Status of the LUX-ZEPLIN (LZ) Experiment

TAUP 2023

Vienna, Austria

Billy Boxer (UC Davis)

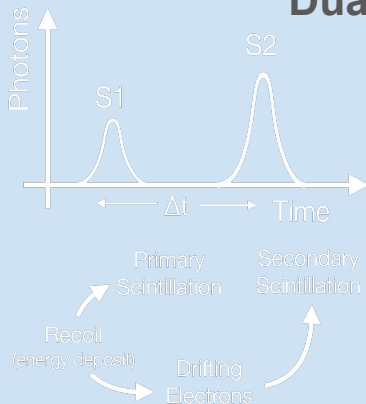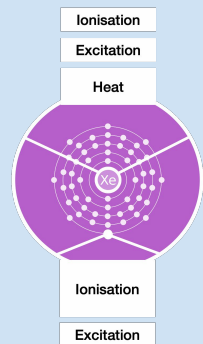**bboxer@ucdavis.edu**

On behalf of the LZ Collaboration
28th August 2023

LZ Overview

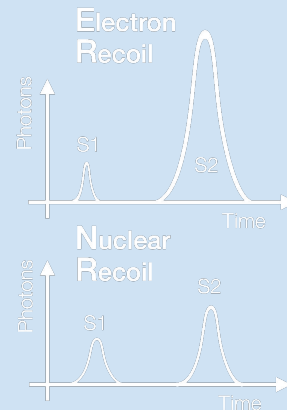## Dual Phase Time Projection Chamber (TPC)

Primary scintillation (light) -> S1

Secondary scintillation (induced from free charge) -> S2

3D reconstruction using S2 top PMT array hit pattern (X,Y) and from drift time (Z) -> allows for fiducilisation

ER/NR discrimination via S2/S1 ratio

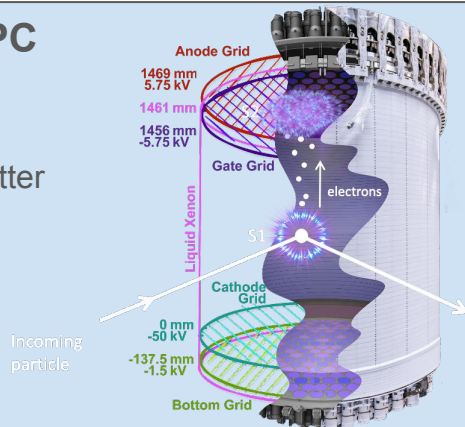## The LZ Liquid Xenon (LXe) TPC

Primary goal:
- Direct detection for WIMP dark matter via low energy nuclear recoils
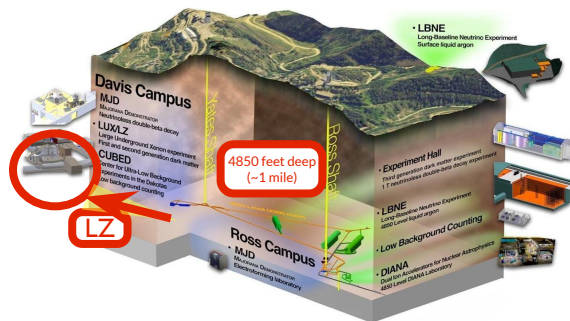
Requirements:
- Large target mass
- Low energy threshold

- 1.5 m diameter x 1.5 m height
- 7 tonne of active liquid xenon
- 494, 3" PMTs split between top and bottom array
- 4-high voltage wire mesh electrodes:
    - Drift field
    - Extraction region
- PTFE Field cage
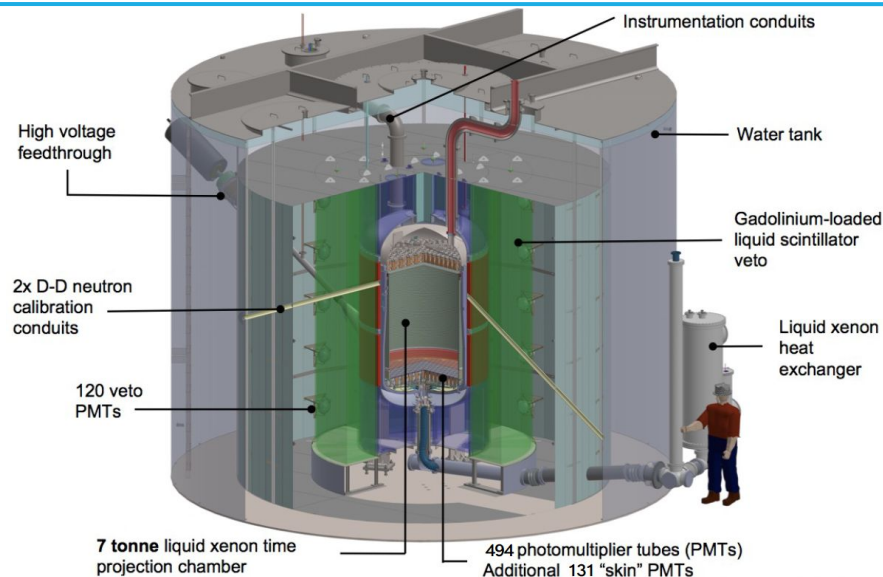- PTFE coverage for increased light collection

The LZ Detector

LZ is located in the Davis cavern at Sanford Underground Research Facility (SURF) in Lead, South Dakota

~1 mile underground -> muon flux reduced by $O(10^6)$, resulting in radiogenic backgrounds being the dominant contributor to the background

Skin: Primarily a gamma-ray veto
- 2 t of LXe surrounding TPC instrumented with 131 1" & 2" PMTs

Outer Detector: Primarily a neutron veto
- 17 t Gd loaded liquid scintillator outfitted in 120 t water, read out by 120 8" PMTs
- Neutron tagging efficiency: 89%

First Science Run

**Stable detector conditions**
- Drift field: 193 V/cm
- Extraction field: 7.3 kV/cm in gas
- > 97 % of PMTs operational
- Liquid temperature (174.1 K)
- Gas Pressure (1.791 bar)
- Liquid level stable within 10 microns
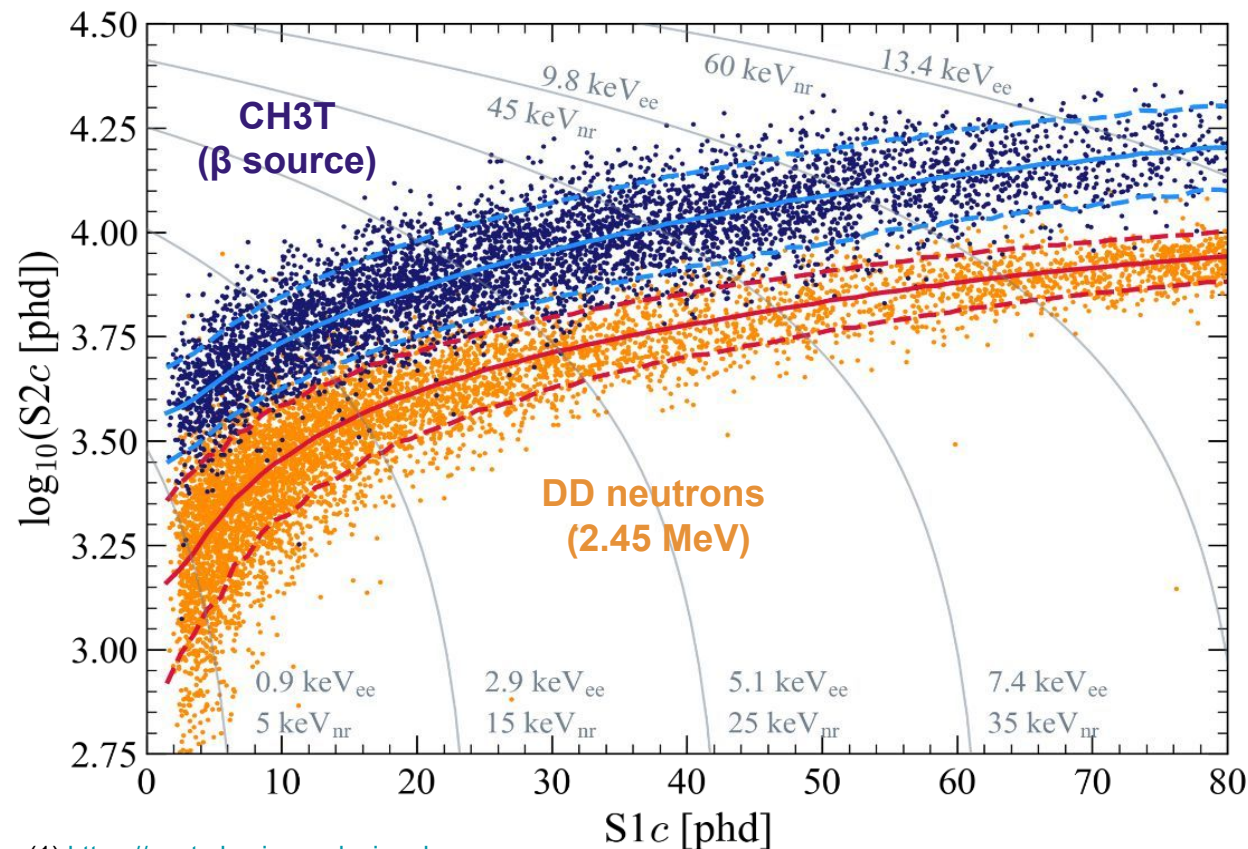
Continuous purification of Xe
- 3.3 t/day through hot getter

