SUB-GEV AND OTHER RARE EVENT SEARCHES WITH THE LUX DETECTOR

Lucie Tvrznikova on behalf of LUX collaboration
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Research Assistant, LBNL
Visiting Student Researcher, UC Berkeley

April APS in Columbus, OH. 14th of April, 2018
LUX detector is searching for dark matter

- Axions
- Axion-like particles
- Light dark matter + light mediators
- WIMPs
- SIMPs

Energy Detection:
- ~meV energy detection
- ~eV energy detection
- ~keV energy detection
LUX collaboration

LUX = Large Underground Xenon Experiment

24 institutions, ~100 people

LUX collaboration meeting, June 2015
Sanford Underground Research Facility, Lead, SD
LUX detector operated 4850’ (1478m) underground

Water tank

- Veto PMTs
- Cryostat
- Source tubes
- Neutron conduit

Inner & outer titanium cryostats
Cooper radiation shield
Top PMT array
Gate, anode & top shield grids
Cathode and bottom shield grids
Bottom PMT array

Liquid xenon target (active mass=250kg, search mass=100kg)
Feedthroughs
PTFE walls
Xenon recirculation and heat exchanger

2018-04-14
Lucie Tvrznikova
Two phase TPC maps detector volume

- Photomultiplier tube (PMT) array
- Anode grid
- Gate grid
- Cathode grid
- Xenon gas
- Liquid gas
- Particle
- S1
- S2
- E field

**TPC = Time Projection Chamber**

ionization electrons
UV scintillation photons (∼175 nm)
Using xenon
- Spin-dependent & independent WIMP detection capabilities
- High atomic mass (A=131 g/mol)
- No intrinsic DM search backgrounds
- Scalable to multi-ton size

with full 3D position reconstruction
- $xy$ reconstructed from S2 light pattern
- $z$ given by time difference between S1 and S2

and S2/S1 discrimination
- Ability to reject backgrounds

LUX is a two phase TPC

TPC = Time Projection Chamber

Photomultiplier tube (PMT) array

- Ionization electrons
- UV scintillation photons ($\sim$175 nm)

Image by CH Faham (Broen)
Distinguish between 2 types of particle recoil

Electron recoil (ER) & Nuclear recoil (NR)

Discriminate electron & nuclear recoils using S2/S1 ratio

- S1 – light signal (178 nm photons)
- S2 – charge signal (electrons)

Electron recoil (ER)
- γ, B

Nuclear recoil (NR)
- Neutrons, WIMPs

Recoil energy (keV)
LUX data improved experimental boundaries

Axion limit

Coupling between galactic ALPs and electrons

Spin-independent & spin-dependent limits

Axions

Axion-like particles

Light dark matter + light mediators

WIMPs

SIMPs
LUX is more sensitive to lower energies of electron recoils

Efficiency of nuclear recoil events in LUX in WS2013 reanalysis

- $S_1$
- $S_2$
- $S_1 + S_2$
- $S_1 + S_2 + \text{threshold}$

50% energy threshold:
- nuclear recoils = 3.3 keV
- electron recoils = 1.2 keV

Efficiency of electron recoil events in LUX

Fit: $\frac{\text{erf} \left(\frac{x - \mu}{\sqrt{2 \cdot \sigma}}\right)}{2} + \frac{1}{2}$

- $\mu = 1.24 \pm 0.026$
- $\sigma = 0.43 \pm 0.042$
LUX can detect sub-GeV DM via bremsstrahlung

Elastic scattering
- Nuclear recoil signal
- Assumed in the standard WIMP search
- LUX searches for $m_{\text{DM}} \gtrsim 5\text{GeV}$

Bremsstrahlung
- Nuclear interaction, but electron recoil signal
- Emission of a photon from a polarized xenon atom
- Gain access to low energy NR interactions by looking for this ER signature since ER signal is much easier to detect at low energies!

$\Rightarrow$ LUX can gain sensitivity to $m_{\text{DM}} \sim \text{MeV}$

Bremsstrahlung allows detection of NR previously below threshold

Scattering rates for 0.5 GeV DM

Heavy mediator ($\gg \text{MeV}$)
$\sigma = 10^{-35} \text{ cm}^2$

Elastic
(nuclear recoil signal)

Bremsstrahlung
(electron recoil signal)

Detector efficiency from tritium

Events/kg/day/keV
Example of a signal expected in LUX from $m_{\chi} = 0.5$ GeV

Scattering rates

- Elastic (nuclear recoil signal)
- Bremsstrahlung (electron recoil signal)

Detector efficiency from tritium

Expected bremsstrahlung signal in LUX

Simulate events for these scattering rates using NEST (Noble Element Simulation Technique package)

JINST 8:C10003 (2013)
Final WS2013 data after cuts (95 live days)

Electron recoil band
Nuclear recoil band for $m_\chi = 50$ GeV
Dashed lines are 10 & 90 percentiles

Expected signal region for 0.5 GeV DM from bremsstrahlung

Black points: $r \leq 18$ cm
Grey points: $18 < r < 20$ cm (edges of the fiducial volume boundary)
LUX limit calculated using profile likelihood ratio

Heavy mediator ($\gg$ MeV)

Mass$_{DM}$ [GeV]

Cross-section [cm$^2$]

Limit is for 95 live-days of data (with 13,775 kg·day exposure). Limit from the complete LUX exposure is forthcoming.

