Low-mass dark matter searches with the LZ experiment

Maria Elena Monzani on behalf of the LZ Collaboration

SLAC, Apr 29, 2016
LZ Detector Overview

- Cathode
- high voltage feedthrough
- Outer detector
- PMTs
- 7 tonne active volume liquid Xe TPC. 10 tonnes total
- Liquid Xe heat exchanger
- Gadolinium-loaded liquid scintillator veto
- Instrumentation conduits
- Existing water tank
Dual-Phase Xenon TPC

• Electron recoil (ER) background rejection:
  – Charge/light ratio (aka “S2/S1”)

• 3D event reconstruction:
  – Vertical coordinate from drift time
  – Horizontal coordinates from S2 light pattern

• External backgrounds:
  – Fiducial volume cuts

• Neutron rejection:
  – Multiple scattering
  – Tagged in skin/veto
State of the Art and Projected Sensitivity

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

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

$2 \times 10^{-48} \text{ cm}^2$

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

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

1 event
$\nu$-N coherent scattering
$\nu$-N coherent, 3$\sigma$ significance
1000 Tonne-years

LZ TDR, in preparation
How to probe the low-mass range?

Integral rate, counts/kg/year vs. threshold recoil energy, keV for different isotopes: Xe, Ge, Ar, Ne.

Isothermal halo
$v_0 = 220 \text{ km/s}$, $v_E = 240 \text{ km/s}$,
$v_{esc} = 600 \text{ km/s}$, $\rho_0 = 0.3 \text{ GeV/cm}^3$

$M_\chi = 100 \text{ GeV}/c^2$
$\sigma_{\chi,SI} = 10^{-9} \text{ pb (10^{-45} cm}^2)$

Threshold!
High Statistics Calibrations from LUX

Electron Recoil (ER) (Tritiated methane)

Nuclear Recoil (NR) (DD neutron gun)

In-situ calibrations, unpreced. accuracy, lower NR threshold
NR Calibrations: towards Lower Threshold

LUX 2015: 1.1 keVnr cutoff

LUX 2014: 3 keVnr cutoff

arXiv: 1512.03506
WIMP Sensitivity with Lower Threshold

LUX 2014

LUX 2015

CDMSlite 2015

SuperCDMS 2014

PandaX 2015

DarkSide–50 2015

XENON100 2012

LUX 2014

This Result

$8_B$

$\sigma_{\text{WIMP-nucleon}} \text{ (zb)}$ vs. $m_{\text{WIMP}} \text{ (GeV/c}^2\text{)}$

$10^{-1}$ to $10^5$

$10^{-5}$ to $10^{-40}$

arXiv: 1512.03506
# Light Dark Matter Searches with LXe

<table>
<thead>
<tr>
<th>Nuclear Recoils</th>
<th>S1 + S2</th>
<th>S2 - only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Vanilla WIMPs</td>
<td>• Light(er) WIMPs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Asymmetric Dark Matter</td>
</tr>
<tr>
<td>Electron Recoils</td>
<td>• (~)keV axion-like particles</td>
<td>• subGeV hidden sector models (Rouven’s talk)</td>
</tr>
</tbody>
</table>

Axion-Like Particles (ALP)

- Sensitivity to axions and ALPs via the axioelectric effect:
  - Nonrelativistic galactic ALPs (DM candidates)
  - ALPs emitted by bremsstrahlung/Compton in the Sun
- Technique pioneered in Xenon100 (see arXiv:1404.1455)
S2-only analysis: Light(er) WIMPs

Cross Section Upper Limits

- DAMA
- CoGeNT
- DAMA (with channeling)
- Trotta et al. CMSSM 95% CL

E. Brown, PhD thesis, unpublished
S2-only analysis: Experimental Challenges

- Xenon10 results were described by Rouven yesterday
- Going to a larger detector doesn’t make this any easier
  - No S2-only results from Xenon100 or LUX so far...

- Limited background rejection with S2-only analysis
  - No S1/S2 discrimination, no Z coordinate available

- Electrons can be captured by impurities in drift volume
  - Depth-dependent effect... but we don’t know Z coordinate

- Incomplete extraction from liquid phase
  - Uniformity issues? increase extraction field?

- Single electron background, difficult to model/subtract
  - Correlated with larger events (at least to some degree)
  - Electrons trapped under the liquid level? increase field?
  - Imperfections in the grids? can we make better grids?
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**Single Electron Sensitivity in LZ**

- Single electron signal depends on field configuration:
  - expected \(>50\) p.e./electron (x2 higher than Xenon10)
  - expected 97.6% extraction efficiency for electrons

### Table: Parameter Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate-Anode separation (and tolerance)</td>
<td>13.0 mm (±0.2 mm)</td>
</tr>
<tr>
<td>Gas gap (and tolerance)</td>
<td>8.0 mm (±0.2 mm)</td>
</tr>
<tr>
<td>Field in LXe (Gx e)</td>
<td>5.2 kV/cm (10.2 kV/cm)</td>
</tr>
<tr>
<td>Electron emission probability</td>
<td>97.6%</td>
</tr>
<tr>
<td>S2 photon yield</td>
<td>820 ph/e</td>
</tr>
<tr>
<td>S2 width FWHM</td>
<td>1.2 μs</td>
</tr>
<tr>
<td>Detailed modeling</td>
<td></td>
</tr>
<tr>
<td>S2 photon yield</td>
<td>910 ph/e</td>
</tr>
<tr>
<td>S2 photon rms</td>
<td>2.0 %</td>
</tr>
<tr>
<td>S2 width FWHM</td>
<td>1.0 μs to 2.0 μs(^a)</td>
</tr>
</tbody>
</table>

\(^a\) The larger value is for diffusion-broadened S2 pulses from interactions near the cathode (see Figure 3.6.4).

- Reaching HV specs has proven elusive in all LXe detectors
  - very extensive fields/grid R&D/testing in progress at SLAC
SLAC Noble Liquid Test Platform
Conclusions

• Low-energy calibrations drastically improved across the field:
  – Lower thresholds in LUX
  – Sensitivity to lighter DM particles

• S2-only analysis is always challenging due to backgrounds
  – No S2/S1 or Z-coordinate cut

• Single electron sensitivity will be greatly enhanced in LZ
  – Single electron background a possible concern (large area)
  – Tackling the single electron background very aggressively
  – Includes full-scale grid testing