

WIMP and Neutrino Direct Detection with XENONnT



XENON

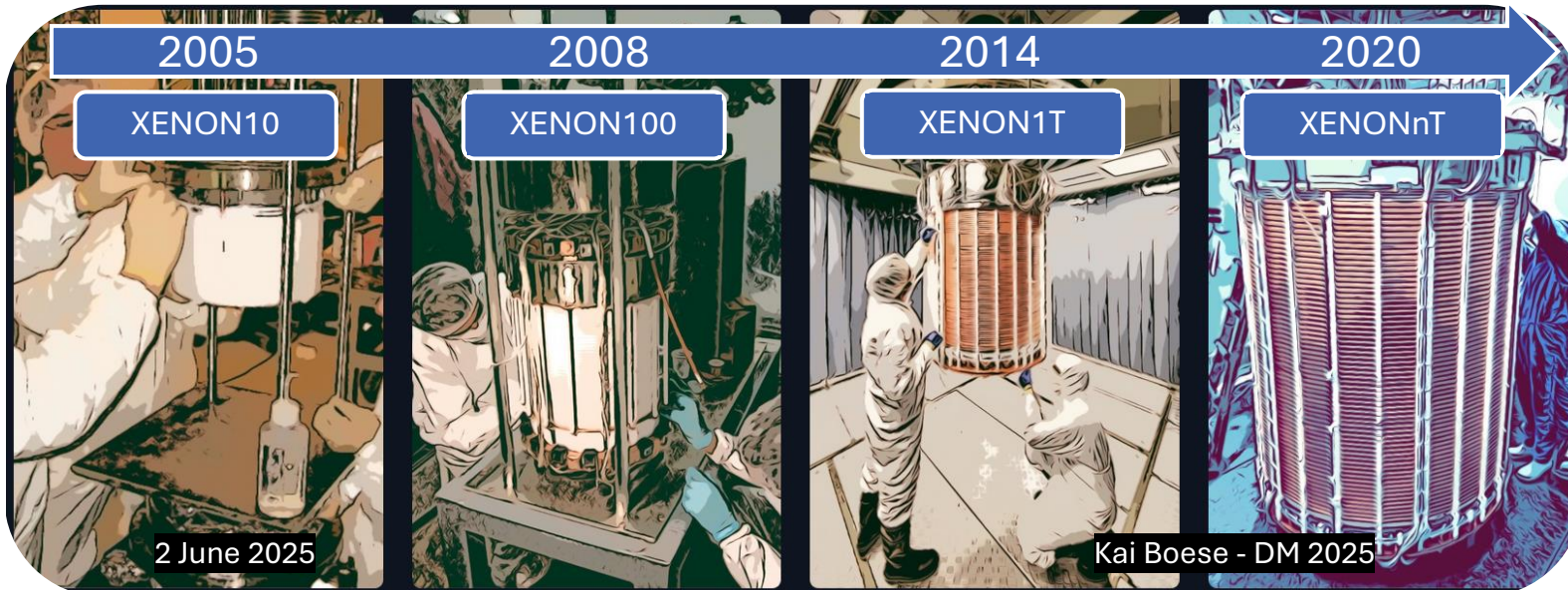
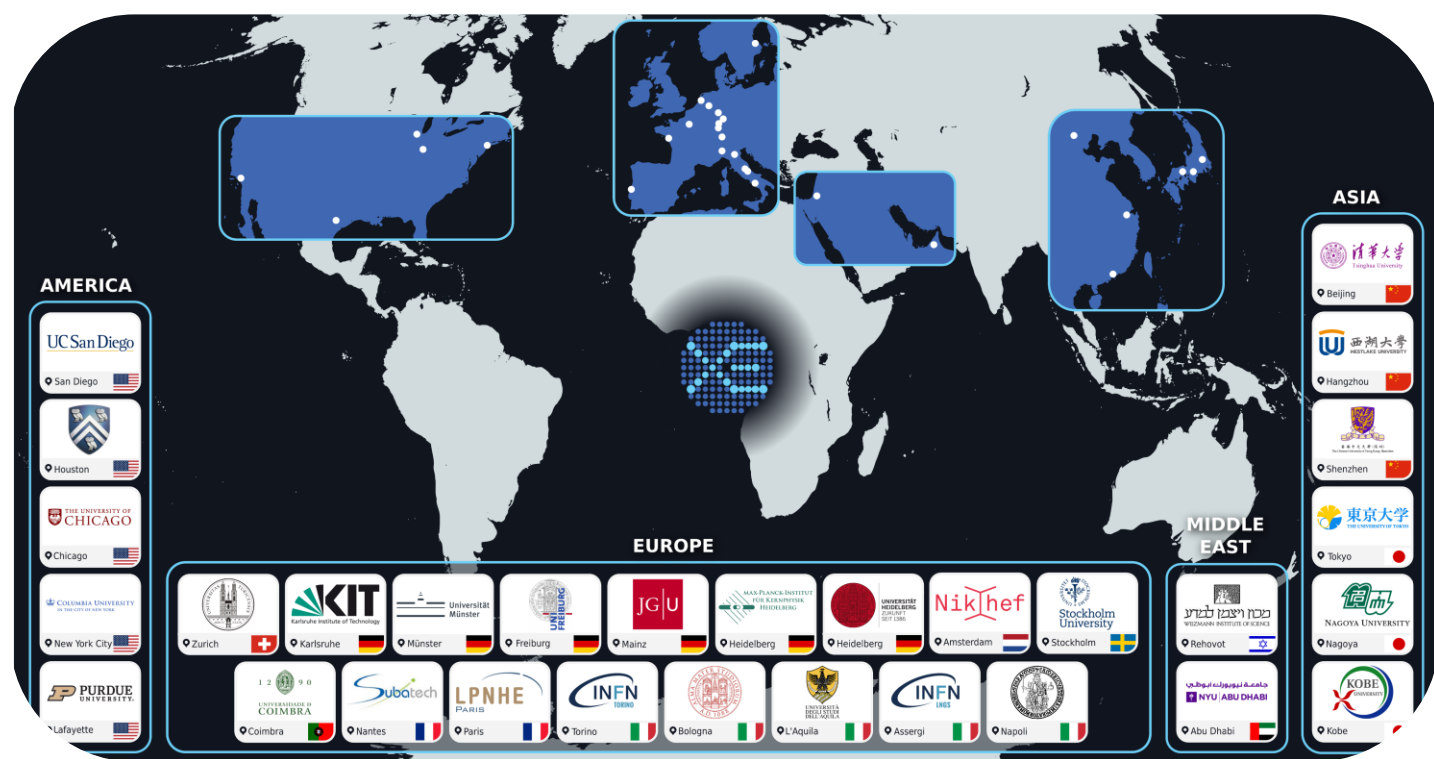
Kai Böse

MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK



The XENON Collaboration

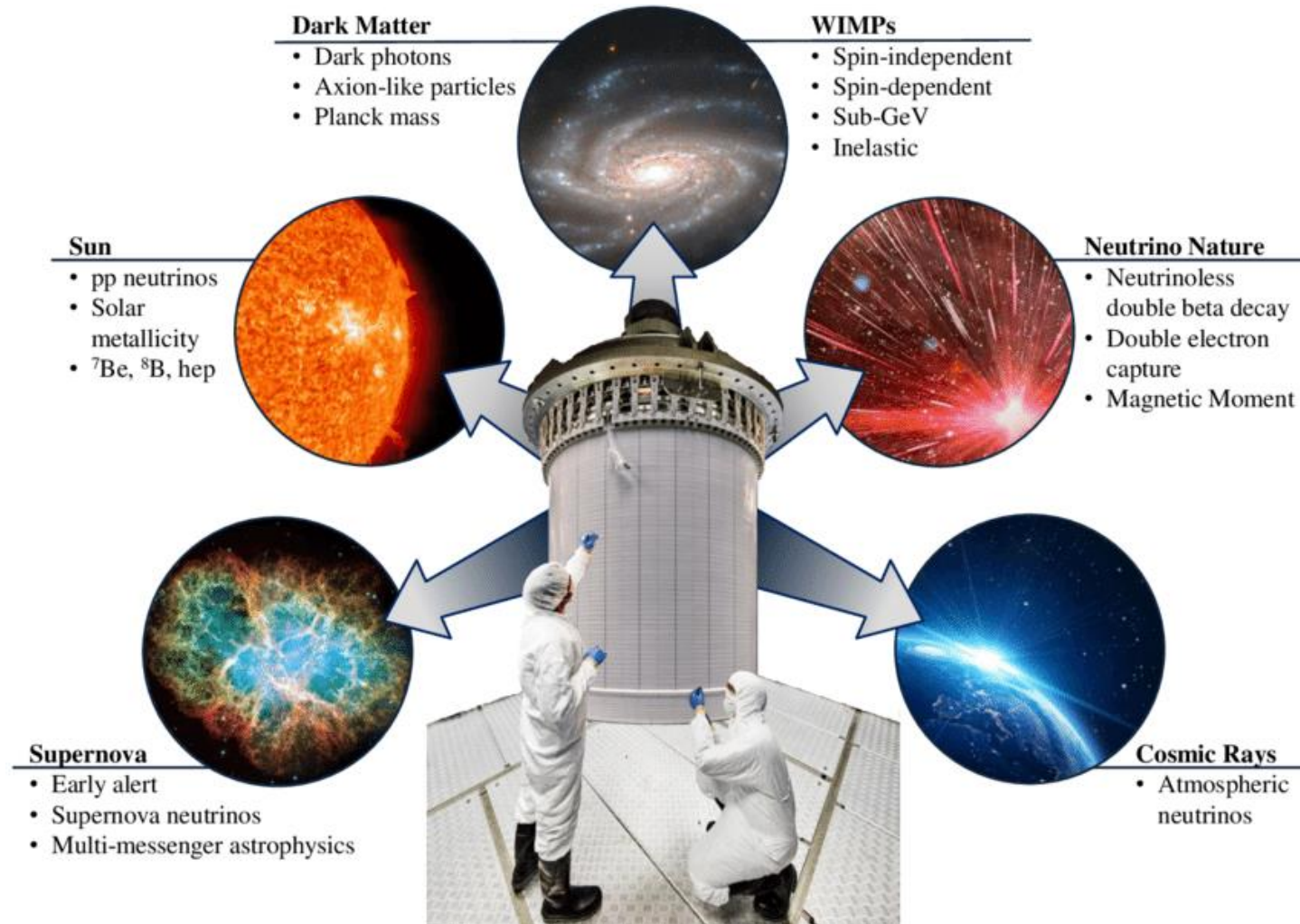
- 200+ people
- 12 countries
- 30 Institutes



Located at Gran Sasso, Italy (LNGS)

Among most sensitive direct DM experiments

Xenon Science



Main science channel: WIMPs

- Weakly Interacting Massive Particle
- Most sensitive to $\mathcal{O}(100 \text{ GeV})$
- Nuclear recoil energies $\lesssim 50 \text{ keV}$

Neutrino Physics

- (Neutrinoless) double weak decay
- **CEvNS** (coherent scattering)
- Solar neutrinos

Sensitive to other dark matter candidates

- Dark Photon
- Axion
- ...

