XENONnT: FIRST MEASUREMENT OF

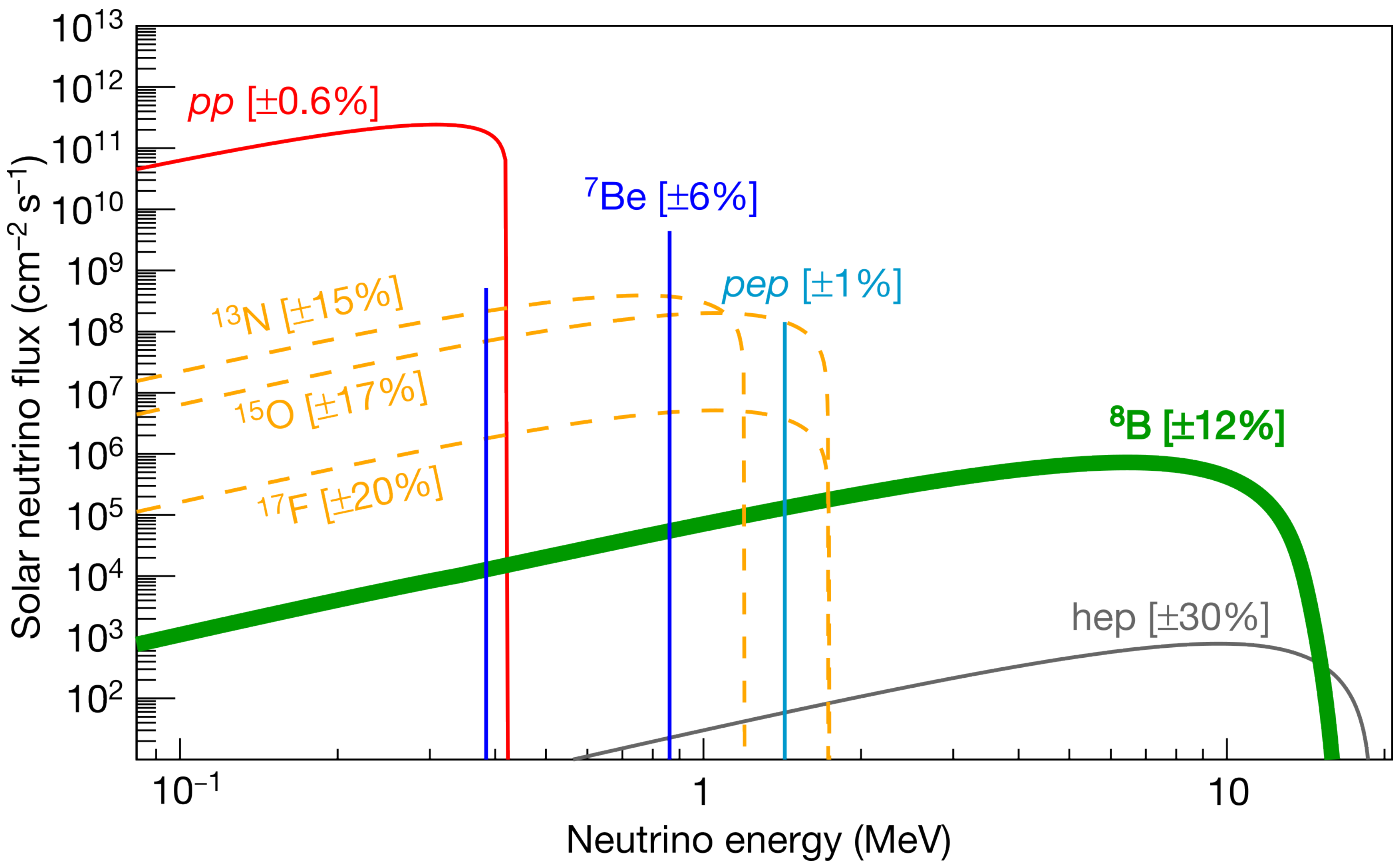
SOLAR ^{8}B CEνNS

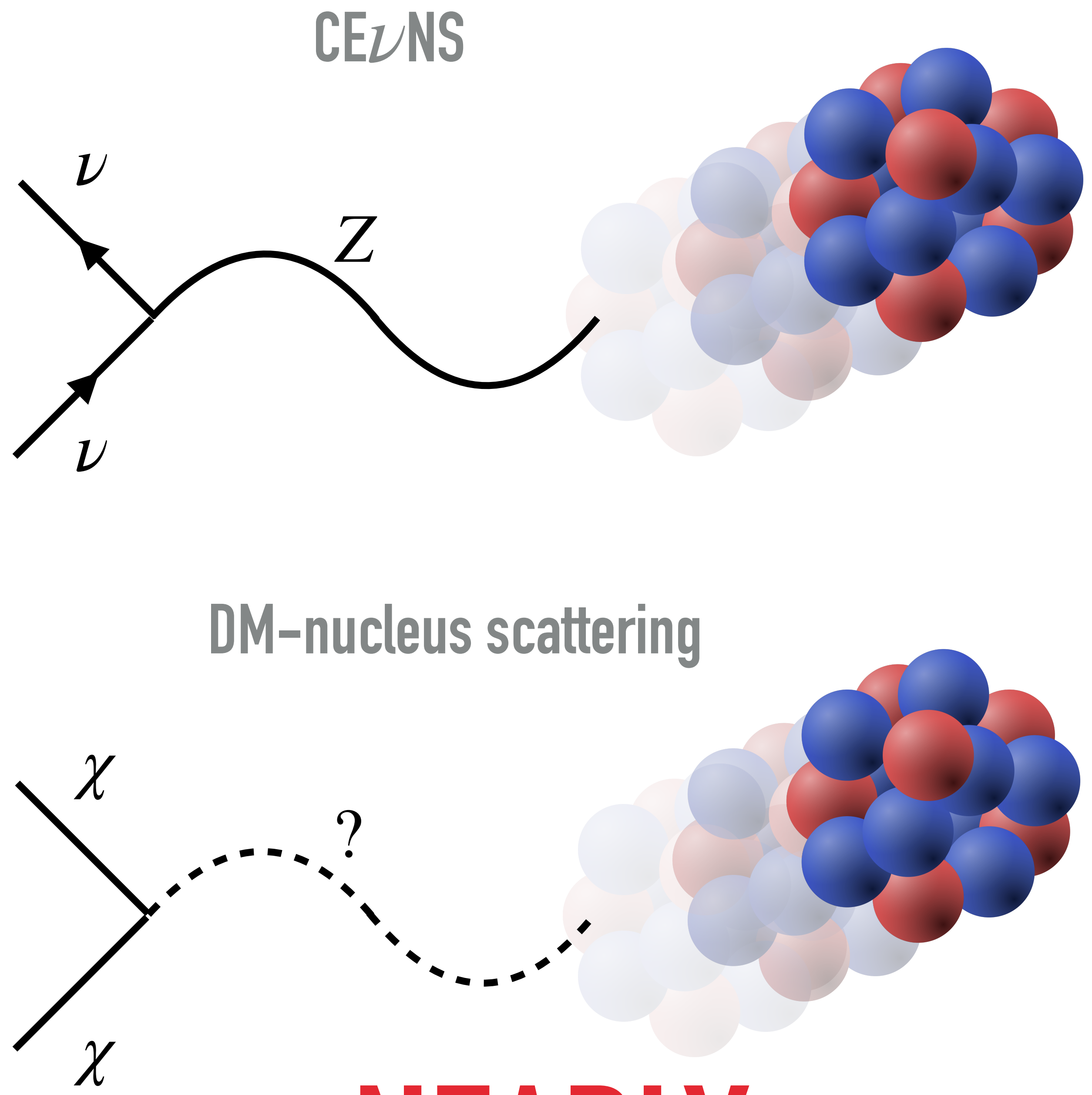
Lanqing Yuan (UChicago), on behalf of the XENON collaboration

Aug 26 2024, TeVPA 2024

XENON

SOLAR ^{8}B CEνNS





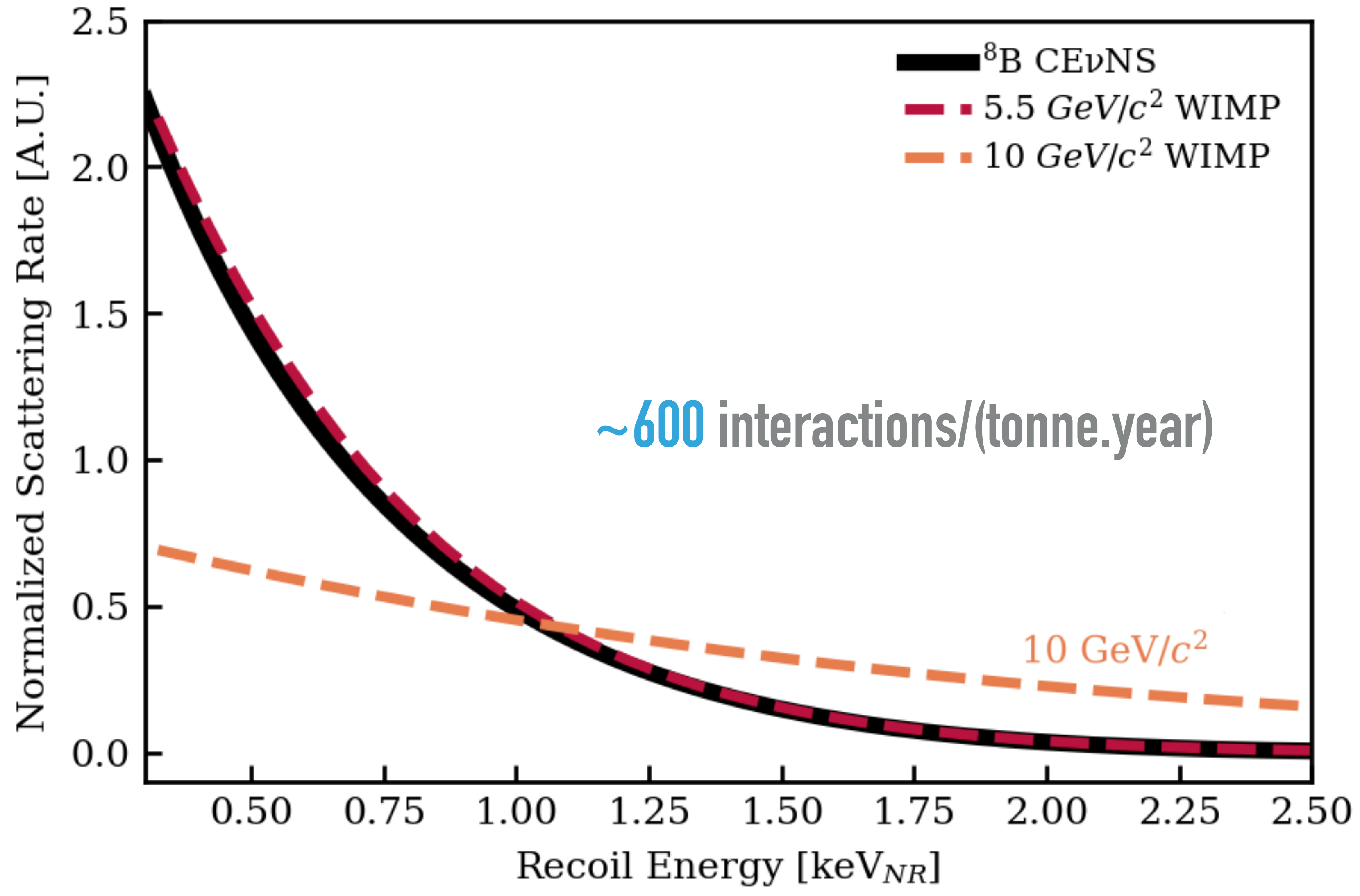
NEARLY INDISTINGUISHABLE

- CEνNS: Coherent Elastic Neutrino-Nucleus Scattering
  - First measured by COHERENT (2017) from a spallation neutron facility
  - Never measured in a xenon target
- ^{8}B CEνNS: Expected to have the largest detectable number of CEνNS events in xenon
  - Signature nearly indistinguishable from $5.5\ \mathrm{GeV}/c^2$ WIMP with spin-independent $\sigma_{\mathrm{SI}} = 4.4 \times 10^{-45}\ \mathrm{cm}^2$ nuclear recoil

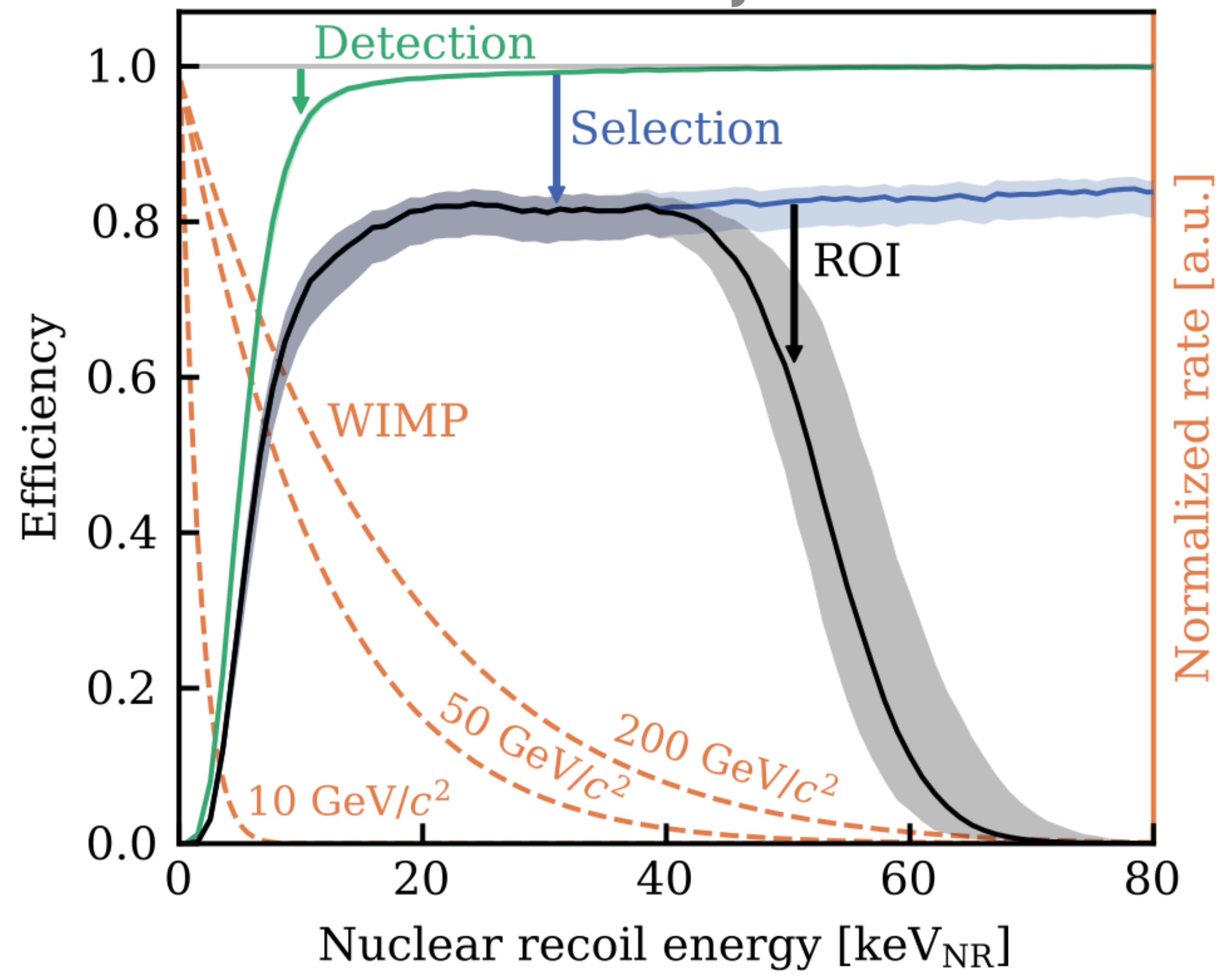
SOLAR ^{8}B CEνNS

- Nearly invisible in conventional 3-fold analysis that requires ≥ 3 detected photons
  - Can try to measure by **lowering energy threshold** in analysis
  - Need to be sensitive to nuclear recoil with energy ~1 keV$_{NR}$
- Goal: A **BLIND** search for ^{8}B CEνNS
- A measurement of ^{8}B CEνNS means:
  - Sensitivity to DM-like weak coherent scattering
  - And…

^{8}B CEνNS Typical recoil energy: ≤ 1.5 keV$_{NR}$



Conventional "3-fold analysis": detection efficiency $\sim 1\,\%$



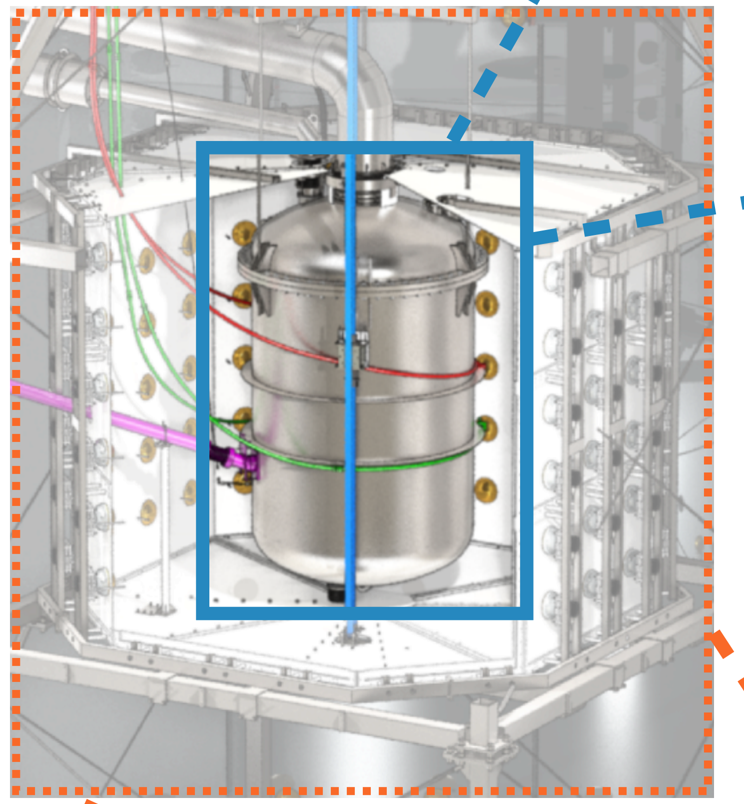
FIRST detected astrophysical ν in a **dark matter detector**

FIRST measured CEνNS from **astrophysical** ν source

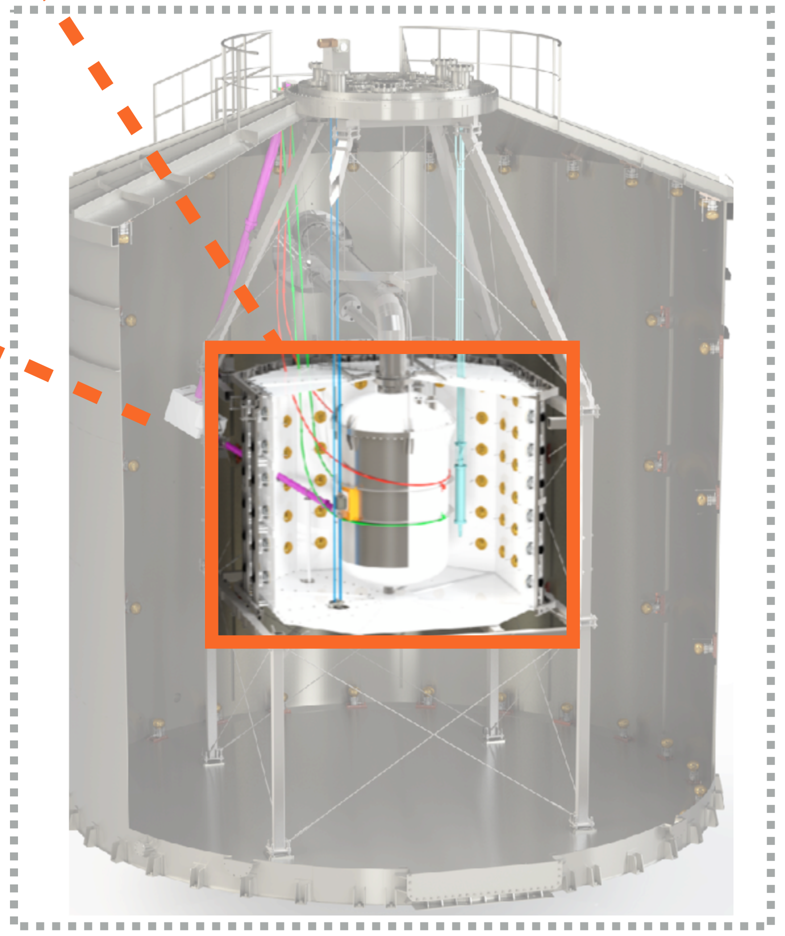
FIRST measured CEνNS with a **Xe** target

XENON COLLABORATION: ~170 SCIENTISTS, 29 INSTITUTIONS, 12 COUNTRIES

LXe Time Projection Chamber (TPC)



Gd-loaded water Cherenkov Neutron Veto (NV)

