The LZ Dark Matter Experiment

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(for the LZ Collaboration)

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The LZ Collaboration

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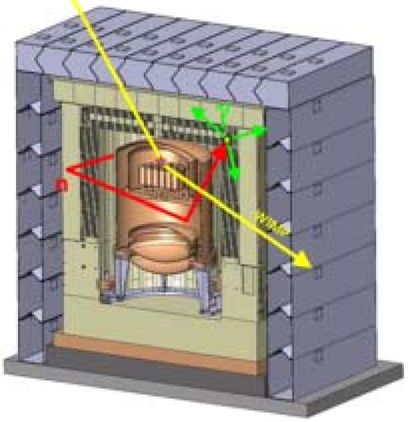
36 institutions; about 250 scientists, engineers, and technicians

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)

LZ = LUX + ZEPLIN

ZEPLIN-III

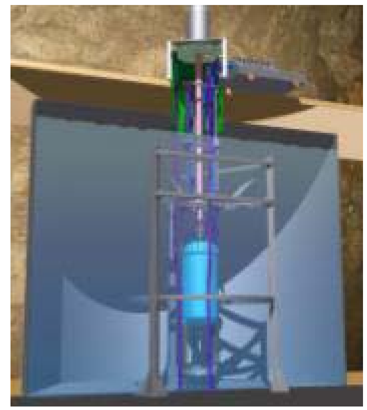


6 kg LXe fid

ZEPLIN pioneered WIMP-search with 2-phase Xe
3.9×10^{-44} cm^2

+

LUX

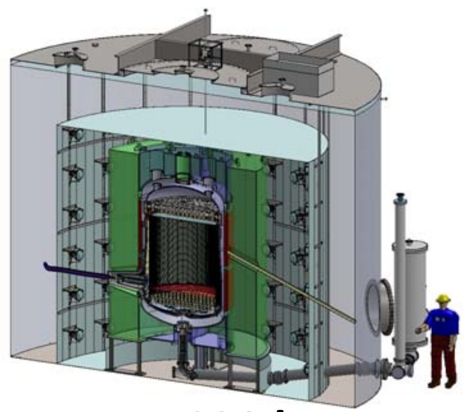


100 kg

1.1×10^{-46} cm^2 at 50 GeV/c^2 (decommissioned in early 2017)

LZ

→



5,600 kg

Scale-up using demonstrated technology and experience for low-risk but aggressive program:

- internal background-free strategy
- some infrastructure inherited from LUX
- **LZ expected sensitivity: 2.3×10^{-48} cm^2 with 3-yr run**

