

Valentina De Romeri
(IFIC Valencia - UV/CSIC)

Implications of solar-neutrino CEvNS in dark matter experiments

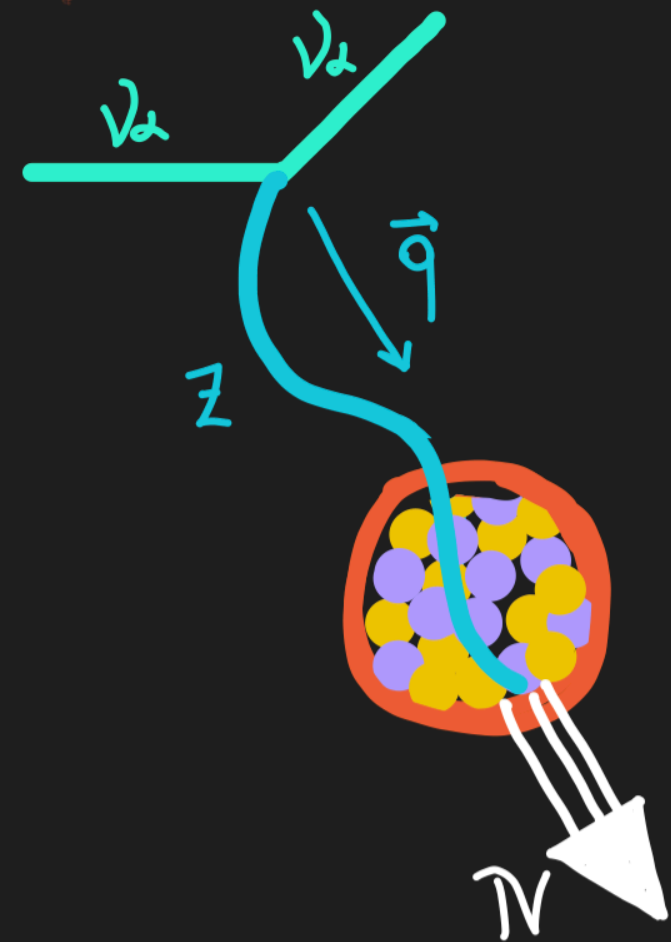
ppc 2026
Sydney (Australia)
31 August 2026



COHERENT ELASTIC NEUTRINO-NUCLEUS SCATTERING (CEvNS)

Neutral-current process: $\nu + N(A,Z) \rightarrow \nu + N(A,Z)$

- ▶ The neutrino sees the nucleus as a whole
- ▶ CEvNS occurs when:
 - Wavelength of the mediator $>$ nuclear radiusor
 - $|\vec{q}| \leq 1/R_{\text{nucleus}}$
- ▶ **Coherent**: target nucleon wave functions remain in phase with each other before and after the collision. **Amplitudes** of scattering on individual nucleons **add**.
- ▶ **Elastic**: no new particles are created and nuclear target remains in the same energy state.



CEvNS CROSS SECTION IN THE SM

CEvNS cross-section in the SM:

(probability of kicking a nucleus with nuclear recoil energy T)

$$\frac{d\sigma}{dT_{\mathcal{N}}} = \frac{\overbrace{G_F^2}^{\text{Fermi constant (SM parameter)}} m_{\mathcal{N}}}{4\pi} \left(\underbrace{1 - \frac{m_{\mathcal{N}} T_{\mathcal{N}}}{2E_{\nu}^2} - \frac{T_{\mathcal{N}}}{E_{\nu}}}_{\text{Kinematics}} \right) \underbrace{Q_W^2}_{\text{Weak nuclear charge}} \underbrace{F_W^2(|\mathbf{q}|^2)}_{\text{Nuclear Form Factor: } F=1 \text{ full coherence}} + \frac{G_F^2 m_{\mathcal{N}}}{4\pi} \left(1 + \frac{m_{\mathcal{N}} T_{\mathcal{N}}}{2E_{\nu}^2} - \frac{T_{\mathcal{N}}}{E_{\nu}} \right) F_A(|\mathbf{q}|^2)$$

$$Q_W = [Z(1 - 4 \sin^2 \theta_W) - \overbrace{N}] \quad \text{sw}^2 = 0.23 \rightarrow \text{protons unimportant}$$

Neutron contribution dominates

- E_{ν} : is the incident neutrino energy
- M : the nuclear mass of the detector material
- 3-momentum transfer $|\vec{q}|^2 = 2MT$
- (Q_A included in F_A)

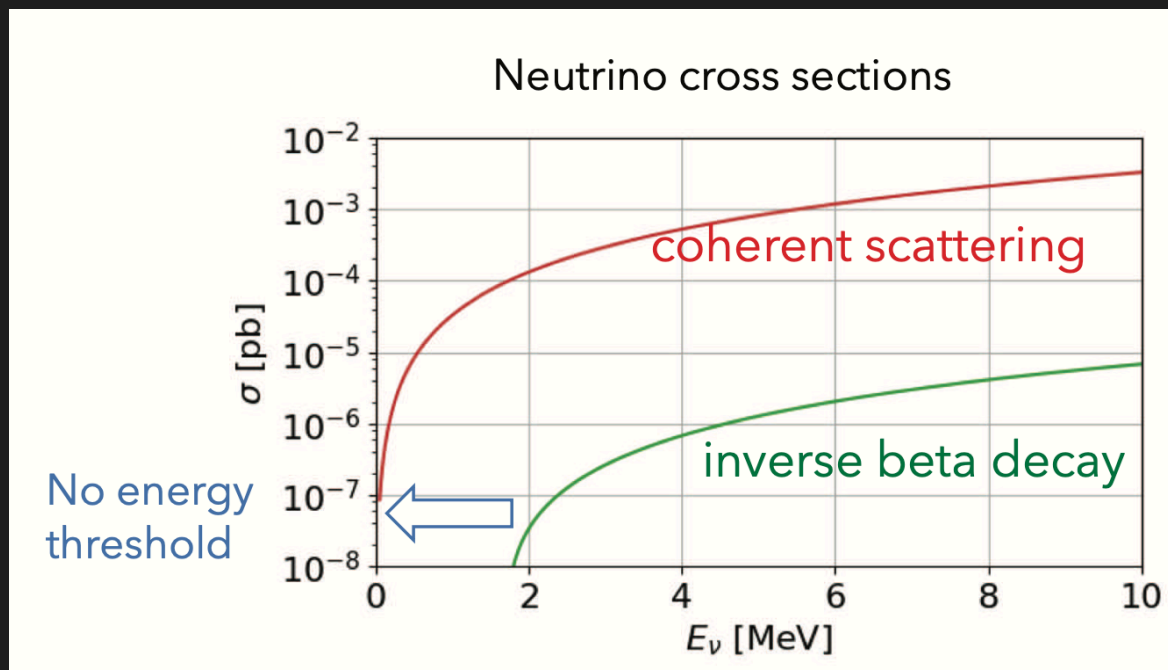
Axial contribution is small for most nuclei, spin-dependent.

It vanishes for nuclei with even number of protons and neutrons

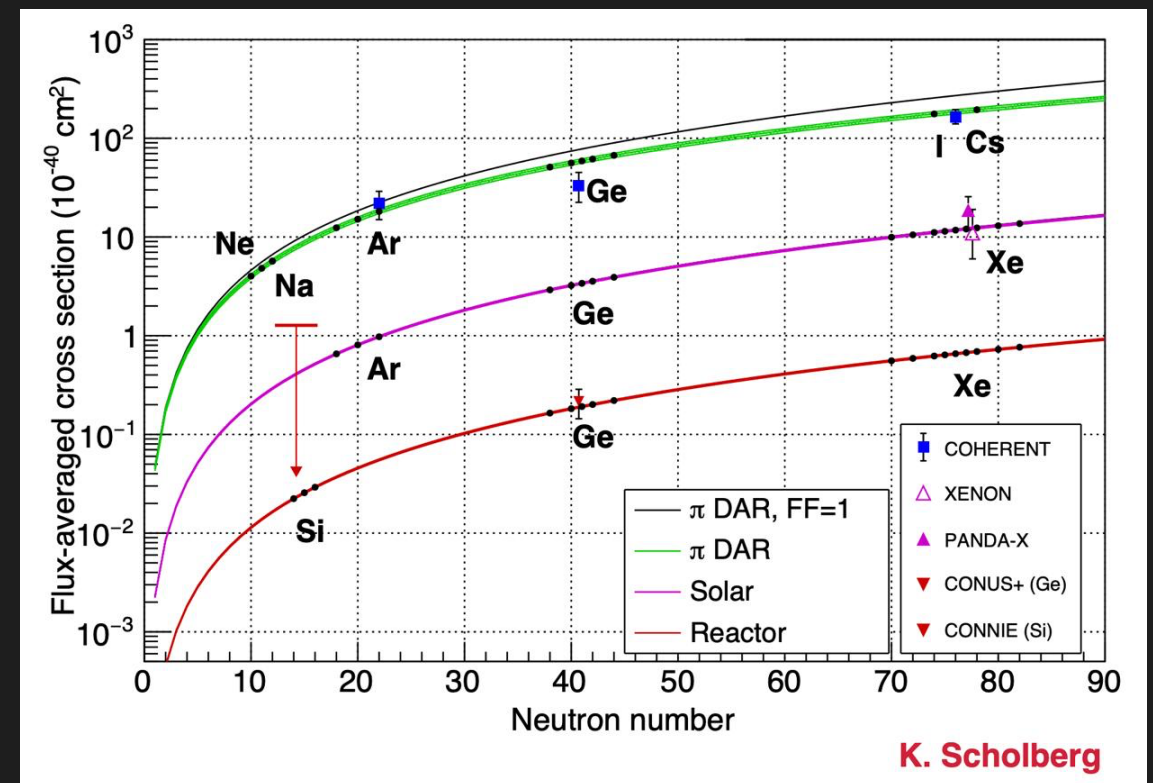
Freedman, PRD 9 (1974) 1389; Drukier, Stodolsky, PRD 30 (1984) 2295; Barranco, Miranda, Rashba, hep-ph/0508299

COHERENT ELASTIC NEUTRINO-NUCLEUS SCATTERING (CEvNS)

- ▶ Total cross section scales approximately like N^2 $\frac{d\sigma}{dE_R} \propto N^2$
- ▶ CEvNS cross section is large!
- ▶ Despite its large cross section, not observed for years due to tiny nuclear recoil energies.



Credit: R. Strauss @ Magnificent CEvNS



K. Scholberg

AN ACT OF HUBRIS

First theoretically predicted in 1974

D.Z. Freedman, Phys. Rev. D 9 (1974)

V.B. Kopeliovich and L.L. Frankfurt, JETP Lett. 19 4 236 (1974)

PHYSICAL REVIEW D

VOLUME 9, NUMBER 5

1 MARCH 1974

Coherent effects of a weak neutral current

Daniel Z. Freedman†

National Accelerator Laboratory, Batavia, Illinois 60510

and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \rightarrow \nu + A$ should have a sharp coherent forward peak just as $e + A \rightarrow e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are very difficult, although the estimated cross sections (about 10^{-38} cm² on carbon) are favorable. The coherent cross sections (in contrast to incoherent) are almost energy-independent. Therefore, energies as low as 100 MeV may be suitable. Quasi-coherent nuclear excitation processes $\nu + A \rightarrow \nu + A^*$ provide possible tests of the conservation of the weak neutral current. Because of strong coherent effects at very low energies, the nuclear elastic scattering process may be important in inhibiting cooling by neutrino emission in stellar collapse and neutron stars.

