# Detecting solar neutrinos with dark matter detectors

With a focus on

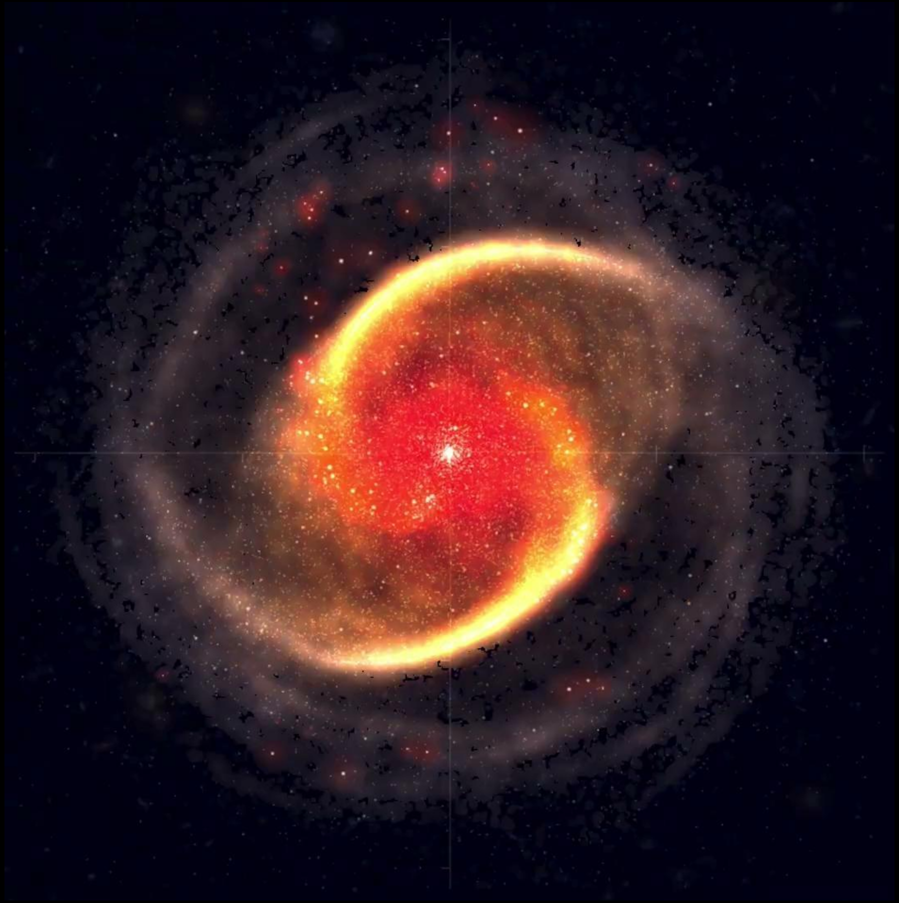
LZ

Chami Amarasinghe, UCSB
3 July 2026

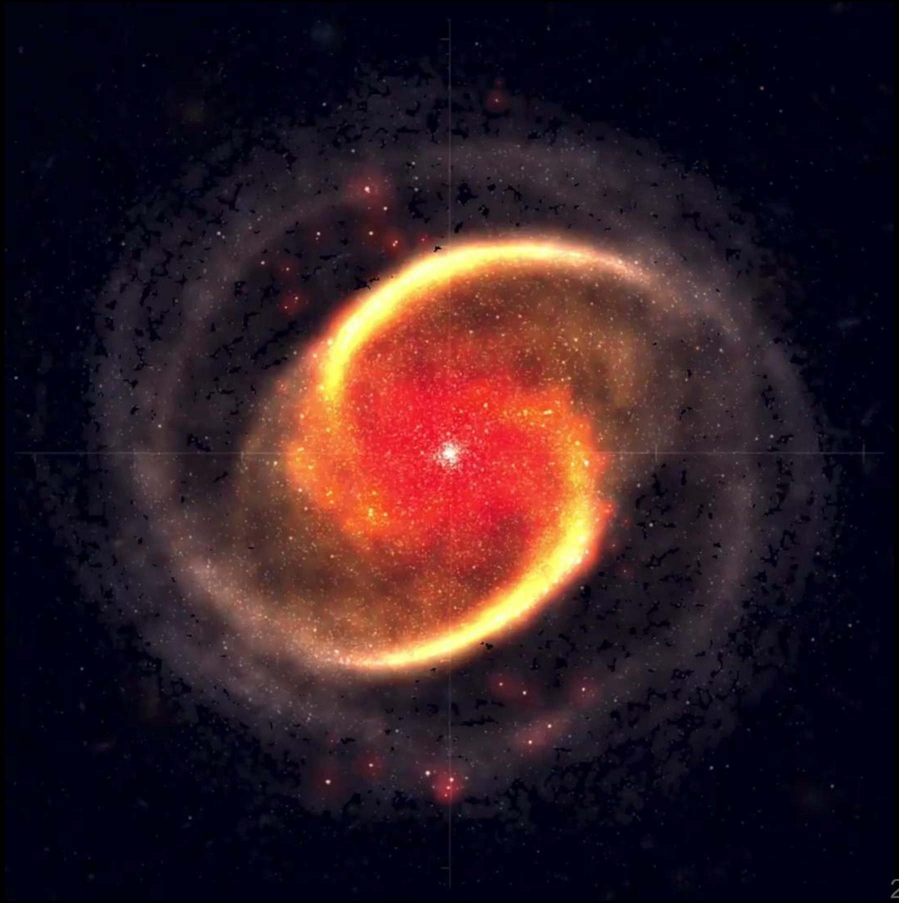
17th International Neutrino Summer School

UCSB

Only stars, dust and gas



Observed

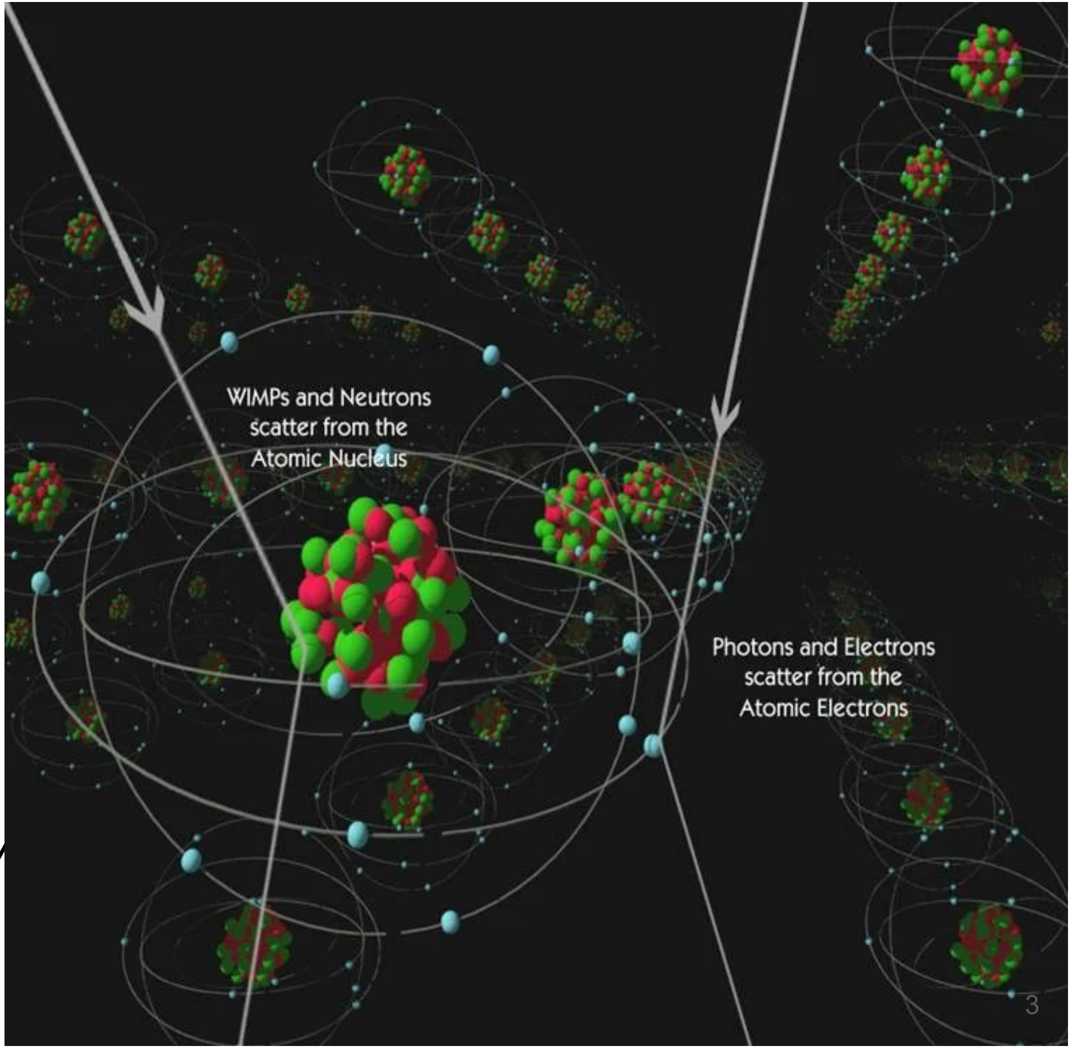


Ingo Berg - https://github.com/beltoforion/Galaxy-Renderer

# Searching for particle recoils

Scattering from particles in atoms
- Protons
- Neutrons
- Electrons

OR from the entire nucleus through a coherent interaction
- Significant enhancement in cross-section $N^2$
- Prime DM candidate: Weakly Interacting Massive Particle (WIM
- Neutrino CEvNS

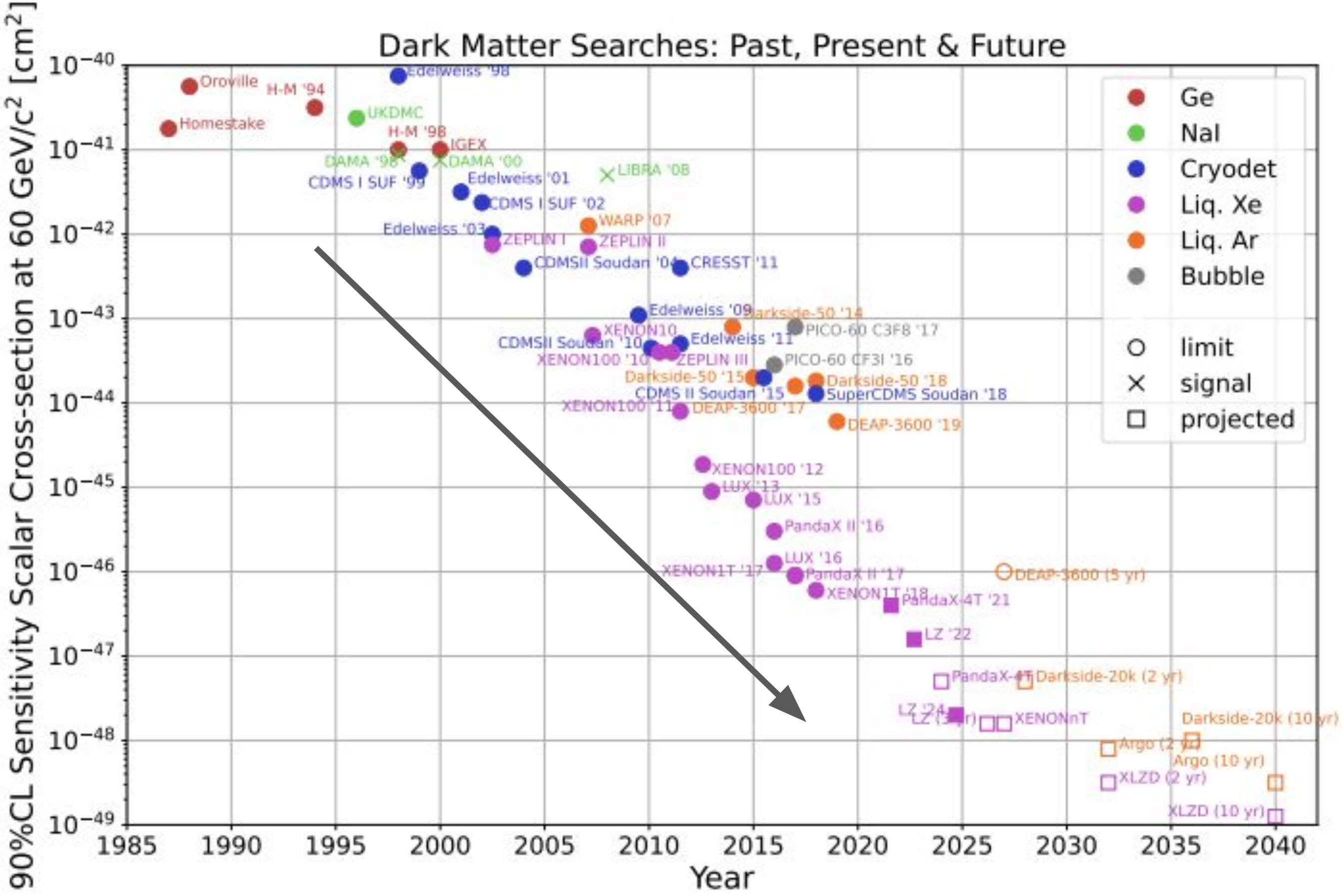


# Searches for WIMPs since 1986

Noble liquids are a key technology

Moore's Law for dark matter searches (2x every 1.5 yrs)

Beating Moore's Law for Compute
(2x every 2 yrs)



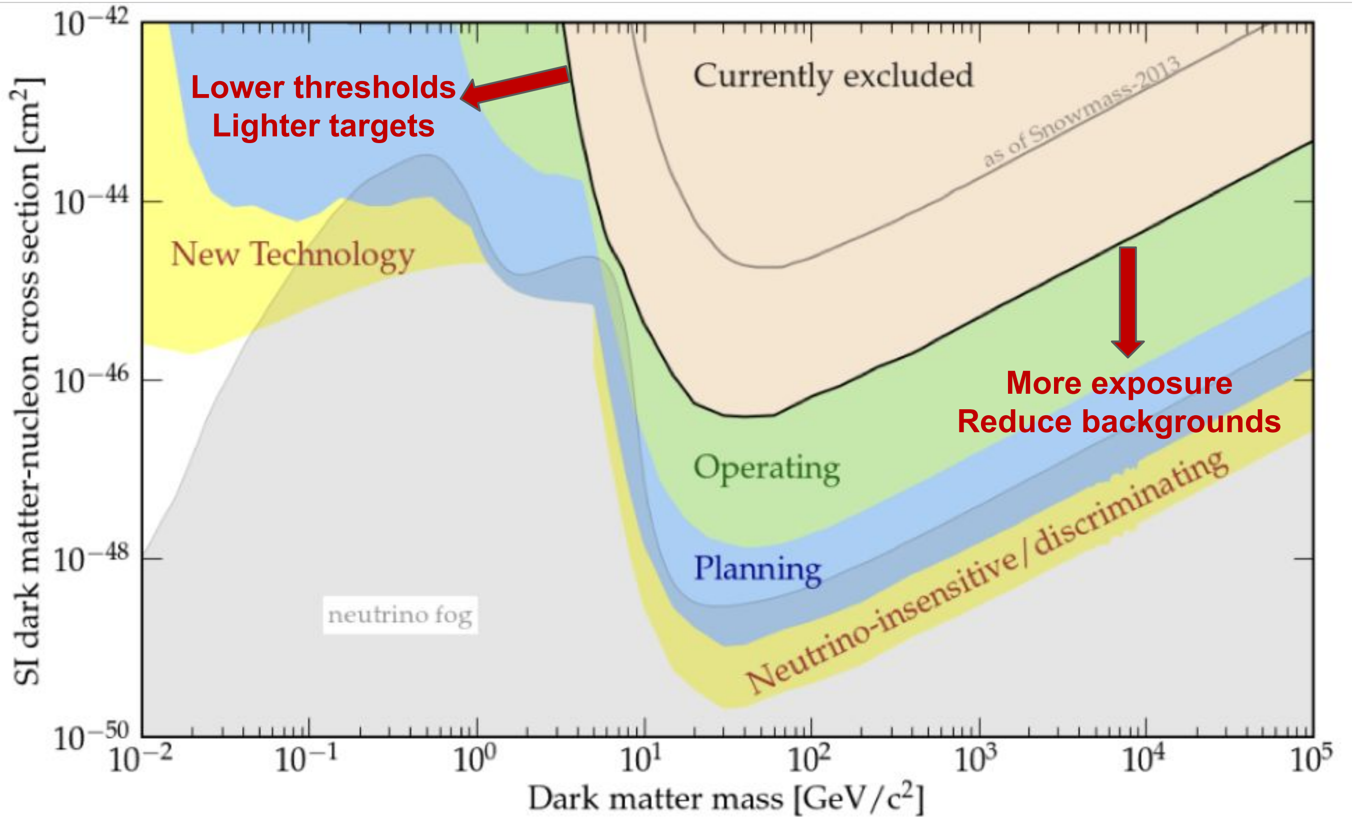

Slide courtesy of Rick Gaitskell

# Neutrinos are a validation AND an existential threat

Limited at high-mass by dark matter number density

Limited at low-mass by detector thresholds – **challenging analyses**

Eventually limited by CEvNS mimicking WIMP signals




Slide courtesy of Hugh Lippincott

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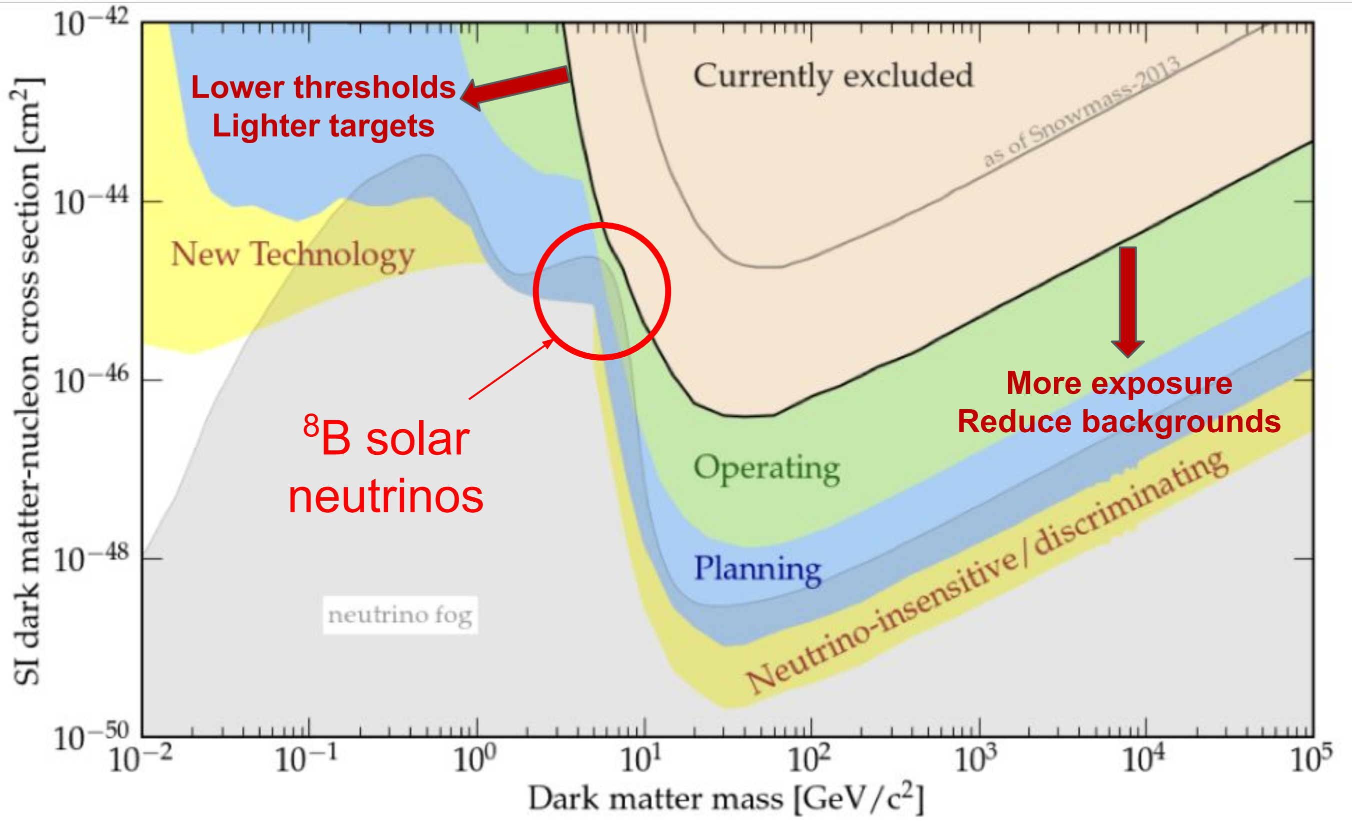
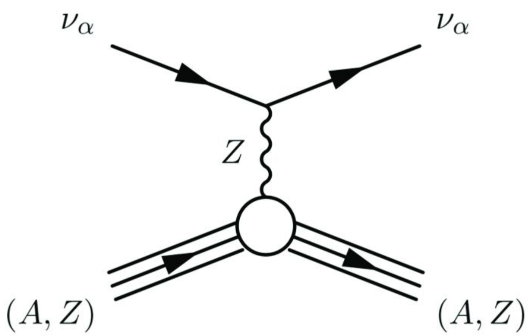



Slide courtesy of Hugh Lippincott

# Coherent Elastic Neutrino-Nucleus Scattering (CE$\nu$NS)

Standard Model process where neutrino “sees” whole nucleus




CEvNS cross-section scales with neutrons squared

- Trade-off: heavier nuclei are harder to recoil, need low thresholds
- Testing same enhancement of WIMP-Xe spin-independent cross-sections
- Modestly-sized LXe detectors can be neutrino observatories

CEvNS first observation in COHERENT experiment (2017) using the Spallation Neutron Source *Science 357, 6356 (2017)*

Measurements with reactor anti-neutrinos:

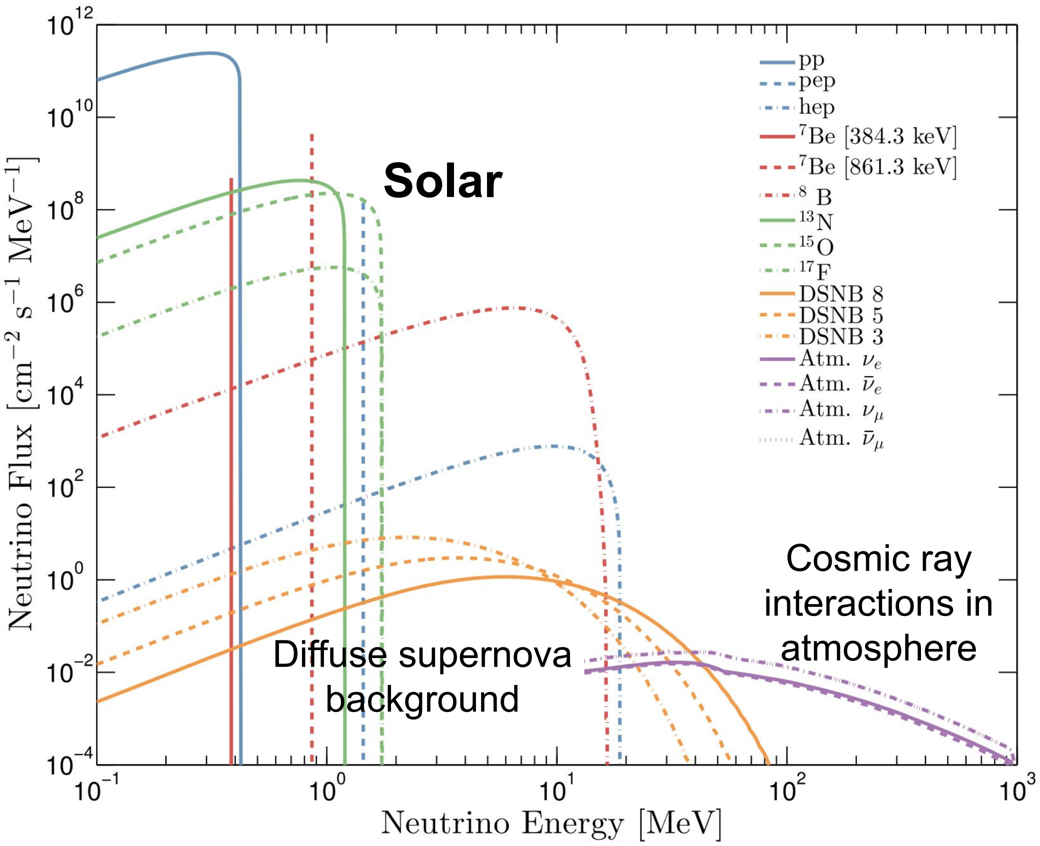
- Dresden-II *PRL 129, 211802 (2022)*
- CONUS+ *Nature 643, 1229-1233 (2025)*

First indications of CE$\nu$NS with solar neutrinos

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

Together with the LZ result (2512.08065, submitted to PRL), these are the first astrophysical CEvNS measurements!

