



Lastest Results from
LUX-ZEPLIN

Sam Eriksen

On behalf of the LZ Collaboration
59th Rencontres de Moriond 2025



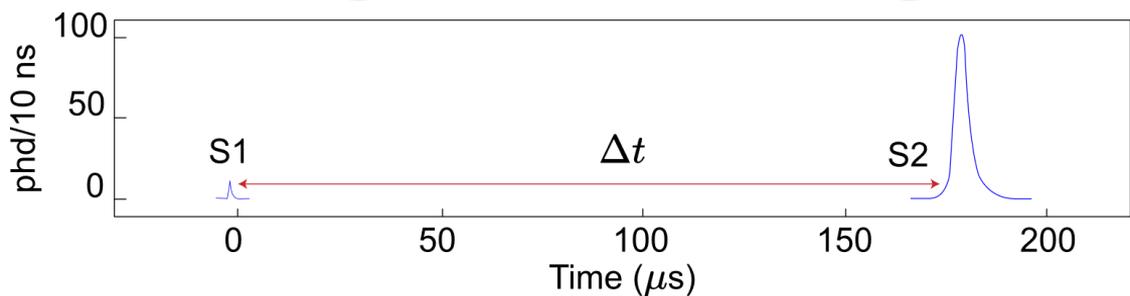
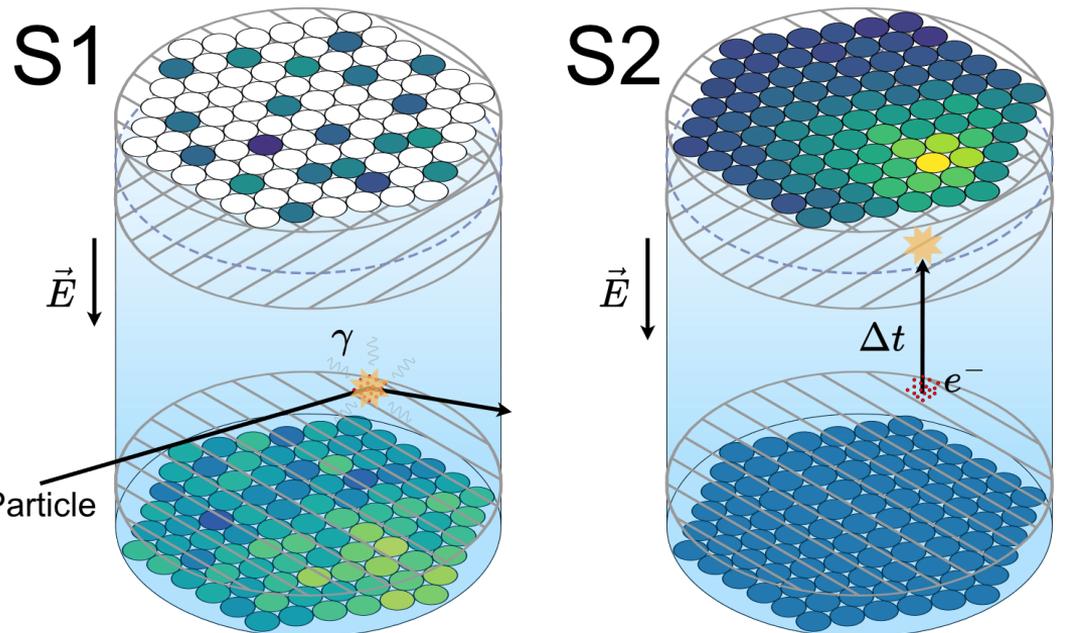


- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King's College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- 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



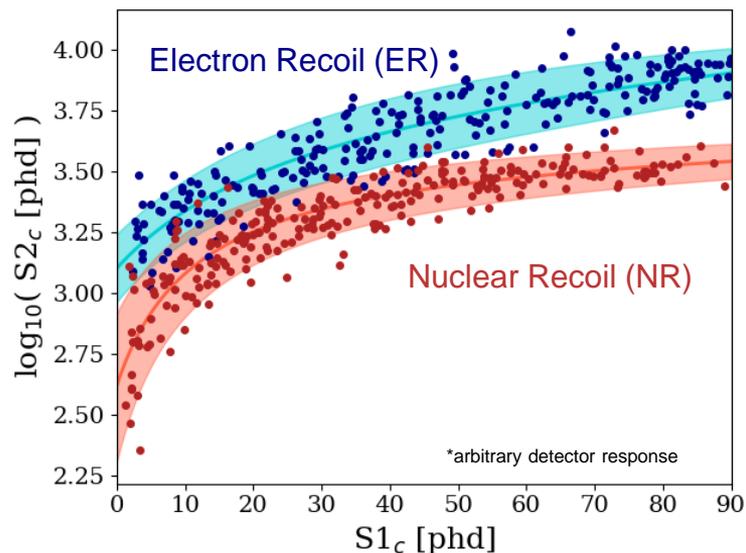
US Europe Asia Oceania

Thanks to our sponsors and participating institutions!



Dual Phase Time Projection Chamber

- Primary scintillation light (S1)
- Secondary scintillation induced from free charge (S2)
- 3D reconstruction allows for fiducialisation
- ER/NR discrimination from S1:S2 ratio



Calibration Source Deployment Tubes (3 Total)

17T Gd-loaded liquid scintillator

60,000 gallons of ultrapure water

120 Outer Detector PMTs

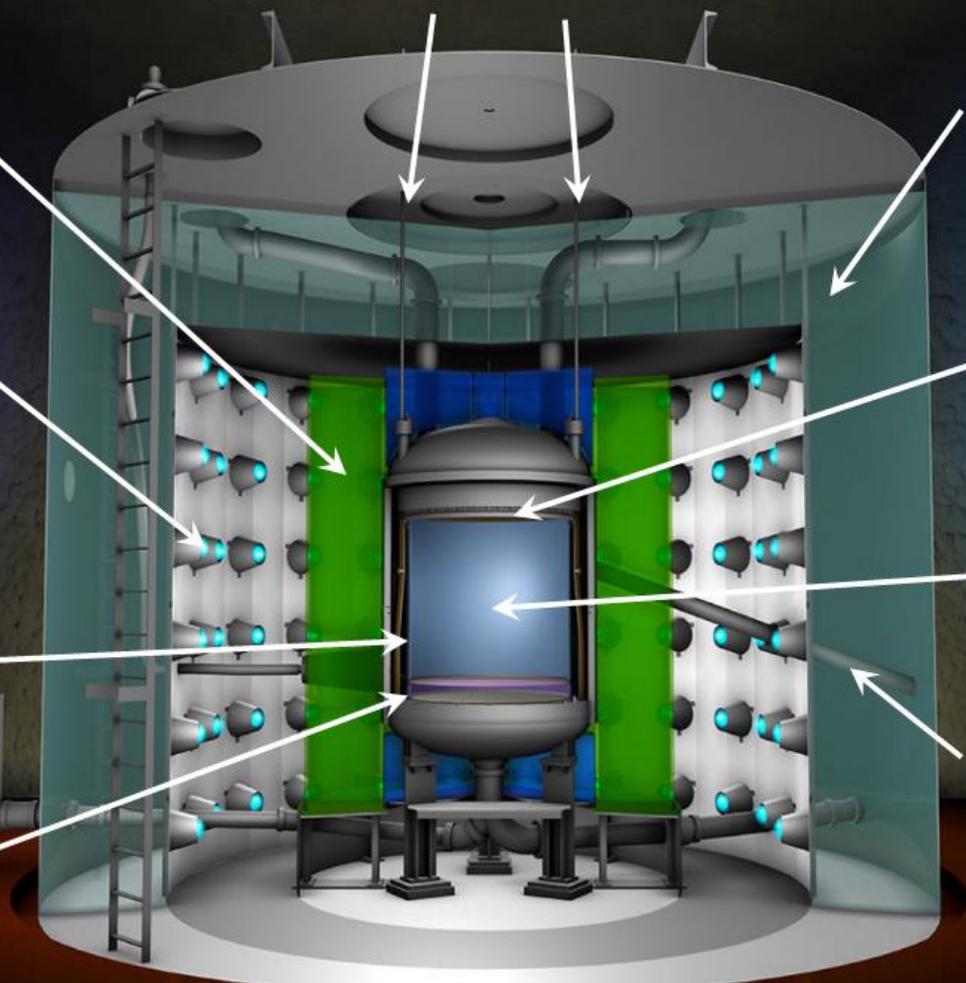
494 LXe PMTs

7T Active LXe Target

2T LXe Skin Veto

Neutron Calibration Conduit (2 total)

131 Skin PMTs



Detector Conditions

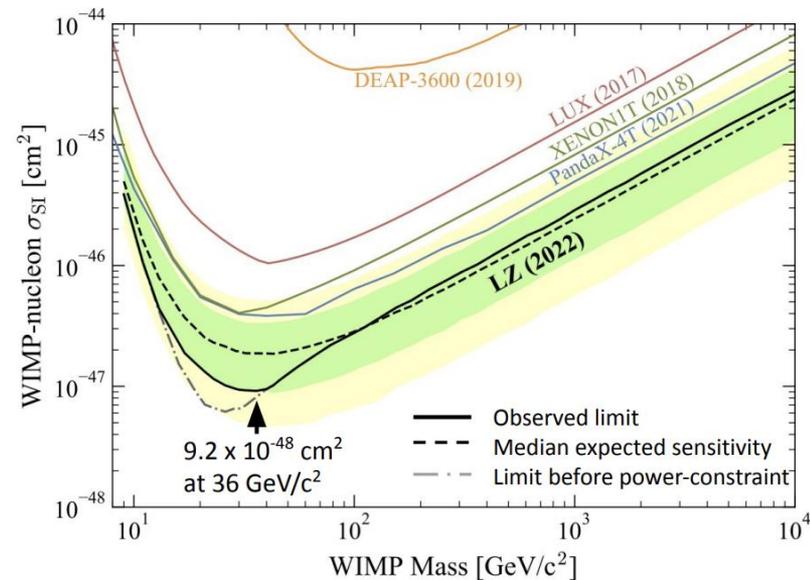
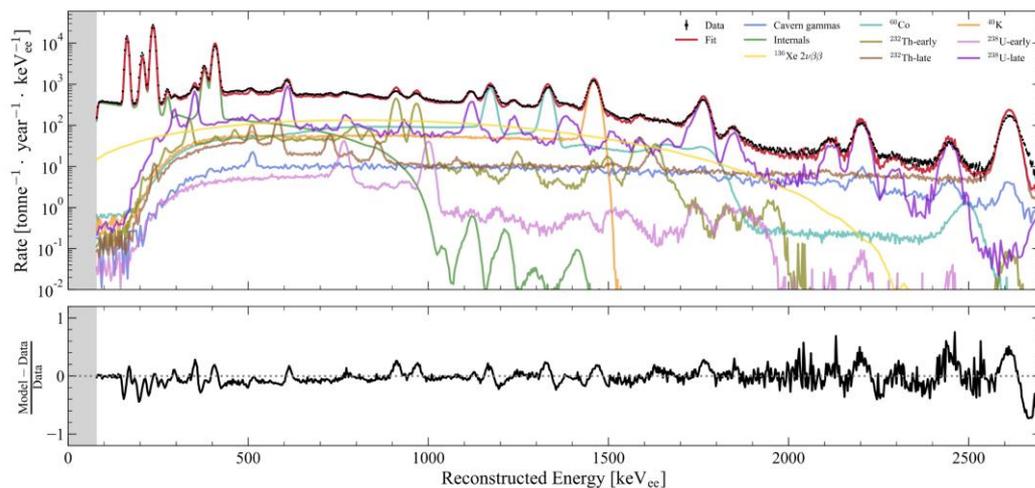
- Drift field: 193 V/cm
- Extraction field: 7.3 kV/cm in gas
- >97% if PMTs operational

