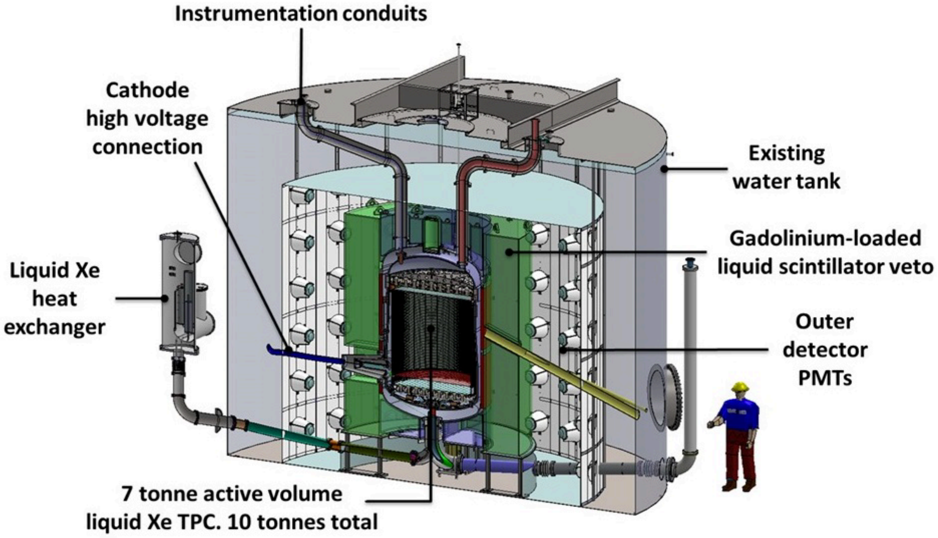
Neutron background in LZ

Vitaly A. Kudryavtsev
University of Sheffield, United Kingdom

for the LZ Collaboration

LZ experiment at SURF

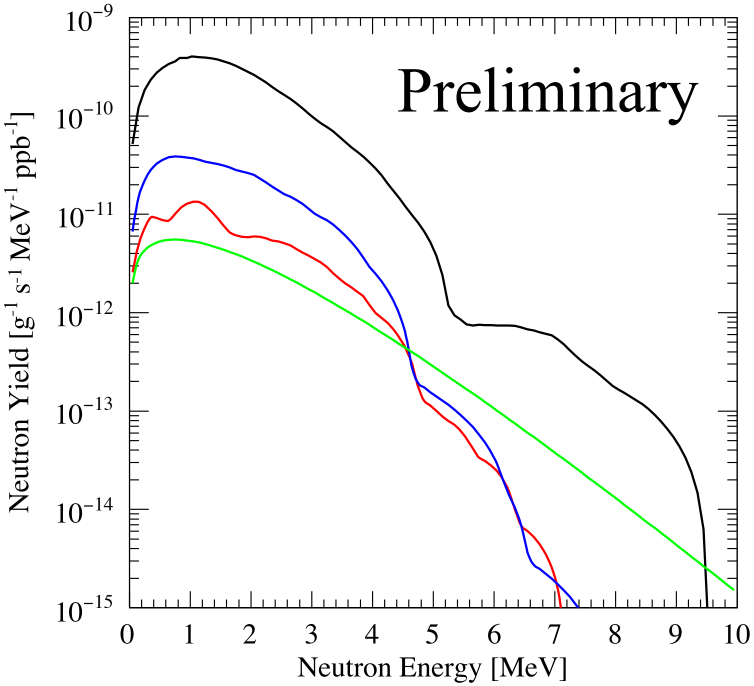
- Dual-phase xenon detector.
- 7 tonnes of active liquid xenon (LXe) in the time projection chamber (TPC).
- 2 tonnes of instrumented LXe skin – helps primarily with rejecting gamma background.
- 10 tonnes of LXe in total.
- Outer detector (OD) with Gd-loaded liquid scintillator – helps primarily with reducing neutron background.
- Located at about 1.5 km underground at Sanford Underground Research Facility (SURF), SD, USA.
- Collaboration of 37 institutions from the USA, UK, Portugal, Korea and Russia.



D. S. Akerib et al (LZ Collaboration). NIMA, 2019, to be published; arXiv: 1910.09124.
B. J. Mount et al. (LZ Collaboration). LZ TDR, arXiv: 1703.09144.