XENONnT Detector

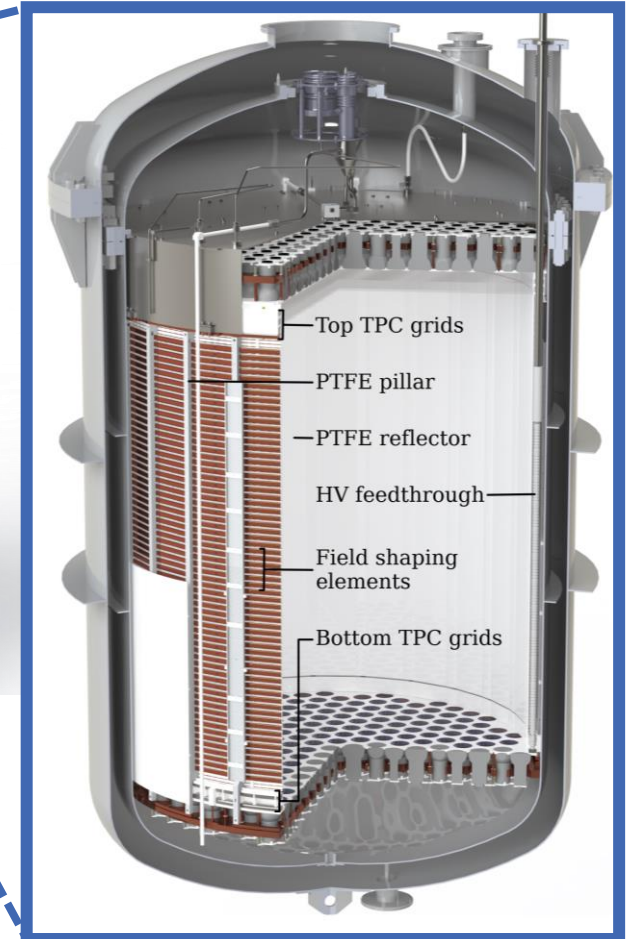
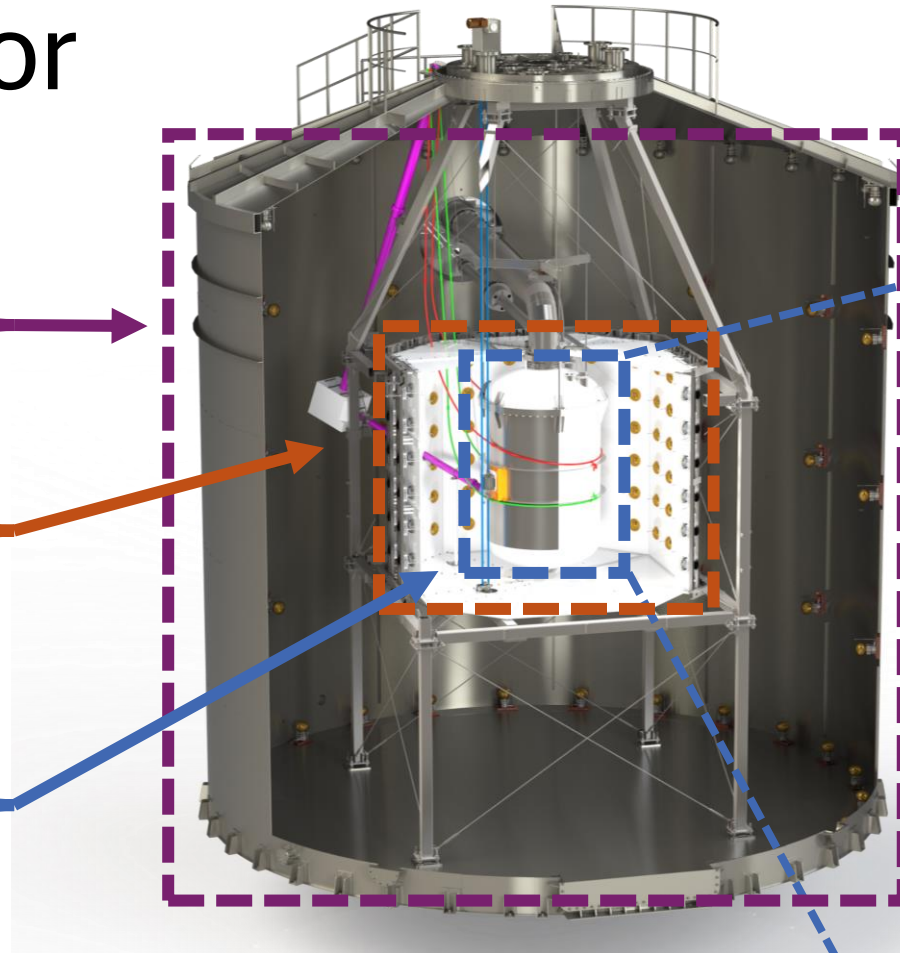
Muon Veto
(Water Cherenkov)

Neutron Veto
(Water Cherenkov)

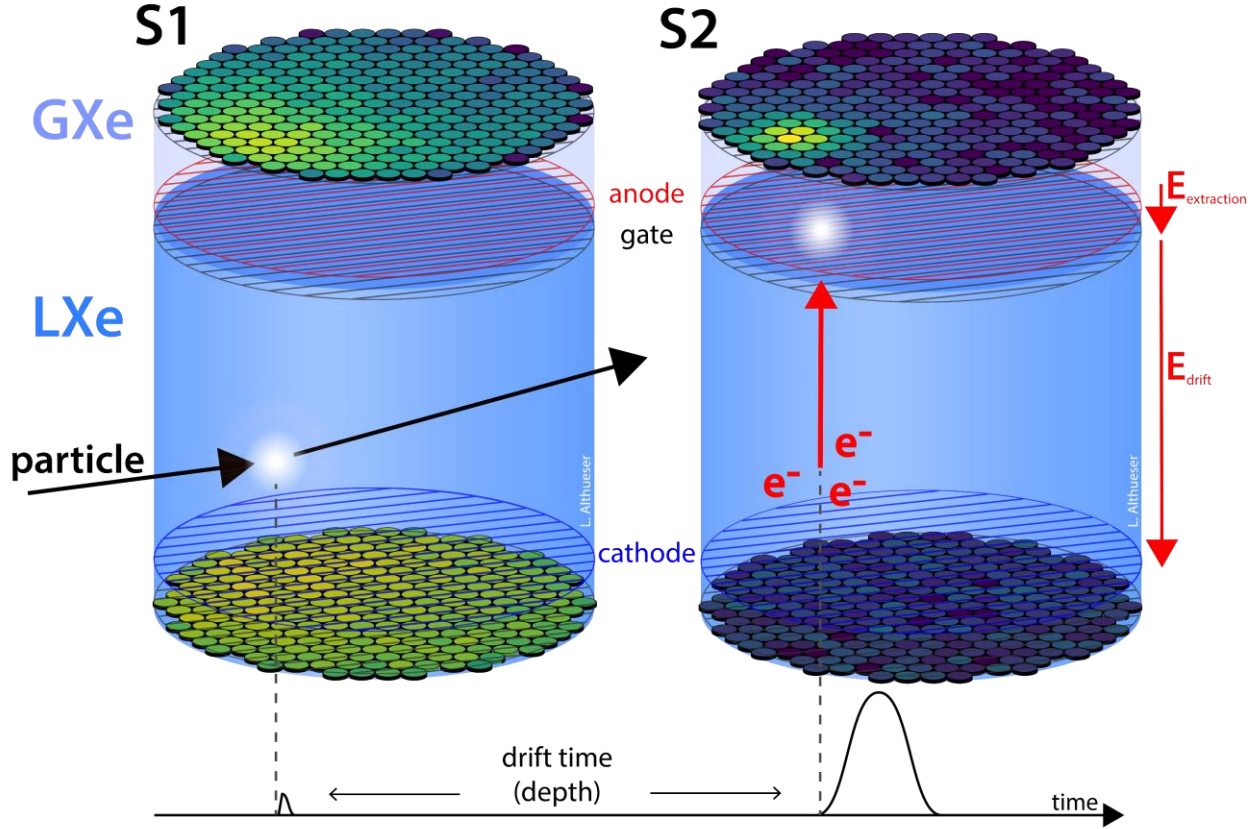
- Doped with gadolinium

Dual-phase xenon TPC

- 5.9 t Xe active target (8.6 total)
- 494 PMTs to measure UV signal
- 23 kV/cm electron drift-field



TPC Working Principle



Position

- X-Y by S2 pattern on PMTs
- Z by electron drift-time

Energy

Amount of light

$$E = W \cdot \left(\frac{S1}{g_1} + \frac{S2}{g_2} \right)$$

Interaction type

$$\left(\frac{S1}{S2} \right)_{NR} < \left(\frac{S1}{S2} \right)_{ER}$$

Nuclear Recoil (NR) & Electronic Recoil (ER)

