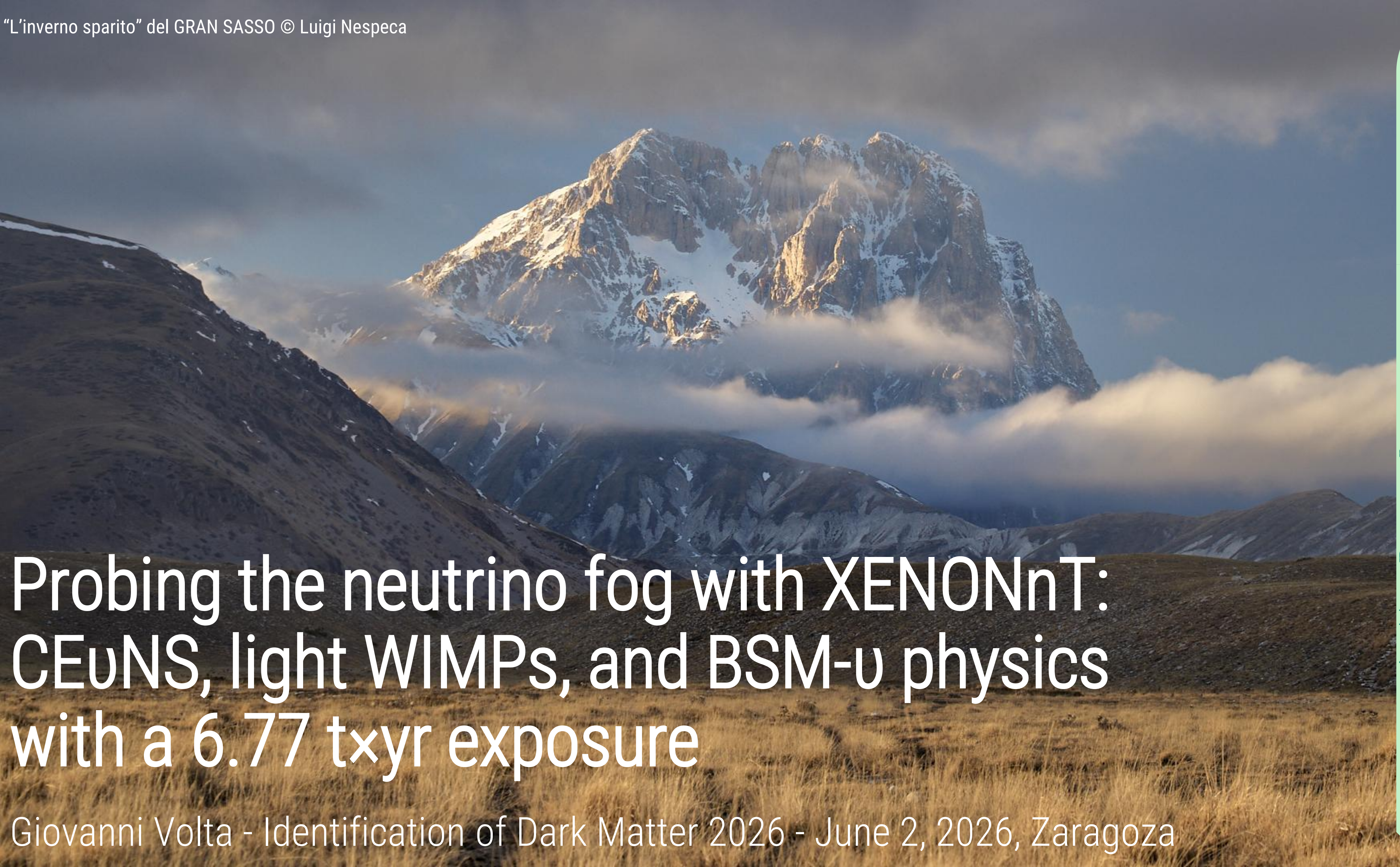

Probing the neutrino fog with XENONnT: CEυNS, light WIMPs, and BSM-υ physics with a 6.77 t×yr exposure

Giovanni Volta - Identification of Dark Matter 2026 - June 2, 2026, Zaragoza

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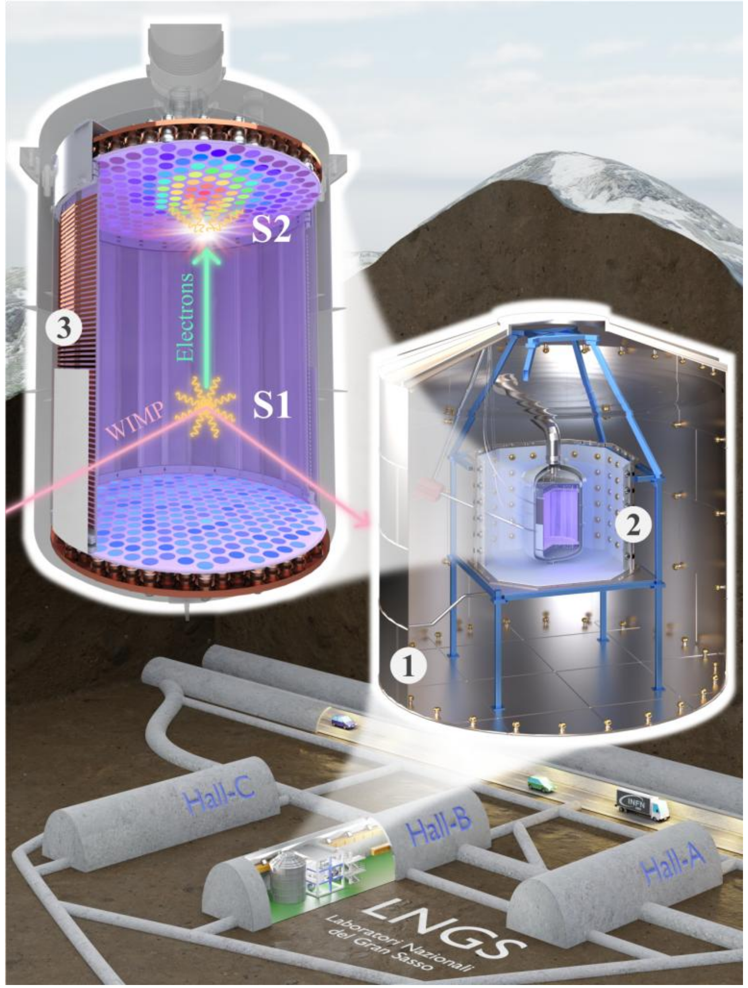
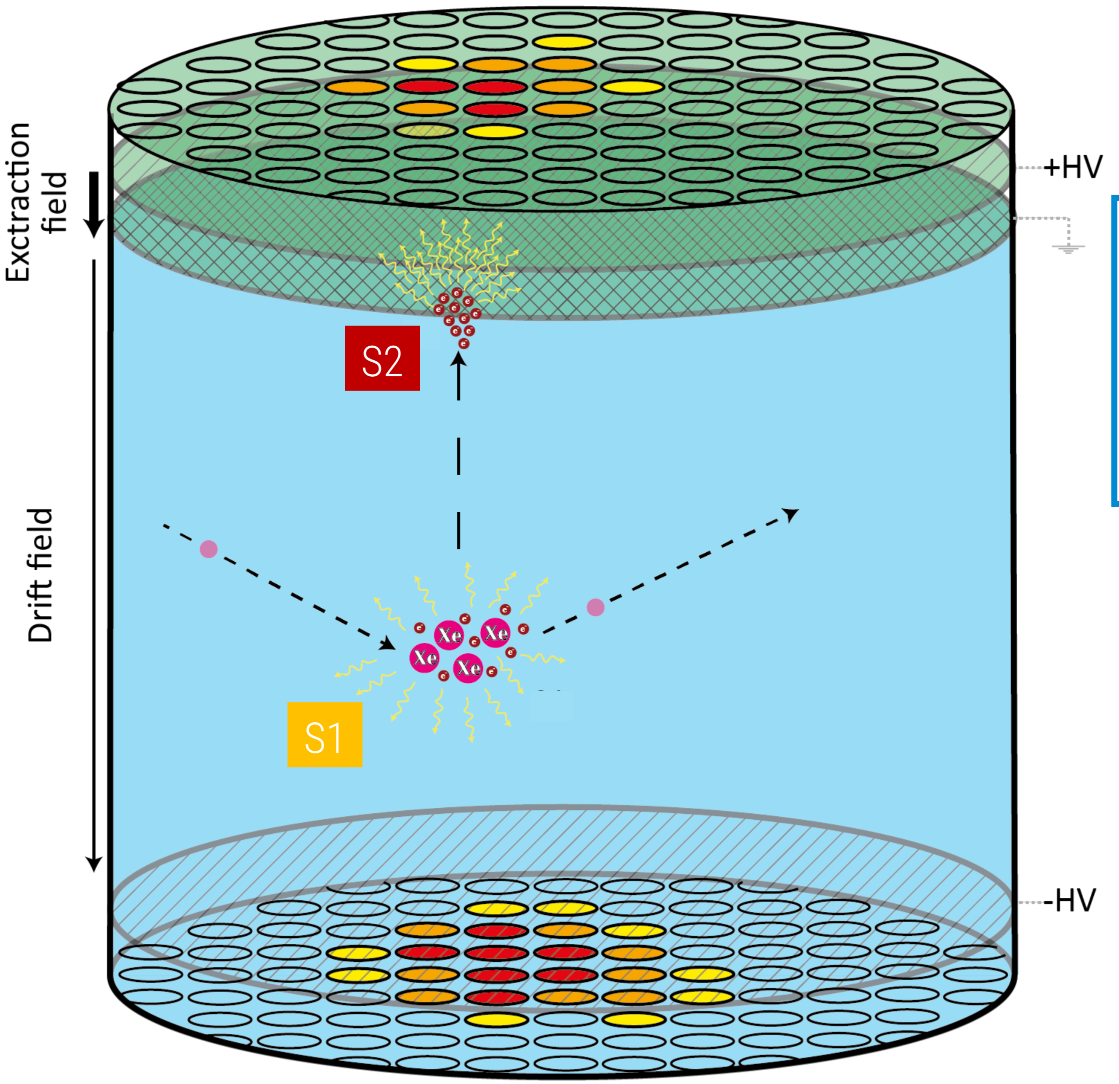
The XENON collaboration

Our primary goal is to detect dark matter (e.g., <u>Weakly Interactive Massive Particles</u>)



