Determination of Backgrounds for the LUX Experiment

Kelsey C Oliver-Mallory
UC Berkeley & Lawrence Berkeley National Laboratory
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On behalf of the LUX collaboration
Large Underground Xenon (LUX) Detector

- Two-phase xenon time projection chamber
- An interacting particle deposits energy in two channels
  - Excitation
  - Ionization
- Prompt scintillation (S1 signal) is immediately detected by PMTs
- Electrons are drifted upward and extracted into the gas phase region creating secondary scintillation detected by the PMTs (S2 signal)
In Jan 2017, LUX published final spin independent WIMP limit (~ 1-10 keVee)
Data from two runs: WS-2013 (95 live days) and WS-2014/16 (332 live days)
Now we’re looking at high energy physics processes
Additional backgrounds from $\beta$, $\epsilon$, and isomeric transition decays in the xenon
This talk will present background search results from WS-2014/16 in the energy range 0 - 425 keVee
Outline

1. Calibration of WS-2014/16 electron recoil energy scale

2. Four sources backgrounds:
   a. Short lived radioisotopes from activation of the xenon with a DD neutron generator calibrations
   b. $^{210}$Pb from $^{222}$Rn daughter plate-out on detector surfaces
   c. Detector effects, such as PMT afterpulsing, photoionization of grids and impurities, and electron trains
   d. Neutron backgrounds from PMTs and PTFE
Every three months we perform:

- Calibrations of the electron recoil (ER) band, light and charge yields with tritium source
- Calibrations of the nuclear recoil (NR) band, light and charge yields with 2.45 MeV neutrons from a DD generator
- Calibrations of the energy of electron recoils in the detector using $^{131m}$Xe, $^{129m}$Xe, $^{125}$Xe xenon activation lines from the DD neutron generator

The data is divided into four date bins and specific energy reconstruction parameters are applied to each bin.
LUX ER Energy Calibration

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

g$^1$ = efficiency for detection of a prompt scintillation photons

g$^2$ = efficiency/gain for detection of electron signal

$W$ = average energy to produce a single excited or ionized atom

- g$^1$ and g$^2$ calculated at each DD calibration time
- g$^1$ and g$^2$ interpolated to the midpoint of each date bin

Error on g$^1$ and g$^2$ includes both statistical and systematic components. The systematic component comes from the elliptical cuts used to select the calibration sources.
Short Lived DD-n Activation of Xe

- In addition to activation peaks, $^{83m}$Kr (continuously being injected for calibration) is visible
- Data on this slide follows the multiple neutron calibration runs over 5 weeks at different z-depths that occurred in Sep 2014

$^{131m}$Xe Fit for Energy
$(E = 164.3 \pm 0.1 \text{ keV})$

$^{131m}$Xe Fit for Half Life
$t_{1/2} = 10.2 \pm 0.4 \text{ days}$

LUX Preliminary

2 Weeks of Background Following Sep 2014 DD Run

LUX Preliminary
# Determination of Short Lived Xe Activation Isotopes

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Energy *</th>
<th>Measured Energy</th>
<th>Half Life *</th>
<th>Measured Decay Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{125}\text{I}$</td>
<td>$\gamma$</td>
<td>67.3 keV **</td>
<td>67.1 ± 0.4 keV</td>
<td>5.4 ± 0.4 d ***</td>
</tr>
<tr>
<td>$^{133}\text{Xe}$</td>
<td>$\beta+\text{IT}$</td>
<td>$Q_{\text{max}} = 346.4 + \text{IT}$ 81 keV</td>
<td>5.2475 d</td>
<td>5.0 ± 0.3 d</td>
</tr>
<tr>
<td>$^{131m}\text{Xe}$</td>
<td>$\text{IT}$</td>
<td>163.9 keV</td>
<td>163.6 ± 0.1 keV</td>
<td>10.7 ± 0.4 d</td>
</tr>
<tr>
<td>$^{129m}\text{Xe}$</td>
<td>$\text{IT}$</td>
<td>236.1 keV</td>
<td>235.3 ± 0.1 keV</td>
<td>9.1 ± 0.3 d</td>
</tr>
<tr>
<td>$^{125}\text{Xe}$</td>
<td>$\gamma$</td>
<td>275 keV **</td>
<td>275.5 ± 0.6 keV</td>
<td>16.9 h</td>
</tr>
</tbody>
</table>

Uncertainties in table are statistical uncertainty in the fit for energy or half life.

