The LUX-ZEPLIN (LZ) Dark Matter Experiment

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(On behalf of the LZ collaboration)

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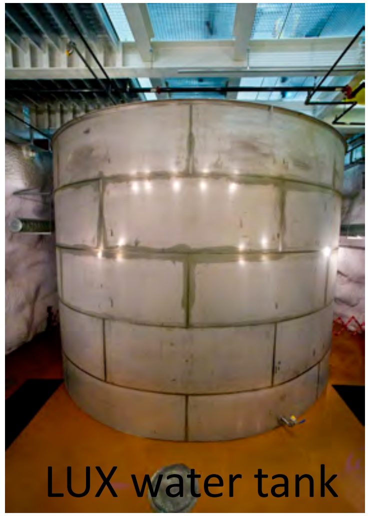
LZ collaboration

36 institutions
250 scientists, engineers, and technicians

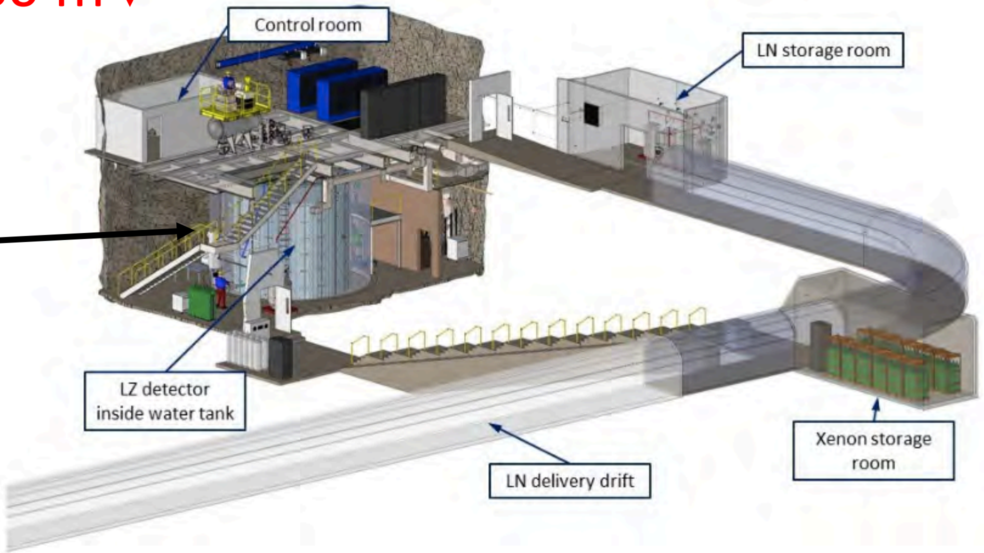
1) Center for Underground Physics (South Korea)
2) LIP Coimbra (Portugal)
3) MEPhI (Russia)
4) Imperial College London (UK)
5) STFC Rutherford Appleton Lab (UK)
6) University College London (UK)
7) University of Bristol (UK)
8) University of Edinburgh (UK)
9) University of Liverpool (UK)
10) University of Oxford (UK)
11) University of Sheffield (UK)
12) Black Hill State University (US)
13) Brookhaven National Lab (US)
14) Brown University (US)
15) Fermi National Accelerator Lab (US)
16) Lawrence Berkeley National Lab (US)
17) Lawrence Livermore National Lab (US)
18) Northwestern University (US)
19) Pennsylvania State University (US)
20) SLAC National Accelerator Lab (US)
21) South Dakota School of Mines and Technology (US)
22) South Dakota Science and Technology Authority (US)
23) Texas A&M University (US)
24) University at Albany (US)
25) University of Alabama (US)
26) University of California, Berkeley (US)
27) University of California, Davis (US)
28) University of California, Santa Barbara (US)
29) University of Maryland (US)
30) University of Massachusetts (US)
31) University of Michigan (US)
32) University of Rochester (US)
33) University of South Dakota (US)
34) University of Wisconsin – Madison (US)
35) Washington University in St. Louis (US)
36) Yale University (US)

Sanford Underground Research Facility in Lead, SD.

