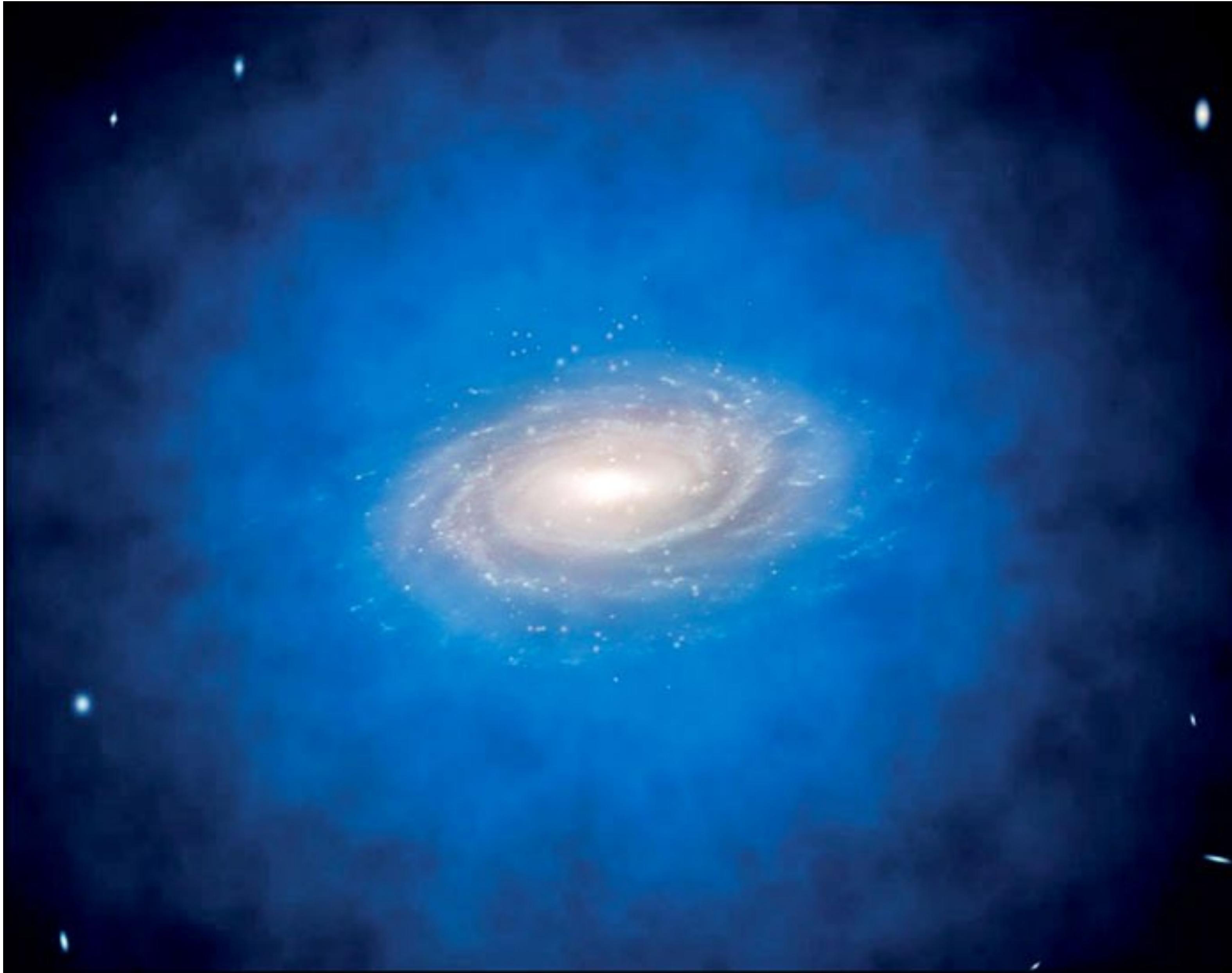


Weakly Interacting Massive Particles (WIMPs) & Light Dark Matter Searches

Bradley J Kavanagh
Instituto de Física de Cantabria (IFCA)
 kavanagh@ifca.unican.es

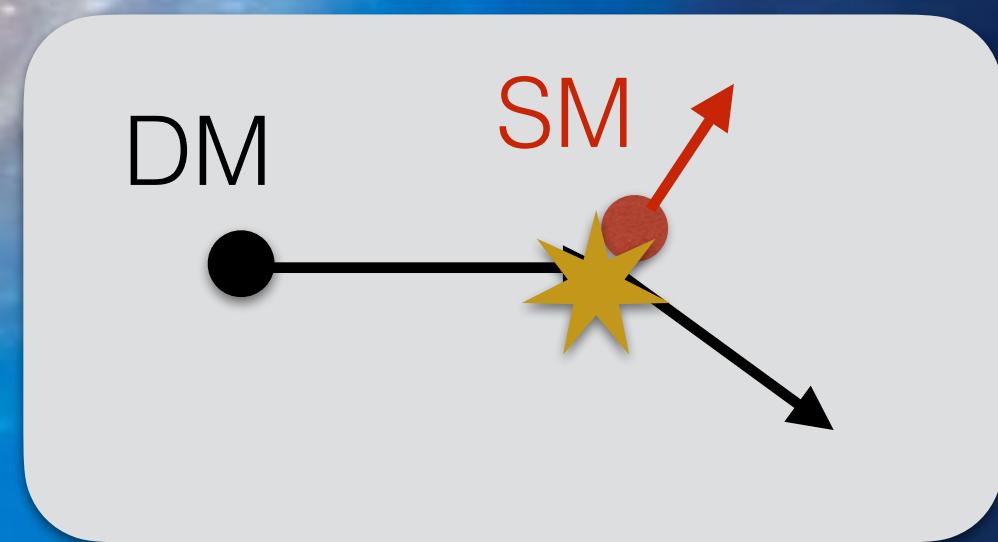
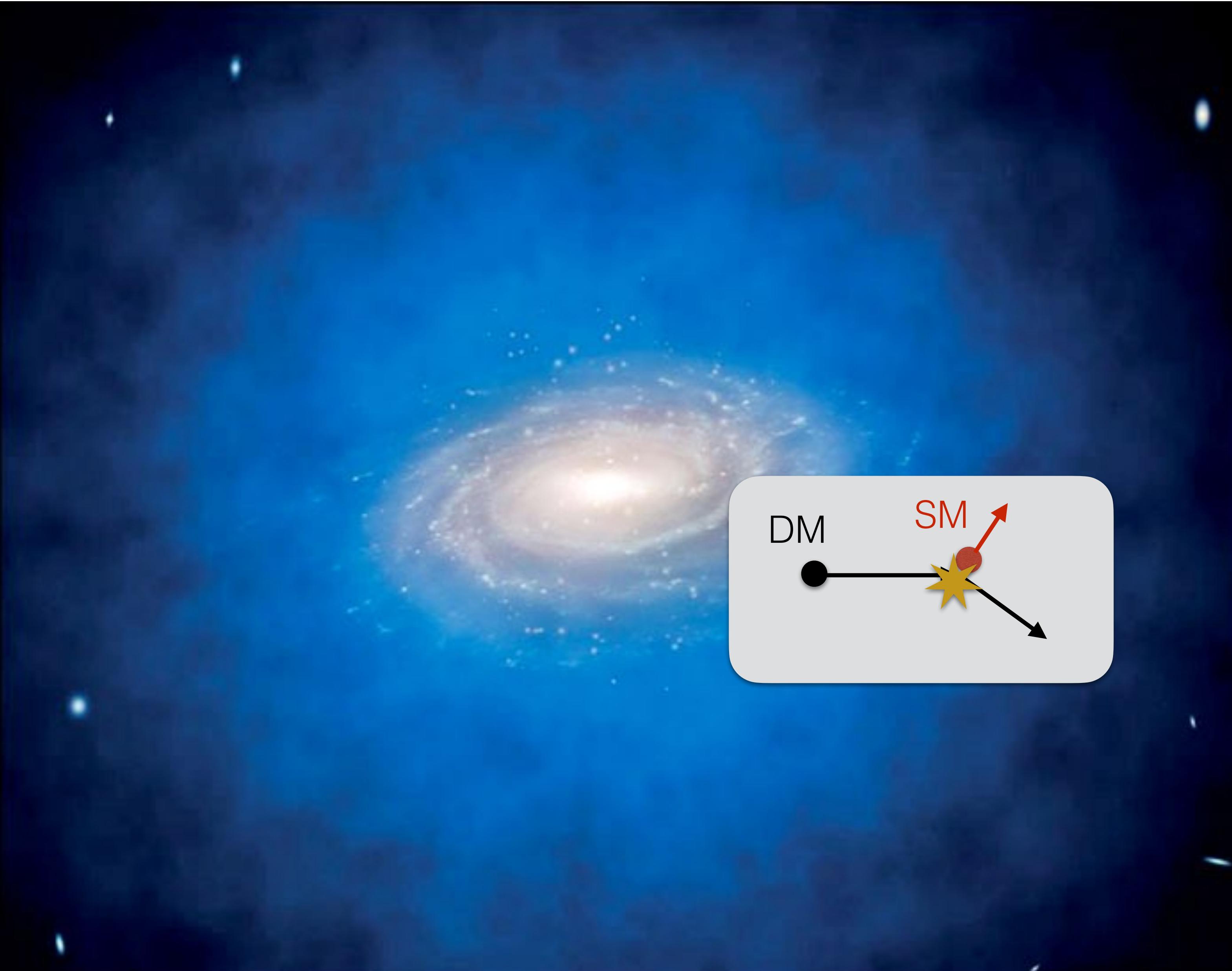
26 November 2025
Plan Complementario ASTRO+HEP

Direct Detection of Dark Matter (DM)



Direct Detection of Dark Matter (DM)

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



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

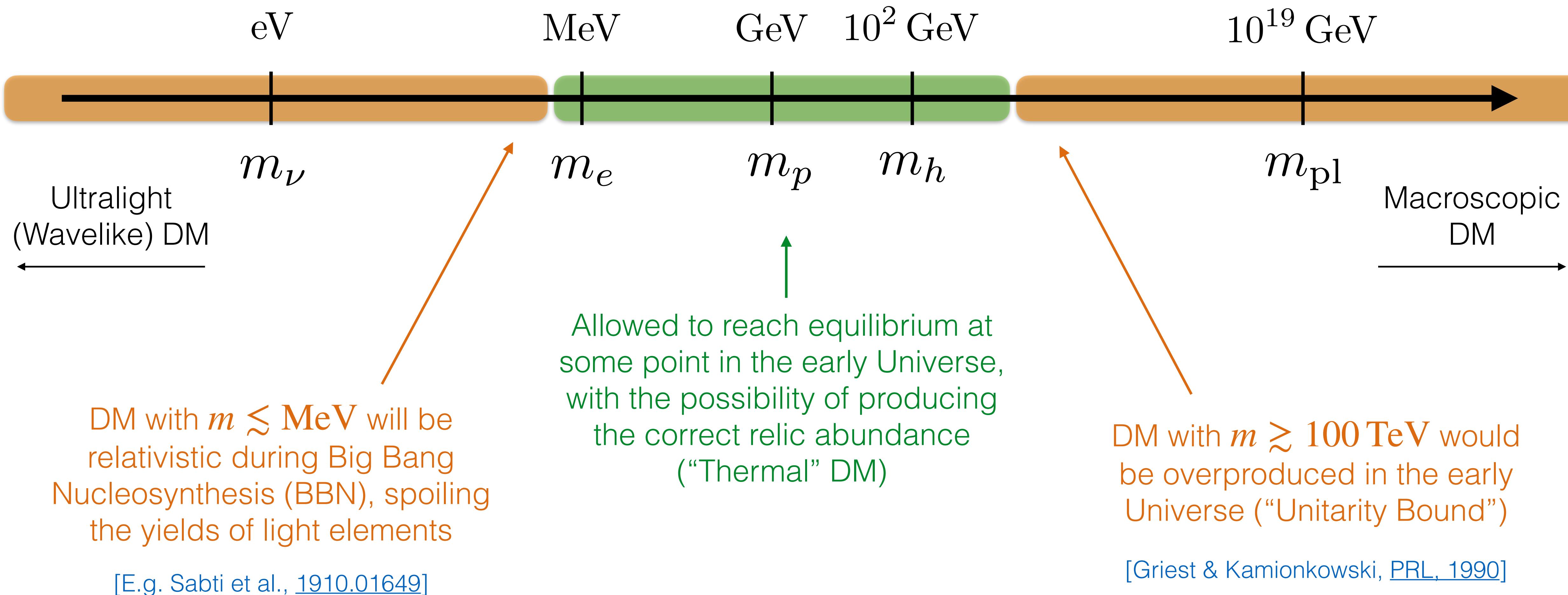
$$\langle v_{\text{DM}} \rangle \sim 300 \text{ km/s}$$
$$\sim 10^{-3} c$$

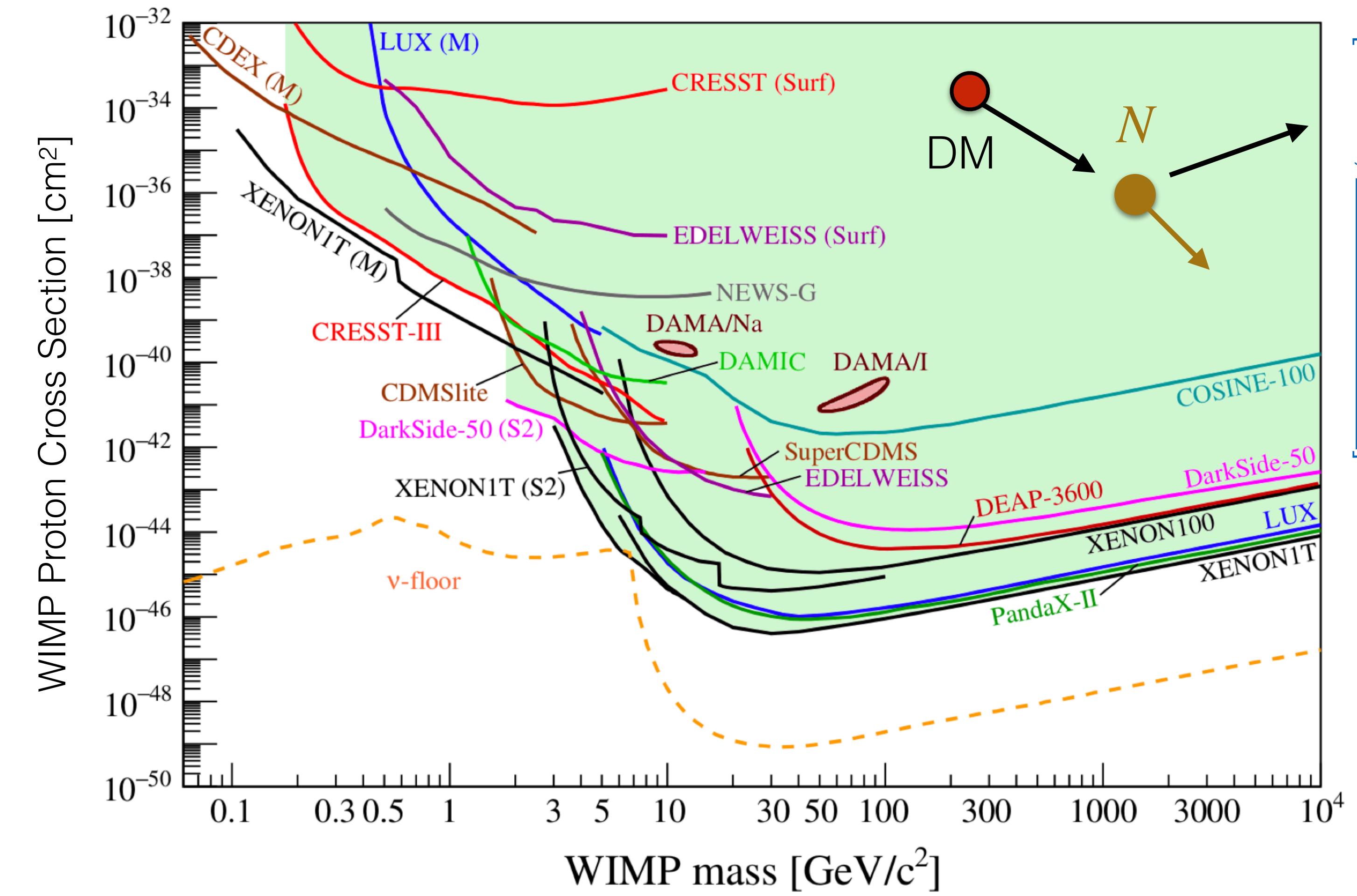
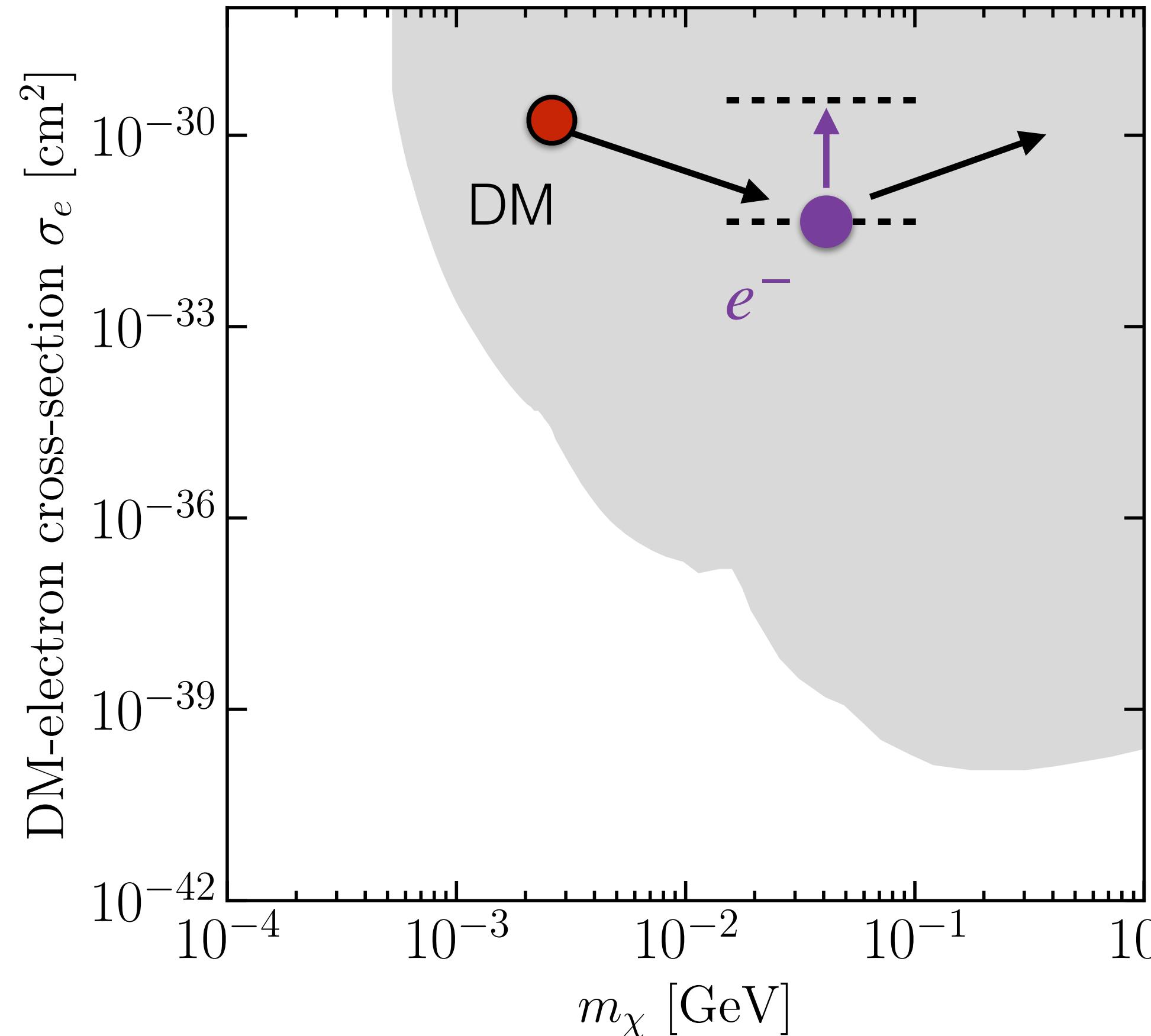
Aim to constrain (detect?) DM scattering cross section σ

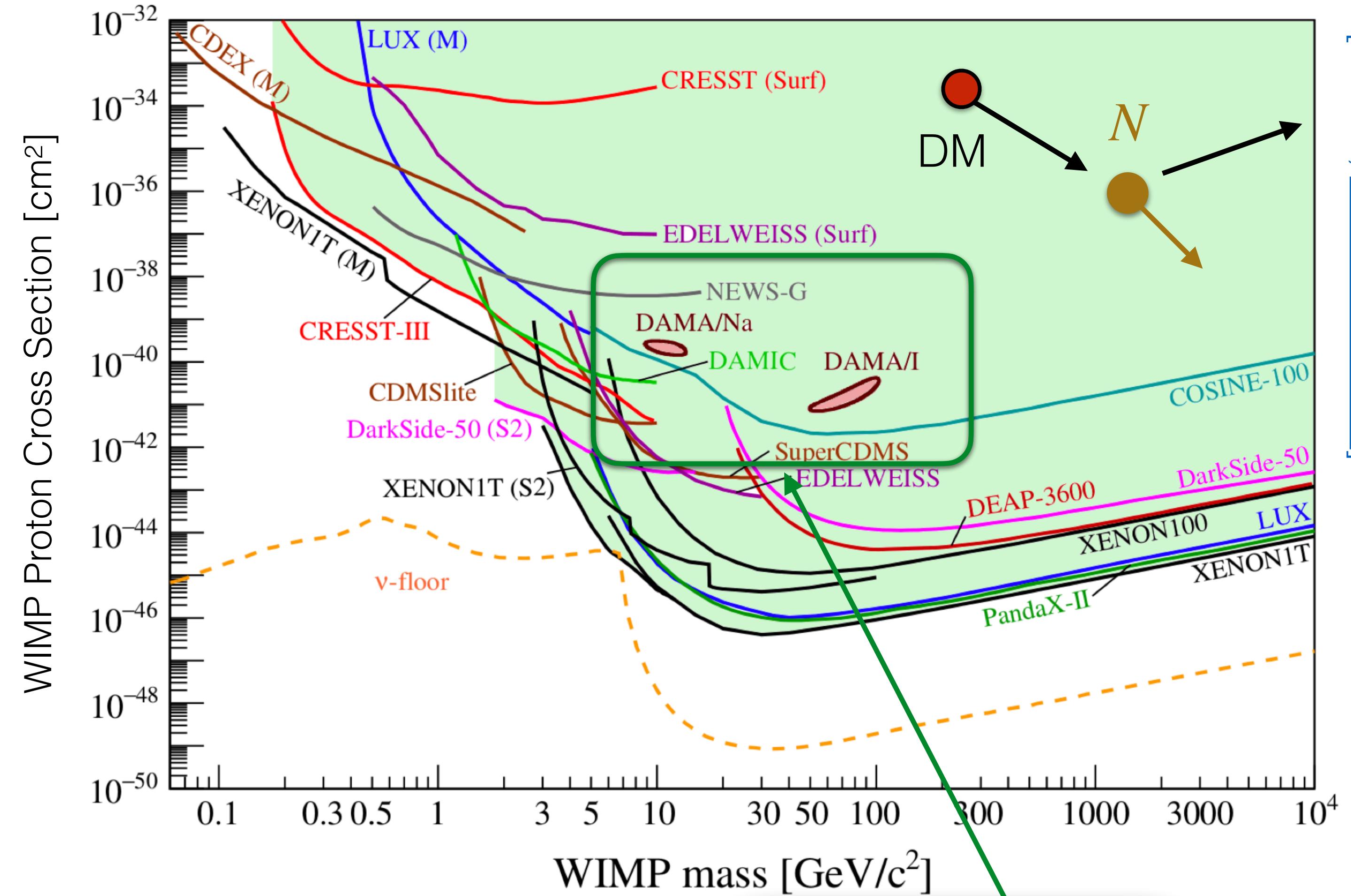
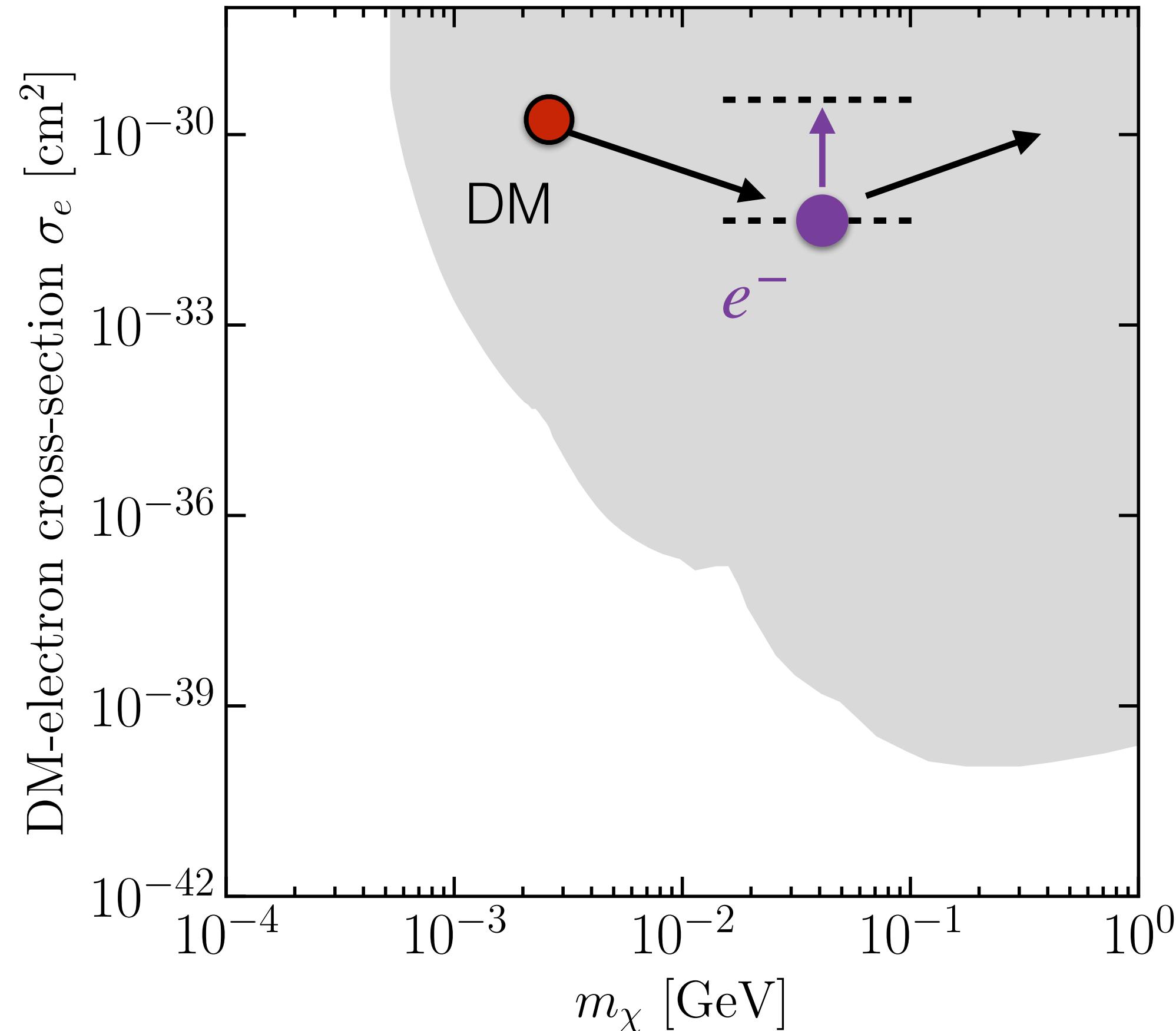
Key detector requirements:

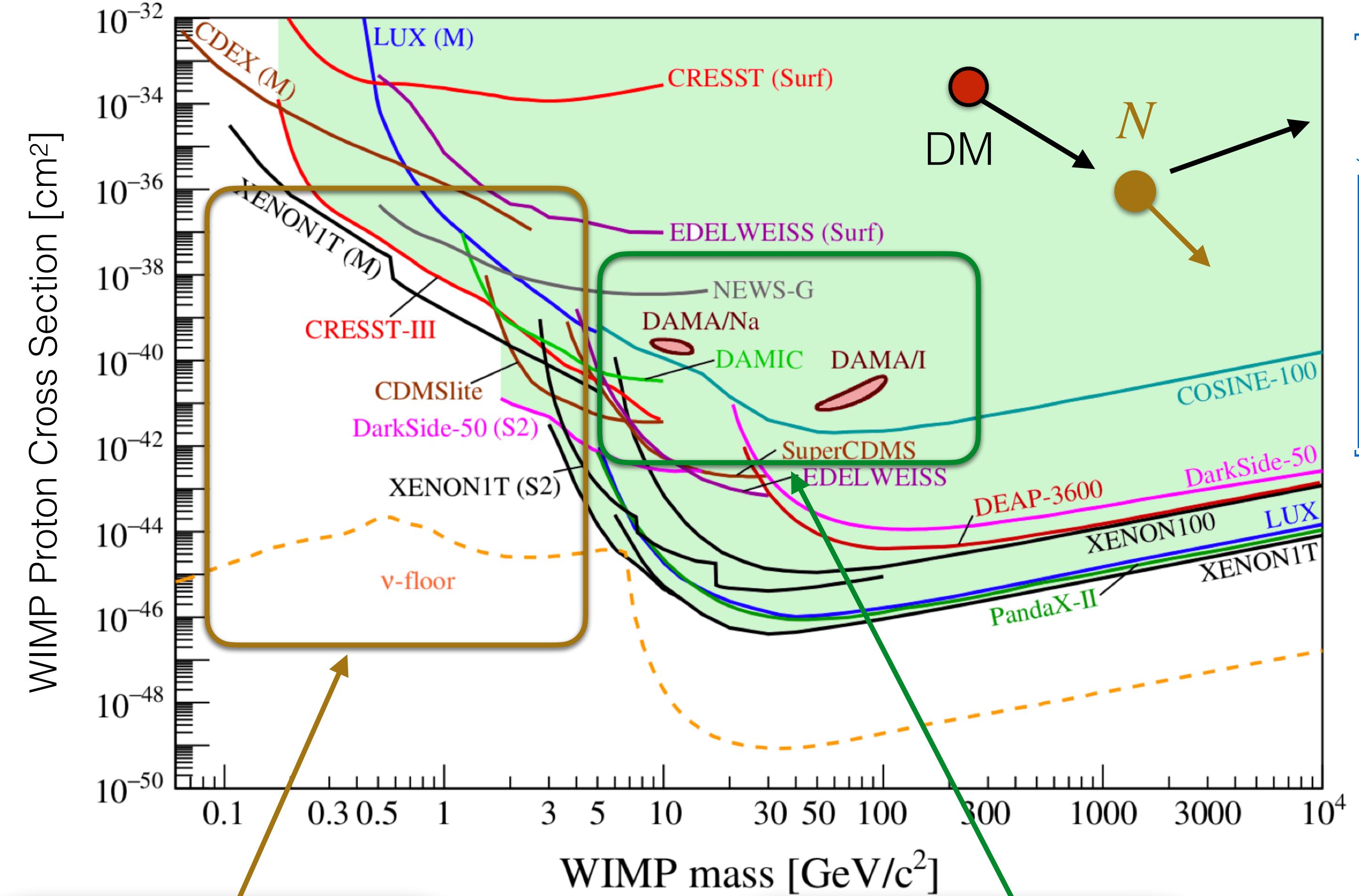
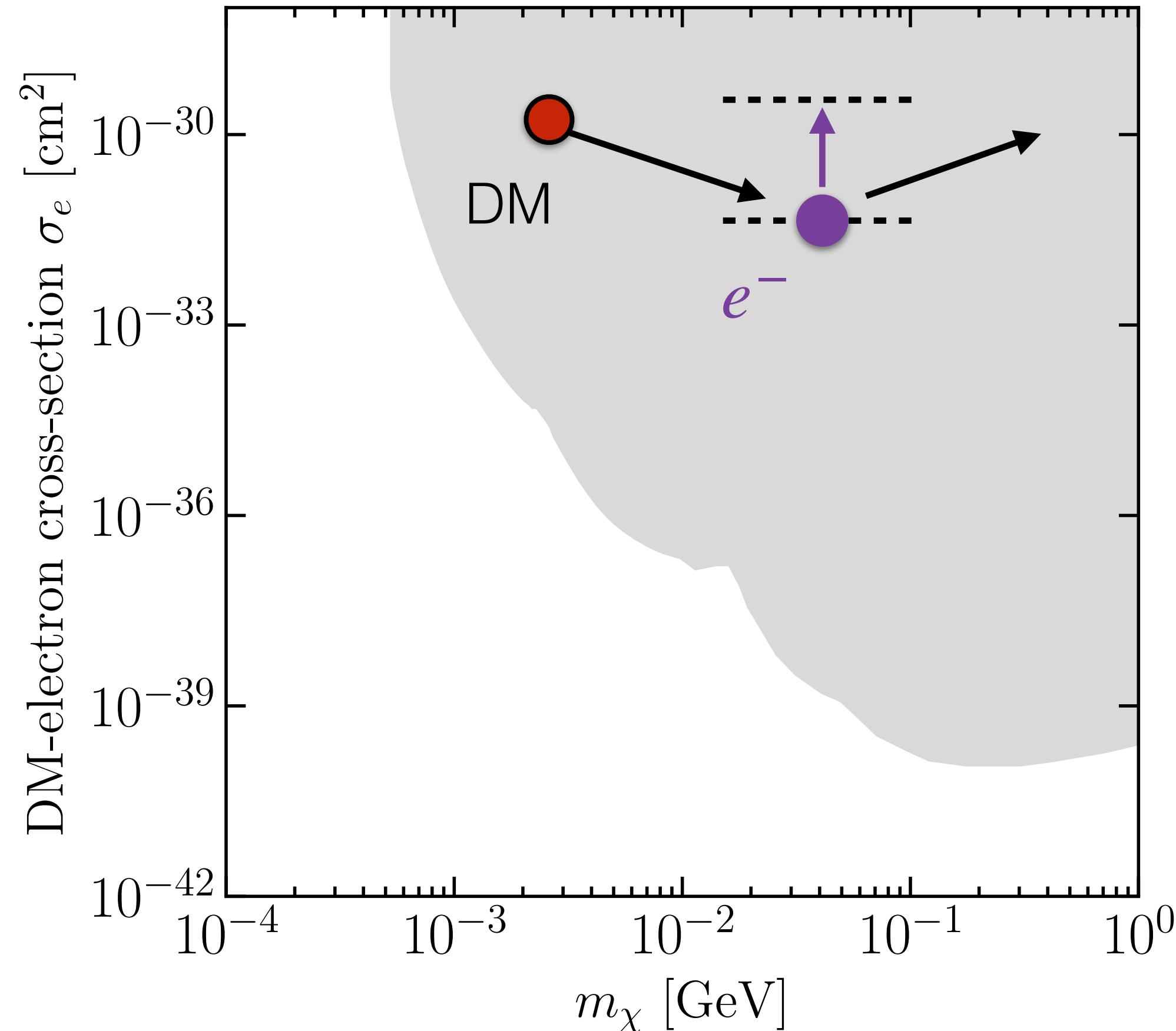
- Low energy threshold
- Low backgrounds
- Large target mass ($N_{\text{target}} \uparrow$)

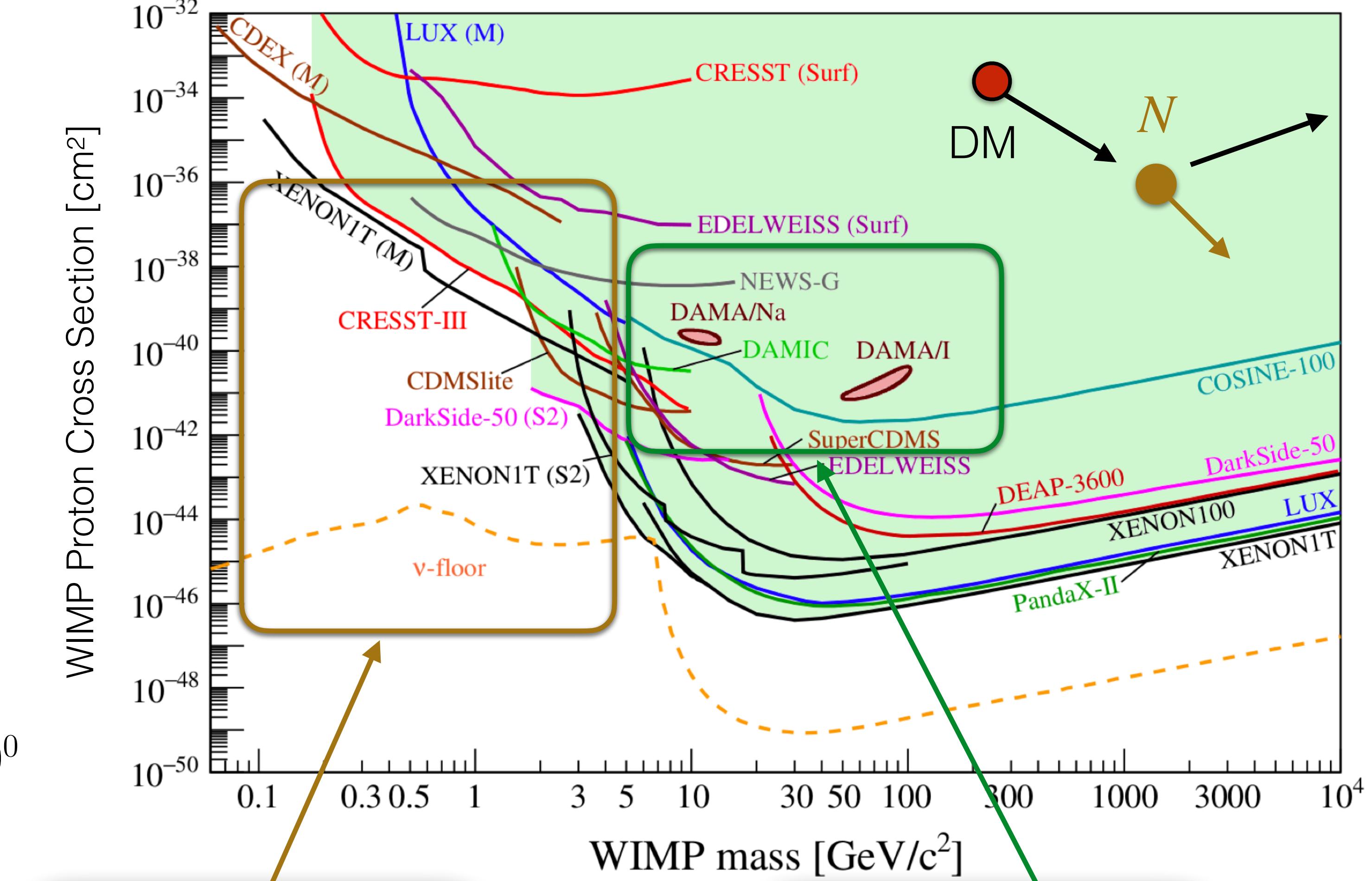
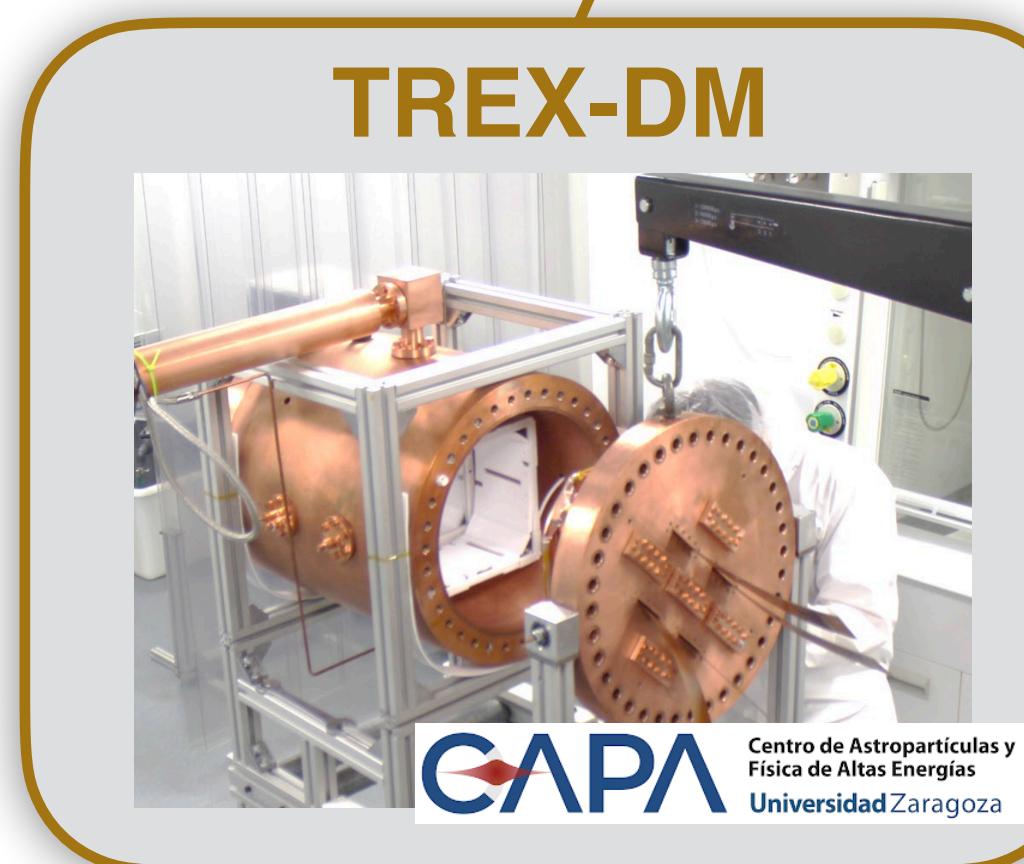
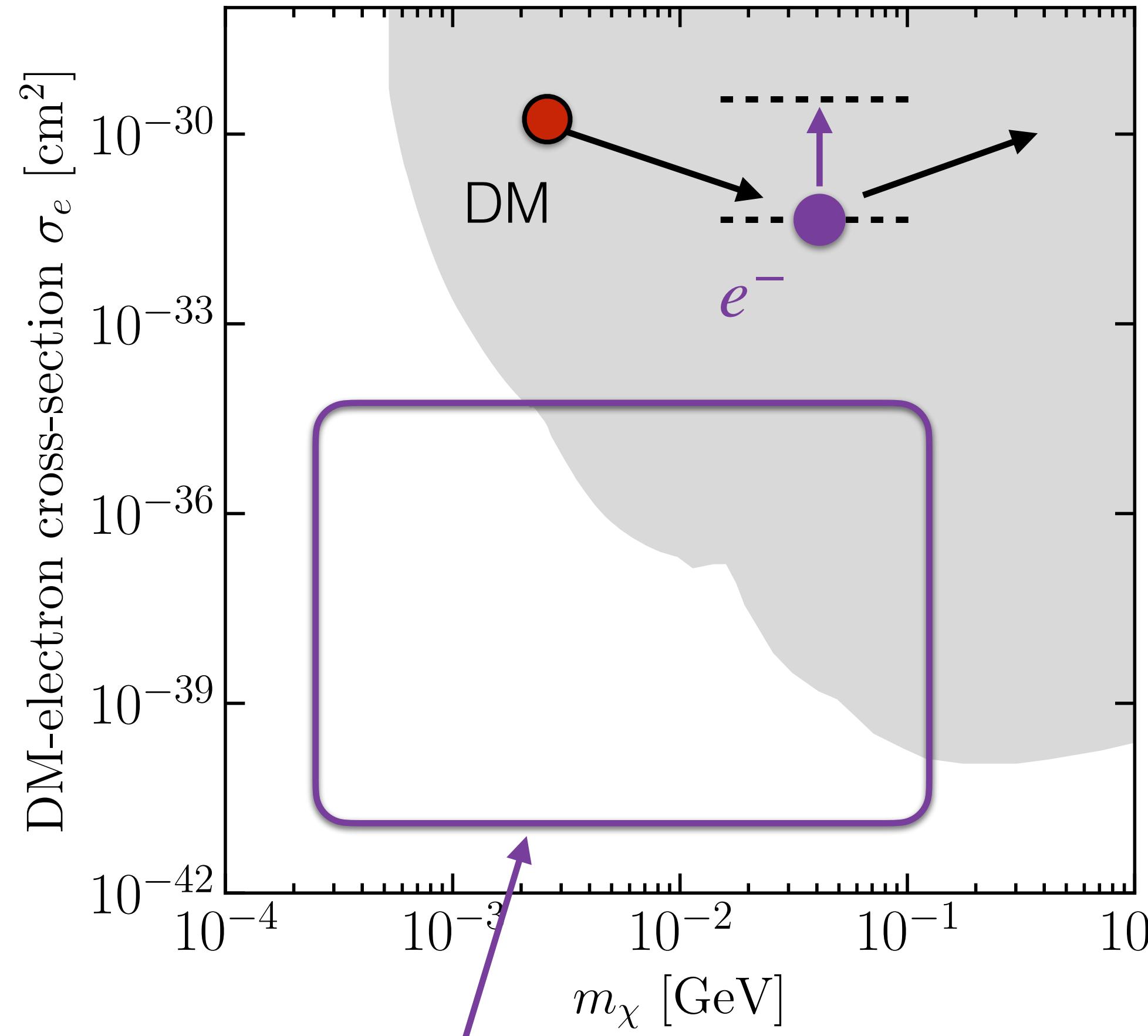
Particle-like Dark Matter



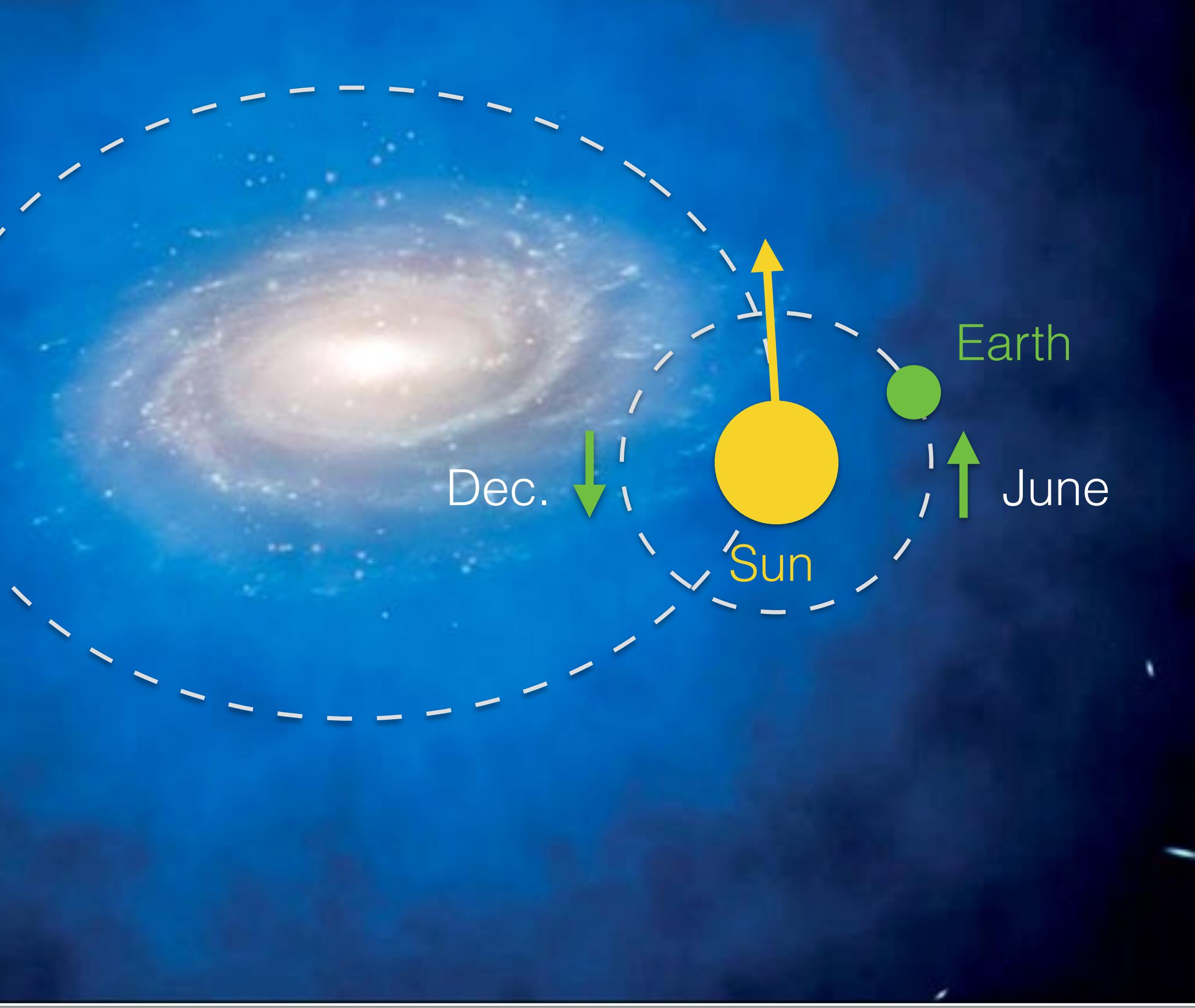








Annual Modulation

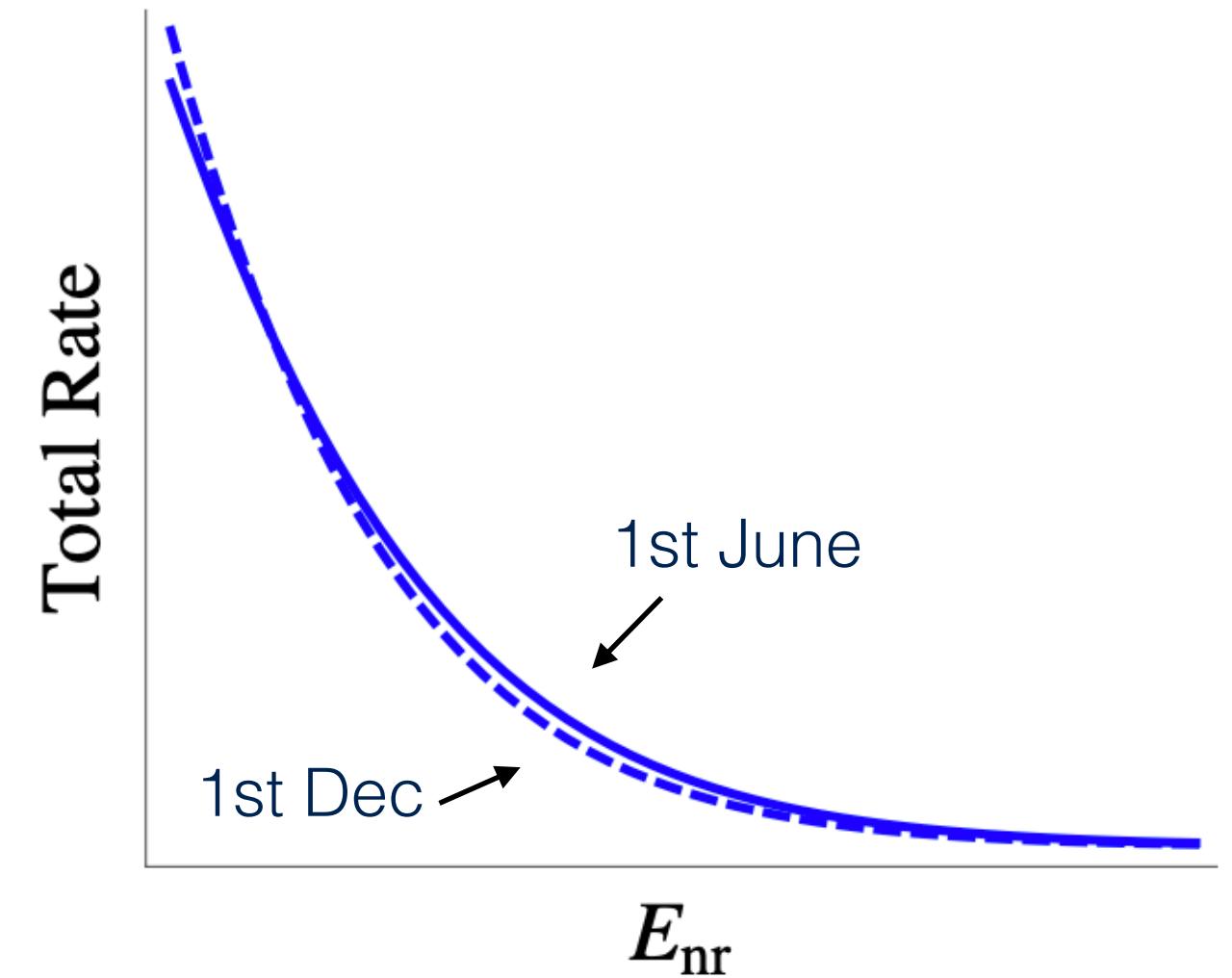


$$\text{Rate} \sim \rho_{\text{DM}} \times v_{\text{DM}} \times \sigma \times N_{\text{target}}$$

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

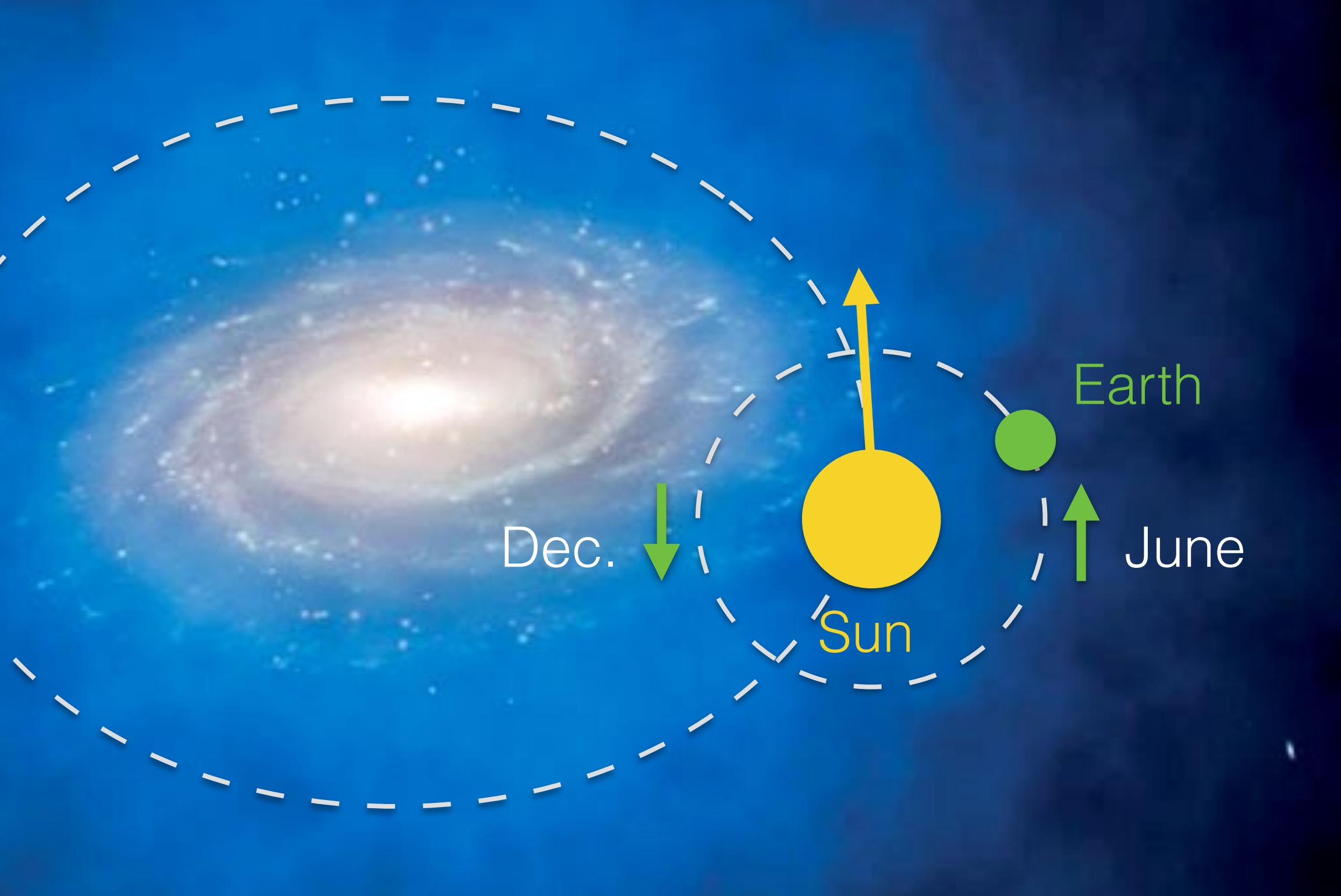
$$\Delta v_{\text{Earth}} \approx 30 \text{ km/s}$$

[1312.1355]



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

Annual Modulation

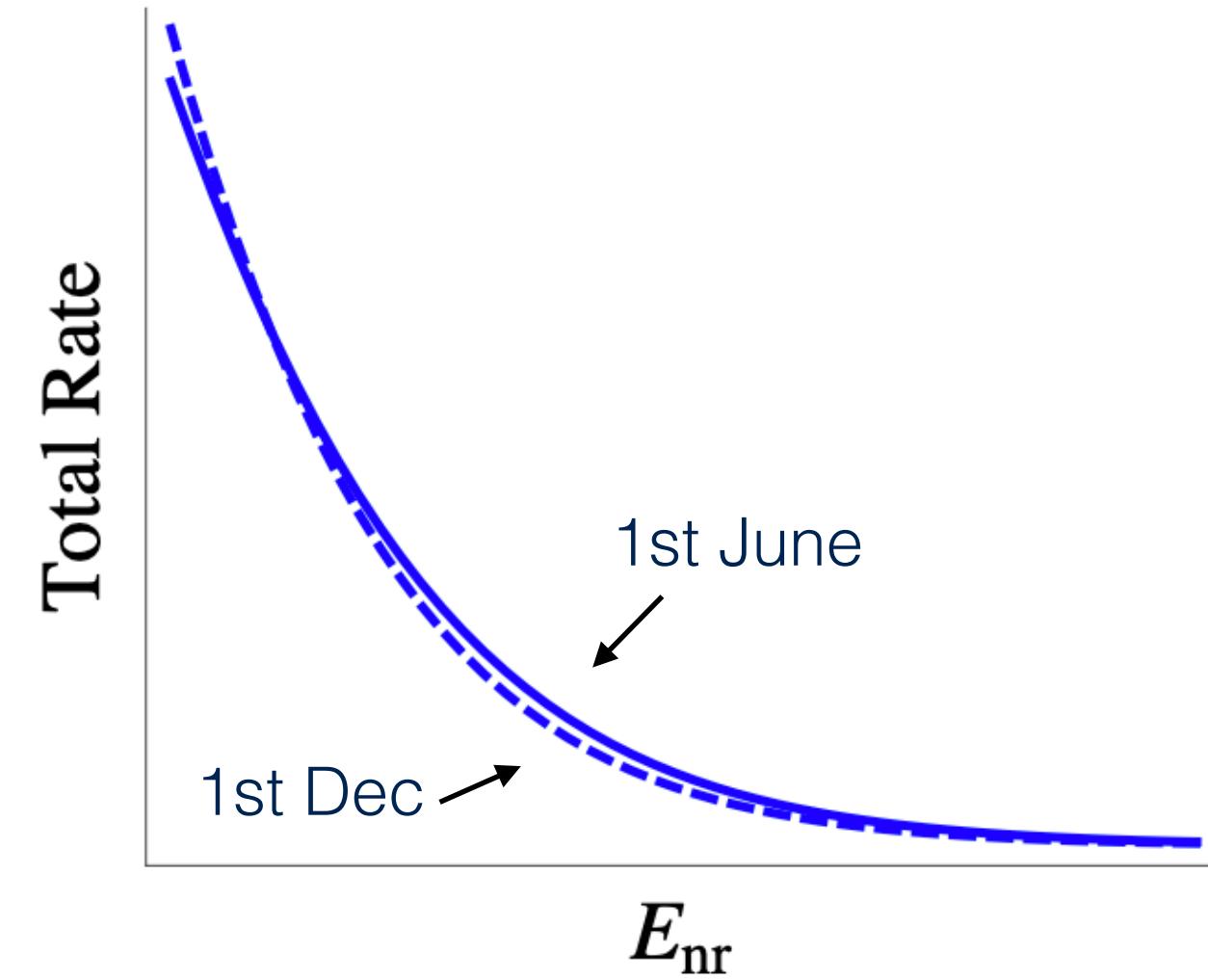


$$\text{Rate} \sim \rho_{\text{DM}} \times v_{\text{DM}} \times \sigma \times N_{\text{target}}$$