Sanford Underground Research Facility

Davis Cavern 1480 m
(4200 mwe)
LZ in LUX Water Tank
South Dakota, USA

LZ Here

Scale up ≈ 50 in Fiducial Mass

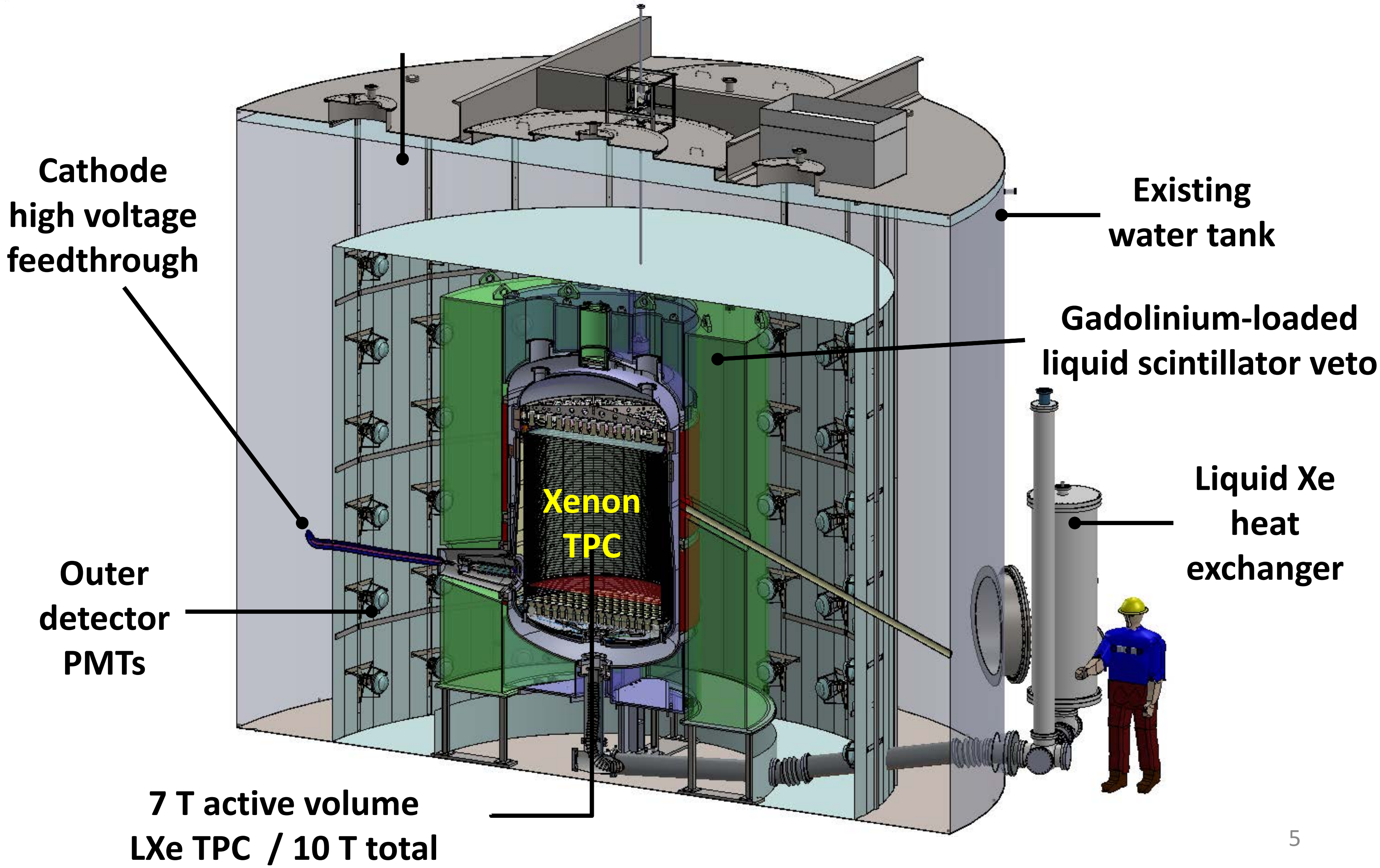
LZ

Total mass – 10 T
WIMP Active Mass – 7 T
WIMP Fiducial Mass – 5.6 T

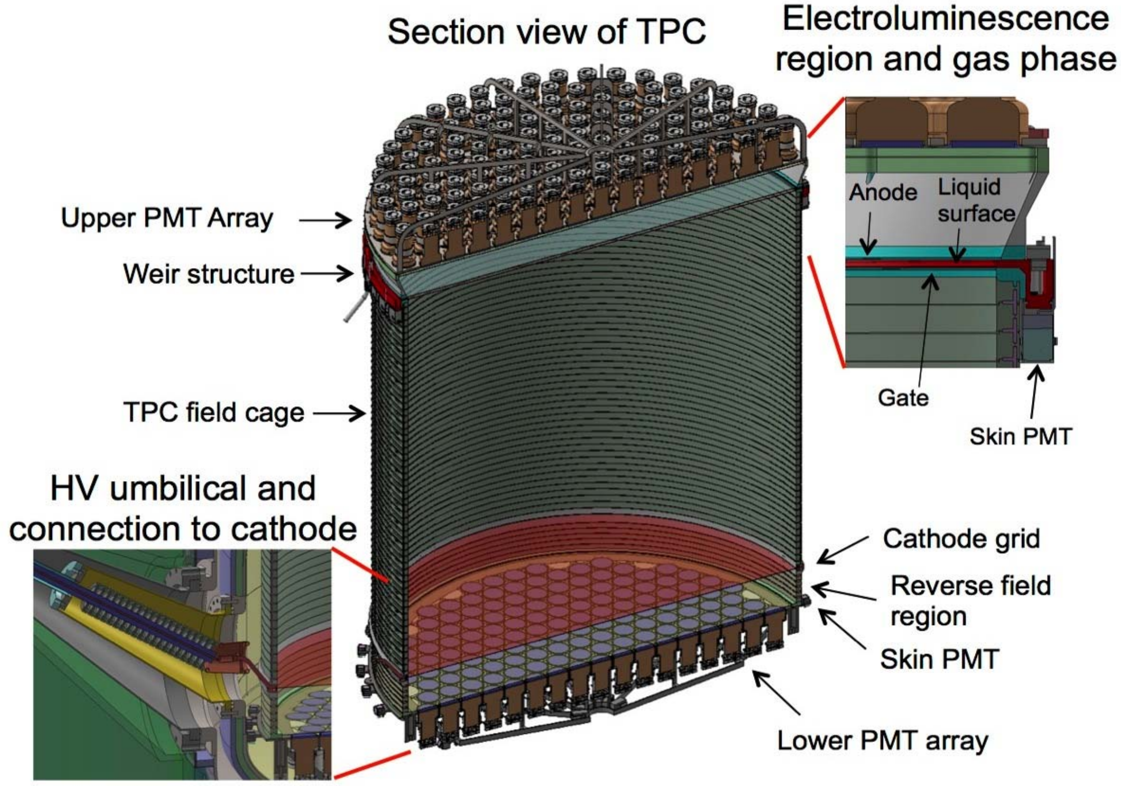
LUX

+ maintain background-free, low-energy response

LZ Detector Overview



Dual-phase liquid xenon TPC



- 7 T active LXe mass, 146 cm diameter, 146 cm length
- 488 PMTs (247 top, 241 bot) 3” R11410 PMTs (activity ~mBq; high QE)
- TPC lined with high-reflectivity PTFE ($R_{PTFE} \geq 95\%$)
- instrumented “Skin” region optically separated from TPC (180 PMT)

