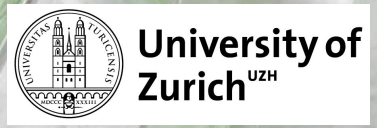
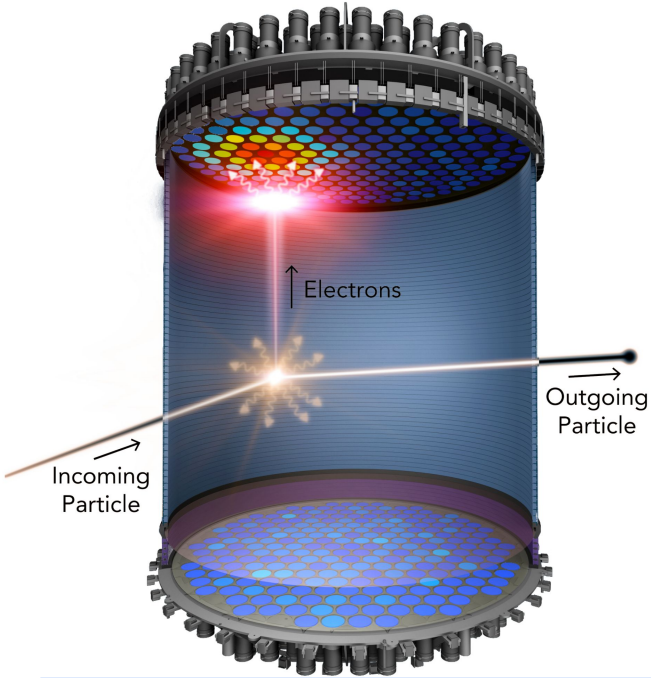
Latest Results from the LUX-Zeplin Experiment

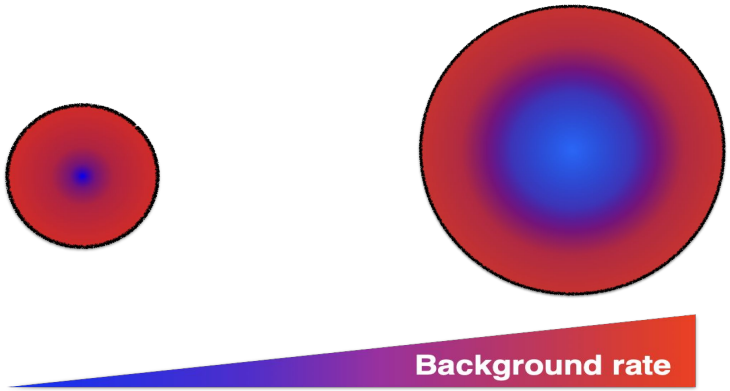
Björn Penning
University of Zürich

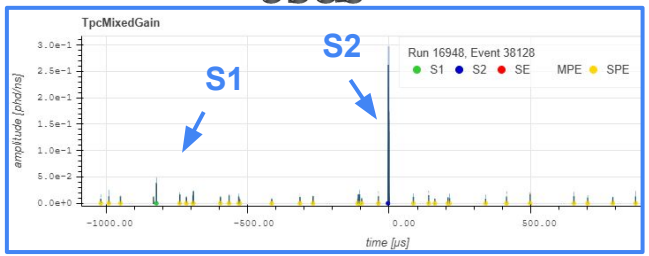
for the LZ Collaboration



- **Dual phase TPC**, two signals
  - Prompt scintillation light (**S1**)
  - Delayed proportional charge signal amplified in gas (**S2**)
- **Depth** (z) from time difference between S1/S2 and light pattern provides (x, y) **position**
- LXe is dense and **self-shielding** → **fiducial volume** (FV)







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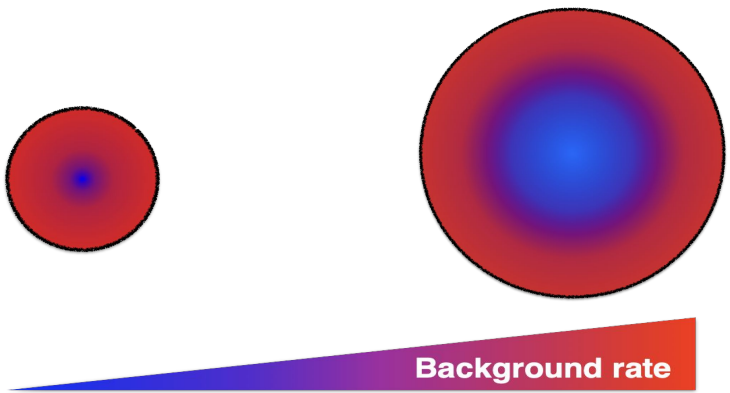
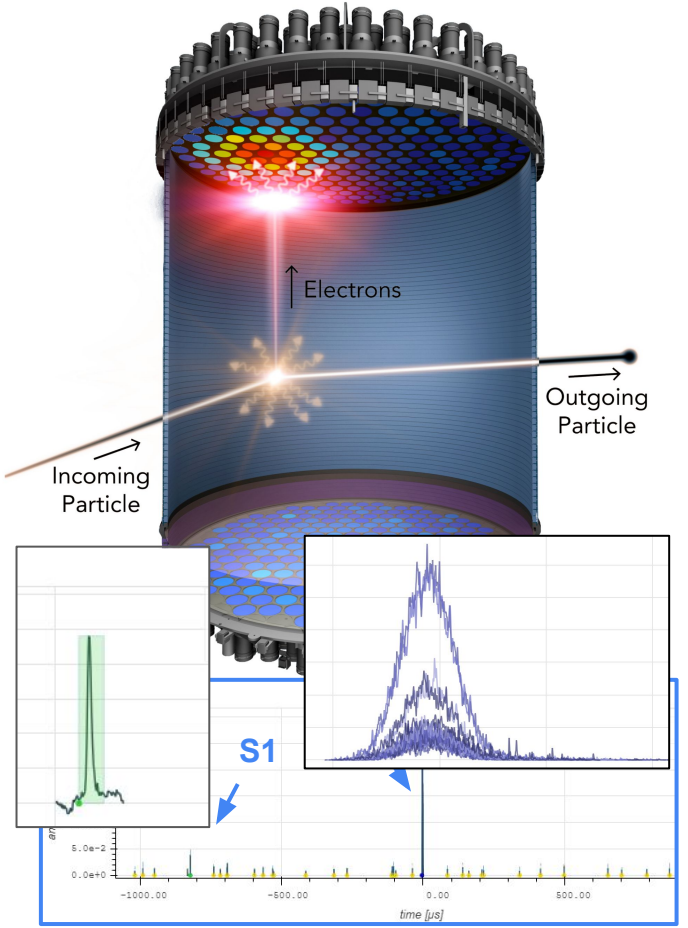
- **Depth** (z) from time difference between S1/S2 and light pattern provides (x, y) **position**
- LXe is dense and **self-shielding** → **fiducial volume** (FV)
- LZ located 1.6 km deep at the Sanford Underground Research Facility (**SURF**)





Water shield:

- 230 t DI water

Outer Detector:

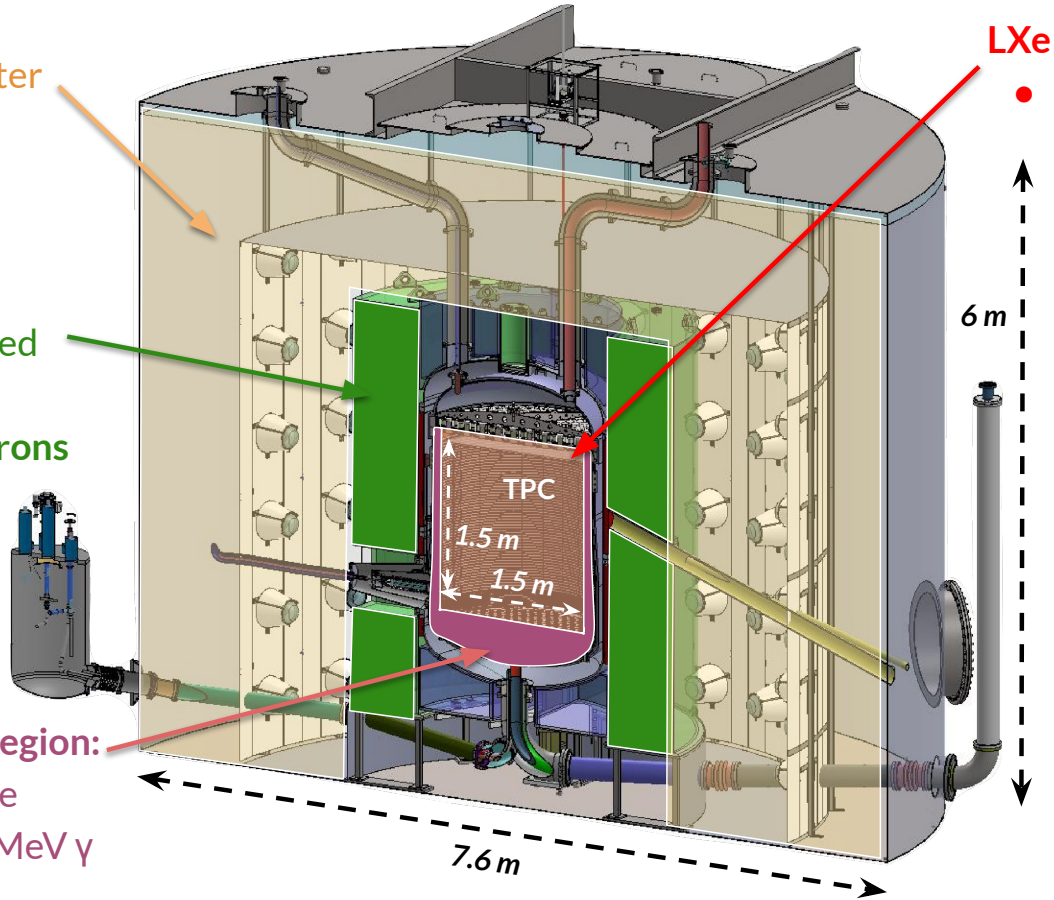
- 17 t Gd loaded scintillator
- Detect neutrons

LXe target:

- 7 t LXe TPC

LXe "skin" region:

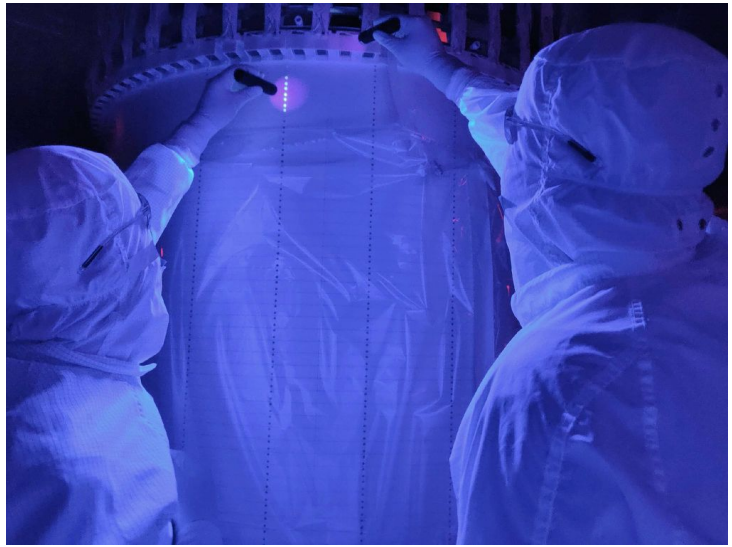
- 2 t LXe
- Veto MeV γ

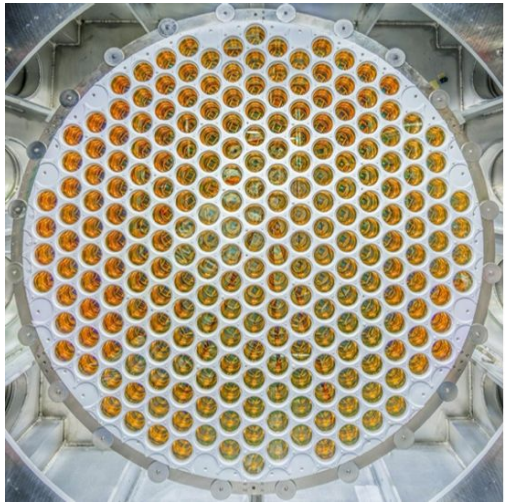


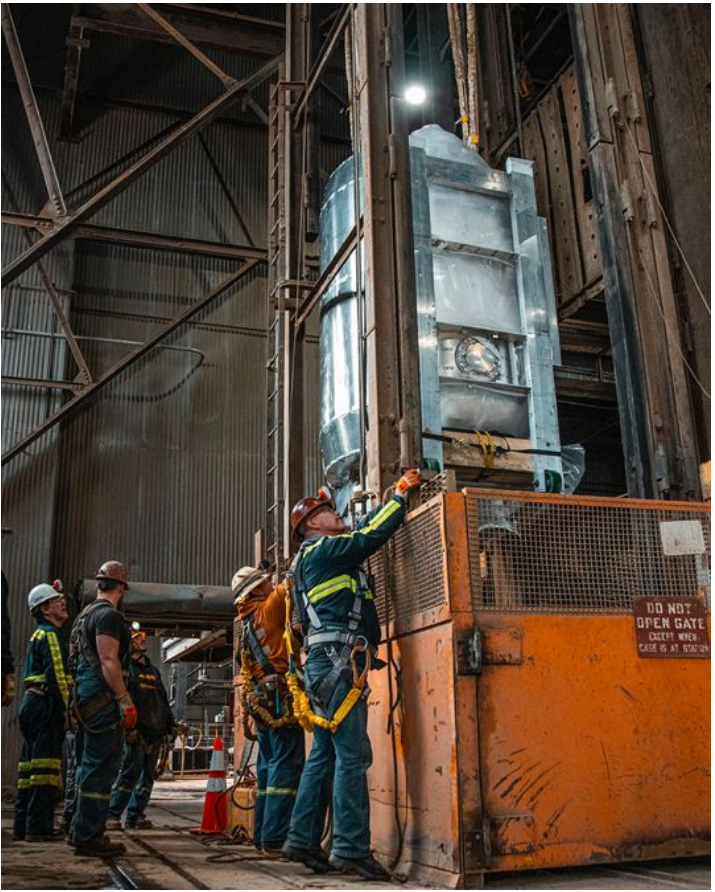
1 Banana = 15 Bq

- Bananas are actually somewhat radioactive due to potassium
  - **15 Bq/Banana** (100 g)
- Our target activity in the Xe: 2 μBq/kg - **1/75M Bananas**
- Cleaning, cleaning, cleaning, cleaning!

- **Need also to avoid all type of internal contaminants**
  - Use purest materials obtainable, screen all materials
  - Build everything in clean room, reduce dust on surfaces to **O(ng/cm^2)**
  - Keep circulating and purifying target material: aim xenon contaminants to **O(0.015 ppt)**



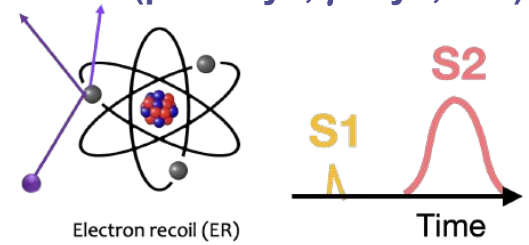


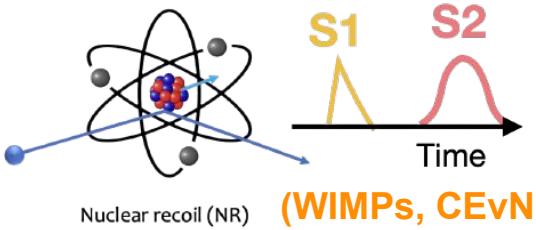

DO NOT
OPEN GATE

Bobcat

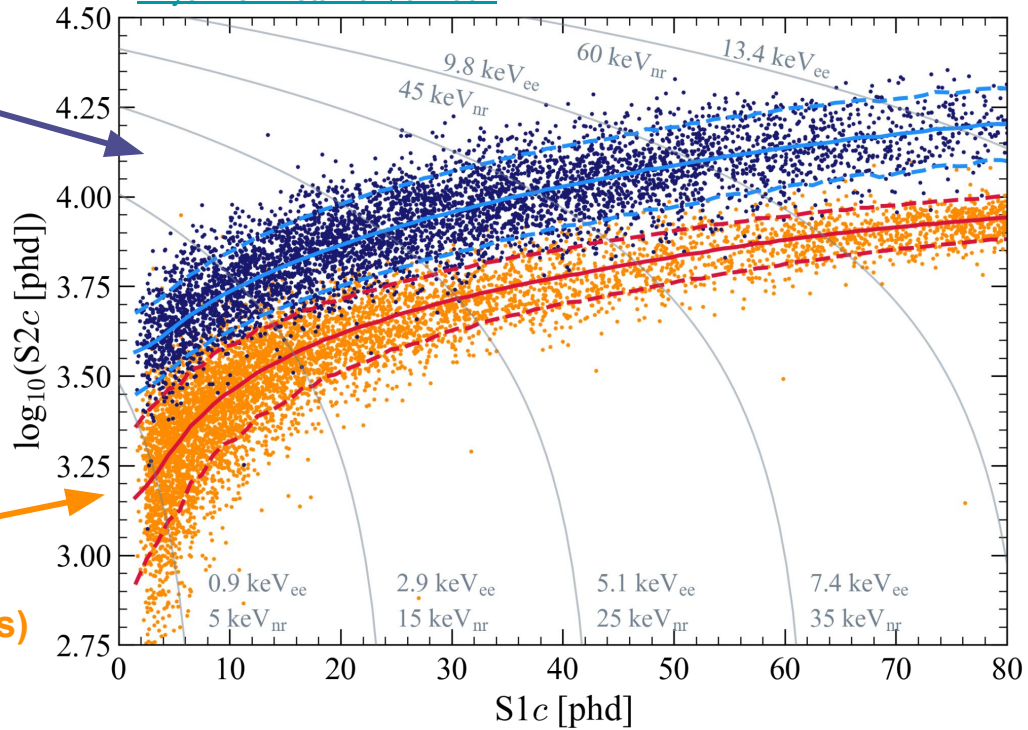
Phys. Rev. Lett. 131, 041002

(β decays, γ rays, ν-e$^-$)

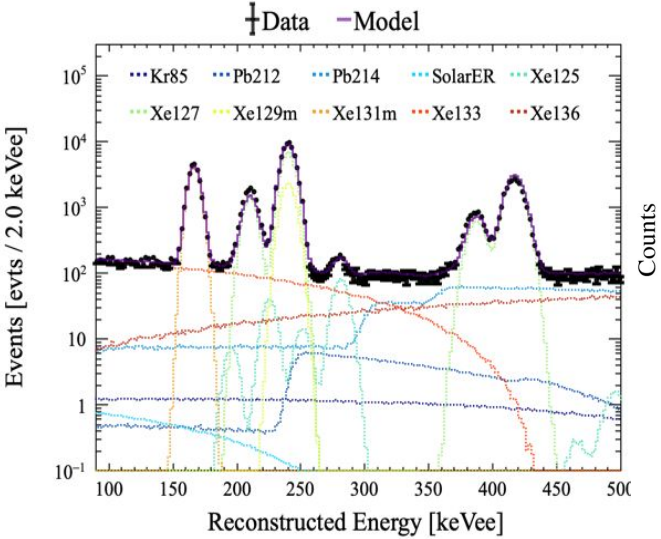




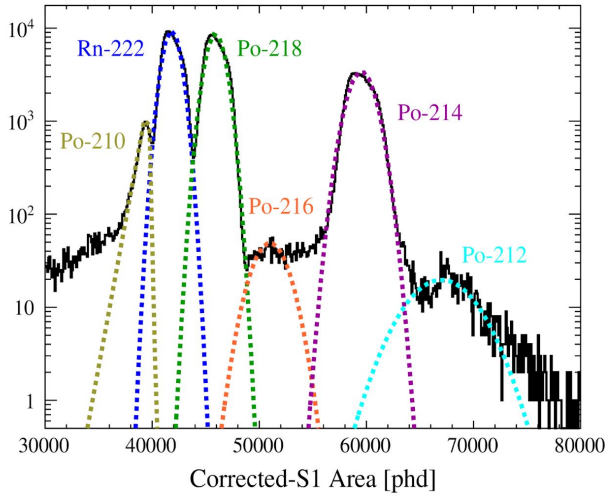
(WIMPs, CEvNS, neutrons)



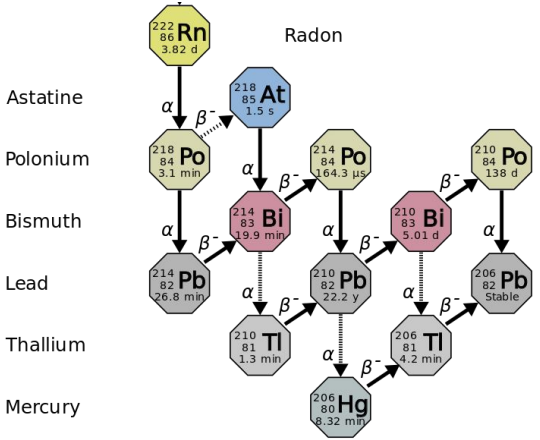
- Backgrounds predominantly electron recoils (ER), WIMPs produce nuclear recoils (NR)
  - **ER band**: Tritiated methane (CH3T) injection, spatially homogeneous β source
  - **NR band**: DD neutron generator (NR band), Monoenergetic 2.45 MeV neutrons

