LUX results and LZ sensitivity to dark matter WIMPs

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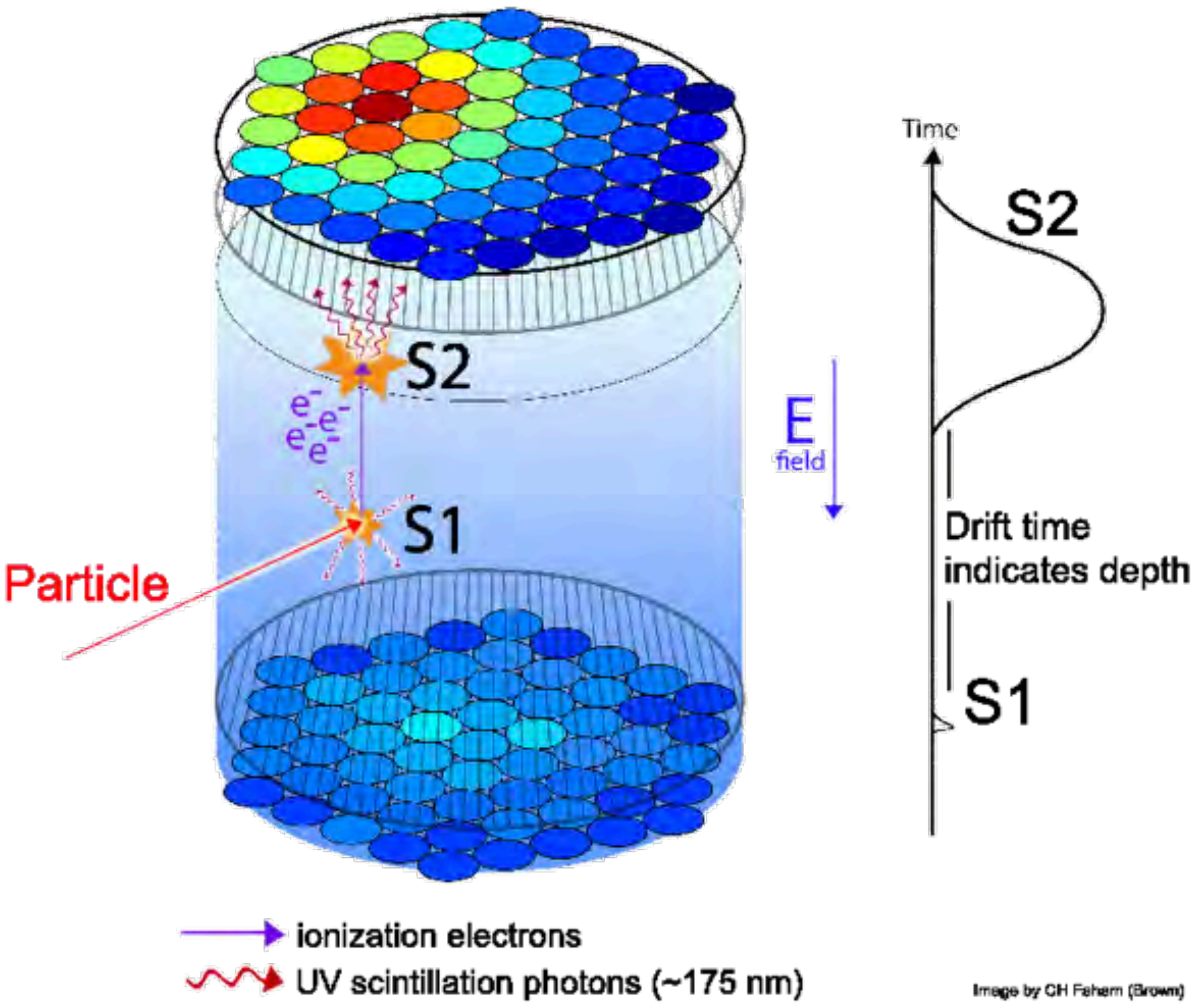
for the LUX and LZ Collaborations

Outline

- Dark matter direct detection with two-phase noble element instruments.
- LUX detector.
- LUX results:
  - WIMPs – spin-independent interactions;
  - WIMPs – spin-dependent interactions;
  - Axions and axion-like particles (ALPs).
  - Modulation search.
- LZ detector.
- Backgrounds
- Sensitivity to WIMPs.
- Conclusions.

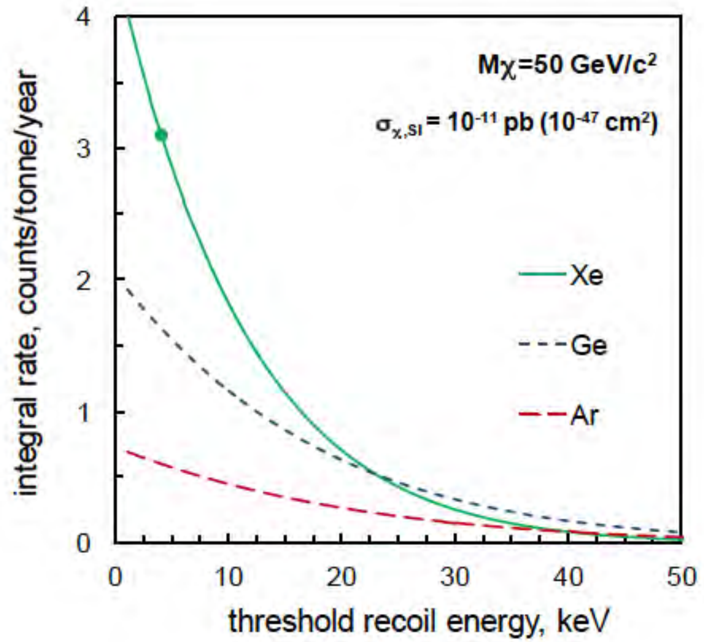
Principle of WIMP detection in LXe TPC

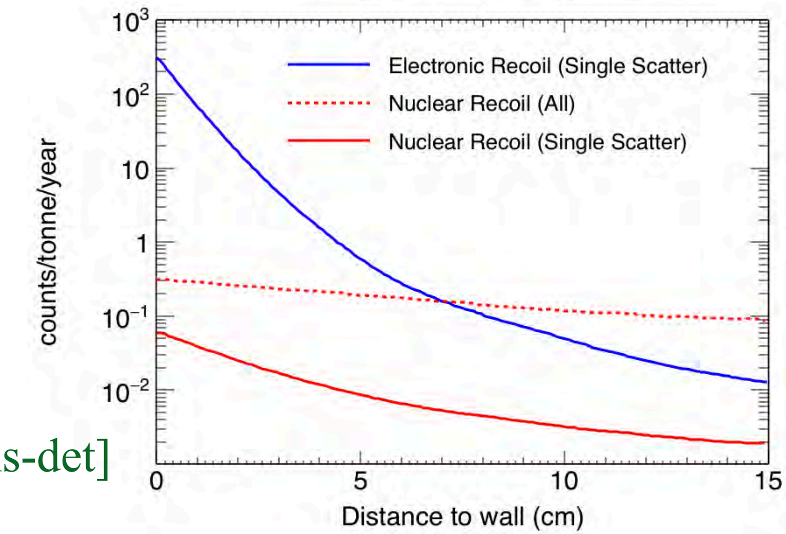


- Liquid xenon time projection chamber – LXe TPC.
- S1 – primary scintillation.
- S2 –secondary scintillation, proportional to ionisation.
- Position reconstruction based on the light pattern in the PMTs and delay between S2 and S1.

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:
  - Axion search,
  - Neutrinoless double-beta decay.



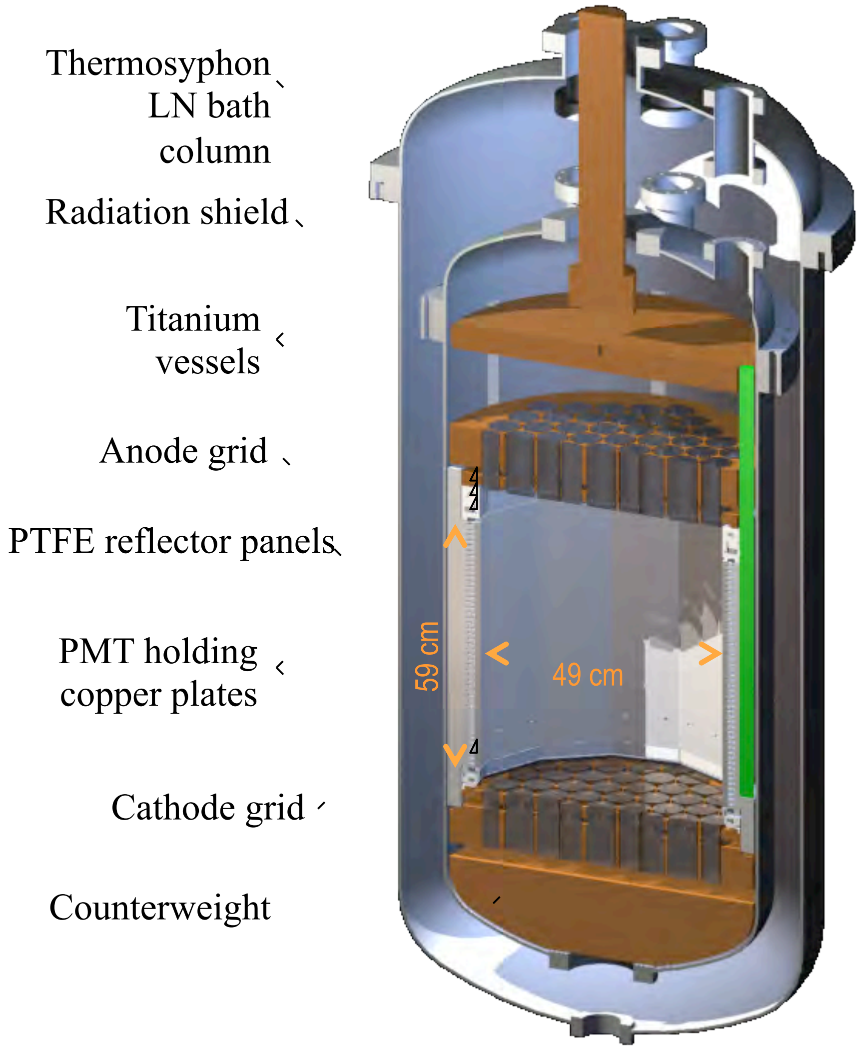


LZ Collaboration, LZ TDR, 1703.09144v1 [physics.ins-det]

