, and ^{40}K, cosmogenic: ^{125}I, ^{113}Sn, and ^{109}Cd



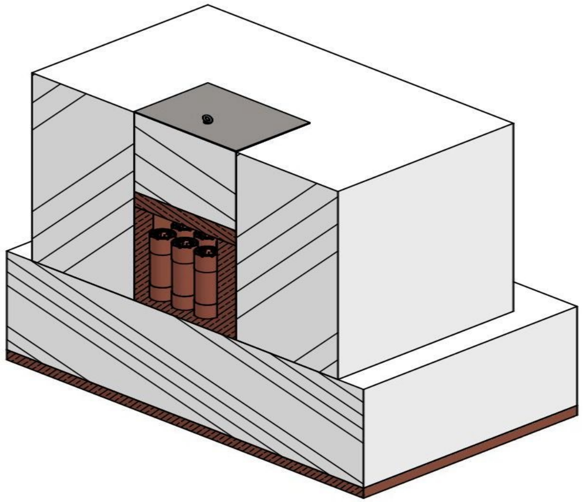
QF determined using Eee calibrated at 59.54 keV → Impact of nPR on the QFs?

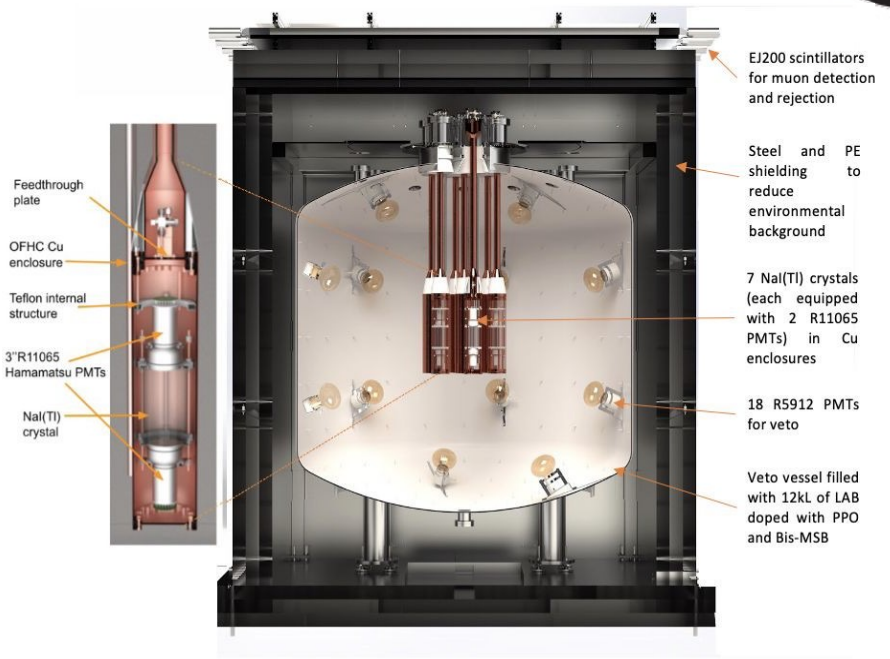
CENTER FOR UNDERGROUND PHYSICS

Measurements of Quenching Factors for NaI(Tl) scintillating crystal

18

NaI-based experiment family – SABRE





SABRE North

- Conceptual design report presented in July 2021, **TDR due in summer 2024**
- **3 x 3 matrix of crystals of ~ 5 kg mass each**
- Fully passive **shielding** design: **15 cm copper + 80 cm PE**
  - → enough shielding power and negligible contribution to the total background
- Expected background **0.5 cpd/kg/keV (with ZR)** or 1 **cpd/kg/keV (w/o ZR)**

SABRE South

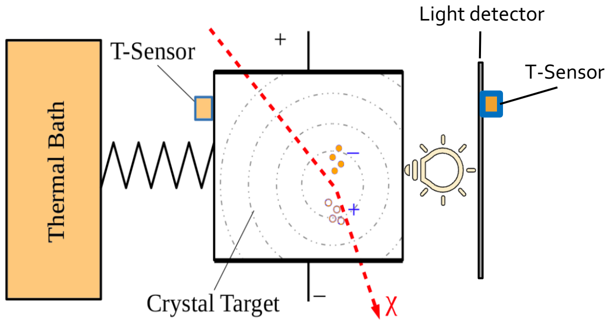
- Design: 7 crystals array of ~5-7 kg mass
- Vessel + LAB, PMTs, muon detector, DAQ electronics, Crystal insertion system … all ready.
- Crystal procurement in synergy with SABRE North
- Highest purity crystals and largest active veto: 0.72 cpd/kg/keV

G. D'Imperio , TAUP 2023

Cryogenic Bolometers

Cryogenic Bolometers

- CRESST
- CDMS/ SuperCDMS
- EDELWEISS
- COSINUS
- …



$$\Delta T = \frac{\Delta E}{C}$$

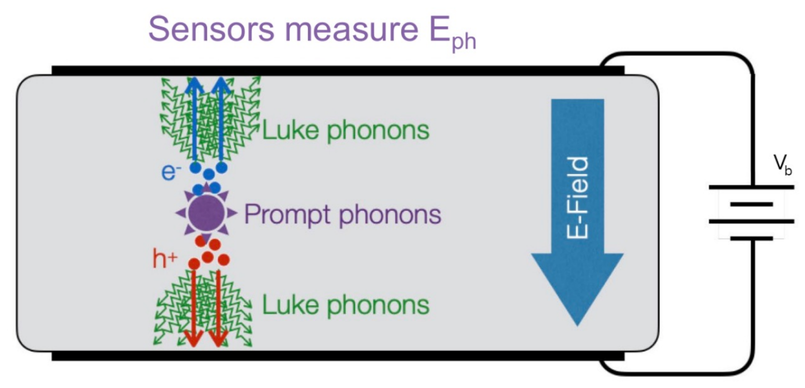
$$C = \left(\frac{T}{\theta_D}\right)^3$$

GeNTD: *Neutron-transmutation-doped sensors. Ge wafer with T-dependent resistance induced by neutron irradiation doping. Sensitive to thermal phonons.* → EDELWEISS

TES: *Transition-edge sensors. Tungsten film operated near T_c and read out by SQUIDs. Dominated by athermal phonons. Sensitive to DT ~0.1 mK* → COSINUS, CRESST

QET: *Quasiparticle-trap-assisted Electrothermal-feedback TES: Arrays of Al fins transmit quasiparticles to the TES. Increases collection area without increasing sensor capacitance and maintains athermal phonon properties.* → CDMS

Cryogenic bolometers –SuperCDMS



	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Total exposure [kg·yr]	45	3.9	36	7.8
Phonon resolution [eV]	33	19	34	13
Ionization resolution [eV_{ee}]	160	180	–	–
Voltage Bias ($V_+ - V_-$) [V]	6	8	100	100

HV detector *→ low threshold*

Drifting charge carriers (e–/h+) across a potential (V_b) generates a large number of Luke phonons (NTL effect)

