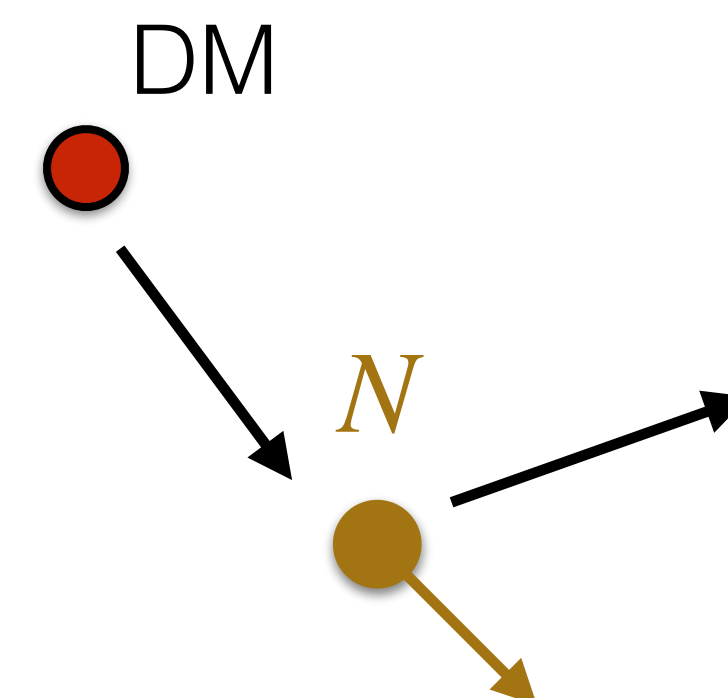
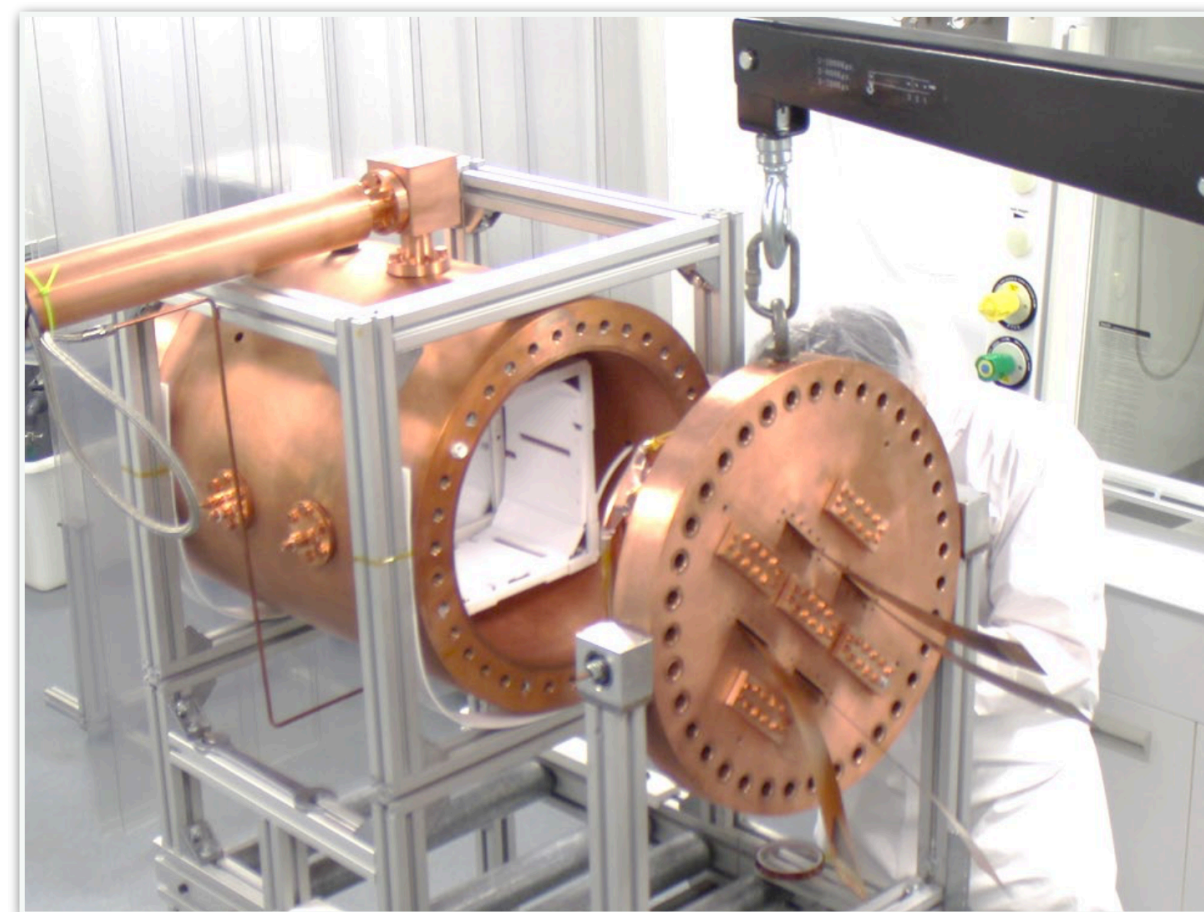
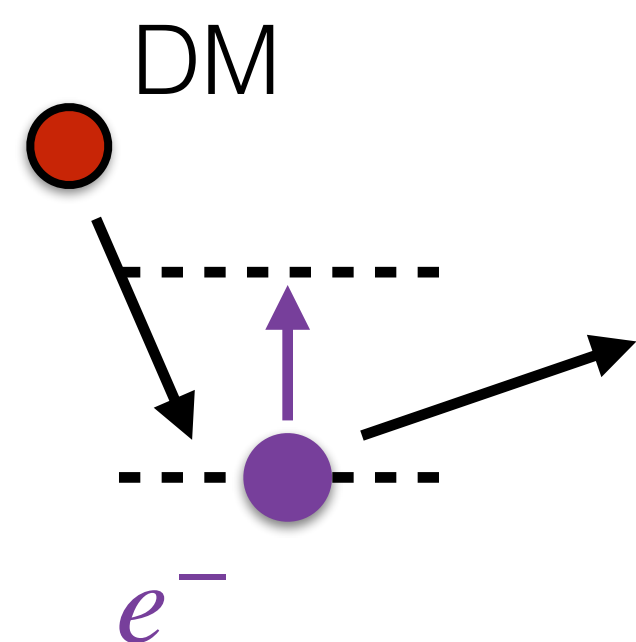




Weakly Interacting Massive Particles (WIMPs) & Light Dark Matter Searches

Bradley J Kavanagh
Instituto de Física de Cantabria (IFCA)

 kavanagh@ifca.unican.es

26 November 2025
Plan Complementario ASTRO+HEP

Direct Detection of Dark Matter (DM)



Direct Detection of Dark Matter (DM)

$$\text{Rate} \sim \rho_{\text{DM}} \times v_{\text{DM}} \times \sigma \times N_{\text{target}}$$

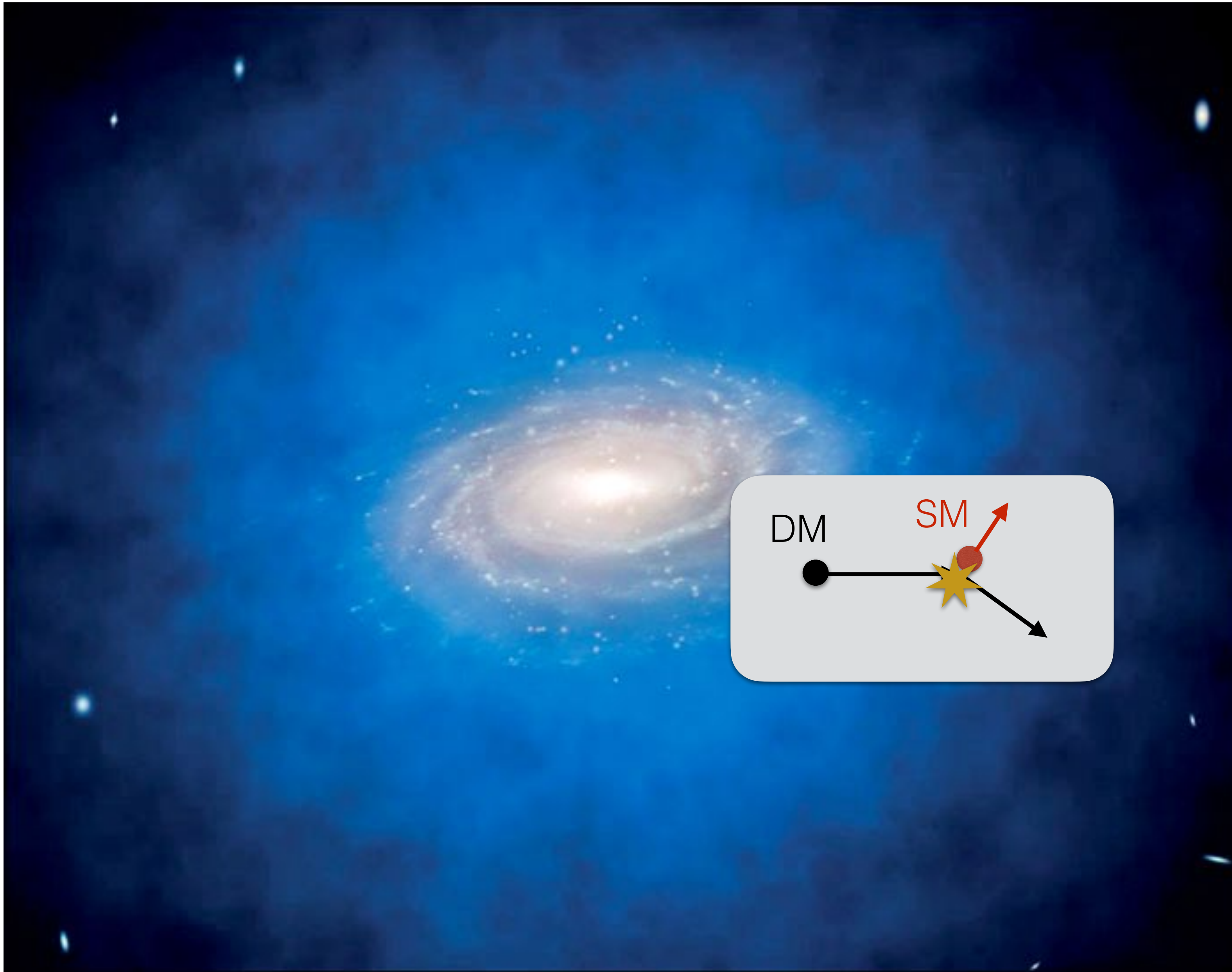
$$\rho_{\text{DM}} \sim 0.3 \text{ GeV}/\text{cm}^3$$

$$\begin{aligned} \langle v_{\text{DM}} \rangle &\sim 300 \text{ km/s} \\ &\sim 10^{-3} c \end{aligned}$$

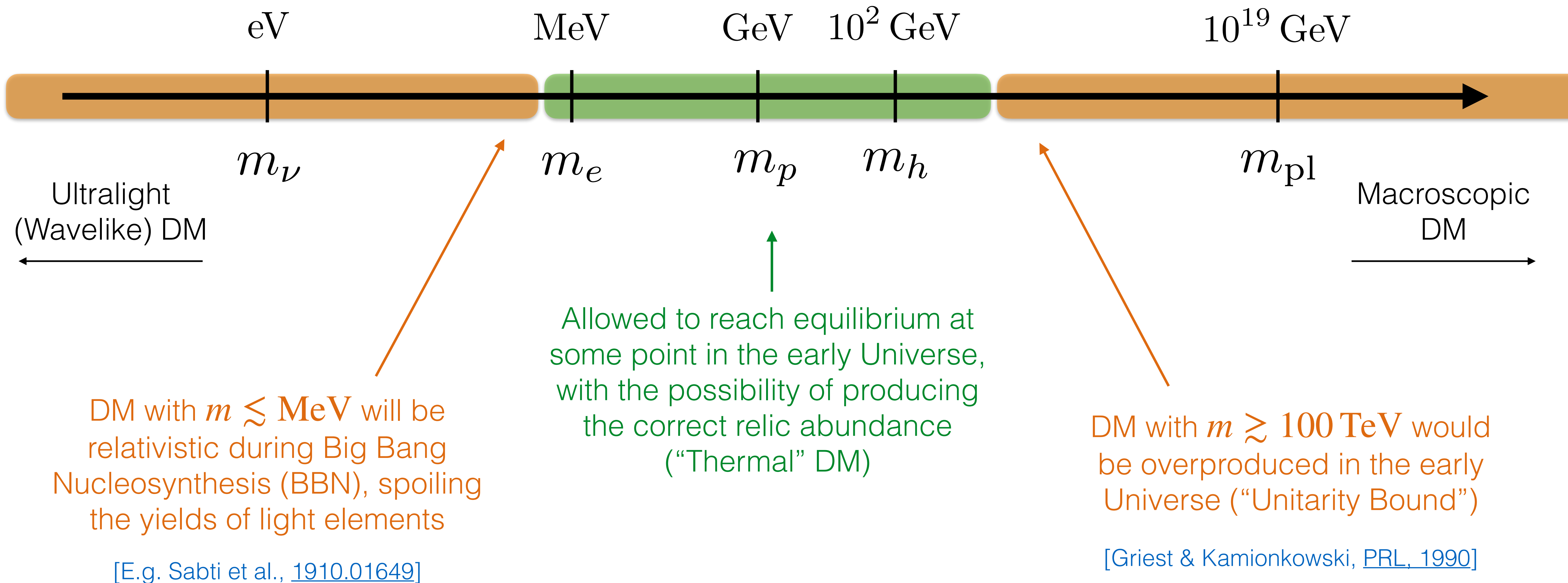
Aim to constrain (detect?) DM
scattering cross section σ

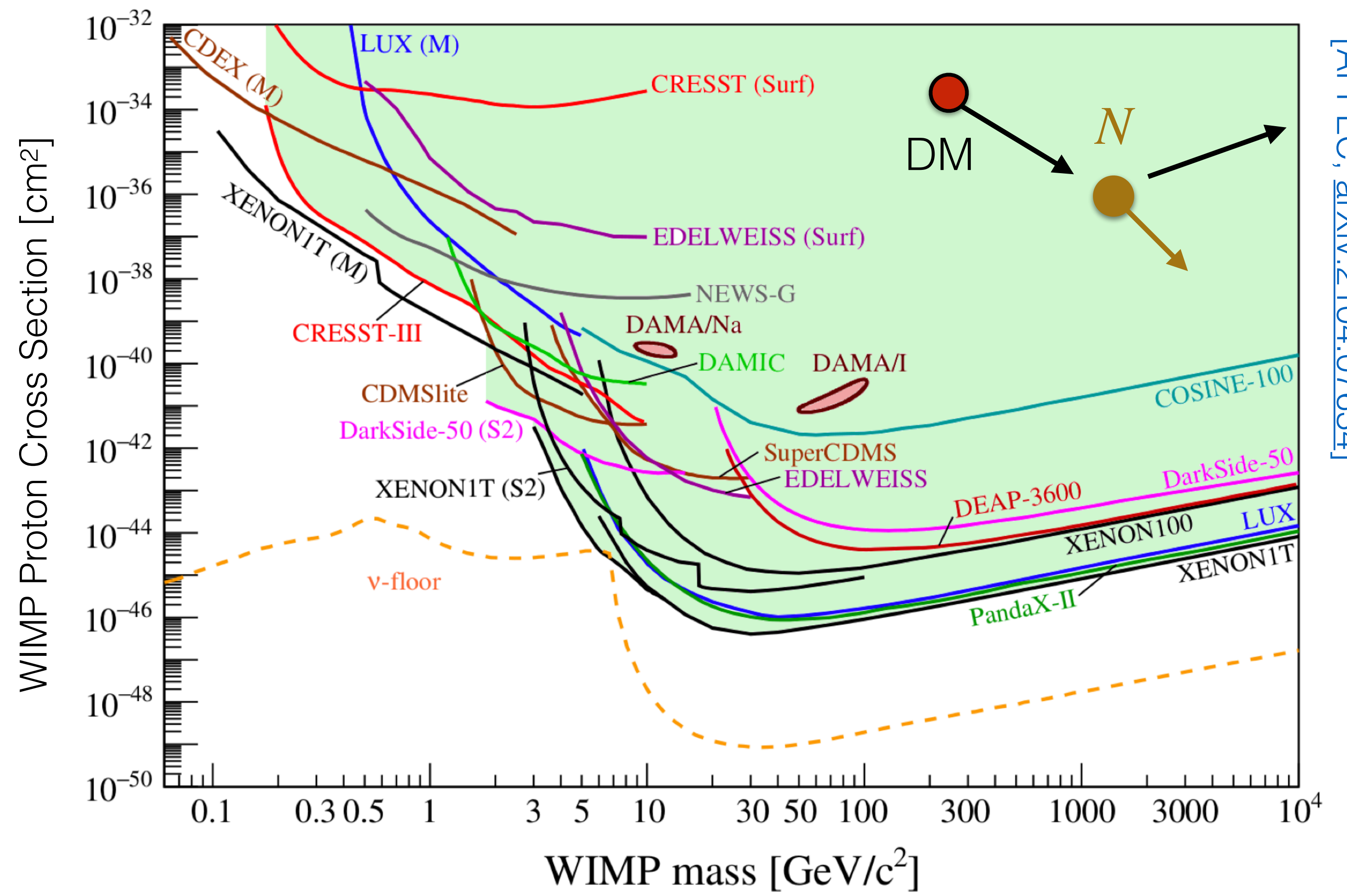
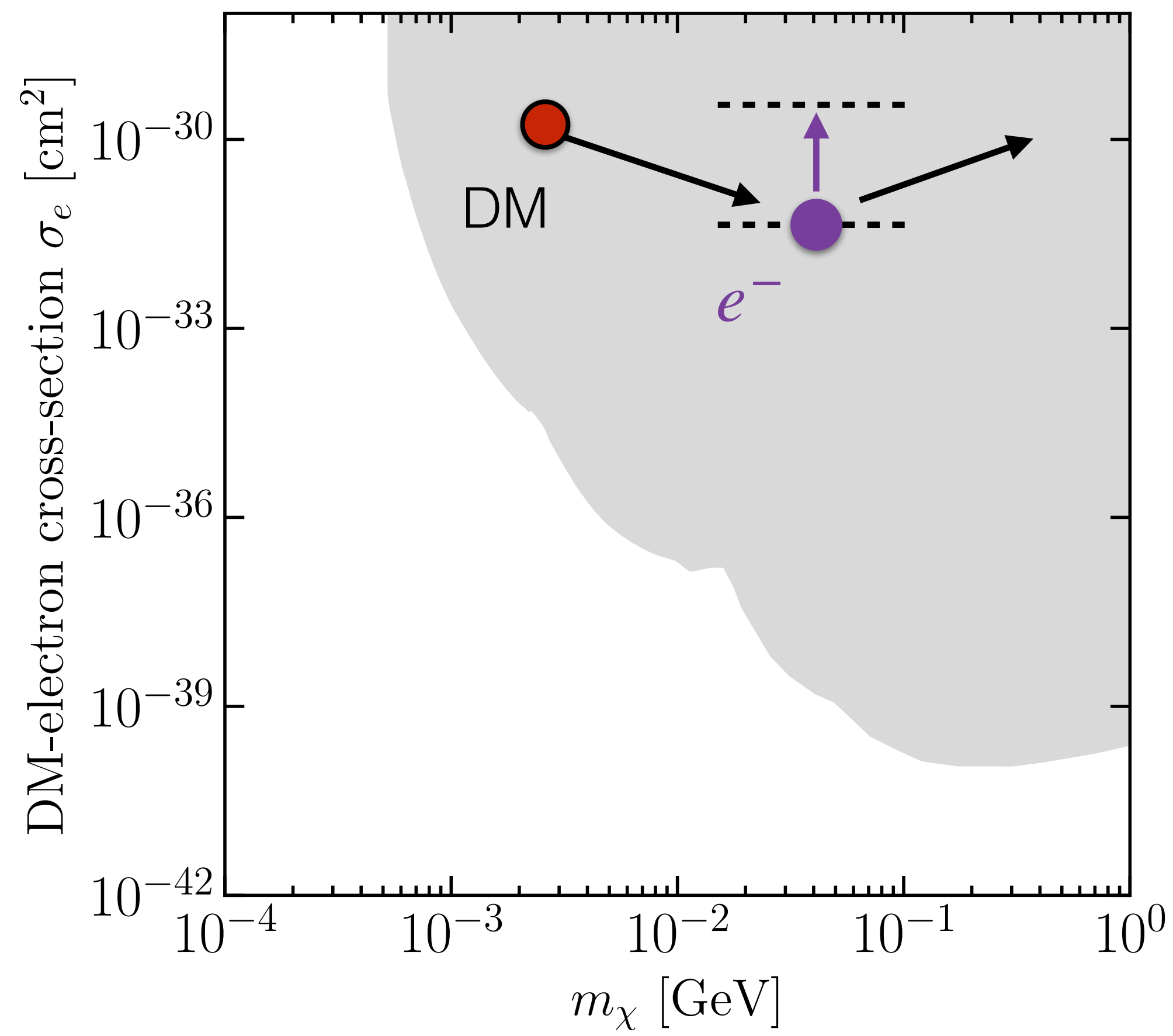
Key detector requirements:

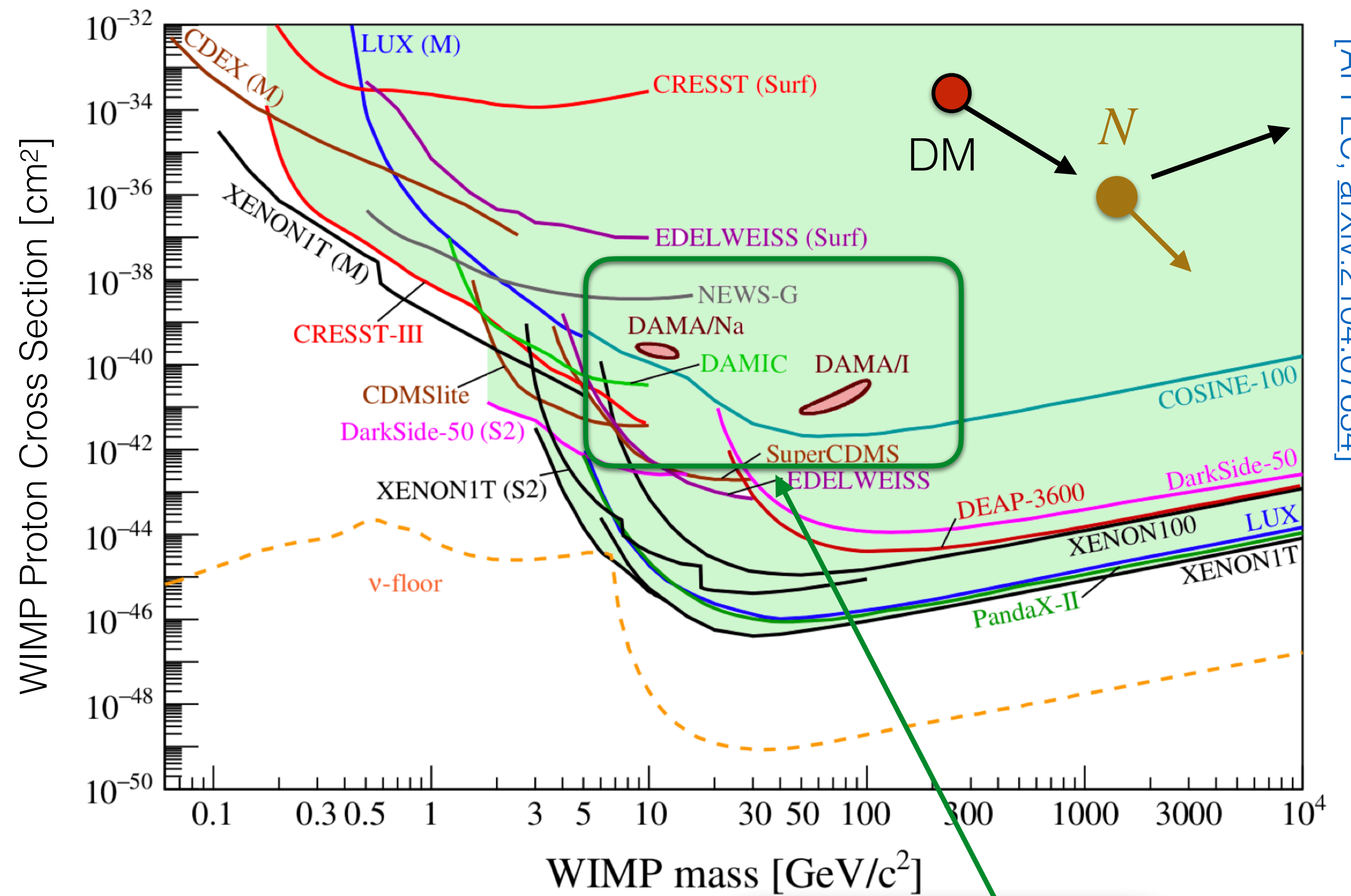
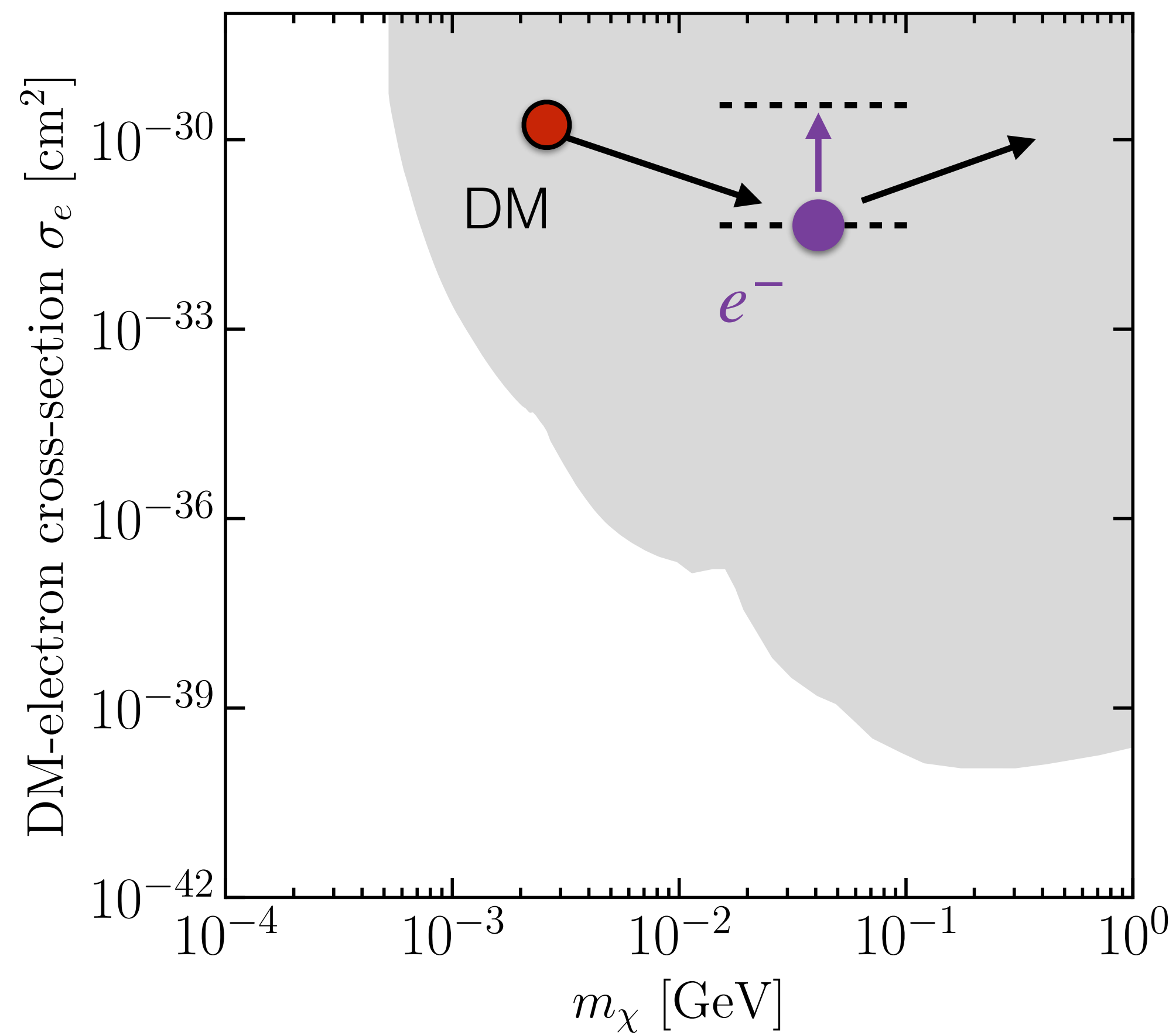
- Low energy threshold
- Low backgrounds
- Large target mass ($N_{\text{target}} \uparrow$)



