Recent results from LUX and status of LZ

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University of Edinburgh
(on behalf of the LUX and LZ collaborations)

51st Rencontres de Moriond
Electro Weak and Unified Theories
La Thuile, 12-19 March, 2016.
Outline

• The Large Underground Xenon (LUX) experiment
  
  New results on WIMP searches and calibration

• The LUX-ZEPLIN experiment
Direct search

Dark matter (DM) Milky Way’s halo
=> flux on Earth $\sim 10^5$ cm$^{-2}$s$^{-1}$
$\rho_\chi \sim 0.3$ GeV/cm$^3$ and 100 GeV/c$^2$

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

Simple dynamics: cross section $\propto (\text{form-factor})^2$

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.

Spin-dependent: form-factor depends on nuclear spin. No coherence enhancement.
Large Underground Xenon
LUX detector

- Davis Cavern @ Sanford Lab (SURF), 4850 ft (1.5 km) underground
- 250 kg (47 x 49 cm²) of active LXe dual phase time projection chamber (TPC)
- Two arrays each of 61 ultra-pure PMTs
- Reducing background:
  - cosmic $\mu$ flux reduced to $6.2 \times 10^{-9}$ cm$^{-2}$s$^{-1}$
  - low background materials
  - 3D event localisation (LXe target fiducialization)
S1, S2 and CES

Liquid xenon / dual-phase time projection chamber (TPC)

(Scintillation) S1

(Ionisation) S2

‘Combined Energy scale’

\[ E = \frac{1}{L(E)} \cdot \left( \frac{S1}{g_1} + \frac{S2}{g_2} \right) \cdot W \]

- \( W = 13.7 \text{ eV} \)
- \( g_1 = \text{Light Collection} \)
- \( g_2 = \text{Extraction + Light Eff.} \)
- \( L(E) = \text{Lindhard Factor} \)
  Nuclear recoil enhancement of heat relative to electron recoils
Nuclear vs. Electron recoil

Combination of Scintillation (S1) and Ionisation (S2) event-by-event particle identification

**Electron Recoil (ER) events**

**Nuclear Recoil (NR) events**

![Graph showing the comparison between S1 and S2 distributions for electron and nuclear recoils.](image)
Reminder: 1st LUX results

Limit on Spin-Independent WIMP-nuclei at 7.6 x 10^{-46} \text{ cm}^2 \text{ at 33 GeV/c}^2
LUX Run03 reanalysis

• Improved PMT response and light measurement:
  1. removed a bias in baselines;
  2. photon digital counting;
  3. photon response calibrated with VUV light.

• Improved calibration:
  1. electronic recoil (ER): mono energetic sources, and CH$_3$T internal source;
  2. nuclear recoil (NR): mono energetic neutrons with \textit{in-situ} D-D generator.

• New WIMP signal and background modelling.

• Improved profile likelihood ratio (PLR) analysis.
ER Calibration

5 - 662 keV Mono-energetic sources in the mean-yields plane. Line fit and $W = 13.7$ eV give absolute quanta.

\begin{equation}
E = \frac{1}{L(E)} \cdot \left( \frac{S_1}{g_1} + \frac{S_2}{g_2} \right) \cdot W
\end{equation}

'Doke plot'

x-intercept $\Rightarrow n_Y \rightarrow 0; \ S_2/E = g_2/W$

y-intercept $\Rightarrow n_e \rightarrow 0; \ S_1/E = g_1/W$
ER Calibration

0 - 18 keV CH$_3$T (tritiated methane) internal source

- Beta-decay to calibrate ER background (peaks at 2.5 keV)
- Bare tritium: 12 year half-life. But CH$_3$T: 6 hr effective half-life via getter

2$^{nd}$ campaign of CH$_3$T calibration in LUX, Dec 2013: 180 000 events

arXiv:1512.03133
NR Calibration

Mono-energetic neutrons: D-D generator

2.45 MeV neutron fired into LUX WIMP-like NR with:
- in situ measurement
- long lever-arm —> unique energy reach
NR Calibration