Electron lifetime: 5 - 8 ms

Bias mitigation: cuts developed on calibration data and assessed on background side bands + vetoes'

116 calendar days -> 60 live days
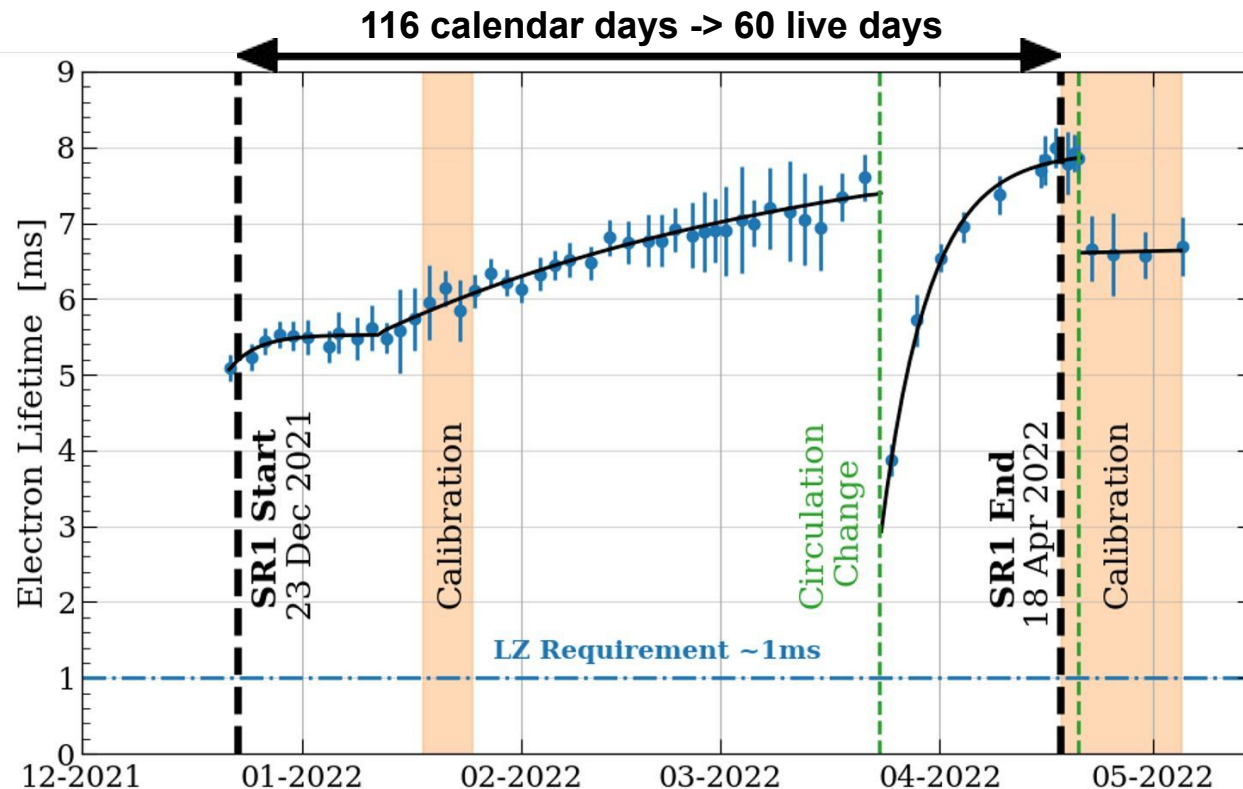
First Science Run: TPC Calibrations

Photon detection efficiency:
    g1 = 0.114 ± 0.002 phd/photon

Charge gain:
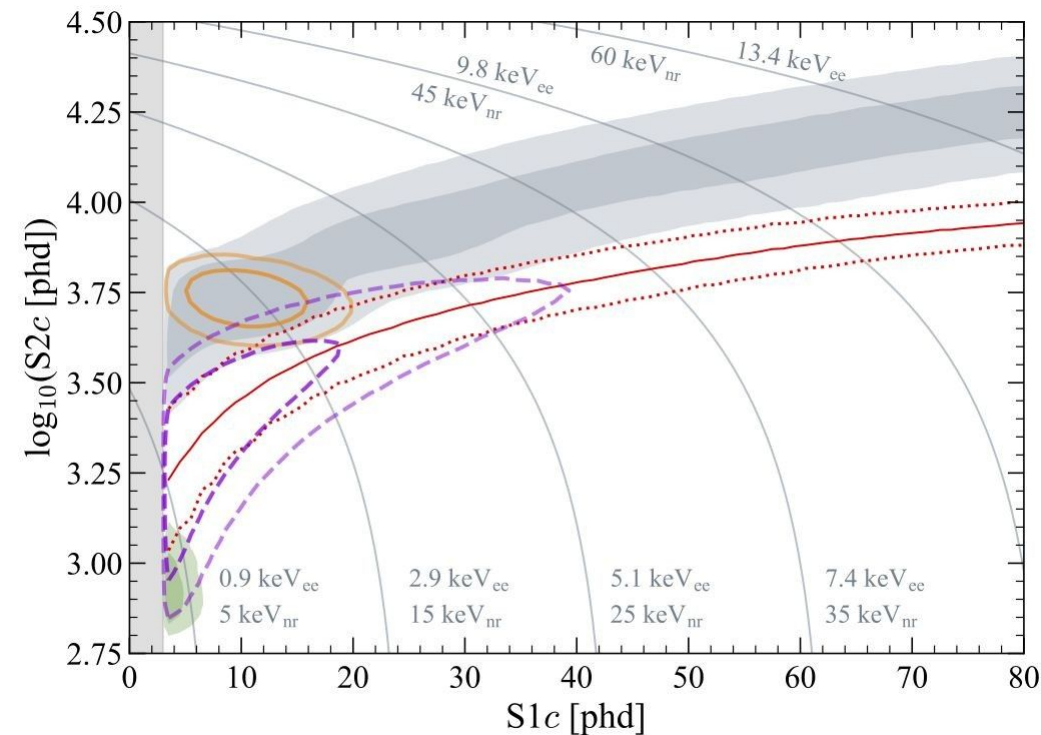   g2 = 47.1 ± 1.1 phd/electron

Band fits performed with NEST v2.3.71

99.9% discrimination of beta backgrounds under NR band median achieved

(1) https://nest.physics.ucdavis.edu

First Science Run: Backgrounds

Source	Expected Events
β decays + det ER	218 ± 36
ν ER	27.3 ± 1.6
^{127}Xe	9.2 ± 0.8
^{124}Xe	5.0 ± 1.4
^{136}Xe	15.2 ± 2.4
^{8}B CEνNS	0.15 ± 0.01
Accidentals	1.2 ± 0.3
Subtotal	276 ± 36
^{37}Ar	$[0, 291]$
Detector neutrons	$0.0^{+0.2}$
$30\,\text{GeV}/c^2$ WIMP	–
Total	–

Backgrounds are modelled using energy deposit + detector response simulations[1]