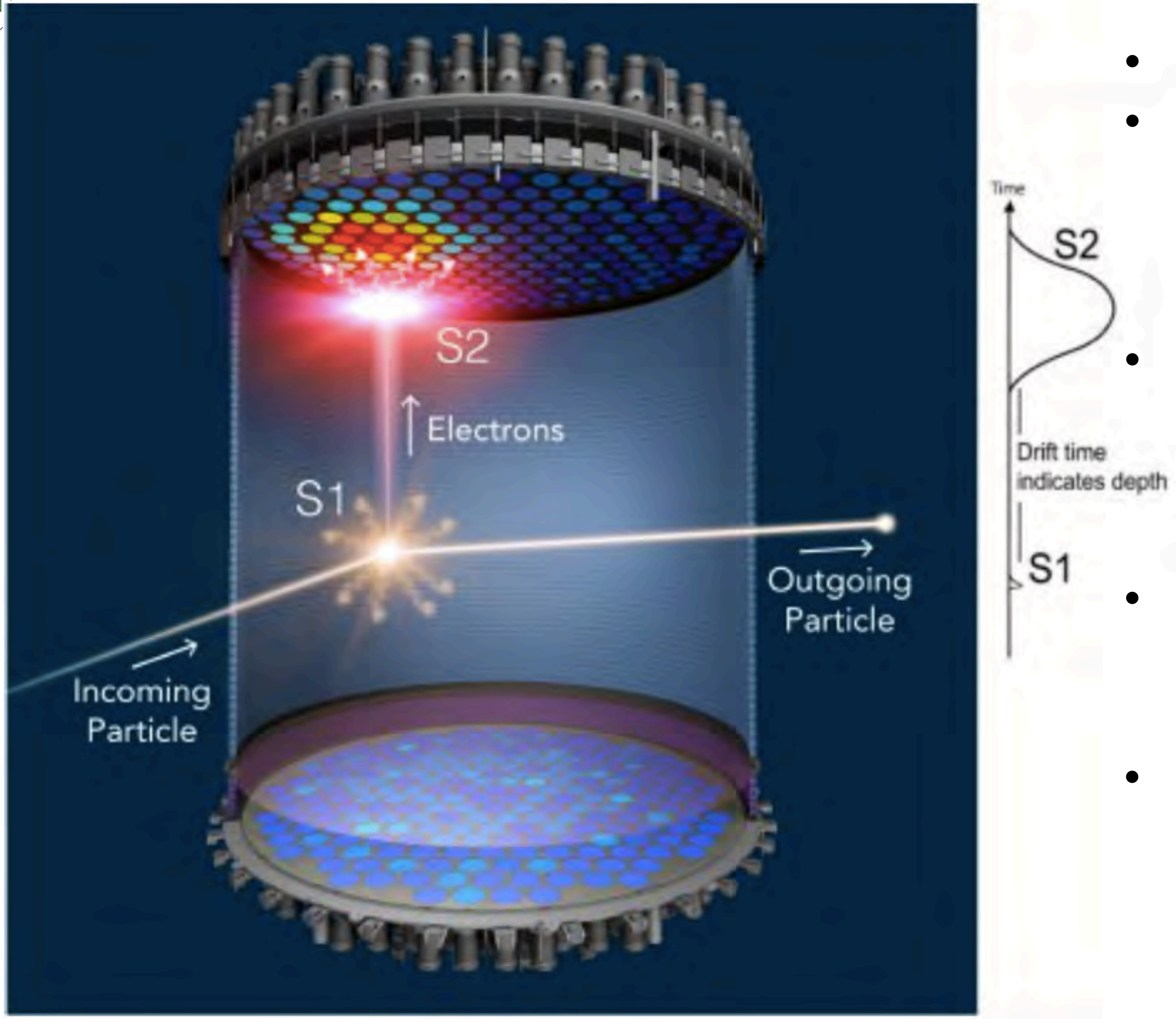
LUX decommissioned in the early 2017



Davis Cavern 1480 m (4200 mwe)

