Latest Results from LUX-ZEPLIN (LZ)

Large
Underground
Xenon
experiment

Zon**E**d **P**roportional
scintillation in **LI**quid
Noble gases

Dr Joshua Robert Green
PDRA @ University College London
On behalf of the LZ collaboration



Who?

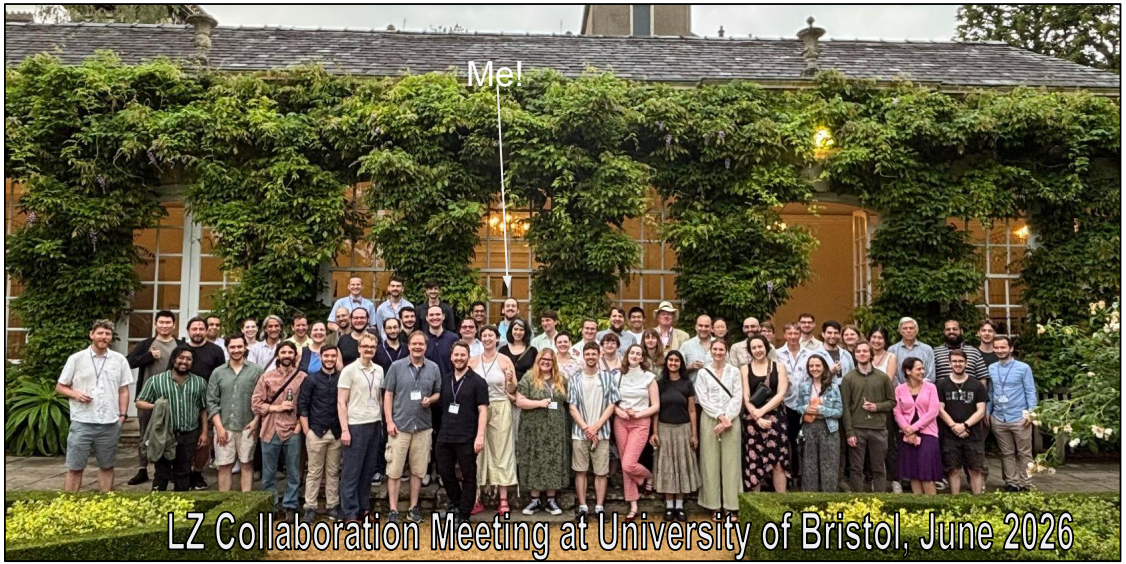
LZ (LUX-ZEPLIN) Collaboration

39 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
Purdue 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

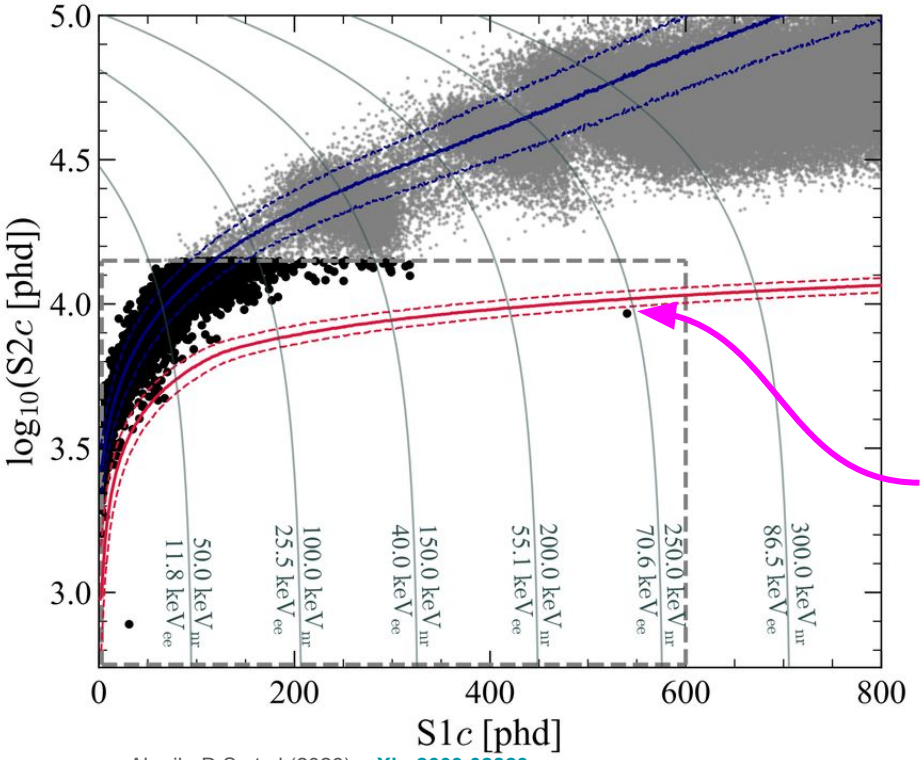
US Europe
Asia Oceania



Thanks to our Sponsors and Participating Institutions!

What?

This talk will be about the recent result finding a high energy event with **2.6σ** global significance against our current background model.



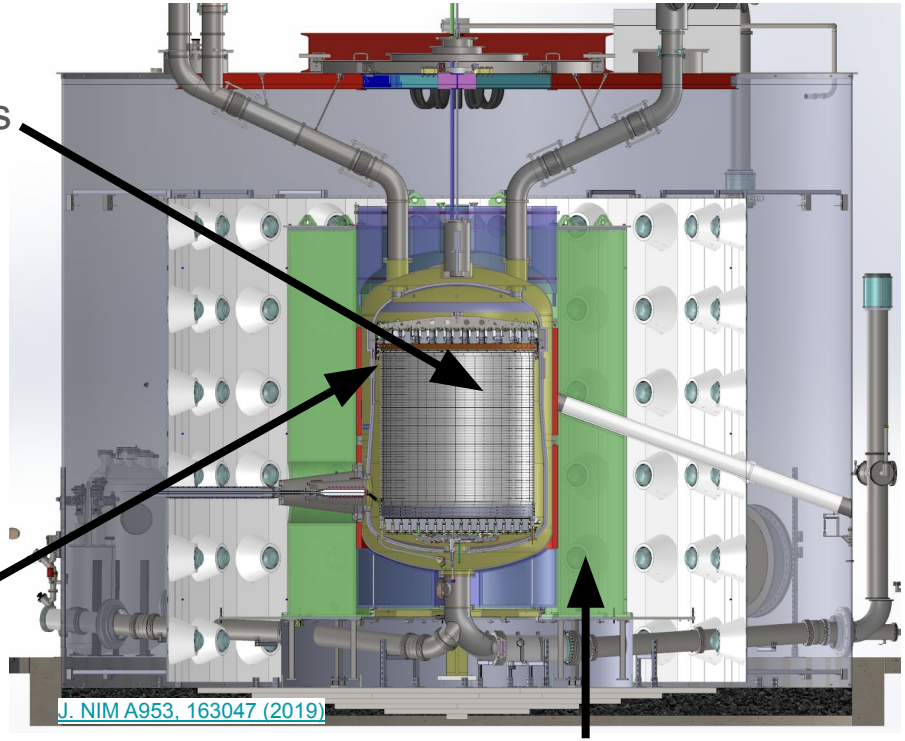
Akerib, D.S et al (2026) arXiv:2609.02823

arXiv:2609.02823

LUX-ZEPLIN Experiment

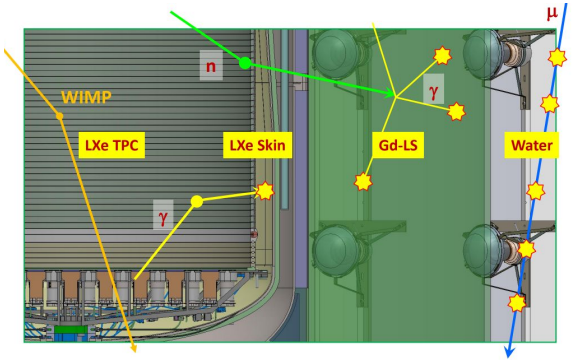
Dual phase time projection chamber (**TPC**) with 7 tonnes of active liquid xenon target

2 tonne liquid xenon **Skin** instrumented for scintillation-only.



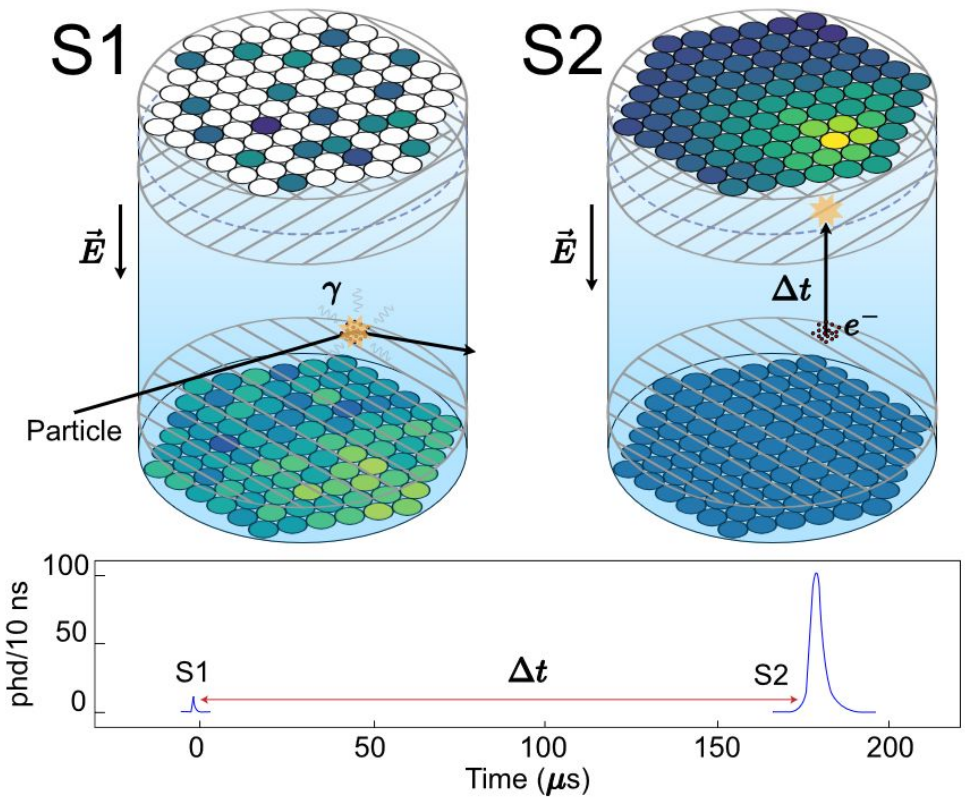
Gadolinium loaded liquid scintillator **Outer Detector (OD).**

4850' Rock Overburden shields against cosmic rays **Water Tank** houses OD and shields against radiation in the cavern.



OD and Skin work together to veto signals from internal and external neutrons and gammas.

Time Projection Chamber



1. Scatter in the detector excites or ionises the Xenon atoms.
2. The excited atoms promptly produce scintillation light (S1)
3. Ionisation electrons are drifted to the extraction region.
4. Extraction region accelerates electrons into a gas phase.
5. Electroluminescence produces a far greater intensity light signal (S2).

