Recent Results of the LUX Dark Matter Experiment

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TeV Particle Astrophysics 2019

Sydney, 5/12/2019

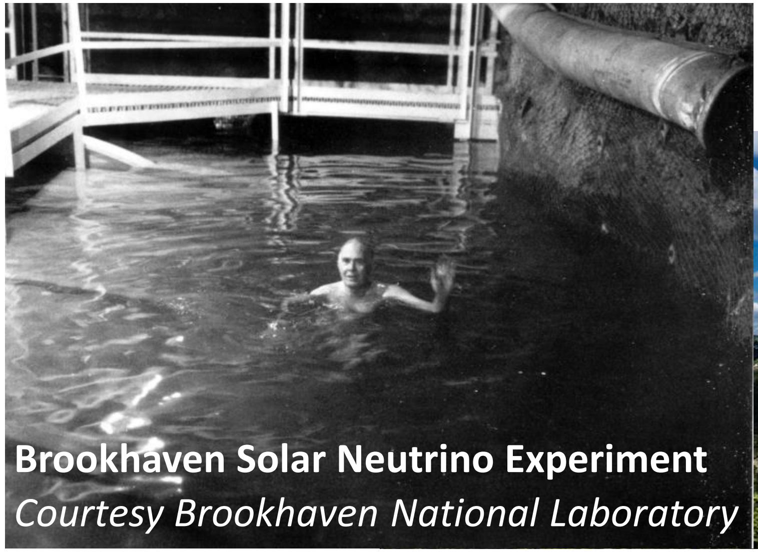
OUTLINE

- LUX
  - Collaboration
  - Detector
  - Timeline
- Results
  - Calibrations
  - (Recent) analyses
    - Disclaimer: plots have not been updated to reflect the current status
  - New analysis techniques

LUX Collaboration

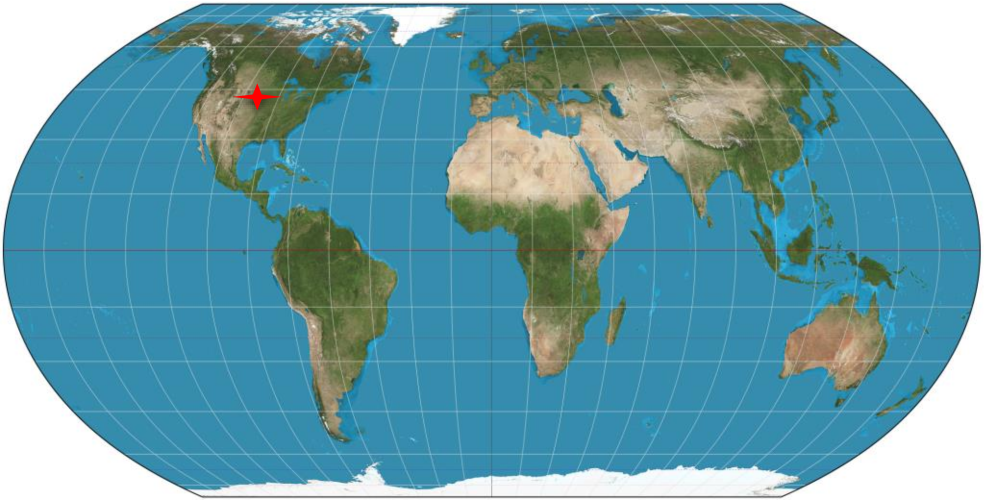
- ❖ Brown University
- ❖ Imperial College London
- ❖ LIP Coimbra, Portugal
- ❖ Lawrence Berkley National Laboratory
- ❖ Lawrence Livermore National Laboratory
- ❖ Pennsylvania State University
- ❖ SLAC National Accelerator Laboratory
- ❖ South Dakota School of Mines and Technology
- ❖ South Dakota Science and Technology Authority
- ❖ Stanislaus State University
- ❖ Texas A&M University
- ❖ University at Albany, SUNY
- ❖ University College London
- ❖ University of California, Berkeley
- ❖ University of California, Davis
- ❖ University of California, Santa Barbara
- ❖ University of Edinburgh
- ❖ University of Liverpool
- ❖ University of Maryland
- ❖ University of Massachusetts
- ❖ University of Rochester
- ❖ University of Sheffield
- ❖ University of South Dakota
- ❖ University of Wisconsin – Madison

LUX Location

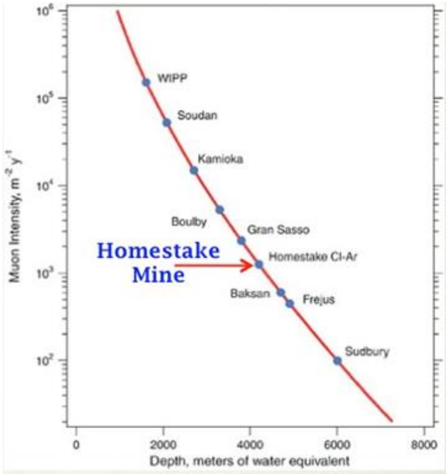

Brookhaven Solar Neutrino Experiment
Courtesy Brookhaven National Laboratory

Davis Cavern 1480m

Lead, SD, USA

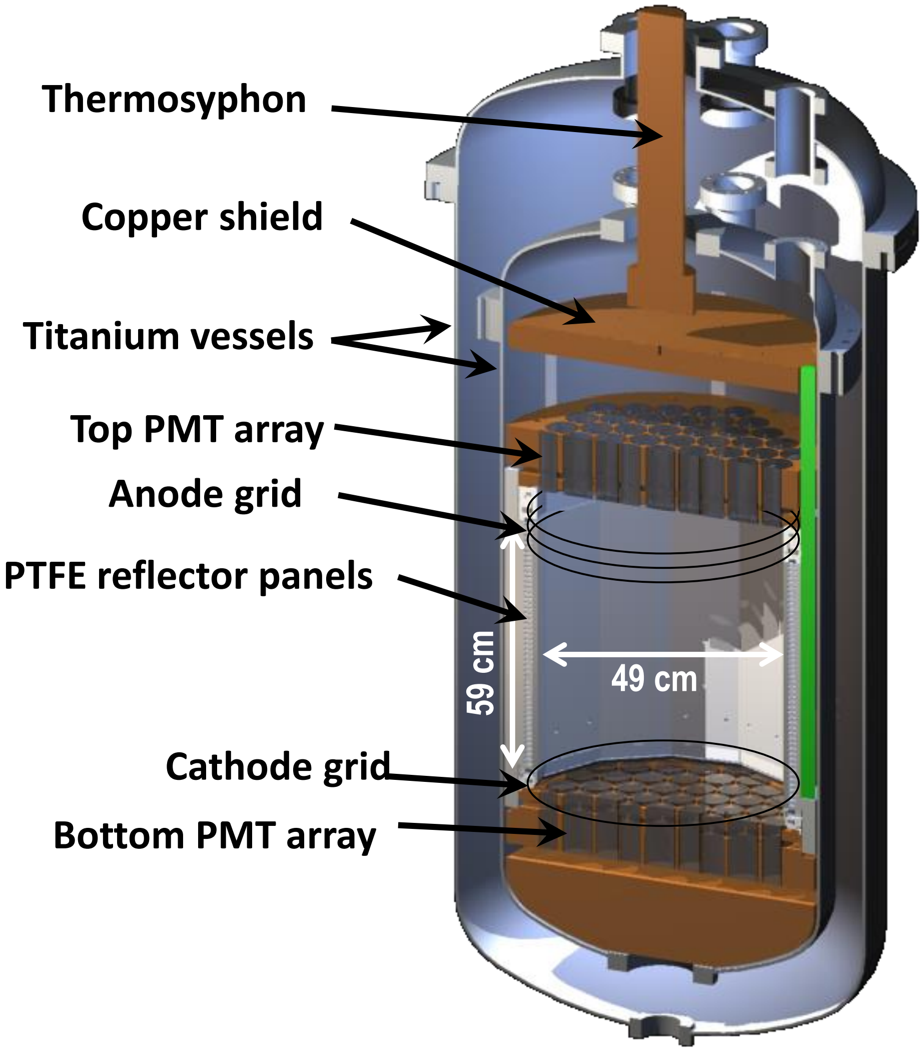


LUX in a 5.8 x 3.8 m water tank



$55.2\ m^{-2}\cdot sec^{-1} \rightarrow 10^{-5}\ m^{-2}\cdot sec^{-1}$

LUX Detector



- 61 top + 61 bottom ultra-low background PMTs
- 370 kg of liquid xenon
  - 250 kg in the active region
  - 120 kg fiducial.
  - Continuously re-circulated to maintain purity.
  - Chromatographic separation reduced Kr content.

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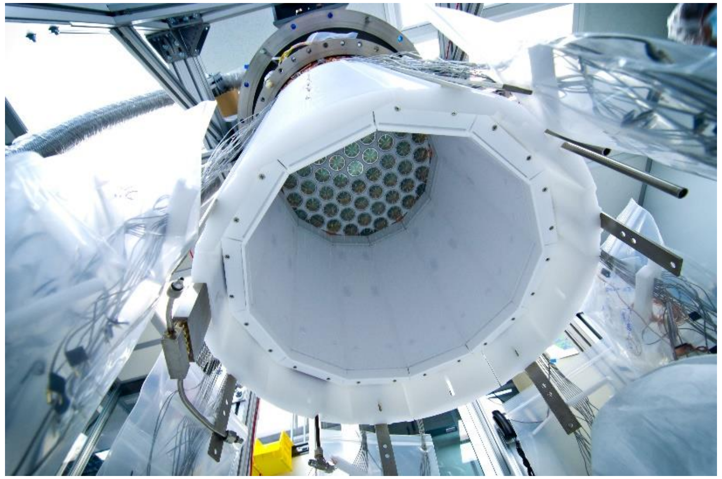
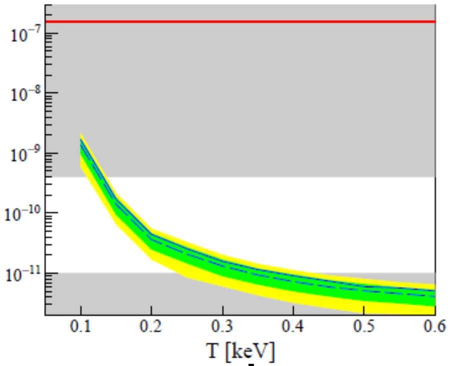




LUX Collaboration formed 2006

2012 LUX moves underground

First science run WS2013 starts 2013 (Apr)

2013 (Nov) 95 live-day results reported

Second science run WS2014-16 starts 2014 (Sep)

Final calibrations 2016 (May-Aug)

2016 332 live-days results reported

LUX decommissioned 2016 (Sep)

2016 (Oct) 427 live-days SI results

2017 (Apr) Axions

2017 (May) SD

LUX in the visitors' center in Lead 2017 (Jul)

2017 (Aug) – 2018 (Feb) 7 technical publications on calibration, trigger, etc.