LUX Collaboration

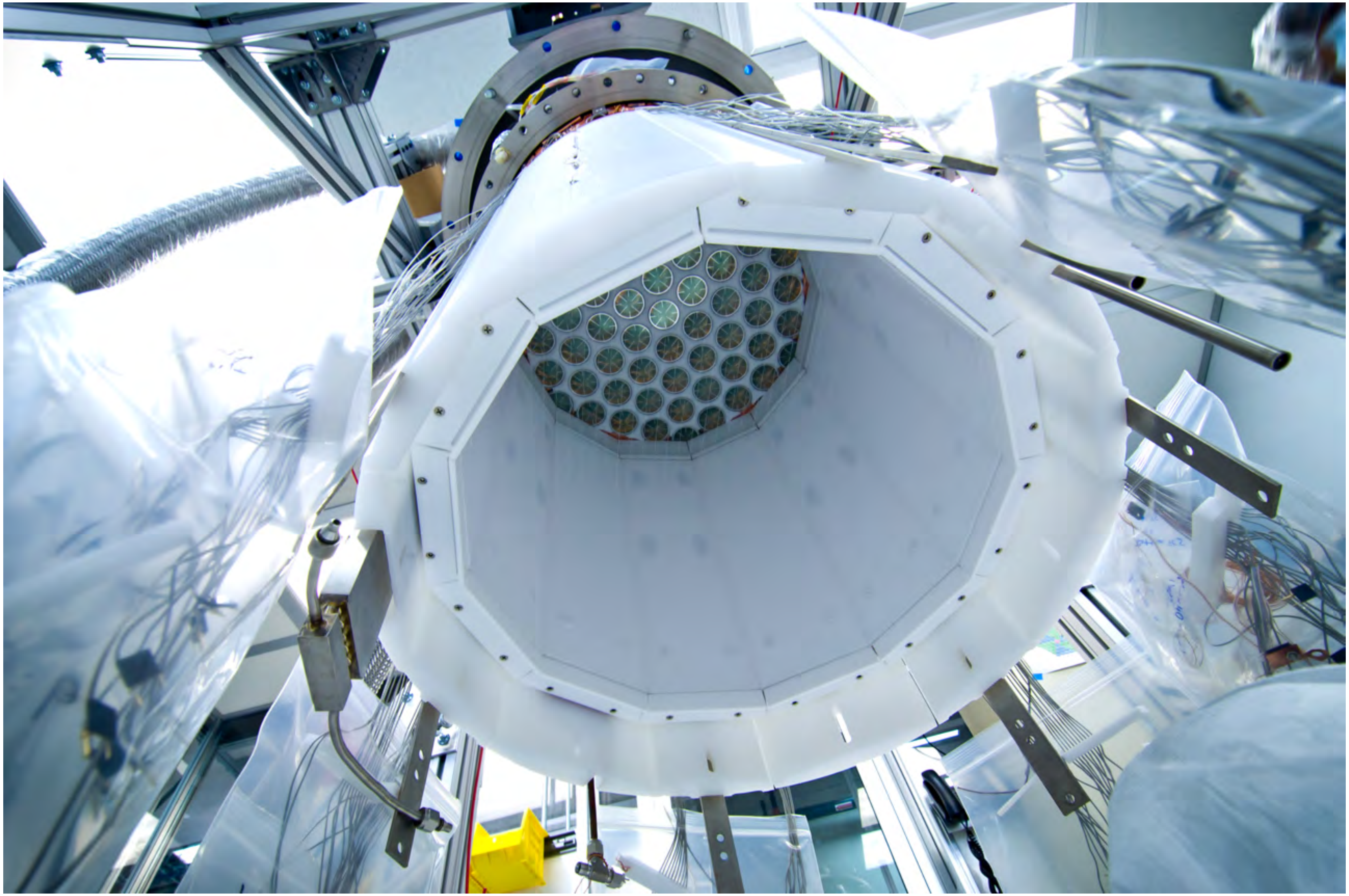
- Brown University
- Imperial College London
- LIP Coimbra, Portugal
- Lawrence Berkley National Laboratory
- Lawrence Livermore National Laboratory
- Pennsylvania State University
- SLAC National Accelerator Laboratory
- South Dakota School of Mines and Technology
- South Dakota Science and Technology 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 detector



- 61 top + 61 bottom ultra-low background PMTs viewing ~250 kg of xenon in the active region (~120 kg fiducial).
- Ultra low background PMTs
- 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.

