# Evidence for Solar $^{8}$B CEνNS Interactions in the LUX-ZEPLIN Experiment


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On Behalf of LZ Collaboration


**Neutrino 2026 @** University of California, Irvine, CA, USA

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Supported by the DOE

# LUX-ZEPLIN (LZ) Collaboration,

## 38 Institutions; 250 scientists, engineers, and technical staff

@lzdarkmatter

https://lz.lbl.gov/

- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King's College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- Northwestern University
- Pennsylvania State University
- Royal Holloway University of London
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- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
- STFC Rutherford Appleton Lab.
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- University of Sheffield
- University of Sydney
- University of Texas at Austin
- University of Wisconsin, Madison
- University of Zürich

US Europe Asia Oceania

LZ Collaboration Meeting at UCLA, March 2025

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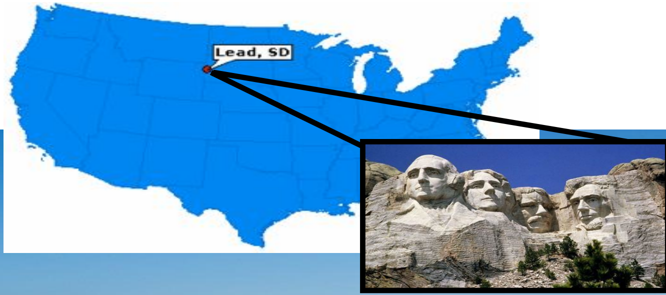
Swiss National Science Foundation

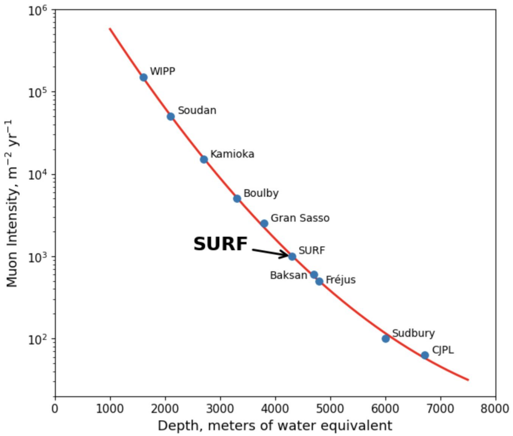
ibs Institute for Basic Science

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

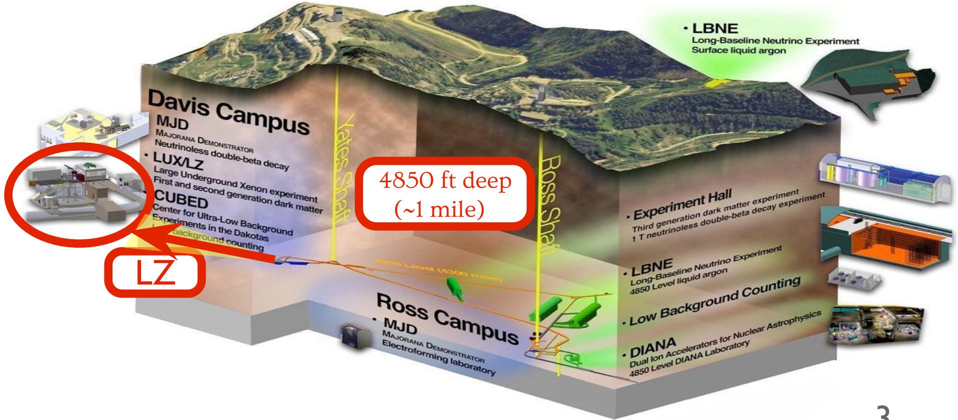
Thanks to our sponsors and participating institutions!

# LZ Experiment @ Sanford Underground Research Facility (SURF) in Lead, SD




Ray Davis, nobel prize winner



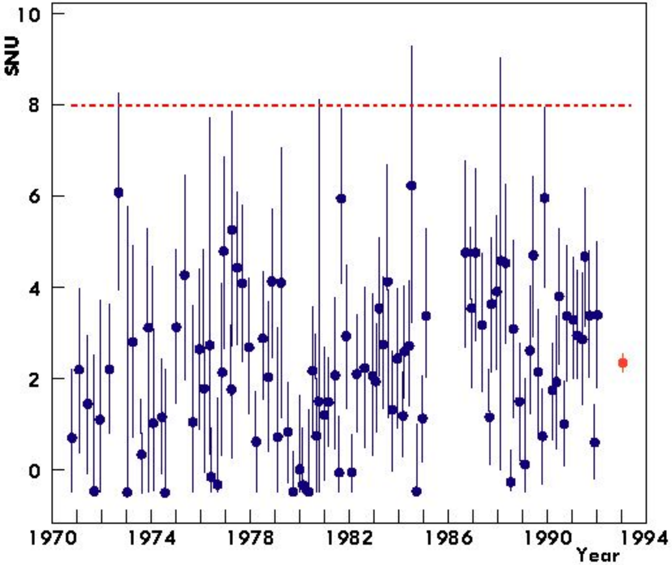

Muon flux reduced by $10^6$ (4.3 km.w.e)

# Solar Neutrino: A Long History at SURF



Solar neutrinos were first detected at the Davis experiment in the Homestake mine (SURF), leading to the **discovery of neutrino oscillations** and the 2002 Nobel Prize

**Davis Experiment Results**



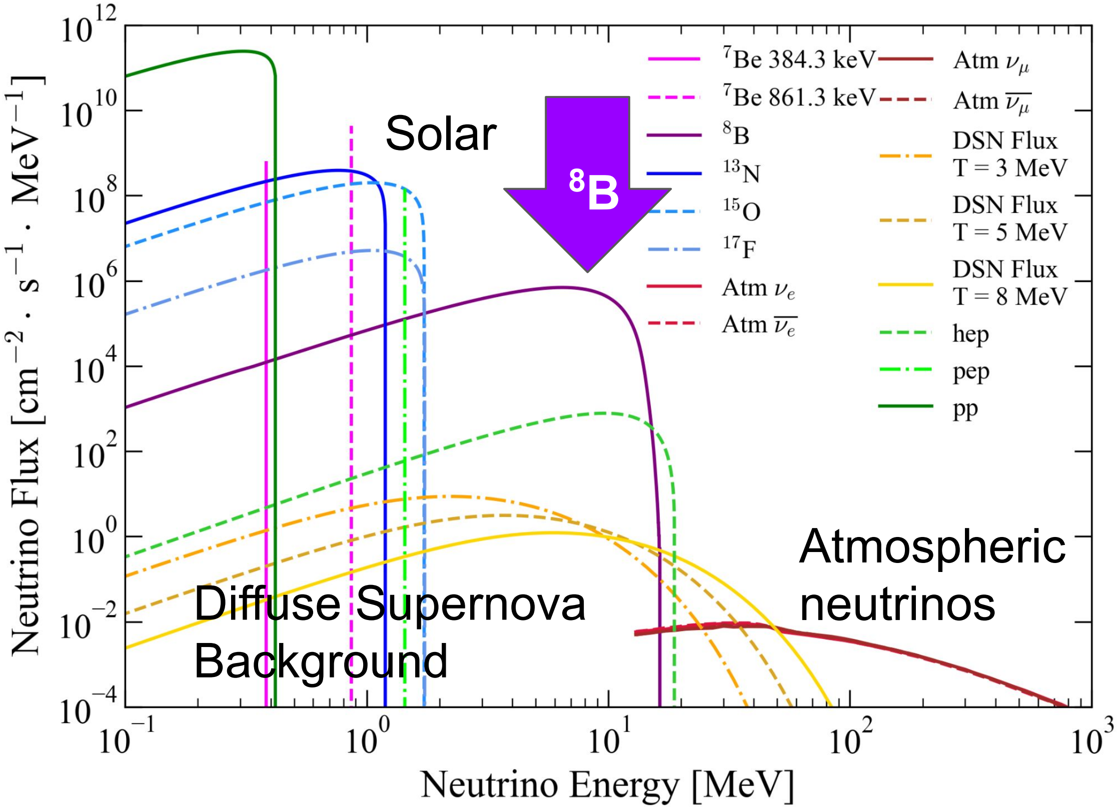

Measured **2.56 ± 0.23** SNU (0.48 atoms/day),

Solar Model Expectation = **7.7 ± 1.3** SNU (1.5 atoms/day)

Observation about 1/3 the expected number of solar neutrinos

1 SNU = 1 neutrino capture per $10^{36}$ target atoms per second

# Solar $^{8}$B Neutrino Signals




$^{8}$B neutrinos occupy a sweet spot: sufficiently high energy and relatively high flux

