Latest results from the LUX-ZEPLIN (LZ) experiment

IDM2026
ZARAGOZA

Alberto Uson
on behalf of the LZ Collaboration

02/06/2026

LZ (LUX-ZEPLIN) collaboration

- 38 institutions
- 250 scientists, engineers, and technical staff

Thanks to our sponsors and participating institutions!

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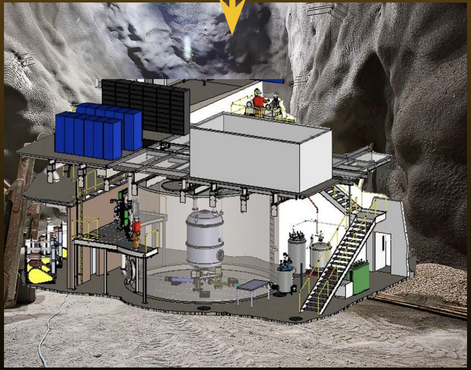
The LUX-ZEPLIN detector

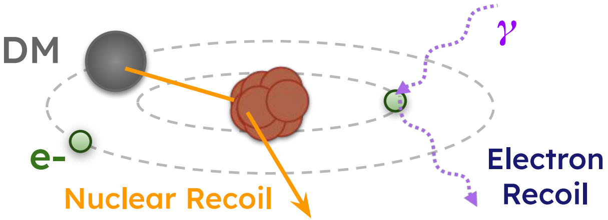
- Optimised for searching WIMPs with masses above ~3 GeV/c^2
- Sensitive to additional processes, including BSM physics: $0\nu\beta\beta$, axions, etc
- Located 1 mile underground at the Sanford Underground Research Facility (SURF), SD (US)
- Comprises:
    - Liquid Xenon (LXe) Time Projection Chamber (TPC)
    - Veto system

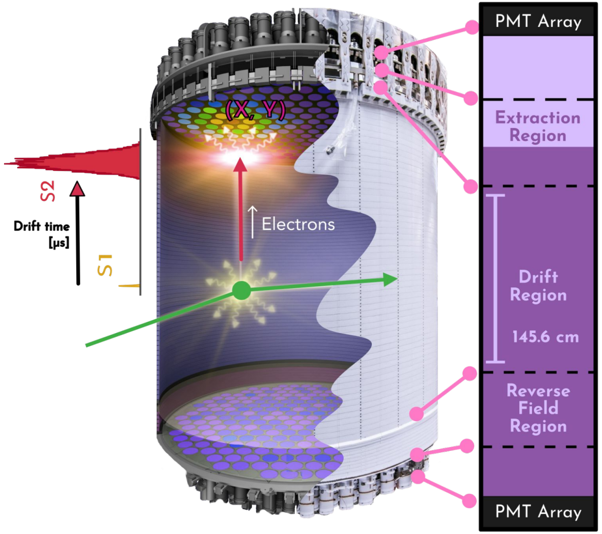
4,300 m.w.e
rock

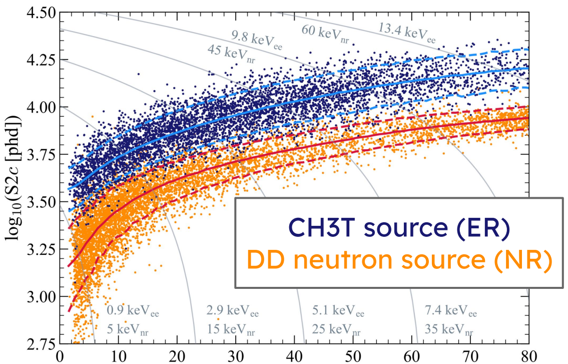


The LUX-ZEPLIN TPC

- 7t active mass dual-phase xenon TPC
- Events reconstructed combining scintillation (S1) and ionisation (S2)
- Light measured by 494 PMTs arranged in two arrays at top and bottom
- Excellent 3D position reconstruction (~mm)
- Single Scatter (SS) vs Multiple Scatter (MS) interactions discrimination
- S2/S1 signal size ratio allows nuclear (NR) vs electron (ER) recoil discrimination







Phys. Rev. Lett. 131, 041002 (2023)

Veto system

Two subsystems:

Outer detector

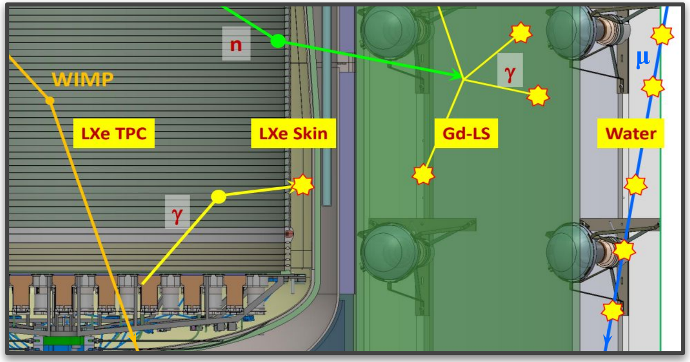
Purpose:

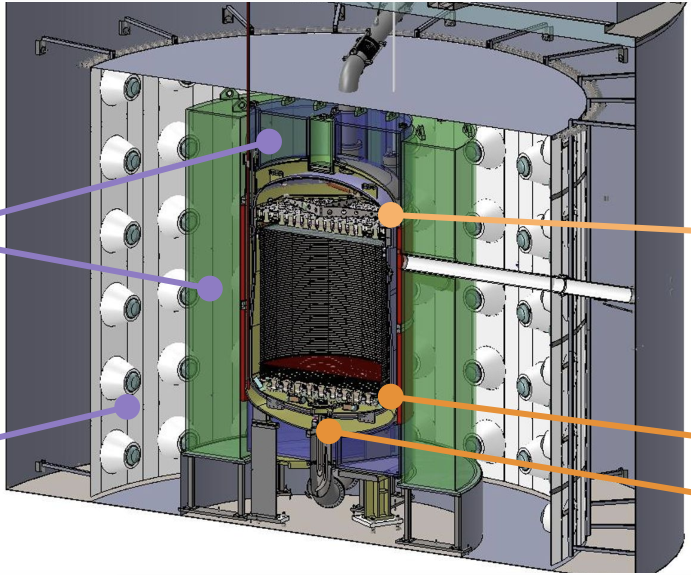
- active muon and internal neutrons veto
- passive external neutron /γ veto

See E. Bishop talk this afternoon

Comprises:

1. 10 UV-transparent acrylic tanks with 17t of Gd-loaded (0.1% by mass) liquid scintillator
2. 238t ultra-pure water tank with 120 8-inch PMTs



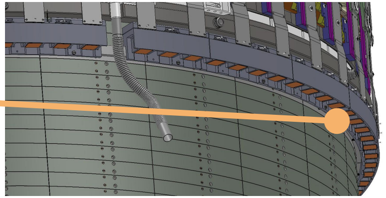


LXe *Skin* detector

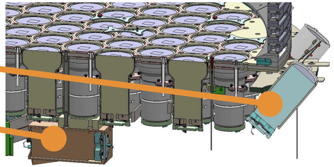
Purpose: veto Compton recoils from ~MeV radiogenic γ-rays

2t-LXe region between TPC outer walls and inner cryostat vessel instrumented with:

- 93 PMTs at the top



- 38 PMTs at the bottom



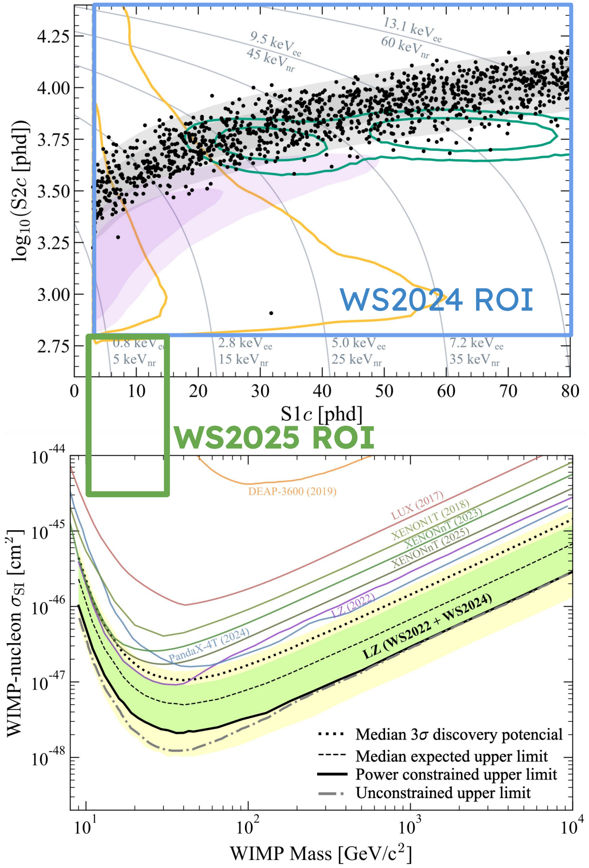
Phys. Rev. Lett. **135**, 011802

WS2024 result

- ROI targeted ≥9 GeV/c^2 DM masses
- Novel features incorporated into the analysis:
  - Rn-tag reduced 60% primary ER BGs
  - Charge yield suppression modelled and measured in EC and DEC
- Bias mitigation technique
- Final exposure included in PLR: 4.2 tonne·yr
  - WS2022: 60 days x 5.5 t = 0.9 tonne·yr exposure
  - WS2024: 220 days x 5.5 t = 3.3 tonne·yr exposure

Result: world leading constraints → 2.2 × 10^{-48} cm^2 for 40 GeV/c^2 WIMP

What's next? Shift to **lighter DM masses** → WS2025
New set of challenges



NR light/charge modelling

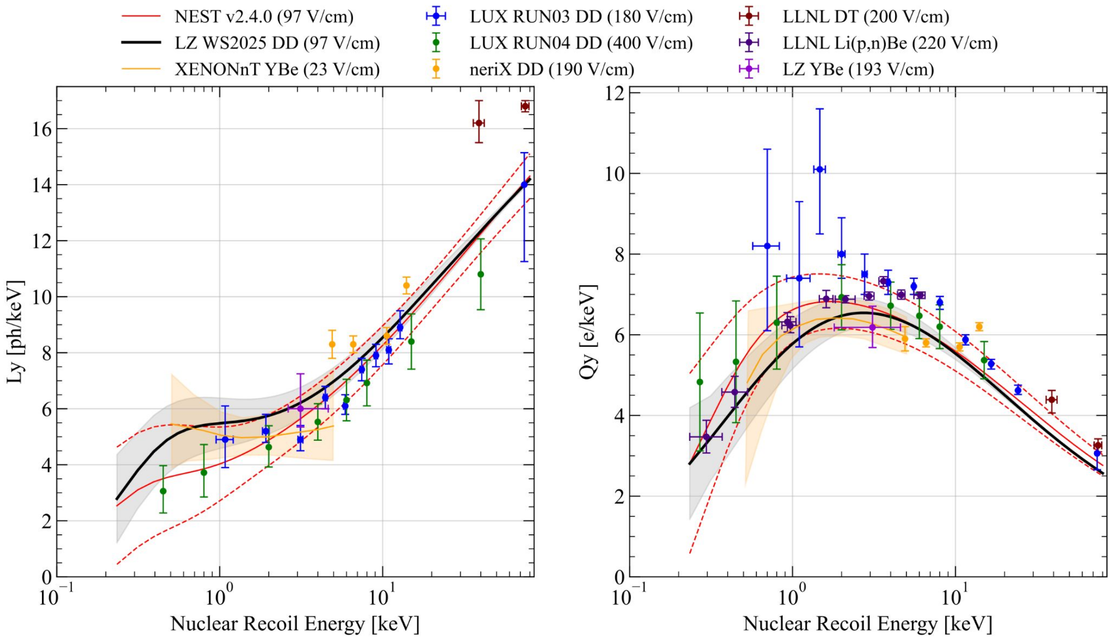
In LZ, NEST (Noble Element Simulation Technique) is used to model ER and NR responses

Such low ROI never explored in the experiment:

- Well calibrated low-energy NR response model with systematic uncertainties required

- DD 2.45 MeV monoenergetic neutron data exploited to model NR up to 74 keV:

  → Markov Chain Monte Carlo used to refine NEST model to match DD response



Accidental backgrounds

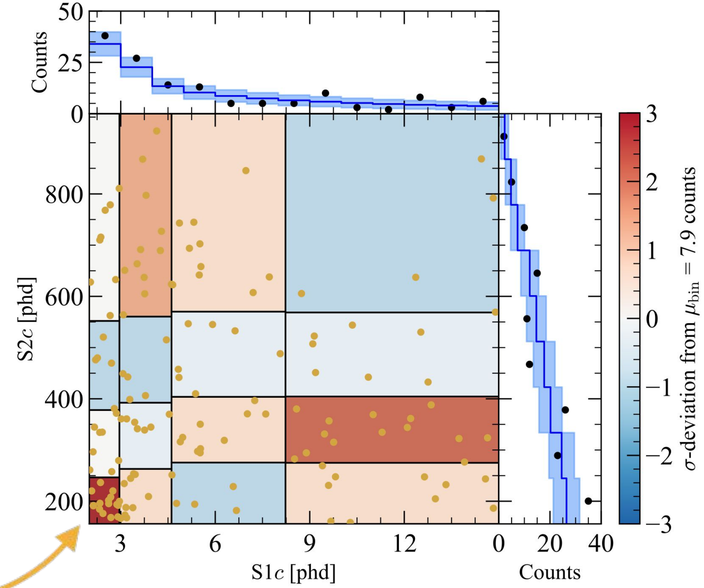
See R. Coronel talk on Thursday for more details!