Mono-energetic neutrons: D-D generator

S2 vs energy via $E(\theta)$ for multiple scatters

\[ E_r = E_n \frac{4m_n m_{Xe}}{(m_n + m_{Xe})^2} \frac{1 - \cos \theta}{2} \]

Systematic uncertainty due to position reconstruction energy bias correction

- Aprile 2013 (XENON100) - 0.53 kV/cm
- Sorensen 2010 (XENON10) - 0.73 kV/cm
- Horn 2011 (ZEPLIN-III combined FSR & SSR) - average of 3.6 kV/cm
- Aprile 2006 - 0.3 kV/cm
- Aprile 2006 - 0.1 kV/cm
- Manzur 2010 - 1 kV/cm
- Manzur 2010 - 4 kV/cm

- LUX model: Lindhard ($k = 0.174$) + biex. quenching
- Alt. LUX model: Ziegler stopping power + biex. quenching
- LUX D-D $Q_y$ at 180 V/cm
NR Calibration

Mono-energetic neutrons: D-D generator

S1 vs energy via E(S2) for single scatters

- LUX D-D $L_y$ at 180 V/cm
- Horn 2011 (ZEPLIN-III combined FSR & SSR)
- Aprile 2013 (XENON100)
- Manzur 2010
- Plante 2011
- Aprile 2009

- LUX model: Lindhard ($k = 0.174$) + biex. quenching
- Alt. LUX model: Ziegler stopping power + biex. quenching

**Sys. uncertainty due to $Q_y$ energy scale**

- Sys. uncertainty due to $S1$ signal corrections and $g_1$
- Sys. uncertainty in $^{83m}$Kr yield (right axis)
- Sys. uncertainty due to neutron source spectrum
# Signal and background

<table>
<thead>
<tr>
<th>Source</th>
<th>Spectrum</th>
<th>‘S2/S1’</th>
<th>Spatial distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>New WIMPs</td>
<td>~ exponential</td>
<td>low (NR)</td>
<td>uniform</td>
</tr>
<tr>
<td>Compton Scatters from material $\gamma$</td>
<td>~ flat</td>
<td>high (ER)</td>
<td>peripheral</td>
</tr>
<tr>
<td>Internal $\beta$ from Kr-85, Rn, impurities</td>
<td>~ flat</td>
<td>high (ER)</td>
<td>uniform</td>
</tr>
<tr>
<td>X-rays from Xe-127 ($\lambda = 36.4$ d)</td>
<td>1 keV, 5 keV lines</td>
<td>high (ER)</td>
<td>peripheral</td>
</tr>
<tr>
<td>New Decays on wall</td>
<td>~ flat</td>
<td>low, variable (NR and ER with charge loss)</td>
<td>high radius</td>
</tr>
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</table>

Paolo Beltrame

Moriond EW 2016
# Signal

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Simulation: Noble Element Simulation Technique (NEST), arXiv:1412.4417
Data: DD-tuned NEST-like model mass-dependence of the WIMP PDFs.
New test statistics profile likelihood: Nuisance params (Lindhard, $g_{2DD} / g_{2WS}$).
Background

- Detector Material: Gamma rays from Co-60, K-40, Tl-208, Bi-214
  Global fit to 3 MeV
  Asymmetric source from top and bottom
- Internal Background (in Xe): Ar-37, Kr-85m, Xe-127

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- Rn-222 - Pb-206
- Occurs on the wall at 24.2 - 5 cm
- Resolution leaks below 18 cm
- Charge loss
- Inclusion of ‘wall background' increase fiducial radius to 20 cm
<table>
<thead>
<tr>
<th></th>
<th>2013 analysis</th>
<th>2015 re-analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Live days [days]</strong></td>
<td>85</td>
<td>95</td>
</tr>
<tr>
<td><strong>Fiducial Volume [kg]</strong></td>
<td>118</td>
<td>145</td>
</tr>
<tr>
<td><strong>S1 cut</strong></td>
<td>2 - 30 phe</td>
<td>1 - 50 phd</td>
</tr>
<tr>
<td><strong>S2 cut</strong></td>
<td>200 phe (on S2 raw)</td>
<td>165 phd (on S2 raw)</td>
</tr>
<tr>
<td><strong>Energy threshold</strong></td>
<td>3 keV =&gt; 5.2 GeV/c²</td>
<td>1.1 keV =&gt; 3.3 GeV/c²</td>
</tr>
</tbody>
</table>
Spin-independent

