Latest WIMPs and CEνNS results from XENONnT

Federica Pompa (Subatech - CNRS/IN2P3)

On behalf of the **XENON** collaboration

03/11/2025 - TeVPA 2025

The XENON Collaboration

~170 scientists, 30 institutions, 12 countries

Main Motivation:

Discover **Weakly Interacting Massive Particles (WIMPs)**

Other studies:

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS), $0\nu\beta\beta$, Solar Axions and ALPs, Supernovae…

How we do it:

- **Very low backgrounds** through active and passive shielding, volume fiducialization.
- Robust tools to correct detector effects and look for very small signals.
- Perform a blind analysis.

The XENON Collaboration

~170 scientists, 30 institutions, 12 countries

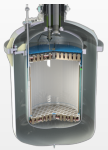
XENON program timeline

XENON10
25 kg LXe

2006
58.6 livedays
BG: 600 / (t.d.keV)

XENON100
160 kg LXe

2008
477 livedays
BG: 5.3 / (t.d.keV)



XENON1T
3200 kg LXe

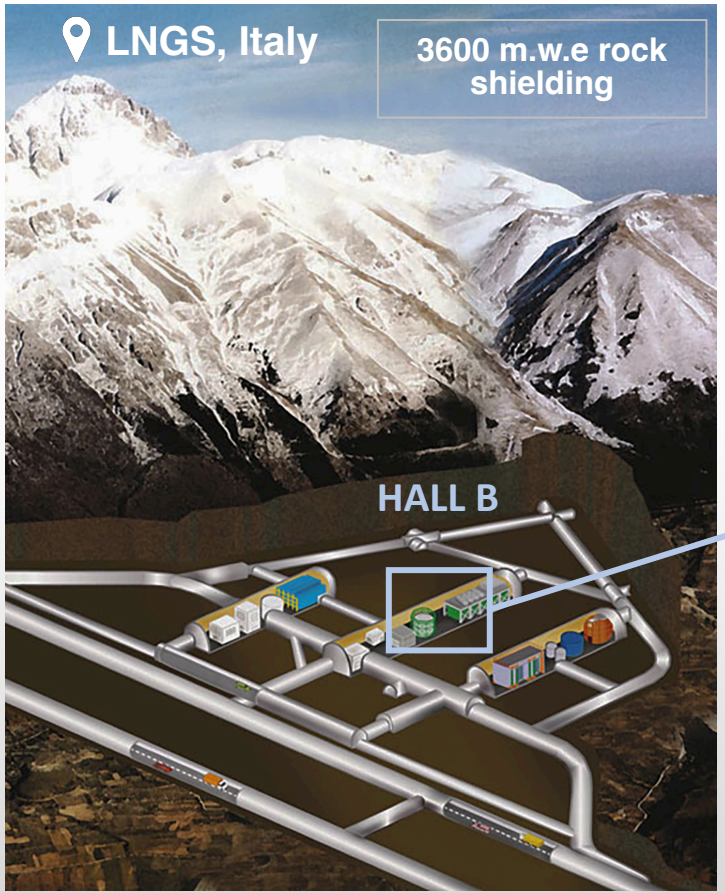
2015
279 livedays
BG: 0.2 / (t.d.keV)

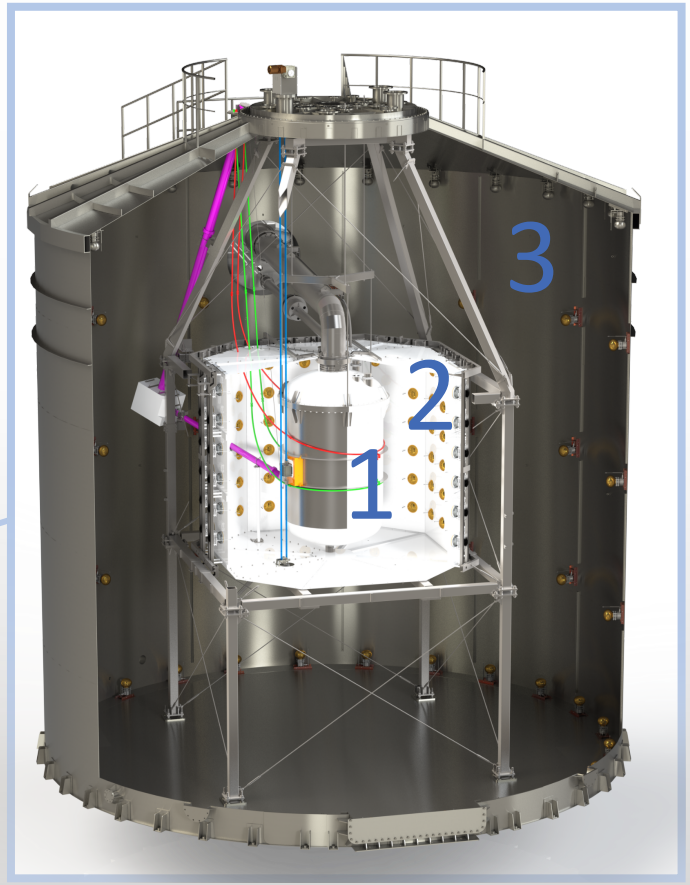
XENONnT
8600 kg LXe

2020
300+ livedays
(ongoing)
BG: 0.04 / (t.d.keV)

Lowest ER background level ever achieved in a LXe based experiment

The XENONnT Experiment





3 Nested Detectors

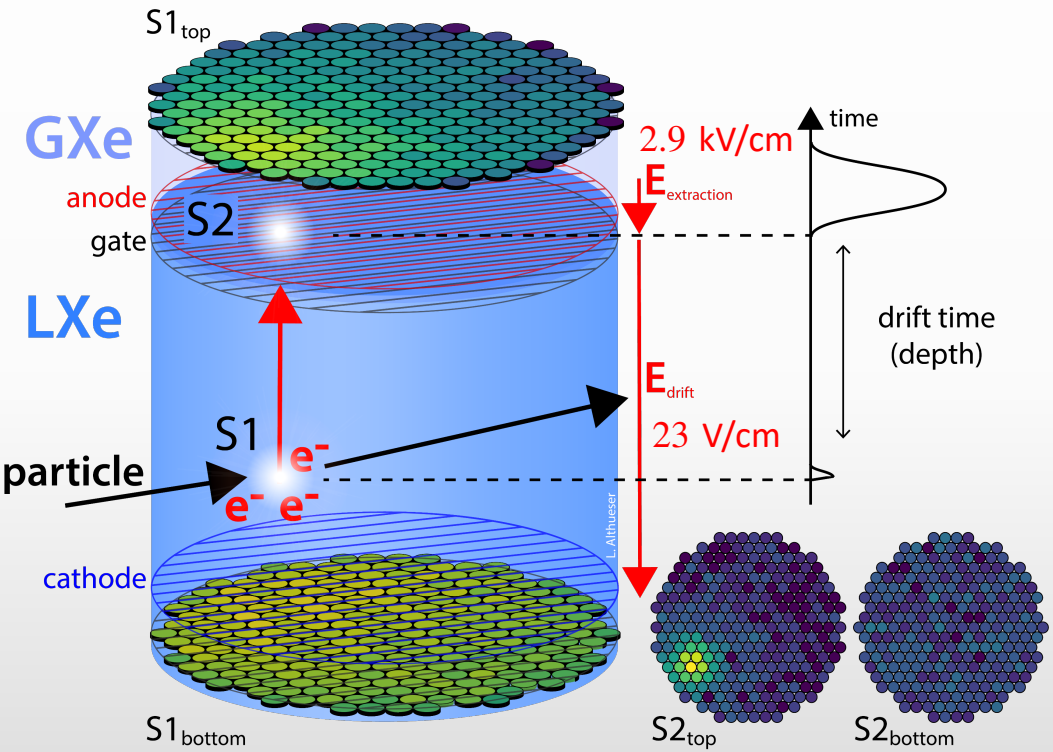
Sharing the same DAQ

1 **Dual Phase Xenon Time Projection Chamber (TPC)** with 5.9ton active volume.
Eur. Phy. J. C 85 (2024) 784