(1) https://doi.org/10.1016/j.astropartphys.2020.102480

First Science Run: Data Selection Cuts
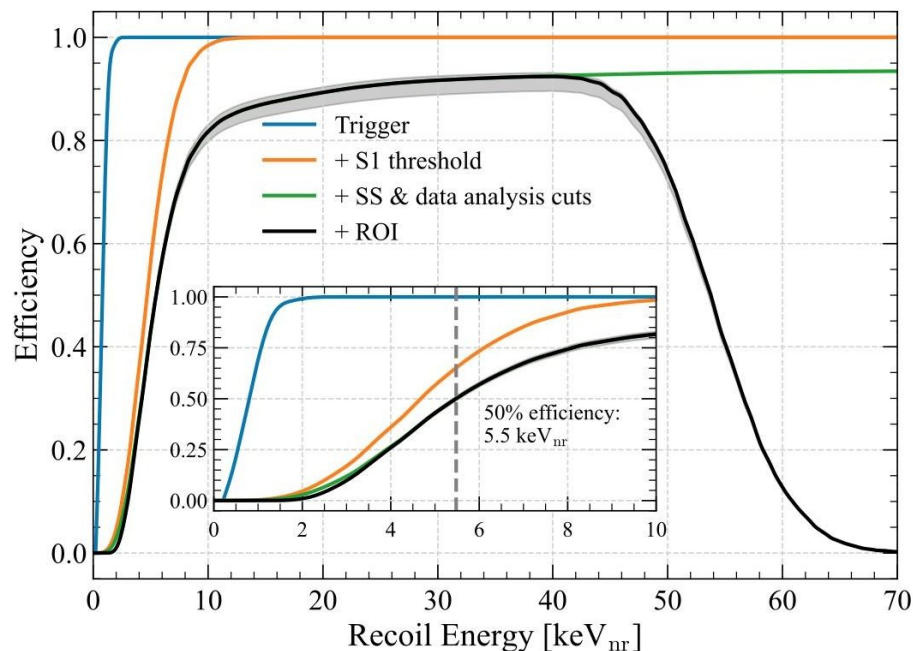
Cuts developed using calibration data and sideband regions outside the WIMP ROI
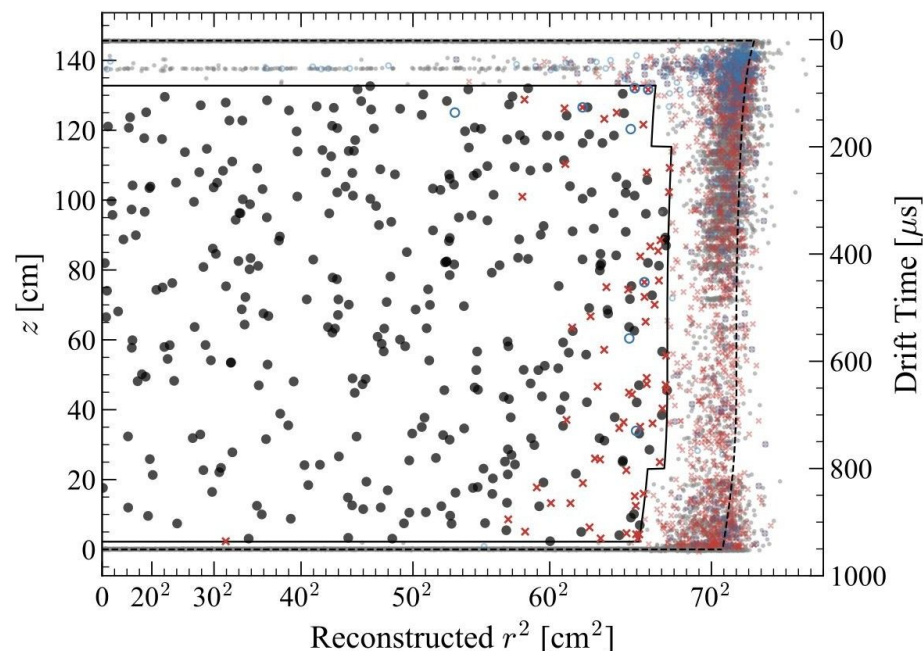
⬤ events passing all cuts

⬤ events outside of fiducial volume

✖ events vetoed by skin (mostly ^{127}Xe)

◯ events vetoed by OD
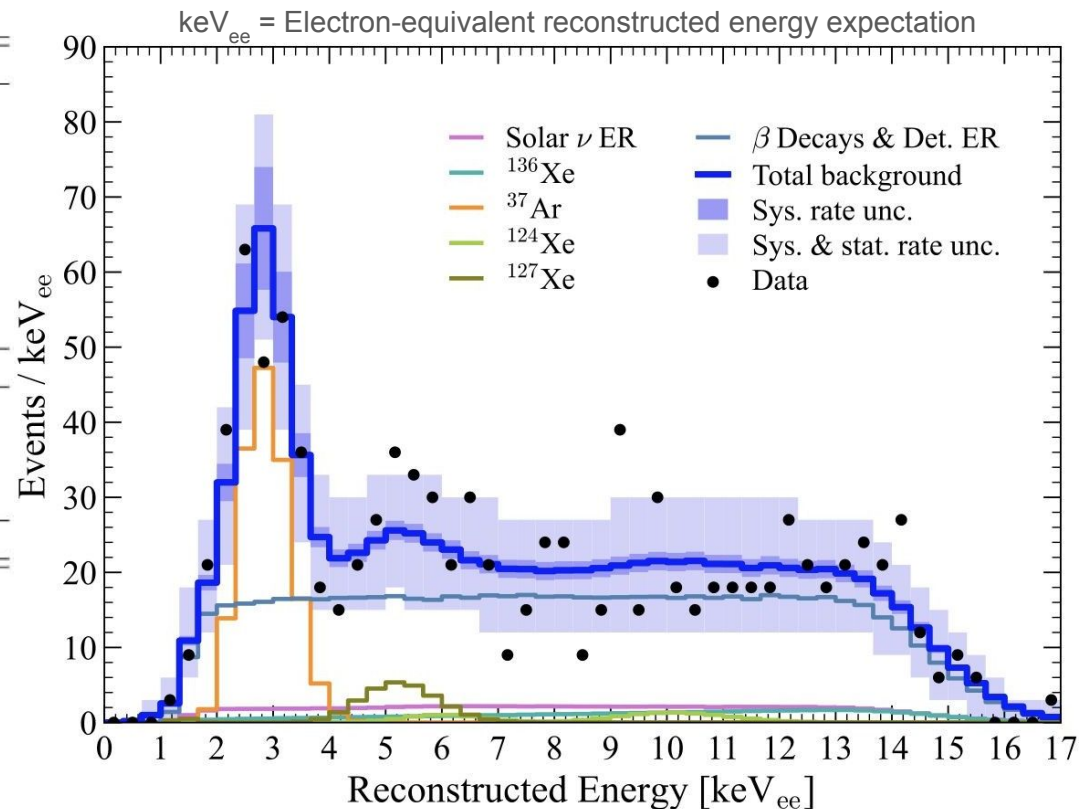
First Science Run: Final Data Set
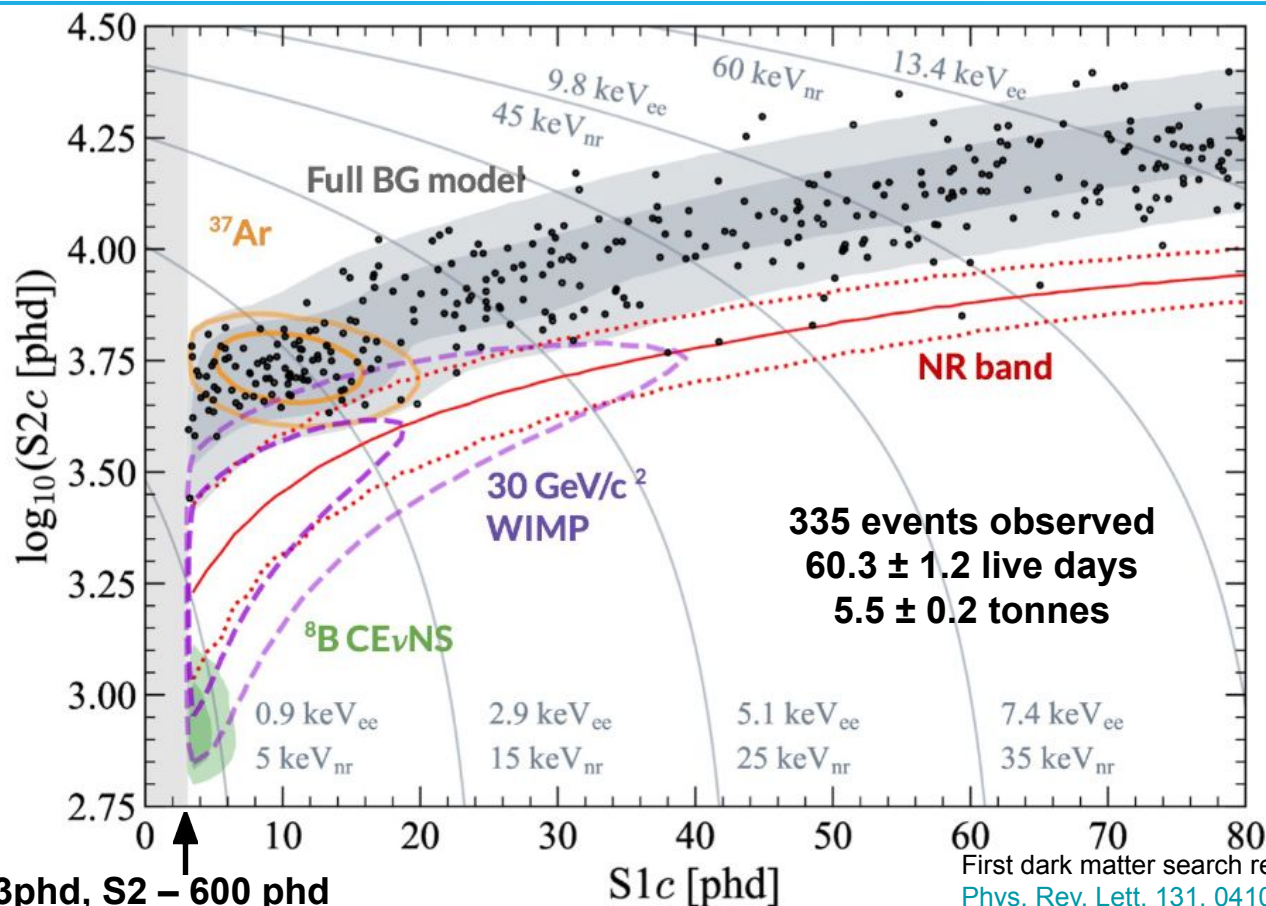
335 events observed
60.3 ± 1.2 live days
5.5 ± 0.2 tonnes