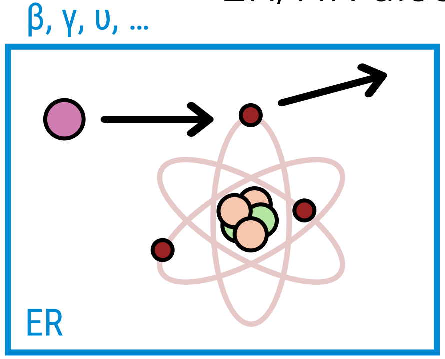
Dual-phase TPC principle

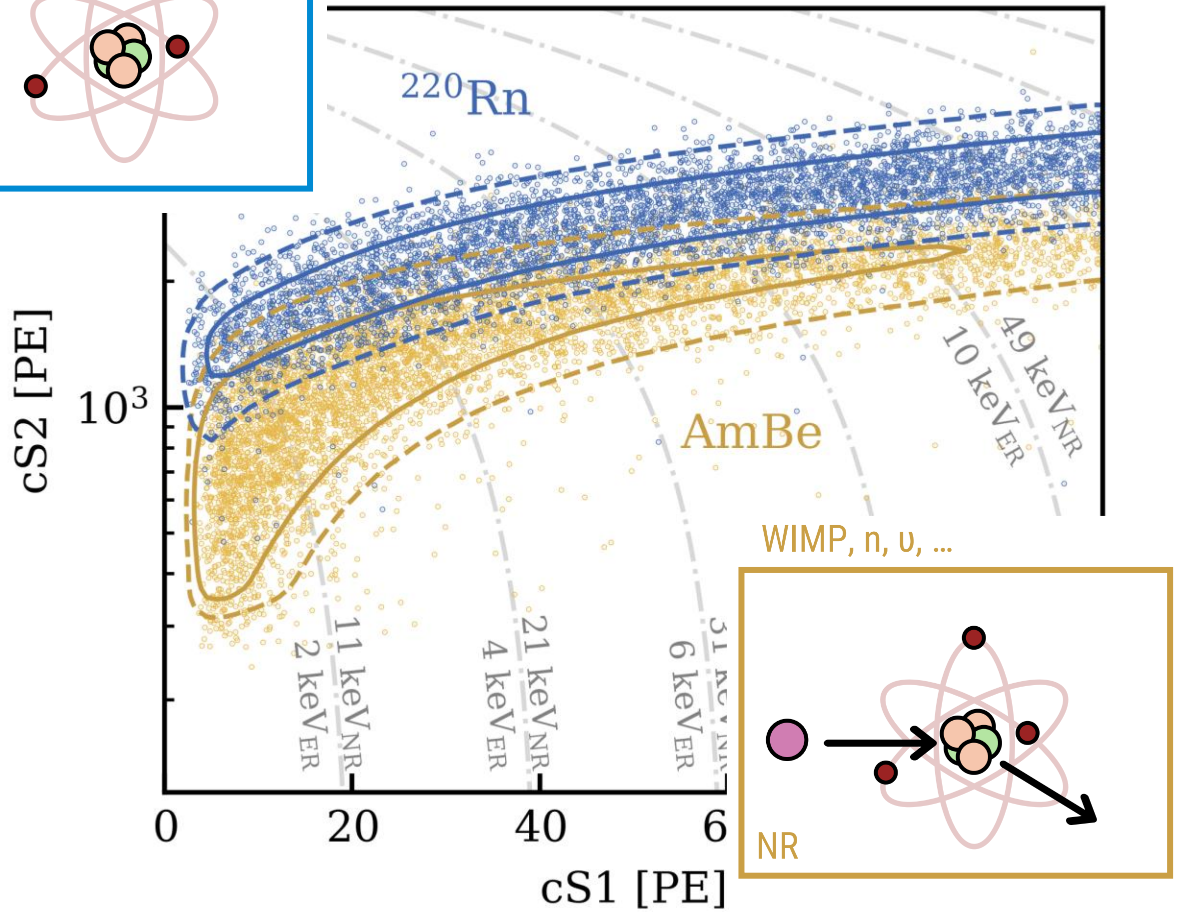


Scintillation photons (S1) and free electrons (∝ S2) are produced from an impinging particle.

Combination of S1 and S2 signals allows for:

- 3D position reconstruction
- $E_{dep} \propto (n_\gamma + n_{e^-})$
- ER/NR discrimination via the charge-to-light ratio





Science data taking

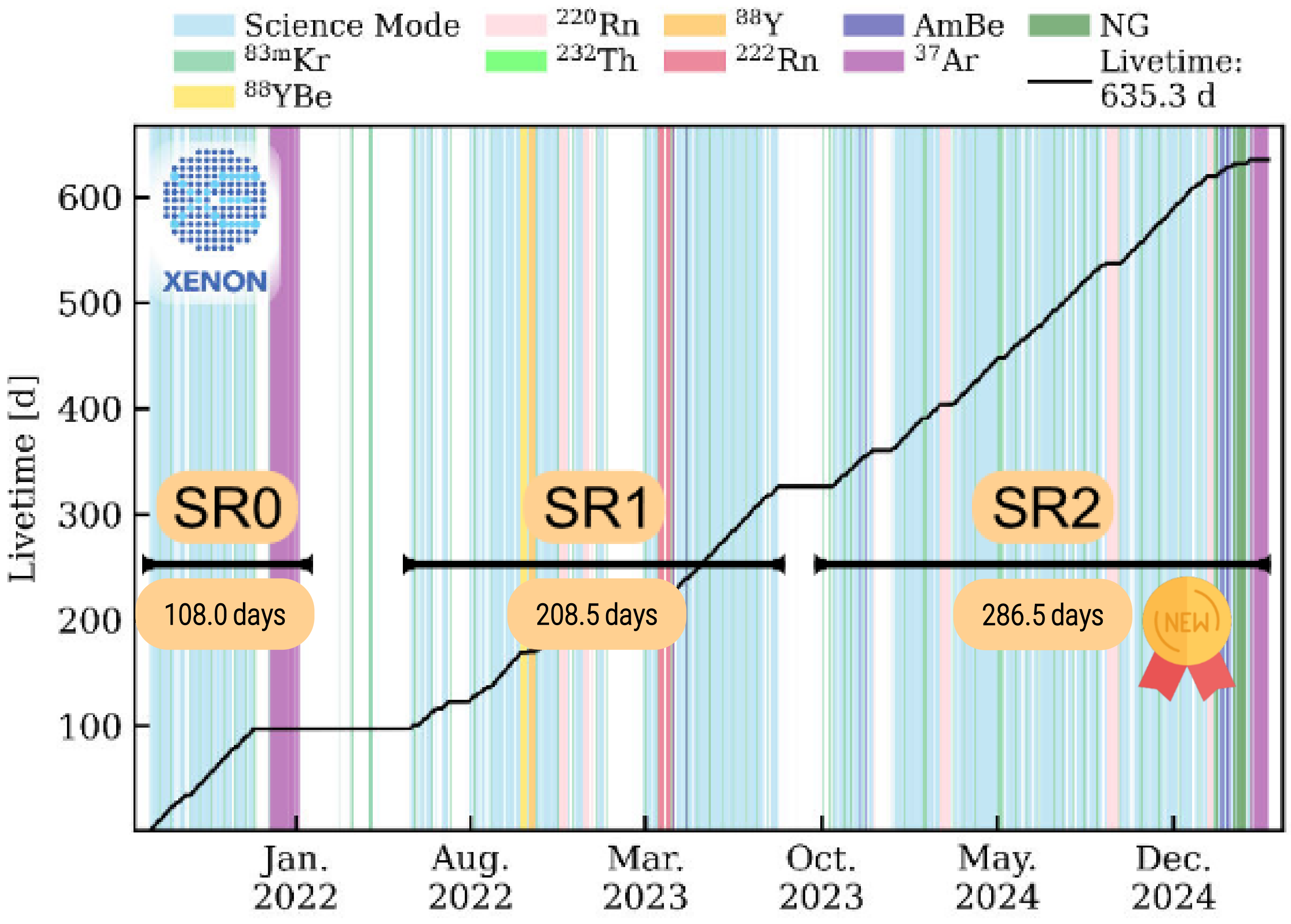
- More than 600 days of science data so far
- Fiducial mass: ~ 4 tonnes

Today:

- Neutrino physic and light dark matter searches in the "neutrino fog"

In this conference:

- Ionization-only and other Dark Matter searches[1] [2]
- Improvement in Neutron Veto[3]
- Further physics channels (pp-neutrinos[4], ...)



[1] New Dark Matter search results from XENONnT with combined science runs Maxime Pierre
[2] Search for Magnetic Inelastic Dark Matter with Delayed NR ER Coincidences in XENONnT, Tianyu Zu
[3] Performance of the Gd-loaded Water Cherenkov Neutron Veto in XENONnT Emanuele Angelino
[4] Rare Event Searches in the Electron Recoil Channel of the XENONnT Experiment Ying-Ting Lin

