The LZ Experiment and the Direct Detection of Dark Matter

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Physics 290E Seminar

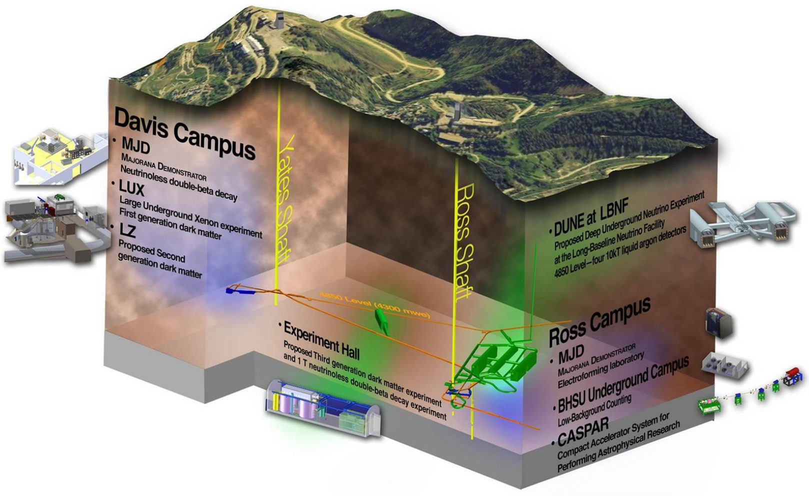
LUX-ZEPLIN

LUX-ZEPLIN

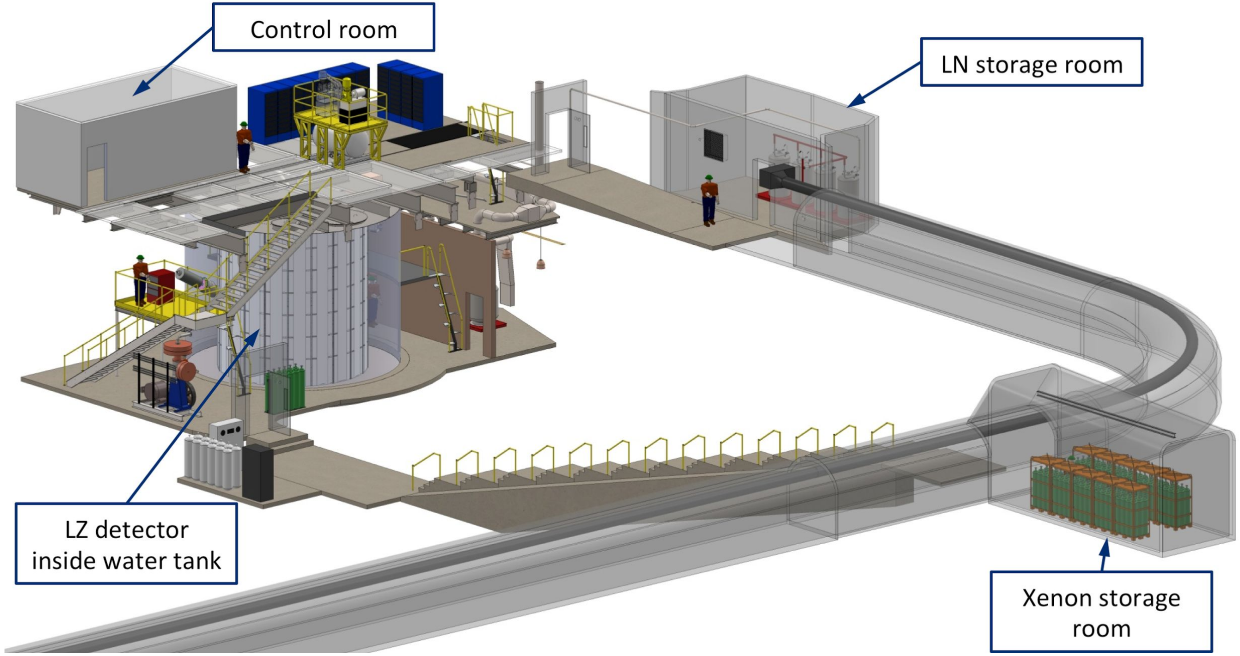
- The LZ collaboration formed in 2012 by combining the LUX and ZEPLIN groups
- Consists of ~200 scientists and engineers from 31 institutions in the US, UK, Portugal, Russia, and Korea

