The LZ Experiment for Dark-Matter Search

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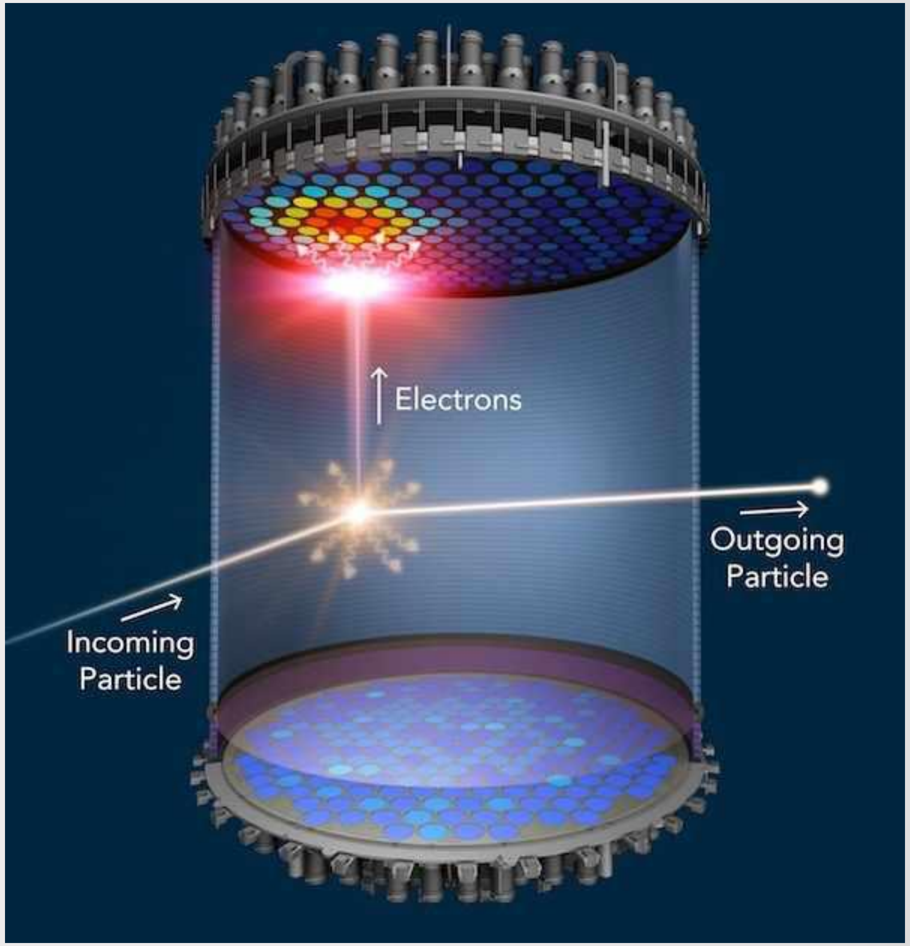
Center for Underground Physics

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



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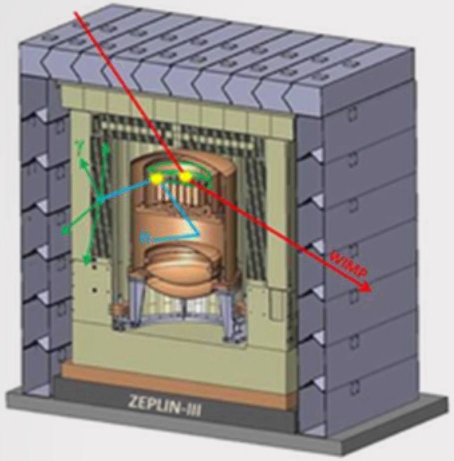
LUX+ZEPLIN:



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

36 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)

LZ: Next Generation

Keep the backgrounds and thresholds low,
and “just” go bigger!

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

LZ

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

LUX

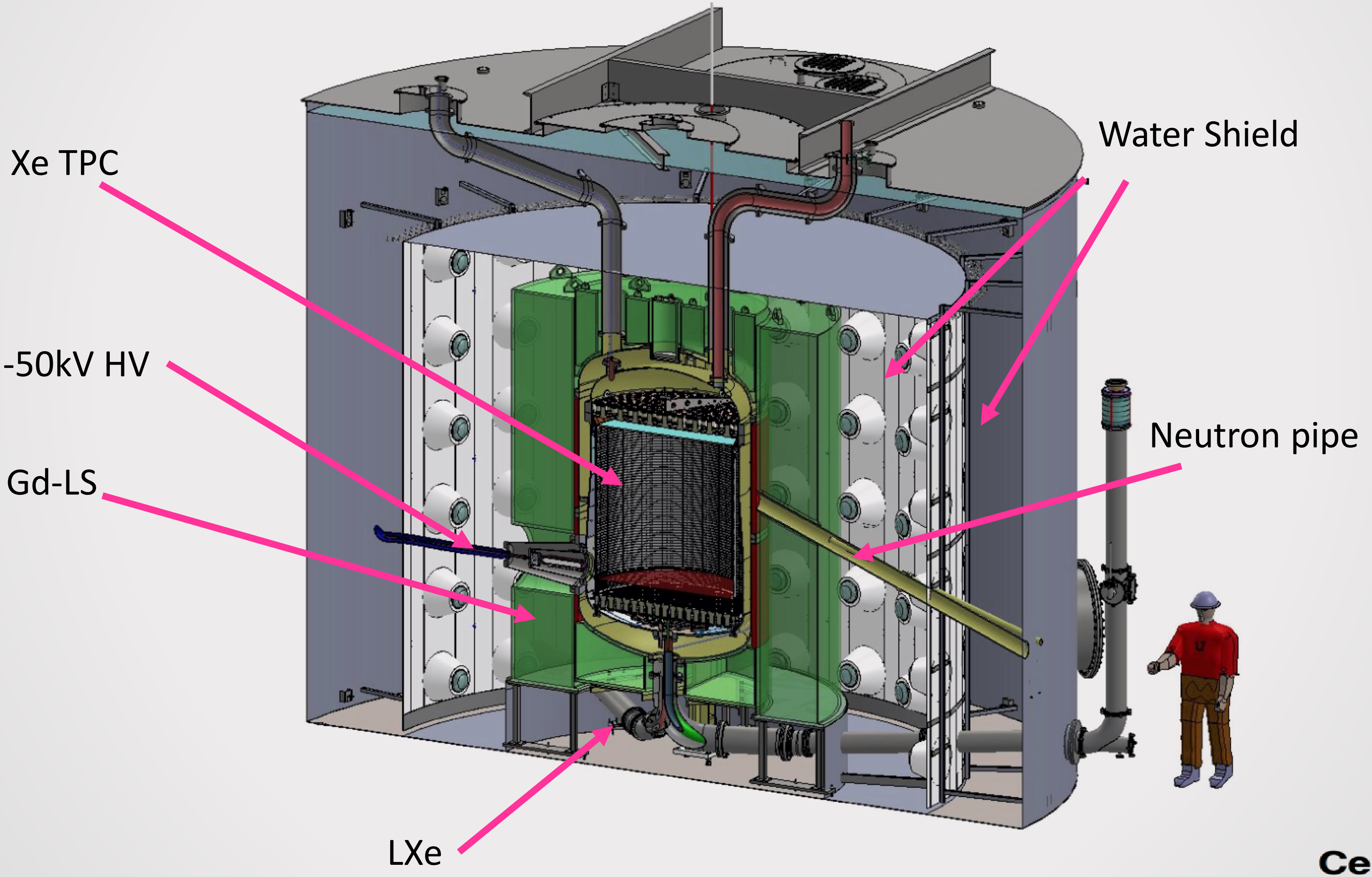
Total mass – 0.37 T
Active mass 0.25 T
Fiducial mass 0.1T