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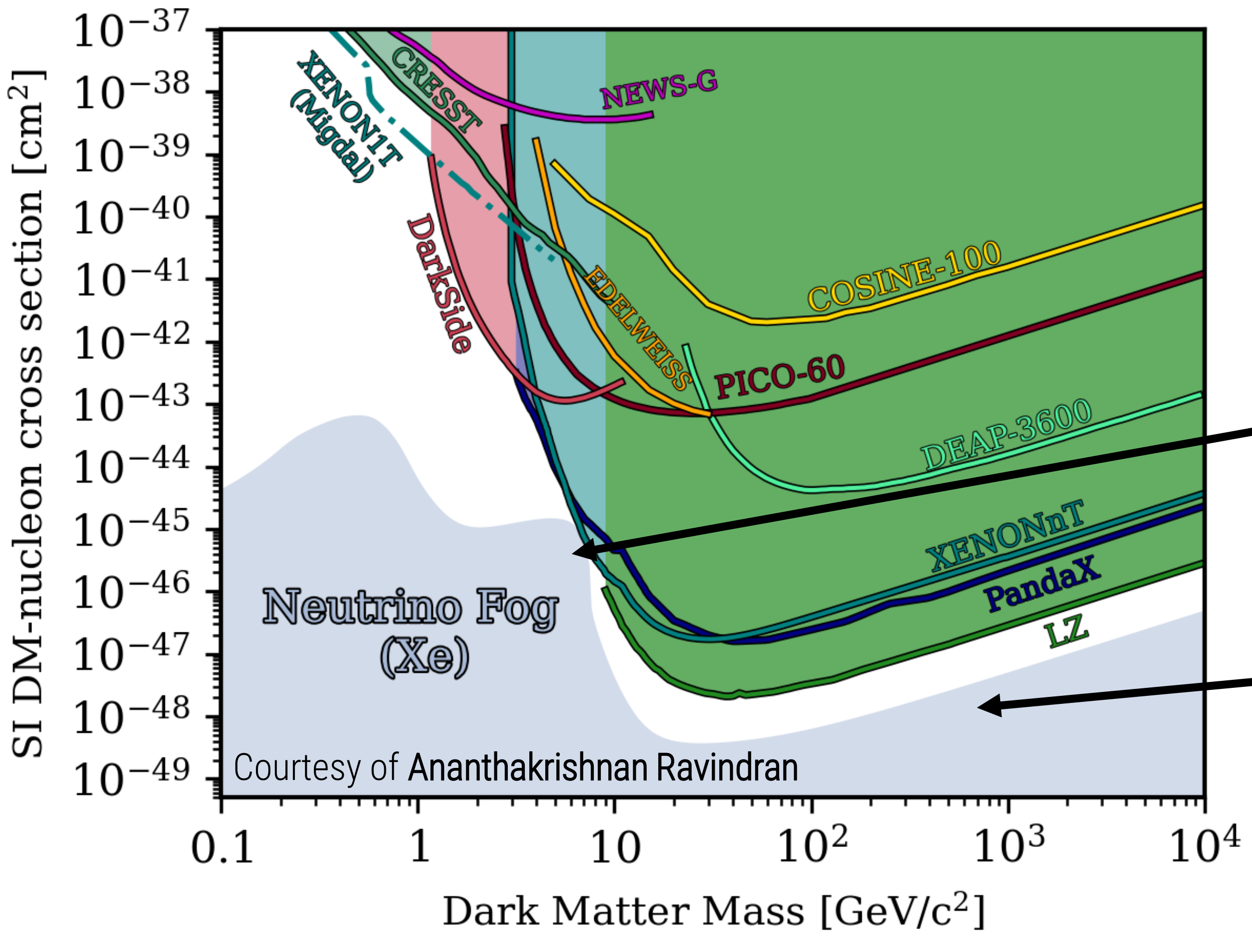
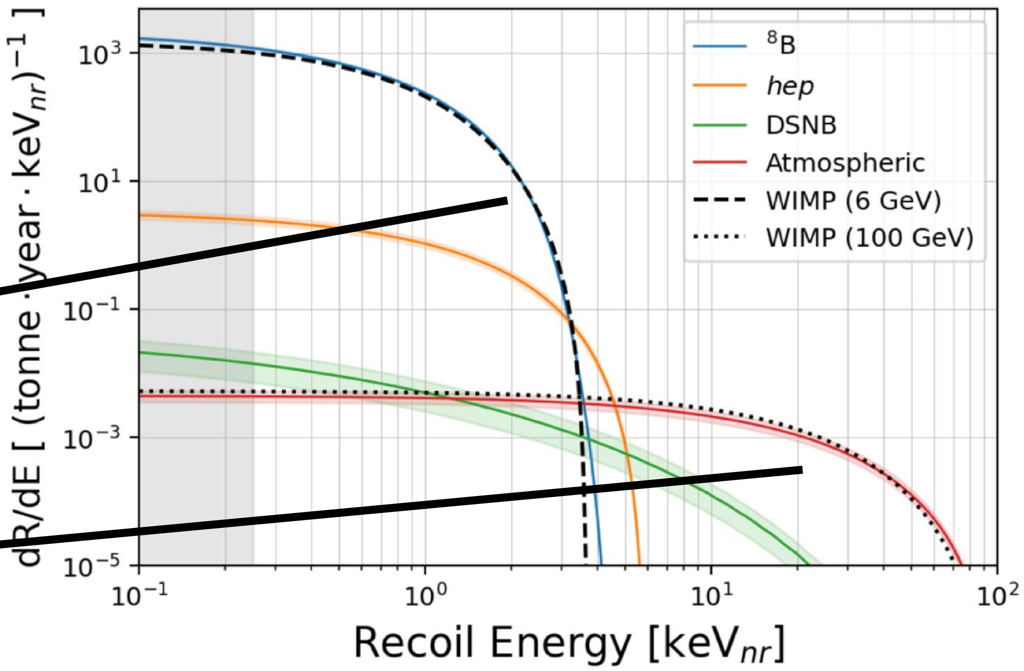
The “neutrino fog”

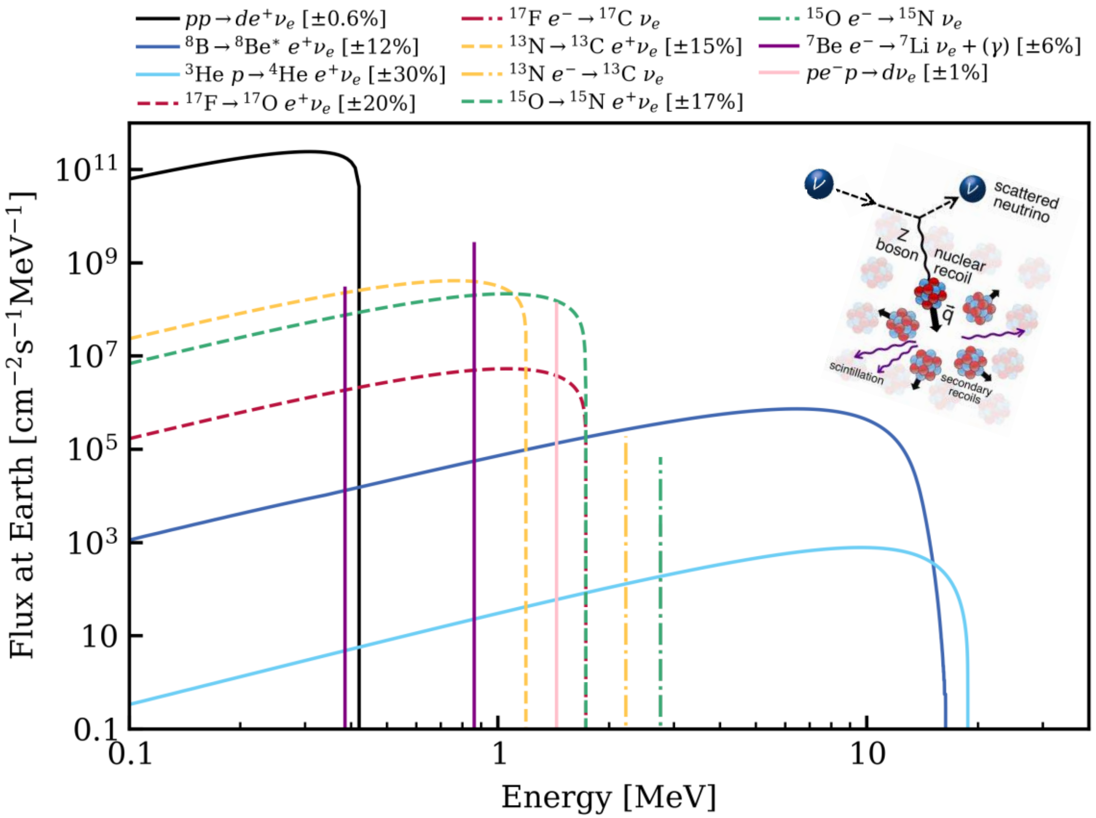
^{8}B solar and atmospheric neutrinos generate NR spectra that look near-identical to O(1) GeV/c^2 and O(100) GeV/c^2 WIMP masses respectively

Discovery power is significantly affected but it also open to new possibilities!



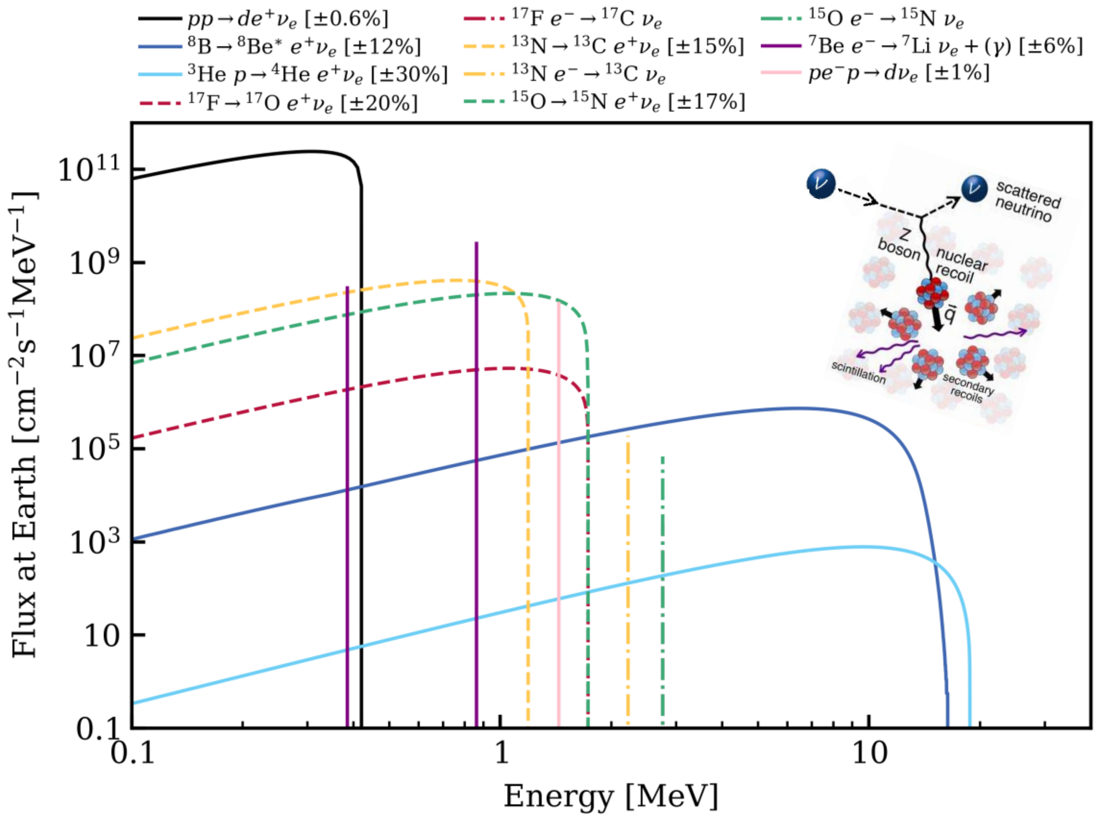


Coherent Elastic Neutrino-Nucleus Scattering



- "Large" cross-section: $\sigma \propto N^2_{neutrons}$
- Low energy deposited: > 90% of detectable recoils below 2.1 keV
- Lowered PMT coincidence from 3-fold (standard NR) to 2-fold to achieve CEυNS sensitivity