S1

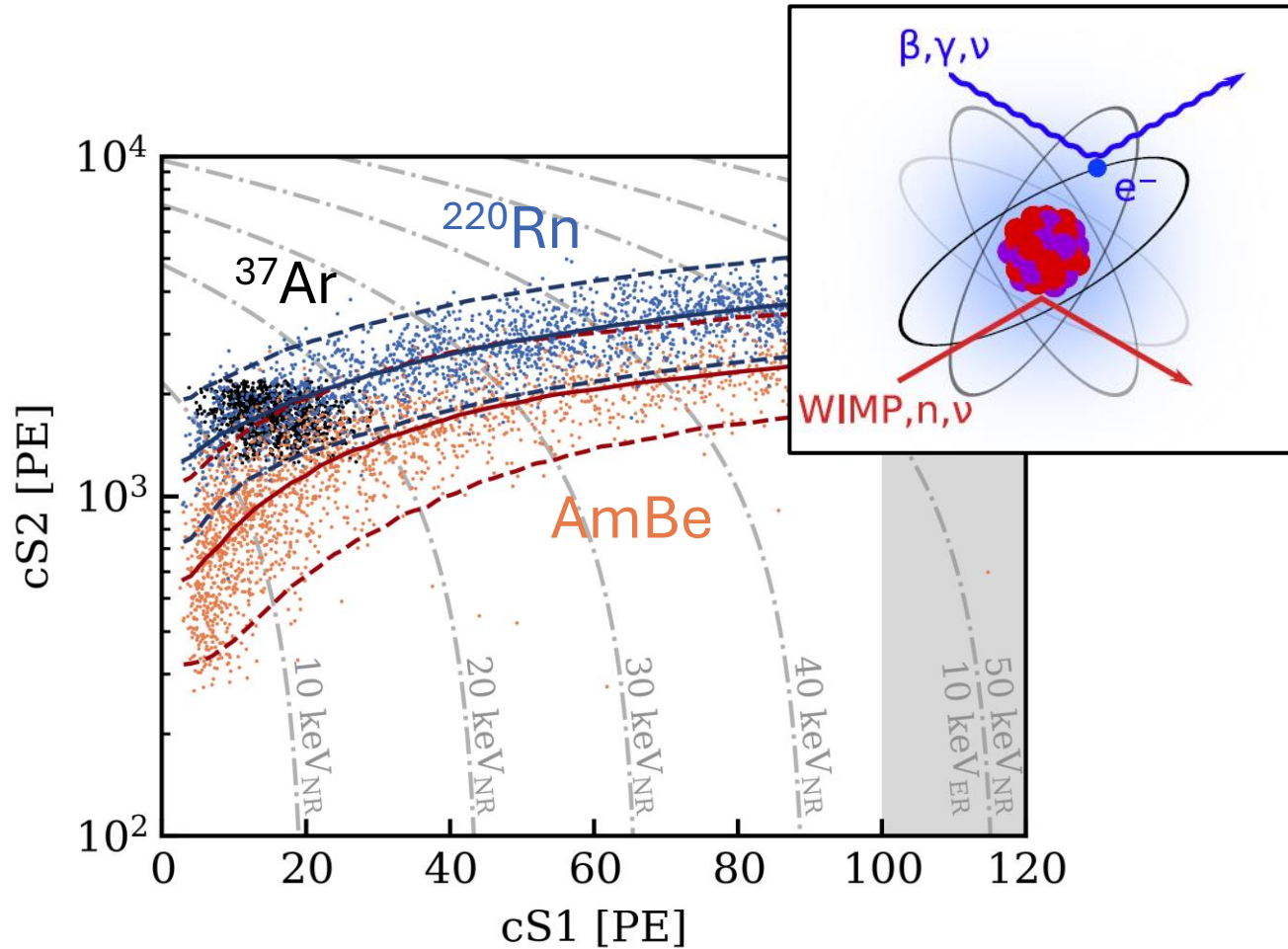
- Prompt scintillation light



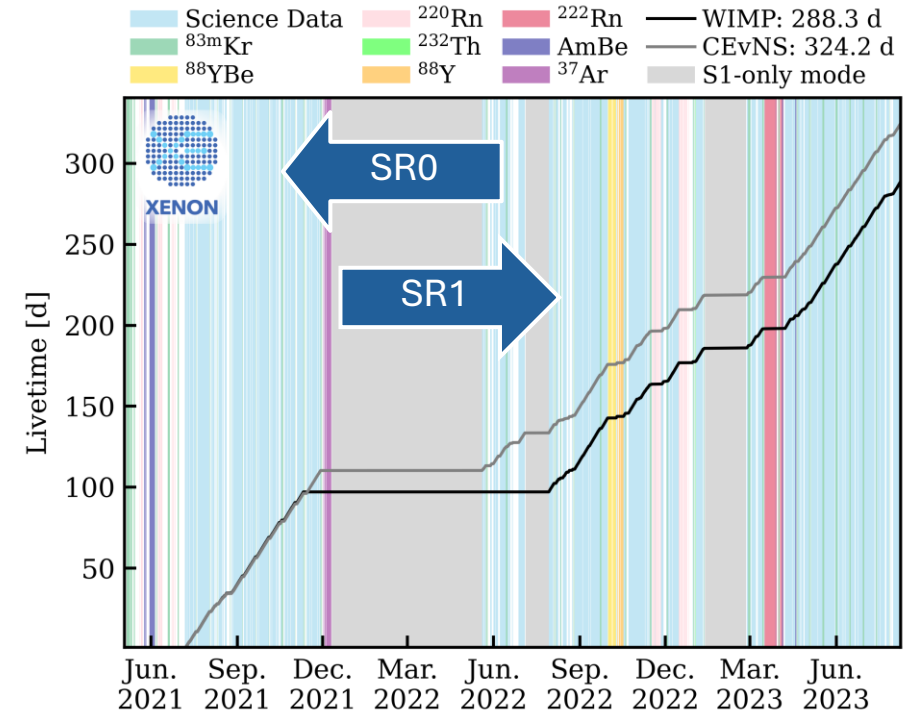
S2

- Delayed electron signal

Signals & Calibration



Phys. Rev. Lett. **131**, 041003 (2023)



Nuclear Recoils (NR)

- AmBe, YBe (low energy)

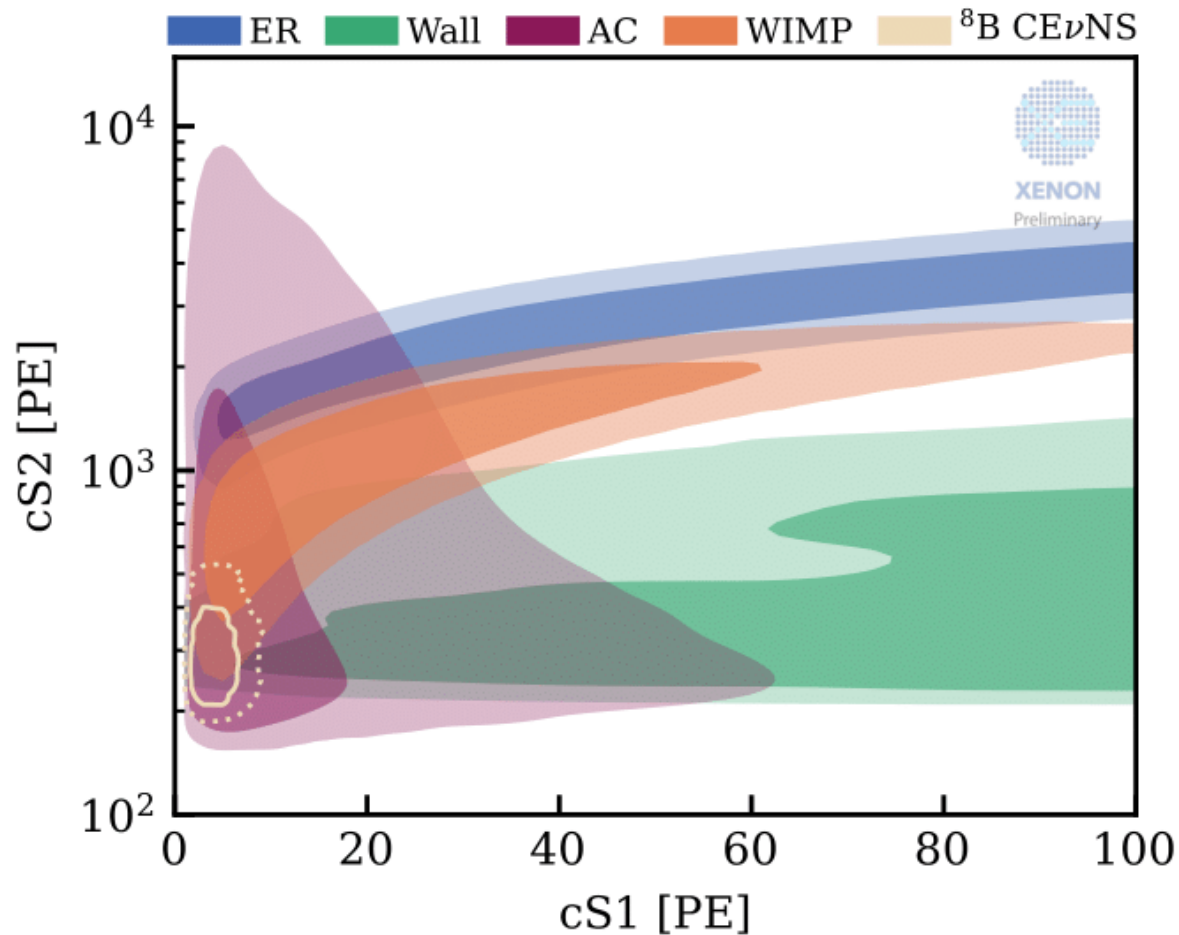
Electronic Recoils (ER)

- ^{220}Rn , ^{37}Ar (low energy)

Other

- LED, ^{83m}Kr , ^{232}Th , ...

WIMP Backgrounds – SR0



Electronic Recoils (ER)

- ^{214}Pb (from ^{226}Ra chain)
- ^{85}Kr (commercial xenon)

Surface

- PTFE walls collect long-lived ^{210}Pb (from ^{226}Ra chain)

Accidental Coincidences (AC)

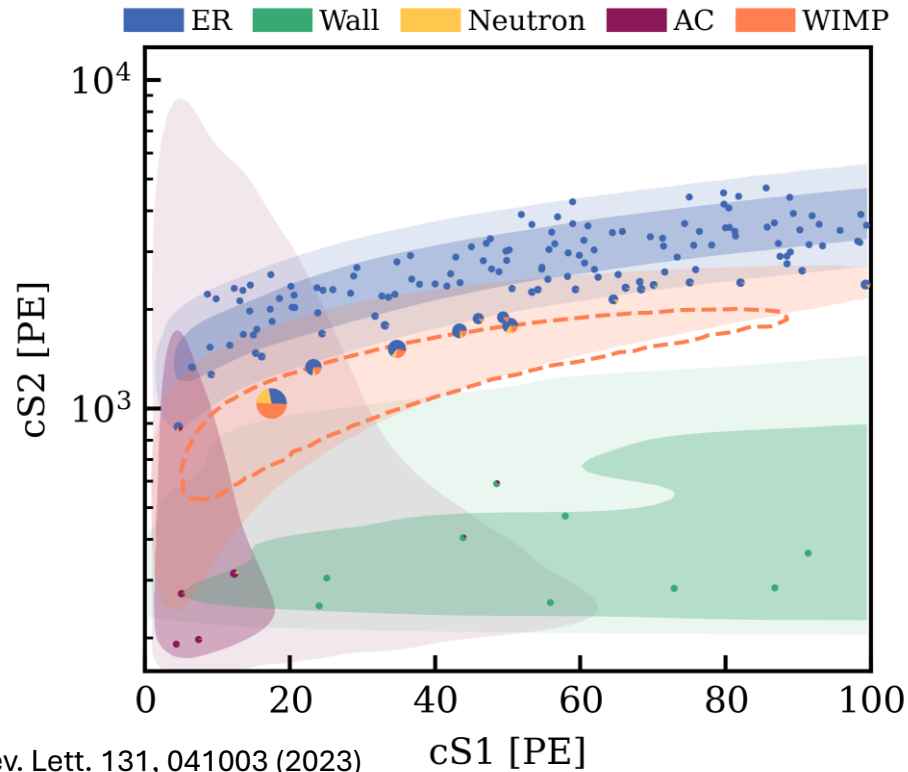
- Accidental pairing of isolated S1 & S2

