Search for dark matter-electron scattering with COSINE-100 and prospects for COSINE-100U

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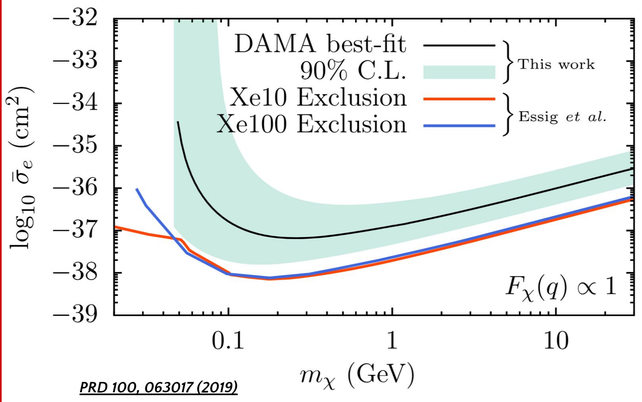
Introduction

- Dark matter (DM) is strongly supported by independent astrophysical and cosmological observations, motivating numerous particle DM candidates.
- Weakly Interacting Massive Particles (WIMPs) have long been among the most compelling DM candidates, as they naturally reproduce the observed relic abundance.
- Searches for GeV-scale DM have significantly constrained the available parameter space, motivating increasing interest in sub-GeV DM scenarios.
- The scattering of light DM with electrons provides a promising detection channel for sub-GeV DM.
- In this framework, the most widely studied model assumes a new vector boson mediating the DM–electron interaction.
- Two limiting cases are commonly considered: heavy and light mediator scenarios.



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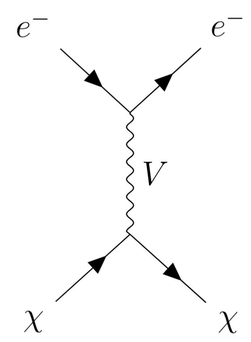
Parameters that best fit the DAMA modulation results, considering a heavy mediator scenario

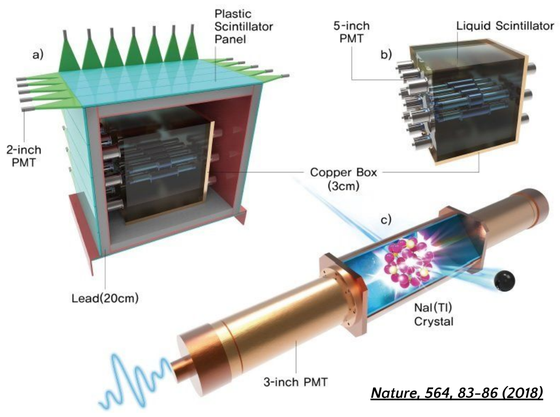


Feynman diagram of the DM-electron scattering

- Previous studies of this DM–electron interaction framework in NaI(Tl) detectors were limited to interpretations of the DAMA/LIBRA modulation signal.
- Another dedicated search with a NaI-based detector could yield competitive constraints compared to other targets.
- This goal of this work is to search for DM–electron scattering in COSINE-100 and derive constraints on the DM–electron cross section.
- Two COSINE-100 datasets were analyzed: the initial 2.82 year dataset with a well-modeled background and an analysis threshold of 8 photoelectrons (0.7 keVee), and the final 3.9 year dataset targeting 2, 3, and 4 photoelectron-like signals (NC).

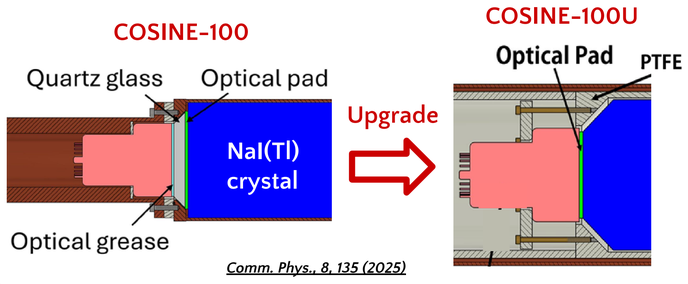
COSINE-100 and COSINE-100U experiments

- The COSINE-100 experiment operated at the Yangyang Underground Laboratory for 6.4 years.
- The primary detector consisted of eight NaI(Tl) crystals with a total mass of 106 kg. The veto system included a LAB-based liquid scintillator and 37 plastic scintillator panels for muon tagging.
- The COSINE-100U experiment, an upgraded version of COSINE-100, was constructed at the Yemilab underground laboratory and began operating in September 2025.
- The main upgrade was a new crystal encapsulation technique applied to all crystals, improving the light collection by the PMTs.