Trade-off: no NR/ER discrimination

$E_t = E_r + (N_{eh} \times e\,Vb)$

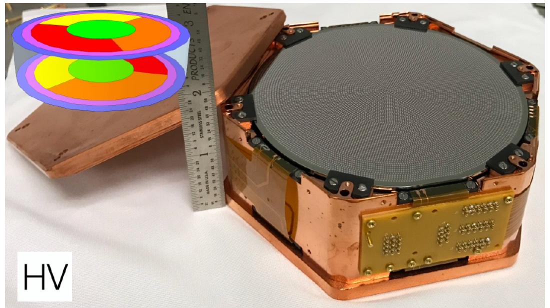
$E_{th} \sim 60\ eV_{nr}$

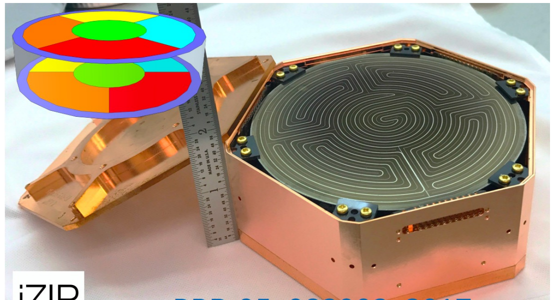
iZIP detector *→ low background*

Interleaved Z-sensitive Ionization and Phonon detector

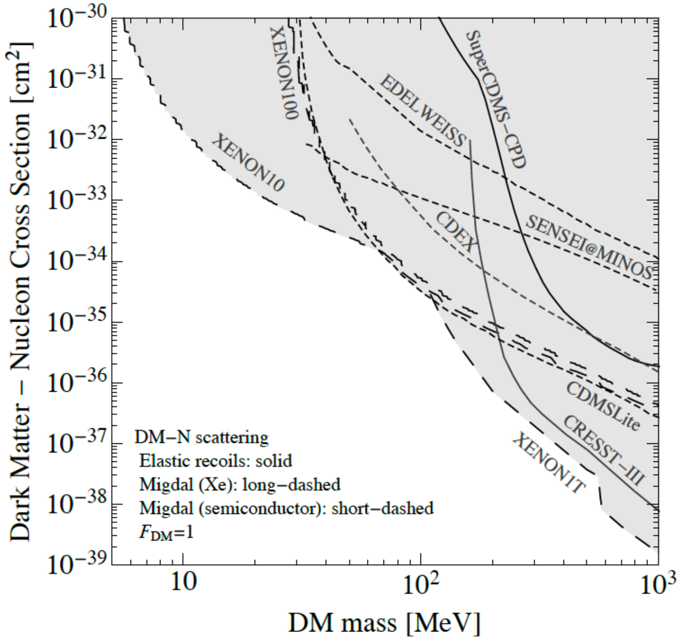
Prompt phonon and ionization signals allow for NR/ER event discrimination

