First measurement of solar ^{8}B CEνNS with the

XENONnT

dark matter experiment

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on behalf of the XENON Collaboration

EPS-HEP
July 8th 2025, Palais du Pharo, Marseille

The XENON Collaboration

XENON10
2005
25 Kg LXe

XENON100
2008
160 Kg LXe

XENON1T
2016
3200 Kg LXe

XENONnT
2020
8500 Kg LXe

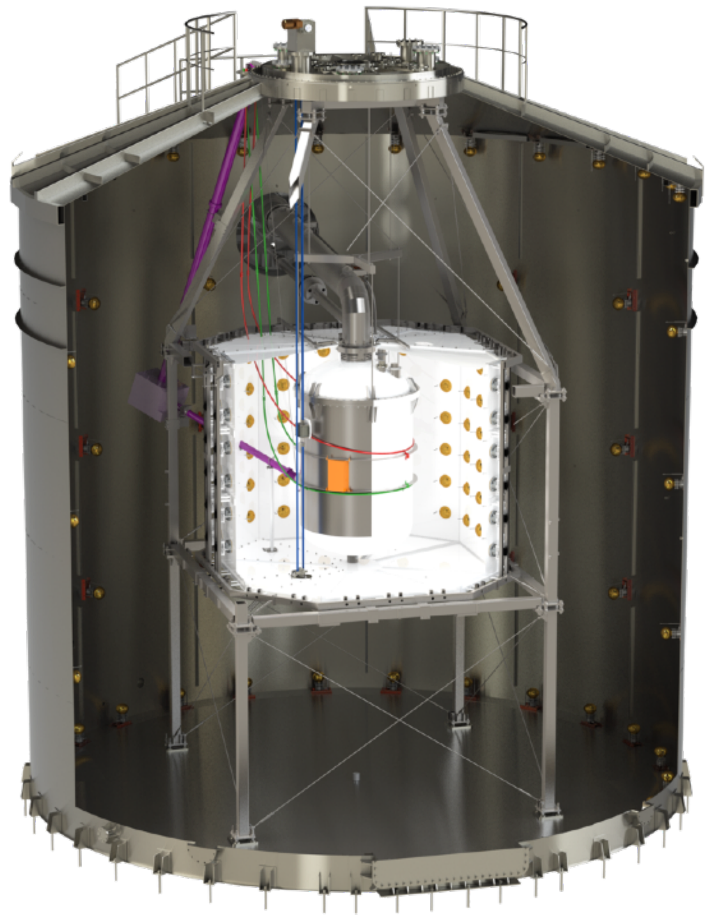
~200 Scientists

30 Institutions

12 countries

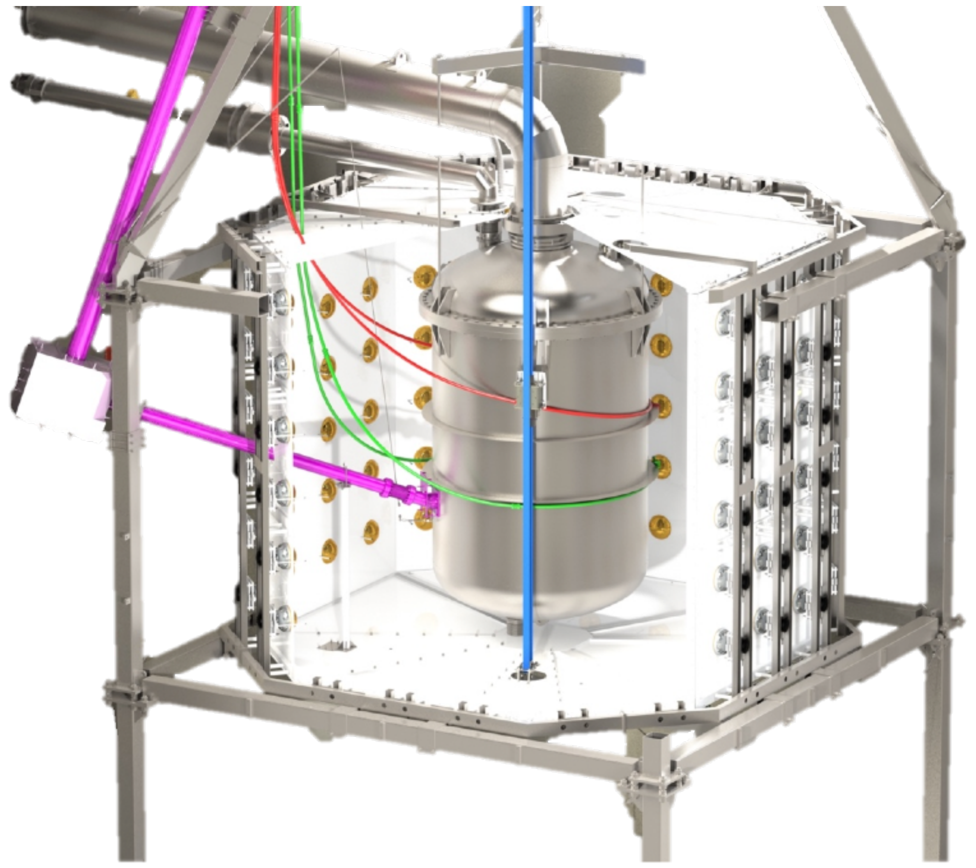
The XENONnT Experiment

Water Cherenkov Muon Veto (MV)



- **~10 x 10 m** diameter ⨉ height
- **84** PMTs (8″ Hamamatsu R5912-ASSY)

Gd-loaded water Cherenkov Neutron Veto (NV)



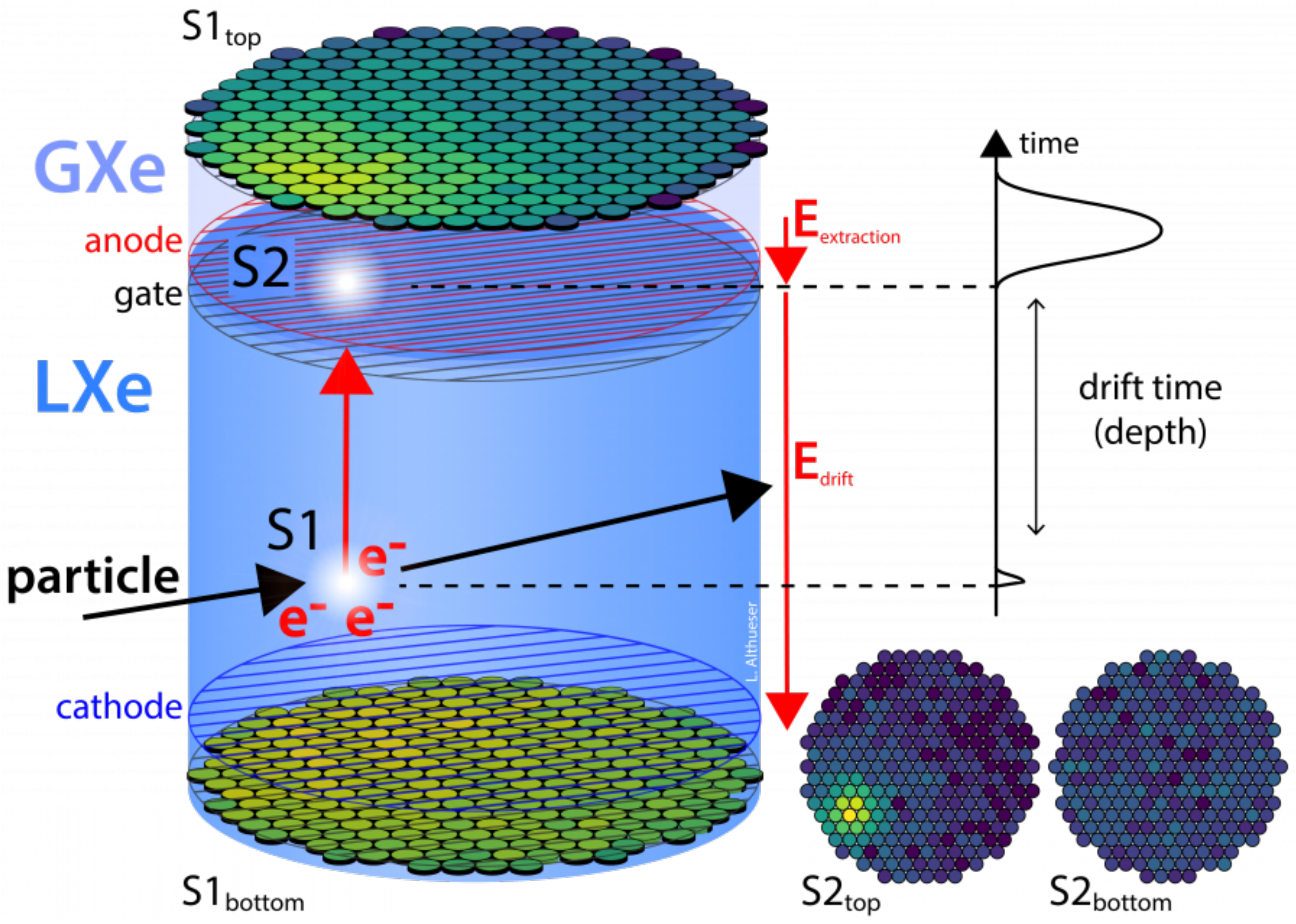
- **~2 x 3 m** radius ⨉ height
- **120** PMTs (8″ Hamamatsu R5912)
- **0.05%** GdSO concentration (since 2023)

LXe Time Projection Chamber (TPC)

- **5.9 t** active LXe mass
- **1.3 x 1.5 m** diameter ⨉ height
- **494** PMTs (3″ Hamamatsu R11410-21)
- **23 V/cm** electric drift field
- **2.9 kV/cm** extraction field

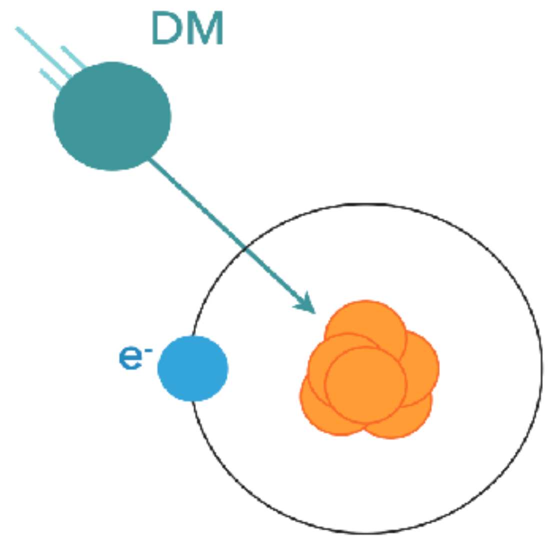
Dark Matter Direct Detection with XENONnT

Main detection channel: coherent elastic weakly interacting massive particle (WIMP) - nucleus scattering



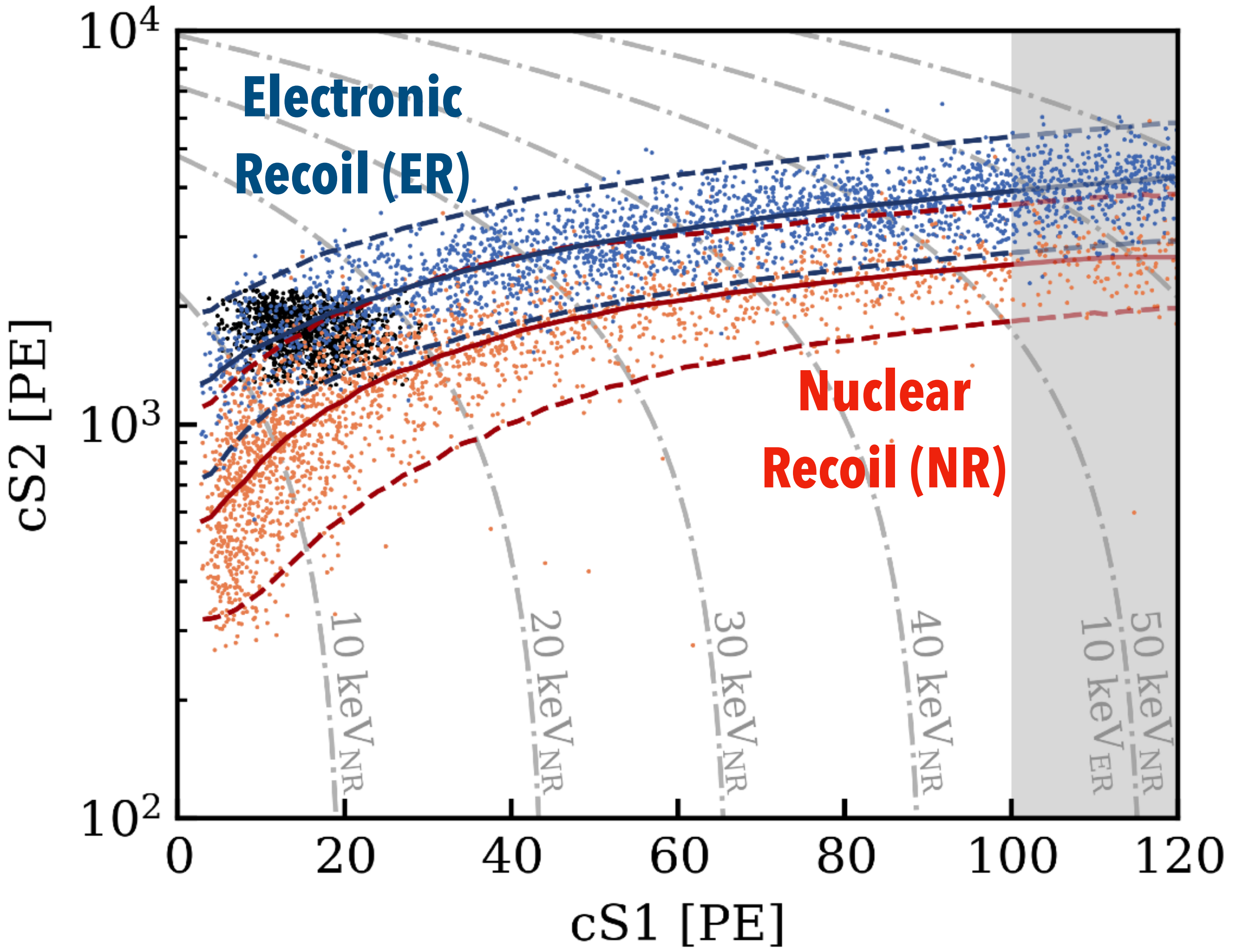
Signals:

- Prompt scintillation light (**S1**) in liquid xenon (LXe)
- Secondary light (**S2**) in gas xenon (GXe) from ionization charges



Dual-phase TPC technology provides:

- 3D position reconstruction
  - x - y from **S2** top photosensor pattern
  - z from **S1-S2** time delay