2018 (Jul) modulation

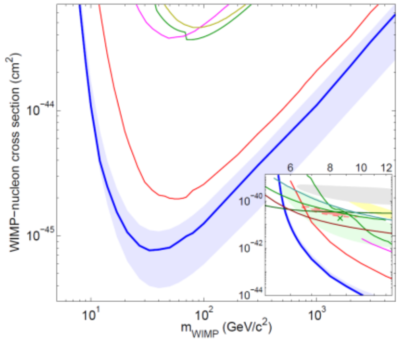
2018 (Nov) subGeV

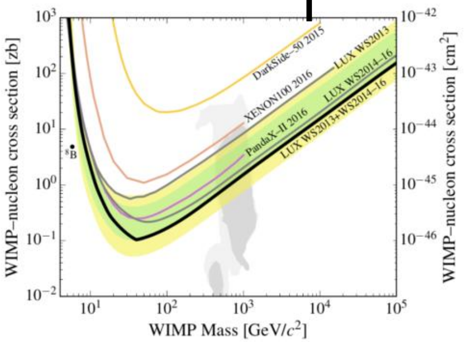
2019 (Mar) Calibration of β-decay

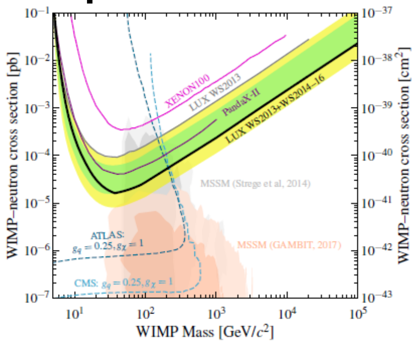
2019 (Jul) Single scint. photon sensitivity

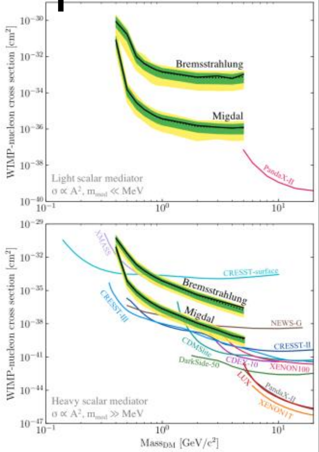
2019 (Aug) Mirror DM

2019 (Oct) β-decay model



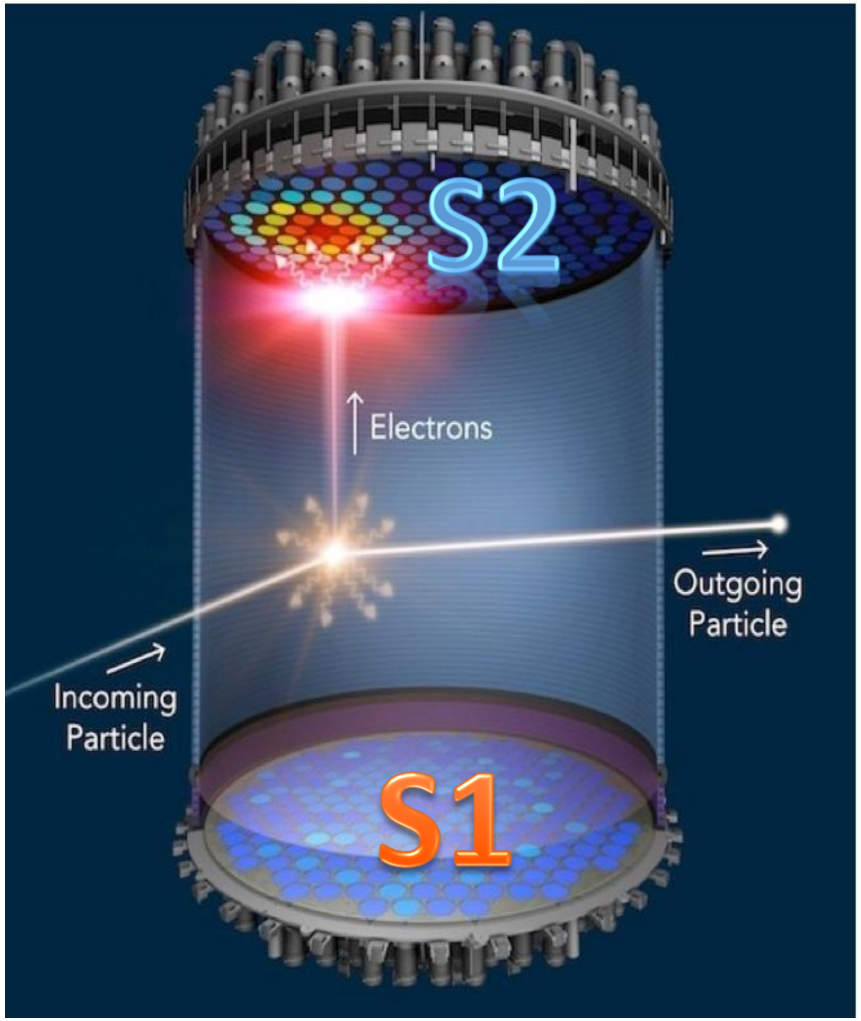


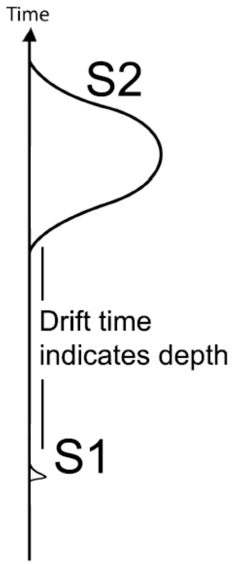




*not all early publications are shown

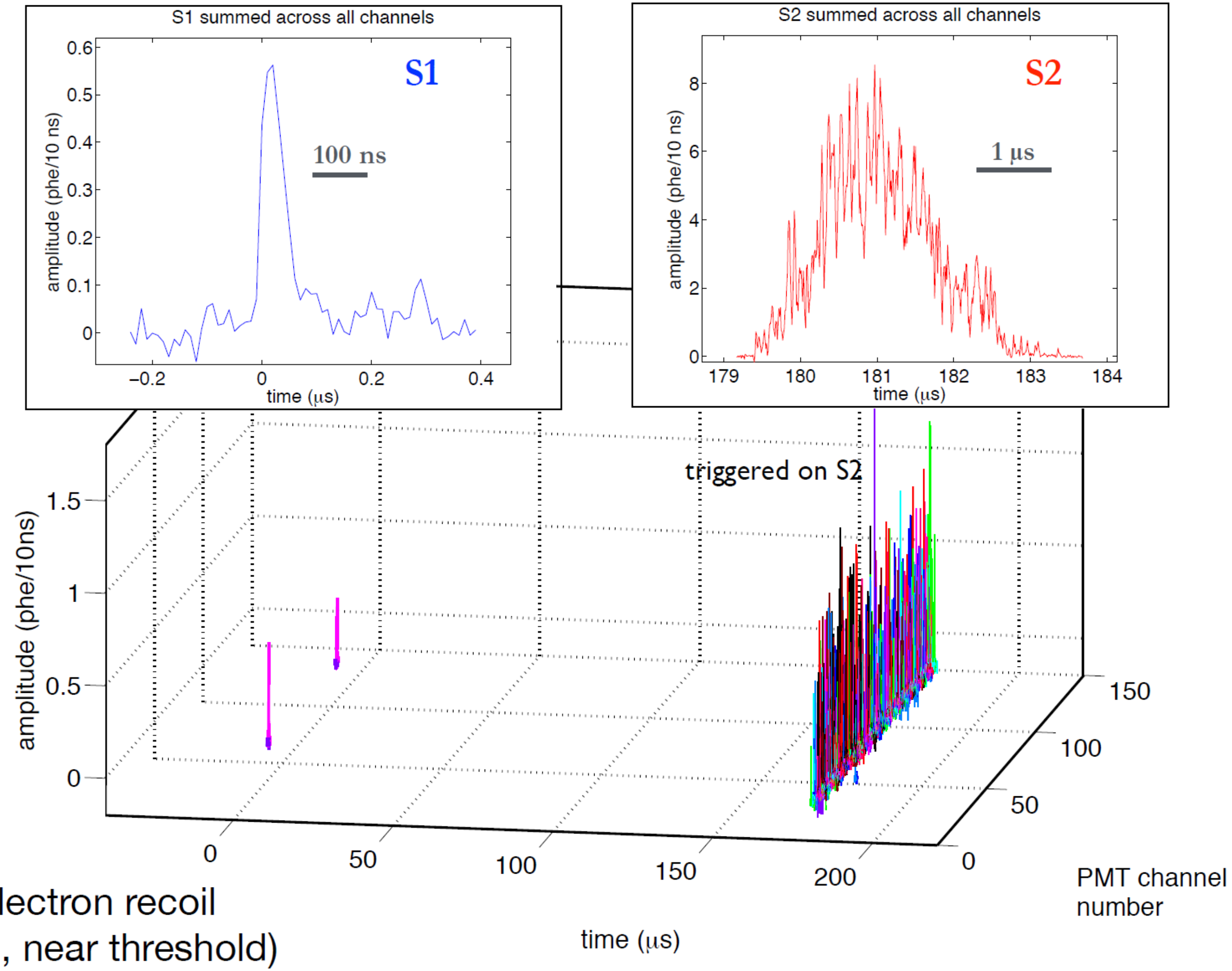
LXe TPC





- Ionization signal S2 and scintillation signal S1
  - Electron Recoil (ER) → larger S2
    - Most of the background
  - Nuclear Recoil (NR) → smaller S2
    - Neutron elastic scattering
- 3D position reconstruction from drift time and S2 light pattern
  - Reject events in the outer Xe layer
    - Self-shielding
  - Reject events with multiple hits

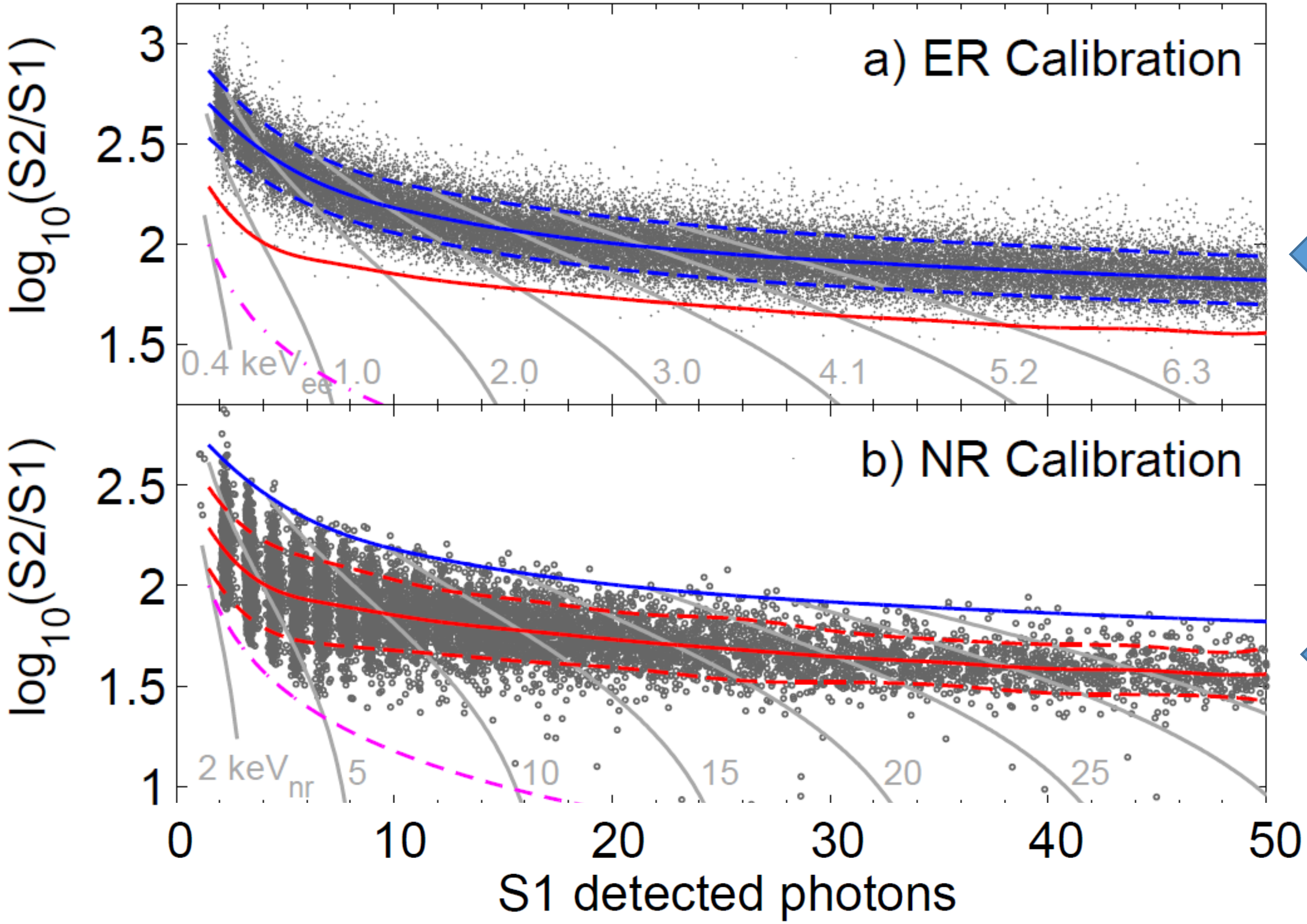
LUX event



1.5 keV electron recoil
(2 phe S1, near threshold)

Calibrations

PRD 97, 102008 (2018)

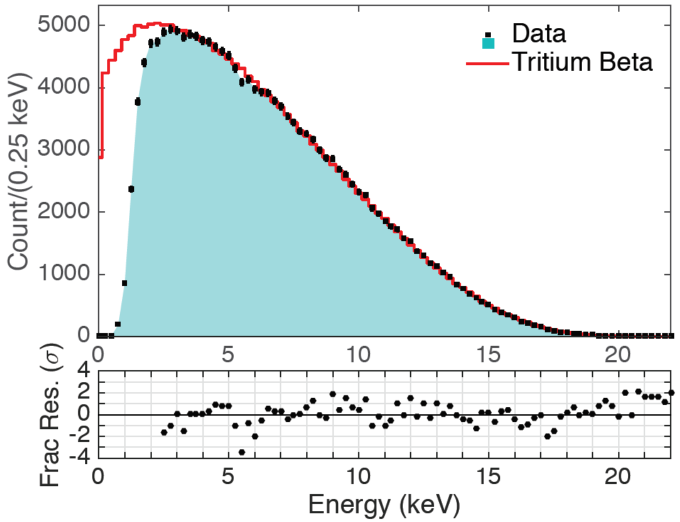


PRD 96, 112009 (2017)

