The LUX-Zeplin Dark Matter Search: detector design and sensitivity

Maria Elena Monzani on behalf of the LZ Collaboration

DPF FNAL, July 31 2017
LZ = LUX + ZEPLIN

LZ collaboration:

- 38 institutions (USA, UK, Portugal, Russia, South Korea)
- 250+ scientists, engineers, and technicians

MEM-DPF17

LZ collaboration meeting, SURF, July 19 2017
Moore’s Law of Direct Detection

![Graph showing direct detection limits for different detectors and years.](image)

- Ge, NaI no discrimination
- Ge, w/discrim.
- LXe, w/discrim.
- LUX
- XENON-1T
- LZ < 2.3×10^{-48} \text{ cm}^2 (XENON-nT)

MEM-DPF17
Noble Liquid TPCs for WIMP Detection

- WIMP-induced nuclear recoils: ~ few keV energy
  - $S_1, S_2 \rightarrow$ event energy
  - $S_2$ image $\rightarrow$ xy coordinate
  - $S_1$-$S_2$ timing $\rightarrow$ z coord.
  - $S_2/S_1$ (Xe) $\rightarrow$ recoil type
  - $S_1$ PSD (Ar) $\rightarrow$ recoil type

- No long-lived isotopes (Xe)
- Self-shielding
- Recoil discrimination
LZ at SURF

4,850 ft (Davis Cavern)

Rn-reduced cleanroom

South Dakota folklore...

SITE OF CAPTURE OF THE ASSASSIN JACK McCALL WHO SHOT "WILD BILL" HICKOK AUG 2, 1876
LZ Detector Overview

- Cathode high voltage feedthrough
- Instrumentation conduits
- Liquid Xe HX
- Existing water tank
- Gadolinium-loaded liquid scintillator veto
- Outer detector PMTs
- 7 tonne active volume liquid Xe TPC. 10 tonnes total
LZ as a Discovery Instrument

- 0.61 m thick Gd-loaded scintillator
- instrumented Xenon “skin”
- we can tag neutrons and gammas

In-situ monitoring of residual backgrounds

ROI + S.S. + Vetoes

Fiducial Mass: 5.6 T (Nominal)
Expected counts in 1,000 live days in an indicative 5.6-tonne fiducial mass in [1.5-6.5] keV$_{ee}$ (ER) and [6-30] keV (NR):

<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>
</tr>
<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 2v$\beta\beta$</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><strong>Total</strong></td>
<td>1244</td>
<td>1.22</td>
</tr>
<tr>
<td><strong>Total (with 99.5% ER discrimination, 50% NR efficiency)</strong></td>
<td>6.22</td>
<td>0.61</td>
</tr>
<tr>
<td><strong>Total ER+NR background events</strong></td>
<td></td>
<td>6.83</td>
</tr>
</tbody>
</table>

- ER/NR rejection is crucial to the success of the experiment
- PLR analysis: very powerful at rejecting residual ER counts
High Statistics Calibrations in LUX

Electron Recoil (ER) (Tritiated methane)

Nuclear Recoil (NR) (DD neutron gun)

LUX 2015: 1.1 keVnr cutoff

LUX 2014: 3 keVnr cutoff

Charge Yield

Light Yield

Efficiency

arXiv:1512.03506
WIMP Signal Region in LZ

PDF known with great precision

arXiv:1703.0914
1,000 days of simulated LZ (5.6 T)

\[ 10^{-48} \text{ cm}^2 \]

- Background
- WIMP (3\(\sigma\) significance, 40 GeV)
- \( ^{8}\text{B} \) neutrinos \( \sigma = 6 \times 10^{-48} \text{ cm}^2 \)

\[ \log_{10}(S2/S1) \]

\[ S1 \text{ [phd]} \]

\[ 1 \text{ keV}_{ee}, 5 \text{ keV}_{nr}, 3 \text{ keV}_{ee}, 14 \text{ keV}_{nr}, 5 \text{ keV}_{ee}, 22 \text{ keV}_{nr} \]

arXiv:1703.0914
PHASE I TEST DETECTOR
FULL-SCALE GRID LOOM AT SLAC
Summary and Outlook

• LZ achieved CD-3 milestone on 02/09/17:
  – 2016: LUX removed from Davis campus
  – July 2017: surface assembly preparation
  – July 2018: underground installation
  – 2020: begin LZ commissioning

• Long lead-time procurements underway
• Quality assurance and testing for hardware underway; material screening program busy
• LZ benefits from excellent LUX calibrations and understanding of backgrounds

• LZ science run to start in 2021:
  – 1000 live days, 5.6 tons fiducial mass
  – Spin-Indep. sensitivity: $2.3 \times 10^{-48}$ cm$^2$
  – Start probing the neutrino floor