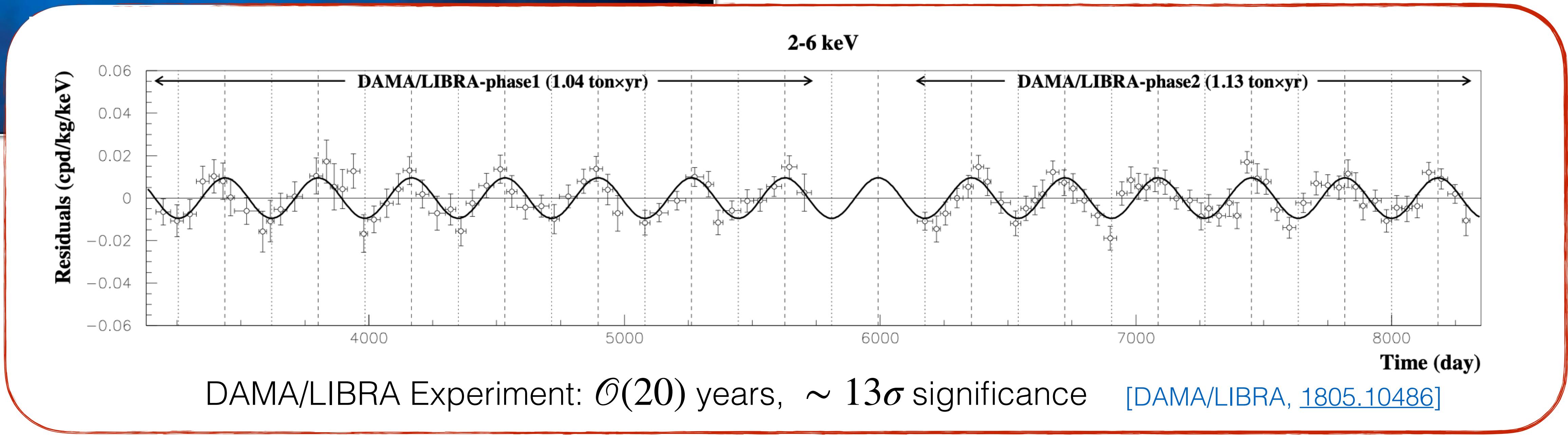
$$v_{\text{Sun}} \approx 220 \text{ km/s}$$

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

[\[1312.1355\]](#)



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



ANAlS

Annual modulation with **Nal** Scintillators

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

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

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

Scintillation produced by energy deposition in Nal 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)

[ANAlS, [2402.12480](#)]



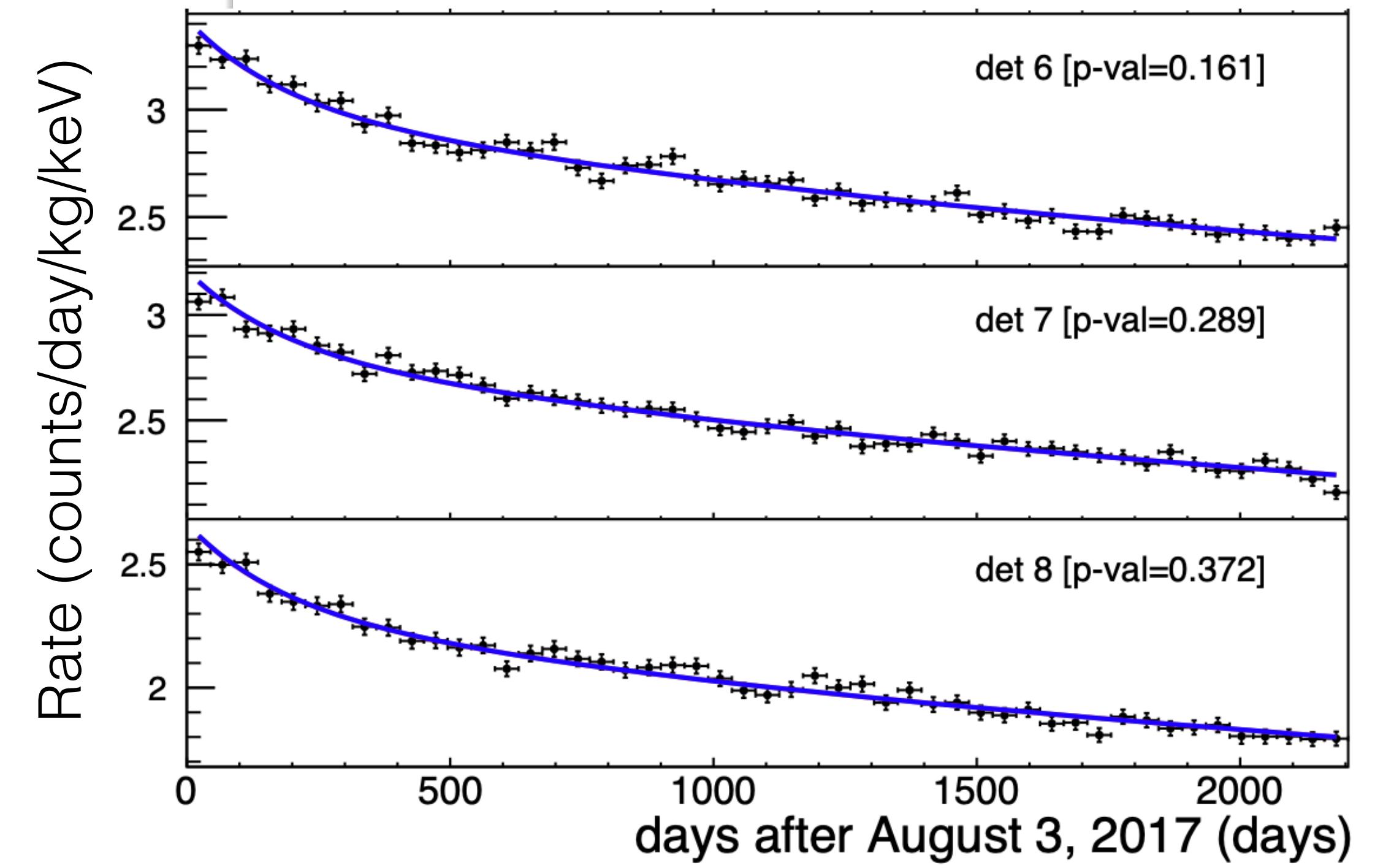
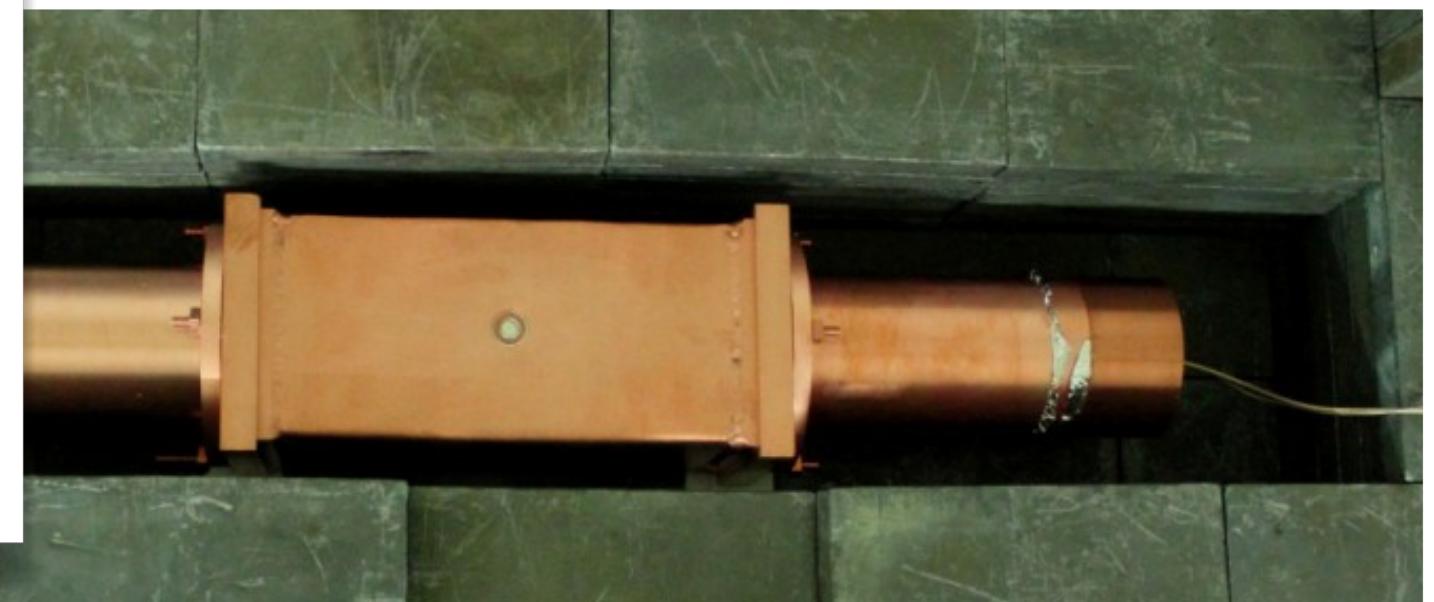
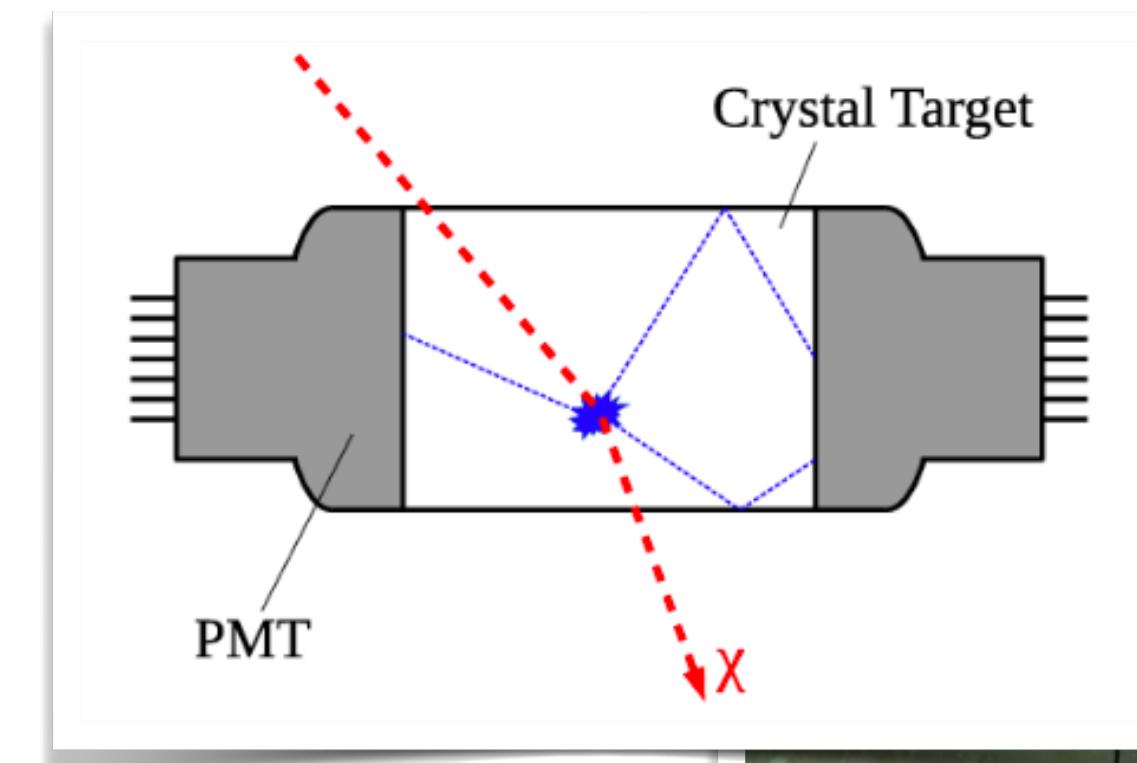
August 2017 - now: in operation in the Canfranc Underground Laboratory (LSC) with 95% live time!



Centro de Astropartículas y
Física de Altas Energías
Universidad Zaragoza



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



ANAlS

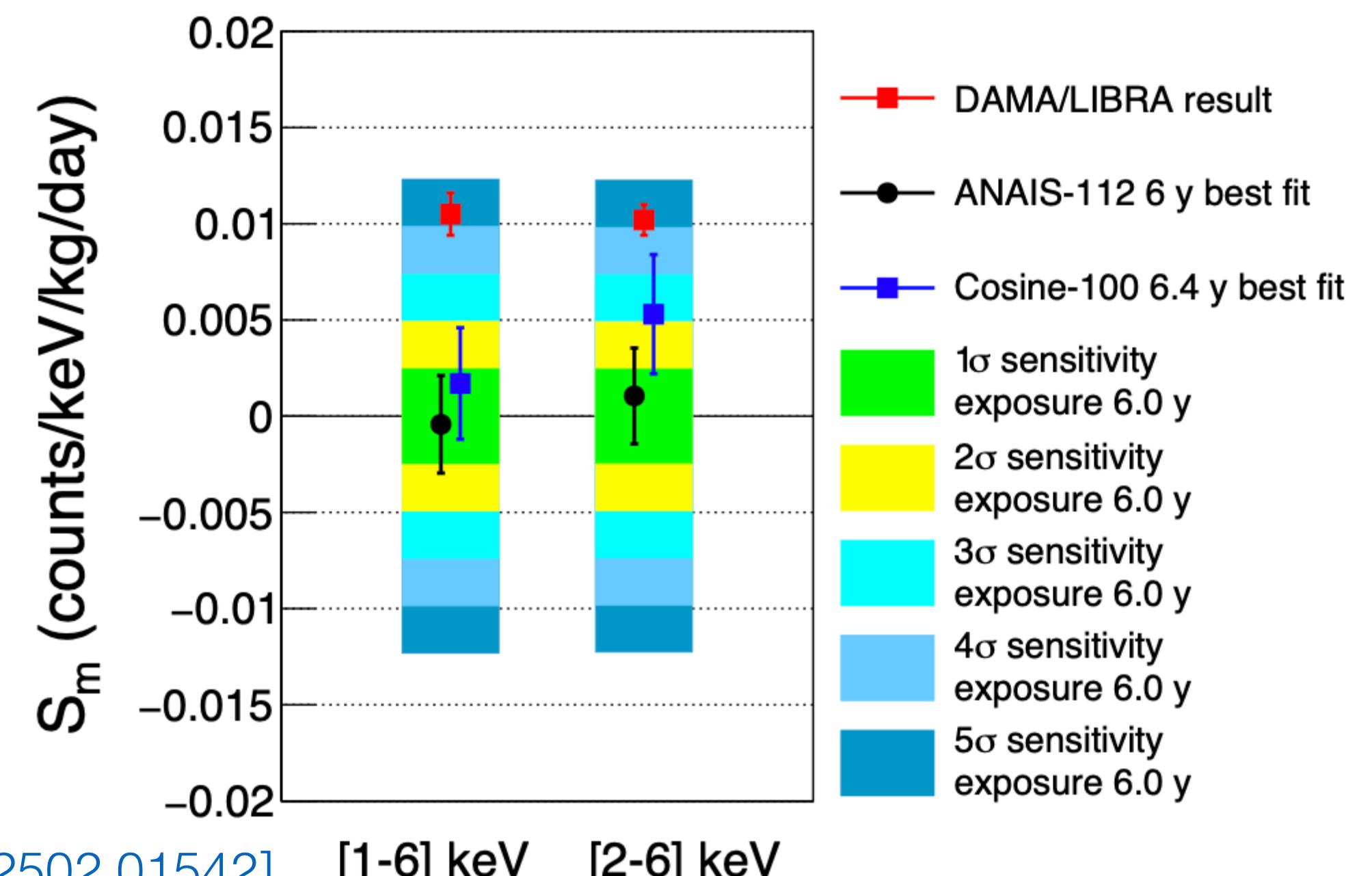
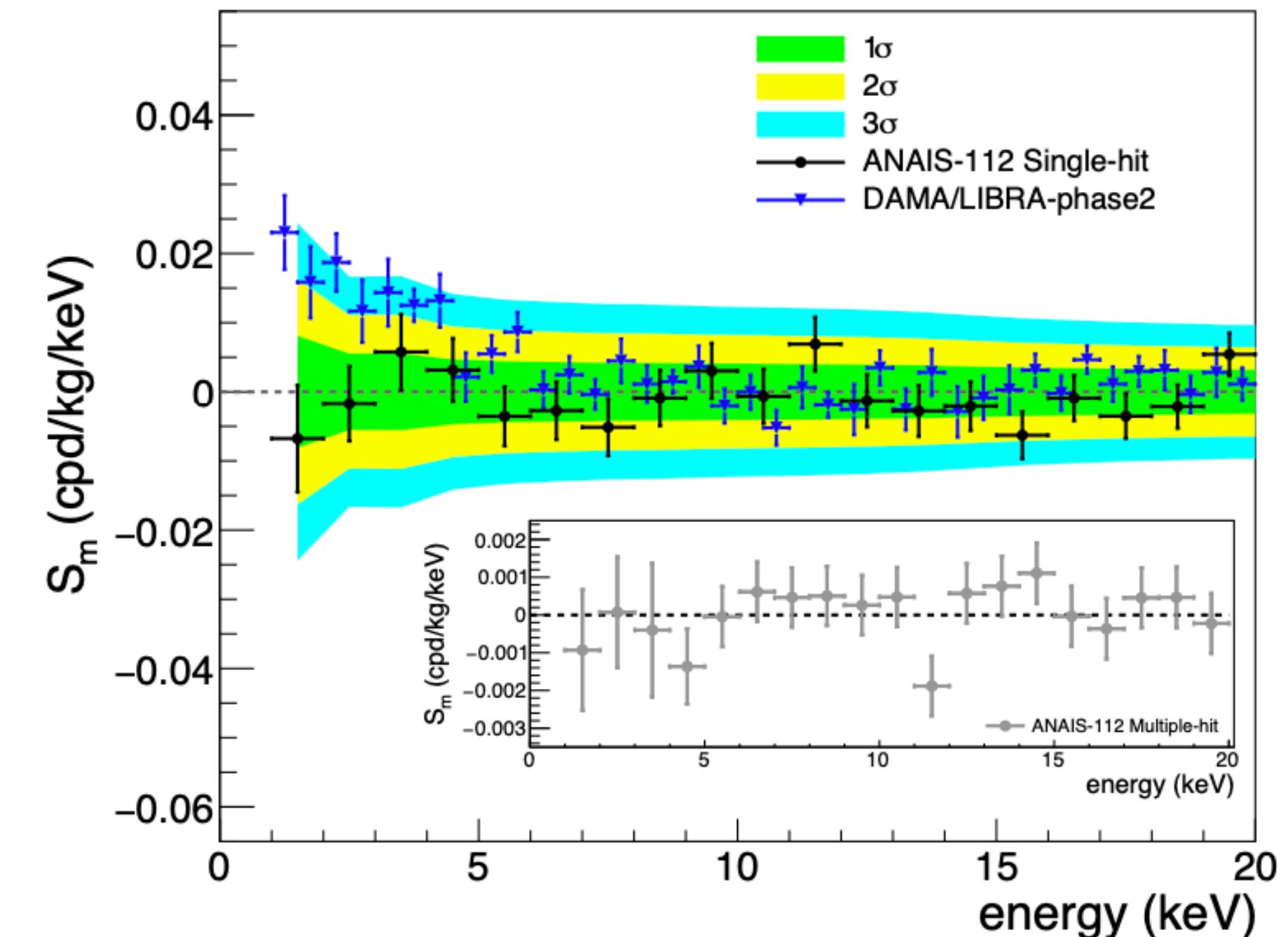
Annual modulation with **Nal S**cintillators

No modulation observed in the 6-year dataset (2017 - 2023)

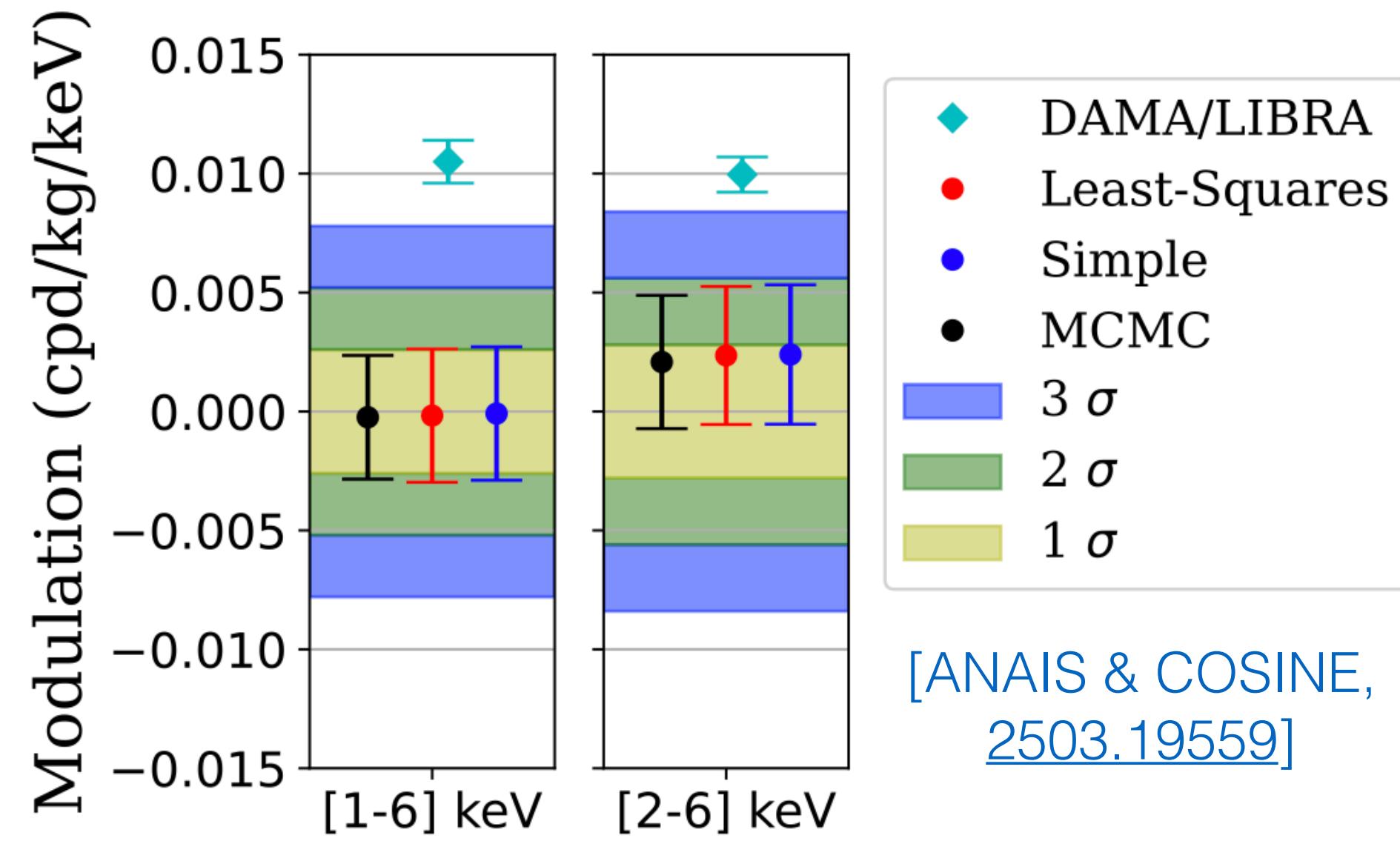
→ most sensitive check of DAMA/LIBRA with Nal

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



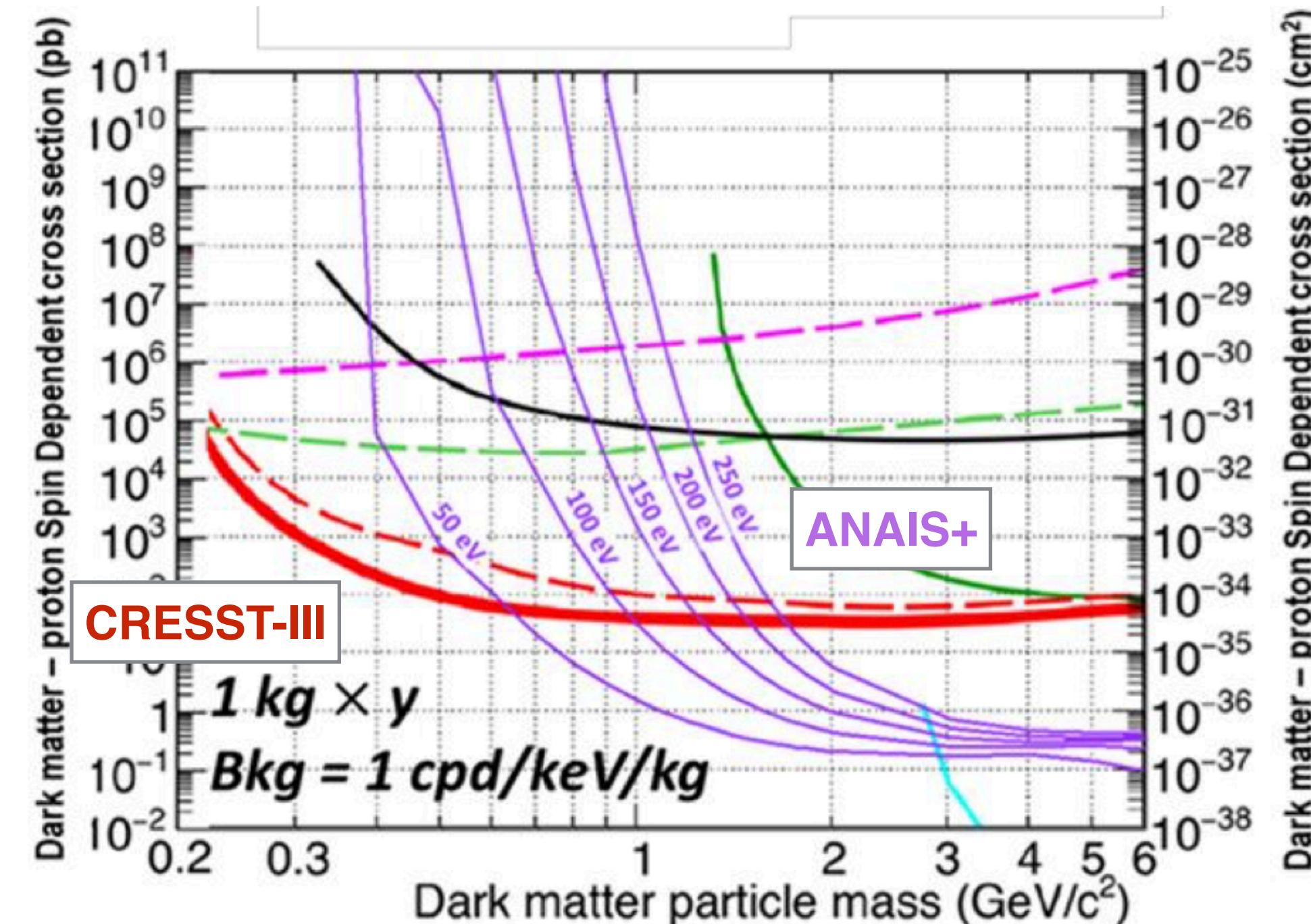
ANAlS+

Annual modulation with **Nal S**cintillators

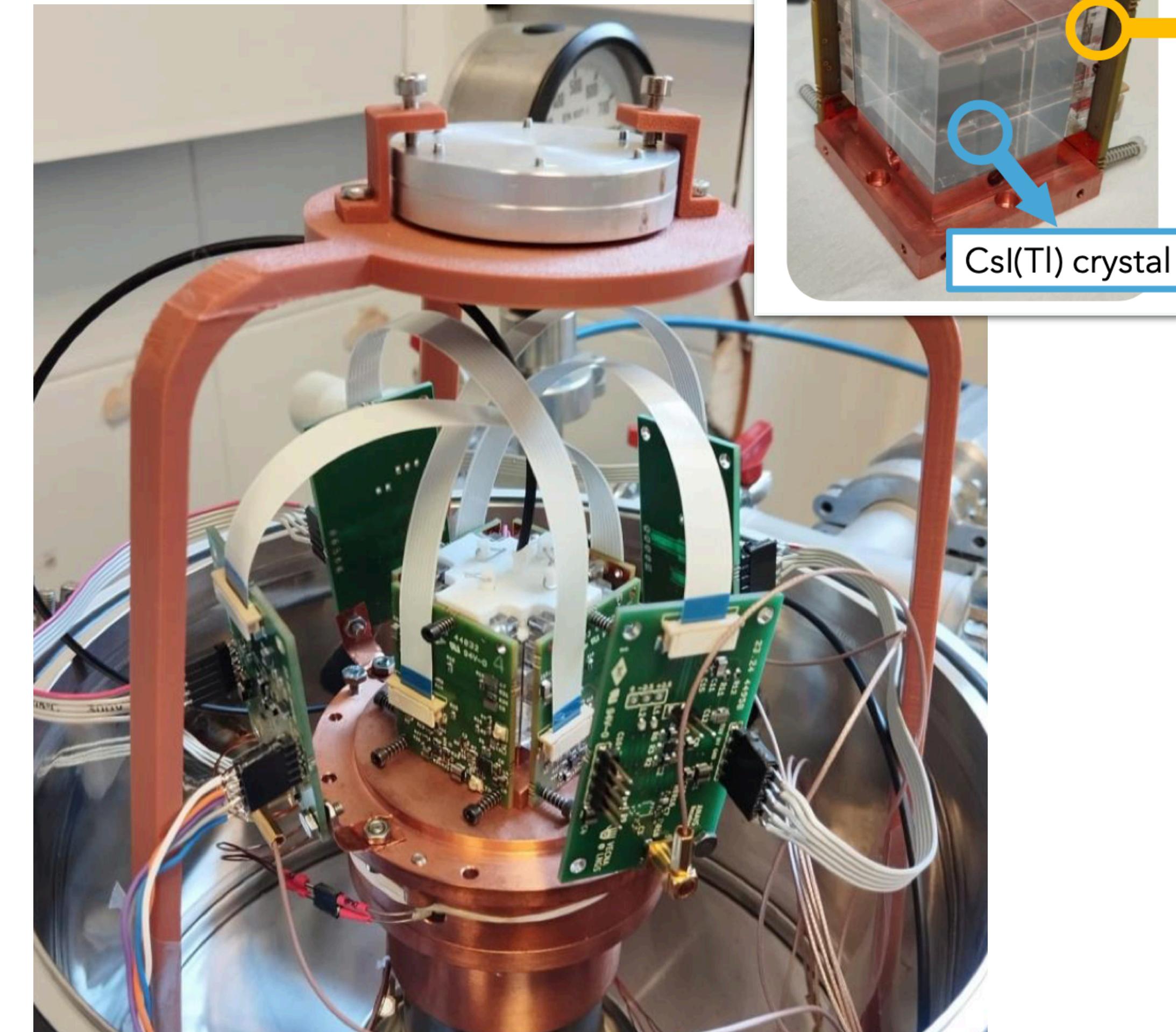
Current ANAIS sensitivity limited by anomalous light events attributed to PMTs

