

Probing Benchmark Models of Hidden-Sector Dark Matter with DAMIC-M

Heng Lin

On behalf of the DAMIC-M Collaboration

Johns Hopkins University



2025/8/25

H.Lin, LEPTON 2025, Madison, WI



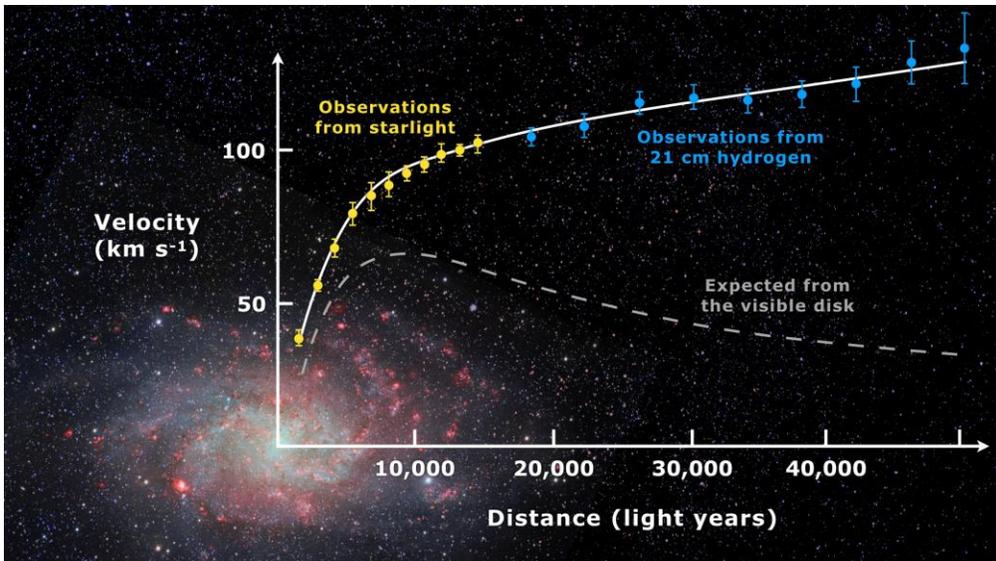
Outline

- **Dark Matter**
- **DAMIC-M Experiment**
- **The prototype : LBC's latest result**
- **DAMIC-M Construction update**

Dark Matter

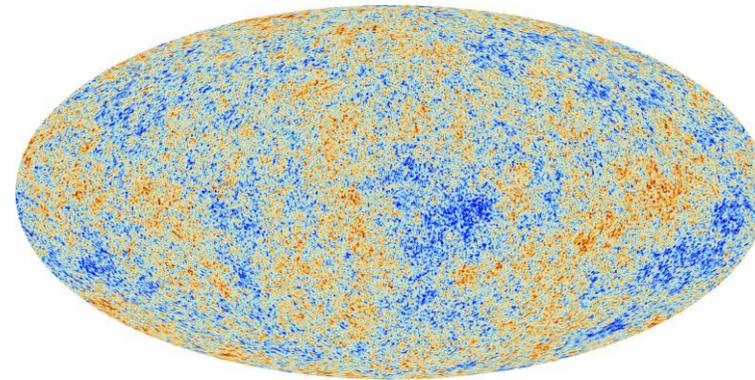
Dark matter explains astronomical observations from galactic to cosmological scales

Galaxy rotation curve



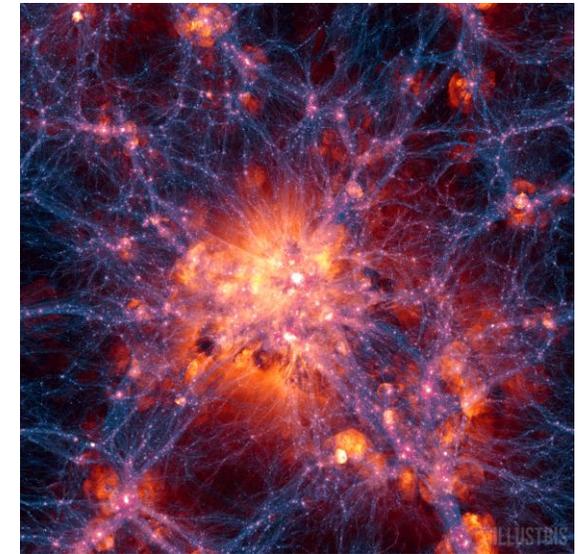
[doi:10.1046/j.1365-8711.2000.03075.x](https://doi.org/10.1046/j.1365-8711.2000.03075.x)

Cosmic Microwave Background



CMB measured by Planck, Image from ESA

Large scale structure of universe



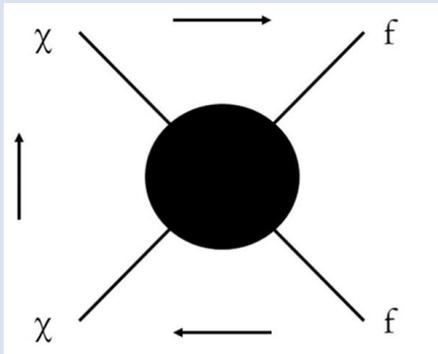
Illustris simulation (illustris-project.org)

Searching for Dark Matter



Strategies:

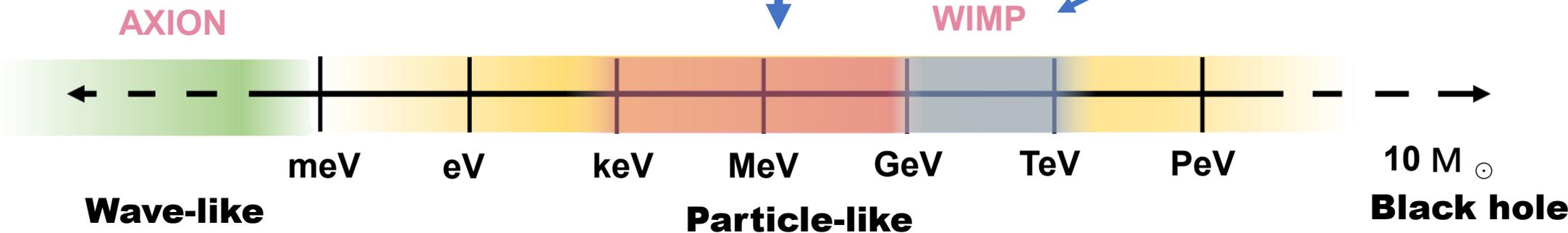
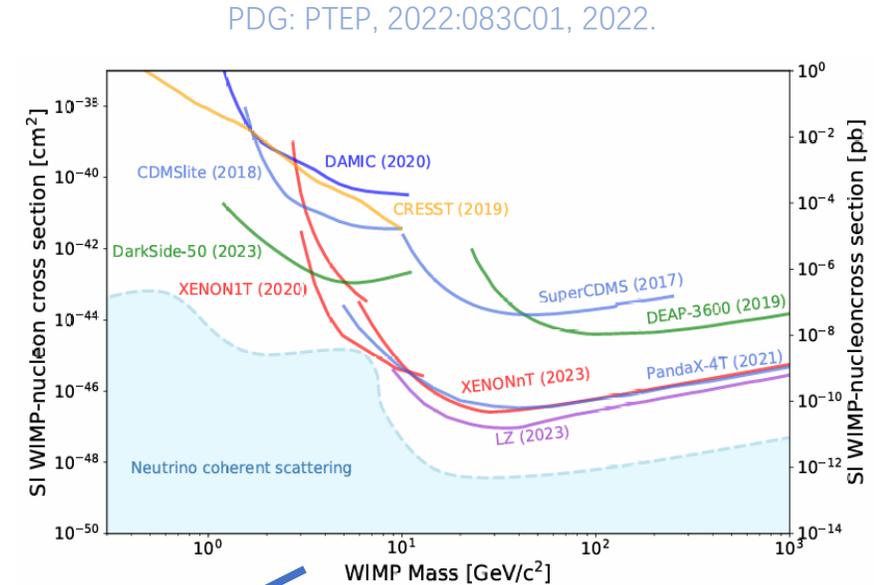
Indirect (DM annihilation)



Direct (DM-SM scattering)

Production (Collider)

