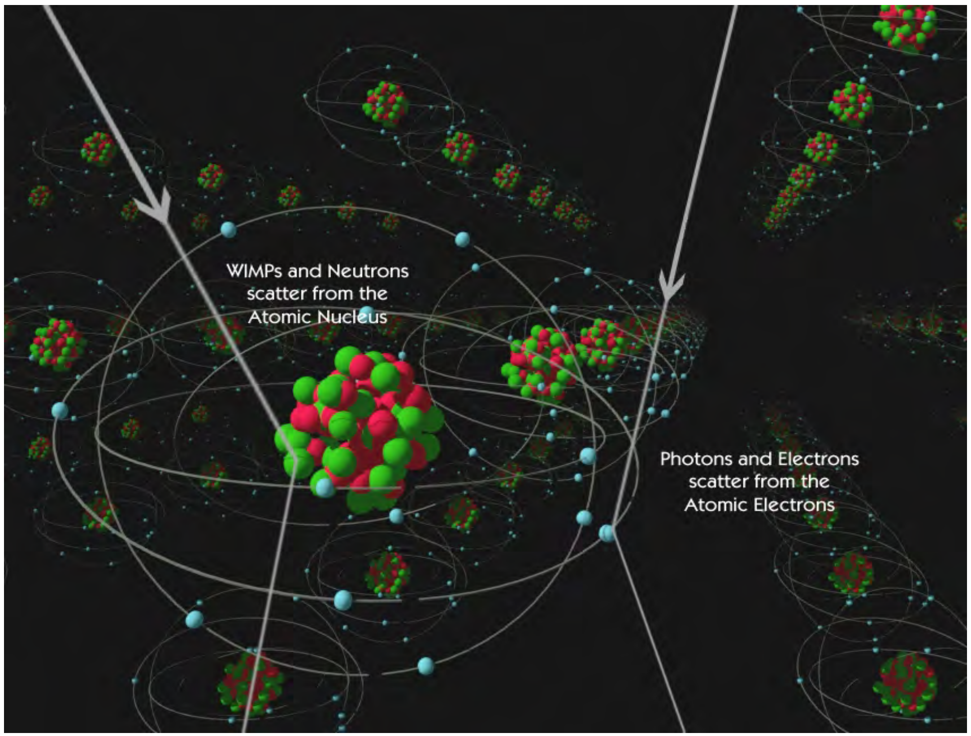
Status of the LUX-ZEPLIN Dark Matter Experiment