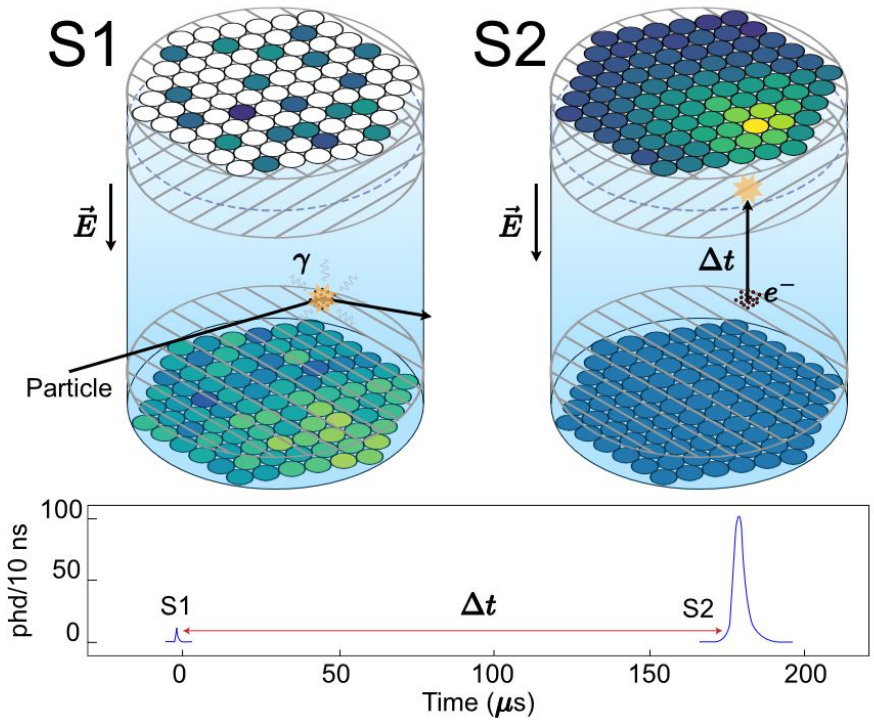
Eli Mizrachi's Thesis "**Studies of Ionization Backgrounds in Noble Liquid Detectors For Dark Matter Searches**" (2024)

Interpreting Our Data

S1 and S2s can be differentiated by their:

Timing:
S2s are “slower” characterised by the traversing electrons & S1s by scintillation time/reflections.

Size:
S1s are typically smaller than S2s.



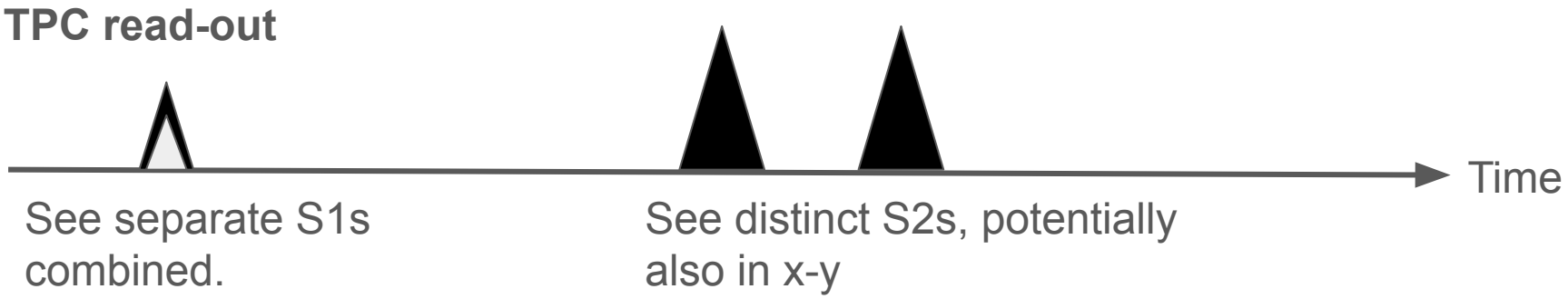
Time between the S1 & S2 gives the vertical position

We use the **position** in x,y and z to remove events near the edges of the TPC. This is called a **Fiducial Volume (FV)**.

Eli Mizrachi’s Thesis “**Studies of Ionization Backgrounds in Noble Liquid Detectors For Dark Matter Searches”** (2024)

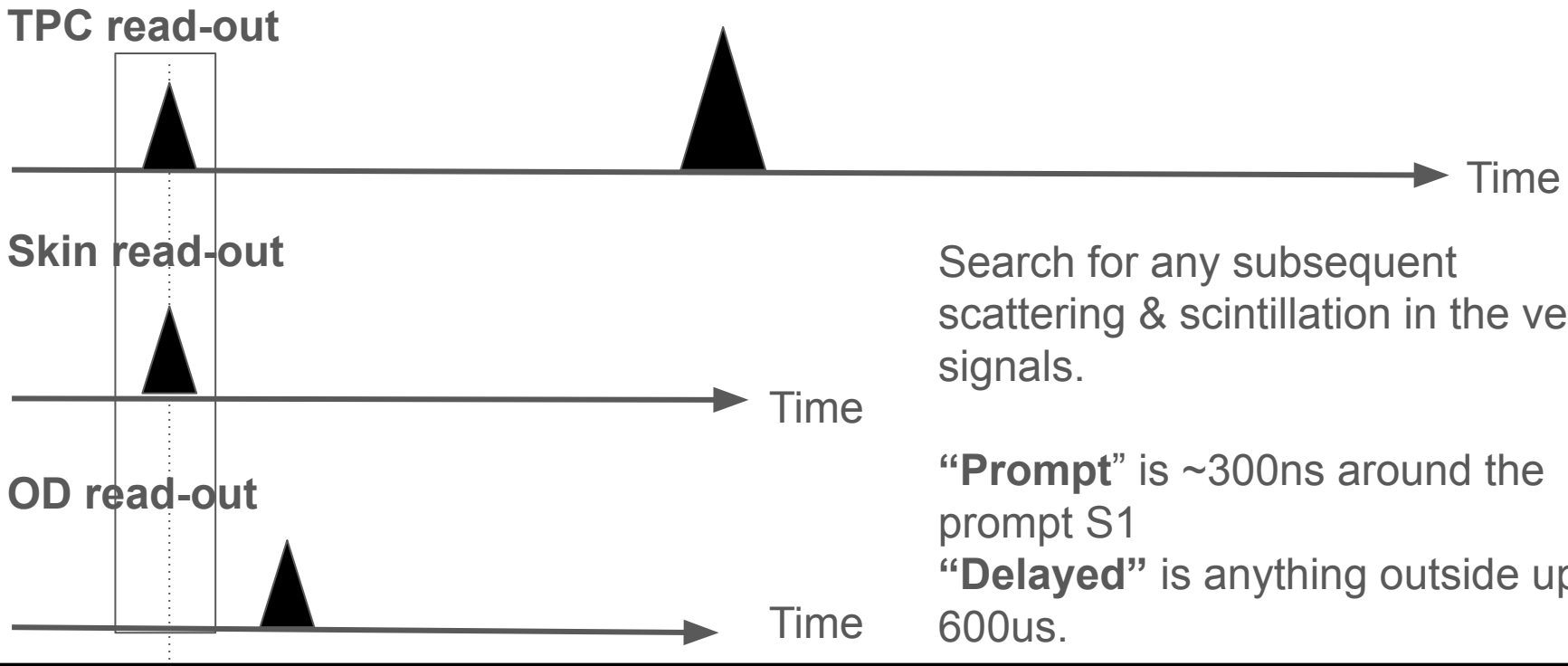
Searching For Signal

WIMP dark matter predicted to have a small cross-section.
Impose a single-scatter condition to reject multiple-scatters.



Searching For Signal

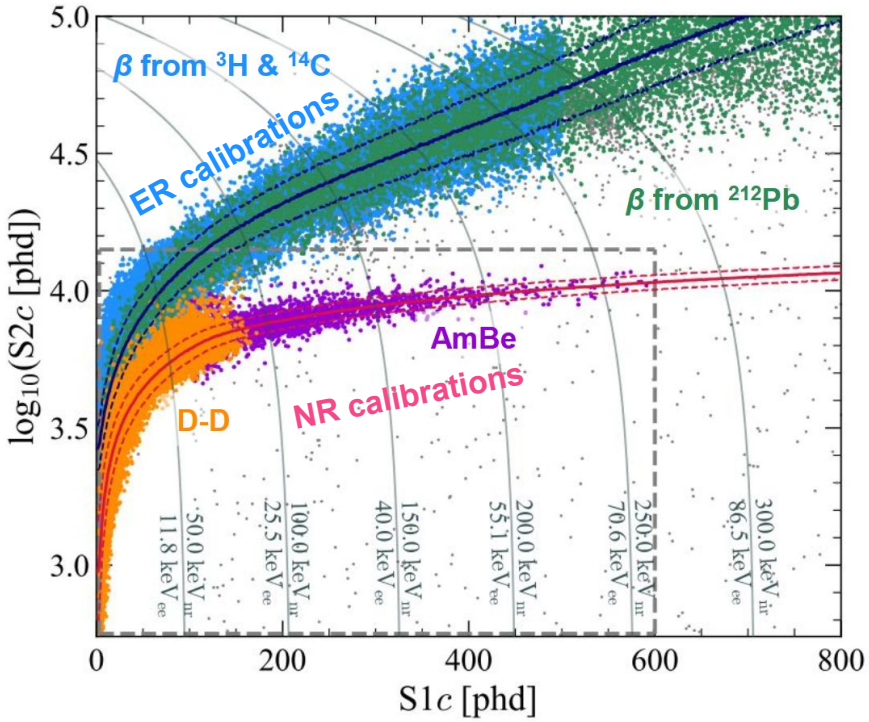
Also reject anything that also scatters inside our veto detectors.



Search for any subsequent scattering & scintillation in the veto signals.

“Prompt” is ~300ns around the prompt S1
“Delayed” is anything outside up to 600us.

Signal vs Background Discrimination



Contains events outside the **FV.

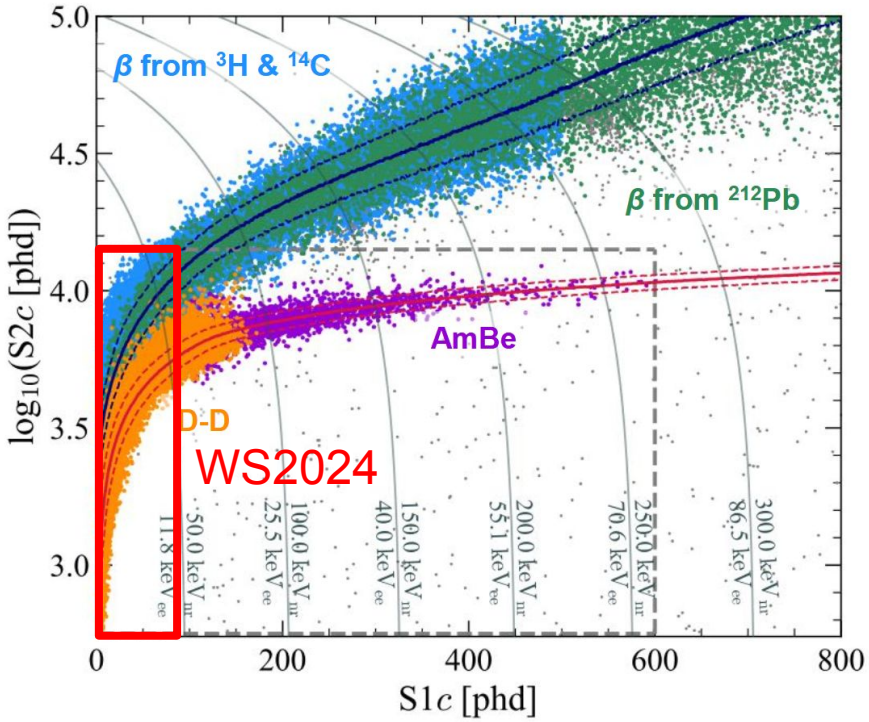
Most scatters within our detector can either be Electronic Recoils (ERs) or Nuclear recoils (NRs). Search for WIMPs through nuclear scattering.

ER backgrounds: single-scatter betas and gammas.

ERs have a greater ionisation to scintillation ratio due to reduced recombination and direct xenon excitation physics. Can discriminate ERs and NRs with S1 and S2 ratio.

Introduction & Signals

This Analysis



Akerib, D.S et al (2026) arXiv:2609.02823

Our previous WIMP search (WS2024: Phys. Rev. Lett. **135**, 011802) focussed on a far smaller **R**egion **O**f **I**nterest (**ROI**) than this study.

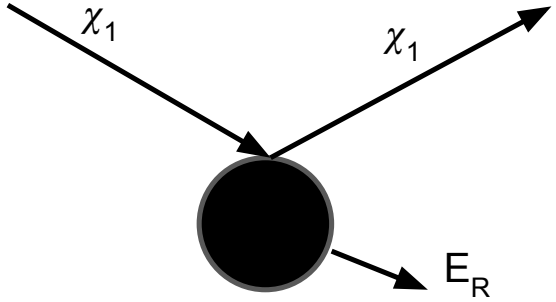
This is because that's where a standard spin-independent WIMP would show up.

