Search for dark matter and ^{8}B solar neutrinos with XENONnT

Carla Macolino
(Univ. of L'Aquila)

on behalf of the XENON collaboration

Istituto Nazionale di Fisica Nucleare

NOW 2024 - Sept. 2024

The XENON collaboration

- 200+ scientists
- 29 institutions
- 12 countries

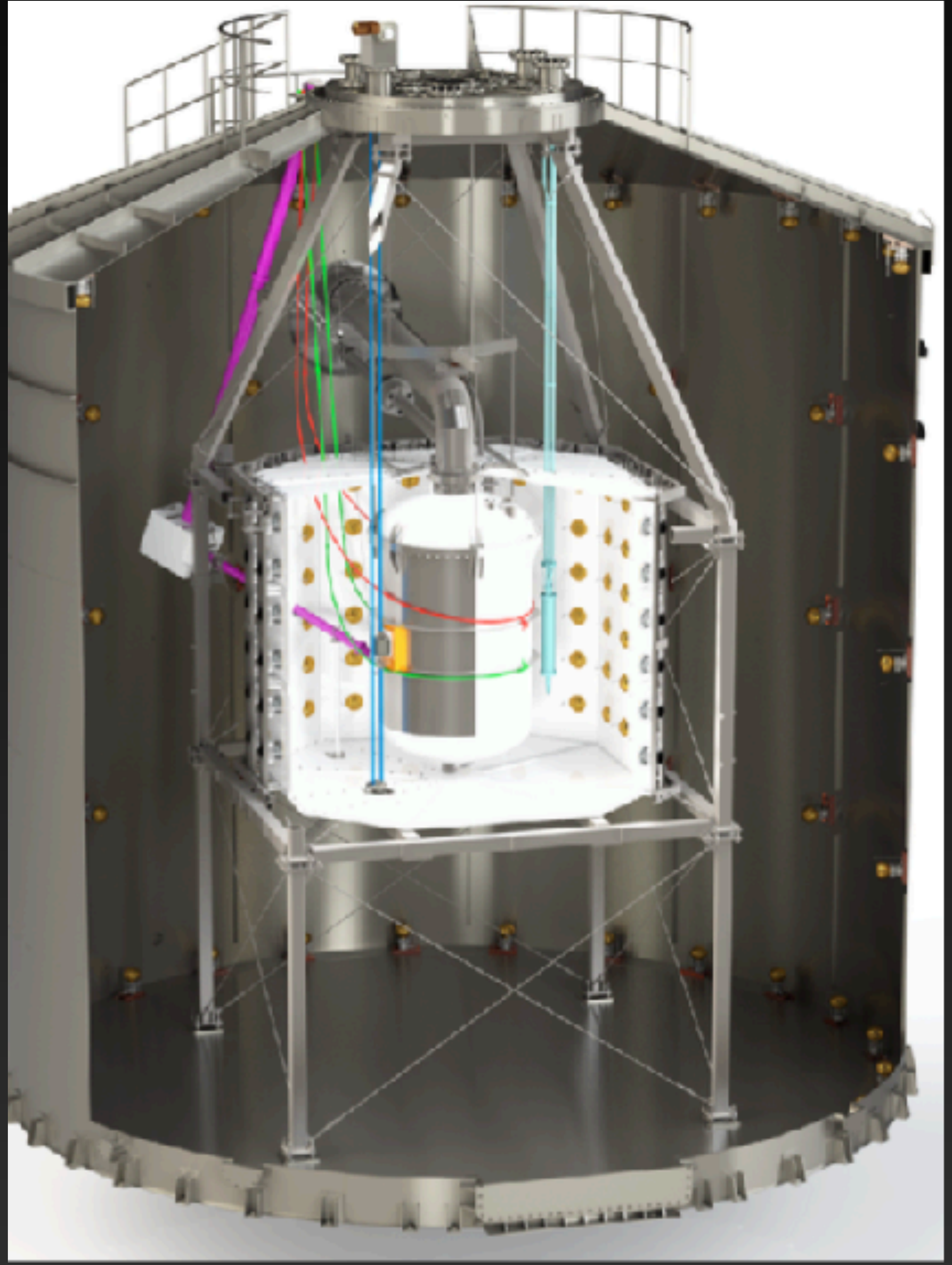
https://xenonexperiment.org
@XENONExperiment
@xenonexperiment
@xenon_experiment

The XENONnT detector

3 nested detectors

Eur. Phys. J. C 84, 784 (2024)

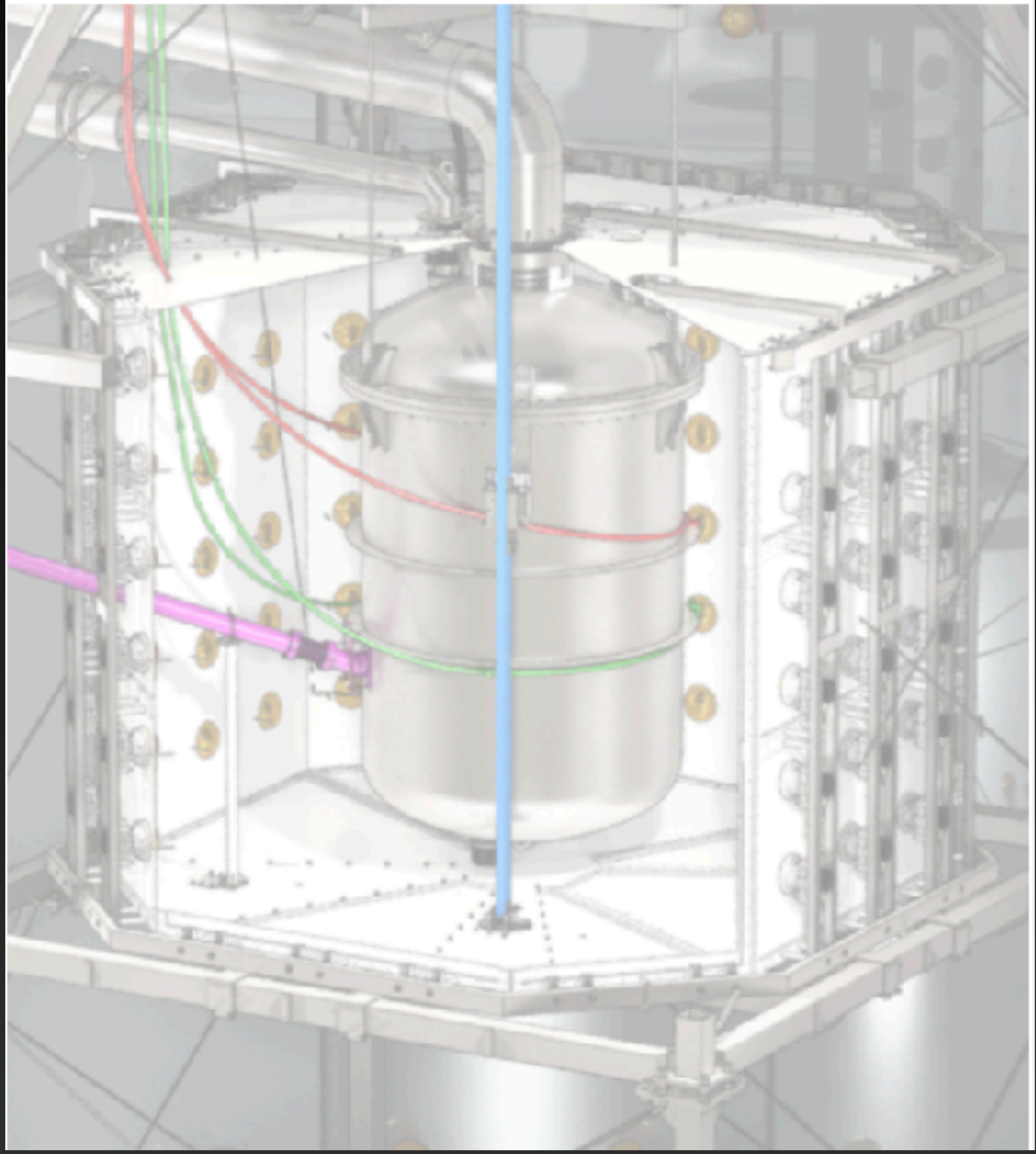
Muon Cherenkov detector (Muon Veto)



Diameter/Height 9.6m/10.2m, **700t** water

- High reflectivity inner coating
- 84 Hamamatsu 8″ PMTs
- Active veto against muon-induced neutrons
- Passive veto against gamma rays

Gd-salted neutron Cherenkov detector (Neutron Veto)



- (Pure water for published results so far)
- 120 8″ high QE PMT
- 33 m3 volume
- Use neutron capture to tag neutron

LXe Time Projection Chamber (TPC)

5.9t active target mass

- including ~8.9% ^{136}Xe (natural
- abundance)
- active target diameter/height:1.3m/1.5m
- 494 Hamamatsu 3″ PMTs

The XENONnT detector

3 nested detectors

Eur. Phys. J. C 84, 784 (2024)

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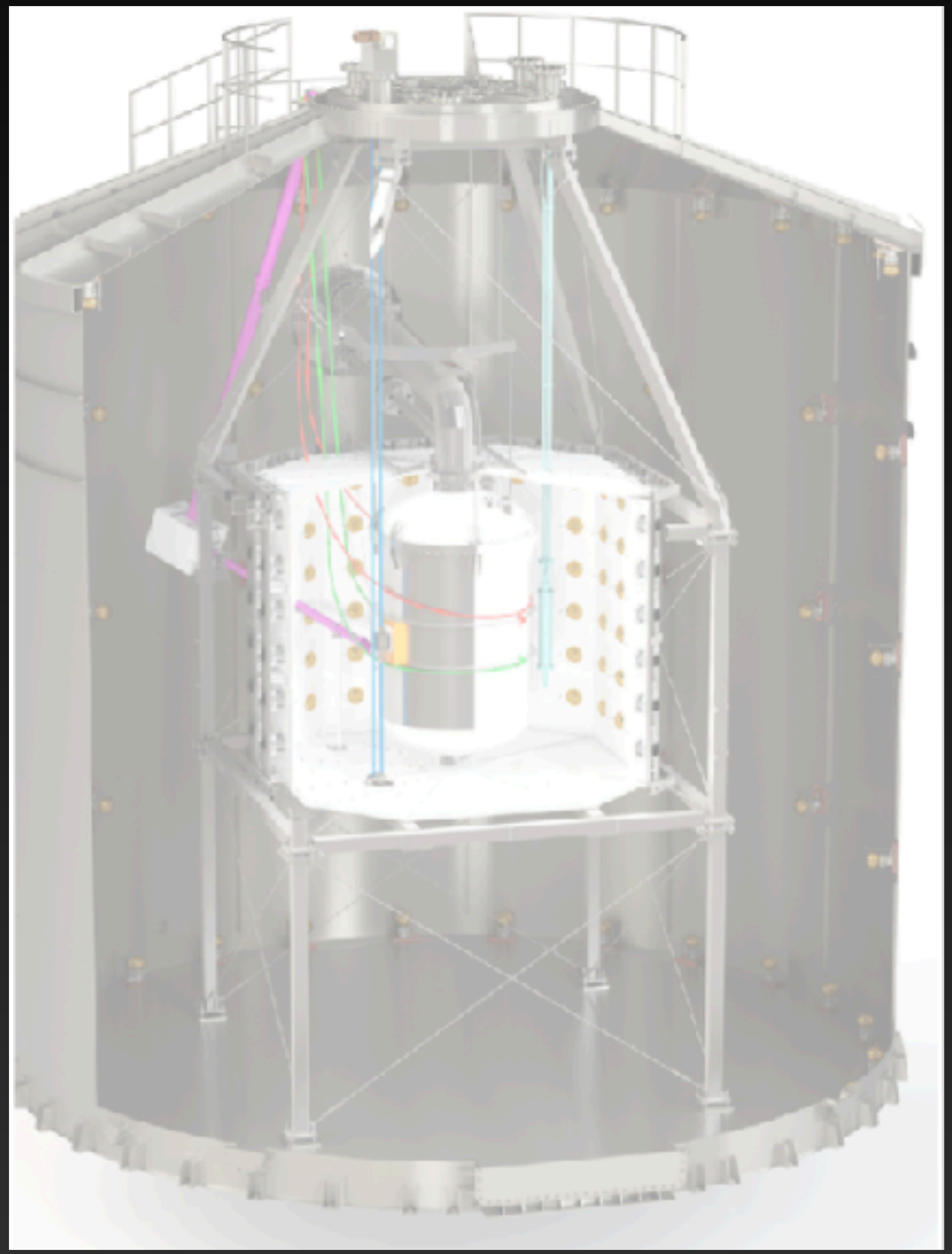

Diameter/Height 9.6m/10.2m, **700t** water

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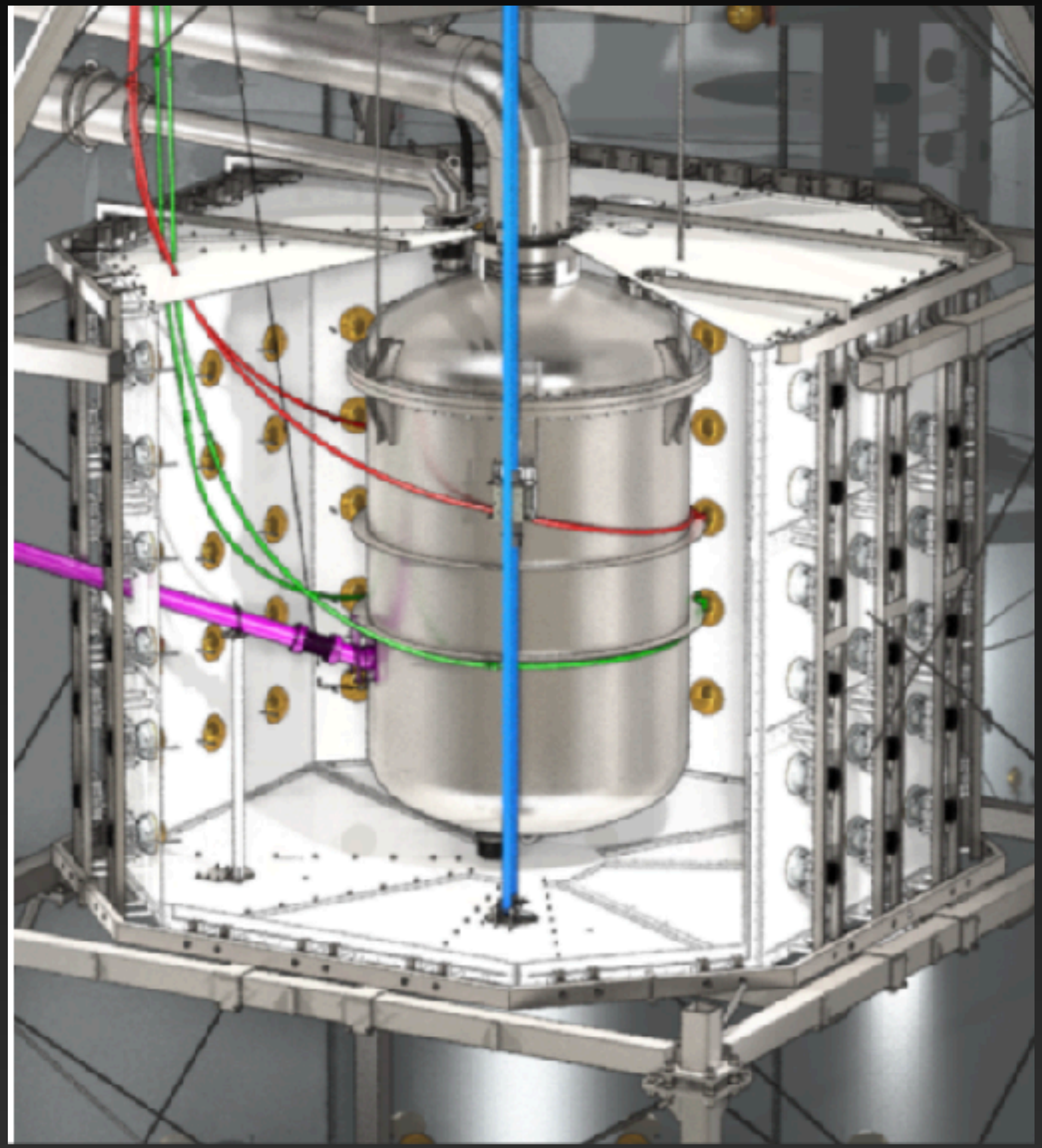

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3 nested detectors

Eur. Phys. J. C 84, 784 (2024)

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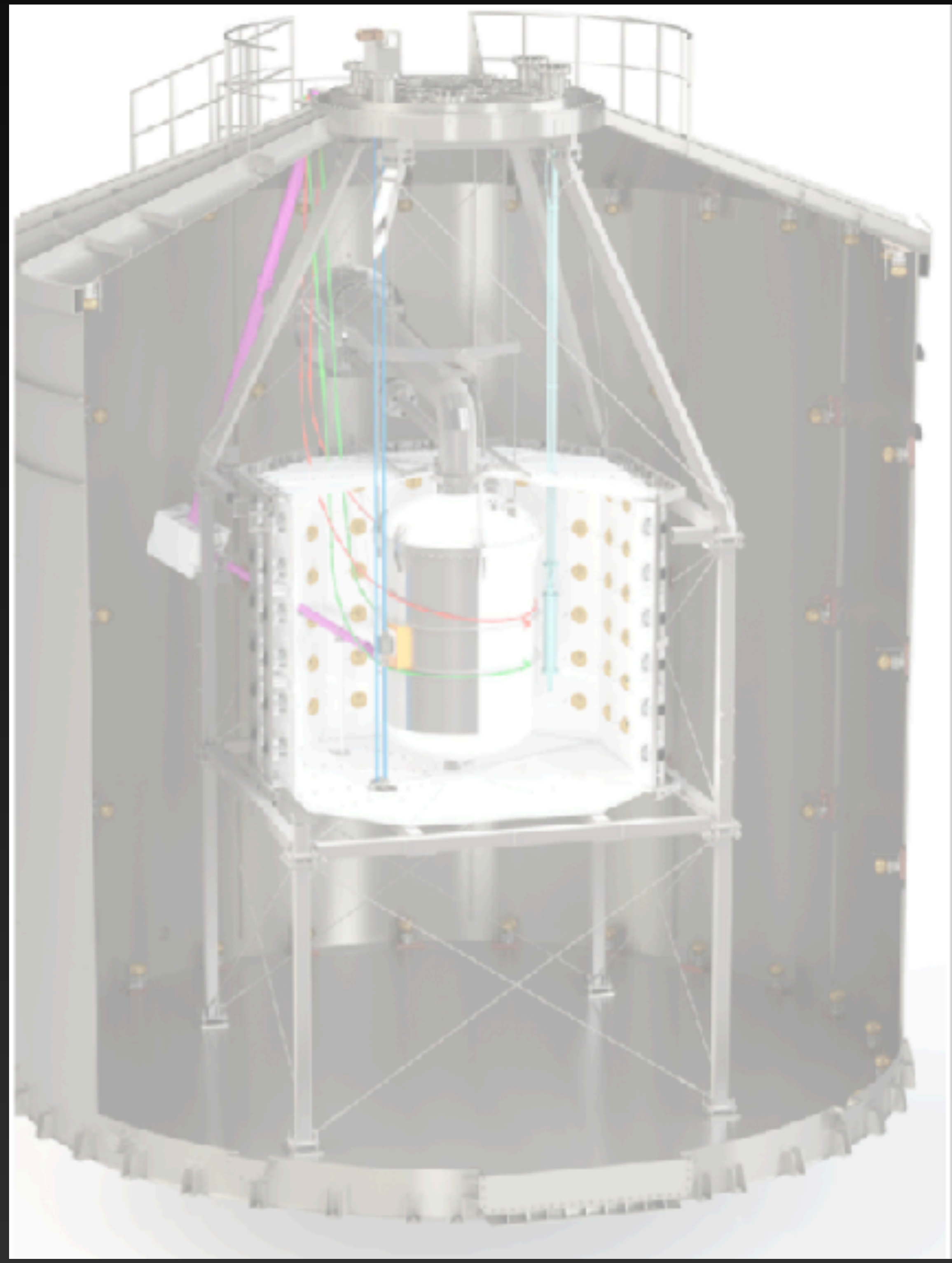

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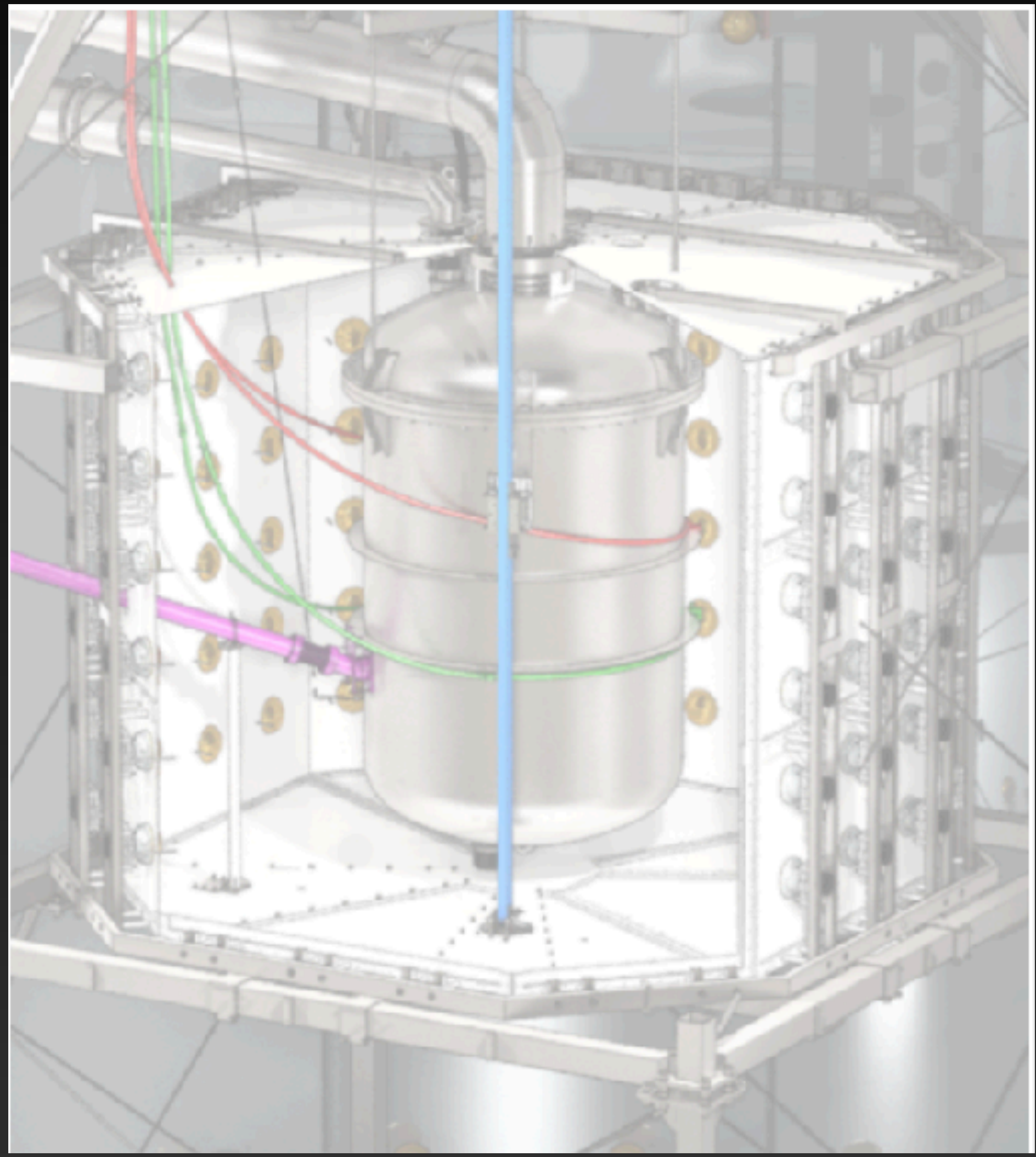