- Detector parameters monitoring: ^{83m}Kr (1.8 hours half-life) weekly

PRD 93, 072009 (2016)

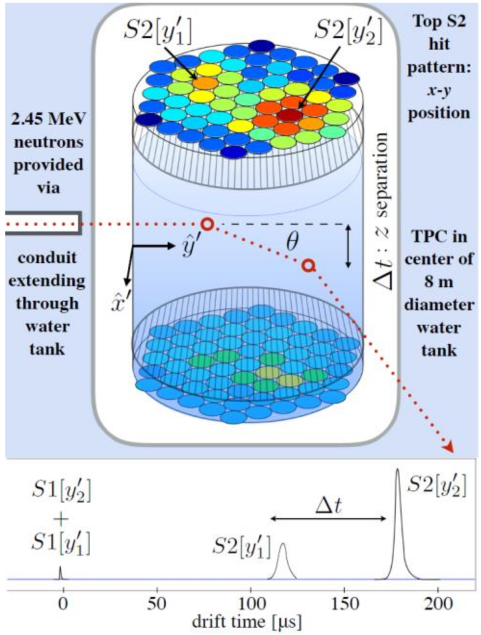
$$E_{total} = W \cdot (n_e + n_\gamma) = W \cdot \left(\frac{S1}{g_1} + \frac{S2}{g_2}\right)$$



CH3T (tritiated methane)
2-3 times a year, removed by purification

arXiv:1608.05381

D-D generator

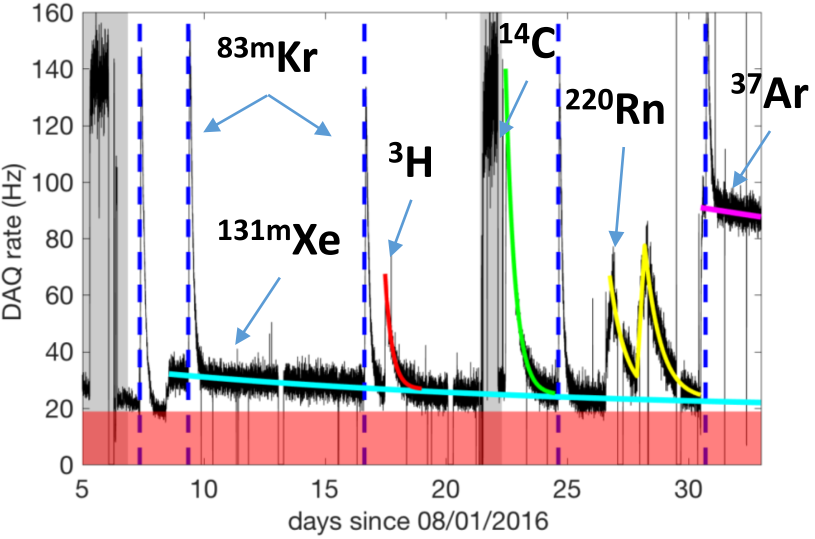


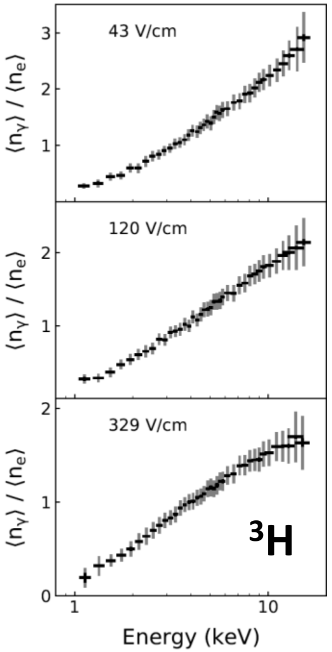
$${}^2_1\mathbf{H} + {}^2_1\mathbf{H} \rightarrow {}^3_2\mathbf{He} + {}^1_0\mathbf{n} + 3.27\ \mathbf{MeV}$$

$$E_{nr} = E_n \frac{4 m_n m_{Xe}}{(m_n + m_{Xe})^2} \frac{1 - \cos(\theta_{CM})}{2}$$

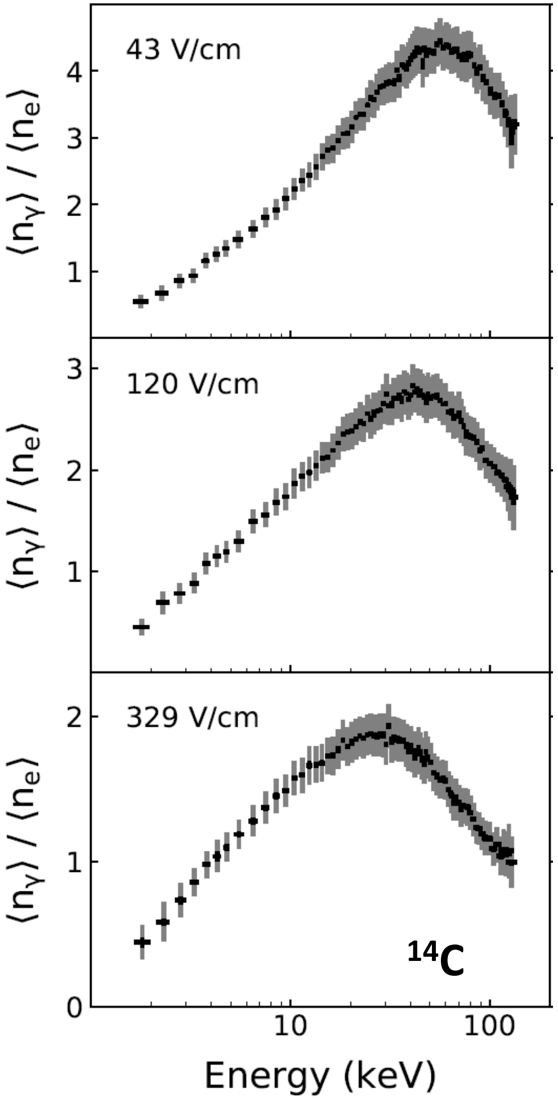
Calibration of response to β-decays

Post science calibrations





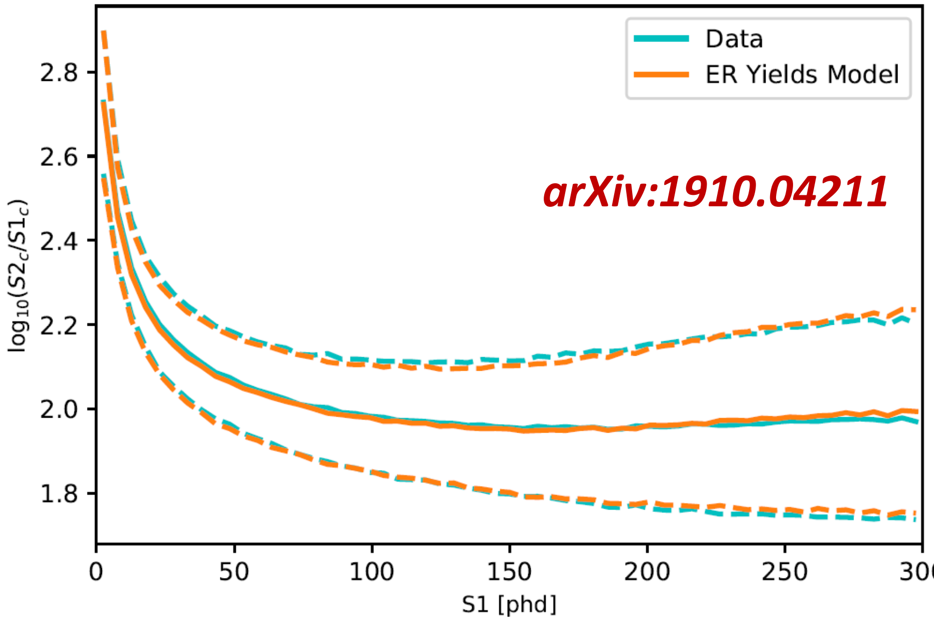
PRD 100, 022002 (2019)



- Non-uniform electric field in LUX allowing measurements of response of LXe to electrons from β-decays at different field strengths

➔ Improved model of ER yields

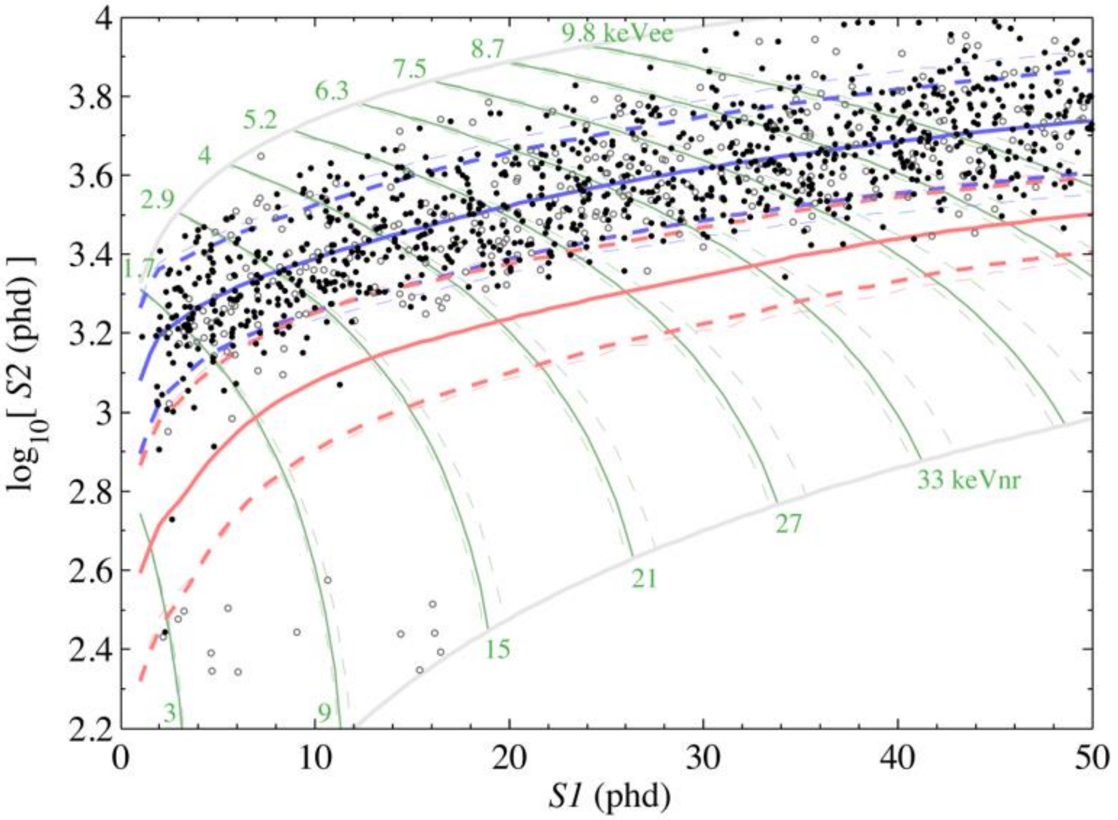
^{14}C Acquisition

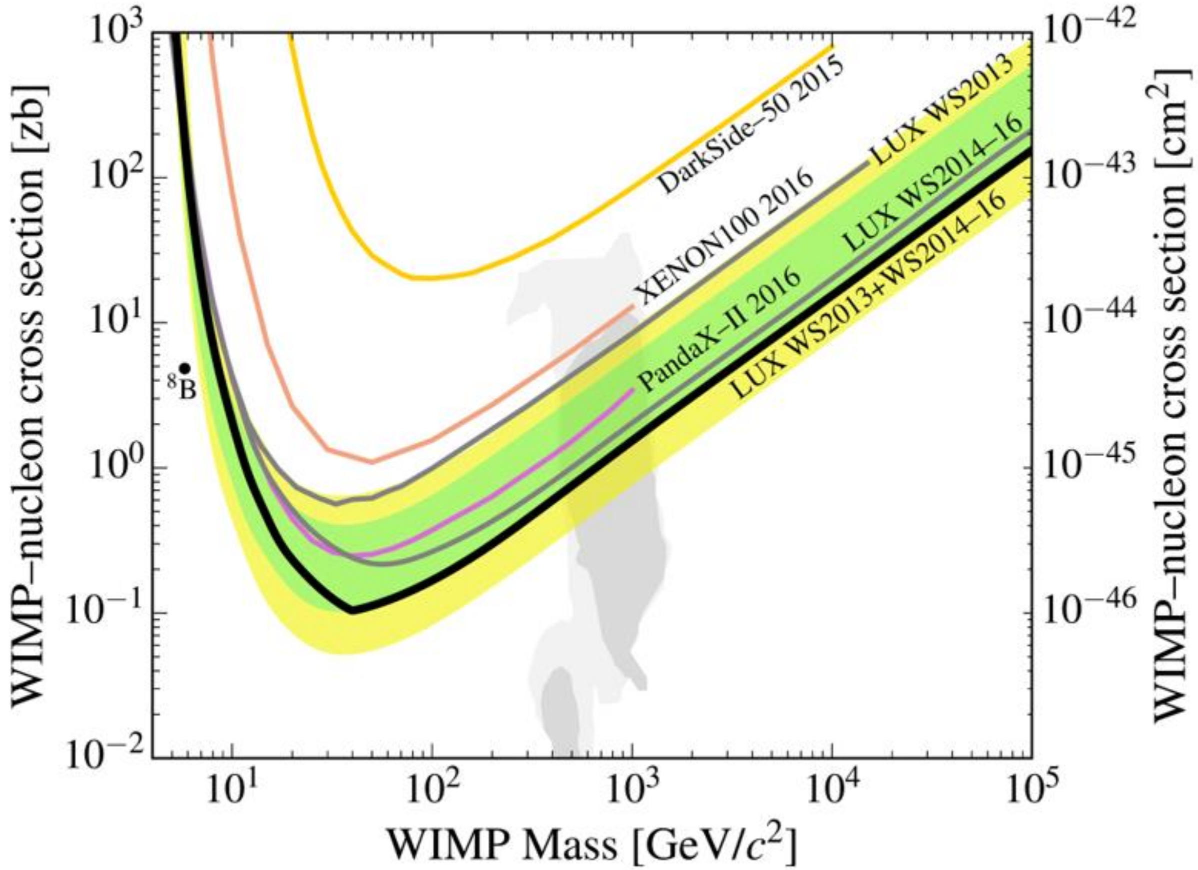


NR

LUX WIMP Search
Spin-Independent Interactions

PRL 118, 021303 (2017)