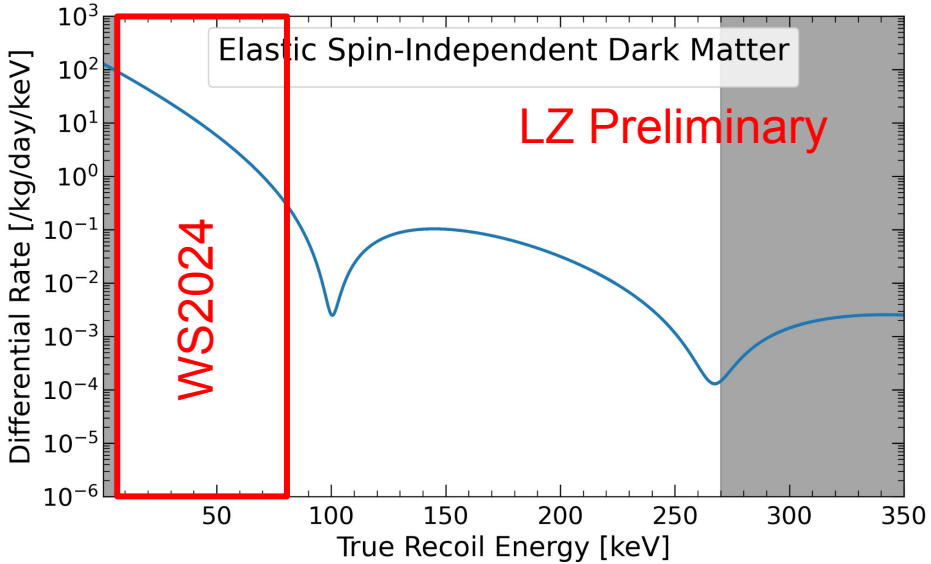
Expanding the ROI required:

- Dedicated ER and NR calibrations
- Consideration of new background topologies.

This search contains the low energy ROI

Standard WIMP



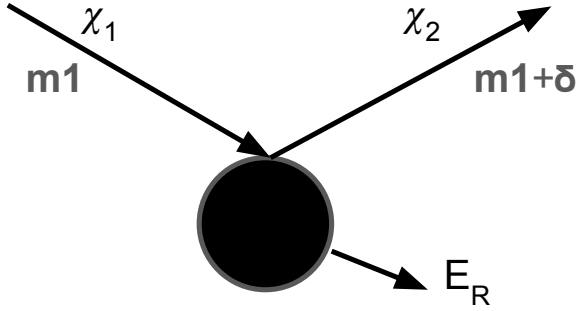


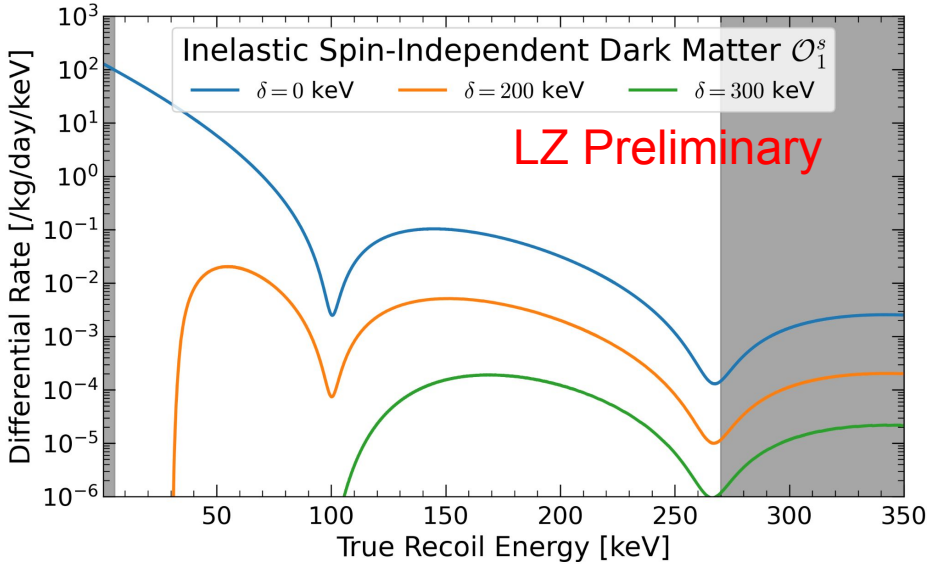
Standard WIMP is a Spin-Independent (SI) interaction which follows the Helm form-factor derived from any SI coupling with the density of the nucleus.

At higher recoil energies, momentum transfer increases and the scattering decoheres.

Typically no reason to search > 80 keV (the first minima).

Why look higher? #1





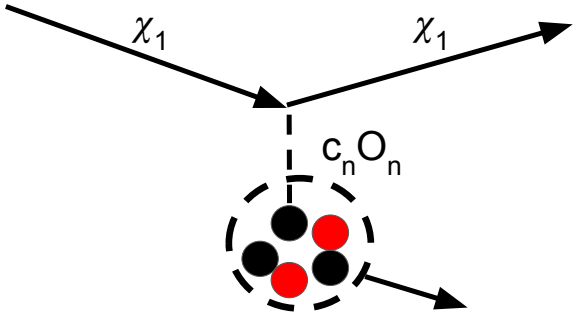
If dark matter originates from a theory with an excited state within a few hundred keV then the relic dark matter state an **inelastic scatter** can occur.

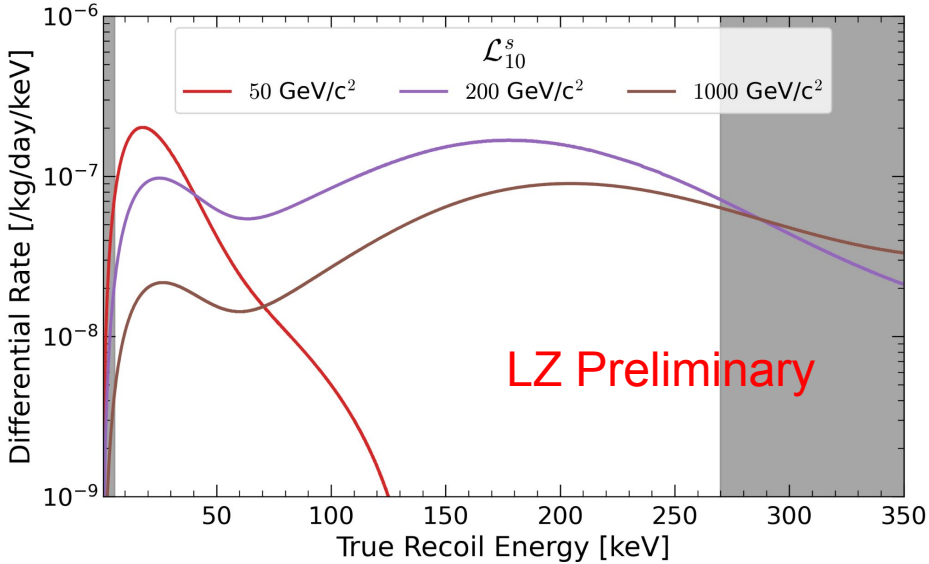
This **suppresses** lower energy recoils meaning a signal isolated within the higher energy region could occur.

$$v_{min} = \frac{1}{\sqrt{2E_R m_N}}\left(\frac{E_R m_N}{\mu} + \delta\right)$$

Smith et al. Phys. Rev. D 64, 043502 (2001)

Why look higher? #2





Allowing all possible forms of non-relativistic couplings to nucleons opens a new window of nuclear and WIMP responses depending on 4 quantities:

$$i\frac{\vec{q}}{m_N}, \quad \vec{v}^{\perp} \equiv \vec{v} + \frac{\vec{q}}{2\mu}, \quad \vec{S}_\chi, \quad \vec{S}_N,$$

This is done through a **Non-Relativistic Effective Field Theory (NREFT)** yielding 15 operators which can be connected to 20 relativistic interaction Lagrangians.

Can favour higher energies due to momentum & velocity dependence.
Summary: Fitzpatrick, et al (2013)

Analysis Details

LZ230616

Interesting event on 20**23/06/16**

Appears to be a 248 ± 23(stat) ± 23(sys) keV nuclear recoil.

Possible signal model:

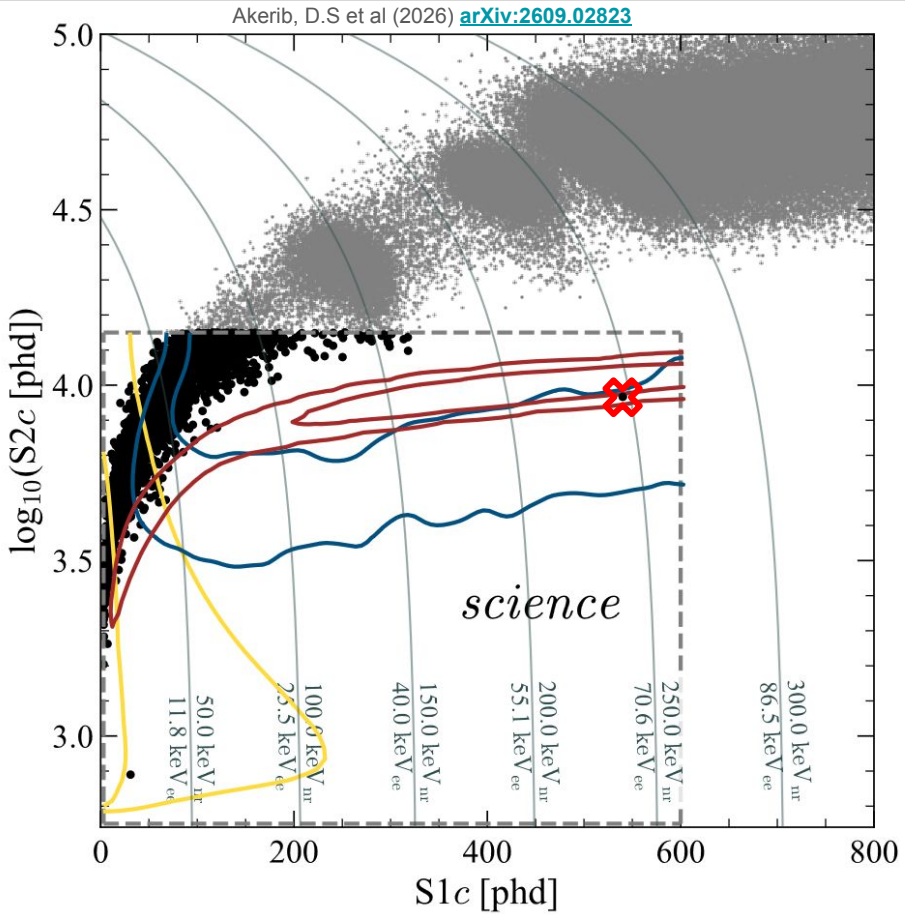
- **1000 GeV/c^2 L10s signal model**

Backgrounds are:

- **Multiple Scintillation - Single Ionisation Events (MSSI)**
- **Accidental Coincidence Event**
- **Neutrons (negligible)**

