# Science Results from the DAMIC-M Low Background Chamber

Benchmark, diurnal-modulation, and solar-reflected searches with the LBC prototype

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***on behalf of DAMIC-M collaboration***

IDM2026
ZARAGOZA

# Overview

This talk focuses* on science results from the DAMIC-M prototype, the Low Background Chamber (LBC).

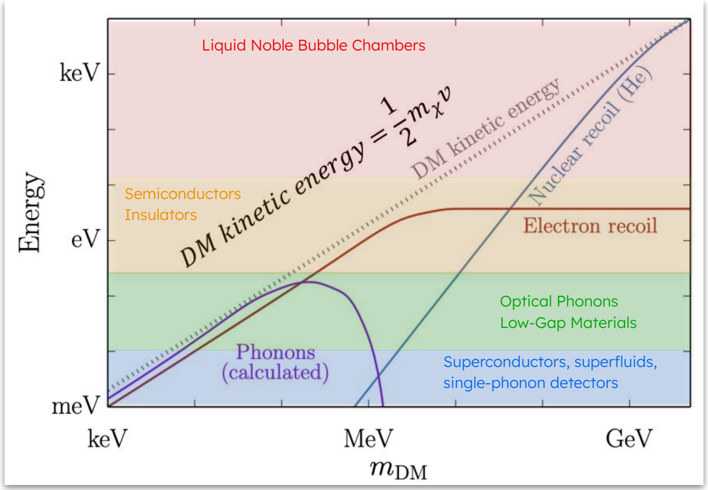
1. Why low-threshold CCDs for light Dark Matter
2. The LBC Science Run 2 dataset
3. **Three complementary searches** on DM-e scattering:
    a. **SHM Benchmark:** *Direct Galactic Halo flux at Earth* [PRL 2025, 135, 071002]
    b. **Diurnal Modulation:** *Earth-attenuation halo flux* [PRD accepted, 2026; arXiv:2511.13962]
    c. **Solar-reflected DM**: *Boosted flux from solar scattering* [PRD to be submitted, 2026]

*DAMIC-M full detector status will be covered by **Rocio Vilar's talk (DDLDM@17:50)**

# Why Light Dark Matter needs electron-scale detectors

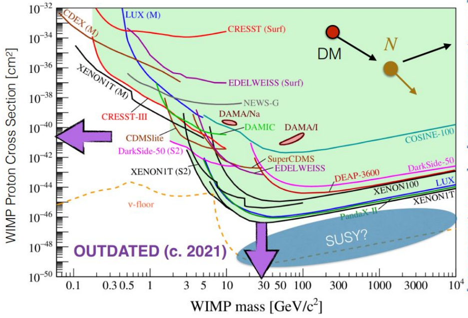
Sub-GeV requires **low thresholds** and **electron-recoil** sensitivity.

- Nuclear recoils rapidly lose sensitivity below the GeV scale
- Hidden-sector models motivate DM-electron scattering
- Skipper CCDs access ionization signals at the single-electron level

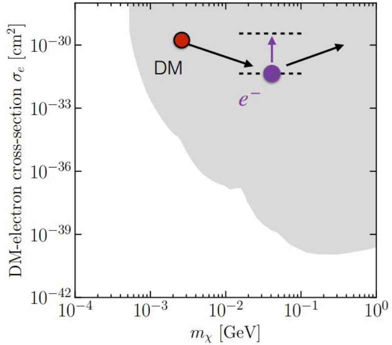



Adapted from: arXiv:1904.07915

**DAMIC-M Experiment (LBC)**




[APPEC, arXiv:2104.07634] [GAMBIT, 1705.07935]



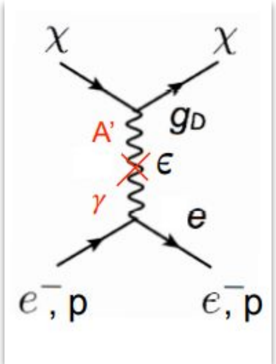

sub-GeV DM WIMP

# Hidden-sector benchmark targets

## Dark-photon-mediated DM-electron scattering

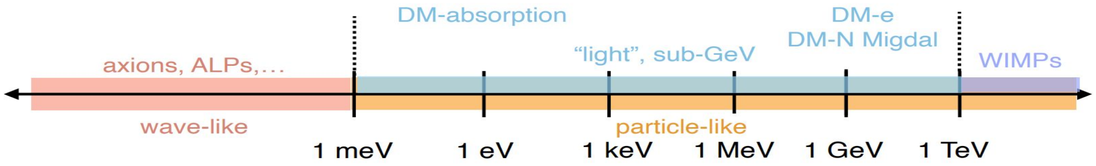
Dark matter may **interact** with the Standard Model **through** a **kinetically mixed dark photon** (A')

**Dark Photon Mediator:** *Add a dark photon (A') that mixes with the ordinary photon. This acts as a portal between the hidden sector and the SM, coupling to both protons and electrons.*




$$\mathcal{L}_{int} \sim A'_\mu (g_D J^\mu_D + \epsilon e J^\mu_{EM})$$

Practically **accessible** via **DM-electron scattering** with very low threshold detectors. Also absorption, Migdal effect, …



# Hidden-sector benchmark targets

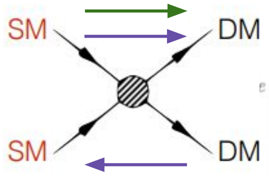
## Two standard mediator limits: heavy (freeze-out) and ultralight (freeze-in) mediator

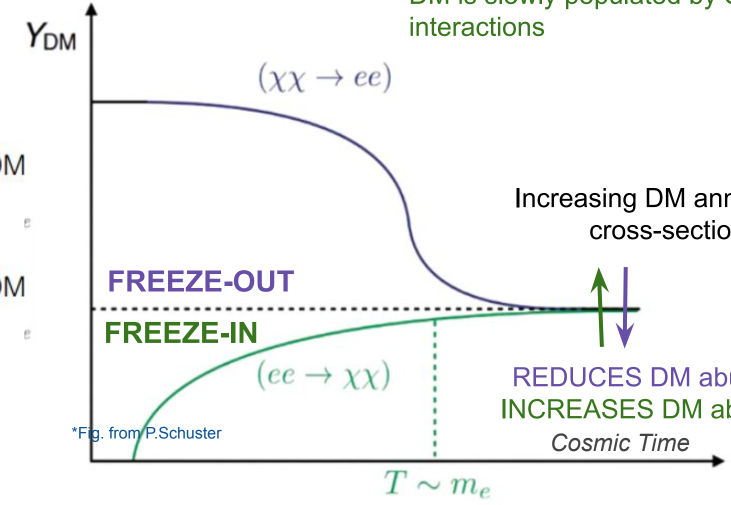
If DM-SM interactions are strong enough, DM is initially in thermal equilibrium

If DM-SM interactions are very weak, DM never reaches thermal equilibrium

As the Universe cools and expands, these interactions become ineffective and the DM number **freezes out**

DM is slowly populated by SM interactions



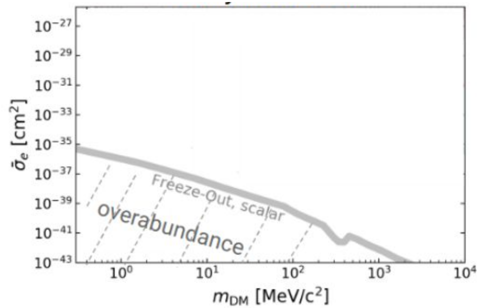

Increasing DM annihilation cross-section,

REDUCES DM abundance

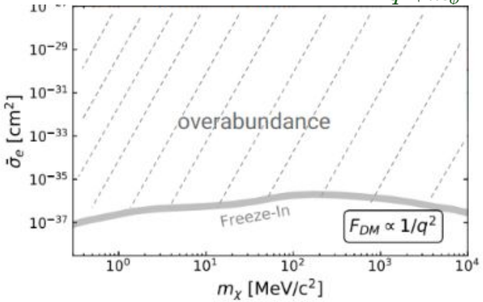
INCREASES DM abundance

*Fig. from P.Schuster

limit where: $m_\phi \gg q$ : $F_{DM} \propto \frac{1}{q^2+{m_\phi}^2} \approx \frac{1}{{m_\phi}^2}$

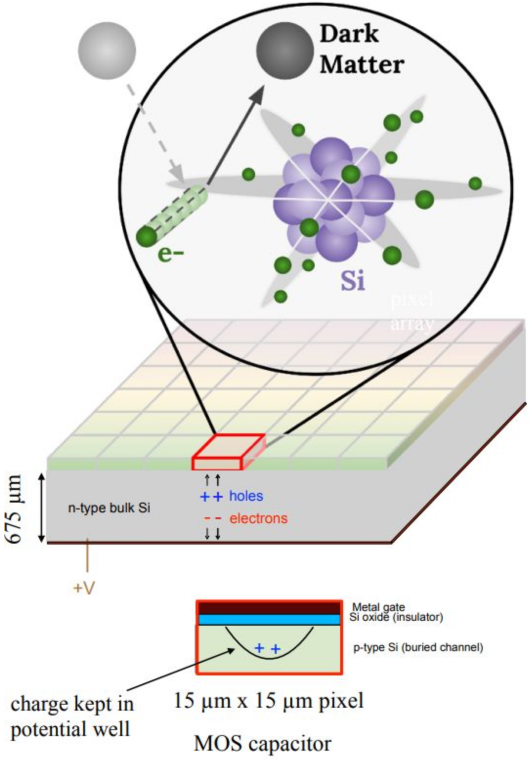



limit where: $m_\phi \ll q$ : $F_{DM} \propto \frac{1}{q^2+{m_\phi}^2} \approx \frac{1}{q^2}$

