New analysis results from the LUX dark matter experiment

Vitaly A. Kudryavtsev
University of Sheffield, United Kingdom

for the LUX Collaboration

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
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- University of Edinburgh
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- University of Maryland
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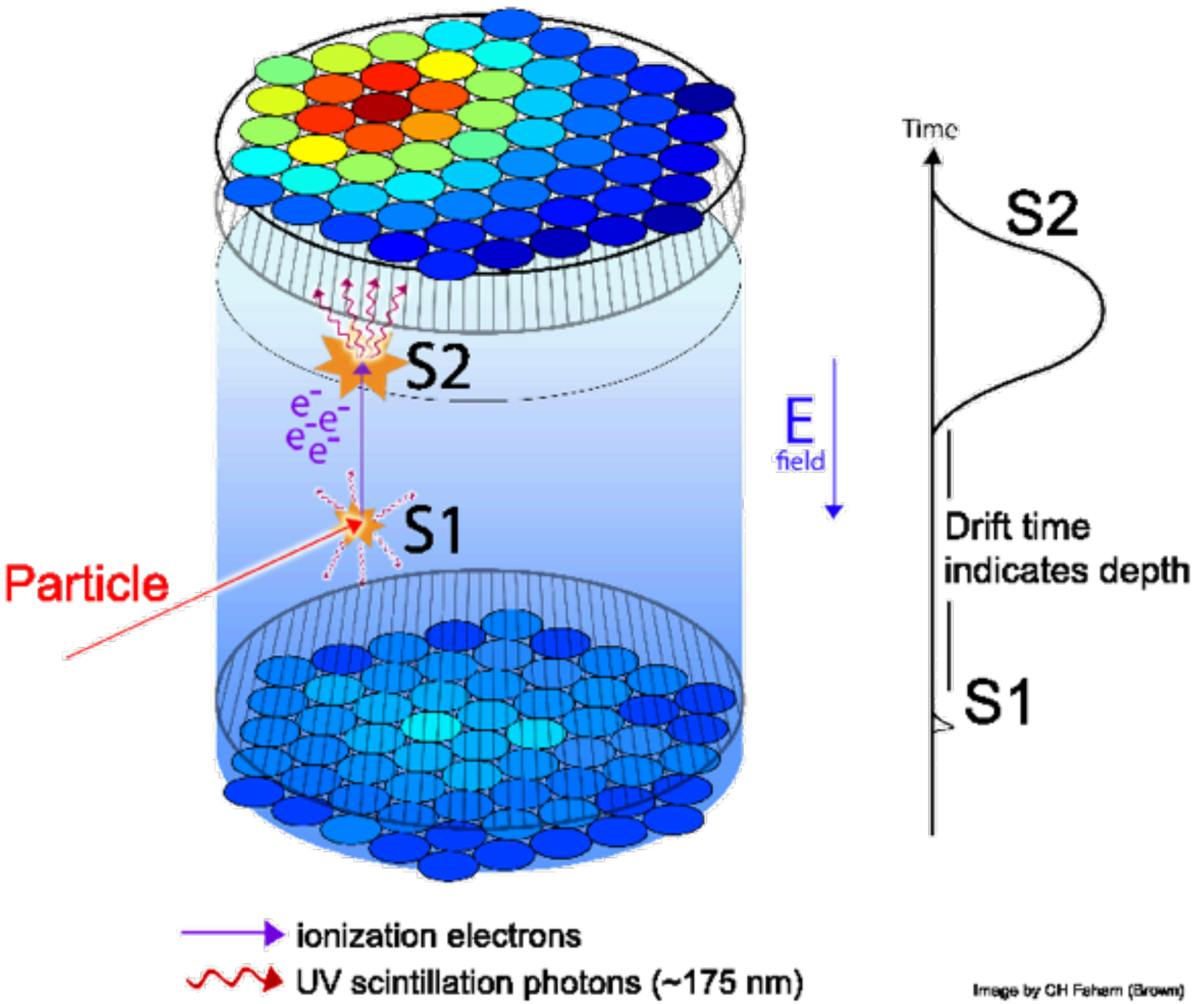
- University of Rochester
- University of Sheffield
- University of South Dakota
- University of Wisconsin – Madison

Outline

- Introduction.
- LUX detector.
- LUX story.
- New LUX results.
- Conclusions.

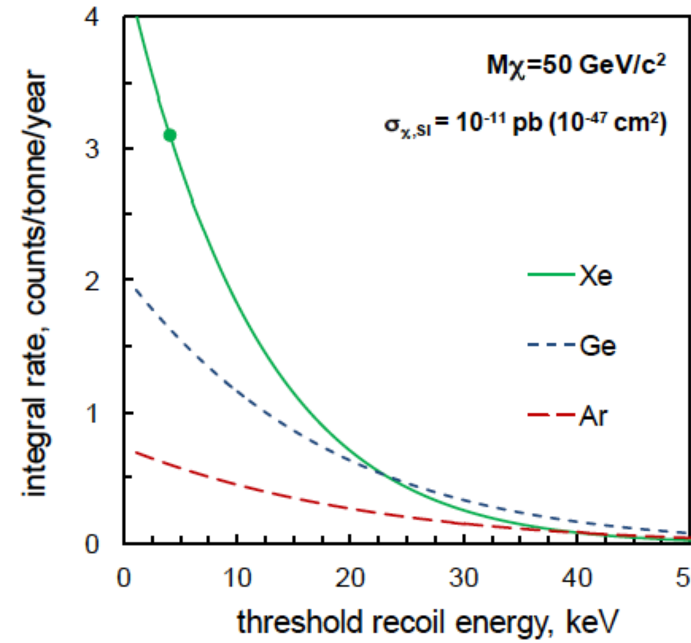
Principle of WIMP detection in LXe TPC

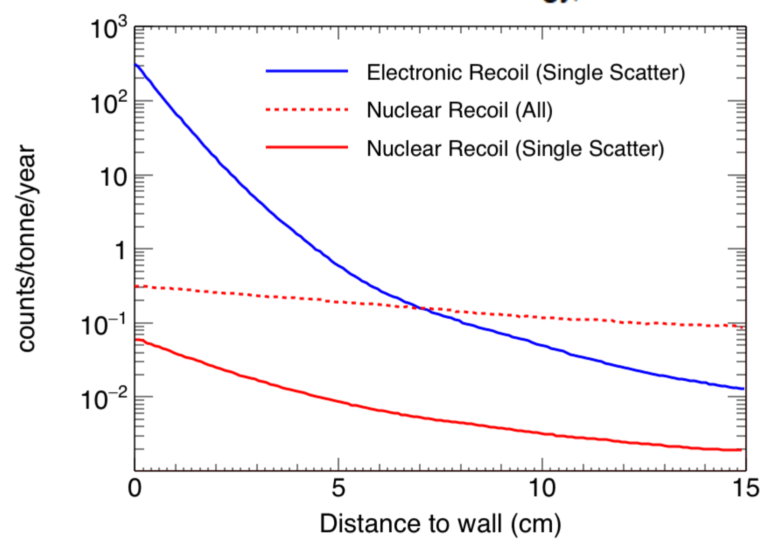


- Liquid xenon time projection chamber – LXe TPC.
- S1 – primary scintillation.
- S2 – secondary scintillation, proportional to ionisation.
- Position reconstruction based on the light pattern in the PMTs and delay between S2 and S1.

Advantages of LXe

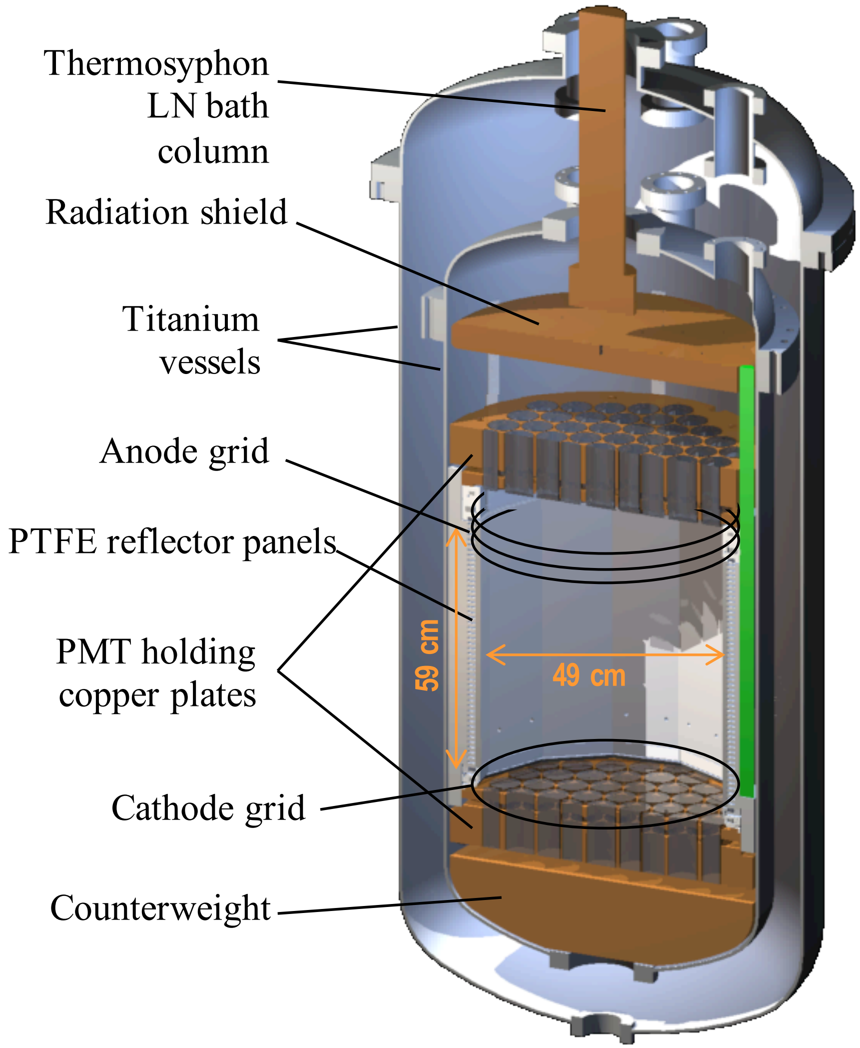
- Good scintillator.
- Two-phase -> TPC with good position resolution.
- Self-shielding.
- Good discrimination between electron recoils (ERs) and nuclear recoils (NRs).
- High atomic mass: spin-independent cross-section $\propto A^2$
- Presence of even-odd isotopes (odd number of neutrons) for spin-dependent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