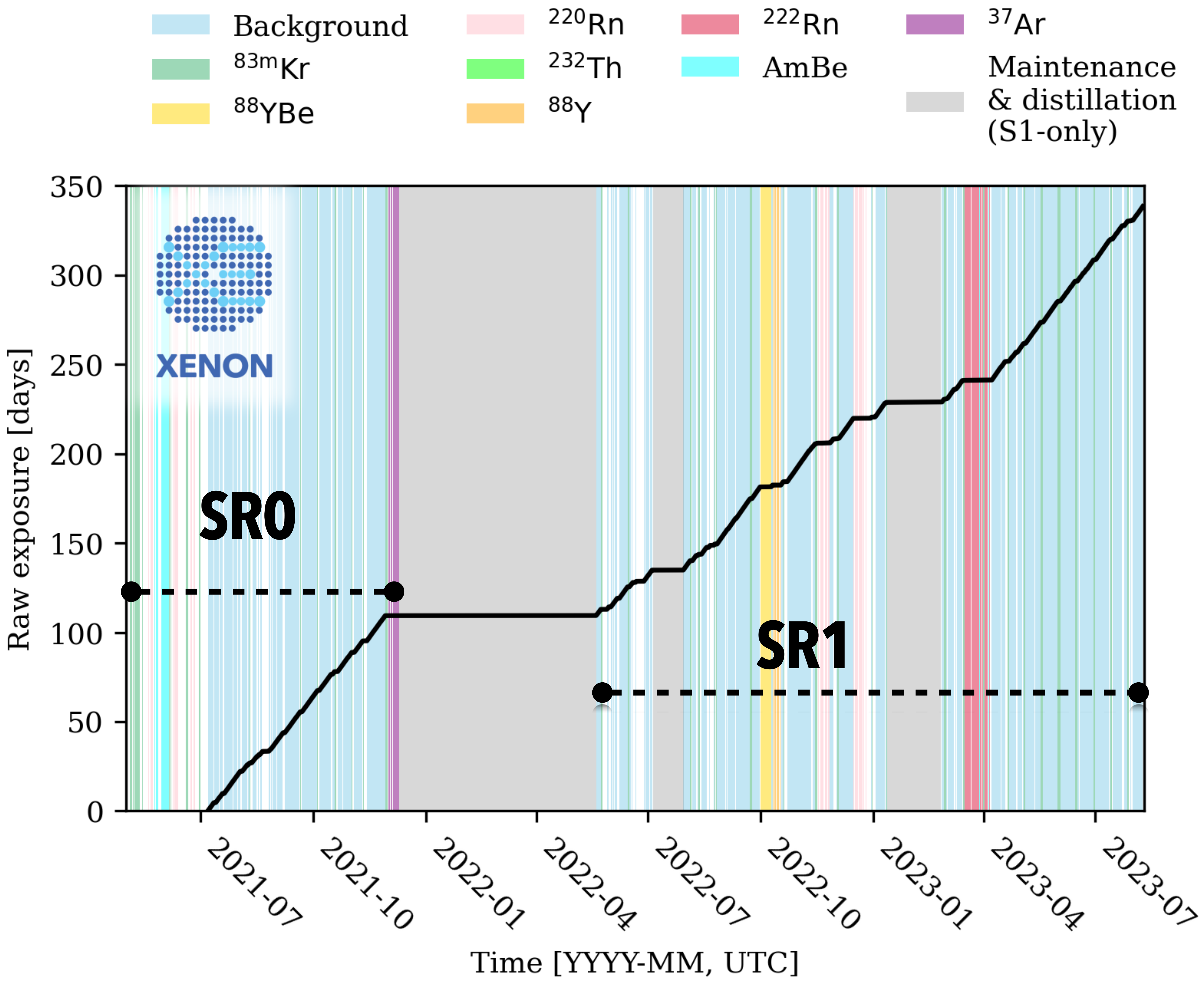
- Energy reconstruction from: $E \propto \left(\frac{S1}{g1} + \frac{S2}{g2}\right)$

- Discrimination of electronic and nuclear recoils using the **S1**/**S2** signal ratio

The first two science runs

- **Data taken between July 2021 and August 2023**
  - ~3.5 t x yr exposure
  - 4 t fiducial mass
- **Stable detector response**
  - Light yield <1 % variation
  - Charge yield <3 % variation
- **High liquid xenon purity**
  - Electron survival probability > 90% at the maximum drift length

Regular calibrations to study detector response and light/charge gains



Physics Results so far

α	χ	ν
ER channel	**NR WIMP dark matter**	**^{8}B solar neutrinos**
Phys.Rev.Lett. 129 (2022) 16, 161805	Phys.Rev.Lett. 131 (2023) 4, 041003 arXiv:2502.18005 (2025)	Phys.Rev.Lett. 133 (2024) 19, 191002
2022	**2023, 2025**	**2024**
SR0	**SR0, SR0 + SR1**	**SR0 + SR1**

Physics Results so far

This talk

ν

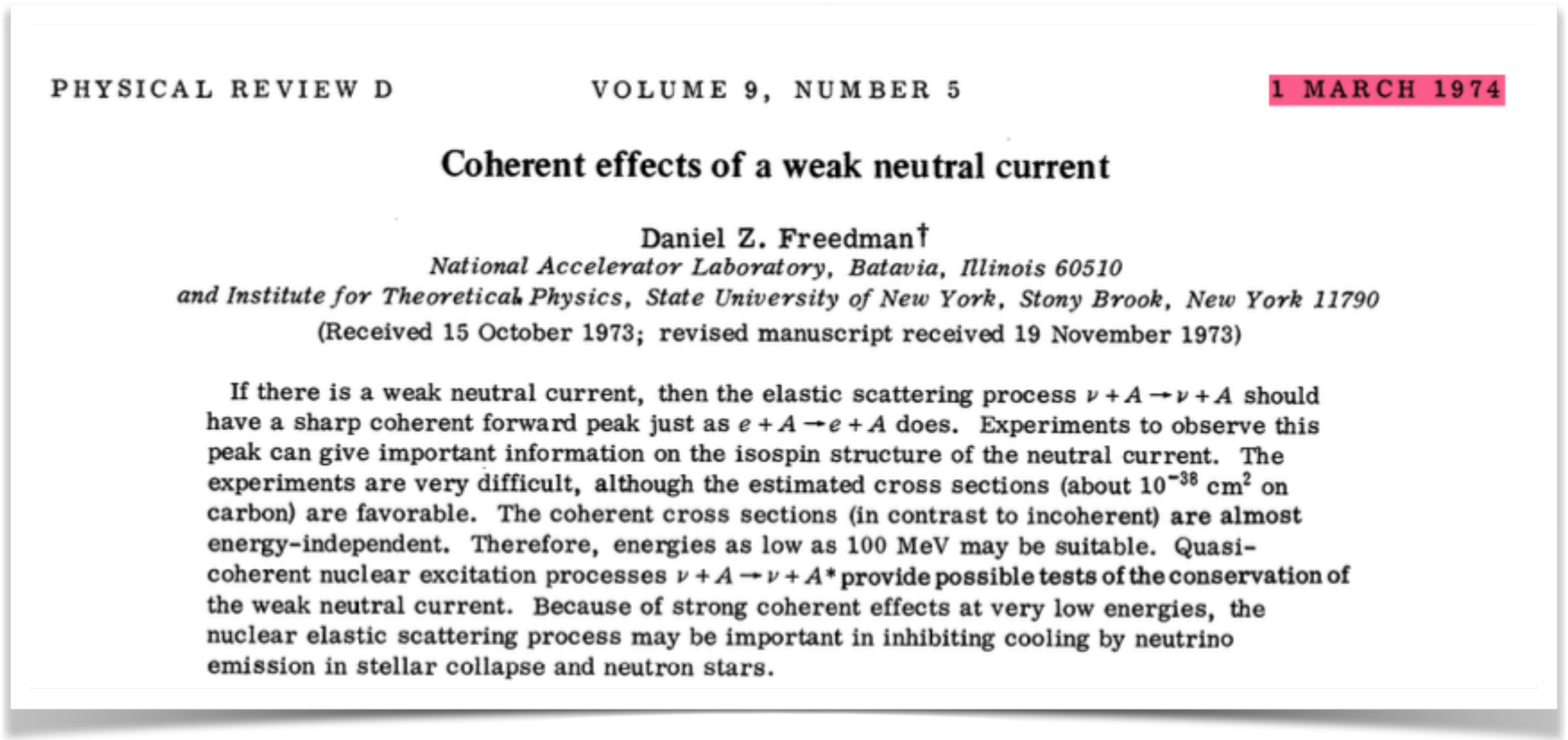
^{8}B solar neutrinos

Phys.Rev.Lett. 133 (2024) 19, 191002

2024

SR0 + SR1

Elastic Scattering of Dark Matter and Neutrinos



PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

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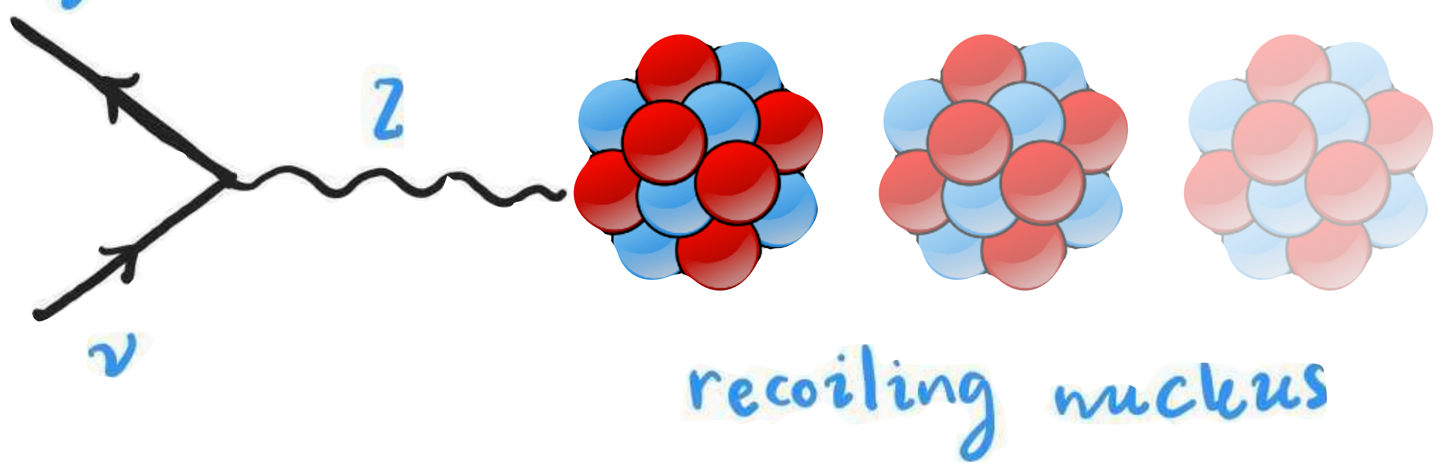
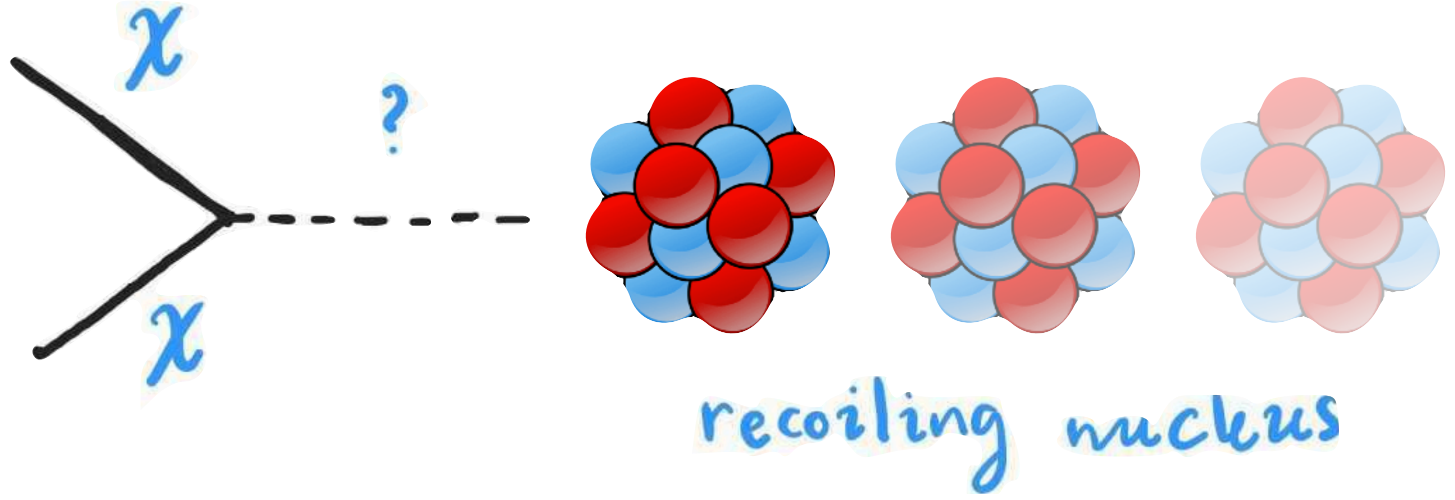
(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ 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} cm^2 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 $\nu + A \to \nu + A^*$ 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.

