The LZ Experiment
Tom Shutt
SLAC

SURF
South Dakota
**LUX - ZEPLIN**

31 Institutions, ~200 people

- University of Alabama
- University at Albany SUNY
- Berkeley Lab (LBNL), UC Berkeley
- Brookhaven National Laboratory
- Brown University
- University of California, Davis
- Fermi National Accelerator Laboratory
- Lawrence Livermore National Laboratory
- University of Maryland
- Northwestern University
- University of Rochester
- University of California, Berkeley
- University of California, Santa Barbara
- University of South Dakota
- South Dakota School of Mines & Technology
- South Dakota Science and Technology Authority
- SLAC National Accelerator Laboratory
- Texas A&M
- Washington University
- University of Wisconsin
- *Yale University*

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7 ton LXe TPC (10 tons LXe total)

- Center for Underground Physics (Korea)
- LIP Coimbra (Portugal)
- MEPhI (Russia)
- Edinburgh University (UK)
- University of Liverpool (UK)
- Imperial College London (UK)
- University College London (UK)
- University of Oxford (UK)
- STFC Rutherford Appleton, and Daresbury, Laboratories (UK)
- University of Sheffield (UK)
Principle of Operation

- 3D imaging rejects external backgrounds
- Electron-recoil backgrounds distinguished by ratio of charge / light ratio
- High purity LXe target
- Single photon and electron sensitivity
The LZ Detector

Low background Ti vessels

HV UMBILICAL AND CONNECTION TO CATHODE

GAS PHASE AND ELECTROLUMINESCENCE REGION

Anode
Gate

Cathode grid
Reverse-field region
Side Skin PMTs

Hamamatsu R11410 3” Ø PMTs, radioactivity: ~mBq, high QE.

“Skin” between TPC and vessel
Performance drivers

• Backgrounds
• Purity for charge drift
• Light Collection
• Drift field, low electron + photon emission
  – Discrimination
  – Threshold
  – Grids: surface fields vs light collection

• Extensive test program: small chambers, HV in LAr, and System Test - T. Biesiadzinski’s talk

<table>
<thead>
<tr>
<th></th>
<th>Requirement / Baseline</th>
<th>Goal</th>
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<tbody>
<tr>
<td>Cathode HV</td>
<td>50 kV</td>
<td>100 kV</td>
</tr>
<tr>
<td>Light collection</td>
<td>7.5%</td>
<td>12%</td>
</tr>
<tr>
<td>e⁻ lifetime (µs)</td>
<td>850</td>
<td>2800</td>
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<tr>
<td>N-fold trigger coincidence</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>$^{222}$Rn</td>
<td>20 mBq</td>
<td>1 mBq</td>
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Discrimination

LUX - 99.8%
~50 GeV WIMP mass, 180 V/cm drift field

Electron Recoil (ER) Background
Tritiated methane (100,000’s)

Nuclear Recoil (NR) Signal
DD neutrons

• LUX - new standard for discrimination calibration
• Discrimination strongest at lowest energy
• LZ requirement: ≥99.5%

LZ Projections
Signal production in liquid Xe

Electron Recoils
Low field, low energy

\[ \text{Xe} \rightarrow \text{Xe}^+ \rightarrow \text{Xe}^* \rightarrow \text{Xe}_2^* \rightarrow \text{VUV photon, 175nm} \rightarrow \text{Heat} \]

Figure: Gibson/Shutt
Signal production in liquid Xe

Electron Recoils
High field, high energy
Signal production in liquid Xe

Xe $\rightarrow$ ion

$\text{Xe}^+$

Excited atom

$\text{Xe}^*$

Recombination

$\text{e}^-$

VUV photon, 175nm

$\text{Xe}_2^*$

Nuclear Recoils

Figure: Gibson/Shutt
Absolute calibration: the “Doke” plot

- Comprehensive framework captured in NEST MC package

T. Shutt - LZ, ULCA DM, Feb 20, 2016
Calibrations

• Expand upon successful LUX program

• Spatial response, temporal variation
  – $^{83m}$Kr, $^{131m}$Xe

• Outer LXe and Gd-scintillator
  – $^{220}$Rn, movable gamma ray sources

• Electron and Nuclear recoils
  – Tritium
  – Variety of high and low energy neutron sources
Outer Detector System

