The LUX-ZEPLIN Dark-Matter Experiment

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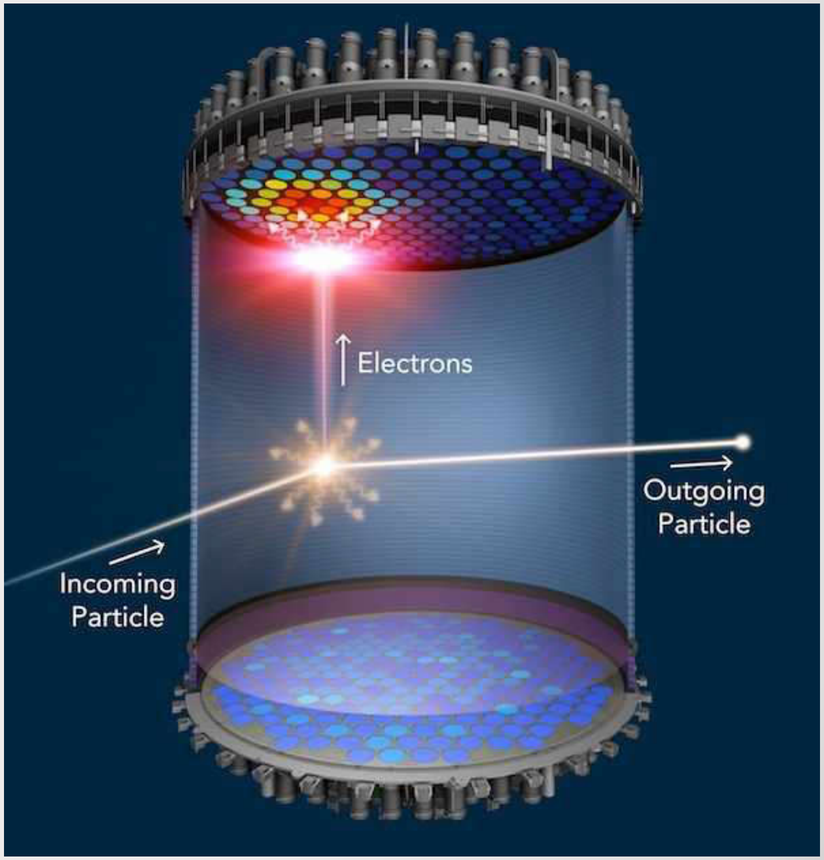
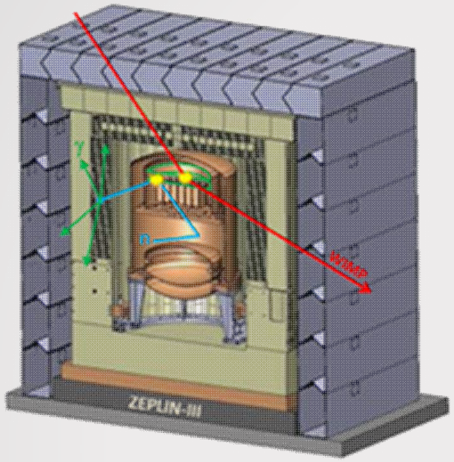
How to Detect Dark Matter: Liquid Xenon 2-phase TPC’s

- WIMP scatters on Xe nucleus in liquid xenon (LXe).
- Energy detected as prompt photons (S1 light), and drifted electrons.
- Drift time gives z position.
- Detection of electroluminescence from drifted electrons (S2-light) localizes X,Y.
- Position resolution removes multi-site backgrounds.
- S2/S1 separates Electron Recoil (ER) from Nuclear Recoil (NR) => Powerful background discrimination.
- Single photon and electron detection possible => low threshold



LUX+ZEPLIN:



ZEPLIN-III

- 6.8 kg liquid Xe (fiducial)
- 3.9x10^{-8} pb exclusion
- ZEPLIN-II was one of 1st 2-phase DM Detector.

LUX

- ~100kg LXE
- 33,000 kg·days
- 0.22 zb exclusion (at 50GeV)
- Best sensitivity in word at time of completion.
- Now on display at Sanford Visitor Center.

LZ collaboration

38 institutions 250 scientists, engineers, and technicians

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

LZ: Next Generation

Keep the backgrounds and thresholds low, and "just" go bigger!

