Status of LUX and LUX-ZEPLIN dark matter searches
The Team
Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment
D. Akerib et al. (E. Monzani)
Physical Review D, Accepted

The LUX-ZEPLIN Experiment
D. Akerib et al.
Nuclear Inst. and Methods in Physics Research, A (2019)163047

Measurement of the Gamma Ray Background in the Davis Cavern at the Sanford Underground Research Facility
D. Akerib et al. (S. Shaw)
Astroparticle Physics 116 (2020) 102391

The Science Capabilities of LUX-ZEPLIN: Searches for New Physics with low energy Electron Recoils
D. Akerib et al. (Edinburgh group)
Improved Modeling of Electronic Recoils in Liquid Xenon Using LUX Calibration Data
D. Akerib et al.

Low-energy (0.7-74 keV) nuclear recoil calibration of the LUX dark matter experiment using D-D neutron scattering kinematics
D. Akerib et al.

Extending light WIMP searches to single scintillation photons in LUX
D. Akerib et al. (Nellie)

First direct detection constraint on mirror dark matter kinetic mixing using LUX 2013 data
D. Akerib et al. (Elizabeth) PRD 2019 (with referees)

Search for two neutrino double electron capture of 124Xe and 126Xe in the full exposure of the LUX detector
D. Akerib et al. (MF Marzioni, ASM, Alex Lindote)
PRC 2019 Submitted

Improved Measurements of the beta-decay Response of Liquid Xenon with the LUX Detector
D. Akerib et al. (Jon B)
Physical Review D 100 (2019) 22002
Publish or perish…

Results of a search for sub-GeV dark matter using 2013 LUX data
D. Akerib et al (Lucie)
Physical Review Letters 122 (2019) 131301

Search for annual and diurnal rate modulations in the LUX experiment
D. Akerib et al. (Jingke Xu)
Physical Review D 98 (2018) 62005

LUX Trigger Efficiency
D. Akerib et al. (Mongkol)

Liquid xenon scintillation measurements and pulse shape discrimination in the LUX dark matter detector
D. Akerib et al. (Dev)
Physical Review D 97 (2018) 112002

Calibration, event reconstruction, data analysis and limits calculation for the LUX dark matter experiment
D. Akerib et al. (Carmen)
Physical Review D 97 (2018) 102008
What are we looking for?

Cosmic Visions report (2017)

xkcd:2035
What are we looking for?

- Strong incentive for searches to be as broad as possible

Cosmic Visions report (2017)

→ Strong incentive for searches to be as broad as possible
New kids on the block...

LZ (7t) 2020-

XENONnT (5.9t) 2019-

PandaX-IV (4t) 2020-

DarkSide-20K (23 t) 2022-
New kids on the block…

LZ (7 t) 2020-

XENONnT (5.9 t) 2019-

PandaX-IV (4 t) 2020-

DarkSide-20K (23 t) 2022-
Sanford Underground Research Facility
Lead, South Dakota, USA

General Homestake Mine Development

Davis Campus Water Tank
Sanford Underground Research Facility
Lead, South Dakota, USA

Davis Campus Water Tank
Science in an extreme environment
LUX-ZEPLIN (LZ)

- 7.0 T active LXe
- 5.6T fiducial
- Instrumented Xe skin detector
- 50 kV cathode high voltage
- 17 tonnes Gd-LS Outer Detector
- LXe supply & return
- Neutron conduit
- Lower PMT cable conduit

arXiv:1910.09124
PMTs

3” Hamamatsu R11410-22

Average QE: 31% (cold); Average Gain: 3.5x10^6; Top array: 253 units; Bottom array: 241 units
Grids

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Voltage (kV)</th>
<th>Diam. (μm)</th>
<th>Pitch (mm)</th>
<th>Num.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode</td>
<td>+5.75</td>
<td>100</td>
<td>2.5</td>
<td>1169</td>
</tr>
<tr>
<td>Gate</td>
<td>−5.75</td>
<td>75</td>
<td>5.0</td>
<td>583</td>
</tr>
<tr>
<td>Cathode</td>
<td>−50.0</td>
<td>100</td>
<td>5.0</td>
<td>579</td>
</tr>
<tr>
<td>Bottom</td>
<td>−1.5</td>
<td>75</td>
<td>5.0</td>
<td>565</td>
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</tbody>
</table>
Cryostats (inner, outer)

Identification of radiopure titanium for the LZ dark matter experiment and future rare event searches
LZ-UK status