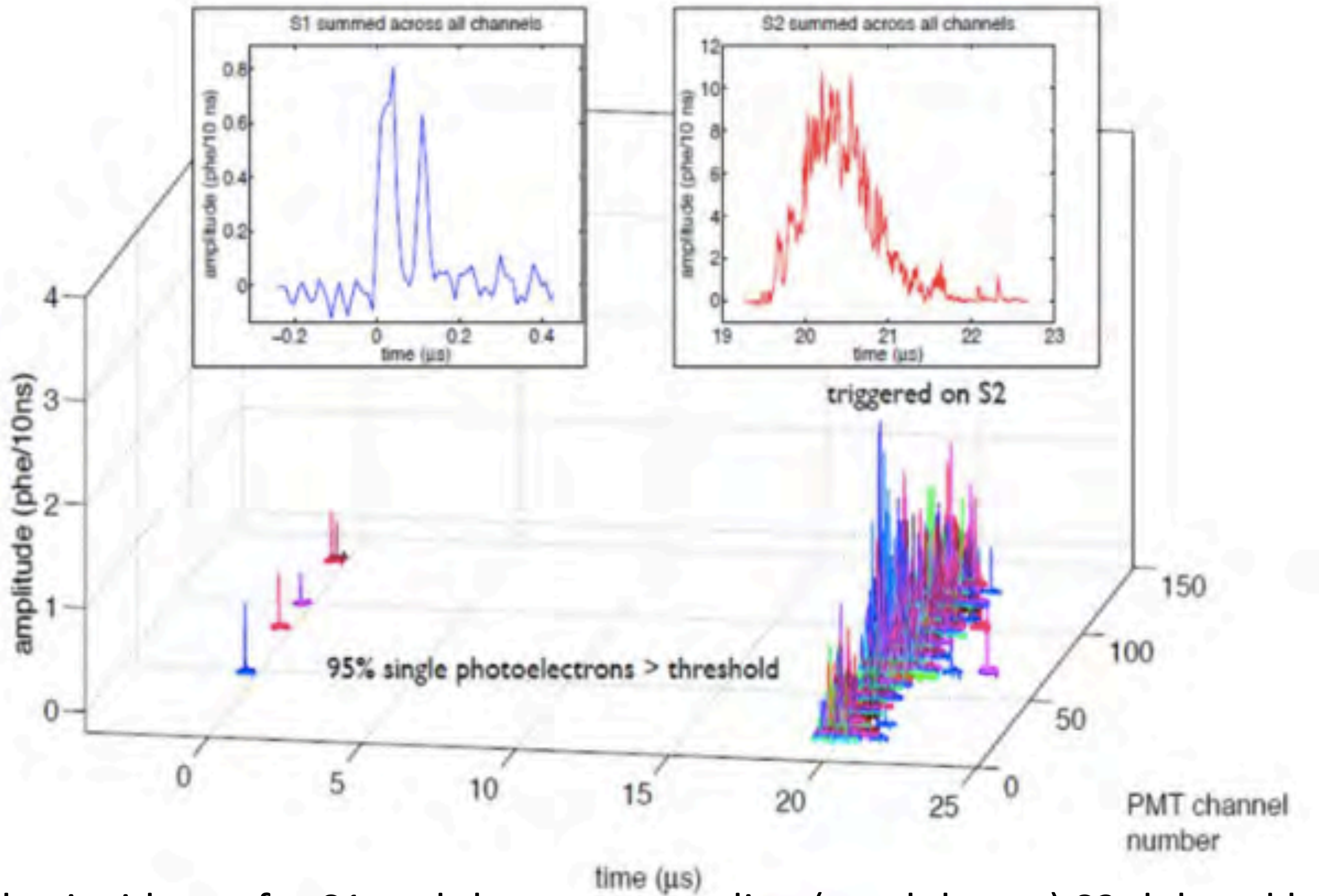


Two-phase liquid/gas Xenon(Xe) TPC



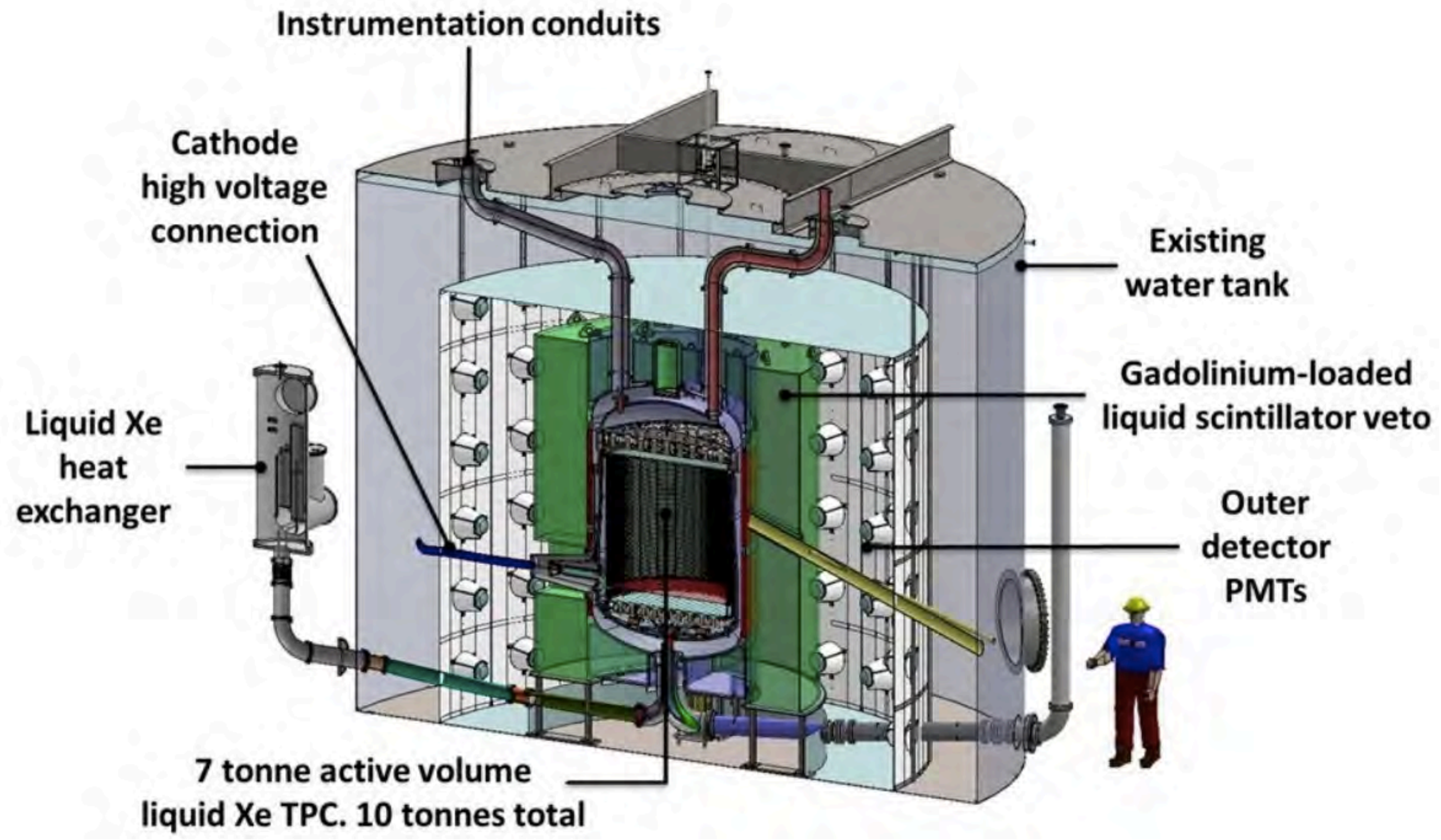
- **High purity Xe target**
- **S1: prompt scintillation signal**
  - Light yield: ~60ph/keV(electron recoil(ER))
  - Scintillation light: 178nm(VUV)
  - Nuclear recoil(NR) threshold ~5keV
- **S2: delayed ionization signal**
  - Electroluminescence in vapor phase
  - Sensitive to single ionization electrons
  - NR threshold~1keV
- **S1 + S2 event by event**
  - ER background rejection by ratio of charge(S2)/light(S1) (>99.5% rejection)
- **3D event reconstructions**
  - Z position from S1-S2 drift time
  - X-Y positions from S2 light pattern
  - reject external background

Two-phase Xe TPC Performance 1.5 keV Electron in LUX



A 5-fold coincidence for S1 and the corresponding (much larger) S2 delayed by 20 µs