$E_{th} \sim 150\ eV_{nr}$

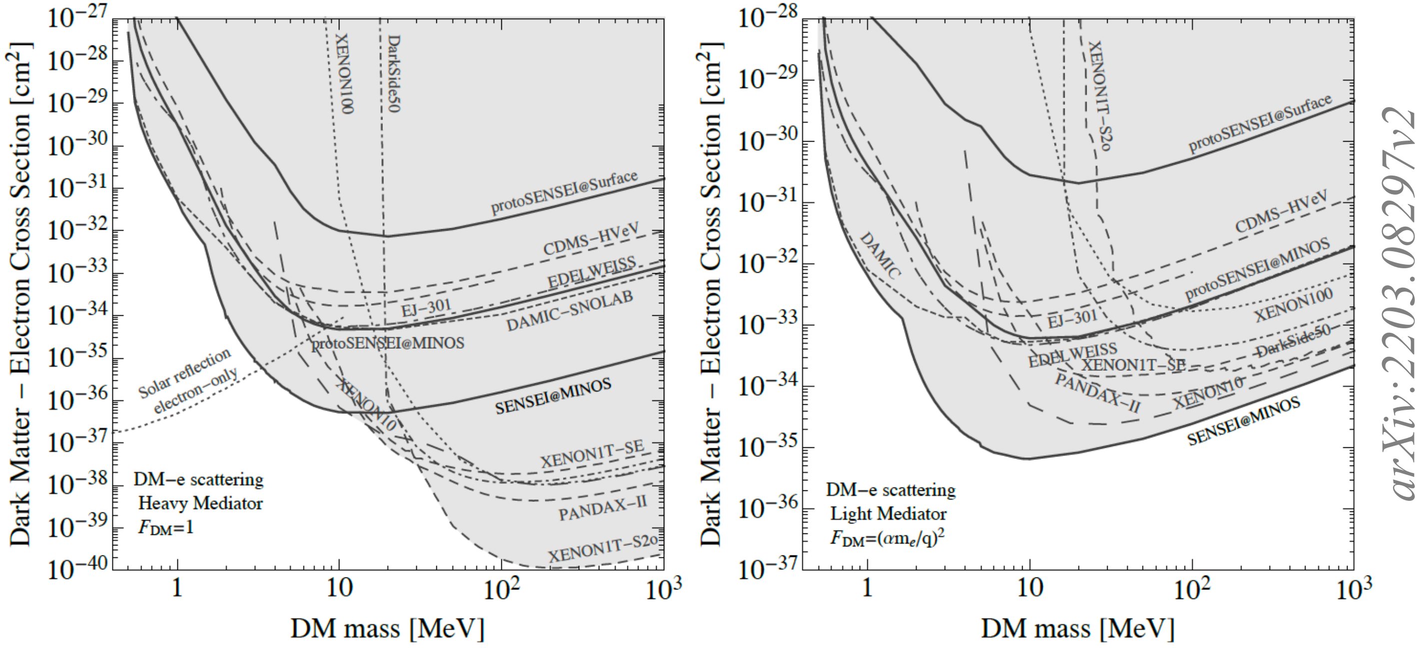




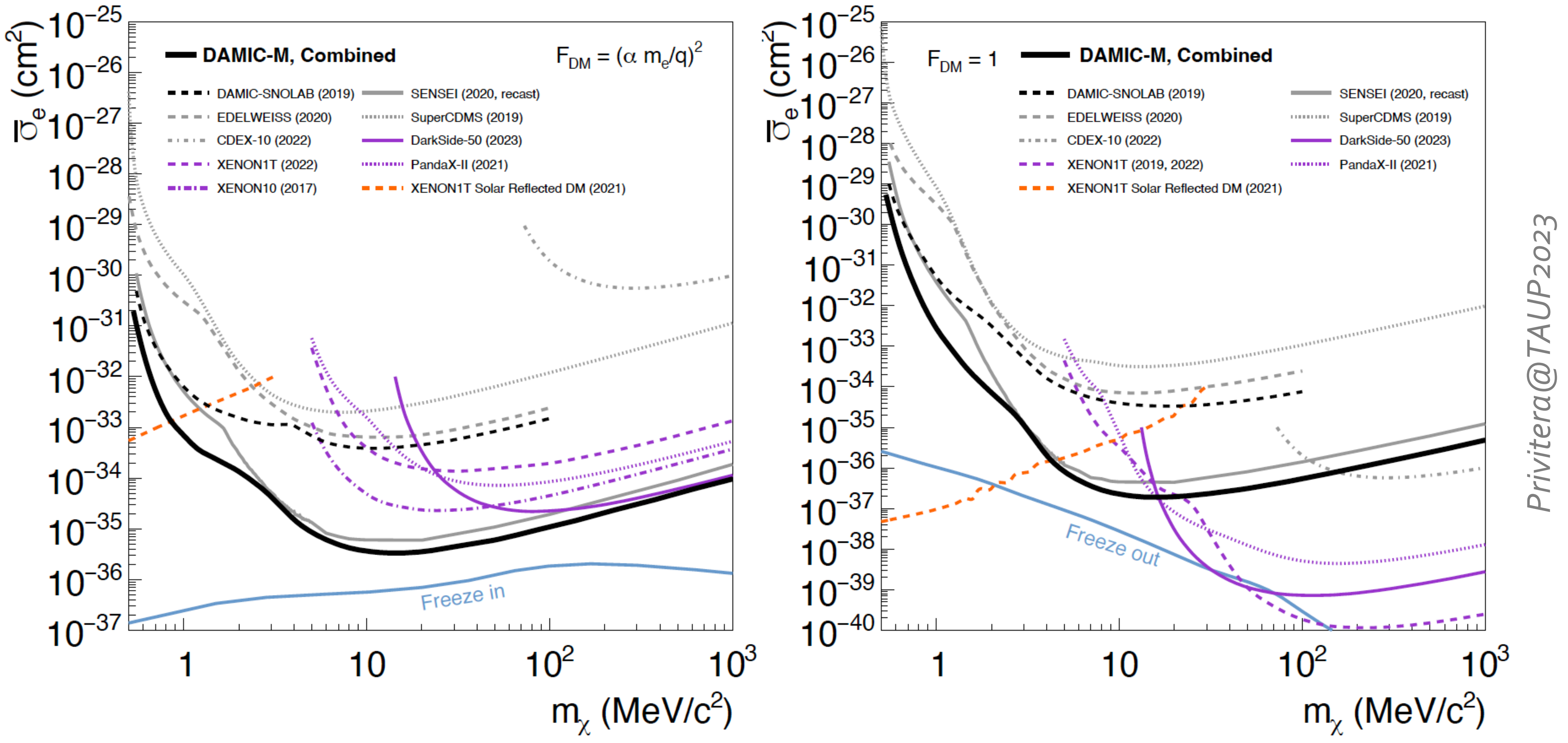
PRD 95, 082002, 2017



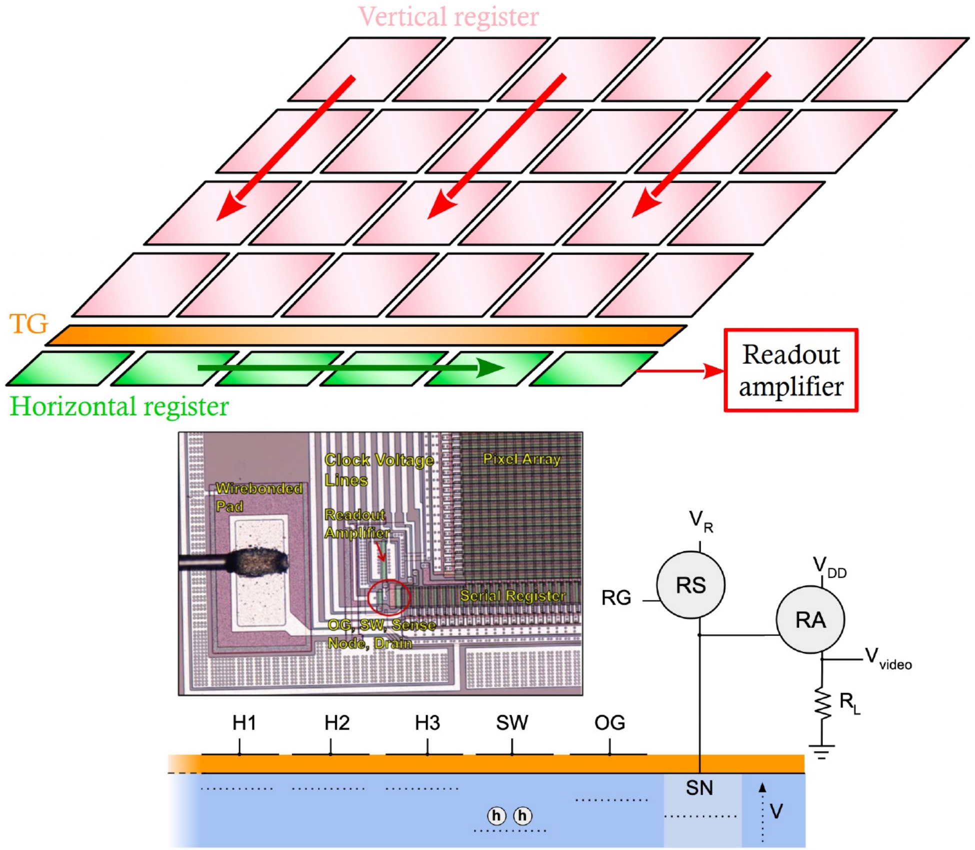
Current 90% c.l. limits on DM-nucleon scattering and on *the Migdal effect from DM-nucleus scattering*



Current 90% c.l. limits on DM-electron scattering through a heavy (left) and ultr-light (right) mediator

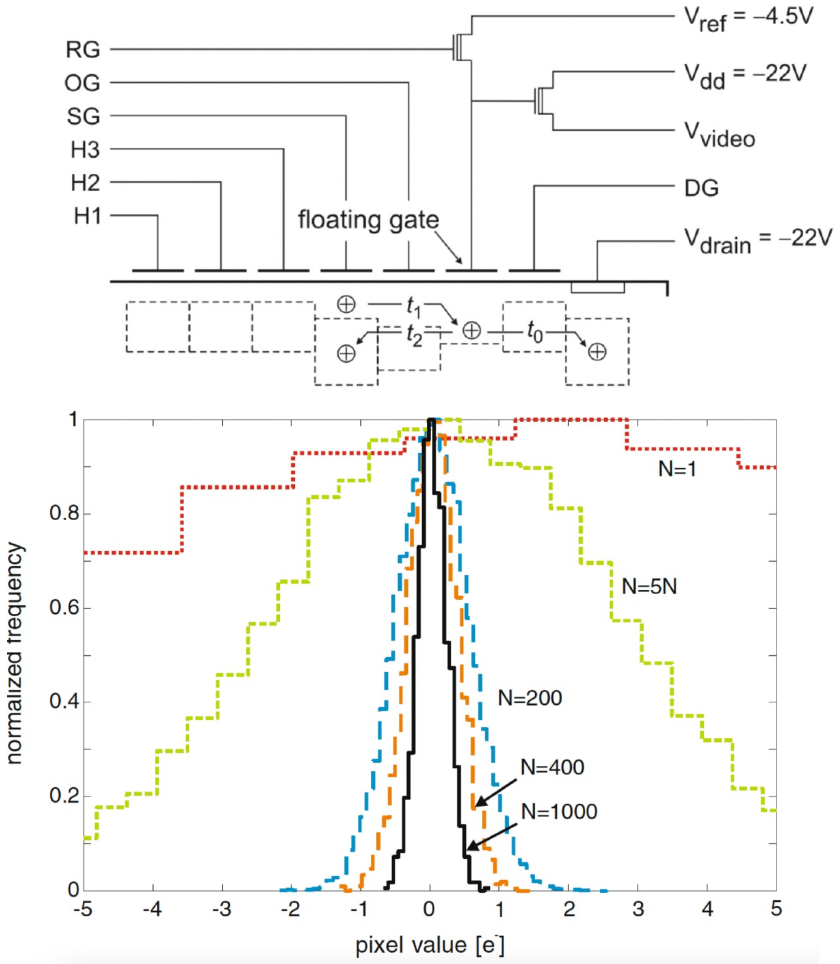

DAMIC-M, Combined
$F_{DM} = (\alpha\, m_e/q)^2$
DAMIC-SNOLAB (2019)
EDELWEISS (2020)
CDEX-10 (2022)
XENON1T (2022)
XENON10 (2017)
SENSEI (2020, recast)
SuperCDMS (2019)
DarkSide-50 (2023)
PandaX-II (2021)
XENON1T Solar Reflected DM (2021)
Freeze in
$\overline{\sigma}_e$ (cm^2)
m_χ (MeV/c^2)
$F_{DM} = 1$
DAMIC-M, Combined
XENON1T (2019, 2022)
Freeze out
Privitera@TAUP2023