2 Active Gd-water Cherenkov **Neutron Veto**: radiogenic neutrons
Eur. Phy. J. C 85 (2025) 695

3 Active Gd-water Cherenkov **Muon Veto**: muon-induced neutrons
2014 JINST 9 P11006

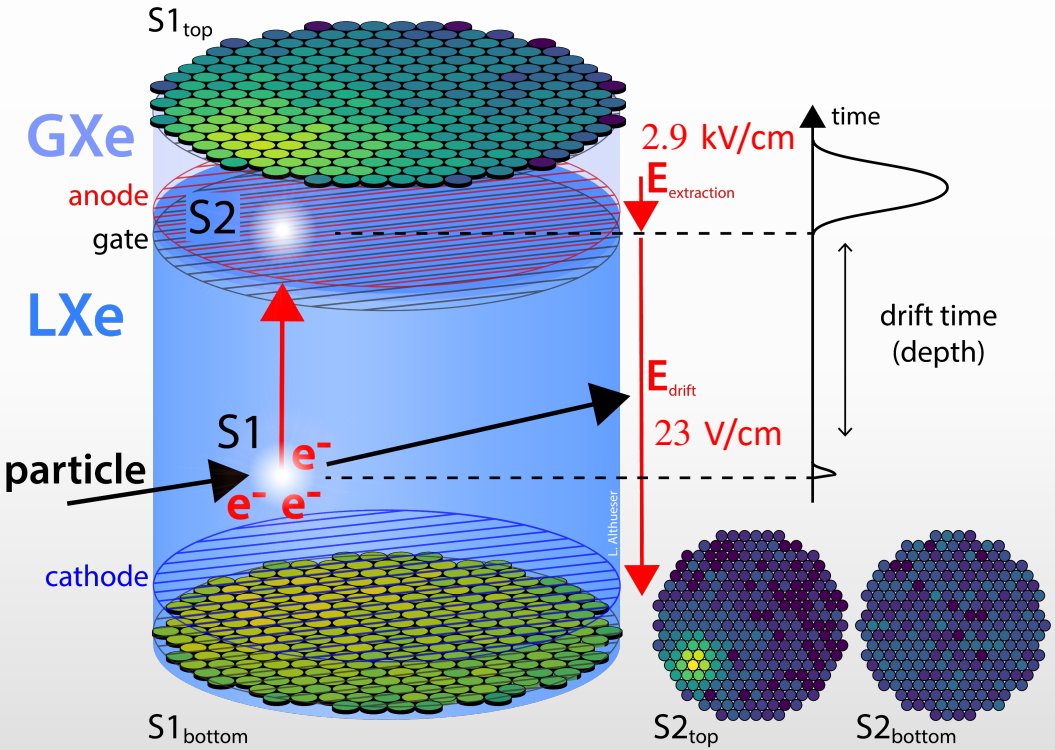
Dual Phase TPC: Working Principle



- Particle interactions in LXe create both **prompt scintillation (S1)** and **delayed ionization** signals.
- Ionization electrons are drifted upwards by a **drift field** and extracted into the gas phase by a stronger **extraction field**, leading to **electroluminescent light (S2)**.
- Signals collected in the top and bottom PMT arrays.

High LXe purity: average electron lifetime ~20 ms

Dual Phase TPC: Working Principle



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3D Position Reconstruction:

(x, y) : S2 hit pattern
z : e^- drift time

Energy Reconstruction:

Combined S1 and S2 area, calibrated with known sources

XENONnT Infrastructure

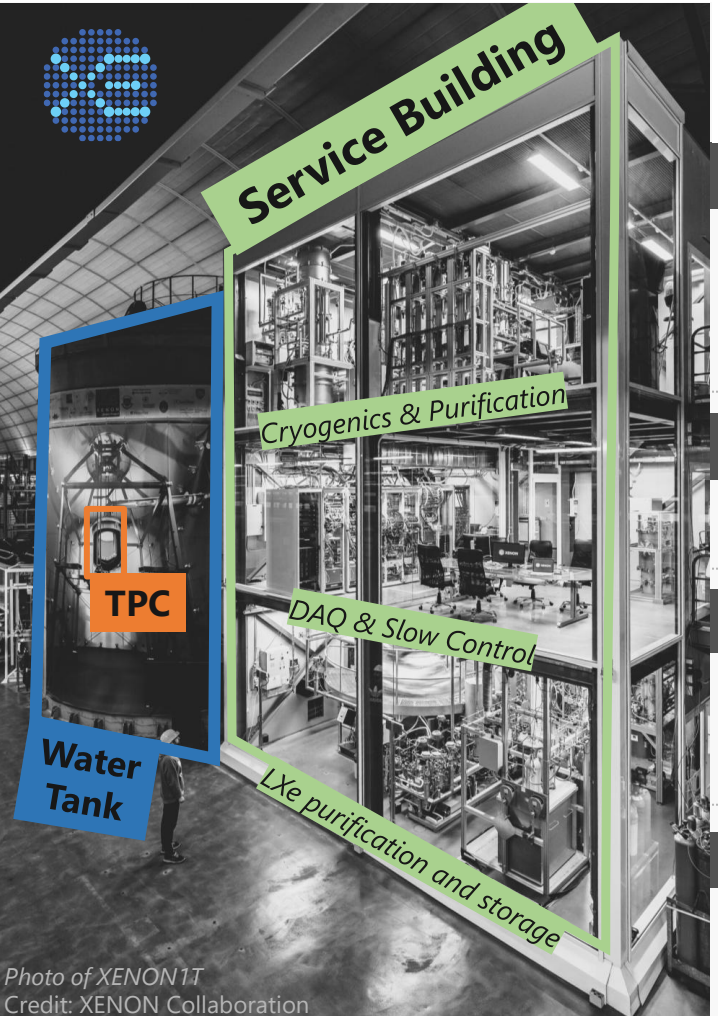


Photo of XENON1T
Credit: XENON Collaboration

Rn Distillation

Eur. Phys. J. C (2022) 82: 1104,

Continuous online distillation.

[^{222}Rn] (SR0): **1.9 µBq/kg**

[^{222}Rn] (SR1): **0.9 µBq/kg**

Phys.Rev.X 15,031079

Kr Distillation

Eur. Phys. J. C 77, 275 (2017)

[^{nat}Kr/Xe] **< 50 ppq**

nT DAQ

2023 JINST 18 P07054

Triggerless DAQ.
Shared between three detectors.

LXe Purification

Eur. Phys. J. C (2022) 82: 860

Removes **electronegative** impurities.

Outside the Service Building

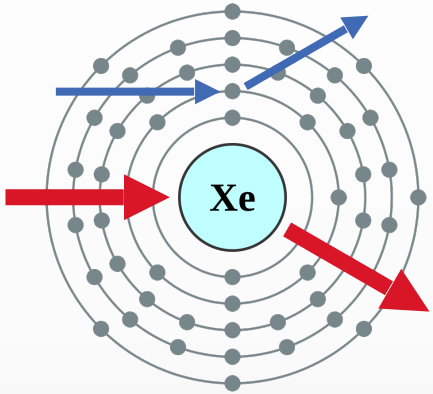
ReStoX

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

Fast **xenon recovery system** and storage, preserving purity.

Recoil Type Calibration: ER or NR

Electronic Recoils (ER)



Nuclear Recoils (NR)

NR

- ✗ | Neutrons
- ✓/✗ | Neutrinos (CEvNS)
- ✓ | WIMPs

ER

- ✗ | Gamma & Beta
- ✓/✗ | ^{136}Xe $0\upsilon\beta\beta$, $2\upsilon\beta\beta$.
- ✓/✗ | Neutrino elastic scattering.
- ✓ | Solar axions, ALPs.

✓ Signal ✗ Background

Recoil Type Calibration: ER or NR

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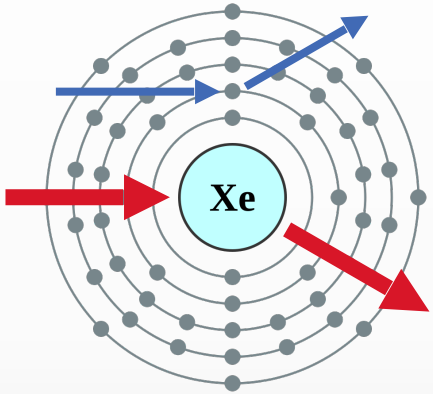

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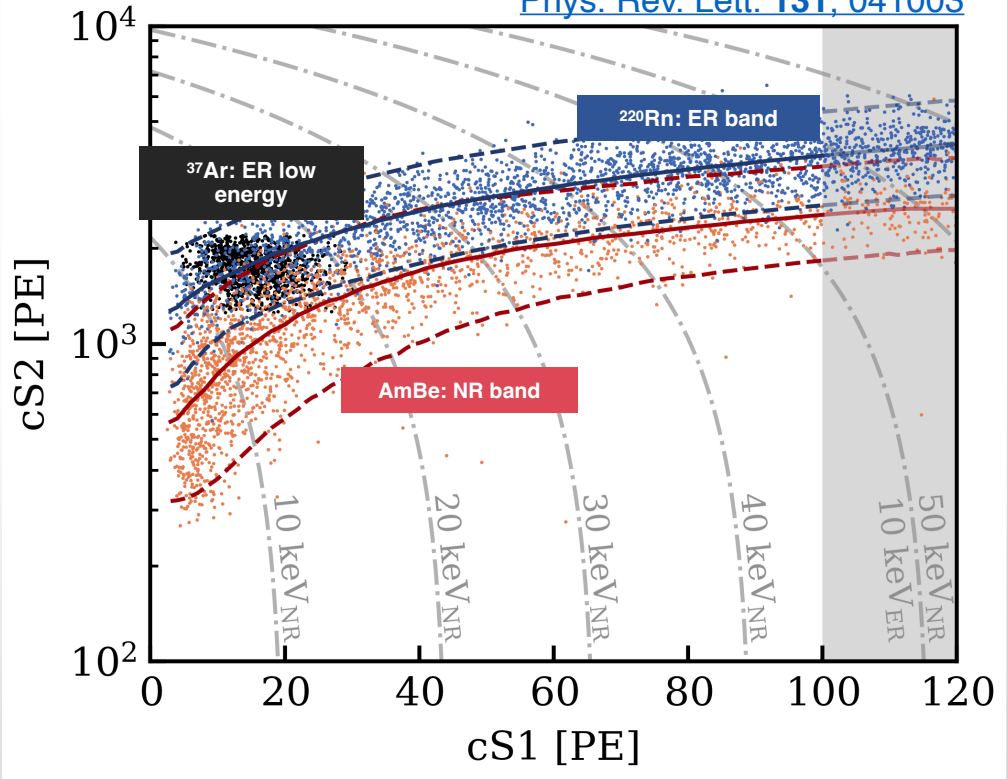
Phys. Rev. Lett. **131**, 041003



Discriminated via different S2/S1 ratio

Other Calibrations

^{83m}Kr

TPC characterization and signal correction.