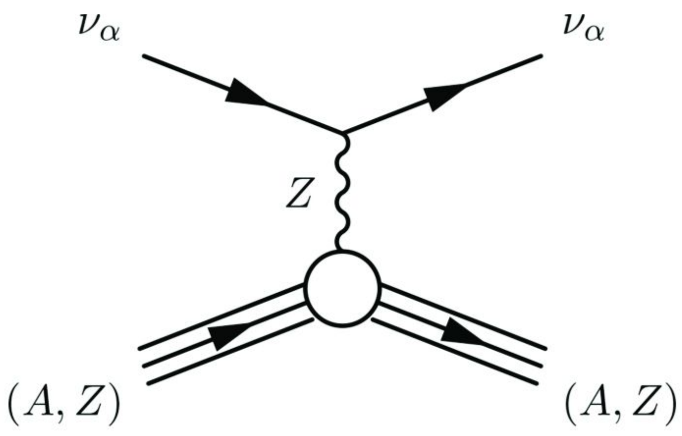
Energetic enough to produce detectable keV-scale Xe nuclear recoils via coherent scattering

Abundant enough to yield an observable event rate in a modest 5-tonne fiducial target originally designed for dark matter (DM) searches

# Coherent Elastic Neutrino-Nucleus Scatter (CEνNS)

**Well-predicted neutral current Standard Model process** proposed in the 1970s where neutrino “sees” whole nucleus

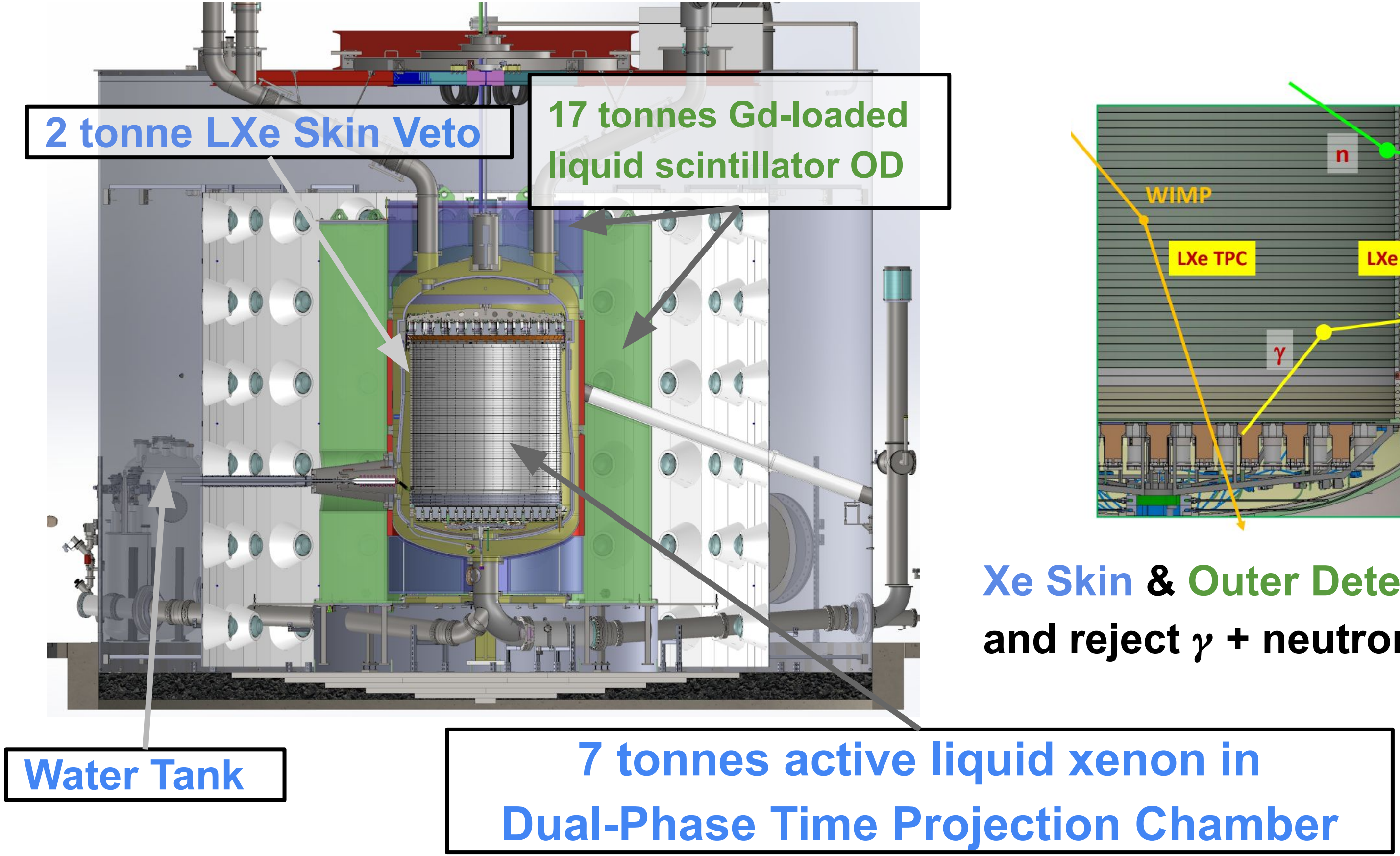
- Cross-section scales with neutrons squared
- First measured by the COHERENT experiment in 2017 using the Spallation Neutron Source *Science 357, 6356 (2017)*
- Additional measurements with reactor neutrinos by Dresden-II *PRL 129, 211802 (2022)*, CONUS+ *Nature 643, 1229-1233 (2025)*

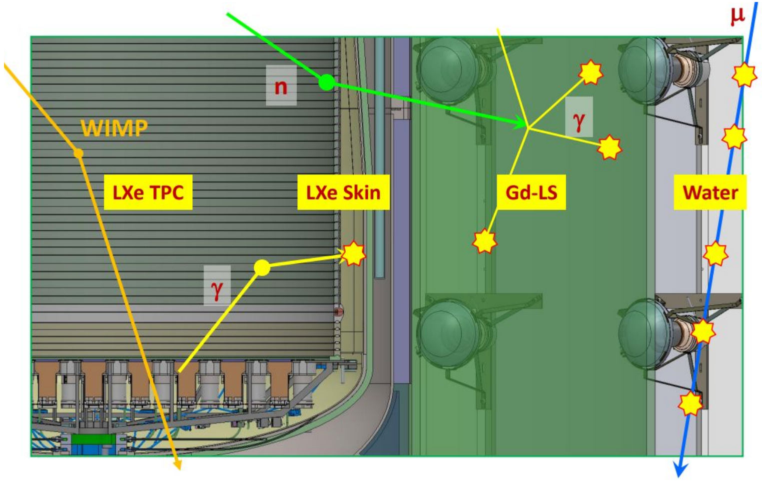



- First indications (< 3σ) of CEνNS with solar neutrinos from PandaX-4T *PRL 133, 191001 (2024)*, XENONnT *PRL 133, 191002 (2024)*

# The LUX-ZEPLIN (LZ) Detector

LZ Detector Design: NIM A, 953 163047 (2020)