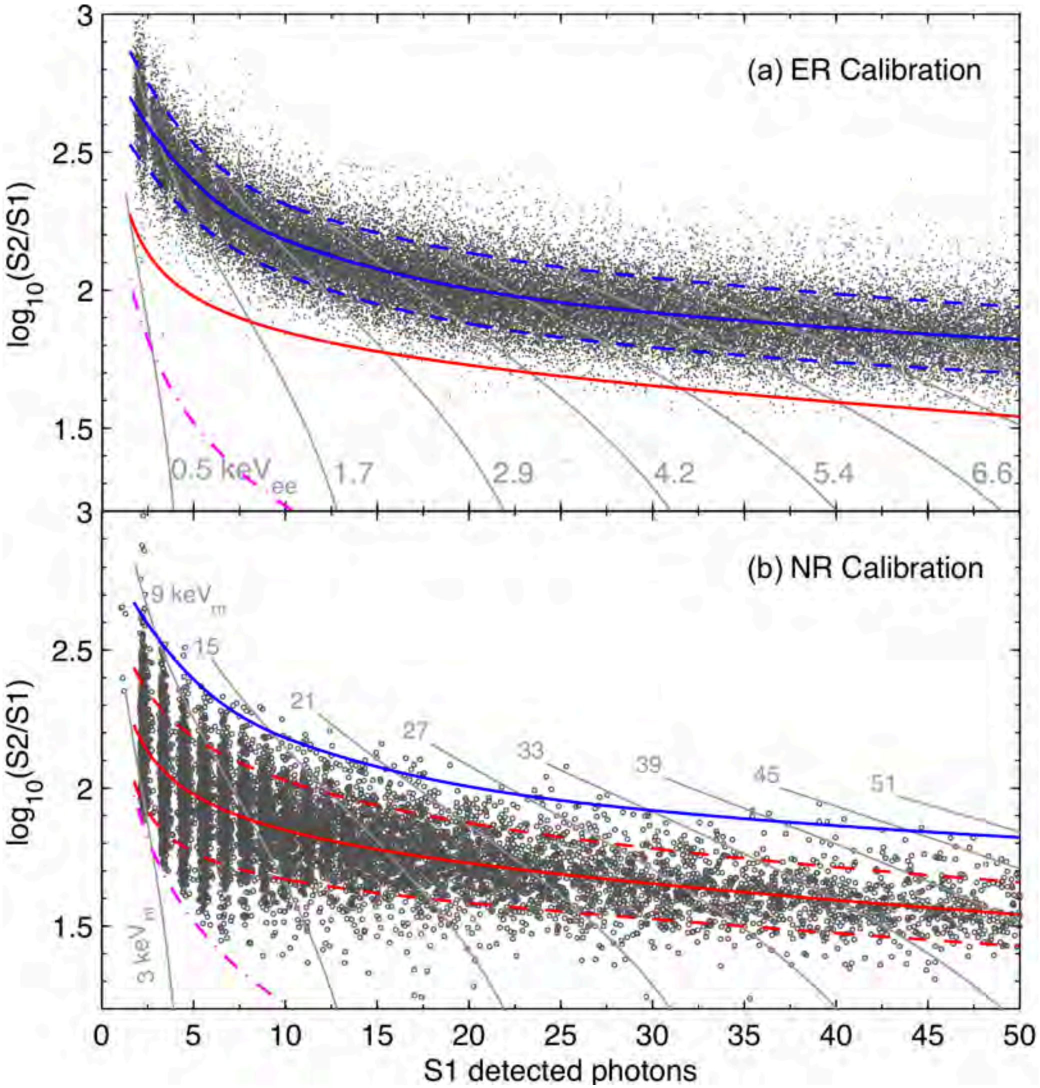
LUX detector



LUX detector

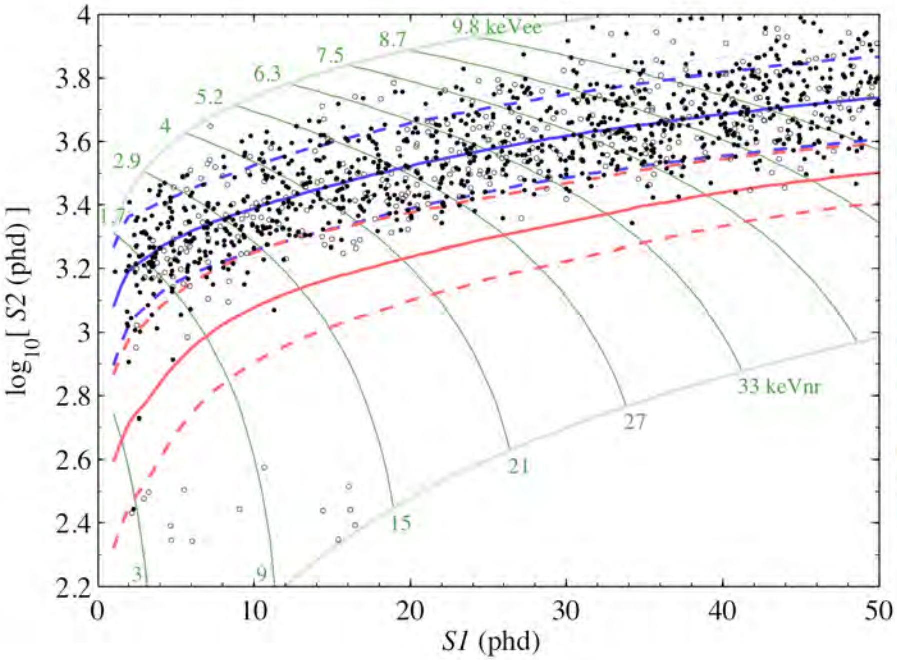
- 4850 ft level at SURF. Muon flux $\sim 6\times10^{-5}$ m^{-2} s^{-1}.
- Muon veto system and shielding: water tank instrumented with PMTs.

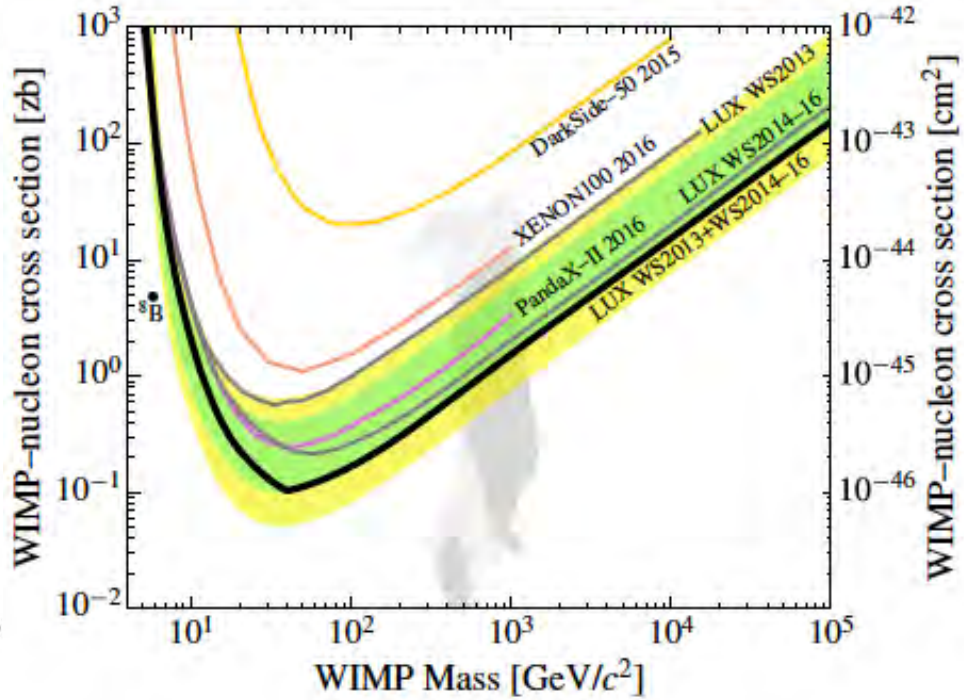
LUX calibrations



- ^{83m}Kr – uniform distribution, 1.8 hours half-life, weekly.
- 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].

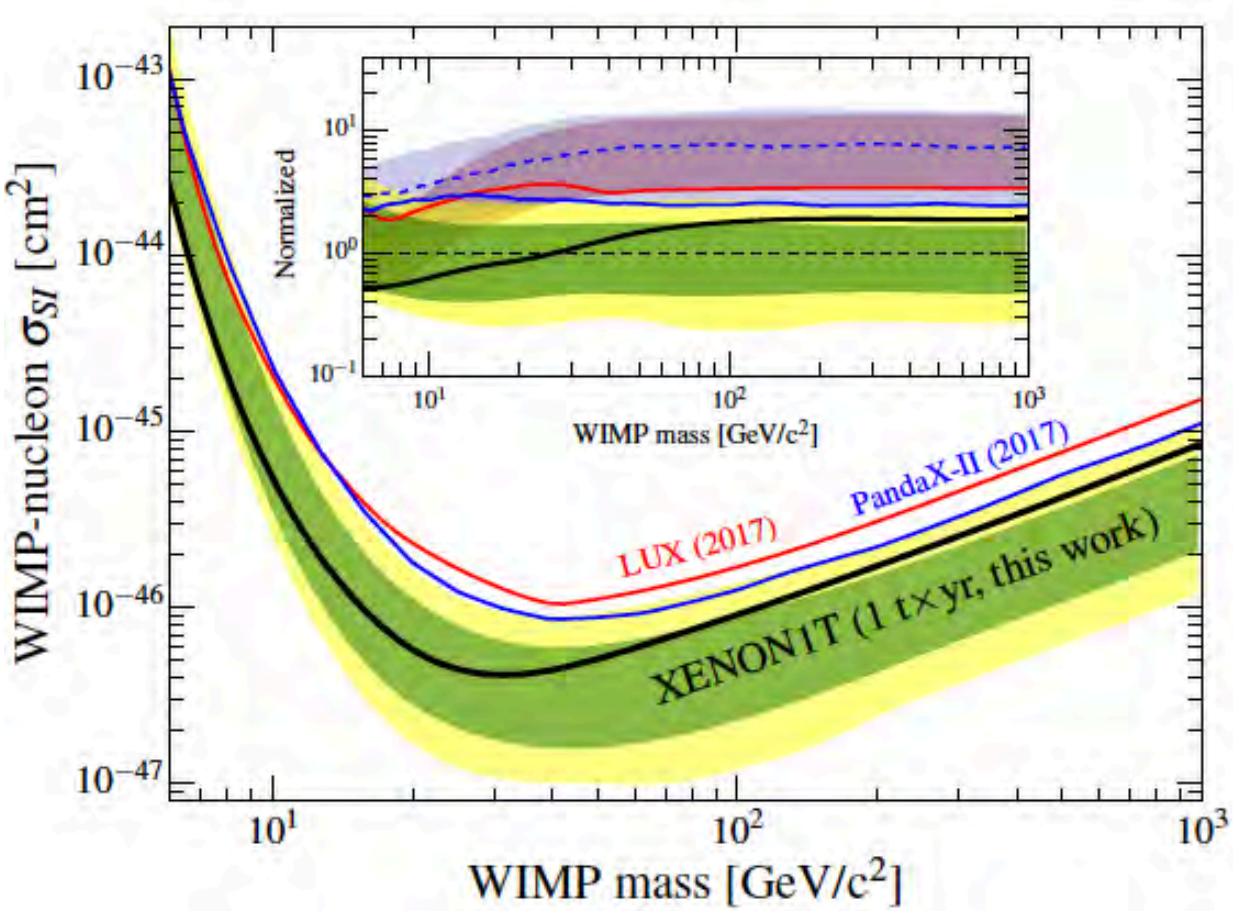
LUX results





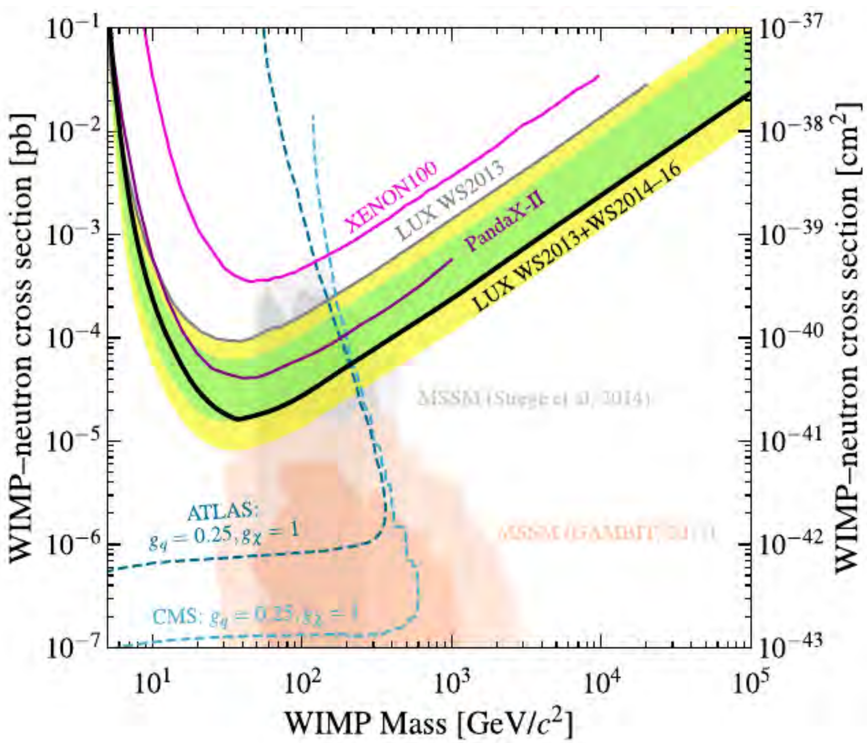
- Data after cuts: 332 live days (left).
- Limits on spin-independent WIMP-nucleon cross-section (right); two runs combined: 2013 – 95 live days, 2015-2016 – 332 live days. Combined exposure 3.35×10^4 kg×days.
- Limit 1.1×10^{-46} cm^2 at 50 GeV/c^2.
- Akerib et al. (LUX Collaboration), PRL 118, 021303 (2017).