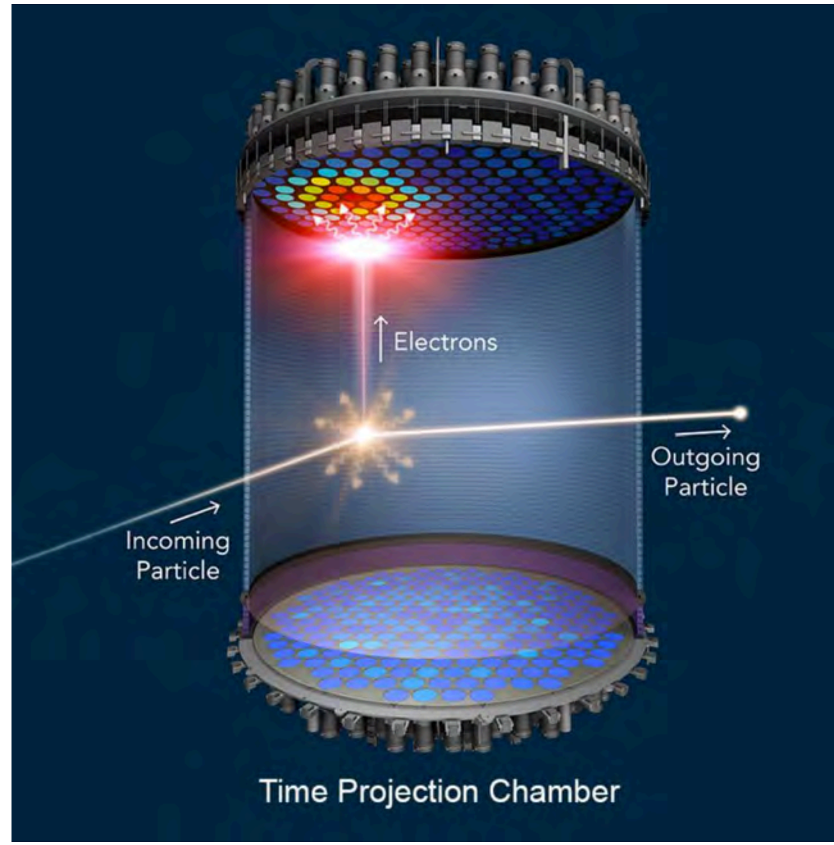
Carter Hall, University of Maryland

June 30, 2018

NDM 2018, Daejeon, Korea

A WIMP search with 10 tonnes of Liquid Xenon

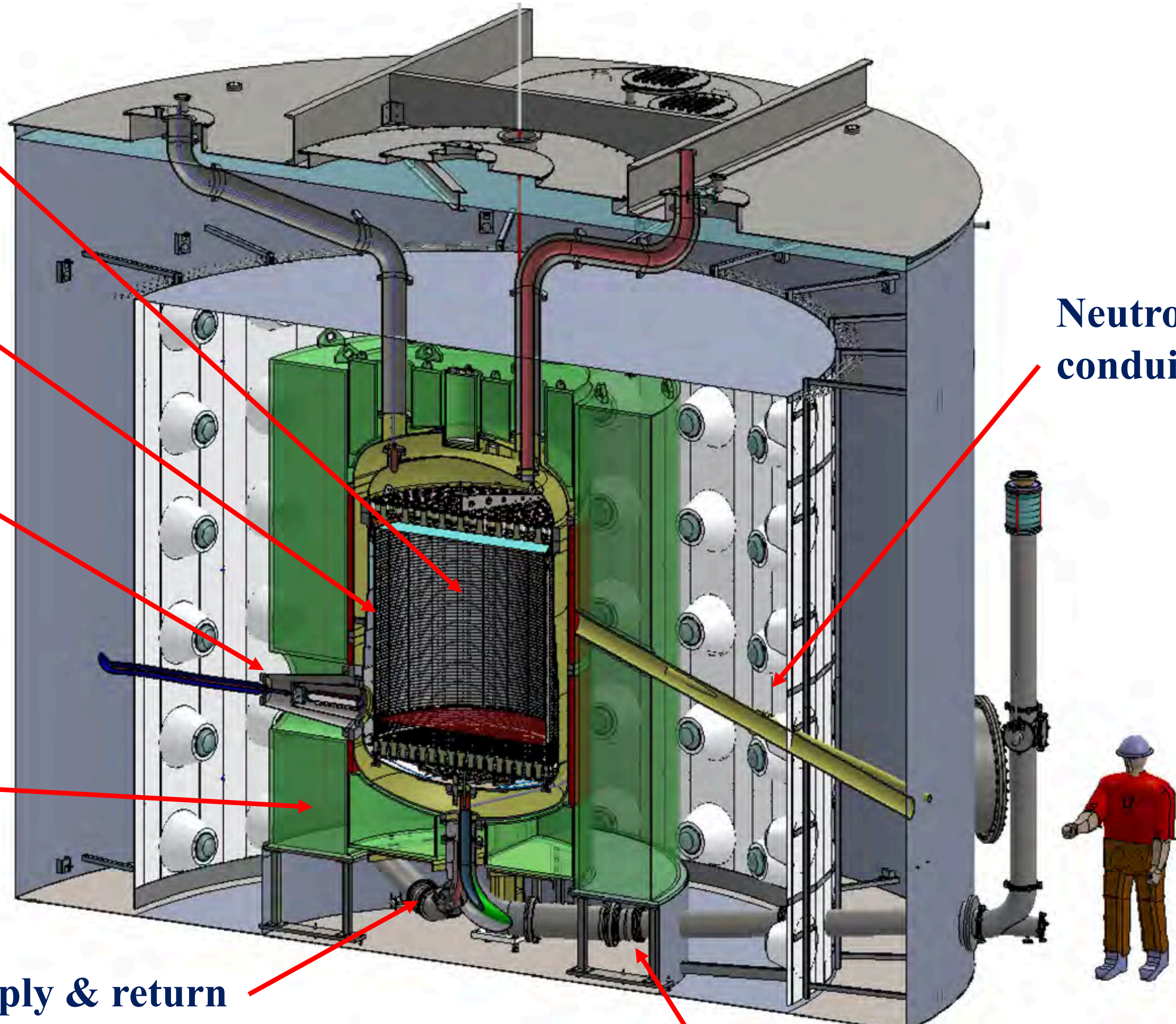