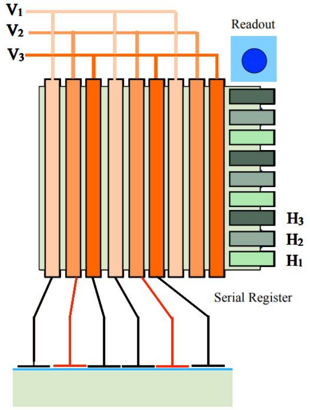


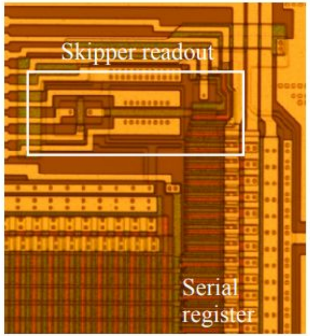
# CCDs as imaging ionization detectors

## Ionization charge is collected, imaged, and read out pixel by pixel

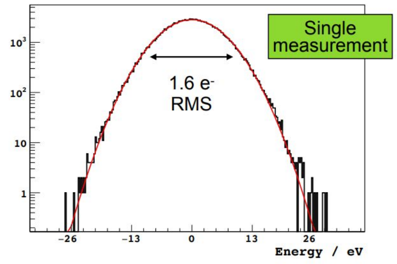



- Ionization charge drifts to the pixel array during exposure
- Lateral diffusion carries spatial/topological information
- Slow readout enables very low noise

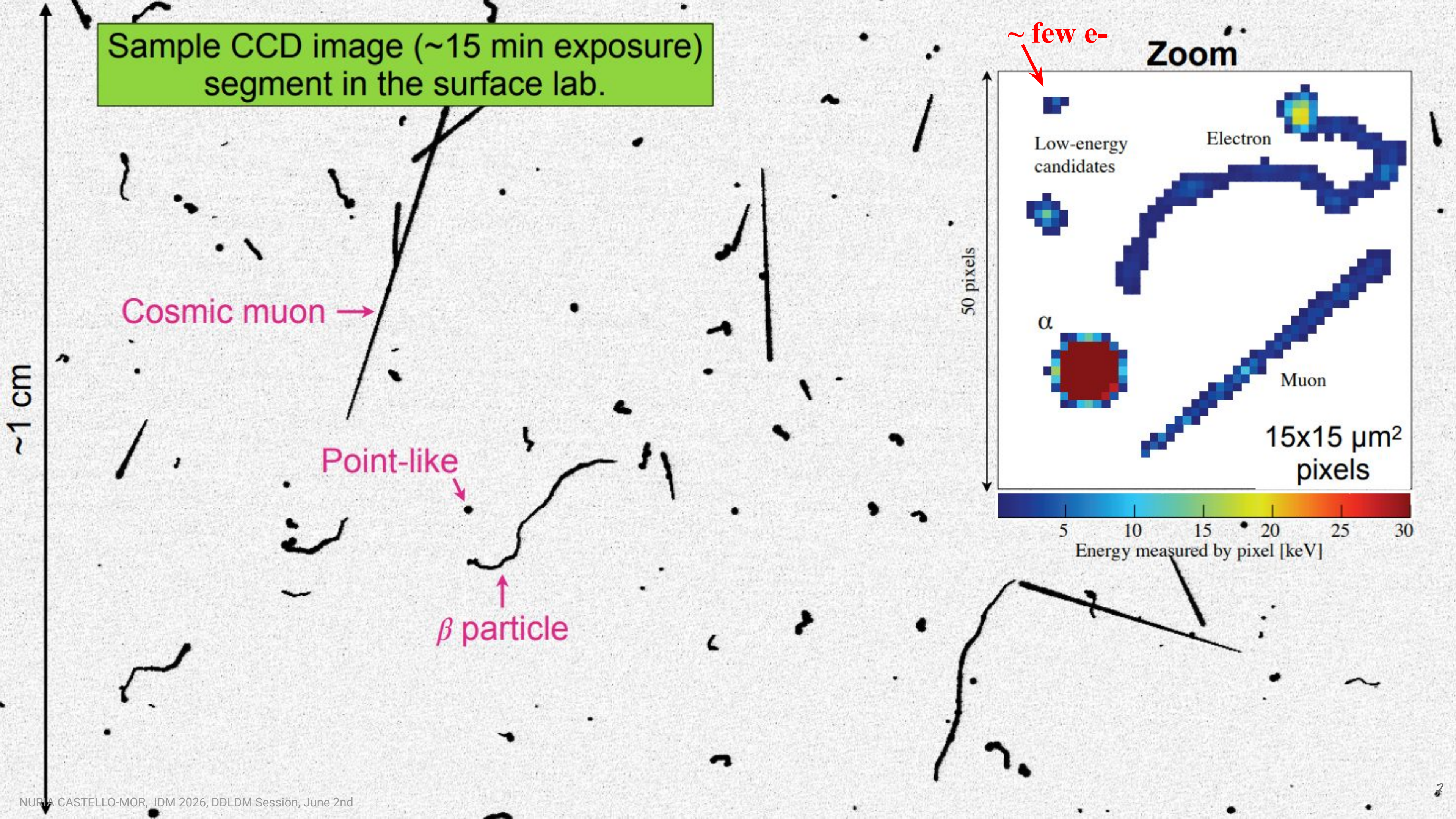



w/ conventional readout amplifiers: ~2e-

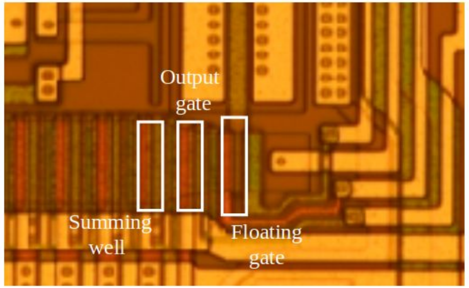


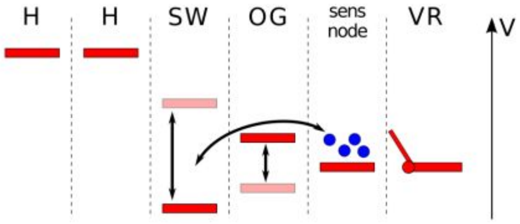
Sample CCD image (~15 min exposure) segment in the surface lab.



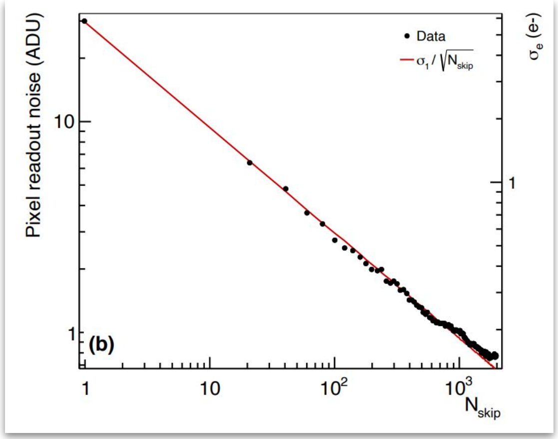
# Skipper CCDs: single-electron detectors

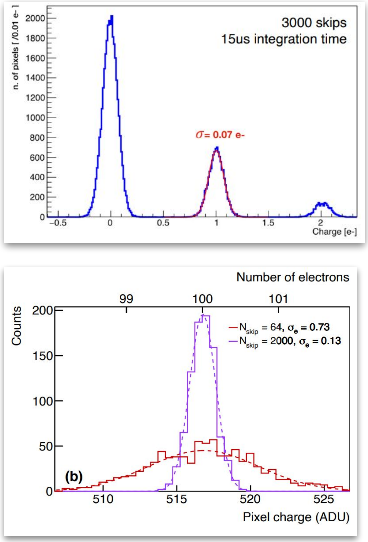
## Resolving individual electrons enables eV-scale dark matter searches




- Ionization charge drifts to the pixel array during exposure
- Lateral diffusion carries spatial/topological information
- Slow readout enables very low noise
- Skipper amplifiers: single-electron resolution by multiple NDCMs



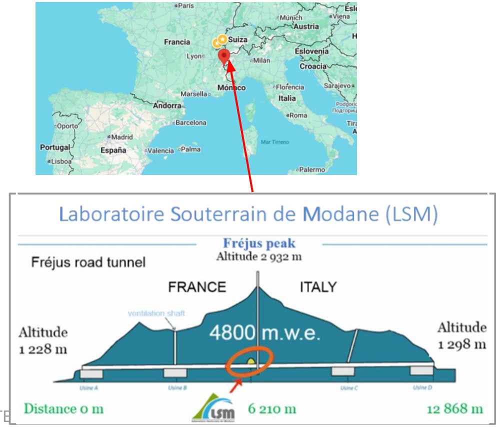

PRD 106, 092001 (2022)

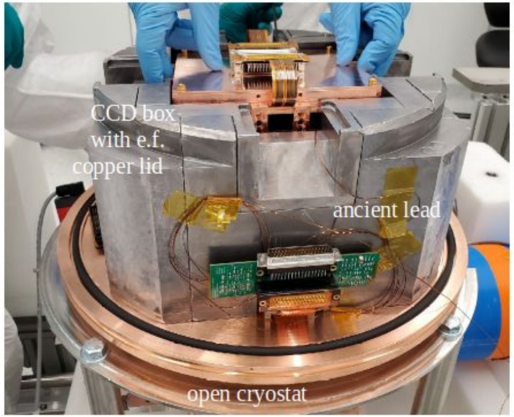
# The Low Background Chamber: DAMIC-M prototype at LSM

## A low-background skipper-CCD setup installed in the DAMIC-M cleanroom

The Low Background Chamber (LBC)

- DAMIC-M **prototype** operating **underground** at **LSM since 2022**
- Installed in the DAMIC-M cleanroom, at **4800 m.w.e. overburden**
- **Low-background** (~7 cts/kg/keV/day) test setup for CCD modules, electronics, shielding, and background studies
- Also a **physics detector for light-DM searches**:
  - 1st run (2022): May-July 2022, 85 g·day
  - 2nd run (2024): Oct. 2024–Jan. 2025: 1.3 kg·day