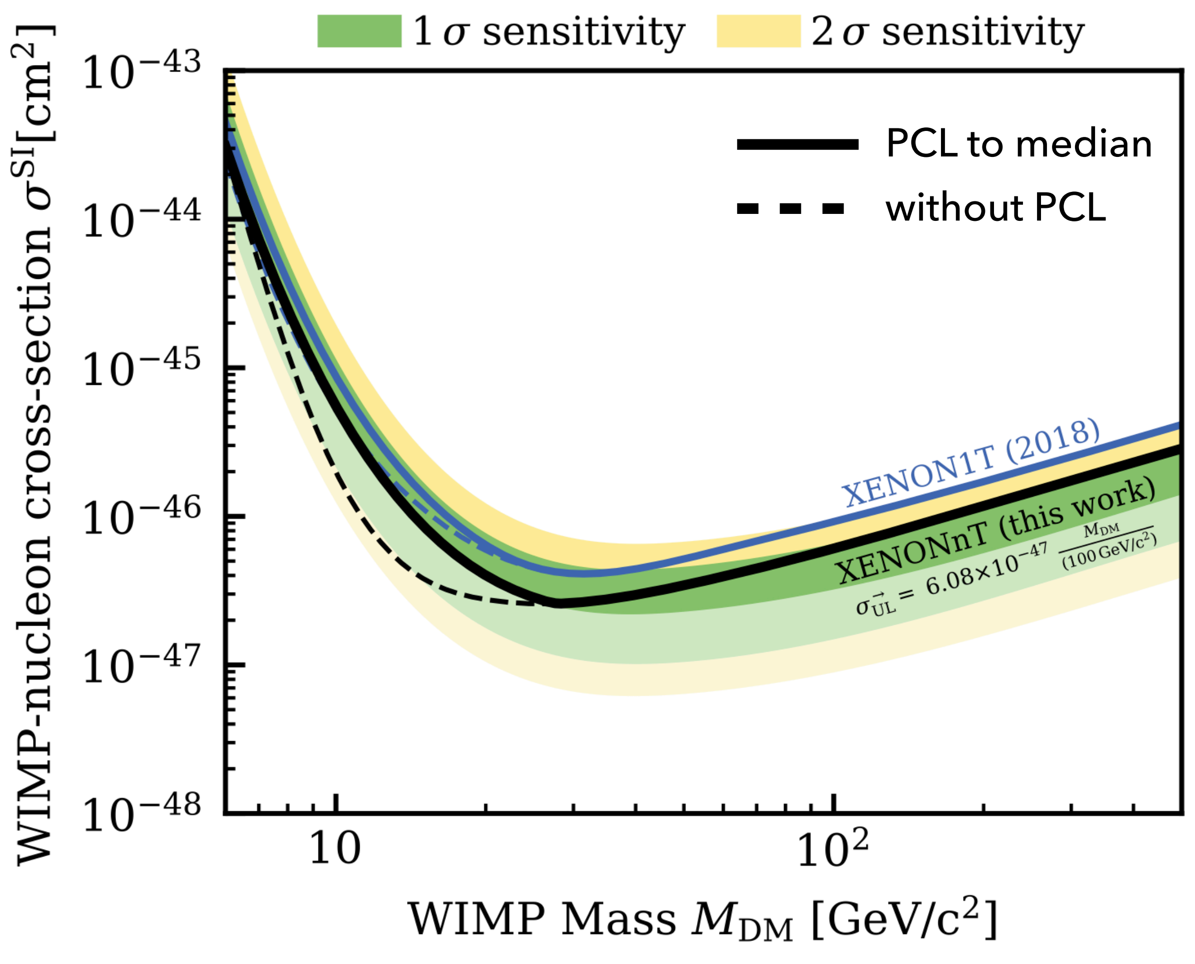


Water Cherenkov Muon Veto (MV)

SR0 & SR1 SCIENCE DATA

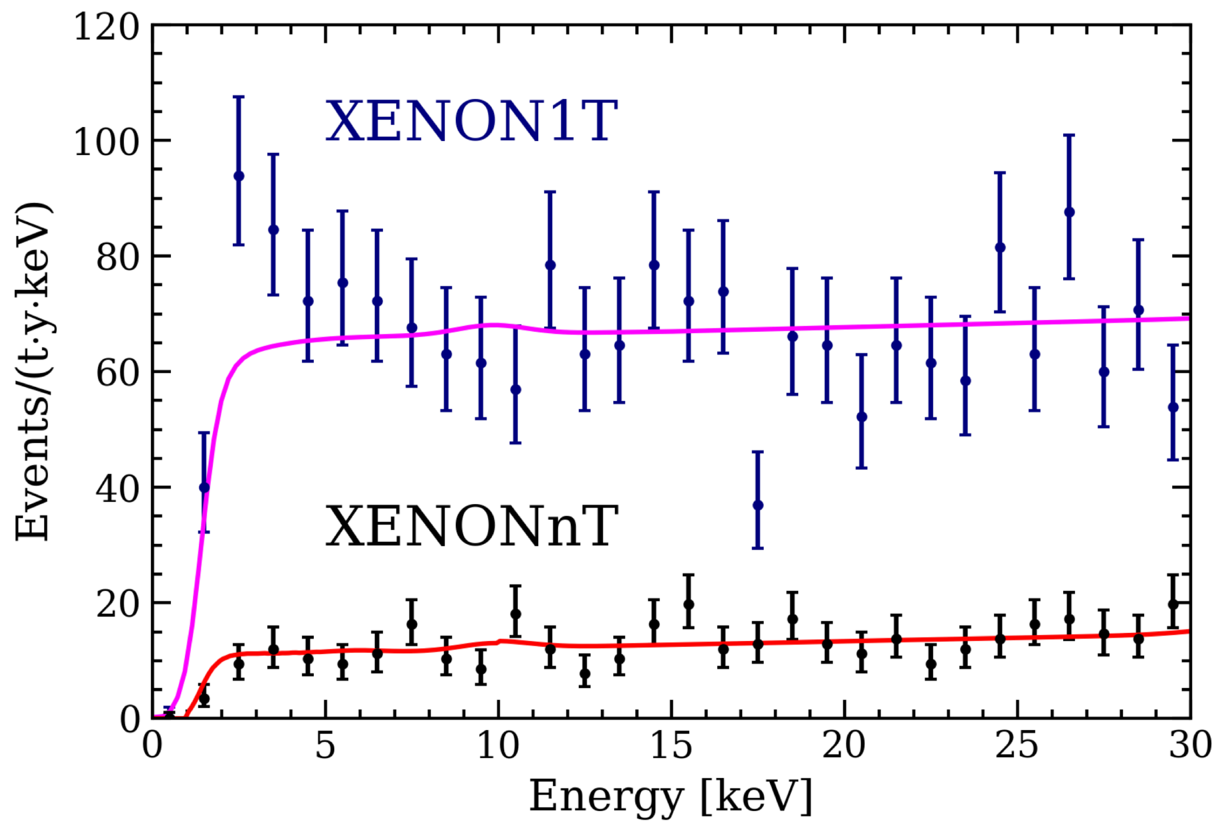
- Data taken between 2021-07 and 2023-08: ~340 days of **raw exposure**
- **Stable detector response**: <1% (<3%) light (charge) yield variation
- **High liquid xenon purity**: Electron lifetime ~20ms
- Regular calibrations:
  - **g1**: 0.1515 ± 0.0014 PE/ph (SR0) & 0.1367 ± 0.0010 PE/ph (SR1)
  - **g2**: 16.45 ± 0.64 PE/e (SR0) & 16.85 ± 0.46 PE/e (SR1)

Blind search for WIMP



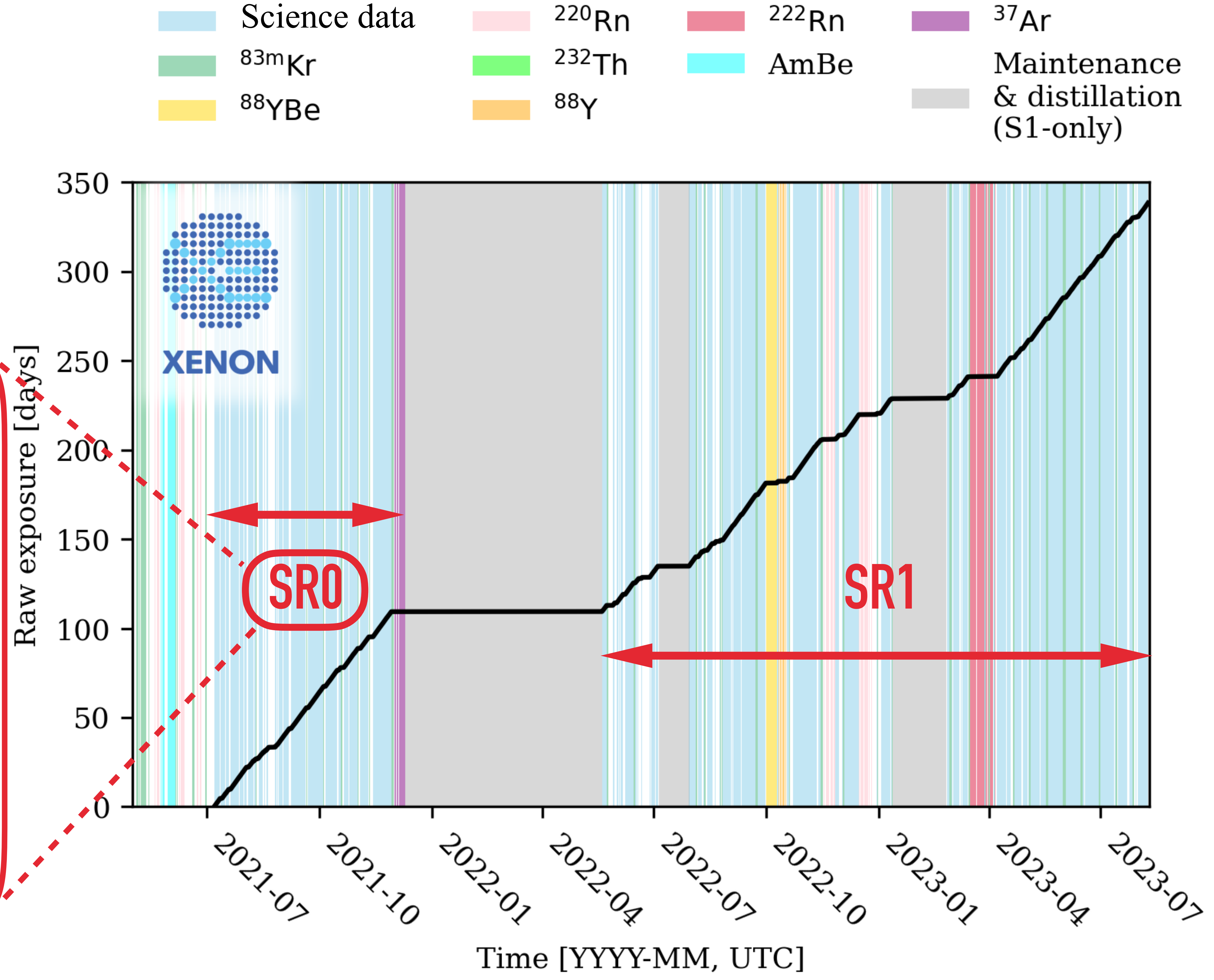
Phys. Rev. Lett. 131, 041003 (2023)