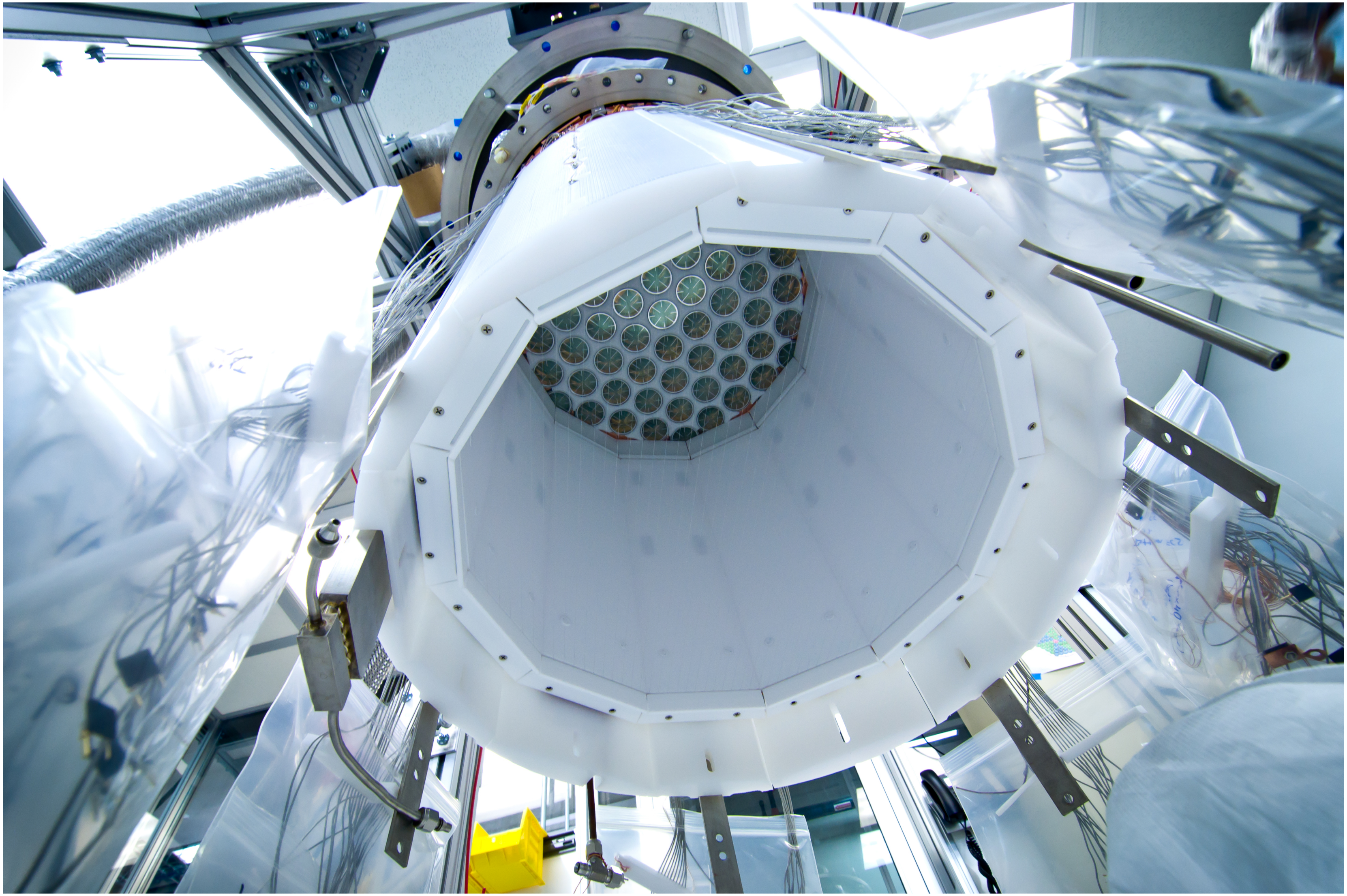
Graphs from LZ TDR, 1703.09144 [physics.ins-det]

LUX detector



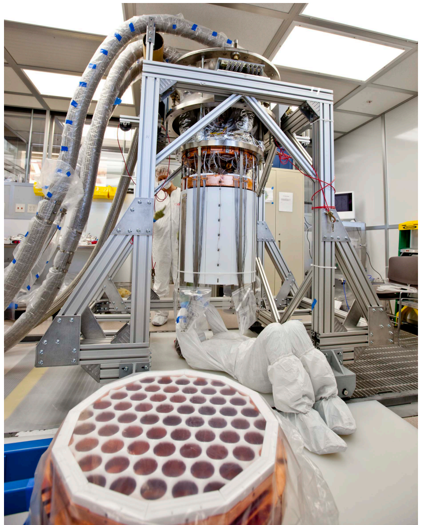
- 61 top + 61 bottom ultra-low background PMTs viewing ~250 kg of xenon in the active region (~120 kg fiducial).
- Ultra-low background titanium cryostat.
- Active region defined by high-reflectivity PTFE walls.
- Maximum drift: 50 cm.
- Xenon continuously re-circulated to maintain purity.
- Chromatographic separation reduced Kr content.

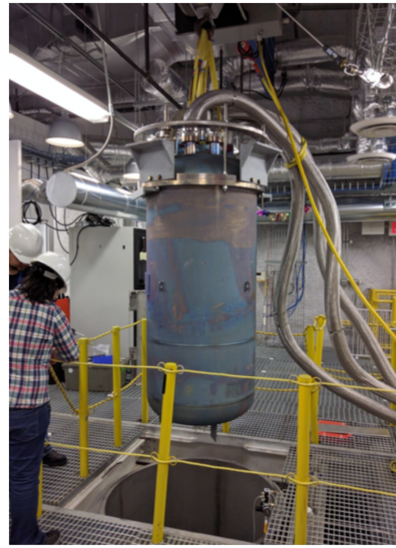
LUX detector



LUX detector

- 4850 ft level at SURF. Muon flux ~6×10^{-5} m^{-2} s^{-1}. Now replaced with LZ.
- Muon veto system and shielding: water tank instrumented with PMTs.





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)

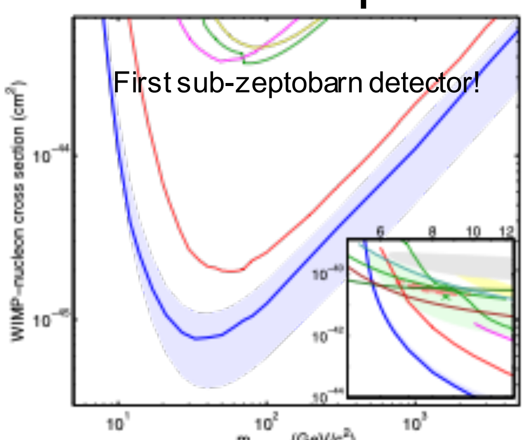
Final calibrations
2016 (May-Aug)

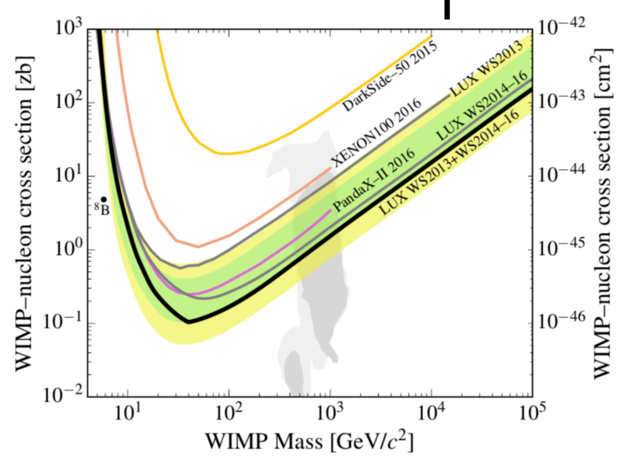
2016
332 live-days results reported

LUX decommissioned
2016 (Sep)