^{232}Th

High energy response.

YBe

Low energy NR response.
arXiv:2412.10451 [physics.ins-det]

SR0+1: WIMP Search Datasets

SR0

95.1 days
[July - November 2021]

- Updated neutron background model with respect to SR0-only
- Rest of the analysis unchanged

SR1a

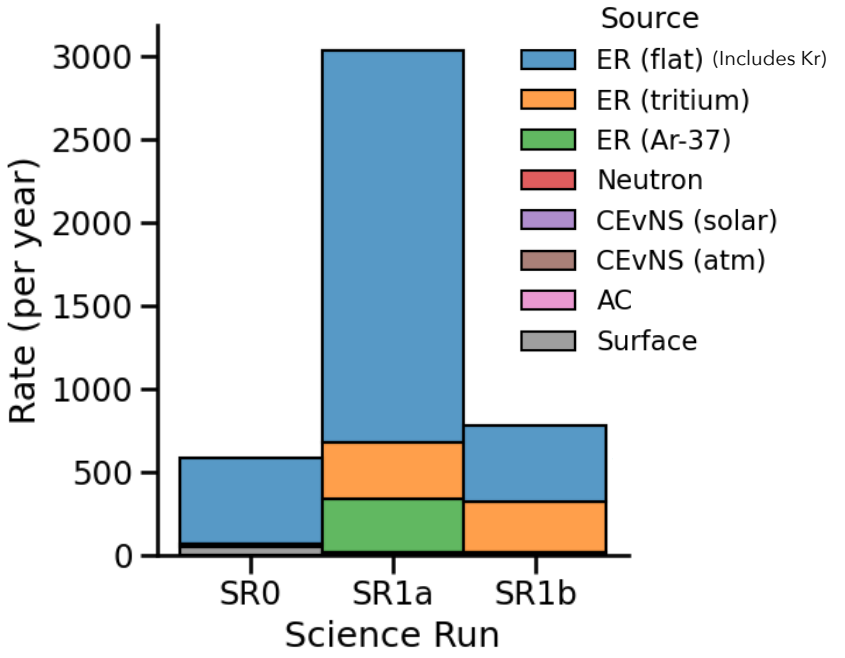
66.6 days
[May - December 2022]

- **High ER rate from ^{85}Kr and ^{37}Ar**
- **^{3}H-like background**: rate left unconstrained
- Smaller fiducial volume to reduce surface background

SR1b

119.9 days
[December 2022 - August 2023]

- **ER rate back to SR0 levels**
- **^{3}H-like component remains**
- Smaller fiducial volume



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Accidental injection of Kr-rich Xe gas

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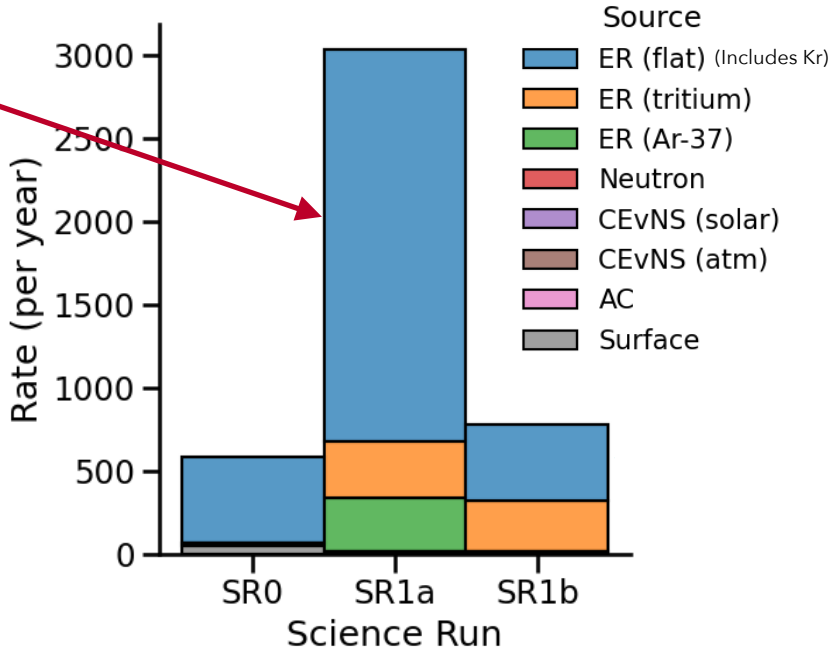

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1 month of cryogenic distillation

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119.9 days
[December 2022 - August 2023]

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- **^{3}H-like component remains**
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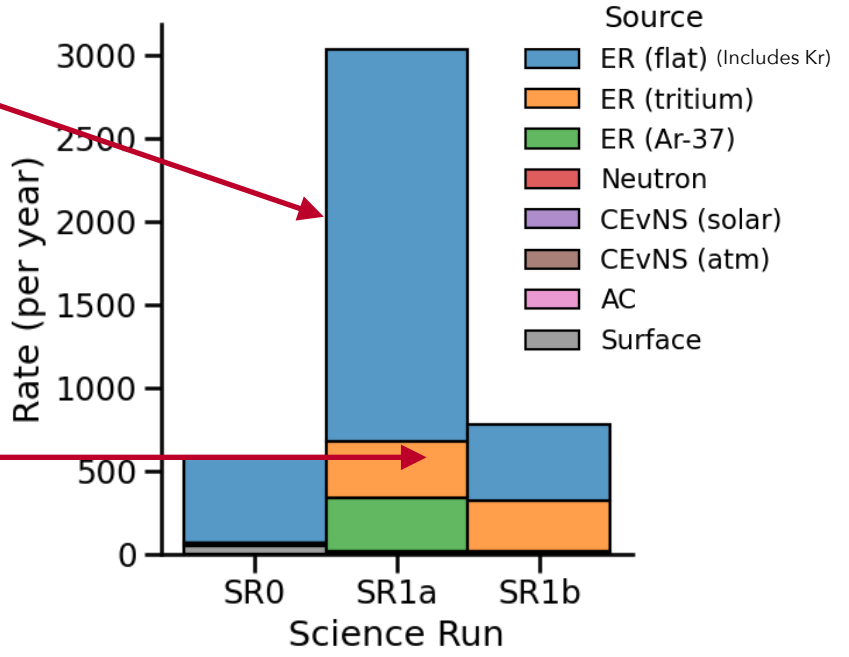
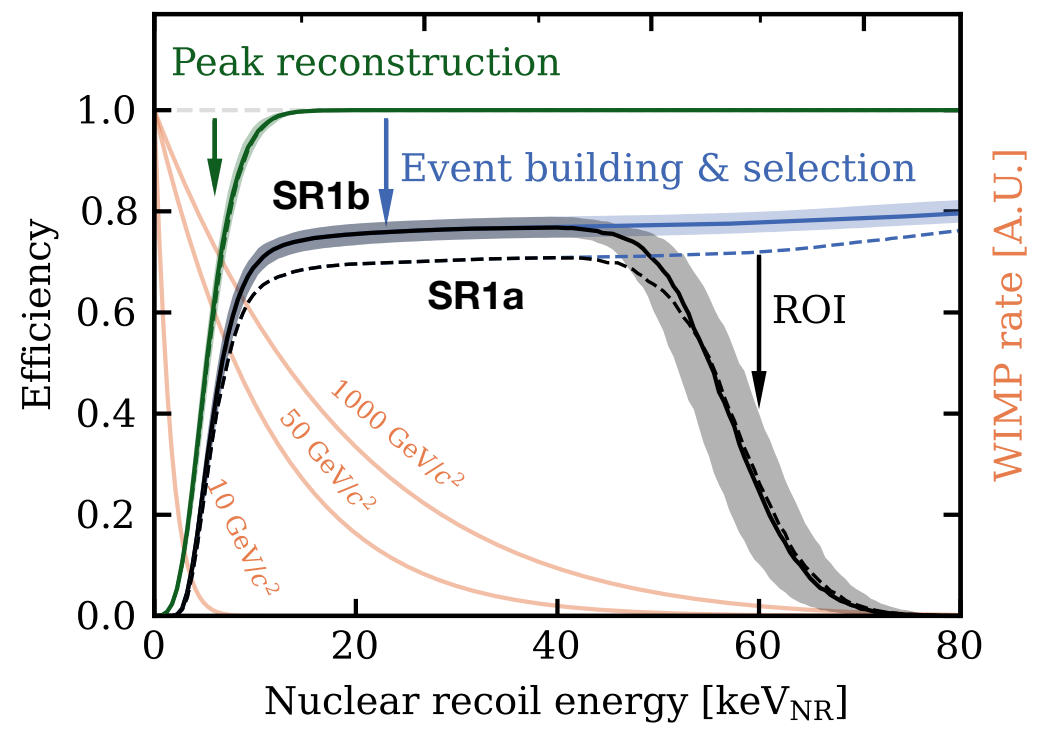


SR0+1: WIMP Search Efficiencies



Peak reconstruction

- Efficiency in detecting and reconstructing S1 and S2 peaks
- dominated by 3-fold requirement (3 PMTs to be in coincidence)

Event building & selection

- Efficiency in successfully pairing S1s and S2s
- efficiency due to cut acceptance

Region Of Interest (ROI) :