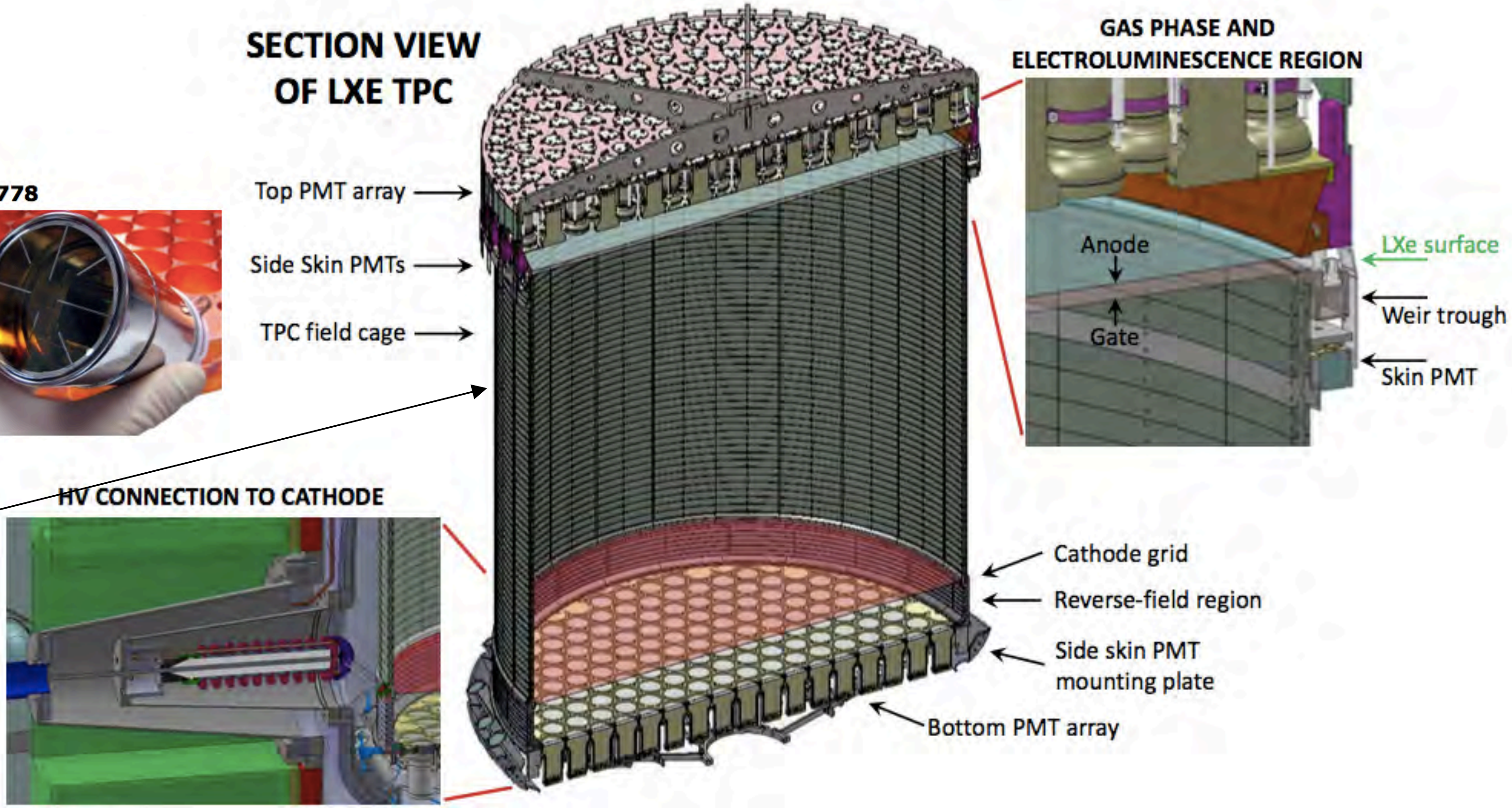
LZ Detector Overview



LZ TPC

PMT

Ti vessel



- 7 tonnes active liquid Xe mass
- 1.5 m diameter/length
- 247 (top) and 241 (bottom) 3-inch PMTs
- Highly reflective PTFE field cage
- 100kV cathode HV

Performance Drivers

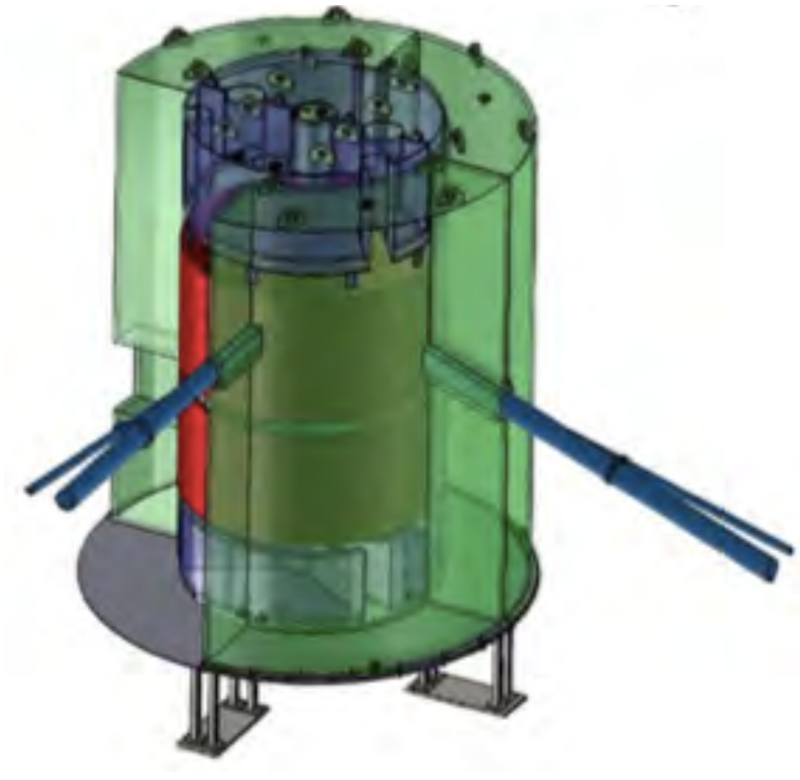
Detector Parameter	Reduced	Baseline	Goal
Light collection (PDE)	0.05	0.075	0.12
Drift field (V/cm)	160	310	650
Electron lifetime (μs)	850	850	2800
PMT phe detection	0.8	0.9	1.0
N-fold trigger coincidence	4	3	2
^{222}Rn (mBq in active region)	13.4	13.4	0.67
Live days	1000	1000	1000

- 5.8 keVnr S1 threshold
- 0.31 kV/cm drift field, 99.5% ER/NR discrimination efficiency

Outer Detector (OD)

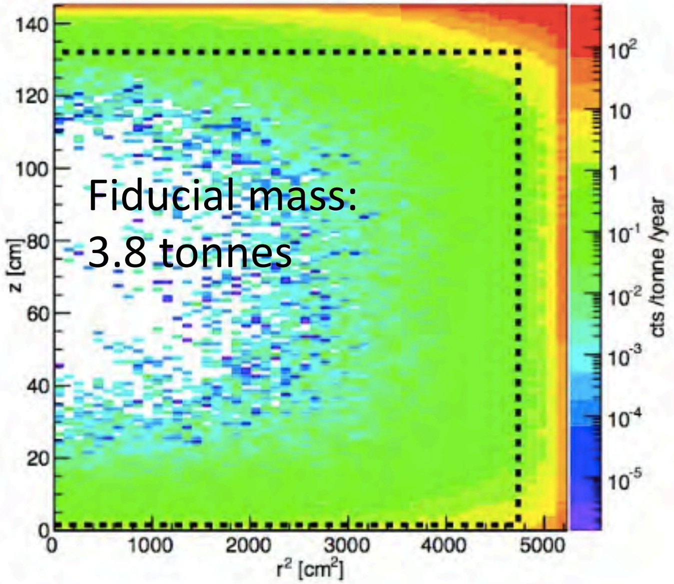
- High veto efficiency for neutron and gamma backgrounds
- Hermetic measurement of penetrating backgrounds

