Latest results from XENONnT

WIMP and neutrinos direct searches

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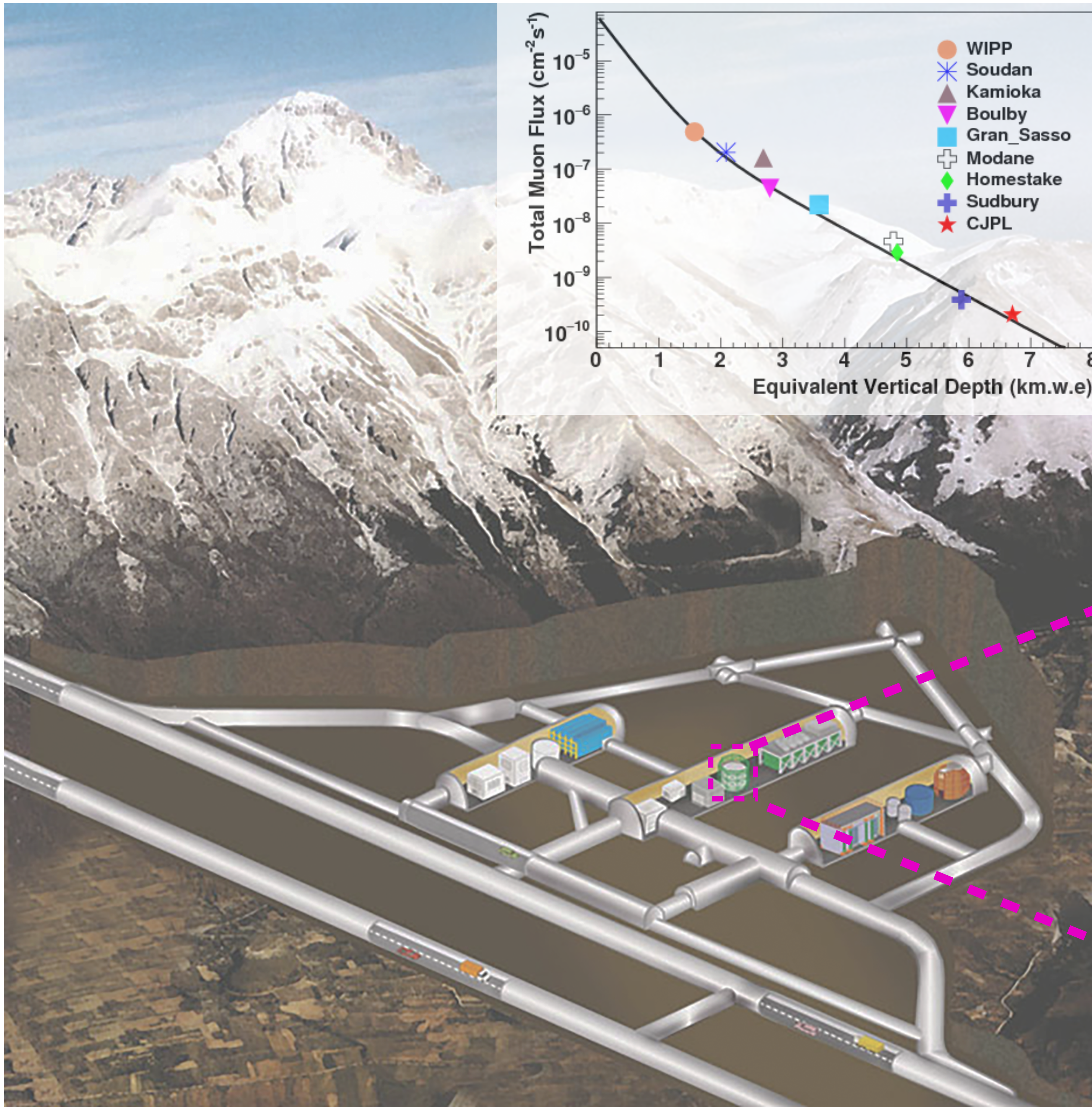
XENON

The XENON collaboration

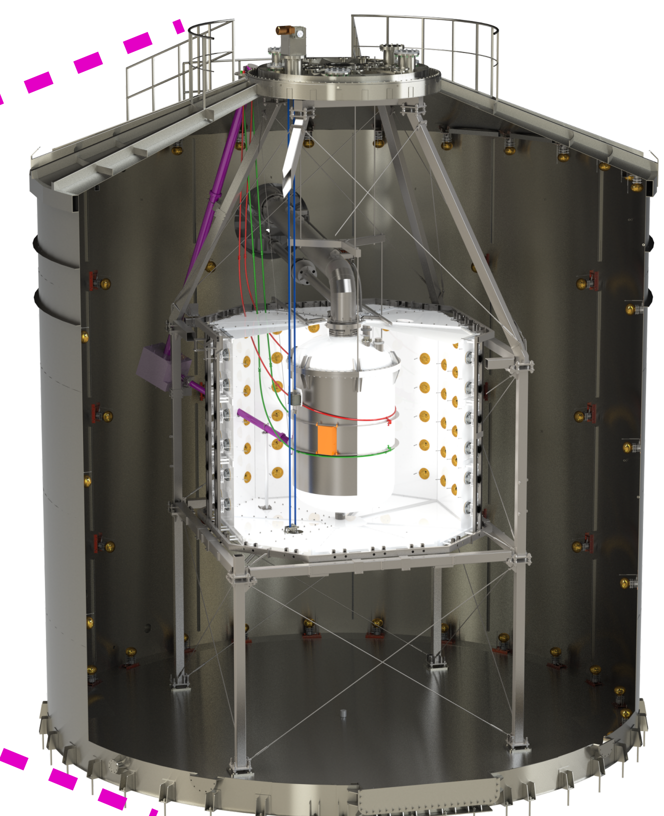
XENONnT @LNGS



The INFN Laboratori Nazionali del Gran Sasso (LNGS) located under 1400 m of rock, shielding the laboratories from cosmic rays.

$\rightarrow 10^6\ \mu$ reduction factor

XENONnT

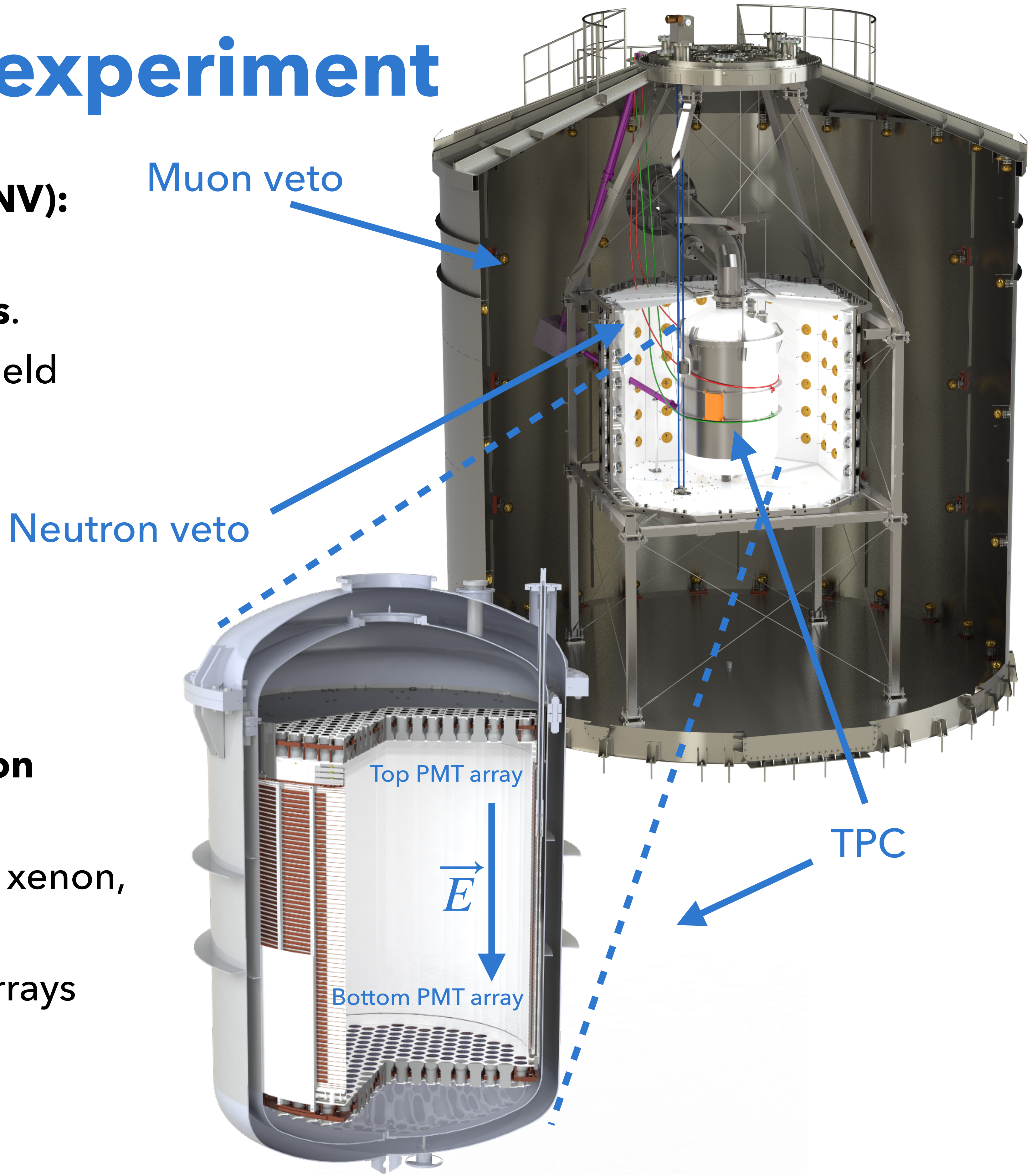


The XENONnT experiment

Muon and neutron veto (MV & NV):

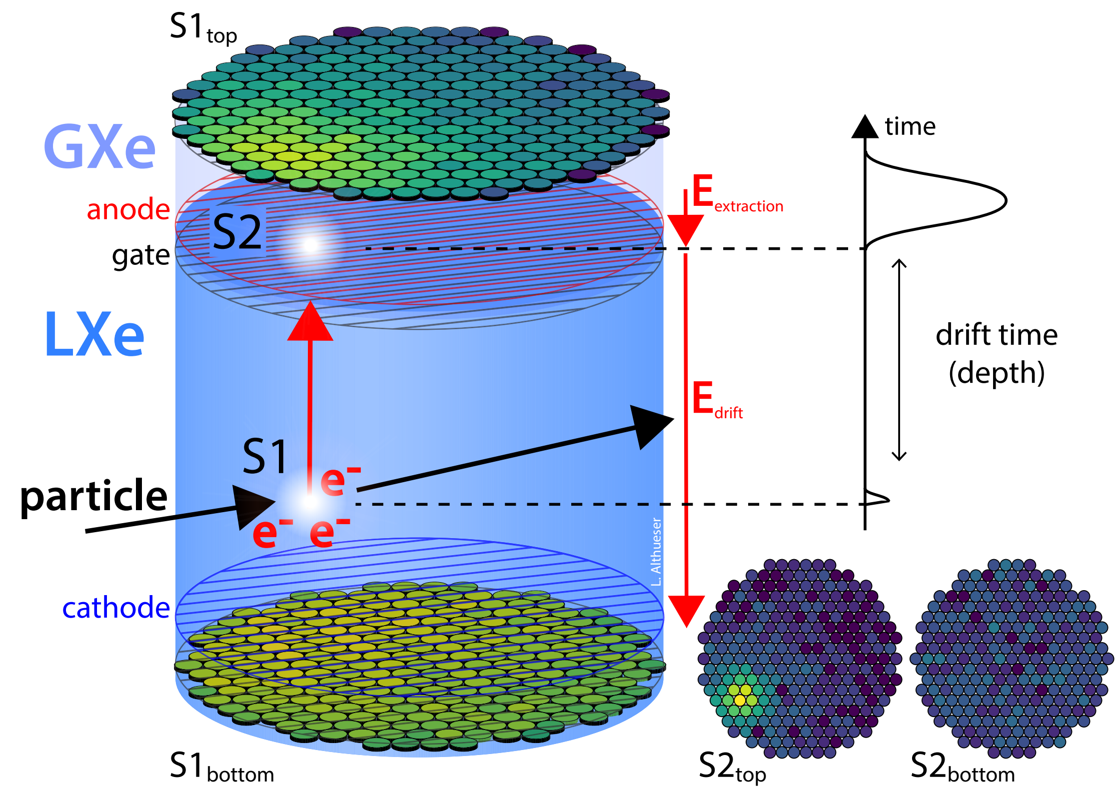
- 700 t Gd loaded **water Cherenkov veto detectors**.
- Both passive and active shield **against cosmogenic and radiogenic neutrons.**
- 84 and 120 PMTs covering their surface

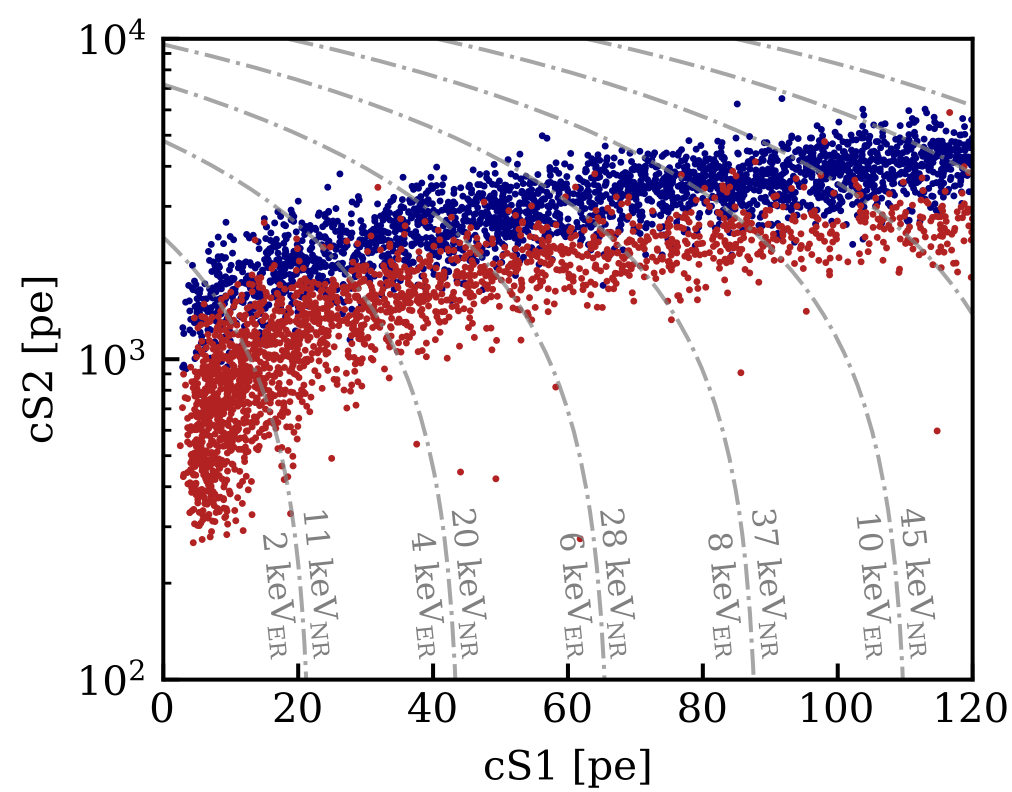
- **TPC**:
  - **Dual phase time-projection chamber.**
  - 8.5 t of liquid and gaseous xenon, 5.9 t of active target.
  - 494 PMTs divided in two arrays (top and bottom).
  - 23 V/cm drift electric field.



Detection principle of TPCs

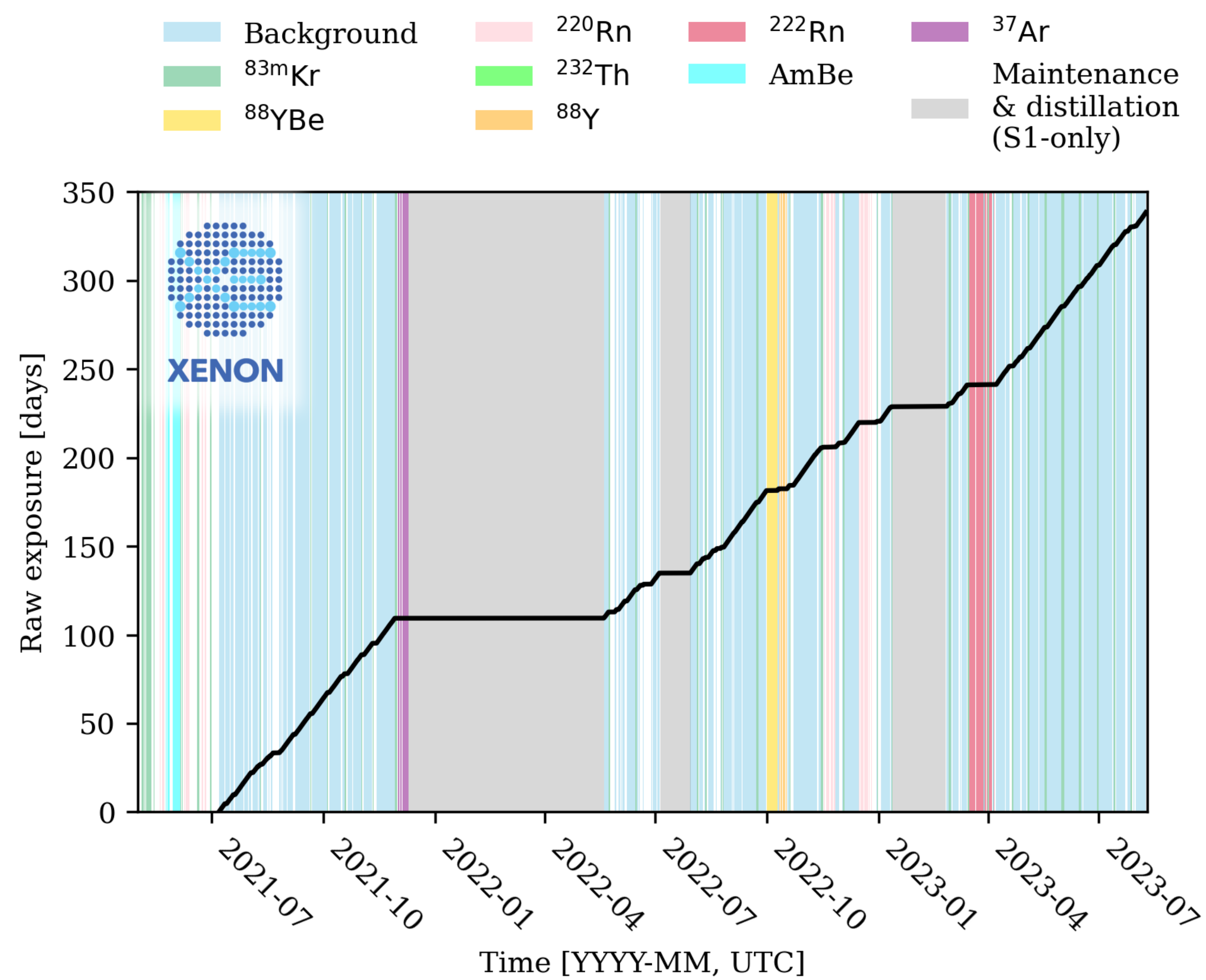
- **Signal detection:**
  - Prompt scintillation (S1) + ionization e⁻ in liquid xenon.
  - Electric field drifts e⁻ towards gaseous xenon.
  - Electrons produce a delayed scintillation signal (S2) at the top of the TPC.
- **3D reconstruction:**
  - x and y from top PMTs.
  - z from drift time times drift velocity.
- **Signal discrimination:**
  - S2/S1 ratio → ER/NR discrimination.