$cS1 < 100$ PE

$cS2 \in [10^{2.1}, 10^{4.1}]$ PE

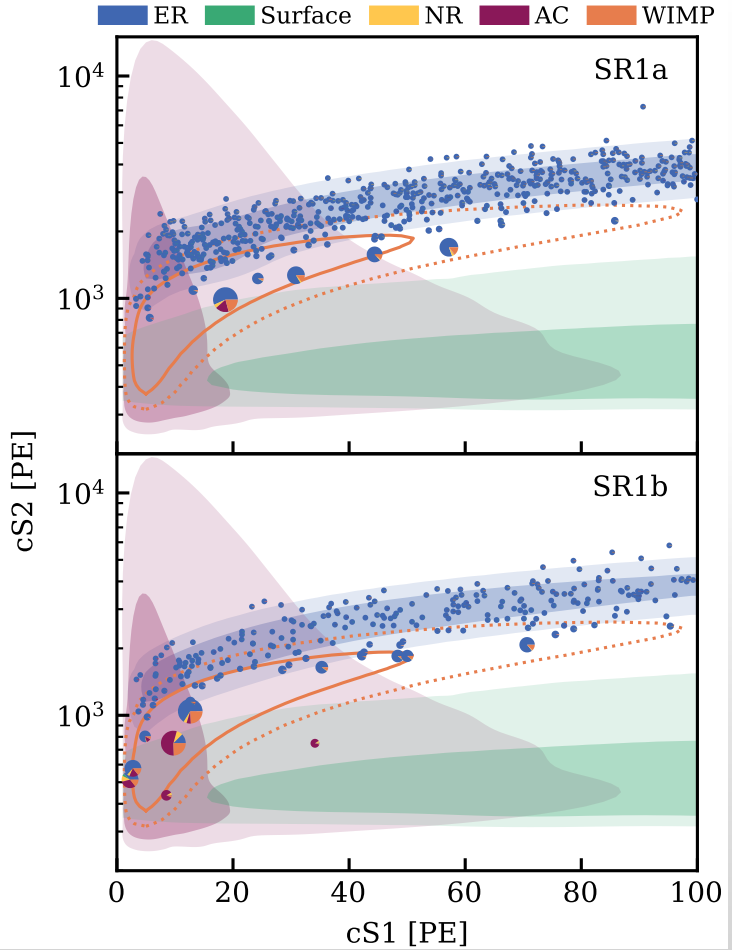
arXiv:2502.18005

SR0+1: WIMP Search Results

Blind analysis with 3.1 ton x year exposure

- **Unbinned likelihood**: separate terms for SR0, SR1a and SR1b
- Shadowed dark (light) regions: 1σ (2σ) background probability density distributions.

No excess over background observed



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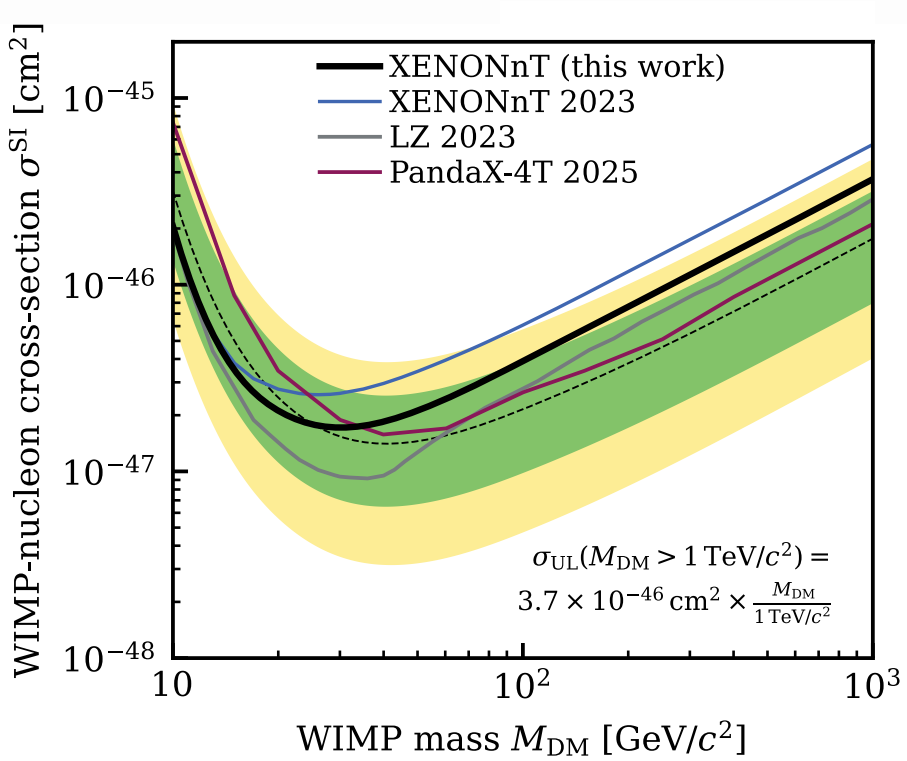


New limits set on WIMP-nucleon cross section.
Improvement from SR0 by a factor of ~ 1.5

Most stringent limit:

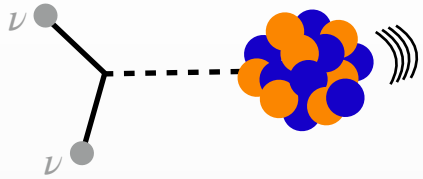
1.7×10^{-47} cm^2 **at 90% C.L.**
for WIMP mass of 30 GeV/c^2

Results consistent with other experiments

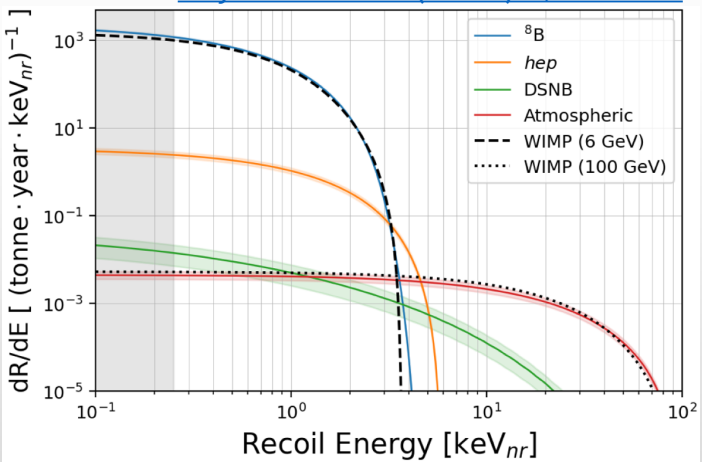
arXiv:2502.18005

First step within the neutrino fog

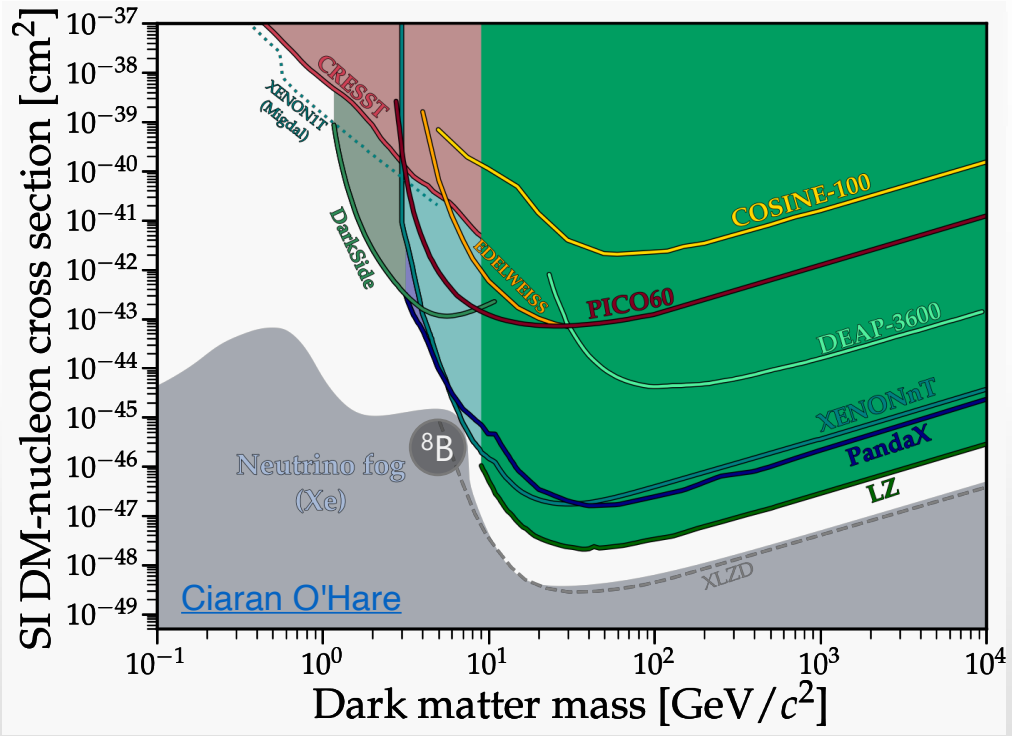
Coherent **E**lastic ν-**N**ucleus **S**cattering