Particle-like Dark Matter

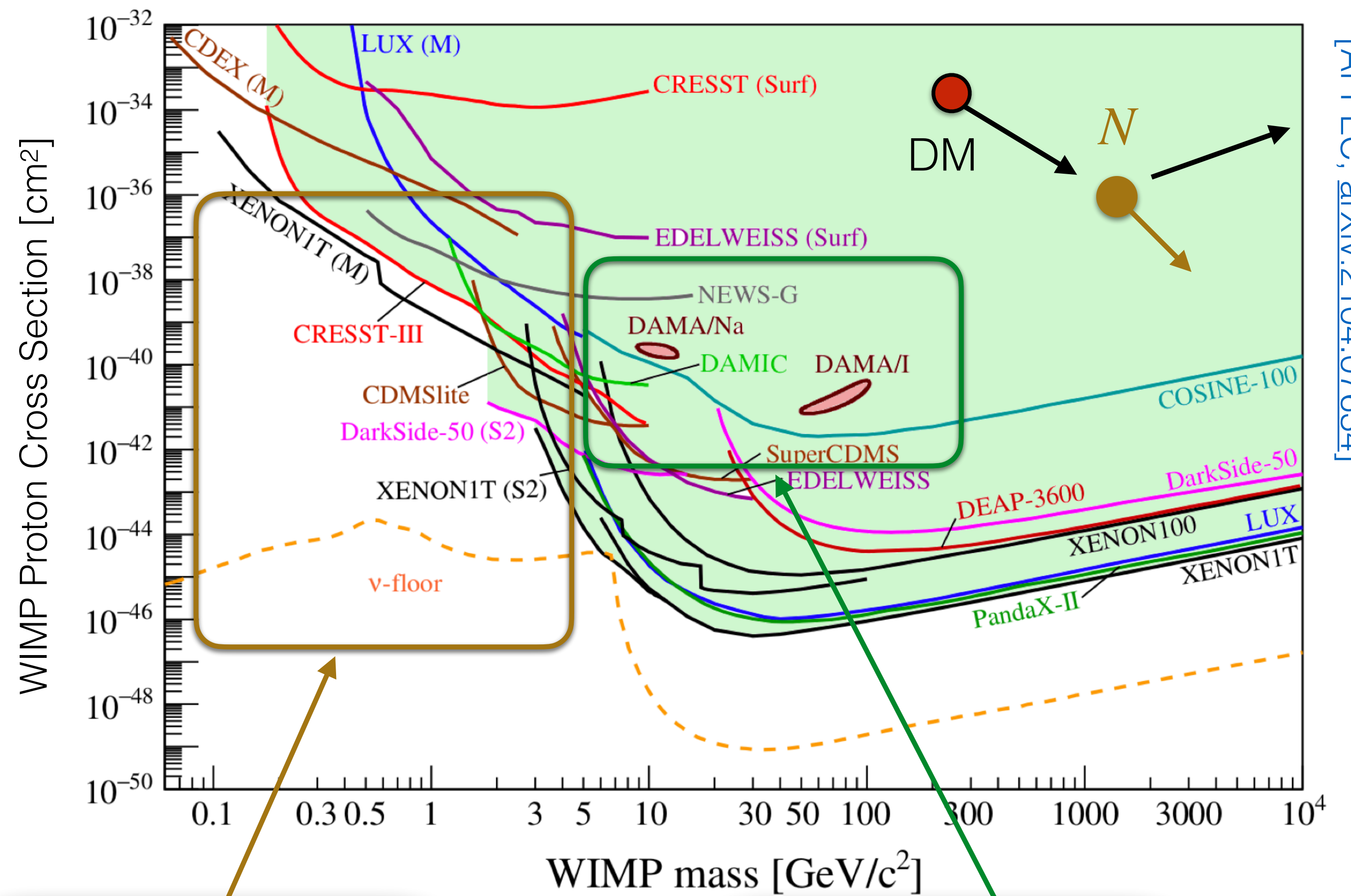
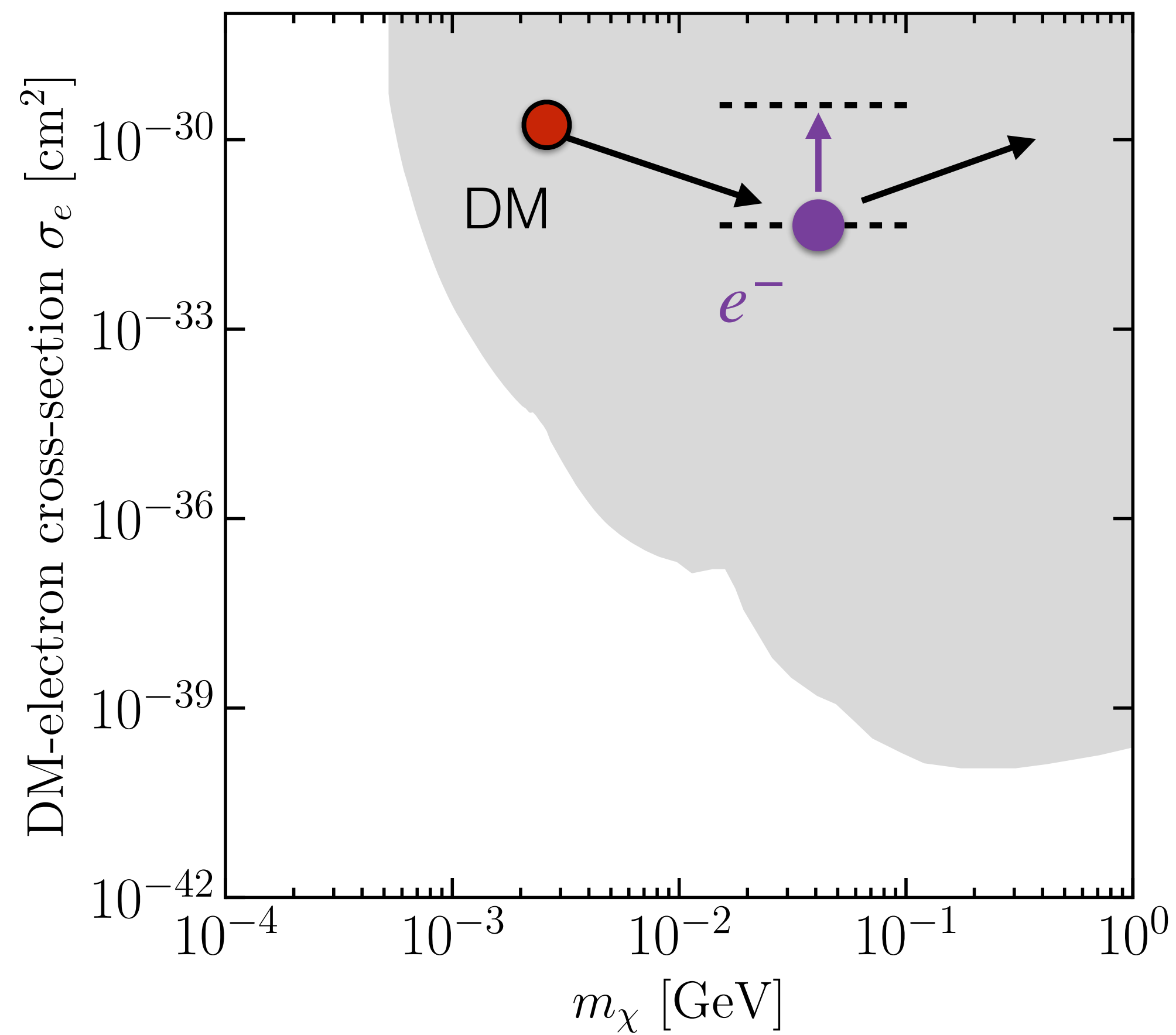






ANAIS



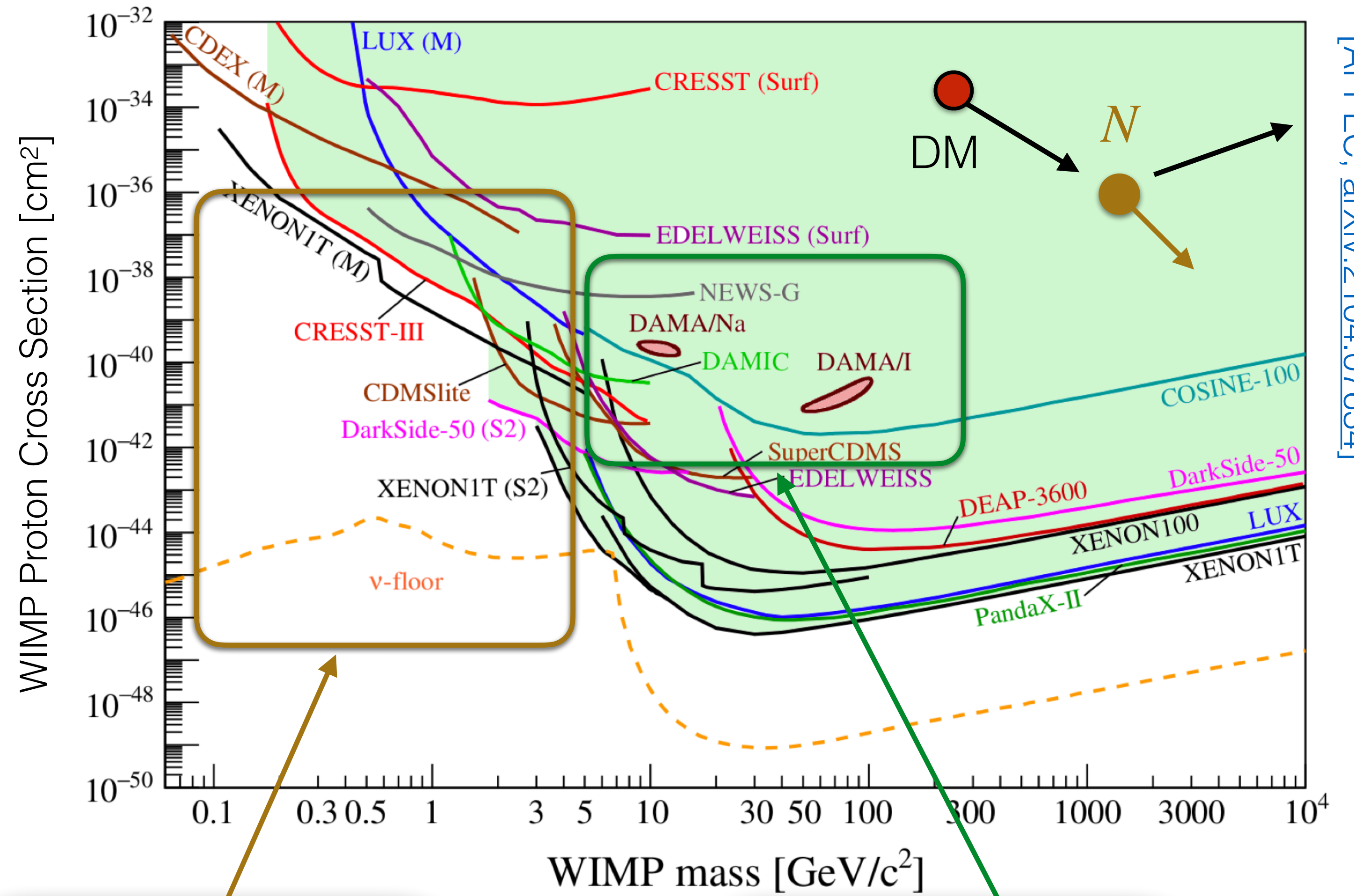
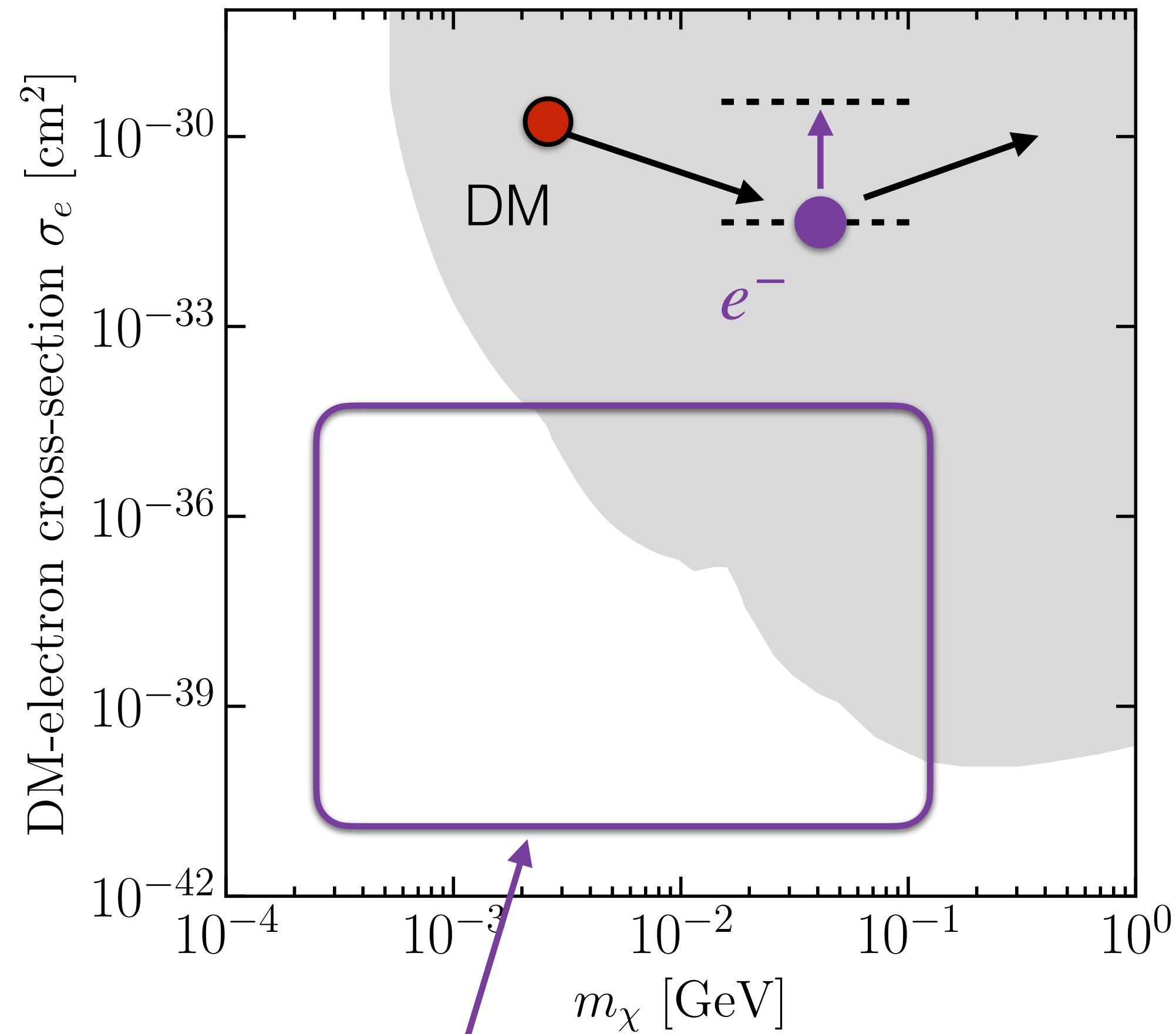


TREX-DM



ANAIS





DAMIC-M



TREX-DM

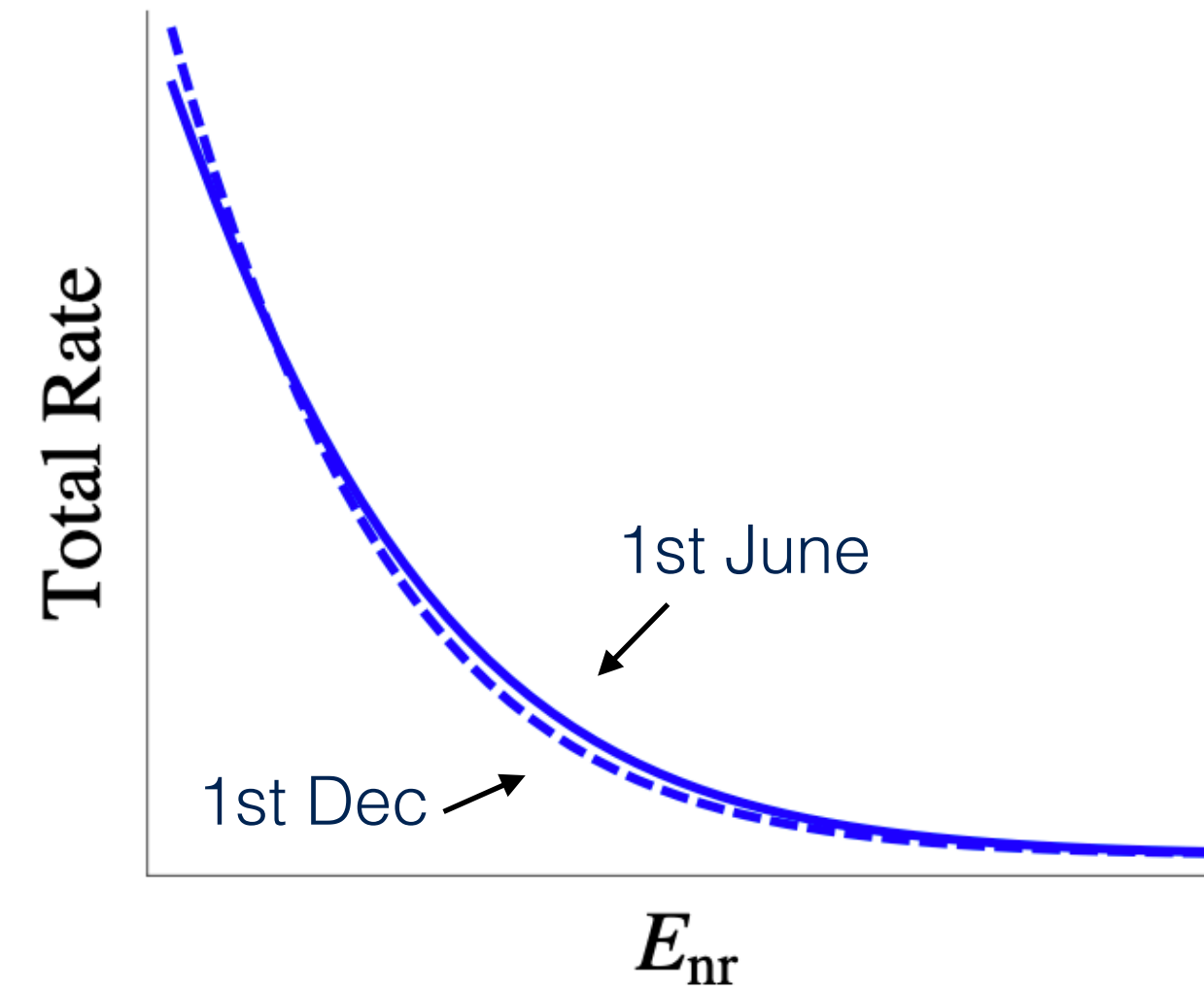


ANAIS



Annual Modulation

$$\text{Rate} \sim \rho_{\text{DM}} \times v_{\text{DM}} \times \sigma \times N_{\text{target}}$$

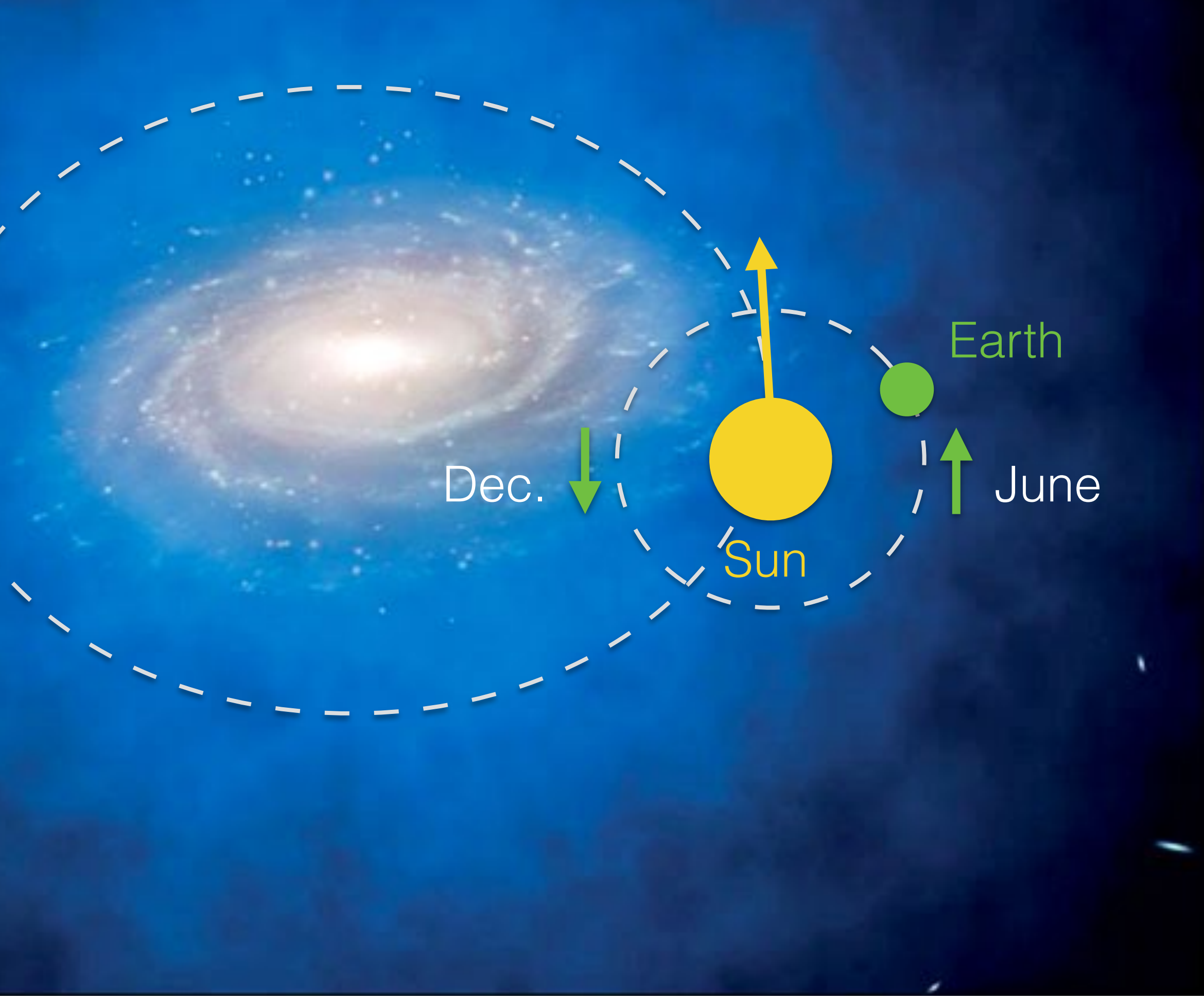


$$v_{\text{Sun}} \approx 220 \text{ km/s}$$

$$\Delta v_{\text{Earth}} \approx 30 \text{ km/s}$$

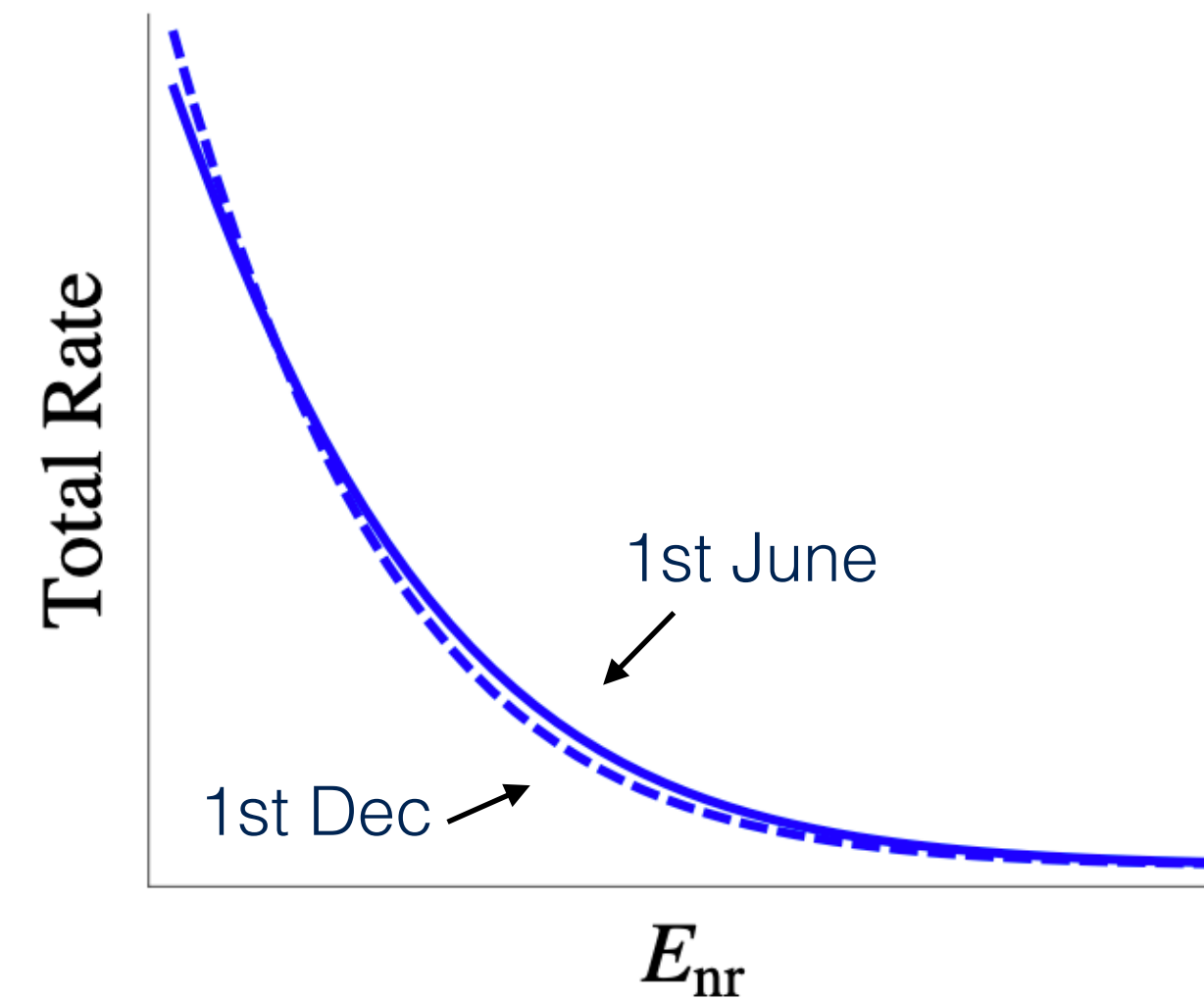
[1312.1355]

$\mathcal{O}(10\%)$ modulation



Annual Modulation

$$\text{Rate} \sim \rho_{\text{DM}} \times v_{\text{DM}} \times \sigma \times N_{\text{target}}$$

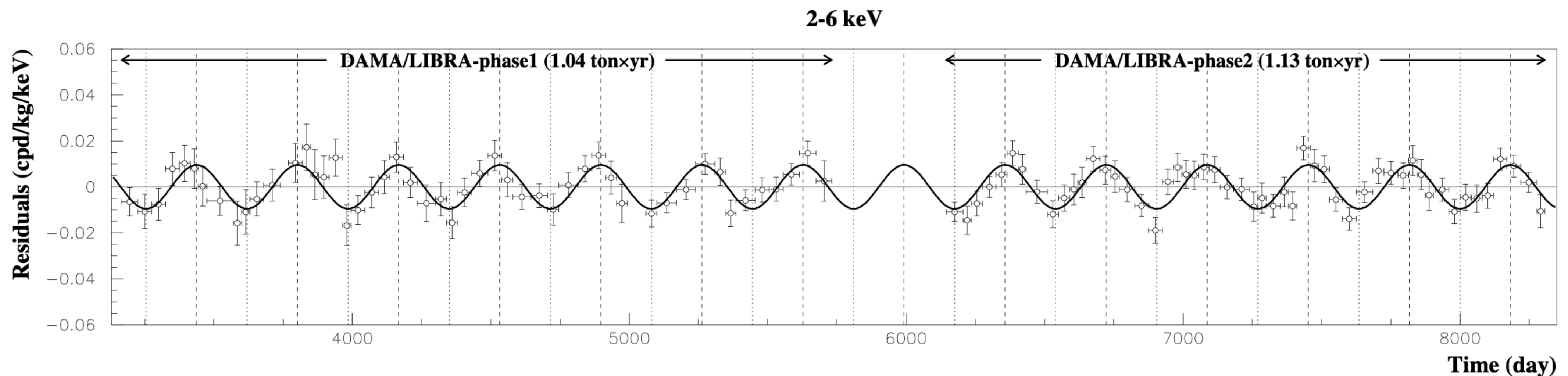


$$v_{\text{Sun}} \approx 220 \text{ km/s}$$

$$\Delta v_{\text{Earth}} \approx 30 \text{ km/s}$$

[1312.1355]

$\mathcal{O}(10\%)$ modulation



DAMA/LIBRA Experiment: $\mathcal{O}(20)$ years, $\sim 13\sigma$ significance [DAMA/LIBRA, 1805.10486]

ANAIS

Annual modulation with **Nal** Scintillators



Centro de Astropartículas y
Física de Altas Energías
Universidad Zaragoza



See also recent talk: [Iván Coarasa \(Nov 2025\)](#)

Model-independent test of the DAMA/LIBRA
signal using the same target: 112.5 kg NaI(Tl)

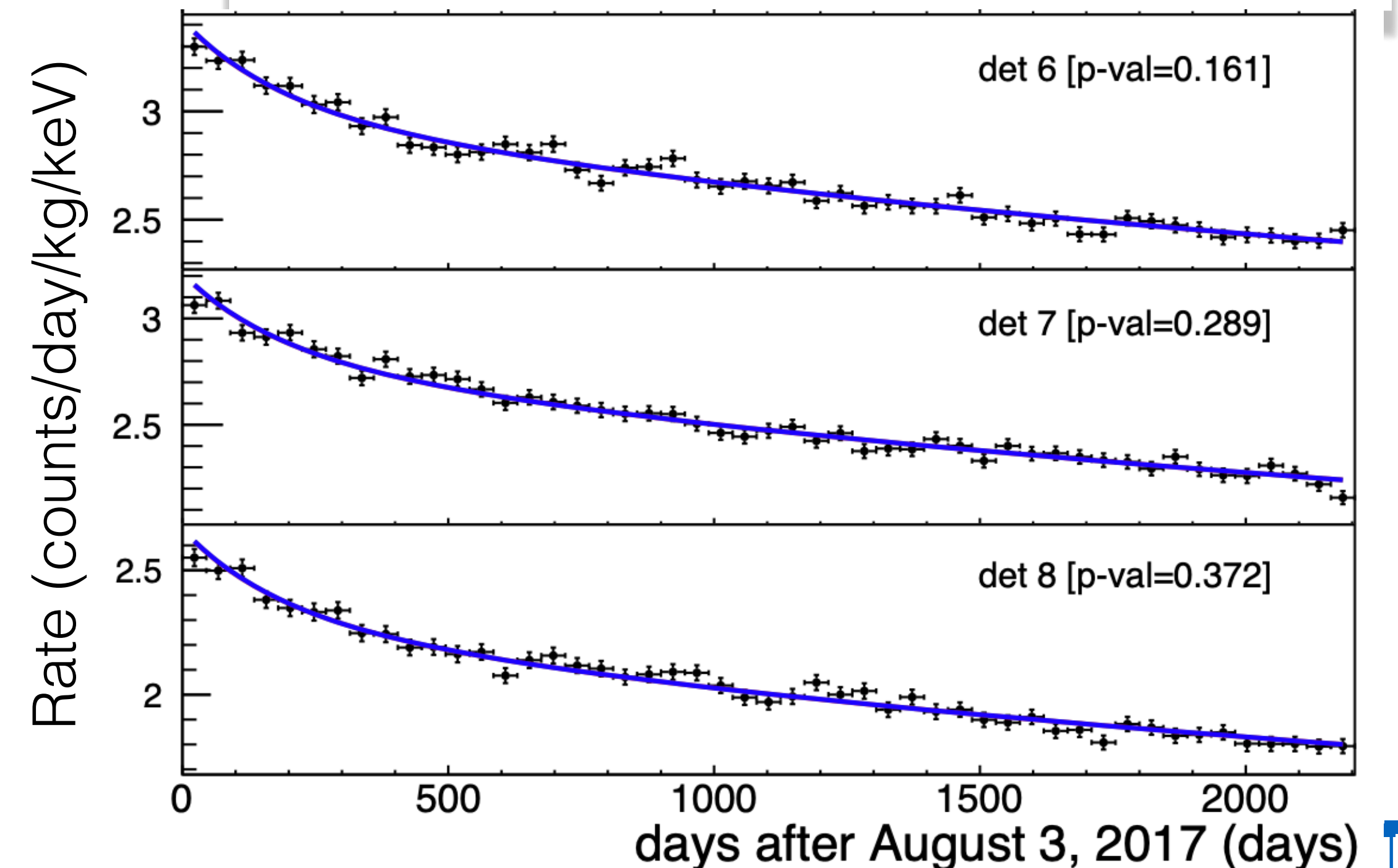
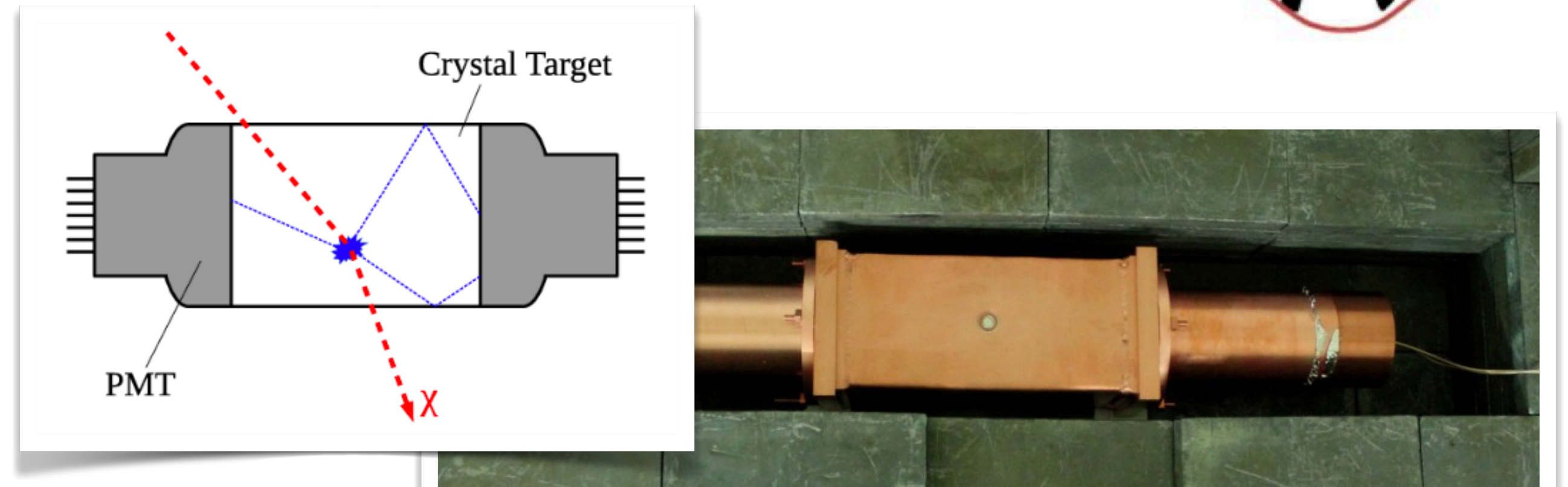
[ANAIS, [1903.03973](#), [2311.03392](#)]

9 cylindrical modules, each containing 12.5kg
of ultrapure NaI(Tl) + 1 'blank' module

Scintillation produced by energy deposition in
NaI is monitored by photomultiplier tubes
(PMTs). Excellent light collection allows for a low
threshold of 1 keVee.