Background dominated by accidental pile-up of unrelated isolated S1 and S2 pulses that mimic expected SS DM events

They can come from, e.g., PMT dark counts, charge loss near TPC walls, large γ/e- rates after big deposits

To deal with them:

1. Targeted by simultaneously optimised set of cuts across multiple spaces
2. Modelled by:
   2.1. Combining iS1s and iS2s from similar γ+e- rate environment
   2.2. Resulting S1c-S2c spectrum rate normalised to known accidental events (SS with unphysical drift)



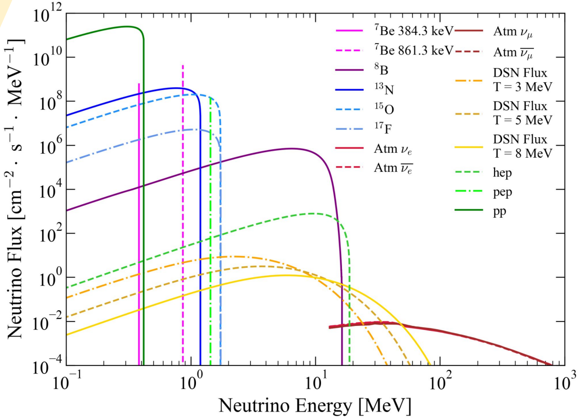
Predict 6.6 ± 0.3 events in full exposure

CEνNS from solar ^{8}B neutrinos

CEνNS first measured by the COHERENT experiment in 2017 using the Spallation Neutron Source

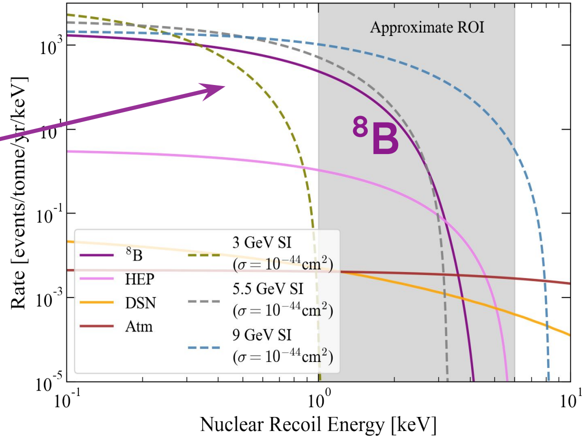
First indications (<3σ) of CEνNS from solar neutrinos in LXe from:

- PandaX-4T *PRL **133**, 191001 (2024)*
- XENONnT *PRL **133**, 191002 (2024)*



- Similar signal to 5.5 GeV/c^2 DM candidate
- Assume Standard Model CEνNS cross-section and ^{8}B flux measured by SNO experiment

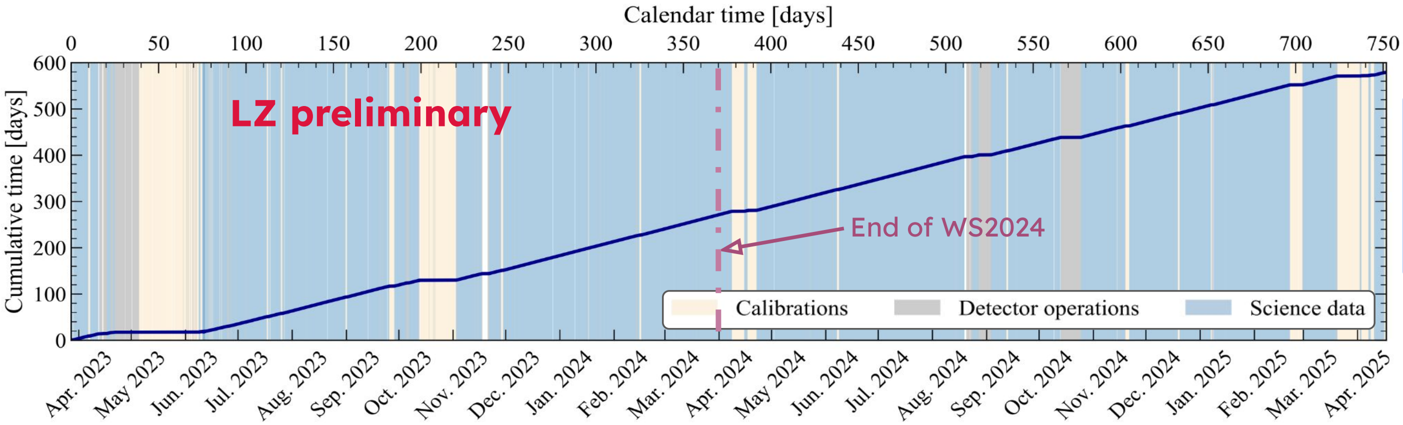
→ Expect **20.6$^{+8.9}_{-6.8}$** events



WS2025 dataset

- From March 2023 to April 2025 → 1 extra year *cf.* WS2024
- Very stable run conditions along run
- Dedicated neutron calibration runs to study veto eff and NR model
- Additional calibrations to correct spatial and temporal variation in detector response

→ 417 live-day exposure (after data-quality/exclusions)



- Drift field 97 V/cm
- Extraction field of 3.4 kV/cm

Bias mitigation: salting

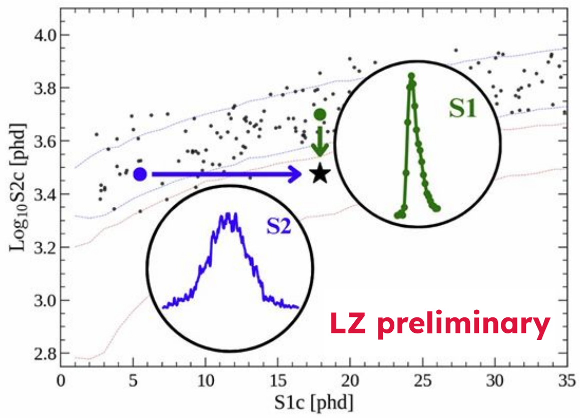
[Eur. Phys. J. C **81**, 907 (2021)]

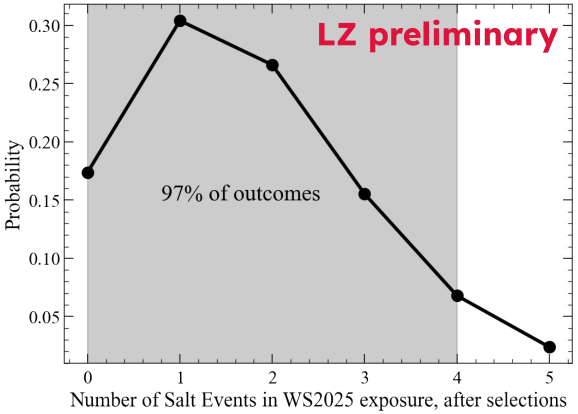
Artificial signal events (salt) are randomly injected into the datastream

- ➔ Salt events generated by combining S1/S2 pulses from sequestered calibration data at waveform level
- ➔ Distributions sampled from expected ^{8}B spectrum and DM-like scatters
- ➔ Injected salt rate chosen to match Poisson uncertainty on expected ^{8}B CEνNS rate based on WS2024 NR model

97% Poisson probability of having 0-4 salt events in WS2025 dataset

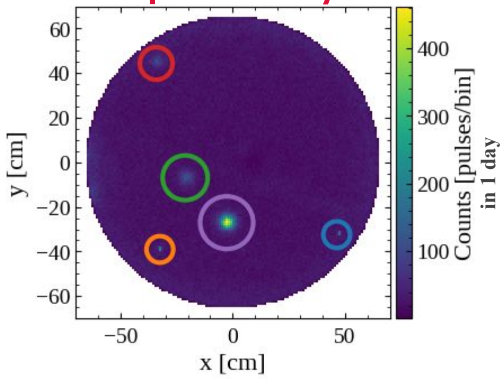
Salt only revealed after all analysis selections and decisions are finalised