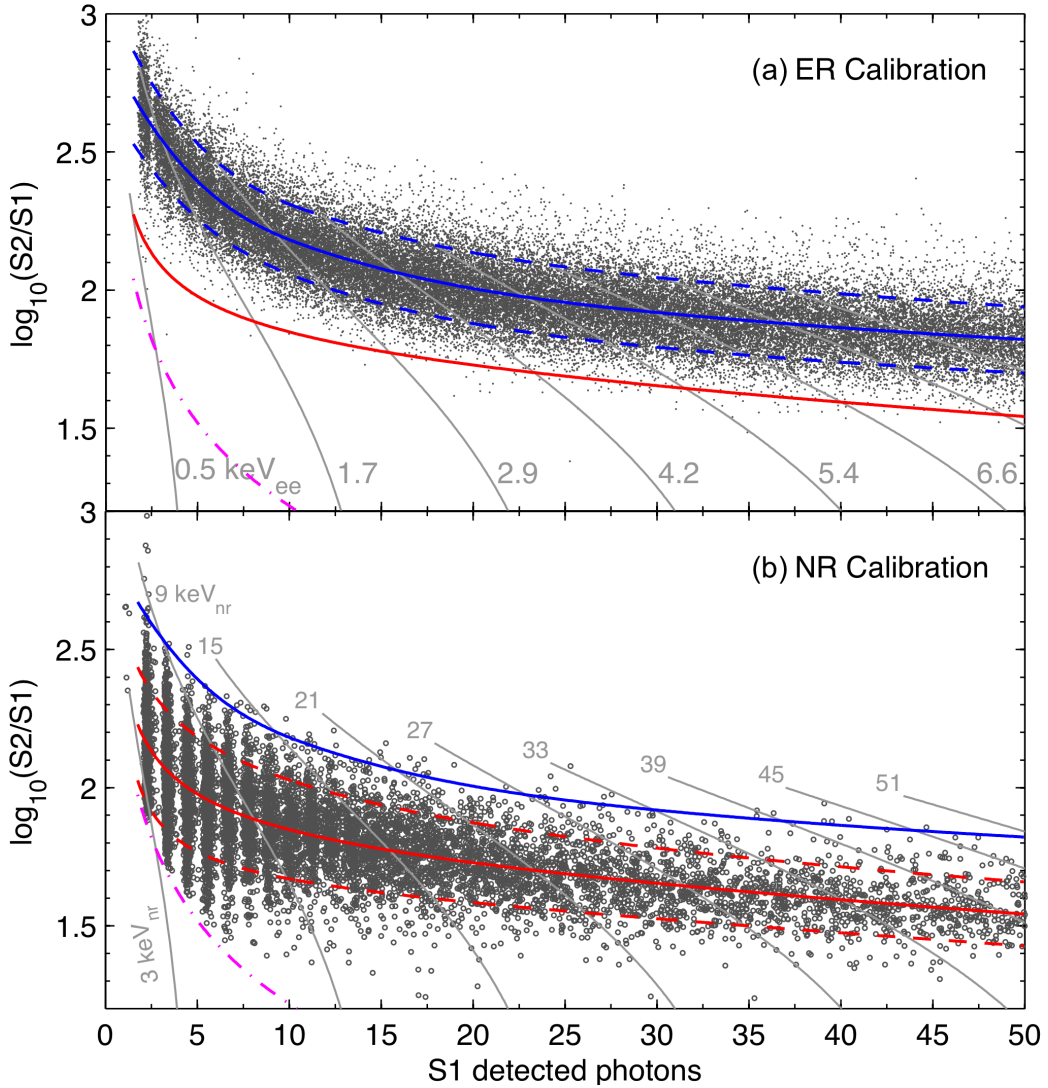
2016 (Oct)
427 live-days results

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



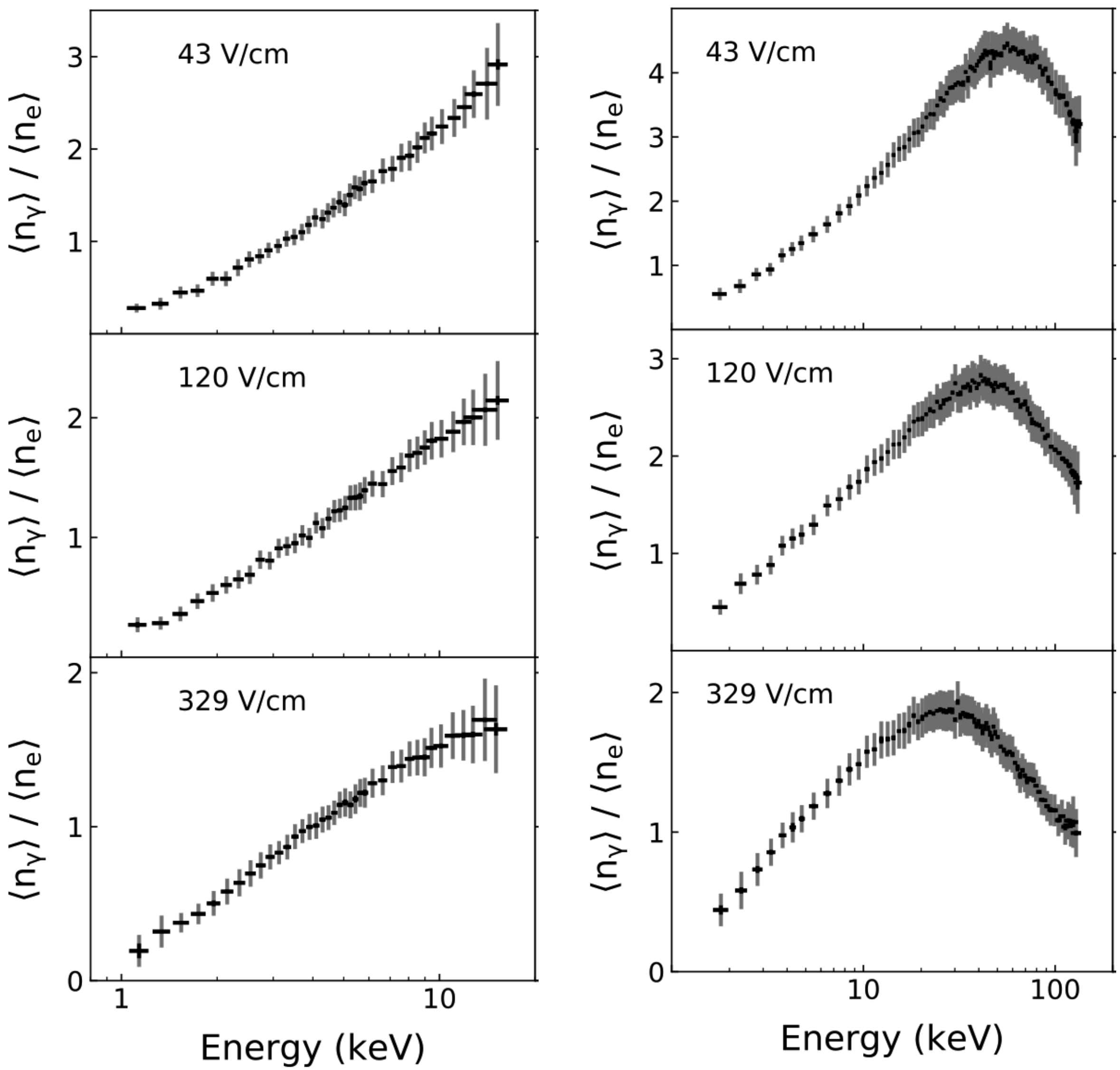


LUX calibrations



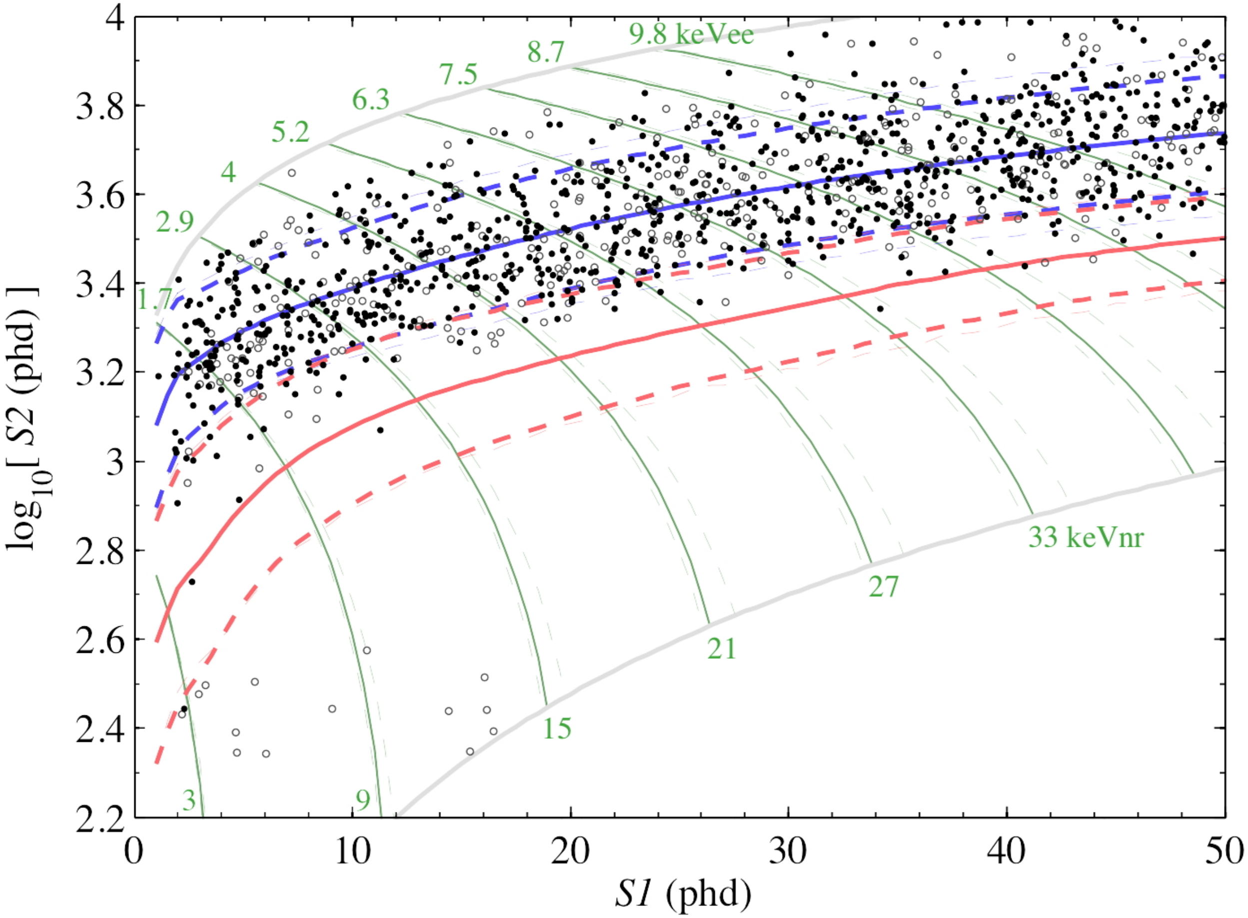
- ^{83m}Kr – uniform distribution, 1.8 hours half-life, weekly. Phys. Rev. D 96, 112009 (2017).
- CH_3T (tritiated methane) – uniform, removed by purification, 2-3 times a year (top figure), D. Akerib et al. (LUX Collaboration), Phys. Rev. D93 (2016) 072009.
- D-D – generator (bottom), 2.45 MeV neutrons, collimated, D. Akerib et al. (LUX Collaboration), arXiv:1608.05381 [physics.ins-det].

Post science run calibrations



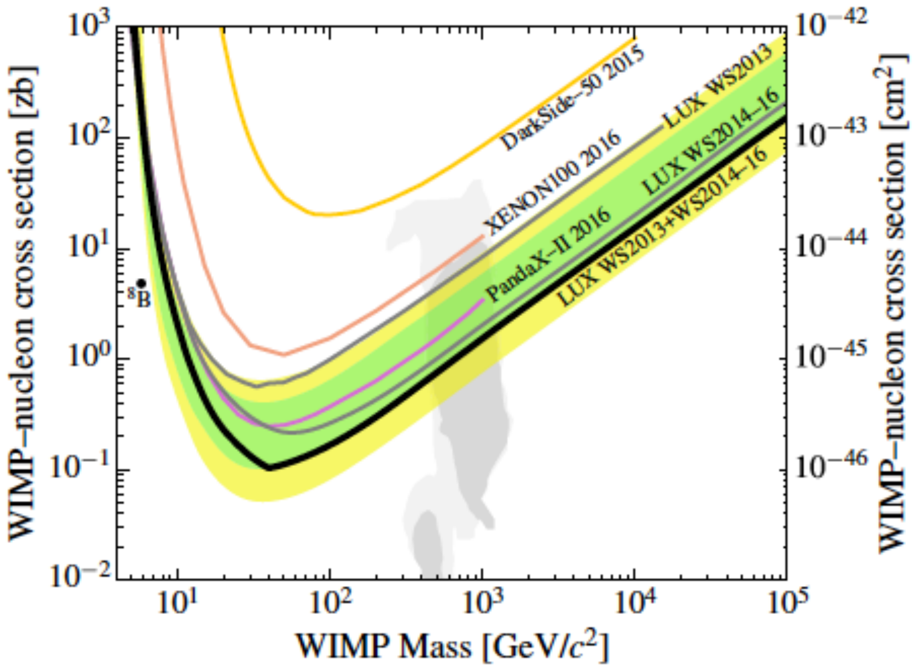
- Improved measurements of the response of LXe to electrons from β-decays.
- Injected radioactive sources: ^{3}H and ^{14}C.