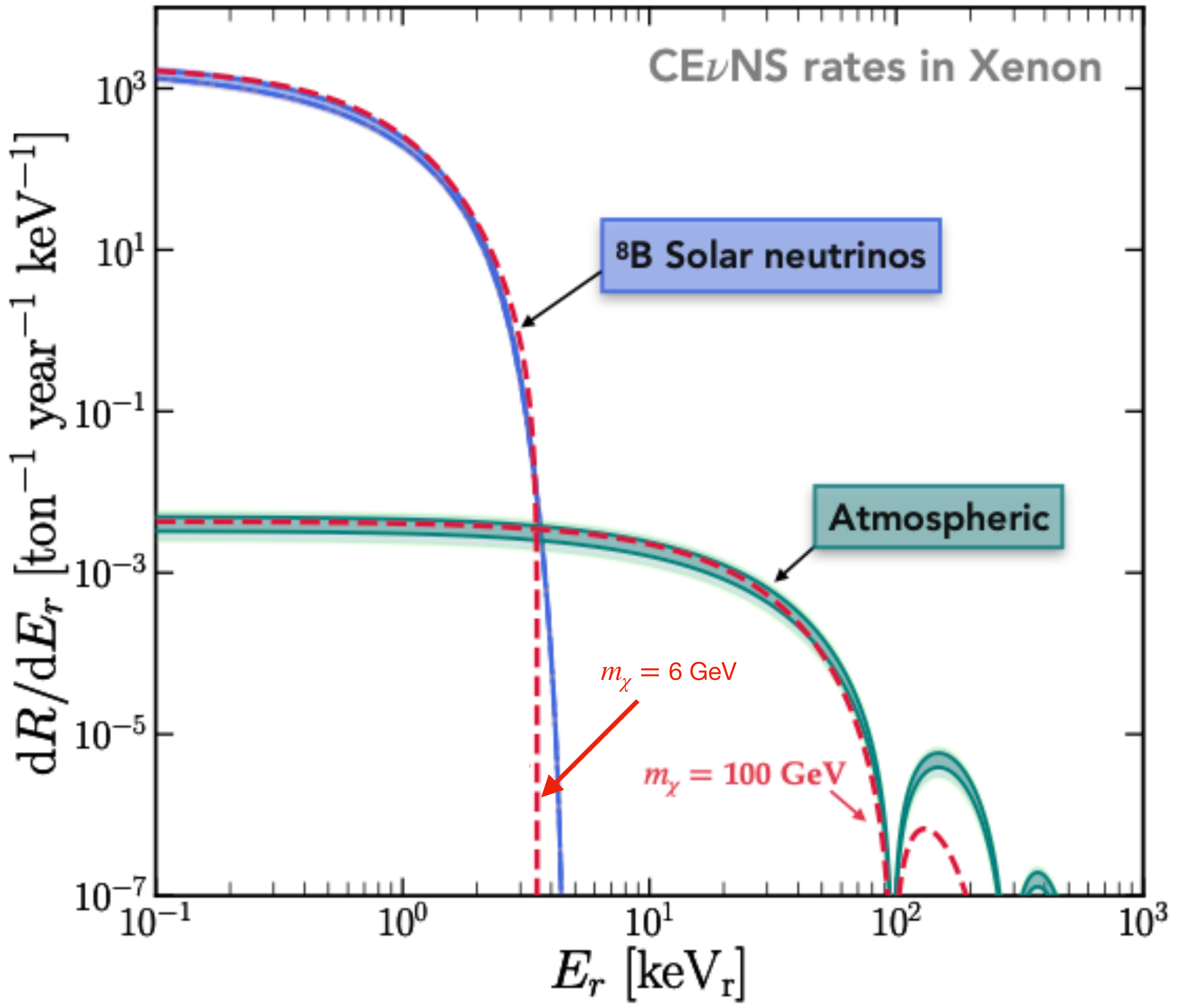
CEνNS



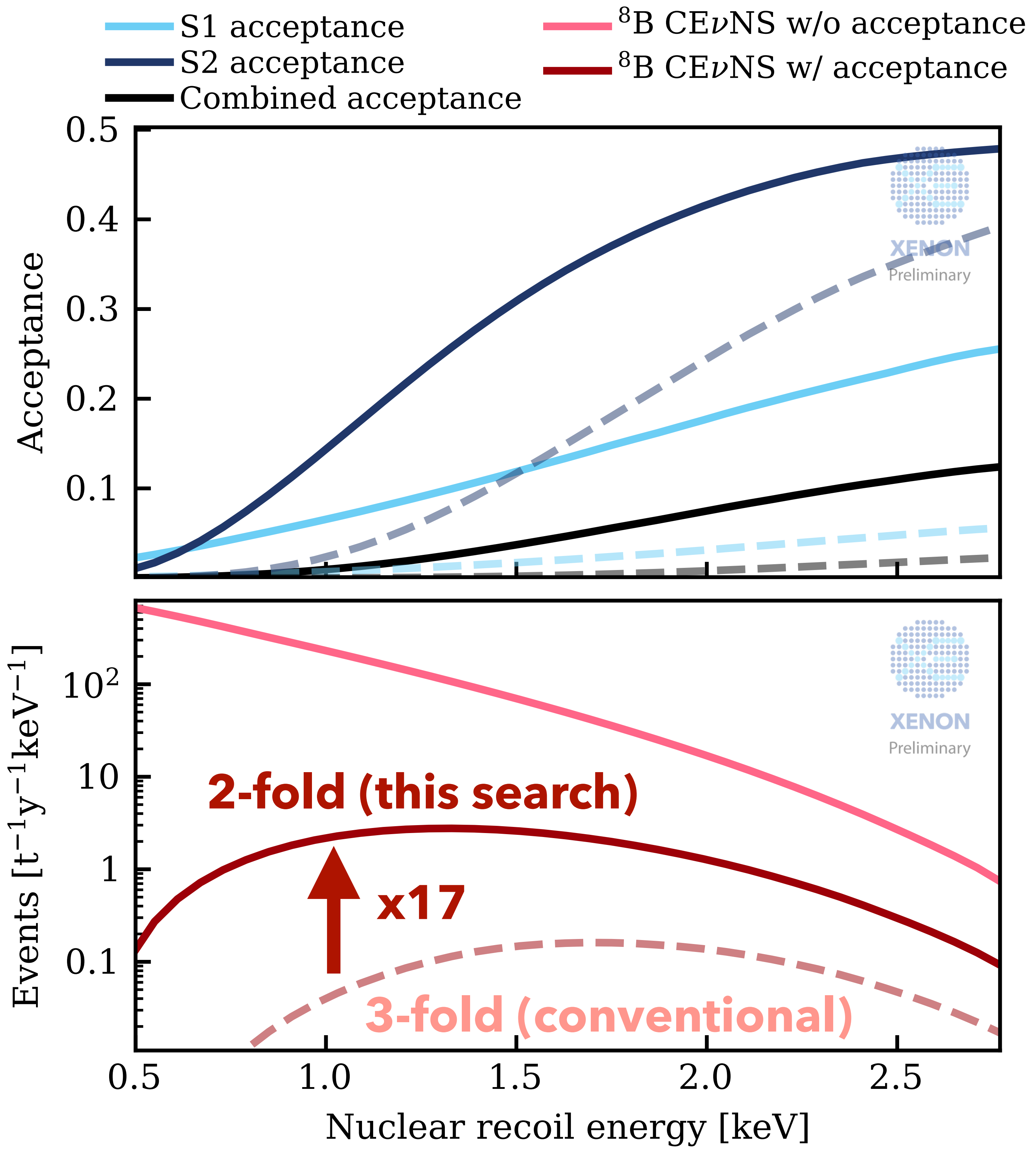
DM - nucleus scattering



- **CEνNS**: **C**oherent **E**lastic **N**eutrino - **N**ucleus **S**cattering
  - First measured by COHERENT (2017) with spallation neutron source
- ^{8}B CEνNS typical recoil energy $\lesssim$ 1.5 keV$_{NR}$
- Mimics single scatter NR signals expected from WIMPs



Lowering the Threshold



- 0.2 ^{8}B events expected in 3-fold conventional analysis
- PMT coincidence requirement reduced from 3 to 2 hits*

Region of interest for ^{8}B CEνNS search:

- S1: [2, 3] hits
- S2: [120, 500] photoelectrons $\simeq$ [4, 17] electrons

~17 times larger ^{8}B CEνNS rate!

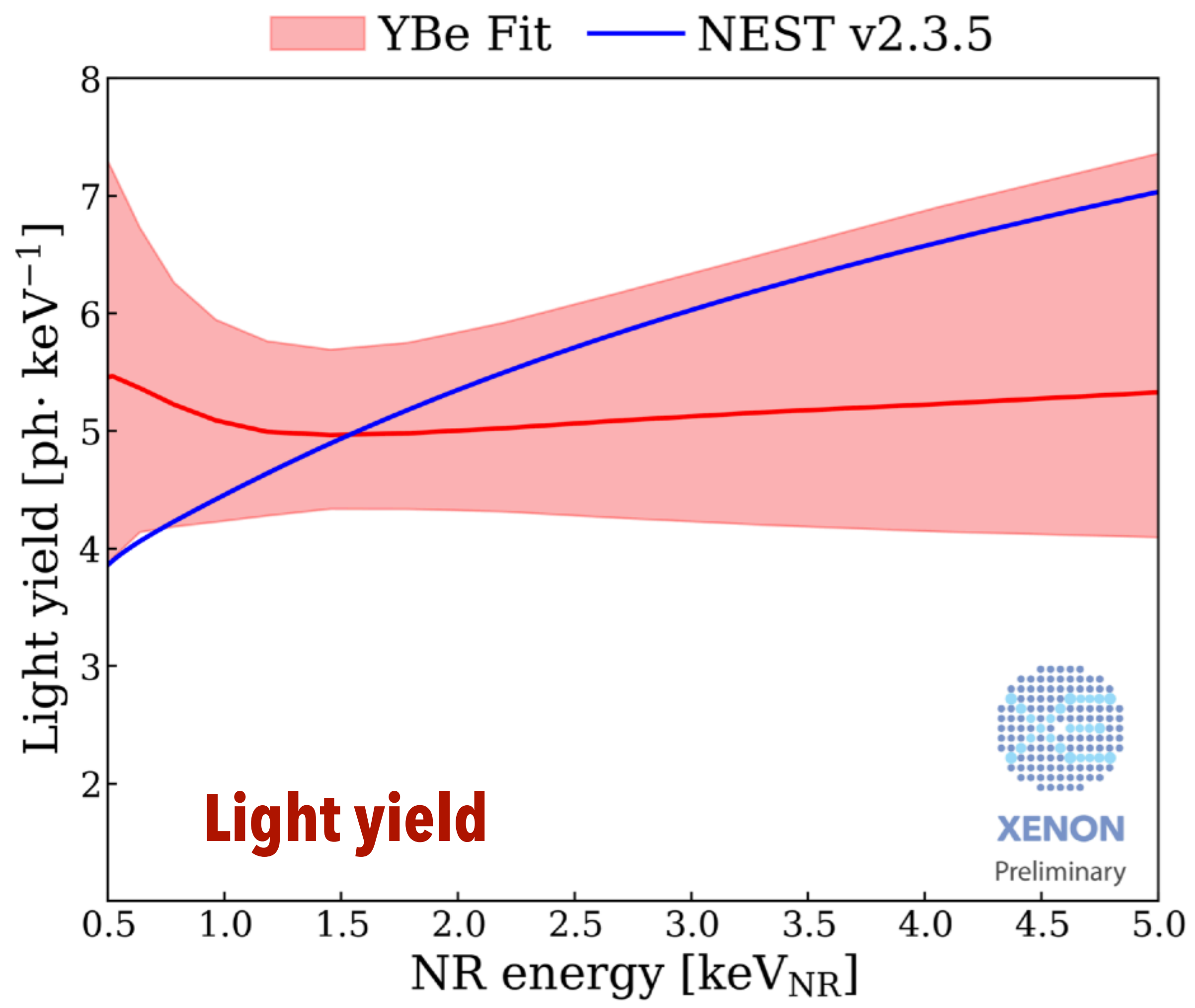
- Lowering the energy threshold is essential to increase the signal acceptance, but requires:
  - Model detector response to low-energy NRs
  - Suppress and constrain increased background

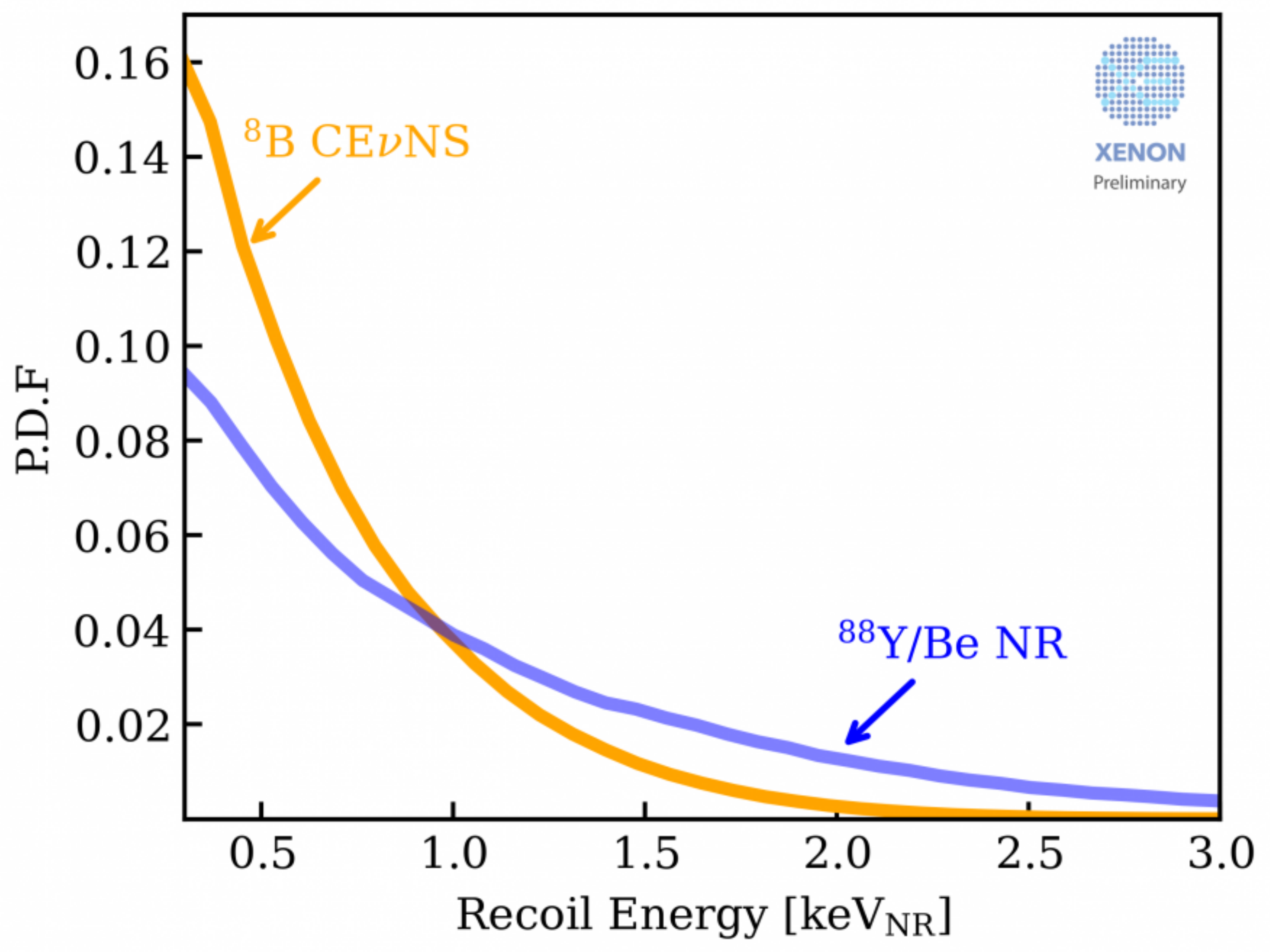
*PMT hit corresponds to a detected photon