SURF

- Sanford Underground Research Facility
- Near Lead, South Dakota
- Home to other experiments, including MAJORANA, DUNE, CASPAR

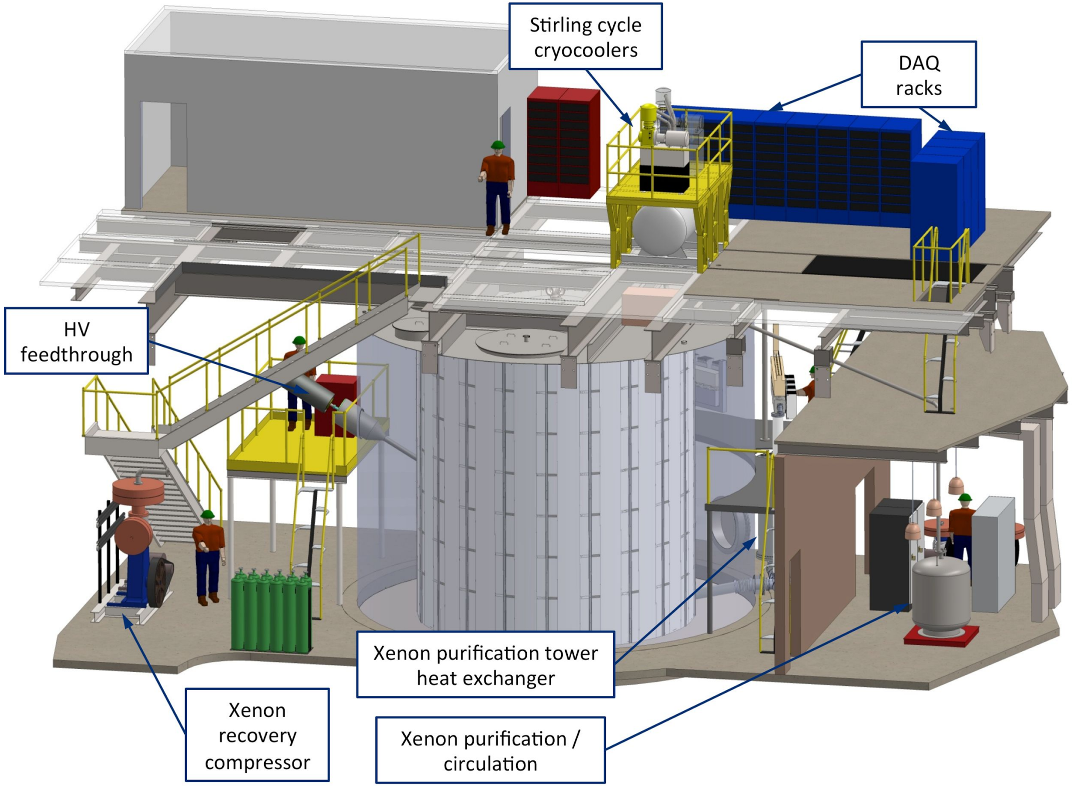


Detector



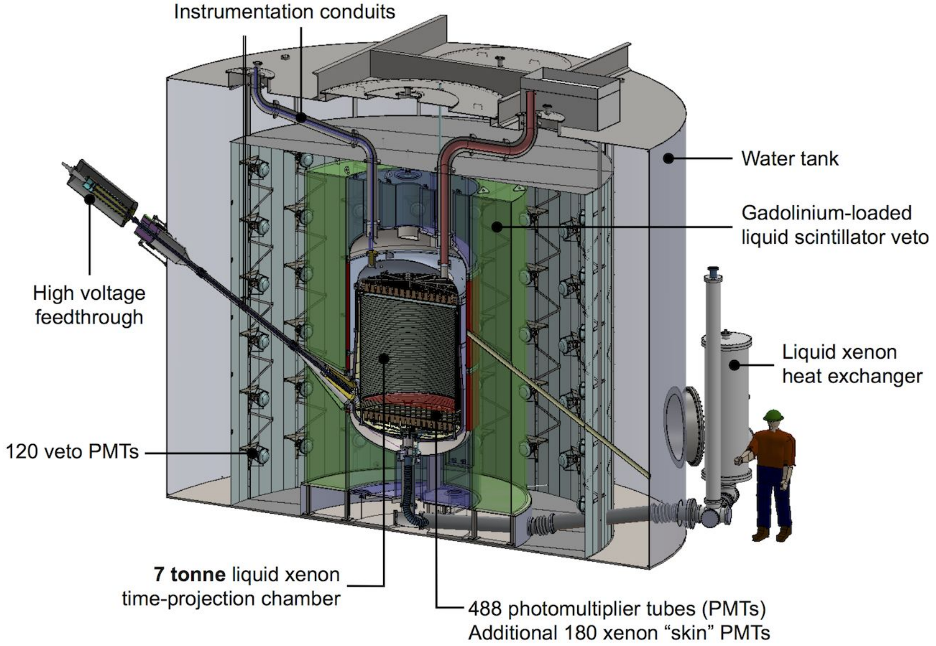
Control room
LN storage room
LZ detector inside water tank
Xenon storage room