Threshold: S1 – 3phd, S2 – 600 phd

First dark matter search result from the LZ Experiment
Phys. Rev. Lett. 131, 041002 (2023)

First Science Run: PLR Fits

Source	Expected Events	Fit Result
β decays + Det. ER	215 ± 36	222 ± 16
ν ER	27.1 ± 1.6	27.2 ± 1.6
^{127}Xe	9.2 ± 0.8	9.3 ± 0.8
^{124}Xe	5.0 ± 1.4	5.2 ± 1.4
^{136}Xe	15.1 ± 2.4	15.2 ± 2.4
^{8}B CEνNS	0.14 ± 0.01	0.15 ± 0.01
Accidentals	1.2 ± 0.3	1.2 ± 0.3
Subtotal	273 ± 36	280 ± 16
^{37}Ar	$[0, 288]$	$52.5^{+9.6}_{-8.9}$
Detector neutrons	$0.0^{+0.2}$	$0.0^{+0.2}$
30 GeV/c^2 WIMP	$-$	$0.0^{+0.6}$
Total	$-$	333 ± 17

Backgrounds within expectations

~25 counts/keV$_{ee}$/tonne/year

keV$_{ee}$ = Electron-equivalent reconstructed energy expectation

Legend: Solar ν ER, ^{136}Xe, ^{37}Ar, ^{124}Xe, ^{127}Xe, β Decays & Det. ER, Total background, Sys. rate unc., Sys. & stat. rate unc., Data

Background Determination for the LUX-ZEPLIN (LZ) Dark Matter Experiment Phys. Rev. D 108, 012010 (2023)

First Science Run: WIMP Search (Spin-Independent)

Consistent with background-only hypothesis

Two-sided PLR EPJC 81, 907 (2021)

Power constraint (-1σ)

G. Cowan et al. arxiv/1105.3166

First dark matter search result from the LZ Experiment
Phys. Rev. Lett. 131, 041002 (2023)
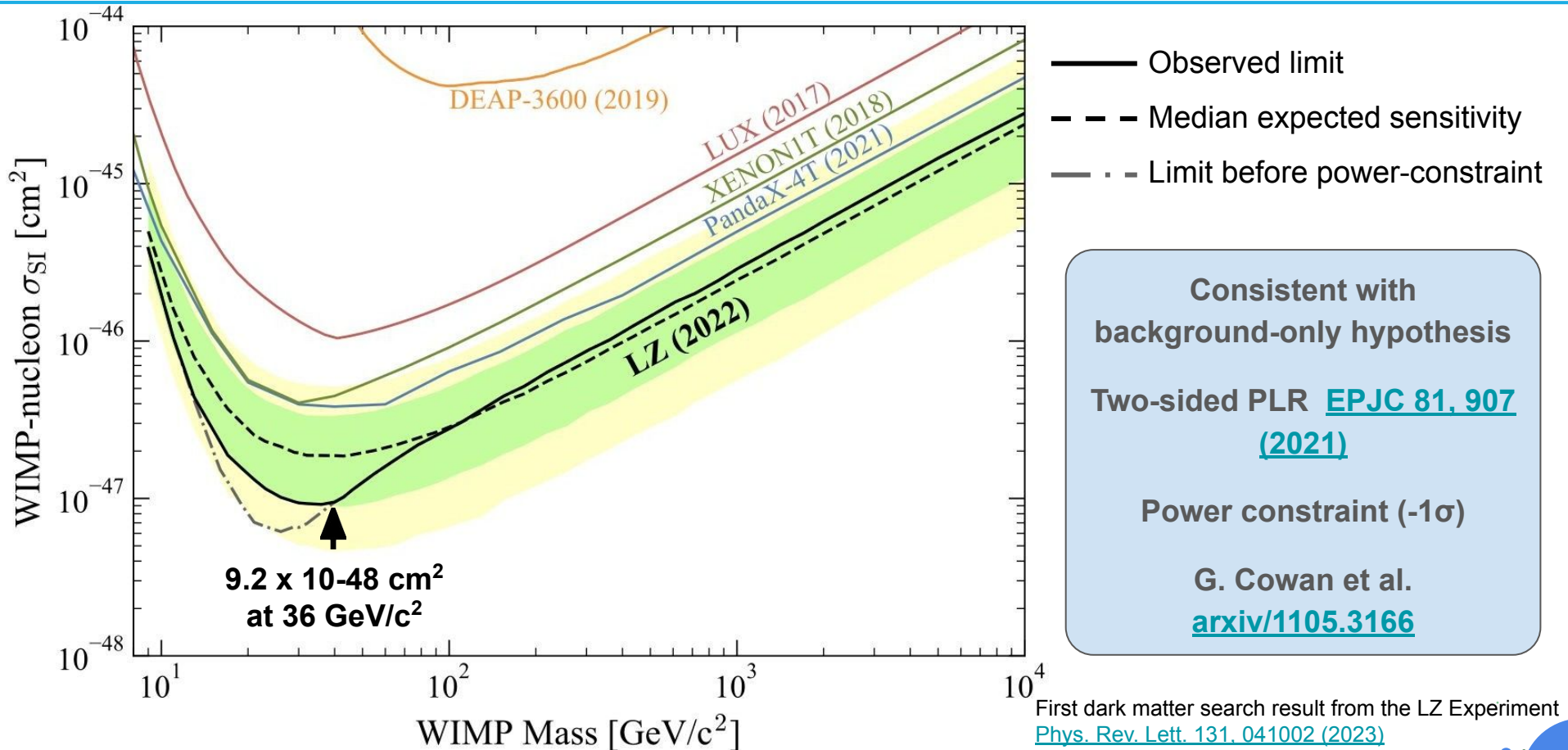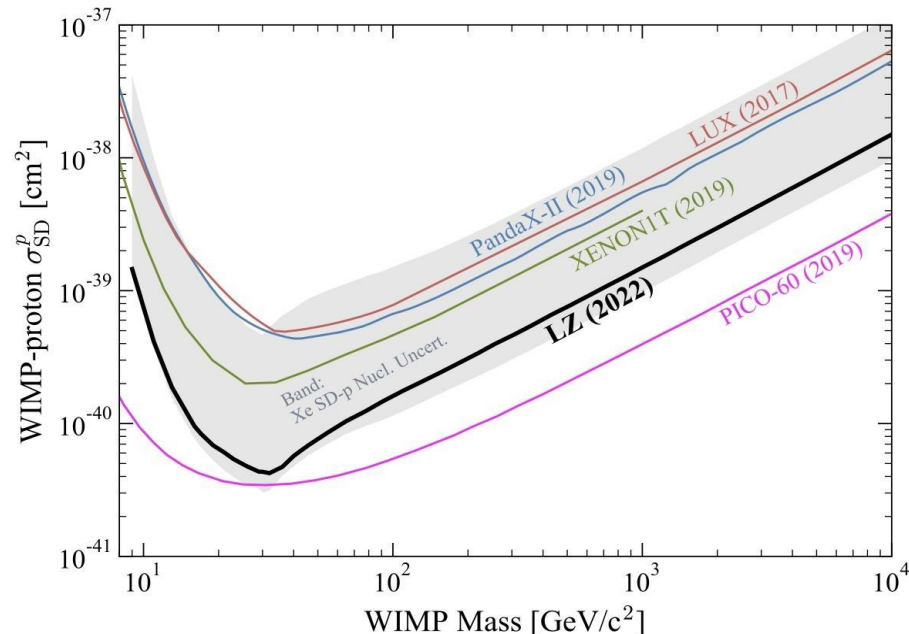
First Science Run: WIMP Search (Spin-Dependent)