**Sub-GeV
light dark matter
Our Experiment Here!**



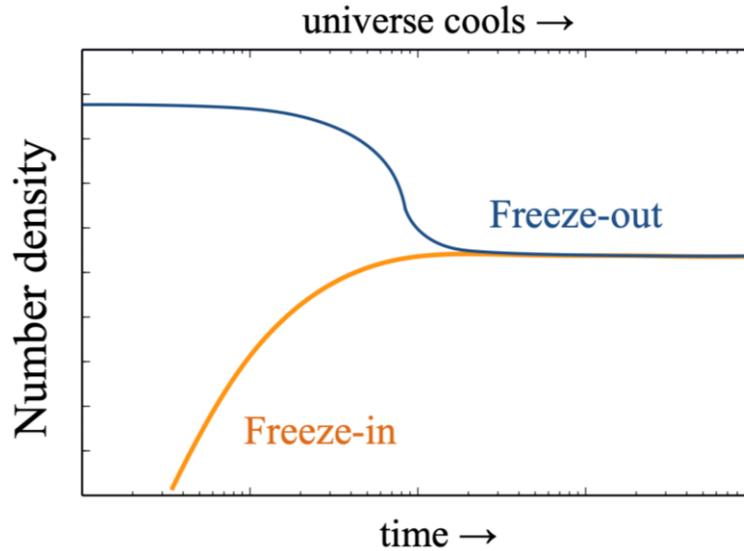
Searching for Dark Matter



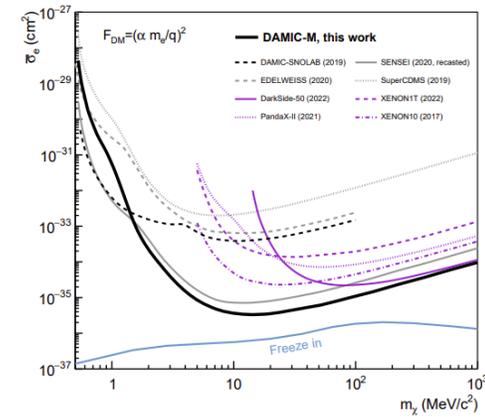
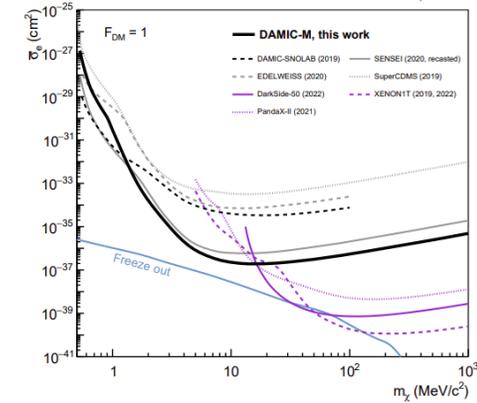
Benchmark models:

two DM production scenarios

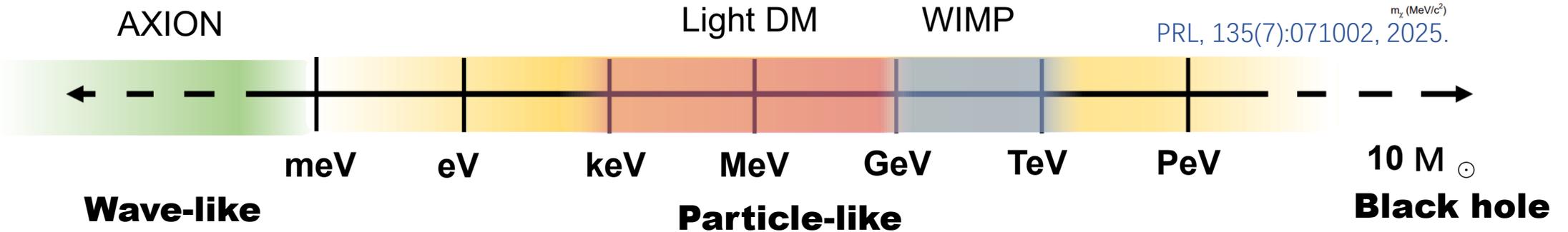
- **Freeze-In:** DM heading towards thermal equilibrium (ultralight mediator)
- **Freeze-Out:** DM heading away from thermal equilibrium (heavy mediator)



Constraints in the cross section-mass parameter space



PRL, 135(7):071002, 2025.

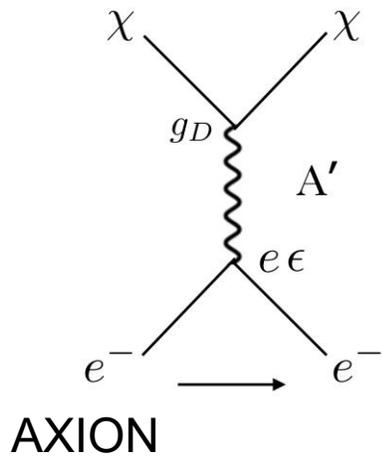


Searching for Dark Matter with CCDs



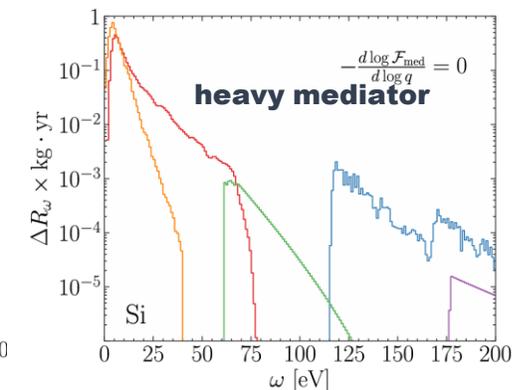
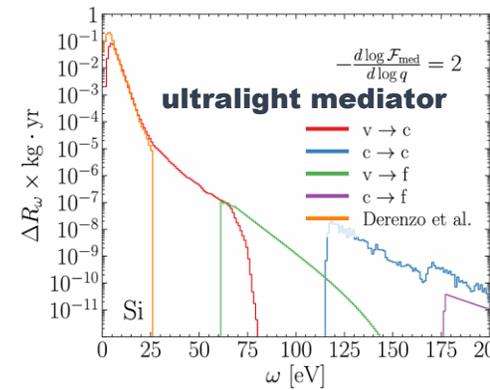
Scattering Physics:

More kinematically matched to electrons

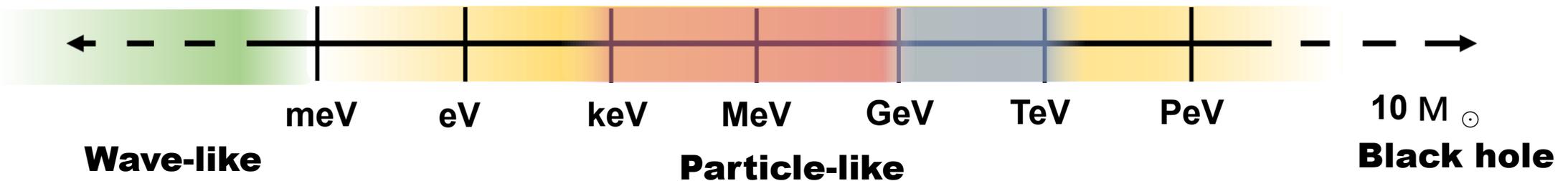


Energy deposition as low as eV scale:
Low energy threshold required!

