New analysis results from the LUX dark matter experiment

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for the LUX Collaboration
LUX Collaboration

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- Imperial College London
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Outline

- Introduction.
- LUX detector.
- LUX story.
- New LUX results.
- Conclusions.
Principle of WIMP detection in LXe TPC

- Liquid xenon time projection chamber – LXe TPC.
- S1 – primary scintillation.
- S2 – secondary scintillation, proportional to ionisation.
- Position reconstruction based on the light pattern in the PMTs and delay between S2 and S1.
Advantages of LXe

- Good scintillator.
- Two-phase -> TPC with good position resolution.
- Self-shielding.
- Good discrimination between electron recoils (ERs) and nuclear recoils (NRs).
- High atomic mass: spin-independent cross-section $\propto A^2$
- Presence of even-odd isotopes (odd number of neutrons) for spin-dependent studies.
- Other physics:
  - Axions, ALPs,
  - $0\nu\beta\beta$,
  - Coherent neutrino scattering, …

Graphs from LZ TDR, 1703.09144 [physics.ins-det]
LUX detector

- 61 top + 61 bottom ultra-low background PMTs viewing ~250 kg of xenon in the active region (~120 kg fiducial).
- Ultra-low background titanium cryostat.
- Active region defined by high-reflectivity PTFE walls.
- Maximum drift: 50 cm.
- Xenon continuously re-circulated to maintain purity.
- Chromatographic separation reduced Kr content.
LUX detector
4850 ft level at SURF. Muon flux $\sim 6 \times 10^{-5}$ m$^{-2}$ s$^{-1}$. Now replaced with LZ.

Muon veto system and shielding: water tank instrumented with PMTs.
LUX calibrations

- CH$_3$T (tritiated methane) – uniform, removed by purification, 2-3 times a year (top figure), D. Akerib et al. (LUX Collaboration), Phys. Rev. D93 (2016) 072009.
Post science run calibrations

- Improved measurements of the response of LXe to electrons from $\beta$-decays.
- Injected radioactive sources: $^3$H and $^{14}$C.
- Non-uniform electric field in LUX allowing measurements at different strength.
- Light to charge ratio as a function of energy for different fields.
- Left $-^3$H, right $-^{14}$C.
- Akerib et al. (LUX Collaborations), PRD 100, 022002 (2019).
- See talk by Jon Balajthy, Thursday, 15:30.
- Data after cuts: 332 live days (2015-2016).
- Profile likelihood ratio analysis; data consistent with background only hypothesis.
Spin-independent interactions

- Limits on spin-independent WIMP-nucleon cross-section (right); two runs combined: 2013 – 95 live days, 2015-2016 – 332 live days. Combined exposure $3.35 \times 10^4 \text{ kg} \times \text{days}$.
- Limit $1.1 \times 10^{-46} \text{ cm}^2$ at 50 GeV/c$^2$. Akerib et al. (LUX Collaboration), PRL 118, 021303 (2017).
- Most recent results from leading two-phase Xe experiments.
Spin-dependent WIMP-neutron cross-section (left): two Xe isotopes with odd number of neutrons.

Spin-dependent WIMP-proton cross-section (right): even number of protons, reduced sensitivity.

Akerib et al. (LUX Collaboration), PRL 118, 251302 (2017).
Axions and axion-like particles (ALPs)

**Axions**

- Solar axions: LUX (2013) excludes $g_{Ae} > 3.5 \times 10^{-12}$ (90% CL).
  - $m_A < 0.12$ eV/c$^2$ (DFSZ model).
  - $m_A < 36.6$ eV/c$^2$ (KSVZ model).

**ALPs**

- Primordial ALPs: LUX (2013) excludes $g_{Ae} > 4.2 \times 10^{-13}$ (90% CL) for 1-16 keV/c$^2$ ALP masses.


Searches are based on axio-electric effect.
Sensitivity to sub-GeV WIMPs

- WIMP-nucleus interactions may result in the emission of bremsstrahlung photons by a polarised xenon atom, C. Kouvaris and J. Pradler, PRL 118, 031803 (2017).

Migdal effect: ionisation of recoiling atom

Bremsstrahlung: photon emission from the moving nucleus
Sensitivity to sub-GeV WIMPs

- ER detection improves sensitivity to low mass WIMPs (down to 0.3 GeV/c^2). Akerib et al. (LUX Collaboration), PRL 122, 131301 (2019). See also Tom Shutt plenary talk.

Modulation studies

Akerib et al. (LUX Collaboration), PRD 98, 062005 (2018)

- Single scatter rate at low energies in the fiducial volume (total rate, i.e. no ER/NR discrimination): \(~2.3\) events/tonne/day/keV, \(5\) times lower than the DAMA modulation amplitude in the same energy range.
- No statistically significant annual or diurnal modulation found.

Diurnal

- day/night: \(2.28 / 2.36\) cpd/keV/ton (siderial)
- Asymmetry: \(-1.7\% \pm 8.7\%\) (stats only)
Modulation studies

- 9.2σ conflict with the DAMA result for the same modulation phase and the same energy window.
Sometimes 2 PEs are emitted per single VUV photon on the photocathode of the PMT. About 17% probability for LUX PMTs.

Replacing 2-fold coincidence requirement with 2 PE requirement.

2013 data: 95 live days, 118 kg fiducial mass.
Double photoelectron analysis

- Scatter plot of detected events: 6 open circles are the background for this analysis.
- NR band is for 50 GeV/c² (10%-90%).
- Colour scheme on the right shows event distribution for 4 GeV/c² WIMP model.
- Signal acceptance and expected number of background events as a function of WIMP mass.
- Low efficiency but almost no dark counts.
Double photoelectron analysis

- Powerful new technique developed and tested with first science run of LUX.
- Will be used in future in LZ data analysis.
- Akerib et al. (LUX Collaboration), arXiv:1907.06272
Mirror DM with kinetic mixing

- Hidden sector -> mirror partners to SM particles (same masses etc).
- Interaction of mirror electrons with Xe electrons.
Mirror DM with kinetic mixing

- Limits on the mixing parameter in kinetic mixing; effectively on the fraction of the electron electric charge for mirror electrons.
- Function of the local temperature of mirror electrons.
- The region allowed astrophysically is shown in white.
- Akerib et al. (LUX Collaboration), arXiv:1908.03479.
Conclusions

- The LUX experiment has achieved the world-best sensitivity at the time of data releases proving the great potential of the time projection chamber technology based on dual-phase xenon, for searching for a very rare signal from dark matter WIMPs.
- The experiment has stopped 3 years ago but the data analysis still continues.
- Recent results include:
  - Search for low mass WIMPs using Migdal effect and bremsstrahlung emission,
  - Modulation analysis,
  - Double photoelectron analysis,
  - Mirror dark matter with kinetic mixing,
  - Calibration studies.
- More analyses are ongoing and new results are expected.
- LUX is now replaced with LUX-ZEPLIN (LZ) that will start data taking in 2020. See several LZ talks at this conference.