XENONnT science search

- **Fiducial mass of ~ 4 tonne.**
- Two science runs (SR):
  - **SR0 (95.1 days).**
  - **SR1 (186.5 days):**
    Radon Removal System in high-flow mode (^{222}Rn activity < 1μBq/kg).
    SR1 divided in two periods:
    - **SR1a (66.6 days):**
      - Higher ER rate from ^{85}Kr, ^{37}Ar, ^{3}H.
    - **SR1b (119.9 days):**
      - Low ^{85}Kr, ^{37}Ar after cryogenic distillation.
      - ^{3}H still present.
  - **SR2 (ended in March 2025)**



SR0	SR0 + SR1
Search of new physics in ER	First indication of solar neutrinos
WIMP search in NR	First search of light DM in neutrino fog
	WIMP search with combined exposure

WIMP search: Background

ER background

- ^{214}**Pb from** ^{222}**Rn,**
- ^{85}**Kr β-decays,**
- ^{124}**Xe DEC,**
- **solar $\nu - e$ scattering.**

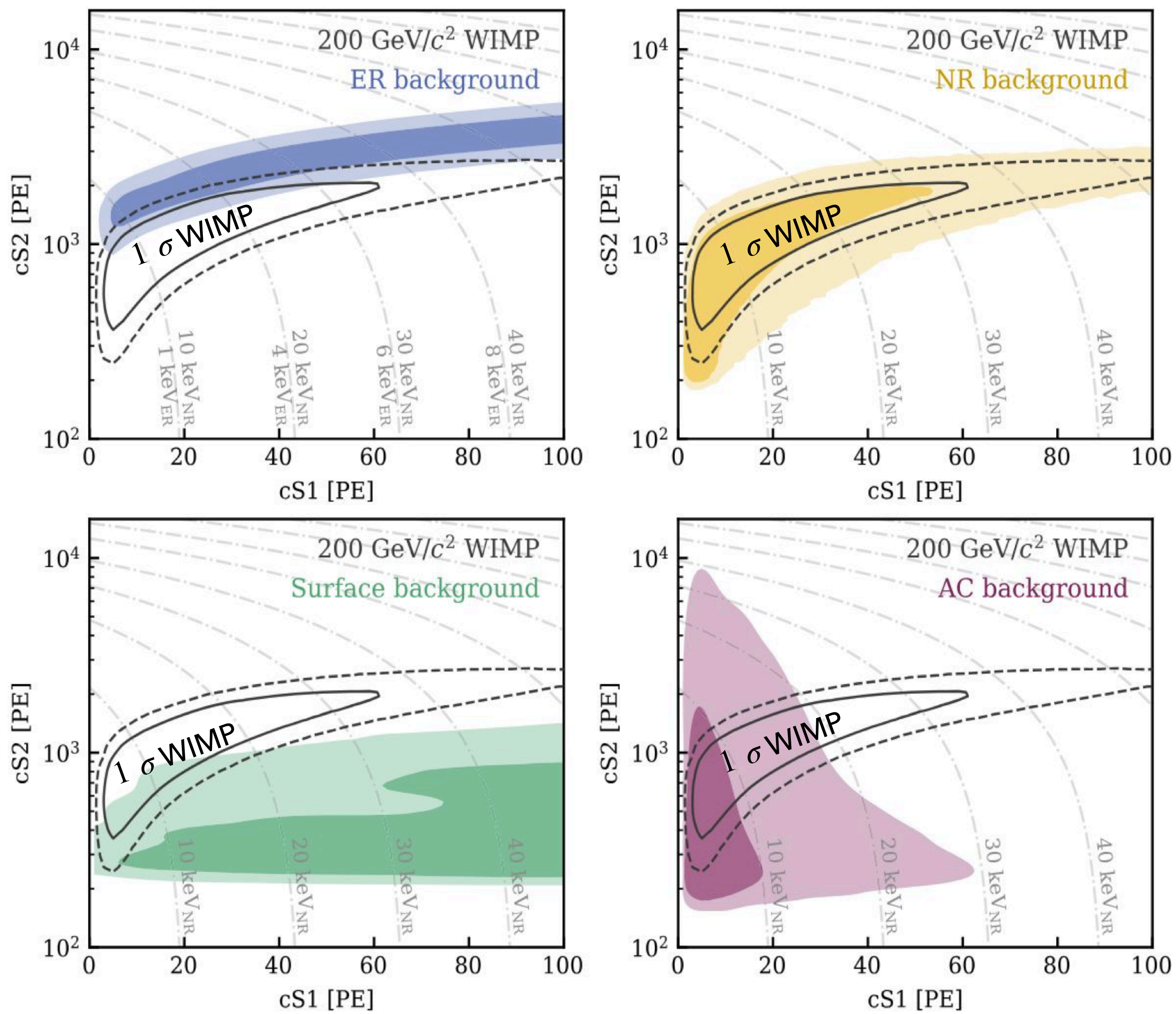
Shape constrained by ^{220}Rn calibration data.

Rate constrained by fit to reconstructed spectrum in $[20{,}140]\ keV_{ER}$.

Surface background

- **Pb decay chain**
  Plate-out effect from the PTFE walls.

Rate constrained by a data-driven method and validated with events outside FV.



arXiv:2502.18005

NR background

- **Radiogenic neutrons**
  Constrained by sideband of multi-scatter events and single-scatter events tagged by n-Veto.
- **CEvNS events in RoI**
  Constrained by neutrino flux and uncertainties in NR emission model.

Accidental coincidence

- **Accidental pairing of isolated S1-S2**

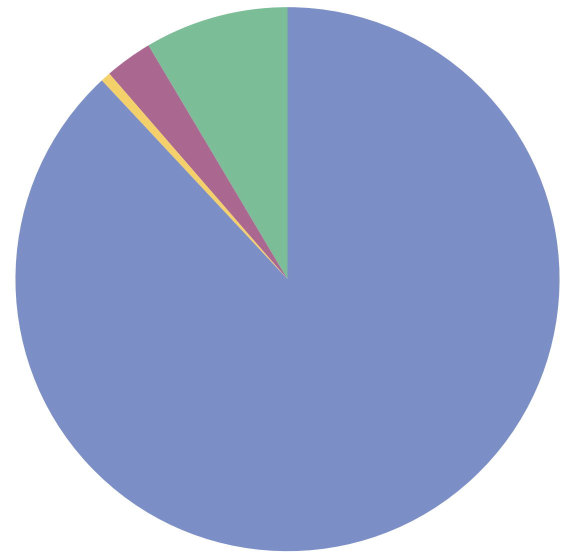
Modeled by a data-driven method.

Validation and uncertainty estimation through a dedicated sideband unblinding.

WIMP search: Background

Electronic Recoil

- ^{214}**Pb from** ^{222}**Rn,**
- ^{85}**Kr** β**-decays,**
- ^{124}**Xe DEC,**
- **solar** $\nu - e$ **scattering.**
- ^{3}**H like**
- ^{37}**Ar**



SR0

(152 expected events)

NR background

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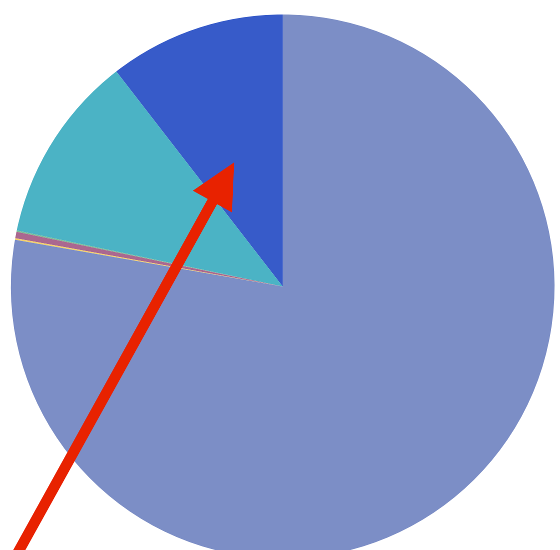
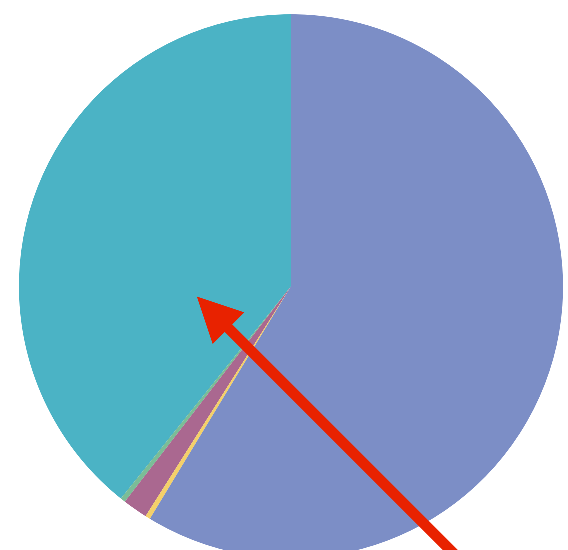


SR1a

(553 expected events)



SR1b

(257 expected events)

Accidental coincidence

- **Accidental pairing of isolated S1-S2**

Modeled by a data-driven method.

Validation and uncertainty estimation through a dedicated sideband unblinding.

Accidental mixture of Kr-rich gas: high rate of ^{85}Kr, ^{37}Ar and ^{3}H

Remaining ^{3}H-like component

WIMP search: reconstruction and efficiencies

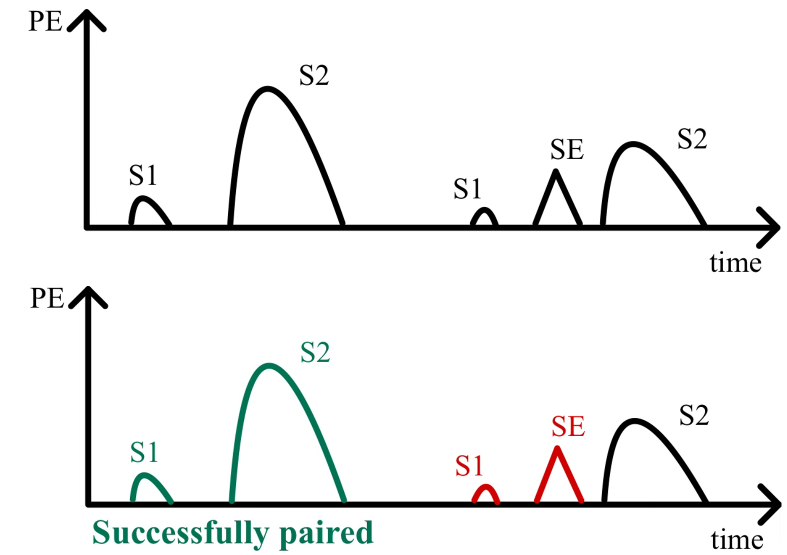
Peak reconstruction/Detection dominated by 3-fold requirement (3 PMTs to be in coincidence) for S1

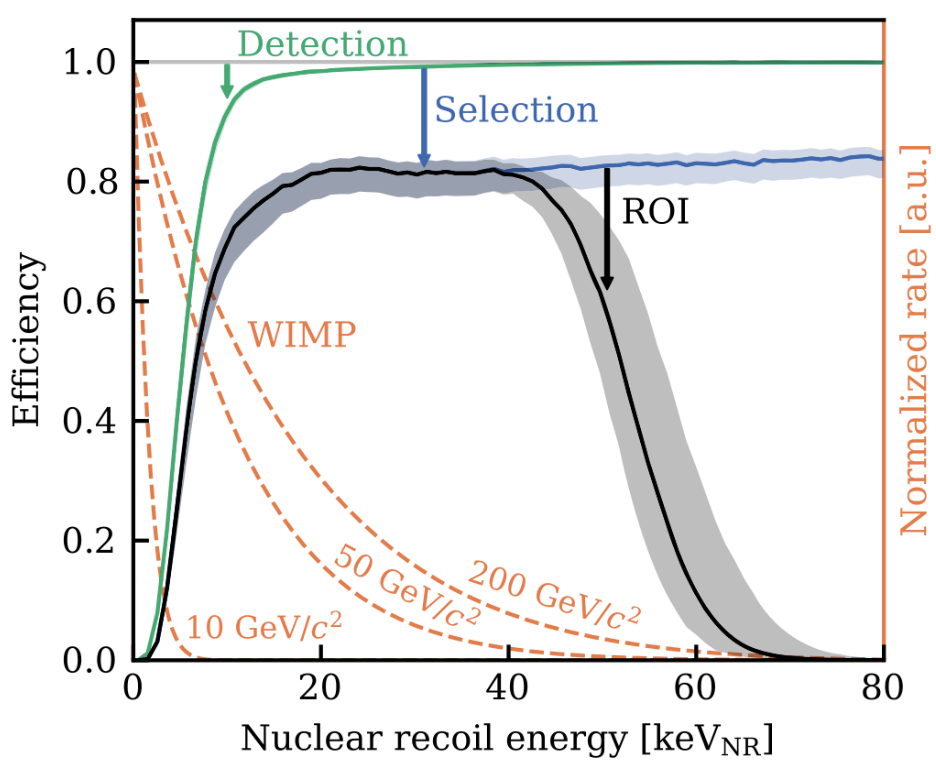
Region of Interest (ROI):

Both SR0 and SR1 are defined as cS1 $\in [0,100]$ PE and cS2 $\in [10^{2.1},10^{4.1}]$ PE.

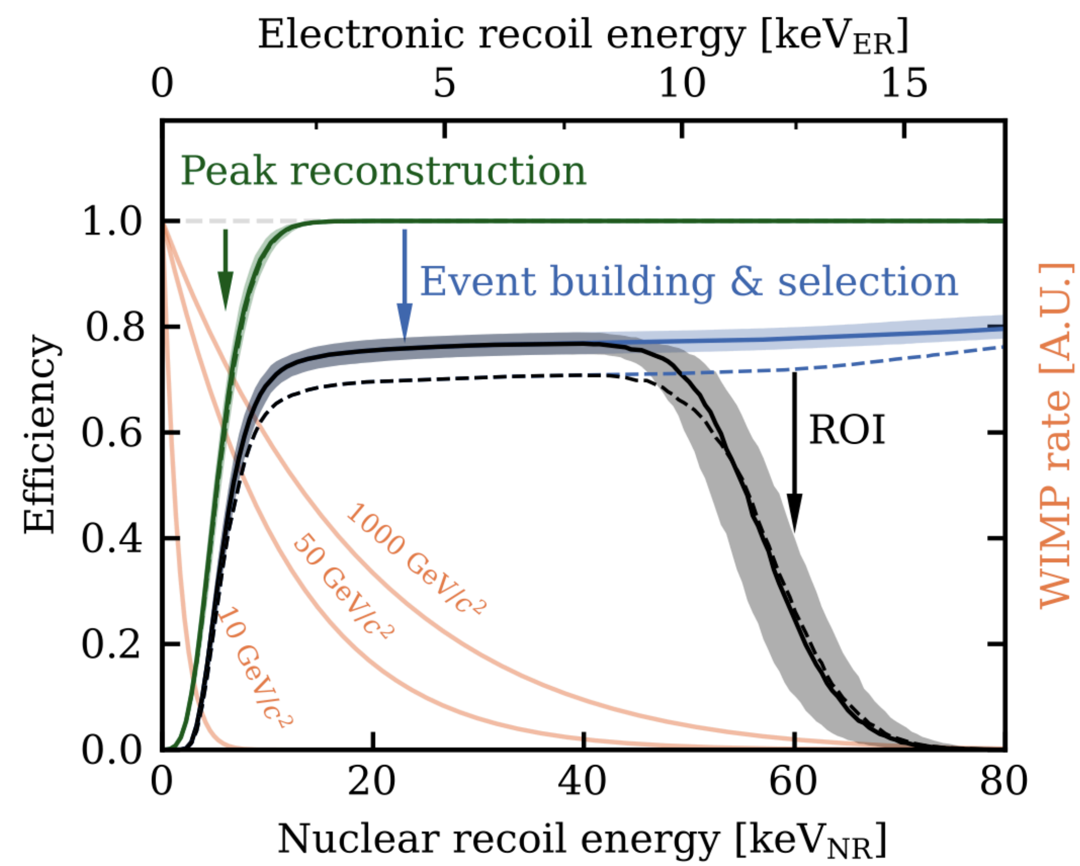
Event building: whether an event is successfully reconstructed.