Unprecedented low ER background



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

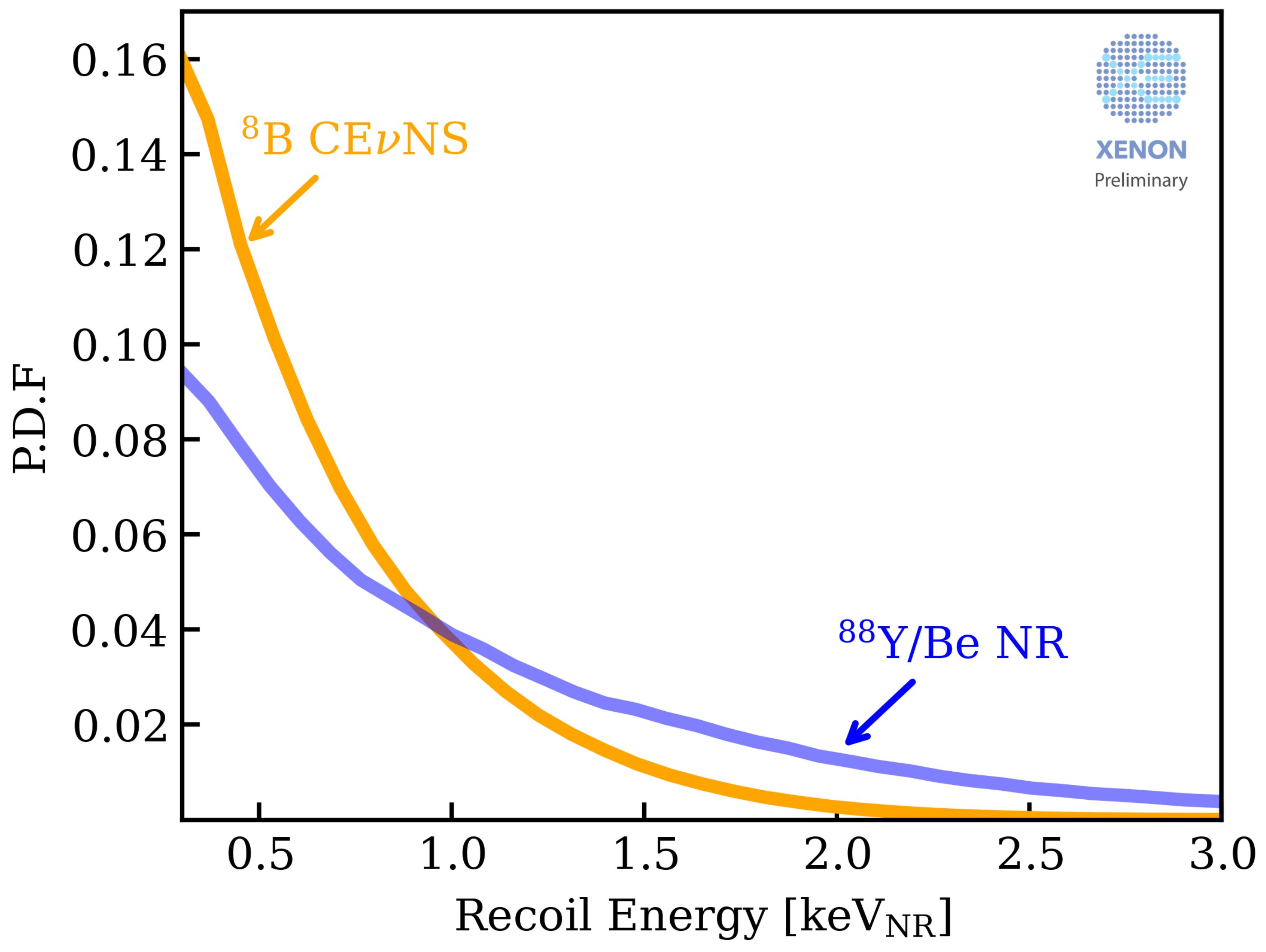
SCIENCE DATA IN ROI IS BLINDED

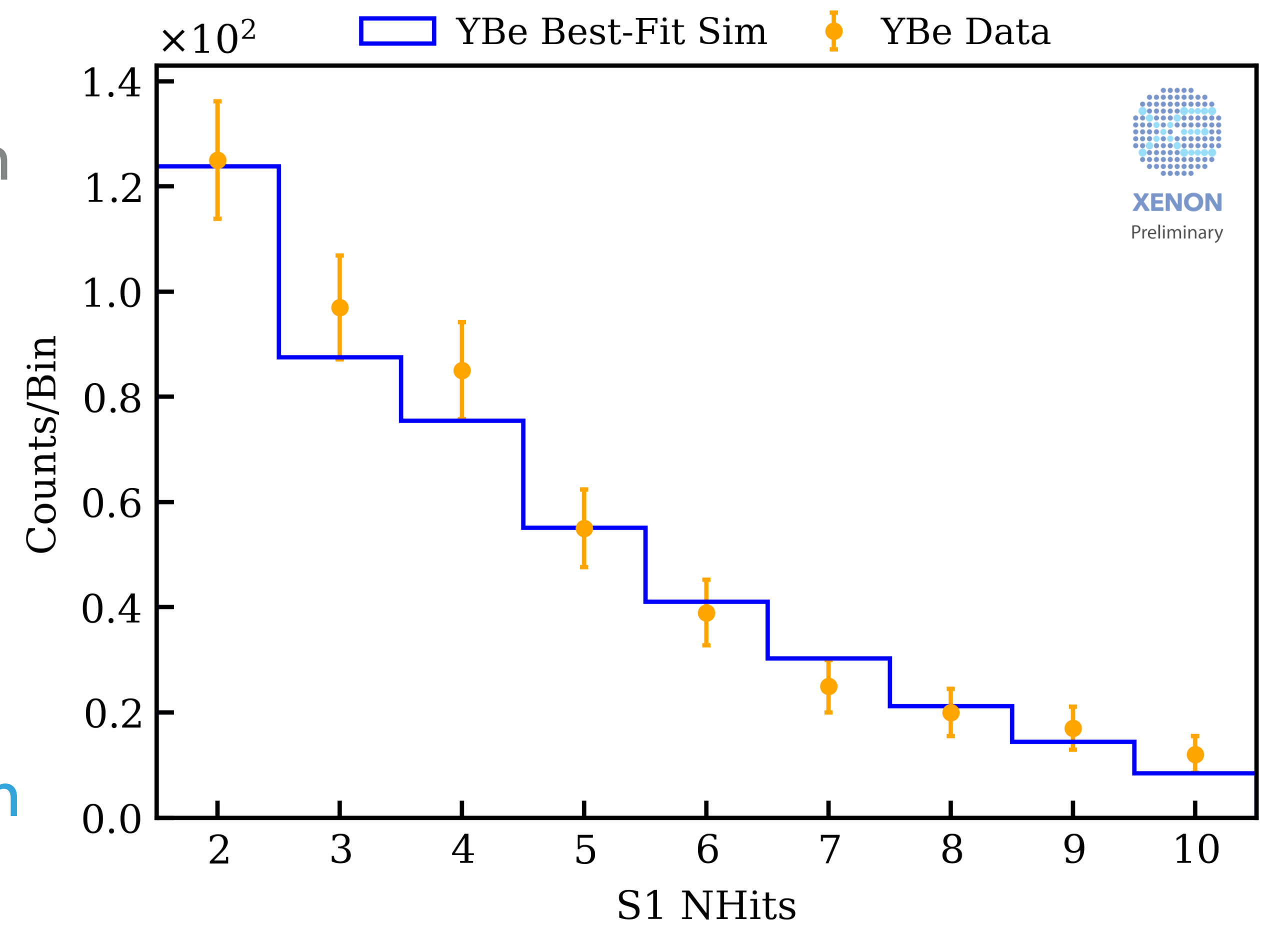


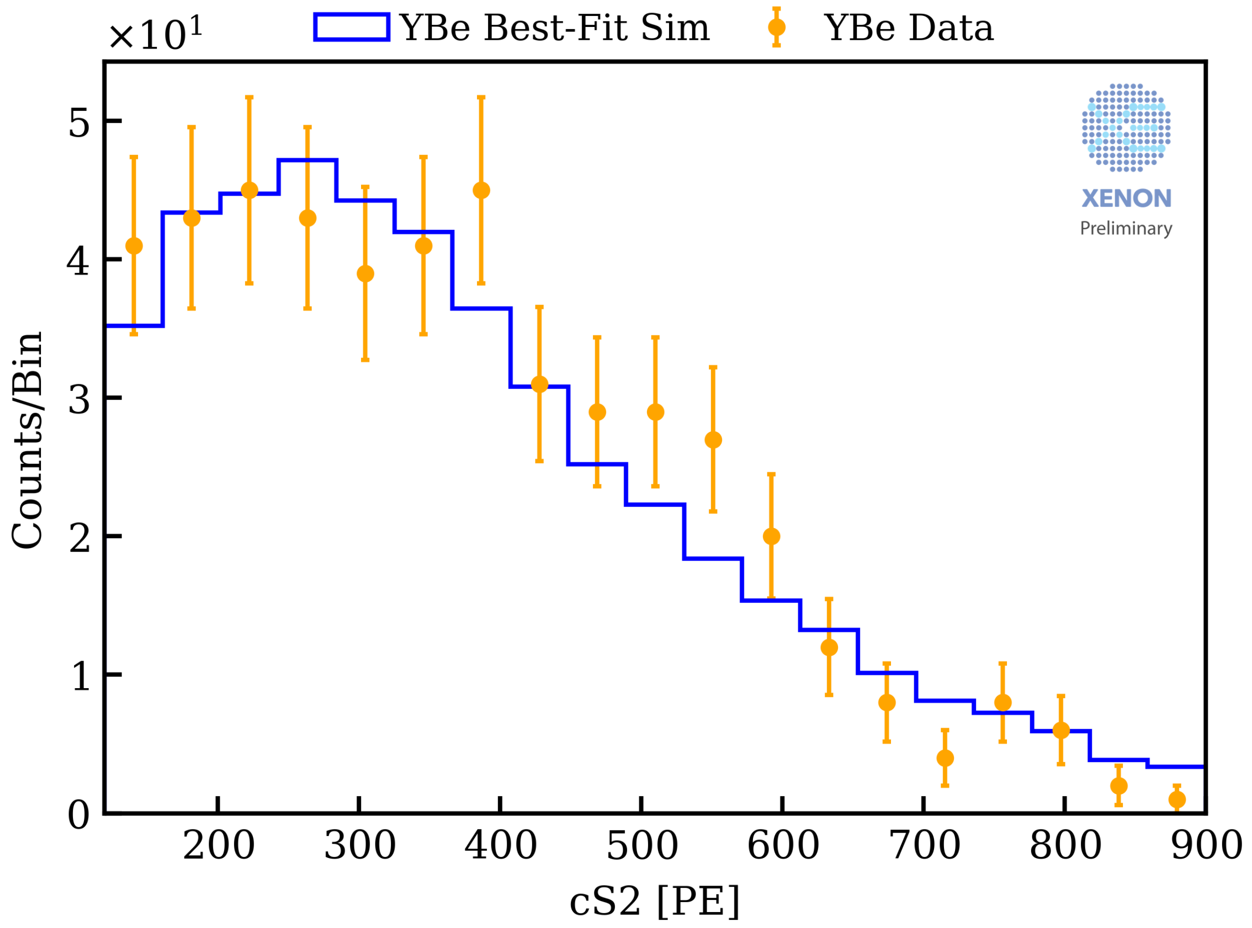
^{88}YBe LOW ENERGY NR CALIBRATION

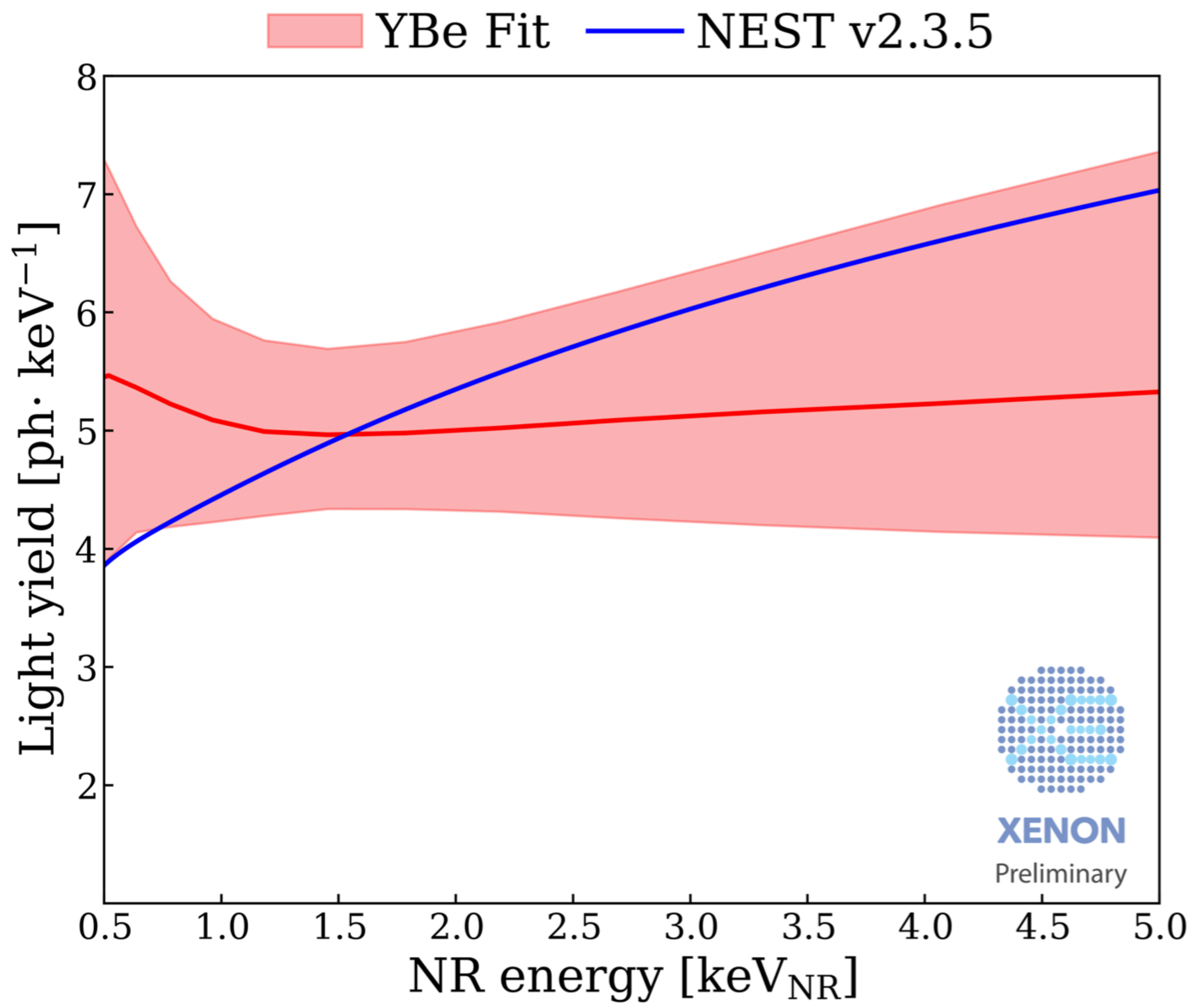
Publication in preparation

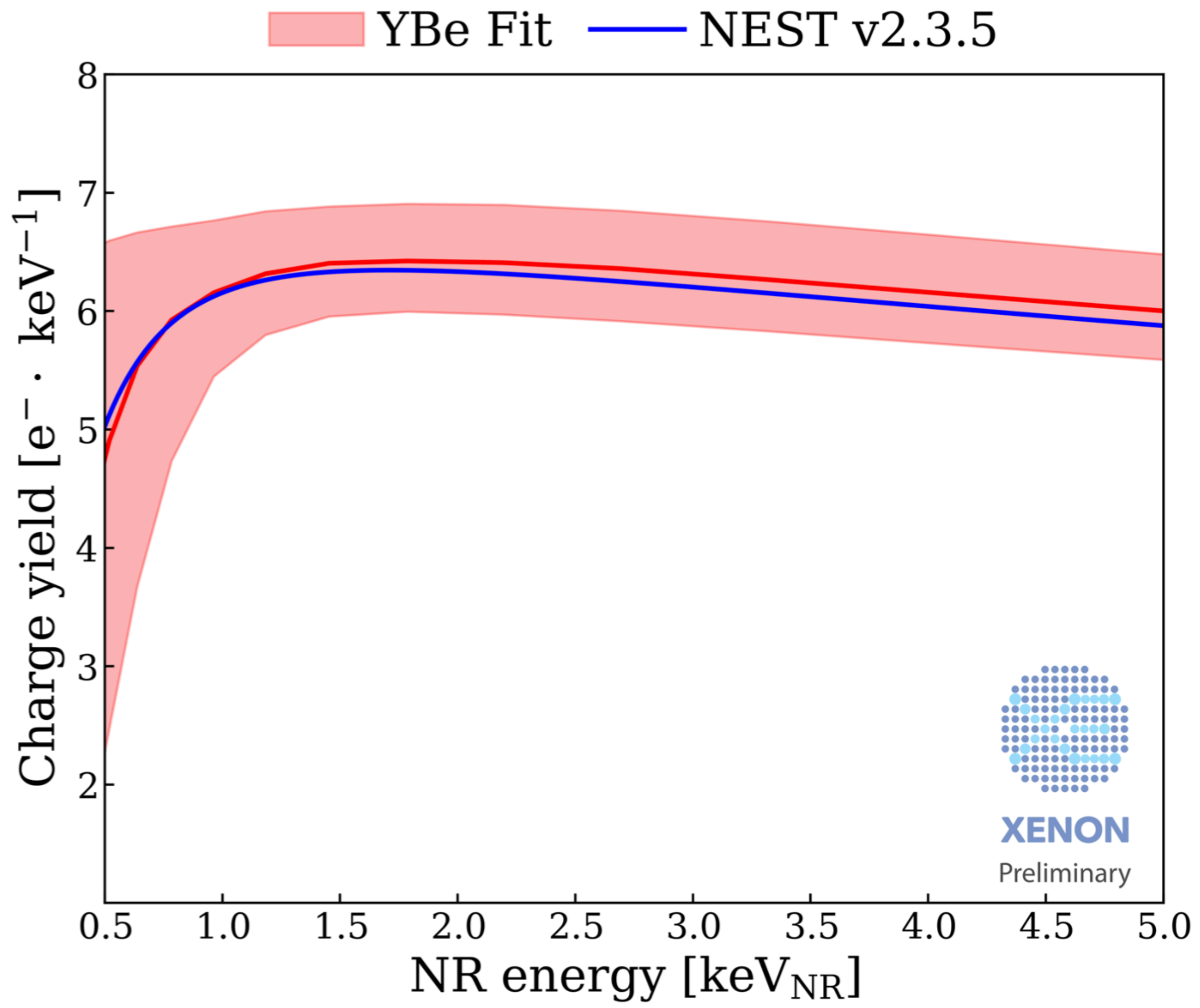
- Low energy NR yield model significantly affects ^{8}B CEνNS detection efficiency:
- 152 keV neutrons from photo-disintegration of ^{9}Be by γ-ray of ^{88}Y
  - **Recoil energy spectrum similar to ^{8}B CEνNS**
- Good match between simulation and data
- **Light/charge yield model** are constrained by ^{88}YBe data at 23V/cm
  - Yield model uncertainty leads to ~34% signal rate uncertainty



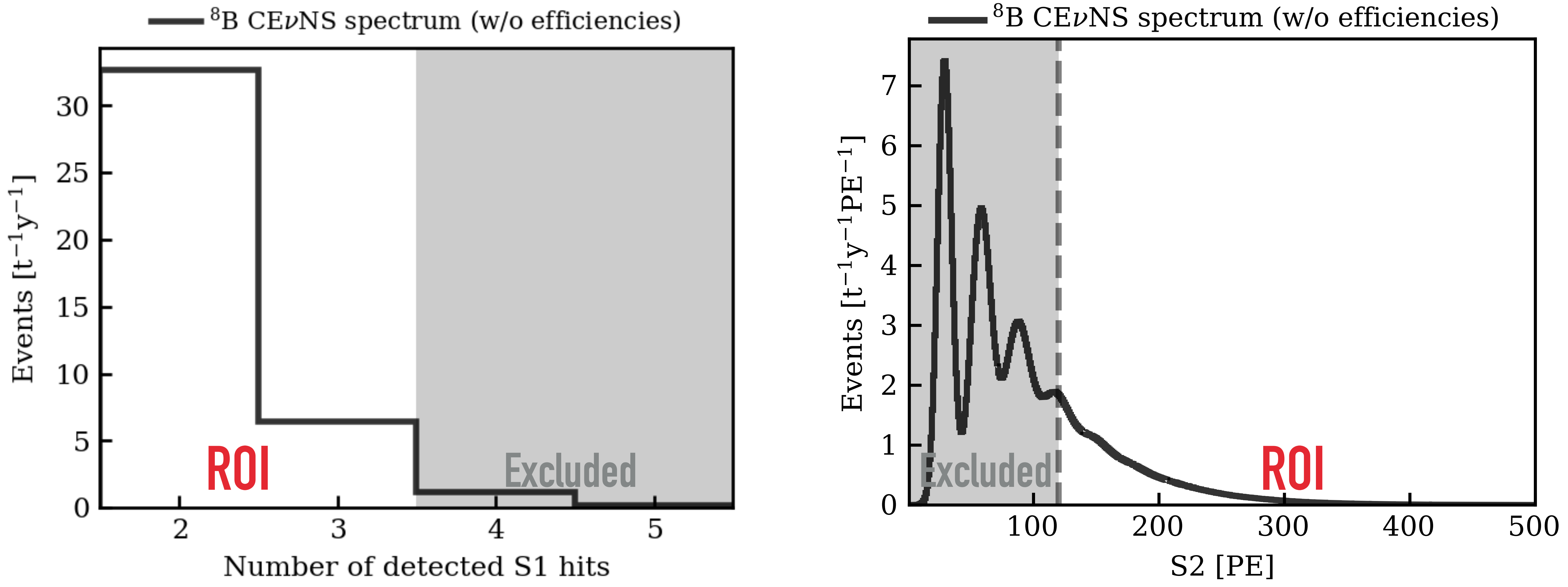








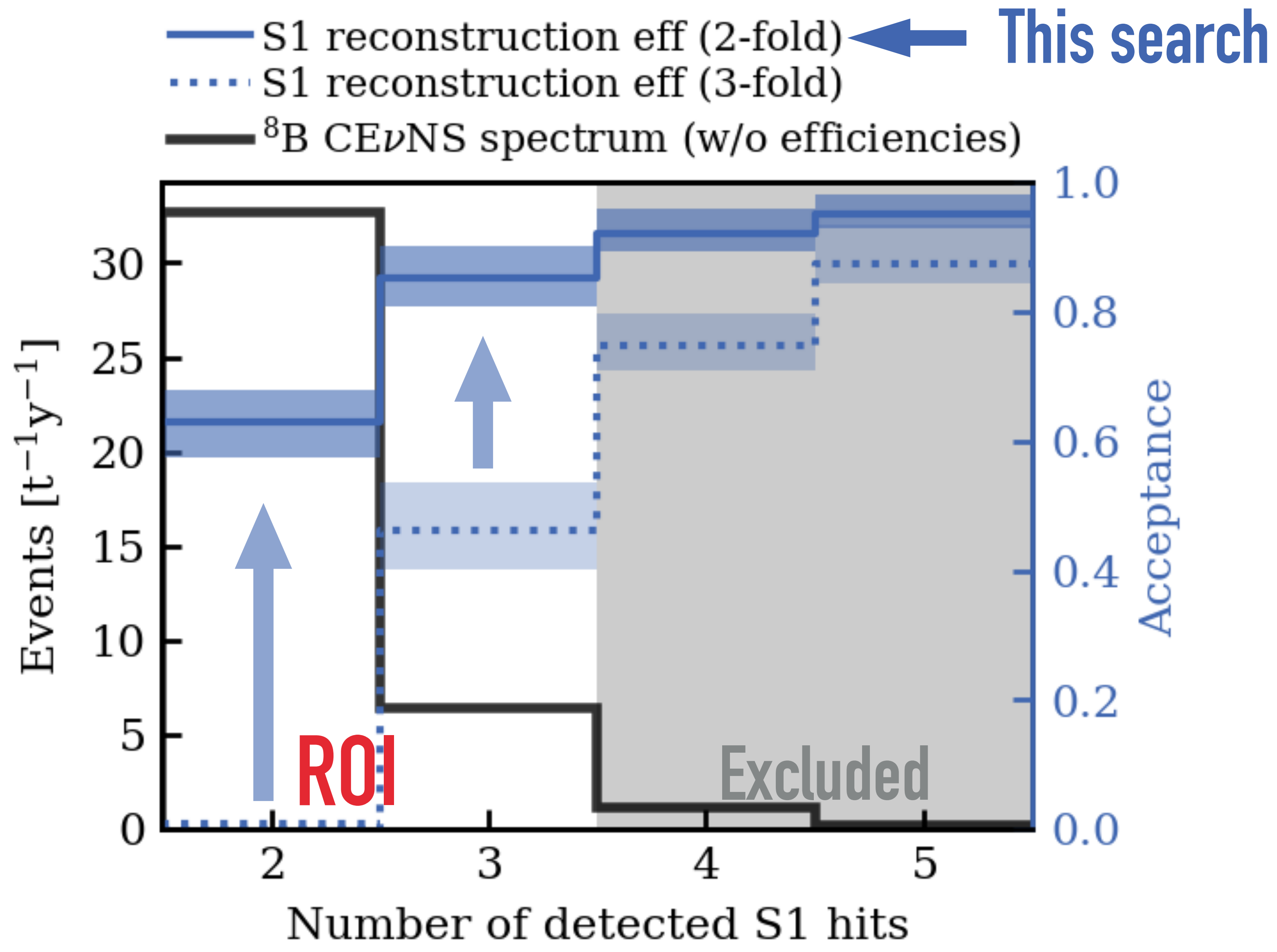
ENERGY THRESHOLD AND REGIONS OF INTEREST

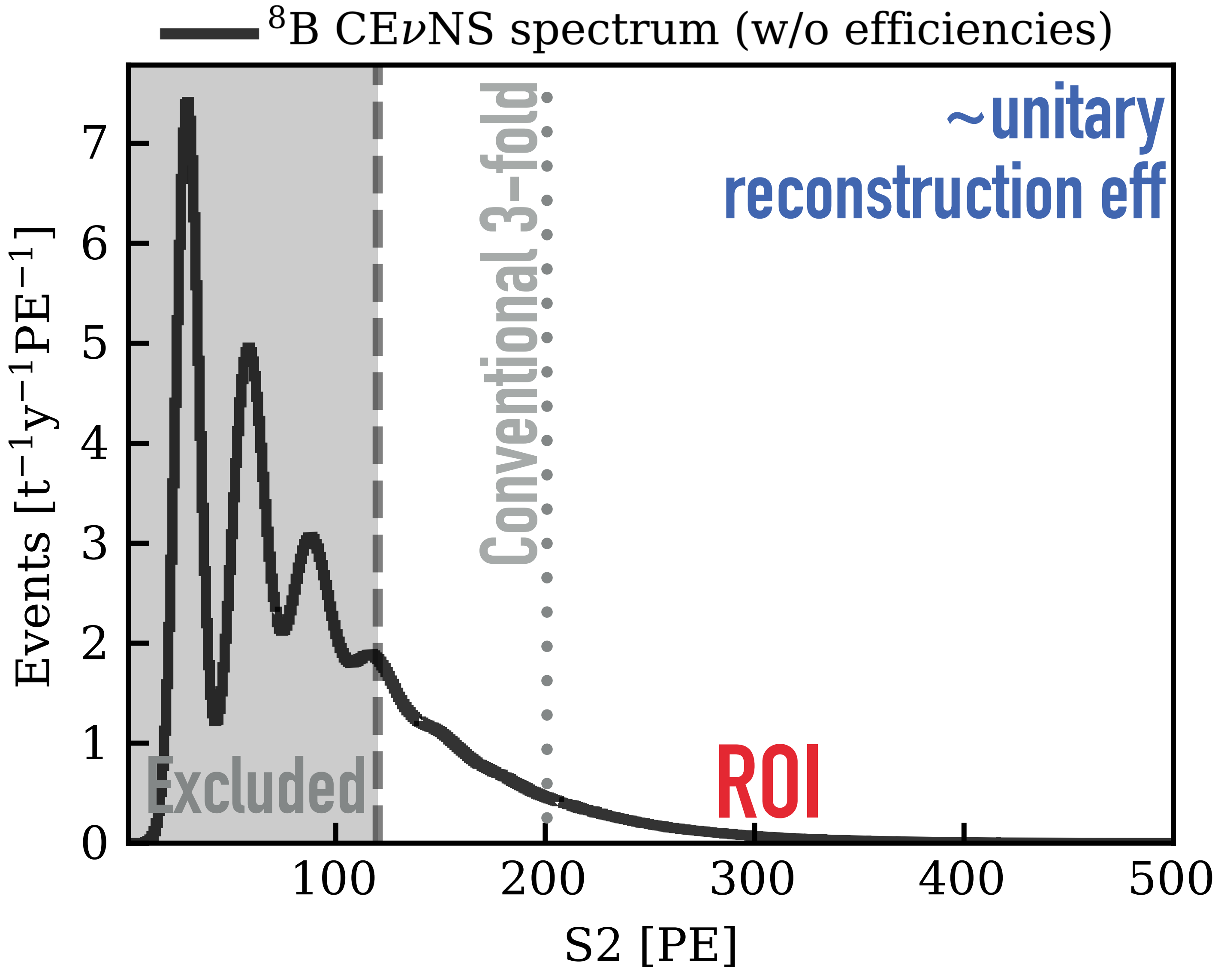


- **S1 ROI**: 2 or 3 hits
  - An S1 hit corresponds to a detected photon
- **S2 ROI:** 120 - 500 PE
  - ~Equivalent to 4 - 16 extracted electrons