- LXe skin scintillation: 4-8 cm (walls), ~20 cm (dome)
- Gd-loaded liquid scintillator (LAB): 60 cm, 21.5 tons.
- ~97% efficient for neutrons
- Hermetic measurement of all penetrating backgrounds
• Significant screening effort: K. Oliver-Mallory talk
• Assessment of backgrounds: M.E. Monzani’s talk
• Internal backgrounds dominate: Kr, Rn. Goal: *Neutrinos dominate!* (and are interesting signal).
Rn Emanation

- Rn (and Kr) - dominant internal radioactive background
- Emanates from most materials
- 20 mBq requirement, 1 mBq goal
- Four separate measurements systems, ~0.1 mBq sensitivity
  - Experience from SNO, KamLAND, EXO, NEMO, Borexino
- “Scrubber” processes purge Xe from warm breakout regions
Xe Purification and Cryogenics

- Kr removal via chromatography
- Gas phase purification through getter - 10 tons / 2.5 days
- Trap-enhanced mass spec: ~ppt
- High efficiency two-phase heat exchange
- LN thermosyphon-based cryogenics - multiple cooling locations. Stirling LN refrigerator.
- Most aspects tested in System Test
- 10 tons Xe in hand or under contract for 2018 delivery

Kr removal

Xe purity
analytics
Kr: ~15 ppq
DAQ, Electronics, Control, Offline

High pe efficiency

Dual channel for dynamic range

Data flow

Slow control in use at System Test
Schedule

- CD1: March 2015
- CD2: April 2016
- LUX removed - Feb 2017
- Underground installation begins - May 2018
- Operations begin - May 2019
Projected Sensitivity

Spin Independent

LZ projected
- 90% CL Median (Baseline)
- 90% CL Median (Goal)

Zeplin III (2011)
LUX (2015)
LUX 300d

Projected Sensitivity
Spin Independent

\[ \log_{10}(\sigma_s) \text{ [pb]} \]

\[ m_\chi \text{ [GeV/c}^2\text{]} \]

1 event
\[ \nu-N \text{ coherent} \]

1000 Tonne-years

\[ 1 \times 10^{-48} \]
Summary

• LXe is pre-eminent target for high mass WIMPs
• LZ leverages LUX innovations in calibrations, cryogenics, purification
• Robust test program optimizing detector performance
• Very high fiducial volume fraction due to outer detector and low background cryostat
• Goal: neutrino-limited sensitivity of $\sim 1 \times 10^{-48} \text{ cm}^2$
• Goal: significant neutrino physics, including strong solar $^8\text{B}$ ν-nuclear coherent scattering signal
Backup
LZ projected

- $3\sigma$ median significance (baseline)
- 90% CL Median (baseline)
- 90% CL Median (goal)

$\sigma_{\nu N}$ coherent scattering

$\nu N$ coherent, $3\sigma$ significance
1000 Tonne-years
Spin Dependent Sensitivity

On Neutrons

On Protons
Nuclear Recoil Spectrum

The graph shows the nuclear recoil spectrum with various contributions labeled as WIMP (weakly interacting massive particle), neutrino, and detector background. The x-axis represents the energy (E_r [keV]) and the y-axis represents the number of counts per kg/day per keV. Different curves correspond to different energy thresholds (50 GeV/c^2, 500 GeV/c^2, 5000 GeV/c^2) and sources (\(^{8}\)B, hep, DSN, atm). The shaded area represents the detector background, with a distinction made between full TPC (7 ton) and 5.6 ton fiducial.
Double Beta decay Sensitivity

EXO-200/KamLAND ZEN

LZ

IH

NH

\(<m_{\beta\beta}^{\text{ee}}>[\text{eV}]\)

\(m_{\text{lightest}}[\text{eV}]\)
Solar Axions