Sanford Underground Research Facility
Lead, South Dakota, USA

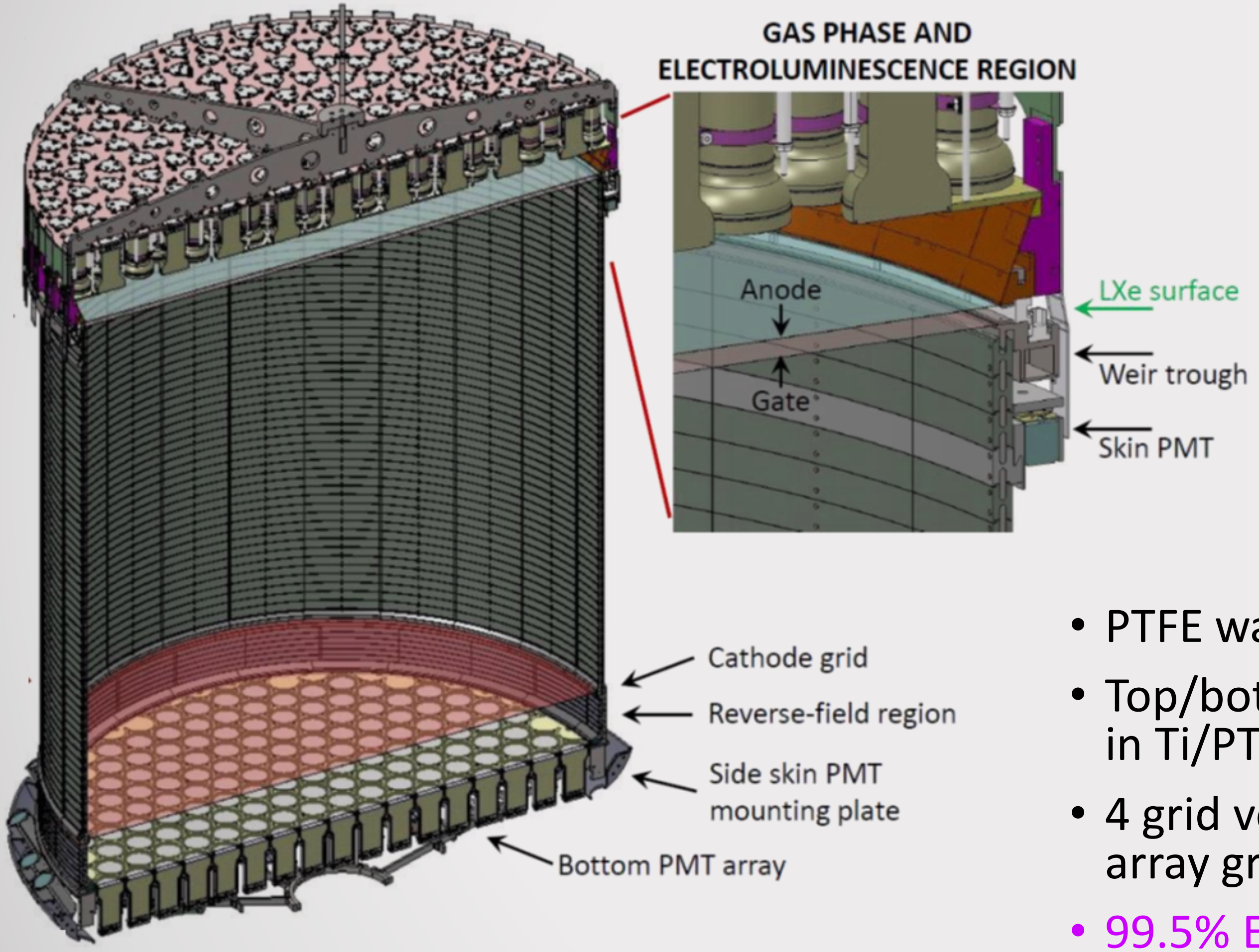
Davis Campus Water Tank
4850 ft level.

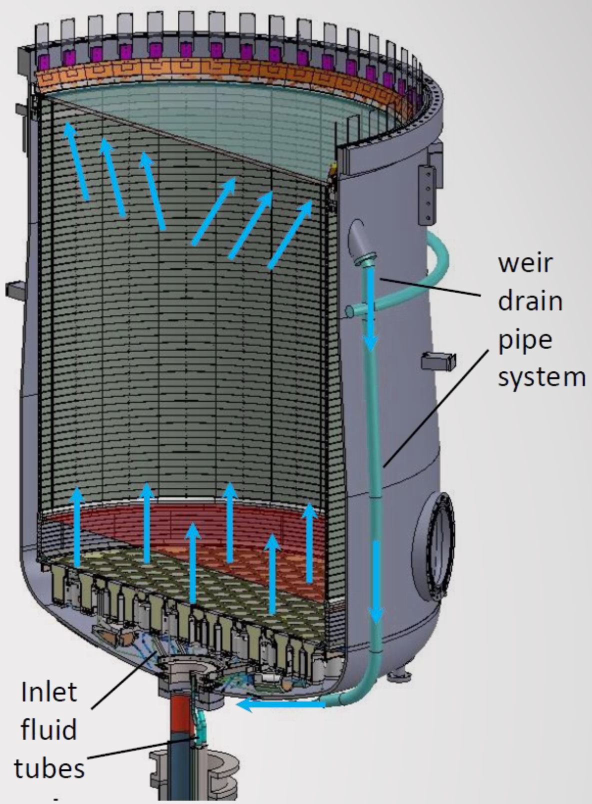
LZ Detector Overview

j.nima.2019.163047



TPC Design





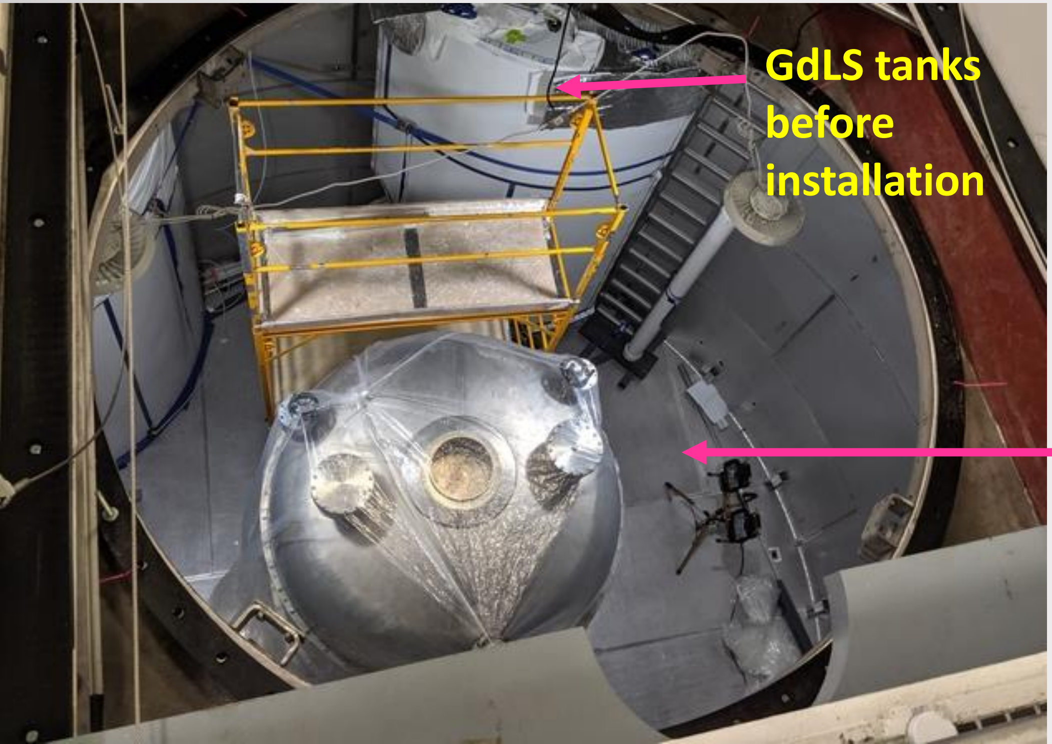
- PTFE walls, Ti field rings
- Top/bottom PMT arrays holding ~494 3” PMTs total in Ti/PTFE structure.
- 4 grid voltages, cathode, gate, anode, and lower array ground shield.
- 99.5% ER discrimination
- 50kV cathode voltage.

Titanium Cryostat

- UK responsibility
- Test Fit in Milan
- Intensive Low activity titanium R&D (arXiv1702.02646)

Inner Cryostat Vessel (ICV)

Outer Cryostat Vessel (OCV)

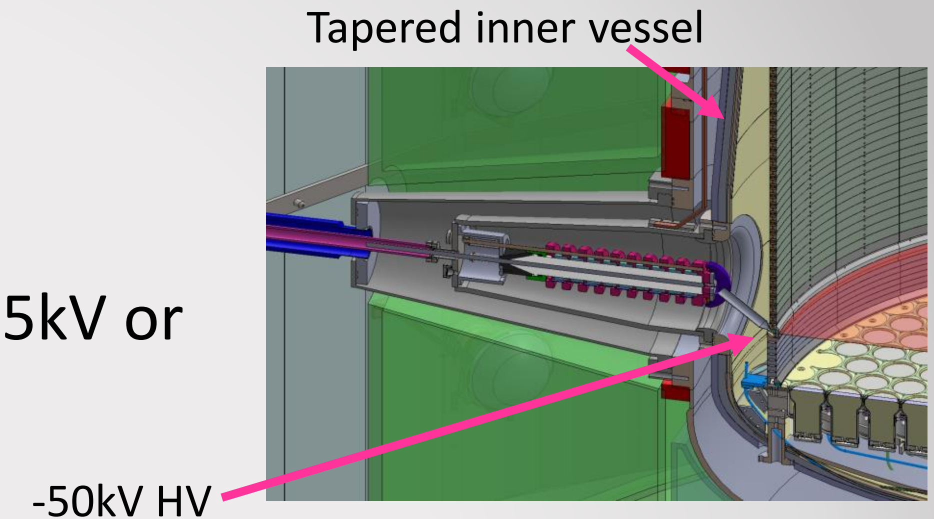


GdLS tanks before installation

- Titanium chosen in part to improve OD veto performance (thinner than Cu).
- Outer vessel (OCV) only, installed in Davis Cavern since summer 2019.