Nature, 564, 83–86 (2018)

Detectors of the COSINE-100 experiment



Comm. Phys., 8, 135 (2025)

More details in COSINE-related presentations

Poster presentation (this session)	Vitor Machado, "Searching for MIMPs with the COSINE-100 experiment"
Direct detection session (06/01)	Gyunho, "Overview and Prospects of COSINE-100U: Upgrade NaI(Tl) Dark Matter Search in Yemilab"
	Jinyoung, "WIMP search results from the full six-year COSINE-100 dataset"
Light DM session (06/02)	Wonkyung, "Pioneering Sub-GeV Dark Matter Limits with COSINE-100"

DM-electron scattering model

- The expected energy spectrum from DM–electron scattering in a target is given by:

$$\frac{d\langle\sigma_e v_\chi\rangle}{dE} = \frac{\bar{\sigma}_e}{2 m_e} \int dv \frac{f(v_\chi)}{v_\chi} \int_{q-}^{q+} a_0^2 q F_\chi^2 f_{crystal}(E,q)\, dq$$

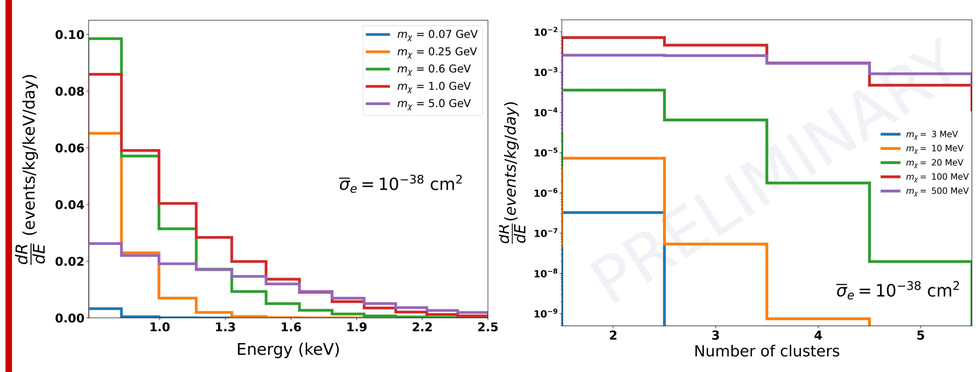
- Different approaches have been used to model the target form factor. In this work, the ionization factor was calculated using a relativistic approach that treats Na and I atoms as unbound (**PRD 93, 115037**).
- The low energy crystal form factor, arising from the NaI(Tl) crystal band structure, was derived using the QEdark code (**JHEP 46, 2016**, and **PRD 110, 123012**).

Heavy Mediator

$$m_{DP} >> \alpha m_e \Rightarrow F_\chi(q) \longrightarrow 1$$

Light Mediator

$$m_{DP} << \alpha m_e \Rightarrow F_\chi(q) \longrightarrow \frac{1}{(a_0 q)^2}$$



Expected DM-electron scattering spectra in COSINE-100 crystals for a heavy mediator

- The expected DM–electron energy spectra were generated for the COSINE-100 crystals in both heavy and light mediator scenarios.

Data analysis

- At the few NC level, where the background cannot be accurately modeled, the data were fitted using an exponentially decreasing background plus the expected annual modulation signal from halo DM–electron scattering.

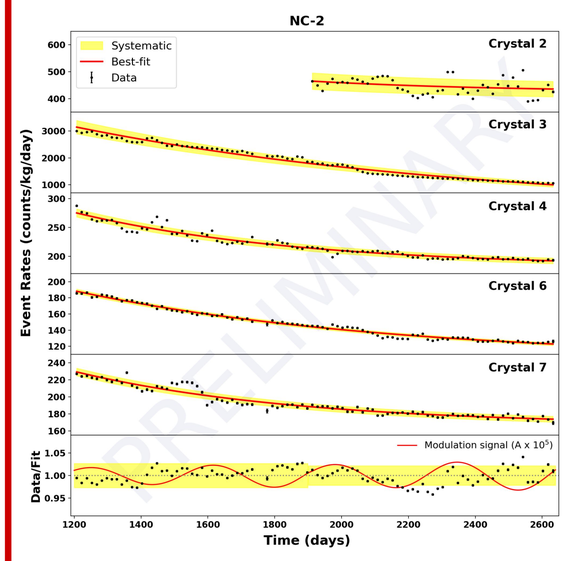
$$F(t;A) = A \cos\left[\frac{2\pi}{365.25}(t - 152.5)\right] + \exp(p_0 + p_1 t_1) + C$$