- Liquid Xe skin scintillation: 4-8 cm (walls), ~20 cm (dome)
- Gd-loaded liquid scintillator (linear alkylbenzene(LAB)): 60 cm, 21.5 tonnes

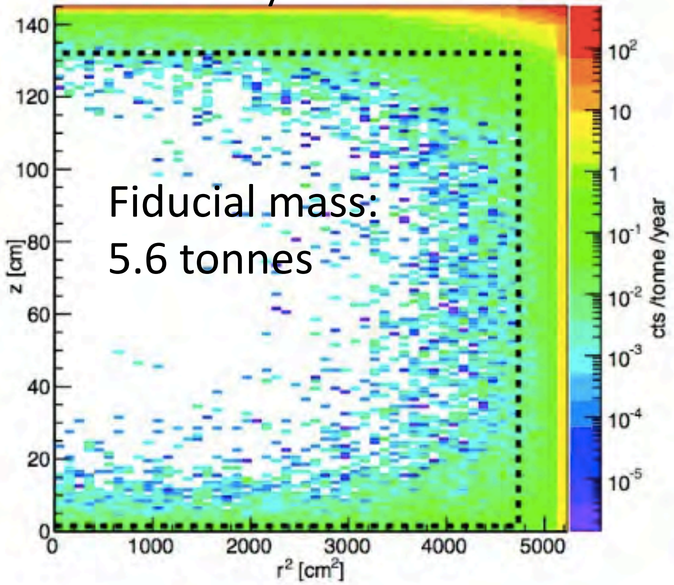


Outer detector

Single NR scatter in TPC



Vetoed by Gd-LS and Skin



- Increases effective fiducial mass from 3.8 to 5.6 tonnes
- Internal backgrounds(Kr, Rn and neutrino-induced) now dominate

Backgrounds Control

- Assay and assess all candidate detector materials and components with many dedicated screening facilities prior to adoption

- Assay techniques:
  - gamma spectroscopy
  - mass spectroscopy
  - neutron activation analysis(NAA)
  - radon emanation counting
  - alpha spectroscopy

Background table

Detector components · *Xenon contaminants* · *Environment, cosmogenic, surface contamination* · *Physics backgrounds*

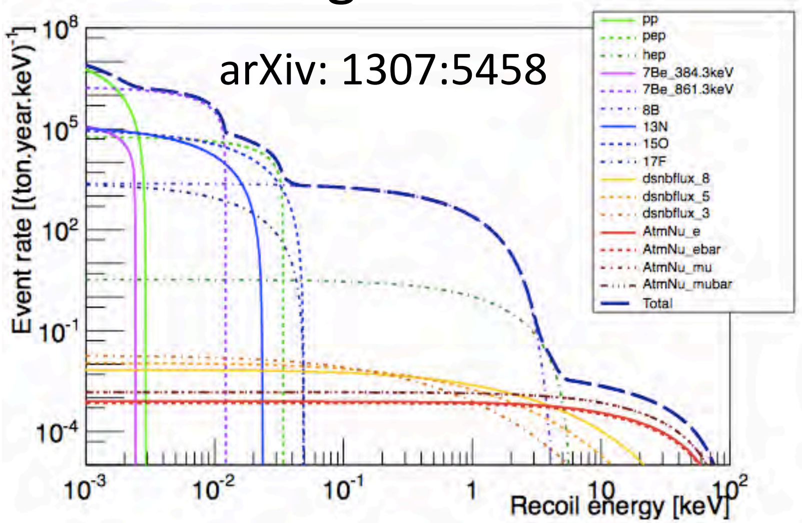
Intrinsic Contamination Backgrounds	Mass (kg)	U early (mBq/kg)	U late (mBq/kg)	Th early (mBq/kg)	Th late (mBq/kg)	Co60 (mBq/kg)	K40 (mBq/kg)	ER (cts)	NR (cts) (w/ SF rej.)
Upper PMT Structure	46.7	5.25	0.80	1.07	0.72	0.03	3.77	0.14	0.001
Lower PMT Structure	71.7	2.69	0.24	0.42	0.30	0.00	1.36	0.08	0.001
R11410 3" PMTs	91.9	71.63	3.20	3.12	2.99	2.82	15.41	1.46	0.013
R11410 PMT Bases	2.8	287.74	75.80	28.36	27.93	1.43	69.39	0.36	0.004
R8778 2" PMTs	6.1	137.50	59.38	16.88	16.88	16.25	412.50	0.13	0.008
R8520 Skin 1" PMTs	2.2	60.50	5.19	4.75	4.75	24.20	332.76	0.02	0.001
R8520 Skin PMT Bases	0.2	212.95	108.46	42.19	37.62	2.23	123.61	0.00	0.000
PMT Cabling	104.2	30.13	1.55	3.32	3.15	0.65	33.12	1.45	0.001
TPC PTFE	184.0	0.02	0.02	0.03	0.03	0.00	0.12	0.06	0.008
Grid Wires	0.18	1.20	0.27	0.33	0.49	1.60	0.40	0.00	0.000
Grid Holders	92.3	2.86	0.83	0.94	0.82	1.42	2.82	0.97	0.008
Field Shaping Rings	92.5	5.49	0.13	0.32	0.26	0.00	0.71	0.27	0.004
TPC Sensors	1.32	22.40	6.94	11.38	9.57	0.35	19.44	0.01	0.002
TPC Thermometers	0.08	335.50	90.46	38.48	25.02	7.26	3,359	0.06	0.000
Xe Recirculation Tubing	15.1	0.79	0.18	0.23	0.33	1.05	0.30	0.00	0.000
HV Conduits and Cables	137.7	2.0	2.0	0.4	0.6	1.4	1.2	0.04	0.001
HX and PMT Conduits	199.6	3.36	0.48	0.48	0.58	1.24	1.47	0.05	0.001
Cryostat Vessel	2409.6	1.70	0.14	0.30	0.25	0.10	0.64	0.72	0.014
Cryostat Seals	33.7	73.91	26.22	3.22	4.24	10.03	69.12	0.45	0.002
Cryostat Insulation	23.8	18.91	18.91	3.45	3.45	1.97	51.65	0.43	0.007
Cryostat Teflon Liner	26.0	0.02	0.02	0.03	0.03	0.00	0.12	0.00	0.000
Outer Detector Tanks	3199.3	0.16	0.39	0.02	0.06	0.04	5.36	0.45	0.001
Liquid Scintillator	17640.3	0.01	0.01	0.01	0.01	0.00	0.00	0.03	0.000
Outer Detector PMTs	204.7	570	470	395	388	0.00	534	0.01	0.000
Outer Detector PMT Supports	770.0	12.35	12.35	4.07	4.07	9.62	9.29	0.00	0.000
Subtotal (Detector Components)								**7.18**	**0.077**
222Rn (1.65 μBq/kg)								597	-
220Rn (0.08 μBq/kg)								101	-
natKr (0.015 ppt g/g)								24.5	-
natAr (0.45 ppb g/g)								2.47	-
210Bi (0.1 μBq/kg)								40.0	-
Laboratory and Cosmogenics								4.3	0.06
Fixed Surface Contamination								0.19	0.37
Subtotal (Non-ν counts)								**776**	**0.50**
Physics Backgrounds									
136Xe 2νββ								67	0
Astrophysical ν counts (pp+7Be+13N)								255	0
Astrophysical ν counts (8B)								0	0
Astrophysical ν counts (Hep)								0	0.21
Astrophysical ν counts (diffuse supernova)								0	0.05
Astrophysical ν counts (atmospheric)								0	0.46
Subtotal (Physics backgrounds)								322	0.72
Total								1,100	1.22
Total (with 99.5% ER discrimination, 50% NR efficiency)								[illegible]	[illegible]
								6.10	