Energy deposition of 1 GeV DM in silicon

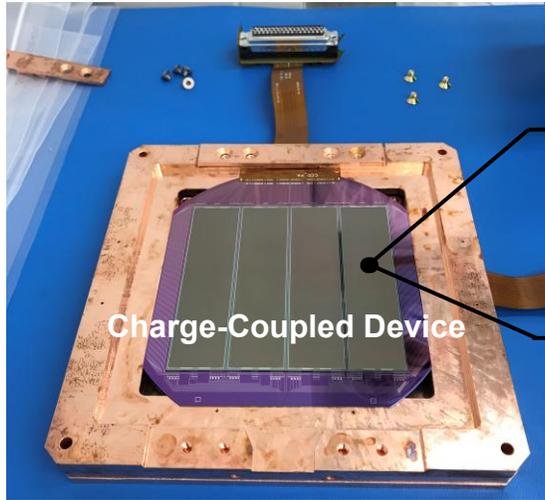


PRD, 104(2021)095015



DAMIC-M Experiment

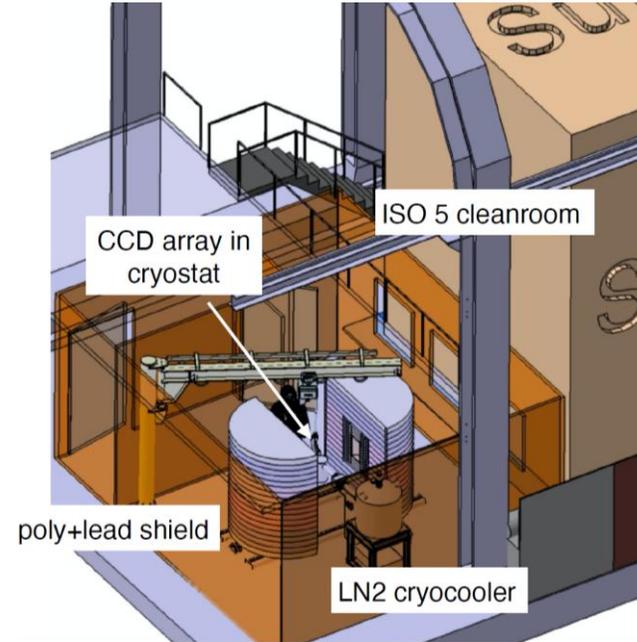
DArk Matter In CCDs at Modane



Charge-Coupled Device

Made from silicon
>10kΩcm, n type

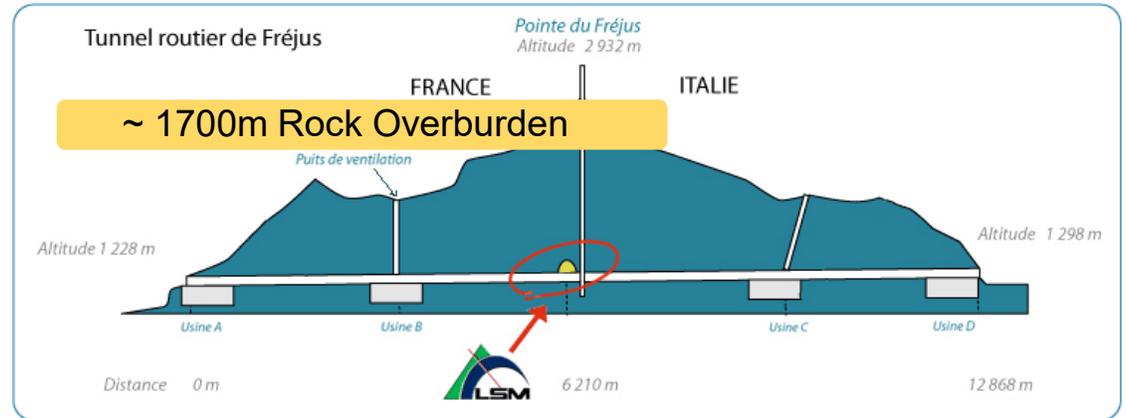
eV energy threshold



Especially sensitive for the sub-GeV hidden sector DM!

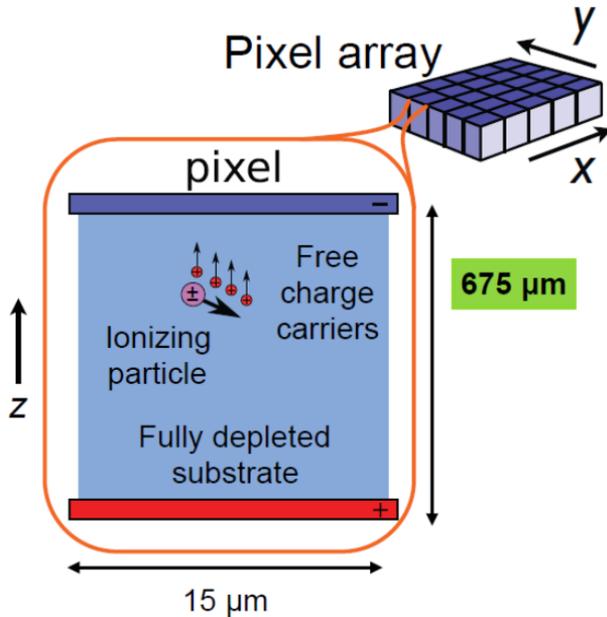
Operated at the Laboratoire Souterrain de Modane (LSM)

- Kilogram-year exposures
- Background target: < 1 dru (event/day-keV·kg)
- ~ eV level energy threshold



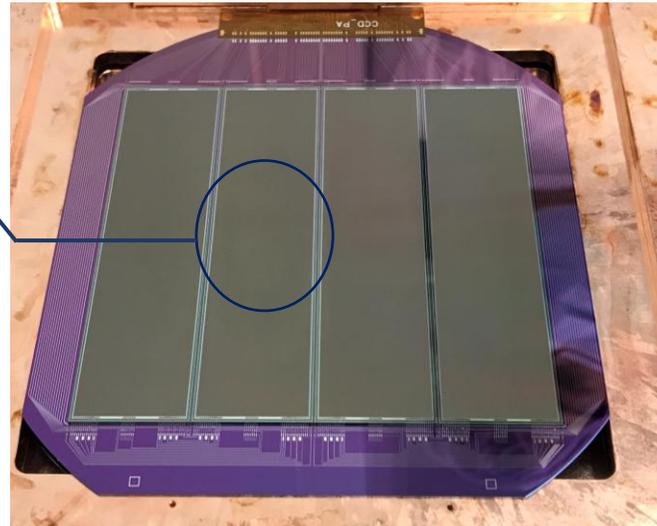
Charge-Coupled Device

Energy deposition

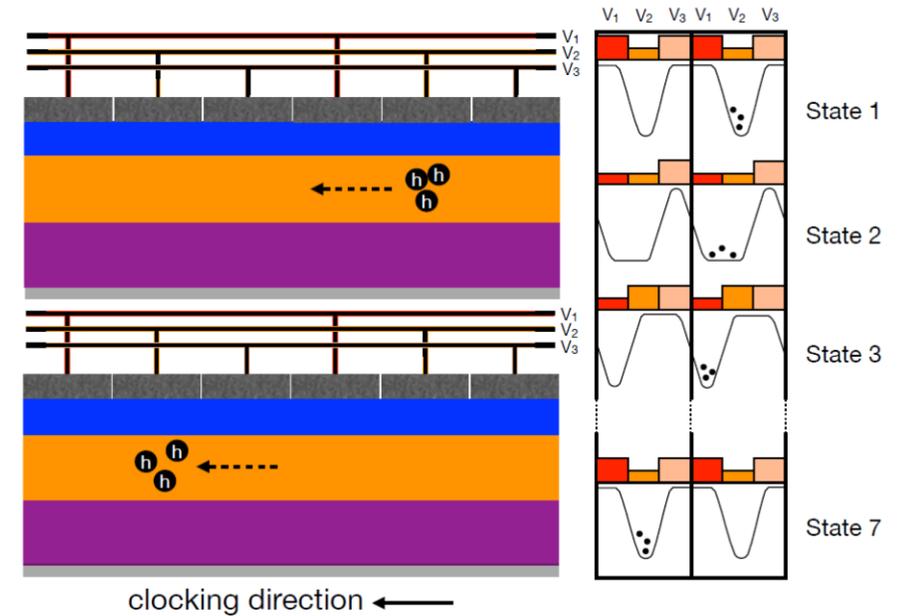


NIM.A 958 (2020) 162933

CCD's surface: pixelated



CCD clocks

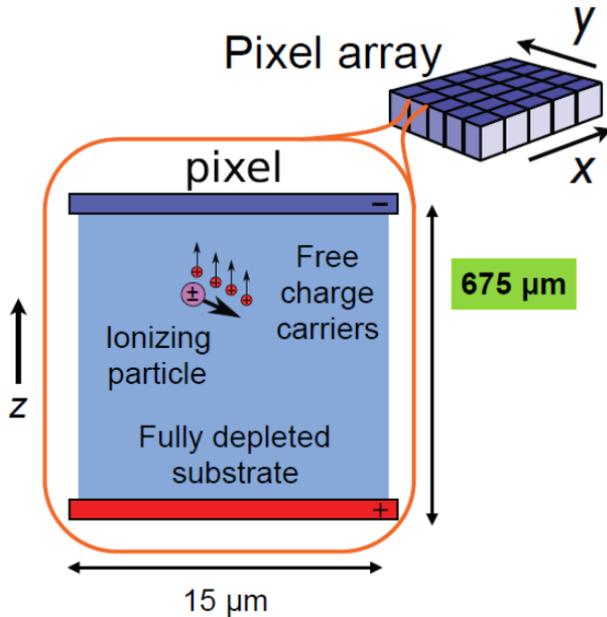


- 670 μm thick, $1.6\text{k} \times 6\text{k}$ pixels ($15 \times 15 \mu\text{m}^2$)
- High resistivity silicon wafer