- WIMP-search data 2014 – 2016 passing all selection criteria
- Unfilled circles: r < 1 cm from fiducial boundary

- Upper limit on spin-independent WIMP-nucleon interactions
- Combined exposure in runs 2013 and 2014-2016: 3.35×10^4 kg × days
- More recent results not shown

LUX WIMP Search
Spin-Dependent Interactions

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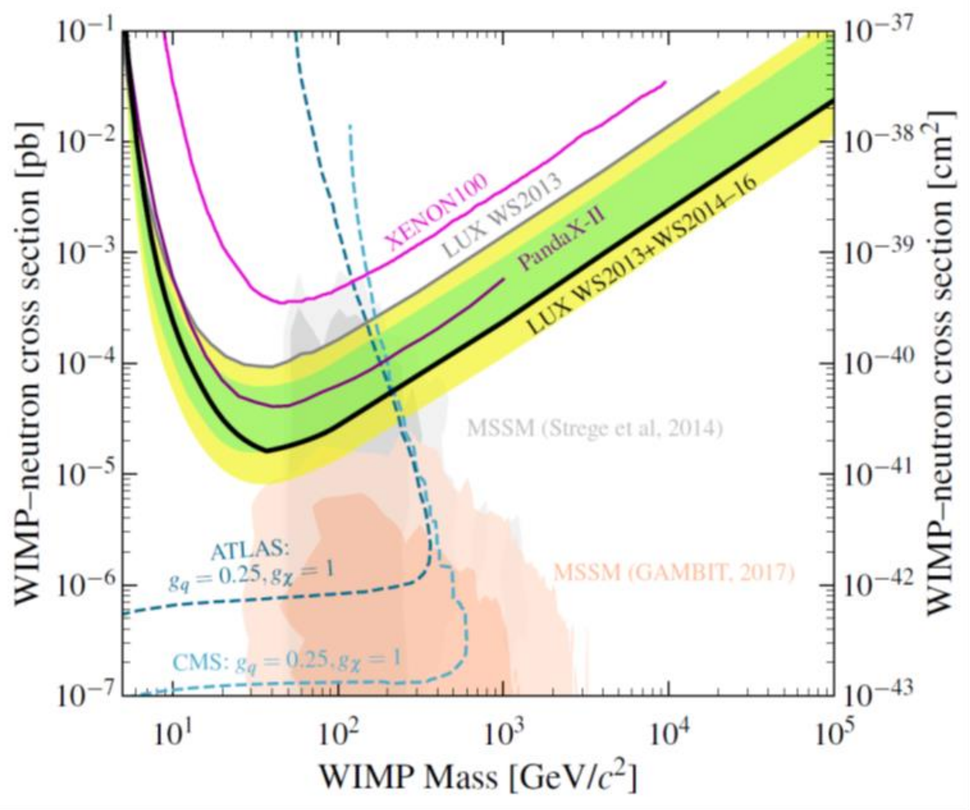
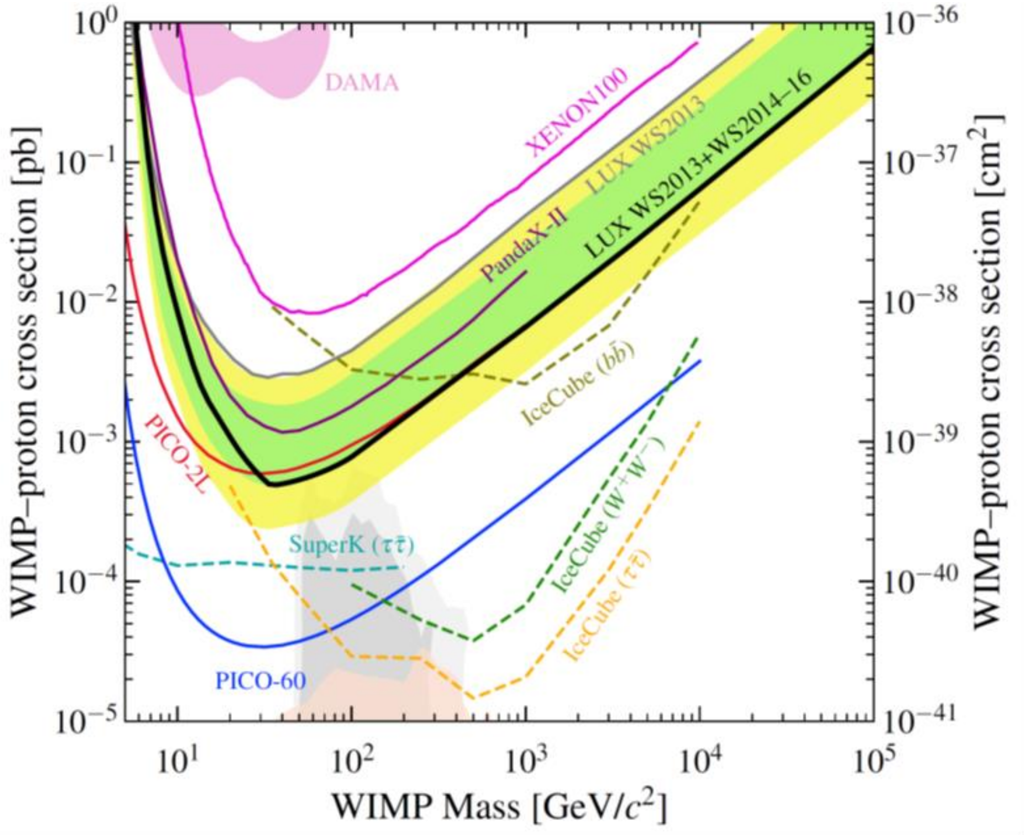
PRL 118, 251302 (2017)



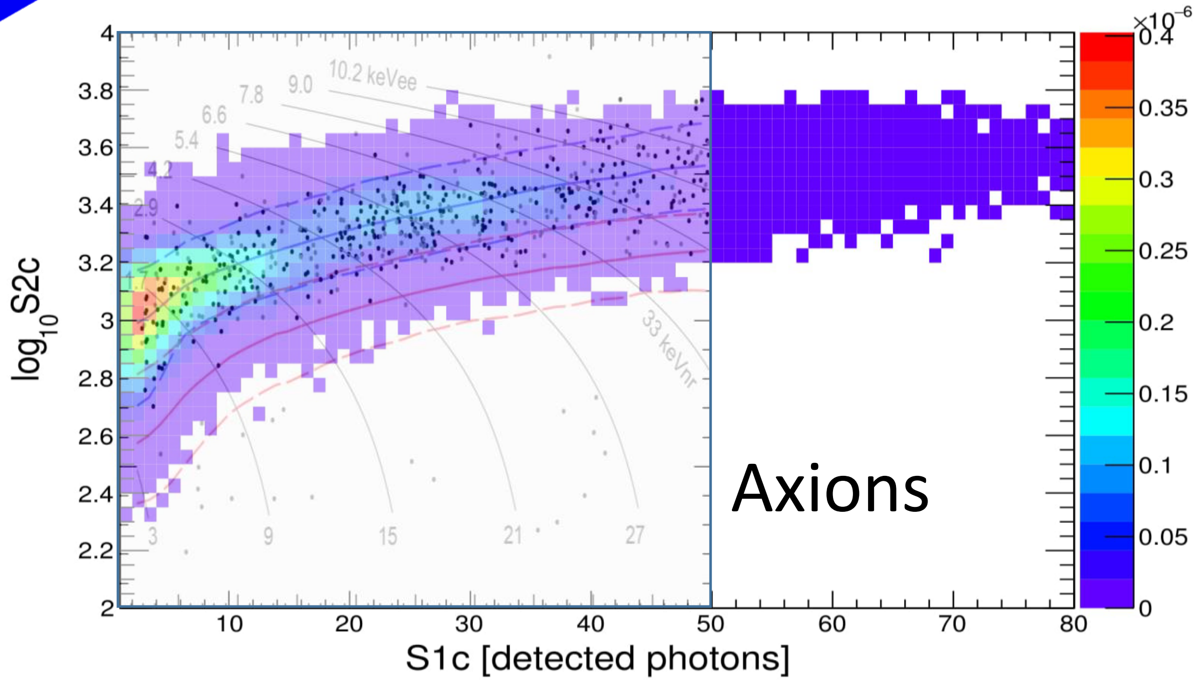


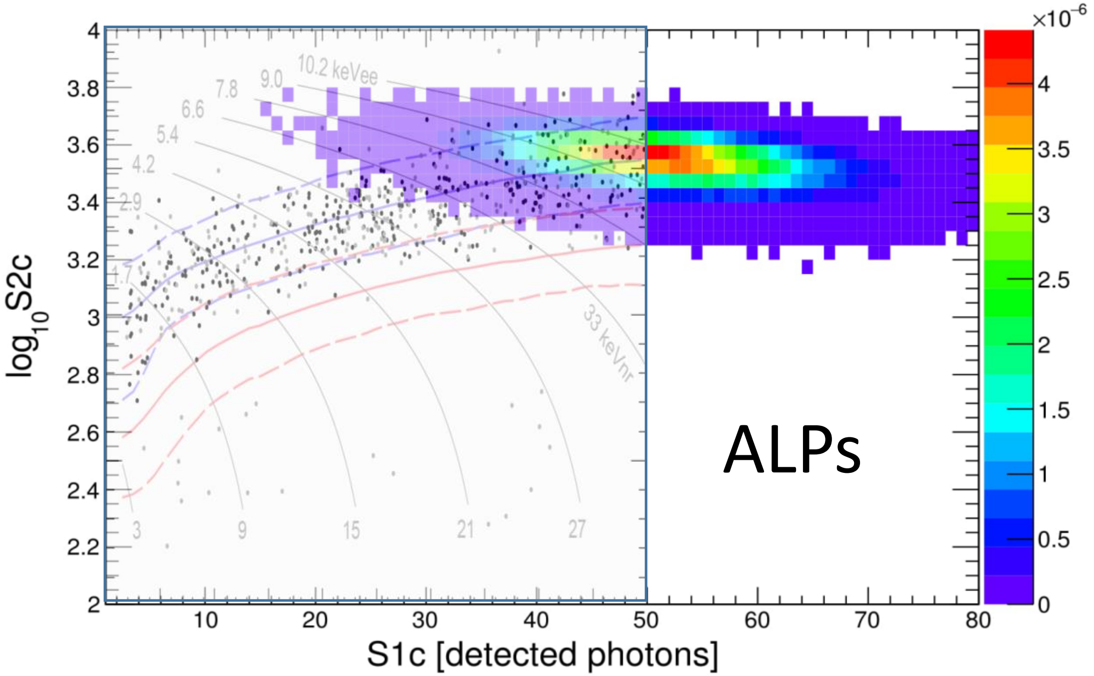
- Two Xe isotopes (^{129}Xe (29.5%) and ^{131}Xe (23.7%)) with unpaired neutrons → better sensitivity to a neutron coupling