Cathode HV

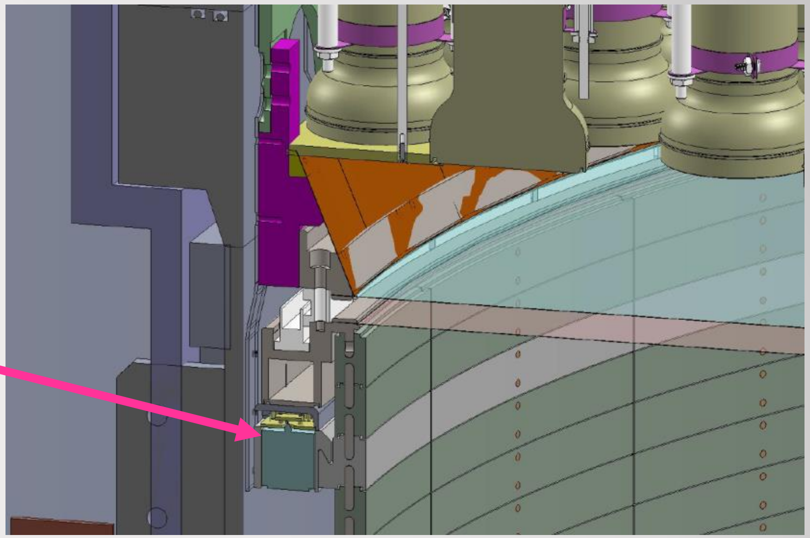
- Many past Xe experiments struggled to reach ~ 15kV or less. (ex: Xenon-100, EXO-200, LUX)
- For LZ drift length, 50kV required (300 V/cm).
- Designed to 100kV.
- Extensive testing and prototyping.
- 120kV reached in liquid argon.
- 50kV tested in LXe.
- Tapered inner vessel reduces fields while saving xenon.
- TPC Field rings designed to minimize stray fields.



LBNL liquid argon test setup

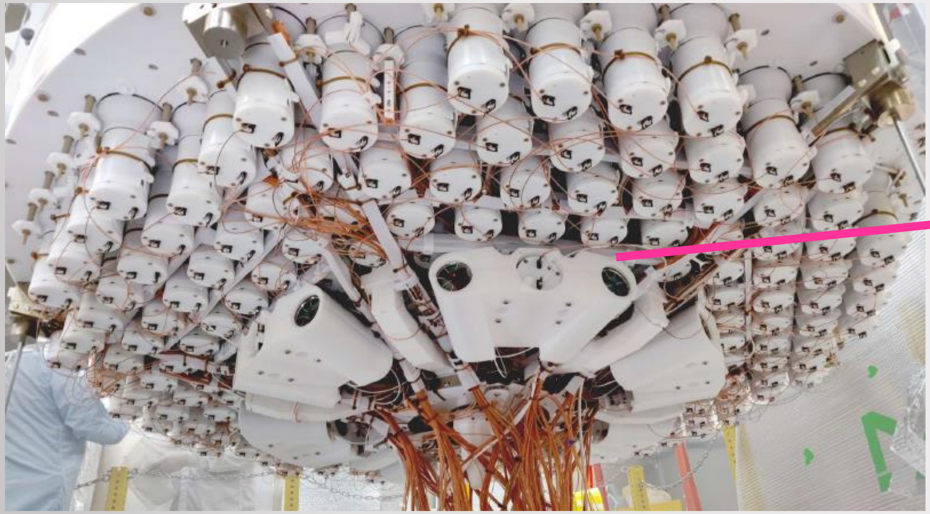
LXe Skin Veto Detector

- 2 tonnes of LXe surrounding TPC but not wasted.
- Instrumented with 93 1” new Hamamatsu PMT’s, 38 2” PMTs (recovered from LUX)
- Creates standoff from field-ring potentials.
- Suppresses alpha-n and other multi-site backgrounds.
- Everything is PTFE covered for light collection.

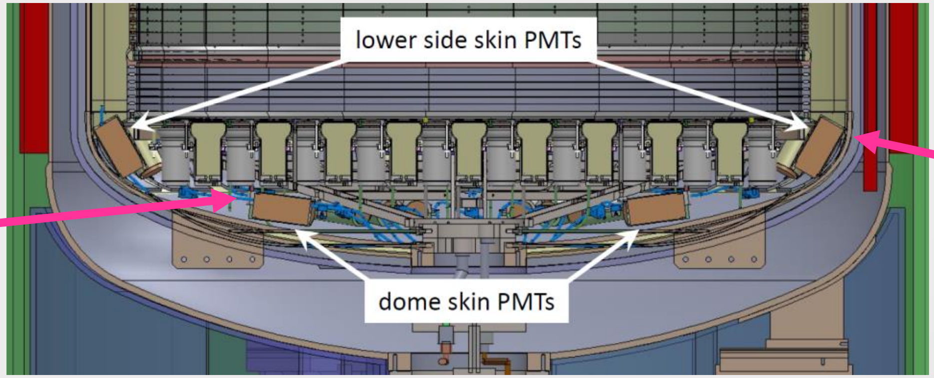


Upper side-skin PMT track

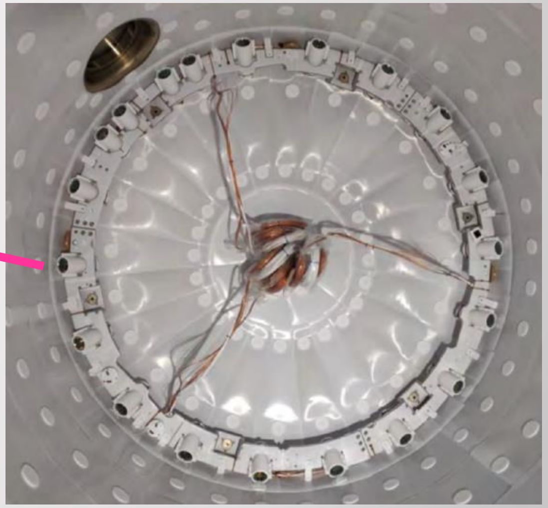
TPC bottom:



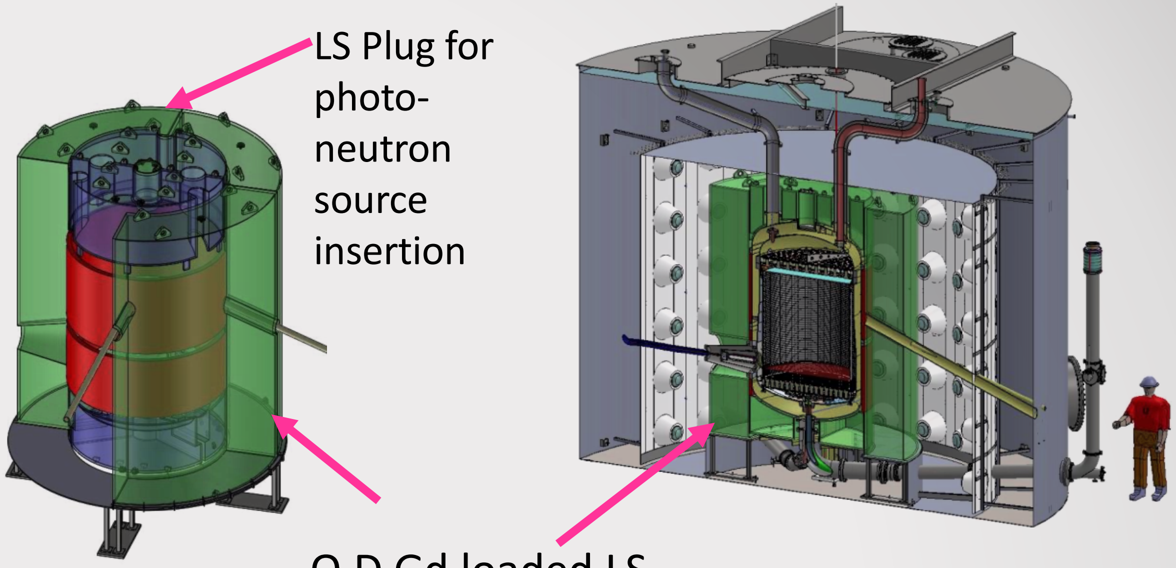
“Skin” instrumented with PMT’s:



View down into ICV:



Outer Detector (OD)


LS Plug for photo-neutron source insertion

O.D Gd loaded LS

- Anti-coincidence for γ and n.
- 17 tons of Gd loaded LS (LAB)
- Segmented, 4π “hermetic” coverage.
- 120 8” R5912 PMT’s (used in Daya Bay, etc), +HV
- LS Distilled at BNL
- Screened in Davis cavern.

  arXiv:1808.05595 NIMA 2019 05 055
- Goal: veto backgrounds efficiently but still minimize backgrounds to reduce dead-time.


