First dark matter search results from the LZ experiment

LIDINE 2022

Warsaw, Poland

Andrew Stevens (UCL/Imperial)

a.stevens@imperial.ac.uk

On behalf of the LZ collaboration

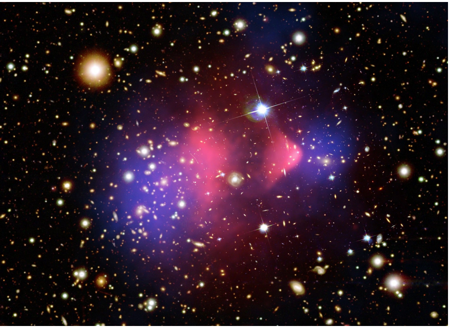
21 September 2022

LUX ZEPLIN

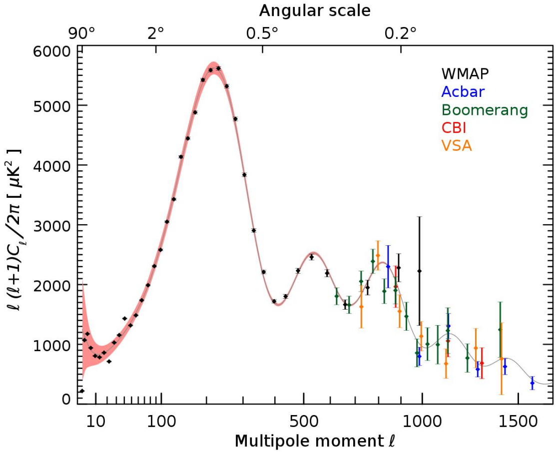
- Black Hills State University
- Brandeis University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- 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 Wisconsin, Madison

LZ detector & Dark Matter

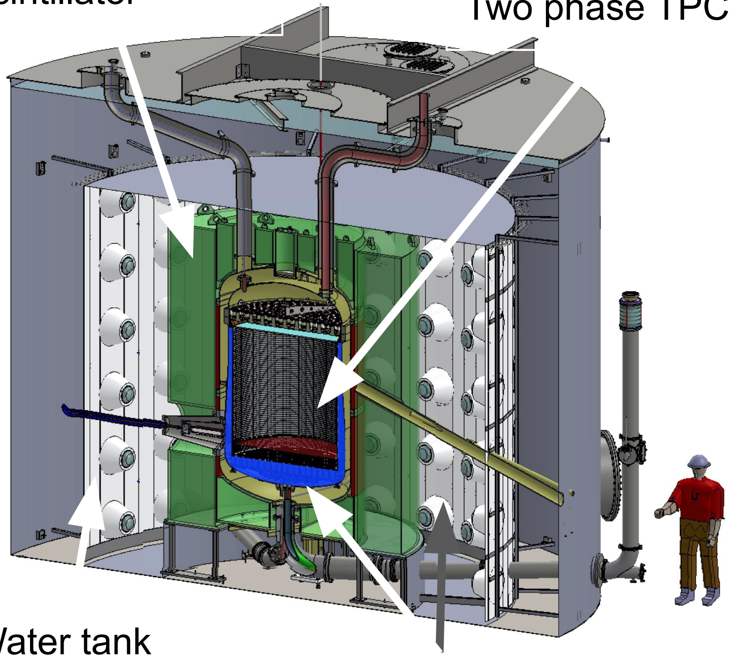
- Dark Matter Detector - particularly sensitive to WIMP candidates
- Dark Matter evidence from rotation curves, bullet cluster, CMB …
- Nature of such a substance is inferred from observation



NASA/CXC/M. Weiss



NASA/WMAP Science Team



TPC

Principles of detection:

- Interactions produce primary scintillation light (S1) and ionisation electrons
- Secondary scintillation signal (S2) from drifted ionisation charge

Position reconstruction - hit pattern and drift time

- Enables separation of single and multiple scatters

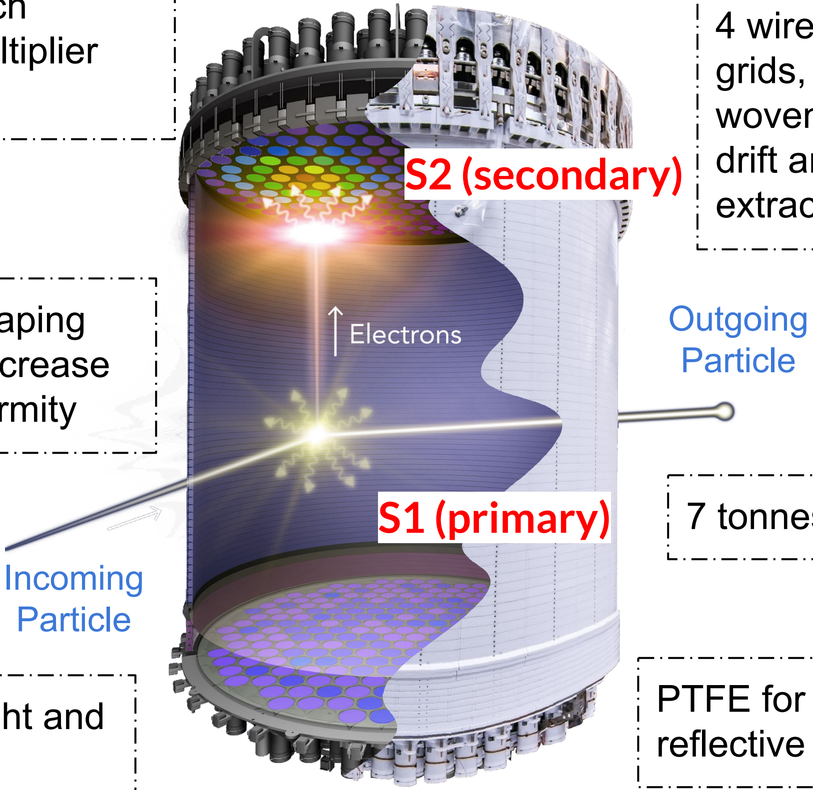
Particle ID from S1/S2 ratio

- Nuclear recoils (signal) and electronic recoils (background)