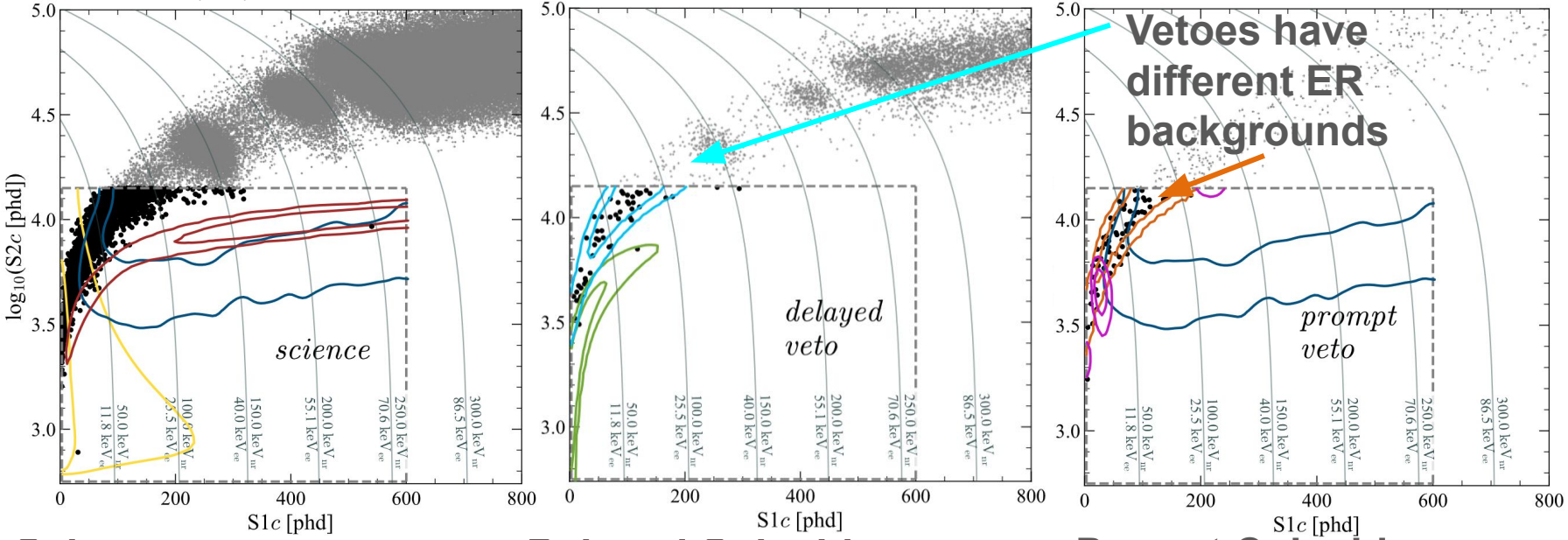
Our likelihood model contains **S1c-log10(S2c)** as observables.

Use a combined likelihood of three useful spaces in our data.



Observed Data

Akerib, D.S et al (2026) arXiv:2609.02823



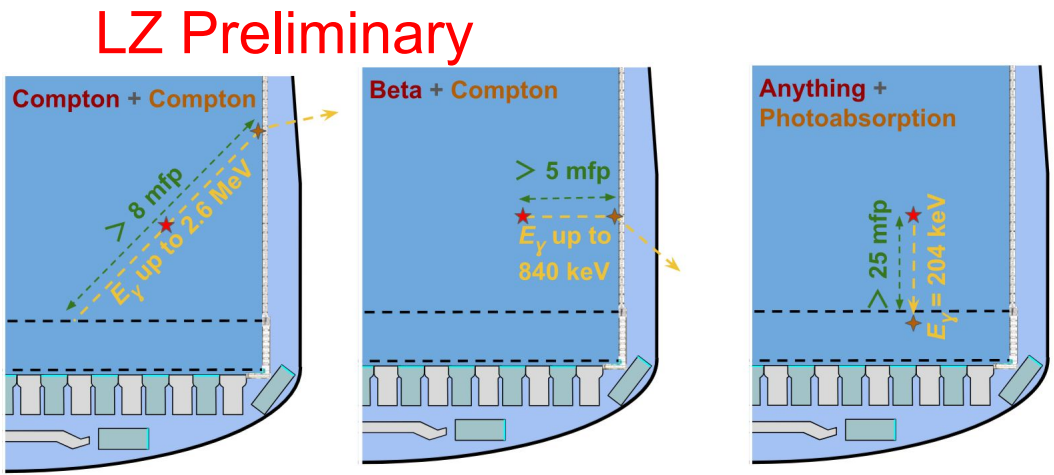
Science:
TPC events, where our signal would show up.

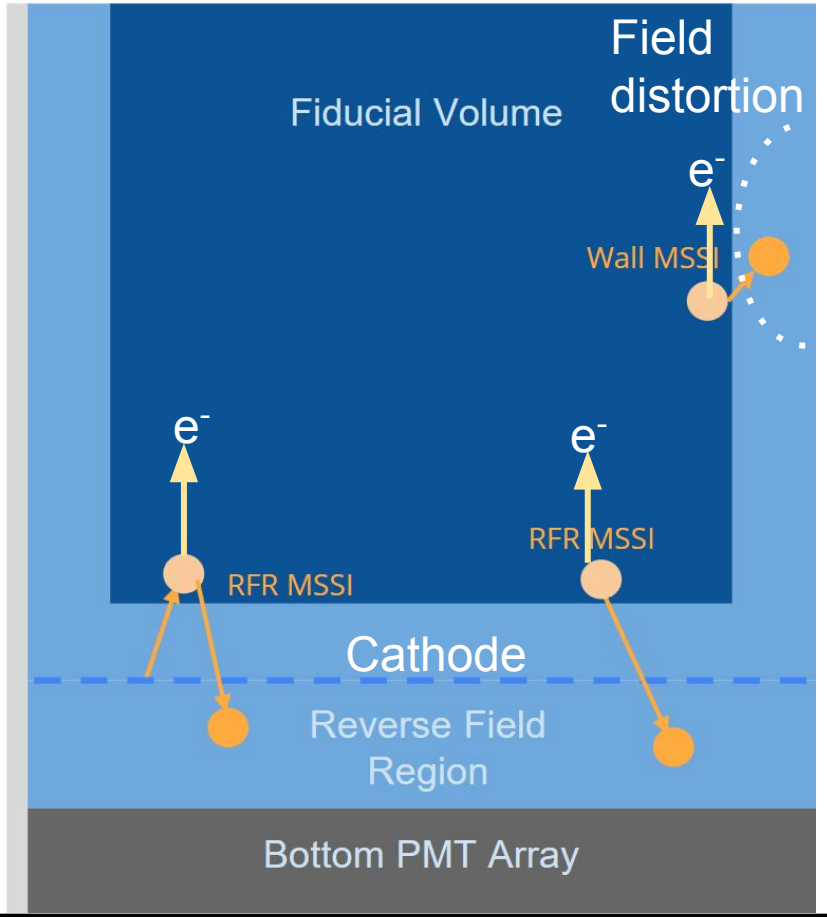
Delayed Coincidence:
Dominated by neutron background scatters in OD.

Prompt Coincidence:
Dominated by gammas in the skin.

What are MSSIs?

Multiple scatters appearing as single scatters because one scatter occurs in our **charge sensitive region** and the other(s) in a **charge insensitive region**



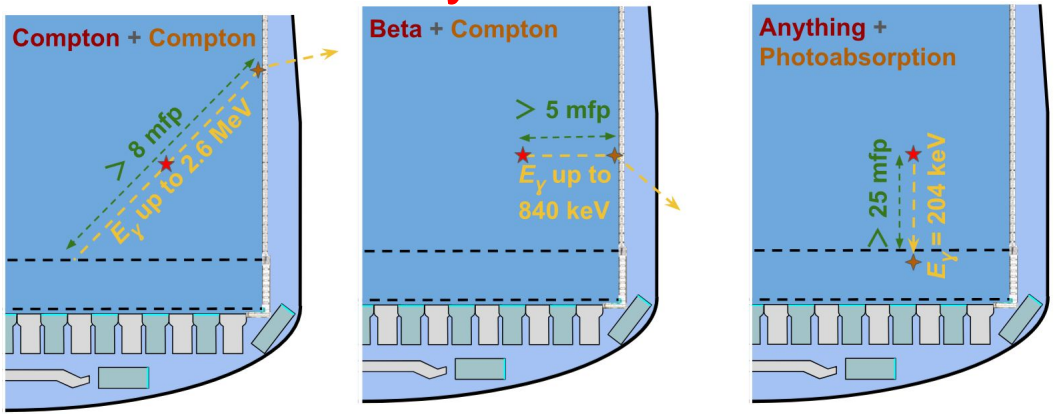


What are MSSIs?

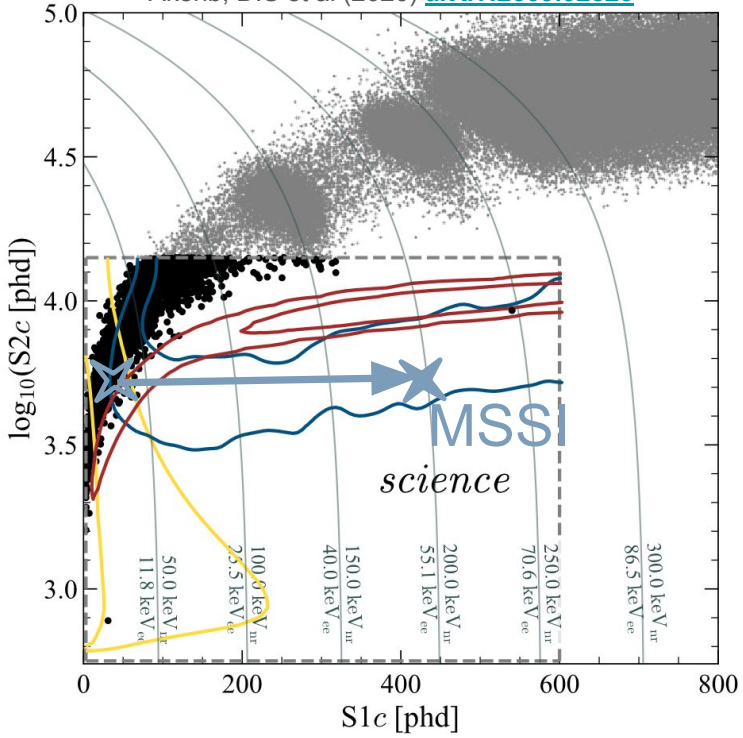
Gammas from detector components and Pb-214 semi-naked decays contribute to the MSSI events

For Pb-214, 89% of the time it leaves Bi-214 in an excited state, releasing a gamma mostly ~O(300)keV.

LZ Preliminary



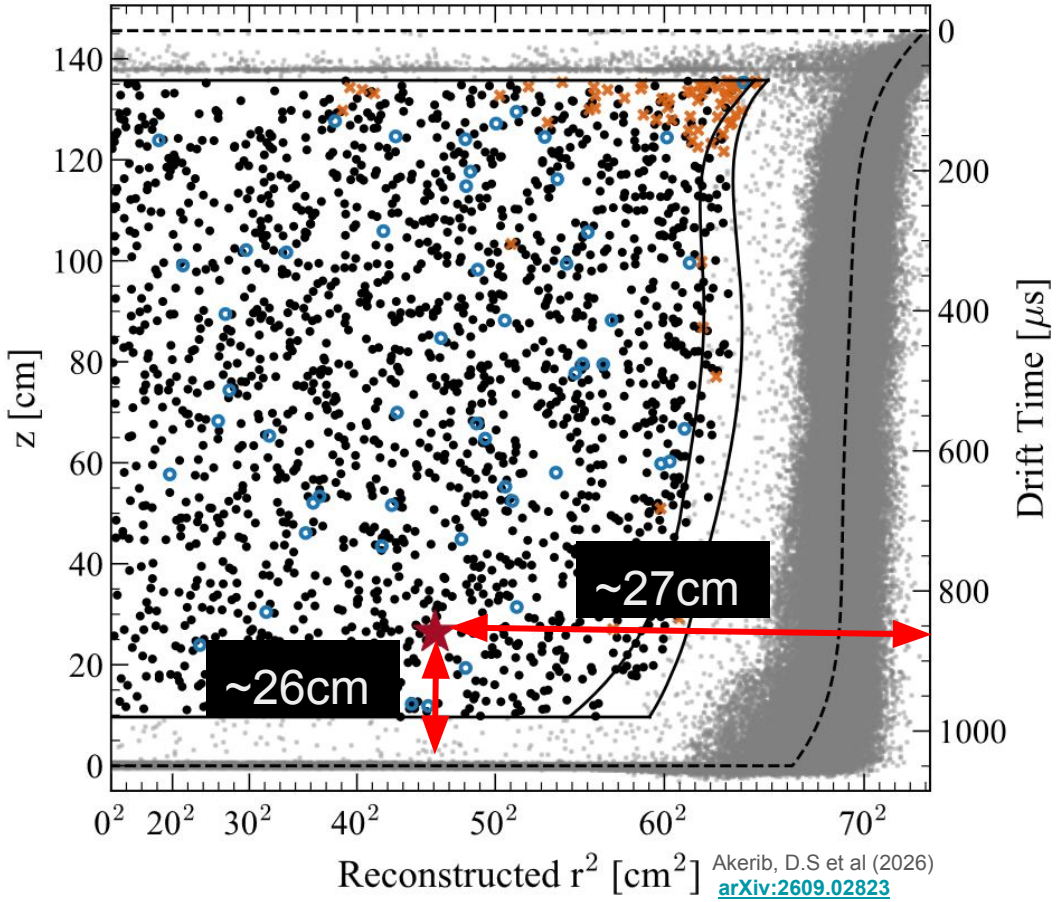
Akerib, D.S et al (2026) arXiv:2609.02823



Why we don’t think it’s MSSI?