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)



TINY OCTOPUS



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 Rare Event eXperiments - Dark Matter



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



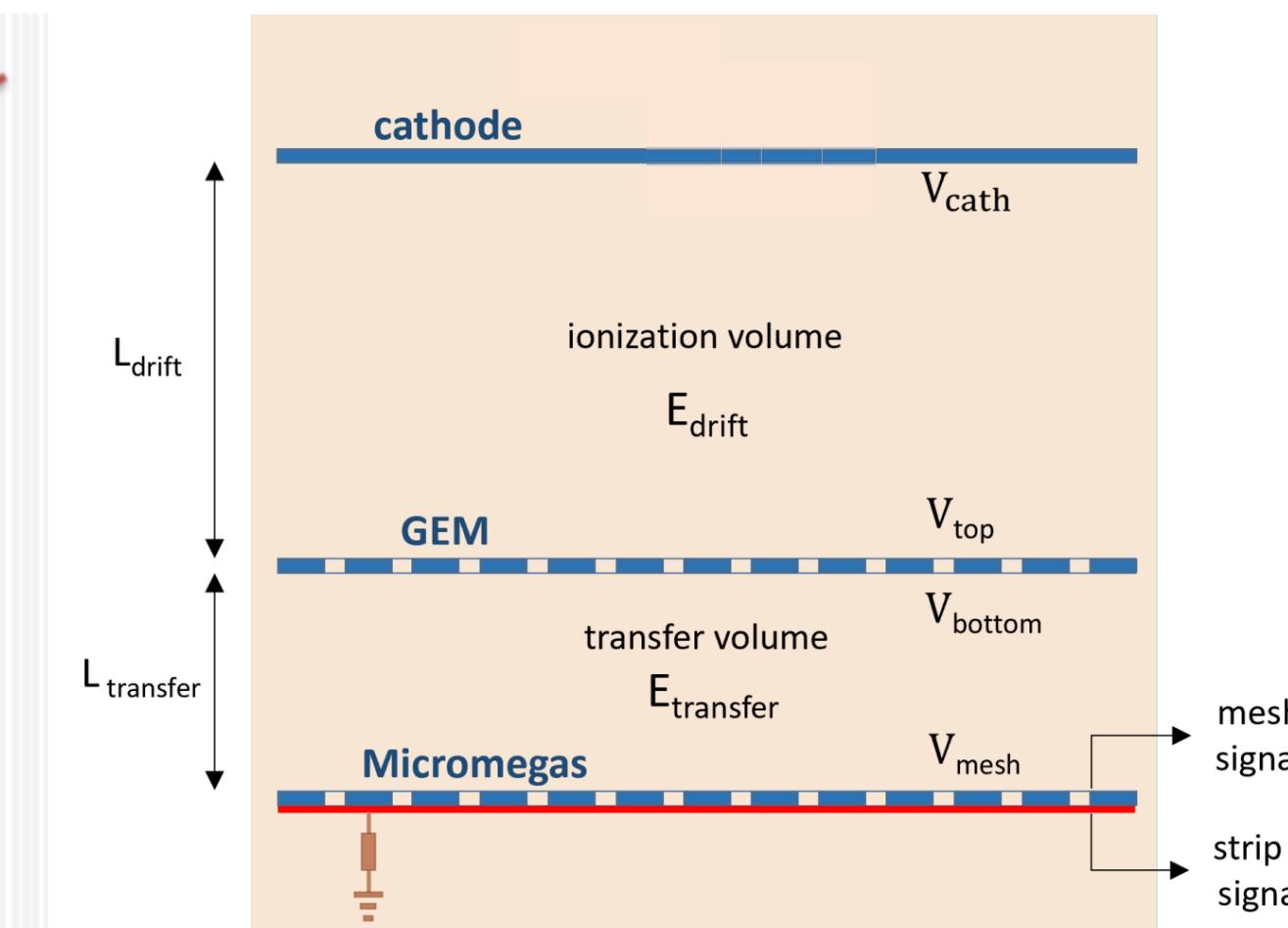
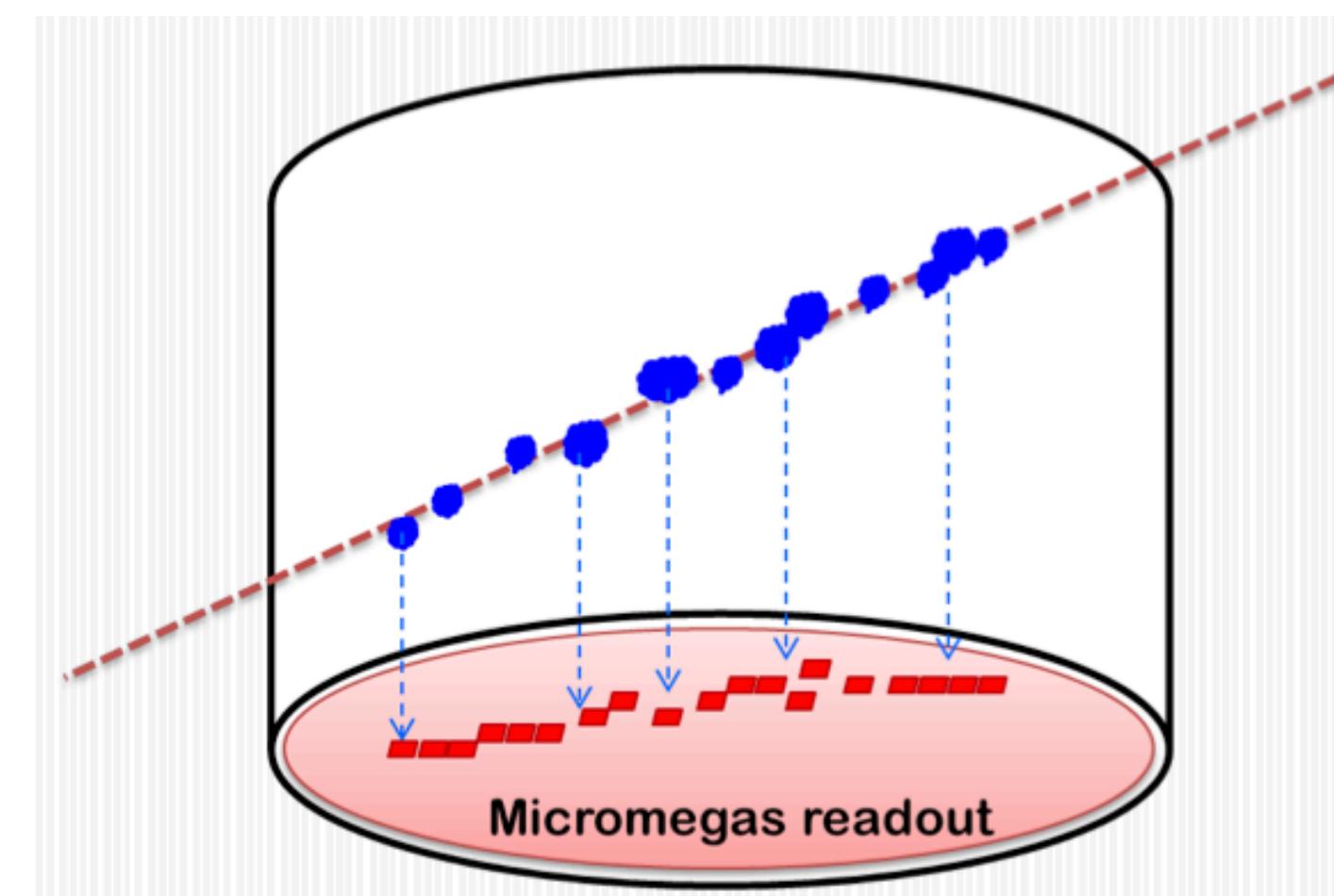
Possibility to change target gases:

- Atmospheric Ar + 1% iC₄H₁₀ (2018 data-taking)
- Ne + 2% iC₄H₁₀ (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 Rare Event eXperiments - Dark Matter

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

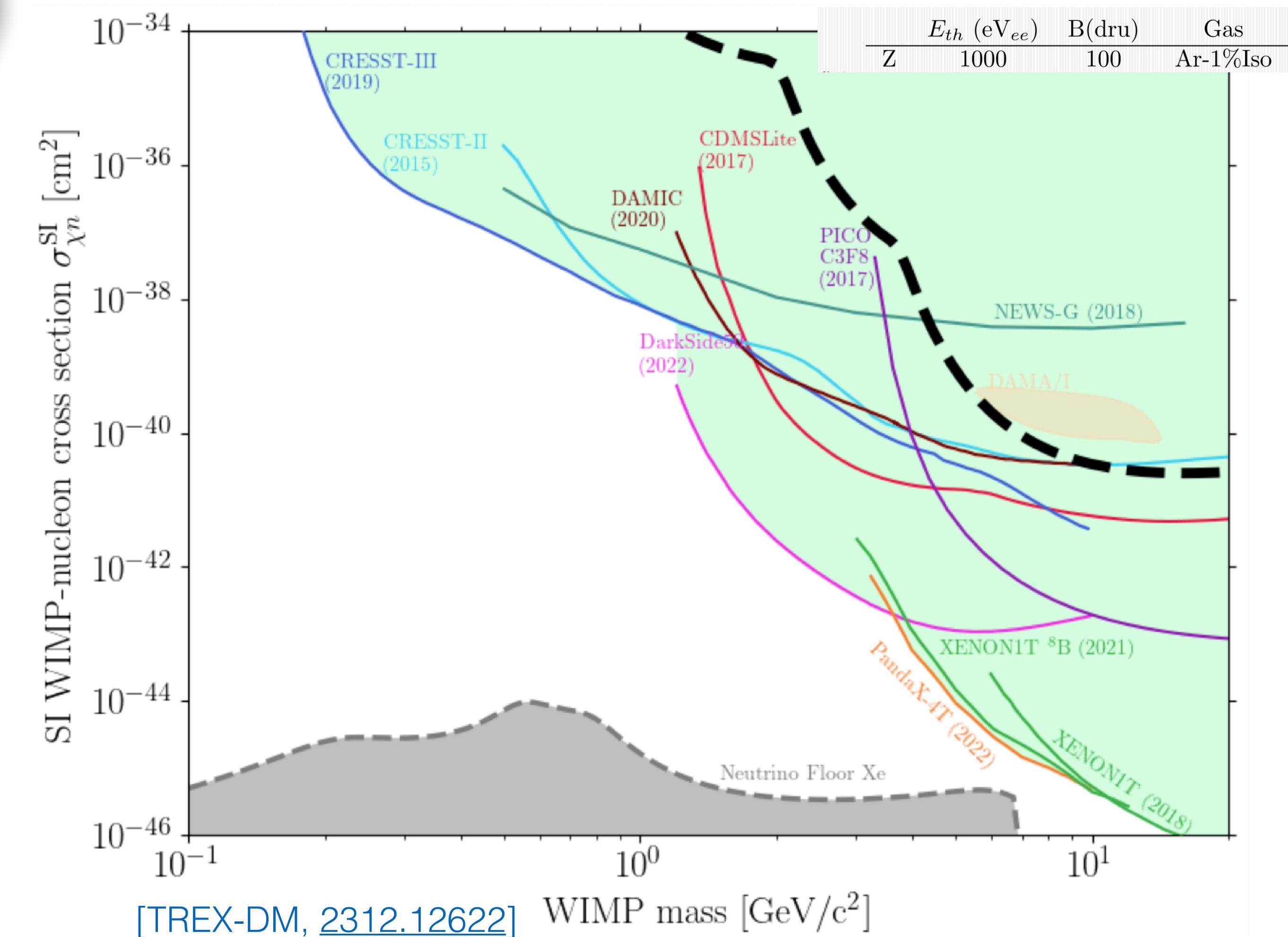


Aug 2023 - present: Data-taking for comparison with 2019-2022 campaign. Calibration and background studies

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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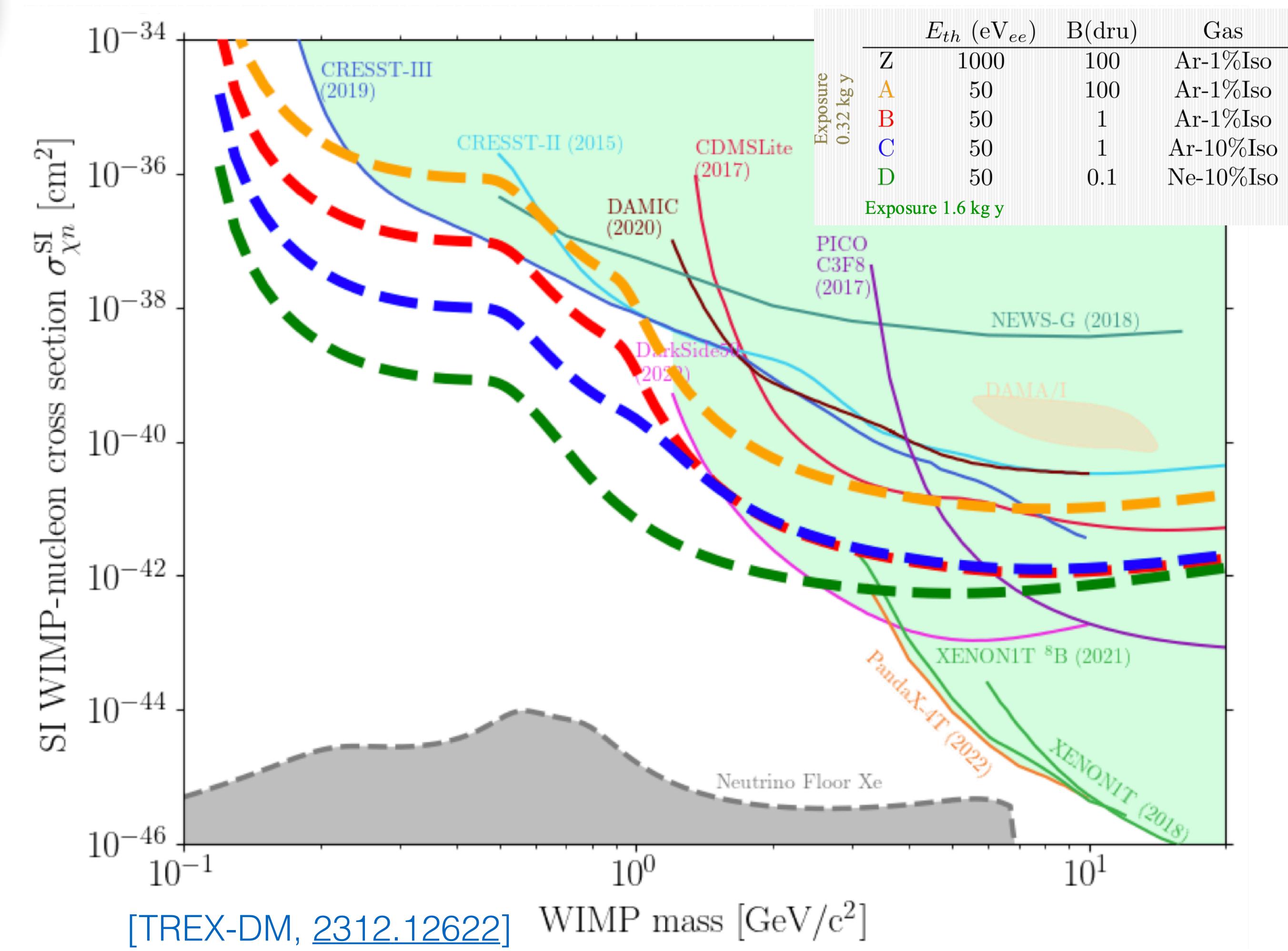


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[TREX-DM, [2510.05877](#)]

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



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

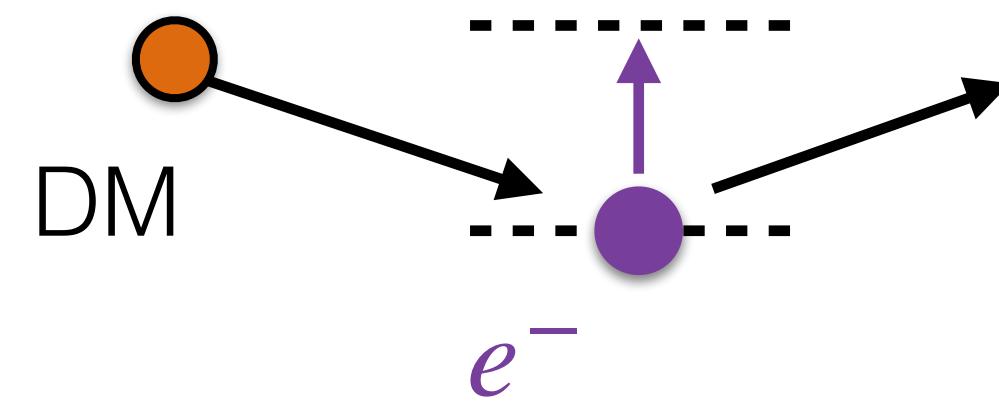
Array of **Charge Coupled Devices (CCDs)** planned to be installed at Laboratoire Souterrain de Modane (LSM), building on success of the DAMIC program at SNOLAB

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

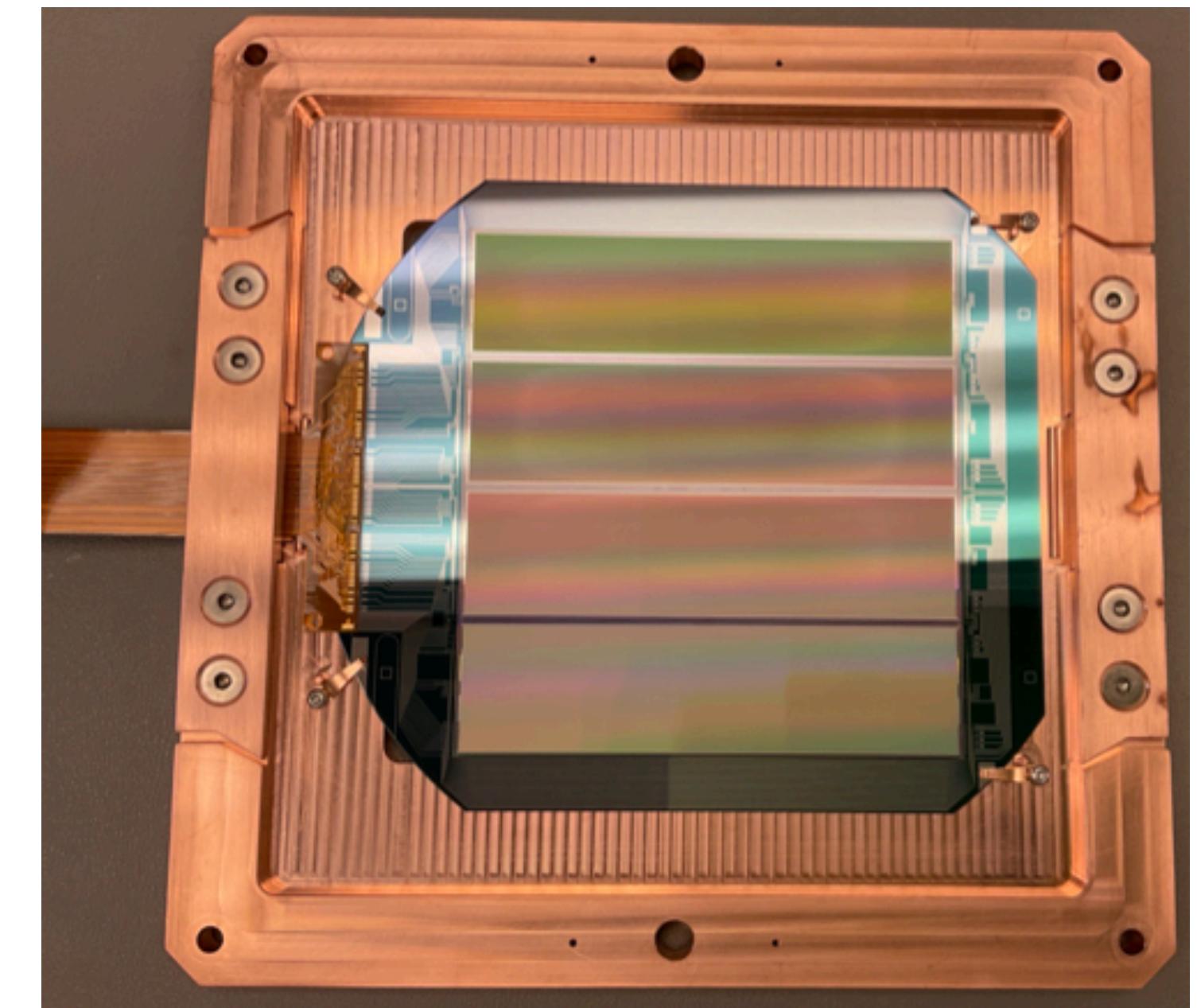
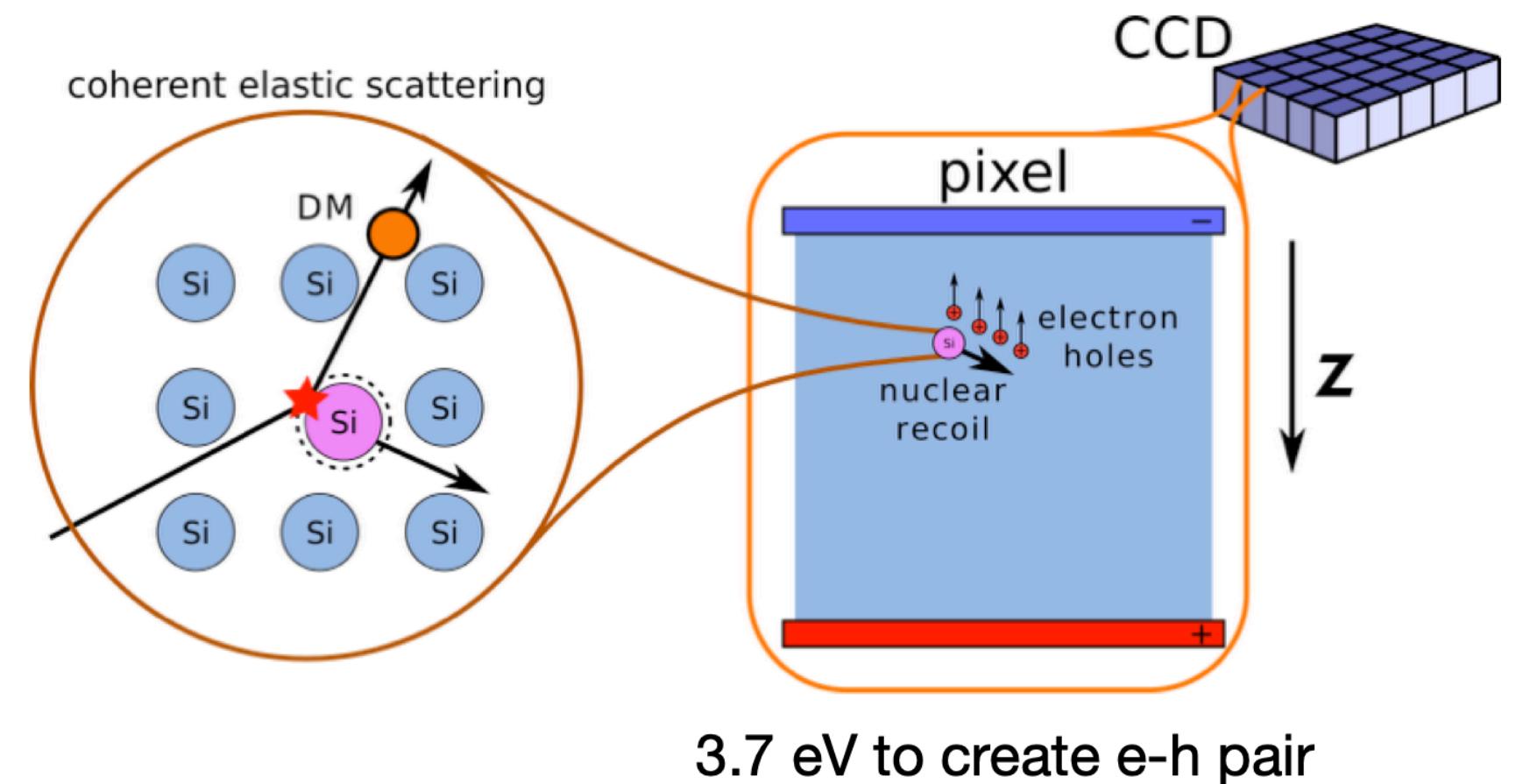
[DAMIC-M, [2001.01476](#)]

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

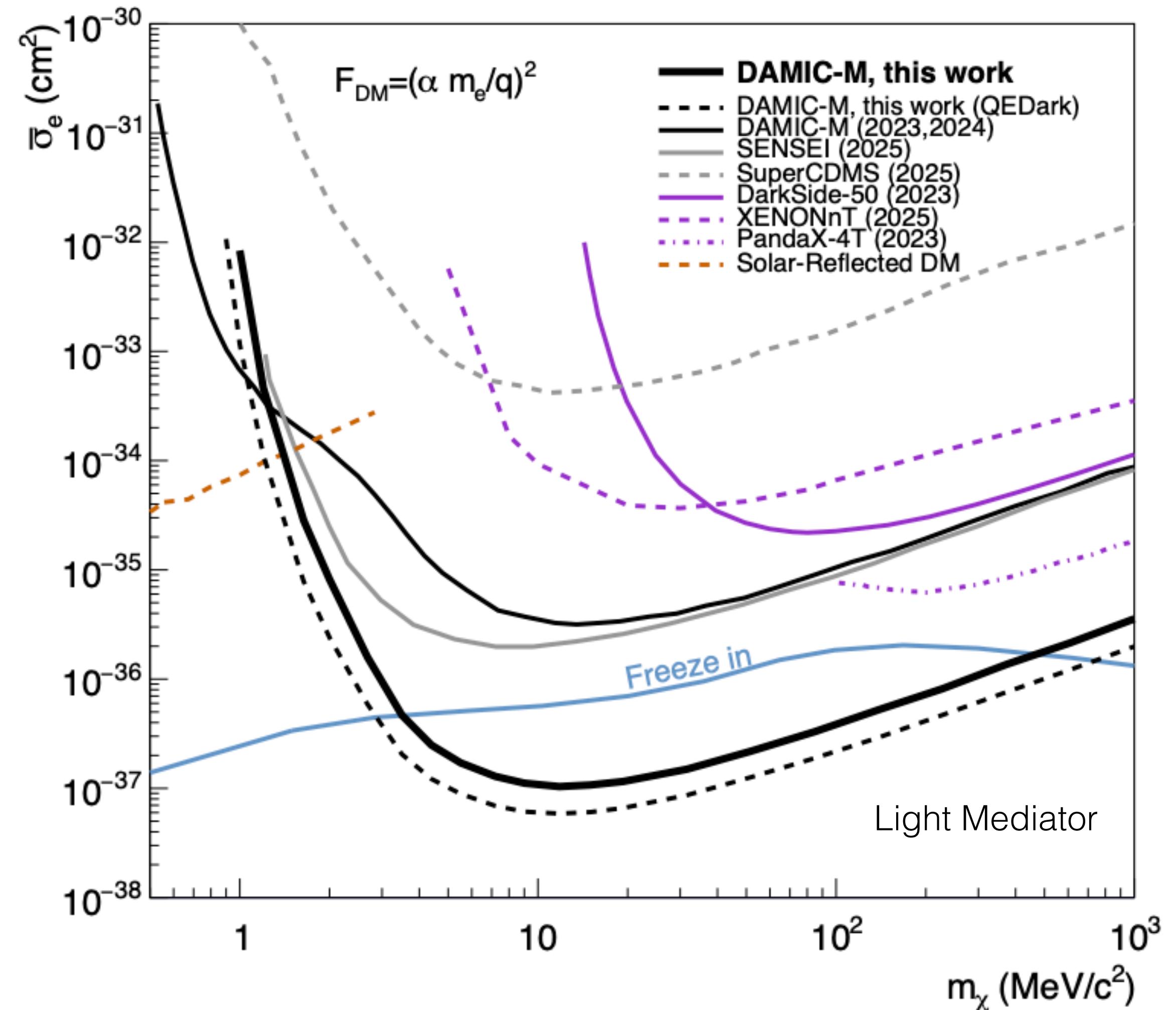
[DAMIC-M, [2302.02372](#), [2307.07251](#)]

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)

