Status of LUX-ZEPLIN
First Dark Matter Searches
April 2024
Ewan Fraser
The LZ Collaboration

38 Institutions, 250 scientists, engineers, and technical staff

Thanks to our sponsors and participating institutions!
LZ at SURF

- LUX-ZEPLIN at Sanford Underground Research Facility
  - SURF - Homestake Mine, Lead, South Dakota
  - ~1 mile underground, Davis Cavern
  - Rock overburden reduces cosmic ray muon flux by $O(10^6)$

4850 feet deep (~1 mile)
LZ - Experiment for Direct Detection of WIMP Dark Matter

Calibration Source Deployment Tubes (3 Total)

17T Gd-loaded liquid scintillator

60,000 gallons of ultrapure water

120 Outer Detector PMTs

494 LXe PMTs

2T LXe Skin Veto

7T Active LXe Target

131 Skin PMTs

Neutron Calibration Conduit (2 total)
Dual-phase Xenon TPCs

Incoming particle

Outgoing particle

Prompt scintillation light

Electroluminescence from electrons accelerated across phase change in extraction region

Position Reconstruction:
- Z - Drift Time
- (X, Y) - PMT hit pattern

Nuclear Recoil (NR): WIMPs, neutrons

Electron Recoil (ER): $\gamma$ and $\beta$ backgrounds

ER/NR discrimination from ratio of $S_1$ and $S_2$
Fully assembled TPC

Bottom PMT array and field cage
LXe Skin Detector

- **2 tonne** of LXe surrounding the TPC
- **131 1” or 2” PMTs**
- Anti-coincidence veto for γ-rays with **78±5% efficiency**
- Reduction of important ER background rates
  - E.g. $^{127}$Xe decay via electron capture

Courtesy of Jack Bargemann APS April 2023
Gd-LS Outer Detector

- **17 tonne** of Gd-loaded liquid scintillator (120 8” PMTs)
- **89±3% SS neutron tagging efficiency**
  - Measured with AmLi neutron calibration
- Neutron capture up to 1200 μs after the S1
  - ~5% livetime reduction
- Used to constrain the rate of SS neutron background
First Science Run: Stability and Calibrations

- Dec 23rd ’21 - May 12th ’22 (60 live days)
- > 97% of PMTs operational
- Liquid T = 174.1 K (0.02% variation)
- Gas P = 1.791 bar(a) (0.2% variation)
- Liquid level stable within 10 microns
- Gas Circulation ~ 3.3 t/day
- Band fits performed using NEST v2.3.7
- $g_1$ (light gain) = $0.114 \pm 0.002$ phd/photon
- $g_2$ (charge gain) = $47.1 \pm 1.1$ phd/e-
- 99.9% ER discrimination below NR band median

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**ER band:** Tritiated methane $\beta$ source

**NR band:** DD 2.45 MeV neutrons
335 events in the final dataset after data quality cuts in 5.5 t fiducial volume

A profile-likelihood ratio shows the data to be consistent with a background-only hypothesis

Best fit with zero WIMP events at all WIMP masses

- Green and yellow are the 1σ and 2σ median sensitivity bands
- Power constraint at -1σ sensitivity band to account for discovery power
- Best limit of $\sigma_{SI} = 9.2 \times 10^{-48}$ at 36 GeV/c$^2$
Comprehensive review of side-band analysis to determine background rates for LZ physics analysis

- In-situ determinations consistent with prior ex-situ radioassays

For example, largest ER background contribution from “naked” beta decays

- $^{214}\text{Pb}$ rate constraint from fitting in the 80-700 keV region
- Bounds on this fit determined from the rate of prior and following decays in the $^{220}\text{Rn}$ decay chain

$^{37}\text{Ar}$ produced by cosmic ray spallation; uncertainty on the spallation yield is about a factor of three

- Rate of $^{37}\text{Ar}$ allowed to float during the WS fit. Post-fit analysis consistent with $^{37}\text{Ar}$ decay
EFT treats the WIMP-nucleon elastic scattering as a four-field interaction

Linear combination of 15 operators contribute to the Lagrangian

Describes a set of possible WIMP-nucleon interactions
Low Energy Electron Recoil Signals

- Time dependent analysis of ER signals
  - Better sensitivity
  - Flat signal model vs decaying background.
- Wealth of potential signals to explore:
  - Neutrino Magnetic Moment and Millicharge
  - Solar Axions/ALPs and Hidden photons
  - Lower mass limits with the Migdal effect

![Graph showing various experimental results and theoretical predictions related to neutrino magnetic moments and effective millicharges.](image-url)
- Multiply Interacting Massive particles (MIMPs)
- Signal: Time ordered multiple scatters along a linear track
- Reconstructed velocity 50-1200 km/s
  - Corresponds to ~μs between S1s
- Unique event topology, < 0.17 expect background events
  - Predominantly single scatter pile-up
- Maximum mass probed by LZ  $3.9 \times 10^{17}$ GeV/c$^2$
- World leading sensitivity
Conclusions

Cutting edge physics:

- **World-leading spin-independent WIMP-nucleon cross-section limit** set using only 60 live days
- **Competitive searches** for physics in low energy electron recoils
- **Extended analysis** for many operators in the EFT high energy nuclear recoil searches
- **New parameter space excluded** by ultra heavy MIMP search

Future work:

- Data taking for further science searches!
- **XLZD** consortium working towards the ultimate xenon observatory

LZ talks at IOP:

- Calculation of Neutron Production in **(alpha, n) Reactions** - Piotr Krawczun - Poster Reception 1
- **LZ Outer Detector** - Sam Woodford - 10:15 Wed 10th (Session D)
- Characterising **Electric Fields** - Sparshita Dey - 11:00 Wed 10th (Session D)
- Multiple Scatter **Neutron Background Measurements** - Jo Orpwood - 11:15 Wed 10th (Session D)
- **Background from environment** for LXe dark matter experiments - Jemima Tranter - 11:30 Wed 10th (Session D)
- **Low energy electron recoil** searches within LZ - Riyat Harkirat - 14:15 Wed 10th (Session D)
- **Fast likelihood functions** for dark matter and rare event searches - Joshua Green - 14:30 Wed 10th (Session D)
Beyond LZ: XLZD Consortium

- XENON, LZ and DARWIN collaborations working towards a G3 xenon observatory
- WIMP sensitivity down to “neutrino fog”
- Plus other dark matter candidates, $0\nu\beta\beta$, atmospheric neutrinos

https://xlzd.org
Data Quality Analysis

Analysis cuts:

- Remove time periods with instabilities and high rates
- Remove accidentals using pulse-based cuts
- Define WIMP Region of Interest and 5.5 t Fiducial Volume
- Veto events with coincident signal in Skin or OD