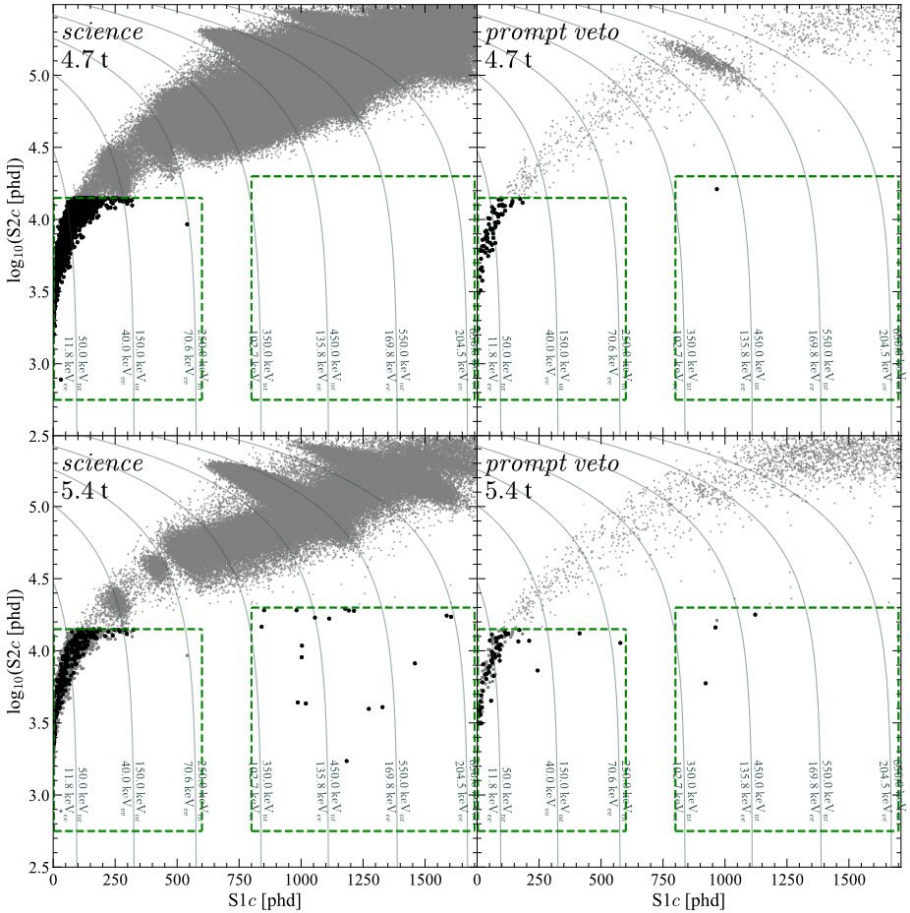
The MSSI rate is constrained by sideband data and simulations to predict (4.9×10^{-3}) events in the **ROI and FV**.

The required gamma paths are far too great for an event with an interaction site of this energy and position.



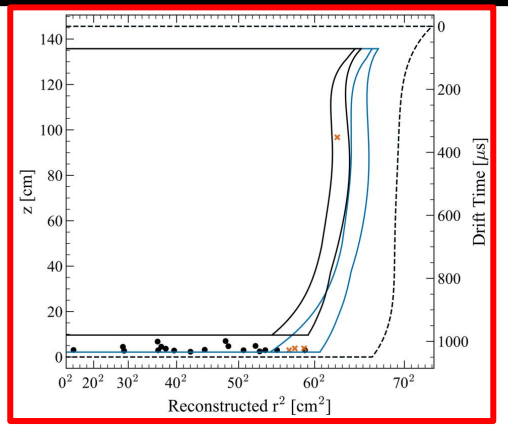
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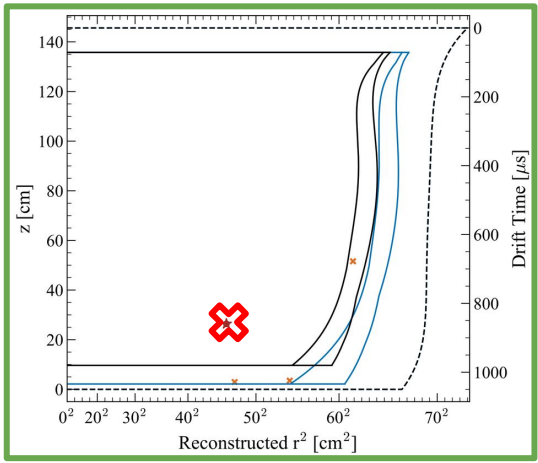
Constrained with data?



We can take a look at the MSSI model in sidebands in an extended volume, higher energy, and WS ROI.

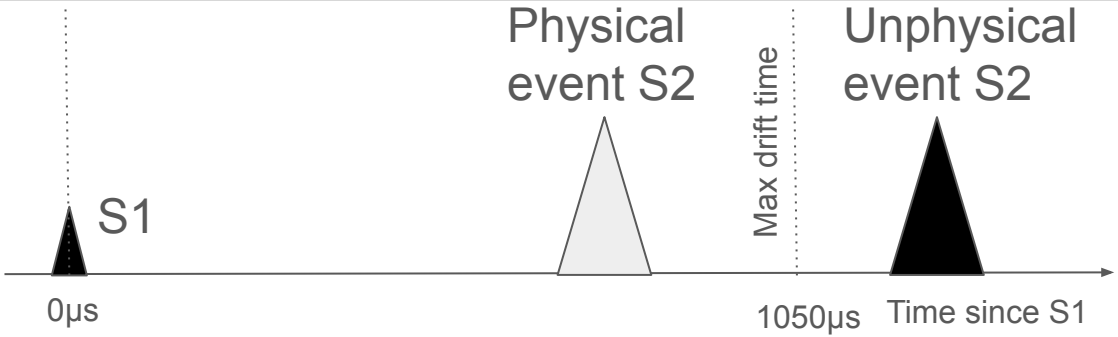
This is used to check the simulation derived rates and shape of the MSSI model.



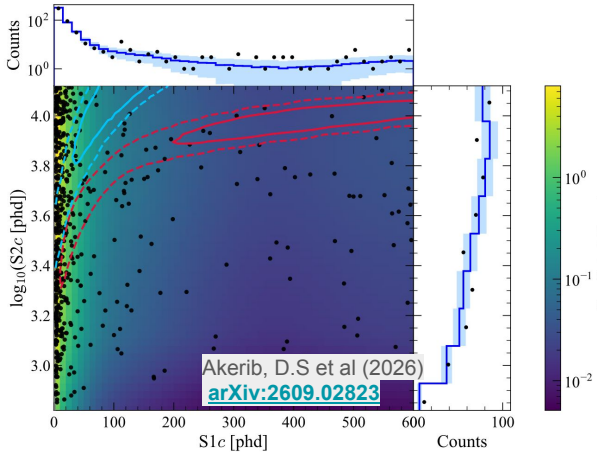


Akerib, D.S et al (2026)
arXiv:2609.02823

Accidental Coincidence Events



Minimal Cuts

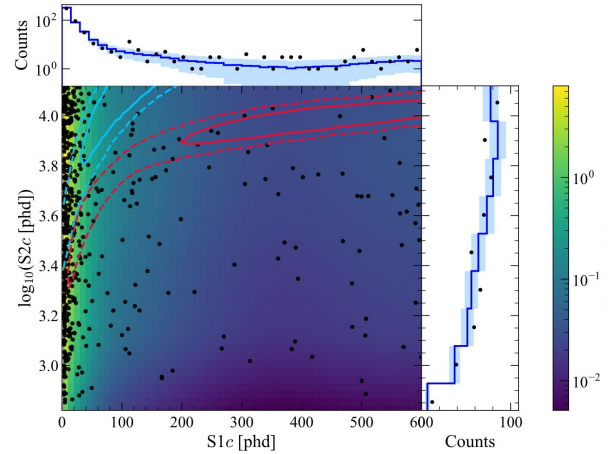


- By definition, events with a drift time greater than the **maximum** in the detector are **unphysical** random pairings.
- Verify our model by analysing these unphysical drift time events.
- Normalise the rate of the model at a point with minimal cuts, and also verify its shape.

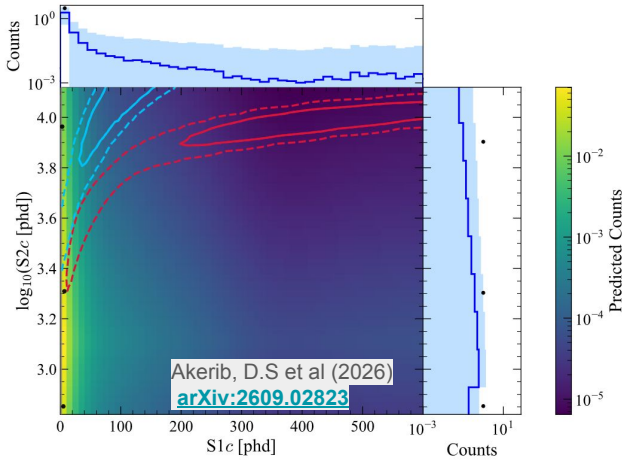
Accidental Coincidence Events

- Rate suppressed by a suite of environmental, S1 pulse shape, S2 pulse shape, and event level cuts to reject these events.
- Not a near miss: event of interest lies within the physical event populations in these cut spaces.
- Studied isolated S1 and S2 rates around the event and found no elevation in rates.