All UK hardware contributions *complete*
ASSAY CAMPAIGN

MONTE CARLO SIMULATION

Known source event rates
### Assay campaign

<table>
<thead>
<tr>
<th>Technique</th>
<th>Isotopic Sensitivity</th>
<th>Typical Sensitivity</th>
<th>Sample Mass</th>
<th>Sampling Duration</th>
<th>Destructive/Non-destructive and Notes</th>
<th>Locations (and Number of Systems if &gt; 1)</th>
<th>Samples Assayed</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPGe</td>
<td>$^{238}\text{U}$, $^{235}\text{U}$, $^{232}\text{Th}$ chains, $^{40}\text{K}$, $^{60}\text{Co}$, $^{137}\text{Cs}$ any γ-ray emitter</td>
<td>$5 \times 10^{-11}$ g/g U, $10^{-10}$ g/g Th</td>
<td>kg</td>
<td>Up to 2 weeks</td>
<td>Non-destructive, very versatile, not as sensitive as other techniques, large samples</td>
<td>SURF ×6, LBNL ×1, U. Alabama ×2, Boulby ×7</td>
<td>926</td>
</tr>
<tr>
<td>ICP-MS</td>
<td>$^{238}\text{U}$, $^{235}\text{U}$, $^{232}\text{Th}$ (top of chain)</td>
<td>$10^{-12}$ g/g</td>
<td>mg to g</td>
<td>Days</td>
<td>Destructive, requires sample digestion, preparation critical</td>
<td>UCL, IBS, BHUC, U. Alabama</td>
<td>157</td>
</tr>
<tr>
<td>NAA</td>
<td>$^{238}\text{U}$, $^{235}\text{U}$, $^{232}\text{Th}$ (top of chain), K</td>
<td>$10^{-12}$ g/g to $10^{-14}$ g/g</td>
<td>g</td>
<td>Days to weeks</td>
<td>Destructive, useful for non-metals, minimal sample preparation</td>
<td>Irradiated at MITR-II, HPGe assay at U. Alabama</td>
<td>3</td>
</tr>
<tr>
<td>GD-MS</td>
<td>$^{238}\text{U}$, $^{235}\text{U}$, $^{232}\text{Th}$ (top of chain)</td>
<td>$10^{-10}$ g/g</td>
<td>mg to g</td>
<td>Days</td>
<td>Destructive, minimal matrix effects, cannot analyze ceramics and other insulators</td>
<td>National Research Council Canada</td>
<td>2</td>
</tr>
<tr>
<td>Radon Emanation</td>
<td>$^{222}\text{Rn}$</td>
<td>0.1 mBq</td>
<td>kg</td>
<td>1 to 3 weeks</td>
<td>Non-destructive, large samples, limited by size of emanation chamber</td>
<td>UCL ×2, U. Maryland, SDSM&amp;T ×2, U. Alabama ×2</td>
<td>175</td>
</tr>
<tr>
<td>Surface α</td>
<td>$^{210}\text{Pb}$, $^{210}\text{Bi}$, $^{210}\text{Po}$</td>
<td>$120 \alpha/(m^2 \cdot day)$</td>
<td>g to kg</td>
<td>&lt;1 week</td>
<td>Non-destructive, thin samples, large surface area required</td>
<td>SDSM&amp;T (Si), Brown (XIA), Boulby (XIA), U. Alabama (Si)</td>
<td>306</td>
</tr>
</tbody>
</table>
Sparing you the details!

→ Complete understanding of ER and NR rates from known sources over the full relevant energy range
  • Cosmics, external, internal, surfaces, $\beta$, $\gamma$, $x$, $\alpha$, $n$, $\nu$, …
  • Includes f.v., LXe skin, OD, water veto
• Further details in backup slides
Backgrounds + Signal Model + PLR → Science Reach (Sensitivity)
What this means for WIMPs…

Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment


(The LUX-ZEPLIN Collaboration)

1SLAC National Accelerator Laboratory, Menlo Park, CA 94025-7015, USA
2Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Stanford, CA 94305-4085, USA
3University of Michigan, Randall Laboratory of Physics, Ann Arbor, MI 48109-1040, USA
4University of Wisconsin-Madison, Department of Physics, Madison, WI 53706-1550, USA
5Imperial College London, Physics Department, Blackett Laboratory, London SW7 2AZ, UK
6South Dakota School of Mines and Technology, Rapid City, SD 57701-3901, USA
7University of Maryland, Department of Physics, College Park, MD 20742-1411, USA

arXiv:1802.06039
Full simulation of event rates

- ER and NR events discriminated from their different S2/S1 proportion
- ER and NR bands obtained through calibration
- Many $\gamma$ and $n$ events occur close to the TPC wall
  - Veto them: Xe skin and OD
  - Define a fiducial region: 5.6 t for the WIMP search
- Simulated dataset inside the fiducial volume for the full LZ exposure (1000 days $\times$ 5600 kg)
  - PLR analysis
  - Blinding via salt