# Neutrinos from astrophysical sources



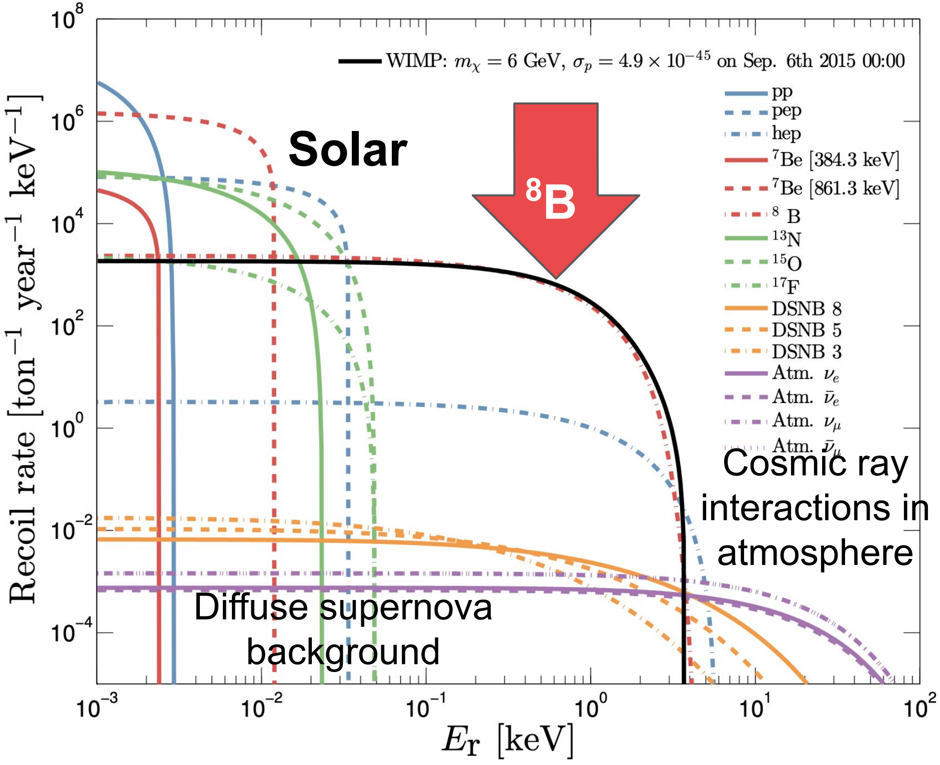

Incredible range of fluxes

Rare-event observatories have been able to detect signals from

- The Sun
- 1987 supernova @ 50kpc
- Galactic plane
- Blazars

O'Hare, et. al. Phys. Rev. D. 92.6 (2015)

# Xenon recoils from $^8$B solar neutrinos CEvNS




**Enhanced rate** → modest 5 tonne fiducial target can record events

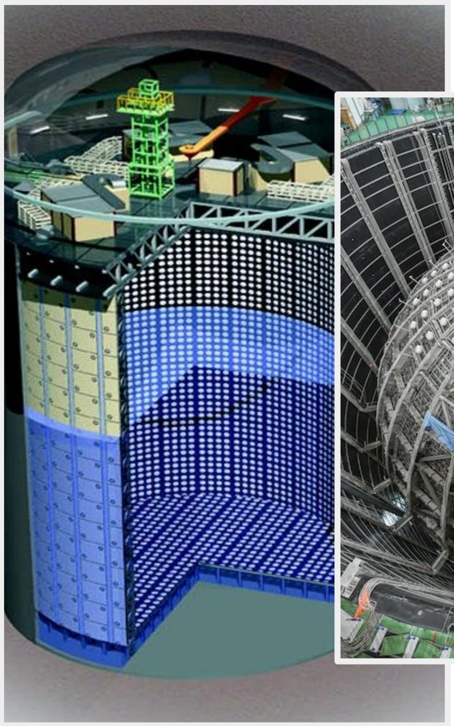
**High-energy** → Xe recoils can be seen above keV thresholds

**Near-identical** signal to 5.5 GeV DM

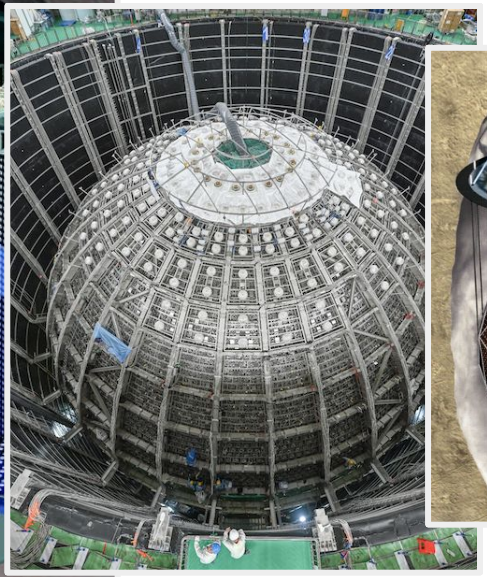
O'Hare, et. al. Phys. Rev. D. 92.6 (2015)

# LXe detectors are the smallest solar neutrino detectors

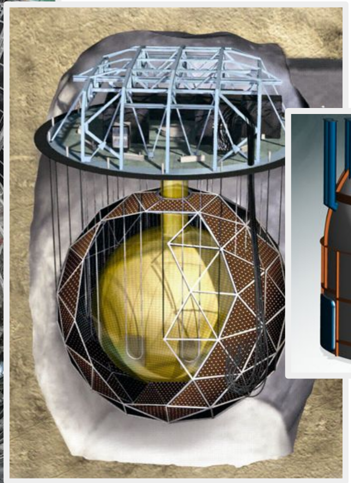
Storke Tower
at UCSB



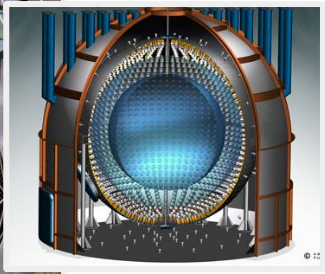
SuperK
50kt



JUNO
20kt

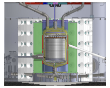


SNO
1000t



Borexino
280t

**Large cross-sections and low detector thresholds**

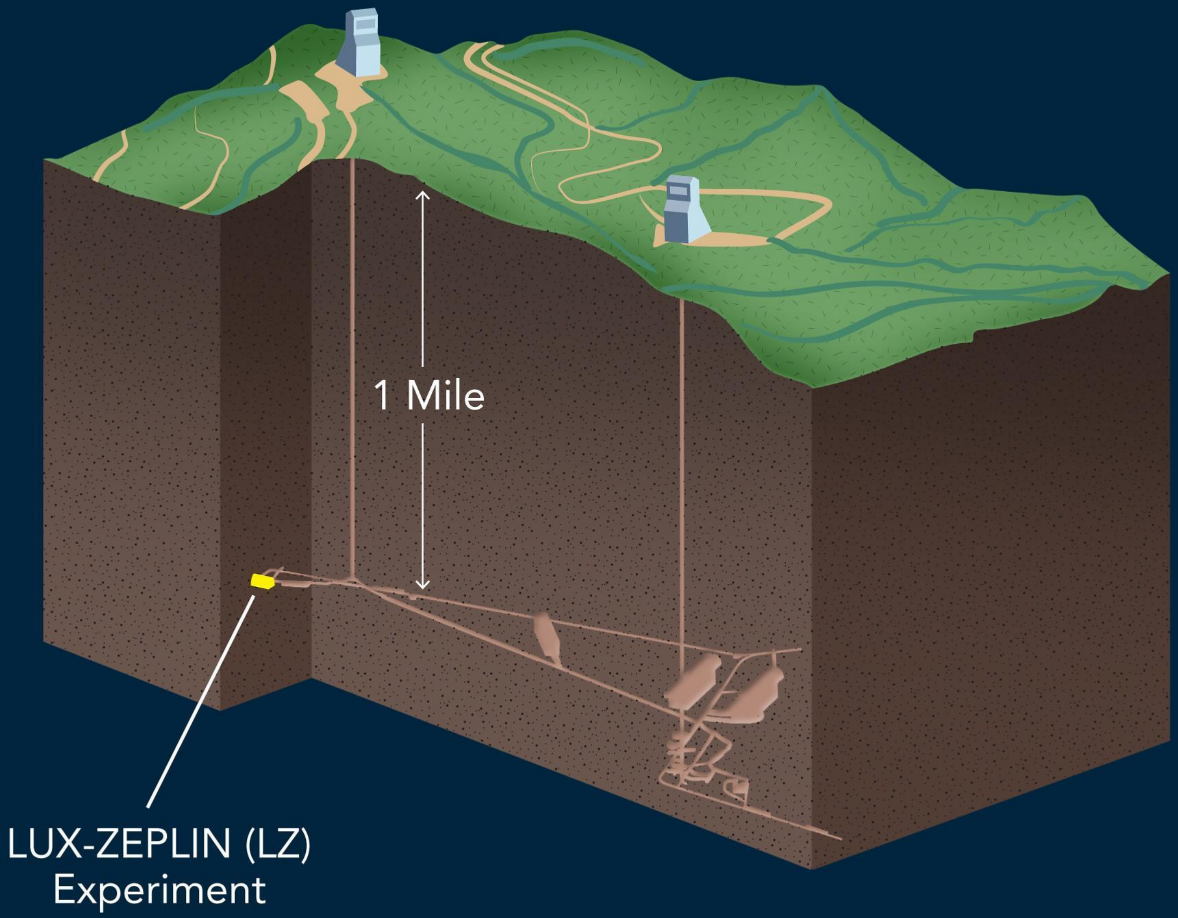


LZ,
PandaX,
XENONnT
6-10t

# Sanford Underground Research Facility (SURF)
Lead, South Dakota

**LZ** is in the **Davis Cavern**

Underground to reduce muon flux by factor of $10^6$



# Long history of solar neutrinos at SURF

Solar neutrinos first detected in the Homestake experiment, leading to the **discovery of neutrino oscillations**

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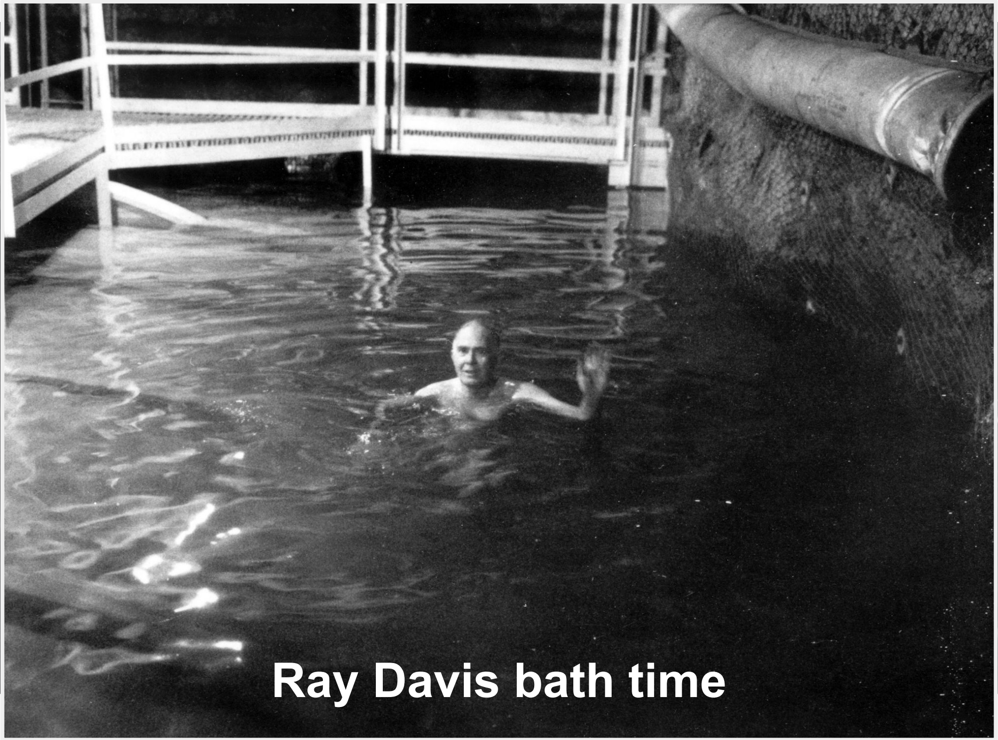
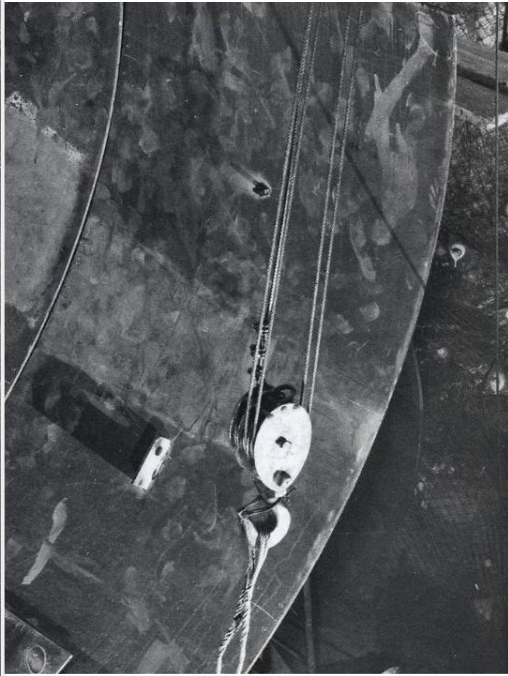
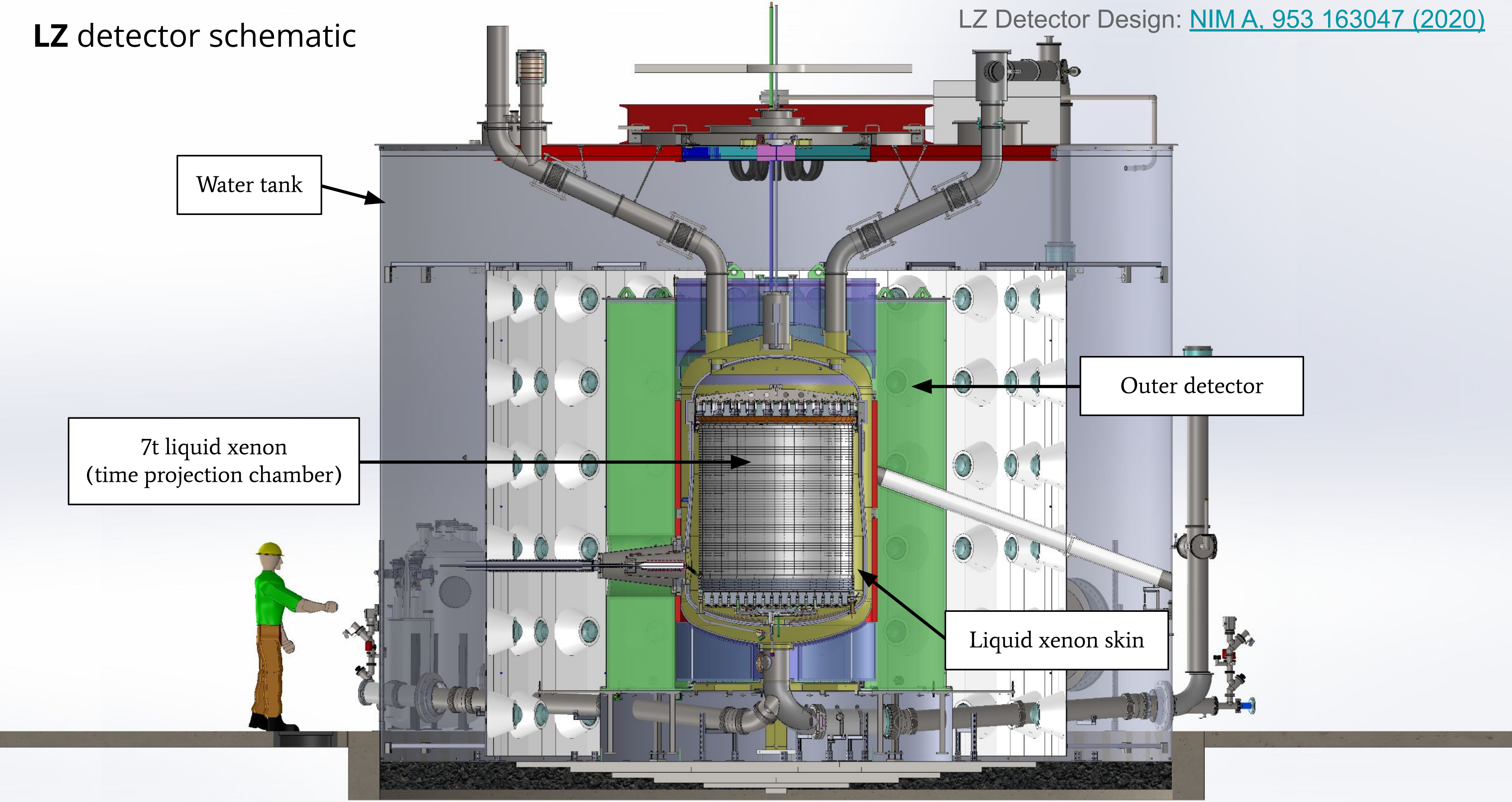


Ray Davis bath time



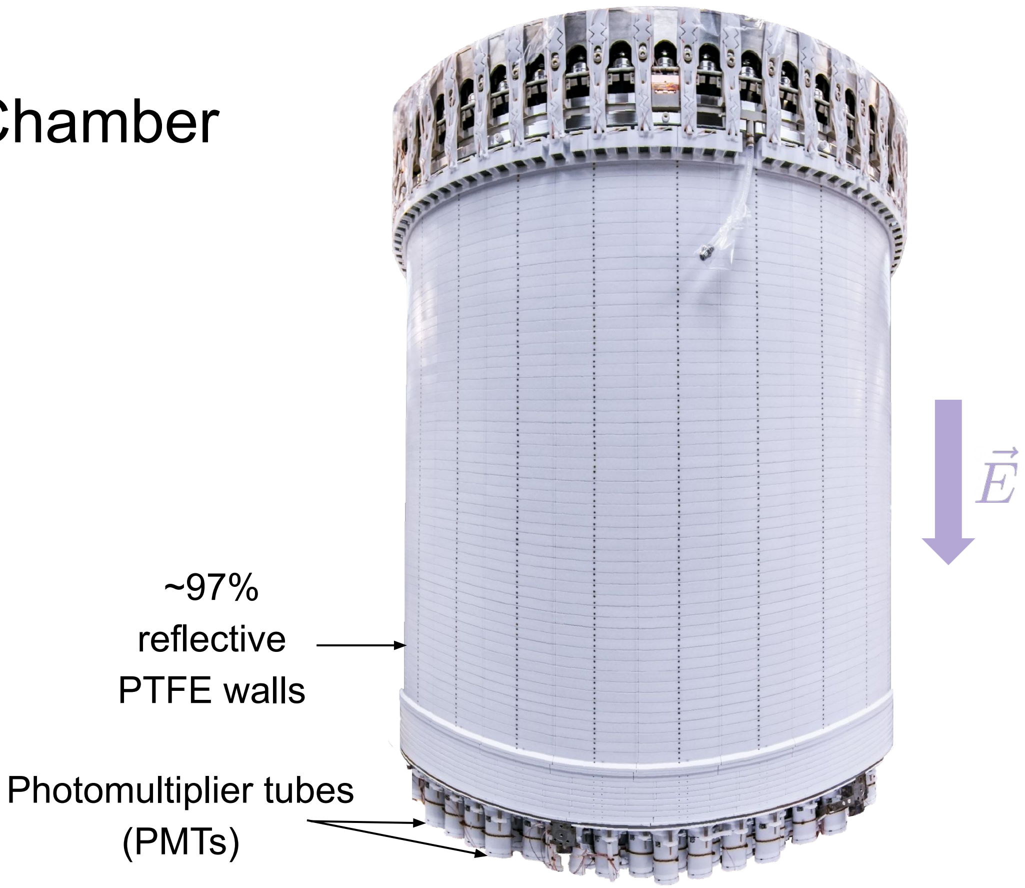
# **LZ** detector schematic

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



# The LZ Time Projection Chamber

- **Key stats**
  - Active mass of **7t** liquid xenon – 20% of global annual production
  - 4 woven grids custom-built at SLAC
  - Two arrays of PMTs, 494 total
- **Operational parameters**
  - ~175K temperature
  - 1.86 bara gas pressure
  - 97 V/cm drift field
  - Electrons drift >20m in Xe of our purity before capture by impurity