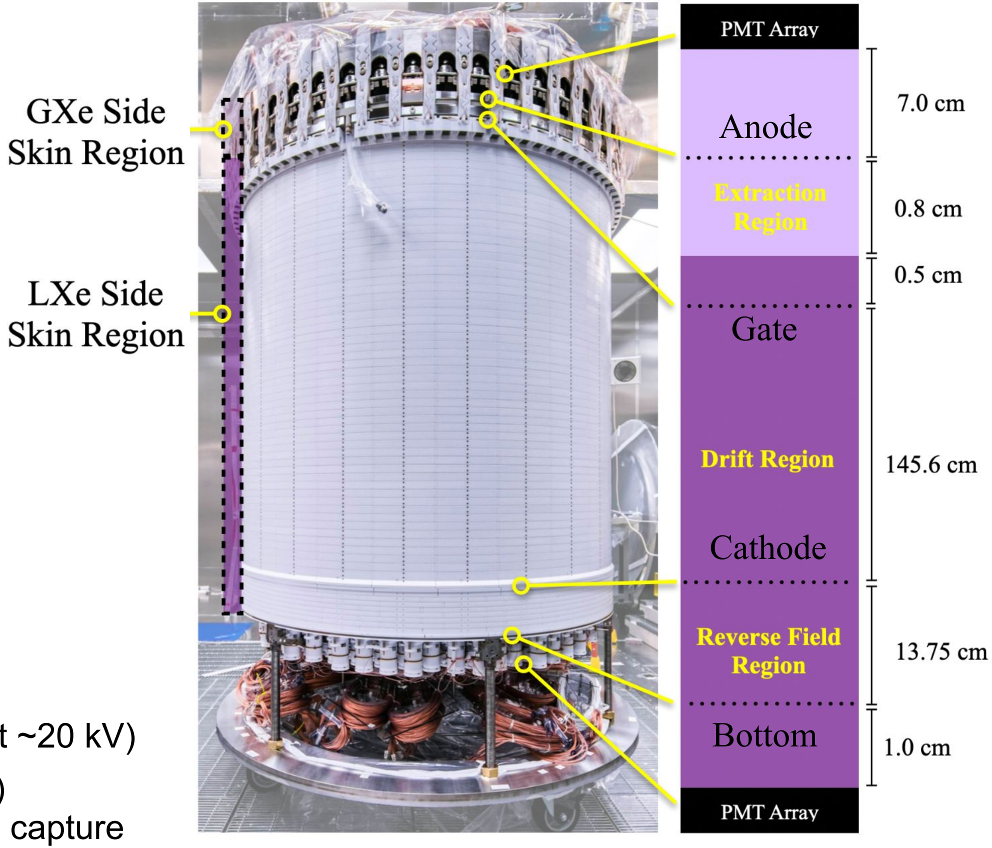




**Xe Skin & Outer Detector (OD) characterize and reject $\gamma$ + neutron backgrounds**

# LZ TPC Characteristics

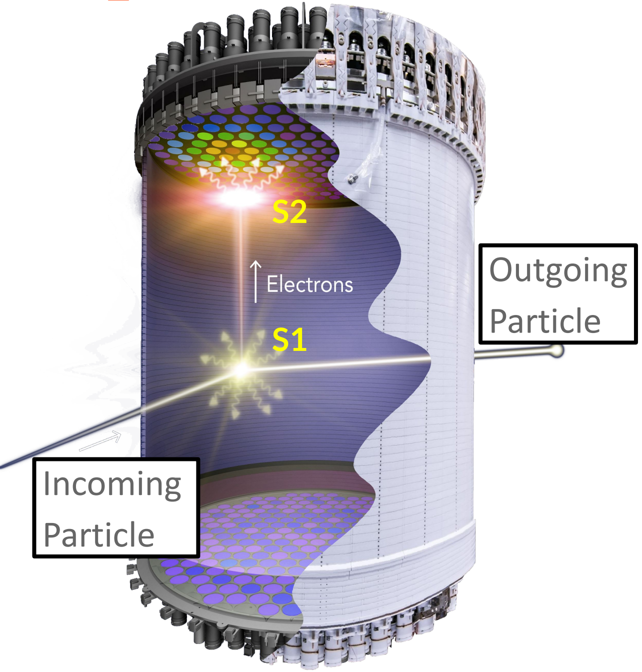
- Key Central TPC Detector:
  - TPC dimensions: **1.5 m tall x 1.5 m dia.**
  - **7 tonnes** active Xe mass -
    **biggest TPC currently operating!**
  - **494 PMTs** (single-photon detectors) in TPC
  - PTFE walls **~97% VUV reflectivity**
  - 4 custom-built woven electrode grids

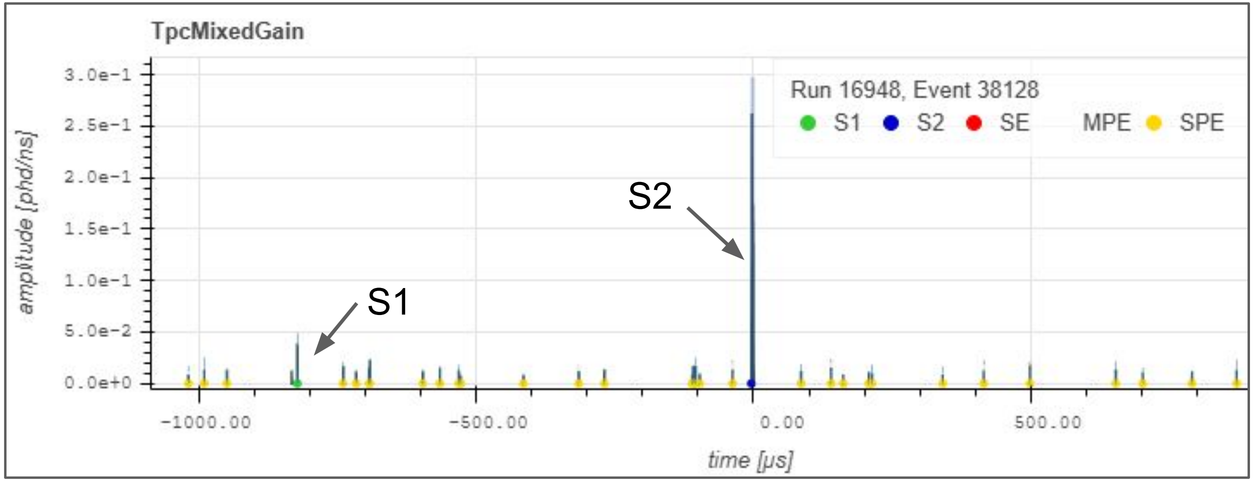
- Operational parameters:
  - Temperature: **~175 K**
  - Gas Pressure: **1.86 bara**
  - Drift Field: **97 V/cm** for this dataset (cathode at ~20 kV)
  - Electron lifetime ~15 ms (max drift time ~1 ms)
    **e- could drift >20 m** in Xe of this purity before capture




LZ electrode grid design:
[NIM A, 165955 (2022)]

# Liquid Xenon TPC Basics




- Two signals: S1 (prompt scintillation) and S2 (scintillation from ionization = drifted electrons)

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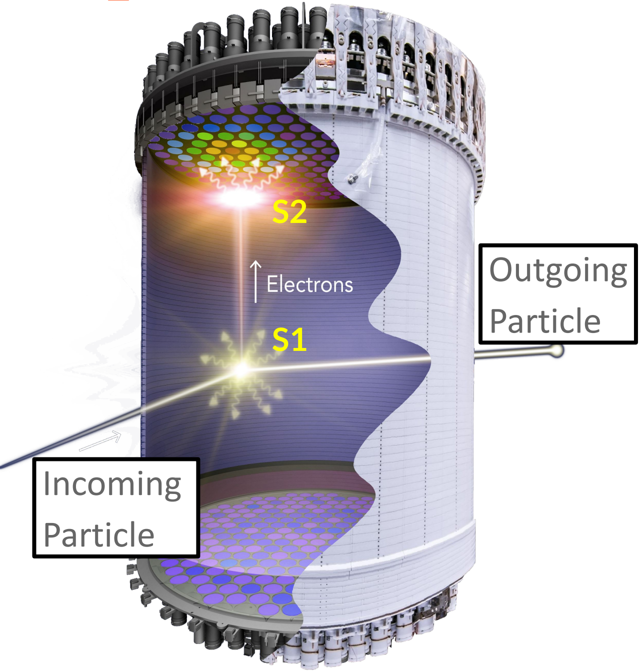