- Non-uniform electric field in LUX allowing measurements at different strength.
- Light to charge ratio as a function of energy for different fields.
- Left – ^{3}H, right – ^{14}C.
- Akerib et al. (LUX Collaborations), PRD 100, 022002 (2019).
- See talk by Jon Balajthy, Thursday, 15:30.

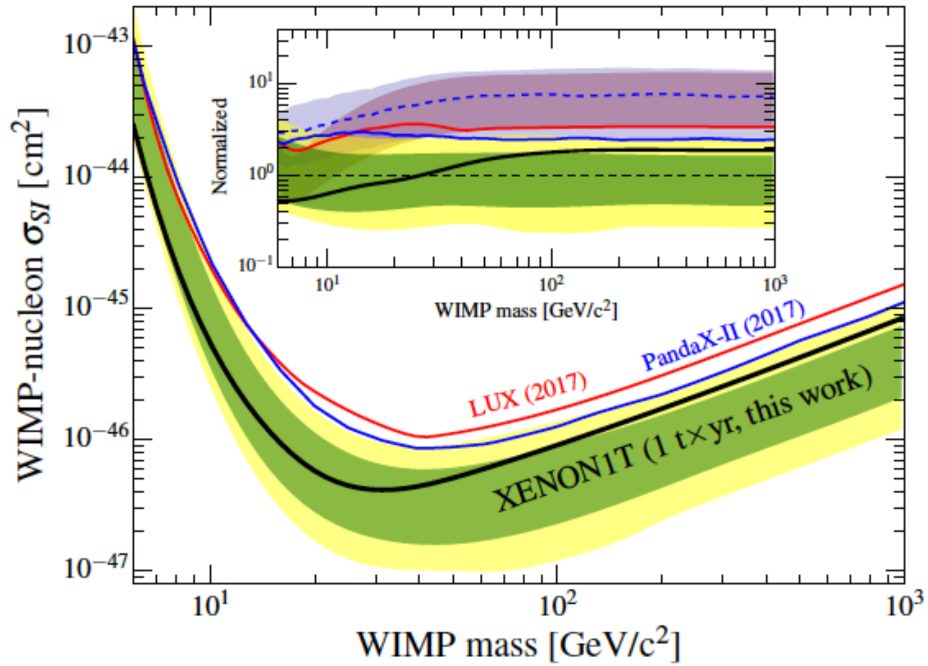
LUX results



- Data after cuts: 332 live days (2015-2016).
- Profile likelihood ratio analysis; data consistent with background only hypothesis.

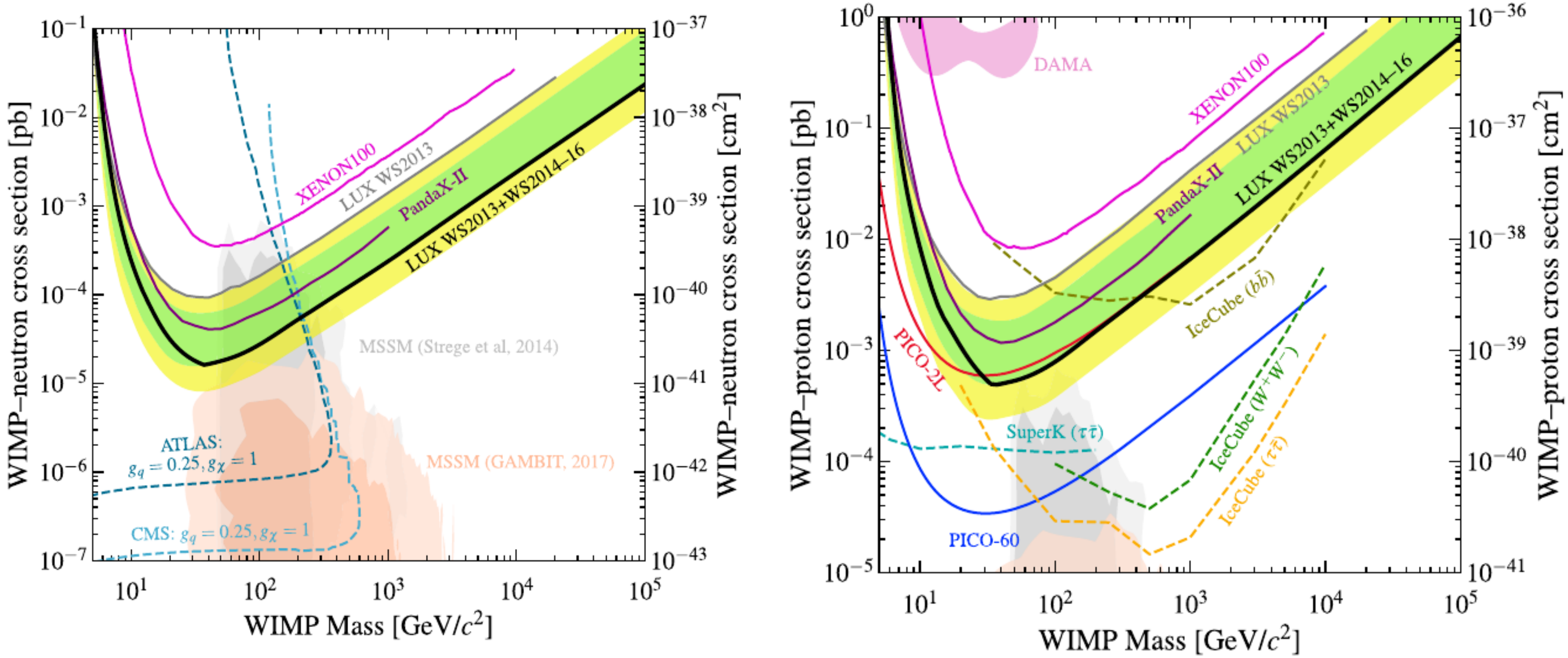
Spin-independent interactions





- Limits on spin-independent WIMP-nucleon cross-section (right); two runs combined: 2013 – 95 live days, 2015-2016 – 332 live days. Combined exposure 3.35×10^{4} kg×days.
- Limit 1.1×10^{-46} 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.
- Plot from Aprile et al. (XENON Collaboration). PRL 121, 111302 (2018).