Phys.Rev.D 108 (2023) 2, 022007

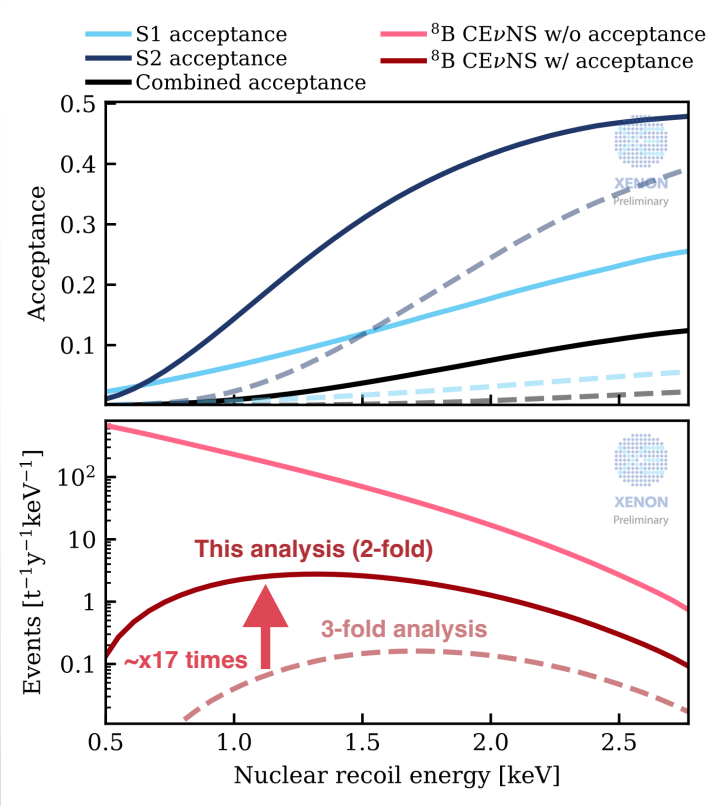


Solar ^{8}B spectrum **almost identical** to that of a 5.5 GeV/c^2 WIMP



Solar neutrinos from ^{8}B are expected to have the highest number of detectable signals in XENONnT

SR0+1: CEνNS Search



Total of 3.51 ton x year exposure

- From 3-fold to 2-fold coincidence requirement
- Accidental Coincidence as major background

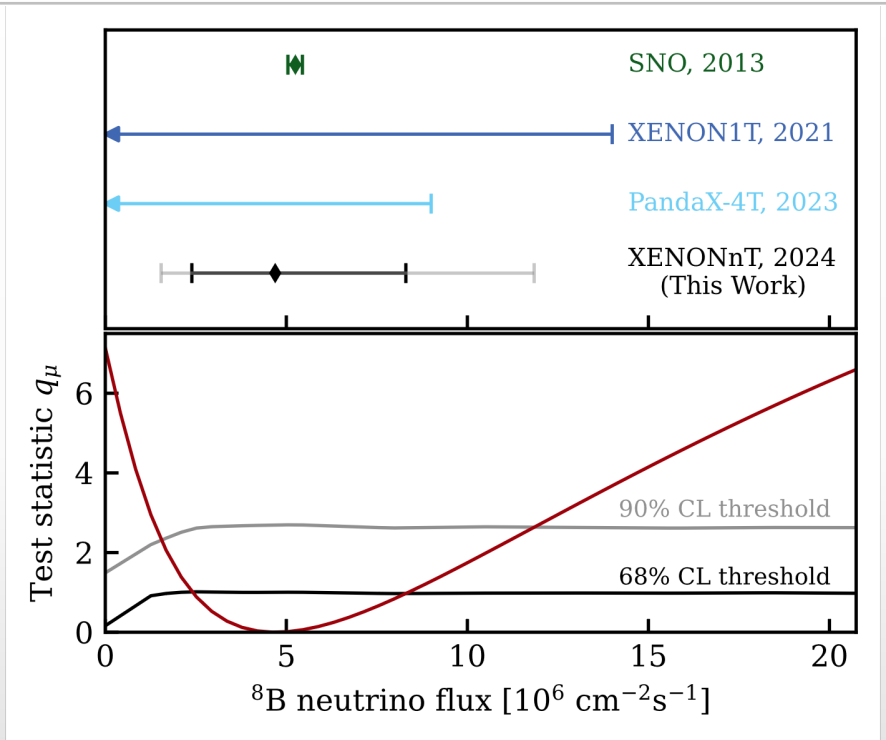
⇩

Observed ^{8}B CEνNS at a significance of 2.73σ

First indication of CEνNS **from astrophysical neutrinos and in Xenon**

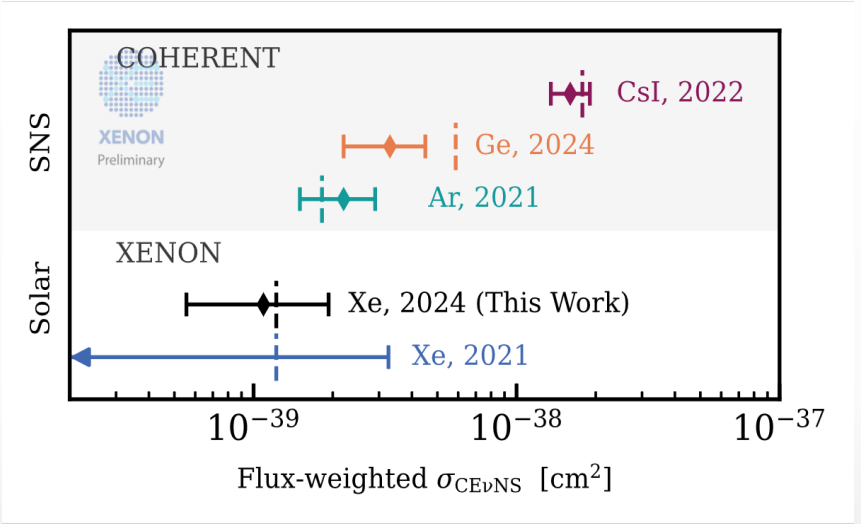
PRL 133, 191002

SR0+1: CEνNS Search Results



Measured ^{8}B flux: $\left(4.7^{+3.6}_{-2.7}\right) \times 10^6\ cm^{-2}s^{-1}$.

In agreement with other measurements.

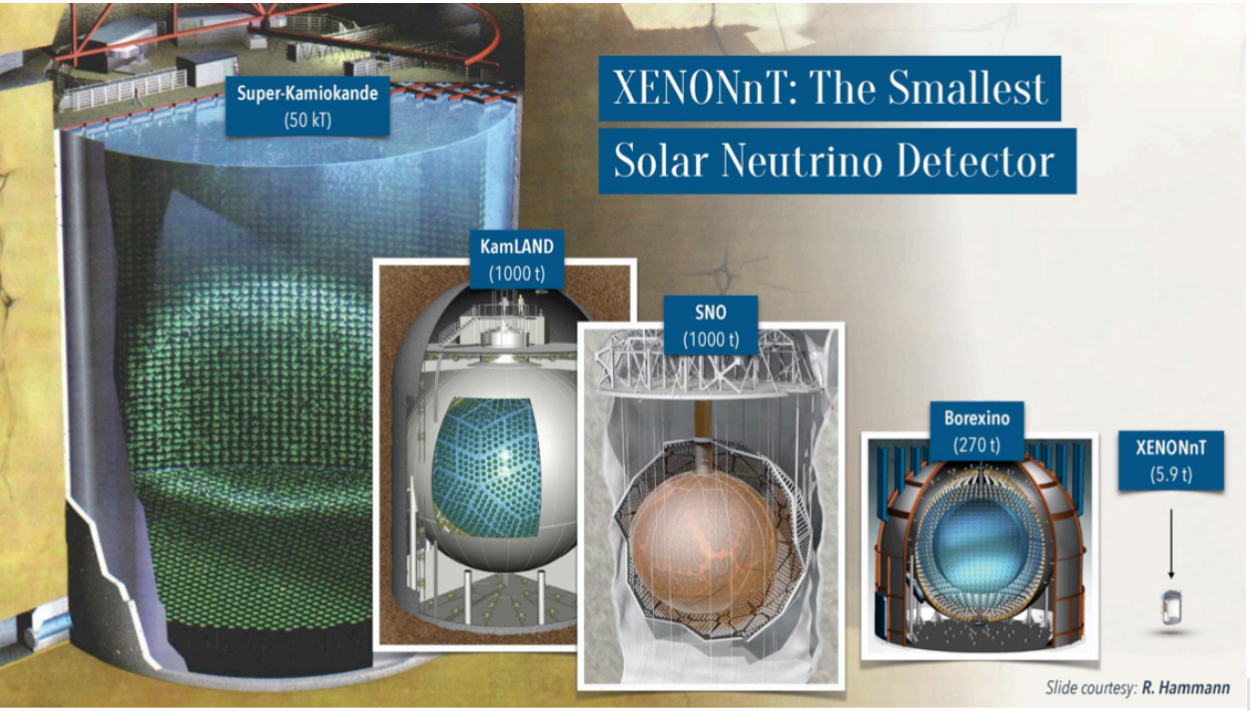


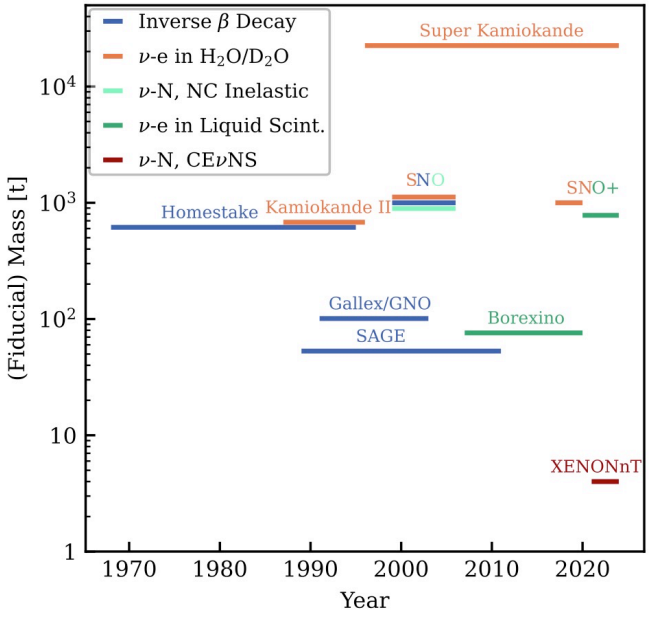
Fix the flux, and calculate cross section.