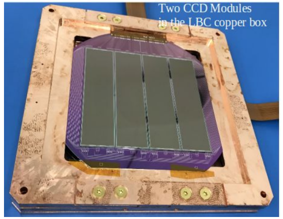



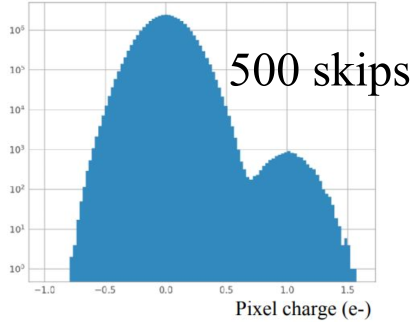

# LBC Science Run 2 dataset

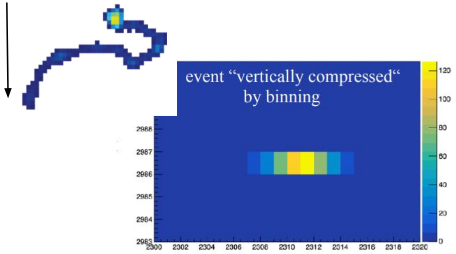
## One dataset, three complementary light-DM searches

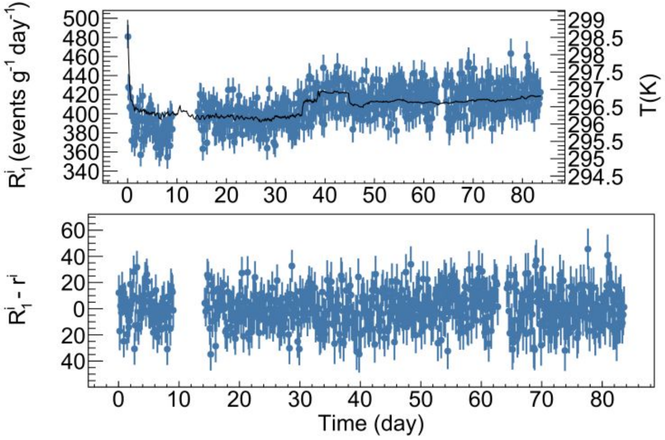
| | |
|---|---|
| Data-taking period | Oct. 2024 – Jan. 2025 |
| CCDs | 8 DAMIC-M skipper CCDs |
| Mass | 26.4 g |
| Exposure | 1.3 kg·day (after selections) |
| Pixel resolution | 0.16 $e^-$ |
| Dark current | 1.3 x $10^{-4}$ $e^-$/pixel/day |
| Readout | 100×1 vertical binning, ~28 min/image |
| Blind strategy | 7-day unblinded subset (~10%) |

**DAMIC-M CCD module**

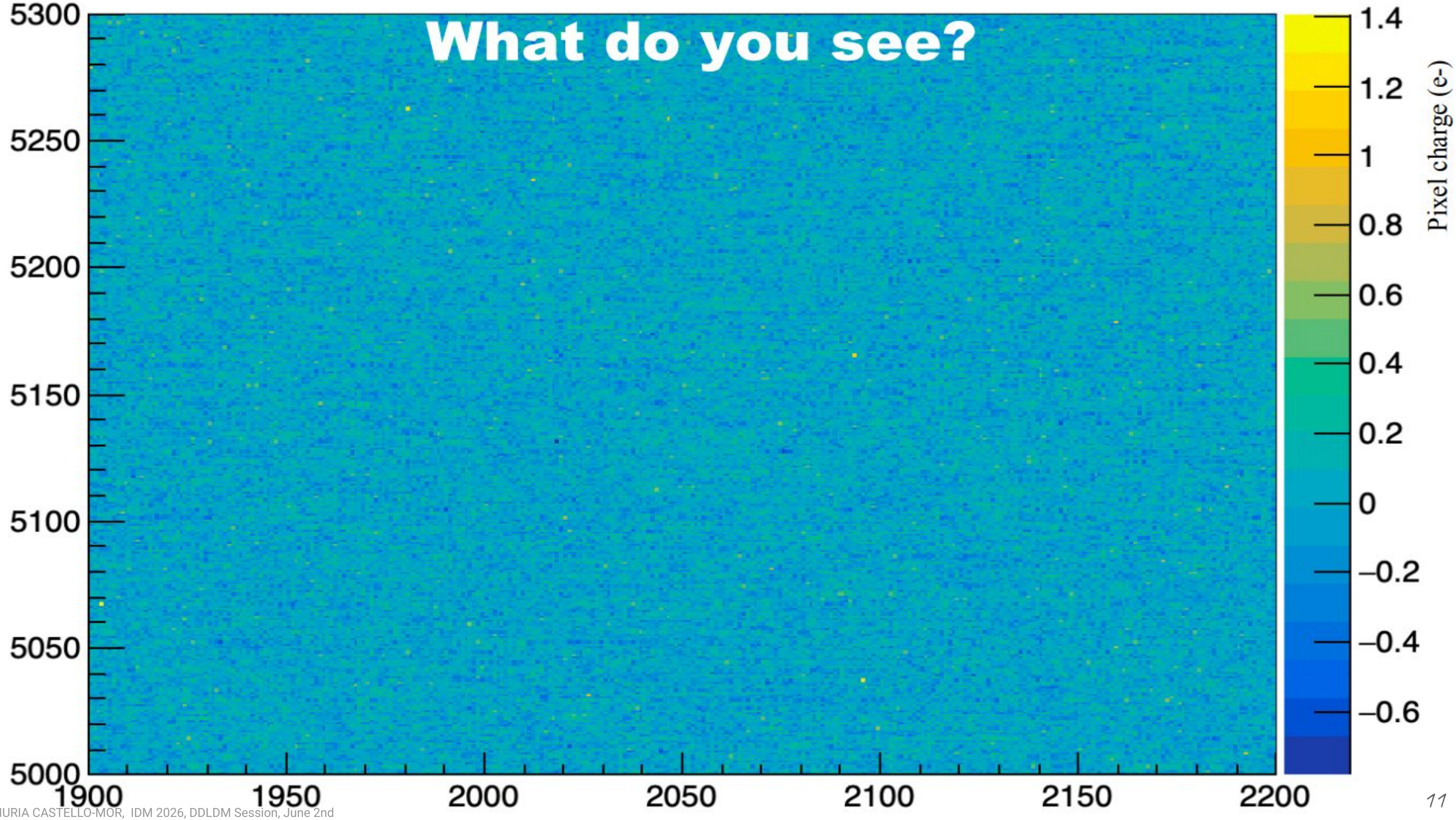


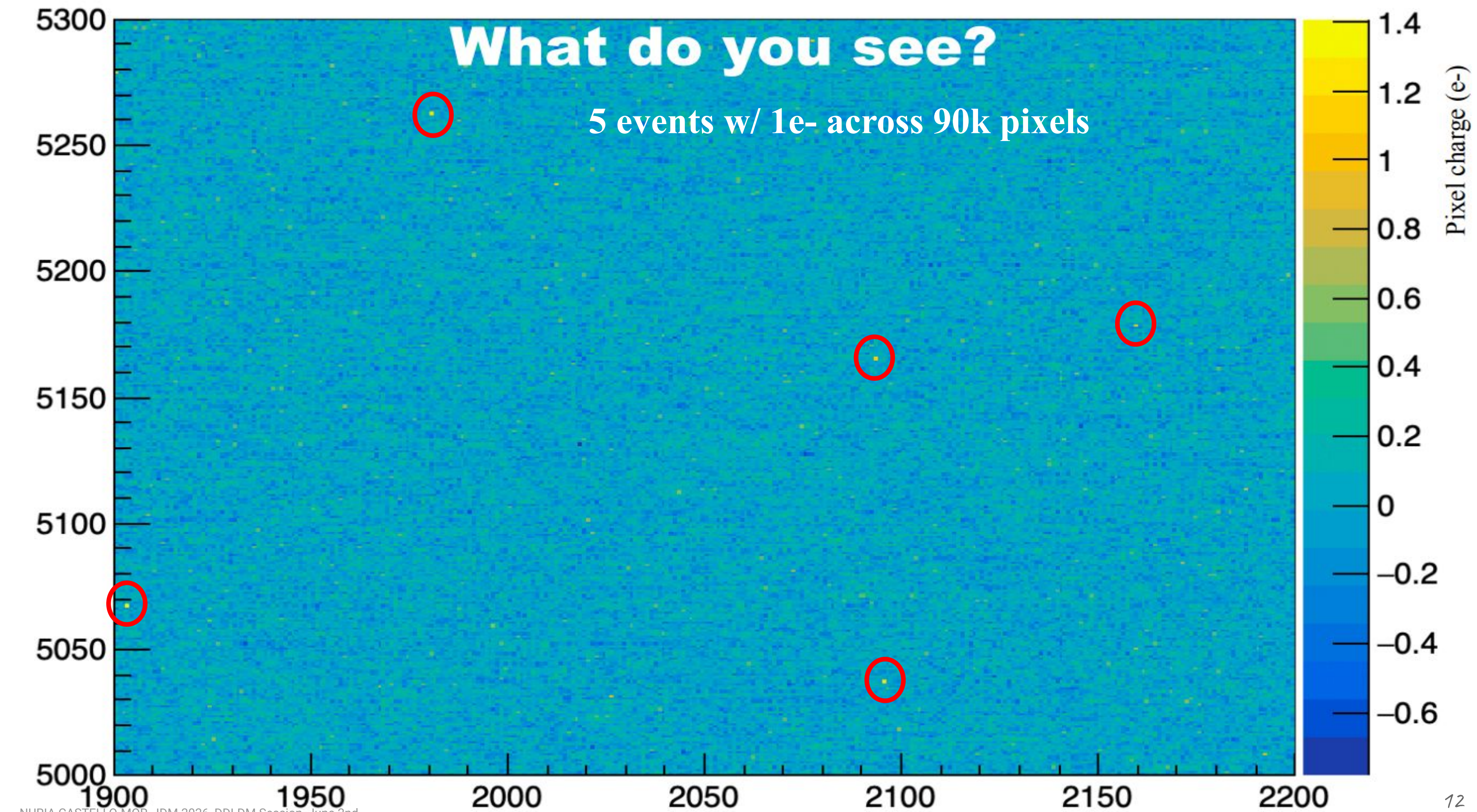




PRL 135, 071002 (2025)    arXiv:2511.13962 (2026, PRD accepted)    PRD submitted, 2026