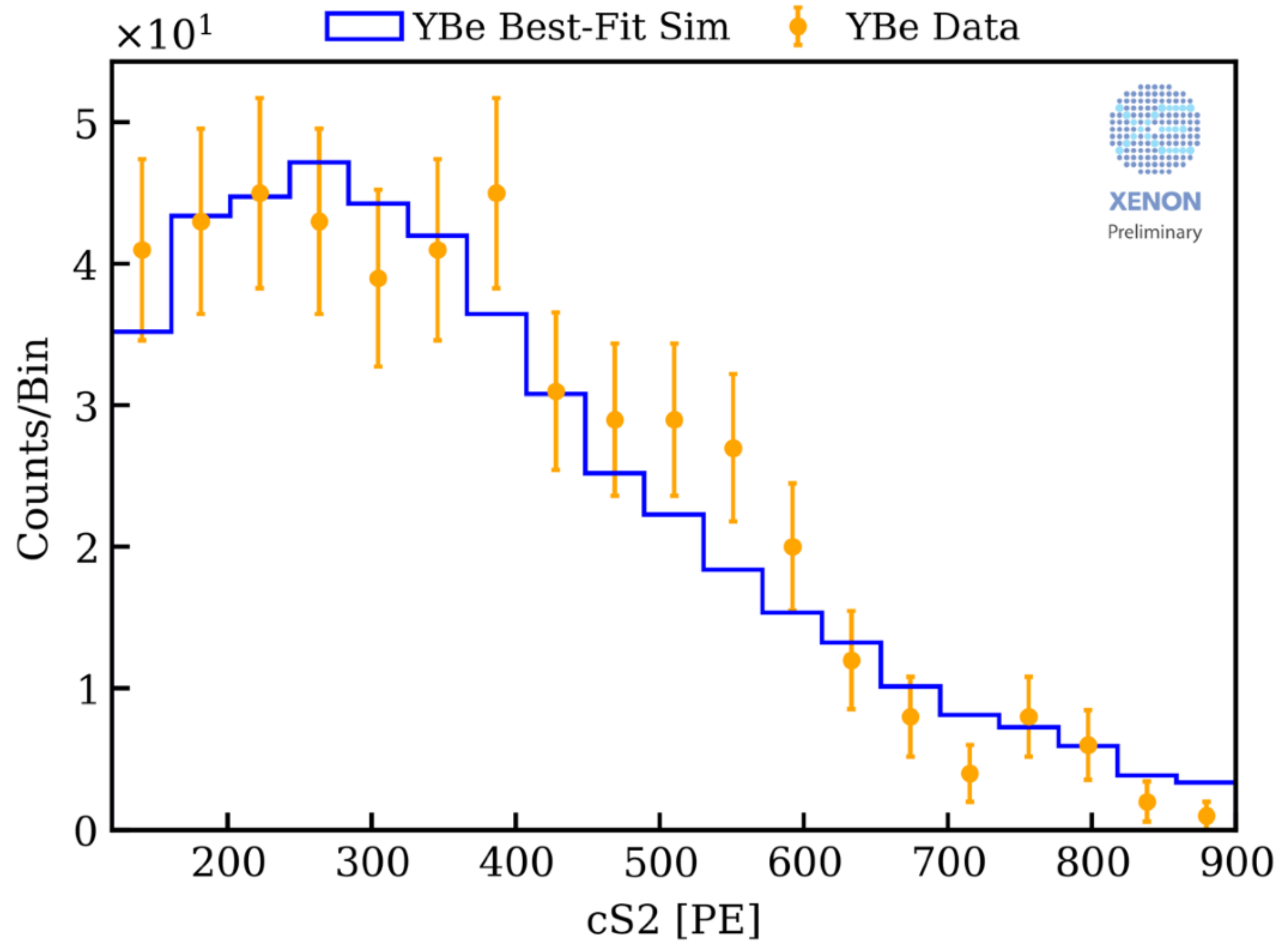
Low-Energy Calibration with ^{88}YBe

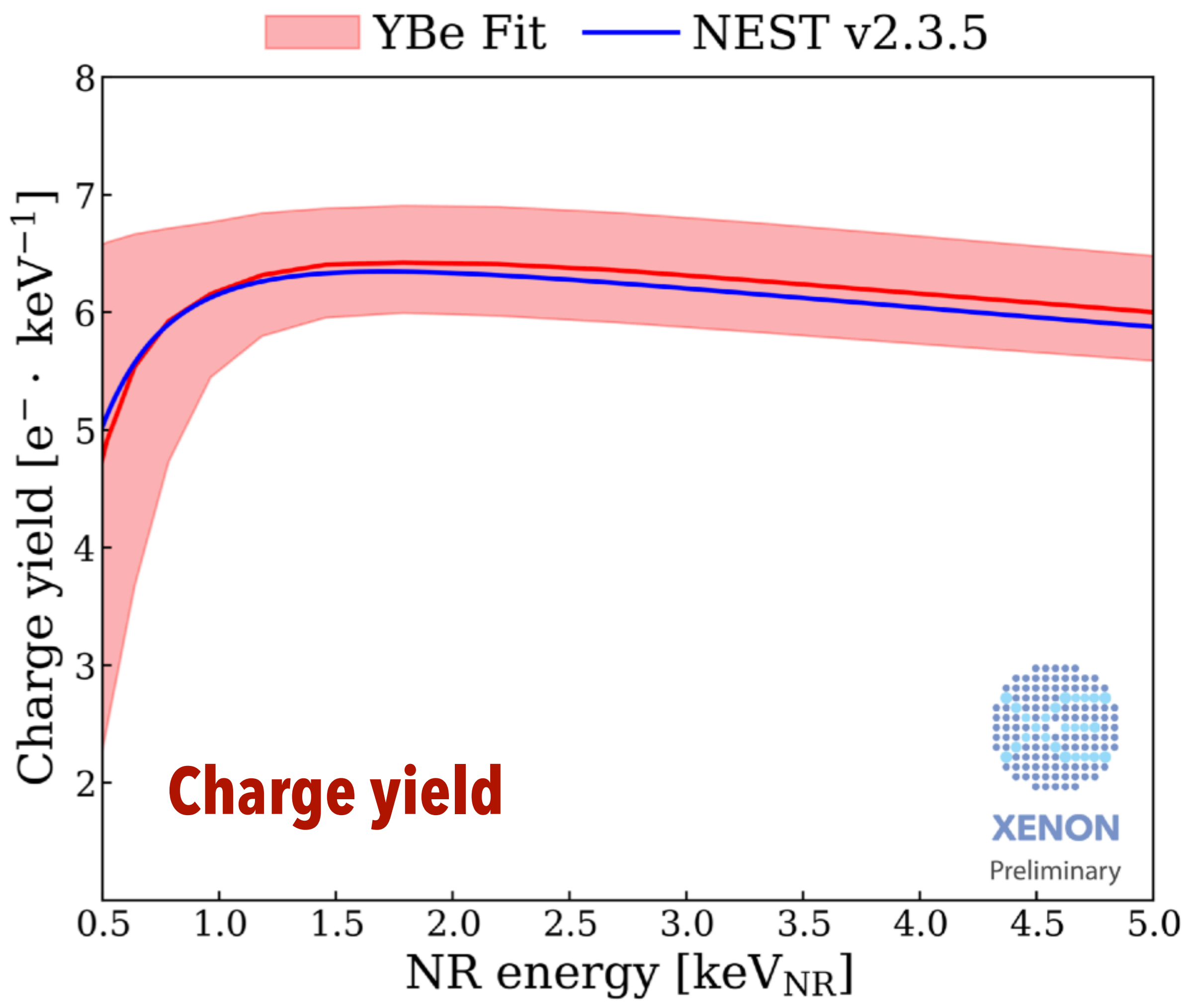
arXiv:2412.10451

- External ^{88}YBe source: $\gamma + {}^{9}\text{Be} \rightarrow \text{n} + {}^{8}\text{Be}$
  - $\sim$quasi-monoenergetic 152 keV neutrons
  - Nuclear recoil spectrum similar to ^{8}B
- Excellent match between simulations and calibration data
- Fit to NEST model to ^{88}YBe data to predict light and charge yields at the XENONnT drift field



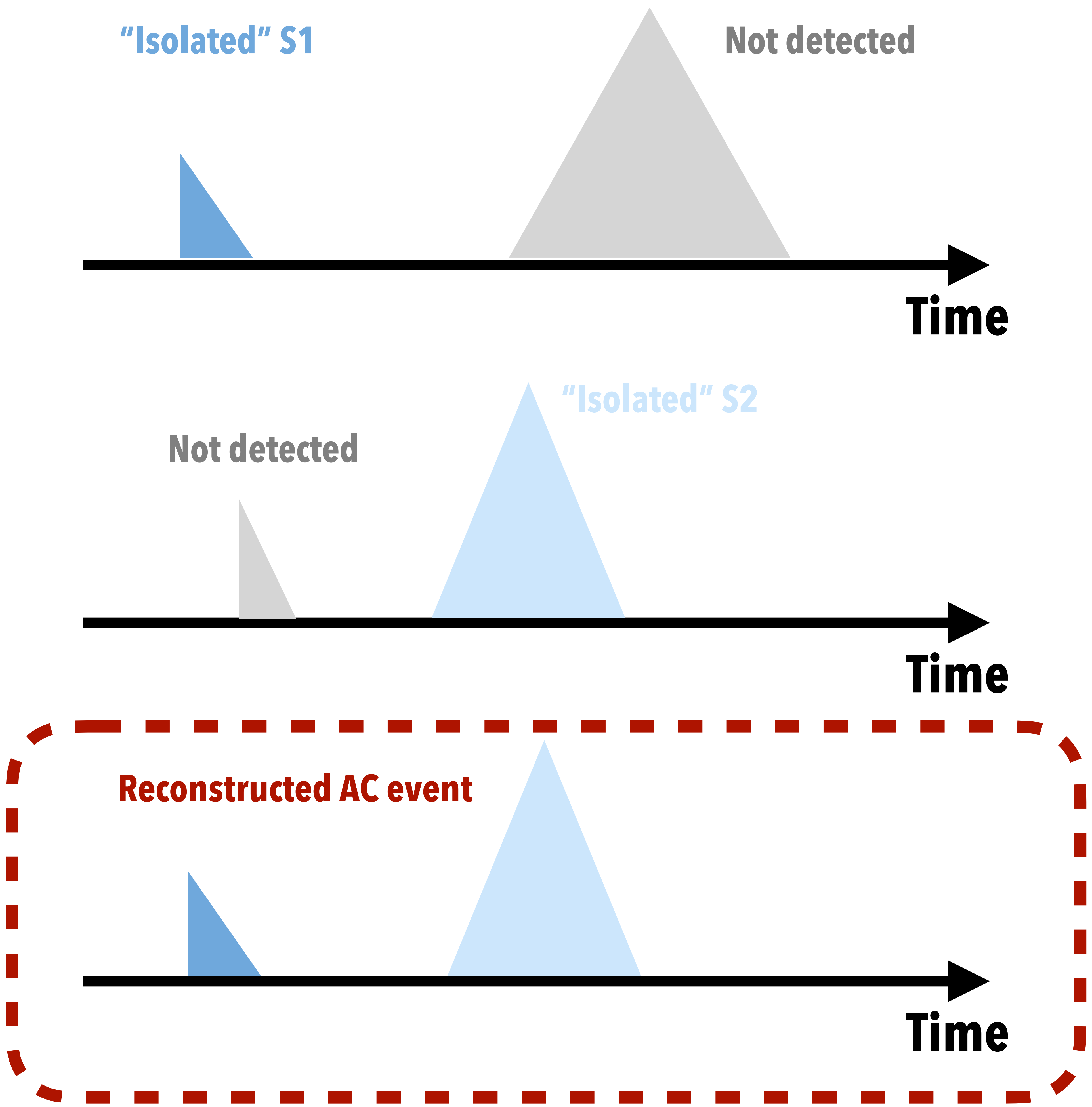






Dominant Background: Accidental Coincidence

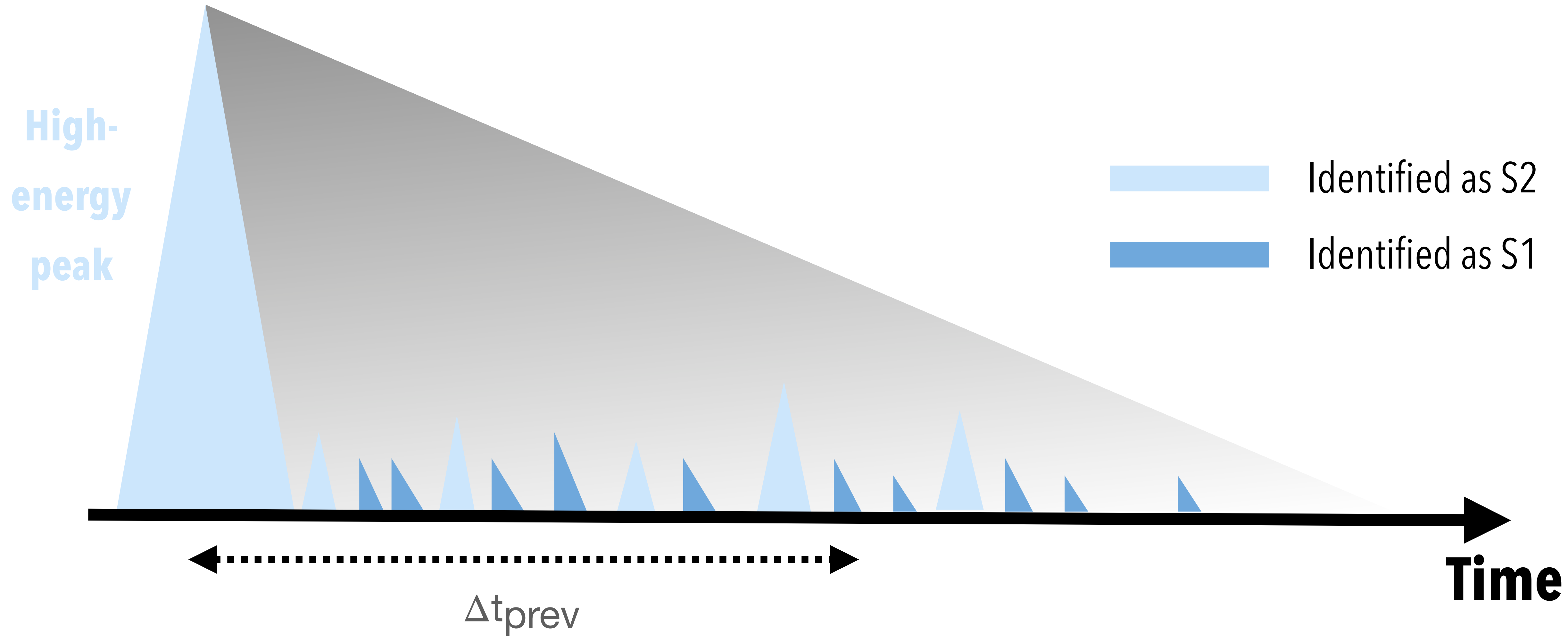
- Random unphysical pairing of **isolated S1** and **S2**
- Dominant background close to the threshold
- Rate before mitigation:
  - **"Isolated" S1**: ~15 Hz
  - **"Isolated" S2**: ~0.15 Hz
  - With max. Drift time of 2.25 ms → ~400 AC events per day
- Mitigation techniques include:
  - S1 and S2 Boosted Decision Tree (BDT) classifiers using waveform shape properties
  - S2 time shadow selection