- Slow readout and low noise
- Single electron resolution from skipper readout

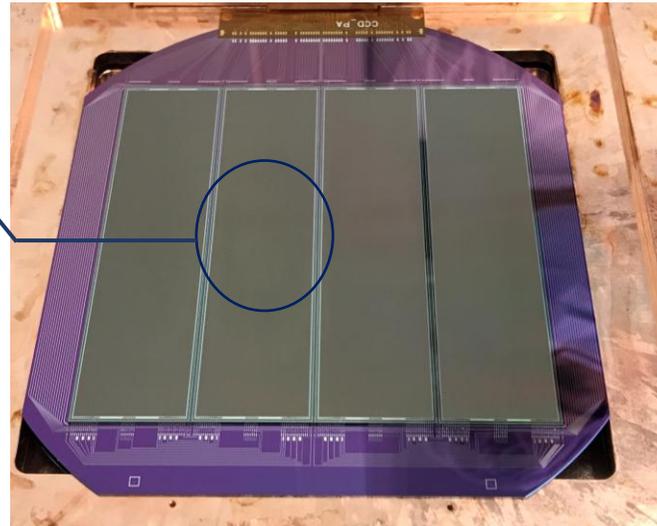
Charge-Coupled Device

Energy deposition

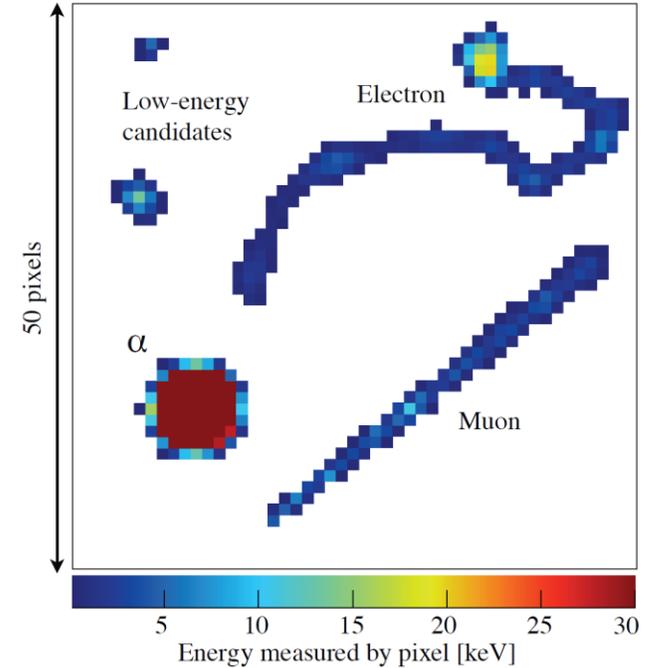


NIM.A 958 (2020) 162933

CCD's surface: pixelated



CCD image



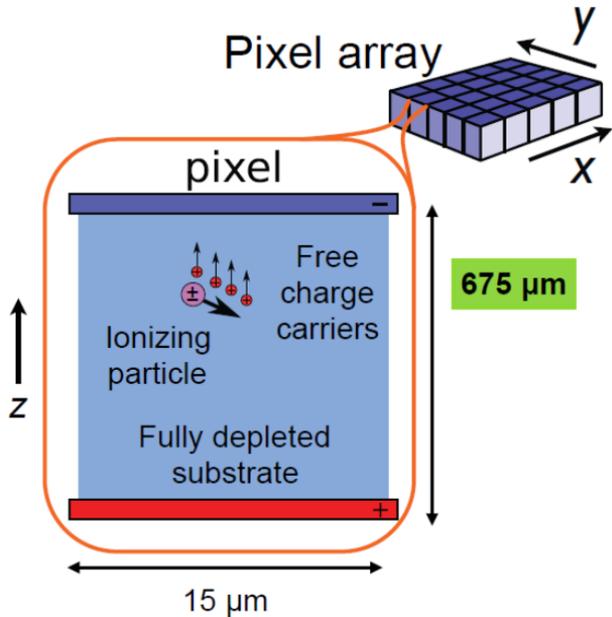
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Charge-Coupled Device: Skipper readout

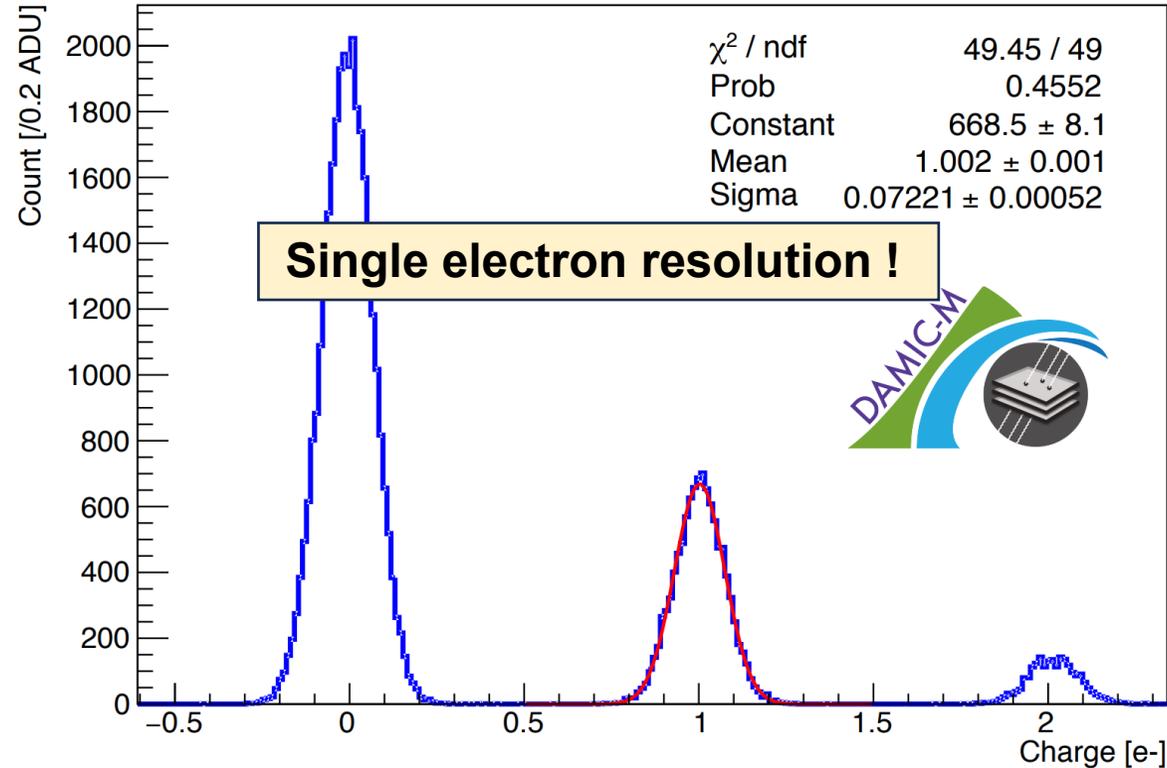


Energy deposition



NIM.A 958 (2020) 162933

Skipper readout

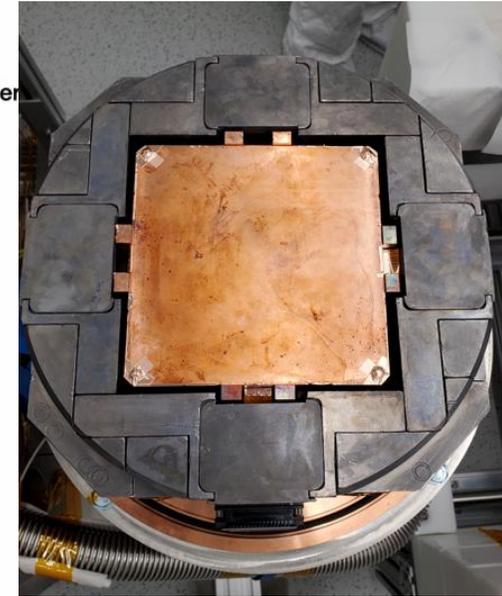
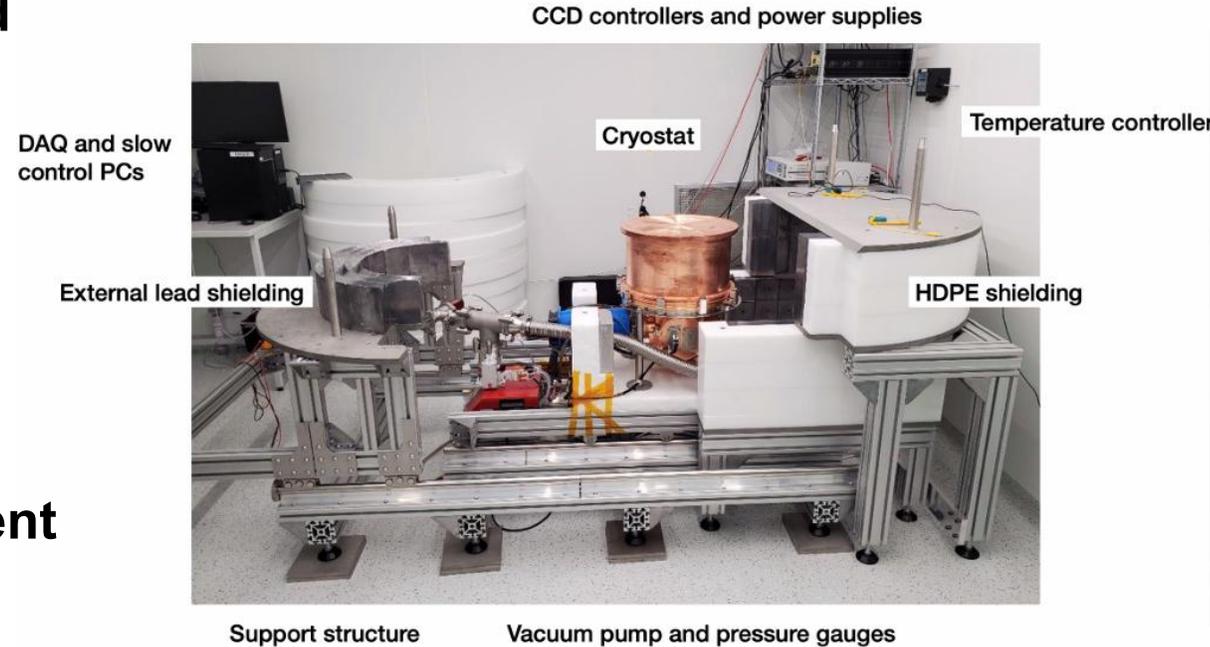