Dataset

- Data taken Dec.2022-May.2023
- **60±1 live days**
- **5.5±0.2 tonne fiducial volume**

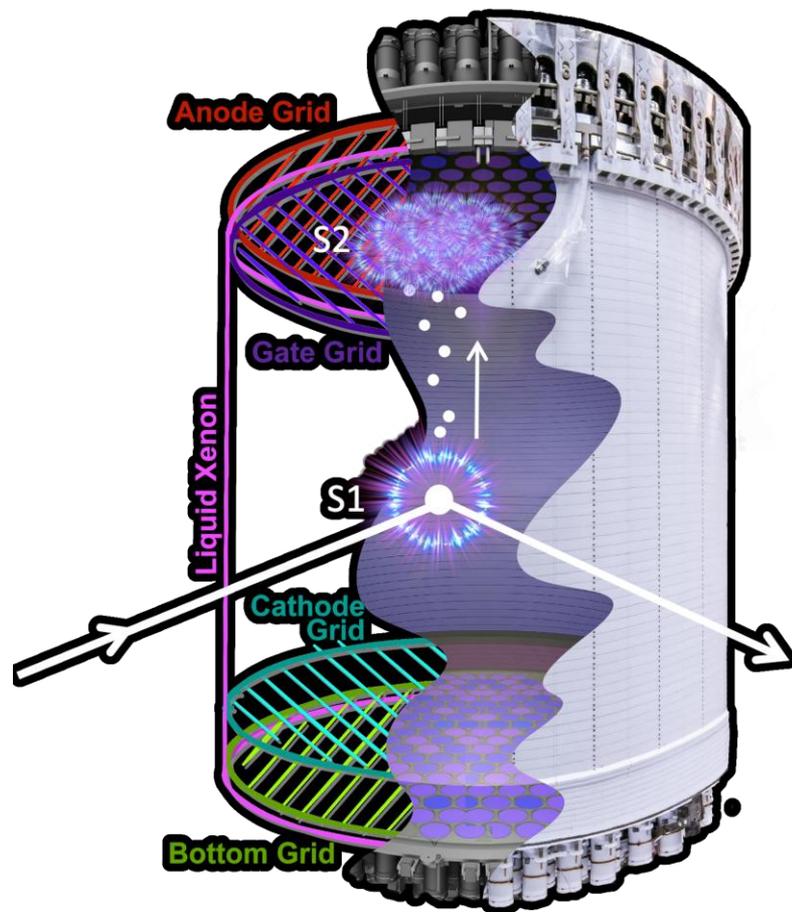
Analysis

- Backgrounds: [Phys. Rev. D 108, 012010](#)
- LENR: [Phys. Rev. Lett. 131, 041002](#)
- HENR: [Phys. Rev. D 109, 092003](#)
- LEER: [Phys. Rev. D 108, 072006](#)
- HEER: [J. Phys. G: Nucl. Part. Phys. 52 015103](#)



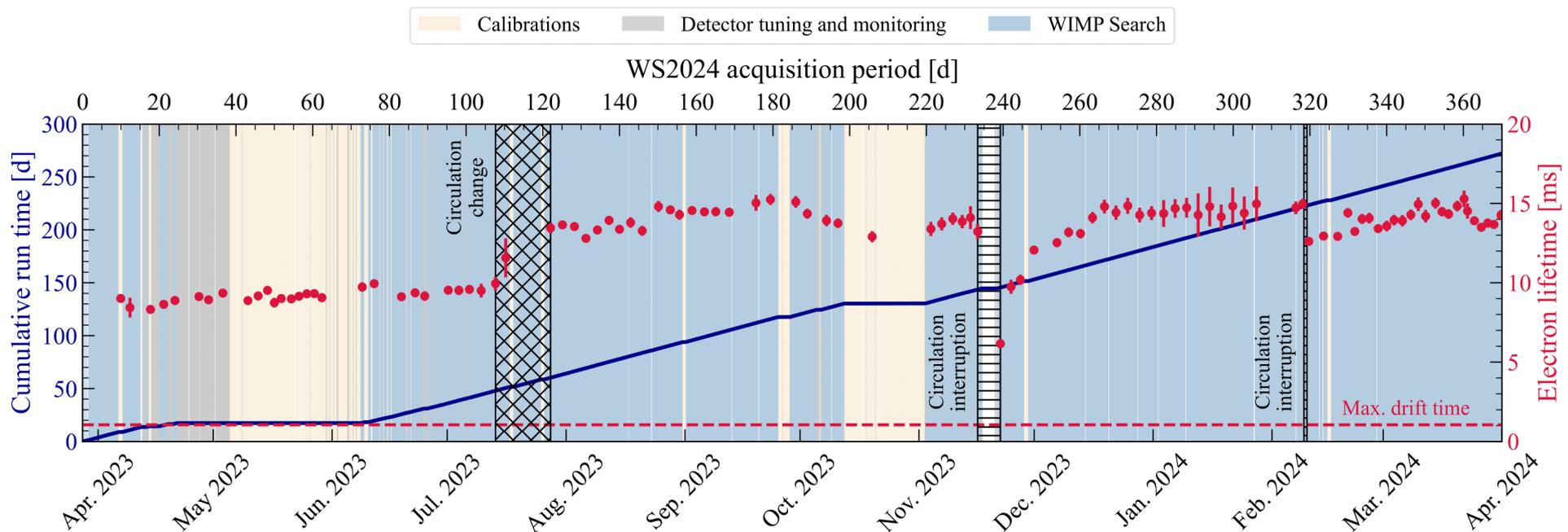
- Conducted various detector optimization campaigns
 - o Grid voltages
 - o Xenon circulation
 - o Calibrations
 - o Trigger configuration
- Lowered extraction region ΔV by 0.5 kV to reduce spurious emission rates
- Cathode voltage lowered in response to light emission observed in the Skin

Run	C/G/A Voltage (kV)	Drift Field (V/cm)	Analysis Live Time (d)
WS2022	-32/-4/+4	193	60
WS2024	-18/-4/+3.5	97	220

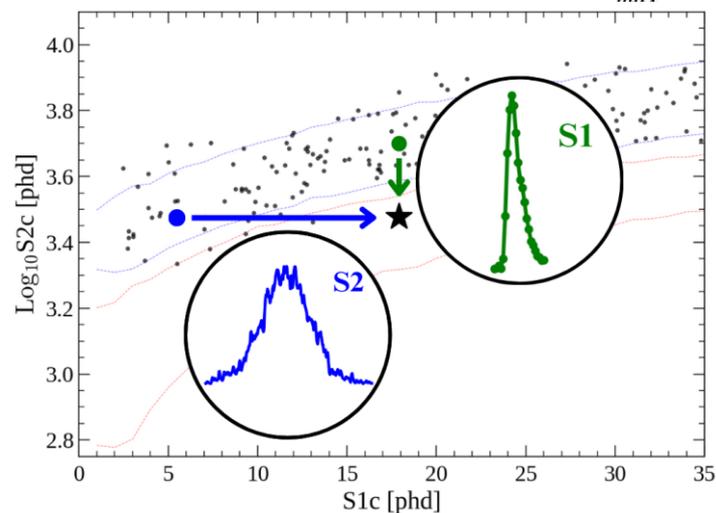
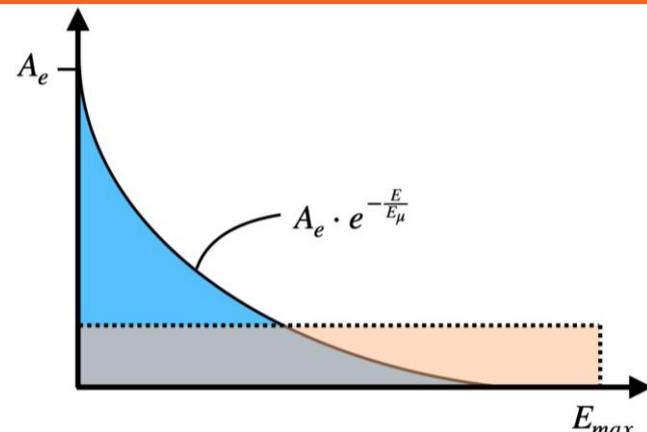


Acquired data for ~370 days

- 95.2% detector up-time
- 220 days of exposure after data quality cuts



- Inject fake signal events at randomly during science data collection
- Events manufactured using S1s and S2s from sequestered calibration data
- Events follow **exponential + flat** spectrum
- Exact parameters are randomly generated and kept hidden
- Identity of salt events is revealed after analysis inputs are finalised for final inference



Electron Recoils (background)

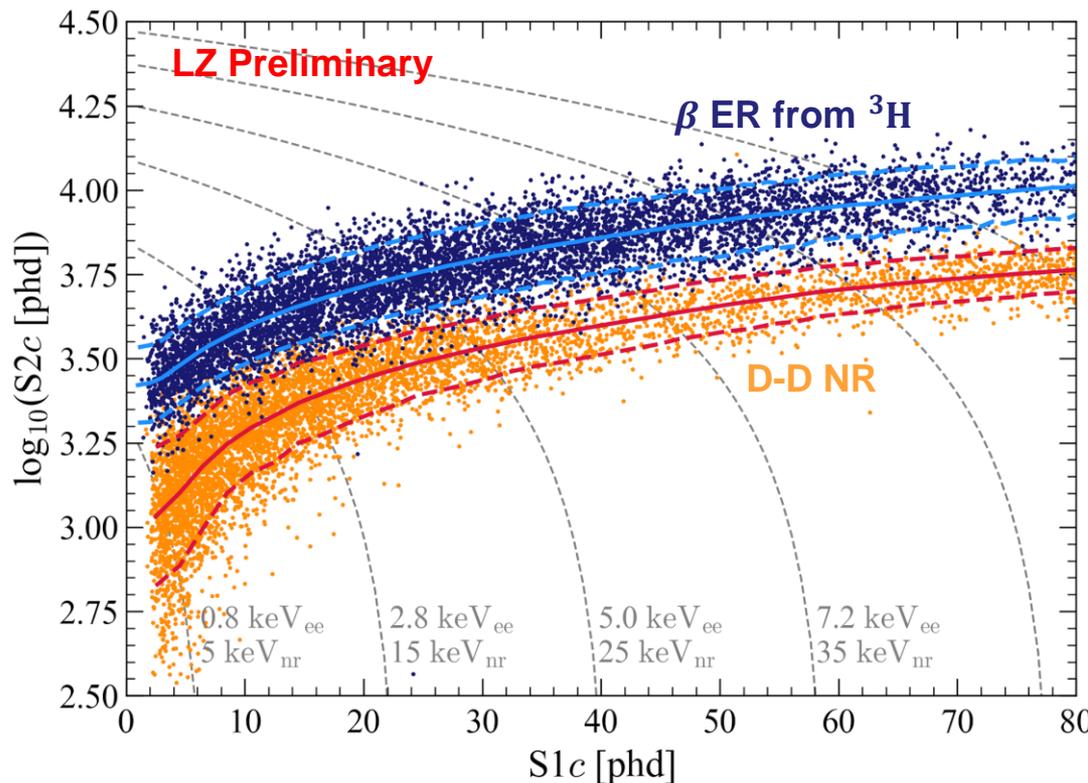
- ^3H (18.6 keV) and ^{14}C (156 keV)
- Others: ^{220}Rn , $^{83\text{m}}\text{Kr}$ and $^{131\text{m}}\text{Xe}$