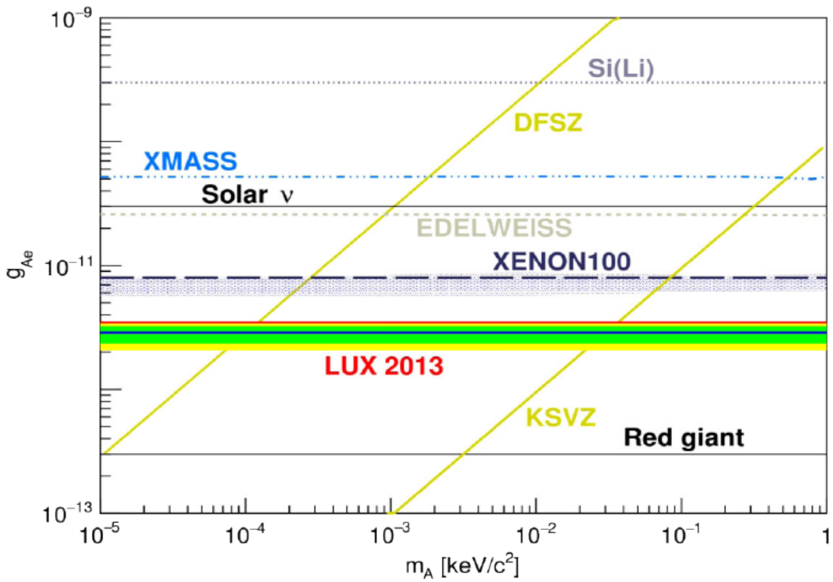
Spin dependent interactions



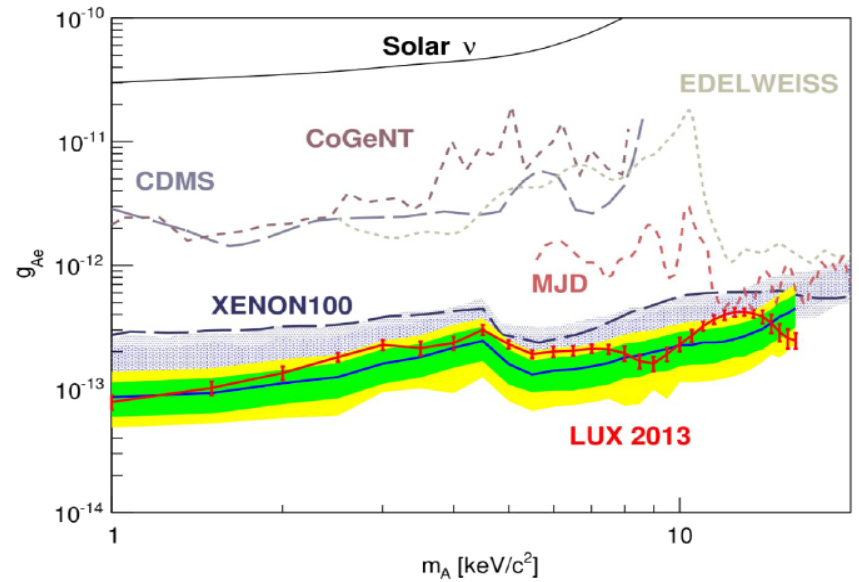
- Spin-dependent WIMP-neutron cross-section (left): two Xe isotopes with odd number of neutrons.
- Spin-dependent WIMP-proton cross-section (right): even number of protons, reduced sensitivity.
- Akerib et al. (LUX Collaboration), PRL 118, 251302 (2017).

Axions and axion-like particles (ALPs)

Axions



ALPs



Searches are based on axio-electric effect.

- Solar axions: LUX (2013) excludes $g_{Ae} > \mathbf{3.5 \times 10^{-12}}$ (90% CL).
  - $m_A < \mathbf{0.12\ eV/c^2}$ (DFSZ model).
  - $m_A < \mathbf{36.6\ eV/c^2}$ (KSVZ model).
- Primordial ALPs: LUX (2013) excludes $\mathbf{g_{Ae} > 4.2 \times 10^{-13}}$ (90% CL) for **1-16 keV/c²** ALP masses.

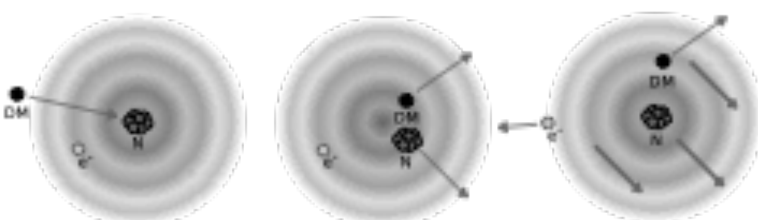
Akerib et al (LUX Collaboration), PRL 118, 261301 (2017)

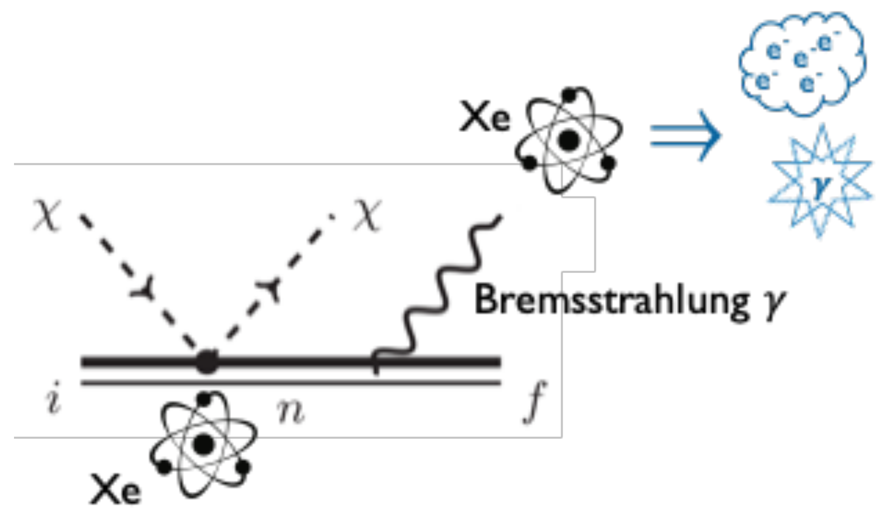
Sensitivity to sub-GeV WIMPs

- Reformulated Migdal effect: ionisation of the recoiling atom, M. Ibe et al. JHEP 03, 194 (2018).
- 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).

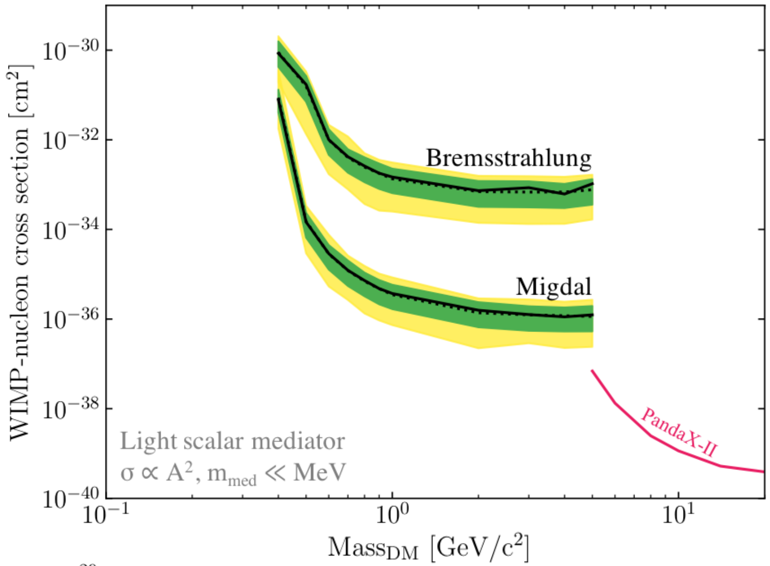
Migdal effect: ionisation of recoiling atom