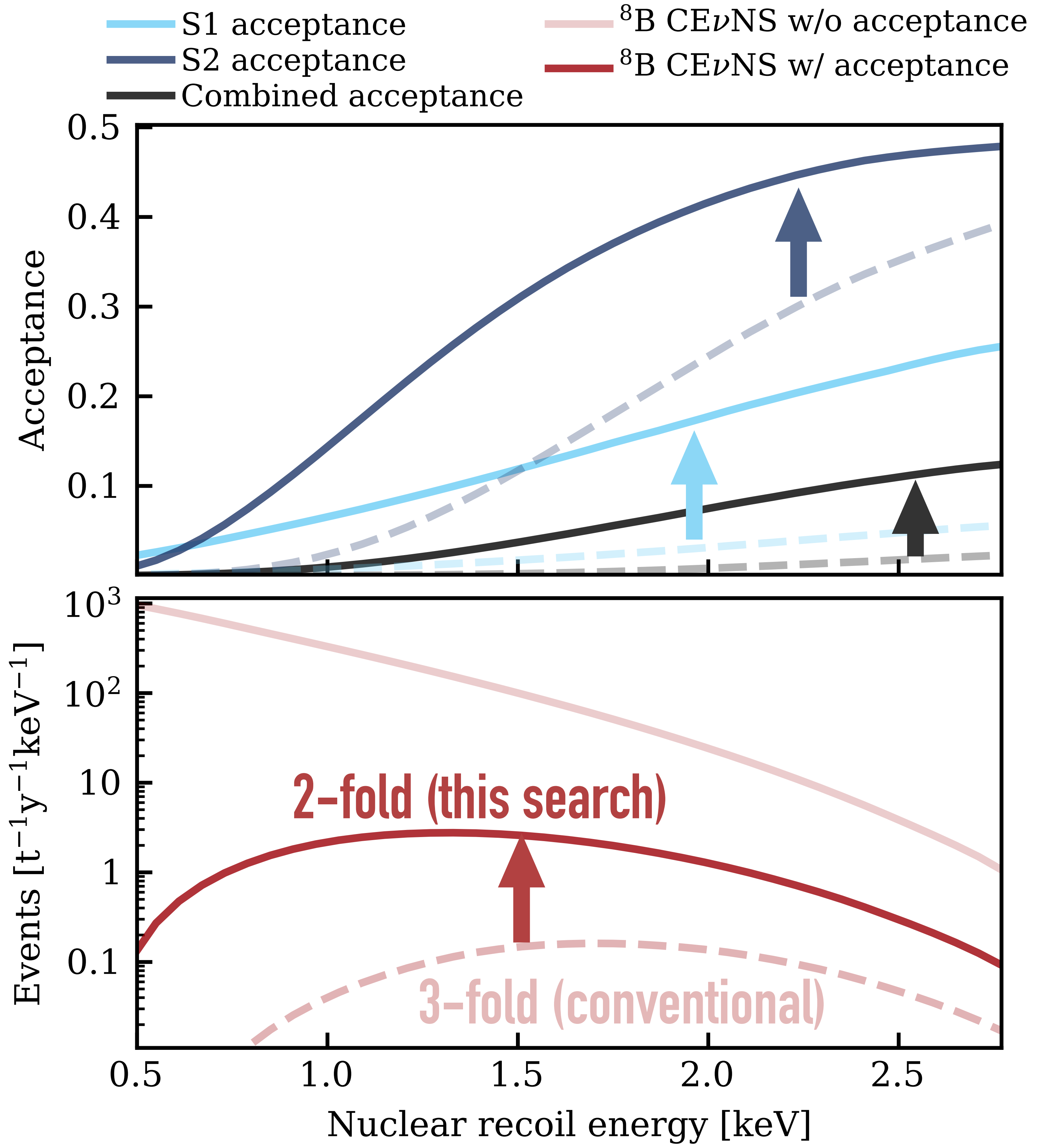
arXiv:2408.02877

ENERGY THRESHOLD AND REGIONS OF INTEREST





Accpetance with data-selection embedded



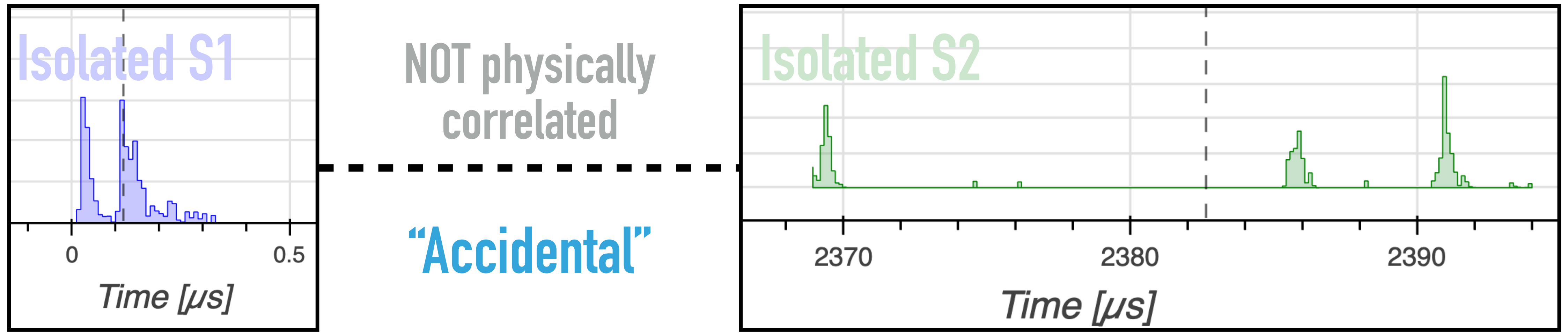
- **S1 ROI:** 2 or 3 hits
  - An S1 hit corresponds to a detected photon
  - Relaxed S1 waveform shape requirement from conventional 3-fold analysis
- **S2 ROI:** 120 - 500 PE
  - ~Equivalent to 4 - 16 extracted electrons
  - Lowered S2 threshold from conventional analysis (200 PE)

~17 TIMES MORE EVENTS

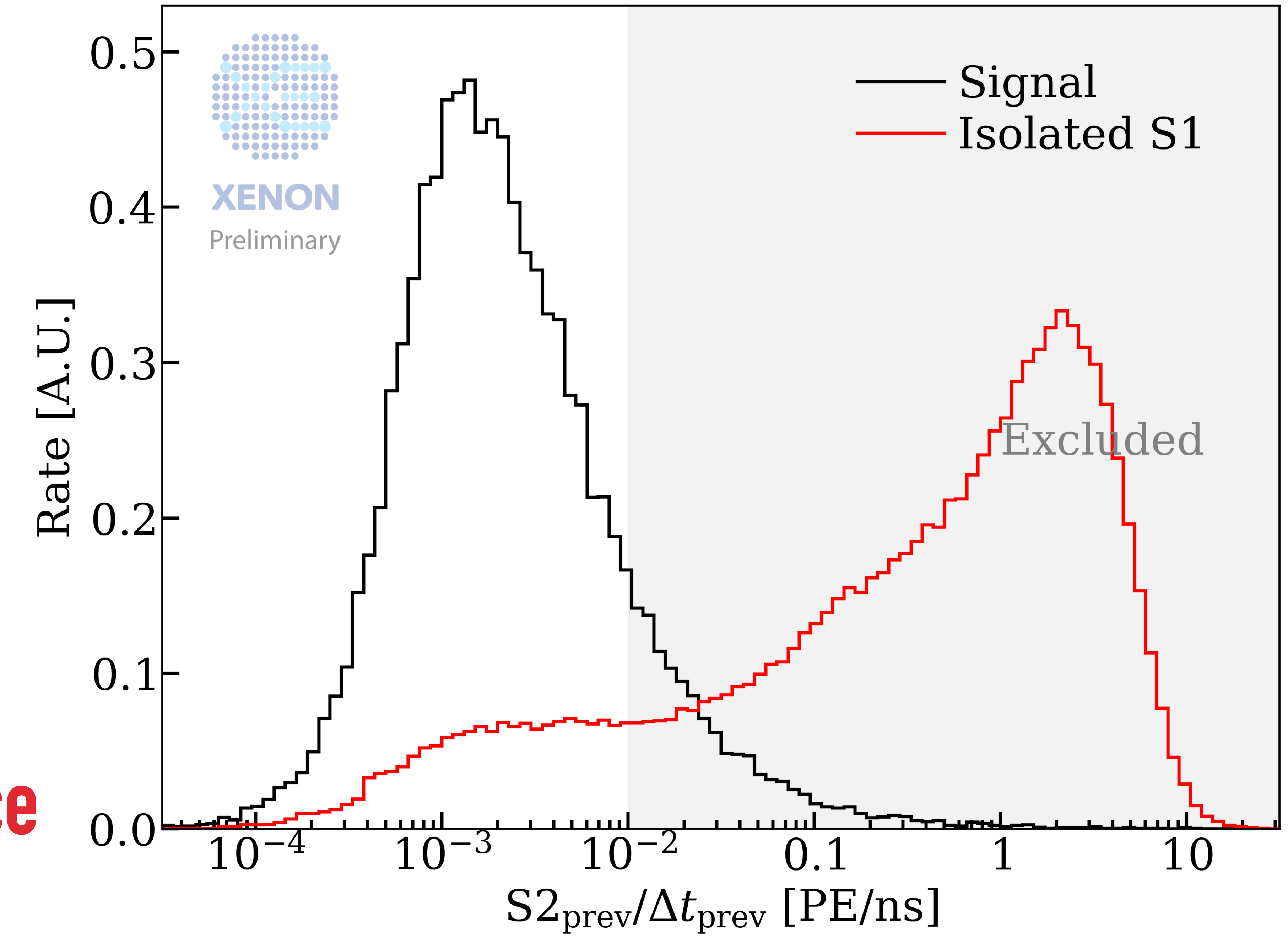
arXiv:2408.02877

DOMINANT BACKGROUND: ACCIDENTAL COINCIDENCE

- **Accidental Coincidence (AC)**: Random unphysical pairing of isolated S1 and isolated S2
    - Isolated peaks are believed to be side products of high energy (HE) interactions
    - Exact physical mechanisms of isolated peaks are under investigation
    - Isolated-S1 Rate before mitigation: 15 Hz
    - Isolated-S2 Rate before mitigation: 150 mHz
- **Mitigated** by utilizing selections based on space&time correlation to previous HE interactions
    - Isolated-S1 rate after mitigation: 2.3 Hz
    - Isolated-S2 rate after mitigation: 25 mHz



TimeShadow $\equiv \mathrm{Max}(S2_{pre}/\Delta t_{pre})$ used in inference

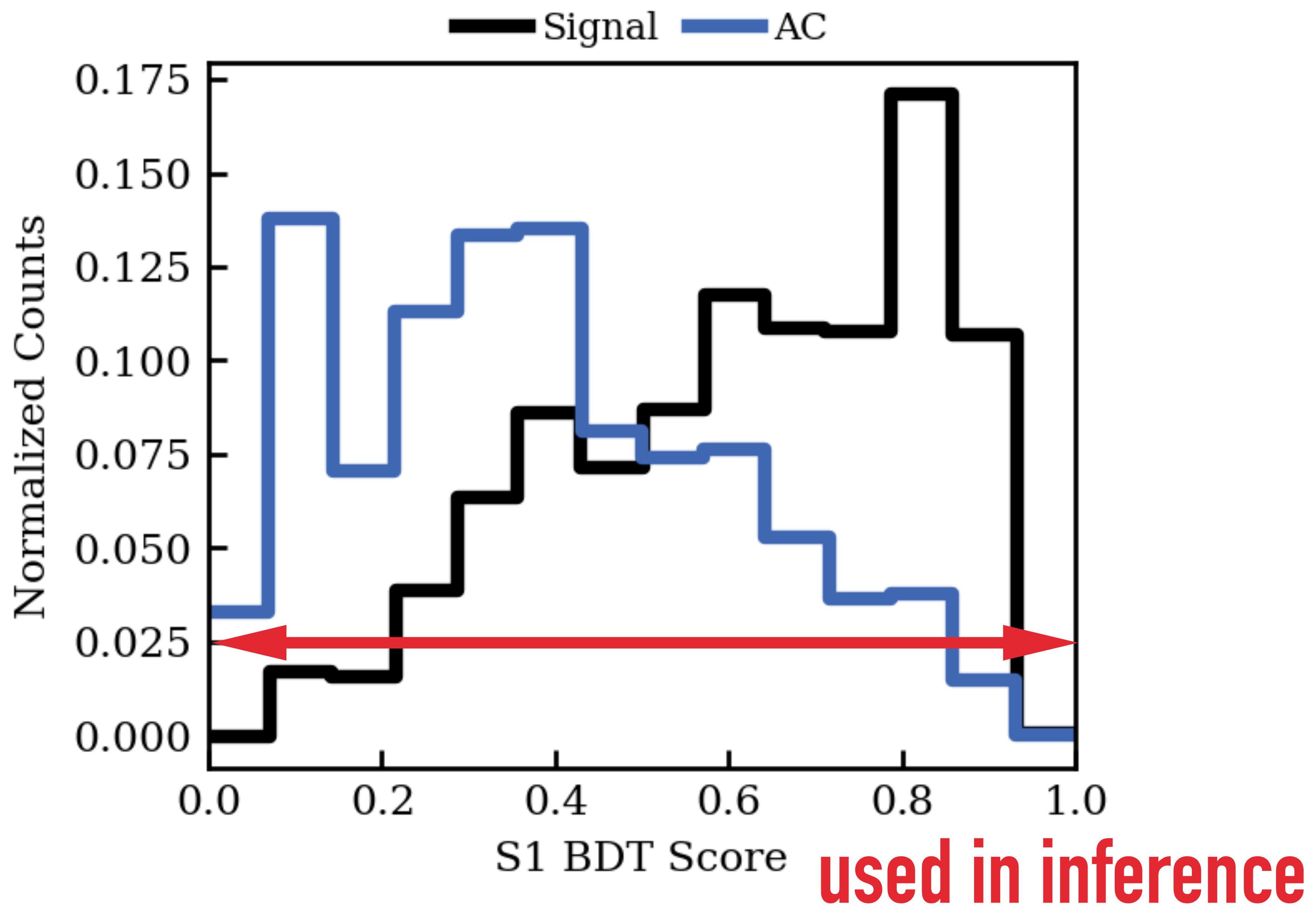


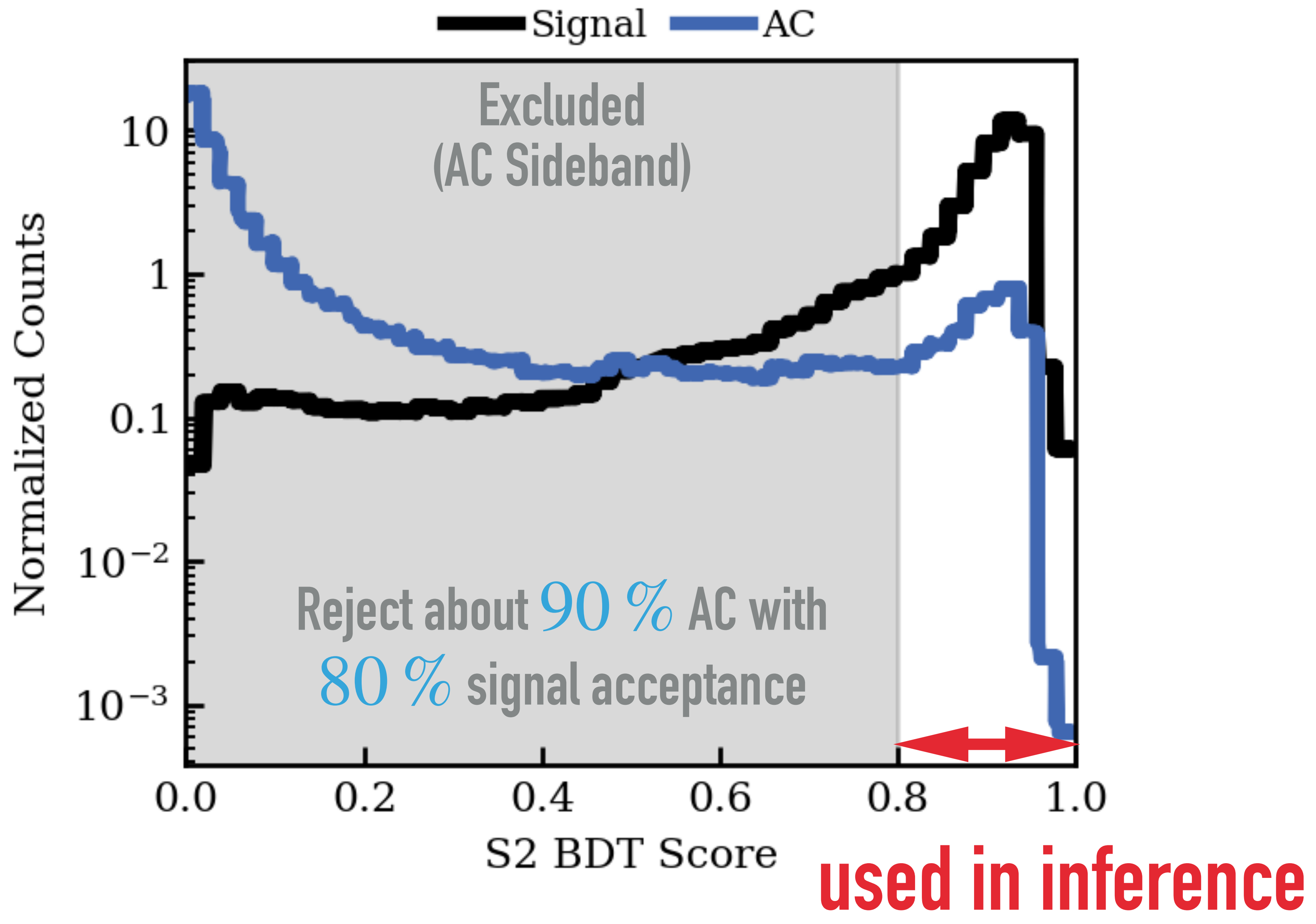
eg. TimeShadow selection on Isolated S1s

arXiv:2408.02877

SUPPRESS AC BACKGROUND

- **Accidental Coincidence (AC):** Random unphysical pairing of isolated S1 and isolated S2
  - Isolated peaks are believed to be side products of high energy (HE) interactions
  - Exact physical mechanisms of isolated peaks are under investigation
- **Further suppressed** AC by 2 Boosted Decision Tree (BDT) selections:
  - **S1 BDT**: xenon photon spectrum + S1 pulse shape & spectrum
  - **S2 BDT**: S2 pulse shape compatible with diffusion law
- 3^4-bins **4D search space** for better discrimination power against AC:
  - (cS2, S1 BDT, S2 BDT, TimeShadow)





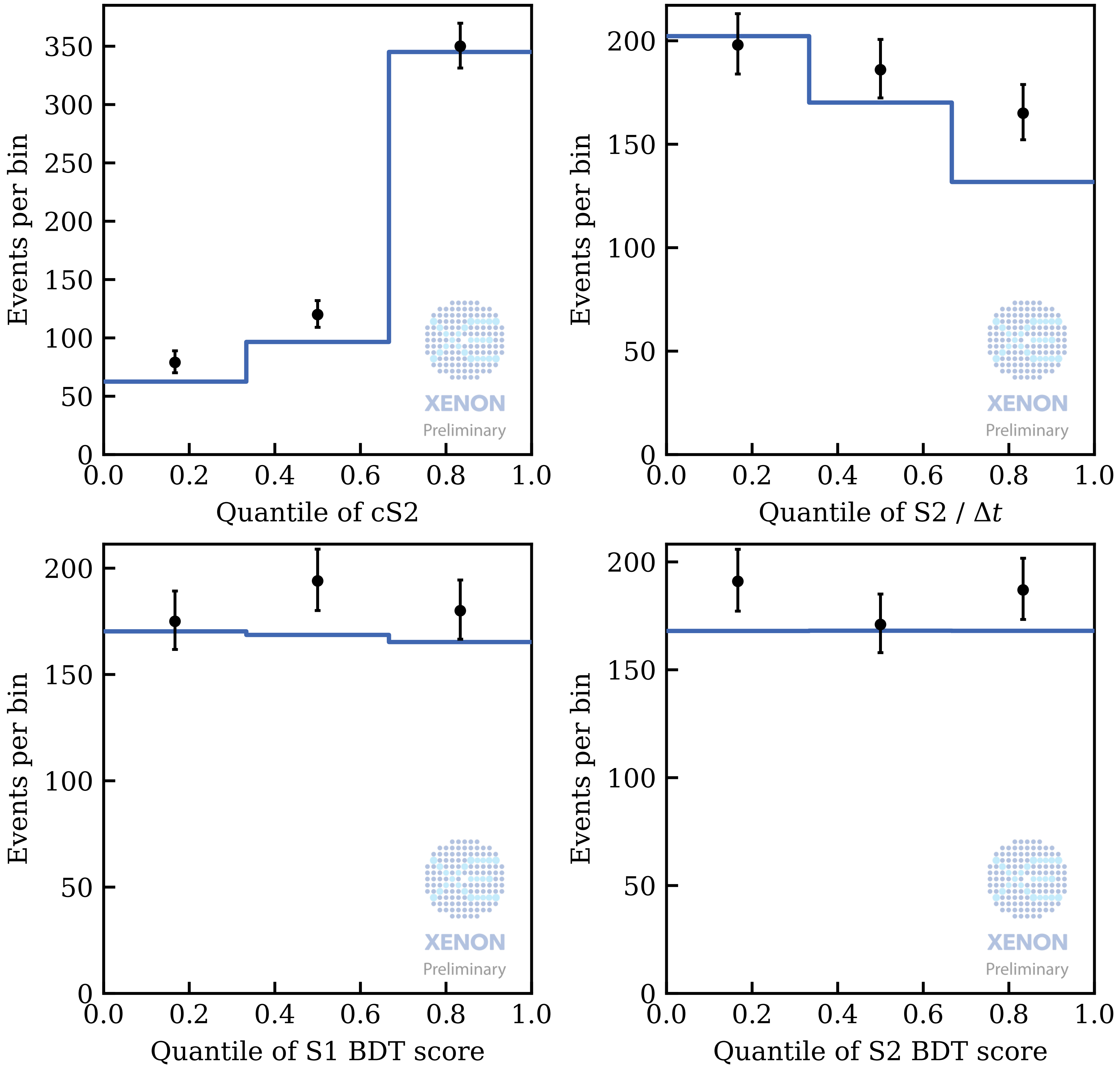
Expected # of AC events:

7.5 ± 0.7 for SR0 & 17.8 ± 1.0 for SR1

VALIDATION OF AC MODEL

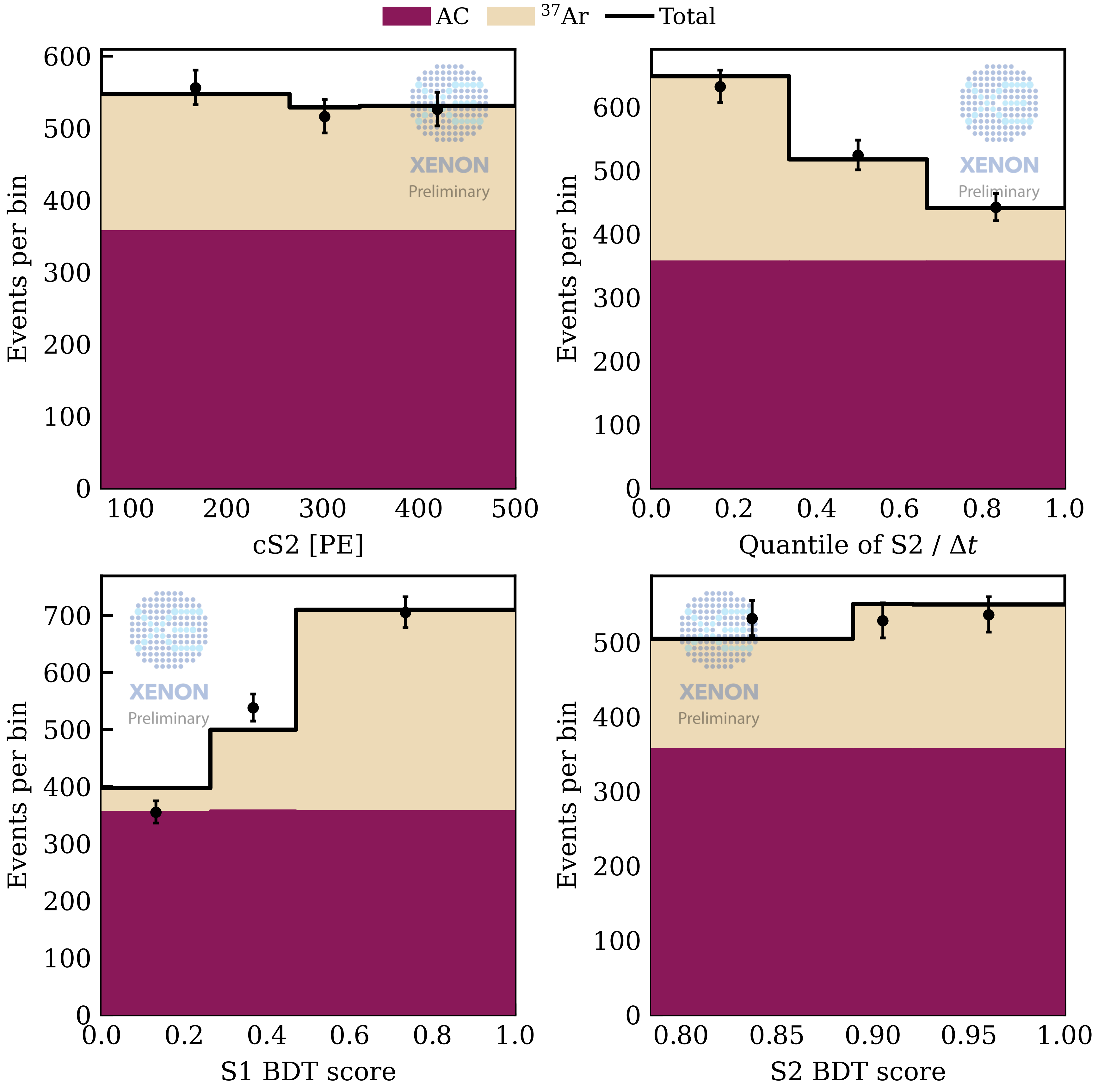
arXiv:2408.02877

AC SIDEBAND



Publication in preparation

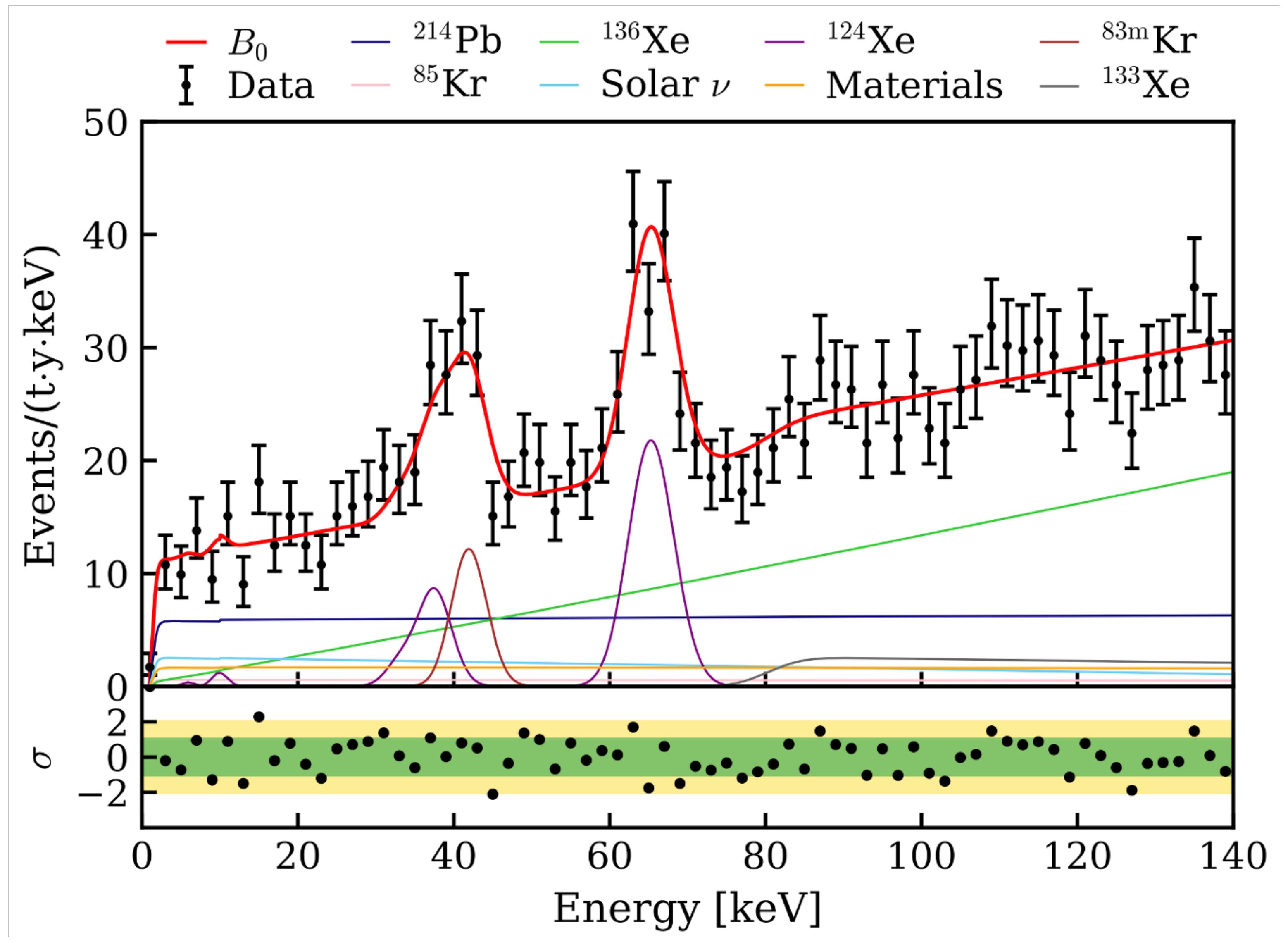
37Ar L-shell EC

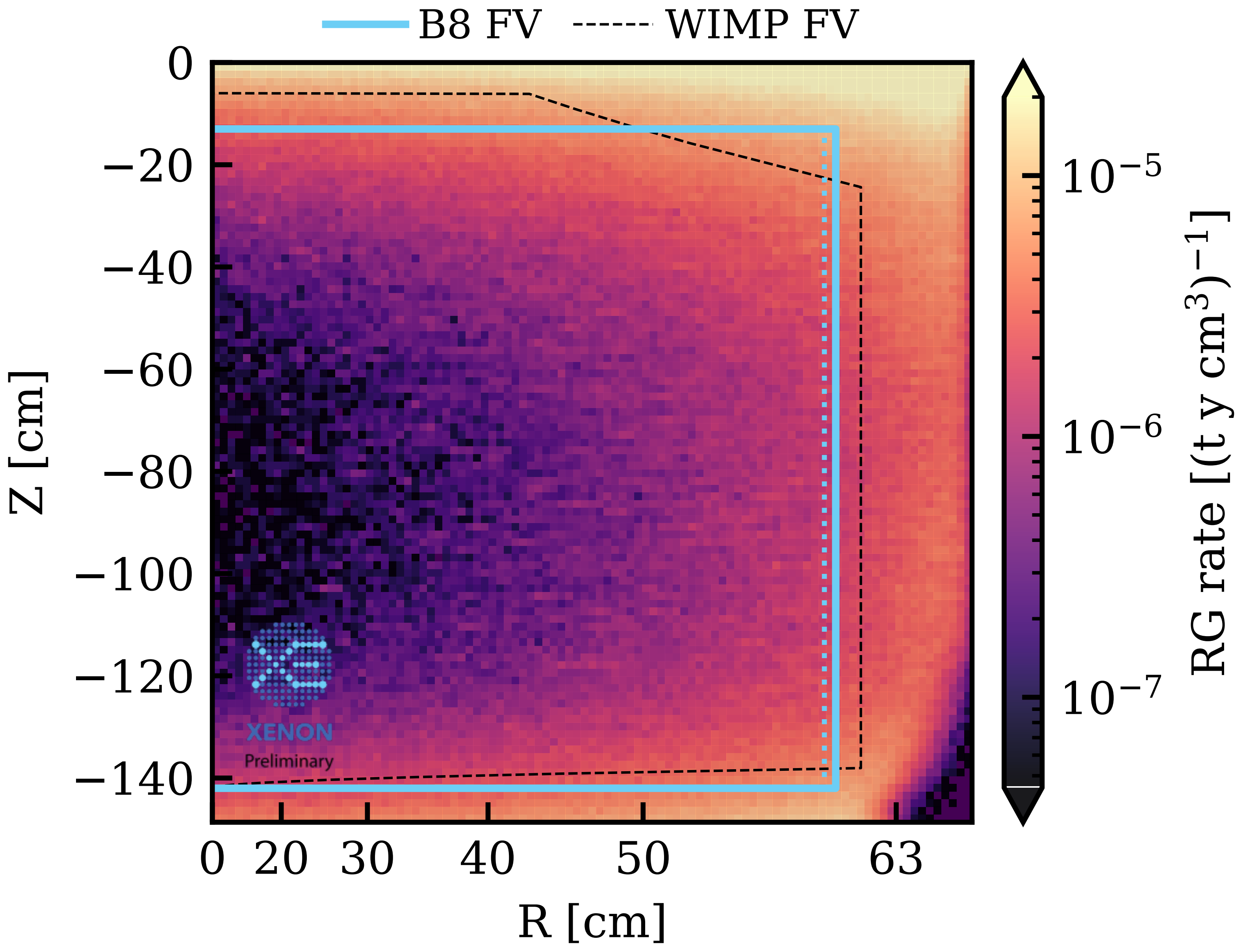


- **Validated** by AC sideband unblinding (events that failed S2 BDT cuts)
- The difference (<10%) is considered when determine systematic uncertainty
- **Validated** by ^{37}Ar L-shell 0.27 keV_{ER} calibration data
- Constrained ER light yield with 1598 observed events

OTHER SUBDOMINANT BACKGROUNDS

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





Science Run	Fiducial Mass [Ton]	Exposure [Ton-Year]
SR0	3.97	1.17
SR1	4.10	2.34

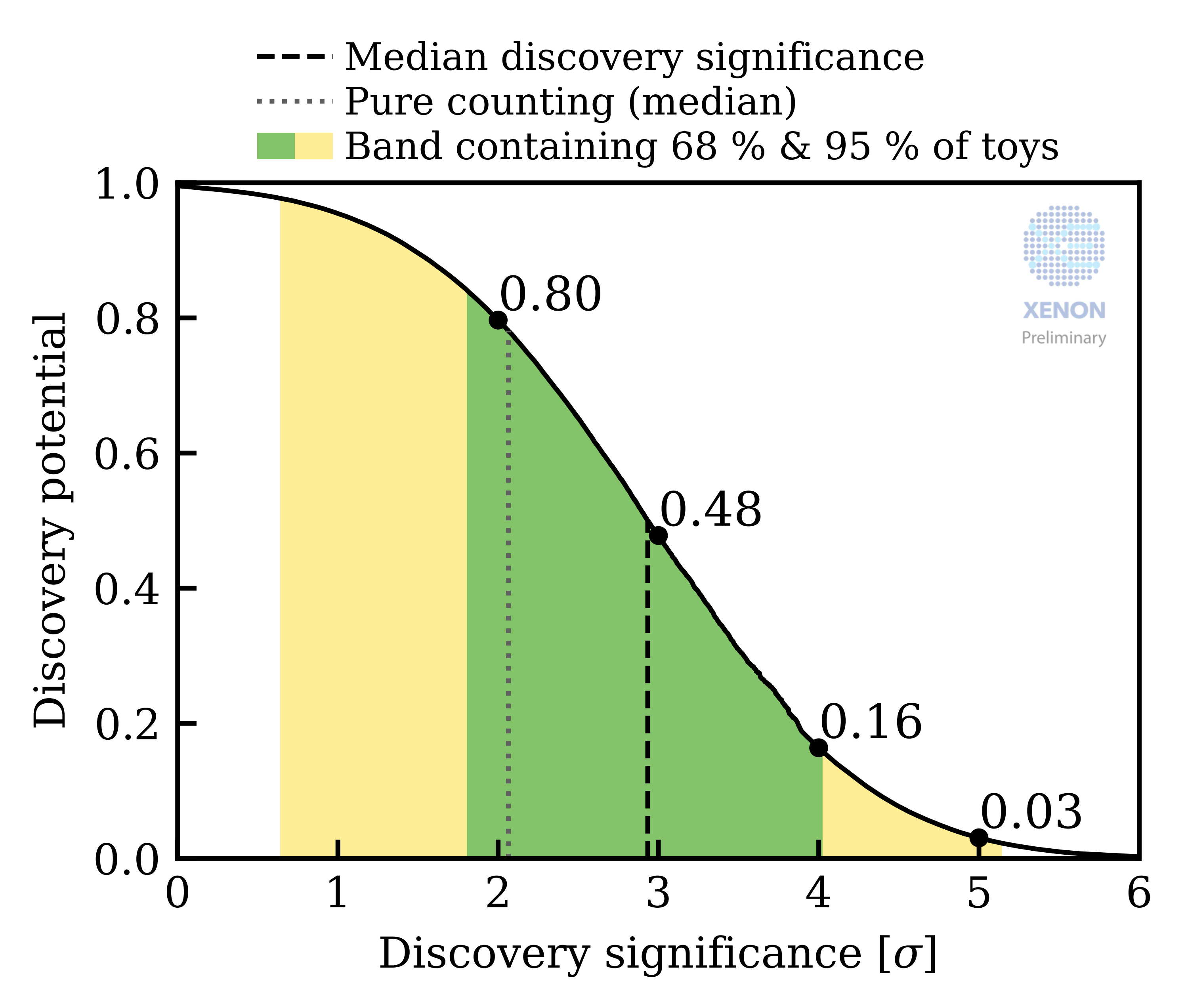
- **Electronic recoils**: Dominated by beta decays from ^{214}Pb
  - Assumed flat spectrum extrapolated from unblinded data
  - Conservatively assigned 100% uncertainty to yield model
  - ER background prediction:
    - SR0: 0.13 ± 0.13 Events
    - SR1: 0.56 ± 0.56 Events

- **Radiogenic neutron**: spontaneous fission and (α,n) reactions
  - Modeled in a combination of data-driven approach and MC
  - Neutron background prediction:
    - SR0: 0.13±0.07 Events
    - SR1: 0.33±0.19 Events
- **Surface background**: ERs from ^{210}Pb plate out at detector walls
  - Data-driven model predicts < 0.3 Events → **negligible**

arXiv:2408.02877

FINAL PREDICTION BEFORE UNBLINDING

Component	Expectation	Best-fit
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	$11.9^{+4.5}_{-4.2}$	
Observed		



Total exposure: 3.51 ton year

Expect ^{8}B CEνNS: $11.9^{+4.5}_{-4.2}$ Events

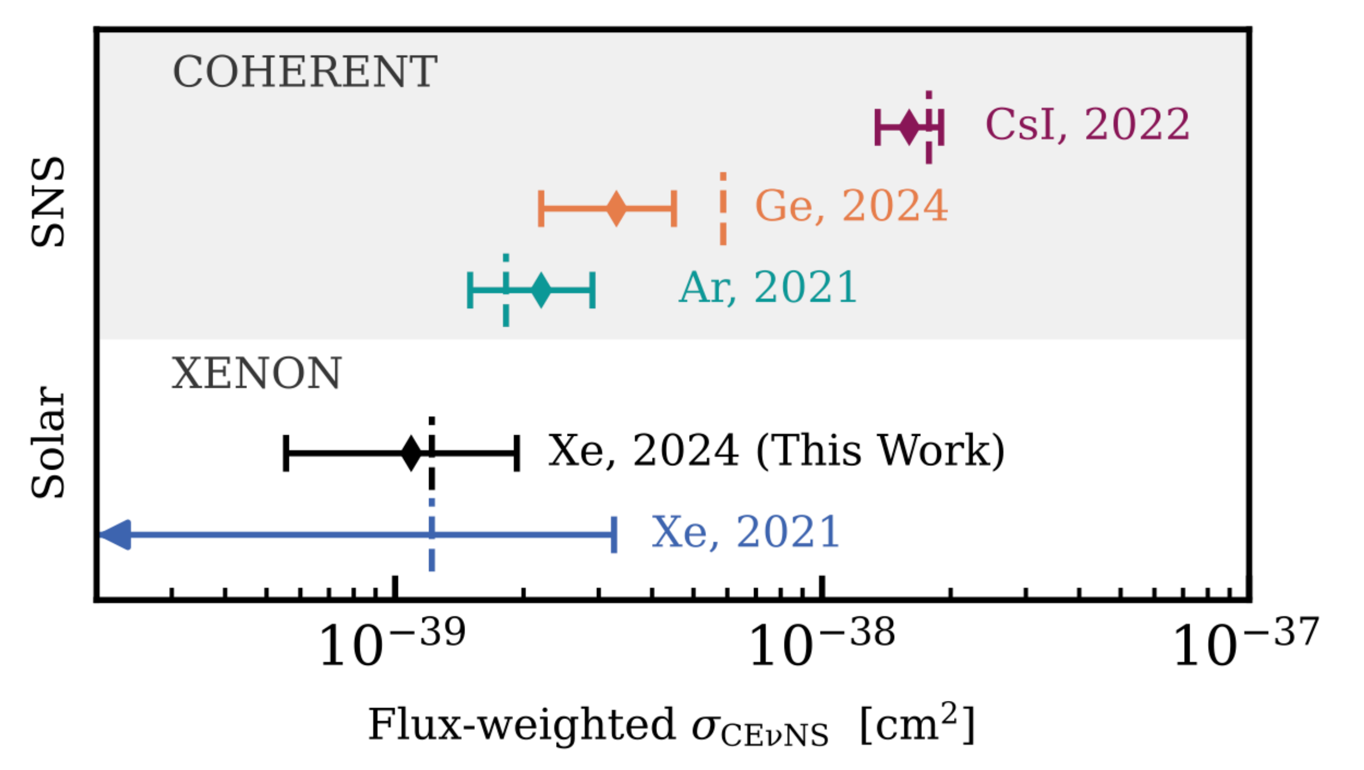
48 % probability to observe $>3\sigma$ significance