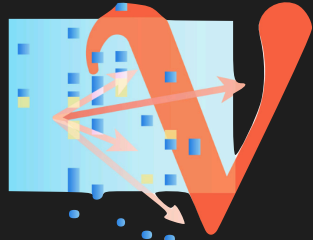
Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering. We will discuss these problems at the end of this note, but first we wish to present the theoretical ideas relevant to the experiments.

Experimentally the most conspicuous and most difficult feature of our process is that the only detectable reaction product is a recoil nucleus of low momentum. Ideally the apparatus should have sufficient resolution to identify and determine the momentum of the recoil nucleus and sufficient mass to achieve a reasonable interaction rate. Neutron background is a serious problem

CE ν NS was **observed for the first time ~40 years later**,
in **2017** by the COHERENT experiment at the Oak Ridge Spallation Neutron Source.

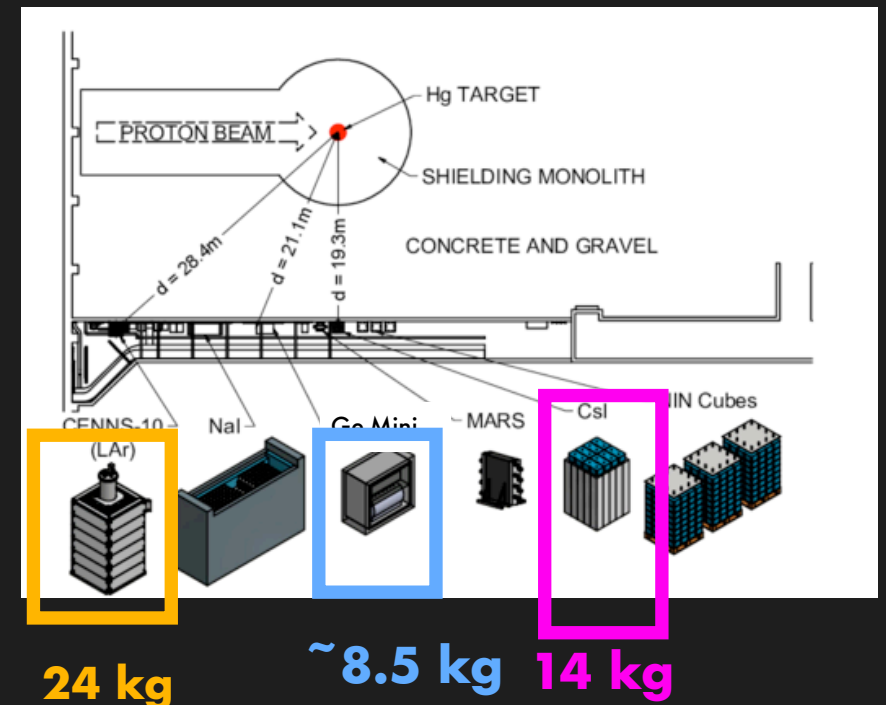
LIST OF CEvNS OBSERVATIONS

Stopped pions
(Decay at rest)



- 2017(->2021): **COHERENT-CsI[Na]**, 11.6σ CL
- 2020: **COHERENT-LAr**, 3.9σ CL
- 2024 (-> 2026): **COHERENT-Ge**, $\sim 7\sigma$ CL

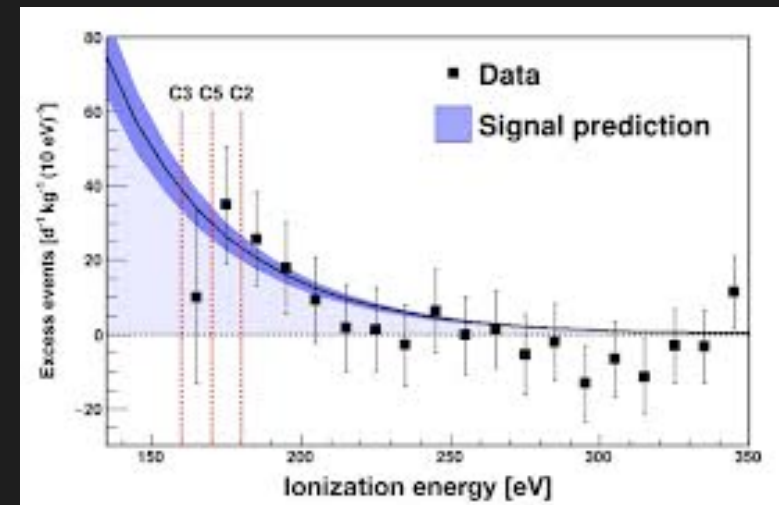
D. Akimov et al. (COHERENT) Science 357, 1123–1126 (2017)
 D. Akimov et al. (COHERENT) Phys. Rev. Lett. 129, 081801
 D. Akimov et al. (COHERENT) Phys. Rev. Lett. 126, 012002 (2021)
 S. Adamski et al. (COHERENT) Phys. Rev. Lett. **134**, 231801 (2025)
 Adhikari et al. (COHERENT) 2603.17951



Reactors



- 2022: Dresden-II, Ge
 Colaresi, Collar et al. Phys. Rev. Lett. 129 (2022) 211802
- 2025: CONUS+, Ge, 3.7σ CL
 Ackermann+ Nature 643 no. 8074, (2025) 1229–1233



CEvNS AND DM DD EXPERIMENTS?

PHYSICAL REVIEW D

VOLUME 9, NUMBER 5

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Coherent effects of a weak neutral current

Daniel Z. Freedman†

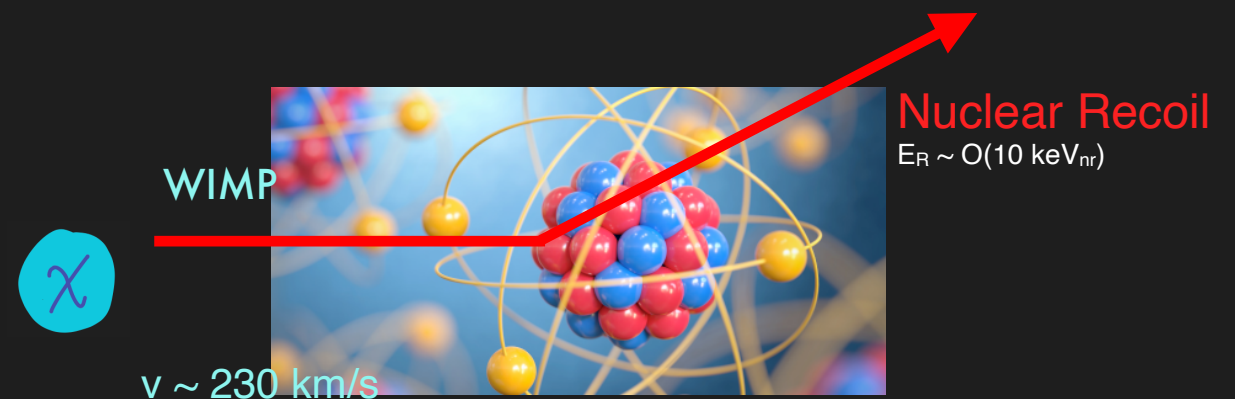
National Accelerator Laboratory, Batavia, Illinois 60510

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Goodman and Witten pointed out that WIMPs could be searched for using the same detectors proposed by Drukier and Stodolsky for CEvNS measurements.



PRINCIPLES AND APPLICATIONS OF A NEUTRAL CURRENT DETECTOR FOR NEUTRINO PHYSICS AND ASTRONOMY

A. Drukier and L. Stodolsky

Max-Planck-Institut für Physik und Astrophysik

- Werner-Heisenberg-Institut für Physik -

Munich (Fed. Rep. Germany)

Abstract

We study neutrino detection through the elastic scattering of neutrinos on nuclei and identification of the recoil energy. The very large value of the cross section compared to previous methods indicates a detector would be relatively light and suggests the possibility of a true "neutrino observatory". We examine a realization in terms of the superconducting grain idea, which appears in principle feasible through extension and extrapolation of presently known techniques. Such a detector would permit determination of the neutrino spectrum and should be intensive to neutrino oscillations. Various applications and tests are discussed, including spallation sources, reactors, supernovas, solar and terrestrial neutrinos. A supernova would permit a simple determination of the number of neutrinos and their masses, while for solar neutrinos rates of thousands of S.N.U. are theoretically attainable. A preliminary estimate of the most difficult backgrounds is attempted.

PHYSICAL REVIEW D

VOLUME 31, NUMBER 12

15 JUNE 1985

Detectability of certain dark-matter candidates

Mark W. Goodman and Edward Witten

Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544

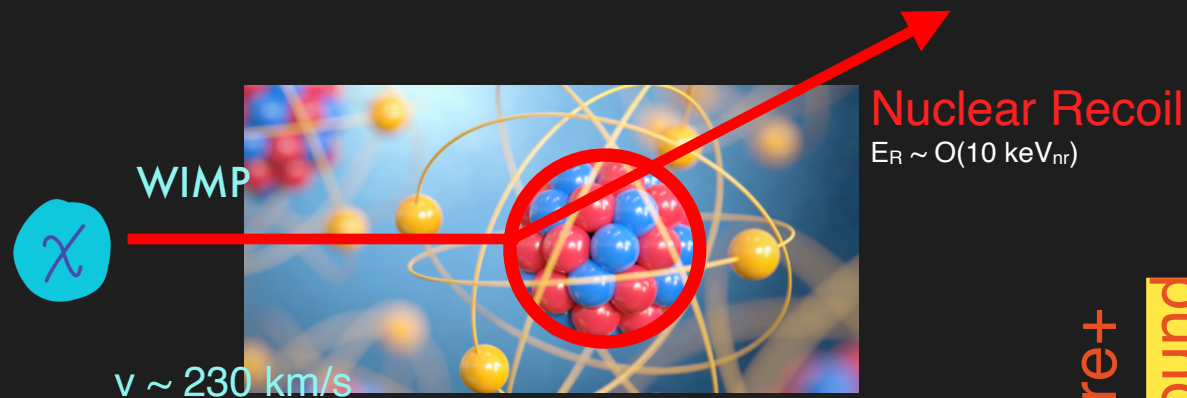
(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.