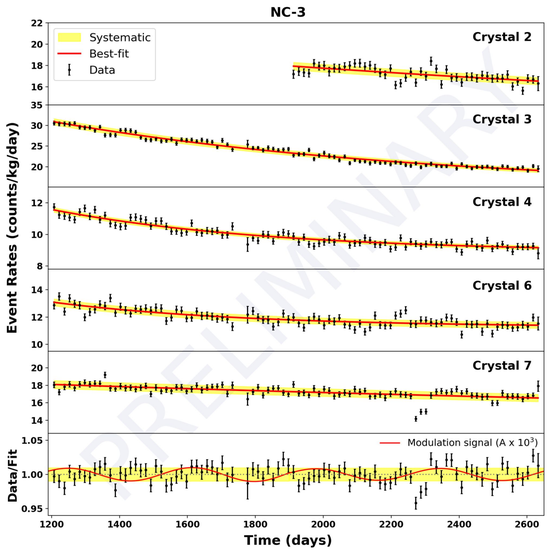
Annual modulation — Background model

Modulation fit results for 2, 3 and 4 NC

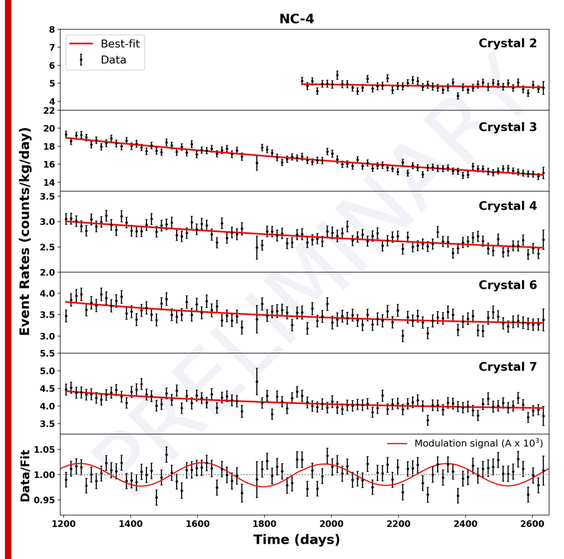
	A (counts/kg/day)	χ^2/ndf
NC-2	0.34 ± 0.27	370.2/409
NC-3	-0.002 ± 0.026	381.9/409
NC-4	0.001 ± 0.011	444.6/409
Simultaneous fit	0.0007 ± 0.0096	1193.7/1229

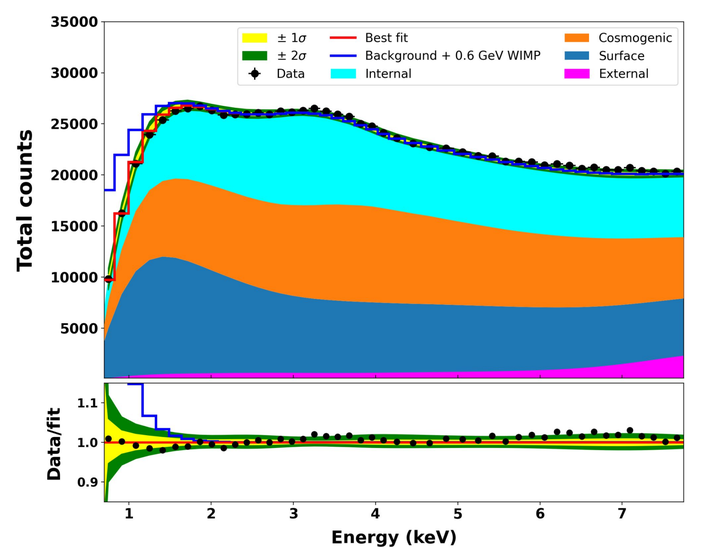
- Single-hit events in the 2, 3, and 4 NC, as well as the single-hit energy spectrum above 8 PEs, were fitted using the expected DM–electron signals.