Nuclear Recoils (NR)

- Radiogenic neutrons
- Neutrinos (solar, atmospheric)

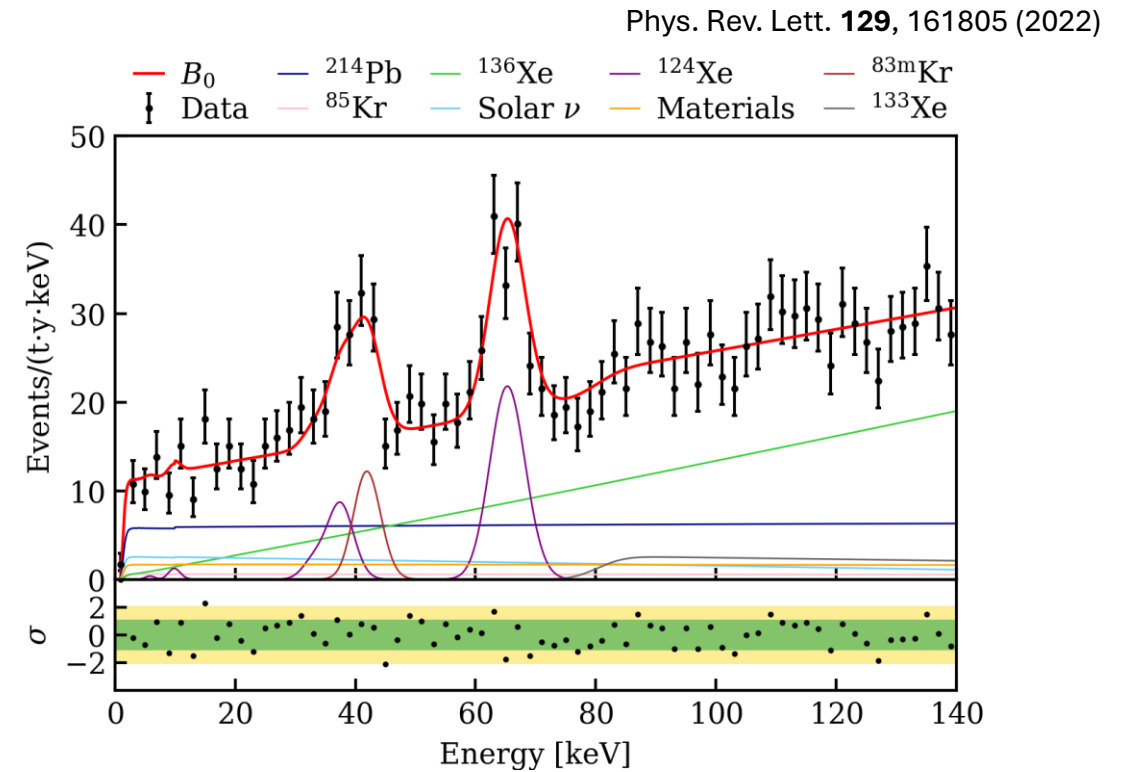
WIMP Backgrounds – SR0

	Nominal	Best fit
ER	134	135^{+12}_{-11}
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.4
CE ν NS	0.23 ± 0.06	0.23 ± 0.06
AC	4.3 ± 0.9	$4.4^{+0.9}_{-0.8}$
Surface	14 ± 3	12 ± 2
Total background	154	152 ± 12
WIMP	...	2.6
Observed	...	152



Phys. Rev. Lett. 131, 041003 (2023)

2 June 2025



SR0 low ER Search

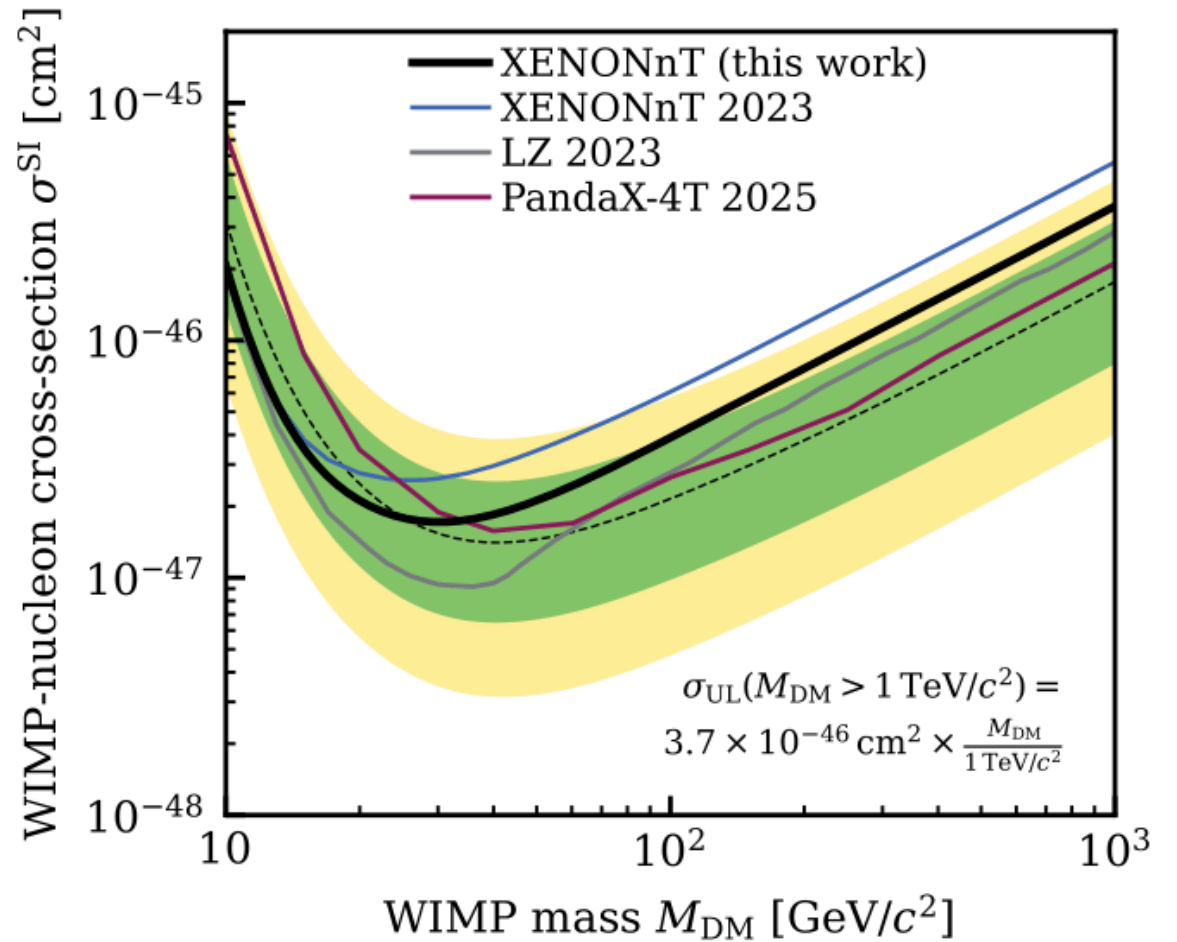
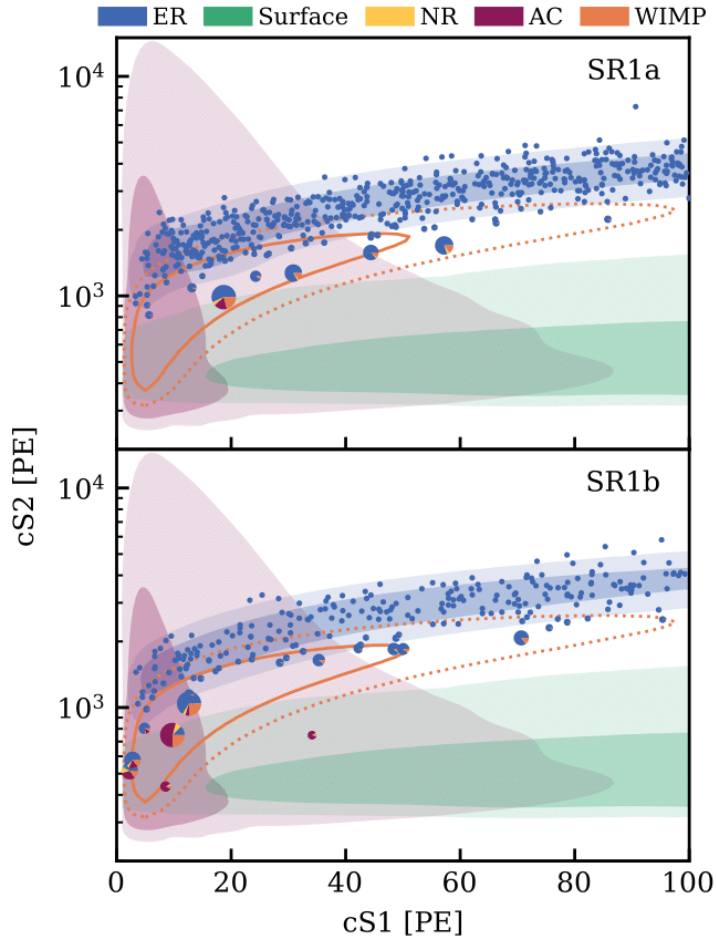
Lowest ER background in direct detection DM searches (in ROI)