arXiv:2408.02877

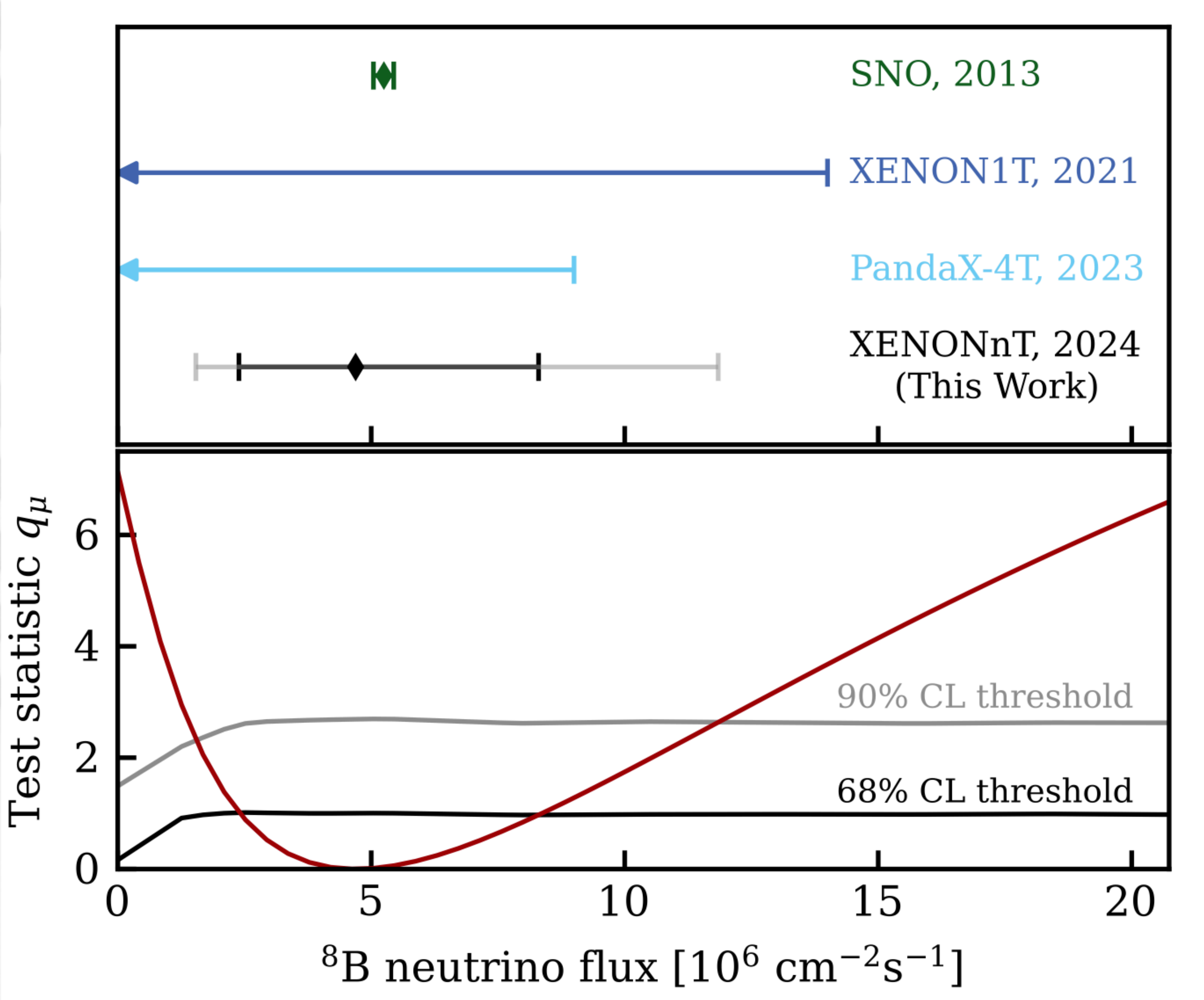

2.73σ

BEST-FIT AFTER UNBLINDING

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	



Flux-weighted $\sigma_{CE\nu NS}$ in agreement with SM

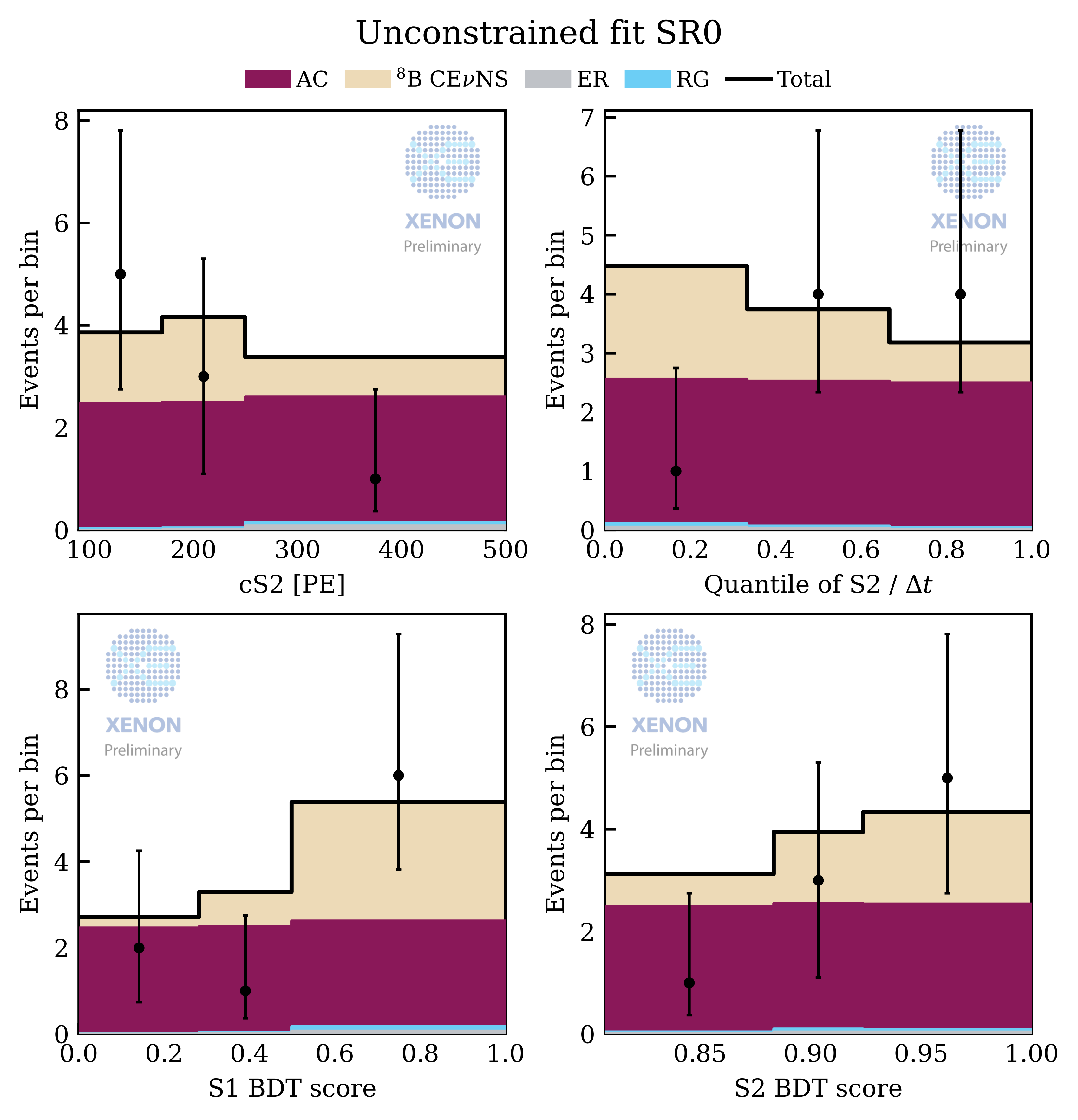


Flux measurement in agreement with SNO (2013)

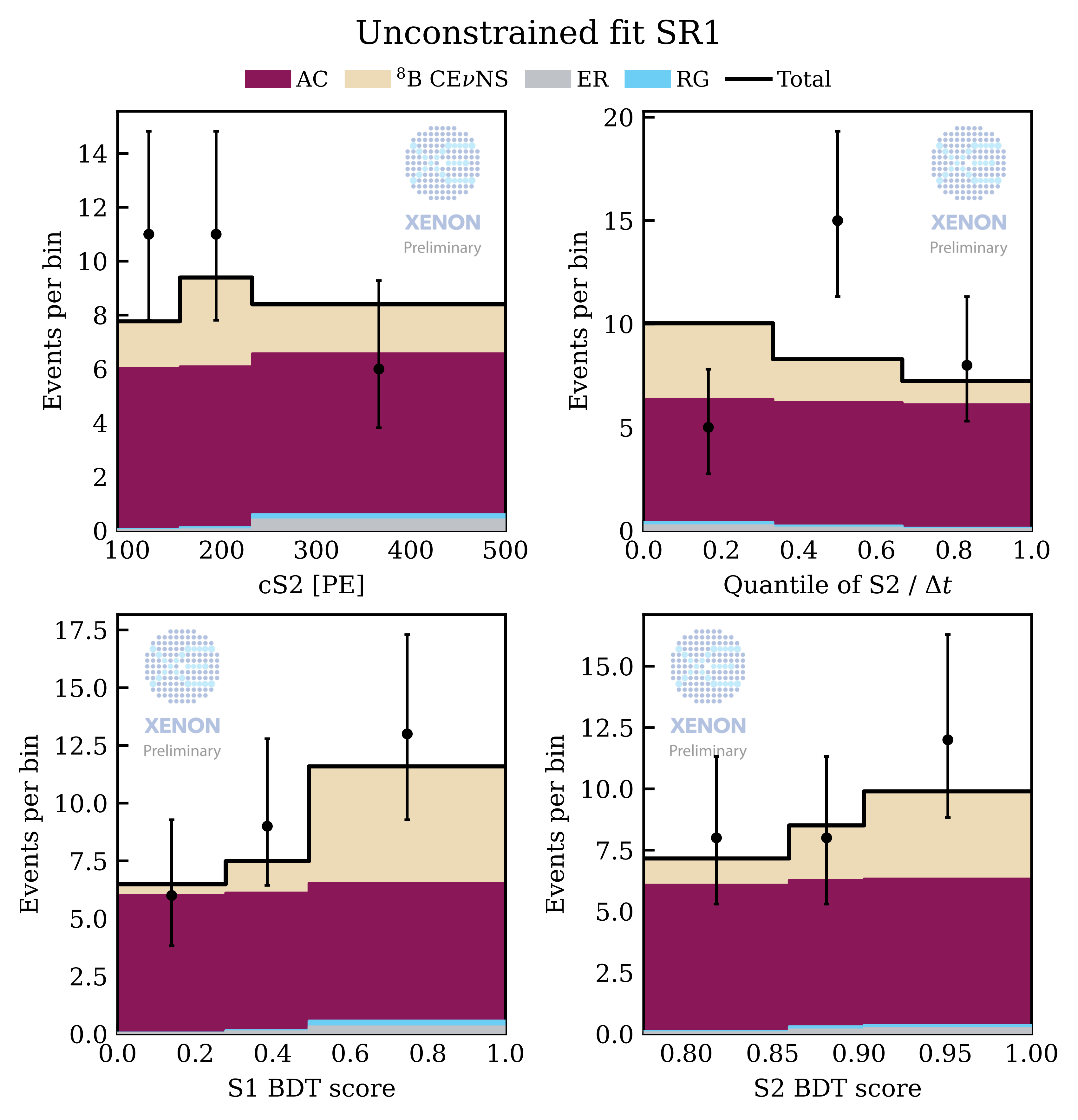
arXiv:2408.02877

AGREEMENT WITH MODEL IN SEARCH SPACE

SR0



SR1



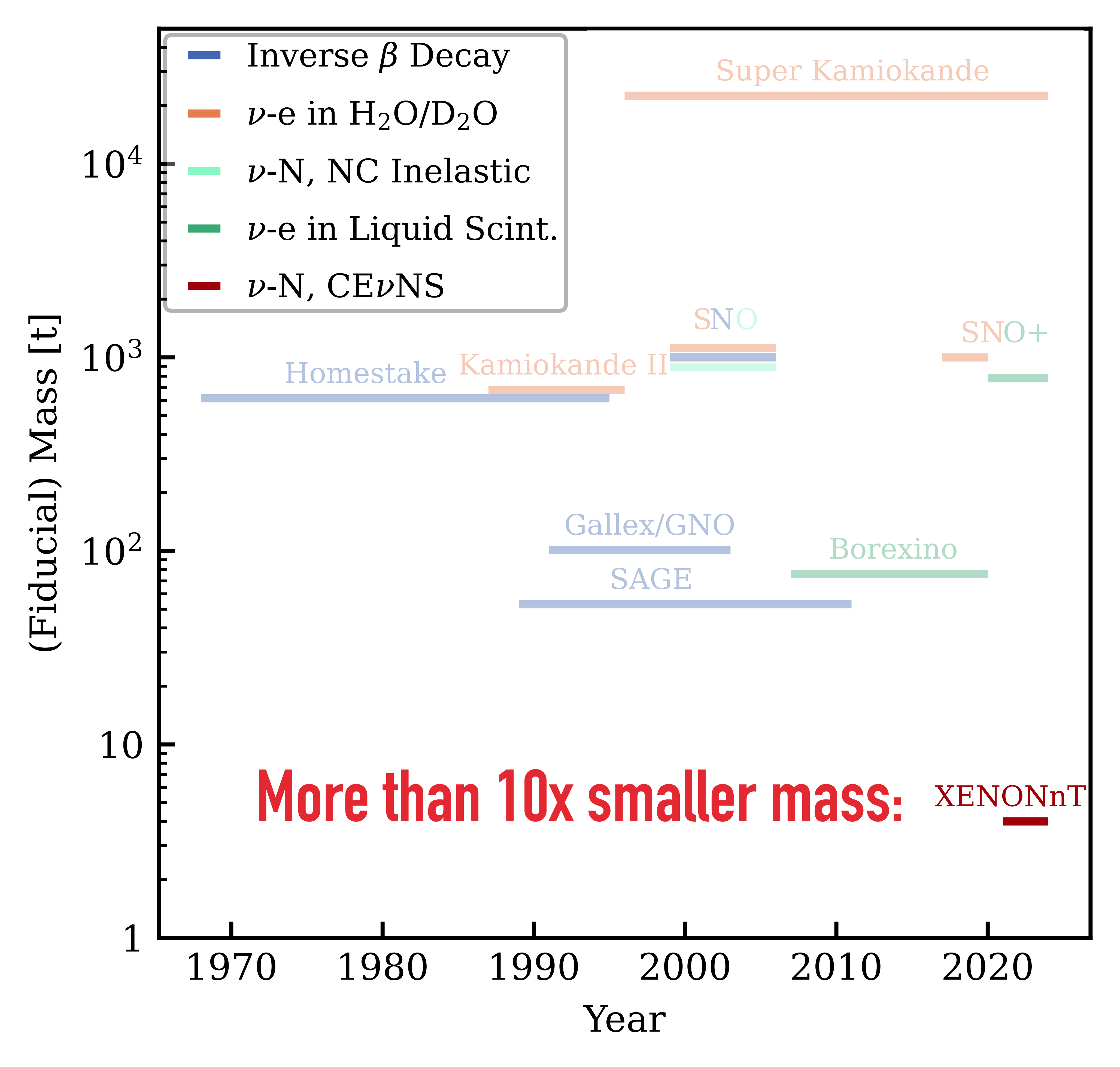
Data agrees with the signal + background expectation

arXiv:2408.02877

CONCLUSIONS AND OUTLOOK

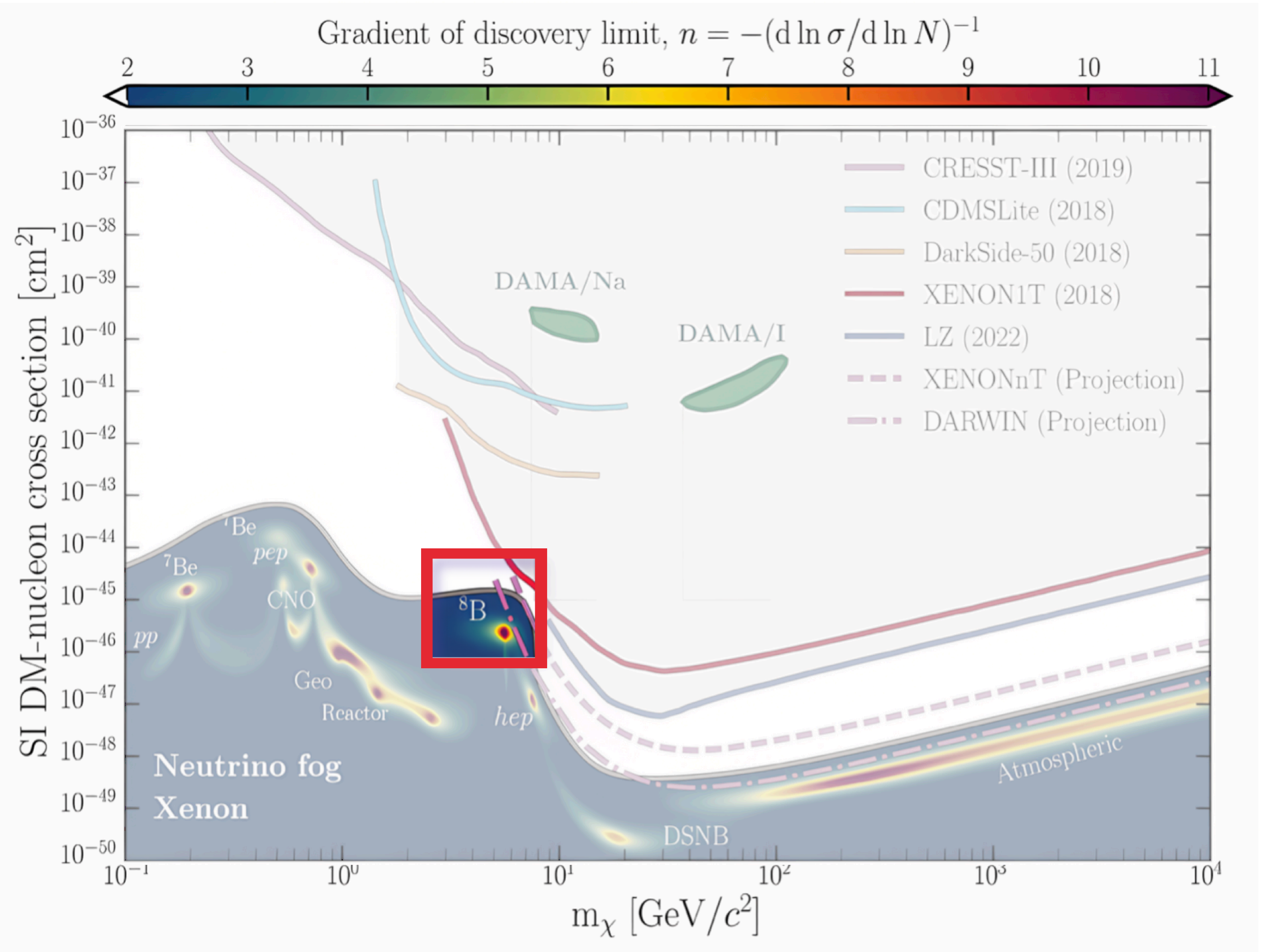
- XENONnT performed a blind search for ^{8}B CEνNS
  - 2.73σ discovery significance
  - The first measurement of ^{8}B CEνNS: $10.7^{+3.7}_{-4.2}$ events

FIRST detected astrophysical ν in a **dark matter detector**
FIRST measured CEνNS from **astrophysical ν** source
FIRST measured CEνNS with a **Xe** target



CONCLUSIONS AND OUTLOOK

- XENONnT performed a blind search for ^{8}B CEνNS
  - 2.73σ discovery significance
  - The first measurement of ^{8}B CEνNS: $10.7^{+3.7}_{-4.2}$ events
- XENONnT sets its first step into the neutrino fog
  - Search for dark matter in the neutrino fog *publication in preparation*
  - Improvement of sensitivity in few GeV WIMP will be slower… while $>\sim 20$ GeV is still unaffected!
  - Much more blinded data has been taken!