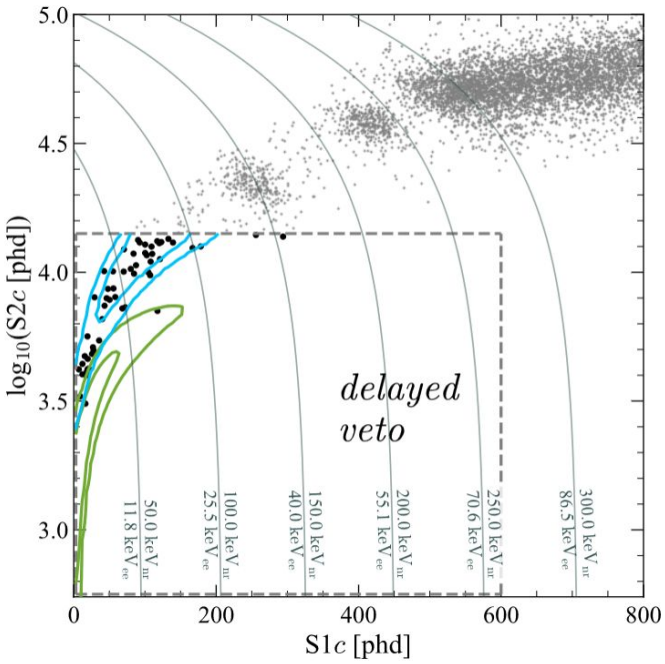
Minimal Cuts



Science Cuts



Neutrons



Akerib, D.S et al (2026) [arXiv:2609.02823]

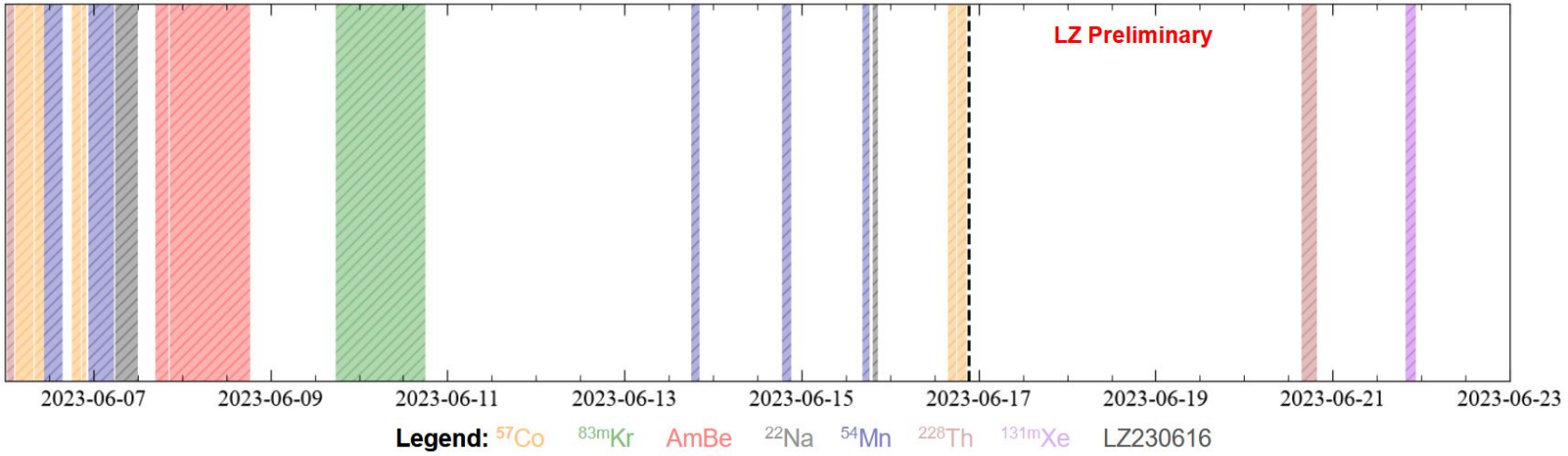
Neutrons can mimic standard WIMP events as they appear in the NR band, also similar spectrum.

To produce a 248 ± 23 (stat) ± 23 (sys) keV we need a neutron at **at least** 8 MeV.

This raises several issues:

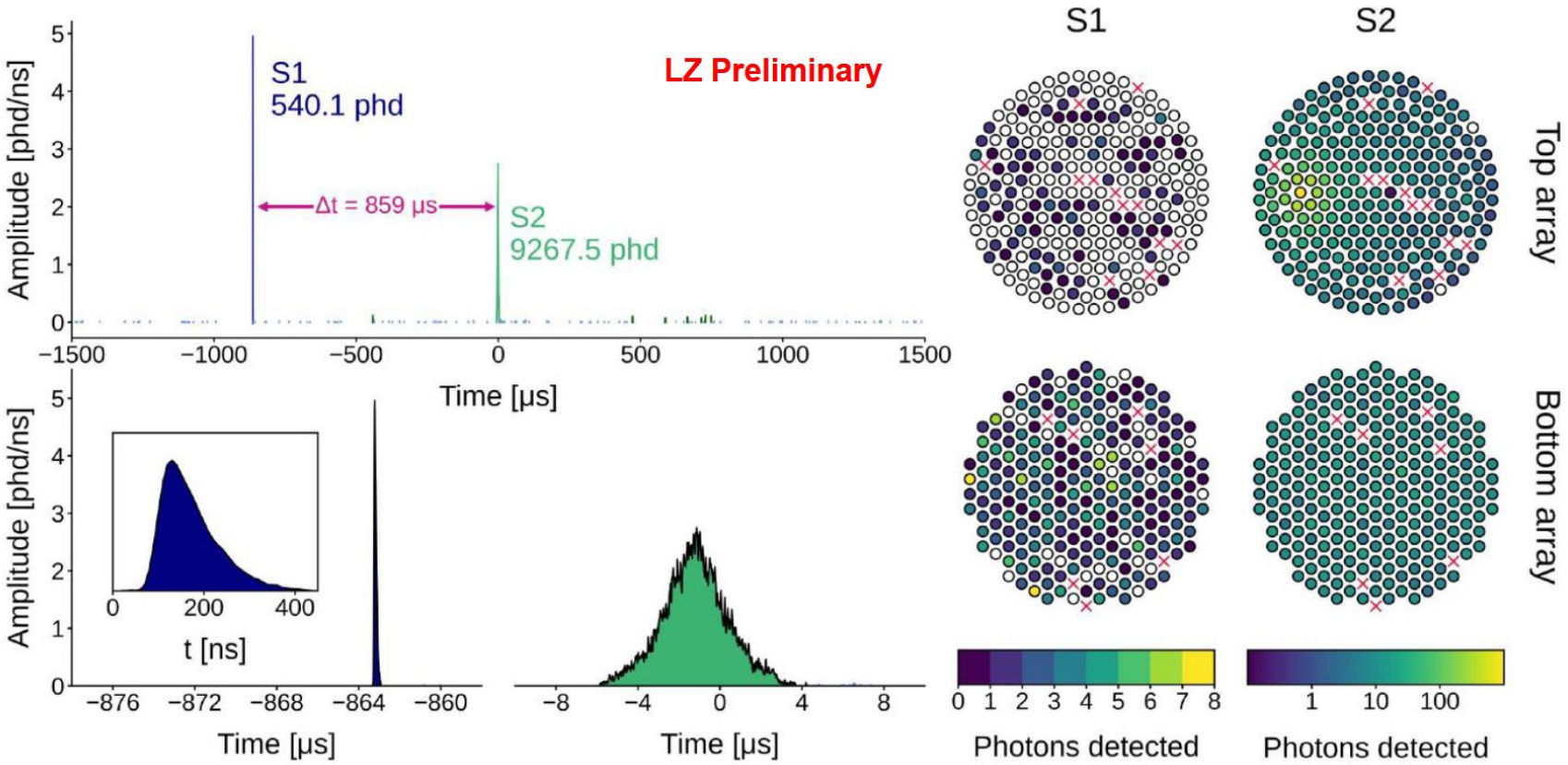
- All neutron models predicting higher energy single scatters predict an unseen larger population at lower energies.
- Neutron rate is constrained by veto with total ~90% efficiency
- For a high energy population would expect a large unseen multiple-scatter population. (not in PLR)

Environment



There were calibrations around our event but they were mostly ERs.
The Co-57 calibration is a low energy gamma calibration on the opposite side of the detector.

Waveform


LZ Preliminary
S1
540.1 phd
Δt = 859 μs
S2
9267.5 phd
Amplitude [phd/ns]
Time [μs]
t [ns]
S1
S2
Top array
Bottom array
Photons detected
Photons detected

Results

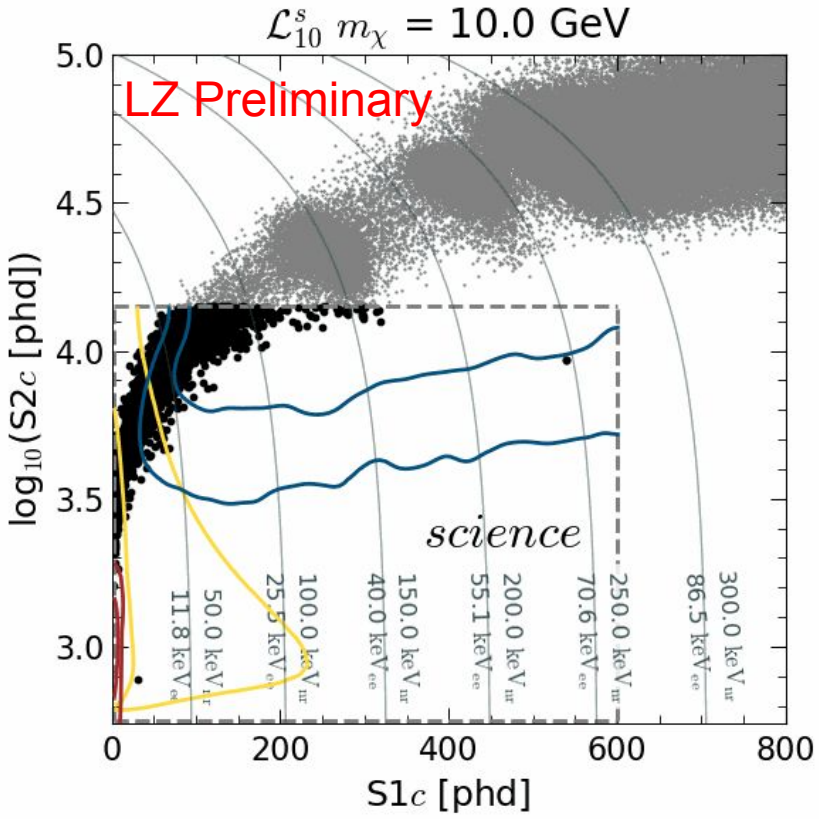
Signal? Look Elsewhere Effect

- Our “greatest significance” is **3.4 sigma**

- But we test many different models
  - Different operators/Lagrangians
  - Different mass splitting
  - Different WIMP masses

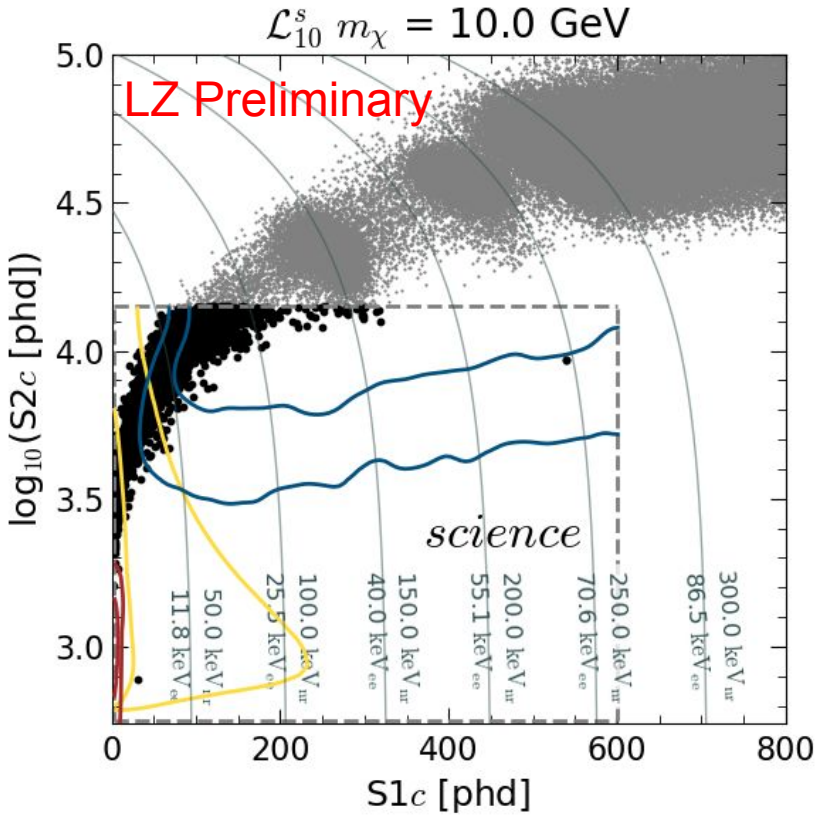
- These unique spectra probe different parts of our background model

- Increases the chance of any single test being significant.



