Status of the LUX-ZEPLIN (LZ) Experiment

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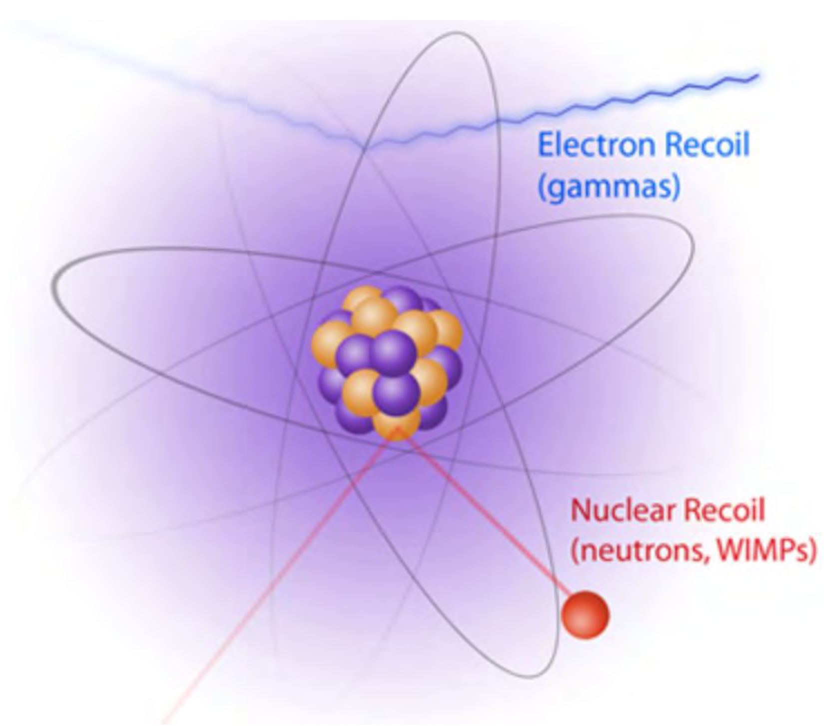
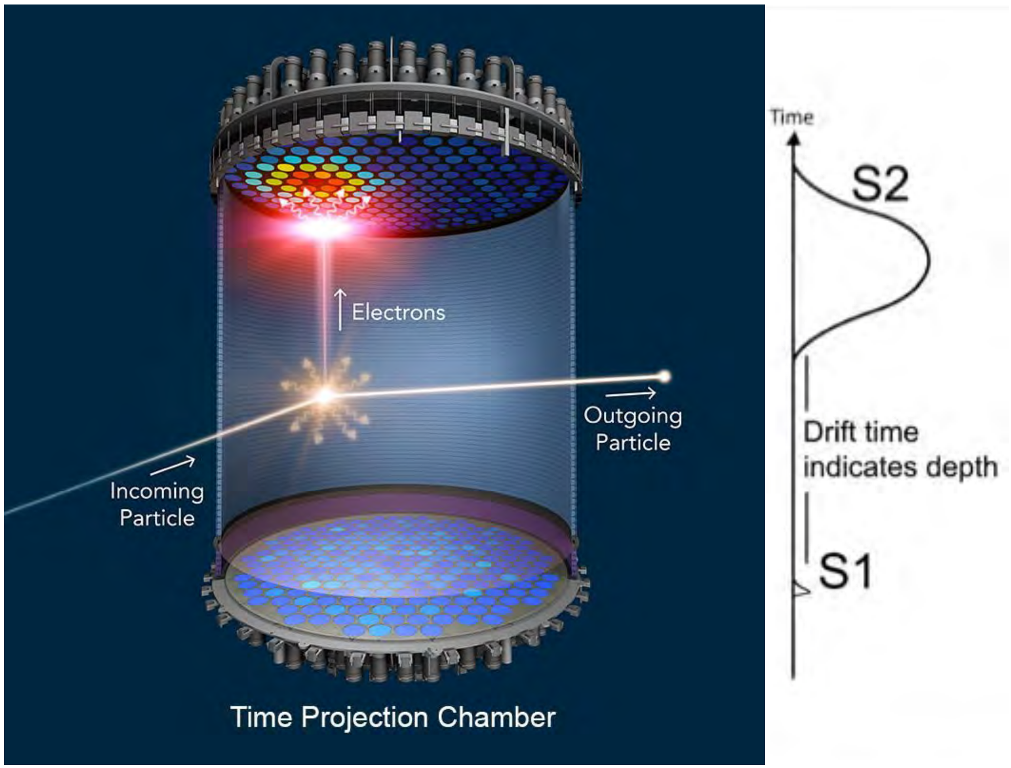
LUX-ZEPLIN (LZ)

- **LZ is a 10 tonnes liquid xenon time projection chamber detector that looks for anomalous xenon recoils events excess above the expected background levels, especially for weakly interacting massive particles (WIMPs), aka dark matter**