Flux weighted CEνNS cross-section
in agreement with Standard Model.

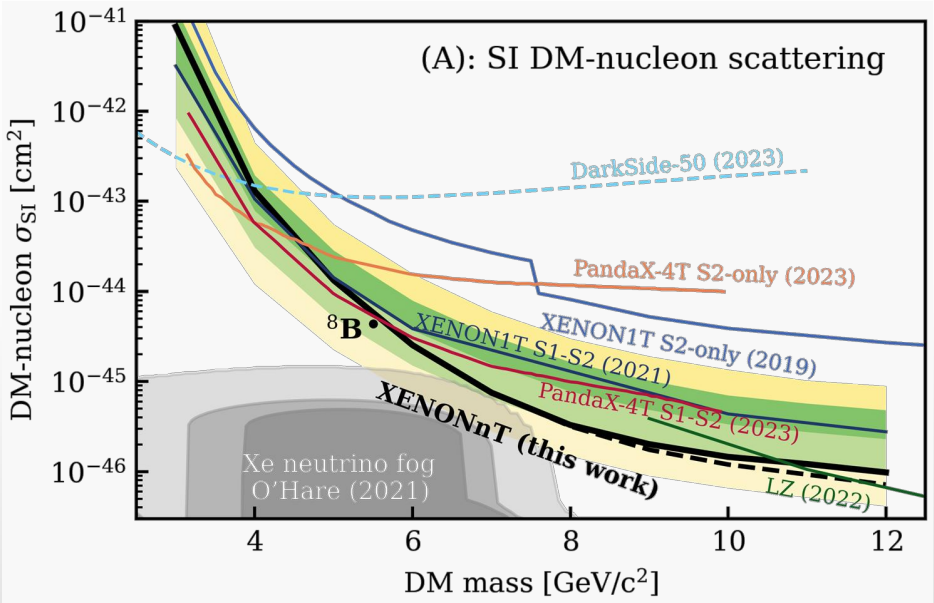
PRL 133, 191002

XENONnT : the smallest solar neutrino detector





SR0+1: Low-mass WIMP Search



- Same dataset and analysis framework for CEνNS search is used
- Here ^{8}B CEνNS becomes a **background**

No excess over background observed

New parameter space excluded

⇩

First search into the neutrino fog

PRL 134, 111802 (2025)

Summary and Outlook

SR0+SR1: Results

WIMP
arXiv:2502.18005

No excess observed
Most stringent limit set at 1.7×10^{-47} cm^2 at 90% C.L. for WIMP mass of 30 GeV/c^2

^{8}B CEνNS
PRL 133, 191002

Observed at 2.73σ
First observation of astrophysical neutrinos via CEνNS in Xenon

Low-mass WIMP
PRL 134, 111802

No excess observed
First dark matter search in the neutrino fog

High-Energy
arXiv:2510.04846

ER signals modeled up to 3.27 MeV
beyond the WIMP energy range

Future results

SR0+SR1

Broad physics program with more results to come
(Solar-pp, $2\nu/0\nu\beta\beta$...)

SR2

- **Data taking now concluded**
- **Gd-doping** in n-Veto for **improved tagging efficiency** $\sim 77\,\%$
- **Ongoing analysis** (more DM and neutrino results coming soon)

Future perspective

Xenon-**L**ux **Z**eplin-**D**arwin collaboration established to build the next generation LXe Observatory down to the neutrino fog

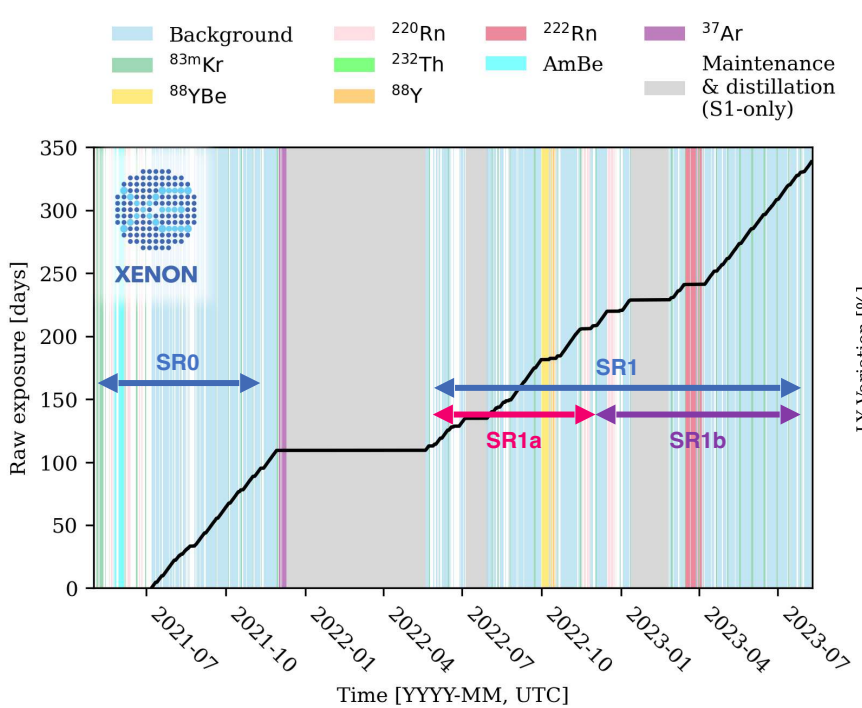
XENON Website: https://xenonexperiment.org/

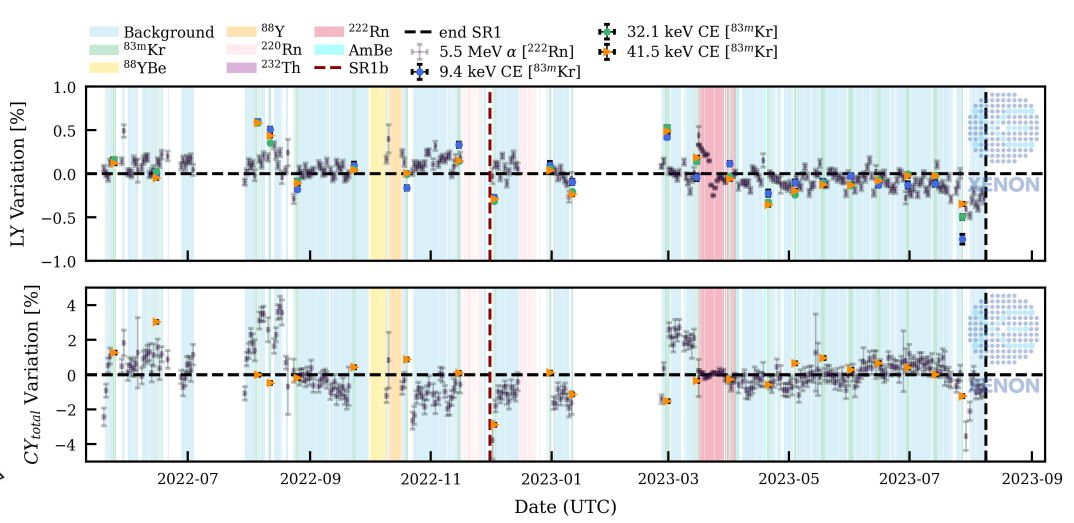
XENON

Backup Slides

XENONnT: Science Data

- Science data divided into various **Science Runs (SR)**. Exposure for science searches up to ~320 days.
- **Very stable detector conditions**: <1% (<3%) variation in Light (Charge) Yield.