Limit on Spin-Independent WIMP-nuclei at $6 \times 10^{-46} \text{ cm}^2$ at 33 GeV/c$^2$
Spin-independent

B-8 Solar Neutrino coherent. Currently contributes 0.1 event to the background

Limit on Spin-Independent WIMP-nuclei at 6 x 10^{-46} cm^2 at 33 GeV/c^2
Spin-independent

Limit on Spin-Independent WIMP-nuclei at $6 \times 10^{-46}$ cm$^2$ at 33 GeV/c$^2$

B-8 Solar Neutrino coherent.
Currently contributes 0.1 event to the background

$\sigma \sim 10^{-2} \lambda_{Z\chi}^2$ pb

$10^{-38}$ cm$^2$
Spin-independent

Limit on Spin-Independent WIMP-nuclei at $6 \times 10^{-46}$ cm$^2$ at 33 GeV/c$^2$

B-8 Solar Neutrino coherent. Currently contributes 0.1 event to the background

$\lambda_{Z\chi}^2$ pb

$\lambda_{h\chi}^2$ pb

arXiv:1512.03506v2
Spin-dependent

\[ \sigma_{p,n} = \frac{3\mu_{p,n}^2 (2J + 1)}{4\pi \mu_N^2} \frac{\sigma_0}{S_A(0)} \]

- Same analysis framework used for Spin Independent
- Xenon \( Z = 54 \)
- Xenon 131 \( \sim 24\% \)
- Xenon 129 \( \sim 29\% \)
- Enhances the Neutron-only scattering
LUX plan

- Currently on data taking until mid of 2016
- Additional 300+ live-days of data (exposure increase by a factor of 4)
- E-field improved model
- Background models with full 3D information (φ)

- Further improvement in WIMP search
- Additional physics:
  - effective field theory limits
  - axion and axion-like particle
  - S2-only analysis
Direct detection timeline

- LZ: $2 \times 10^{-48}$ cm$^2$
- XENON1T: Ge, NaI no discrimination
- ZEPLIN-III: Ge, w/discrim.
- LXe, w/discrim.
- CDMS
- Darkside
- SCDMS

Year:
- 1985
- 1995
- 2005
- 2015
- 2025
LZ = LUX + ZEPLIN

Counts: 31 Institutions
≈ 200 Headcount

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)

University of Alabama
University at Albany SUNY
Berkeley Lab (LBNL)
Brookhaven National Laboratory
University of California Berkeley
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, 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
The detector

(LUX): world leading Generation-1 experiment, Sanford Underground Research Facility (SURF), 250 kg of active LXe target

LUX-ZEPLIN (LZ): Generation-2 flagship experiment for Direct Detection in US and UK, 7 tonnes of active LXe target

Cathode
high voltage feedthrough

Existing water tank

Outer Detector
Gd-loaded liquid scintillator

7 tonne active LXe
TPC PMTs: 488
Skin PMTs: (192)