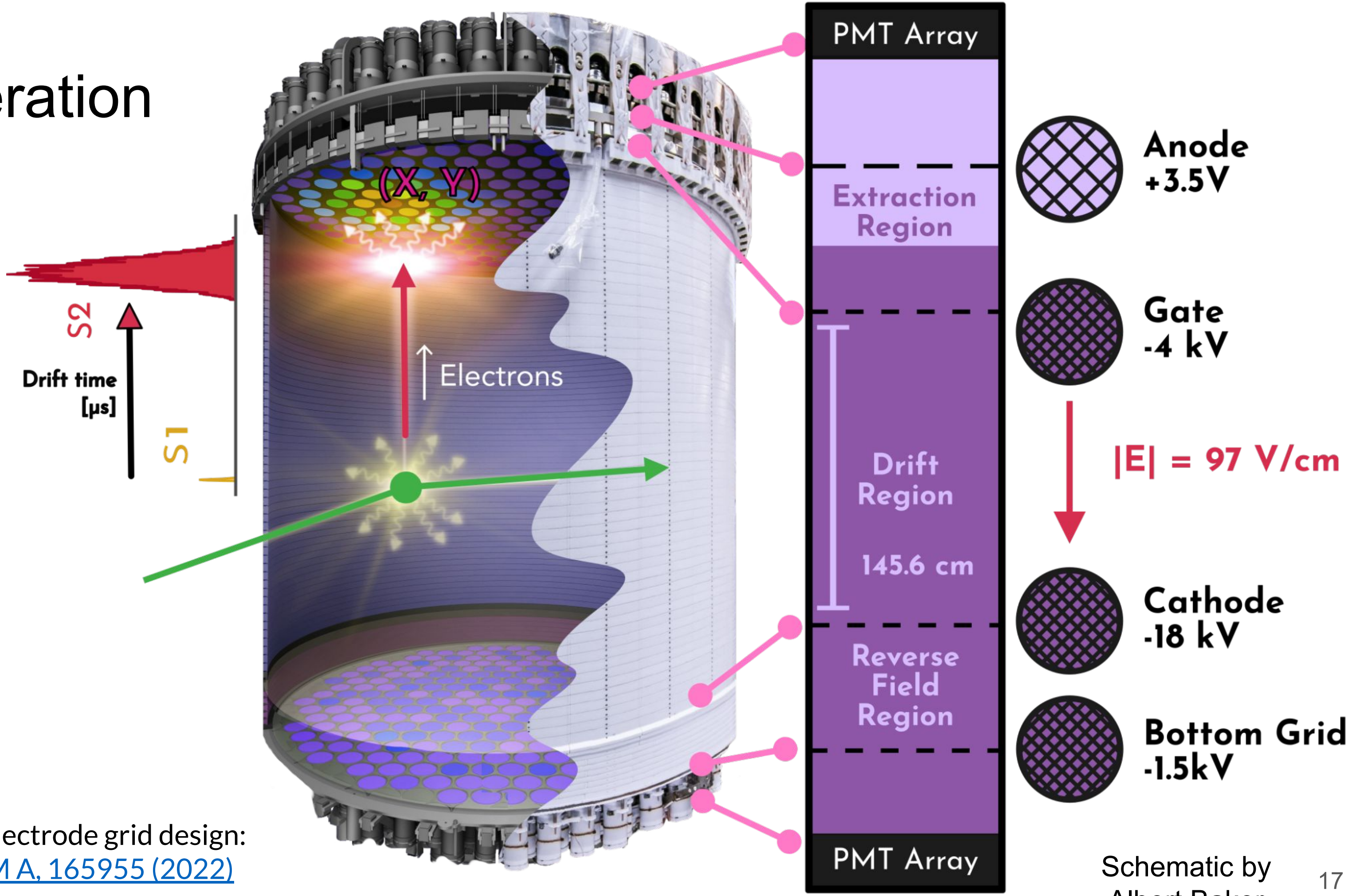

**Measurement of PTFE reflectance**
*JINST* 12.01 (2017): P01017-P01017.

# TPC operation

S1 scintillation light collected promptly

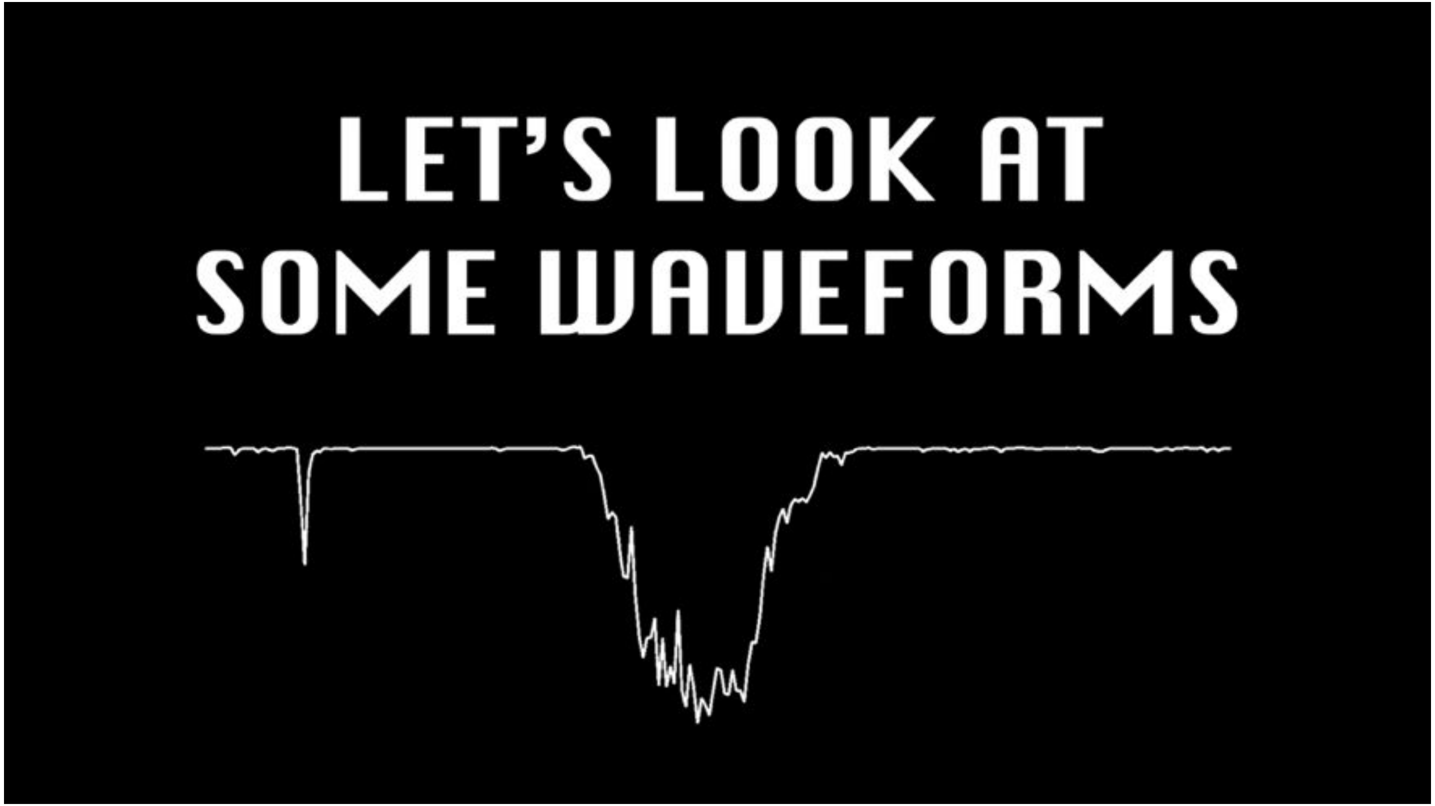
Electrons drift and are extracted into gas, where S2 scintillation light is produced

**3D position reconstruction:** x-y from S2 hitmap, z (depth) from drift time



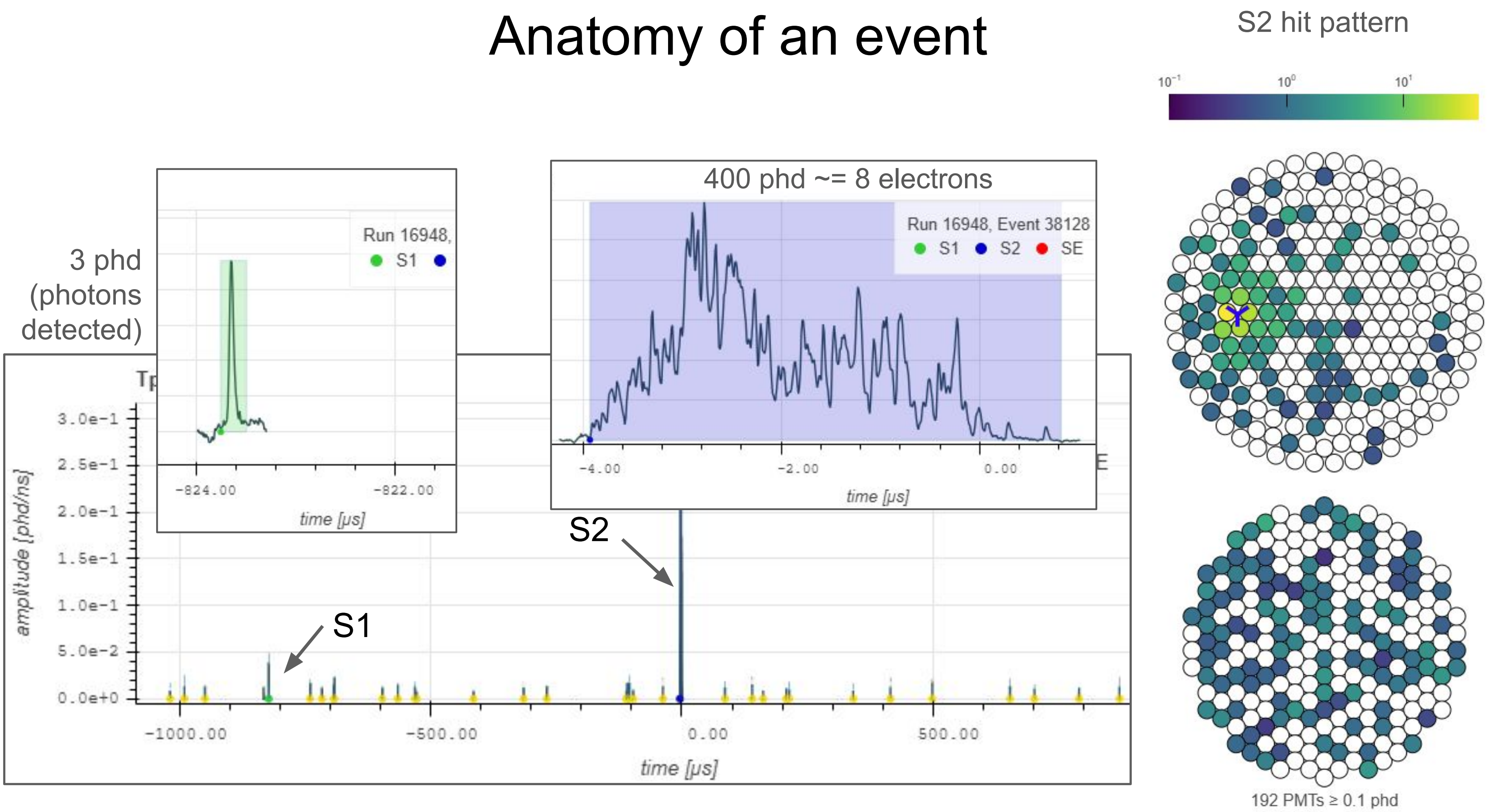

LZ electrode grid design: [NIM A, 165955 (2022)](https://doi.org/)

Schematic by Albert Baker




Courtesy former UCSB postdoc Alissa Monte. You can get this on a t-shirt, along with other LZ-related gear at our store (https://alissas-store-3.creator-spring.com/)

# Anatomy of an event

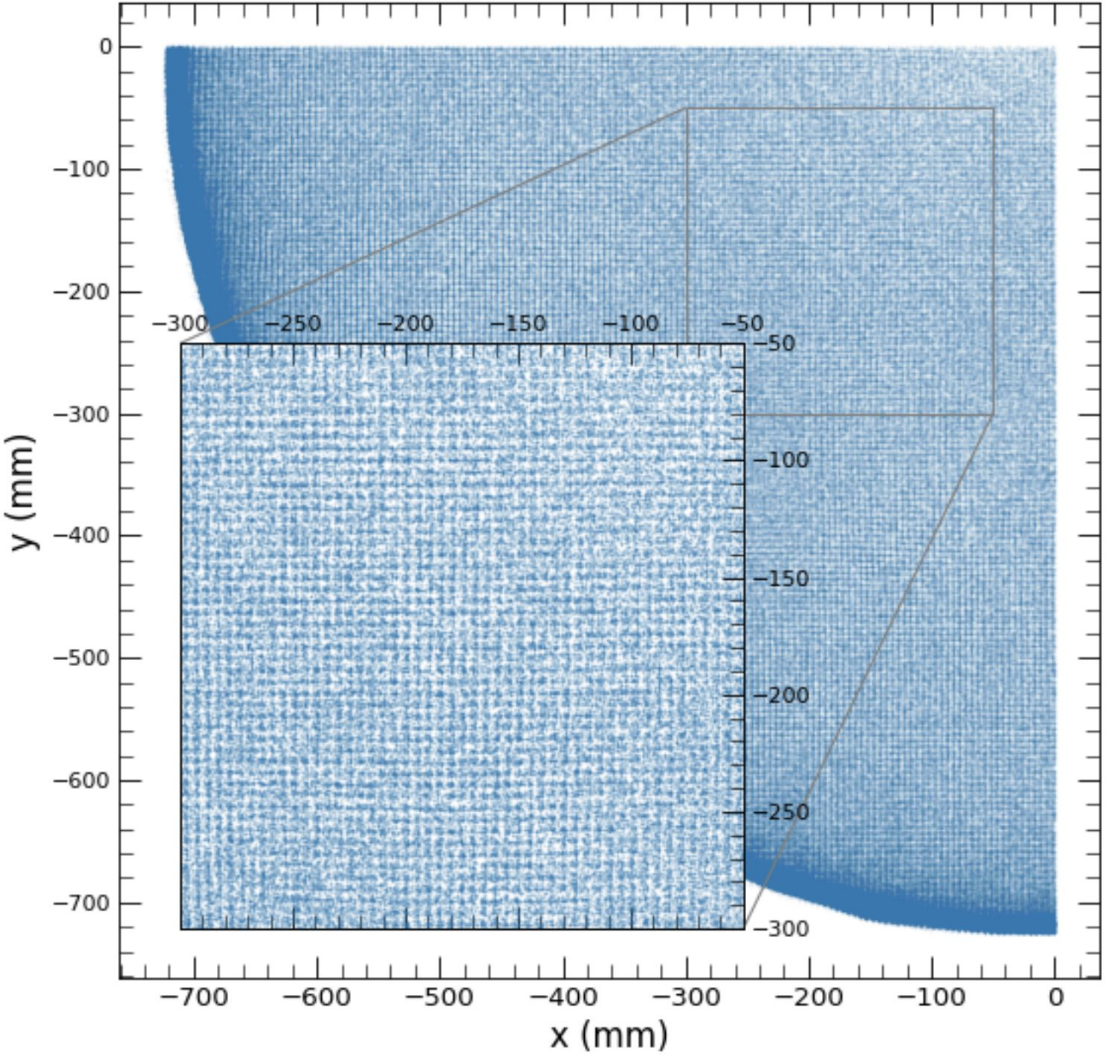


# Position resolution

At the 1mm level for both XY and Z

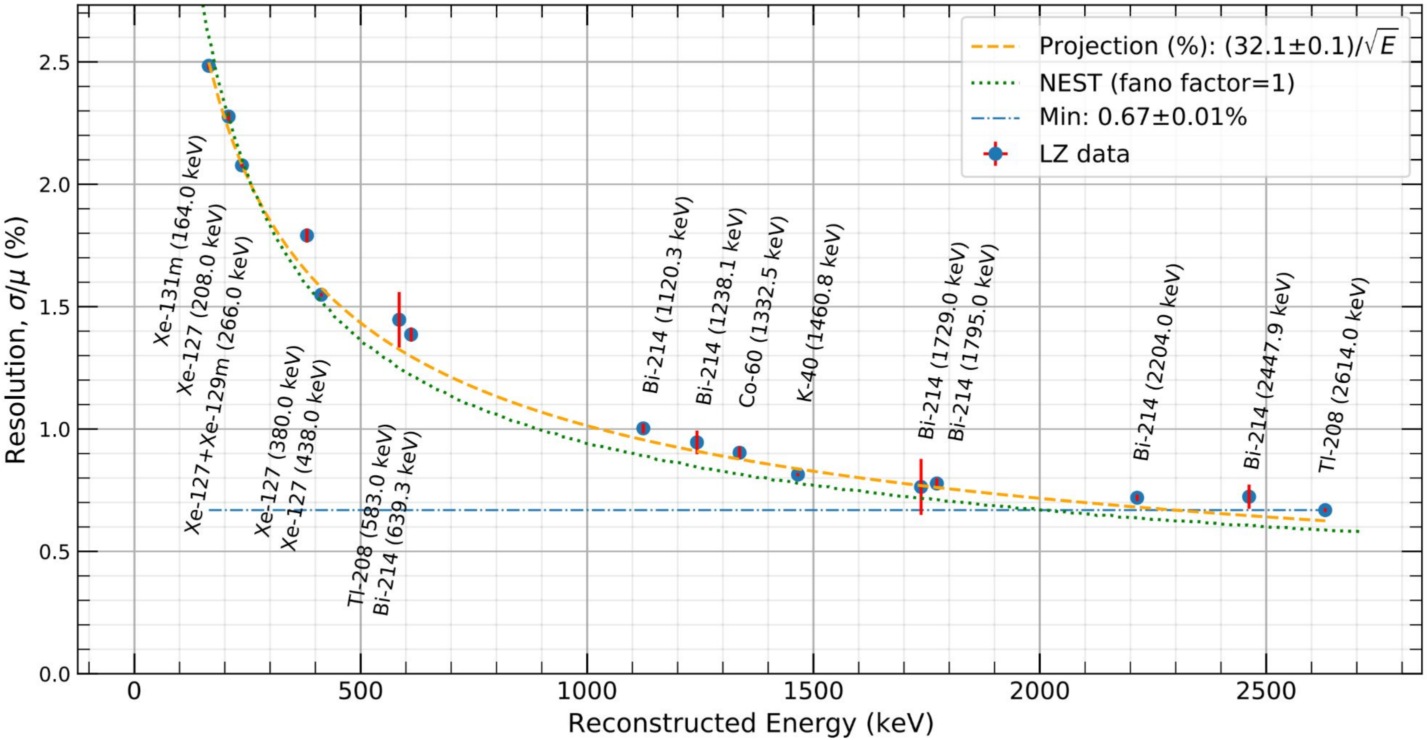
Able to resolve electrons funneling through the gate grid (5mm pitch)

Pereira, Guilherme. ***Continuous Calibration and Monitoring for LZ Dark Matter Experiment.*** PhD Diss. Universidade de Coimbra (Portugal), 2022.



# Energy resolution

Unprecedented energy resolution for any liquid xenon TPC




**Energy resolution of LZ:**
*JINST* 18.04 (2023): C04007.

# Liquid xenon can distinguish between ***electron recoils*** and ***nuclear recoils***

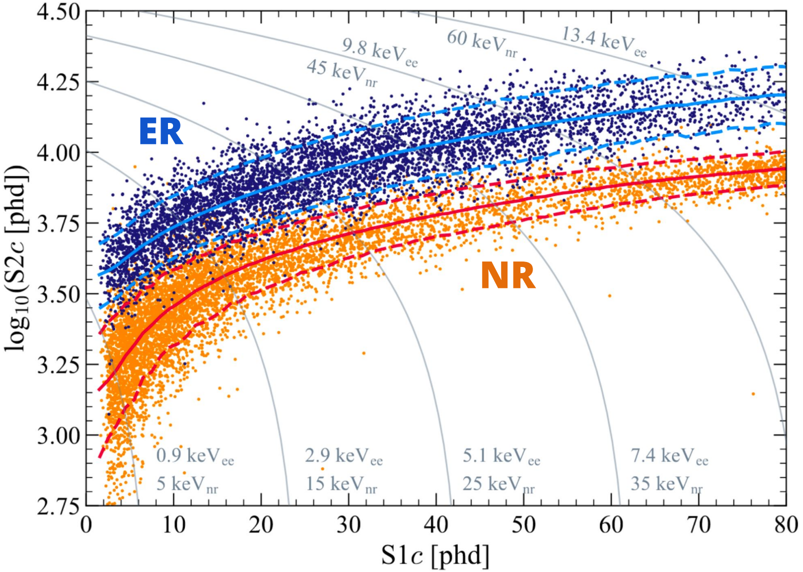
**ER** - *interaction with atomic electrons*

- $\gamma$, $\beta$ radiation
- solar neutrinos

**NR** - *interaction with nuclei*

- neutrons
- coherent nucleus–neutrino scatter
- ***WIMPs***

Differing exciton-ion ratios and recombination

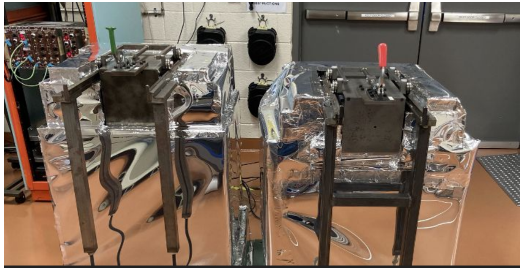



▲ **LZ tritium & neutron calibrations,**
First WIMP search

99.9% discrimination of flat ER background below median of 40 GeV WIMP

# Extreme background reduction during construction

- WIMPs go through **hundreds of light years of lead without scattering**
- Backgrounds must be low enough to see **<10 DM events in years of data**
- All detector components carefully screened for low radioactivity
    - **A typical person is ~100,000x more radioactive than LZ**
  - TPC assembled in Rn-reduced cleanroom - **<1 gram of dust in TPC**
  - Xe distilled off-site for Kr removal (**<300 ppq**)



HPGe counters at SURF

Kr removal system at SLAC

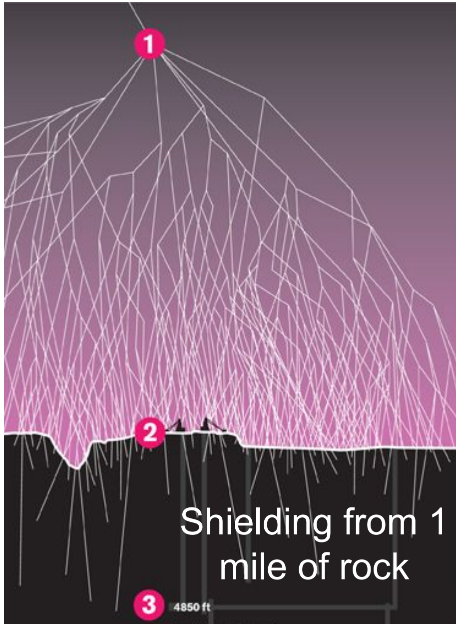
Radioassay and cleanliness: EPJC, Vol 80: 1044 (2020)

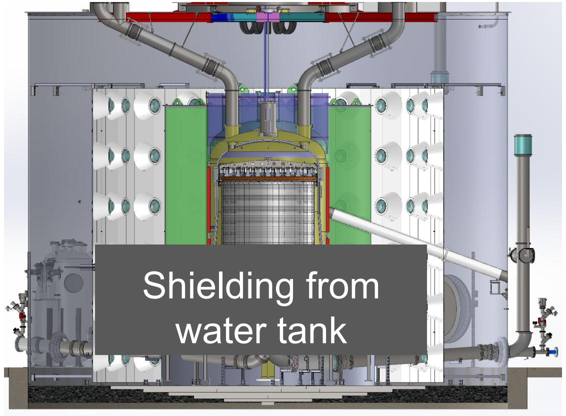
Ultrapure titanium cryostat: Astropart. Phys. 96, 1 2017

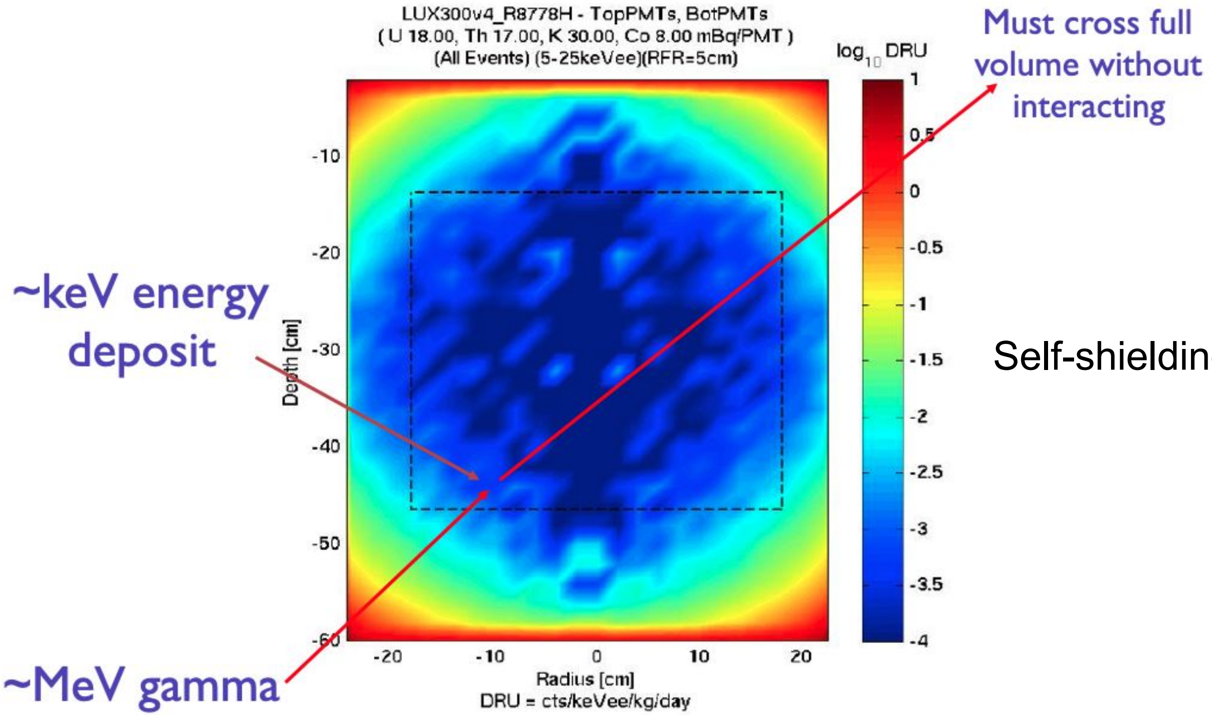


Slide courtesy of Scott Kravitz

# Extreme background reduction from shielding



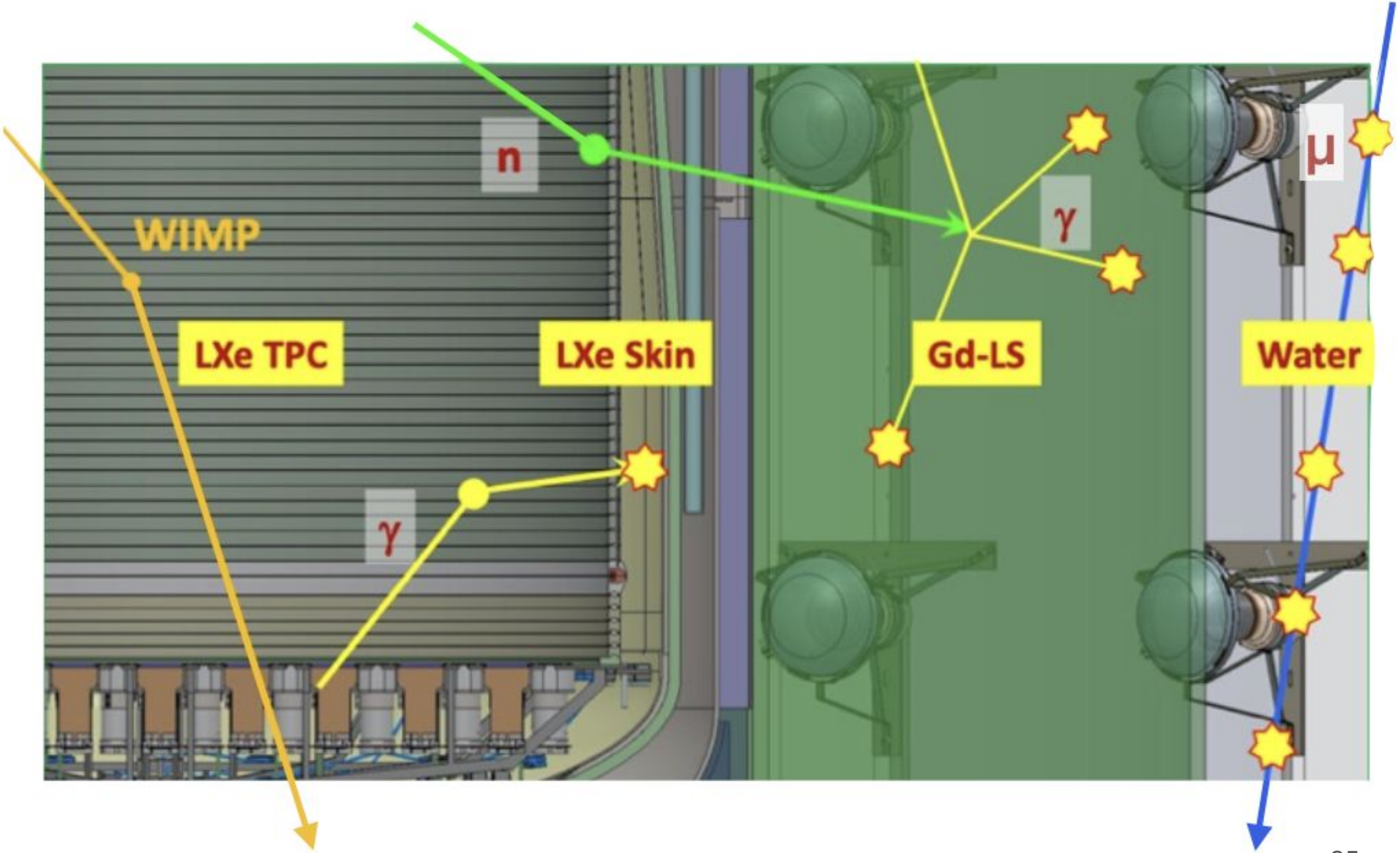




Self-shielding!