Nuclear Recoils (signal)

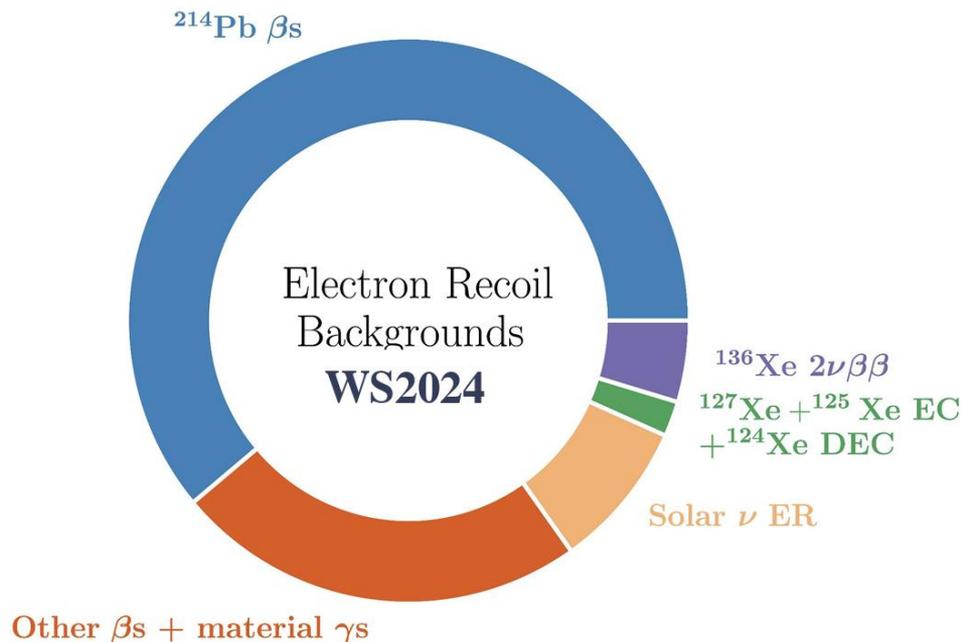
- D-D neutrons
- Others: AmLi and AmBe

Detector Modelling with NESTv2.4

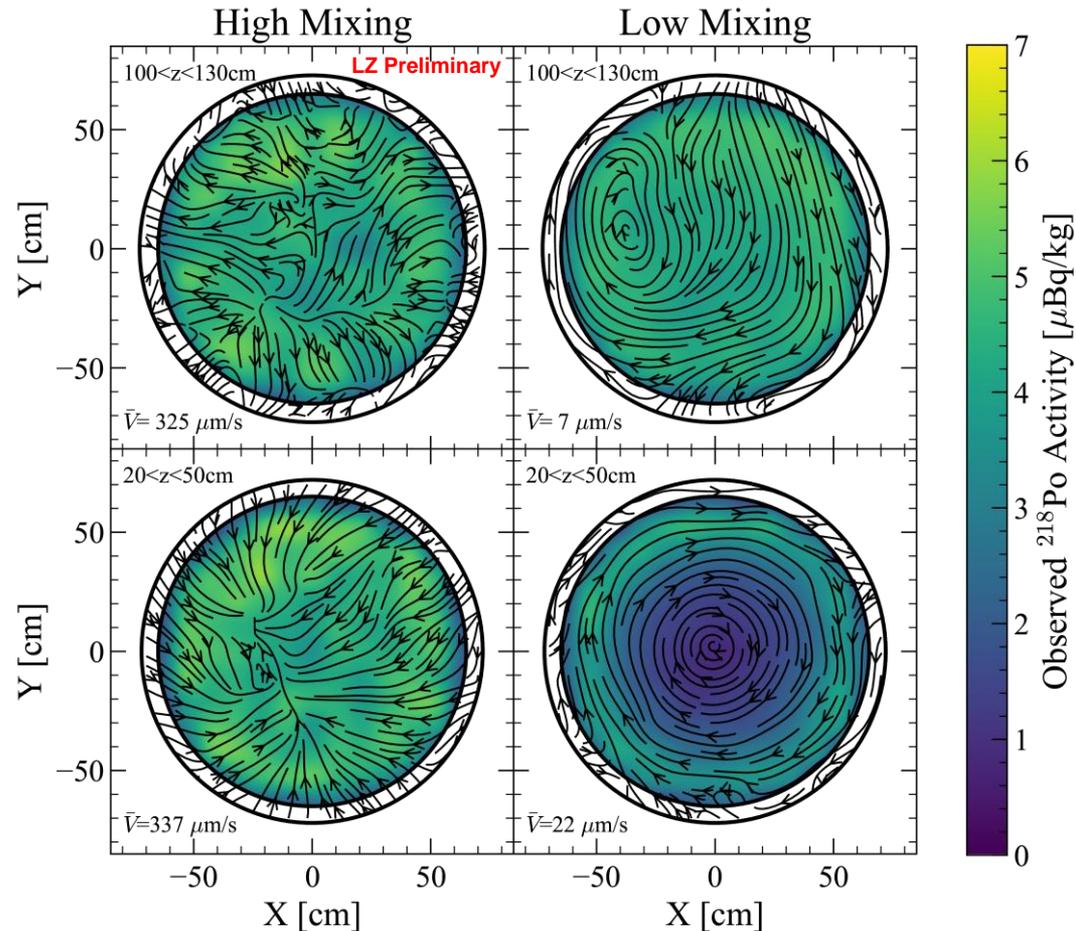
- Tuned to match calibration data
- $g_1 = 0.112 \pm 0.002$ phd/photon
- $g_2 = 34.0 \pm 0.9$ phd/electron
- Single Electron Size: 44.5 phd



- **Dissolved β emitters**
 - o ^{214}Pb , ^{212}Pb , ^{85}Kr , ^{136}Xe
- **Dissolved EC decays**
 - o Neutron activated: ^{127}Xe , ^{125}Xe
 - o ^{124}Xe double EC
- **Instrumental**
 - o Accidentals
- **Solar Neutrinos**
 - o ER: $\text{pp} + ^7\text{Be}$
 - o NR: $^8\text{B} + \text{hep}$
- **Detector Components (long-lived γ sources)**
 - o ^{238}U chain, ^{232}Th chain, ^{40}K , ^{60}Co
- **Neutrons from detector materials**
 - o Spontaneous fission
 - o (α, n)

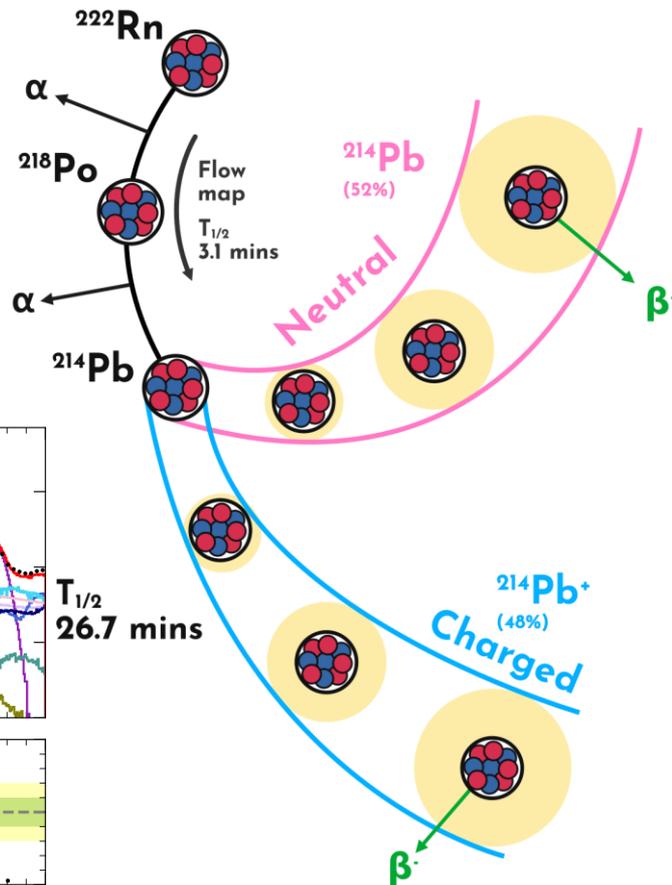
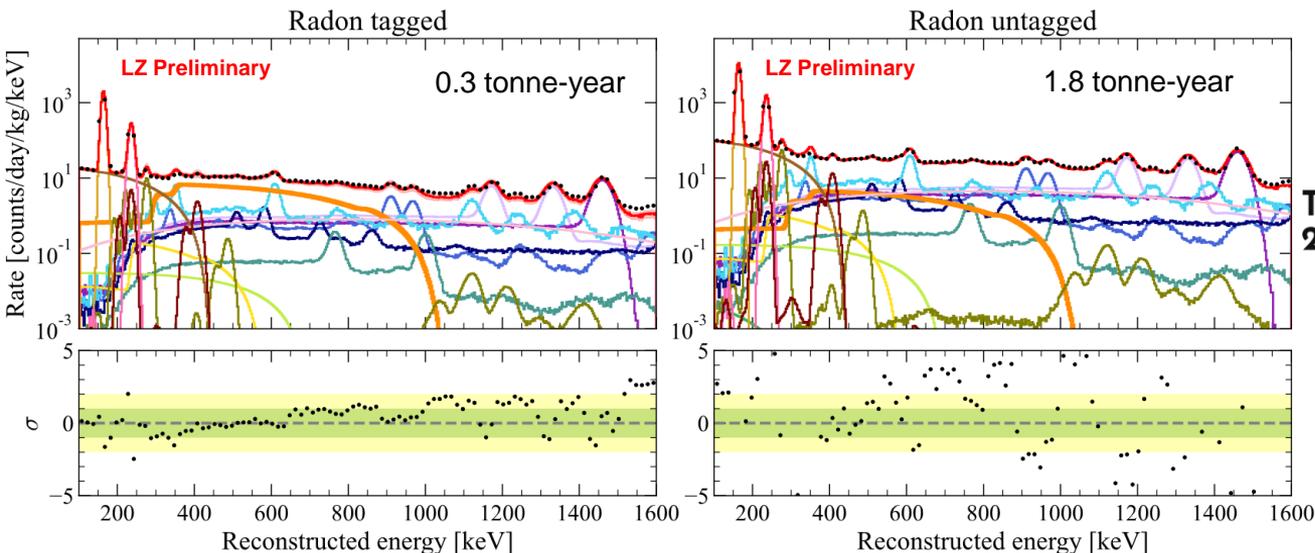
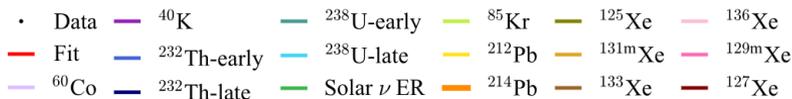