Outer Detector PMTs

LXe heat exchanger

arXiv:1509.02910
Backgrounds rejection

Detector material component backgrounds

LXe self shielding, TPC multiple hit

LXe self shielding, TPC multiple hit
+ LXe skin
+ Outer Detector

5.6 tonnes

5.6 tonnes
Backgrounds

Vast screening materials campaign for radio-pure components identification

Detailed simulation based on NEST and S1+S2 analysis

Projected sensitivity performed with PLR

<table>
<thead>
<tr>
<th>Background</th>
<th>Type</th>
<th>Counts in LZ nominal exposure (5,600 tonne-days)</th>
<th>Nuisance parameter uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^8$B</td>
<td>NR</td>
<td>7</td>
<td>±10 %</td>
</tr>
<tr>
<td>HEP</td>
<td>NR</td>
<td>0.21</td>
<td>±30 %</td>
</tr>
<tr>
<td>DSN</td>
<td>NR</td>
<td>0.05</td>
<td>±50 %</td>
</tr>
<tr>
<td>ATM</td>
<td>NR</td>
<td>0.46</td>
<td>+33 %</td>
</tr>
<tr>
<td>pp solar $\nu$</td>
<td>ER</td>
<td>255</td>
<td>1 %</td>
</tr>
<tr>
<td>$^{136}$Xe (2$\nu\beta\beta$)</td>
<td>ER</td>
<td>67</td>
<td>7 %</td>
</tr>
<tr>
<td>$^{85}$Kr</td>
<td>ER</td>
<td>24.5</td>
<td>±5 %</td>
</tr>
<tr>
<td>$^{222}$Rn</td>
<td>ER</td>
<td>782</td>
<td>±10 %</td>
</tr>
<tr>
<td>$^{220}$Rn</td>
<td>ER</td>
<td>129</td>
<td>±10 %</td>
</tr>
<tr>
<td>Det. components</td>
<td>ER</td>
<td>62</td>
<td>±10 %</td>
</tr>
<tr>
<td>Det. components</td>
<td>NR</td>
<td>0.9</td>
<td>±10 %</td>
</tr>
</tbody>
</table>
Signal and background

Advanced analysis procedure PDFs for PLR

Signal and background models
distributions

Simulated LZ experiment
(1000 days, 5.6 tonnes fiducial)

$\sigma = 6 \times 10^{-48} \text{ cm}^2$

$B - 8 \times 500$

$\text{ER background} \times 5$

WIMP $3\sigma$ significance, 40 GeV

$S1 [\text{phd}]$

$\log_{10}(S2/S1)$
Projected sensitivity

Simulated LZ experiment (1000 days, 5.6 tonnes fiducial)

Baseline
\[ \sigma_{SI} = 2.2 \times 10^{-48} \text{ cm}^2 \]
B-8 = 7
ATM \( \nu = 0.4 \)

Goal
\[ \sigma_{SI} = 1.2 \times 10^{-48} \text{ cm}^2 \]
B-8 = 220
ATM \( \nu = 3 \)
Projected sensitivity

Simulated LZ experiment (1000 days, 5.6 tonnes fiducial)
Projected sensitivity

Simulated LZ experiment (1000 days, 5.6 tonnes fiducial)

Lower threshold.
No 3 keVnr cutoff.
Updated Xe response from LUX

-3
-5
-7
-9
-11
-13
-14

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

10
100
1000

m_x [\text{GeV}/c^2]

10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}

-3
-4
-5
-6
-7
-8
-9

LZ projected
90% CL Median CDR (arXiv:1509.02910)
90% CL Median (Baseline)
90% CL Median (Goal)

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

ν-N coherent scattering

1 event

ν-N coherent, 3σ significance

1000 Tonne-years
Projected sensitivity

Simulated LZ experiment (1000 days, 5.6 tonnes fiducial)

Lower threshold.
No 3 keVnr cutoff.
Updated Xe response from LUX

B-8 ~ 10 events
Projected sensitivity

Simulated LZ experiment (1000 days, 5.6 tonnes fiducial)

Lower threshold.
No 3 keVnr cutoff.
Updated Xe response from LUX

Minimum at 40 GeV/c²
Projected sensitivity

Simulated LZ experiment (1000 days, 5.6 tonnes fiducial)

Lower threshold.
No 3 keVnr cutoff.
Updated Xe response from LUX

New sensitivity study performed with updated low E LXe response and with PLR instead of Feldman-Cousins