Search for anomalous low-energy nuclear recoils

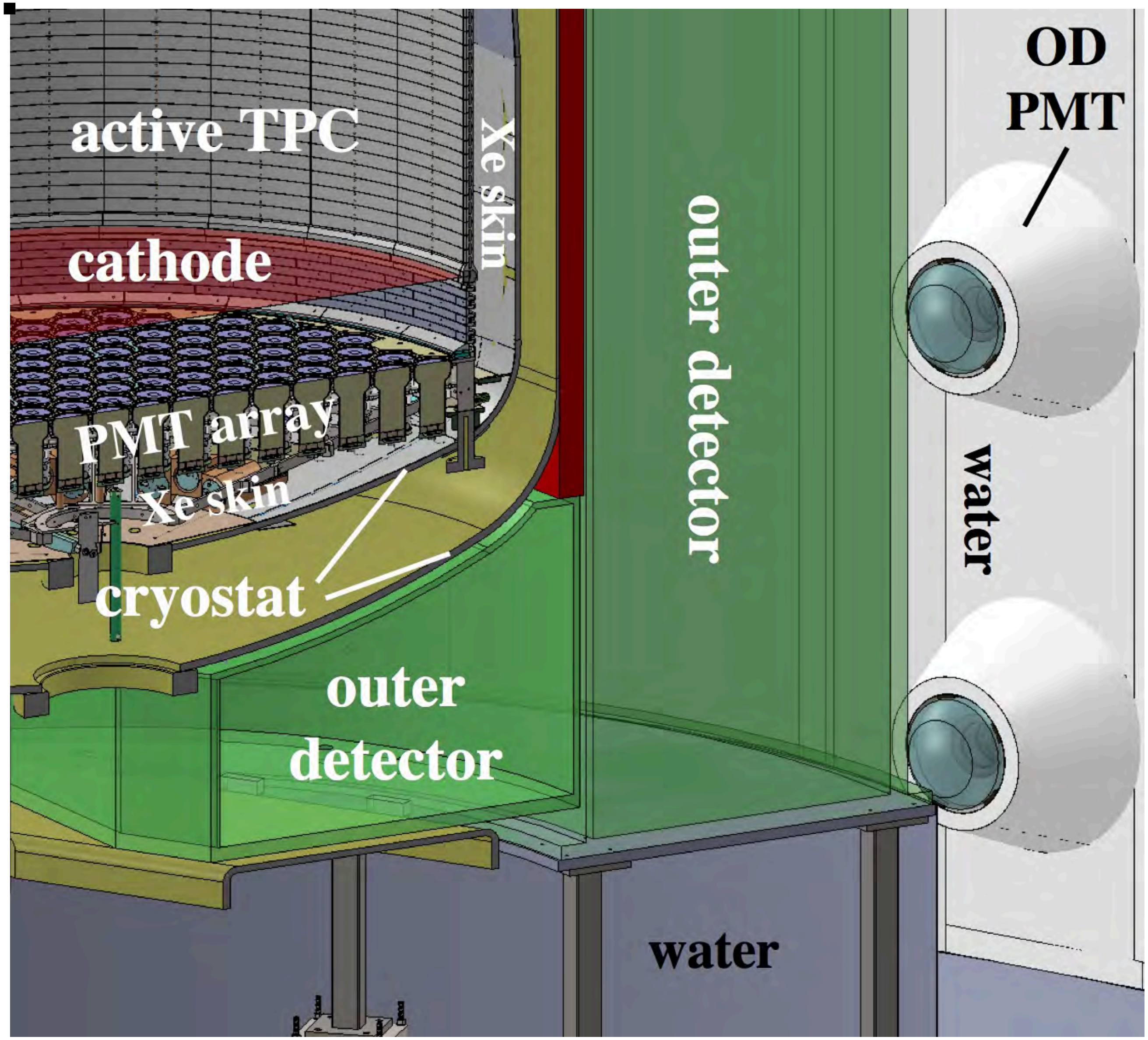
Requirements: large target mass + low energy threshold + background control.

LUX-ZEPLIN (LZ) detector



Technical Design Report, arXiv:1703.09144.