# **Vetoes**: Backgrounds scatter multiple times, WIMPs only once

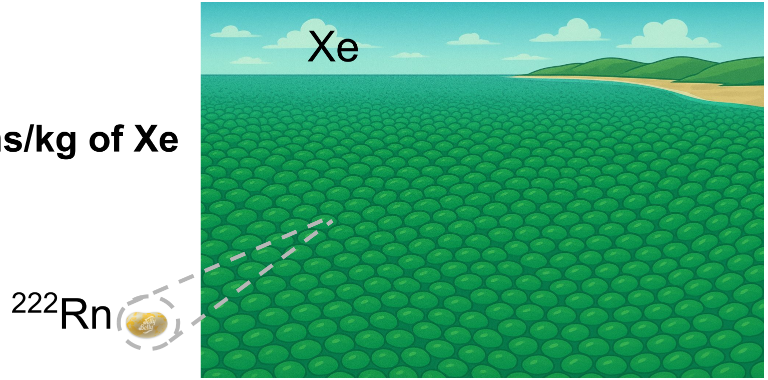
Instrumented LXe skin and outer detector form the **Veto system**

Designed to reject γ + neutron backgrounds

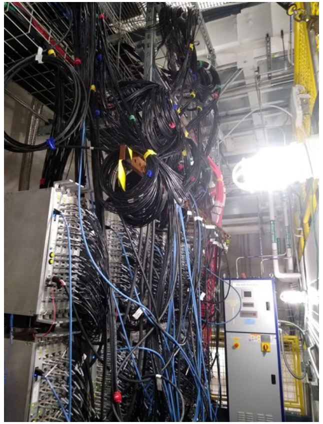


# Extreme background reduction during operation

- Xenon purification
  - Xe continuously circulated and purified
  - Biggest background for standard WIMP: Rn at ~**2 atoms/kg of Xe**
    - **Like a single jelly bean in all the oceans**




- High sensitivity = high data volume
  - Many processes produce just a few detectable photons / electrons!
  - Each PMT **read out every 10 ns** of active response
  - Data acquisition **uptime >95%** - no sleep for detector!
    - **~1 PB of data/year** = 1 MB photo every ~30 ms
  - Analysis cuts **distill data to ~1 in 50 million** - critical to success



DAQ: NIM A, 1068 169712 (2024)



Slide courtesy of Scott Kravitz

# Timeline of LZ Science

**Commissioning begins**

**WS2022 results (60 live days)**

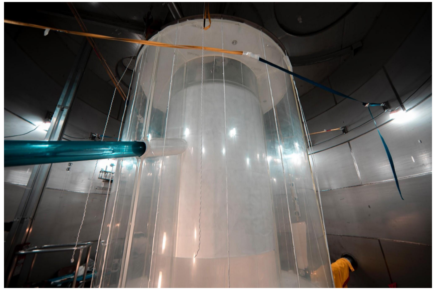
**WS2024 results (60 + 220 live days)**

**Run to end 2027 = 2x data**

2021 2022 2023 2024 2025 2026

**First WIMP search starts (WS2022)**

**WS2024 starts**

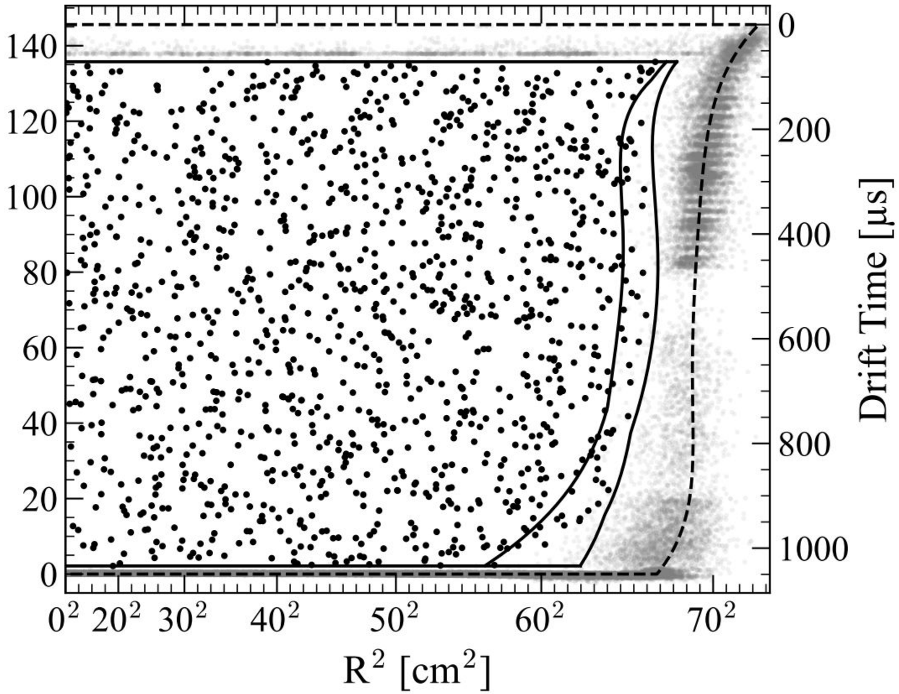


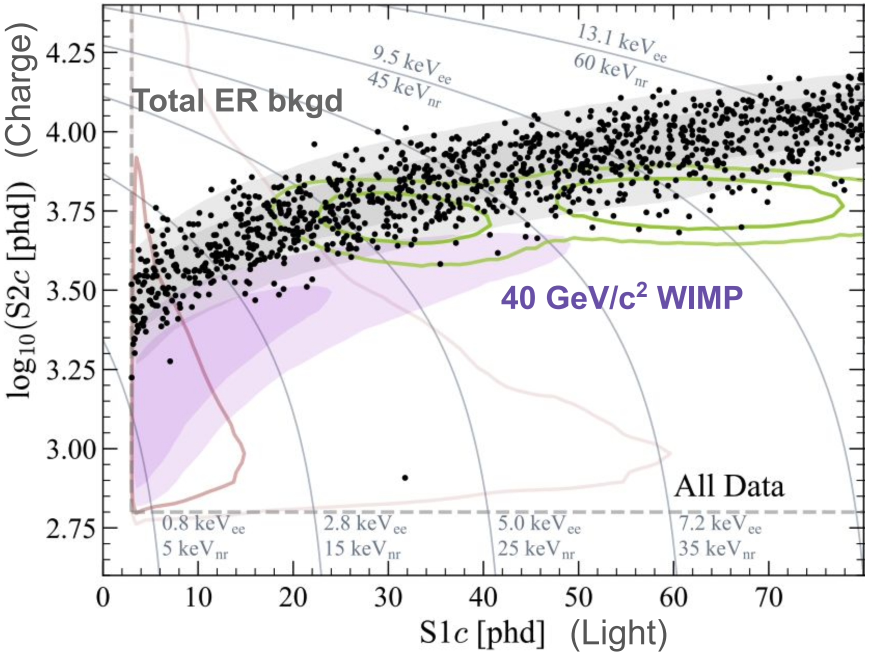
**WS2025 results (417 live days)**

**Periodic calibration throughout**

# LZ’s Previous WIMP Search (WS2024) Dataset

220 live days x 5.5 tonne FV = 3.3 tonne-yr

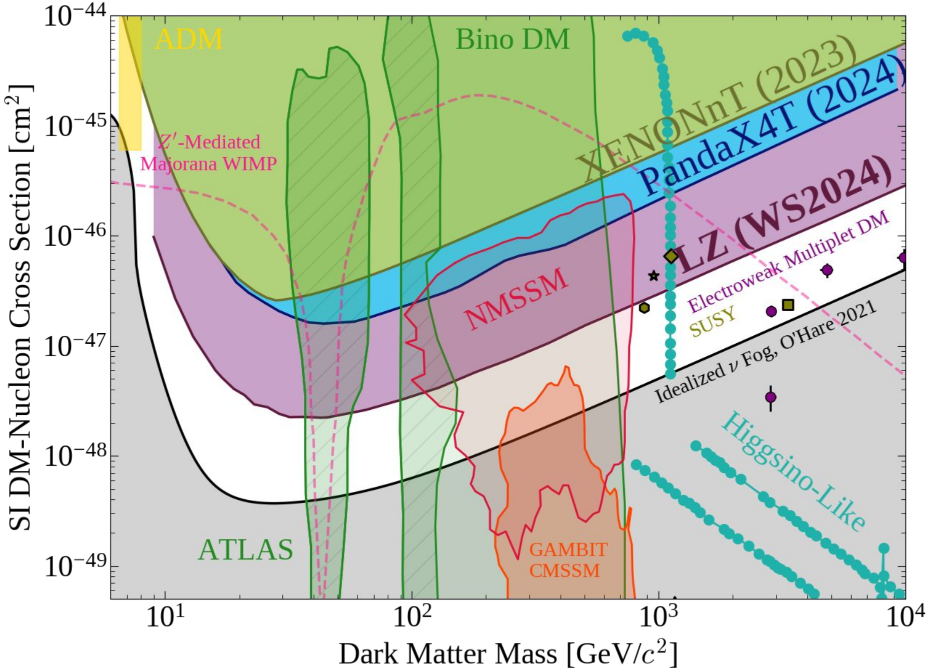



WS2024 results: *PRL 135, 011802 (2025)*

# WS2024 Results

- **World-leading limits** for heavy DM (masses > 9 GeV)
- Narrowing down where DM might be hiding!



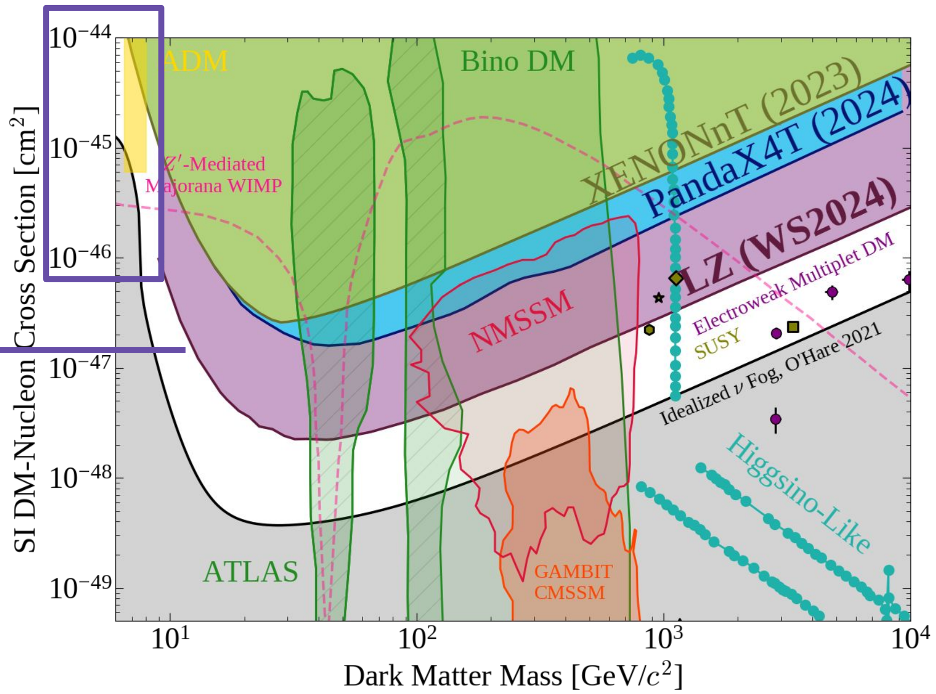

*Thanks to C. O'Hare for compiling theory models of interest

# WS2024 Results

- **World-leading limits** for heavy DM (masses > 9 GeV)
- Narrowing down where DM might be hiding!

**Lighter candidates produce low-energy signals with handful of photons + electrons → Unique set of challenges**

Onward, to light DM!

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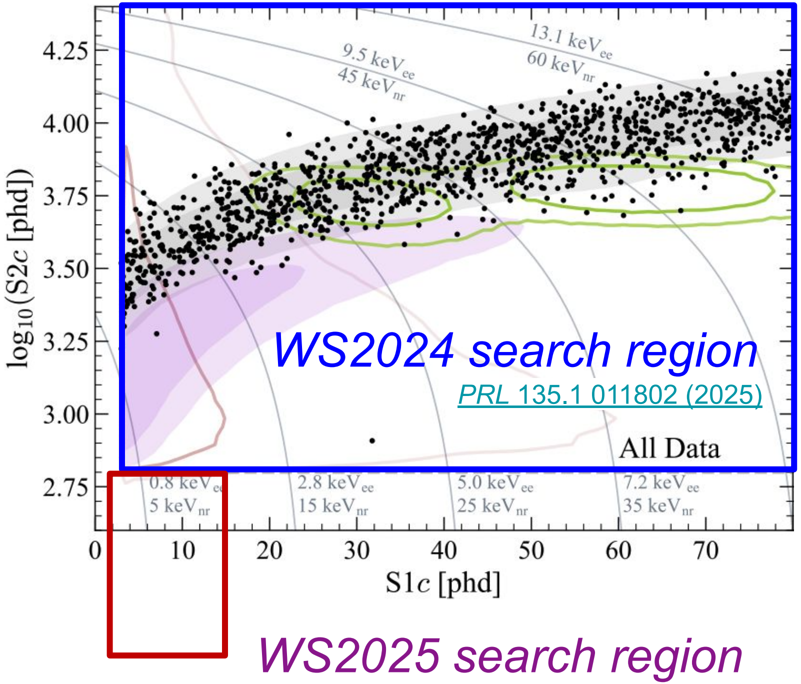
# 8B CEvNS and light WIMP search region

Search for single scatters: single S1 and single S2

Focus on events with 1-6 keV recoil energy

- **S1 required to have >= 3 PMTs hits**
- Corrected area S1c ∈ [2,15] photons detected (phd)
- S2 ∈ [3.5,14.5] electrons (44.5 phd/electron)



# Accidental coincidences are the major background

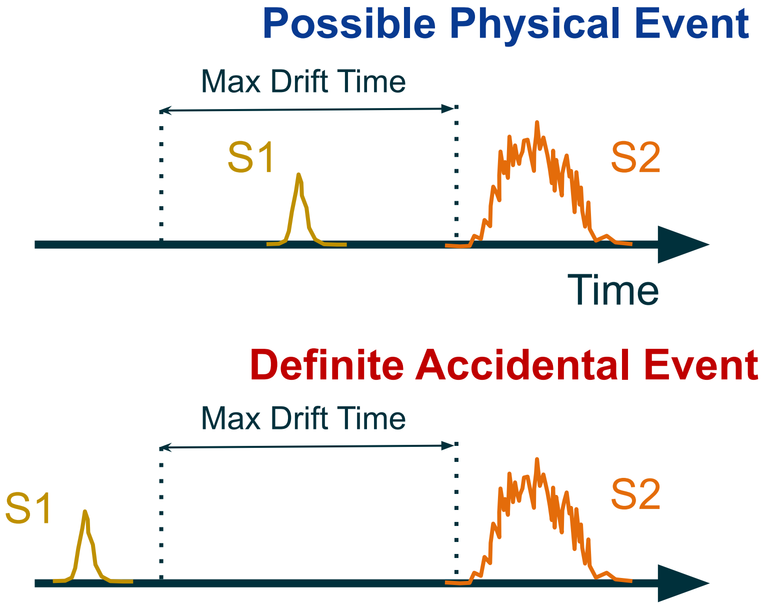
**Underground location and clean materials eliminate radiogenic backgrounds at low-energies**

**Accidental coincidence**: random pairing of S1 and S2 pulses that do not come from the same energy deposition

Isolated S1s and S2s come from instrumental effects, e.g.:

- PMT dark counts,
- photon/electron noise after big energy depositions

We cut away these backgrounds as much as possible and model what is left



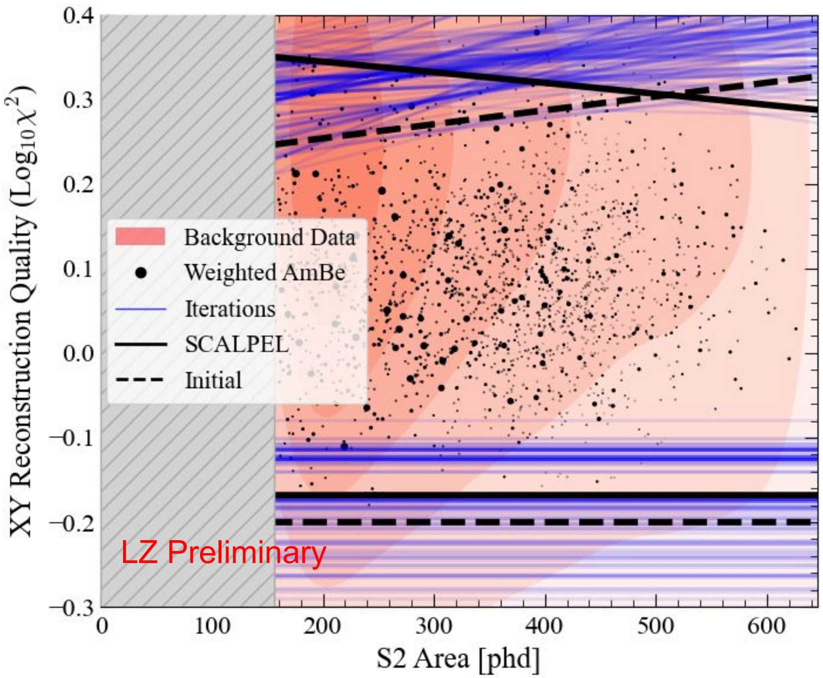

*Max drift time = time for electron to drift from cathode to liquid surface (~1 ms)*

# Cuts targeting accidental coincidence backgrounds

Data removed:

- Time periods following large energy depositions
- Events near detector edge
- Events with coincident signals in veto detectors, targeting neutrons
- Additionally target anomalous S1 and S2 pulses (pulse shape, PMT hit map)

Selections are designed and optimized using neutron (AmBe) calibration and fabricated datasets




Optimization technique SCALPEL[1] simultaneously tunes cuts in multiple parameter spaces

[1]Using Covariance Matrix Adaptation Evolution Strategy

# Accidentals modeling

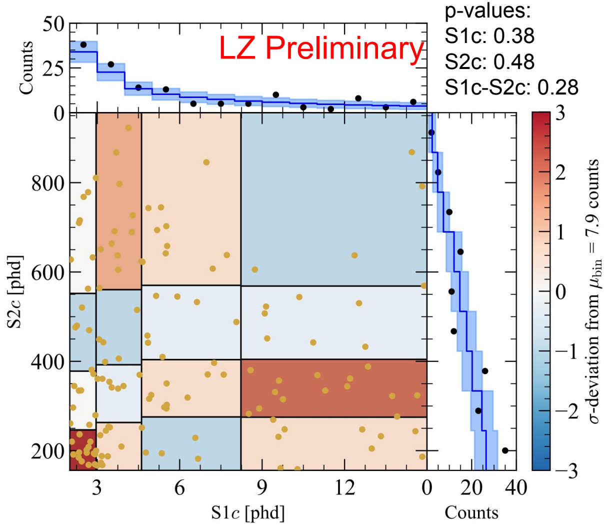

LZ accidentals model *captures time-varying environment*

Generated from stitching together isolated S1s and S2s. Total rate normalized to a known accidentals sideband (> max drift time)

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

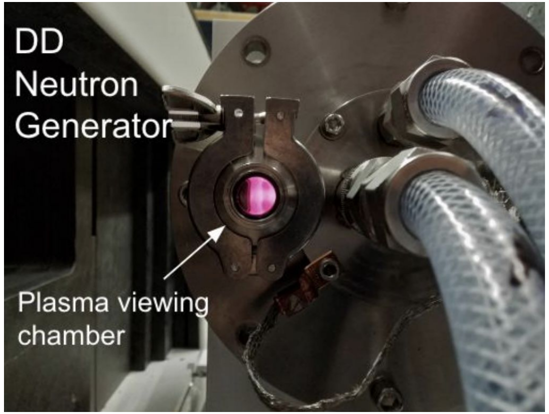
Excellent agreement across a variety of detector conditions (neutron calibrations and high-photon/electron conditions) – paper in prep