Determination of quenching factors with neutron
calibration underway (mapping between
electron and nuclear recoil energy scales)

[ANAIS, [2402.12480](#)]



August 2017 - now: in operation in the
Canfranc Underground Laboratory (LSC) with
95% live time!

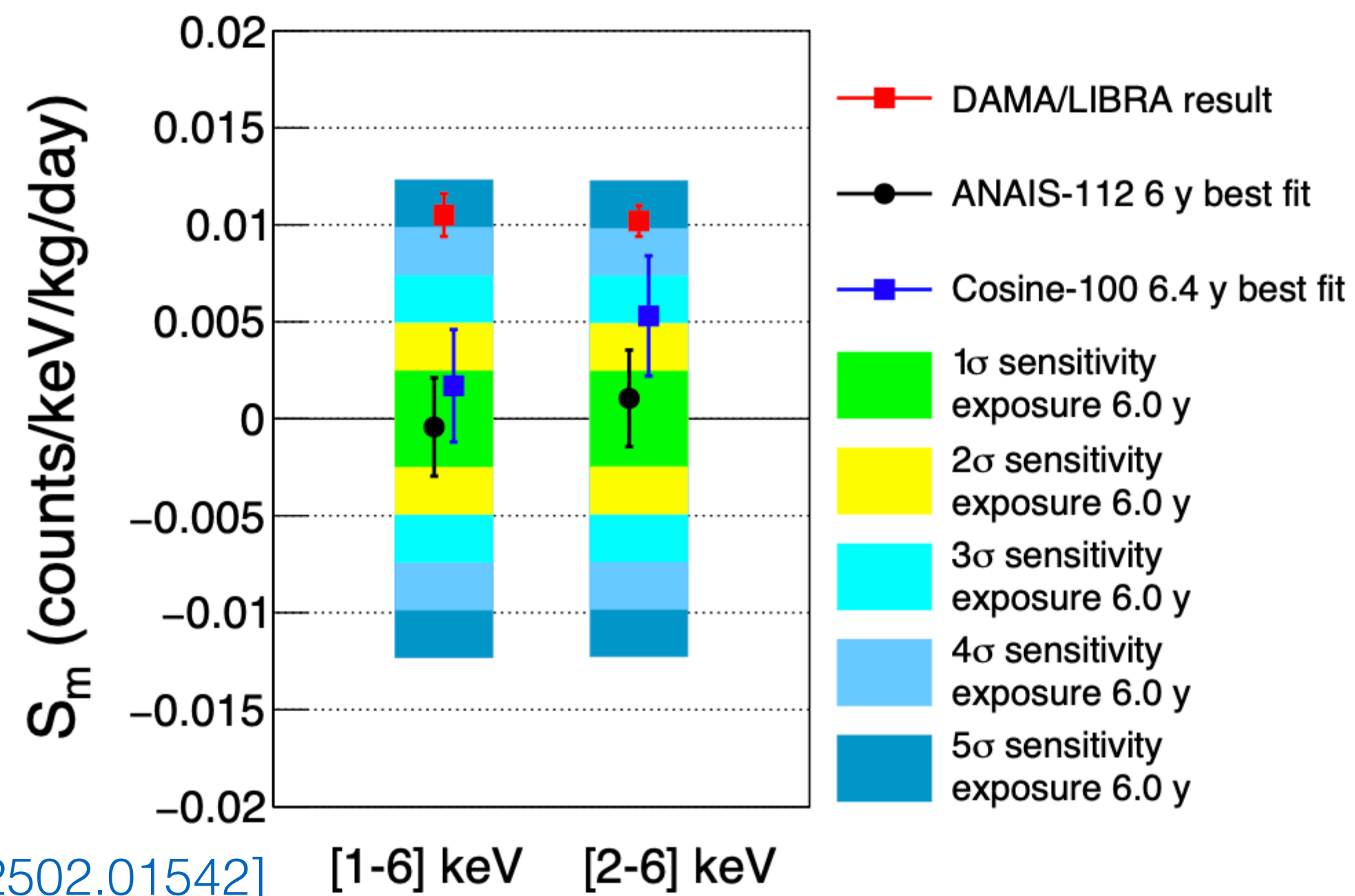
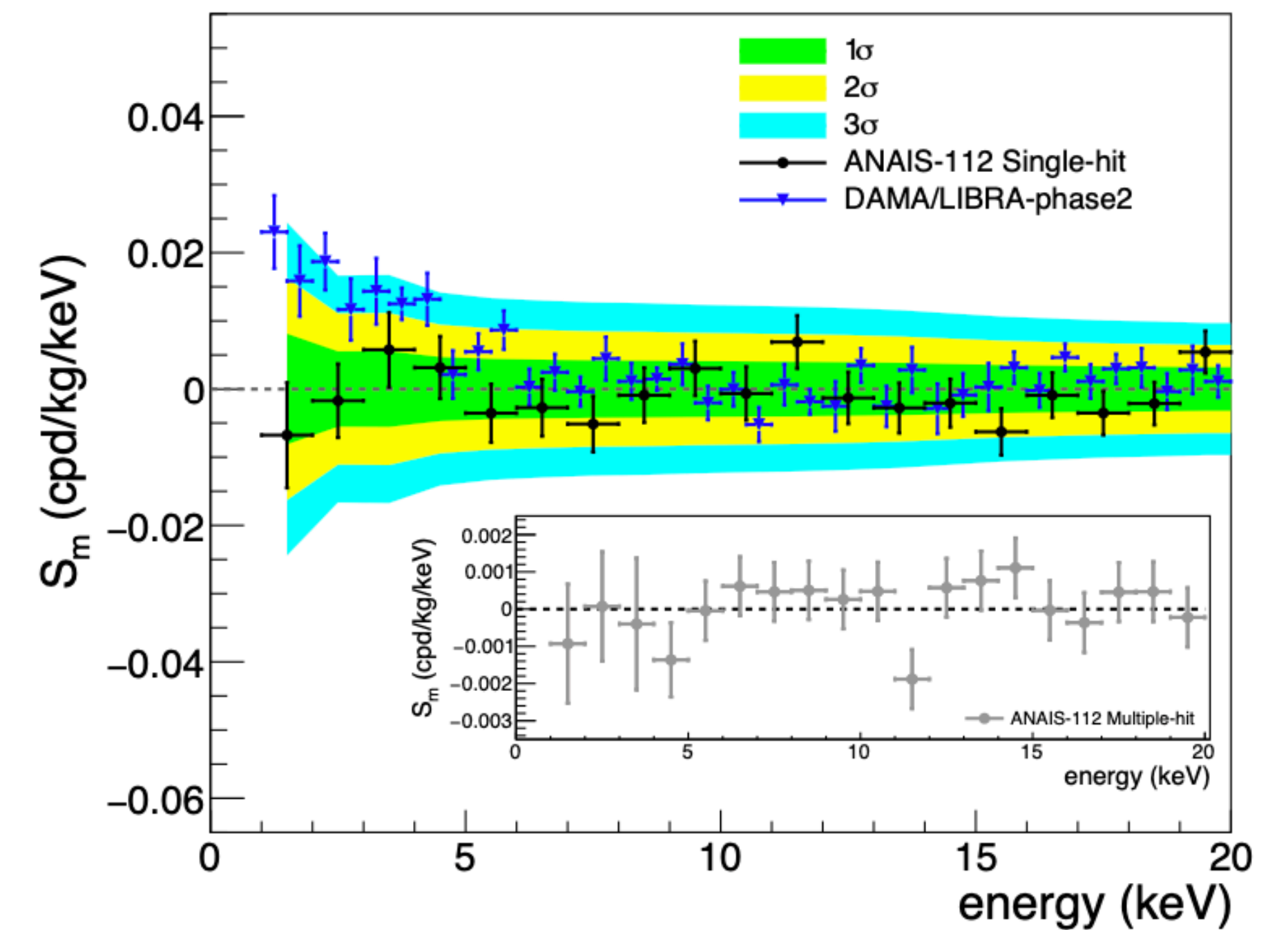
ANAIS

Annual modulation with NaI Scintillators

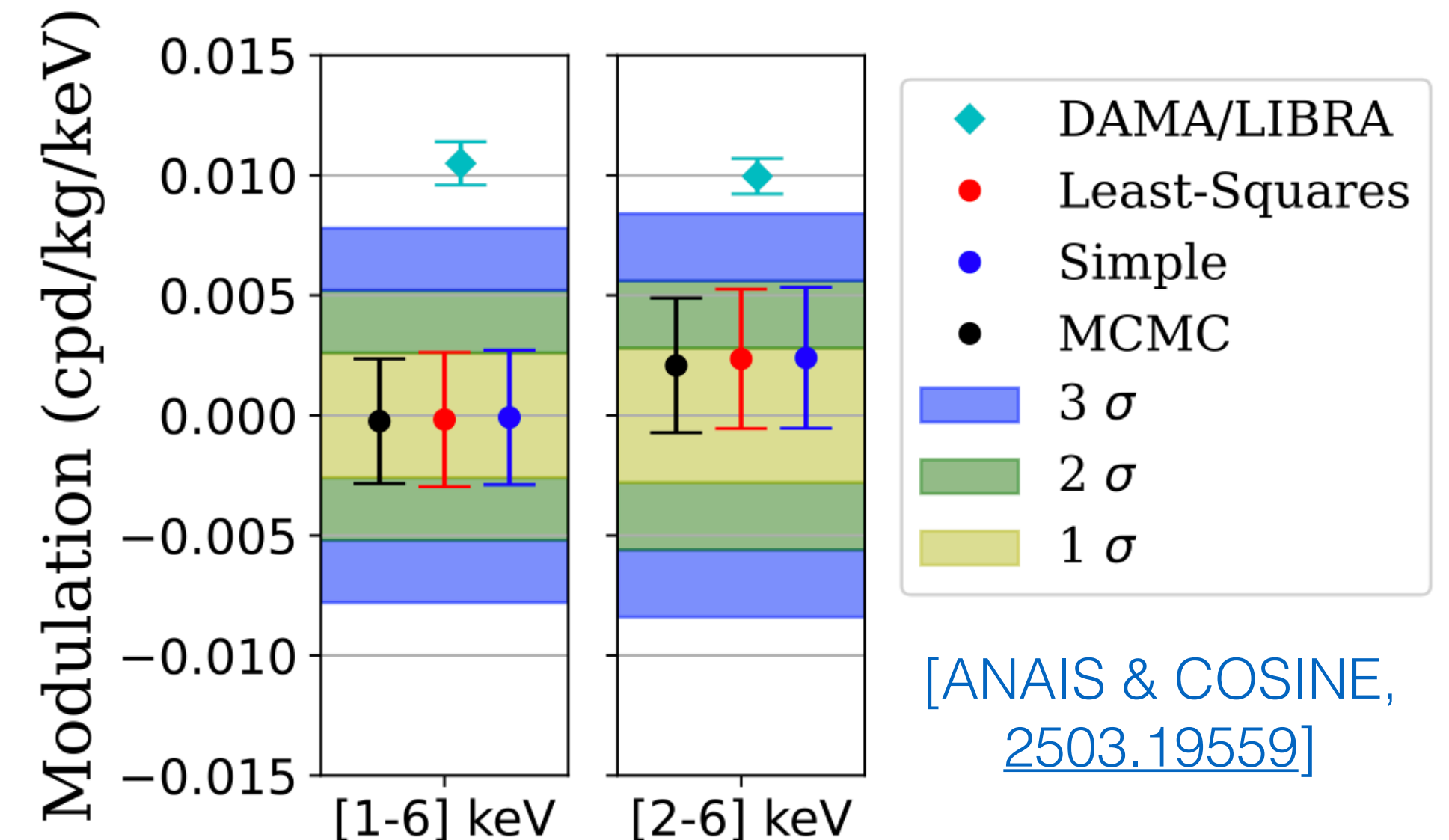
No modulation observed in the 6-year dataset (2017 - 2023)
→ most sensitive check of DAMA/LIBRA with NaI

DAMA/LIBRA signal **excluded at $3.5\text{-}4\sigma$** depending on the energy range under consideration

Data-taking continuing into **late 2025** (8 years) in order to reach 5σ sensitivity



Combination with
COSINE-100



[ANAIS & COSINE,
[2503.19559](https://arxiv.org/abs/2503.19559)]

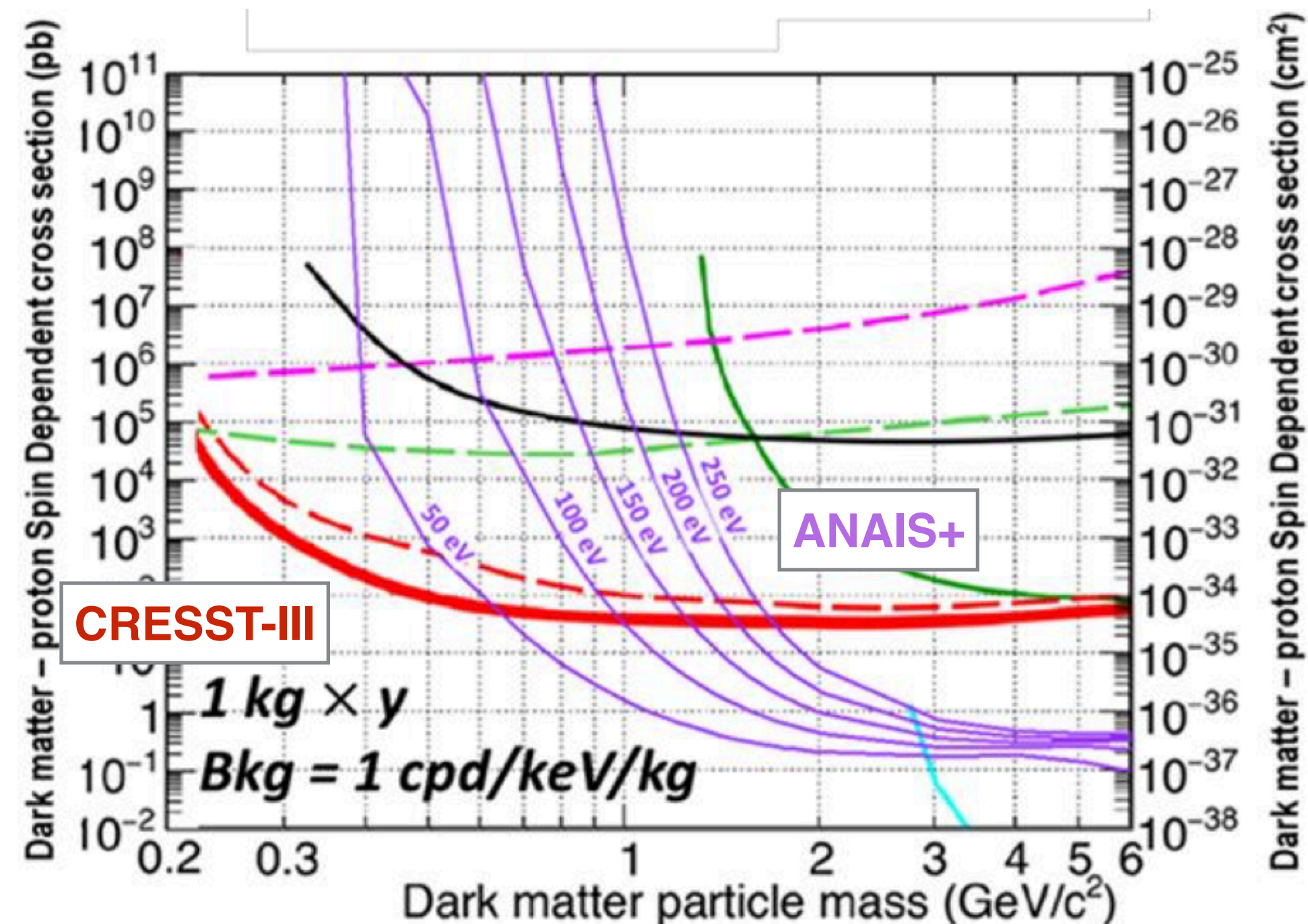
ANAIIS+

Annual modulation with **NaI** Scintillators

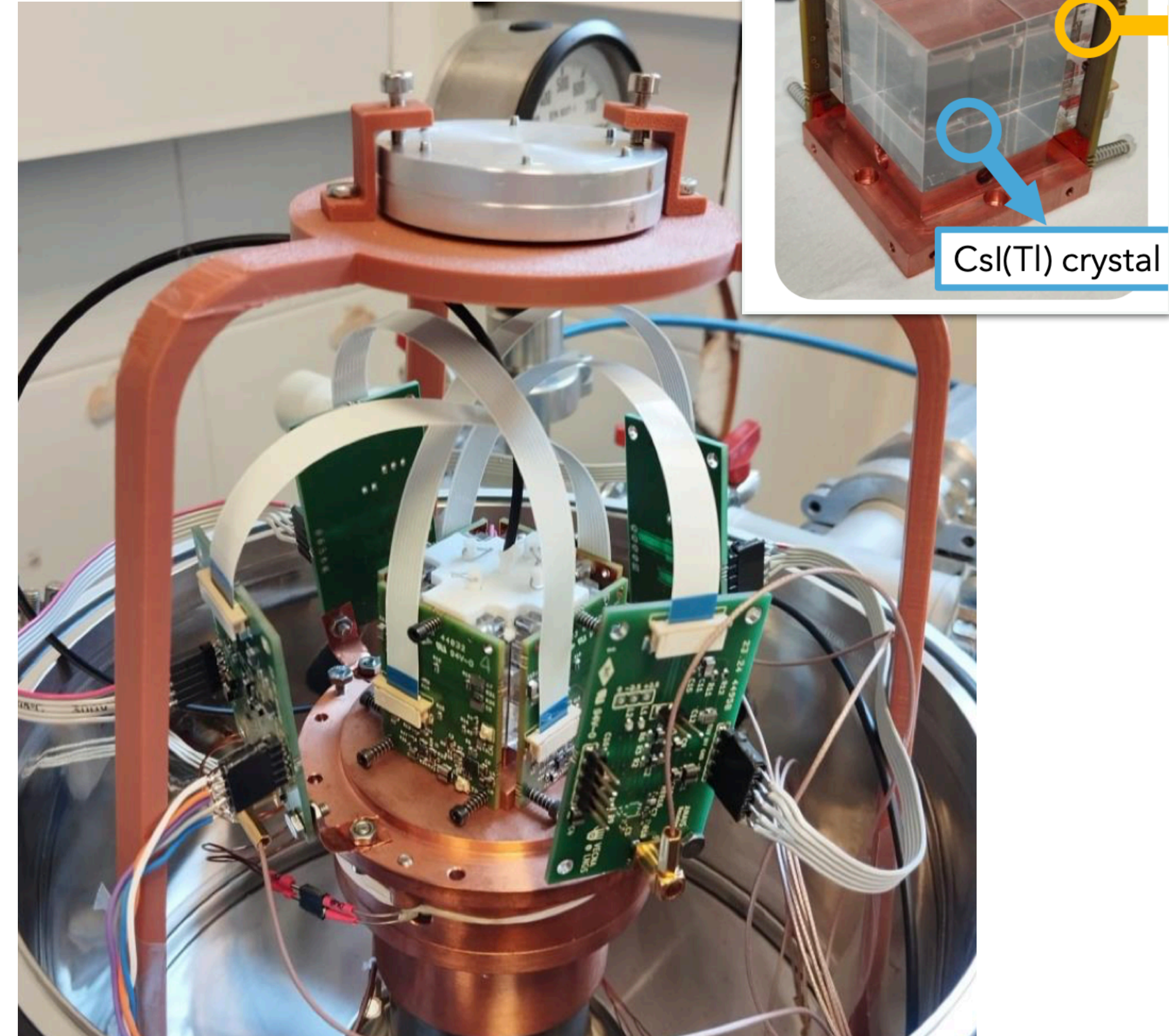
Current ANAIS sensitivity limited by anomalous light events attributed to PMTs

Aim to lower threshold and backgrounds by replacing PMTs by SiPMs (operated at low $T < 100\text{K}$)

Threshold reduction down to $\sim 100\text{ eV}$ would allow **sensitivity to GeV-scale DM** (esp. spin-dependent)



TINYOCTOPUS



First prototype built and being tested in Zaragoza
Collaboration between Zaragoza, CIEMAT, LNGS

[See [Slides by Jaime Apilluelo Allué \(MultiDark 2024\)](#)]

TREX-DM

TPC for **R**are **E**vent **eX**periments - **D**ark **M**atter



Centro de Astropartículas y
Física de Altas Energías
Universidad Zaragoza

See also recent talk:
[Ana Quintana \(Nov 2025\)](#)

High pressure gas TPC (20 L up to 10 bar) installed at Canfranc Underground Laboratory (LSC)

[TREX-DM, [1910.13957](#)]

Detector with very low energy threshold ($<1 \text{ keV}_{ee}$), and light elements as targets to probe sub-GeV DM-nucleon scattering

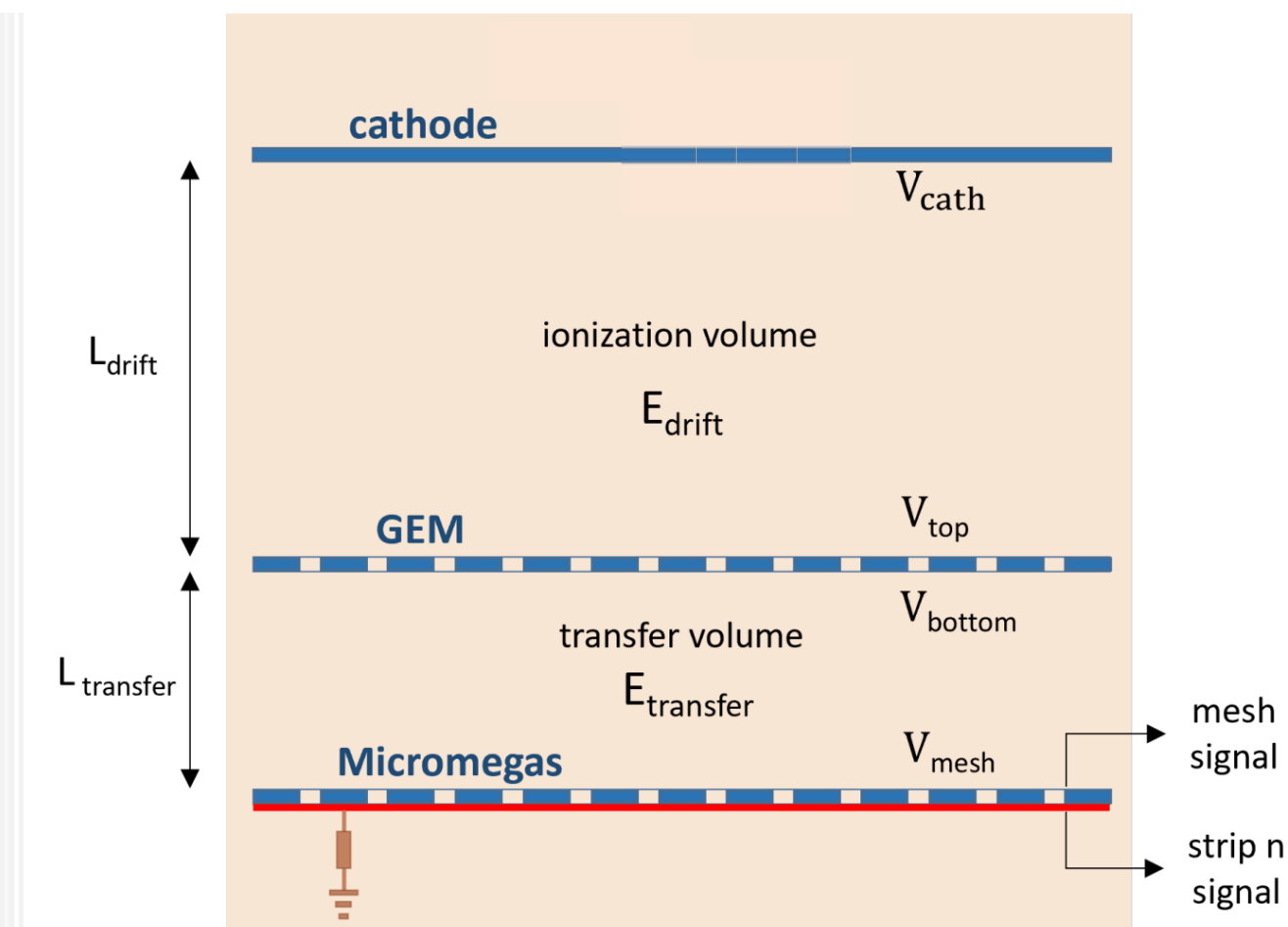
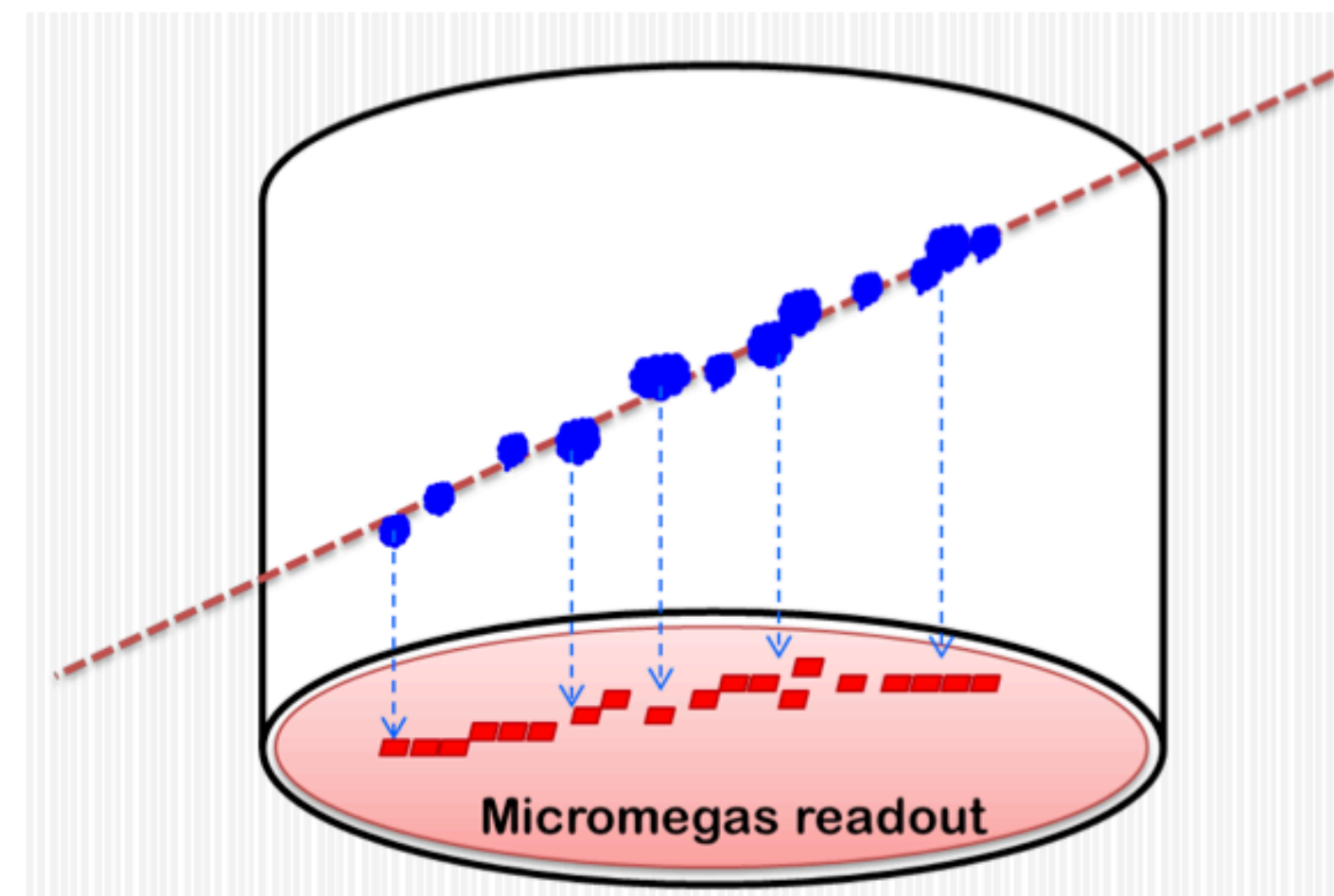
Possibility to change target gases:

- Atmospheric Ar + 1% $i\text{C}_4\text{H}_{10}$ (2018 data-taking)
- Ne + 2% $i\text{C}_4\text{H}_{10}$ (2019-2022 data-taking)

Read-out ionisation due to nuclear recoils using microbulk **Micromegas (MM)**

Pre-amplification stage (Gas Electron Multiplier, GEM) recently installed on top of the Micromegas in order to reduce threshold

[TREX-DM, [2412.19864](#)]



TREX-DM

TPC for **R**are **E**vent **eX**periments - **D**ark **M**atter

2019 - 2022: Data-taking at LSC with Ar & Ne (4 bar). Achieved energy threshold of 900 eV

Background levels initially dominated by ^{222}Rn contamination. Reduced down to $\mathcal{O}(100)$ dru*

Sep 2022 - July 2023: Relocation and commissioning in LAB2500 at LSC

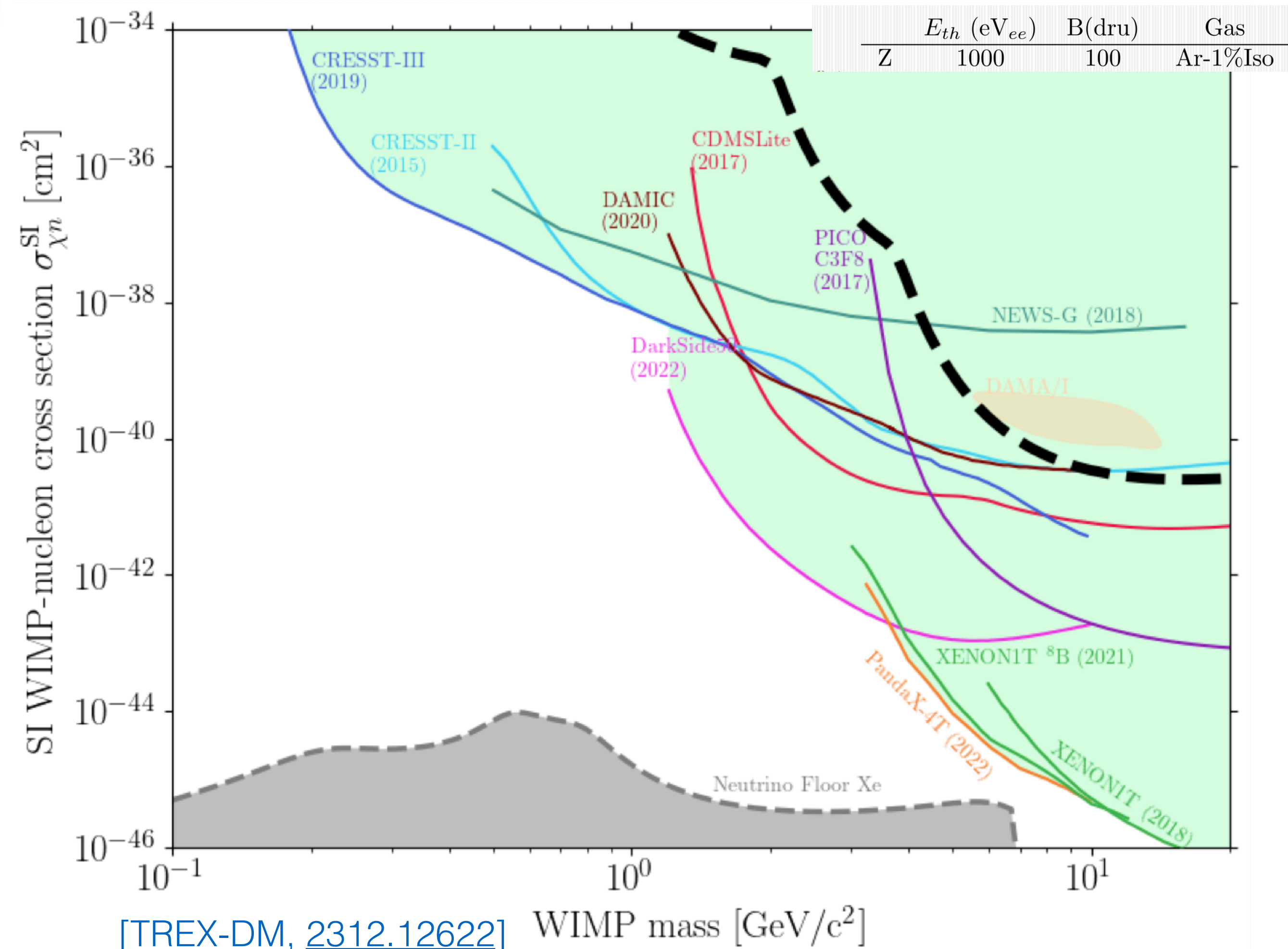


Aug 2023 - present: Data-taking for comparison with 2019-2022 campaign. Calibration and background studies

2024 - 2025: Installation + commissioning of GEM+MM setup. Demonstrated energy threshold down to $\mathcal{O}(20)$ eV (~single-electron ionisation in Ar).

[TREX-DM, [2510.05877](#)]

*1 dru = 1 event/kg/keV/day



TREX-DM

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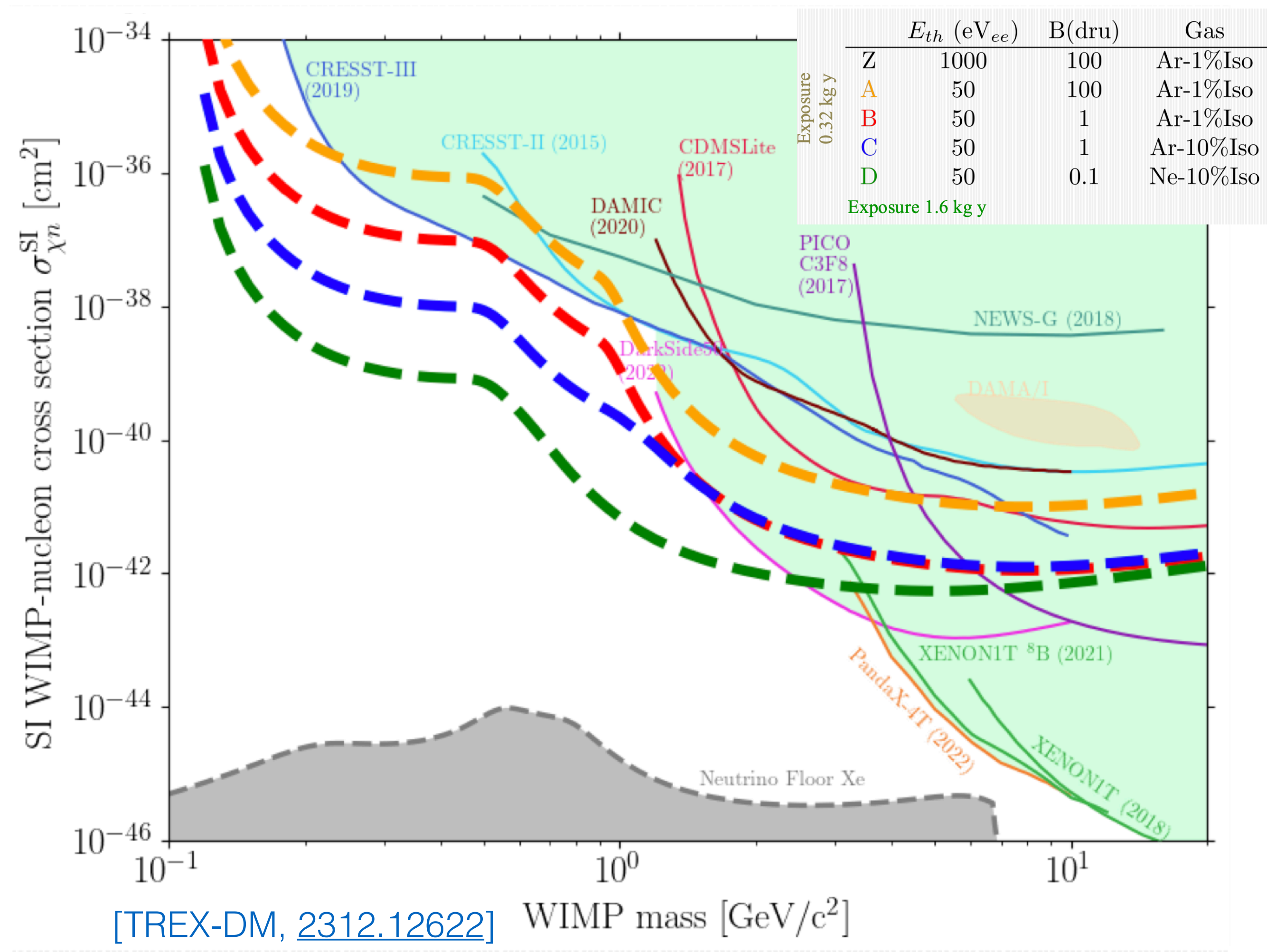


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[TREX-DM, [2510.05877](#)]

*1 dru = 1 event/kg/keV/day



First half of 2026: Planned physics run with Ne+2% isobutane

DAMIC-M

DARk MATter IN CCDs at MODane

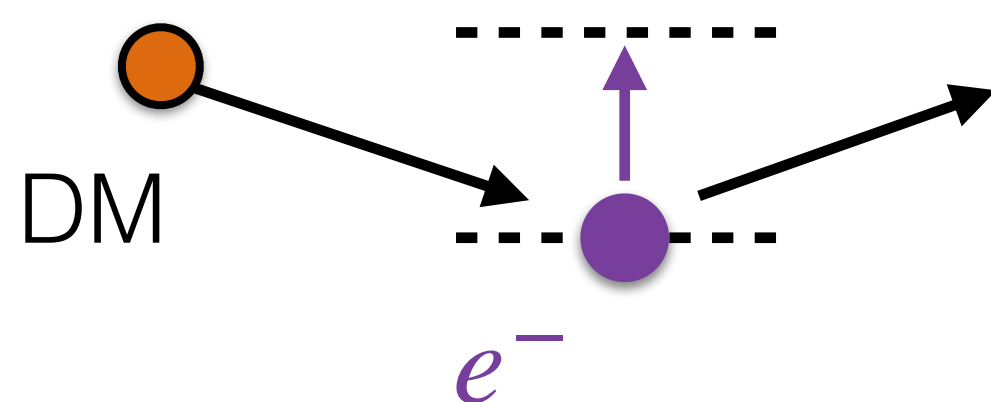
Array of **Charge Coupled Devices (CCDs)** planned to be installed at Laboratoire Souterrain de Modane (LSM), building on success of the DAMIC program at SNOLAB

CCDs act as ionisation detectors. **“Skipper” amplifier** readout allows for repeated non-destructive charge measurement, allowing for single electron energy resolution (sub-eV)!

Plans for array of 104 thick (675um), massive (~3.5g), 9 Mpixel Silicon CCDs for kg-scale mass

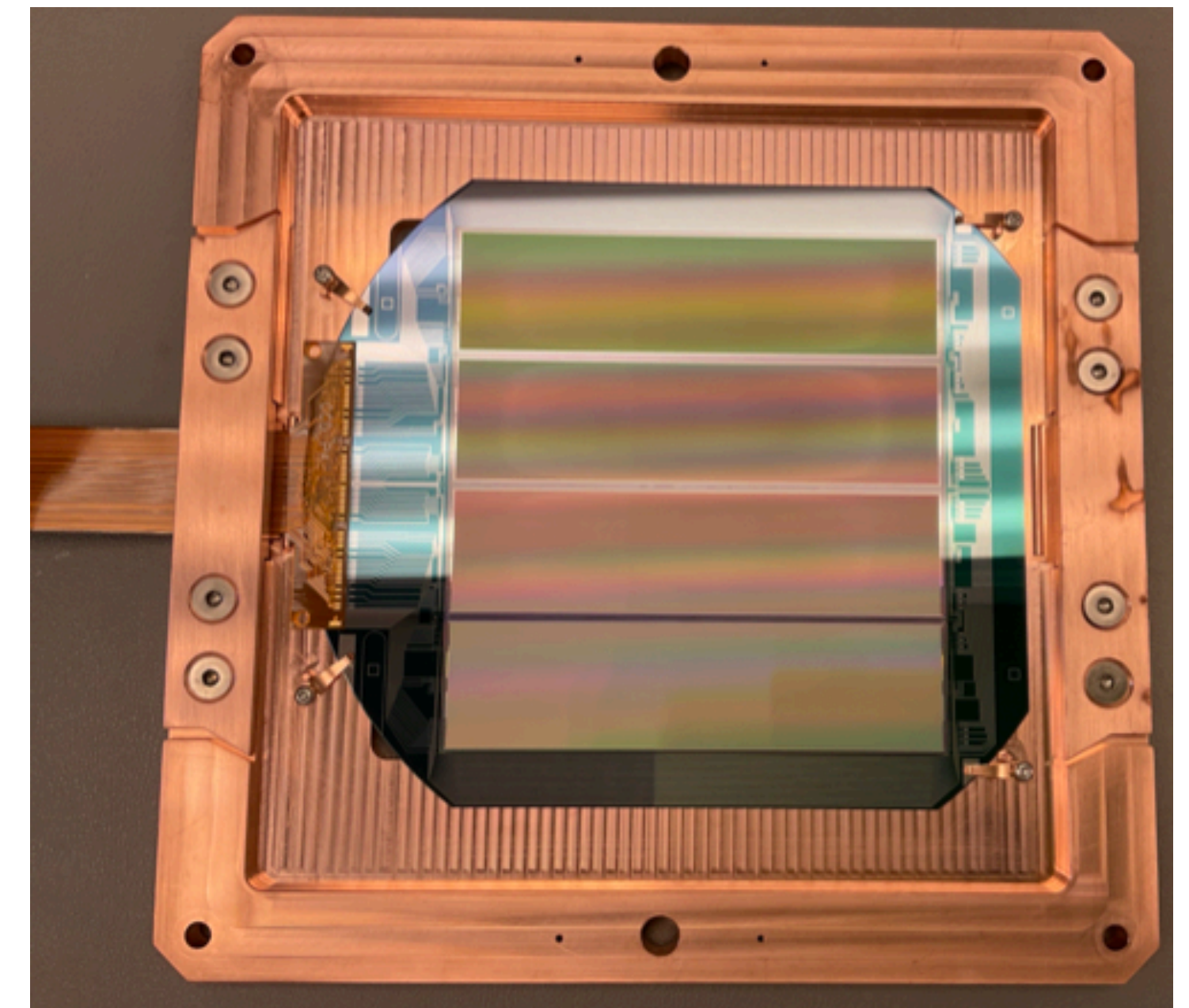
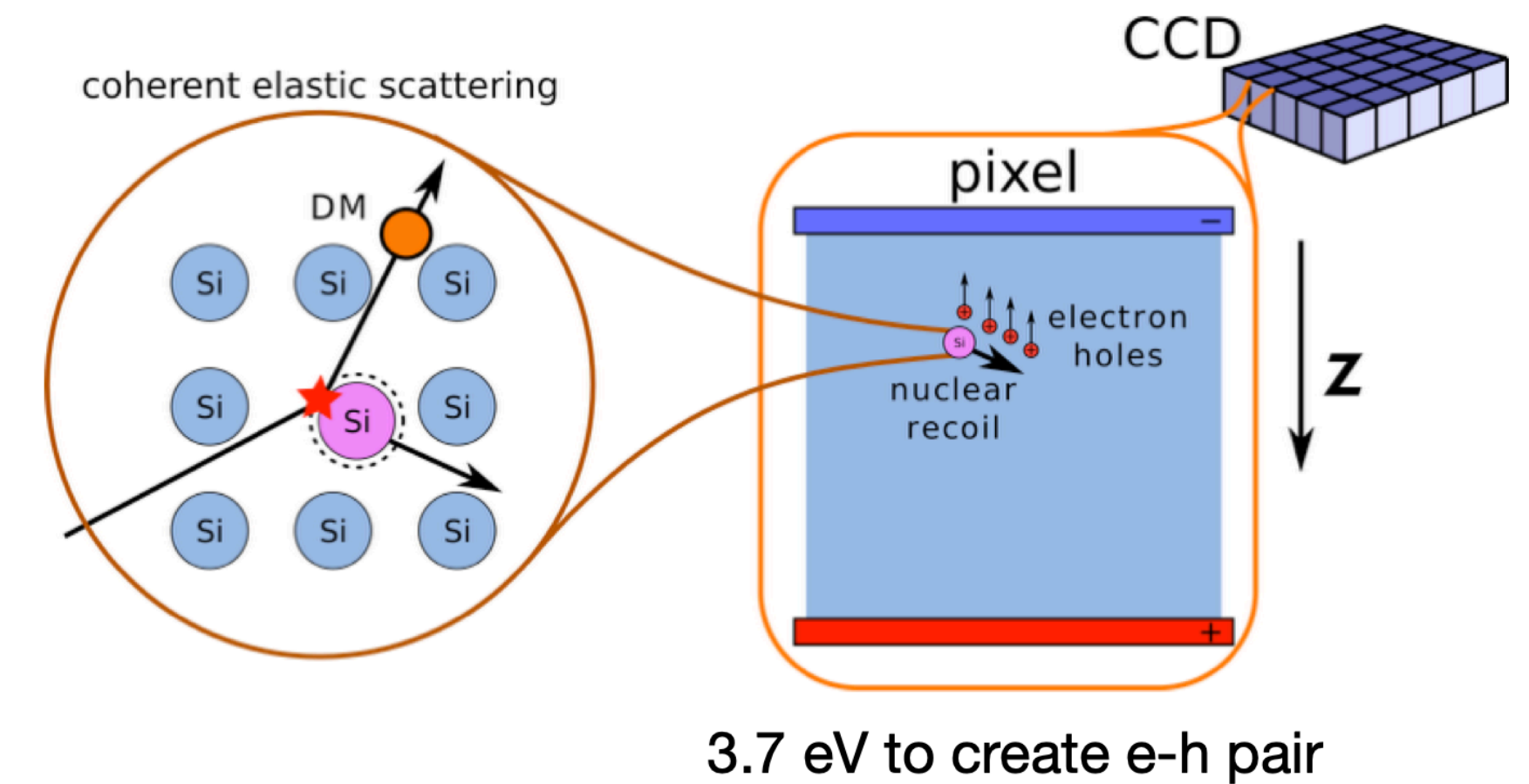
[DAMIC-M, [2001.01476](#)]

Sensitivity to sub-GeV DM-nucleus scattering as well as MeV-scale DM-electron scattering!



$$\Delta E_e \leq \frac{1}{2} \mu_{\chi N} v^2 \simeq \frac{1}{2} \text{ eV} \times \left(\frac{m_\chi}{\text{MeV}} \right)$$

[Essig et al., [1108.5383](#), [1509.01598](#)]



DAMIC-M

DARk MATter In CCDs at Modane

Since Feb 2022: Operation of the Prototype Low-background chamber (LBC) at Modane

[DAMIC-M, [2407.17872](#)]

May - Nov 2022: Science runs for DM-electron analysis (85 g-days) and daily modulation search (40 g-days) using 2 prototype skipper CCDs

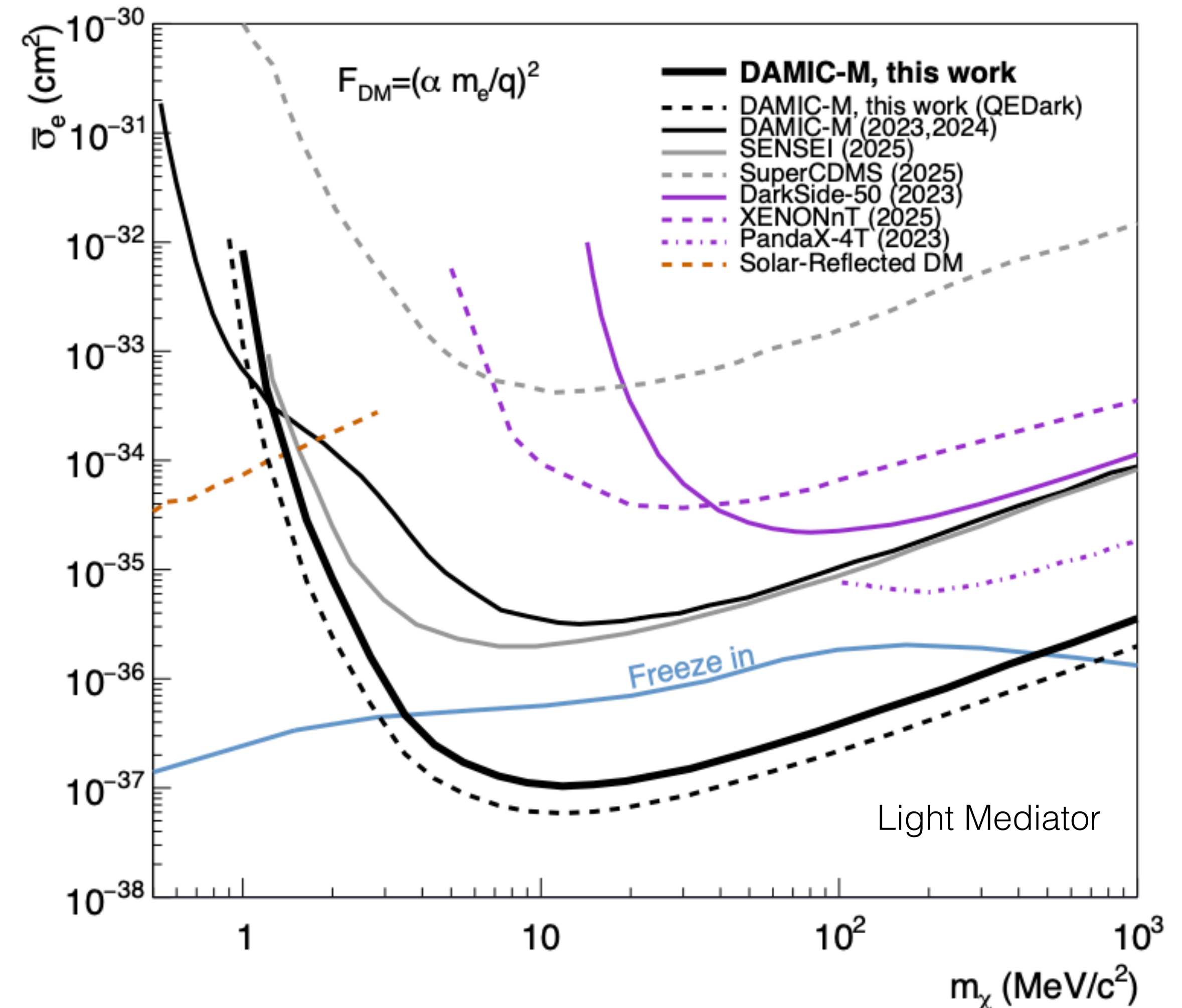
[DAMIC-M, [2302.02372](#), [2307.07251](#)]

Oct 2024 - Jan 2025: Second science run with 8 production CCDs (~1.3 kg-days)

First exploration of key 'benchmark models' of DM (with sensitivity to sub-MeV from daily modulation searches)

[DAMIC-M, [2503.14617](#), [2511.13962](#)]

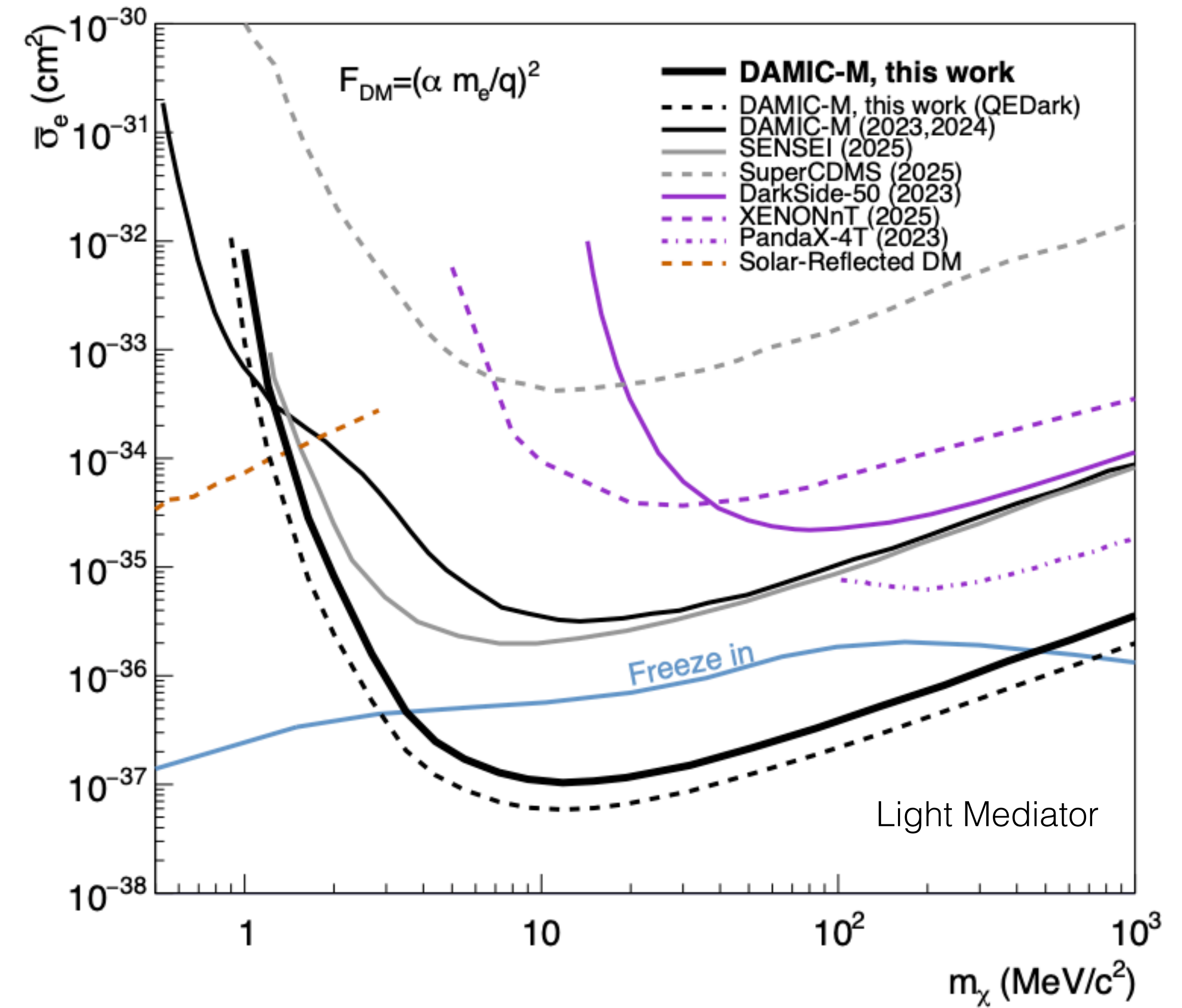
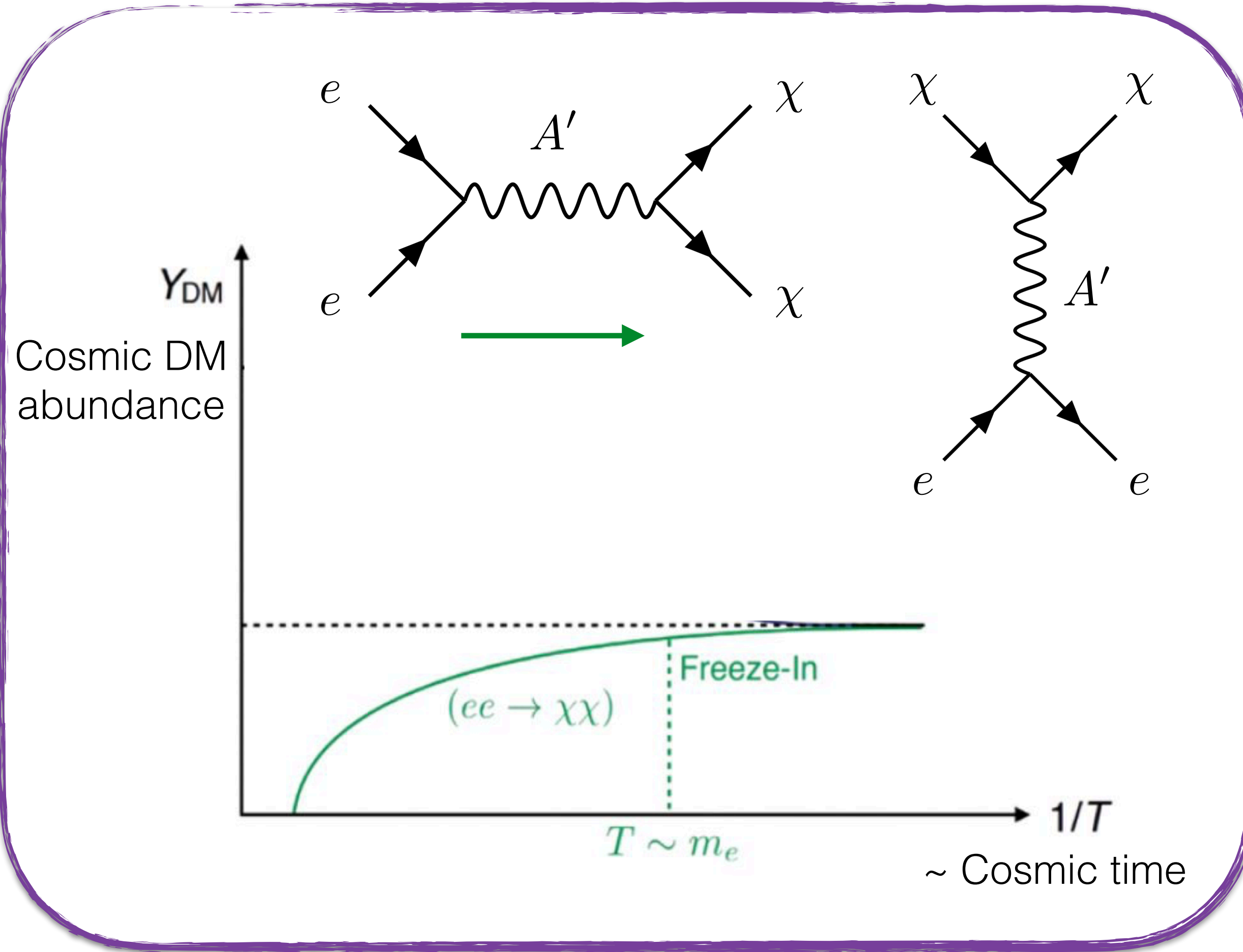
[DAMIC-M, [2503.14617](#)]