494 3 inch photomultiplier tubes

Ti field shaping rings to increase field uniformity

~1.5m height and diameter



4 wire mesh grids, bespokely woven define the drift and extraction fields

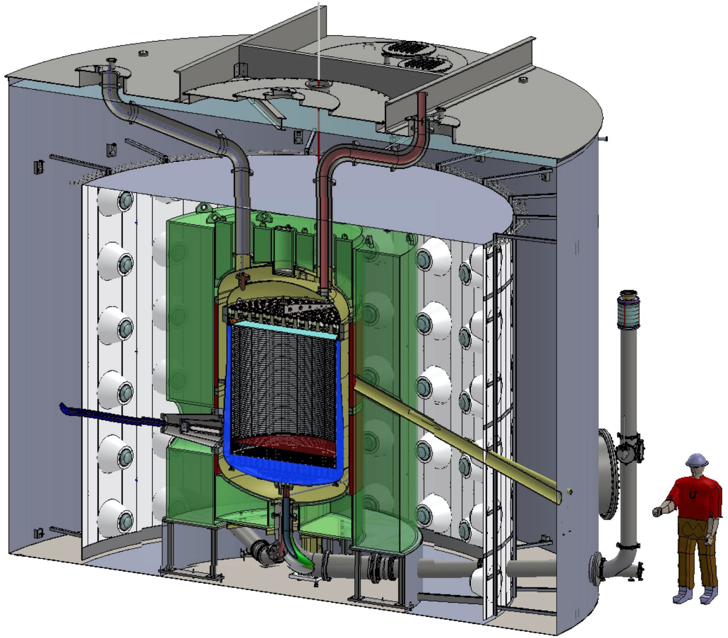
7 tonnes of LXe

PTFE for efficient reflective ability

Veto systems

Xenon 'Skin'

- Surrounds the TPC volume (~2 tonnes)
- Actively instrumented with 1" and 2" PMTs at the top and bottom - active veto.
- Optically isolated from other detectors
- Anti-coincident gamma ray detector

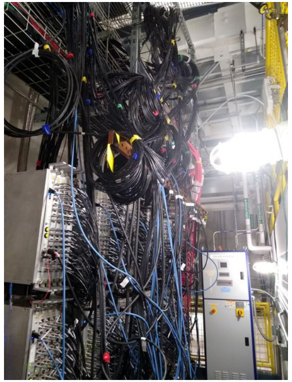


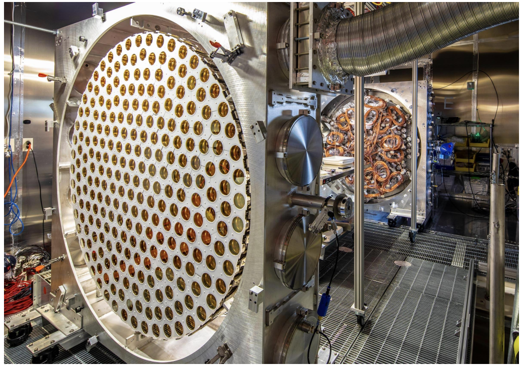
Outer Detector

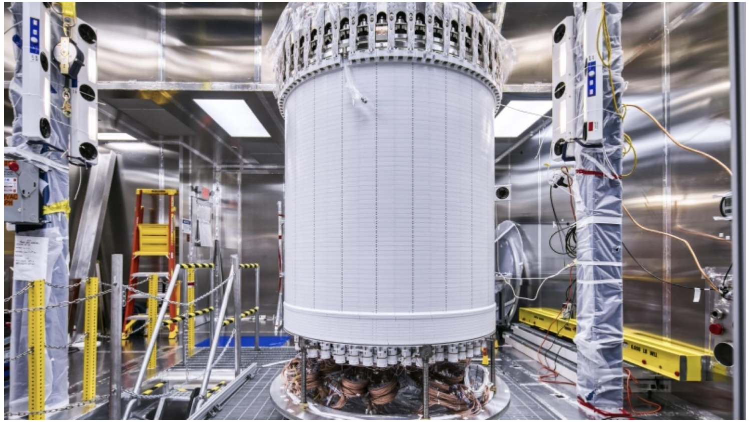
- Gadolinium liquid scintillator surrounding detector.
- Located within an instrumented water tank (8" PMTs)
- Anti-coincident neutron and gamma detector

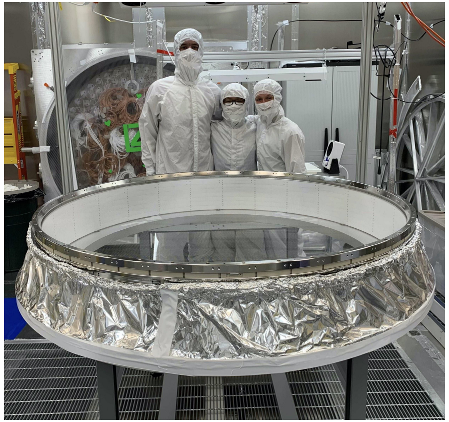
Vetos providing ~88% neutron detection efficiency