Gd-LS Screener. 10^{-4} mBq/kg sens.

Tank placement at SURF

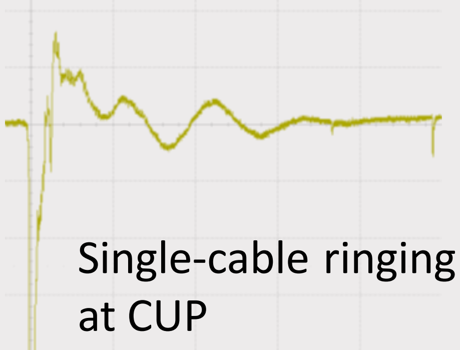
OD PMT testing and installation.

- PMTs tested in Korea and Brandies.
- Two-cable design eliminates piezo-electric ringing in ceramic decoupling cap.

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

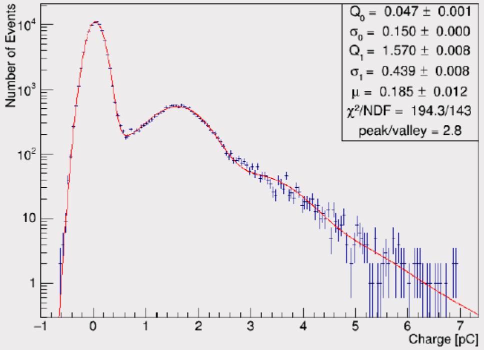
Installation in spring 2020

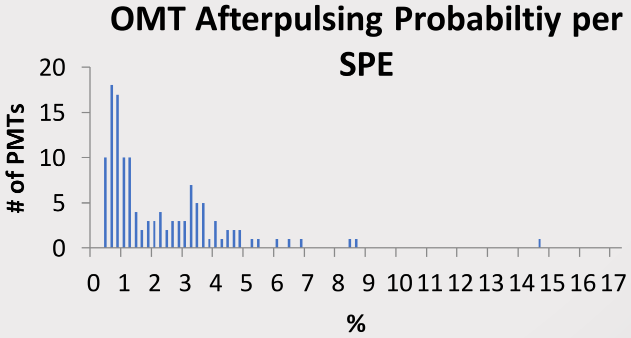
Dark box at CUP



Single-cable ringing at CUP

Single Photo-electron spectrum





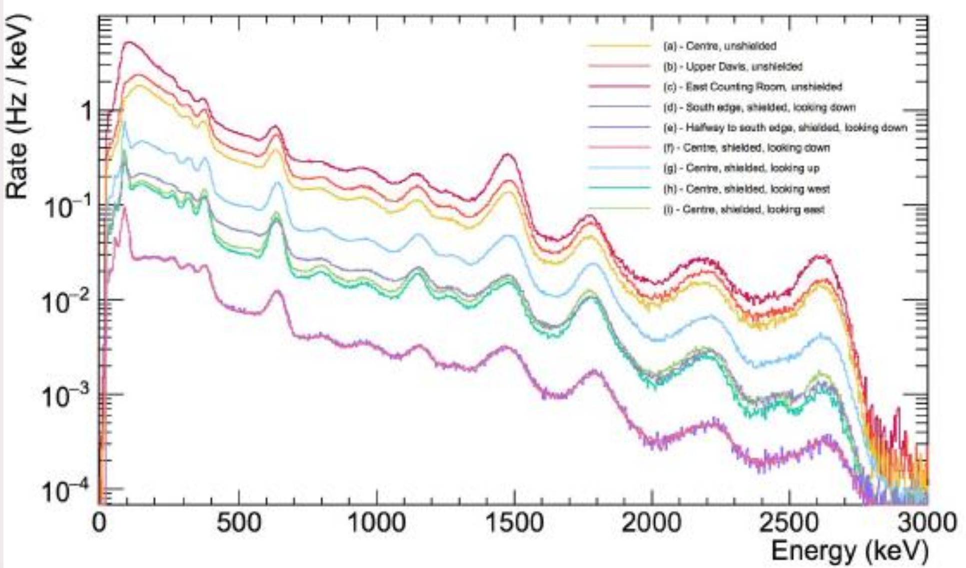
OMT Afterpulsing Probabiltiy per SPE

Test installation at SURF with Dummy PMTS

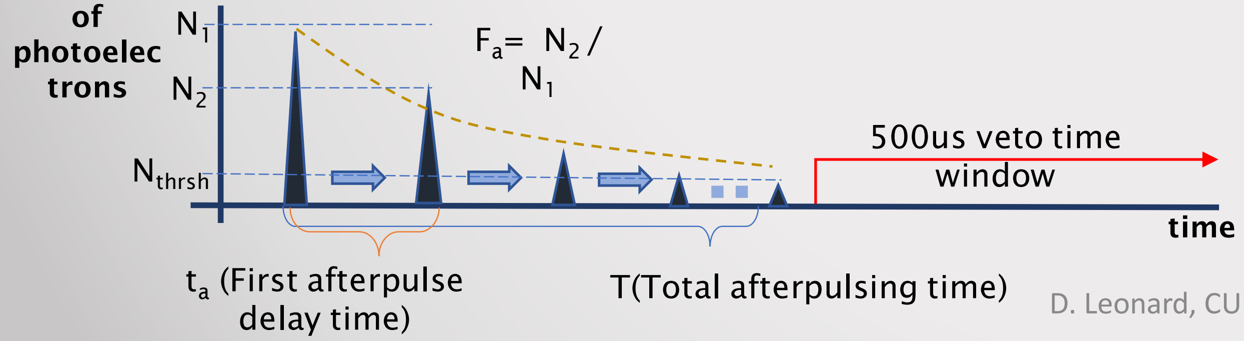
OD Dead Time

- 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.
- 5% Dead time goal requires < 100 Hz for 500 μs veto.
- Cavern activity measured with NaI about 4x below assumptions => ~ 30 Hz arXiv:1904.02112
- PMT measured activity < ~ 20Bq/PMT of each ^{238}U,^{232}Th,^{40}K => ~1Hz.
- Scintilator and other items ~ 20Hz.
- Total, around 50Hz, half of goal.

NaI water-tank gamma flux scan Oct 2017



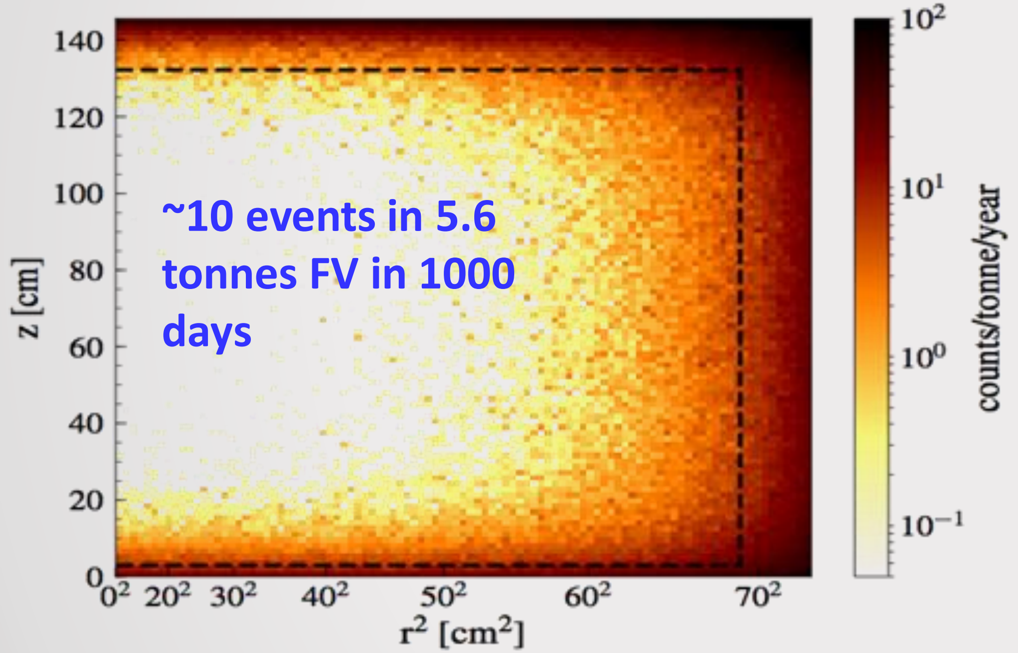
Multiple-afterpulsing deadtime modelled



Veto Performance (Skin +OD)