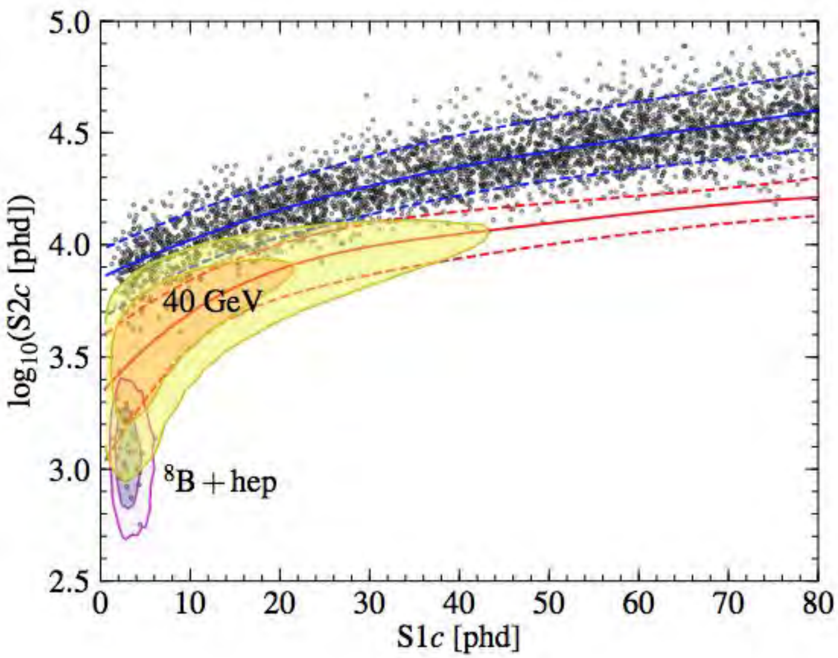




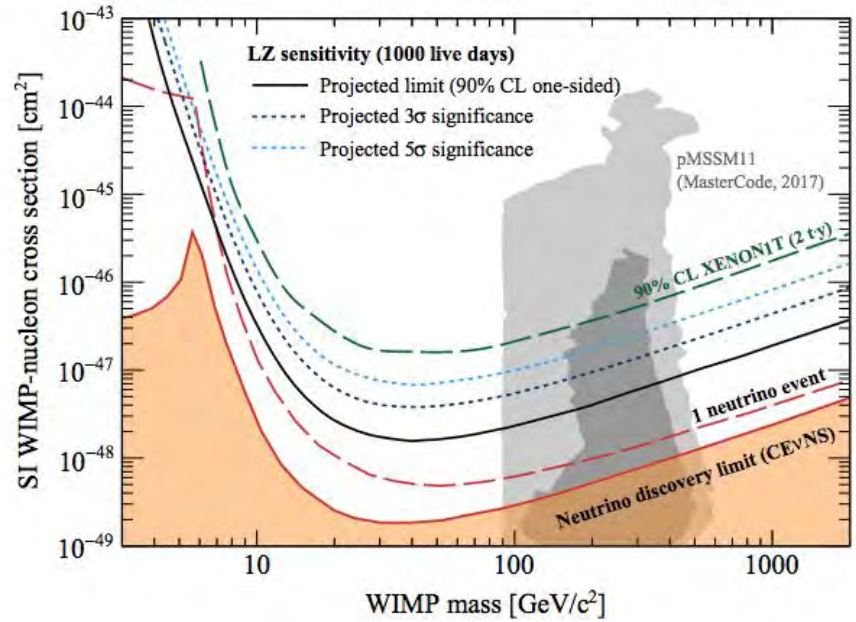
- **This talk focuses on the LZ detector construction status**

Physics Goals

1000-day simulation run of LZ



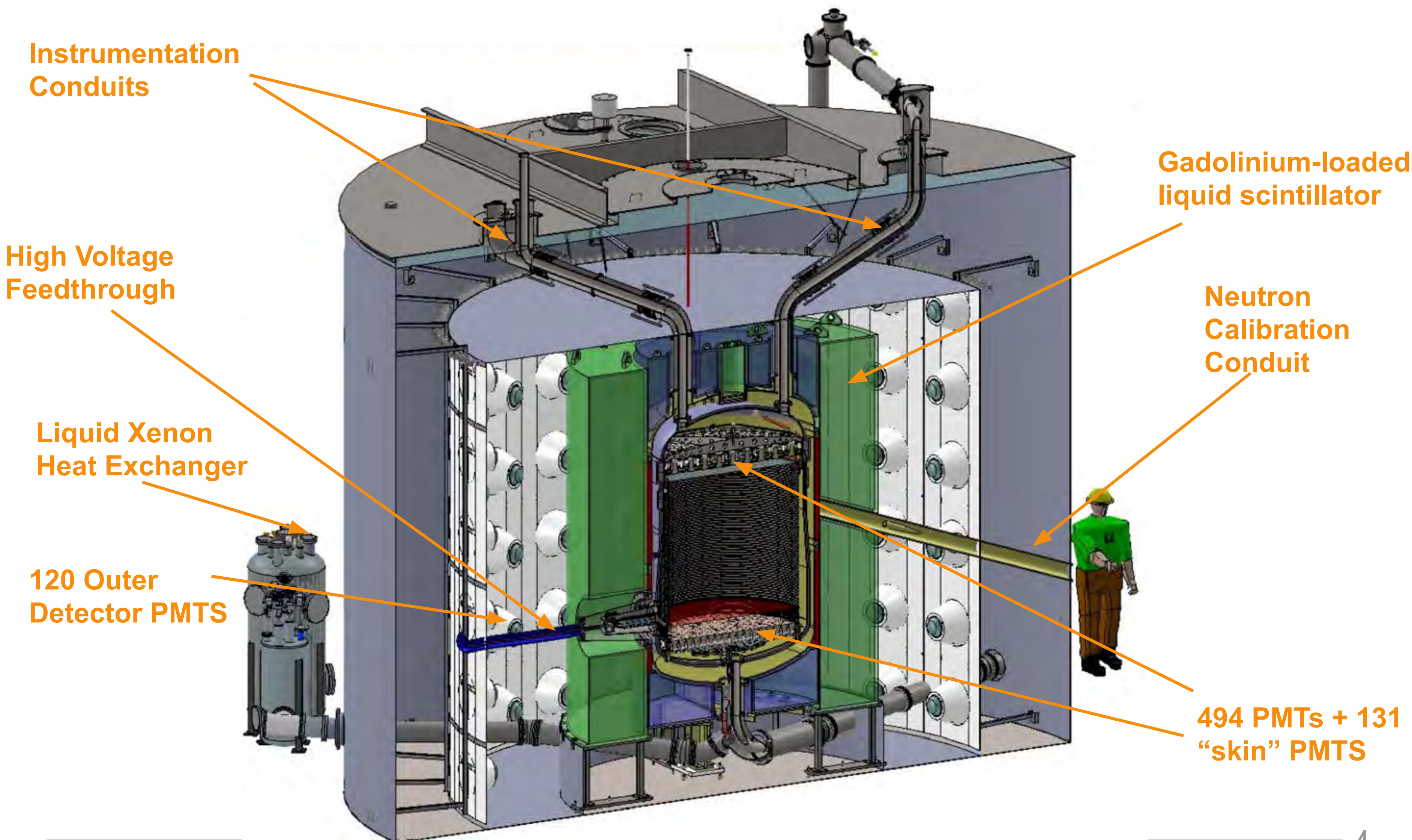
Spin-independent projected sensitivity limit



- **Although LZ main objective is to look for dark matter, it has a rich physics program that includes (but not limited to) the following potential searches:**
  - **WIMPs**
  - **Axion-like particles**
  - **Coherent neutrino scattering from solar neutrinos**
  - **Rare decays, eg. ^{124}Xe double electron capture, ^{136}Xe $2\nu\beta\beta$, $0\nu\beta\beta$ decay**
- **See David Woodward's talk on LUX analysis**

