Background Modeling and Materials Screening for the LUX and LZ Detectors

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LUX Collaboration
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Summary

- LUX screening program limits background contributions from all major internal components to <1 WIMP-like BG evt / 300 livedays
- Emphasis on discovery mode for WIMPs. Small number of BG evts competing
- Monte Carlo modeling performed for background contributions from all detector components
- LZ background modeling includes a broad range of topics, from muon spectra through shield and veto design
The LUX Experiment

- Photomultiplier Tubes
- 350 kg Liquid Xenon
- Cathode Grid
- Anode and Electron Extraction Grids
- Time Projection Chamber
- Thermosyphon
- Feedthroughs
- Water Shield
- Xenon Recirculation and Heat Exchanger
- Titanium Cryostats
- Internal Structure PMT Cu Holders
- 3
- 2
- 4
- 1
- 3
- 5
- 6
Sanford Surface Lab

- Full deployment of ALL detector, external hardware, and electronics that will subsequently be deployed underground
- 3m water shield at surface reduces ambient gamma BG - improves calibration data quality
- Precise physical replica of underground lab space
- Final deployment in Davis Lab (4850 ft. level)
Xenon TPCs

- Two-channel experiment
- Scintillation + ionization
- Only scintillation light read out directly
- Two-phase Xe
- Primary scintillation (S1) immediately detected
- Ionization electrons drifted into gas region, creating secondary scintillation (S2)
Background Rejection

- Xe self-shields very effectively
  - attenuation length (1 MeV $\gamma$) $\sim$ 6 cm
- Exp fall in event rate toward center (fiducialization)
- Narrow energy window
- Multiple scatters rejected

$DRU_{ee} = \text{cts/keV}_{ee}/\text{kg/day}$
ER vs. NR

- Scintillation/ionization ratio differs for ER, NR
- Discrimination measured by XENON10: >99.5% rejection of ER evts
- 50% NR acceptance in WIMP search window

XENON10 NR/ER Bands

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Internal Backgrounds

- Construction materials chosen for low radioactivity (Ti, Cu, PTFE)
- Majority of materials heavily shielded by Cu
- PMT radioactivity gives dominant background
- Internal backgrounds dominate over external (from cavern rock)
External Backgrounds

- Davis Lab 4.3 km.w.e. rock overburden
- 300 tonne water shield instrumented as Cerenkov veto
- Primary external background: muon-induced neutrons in water shield, cavern rock
- After muon veto and analysis cuts: Summing above sources ~0.01 NR evts / 300 livedays / 100 kg
Background Modeling

- Monte Carlo studies required to understand backgrounds from all internals
- Standardized geometry used -- LUXSim (Kareem Kazkaz’s talk)
- MC studies set required counting goals for various materials
Modeling with LUXSim

- Studies performed for all major LUX internals to determine Xe activity per mBq for major isotopes ($^{238}$U, $^{232}$Th, $^{60}$Co, $^{40}$K ...)
- Analysis cuts applied to Monte Carlo data
- Scaling factor DRU/mBq found

$$\text{DRU}_{ee} / ^{60}\text{Co mBq} \text{ (activity summed for entire PMT arrays top and bottom)}$$

$$\text{DRU}_{ee} = \text{cts/keV}_{ee}/\text{kg/day}$$
Modeling with LUXSim

- Generic background modeling performed to account for all low-mass components
- Each component assigned a BG contribution expectation given its location
- Region boundaries set by detector geometry, physics
# LUX Material Screening

<table>
<thead>
<tr>
<th>Unit</th>
<th>Screening Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U238</td>
</tr>
<tr>
<td><strong>PMTs</strong></td>
<td>mBq/PMT</td>
</tr>
<tr>
<td><strong>Ti</strong></td>
<td>mBq/kg</td>
</tr>
<tr>
<td><strong>Cu</strong></td>
<td>mBq/kg</td>
</tr>
<tr>
<td><strong>PTFE</strong></td>
<td>mBq/kg</td>
</tr>
<tr>
<td><strong>HDPE</strong></td>
<td>mBq/kg</td>
</tr>
<tr>
<td><strong>Stainless steel</strong></td>
<td>mBq/kg</td>
</tr>
</tbody>
</table>

**Type 304 stainless steel used in electric field grids**

*Cosmogenic equilibrium at 1 mile above SL; decays below ground
LUX Material Screening

- Screening of all major components ensures <1 WIMP-like event in 300 livedays
- Sums includes applied analysis cuts
  - Energy window
  - Single-scatter
  - Fiducial
  - ER/NR rejection

<table>
<thead>
<tr>
<th></th>
<th>WIMP-Like Events (300 Livedays)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ER</td>
</tr>
<tr>
<td>PMTs</td>
<td>0.4</td>
</tr>
<tr>
<td>Cryostats</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Grid wires</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>PTFE panels</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>HDPE</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt;0.03</td>
</tr>
<tr>
<td>$^{85}$Kr</td>
<td>&lt;0.07</td>
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<tr>
<td>Total</td>
<td>&lt;0.59</td>
</tr>
</tbody>
</table>
The LZ Detectors

- Scaling LUX to the multi-tonne level
  - LZS: 1.5-3 tonnes
  - LZD: 10-20 tonnes
- Increase in sensitivity by over two orders of magnitude
Internal Backgrounds for Scaled Detectors

- Self-shielding properties allow fiducial volume >2/3 of total Xe mass used
- Large “instant discovery” zone

Assuming 5 n/PMT/yr (x6 higher than R8778s)
LZ Background Modeling

• Active area of research
  • Muon energy spectrum < 1 GeV at Davis cavern level and lower
  • $\mu$-induced n spectrum in rock, water
  • Attenuation by 12 m water shield
  • Scintillator veto effectiveness
  • Internal background scaling
  • Cosmogenic activation of Xe, construction materials
  • Fundamental neutrino backgrounds
• Large community effort focused on R&D
Next-Generation PMTs

- PMT background contributions dominate total background
- Require PMT with larger surface area, lower radioactivity per unit area
- Comparable or better sensitivity as R8778 to 178 nm photons
3" R1410 MOD

- Twice the cathode area of the R8778
- >35% QE for Xe scintillation light
- $^{238}\text{U} < 0.4 \text{ mBq/PMT} \ 90\% \text{ CL}$
  $^{232}\text{Th} < 0.3 \text{ mBq/PMT} \ 90\% \text{ CL}$
- $x1/27$ reduction in U238; $x1/9$ reduction in Th232 (below R8778)
- Publication in review
Conclusions

• LUX screening program projects background expectation ~$\times 1/2$ below the LUX proposal goal

• Detailed Monte Carlo estimates are generated for all major internal items; other items modeled generically by location in detector

• LZ background modeling includes a broad range of topics, from muon spectra through shield and veto design; ultra-low background PMTs will ensure subdominance of construction material BG
References


• LUX and ZEPLIN collaborations, “LZS: The LZ Liquid Xenon Dark Matter Search at Sanford Lab.”

• LUX and ZEPLIN collaborations, “LZ20 Development: the LUX-ZEPLIN 20 Tonne Dark Matter Experiment Technical Development Plan for DUSEL.”

Additional Slides
SOLO

- 0.6 kg HPGe detector
- Soudan Lab (2.0 km.w.e.)
- Workhorse for LUX internals counting