- Circulation and cooling systems allow fine-control of Xe flow
- In WS2024 data, two flow states
 - o **High mixing:** turbulent and uniform distribution of dissolved sources
 - o **Low mixing:** slow laminar-like flow, Rn backgrounds can't reach the centre



In low mixing state

- Use field and flow model to predict the location ^{214}Pb
- Observe ^{218}Po and track for 81 minutes ($\sim 3 \times ^{214}\text{Pb}\tau_{1/2}$)
- $\sim 60\%$ tagging efficiency

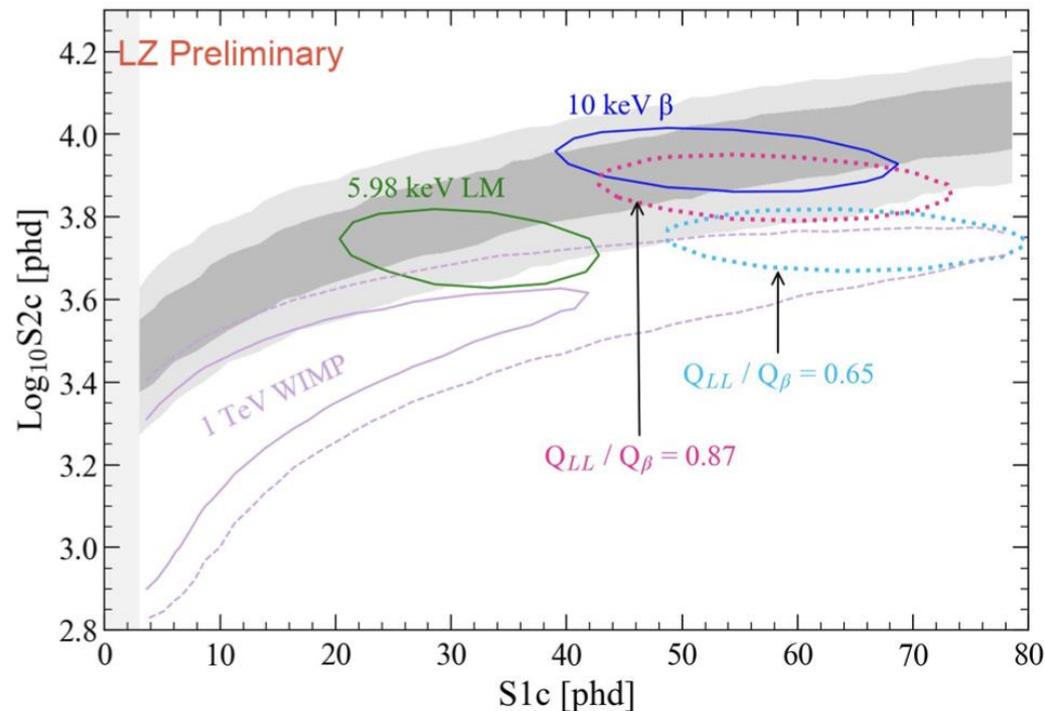


Single Electron Captures

- ^{125}Xe and ^{127}Xe from neutron activation
- X-ray + Auger emission is charge suppressed compared to β
- Measured in-situ: $Q_L/Q_\beta = 0.87 \pm 0.03$

Double Electron Capture

- ^{124}Xe 0.095% natural abundance
- Expect LL decays to be further suppressed $0.65 < Q_{LL}/Q_\beta < Q_L/Q_\beta$

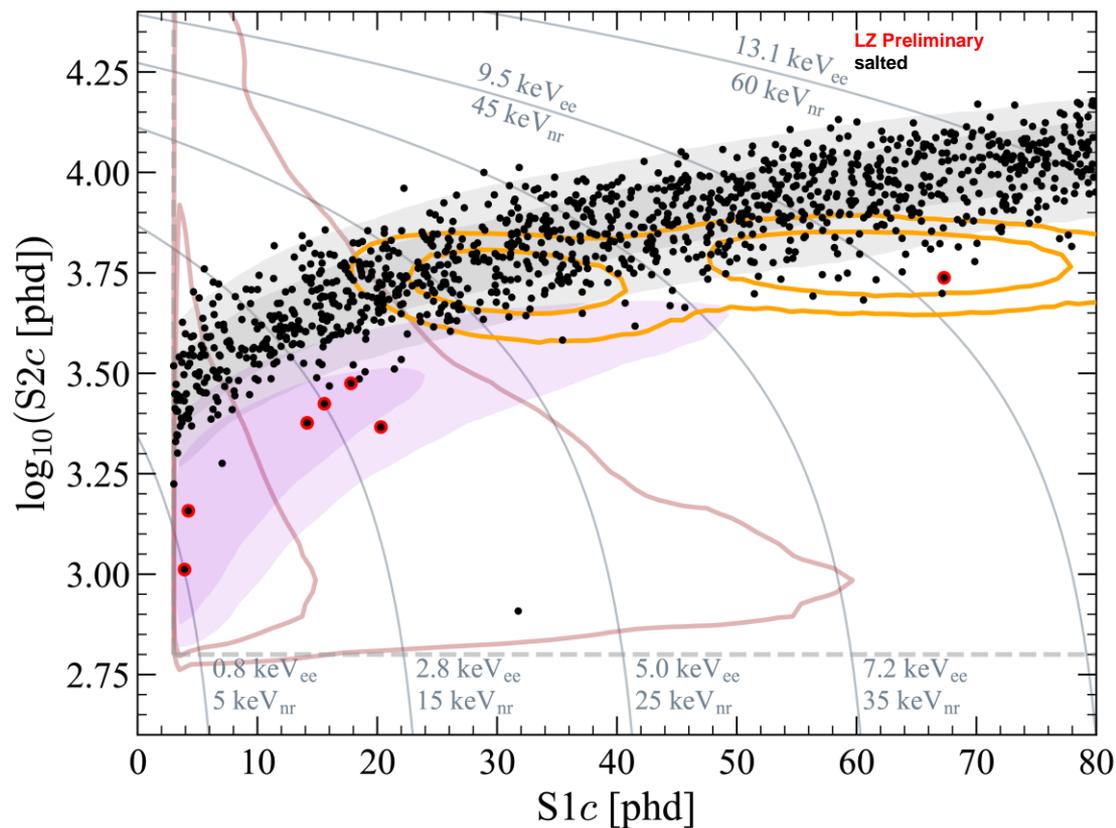


LZ paper on EC charge yields: [arxiv:2503.05679](https://arxiv.org/abs/2503.05679)

- Final exposure
 - 220 livedays \times 5.5 tonnes
 - 3.3 tonne years

- 7 salt events present
 - 8 injected in WS2024
 - Consistent with signal efficiency

- 1220 events after unsalting



40 GeV WIMP Accidentals
 Total ER background
 ^{124}Xe best-fit Q_{LL}/Q_{β}

Exposure in each sample [tonne years]

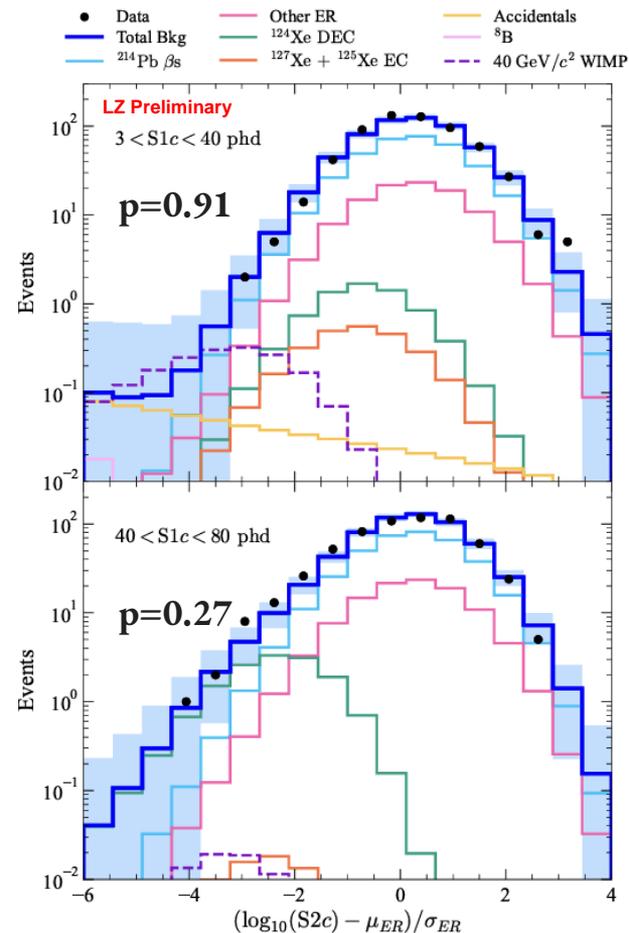
High Mixing State	Radon Tag Inactive	Radon Tagged	Radon Untagged	OD/Skin Vetoed	WS2022
0.6	0.6	0.3	1.8	n/a	0.9

Likelihood fit contains six samples

- **WS2024**: 3.3 tonne years
- **OD/Skin**: full 3.3 tonne years but failing veto coincidence cuts. Provides constraint on neutron background
- **WS2022**: unmodified from [Phys. Rev. Lett. 131, 041002](https://arxiv.org/abs/1304.1002). Maximize exposure