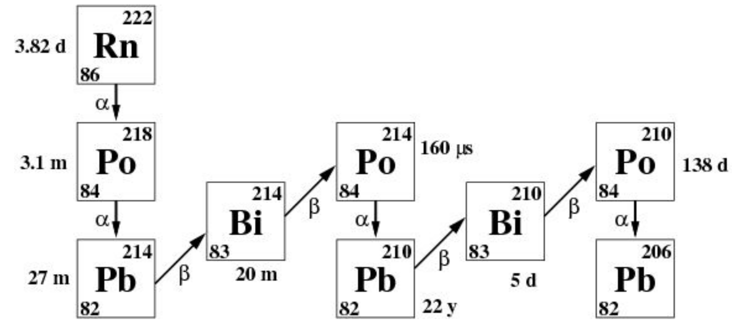
LZ Detector

- Detector submerged in a 8m diameter x 6m high water tank background shield



Background Sources, Suppression Strategies

- External backgrounds
  - Water tank 1.5 km underground + Gd-LS outer detector + xenon skin for veto
- Detector materials
  - Extensive radio-assay campaigns -- gamma screening, neutron activation analysis, ICPMS
- Radon emanation
  - Four radon emanation sites
  - Target radon activity - 2 μBq / kg



- Radon daughters and dust on surfaces
  - TPC assembled in radon-reduced cleanroom to limit dust exposure and radon daughter on surfaces
  - Dust (^{214}Pb) < 500 ng / cm^2 on all LXe surfaces
  - Rn-daughter plate on TPC walls (^{210}Pb alpha, n) < 0.5 mBq / m^2
- Xenon impurities / contaminants
  - Facility at SLAC using charcoal chromatography to remove ^{85}Kr and ^{39}Ar
  - Final Kr/Xe 0.015 ppt

Backgrounds Summary

- 5.6 tonnes fiducial volume, 1000 live-days WIMP search exposure, using 40 GeV WIMP in ~1.5 - 6.5 keV$_{ee}$ (6-30 keV$_{nr}$) ROI, after single scatter, fiducial and veto cuts

- WIMP sensitivity paper [arXiv:1802.06039](https://arxiv.org/abs/1802.06039)

- NR backgrounds mostly from neutrons coming from alpha,n on PTFE surfaces

- ER backgrounds mostly from radon daughters

Background Source	Mass (kg)	^{238}U$_e$	^{238}U$_l$	^{232}Th$_e$	^{232}Th$_l$	^{60}Co	^{40}K	n/yr	ER (cts)	NR (cts)
		mBq/kg								
Detector Components										
PMT systems	308	31.2	5.20	2.32	2.29	1.46	18.6	248	2.82	0.027
TPC systems	373	3.28	1.01	0.84	0.76	2.58	7.80	79.9	4.33	0.022
Cryostat	2778	2.88	0.63	0.48	0.51	0.31	2.62	323	1.27	0.018
Outer detector (OD)	22950	6.13	4.74	3.78	3.71	0.33	13.8	8061	0.62	0.001
All else	358	3.61	1.25	0.55	0.65	1.31	2.64	39.1	0.11	0.003
								subtotal	**9**	**0.07**
Surface Contamination										
Dust (intrinsic activity, 500 ng/cm^2)									0.2	0.05
Plate-out (PTFE panels, 50 nBq/cm^2)									-	0.05
^{210}Bi mobility (0.1 µBq/kg LXe)									40.0	-
Ion misreconstruction (50 nBq/cm^2)									-	0.16
^{210}Pb (in bulk PTFE, 10 mBq/kg PTFE)									-	0.12
								subtotal	**40**	**0.39**
Xenon contaminants										
^{222}Rn (1.81 µBq/kg)									681	-
^{220}Rn (0.09 µBq/kg)									111	-
^{nat}Kr (0.015 ppt g/g)									24.5	-
^{nat}Ar (0.45 ppb g/g)									2.5	-
								subtotal	**819**	**0**
Laboratory and Cosmogenics										
Laboratory rock walls									4.6	0.00
Muon induced neutrons									-	0.06
Cosmogenic activation									0.2	-
								subtotal	**5**	**0.06**
Physics										
^{136}Xe $2\nu\beta\beta$									67	-
Solar neutrinos: pp+^{7}Be+^{13}N									255	-
Diffuse supernova neutrinos (DSN)									-	0.05
Atmospheric neutrinos (Atm)									-	0.46
								subtotal	**322**	**0.51**
Total									1195	1.03
Total (with 99.5% ER discrimination, 50% NR efficiency)									5.97	0.52
Sum of ER and NR in LZ for 1000 days, 5.6 tonne FV, with all analysis cuts									**6.49**	

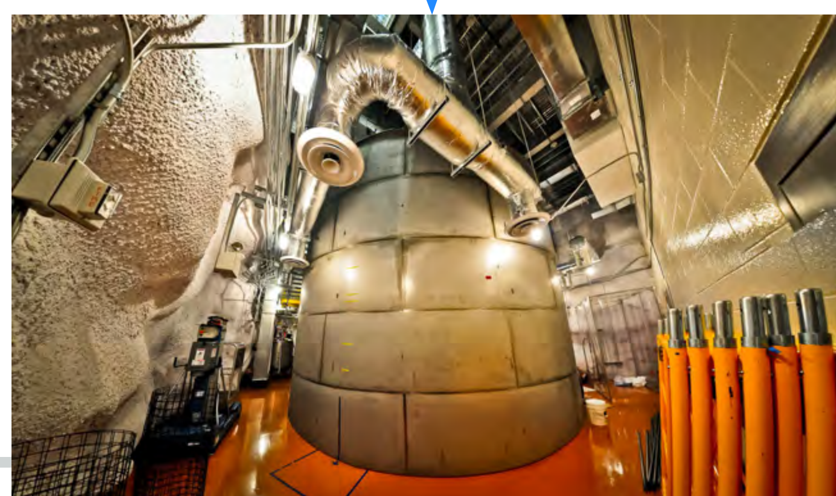
SURF

- Whole detector + water tank infrastructure will be located at the 4850’ (1.5 km) level of Sanford Underground Research Facility in Lead, South Dakota