Simulation of neutrons

- Modified SOURCES4A
  - Extended alpha-range to 10 MeV.
  - 'New' cross-sections and excitation functions added (from EMPIRE2.19).
  - Can calculate both spontaneous fission (SF) and (α,n) reactions.
- W.B. Wilson, et al., SOURCES4A: a code for calculating (α,n), spontaneous fission, and delayed neutron sources and spectra, Technical Report LA-13639-MS, Los Alamos, 1999;
- Modifications explained in Tomasello et al. NIMA, 595 (2008) 431, and references therein.



Example spectra of neutrons from (α,n) reactions and SF in natural uranium decay chains (in equilibrium). Black – PTFE, Blue – ceramics (Al_2O_3), red – titanium, green – SF.

Simulation of neutrons

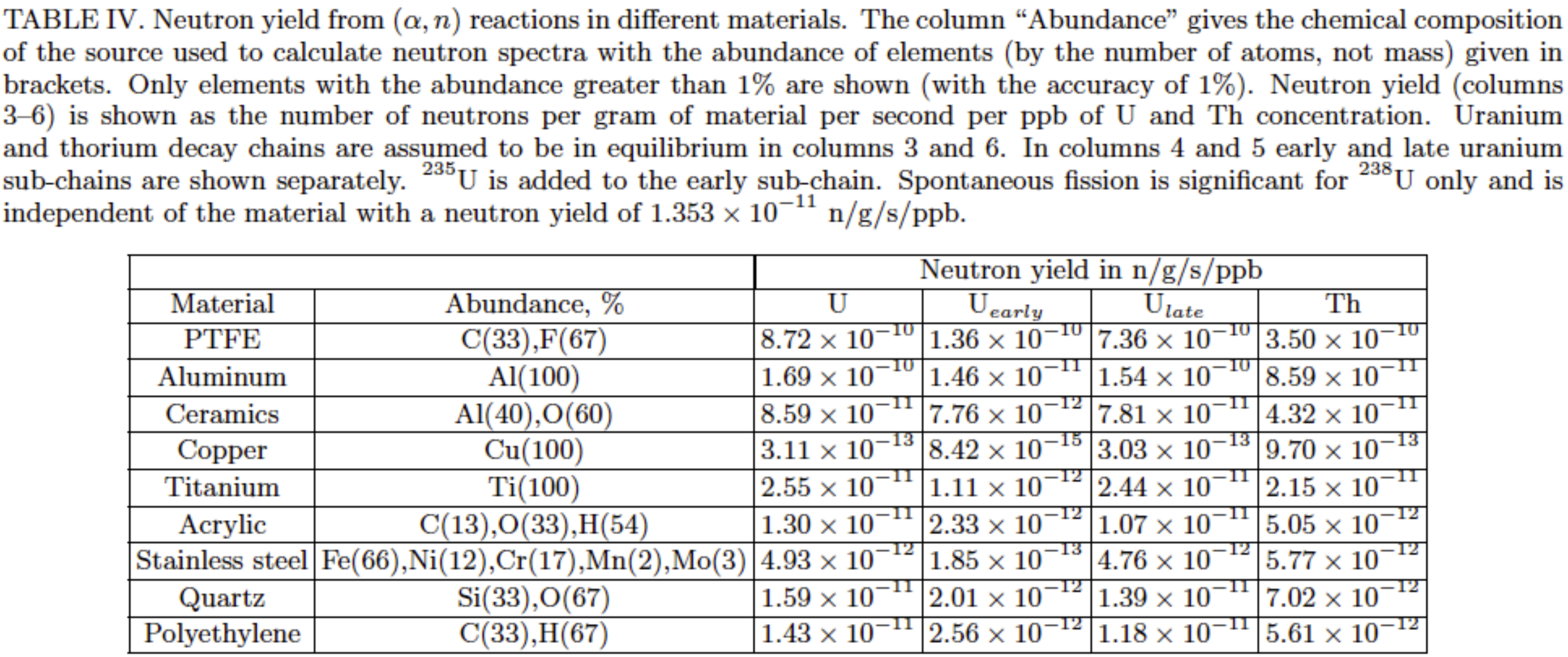


TABLE IV. Neutron yield from (α, n) reactions in different materials. The column "Abundance" gives the chemical composition of the source used to calculate neutron spectra with the abundance of elements (by the number of atoms, not mass) given in brackets. Only elements with the abundance greater than 1% are shown (with the accuracy of 1%). Neutron yield (columns 3–6) is shown as the number of neutrons per gram of material per second per ppb of U and Th concentration. Uranium and thorium decay chains are