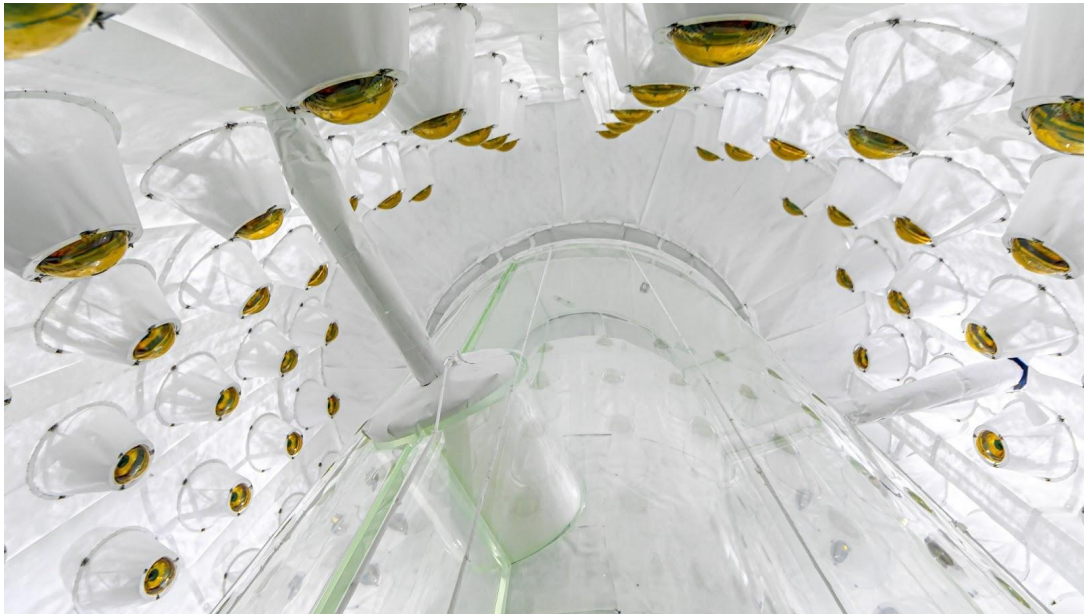


Phys. Rev. D 108, 012010 (2023)

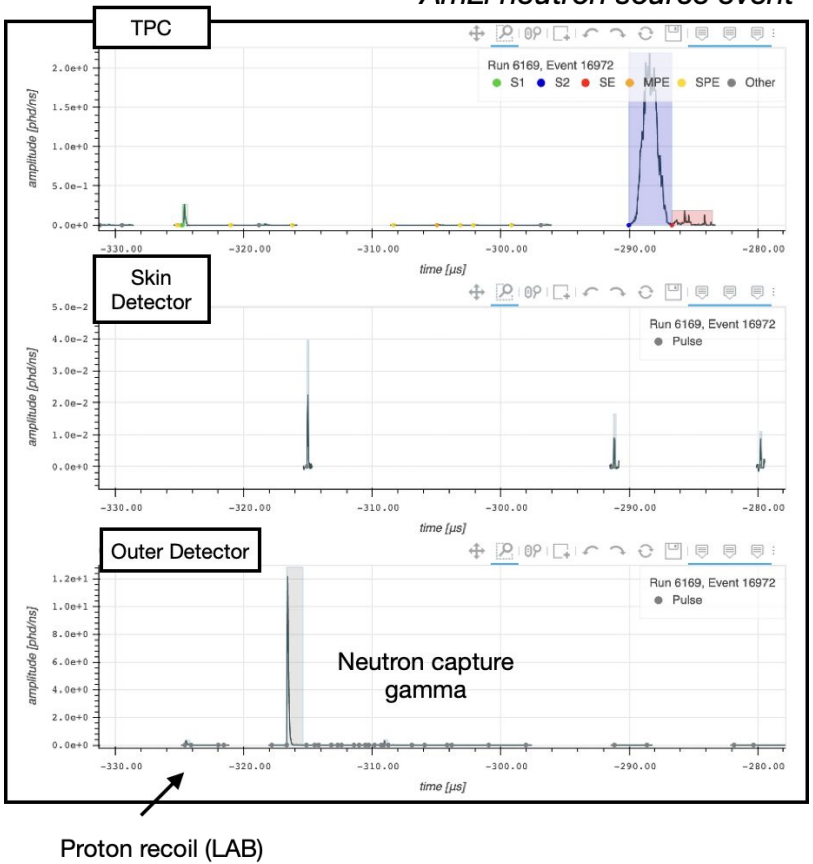


- Calibrations via a series of ɣ- and neutron sources (^{228}Th, ^{83m}Kr, ^{57}Co,^{22}Na, ^{54}Mn, DD, AmLi, AmBe,)
- Peaks from α-emitters bracket β-emitters that are fitted





AmLi neutron source event

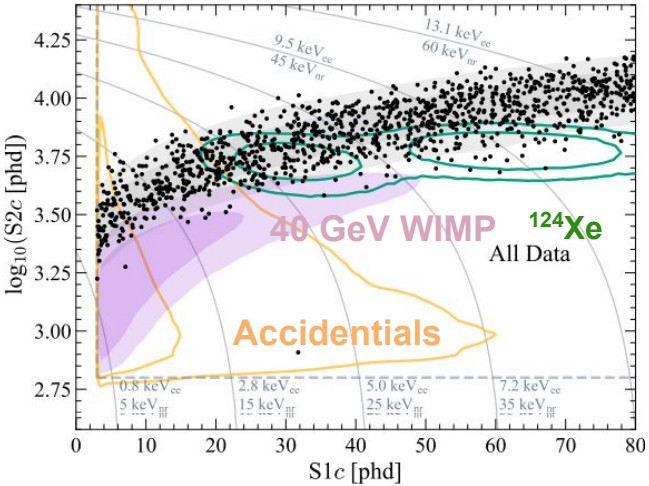


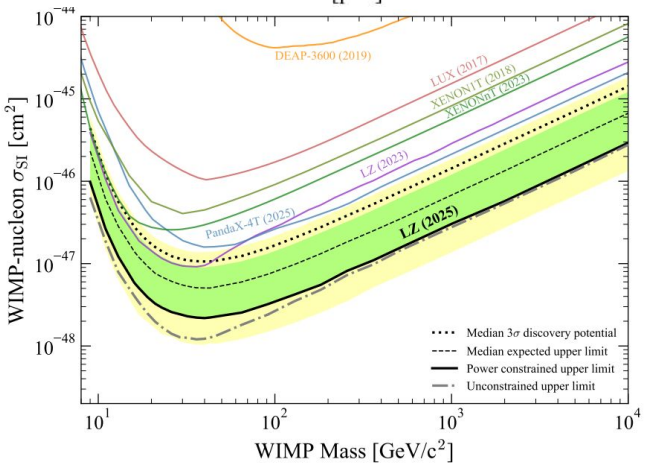
- Neutrons are **main WIMP background**
- OD and Skin serve as active vetoes to reject neutrons
- Total neutron veto efficiency: 92 ± 4 %

WIMP Results (WS2024)

- Total **WS2024 exposure**: 280 days (4.2 tonne-years)
  - 220 days of new data
  - Combined with the WS2022 result (60 days)
- Base/WIMP analysis selections
  - 3 phd ≤ S1c < 80 phd, S1 coinc. ≥ 3,
  - S2 ≥ 645 phd (14.5e^-), S2c ≤ 10^5 phd
- Profile likelihood ratio (PLR) analysis
- World's **best sensitivity for SI WIMP-type DM**
- Observed SI exclusion:

  σ_{DM}^{SI} =2.2 ×10^{-48} cm² at 40 GeV/c²

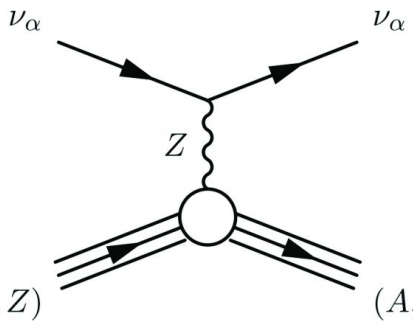


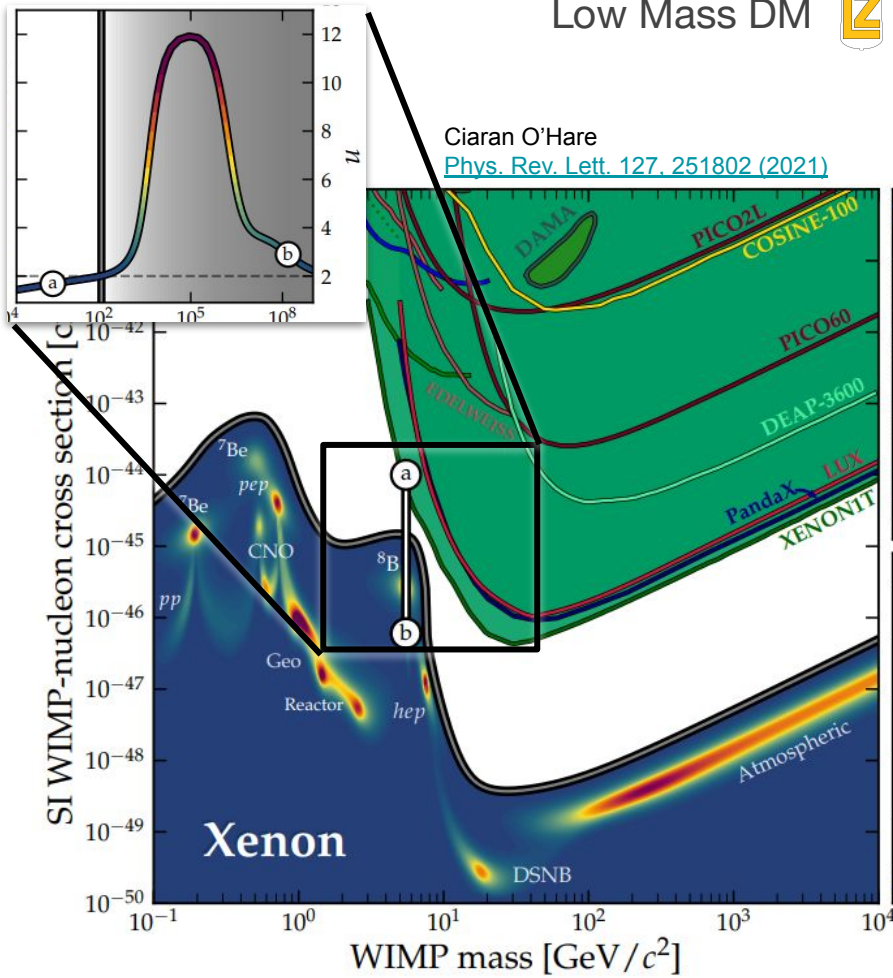


Phys. Rev. Lett. 135, 011802 (2025)