- The rock reduces cosmic muon flux by over 6 orders of magnitude

- Detector shown in previous slide now being constructed in the SURF Surface Assembly Lab with radon reduction system

4850 feet



Cryostat Vessel

- Delivered from the UK to SURF in May 2018
- Specific low background titanium material used for vessel production (arXiv:1702.02646)
- Acceptance tests complete
- Outer vessel taken underground, staged in water tank

PMT System in Liquid Xenon TPC

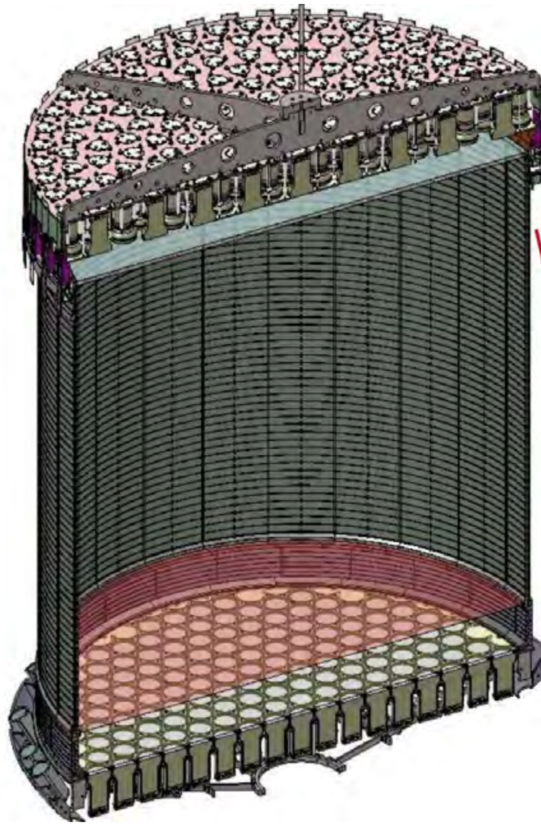
253 R11410 PMTs in top array

93 R8520 1 inch skin PMTs monitoring skin region below

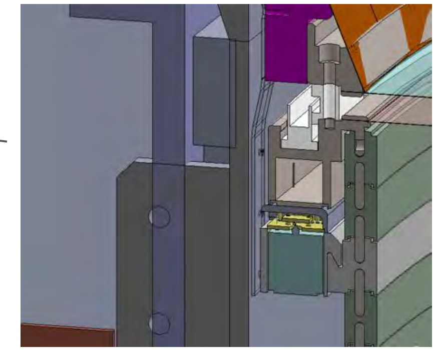
PMT Base

PTFE Reflectors

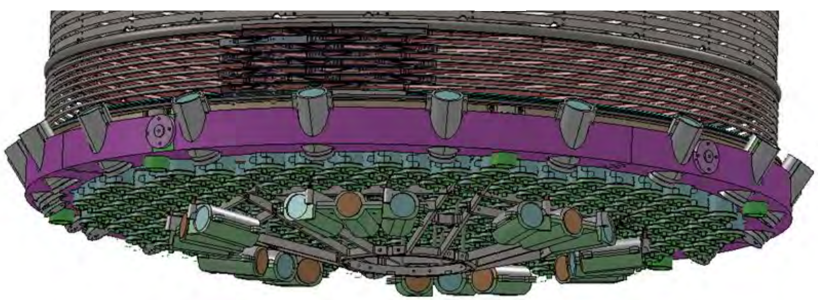
PTFE Sleeve and Back Reflectors for Bottom PMTs to recycle light