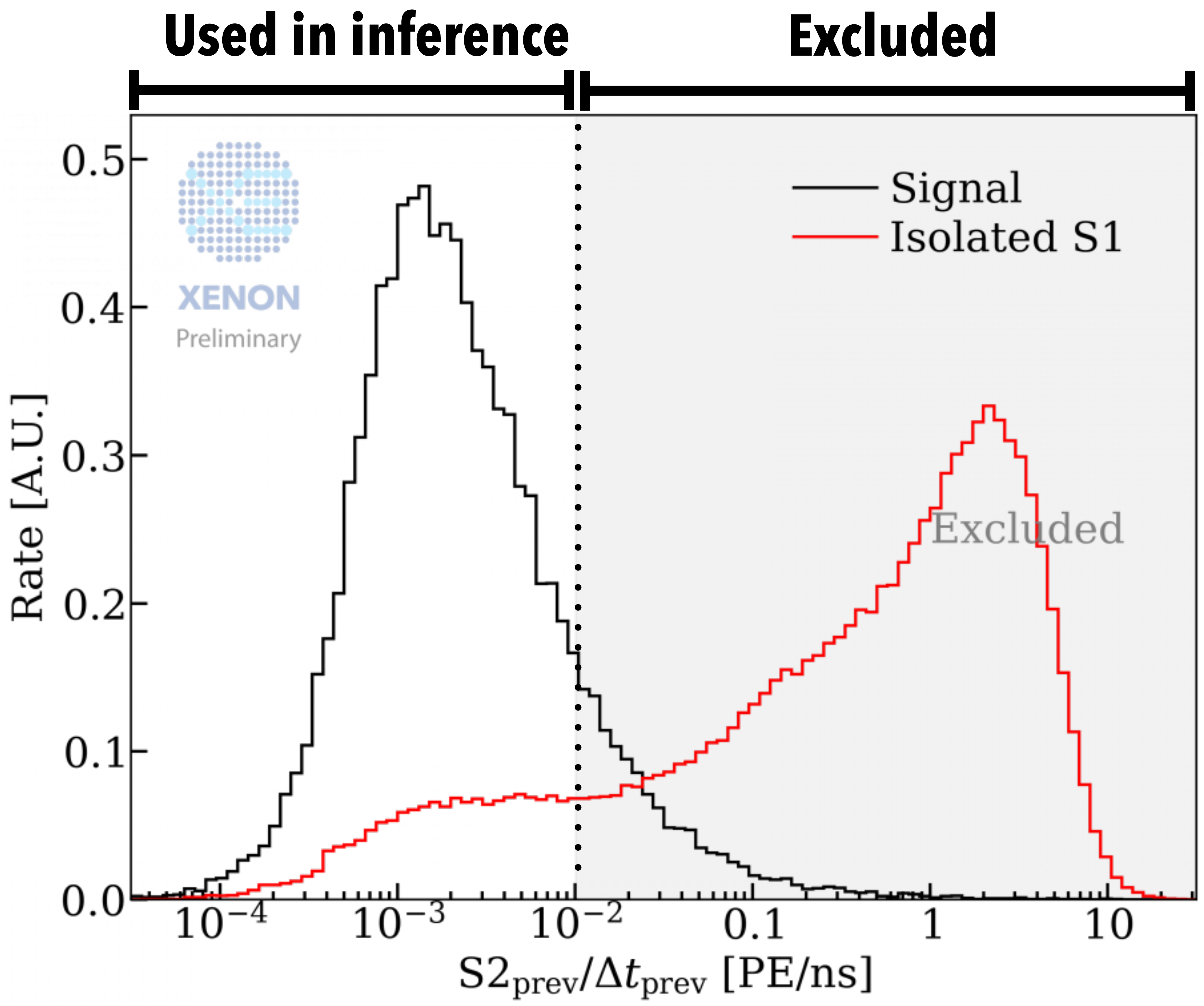


AC Background Suppression

- Mitigated utilizing selections based on time and position correlation to their preceding high-energy S2 peak

$$\textbf{Time shadow} \equiv \mathrm{Max}\left(\frac{S2_{prev}}{\Delta t_{prev}}\right)$$



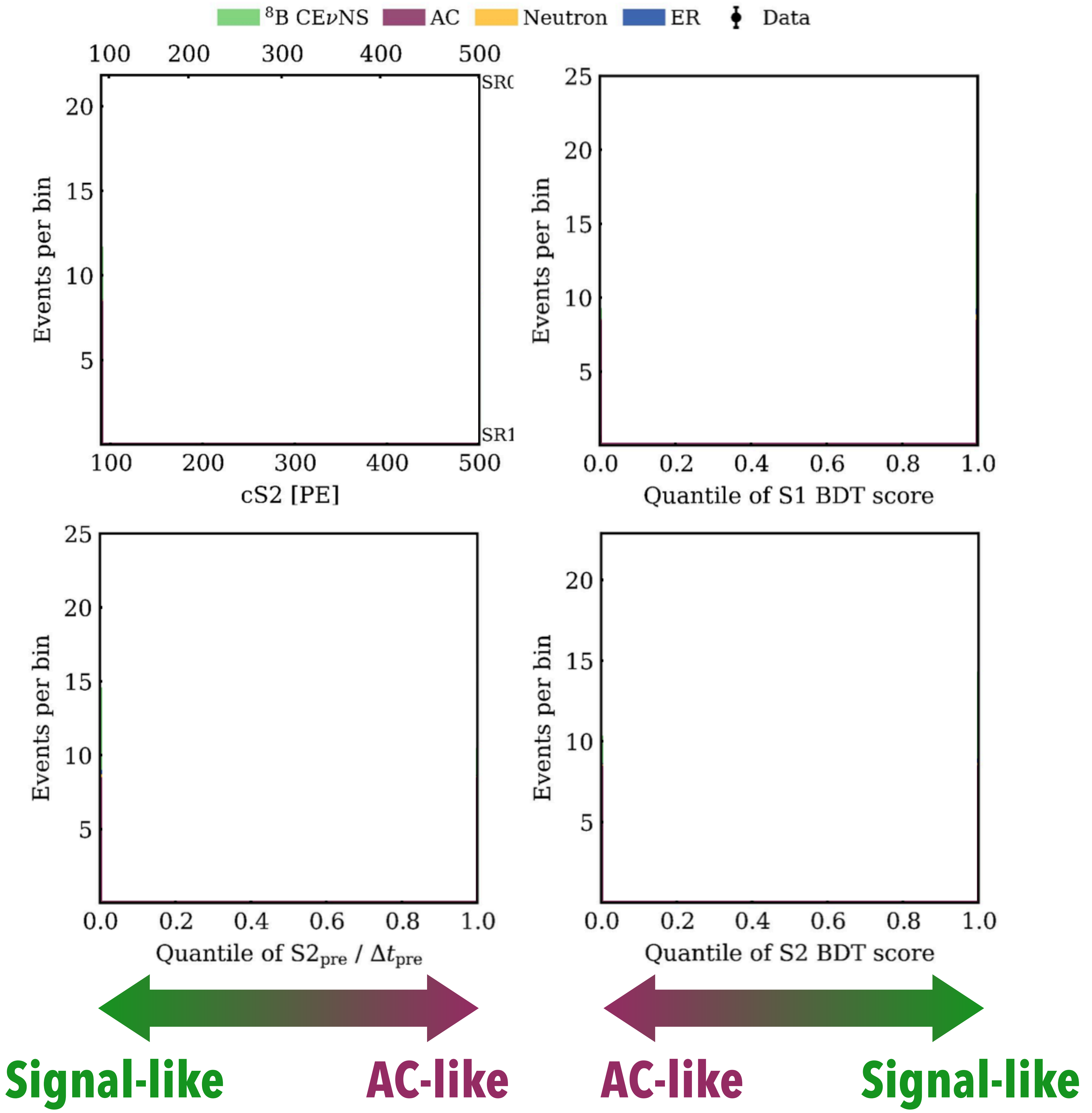


Signal & Background Prediction

Component	Expectation
AC (SR0)	7.5 ± 0.7
AC (SR1)	17.8 ± 1.0
ER	0.7 ± 0.7
Neutron	$0.5^{+0.2}_{-0.3}$
Total background	$26.4^{+1.4}_{-1.3}$
^{8}B	$11.9^{+4.5}_{-4.2}$

Total exposure: **3.51** ton·year

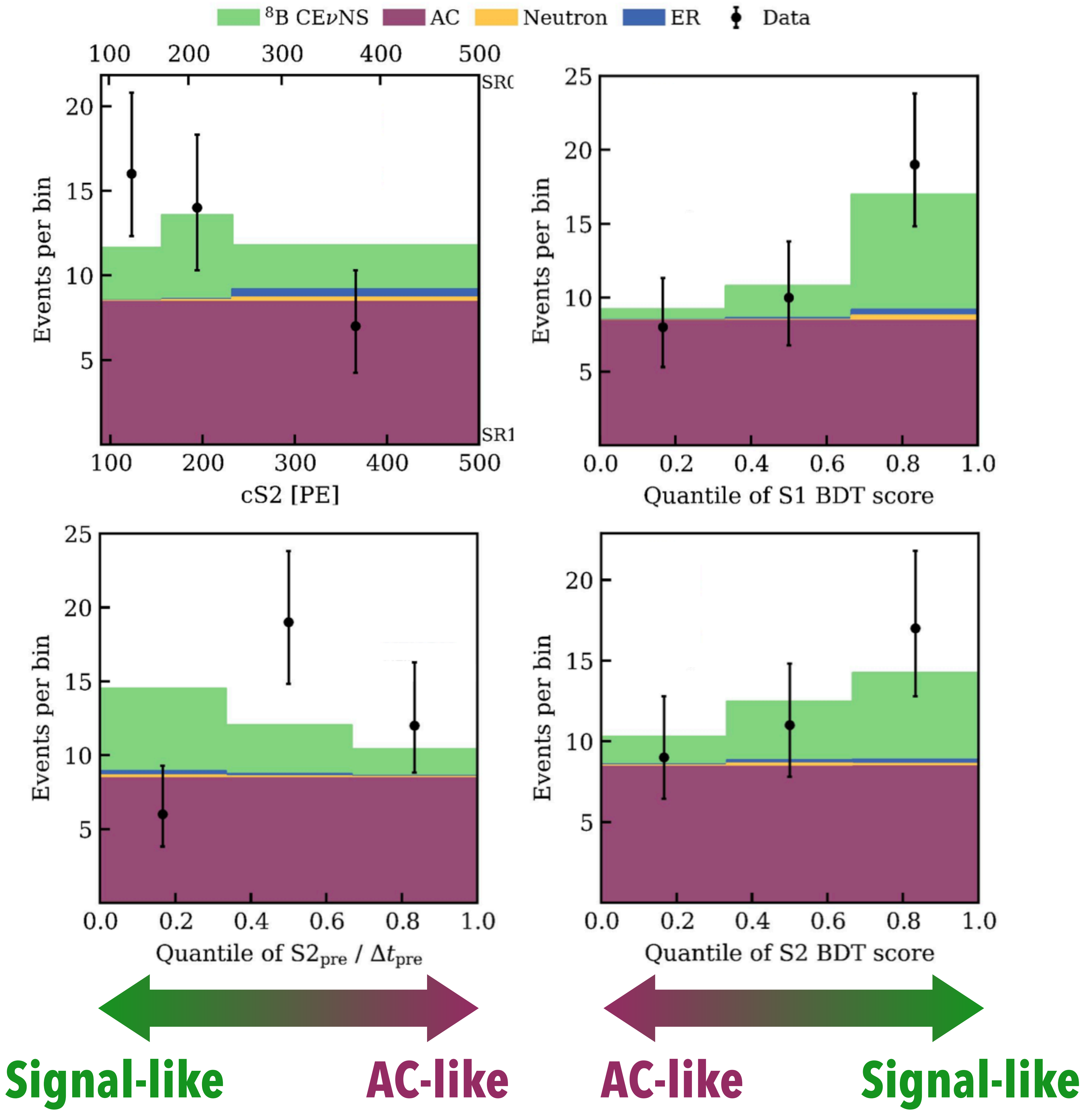
Expect ^{8}B CEνNS: $\mathbf{11.9}^{+4.5}_{-4.2}$ events



Unblinding Results

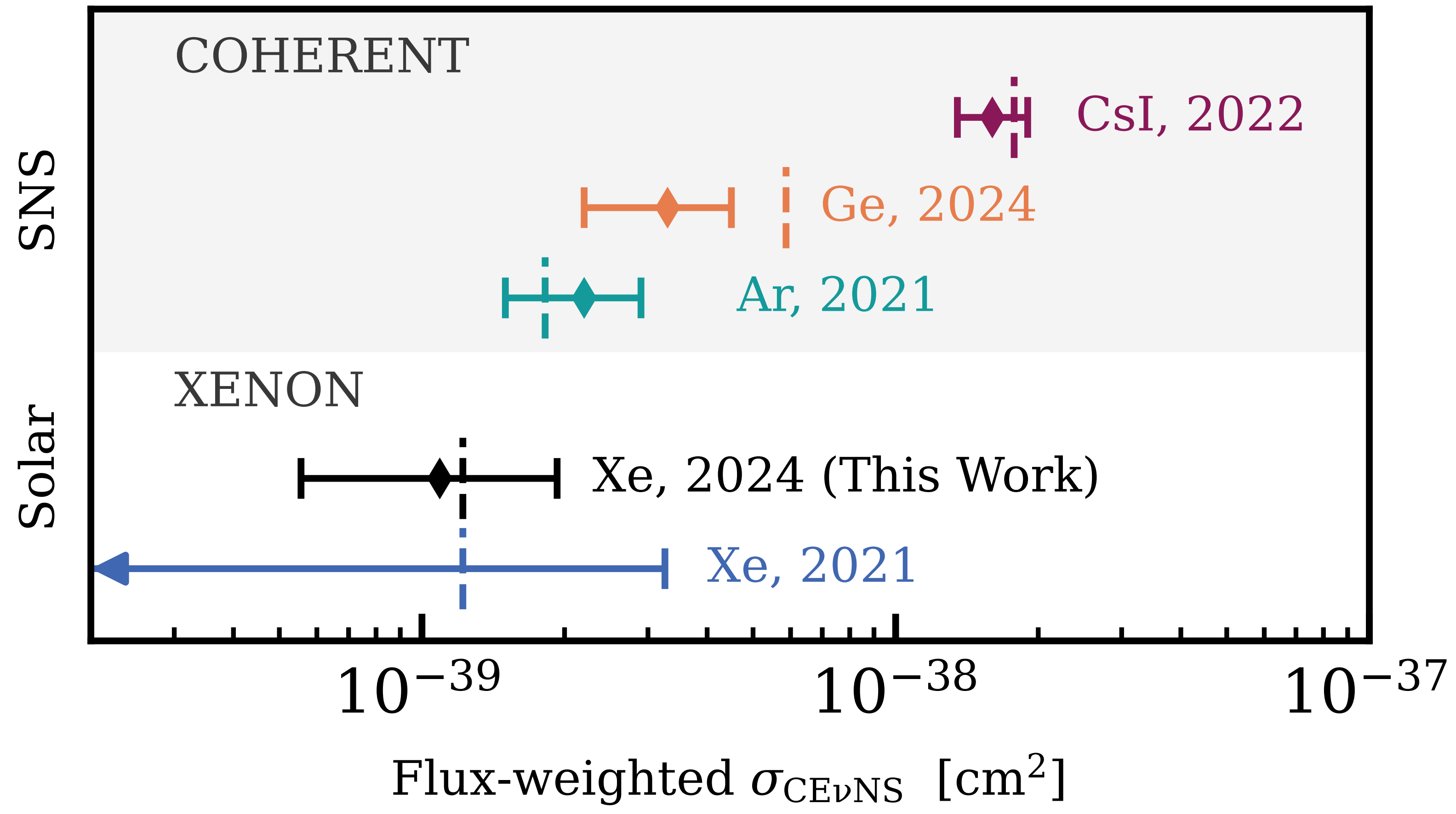
Component	Expectation	Best-fit
AC (SR0)	7.5 ± 0.7	7.4 ± 0.7
AC (SR1)	17.8 ± 1.0	17.9 ± 1.0
ER	0.7 ± 0.7	$0.5^{+0.7}_{-0.6}$
Neutron	$0.5^{+0.2}_{-0.3}$	0.5 ± 0.3
Total background	$26.4^{+1.4}_{-1.3}$	26.3 ± 1.4
^{8}B	$11.9^{+4.5}_{-4.2}$	$10.7^{+3.7}_{-4.2}$
Observed	37	