Kai Boese - DM 2025

8

WIMP Search arXiv:2502.18005

- SR0 & SR1

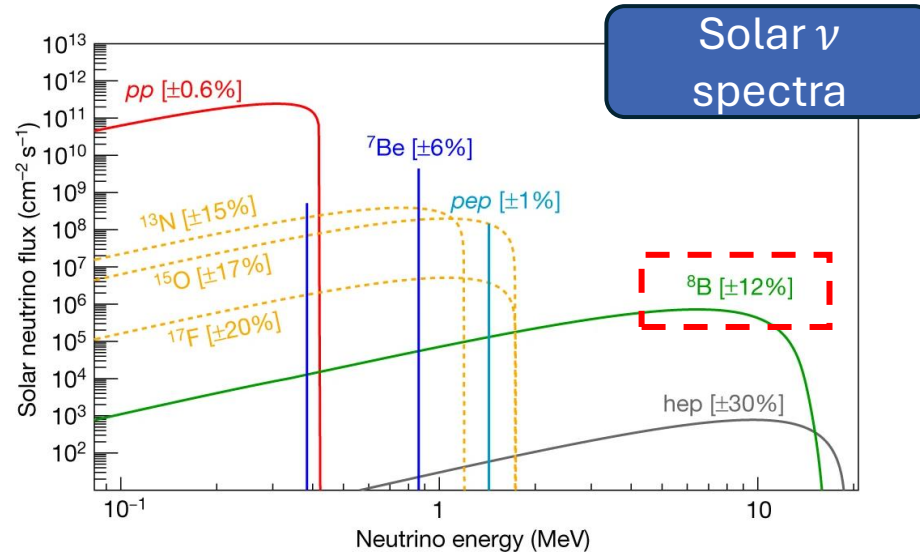


3.1 ton x year exposure

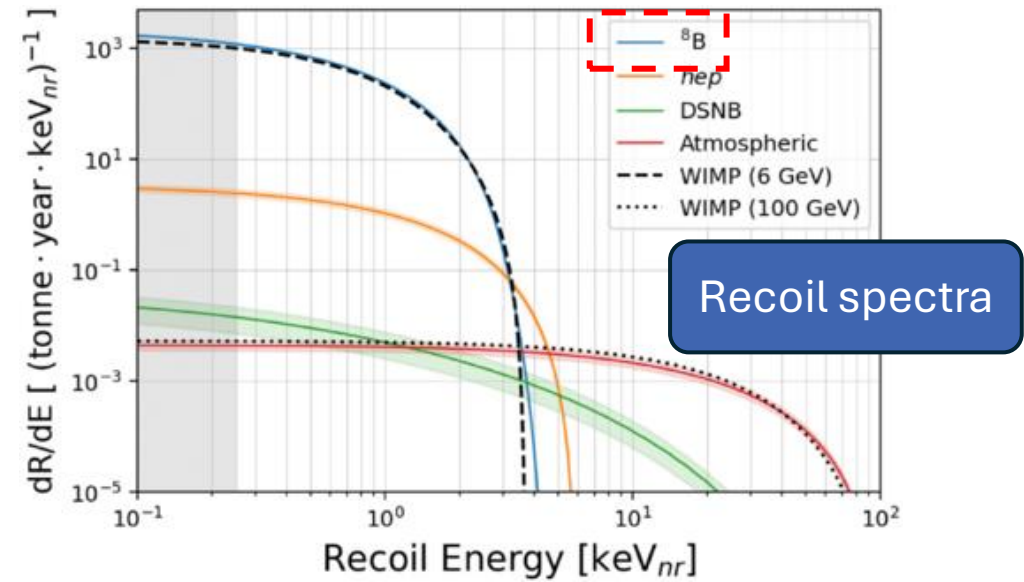
Improved SR0-only sensitivity by factor 1.8

CEvNS

Nature 562, 505–510 (2018)



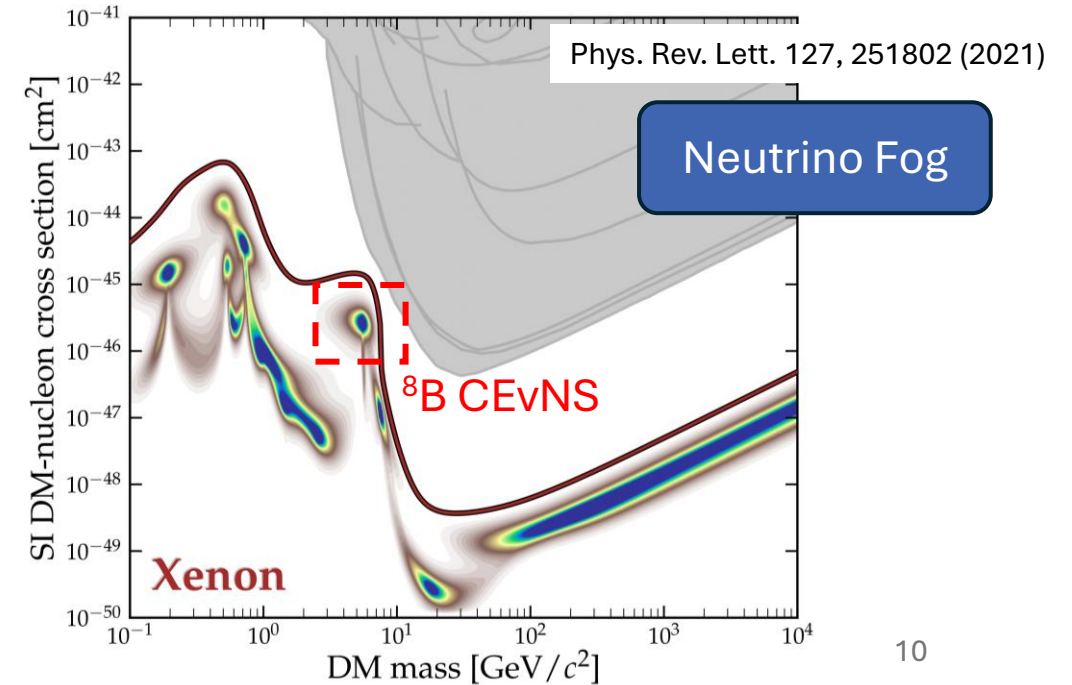
Phys. Rev. D 108, 022007 (2023)



- Coherent Elastic neutrino-Nucleus Scattering (CEvNS):

$$\lambda_\nu \sim \text{nucleus}$$

- 6 GeV WIMP has similar recoil spectrum to ^8B CEvNS \rightarrow “Neutrino Fog”
- Special calibration with 152 keV neutrons from ^{88}YBe



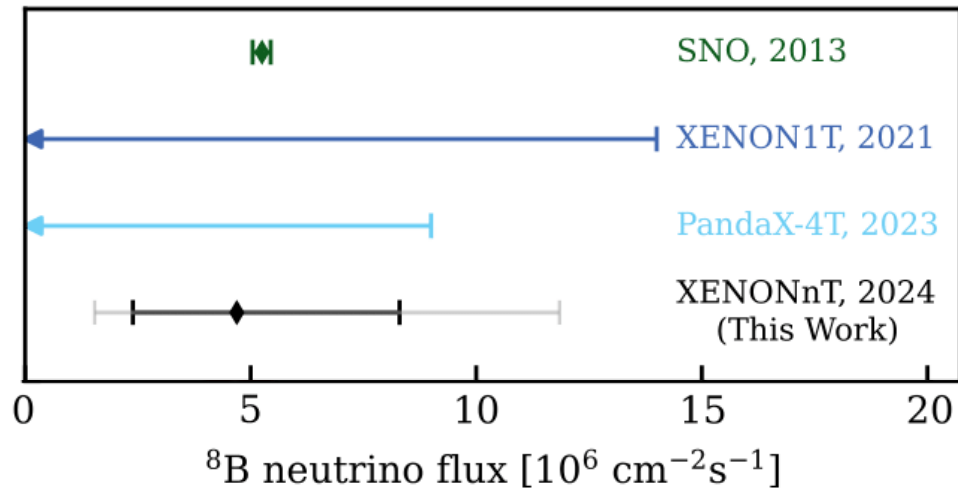
CEvNS Results

Component	Expectation	Best fit
Total background	$26.4^{+1.4}_{-1.3}$	26.3 ± 1.4
^8B	$11.9^{+4.5}_{-4.2}$	$10.7^{+3.7}_{-4.2}$
Observed		37

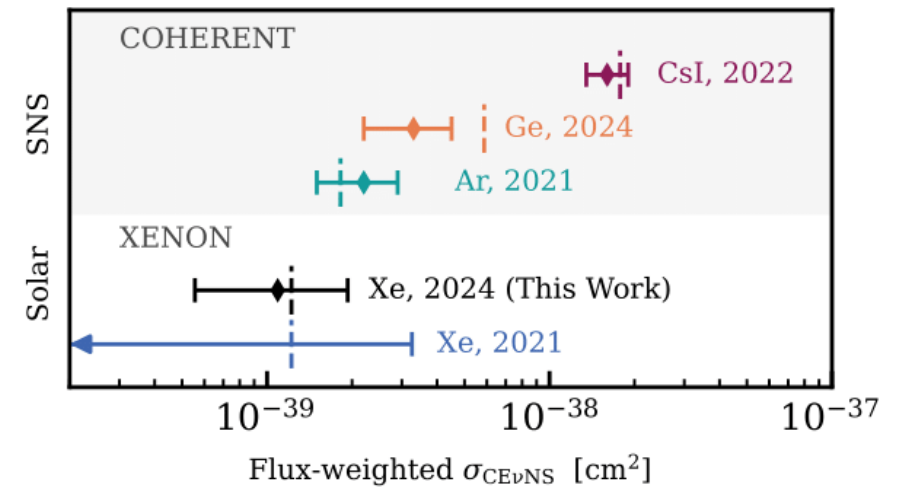
2.7 σ measurement of solar CEvNS

- **11 events** observed above background, 37 in total, consistent with expectations
- Complements COHERENT (spallation source) and CONUS+ (reactor source)