assumed to be in equilibrium in columns 3 and 6. In columns 4 and 5 early and late uranium sub-chains are shown separately. ^{235}U is added to the early sub-chain. Spontaneous fission is significant for ^{238}U only and is independent of the material with a neutron yield of 1.353×10^{-11} n/g/s/ppb.

		Neutron yield in n/g/s/ppb			
Material	Abundance, %	U	U_{early}	U_{late}	Th
PTFE	C(33),F(67)	8.72×10^{-10}	1.36×10^{-10}	7.36×10^{-10}	3.50×10^{-10}
Aluminum	Al(100)	1.69×10^{-10}	1.46×10^{-11}	1.54×10^{-10}	8.59×10^{-11}
Ceramics	Al(40),O(60)	8.59×10^{-11}	7.76×10^{-12}	7.81×10^{-11}	4.32×10^{-11}
Copper	Cu(100)	3.11×10^{-13}	8.42×10^{-15}	3.03×10^{-13}	9.70×10^{-13}
Titanium	Ti(100)	2.55×10^{-11}	1.11×10^{-12}	2.44×10^{-11}	2.15×10^{-11}
Acrylic	C(13),O(33),H(54)	1.30×10^{-11}	2.33×10^{-12}	1.07×10^{-11}	5.05×10^{-12}
Stainless steel	Fe(66),Ni(12),Cr(17),Mn(2),Mo(3)	4.93×10^{-12}	1.85×10^{-13}	4.76×10^{-12}	5.77×10^{-12}
Quartz	Si(33),O(67)	1.59×10^{-11}	2.01×10^{-12}	1.39×10^{-11}	7.02×10^{-12}
Polyethylene	C(33),H(67)	1.43×10^{-11}	2.56×10^{-12}	1.18×10^{-11}	5.61×10^{-12}

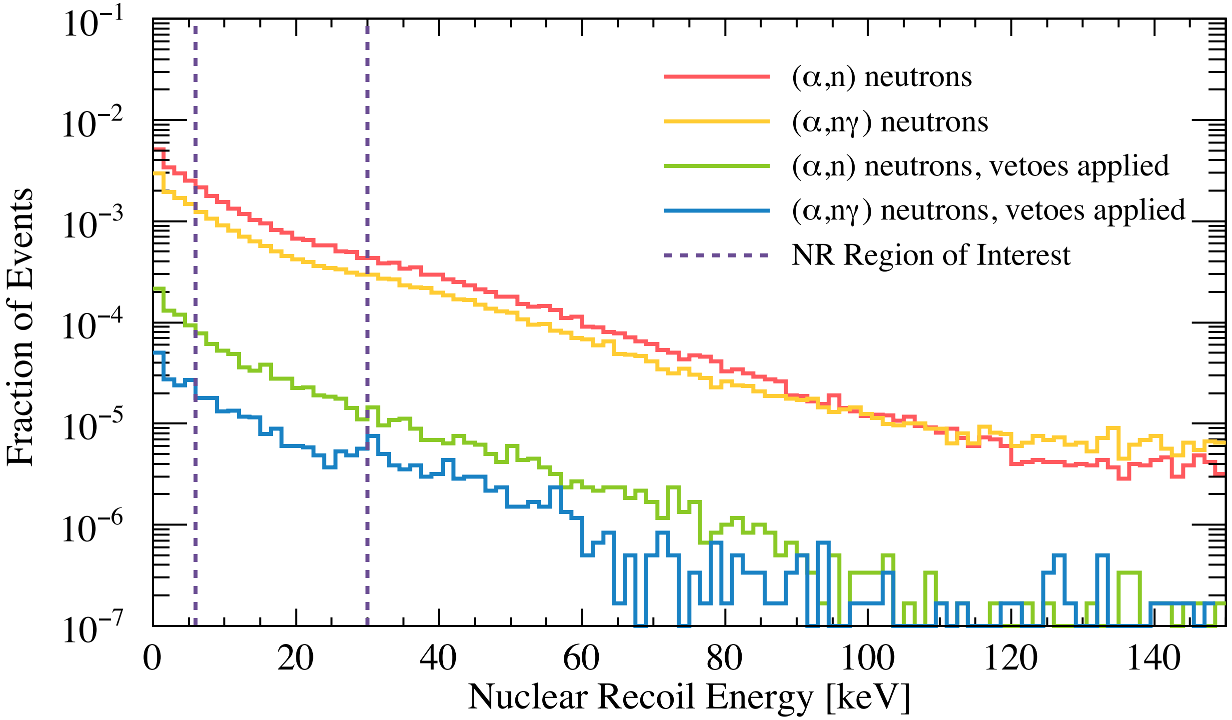
Preliminary; LZ Collaboration, "Simulation of events in the LUX_ZEPLIN (LZ) dark matter experiment", in preparation.