LZ

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

- More xenon (simple)
- Higher voltage
- Less xenon wastage

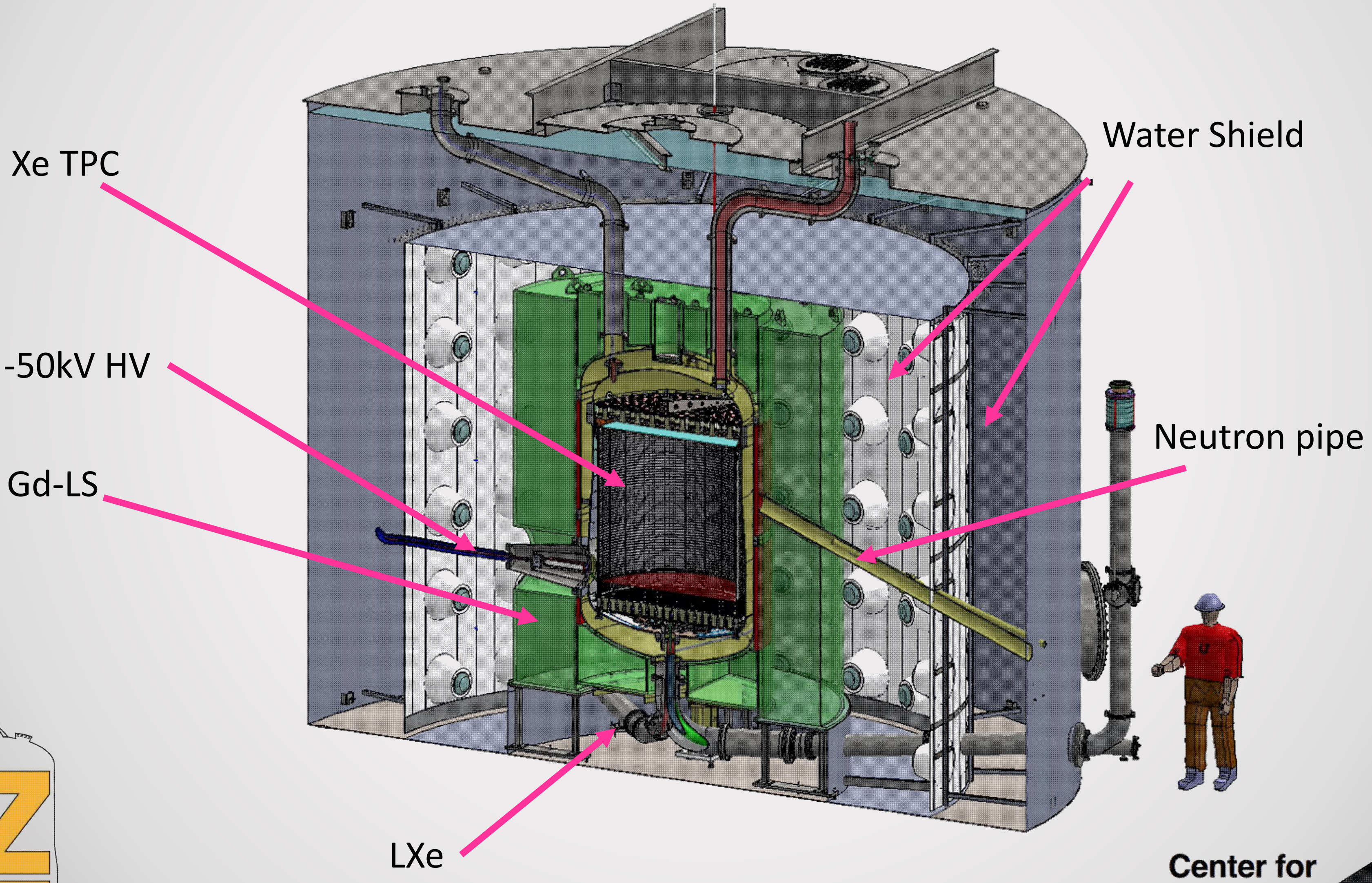
LUX

Total mass – 0.37 T
Active mass 0.25 T
Fiducial mass 0.1T

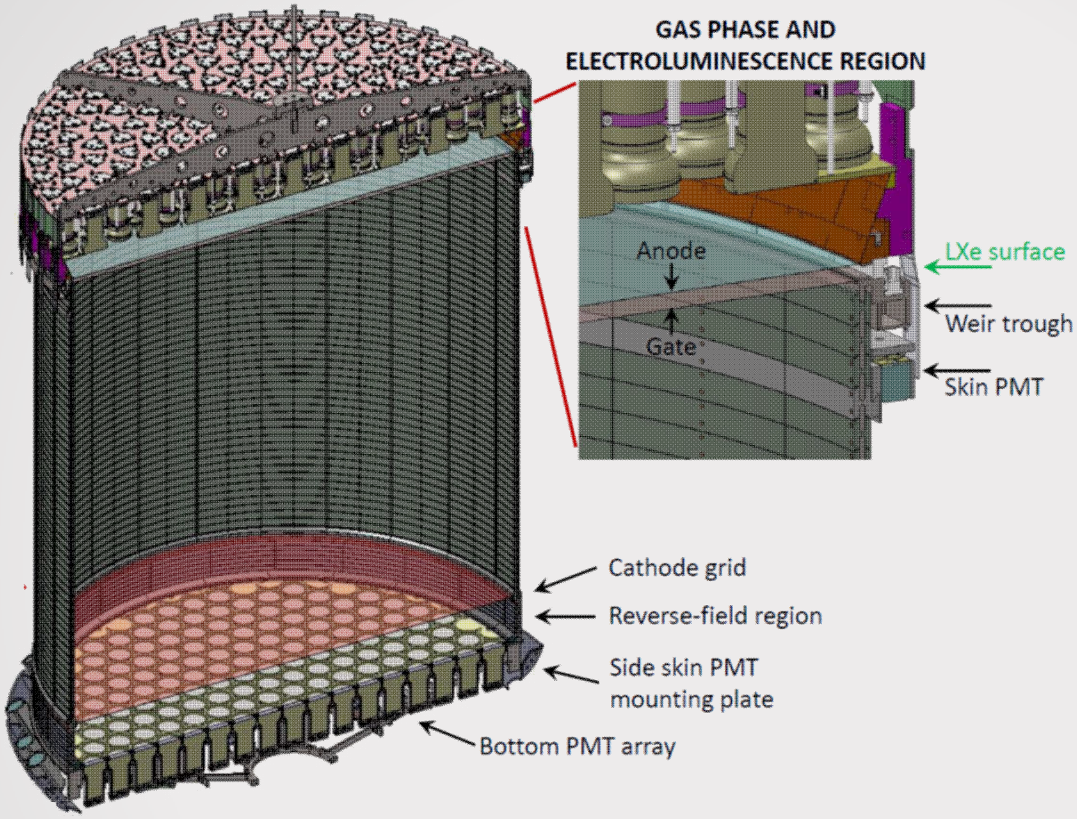
Sanford Underground Research Facility
Lead, South Dakota, USA