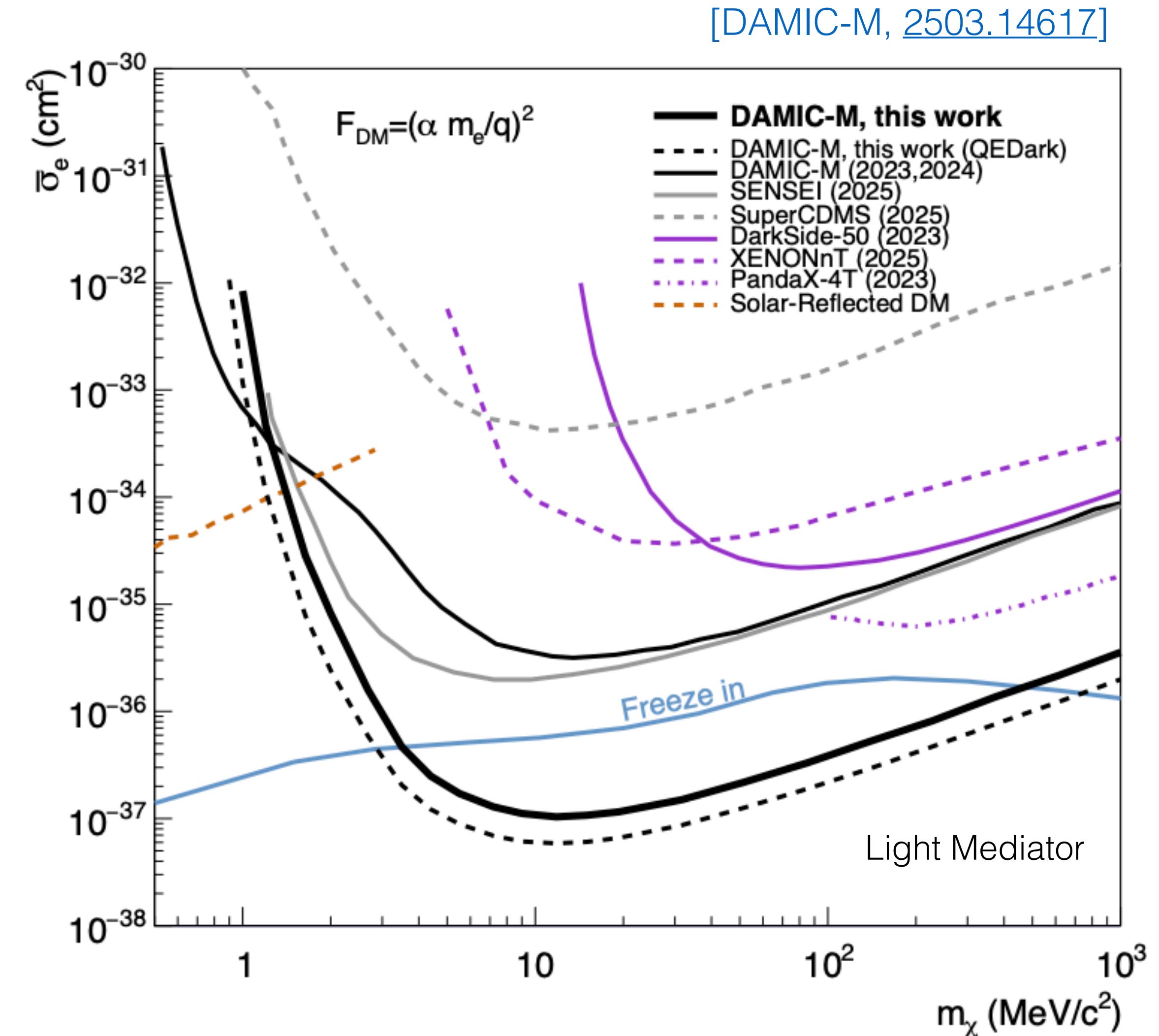
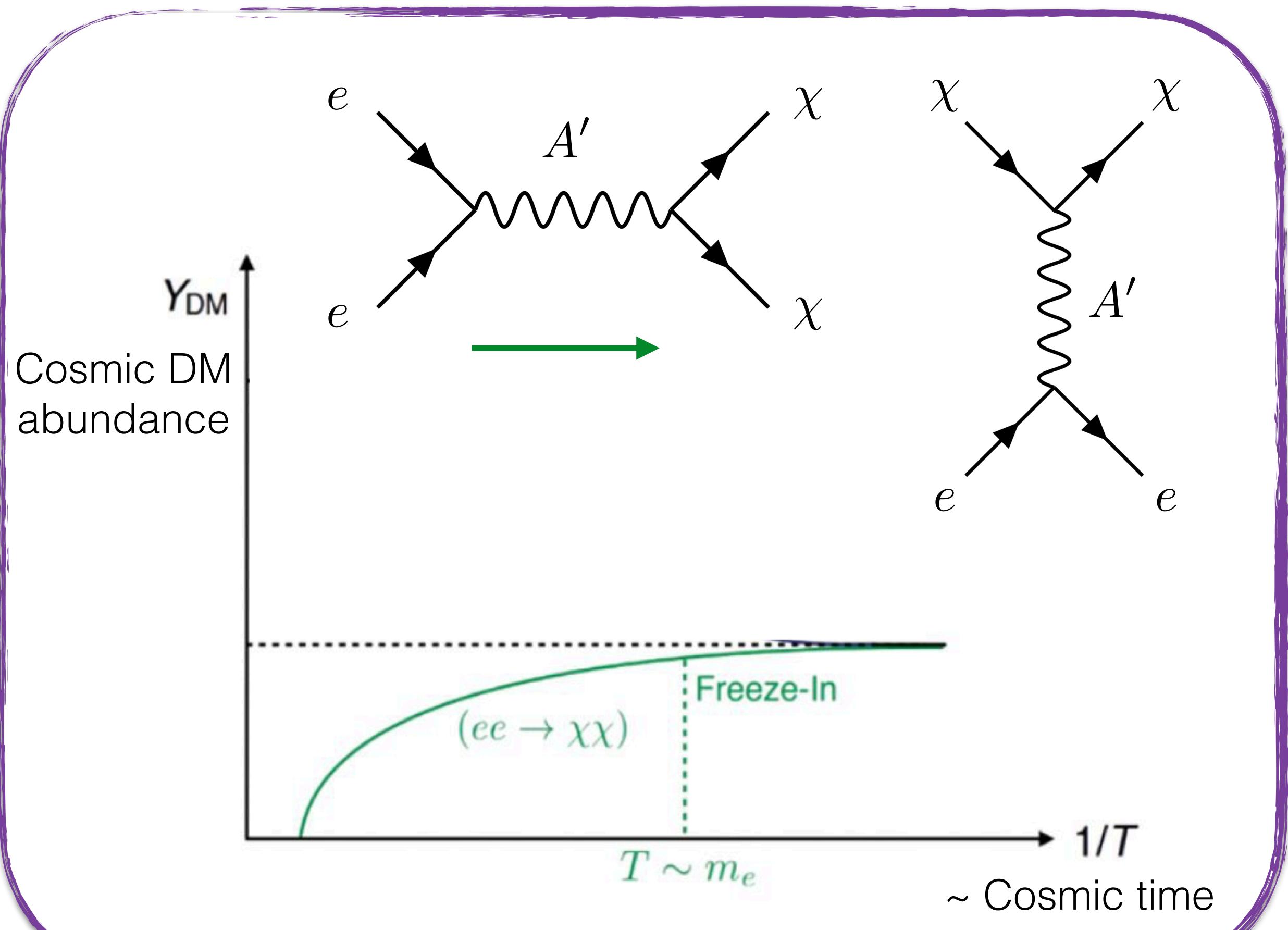
[DAMIC-M, [2503.14617](#), [2511.13962](#)]

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



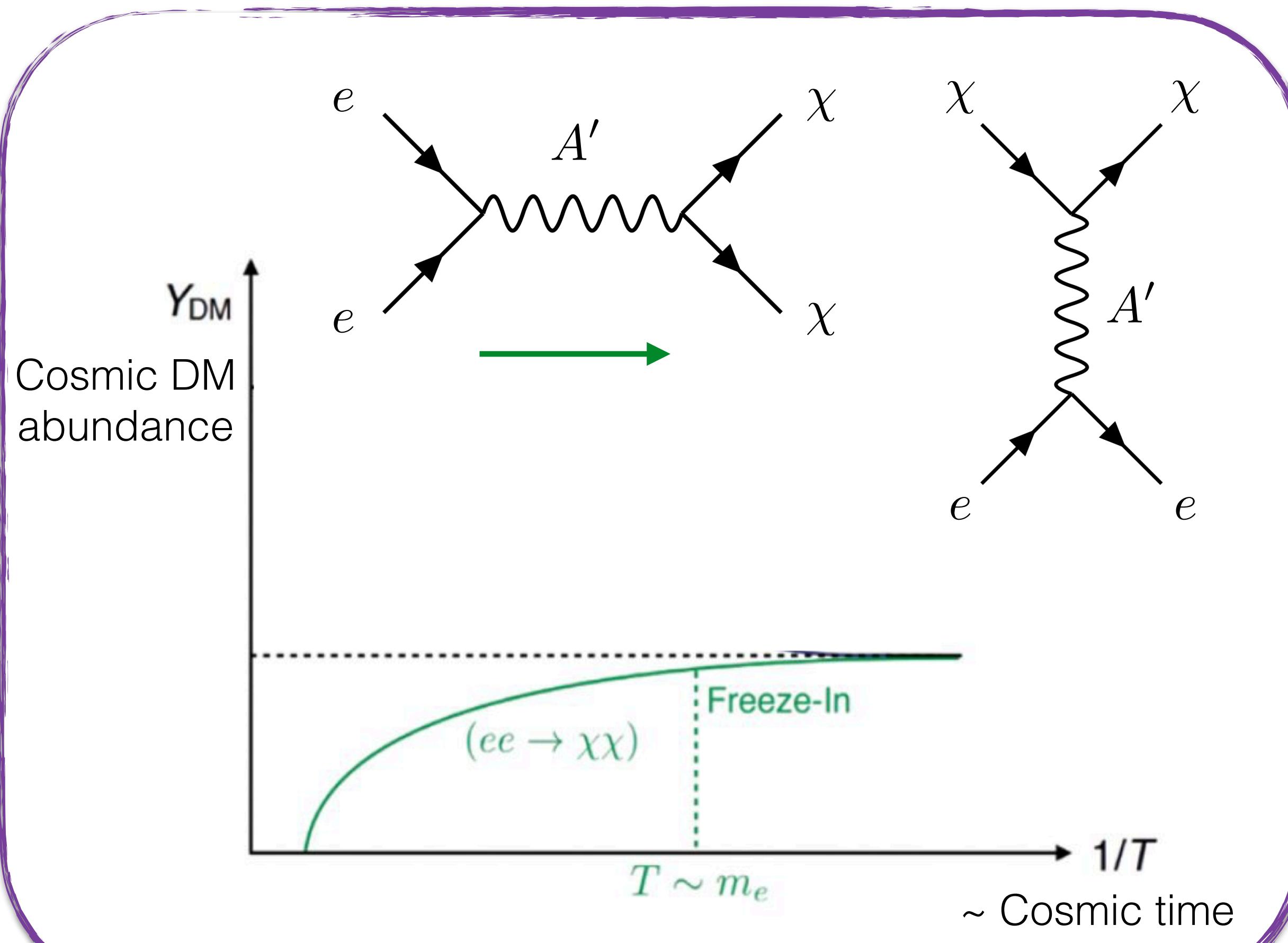
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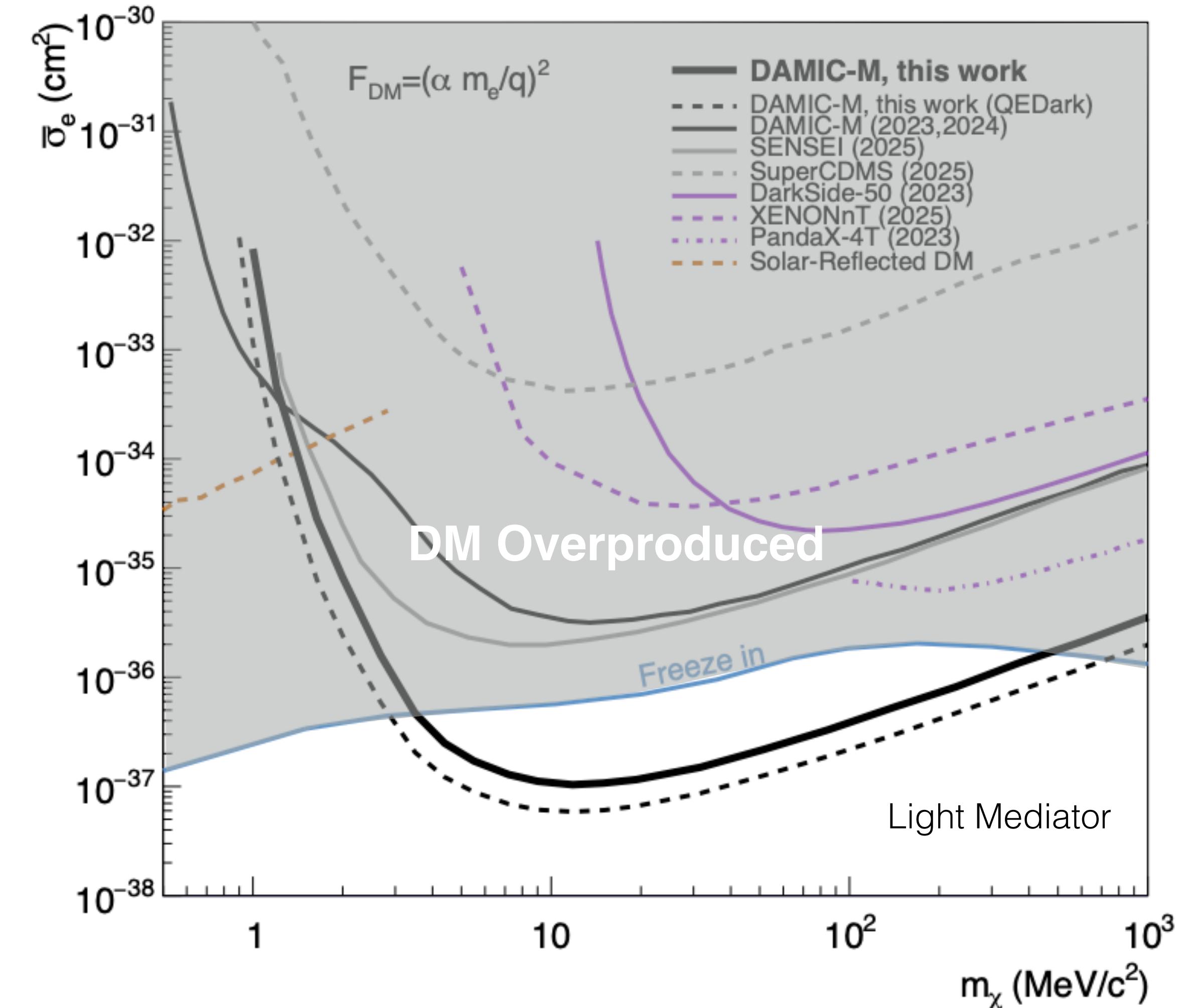


DAMIC-M

DArk Matter In CCDs at Modane



[DAMIC-M, 2503.14617]



DAMIC-M

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

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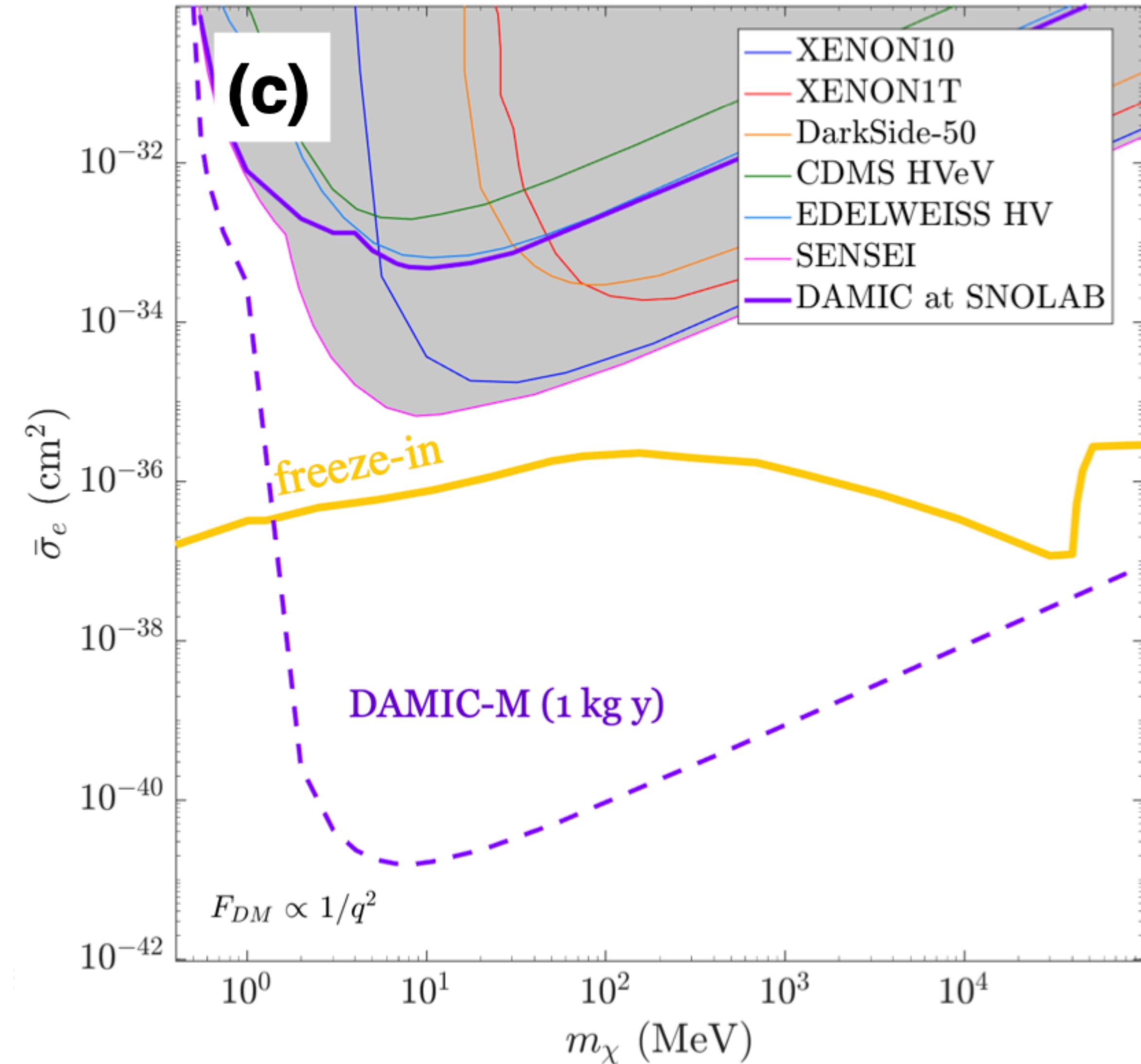
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[DAMIC-M, [2503.14617](#), [2511.13962](#)]

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

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

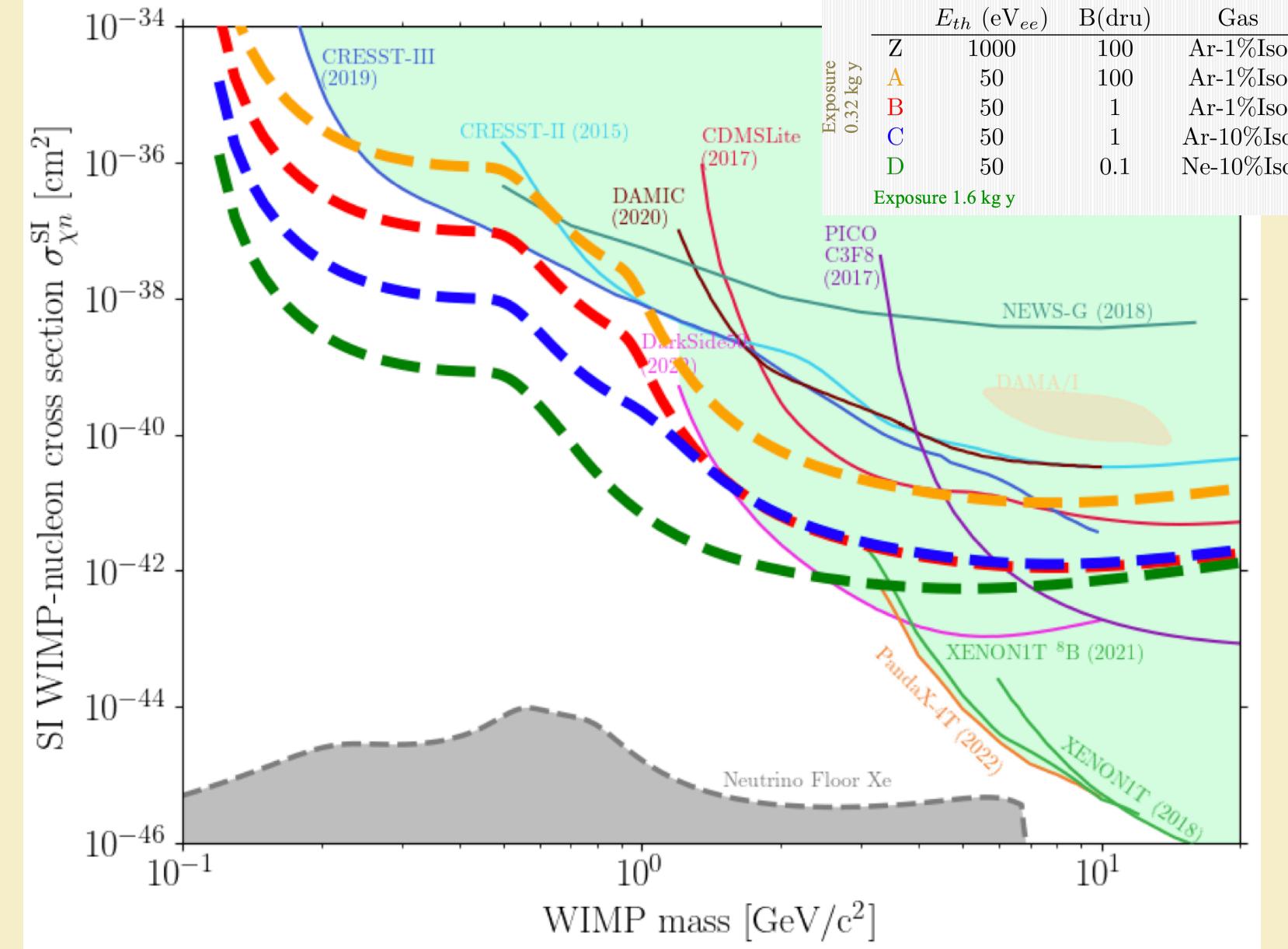


Final characterization and optimization underway at Modane, with installation of 26 modules in the DAMIC-M detector planned for **early 2026**.

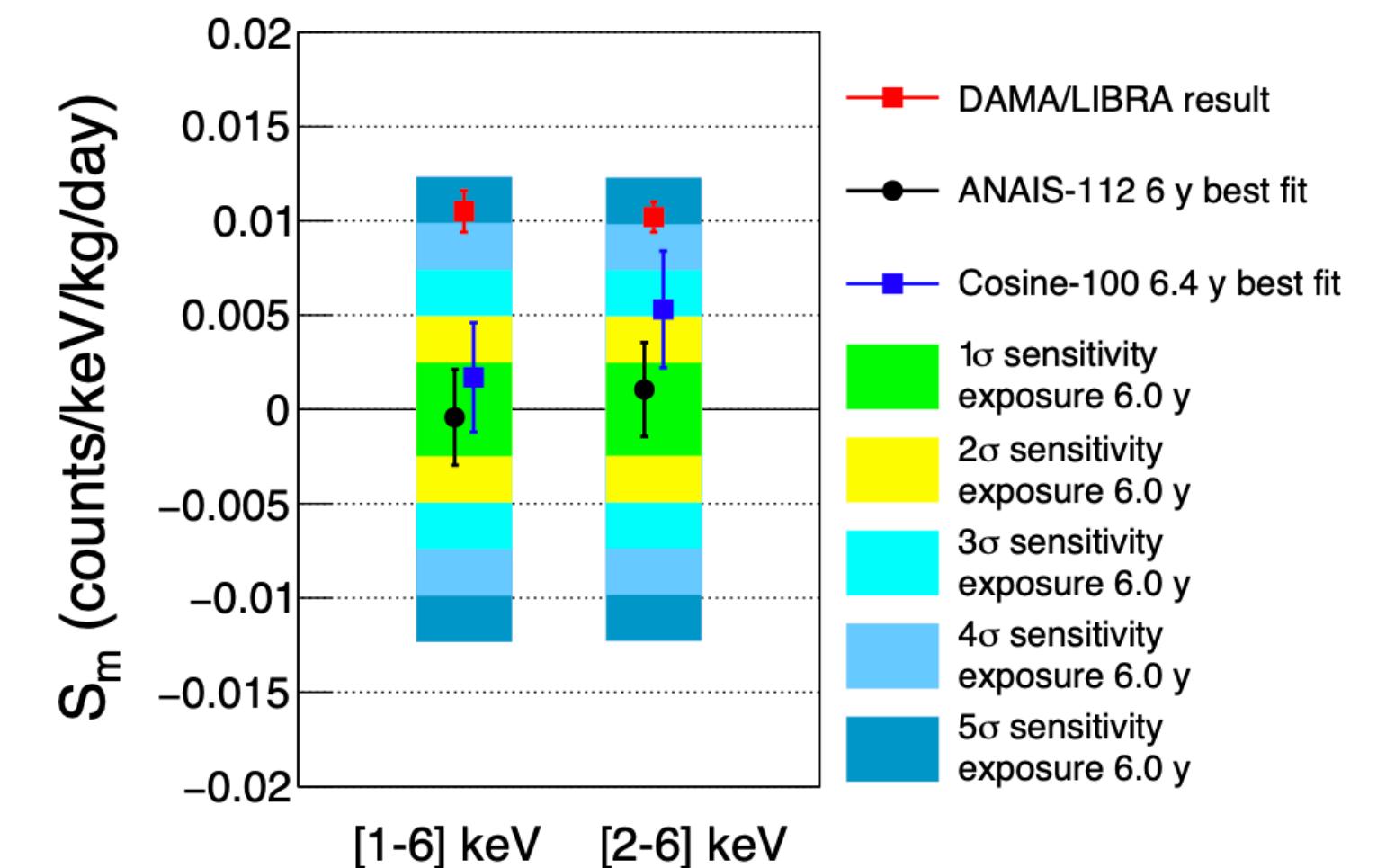
Conclusions

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

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

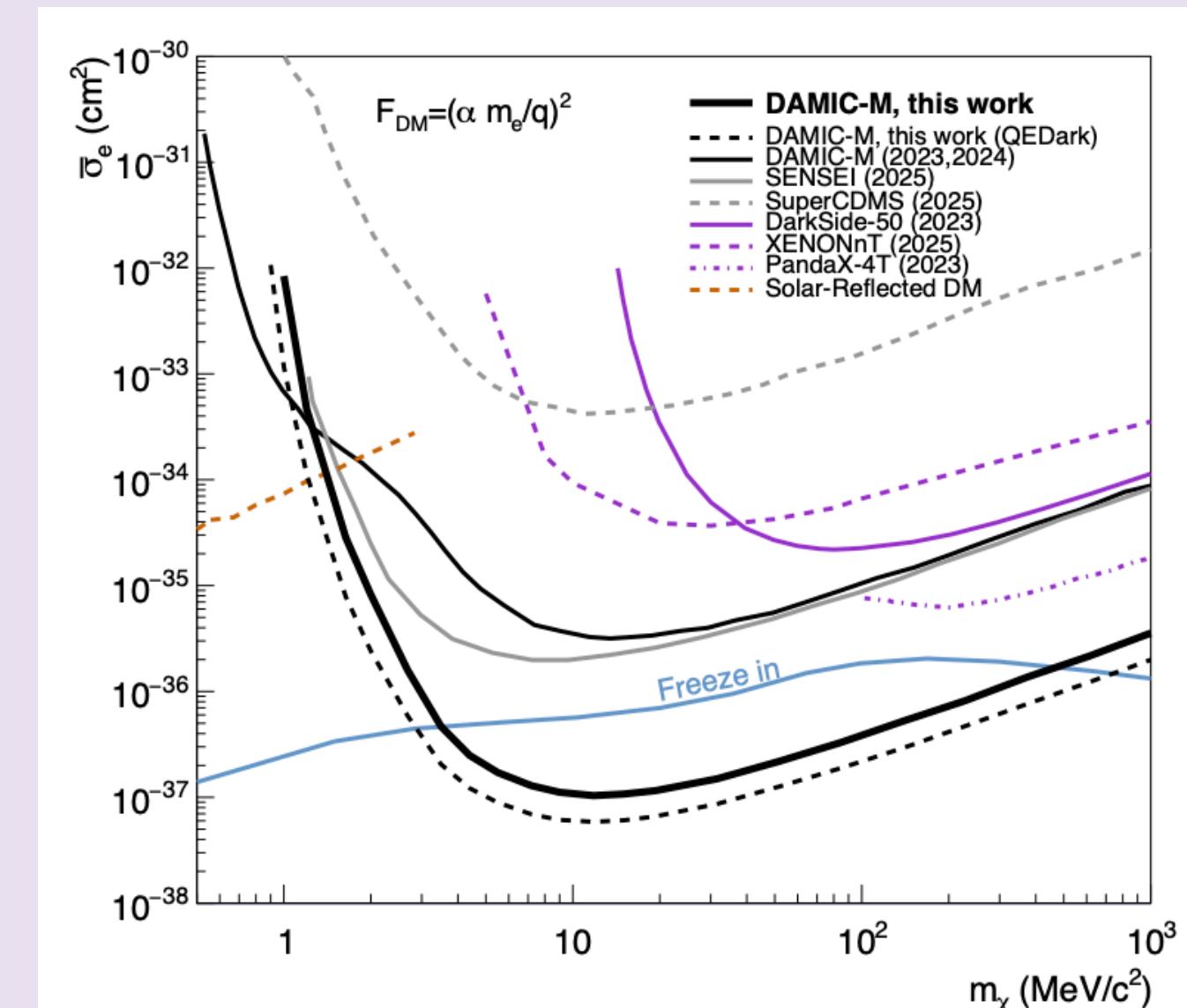


TREX-DM has demonstrated impressive 20 eV thresholds, paving the way to lead sensitivity to 0.1 - 1 GeV WIMPs