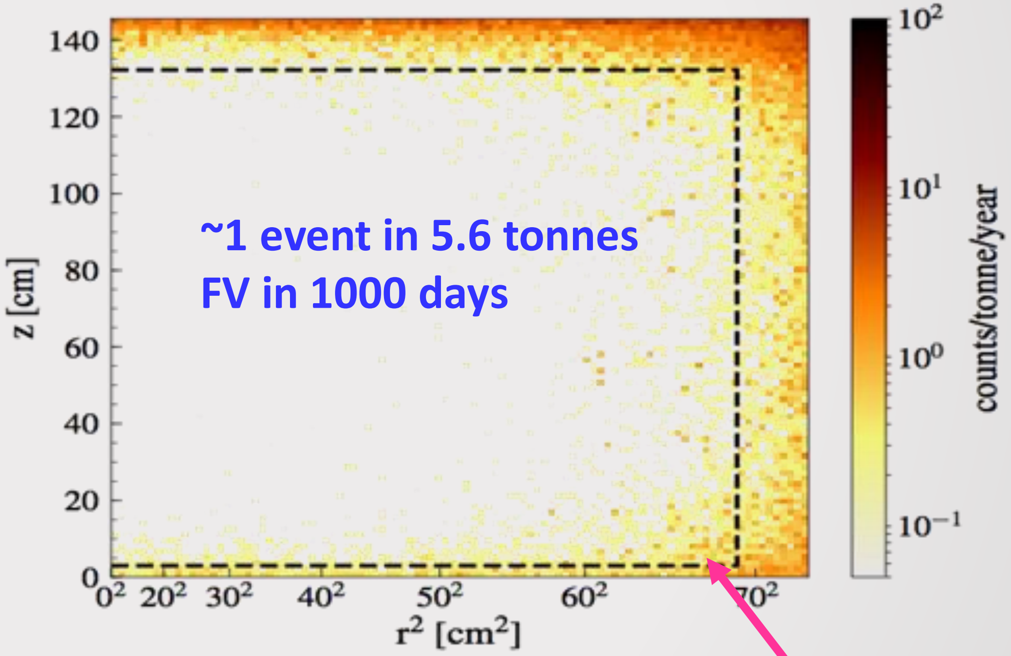
Enables Fiducial volume increase from 3.2 tonnes to 5.6 tonnes.

Without veto rejection



~10 events in 5.6 tonnes FV in 1000 days

With veto rejection

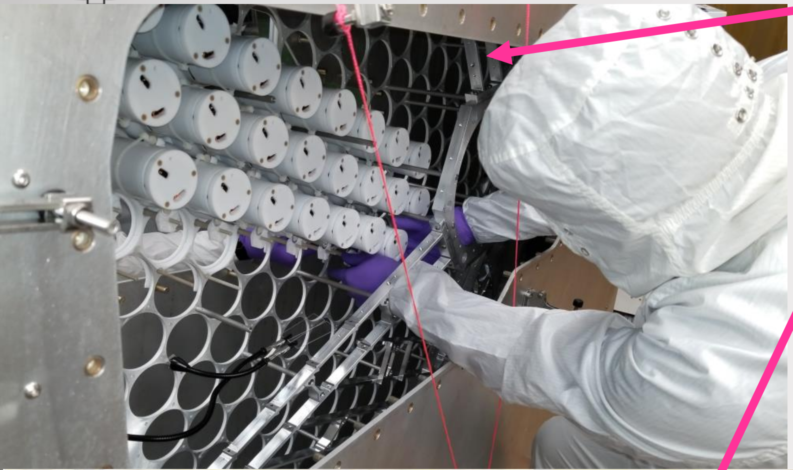


~1 event in 5.6 tonnes FV in 1000 days

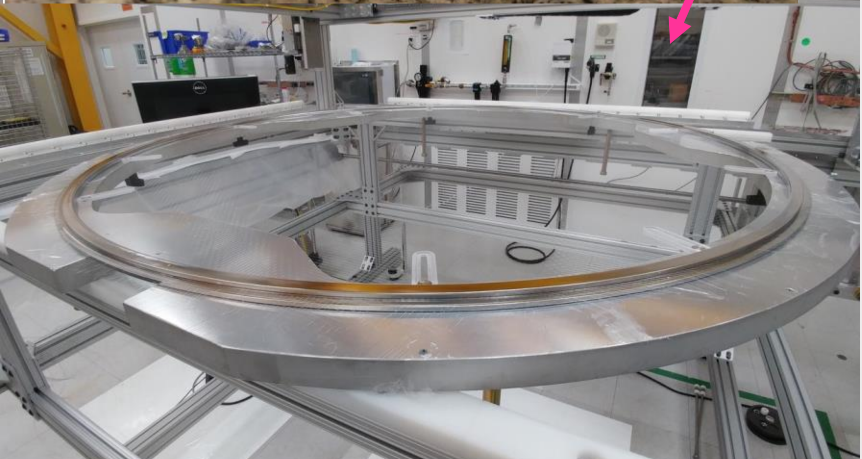
5.6 tonnes

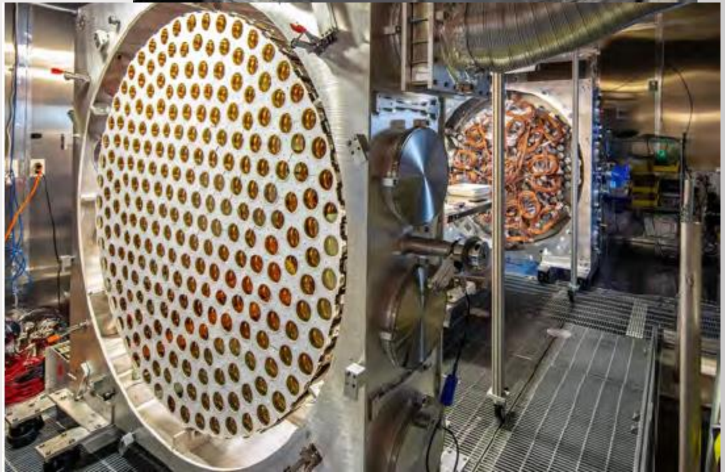
Single site nuclear recoil events in 6-30 keV region of interest

TPC Construction



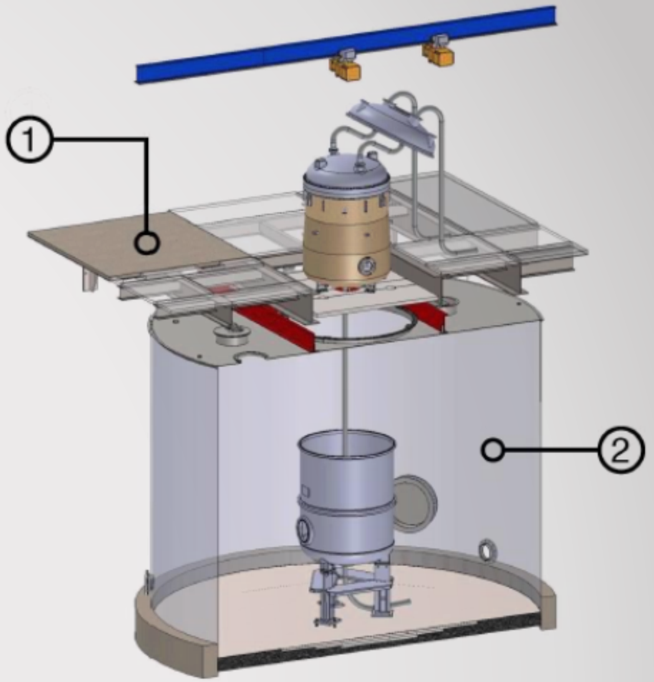
- Arrays constructed at Brown in low Rn, Dust-filtered enclosure.
- PTFE covered, light-tight field rings test assembly completed at LBNL.
- TPC grids being woven, with electron emission treatment (arXiv:1801.07231)
- Assembly completed and installed in inner vessel, fall, 2019.