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- Single electron resolution from skipper readout

Prototype: Low Background Chamber



- Prototype detector installed and operating at LSM; Commissioning started by Feb 2022
- 2 CCD modules with 26 g target mass (in this result)
- Shielded by: HDPE + Ancient lead OFHC Cu+ Electroformed Cu



Previous result (2023, first constraints on DM-e scattering): [PRL.130.171003](#)
and (2024, daily modulation): [PRL. 132 \(2024\) 10, 101006](#)

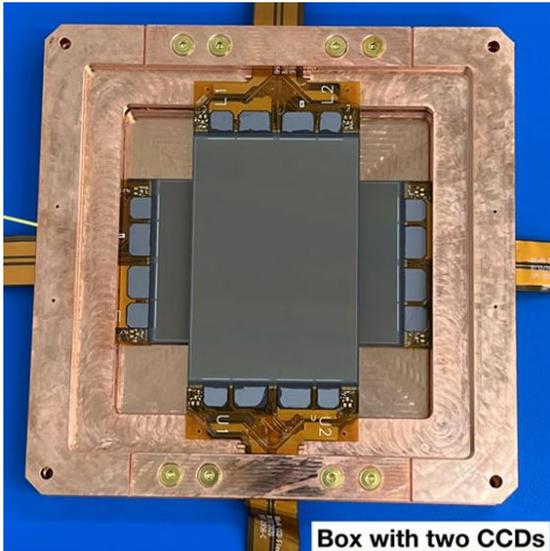
Prototype: Low Background Chamber



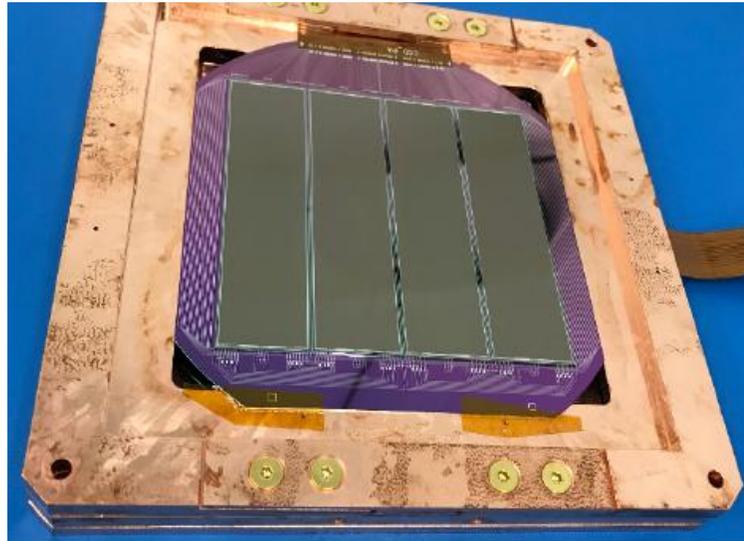
Oct 2024- Jan 2025 Science RUN 2
(this presentation):

the DAMIC-M CCD detector was implemented in this science run, exhibiting excellent performance

- 1.3 kg days' exposure (10 times larger)
- Significant single electron rate suppression (by a factor of ~50)
- Background: 10 dru -> 15 dru (shield partially open to improve the electrical grounding)
- Energy resolution: $0.2 e^-$ -> $0.16 e^-$



Box with two CCDs



- 2 Damic-M CCD modules:
- 6144* 1536 pixels for each CCD
- 4 CCD glued on each modules
- 6300 columns* 16 rows
Continuously readout from one amplifier for each CCD;

LBC Latest Result



- **Very Low dark current !**

single electron rate: $2.4 - 3.1 \cdot 10^{-4} e^-/\text{pixel}/\text{image}(1668\text{s})$,
only a few electrons/pixel every year !

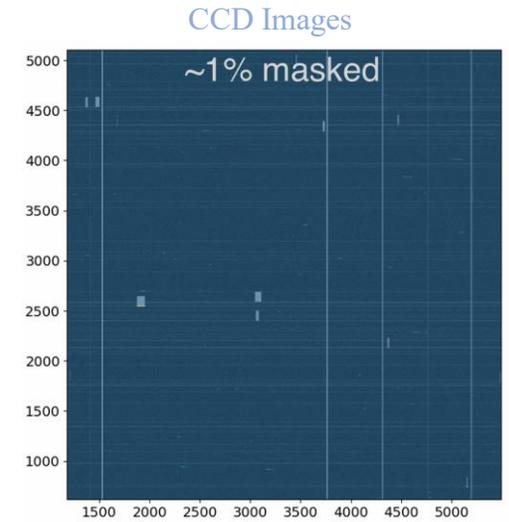


Nearly background free in the ROI

- **Excellent CCD performance: ~95% of the data survive the cut**

***established with 130 g*day data (D1) -> blind analysis for rest 1.3 kg*day of the data (D2)**

- Mask "Hot Columns" by number of pixels with charge $>1 e^-$
- Clusters identified -> mask clusters found always at the same position eliminate possible cross talks
- Mask the pixel following a high charge one to reject the trailing charge
- Mask Pixel with unstable performance in the multiple skip measurements
- A more stringent hot columns/rows mask
- Mask isolated columns



Step	f_{sel}	
	CCD 1-D	CCD 2-D
1 + 2	0.9862	0.9820
3	0.9747	0.9724
4	0.9746	0.9722
5	0.9431	0.9492
6	0.9414	0.9474

Events that survive the data selection in different steps

LBC Latest Result: Pixel pattern analysis



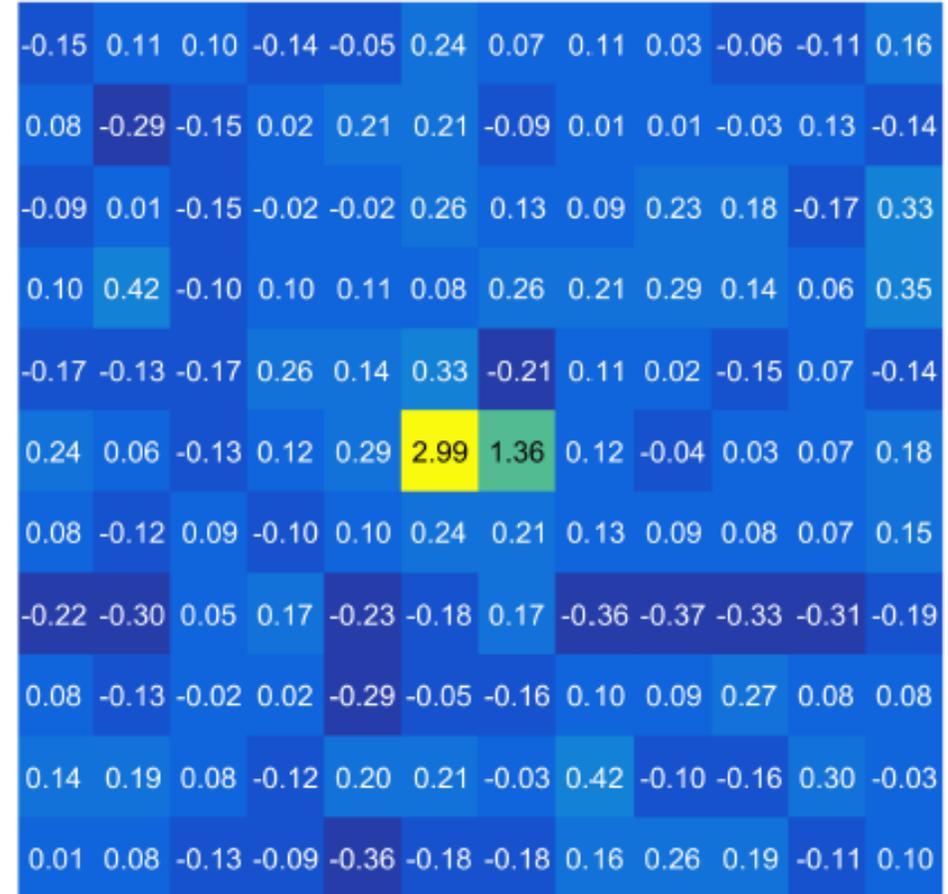
Data Selection: dark matter candidates of 2 to 5 e⁻