B-8 ~ 10 events

Minimum at 40 GeV/c²

\(\log_{10}(\sigma_{\nu N}) [\text{pb}]\)
<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>March</td>
<td>LZ (LUX-ZEPLIN) collaboration formed</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>DOE CD-0 for G2 dark matter experiments</td>
</tr>
<tr>
<td>2013</td>
<td>November</td>
<td>LZ R&amp;D report submitted</td>
</tr>
<tr>
<td>2014</td>
<td>July</td>
<td>LZ Project selected in US and UK</td>
</tr>
<tr>
<td>2015</td>
<td>April</td>
<td>DOE CD-1/3a approval, similar in UK Begin long-lead procurements (Xe, PMT, cryostat)</td>
</tr>
<tr>
<td>2016</td>
<td>April</td>
<td>DOE CD-2/3b review</td>
</tr>
<tr>
<td>2017</td>
<td>February</td>
<td>LUX removed from underground</td>
</tr>
<tr>
<td>2017</td>
<td>July</td>
<td>Begin surface assembly prep @ SURF</td>
</tr>
<tr>
<td>2018</td>
<td>May</td>
<td>Begin underground installation</td>
</tr>
<tr>
<td>2019</td>
<td>April</td>
<td>Begin commissioning</td>
</tr>
<tr>
<td>2021</td>
<td>Q3FY21</td>
<td>CD-4 milestone (early finish July 2019)</td>
</tr>
<tr>
<td>2025</td>
<td></td>
<td>Planning on ~5 year of operations</td>
</tr>
</tbody>
</table>
Thank you for the attention
Thank you for the attention

“That isn’t dark matter, sir—you just forgot to take off the lens cap.”
Backup Slides
Liquid xenon

Noble element
\[\Rightarrow\text{Inert. Purified via gettering techniques}\]

No long-lived radio-isotopes
\[\Rightarrow\text{useful in calibration}\]

High density (~ 3 g/cm\(^3\))
\[\Rightarrow\text{self-shielding}\]

Long electron drift lengths (few m)
\[\Rightarrow\text{scalable}\]

Efficient scintillator

Higher sensitivity in the 2 - 25 keV energy deposit range
Liquid xenon

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Efficient scintillator

Higher sensitivity in the 2 - 25 keV energy deposit range
Reminder: 1st LUX results

- 118 kg fiducial x 85 live day
- Energy threshold at 3 keVnr
- $2 \leq S1 \leq 30$ phe
- $S2 > 200$ phe
- $(99.6 \pm 0.1\%)$ ER rejection at 50% signal acceptance (180 V/cm)
- 160 events observed in data after selection cuts

Analysis 4-parameter profile likelihood, p-value of 35% consistent with backgrounds

Limit on Spin-Independent WIMP-nuclei at $7.6 \times 10^{-46}$ cm² at 33 GeV/c²
Measuring light

Better estimators for detected photons

1. Removed a bias in baselines
Measuring light

Better estimators for detected photons

1. Removed a bias in baselines

2. Digital counting of photons in PMT waveforms: less variance than area for sparse light
Measuring light

Better estimators for detected photons

1. Removed a bias in baselines

2. Digital counting of photons in PMT waveforms: less variance than area for sparse light

3. Photon response calibrated in the VUV (accounting for ~20% of 2phe from 1photon)

arXiv:1506.08748
Calibration NR

- NEST simulation package parameter best fit to DD-data in both charge and light yields
- Given $g_1$ and $g_2$, determine the $L(\theta | E)$. $\theta$ are 5 Lindhard NR Parameters
- Implement full NEST simulation in the sensitivity calculation

Where:

$$E = \frac{1}{L(E)} \cdot \left( \frac{S_1}{g_1} + \frac{S_2}{g_2} \right) \cdot W$$

$$L = \frac{k_g}{1 + k_g}$$

$$r = 1 - \frac{\ln(1 + \text{TIB} N_i)}{\text{TIB} N_i}$$

$$q_f = 1 - \frac{1}{1 + \beta \epsilon^{1/2}}$$
Calibrations

a) ER Calibration

b) NR Calibration

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

S1 detected photons

1.0 keV\textsubscript{ee}
Efficiency for NR

Signal calibration extended to < 1% efficiency threshold.
Modelling cutoff 3 keV $\rightarrow$ 1.1 keV: WIMP 5.2 GeV/c$^2$ $\rightarrow$ 3.3 GeV/c$^2$.
Bezrukov an alternative to the Lindhard model of NR energy loss to electrons.
Both consistent w/data; set limit with lower-yield Lindhard.
Background Rejection