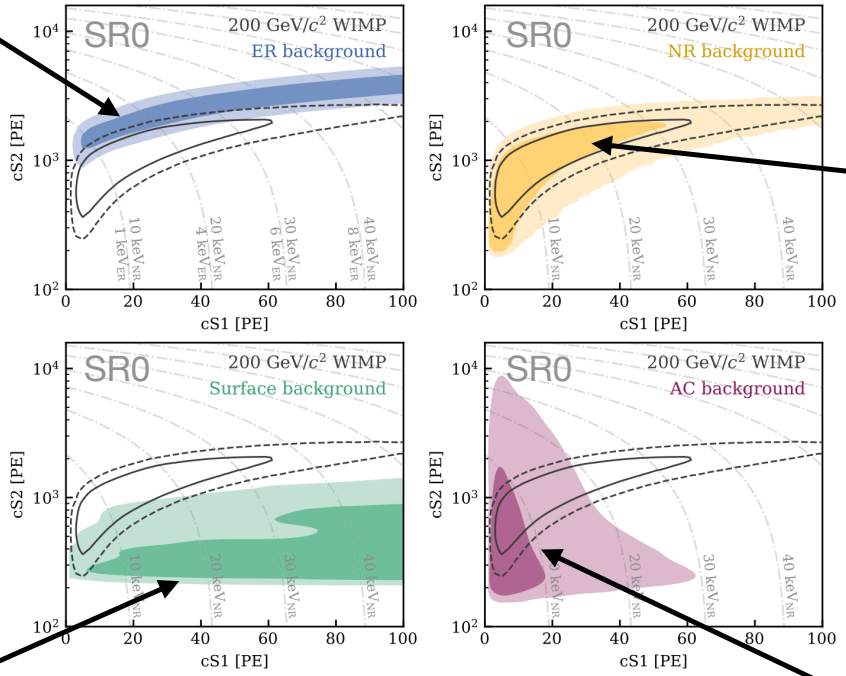
WIMP Background Model

Electronic Recoils:

- **^{214}Pb, ^{85}Kr** β-decays, **^{124}Xe** 2**ν**ECEC, **solar ν-e$^-$** scatter
- Shape constrained with **^{220}Rn calibration**
- Rate constrained by **fit to reconstructed spectrum** in [20, 140] keV$_{ER}$

Surface:

- **^{210}Pb β-decay** from PTFE walls due to **plate-out effect**
- Suppressed by **fiducial volume** (FV) selection
- **Data-driven** constrain validated **outside FV**



[Phys. Rev. D 111 (2025) 103040]

Nuclear Recoils:

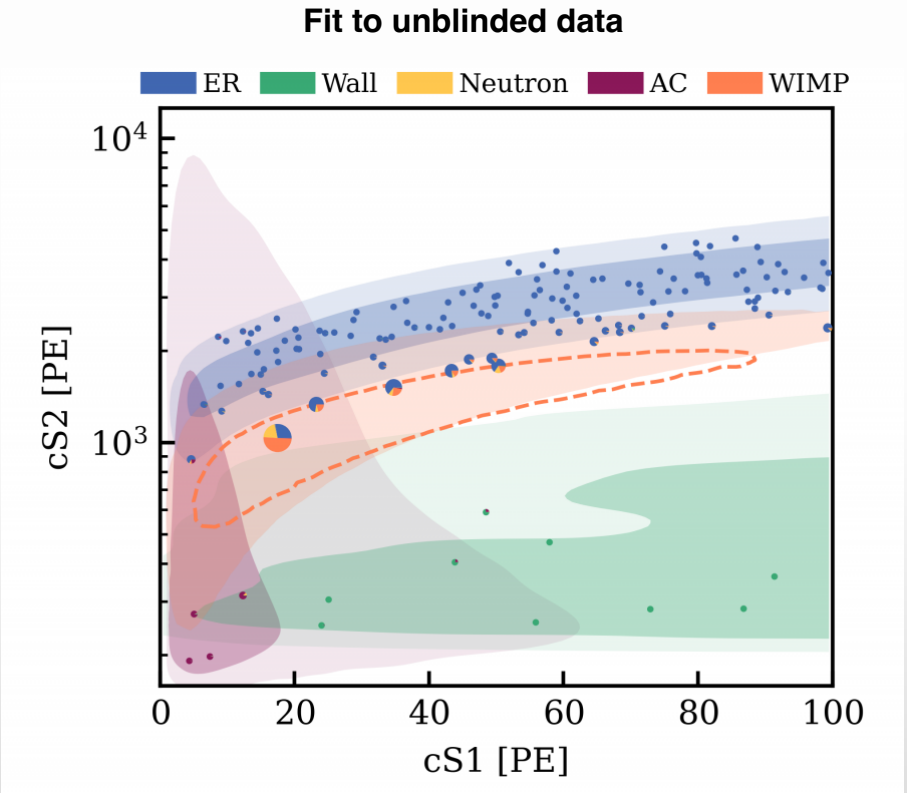
- **Radiogenic neutrons** from materials, suppressed by **NV tagging** and **multi-scatter** (MS) **rejection** and constrained by **sideband** of MS and single-scatter events tagged by NV
- **CEvNS**, constrained by **neutrino flux** and **uncertainties on NR emission model**

Accidental Coincidence:

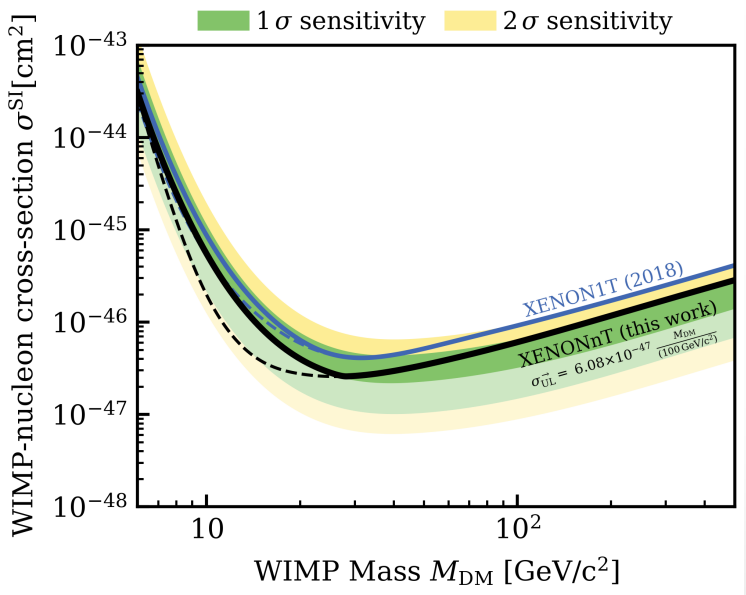
- Accidental pairing of isolated S1-S2, removed by **dedicated machine learning** based **cuts**
- **Data-driven** modeling, validated with **sideband** unblinding

Recap : SR0 WIMP Results

Phys. Rev. Lett. **131**, 041003



Exposure: 1.09ty



No significant excess observed.

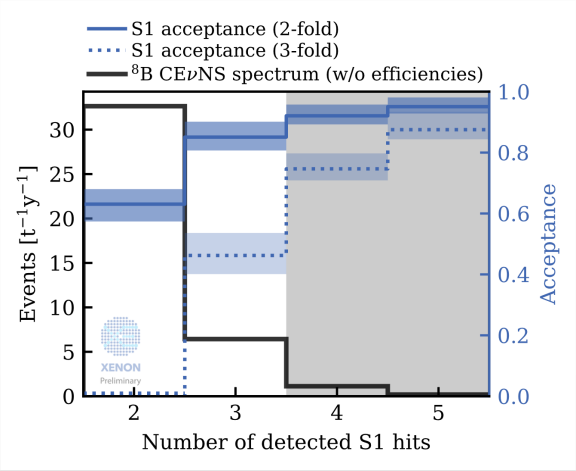
Best exclusion limit of $\mathbf{2.6 \times 10^{-47} cm^2}$ at $28 GeV/c^2$

PCL to median sensitivity to avoid spurious limits

SR0+1: CEvNS Search

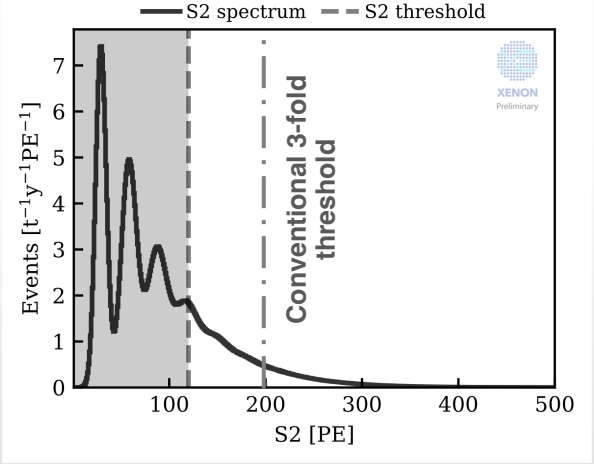
Lowering the threshold

^{8}B CEvNS rate is too small for detection with classical 3-fold analysis (requiring 3 PMT coincidence; 3 hits).



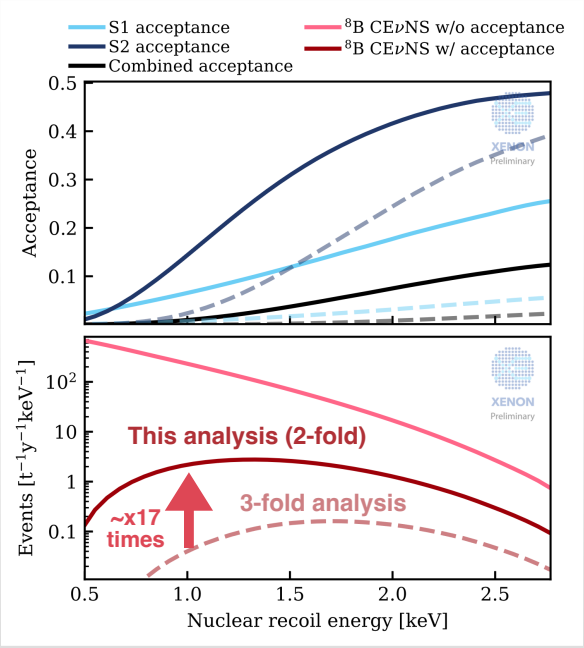
S1 ROI: 2 or 3 PMT coincidence.

S2 threshold also has to be reduced, but should be high enough to reject high isolated S2 rate.