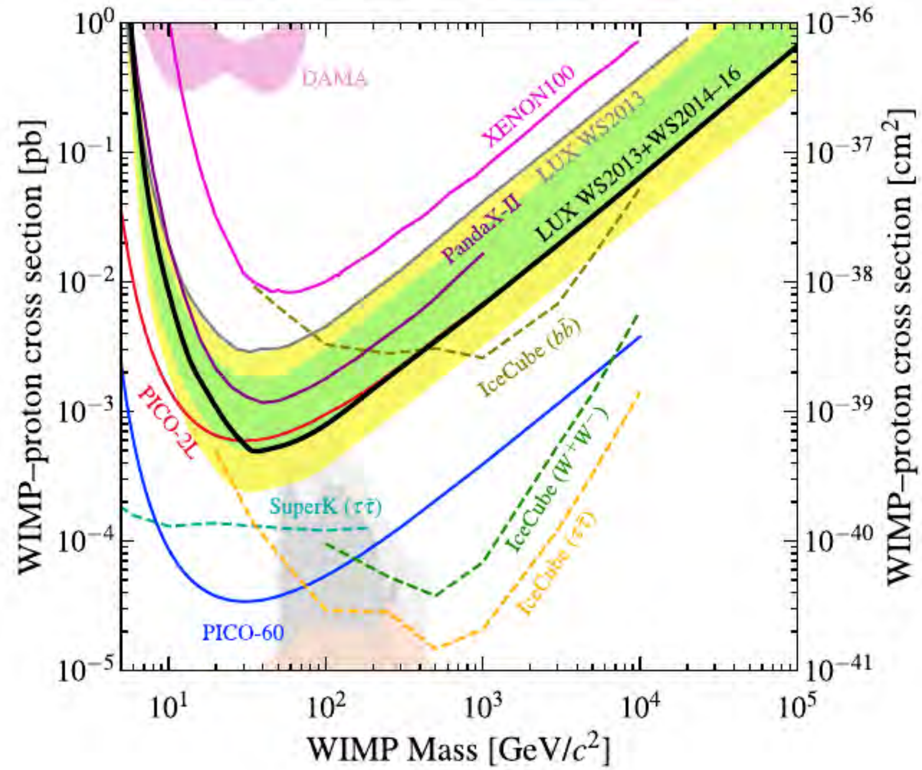
Most recent results



- Most recent results from leading two-phase Xe experiments.
- Plot from Aprile et al (XENON Collaboration). arXiv:1805.12562v1 [astro-ph.CO]

Spin dependent interactions

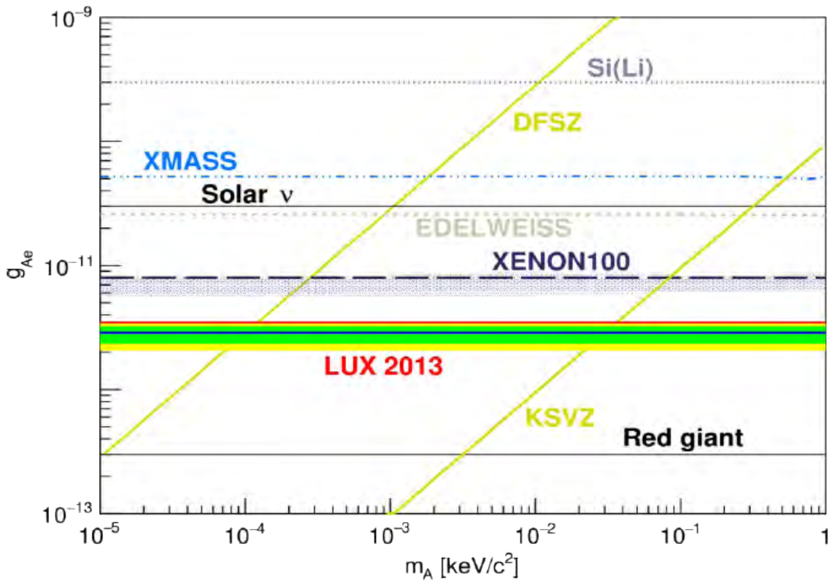




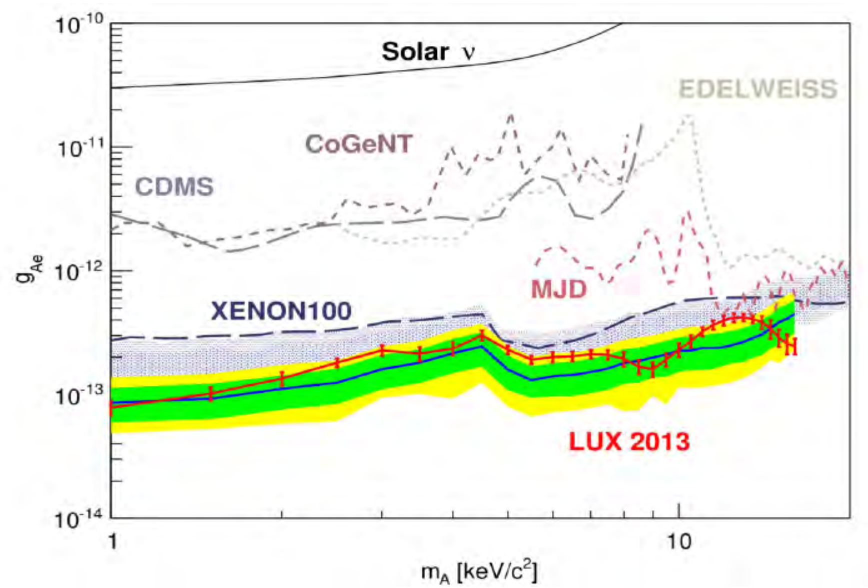
- Spin-dependent WIMP-neutron cross-section (left): two Xe isotopes with odd number of neutrons.
- Spin-dependent WIMP-proton cross-section (right): even number of protons.

Axions and axion-like particles (ALPs)

Axions



ALPs



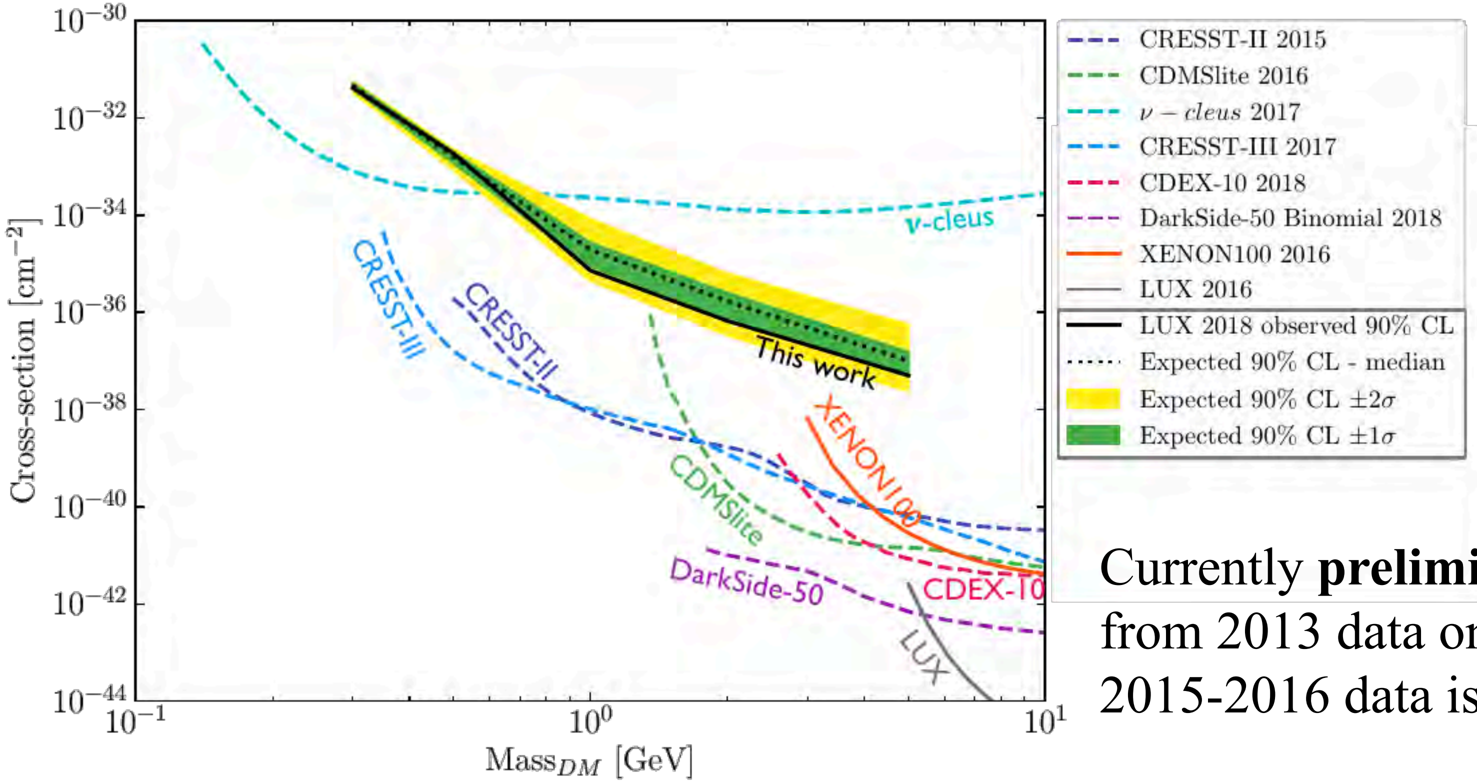
- LUX (2013) excludes $g_{Ae} > \mathbf{3.5\times10^{-12}}$ (90% CL).
  - $m_A < \mathbf{0.12\ eV/c^2}$ (DFSZ model).
  - $m_A < \mathbf{36.6\ eV/c^2}$ (KSVZ model).