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- including ~8.9% ^{136}Xe (natural
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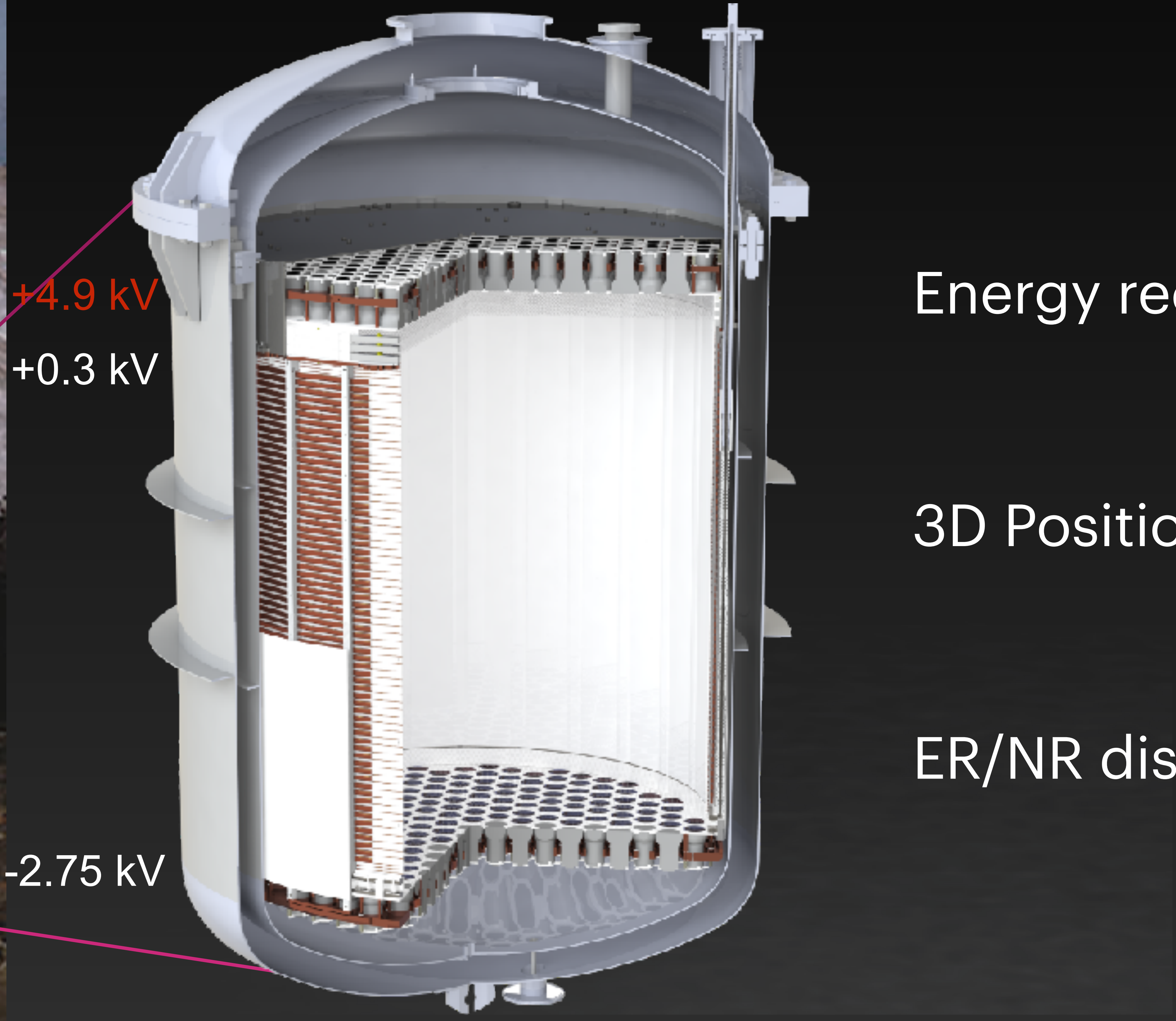
The XENONnT detector

LXe dual-phase TPC

Eur. Phys. J. C 84, 784 (2024)



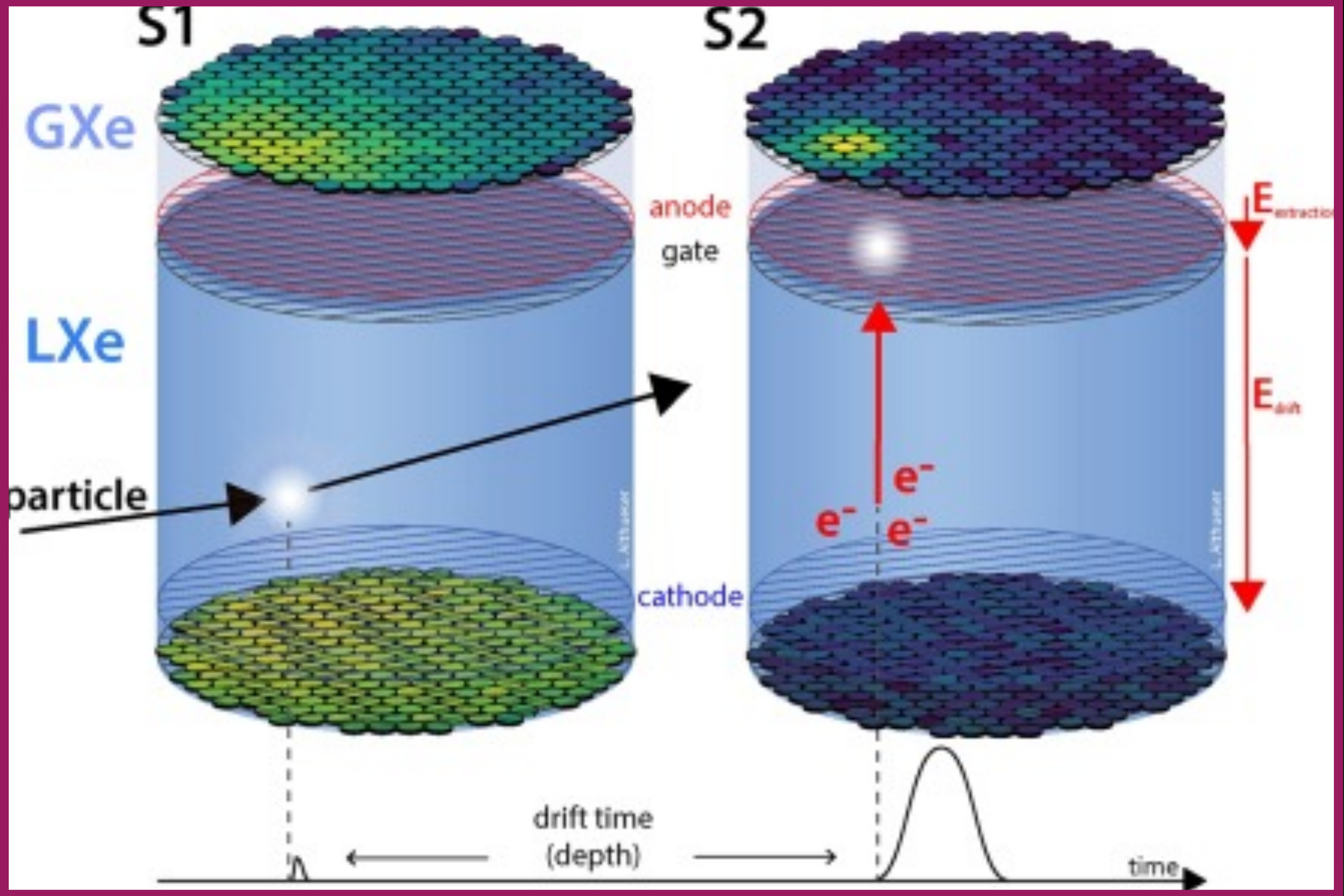
Energy reconstruction

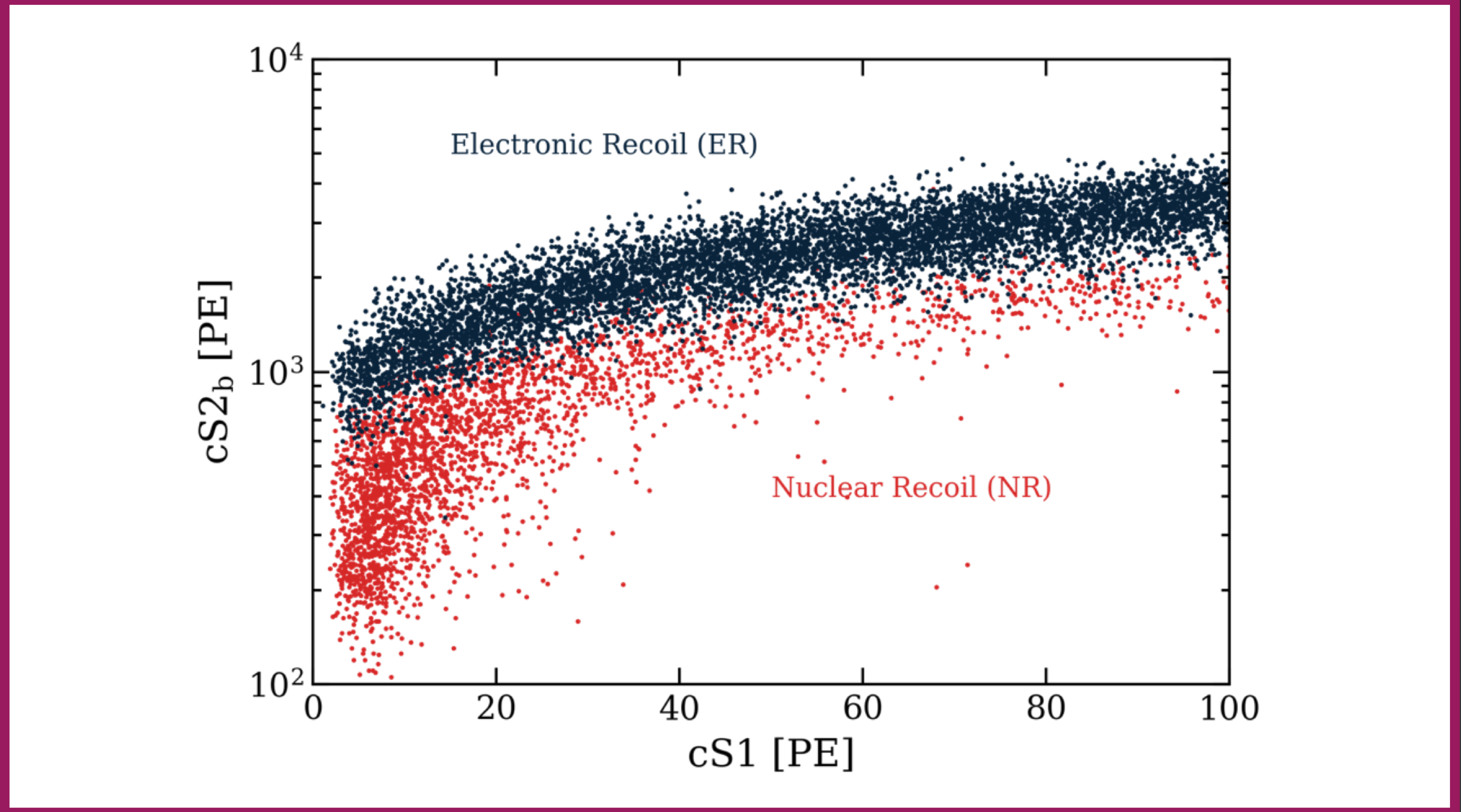
3D Position reconstruction

ER/NR discrimination

Drift Length	Diameter	Sensitive Target	Drift Field
1.5m	1.32m	5.9 tonne	23 V/cm

Event discrimination





SCINTILLATION channel: S1 signal (prompt scintillation)

Drift of ionization electrons

IONIZATION channel: S2 signal (secondary GXe scintillation)

ER recoil (electronic recoil)

- Gamma
- Beta
- Neutrino elastic scattering
- Solar axions, ALPs

NR recoil (nuclear recoil)

- Neutron elastic scattering
- WIMP dark matter
- Neutrino CEvNS (coherent elastic neutrino-nucleus scattering)

XENONnT timeline

2 scientific runs completed: SR0 and SR1

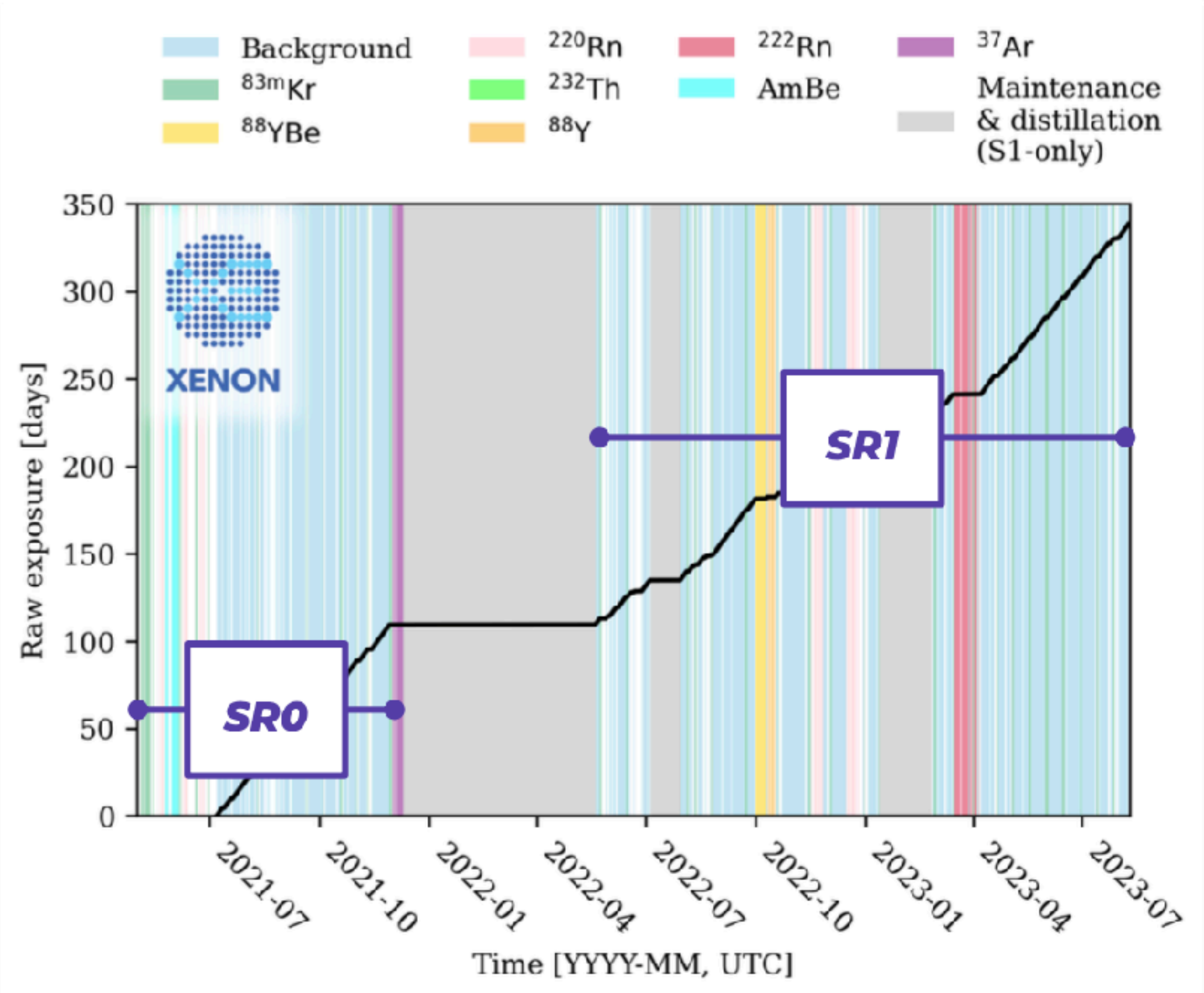
SCIENCE RUN 0: Jul 2021 - Nov 2021

SCIENCE RUN 1: May 2022 - Aug 2023

2023

GdSO in water

Start of SR2



EXCELLENT STABILITY

- Light and charge yields within 1%
- 478/494 PMTs active (97%)
- SR2 ongoing

SRO WIMP results

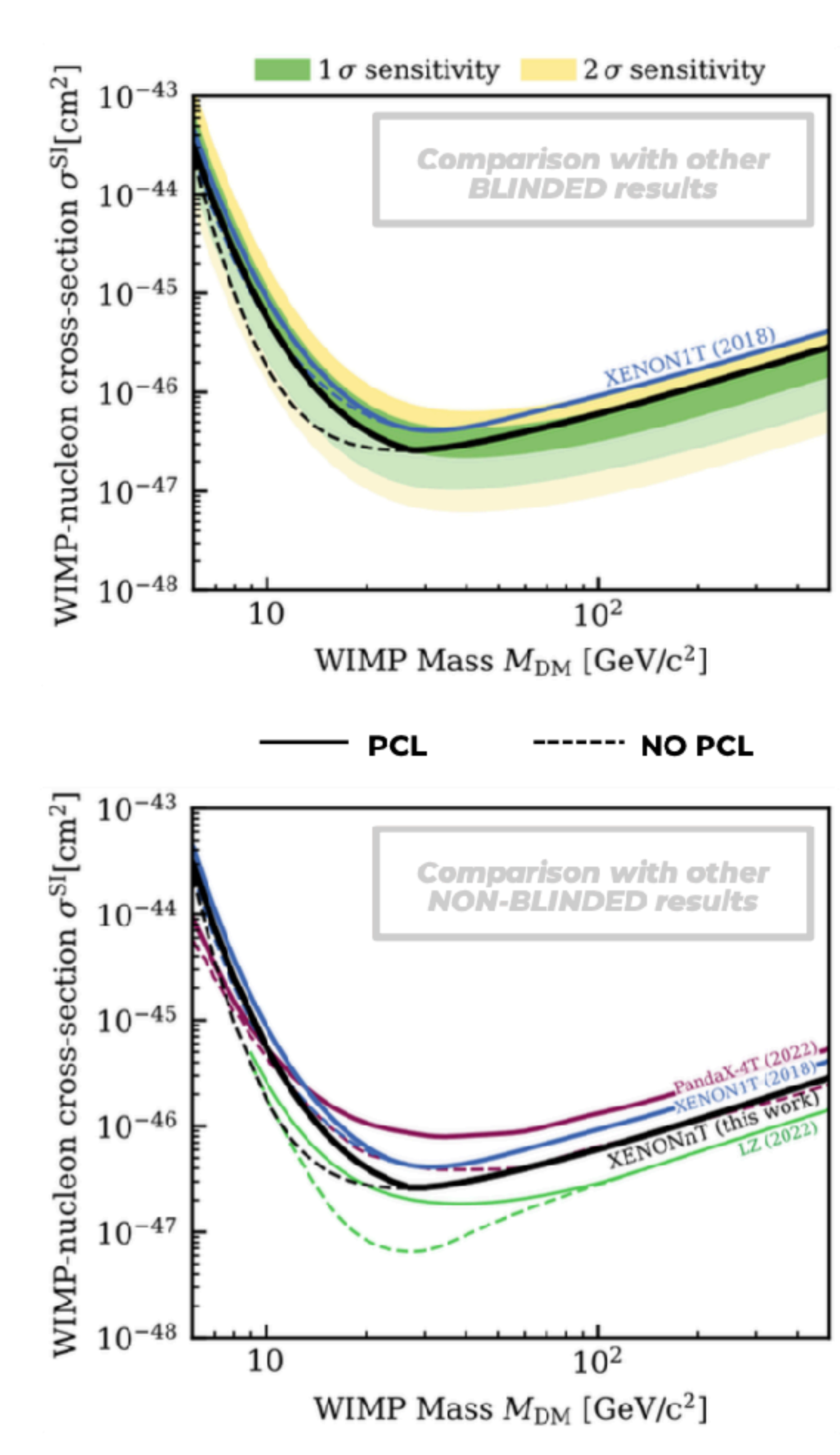
First search for WIMP dark matter

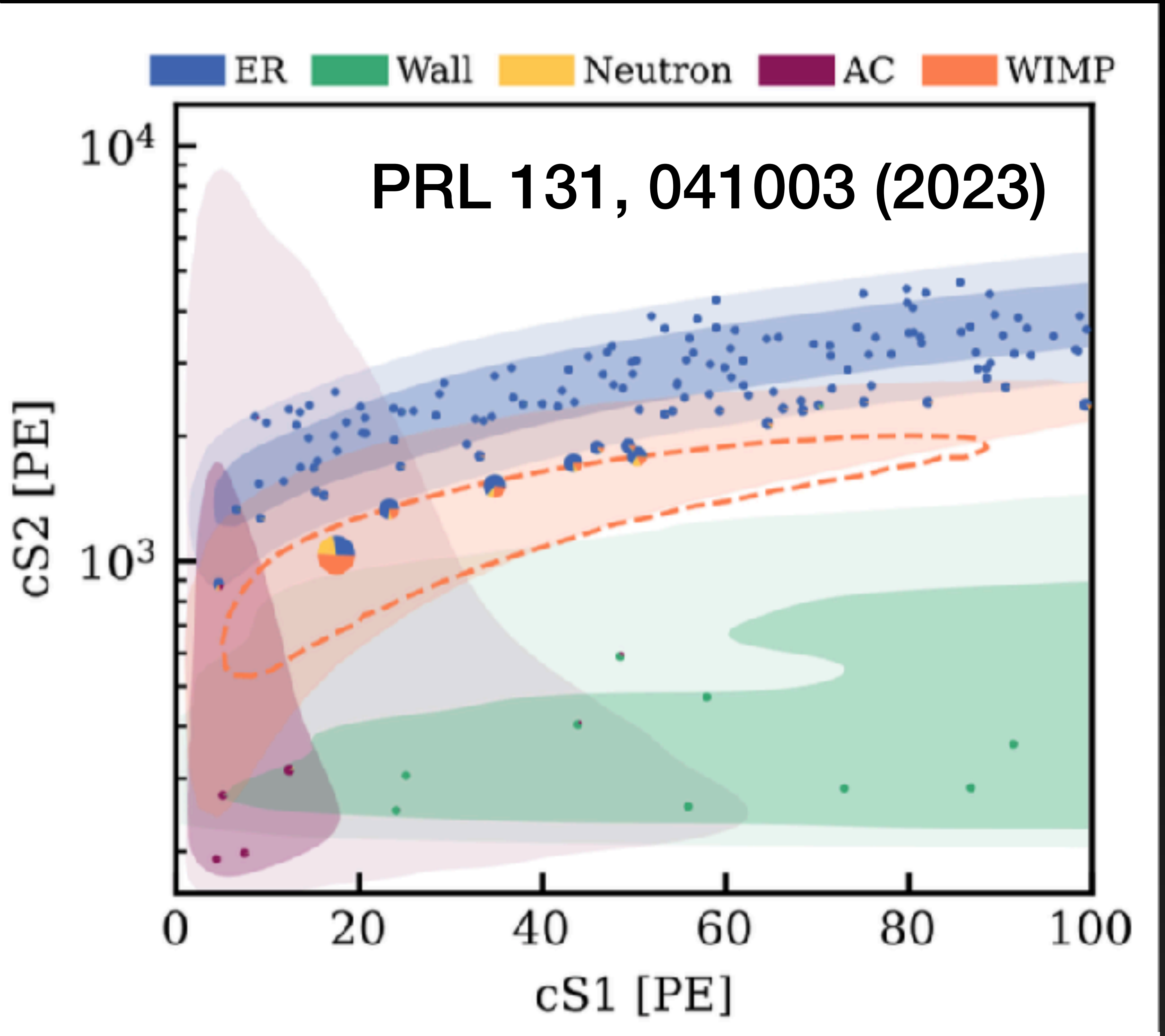
- Data taken between Jul. 2021 and Aug. 2023: ~340 days of raw data
- **High liquid xenon purity**: Electron lifetime ~20ms
- Regular calibrations:
  - **g1**: 0.1515 ± 0.0014 PE/ph (SR0) & 0.1367 ± 0.0010 PE/ph (SR1)
  - **g2**: 16.45 ± 0.64 PE/e (SR0) & 16.85 ± 0.46 PE/e (SR1)

Exclusion limit

- No significant excess
- 152 events in ER/NR region
- 16 events in NR blinded region