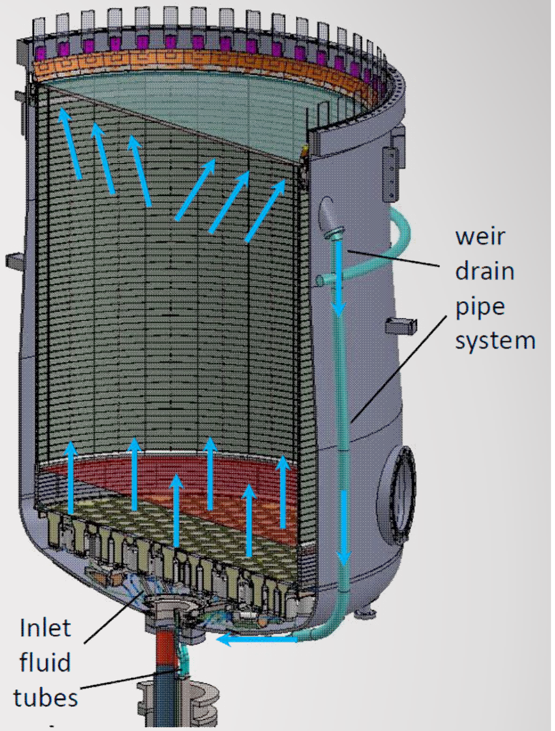
Davis Campus Water Tank
4850 ft level.

LZ Detector Overview



TPC Design



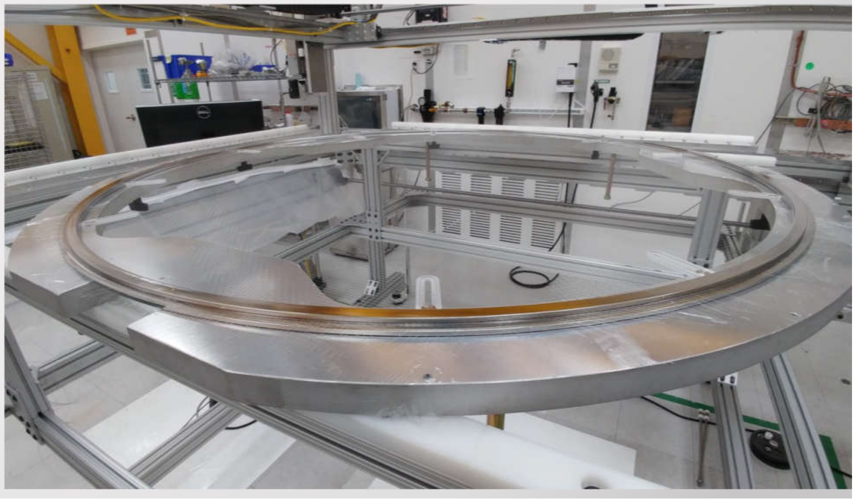


- PTFE walls, Ti field rings
- Ti/PTFE top/bottom PMT arrays holding ~493 3” PMTs total.
- 4 grid voltages, cathode, gate, anode, and lower array ground shield.
- 99.5% ER discrimination
- 50kV cathode voltage.

TPC Construction

- Arrays constructed at Brown in low Rn, Dust-filtered enclosure.
- PTFE covered, light-tight field rings test assembly completed at LBNL.
- TPC grids being woven, with electron emission treatment (arXiv:1801.07231)
- Full assembly to start above ground at SURF in September.