Spin-dependent WIMP-neutron scattering
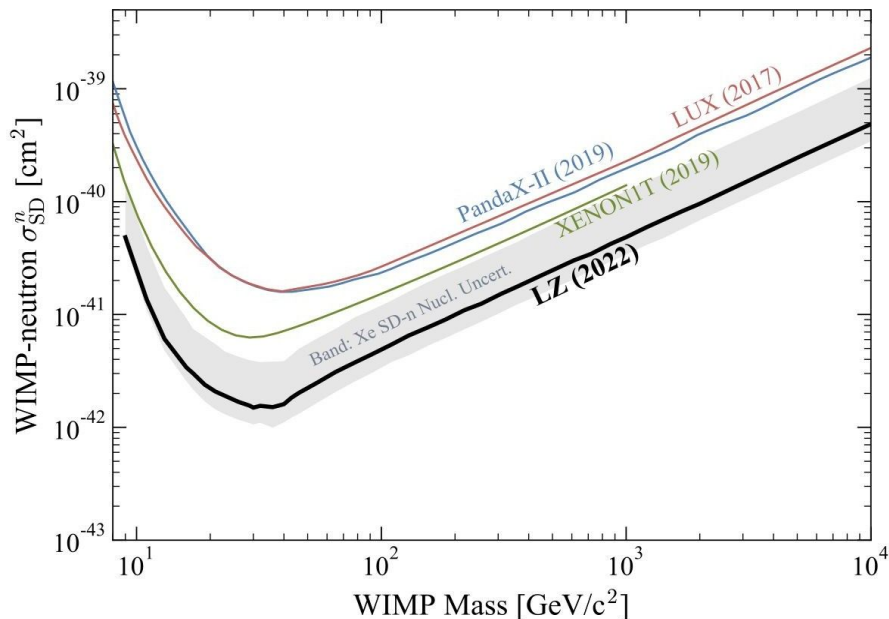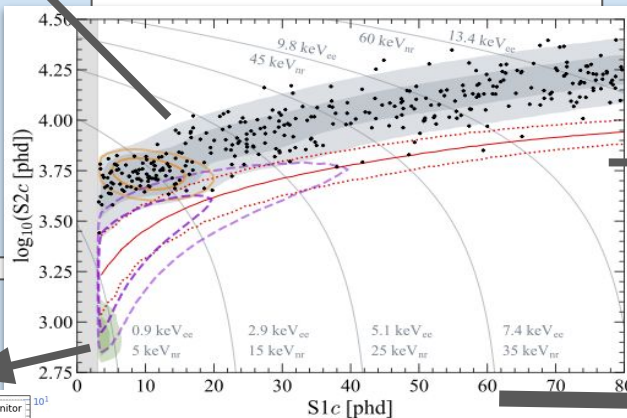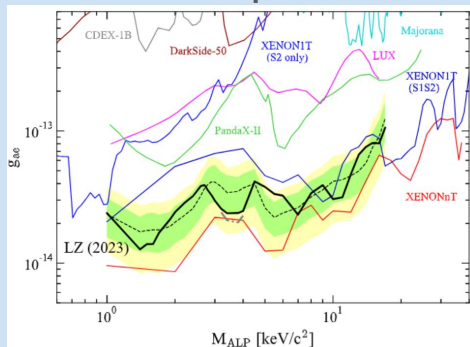
Spin-dependent WIMP-proton scattering

Grey uncertainty band represents uncertainty on Xe form factor[1]

(1) P. Klos, J. Menéndez, D. Gazit, and A. Schwenk Phys. Rev. D 88, 083516 (2013)
First dark matter search result from the LZ Experiment Phys. Rev. Lett. 131, 041002 (2023)

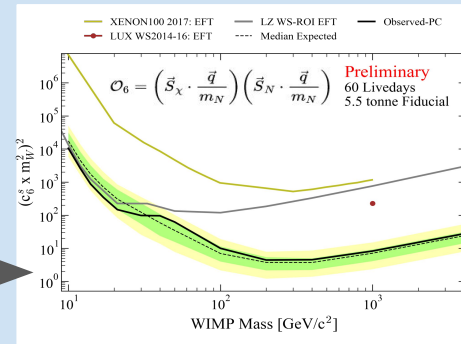# Beyond The WIMP-Search

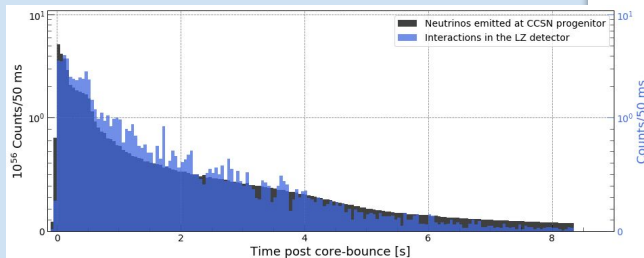**ER band searches: mirror dark matter, ALPs, hidden photons**

https://arxiv.org/pdf/2307.15753.pdf

High energy (<400 keV) nuclear recoil EFT

$$\mathcal{O}_6 = \left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N} \right) \left(\vec{S}_N \cdot \frac{\vec{q}}{m_N} \right)$$

Preliminary
60 Livedays
5.5 tonne Fiducial

^{8}B CEvNS and SN neutrinos
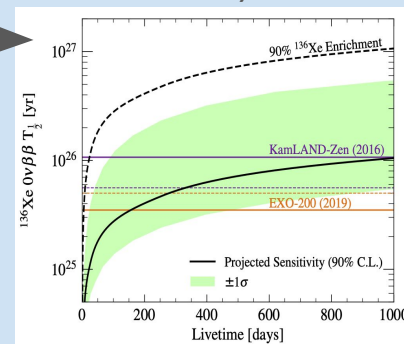
Other Searches:

LZ S2-only and Migdal sensitivity:
https://arxiv.org/abs/2101.08753 (2021)

0νββ (2.45 MeV/0.83 MeV) and 2νDEC (2.86 MeV)

Phys.Rev.C 102 (2020) 1, 014602

Outlook For LZ

There's much more data to come! Planning for a total 1000 live days (x 17 more exposure than SR1)
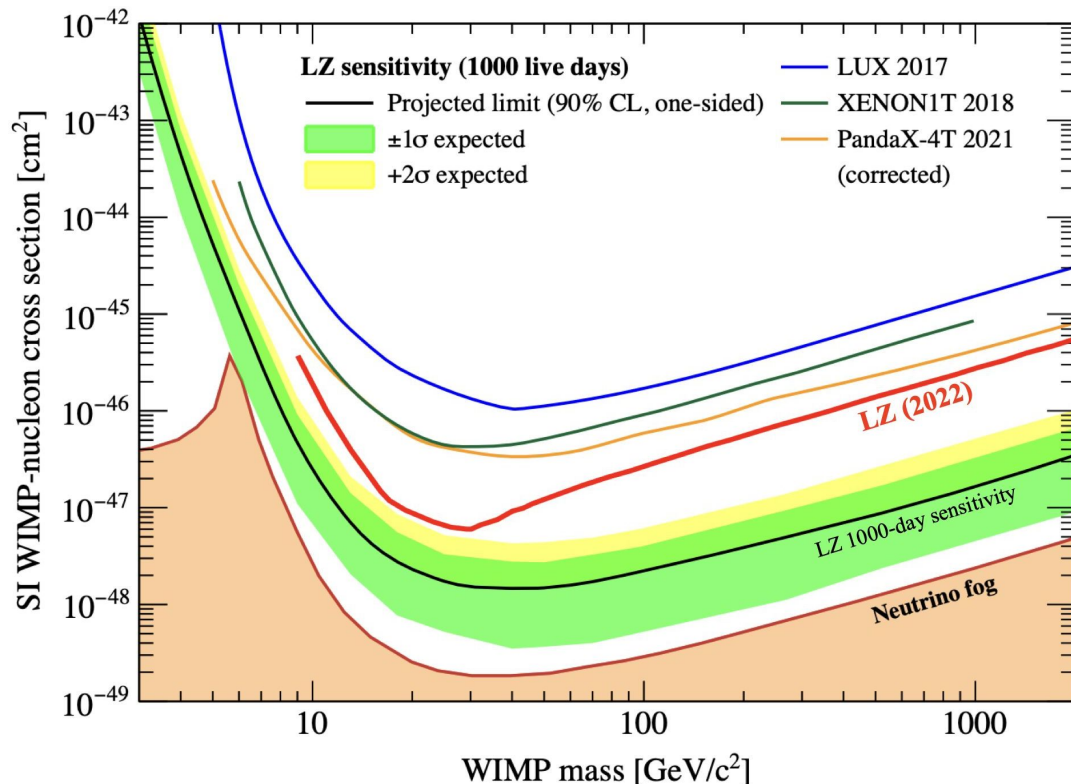
Current limit compared to projected sensitivity for 1000-day exposure

All LZ systems are performing well and backgrounds are within expectations

Short engineering run has produced world-leading WIMP limits!

Much more to come for LZ:

Ultimately planning for 1000 live-days

Many more physics searches (Talk later in this session by Michael Williams: Effective Field Theory Dark Matter Searches with the LZ Detector)

Beyond LZ: xenon community is uniting in XLZD consortium

LZ (LUX-ZEPLIN) Collaboration, 37 Institutions

250 scientists, engineers, and technical staff

@lzdarkmatter

https://lz.lbl.gov/

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

US   UK   Portugal   Korea   Australia

LZ Collaboration Meeting
SURF
June 2023

Science and Technology Facilities Council

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

Sanford
Underground Research Facility
South Dakota Science and Technology Authority

ibS Institute for Basic Science

Thanks to our sponsors and participating institutions!

Thank you!