2.6 10^{-47} cm² at 28 Gev/c²



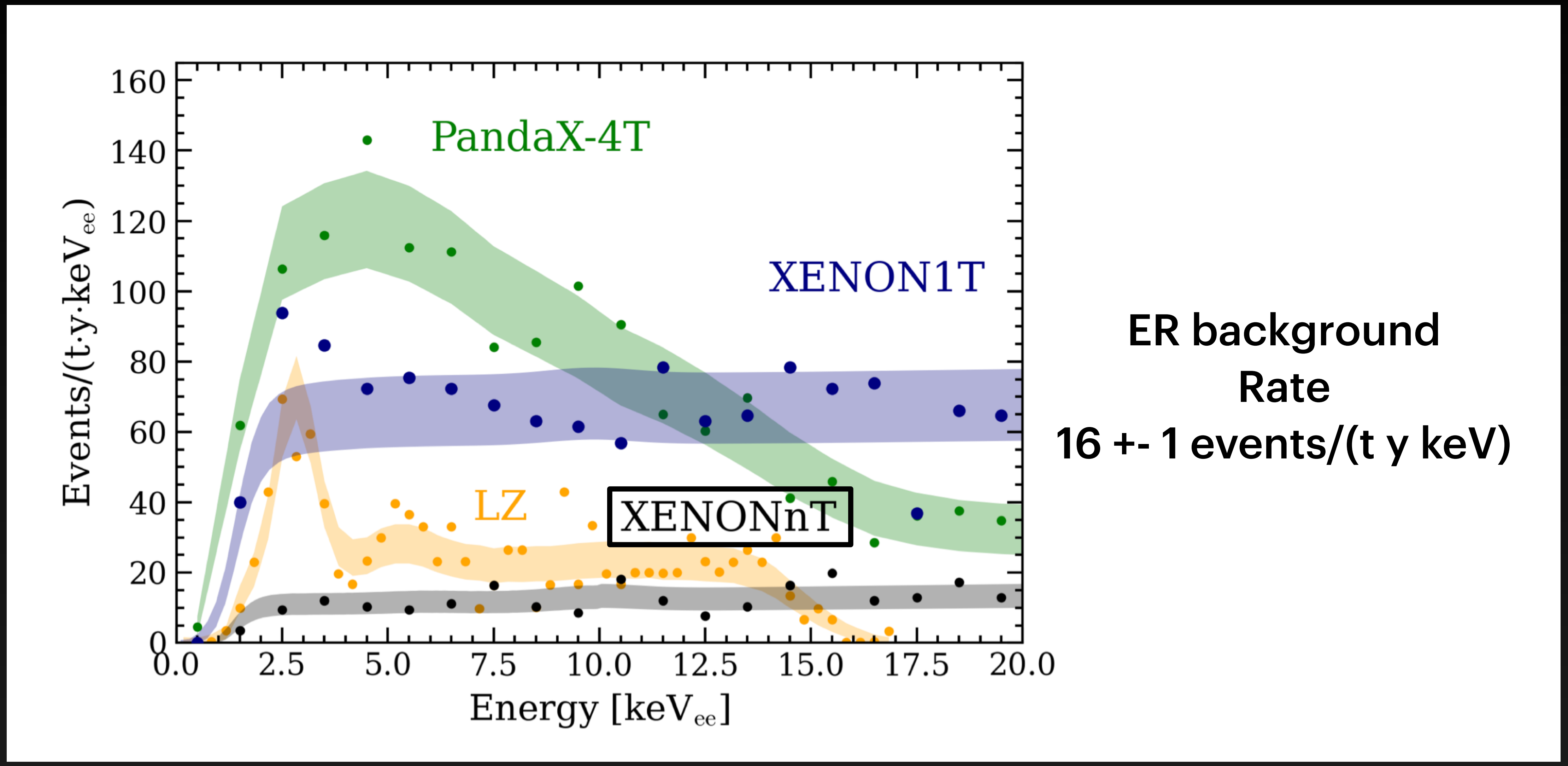


	Nominal	Best Fit	
		ROI	Signal-like
ER	134	135^{+12}_{-11}	0.92 ± 0.08
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.4	0.42 ± 0.16
CEνNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.006
AC	4.3 ± 0.9	$4.4^{+0.9}_{-0.8}$	0.32 ± 0.06
Surface	14 ± 3	12 ± 2	0.35 ± 0.07
Total Background	154	152 ± 12	$2.03^{+0.17}_{-0.15}$
WIMP	-	2.6	1.3
Observed	-	152	3

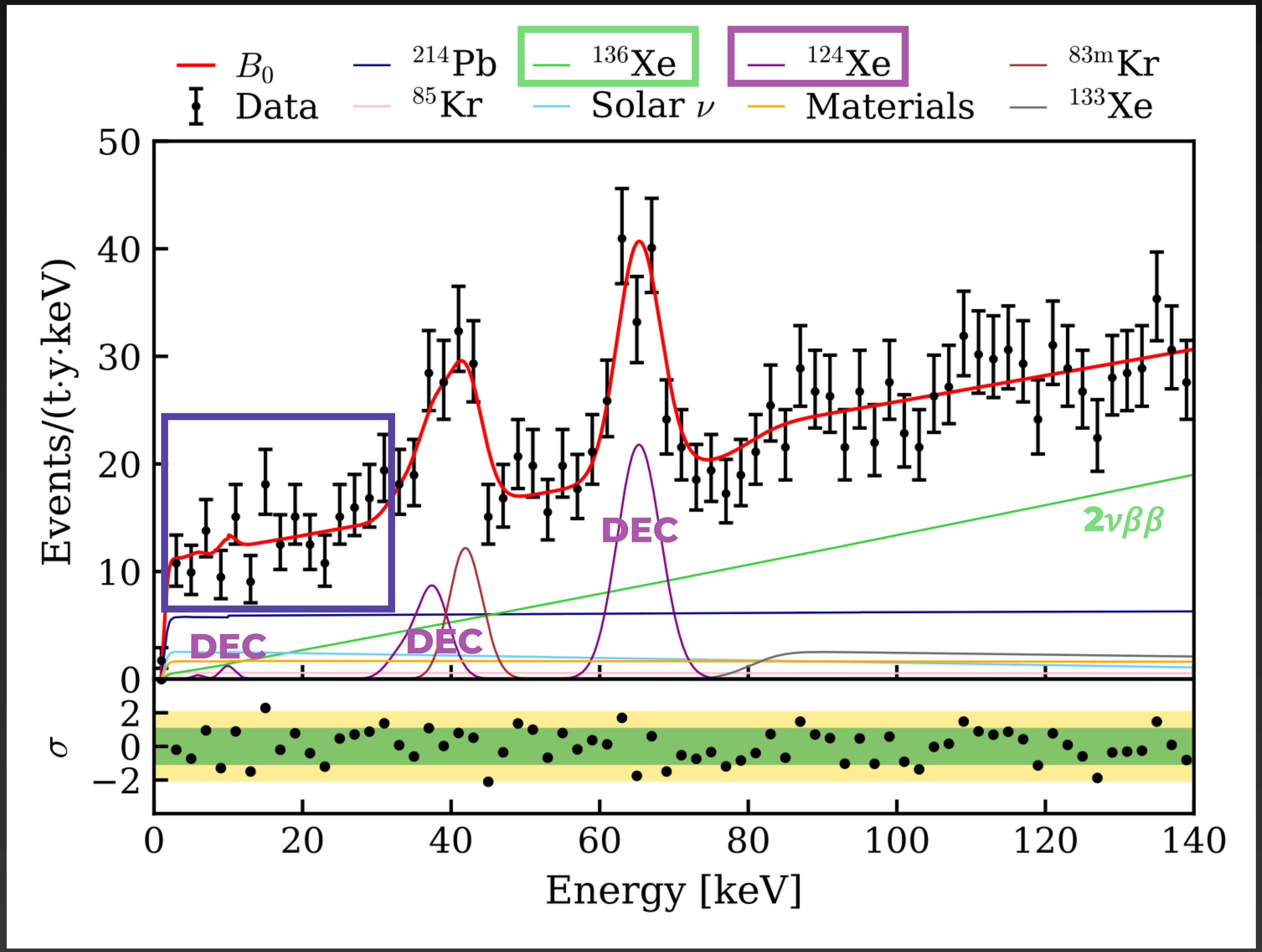
SRO ER searches

LowE ER searches: new constraints on BSM physics

Lowest background rate ever achieved in LXe-based dark matter detectors



ER background Rate
16 +- 1 events/(t y keV)

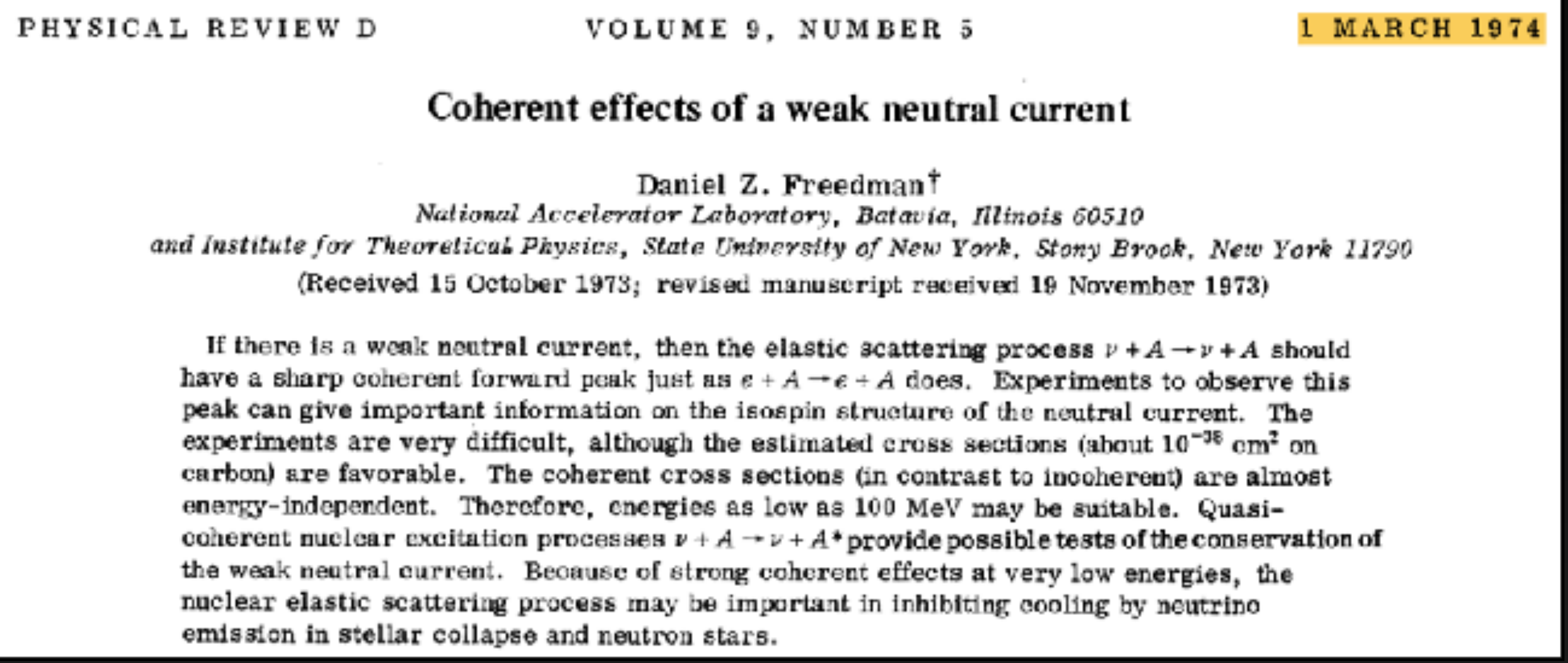


- DEC of ^{124}Xe discovered by XENON1T in 2019 with half-life 2 • 10^{22} yr
- LEADING LIMITS with non-astronomical observations on:
  - ✳SOLAR AXIONS: couplings to gamma, electron, nucleon
  - ✳NEUTRINO MAGNETIC MOMENT $\mu_\nu < 6.3 \cdot 10^{-12}\ \mu_B$
  - ✳BOSONIC DARK MATTER: Dark photons, axion-like particles

Phys. Rev. Lett. 129, 161805 (2022)

Detection of CEvNS

ELASTIC SCATTERING OF DARK MATTER and NEUTRINOS
CEvNS: Coherent Elastic Neutrino-Nucleus Scattering


PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

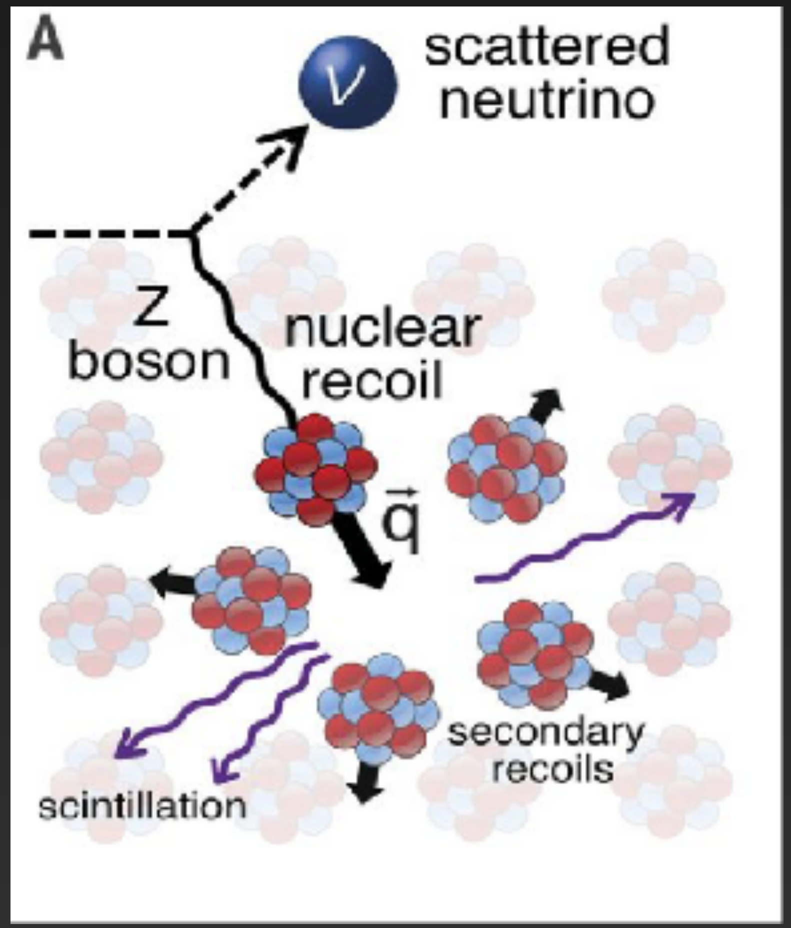
Coherent effects of a weak neutral current

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)

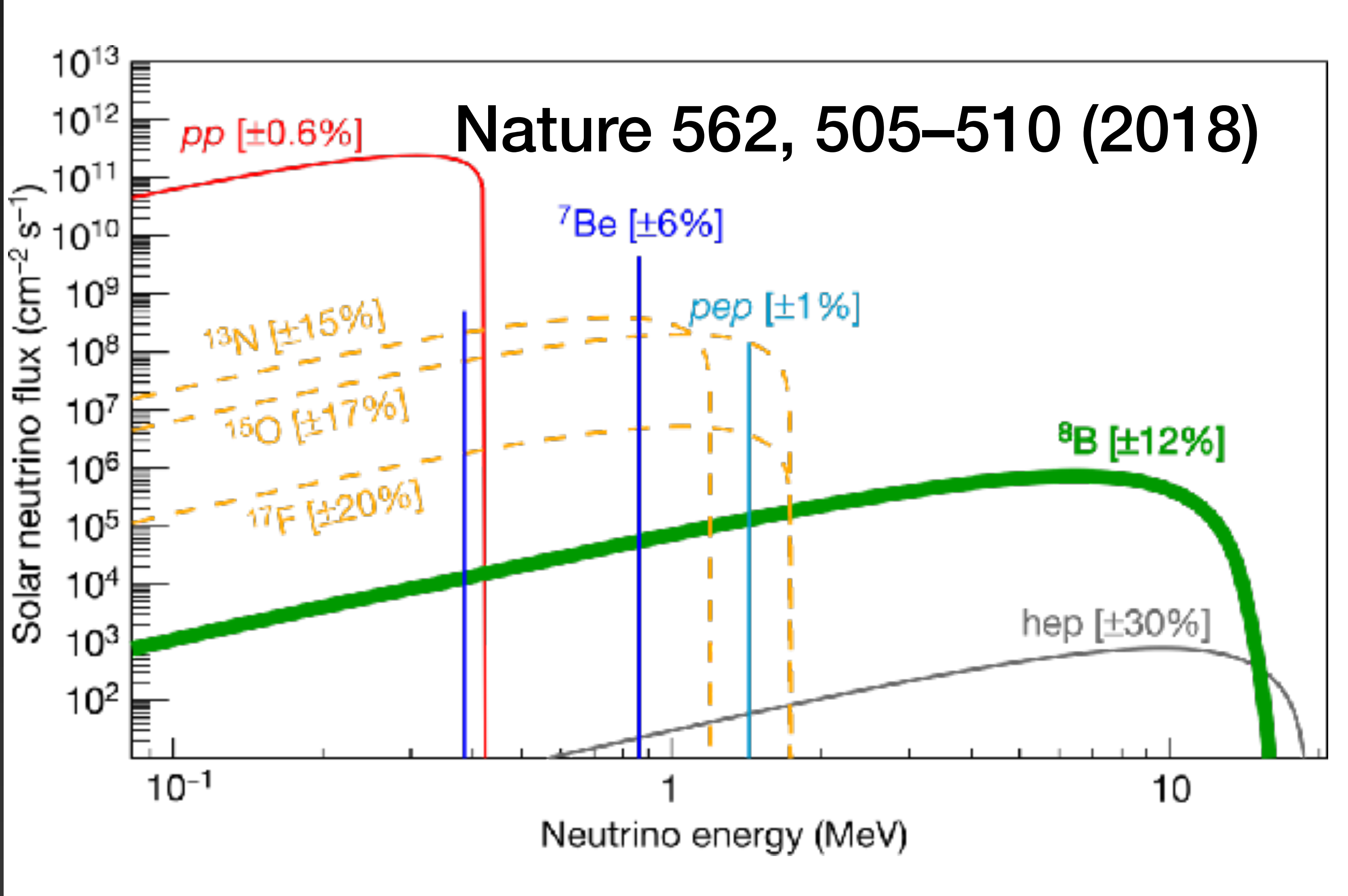
If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are 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.

^{8}B CEvNS: Signature nearly indistinguishable from 5.5 WIMP with spin-independent nuclear recoil
$\sigma_{SI} = 4.4 \times 10^{-45}$ cm^2

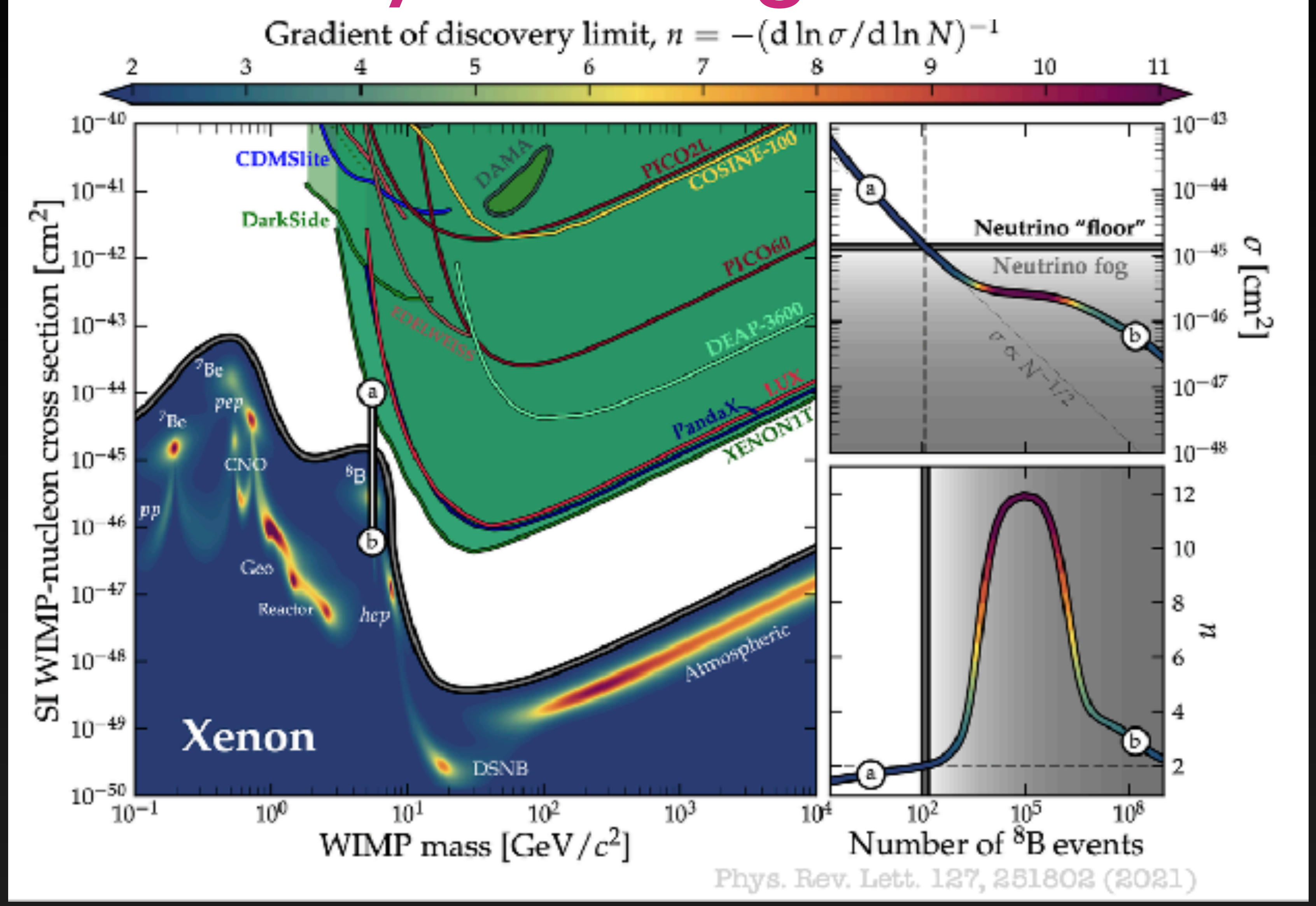
Solar neutrinos at the edge of usual S1 threshold (3-fold) for WIMP search