Reflective coating

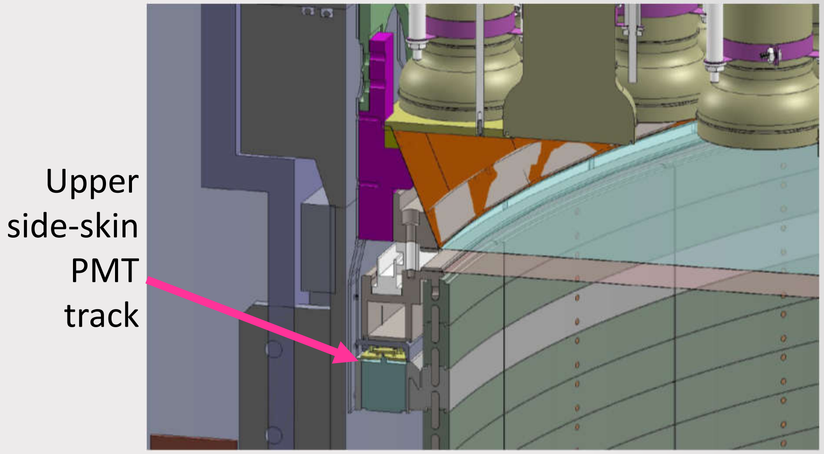


All Xe in hand or contracted

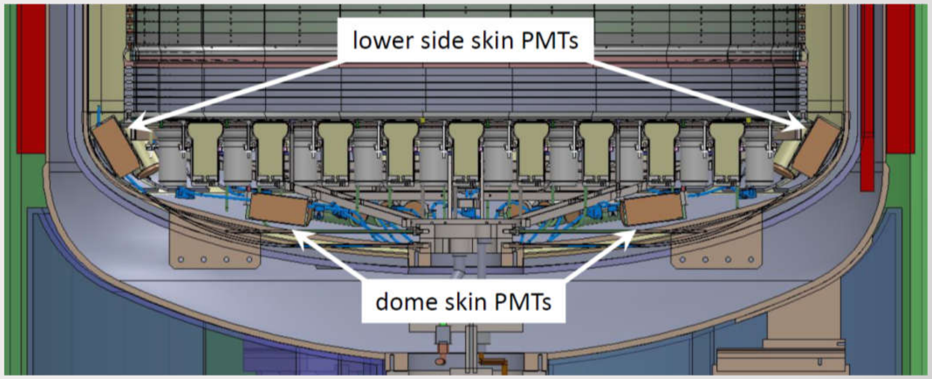
LXe Skin Veto Detector

- Instrumented with 93 1” new Hamamatsu PMT’s, 38 2” PMTs (recovered from LUX)
- Creates standoff from field-ring potentials.
- PTFE tiled, light isolated.
- Suppresses alpha-n and other multi-site backgrounds.

TPC top

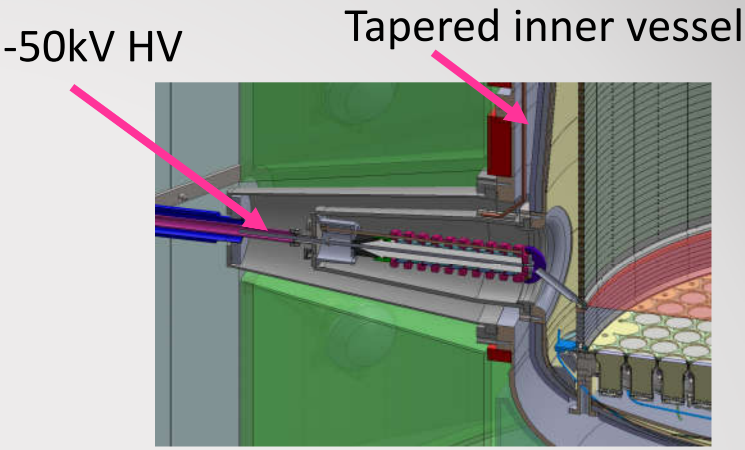


“Skin” instrumented with PMT’s



TPC bottom

Cathode HV



- Many past Xe experiments struggled to reach ~ 15kV or less. (ex: Xenon-100, EXO-200, LUX)
- For LZ drift length, 50kV required

  (300 V/cm).
- Designed to 100kV.
- Extensive testing and prototyping.
- 120kV reached in liquid argon.
- 50kV tested in LXe.
- Tapered inner vessel reduces fields while saving xenon.
- TPC Field rings designed to minimize stray fields.

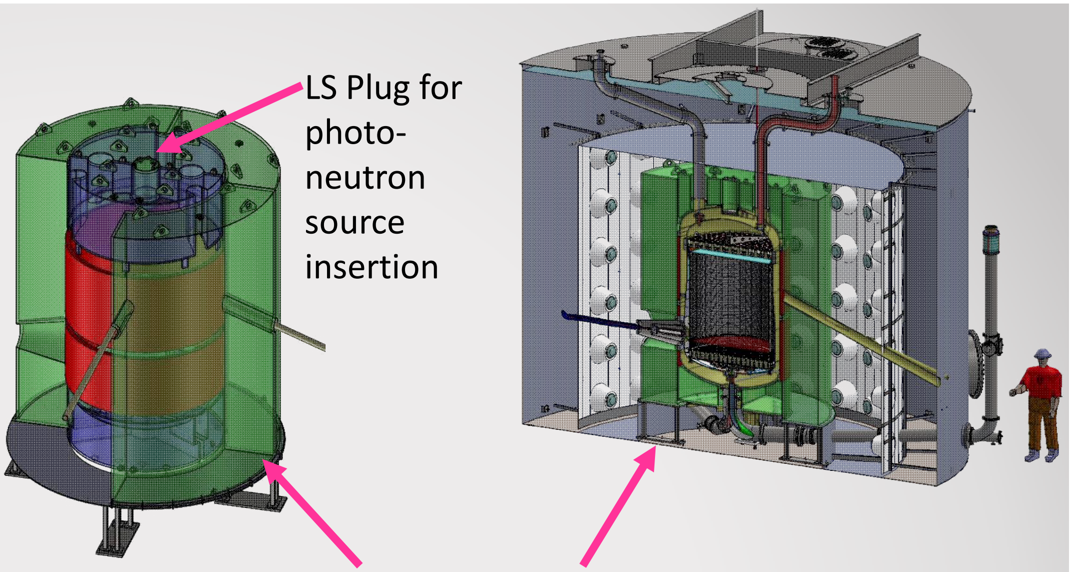
LBNL liquid argon test setup

Titanium Cryostat

- UK responsibility
- Test Fit in Milan
- Intensive Low activity titanium R&D (arXiv1702.02646)
- Titanium chosen in part to improve OD veto performance (thinner than Cu).
- At SURF since May
- Outer vessel testing passed, inner vessel ongoing.