Anode Grid
1469 mm
5.75 kV
1461 mm
1456 mm
-5.75 kV
Gate Grid
S2
electrons
Liquid Xenon
S1
Cathode Grid
0 mm
-50 kV
-137.5 mm
-1.5 kV
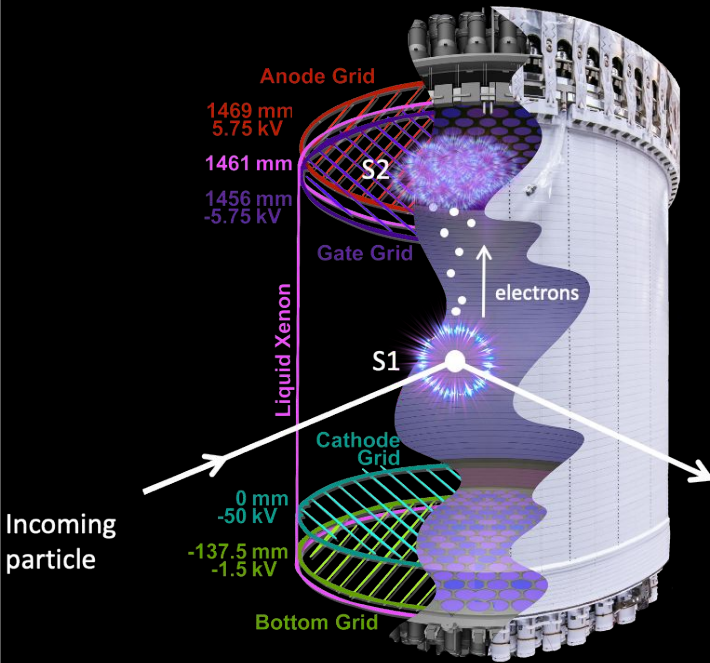Bottom Grid
Incoming particle

Image produced by Nicolas Angelides (Imperial)

Thanks to our sponsors and 37 participating institutions!
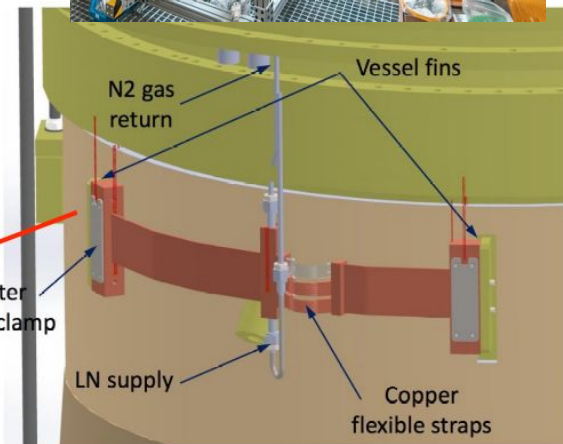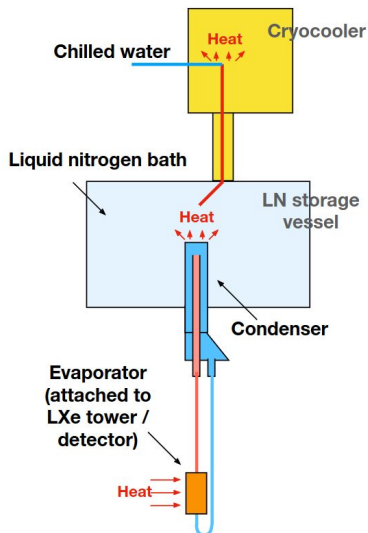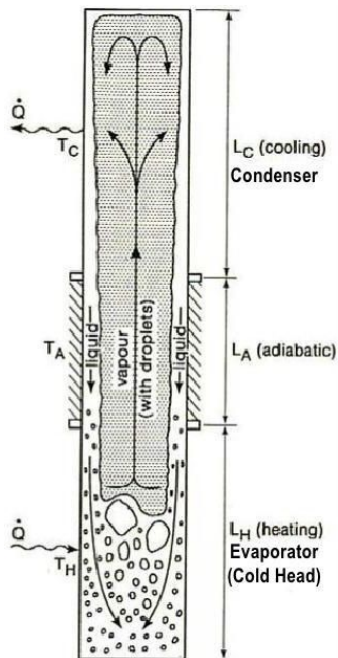

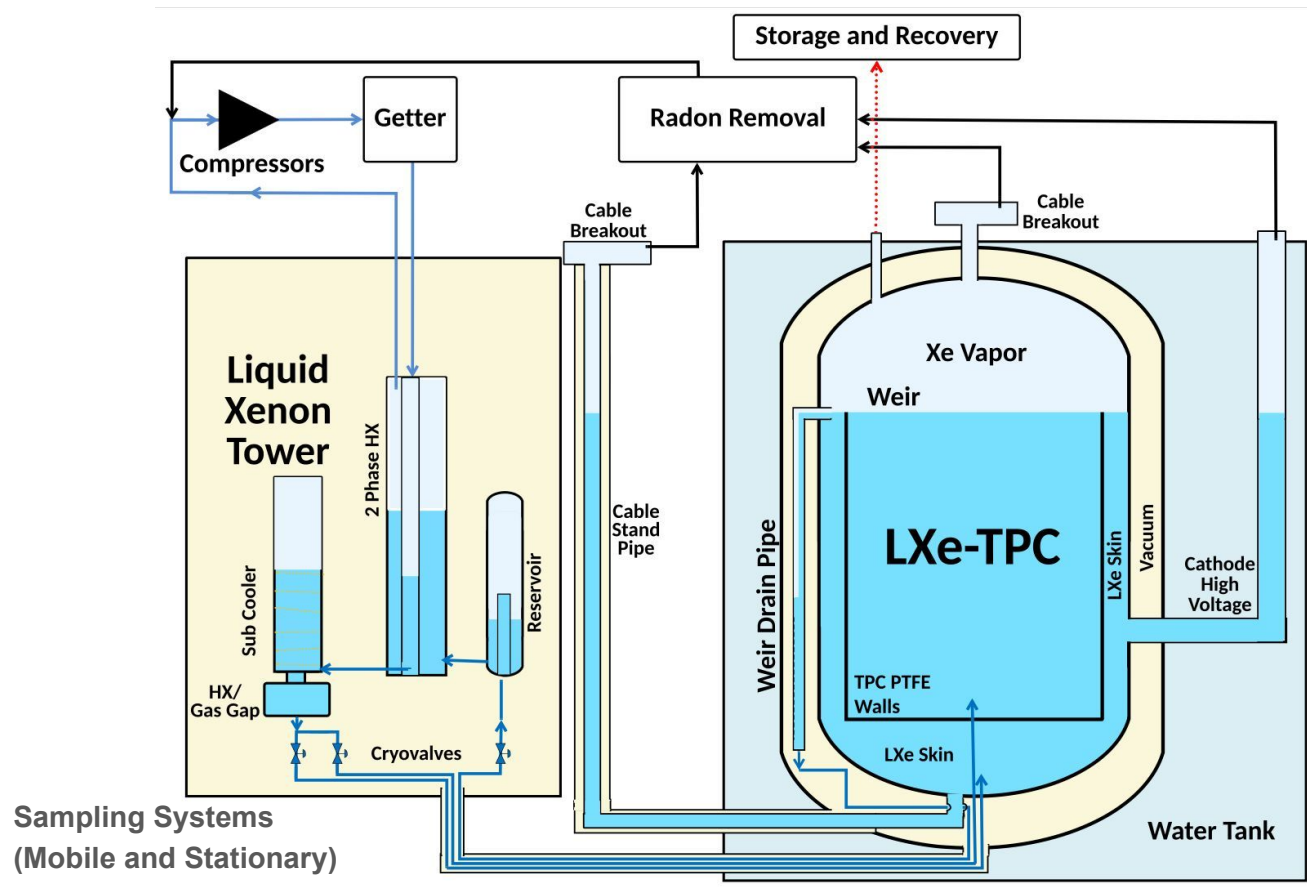U.S. Department of Energy
Office of Science

Backup: LZ Cryogenics

Thermosyphon principle

Cooling provided by thermosyphon technology (also used in LUX)
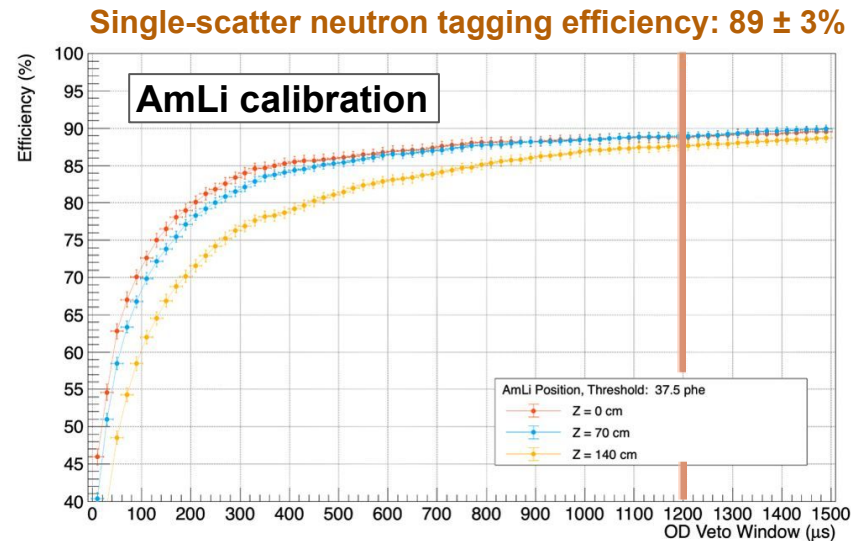
Backup: Xenon Circulation System

TAUP-2023: Status of the LUX-ZEPLIN Experiment (B. Boxer)