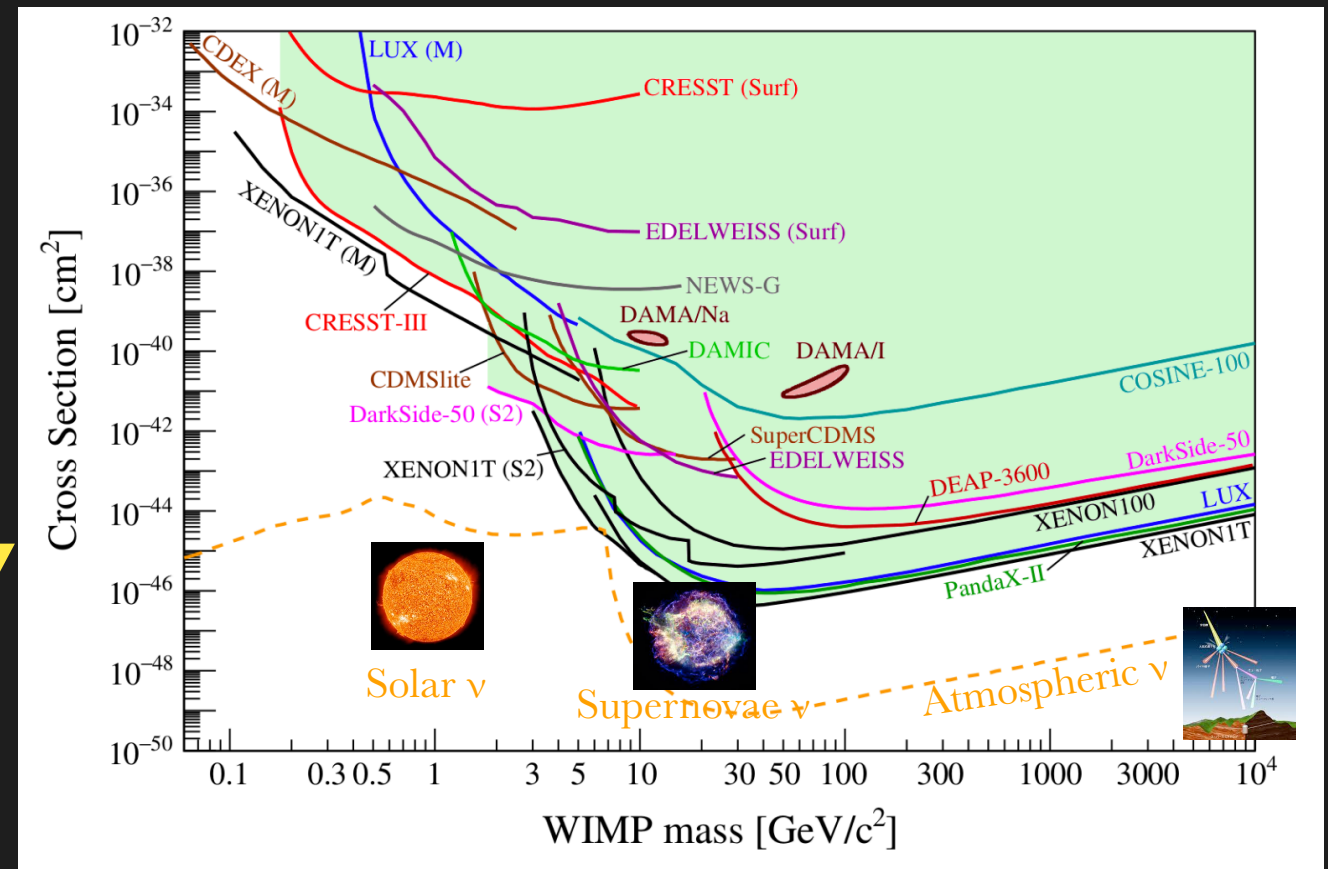
Goodman and E. Witten, Phys. Rev. D 31 (1985) 3059
A. Drukier and L. Stodolsky, Phys. Rev. D 30 (1984) 2295
D.Z. Freedman, Phys. Rev. D 9 (1974)

DM-NUCLEI SCATTERING SEARCHES

- spin-independent (strong bounds due to coherent enhancement)
- spin-dependent (weaker bounds)



spin-independent WIMP-nucleon interactions



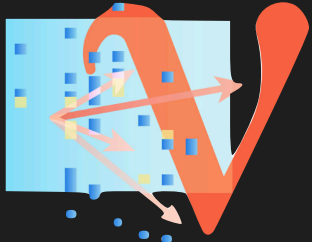
Strigari, New J. Phys. 11 (2009) 105011,
 Monroe and Fisher, PRD 76 (2007) 033007
 Vergados and Ejiri, Nucl. Phys. B 804 (2008) 144–159
 Billard, Strigari, and Figueroa-Feliciano, PRD 89 no. 2, (2014) 023524, [13]
 O'Hare, PRD 94 no. 6, (2016) 063527
 O'Hare, PRL 127 no. 25, (2021) 251802
 [...]

Threshold

Direct Detection of Dark Matter – APPEC Committee Report 2021

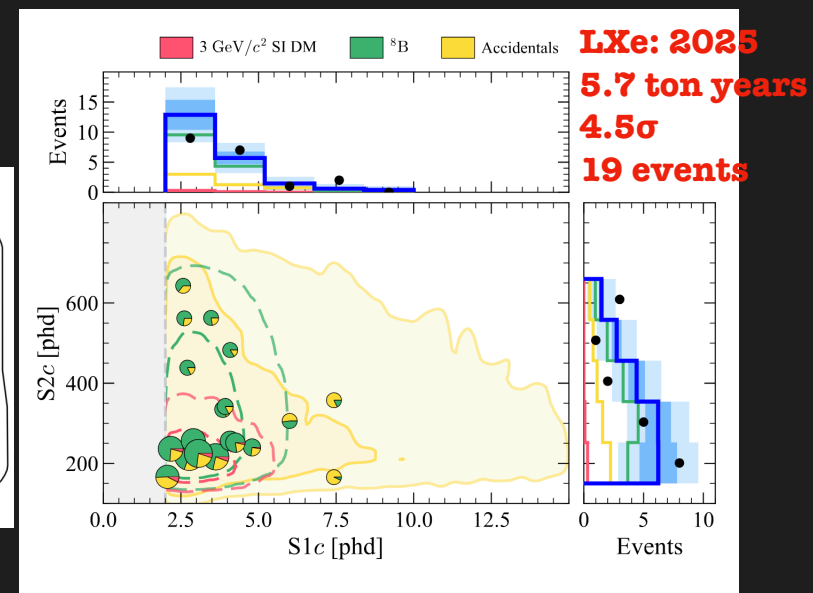
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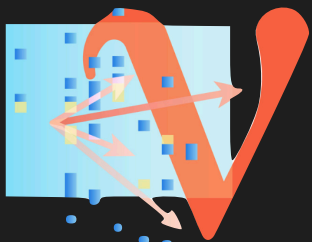


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Adhikari et al. (COHERENT) 2603.17951



Reactors

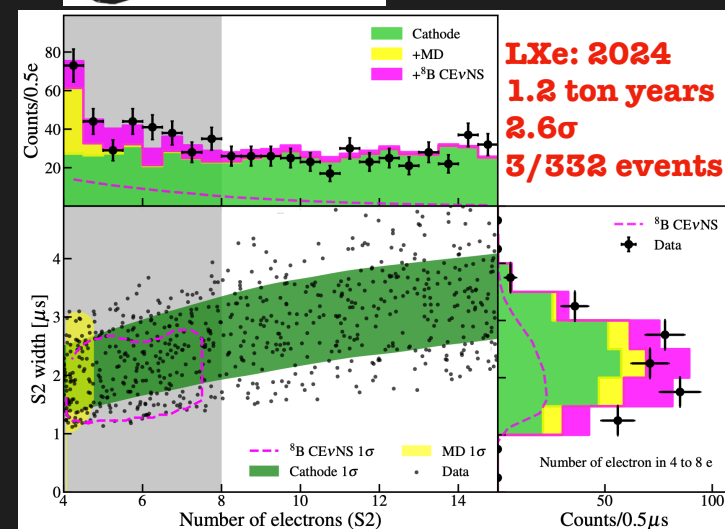


- 2022: Dresden-II, Ge

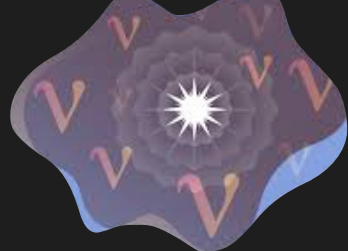
Colaesi, Collar et al. Phys. Rev. Lett. 129 (2022) 211802

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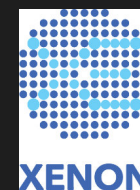


^8B Solar
neutrinos

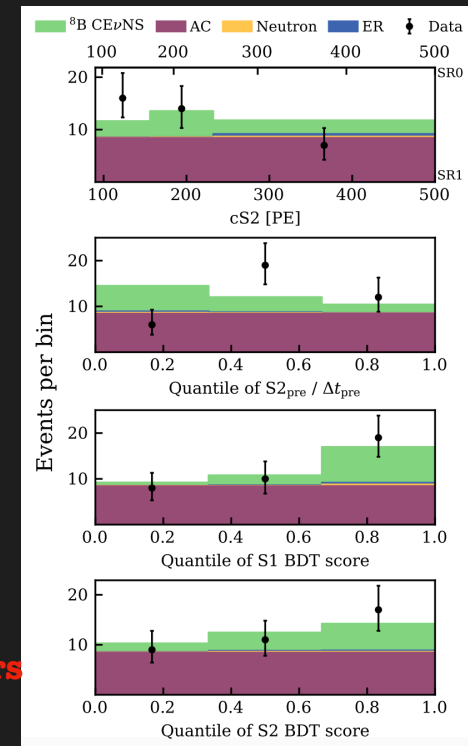


- 2024(->2026): **XENONnT-Xe**, 3.3σ CL
- 2024: **PandaX-4T-Xe**, 2.64σ CL
- 2025: **LZ-Xe**, 4.5σ CL

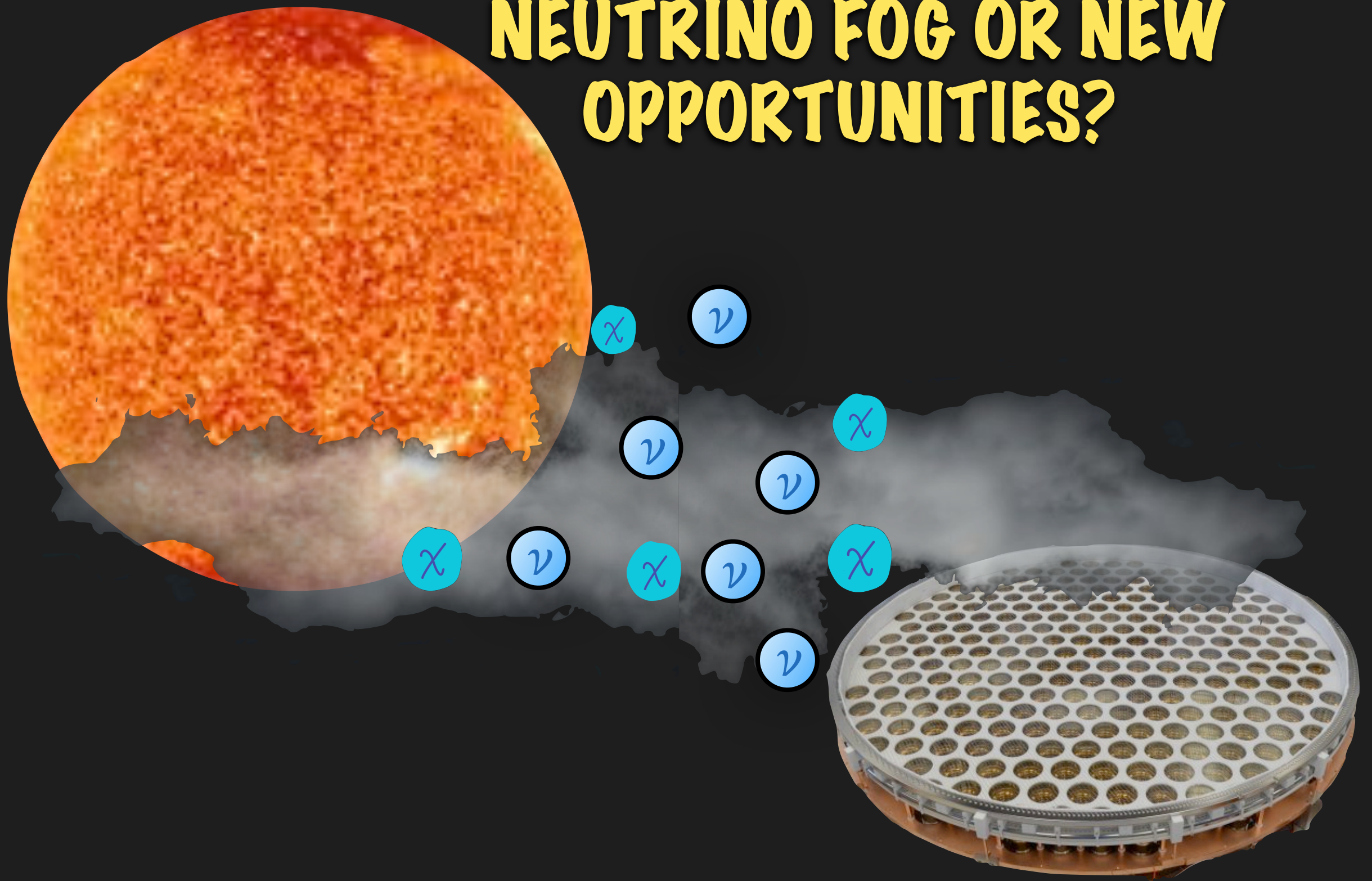
E. Aprile et al. (XENONnT) PRL 133, 191002 (2024)
E. Aprile et al. (XENONnT) 2604.06002
Z. Bo et al. (PandaX) PRL 133, 191001
Akerib et al. LUX-ZEPLIN (LZ), arXiv:2512.08065



LXe: 2024
3.5 ton years
 2.7σ
37 events



IMPLICATIONS: NEUTRINO FOG OR NEW OPPORTUNITIES?