Figure of merit: ER rejection at 50% acceptance of NR calibration, based on charge/light

Analysis improvements and large tritium calibration sample boost performance and precision
Background Model

Figure 3: LUX ray spectrum in the LUX drift region (black), with peak identification labels. A 225 kg fiducial volume is used for the analysis, removing the top and bottom 2 cm of the drift region, with event energies reconstructed from the combination of S1 and S2 signals. Horizontal error bars are shown, representing systematic error in particular on the flux of thermal neutrons. Those are the variation in the thermal neutron flux. Those are the isotopes modeled in high-energy ray analysis. Screening estimate values are estimated to be 25%.

Table 3: Screening estimate and best-fit activity values for radioisotopes. The uncertainty on the neutron flux and separate simulation results from 49 days and seven days experiments. In the calculations below, the sea-level activation parameters variations. The sea-level activation cross section is known to be different from that of underground operations, the isotopes modeled in high-energy ray analysis. Screening estimate values are estimated to be 25%.

<table>
<thead>
<tr>
<th>Region</th>
<th>Isotope</th>
<th>Screening Estimate [Bq]</th>
<th>Fit [Bq]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>214Pb (238U)</td>
<td>42 ± 16</td>
<td>36 ± 9</td>
</tr>
<tr>
<td>Bottom</td>
<td>214Pb (238U)</td>
<td>40 ± 16</td>
<td>38 ± 16</td>
</tr>
<tr>
<td>Side</td>
<td>214Pb (238U)</td>
<td>60 ± 25</td>
<td>58 ± 16</td>
</tr>
<tr>
<td>Top</td>
<td>228Ac (232Th)</td>
<td>40 ± 16</td>
<td>36 ± 9</td>
</tr>
<tr>
<td>Bottom</td>
<td>228Ac (232Th)</td>
<td>40 ± 16</td>
<td>38 ± 16</td>
</tr>
<tr>
<td>Side</td>
<td>228Ac (232Th)</td>
<td>60 ± 25</td>
<td>58 ± 16</td>
</tr>
<tr>
<td>Top</td>
<td>208Tl (232Th)</td>
<td>87 ± 43</td>
<td>72 ± 22</td>
</tr>
<tr>
<td>Bottom</td>
<td>208Tl (232Th)</td>
<td>87 ± 43</td>
<td>72 ± 22</td>
</tr>
<tr>
<td>Side</td>
<td>208Tl (232Th)</td>
<td>149 ± 87</td>
<td>127 ± 62</td>
</tr>
<tr>
<td>Top</td>
<td>129Xe</td>
<td>311 ± 172</td>
<td>293 ± 115</td>
</tr>
<tr>
<td>Bottom</td>
<td>129Xe</td>
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Profile Likelihood

\[ L(\sigma_{\text{WIMP}}, \theta; x) = P(x; \sigma_{\text{WIMP}}, \theta) = \prod_{i=1}^{n} P(x_i | \sigma_{\text{WIMP}}, \theta) \]
\[ x = \{ S1, \log(S2), r, z \} \]
\[ \theta = \{ N_{\text{bkg}}, \nu_{\text{signal}} \} \]
\[ \lambda = \frac{L(\sigma_{\text{Test}}, \theta; x)}{L(\sigma_{\text{WIMP}}, \theta; x)} \]
\[ q = -2 \ln(\lambda) \]

- Fraction of Bkg.+Sig. MC above the Data in \( q \) (obs. limit)
- Translate \( L \) \( \rightarrow \) \( p \)-values
- Expected limits: counting from the mean of the Bkg.-only MC to Bkg.+Sig. Model
- \( \pm 1\sigma \), \( \pm 2\sigma \) quantiles are shown in green and yellow

\( q(\text{Model}_{\text{test}}; \text{Data}) \)
\( q(\text{Model}_{\text{test}}; \text{MC}_{\text{Model}}) \)
\( q(\text{Model}_{\text{Test}}; \text{MC}_{\text{Bkg}}) \)

50 GeV/c²

HypoTestInverter Result For xsec

50 GeV/c² WIMP
Profile Likelihood

Multivariate background rejection, per-event discriminant.

