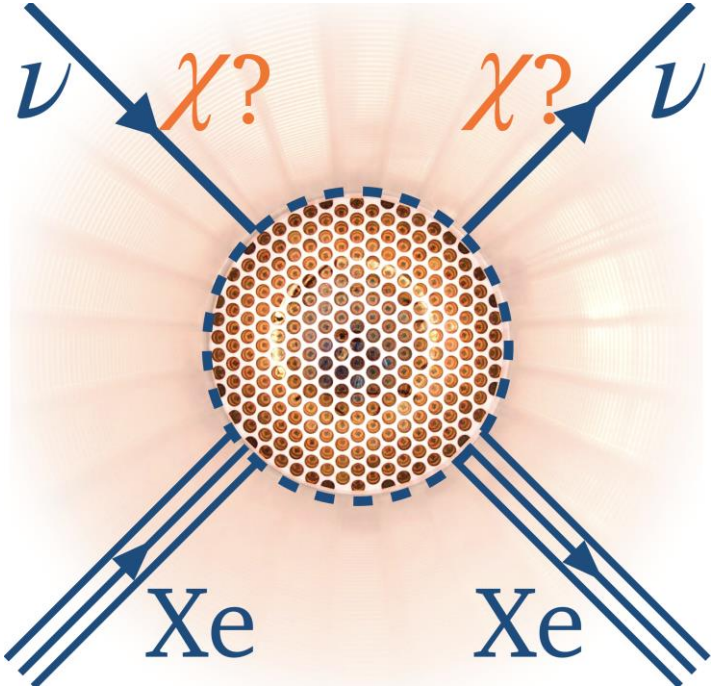
Probing Solar ^{8}B Neutrinos and Light Dark Matter with XENONnT

Shengchao Li
Westlake University
on behalf of XENON collaboration



XENON Westlake University | DM and neutrino lab

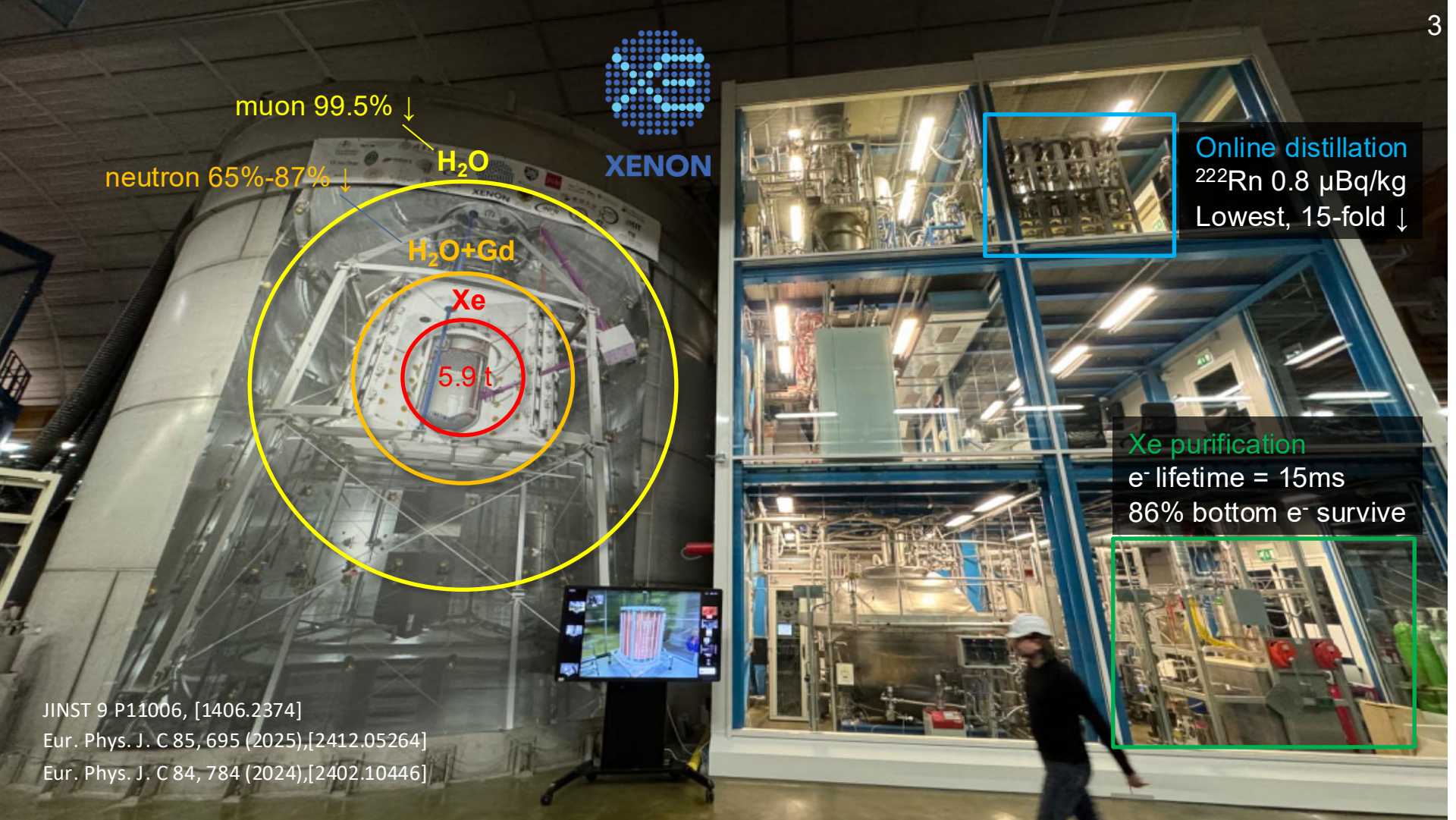
NPhiS, Nanjing
2026.5.17

PRL 133, 191002 (2024)
PRL 134, 111802 (2025)
2412.10451
2604.06002

XENON

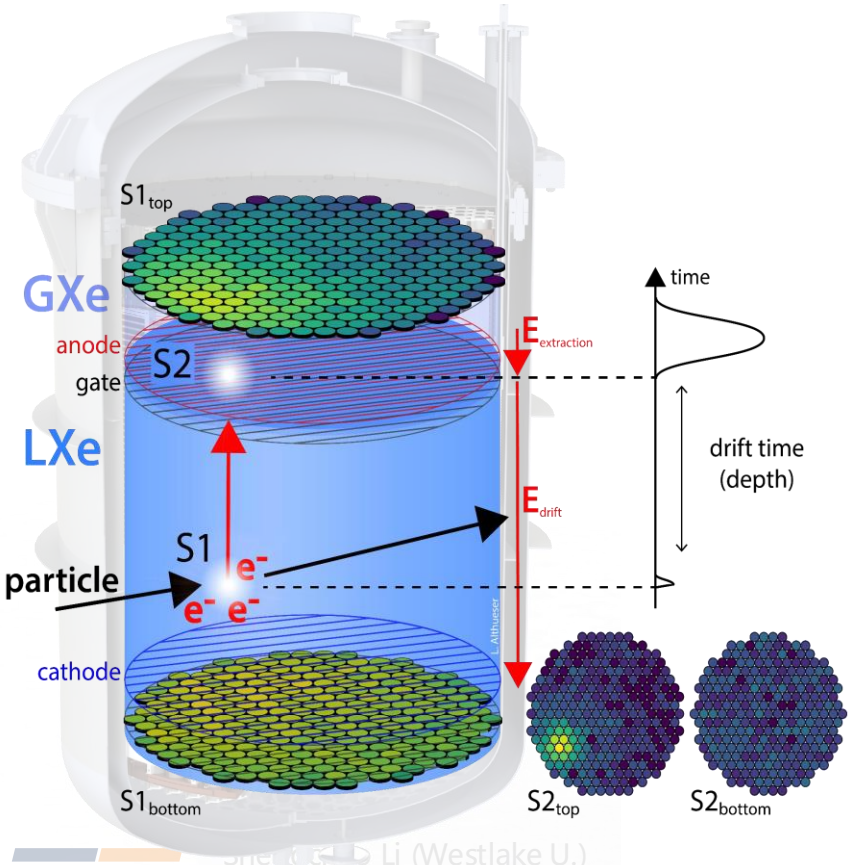
12 countries
30+ institutions
170 members

XENON | Westlake | DM and neutrino lab



JINST 9 P11006, [1406.2374]
Eur. Phys. J. C 85, 695 (2025),[2412.05264]
Eur. Phys. J. C 84, 784 (2024),[2402.10446]

Dual-phase Time Projection Chamber (TPC)



Redundant readout:

S1: light signal (prompt)

S2: charge signal (delayed)

3D position info:

-XY from PMT hit pattern

-Z from drift time

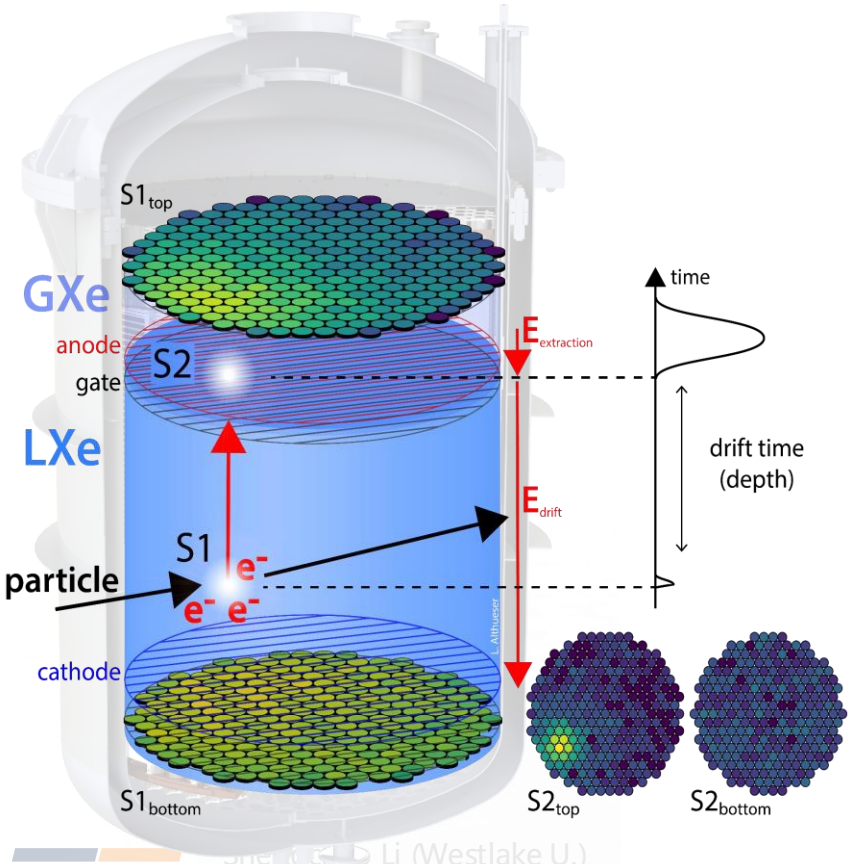
Energy reconstruction:

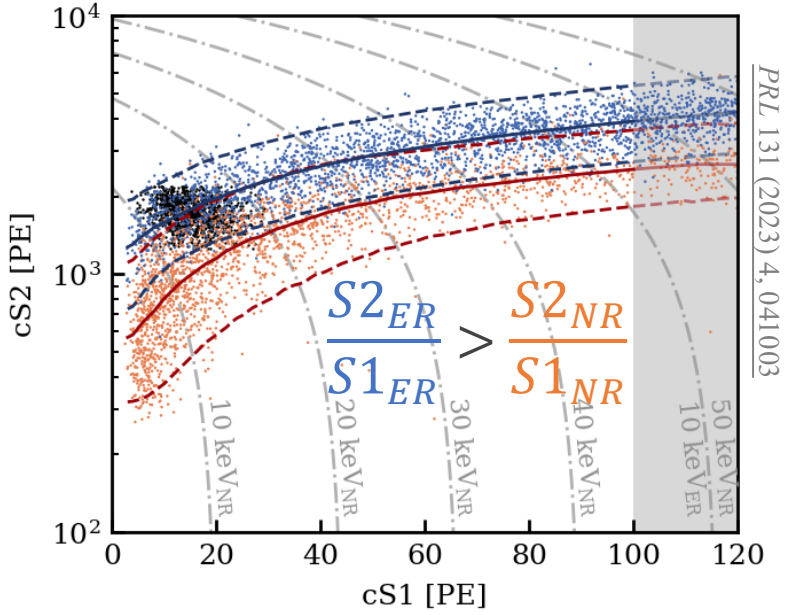
$E = 13.7eV \times (N_{ph}+N_e)$

Particle discrimination:

ratio of charge/light (ERs vs. NRs)

Dual-phase Time Projection Chamber (TPC)





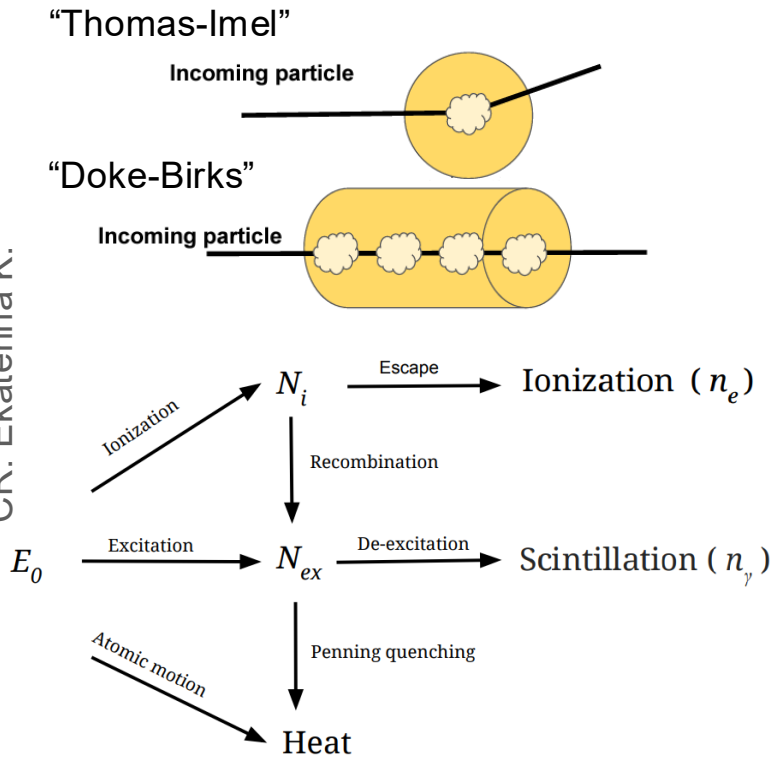
Particle discrimination:

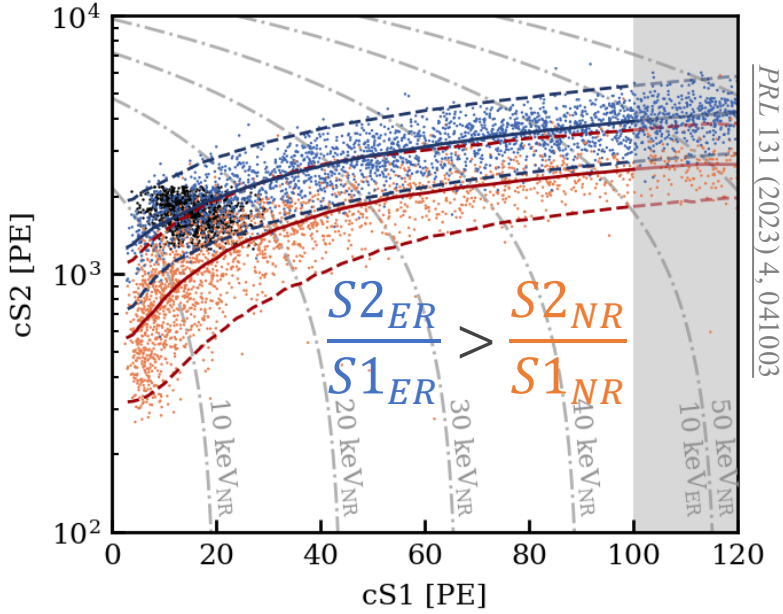
ratio of charge/light (ERs vs. NRs)

Dual-phase Time Projection Chamber (TPC)

XENON Westlake | DM and neutrino lab

CR: Ekaterina K.





Particle discrimination:

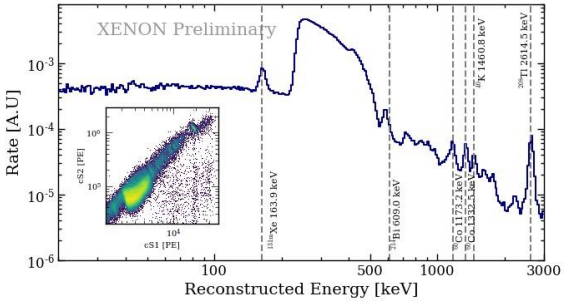
ratio of charge/light (ERs vs. NRs)

Inputs: energy, electric field, "Lindhard factor" → response difficult to derive theoretically

Detector Response Calibration

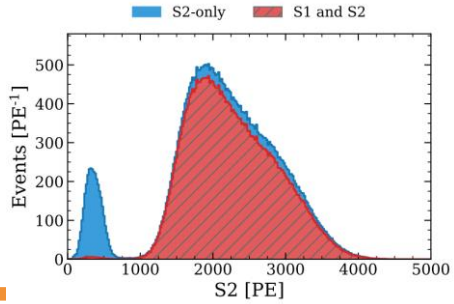
- In the WIMP search, radioactive sources are introduced to model the **light/charge** response and **threshold** effect

^{220}Rn: flat spectrum from beta

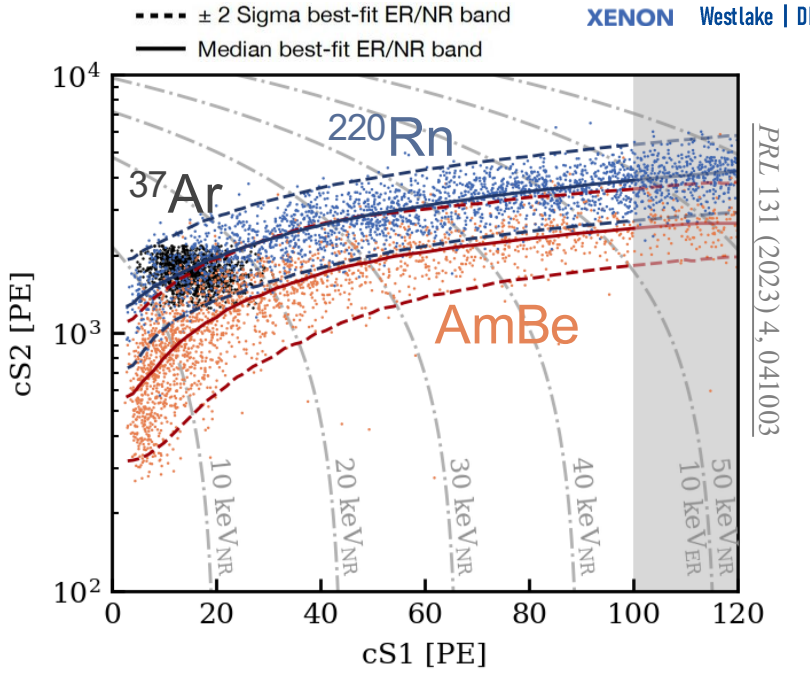


JINST 18 (2023) 11

^{37}Ar: electron-capture line(s) **2.82 keV** (K-shell) 0.27 keV (L-shell)

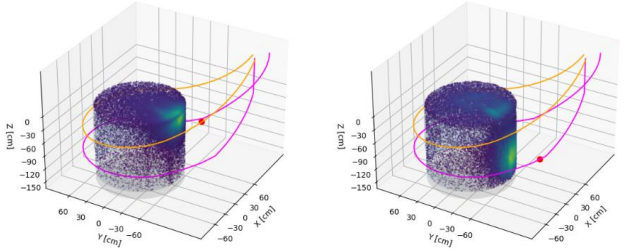


EPJC 83 (2023) 6, 542



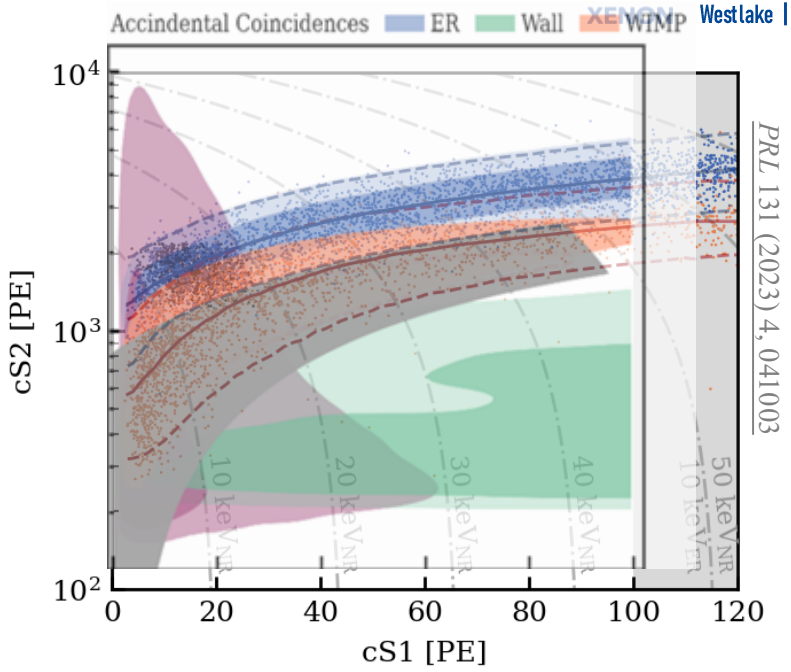
PRL 131 (2023) 4, 041003

AmBe: MeV neutron coincident with ɣ-ray in nVeto



XENON WIMP Search

- In the WIMP search, radioactive sources are introduced to model the **light/charge** response and **threshold** effect

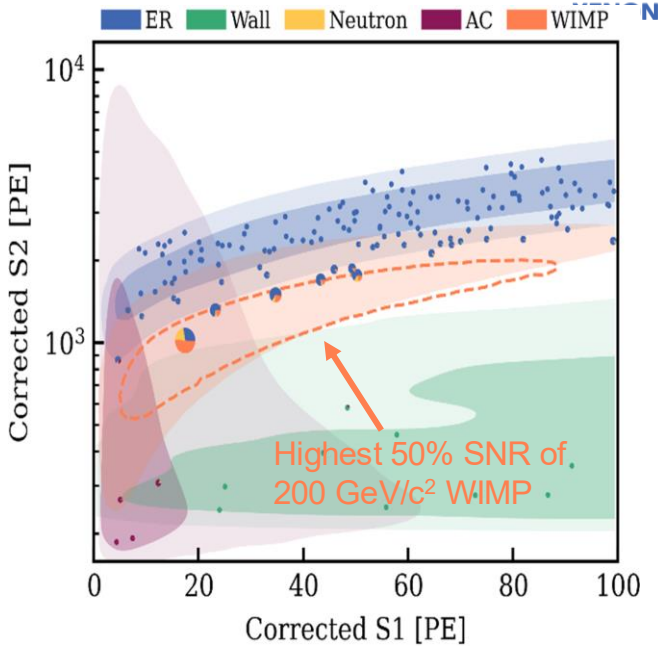


Signal region blinded

XENON WIMP Search

- In the WIMP search, radioactive sources are introduced to model the **light/charge** response and **threshold** effect
- **No excess** found regarding the WIMP