Backup: Outer Detector Efficiency

Single-scatter neutron tagging efficiency: 89 ± 3%
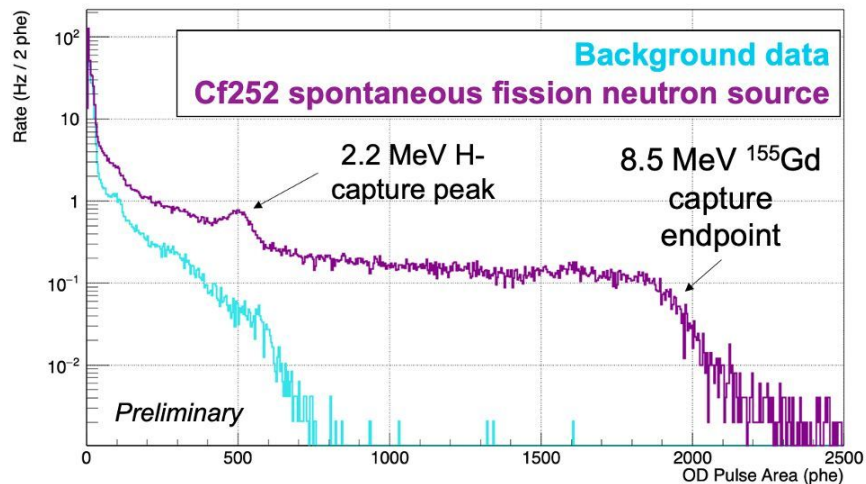
Neutron capture on Gd produces gamma emission of up to 8.5 MeV

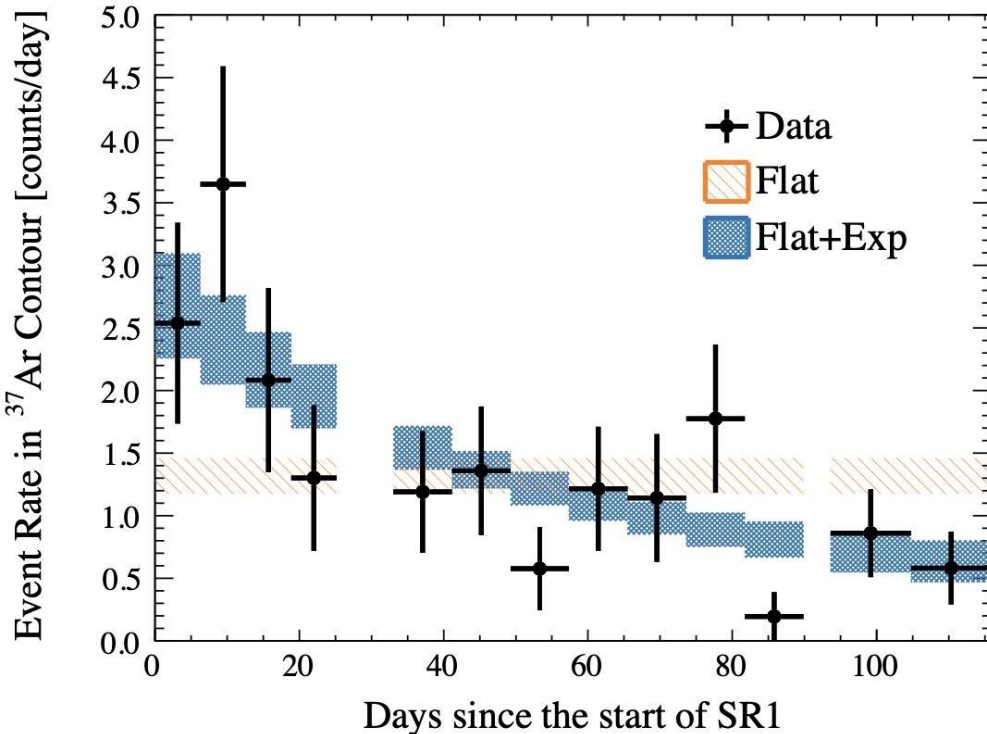**Time delay between neutron scatter in LXe and capture is O(0.1 - 1 ms)**

OD neutron tagging settings:

- ≥ 200 keV
- Δt ≤ 1200 µs

Live-time hit: 5%

Backup: ^{37}Ar

- ^{37}Ar is a significant background in early LZ data ($t_{1/2}$ = 35 d)
- Occurs naturally in atmosphere via e.g. Ca(n,α)Ar[1], but suppressed during Xe purification by charcoal chromatography
- Produced by cosmic spallation of natural xenon
- Estimating exposure during transport allows calculation of expected activity
  - ➢ We expect ~100 decays of ^{37}Ar in SR1 with a large uncertainty.[2]

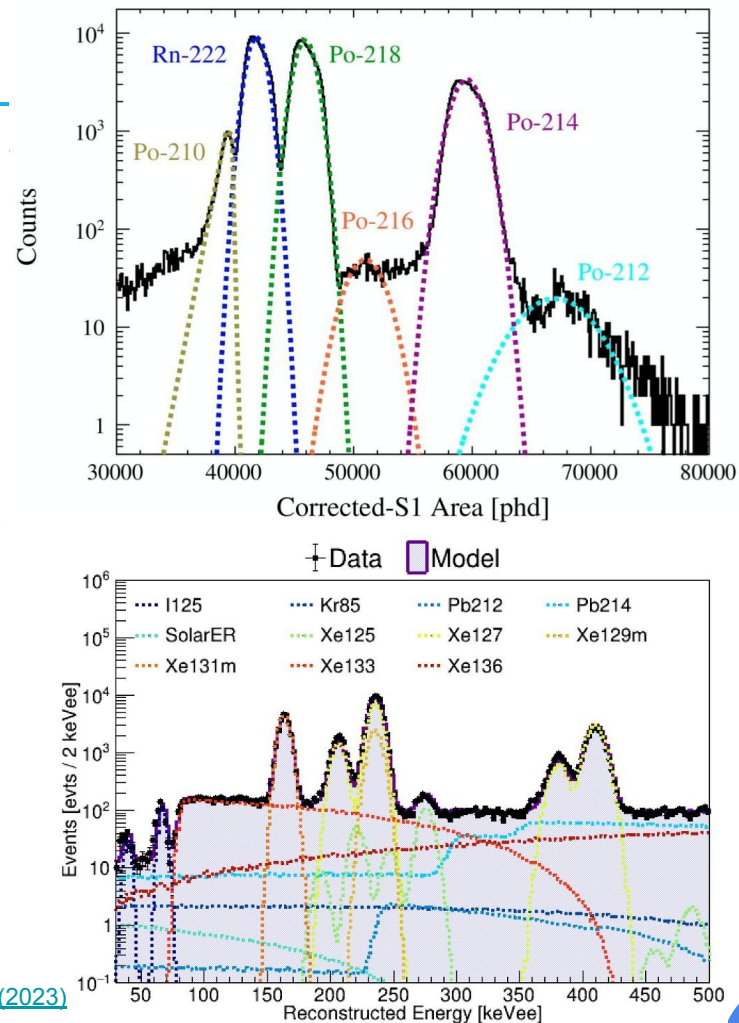(1) R.A. Riedmann, R. Purtschert, Environ. Sci. Technol. (2011) 45(20), 8656-8664
(2) LZ Collaboration, Phys. Rev. D 105, 082004 (2022), 2201.02858
Background Determination for the LUX-ZEPLIN (LZ) Dark Matter Experiment Phys. Rev. D 108, 012010 (2023)

Backup: Radon
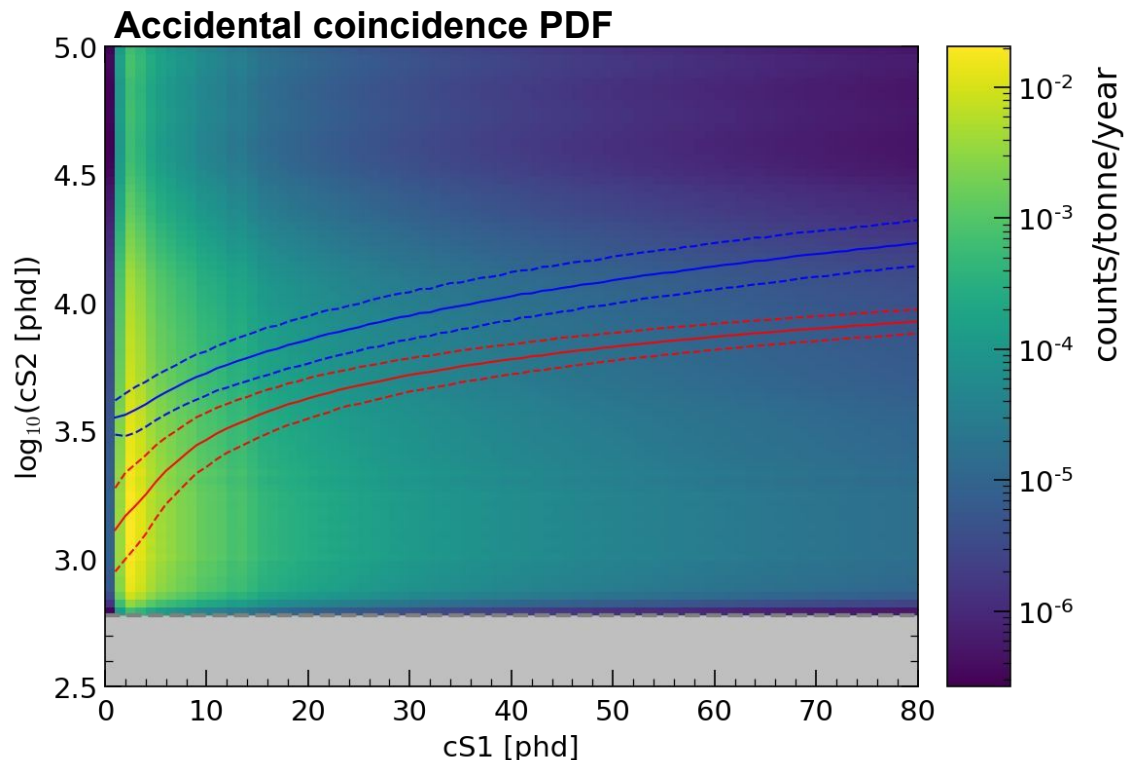
- **Naked 214Pb β-decays are the main WIMP background**