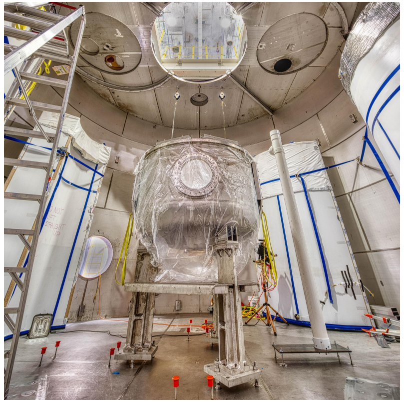
Construction

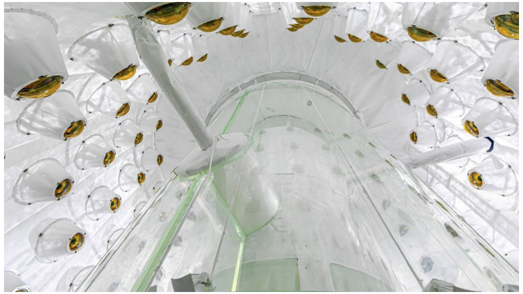






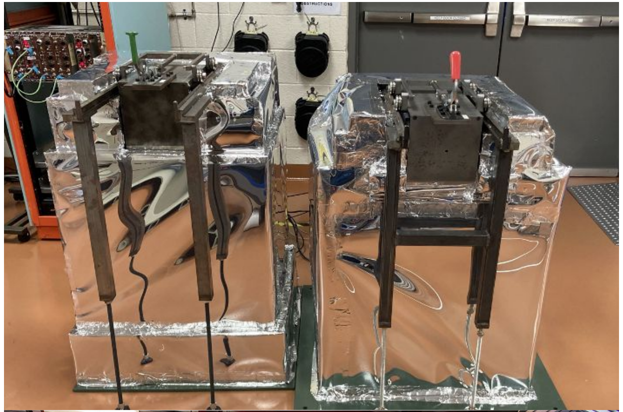






Background mitigation

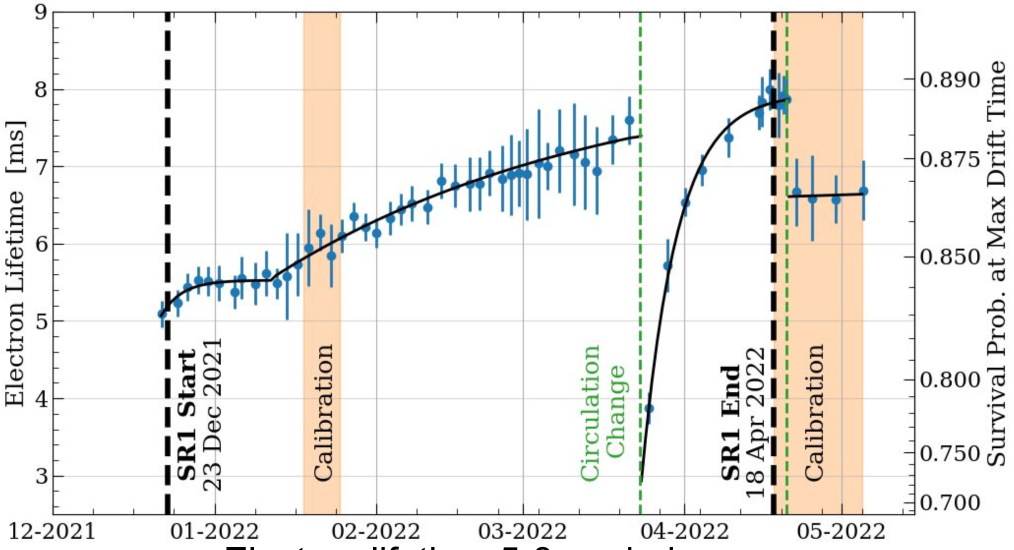
- Material selection
    - Material screening for U,Th,K,Co determined material selection.
    - Screening in Ge facilities (Boulby (UK), SURF (US)), ICP-MS, Radon
- Shielding
    - LZ is 4850 ft (~1 mile) underground - muon flux reduced by over a million.
    - Water tank and Xe self shielding
- Cleanliness/Rn daughter
    - Parts were cleaned and construction performed in a cleanroom
    - Requirements: Dust <500 ng/cm^2 on all LXe wetted surfaces
    - Rn-daughter plate-out on TPC walls <0.5 mBq/m^2
- Xenon contaminant removal
    - ^{85}Kr/^{39}Ar Removal
    - Purification underground with a warm getter



Eur.Phys.J.C 80 (2020) 11, 1044

First science run

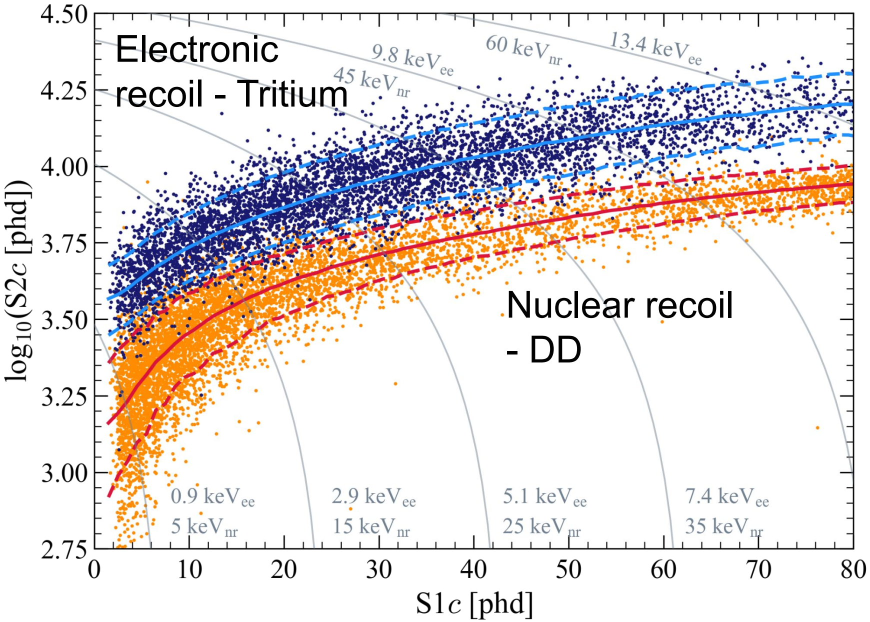
- Goals:
  1. Demonstrate physics capabilities of the detector (not blinded)
  2. Perform competitively with other similar experiments
- Key information:
  1. Livetime 60 days (Data from 23rd Dec 2021 to 12th May 2022)
  2. PMTs: >97% operational throughout run
  3. Liquid temperature: 174.1 K (0.02%)
  4. Gas pressure: 1.791 bar(a) (0.2%)
  5. Gas circulation: 3.3t/day
  6. Drift field: 193 V/cm (32 kV cathode, uniform to 4% in fiducial volume)
  7. Extraction field: 7.3 kV/cm in gas (8 kV gate-anode ΔV)



Electron lifetime 5-8ms during run

Calibrations

- Many sources:
  - ^{83m}Kr: monoenergetic ERs, 32.1 keV and 9.4 keV
  - ^{131m}Xe: monoenergetic ER, 164 keV
  - **CH_3T (tritium): beta spectrum - Q-value: 18.6 keV**
  - **Deuterium-deuterium (DD): triggered 2.45 MeV neutrons**
  - Activation lines
  - AmLi: continuum neutrons, isotropic
  - Alphas
  - And more (^{220}Rn, YBe, ^{252}Cf, ^{22}Na, ^{228}Th, etc)
- Some uses:
  - Tune the position reconstruction algorithm in horizontal plane
  - Flat fielding of S1 and S2 signals
  - NEST (https://nest.physics.ucdavis.edu/) model tuned to the response of tritium and validated on DD



- Light gain g1: 0.114 ± 0.002 phd/photon
- Charge gain g2: 47.1 ± 1.1 phd/electron
- Single electron size: 58.5 phd

Background Model

Electronic Recoils

Dissolved contaminants (beta decay):