Model validated using events with drift time > max drift time

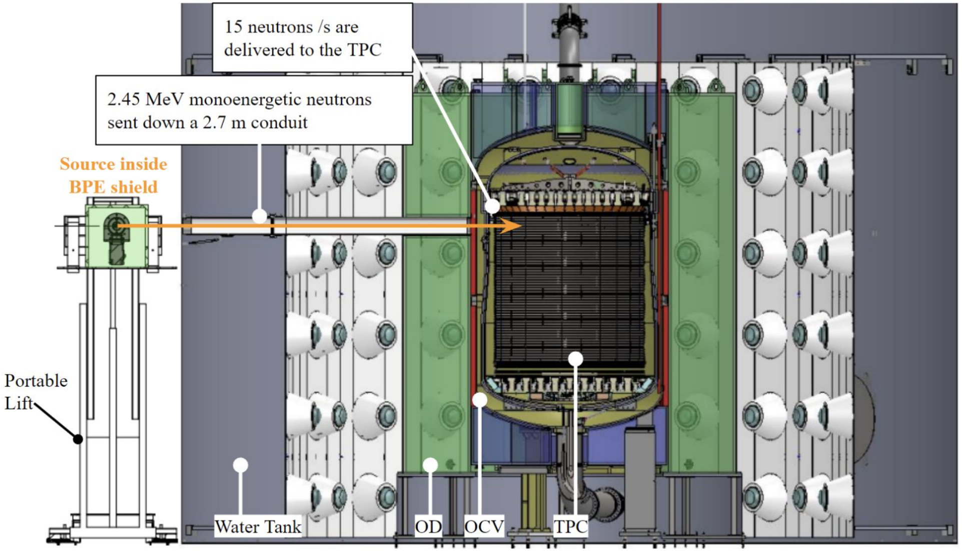


# Calibrating nuclear recoil response

Need to calibrate nuclear recoil response and quantify uncertainties

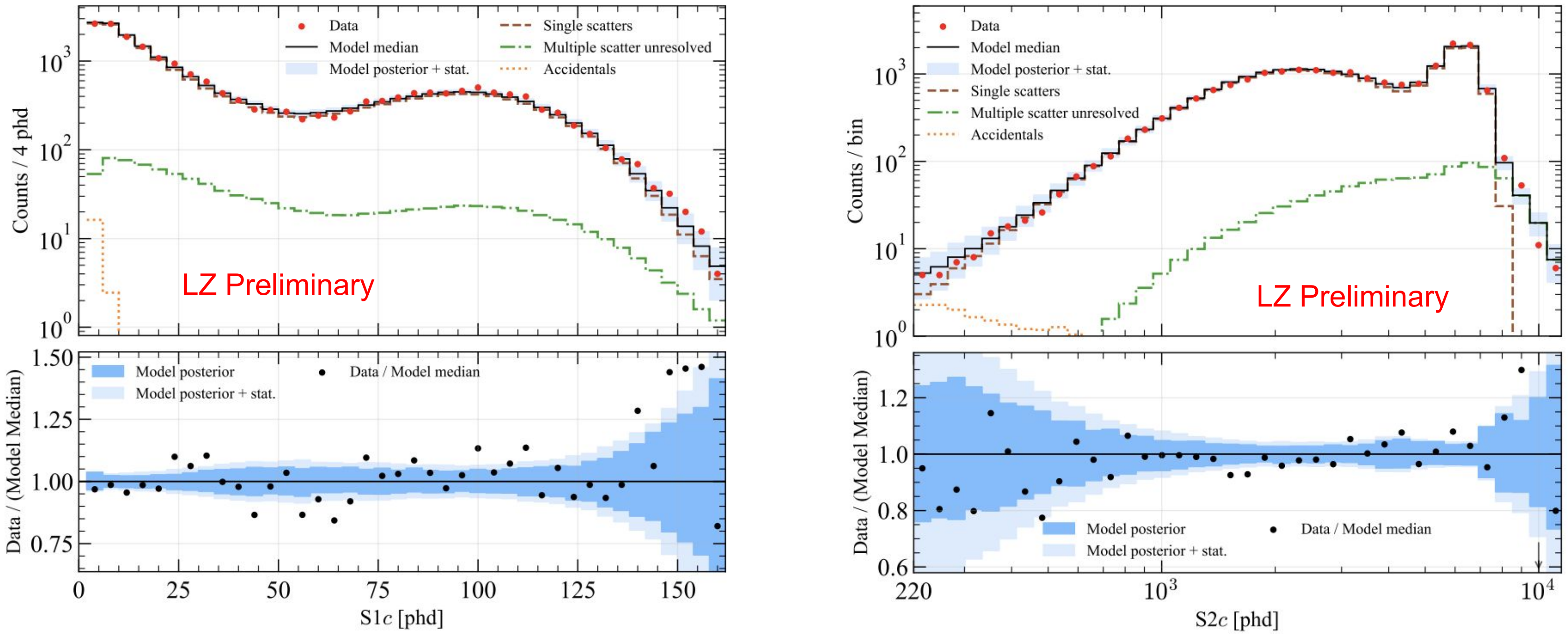



- Nearly mono-energetic 2.45 MeV neutrons from an Adelphi deuterium-deuterium (DD) source
- DD neutrons produce nuclear recoils from 0-74 keV
- Constrain both high and low energy nuclear recoil behavior in xenon



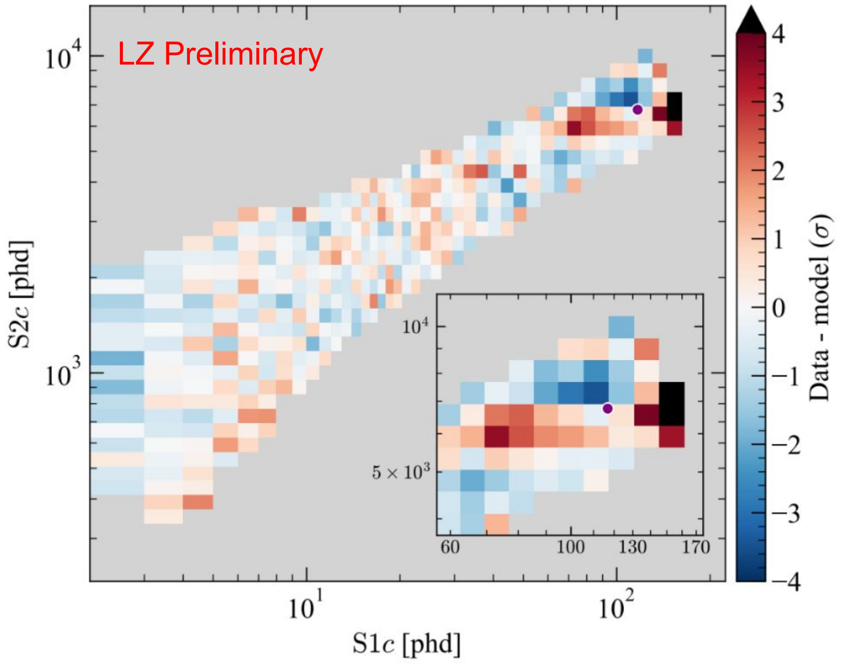

Schematic of DD neutron generator and the neutron's path into the TPC

# Fit to neutron calibration data



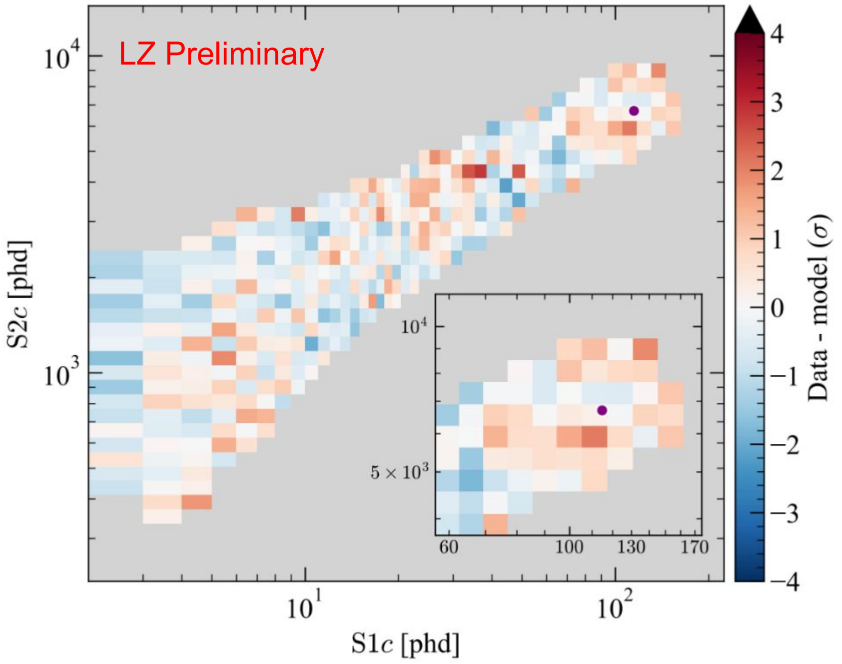

Excellent fit across 1-74 keV energy range

# Require new LXe physics to describe neutron data




NEST v2.4.0 LXe microphysics framework underpredicts S1 variance

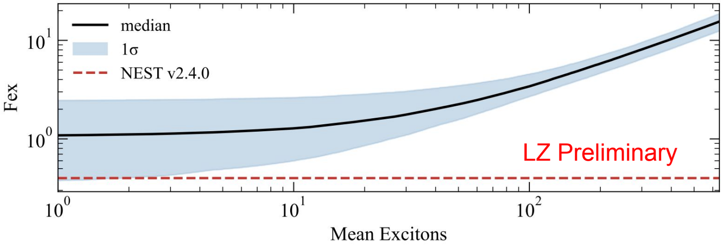
Cannot be explained by detector effects



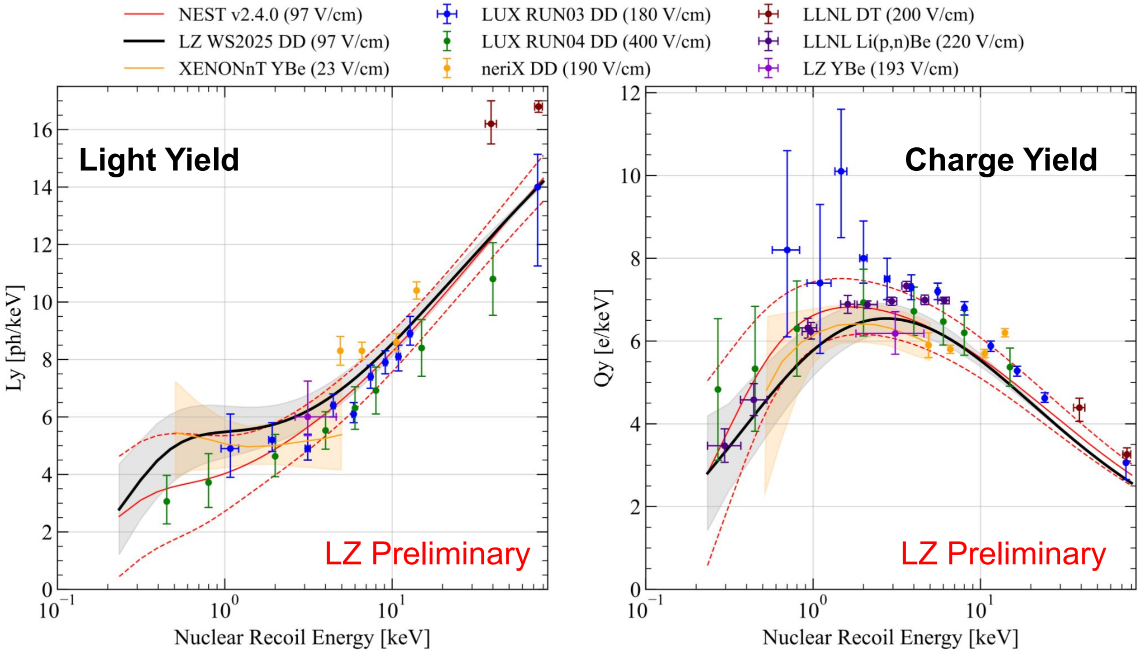

Modified microphysics with energy-dependent fluctuations – paper in prep

# Nuclear recoil yield and fluctuation results

Quantified systematic uncertainty associated with yields, fluctuations and detection efficiencies




Exciton (photon) Fano factor as a function of excitons produced

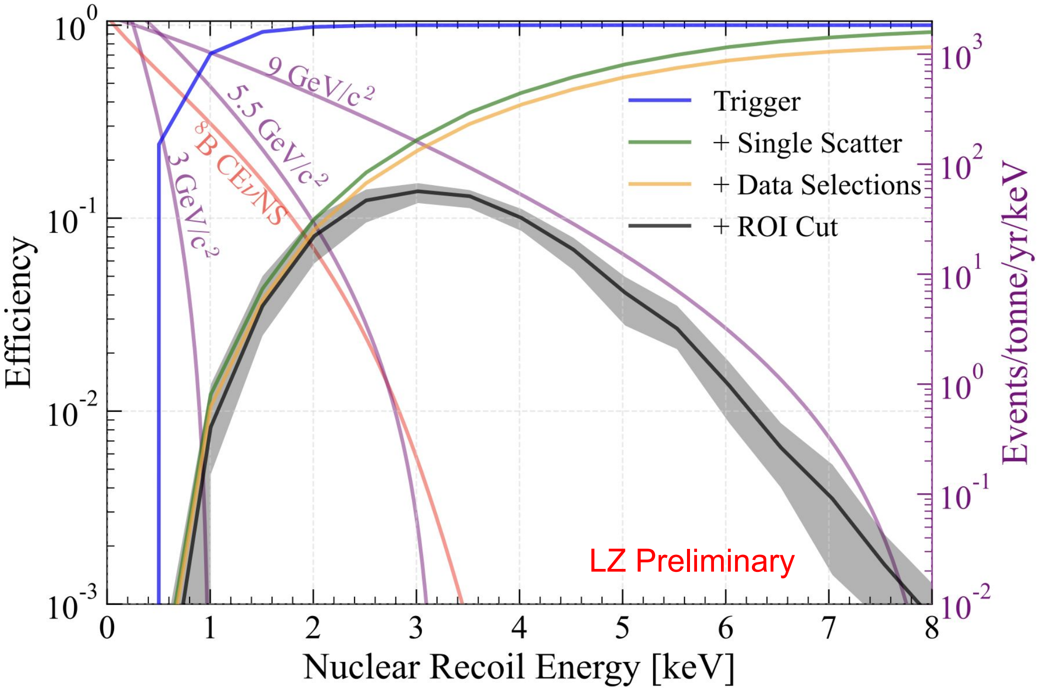



Light and charge yields from LZ (black) compared to other experimental results arXiV:2512.08065

# Signal efficiency

Threshold is set by 3-fold S1 requirement, and measured with calibration events

$^{8}B$ CEvNS and low-mass WIMP detection strategy: S1 fluctuations above threshold, constrained by neutron data



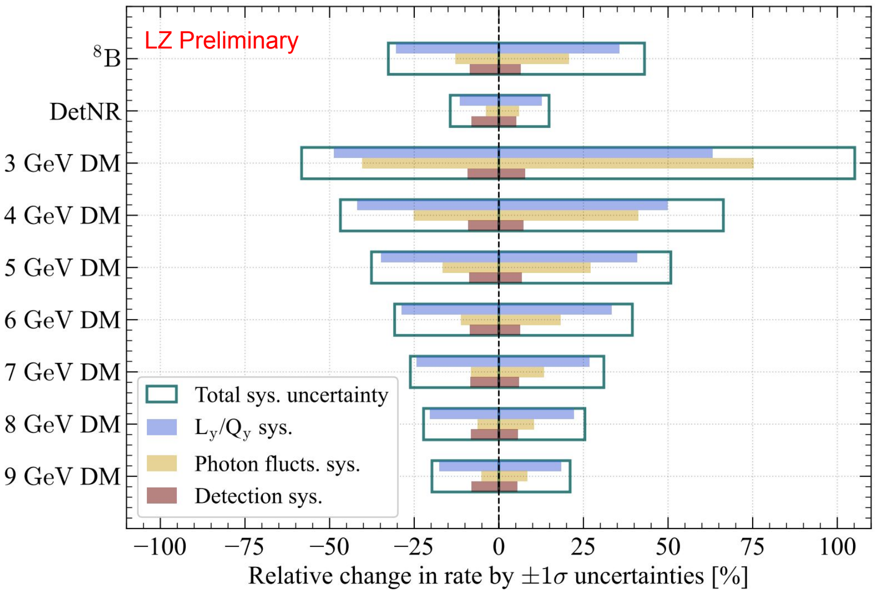

Signal efficiency as a function of nuclear recoil energy
arXiV:2512.08065

# Expectations and uncertainty budget

Total uncertainty on detector response contains contributions from:

- Mean nuclear recoil yields
- Nuclear recoil fluctuations
- Threshold characterization

**$^{8}$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

# Bias mitigation

Artificial signal events (salt) are randomly injected into the datastream to obscure true counts

No backgrounds were measured or data selections developed using search region data

Salt revealed after analysis decisions are finalized

# Data in search region

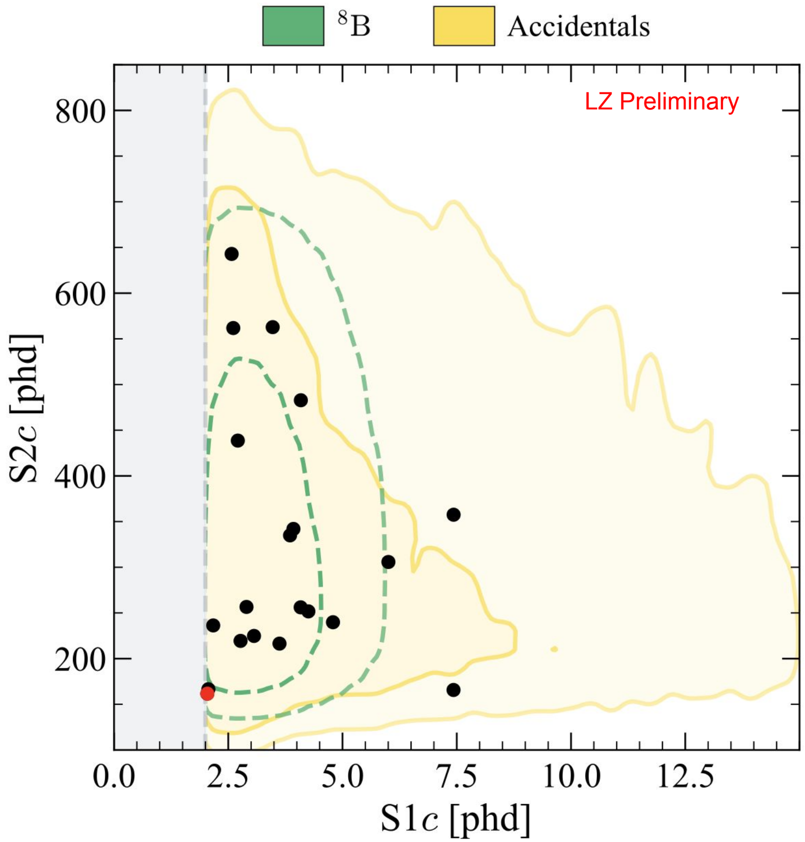
20 events in dataset after all selections

1 event was salt (red)

**19 remaining events**

Sideband dataset of "neutron-rich" data: passing all selections except 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)

# Hypothesis tests

Profile likelihood ratio (PLR) test performed in

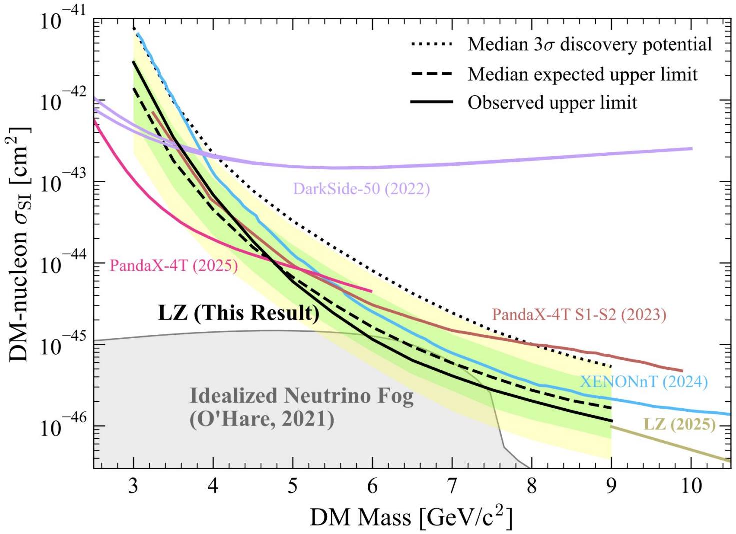
1. **Search for 3-9 GeV/$c^2$ dark matter**
   a. Backgrounds: $^8$B CE$\nu$NS, accidental coincidences, detector neutrons
   b. Assume $^8$B CE$\nu$NS rate from Standard Model[1] and flux measured by SNO experiment[2]
2. **Search for $^8$B CE$\nu$NS**
   a. Assume *zero* DM events
   b. Backgrounds: accidental coincidences and detector neutrons
   c. $^8$B CE$\nu$NS rate is floated freely

[1] Phys. Rev., D 9, 1389 (1974)
[2] Phys. Rev. C 88, 025501 (2013)

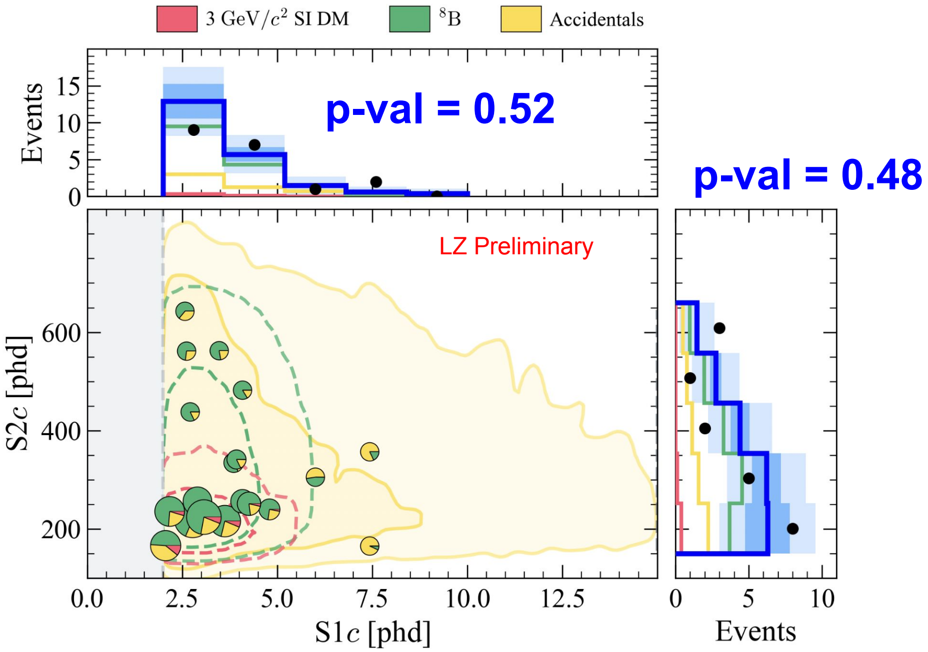
# Low-mass dark matter

$^8$B CE$\nu$NS, Accidentals, and Neutrons are backgrounds in this test

Best-fit number of DM events is consistent with 0 across all DM masses tested




Limit setting for Spin Independent (SI) DM-nucleon interaction strength using two-sided test statistic

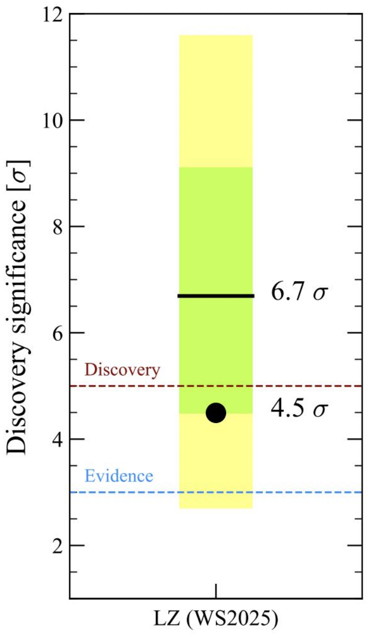


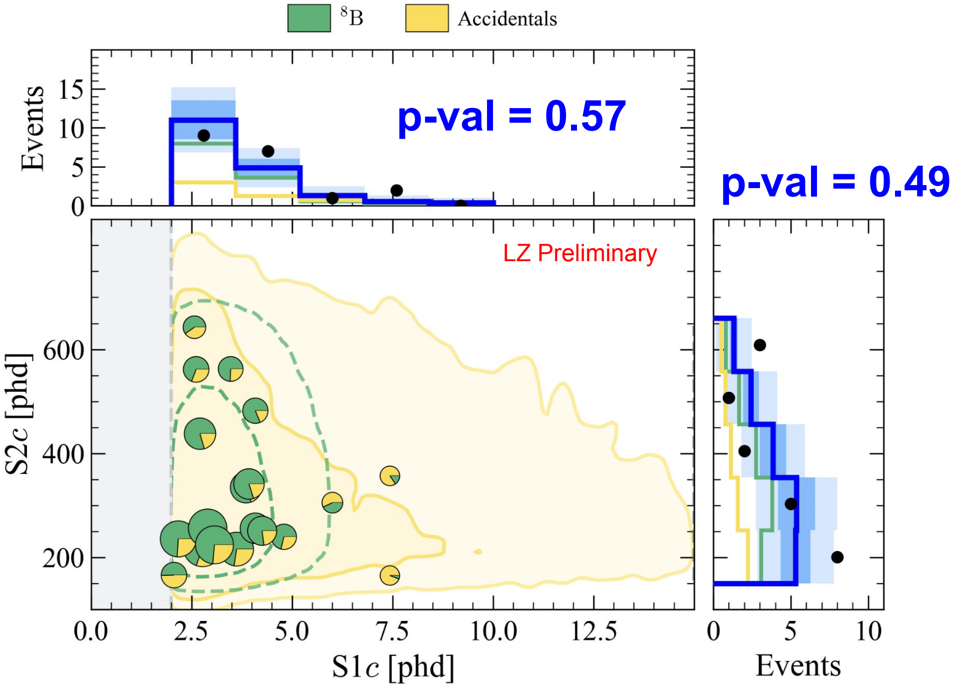

| Components | Expectation | 3 GeV/$c^2$ Fit |
|---|---|---|
| Spin-Independent DM | - | $0.5^{+5.1}_{-0.5}$ |
| $^8$B CE$\nu$NS | $20.6^{+8.9}_{-6.8}$ | $14.7^{+3.1}_{-2.7}$ |
| Accidental coincidences | $6.6 \pm 0.3$ | $6.5 \pm 0.3$ |
| Detector neutrons | $0.04^{+0.25}_{-0.04}$ | $0.1^{+0.2}_{-0.1}$ |
| Total | $27.2^{+9.2}_{-6.7}$ | $21.7^{+7.1}_{-4.2}$ |