- **Rn emanating from detector materials into TPC xenon**

- **Constrain β-decay rate with two methods:**

  - **Rn-chain α tagging**

  - **Spectral fit of all internal BGs outside of energy ROI**

^{222}Rn (μBq/kg)	^{214}Pb (μBq/kg)	^{214}Po (μBq/kg)
4.37 ± 0.31 (stat)	3.26 ± 0.13(stat) ± 0.57(sys)	2.56 ± 0.21 (stat)

Background Determination for the LUX-ZEPLIN (LZ) Dark Matter Experiment Phys. Rev. D 108, 012010 (2023)
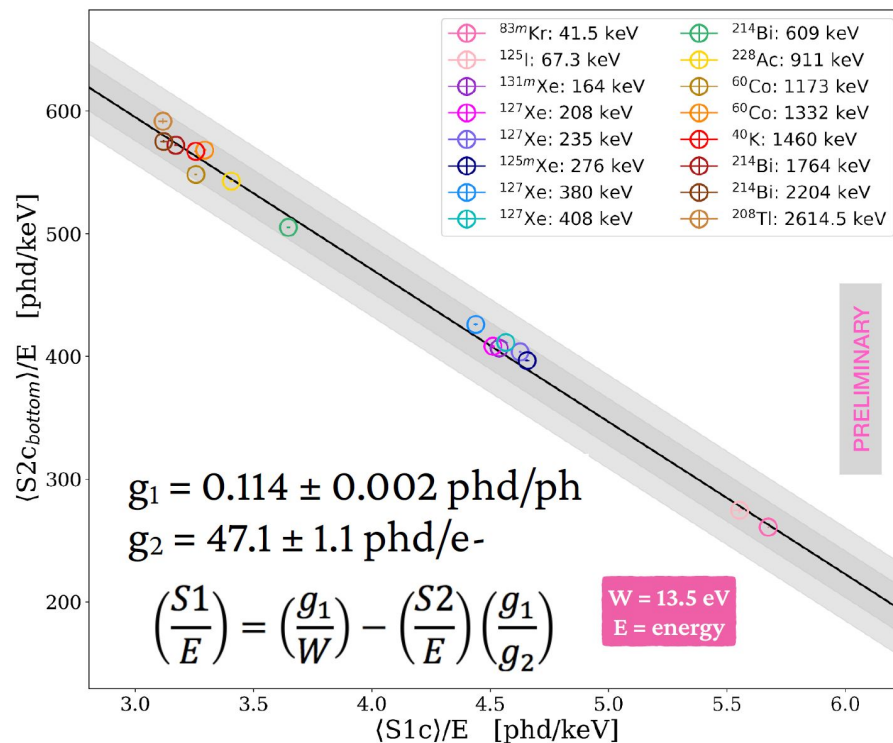
Backup: Accidental Coincidences

Accidental coincidence PDF

- **Isolated S1s & S2s can accidentally combine to form WIMP ROI events**

- **Data quality cuts successfully developed to address this background**

- **To construct PDF, stitch isolated raw pulses together for fake events. Normalised using events with unphysical drift time**

- **(i.e. drift time > TPC height)**

- **Expect 1.2 ± 0.3 events in SR1**

Background Determination for the LUX-ZEPLIN (LZ) Dark Matter Experiment Phys. Rev. D 108, 012010 (2023)
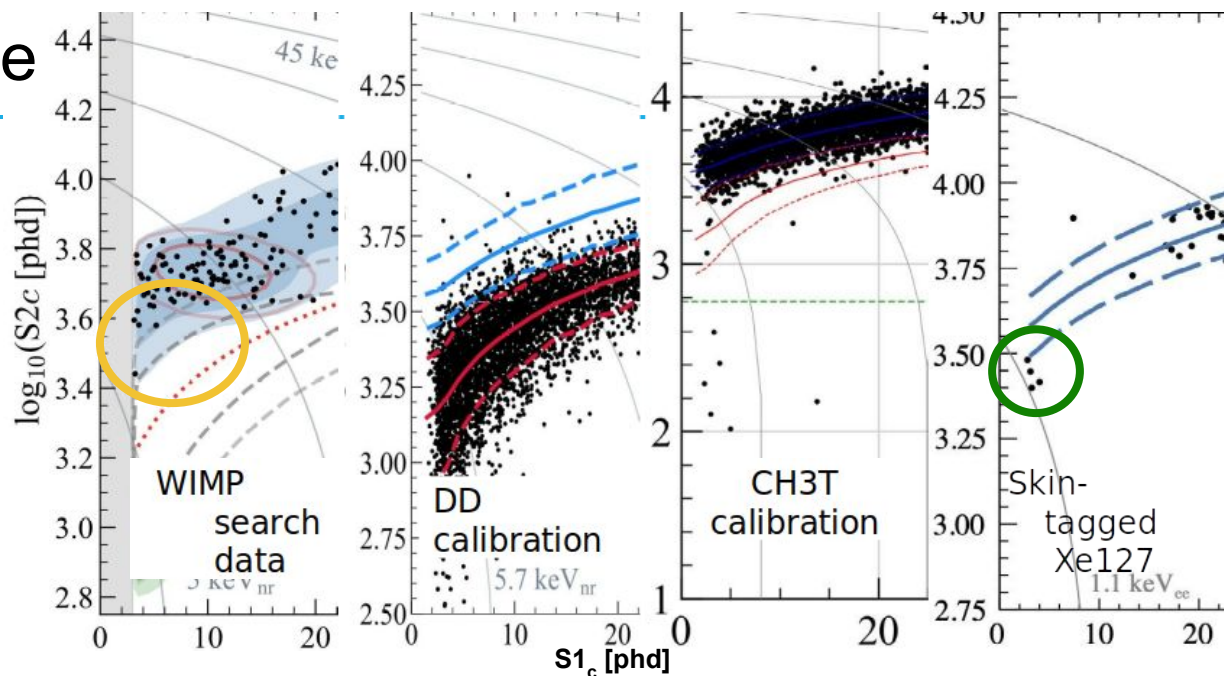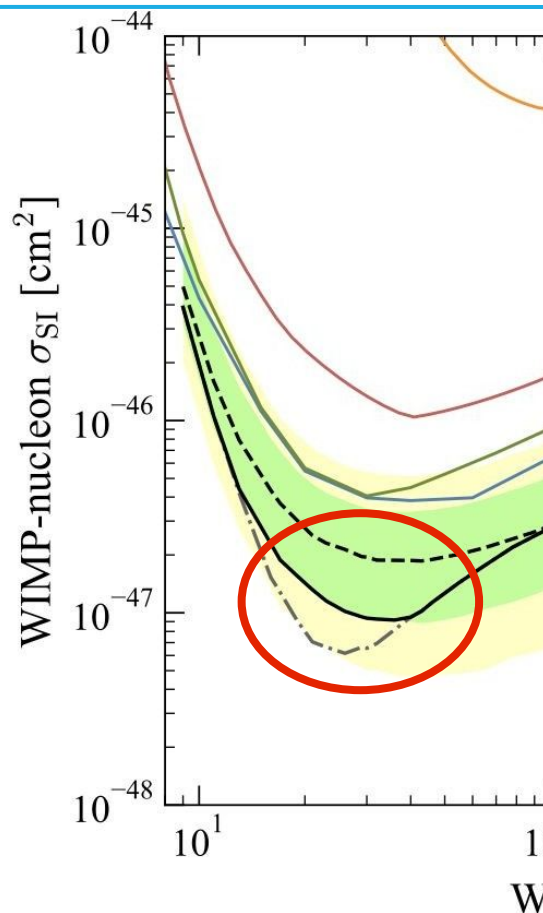
Backup: TPC Energy Response (Doke PLot)

S1s & S2s position-corrected using ^{131m}Xe background, ^{83m}Kr calibration.

Doke plot constructed with mono-energetic electron recoil peaks

Backup: Limit Shape

Downward fluctuation in the observed upper limit (**red ellipse**) is a result of the deficiency of events under the Ar-37 population (**yellow ellipse**).

Calibration (both DD and CH3T) and Xe127 M-shell counts (**green ellipse**) in this region are as expected with our signal acceptance model.

=> Deficit in WIMP search data appears consistent with under-fluctuation of backgrounds