LZ: A Second Generation Experiment for the Direct Detection of Dark Matter

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The Dark Matter Problem

A good problem to have. There is a known effect looking for an answer ... as opposed to proposed models looking for an experimental effect.

A real challenge/opportunity for experimentalists to study this known energy density.

• Postulate 1: DM is a particle.

• Postulate 2: DM and SM particles interact with some force that is very weak but much stronger than gravity.
Direct Detection of DM

Basic goal: search for nuclear recoil from DM elastic scattering.

Simple dynamics. Cross section $\alpha (\text{form factor})^2$

Spin-independent: Nucleon form factor gives rise to $A^2$ enhancement due to coherence. The dependence on $q^2$ is also contained in the form-factors.

WIMPs are the leading candidates for GeV-scale mass.

Spin-dependent: Form factor depends on nuclear spin. No coherence enhancement.
A compact history of WIMP Searches

LZ is poised to possibly provide an end-point to this saga ... hopefully by discovering WIMPs or, by ruling out most of the theoretical and experimentally accessible landscape.

Plots compiled by Mike Witherell, UCSB
A Compilation of Limits and Reaches
LZ Collaboration

38 institutions from US, UK, Portugal, Russia and South Korea. Still growing. At present >250 members.
Two-phase TPC Technique

Excellent introduction yesterday by Alex Bolozdynya

- 5.6 ton total fiducial mass nominally
- Turn-on in 2020, with 1,000 live-days of running.
- 6 keVnr threshold with >99.5% discrimination
- Spin-independent WIMP search sensitivity goal of \( \leq 2.3 \times 10^{-48} \text{ cm}^2 \) interaction cross-section for a WIMP mass of 40 GeV
LZ
Total mass – 10 T
Active Mass – 7 T
Fiducial Mass – 5.6 T

Scale Up ~50x in Fiducial Mass
Doubly Shielded TPC

Dual phase xenon TPC, with 494 TPC + 131 Xe skin PMTs

LXe Heat Exchanger

Cathode HV Feedthrough

Instrumentation Conduits

Existing Water Tank, and SURF Infrastructure

Gd-Loaded Liquid Scintillator Veto

Outer Detector PMTs (120)

D-D neutron tube
Sanford Underground Research Facility

LUX was operated ~1.5 km underground in the Davis cavern. ~$10^{-7}$ reduction in muon flux. ~6m diameter water shield.

LZ will utilize infrastructure developed for LUX
• WIMPs detected via nuclear recoils (NR). Majority of BG is from electronic recoils (ER).
• Shape of observed spectrum gives info on WIMP mass.
• Low mass sensitivity affected by NR from $^8$B solar neutrinos ($7\pm3$ events in 1000d).

ER and CNS spectra have been highly exaggerated to show shapes.
Background Rejection

Three layers of defense against BG
1. instrumented xenon “skin” layer
2. 61-cm thick Gd-loaded scintillator
3. water shield, an active muon veto
Sources of Background

<table>
<thead>
<tr>
<th>Item</th>
<th>ER cts</th>
<th>NR cts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector Components</td>
<td>6.2</td>
<td>0.07</td>
</tr>
<tr>
<td>Dispersed radionuclides (Rn, Kr, Ar)</td>
<td>911</td>
<td>-</td>
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<tr>
<td>Laboratory and cosmogenic</td>
<td>4.3</td>
<td>0.06</td>
</tr>
<tr>
<td>Fixed surface contamination</td>
<td>0.19</td>
<td>0.37</td>
</tr>
<tr>
<td>$^{136}$Xe 2νββ</td>
<td>67</td>
<td>-</td>
</tr>
<tr>
<td>Neutrinos ($\nu$-e, $\nu$-A)</td>
<td>255</td>
<td>0.72</td>
</tr>
<tr>
<td>Total</td>
<td>1244</td>
<td>1.22</td>
</tr>
<tr>
<td>Total (with 99.5% ER discrimination, 50% NR efficiency)</td>
<td>6.22</td>
<td>0.61</td>
</tr>
<tr>
<td>Total ER+NR background events</td>
<td>6.83</td>
<td></td>
</tr>
</tbody>
</table>

Estimates for 5.6M kg-days and energy ranges: 1.5-6.5 keV$_{ee}$/6-30 keV$_{nr}$
Sensitivity Projection

- LZ 90%CL Median (Baseline)
- LZ 90%CL Median (Goal)
- CMSSM (1σ)
- CMSSM (2σ)
- Zeplin-III (2011)
- PandaX (2016)
- LUX WS2013+WS2014-16
- XENON1T (2017)

- ν-N coherent scattering
- 1 event
- 3σ significance
- 1000 tonne-years

WIMP mass [GeV/c^2]
Summary

- LZ has been fully approved by funding agencies and is in the process of construction.
- There are no major technical risks at this point.
- Expected completion by early 2020.
- Data taking in late 2020.
- Stay tuned.