For Clusters < 6 e⁻

Recognize patterns: {1,1}; {2,1}; {1,1,1}; {3,1}; {2,2}; {2,1,1}

- DM candidates
- Radioactive background
(scaled from the 2.5-7.5 keV data and Geant4 simulation)
- Random coincidences

	Pattern p		
	{11}	{21}	{111}
D_p	144	0	0
B_p^{rc}	141.4	0.111	0.042
B_p^{rad}	0.039	0.039	0.016
	{31}	{22}	{211}
D_p	1	0	0
B_p^{rc}	0.019	2.5×10^{-5}	5.8×10^{-5}
B_p^{rad}	0.052	0.011	0.035



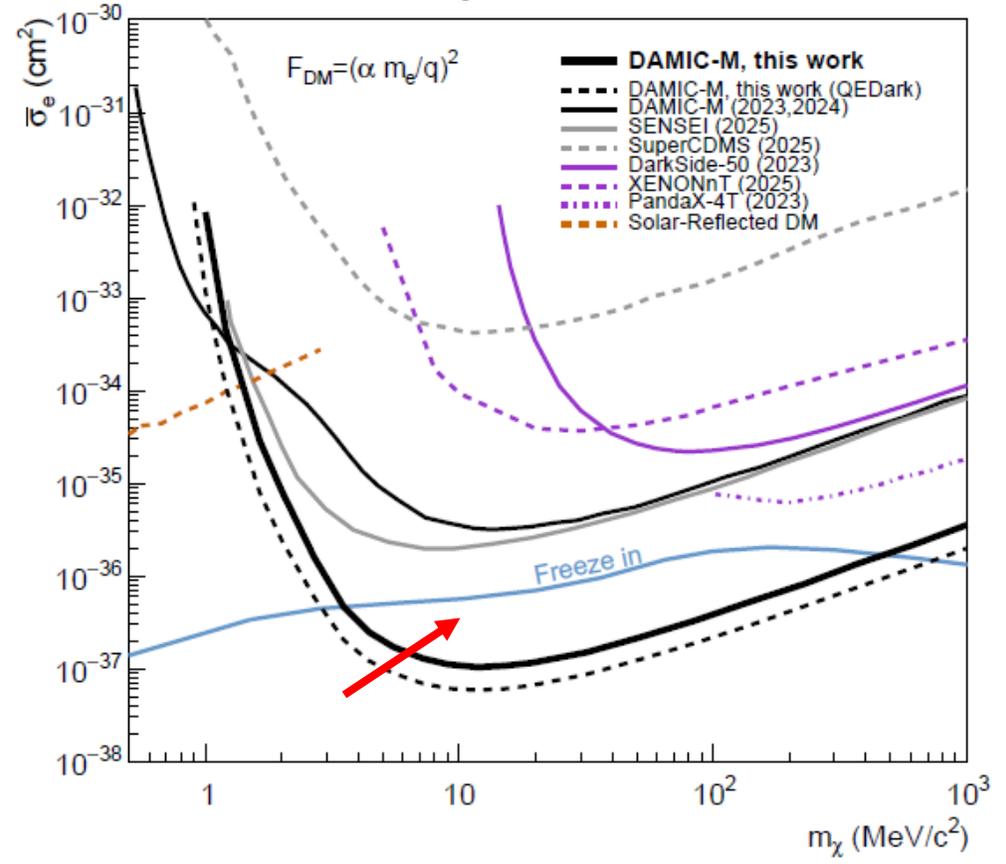
Part of the CCD image with the {3,1} pattern

LBC Latest Result : DM-e interaction

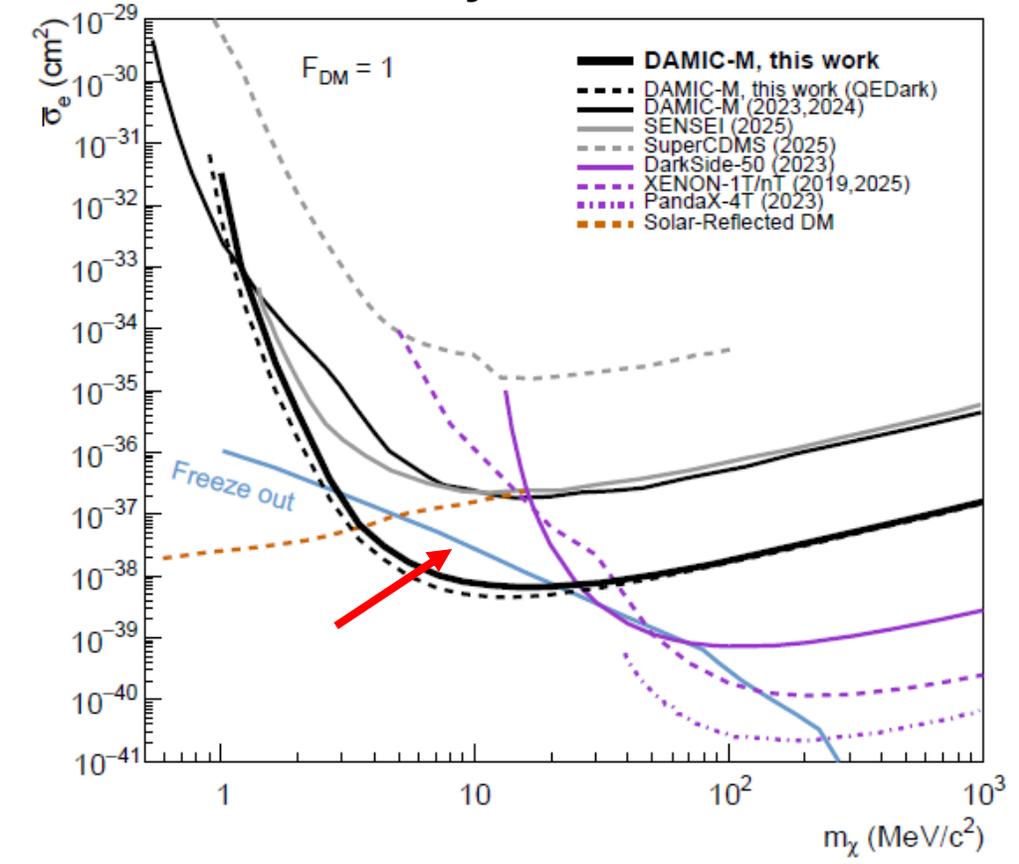


DAMIC-M 90% C.L. upper limits on DM-e interaction

Ultra light mediator



Heavy mediator



PRL, 135(7):071002, 2025.

DAMIC-M Detector



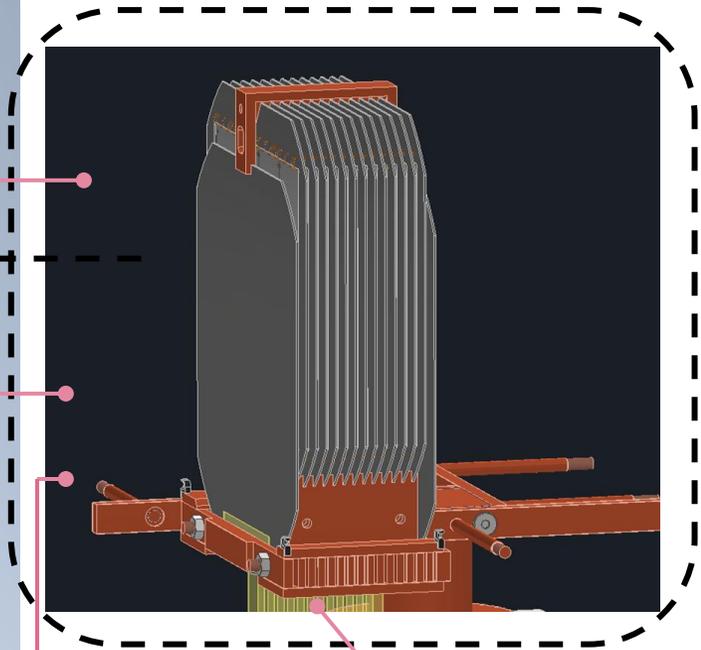
Kg*year target exposure!