PTFE electric field cage



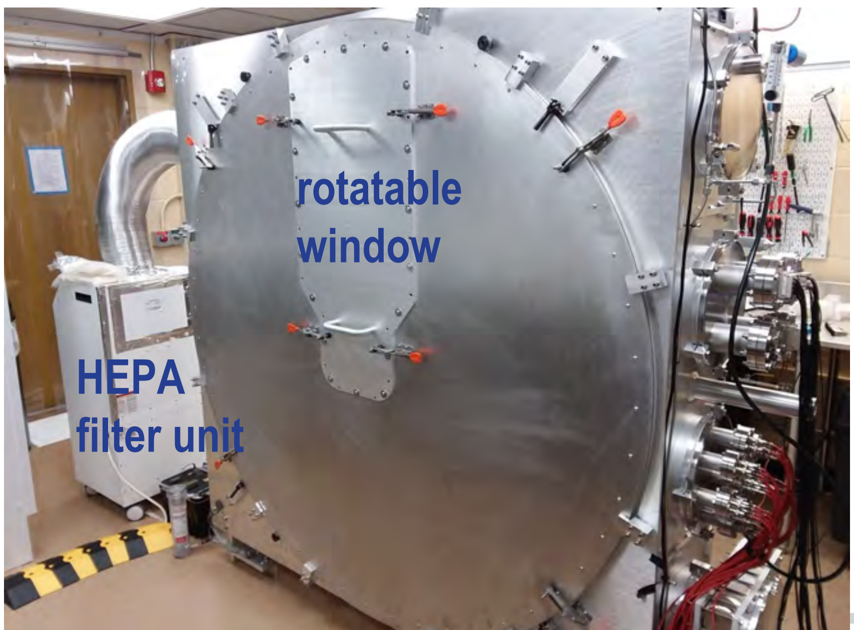
241 R11410 PMTs in bottom array



38 LUX R8778 PMTs in bottom side skin and dome skin region

PMT Testing & Array Assembly

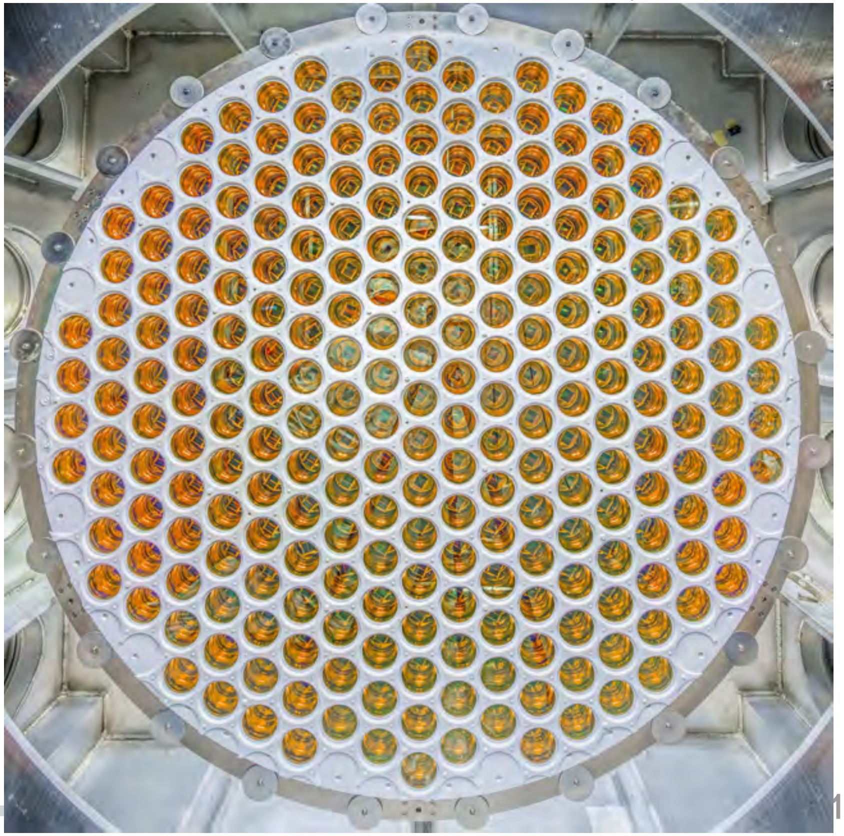
- 14,000 hours of R11410 PMT performance testing 2016-2018
- Testing program includes warm testing, cold testing, Ge screening
- Array statistics:
  - Average QE_H(*) : 33% (*) Hamamatsu QE is determined at factory at room temp. using continuous blue light source
  - Average cold dark rate at -1500 V (in 4 bar N2 gas) : 36 Hz
  - Average cold gain at HV bias of -1500 V : 6 x 10^6
- 494 PMTs were installed during Feb - Dec 2018 in dedicated cleanroom at Brown University, in ultraclean (class 10) vessels called PALACE (PMT Arrays Lifting And Commissioning Enclosure) with extensive dust monitor and QA.
  - 19,000 parts installed, 6000 person-hours assembly



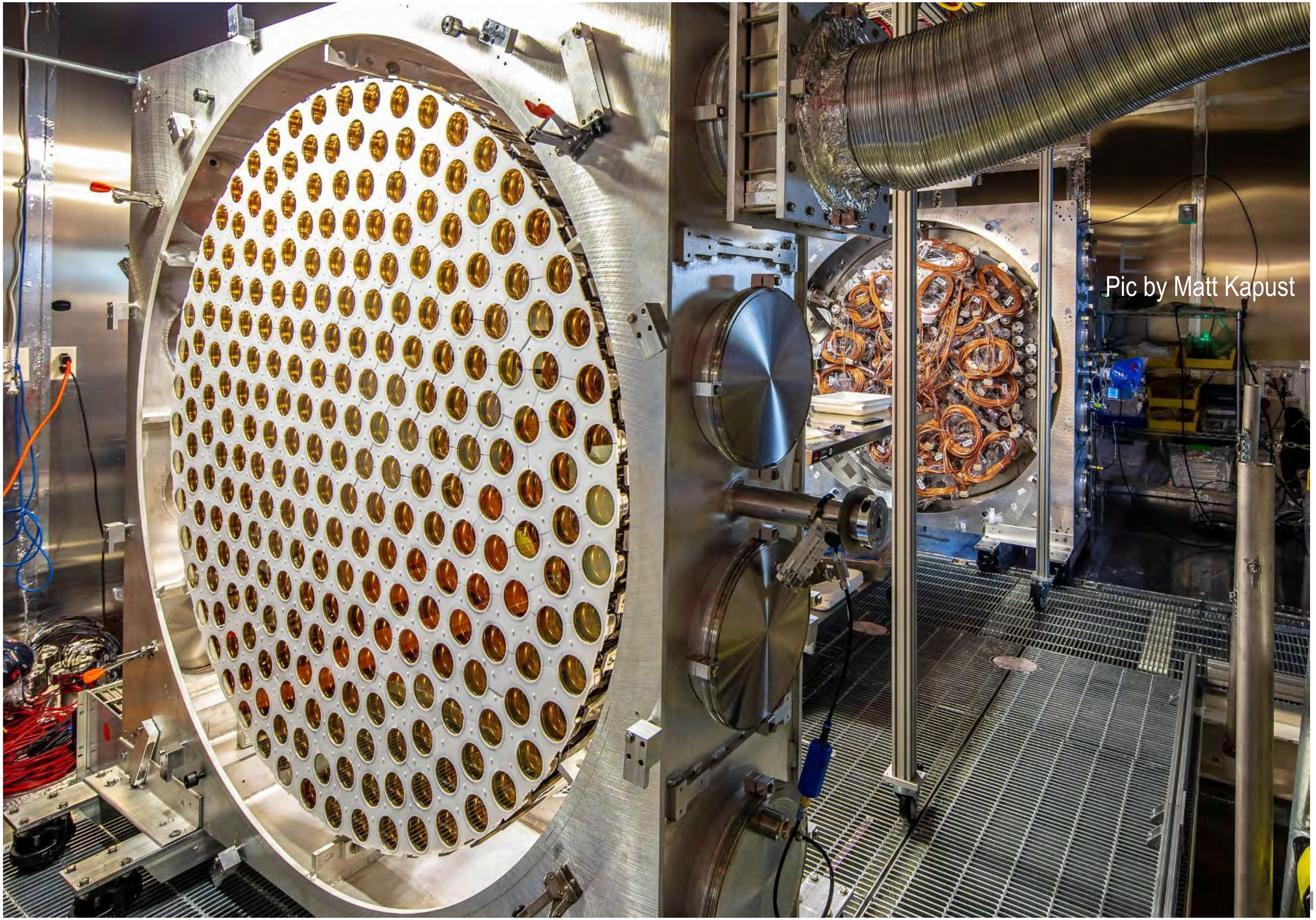
PMT Array Delivery

- Bottom array delivered to SURF in Dec 2018 ; top array delivered in Jan 2019
- Custom dual spring pallet, air ride truck, and acceleration monitoring throughout
- Recorded data during drive consistent with goals (<5 g impacts throughout)
    - No effect on PMT functionality observed during post-transport SURF checkouts
- PTFE field cage construction started from the bottom PMT Array after they passed acceptance tests at SURF