Background Reduction: key design points

- Photomultipliers of ultra-low natural radioactivity
- Low background titanium cryostat
- LUX water shield and an added Gadolinium-loaded liquid scintillator active veto
- Instrumented “skin” region of peripheral xenon as another veto system
- Radon suppression during construction, assembly and operations
- Ultra-low levels of Kr in Xe

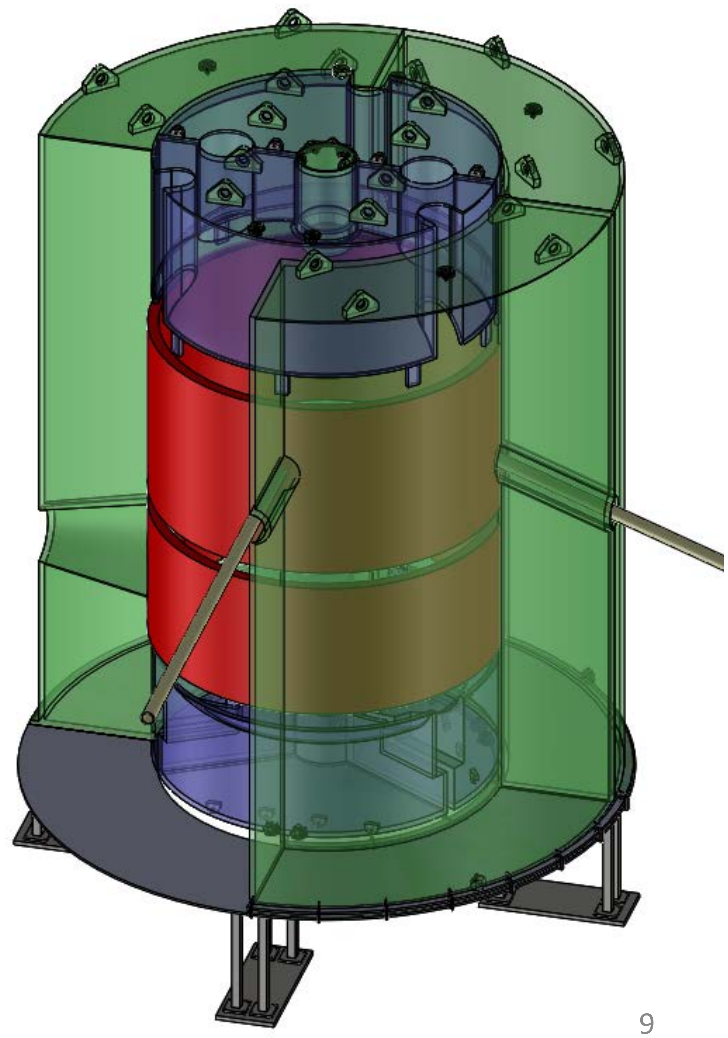
Performance Drivers

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 keV_{nr} S1 threshold (4.5 keV_{nr} LUX)
- 0.31 kV/cm drift field, 99.5% ER/NR disc.
  (already surpassed in LUX at 0.2 kV/cm)

The Outer Detector (OD)