Phys. Rev. Lett. 127, 251802 (2021)

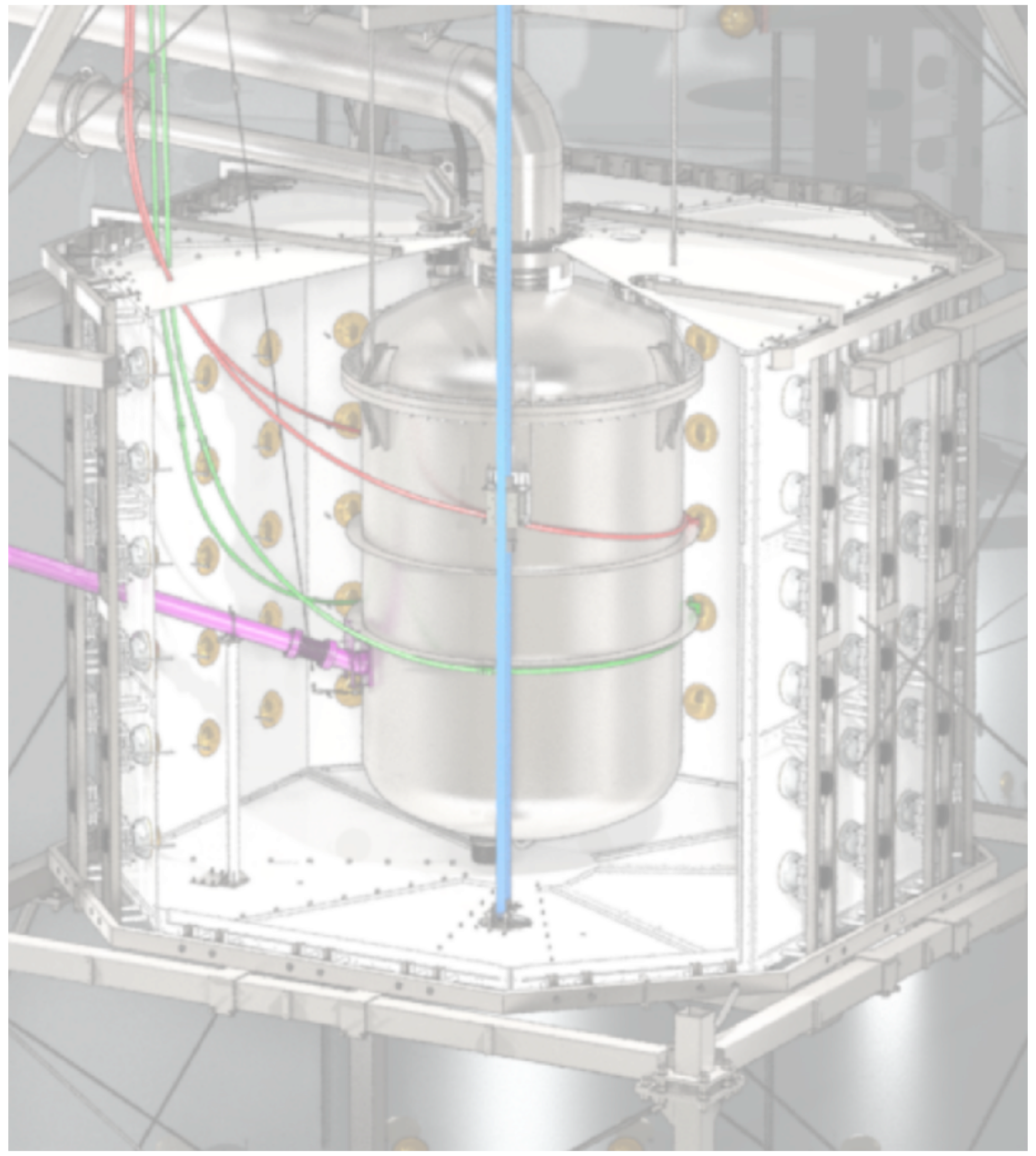
3 NESTED DETECTORS: TPC/NV/MV SHARING SAME DAQ

JINST 18 P07054 (2023)
JCAP 11 031 (2020)
Eur.Phys.J.C 84 (2024) 8, 784

LXe Time Projection Chamber (TPC)

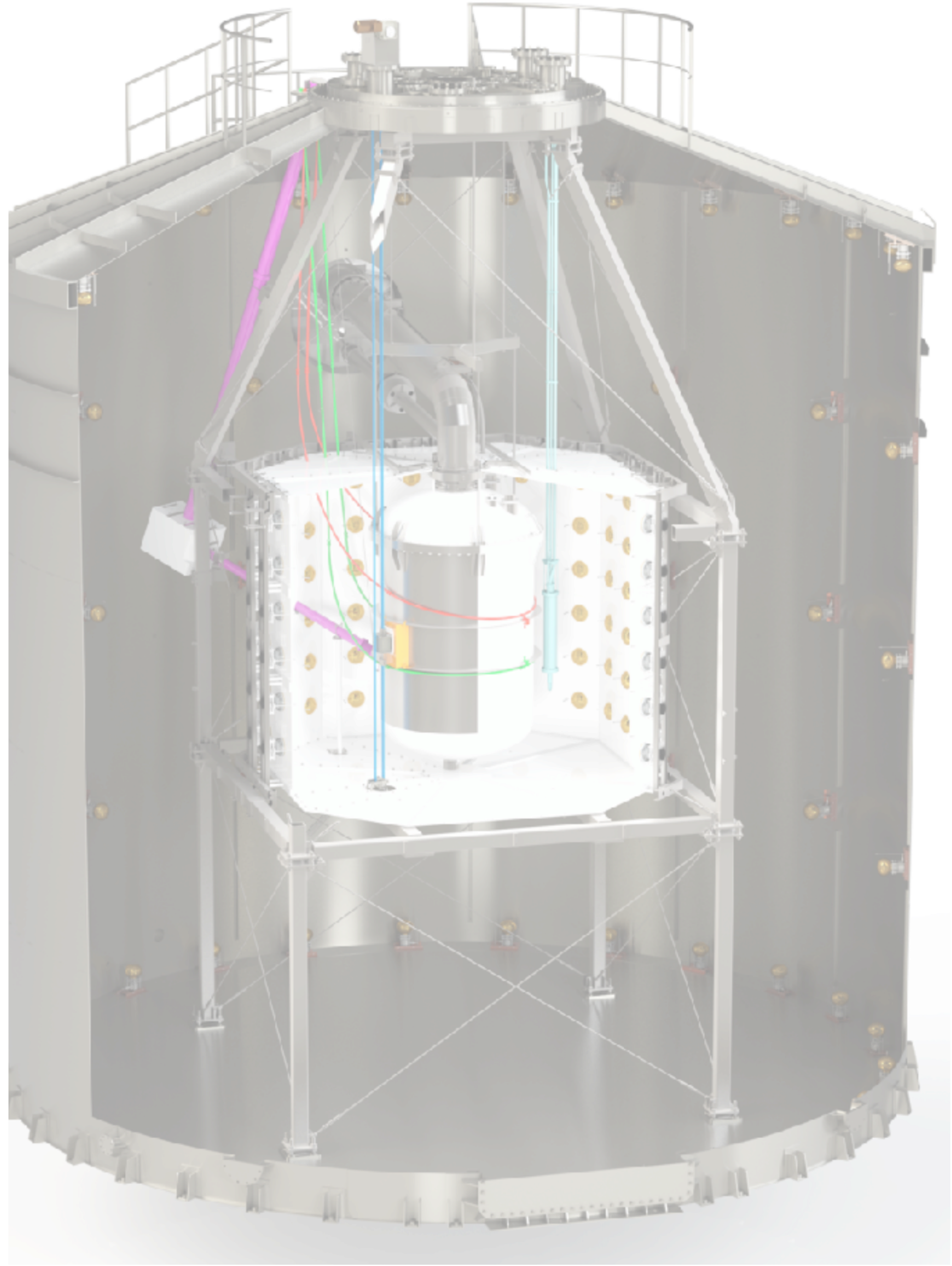
- **5.9t** active target mass
- including ~8.9% ^{136}Xe by natural abundance
- active target diameter/height: 1.3m/1.5m
- 494 Hamamatsu 3" PMTs

Gd-loaded Water Cherenkov Neutron Veto (NV)



- (Pure water for published results so far)
- 120 8" high QE PMT
- 33 m^3 volume
- Use neutron capture to tag neutron events at the efficiency of **53%** in pure water
- High reflectivity expanded PTFE

Water-based muon Cherenkov Detector Muon Veto (MV)



- 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 and neutrons from natural radioactivity

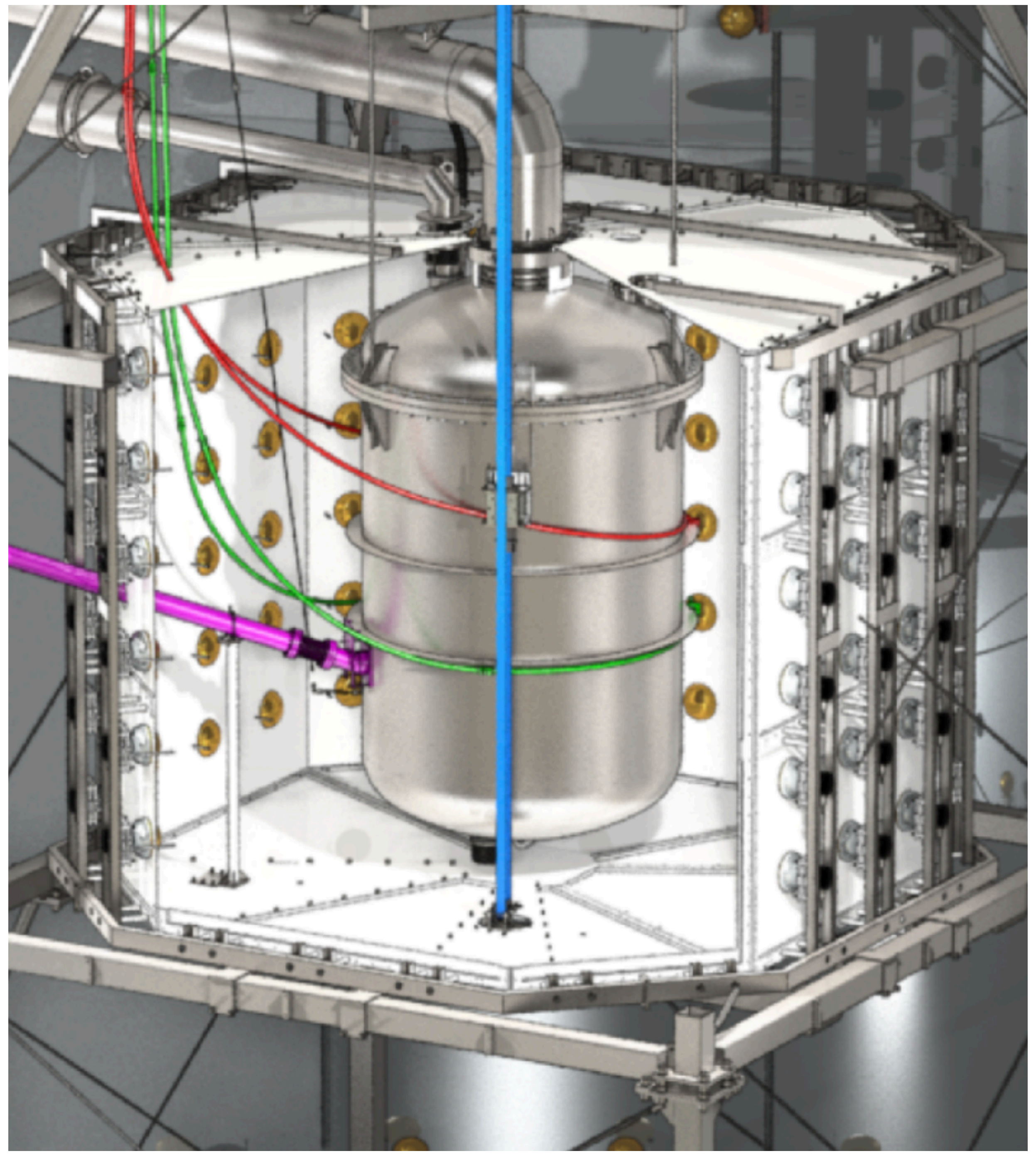
3 NESTED DETECTORS: TPC/NV/MV SHARING SAME DAQ

JINST 18 P07054 (2023)
JCAP 11 031 (2020)
Eur.Phys.J.C 84 (2024) 8, 784

LXe Time Projection Chamber (TPC)

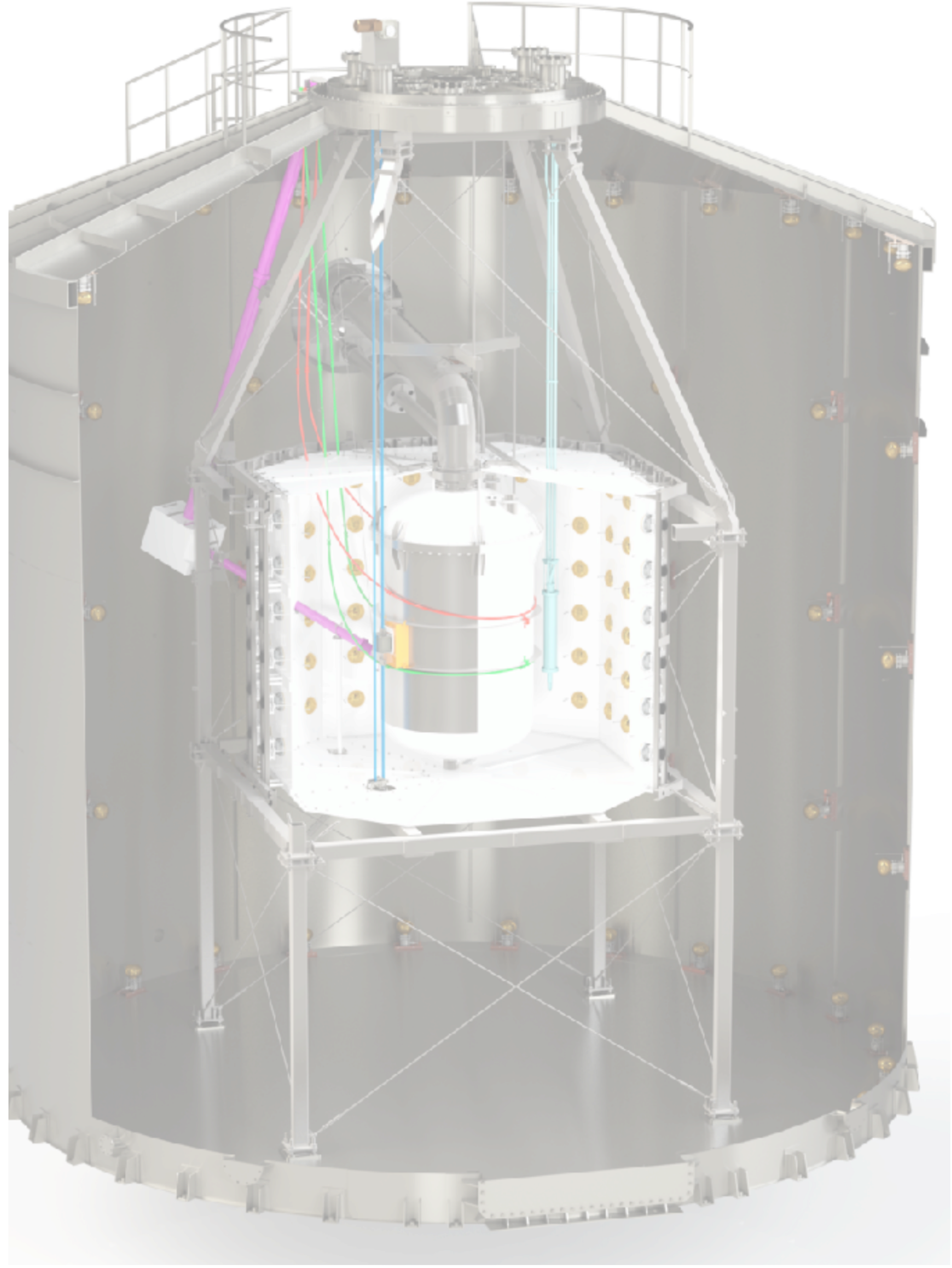
- 5.9t active target mass
- including ~8.9% ^{136}Xe by natural abundance
- active target diameter/height:1.3m/1.5m
- 494 Hamamatsu 3" PMTs

Gd-loaded Water Cherenkov Neutron Veto (NV)



- (Pure water for published results so far)
- 120 8" high QE PMT
- 33 m^3 volume
- Use neutron capture to tag neutron events at the efficiency of **53%** in pure water
- High reflectivity expanded PTFE

Water-based muon Cherenkov Detector Muon Veto (MV)



- 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 and neutrons from natural radioactivity

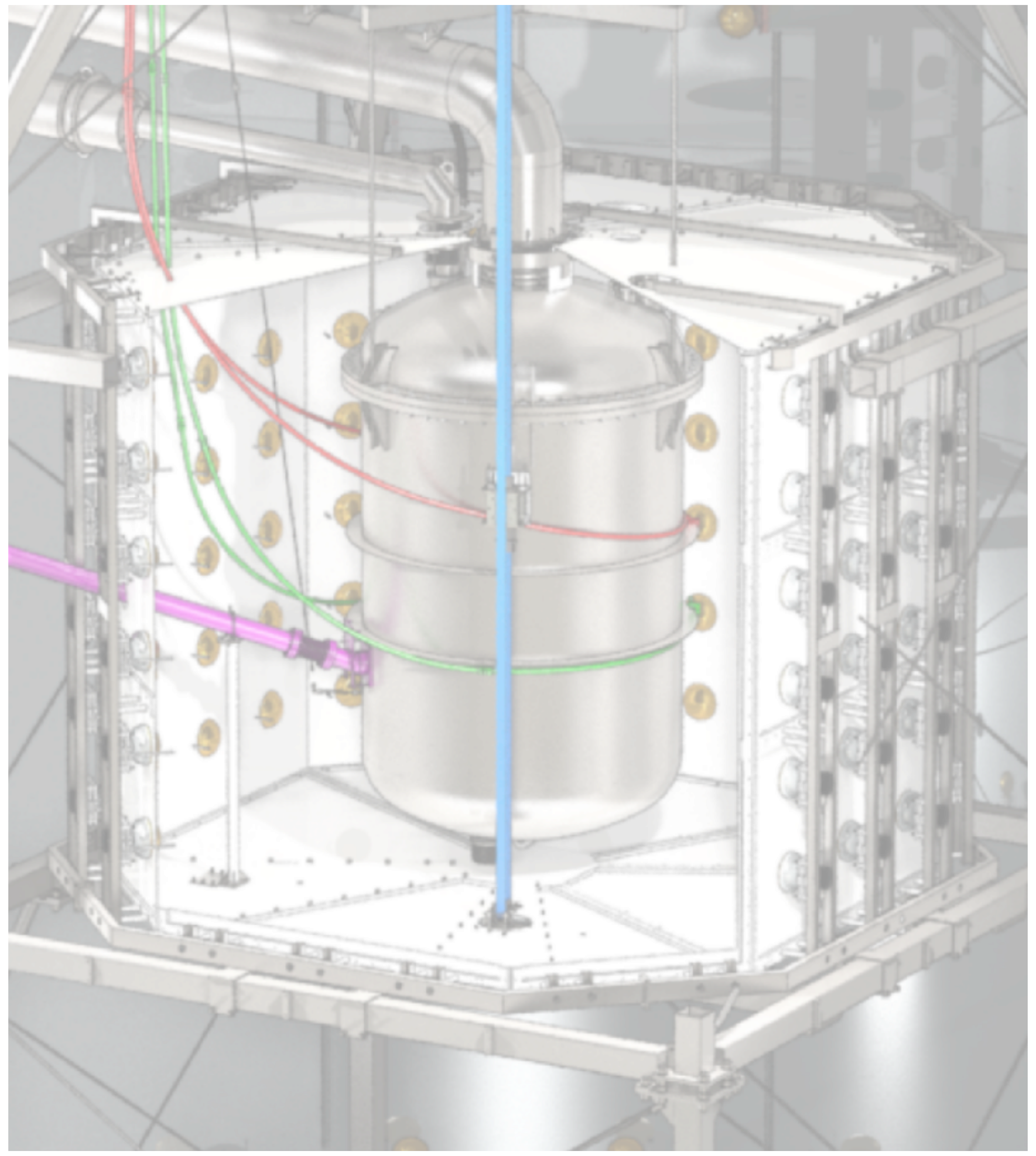
JINST 18 P07054 (2023)
JCAP 11 031 (2020)
Eur.Phys.J.C 84 (2024) 8, 784

3 NESTED DETECTORS: TPC/NV/MV SHARING SAME DAQ

LXe Time Projection Chamber (TPC)

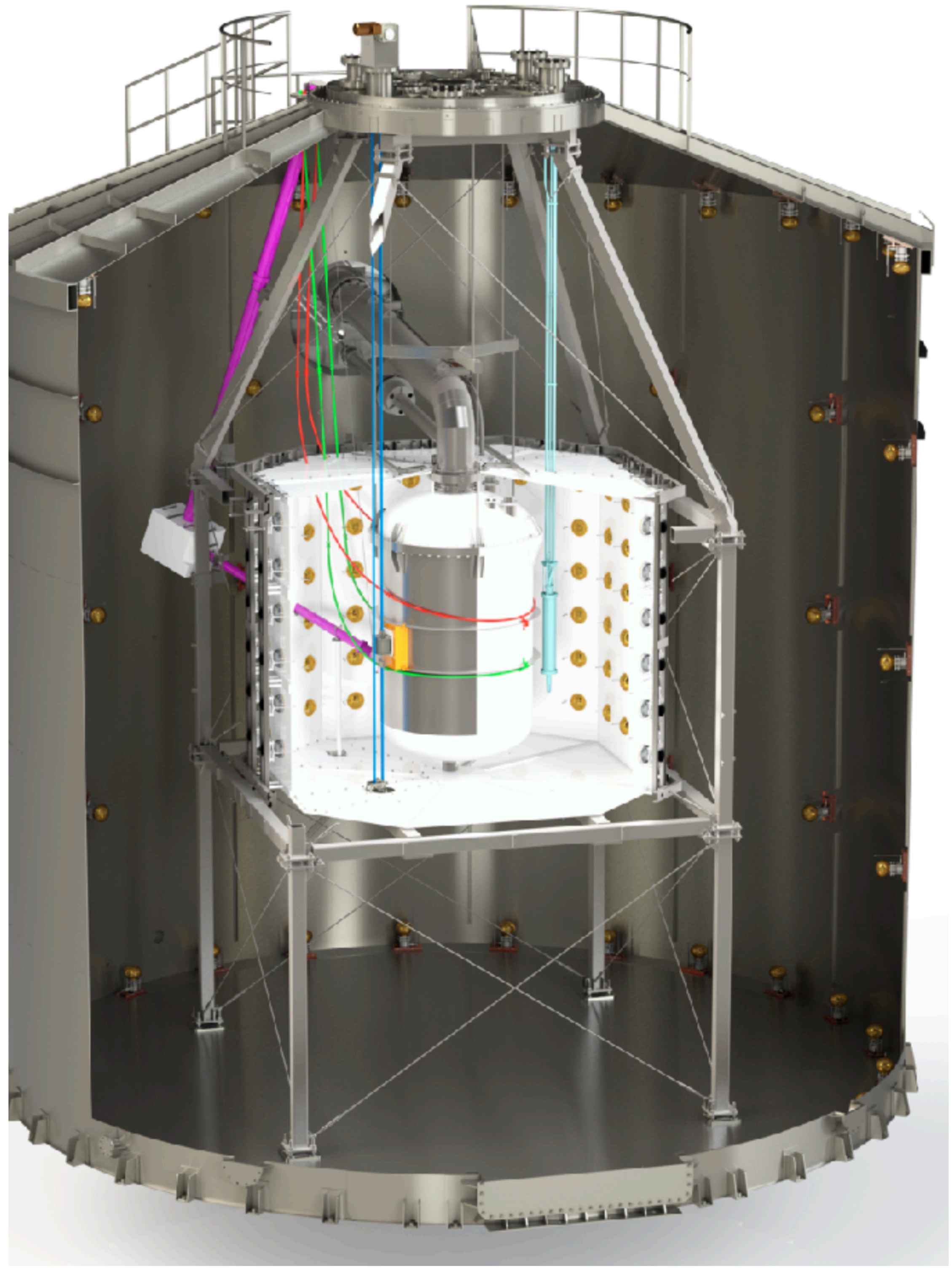
- 5.9t active target mass
- including ~8.9% ^{136}Xe by natural abundance
- active target diameter/height:1.3m/1.5m
- 494 Hamamatsu 3" PMTs