- Overall data agrees with the signal + background expectation in the four-dimension analysis
- Tension in the time shadow dimension is under investigation

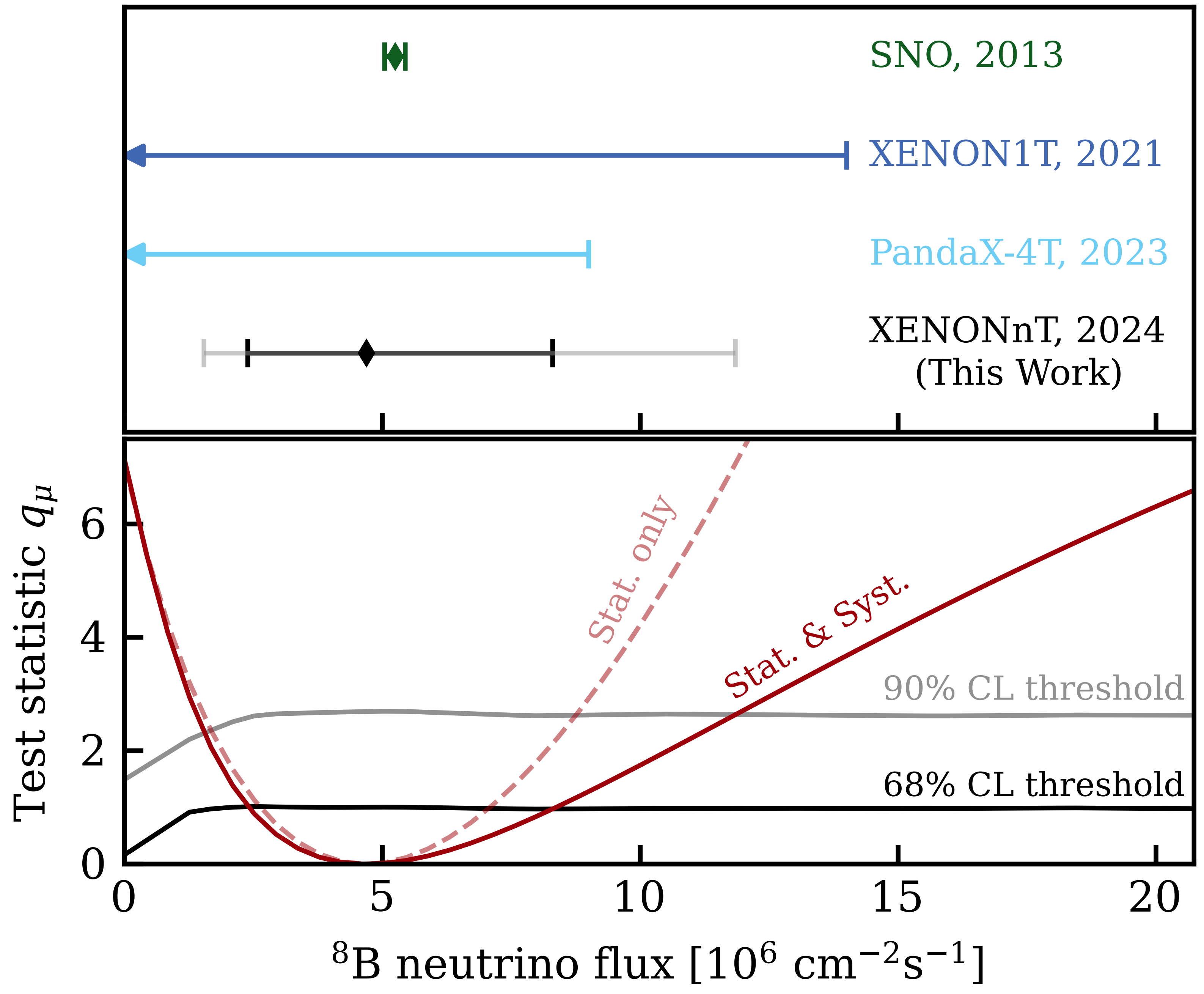


Statistical Inference

- The background-only hypothesis is disfavored at 2.73σ
- Measured ^{8}B neutrino flux: $(4.7^{+3.6}_{-2.3}) \times 10^{6}\ \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$
- Flux measurement in agreement with SNO (2013)

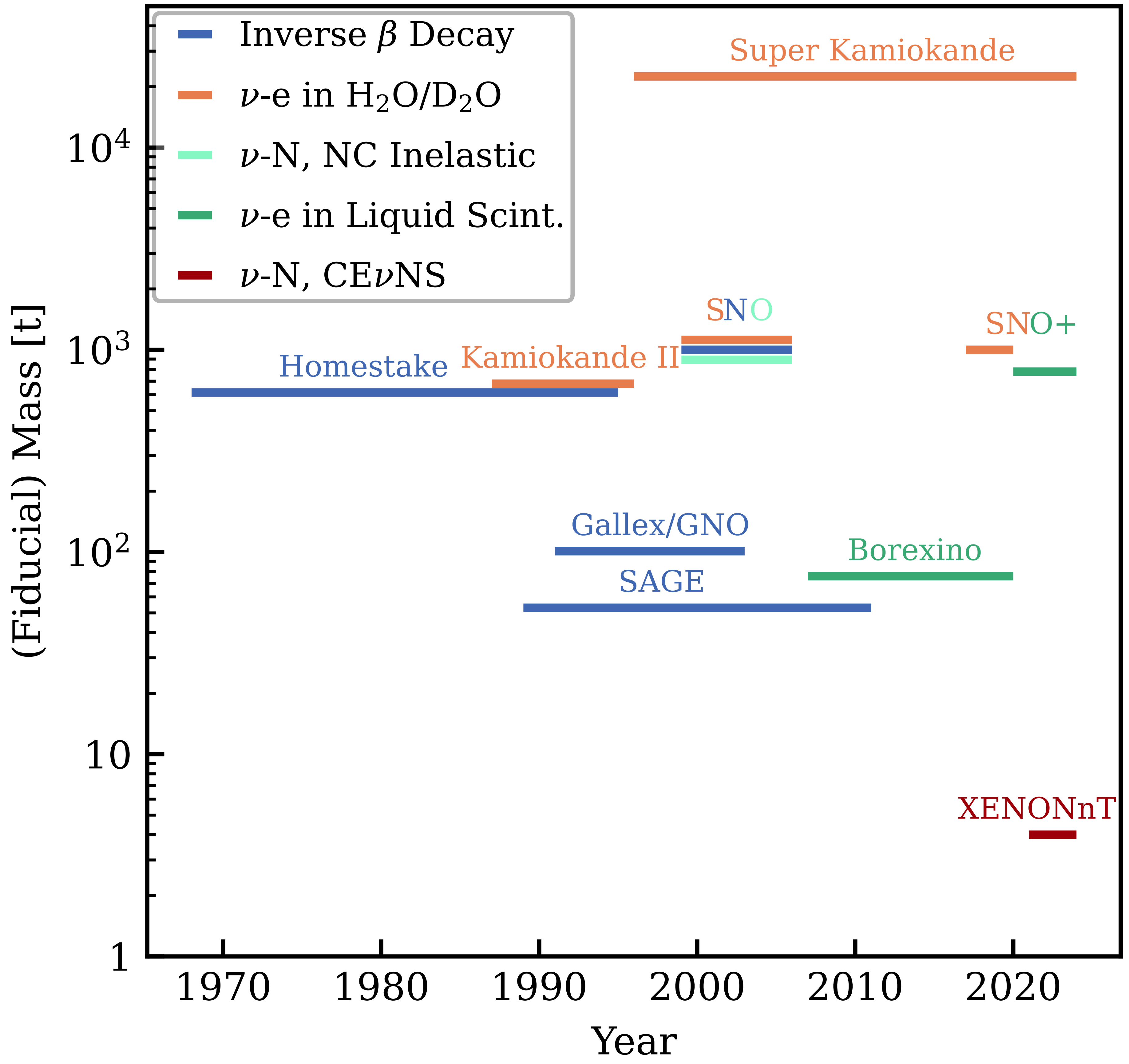


Similar results by Panda-X-4T
Phys. Rev. Lett. 133, 191002 (2024)



- $\sigma_{\mathrm{CE\nu NS}}$ in agreement with standard model prediction

Summary



- **XENONnT performed a blind search for ^{8}B CEνNS**
  - 2.73σ discovery significance
  - Measured ^{8}B neutrino flux: $4.7^{+3.6}_{-2.3} \times 10^6 \text{ cm}^{-2} \cdot \text{s}^{-1}$
- **First** detected astrophysical ν in a dark matter detector
- **First** measured CEνNS from astrophysical ν source
- **First** measured CEνNS with a Xe target
- XENONnT already finalized the third science run (SR2): **stay tuned for more results…**

Thank you.

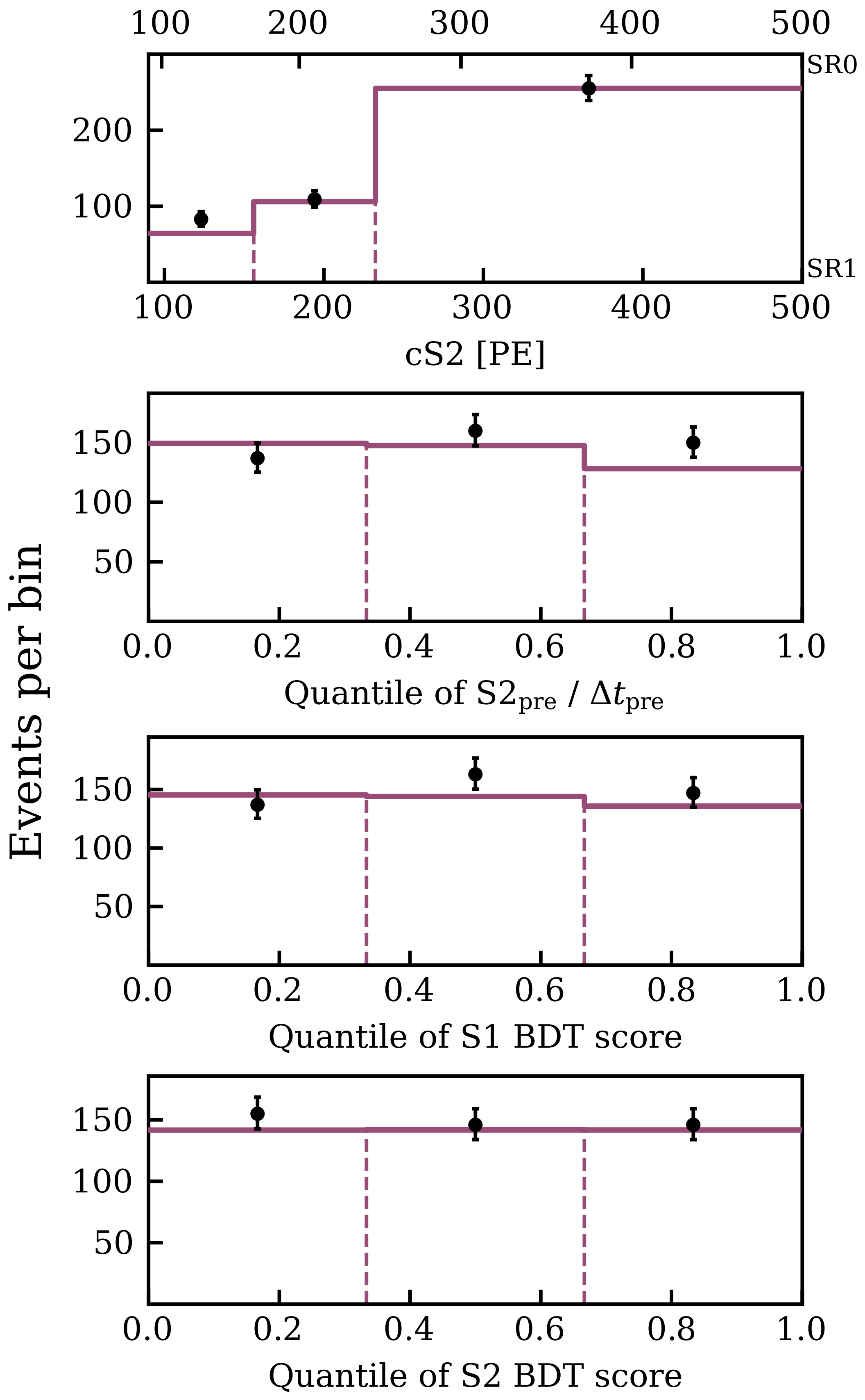
XENONnT: The Smallest Solar Neutrino Detector