- LUX (2013) excludes $\mathbf{g_{Ae} > 4.2 \times 10^{-13}}$ (90% CL) across the range **1-16 keV/c²** in ALP mass.

PRL 118, 261301 (2017)
Analysis of 2015-2016 data is in progress.

Sensitivity to sub-GeV WIMPs

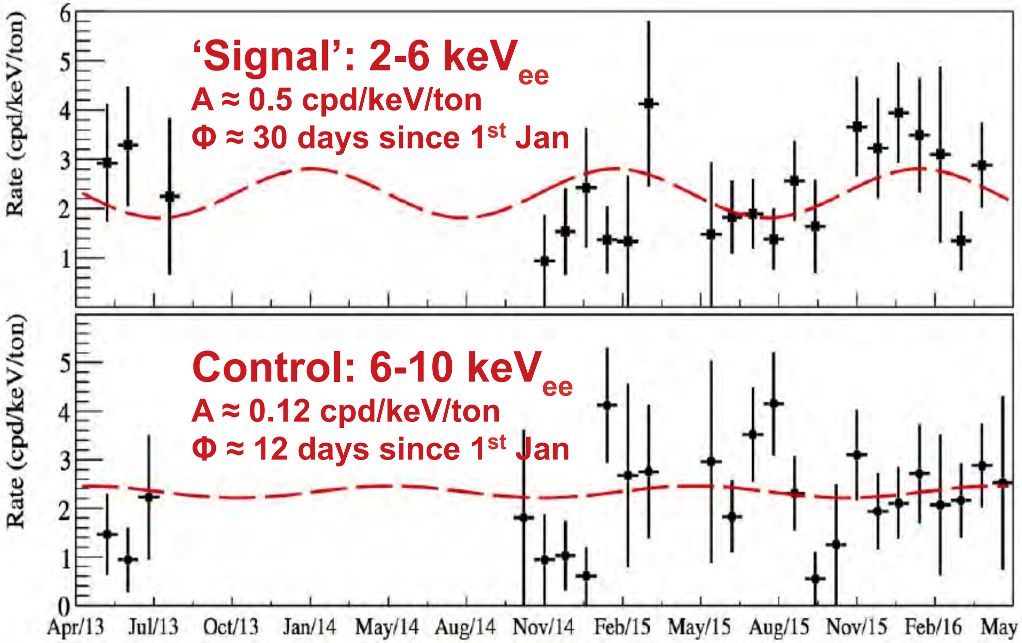
- WIMP-nucleus interactions may result in the emission of bremsstrahlung photons by a polarised xenon atom.
- Detection of these photons – improved sensitivity to low mass WIMPs (down to 0.3 GeV/c^2).



Currently **preliminary** results from 2013 data only; analysis of 2015-2016 data is ongoing.

Modulation studies

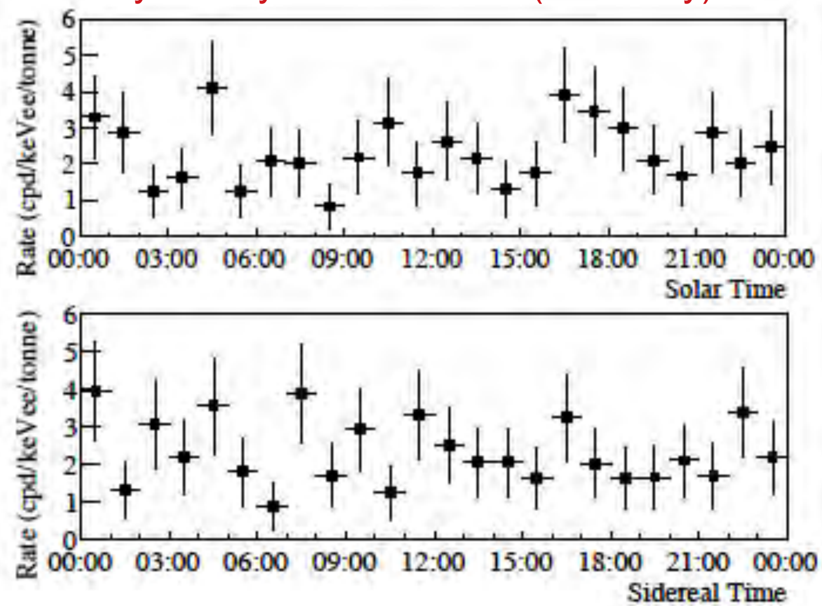
Annual (Preliminary)



Diurnal (Preliminary)

day/night: 2.28 / 2.36 cpd/keV/ton (siderial)

Asymmetry: -1.7% ± 8.7% (stats only)



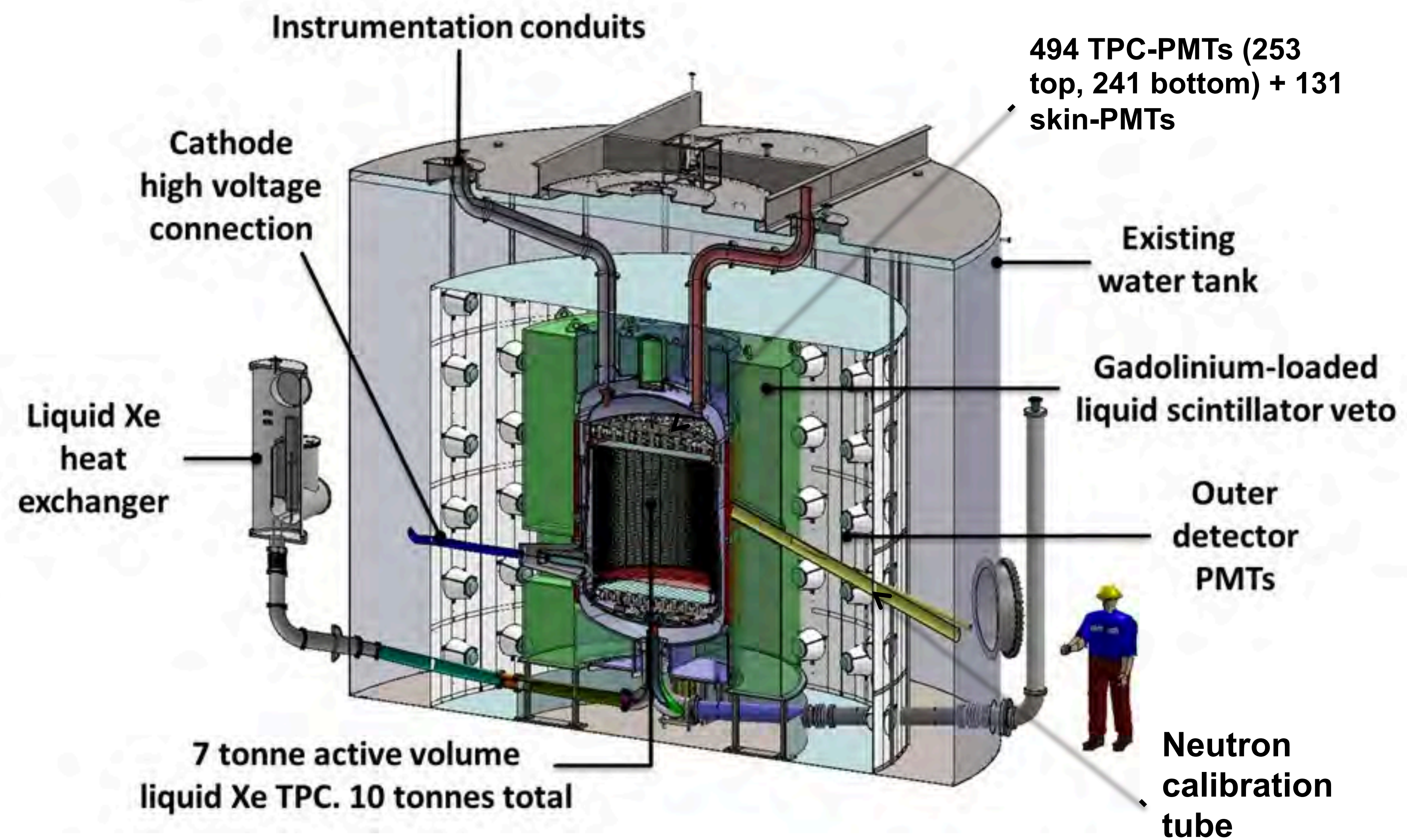
- The rate at low energies: ~2 events/ton/day/keV, 10-20 times lower than the DAMA modulation amplitude.
- No statistically significant annual or diurnal modulation found.