Detector


Stirling cycle cryocoolers
DAQ racks
HV feedthrough
Xenon purification tower heat exchanger
Xenon recovery compressor
Xenon purification / circulation

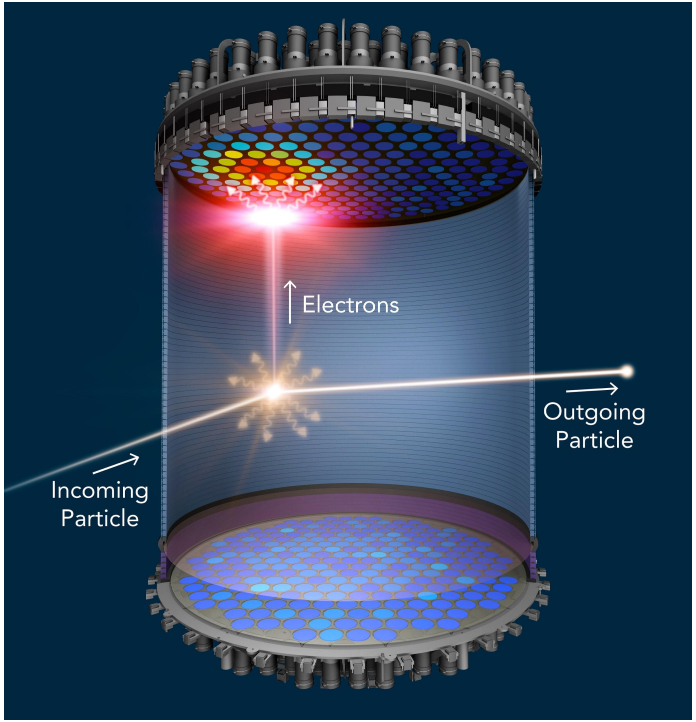
Detector

- Lab is 4850 feet underground
- Will be deployed where in the Davis Cavern at SURF, replacing LUX
- 10 tonnes of liquid xenon, 7 tonnes of which are active, and an approximate 5.6 tonne fiducial mass



Detector

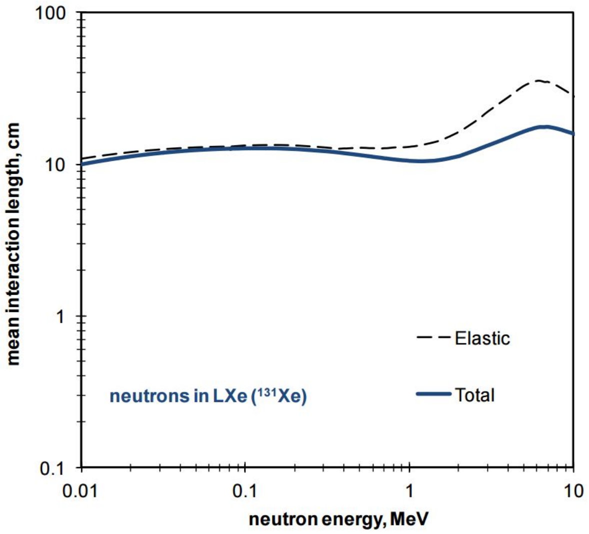
- Two-phase liquid xenon time projection chamber
- Scattering events in LXe create a scintillation signal (S1) and free electrons
- Electric fields are employed to drift the electrons to the liquid surface, extract them into the gas above, and accelerate them to create a proportional scintillation signal (S2)
- The ratio of S2 to S1 discriminates between ERs and NRs