Internal Backgrounds

Rn, Kr and neutrinos induced backgrounds dominate after applying vetoes

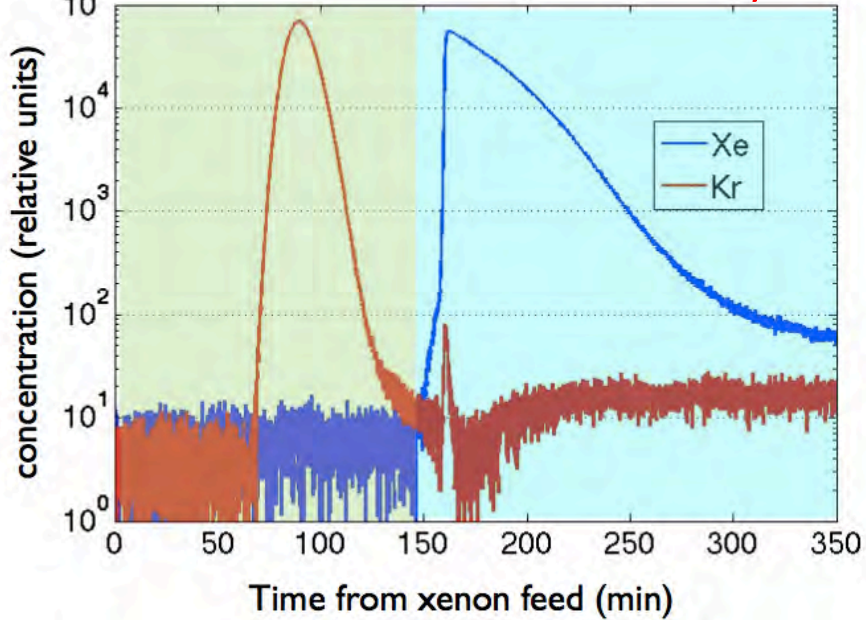
- Rn:
  - Measure Rn emanation rate for most materials/parts
  - 4 emanation systems with ~0.1 mBq sensitivity
  - Main assembly laboratory at SURF will have reduced radon air system
- Kr: Remove Kr to <15 ppq using gas chromatography
- Neutrino-induced backgrounds