	SR0 Nominal	95 days Best fit
ER (flat)	134	136 ± 12
ER (^{3}H-like)	–	–
ER (^{37}Ar)	–	–
Neutron	0.7 ± 0.3	0.6 ± 0.3
CEνNS (solar)	0.16 ± 0.05	0.16 ± 0.05
CEνNS (atm.+DSNB)	0.04 ± 0.02	0.04 ± 0.02
AC	4.3 ± 0.9	$4.4^{+0.9}_{-0.8}$
Surface	13 ± 3	11 ± 2
Total background	152	152 ± 12
WIMP ($200\,\mathrm{GeV}/c^2$)	–	1.8
Observed	152	



PRL 131 (2023) 4, 041003

XENON WIMP Search

XENON Westlake | DM and neutrino lab

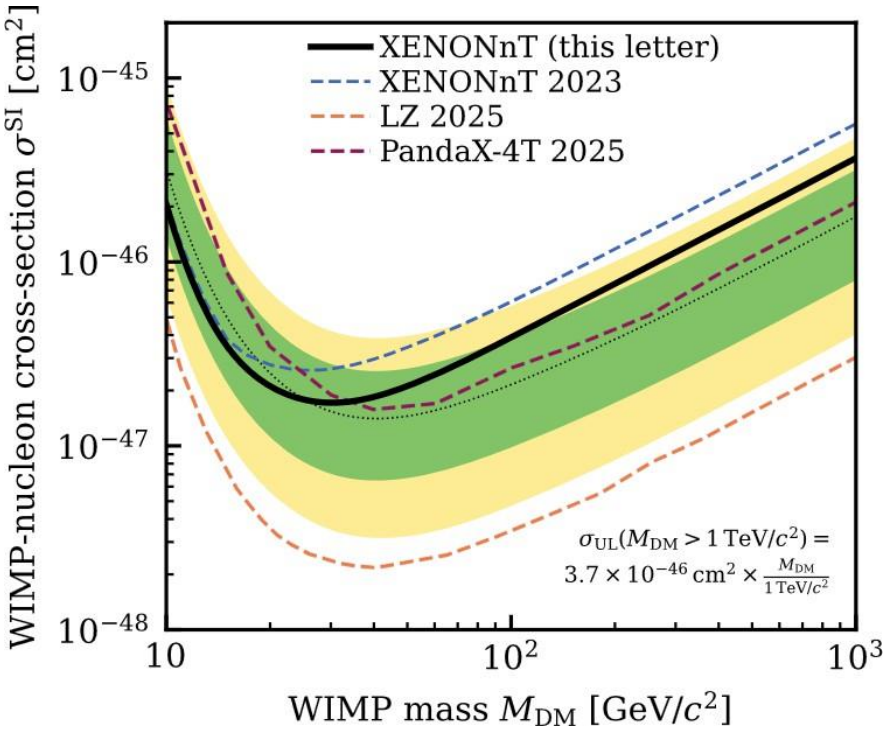
- In the WIMP search, radioactive sources are introduced to model the **light/charge** response and **threshold** effect
- **No excess** found regarding the WIMP

PRL 135 (2025) 22, 221003
PRL 131 (2023) 4, 041003

	SR0 95 days		SR1a +187 days		SR1b	
	Nominal	Best fit	Nominal	Best fit	Nominal	Best fit
ER (flat)	134	136 ± 12	430 ± 30	450 ± 20	151 ± 11	154 ± 10
ER (^{3}H-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
CEνNS (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
CEνNS (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	

XENON WIMP Search

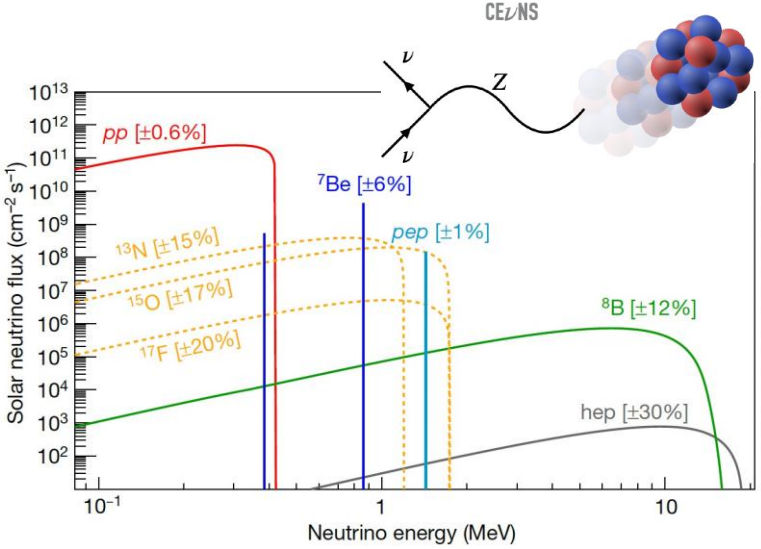
- In the WIMP search, radioactive sources are introduced to model the **light/charge** response and **threshold** effect
- **No excess** found regarding the WIMP, thus setting a **WIMP limit**

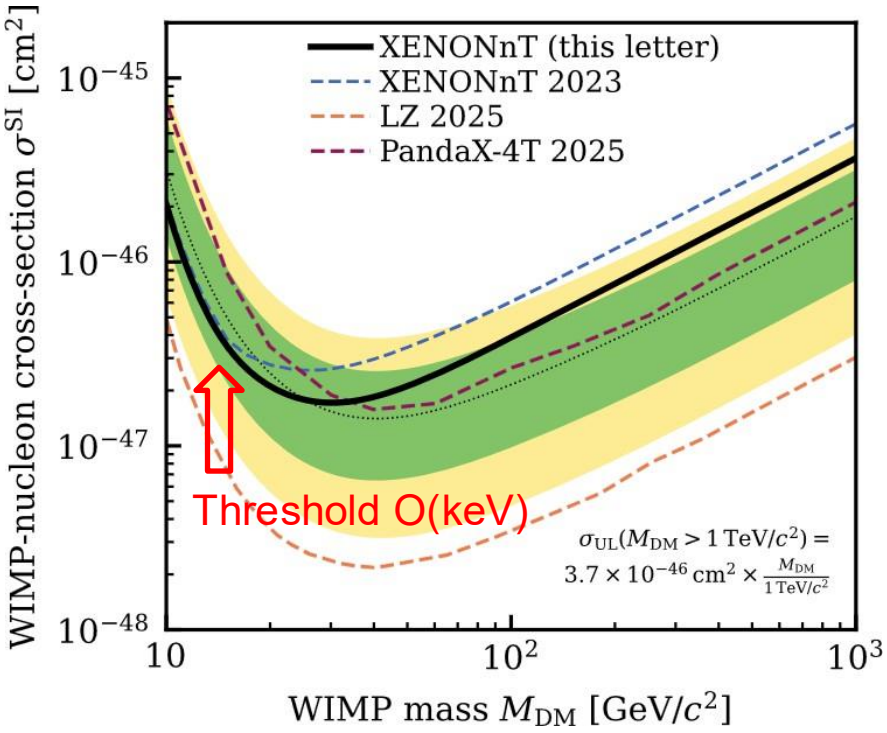


PRL 135 (2025) 22, 221003
PRL 131 (2023) 4, 041003

XENON WIMP Search

- In the WIMP search, radioactive sources are introduced to model the **light/charge** response and **threshold** effect
- **No excess** found regarding the WIMP, thus setting a **WIMP limit**



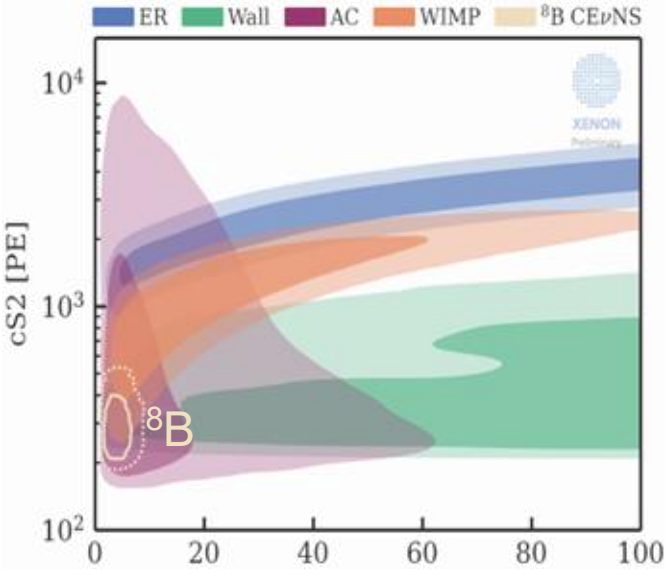


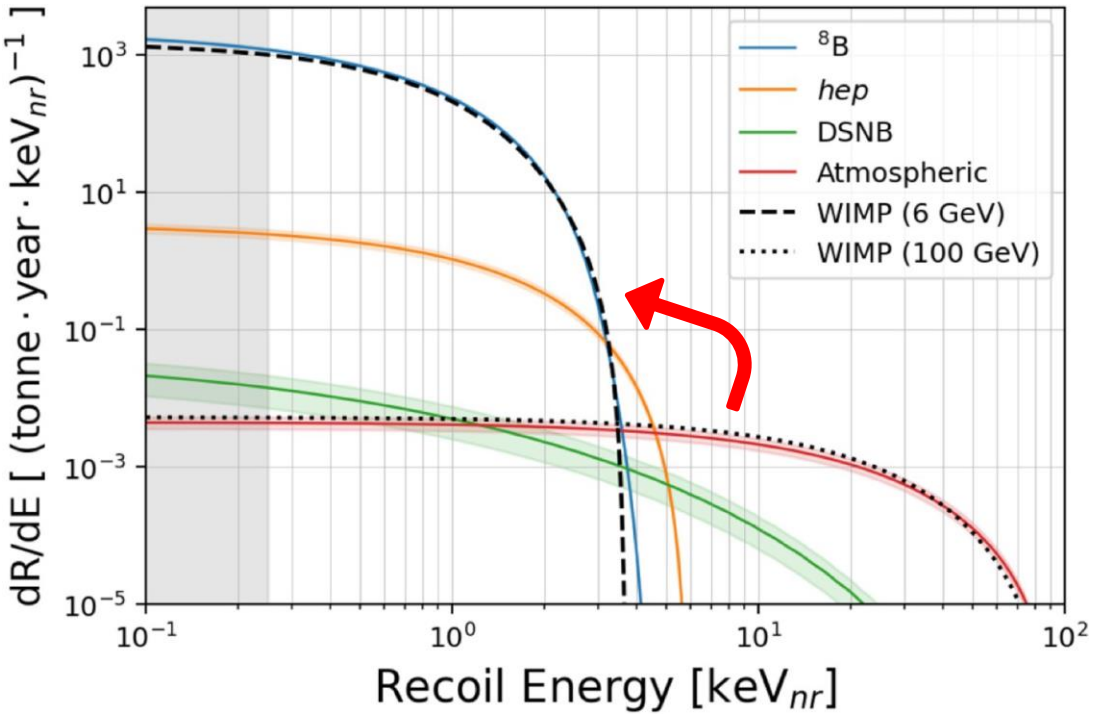
PRL 135 (2025) 22, 221003
PRL 131 (2023) 4, 041003