Selection: S1/S2 is signal-like, S2 consistent with e- diffusion, quality cuts, etc …





[PRL 131, 041003 (2023)](#)

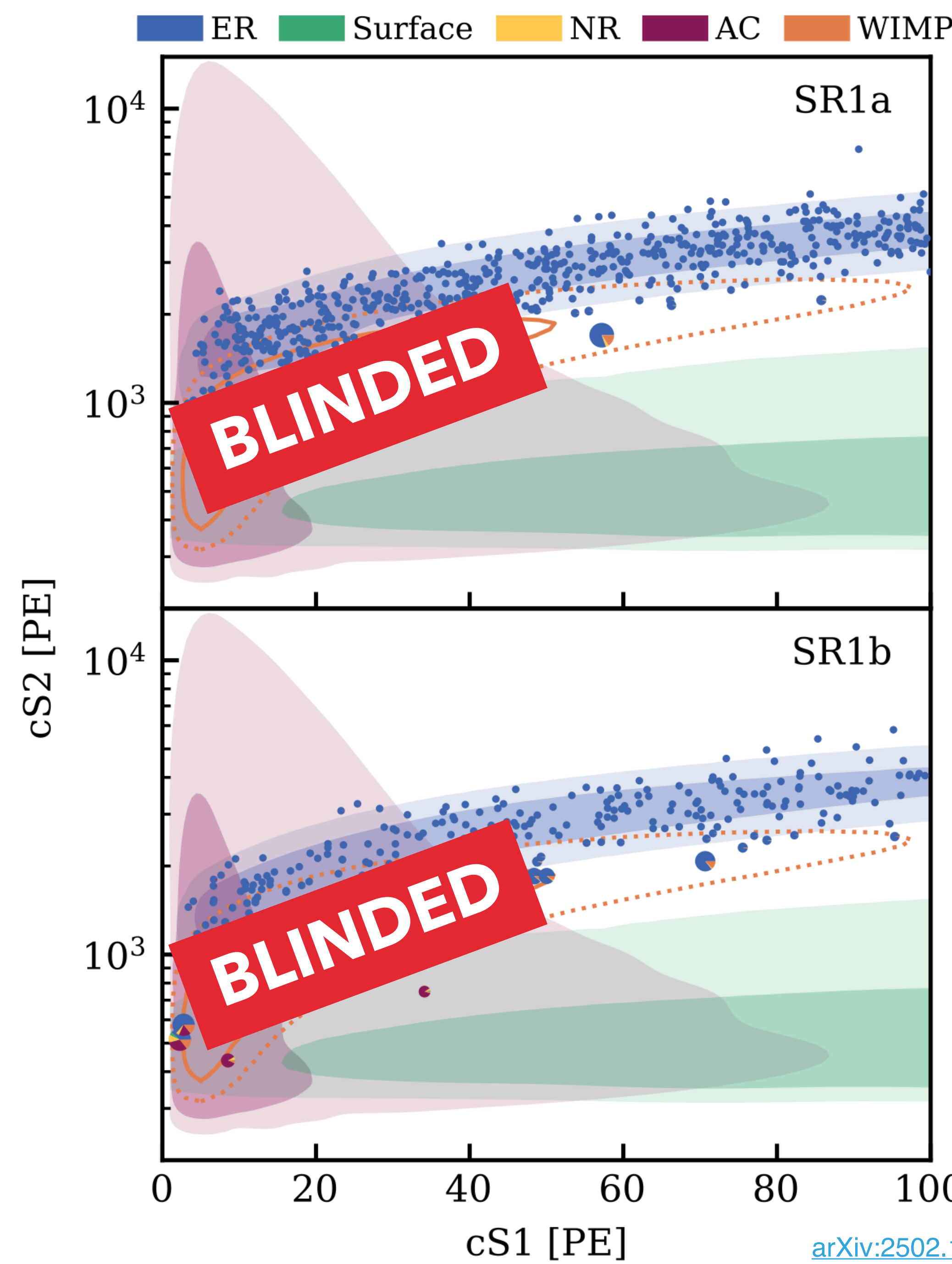


[arXiv:2502.18005](#)

WIMP search: SR0 + SR1 results

Total exposure: 3.5 tonnes year.

- **SR0 re-analysis:**
  - Already unblinded data kept untouched.
  - Updated neutron background model.
- **SR1 blind analysis:**
  - Blinded events in WIMP ROI.



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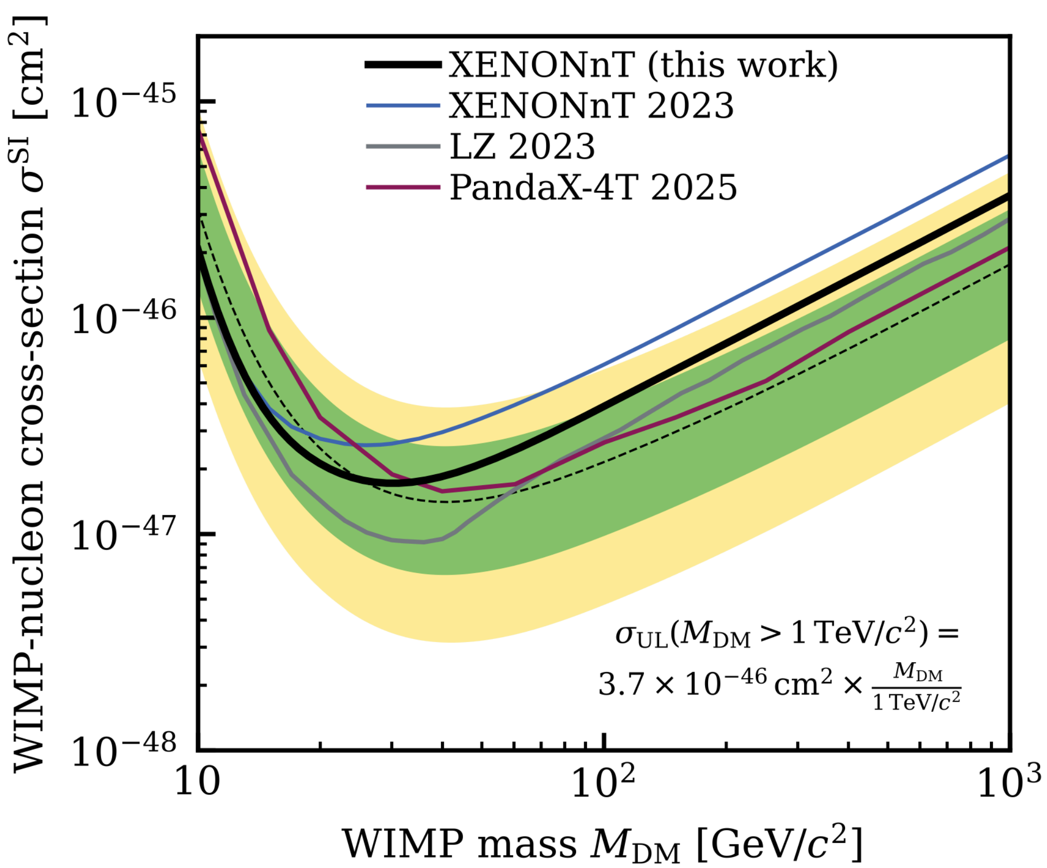
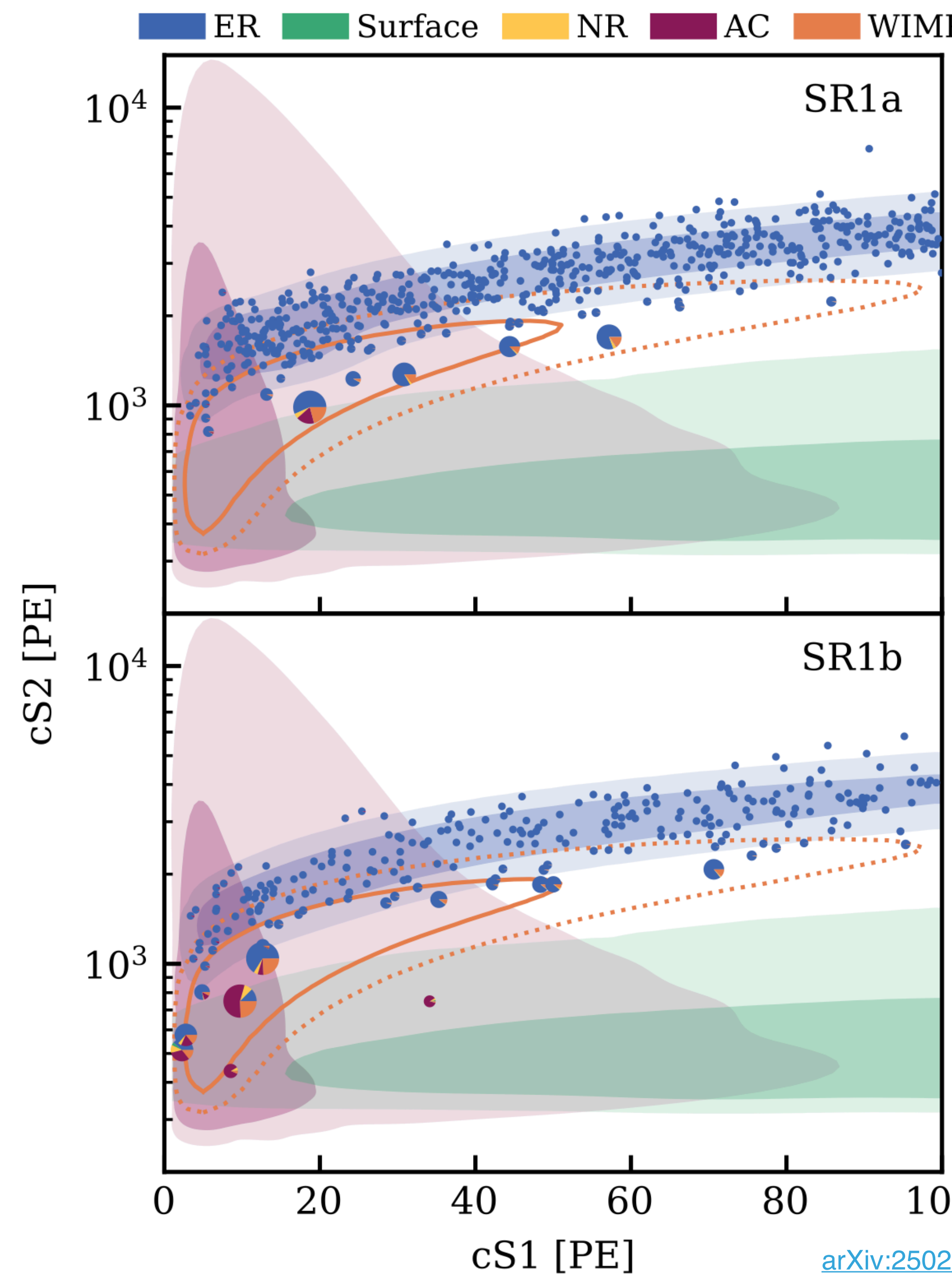
New limits on WIMP-nucleon cross section:
1.7×10^{-47}cm^2 at $m_\chi = 30$ GeV/c^2.
Factor 1.8 improvement wrt SR0.



No excess over background

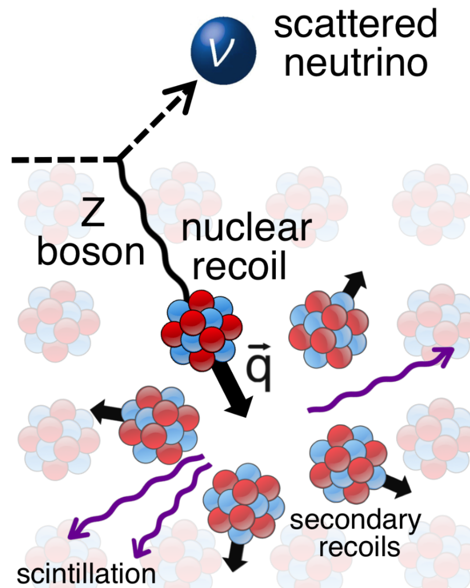


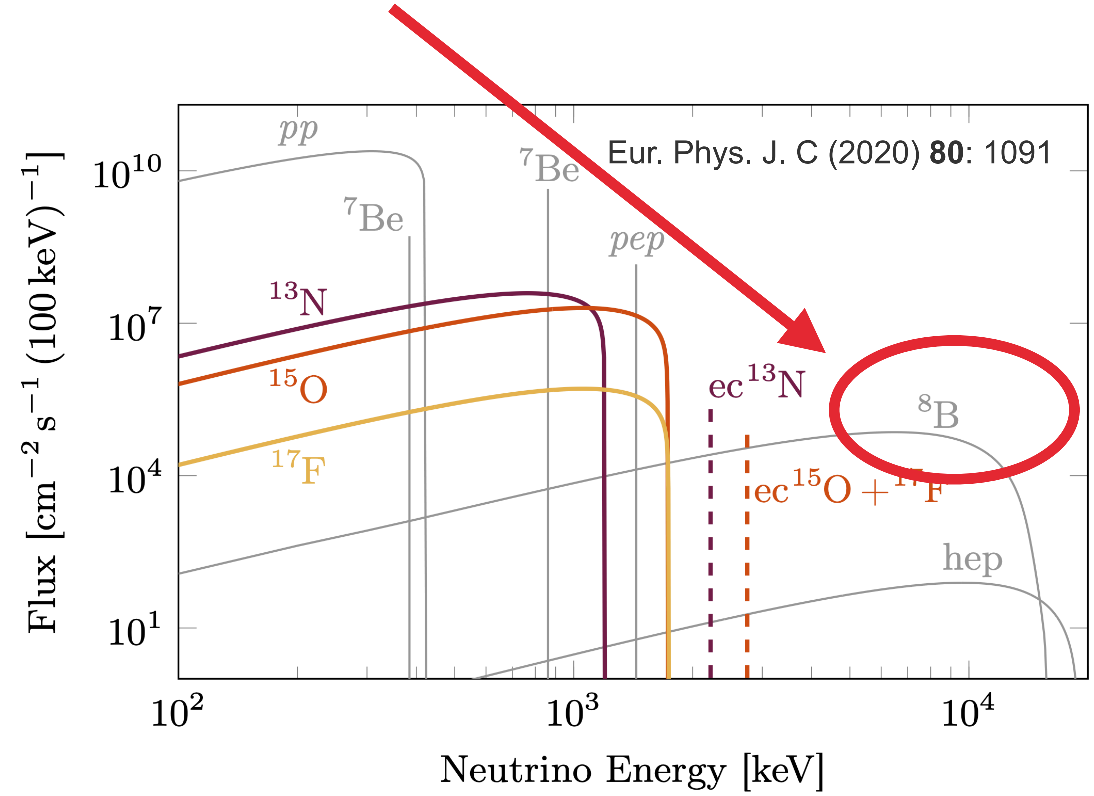
arXiv:2502.18005

^{8}B CEvNS search

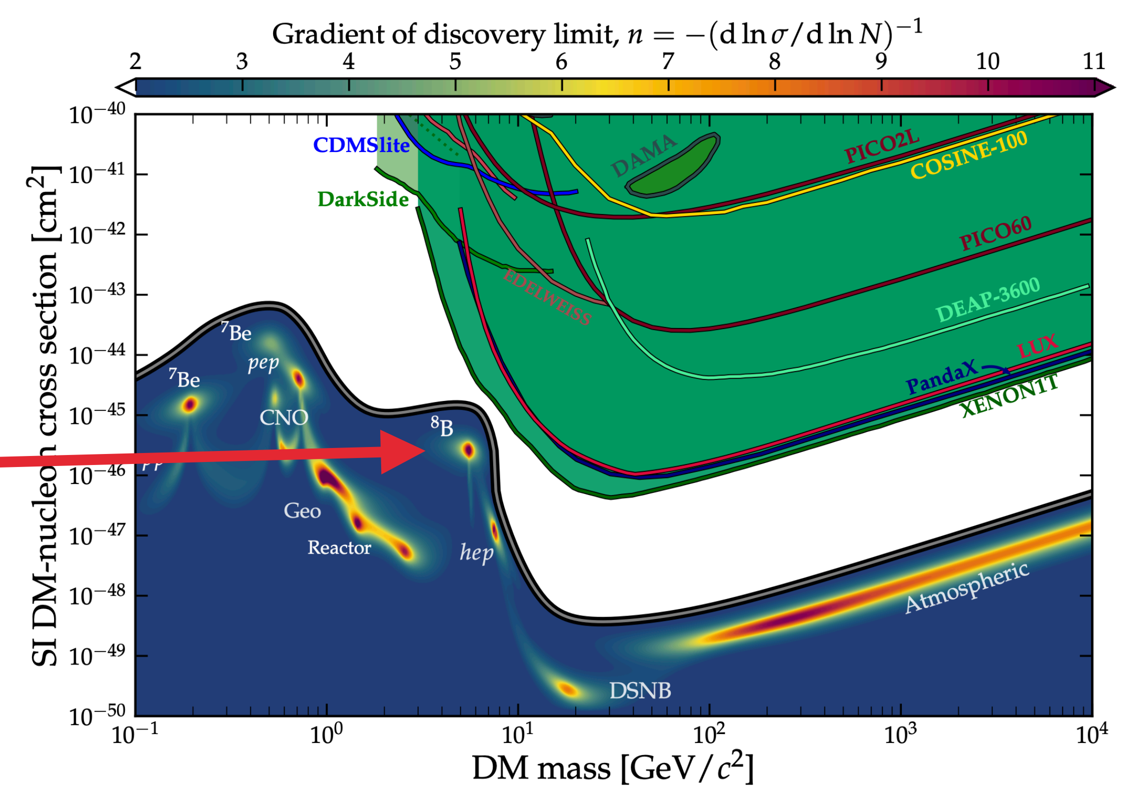
Coherent Elastic ν-Nucleus Scattering (CEvNS).

- Standard model process first predicted in 1974 and observed by COHERENT in 2017.
- Previously never observed with Xe detector or from astrophysical source.
- Solar ν from ^{8}B.





- Highest rate of detectable signals in LXe detectors:
  - Elastic ν-N scattering: $\sigma \propto N_n^2$.
  - Low-energy NR (< 3 keV).
- Indistinguishable from 6 GeV WIMP.
- Region where DM experiments are limited by irreducible background from solar or atmospheric neutrinos.



Prog. Part. Nucl. Phys. 131 (2023) 104043

^{8}B CEvNS search: threshold and background

Lowering the threshold

CEvNS are produced at **detection threshold** $\sim$ **keV$_{NR}$** , lower than the WIMP one.

- S1 with **2-fold** and **3-fold** coincidence → 17× higher ^{8}B CEvNS expected rate.
- S2 $\in (120, 500)$ PE → $(4{,}17)$ electrons.