Vacuum & Electronics Feedthrough

OFHC copper

Lead & Poly Shield (Partially shown)

Cryocooler (CCD operated at ~130K)



Radio-pure flex

EPJ Tech. Instrum., 10(1):17, 2023.

Ancient Lead

E.F. Copper

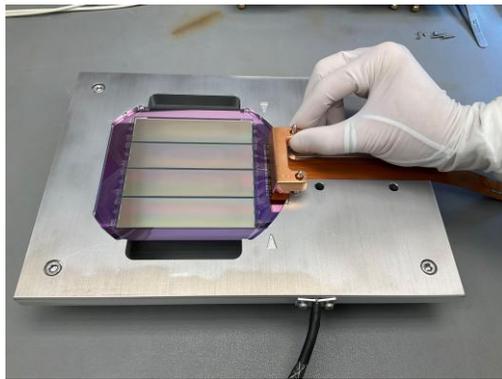
Phase I: Array of 26 CCD Modules (340 g silicon target)

Coming Soon: DAMIC-M



The DAMIC-M detector:
larger mass and lower background !

- Modules fabrication has been done at UW (Seattle), following strict background controlling protocols (paper to be submitted)



× 26

Array of 26 CCD Modules
(~340 g silicon target)

- E.F copper produced and machined underground at SURF (MAJORANA) and Canfranc
- Customed low radioactive flex cable reducing the background by a factor of 20 (^{232}Th) and 84 (^{238}U) *EPJ Tech. Instrum.*, 10(1):17, 2023.



- Surface exposure of silicon strictly limited (shipping budget ~ 2 weeks); Customed shielding container reduce the activation during shipping to ~5%

Coming Soon: DAMIC-M



Test stand set up in the LSM clean room to validate the module performance

- DAMIC-M Module underground test is on-going now at LSM
- Assembly and commissioning of DAMIC-M detector is happening soon!
- JHU group: DAMIC-M module test, module array assembly, etc.



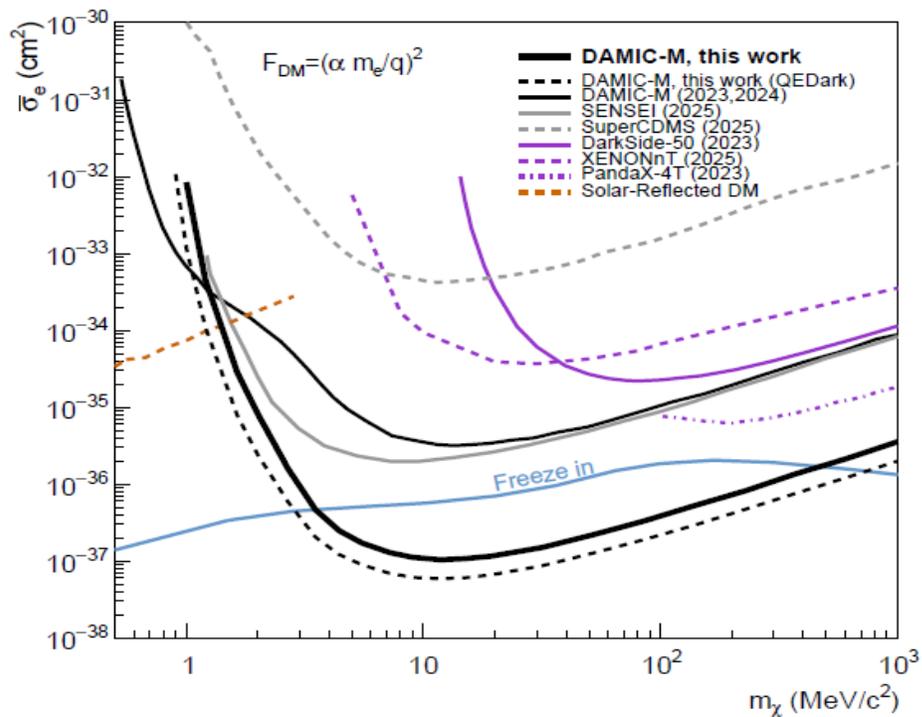
Feedthrough box designed by the JHU group for the detector's electronics readout

- Lower background !
15 DRU → < 1 DRU
- Kg*year target mass
(one order of magnitude higher)

Summary



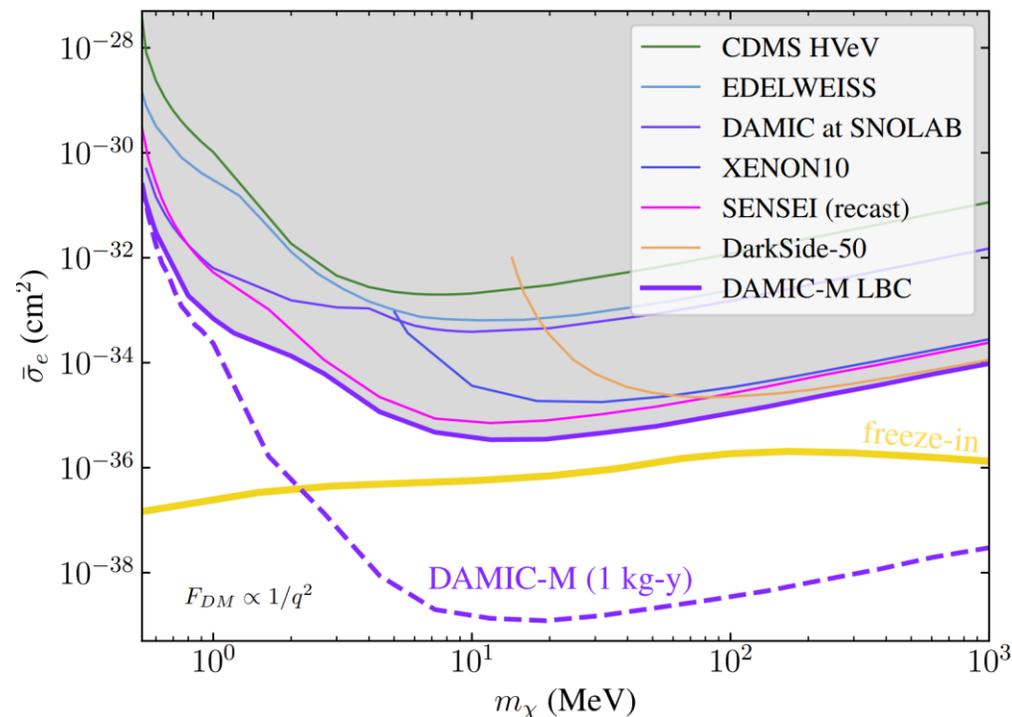
- The DAMIC-M prototype for the first time excludes a wide range of the bench mark model of the hidden sector dark matter with the DAMIC-M's CCD module implemented



Summary



- The DAMIC-M prototype for the first time excludes a wide range of the bench mark model of the hidden sector dark matter with the DAMIC-M's CCD module implemented
- DAMIC-M aims at a target exposure time of 1 kg·yr and a target background rate of a few 0.1 event/day·keV·kg; It is happening soon!