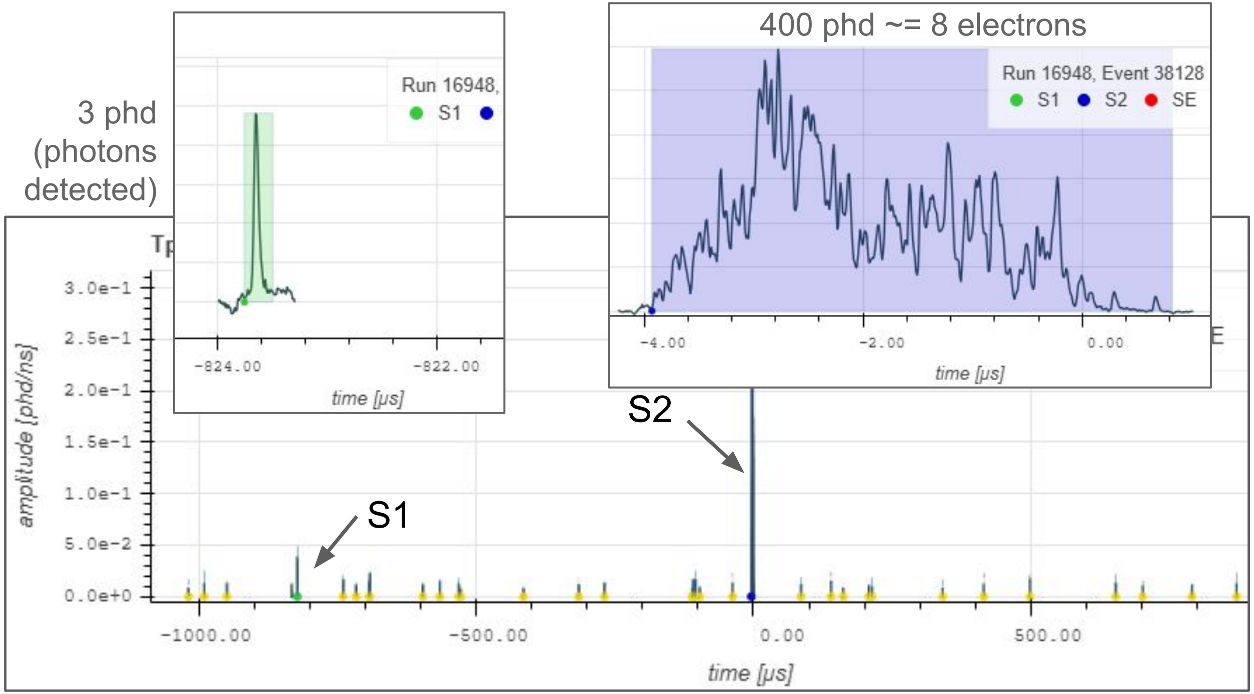


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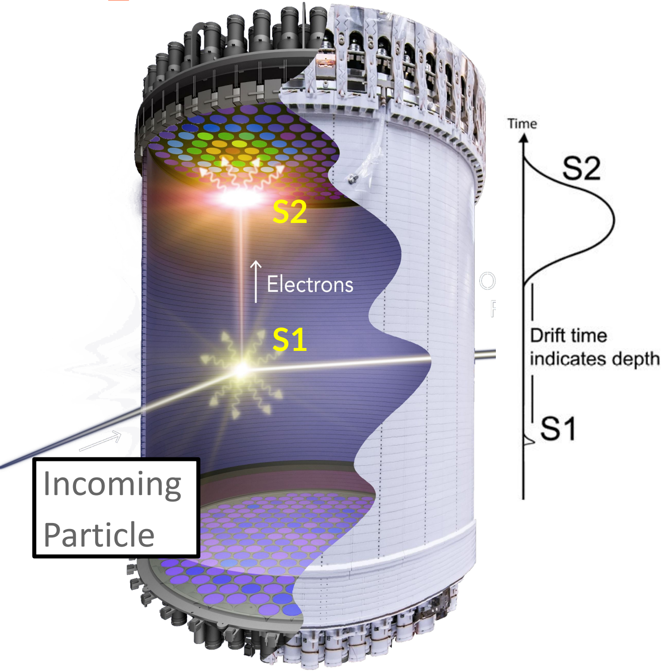
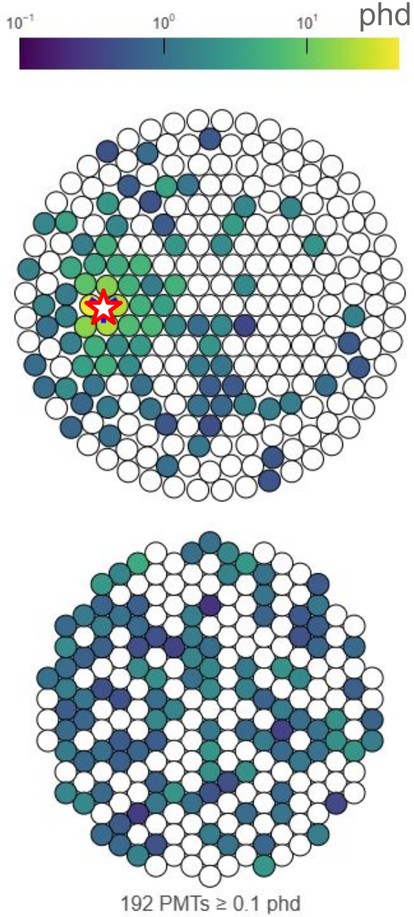
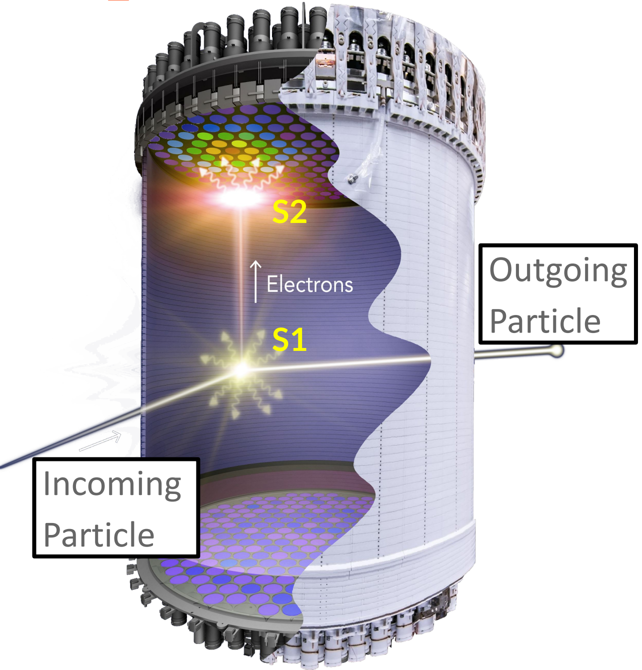




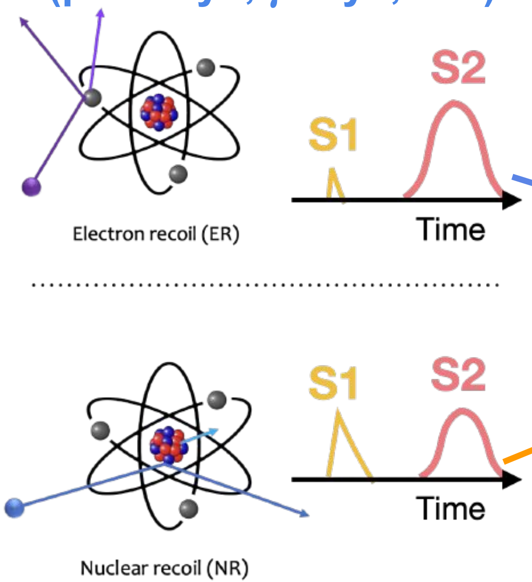


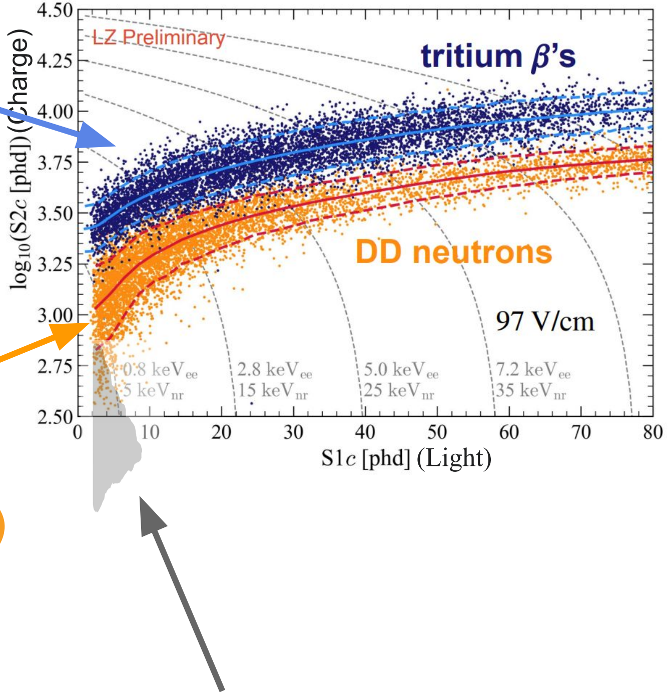

- 3D position reconstruction: x-y from S2 hitmap, z (depth) from drift time
- Xenon is self-shielding ⇒ reduced background near center
- Further discrimination from single vs multiple scatters

# Liquid Xenon TPC Basics




($\beta$ decays, $\gamma$ rays, $\nu$-$e^-$)