Spontaneous fission and (*α*,*n*) reactions

- SF contribution from (near) detector components removed at a later stage due to coincident gammas and neutrons
    - On average 2.01 neutrons from ^{238}U; Holden and Zucker, BNL-NCS-35513 (1984).
    - On average about 6 gammas; Valentine, Ann. Nucl. Eng. 28, 191 (2001).
    - Special code based on neutron and gammas multiplicities from FREYA; Verbeke et al. "Simulation of Neutron and Gamma Ray Emission from Fission and Photofission", LLNL, UCRL-AR-228518 (2014).
    - Suppression of single scatter events by a factor of 34 (from cryostat) and 55 (PMTs).
- (α,n) reactions: background reduction due to coincident gammas if the final state nucleus moves to the excited state.
    - Tested for PTFE (fluorine) – high neutron yield (per unit radioactivity) and large probability of transition to the excited state but low measured radioactivity.
    - Uses SOURCES4 for transition probabilities and neutron spectra associated with a particular transition.
    - Full model of a gamma cascade from each excited state of ^{22}Na.
    - Not a big effect overall due to low contamination of PTFE but important for testing capability of detecting coincident gammas.

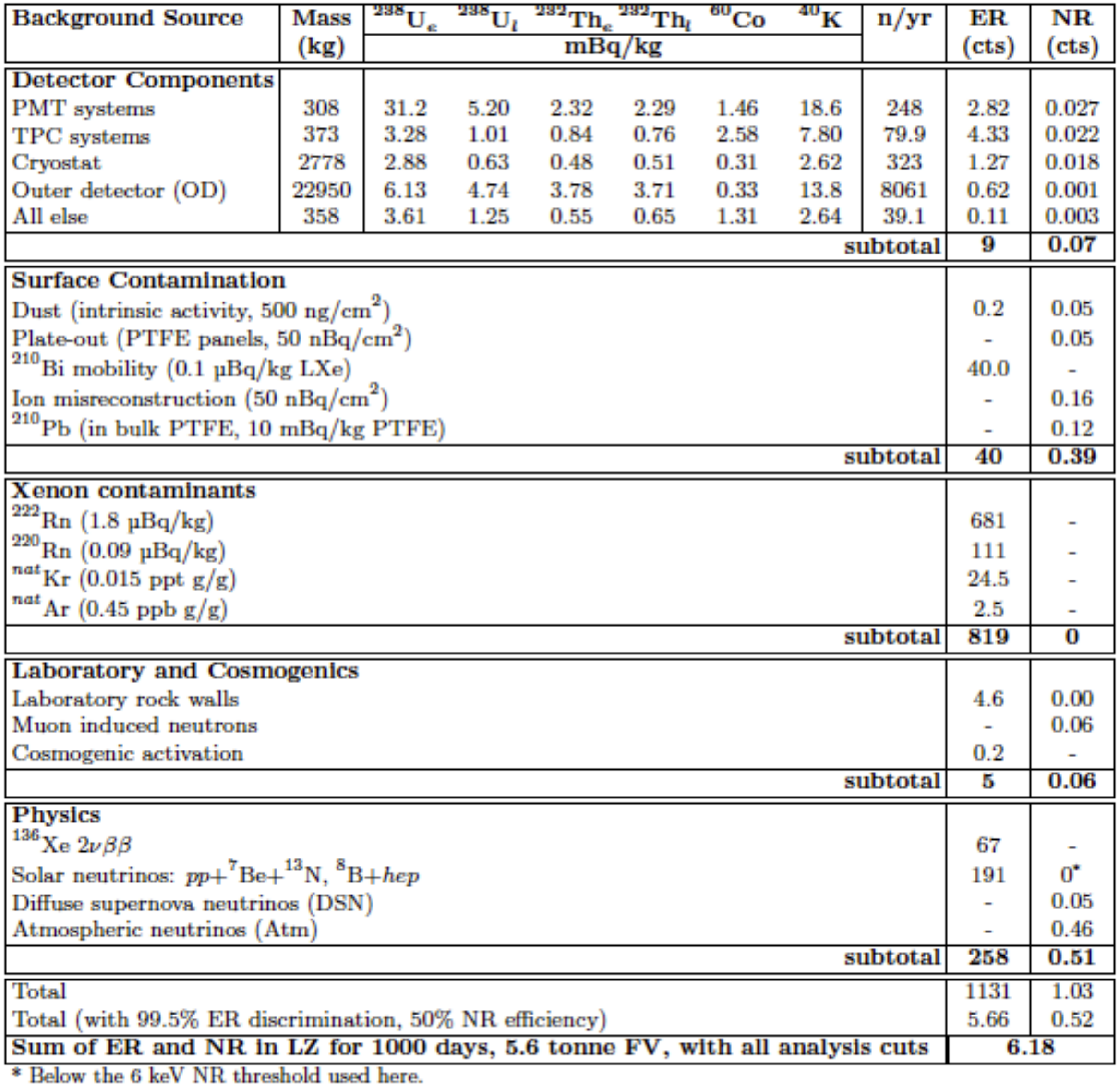
(*α*,*n*) reactions

Preliminary



Energy spectra of nuclear recoils in LZ produced by single scatter neutrons from (*α*,*n*) reactions in PTFE, before and after application of veto cuts. The red and green histograms use only neutrons from the two 'standard' generators, whilst the blue and yellow include coincident gamma-rays and correctly populated neutron groups.