LUX-ZEPLIN (LZ) experiment

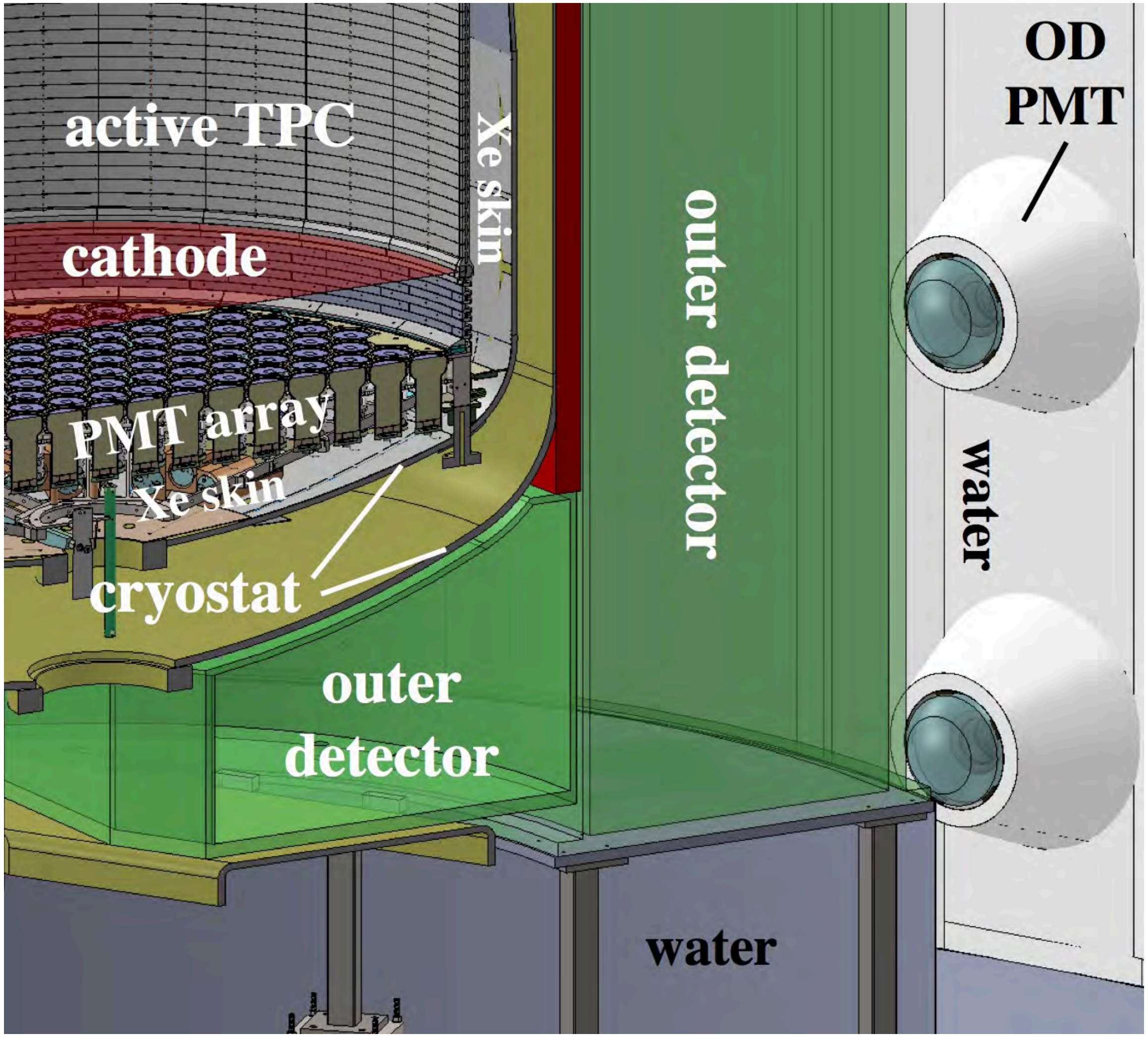
- Black Hills State University
- Brandeis University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics, Korea
- Fermi National Accelerator Laboratory
- Imperial College London
- LIP Coimbra, Portugal
- Lawrence Berkley National Laboratory
- Lawrence Livermore National Laboratory
- MEPhI-Moscow, Russia
- Northwestern University
- Pennsylvania State University
- Royal Holloway, University of London
- SLAC National Accelerator Laboratory
- South Dakota School of Mines and Technology
- South Dakota Science and Technology Authority
- STFC Rutherford Appleton Laboratory
- Texas A&M University
- University at Albany, SUNY
- University College London
- University of Alabama
- University of Bristol
- University of California, Berkeley
- University of California, Davis
- University of California, Santa Barbara
- University of Edinburgh
- University of Liverpool
- University of Maryland
- University of Michigan
- University of Massachusetts
- University of Oxford
- University of Rochester
- University of Sheffield
- University of South Dakota
- University of Wisconsin – Madison
- Washington University in St. Louis
- Yale University

LZ detector

LZ Collaboration, arXiv:1509.02910[physics.ins-det], 1703.09144v1 [physics.ins-det]



LZ detector



- From D. S. Akerib et al. (LZ Collaboration), arXiv: 1802.06039 [astro-ph.IM].
- 3'' PMTs viewing the target volume.
- 5.8 keV nuclear recoil energy threshold for 3-fold coincidences.
- 0.31-0.65 kV/cm drift field, 99.5% ER/NR discrimination.
- Max drift time ~0.8 ms defines the window for recording an event.
- 5.6 t fiducial volume (to remove events from walls and wires).

Expected background

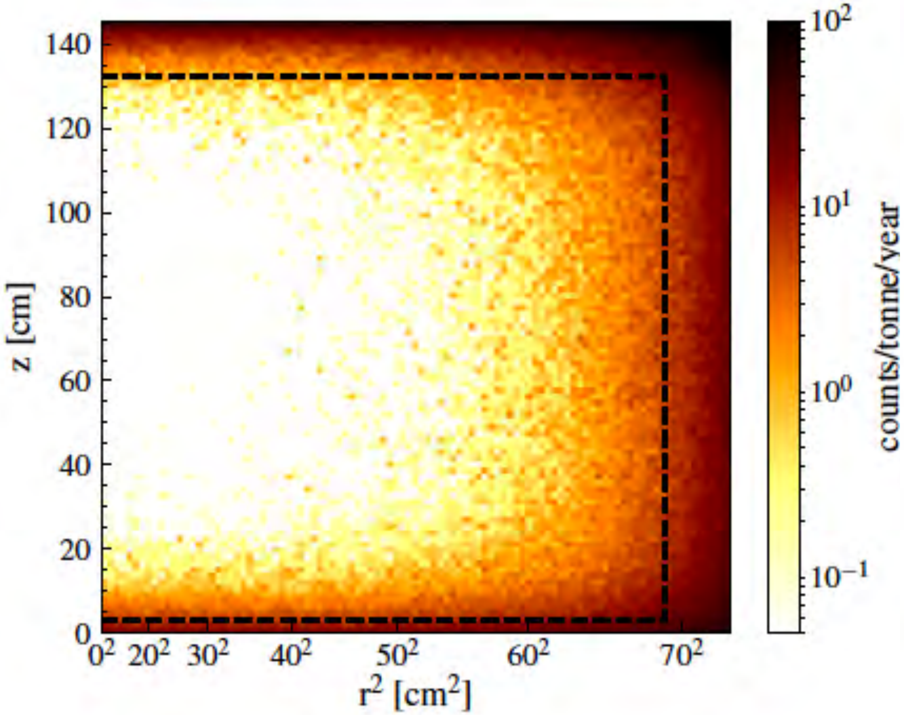
Background Source	Mass (kg)	$^{238}U_e$	$^{238}U_l$	$^{232}Th_e$	$^{232}Th_l$	^{60}Co	^{40}K	n/yr	ER (cts)	NR (cts)
		mBq/kg								
Detector Components										
PMT systems	308	31.2	5.20	2.32	2.29	1.46	18.6	248	2.82	0.027
TPC systems	373	3.28	1.01	0.84	0.76	2.58	7.80	79.9	4.33	0.022
Cryostat	2778	2.88	0.63	0.48	0.51	0.31	2.62	323	1.27	0.018
Outer detector (OD)	22950	6.13	4.74	3.78	3.71	0.33	13.8	8061	0.62	0.001
All else	358	3.61	1.25	0.55	0.65	1.31	2.64	39.1	0.11	0.003
								subtotal	**9**	**0.07**
Surface Contamination										
Dust (intrinsic activity, 500 ng/cm^2)									0.2	0.05
Plate-out (PTFE panels, 50 nBq/cm^2)									-	0.05
^{210}Bi mobility (0.1 μBq/kg LXe)									40.0	-
Ion misreconstruction (50 nBq/cm^2)									-	0.16
^{210}Pb (in bulk PTFE, 10 mBq/kg PTFE)									-	0.12
								subtotal	**40**	**0.39**
Xenon contaminants										
^{222}Rn (1.81 μBq/kg)									681	-
^{220}Rn (0.09 μBq/kg)									111	-
^{nat}Kr (0.015 ppt g/g)									24.5	-
^{nat}Ar (0.45 ppb g/g)									2.5	-
								subtotal	**819**	**0**
Laboratory and Cosmogenics										
Laboratory rock walls									4.6	0.00
Muon induced neutrons									-	0.06
Cosmogenic activation									0.2	-
								subtotal	**5**	**0.06**
Physics										
^{136}Xe $2\nu\beta\beta$									67	-
Solar neutrinos: pp+^{7}Be+^{13}N									255	-
Diffuse supernova neutrinos (DSN)									-	0.05
Atmospheric neutrinos (Atm)									-	0.46
								subtotal	**322**	**0.51**
Total									1195	1.03
Total (with 99.5% ER discrimination, 50% NR efficiency)									5.97	0.52
Sum of ER and NR in LZ for 1000 days, 5.6 tonne FV, with all analysis cuts									**6.49**	