Gd-loaded Water Cherenkov Neutron Veto (NV)



- (Pure water for published results so far)
- 120 8" high QE PMT
- 33 m^3 volume
- Use neutron capture to tag neutron events at the efficiency of **53%** in pure water
- High reflectivity expanded PTFE

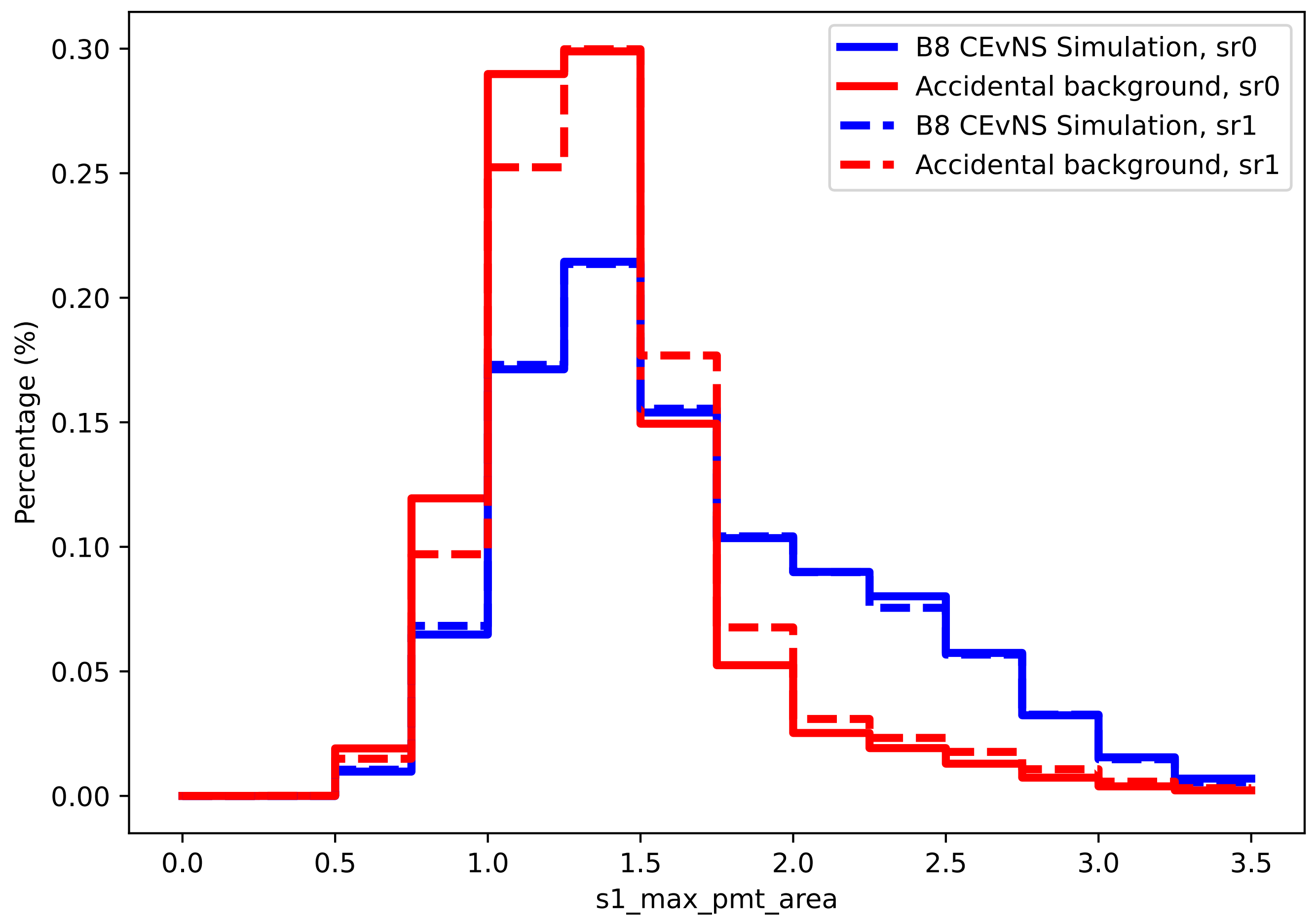
Water-based muon Cherenkov Detector Muon Veto (MV)

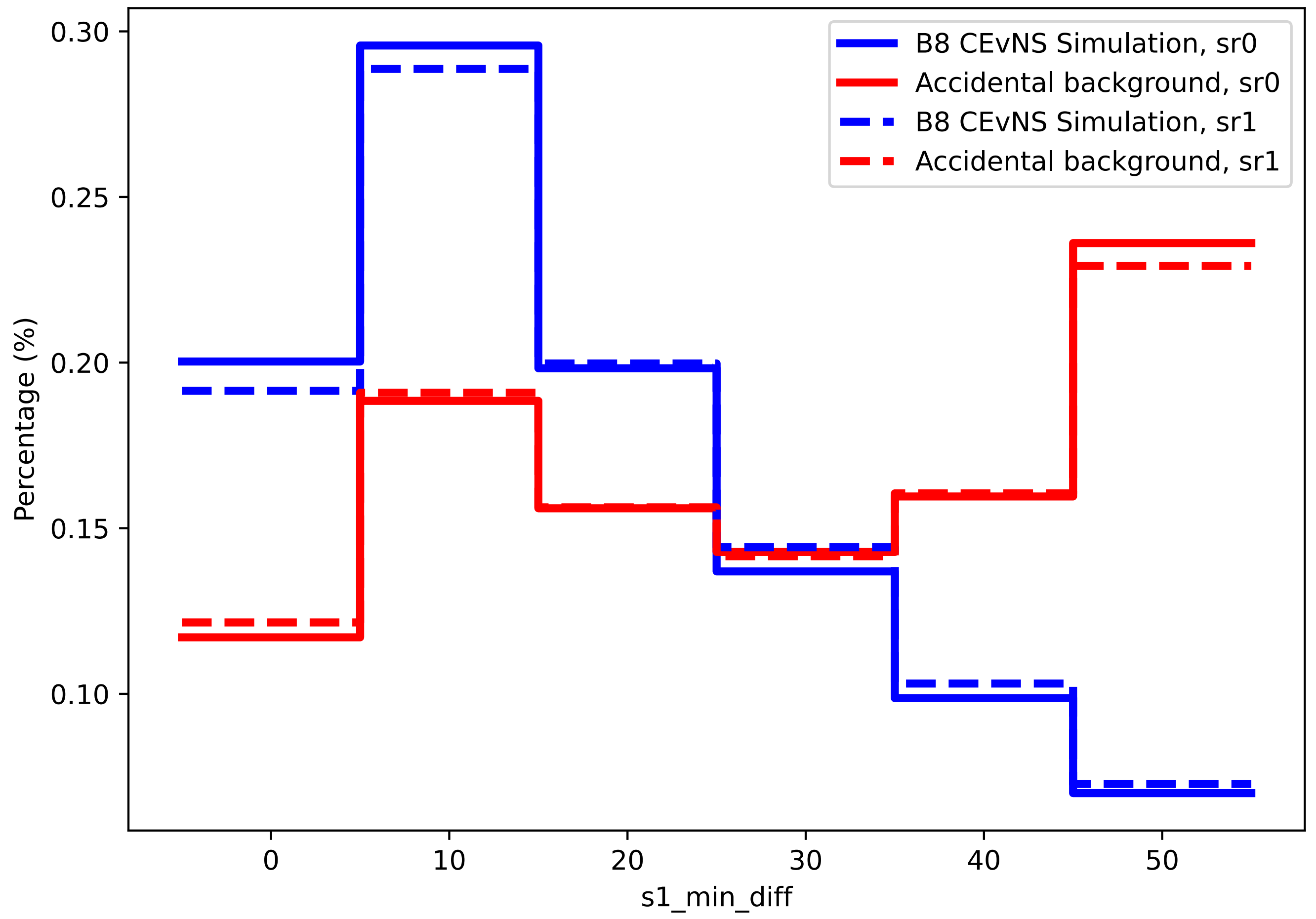


- Diameter/Height 9.6m/10.2m, **700t** water
- High reflectivity inner coating
- 84 Hamamatsu 8" PMTs
- Active veto against muon-induced neutrons
- Passive veto against gamma rays and neutrons from natural radioactivity

S1 BDT FEATURES

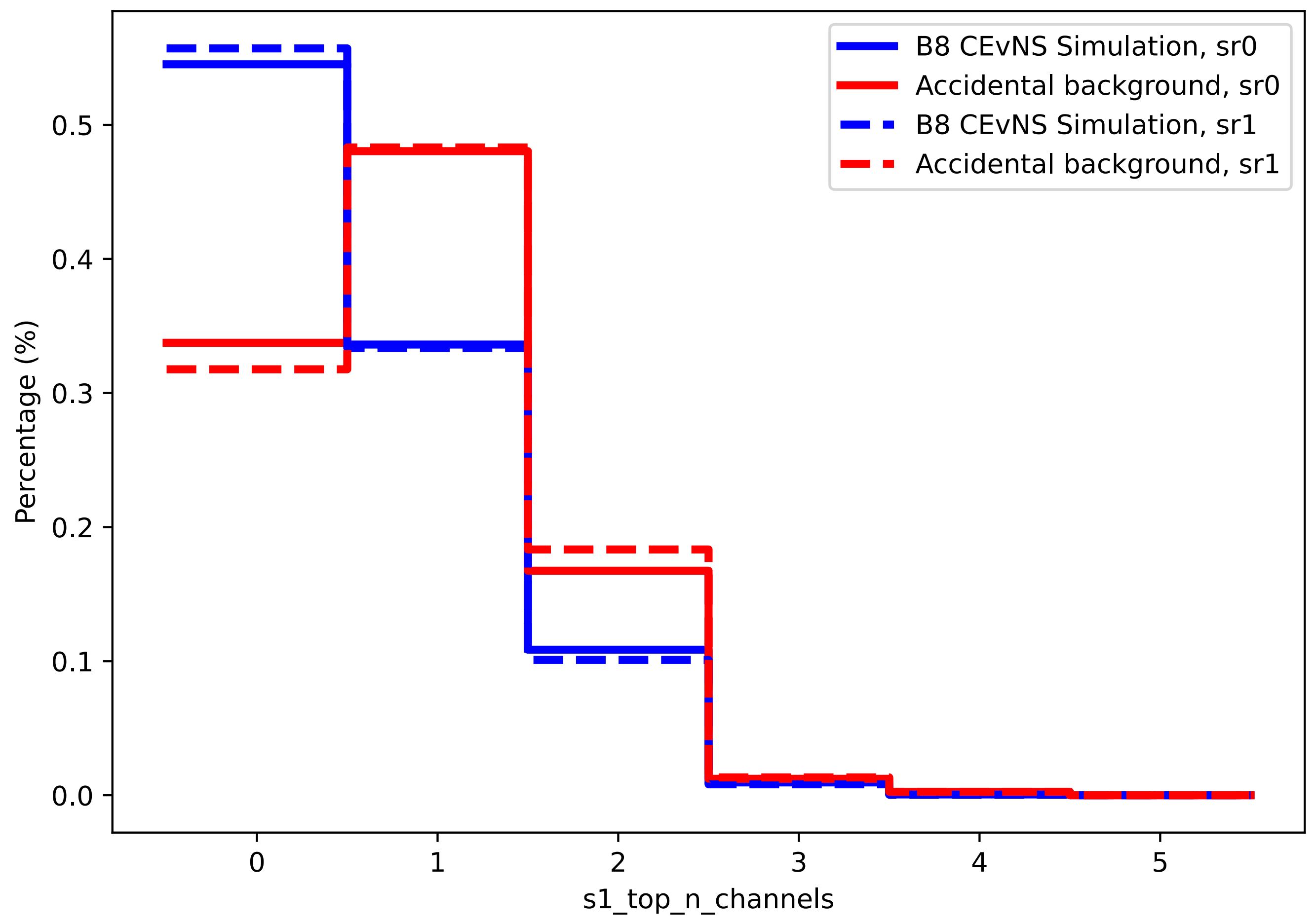
NO.1 max hit area

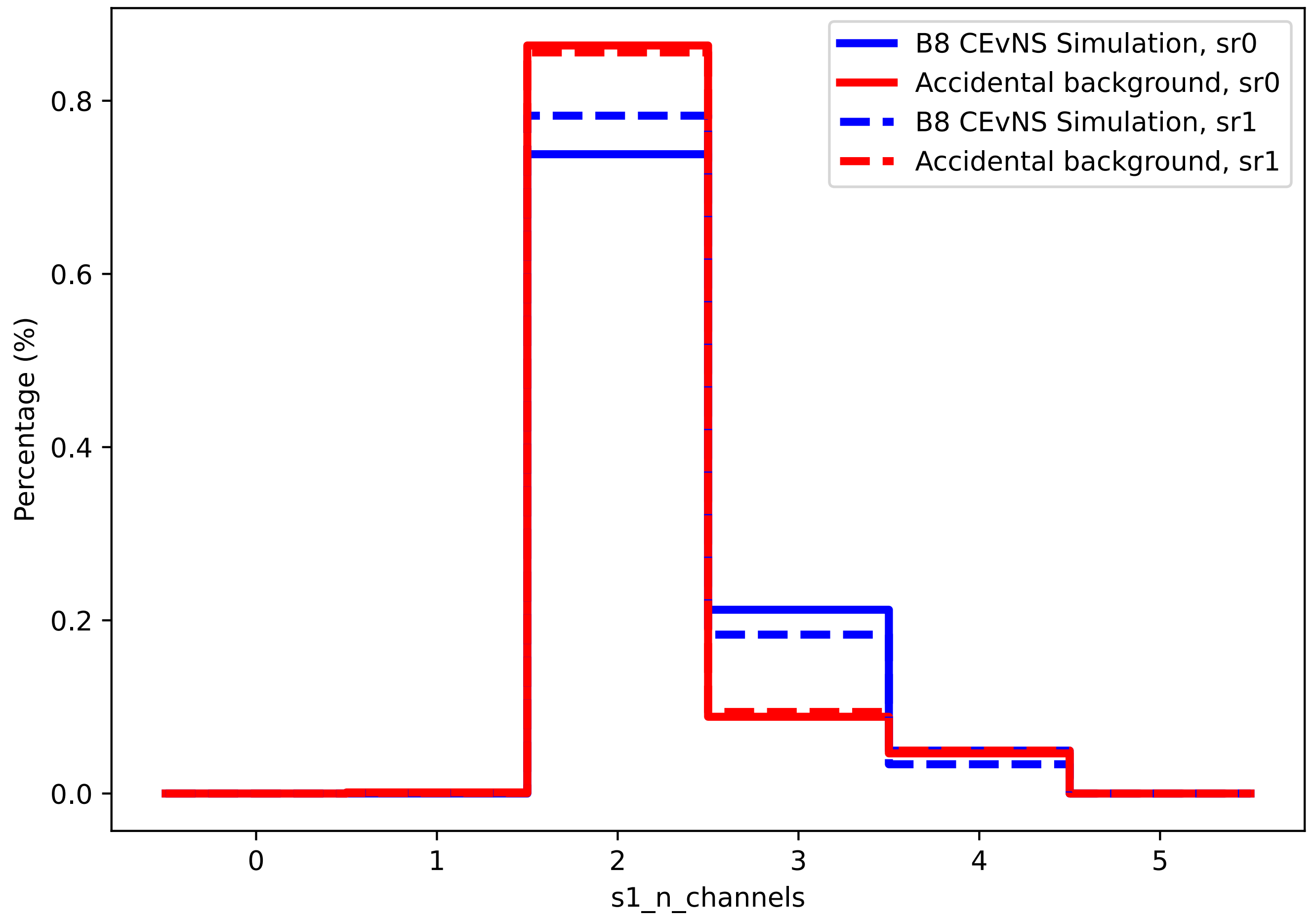




NO.2 min time between hits

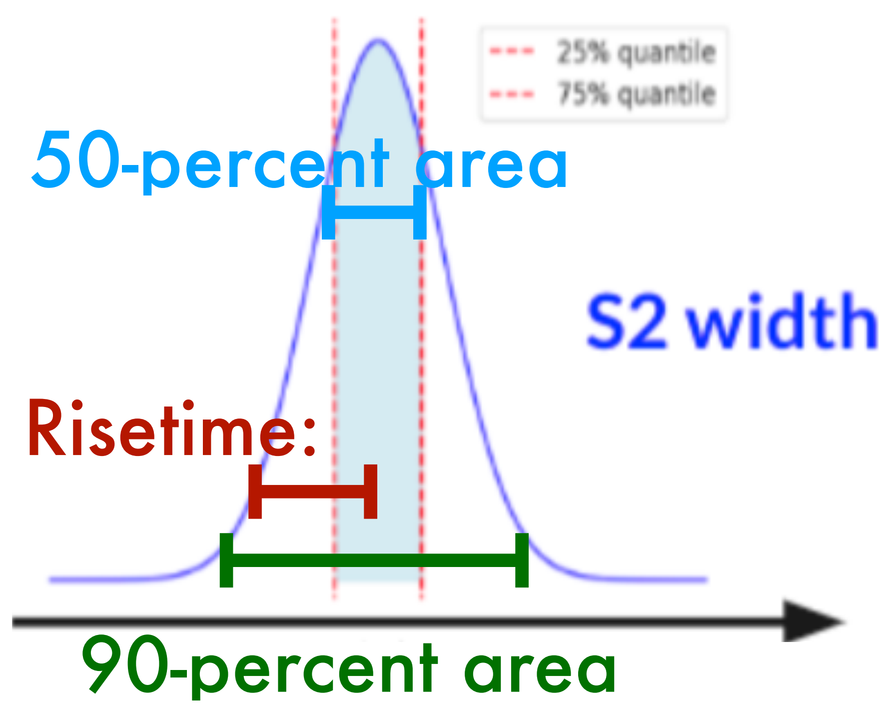
NO.3 hit count in top array

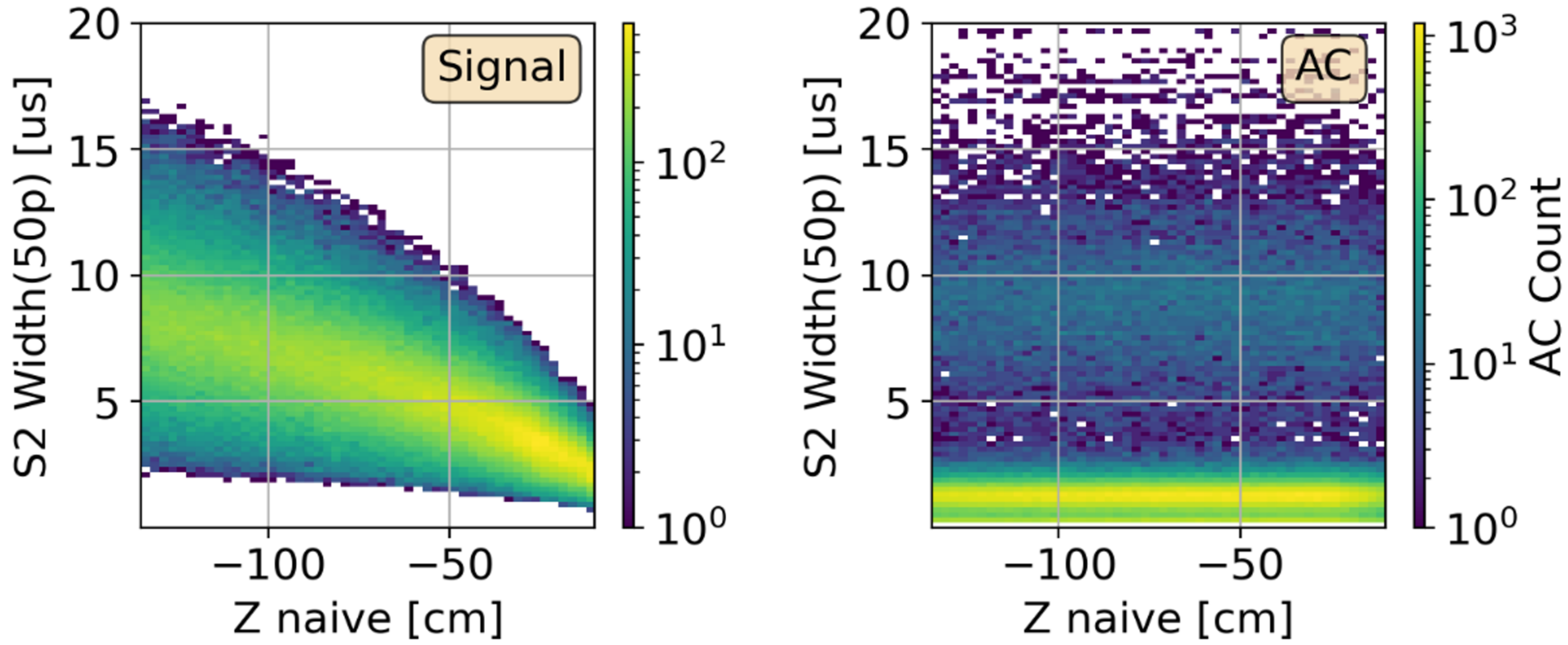




NO.4 total hit count

S2 BDT FEATURES





NO.1 50-percent area range   NO.2 Risetime   NO.3 90-percent area range   NO.4 drift-time

ISO-PEAKS' SPACE&TIME CORRELATION TO HE INTERACTIONS