Charge Coupled Devices



- After exposure of the active target and charge generations the readout take place
- A series of 3 voltage clocks create potential walls that are used to move the charges through the pixels
- In a vertical transfer one row of pixels is moved one row closer to the horizontal register
- The charge in the horizontal register is moved pixel-by-pixel to a readout amplifier
- The charge fall into the SW gate and then to the SN where it is measured

Charge Coupled Devices

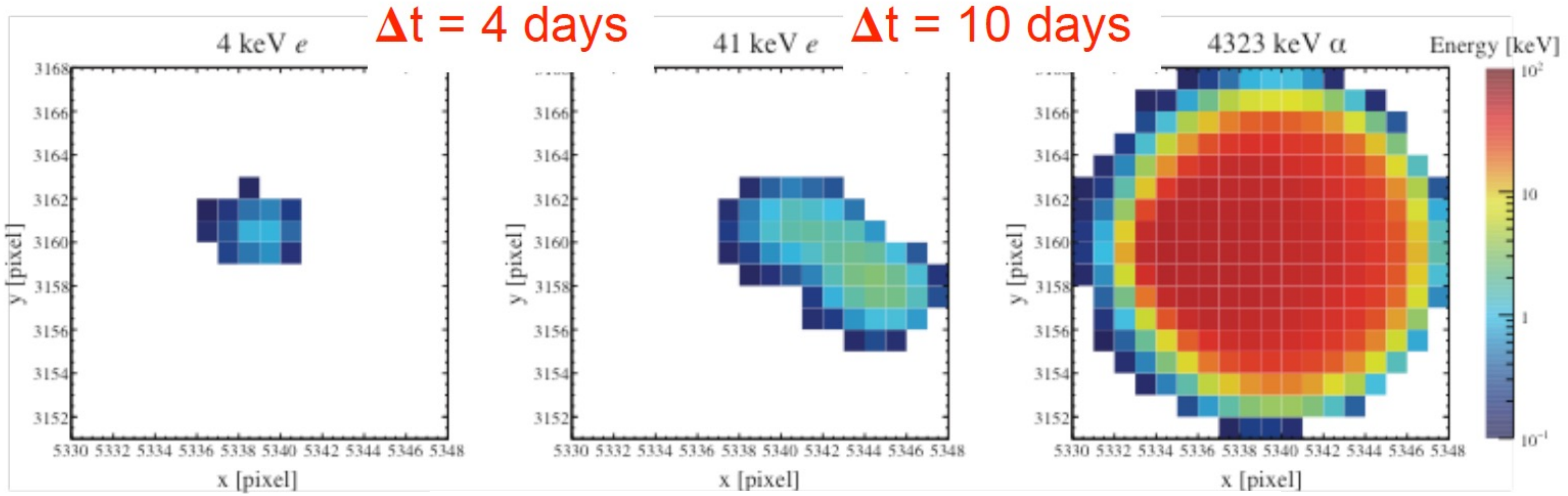


Exp Astron 34, 43–64 (2012)

- Using a floating gate as SN and replacing the bias VOG with a clock, permits a multiple non-destructive measurement of the charge packet
- The measurement error σ will decrease as $\sim \sqrt{\frac{1}{N_{skip}}}$
- Thus the 1/f amplifier low frequency noise is now subdominant
- For a large number N_{skip} of the resolution reaches sub-electron values
- But $t_{readout} \sim N_{skip}$

Ionization detectors - DAMIC

measurement (and rejection) of surface and bulk backgrounds: decay chains detected as spatially correlated, time separated energy clusters



Candidate ^{210}Pb decay chain

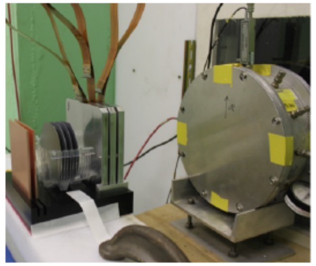
Ionization detectors - OSCURA

Oscura: Background control

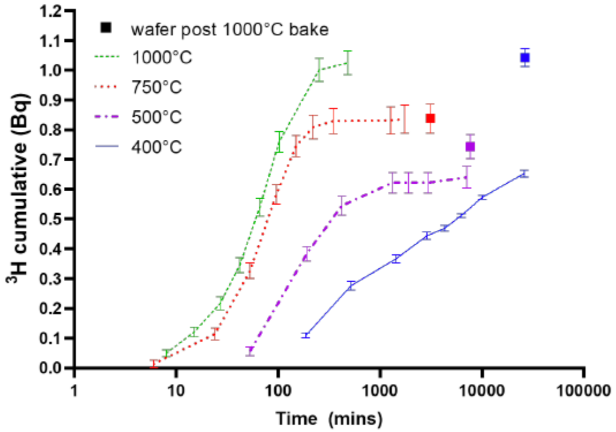
Goal: 0.01 dru → Pathfinder experiments paving the way
Decisions driven by simulations

Sources:

- Cosmogenic activation of Si and Cu
  ^{3}H in Si: Main bkgd (2 mdru/day at sea level)
  → <5 days on surface
  Can be baked out during fab! ("total" removal at 1000°C)

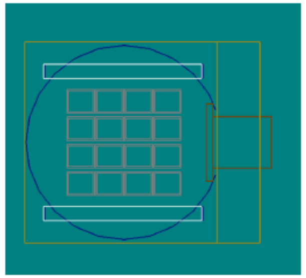


[PRD 102, 102006]

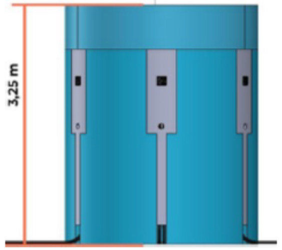


- Isotopic contamination on front-end electronics, cables and components near the sensors
  Low radioactive flex cable [arXiv:2303.10862]
  Simulations of ^{238}U, ^{232}Th and ^{40}K
  → 4cm of cable visible to CCDs
  → Electronics behind inner shield (width>10cm)

DAMIC-M cable	^{238}U [ppt]	^{232}Th [ppt]
Commercial	2600 +/- 40	261 +/- 12
Customed	31 +/- 2	13 +/- 3