Pic by Matt Kapust

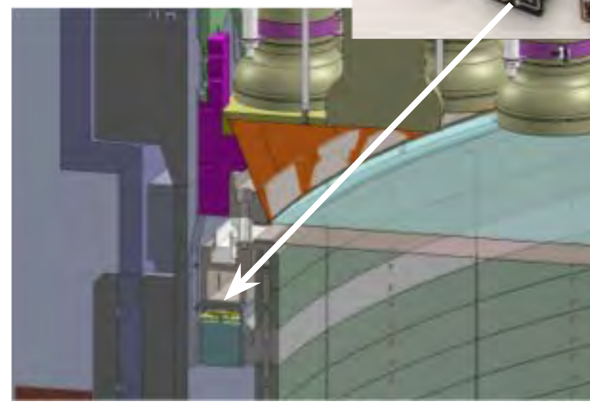


PMT Arrays at SURF SAL

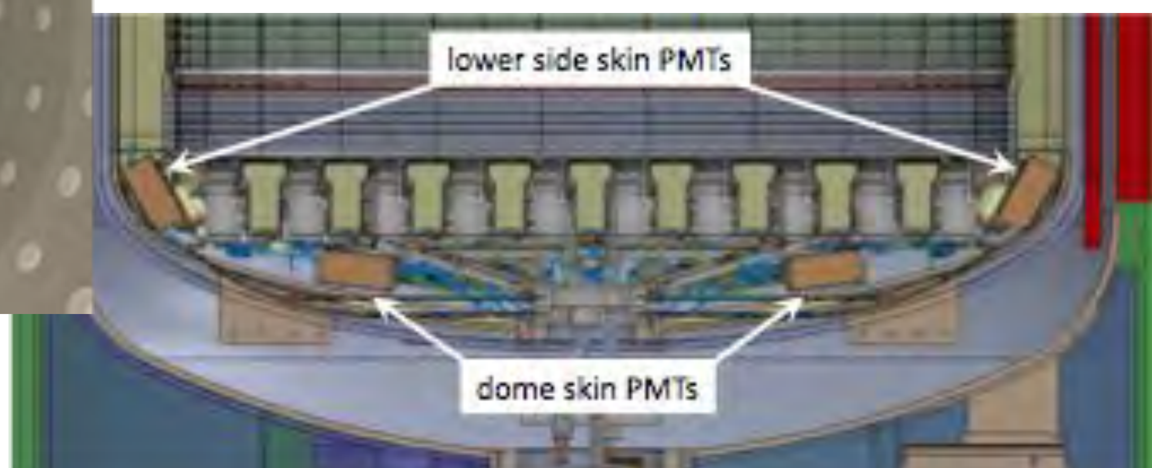


Veto System - Skin PMTs

- Top side skin - 93 R8520 1” PMTs looking down into LXe
- R8520 PMTs all delivered and tested at Edinburgh, UK, all PMTs passed specifications, accepted at SURF
- Bottom side skin - 20 R8778 2” (LUX) PMTs looking up
- Dome skin region - 18 more R8778 PMTs

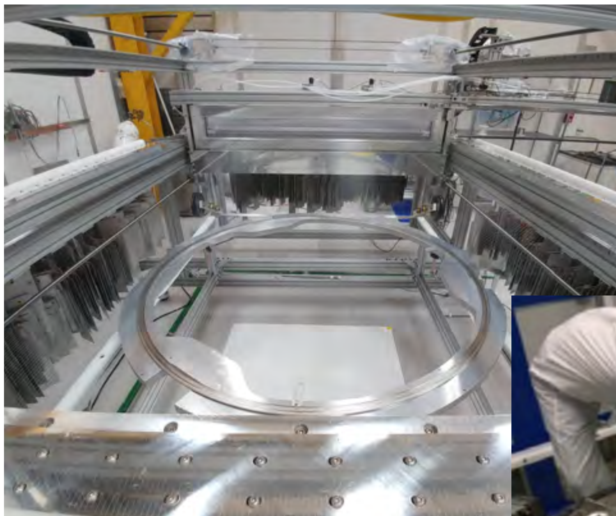


Bottom side skin assembly and PTFE tiling

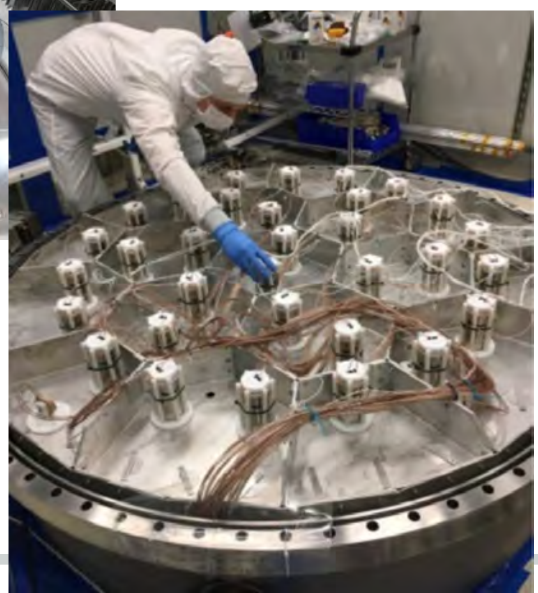


HV Grids

- Bottom grid completed and delivered from SLAC to SURF in May 2019
- Cathode grid manufacture done, in last stage of shipment preparation
- Gate and anode grids being tested at SLAC System Test
- Post-weaving wire treatment to reduce electron emission (arXiv:1801.07231)
- Automated loom in action: https://www.youtube.com/watch?v=yNycDcMQkss