Fix σ to theory \rightarrow determine flux:
compatible with SNO measurements



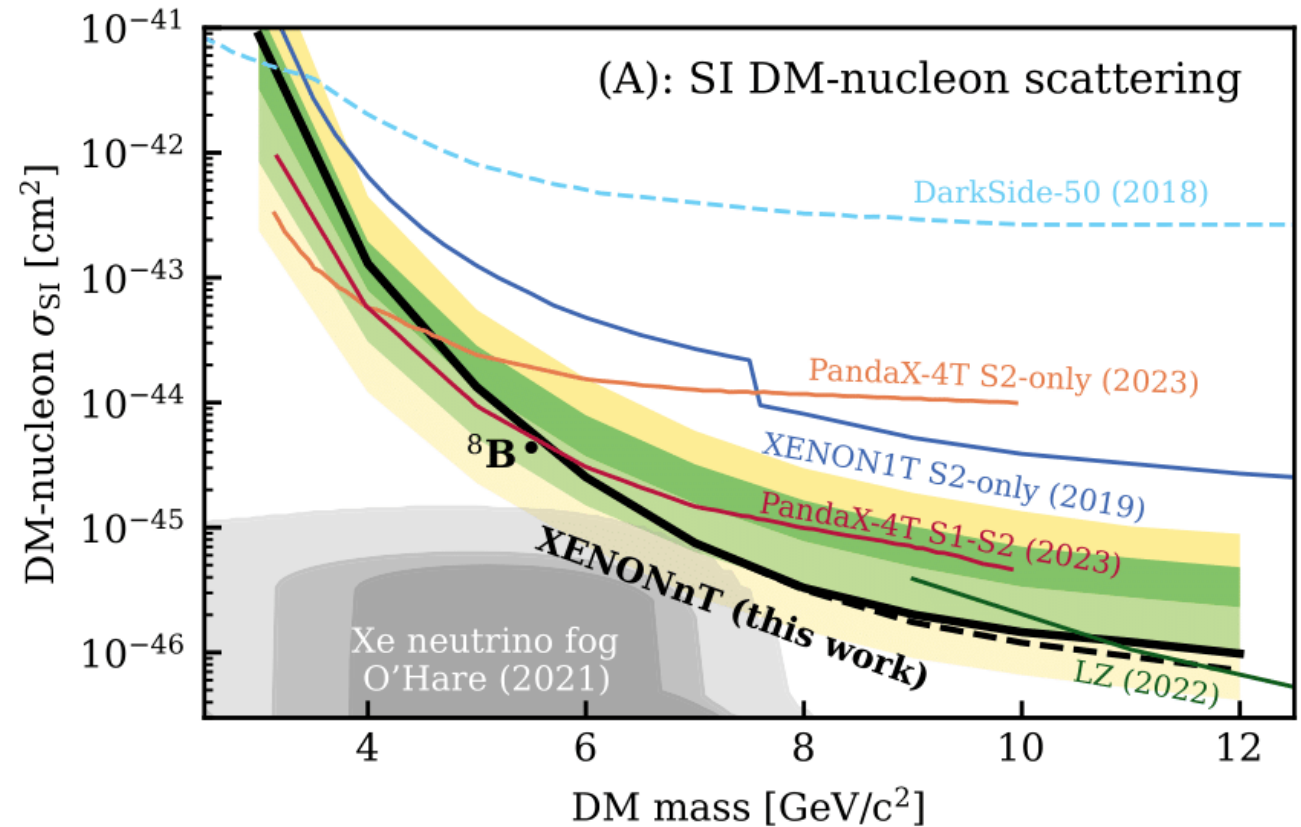
Fix flux to measurements \rightarrow determine σ :
compatible with expectations



Light Dark Matter in the Neutrino Fog

DM sensitivity approaches the “neutrino fog”

- 37 events observed
- CE ν NS as background
- No excess found
→ New parameter-space excluded



Component	^8B -only	4 GeV/c ²	6 GeV/c ²	10 GeV/c ²
SI DM	–	3.2	0.0	0.0
^8B CE ν NS	11.4 ^{+2.0} _{-3.6}	10.2 ± 2.7	11.4 ^{+2.7} _{-2.6}	11.4 ^{+2.7} _{-2.6}
Total background	37.7 ^{+2.5} _{-3.9}	36.4 ^{+3.0} _{-3.0}	37.7 ^{+3.0} _{-2.9}	37.7 ^{+3.0} _{-2.9}
Observed	37	37	37	37

Summary

- SR0+SR1 WIMP Results [arXiv:2502.18005](https://arxiv.org/abs/2502.18005)
- First solar CEvNS measurement [Phys. Rev. Lett. 133, 191002 \(2024\)](https://doi.org/10.1103/PhysRevLett.133.191002)
- Neutrino fog light DM search [Phys. Rev. Lett. 133, 191002 \(2024\)](https://doi.org/10.1103/PhysRevLett.133.191002)

Outlook

- SR2 now concluded
- More neutrino physics to come
- S2-only just published (e.g. dark photons limits)
[Phys. Rev. Lett. 134, 161004 \(2025\)](https://doi.org/10.1103/PhysRevLett.134.161004)

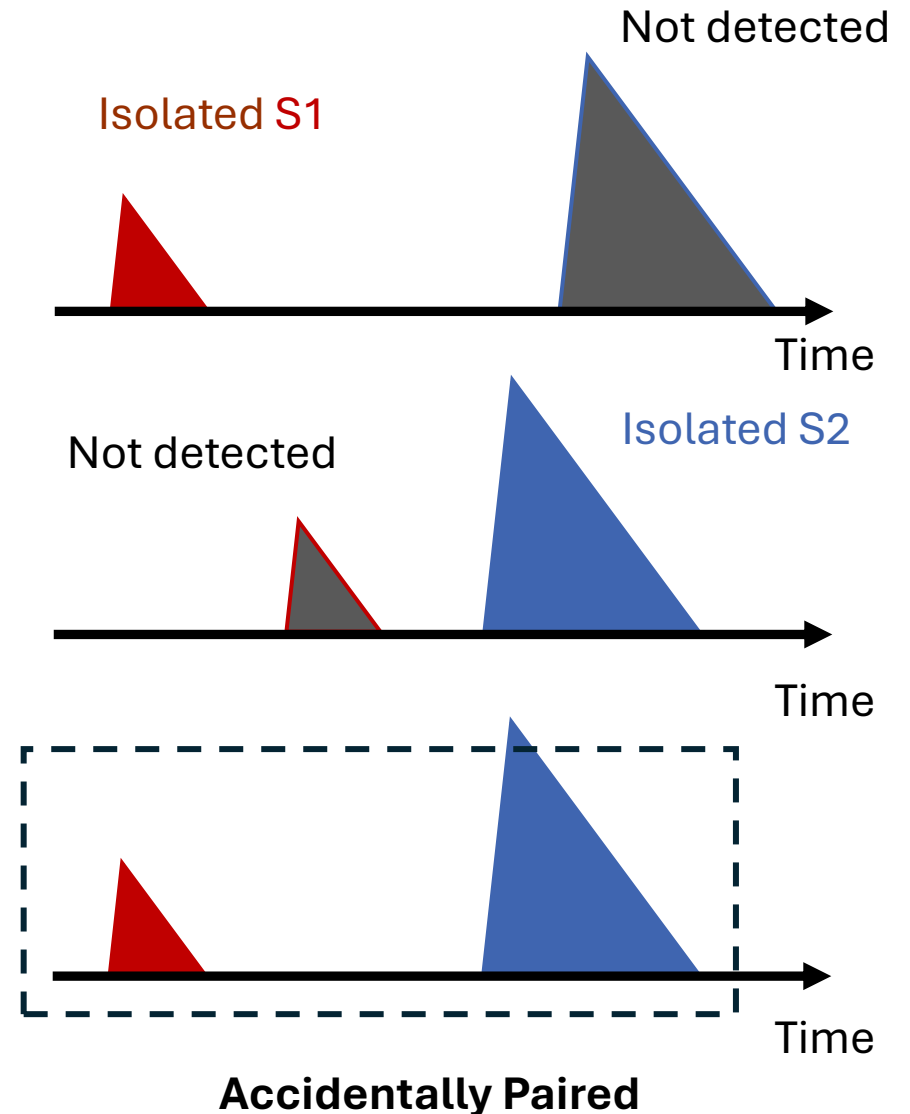
Thank You!



Backup

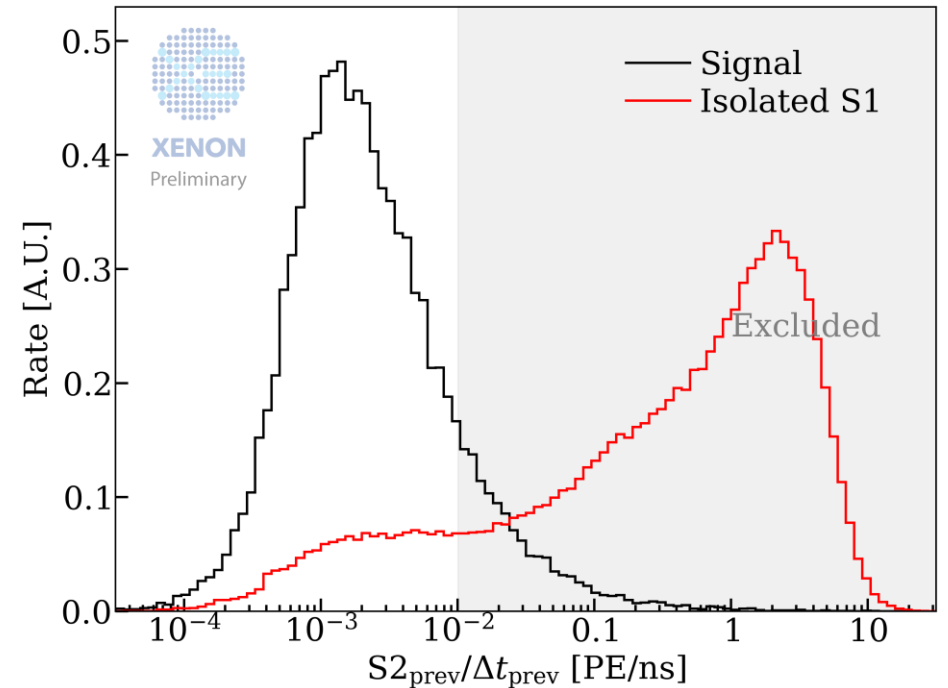
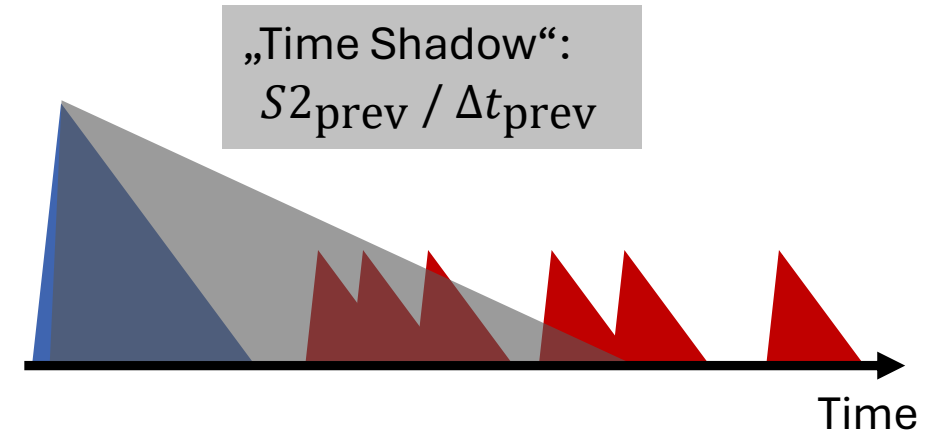
Accidental Coincidences

- Dominant Background at low energies
- Isolated S1 & S2 paired just by chance
- Raw AC rate: ~400 per day
 - “Isolated” S1: ~15 Hz
 - “Isolated” S2: ~0.15 Hz
- Data driven model: Validated by sideband unblinding and measurement of light yield of ^{37}Ar L-shell EC



Accidental Coincidences

- Isolated S1 often follow large S2
- Define “Time Shadow” as additional variable
 $S2_{\text{prev}} / \Delta t_{\text{prev}}$
- Isolated S1 closer to larger S2 are excluded/disfavored