Background

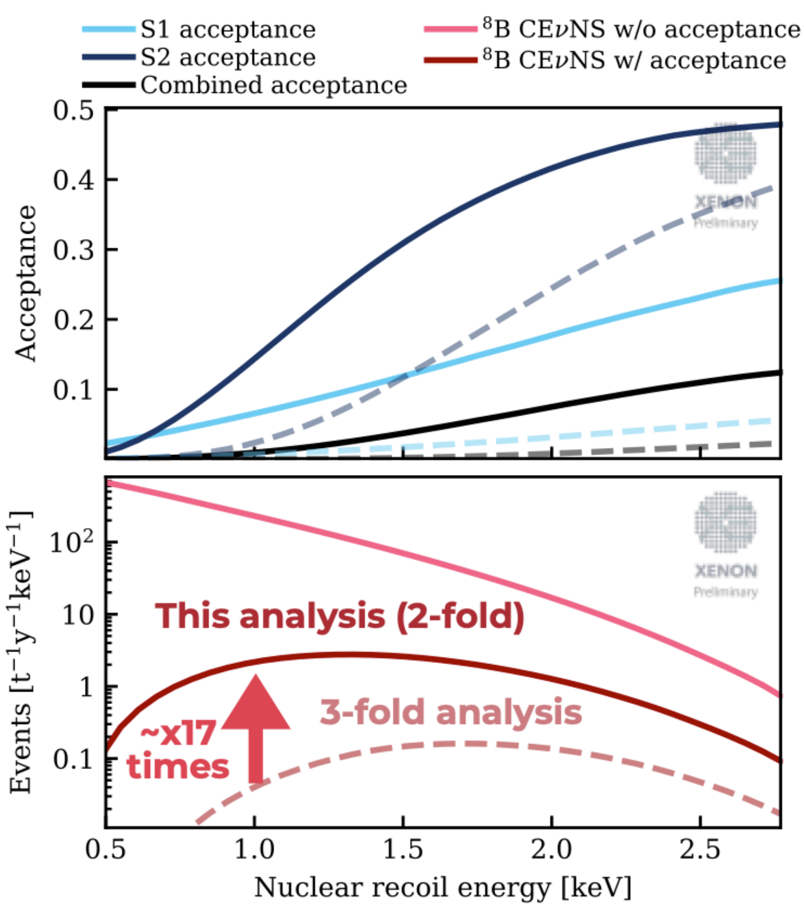
- Dominated by **ACs:** $\sim$ **400 events/day.**

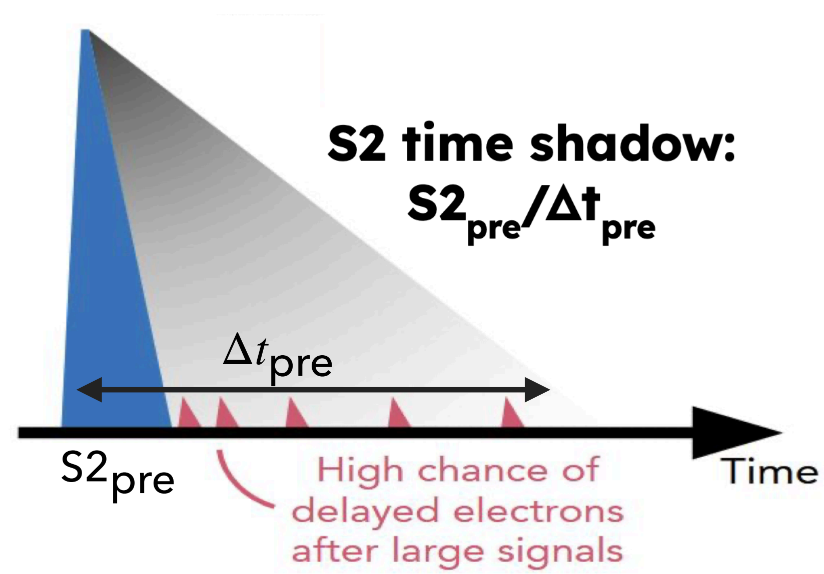
Mitigation

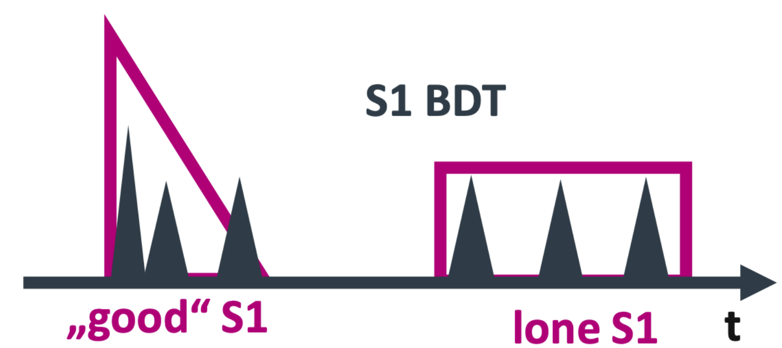
- Analysis cuts based on time and space information of peaks following a high energy peak (“shadow”).
- **Expected AC Events after Mitigation: SR0: 7.5 ± 0.7 | SR1: 17.8 ± 1.0.**

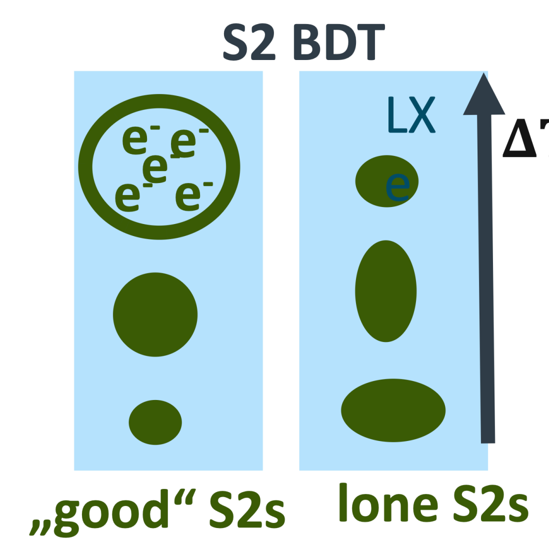
Add extra analysis dimensions

- cS2.
- S2$_{pre}$/Δt_{pre}.
- Boosted data tree (BDT) score :
  - S1 BDT score from S1 hit distribution.
  - S2 BDT score from S2 signal shape and time correlation with S1.







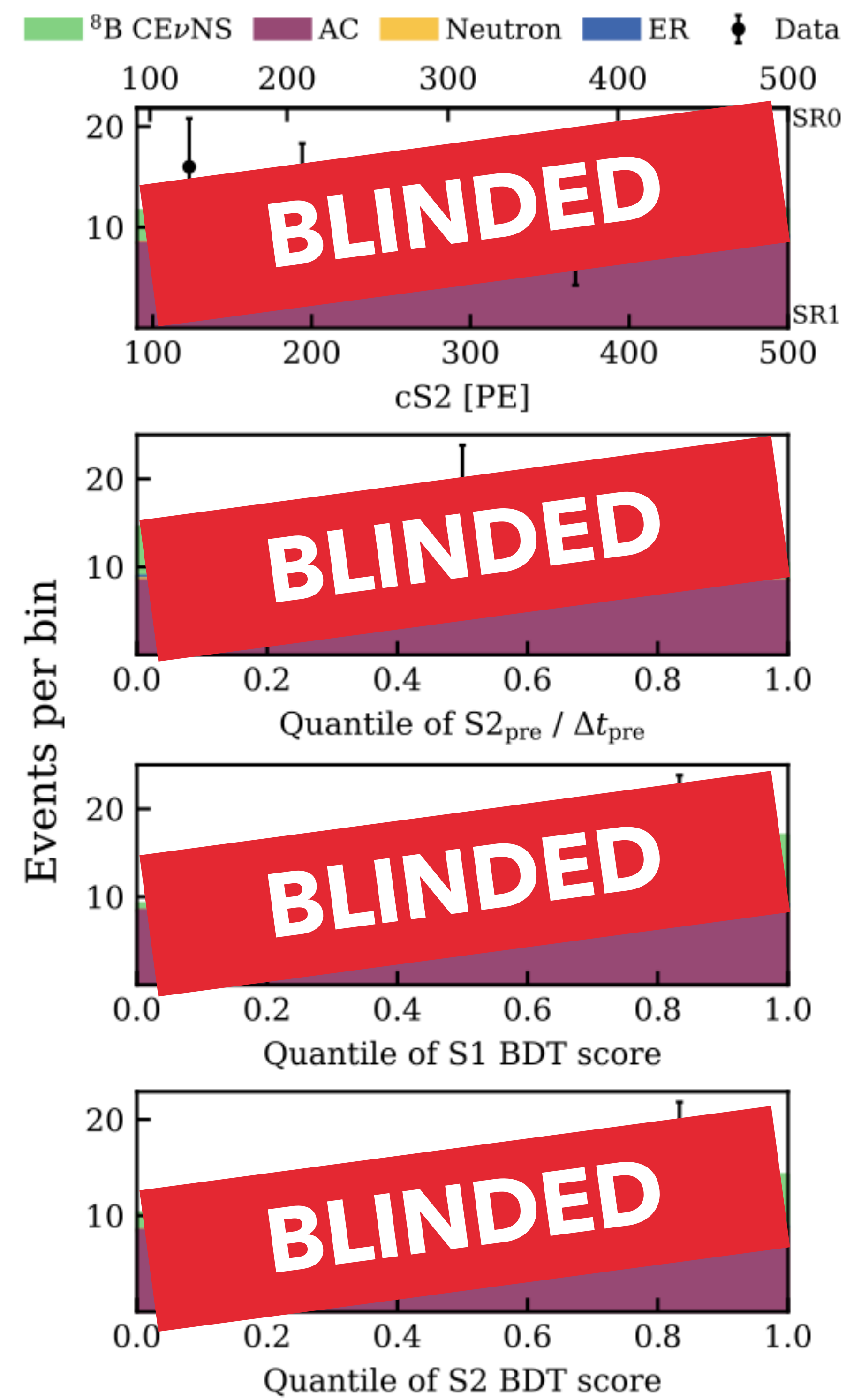


^{8}B CEvNS search: results

- **Total SR0+1 exposure: 3.51 tonne year.**
- Inference with a 4-D binned likelihood in 3^4 bins.

OBSERVED EVENTS: ??

	Expected	Best fit
Background	26.4 ± 1.4	?
Signal	11.9 ± 4.5	?



^{8}B CEvNS search: results

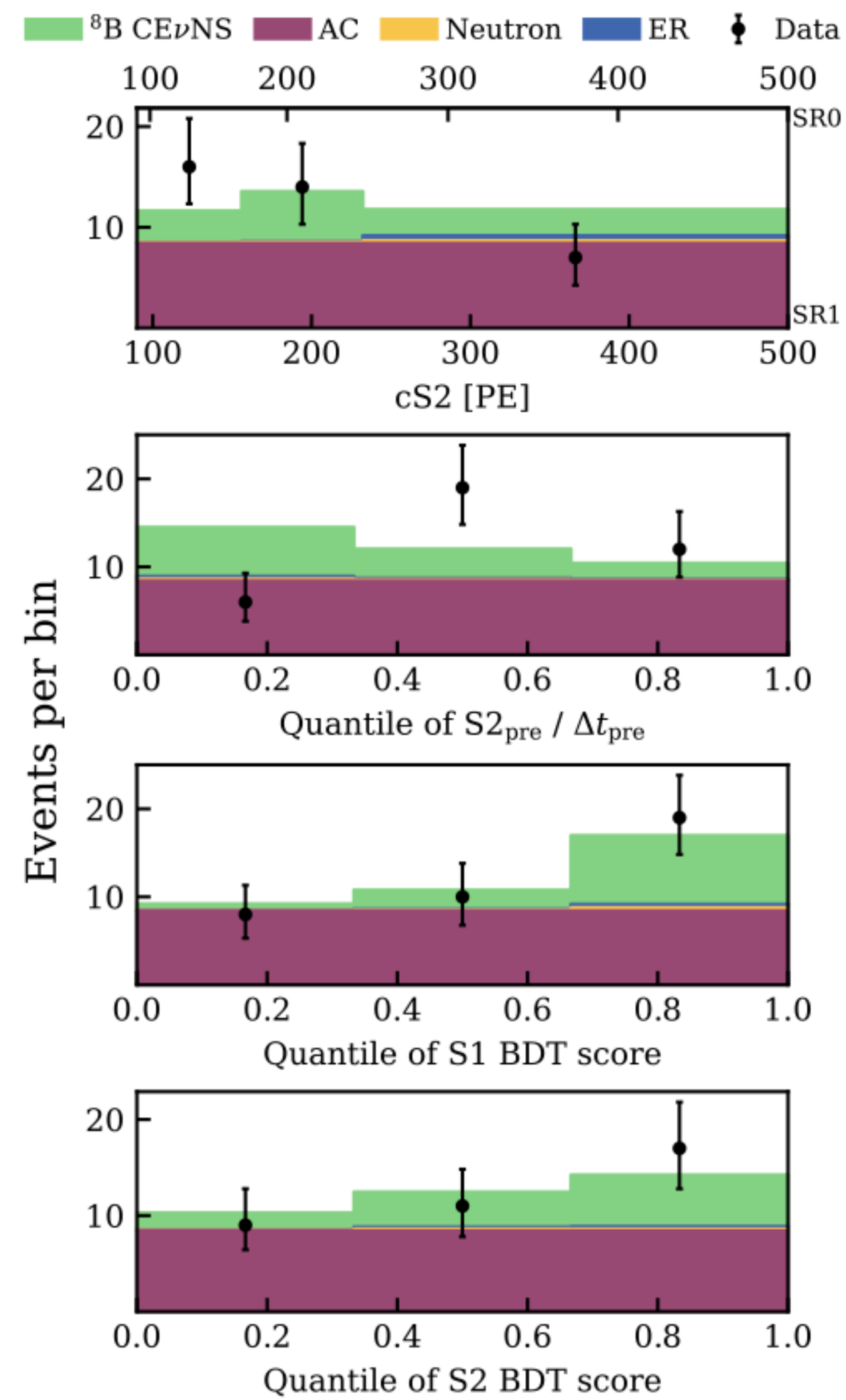
- **Total SR0+1 exposure: 3.51 tonne year.**
- Inference with a 4-D binned likelihood in 3^4 bins.

OBSERVED EVENTS: 37

	Expected	Best fit
Background	26.4 ± 1.4	26.3 ± 1.4
Signal	11.9 ± 4.5	$10.7^{+3.7}_{-4.2}$

SIGNIFICANCE OF 2.73σ

- **First measurement of CEvNS from astrophysical neutrinos and in xenon target**, obtained at same time with PandaX-4T ($\sim$ 1 t × y, 2.64σ).



^{8}B CEvNS search: results

Smallest solar ν detector

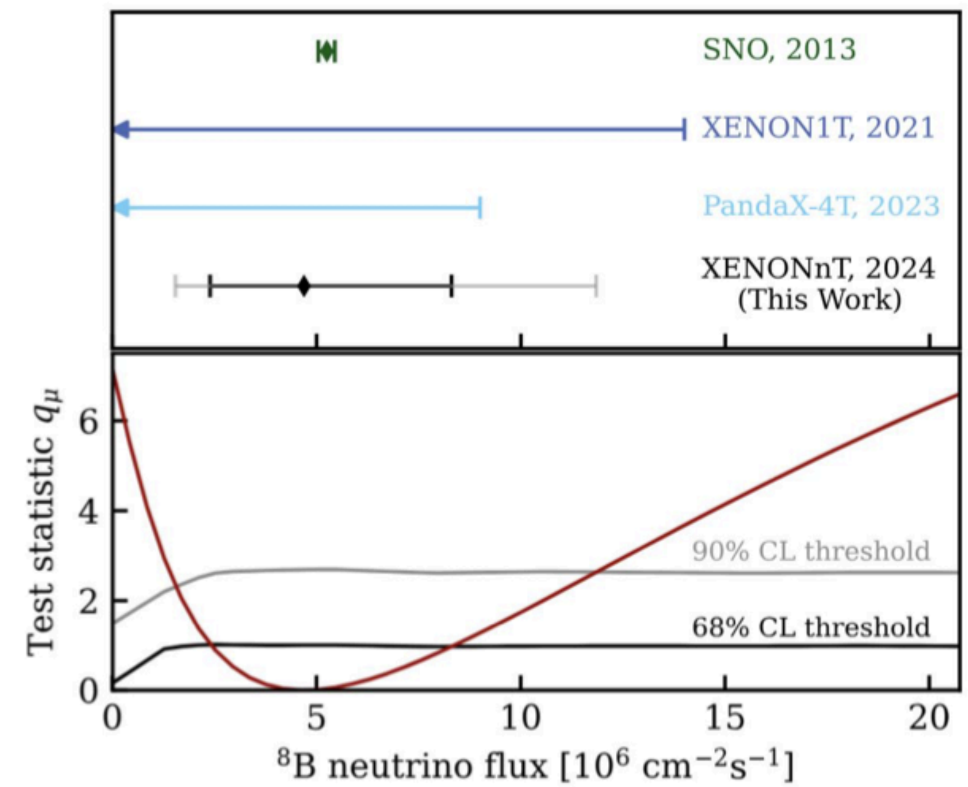
- With few tons of Xe target, dual-phase TPCs are orders of magnitude smaller than water Cherenkov or liquid scintillator detectors.

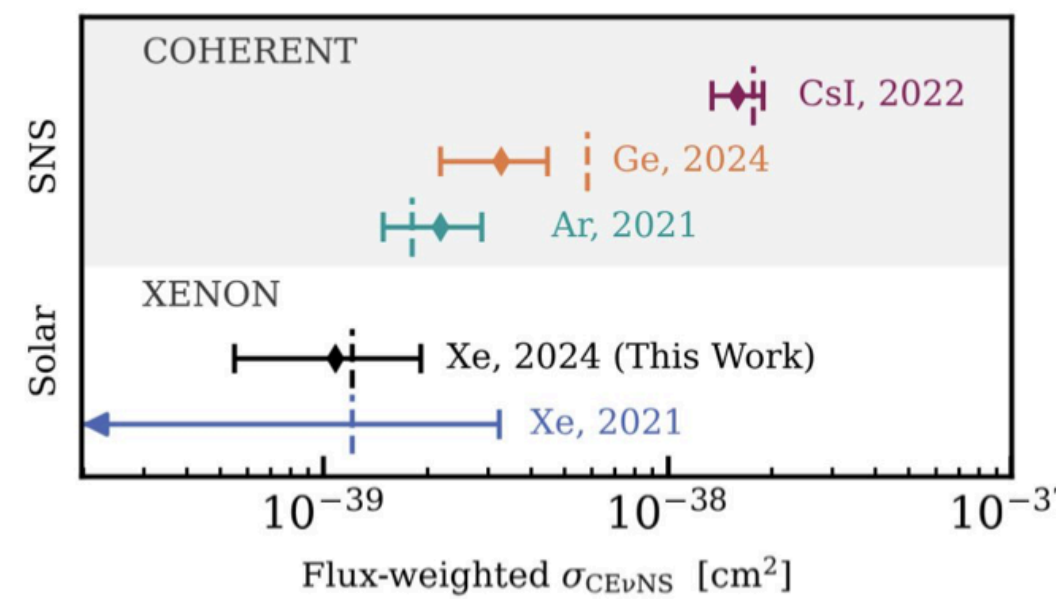
Measurement of solar ^{8}B flux

- Fixed cross-section, fit for the flux.
- Result: $\Phi = 4.7^{+3.6}_{-2.3} \times 10^6$ cm^{-2} s^{-1}.
- Compatible with SNO measurement.

Measurement of CEvNS cross-section in Xe

- Fixed neutrino flux, fit for cross section.
- Result: $\sigma = 1.1^{+0.8}_{-0.5} \times 10^{-39} cm^2$.
- Compatible with Standard Model prediction.
- Consistent with PandaX-4T results[1].