Limit is un-binned PLR with 4 observables.

Nuisance parameters:
- background population normalisation
- WIMP PDF & efficiency.

Power constraint at median background-only limit.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Constraint</th>
<th>Fit value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lindhard $k$</td>
<td>$0.174 \pm 0.006$</td>
<td>-</td>
</tr>
<tr>
<td>S2 gain ratio: $g_{2,DD}/g_{2,WS}$</td>
<td>$0.94 \pm 0.04$</td>
<td>-</td>
</tr>
<tr>
<td>Low-z-origin $\gamma$ counts: $\mu_{\gamma,\text{bottom}}$</td>
<td>$172 \pm 74$</td>
<td>$165 \pm 16$</td>
</tr>
<tr>
<td>Other $\gamma$ counts: $\mu_{\gamma,\text{rest}}$</td>
<td>$247 \pm 106$</td>
<td>$228 \pm 19$</td>
</tr>
<tr>
<td>$\beta$ counts: $\mu_\beta$</td>
<td>$55 \pm 22$</td>
<td>$84 \pm 15$</td>
</tr>
<tr>
<td>$^{127}$Xe counts: $\mu_{\text{Xe-127}}$</td>
<td>$91 \pm 27$</td>
<td>$78 \pm 12$</td>
</tr>
<tr>
<td>$^{37}$Ar counts: $\mu_{\text{Ar-37}}$</td>
<td>-</td>
<td>$12 \pm 8$</td>
</tr>
<tr>
<td>Wall counts: $\mu_{\text{wall}}$</td>
<td>$24 \pm 7$</td>
<td>$22 \pm 4$</td>
</tr>
</tbody>
</table>
The detector

Section view of TPC

Upper PMT Array
Weir structure
TPC field cage

Electroluminescence region and gas phase

Anode
Liquid surface
Gate
Skin PMT

HV umbilical and connection to cathode
Cathode grid
Reverse field region
Skin PMT
Lower PMT array
Extensive calibration

- Building on experience from LUX
  - Kr-83m (routine, roughly weekly)
  - Tritiated methane (every few months)
  - External radioisotope neutron sources
  - External radioisotope gamma sources
  - DD neutron generator (upgraded early next year to shorten pulse)

- New in LZ
  - Activated Xe (Xe-129m and Xe-131m)
  - Rn-220
  - Am-Li
  - YBe
Neutrinoless Double Beta Decay of Xe-126

- Use self-shielding to reduce gamma-ray backgrounds in a 1-2 tonne fiducial mass
- Projected sensitivity: 90% confidence level $T^{0\nu}_{1/2}$ of $2 \times 10^{26}$ years
- Enriching the Xe target could increase this to $\sim 2 \times 10^{27}$ years
- Current limit is $2.6 \times 10^{25}$ years (preliminary) from KamLND-Zen
External Neutrino Physics

- Solar neutrinos
  - Expect about 850 pp neutrino events between 1.5 and 20 keV\textsubscript{ee}

- Supernova neutrinos
  - Via flavor-blind coherent neutrino-nucleus scattering
  - For a 10 kpc SN, LZ would see about 50 events with energy > 6 keV and 100 events > 3 keV

- Sterile neutrinos
  - Could use a 5 MCi Cr-51 source near LZ
  - Excellent position reconstruction for better source normalization, higher sterile neutrino masses.

- Neutrino magnetic moment
  - Sensitivity near astrophysical limit of 2 \times 10^{-12} Bohr magnetons.