What do you see?
5300
5250
5200
5150
5100
5050
5000
1900
1950
2000
2050
2100
2150
2200
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
Pixel charge (e-)


What do you see?
5 events w/ 1e- across 90k pixels
Pixel charge (e-)
5300
5250
5200
5150
5100
5050
5000
1900
1950
2000
2050
2100
2150
2200
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6

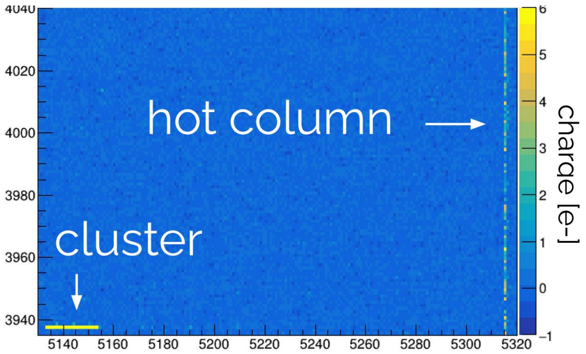
# Blind low-charge sample selection

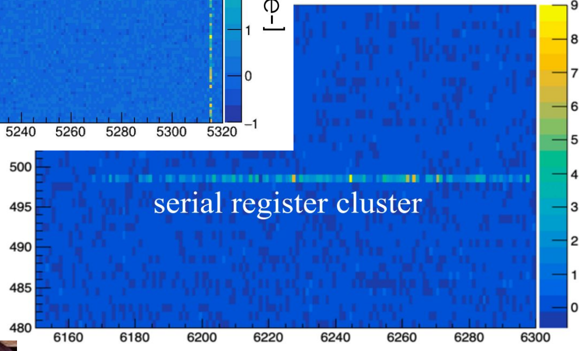
Instrumental artifacts are masked before defining DM candidates

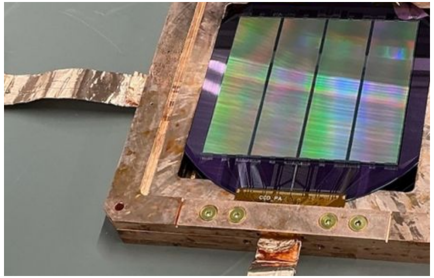
Selections defined on the 7-day unblinded subset

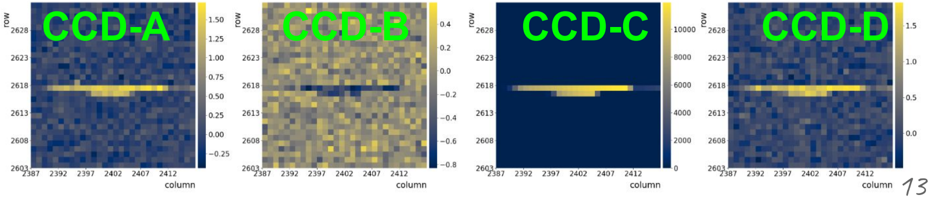
Masked/rejected events:

- **Hot columns and serial registers**
- **Cross-talk between synchronously read CCDs**
- Correlated-noise or large-RMS pixels
- Charge-transfer trails after high-charge pixels (CTI  and/or traps)
- Clusters outside the low-range ROI (Q>5e$^-$)





# Blind low-charge sample selection

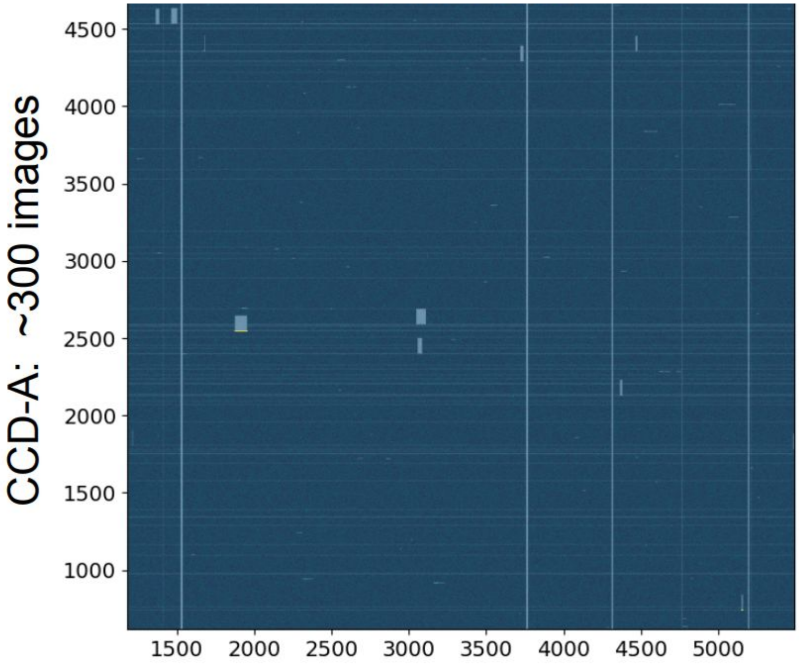
95% of the data are kept!

Instrumental artifacts are masked before defining DM candidates

Selections defined on the 7-day unblinded subset

Masked/rejected events:

- Hot columns and serial registers
- Cross-talk between synchronously read CCDs
- Correlated-noise or large-RMS pixels
- Charge-transfer trails after high-charge pixels (CTI and/or traps)
- Clusters outside the low-range ROI ($E<6e^{-}$)



# Defining DM candidates: from spectrum to topology

**Charge patterns provide a robust benchmark signal region**

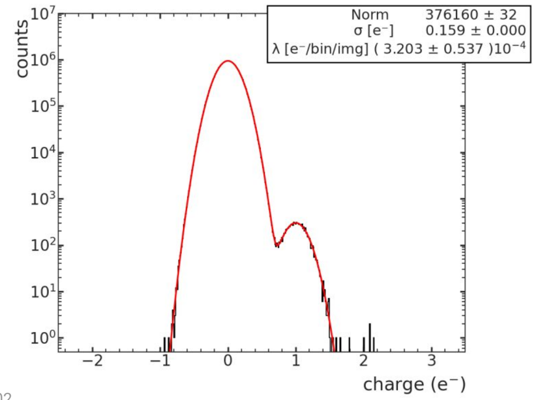
**Key idea:** isolated pixels occupancies are used to predict random coincidences, not used as the benchmark signal region

## Spectrum-only search

Counts **isolated** 1e, 2e, 3e, … **pixels**

**Isolated** multi-e pixels **show** an **excess** over **Poisson expectation**

This population is **correlated** with **CCD operation conditions**




## Pattern search

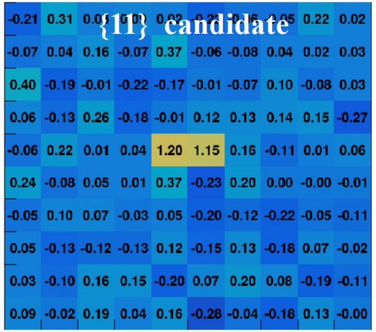
Searches **neighboring charged pixels**

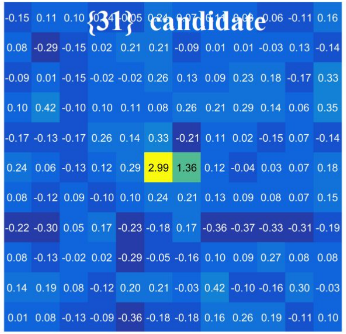
**Diffusion** can **spread** real **bulk ionization** across adjacent pixels

**Accidental patterns** are **predicted** from measured **isolated**-pixel **occupancies**

E<6e⁻: {11}, {21}, {111}, {22}, {31}, {211}

*Each digit is the charge, in e⁻, assigned to one pixel.