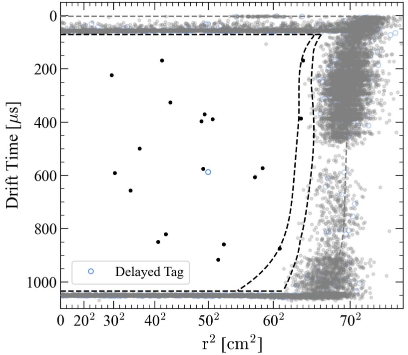


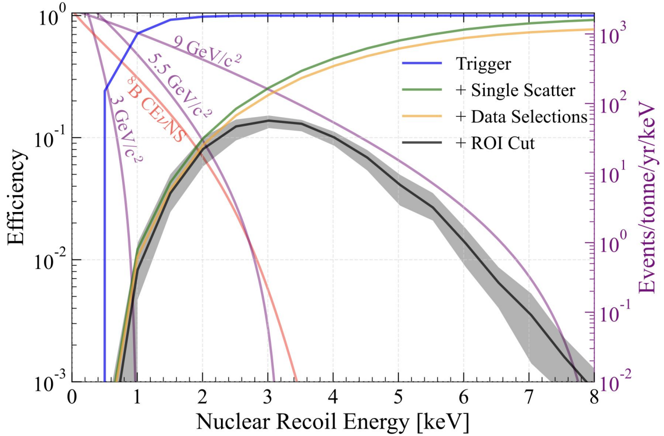


Analysis cuts overview

- **ROI:**
  - **≥3-fold** PMT S1
  - S1c in [2,15] phd
  - S2 in [3.5, 14.5] e-
- **Data quality**: time-based exclusions, hold-offs after large energy depositions,...
- **Fiducial volume** → 5.09 ± 0.15 tonnes
- Additional **hotspot veto (~1% exposure reduction)** removes periods in time and space due to electrode electron emission See Y. Zhou poster
- **S1**- and **S2**-based cuts for accidentals reduction
- External **vetoes**: prompt + delayed Skin or/and OD → 92 ± 4 % neutron-tag efficiency (from BG neutron simulations tuned with AmBe+AmLi)

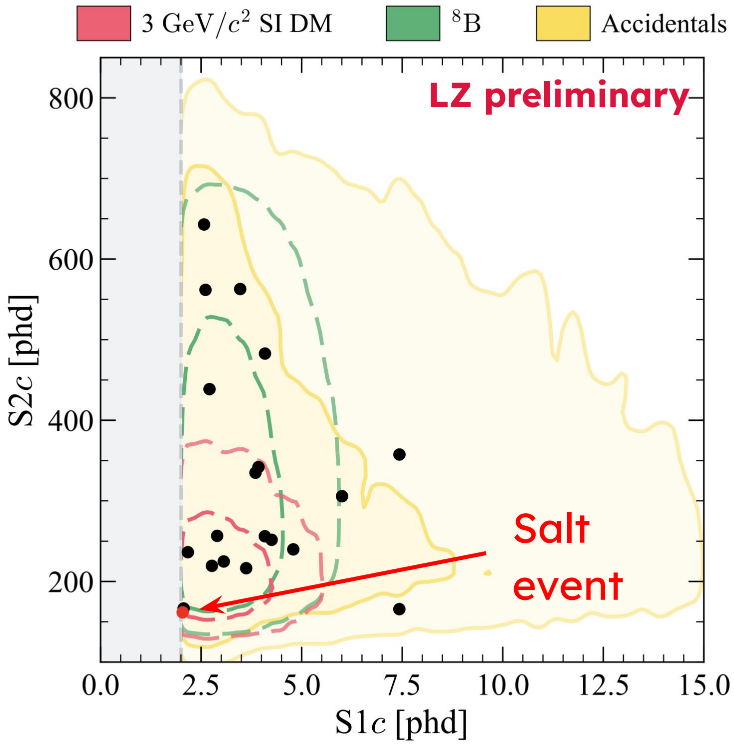






Final dataset

- **20 events** in dataset after all selections
  → 1 of them revealed to be salt
- No post-unsalting changes to model
- "Neutron-rich" sideband included (i.e. passing all selection but delayed veto) → 1 event (Expected $0.04^{+0.25}_{-0.04}$)
- Statistical analysis in observed S1c vs $\log_{10}$(S2c) space
- Data used in two PLR tests:
  1) 3-9 GeV/c^2 dark matter search
  2) ^{8}B CEνNS search



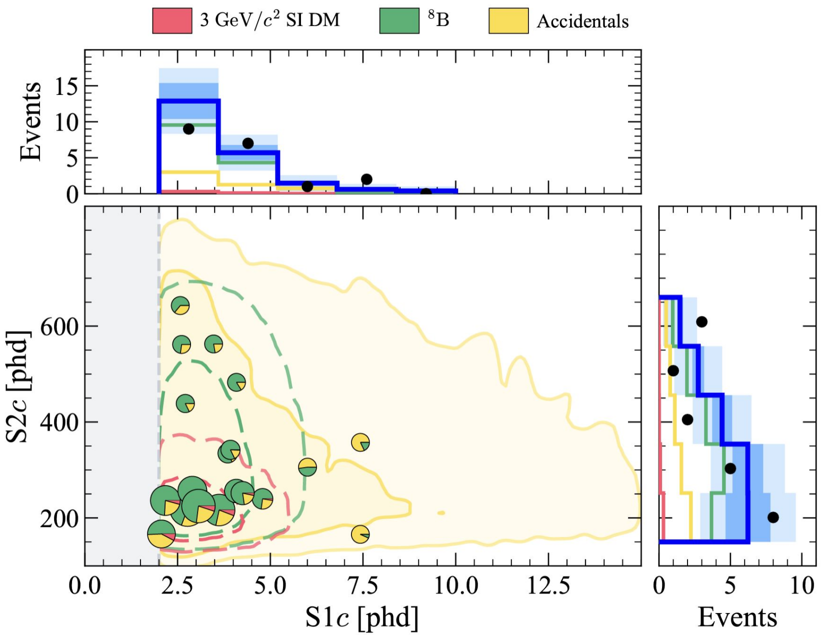
Low-mass WS search

arXiv:2512.08065

- Backgrounds: ^{8}B CEνNS, accidental coincidences, and detector neutrons
- ^{8}B CEνNS rate constrained based on predictions using SNO measurement*

- Best-fit number of DM events consistent with **0** at all DM masses tested

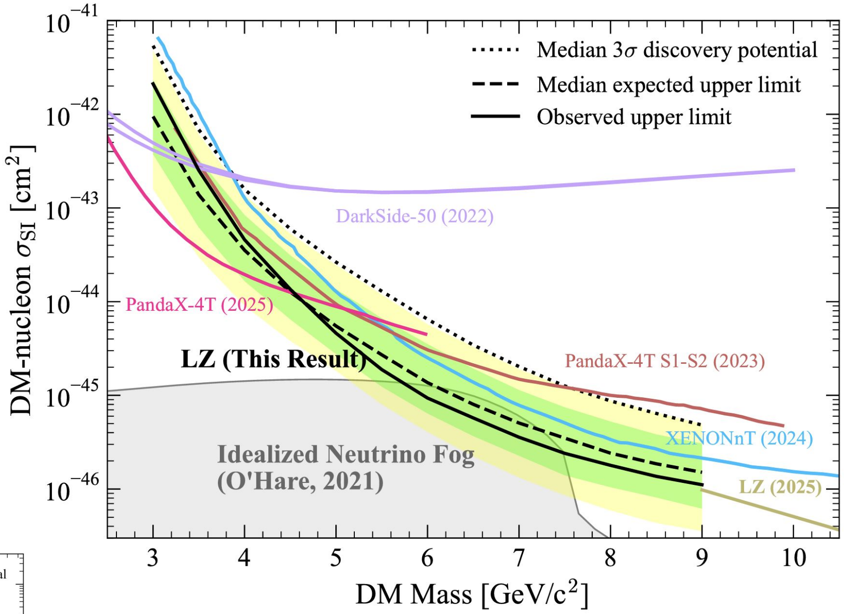
Components	Expectation	Background-Only Fit	3 GeV/c^2 Fit	9 GeV/c^2 Fit
SI DM	-	-	$0.4^{+5.4}_{-0.4}$	$0.0^{+4.0}_{-0.0}$
^{8}B CEνNS	$20.6^{+8.9}_{-6.8}$	$15.0^{+2.9}_{-2.5}$	$14.7^{+3.0}_{-2.8}$	$15.0^{+2.9}_{-2.5}$
Accidental coinc.	6.6 ± 0.3	6.5 ± 0.3	6.5 ± 0.3	6.5 ± 0.3
Detector neutrons	$0.04^{+0.25}_{-0.04}$	$0.1^{+0.2}_{-0.1}$	$0.1^{+0.2}_{-0.1}$	$0.1^{+0.2}_{-0.1}$
Total	$27.2^{+10.1}_{-7.3}$	$21.6^{+4.7}_{-3.8}$	$21.7^{+6.2}_{-2.8}$	$21.6^{+5.0}_{-2.5}$
σ_{eff}	0 ± 1	$-0.81^{+0.59}_{-0.60}$	$-0.86^{+0.63}_{-0.71}$	$-0.81^{+0.58}_{-0.60}$