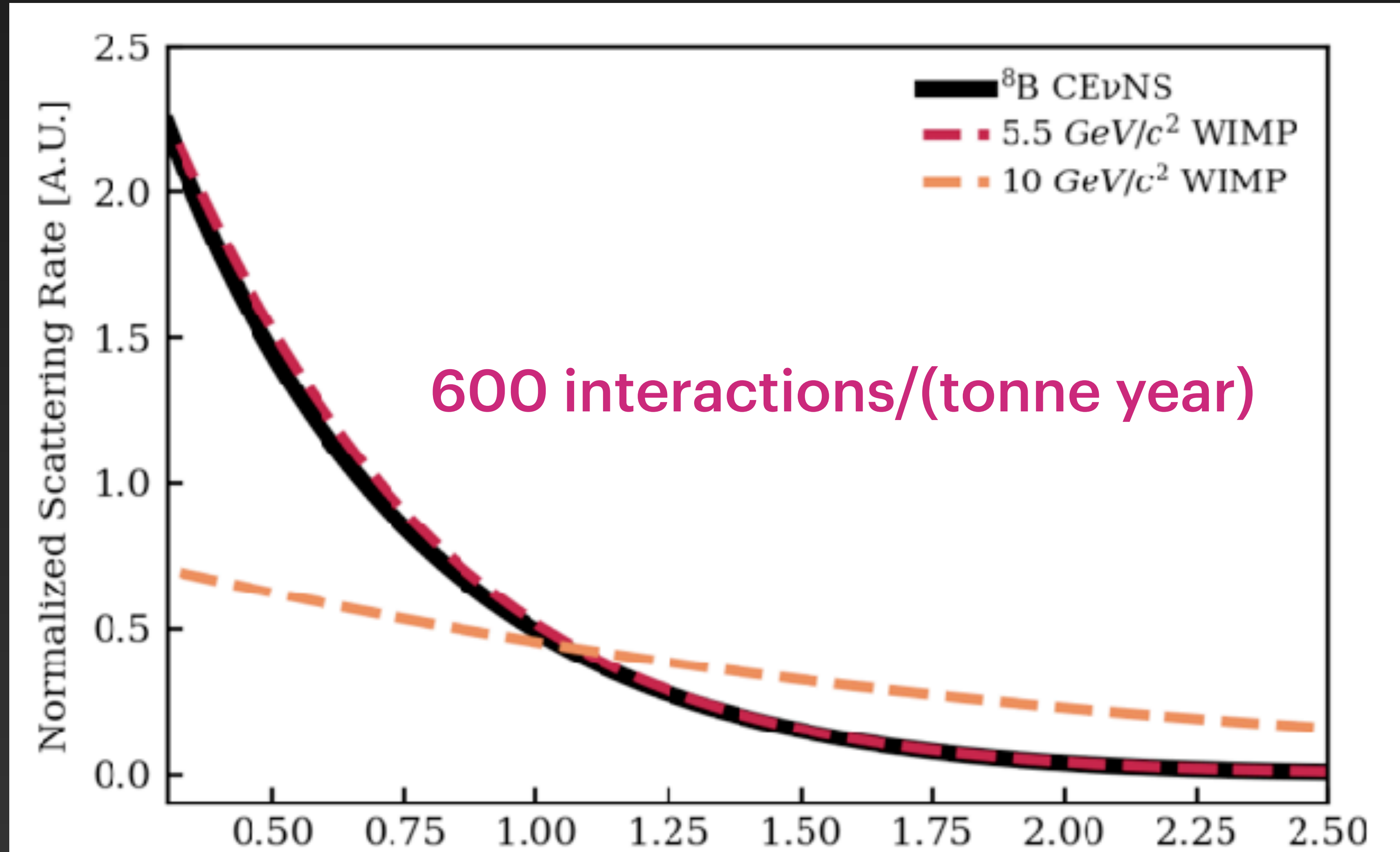


D. Akimov et al, Science 357 (2017)



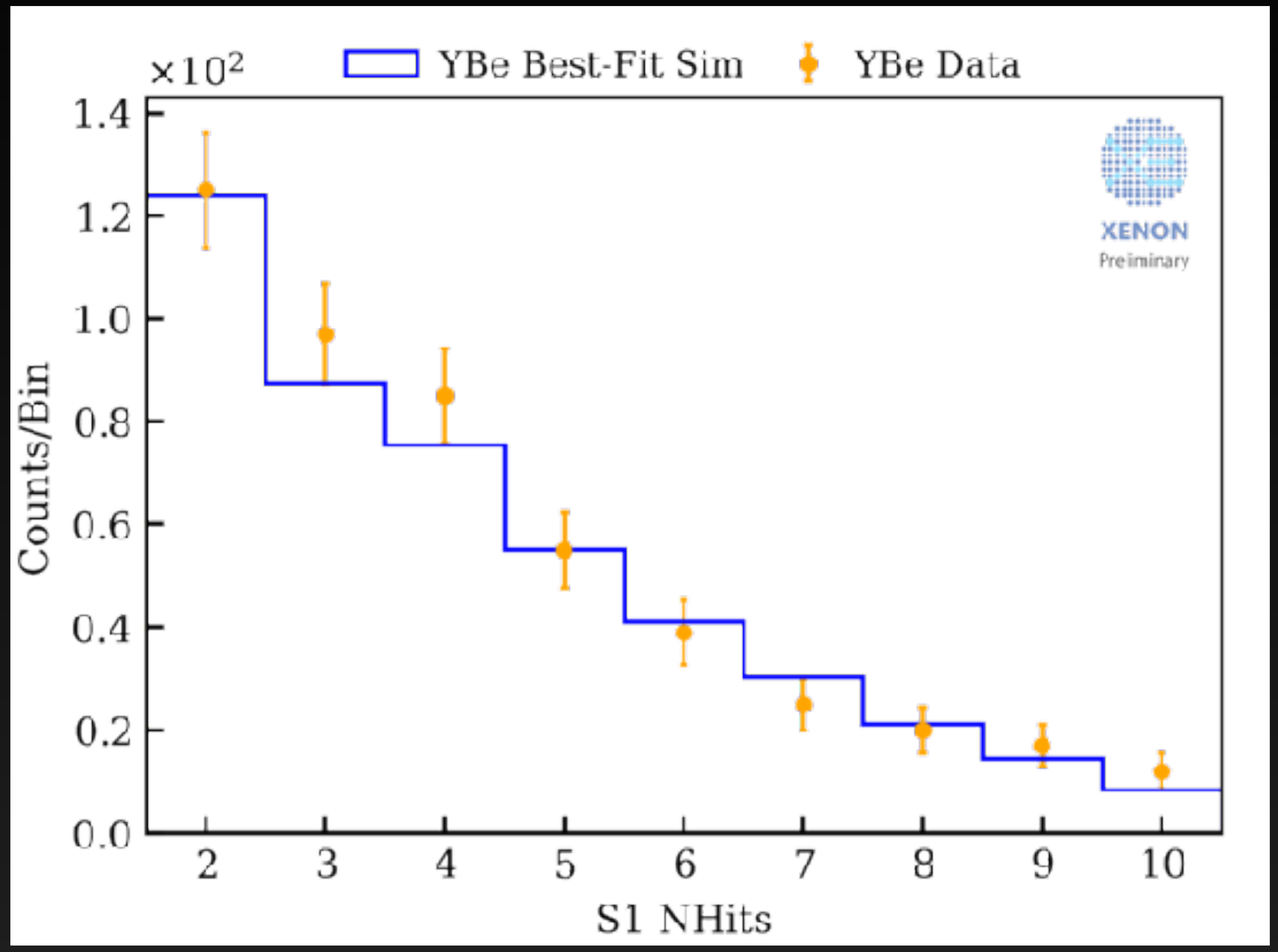
Nearly indistinguishable

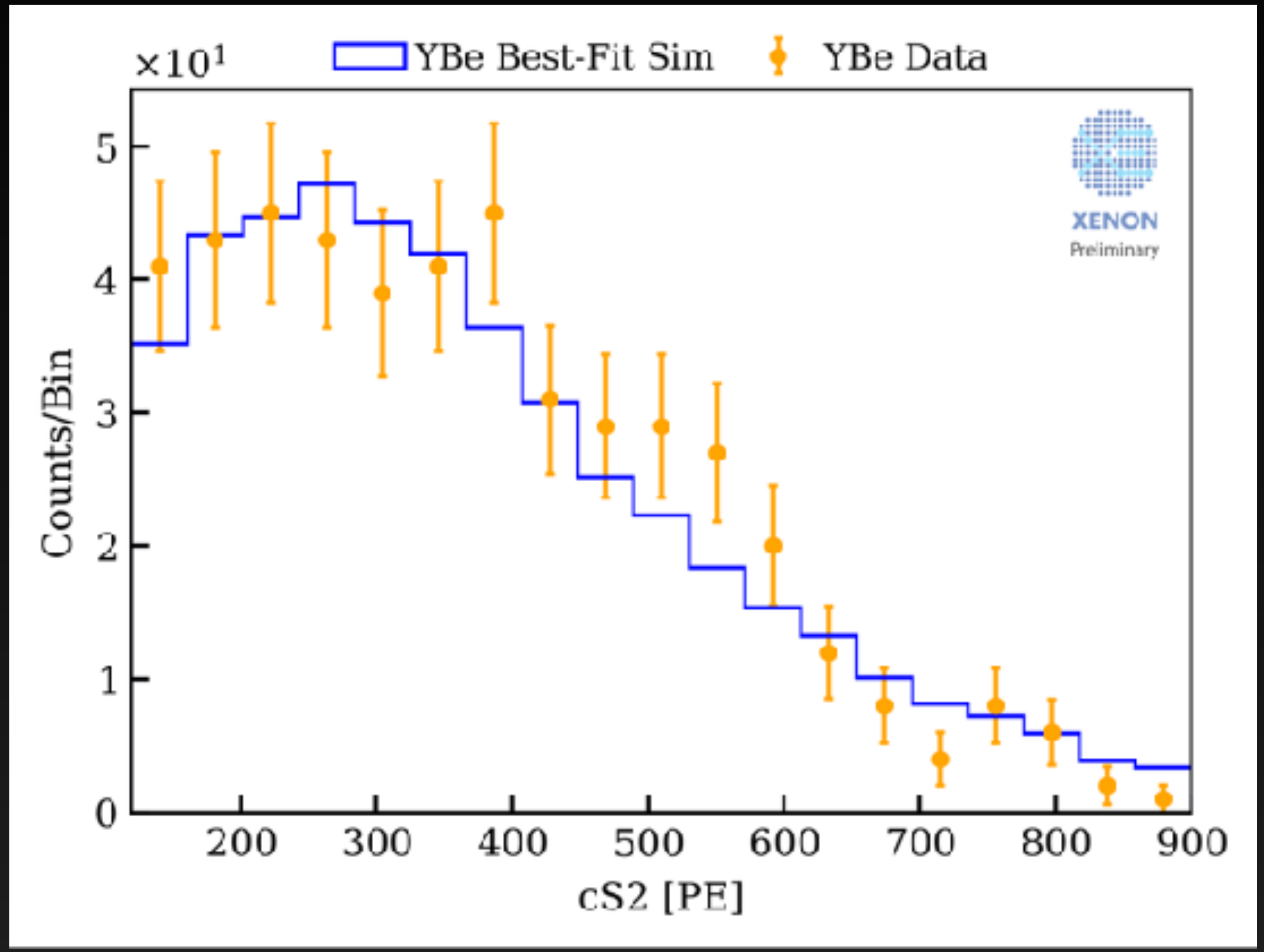


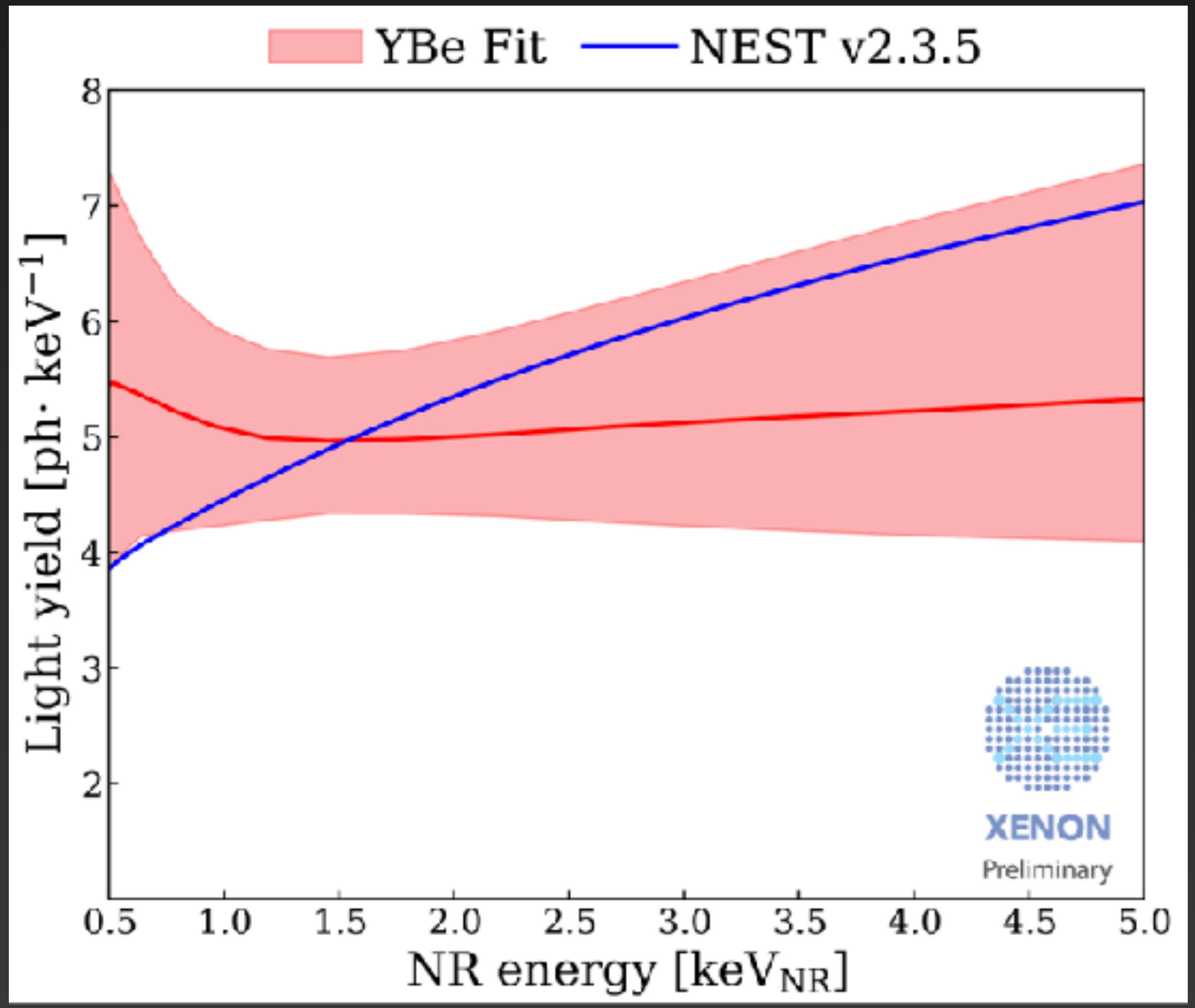


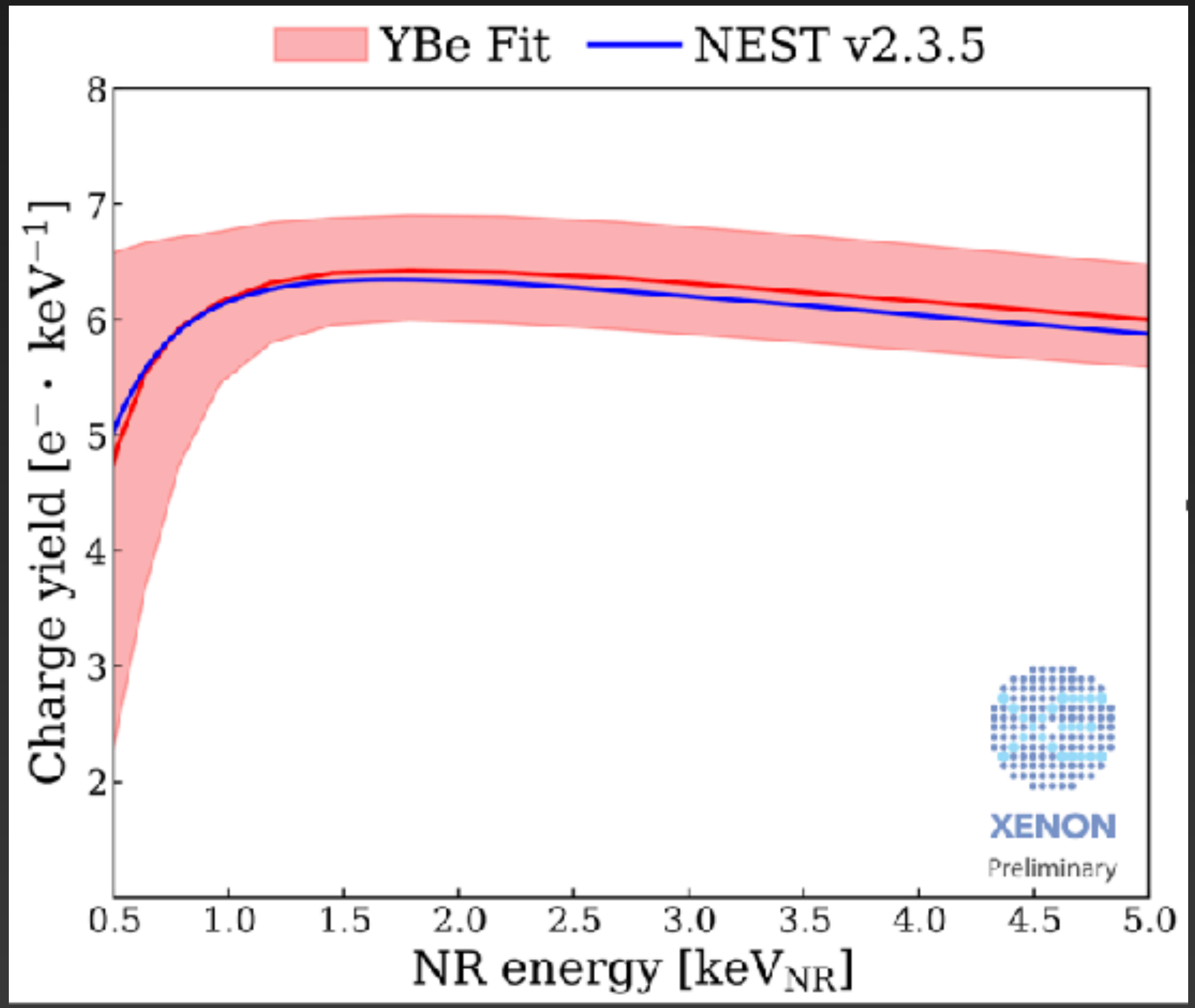
Plot by L. Yuan

CEvNS : YBe calibration lowE NR calibration



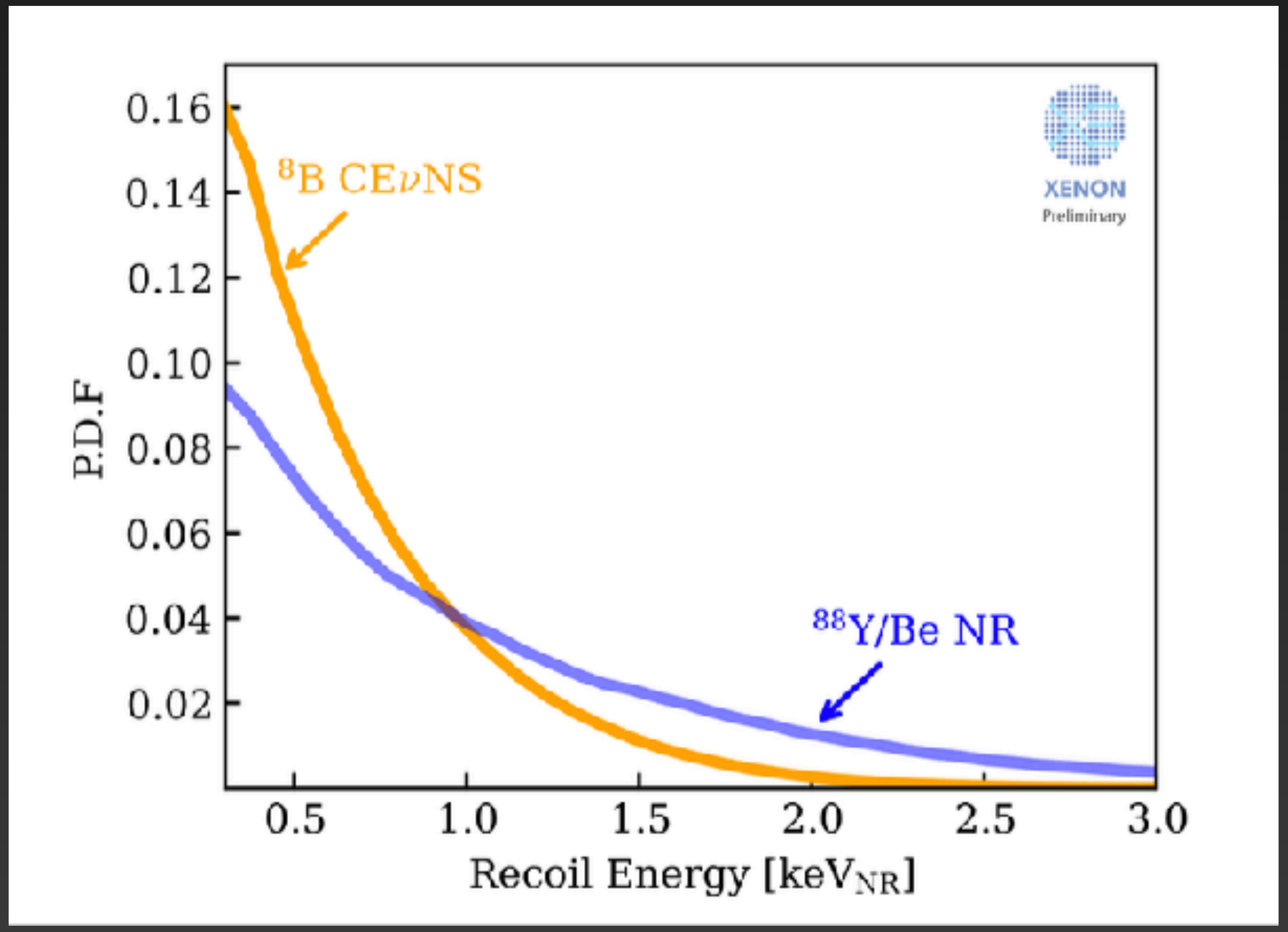






^{8}B CEvNS detection efficiency depends on low energy NR yield model

- 152 keV neutrons from photo-disintegration of ^{9}Be by γ-ray of ^{88}Y
- Recoil energy spectrum similar to ^{8}B CEvNS
- Good agreement between simulation and data
- NEST model is constrained by YBe data at 23V/cm
- Yield model uncertainty translates in ~34% signal rate uncertainty



CEvNS: Region of interest and energy threshold

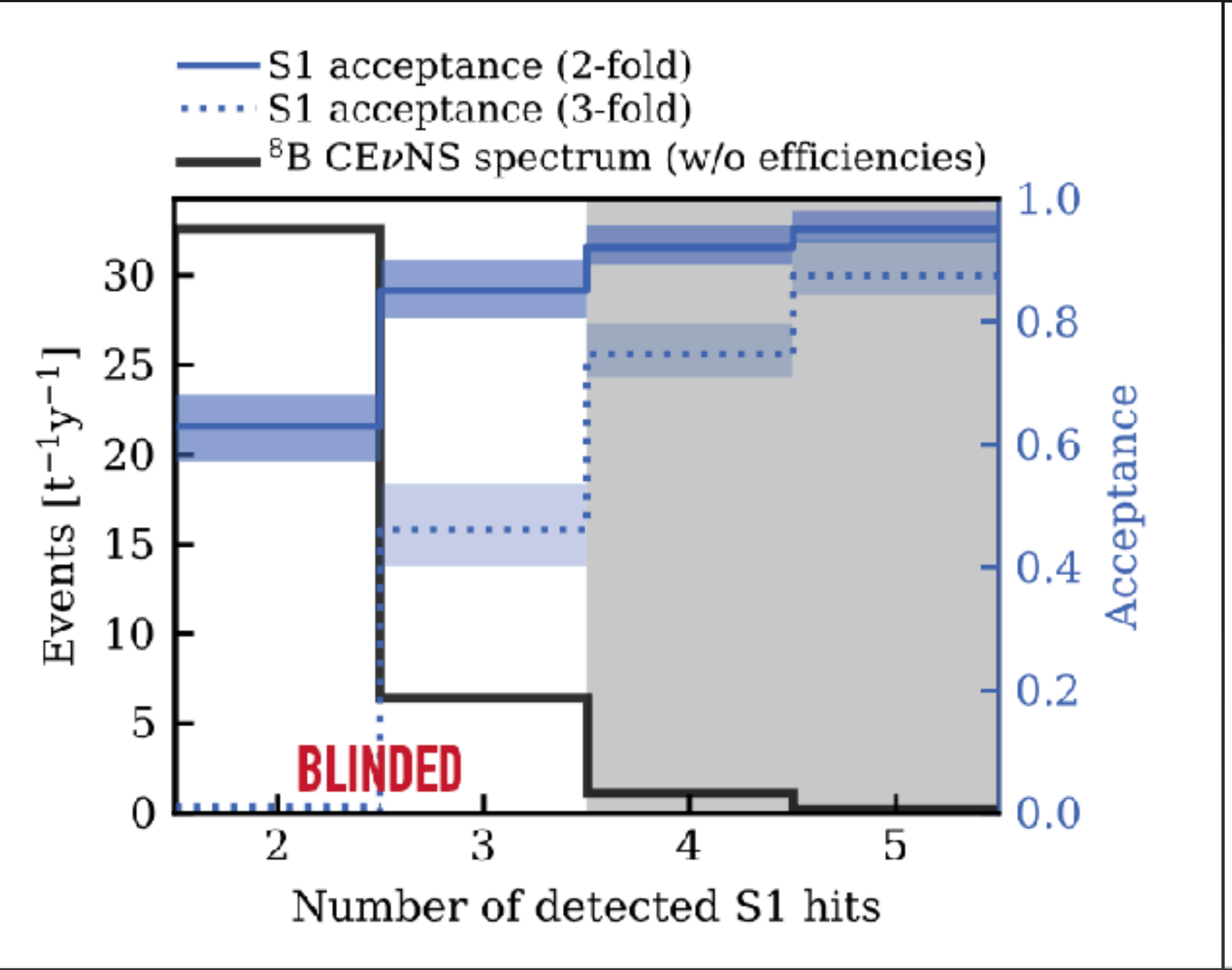
S1: 2 or 3 hits with relaxed waveform shape requirements
1 hit = a photon hitting the PMT
S1 Reconstruction efficiency validated by a data-driven method and waveform simulations

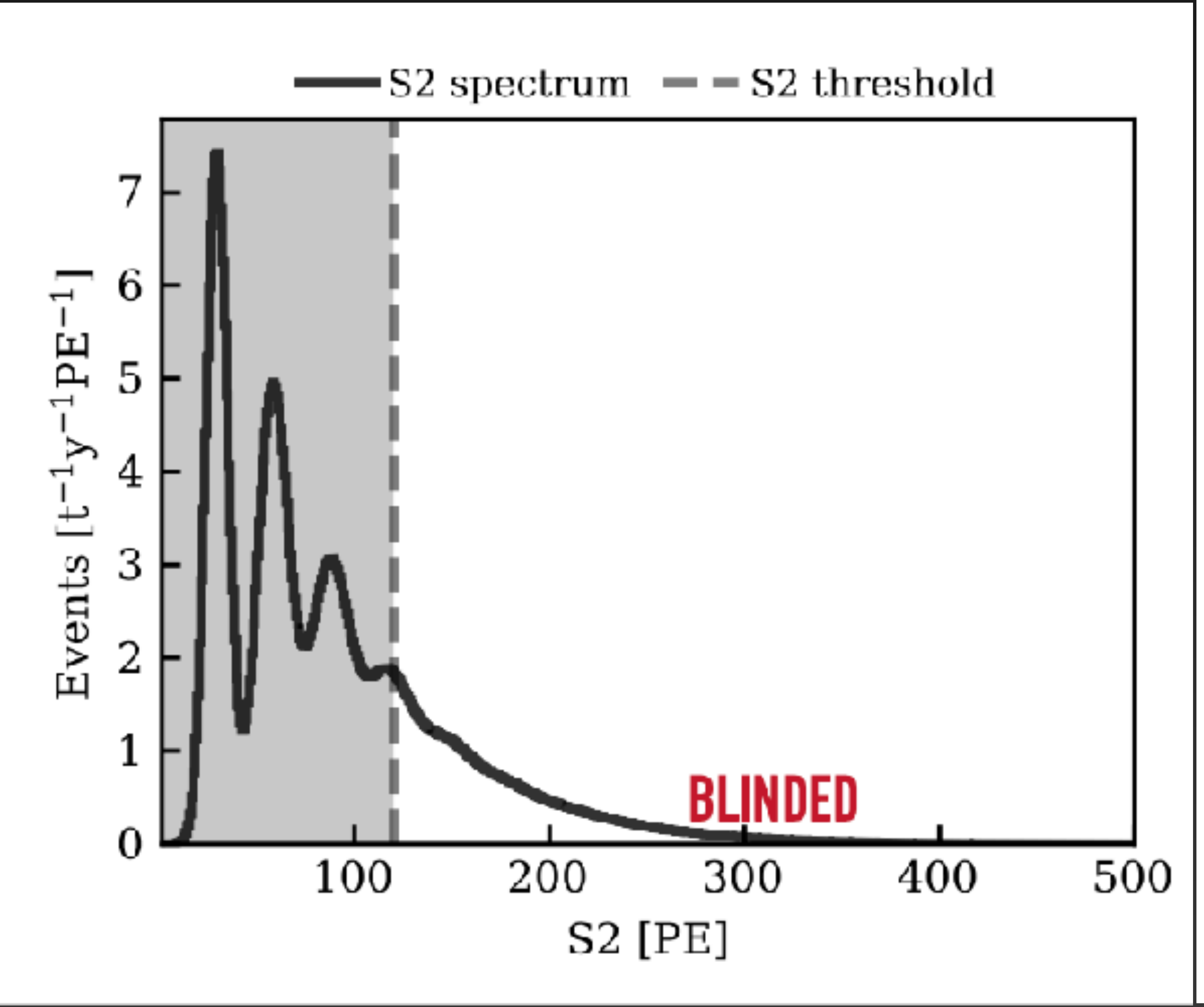
S2: 120 - 500 PE
Corresponds to 4 - 16 extracted electrons
Lowered S2 threshold with respect to 200 PE
S2 threshold of 120PE to reject high isolated S2 background below it.