UA Rn emanation system



Neutrino-induced NR spectra for a Xe target

Test data of the LUX Kr removal system



Calibration for LZ

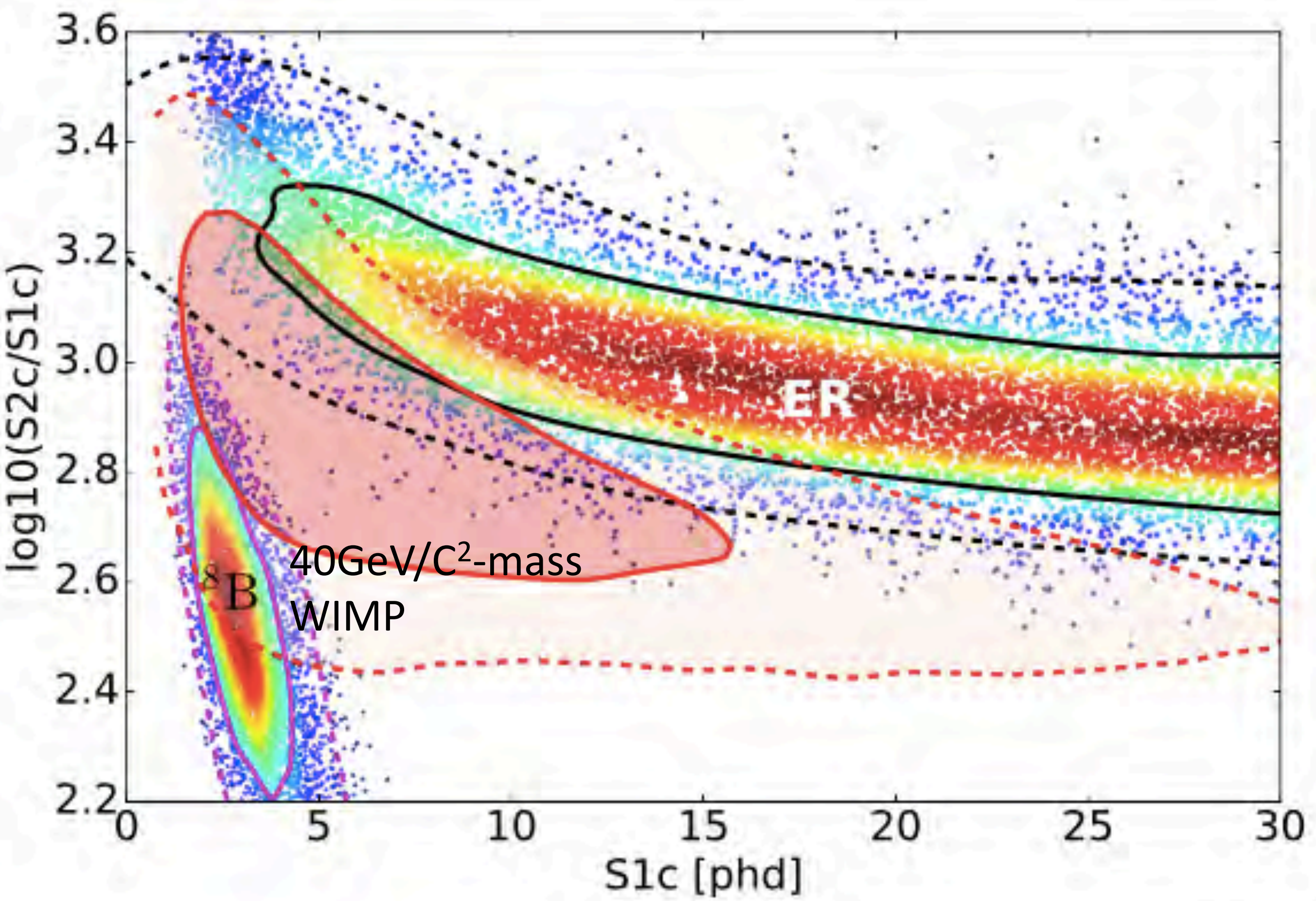
Isotope	What	Purpose	Deployment
Tritium	beta, Q = 18.6 keV	ER band	Internal
^{83m}Kr	beta/gamma, 32.1 keV and 9.4 keV	TPC (x, y, z)	Internal
^{131m}Xe	164 keV γ	TPC (x, y, z), Xe skin	Internal
^{220}Rn	various α's	xenon skin	Internal
AmLi	(α, n)	NR band	CSD*
^{252}Cf	spontaneous fission	NR efficiency	CSD
^{57}Co	122 keV γ	Xe skin threshold	CSD
^{228}Th	2.615 MeV γ, various others	OD energy scale	CSD
^{22}Na	back-to-back 511 keV γ's	TPC and OD sync	CSD
^{88}Y Be	152 keV neutron	low-energy NR response	External
^{205}Bi Be	88.5 keV neutron	low-energy NR response	External
^{206}Bi Be	47 keV neutron	low-energy NR response	External
DD	2,450 keV neutron	NR light and charge yields	External
DD	272 keV neutron	NR light and charge yields	External

*Calibration source deployment

LZ Detector Key Points

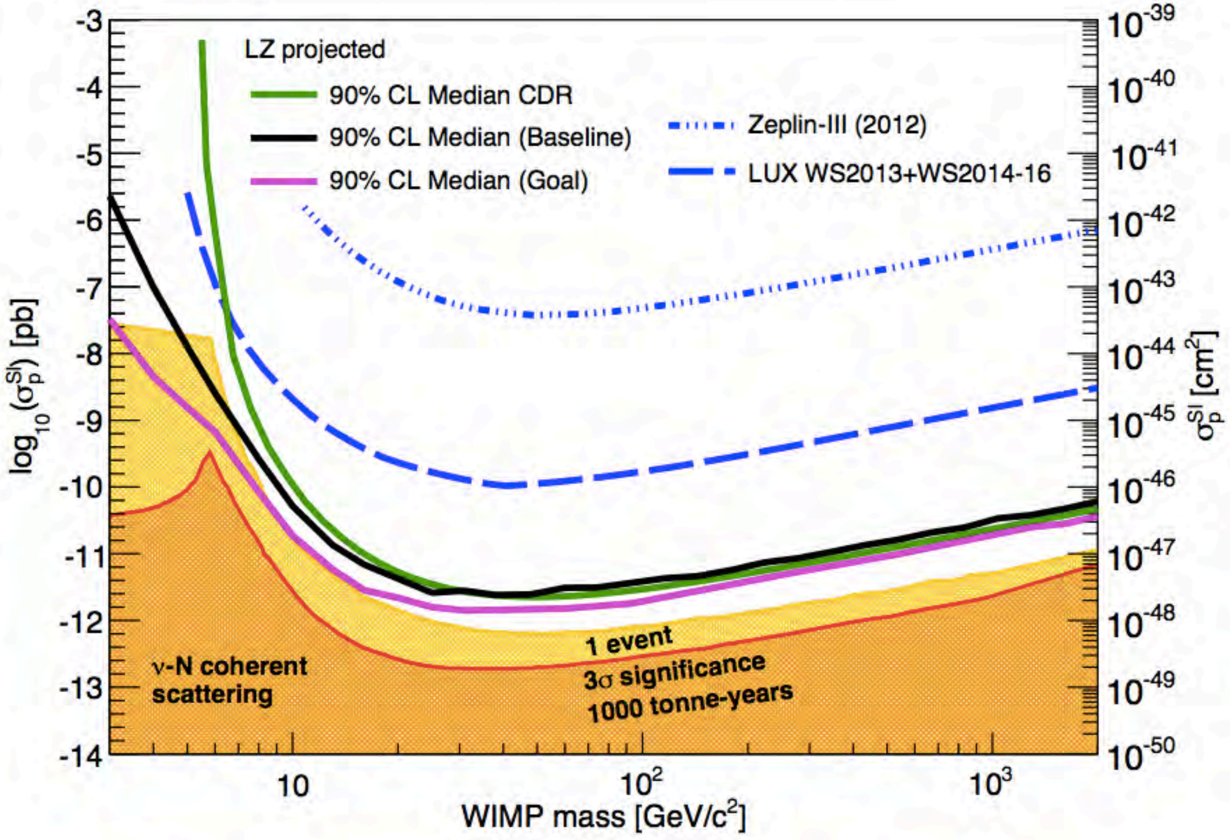
- Two-phase liquid/gas Xe TPC is utilized with good light collection and background rejection with ER discrimination.
- 7 tonnes active of liquid Xe can achieve WIMP-nucleon spin-independent cross section of 2.3×10^{-48} cm^2 for a 40 GeV/c^2 WIMP mass with 1,000 live days and 5.6 tonnes fiducial mass.
- Veto system (skin PMTs + scintillator + water tank) increases reliability of background measurements and allows maximum fiducial volume.
- Both internal (within LXe) and external backgrounds from the detector components and environment need to be well controlled.
- The LZ calibration strategy is ready to address the widest possible range of predicted dark-matter signatures.

