The LUX-ZEPLIN Dark Matter Search

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for the LZ collaboration

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LUX-ZEPLIN

A direct-detection search, looking primarily (but not only) for WIMP dark matter with a xenon nucleus
LZ collaboration, June 2018
36 institutions
250 scientists, engineers, and technicians

1) IBS Center for Underground Physics (South Korea)
2) LIP Coimbra (Portugal)
3) MEPhI (Russia)
4) Imperial College London (UK)
5) STFC Rutherford Appleton Lab (UK)
6) University College London (UK)
7) University of Bristol (UK)
8) University of Edinburgh (UK)
9) University of Liverpool (UK)
10) University of Oxford (UK)
11) University of Sheffield (UK)
12) Black Hill State University (US)
13) Brookhaven National Lab (US)
14) Brown University (US)
15) Fermi National Accelerator Lab (US)
16) Lawrence Berkeley National Lab (US)
17) Lawrence Livermore National Lab (US)
18) Northwestern University (US)
19) Pennsylvania State University (US)
20) SLAC National Accelerator Lab (US)
21) South Dakota School of Mines and Technology (US)
22) South Dakota Science and Technology Authority (US)
23) Texas A&M University (US)
24) University at Albany (US)
25) University of Alabama (US)
26) University of California, Berkeley (US)
27) University of California, Davis (US)
28) University of California, Santa Barbara (US)
29) University of Maryland (US)
30) University of Massachusetts (US)
31) University of Michigan (US)
32) University of Rochester (US)
33) University of South Dakota (US)
34) University of Wisconsin - Madison (US)
35) Washington University in St. Louis (US)
36) Yale University (US)
Why use liquid xenon?
Why use liquid xenon?

Large signal

- Scalar WIMP-nucleus interactions feature an \( A^2 \) dependence on the scattering rate. \textit{Xe has a large} \( A \).
- Natural xenon contains \(~50\%\) odd isotopes, giving high sensitivity to spin-coupled interactions.

\[ M_\chi = 50 \text{ GeV}, \sigma_{\text{nucleon}} = 10^{-46} \text{ cm}^2 \]
Why use liquid xenon?

Low background

1. Easily scalable to large size
2. 3-D localization of events
3. 1 and 2 permit an ultra-low-background inner region to be defined.

* "DRU" = evt/kg/day/keV

It's quiet in the middle
Moore’s Law

Doubling every 2 years

Factor 10 every 6.5 years

Courtesy R. Gaitskell

http://education.mrsec.wisc.edu/SlideShow/images/computer/Moores_Law.png
The LUX-ZEPLIN Dark Matter Search

A. Manalaysay

Limit Scalar Cross-section [60 GeV WIMP]

Year

Dark Matter Searches: Past, Present & Future

~ 1 event kg\(^{-1}\) day\(^{-1}\)

~ 1 event 100 kg\(^{-1}\) yr\(^{-1}\)

Ge
Nal
Cryodet
Liq. Noble
Projected
Signal

SuperCDMS also focuses on light WIMPs

Courtesy R. Gaitskell
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Dark Matter Searches: Past, Present & Future

Limit Scalar Cross-section cm$^2$ [60 GeV WIMP]

~ 1 event kg$^{-1}$ day$^{-1}$

~ 1 event 100 kg$^{-1}$ yr$^{-1}$

Year


10$^{-47}$ 10$^{-46}$ 10$^{-45}$ 10$^{-44}$ 10$^{-43}$ 10$^{-42}$ 10$^{-41}$ 10$^{-40}$

SuperCDMS also focuses on light WIMPs

Courtesy R. Gaitskell
Dark Matter Searches: Past, Present & Future

Limit Scalar Cross-section cm$^2$ [60 GeV WIMP]

- ~ 1 event kg$^{-1}$ day$^{-1}$
- ~ 1 event 100 kg$^{-1}$ yr$^{-1}$

- Ge
- NaI
- Cryodet
- Liq. Noble
- Projected
- Signal

Year


SuperCDMS also focuses on light WIMPs

Moore's Law

Courtesy R. Gaitskell
Dual-phase time projection chamber (TPC)

- Main target is liquid xenon (180 K).
- Primary scintillation light (S1) emitted from interaction vertex.
- Ionized $e^-$ drift to the liq. surface; produce prop. light as they travel through gas (S2).
- S1 and S2 permit:
  - Energy reconstruction
  - 3-D position reconstruction
  - Background rejection

Details in our Technical Design Report: arXiv/1703.09144
WIMPs: expected signal

- Majority of BG is from electronic recoils (ER).
- WIMPs detected via nuclear recoils (NR).
- ER and NR have different S1/S2 ratio.