DAMIC-M

DARK Matter IN CCDs at MODANE

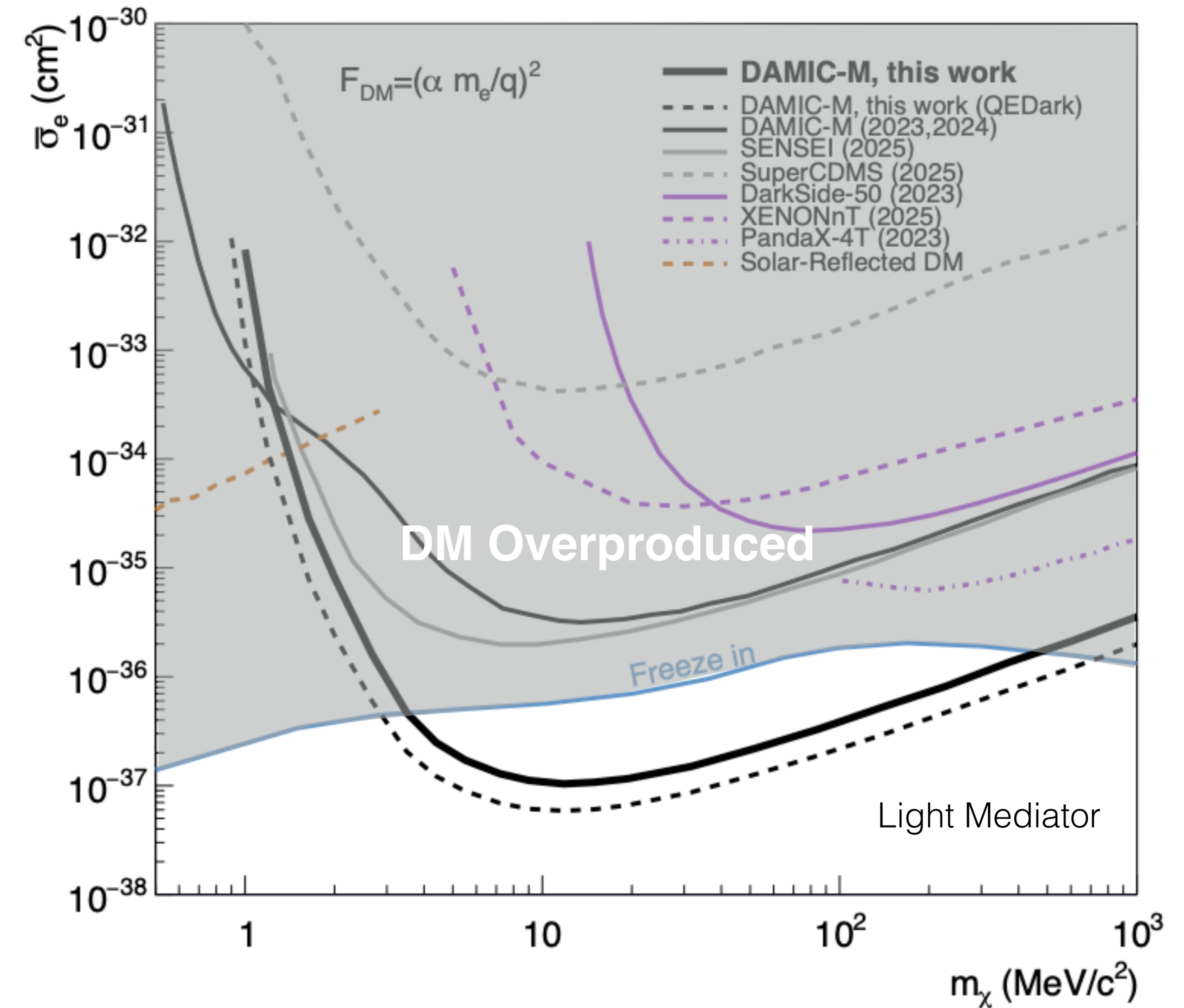
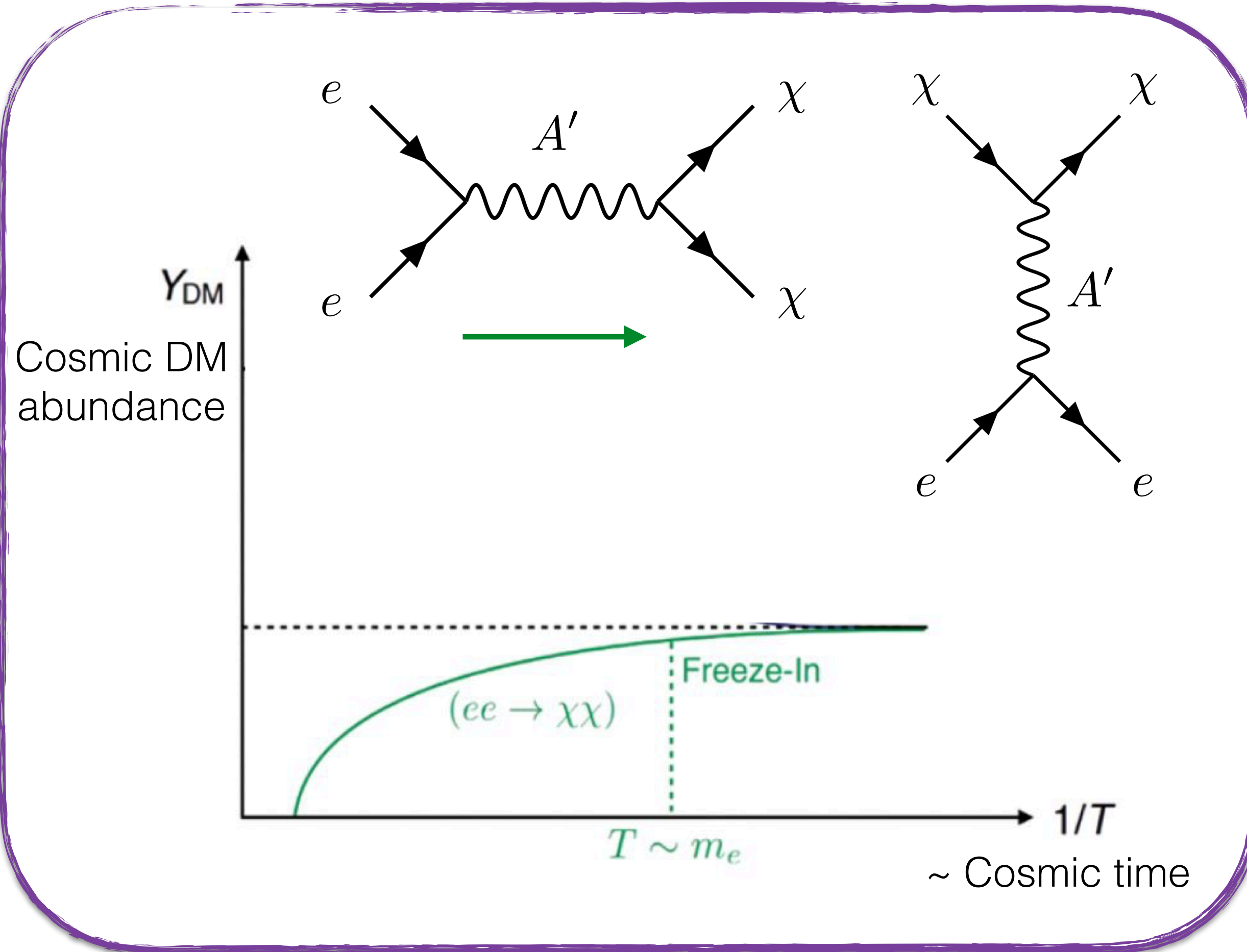
[DAMIC-M, 2503.14617]



DAMIC-M

Dark Matter In CCDs at Modane

[DAMIC-M, 2503.14617]



DAMIC-M

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[DAMIC-M, [2407.17872](#)]

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[DAMIC-M, [2302.02372](#), [2307.07251](#)]

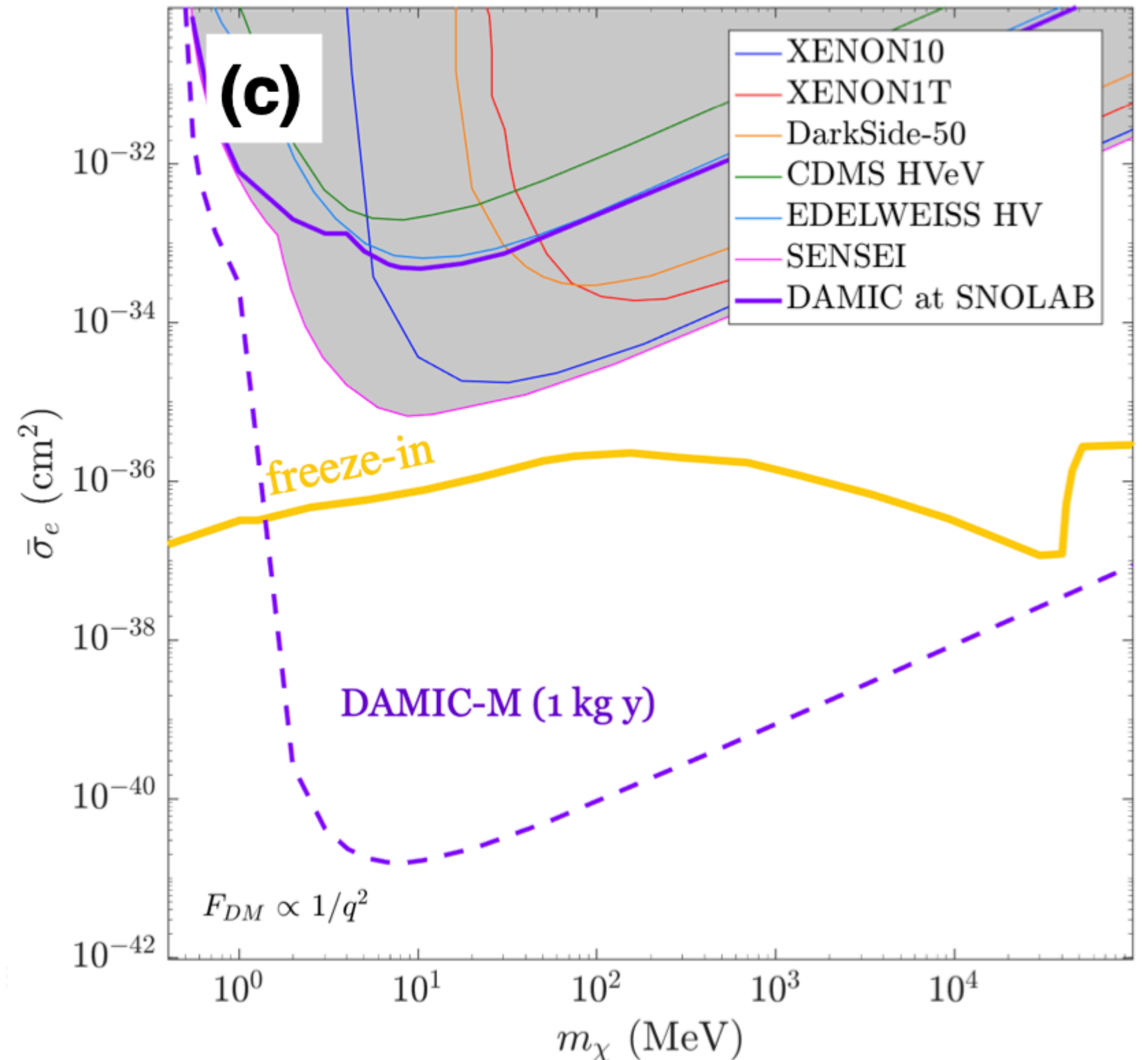
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[DAMIC-M, [2503.14617](#), [2511.13962](#)]

December 2024: Testing and packaging of 28 CCD Modules (112 CCDs, ~350g active mass) completed

[DAMIC-M, [2509.06943](#)]

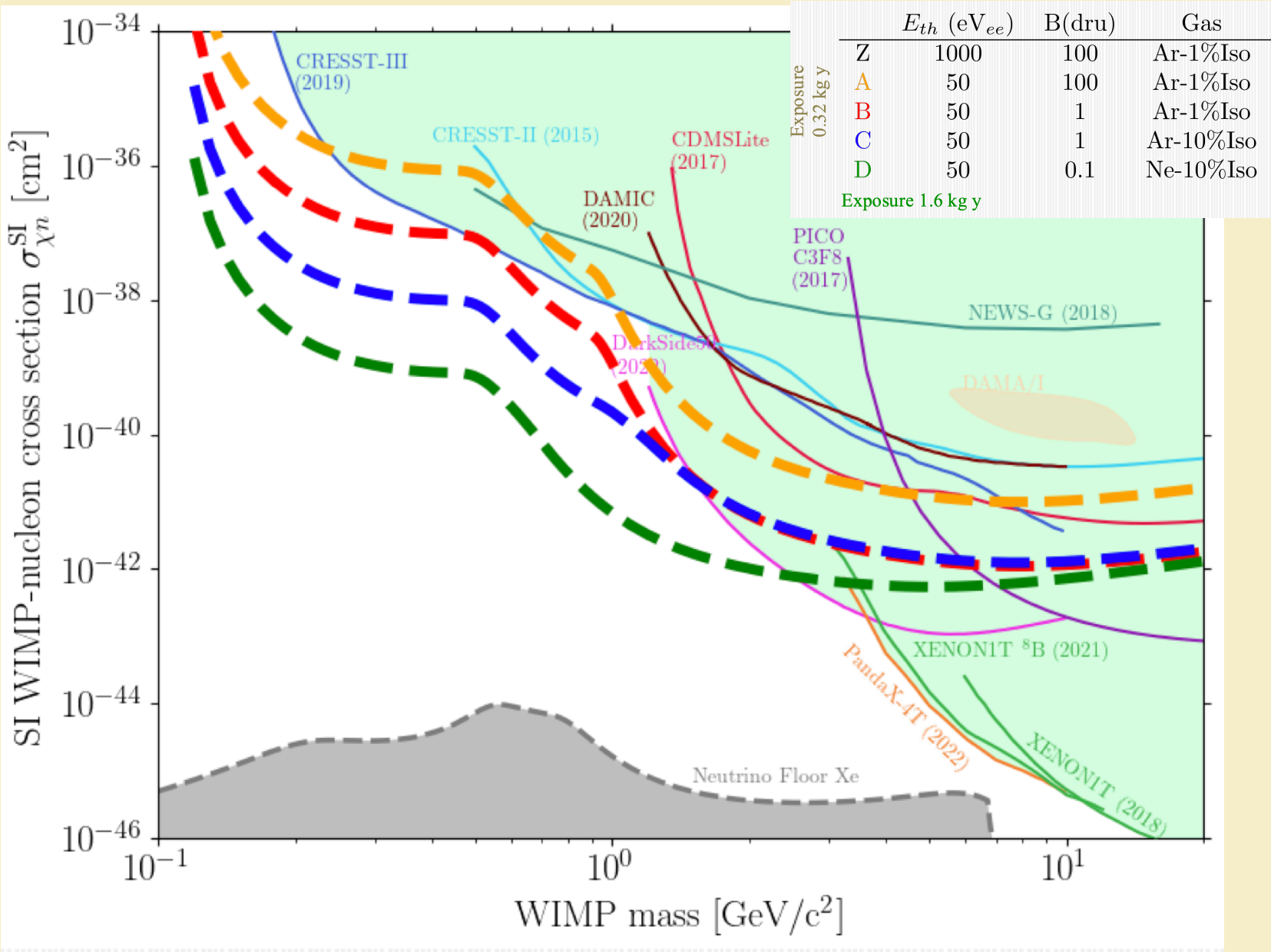
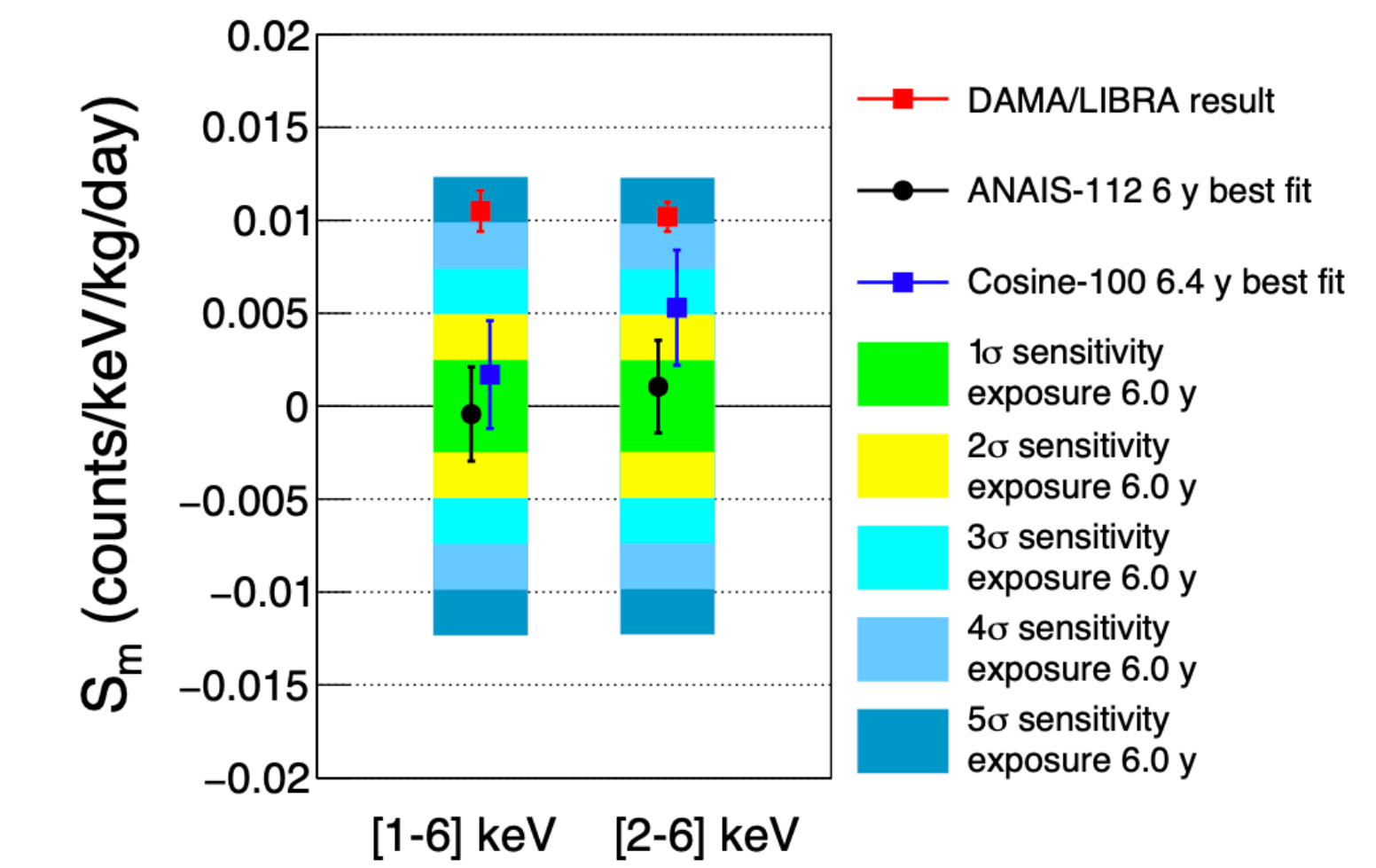


Final characterization and optimization underway at Modane, with installation of 26 modules in the DAMIC-M detector planned for **early 2026**.

Conclusions

LIA5 experiments are well-positioned in the international context across a wide range of Dark Matter masses and models!

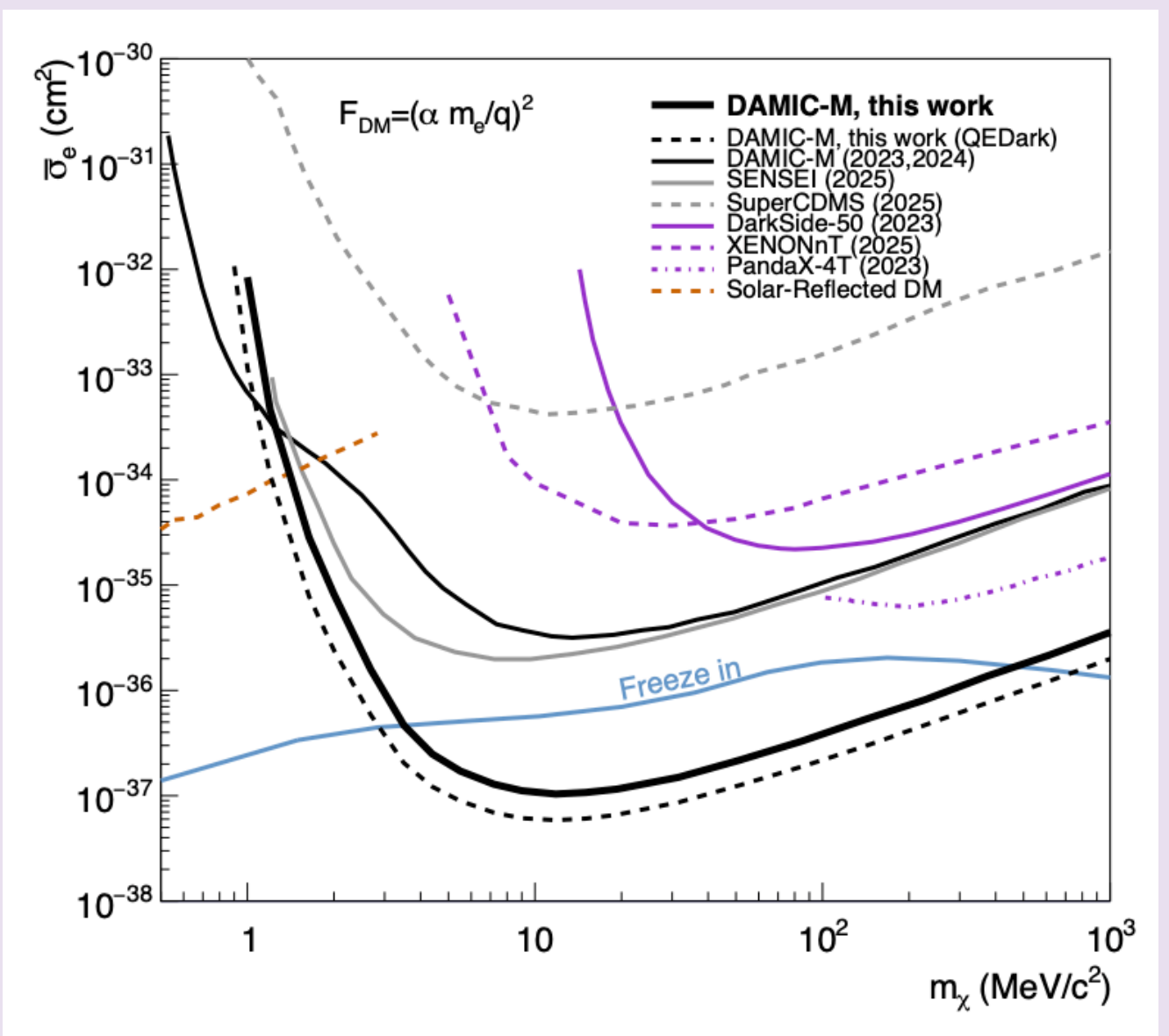
ANAIS has excluded the DAMA/LIBRA signal at $\sim 4\sigma$ with 5σ imminent. **ANAIS+** in development to probe sub-GeV WIMPs



TREX-DM has demonstrated impressive 20 eV thresholds, paving the way to lead sensitivity to 0.1 - 1 GeV WIMPs

DAMIC-M has already produced world-leading constraints on benchmark models of MeV DM, with the full detector in preparation

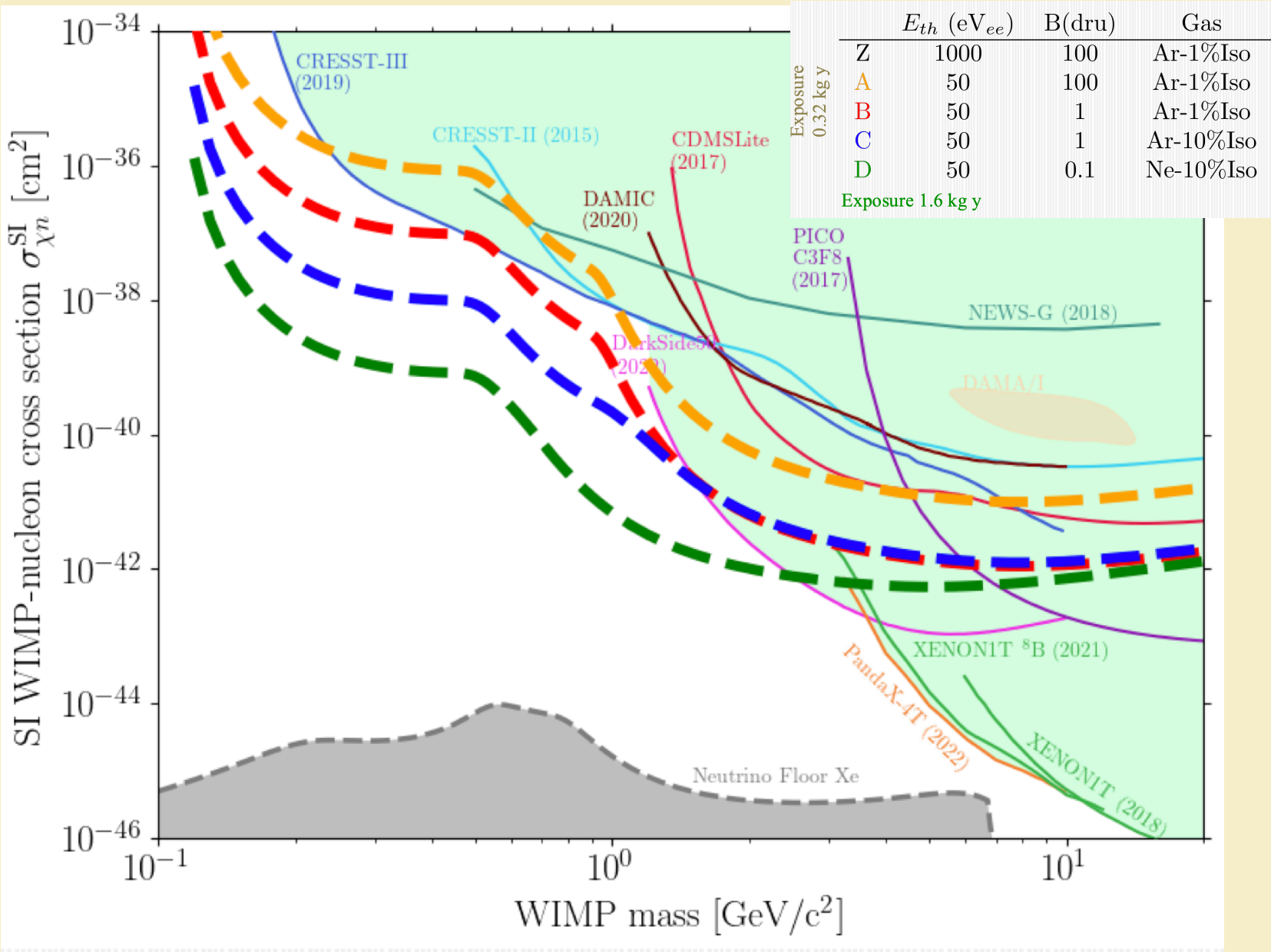
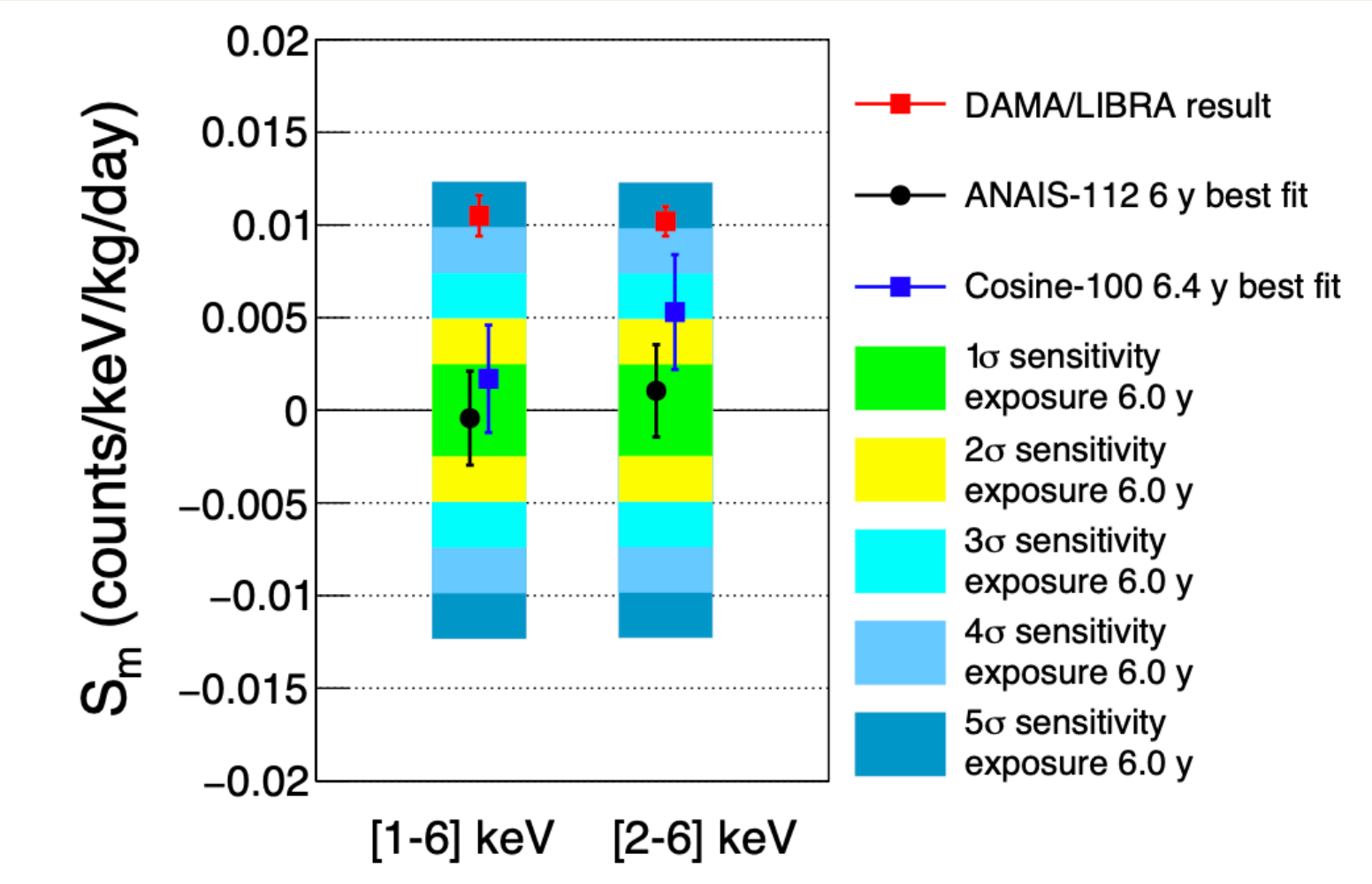
PPCC has also supported ‘spin-offs’ with similar technologies to TREX-DM and DAMIC-M, for radiopurity measurements