Coherent Elastic Neutrino-Nucleus Scattering



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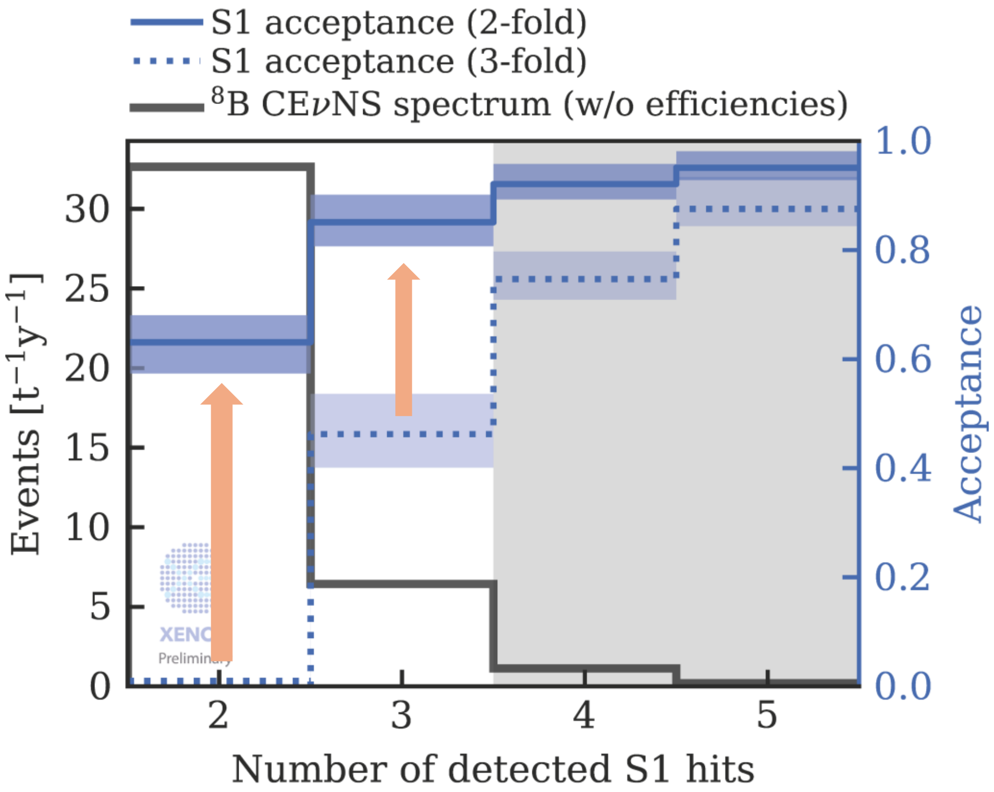
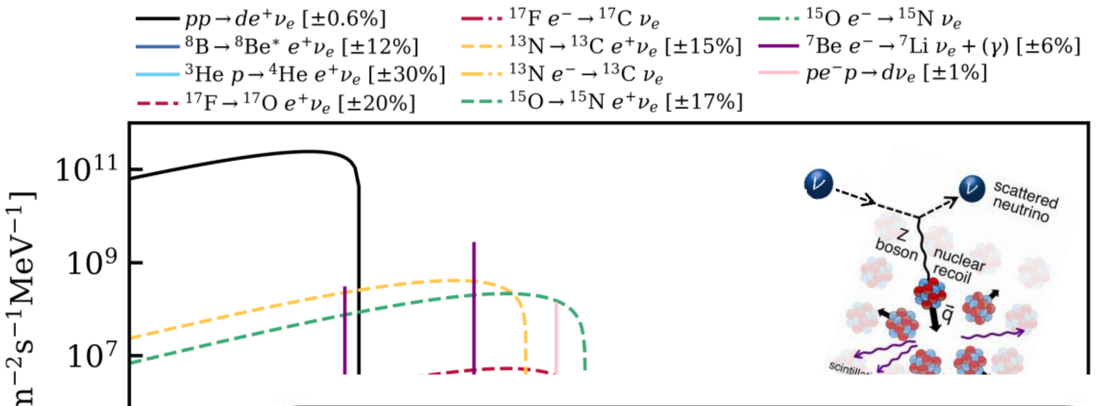


Coherent Elastic Neutrino-Nucleus Scattering

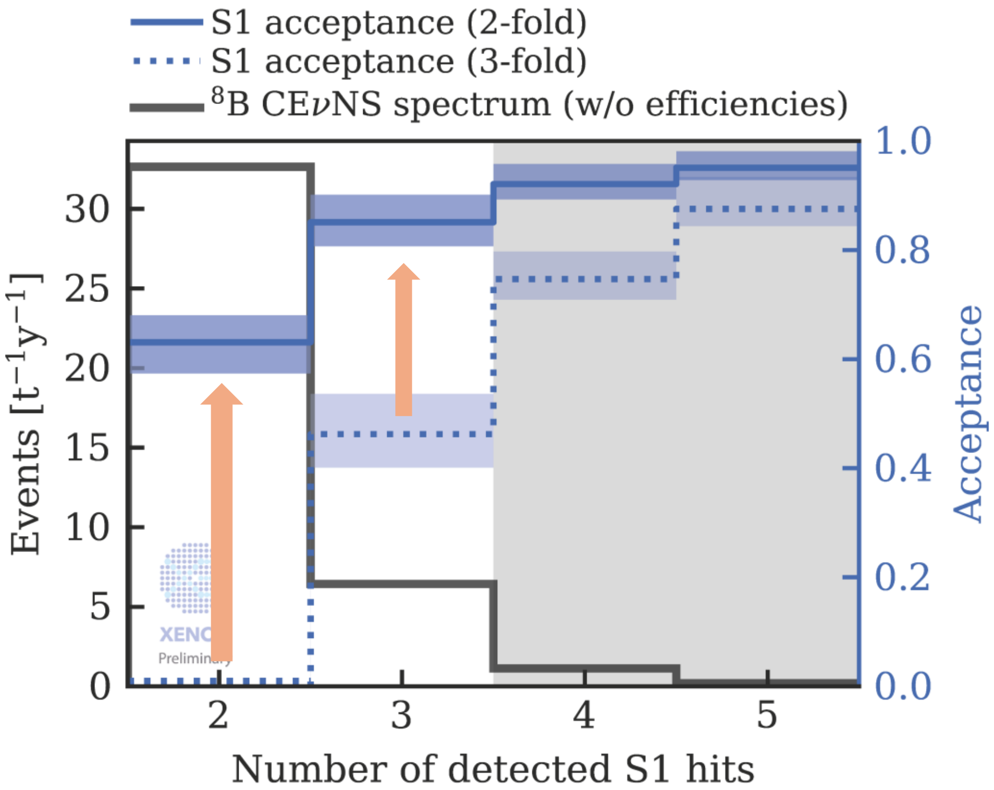


Searching for 2 or 3 photons S1, S2 in [120, 500] PE (~4-17) electrons

Less-understood LXe response

Higher background

- "Large" cross-section: $\sigma \propto N^2_{neutrons}$
- Low energy deposited: > 90% of detectable recoils below 2.1 keV
- Lowered PMT coincidence from 3-fold (standard NR) to 2-fold to achieve CEυNS sensitivity



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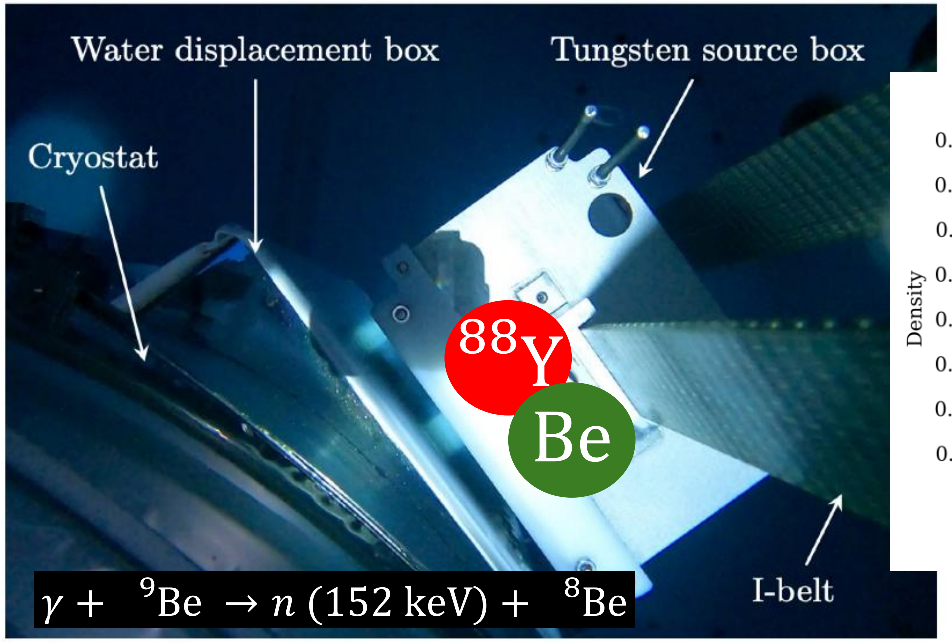
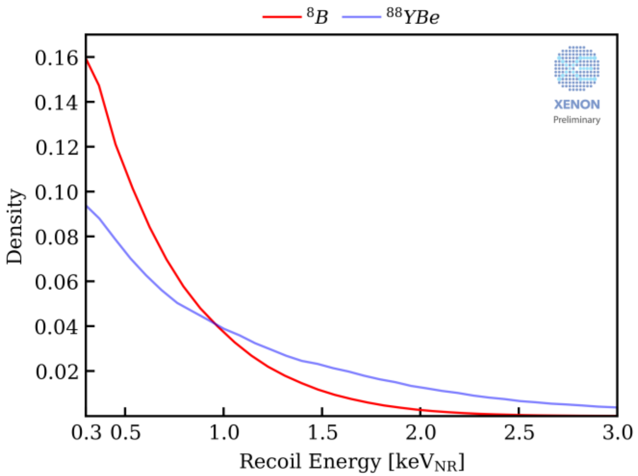
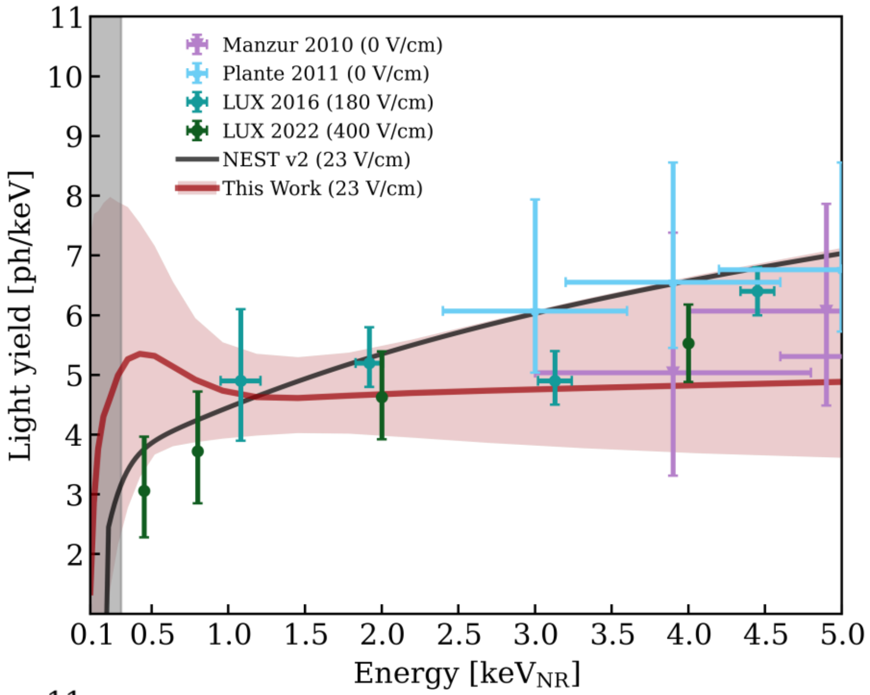
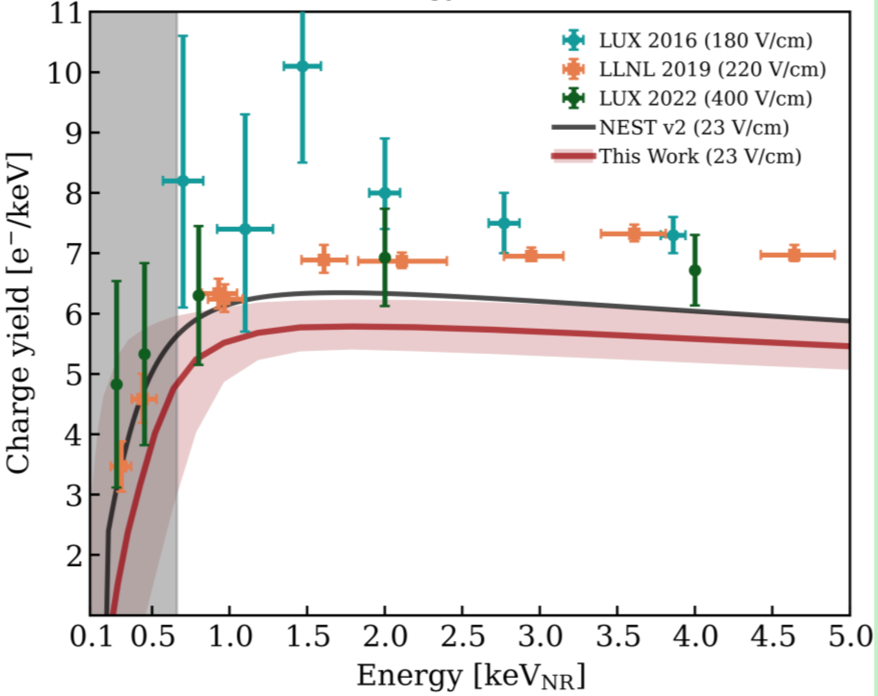
Low energy NR calibration with ^{88}YBe