# Expected backgrounds in the pattern channels

Random coincidences plus a radiogenic component

### Random coincidences

**Data-driven** estimate

**Built** from **measured** isolated **1e, 2e, 3e occupancies**

Includes **finite** charge **resolution** and pattern **mis-identification**

**Dominant** for **low-charge** pattern channels

$$B^{\mathrm{rc}}_{p,i} = \sum_{c} \sum_{q \in \mathcal{Q}_p} N^{i}_{q,c} \, P^{(c)}_{q,i} \, \epsilon_{q \to p},$$

### Radiogenic / external background

**Physical ionization** clusters from **γ-backgrounds**

Normalized with a high-energy **control region** (2-20 keV)

**Extrapolated to** the **low-charge** using γ-background **simulations**

**Constrained** by the control-region data in the **likelihood**

$$B^{\mathrm{rad}}_{p,i} = R_{\mathrm{ctrl}} \, \tau \, \mathcal{E}^{i}_{\mathrm{D2}} \, \epsilon_{\mathrm{eh}} \sum_{n_e=2}^{5} \epsilon_{n_e \to p}$$

**Each pattern channel has its own expected background:**

$$B_{p,i}(\theta_{\mathrm{rad}}) = B^{\mathrm{rc}}_{p,i} + \Theta_{\mathrm{rad}} B^{\mathrm{rad}}_{p,i} \, ,$$

# Observed pattern counts

The benchmark signal region is consistent with background

{11}: dominated by random coincidences
{31}: one observed event

| | found {11} | {21} | {111} | found {31} | {22} | {211} |
|---|---|---|---|---|---|---|
| $D_p$ | **144** | 0 | 0 | **1** | 0 | 0 |
| $B_p^{\mathrm{rc}}$ | 141.4 | 0.111 | 0.042 | 0.019 | $2.5 \cdot 10^{-5}$ | $5.8 \cdot 10^{-5}$ |
| $B_p^{\mathrm{rad}}$ | 0.039 | 0.039 | 0.016 | 0.052 | 0.011 | 0.035 |
| | 141.44 expected | | | 0.071 expected | | |

The overall result is consistent with the background expectation, so we set upper limits on the DM-electron scattering cross section

$\bar{\sigma}_e$ → $\mu$; nuisance → $\theta$

$$\mathcal{L}(\mu, \theta) = \prod_p \frac{(S_p(\mu)+B_p^{rc}+\theta B_p^{rad})^{D_p} e^{-(S_p(\mu)+B_p^{rc}+\theta B_p^{rad})}}{D_p!} \prod_p \frac{(\theta \tau_p B_p^{rad})^{N_{rad}} e^{-(\theta \tau_p B_p^{rad})}}{N_{rad}!}$$

$N_{rad}!$ ← "control sample"

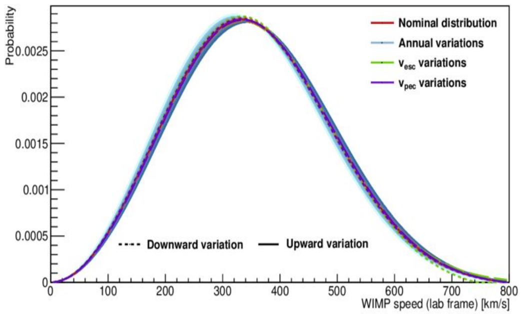
# Signal hypotheses: the velocity distribution / flux

$$\frac{dR}{dE_e}(t) \propto \int dq \, \frac{|F_{\rm DM}(q)|^2 \, |f_c(q,E_e)|^2}{q^2} \int_{v>v_{\min}(q,E_e)} d^3v \, \frac{f(\mathbf{v},t)}{v}$$

modified depending on the signal hypothesis

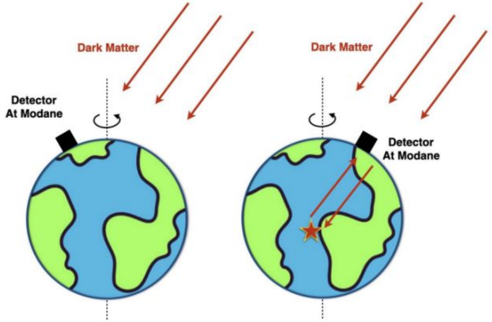
PRL 135, 071002 (2025)

**SHM Benchmark**
*Direct Galactic halo flux at Earth*



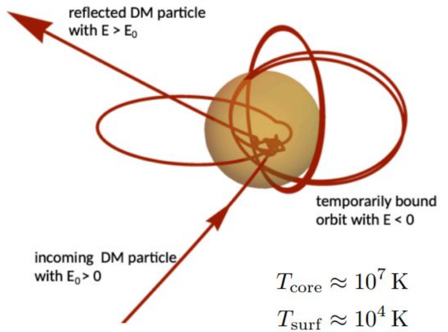

arXiv:2511.13962 (2026, PRD accepted)

**Diurnal Modulation**
*Earth-attenuated halo flux*




PRD submitted, 2026

**Solar-Reflected DM**
*Boosted flux from solar scattering*



# Signal hypotheses: the velocity distribution / flux

$$\frac{dR}{dE_e}(t) \propto \int dq \, \frac{|F_{\rm DM}(q)|^2 \, |f_c(q,E_e)|^2}{q^2} \int_{v>v_{\min}(q,E_e)} d^3v \, \frac{f(\mathbf{v},t)}{v}$$

modified depending on the signal hypothesis

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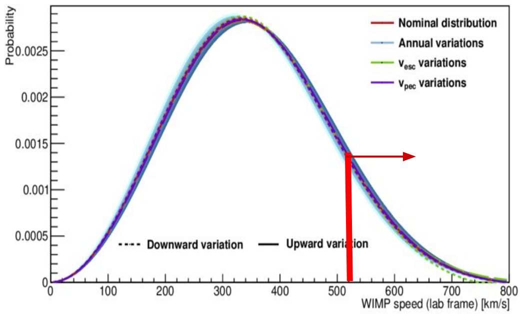


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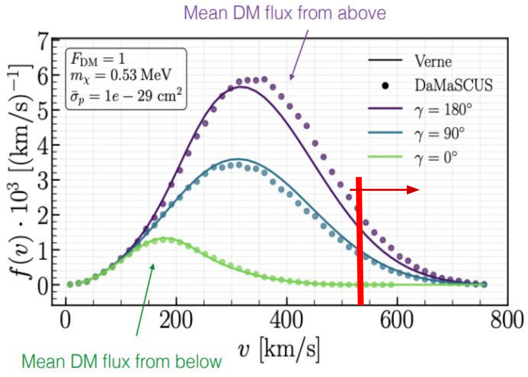


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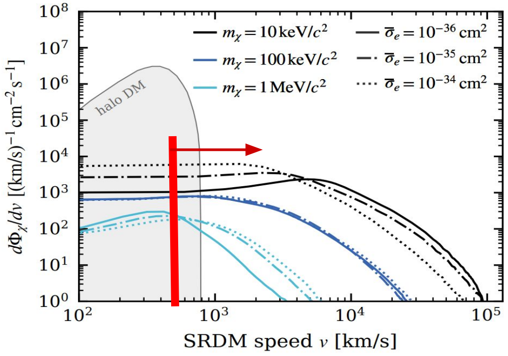
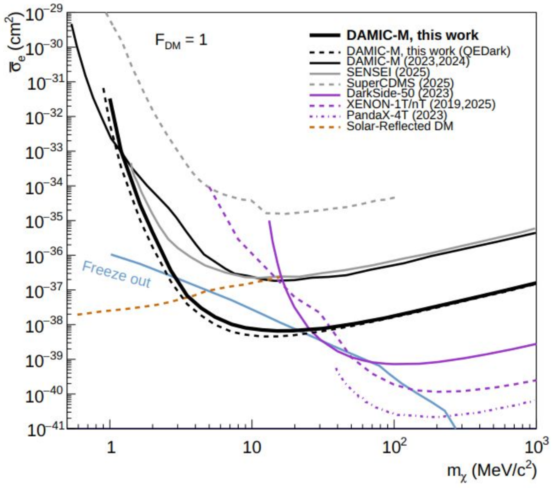


# Heavy-mediator benchmark constraints

Complementary flux hypotheses extend the LBC reach: SRDM pushes below the SHM kinematic threshold, while diurnal modulation probes Earth-attenuated halo DM.

**SHM Benchmark**
*Direct Galactic halo flux at Earth*

PRL 135, 071002 (2025)




**Diurnal Modulation**
*Earth-attenuated halo flux*

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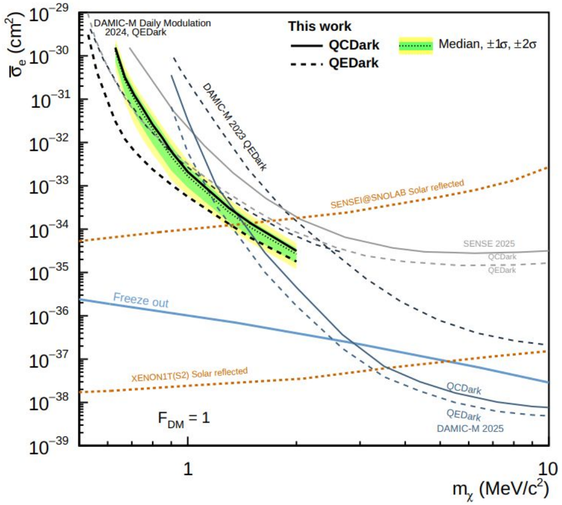


**Solar-Reflected DM**
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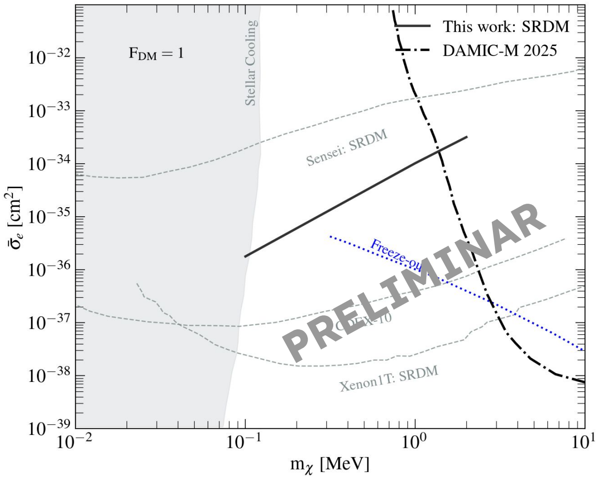
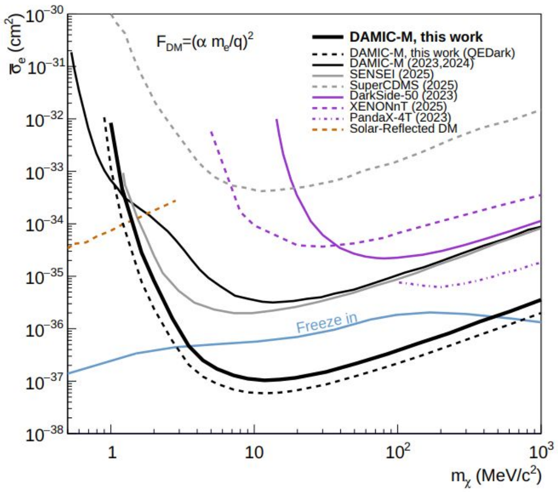