XENON Light DM and ^{8}B Neutrino Search

XENON Westlake | DM and neutrino lab

- **CEvNS**: **C**oherent **E**lastic **Neutrino**-**N**ucleus **S**cattering ($\sigma \propto N^2 \simeq 6000$)
- Single scatter NR signal mimic WIMP -> “neutrino fog”
- Low momentum transfer, e.g.,
  ^{8}B solar neutrino: E_{NR} < 4 keV





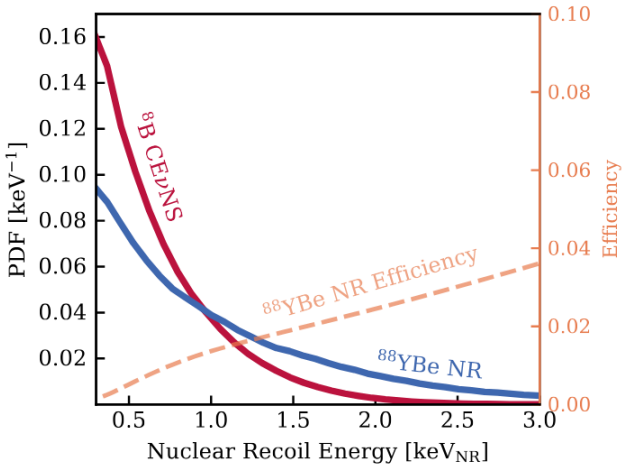
XENON Light DM and ^{8}B Neutrino Search

Challenge 1: signal

XENON Westlake | DM and neutrino lab

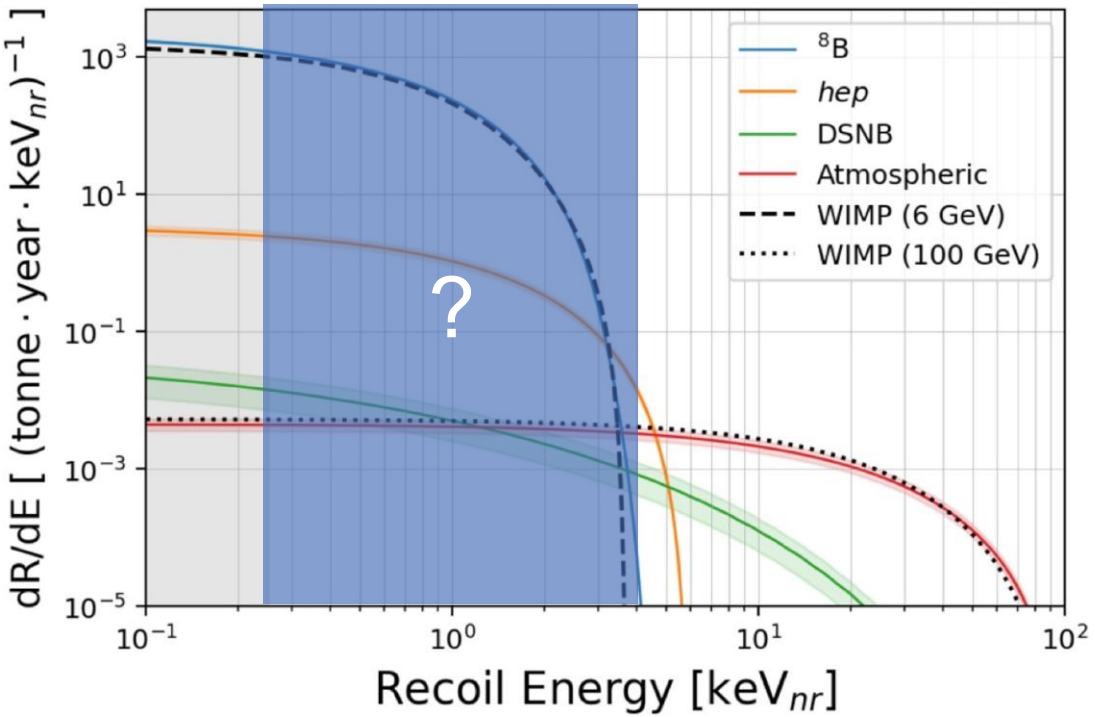
- **CEvNS**: **C**oherent **E**lastic **Neutrino**-**N**ucleus **S**cattering ($\sigma \propto N^2 \simeq 6000$)
- Single scatter NR signal mimic WIMP -> "neutrino fog"
- Low momentum transfer, e.g.,

^{8}B solar neutrino: E_{NR} < 4 keV



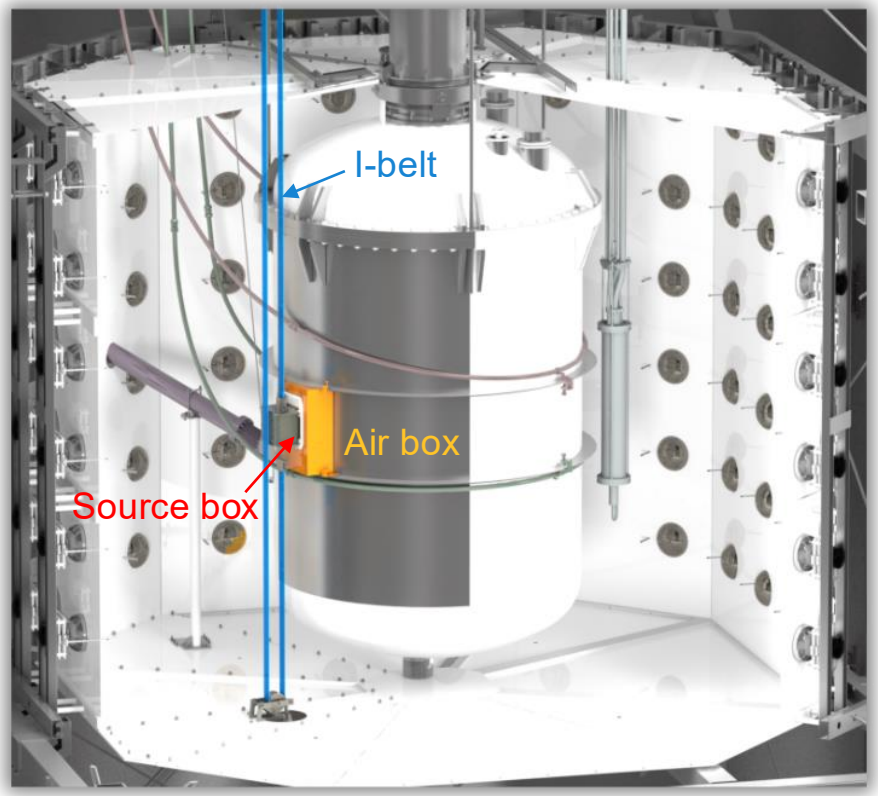
Yttrium-Beryllium (YBe) source

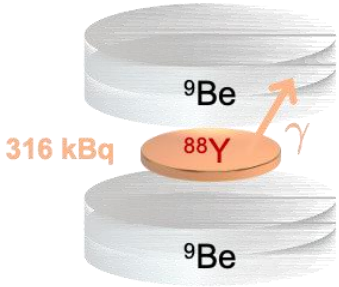
- γ + ^{9}Be → n + ^{8}Be
- emits 152 keV neutrons



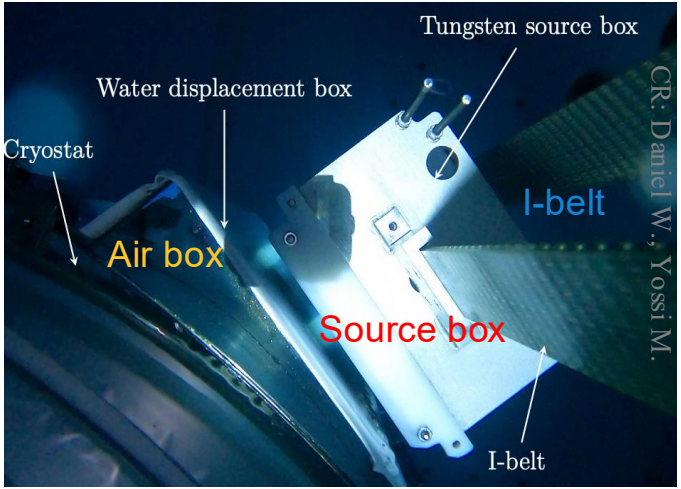
YBe Calibration

Design: *EPJC* 84 (2024) 8, 784



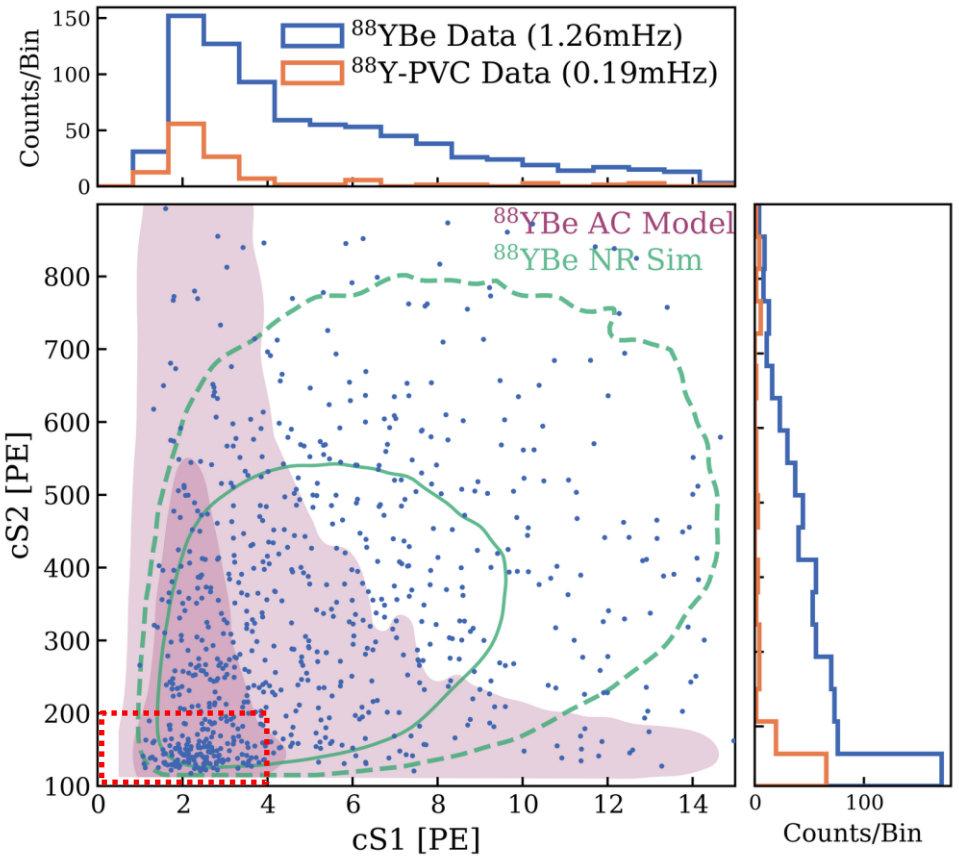


- only 0.65 mb cross-section
- 10 cm tungsten optimized with MC
- final γ:n = 10^5:1 → **1600:1**

