Status of the LZ experiment

Alden Fan for the LZ collaboration
(Stanford/KIPAC/SLAC)

9th Symposium on Large TPCs for Low-energy Rare Event Detection
December 13, 2018
Dark matter search with a dual-phase Xe TPC

• Primary: search for rare nuclear recoils from WIMP dark matter
• Also sensitive to low energy recoils from other exotica

• Dual-phase time projection chamber with Xe gives precise 3D position, energy, electron/nuclear recoil discrimination
Nested detectors

- Xe TPC
- Xe skin region
- Liquid scintillator
- High purity water
Xenon TPC

- 1.5 m diameter x 1.5 m height
- 7t active LXe (5.6t fiducial)
- 50 kV cathode HV
- 494x 3” PMTs

- Gas circulation @ 500 slpm (turnover full mass in 2.5 days)
- Instrumented Xe skin region, outside the field cage
Gd-loaded outer detector

• **Capabilities:**
  - Tag individual neutrons
  - Characterize LZ radiation environment
  - 17.3 tonnes Gd-loaded liquid scintillator
  - Neutrons thermalize & capture
    - $n + \text{Gd} \rightarrow \text{Gd} + (4-5x) \gamma (~8.5 \text{ MeV})$
    - $\text{natGd} \text{ thermal n-capture } \sigma \rightarrow 40 \text{ kbarn}$
    - Capture time: 30 $\mu$s w/ 0.1% Gd loading
  - 200 keV threshold
Background sources and mitigation

• Detector materials
  • Radio-assay campaign with gamma-screening, ICPMS, NAA

• Rn emanation
  • Four Rn emanation screening sites
  • Target Rn activity: 2 μBq/kg

• Rn daughters and dust on surfaces
  • TPC assembly in Rn-reduced cleanroom
  • Dust <500 ng/cm³ on all LXe wetted surfaces
  • Rn-daughter plate-out on TPC walls <0.5 mBq/m²

• Xenon contaminants — \(^{85}\text{Kr}, {^{39}\text{Ar}}\)
  • Charcoal chromatography @ SLAC
  • Final natKr/Xe 0.015 ppt

• Cosmogenics and externals
  • 4300 m.w.e. underground at Sanford Underground Research Facility in Lead, SD
  • Instrumented Xe skin region
  • Gd-LS outer detector
  • High purity water shield

Many sources of BG
Many methods for BG mitigation
Background suppression

Expected BG NR cts / 1000 days in 5.6t FV in 6-30 keV_{nr}:

Without vetoing: 10.43
With skin and OD vetoes: 1.03

NR BG equivalent fiducial volume:
Without vetoing: 3.2t
With skin and OD vetoes: 5.6t
Discrimination

- Light vs. charge distribution varies for ERs vs. NRs → discrimination
- Build on exquisite high statistics calibrations in LUX
- Model with NEST for sensitivity projection
- Extensive calibrations planned for LZ to map bands in situ

ER and NR band calibrations from LUX
**Expected backgrounds**

5.6 ton fiducial, 1000 live-days  
1.5-6.5 keV\textsubscript{ee} (6-30 keV\textsubscript{nr})  
single scatters, anti-coincidence with vetoes

<table>
<thead>
<tr>
<th>Background Source</th>
<th>ER [cts]</th>
<th>NR [cts]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector components</td>
<td>9</td>
<td>0.07</td>
</tr>
<tr>
<td>Dispersed Radionuclides — Rn, Kr, Ar</td>
<td>819</td>
<td>—</td>
</tr>
<tr>
<td>Laboratory and Cosmogenics</td>
<td>5</td>
<td>0.06</td>
</tr>
<tr>
<td>Surface Contamination and Dust</td>
<td>40</td>
<td>0.39</td>
</tr>
<tr>
<td>Physics Backgrounds — 2(\beta) decay, neutrinos*</td>
<td>322</td>
<td>0.51</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1195</td>
<td>1.03</td>
</tr>
<tr>
<td><strong>After 99.5% ER discrimination, 50% NR efficiency</strong></td>
<td>5.97</td>
<td>0.51</td>
</tr>
</tbody>
</table>

* not including \(^{8}\text{B}\) and HEP
Sensitivity

Simulation of a 1000 day run of LZ

Projected detection and exclusion curves

Projected:

90% CL limit

3σ

5σ

90% CL minimum of $1.6 \times 10^{-48}$ cm$^2$ at 40 GeV/c$^2$

TPC: PMTs

- PMT arrays assembled in PALACE
  - PMT dark electrical testing
  - Shipping housing
  - Dust control with HEPA filtered air
- Low airborne Rn, 2-4 Bq/m³
- Witness plates for dust surveillance
TPC: field cage

Assembling *now*
TPC: grids

• (Semi-)automated loom for weaving SS wire meshes
• Video of the weaving process: https://www.youtube.com/watch?v=yNycDcMQkss
• Final LZ grids in production
SLAC test platform

Phase 1

• Field cage and “extraction region” design
• Cryogenics and circulation design
• Instrumentation testbed

Phase 2

• Validate LZ grids
• Gas Xe
• Single electron sensitivity
Cathode HV

- Extensive prototyping at design field (50 kV/cm)
- Tests of cathode cable grading structure in liquid argon; successfully reaches 120 kV (50 kV required)
- Embedded polyethylene conductive components in HV cable $\rightarrow$ simple O-ring seal
Titanium cryostat

- Intensive R&D program identified low activity titanium material (Astropart. Phys. 96 (2017) 1-10)
- Arrived at SURF May 14, 2018
Outer detector

- Acrylic vessels staged underground in water tank
- Gd-LS production equipment being installed at BNL
- All PMTs in hand, testing at IBS (Korea) is nearly done
Xe procurement and Kr removal

- 7t Xe in hand
- Chromatography to separate Kr from Xe.
  - Demonstration of 0.06 ppt in R&D at SLAC
  - Production system designed to remove to 0.015 ppt (1/10 solar neutrino BG)
- Kr removal at SLAC on track to start by July 2019 and finish by end 2019.
Mock data challenges

- Develop and validate all software before first physics data
- Simulate 6 months of LZ data taking, including detector pathologies, through realistic waveforms
- Analyzers search for injected signal (possibly none!)
Timeline

- **2015**
  - CDR: Sep 2015
  - US CD-1: Mar 2015

- **2016**
  - Titanium paper: Feb 2017

- **2017**
  - TDR: Mar 2017
  - US CD-3: Jan 2017
  - TPC moves underground: Summer 2019

- **2018**
  - WIMP sensitivity paper: Feb 2018

- **2019**
  - Operations start: Apr 2020
  - US CD-4: Apr 2020
LZ collaboration

38 institutions, ~250 scientists, engineers, technicians

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