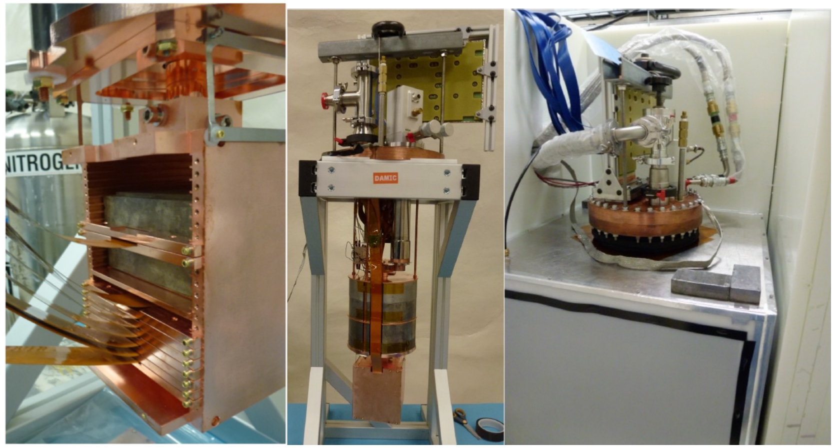
- External backgrounds
  Outer shield: polyethylene
  Inner shield: ancient lead and electroformed copper



Ionization detectors - DAMIC

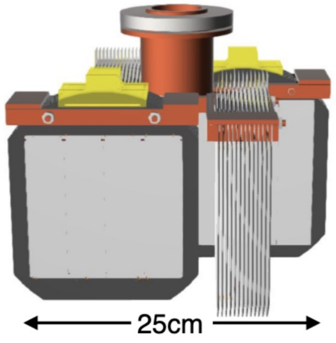
DAMIC@SNOLAB

- 7 CCDs (6.0 g, 16 Mpix)
- Operated @ 140 K.
- Total (bulk) background rate: ~10 (5) d.r.u.
- Low pixel noise 1.6 e- with conventional readout.
- Extremely low leakage current: 2 x 10^{-22} A cm^{-2}
- **PRL123(2019)181802; PRL125(2020)241803; PRD105(2022)062003**

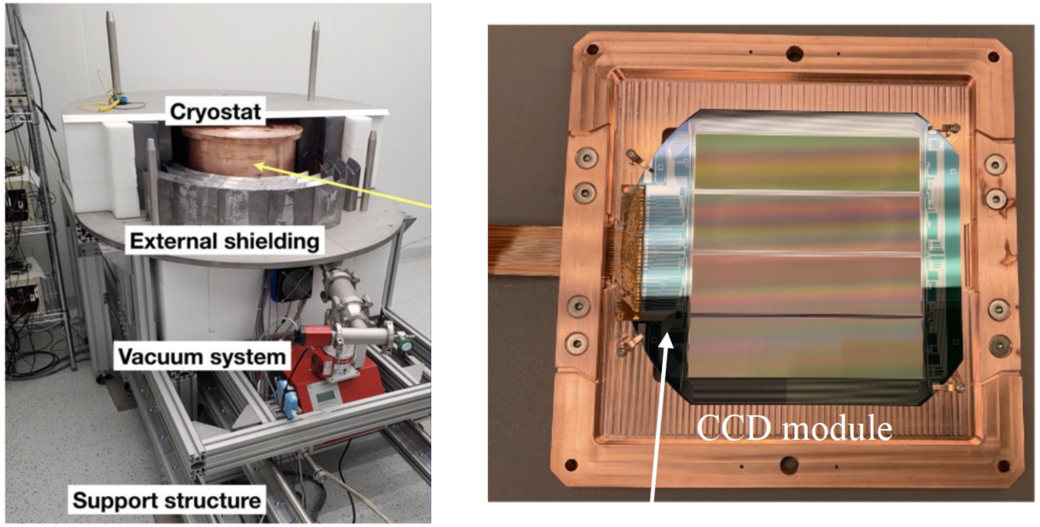


DAMIC-M@MODANE

- target exposure ~ **1 kg yr** with CCD detectors
- **single electron resolution** to ionization signals
- **2-3 electron threshold** (~eV)
- low background rate goal of **~0.1 dru**
- scheduled for installation at the Laboratoire Souterrain de Modane (LSM) end of 2024



52 CCD modules
208 CCDs, total mass ~ 0.7 kg



PRL 130, 171003 (2023)

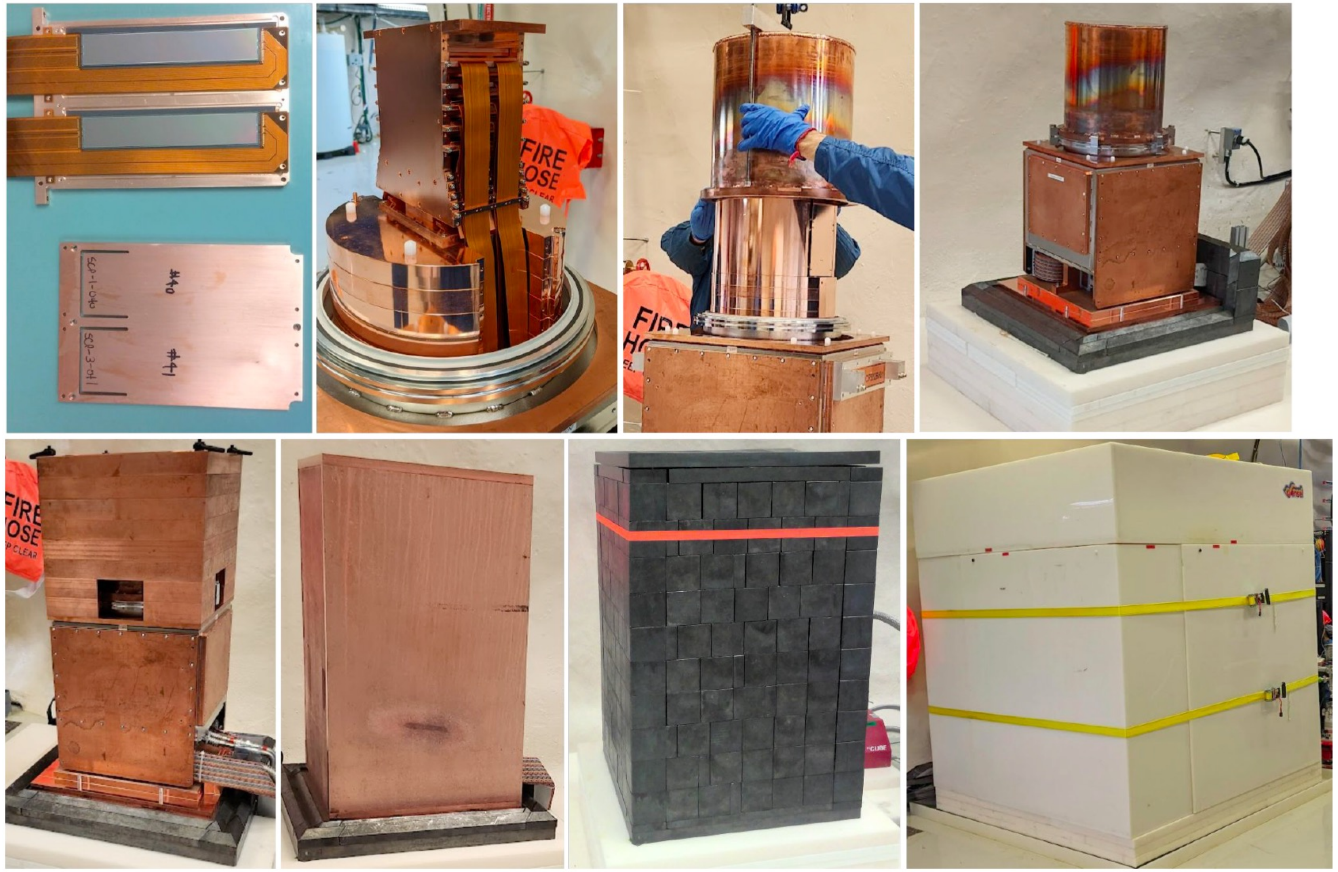
Ionization detectors - SENSEI

SENSEI@MINOS (230 m.w.e.)