# Ultralight-mediator benchmark constraints

## Prototype LBC data reach the freeze-in target

**SHM Benchmark**
*Direct Galactic halo flux at Earth*

PRL 135, 071002 (2025)

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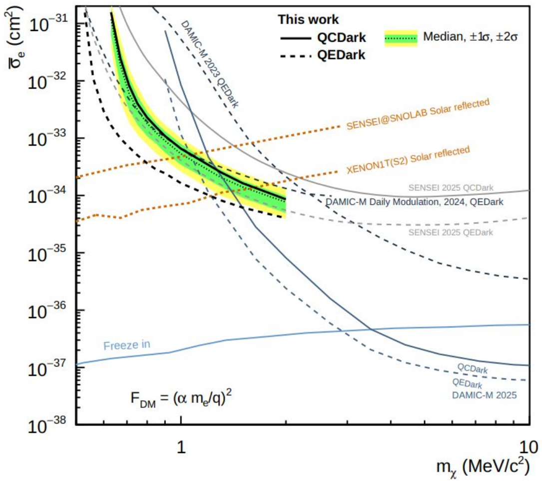
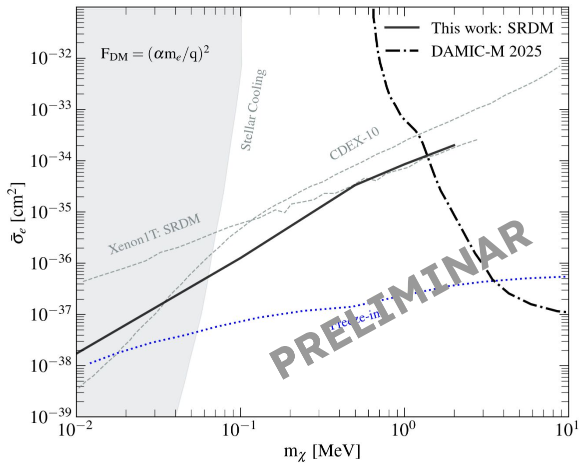



**Solar-Reflected DM**
*Boosted flux from solar scattering*

PRD submitted, 2026




Reaching hidden-sector freeze-in targets for first time!

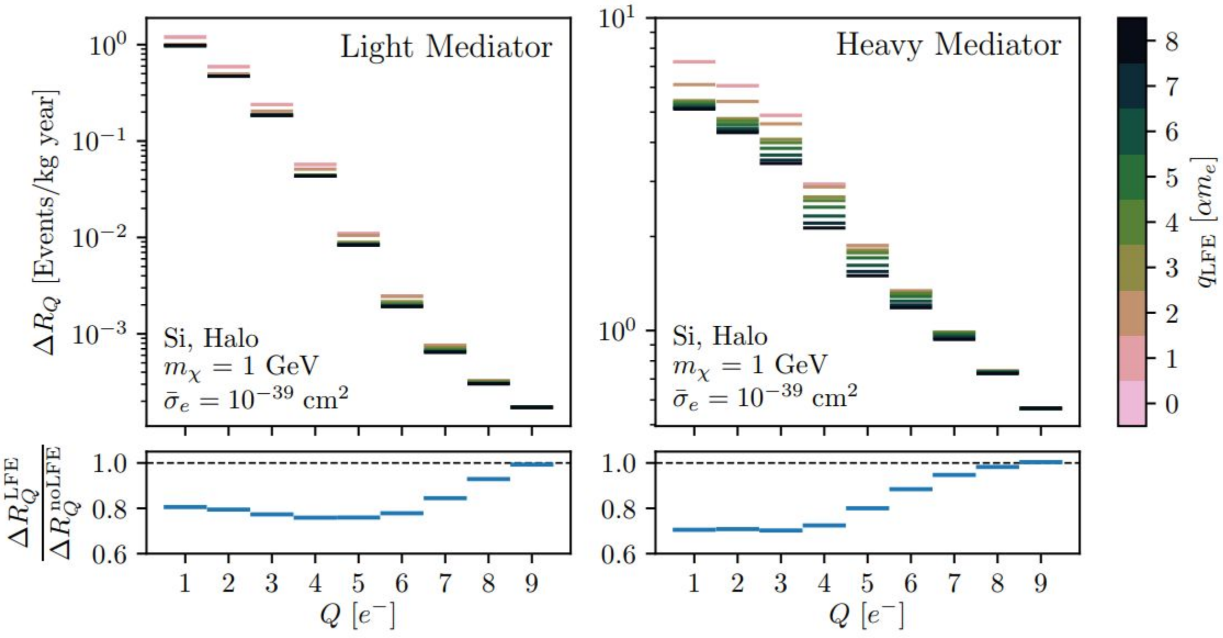
# Summary

**LBC is the physics demonstrator for DAMIC-M**

- DAMIC-M skipper-CCD modules operated underground with **single-electron sensitivity** and low dark current
- Pattern data are consistent with background, enabling competitive hidden-sector DM-e constraints.
- The prototype already probes hidden-sector benchmark parameter space, including freeze-in targets for an ultralight mediator
- This talk focuses on DM-e scattering, but **DAMIC-M** is also **sensitive** to **light WIMPs**, through the Migdal effect or hidden-photon absorption

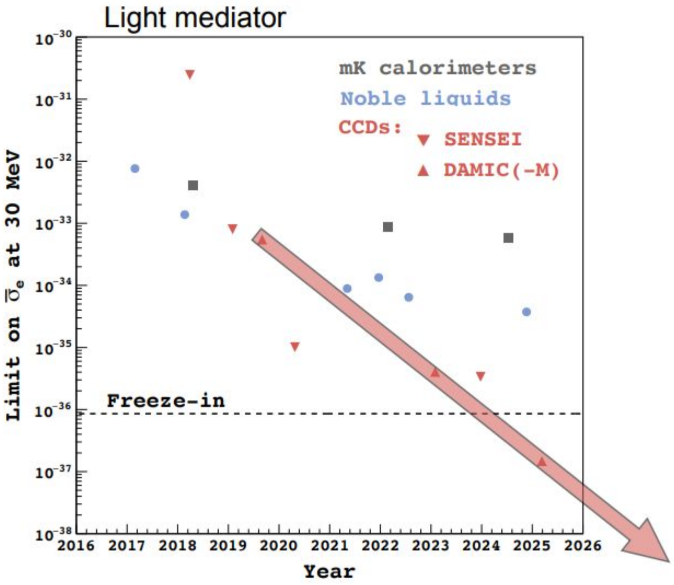
DAMIC-M will scale this demonstrated low-threshold program to a larger exposure (see Rocio Vilar's talk@17:50)

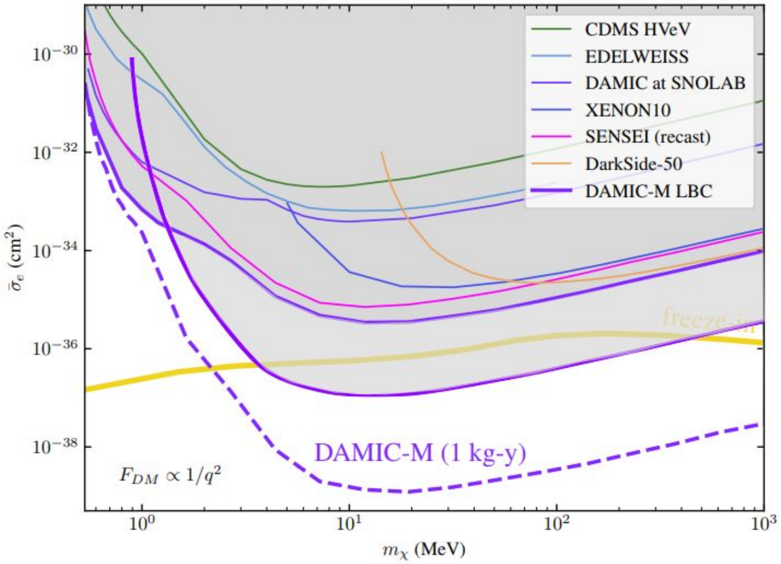
# Electron recoil spectra in Si [QCDark2]