NEUTRINOS AT DIRECT DETECTION EXPERIMENTS

- Solar neutrinos

W. C. Haxton, R. G. Hamish Robertson, and A. M. Serenelli, *Ann. Rev. Astron. Astrophys.* 51 (2013), 21

- Atmospheric neutrinos (FLUKA)

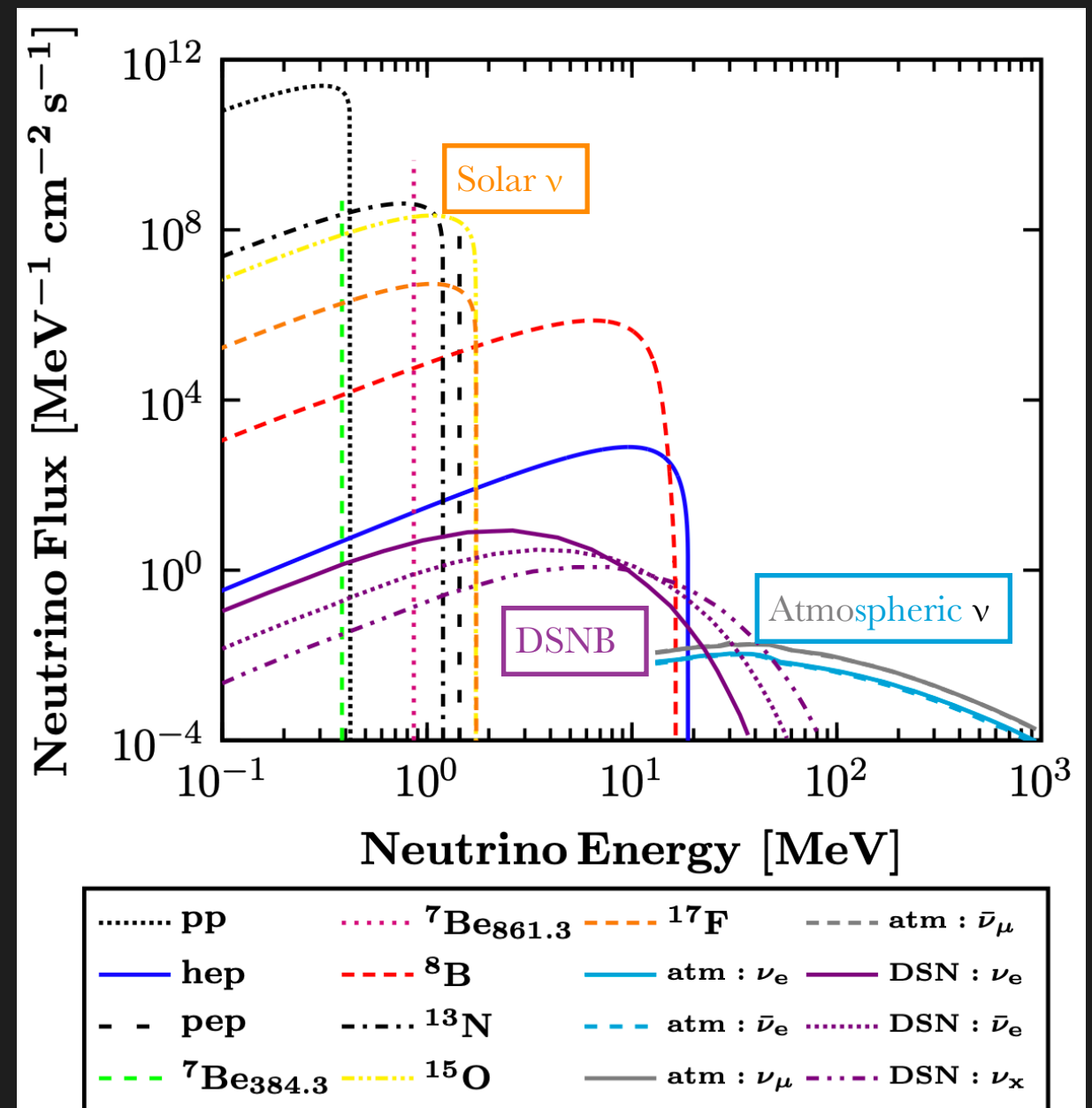
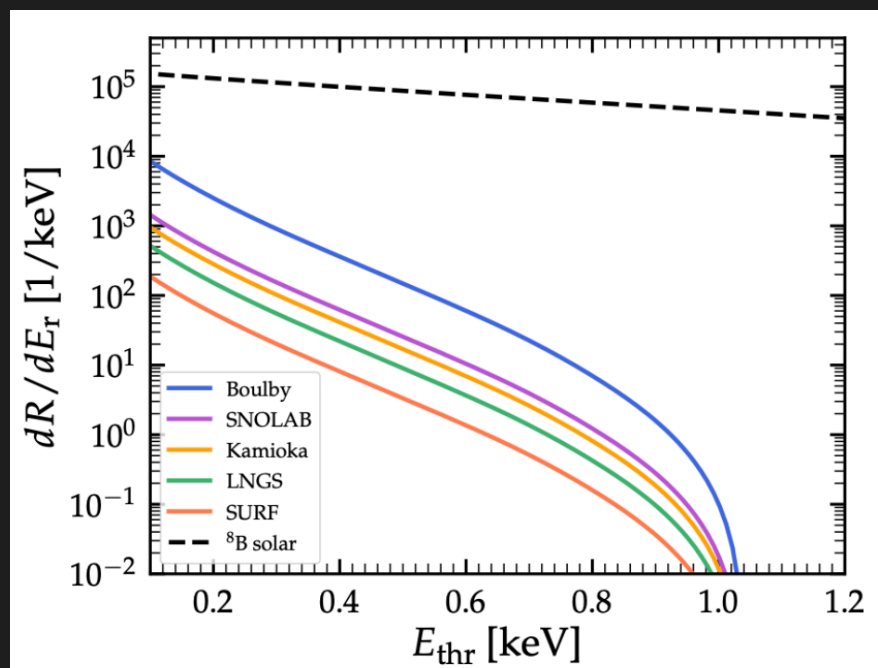
G. Battistoni, A. Ferrari, T. Montaruli, and P. R. Sala, *Astropart. Phys.* 23 (2005) 526

- Diffuse Supernova Neutrinos (DSN)

Horiuchi, Beacom, Dwek, *PR D79* (2009) 083013

- Reactor neutrinos

Aristizabal, VDR, Ternes *Phys.Rev.D* 109 (2024) 11, 115026



NEUTRINO FLOOR?

- ▶ Neutrino backgrounds induce **coherent elastic-neutrino nucleus scattering** and produce nuclear recoil spectra, which can have a strong degeneracy with those expected from spin-independent WIMP interactions.
- ▶ Increasing exposure does not imply a linear improvement of sensitivities but rather a saturation of its discovery limit, typically referred to as **neutrino floor**.

Strigari, New J. Phys. 11 (2009) 105011
Billard+, Phys. Rev. D89 no. 2, (2014) 023524
Ruppin+, Phys. Rev. D90 no. 8, (2014) 083510

O'Hare, Phys. Rev. D94 no. 6, (2016) 063527
Dutta+, Phys. Lett. B773 (2017) 242–246
Bertuzzo+ JHEP 04 (2017) 073
Aristizabal+, JHEP 03 (2018) 197
Papoulias+, Adv.High Energy Phys. 2018 6031362
Boehm+, JCAP 01 (2019) 043
O'Hare, 2109.03116
Snowmass 2203.08084
...

- ▶ Neutrino floors vary depending on:

- Astrophysical uncertainties
- Nuclear physics uncertainties
- Neutrino flux uncertainties
- Non-standard interactions
- New mediators

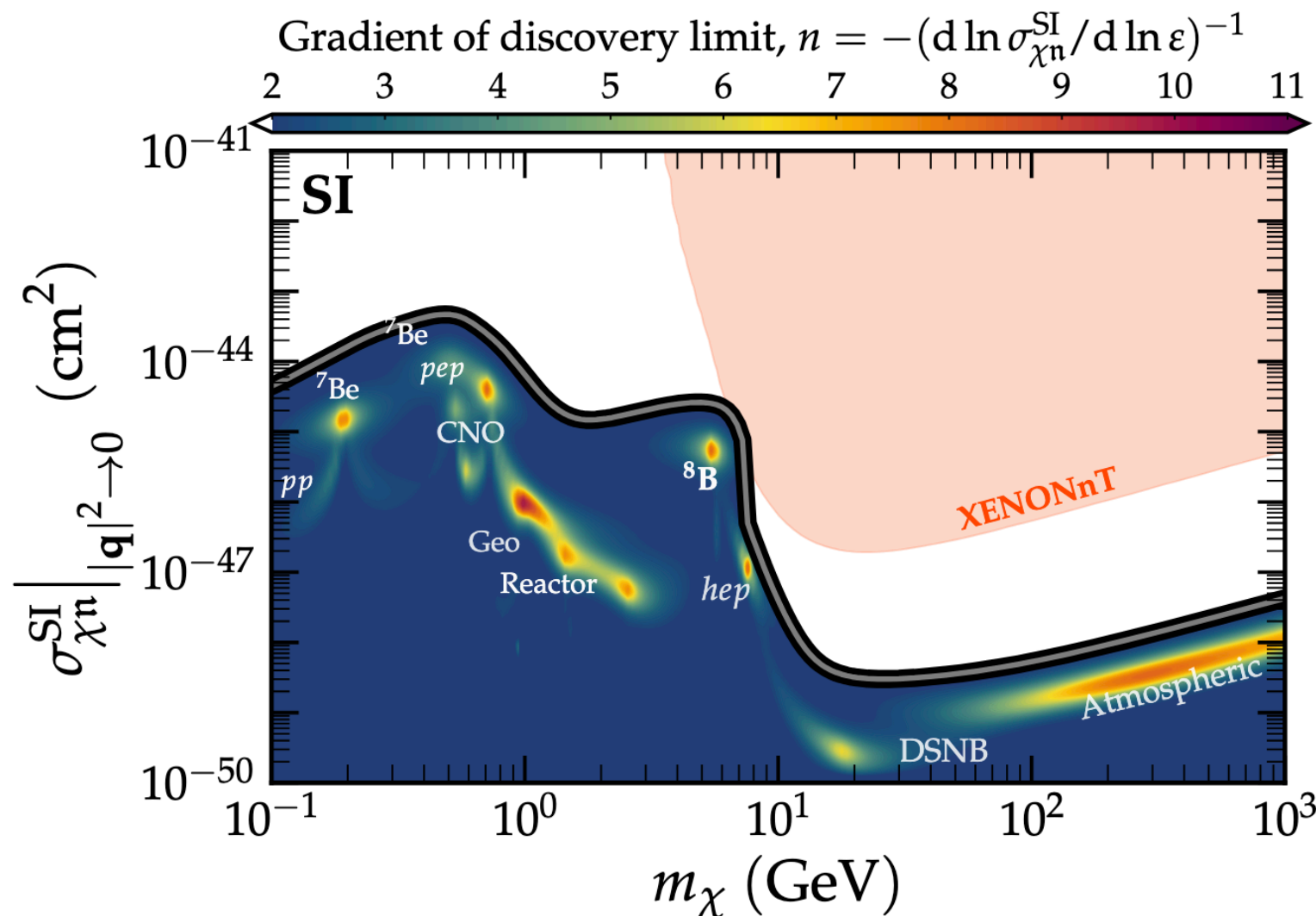
- ▶ Can be overcome with measurements of the WIMP and neutrino recoil spectra tails, directionality, measurements with different material targets and annual modulation.