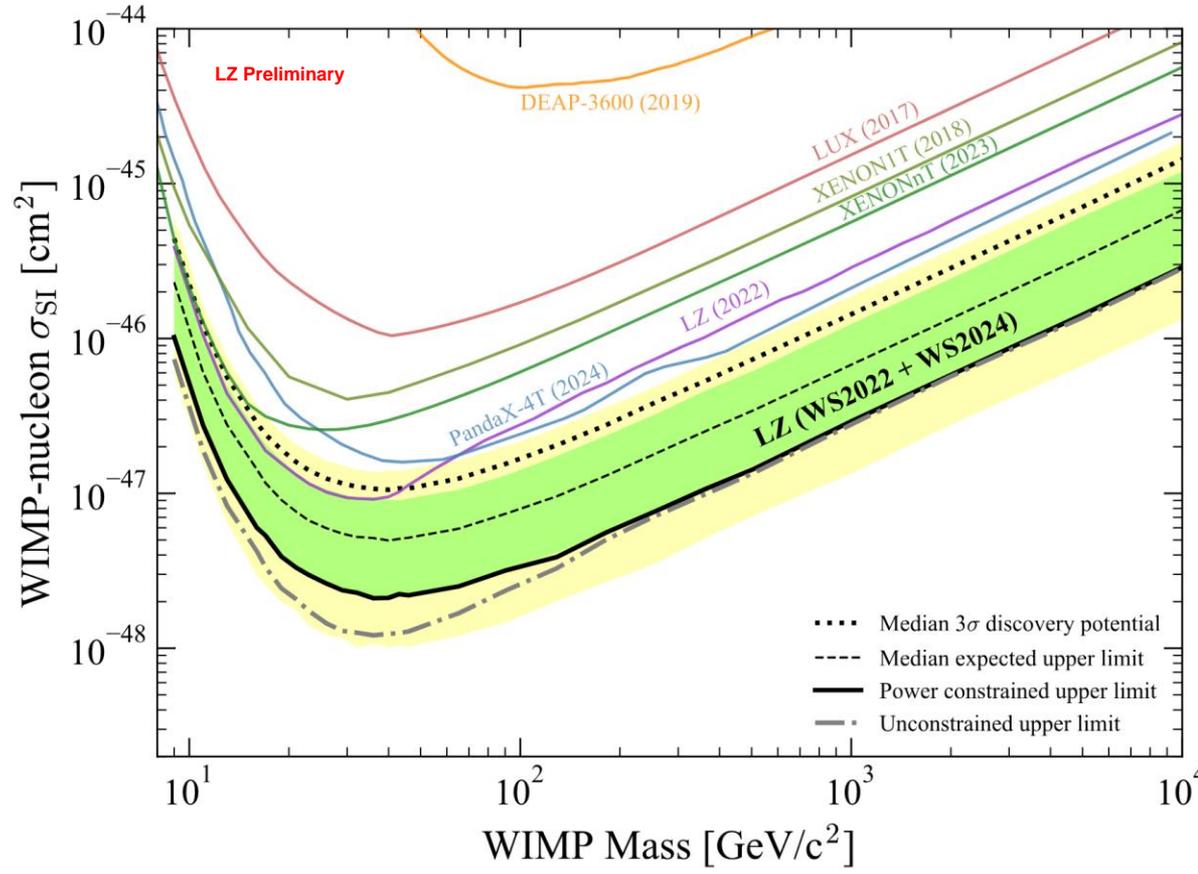
Source	Pre-fit Expectation	Fit Result
$^{214}\text{Pb } \beta\text{s}$	743 ± 88	733 ± 34
$^{85}\text{Kr} + ^{39}\text{Ar } \beta\text{s} + \text{det. } \gamma\text{s}$	162 ± 22	161 ± 21
Solar ν ER	102 ± 6	102 ± 6
$^{212}\text{Pb} + ^{218}\text{Po } \beta\text{s}$	62.7 ± 7.5	63.7 ± 7.4
Tritium+ $^{14}\text{C } \beta\text{s}$	58.3 ± 3.3	59.7 ± 3.3
$^{136}\text{Xe } 2\nu\beta\beta$	55.6 ± 8.3	55.8 ± 8.2
^{124}Xe DEC	19.4 ± 3.9	21.4 ± 3.6
$^{127}\text{Xe} + ^{125}\text{Xe}$ EC	3.2 ± 0.6	2.7 ± 0.6
Accidental coincidences	2.8 ± 0.6	2.6 ± 0.6
Atm. ν NR	0.12 ± 0.02	0.12 ± 0.02
$^8\text{B} + \text{hep } \nu$ NR	0.06 ± 0.01	0.06 ± 0.01
Detector neutrons	$^a 0.0^{+0.2}$	$0.0^{+0.2}$
40 GeV/c ² WIMP	–	$0.0^{+0.6}$
Total	1210 ± 91	1203 ± 42

- Best fit no. of WIMPs is **0** at all tested masses (9 GeV-10 TeV)
- Strong agreement with background-only model





- Exceeds previous best constraint by factor > 4
- Minimum cross section $\sigma_{SI} = 2.1 \times 10^{-48} \text{ cm}^2$ at $36 \text{ GeV}/c^2$
- Upper limit is power constrained at -1σ sensitivity band [EPJC 81, 907](#)



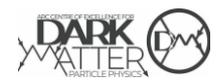


- LZ is the world's most sensitive WIMP direct detection experiment
 - o Total exposure 4.2 tonne-years
 - o Exceeds previous best constraint by factor > 4
- Radon tag developed and deployed
 - o 60% reduction in main ER background
- LZ will continue to take data until 2028
 - o Towards 1000 livedays
- Many more physics searches happening with this dataset
 - o ${}^8\text{B}$ CEvNS
 - o Low mass WIMPs
 - o EFT-NR
 - o ER searches
 - o $0\nu\beta\beta$

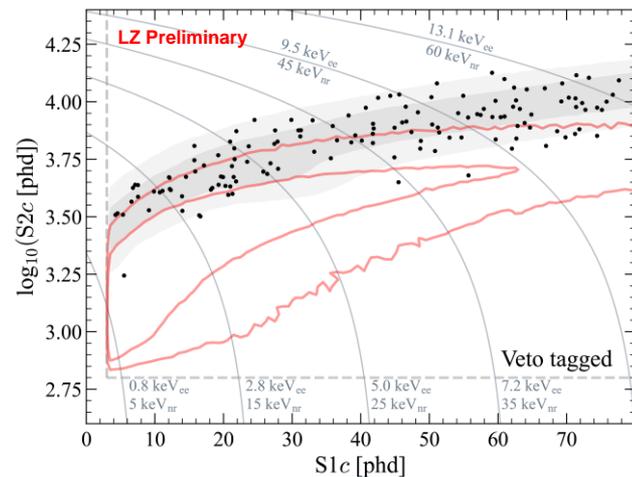
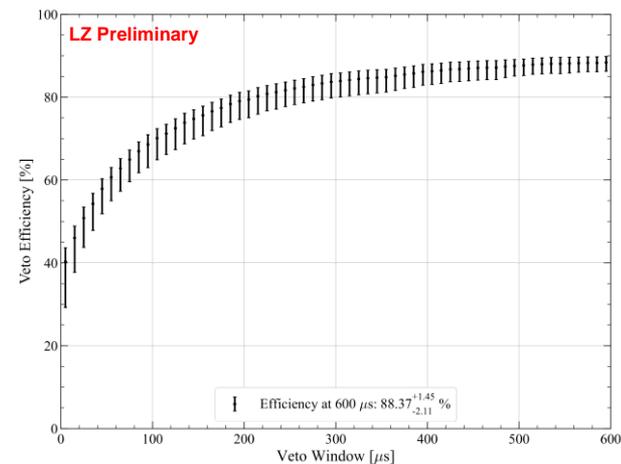
WS2024 Paper
[arxiv:2410.17036](https://arxiv.org/abs/2410.17036)



Backup



- Neutron veto efficiency
 - o $89 \pm 3\%$ from AmLi calibration
 - o 3% deadtime
- Background simulations suggest higher veto efficiency
 - o Additional gammas from (α, n) and USF
 - o $92 \pm 4\%$
- Neutron rate from fitting Skin/OD sideband
 - o Decays with gammas
 - o Random pile-up
- Veto sideband fit gives $0^{+0.2}$ neutrons in WS
- Separate multiple scatter analysis predicts 0.3 ± 0.2





Time Exclusion

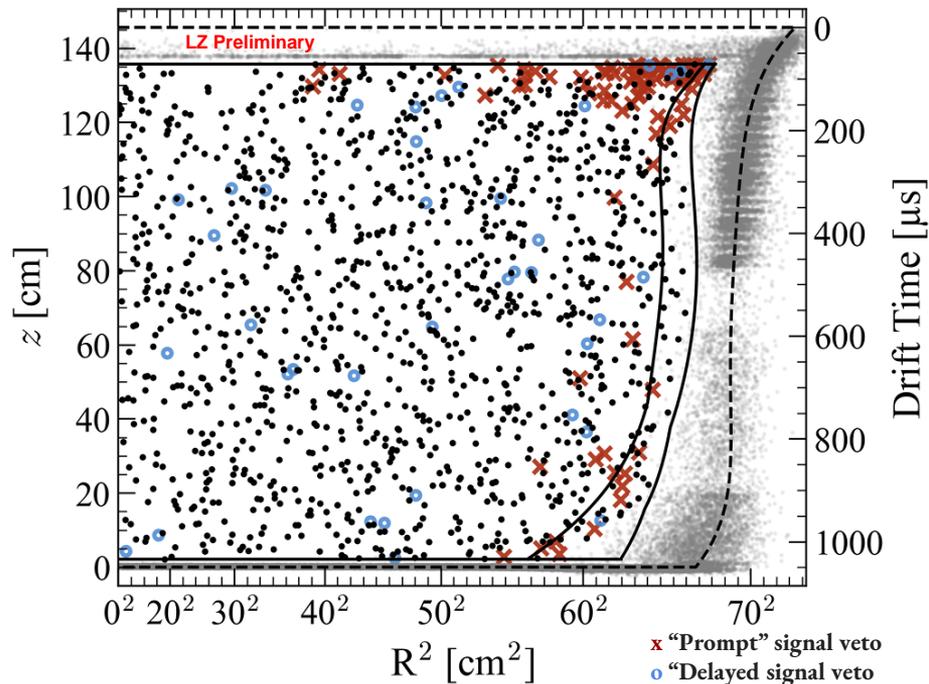
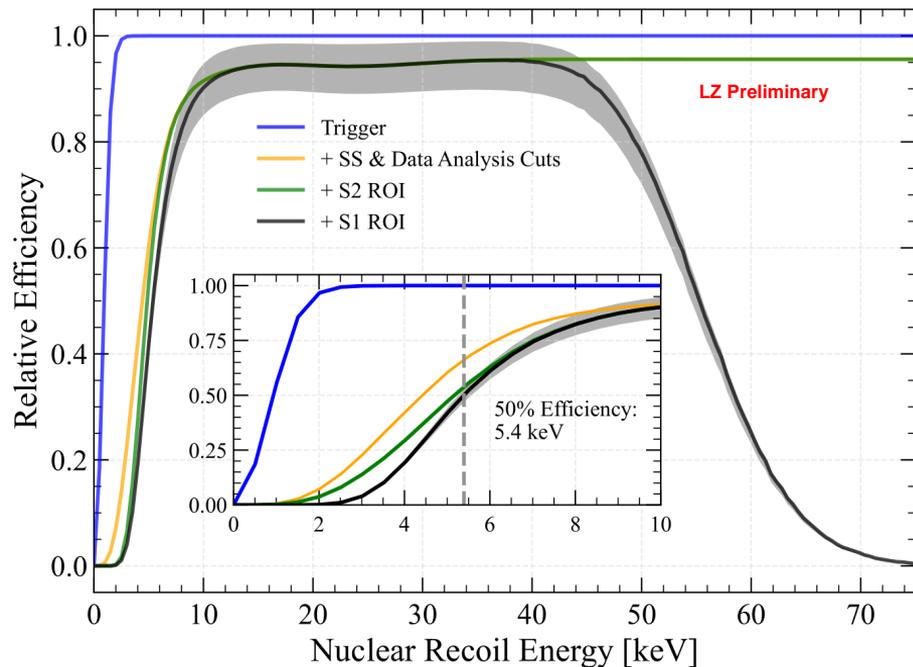
- Periods of high rate
- Detector instability
- Hold-off after large S2s