TPC Moves to Underground

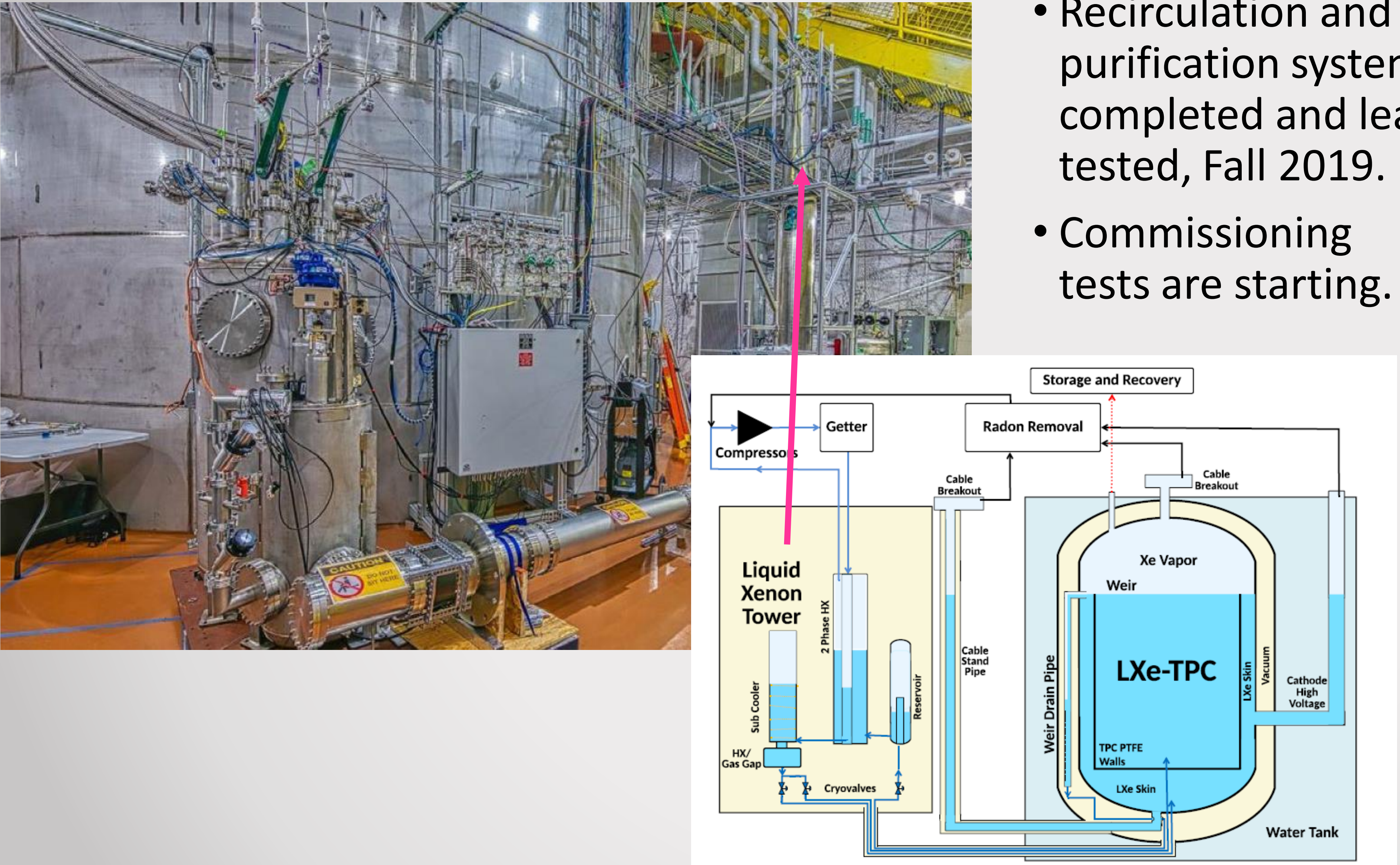
- Arrives in Davis Cavern in October, 2019 (left)
- Now preparing for installation in Rn reduced tent. (right)



Youtube timelapse

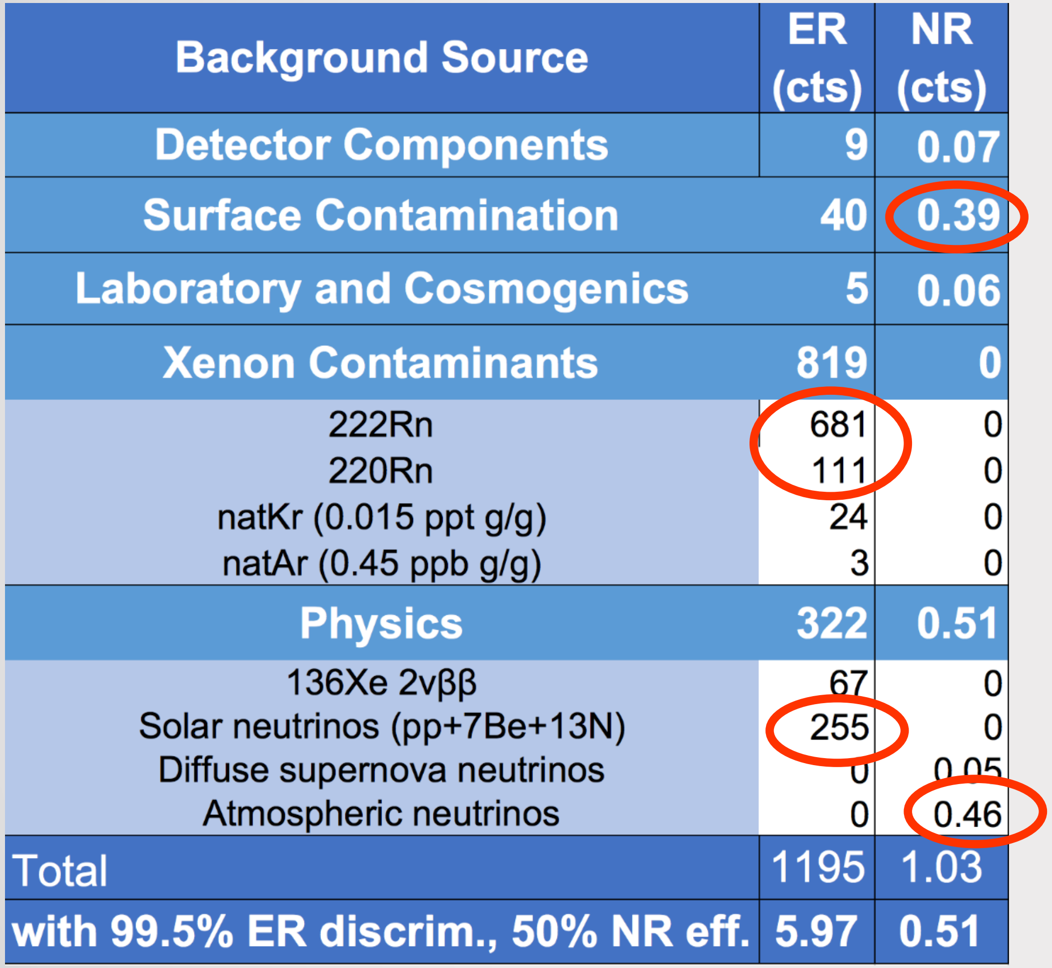
Xe Recirculation

- Recirculation and purification systems completed and leak tested, Fall 2019.
- Commissioning tests are starting.



Xe bottles now onsite for after ^{85}Kr removal.