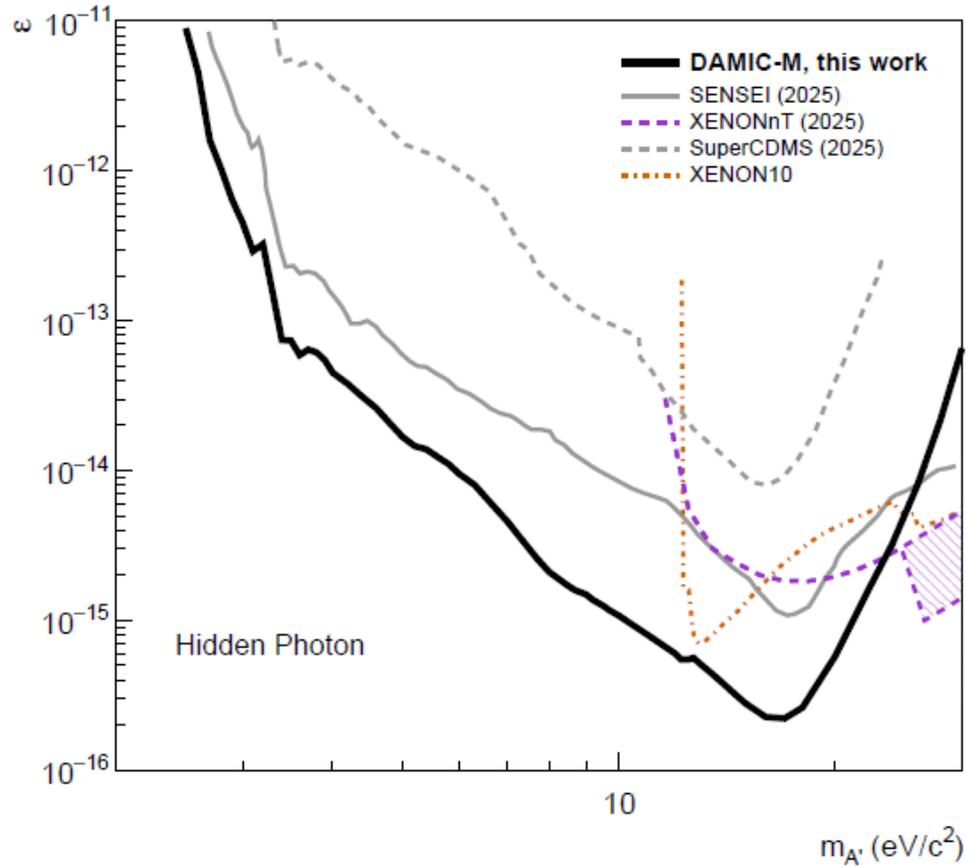
Thank You

Back Ups

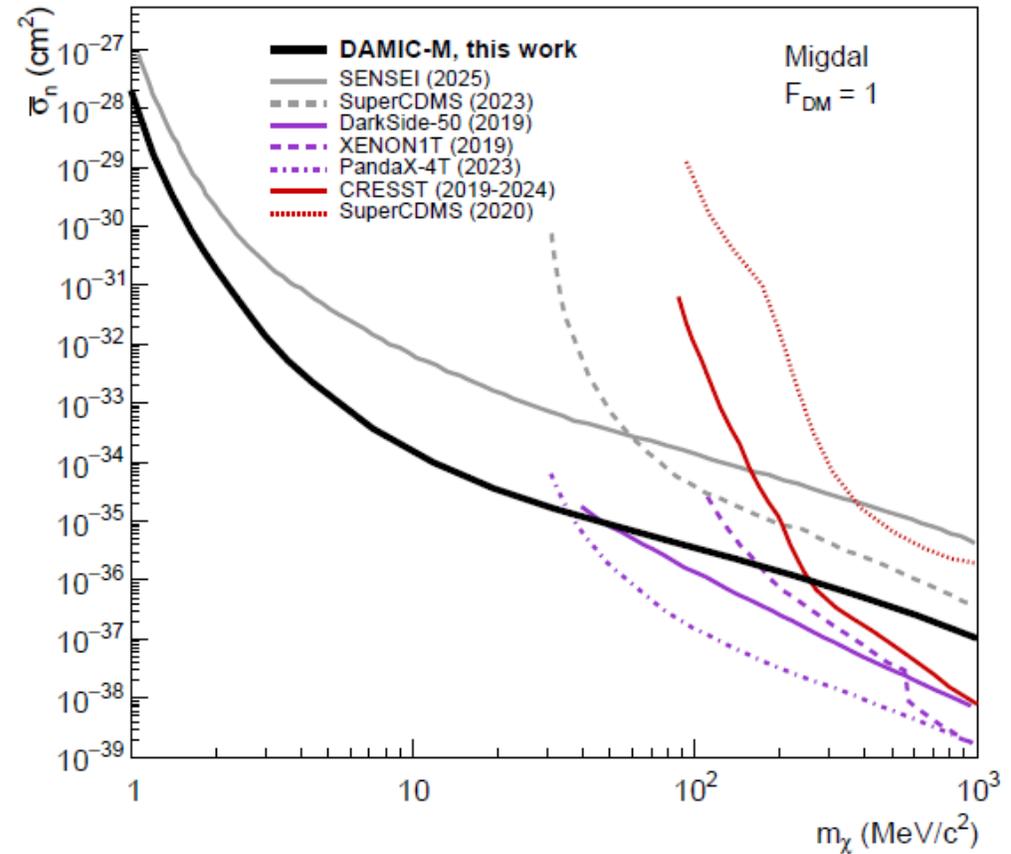
LBC Science RUN 2: other models



Dark photon absorption



Migdal effect

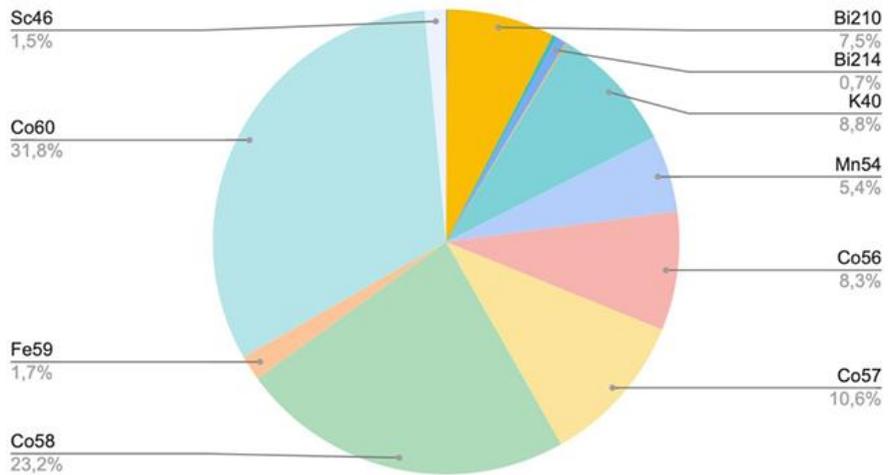


PRL: doi.org/10.1103/2tcc-bqck

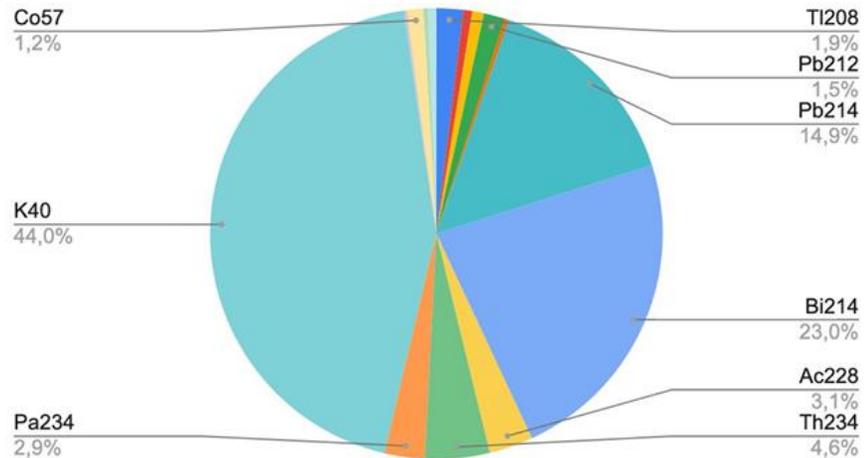
Major contributors to bkg in cryostat



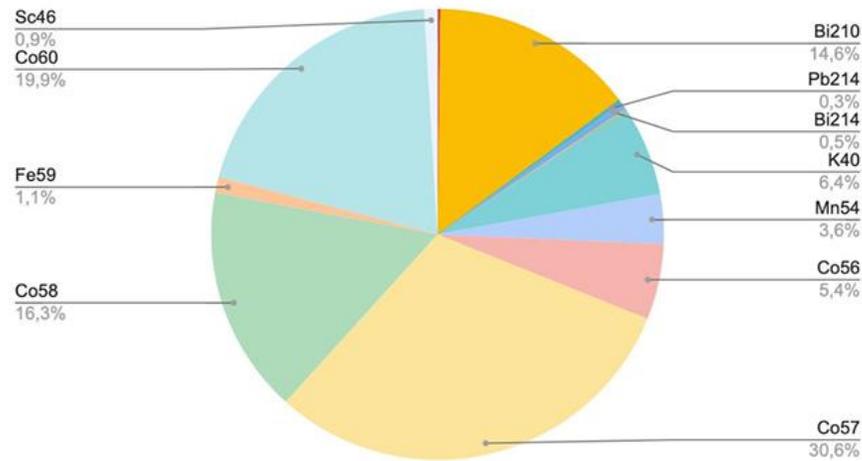
Vacuum can shield - 0.063 d.r.u



Kapton Cables - 0.06 d.r.u



Vacuum can - 0.045 d.r.u



if Vacuum can in
Luvata Cu: 1.43 d.r.u