- ^{214}Pb (^{222}Rn daughter)
- ^{212}Pb (^{220}Rn daughter)
- ^{85}Kr

Dissolved contaminants (electron capture):

- ^{37}Ar
- ^{127}Xe
- ^{124}Xe (double e-capture)

Gamma emitters in detector materials
^{60}Co, ^{40}K, ^{238}U chain, ^{232}Th chain

Nuclear Recoils

- Neutron emission from spontaneous fission and (α,n)
- ^{8}B solar neutrinos

Expected numbers of events:

Electronic recoils: 276 + [0, 291] from ^{37}Ar

Nuclear recoils: 0.15

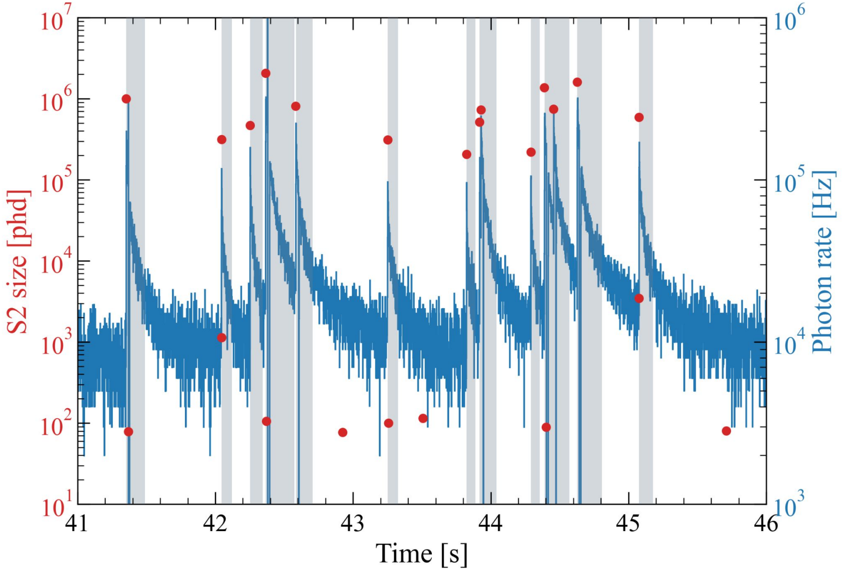
Data quality

There is contamination from spurious signals:

- Electron and photon rates are higher after larger S2s
- Isolated S1 and S2 pulses from charge or light insensitive regions
- Gas events

Solution - data quality cuts:

- **Pulse based cuts**
  Targets accidental pileup topologies
  Cut mainly on hit pattern and pulse shape
  Tuned with tritium and AmLi calibration data
- **Timing cuts**
  Removes the high rates of electron and photon emission following S2s



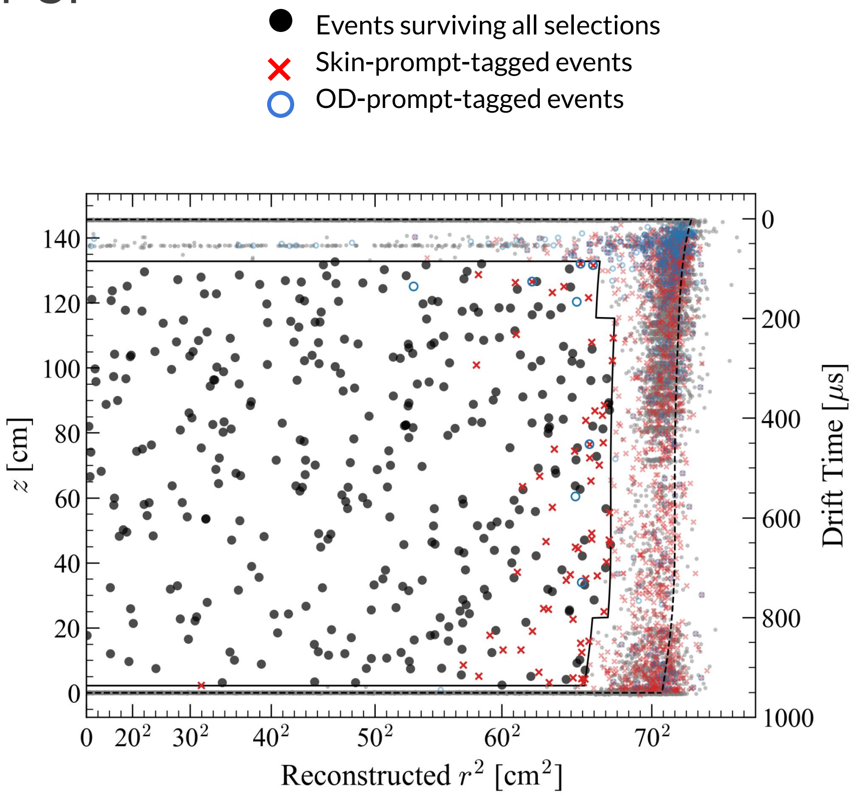
Vetos and fiducialisation

Vetos considered in anti-coincidence with the TPC:

- Prompt OD and Skin cut
  - Used for vetoing gammas
  - Significantly reducing the L,M ^{127}Xe background
- Delayed OD cut
  - Looking for neutron capture on Gd
  - ~ 200 keV threshold
  - In situ expected rate of $^{+0.2}0$

Fiducialisation:

- Inner 5.5 tonnes of Xenon considered for the analysis
- Optimise fiducial volume and lower S2 threshold together