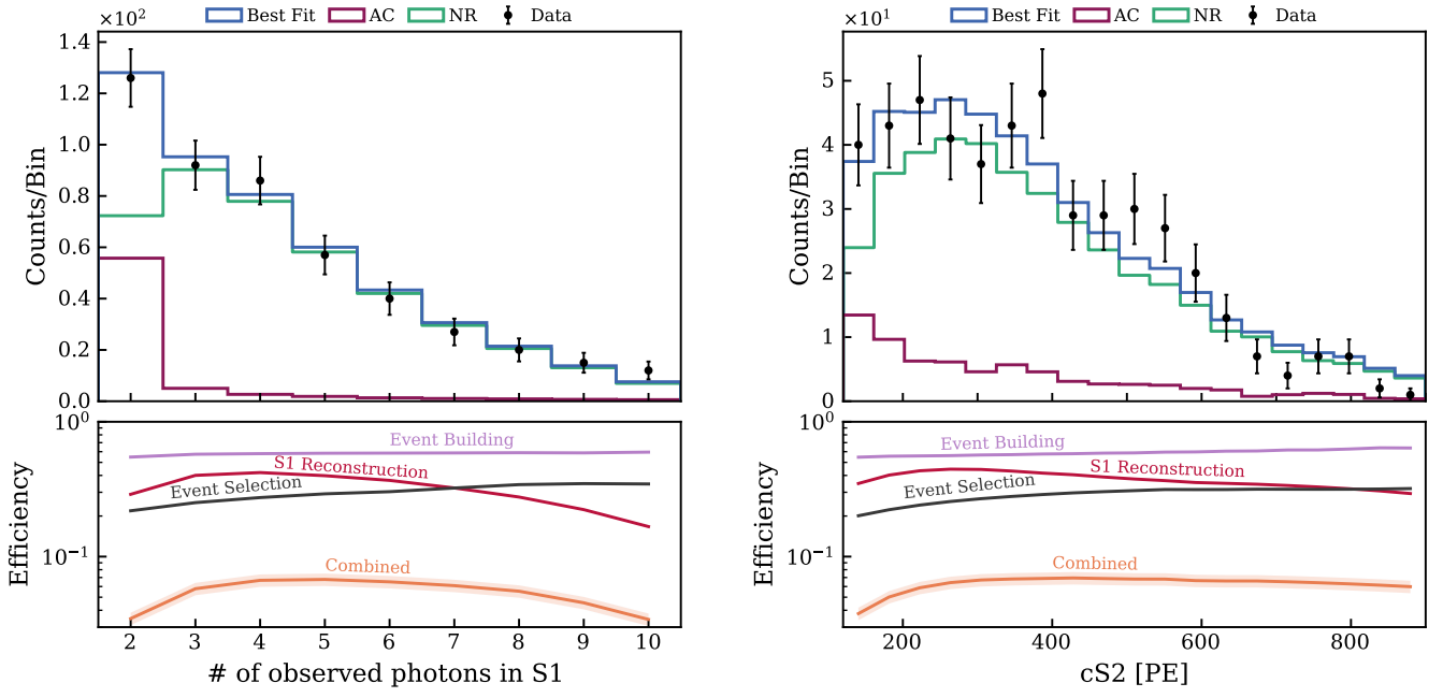


YBe Calibration Analysis

- Neutrons in YBe dataset with Y-PVC dataset as controlled sample
- **Accidental coincidence (AC)** in box overlap with the simulated YBe NR signal
- **BDT machine** trained on AC model was used to suppress AC background by **91%**



Best-fit YBe spectrum

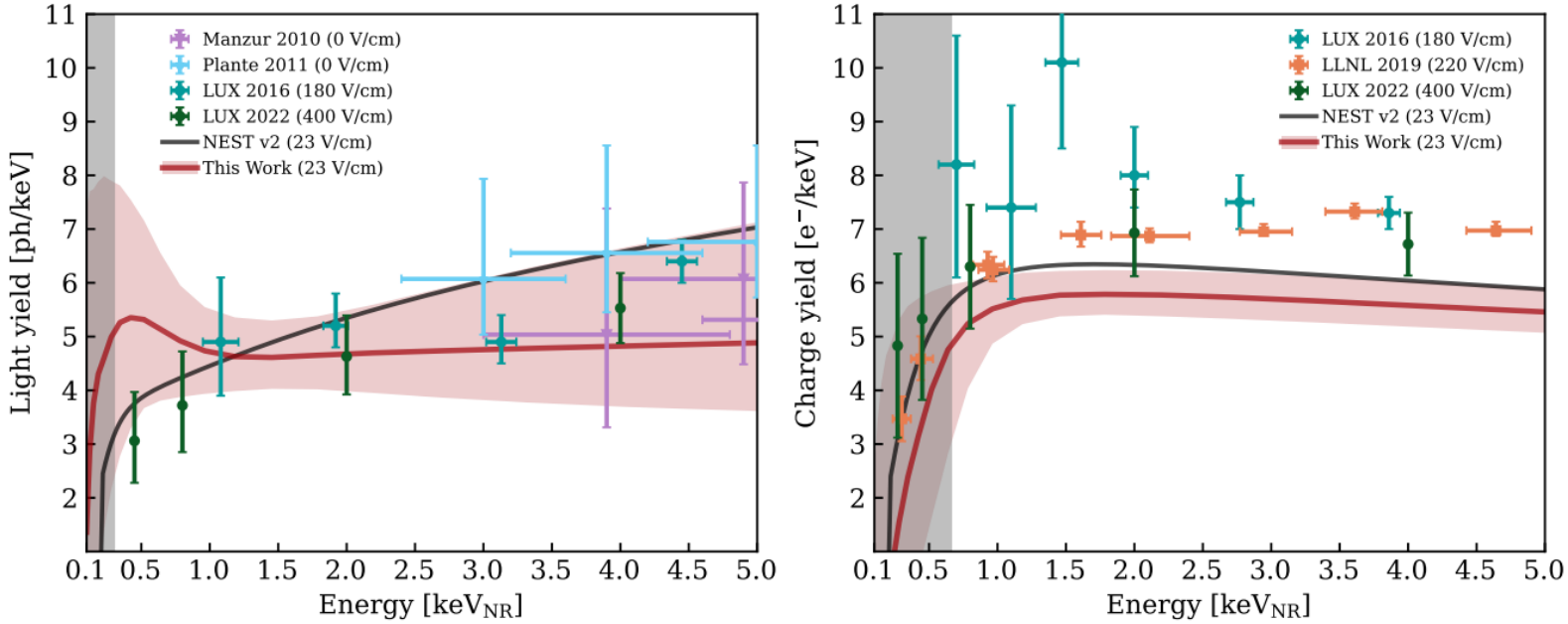


- Good match in spectrum, down to **2** observed photons
- Overall efficiency 10%, difficult detection

XENON Westlake | DM and neutrino lab

Best-fit NR yields

NEST v2 parameterization



- **30% uncertainty** band from fitted posterior
- **Minimum threshold** for light (*charge*) yield at 0.3 (*0.7*) keV$_{NR}$, **lowest** in ton-scale detectors