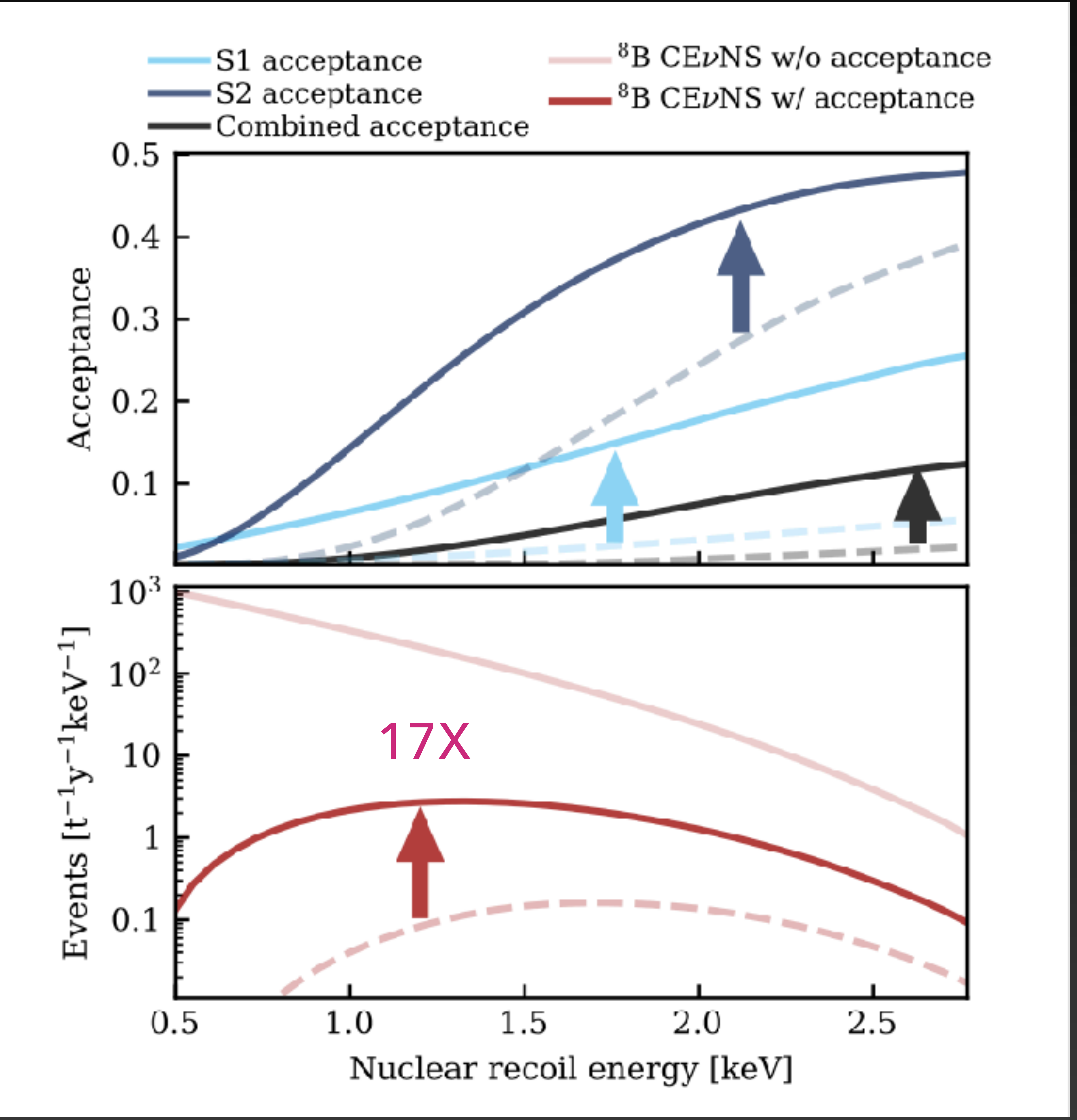
Nature 562, 505–510 (2018)

3.7 (3.3) events/(t x yr)

Blind search in Region of Interest







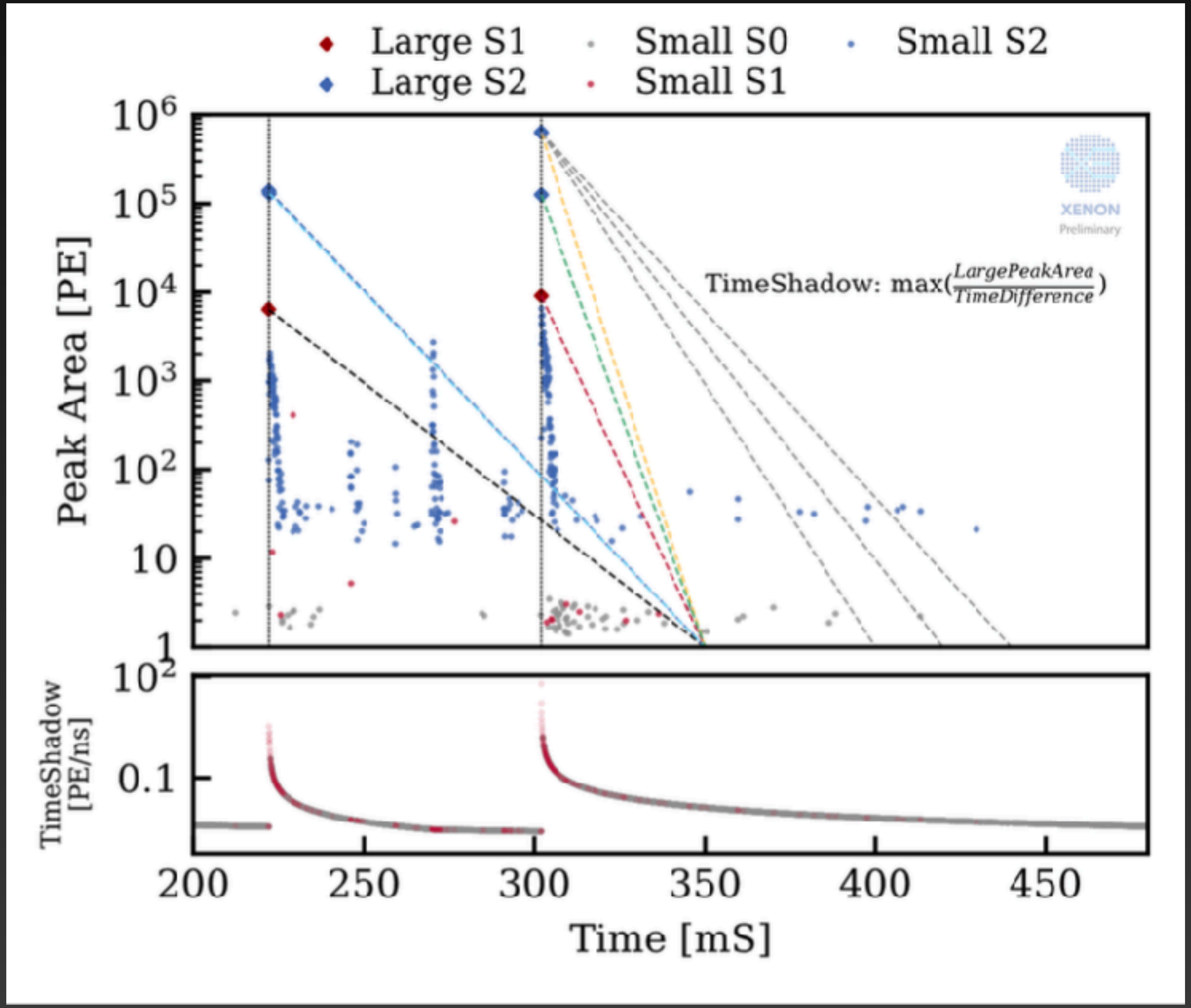
CEvNS: accidental coincidence background (AC)

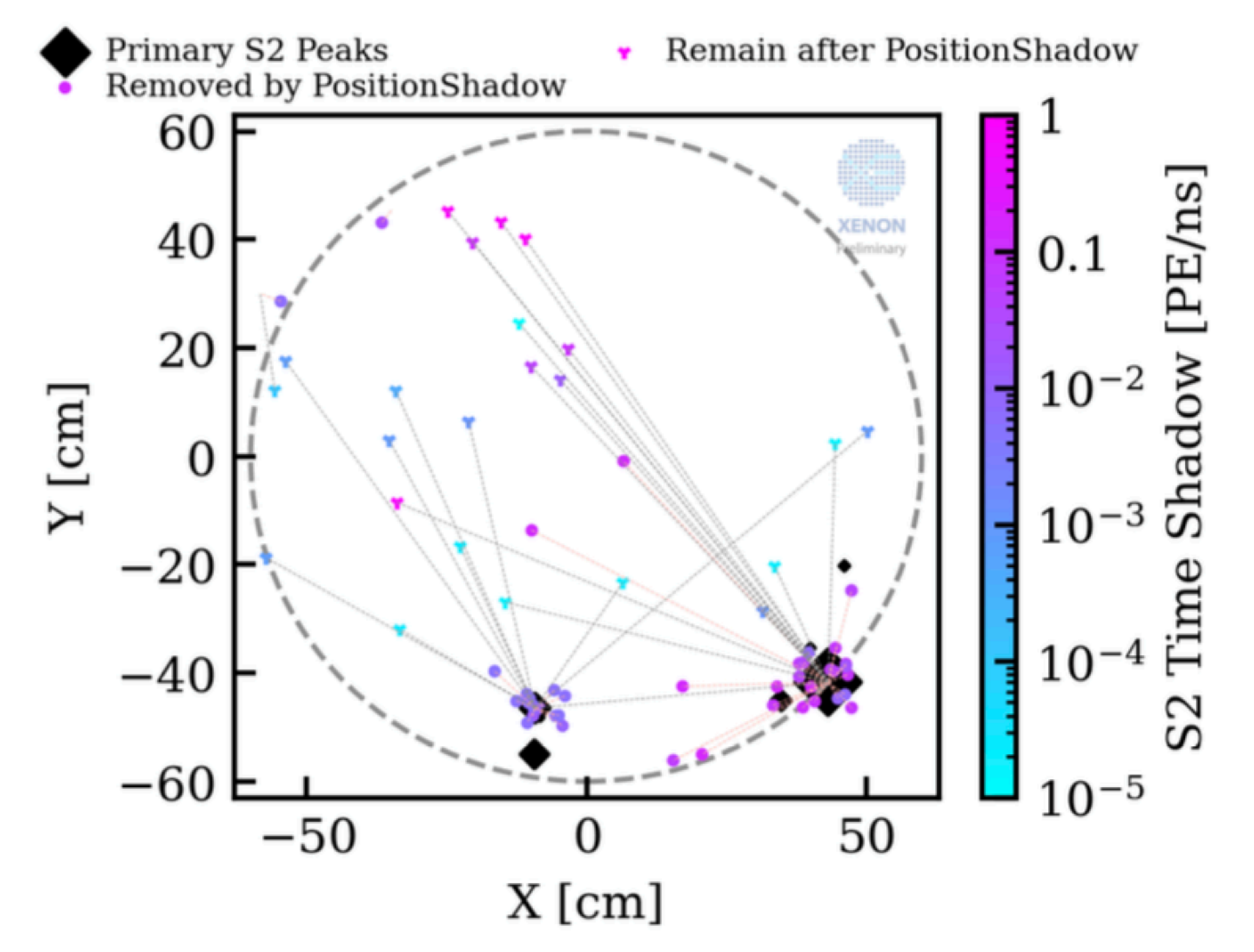
AC = accidental coincidence background due to random pairing of S1 and S2 (not physical)

Dominant background for ^{8}B CEvNS search

Mitigated by selecting spacetime correlation to previous HE events

- Isolated S1: 15 Hz → 2.3 Hz
- Isolated S2: 150 mHz → 25 mHz





CEvNS: accidental coincidence background (AC)

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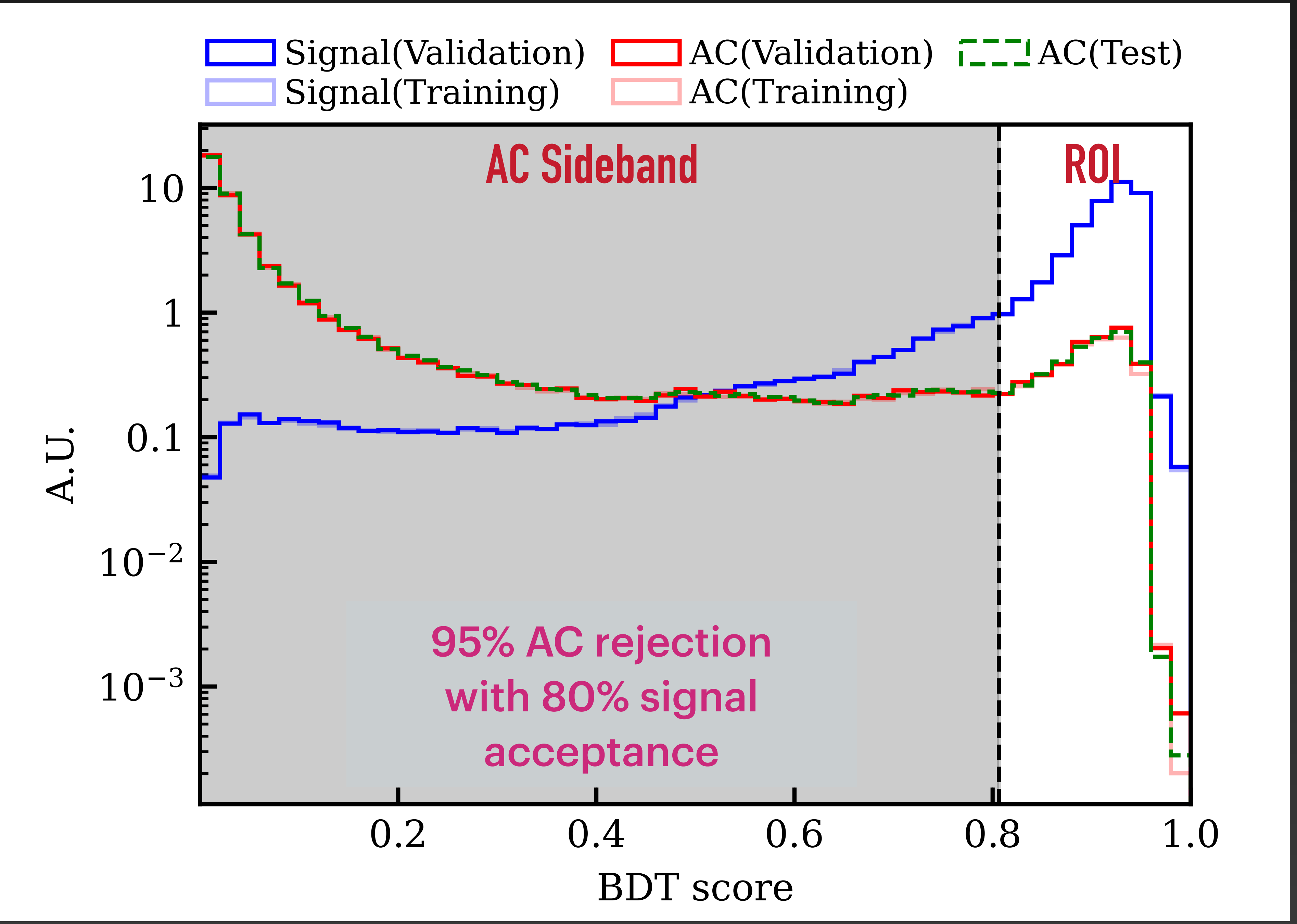
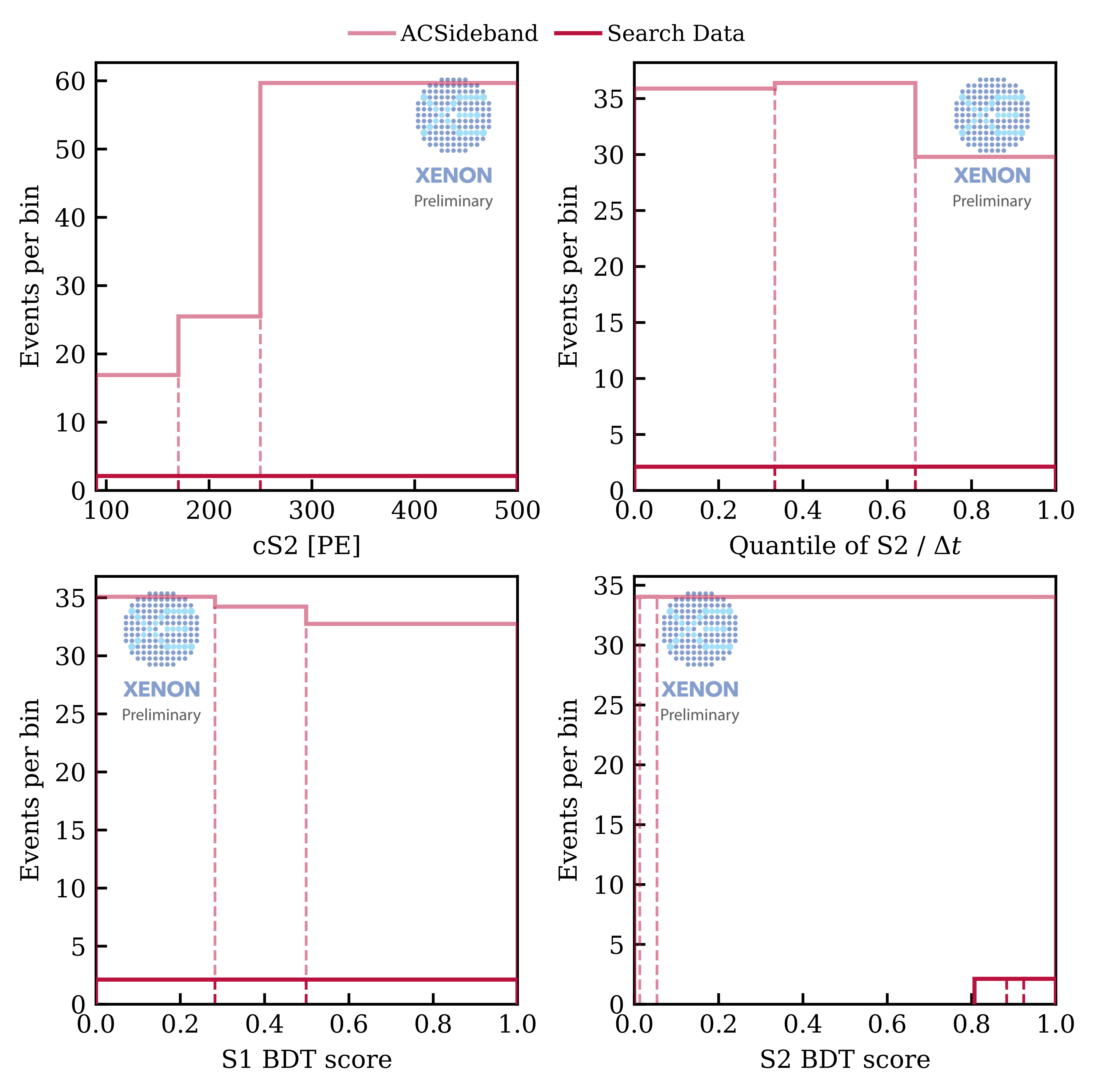
Dominant background for ^8B CEvNS search

Further suppressed with BDT analysis:
S1 BDT: VUV photon spectrum + S1 pulse shape & spectrum
S2 BDT: S2 pulse shape checked by diffusion law

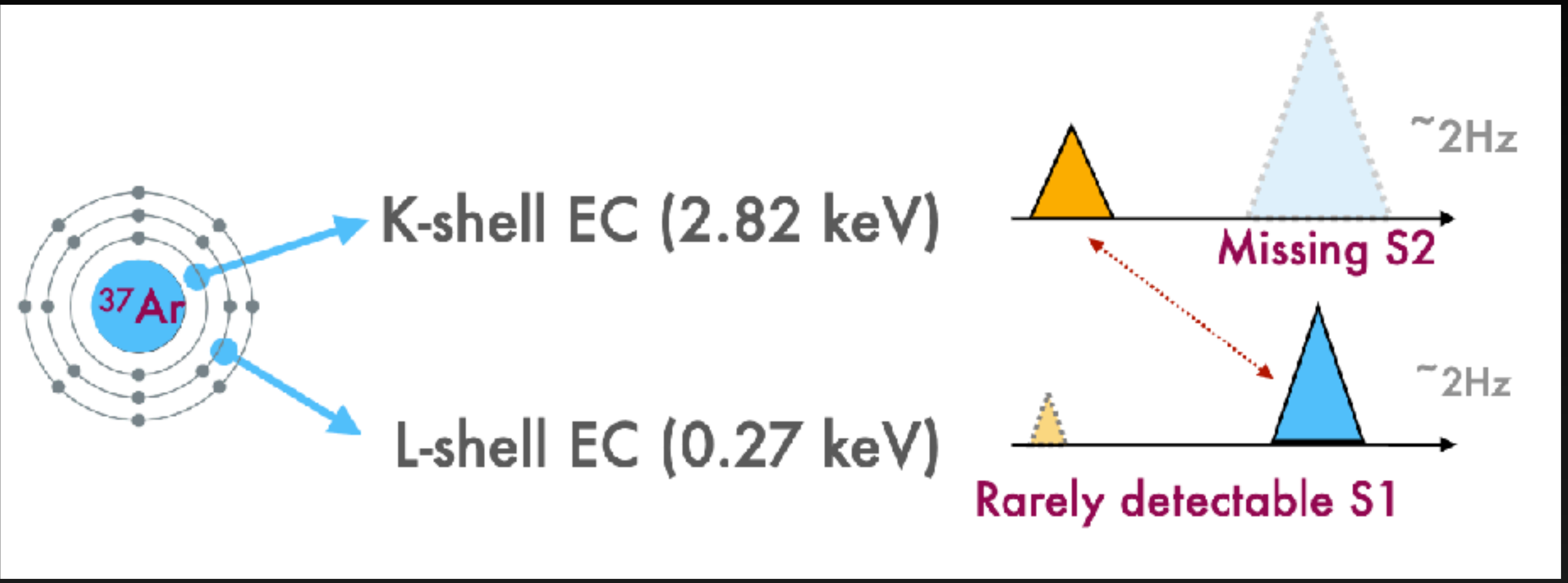
81-bins 4D search space: (cS2, S1 BDT, S2 BDT, $S2_{pre}/\Delta t_{pre}$)