- 5.5 Mpix of 15 µm
- 675 µm thick
- Active mass 2g
- 135 K
- 3000 dru

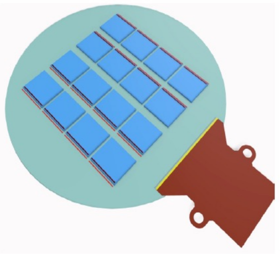
SENSEI@SNOLAB (6000 m.w.e.)

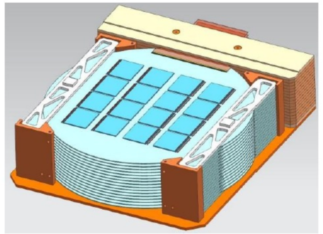
- 100 g
- Goal 5 dru
- 1^{st} science run with *6 CCDs (~13 g),*
- 2^{nd} science run with 19 CCDs (~40 g)



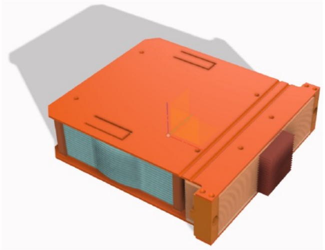
Ionization detectors - OSCURA

Multi-Chip Module
(16 skipper-CCDs)

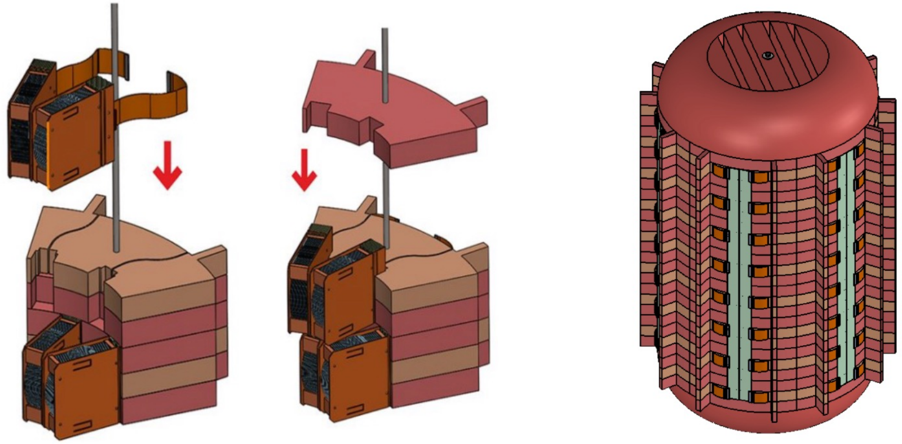




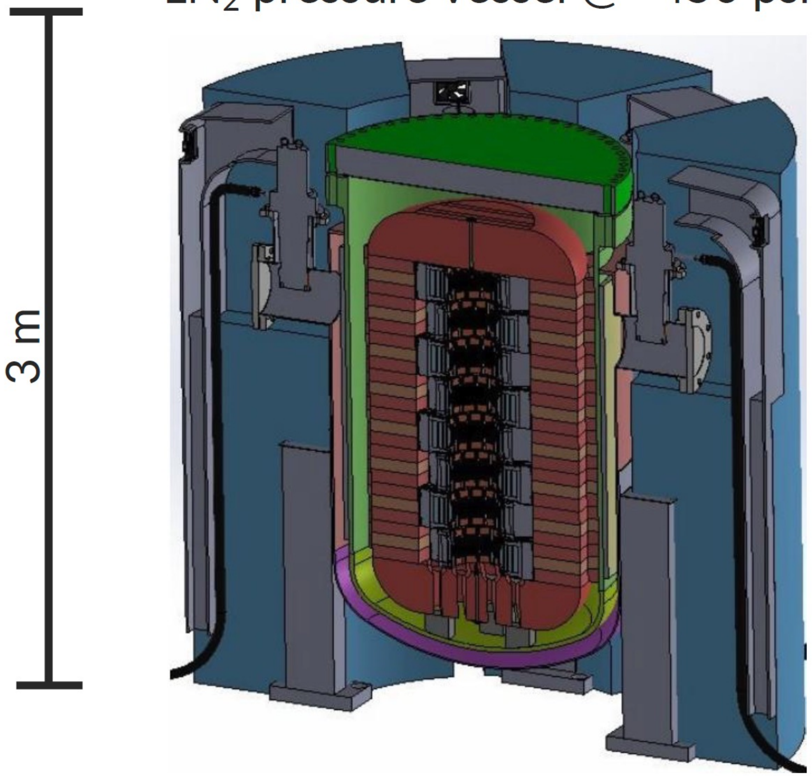
Super Module
(16 MCMs)



Detector payload in 6 columnar slices (96 SMs)