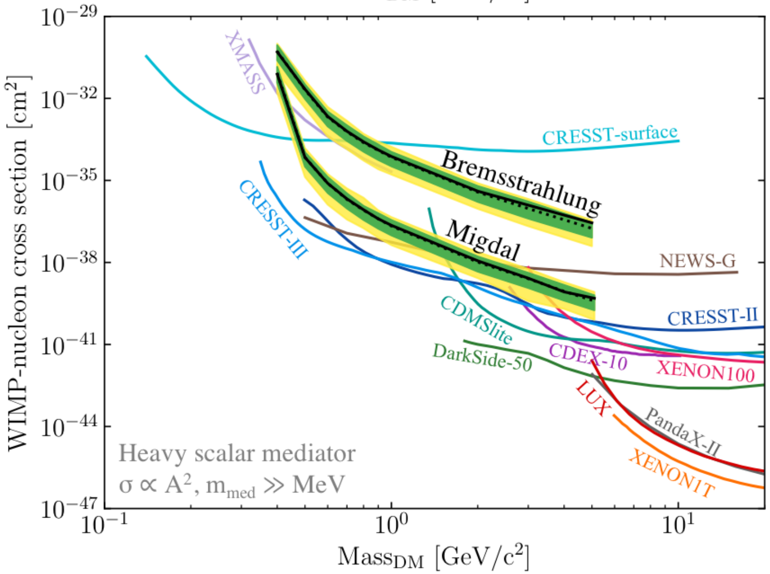
Bremsstrahlung: photon emission from the moving nucleus



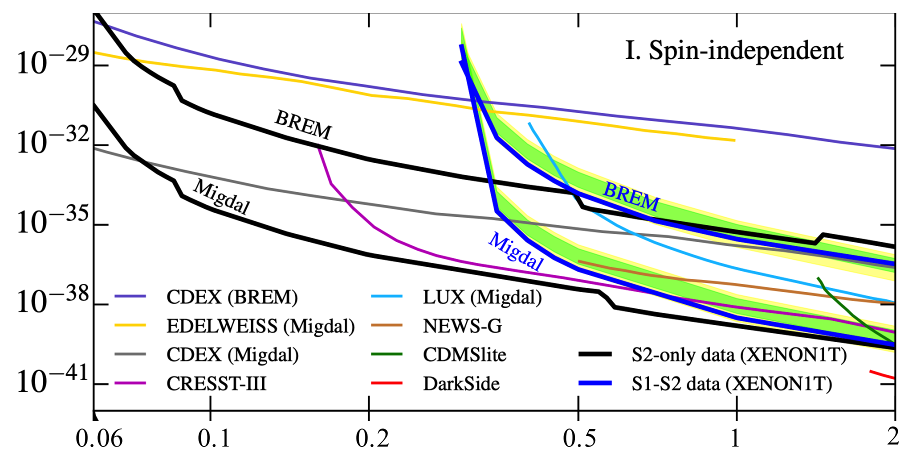


Sensitivity to sub-GeV WIMPs





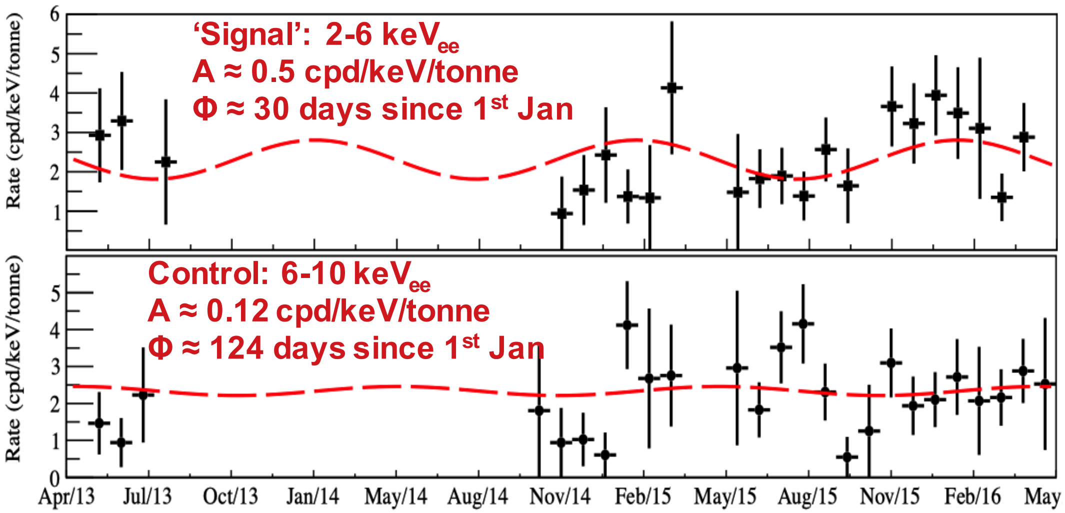
- ER detection improves sensitivity to low mass WIMPs (down to 0.3 GeV/c^2). Akerib et al. (LUX Collaboration), PRL 122, 131301 (2019). See also Tom Shutt plenary talk.
- More limits added recently from EDELWEISS team (32 g bolometer above ground, Armengaud et al., (The Edelweiss Collaboration), PRD, 99, 082003 (2019)) and XENON1t (Aprile et al. (XENON Collaboration), arXiv:1907.12771).



Modulation studies

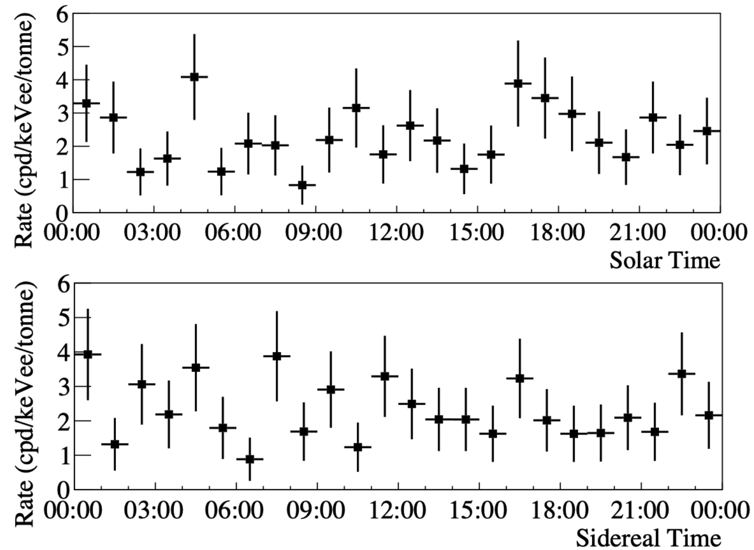
Akerib et al. (LUX Collaboration), PRD 98, 062005 (2018)

Annual



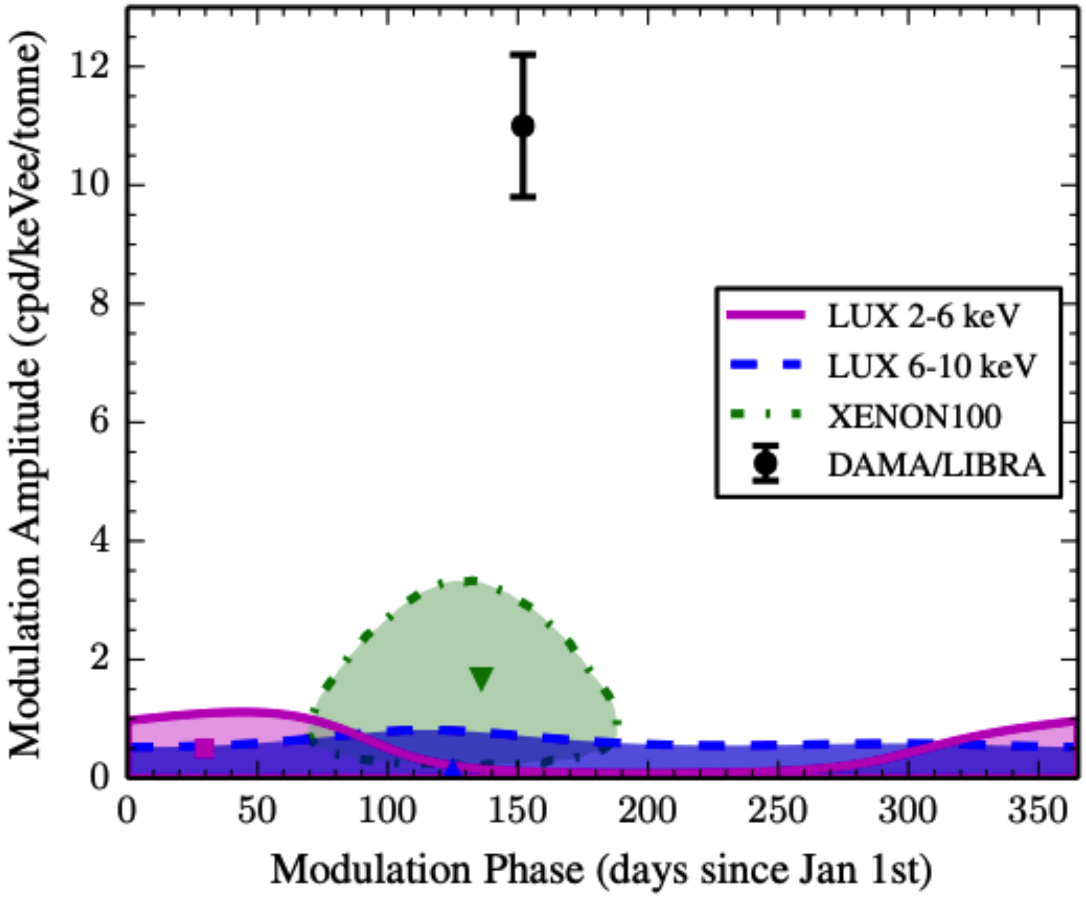
Diurnal

day/night: 2.28 / 2.36 cpd/keV/ton (siderial)
Asymmetry: -1.7% ± 8.7% (stats only)



- 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.