Component	Sideband	Search Data
AC - SR0	123,7	7,48
AC - SR1	350	17,77
^8B	< 2	11,93



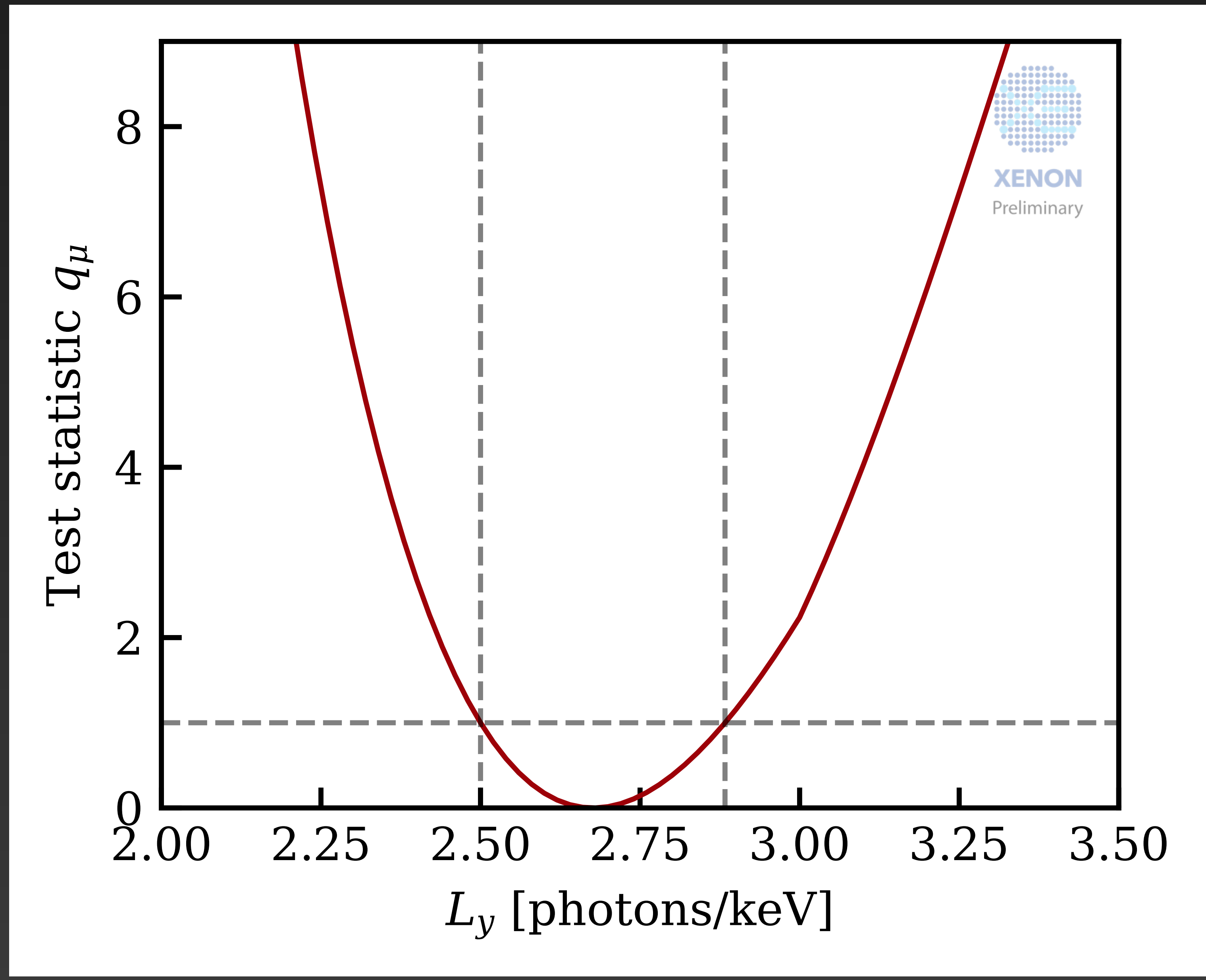


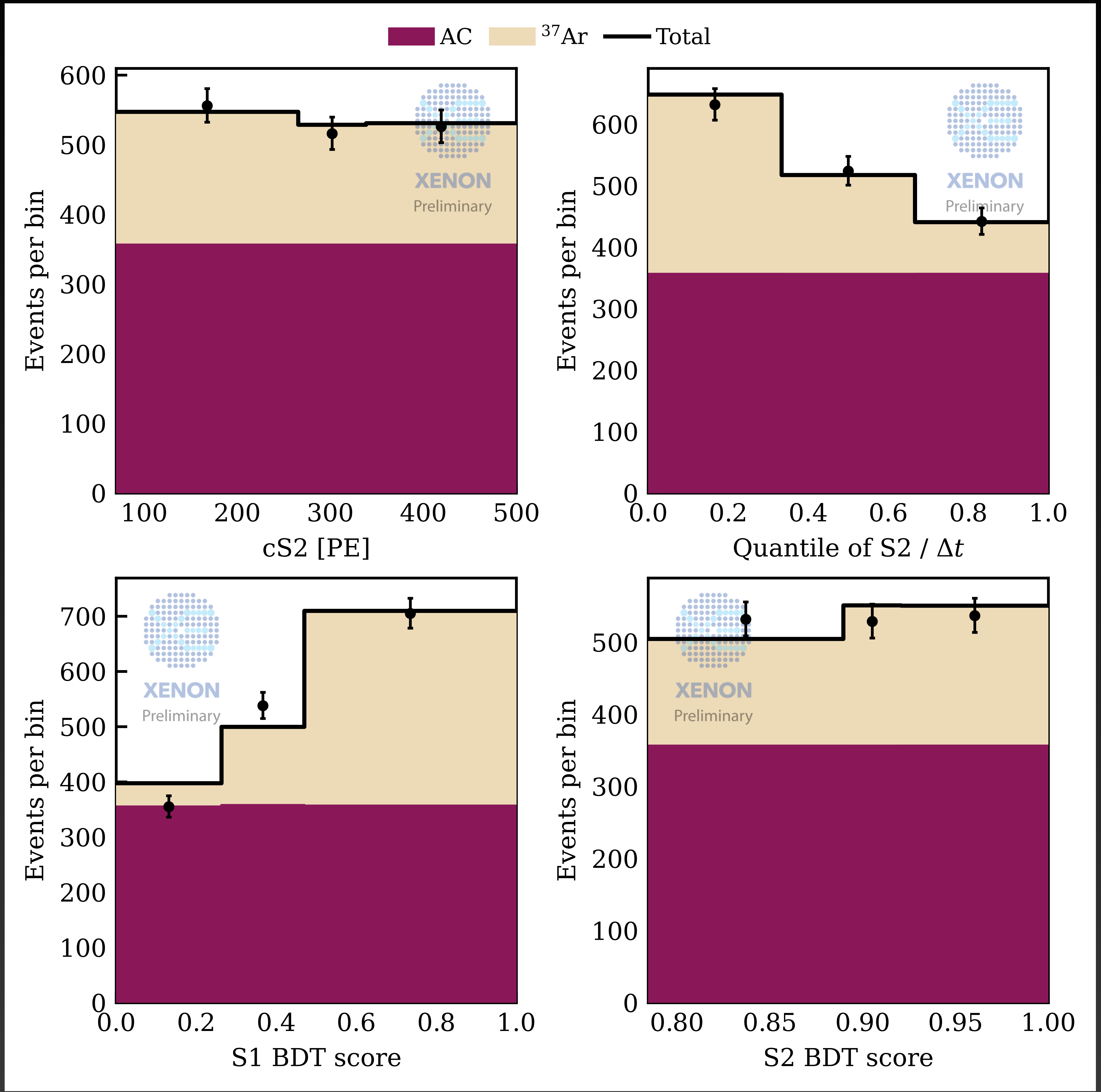
CEvNS: analysis validation with ^{37}Ar



Validated by ^{37}Ar L-shell 0.27 keV ER calibration data

Constrained ER light yield: 2.69 +- 0.19 PE/keV$_{ER}$





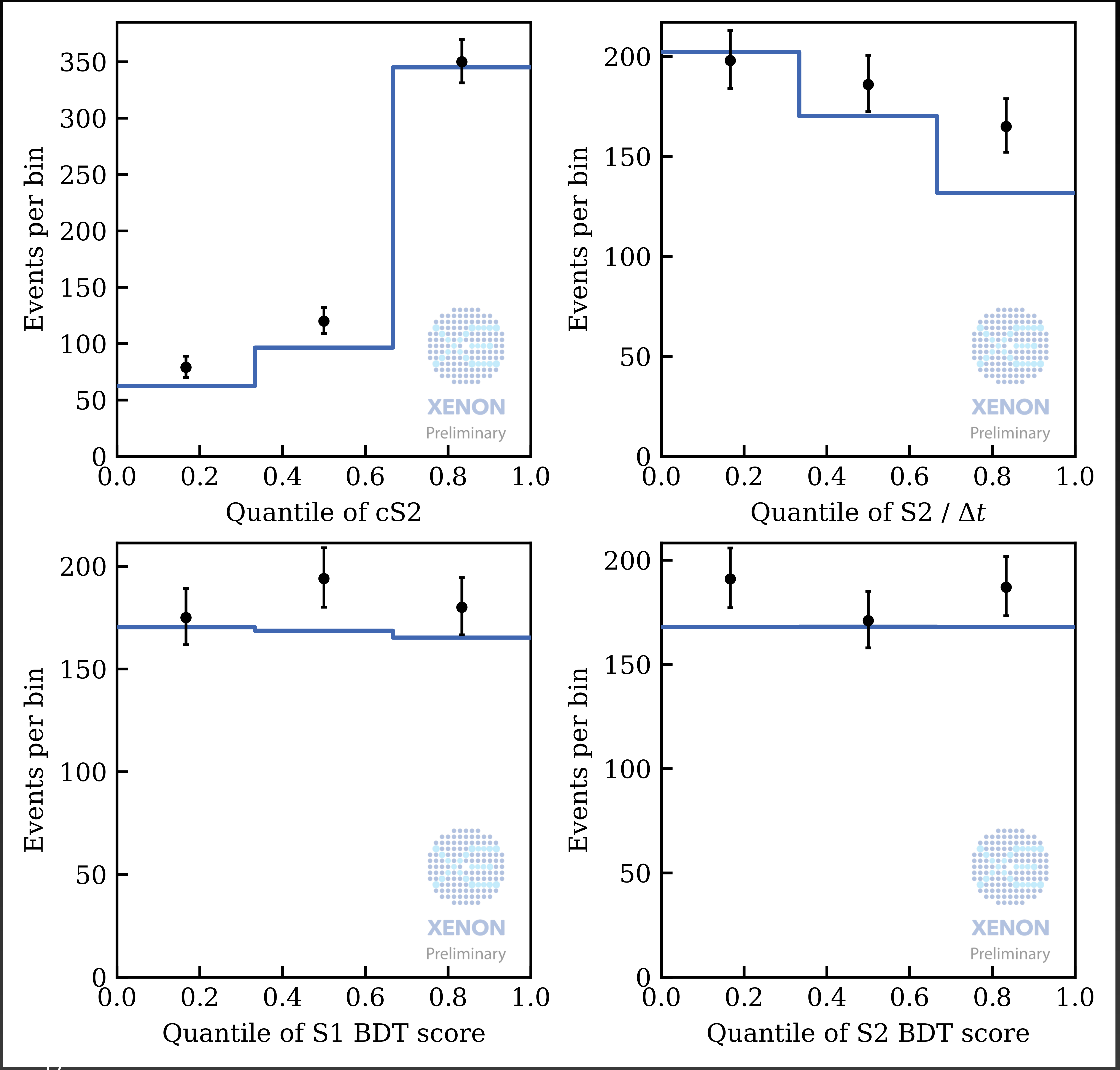
CEvNS: AC sideband unblinding

Validated by AC sideband unblinding (events that failed S2 BDT cuts)

S2 threshold is increased to 120 PE after sideband unblinding

Science Run	Expectation	Observation	P-value (4D)	Deviation from expectation
SR0	122,7	121	0,33	-0.15 sigma
SR1	290,0	310	0,252	1.17 sigma

The remaining differences of less than 10% are considered as systematic uncertainty



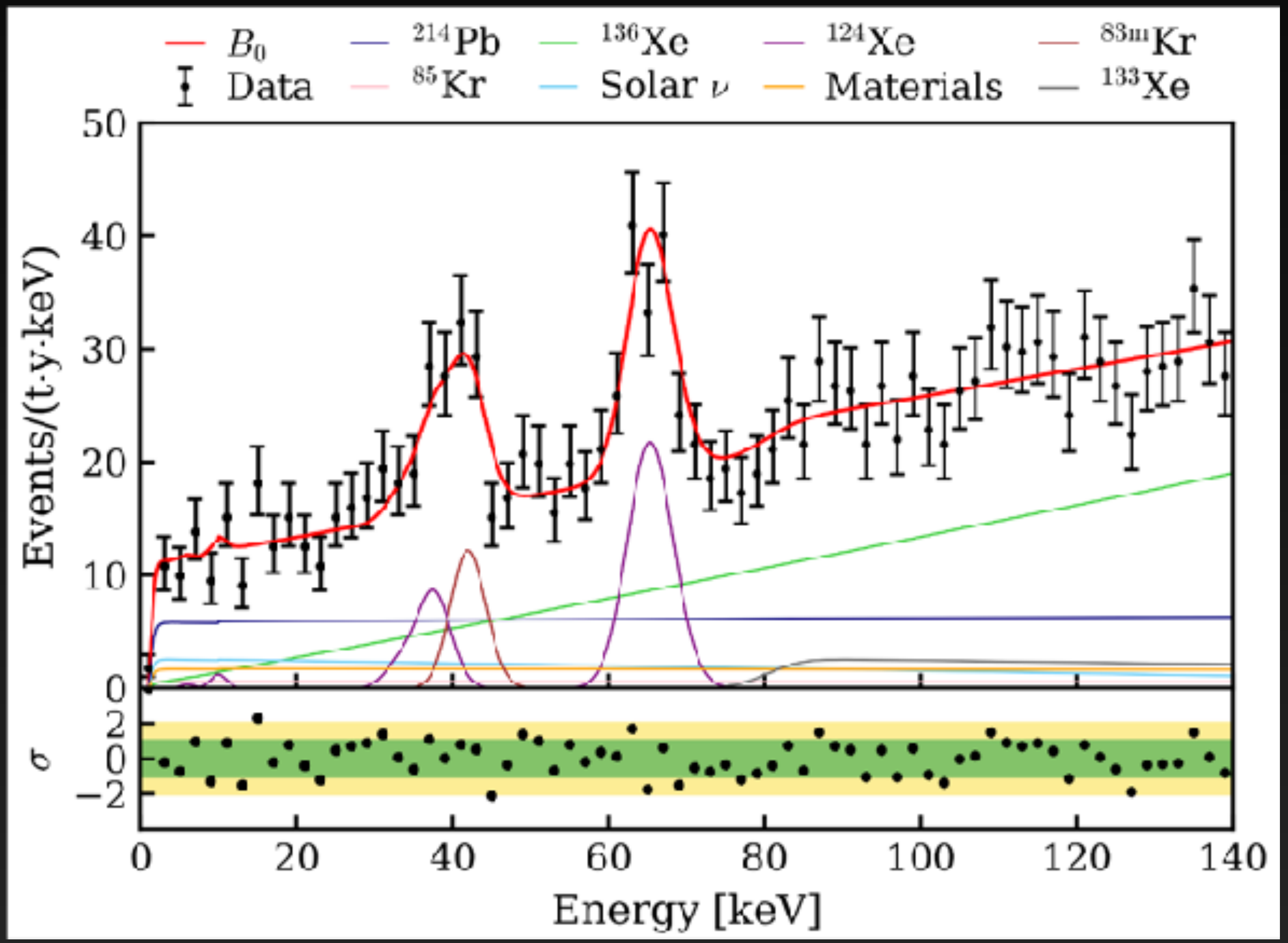
CEvNS: subdominant backgrounds

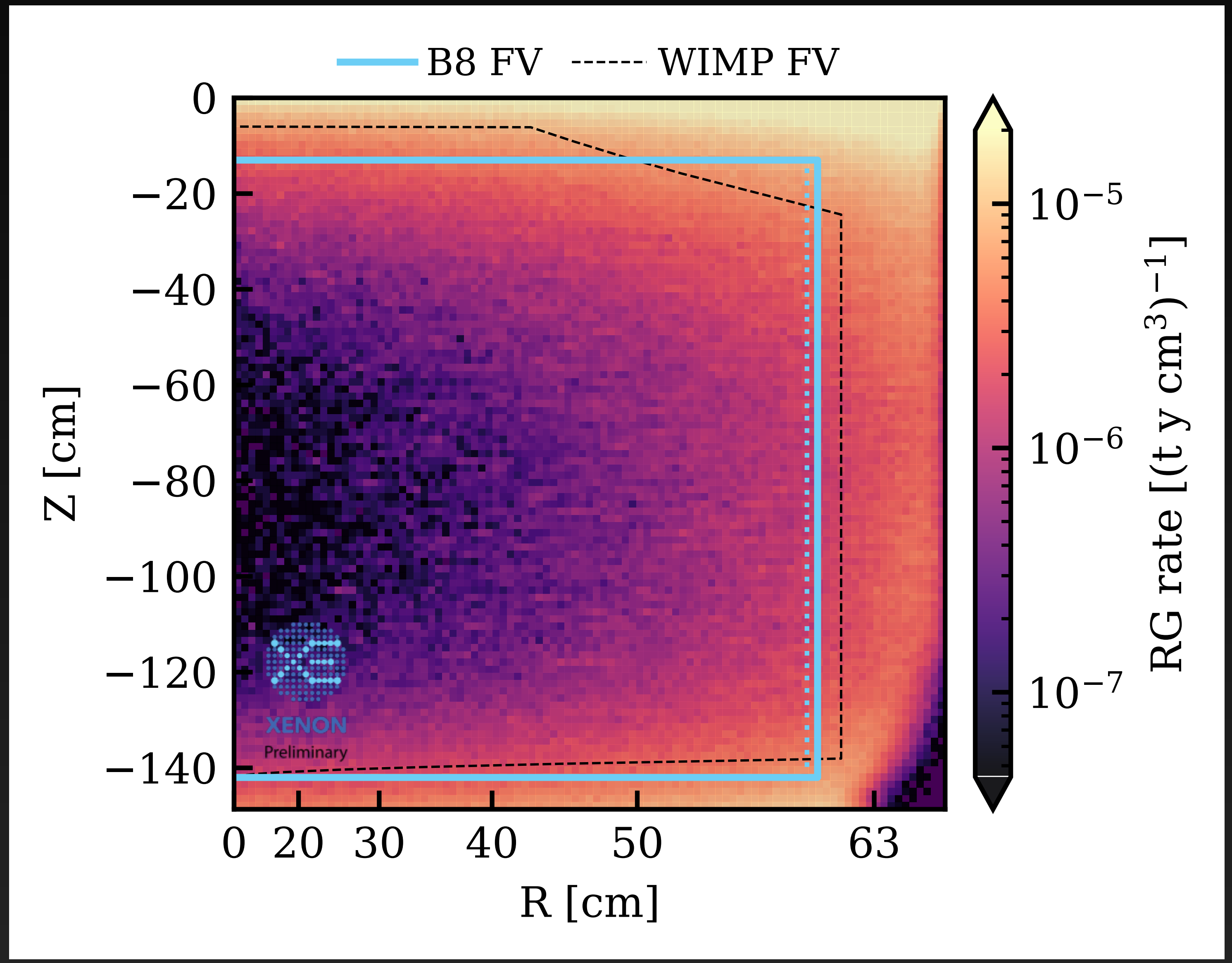
Electronic recoil

Mostly ^{214}Pb beta decays

Flat spectrum from unblinded region

Conservative value of 100% uncertainty to yield model





Radiogenic neutrons

spontaneous fission and (α,n) reactions

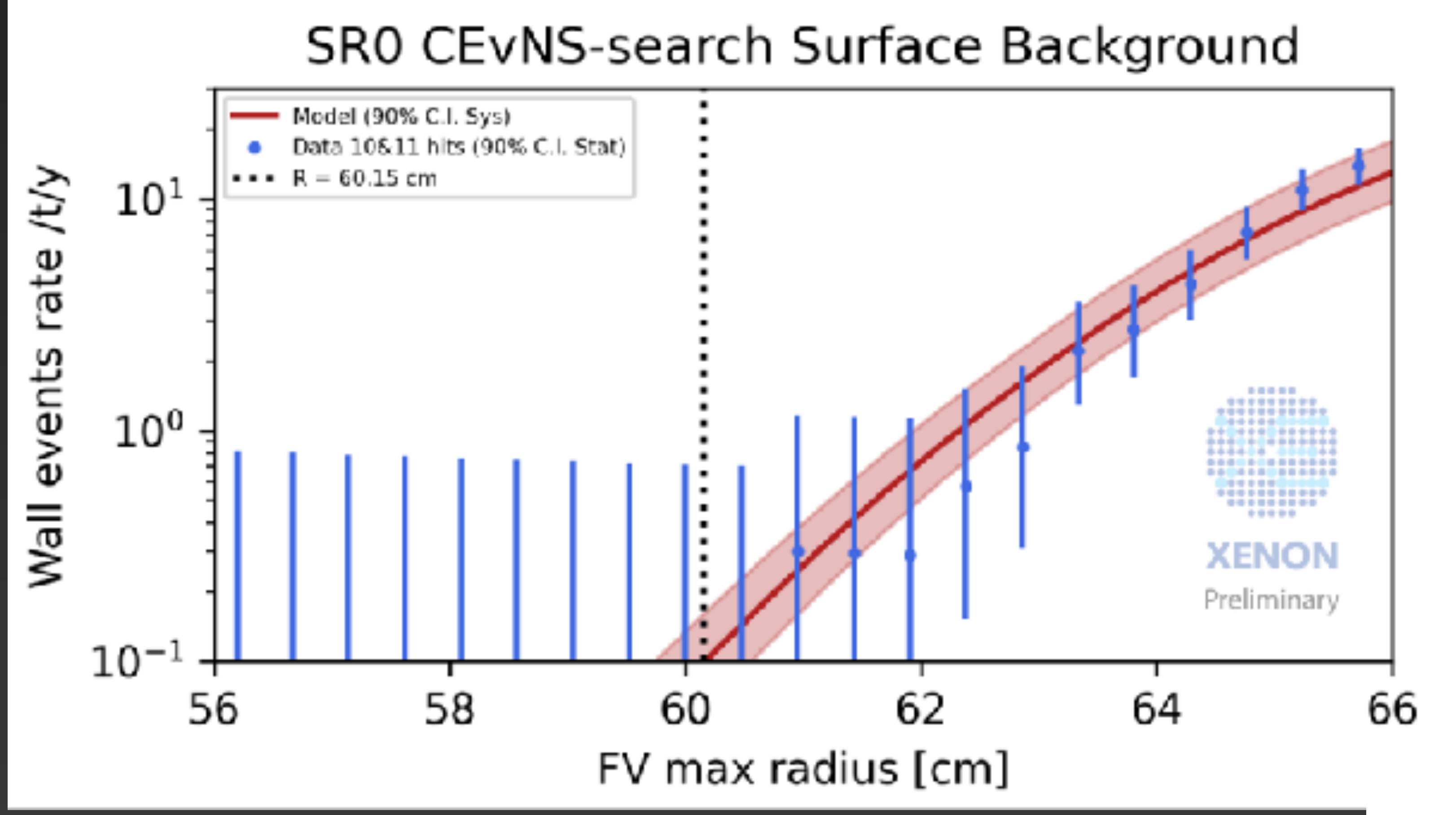
SR0: 0.13±0.07 Events

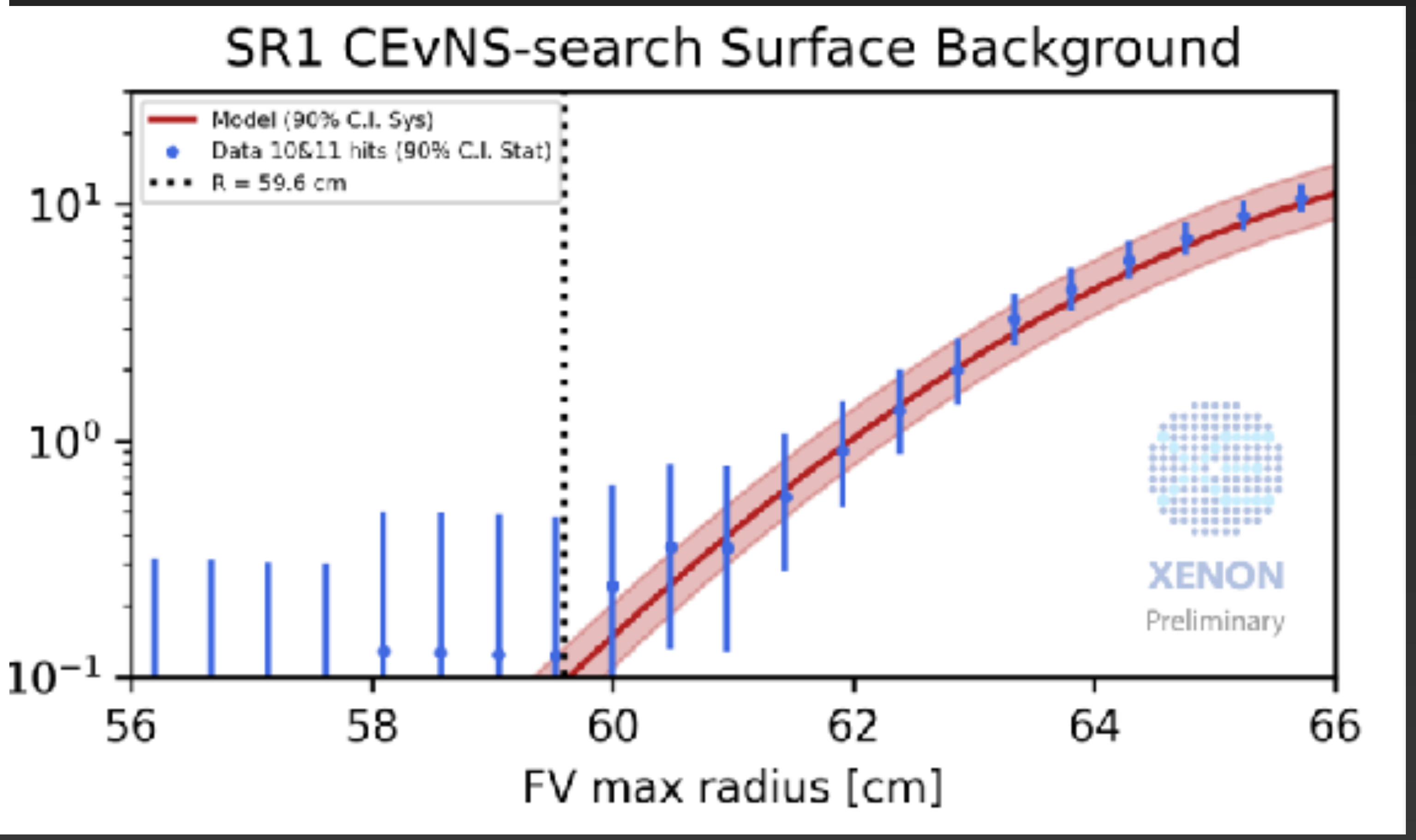
SR1: 0.33±0.19 Events

Surface background

ERs from ^{210}Pb plate-out at walls of the detector (radial cut applied)