Conclusions

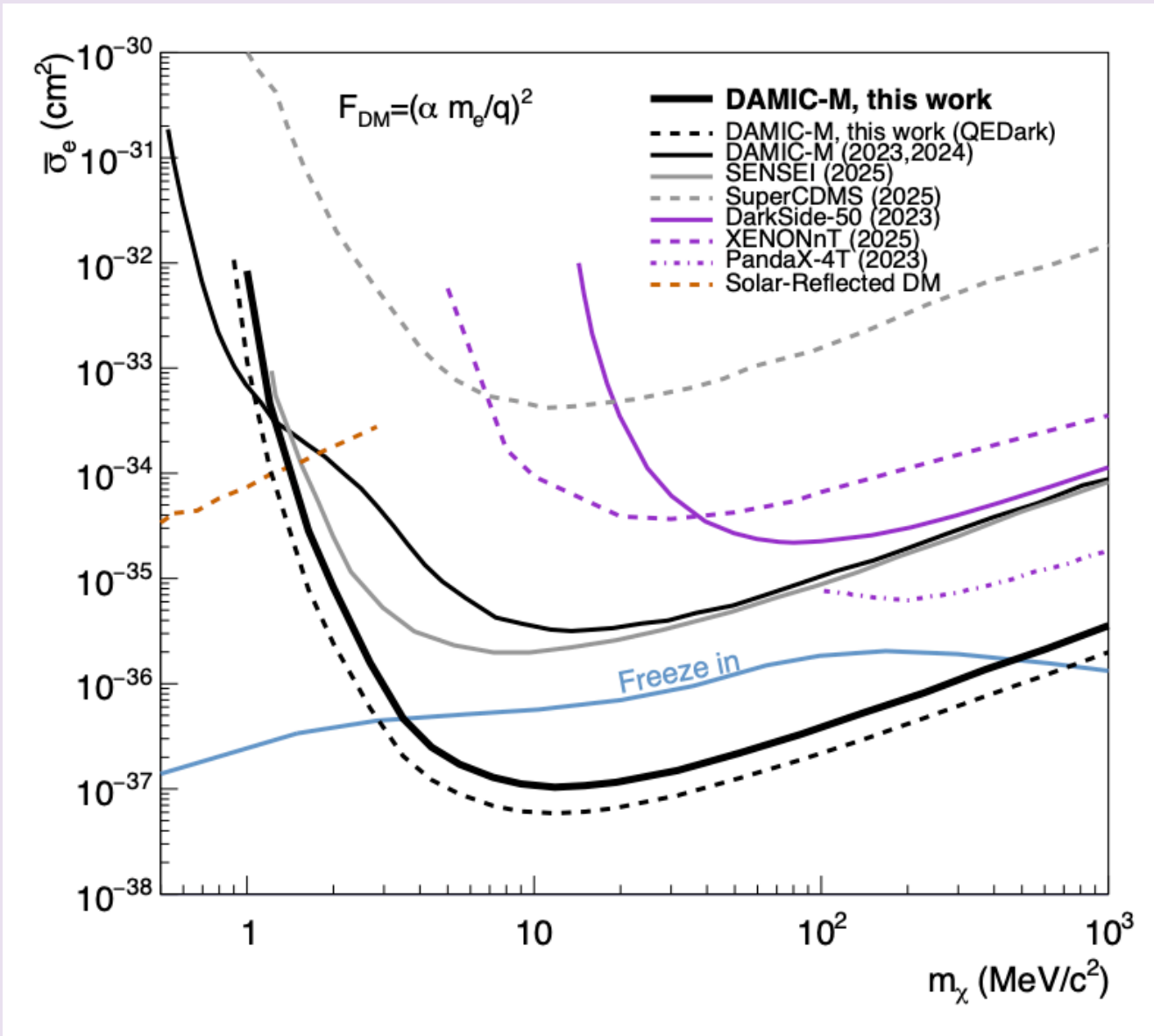
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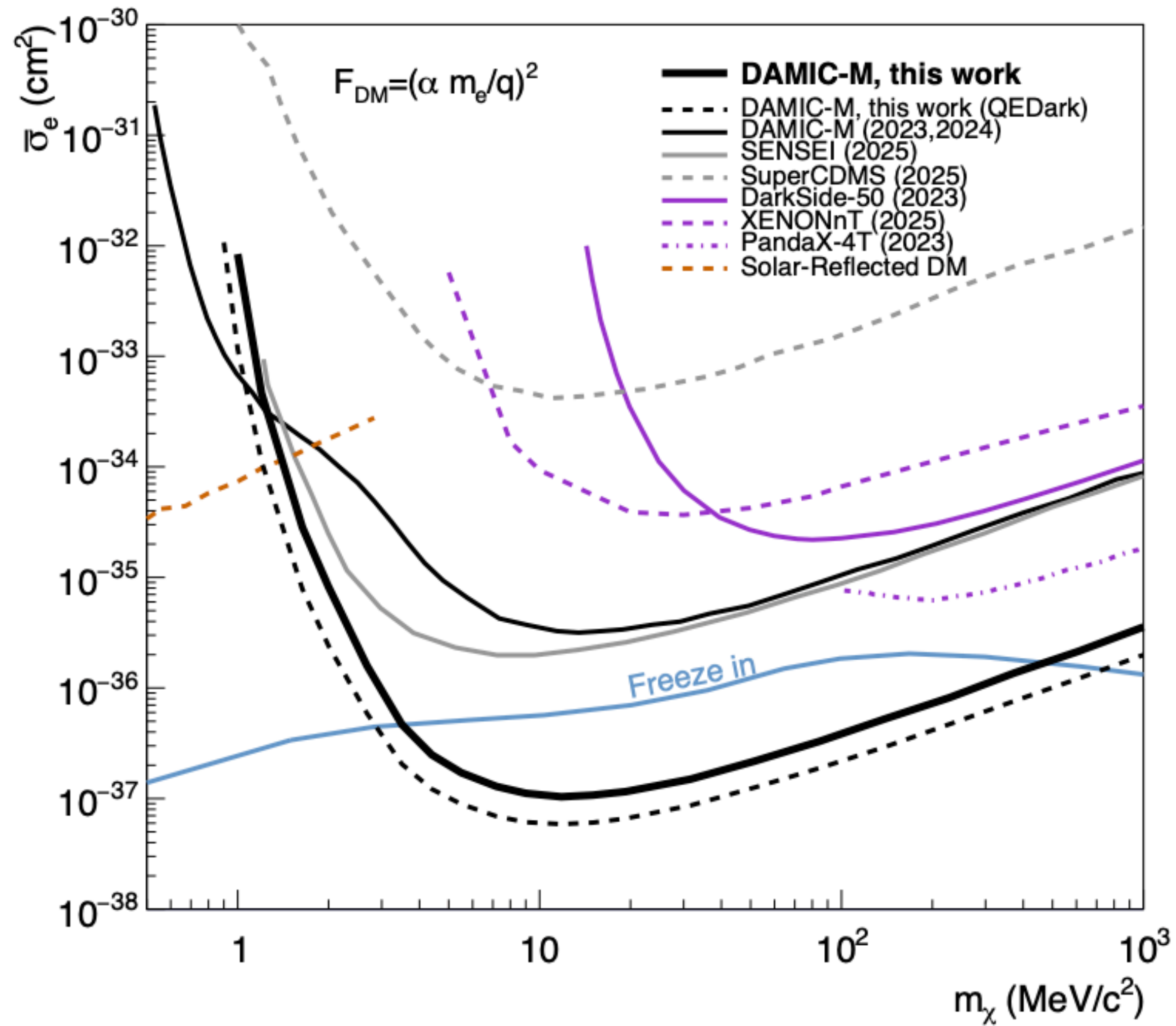
Thank you!

Backup Slides

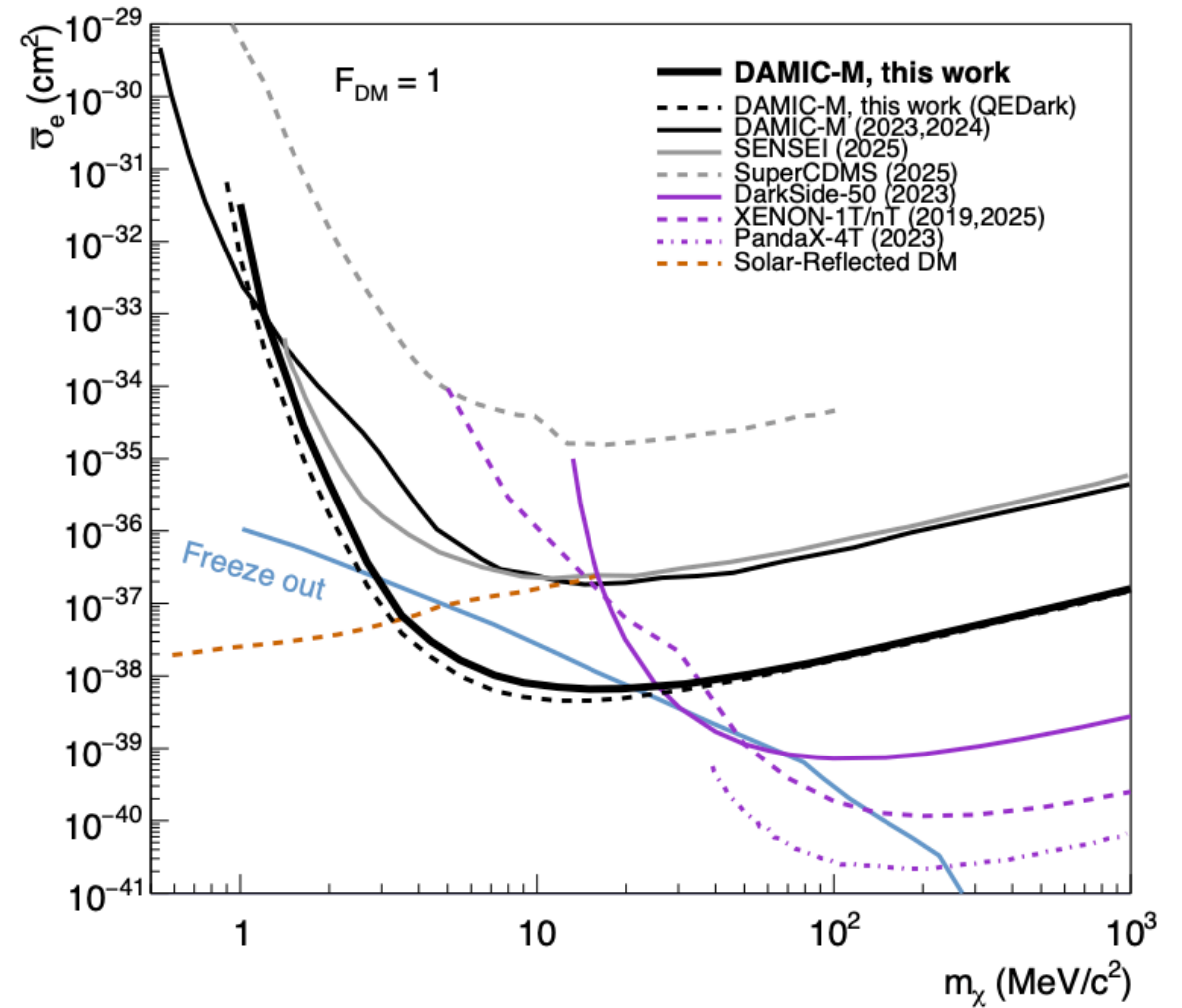
DAMIC-M

Dark Matter In CCDs at Modane

[DAMIC-M Collaboration, PRL, [2503.14617](#)]



Ultralight Dark Photon Mediator

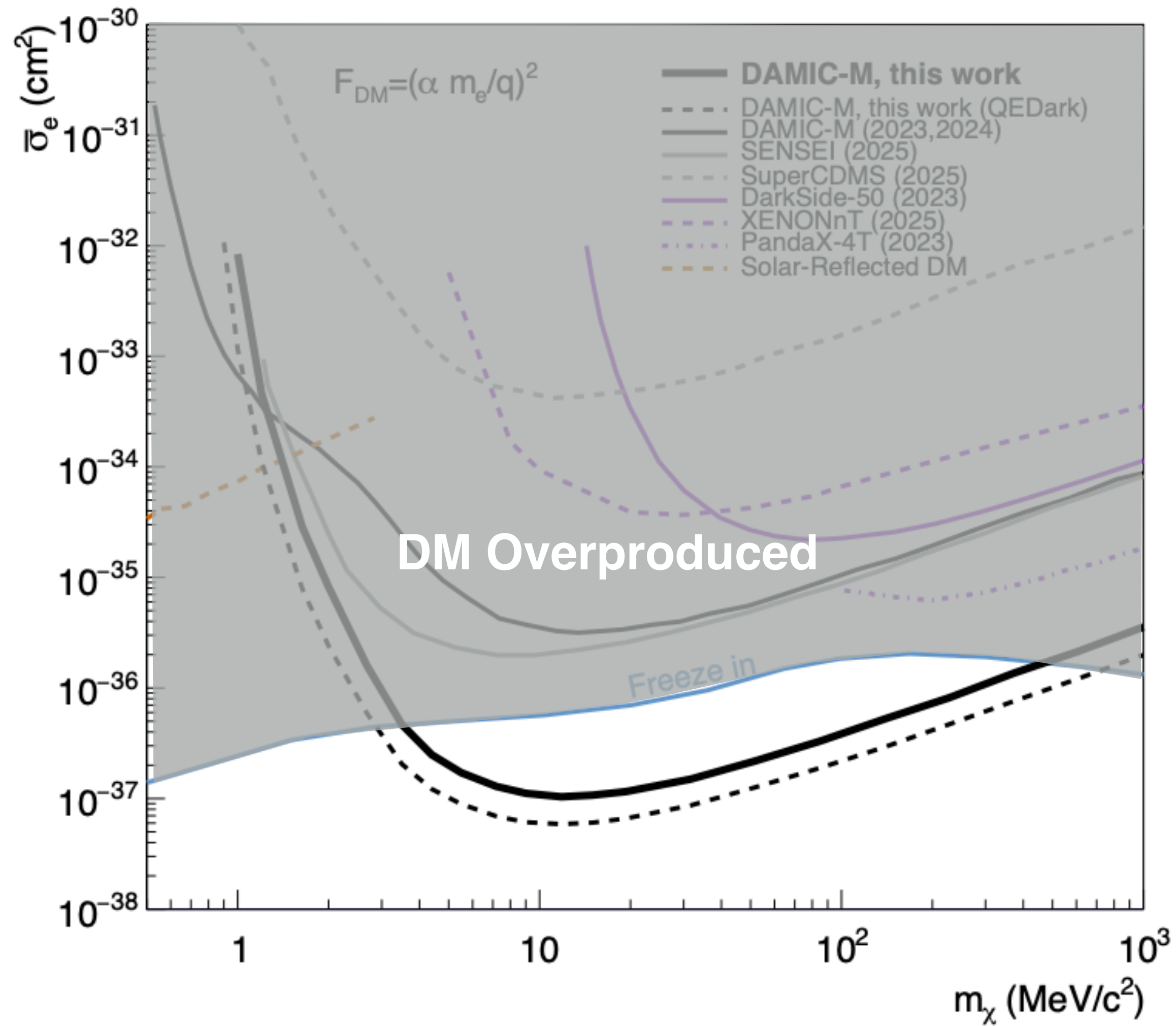


Heavy Dark Photon Mediator

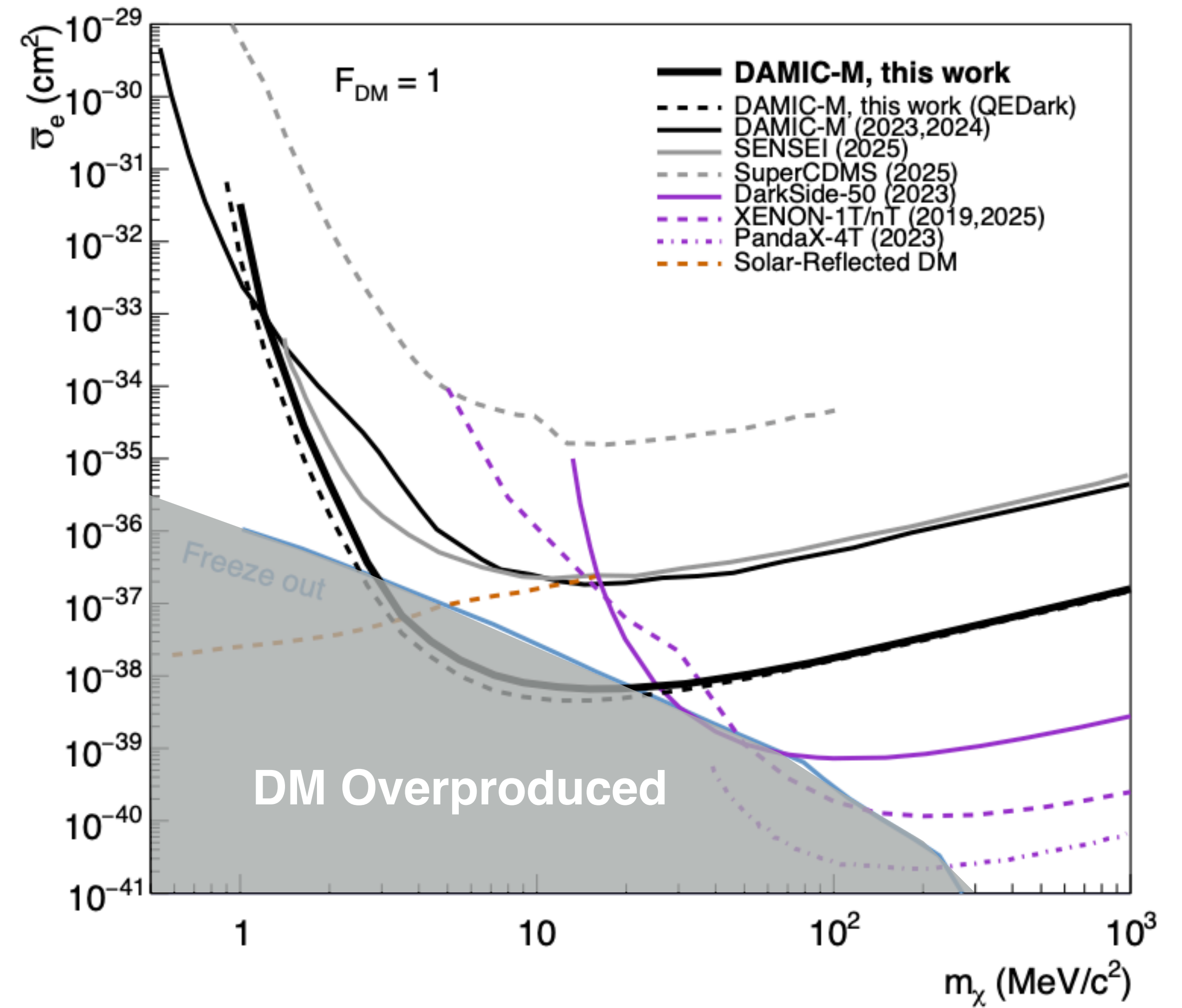
DAMIC-M

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[DAMIC-M Collaboration, PRL, [2503.14617](#)]



Ultralight Dark Photon Mediator

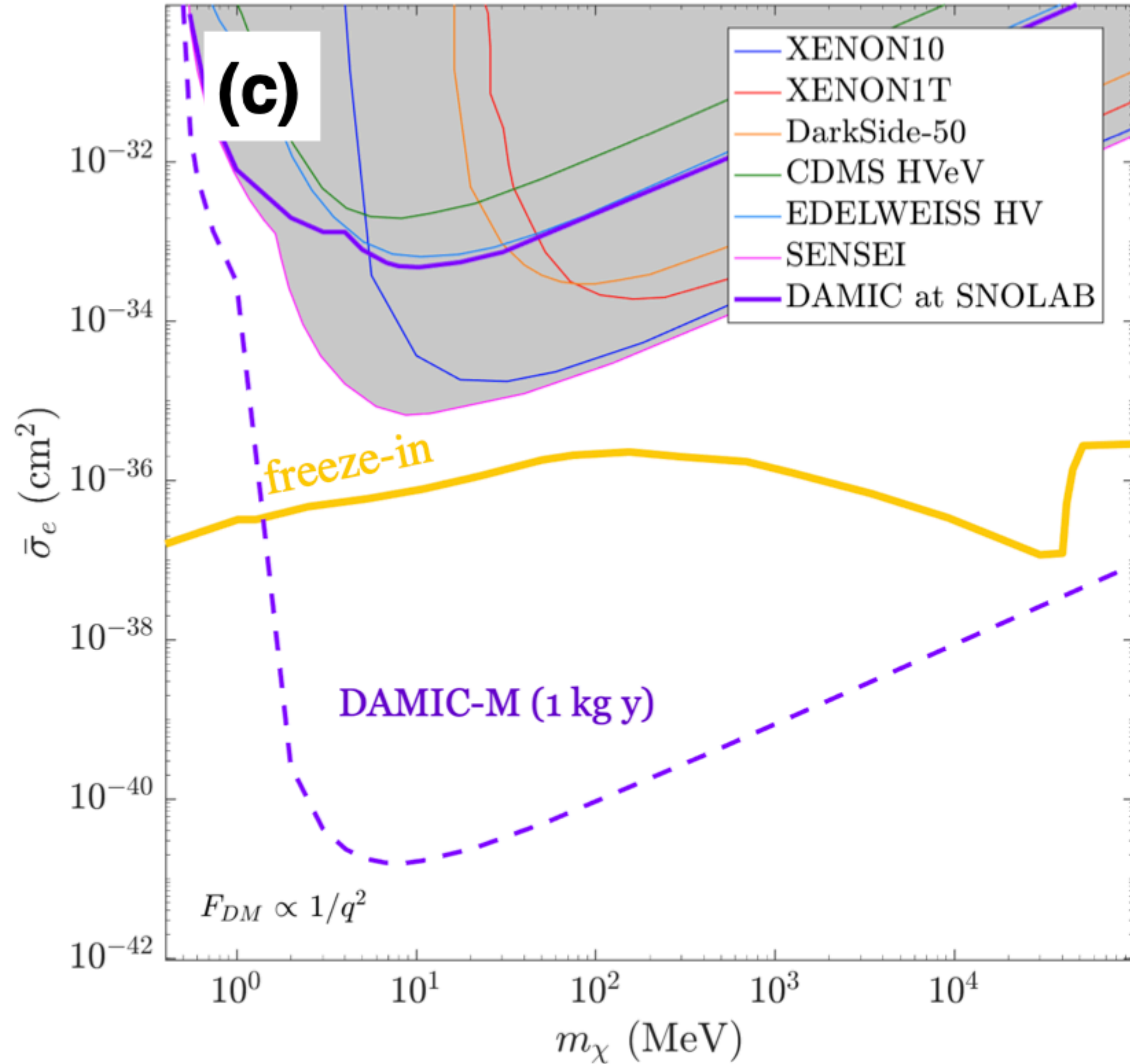


Heavy Dark Photon Mediator

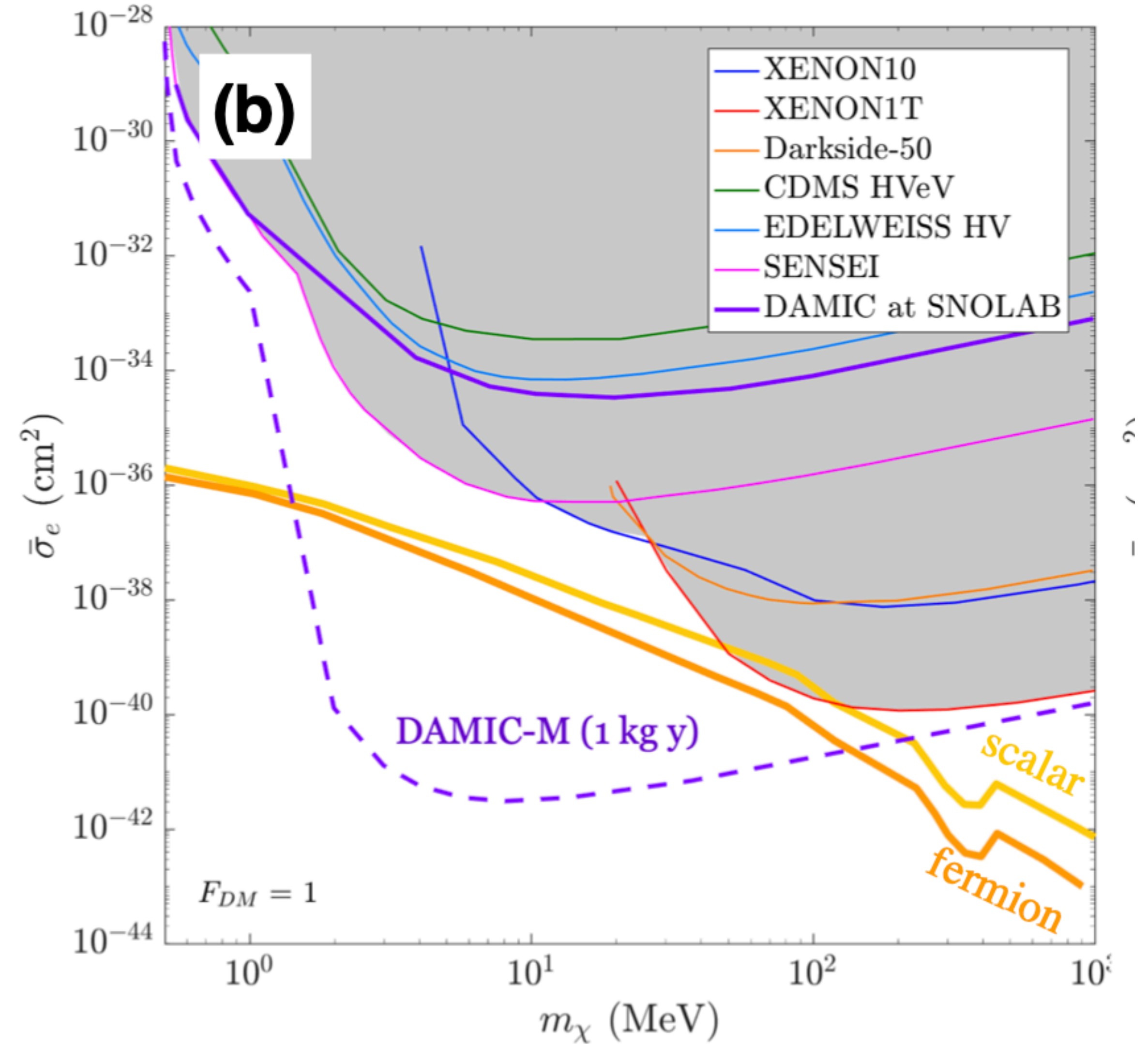
DAMIC-M

Dark Matter In CCDs at Modane

[DAMIC-M Collaboration, PRL, [2503.14617](#)]