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

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

**Demonstrated ability to detect a WIMP-like signal!**



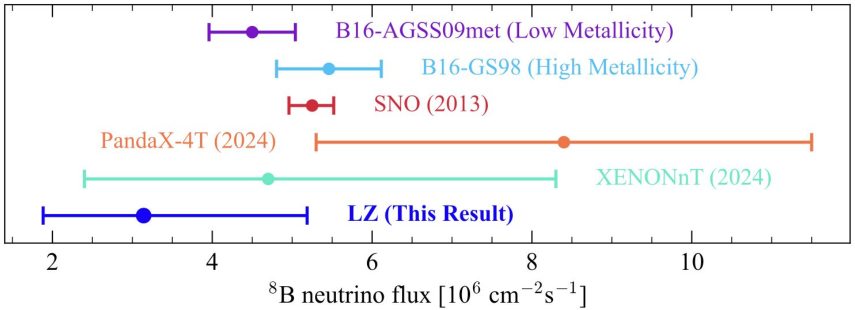



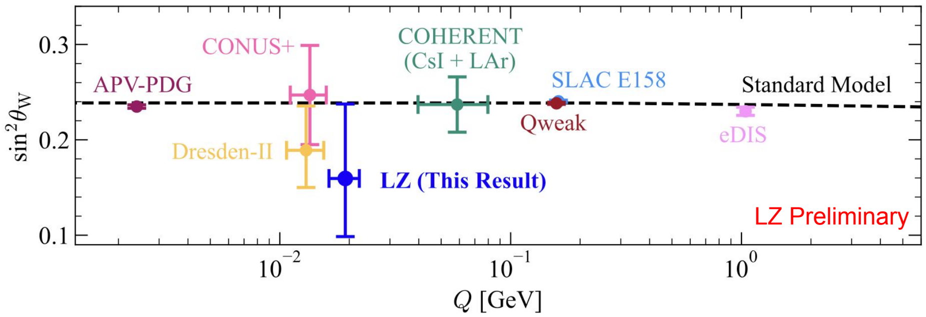

| Components | Expectation | Fit Results |
|---|---|---|
| $^8$B CE$\nu$NS | - | $12.3^{+7.0}_{-5.4}$ |
| Accidental coincidences | $6.6 \pm 0.3$ | $6.6 \pm 0.3$ |
| Detector neutrons | $0.04^{+0.25}_{-0.04}$ | $0.1^{+0.2}_{-0.1}$ |
| Total | $6.6 \pm 0.3$ | $18.9^{+7.0}_{-5.5}$ |

# Result consistent with flux measurements and SM

$^8$B CE$\nu$NS used for

- Flavor-independent constraint of $^8$B solar neutrino flux
- Constrain weak-mixing angle ($\sin^2\theta_W$) at low momentum transfer (Q)

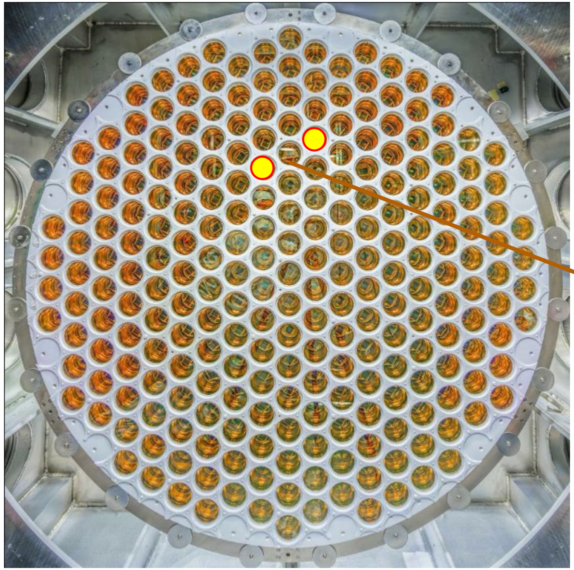


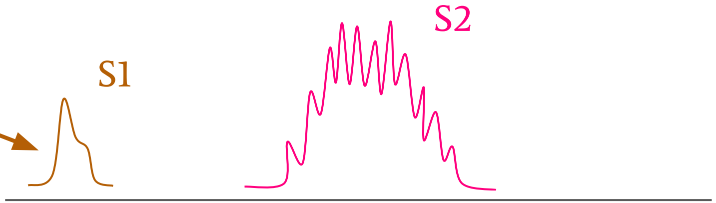
# What's next?

<u>WS2025:</u>
Demonstration of LZ's ability to detect a low-energy signals

<u>WS2026:</u>
- Push the threshold for low-energy DM and neutrinos
- Better control of systematics & backgrounds



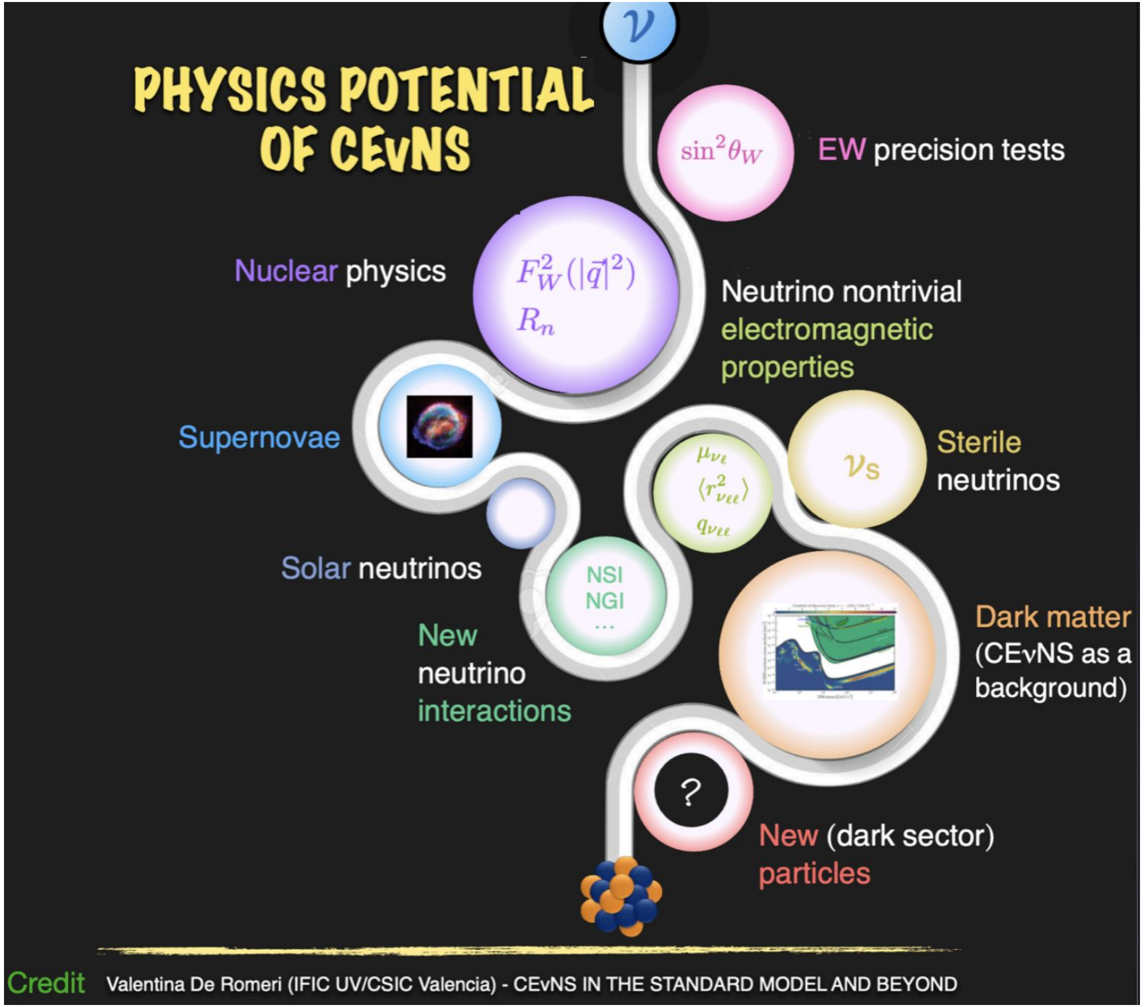
**Promotes pushing threshold on primary scintillation signal i.e. going to a 2-fold coincidence!**



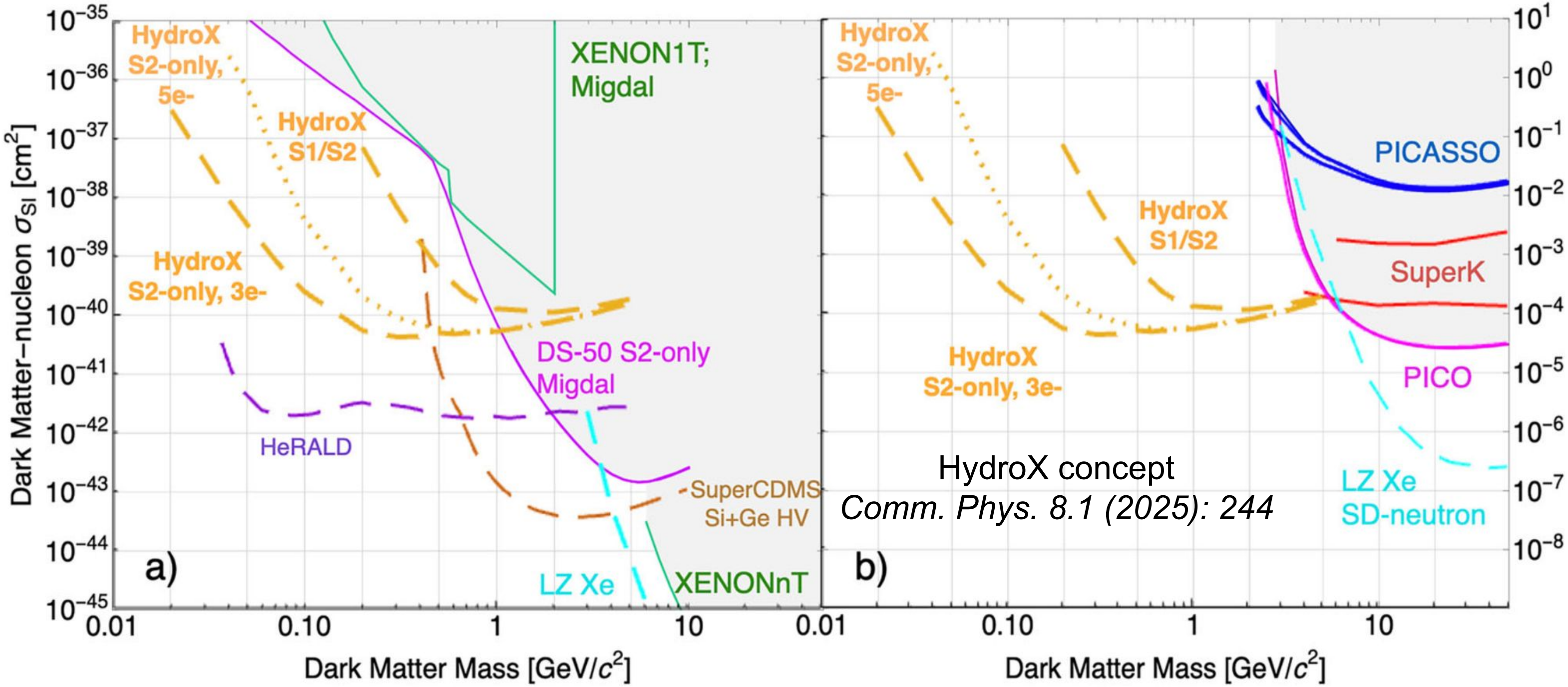

Slide courtesy of Emily Perry

# Outlook

- Liquid xenon experiments are exquisitely sensitive to WIMP dark matter and CEvNS
- Highly significant detection of $^{8}B$ CEvNS interactions
- Yesterday's signal is today's background
- Liquid xenon is also sensitive to other solar neutrino interactions
  - Davis-style neutrino capture
  - Argon: see DEAP3600 CC measurement of 8B neutrinos [2605.12769]



# Further ahead: HydroX (Hydrogen in Xenon)




- Dope LZ xenon with hydrogen to increase reach at lower DM masses
  - Better kinematics, better signal production
  - Significant RnD push at UCSB, LBNL, SLAC, U-Michigan to determine viability
- **Tour solubility measurement setup on Wednesday!**

# More physics with LZ

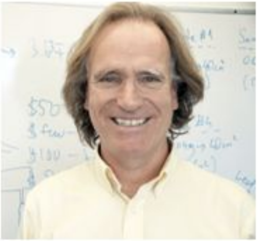
- LZ is the largest and most sensitive liquid xenon TPC in the world! Phys.Rev.Lett. 135 (2025) 1, 011802
- Other physics searches being performed in LZ…
  - Effective field theory coupling of DM to xenon nuclei — Phys.Rev.D 109 (2024) 9, 092003
  - Solar axions, axion-like particles, dark photons — Phys.Rev.Lett. 133 (2024) 22, 221801; Phys.Rev.D 108 (2023) 7, 072006
  - $^{136}$Xe $2\nu\beta\beta$ and $0\nu\beta\beta$, also $^{124}$Xe double-electron capture — arXiv:2511.17350
  - Ultraheavy Dark matter — Phys.Rev.D 109 (2024) 11, 112010
  - Cosmic ray boosted DM — Phys.Rev.Lett. 134 (2025) 24, 241801
  - Atmospheric millicharged particles — Phys.Rev.Lett. 134 (2025) 24, 241802
  - And much more…

# Dark matter team at UCSB

Plus new undergraduate members (not pictured)

- Lynx Xu
- Nova Lian
- Darius Vlad
- Kian Hammer (REU)

Hugh Lippincott



Harry Nelson

Chami Amarasinghe

Sabrina Zacarias

Ryan Zhang

Makayla Trask

Jeonghwa Kim

Lindsey Weeldreyer

Jordan Thomas

Haley Fogg

Janhavi Singhal

Colin Ripley

X

Syon Maskey

High Energy Physics Dark Matter Group

# LZ (LUX-ZEPLIN) Collaboration, 38 institutions

@lzdarkmatter

- 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
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
- STFC Rutherford Appleton Lab.
- Texas A&M University
- University of Albany, SUNY
- University of Alabama
- University of Bristol
- University College London
- University of California Berkeley
- University of California Davis
- University of California Los Angeles
- University of California Santa Barbara
- University of Liverpool
- University of Maryland
- University of Massachusetts, Amherst
- University of Michigan
- University of Oxford
- University of Rochester
- University of Sheffield
- University of Sydney
- University of Texas at Austin
- University of Wisconsin, Madison
- University of Zürich

US Europe Asia Oceania

**250 scientists, engineers, and technical staff**

LZ Collaboration Meeting at UCLA, March 2025

**https://lz.lbl.gov/**

US DOE

Science and Technology Facilities Council

fct Fundação para a Ciência e a Tecnologia

SANFORD UNDERGROUND RESEARCH FACILITY

Swiss National Science Foundation

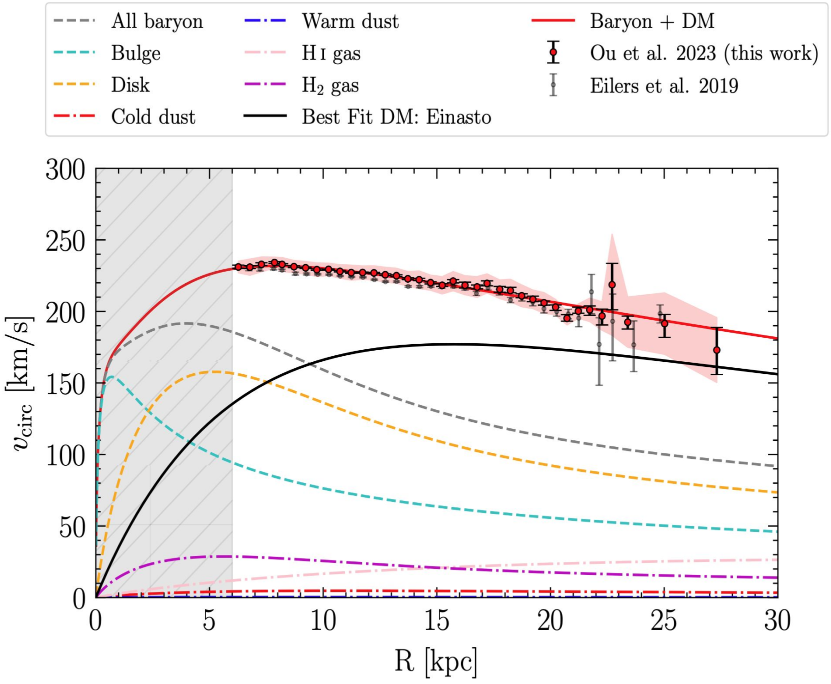
ibs Institute for Basic Science

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Thanks to our sponsors and participating institutions!

# SUPPORTING MATERIAL

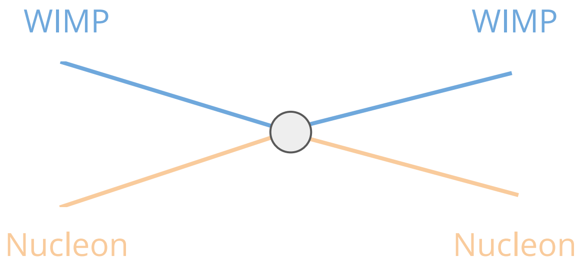
# Dark matter ***may*** interact with terrestrial nuclei



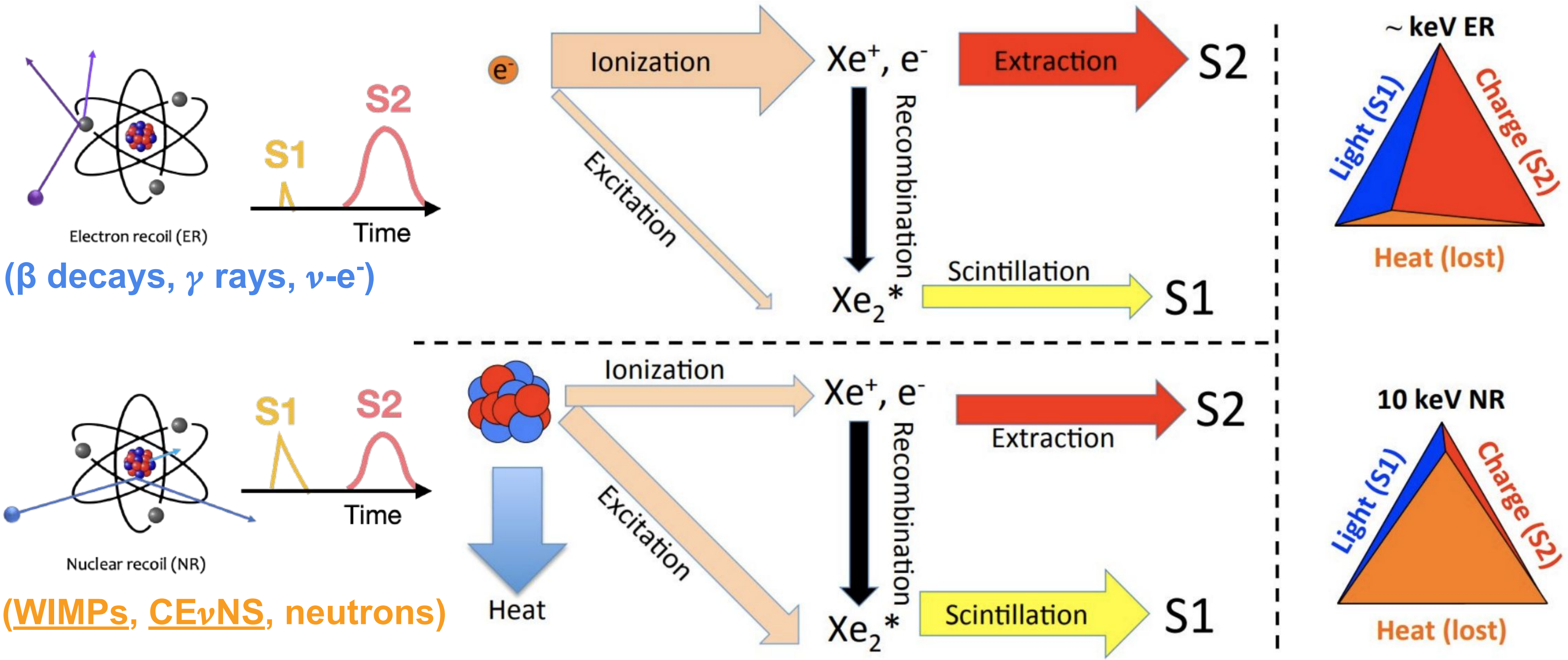

▲ **Dark matter in the Milky Way,**
Ou+ [2303.12838]

Local dark matter density

$$0.2 - 0.6\ \mathrm{GeV/cm^3}$$



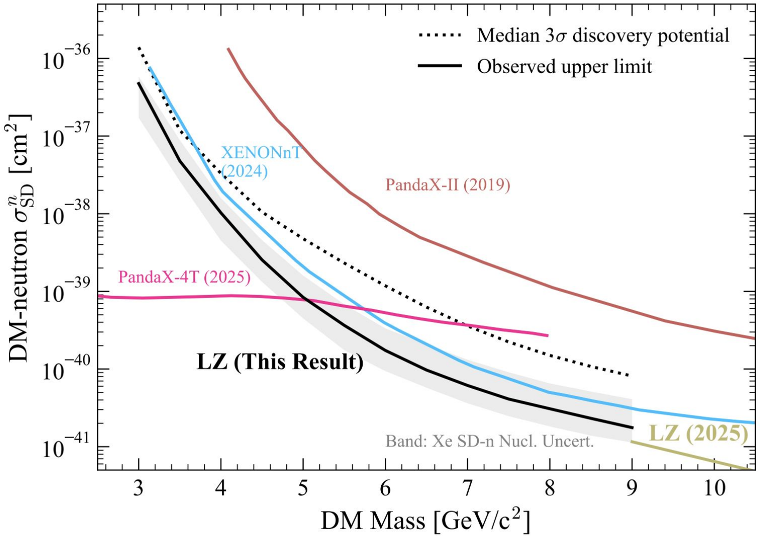
# Signal production in liquid xenon

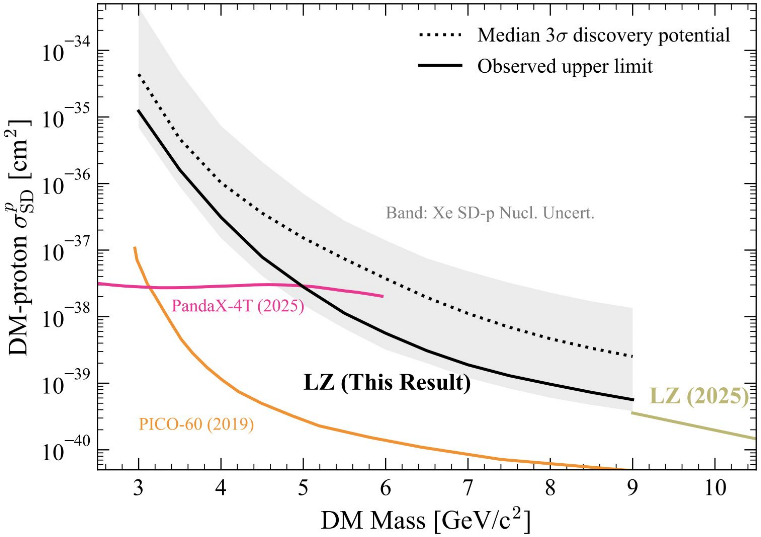



Courtesy Eric Dahl

# Spin Dependent DM Results

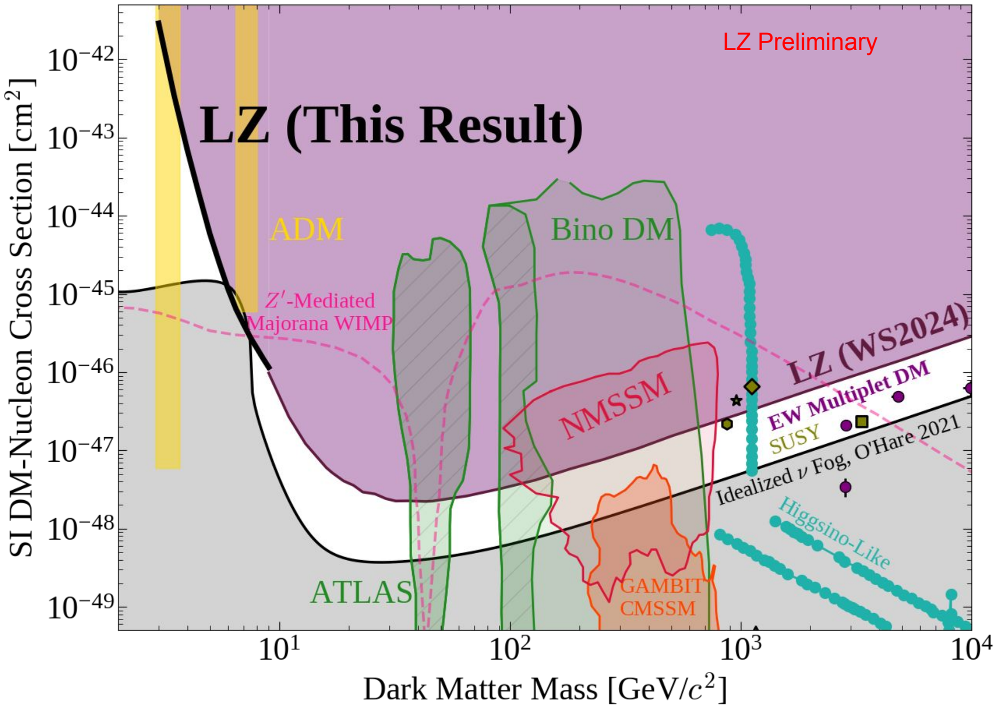
- Limits set on neutron-only or proton-only coupling to $^{129}Xe$ (26%) and $^{131}Xe$ (21%) which have unpaired neutrons leading to non-zero nuclear spin