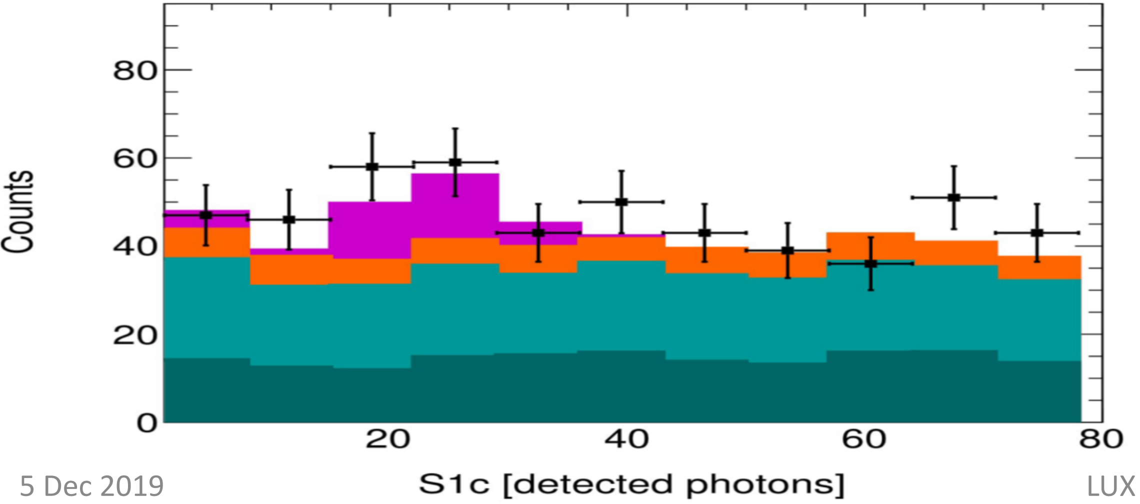
- Even number of protons → worse sensitivity to a proton coupling

Axions and Axion-Like Particles (ALP)

PRL 118, 261301 (2017)



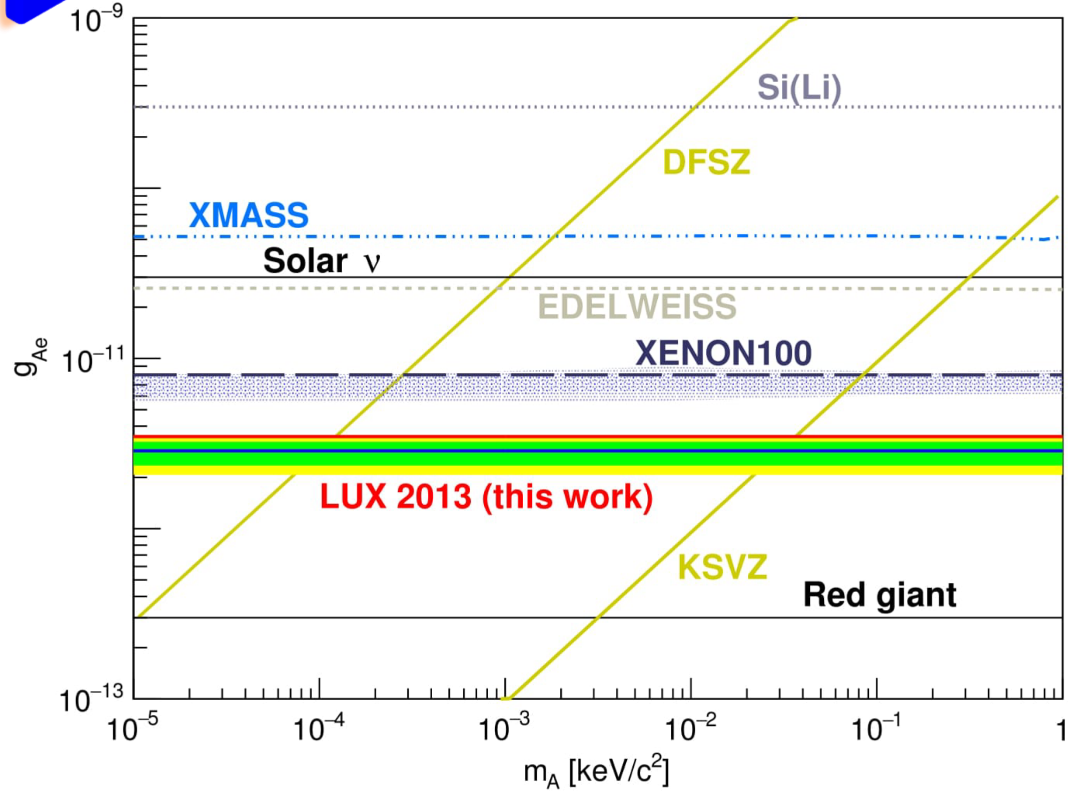


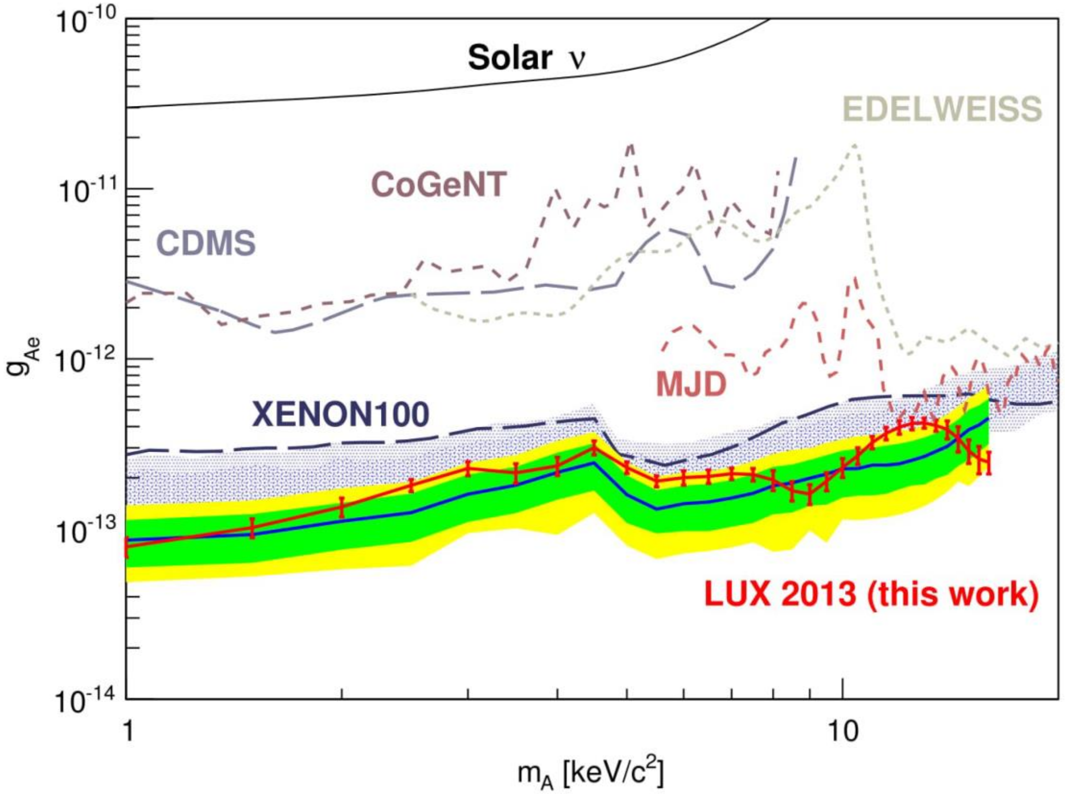


- Axions from the Sun and primordial ALPs could be detected through coupling to electrons via axio-electric effect
- LUX data collected in 2013
  - data published in ***PRL 116, 161301 (2016)*** were superimposed to show the relative location of expected signal events
- Background model describes the data well

Axions and Axion-Like Particles

PRL 118, 261301 (2017)





- Limits on axion coupling to electron
- $g_{Ae} < 3.5 \times 10^{-12}$ @ 90% CL

→$m_A < 0.12$ eV/c^2 (DFSZ model)

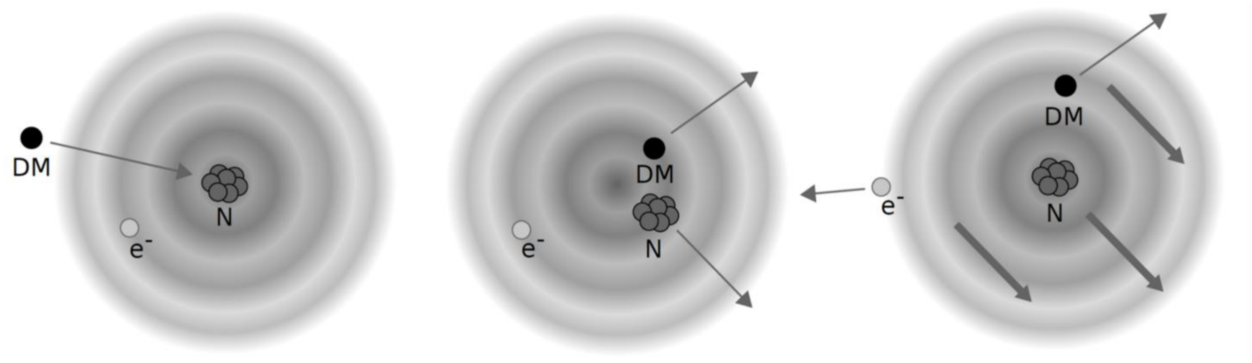
→$m_A < 36.6$ eV/c^2 (KSVZ model)

- Limits on ALP coupling to electron assuming that ALPs constitute all of the galactic DM

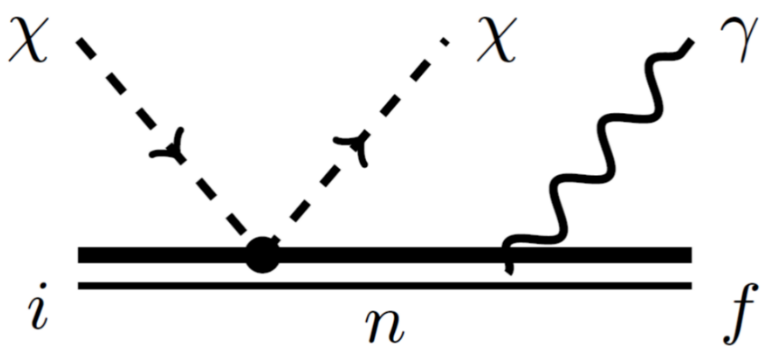
Sensitivity to Sub-GeV DM

- NR is too low in LXe detectors for Sub-GeV DM particles
- Still the Migdal effect and Bremsstrahlung could provide some sensitivity through detection of electron or photon
- Suggested by Chris Kouvaris and Josef Pradler (PRL 118, 031803 (2017))

Migdal effect: Emission of electron due to recoiling nucleus
Theory in JHEP 03, 194 (2018)