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

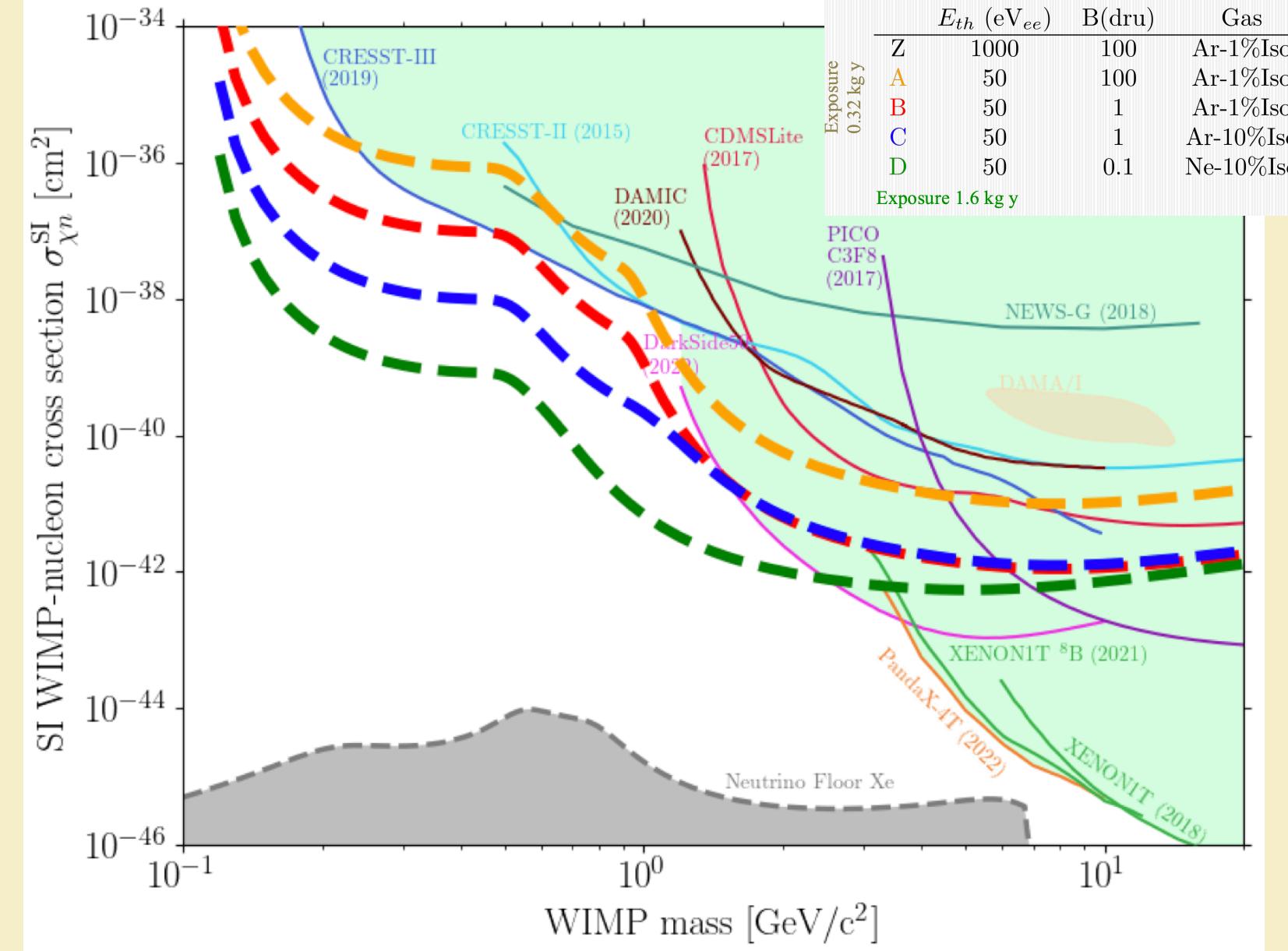
PPCC has also supported ‘spin-offs’ with similar technologies to TREX-DM and DAMIC-M, for radiopurity measurements



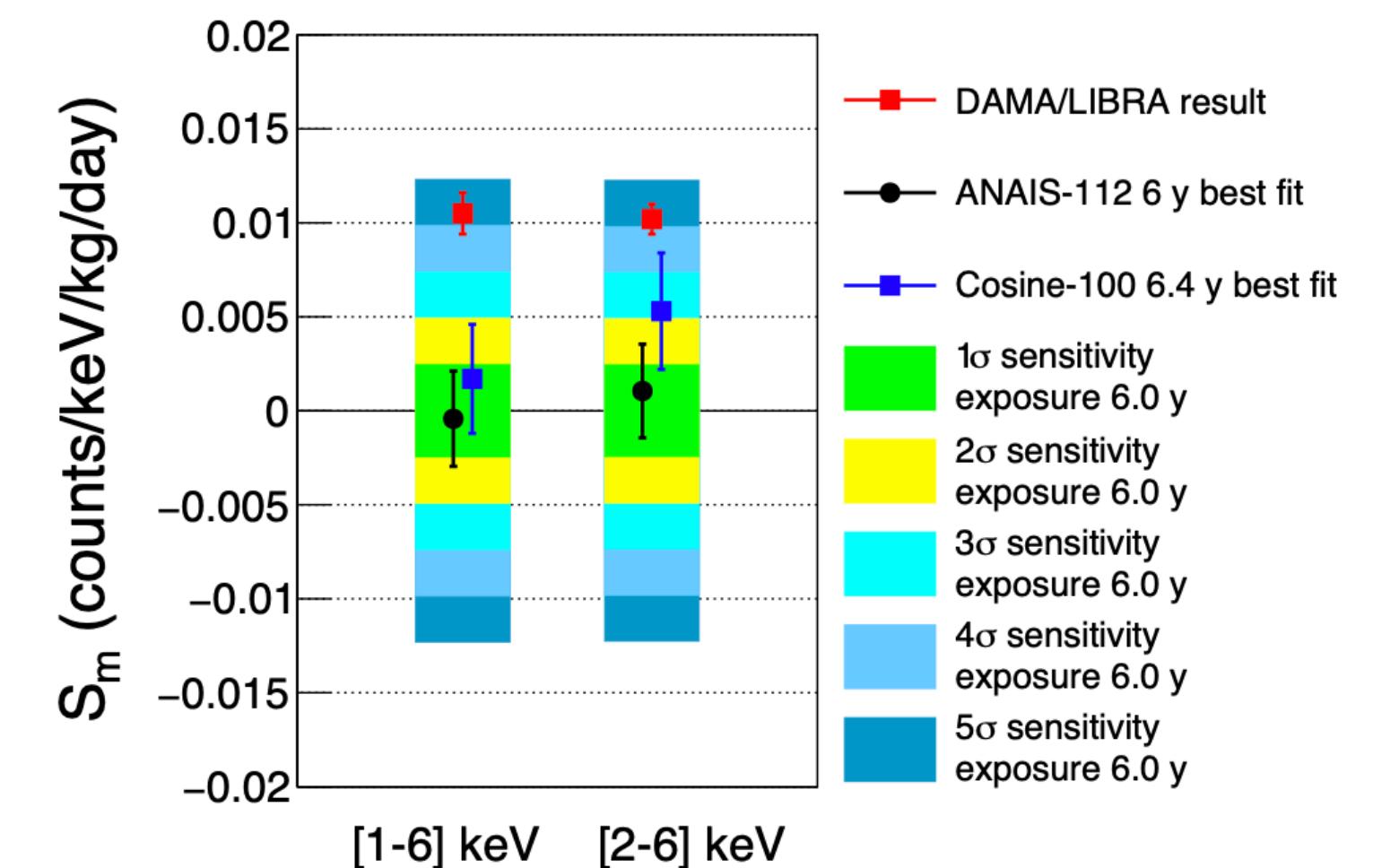
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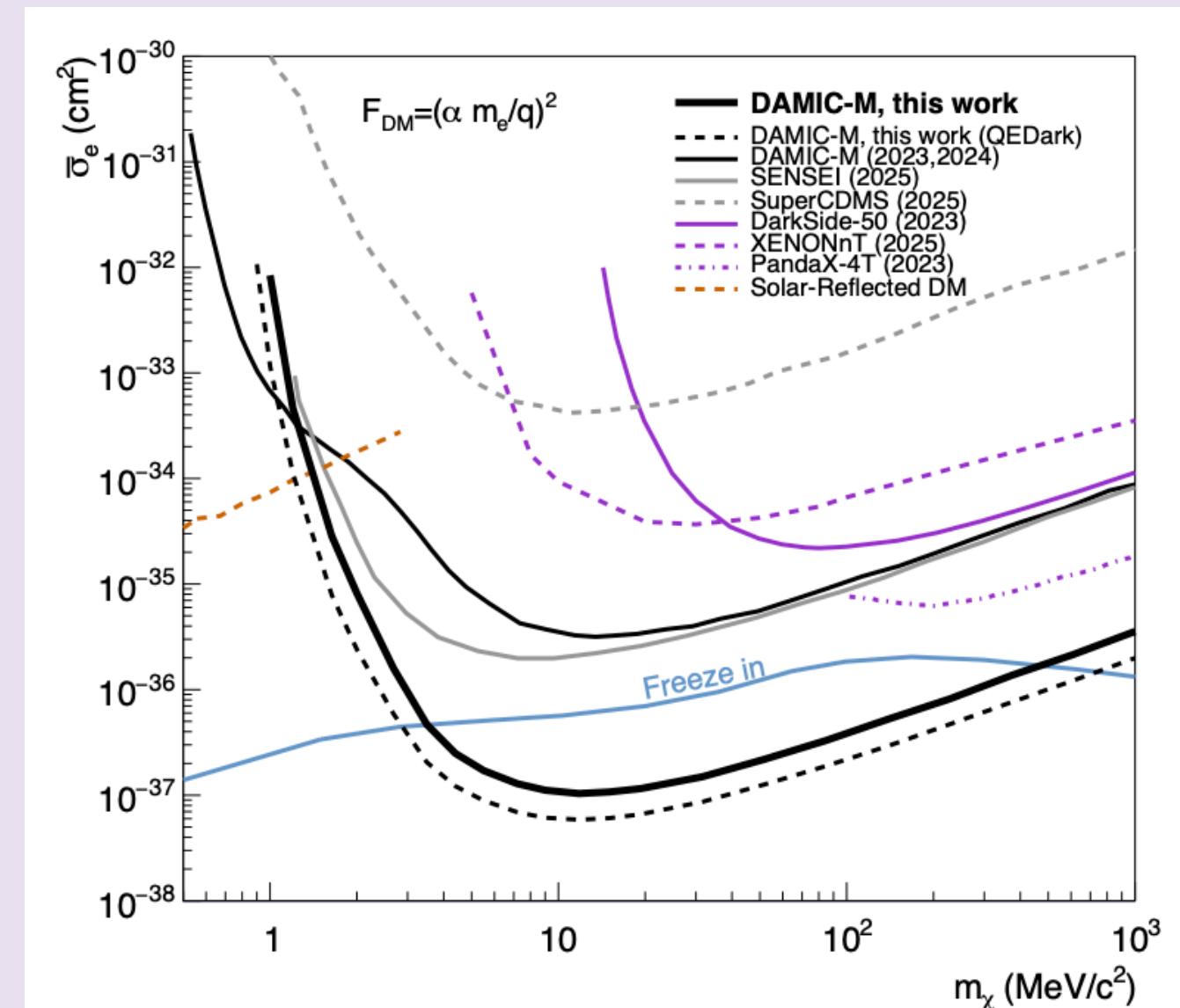
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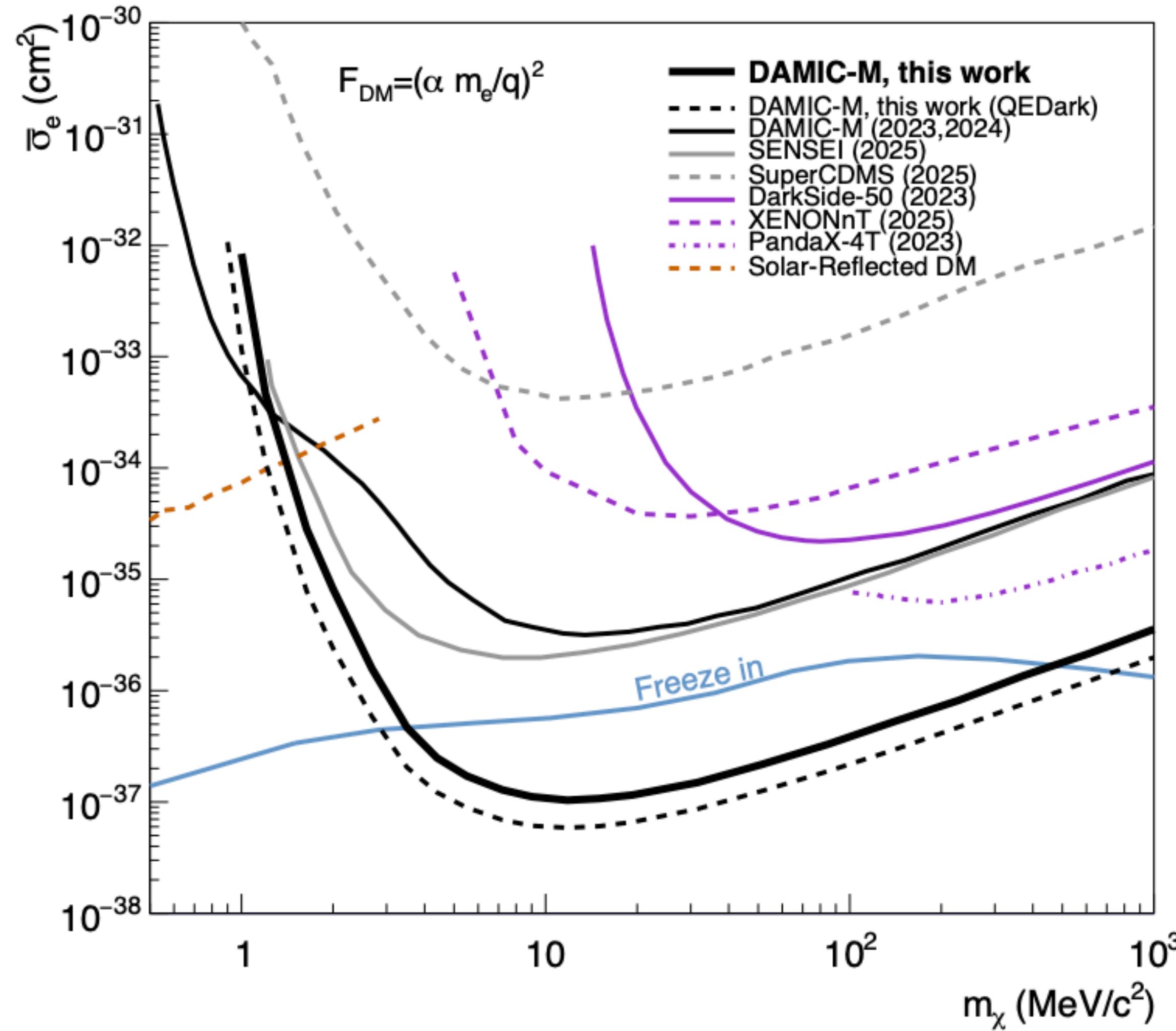
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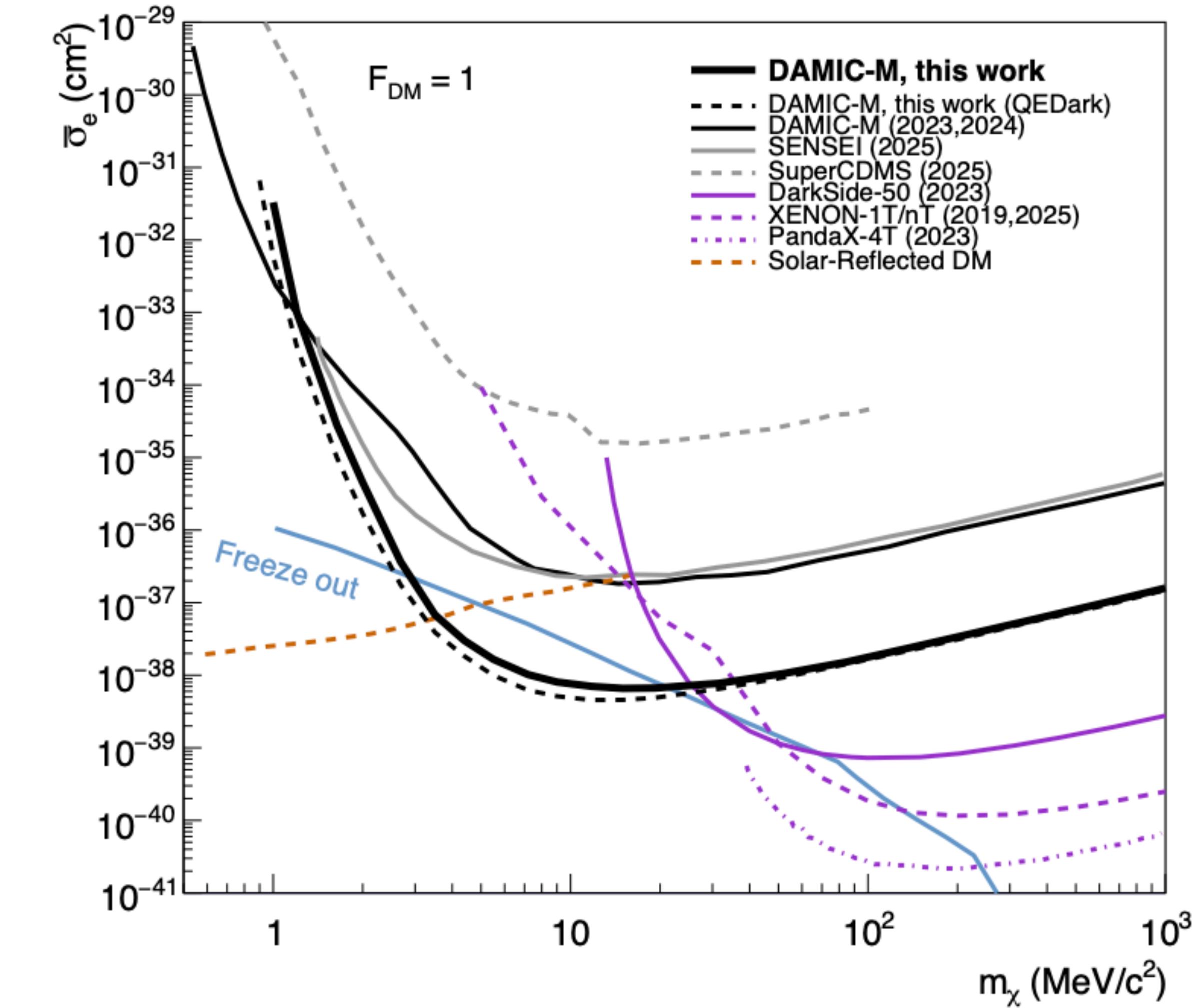
Thank you!