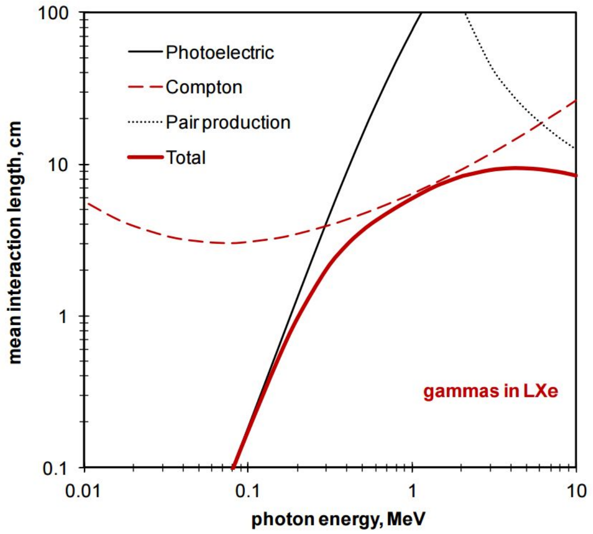


Liquid Xenon

- Relatively inexpensive and easy to obtain
- Large target and high mass, which has self-shielding properties such that neutrons, gamma rays, and X-rays do not penetrate more than a few cm
- Scalability when increasing the amount needed (e.g. from 370 kg in LUX to 7 tonnes in LZ)
- Easily purified
- Does not have long-lived radioactive isotopes

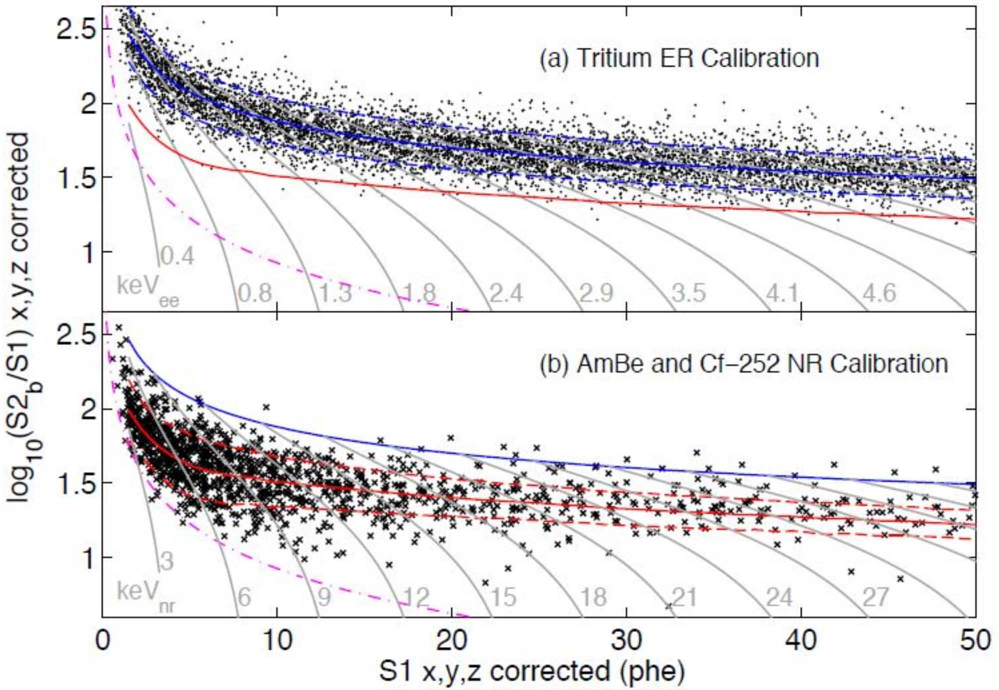
Self-Shielding





Electron and Nuclear Recoil Discrimination

- Electron recoils (ERs) happen due to photons or beta particles
- Nuclear recoils (NRs) happen due to neutrons or WIMPs
- Looking at the ratio of S2/S1, we can reject ERs
- NRs can be due to either neutrons or WIMPs, but background neutrons can be filtered out