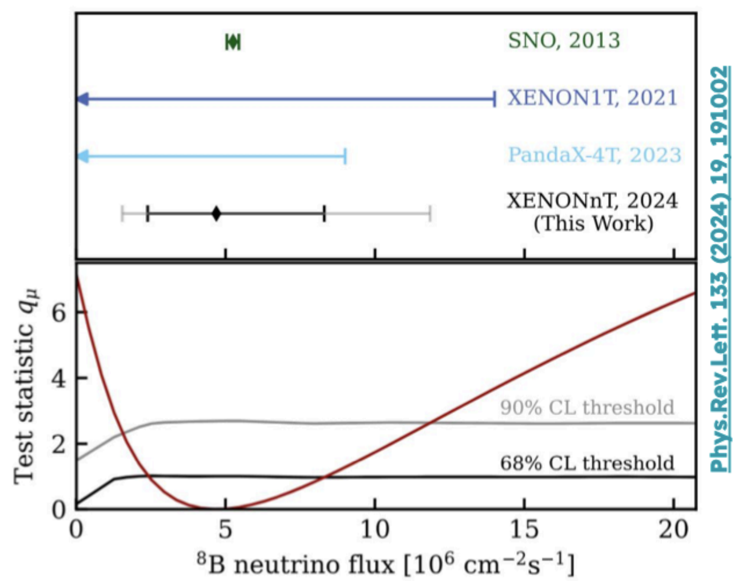


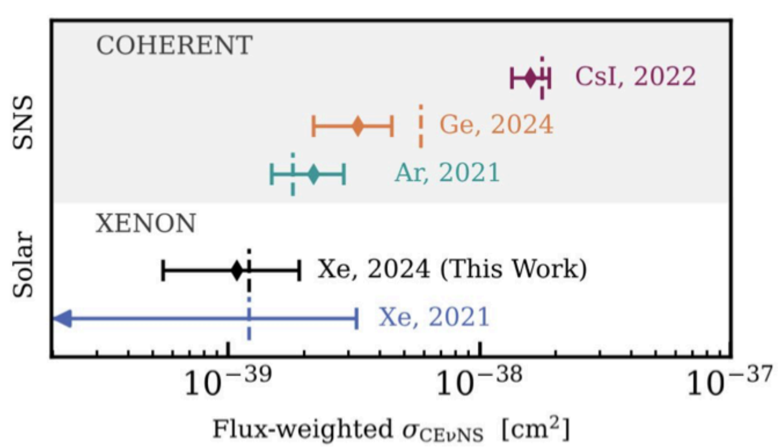
[1]Phys. Rev. Lett. 133, 191002 (2024)

Summary and outlook

CEvNS

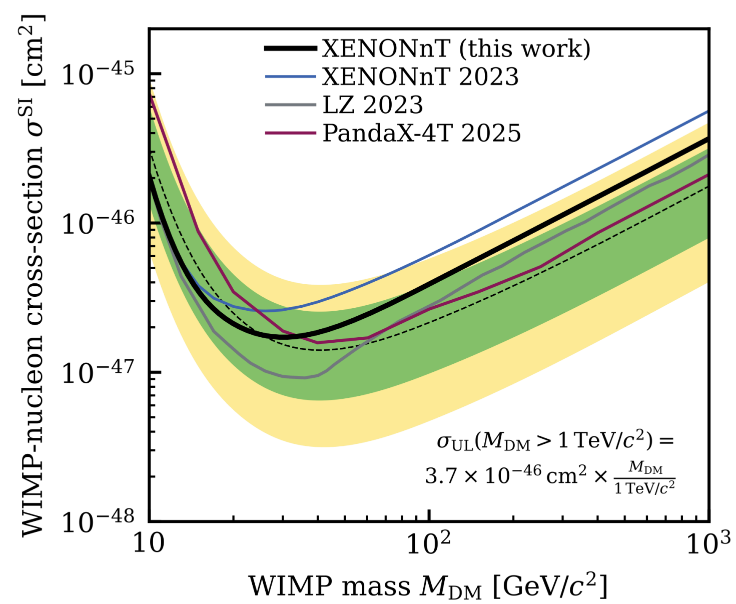
- **Observed ^{8}B CEvNS at $2.73\,\sigma$:** 1st observation in a xenon experiment and with astrophysical neutrinos.





WIMP

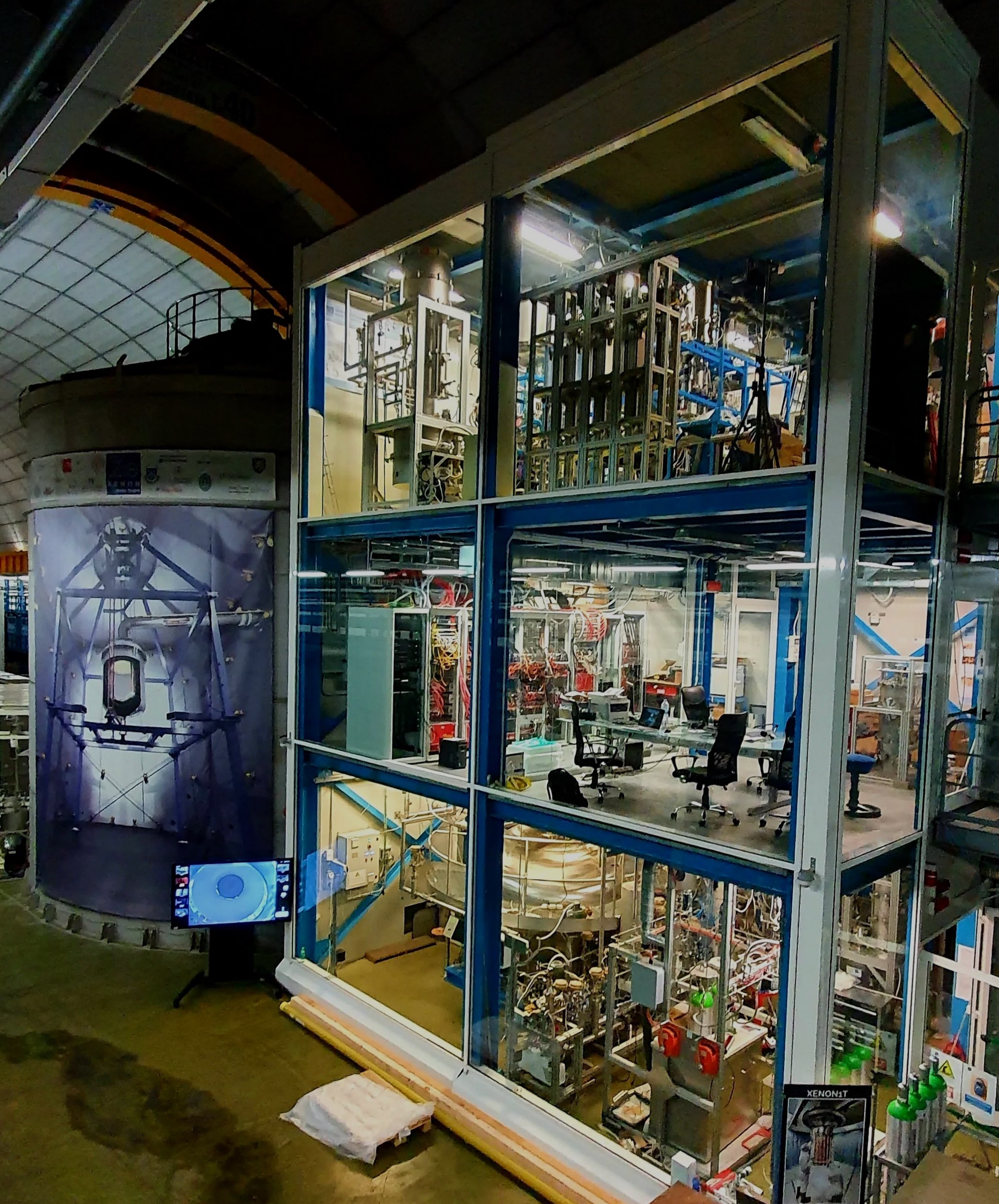
- **New limits on WIMP-nucleon cross section: 1.7×10^{-47} cm^2** at $\mathbf{m}_\chi = 30$ GeV/c^2.
- Factor 1.8 improvement wrt SR0.



Outlook

- **Just finished SR2 data taking**, with high neutron tagging efficiency (77%) thanks to Gd insertion.
- **Ongoing searches:** Solar 8B CEvNS with higher statistics, solar-pp neutrinos via e- scattering, Supernova neutrinos, new WIMPs limits, $0\nu\beta\beta$ and much more…
- **XLZD** Xenon-Lux Zeplin-Darwin collaboration established to build the next gen-LXe TPC with up to 60t target mass.

THANK YOU FOR YOUR ATTENTION!



BACKUP

SR2: Gd-water in neutron veto

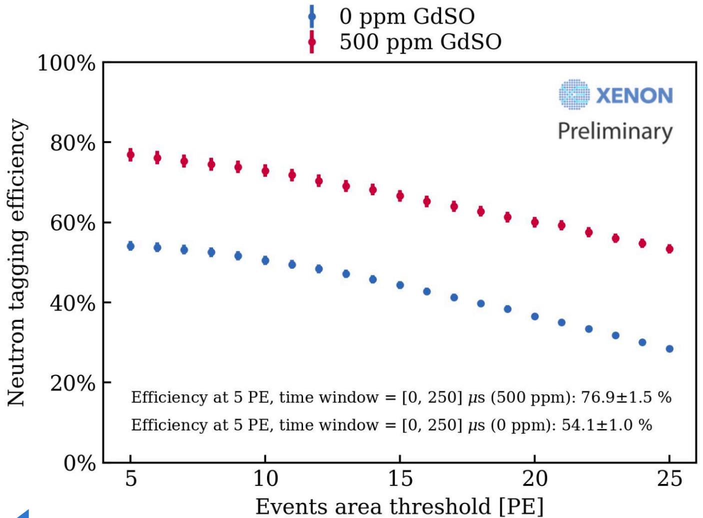
SR0+SR1: Pure water

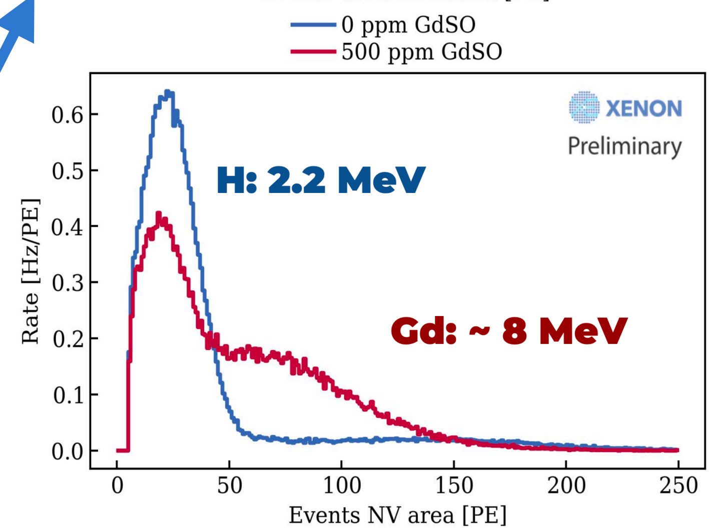
- NV tagging efficiency: **53 ± 1 %.**
- H capture: **2.2 MeV, 1 γ.**
- Capture time H-only: **160 μs.**

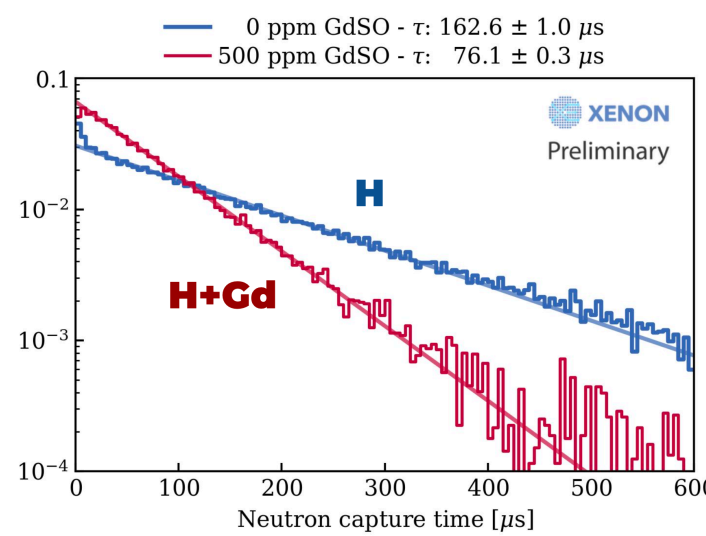
Gd-sulphate loading: 350 kg in 700 tons of water (500 ppm), Gd mass concentration at 0.02%.

SR2: Gd-loaded water (0.02%.)

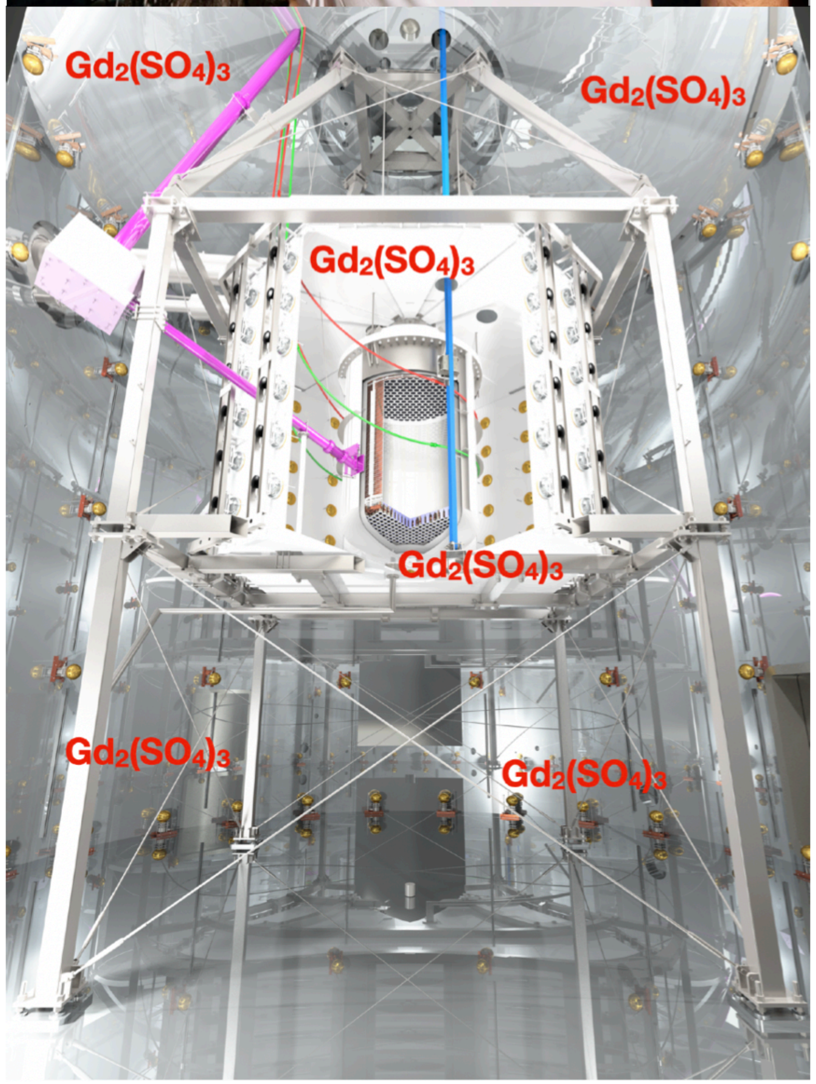
- NV tagging efficiency: **77 ± 1 %.**
- Gd capture: **8 MeV, 3-4 γ.**
- Capture time H+Gd: 75 μs.
- **A factor 2 neutron background reduction wrt SR0 with demi-water.**
- Planned 10x higher Gd mass: expected tagging efficiency of 87%.





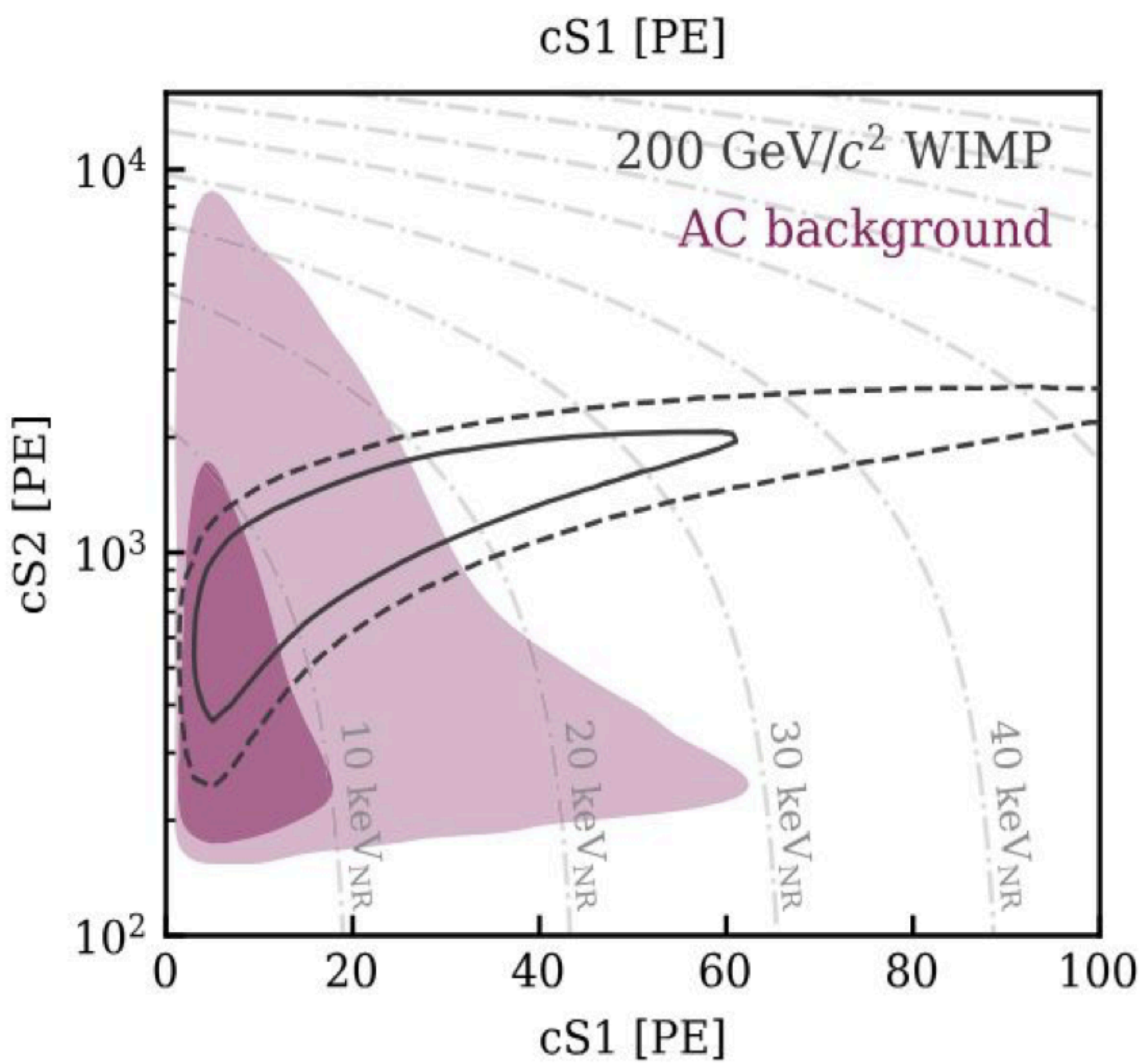


TPC-NV coincidence window 250 μs



Accidental Coincidences (ACs)

- ACs are accidental pairings of Isolated S1 and isolated S2 signals. Major background near threshold.