https://arxiv.org/pdf/2603.12326

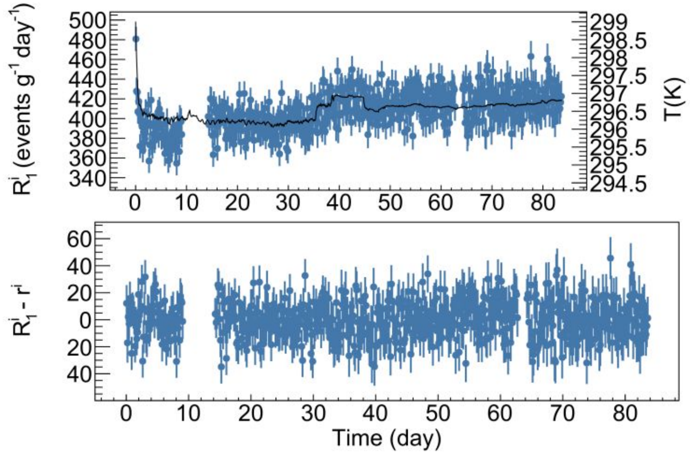
# The future with DAMIC-M

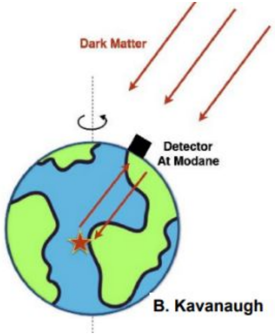


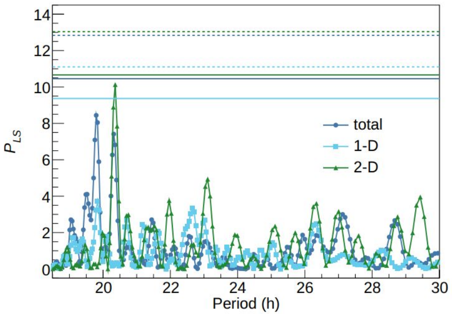



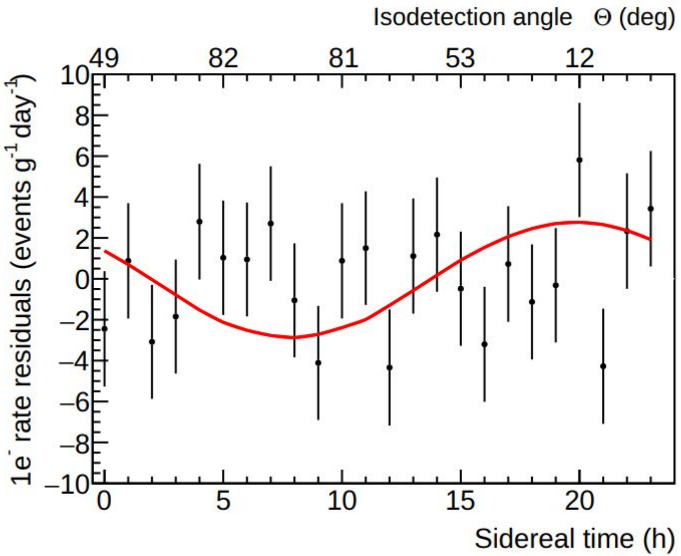

**Thanks for your attention!**

# Daily Modulation (SR2)

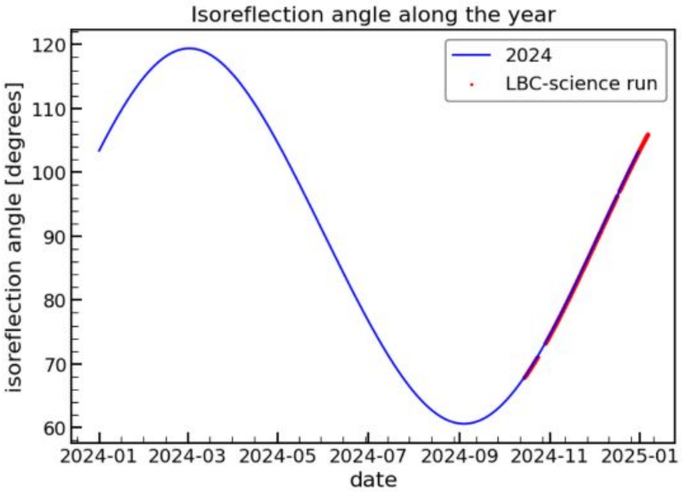


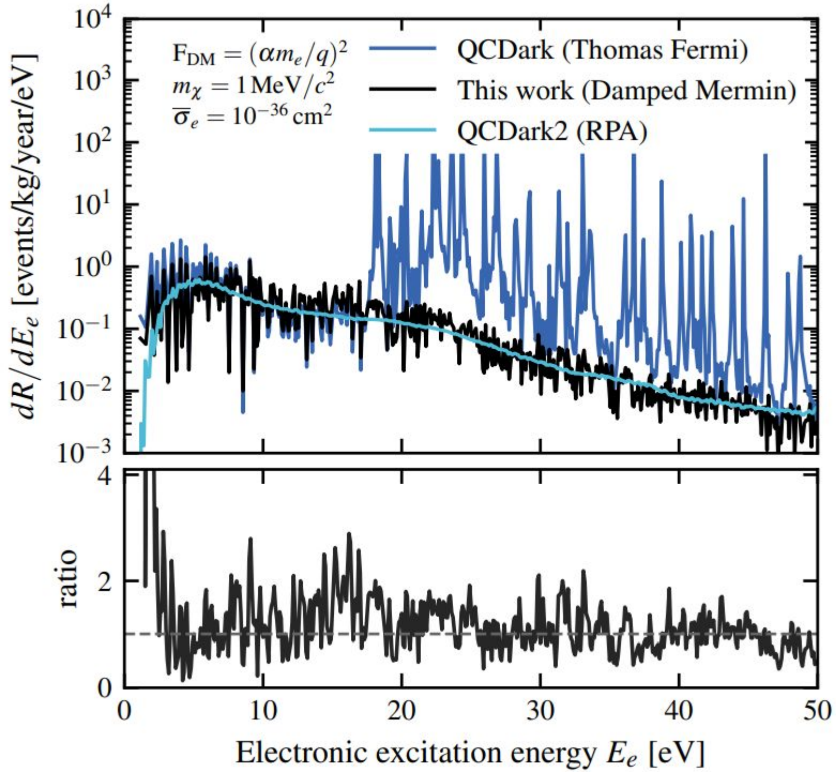



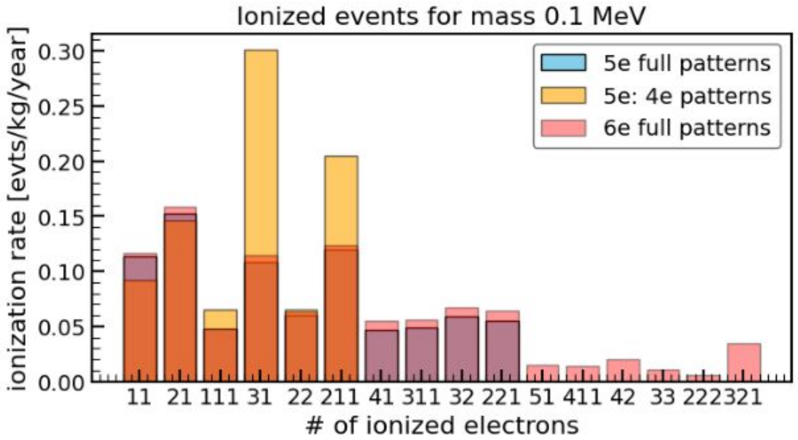



# Solar-reflected DM (SR2)

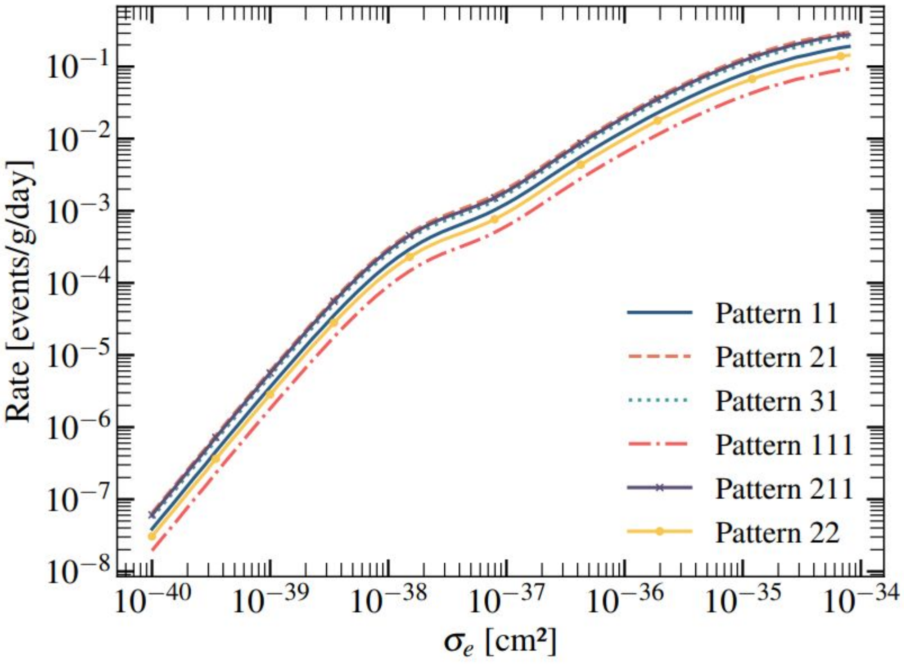


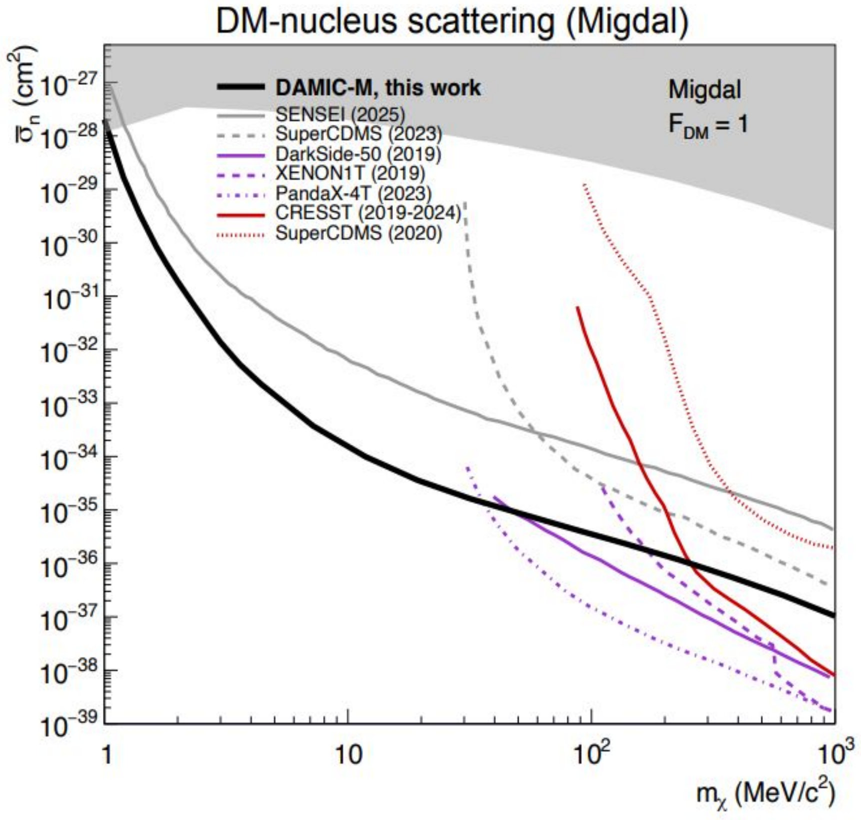
# Solar-reflected DM (SR2)