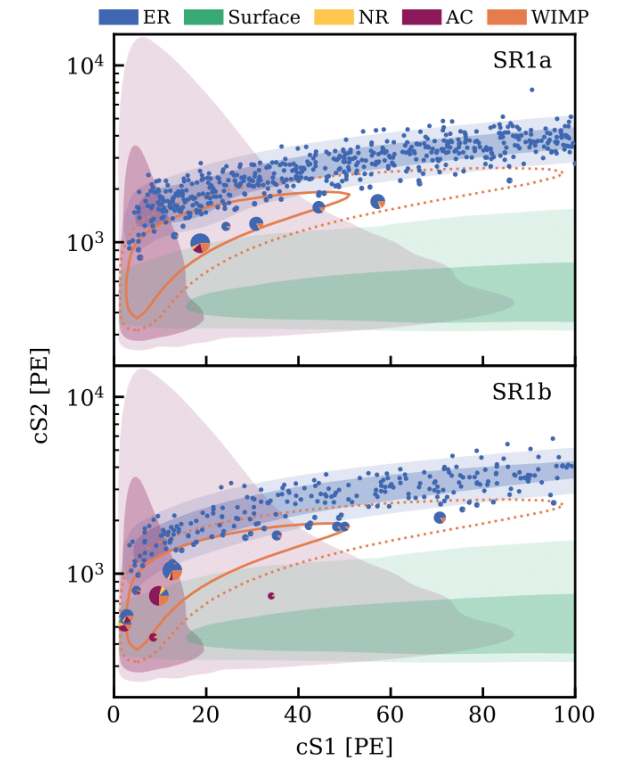


SR1 Backgrounds

$$\mathcal{L}(\sigma, \theta) = \prod_{\text{SR} \in \{\text{SR0}, \text{SR1a}, \text{SR1b}\}} \mathcal{L}_{\text{SR}}(\sigma, \theta)$$

$$\mathcal{L}_{\text{SR}}(\sigma, \theta) = \mathcal{L}_{\text{SR}}^{\text{far-wire}}(\sigma, \theta) \times \mathcal{L}_{\text{SR}}^{\text{near-wire}}(\sigma, \theta) \times \mathcal{L}_{\text{SR}}^{\text{anc}}(\theta)$$

	SR0		SR1a		SR1b	
	Nominal	Best fit	Nominal	Best fit	Nominal	Best fit
ER (flat)	134	136 ± 12	430 ± 30	450 ± 20	151 ± 11	154 ± 10
ER (^3H -like)	–	–	62	40 ± 30	101	80^{+18}_{-17}
ER (^{37}Ar)	–	–	58 ± 6	55 ± 5	–	–
Neutron	0.7 ± 0.3	0.6 ± 0.3	0.47 ± 0.19	0.45 ± 0.19	0.7 ± 0.3	0.7 ± 0.3
CE ν NS (solar)	0.16 ± 0.05	0.16 ± 0.05	0.010 ± 0.003	0.010 ± 0.003	0.019 ± 0.006	0.019 ± 0.006
CE ν NS (atm.+DSNB)	0.04 ± 0.02	0.04 ± 0.02	0.024 ± 0.012	0.024 ± 0.012	0.05 ± 0.02	0.05 ± 0.02
AC	4.3 ± 0.9	$4.4^{+0.9}_{-0.8}$	2.12 ± 0.18	2.10 ± 0.18	3.8 ± 0.3	3.8 ± 0.3
Surface	13 ± 3	11 ± 2	0.43 ± 0.05	0.42 ± 0.05	0.77 ± 0.09	0.76 ± 0.09
Total background	152	152 ± 12	553	550 ± 20	257	239 ± 15
WIMP (200 GeV/ c^2)	–	1.8	–	1.1	–	2.1
Observed	152		560		245	

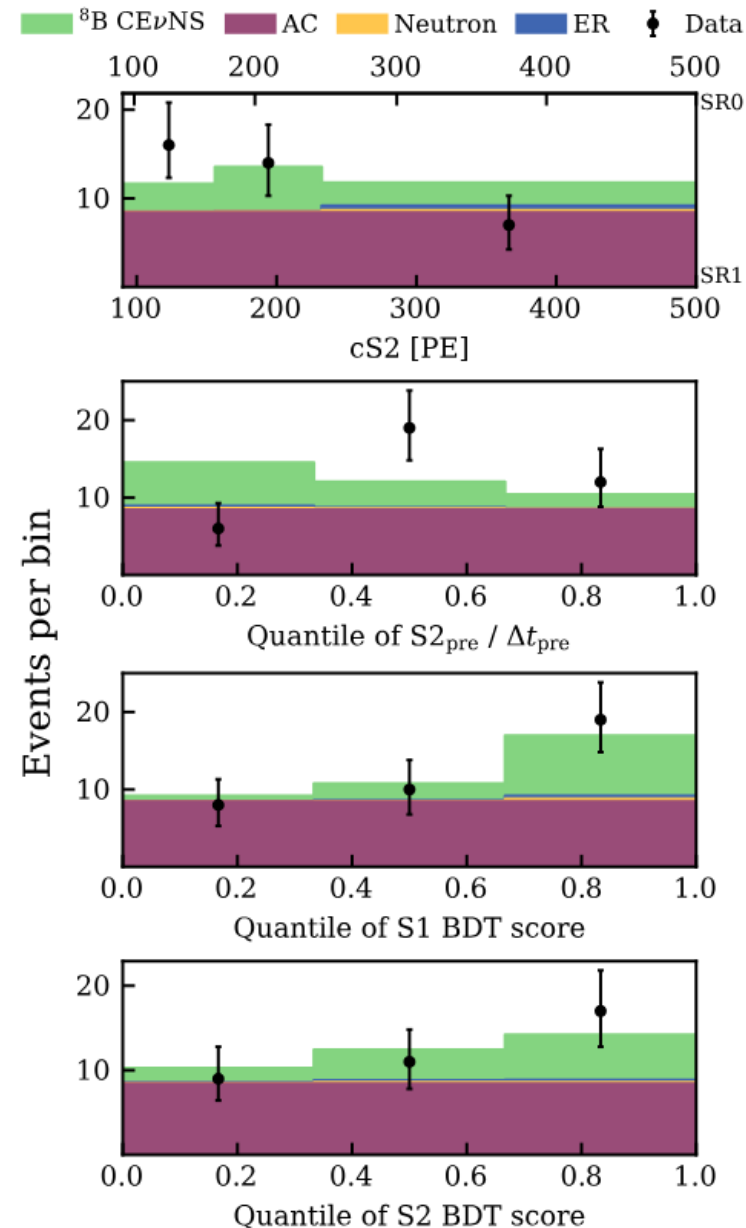
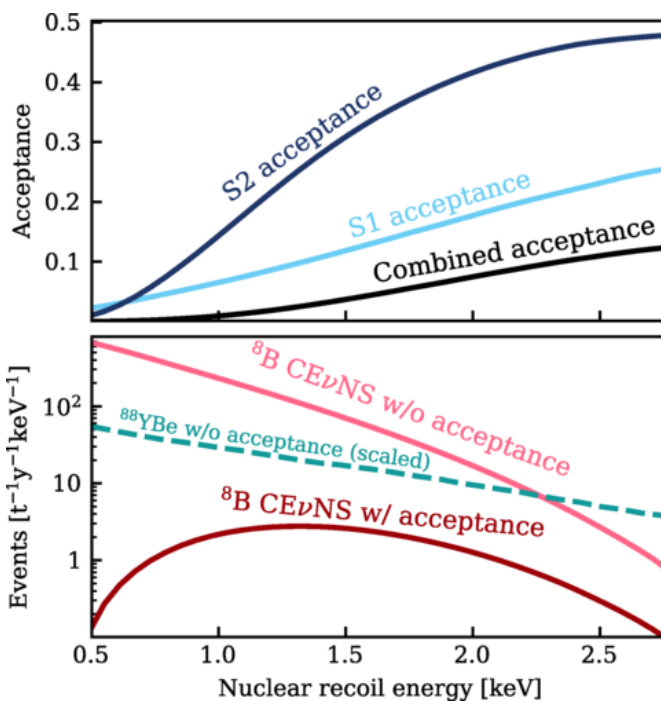


CEvNS Analysis

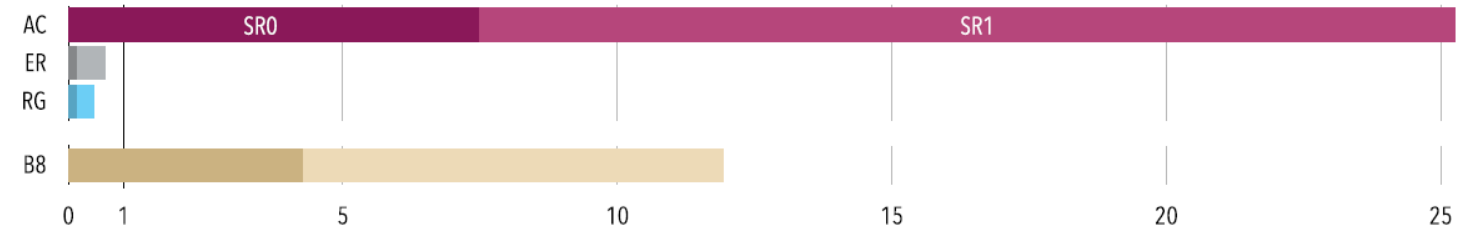
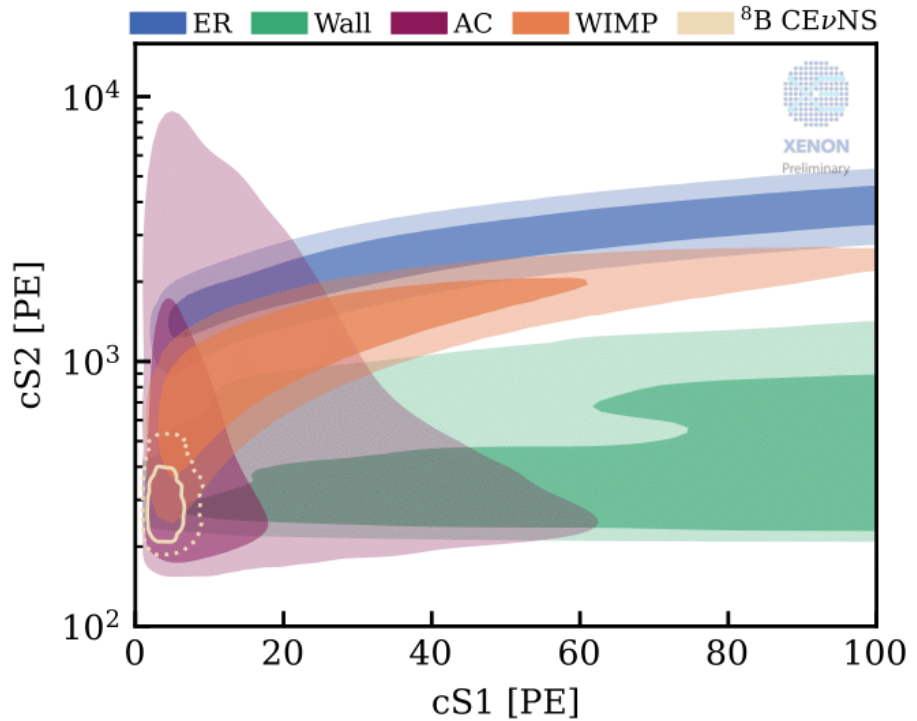
$$\mathcal{L}(\mu, \vec{\theta}) = \prod_{i=0,1} \mathcal{L}_i(\mu, \vec{\theta}) \times \prod_m \mathcal{L}_m(\theta_m)$$