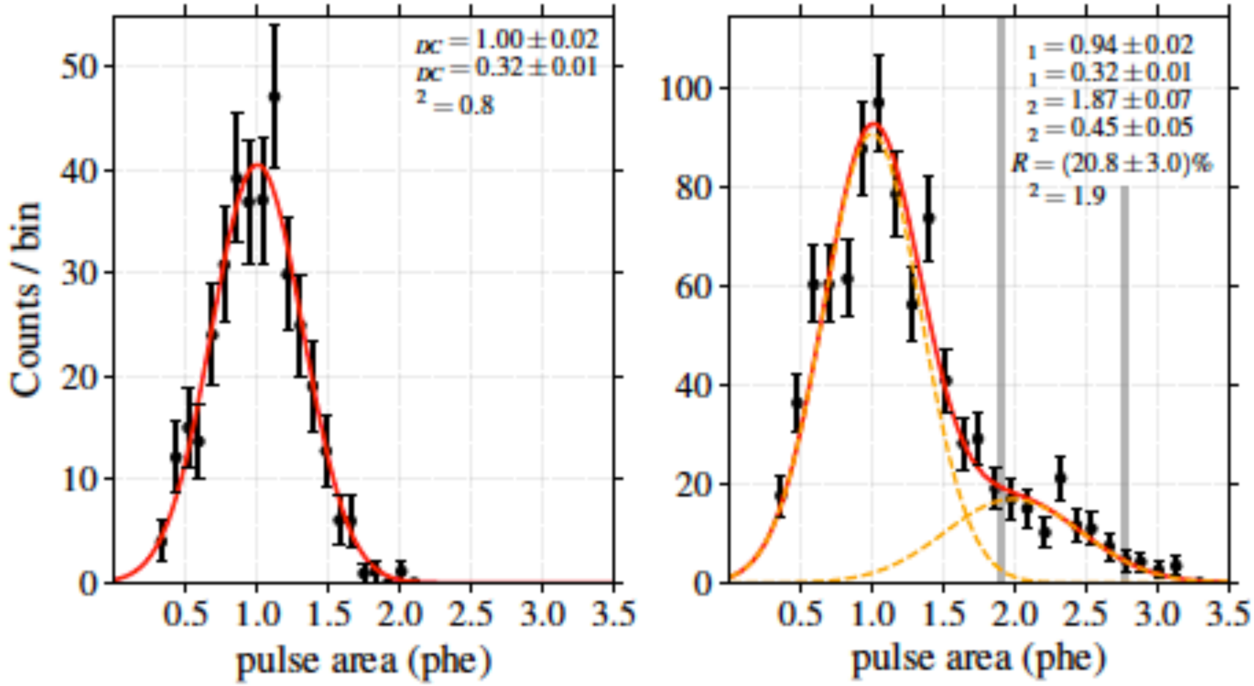
Modulation studies



- 9.2σ conflict with the DAMA result for the same modulation phase and the same energy window.

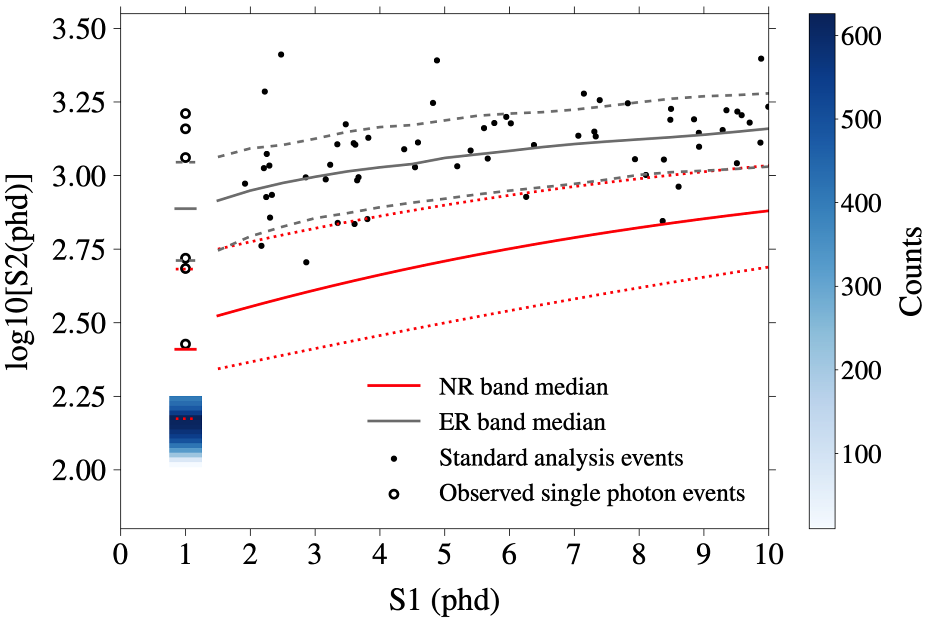
Double photoelectron analysis

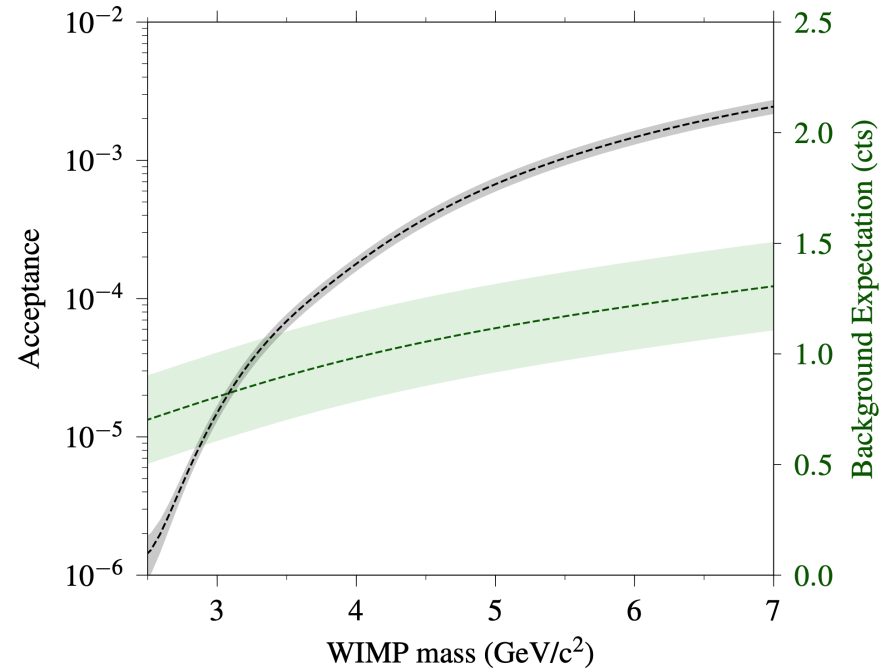
Akerib et al. (LUX Collaboration) arXiv:1907.06272