- The low-energy NR response is calibrated with 152 keV neutrons from an external ^{88}YBe source
- Calibrate detector with neutrons on/off (Yttrium-PVC gamma-only source)
- Light and charge yield (and uncertainties) from best fit of NESTv2.3 yield model









[Low-Energy Nuclear Recoil Calibration of XENONnT with a 88YBe Photoneutron Source]

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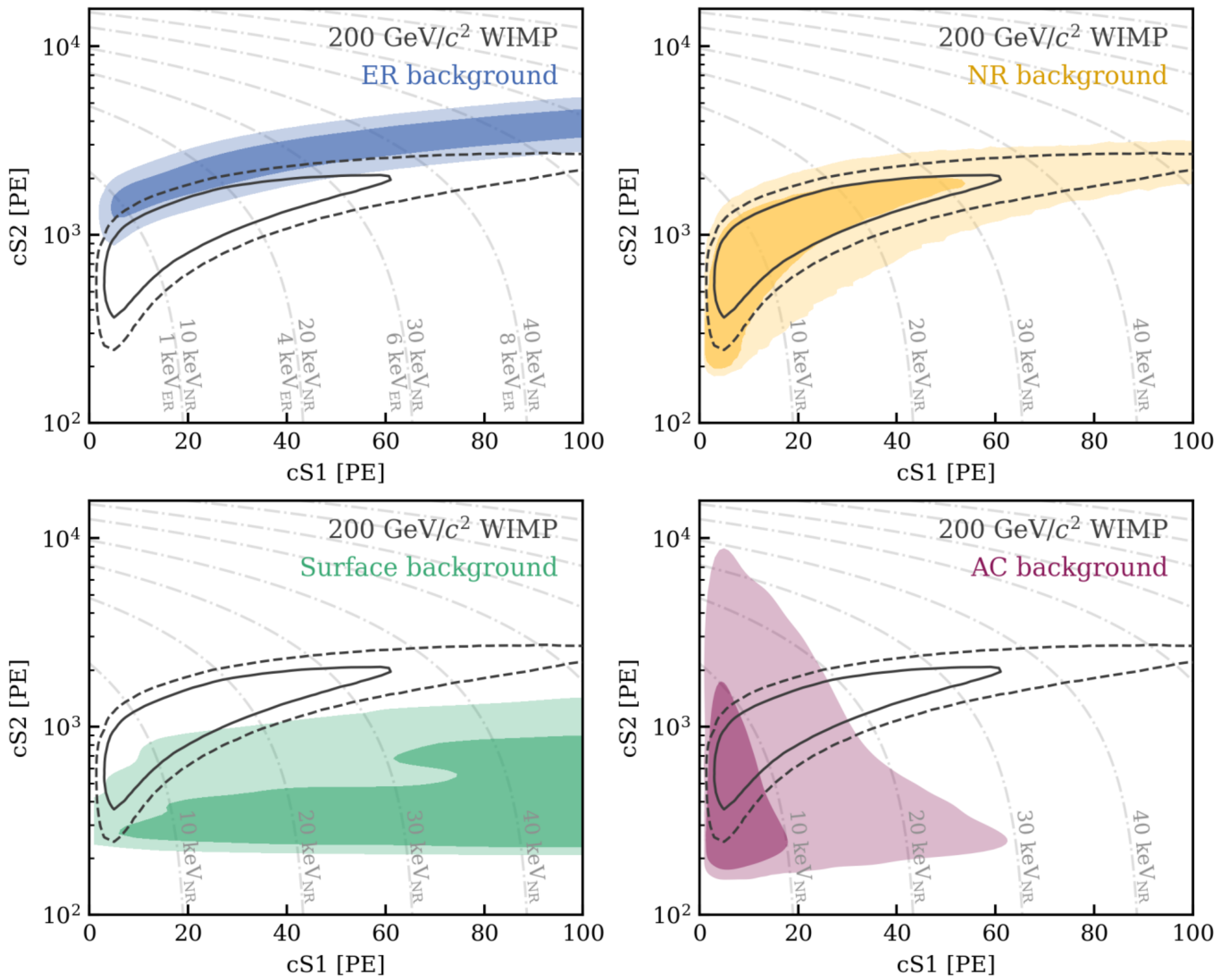
Background

Background in traditional WIMP search



ER Background
Intrinsic radioactive contaminants in xenon volume

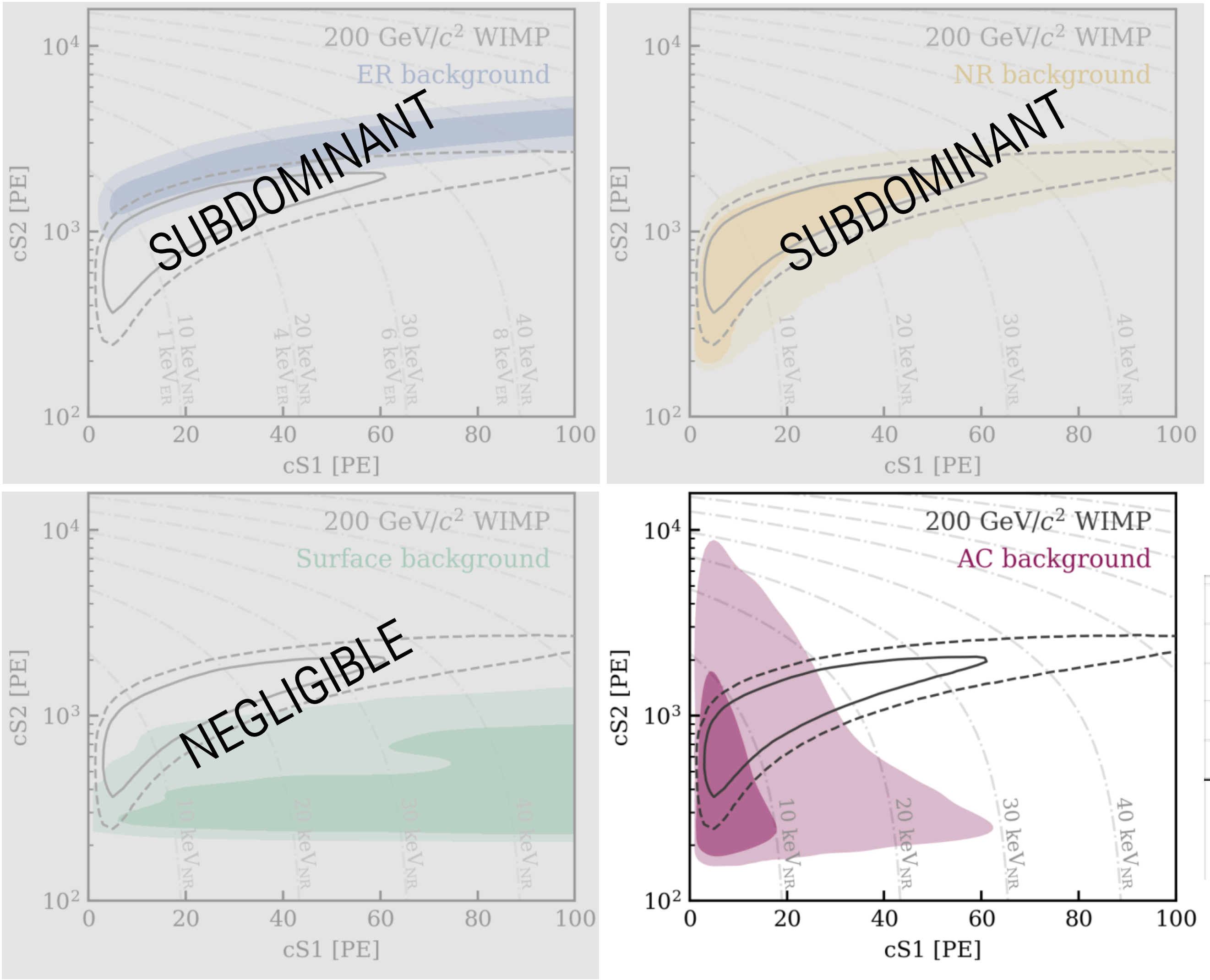
Surface Background
Radon daughters plating out into PTFE wall