Outer Detector

- 17 tons of Gd loaded LS (LAB)
- Distillation equipment now being installed at BNL
- Segmented, 4π “hermetic” coverage.
- 120 8” R5912 PMT’s (used in Daya Bay, etc), +HV
- Goal: veto backgrounds efficiently but still minimize backgrounds to reduce dead-time.



LS Plug for photo-neutron source insertion

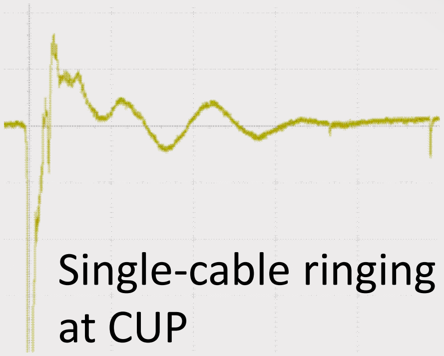
O.D Gd loaded LS

Acrylic Tank construction at Reynolds

OD PMT testing

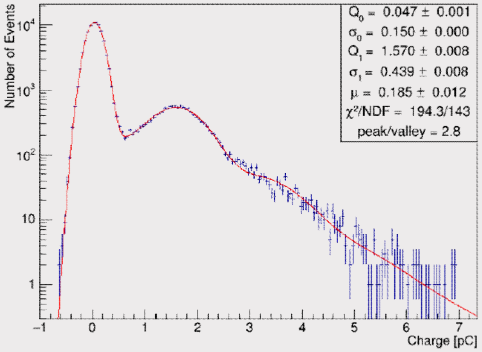
- PMT testing in Korea.
- Two-cable design eliminates piezo-electric ringing in ceramic decoupling cap.

  (Jiang et al Chinese. Phys C 36 (2012) 235)
- Testing all 120 (plus spares) for gain, dark-rate, SPE response, etc.
- HPGe counting for activity.



Single-cable ringing at CUP

Single Photo-electron spectrum



Dark box at CUP

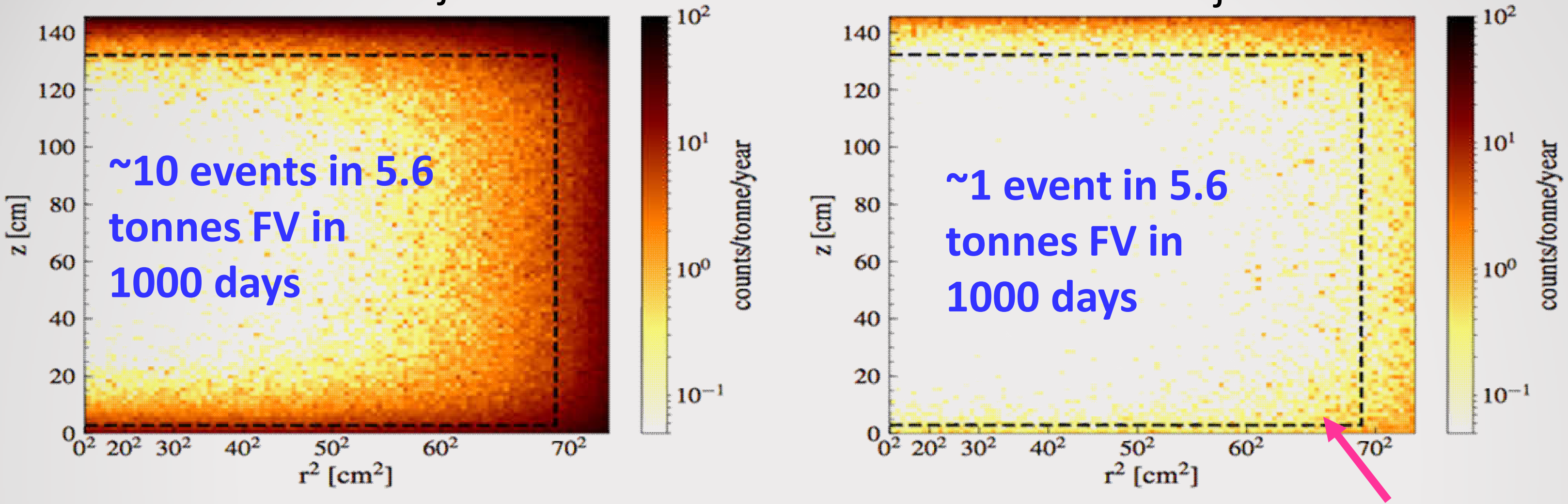
HPGe Counting

OD Dead Time

- GdLS neutron capture time ~ 30µs: 2.2 or 8 MeV total gamma energy.
- Window conservatively planned for 500 µs, 200 keV threshold (~25P.E.) => 96.5% neutron rejection.
- Cavern activity measured with NaI about 4x below assumptions => 18 Hz even at 100keV thresh.
- Worst case estimate, 20Bq/PMT of each ^{238}U,^{232}Th,^{40}K => 7Hz at 200keV. Few Hz from other parts.
- Still evaluating PMT activity data, but total OD deadtime is well under control (<5% goal).