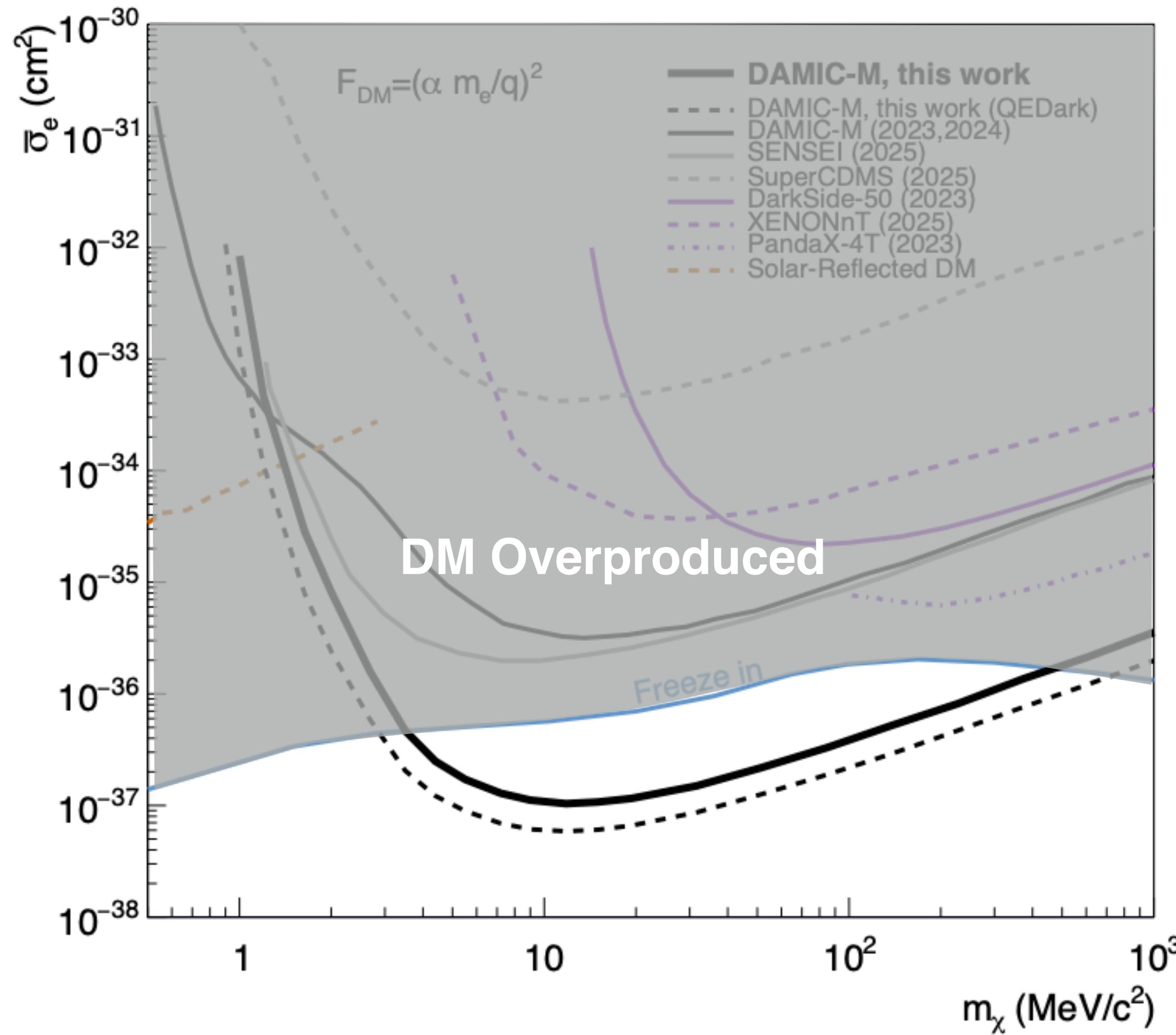
Backup Slides



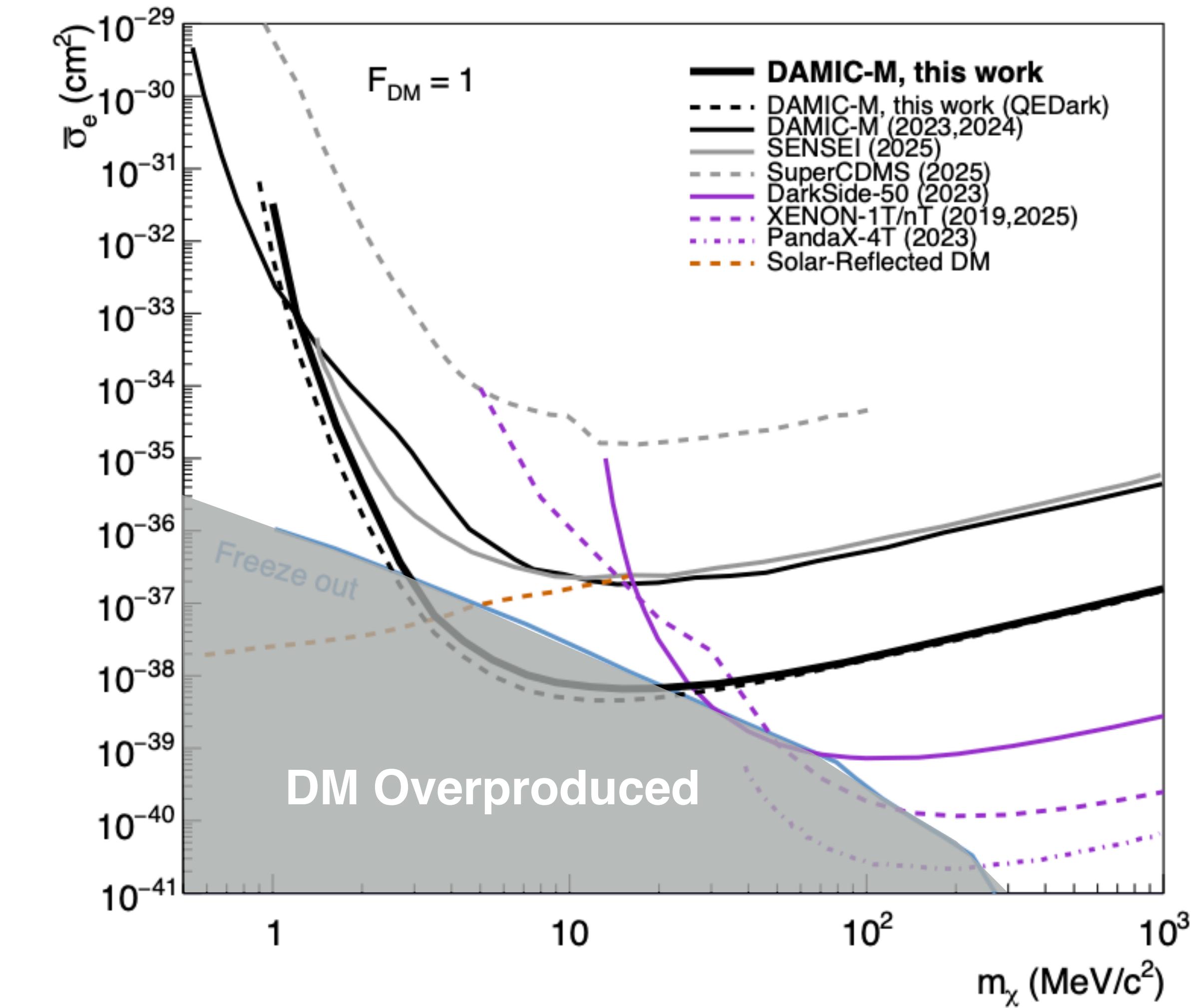
Ultralight Dark Photon Mediator



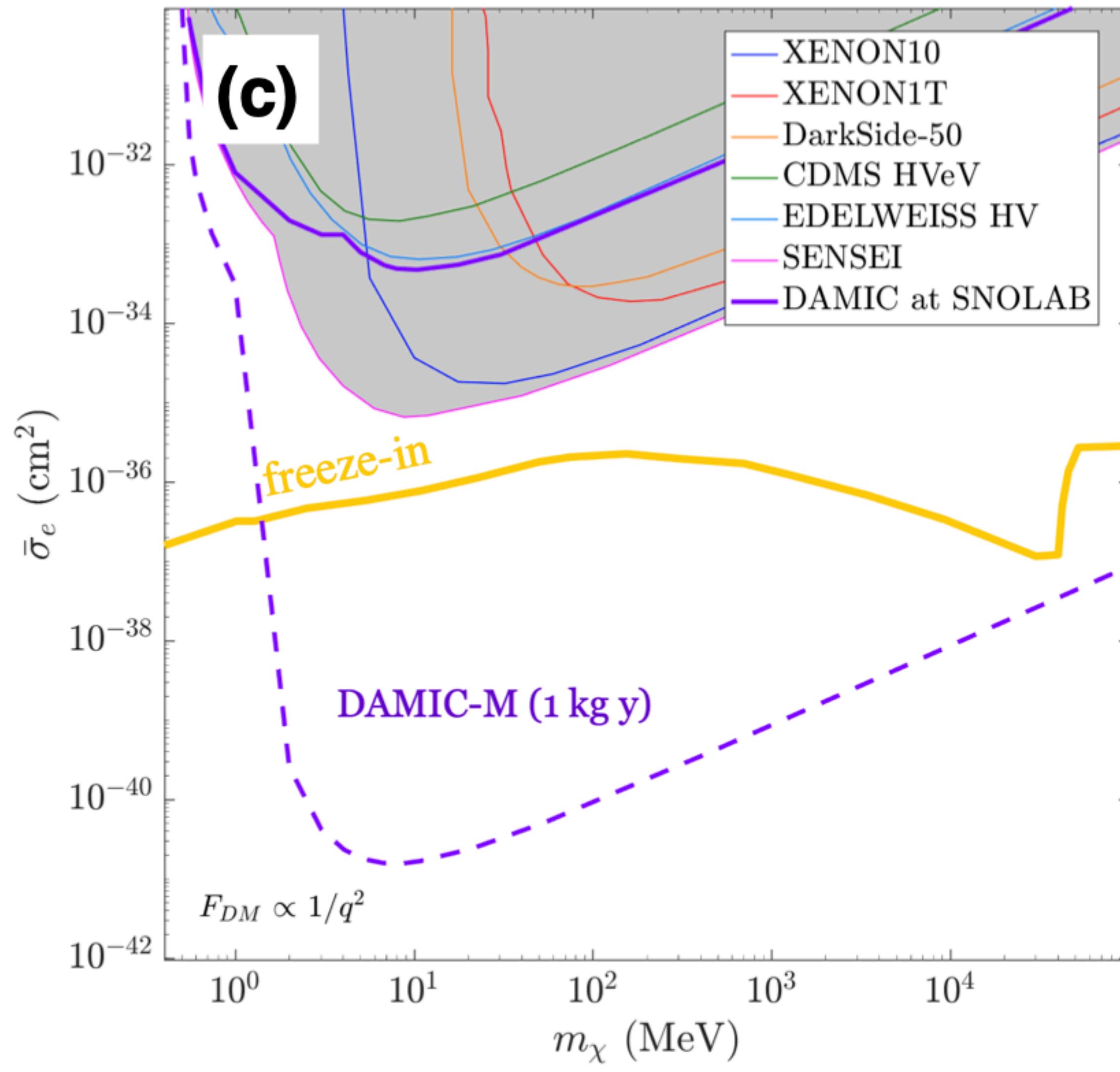
Heavy Dark Photon Mediator



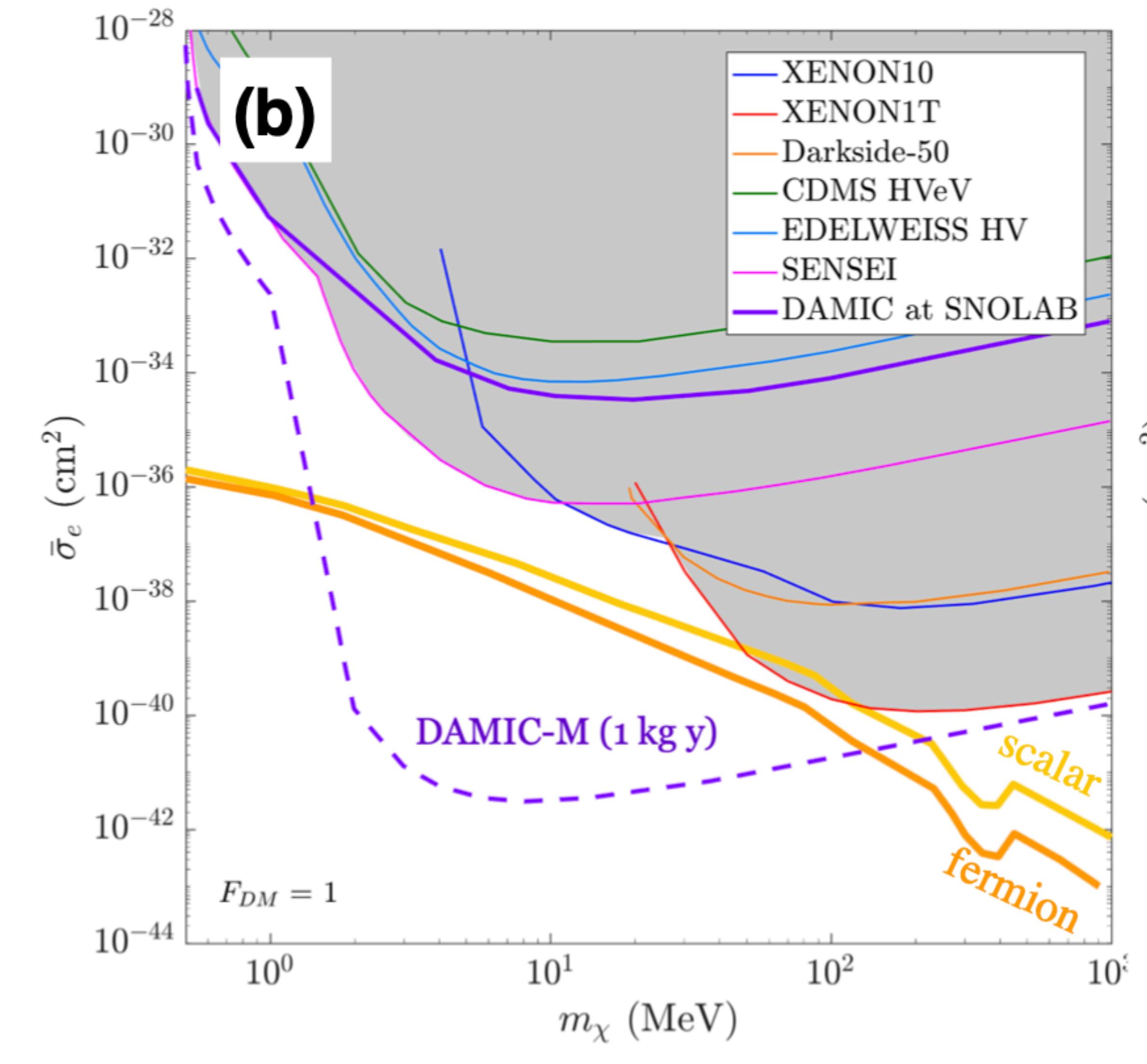
Ultralight Dark Photon Mediator



Heavy Dark Photon Mediator



Ultralight Dark Photon Mediator

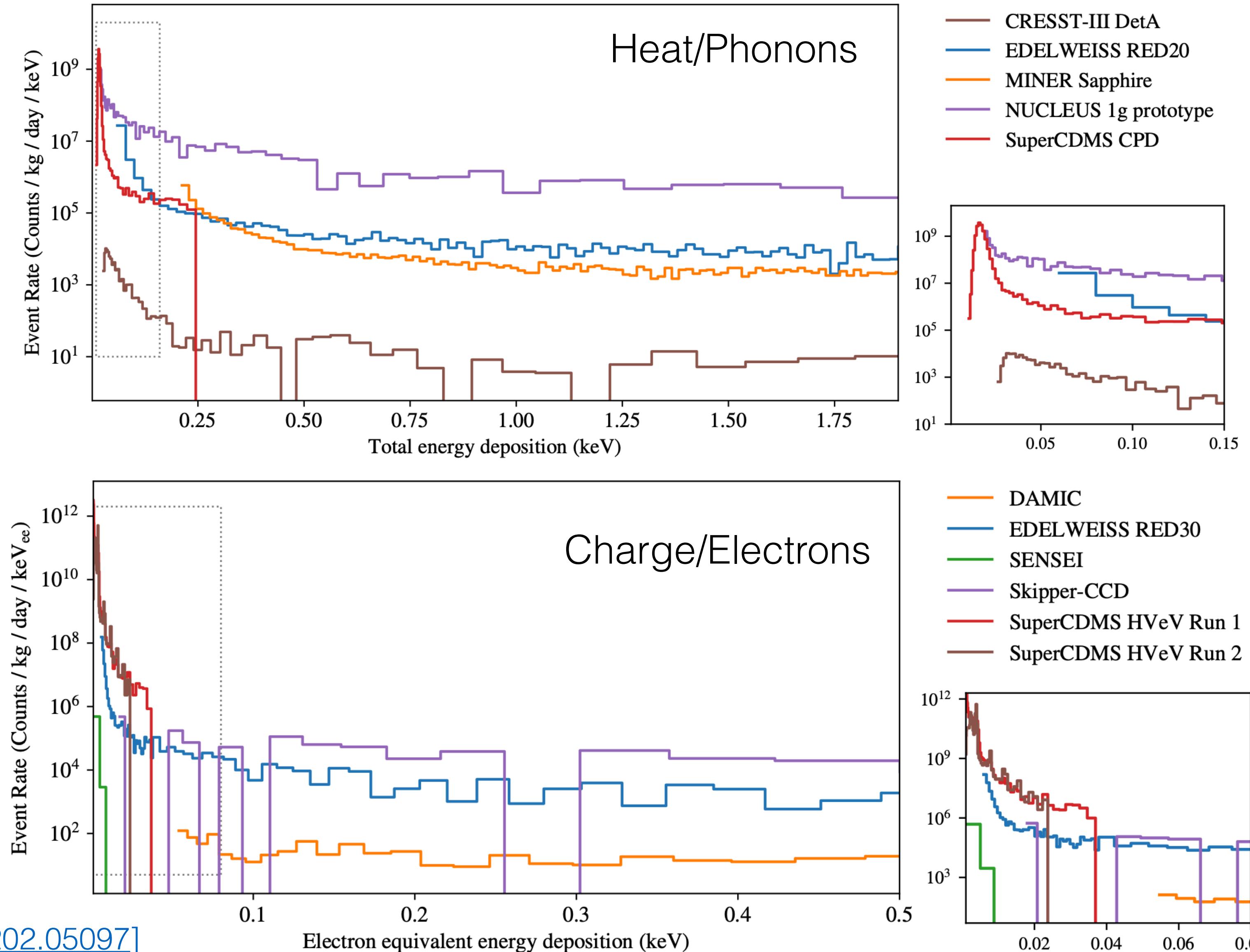


Heavy Dark Photon Mediator

EXCESS

Understanding low-energy excesses

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



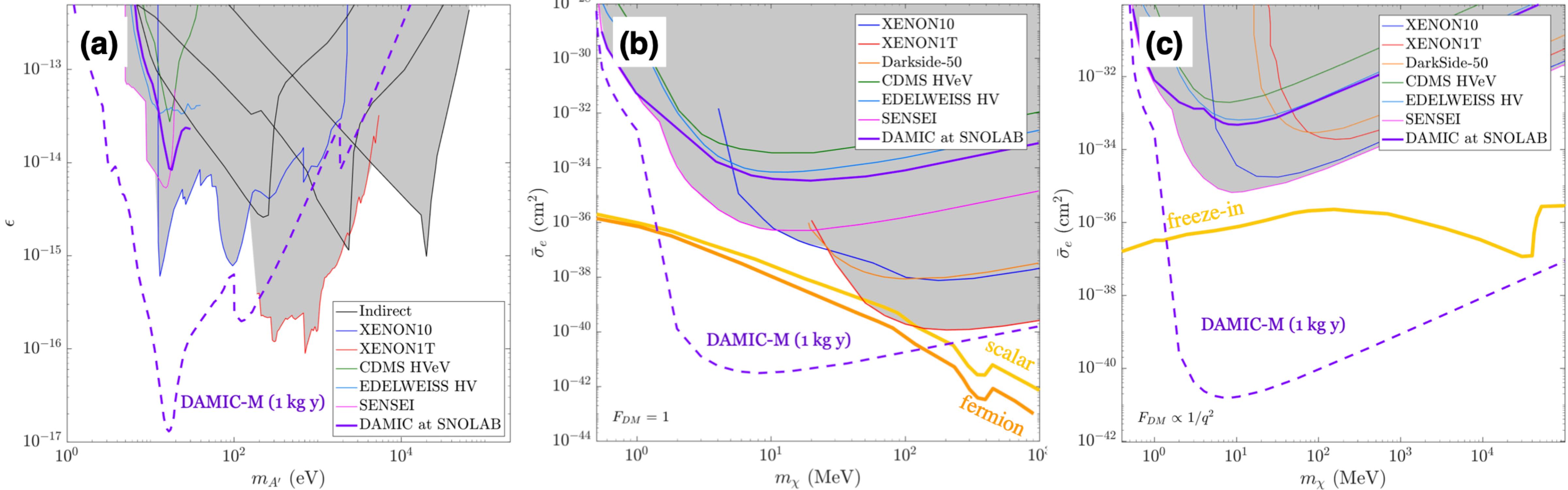
Excess event rate seen in many low-threshold experiments below 1 keV.

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:

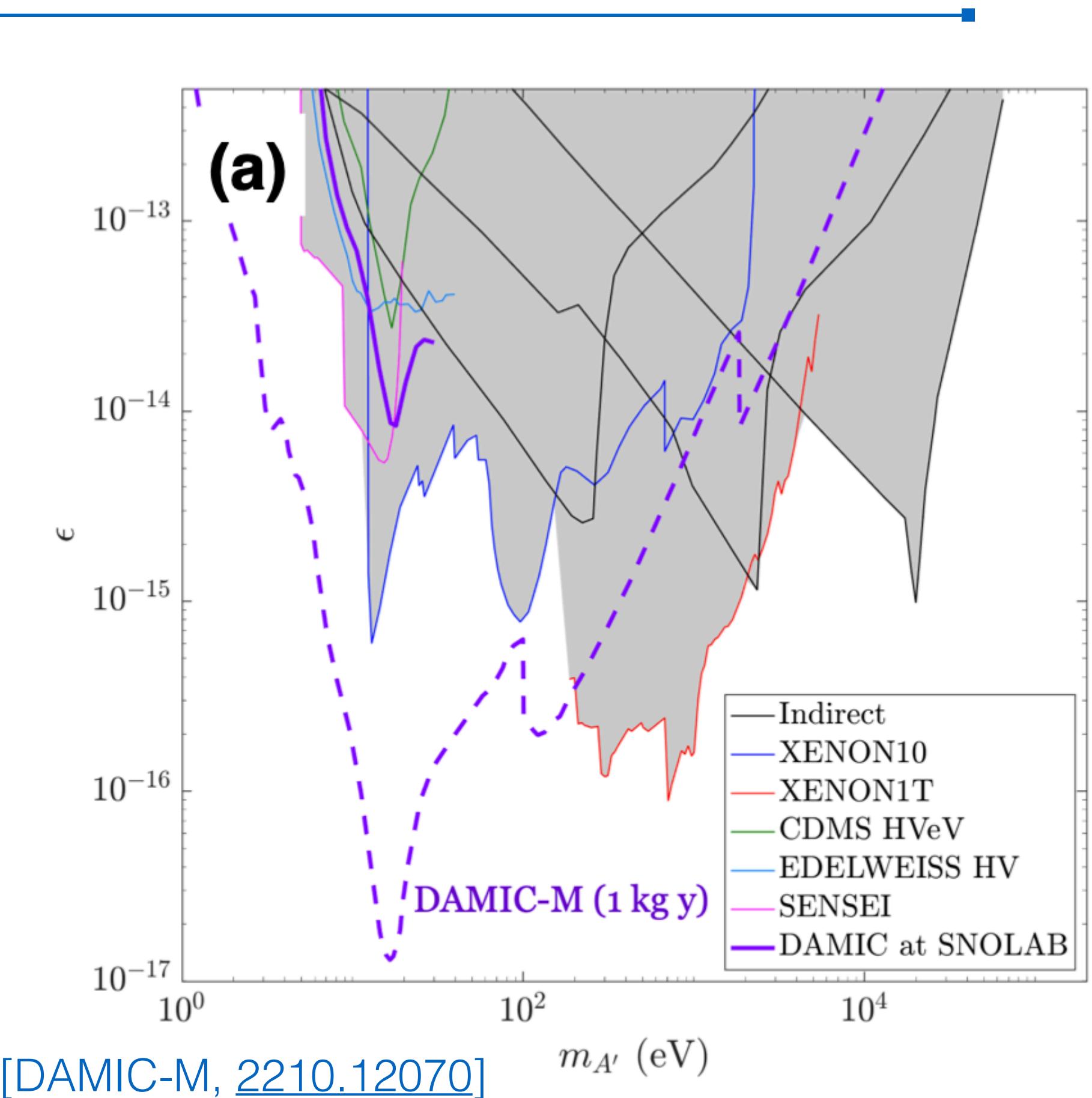
- Relaxation of the sensor
- Relaxation of the target material
- Relaxation of supports
- Energy stored in interfaces

DAMIC-M Projections



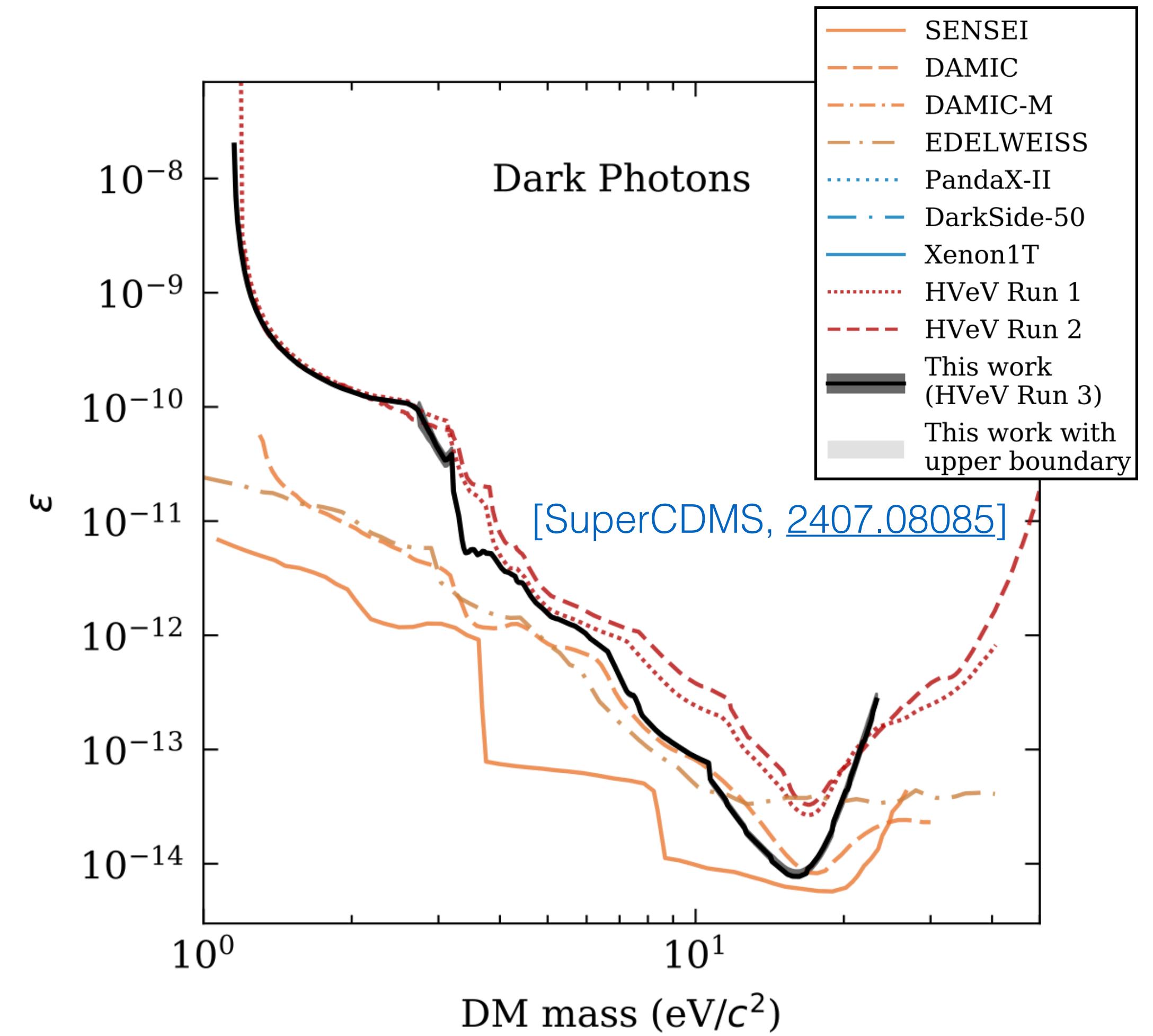
[DAMIC-M, [2210.12070](#)]

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

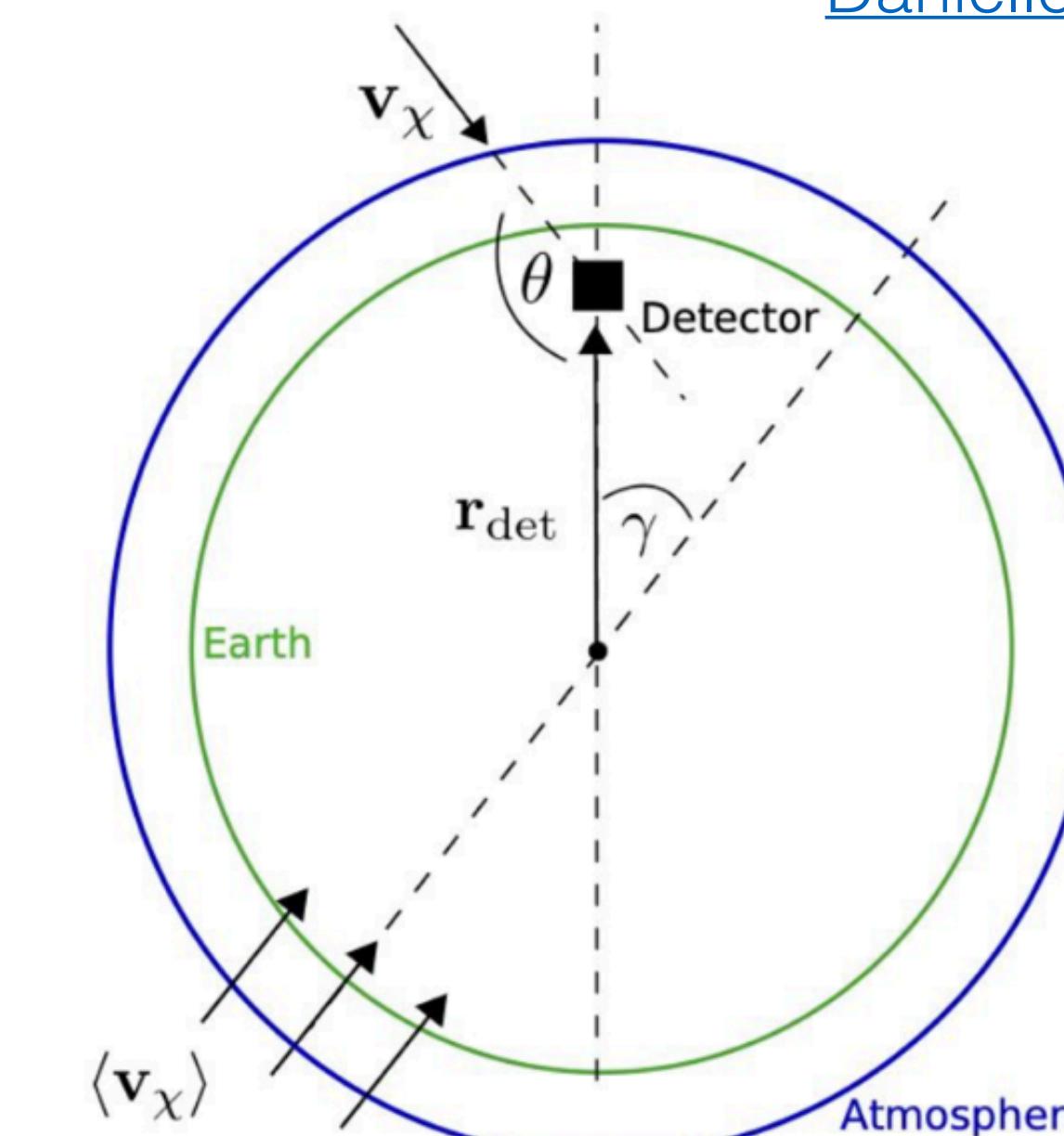
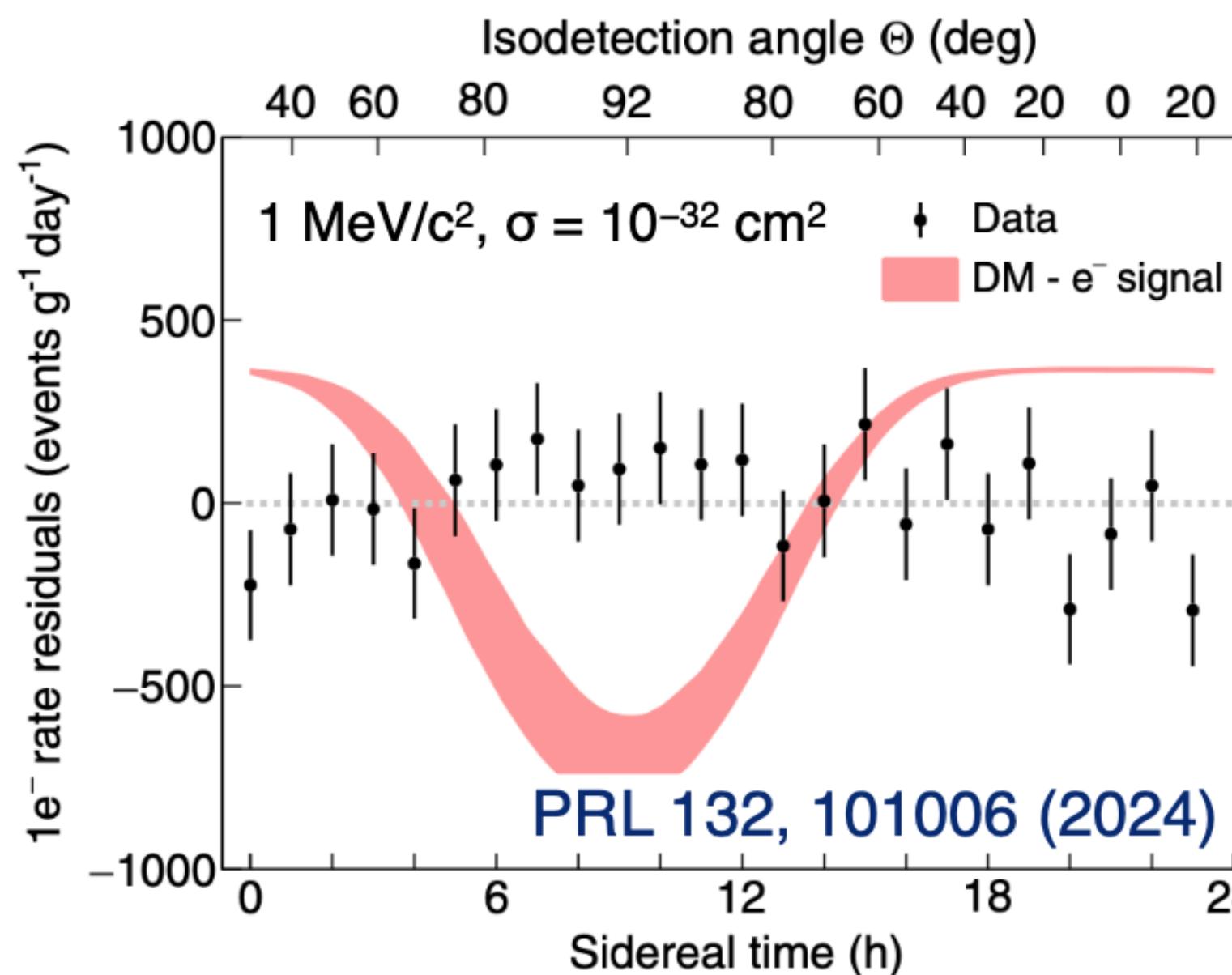
[Hochberg et al., [1604.06800](#)]

Daily modulation search

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

Motivation:

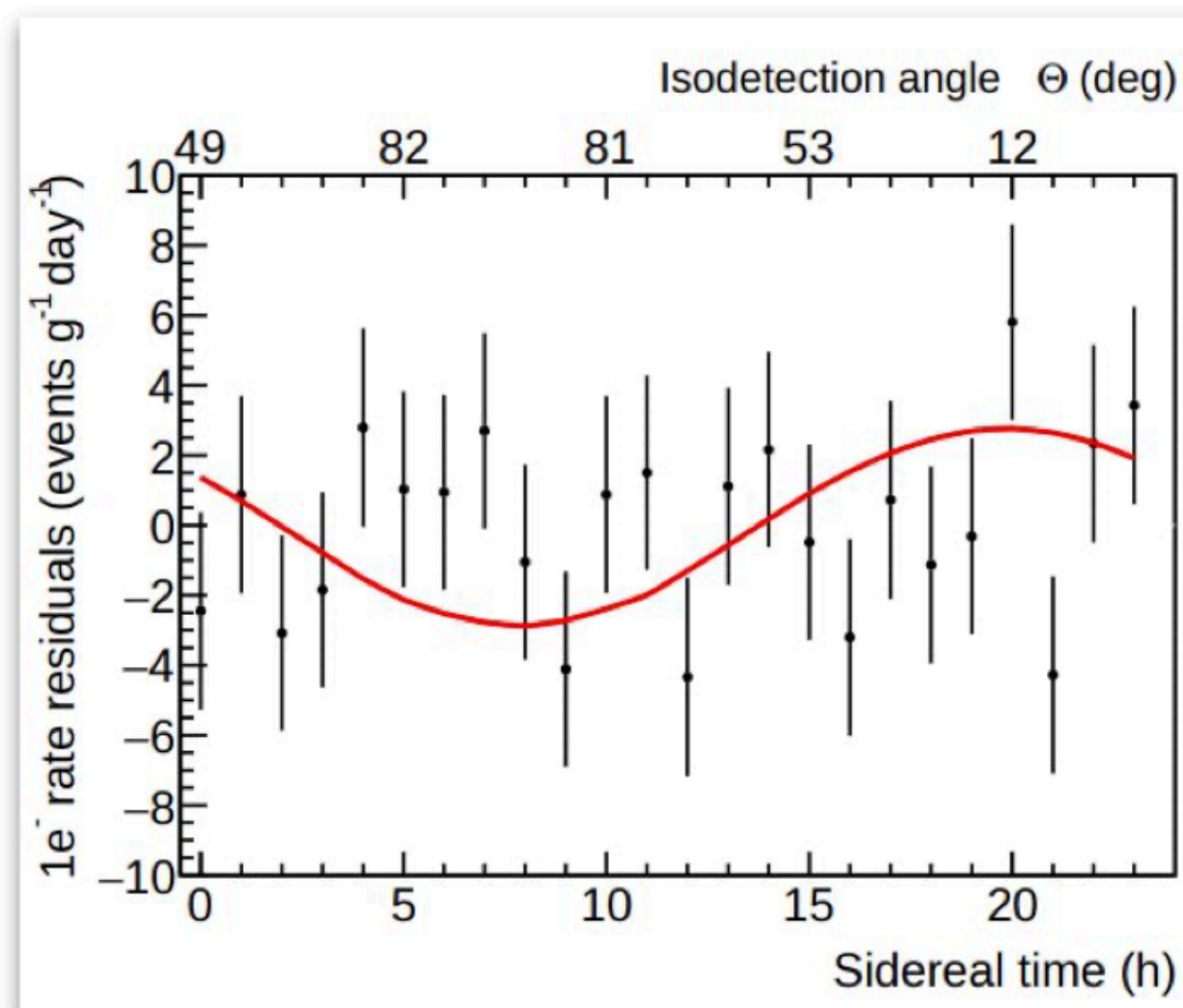
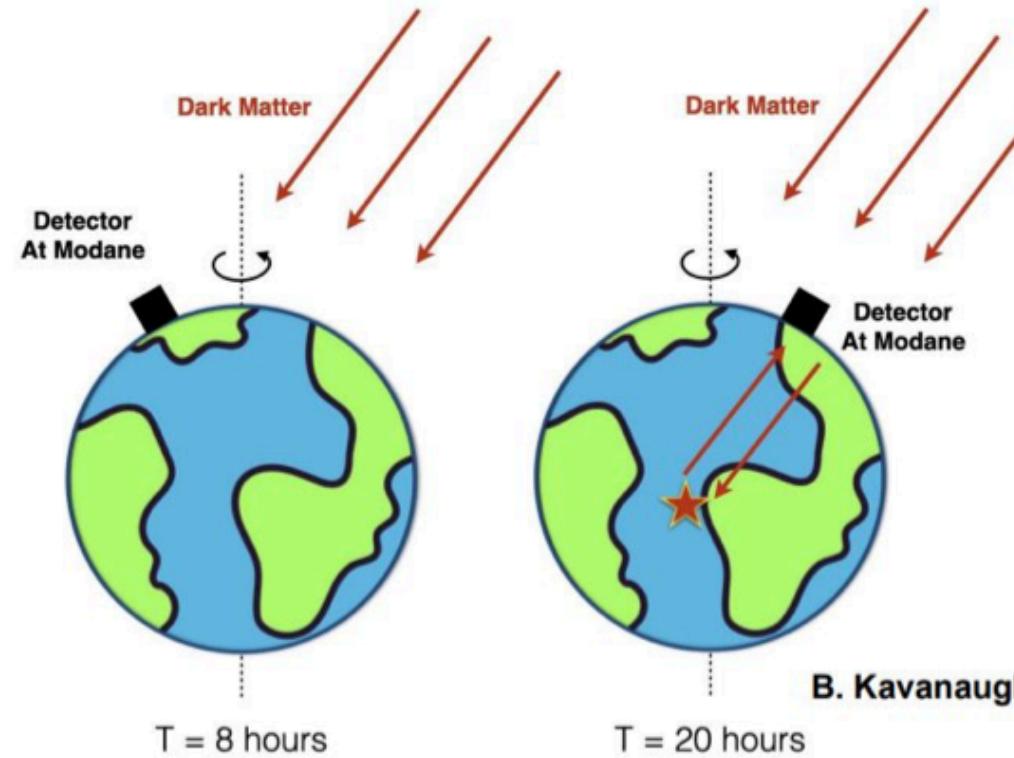
- MeV-scale DM candidates with large cross sections have not been ruled out
- scattering in Earth's bulk becomes relevant for flux/velocity distribution, DM signal can modulate over day
- in LBC, time-dependent signal vs. independent background strong discriminating power
- new approach for constraining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