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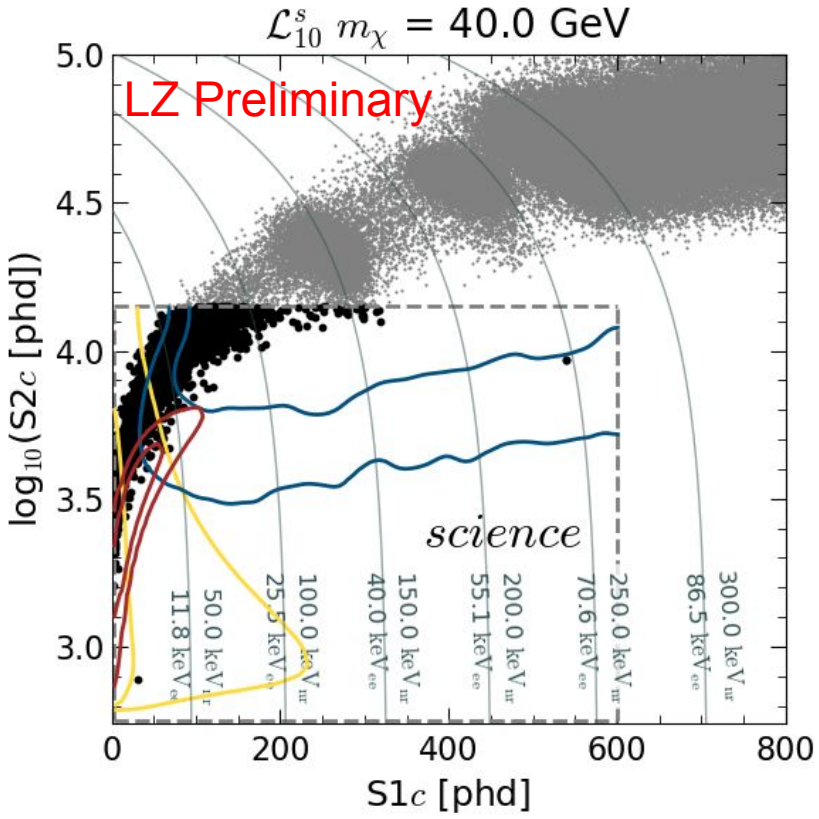
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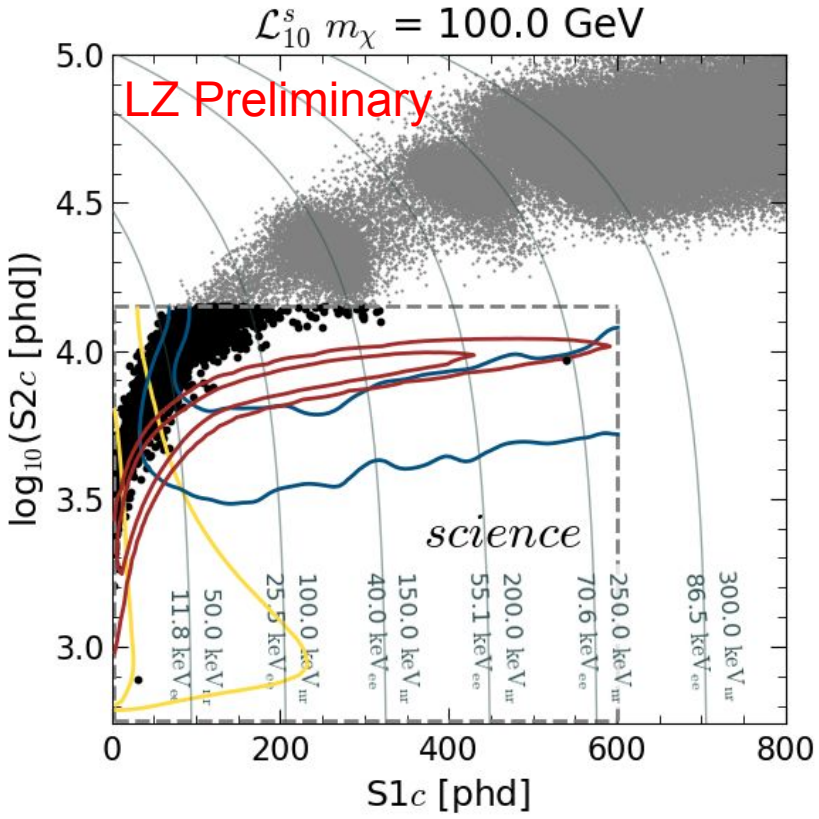
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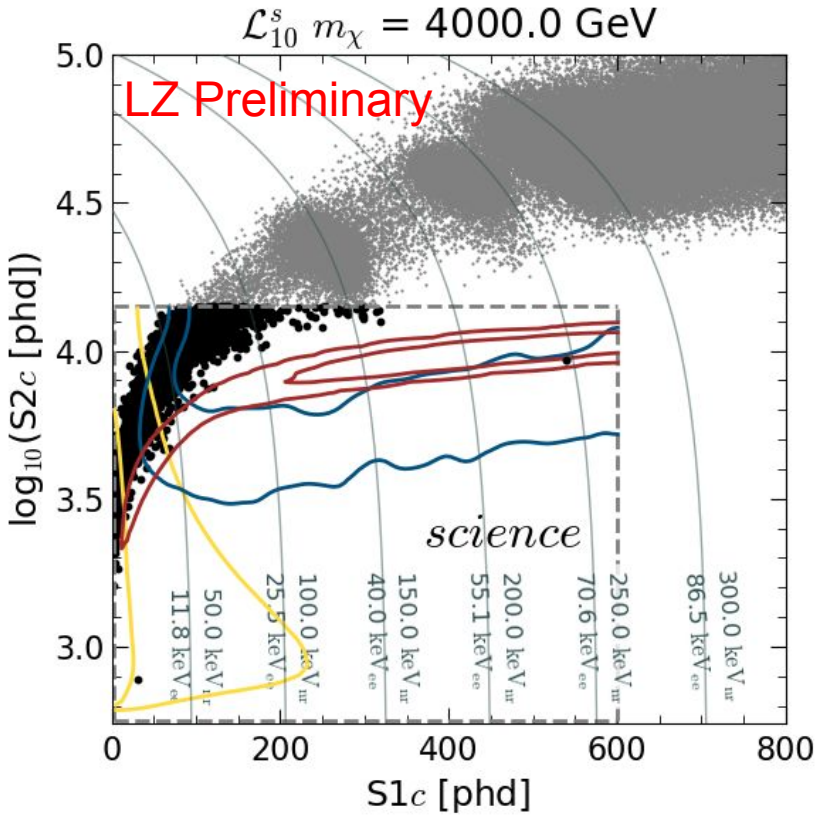
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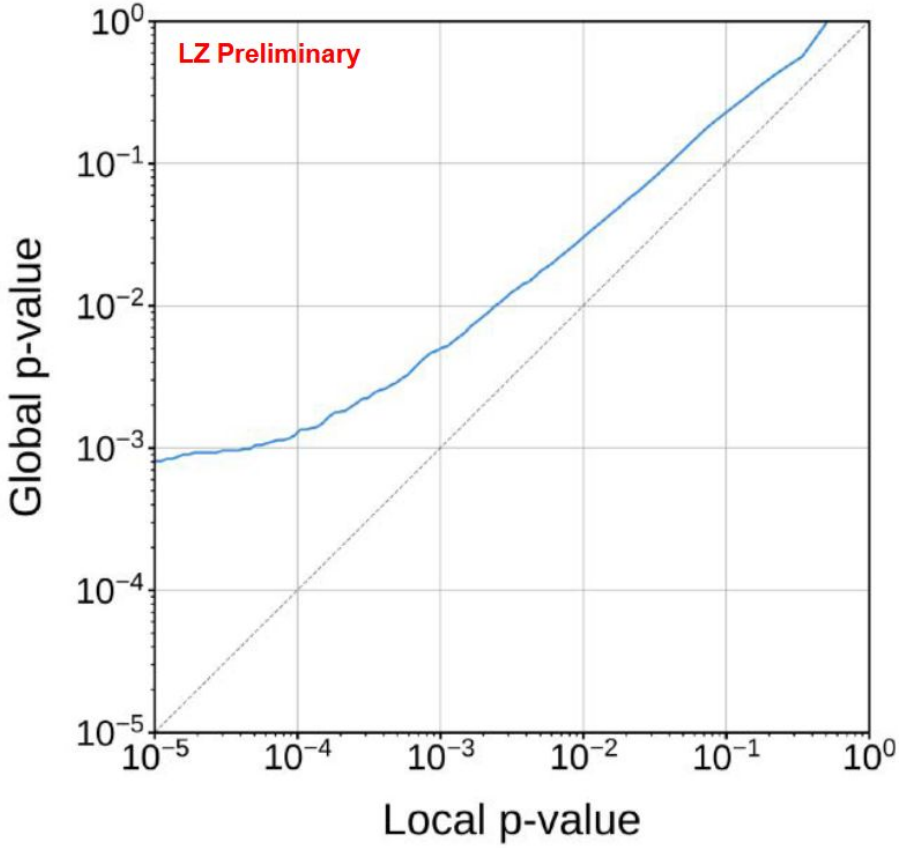
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Signal?

- The max significance of each Lagrangian/mass/splitting is a **local significance**
- Calculated global significance by simulating background-only toys & scanning all considered models.
- Store local significance for each
- This was evaluated non-asymptotically over 616 models to give **2.6 sigma global significance**.
- Is not evidence, **yet**. Let's say "hint".
  - Only 220 livedays out of 1000!



Other material

Sam Eriksen's TEvPA 2026 talk is a treasure trove of public information other than the paper.



Community Attention

In-elastic Higgsino:

Strong Constraints on Higgsino Dark Matter from Solar Capture

Maxim Pospelov, Harikrishnan Ramani arXiv:2609.02775

Confronting the Higgsino Interpretation of the LZ Event with the High-Energy Sideband

Nicholas L. Rodd, Benjamin R. Safdi, Tracy R. Slatyer, Weishuang Linda Xu arXiv:2609.04175

A lightest particle in SUSY, strongly constrained by our high energy data and neutrinos from annihilation of solar captured DM.

Inelastic type:

Inelastic Dark Matter and High-Energy Recoil Signatures in LZ

Zi-Tong Fan, Hong-Jian He, Yu-Chen Wang, Yue Zhao arXiv:2609.10491

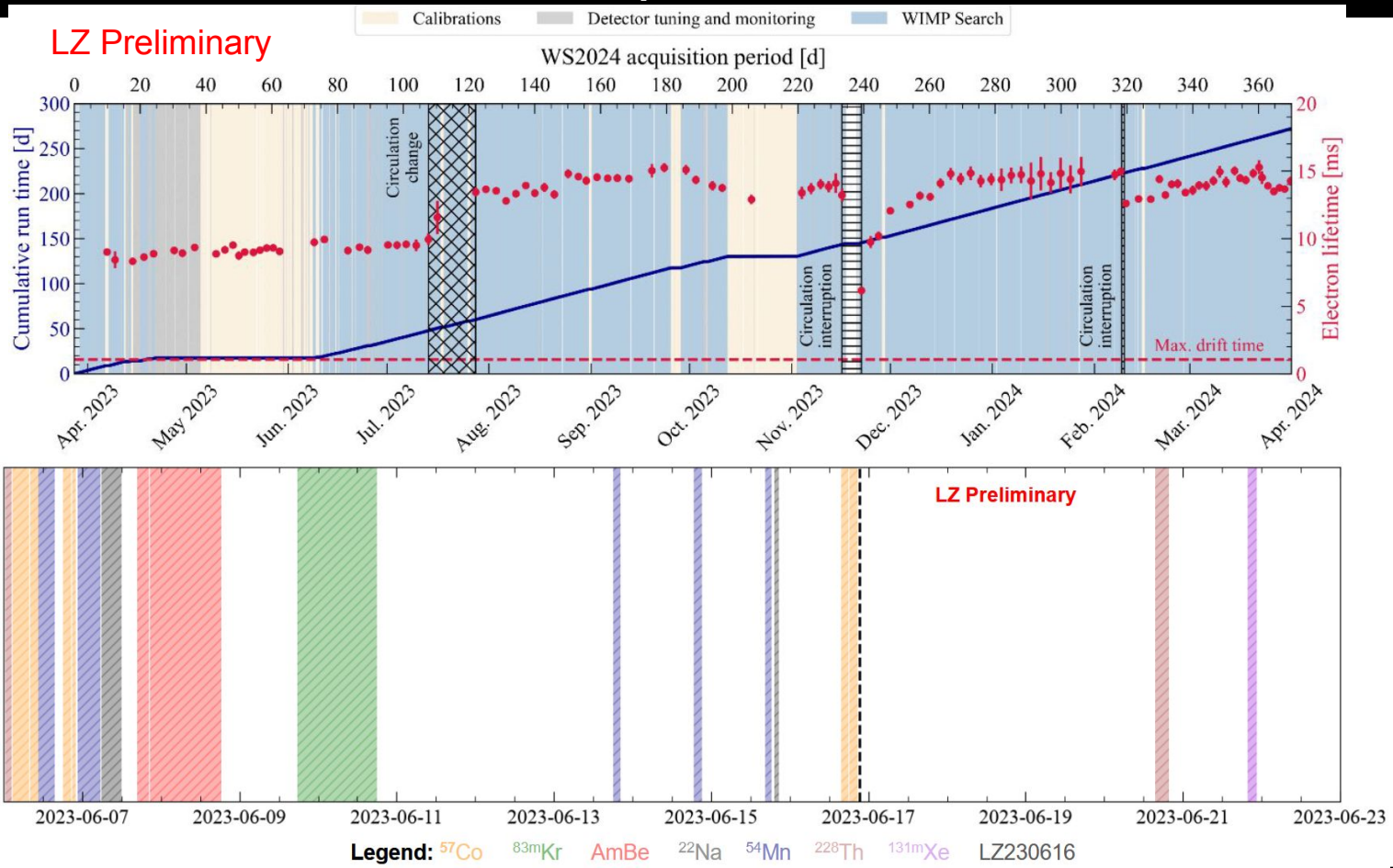
We typically consider “endothermic” inelastic dark matter where the DM is in the lighter state, this argues the heavier state could be stable and it is exothermic, relaxing constraints.