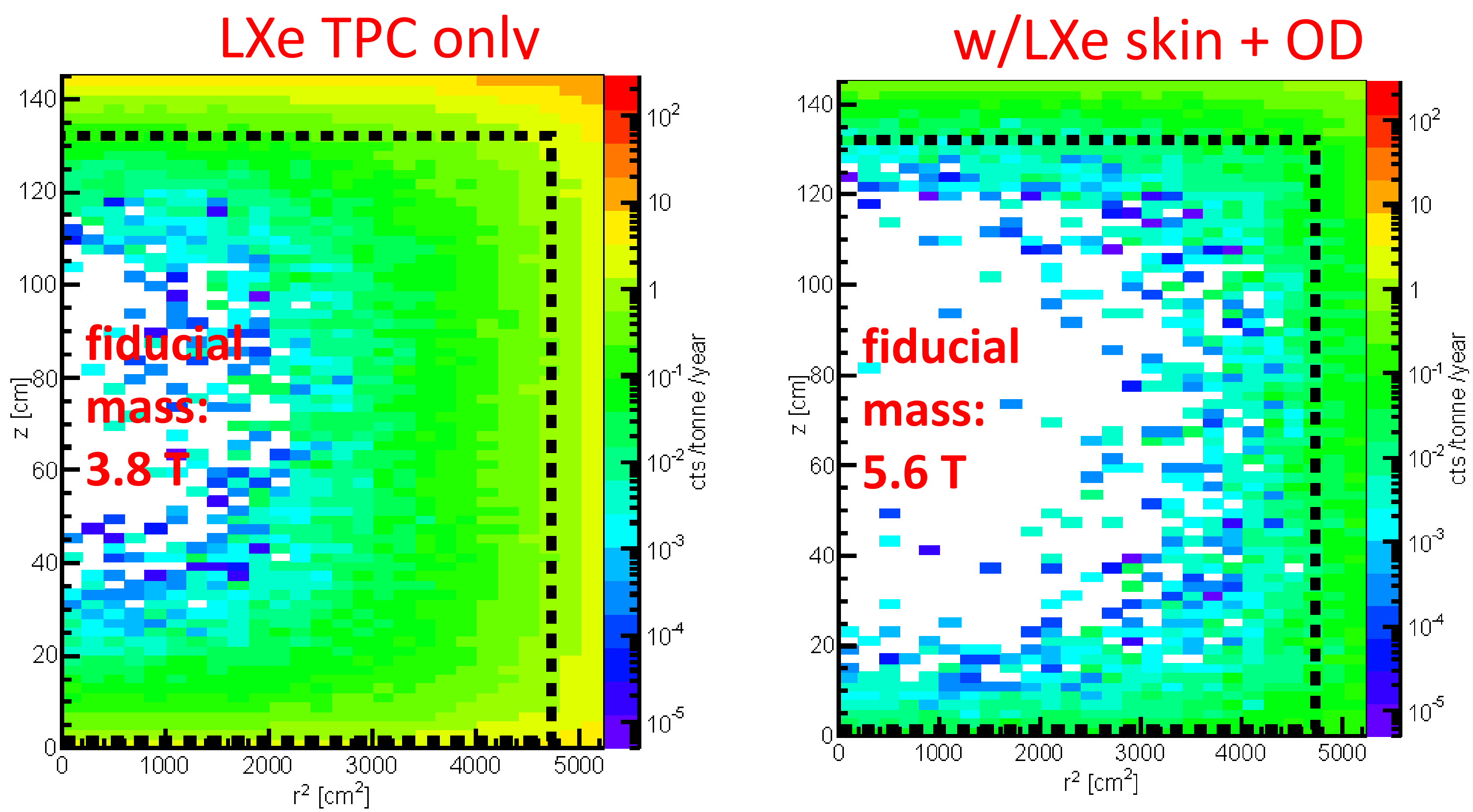
- Essential to utilize most Xe, maximize fiducial volume
- Hermetic measurement of penetrating backgrounds
- Segmented tanks – installation constraints (shaft, water tank)
- 60 cm thick, 21.5 T of Gadolinium-loaded LAB* liquid scintillator, OK underground
- 97% efficiency for neutrons
- Daya Bay legacy, scintillator & tanks (and people)



* Linear AlkylBenzene

Powerful Background Rejection

Simulated single NR scatter in TPC before/after Skin+OD vetoes



- Increases effective fiducial mass from 3.8 T → 5.6 T
- Internal backgrounds now dominate