NaI water-tank gamma flux scan
Oct 2017

Veto Performance (Skin +OD)



Without veto rejection

With veto rejection

~10 events in 5.6 tonnes FV in 1000 days

~1 event in 5.6 tonnes FV in 1000 days

5.6 tonnes

Single site nuclear recoil events in 6-30 keV region of interest

Enables Fiducial volume increase from 3.2 tonnes to 5.6 tonnes.

LZ Backgrounds: 5.6 tonnes, 1000 days, 1.5 to 6.5 keV

Background Source	ER (cts)	NR (cts)
Detector Components	**9**	**0.07**
Surface Contamination	**40**	**0.39**
Laboratory and Cosmogenics	**5**	**0.06**
Xenon Contaminants	**819**	**0**
222Rn	681	0
220Rn	111	0
natKr (0.015 ppt g/g)	24	0
natAr (0.45 ppb g/g)	3	0
Physics	**322**	**0.51**
136Xe 2νββ	67	0
Solar neutrinos (pp+7Be+13N)	255	0
Diffuse supernova neutrinos	0	0.05
Atmospheric neutrinos	0	0.46
Total	1195	1.03
with 99.5% ER discrim., 50% NR eff.	**5.97**	**0.51**

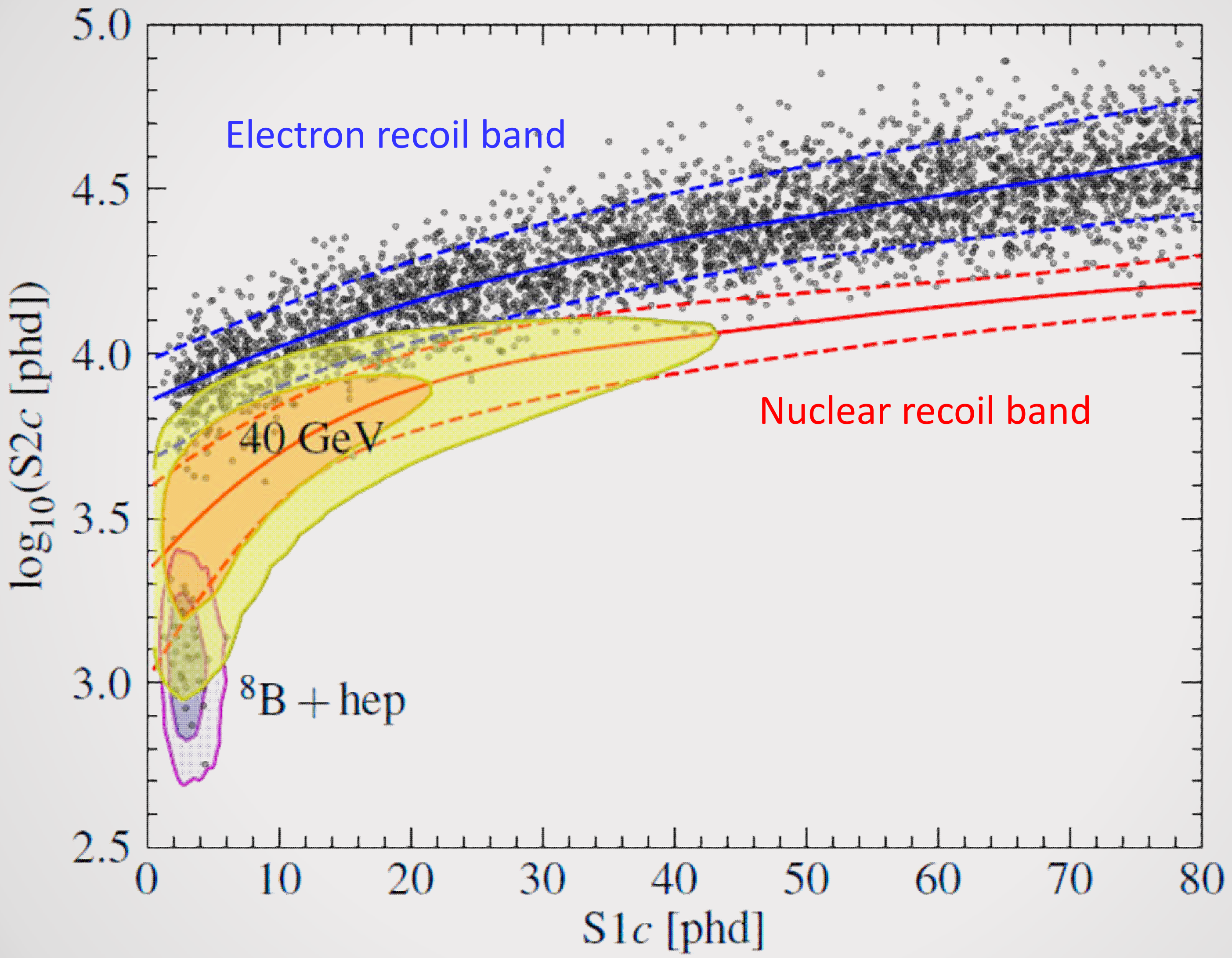
arXiv:1802.06039

Background Control:

- Two active vetos
- Rn emanation screening

  (2 µBq/kg targets)
- Charcoal chromatography for ^{85}Kr and ^{39}Ar removal.
- Radio-assay: HPGe, ICP-MS, NAA
- Rn and dust surface control:
  - Rn reduced cleanrooms,
  - Dust witness measurements

Simulated exposure, 1000 days, 5.6 tonnes

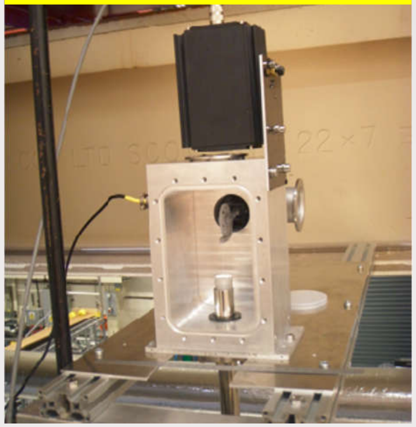


Center for Underground Physics

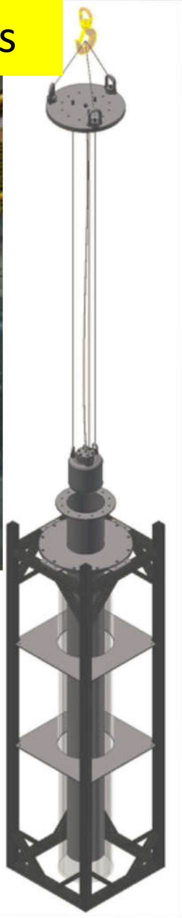
Calibration Systems

- Tubes between cryostat vessels for deployment of sources
  - Gamma, (α,n), etc
  - System being tested in UK
- Photoneutron sources
  - Deployed on top of cryostat
  - Ex: ^{88}Y Be, NR endpoints at 2.7 keV$_{nr}$ & 4.6 keV$_{nr}$
  - Mechanical tests at LBNL
- D-D neutron generator
  - 10^9 2.45 MeV neutrons/s
  - Multi-scatter tags energy
- Xe-injected internal sources
  - CH3T: $T_{1/2}$=12.3y 1.82keVβ (few months)
  - ^{83m}Kr:T1/2=1.8h, 41keV IC e$^-$ (weekly)
  - Advanced prototyping @ U. Mass
  - 6 hour removal
  - Techniques proven in LUX.

Source Deployment



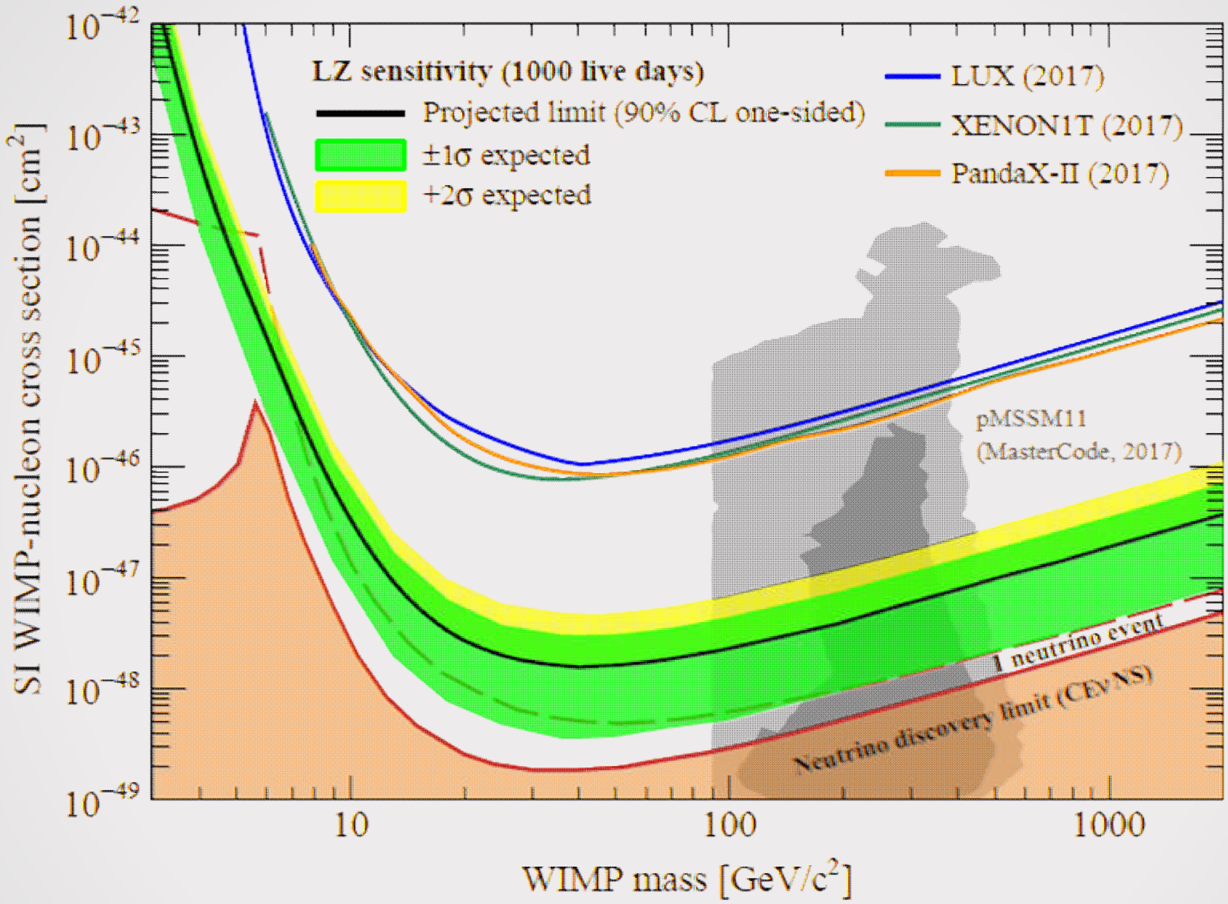
LBNL Tests



Internal Source (U Mass.)