NR Background
Radiogenic neutrons from detector materials

Accidental Coincidences
Random pairing of isolated S1 and S2 signals

Background

Background in traditional WIMP search



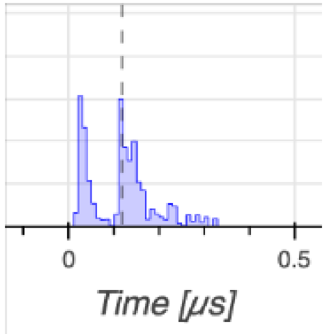
Before any suppression:

Isolate S1 rate: ~15 Hz

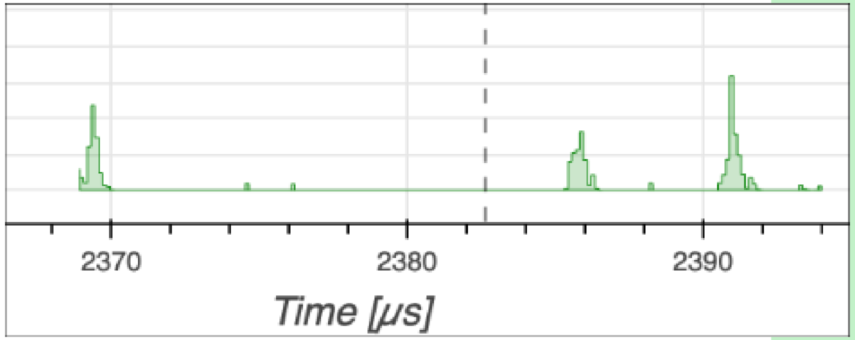
Isolate S2 rate: ~0.15 Hz

Max drift time (23 V/cm): 2.2 ms

→ ~ 400 events/day !



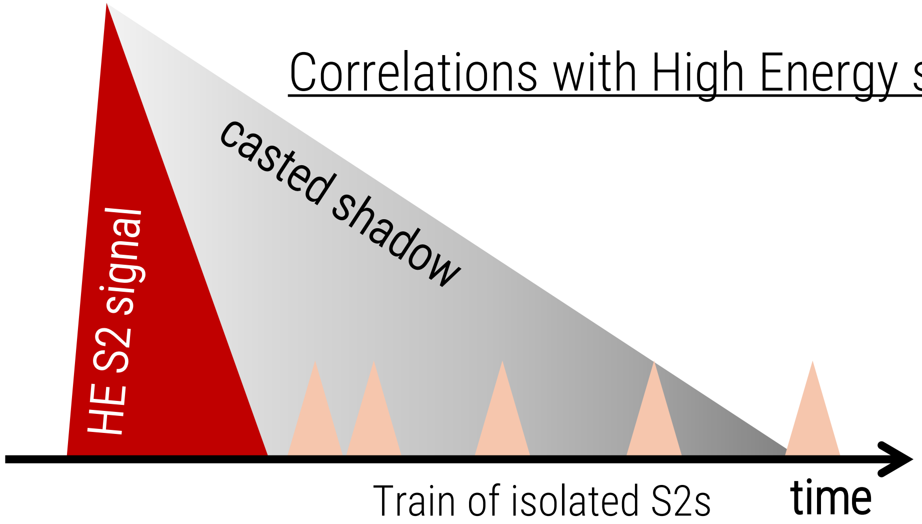
Isolate S1: PMT lone-hits pile-ups, …

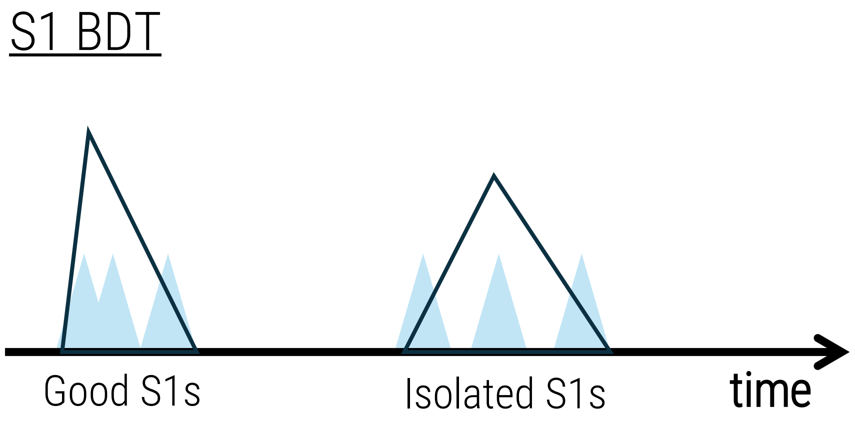


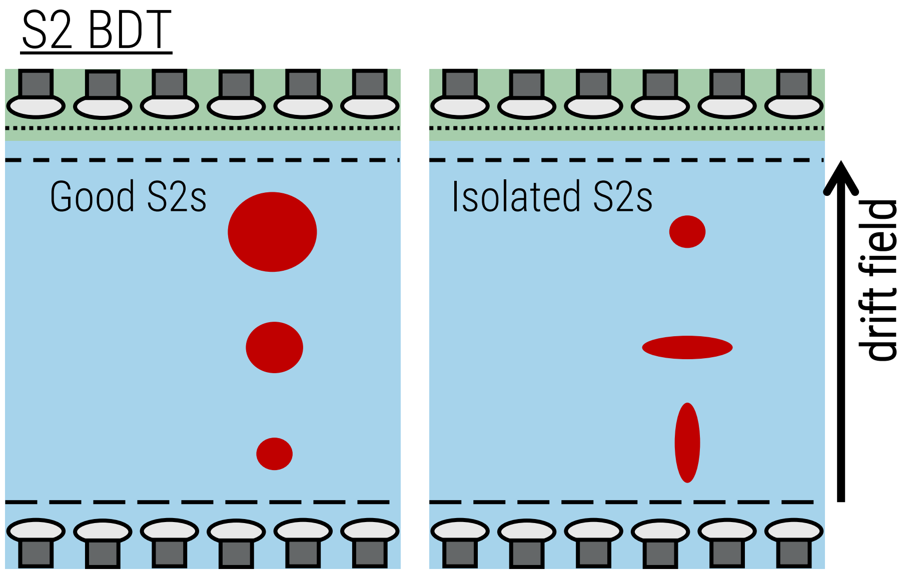
Isolate S2: delayed electrons, from electrodes …

AC suppression

Isolate S1 and S2 rate and discrimination of AC events based on time and spatial correlation with preceding signals and boosted decision tree (BDT) trained on S1 and S2 waveforms: **rejection power around 90%** with a **signal acceptance of 80%** !







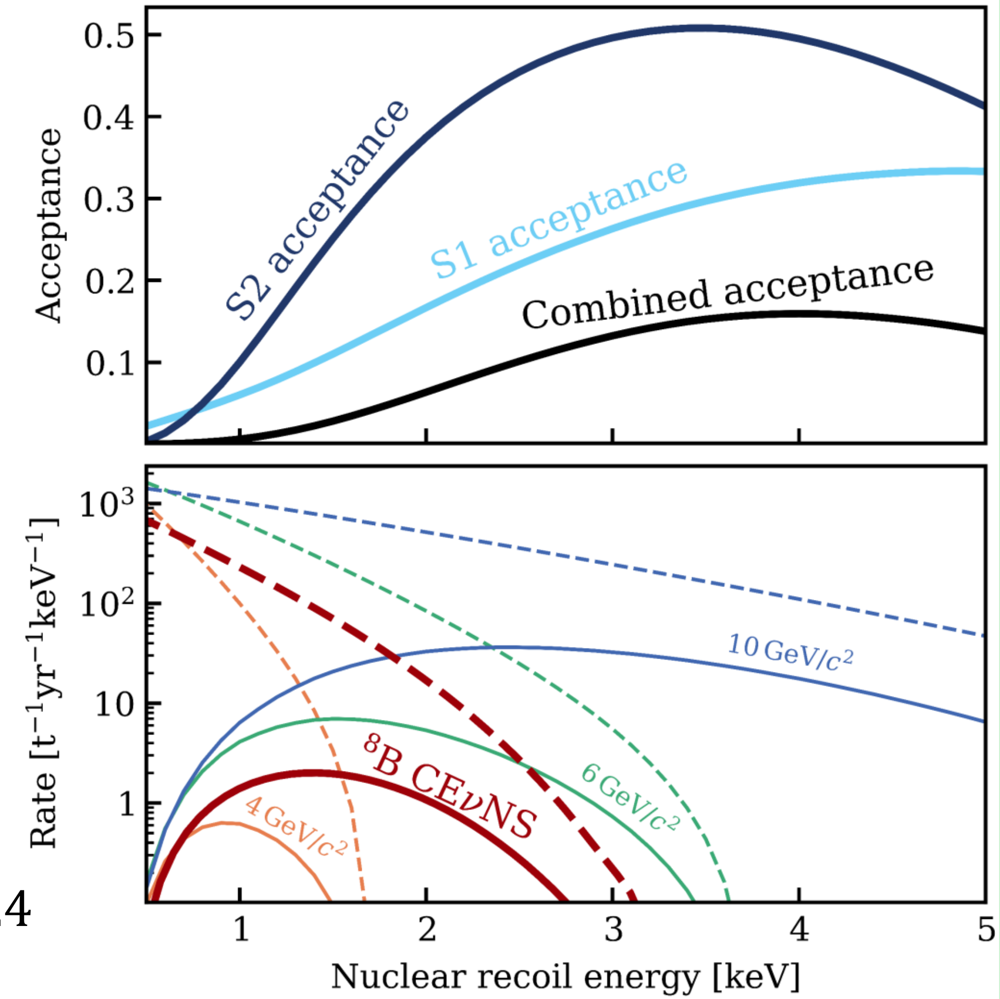
After suppression:

SR	S1 [Hz]	S2 [mHz]	AC [μHz]
SR0	2.3	16.6	0.80
SR1	2.2	21.5	0.99
SR2	1.7	17.7	0.60

Additional ~20% suppression in SR2 via advanced peak classification and S2 merging!