Background 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

Detector components

Xenon contaminants

Environment, cosmogenic, surface contamination

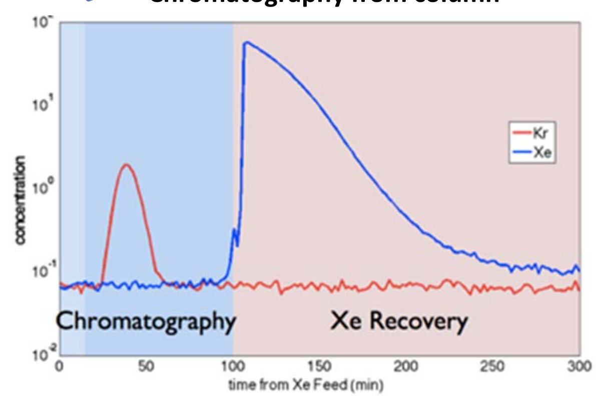
Physics backgrounds

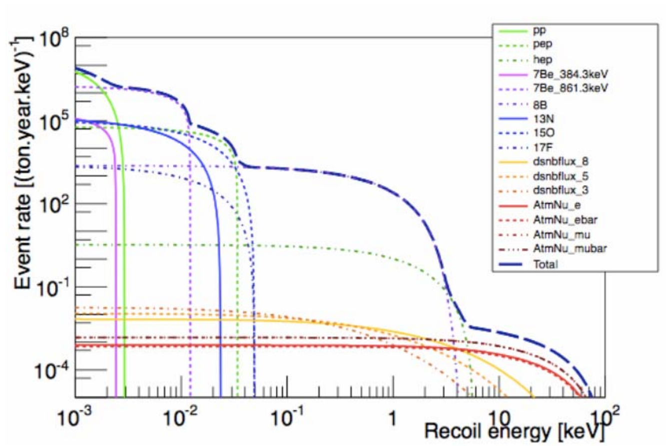
Intrinsic Contamination Backgrounds	Mass (kg)	U early (mBq/kg)	U late (mBq/kg)	Th early (mBq/kg)	Th late (mBq/kg)	Co60 (mBq/kg)	K40 (mBq/kg)	ER (cts)	NR (cts) (w/ SF rej.)
Upper PMT Structure	46.7	5.25	0.80	1.07	0.72	0.03	3.77	0.14	0.001
Lower PMT Structure	71.7	2.69	0.24	0.42	0.30	0.00	1.36	0.08	0.001
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	8.94	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 (and Kr) dominant internal background sources
- Rn:
  - Emanates from most materials
  - 13.4 mBq requirement, 0.67 mBq goal (active region)
    - Rn removal system at UMich
  - Four measurement systems with ~0.1 mBq sensitivity
  - Main assembly laboratory at SURF will have reduced radon air system
- Kr:
  - Remove ^{85}Kr to <15 ppq using gas chromatography
  - Neutrino-induced backgrounds

Chromatography from column

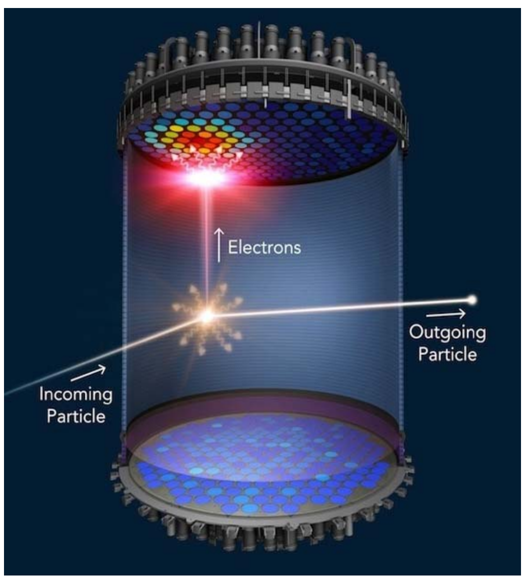




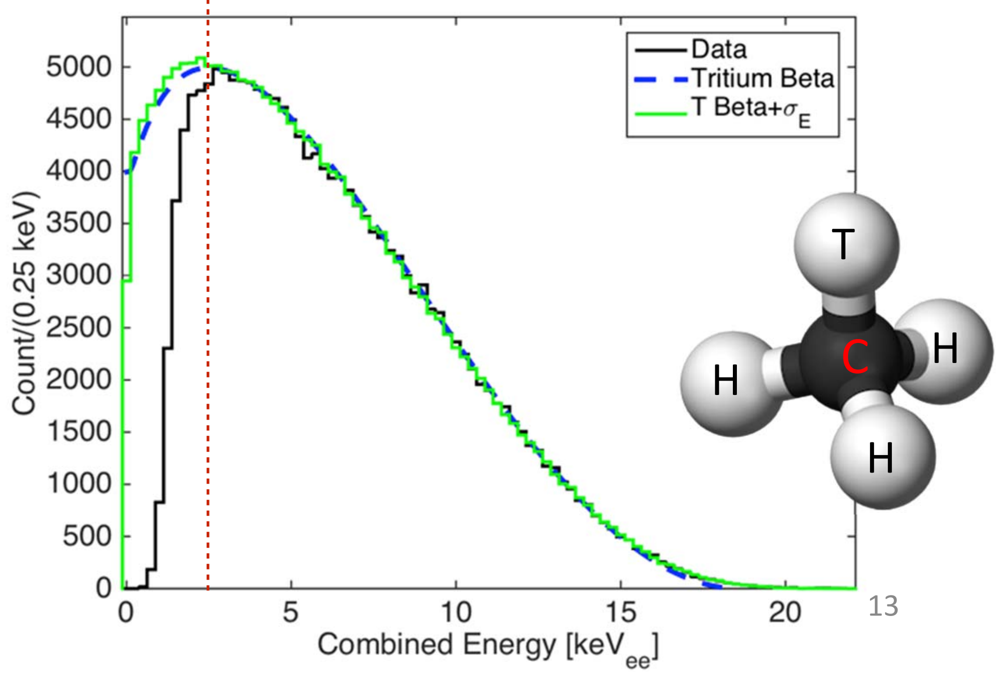
Calibrations

- Expand upon successful LUX program (and other experience)
- DD Neutron Generator (Nuclear Recoils)
- Tritiated Methane (Electron Recoils)
- Movable photon sources e.g. tubes penetrating cryostat
- Additional sources e.g. YBe source for low energy (Nuclear Recoils)