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



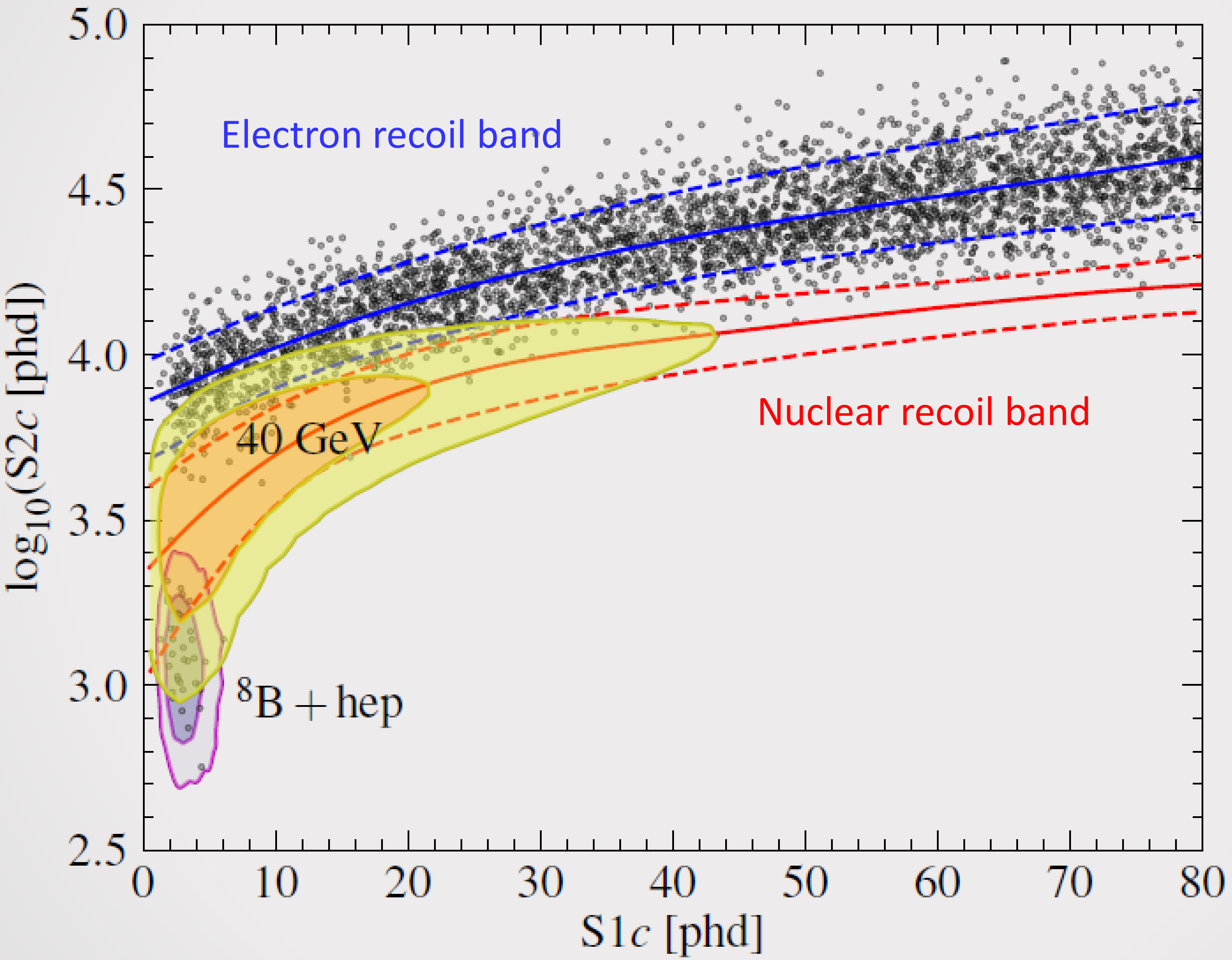
Background Source	ER (cts)	NR (cts)
Detector Components	**9**	**0.07**
Surface Contamination	**40**	**0.39**
Laboratory and Cosmogenics	**5**	**0.06**
Xenon Contaminants	**819**	**0**
222Rn	681	0
220Rn	111	0
natKr (0.015 ppt g/g)	24	0
natAr (0.45 ppb g/g)	3	0
Physics	**322**	**0.51**
136Xe 2νββ	67	0
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
- Charcoal chromatography for ^{85}Kr and ^{39}Ar removal.
  ^{nat}Kr/Xe ➔ 0.015ppt
- Radio-assay: HPGe, ICP-MS, NAA
- Rn emanation screening
  (2 µBq/kg targets)
- Rn removal > 10x doi:10.1016/j.nima.2018.06.076
- Rn and dust surface control:
  - Rn reduced cleanrooms,
  - Dust witness measurements <500ng/cm^3 onLXe surfaces.
  - TPC plateout <0.5mBq/m^2

Simulated exposure, 1000 days, 5.6 tonnes



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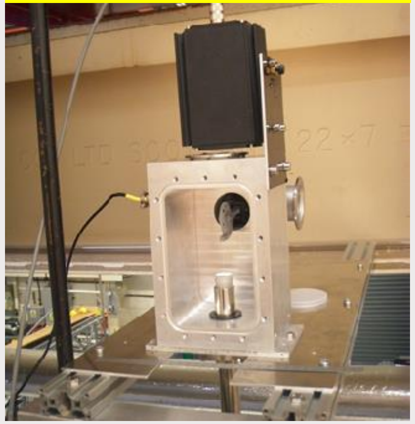
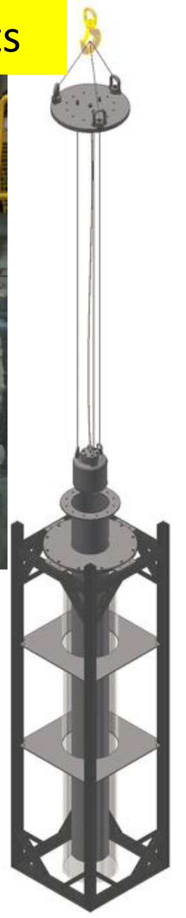
Calibration Systems

- 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
  - D2O scatter for reduced 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

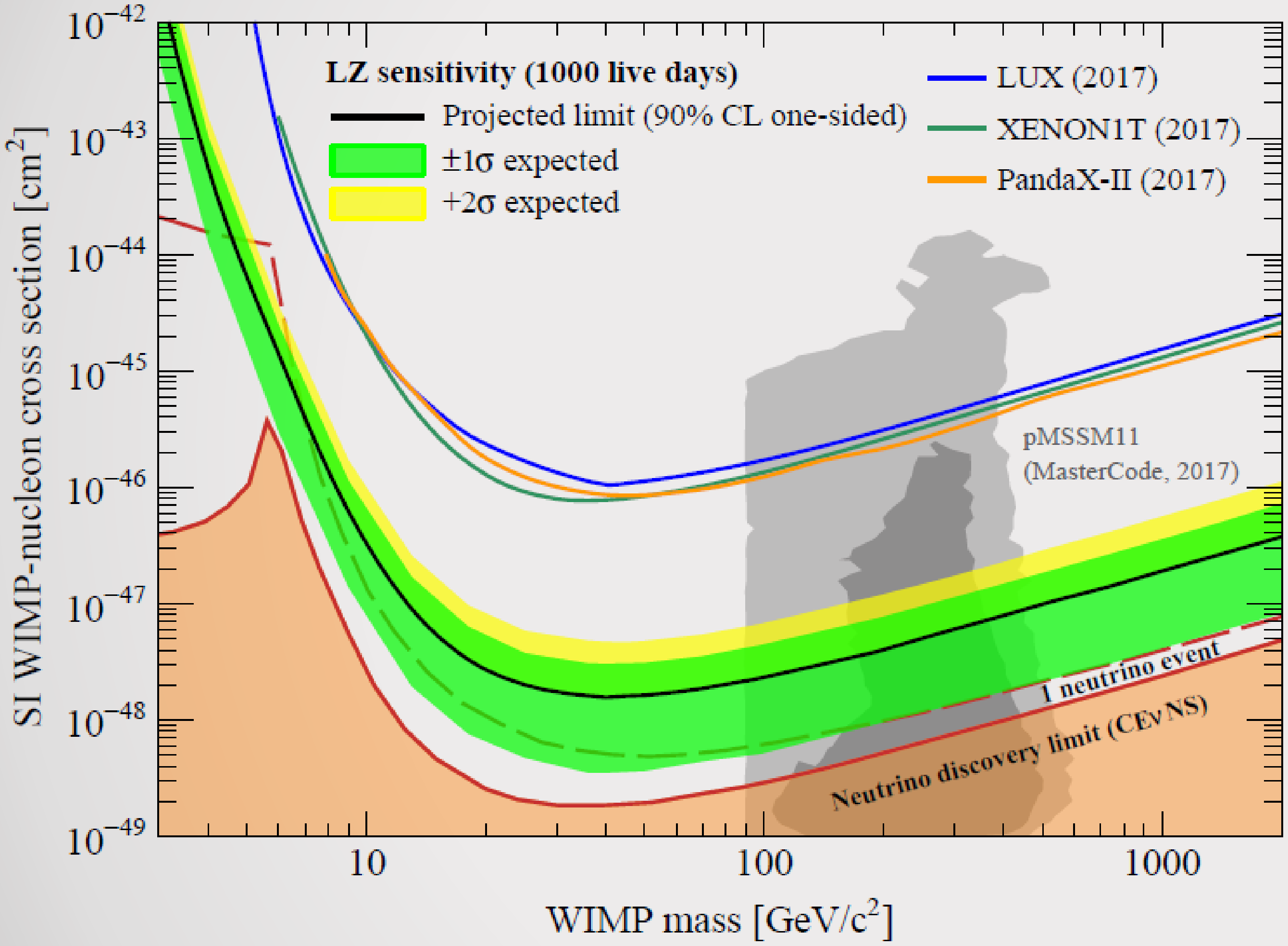


LBNL Tests



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.