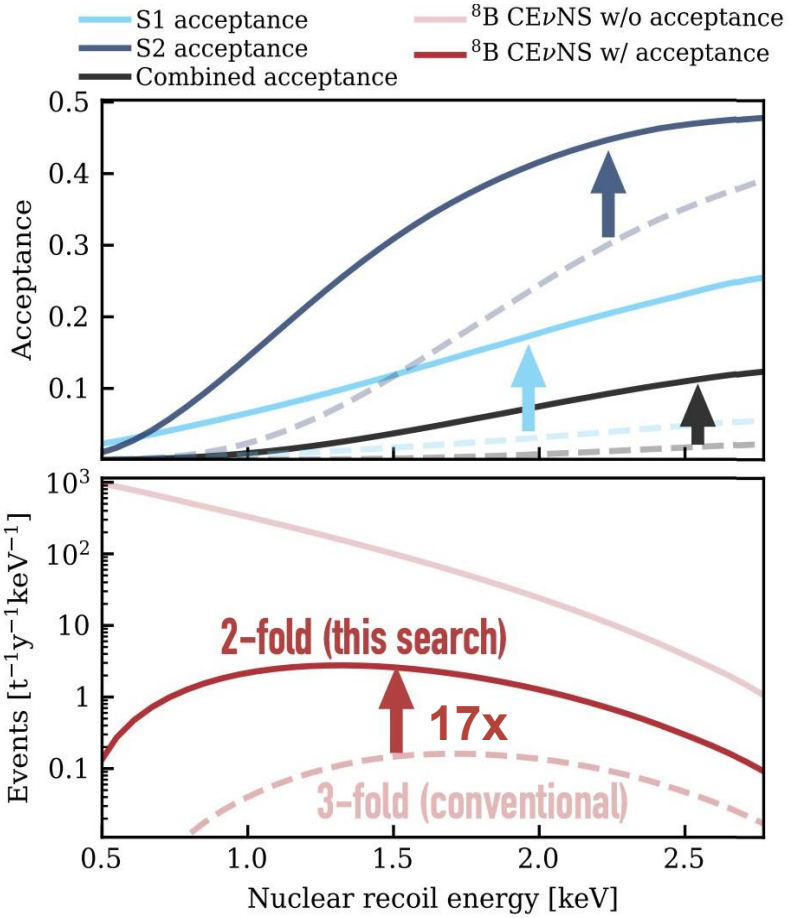
2412.10451 PRD accepted

XENON Light DM and ^{8}B Neutrino Search

Challenge 2: background

XENON Westlake | DM and neutrino lab

- Lower threshold for **17x** signals

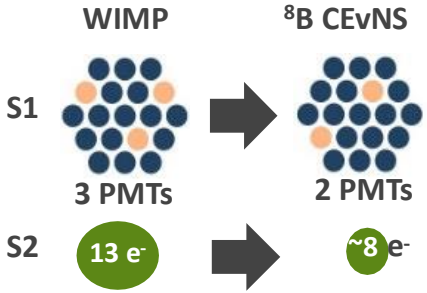


XENON Light DM and ^{8}B Neutrino Search

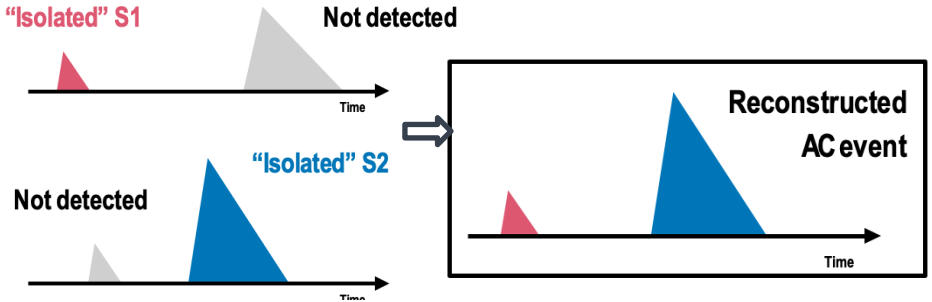
Challenge 2: background

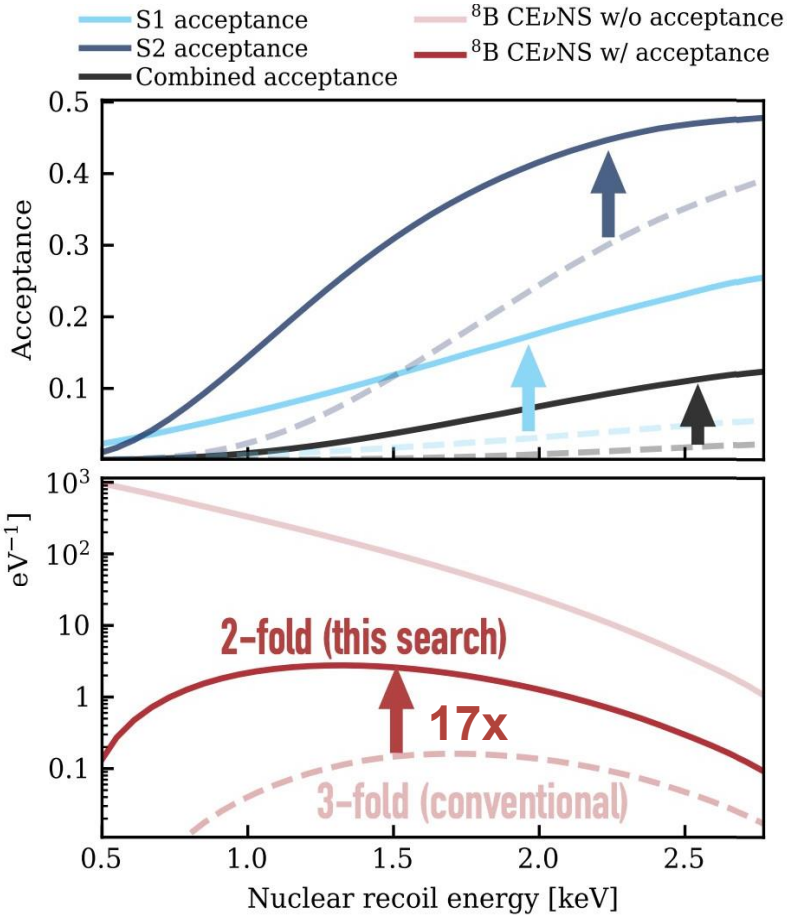
XENON | Westlake | DM and neutrino lab

- Lower threshold for **17x** signals

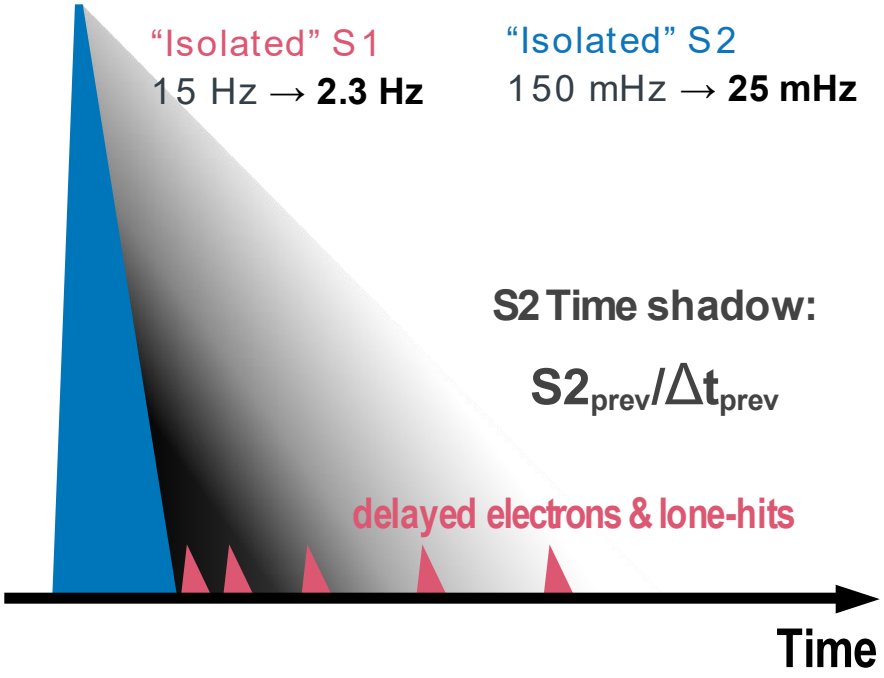


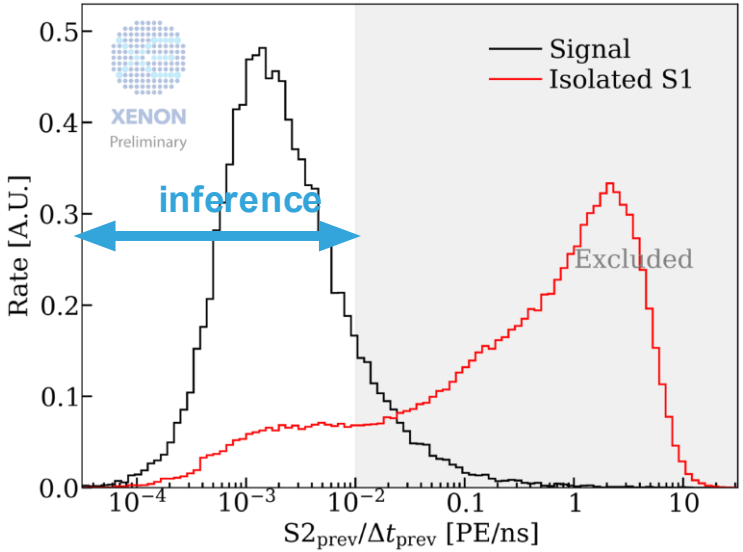
- **Cost:** 400/day <u>accidental background</u>





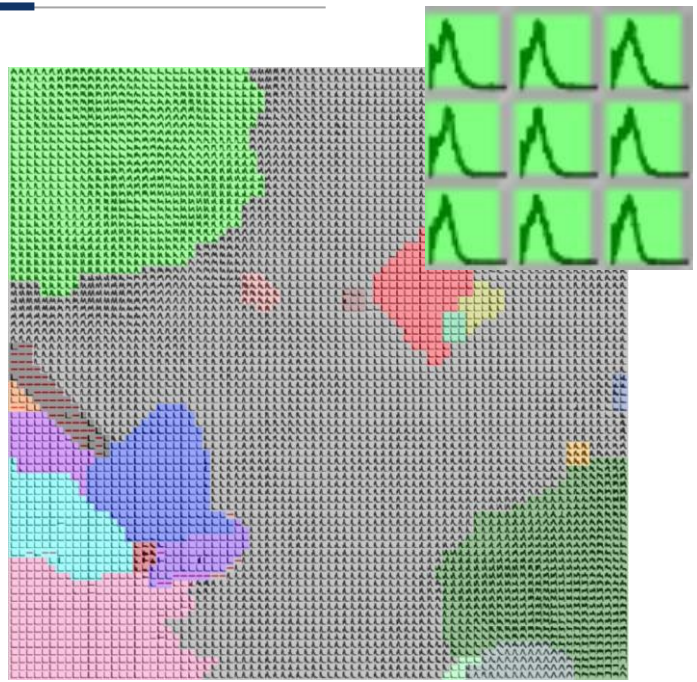
AC Suppression: coincidence



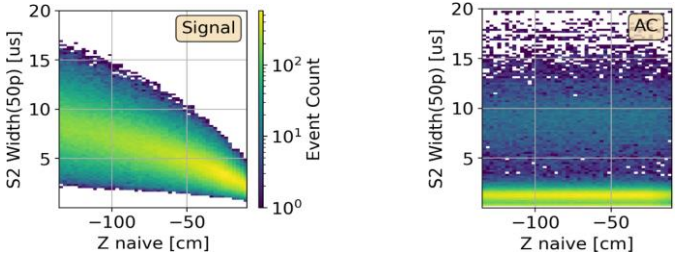


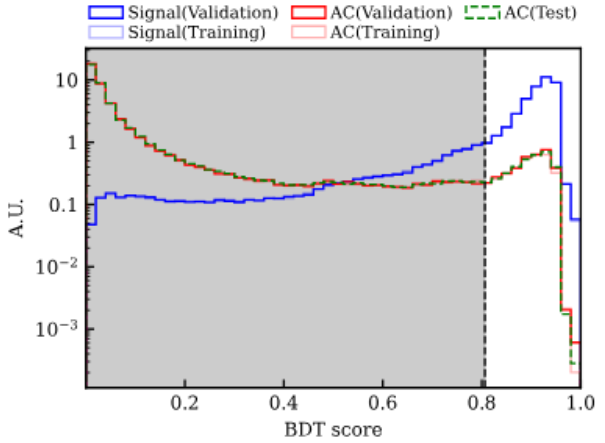
- Most isolated S1/S2 peaks removed
- Signal acceptance ~80%

AC Suppression: machine learning



+

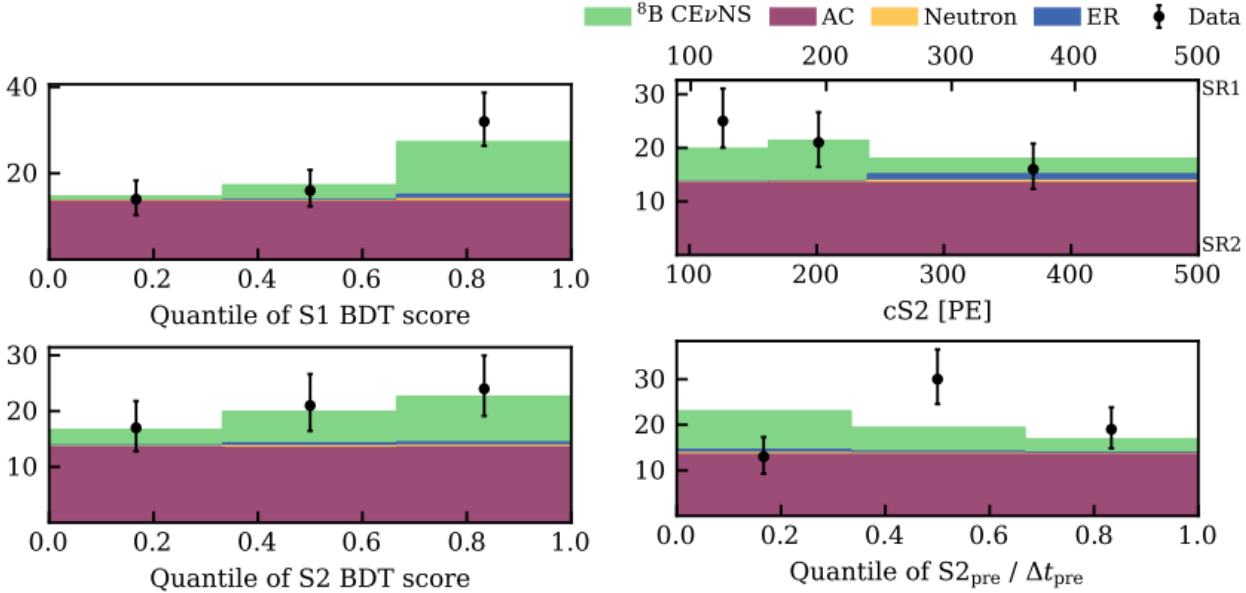




- Unsupervised **S**elf-**O**rganized **M**aps (SOM) new
- Better peak classification & multi-scatter rejection
- **B**oosted **D**ecision **T**ree (BDT)
- Discrimination from electron diffusion

= 8x SNR

XENON ^{8}B CEvNS Result 2026



AC	(40.2 ± 1.4) evts
ER background	(1.2 ± 1.2) evts
Neutron	$0.8^{+0.4}_{-0.5}$ evts

Expected:

Background: (42 ± 2)

Signal: (16 ± **5**)

Total: 58 ± 5

Observed:

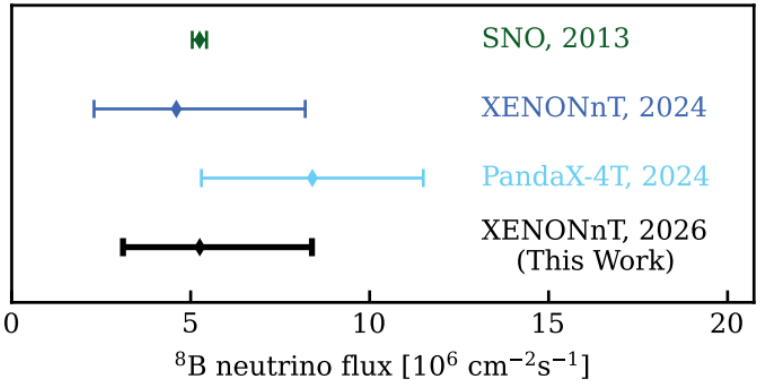
62 events

25 new

Significance = 2.7σ → **3.3σ**

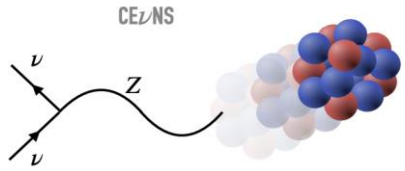
PRL2024

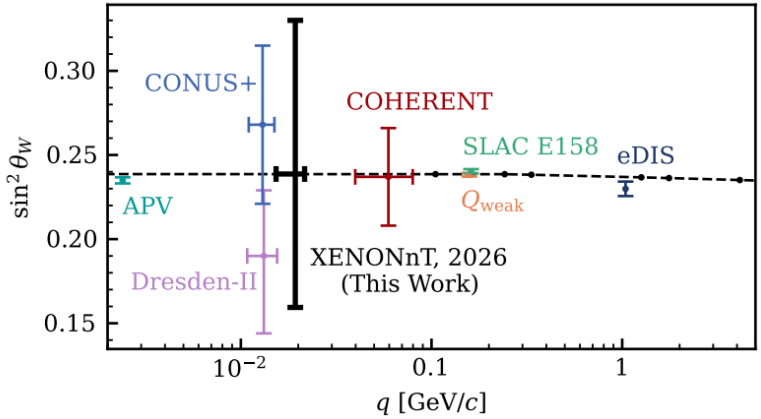
XENON Measurement 2026 [2604.06002]



$$\phi_{B8} = (5^{+3}_{-2}) \times 10^6 \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

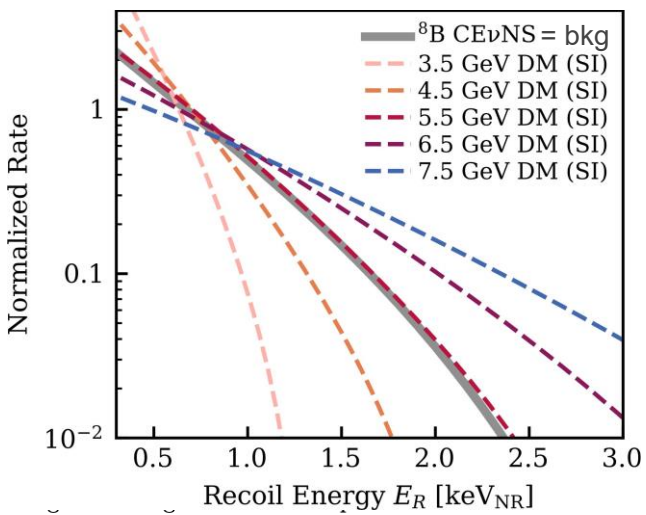
$$g_V^p = \frac{1}{2} - 2\sin^2\theta_W$$

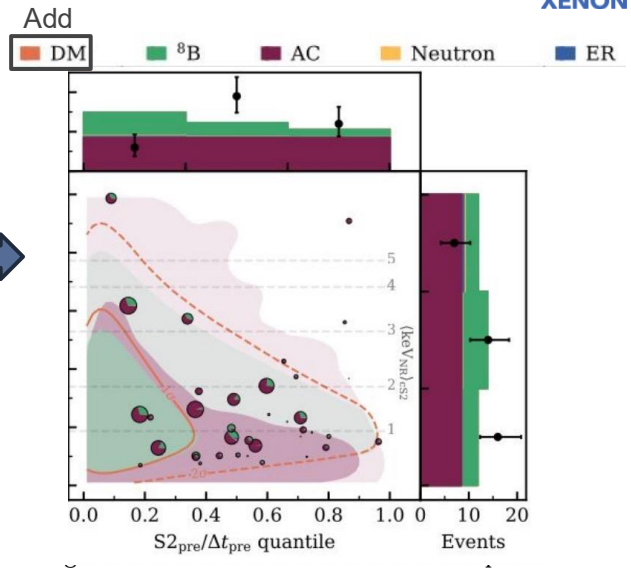




$\sin^2\theta_w \in [0.159, 0.330]$ at q=0.02 GeV/c

Light DM Search with Neutrino Fog





Component	Expectation	Background-only	4 GeV/c^2	6 GeV/c^2	10 GeV/c^2
SI DM	–	–	3.2 (1.6)	0.0 (0.0)	0.0 (0.0)
^{8}B CEνNS	$11.9^{+4.5}_{-4.2}$	$11.4^{+2.0}_{-3.6}$	10.2 ±2.7 (2.5 ± 0.7)	$11.4^{+2.7}_{-2.6}$ (6.0 ± 1.4)	$11.4^{+2.7}_{-2.6}$ ($5.4^{+1.3}_{-1.2}$)
AC	25.3 ± 1.2	$25.3^{+1.1}_{-1.3}$	25.1 ±1.2 (3.7 ± 0.1)	25.3 ± 1.2 (4.1 ± 0.2)	25.3 ± 1.2 (3.3 ± 0.1)
ER	0.7 ± 0.7	$0.5^{+0.7}_{-0.6}$	$0.6^{+0.7}_{-0.6}$ (0.0 ± 0.0)	$0.5^{+0.6}_{-0.5}$ (0.3 ± 0.3)	$0.5^{+0.7}_{-0.5}$ ($0.4^{+0.5}_{-0.4}$)
Neutron	$0.5^{+0.2}_{-0.3}$	0.5 ± 0.3	0.5 ±0.3 (0.1 ± 0.1)	0.5 ± 0.3 (0.2 ± 0.1)	0.5 ± 0.3 (0.2 ± 0.1)
Total background	$38.3^{+4.7}_{-4.4}$	$37.7^{+2.5}_{-3.9}$	$36.4^{+3.0}_{-3.0}$ ($6.3^{+0.7}_{-0.7}$)	$37.7^{+3.0}_{-2.9}$ ($10.6^{+1.5}_{-1.4}$)	$37.7^{+3.0}_{-2.9}$ ($9.2^{+1.4}_{-1.3}$)
Observed	–	37	37 (10)	37 (10)	37 (4)

CEvNS becomes **dominant** background in signal region

PRL 134, 111802 (2025)

XENON Westlake | DM and neutrino lab

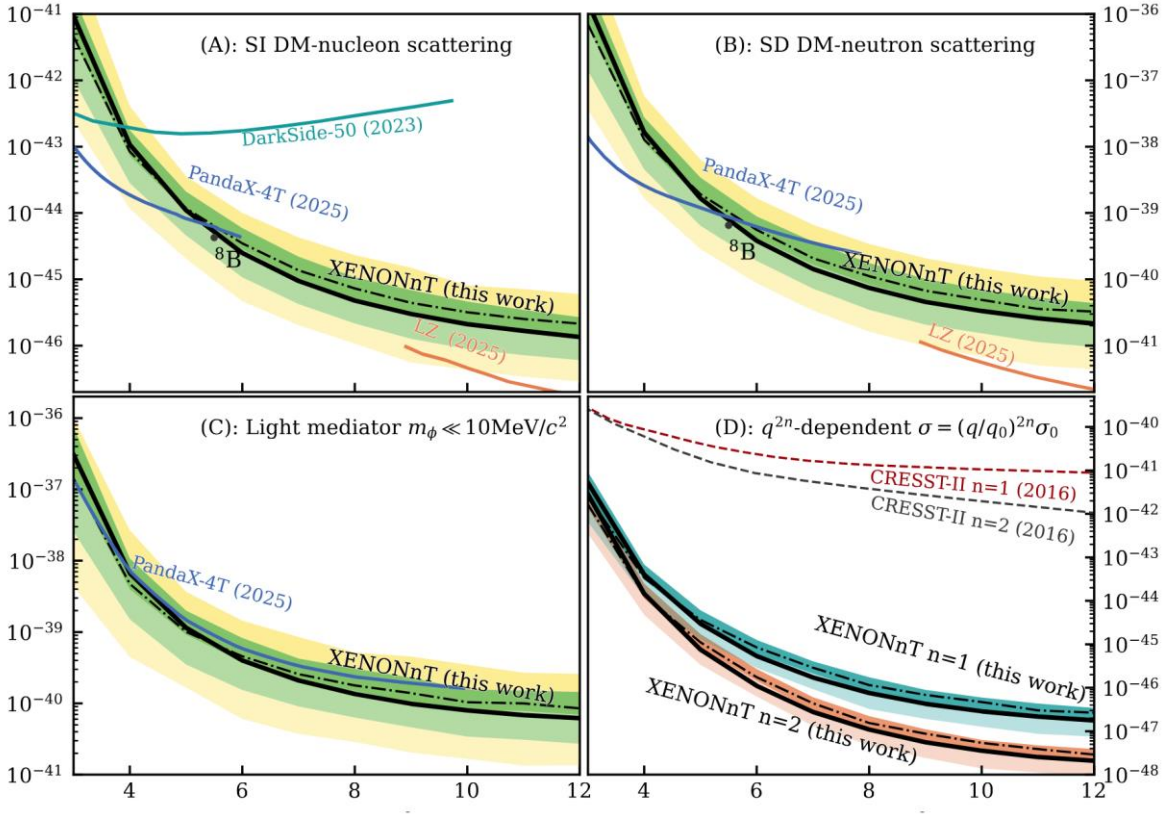
Light DM Limits 2026

- No significant signal rate over mass range [3, 12] GeV/c^2

→ new exclusion

- **10%** gain in sensitivity compared to 2024 PRL alone, with **93%** increase of exposure

→ fog-limited DM search



..and other BSM physics [2604.06002]

Summary & outlook

- **Sub-keV** nuclear recoil searches with XENON 2021-25 data
- **YBe** calibrates signal yields down to 0.3 keV_{NR}
- **3.3 sigma** for solar ^{8}B CEvNS
- **Fog-limited** light DM search

Calibration team during 2025 upgrade

XENONnT detector upgrade:

- Better **E-field** for improved efficiency and background
- New NR **calibration** system for improved yield model
- We hope to eventually measure ^{8}B CEvNS at **5σ**!