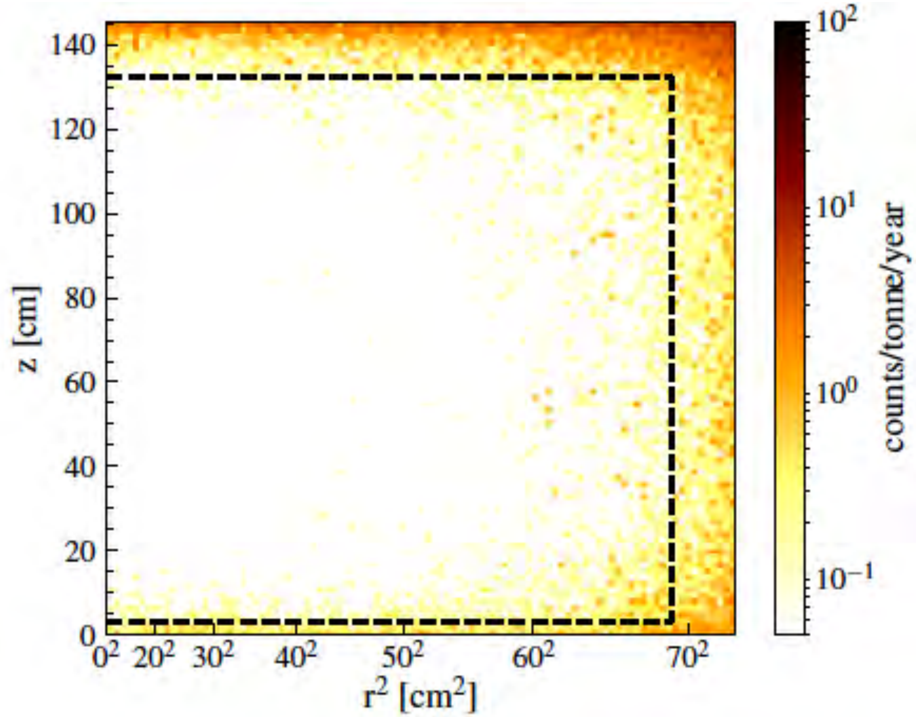
From D. S. Akerib et al. (LZ Collaboration), arXiv:1802.06039.

Planned live time 1000 days.

Complementarity of high-sensitivity measurements of backgrounds (HPGe, ICPMS, radon measurements and control, neutron activation analysis) and accurate modelling of their effects in the detector (BACCARAT based on GEANT4 + NEST + detector response).

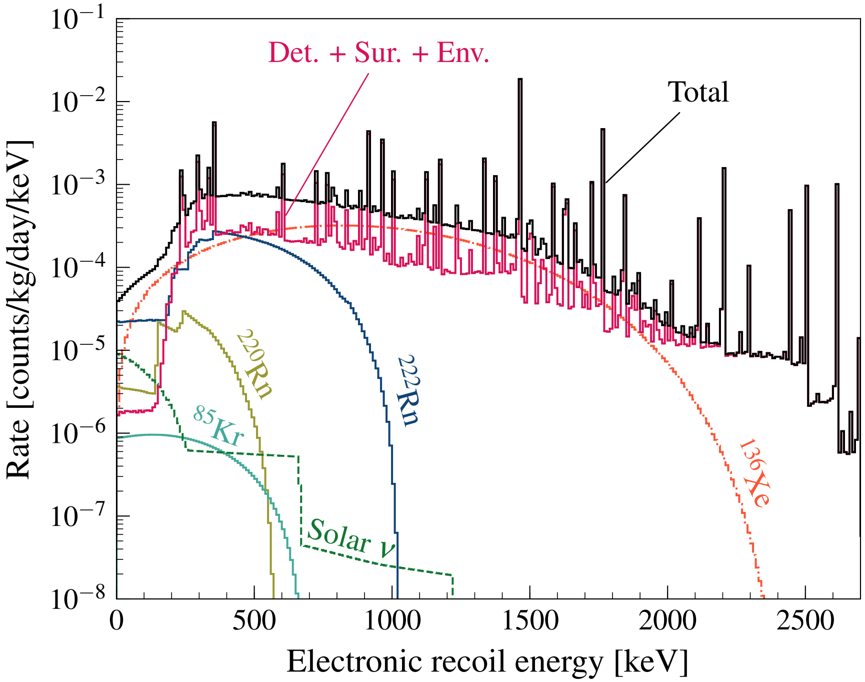
Background events

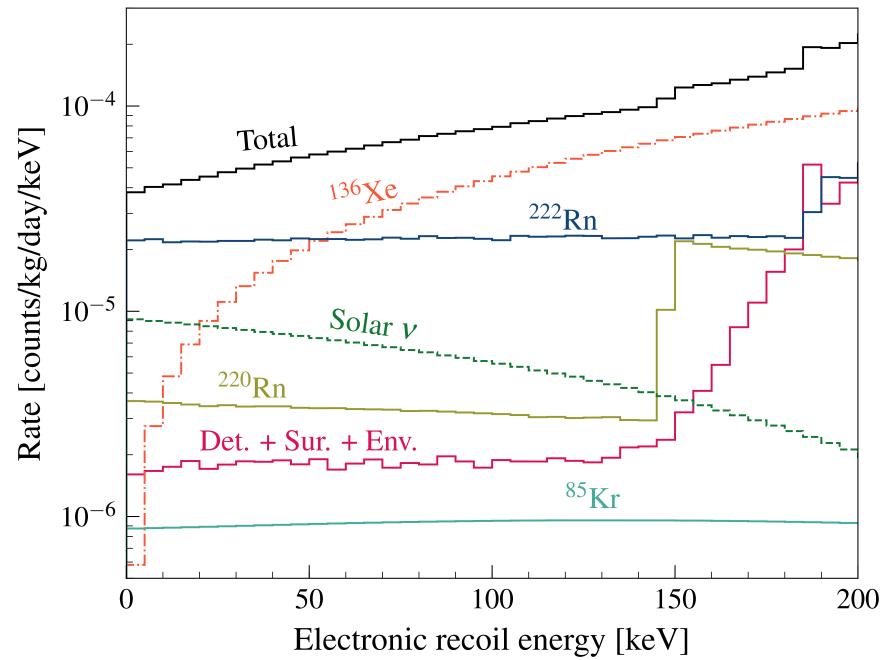




- Single scatter nuclear recoil events in the LXe active volume before (left) and after (right) rejecting events in coincidence with veto system (LXe skin and the Outer Detector (OD).