DD neutron calibration



Tritium Beta Spectrum Measured in LUX



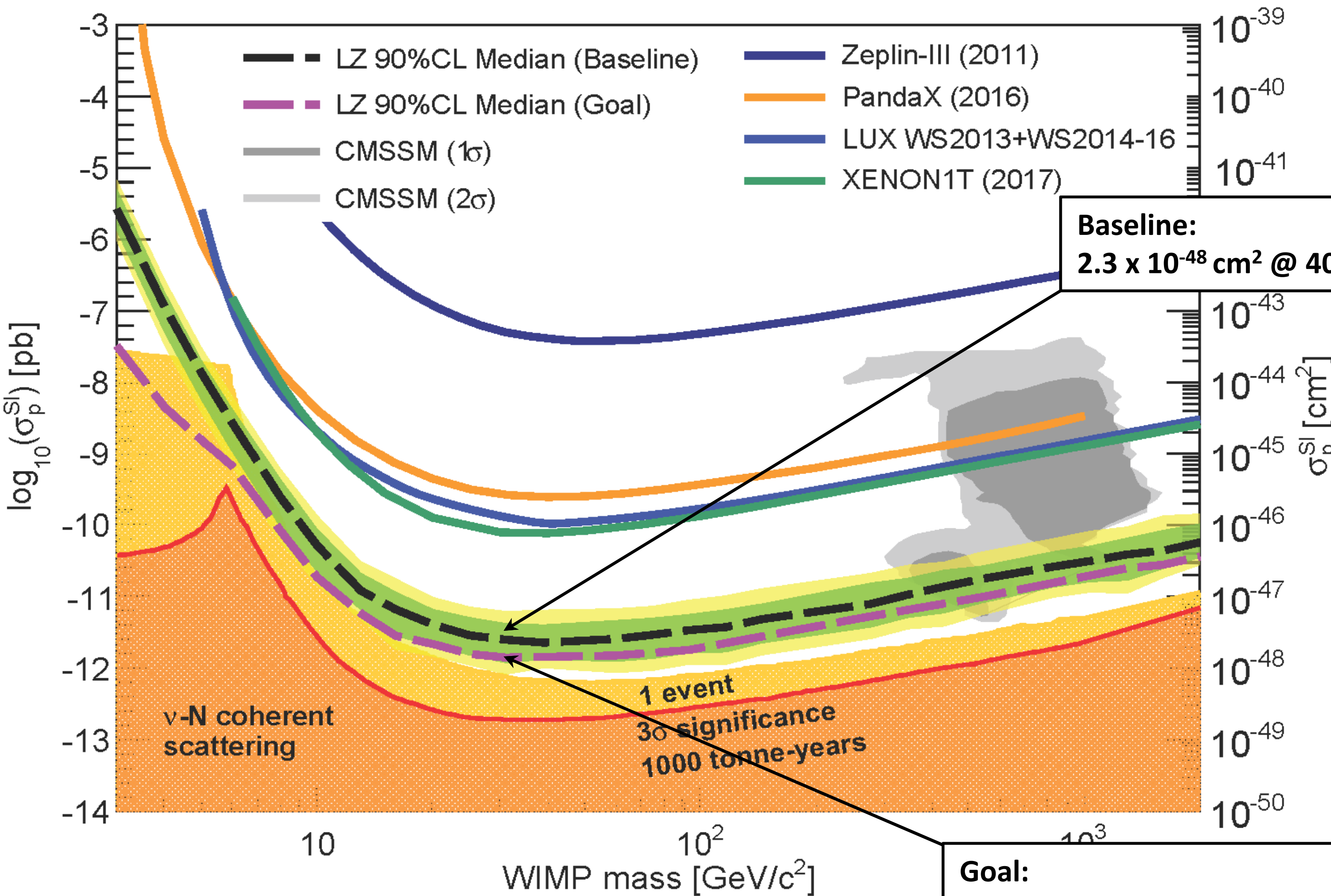
Detector Prototyping

Extensive program of prototype development undertaken, with three general approaches:

- Testing in liquid argon, primarily of HV elements at LBNL
- Design choice and validation in small (few kg) LXe test chambers in many locations: LLNL, UC Berkeley, LBNL, U Michigan, UC Davis, Imperial College, MEPhI, LIP (arXiv:1507.01310, [JINST 10, (2015) P10040], arXiv:1608.01717 [NIMA 856 (2017) 86])
- System test platform at SLAC,
  - Phase I about 100 kg of LXe
  - Phase II GXe only: full scale grids (preproduction and final LZ grids)