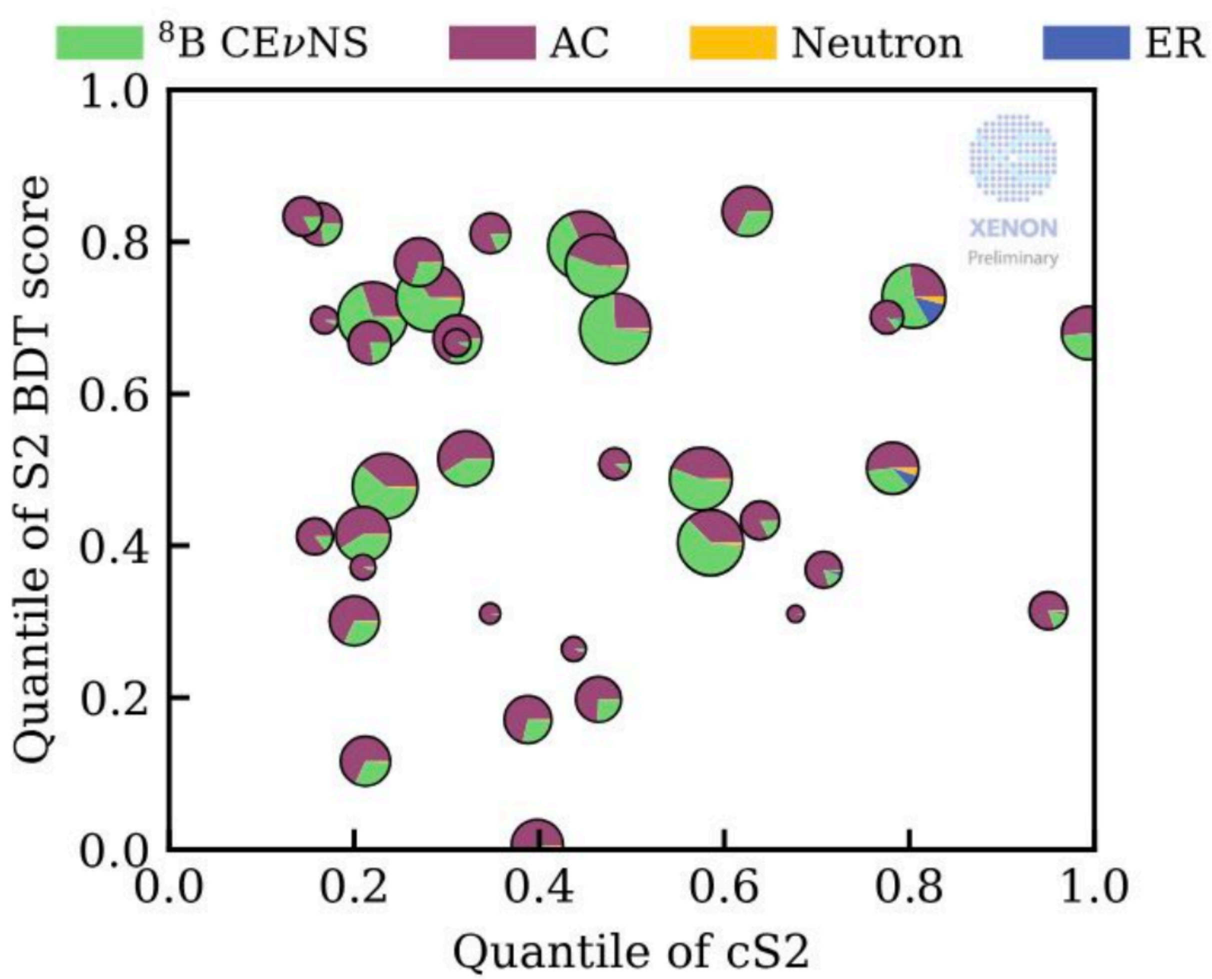
WIMP best fit

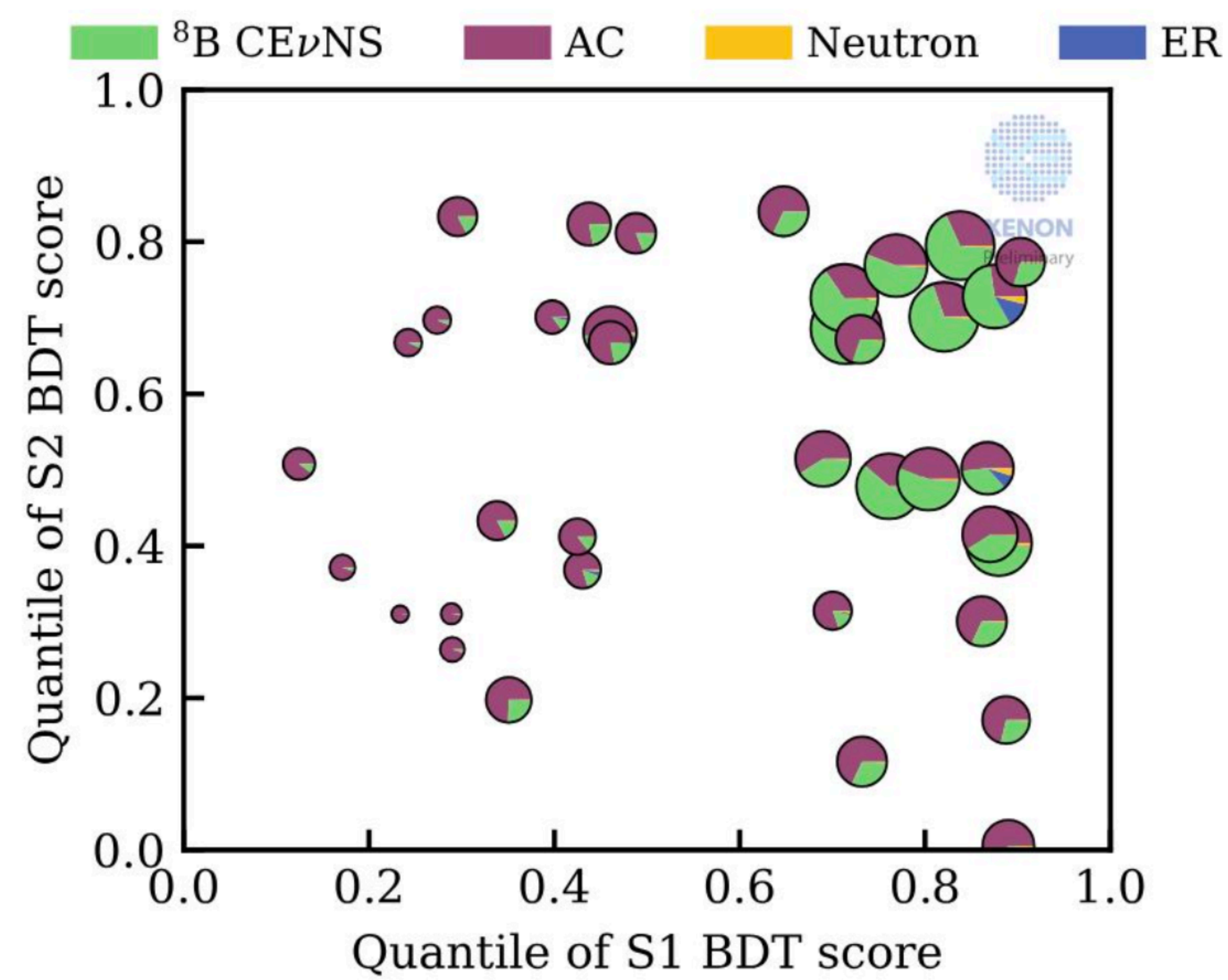
- Expectation values of the nominal (pre-fit) and best-fit models for SR0 (1.09 tonne× year), SR1a (0.73 tonne× year), and SR1b (1.31 tonne × year), including an unconstrained WIMP signal with a mass of 200 GeV/c^2.
- Equal background colors indicate which components share a scaling parameter, coupling their rates across different science runs.

	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 (^{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	

^{8}B CEvNS results

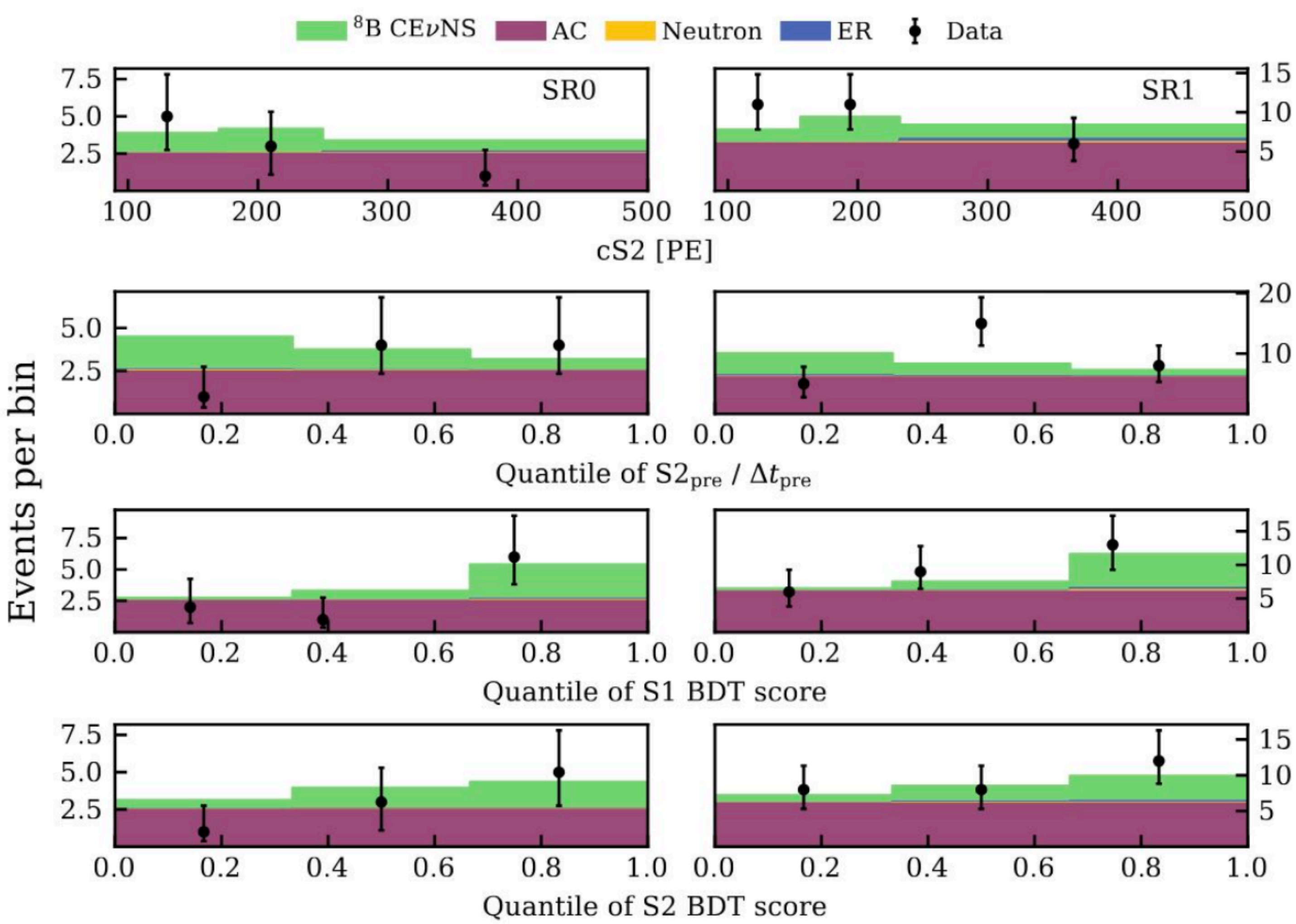
- Distribution of events in the analysis dimensions of CEvNS search. All data points are represented as pie charts indicating the fraction of the likelihood from the best-fit model evaluated at the data point. The scatter size is scaled according to the CEvNS likelihood fraction for visualization only.





^{8}B CEvNS results

- Distributions of best-fit signal and background, together with the data in the projected analysis dimensions summing both science runs.



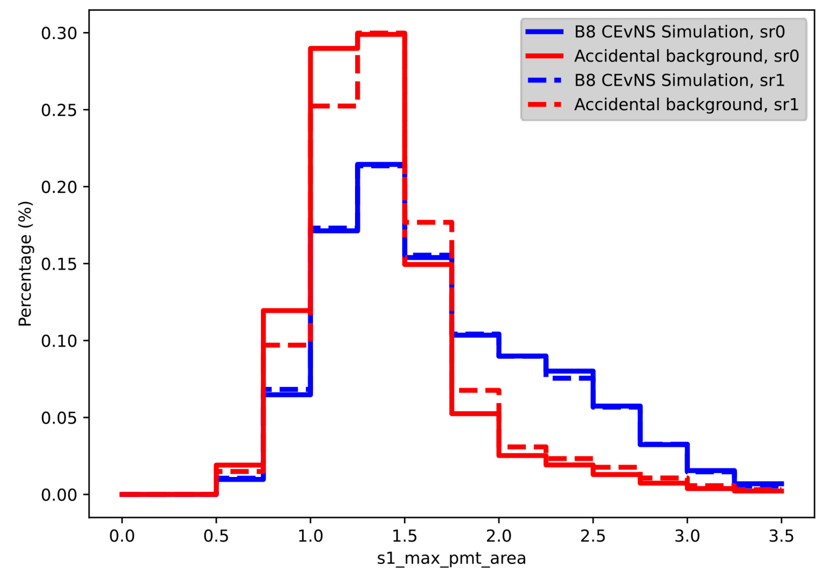
Component	Expectation	Best-fit
AC (SR0)	7.5 ± 0.7	7.4 ± 0.7
AC (SR1)	17.8 ± 1.0	17.9 ± 1.0
ER	0.7 ± 0.7	$0.5^{+0.7}_{-0.6}$
Neutron	$0.5^{+0.2}_{-0.3}$	0.5 ± 0.3
Total background	$26.4^{+1.4}_{-1.3}$	26.3 ± 1.4
^{8}B	$11.9^{+4.5}_{-4.2}$	$10.7^{+3.7}_{-4.2}$
Observed	37	

S1 BDT Features

In order of importance:

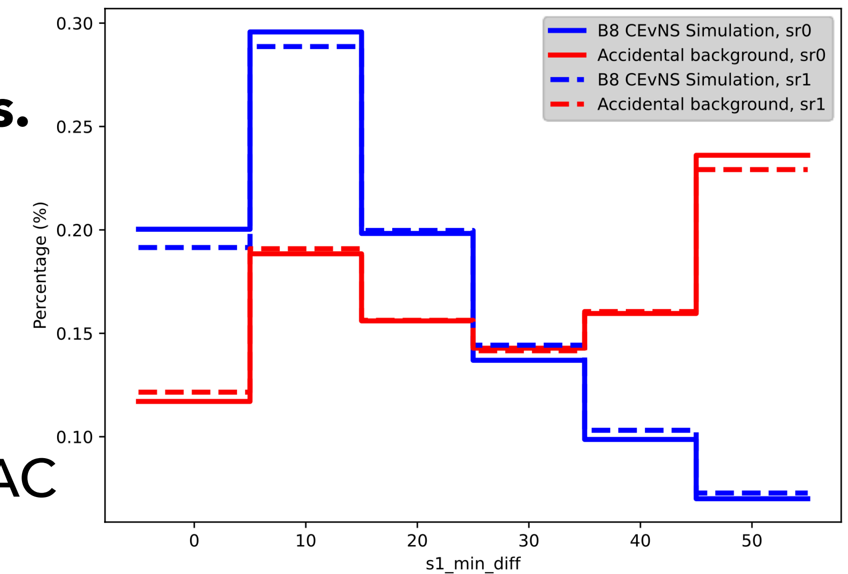
1) Max S1 hit area.

ACs are mostly lone hits: S1 > 2PE on one PMT is unlikely to be AC.



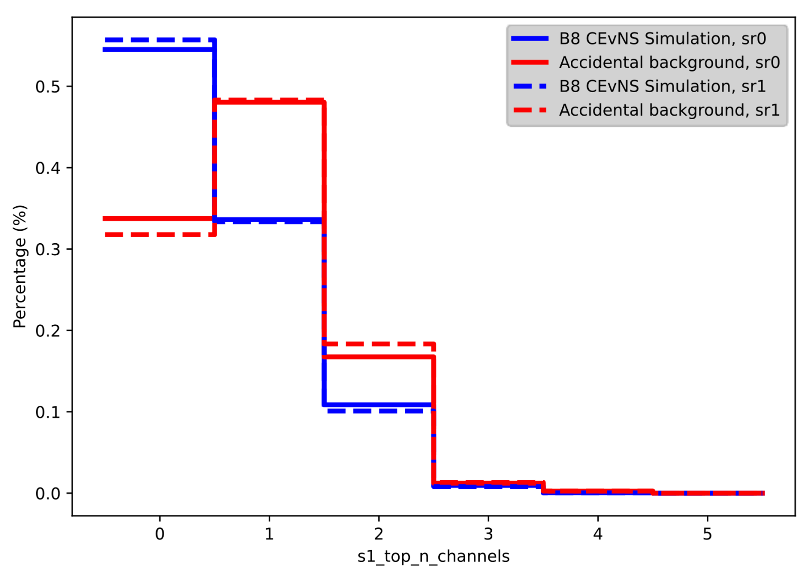
2) Min time between S1 hits.