$\log_{10}(S2c [phd])$ vs $S1c [phd]$

ER band

NR band

Energy isoncontour lines

ER: electron recoil
NR: neutron recoil
Expected limits on spin-independent cross-sections for 1000 days of live time (left) and discovery potential (right).
More Science

**SD interactions**, axions, axion-like particles (ALPs), sub-GeV dark matter, leptophillic axial vector DM, astrophysical neutrinos, $0\nu\beta\beta$'s, EFT analyses...

SD WIMP-neutron (left) and WIMP-proton (right) scattering for a 1000 live day run with a 5.6 tonne fiducial mass.

More Science

SD interactions, axions, axion-like particles (ALPs), **sub-GeV dark matter**, leptophillic axial vector DM, astrophysical neutrinos, $0\nu\beta\beta$’s, EFT analyses...

**Migdal effect**

- $\chi$-n scatter leads to *additional* ER signal
- ER quenching is $<<$ NR quenching
- Even if NR signal is below threshold, ER may still be visible
- Extends low mass sensitivity
- **Note:** *The reality of the Migdal effect is yet to be confirmed!*

Matthew J. Dolan, Felix Kahlhoefer, and Christopher McCabe
More Science

SD interactions, axions, axion-like particles (ALPs), sub-GeV dark matter, leptophillic axial vector DM, astrophysical neutrinos, $0\nu\beta\beta$’s, EFT analyses...

Migdal effect

D. S. Akerib et al. (LUX Collaboration) Phys. Rev. Lett. 122, 131301
More Science

SD interactions, axions, axion-like particles (ALPs), sub-GeV dark matter, **Mirror dark matter**

- Submitted PRD -

[Graphs showing recoil rate and sensitivity for different energies]
In the context of this meeting...

Updating the SHM

What is the impact on direct detection (with LZ)?

Looking *beyond* LZ…
XENON FUTURES:

R&D FOR A GLOBAL RARE EVENT OBSERVATORY
“Generation 3” dark matter

A ~50 ton LXe rare event observatory
- Expect to be operating by ~2030
- Broad science remit

Requires R&D now. UK Objectives:
- Direct observation of Migdal effect
- Enhanced liquid xenon technology & readout
- Cryogenic low background electronics
- Advanced radiopurity control techniques
- Design studies for a G3 experiment

‘Phase 1’ (18mo) just approved by STFC
‘Phase 2’ (24 mo) under evaluation.
In parallel...

STFC Opportunities Call 2019
Lead: Tim Sumner, Imperial College

Feasibility Study for Developing the Boulby Underground Laboratory into a Facility for Future Major International Projects

• Typical experiment requirements and expectations of facility support
• Use cases for 50-500 tonnes liquid targets for Dark Matter and 1000kg solid targets for 0νBB derived from existing experiments/proposals
• Consultation with wider community
• Recommendation for future developments with timescales and costs
Great Progress

To summarise...
To summarise...

Great Progress
Still lots to do
Great Progress
Still lots to do
Roll on 2020!
The LUX-ZEPLIN Collaboration

- Black Hills State University
- Brandeis University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics, Korea
- Fermi National Accelerator Laboratory
- Imperial College London
- LIP Coimbra, Portugal
- Lawrence Berkley National Laboratory
- Lawrence Livermore National Laboratory
- MEPhl-Moscow, Russia
- Northwestern University
- Pennsylvania State University
- Royal Holloway, University of London
- SLAC National Accelerator Laboratory
- South Dakota School of Mines and Technology
- South Dakota Science and Technology Authority
- STFC Rutherford Appleton Laboratory
- Texas A&M University
- University at Albany, SUNY
- University College London
- University of Alabama
- University of Bristol
- University of California, Berkeley
- University of California, Davis
- University of California, Santa Barbara
- University of Edinburgh
- University of Liverpool
- University of Maryland
- University of Michigan
- University of Massachusetts
- University of Oxford
- University of Rochester
- University of Sheffield
- University of South Dakota
- University of Wisconsin – Madison
- Washington University in St. Louis
- Yale University