- Shape of observed spectrum gives info on WIMP mass.
- Low mass sensitivity affected by NR from $^8$B solar neutrinos (~7 events in 1000d, depends strongly on low-en. NR efficiency).
Sanford Underground Research Facility

LUX/LZ, located on the 4850 level (~1.5 km underground) in Lead, South Dakota. Solar neutrinos first detected here. Muon flux down by $10^7$. 
The LUX-ZEPLIN Dark Matter Search

- LZ: factor of ~50 larger fiducial than LUX
- Lower backgrounds

(See talk by Shaw Sally)
Cryostat vessels

Outer cryostat vessel

UV reflectors in the inner cryostat vessel
• 7 tonnes active mass.
• Active LXe “skin” veto (outside of TPC)
• Gd-loaded LAB scintillator veto
• LUX’s water shield
• External liquefaction/purification tower
Photomultiplier Tubes

Hamamatsu

R11410

R8520

R8778 (recycled from LUX)

Main TPC

Xe “skin” veto

Scintillator veto

R5912

3 inch

1 inch

2 inch

8 inch
Photomultiplier Tubes

Hamamatsu

R11410

3 inch

R8520

1 inch

Completed lower PMT array

Main TPC

Xe “skin” veto

Scintillator veto
TPC

SECTION VIEW OF LXe TPC

Top PMT array
Side Skin PMTs
TPC field cage

GAS PHASE AND ELECTROLUMINESCENCE REGION

Anode
Gate
LXe surface
Weir trough
Skin PMT

Bottom PMT array
Side skin PMT mounting plate
Reverse-field region
Cathode grid

HV CONNECTION TO CATHODE
Outer detector

- Gd-doped LAB liquid scintillator.
- Neutron and gamma veto.
- $4\pi$ coverage
- Cutouts for cryogenics, electronics, neutron tubes, HV
- Screener vessel already deployed in LUX water shield, good results.
Outer detector

• Gd-doped LAB liquid scintillator.
• Neutron and gamma veto.
• 4\(\pi\) coverage
• Cutouts for cryogenics, electronics, neutron tubes, HV
• Screener vessel already deployed in LUX water shield, good results.
Backgrounds

No vetoes

With vetoes (LXe skin and liquid scint.)
Scientific Reach — Standard WIMPs

Min. SI sensitivity vs. live-time

- Reach LUX sensitivity within ~4-5 days
- Reach XENON1T (2018) sensitivity within ~2 weeks
- Min. sensitivity $1.6 \times 10^{-48} \text{ cm}^2$ after 1000 live-days

arXiv:1802.06039
Scientific Reach — Standard WIMPs

Proj. [SI] sensitivity vs. WIMP mass

- With LZ, we begin to probe a significant region of param. space favored in pMSSM
- Sensitivity not yet limited by CNNS irreducible BG
- But expect to see many CNNS events from $^8$B, and potentially 1 event from atm+DSNB.

arXiv:1802.06039
The LUX-ZEPLIN Dark Matter Search

Scientific Reach — Standard WIMPs

Discovery potential

- Setting limits is great, but really we are doing this to make a detection.
- Projected detection potential reaches (at min)
  - $3.8 \times 10^{-48} \text{ cm}^2$ at $3\sigma$
  - $6.7 \times 10^{-48} \text{ cm}^2$ at $5\sigma$

arXiv:1802.06039
Scientific Reach — Axions and ALPs

Dark-matter ALPs

Solar axions

The LUX-ZEPLIN Dark Matter Search

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UC DAVIS
Neutrinoless double beta decay

- $^{136}$Xe Q value at 2458 keV
- We project 1% energy resolution at Q value.
- Main BG from PMTs+Cryostat
- Dedicated fiducial volume: 957 kg (BG optimized)
- 1000 live-day run
- Median 90% CL sensitivity on $^{136}$Xe 0νββ half-life:
  \[ T_{1/2}^{0ν} > 0.74 \times 10^{26} \text{ years (median)} \]
Summary

- Noble-liquid TPCs leading the field in sensitivity to WIMP

- LZ is the successor to ZEPLIN and LUX. 7 tonnes LXe (5.6 tonnes fiducial)

- LZ will reach sensitivity of $1.6 \times 10^{-48}$ cm$^2$ for SI WIMP-nucleon interactions. Other dark-matter results expected as well.

- Sensitivity to $0\nu\beta\beta$ of $^{136}$Xe of $0.74 \times 10^{26}$ years

- LZ is at an advanced stage. Construction already begun, planning first science data in 2020.