*Energy and half life measurements from National Nuclear Data Center website (http://www.nndc.bnl.gov/chart/chartNuc.jsp)*

**An estimate of energy deposited in electron recoils in LUX from a K-shell electron capture**

***Effective half life. Represents rate at which $^{125}\text{I}$ is removed from the xenon by the getter. Energy is the close the two neutrino Double Electron Capture $^{124}\text{Xe}$ Energy (63.6 keV)***

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LUX Preliminary
210Pb on Detector surfaces

- During construction, 222Rn progeny plate out on the inner PTFE walls of the detector.
- All short lived isotopes decay away leaving 210Pb, 210Bi, and 210Po.
- These isotopes can be absorbed off of the walls into the xenon.
\( ^{210}\text{Pb} \) on Walls

Fit requires contributions from \(^{210}\text{Pb} \) conversion electrons in the range 30.1-33.1 keV, \(^{210}\text{Pb} \) conversion electrons and gamma ray in range 42.6-46.5 keV, and xenon fluorescence in range 29.5-34.5 keV. Lower limit is set assuming LUX is capable of seeing a fraction of the \(^{210}\text{Pb} \) decay products on the wall.

Activity of \(^{210}\text{Pb} \) on wall in the fiducial volume drift range for WS-2014/16
\[
> 9.6 \pm 0.6 \text{ mBq}
\]

Activity of $^{210}\text{Pb}$ in fiducial volume < 0.099 μBq/kg

J. Low Temp. Phys. 176 (2014) no.5-6, 959-965
Limit on Leaching of $^{210}$Pb into Xenon

- Activity of $^{210}$Pb was measured for each date bin.
- If there is no leaching, $^{210}$Pb activity will decay by 4% over length of WS-2014/16.
- Limit on decay constant for leaching of $^{210}$Pb from detector walls is given as the fit value less $1\sigma$, correcting for 4% $^{210}$Pb decay.

$t_{1/2}$ of $^{210}$Pb leaching off wall $> 1.6 \times 10^3$ days
Detector Effects: High Energy Event Classification

Following Large S1s:

- PMT afterpulsing
  - During PMT calibrations the probability of afterpulsing was measured
  - The results of this calibration were not folded into the pulse/event classification algorithm for high energy data
- Photo-ionization of the grids and impurities in the xenon

Following Large S2s:

- Electron trains
  - Trails of electrons caused by:
    - Photo-ionization of impurities
    - Emission of thermalized electrons not emitted in the primary S2 signal
    - Etc.
Spurious Pulse Classification Algorithm

- Above ~45 keVee, the detector effects described on previous slide can introduce spurious pulses that have the topology of an S1 or an S2.
- A new algorithm was developed to identify and classify spurious pulses in high energy events.
- In the $^{131m}$Xe data, the resulting acceptance of single S1, S2 events increases by a factor of 10 (efficiency of ~100%).
- Does not affect existing publications.
Simulation of Neutron Backgrounds

- **PMTs**
  - Neutrons from \((\alpha,n)\) from \(^{238}\text{U}\)-chain \(\alpha\)’s
  - Neutrons from \((\alpha,n)\) from \(^{232}\text{Th}\)-chain \(\alpha\)’s
  - Neutrons from \(^{235}\text{U}\)-chain fission

- **PTFE**
  - Neutrons from \((\alpha,n)\) from \(^{210}\text{Po} (^{238}\text{U} \text{ late})\) chain \(\alpha\)’s

- LUXSim was used to simulate energy depositions and libNEST was used to simulate the detector response

- Applied relevant data quality cuts

- Results (WIMP search ROI during WS-2014/16, 332 live days)
  - 0.16 events from PMTs
  - 0.016 events from PTFE

View of LUX TPC from below
Conclusion

- Short lived activation products from DD neutron generator (including $^{125}$I with effective decay constant $5.4 \pm 0.4$ days)
- $^{210}$Pb on the detector wall and in the fiducial volume ($1600$ day $t_{1/2}$ for leaching from the walls into the fiducial volume)
- Detector effects, such as PMT afterpulsing, photoionization of grids and impurities, and electron trains ($10x$ acceptance increase for $^{131m}$Xe)
- Neutron background from PMTs ($0.16$ events during WS-2014/16) and PTFE ($0.016$ events during WS-2014/16)

Thanks go to: the LUX Collaboration

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