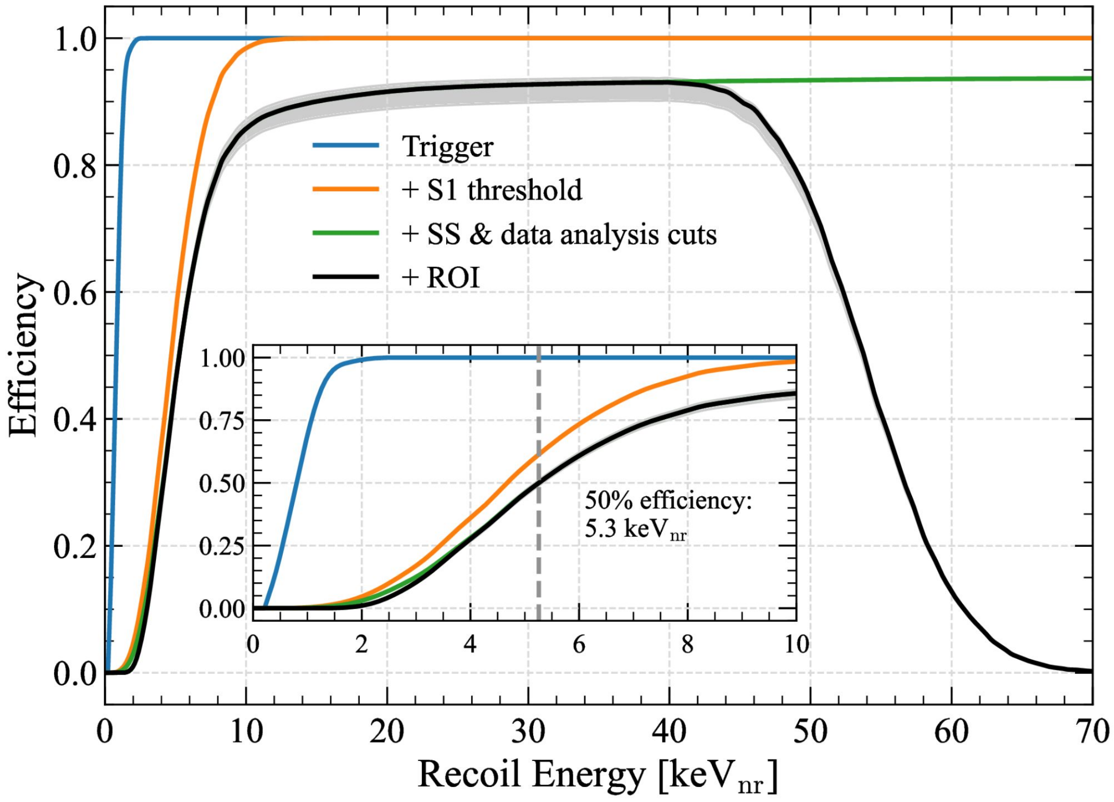
Efficiencies

Trigger - all events triggered

S1 threshold - apply S1 three fold coincidence requirement

SS & data analysis cuts - single scatter cut and application of cuts previously considered

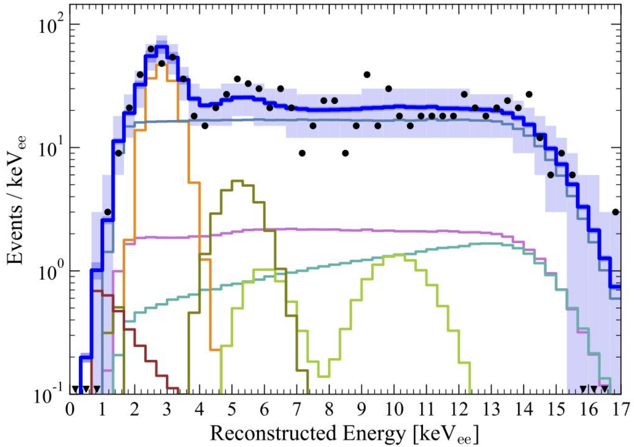
ROI - Considering events in the energy range shown, cut applied in S1, S2 space

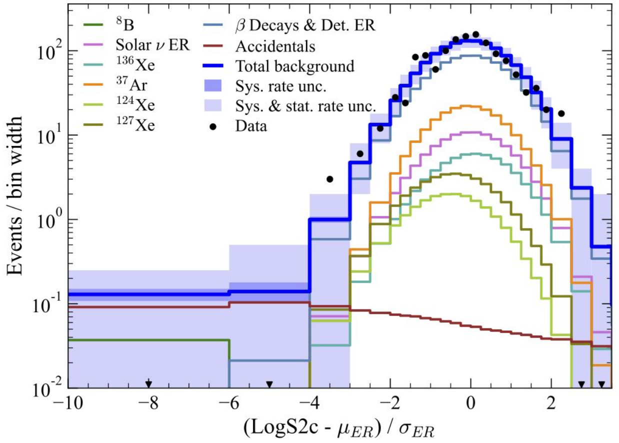


Result

Source	Expected Events	Best Fit
β decays + Det. ER	218 ± 36	222 ± 16
ν ER	27.3 ± 1.6	27.3 ± 1.6
^{127}Xe	9.2 ± 0.8	9.3 ± 0.8
^{124}Xe	5.0 ± 1.4	5.2 ± 1.4
^{136}Xe	15.2 ± 2.4	15.3 ± 2.4
^{8}B CEνNS	0.15 ± 0.01	0.15 ± 0.01
Accidentals	1.2 ± 0.3	1.2 ± 0.3
Subtotal	276 ± 36	281 ± 16
^{37}Ar	[0, 291]	$52.1^{+9.6}_{-8.9}$
Detector neutrons	$0.0^{+0.2}$	$0.0^{+0.2}$
30 GeV/c^2 WIMP	–	$0.0^{+0.6}$
Total	–	333 ± 17