Signal S1 pulse timing impacted by physical processes and DAQ response, AC is random

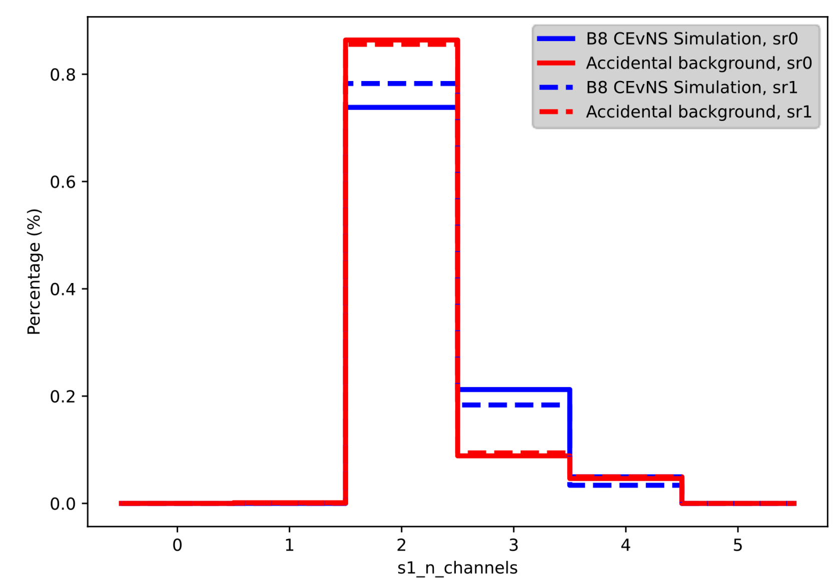


3) No. of hits in top PMT array.

Due to LXe-GXe interface, most signal S1s are collected at bottom array. ACs are random.



4) Total no. of hits. Reproduces the full recoil spectrum.



S2 BDT Features

In order of importance:

1) S2 width at 50%

Width (ns) at 50% area (PE) around the maximum.

2) Rise time

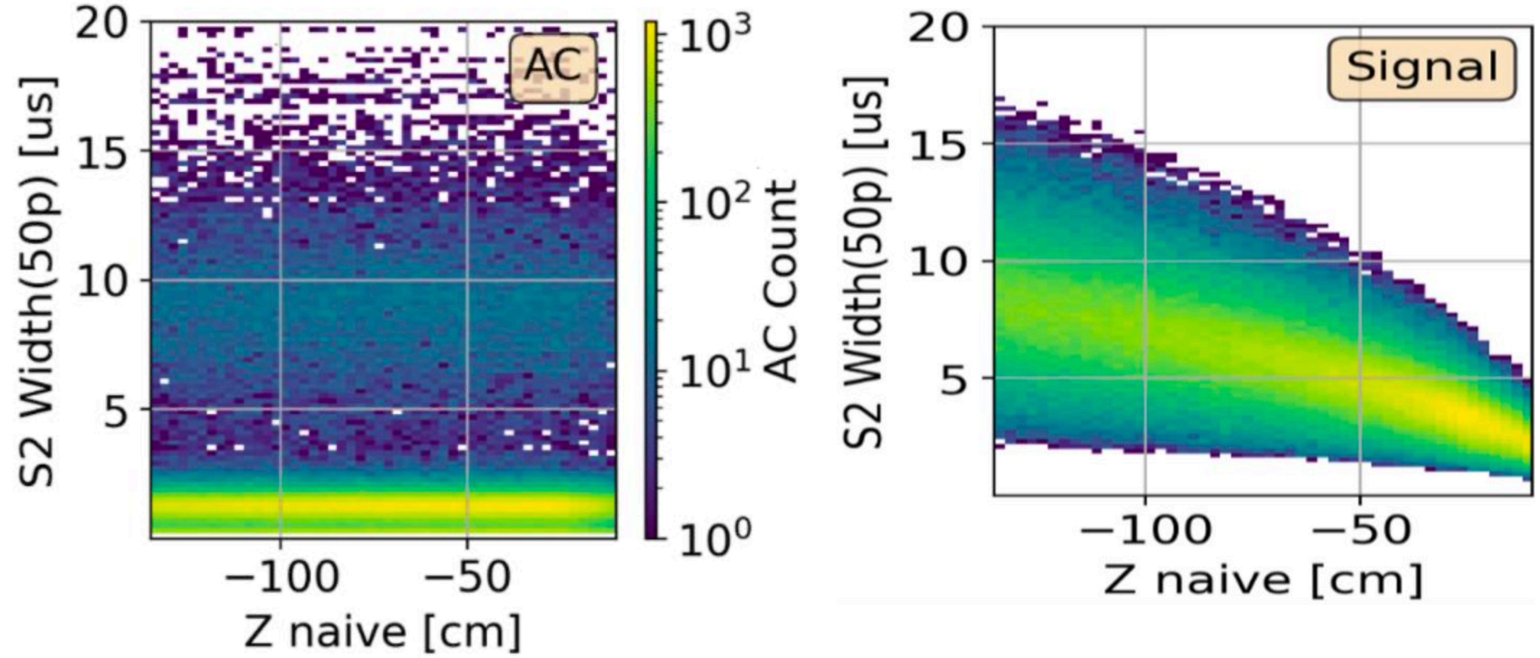
Time between 10% and 50% area quantiles [ns].

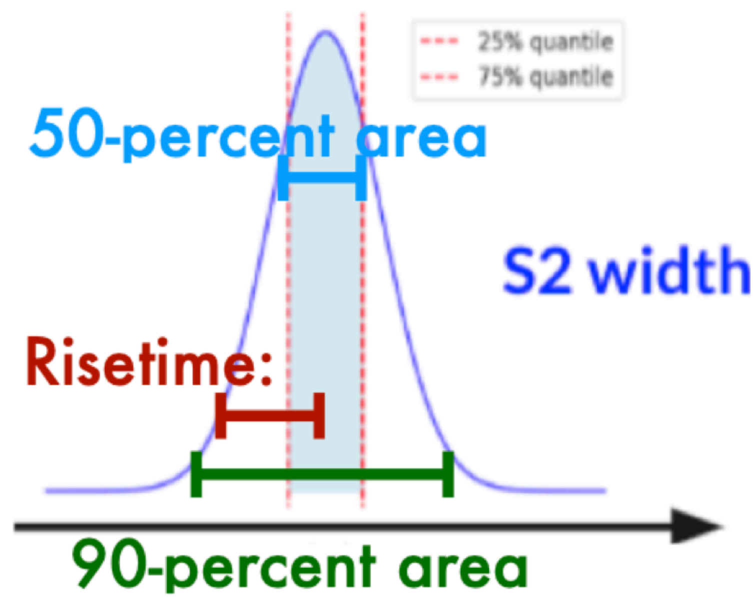
3) S2 width at 90%

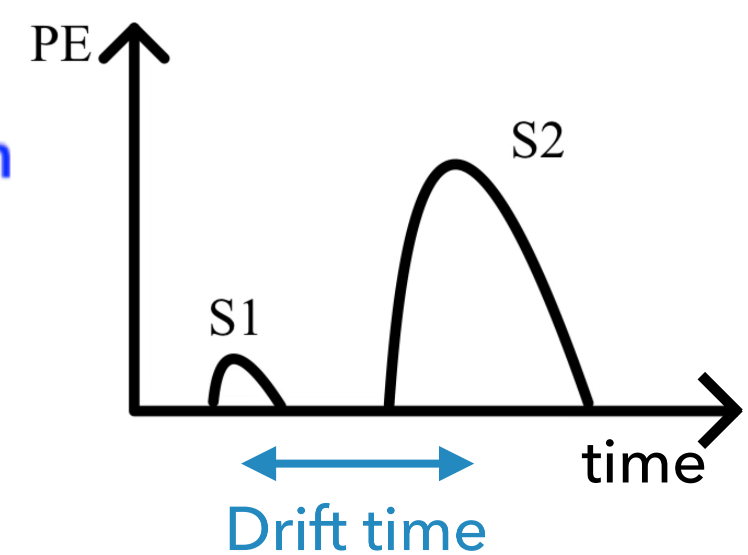
Width (ns) at 90% area (PE) around the maximum.

4) Drift time

Time between S1 and S2 peak.





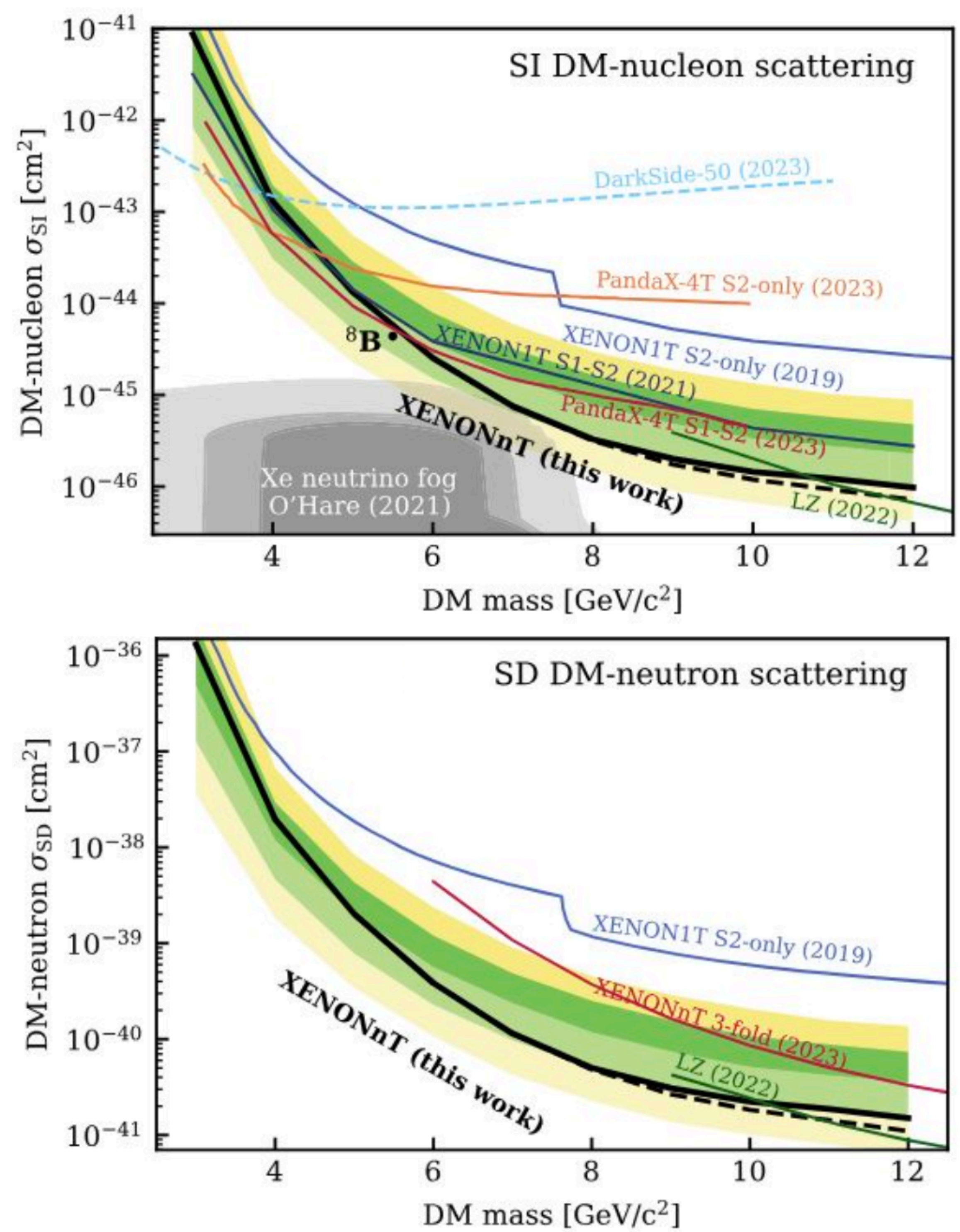


Light dark matter search

- First dark matter search in neutrino fog.
- Same dataset and analysis framework used for CEvNS search (3.5 t × y).
- Now 8B CEvNS considered as a irreducible background component!

- **No excess over background observed-**

- New parameter space excluded for low-mass.
- WIMPs-nucleon cross section: $\sigma_{SI} > 2.5 \times 10^{-45}$ cm^2 @ 6 GeV/c^2.



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Low energy ER search in SR0

- Background model including 9 components.
- Full blind analysis.
- ^{124}Xe 2νDEC (half-life $\sim 1.8 \times 10^{22}$ yr, rarest process observed, first time in XENON1T) now used for energy reconstruction.
- ^{214}Pb (from ^{222}Rn chain) dominant component below 30 keV with concentration of about 1.3 μBq/kg (1 atom in 10 mol Xe).
- Background ~5x smaller than in XENON1T.
- Lowest ER background ever for a DM experiment: (15.8 ± 1.3) events/(t · y · keV).
- An excess of the XENON1T magnitude is excluded at 8.6σ.
- XENON1T excess was probably due to 3H tritium.

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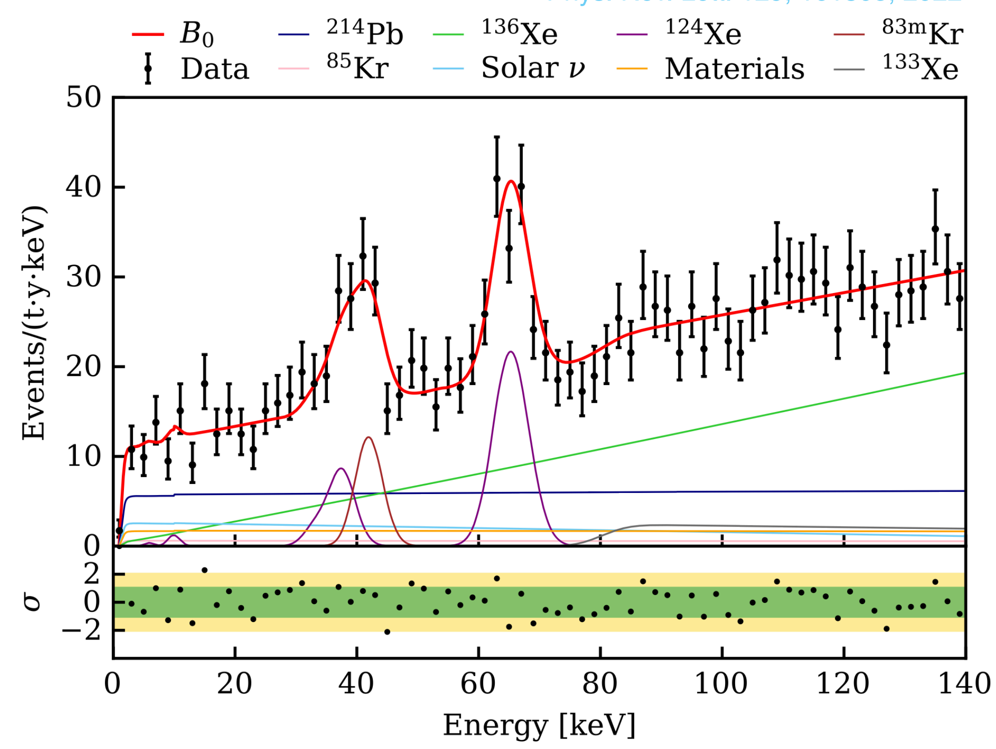
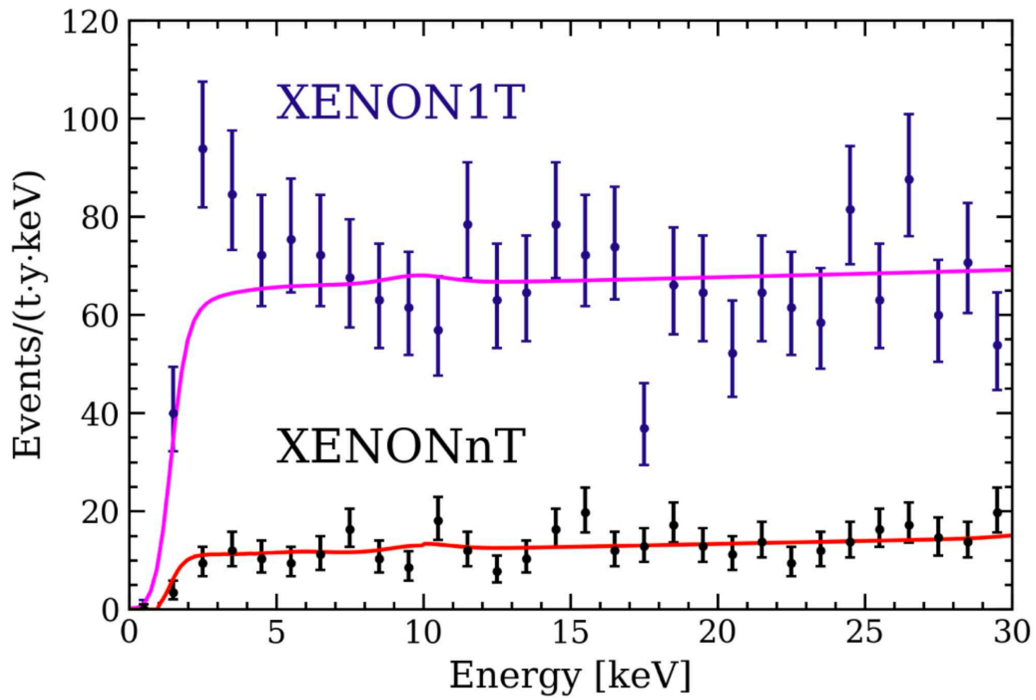
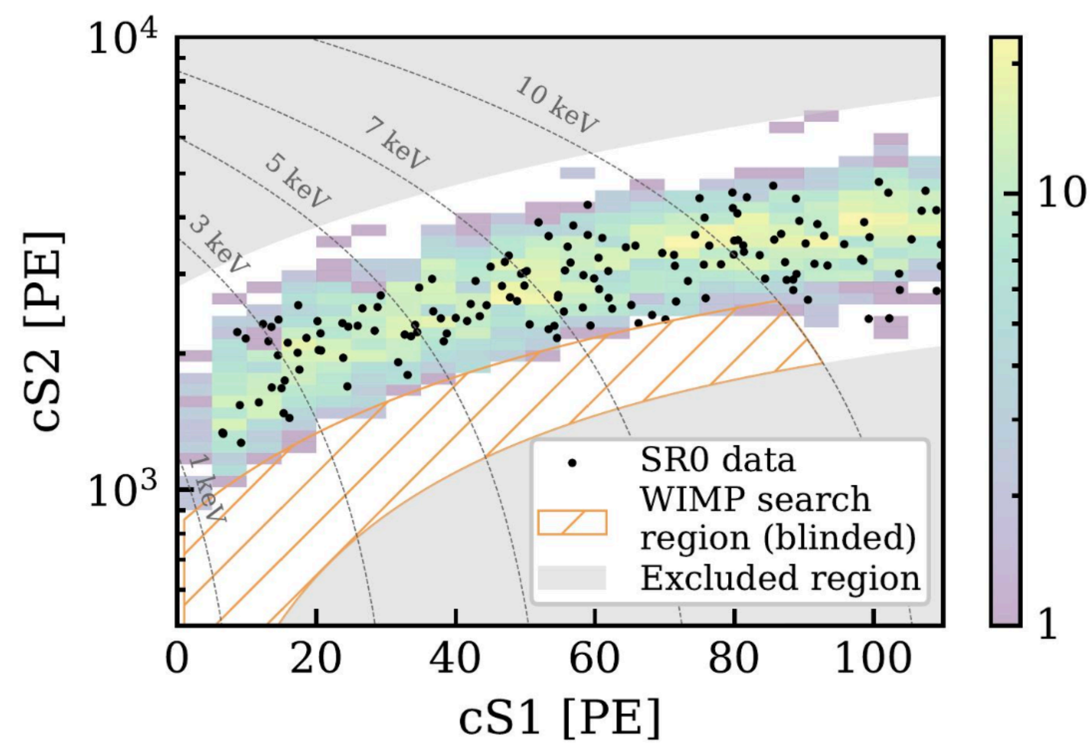
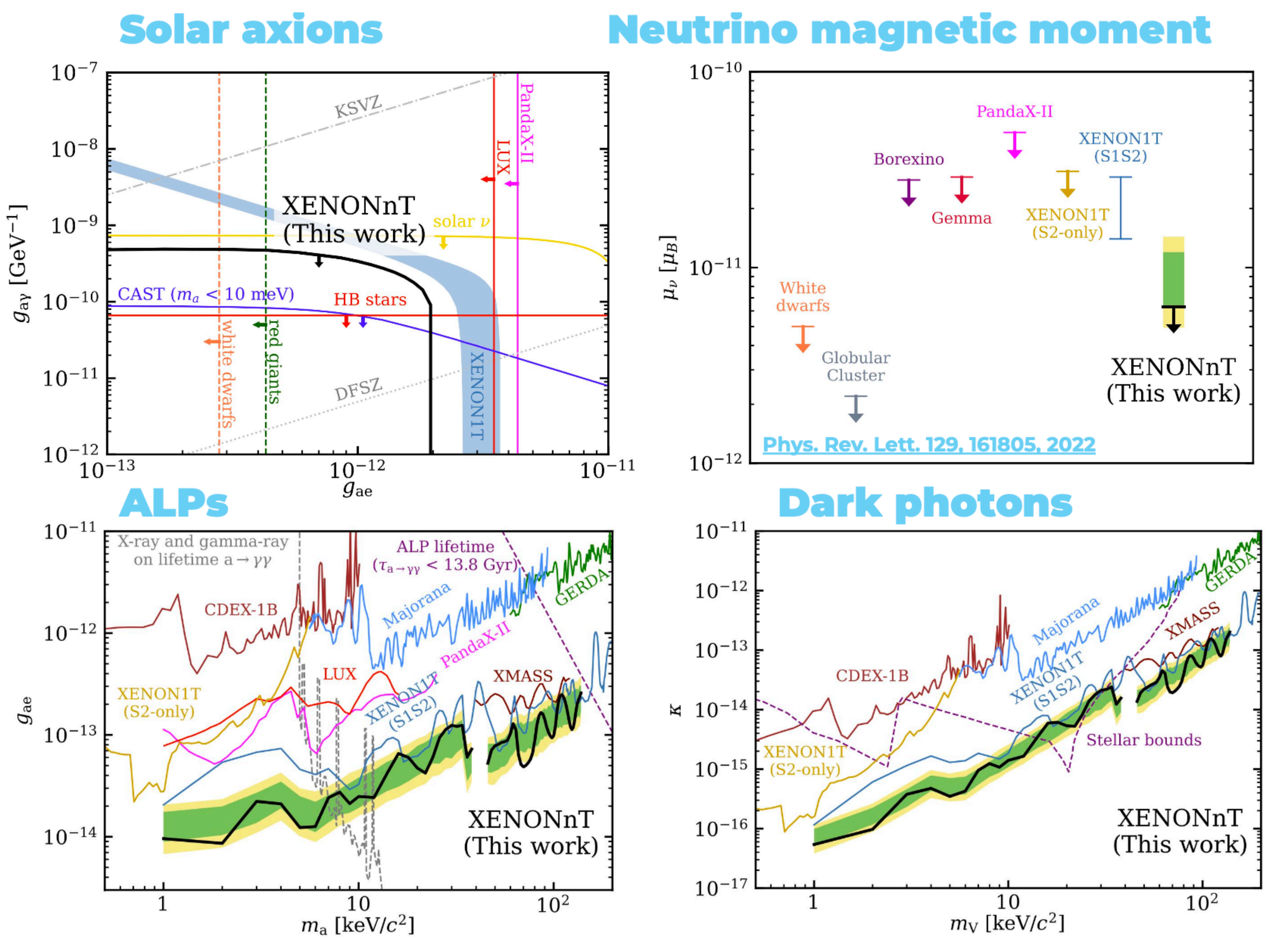






