Direct search for WIMP Dark Matter particles with the LUX-ZEPLIN (LZ) detector

Kirill Pushkin
University of Michigan
on behalf of the LZ collaboration

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The LZ collaboration
April, 2018
(250 scientists, engineers and technicians; 37 institutions)
LZ = LUX + ZEPLIN

ZEPLIN-III (UK, Boulby)

ZEPLIN pioneered WIMP-search with two-phase Xe
3.9 × 10^{-44} \text{ cm}^2

6 kg fiducial volume (FV)

LUX (USA, SURF)

LZ
5,600 kg FV

100 kg FV

1.1 × 10^{-46} \text{ cm}^2
at 50 \text{ GeV}/c^2
(decommissioned in early 2017)

Scale-up using demonstrated technology and experience for low-risk but aggressive program:
- Very low internal background strategy
- Infrastructure inherited from LUX
- LZ expected sensitivity: 1.6 × 10^{-48} \text{ cm}^2 in 1000 days

Sanford Underground Research Facility
(Lead, South Dakota)
Why LXe is suitable for Dark Matter search

Properties of Xenon

- Atomic Number (Z): 54
- Mass number (A): 131.30
- Number of electrons per energy level: 2, 8, 18, 18, 8
- Density STP: 5.894 g/L
- Melting point: 161.4 K
- Boiling point: 165.1 K
- Triple point: 161.405 K

- Dense liquid (3 g/cm$^3$) for a massive WIMP target at modest cost (~2000 USD/kg) and scale.
- No intrinsic radioactivity other than $^{85}$Kr and $^{222}$Rn which both can be significantly removed using certain techniques (cryogenic distillation and radon reduction using gas chromatography).
- High sensitivity to spin-independent (SI) WIMP interactions due to its high atomic mass (acts coherently on the entire nucleus and scales as A$^2$).
- For spin-dependent coupling, the cross-section depends on the nuclear spin factor. Does not scale with nuclear size ($^{129}$Xe and $^{131}$Xe).
Two phase time-projection chamber

- WIMPs/Neutrons
- Nuclear recoil
- Gammas
- Electron recoil

S1 – primary scintillation
S2 – electroluminescence

\[(S_2/S_1)_{\text{WIMP}} < (S_2/S_1)_{\text{gamma}}\]
LZ (LUX-ZEPLIN)

- LXe TPC: 50 times larger than LUX
- 1.6 km underground (4300 m.w.e.), SURF, Davis Campus
- Underground installation will start in fall 2018
- Physics data taking will start in 2020

LZ
Total mass: 10 T
WIMP active mass: 7 T
WIMP fiducial mass: 5.6 T
• 494 Hamamatsu PMTs, R11410-22, 3” (low radioactive)
• TPC walls are covered with highly VUV light reflective PTFE
• Nominal cathode operating voltage ≈50 kV, E≈310 V/cm
• ~2 T of LXe in the skin veto region (93 Hamamatsu, R8520 PMTs and further 38 Hamamatsu R8778 PMTs)
• The second veto system contains liquid scintillator – Gadolinium (17.3 T) to tag neutrons.
• 120 Hamamatsu R5912 PMTs mounted in water tank
Radioactive background strategy

◆ Xenon purification from $^{85}$Kr and $^{39}$Ar

- Distillation system at SLAC based on LUX R&D
- Final $^{84}$Kr/Xe ~ 0.015 ppt (g/g)

◆ Extensive radioactive assay of detector materials

- Gamma screening with inductively coupled plasma mass-spectrometry (ICP-MS), neutron activation analysis (NAA)
- Comprehensive radon emanation measurements

◆ Strict surface cleanliness protocols

- Detector assembly in $^{222}$Rn reduced clean rooms
- Dust control, < 500 ng/cm$^2$ on all LXe wetted surfaces
- Rn-daughters plate on TPC walls <0.5 mBq/m$^2$
$^{222}\text{Rn}$ reduction system for LZ
(designed and constructed at the University of Michigan)

Vacuum-jacketed cryostat with 11 kg of $\text{HNO}_3$ etched Saratech adsorbent

$^{222}\text{Rn}$ emanation from some charcoals
(the list is not complete, read the article)

- Carboact: $(0.23\pm0.19)$ mBq/kg
- Regular Saratech: $(1.71\pm0.20)$ mBq/kg
- $\text{HNO}_3$ etched Saratech: $(0.51\pm0.09)$ mBq/kg

Veto system performance

- WIMP-like nuclear recoil backgrounds in 6-30 keV region of interest
- Before and after application of outer detector plus skin veto

Before veto

\[ \approx 10 \text{ events/5.6 ton in FV} \]

After veto

\[ \approx 1 \text{ event/5.6 ton in FV} \]
Projected background rates

- Counts/kg/day/keV in 5.6 ton fiducial volume
- Signal scatter events with no veto signal

Nuclear recoils

Electron recoils
Counts/1000 days: WIMP search region-of-interest (ROI)

LZ 1000 day exposure; Counts for a 40 GeV/c^2 WIMP ROI

<table>
<thead>
<tr>
<th>Background Source</th>
<th>ERs</th>
<th>NRs</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>816</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 — 2β decay, neutrinos*</td>
<td>322</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Total sum of ER and NR with 99.5% ER discrimination and 50% NR efficiency: 6.49 events
Projected LZ sensitivity, spin-independent, (5.6 ton FV, 1000 live-days)

LZ schedule

- Critical decision, step 1 – (CD1) Review – March 2015
- CD2 Review – April 2016
- CD3 Review – February 2017 construction can start in earnest
- Cryostat fabrication has recently been completed
- PMT array assembly began in March of 2018
- Xenon handling installation and commissioning starts this fall
- TPC installation will start in Spring-Summer of 2019
- Xe liquefaction will start in winter of 2019
- First physics data are expected in Spring of 2020
Summary

• The LZ detector will be the largest dual-phase Xe detector in the world with an active mass of 7 tons optimized for a potential discovery of WIMPs.
• The detector’s components are carefully selected and meticulously assayed for the presence of radioactive background.
• The active veto system will help to suppress NR background.
• The LZ detector will have an order of magnitude sensitivity improvement compared to the currently running LXe experiments.
• The underground installation will begin this fall and data taking will start in 2020.
Backups
LZ sensitivity vs $^{222}$Rn level

LZ sensitivity (1000 live days)
- Projected limit (90% CL one-sided)

WIMP-nucleon cross section at 40 GeV/c$^2$ [cm$^2$]

$^{222}$Rn specific activity [µBq/kg]
17 T gadolinium loaded liquid scintillator GdLS
Neutron emitted from PMTs

Gd

NR