Prediction from data-driven model is negligible (<0.3 events)



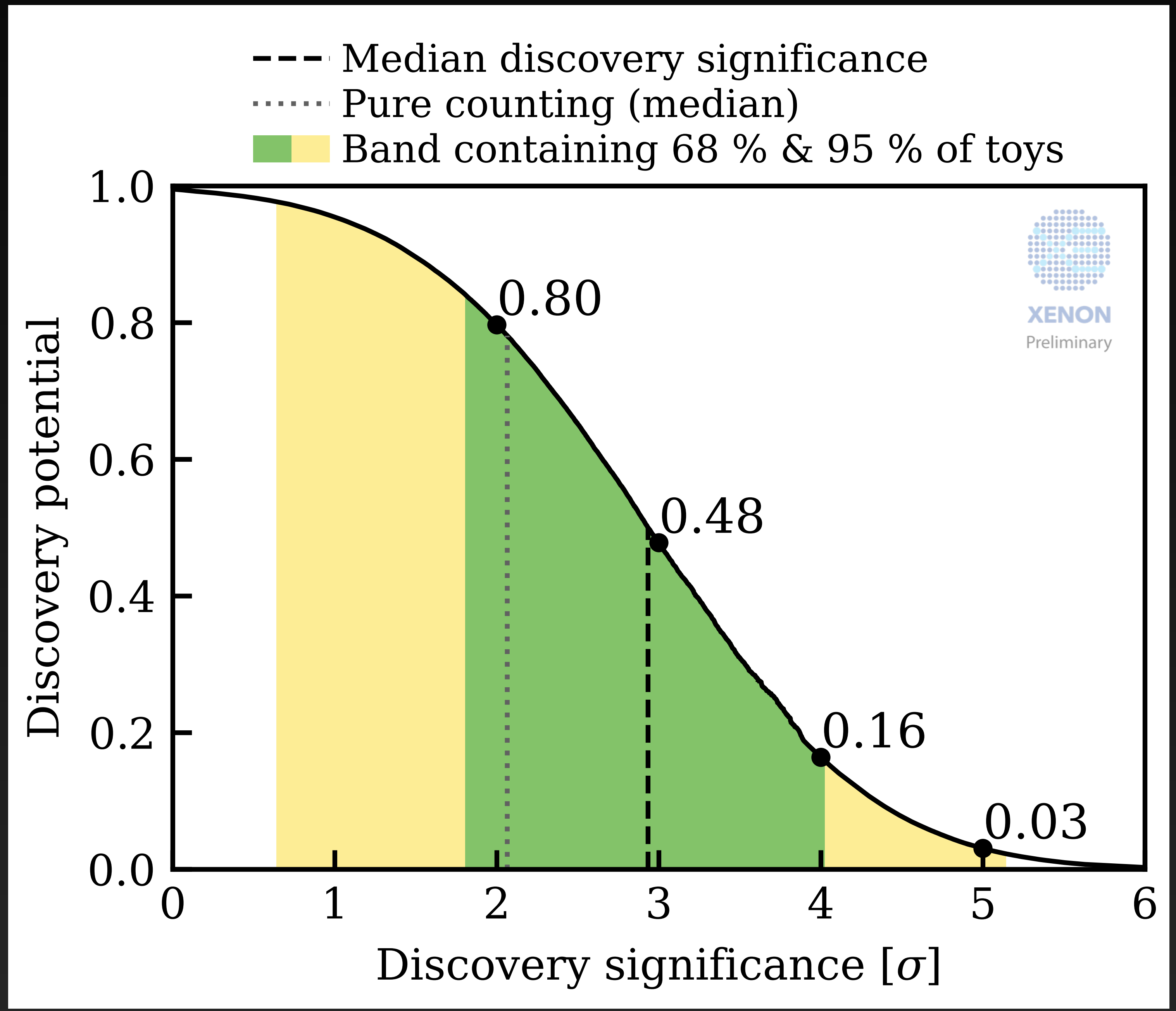


CEvNS: results from unblinding

Total exposure: 3.51 ton year

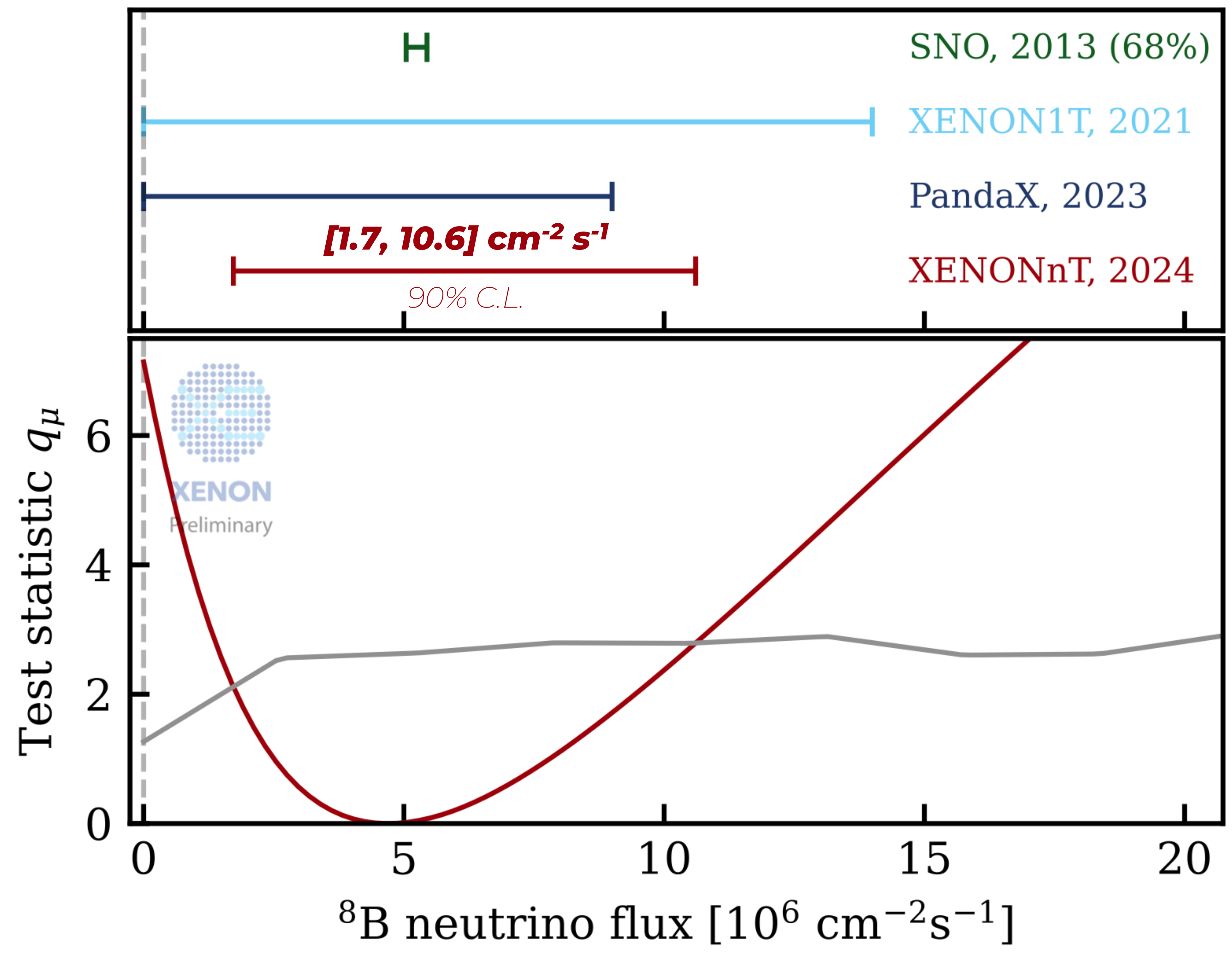
48% probability to observe >3σ significance

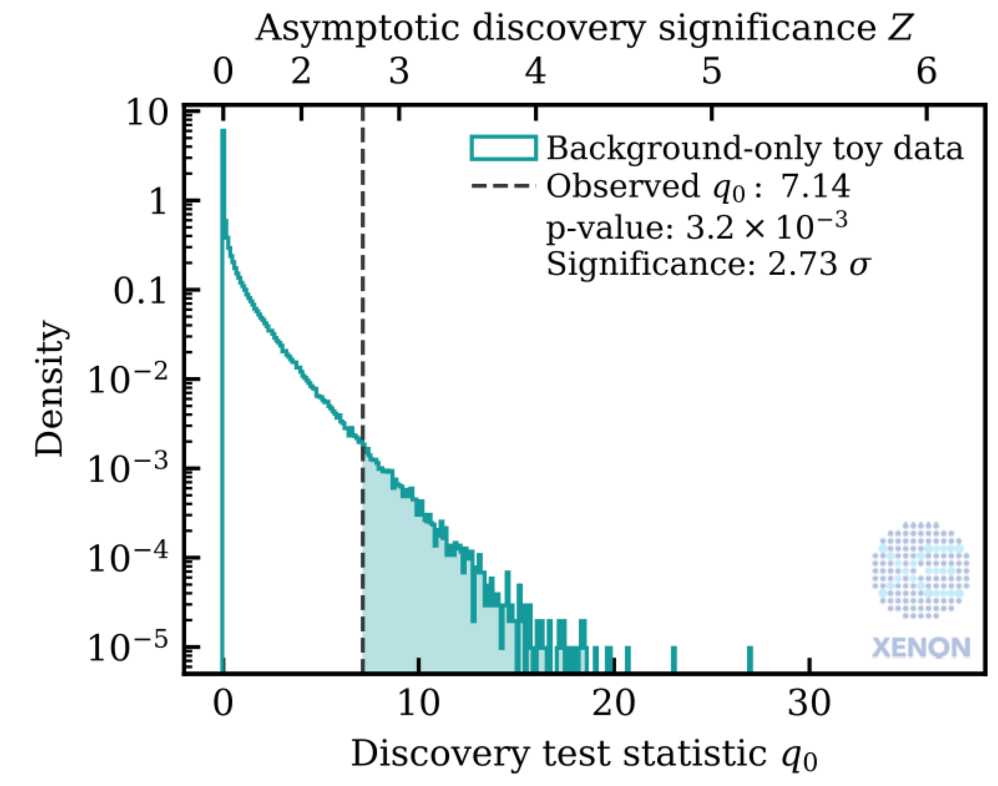
Solar ^{8}B flux measurement in agreement with SNO (2013) as [1.72, 10.6] 10^6 cm^{-2} s^{-1} at 90% C.L.



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	

Submitted to PRL, arXiv: 2408.02877

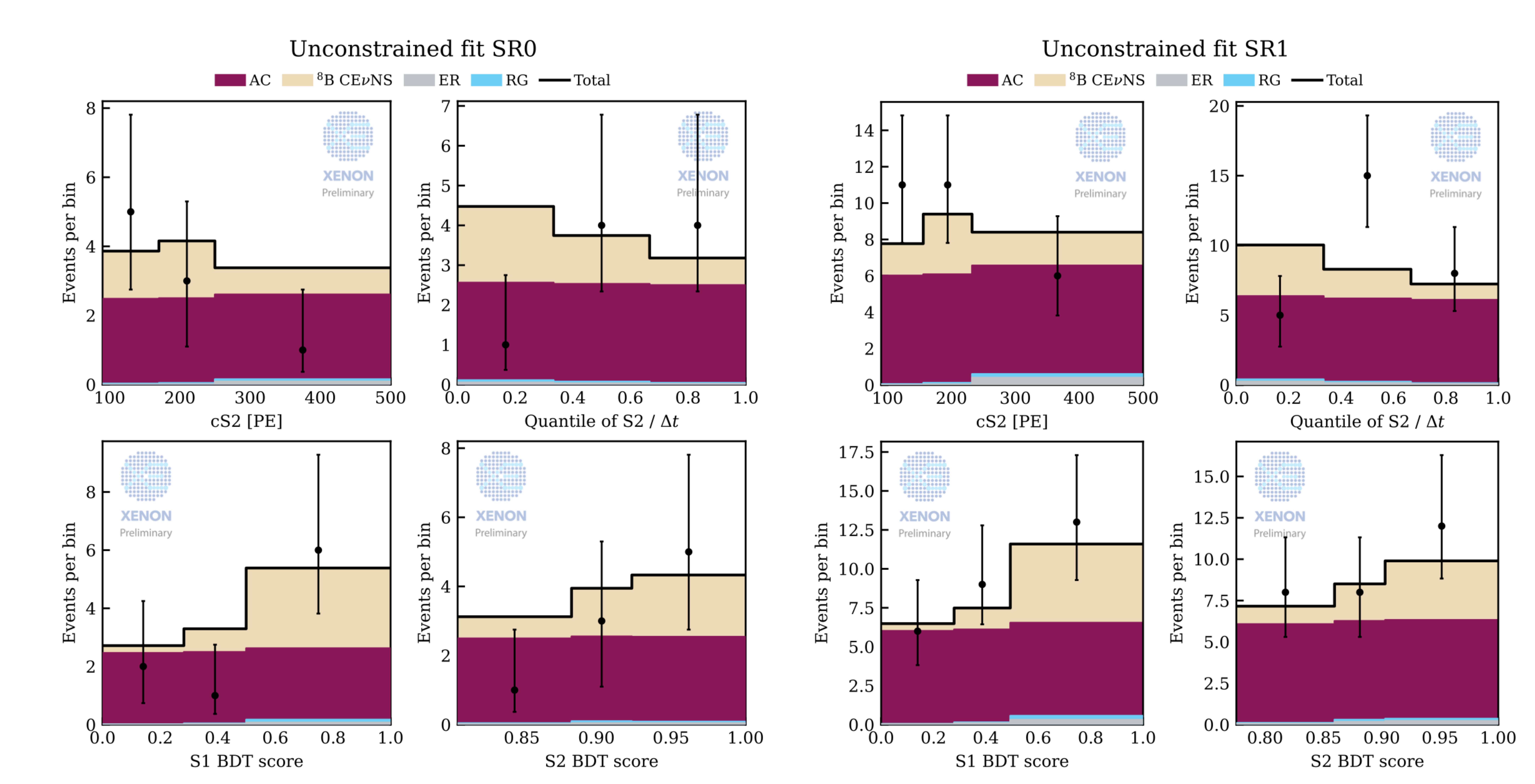




Background-only hypothesis rejected with **2.73σ significance**

CEvNS: results from unblinding

37 OBSERVED EVENTS - no deviation of background and signal models paramenters



CEvNS: first measurement for a Xe target

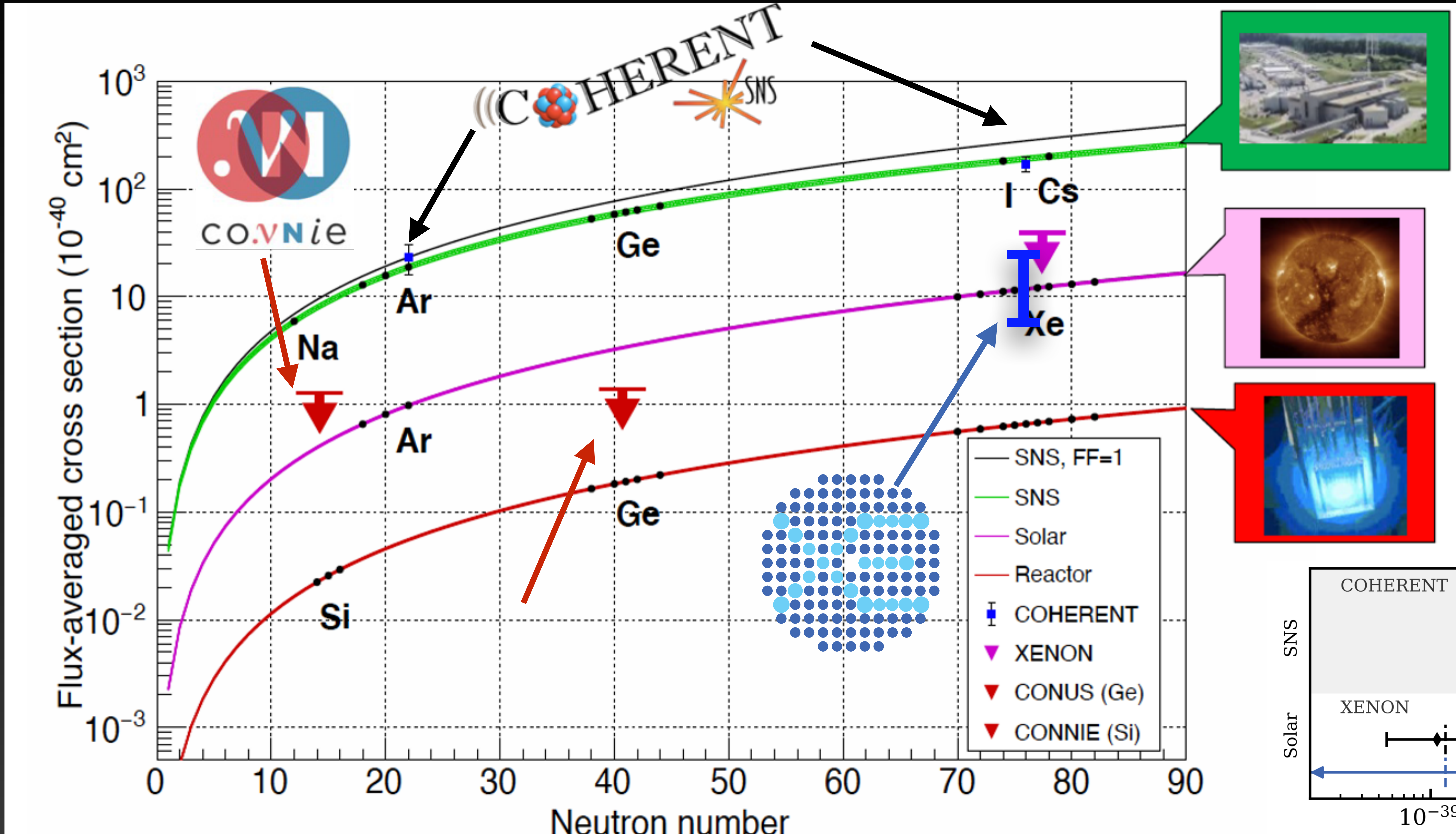
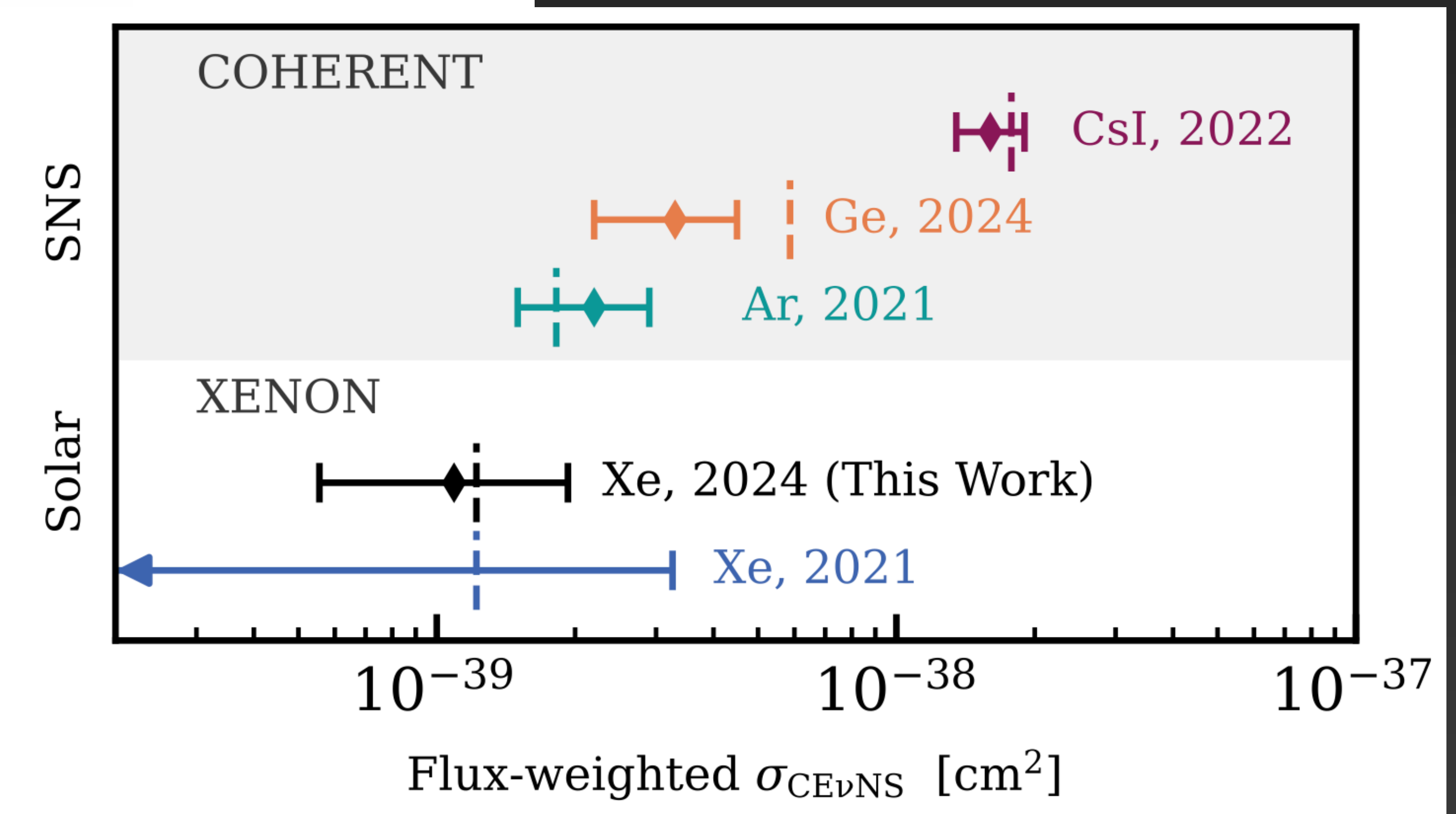