Slide courtesy: ***R. Hammann***

Additional slides

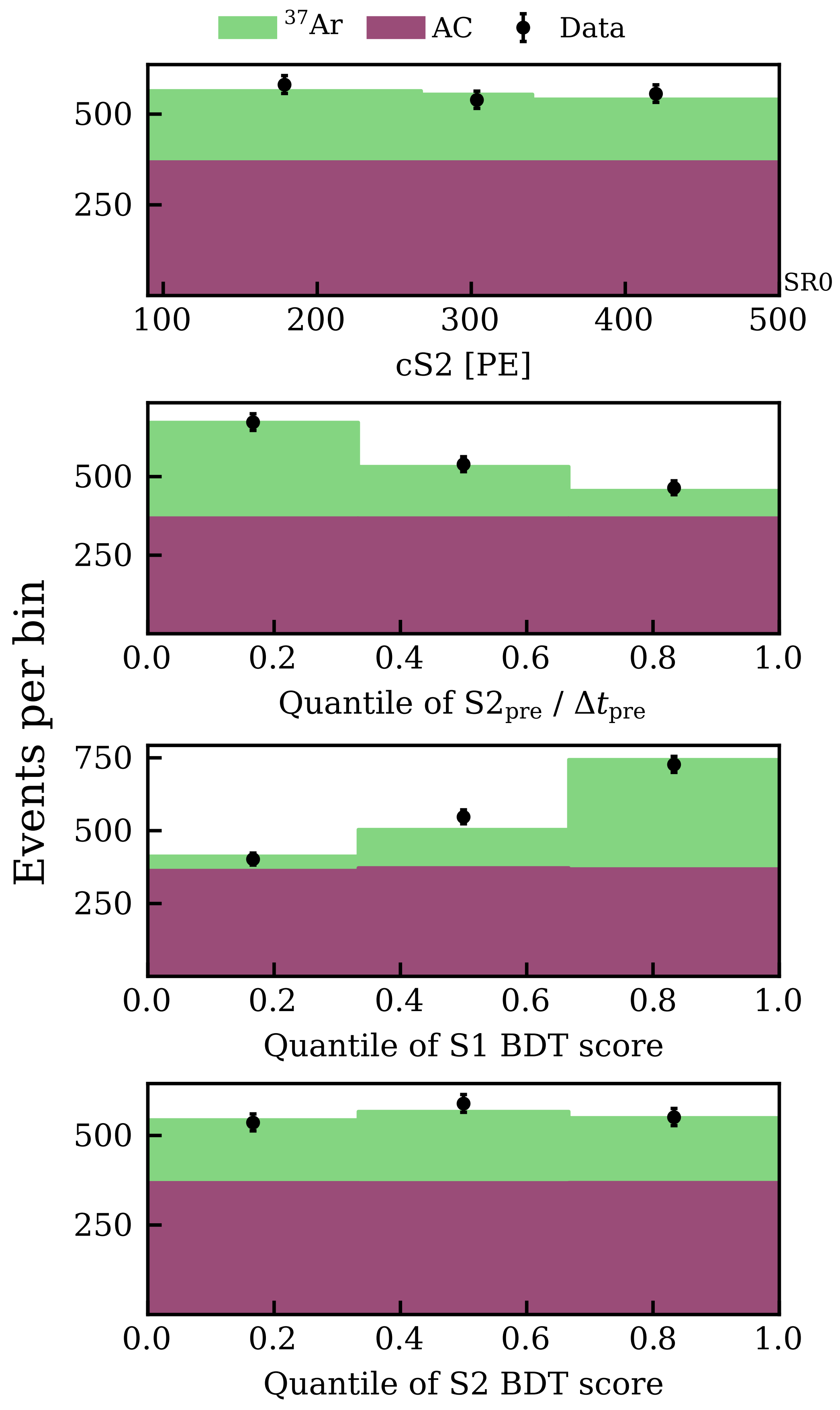
Validation of AC model

AC SIDE BAND



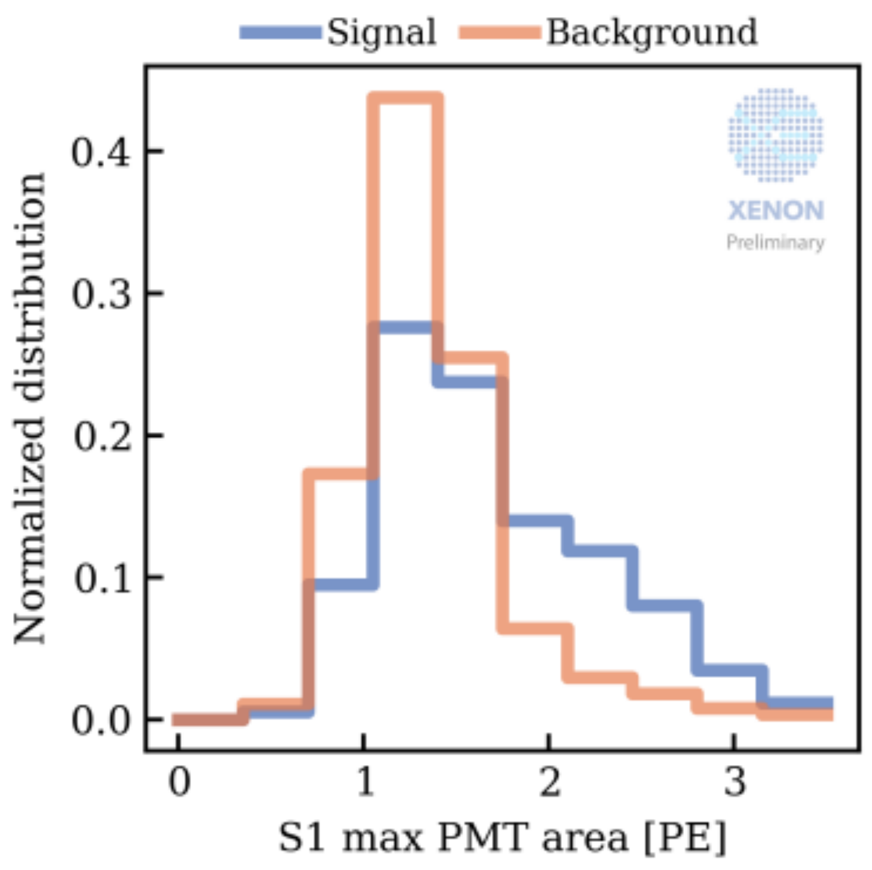
- Validated with AC-rich sideband (events that failed the S2 BDT cut)
- AC model validated with 4D GOF test (p-value =0.16)
- The difference (< 10%) is propagated as systematic uncertainty to final likelihood

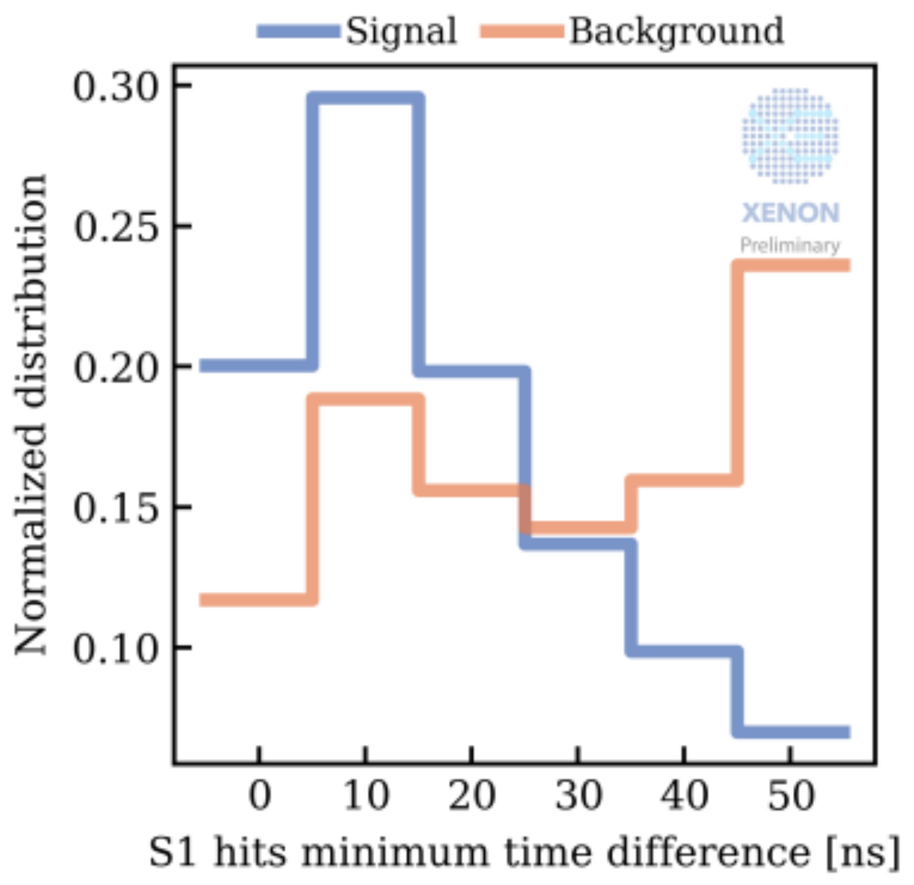
^{37}Ar L-shell EC

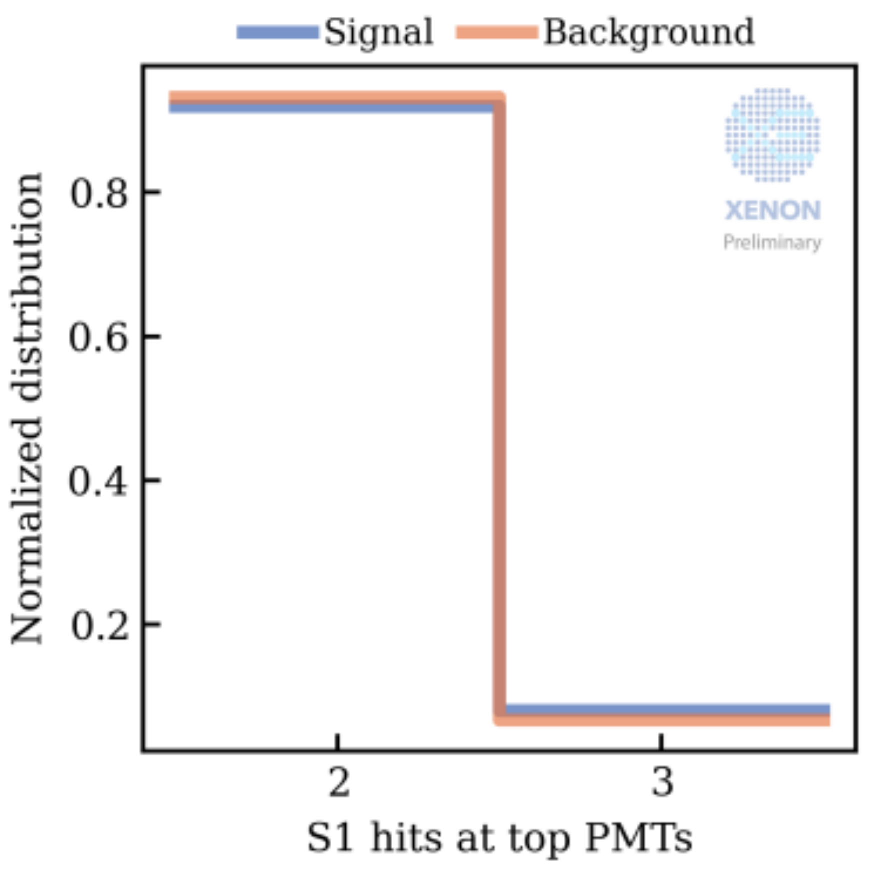


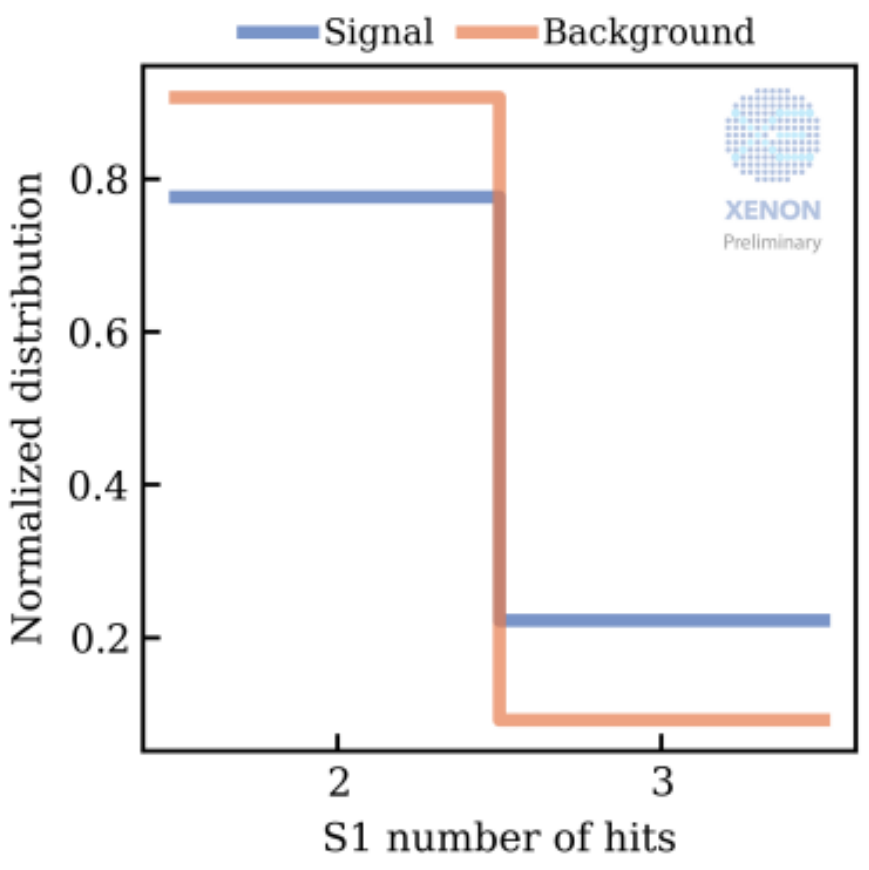
- Validated by ^{37}Ar L-shell 0.27 keV ER calibration data
- Fit match signal + background model
- 4D GOF test: p-value 0.92