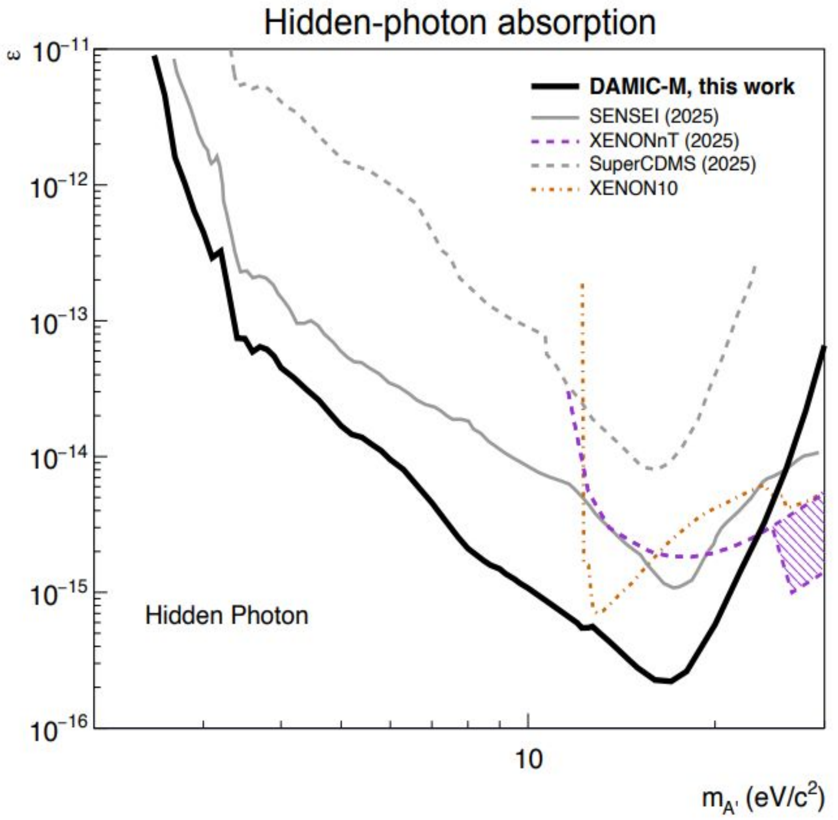



$$S_{p,i}(m_\chi, \bar{\sigma}_e) = \mathcal{E}^i_{\mathrm{D2}} \sum_{n_{eh}} \mathcal{P}(p|n_{eh}) \times \int dE_e \left.\frac{dR}{dE_e}\right|_{\theta_{\mathrm{iso}}=\theta^{\mathrm{ref}}_{\mathrm{iso}}} \mathcal{P}(n_{eh}|E_e),$$



# Other exclusion limits



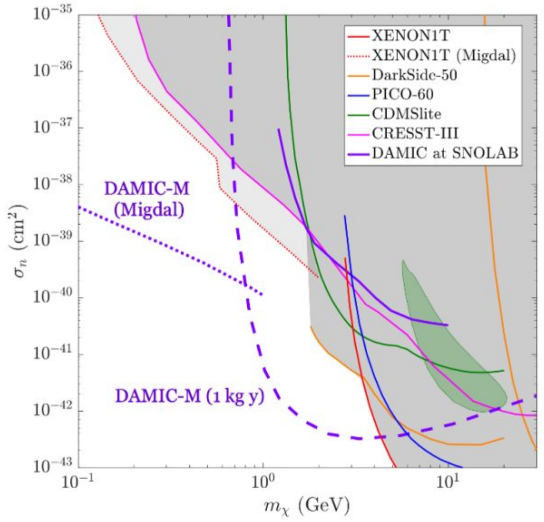



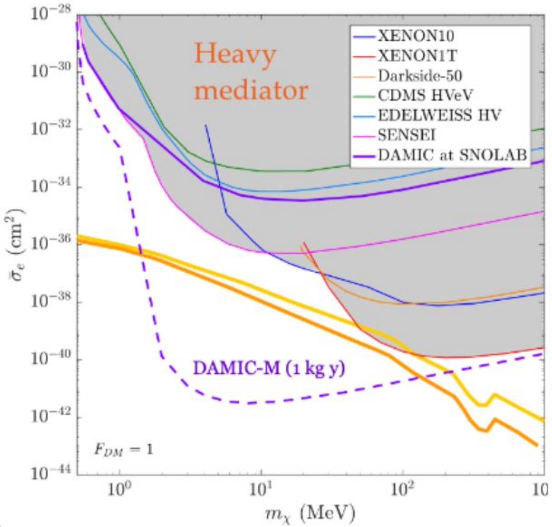

**More world-leading DM exclusion limits from DAMIC-M!**

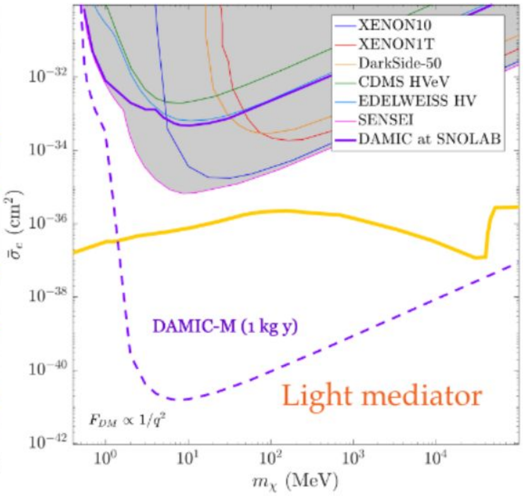
**DAMIC-M is using novel skipper CCDs** to push energy threshold limits and search for light dark matter into new, unexplored regions… **even with 10s gram-scale prototype detectors!**

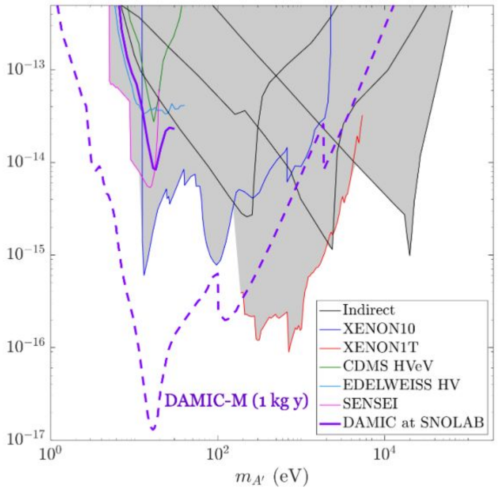
**Coming soon, online by end 2025 !** We are currently in the construction phase on-site at LSM, receiving CCDs underground, and procuring the ultra-low background materials needed for the detector infrastructure.

Be on the look-out for the dark matter models we can **explore with 1kg-year!**



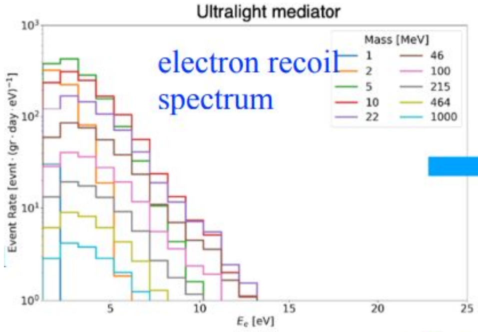



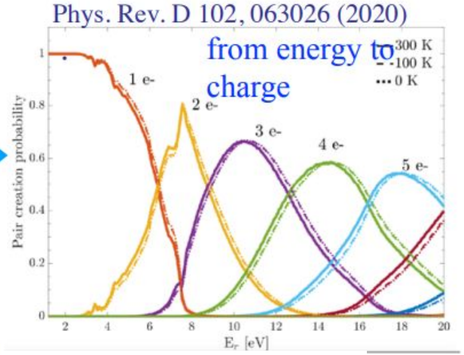
# Signal Model and Limit setting

**theory input**

DM-e cross section, DM galactic halo, DM form factor, crystal

$$\frac{dR}{dE_e} \propto \bar{\sigma}_e \int \frac{dq}{q^2}\left[\int \frac{f(\mathbf{v})}{\mathrm{v}} d^3\mathrm{v}\right] |F_{\mathrm{DM}}(q)|^2 \, |F_c(q, E_e)|^2$$



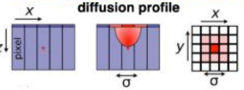

**N. of patterns p**

**number of DM interactions resulting in $q_e$ ionization charges**

$$S_p = \sum_{q_e} N_{q_e}(\bar{\sigma}_e, m_\chi) P_{q_e \to p}$$

**Probability that $q_e$ charges result in a pattern p**

from MC simulation, including charge diffusion and pattern selection




$\bar{\sigma}_e$ — nuisance

$$\mathcal{L}(\mu, \theta) = \prod_p \frac{(S_p(\mu) + B_p^{rc} + \theta B_p^{rad})^{D_p} e^{-(S_p(\mu) + B_p^{rc} + \theta B_p^{rad})}}{D_p!} \prod_p \frac{(\theta \tau_p B_p^{rad})^{N_{rad}} e^{-(\theta \tau_p B_p^{rad})}}{N_{rad}!}$$

$N_{rad}$ ← "control sample"

The background-only null hypothesis has **$p_0$ = 0.24 (0.10)**, so **we place limits using the profile likelihood ratio test statistics**