Calibration

- Two basic questions that need to be answered about any event in the detector: How did the particle interact? How much energy did it deposit?
- Comprehensive calibration strategies have been adopted in order to answer these questions
- 3D Position Reconstruction, Definition of Background Expected Signal Bands, Nuclear Recoil Calibration, Time Stability, Xenon Skin and Liquid Scintillator Veto

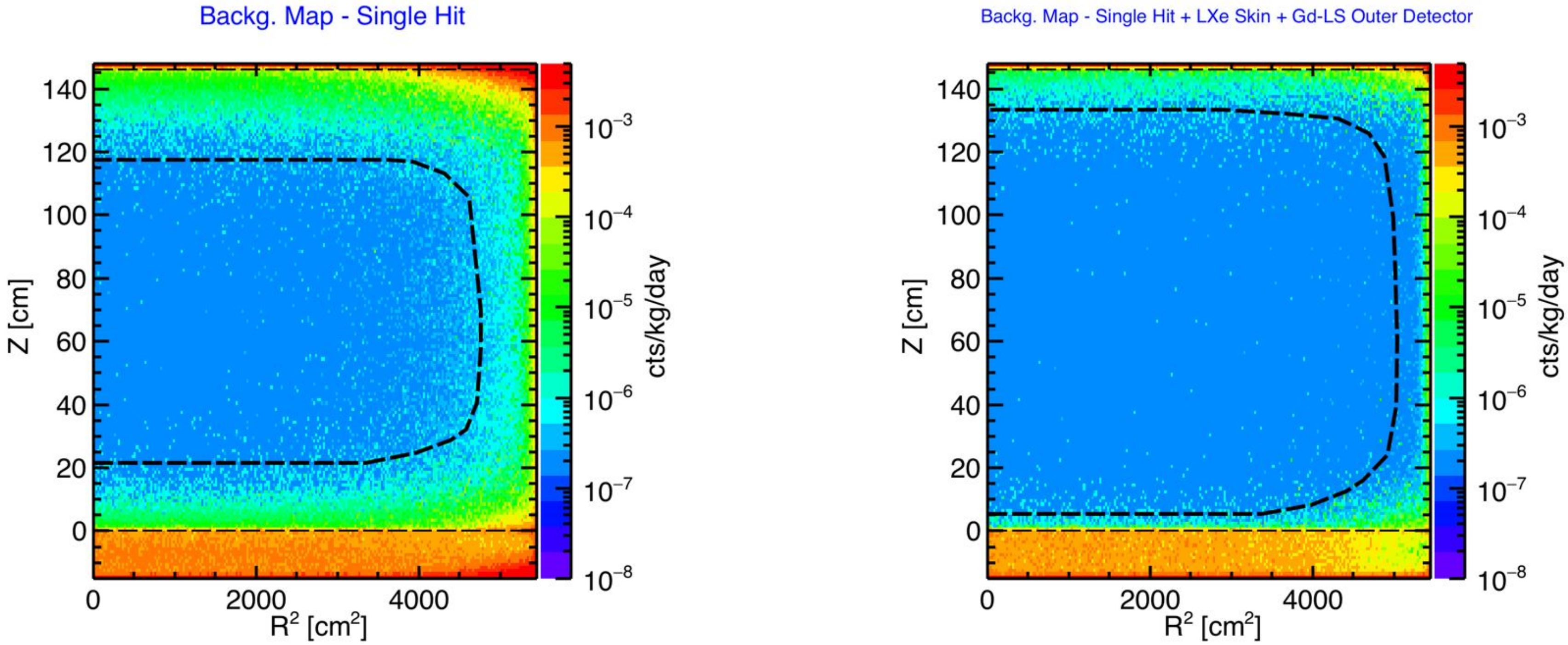
Achieving Low Backgrounds

- 4850 feet of Earth reduces much of the (muon-induced) cosmogenic backgrounds
- 80,000 gallon water tank tags the remaining muons via Cherenkov radiation
- Liquid scintillator outer detector for gamma ray and neutron anticoincidence
- 4-8 cm liquid xenon “skin” in which scintillation light is read out for anticoincidence detection and for tagging of external liquid xenon interactions with VUV photons