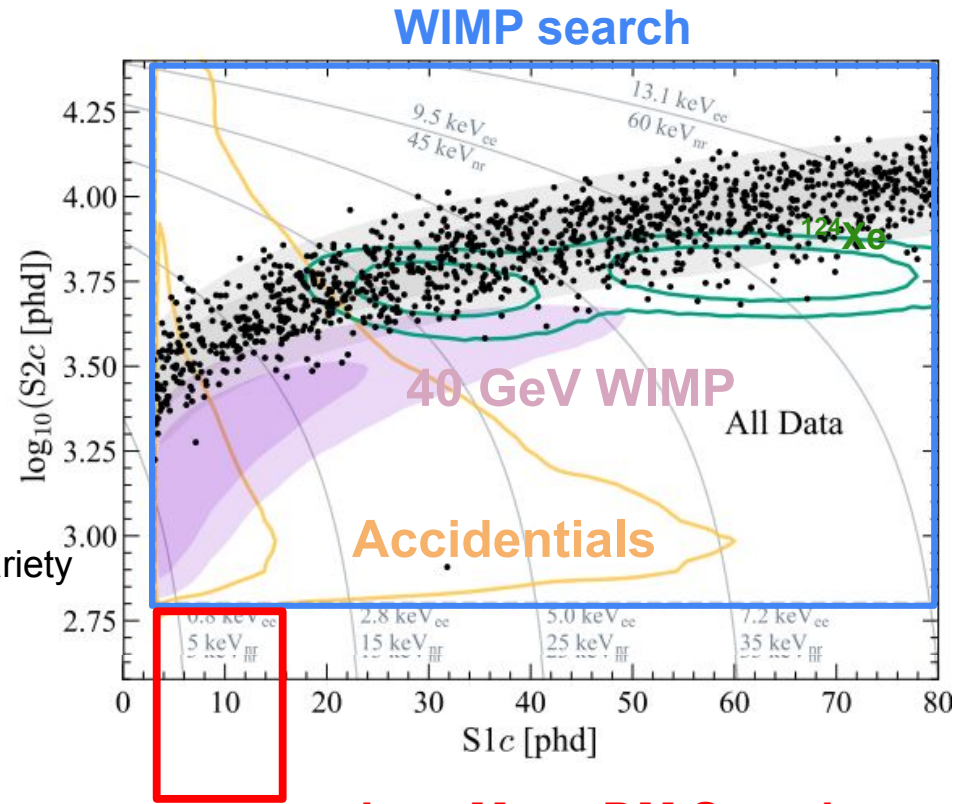
Low Mass DM

- **DM** might also be at **lower masses**
- **Neutrino fog also much higher** (**CEvNS** from **^{8}B solar neutrinos**) at lower recoil energies
- Not a hard floor, a slowly **rising fog**
  - Energy and position dependent
  - Imagine: Going from $e^+e^- \rightarrow pp$
- First observation & novel SM measurements
- **First indications** by PandaX-4T & XENONnT (< 3σ)

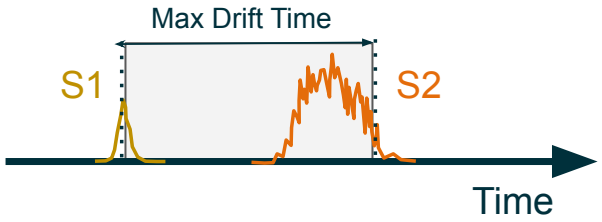




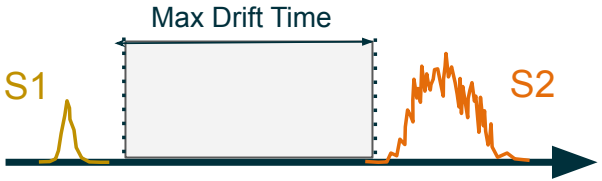
- **Low energy signals** are very **challenging**
- Single scatters at **very low energies** (ROI about 1-6 keV_{NR})
- Different background composition:
  - Betas, gammas (**ER**) are **negligible**
  - Neutron backgrounds are << 1 event
  - Dominated by **accidental coincidence** events (very hard!)
- **Accidentials**: S1s and S2s mostly from a large variety of instrumental effects, e.g.
  - PMT dark counts
  - Charge loss near walls
  - Grid emissions
  - Photon/electron ‘trains’ after large energy deposits



Possible Physical Event



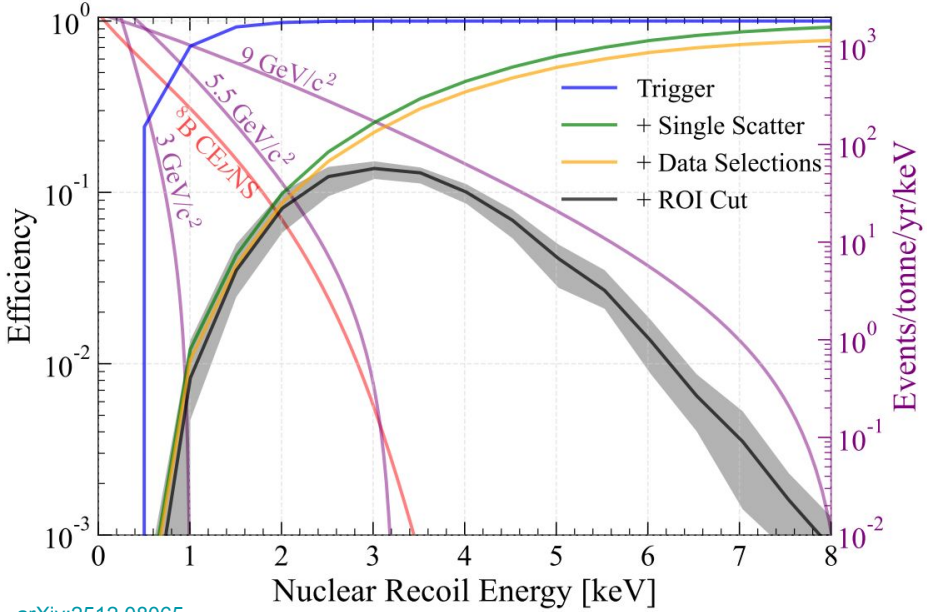
Definite Accidental Event



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

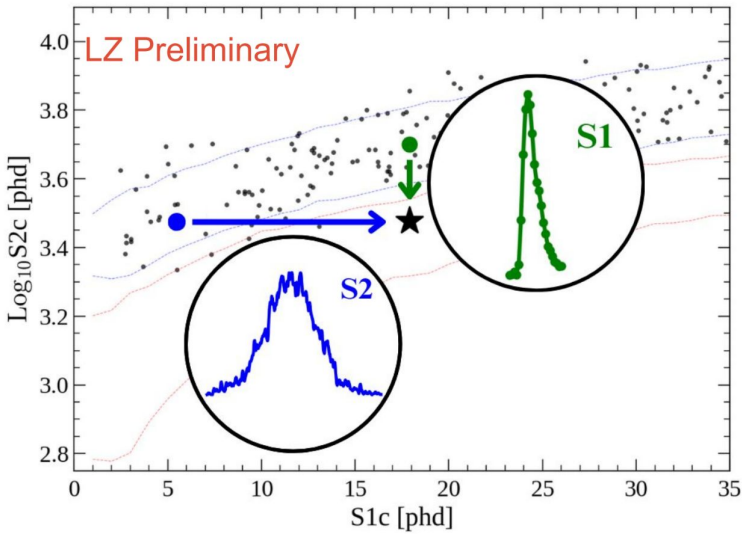
- Selection criteria developed on non-WIMP ROI background & calibration data
- Rejection of live time with detector instabilities, hig TPC pulse rates
- Apply data quality, FV, base selections

- **Event selections:**
  - Primary selection: 3-fold S1 coincidence
    $2 \leq S1c \leq 15$ phd, $3.5 \leq S2c \leq 14.5$ e^- (44.5 phd/e^-)
  - 417 live days, 5.1 T LXe FV

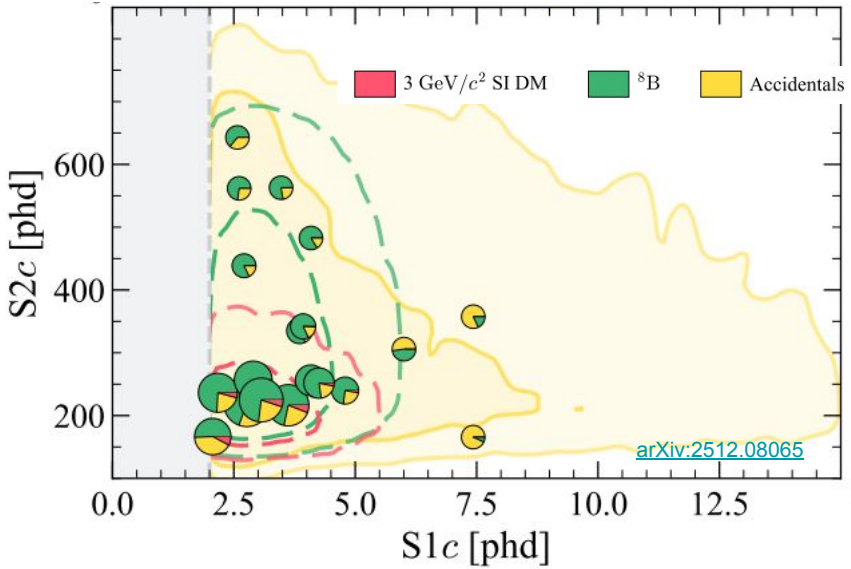


arXiv:2512.08065

- Slightly tighter 5.1 tonne fiducial volume for lowest background and uniform signals
- 'Blind' the data by injecting data drive **fake events**



Final data events, each pie chart represents the relative fit contributions and weight



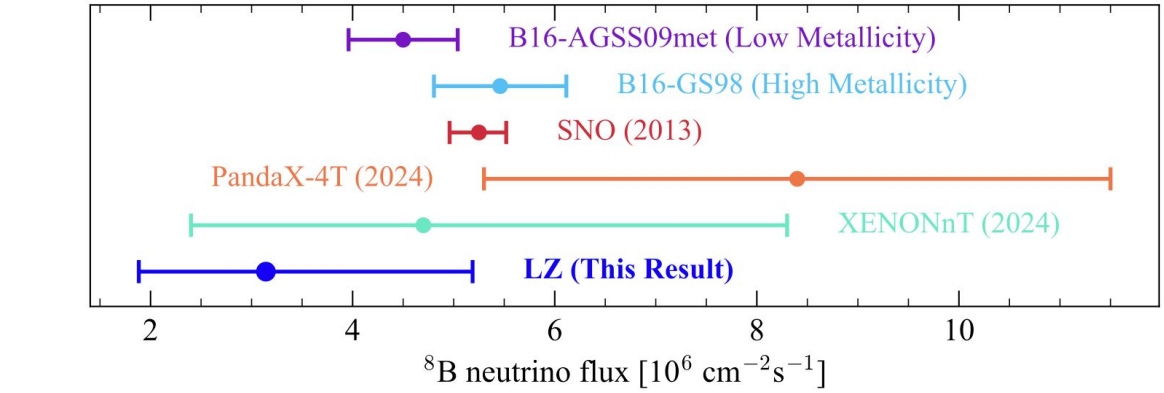
- **Expected** yields:
  - **Bkgds**: ~6.6 ± 0.4 events
  - **^{8}B CEvNS:** $20.6^{+8.9}_{-6.8}$ events

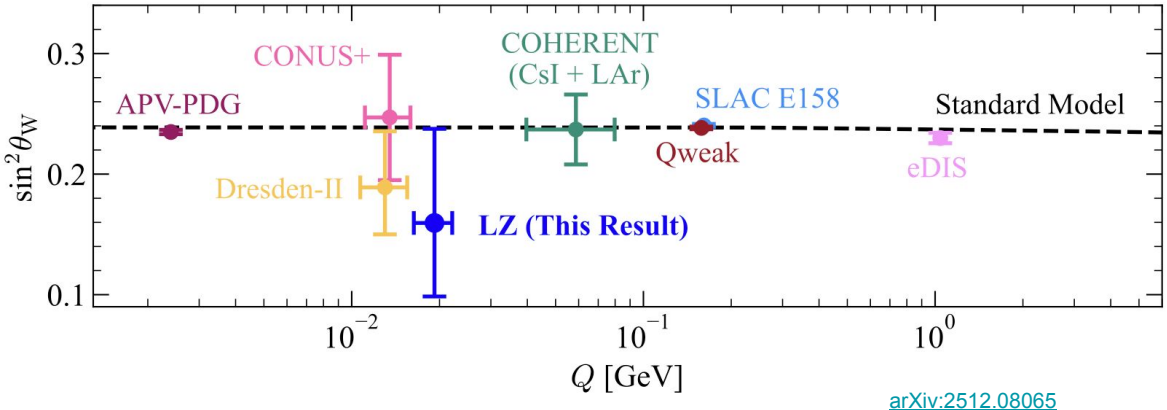
Obs: 19

Fit: $18.9^{+7.0}_{-5.5}$

4.50 σ ^{8}B observation!