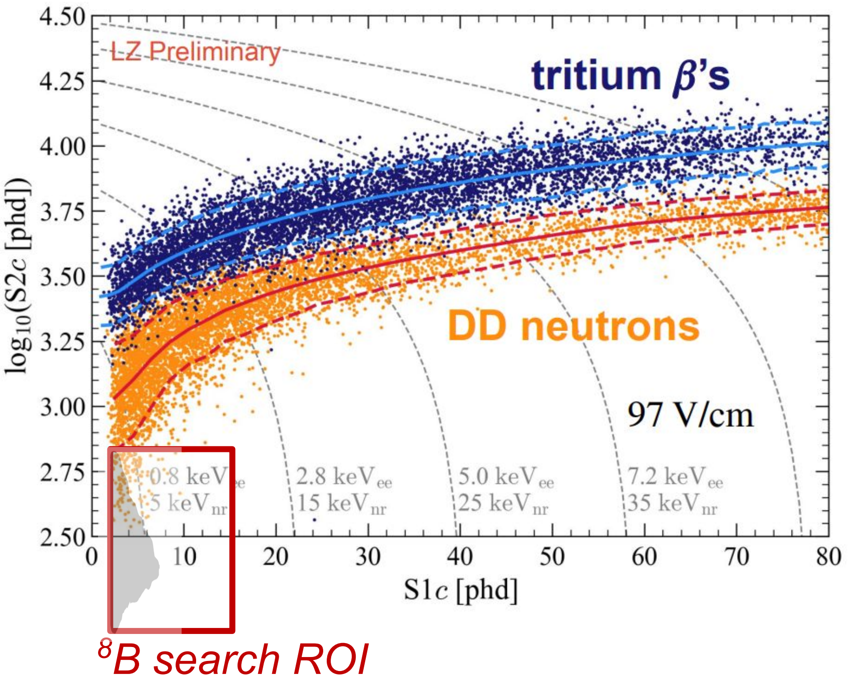



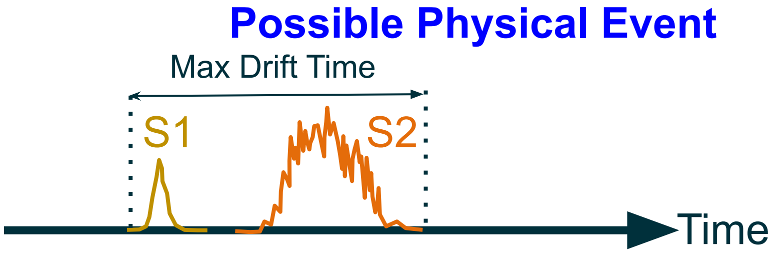

(CE$\nu$NS, WIMPs, neutrons)

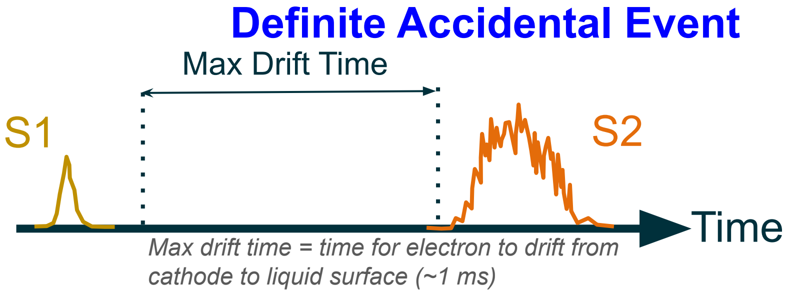
- S1-S2 ratio → Particle discrimination
  - Many backgrounds are electron recoils (**ER**)
  - WIMP and neutrino signals are nuclear recoils (**NR**)
  - Instrumental (accidental) backgrounds also fill a distinct region of this 2D space (approximately indicated by the gray region)

# What Are The Backgrounds for $^8$B CEνNS Search in LZ?

- Electron recoil (ER) backgrounds (betas, gammas) are **negligible**
- Neutron backgrounds are < 1 event (tag with OD and Skin)
- **Dominated by accidental coincidence events**
  - Isolated S1s and S2s (where the **S1 and S2 do not come from the same energy deposition**) can pile-up to fake a true single scatter.



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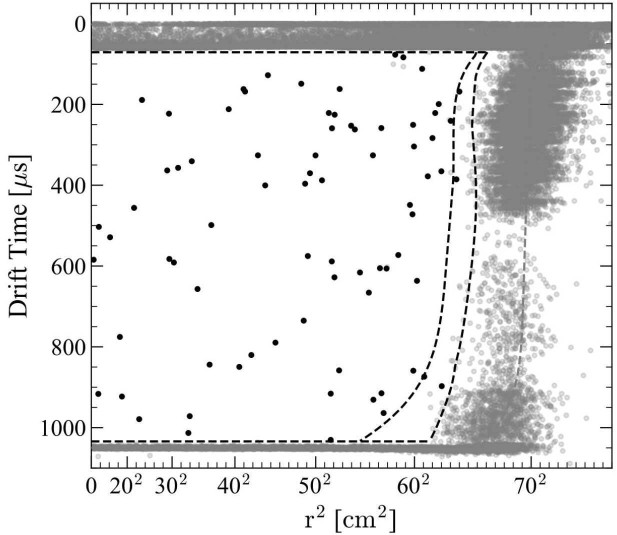
# Event Selection Cuts

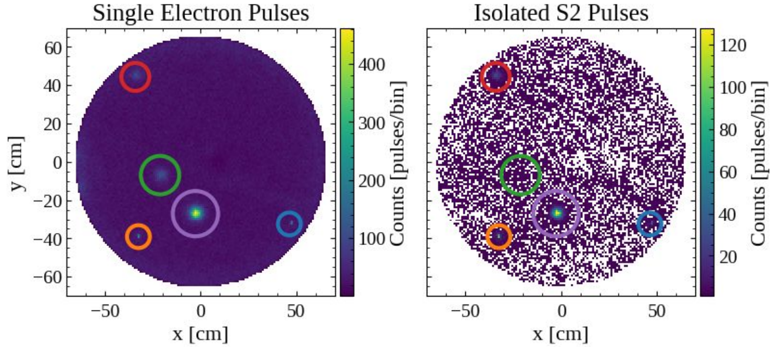
- Data quality cuts:
  - time-based exclusions, hold-offs after large energy depositions, operational issues
- Fiducial volume:
  - reject external backgrounds and detector edge effects
- S1 and S2 based cuts:
  - target accidental coincidence backgrounds
- External vetoes:
  - target neutrons which produce coincident signals in the OD/Skin
- Optimization technique (CMA-ES[1]) used to simultaneously tune several selections across multiple parameter spaces for improved accidental rejection

[1]Covariance Matrix Adaptation Evolution Strategy

Fiducial volume cut




*Loosened selection of events in ROI (not all cuts applied)*




*Intense day of electrode electron emission*

# Accidental Coincidence Modeling

- Photon and electron rates vary on ms time-scales➜ necessitates model that *captures time-varying environment*
- Fabricate S1-S2 events from lone S1s and S2s according to ambient photon + electron rate environment

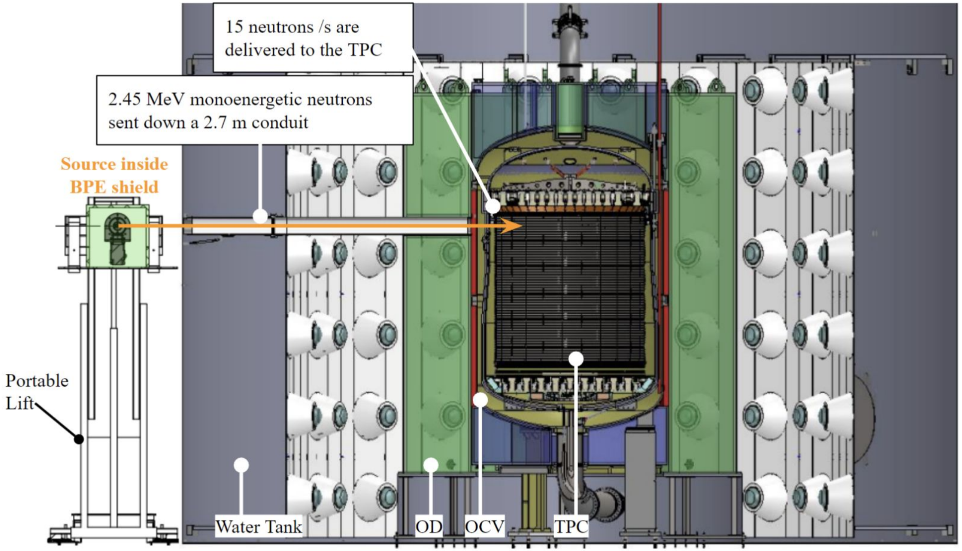

- Resulting S1-S2 spectrum is normalized by rate in sideband of known accidental events (> max drift time)

**Prediction: 6.6 ± 0.3 events in full exposure (5.7 tonne-years)**

# Calibrating Nuclear Recoil Response

- Need to carefully calibrate low-energy nuclear recoil response and quantify systematic uncertainties associated with **$^{8}$B CEvNS signal modeling in LZ**