Others:

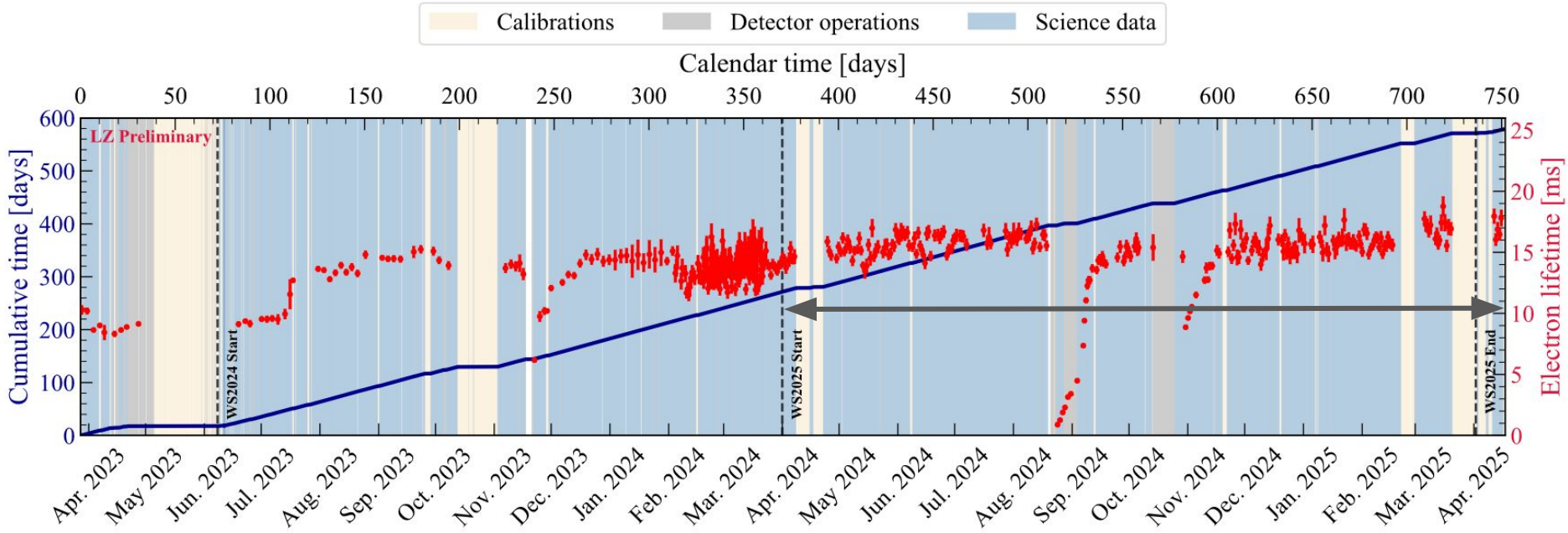
Neutron disappearance: To incur mono-energetic lines you incur n+χ -> ϕ (arXiv:2609.15933v1) or n+n ->/ϕ (arXiv:2609.12045v1)

Fin.

Exposure


LZ Preliminary
Calibrations
Detector tuning and monitoring
WIMP Search
WS2024 acquisition period [d]
Cumulative run time [d]
Electron lifetime [ms]
Circulation change
Circulation interruption
Circulation interruption
Max. drift time
Apr. 2023
May 2023
Jun. 2023
Jul. 2023
Aug. 2023
Sep. 2023
Oct. 2023
Nov. 2023
Dec. 2023
Jan. 2024
Feb. 2024
Mar. 2024
Apr. 2024
LZ Preliminary
2023-06-07
2023-06-09
2023-06-11
2023-06-13
2023-06-15
2023-06-17
2023-06-19
2023-06-21
2023-06-23
Legend: 57Co 83mKr AmBe 22Na 54Mn 228Th 131mXe LZ230616

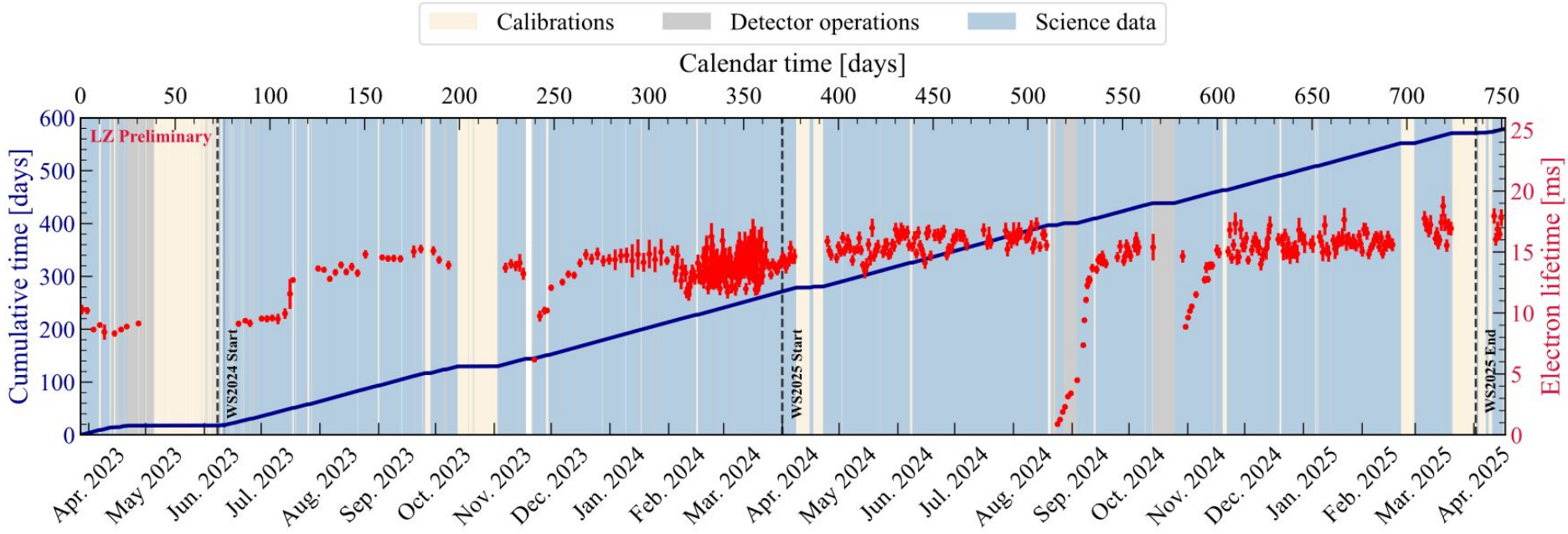
Any more Exposure?



https://iopscience.iop.org/article/10.1088/1475-7516/2013/02/004

j	$\mathcal{L}^j_{\rm int}$	$\Sigma_i c_i \mathcal{O}_i$
6	$\bar{\chi}\gamma^\mu\chi\bar{N}i\sigma_{\mu\alpha}(q^\alpha/m_M)N$	$(\vec{q}^2/2m_N m_M)\mathcal{O}_1 - 2(m_N/m_{\rm M})\mathcal{O}_3 + 2(m_N^2/m_M m_\chi)[(q^2/m_N^2)\mathcal{O}_4 - \mathcal{O}_6]$
9	$\bar{\chi}i\sigma^{\mu\nu}(q_\nu/m_M)\chi\bar{N}\gamma_\mu N$	$(\vec{q}^2/2m_\chi m_M)\mathcal{O}_1 + (2m_N/m_M)\mathcal{O}_5 - 2(m_N/m_M)[(\vec{q}^2/m_N^2)\mathcal{O}_4 - \mathcal{O}_6]$
10	$\bar{\chi}i\sigma^{\mu\nu}(q_\nu/m_M)\chi\bar{N}i\sigma_{\mu\alpha}(q^\alpha/m_M)N$	$4[(\vec{q}^2/m_M^2)\mathcal{O}_4 - (m_N^2/m_M^2)\mathcal{O}_6]$
12	$i\bar{\chi}i\sigma^{\mu\nu}(q_\nu/m_M)\chi\bar{N}i\sigma_{\mu\alpha}(q^\alpha/m_M)\gamma^5 N$	$-(m_N/m_\chi)(\vec{q}^2/m_{\rm M}^2)\mathcal{O}_{10} - 4(\vec{q}^2/m_{\rm M}^2)\mathcal{O}_{12} - 4(m_N^2/m_{\rm M}^2)\mathcal{O}_{15}$
18	$i\bar{\chi}i\sigma^{\mu\nu}(q_\nu/m_M)\gamma^5\chi N i\sigma_{\mu\alpha}(q^\alpha/m_M)N$	$(\vec{q}^2/m_{\rm M}^2)\mathcal{O}_{11} + 4(m_N^2/m_{\rm M}^2)\mathcal{O}_{15}$

$$\mathcal{O}_1 = \mathbf{1}$$
$$\mathcal{O}_3 = i\vec{S}_N \cdot (\vec{q} \times \vec{v})$$
$$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$$
$$\mathcal{O}_5 = i\vec{S}_\chi \cdot (\vec{q} \times \vec{v})$$
$$\mathcal{O}_6 = (\vec{S}_\chi \cdot \vec{q})(\vec{S}_N \cdot \vec{q})$$
$$\mathcal{O}_7 = \vec{S}_N \cdot \vec{v}^\perp$$
$$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}^\perp$$
$$\mathcal{O}_9 = i\vec{S}_\chi \cdot (\vec{S}_N \times \vec{q})$$
$$\mathcal{O}_{10} = i\vec{S}_N \cdot \vec{q}$$
$$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \vec{q}$$


Calibrations
Detector operations
Science data
Calendar time [days]
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
LZ Preliminary
WS2024 Start
WS2025 Start
WS2025 End
Cumulative time [days]
600
500
400
300
200
100
0
Electron lifetime [ms]
25
20
15
10
5
0
Apr. 2023
May 2023
Jun. 2023
Jul. 2023
Aug. 2023
Sep. 2023
Oct. 2023
Nov. 2023
Dec. 2023
Jan. 2024
Feb. 2024
Mar. 2024
Apr. 2024
May 2024
Jun. 2024
Jul. 2024
Aug. 2024
Sep. 2024
Oct. 2024
Nov. 2024
Dec. 2024
Jan. 2025
Feb. 2025
Mar. 2025
Apr. 2025

Signal? Look Elsewhere Effect (**alt**)

- Our “greatest significance” is **3.4 sigma**

- But we test many different models
  - Different operators/Lagrangians
  - Different mass splitting
  - Different WIMP masses

- These unique spectra probe different parts of our background model

- Increases the chance of any single test being significant.