S1 and S2 cuts

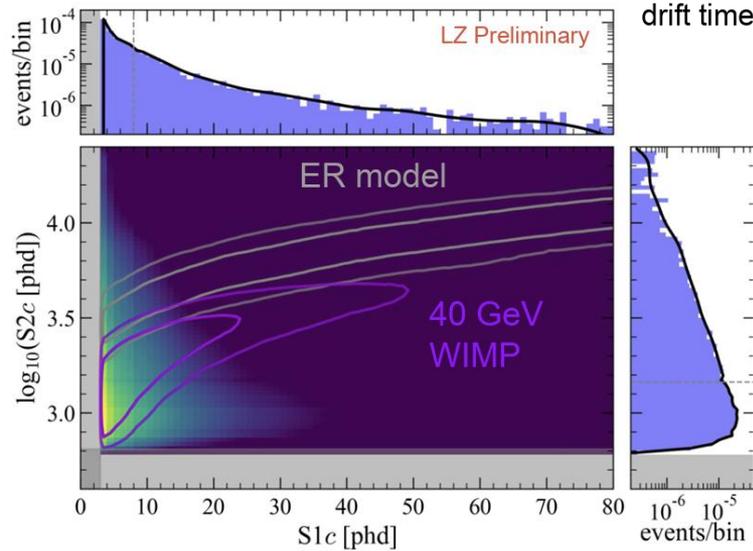
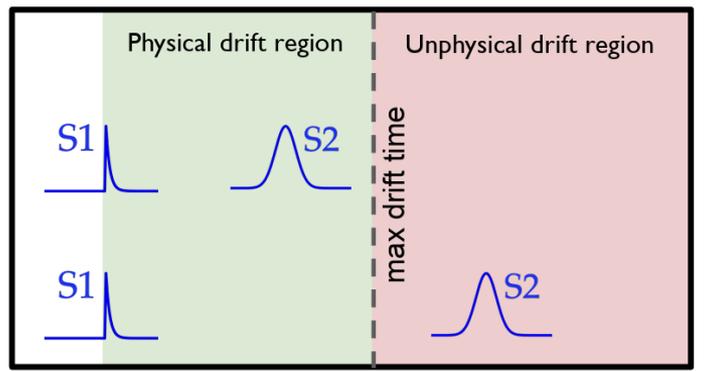
- Pathologies targeting accidentals
- Acceptance quantified on calibration data

Fiducial Volume

- Azimuthally & drift time dependent
- < 0.01 charge loss events
- 5.5 ± 0.2 tonne mass

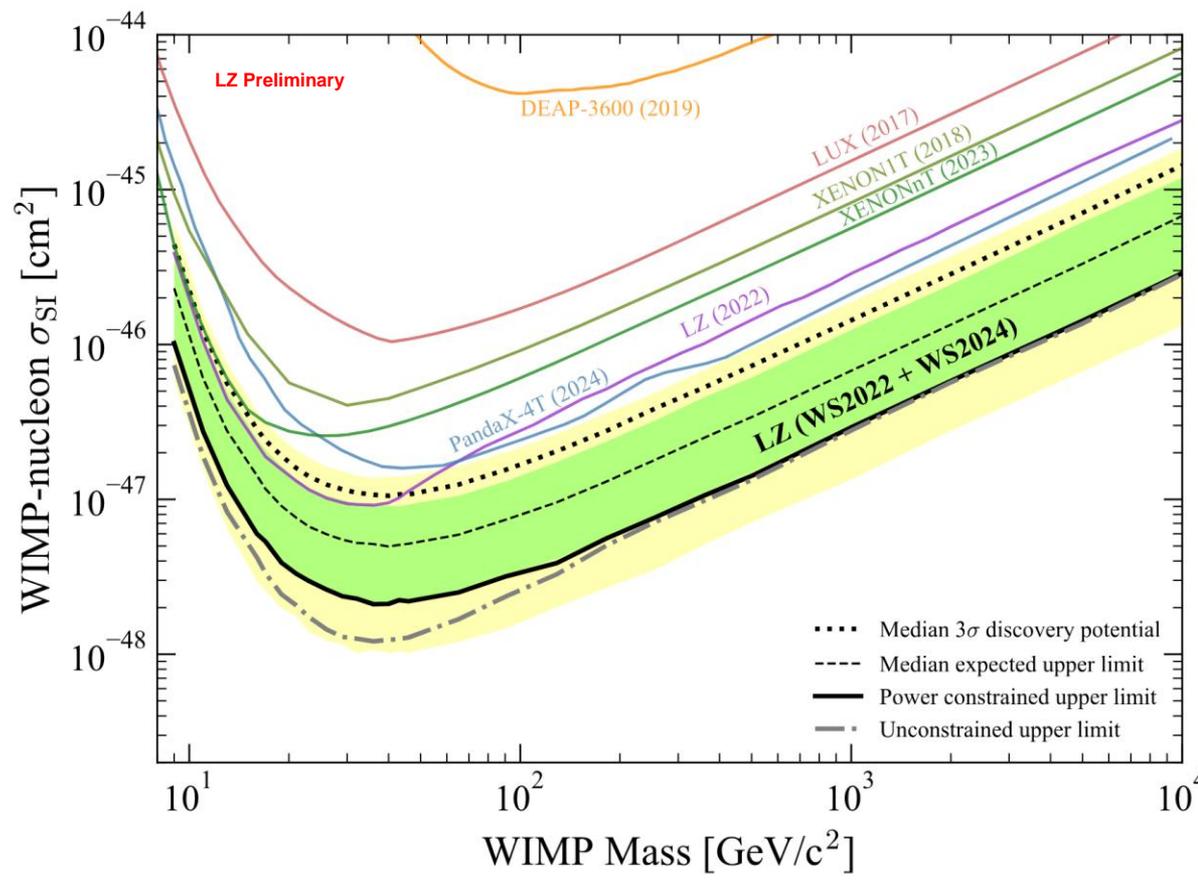


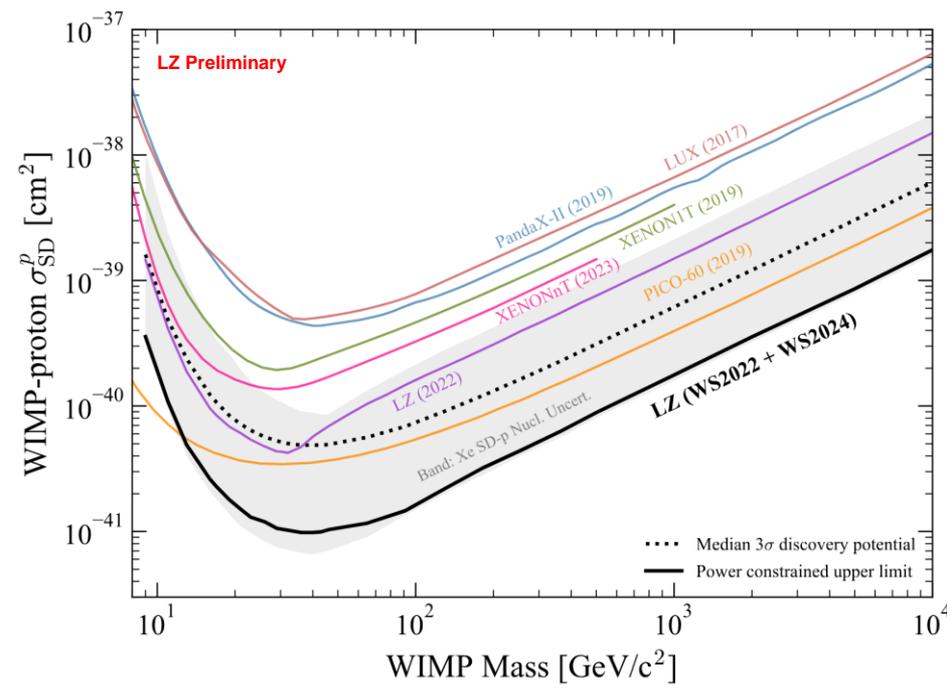
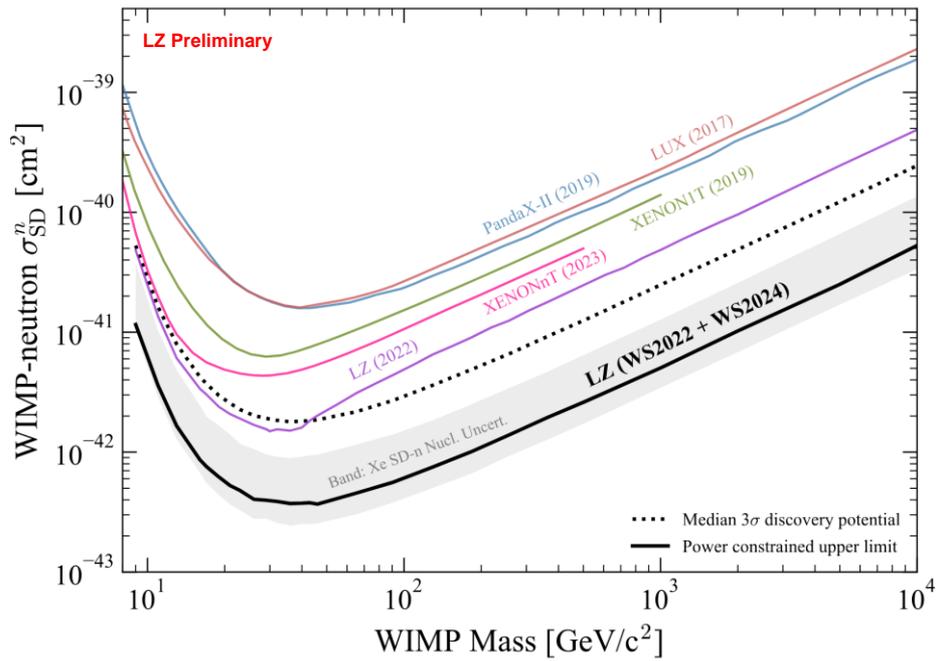
- Accidental coincidence of uncorrelated isolated S1 and S2 pulses
- Accidentals model
 - o **Rate:** Measure rate of unphysical drift time single scatters. Analysis cut efficiencies analysed using manufactured accidental events
 - o **Shape:** Manufactured by combining isolated S1 and S2 waveforms and applying analysis cut efficiencies
- Expectation
 - o **2.8 ± 0.6**
 - o Analysis cuts have 99.5% rejection power
 - o Uncertainty dominated by difference in cut survival fractions between manufactured accidentals and those observed in unphysical drift window