Best fits at all masses are for zero WIMP events

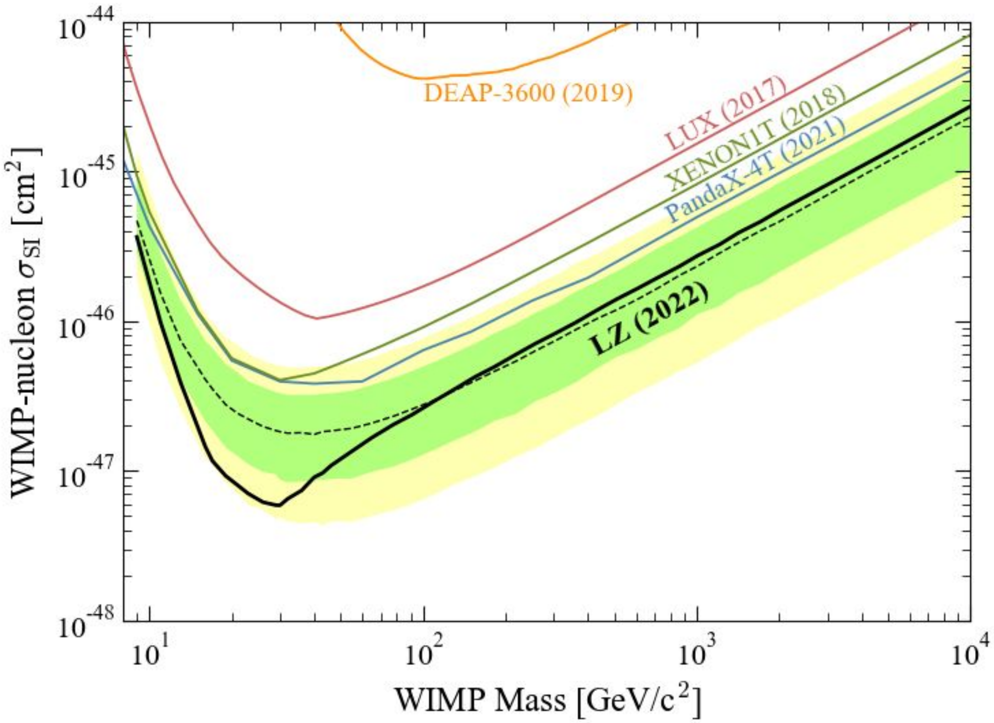




Result

90% CL upper limit on WIMP-nucleon σ_{SI} is 5.9 x 10^{-48} cm^2 at 30 GeV/c^2 WIMP mass

- Limit constructed using frequentist profile likelihood ratio (PLR)
- Two sided
- Signal rate constrained to be positive only



Next steps

Results here are only a small fraction of the total exposure of the experiment (~17x more exposure)

LZ is multi-physics device:

- Solar axions and axion like particles
- Neutrinoless double beta decay ($^{136}Xe/^{134}Xe$)
- Low mass dark matter (S2 only, Migdal)
- Higher mass dark matter (EFT)
- Etc.

XLZD Consortium

Leading Xenon Researchers unite to build next-generation Dark Matter Detector

SURF is distributing this press release on behalf of the DARWIN and LZ collaborations

July 20, 2021

- Consortium formed between LZ, XENON, DARWIN
- Successful XLZD meeting 27-29 June 2022 at Karlsruhe Institute of Technology
- https://xlzd.org/
- White paper (2203.02309)

Summary

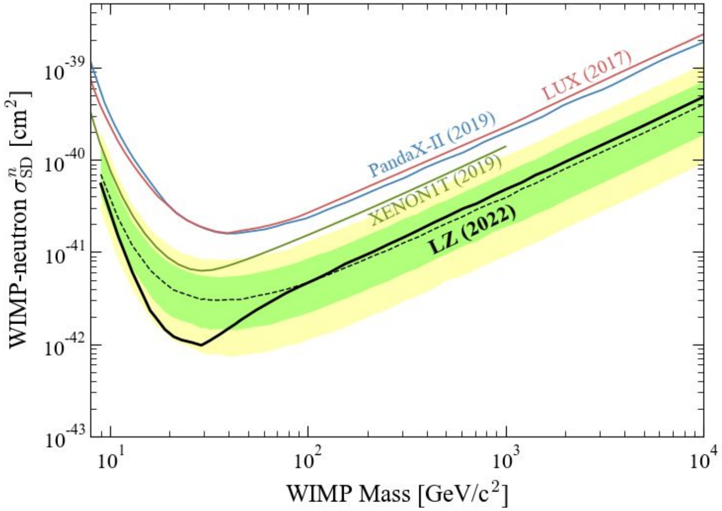
LZ is now the most sensitive experiment in the world in the considered mass range. See the paper: **arXiv:2207.03764**

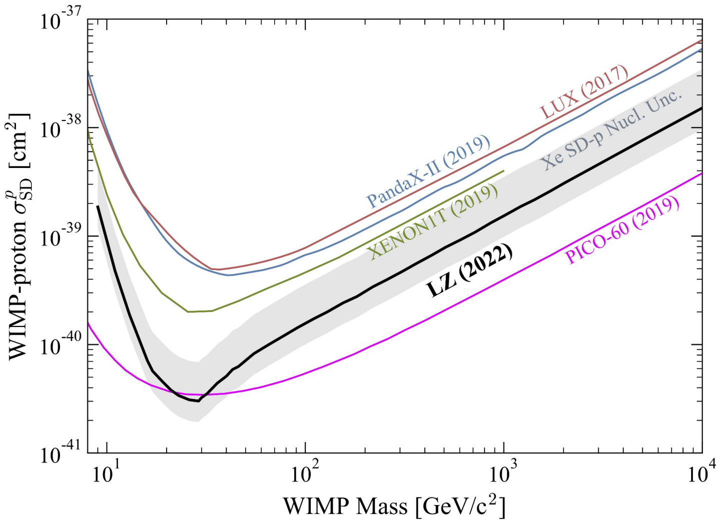
The detector is performing well, and is producing high quality data

Exciting times still lie ahead…

Backup

Spin Dependent results

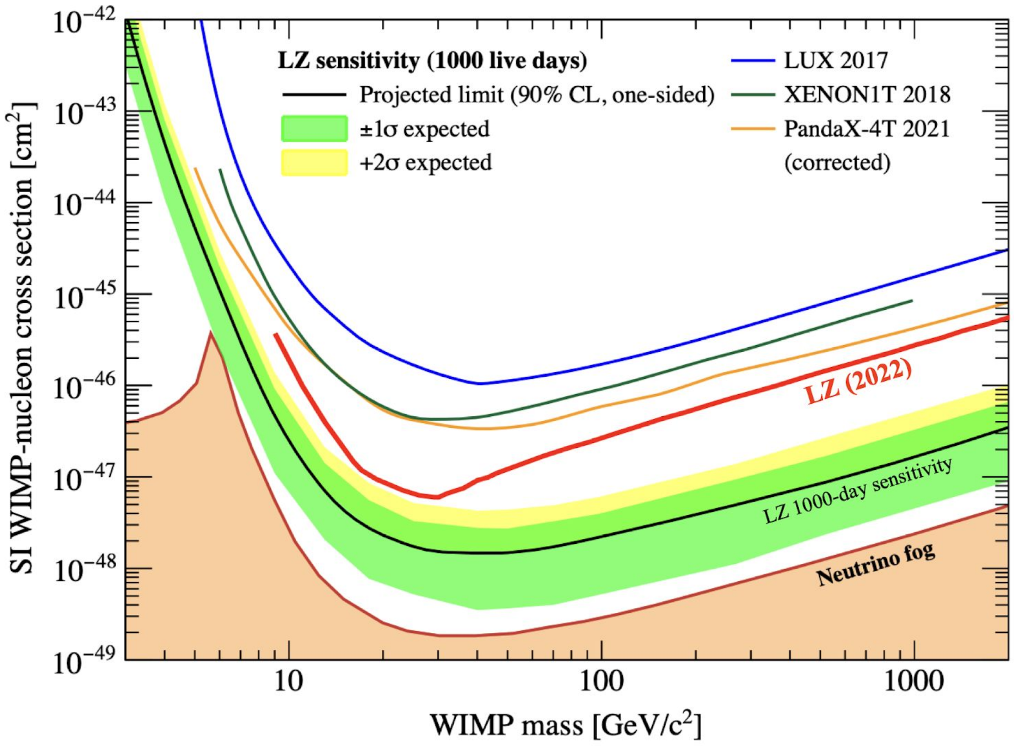




Uncertainty band to on nuclear form factor for Xe (*). “Brazil” band omitted for clarity