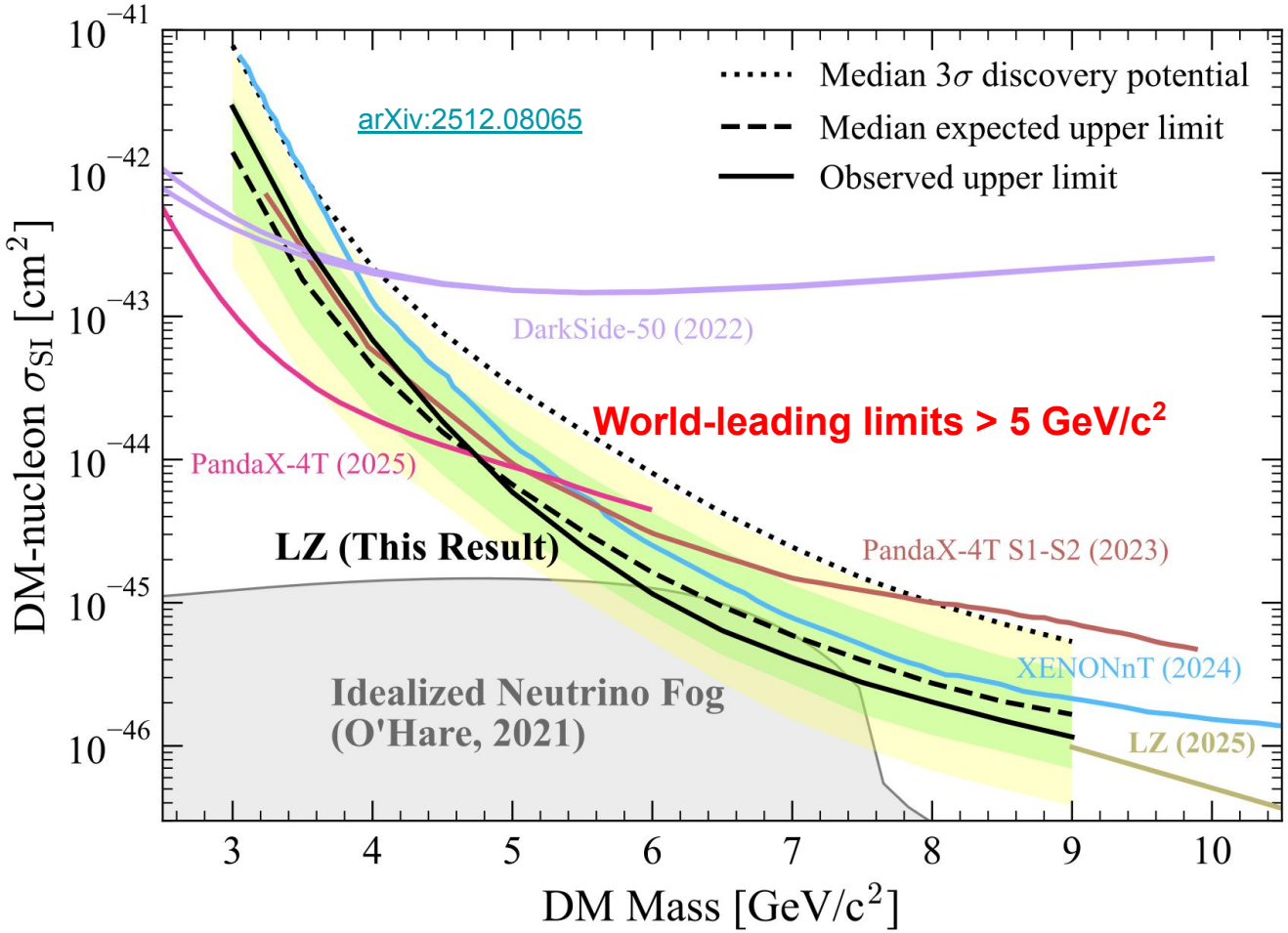
- Measurement of 8B CEνNS can be used for …
  - Flavor-independent measurement of the ^{8}B solar neutrino flux
  - Measurement of the weak-mixing angle ($\sin^2\Theta_W$) at low momentum transfer Q
- Precision will improve with increased statistics and precision





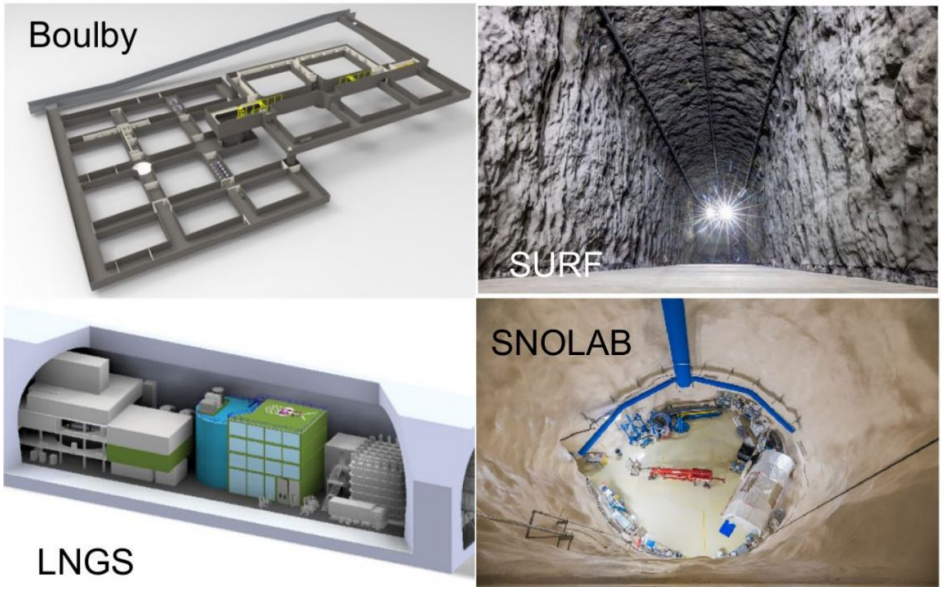
arXiv:2512.08065

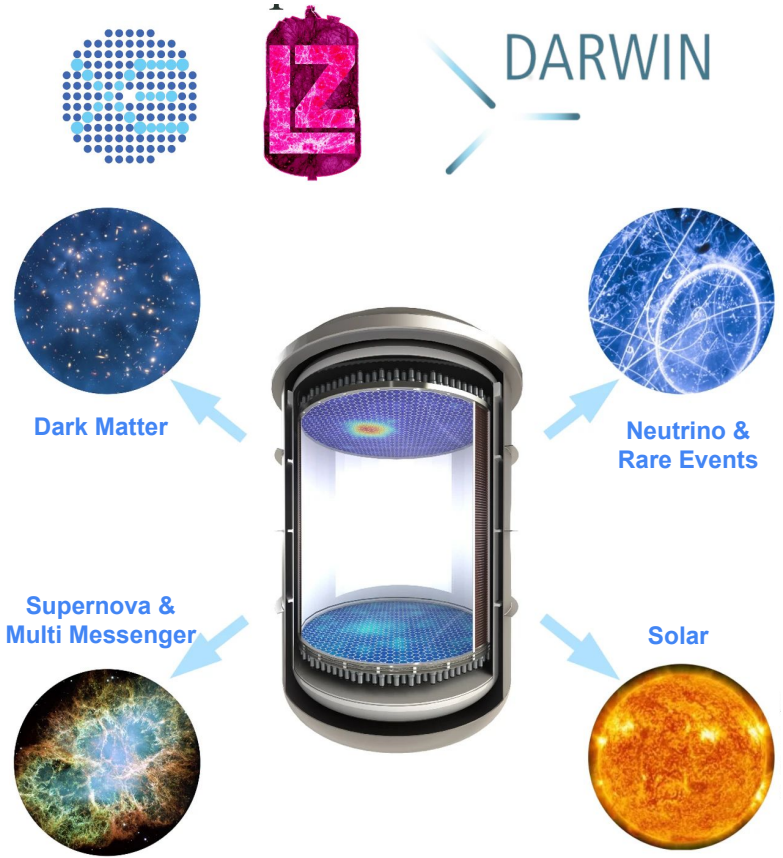
Low Mass DM results



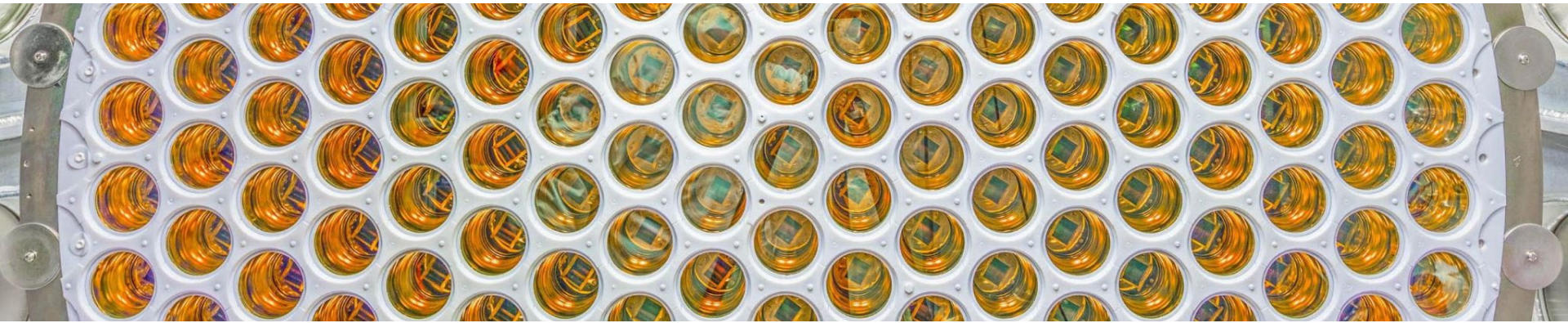
- LZ is the largest & most sensitive WIMP liquid xenon TPC (*Phys.Rev.Lett.* 135 (2025) 1, 011802)
- Other physics searches being performed in LZ…
  - Effective field theory coupling of DM to xenon nuclei (*Phys.Rev.D 109 (2024) 9, 092003*, *Phys.Rev.Lett. 133 (2024) 22, 221801*)
  - Solar axions, axion-like particles, dark photons (*Phys.Rev.D 108 (2023) 7, 072006*, *arXiv:2511.17350*)
  - Ultra heavy 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)
  - Muon Flux measurement (arXiv.org:2602.16799)
  - ^{136}Xe $2\nu\beta\beta$ and $0\nu\beta\beta$, also DEC
- And many more…