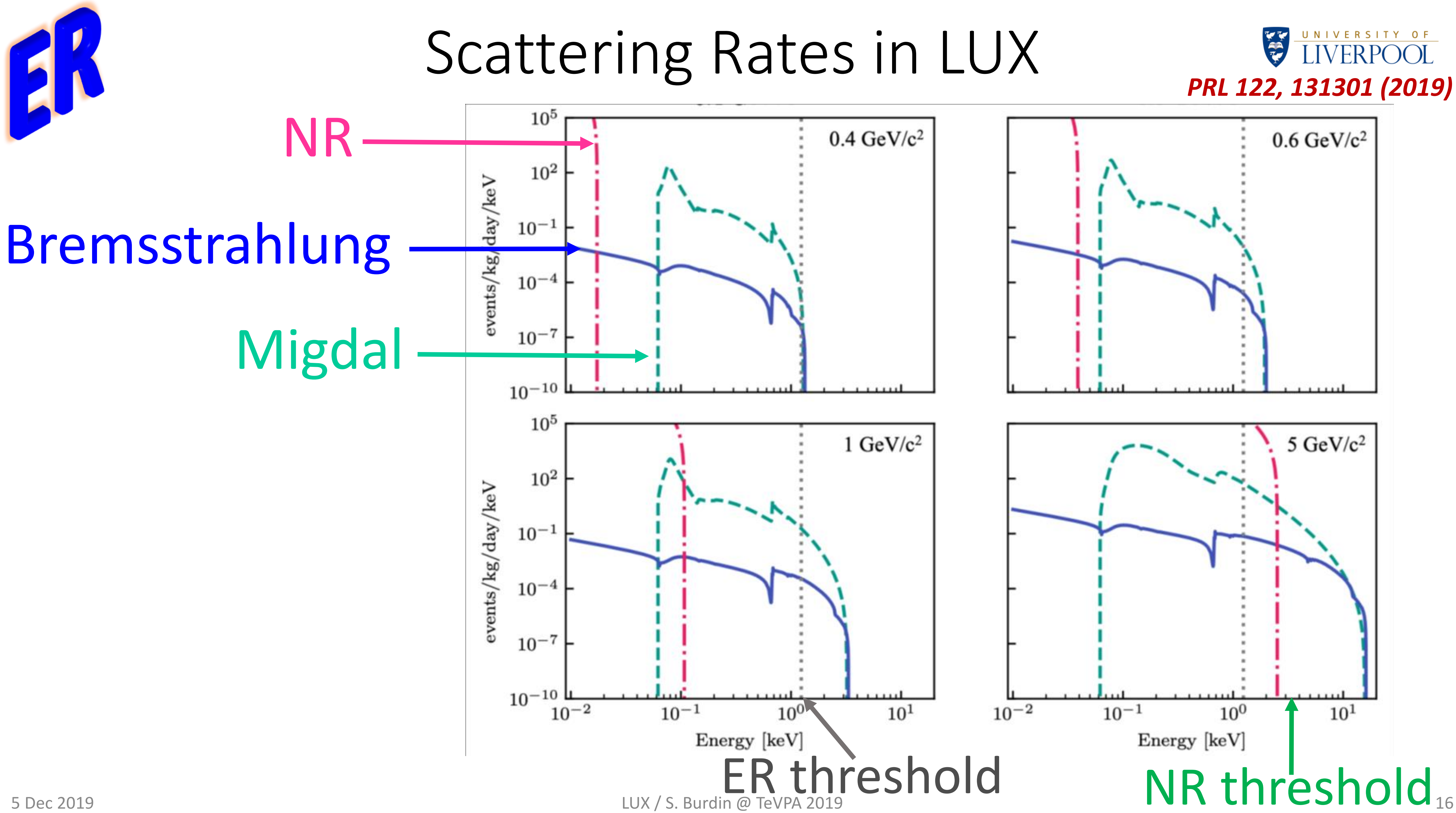


Bremsstrahlung: photon emission from Xe atom due to DM-nucleus scattering



Scattering Rates in LUX

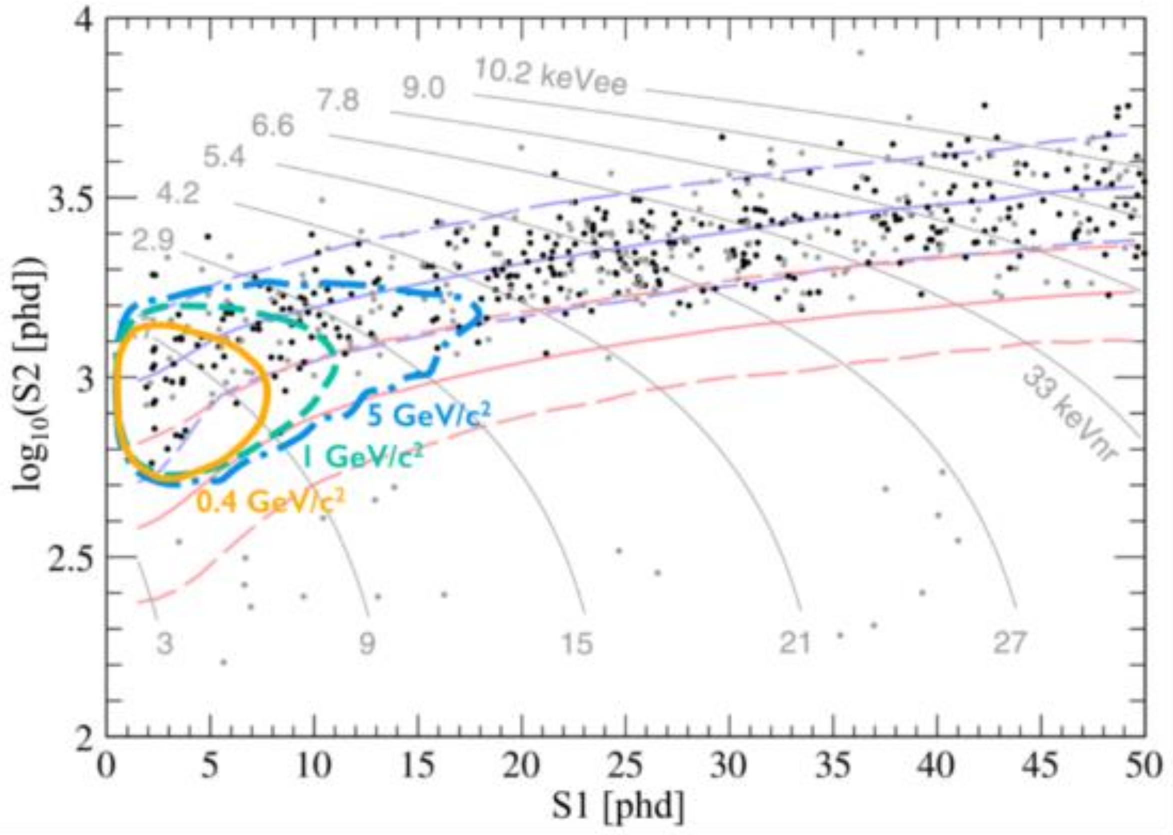
PRL 122, 131301 (2019)

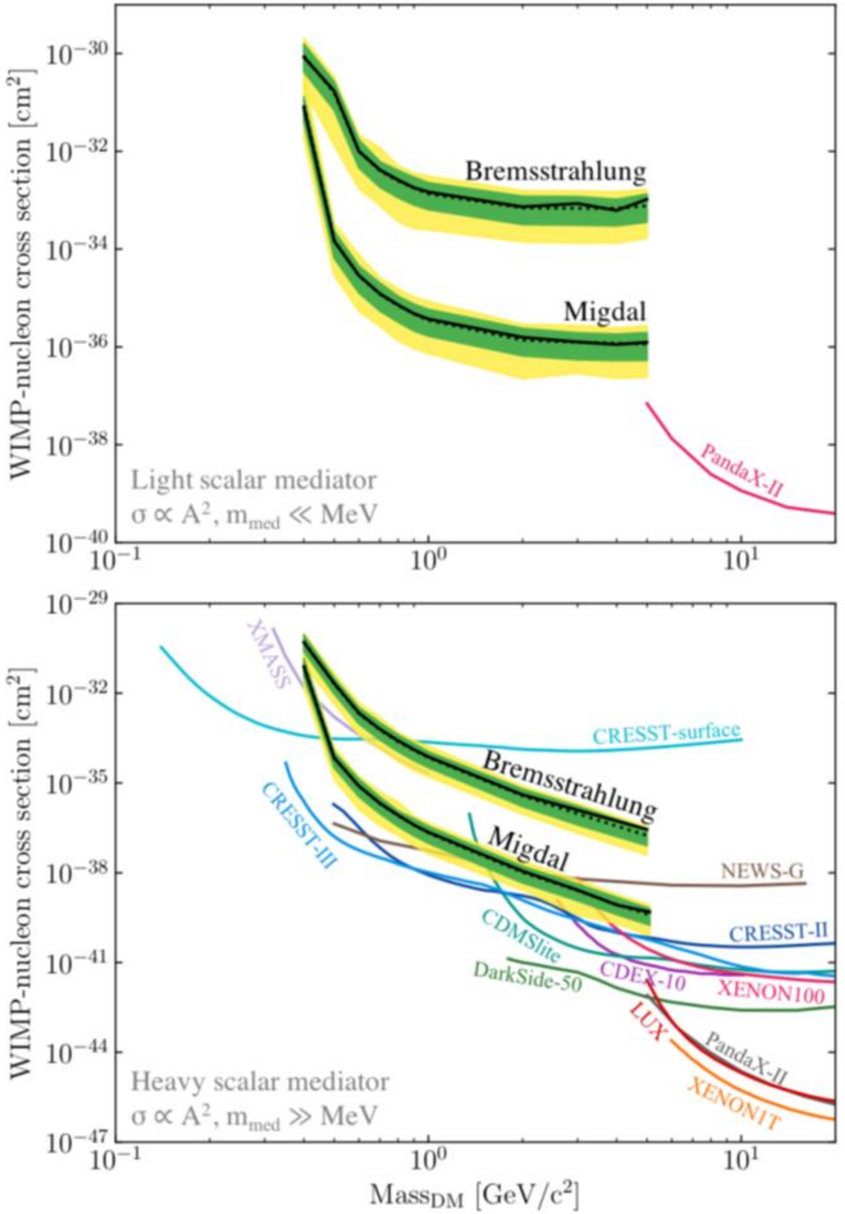


ER

LUX Sub-GeV Results

PRL 122, 131301 (2019)



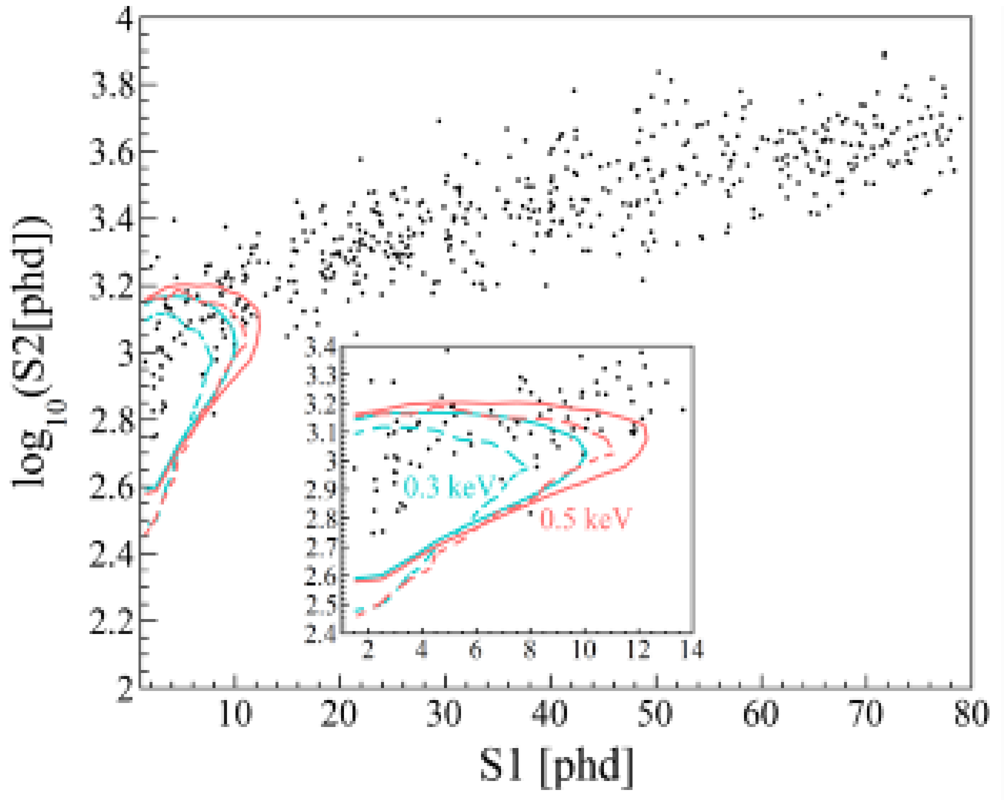


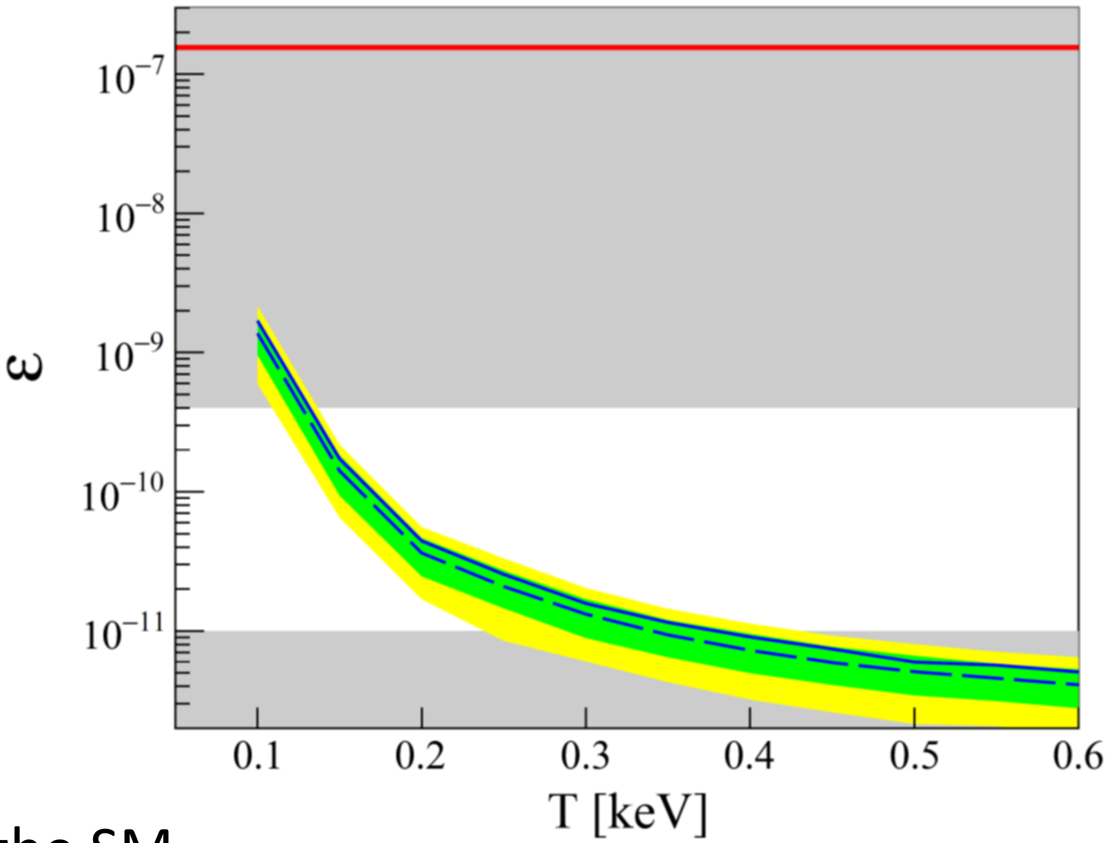
- Using 95 live-days x 118 kg of LUX data collected in 2013
- Energy spectra and simulated detector response to derive signal model for energies above ER detection threshold