(*) P. Klos, J. Menéndez, D. Gazit, and A. Schwenk Phys. Rev. D 88, 083516 (2013)

Predicted sensitivity



90% CL minimum (**one sided**) of 1.4×10^{-48} cm^2 at 40 GeV/c^2 from Phys. Rev. D 101, 052002 (2020)

Radon

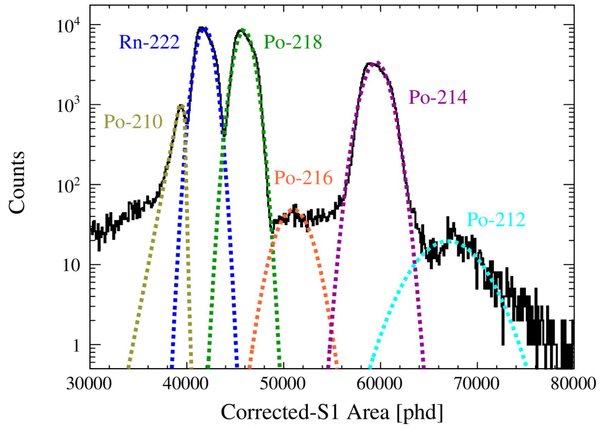
^{214}Pb is dominant electronic recoil background (^{222}Rn decay chain)

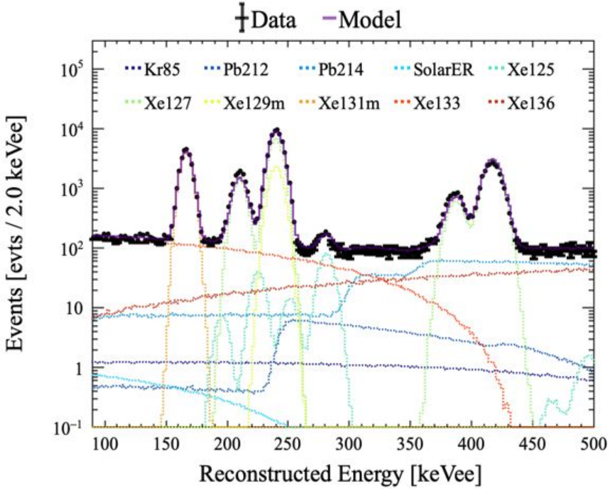
Constrain the rate within the WIMP search:

1. Constraining backgrounds in the sideband
2. Alpha tagging

Consistent with assay campaign

Isotope (decay)	Activity [µBq/kg]
^{222}Rn (alpha)	4.37 ± 0.31 (stat)
^{218}Po (alpha)	4.51 ± 0.32 (stat)
^{214}Pb (beta)	**3.26** ± 0.13(stat) ± 0.57(sys)
^{214}Po (alpha)	2.56 ± 0.21 (stat)

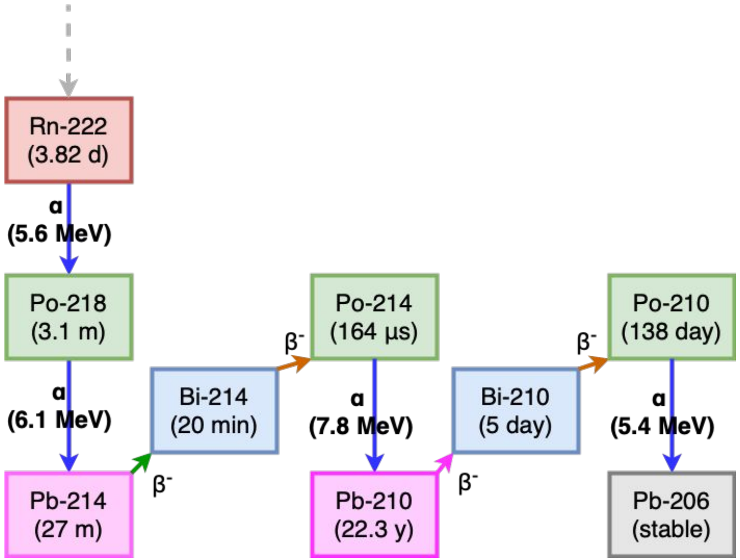


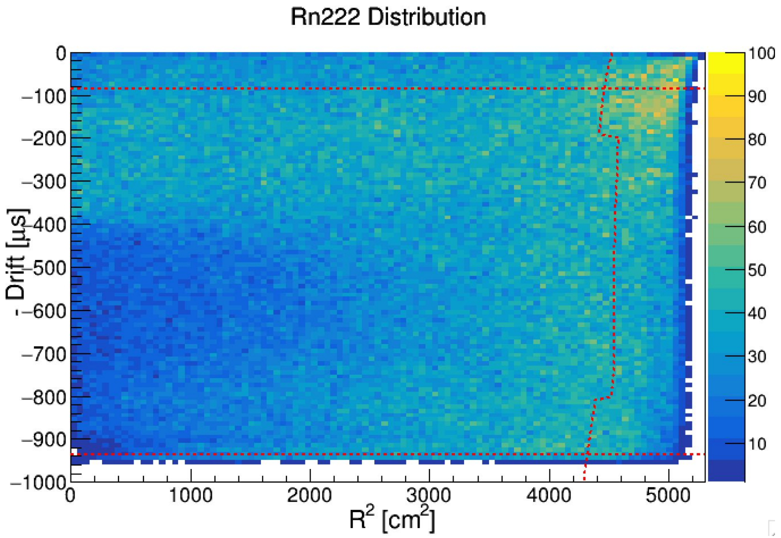


Radon chain backgrounds

^{222}Rn not uniformly distributed.