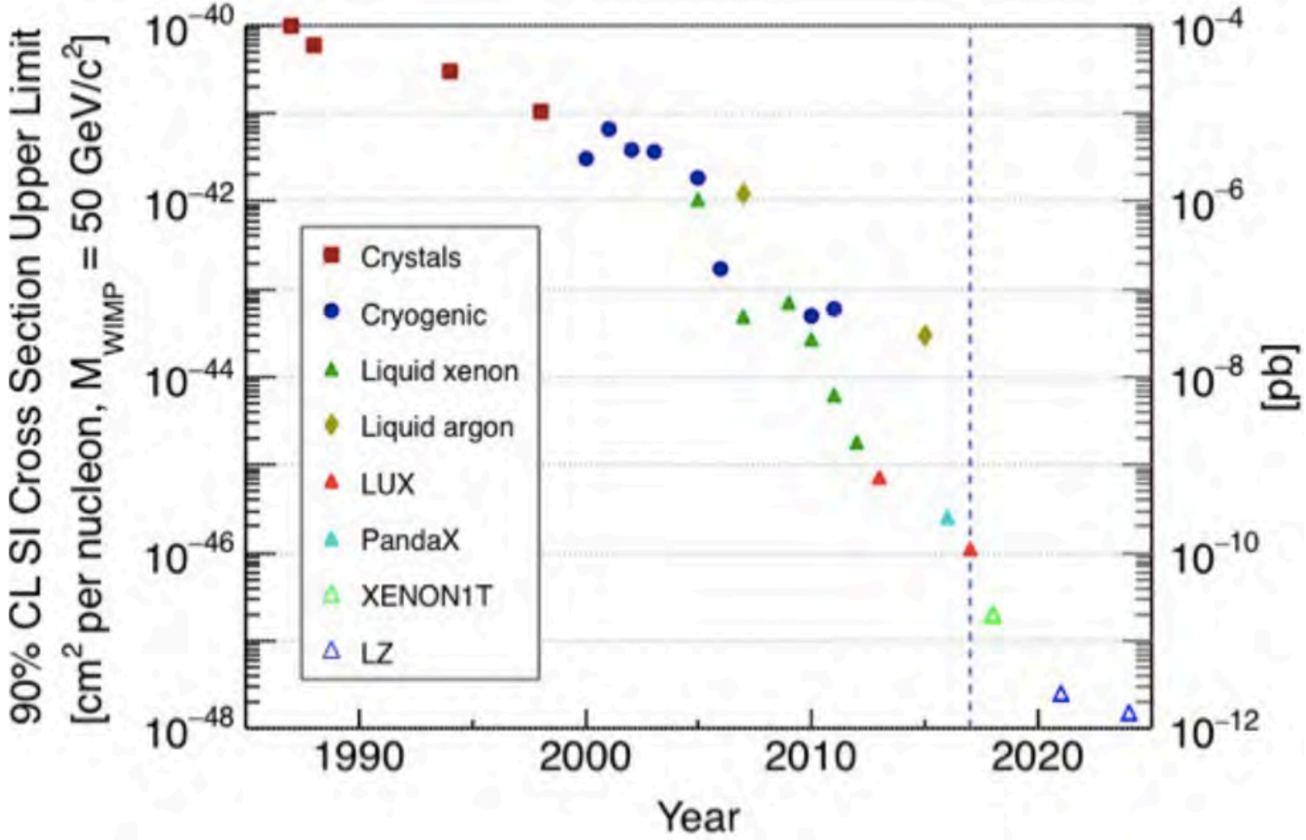
Simulation of NR/ER backgrounds



Simulations of the most prominent ER and NR (from 8B) backgrounds are plotted in the log10(S2c/S1c)-S1c plane. **The statistics shown represent 5x the expected ER background and 500x the expected NR background in the nominal LZ exposure**. The red tinted area shows the expectation for events from a 40 GeV/c 2 -mass WIMP, falling between the two background populations with the region enclosed by the solid(dashed) line representing the 1 σ(2 σ) band.

Projected Sensitivity and Time Evolution





Timeline

Year	Month	Milestone
2012	March	LUX-ZEPLIN (LZ collaboration formed)
2012	September	DOE CD-0 for G2 dark matter experiments
2013	November	R&D report submitted
2014	July	LZ dark matter experiment selected in US and UK. Begin long-lead procurements (Xe, PMT, cryostat)
2015	April	DOE CD-1/3a approval Conceptual design report: arXiv:1509.02910
2016	April	DOE CD-2/3b approval Technical design report: arXiv: 1703.09144
2017	June	Begin preparations for surface assembly at SURF
2018	July	Begin underground installation
2019		Begin commissioning

Summary

- LZ dark matter experiment proceeds on schedule
- Long lead-time item procurement underway: Xenon, PMTs, Cryostat vessel, etc.
- Materials screening programme well underway
- LZ benefits from LUX calibration techniques and understanding of backgrounds
- WIMP sensitivity 2.3×10^{-48} cm^2 for a 40 GeV/c^2 WIMP mass with 1,000 live days and 5.6 tonnes fiducial mass