Ultralight Dark Photon Mediator

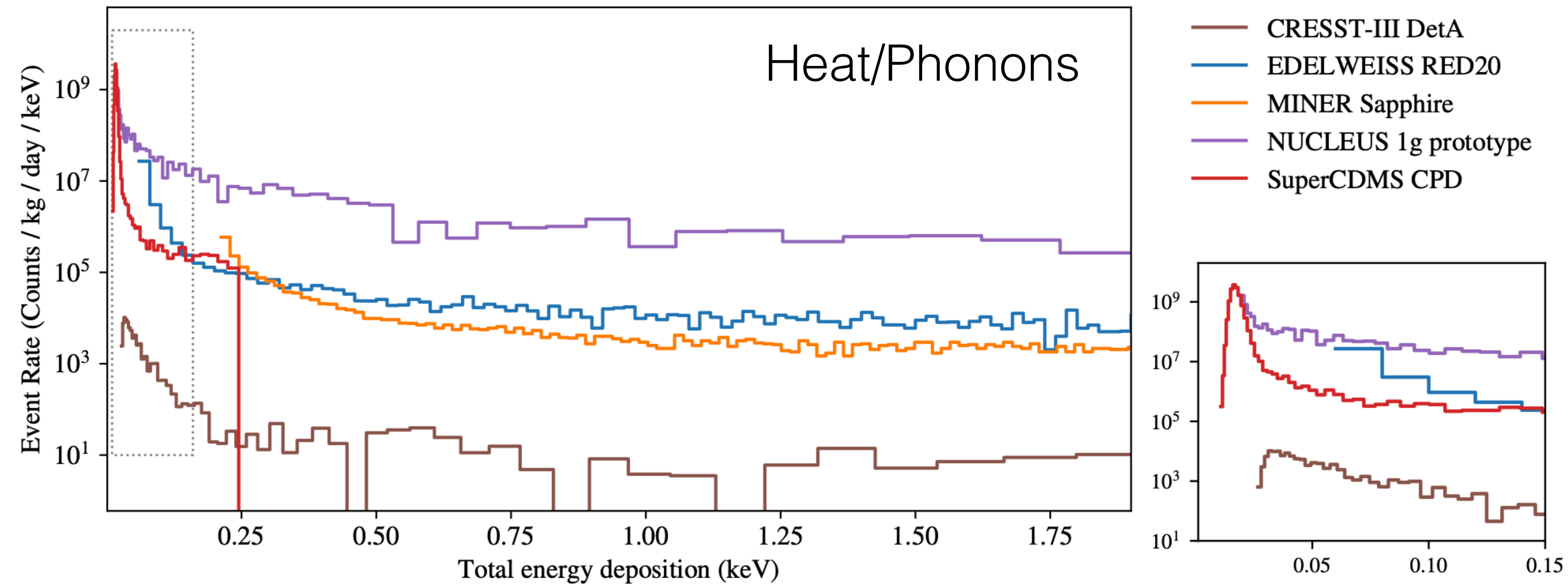


Heavy Dark Photon Mediator

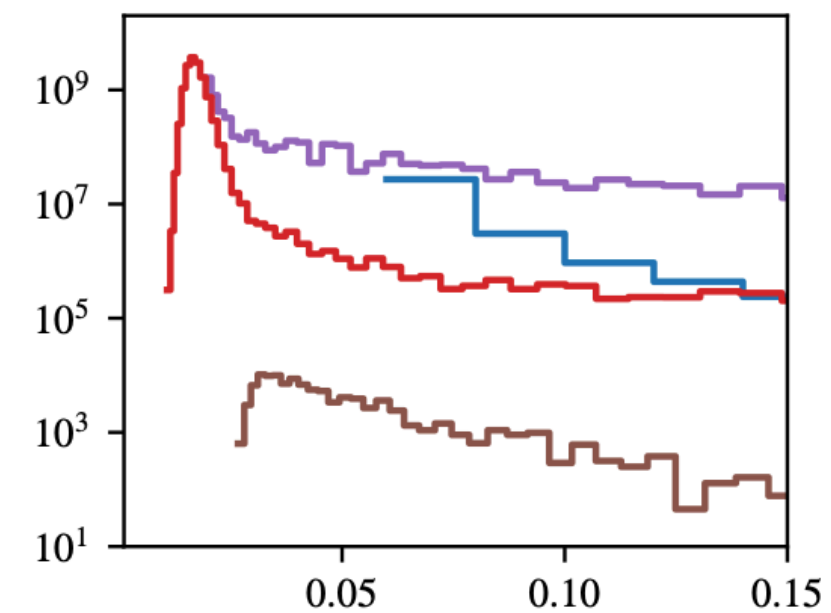
EXCESS

Understanding low-energy excesses

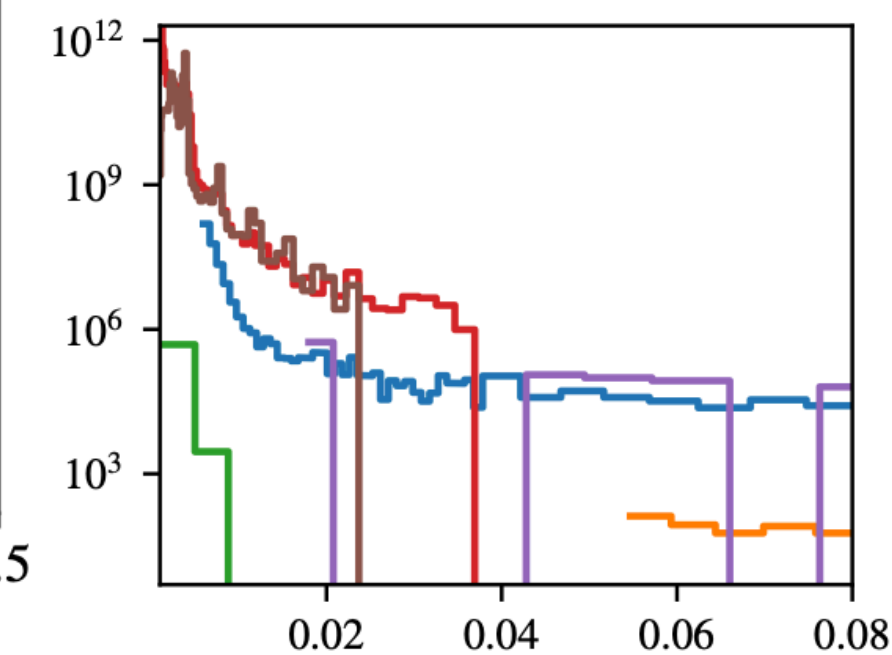
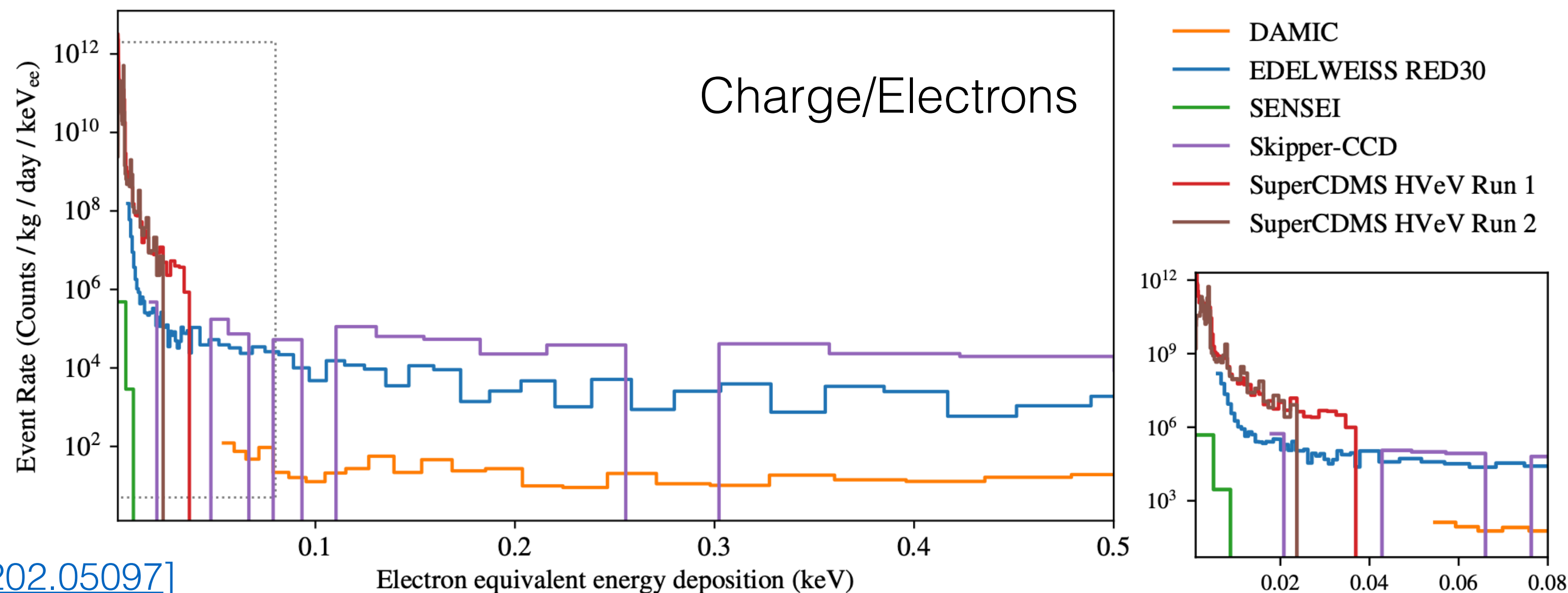
[EXCESS Workshop Series,
<https://agenda.infn.it/event/39007/>]



Excess event rate seen in many low-threshold experiments below 1 keV.



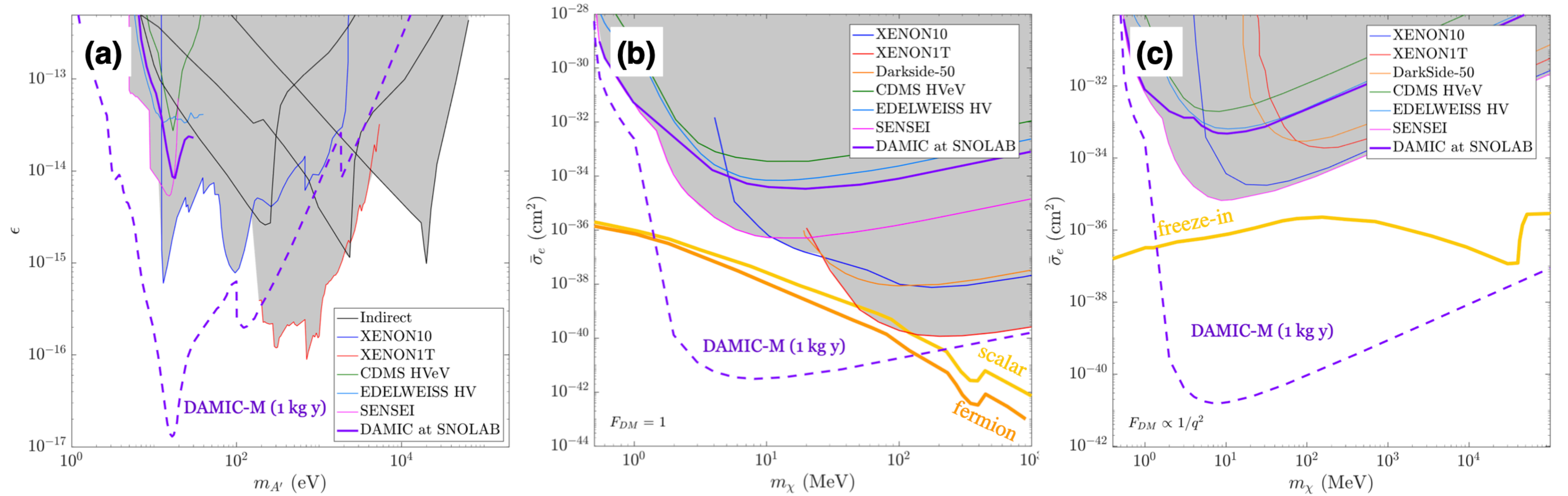
Time-dependence and cross-checks in multiple channels suggests that this is not due to DM, but could have a **profound impact on low mass DM sensitivity!**



Ongoing work to understand this excess, but could be due to:

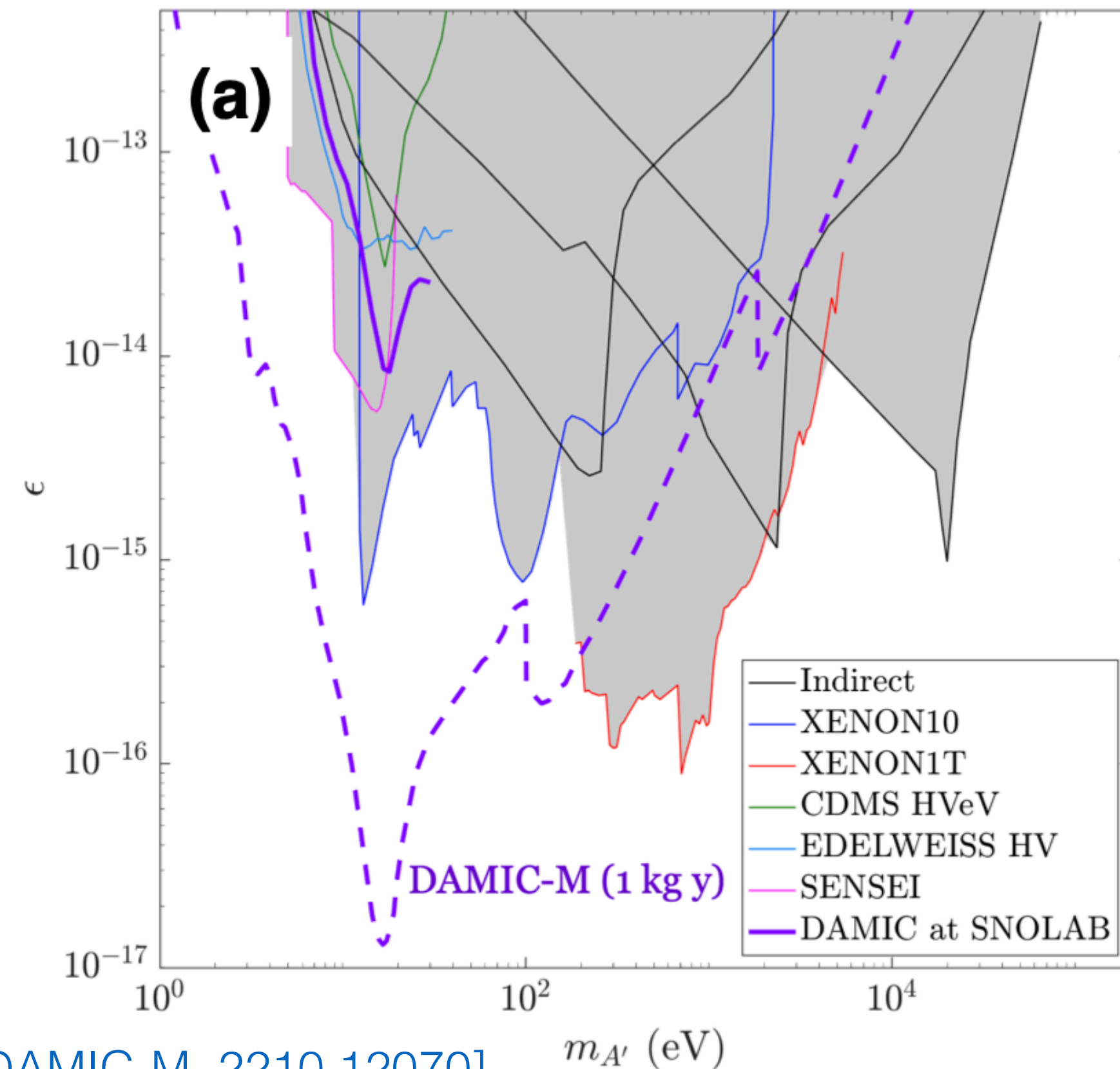
- Relaxation of the sensor
- Relaxation of the target material
- Relaxation of supports
- Energy stored in interfaces

DAMIC-M Projections



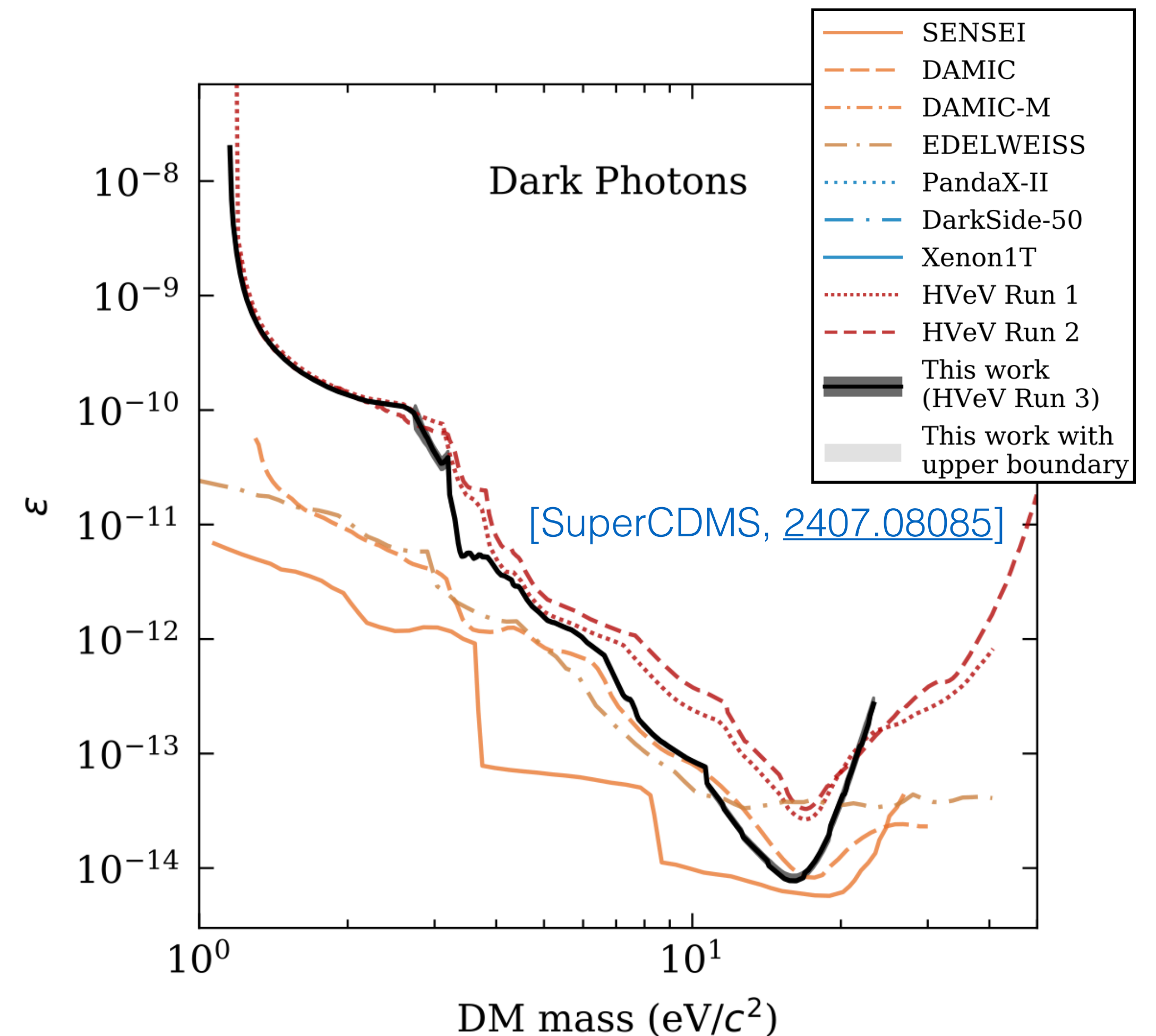
[DAMIC-M, [2210.12070](#)]

Dark Matter Absorption



Very light vector particles A' may be absorbed directly by electrons, in analogy with the photo-electric effect

Look for a peak of events with a given energy



$$R(\omega) = \frac{\rho_{\text{DM}}}{m_{A'}} \epsilon_{\text{eff}}^2 \sigma_{\gamma} (\omega = m_{A'})$$

Effective photon-dark
photon mixing

Photo-electric cross-
section

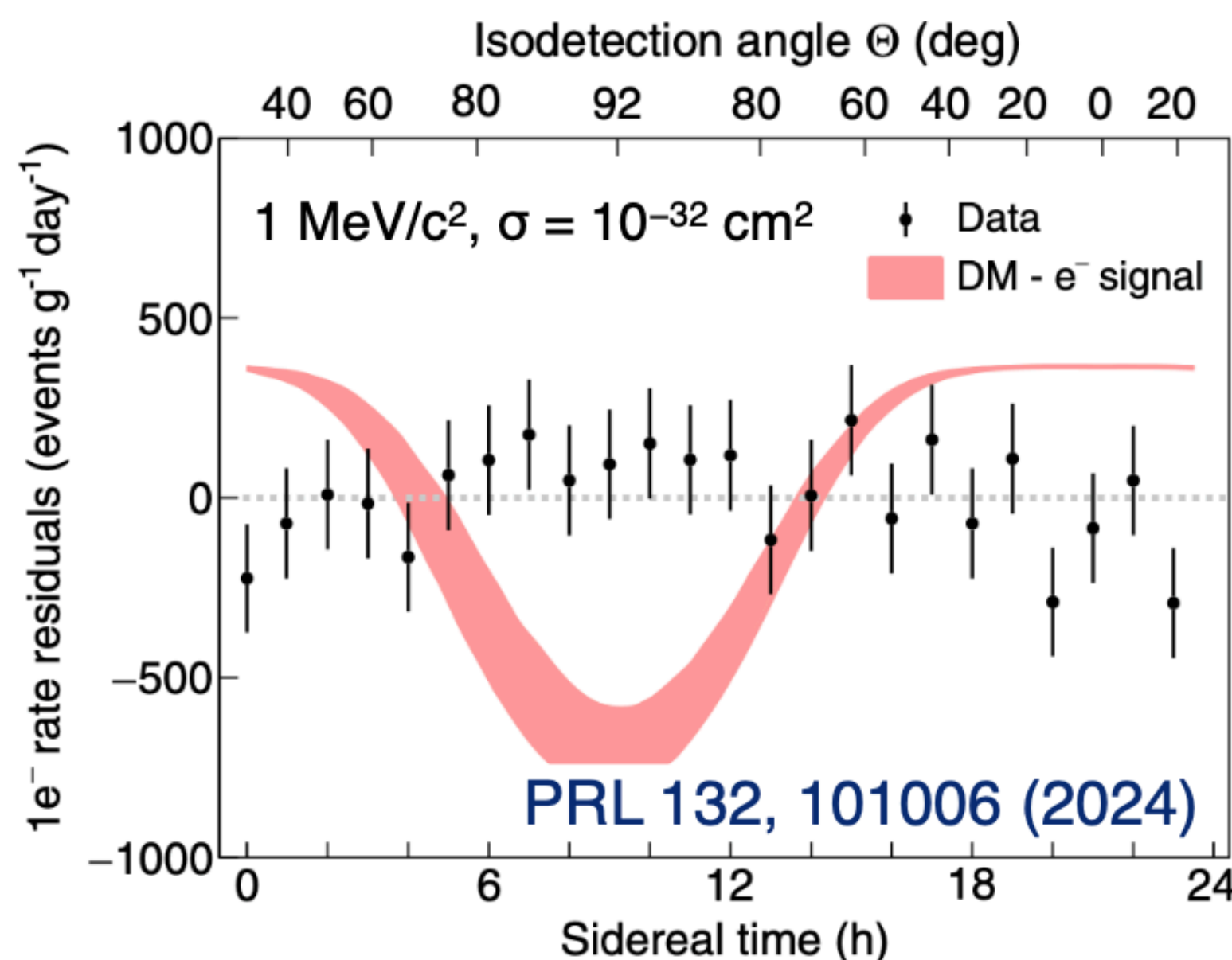
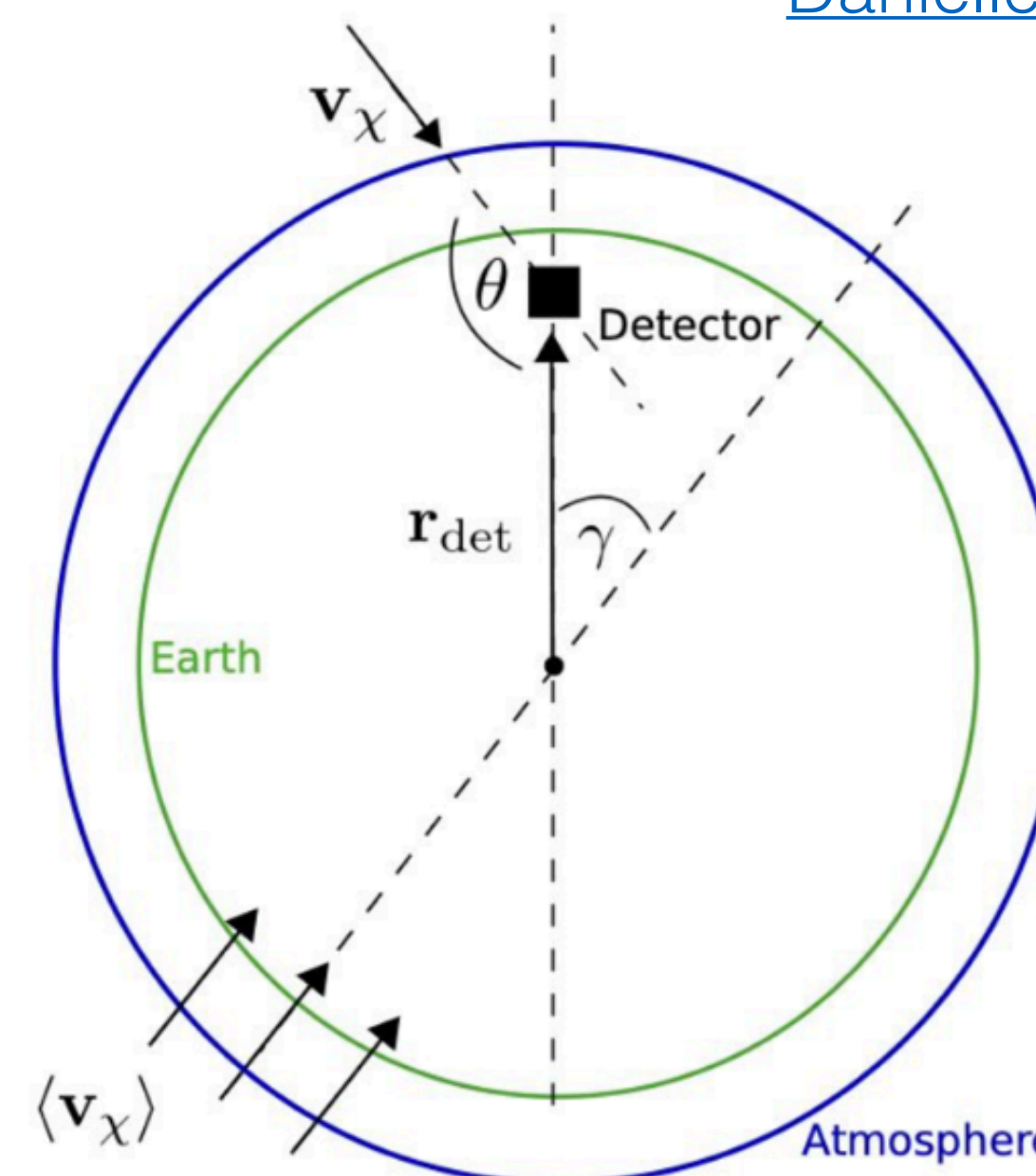
[Hochberg et al., [1604.06800](#)]

Daily modulation search

[Danielle Norcini \(Jul 2024\)](#)

Motivation:

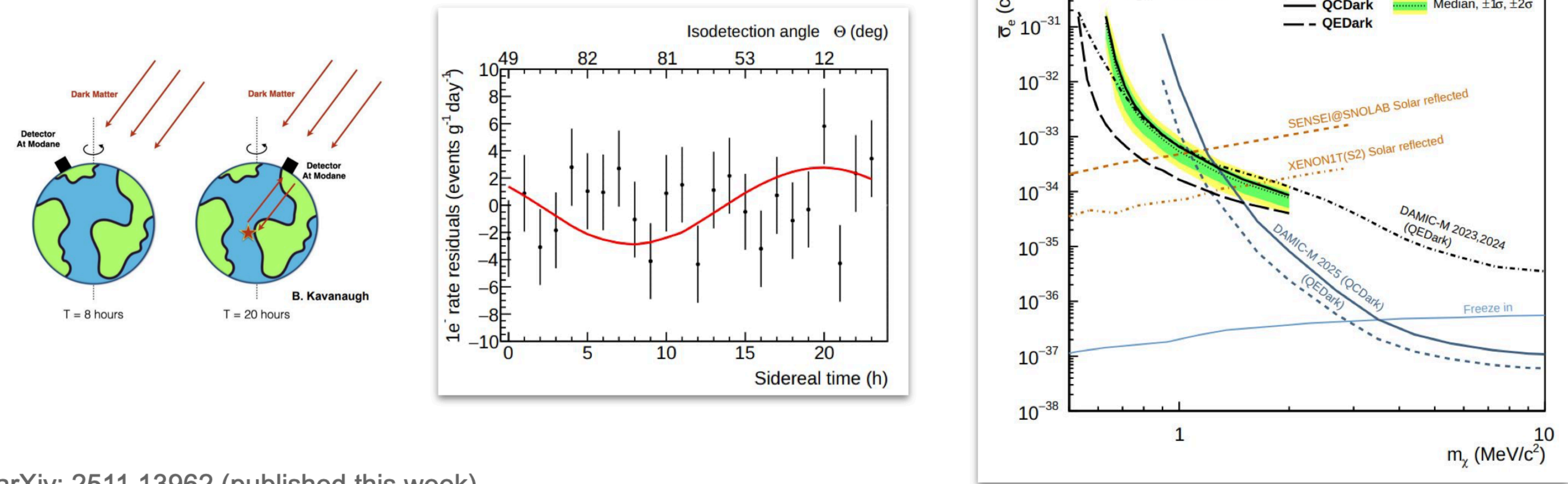
- MeV-scale DM candidates with large cross sections have not been ruled out
- scattering in Earth's bulk becomes relevant for flux/velocity distribution, DM signal can modulate over day
- in LBC, time-dependent signal vs. independent background strong discriminating power
- new approach for constraining DM-e scattering