Projected LZ Sensitivity – Spin Independent

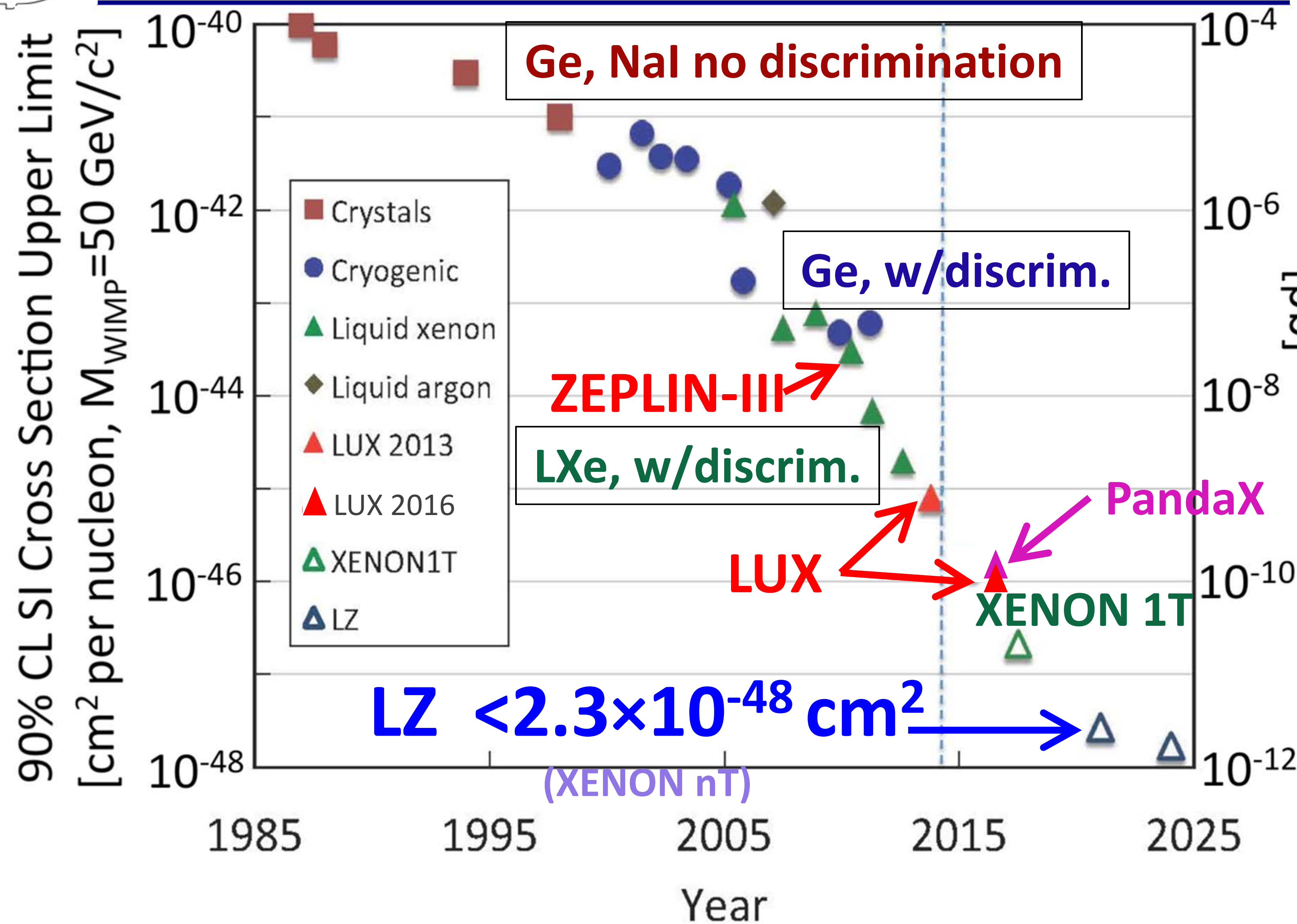
(5.6 T fiducial, 1000 live-days)



Baseline:
2.3×10^{-48} cm^2 @ 40 GeV/c^2

Goal:
1.3×10^{-48} cm^2 @ 40 GeV/c^2

Time Evolution



Timeline

Year	Month	Activity
2012	March	LZ (LUX-ZEPLIN) collaboration formed
2014	July	LZ Project selected in US and UK
2015	April	DOE CD-1/3a approval, similar in UK Conceptual Design Report arXiv: 1509.02910
2017	February	DOE CD-2/3b approval Technical Design Report arXiv: 1703.09144
2017	March	LUX removed from underground
2017	June	Begin preparations for surface assembly at SURF
2018	July	Begin underground installation
2019	late	Begin commissioning
2024+		Planning on 5+ years of operations