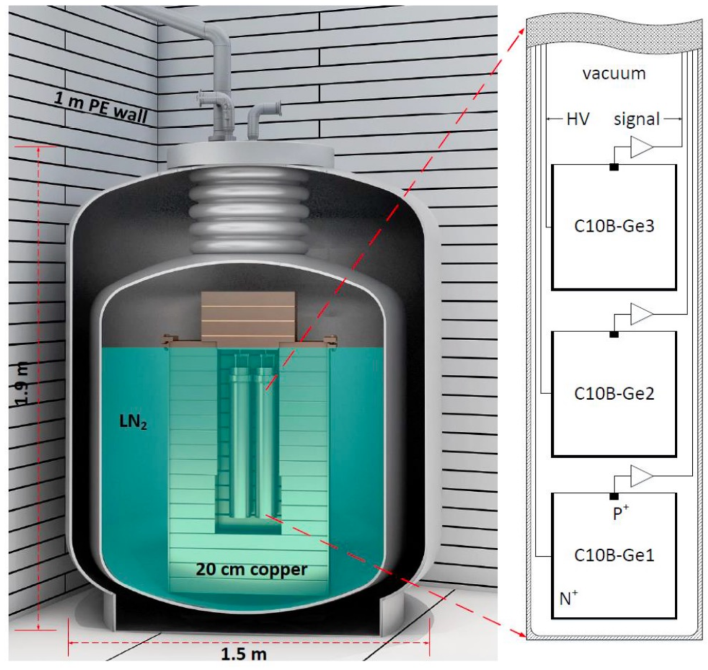


LN_2 pressure vessel @ ~450 psi



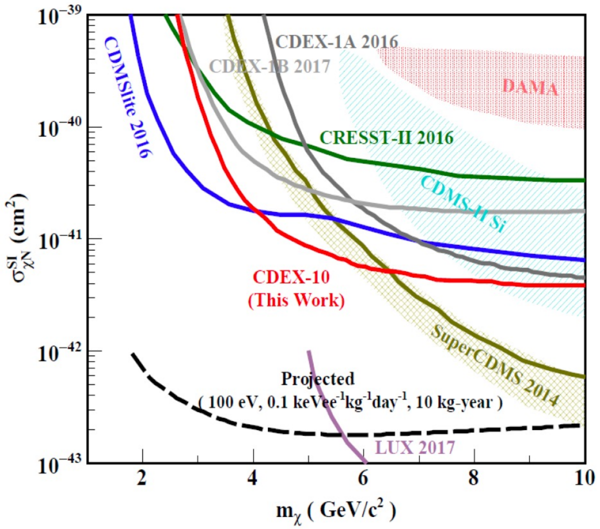
arXiv:2202.10518

Ionization detectors - CDEX

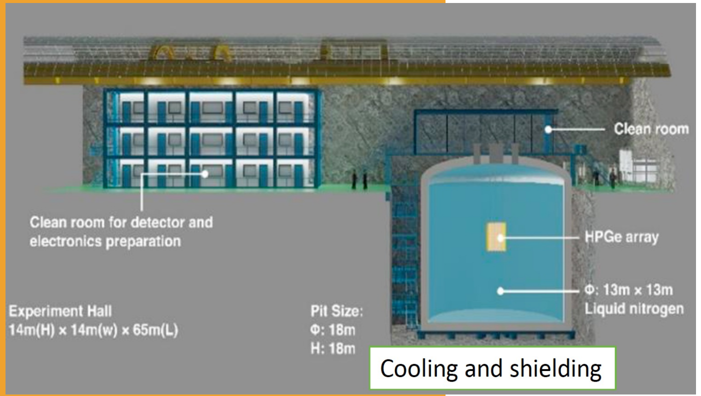


CDEX-10 @CJPL
(China Jingping Underground Lab)

- 3 strings array, 3 PPC/each, ~10kg total;
- Direct immersion in LN2;
- 102.8 kg·day exposure, threshold =160 eVee;
- Bkg level: ~2 cpkkd@ 2-4 keV;



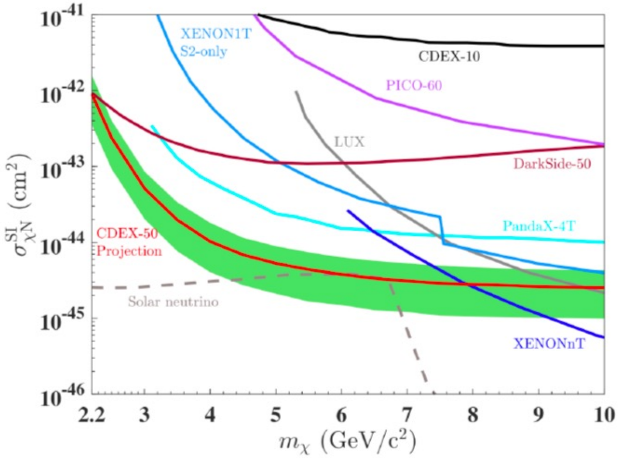
Phys. Rev. Lett. 120, 241301 (2018)



Cooling and shielding

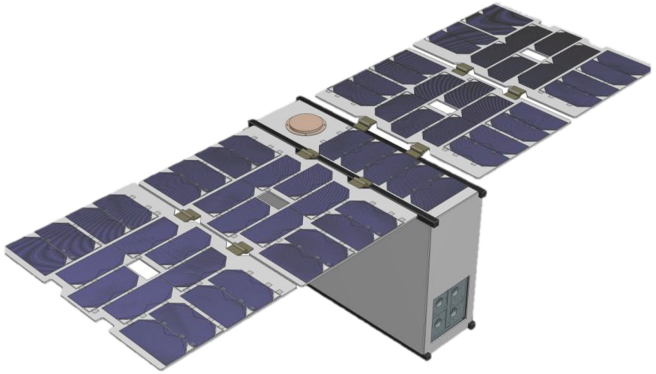
CDEX-50 @ CJPL-II

- 10 strings array, 5 HPGe/each, ~50kg total
- BEGe + PPC – LN2
- Bkg level: <0.01 cts/(keV·kg·day) @1 keV
- Energy threshold = 160 eV
- Exposure goal ~50 kg·year
- WIMP SI sensitivity → 10^{-44}cm^2



Many many others

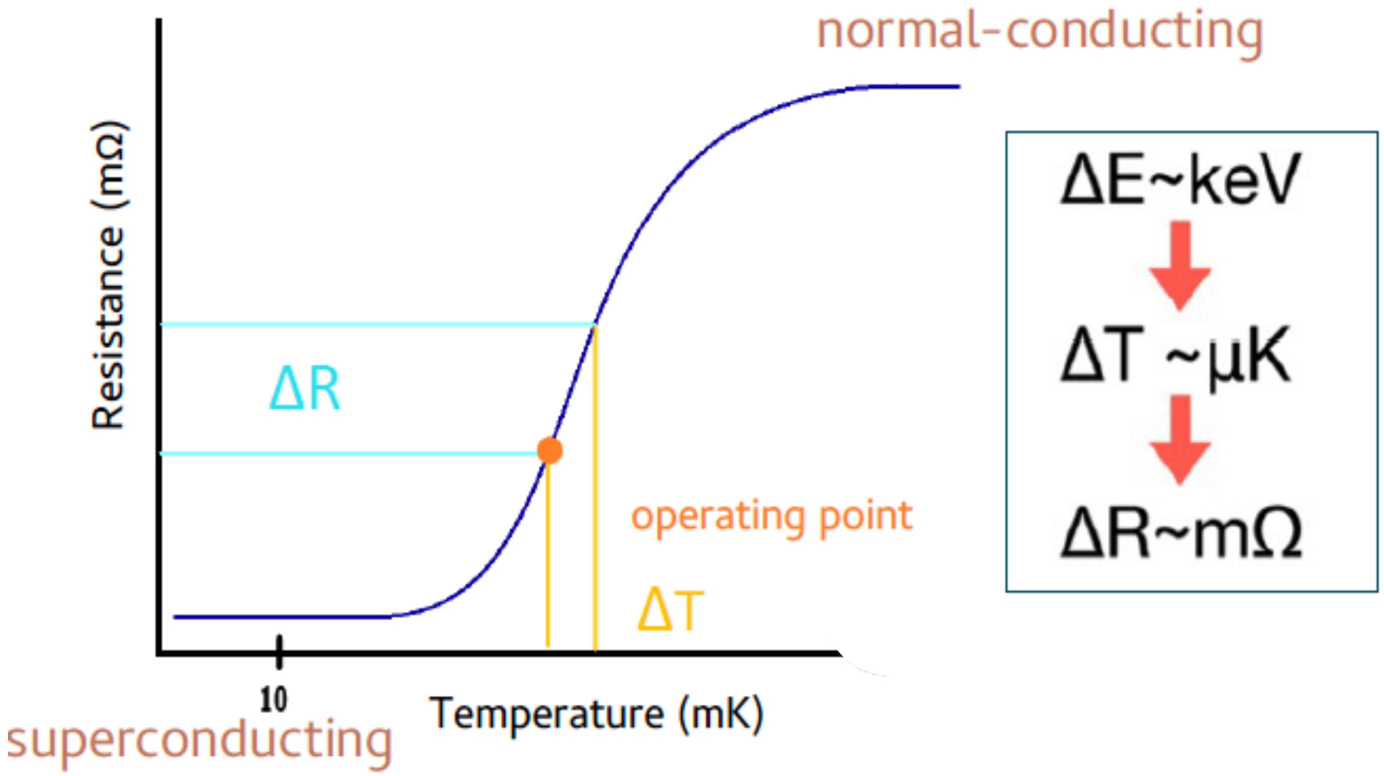
DarkNESS: Dark matter Nanosatellite Equipped with Skipper Sensors