...OR RATHER FOG (Xe target)

Neutrino “fog” can be quantified by looking at the scaling of sensitivity. Defines how badly the CEvNS background slows progress through DM parameter space.

O'Hare Phys. Rev. Lett. 127, 251802 (2021)



VDR, Anirban Majumdar, D. K. Papoulias, R. Srivastava, JCAP 05 (2026) 093

Neutrino fog opacity:

$$n = - \left(\frac{d \ln \sigma_{\chi n}}{d \ln \epsilon} \right)$$

n=2 Poissonian bckg subtraction

n>2 worse than Poissonian

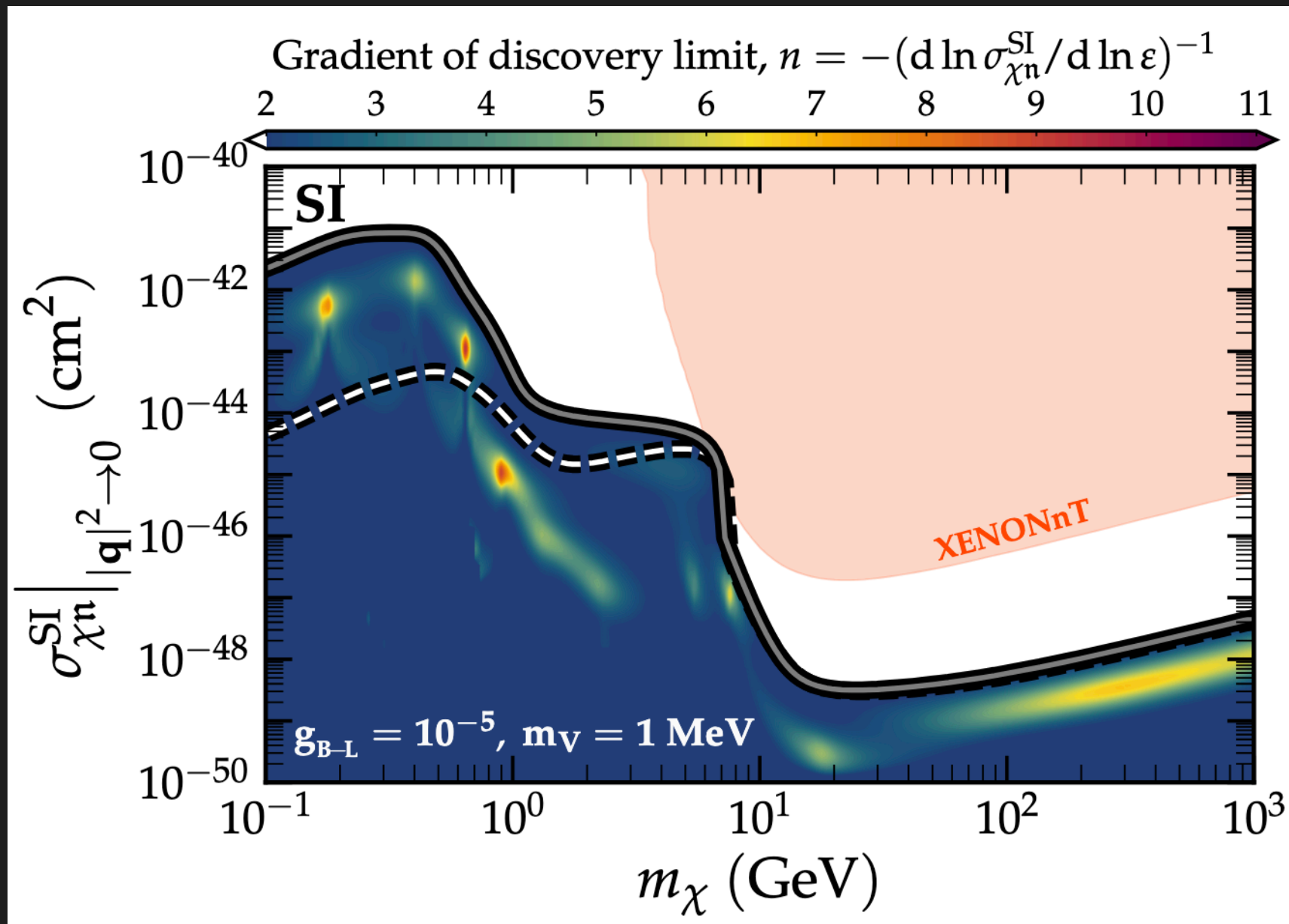
Index n: how fast we can improve upon background

Obtaining a 10 times lower cross section sensitivity requires at least 10^n more exposure.

NEUTRINO FOG: LIGHT MEDIATORS

Orange exclusion area in light of XENONnT 2024 data

E. Aprile et al. (XENONnT)
PRL 133, 191002 (2024)
PRL 134 no. 11, (2025) 111802

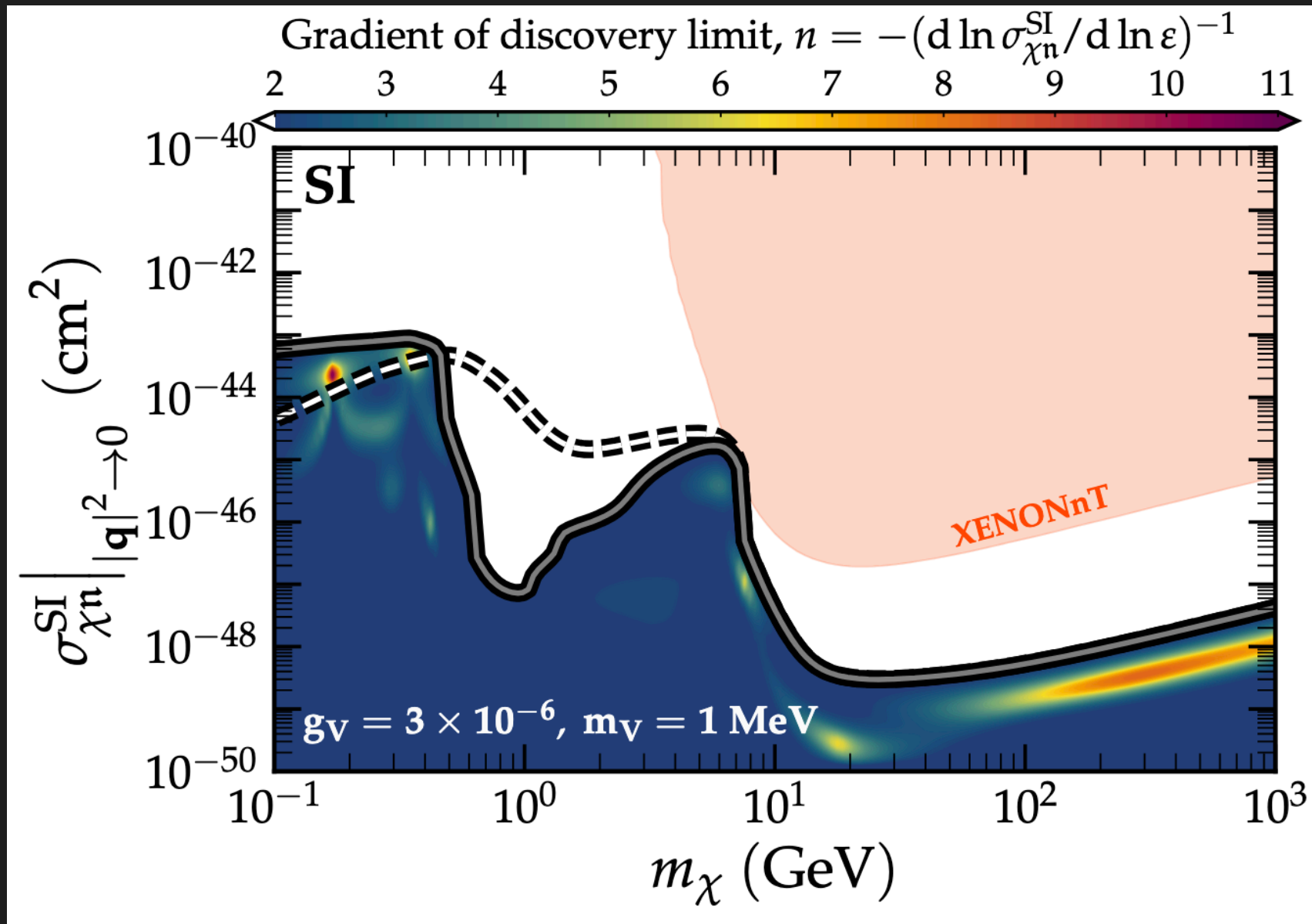


A light vector mediator with B-L couplings in the CEvNS interaction worsen the discovery reach of a Xe detector at low DM masses.

Previous similar studies:
Aristizabal-Sierra+ JHEP 03 (2018) 197
Bertuzzo+ JHEP 04 (2017) 073
Aristizabal-Sierra, VDR+ JCAP 01, (2022) 055
...