Grid weaving loom and testing facility at SLAC

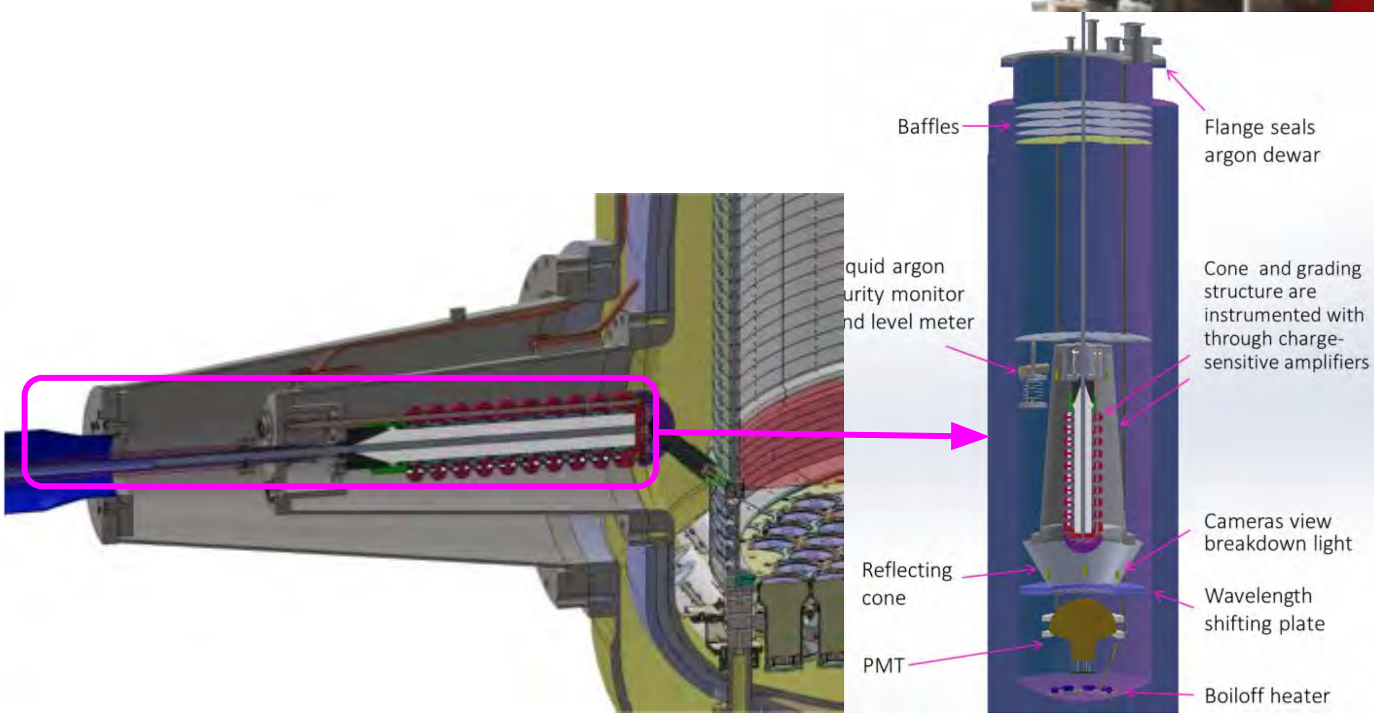


→ SURF SAL

Cathode HV

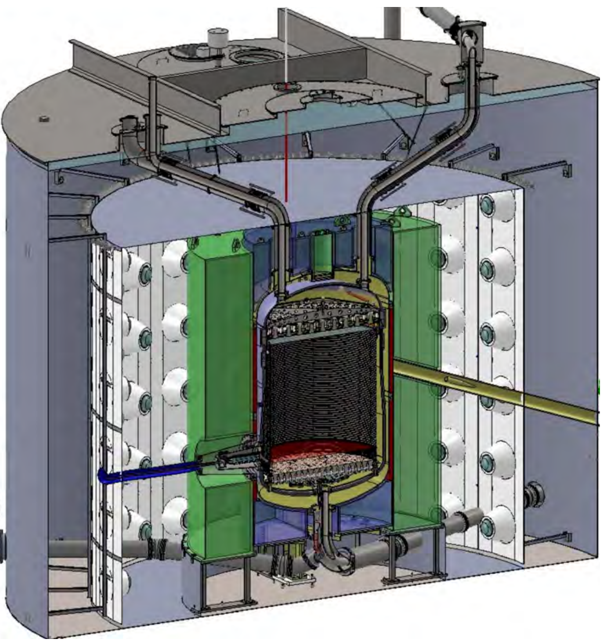
- Target voltage in LZ - 50 kV
- Test of cathode cable feedthrough grading structure in liquid argon successfully reached 120 kV (test setup shown on the right)
- Other components fabrication underway

LAr test setup at LBNL



Outer Detector

- Gadolinium-loaded liquid plastic scintillator in 10 acrylic tanks surrounded by 120 Hamamatsu R5912 8” PMTs
- Scintillator delivery about half complete, ahead of schedule
- All 4 side tanks tanks manufacture completed and delivered, staged in SURF 4850’ level water tank Nov, 2018
- All PMTs delivered, testing completed by IBS Korea
- PMT mounts fabrication underway, expect installation fall 2019

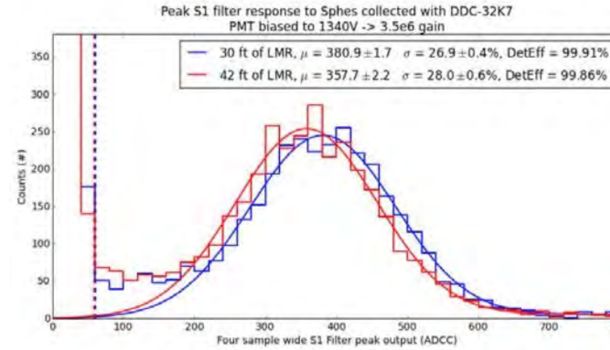


Cryogenics, Xenon Purification

- ~6.5 tonnes xenon in hand, remaining xenon contracted ; cylinder packs and 4 compressors delivered to PSL
- Kr removal system at SLAC ready to start July - end of 2019
- Thermosyphons in production, staged delivery on schedule since Oct 2018
- Test cryostat for circulation test installed at SURF underground
- Xenon purification getter at SURF, system designed to be capable of 500 slpm circulation rate, 2.3 days to purify 10 tonnes of xenon

DAQ Electronics

- Good single photoelectron detection efficiency >95% seen in electronic chain test at target operation gain
- Production of 32-channel digitizers began
- Programmable logic controllers (PLC) delivered
- Power supplies delivered ; electronics racks and cable trays design finalized
- Online event display and data quality monitor, run control systems are being developed