Figure credit: K. Scholberg

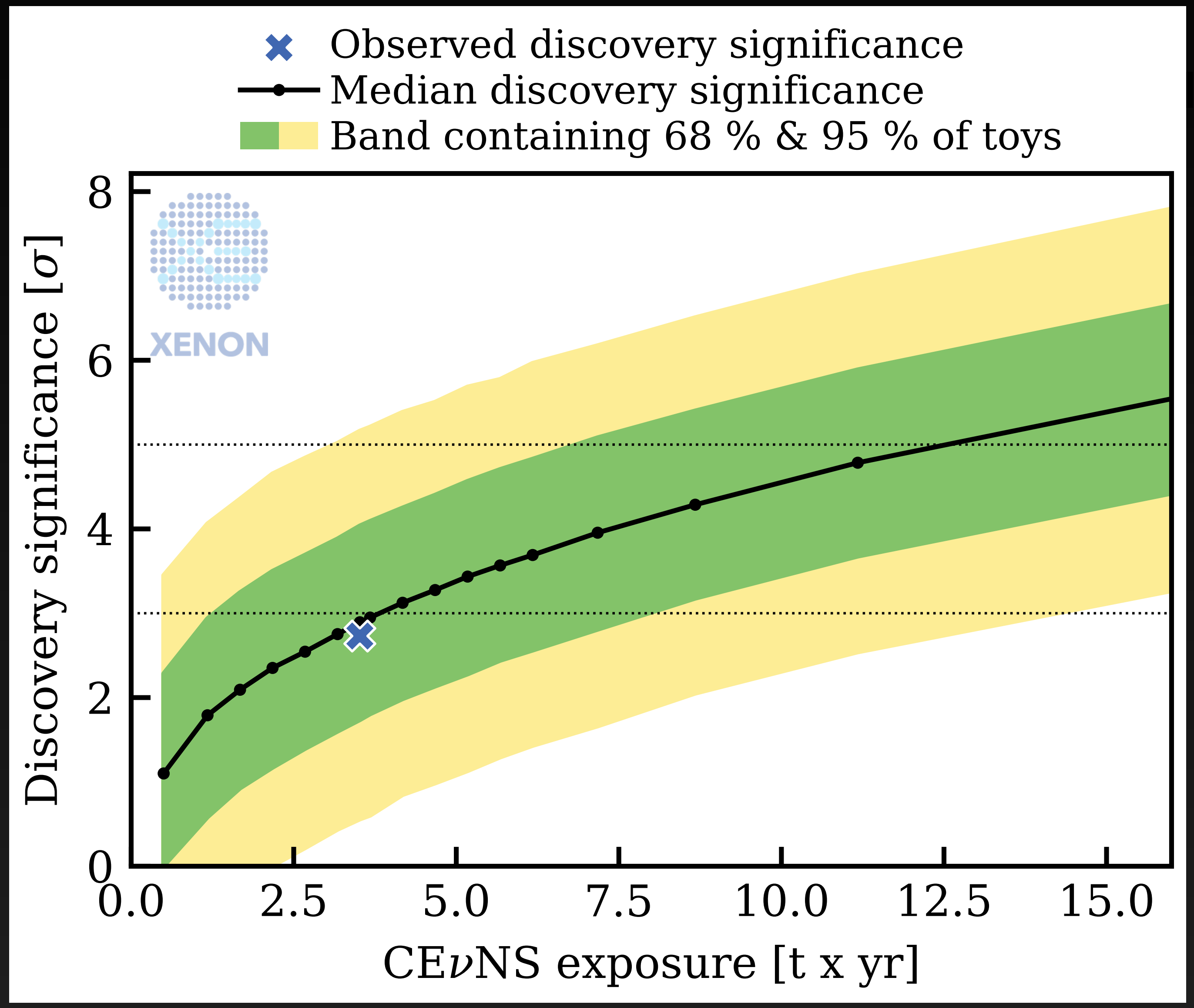
First:

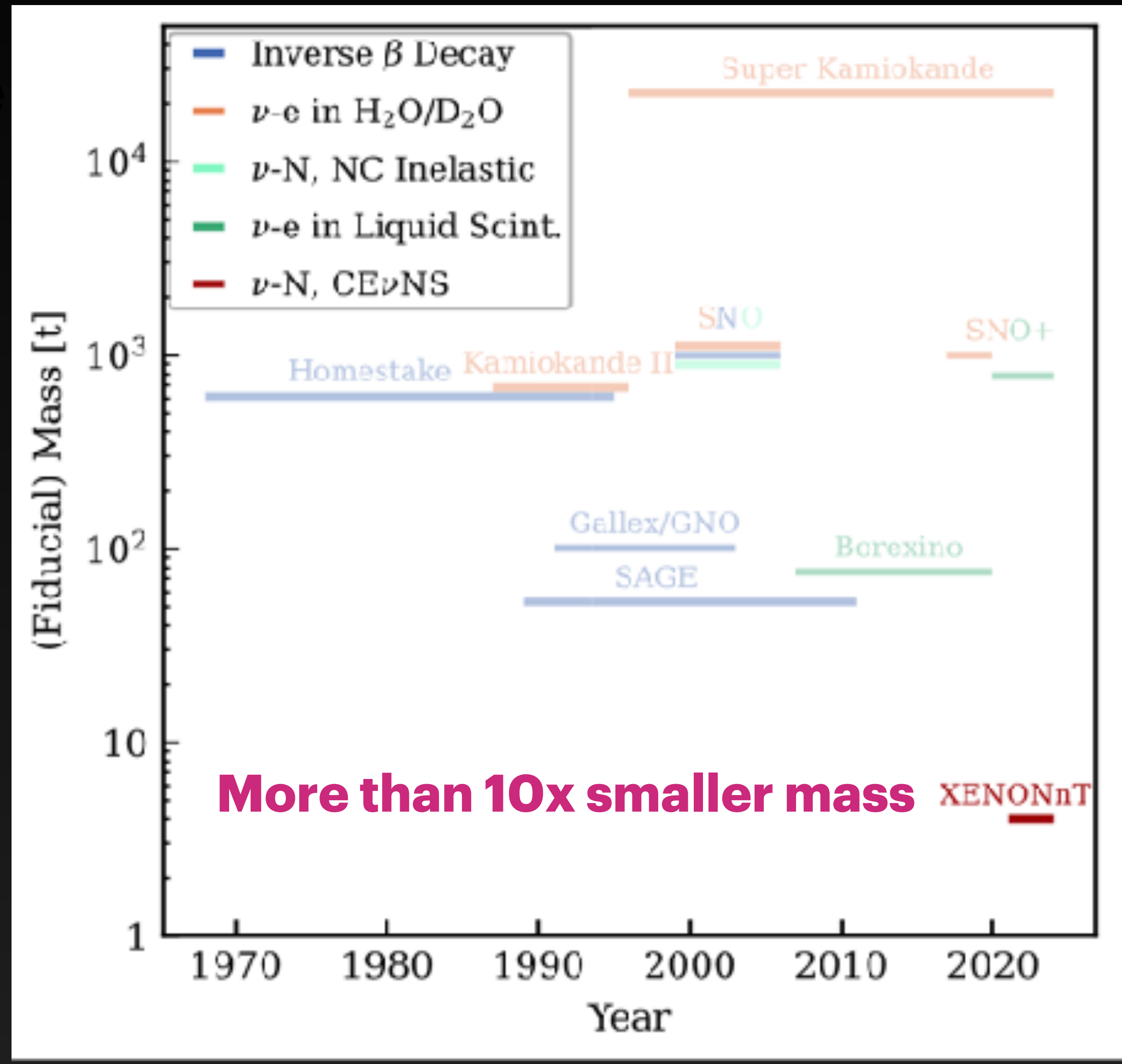
- detection of elastic NRs from astrophysical neutrinos
- measurement of the CEvNS process with a Xe target
- step into the "neutrino fog" by a DM experiment



Conclusions and outlook

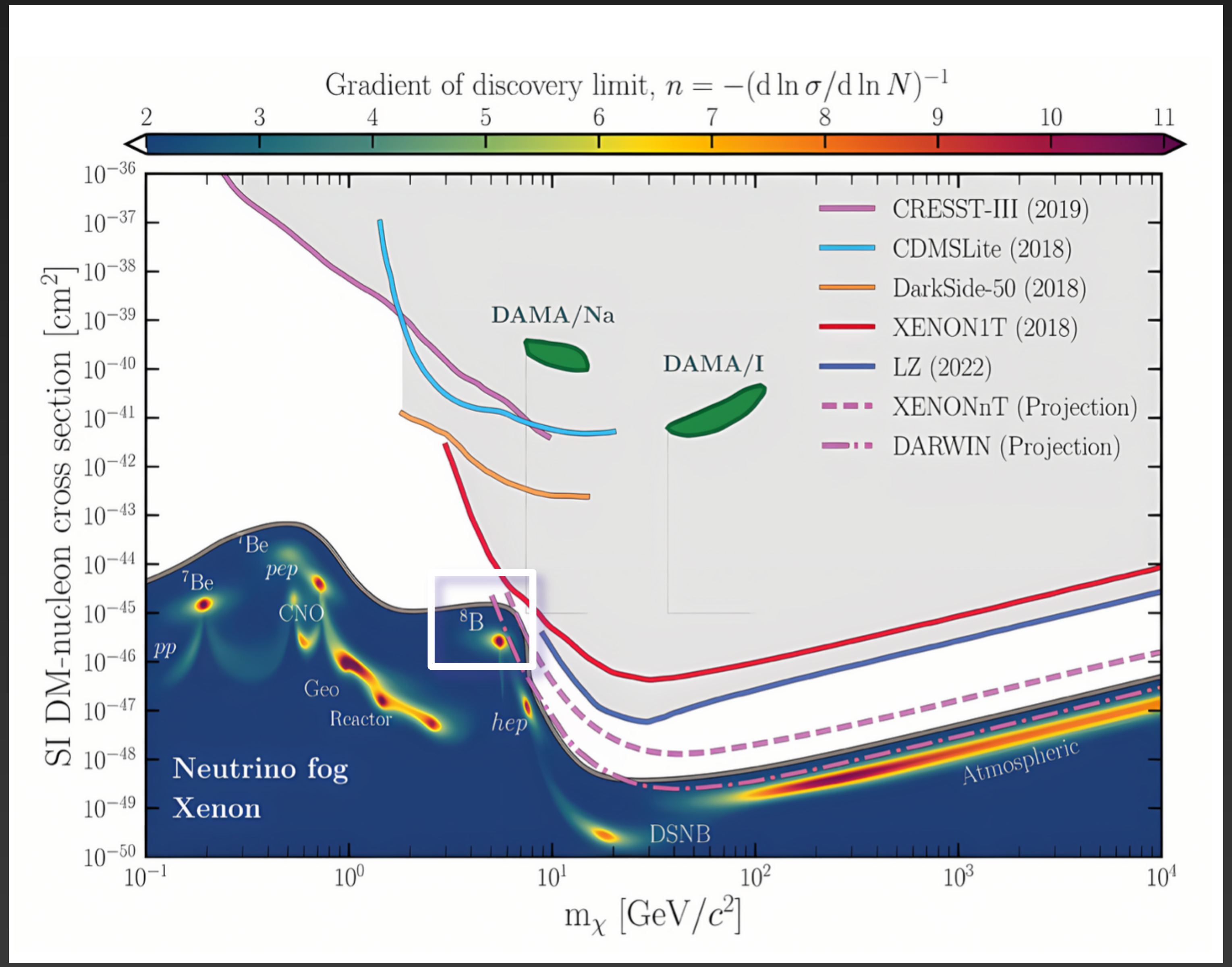
- XENONnT measures the **CEvNS signal** in Xe from solar 8B neutrinos for the first time! Submitted to PRL, arXiv: 2408.02877
- With more exposure, we expect to measure the solar ^{8}B neutrino signal at higher significance and to better constrain the ^{8}B neutrino flux
- The improvements in flux measurement are limited by uncertainties of the LXe response to nuclear recoils.





Physics reach of XENONnT:

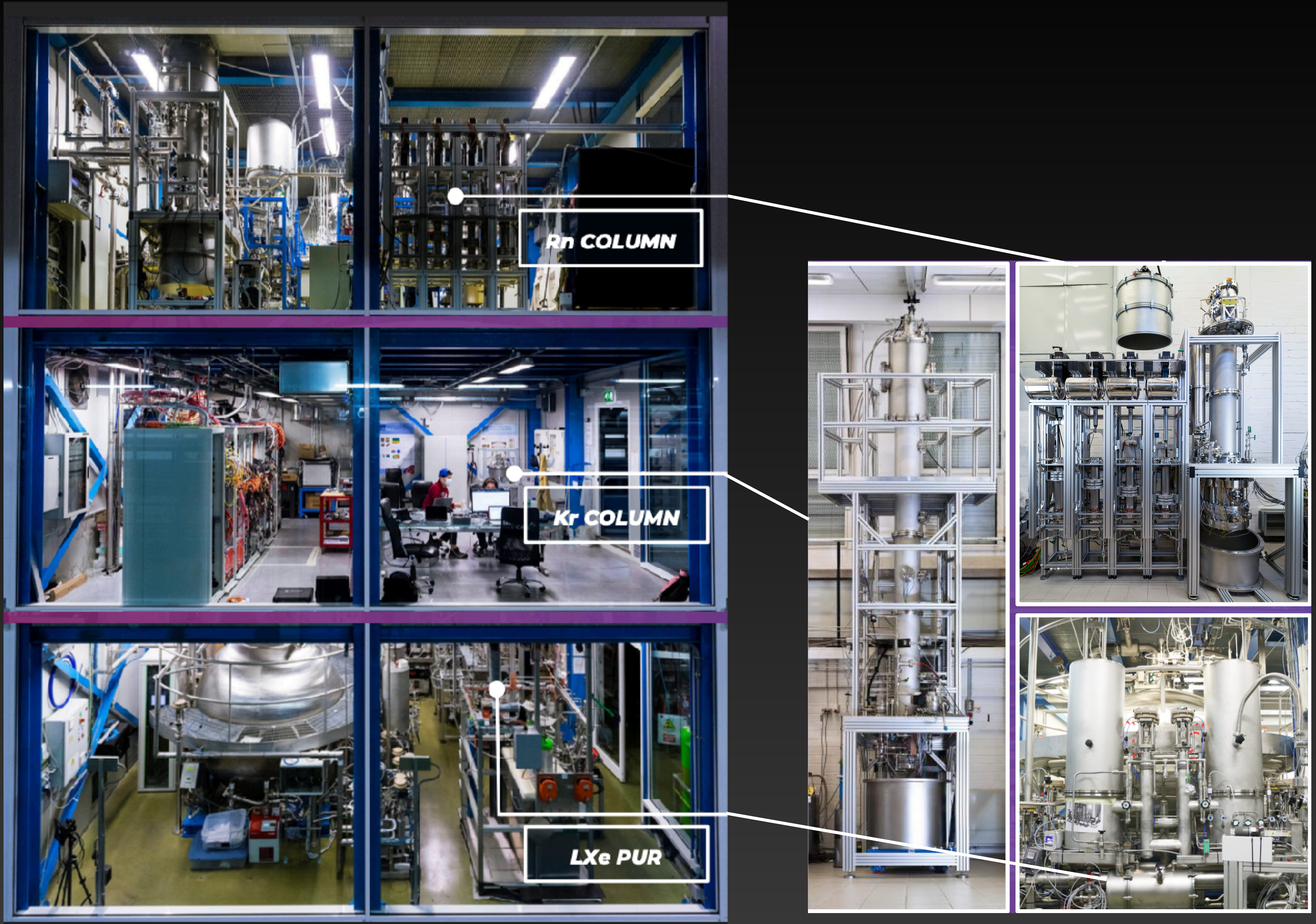
- **WIMP** dark matter (standard and low-mass)
- Other DM Models (Dark photons, ALPs,…)
- **Solar neutrinos** (^{8}B, hep, ^{7}Be CEvNS, pp elastic scattering)
- **Neutrino nature** (Neutrinoless double-beta decay,…)
- **Astrophysics** (Supernova neutrinos, Atmospheric neutrinos, GW multi-messenger,…)



Backup slides

Nature 562, 505–510 (2018)

Liquid purification and cryogenic distillation



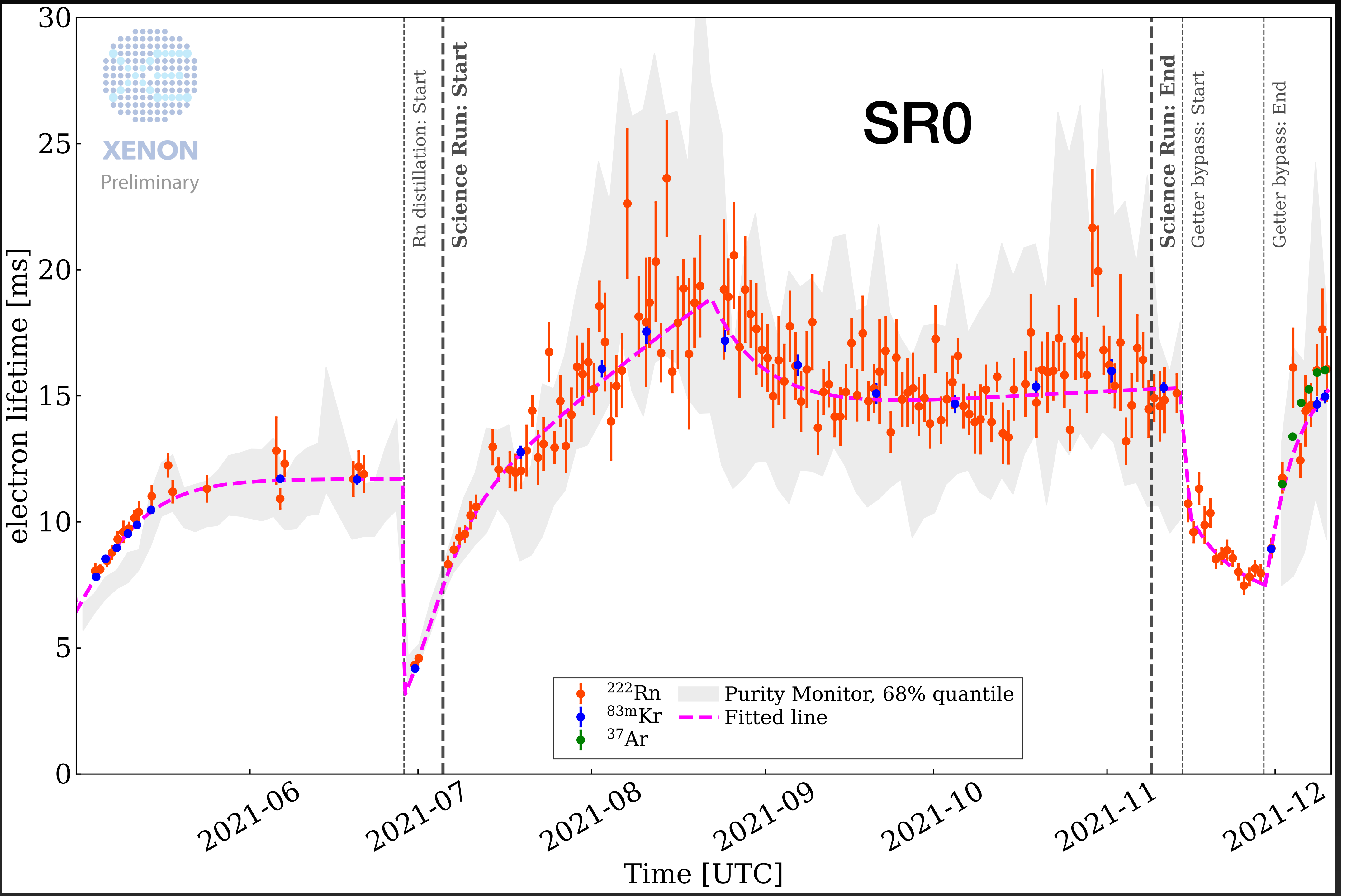
Nature 562, 505–510 (2018)

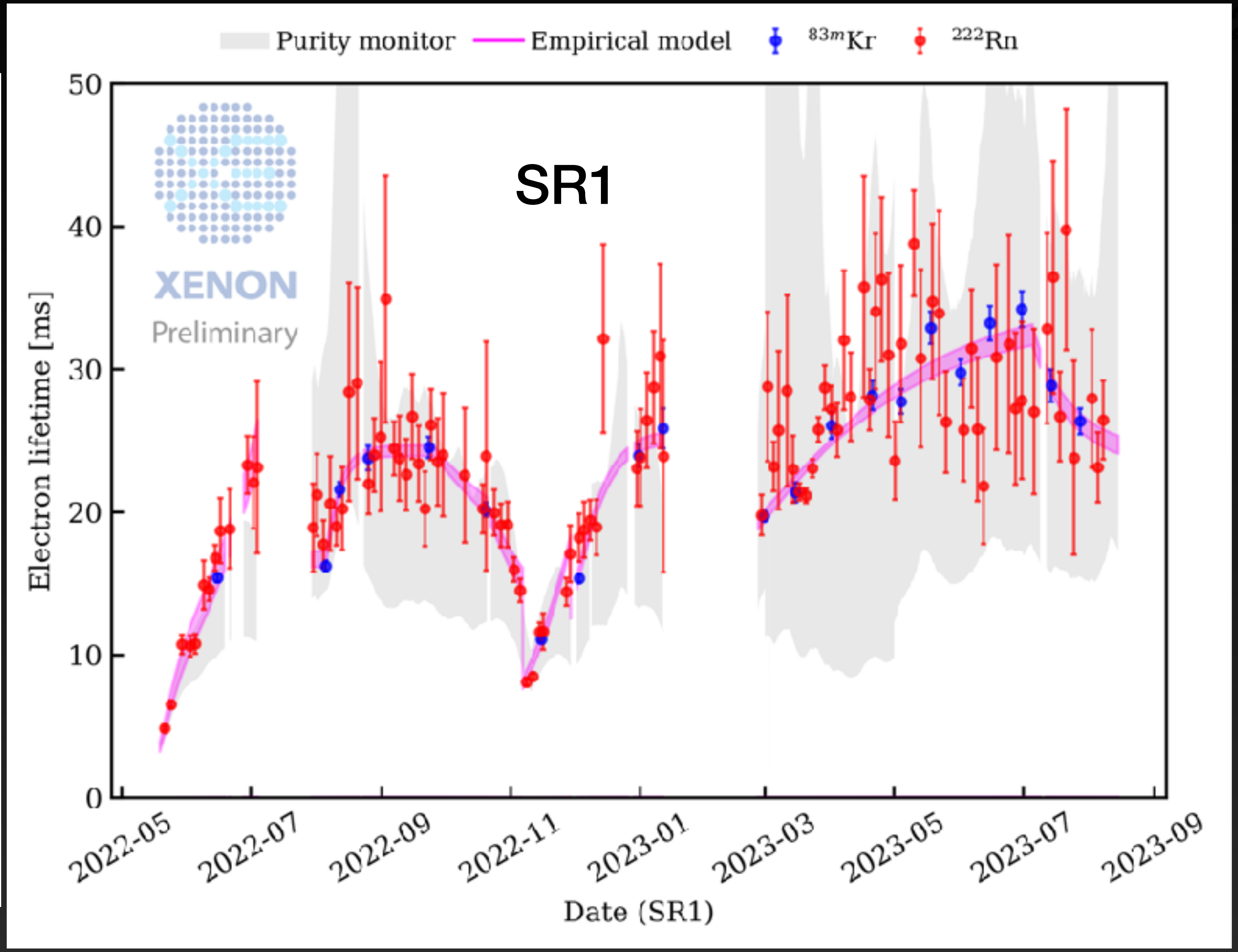
^{222}Rn cryo-distillation
Continuous online distillation
^{222}Rn conc. (SR0): 1.8 µBq/kg
^{222}Rn conc. (SR1): 0.8 µBq/kg !
Was the dominant bkg in XENON1T

^{85}Kr cryo-distillation
natKr/Xe concentration : <50 ppt
Made subdominant since XENON1T

Liquid purification
Removal of electronegative impurities
GXe and LXe purification systems
Electron lifetime achieved: >30 ms !
Full TPC drift time: 2.2 ms

Liquid purification and cryogenic distillation





Liquid purification

Removal of electronegative impurities GXe and LXe purification systems

Electron lifetime achieved: >30 ms !

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