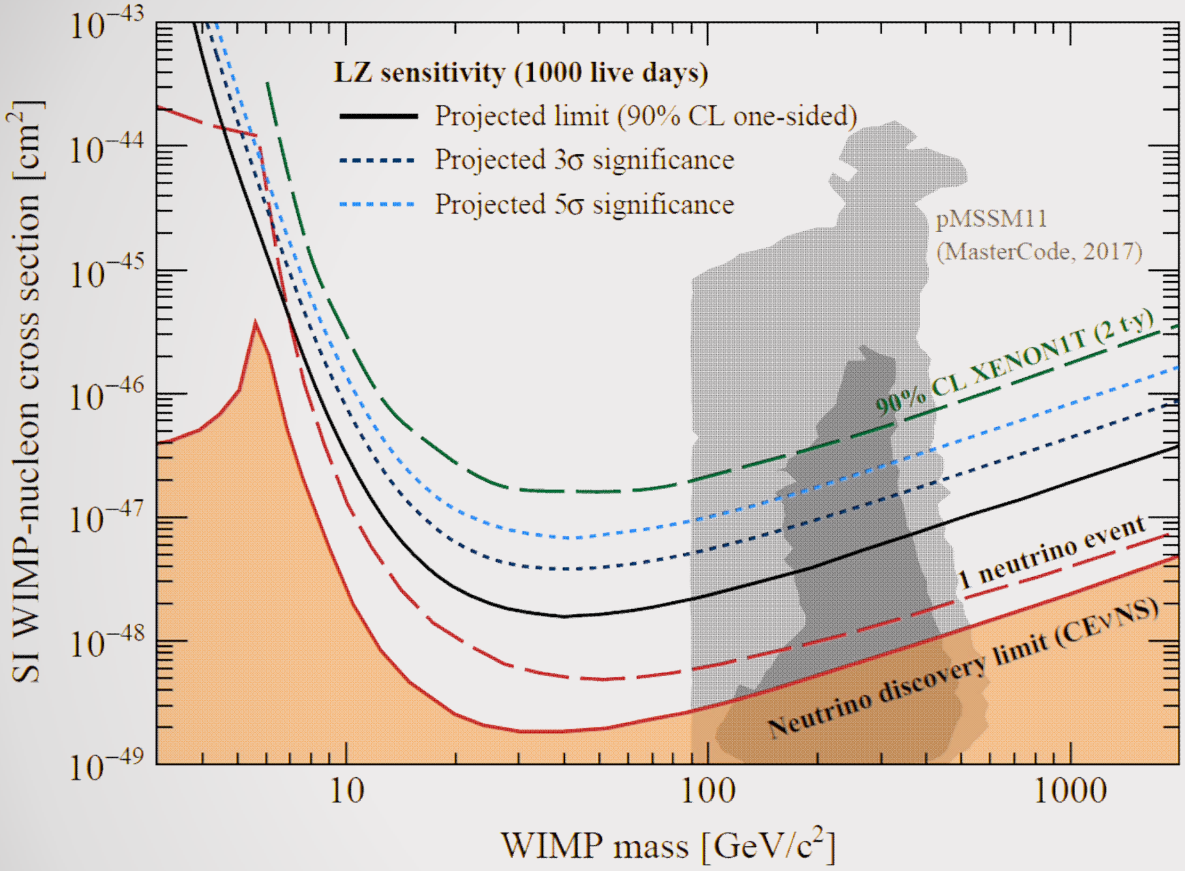
Spin Independent WIMP Sensitivity

arXiv:1802.06039



Baseline sensitivity: 1.6x 10^{-48} @ 40GeV/c^2, 1000 days, 5.6 tonne fiducial mass.

WIMP Discovery Potential



arXiv:
1802.06039

5 sigma discovery potential: $6.7\text{x}10^{-48}$ (5.6 tonnes, 1000 days livetime)

Below Xenon1T sensitivity projection for 2-tonne-year exposure .

LZ Timeline

Year	Month	Activity
2008	April	LZ collaboration forms
2014	July	LZ Project selected by US DOE, NSF< & UK STFC
2015	April	CD-1 Review, conceptual design
	September	Conceptual Design Report (arXiv:1509.02910)
2016	April	CD-2 Review, project baseline
2017	January	CD-3 Revew, construction start
	March	Technical Design Report (arXiv:1703.09144)
2018	February	Wimp sensitivity paper (arXiv:1802.06039)
	May	Titanium cryostat delivered to SURF
2019	Summer	TPC moves underground
2020	Spring	Ready for operations