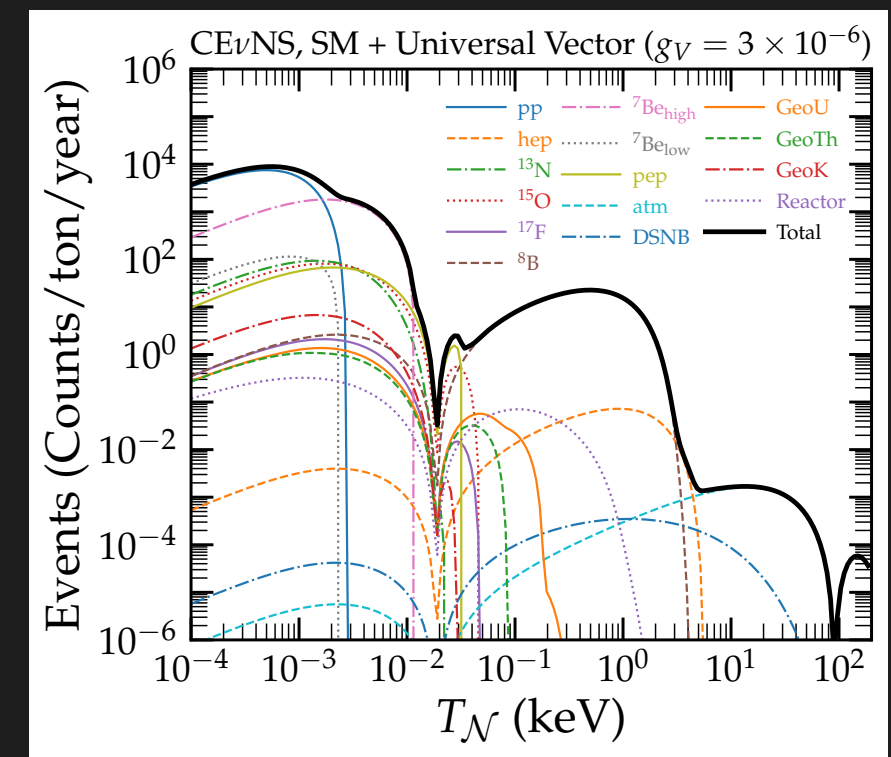
VDR, Anirban Majumdar, D. K. Papoulias, R. Srivastava, JCAP 05 (2026) 093

NEUTRINO FOG: LIGHT MEDIATORS

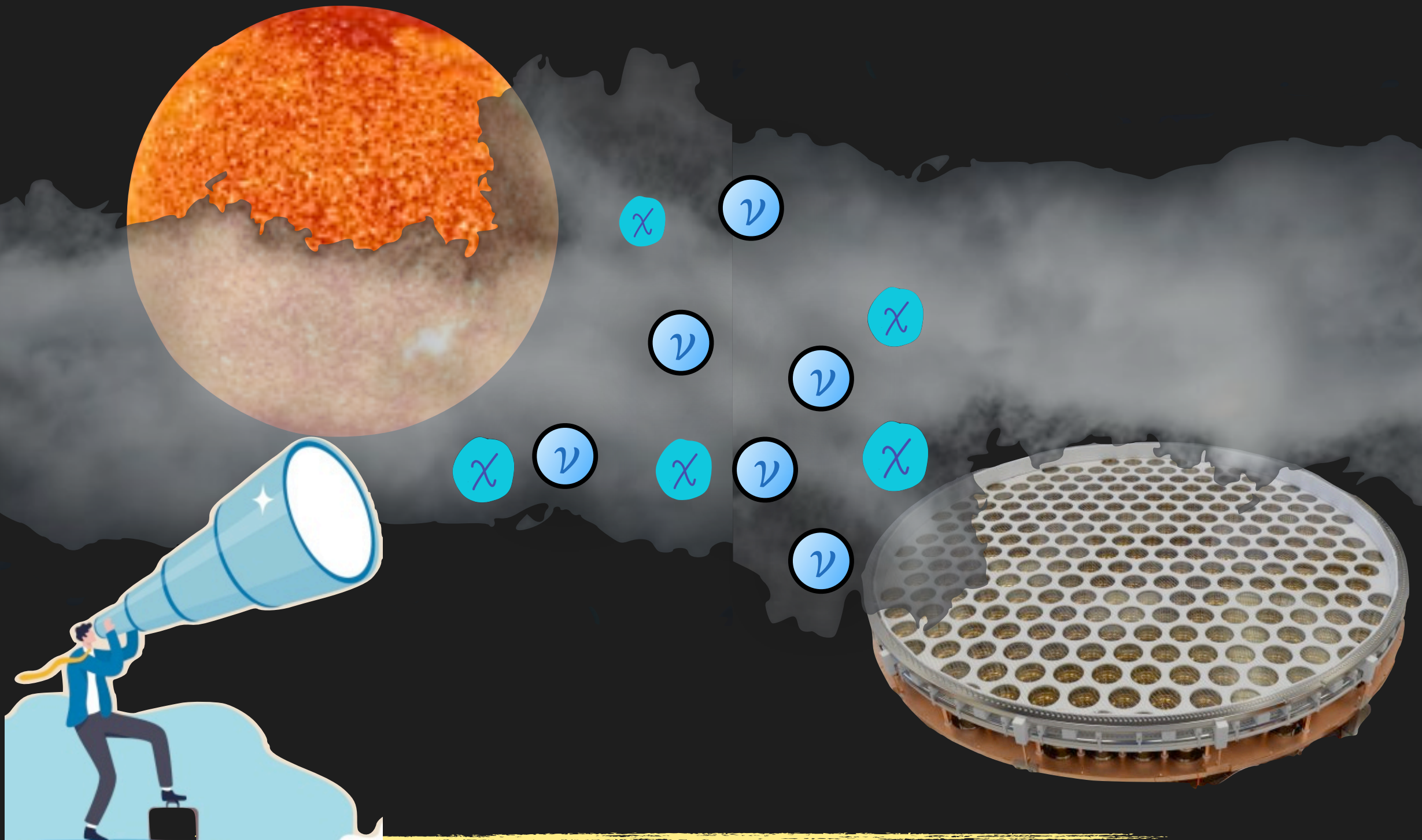


VDR, Anirban Majumdar, D. K. Papoulias, R. Srivastava, JCAP 05 (2026) 093

A light vector mediator with **universal couplings** in the CEvNS interaction also worsen the discovery reach of a Xe detector at low DM masses; at intermediate masses, **destructive interference** with the SM contribution is possible.



INTO THE (NEUTRINO) FOG: SM TESTS AND NEW PHYSICS



PHYSICS POTENTIAL OF NEUTRINOS AT DM DIRECT DETECTION FACILITIES



STANDARD MODEL TESTS: WEAK MIXING ANGLE WITH CEvNS

$$\left. \frac{d\sigma_{\nu\mathcal{N}}}{dE_{\text{nr}}} \right|_{\text{CEvNS}}^{\text{SM}} = \frac{G_F^2 m_N}{\pi} F_W^2(\mathbf{q}^2) Q_W^2 \left(1 - \frac{m_N E_{\text{nr}}}{2E_\nu^2} - \frac{E_{\text{nr}}}{E_\nu} + \frac{E_{\text{nr}}^2}{2E_\nu^2} \right)$$

$$Q_W = -N/2 + (1/2 - 2\sin^2\theta_w)Z \quad \text{sw}^2 = 0.23 \rightarrow \text{protons unimportant}$$

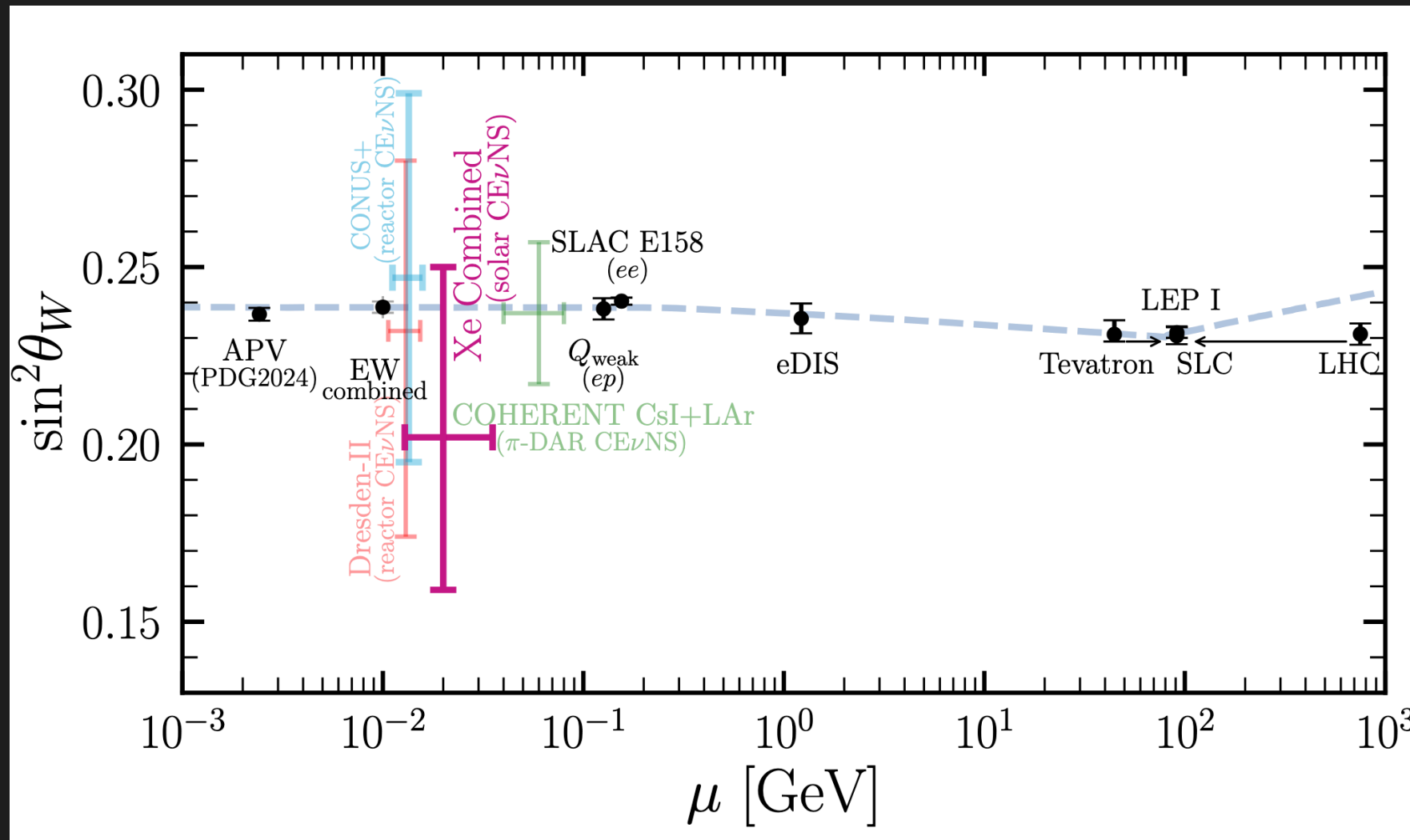
Neutron contribution dominates

Information on the value of the neutrino neutral-current interaction at low energy:

- Observable: $\sin^2\theta_w$
- poorly measured at low energies
- Affects the normalization of CEvNS spectra

EW PRECISION TESTS: WEAK MIXING ANGLE

PandaX-4T (2024) + XENONnT (2026) + LZ (2025)