SR0+SR1+SR2 CEυNS measurement...recap

- ^{8}B CEυNS signal model neutrino from Standard Solar Model and Standard Model cross section
- 2 or 3 photons S1 and S2 in [120, 500] PE with 6.77 tonne x year exposure
- Performed in a blind fashion
- Extended binned likelihood in 4D parameter space
  i. cS2 [PE], quantile of S2/Δt, S1 BDT score, S2 BDT score
  ii. Separate terms for each SRs
  iii. Constraints on rates and yields from ancillary measurements



Expected number of events:

AC: SR0 | SR1 | SR2 — 40.2 ± 1.4

ER — 1.2 ± 1.2

NR — $0.8^{+0.4}_{-0.5}$

^{8}B: SR0 | SR1 | SR2 — 16^{+5}_{-4}

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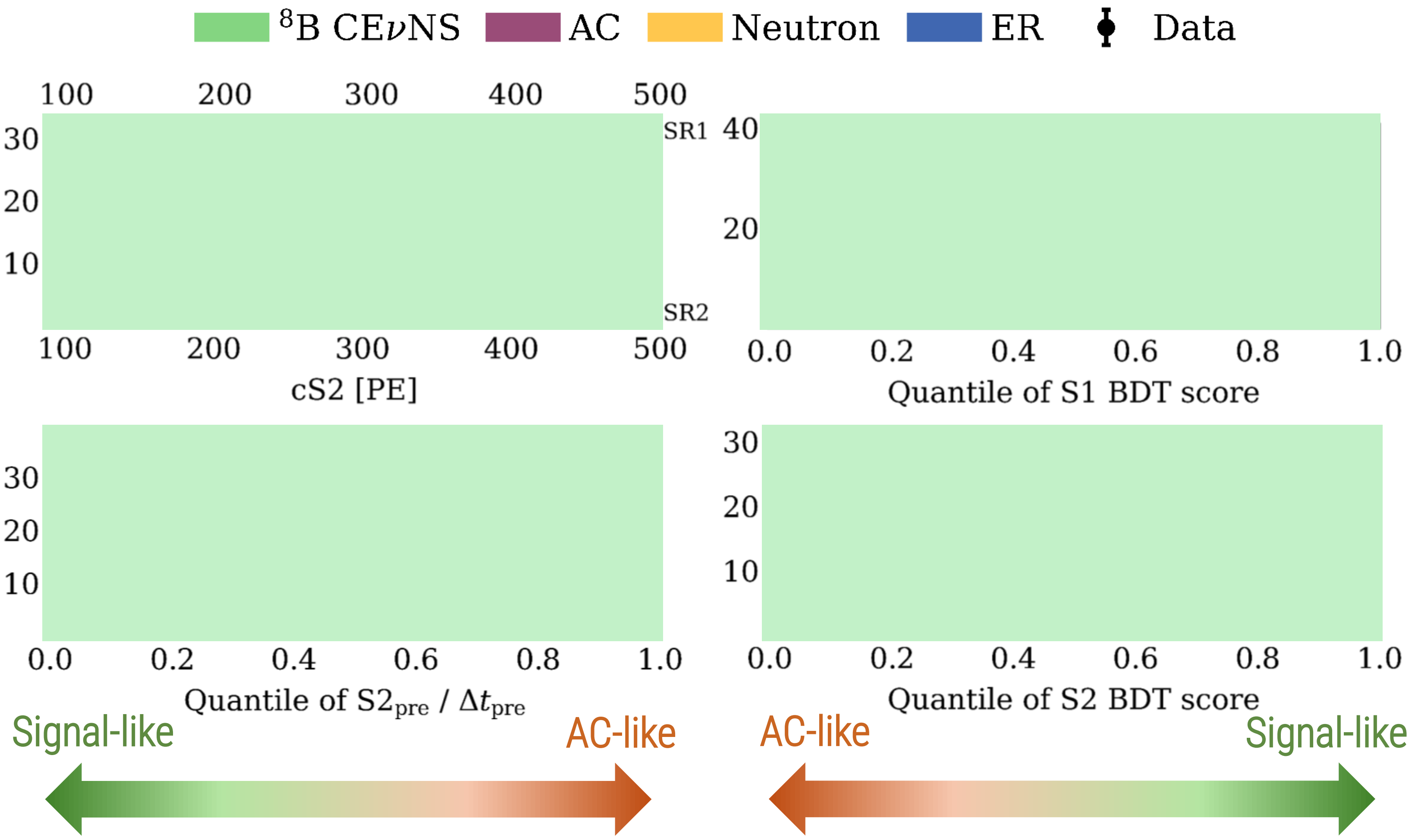
SR0+SR1+SR2 CEνNS measurement



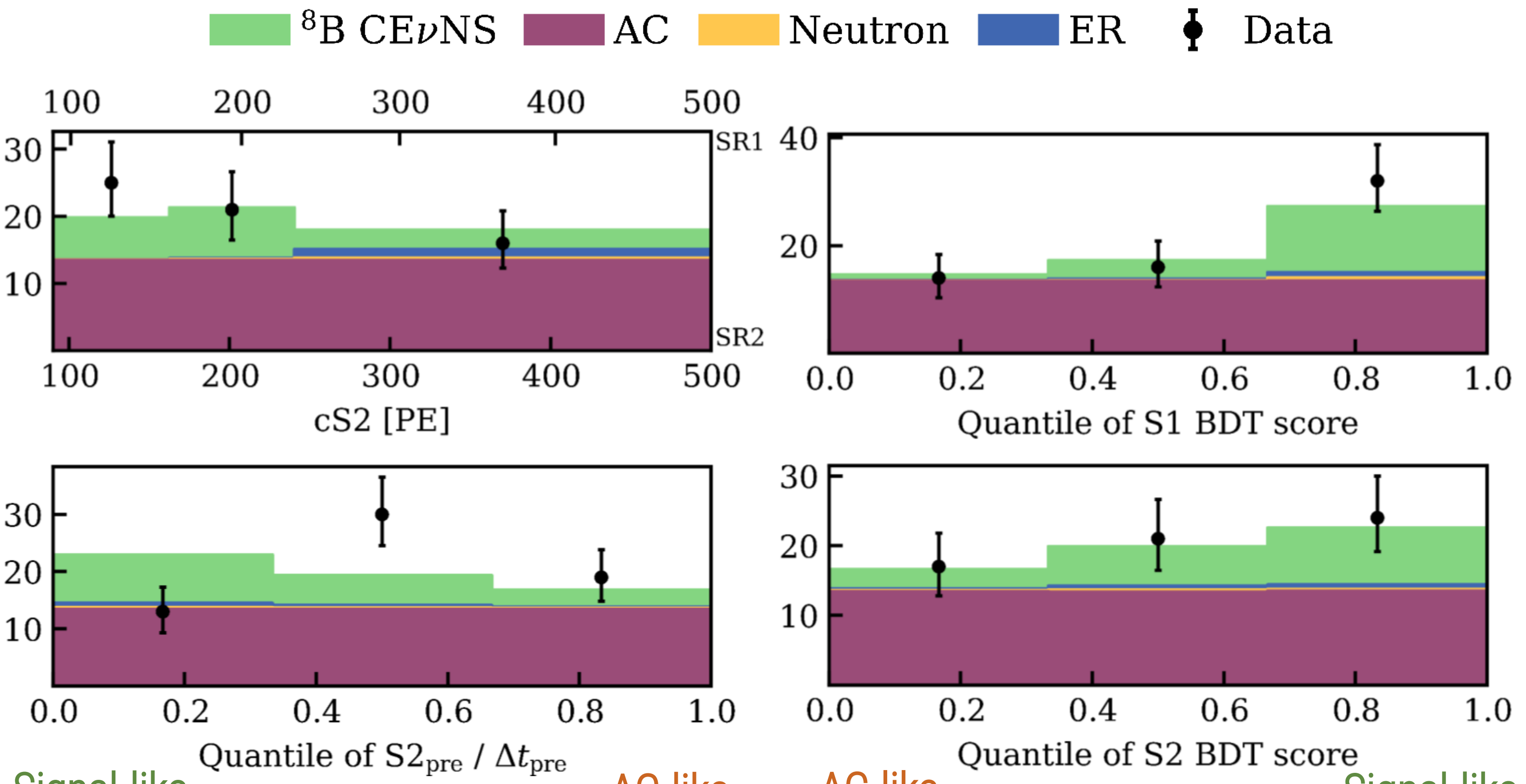
Expected Background:

$42.1^{+1.9}_{-1.7}$

Expected Signal:

16^{+5}_{-4}

SR0+SR1+SR2 CEνNS measurement



Signal-like AC-like

AC-like Signal-like

Expected Background:
$42.1^{+1.9}_{-1.7}$

Expected Signal:
16^{+5}_{-4}

Events Observed:
62

Best-fit number of ^{8}B signal events:

17 ± 5

3.3 σ significant

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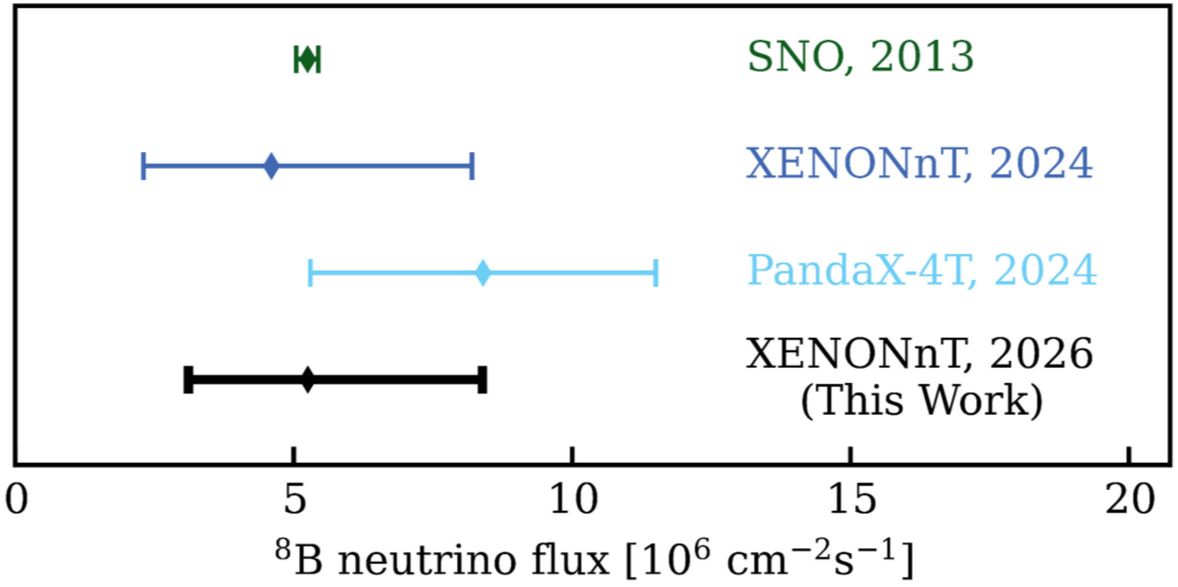
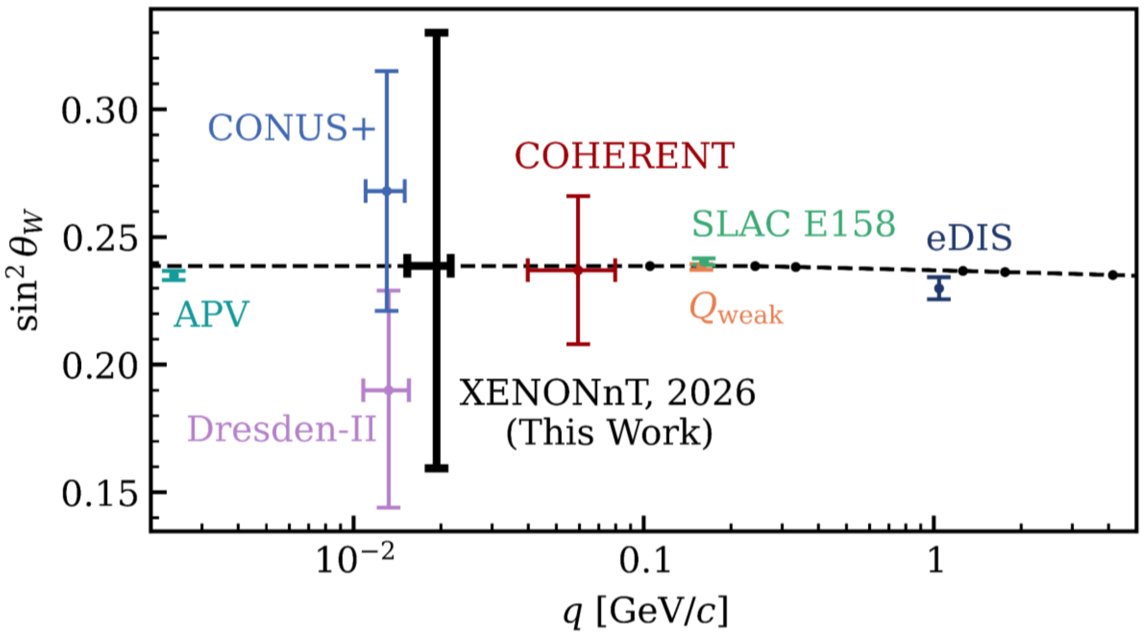
^{8}B CEνNS Results

- Fix cross-section → Measurement of the solar ^{8}B flux:

$$\phi = 5^{+3}_{-2} \times 10^{6}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$$

- Compatible with SNO measurement





- Fix flux → Measurement of the weak mixing angle at low momentum transfer (~0.02 GeV/c):

$$\theta_{\mathrm{W}} \in [0.159, 0.330]$$

- Competitive constrains on flavor-universal neutrino charge radius and Z' coupling strength

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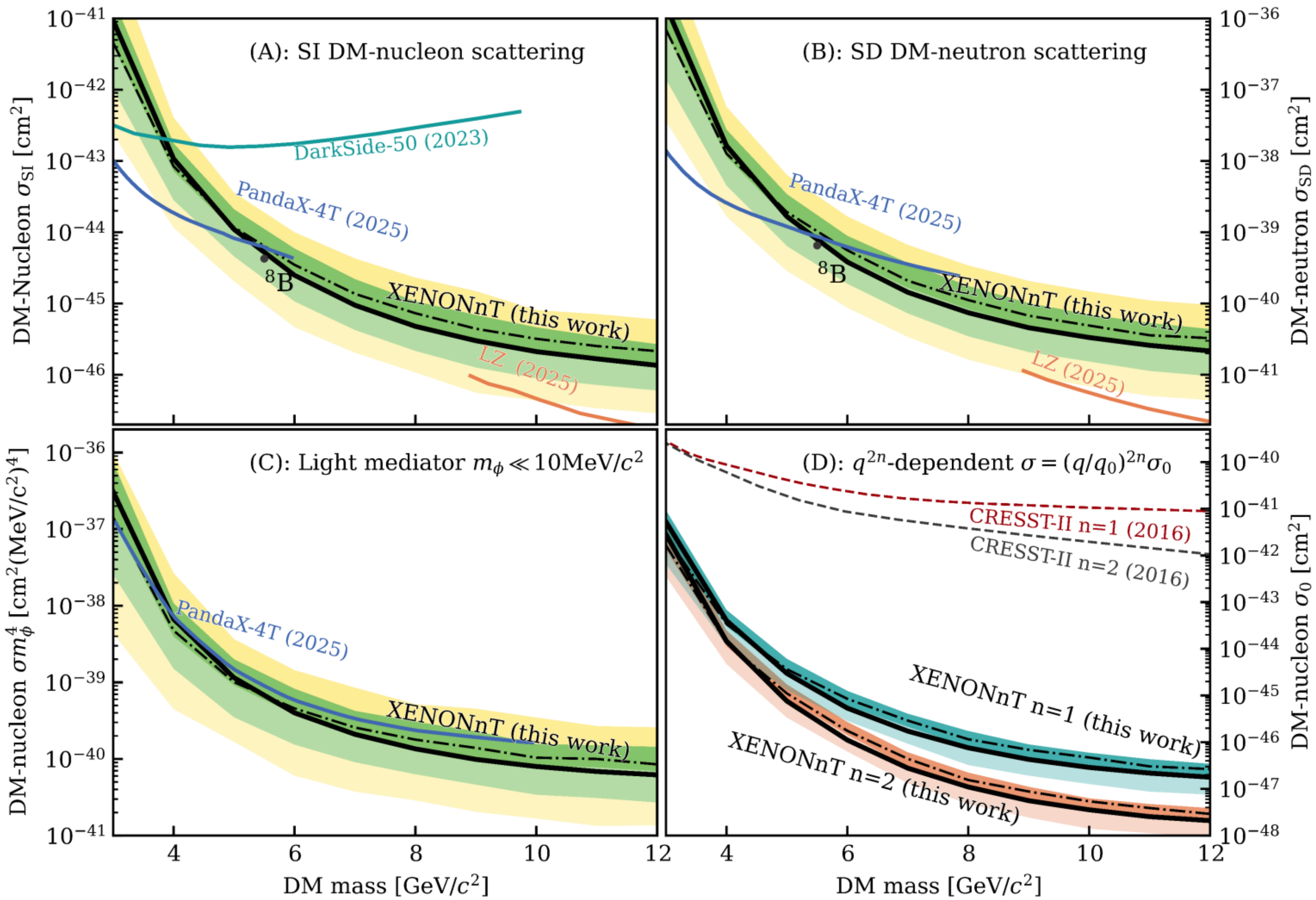
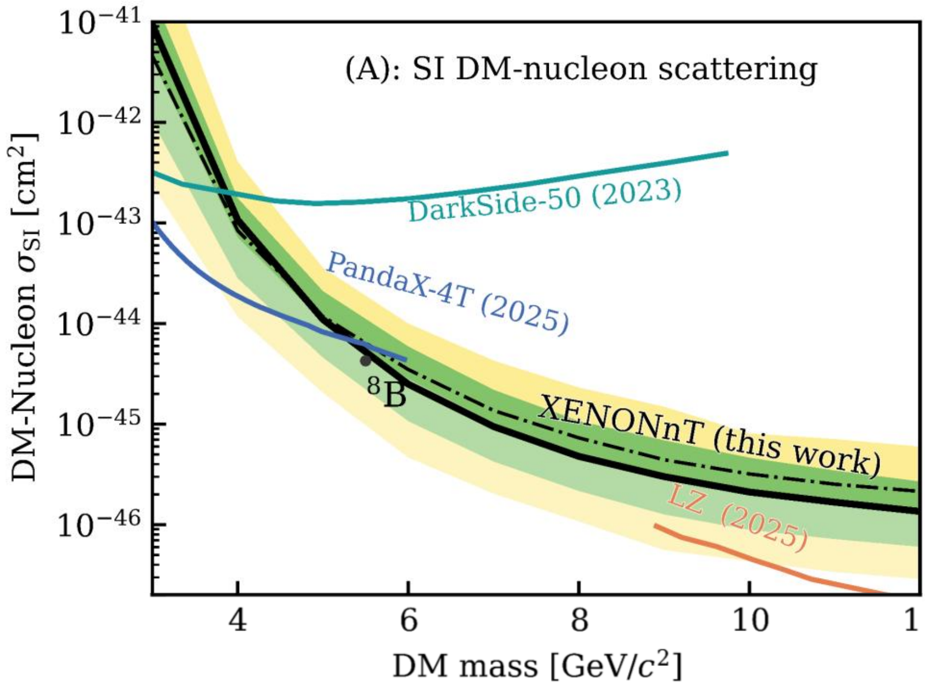
Search for Light WIMPs in the neutrino fog

- Treating the ^{8}B neutrino component as background source
- No significant signal rate over mass range [3, 12] GeV/c^2
- $\sim$10% improvement in sensitivity vs. SR0 + SR1 data (^{8}B neutrino background starts become relevant).
- New competitive limits on standard SI/SD WIMP interactions, light-mediator SI models, and momentum-dependent scenarios.



Summary and outlook

- A blind search across three XENONnT SRs yields a 3.3σ observation of CEνNS from ^{8}B solar neutrinos, alongside constraints on light WIMP dark matter -> e-print paper here
- The search for dark matter with LXe detectors has officially reached the neutrino fog!



Following a 1-year upgrade after SR2, 'XENONnT 2.0' is now in commissioning!

- New electrodes;
- Exchange of problematic PMTs;
- Improvement in TPC condition stability;

Searches for Light Dark Matter and Evidence of Coherent Elastic Neutrino-Nucleus Scattering of Solar Neutrinos with the LUX-ZEPLIN (LZ) Experiment
First Indication of Solar 8B Neutrinos through Coherent Elastic Neutrino-Nucleus Scattering in PandaX-4T

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“L’inverno sparito” del GRAN SASSO © Luigi Nespeca

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BACK-UP SLIDES

Light WIMP results S2-Only+CEυNS