Achieving Low Backgrounds

- All materials chosen to be used with LZ are subject to stringent radioactivity constraints
- Adherence to cleanliness protocols for control of airborne radioactivity and particulates
- Removal of radioactive elements, e.g. Kr, Ar, or Rn, from the liquid xenon
- Purification system to control the concentration of electronegative impurities (e.g. oxygen and water)

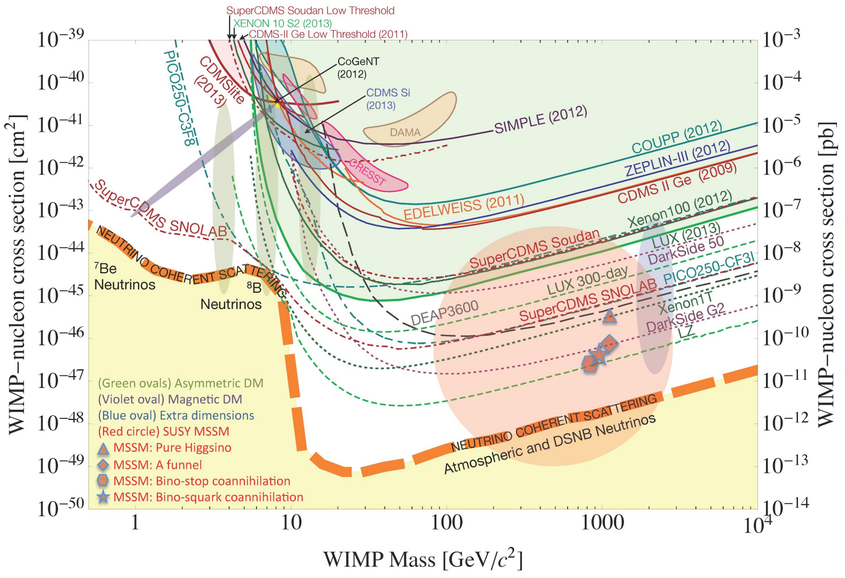
Fiducial Volume

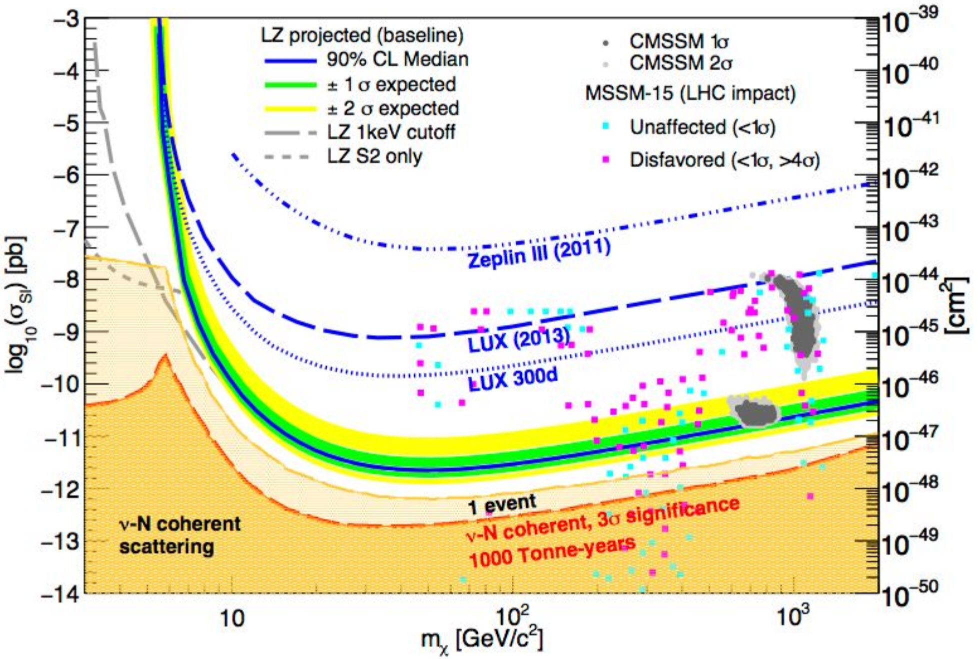


Summary of Backgrounds

Item	Mass kg	U mBq/kg	Th mBq/kg	^{60}Co mBq/kg	^{40}K mBq/kg	n/yr	ER cts	NR cts
R11410 PMTs	93.7	2.7	2.0	3.9	62.1	373	1.24	0.20
R11410 bases	2.7	74.6	29.1	3.6	109.2	77	0.17	0.03
Cryostat vessels	2,140	0.09	0.23	≈0	0.54	213	0.86	0.02
OD PMTs	122	1,507	1,065	≈0	3,900	20,850	0.08	0.02
Other components	-	-	-	-	-	602	9.5	0.05
Total components							11.9	0.32
Dispersed radionuclides (Rn, Kr, Ar)							54.8	-
^{136}Xe 2νββ							53.8	-
Neutrinos (ν-e, ν-A)							271	0.5
Total events							391.5	0.82
WIMP background events (99.5% ER discrimination, 50% NR acceptance)							1.96	0.41
Total ER+NR background events							2.37	

Sensitivity Plots





Other Physics

Many other physics processes can be probed by the selective detection of NRs and ERs

- Interactions of WIMPs with atomic electrons
- Solar and certain dark-matter axion-like particles (ALPs), which interact via the axioelectric effect
- Potential to study various aspects of neutrinos, e.g. solar neutrinos, supernova neutrinos, $0\nu\beta\beta$ of ^{136}Xe, neutrino oscillations with parameters motivated by the current reactor/source anomalies, and a neutrino magnetic moment

Expected Timeline

Year	Month	Activity
2012	March	LZ Collaboration Formed
	September	DOE CD-0 for G2 Dark Matter Experiments
2013	November	LZ R&D Report Submitted
2014	July	LZ Project Selected in US and UK
2015	April	DOE CD-1, Begin Ordering Xenon, PMTs, Cryostat
2016	September	DOE CD-2, Baseline Project Formalized, Fabrication Starts