*Phys. Rev. C **88**, 025501 (2013)

Low-mass WS search

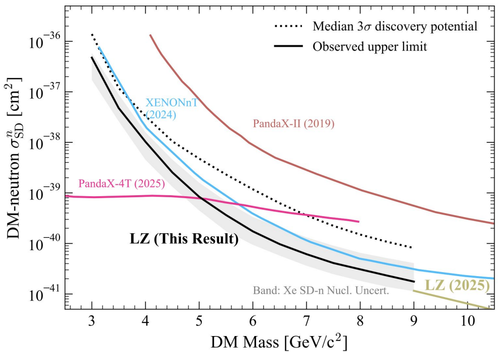
arXiv:2512.08065

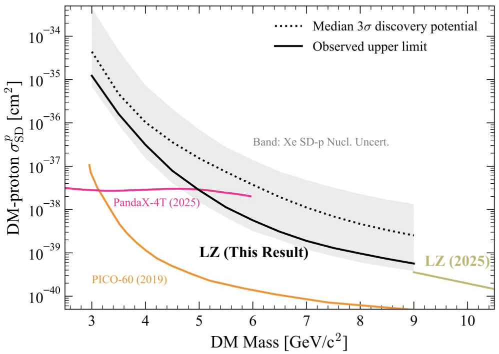


Exclusion limit with two-sided test statistic

- Factor of two improvement in sensitivity over existing limits between 5 and 9 GeV/c^2
- World-leading limits > 5 GeV/c^2

Limits on SD neutron-only and proton-only:





8B CEνNS measurement

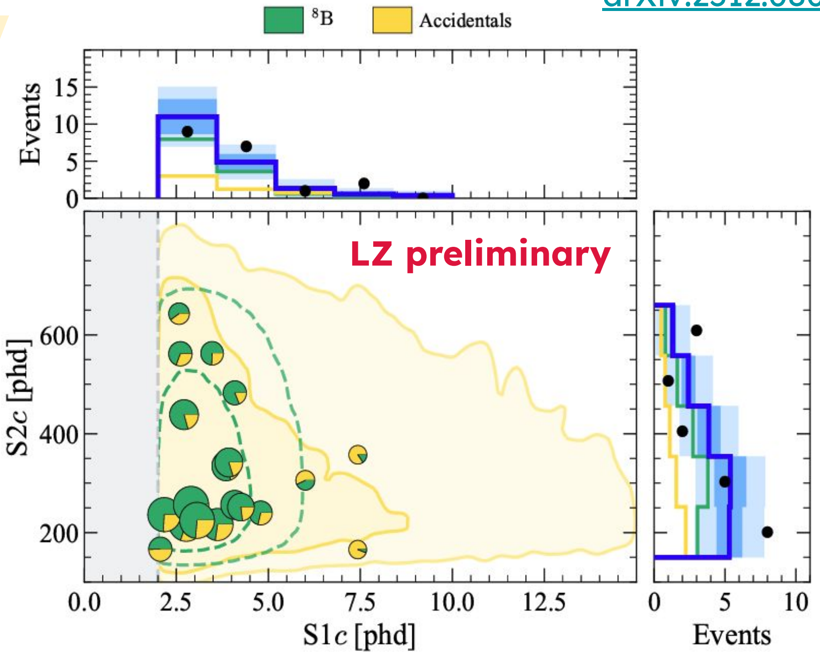
PLR test statistic to reject background-only model

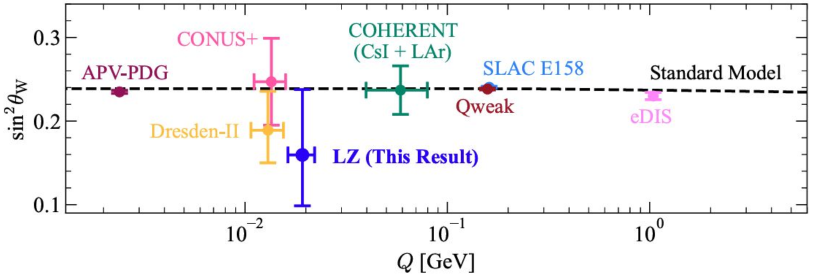
- Assumed no DM events
- Unconstrained ^{8}B CEνNS rate

Components	Expectation	Fit Results
^{8}B CEνNS	-	$12.3^{+7.0}_{-5.4}$
Accidental coincidences	6.6 ± 0.3	6.6 ± 0.3
Detector neutrons	$0.04^{+0.25}_{-0.04}$	$0.1^{+0.2}_{-0.1}$
Total	6.6 ± 0.3	$18.9^{+7.0}_{-5.5}$

➔ Background-only model rejected with 4.5σ significance

Measure weak-mixing angle ($\sin^2\theta_W$) at low momentum transfer (Q), consistent with SM





Other LZ DM searches and prospects

LZ can search for alternative candidates and in different energy regimes:

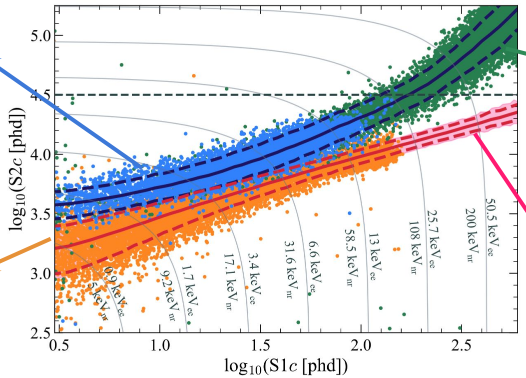
Low-energy ER

- LEER searches (*Phys.Rev.D **108**,072006 (2023)*)
- Atmospheric millicharge particles (*PRL **134**, 241802 (2025)*)

Low-energy NR

- Cosmic ray-boosted Dark Matter - *PRL **134**, 241801 (2025)*
- WIMP-pion - *Commun Phys **7**,292 (2024)*

Phys. Rev. D **109**, 092003 (2024)



High-energy ER

- e.g. Lightly Ionizing Particle searches

High-energy NR

- WIMP-nucleon EFT - *PRL **133**, 221801 (2024)*
- Ultraheavy DM - *Phys. Rev. D **109**, 112010 (2024)*

Plus other non-DM searches in the horizon → **$0\nu\beta\beta$**

Further into the future, much larger exposures needed to fully cover the space parameter until the neutrino fog at larger DM masses…

See related contributions from Adam S-B., Ferdos D., Rebecca H.

arXiv:2410.17137

Summary

- World leading limit to WIMP dark matter >5 GeV/c^2
- Strongest evidence (4.5σ) of solar neutrinos CEvNS in xenon
- Higher mass DM searches are not yet entering the neutrino fog, still larger exposures needed
- LZ continues to operate as we take data towards a 1000 day DM discovery dataset by end 2027
- Many other alternative candidate searches in the horizon $\rightarrow$ stay tuned!