- 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



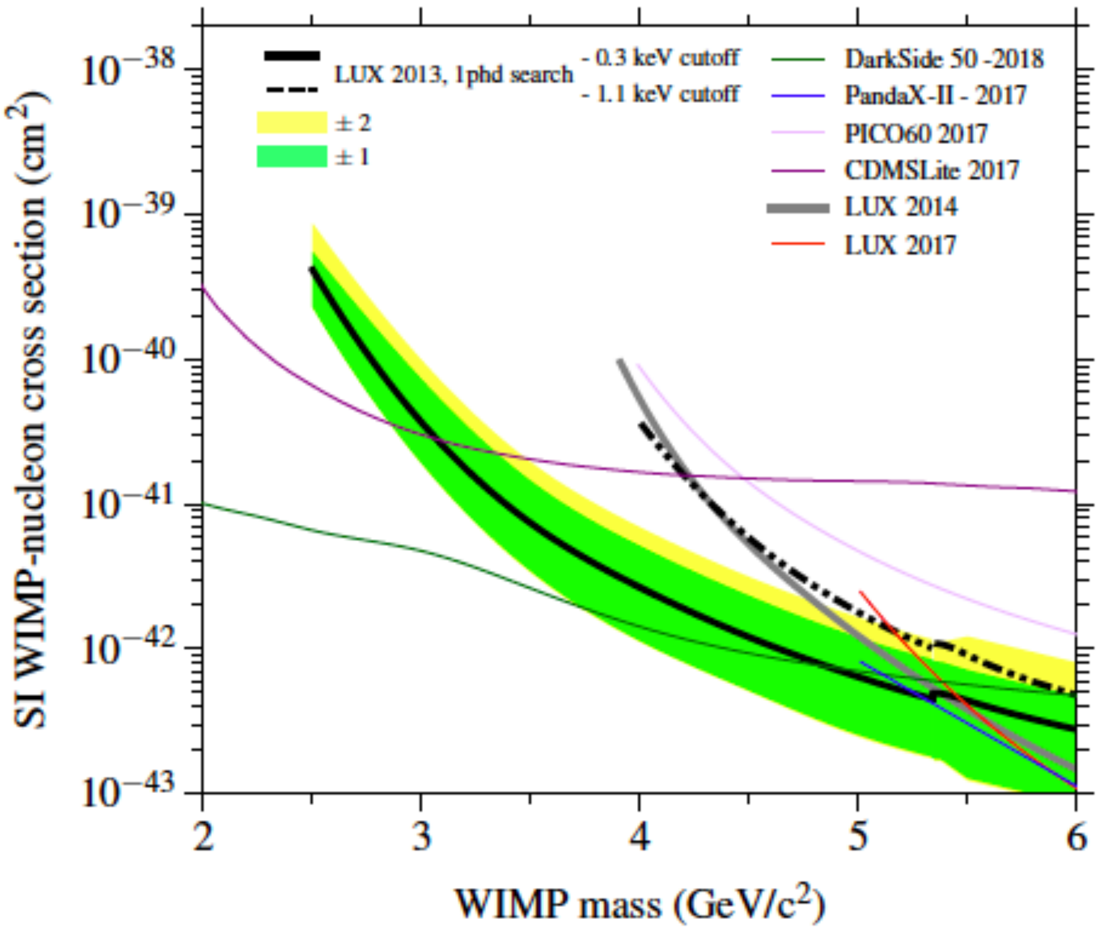


- Scatter plot of detected events: 6 open circles are the background for this analysis.
- NR band is for 50 GeV/c^2 (10%-90%).
- Colour scheme on the right shows event distribution for 4 GeV/c^2 WIMP model.

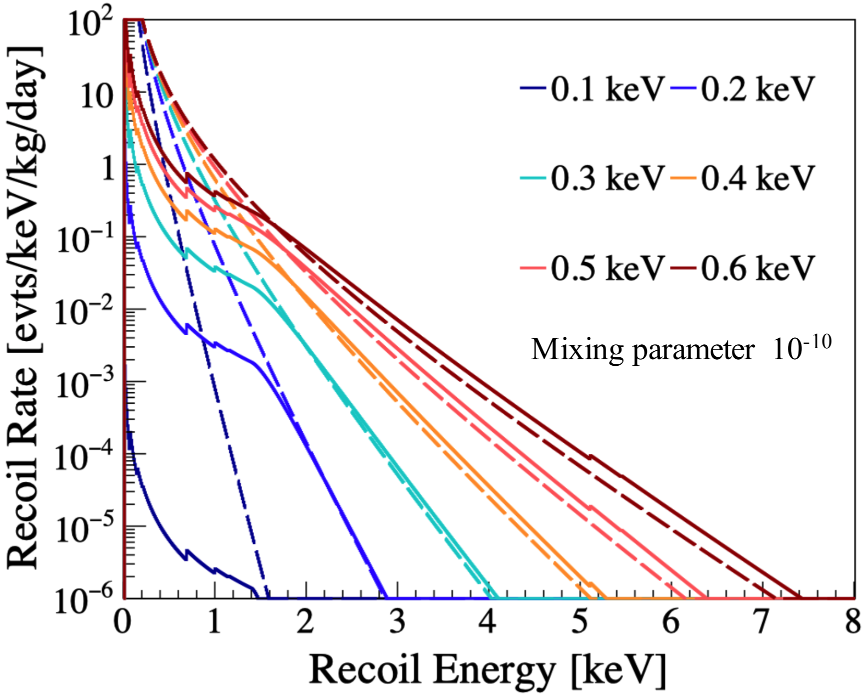
- Signal acceptance and expected number of background events as a function of WIMP mass.
- Low efficiency but almost no dark counts.

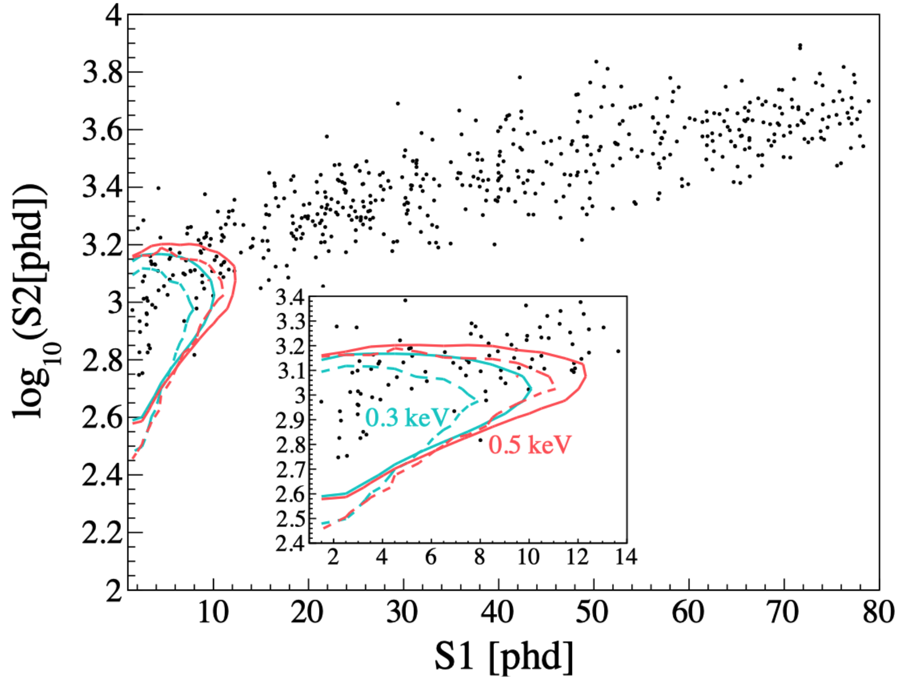
Double photoelectron analysis

- 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**



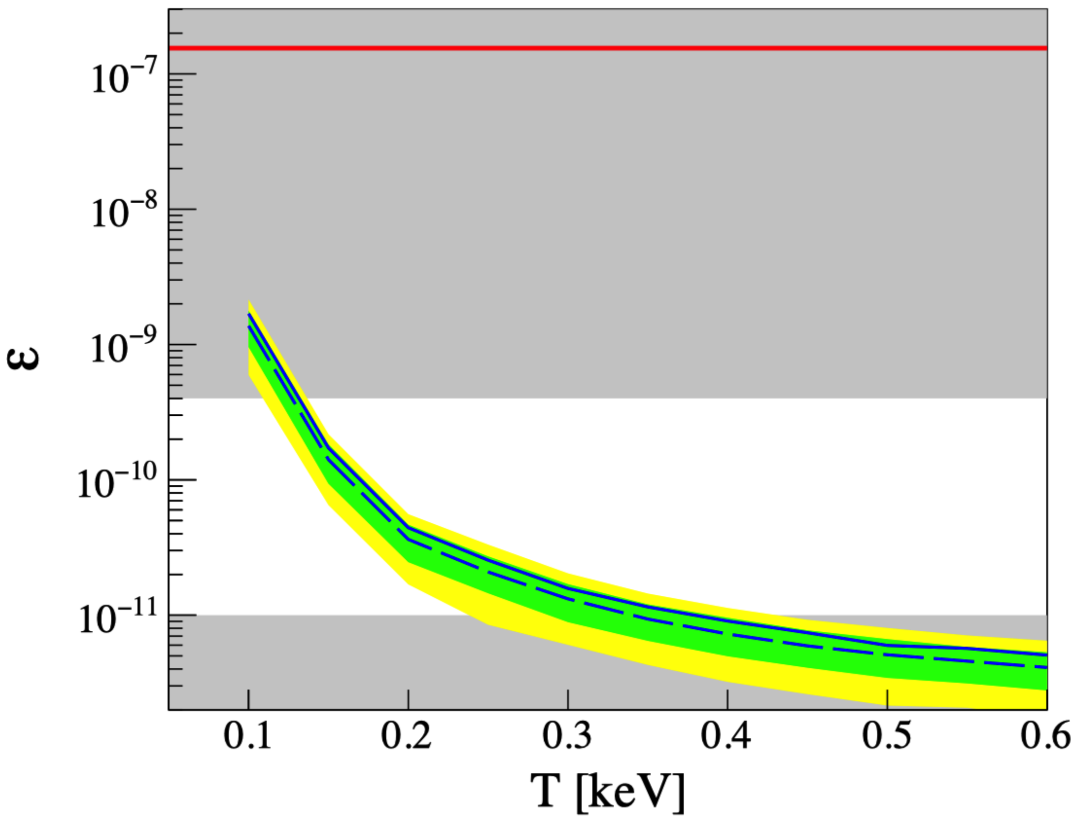
Mirror DM with kinetic mixing





- Hidden sector -> mirror partners to SM particles (same masses etc).
- Possible kinetic mixing induces very small electric charges: R. Foot, Int. J. Mod. Phys. A 29, 1430013 (2014), R. Foot et al., Phys. Lett. B 272, 67 (1991), B. Holdom, Phys. Lett. B 166, 196 (1986).
- 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.