The LZ Photoneutron Calibration Source

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UC Berkeley
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on behalf of the LZ Collaboration
The LZ Collaboration

37 institutions; 250 scientists, engineers, and technicians

The LZ detector is being built at SURF in Lead, SD
The LZ Detector

LXe Time Projection Chamber
7 tons active Xe
5.6 ton fiducial volume

High purity water
Gd-loaded liquid scintillator
Instrumented Xe skin region
Veto system

Liquid scintillator filled plug

LZ TDR: arXiv:1703.09144
How LZ Works

- Energy deposited by particle interactions
  - S1 light: prompt scintillation
  - S2 light: electroluminescence from drifted electrons

- 3D position reconstruction

- Discrimination between electron recoils (ERs) and nuclear recoils (NRs)

- Possibility of low energy S2 only analysis
  - complicated by lack of discrimination
Low Energy Nuclear Recoil Backgrounds

Single scatter NR events in LZ fiducial volume*

Rate [counts/kg/day/keV] against Nuclear recoil energy [keV]

- $^8$B
- hep
- Det. + Sur. + Env.
- Total

* after outer detector and skin vetoes applied, before efficiency and S1 selection cuts

Simulated NR detection efficiency, extrapolated by Lindhard theory below 1.1 keV**

Photoneutron calibration

WIMP search criteria:
- S1 > 3 phd
- S2 > 3 e-
- S1 < 80 phd

LZ sensitivity paper: arXiv:1802.06039

** multiple low-energy NR calibrations planned; see TDR
Photoneutrons

- Match gamma energy to Q for low energy neutrons
- First order: monoenergetic neutrons from monoenergetic gammas
- Process has fairly small cross section

\[ ^9\text{Be} + \gamma \rightarrow ^8\text{Be} + n \quad (Q = -1.667 \text{ MeV}) \]

\[ E_n \propto E_\gamma + Q \]

\[ N_\gamma : N_n \sim 10^4 : 1 \]

<table>
<thead>
<tr>
<th>Gamma Source</th>
<th>Neutron Energy [keV]</th>
<th>Xenon Recoil Endpoint [keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{88}\text{Y})</td>
<td>153</td>
<td>4.6</td>
</tr>
<tr>
<td>(^{205}\text{Bi})</td>
<td>88.5</td>
<td>2.7</td>
</tr>
<tr>
<td>(^{206}\text{Bi})</td>
<td>47.5</td>
<td>1.4</td>
</tr>
<tr>
<td>(^{124}\text{Sb})</td>
<td>22.5</td>
<td>0.7</td>
</tr>
</tbody>
</table>


A Photoneutron Calibration Source

photoneutron source assembly

Tungsten cap
BeO / $^{88}$Y source
Tungsten source capsule
Tungsten shield block

stainless steel guide tube

LZ TPC
What Could Go Wrong?

- Radiation from YBe source:
  1. 3.7 MBq $^{88}$Y MeV-scale gammas
  2. 270 neutrons per second
  3. MeV-scale gammas from neutron capture

- Key questions about event pileup:
  - Will the total event rate overwhelm matching of S1s and S2s from photoneutron events?
  - Will there be a well-defined endpoint in the photoneutron single scattering spectrum?
  - Will we be able to distinguish signals from backgrounds such as delayed electron noise?

Current Simulation Approach

- Full model of LZ in a GEANT4-based simulation
  - $^{88}\text{Y}$ gammas directly from decay in GEANT4
  - Photoneutrons from virtual gamma vectors
    - Sample locations and momentum-energy relation more accurately
  - First-order approximation from photoneutron cross section to scale datasets together
The Total Event Rate

- No cuts on events after post-processing
- 3.7 MBq $^{88}$Y decay gammas main source of event rate
- Gamma rate from neutron capture coupled to photoneutron rate (1st bin)
- Source events towards top of TPC, so less time between S1 and S2
  - Define small fiducial region towards the top of the detector as signal region

Event Rate [Cts / keV / sec]

- Total NR rate*: 1 Cts / sec
- Total ER rate: 206 Cts / sec
- ER from $^{88}$Y decays: 179 Cts / sec

*Non-thermal neutrons
The Signal Region

- Signal region looks great!
- S2 only (no S1 detected) events shown, but not the focus of this talk
Calibrating Expected Signals

- What 24 hours of calibration data could look like
- Radiogenic detector backgrounds negligible in fiducial region (<< 1 Cts / day)
- Nice overlap with coherent neutrino scattering signal region, mainly from $^8$B solar neutrinos
Summary

- Incorporate full optical response, electronics response, and analysis framework into simulation analysis
  - e.g. “LZ Mock Data Challenge 3” happening soon

- Incorporate more sophisticated event overlap and delayed electron noise in simulations

- Consider physics simulation accuracy
  - e.g. A. E. Robinson, PRC, 89(3), March 2014

- We will have a physical source later this year
Special Thanks

- Lawrence Berkeley National Lab
- LZ Collaboration
  - Specifically: Junsong Lin, Quentin Riffard, Peter Sorensen, Rick Gaitskell, Dan McKinsey
- NSF GRFP Program for support
Backup Slides
Outgoing Neutron Spectrum

- 180 photoneutrons per second leave the tungsten shield block
Mean z of Events

- Largest z-position of each event (single and multiple scatters)
- Use mean z for back of the envelope Poisson calculation of event overlap fraction
- Mean z: -160 mm
- Mean drift time 94 µs (assuming uniform drift field)
Fiducial Volume

- Single scattering events in signal region
- Consider NRs near endpoint (4.6 keVnr)
Signal Energy Spectrum in LXe

- MC events from slide 11 and 12 before detector response effects applied
Pushing to Lower Energies

- S1+S2 events are mostly > 10 e-
  - Confusion with delayed electron events less likely (at toy MC level)
- S2 only spectrum needs more detailed simulation to understand delayed electron effect

- S2 only (no S1 detected) events shown, but not the focus of this talk