- **XLZD** = XENON + LUX-ZEPLIN + DARWIN for a future 60-80 tonnes DM and neutrino experiment (Eur. Phys. J. C (2025) 85: 1192)
- 17 countries, 76 institutions, 440+ members
- Four candidate sites:





- LZ has the **world leading sensitivity** for WIMP masses > 5 GeV/c²
- First ^{8}**B CEvNS observation** with 4.50 σ (exp. 6.70 σ)
- LZ continues towards **1000 live days** of data and many more searches…
  - Investigating **extension beyond 2028**
- Beyond LZ we are planning a next generation experiment with the **XLZD collaboration**



- 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

https://lz.lbl.gov/

US DOE

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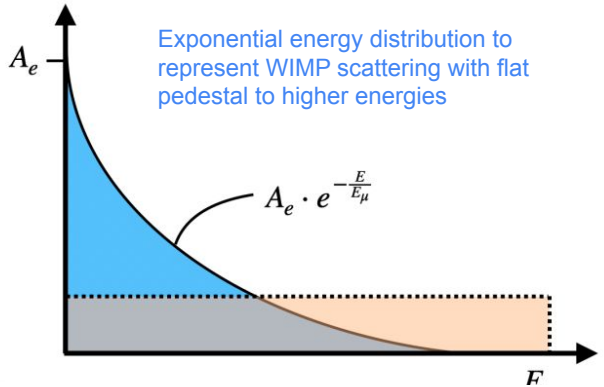
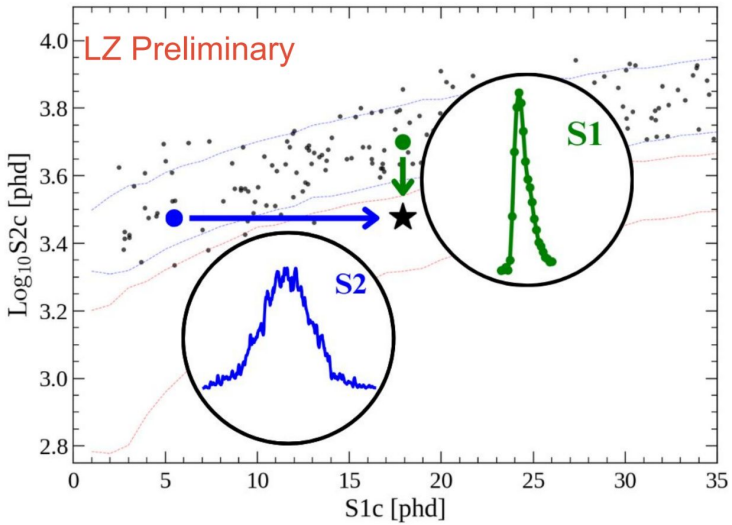
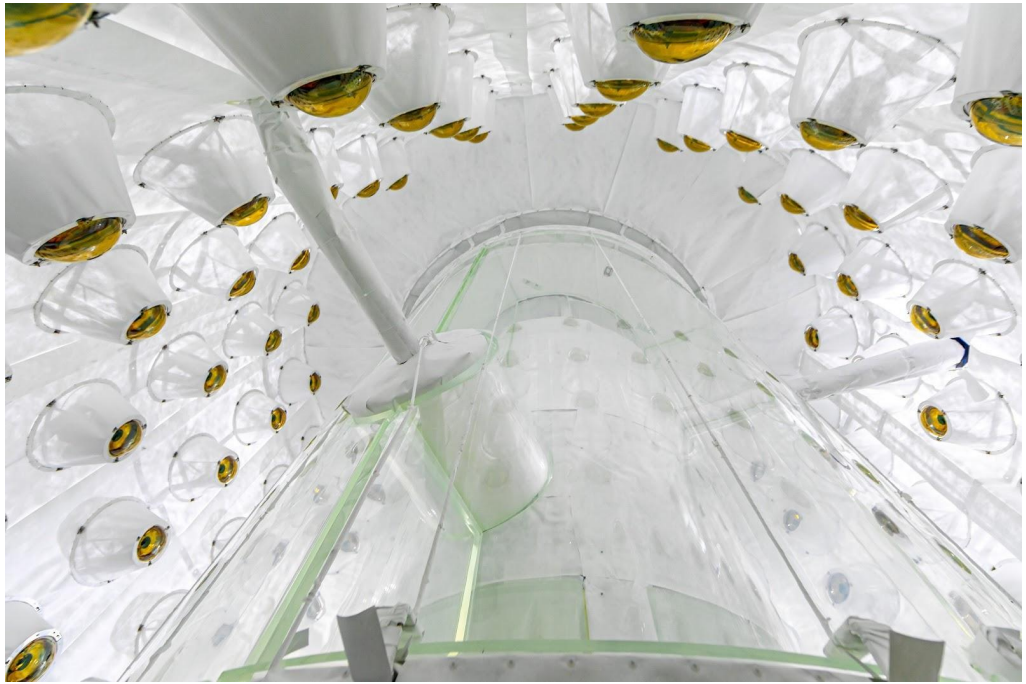
38 institutions, 250 scientists, engineers, and technical staff

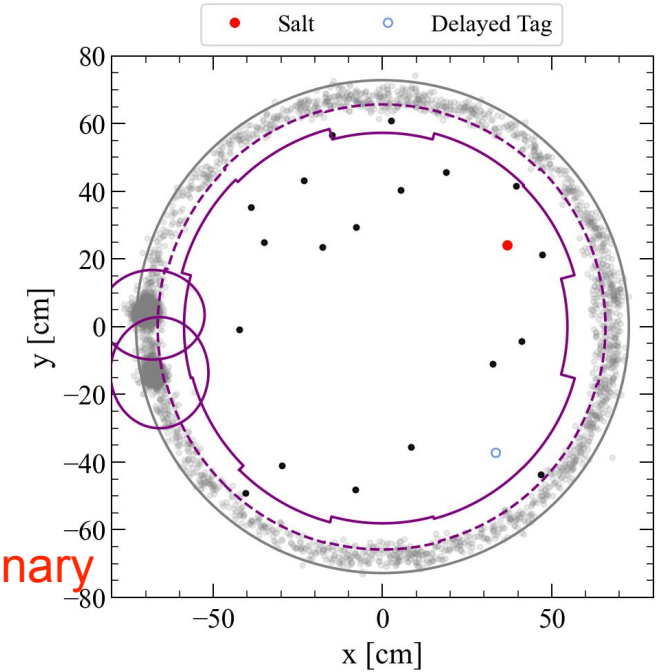
Backup

- **Salting**: ‘Blind’ the data by injecting fake events
- Generated by **combining real S1 & S2** pulses from **calibration data** using exponential + flat spectrum
  - Events follow exponential+flat spectrum (exact parameters randomly generated, kept hidden)
  - Covers WIMP and higher-energy NR regions of
  - Injected salt rate chosen to match Poisson uncertainty on expected ^{8}B CEνNS rate based on WS2024 NR model
- Identity of salt events revealed after analysis is finalised