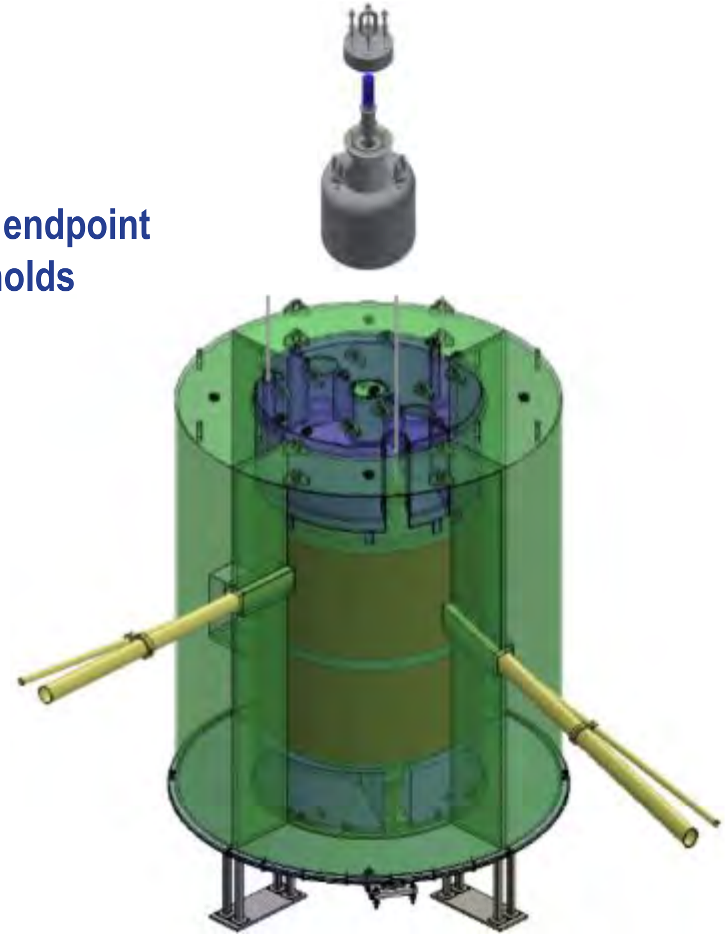
Excellent results obtained with prototype 1.

Chain Test Images

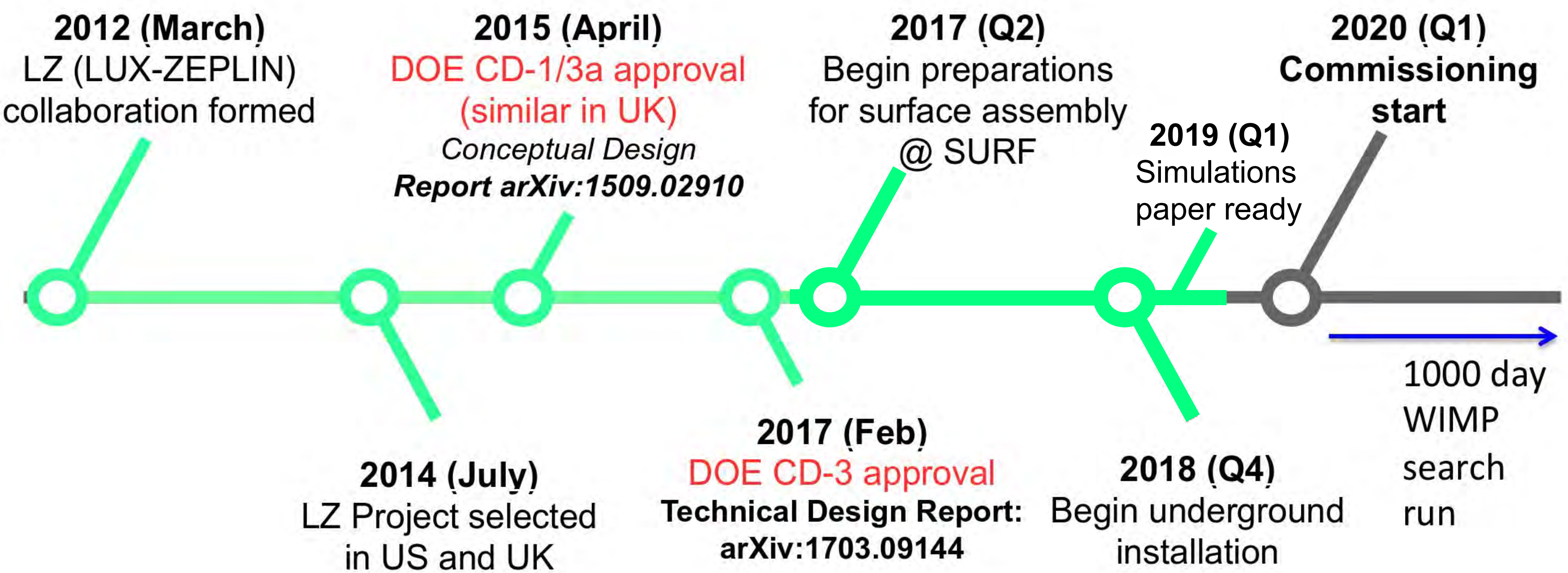
Calibrations

- Internal sources
  - ^{83m}Kr, ^{14}C, ^{220}Rn, tritium in CH3T (injected into xenon)
  - ^{131m}Xe as its own calibration source too
  - Calibrate ER light and charge yields, light collection efficiency, electron extraction efficiency, detector thresholds, corrections etc.

- External sources
  - D-D neutron (through 2 conduits)
    - 2.45 MeV monoenergetic neutrons → 74 keV$_{NR}$ endpoint
    - Calibrate NR light and charge yields and thresholds
  - Photoneutron (from top of detector)
    - ^{88}Y Be: 152 keV neutron → 4.6 keV$_{NR}$ endpoint
    - ^{205}Bi Be: 88 keV neutron → 2.7 keV$_{NR}$ endpoint
    - Calibrate low mass WIMPs, ^{8}B neutrinos
  - Other commercial sources (source tube on side)
    - ^{57}Co, ^{22}Na, ^{252}Cf, etc.



LZ Timeline



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 (Feb)
DOE CD-3 approval
Technical Design Report: arXiv:1703.09144
2017 (Q2)
Begin preparations for surface assembly @ SURF
2018 (Q4)
Begin underground installation
2019 (Q1)
Simulations paper ready
2020 (Q1)
Commissioning start
1000 day WIMP search run

Collaboration

1)IBS-CUP (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)Yale University (US)