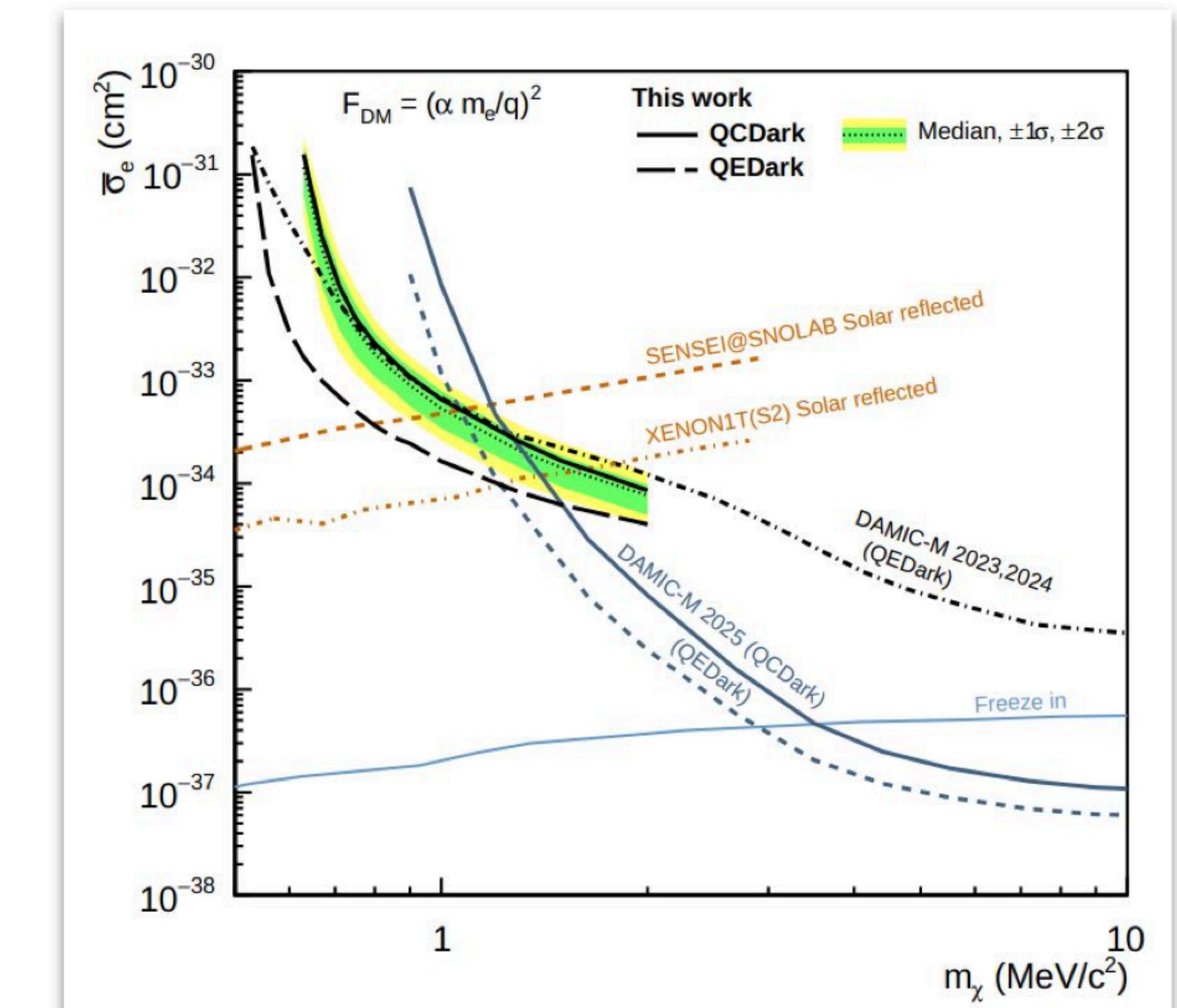
LBC result:

- 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 ruled out, reaching freeze-in for the first time ... AND PUSHING TO LOWER ENERGIES WITH DAILY MODULATION



arXiv: 2511.13962 (published this week)



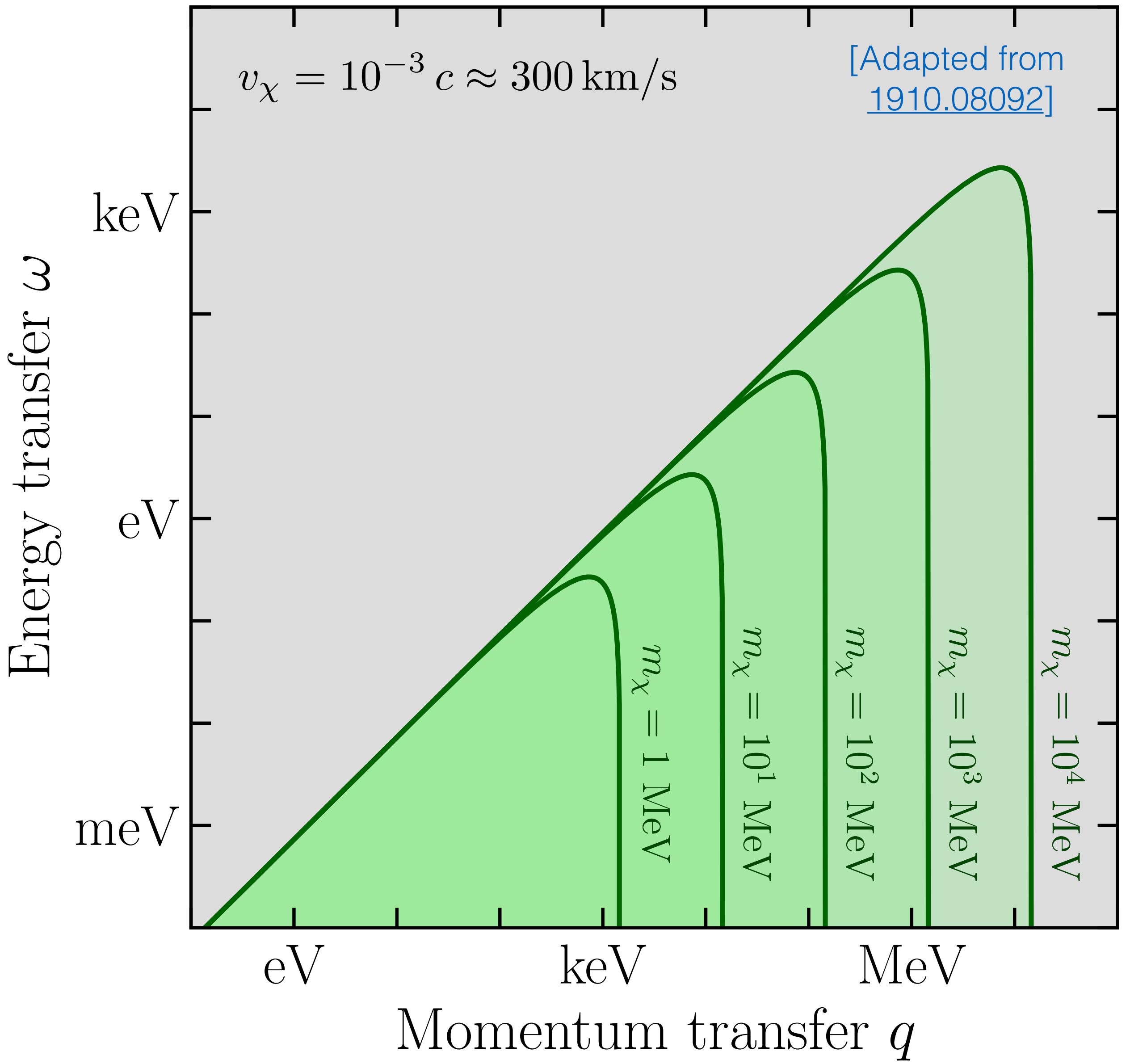
Scattering Kinematics

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 keV $\rightarrow m_\chi \gtrsim$ GeV
- **Electron ionisation** - possible for $\omega > \Delta \sim$ eV $\rightarrow m_\chi \gtrsim$ MeV
- **Phonon interactions** - possible for sufficiently small q , with $\omega_{\text{ph}} \sim \mathcal{O}(10\text{s})$ meV $\rightarrow m_\chi \sim$ keV – 50 MeV



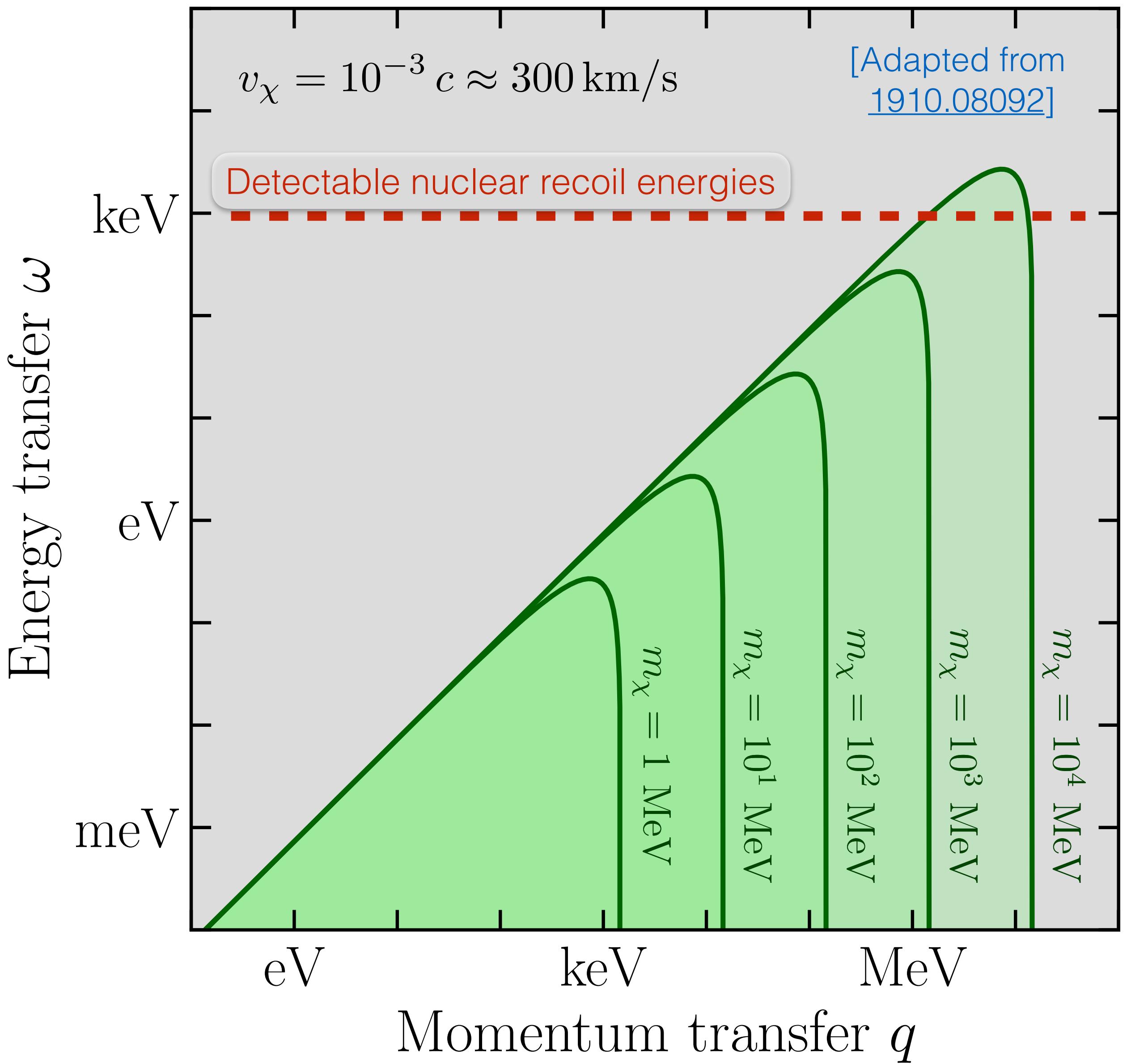
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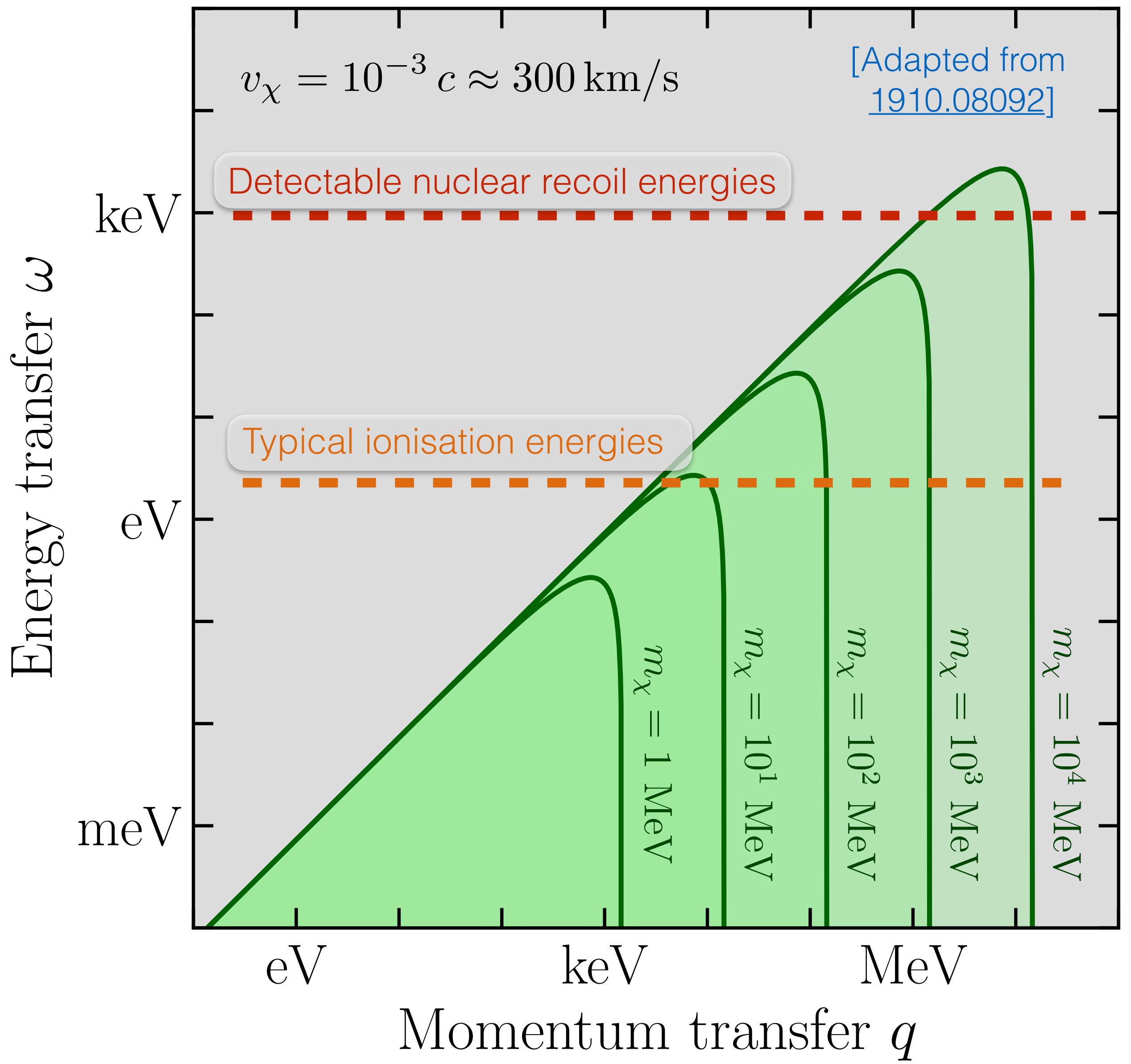
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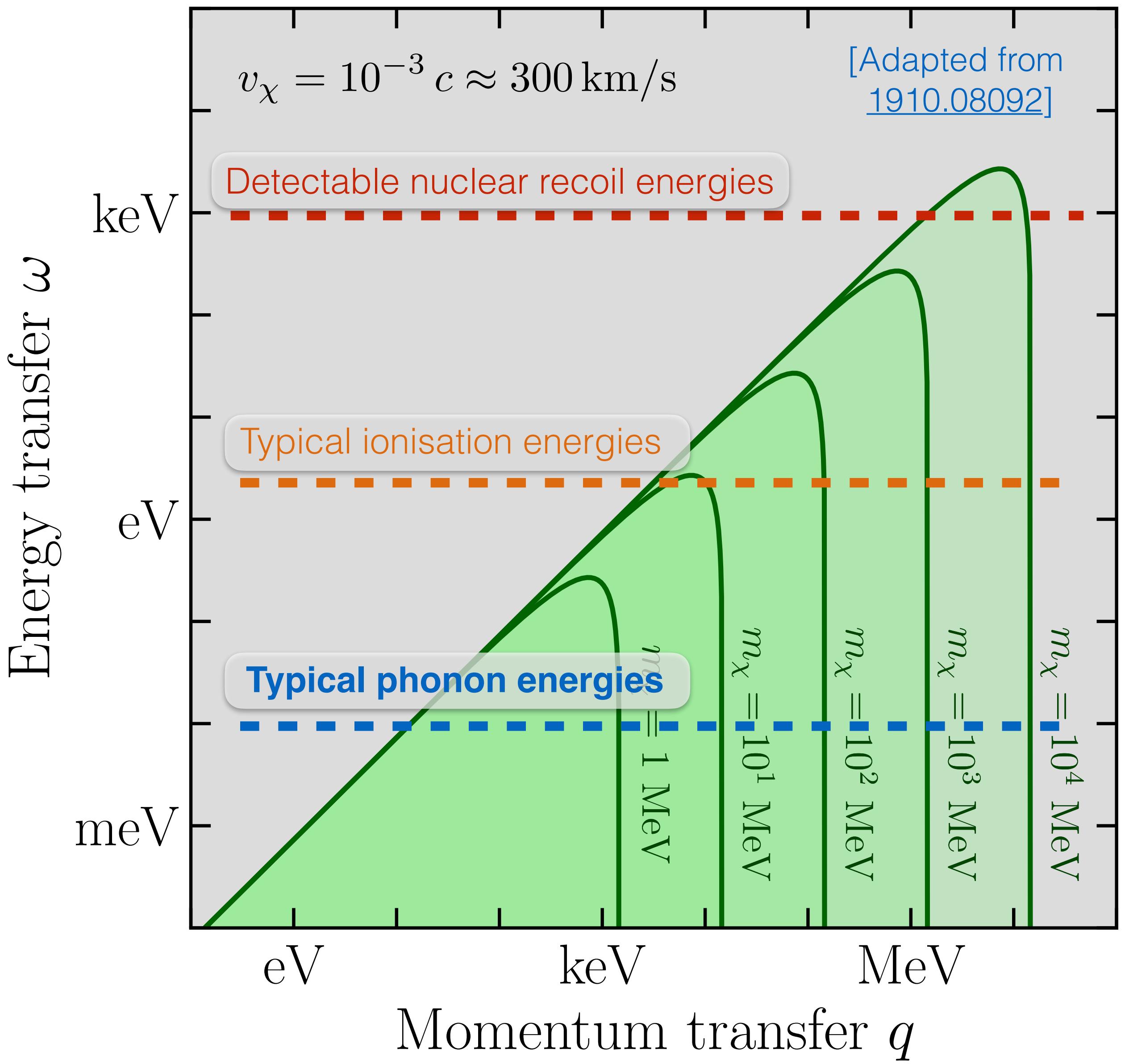
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DM mass ranges:

meV

eV

keV

MeV

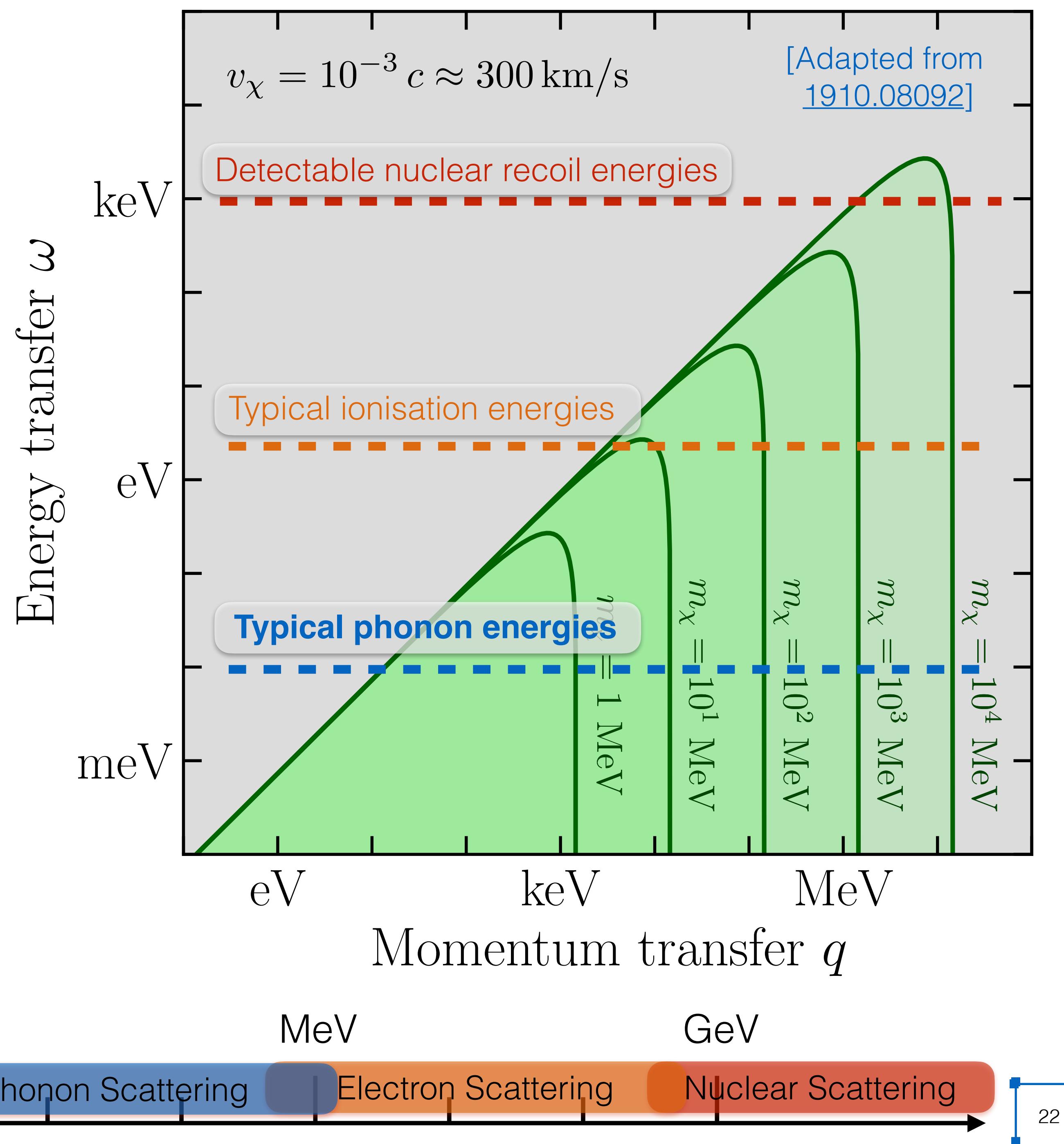
GeV

Absorption into Phonons

Phonon Scattering

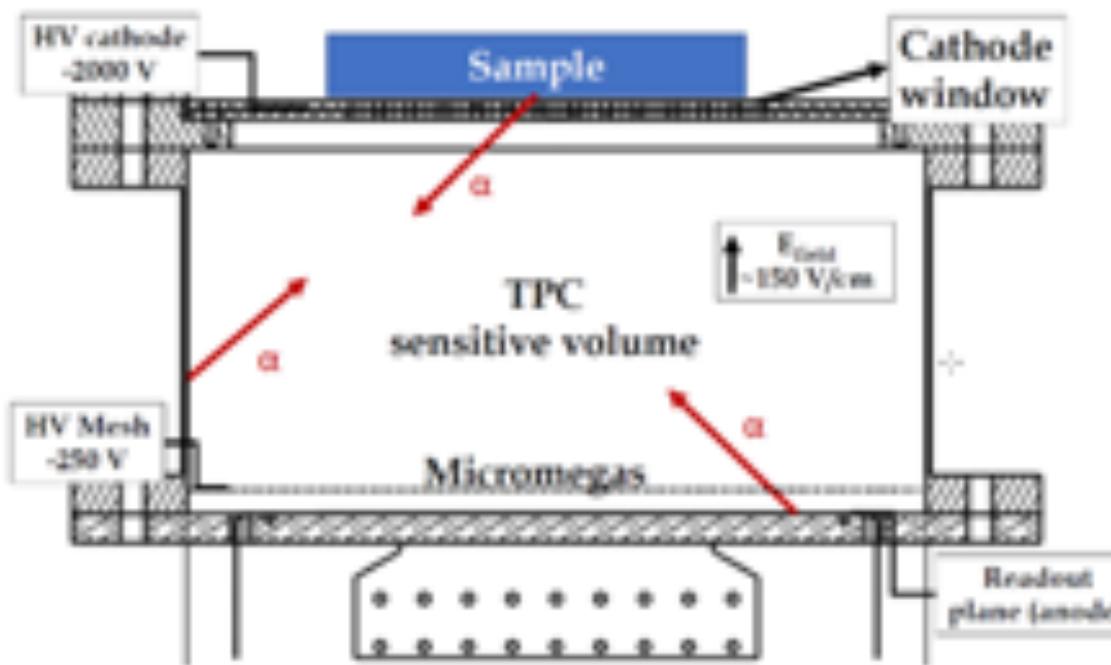
Electron Scattering

Nuclear Scattering



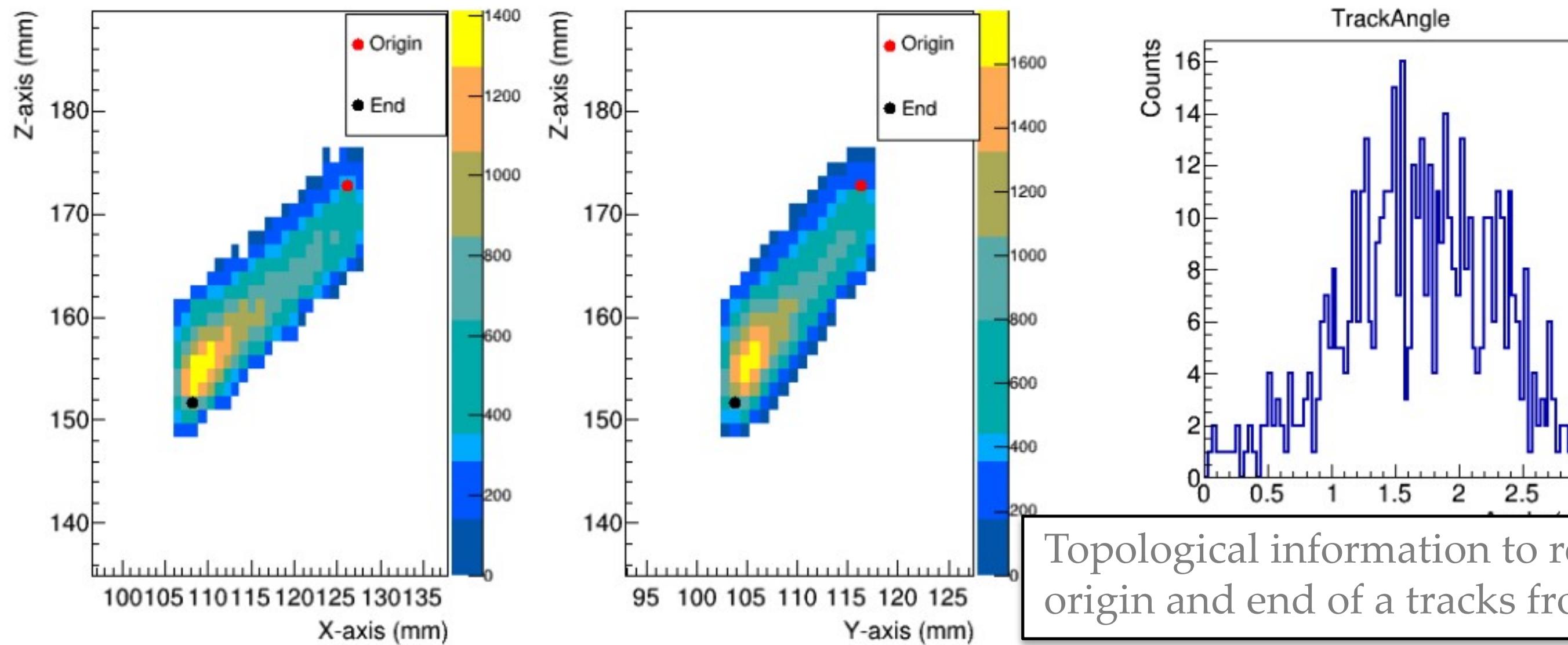
AlphaCAMM (Alpha CAMera Micromegas)

- 'Spin-off' of TREX-DM: gaseous chamber with a segmented mM (25cm x 25cm) to measure ^{210}Pb surface contamination of flat samples down to 100 nBq/cm²



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