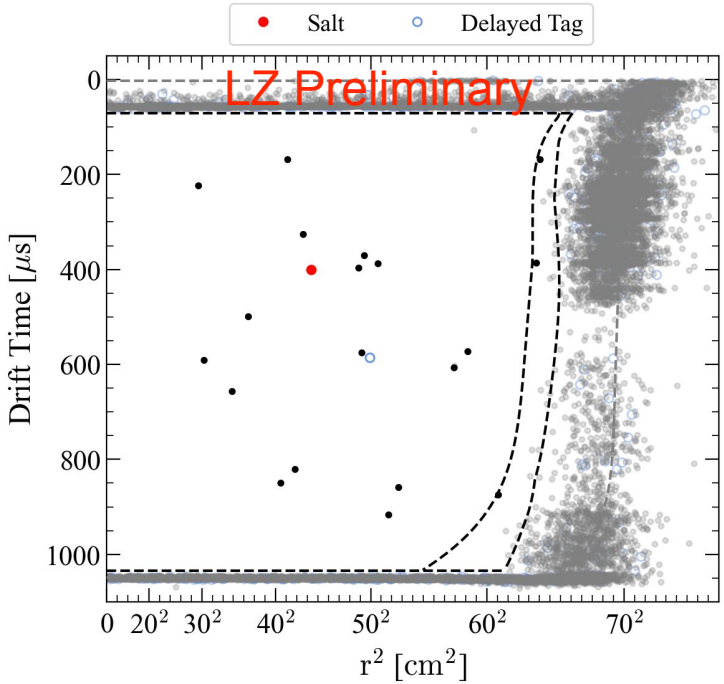




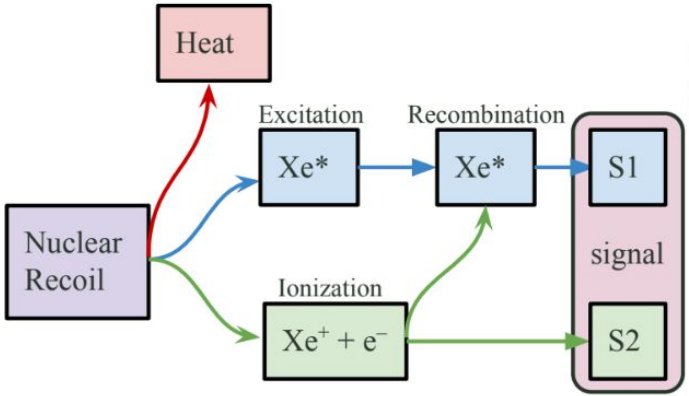


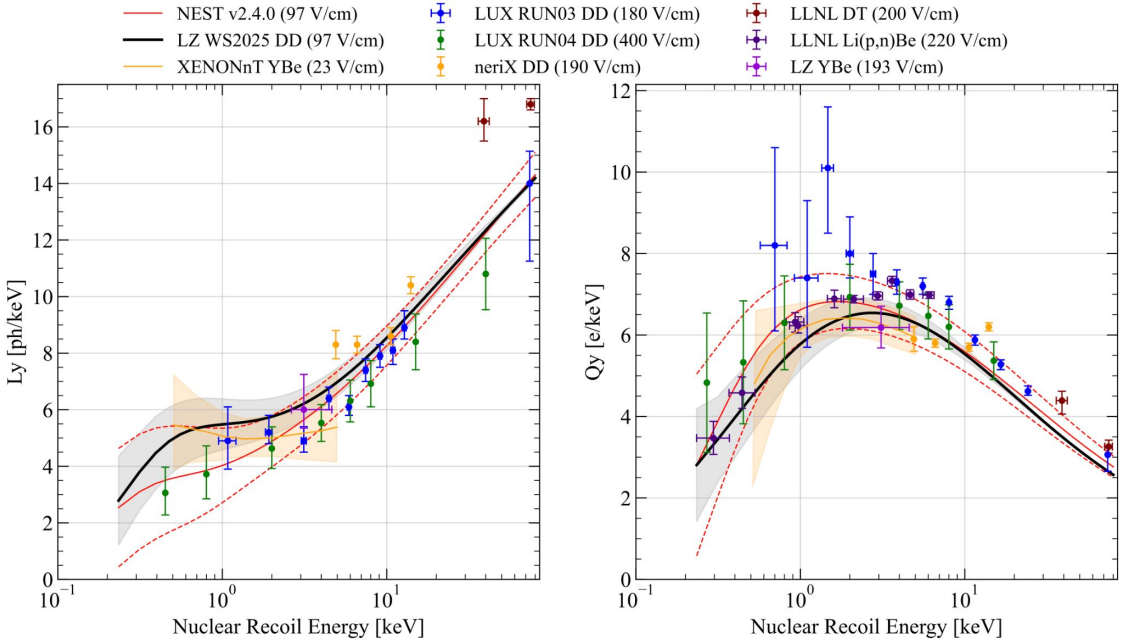


LZ Preliminary

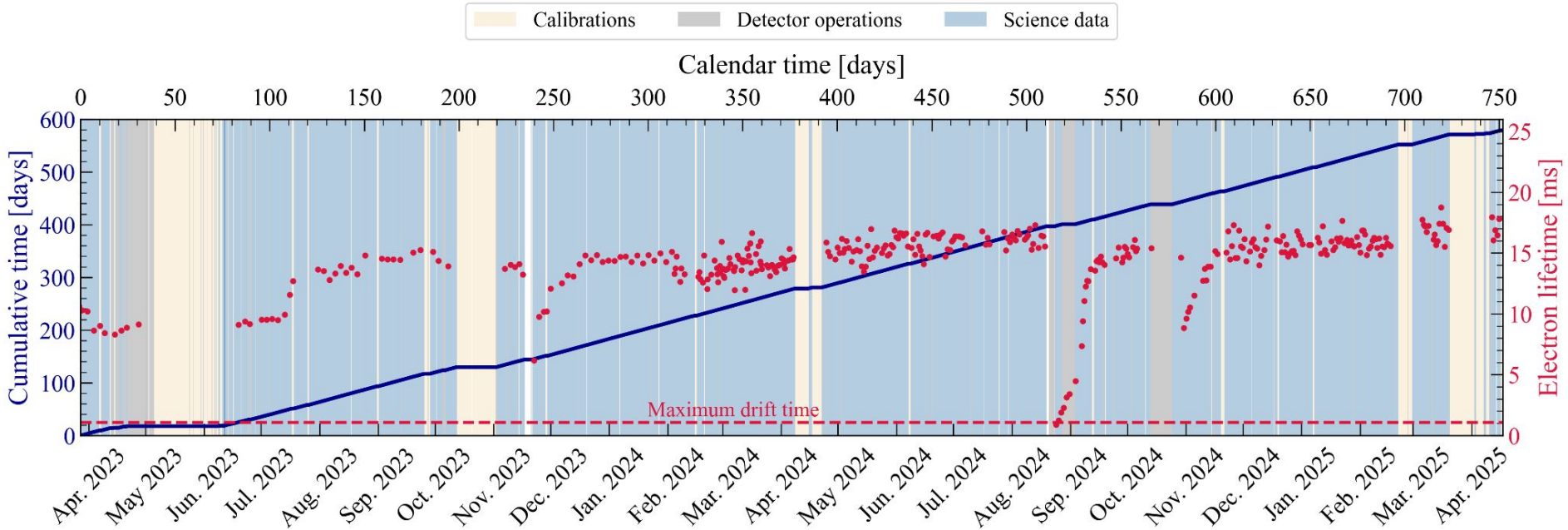


- Gray: TPC edge
- Purple: FVr extents at the top and bottom of the FVz
- Purple circles: Resistor cutout





- Carefully calibrate low energy NR response and quantify systematic uncertainties
- Use mono-energetic 2.45 MeV DD neutron source, additional AmBe and AmLi calibrations
- Quantified systematic uncertainty associated with yields, fluctuations and detection efficiencies

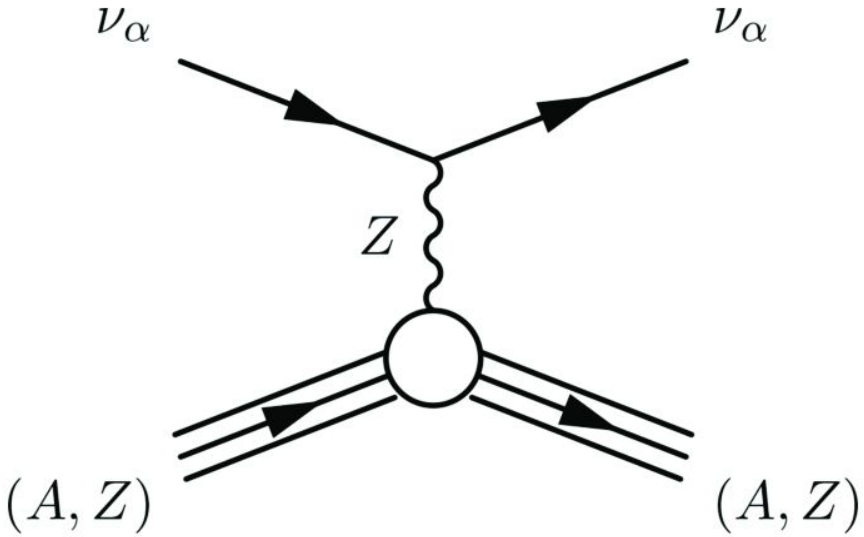


- Data taken from April 2023 - March 2025: 417 days
- Drift field of 97 V/cm, Extraction field of 3.4 kV/cm
- Dedicated AmBe and DD neutron calibrations
- Calibrated for uniformity in S1 and S2 response in time and space

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)

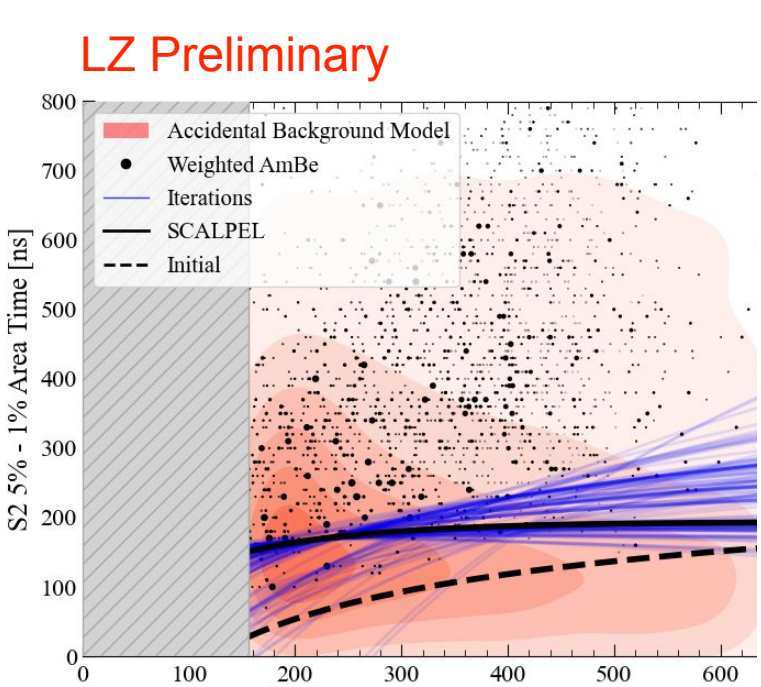
- Well-predicted neutral current Standard Model process proposed in the 1970s where neutrino “sees” whole nucleus
  - Cross-section scales with neutrons squared
- First measured by the COHERENT experiment in 2017 using the Spallation Neutron Source Science 357, 6356 (2017)
- Additional measurements with reactor anti-neutrinos, anti-neutrinos by Dresden-II

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

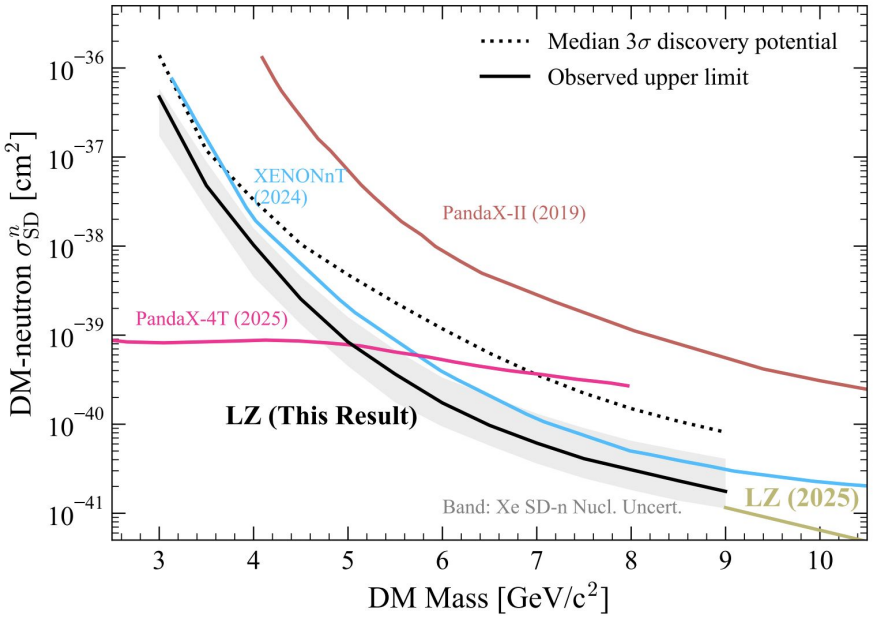


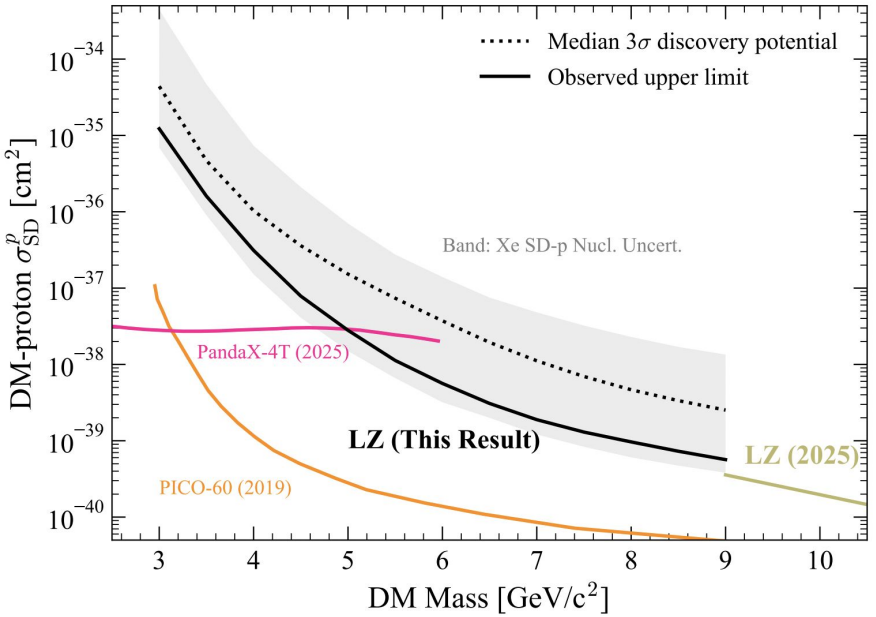
- First indications (< 3σ) of CEνNS with solar neutrinos from PandaX-4T *PRL 133, 191001 (2024)*, XENONnT *PRL 133, 191002 (2024)*

- Isolated S1s and S2s can **pile-up to fake a scatter**, where the S1 and S2 do not come from the same energy deposition
- Sources of S1s and S2s largely from a wide variety of instrumental effects, e.g.:
  - PMT dark counts
  - Charge loss near the TPC walls which degrades the S2 signal
  - Large photon/electron rates after big energy depositions
- Selections are designed and optimized using neutron (AmBe) calibration and fabricated background datasets
- Optimization technique (CMA-ES[1]) used to simultaneously tune several selections across multiple parameter spaces
- Powerful, and not a black box!