For $m=1$ GeV: $n_{\text{Sig}}$ limit = 3.3 events
Conclusion

- Bremsstrahlung signal allows LUX to search for sub-GeV DM
- LUX sensitivity extends down to DM with masses of 0.3 GeV, providing the most stringent limit for LXe detectors for light DM
- Learn more about LUX & LZ at the April APS:
  - Session J09, Sunday 1:30pm
    - Signal yields in liquid xenon with LUX (V Velan)
    - Charge and light yields of liquid xenon using $^{14}$C and tritium beta decay sources in LUX (J Balajthy)
    - Xenon circulation and liquid-level stability in LZ (D Temples)
    - Development of the LZ high voltage grids (R Linehan)
    - Status of LZ cathode high voltage research and design project (J Watson)
    - Recent results from the LZ System Test platform at SLAC (K Stifter)
  - Session J10, Sunday & Monday 1:30pm
    - Measurement of the Davis Cavern gamma-ray background at the Sanford Underground Research Facility (S Shaw)
    - Simulations of external backgrounds at SURF for the LUX and LZ experiments (D Woodward)
    - The active veto system for LUX and underground muon signals (D Tiedt)
    - The LZ liquid scintillator screener detector (S Haselschwardt)
    - Radiogenic backgrounds in the LUX xenon and detector components (K Mallory)
LUX collected data from 2013-2016

- 2008: LUX funded (DOE + NSF)
- 2006: LUX collaboration formed
- 2012: LUX moves UG
- April 2013: First science run starts
- Nov 2013: First WS results reported (85.3 live-days)
- August 2013: Joined LUX
- Sept 2013: 332-day run start
- Sept 2014: 332-day run start
- May 2016: WS2014-16 finished
- July 2016: 332-day WS result announced
- Sept 2016: decommissioning start
- Analysis still ongoing
- June 2017: LUX installed in a museum

**Fig. 5** (color online). The LUX 90% confidence limit on the WIMP mass is shown in Fig. 5, along with the allowed region from CRESST II (green line), ZEPLIN-III (dark green line), XENON100 (blue line), CDMS II (yellow shaded) and centroid (green x), 90% exclusion limits from low threshold re-analysis of CDMS II data (grey line), CDMSlite (light red, shaded), along with the 90% upper C.L. cross sections for spin-independent WIMP models are thus shown in Fig. 5.

**References**

- PRL, 112, 091303 (2014)
- PRL, 116, 161301 (2016)
- PRL, 116, 161302 (2016)
- PRL, 118, 021303 (2017)
Photon emission rates in xenon were first calculated by C. Kouvaris & J. Pradler

PRL 118, 031803 (2017)

Expected scattering rates in xenon for $\sigma = 10^{-35}$ cm$^2$

- **Bremsstrahlung (electron recoil)**
- **Elastic (nuclear recoil)**
Expected signal for $m = 0.5$ GeV DM from LibNEST
Expected signal spectra simulated by NEST at $\sigma=10^{-35}\text{cm}^2$

- $m = 0.1$ GeV
- $m = 0.5$ GeV
- $m = 1$ GeV
- $m = 5$ GeV

LUX Preliminary
Only a fraction of events have both S1 & S2 signals.
Tritium and DD calibrate detector response

Deuterium-Deuterium neutron generator
- $E = 2.45$ MeV
- Located outside of the water tank
- Injected quarterly at different $z$
- Double scatters used for $Q_y$ analysis
- Single scatters used for $L_y$ analysis and NR band

CH$_3$T
- Tritium $\beta$ spectrum coincides with WIMP interaction energy
- $T_{1/2} = 12.3$ yr
  - Removed by getter
- Injected quarterly

Electron recoil (ER)
Nuclear recoil (NR)

PRD 93, 072009 (2016)
PRD 95, 012008 (2017)
arXiv:1608.05381
Krypton-83m is injected regularly into the detector to characterize detector response and monitor stability.

- Mixes homogenously with LXe
- Used for:
  - Overall stability monitoring
  - Position reconstruction
  - Electron lifetime
  - S1 & S2 position corrections
  - Electric field modeling
- Decays by emitting 2 internal conversion electrons
  - 32.2 keV followed by 9.4 keV ($T_{1/2} = 154$ ns)
  - Monoenergetic for our standard analysis
- $T_{1/2} = 1.83$ h
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C. McCabe published a paper inferring LUX sensitivity to the sub-GeV signal and calculated limits for LUX & LZ.

Earth heating = constraint from Earth heating by DM annihilation