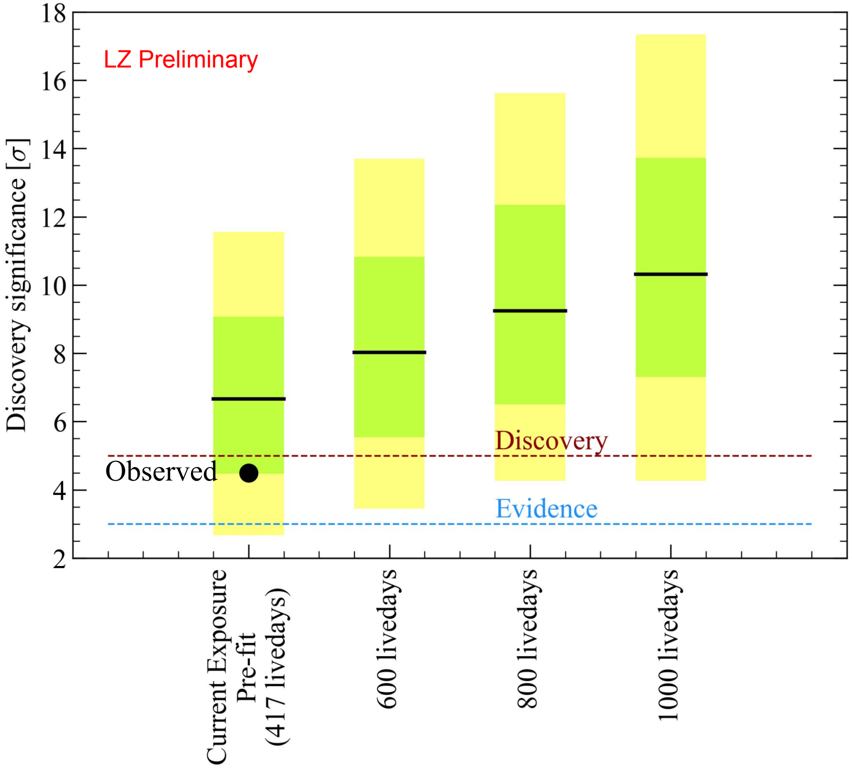



# Models in limit plot

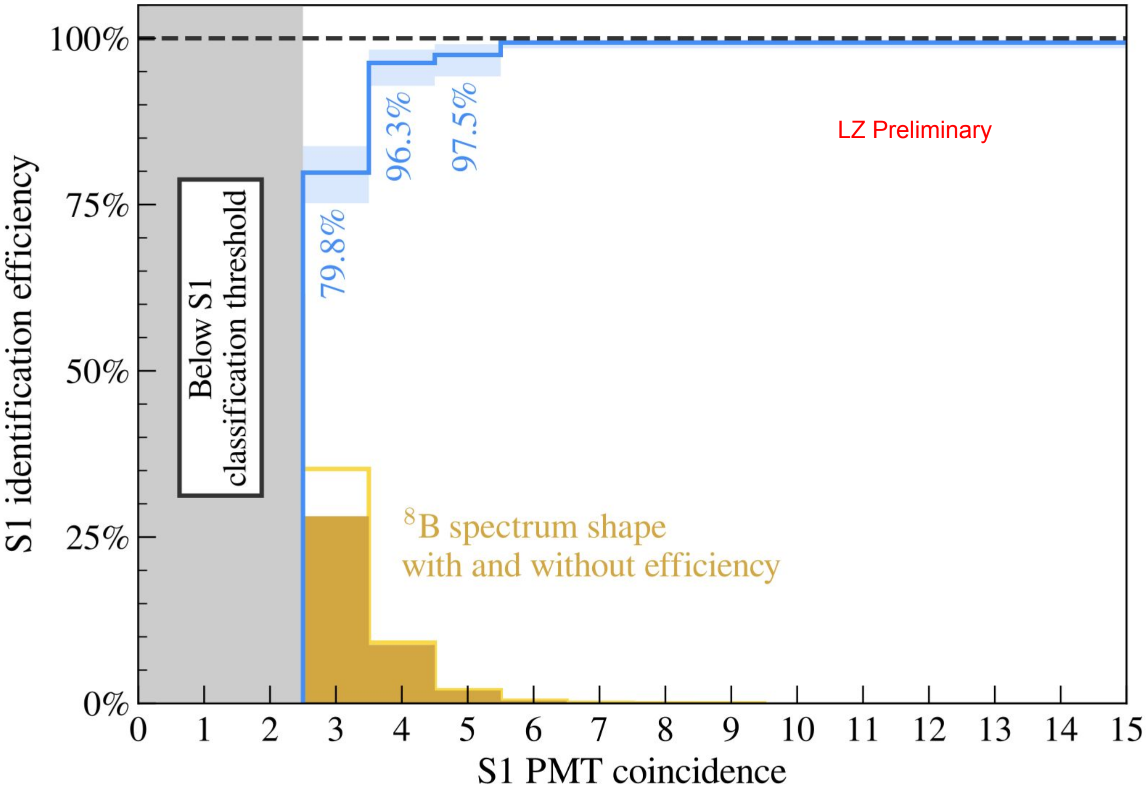
- ADM: Asymmetric Dark Matter, *PRD 82, 056001 (2010)*
- ATLAS Bino DM, JHEP 05 106 (2024)
- Z'-Mediated Majorana WIMP, *JCAP11 024 (2019)*
- GAMBIT CMSSM, *Eur. Phys. J. C. 77, 824 (2017)*
- NMSSM, *JHEP 2024, 212 (2024)*
- EW Multiplet DM, *Eur.Phys.J.C 82 (2022) 1, 31*; *arXiv:2410.02723*
- Higgsino-Like, *Eur. Phys. J. C. 83, 246 (2023)*
- SUSY electroweakinos, *Ann.Rev.Nucl.Part.Sci. 70 (2020) 425-454*



# Projected $^{8}$B CE$\nu$NS discovery significance sensitivity



# S1 reconstruction efficiency



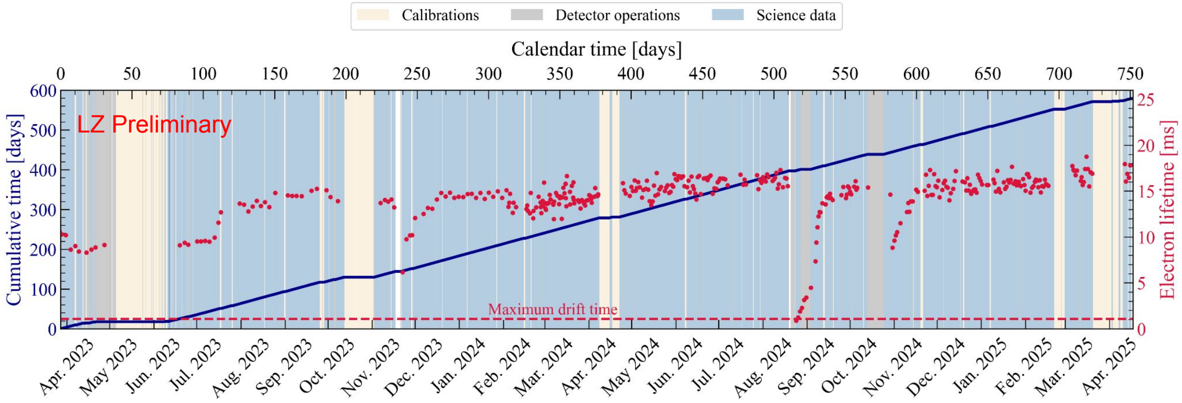
# Search dataset

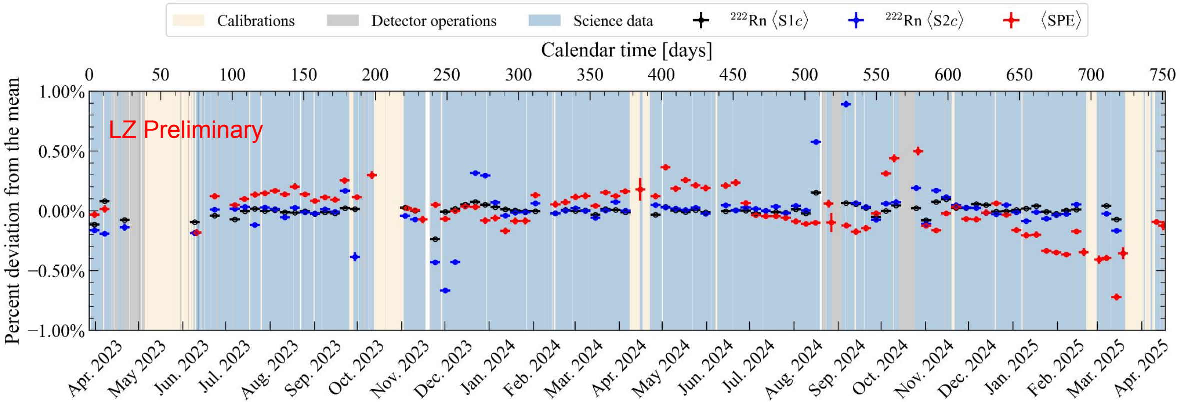
April 2023 to March 2025

- Excellent electron lifetime
- Stable drift field of 97V/cm
- Stable extraction field of 3.4 kV/cm

S1 and S2 pulse sizes are corrected for uniformity in time and space

Corrected quantities: S1c, S2c



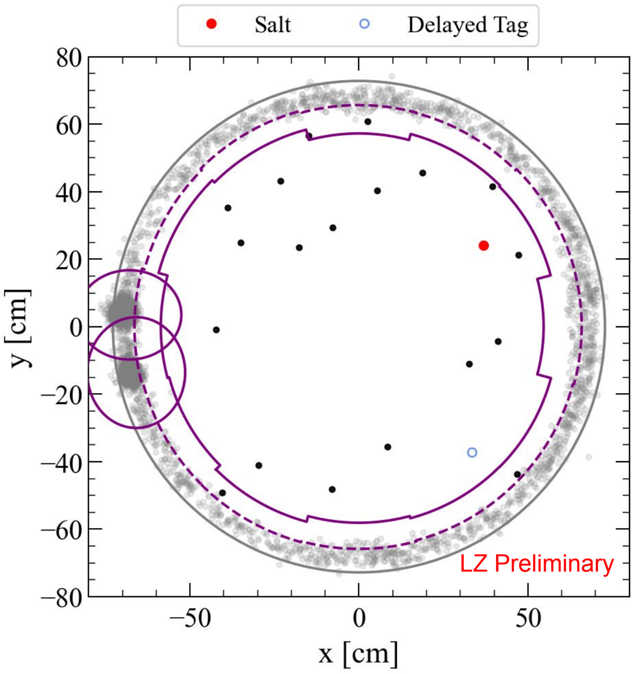



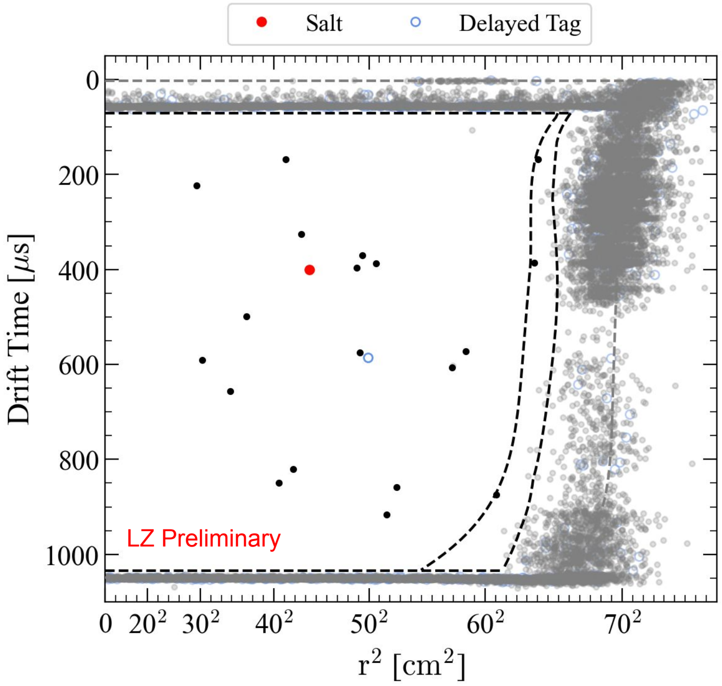
# Final dataset - position distribution

Gray:
TPC edge

Purple:
FVr extents at the top and bottom of the FVz

Purple circles:
Resistor cutouts

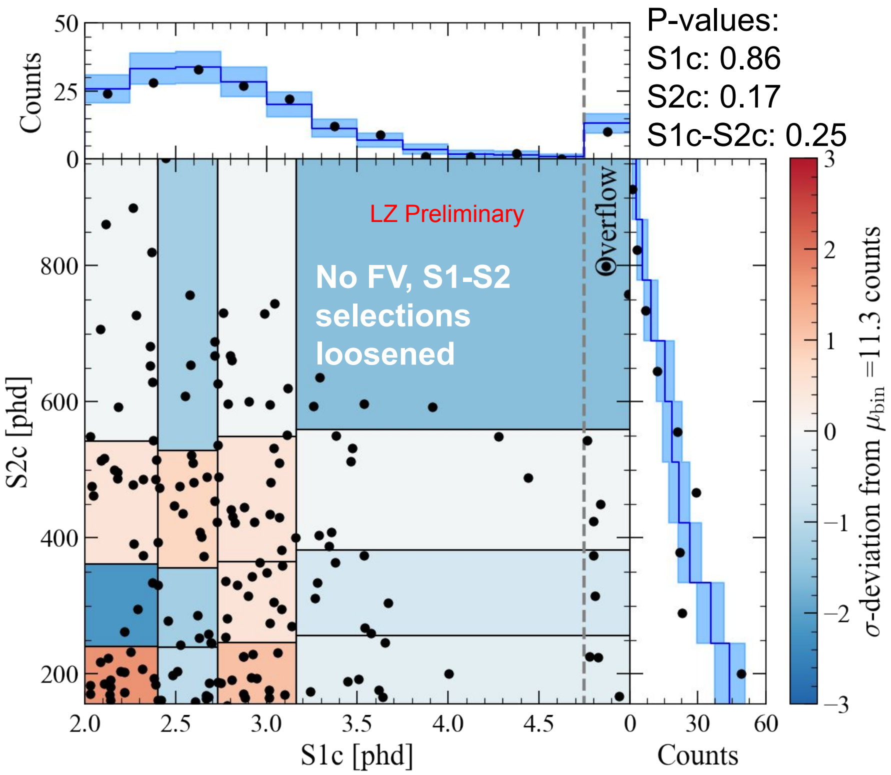


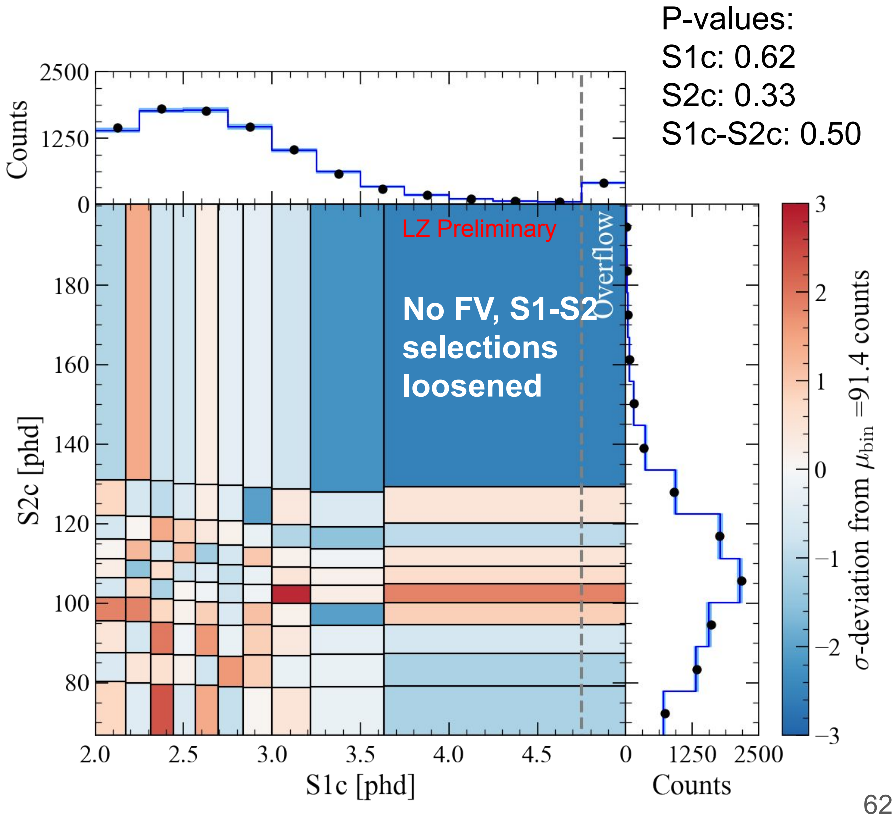




Gray:
Phi-averaged wall

Black:
Min and max FVr

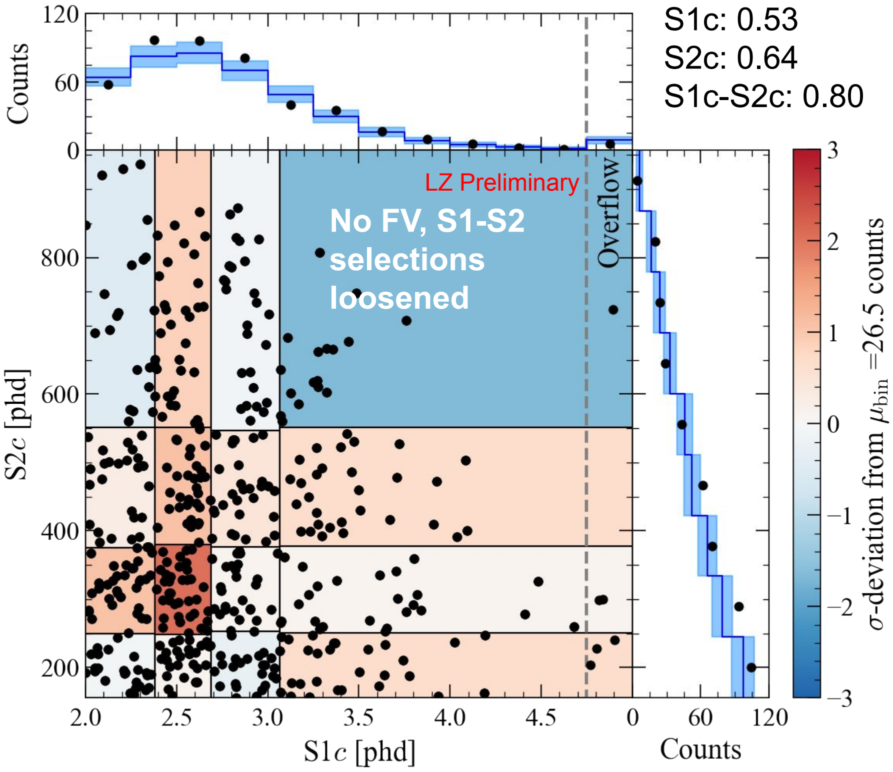
# High-rate validation



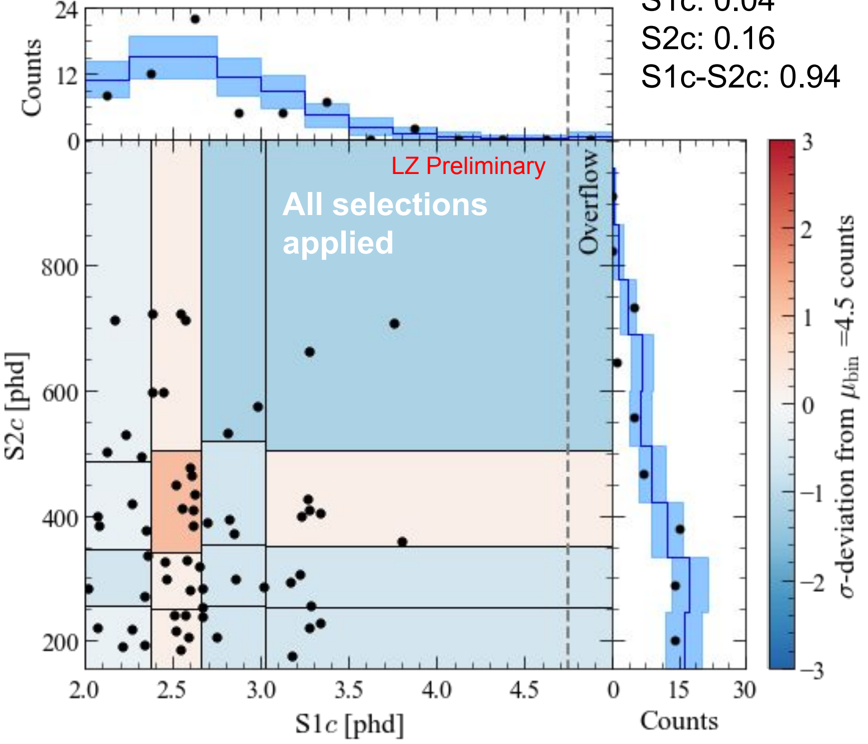



# AmLi validation

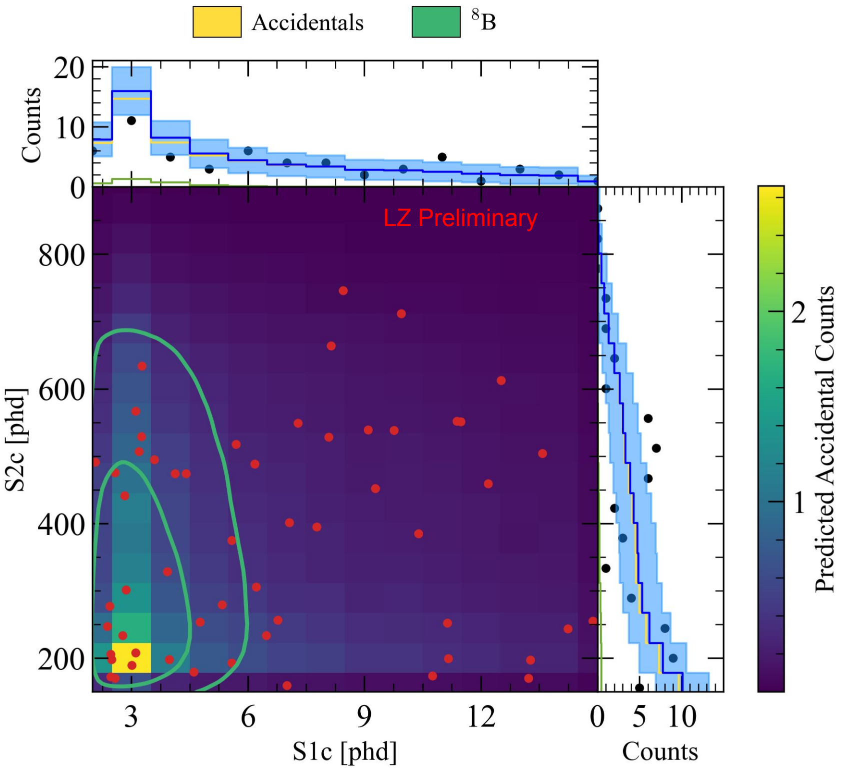
P-values:
S1c: 0.53
S2c: 0.64
S1c-S2c: 0.80