Neutron background in LZ

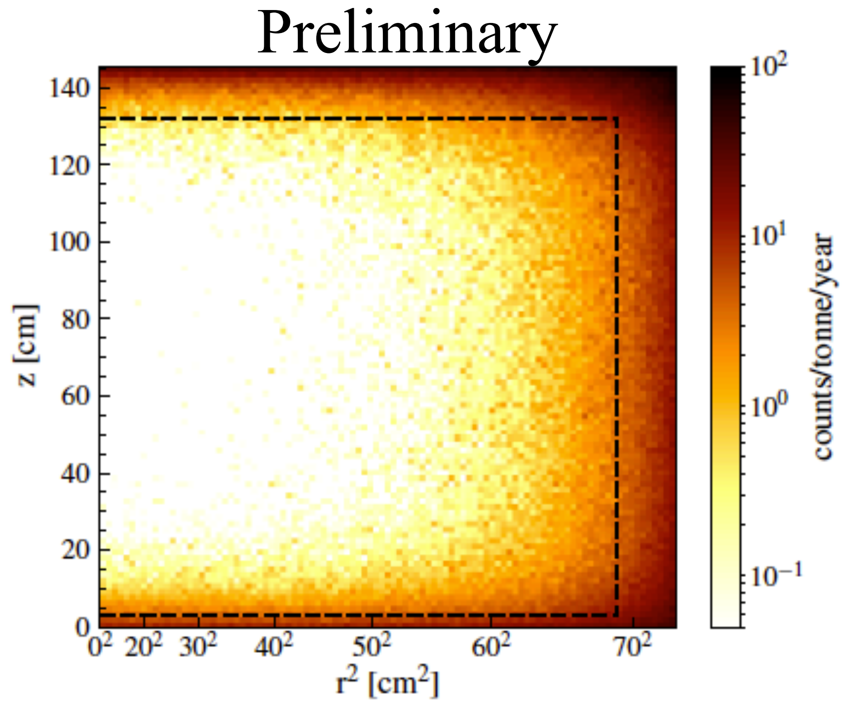


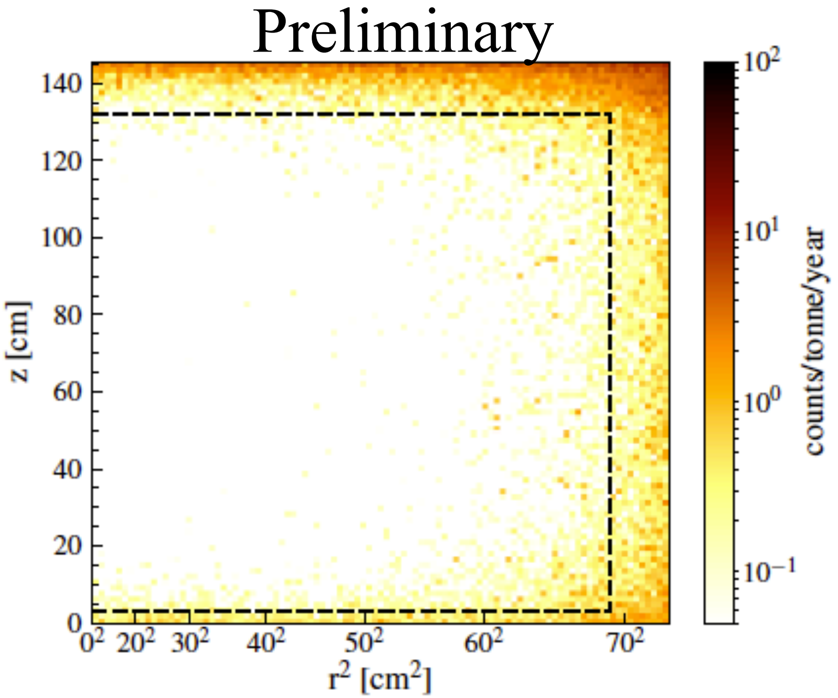
Background Source	Mass (kg)	^{238}U$_e$	^{238}U$_l$	^{232}Th$_e$	^{232}Th$_l$	^{60}Co	^{40}K	n/yr	ER (cts)	NR (cts)
		mBq/kg								
Detector Components										
PMT systems	308	31.2	5.20	2.32	2.29	1.46	18.6	248	2.82	0.027
TPC systems	373	3.28	1.01	0.84	0.76	2.58	7.80	79.9	4.33	0.022
Cryostat	2778	2.88	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 (1.8 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, ^{8}B+hep									191	0*
Diffuse supernova neutrinos (DSN)									-	0.05
Atmospheric neutrinos (Atm)									-	0.46
								subtotal	**258**	**0.51**
Total									1131	1.03
Total (with 99.5% ER discrimination, 50% NR efficiency)									5.66	0.52
Sum of ER and NR in LZ for 1000 days, 5.6 tonne FV, with all analysis cuts									**6.18**	

* Below the 6 keV NR threshold used here.

- 5.6 tonnes fiducial mass
- 1000 days of live time
- Region of interest for 40 GeV/c^2 WIMPs: 1.5-6.5 keV electron recoil energies; 6-30 keV nuclear recoil energies
- Single scatters
- No signal in the skin above 100 keV
- No signal in the OD above 200 keV (in the time window of 500 μs)
- D. S. Akerib et al. (LZ Collaboration), submitted to Phys. Rev. D, arXiv:1802.06039.

Effect of vetoes





- Spatial distribution of single scatter NR events at 6-30 keV.
- Left – before veto cuts (skin and the OD).
- Right – after veto cuts.
- Uniform distribution of NRs from solar neutrinos and sharply falling wall contribution (NRs from the surface of PTFE) are not included.
- Reduction from 10.4 down to 1.03 NRs in 1000 days.

Conclusions

- Robust predictions of neutron background based on validated codes.
- Events from SF in near detector components almost fully rejected due to high neutron and gamma multiplicities.
- Coincident gammas from (α,n) reactions may suppress the background event rate further (not included in the current background model but potential for background reduction). Simulations for PTFE suggest a factor of 5 reduction in NR background from PTFE.
- High efficiency of veto systems (skin and OD) helps with rejecting both gamma and neutron induced events.
- Sensitivity down to 1.4×10^{-12} pb to spin-independent WIMP-nucleon interactions for 40 GeV/c^2 WIMPs.