Low energy ER results in SR0

- Leading limits among non-astronomical observation for physics beyond standard model.



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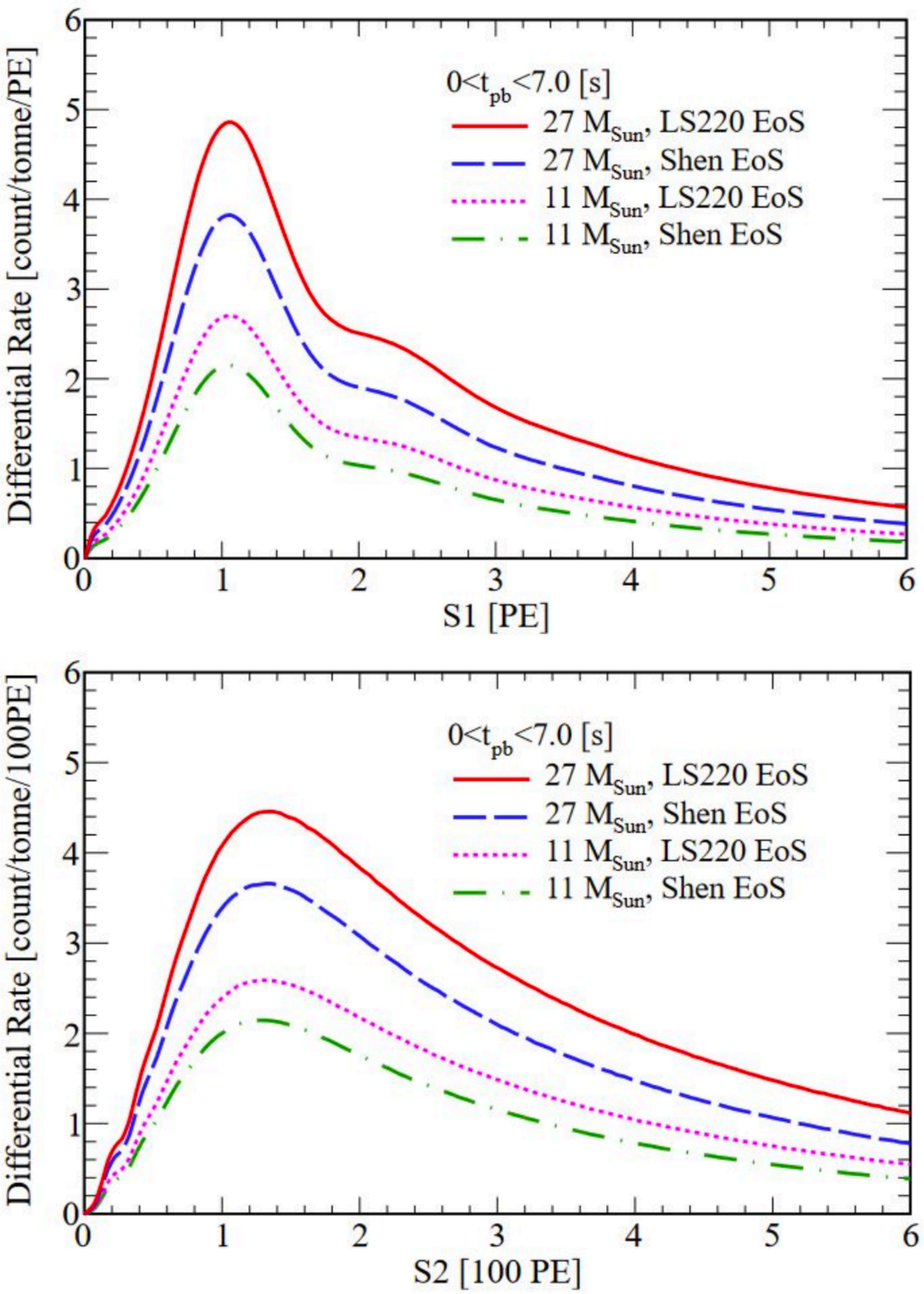
XENONnT as supernova neutrino telescope

Supernova neutrino channels in XENONnT.

- **TPC**
  - 6 t of LXe.
  - $\nu_{e,\mu,\tau}$, $\bar{\nu}_{e,\mu,\tau}$via CEvNS (charged and other neutral current are subdominant).
  - Neutrinos deposit O(1) keV in LXe.
  - ~ 100 expected events from supernova at 10 kpc.
- **Muon & Neutron veto**
  - 700 t ultra-pure water.
  - $\bar{\nu}_e$ via inverse beta decay with H.
  - ~ 70 - 200 expected events from supernova at 10 kpc.

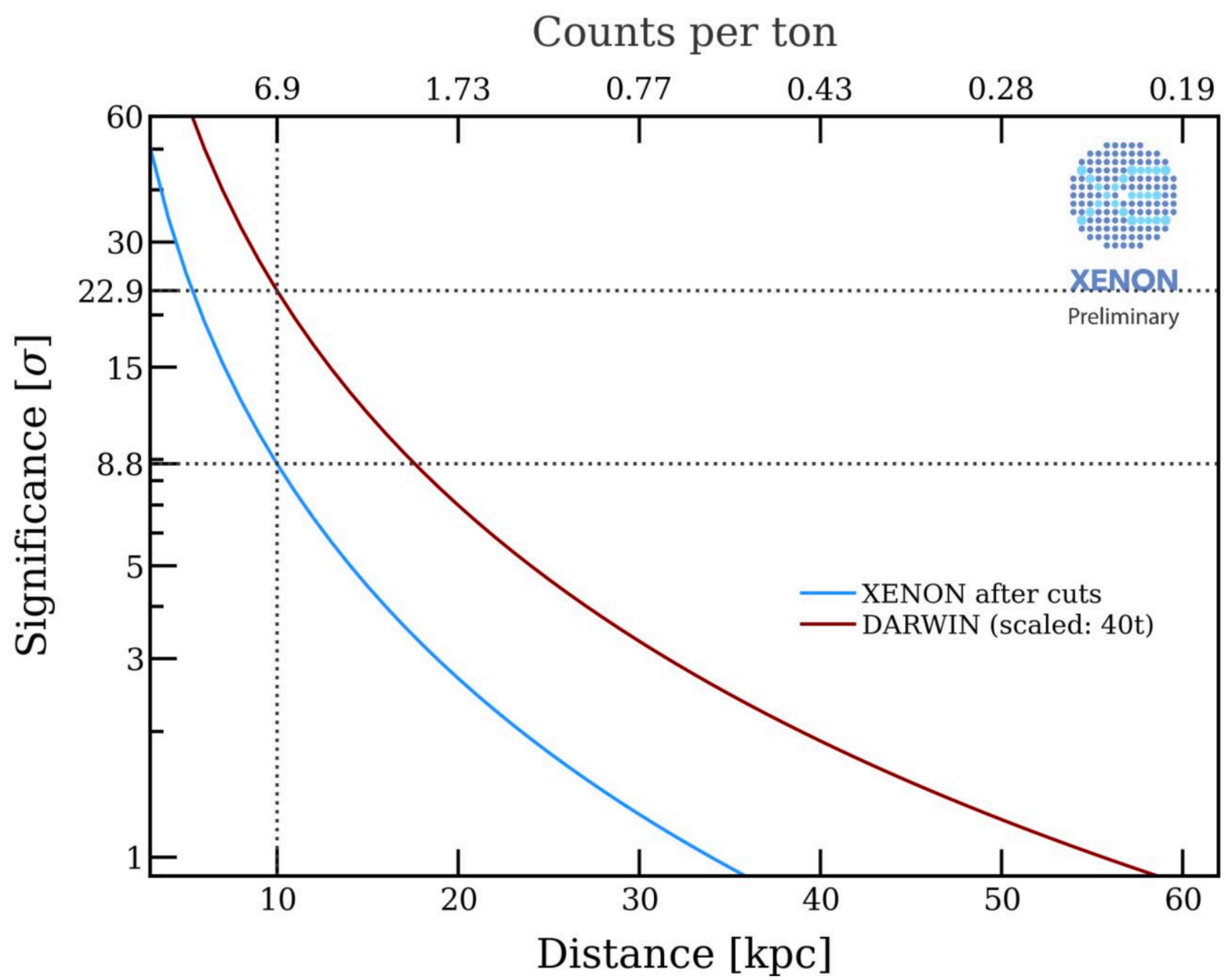
Neutrino rate in LXe

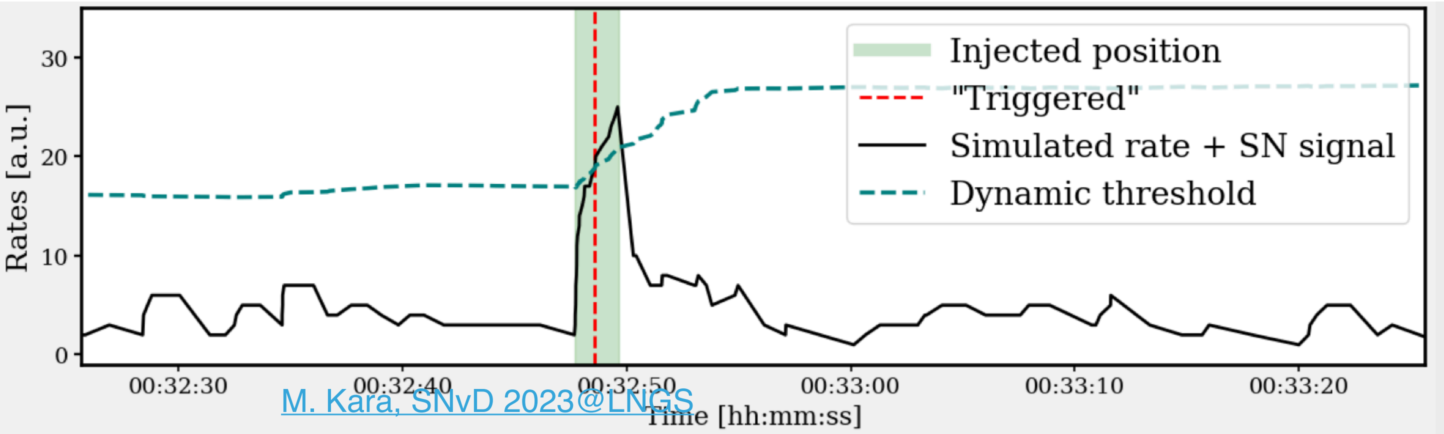


XENONnT as supernova neutrino telescope

Sensitivity projections

- Cuts can reduce background down to ~3 Hz, while average signal (SN at 10 kpc) will results in ~45 events in ~ 6 s (~ 18 background events).
- Triggerless DAQ allows continuous data taking and increases in rate with respect to a dynamic threshold can be monitored online.
- Considering signal evolution, time window can be optimized, resulting in ~8σ significance (10 kpc).





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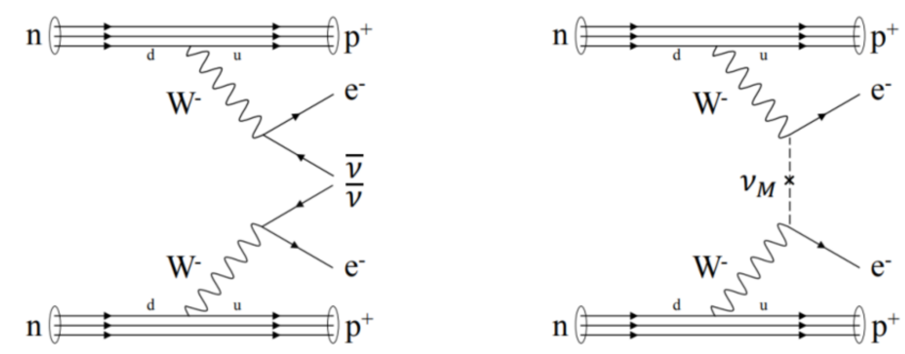
Snews integration

- XENONnT is ready to join the Supernova Early Warning System (SNEWS).
- It will receive incoming alerts to check data and send possible supernova observations.

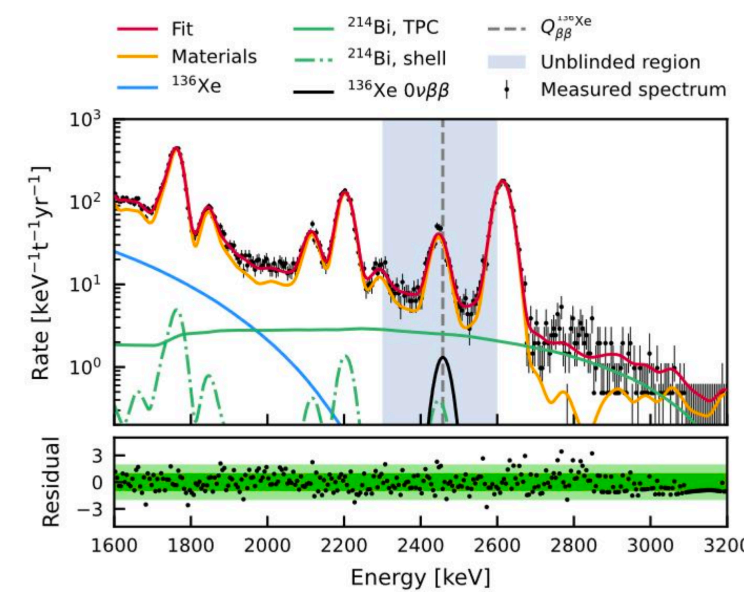
Neutrinoless $\beta\beta$ decay in ^{136}Xe

- 0vββ would demonstrate the violation of total lepton number and a nonzero Majorana component of neutrino mass.
- First observation of ^{124}Xe 2νDEC in XENON1T demonstrated sensitivity to extremely rare events.
- 2vββ decay ^{136}Xe → ^{136}Ba, with $Q^{\beta\beta}$ = (2457.83 ± 0.37) keV is a good candidate for 0vββ.
- 8.9% abundance in XENONnT.



XENON1T results

- $T_{1/2}^{0\nu\beta\beta} > 1.2 \times 10^{24}$ yr with tonne-scale fiducial mass, resulting in isotope exposure of 36.16 kg × yr.
- Best results for a non enriched target detector.



XENONnT sensitivity projection

- With 275 kg × yr exposure, expected upper limit of $T_{1/2}^{0\nu\beta\beta} > 2.1 \times 10^{25}$ yr.
- Future xenon DM detector with optimized high-energy backgrounds and larger exposure can perform also 0νββ searches.