Mirror DM

ER

arXiv:1908.03479





- Hidden sector could be isomorphic to the SM
  - → Mirror partners with the same masses, etc.
  - → Interactions with the SM through kinetic mixing which induces tiny electric charges for the mirror protons and electrons → electromagnetic interactions
  - → Theoretical constraints on the mixing parameter: $10^{-11} \leq \varepsilon \leq 4 \times 10^{-10}$
  - → LUX limit is set VS local mirror electron temperature which is expected to be ~0.3 keV

ER + (NR)

Annual Modulations

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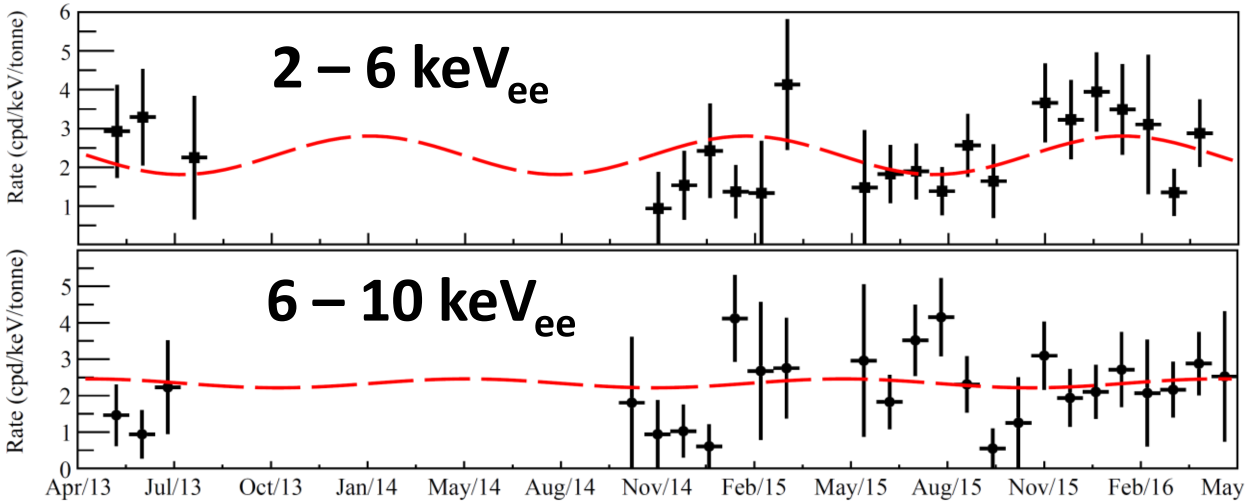
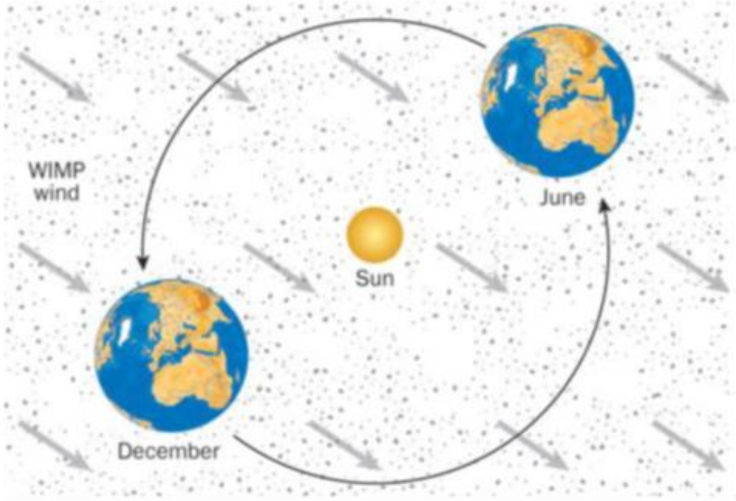
PRD 98, 062005 (2018)





- Annual modulations due to the Earth rotation around the Sun
- Very low background: 2.3 ± 0.2 cts/day/keV$_{ee}$/tonne
- Single scatters in innermost 51.4 kg of LXe
- 271 live days with periods of detector instabilities excluded

ER + (NR)

Annual Modulations

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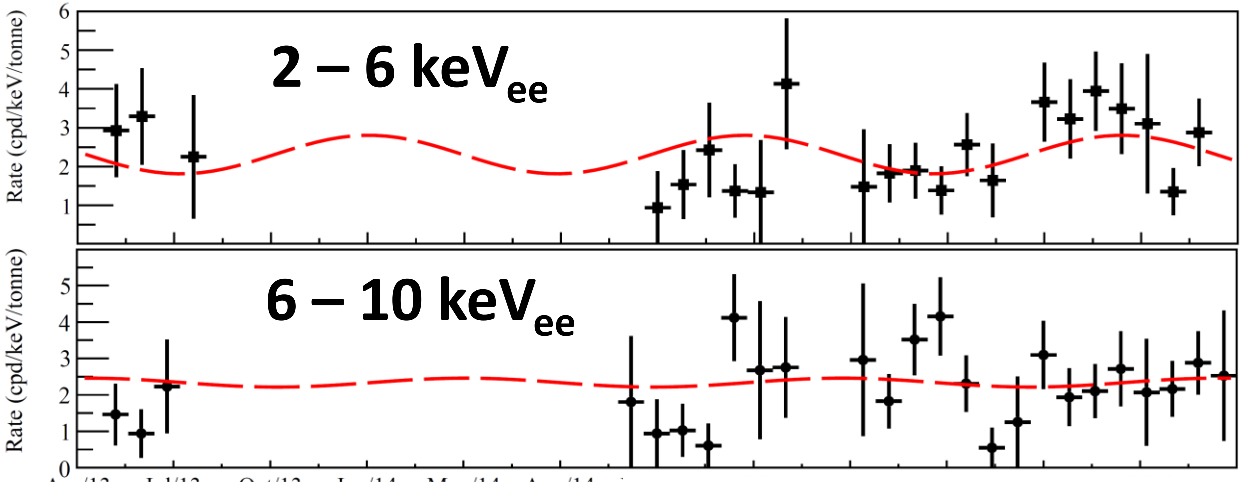
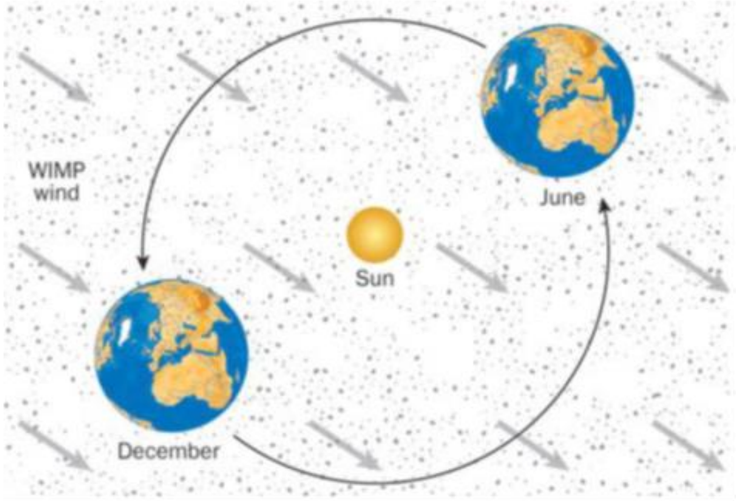
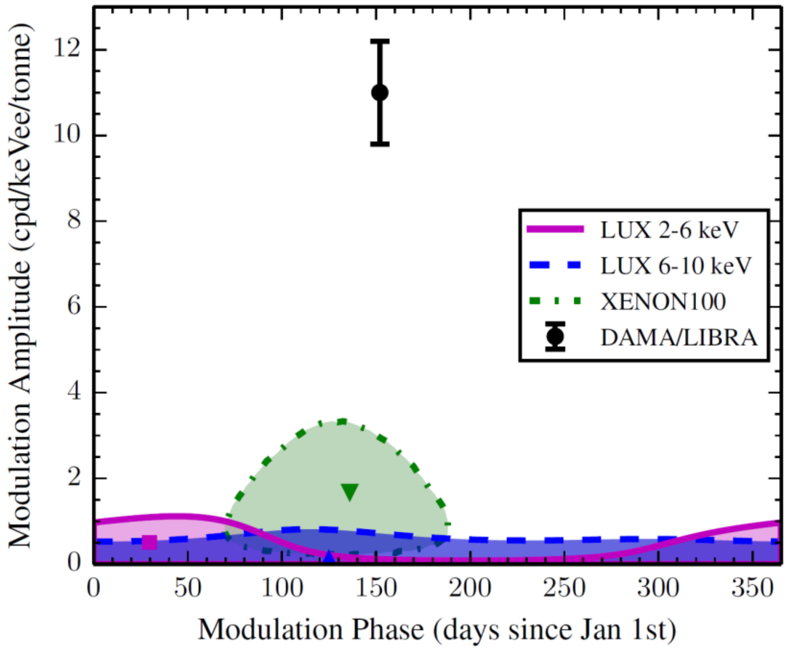
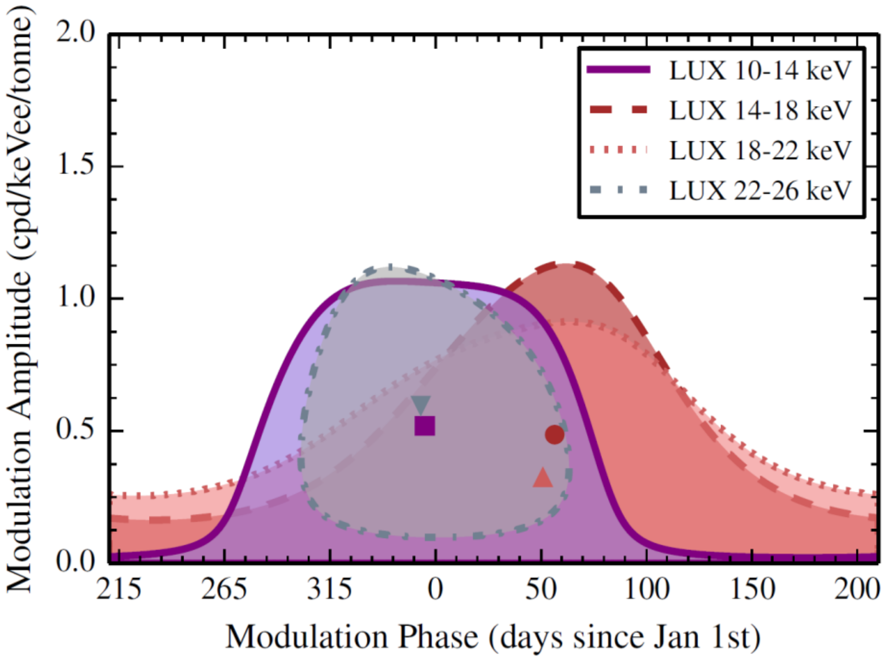
PRD 98, 062005 (2018)