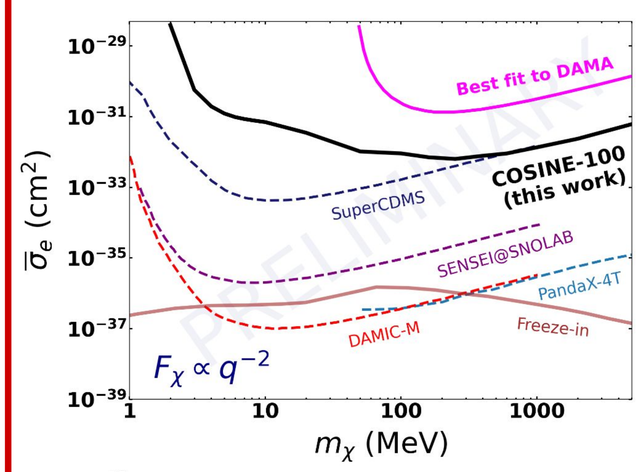


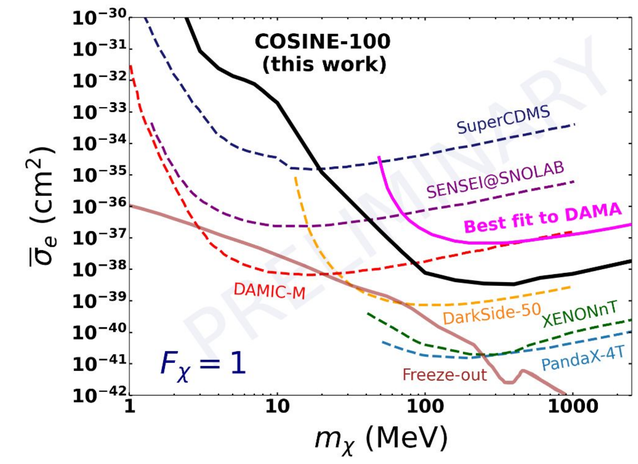
Modulation fits to the NC-2, NC-3, and NC-4 COSINE-100 datasets, together with the spectrum fit for data above 0.7 keV

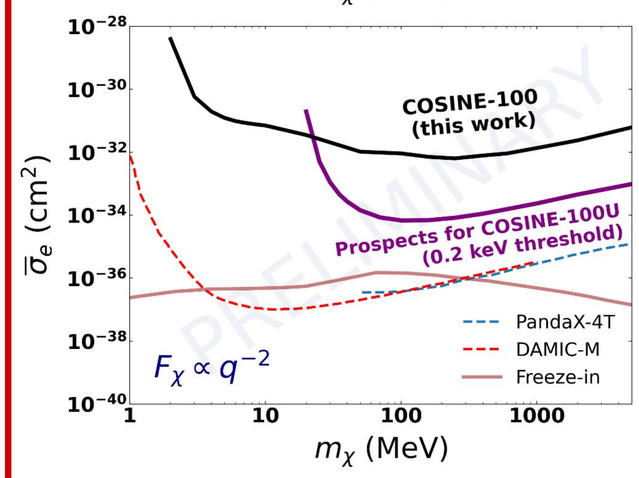


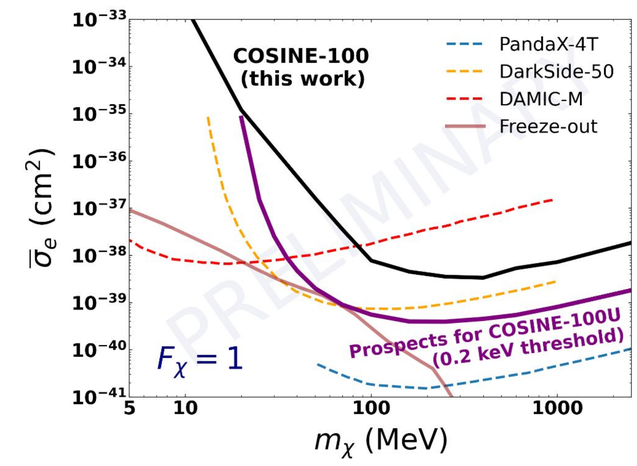


- No evidence for DM–electron scattering was observed in COSINE-100. Therefore, upper limits on the DM–electron cross section and sensitivity projections for COSINE-100U (assuming a 0.2 keV threshold) were derived.









Constraints for COSINE-100 and prospects for COSINE-100U (0.2 keV threshold) to the DM-electron interaction cross section for the light (left) and heavy (right) mediator scenarios

- The COSINE-100 constraints completely exclude the interpretation of the DAMA/LIBRA modulation signal within both heavy and light mediator scenarios and provide the strongest constraints for a NaI(Tl) target to date.

Summary

- No evidence for DM–electron scattering was observed in COSINE-100, and constraints on the DM–electron scattering cross section were established.
- Low temperature operation of COSINE-100U is expected to reduce the event rate in the crystals, improving the sensitivity to DM–electron interactions.
- See **PRD 113, 072012** and "**arXiv:2603.22411**" (submitted to PRL) for further details.

Future Plans:

- Evaluate the impact of the rock overburden on the constraints.
- Analyze the random photon rate at the single PE level in low temperature COSINE-100U data.