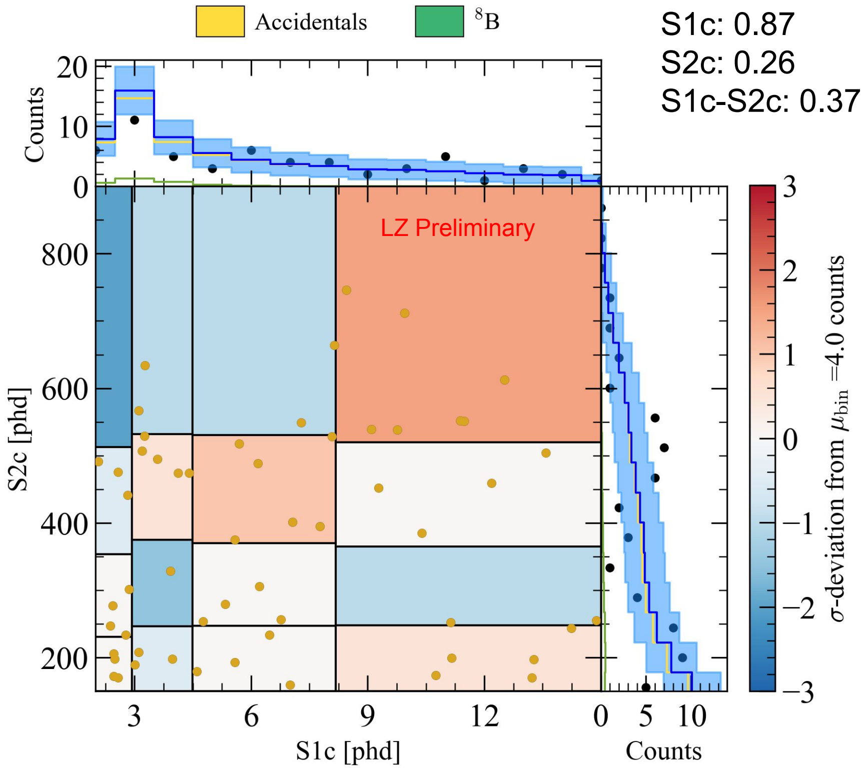

P-values:
S1c: 0.04
S2c: 0.16
S1c-S2c: 0.94



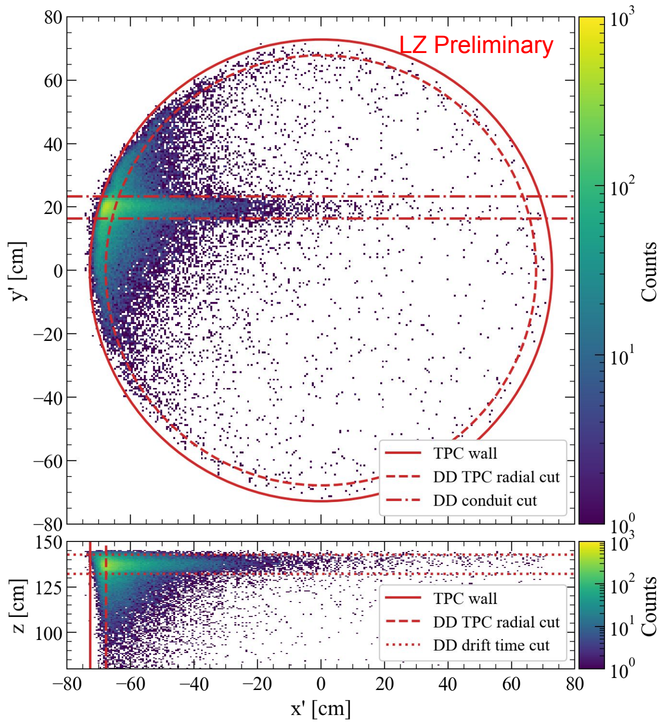
# Inverted S1-S2 validation



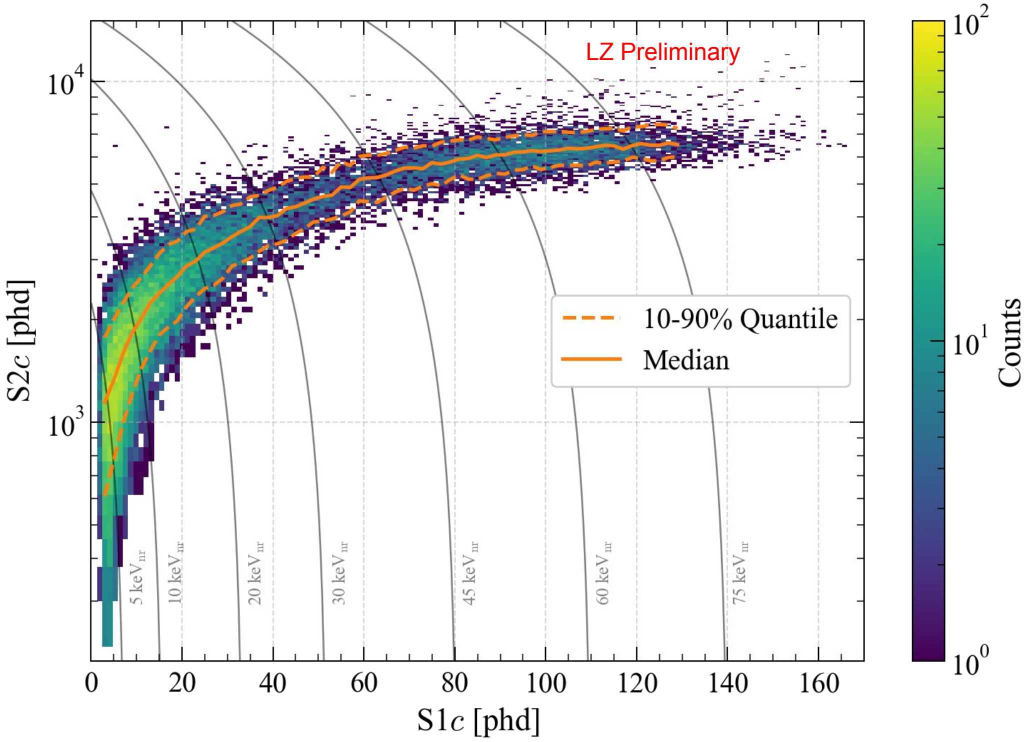

P-values:
S1c: 0.87
S2c: 0.26
S1c-S2c: 0.37



# DD spectra in LZ

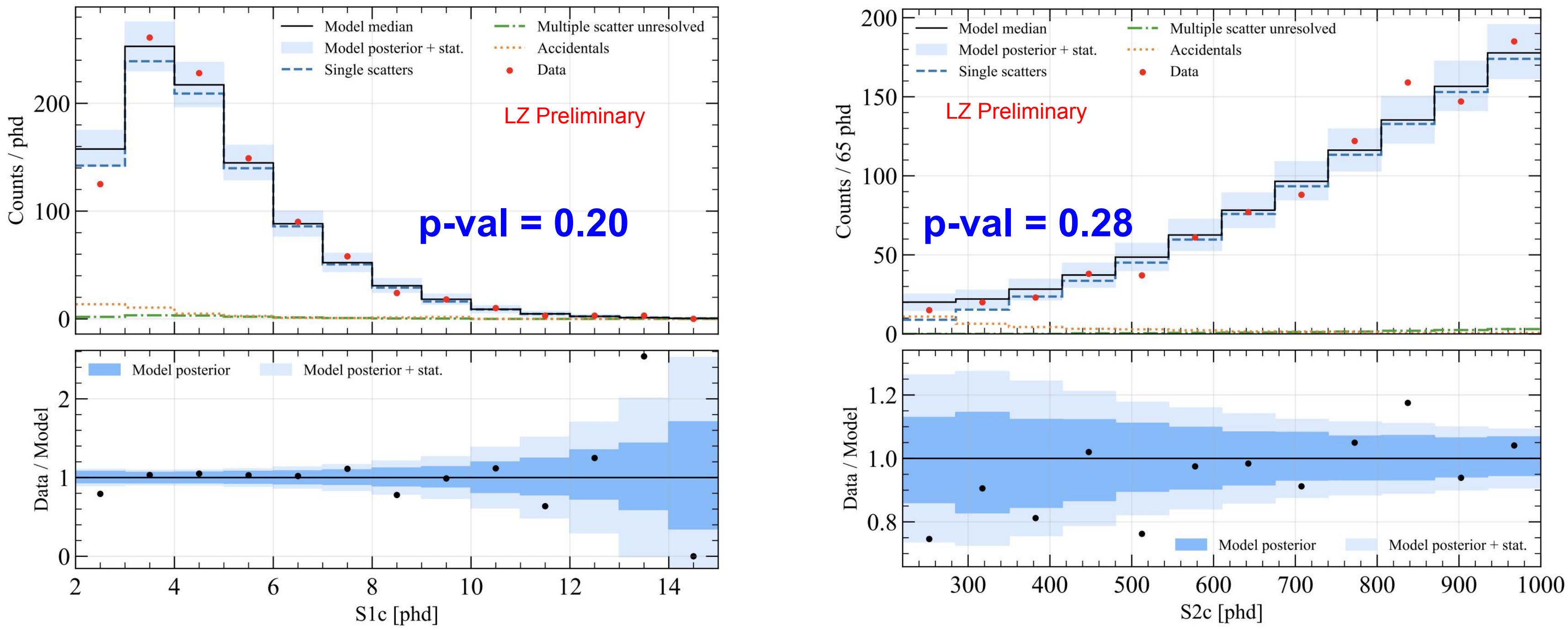



*Single scatter position distribution of DD neutrons in the TPC. The x, y position is rotated 8 degrees to x', y'*




*Single scatter nuclear recoil spectra of DD neutrons in the TPC*

# Best-fit nuclear recoil model

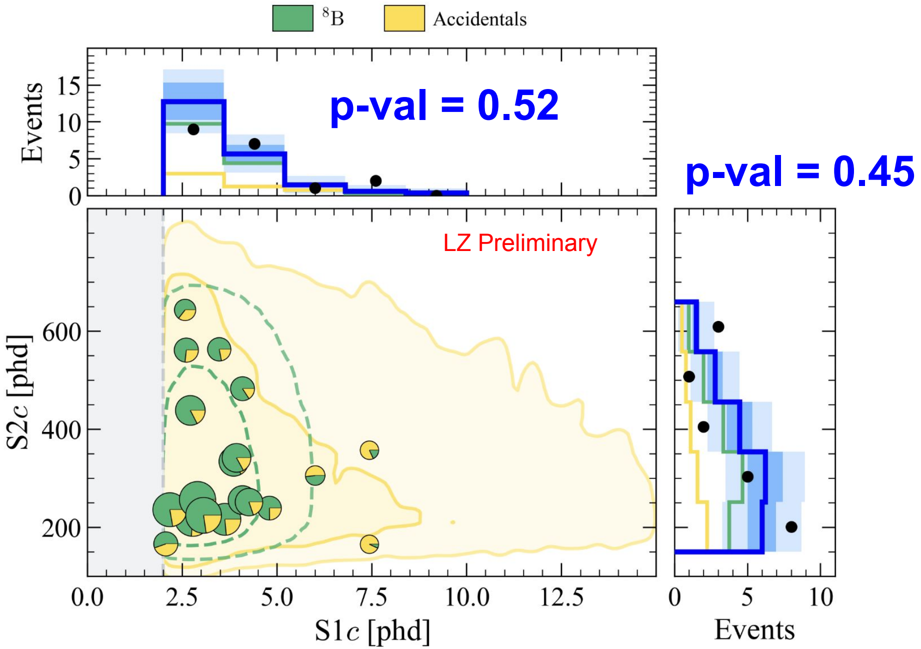



- Allow charge/light yield and photon/electron fluctuations to vary
- Consider different parameterization of recombination and fluctuation models

# Background-only fit

$^8$B CE$\nu$NS, Accidentals, and Neutrons are backgrounds in this model

- Negligible ER backgrounds in this ROI
- $^8$B CE$\nu$NS rate is **constrained** in fits
- Excellent data-model agreement!

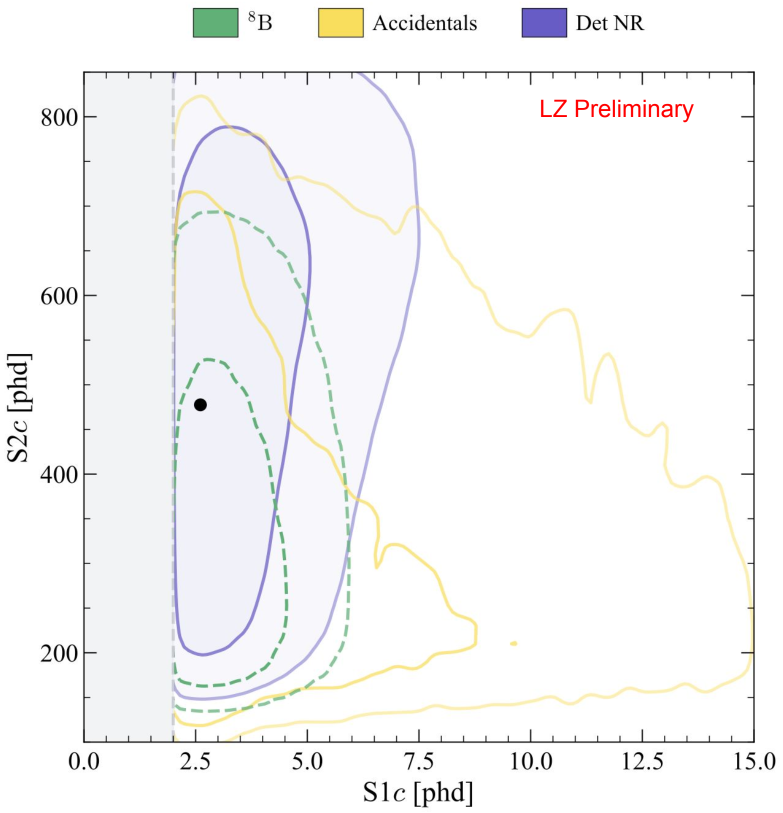



| Components | Expectation | Background-Only Fit |
|---|---|---|
| Spin-Independent DM | - | - |
| $^8$B CE$\nu$NS | $20.6^{+8.9}_{-6.8}$ | $15.0^{+2.9}_{-2.5}$ |
| Accidental coincidences | $6.6 \pm 0.3$ | $6.5 \pm 0.3$ |
| Detector neutrons | $0.04^{+0.25}_{-0.04}$ | $0.1^{+0.2}_{-0.1}$ |
| Total | $27.2^{+9.2}_{-6.7}$ | $21.6^{+4.7}_{-3.8}$ |

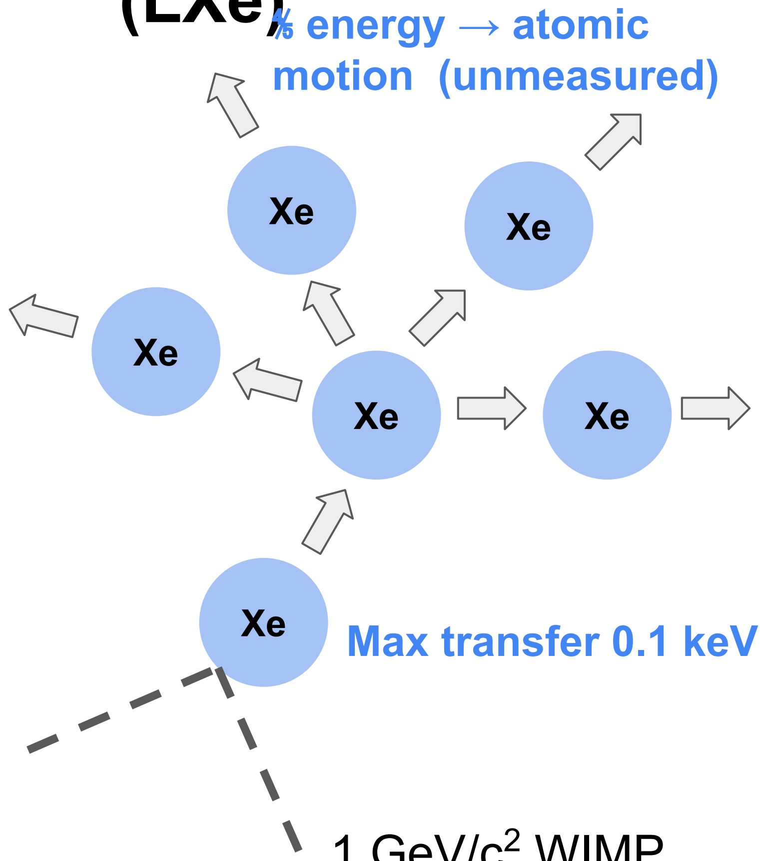
# Neutron-rich sideband

- Detector neutron rate constrained *in-situ* using dataset passing all selections except delayed OD/Skin veto
- $^{8}$B CE$\nu$NS and accidental coincidences leak into this dataset due to false veto rate (3%)

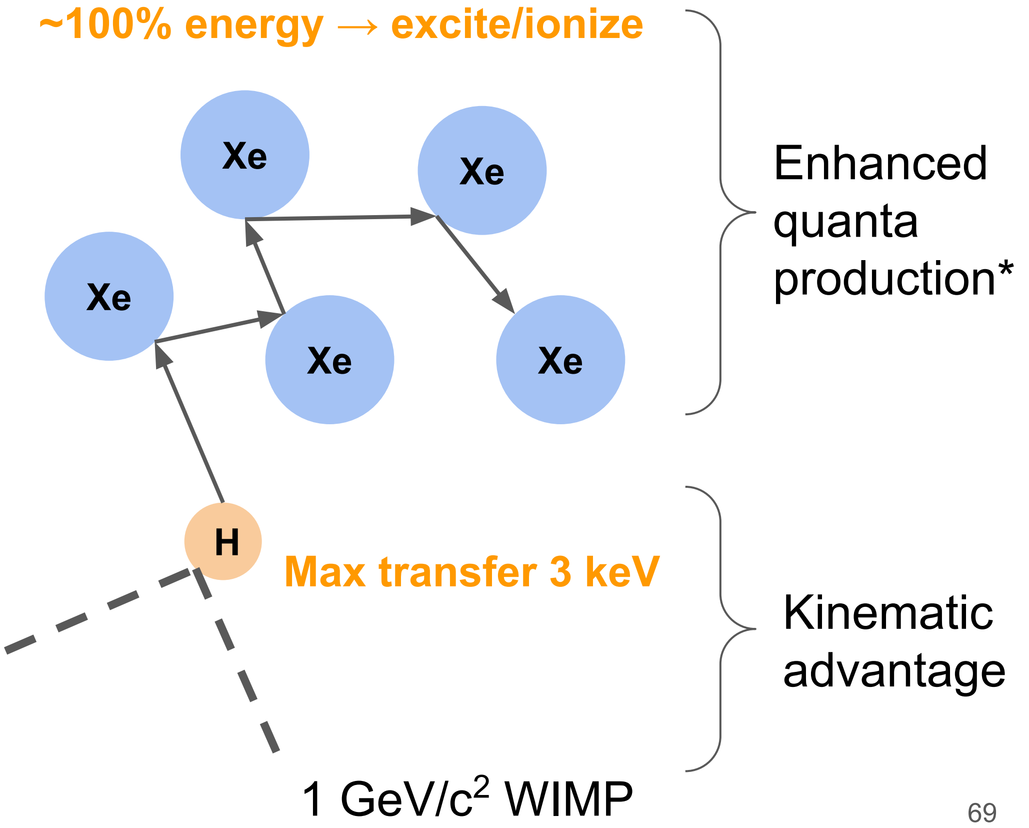
**Neutron expectation in full exposure (5.7 tonne-years) is $0.04^{+0.25}_{-0.04}$ events**



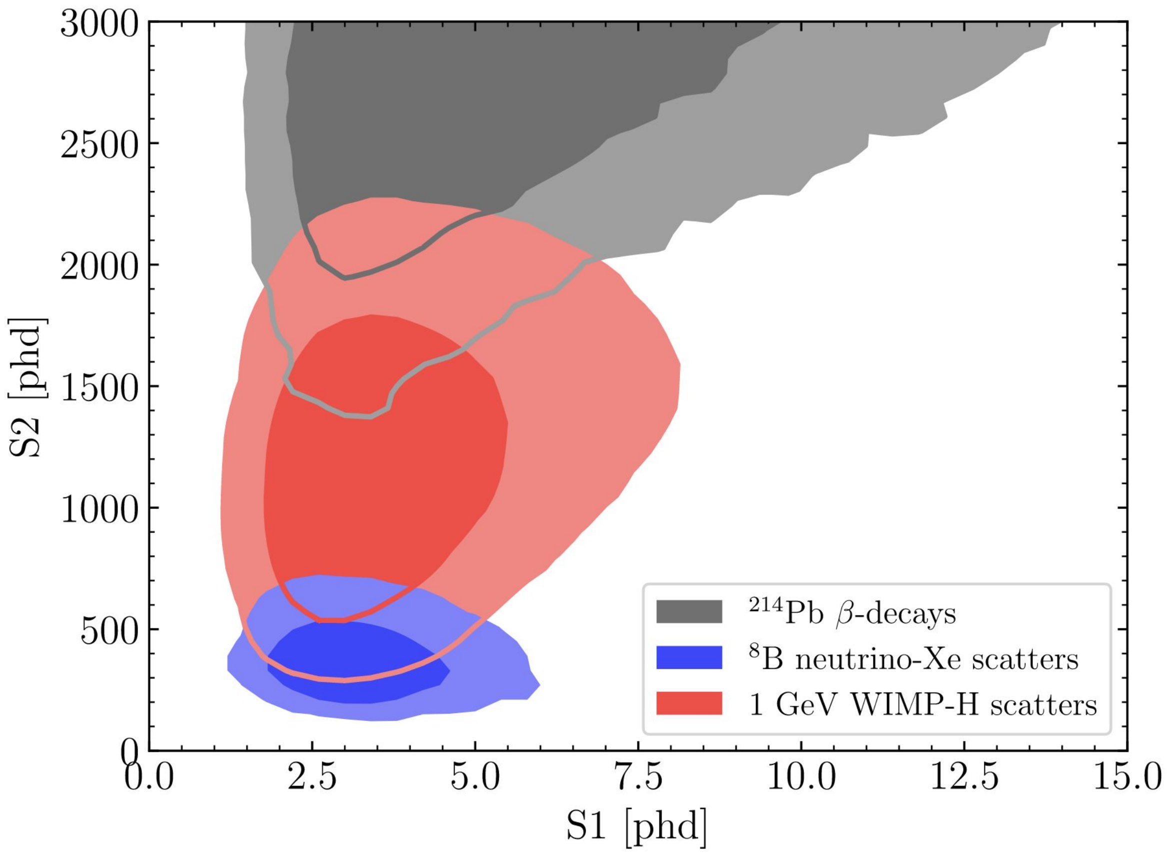
# Liquid xenon (LXe)




# Hydrogen-doped LXe



# HydroX signal and background distributions




LZ-like background model (from 1802.06039), 3-fold coincidence

Take with a grain of salt – Calibration of proton recoils determines dominant backgrounds

Accidental S1–S2 coincidences also not included (LZ would see ~5 in 500 days)