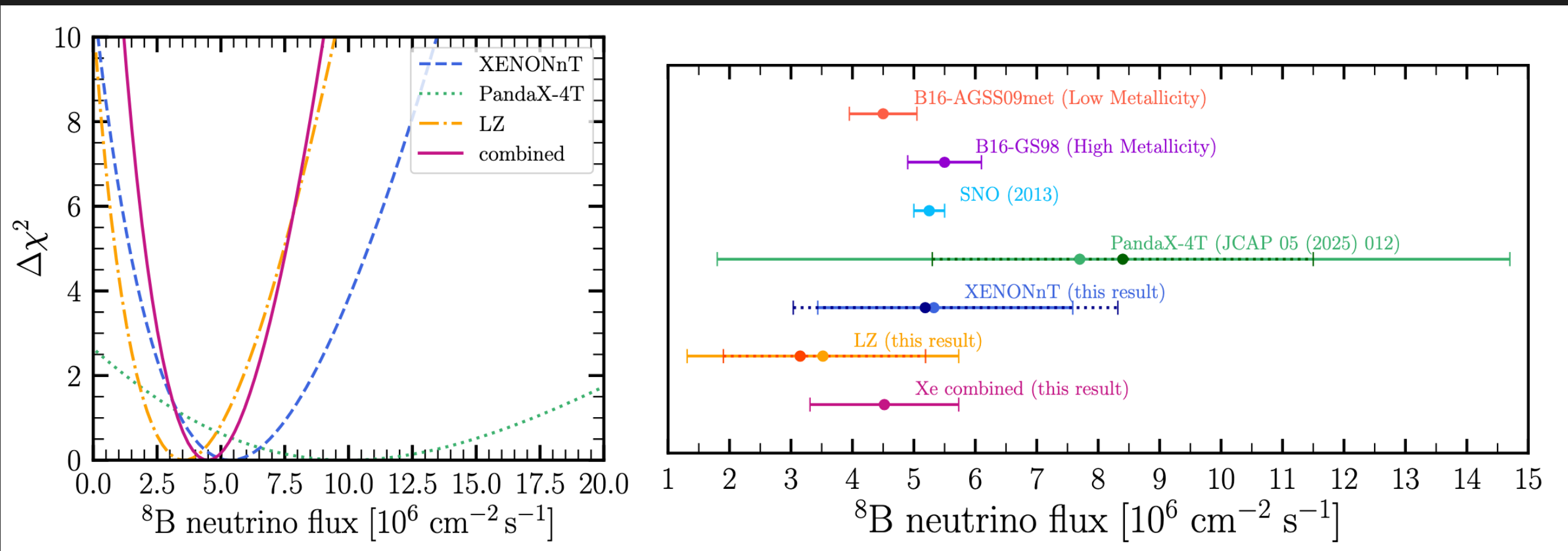
VDR, Papoulias, Pompa, Sanchez Garcia, Ternes, arXiv: 2603.00554

Other (previous) CEvNS analyses:
Miranda et al. JHEP 05 (2020) 130
VDR, Miranda, Papoulias+ JHEP 04 (2023) 035
See also Cadeddu et al. '20,'21,'22,'23,'24...
(Also combination with APV data)

VDR, Papoulias, Sanchez Garcia PRD 111, 075025 (2025)
Alpizar-Vanegas+ 2501.10355, Chattaraj+ 2501.12441
Majumdar+ Phys.Rev.D 106 (2022) 9, 093010
Boehm, Maity PRD 112 no. 5, (2025) 053001
VDR, Papoulias, Ternes JCAP 05 (2025) 012
Akerib et al. LUX-ZEPLIN (LZ), arXiv:2512.08065

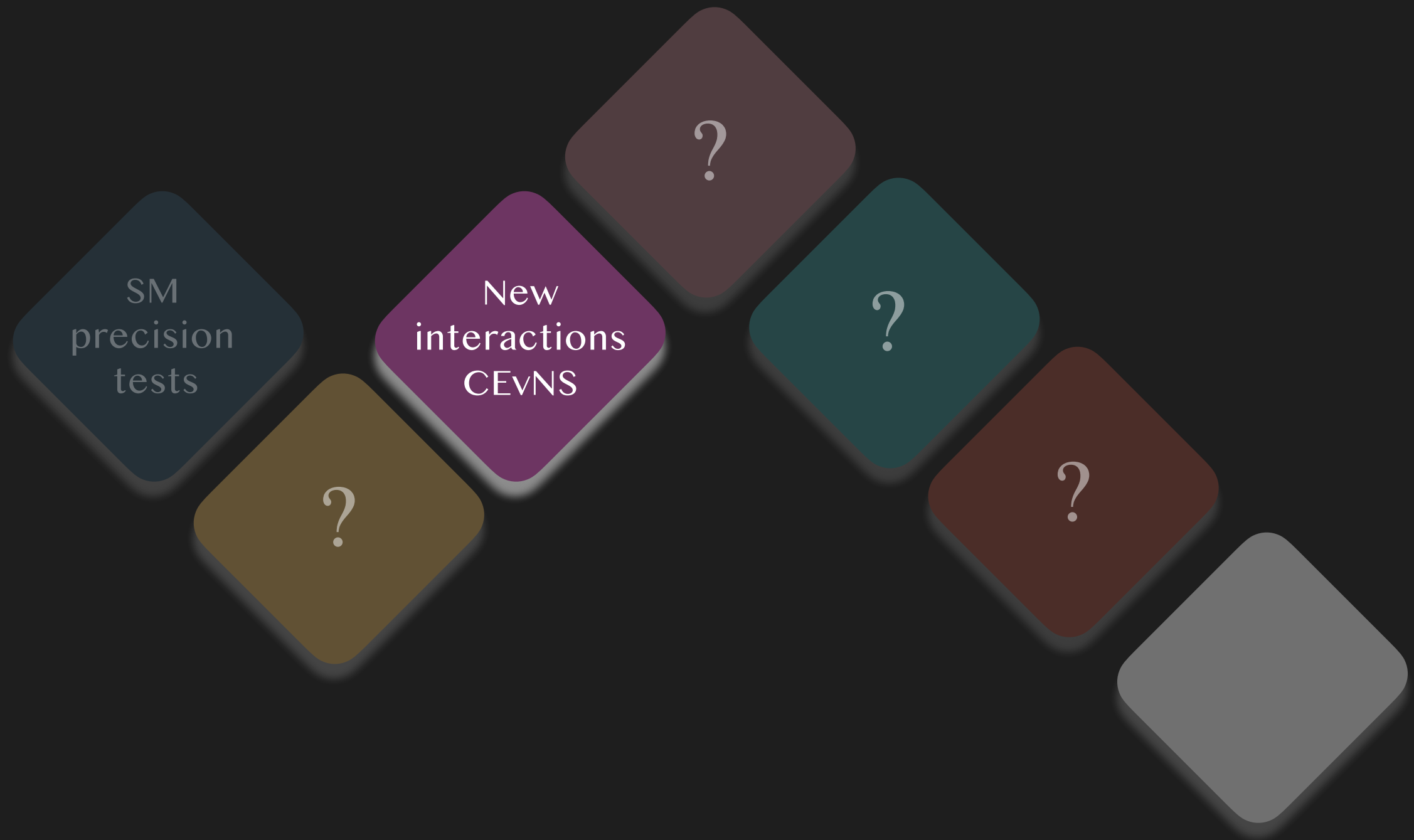
^8B SOLAR NEUTRINO FLUX

PandaX-4T (2024) + XENONnT (2026) + LZ (2025)



VDR, Papoulias, Pompa, Sanchez Garcia, Ternes, arXiv: 2603.00554

PHYSICS POTENTIAL OF NEUTRINOS AT DM DIRECT DETECTION FACILITIES



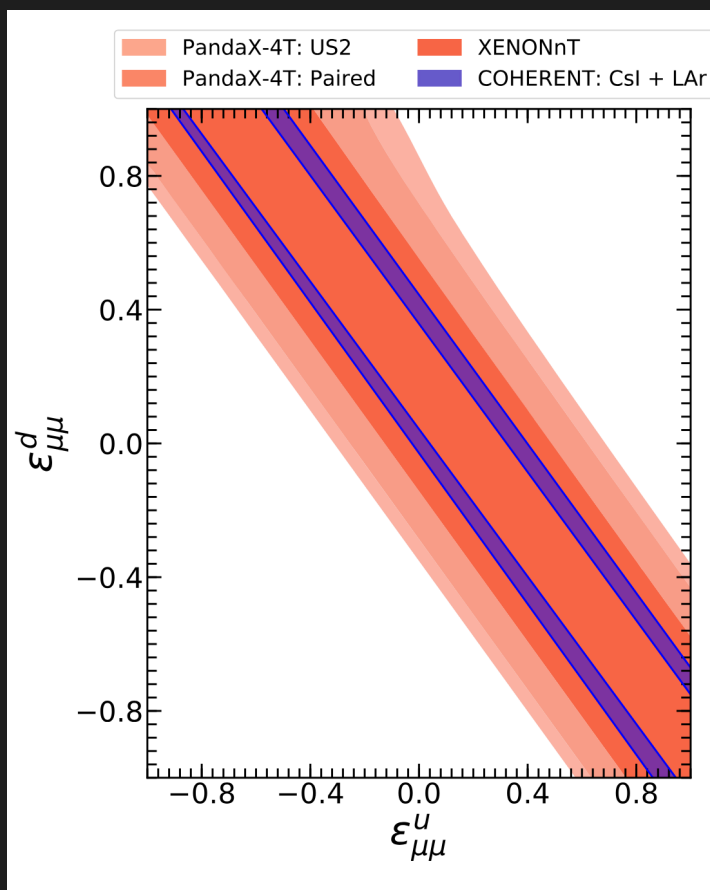
NEW NEUTRINO INTERACTIONS: NSI

Neutrino NSI can be formulated in terms of the effective four-fermion Lagrangian:

$$\mathcal{L}_{\text{NC}}^{\text{NSI}} = -2\sqrt{2}G_F \sum_{q,\ell,\ell'} \epsilon_{\ell\ell'}^{qX} (\bar{\nu}_\ell \gamma^\mu P_L \nu_{\ell'}) (\bar{f} \gamma_\mu P_X f)$$

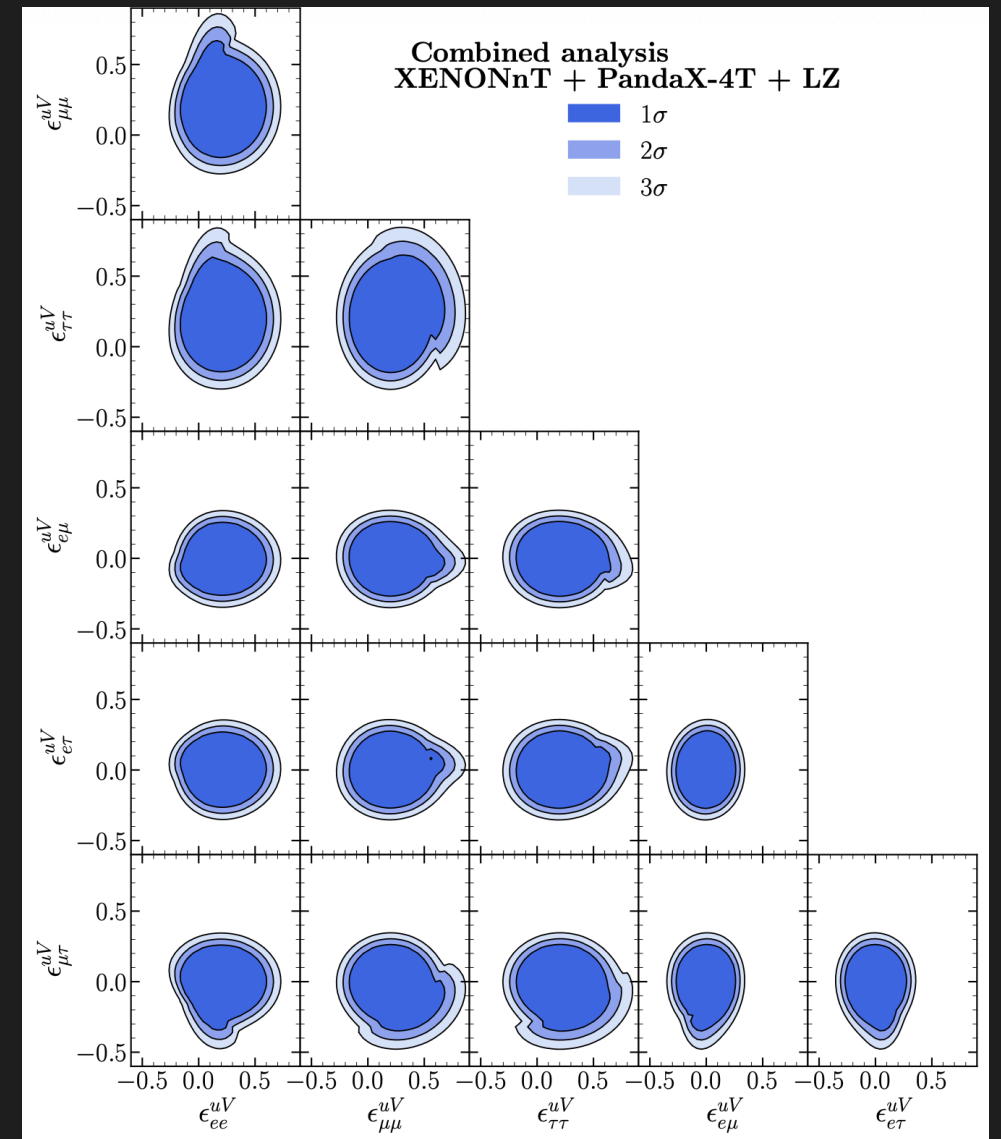
NSI modify the event rates in two ways:

- introduce additional contributions to the matter potential, thus altering neutrino flavor evolution inside the Sun
- Contribute to the CE ν NS cross section



Aristizabal+ PRD 111 (2025) 5, 055007

Direct detection experiments become crucial to constrain neutrino NSI.