- -1σ fluctuation across the entire mass range primarily attributed to an underfluctuation of the accidental coincidence background in the region of largest overlap with expected WIMP distributions





- Sensitive from ^{129}Xe (spin 1/2) and ^{131}Xe (spin 3/2)
- Gray bands show theoretical uncertainties on SD form factors

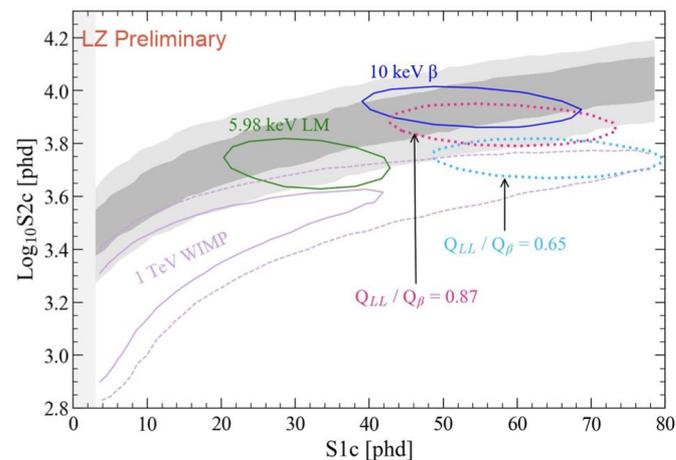
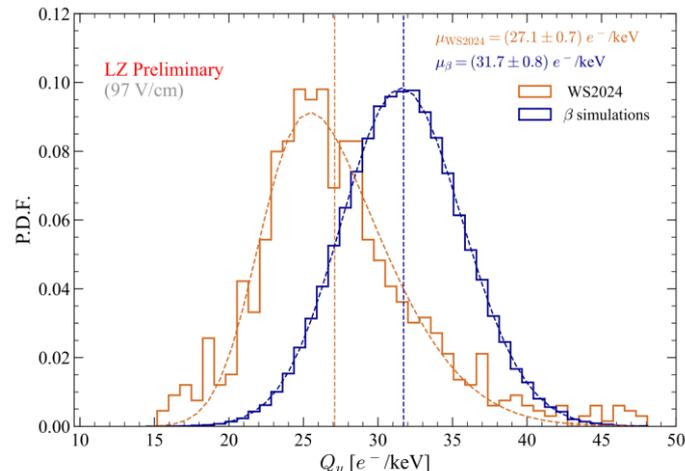


Single Electron Captures

- ^{125}Xe and ^{127}Xe from neutron activation
- L-shell (5.2 keV)
- X-ray + Auger emission is charge suppressed compared to β
- Measured in-situ: $Q_L/Q_\beta = 0.87 \pm 0.03$
- In-situ from skin-tagged and multiple scatter decays

Double Electron Capture

- ^{124}Xe 0.095% natural abundance
- LM-shell (5.98 keV) and LL-shell (10 keV)
- Expect LL decays to be further suppressed $0.65 < Q_{LL}/Q_\beta < Q_L/Q_\beta$
- Allowed to float in statistical analysis to 2x ionization density
- Best fit to WS2024 data $Q_{LL}/Q_\beta = 0.70 \pm 0.04$



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Electron Recoils (background)

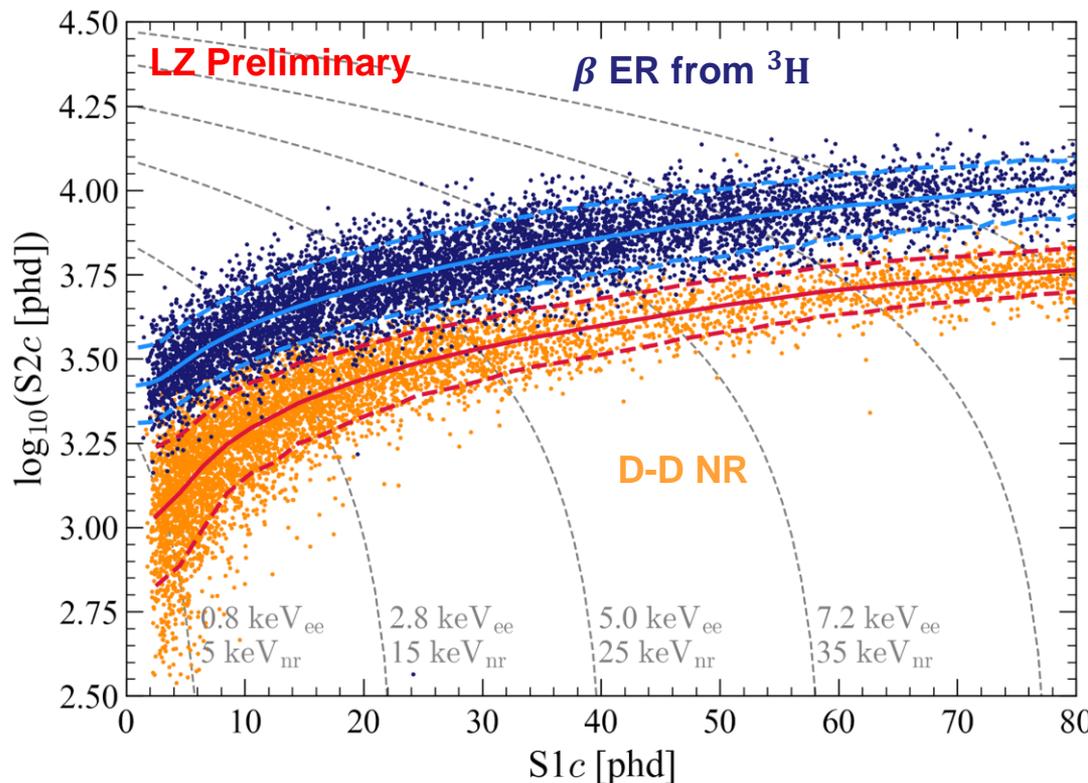
- High statistics (~156k events) from injection of radiolabelled methane containing ^3H (18.6 keV) and ^{14}C (156 keV)
- Spatially homogeneous β
- Others: ^{220}Rn , $^{83\text{m}}\text{Kr}$ and $^{131\text{m}}\text{Xe}$

Nuclear Recoils (signal)

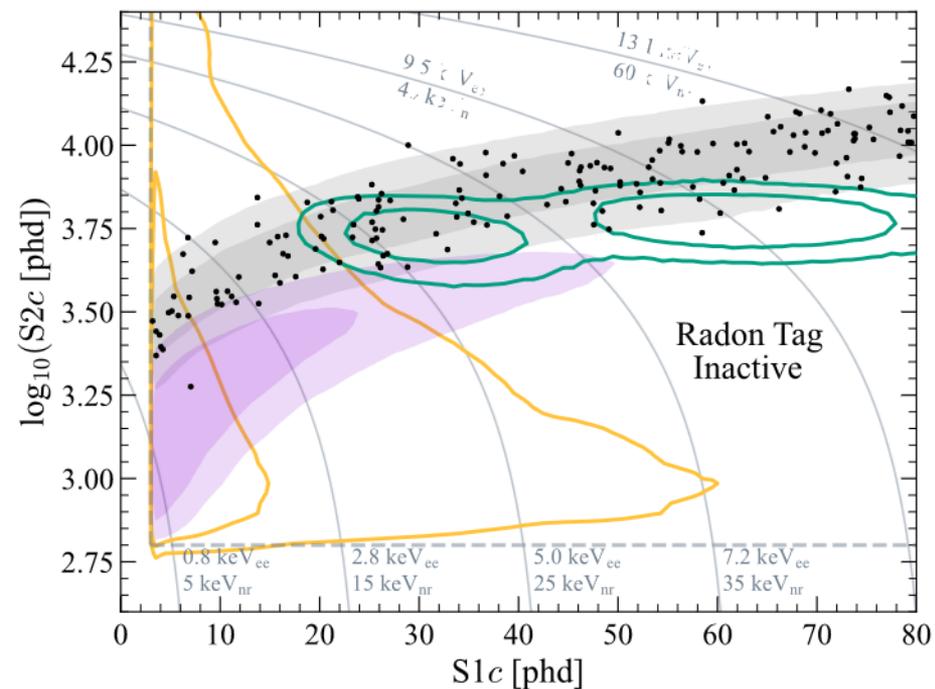
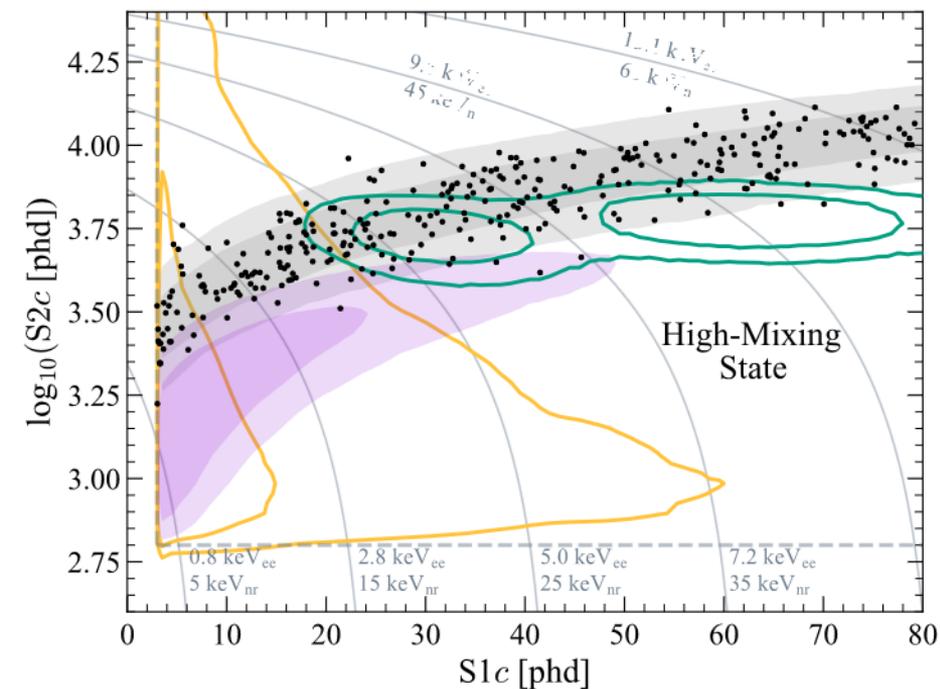
- High statistics (~11k events) from 2.45 MeV neutrons from D-D
- AmLi and AmBe in source deployment tubes