Summary

- LZ Project well underway, on schedule
- Long lead-time item procurement underway: Xenon, PMTs, Cryostat, vessel, etc.
- Materials screening program well underway
- LZ benefits from the excellent LUX calibration techniques and understanding of background
- Will explore significant fraction of available phase space:
    - WIMP sensitivity 2.3×10^{-48} cm^2 @ 40 GeV/c^2 with 1,000 live days (and approaching neutrino floor)

Extra Slides

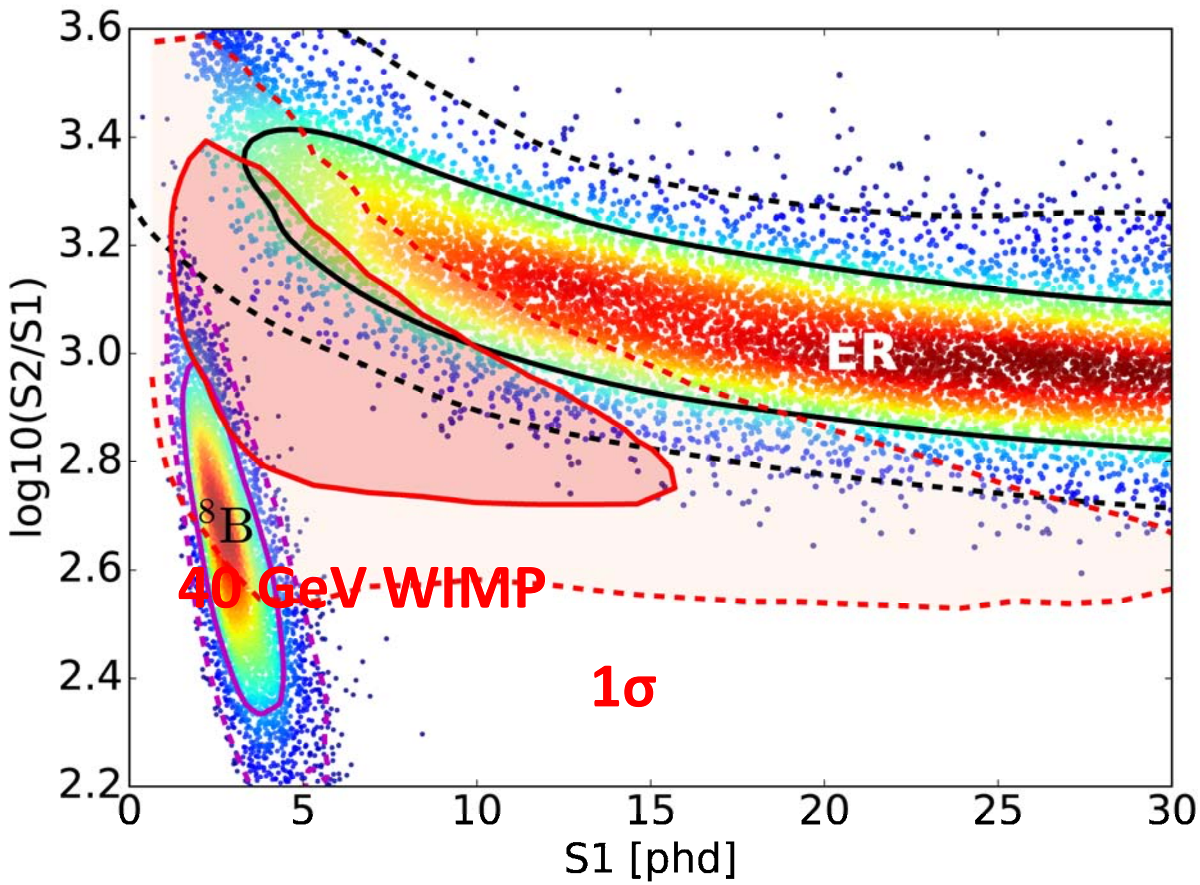
LZ Calibration (details)

Isotope	What	Purpose	Deployment
Tritium	beta, $Q = 18.6\,\text{keV}$	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

Xe purification and cryogenics

- Gas phase purification through getter: 10 tons/2.5 days
- Achieved sensitivity is 0.007 ppt (g/g), or 7 ppq (g/g).
- High-efficiency two-phase heat exchange
- LN_2 thermosiphon-based cryogenics: multiple cooling locations

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.

Non-WIMP physics

- Effective Field Theory Interaction Decomposition
- Neutrinoless Double Beta Decay
- Axions/Axion-like-particles, leptophilic DM, fractionally charged particles
- External Neutrino Physics:
  - Solar
  - Supernova
  - Sterile Neutrino