S2 ROI: 150 – 500 PE.

^{8}B CEvNS Signal Acceptance for the search.

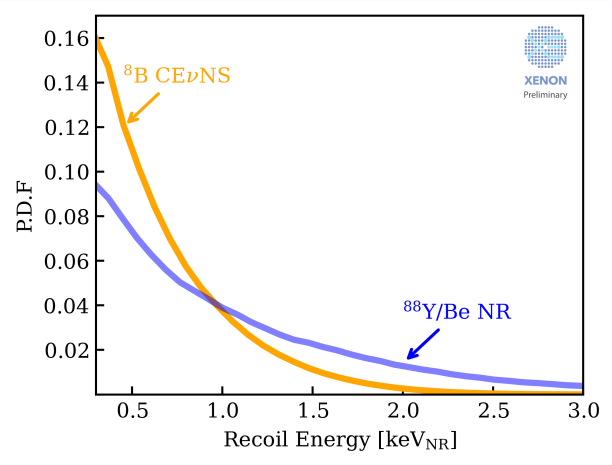


Phys. Rev. Lett. 133, 191002

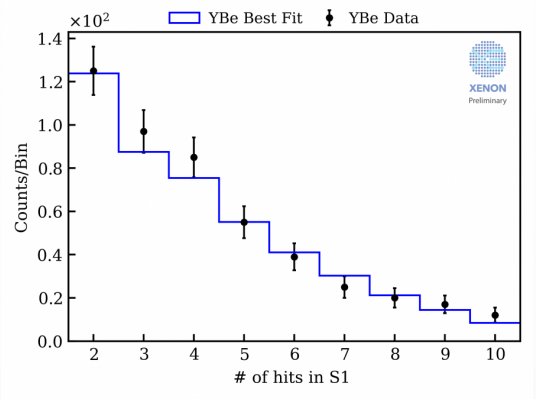
YBe Calibration: Low Energy NR Response

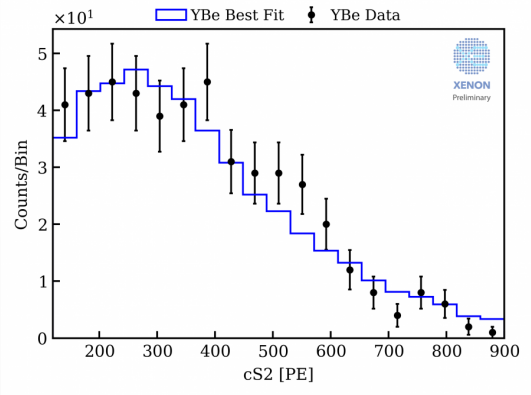
arXiv:2412.10451 [physics.ins-det]

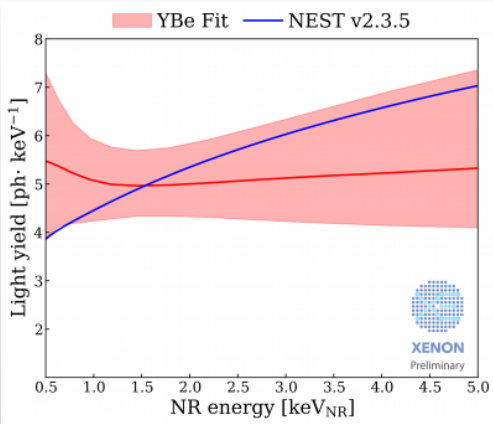
- **152 keV neutrons** produced by **photodisintegration of ^{9}Be due to γ from ^{88}Y** show similar recoil energy spectrum in TPC as ^{8}B CEvNS.

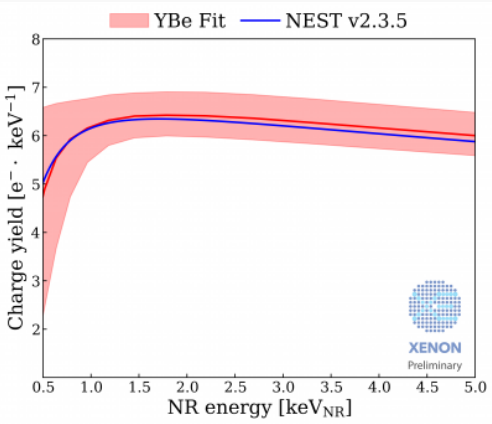


- **Good matching with model**. Fit the NEST model with the ^{88}YBe data to predict the light and charge yield in the ^{8}B CEvNS energy range at the XENONnT drift field (23 V/cm).









SR0+1: CEvNS Search

Accidental Coincidence Background (AC)

- ACs are accidental pairings of **Isolated S1** and **Isolated S2** signals. Major background near threshold.
- AC rate before mitigation:
  - ➢ Isolated S1 rate: ~15 Hz
  - ➢ Isolated S2 rate: ~150mHz
  - ➢ Raw AC rate: **~400 events/day**

- Mitigated using **analysis cuts** based on time and space information of peaks following a high energy peak.

Expected AC Events after Mitigation:

SR0: 7.5 ± 0.7 | SR1: 17.8 ± 1.0

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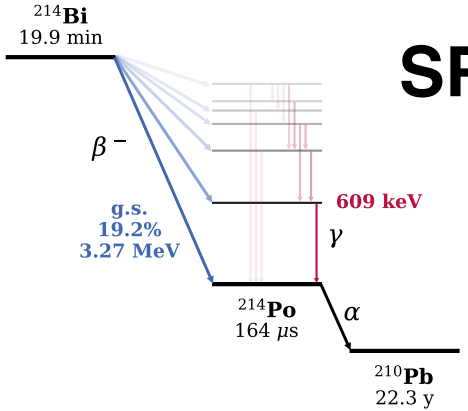
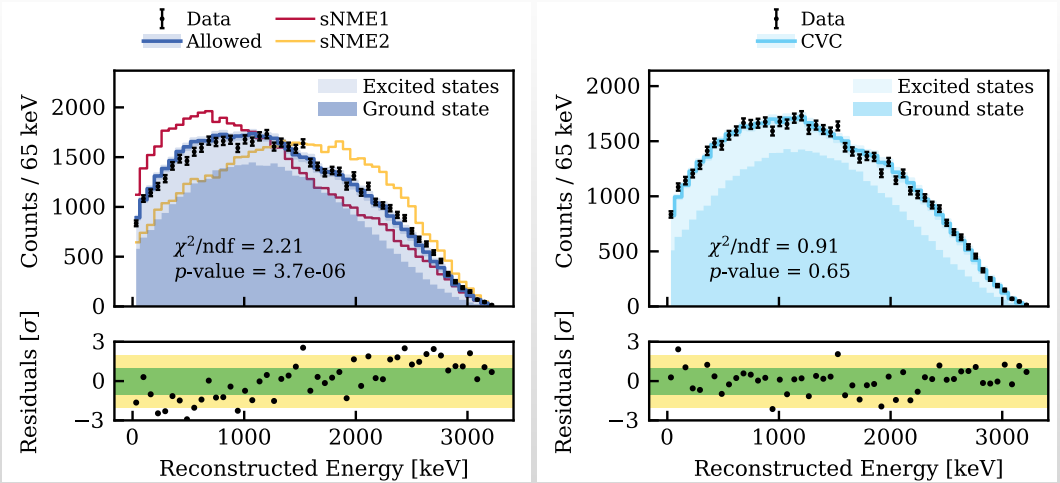
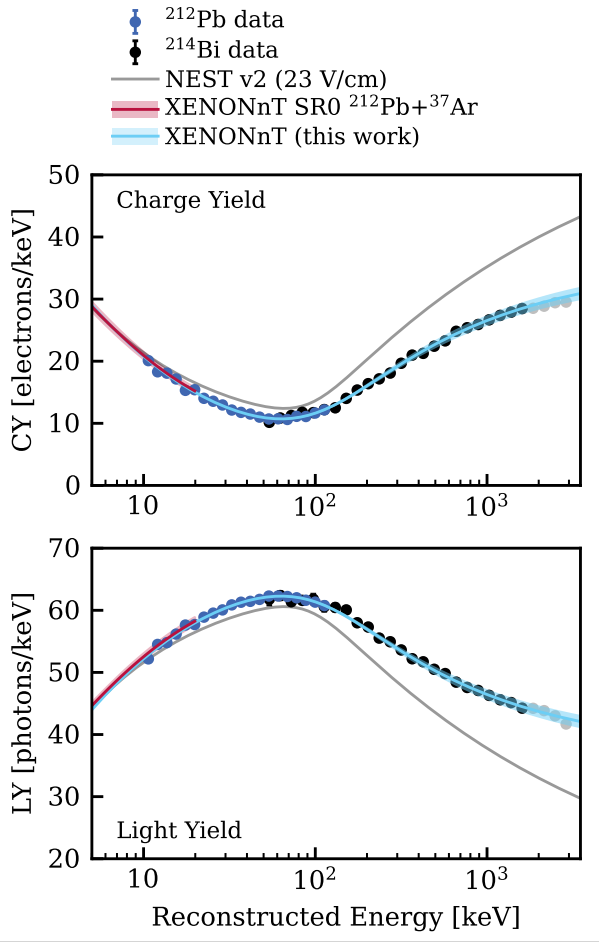
SR0+1: High-Energy Modeling



Important to model the charge and light yield curves for ER, extending detector response up to the MeV scale.

Theoretical spectrum calculated under the conserved vector current (CVC) strongly favored by analysis.





arXiv:2510.04846