Thank you for listening!

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LZ

And don't forget to check all the other LZ contributions!

Constraining Environmental Backgrounds for Rare Event Searches with LZ (talk) E. Bishop

Electrode backgrounds in the LZ experiment (poster) Y. Zhou

First observation of positron emission decay of Xe-125 in a liquid xenon detector from the LUX-ZEPLIN Experiment (poster) M. Hernandez

Modeling the low-energy accidental coincidence background in the LUX-ZEPLIN experiment (talk) R. Coronel

@lzdarkmatter

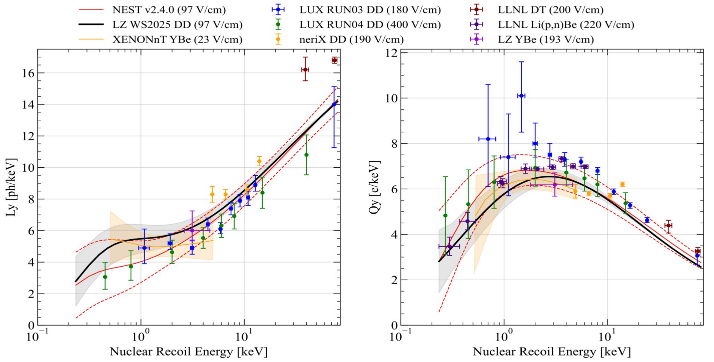
LZ Collaboration Meeting at SURF, June 2023

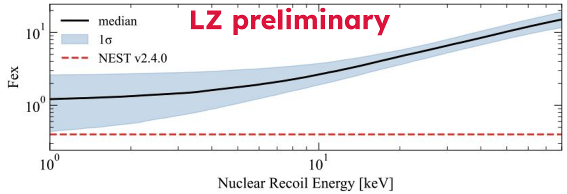
backup

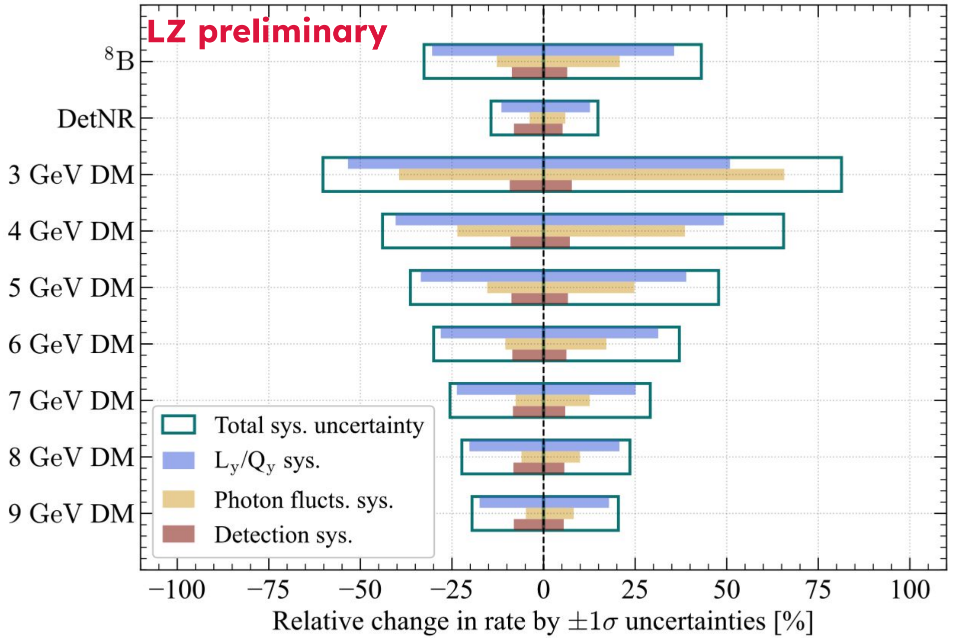
Systematic Uncertainties

Total uncertainty combined the one coming from the updated DD-based NR model (from both yields and fluctuations) and detector response

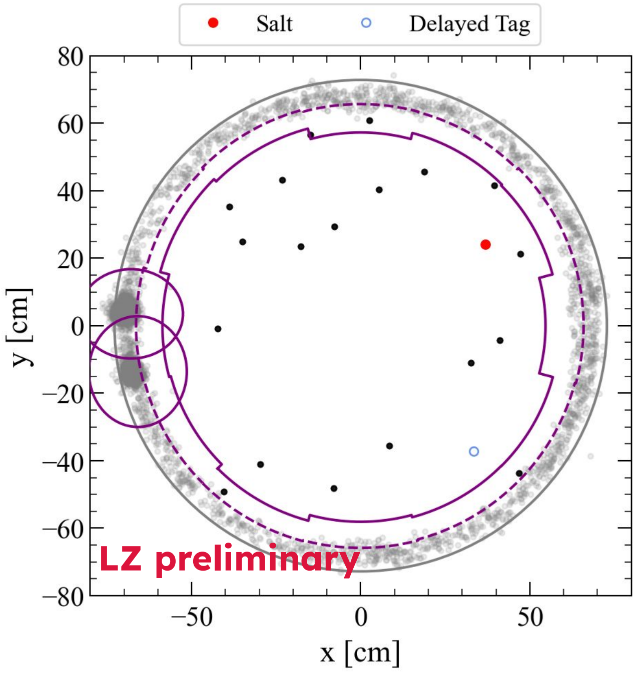
The former dominates:

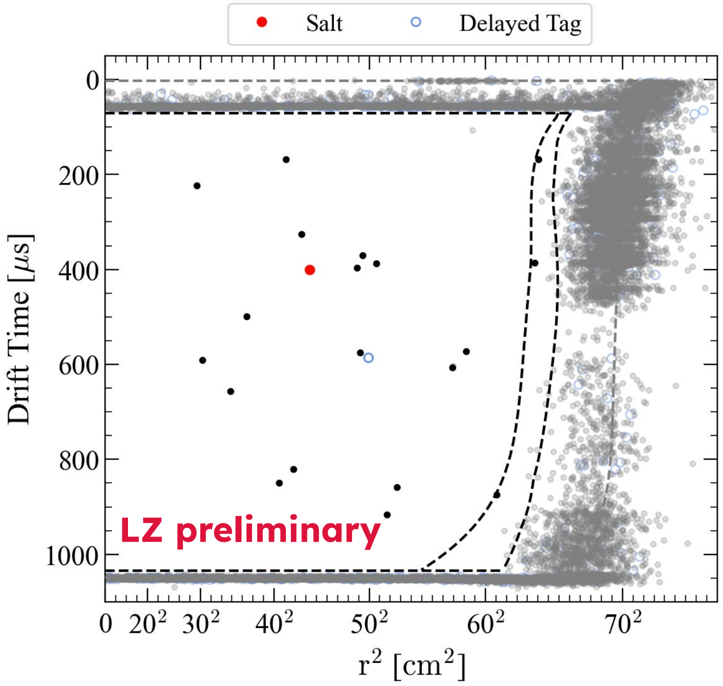






Final dataset - position in TPC

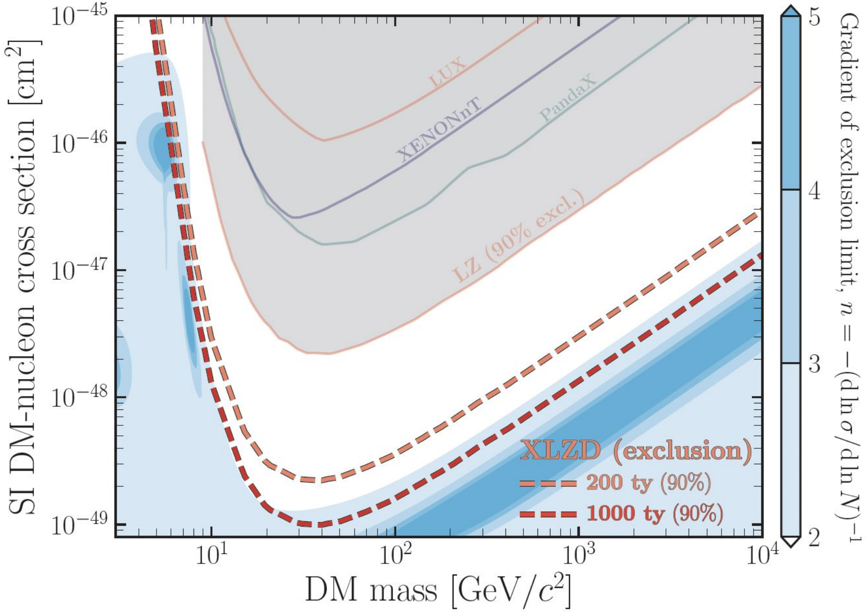




Future DM searches: XLZD

- Collaboration of LZ+XENONnT+DARWIN
- Baseline detector of ~60t
- Rare physics observatory
- Site not decided yet

XLZD last collaboration meeting at LNGS, July 2026



Eur. Phys. J. C (2025) **85**: 1192

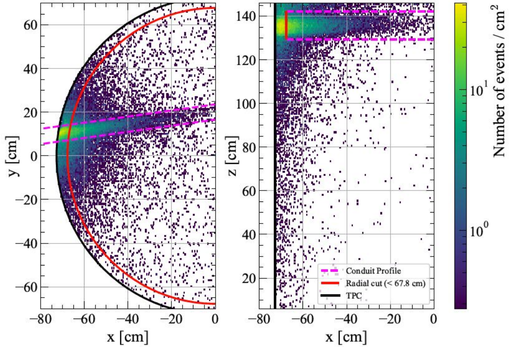
LZ NR calibration

We need to understand/model our detector response in this new regime

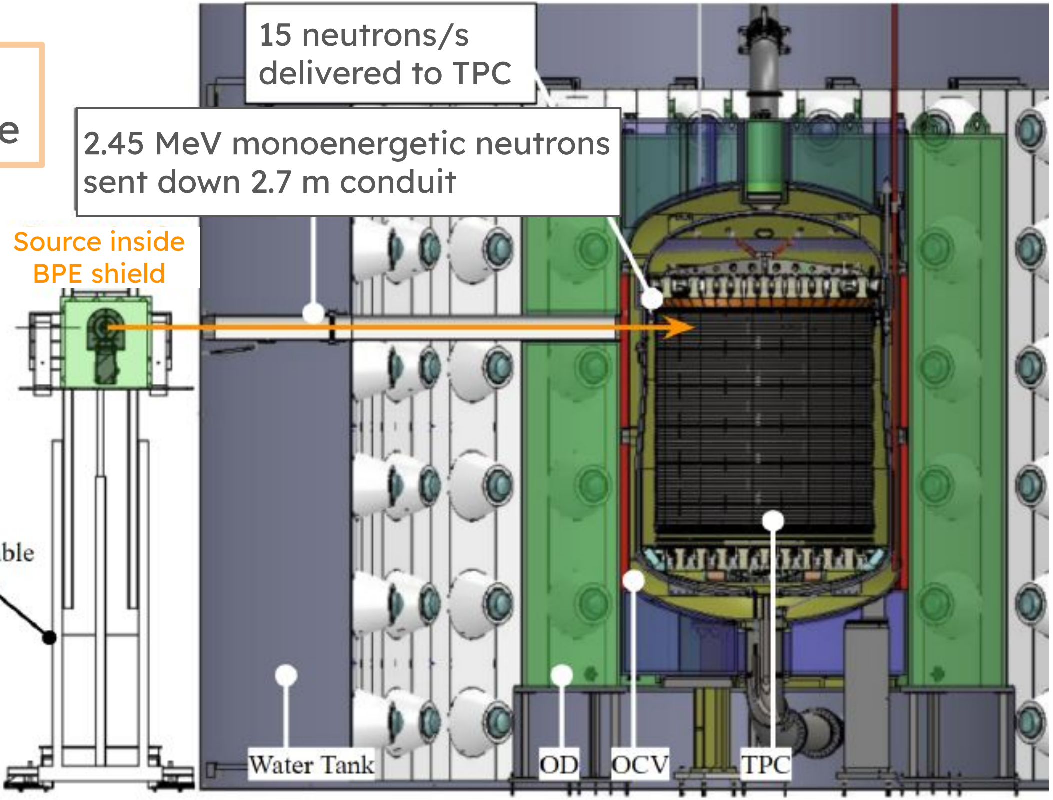
- Neutrons with 2.45 MeV produced from Deuterium-Deuterium (DD) fusion:

$$^{2}H + {}^{2}H \rightarrow {}^{3}He + n$$

- Triggered using plasma ignition



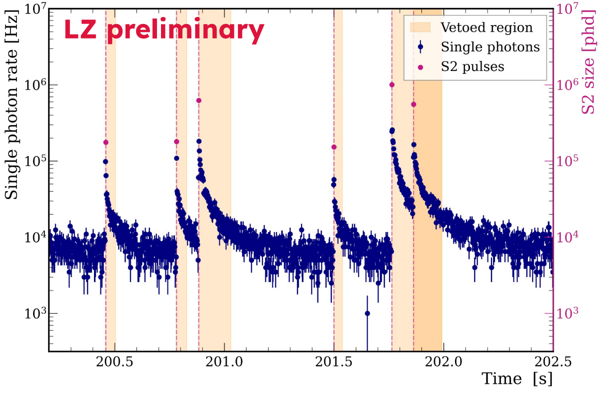
[JINST 19 P08027 (2024)]

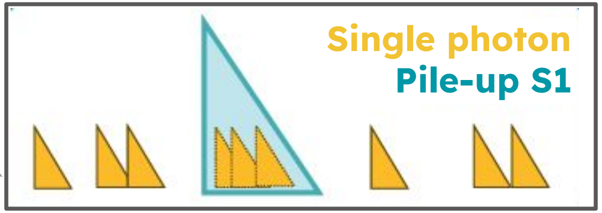


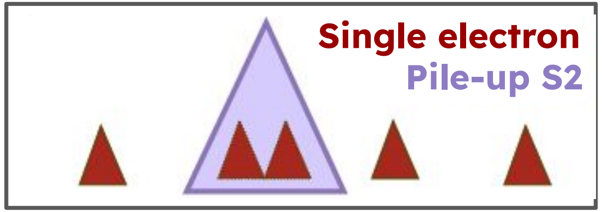
Accidental coincidences

Isolated S1s and S2s appear from a wide variety of instrumental effects, e.g.:

- PMT dark counts
- Insensitive regions (e.g. charge loss near the TPC walls)
- Large photon/electron rates after big energy depositions → single photons/e- can pile up to form isolated S1s and S2s respectively







They can pile-up to **fake single scatters**, especially forming small pulses…

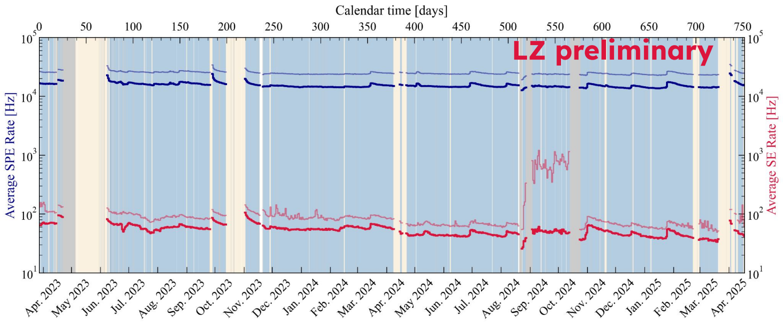
Main contribution to backgrounds in this search, given the small size of S2s considered

⇨ Need to <u>mitigate</u> & <u>model</u> them!

Accidental coincidence model

Step 1: Create data-driven synthetic accidental-like dataset

⟹ **Idea**: pair iS1 and iS2 events to create artificial SS-like event



However, pile-up S1 more likely to be accidentally paired with pile-up S2

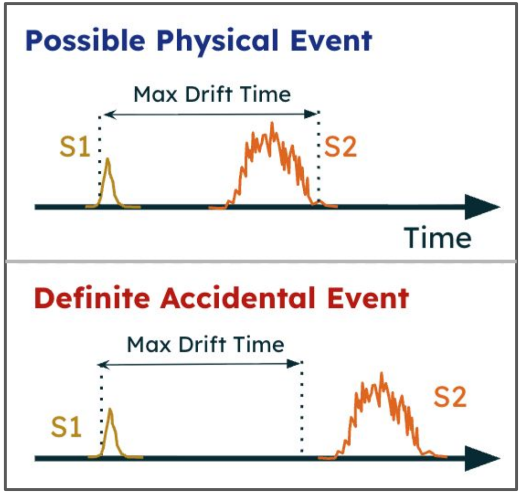
To consider that → isolated pulses <u>from same single-photon and single-electron rate environment</u> are stitched

Accidental coincidence model

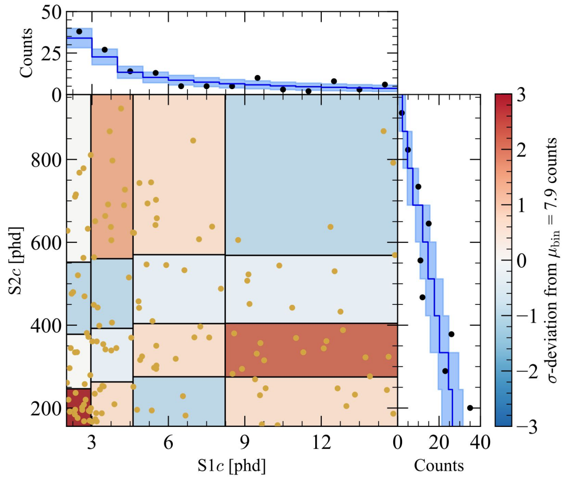
Step 2: Normalise rate of artificial dataset

➡ **Idea**: use SS with unphysically long drift times

Prediction: **6.6 ± 0.3** events in full exposure



Step 3: Validate model with multiple datasets



arXiv:2512.08065

Observe excellent agreement across datasets with a variety of detector conditions

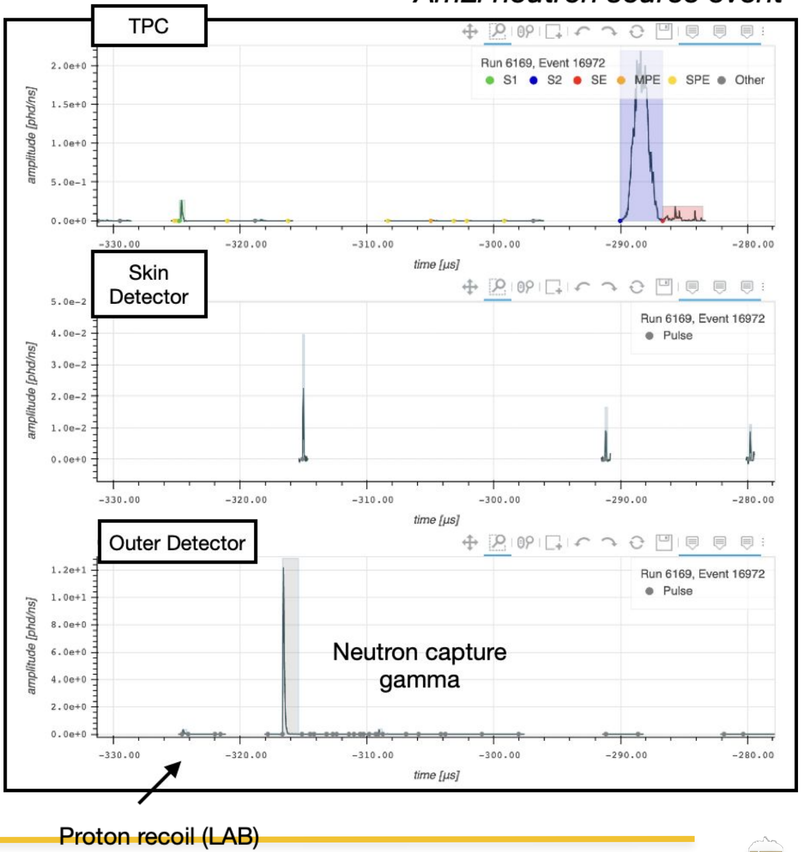
Analysis cuts overview: vetoes

- OD and Skin serve as active vetoes to reject radiogenic neutrons with prompt and delayed coincidences (wrt S1)
- Delayed-Only neutron veto efficiency is 87 ± 2 %

Total neutron veto efficiency is **92 ± 4 %**

- Calculated from background neutrons simulations after validating with AmLi and AmBe neutron calibration data

AmLi neutron source event



Why Liquid Xenon (LXe)?

- Noble elements excellent media for building large, homogeneous, compact and self-shielding detectors.
- LXe & LAr excellent scintillators and good ionisers
- Liquid targets: high level of radiopurity / scalability
- Coherent scalar WIMP-nucleus scattering ($\sigma \propto A^2$)
- And more effective self-shielding
- In xenon: easy to remove Kr-85, but more difficult to remove Rn (comparable Z)
- Argon is spin=0, no option to perform spin-dependent searches
- Argon from atmosphere highly contaminated by Ar-39 -> U-Ar (difficult to extract and distillate large amounts)
- Xenon vs argon boiling point