Backup

BSM Physics

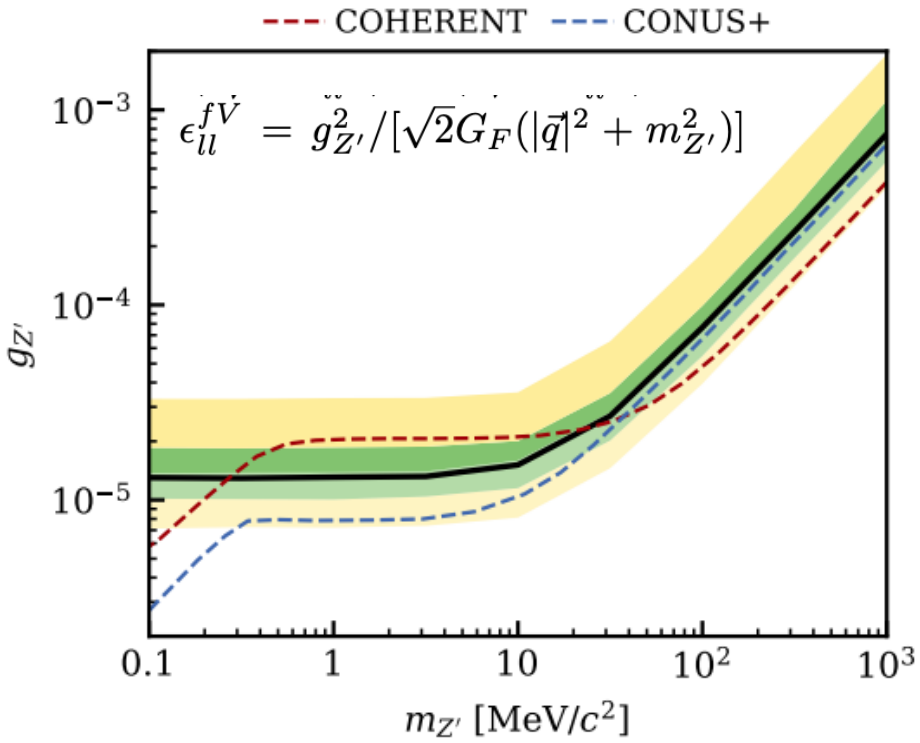


Figure: new light vector mediator through the q-dependent modification of the CEvNS cross section

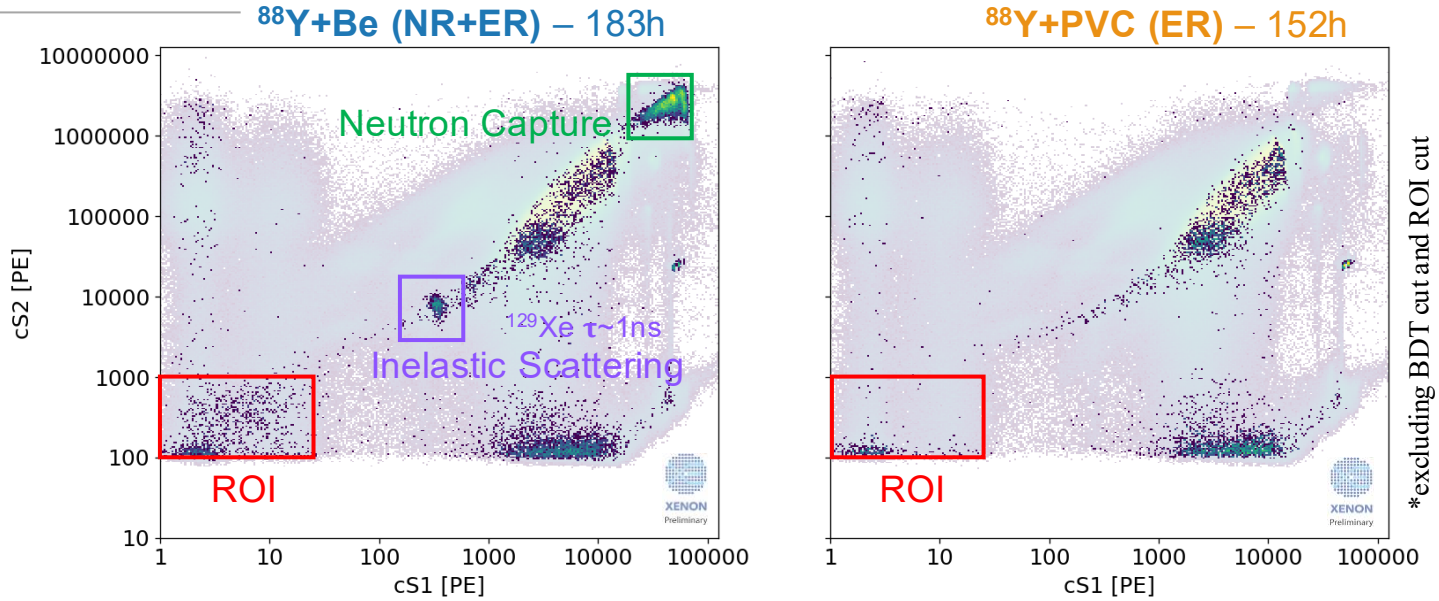
A flavor-universal neutrino charge radius $\langle r^2_{\nu l} \rangle$ is constrained to two allowed 90% CL intervals: [-72,-48] and [-10,14] x 10^{-32} cm^2

2024 vs 2026 Results

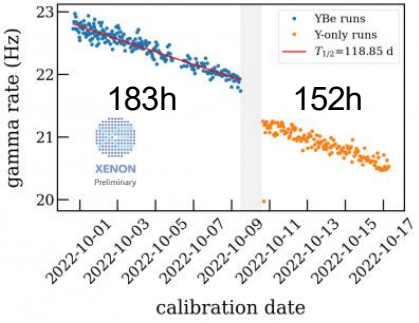
XENON Westlake | DM and neutrino lab

Item	2408.02877	2604.06002
Role	First indication of solar 8B CEvNS	8B fog physics with SR2 included
Exposure	3.51 t yr	6.77 t yr
Observed	37 events	62 events
Background	26.4 +1.4/1.3	42.4 +/- 1.9 best fit
Significance	2.73 sigma	3.3 sigma
8B flux	4.7 +3.6/2.3	5 +3/-2
Extra physics	CEvNSflux and Xe cross section	Light DM, weak mixing, mediator, charge radius

^{88}Y+Be and ^{88}Y+PVC calibrations



- PVC plastic replaces Be target, similar gamma attenuation, but **no neutrons**
- To **model** background components related to **^{88}Y gamma**



Steady source decay monitored with gamma

AC suppression with machine learning

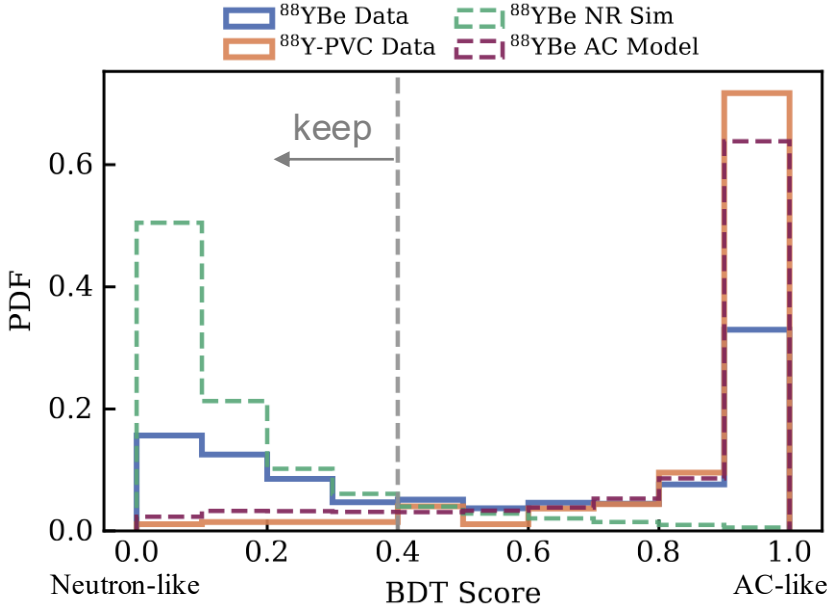
- Prepare **two** datasets:

1. ^{88}YBe neutron simulation
2. Data-driven AC model from ^{88}YBe/^{88}YPVC runs (**rate** and **shape**)

- Train a **Boosted Decision Tree (BDT)** using **physics-inspired** parameters, such as:

Diffusion:
S2 width and electron drift time correlation

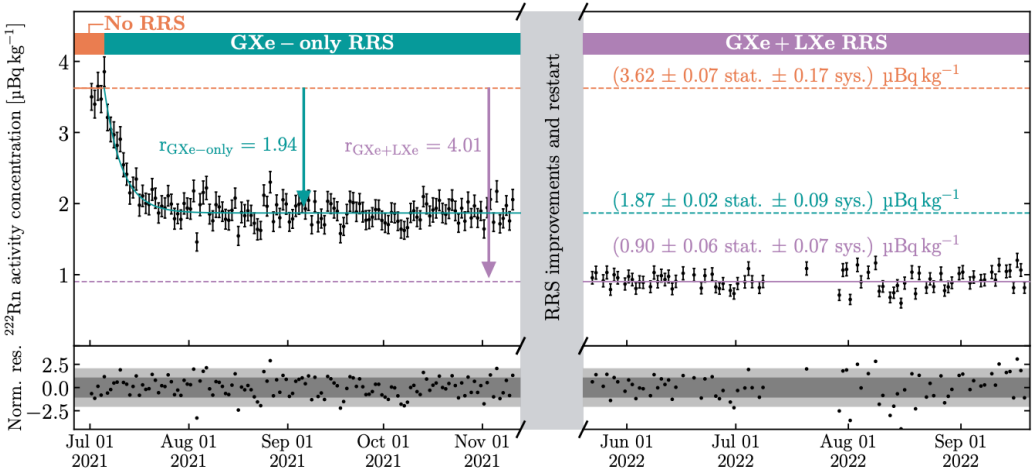
NR multi-scatter:
space and time correlation between S2s

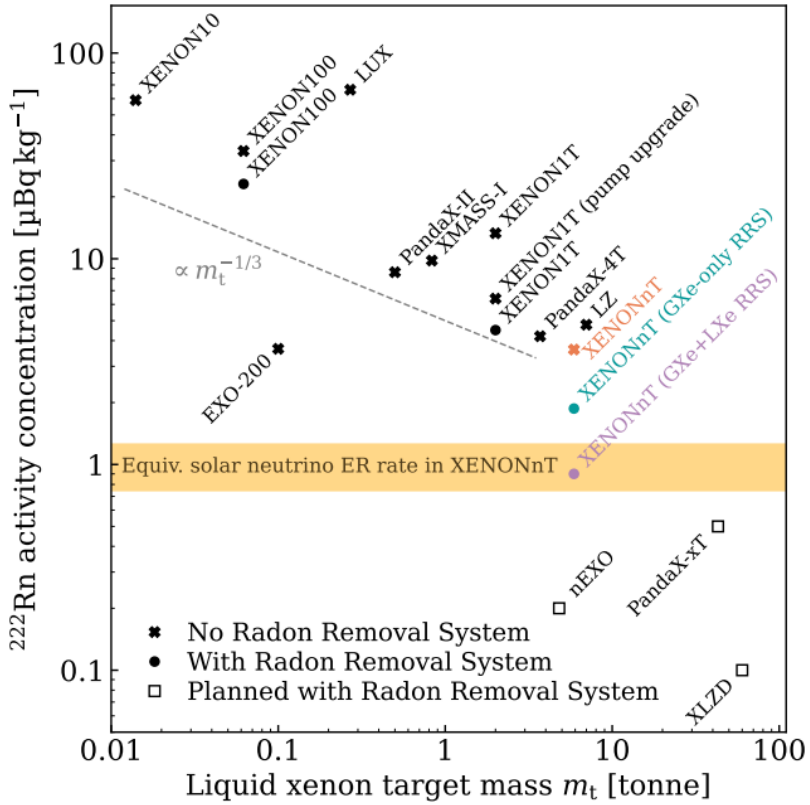


Separation in **BDT score** dimension:

- rejects 91% of AC events
- retaining 89% of ^{88}YBe MS NRs

^{88}Y-PVC data suggests accurate AC model





Phys.Rev.X 15 (2025) 3, 031079