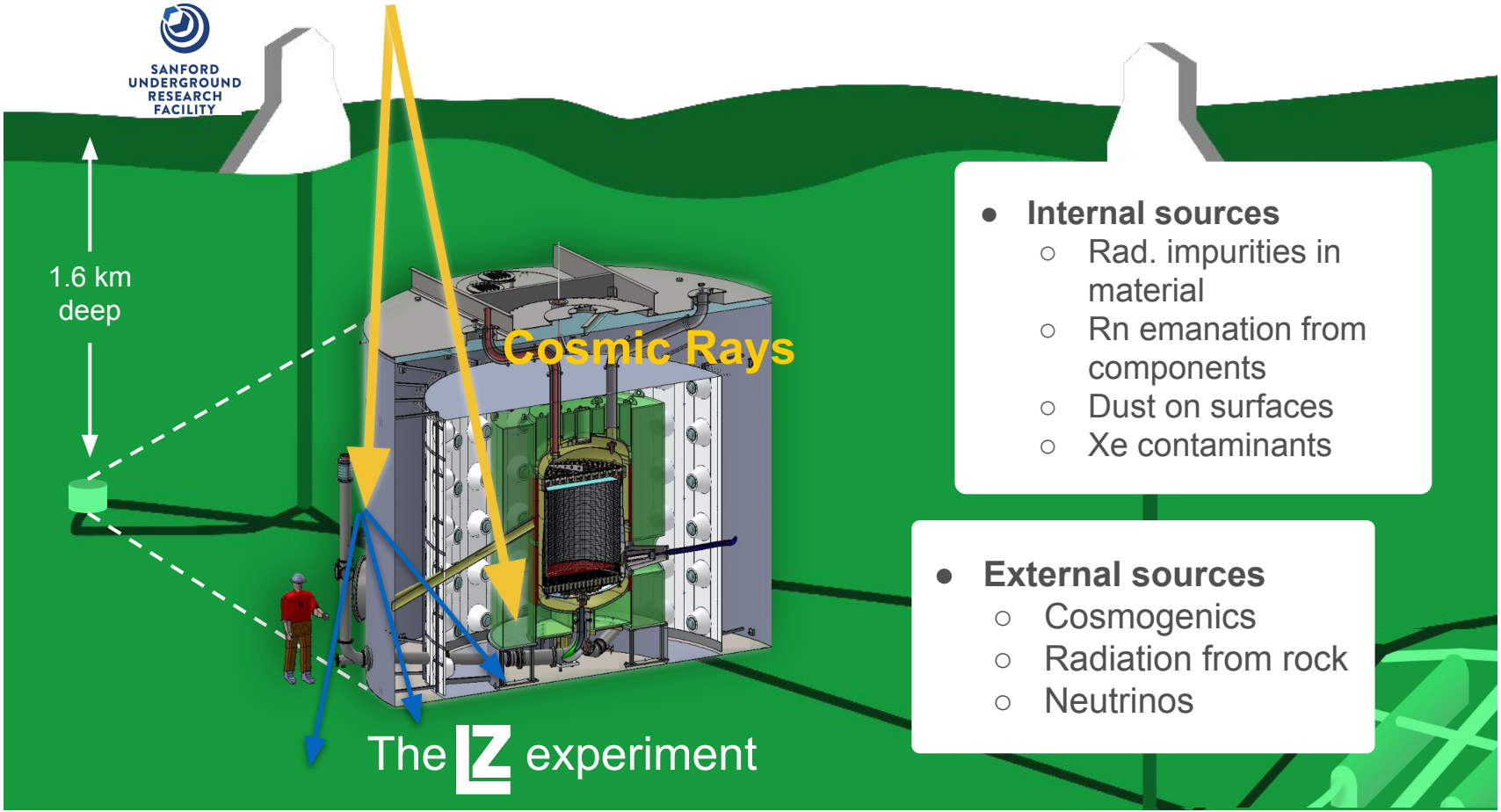


[1]Covariance Matrix Adaptation Evolution Strategy





Constraining neutron-only or proton-only coupling to 129Xe (26%) and 131Xe (21%) which have unpaired neutrons leading to non-zero nuclear spin



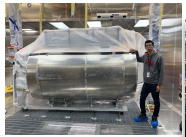
- **Internal sources**
  - Rad. impurities in material
  - Rn emanation from components
  - Dust on surfaces
  - Xe contaminants

- **External sources**
  - Cosmogenics
  - Radiation from rock
  - Neutrinos

CD3 and TDR, March 2017

PMT arrays arrive Dec 2018, Jan 2019

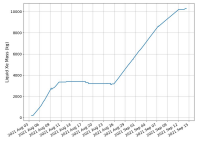
TPC Complete, Aug 2019



Underground, Oct 2019

RSS 2020

Kr Removal Jan-Aug 2021



Xe Fill Aug-Sep 2021

Science Running!

2017

2018

2019

2020

2021

2022

Cryostat arrives, May 2018

FFR Assembly Dec 2018

Grids, Spring 2019

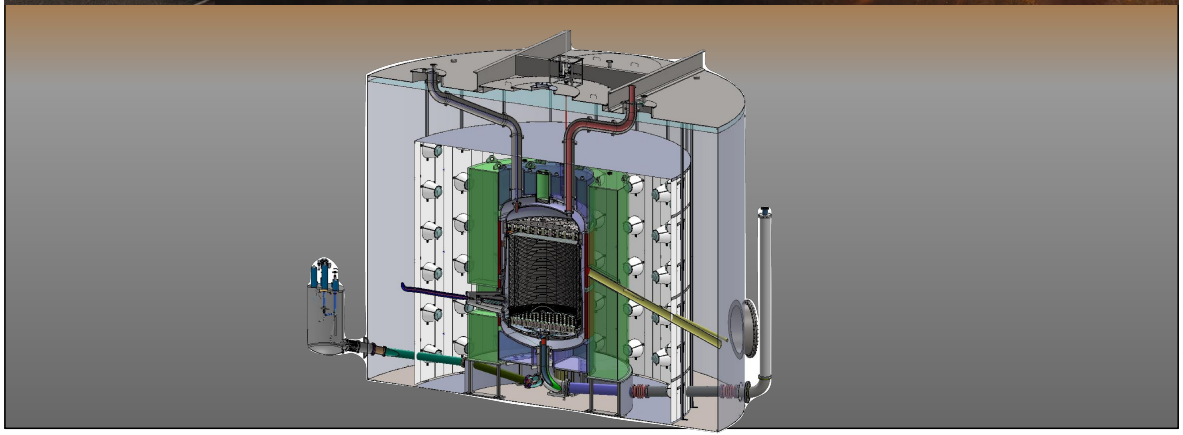
Sealed Up March 2020

OD Construction Winter 2020-2021

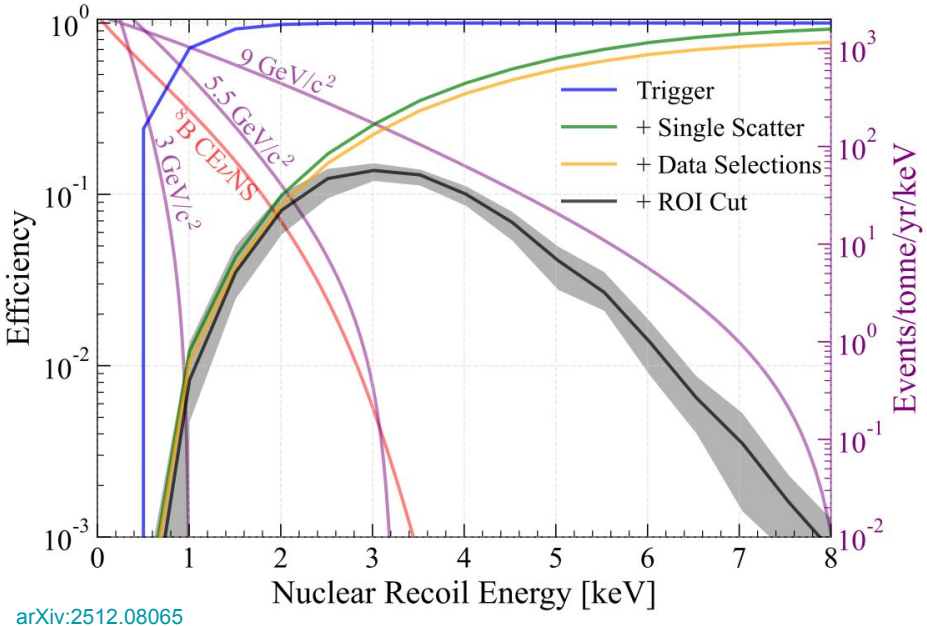
OD Fill June 2021

Commissioning Fall 2021

CAUTION

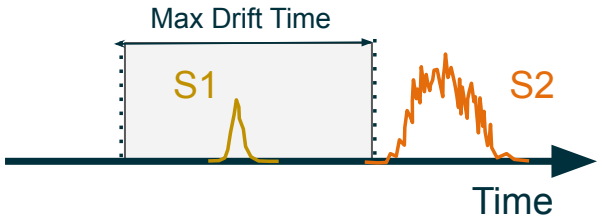


- **Event selections:**
  - Primary selection: 3-fold S1 coincidence
    2≤S1c≤15 phd, 3.5≤S2c≤14.5 e^- (44.5 phd/e^-)
  - Apply data quality, FV, base selections

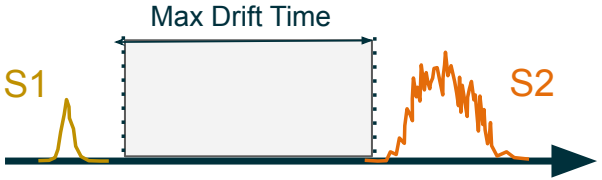


arXiv:2512.08065

Possible Physical Event



Definite Accidental Event



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

- Selection criteria developed on non-WIMP ROI background & calibration data
- Rejection of live time with detector instabilities, high TPC pulse rates
- **Key numbers**:
  - 417 live days, 5.1 T LXe FV