Upward view through the LUX TPC

Searching for dark matter with LUX and LZ

Peter Sorensen on behalf of the LUX Collaboration and the LZ Collaboration
LUX is dead; long live LUX!

- 6 Oct, 2016: LUX comes up for air after 3+ years in the water shield
- 13 Jan, 2017: WIMP search results from total 95+332 live day exposure published in PRL
- LUX is presently the most sensitive direct detection experiment and a rich physics program is on-going
LUX by the numbers

- Central detector:
  - 0.5 m diameter x 0.5 m height dodecagon
  - 370 kg liquid xenon TPC, 250 kg active target mass, ~100 kg fiducial target mass
  - 122 Photomultiplier tubes, Hamamatsu R8778
- 2 ultra low background titanium cryostats
- 1 ultra pure water shield
- Pioneering in-situ calibration program including $^{83m}$Kr, $^3$H and DD neutron
Background minimization

- **Internal**
  - We count and then build with low-background materials (Cu, Ti)
  - Fiducialization takes advantage of xenon’s self-shielding

- **Intrinsic**
  - Dedicated purification system for Kr removal ($^{85}$Kr beta decay) from Xe via chromatographic separation.

- **External**
  - 70,000-gallon water tank with active PMT veto system for muon tagging
  - Overburden for reduction of cosmic backgrounds

![Graph showing measured DRU (89 livedays, 89 eff) with 3.6+/-0.3 mdru in the center.](image)

Liquid Xe self-shielding from LUX2013 data
LUX 332 live day exposure (salted)

- **filled**: bulk event
- **open**: outer 1 cm of bulk
- **black**: recorded events
- **blue**: sprinkled salt
- **blue bands**: background distribution 10% - 90%
- **red bands**: signal distribution 10% - 90%
- **green curves**: keV energy
LUX 332 live day exposure (salt-free!)

- Salt is now removed
- Red events removed by post-unsalting cut
LUX 332 + 95 live days results

- LUX 2013 results reported on 95 live days
- LUX 2014-2016 results reported on 332 live days
- Total of 33,500 kg-days (~0.1 tonne-year)
- Limits calculated using 5 dimensional unbinned PLR (r, φ, dt, S1, S2)
- in between these search campaigns: calibrations and conditioning

Phys. Rev. Lett. 118, 021303
Signal detection efficiency

- S2 efficiency (red)
- S1 efficiency (green)
- combined S1+S2 (blue)
- total after analysis cuts (black)
- range (dashed) is extrema of 16 detectors
Electrode conditioning

✧ Standard technique for electron drift detectors
✧ Consists of maintaining electrode at a voltage just at/above discharge threshold
✧ Performed after 95 live day result, in cold gas xenon
✧ Modest success - increased electron emission efficiency from ~50% to about 75%
✧ Unintended consequence - negative charge build-up on PTFE
Electrode conditioning affect on e− trajectories
Mitigation: 16 detectors

Gray density: CH$_3$T calibration (ER)

Orange density: DD calibration (NR)

Solid lines: NEST model, ER, NR band mean

Dashed lines: NEST model, 10-90 percentile.
DD neutron calibration

\[ E_R = E_0 \frac{4m_n m_{Xe}}{(m_n + m_{Xe})^2} \left(1 - \cos \theta \right) \]

\[ \Delta t : z' \text{ separation} \]

\[ \theta : \text{energy calculation} \]

\[ Q_y (e^- / \text{keV}) \]

\[ L_y (\text{ph} / \text{keV}) \]

\[ \text{Efficiency} \]

\[ \text{Nuclear recoil energy (keV)} \]

arXiv:1608.05381
LUX detector physics results

- Too many publications to cover here (and more in the works)
- Partial list below


"Low-energy (0.7-74 keV) nuclear recoil calibration of the LUX dark matter experiment using D-D neutron scattering kinematics" (2016), submitted to PRC, arXiv:1608.05381


As a benchmark, sensitivity to 50 GeV WIMPs over 4 decades

LZ design goal approaches $1 \times 10^{-48}$ cm$^2$

Note factor $\sim x20$ in mass results in factor $\sim x100$ in sensitivity

Due to self shielding Xe and additional background reduction
LZ sensitivity

- LZ projected WIMP sensitivity
- This and other plots from the forthcoming LZ Technical Design Report (TDR)
- Expected to appear on arXiv in March
LZ instrument
Projected NR-like signal distribution

Total of 6.8 signal-like background events in complete exposure
Rn is dominant component
followed by v-e solar neutrino scattering, and atmospheric v-A scattering
$^8$B neutrino-nucleus scattering

- Background can be profiled due to distinctive shape
- Multiple calibration sources: DD neutron scattering, novel D-reflector neutron scattering, photoneutron scattering
LUX and LZ Collaborations

- **LUX:**
  - ~20 institutions and ~100 scientists
  - luxdarkmatter.org

- **LZ:**
  - ~30 institutions and ~200 scientists / engineers
  - lzdarkmatter.org

Searching for dark matter with LUX and LZ
Summary

❖ LUX had an extremely productive 4-year run and is still producing new physics results

❖ The LZ Collaboration is working to ensure a successful follow-on experiment is deployed on or ahead of schedule (presently 2020)
Extra Slides Follow
Post-unsalting cuts for new pathologies

- Cuts with high signal acceptance were defined on DD and CH$_3$T calibration data (shown below).
- Flat signal acceptance of 98.5% with both cuts applied.

Density map: CH$_3$T calibration data
- $\times$ : WS2014-16 data passing S1 cuts
- $\circ$ : WS2014-16 data cut by S1 Max. PMT Area cut
- $\times$ : WS2014-16 data cut by S1 Prompt Fraction cut

Removes events with S1 light overly-concentrated in a single PMT.

Removes events with S1 that has gas-event-like time structure.
Wall-surface backgrounds

- Understood as radon plate-out on PTFE during exposure to air in construction
- Survives as $^{210}\text{Pb}$ and its daughters ($^{210}\text{Bi}$, $^{210}\text{Po}$)
- Recoils occur short (~mm) distances from the wall
- Observed wall width due to finite position resolution
- Two-part solution in negotiating this background:
  - a fiducial volume cut 3 cm inwards from the measured wall position
  - a model for the number and position of events originating from the wall-surface backgrounds

![Graphs showing data and model predictions for events at different distances from the wall.](image)