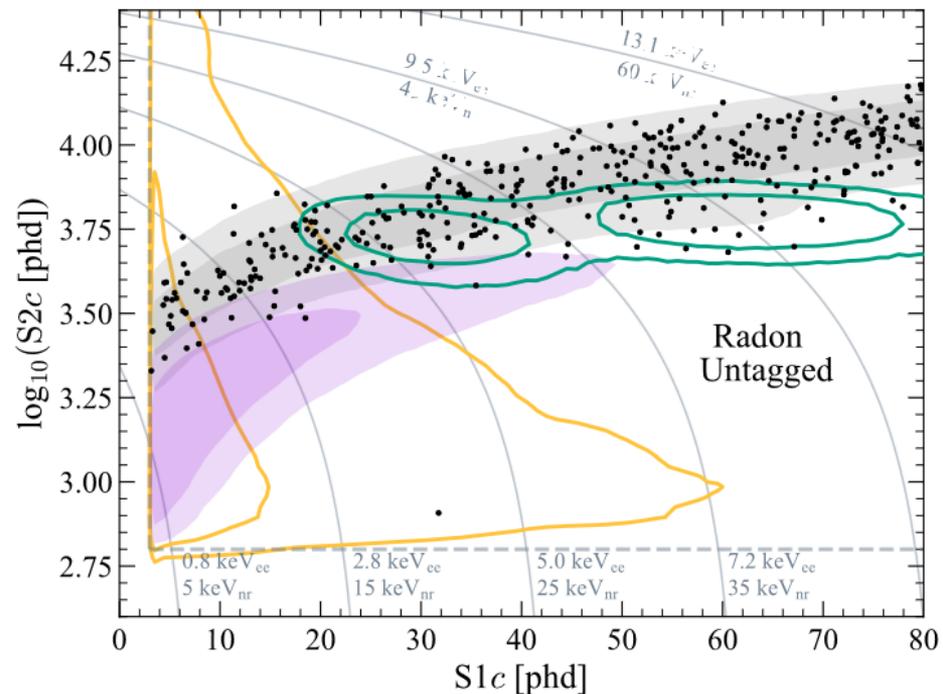
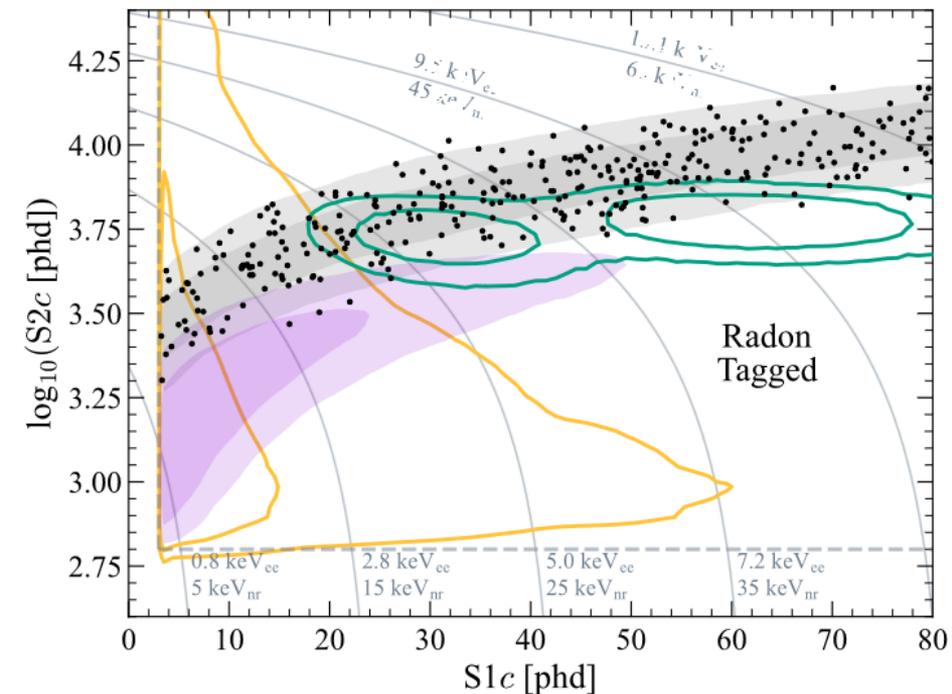
Modelling with NESTv2.4

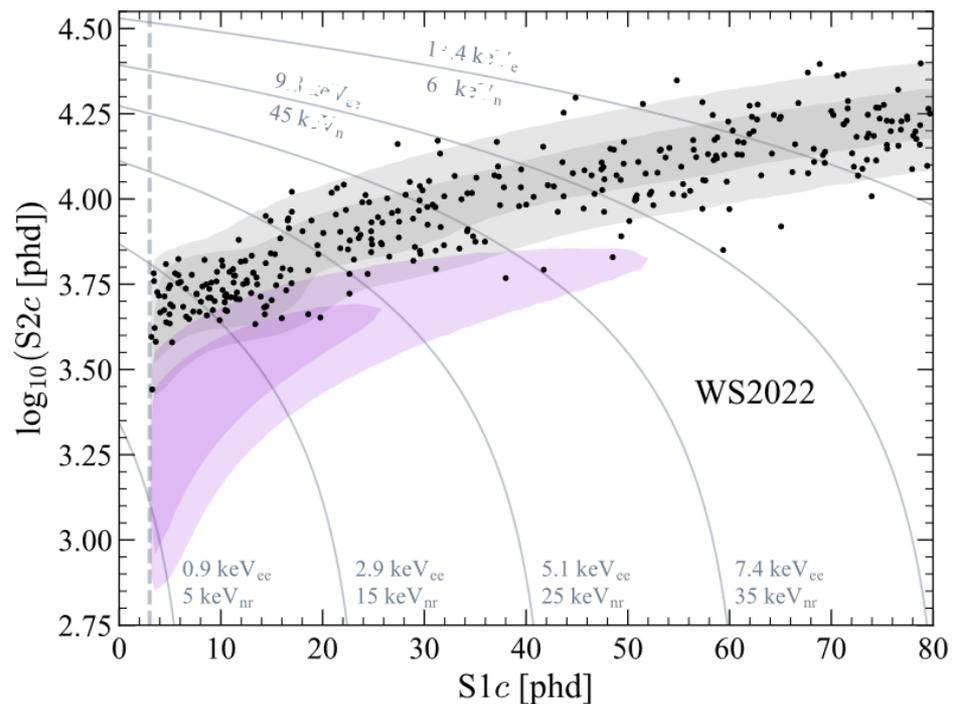
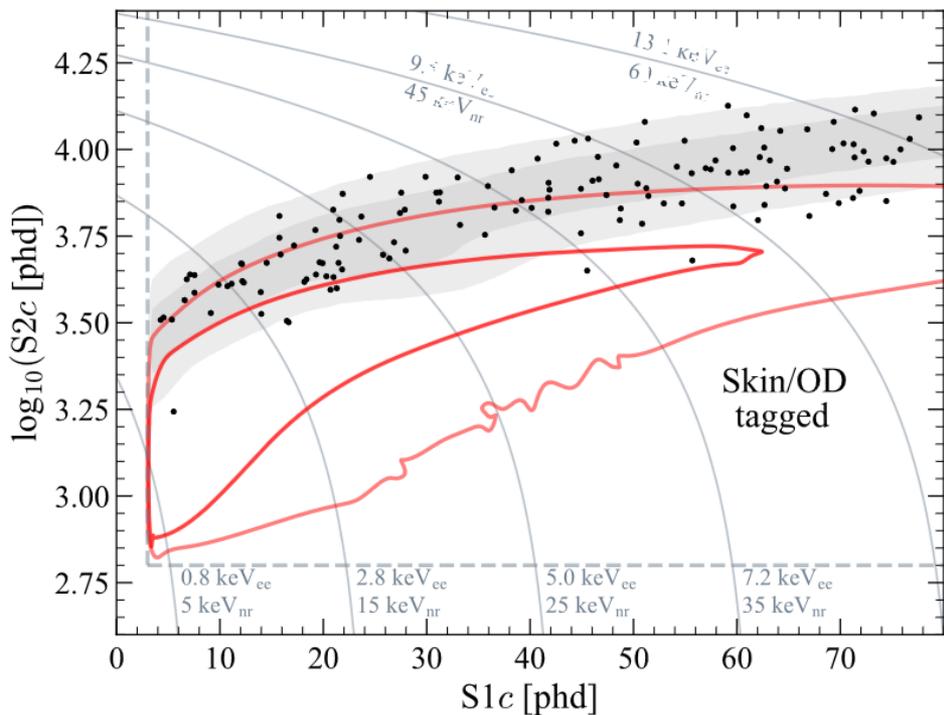
- Tuned to match calibration data
- $g_1 = 0.112 \pm 0.002$ phd/photon
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- Single Electron Size: 44.5 phd

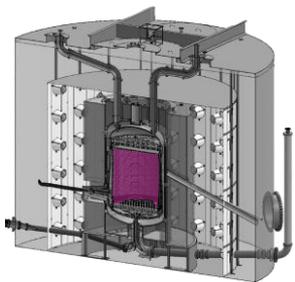


99.9% ER/NR discrimination at 50% acceptance for a 40 GeV WIMP



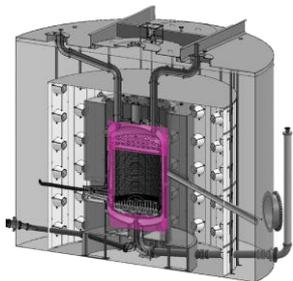






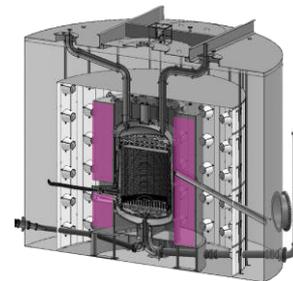
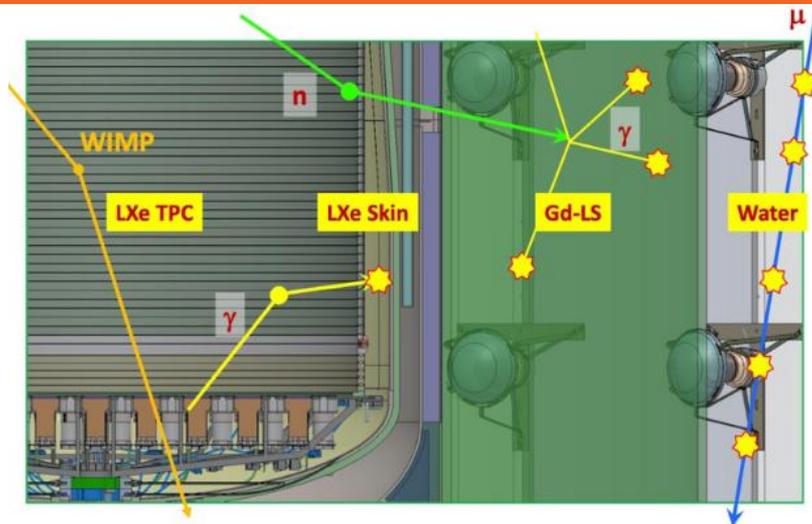
- 1.5 m diameter x 1.5 m height
- 7 tonnes active liquid Xenon
- High Light Collection Efficiency
 - 253 x 3" PMTs Top
 - 241 x 3" PMTs Bottom
 - PTFE walls





Skin

- 2 tonnes liquid Xenon
- 93 x 1" and 38 x 2" PMTs
- anti-coincidence for γ -ray



Outer Detector

- 17 tonnes Gd-loaded scintillator
- 120 8" PMTs
- anti-coincidence for neutrons and γ -ray