- Nearly mono-energetic 2.45 MeV neutrons are used from well-characterized Adelphi deuterium-deuterium (DD) source
  - DD Neutrons produce nuclear recoils from 0-74 keV
  - Constrain both high and low energy nuclear recoil behavior in xenon

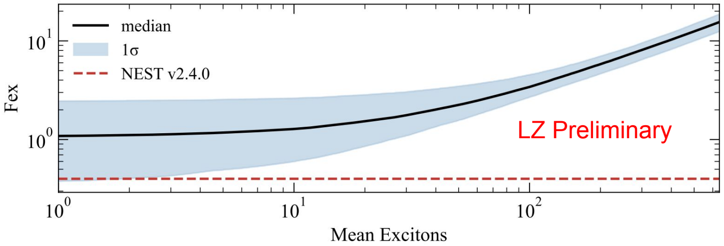



*Schematic of DD neutron generator and the neutron's path into the TPC*

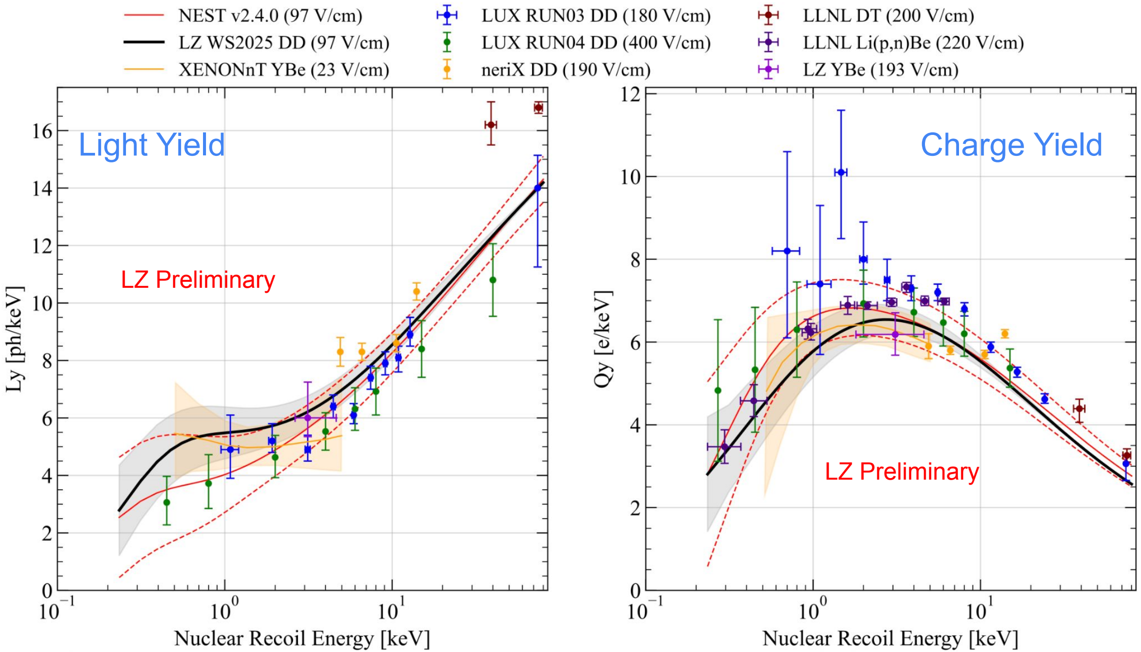
# Best-fit Yields and Fluctuations

**LUX*/LZ Collaboration have directly calibrated the LXe response to very low energy nuclear recoils, down to 0.27 keV (green points)**

- We quantified systematic uncertainty associated with yields, fluctuations and detection efficiencies




*Best-fit model for exciton (photon) quanta fluctuations as a function of quanta produced*

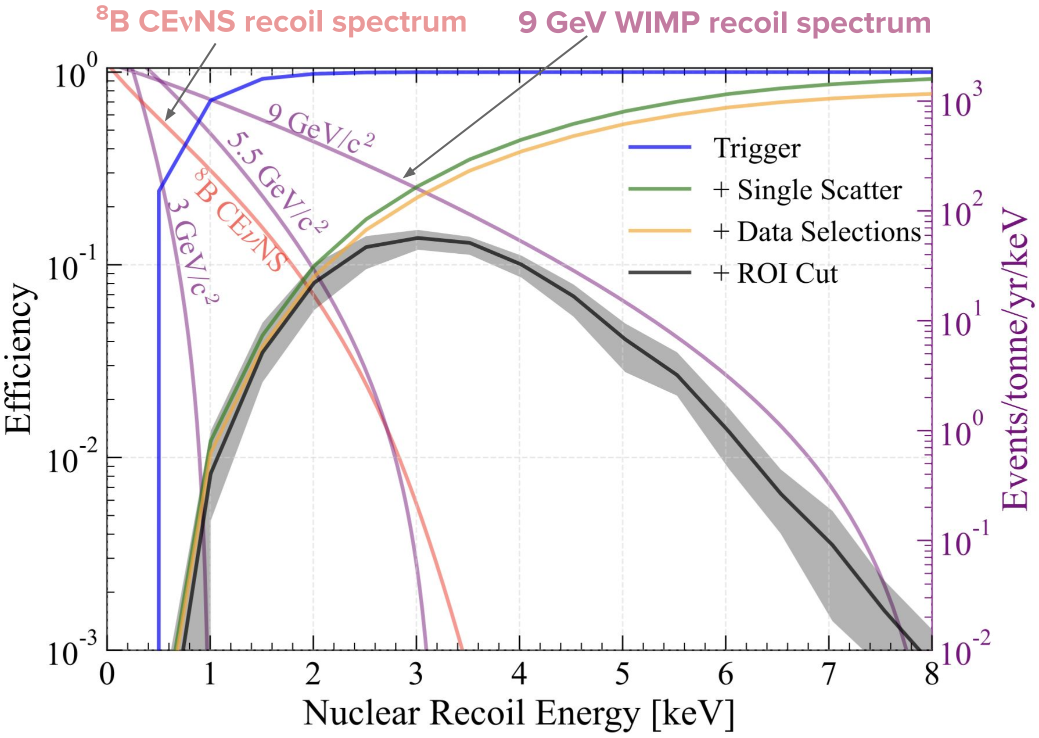



*Best-fit light yields (left) and charge yield (right) from this analysis (black) compared to other experimental results*

*LUX was the predecessor experiment to LZ

# $^8$B CEνNS Recoil Spectrum and Detection Efficiency in LZ

- 95% trigger efficiency to 4e⁻ sized S2s
- Threshold predominantly set by 3-fold S1 requirement
- Reconstruction and selection of S1s and S2s determined with calibration events
- Gray uncertainty band shows quadrature of uncertainties as discussed in next slide




*Detection efficiency as a function of nuclear recoil energy*



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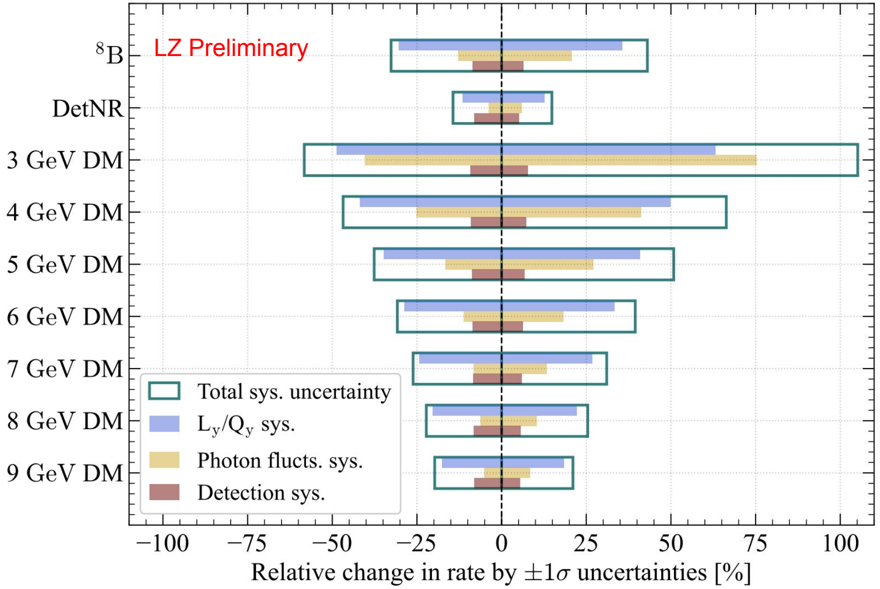
# Signal Expectations and Uncertainty Budget

Monte Carlo simulations to predict rates and uncertainties

Total systematic on detector response contains uncertainties from:

- Yields
- Fluctuations
- Detection ability (reconstruction and selections)

**$^8$B CE$\nu$NS expectation in full exposure (5.7 tonne-yrs): $20.6^{+8.9}_{-6.8}$ events**

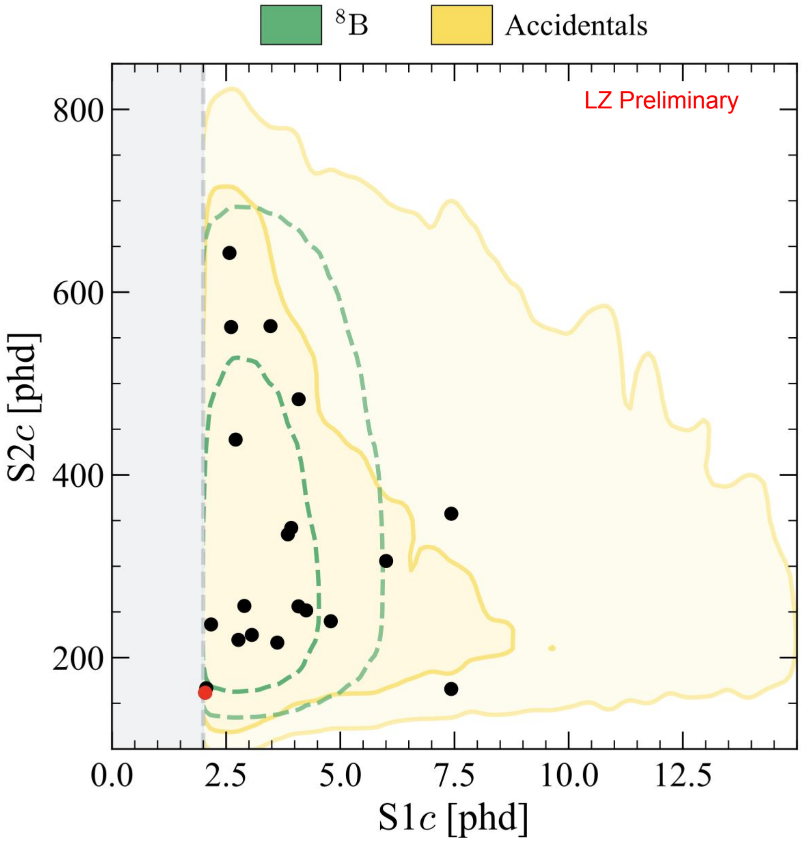



*Total percent uncertainty and its breakdown by contribution for each simulated NR component*

DetNR: Detector Neutron Recoils

# Final dataset with Signal and Background Models

- **20 events in dataset after all selections**
  - 1 revealed to be an injected artificial signal ("salt") event (red)
- **19 events with which to perform science search**
- Sideband dataset of “neutron-rich” data: passing all selections except delayed veto
  - **1 event** ➔ in-situ constraint for neutrons
  - **Neutron expectation in main dataset**: **$0.04^{+0.25}_{-0.04}$ events**




*Final science dataset (black) with the one injected and recovered salt event (red)*



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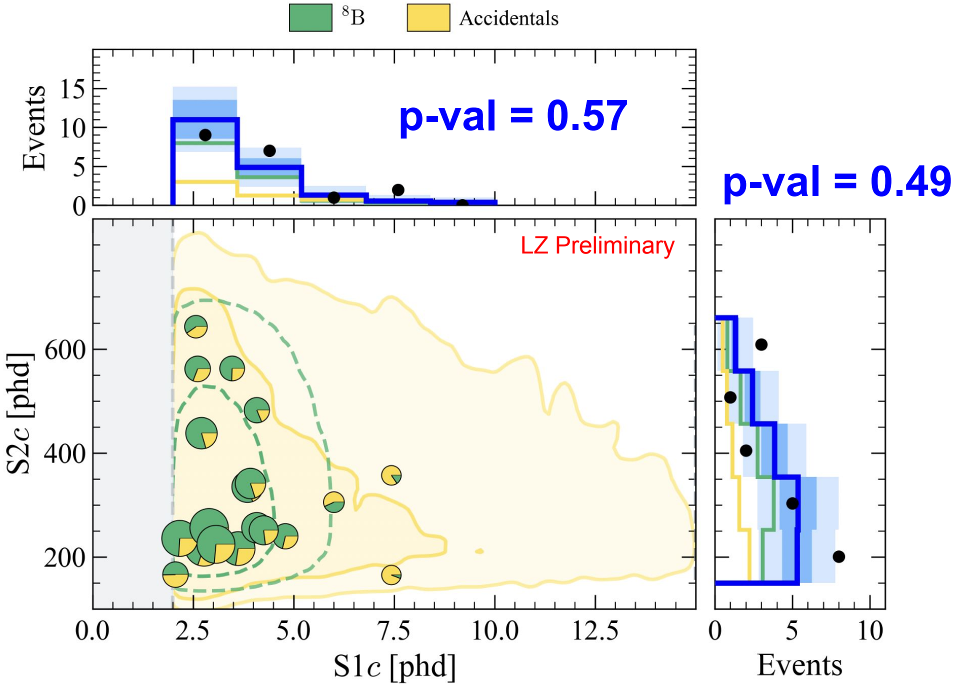
# Searching for $^8$B CE$\nu$NS

- Search for $^8$B CE$\nu$NS events, ***assuming zero DM events***
- $^8$B CE$\nu$NS rate is **unconstrained**, floating freely in fits
- Best-fit number of $^8$B CE$\nu$NS events: $12.3^{+7.0}_{-5.4}$
    - Consistent with prediction of $20.6^{+8.9}_{-6.8}$ events

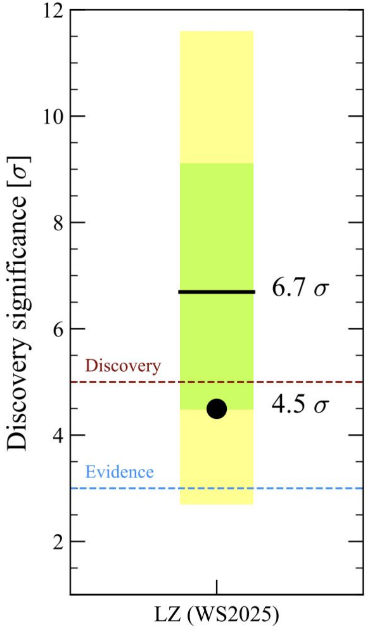


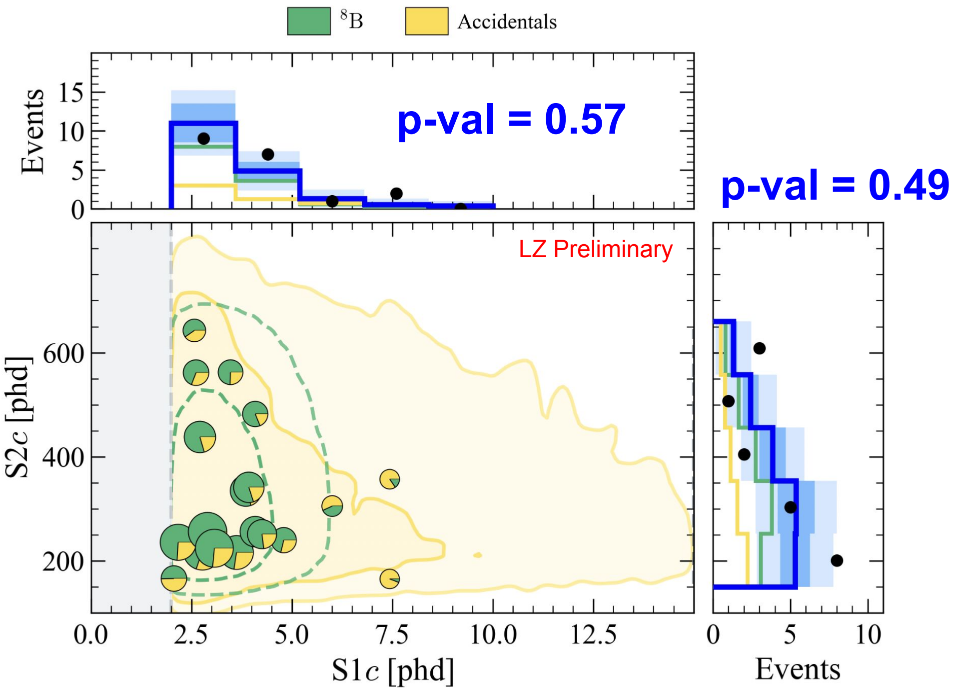

| Components | Expectation | Fit Results |
|---|---|---|
| $^8$B CE$\nu$NS | - | $12.3^{+7.0}_{-5.4}$ |
| Accidental coincidences | $6.6 \pm 0.3$ | $6.6 \pm 0.3$ |
| Detector neutrons | $0.04^{+0.25}_{-0.04}$ | $0.1^{+0.2}_{-0.1}$ |
| Total | $6.6 \pm 0.3$ | $18.9^{+7.0}_{-5.5}$ |