2017	June	Begin Preparations for Surface Assembly at SURF
2018	July	Begin Underground Installation
2019	February	Begin Commissioning and Running

Estimated Cost (as of 2015)

WBS / TASK NAME	DOE Base	Foreign	SDSTA	DOE Cont.	Other Cont.	TOTAL COST
1.1 Xe Procurement		6,060,000	14,140,000			20,200,000
1.2 Xe Vessel		1,937,445			416,000	2,353,445
1.3 Cryogenic System	1,483,450			465,926		1,949,376
1.4 Xe Purification	5,782,541	247,582	279,924	2,017,761		8,327,808
1.5 Xe Detector System	7,478,267	2,706,965		2,279,357		12,464,589
1.6 Outer Detector	3,961,426	225,865		1,230,873		5,418,164
1.7 LZ Calibration System	600,621	93,580		180,186		874,387
1.8 Electronics, DAQ, Controls & Computing	3,311,935	151,065		970,947		4,433,947
1.9 Integration and Installation	3,504,935		1,252,800	1,057,582	300,000	6,115,317
1.10 Cleanliness and Screening	1,214,661	822,926		353,250		2,390,837
1.11 Offline Computing	2,127,320	399,176		638,195		3,164,691
1.12 Project Management	3,222,607			930,285		4,152,892
Risk Based Contingency				4,652,000		4,652,000
TOTAL COST	**32,687,763**	**12,644,604**	**15,672,724**	**14,776,362**	**716,000**	**76,497,453**

In the Meantime...

- Upcoming study on high-voltage breakdown and electroluminescence in liquid xenon and argon to help understand these processes that limit the voltages that may be applied to conductors immersed in these liquids
- Development of a physical model for Polytetrafluoroethylene (PTFE, Teflon) reflectivity in liquid xenon, which covers the inside wall of the TPC. Current liquid xenon experiments see a >95% reflectivity, which is not physically understood

References

- The LZ Dark Matter Experiment, http://lz.lbl.gov/
- Sanford Underground Research Laboratory, http://www.sanfordlab.org/
- LUX-ZEPLIN (LZ) Conceptual Design Report, arXiv:1509.02910 [physics.ins-det]
- Araujo, H., Tipp 2014, “Mining for WIMPs: The LUX-ZEPLIN (LZ) Experiment”
- McKinsey, D., Physics 251 Seminar, “Searching for Dark matter in a Gold Mine”