- 5 sigma discovery potential:

6.7x10^{-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	Oct	TPC moves underground
2020	Spring	OD and electronics install., Cryogenics comissiong.
2020	Summer	Ready for operations (CD4)

The End of the Talk

Backup

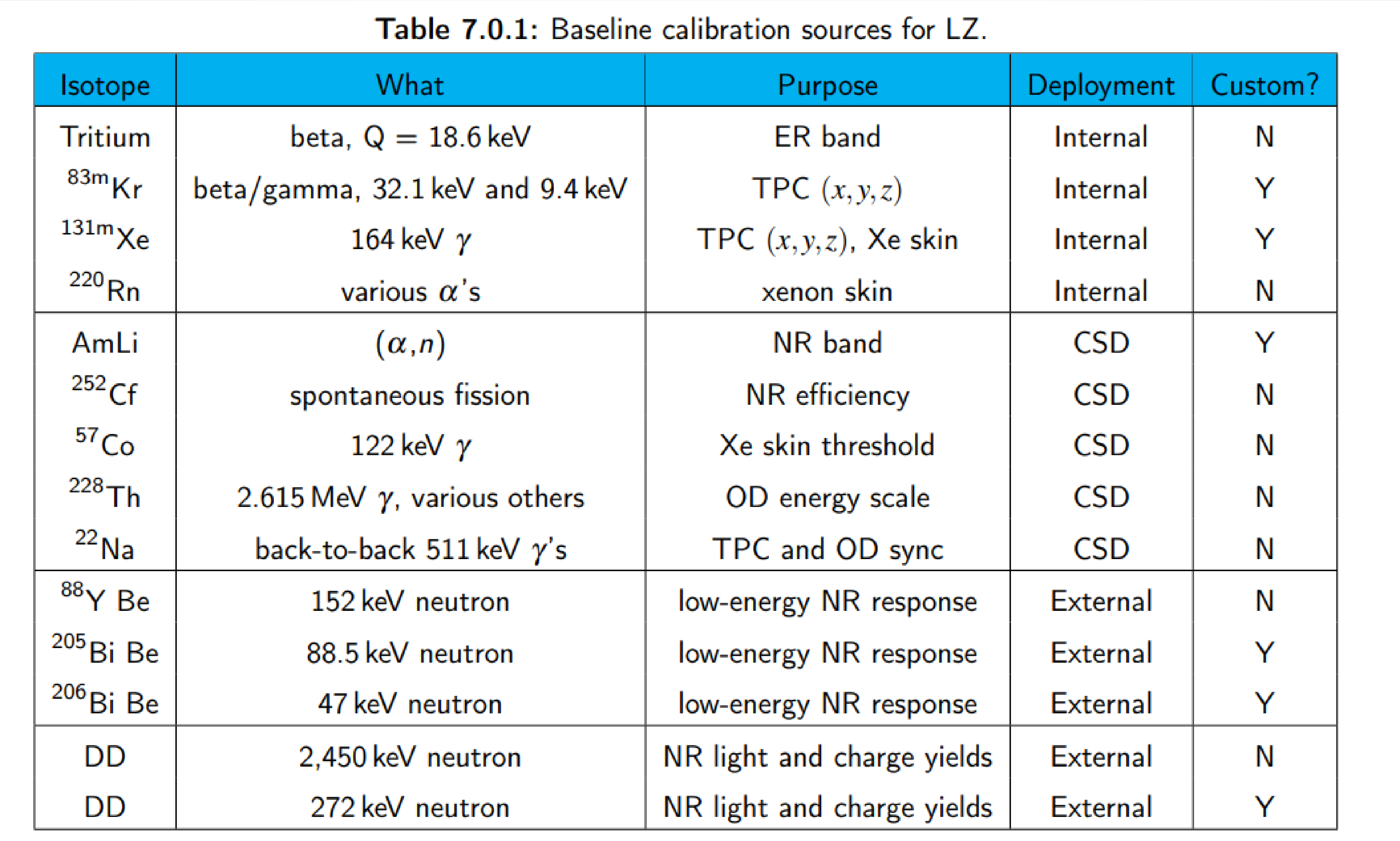
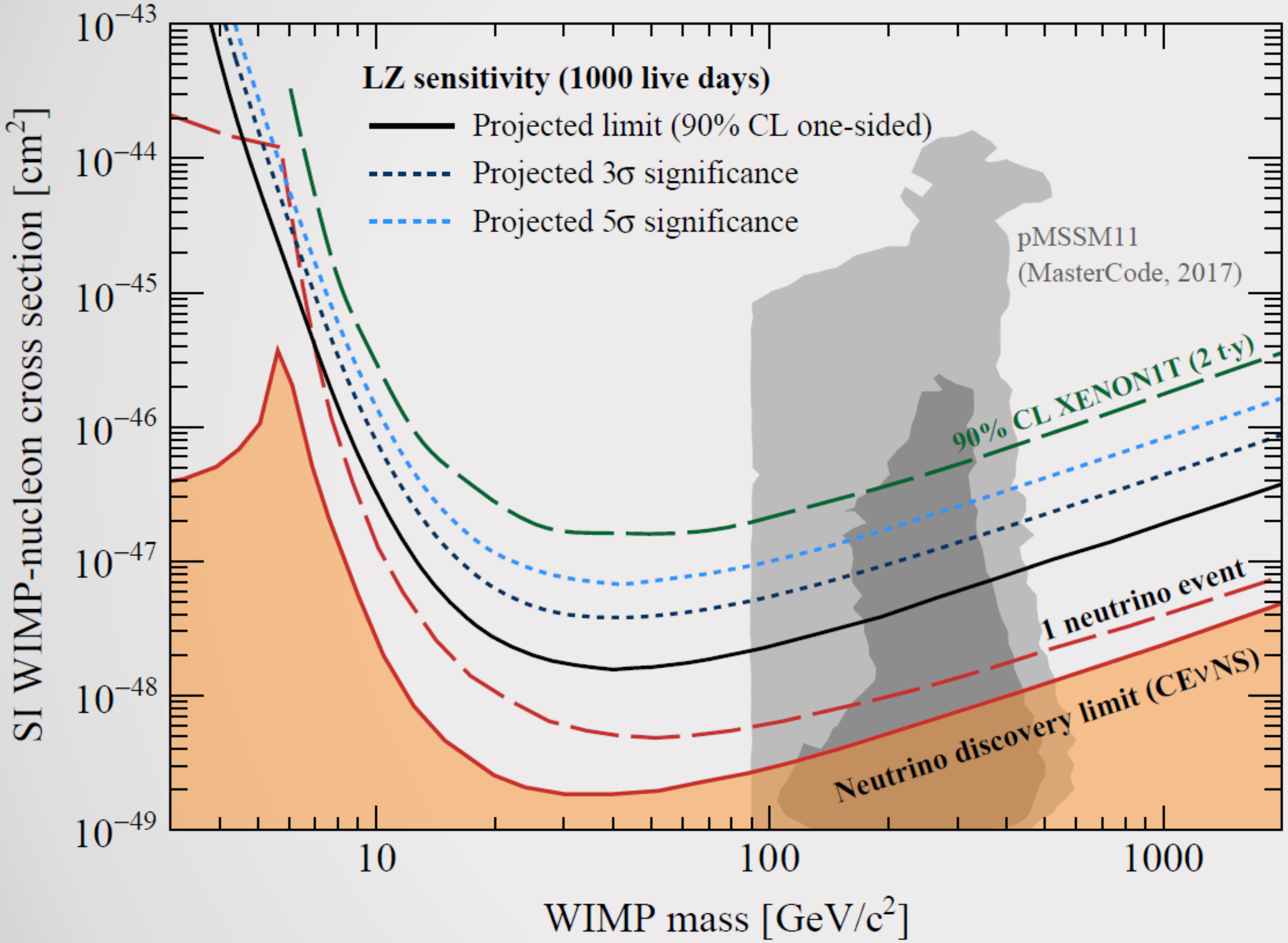


Table 7.0.1: Baseline calibration sources for LZ.

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

WIMP Discovery Potential



arXiv:
1802.06039

5 sigma discovery potential: 6.7x10^{-48} (5.6 tonnes, 1000 days livetime)

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