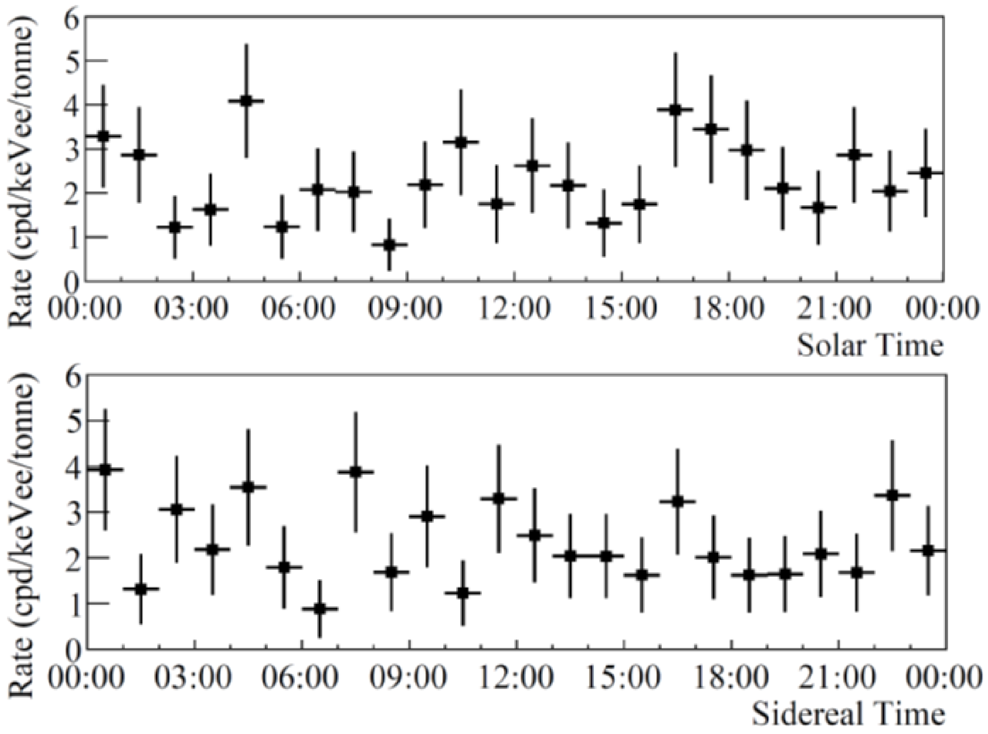
- No statistically significant annual modulations

ER + (NR)

Diurnal Modulations

PRD 98, 062005 (2018)

Asymmetry: $$\mathcal{A}_t = \frac{R_t - \bar{R}_t}{R_t + \bar{R}_t}$$



- Day/Night asymmetry : -5.3 ± 8.7%
- Morning/Evening: -2.5 ± 8.7%

- Day/Night: -1.7 ± 8.7%
- Morning/Evening: -6.7 ± 8.8%

No statistically significant diurnal modulations at the sensitivity level ~9% or ~0.2 cpd/keV$_{ee}$/tonne

Sensitivity @ Single Scintillation Photon level

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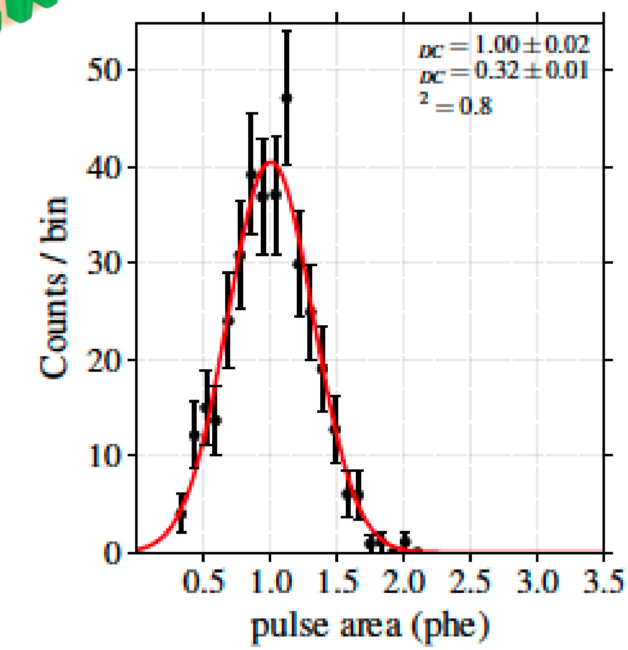
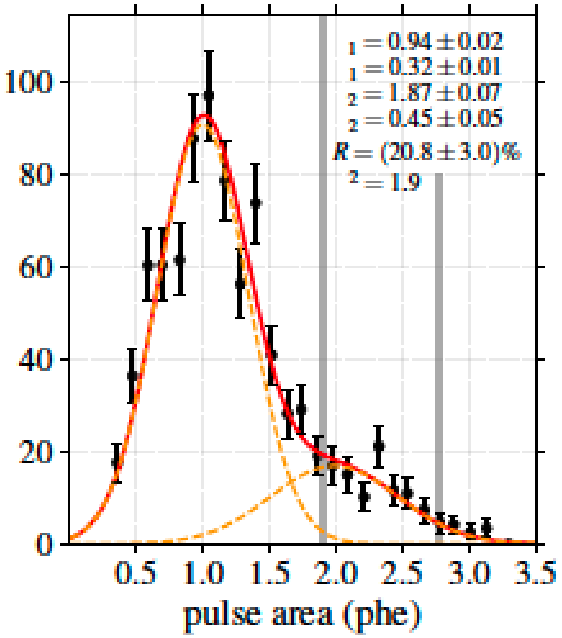
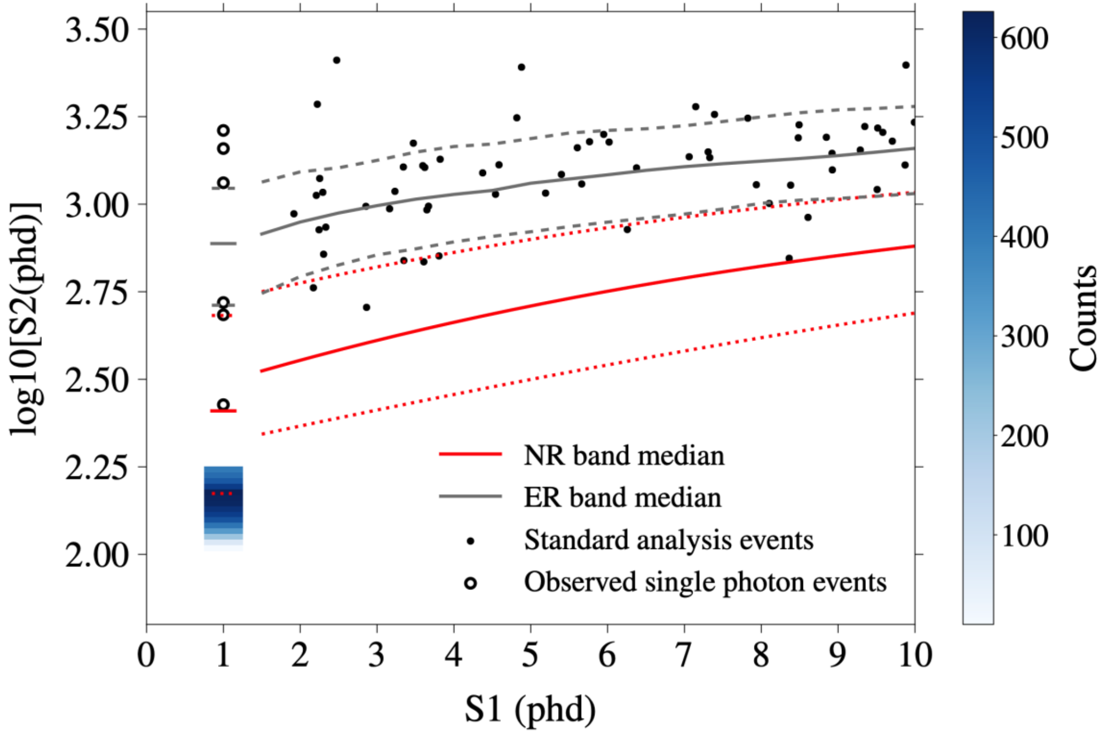
arXiv:1907.06272







- Single VUV photon produces two photoelectrons (DPE) in LUX PMTs (~17% probability)
  - Requiring DPE in 1 PMT recovers some events cut but 2-fold coincidence requirement
  - Effective suppression of Dark Counts and visible light

- NR threshold could be lowered to 0.3 keV
- Tested with LUX 2013 data
- 6 detected events agree with background expectations (dark counts leakage coinciding with S2)

New Tech

→ Sensitivity to Lower Mass DM

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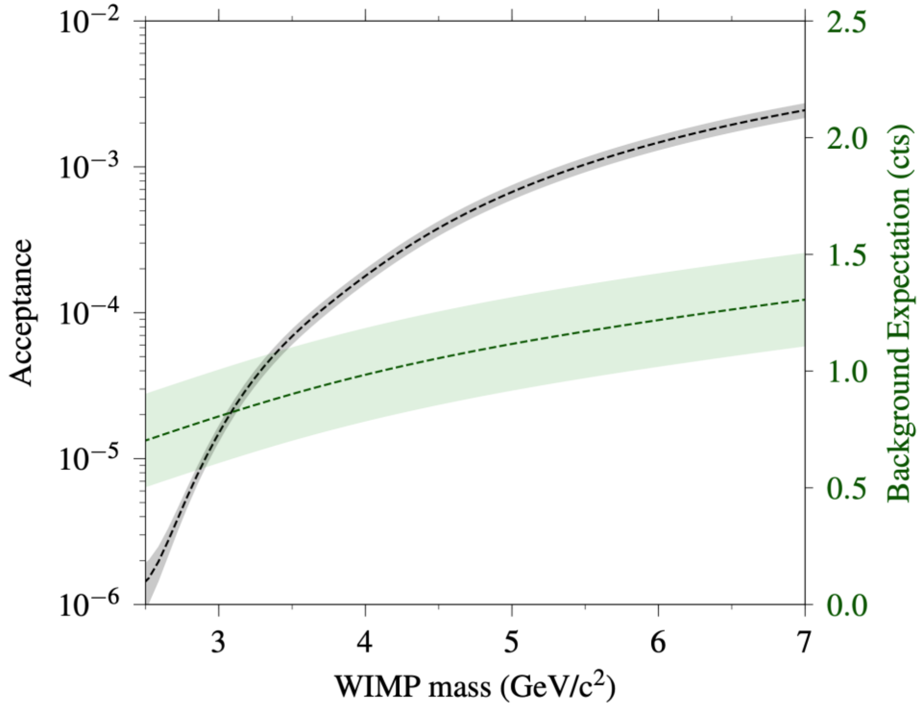
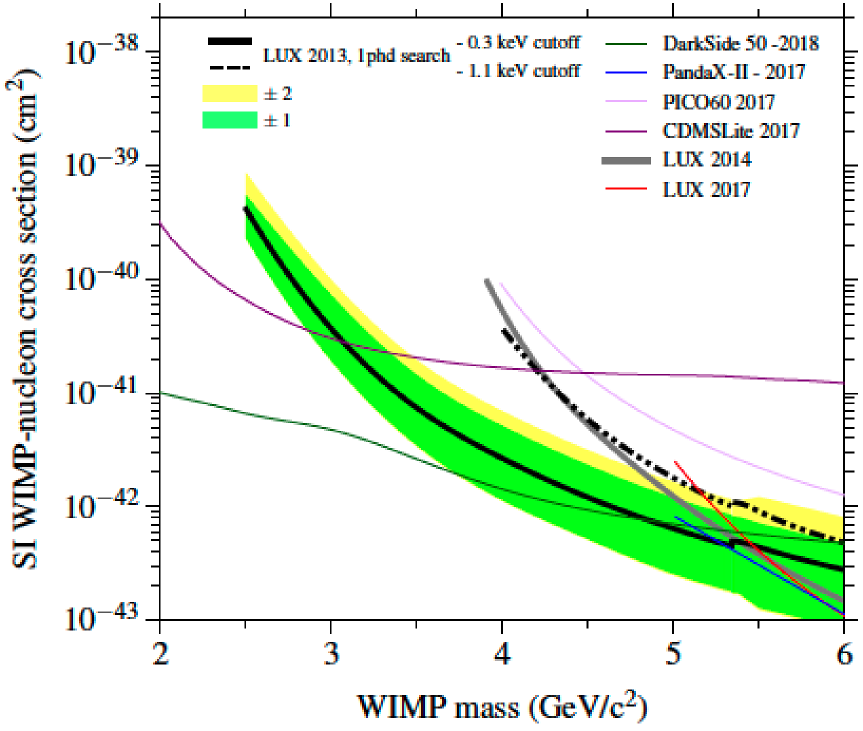
arXiv:1907.06272





- Low efficiency but
  - very low background
  - retaining 3D reconstruction capabilities

- Significant improvement in sensitivity to lower mass DM

Summary

- In addition to the best limits (for its time) on SI DM interactions the LUX provided data which is indispensable for many more analyses
- Better understanding of processes in LXe in large range of recoil energies
  - Improved models for future experiments
- Pioneering new analyses and testing different DM signal models
- Developing new analysis techniques
- More analyses in the pipeline
- Stay tuned!