μ : ^8B -flux Φ or σ_{CEvNS} , i : two science runs,
 Θ : nuisance parameters, m : nuisance terms

- Require three or two hits for S1 signals
- (120, 500) PE for S2 signals
- Differentiate AC & Signal via time-shadow and Boosted Decision Trees (BDTs)



CEvNS Background



Electronic recoils (ER)

- Flat spectrum from 0 to 10 keV
- Response of LXe to low energy ERs uncertain. Assign a conservative 100% uncertainty

Surface background

- Reduced to negligible levels by spatial selection (fiducial volume)
- Not included in the likelihood

Radiogenic neutrons (RG)

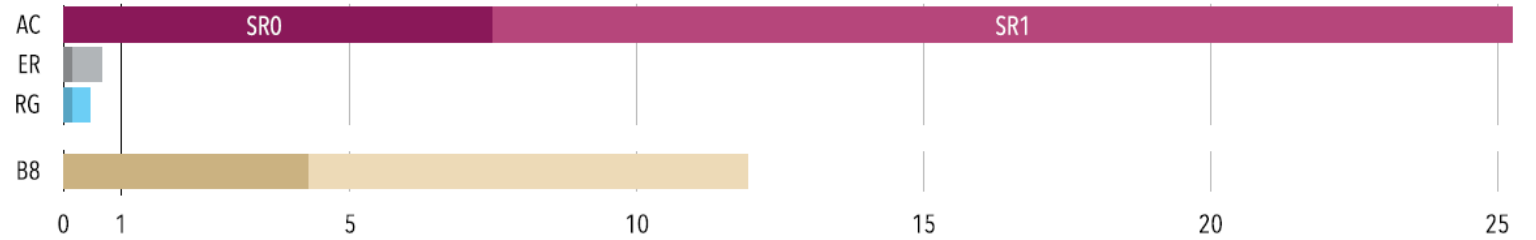
- 58% uncertainty from side band of neutron veto tagged events

⁸B neutrino signal

- 35% uncertainty from detection efficiency and signal yield in LXe.
- Flux is kept as a free parameter

Component	Expectation	Best fit
AC (SR0)	7.5 ± 0.7	7.4 ± 0.7
AC (SR1)	17.8 ± 1.0	17.9 ± 1.0
ER	0.7 ± 0.7	$0.5^{+0.7}_{-0.6}$
Neutron	$0.5^{+0.2}_{-0.3}$	0.5 ± 0.3
Total background	$26.4^{+1.4}_{-1.3}$	26.3 ± 1.4
⁸ B	$11.9^{+4.5}_{-4.2}$	$10.7^{+3.7}_{-4.2}$
Observed		37

CEvNS Background



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- Flat spectrum from 0 to 10 keV
- Response of LXe to low energy ERs uncertain. Assign a conservative 100% uncertainty

Surface background

- Reduced to negligible levels by spatial selection (fiducial volume)
- Not included in the likelihood

Radiogenic neutrons (RG)

- 58% uncertainty from side band of neutron veto tagged events

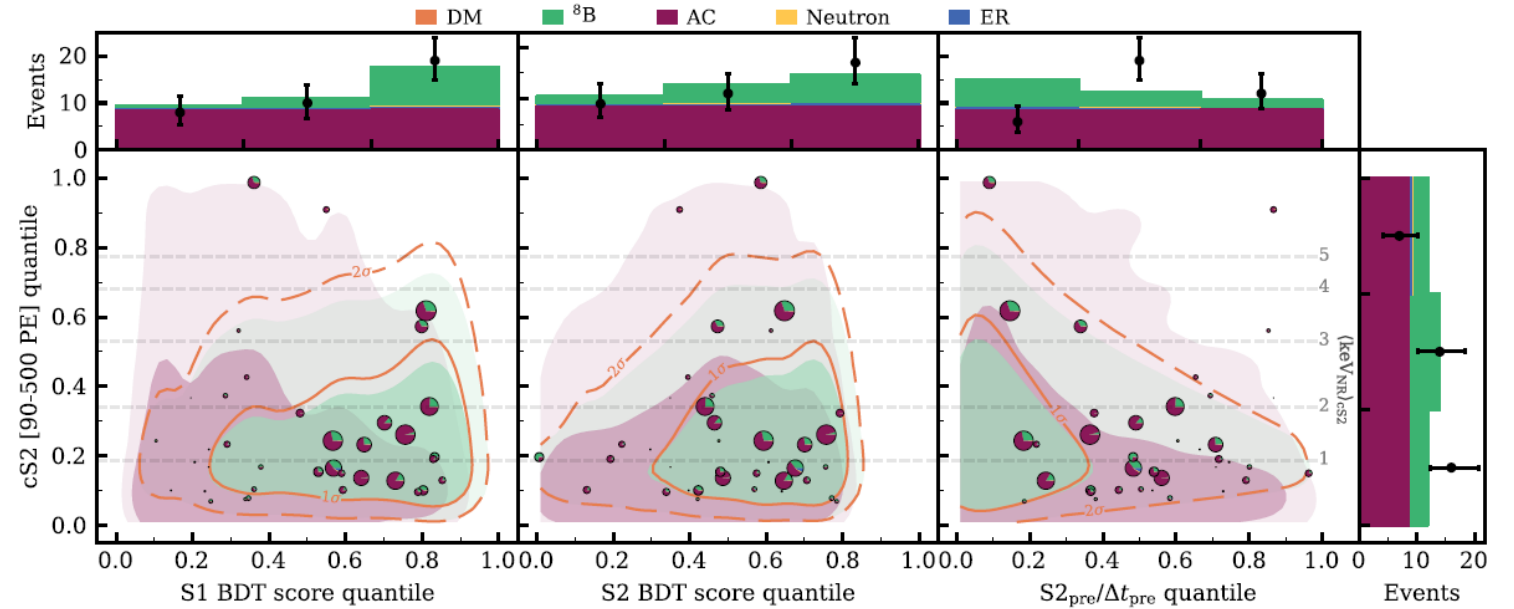
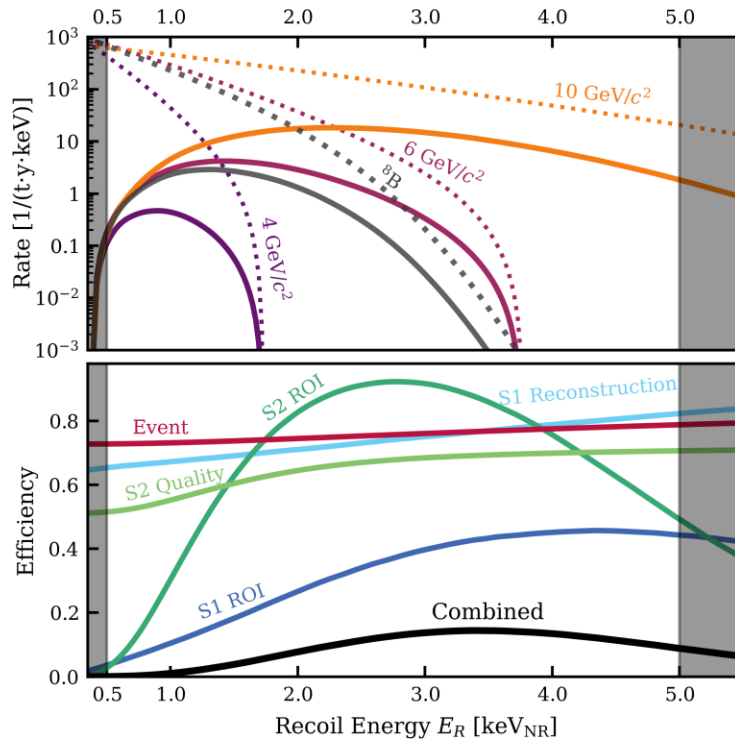
^8B neutrino signal

- 35% uncertainty from detection efficiency and signal yield in LXe.
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Component	Expectation	Best fit
AC (SR0)	7.5 ± 0.7	7.4 ± 0.7
AC (SR1)	17.8 ± 1.0	17.9 ± 1.0
ER	0.7 ± 0.7	$0.5^{+0.7}_{-0.6}$
Neutron	$0.5^{+0.2}_{-0.3}$	0.5 ± 0.3
Total background	$26.4^{+1.4}_{-1.3}$	26.3 ± 1.4
^8B	$11.9^{+4.5}_{-4.2}$	$10.7^{+3.7}_{-4.2}$
Observed	37	

Neutrino Fog – Analysis

Component	Expectation	Background only	4 GeV/c ²	6 GeV/c ²	10 GeV/c ²
SI-DM	3.2	(1.6)	0.0
⁸ B CELNS	11.9 ^{+4.5} _{-4.2}	11.4 ^{+2.0} _{-3.6}	10.2 ± 2.7	(2.5 ± 0.7)	11.4 ^{+2.7} _{-2.6}
AC	25.3 ± 1.2	25.3 ^{+1.1} _{-1.3}	25.1 ± 1.2	(3.7 ± 0.1)	25.3 ± 1.2
ER	0.7 ± 0.7	0.5 ^{+0.7} _{-0.6}	0.6 ^{+0.7} _{-0.6}	(0.0 ± 0.0)	0.5 ^{+0.6} _{-0.5}
Neutron	0.5 ^{+0.2} _{-0.3}	0.5 ± 0.3	0.5 ± 0.3	(0.1 ± 0.1)	0.5 ± 0.3
Total background	38.3 ^{+4.7} _{-4.4}	37.7 ^{+2.5} _{-3.9}	36.4 ^{+3.0} _{-3.0}	(6.3 ^{+0.7} _{-0.7})	37.7 ^{+3.0} _{-2.9}
Observed	...	37	37	(10)	37



$$\mathcal{L}(\sigma, \theta) = \mathcal{L}_{\text{SR0}}(\sigma, \theta) \times \mathcal{L}_{\text{SR1}}(\sigma, \theta) \times \prod_m \mathcal{L}_m^{\text{anc}}(\theta_m)$$