VDR, Papoulias, Pompa, Sanchez Garcia, Ternes, arXiv: 2603.00554

See also Amaral+ JHEP 07 (2023) 071, 2607.22817

Li+ PRD 111 (2025) 3, 035002

Gehrlein, Kushwaha, PRD 112 (2025) 9, 095032

NEW NEUTRINO INTERACTIONS: LIGHT MEDIATORS

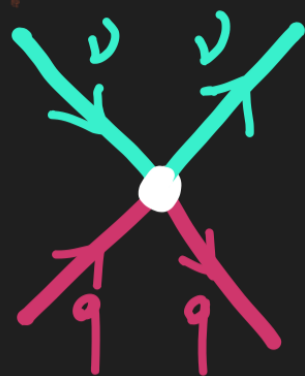
New BSM scenarios might be associated with different types of interactions and mediators. These mediators would contribute to CE ν NS leading to detectable **distortions of the event rates, especially at low-energy recoils.**

Cerdeño+ JHEP 1605 (2016) 118
Bertuzzo+ JHEP 1704 (2017) 073
Farzan+ JHEP 1805 (2018) 066
Denton+ PRD 106 (2022) 015022

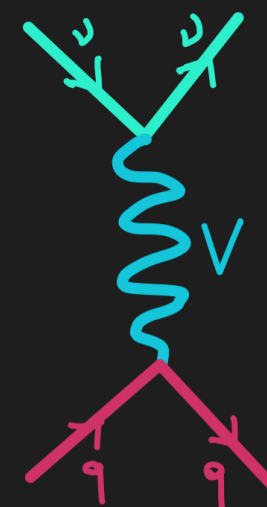
Low-energy neutrino experiments are sensitive to interactions involving light mediators, inducing spectral distortions at low recoil energies.

We may consider **light mediators** with a mass comparable to the typical momentum transfer

$$|\mathbf{q}| \approx \sqrt{2m_{\mathcal{N}}E_{\text{nr}}}$$

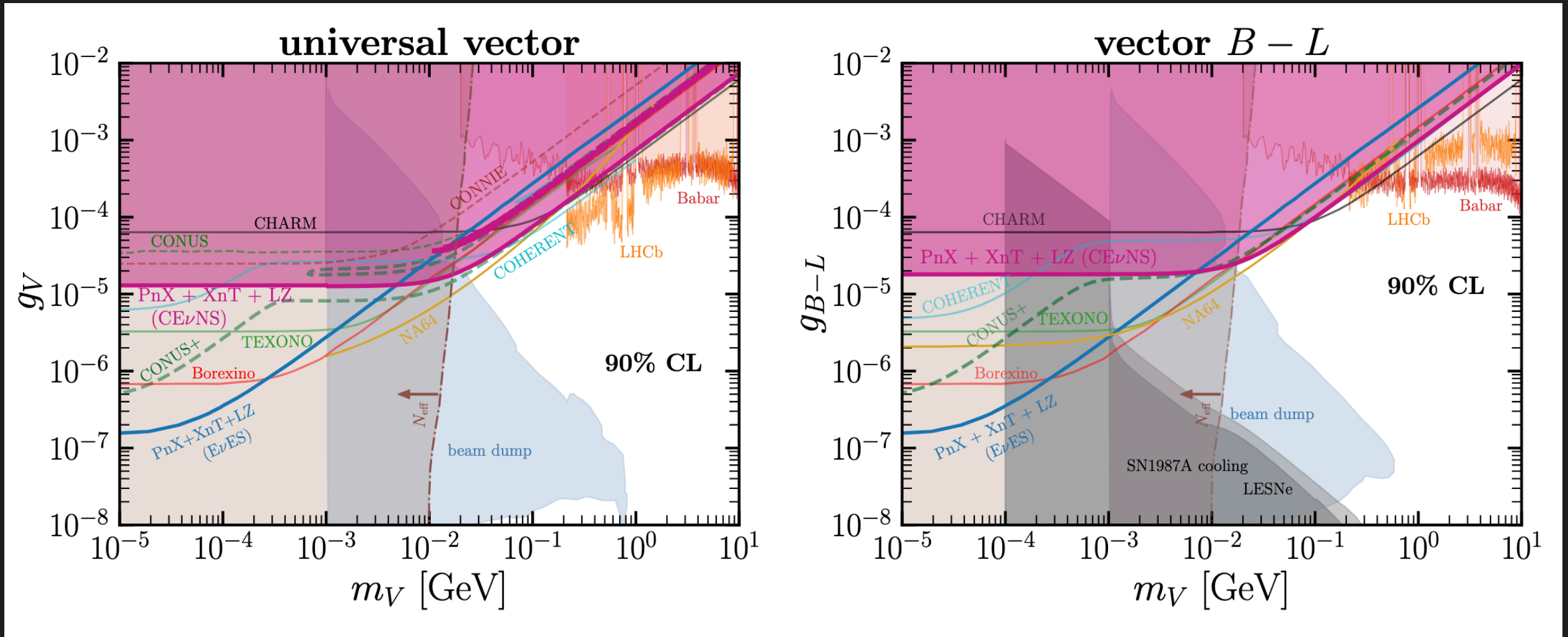


$$G_F^2 |\varepsilon_\ell^X|^2 \rightarrow \frac{2g_X^4}{(m_X^2 + |\mathbf{q}|^2)^2}$$



NEW NEUTRINO INTERACTIONS: LV

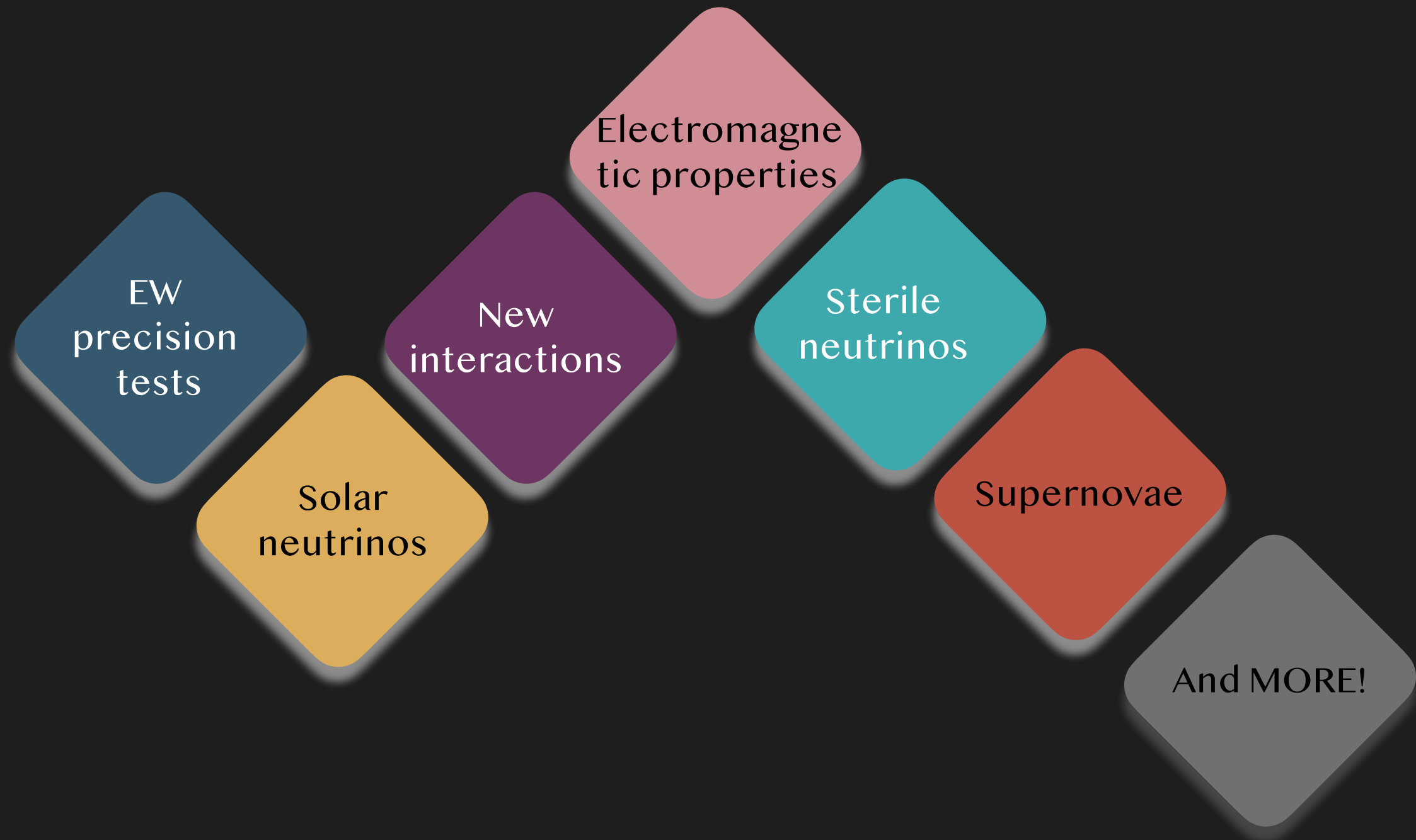
PandaX-4T (2024) + XENONnT (2026) + LZ (2025)



VDR, Papoulias, Pompa, Sanchez Garcia, Ternes, arXiv: 2603.00554

Complementary analyses in: Blanco-Mas+ JHEP 08 (2025) 043 and ShivaSankar K. A., Phys.Lett.B 839 (2023) 137742 for EvES data
VDR, Papoulias, Ternes JCAP 05 (2025) 012

PHYSICS POTENTIAL OF NEUTRINOS AT DM DIRECT DETECTION FACILITIES



SUMMARY

- ▶ The **large exposures** achieved at recent DM DD experiments, combined with the very **low threshold** operation capabilities of recent and future detectors, mark a turning point in **solar neutrino detection**. **Dark matter detectors are becoming complementary to terrestrial experiments in detecting $\sim$ MeV neutrinos**.
- ▶ Complementarity of **CE ν NS** and **E ν ES** channels.
- ▶ **Impact of new physics on the neutrino floor/fog**. Careful determination and interplay with terrestrial experiments.
- ▶ **Competitive constraints** on the relevant parameter space of **new physics** (light mediators and neutrino electromagnetic properties) can already be inferred; probe the weak mixing angle at low energy and **test the SM**.
- ▶ Future DM experiments—given their large size— will offer further improvements. **Direct detection data** will have to be **included in global fits with diverse neutrino probes** (various experimental targets and sources).

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