DMSQUARE: Daily Modulation experiment

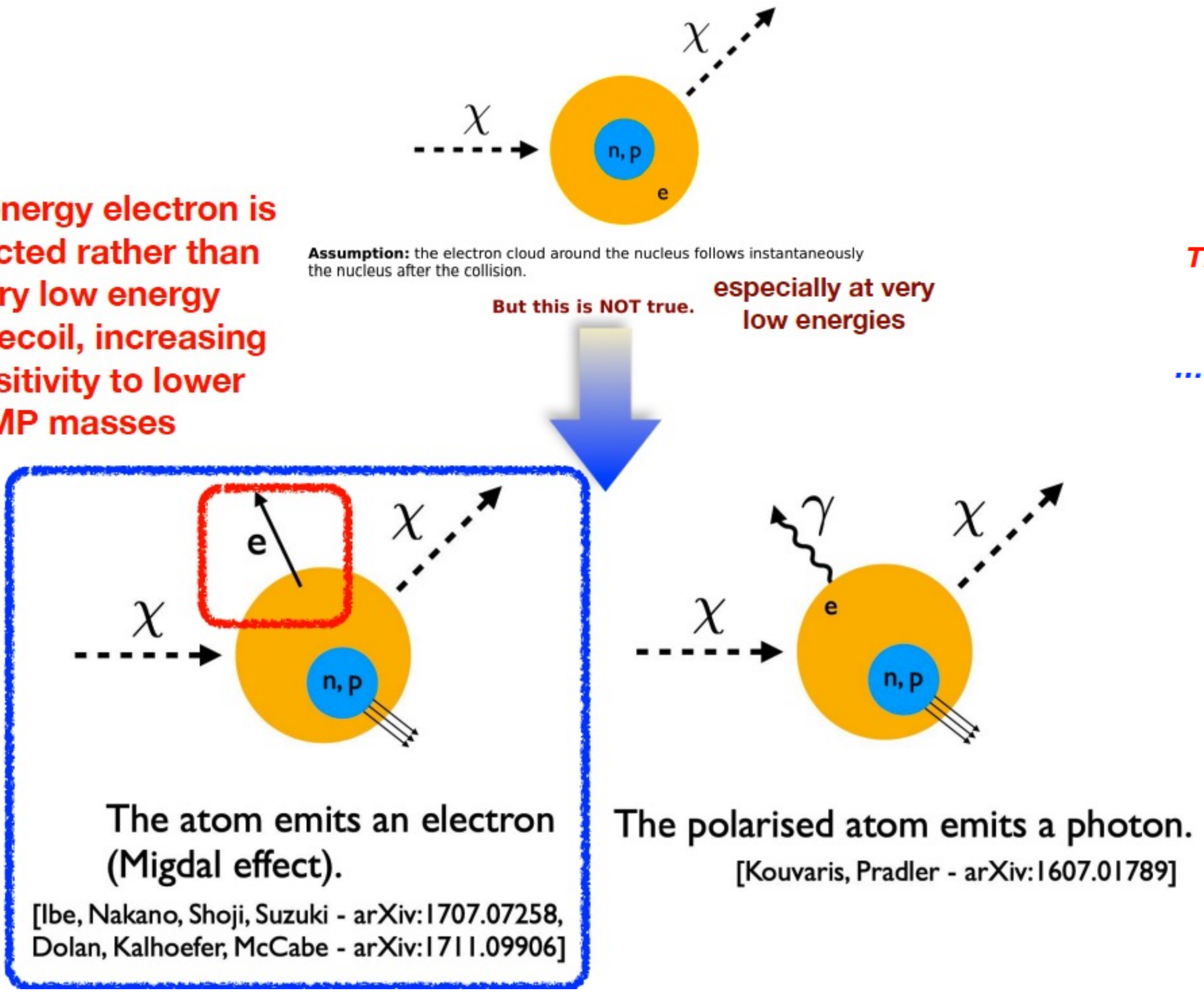
CEνNS

- CONNIE (COherentNeutrino-Nucleus Interaction Experiment)@Angras dos Reis
- Atucha II - Lima, Buenos Aires, Argentina

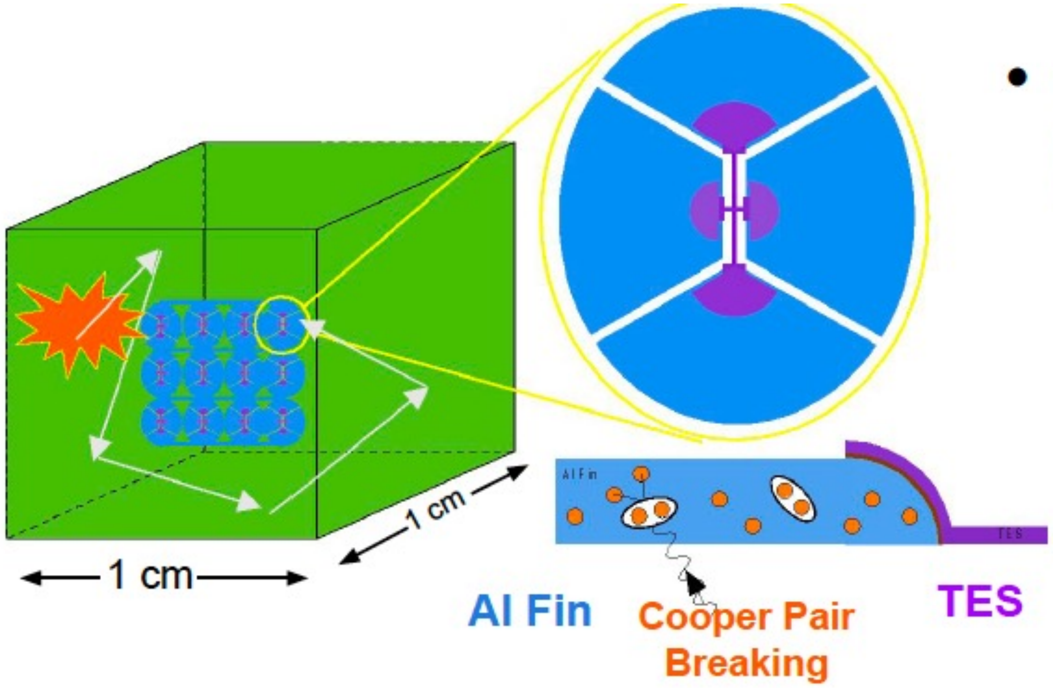

normal-conducting
Resistance (mΩ)
ΔR
operating point
ΔT
10
Temperature (mK)
superconducting
ΔE~keV
ΔT ~µK
ΔR~mΩ

MIGDAL effect

The low energy electron is the detected rather than the very low energy nuclear recoil, increasing the sensitivity to lower WIMP masses



Through Migdal electron, DM detector can extend their sensitivity to lower WIMP masses if they can measure very low energy electrons
…but there is a big penalty rate, therefore Migdal is mostly exploited by large 1 Ton experiments



- Collect and concentrate athermal phonon energy into Al fins
  - Phonons break Al cooper pairs
  - Quasiparticles are absorbed by W TES connected to Al fin

- Large collection area without the drawback of the heat capacity of a large sensor
  - Signal is degraded by phonon collection efficiency factor (~20%)
- **Readout of all targets identical** except the substrate
- More **DM science doesn't increase cost** significantly!