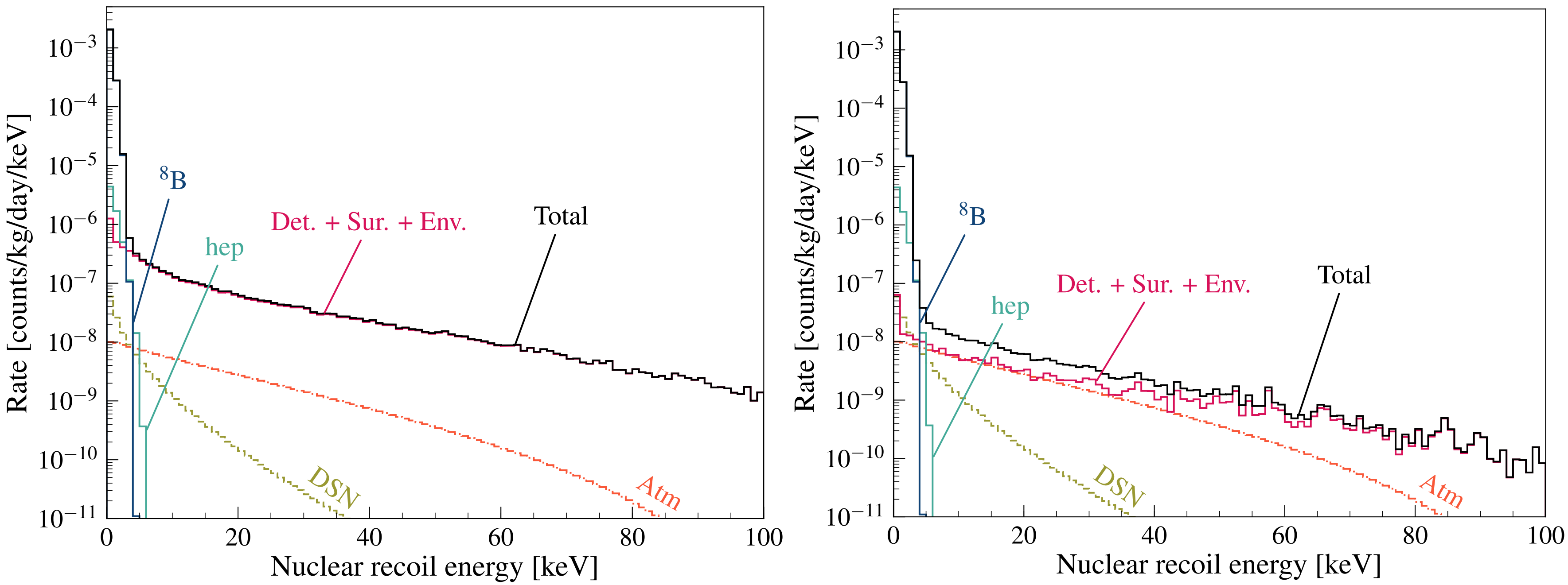
Event spectra: ERs





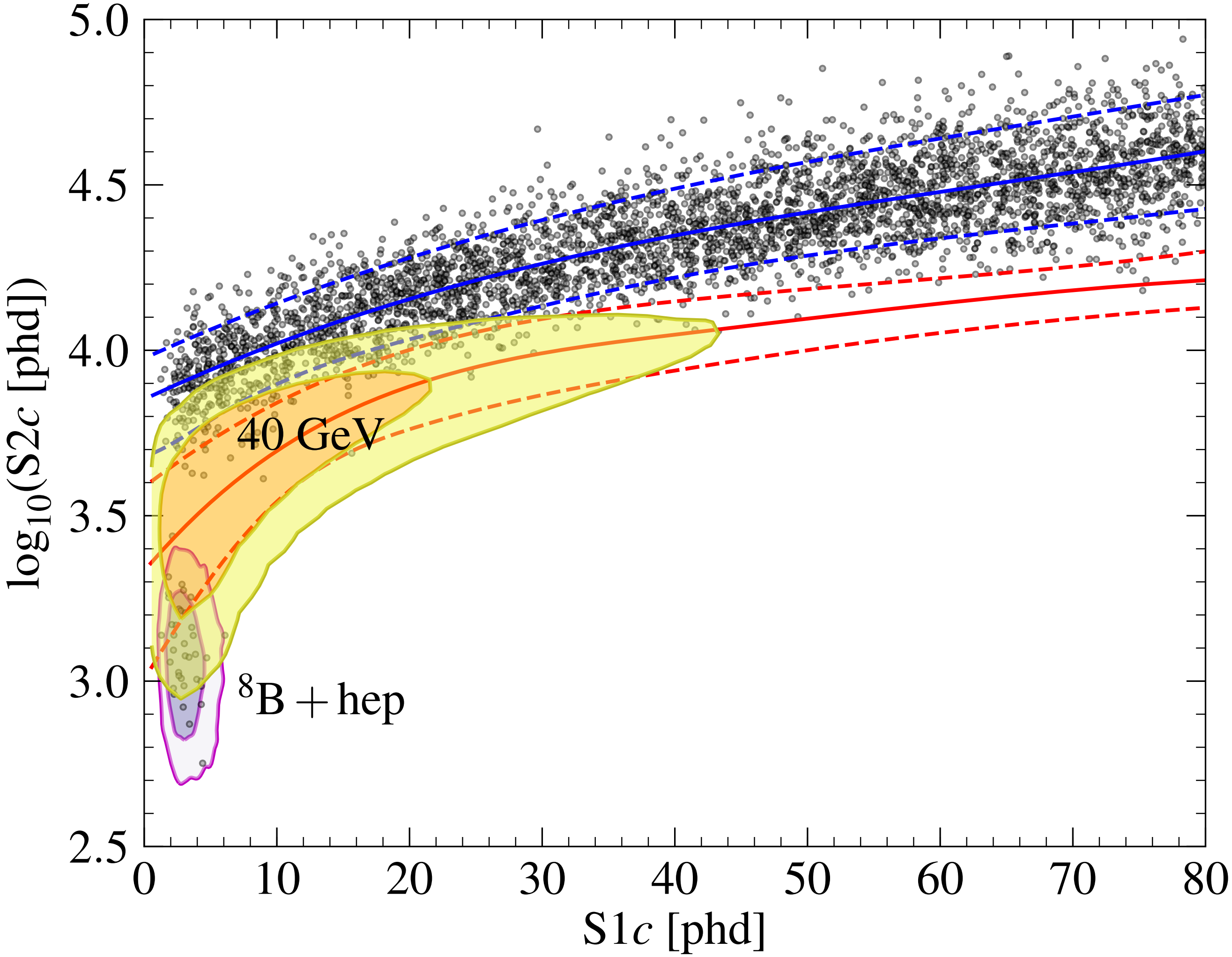
- Energy spectra of electron recoil background from various sources.
- ^{222}Rn dominates at low energies.
- Environmental background and components are not major sources of background events.

Event spectra: NRs



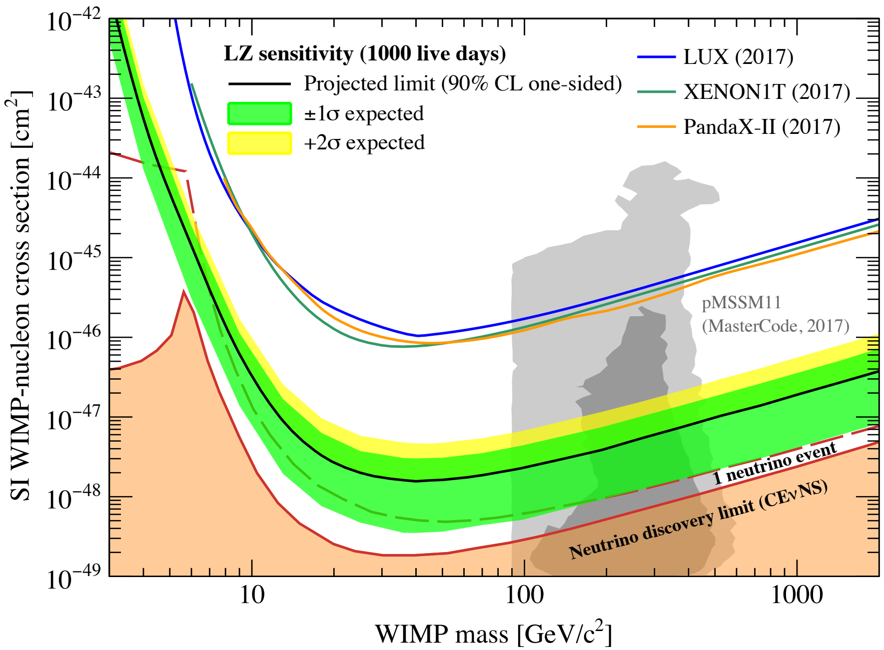
- Single scatter neutron recoil spectra before (left) and after (right) rejecting events coincident with veto systems.
- The background rate is dominated by ^{8}B solar neutrinos below 4 keV and atmospheric neutrinos above 4 keV (after cuts).
- Surface contamination (from radon daughters) is another contributor.

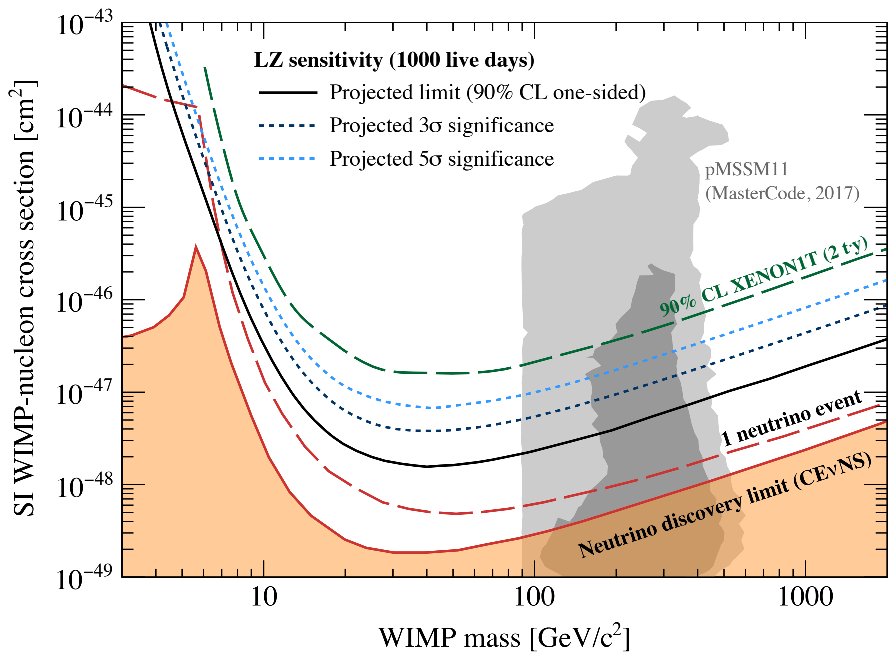
WIMPs, ^{8}B neutrinos and other backgrounds



- ^{8}B events will limit the sensitivity to low mass WIMPs.

Sensitivity to WIMPs





- Expected limits on spin-independent cross-sections for 1000 days of live time (left) and discovery potential (right).

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 two-phase xenon for searching for a very rare signal from dark matter WIMPs.
- The LZ experiment is replacing LUX at SURF and will be operational in 2020 with 7 tonnes of liquid xenon as a target material.
- The LZ is expected to reach the sensitivity of 1.6×10^{-48} cm^2 to spin-independent WIMP-nucleon cross-section and 2.7×10^{-43} cm^2 to spin-dependent WIMP-neutron cross-section.
- Other physics include search for axions and ALPs, extending WIMP search to masses below 5 GeV and search for neutrinoless double-beta decay.