# Evidence for $^8$B CE$\nu$NS

- Background-only model rejected with **4.5σ significance** (expected 6.7σ)

- **Demonstration of LZ's ability to detect a low-energy signal!**

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| Total | 6.6 ± 0.3 | $18.9^{+7.0}_{-5.5}$ |

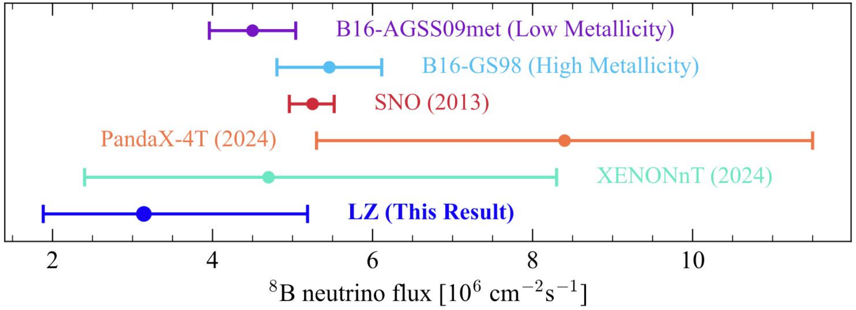
https://arxiv.org/html/2512.08065 [also submitted to PRL]

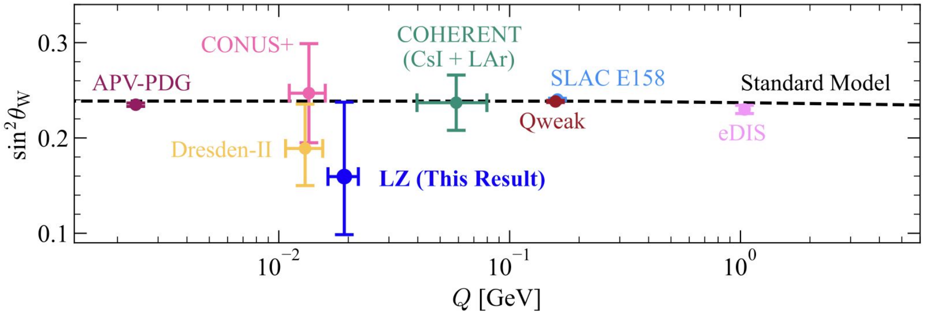
# Measurements with $^8$B CE$\nu$NS

Measurement of $^8$B CE$\nu$NS can be used to

- Make a flavor-independent measurement of $^8$B solar neutrino flux
- Measure weak-mixing angle ($\sin^2\theta_W$) at low momentum transfer (Q)

**These measurements will improve with increased statistics and improved detector modeling (e.g. NR response)**

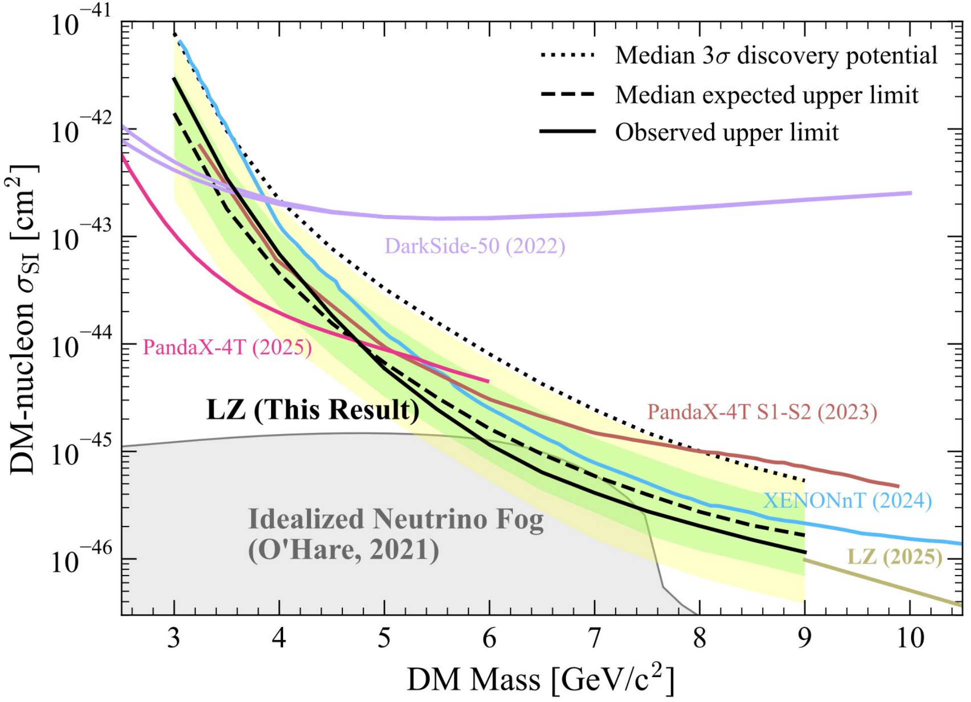


# LZ Low-Mass DM results

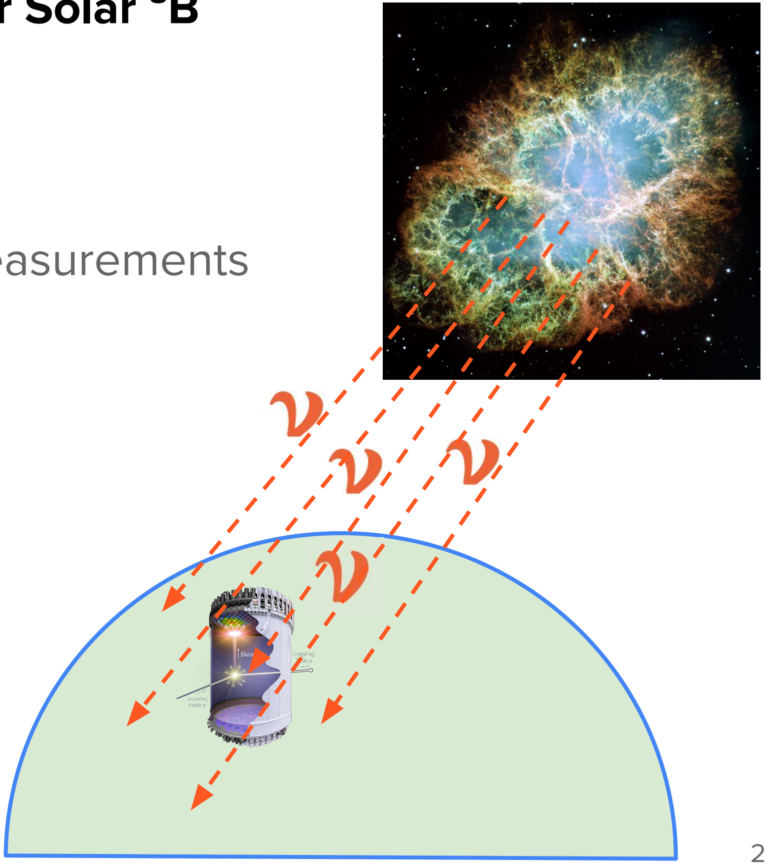
In the same ROI used for the Solar $^{8}$B CEνNS search, we also searched for low-mass dark matter, with the $^{8}$B rate constrained in the fit.

- Limit setting for Spin Independent (SI) DM-nucleon interaction strength using two-sided profile-likelihood-ratio test statistic
- **World-leading DM limits for masses above > 5 GeV/c²**
- The resulting limits reach into the neutrino fog, as shown in the figure



# Conclusion and Future Neutrino Physics with LZ

- **LZ reports the strongest evidence to date for Solar $^{8}$B CEνNS interactions (4.5σ)****
- CEνNS opens a portal to
  - flavor-independent solar neutrino flux measurements
  - Sensitivity to weak-mixing angle at low-Q
  - Non-standard neutrino interactions
  - Supernova neutrinos
    - For 27 solar-mass progenitor, 10 kpc (~33 light-years) away, predict ~80 CEνNS events in ~10 s




**For reference: First indications (< 3σ) of CEνNS with solar neutrinos from PandaX-4T *PRL 133, 191001 (2024)*, XENONnT *PRL 133, 191002 (2024)*