Stratification in LXe flow is a possible tool to reject ^{214}Pb in future





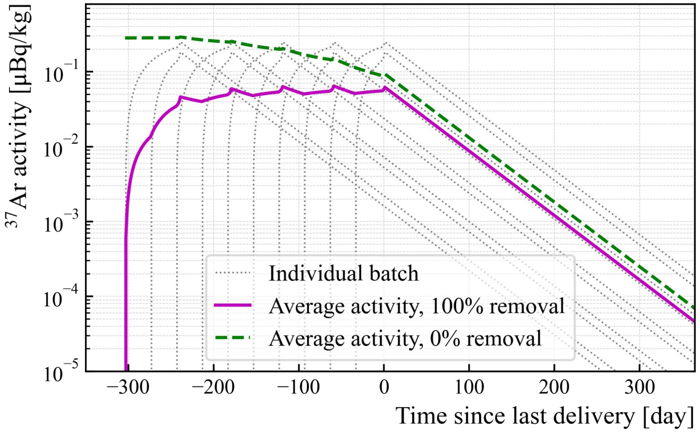
Argon

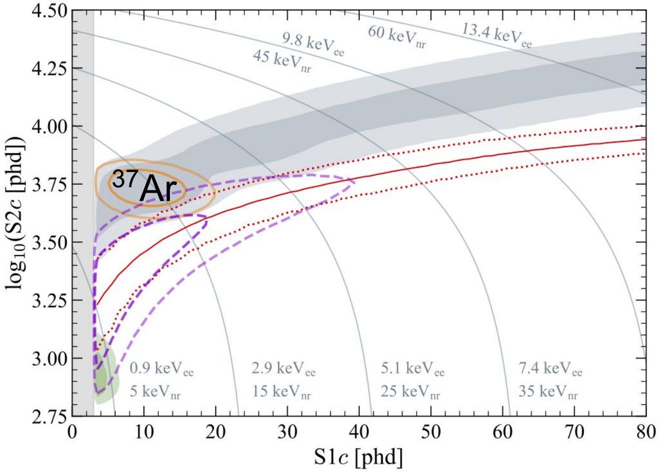
^{37}Ar decays ($T_{1/2}$ = 35 d, monoenergetic 2.8 keV ER deposition)

Predominant source of argon in LZ is through cosmogenic spallation

LZ Collaboration, Phys. Rev. D 105, 082004 (2022), 2201.02858

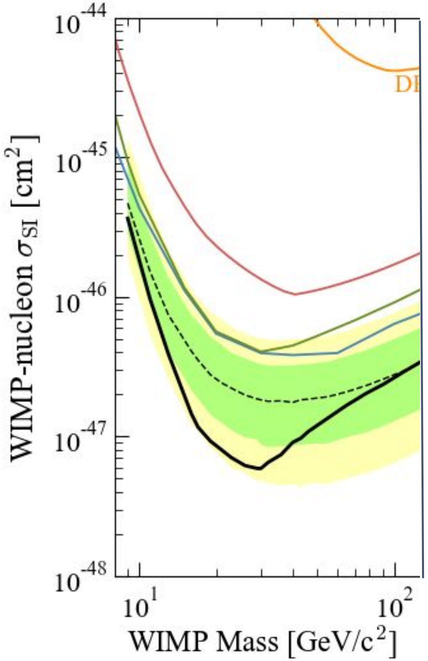
Activity estimates can be formed showing approximately 100 decays in data (large uncertainty)

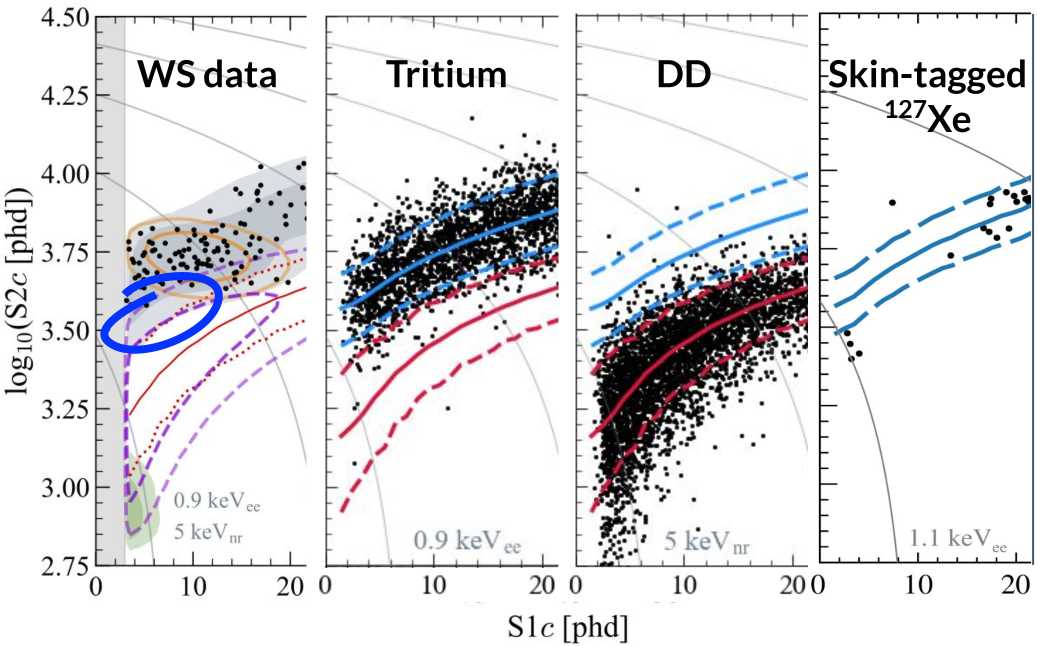




Low energy recoils

1. Downward fluctuation in the observed upper limit near 30 GeV/c^2 is a result of the deficit of events under the ^{37}Ar population.
2. **Tritium** data analyzed identically to WS data; well-covered
3. **DD** data also shows deficit region is well-covered.





4. M-shell decays of ^{127}Xe populate near deficit region. Observed rate of M-shell decays with coincident γ-ray tagged by the skin is consistent with expectation, given signal efficiencies.
5. Conclusion: Deficit appears consistent with under-fluctuation of background.

Events

Selection description	Events after selection
All triggers	1.1×10^8
Analysis time hold-offs	6.0×10^7
Single scatter	1.0×10^7
Region-of-interest	1.8×10^5
Analysis cuts for accidentals	3.1×10^4
Fiducial volume	416
OD and Skin vetoes	335

Doke Plot - energy calibration