S1 BDT









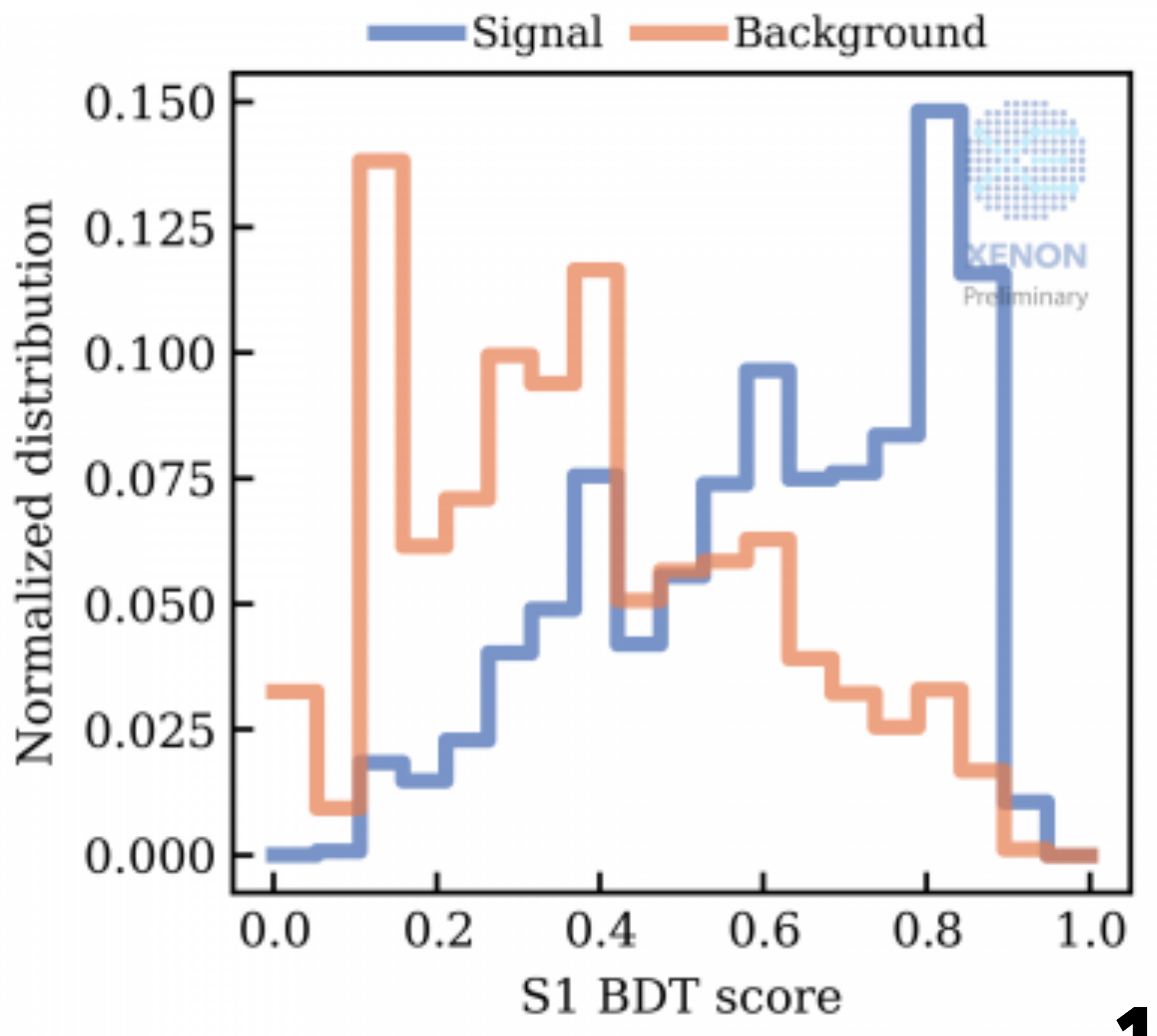
4th: Total hit count

1st: Max hit area

2nd: Minimum time between hits

3rd: Hit count in top photosensor array

Feature importance ←



S2 BDT

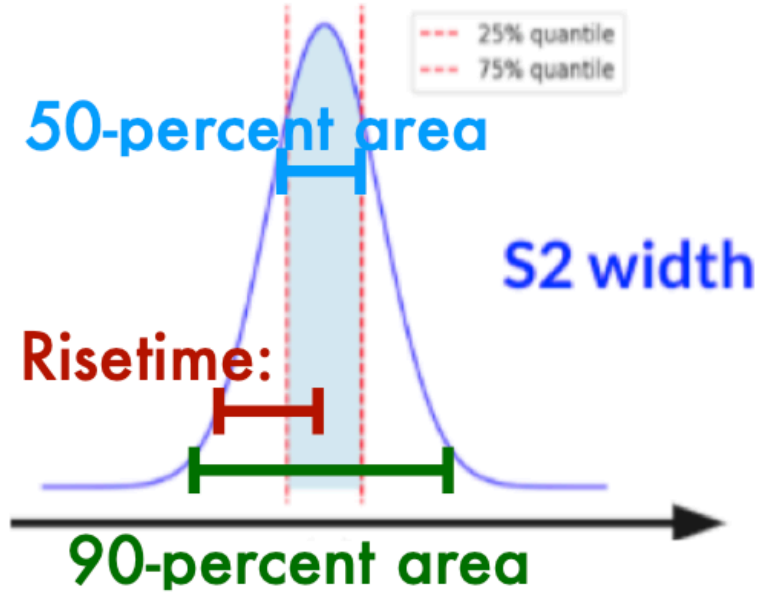
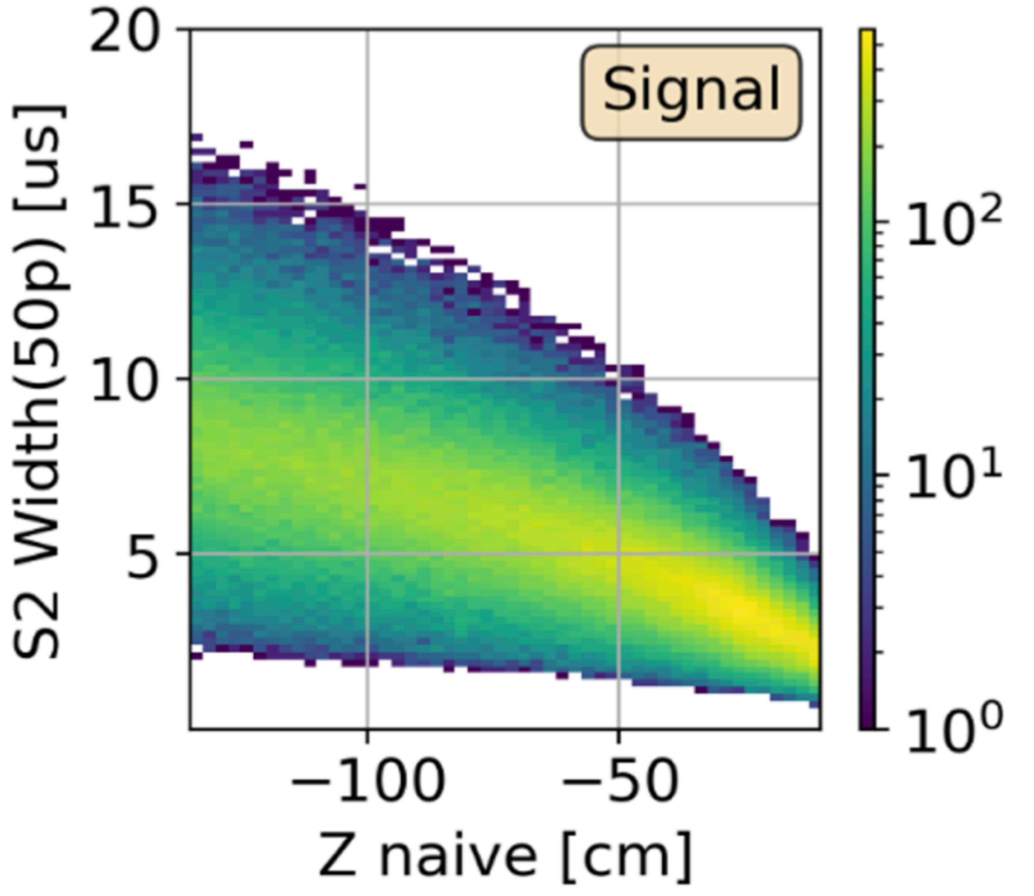
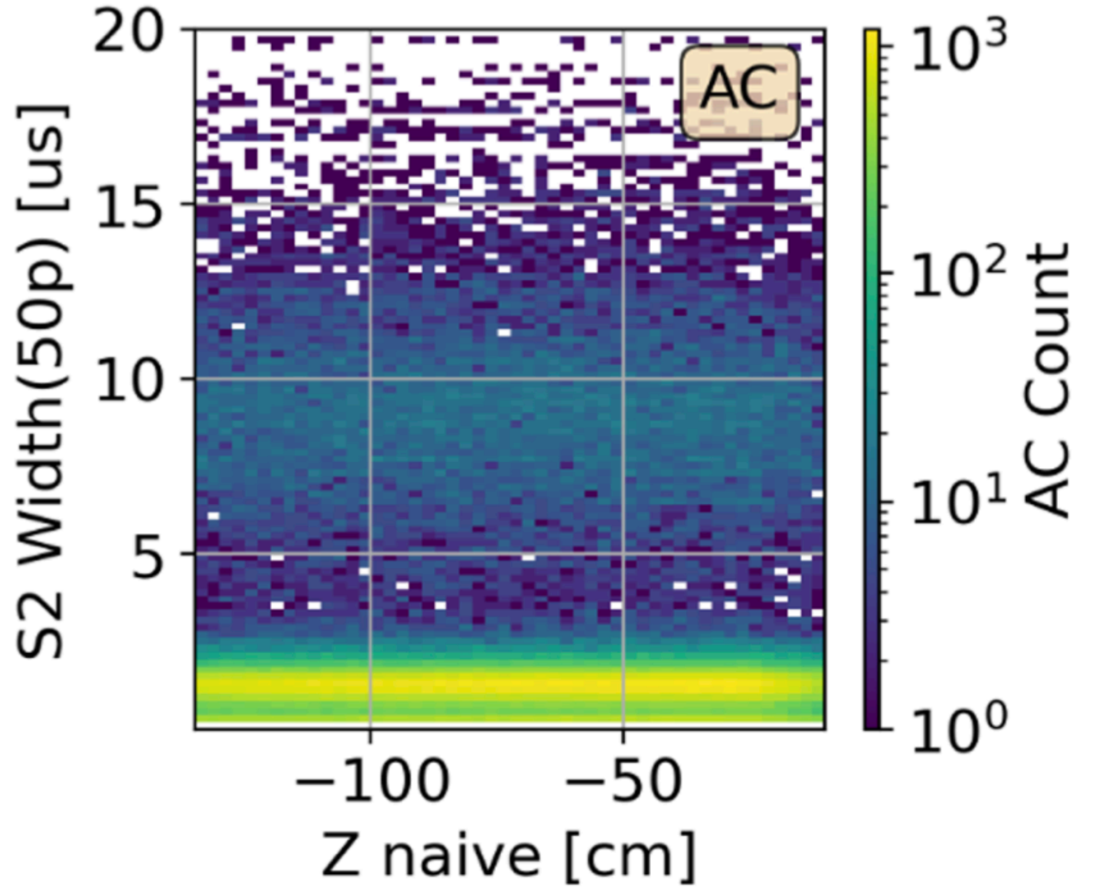
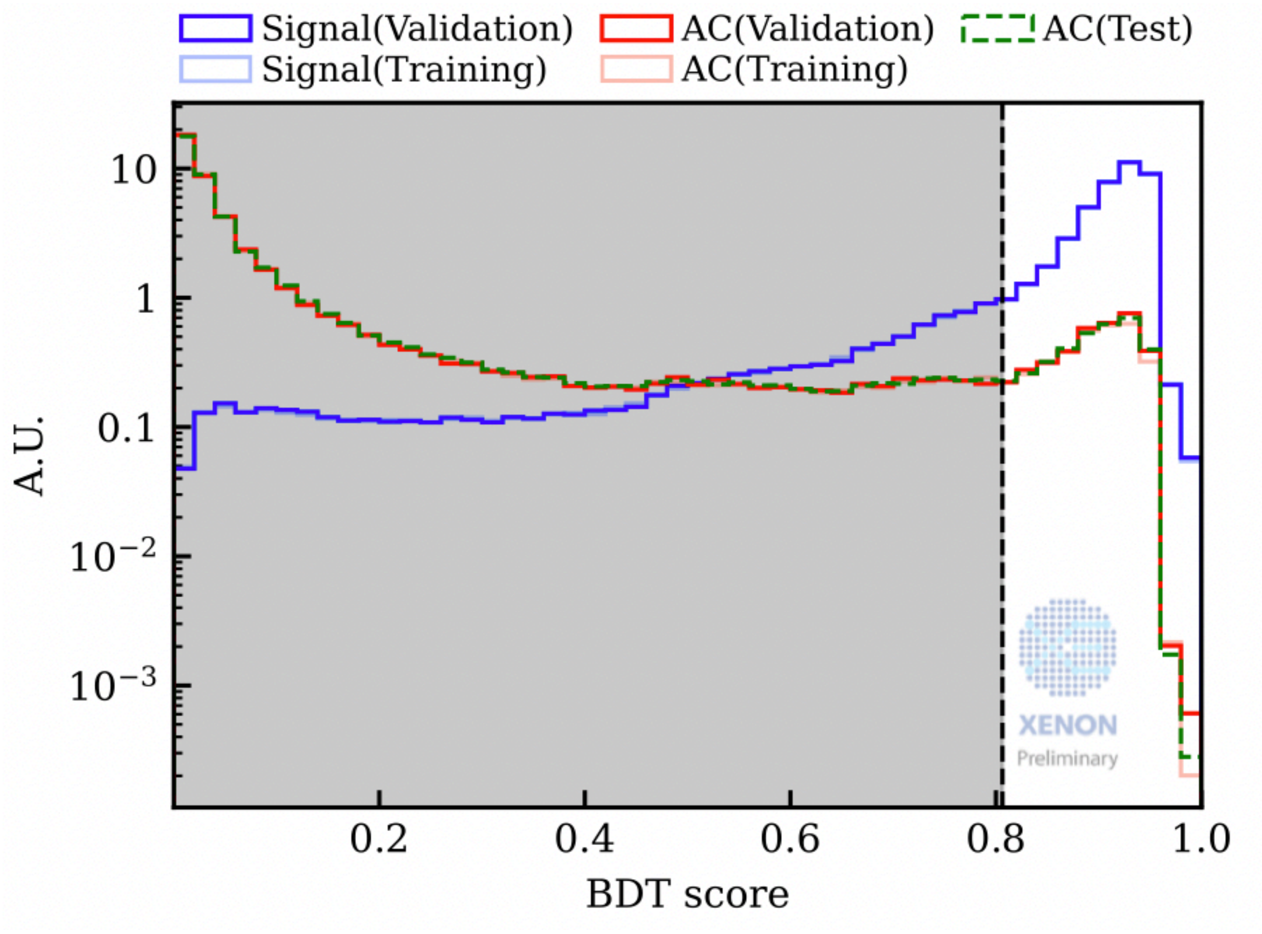


Image from Lanqing Yuang







Reject about 90% AC with 80% signal acceptance

1st: S2 width at 50 %

4th: Drift time

2nd: Rise time

3rd: S2 width at 90 %