LBC result:

- search in 1e- bin, as >1e- already constrained
- same data set as DM-e scattering, except using images taken consecutively every 10min
- no modulation signal found for periods of 1-48 hr
- improves first LBC DM-e by 2 orders of magnitude

DAMIC-M probes benchmark hidden-sector dark matter models: freeze-out rolued out, reaching freeze-in for the first time ... **AND PUSHING TO LOWER ENERGIES WITH DAILY MODULATION**



arXiv: 2511.13962 (published this week)

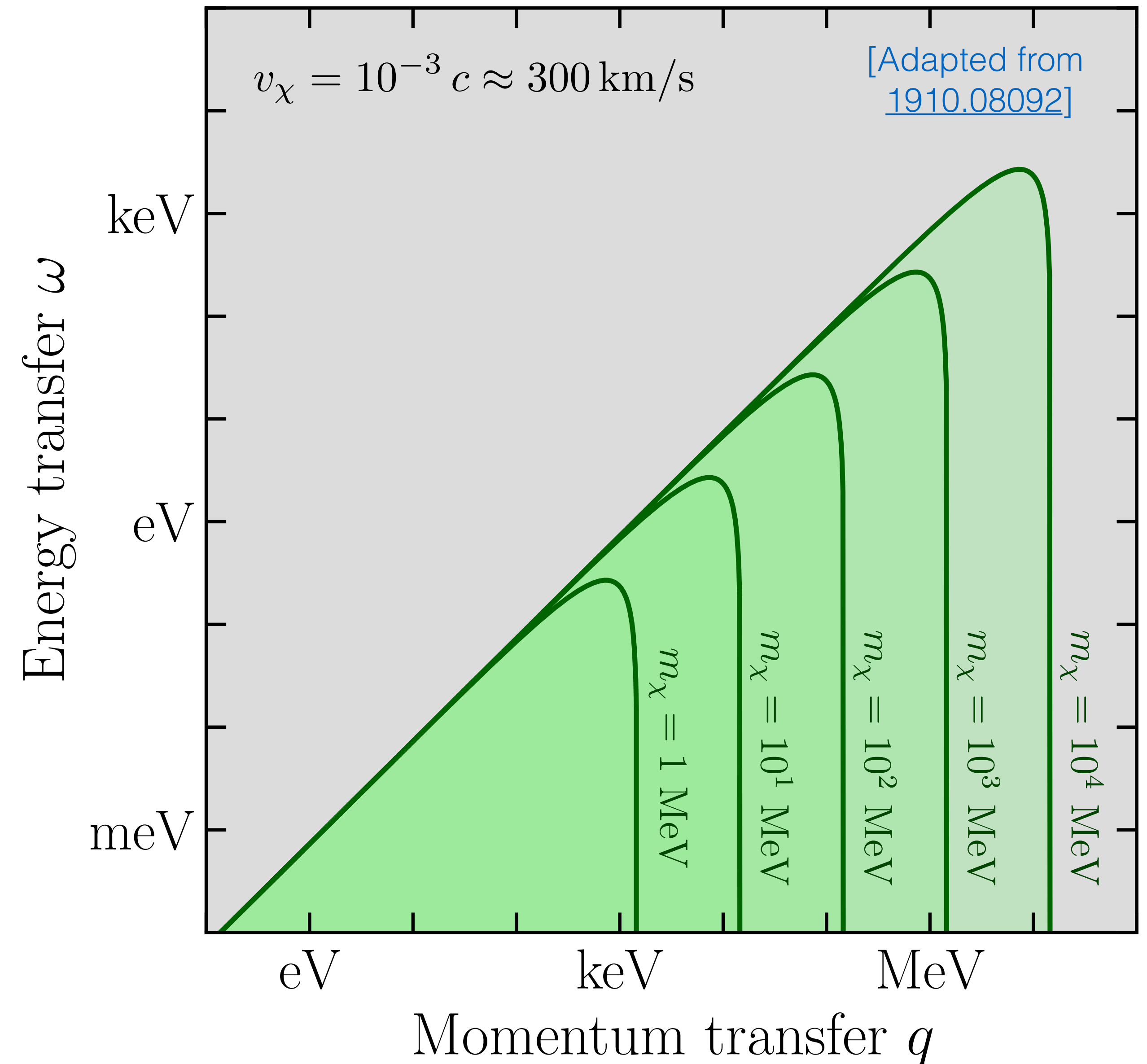
Scattering Kinematics

Allowed range of (ω, q) set by kinematics (green regions):

$$\omega \leq qv_\chi - q^2/2m_\chi$$

Consider:

- **Nuclear recoils** - can probe energies down to eV, but realistically can only measure recoil energies down to $\sim \text{keV} \rightarrow m_\chi \gtrsim \text{GeV}$
- **Electron ionisation** - possible for $\omega > \Delta \sim \text{eV} \rightarrow m_\chi \gtrsim \text{MeV}$
- **Phonon interactions** - possible for sufficiently small q , with $\omega_{\text{ph}} \sim \mathcal{O}(10\text{s}) \text{ meV} \rightarrow m_\chi \sim \text{keV} - 50 \text{ MeV}$



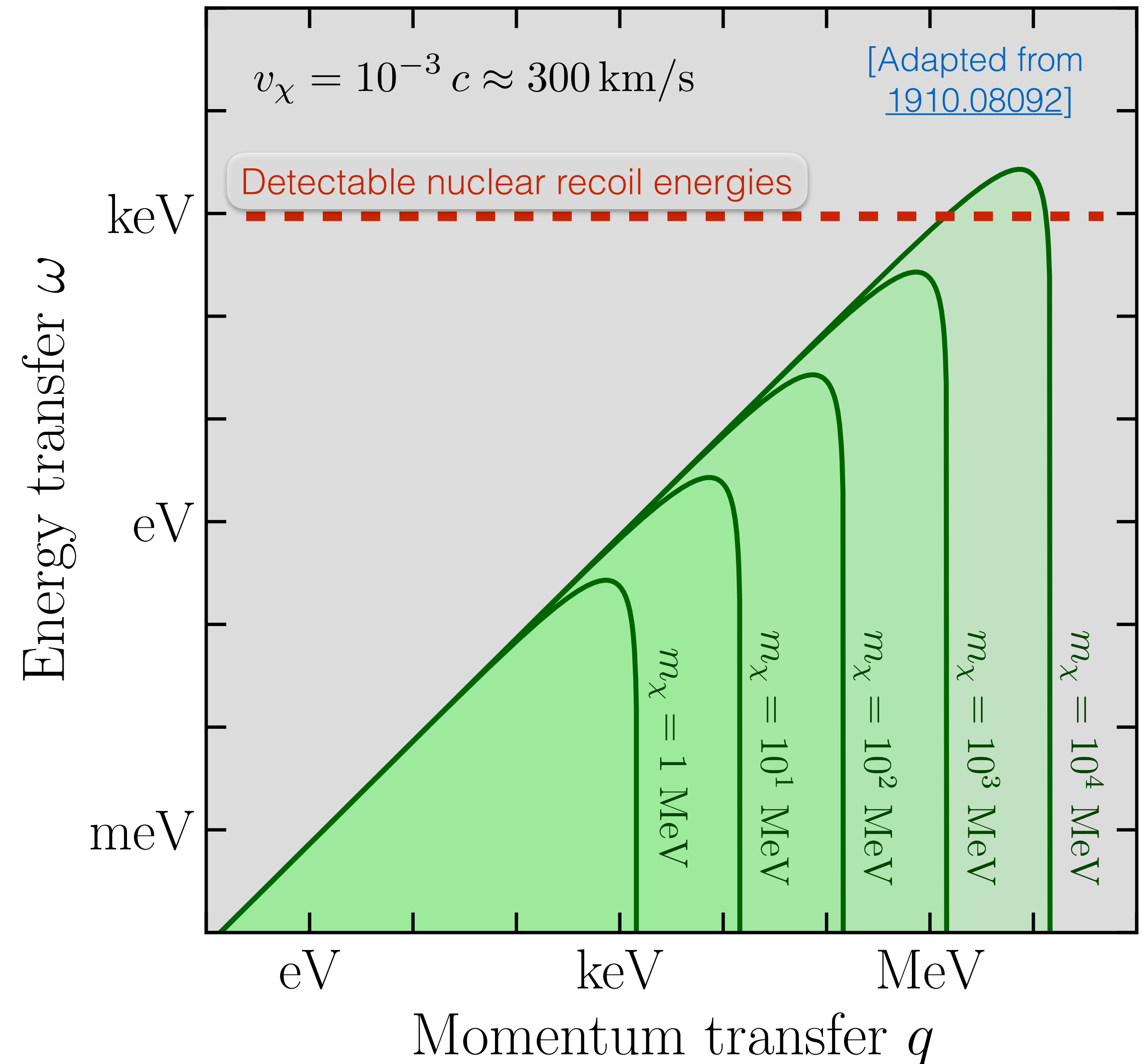
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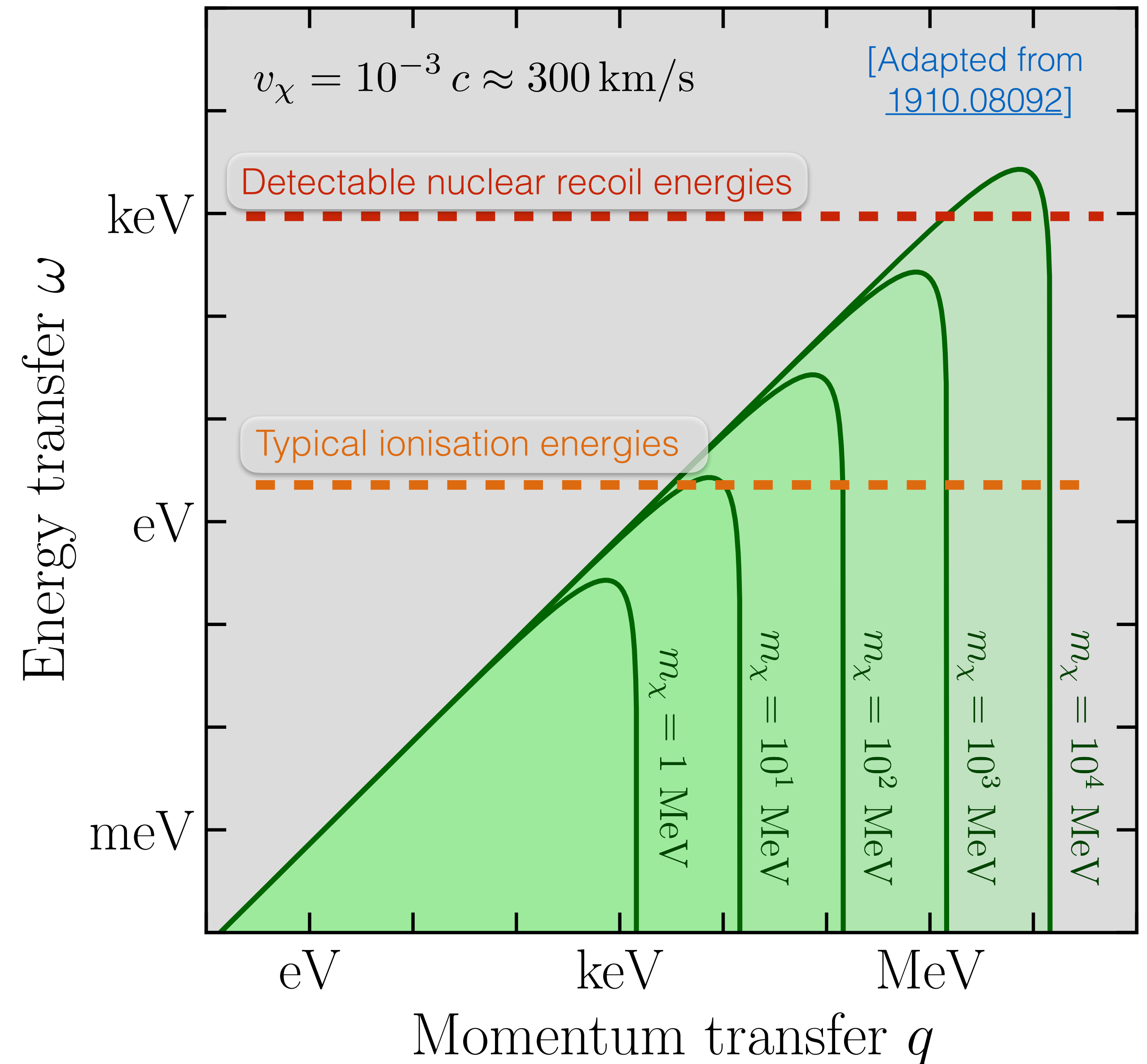
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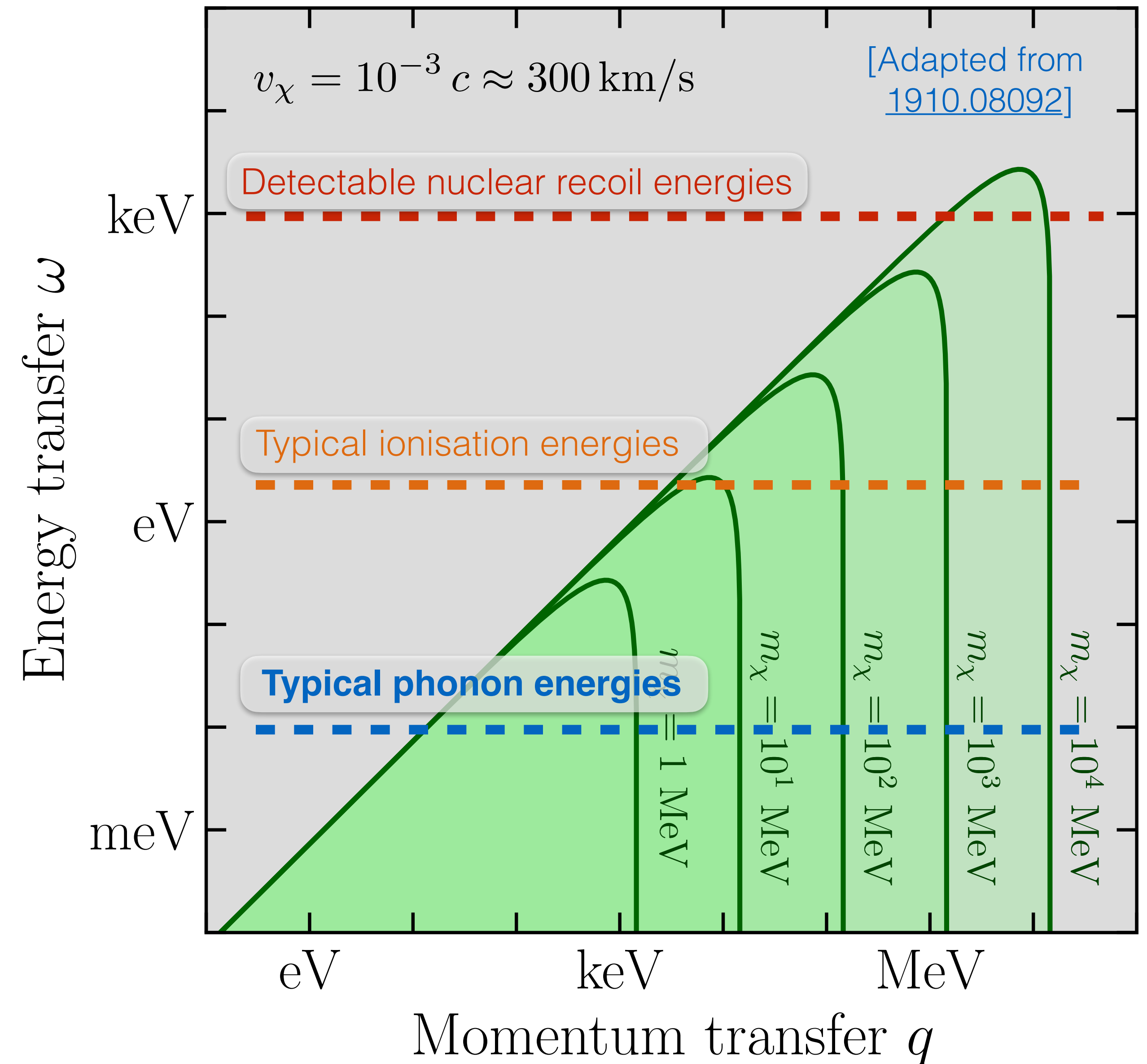
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Scattering Kinematics

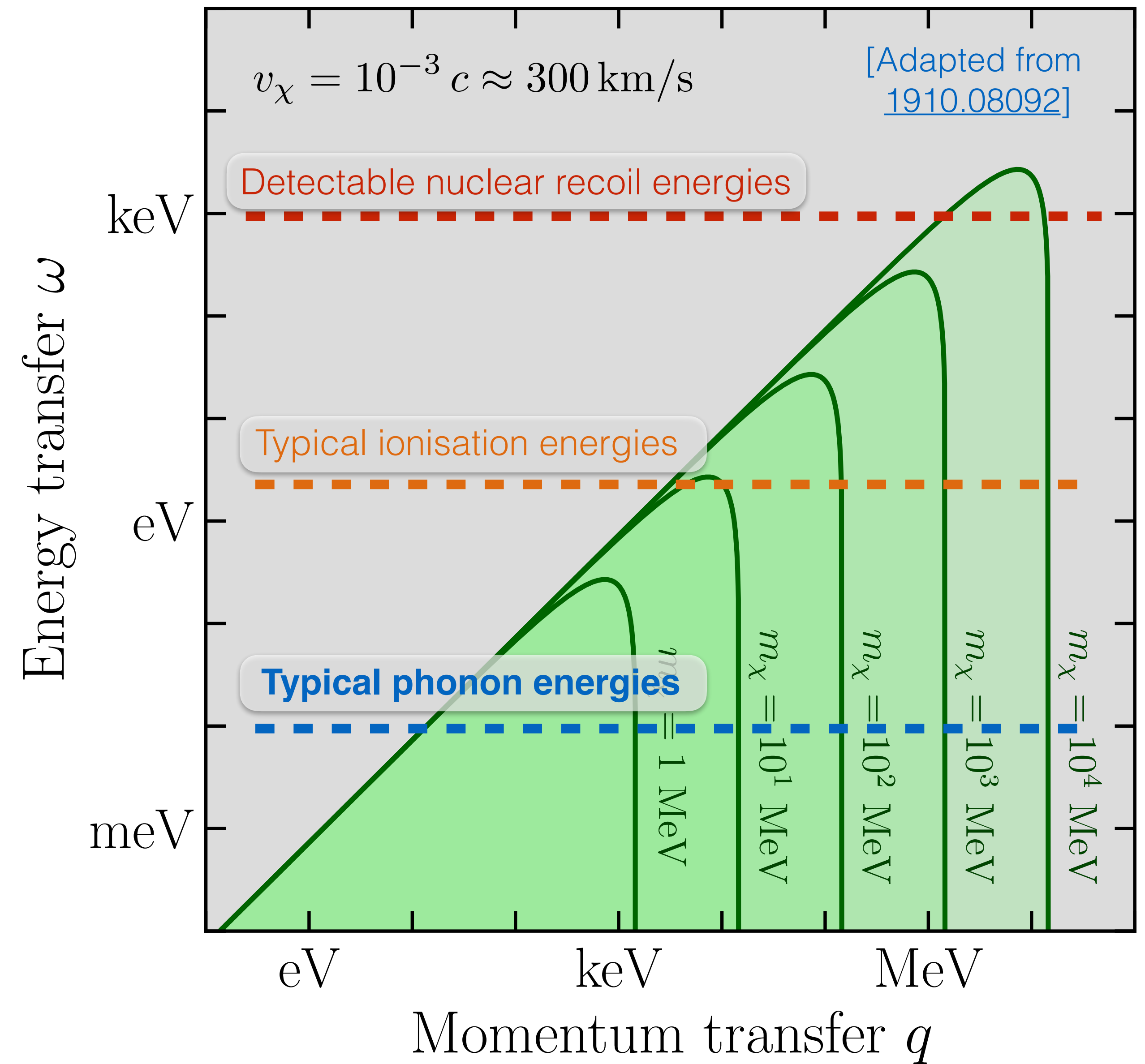
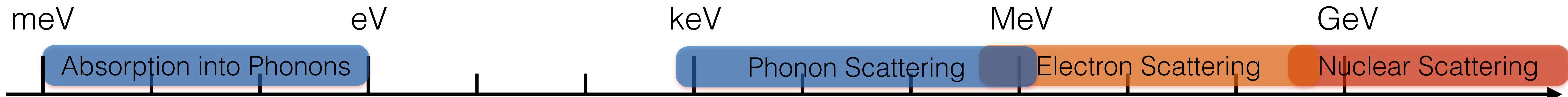
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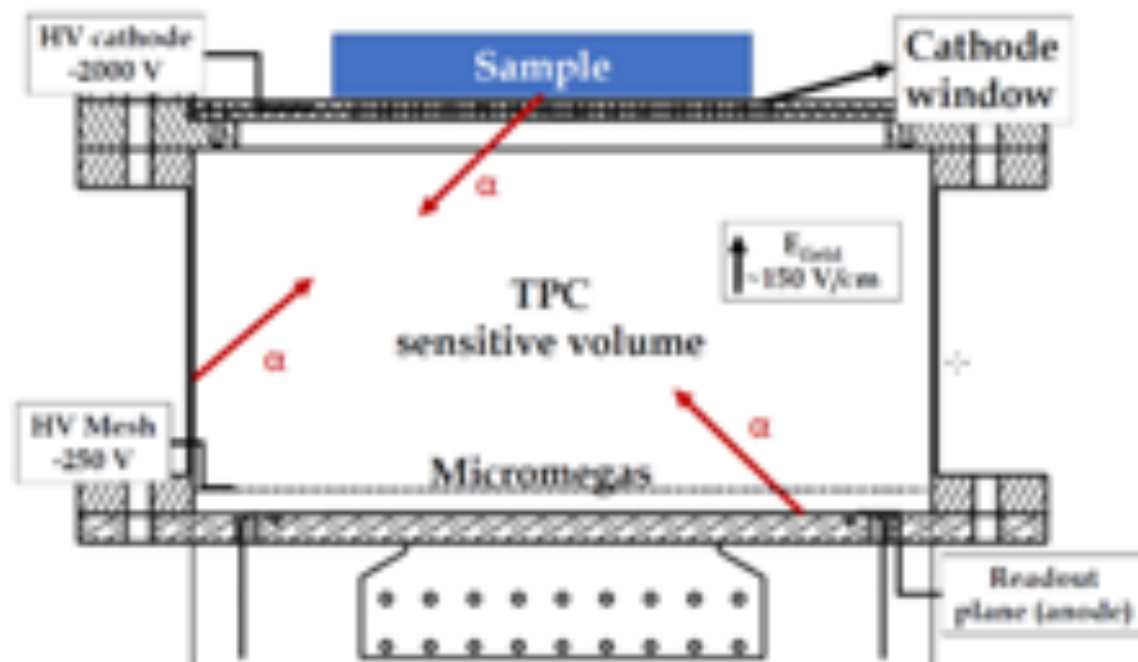
DM mass ranges:



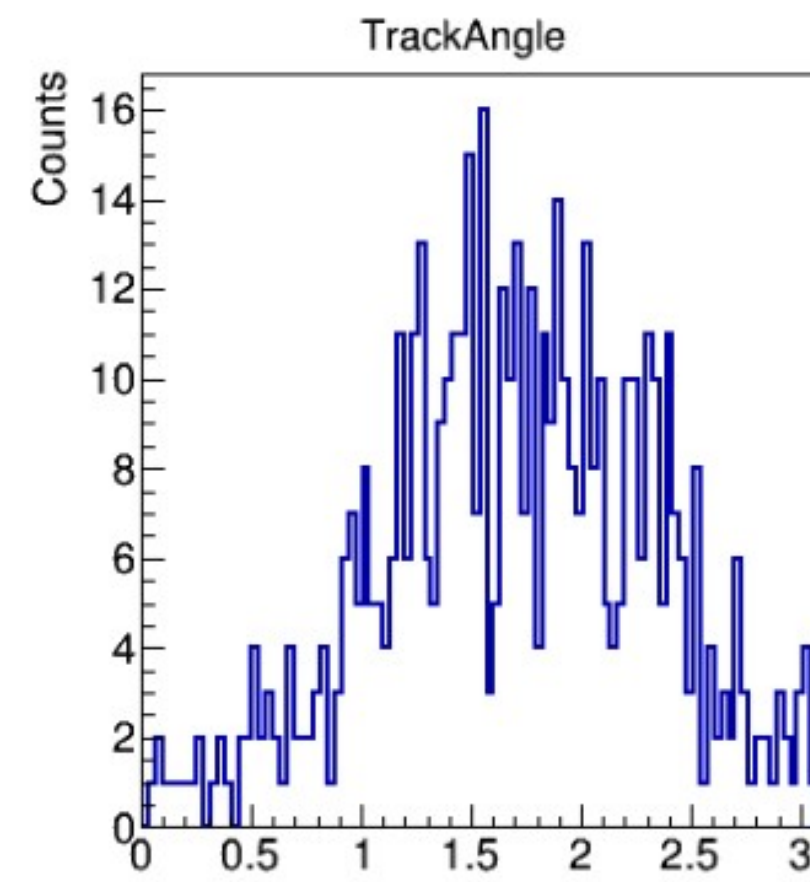
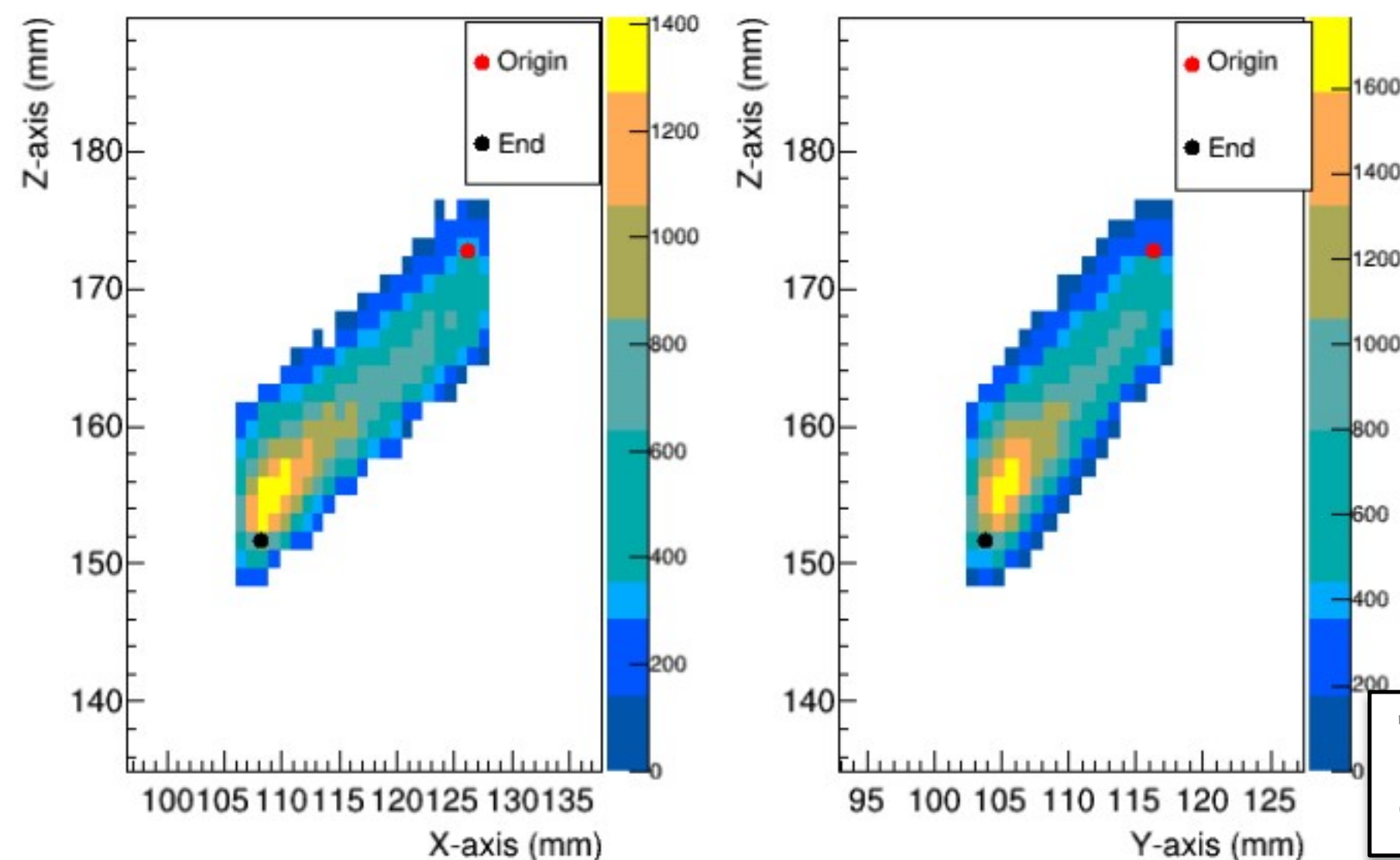
AlphaCamm (Alpha CAMera Micromegas)

- ‘Spin-off’ of TRES-DM: gaseous chamber with a segmented mM (25cm x 25cm) to measure ^{210}Pb surface contamination of flat samples down to 100 nBq/cm^2

K. Altenmuller et al, 2022 JINST 17 P08035



Measurements of materials of interest already started:
aluminised mylar, ‘clean’ copper wires, copper-clad kapton, copper strips on kapton...



Topological information to reconstruct origin and end of a tracks from ^{210}Po