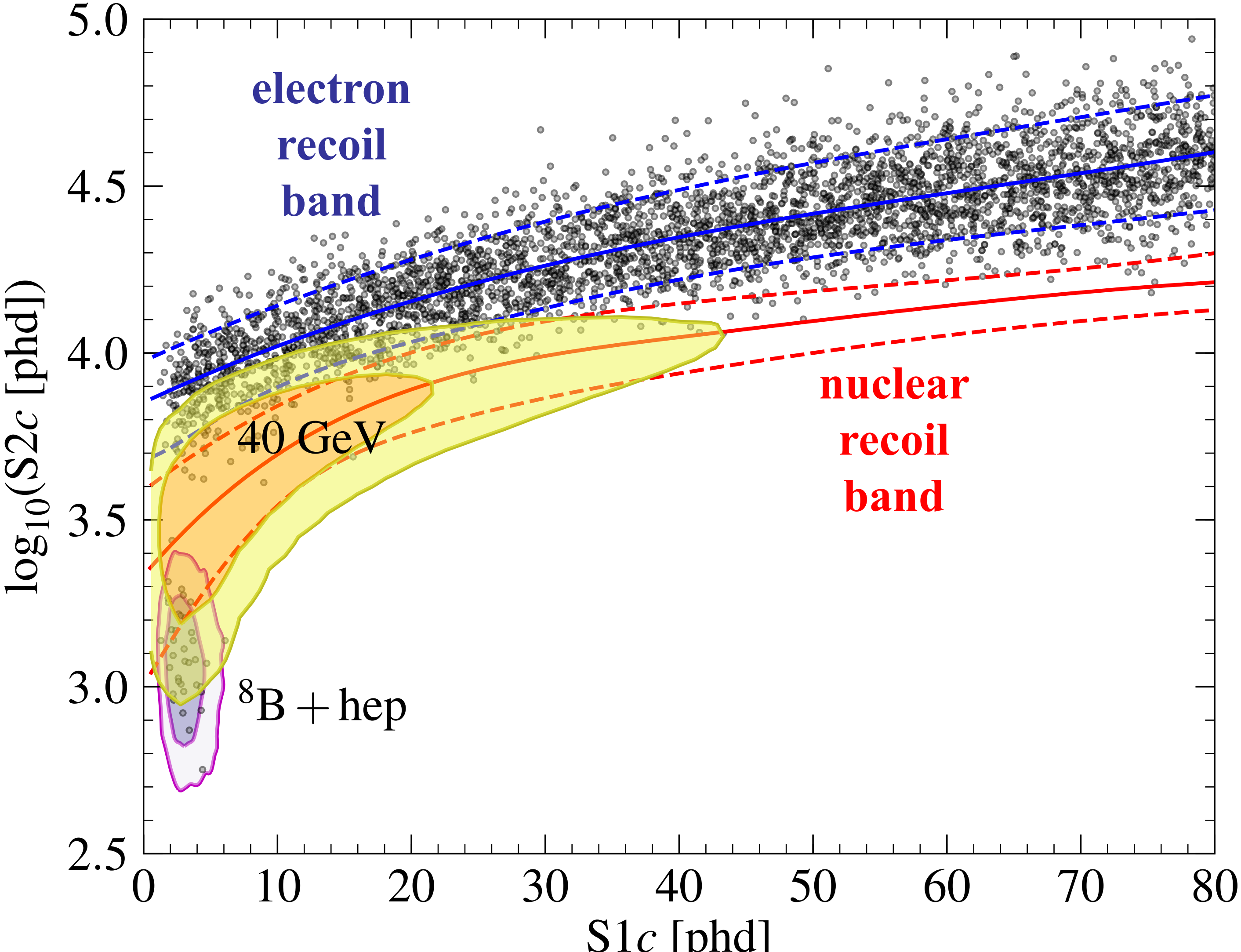
Two veto systems: Xe skin PMTs & Outer Detector



LZ Technical Design Report, arXiv:1703.09144

Simulated LZ full exposure with 40 GeV/c² WIMP

1000 days, 5.6 Tons



WIMP backgrounds summary

5.6 tonnes x 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

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Radon dominates ER backgrounds

νe scattering of *pp* solar ν's; (atomic electron recoils)

arXiv:1802.06039

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Neutrons, mostly from alpha-n on PTFE

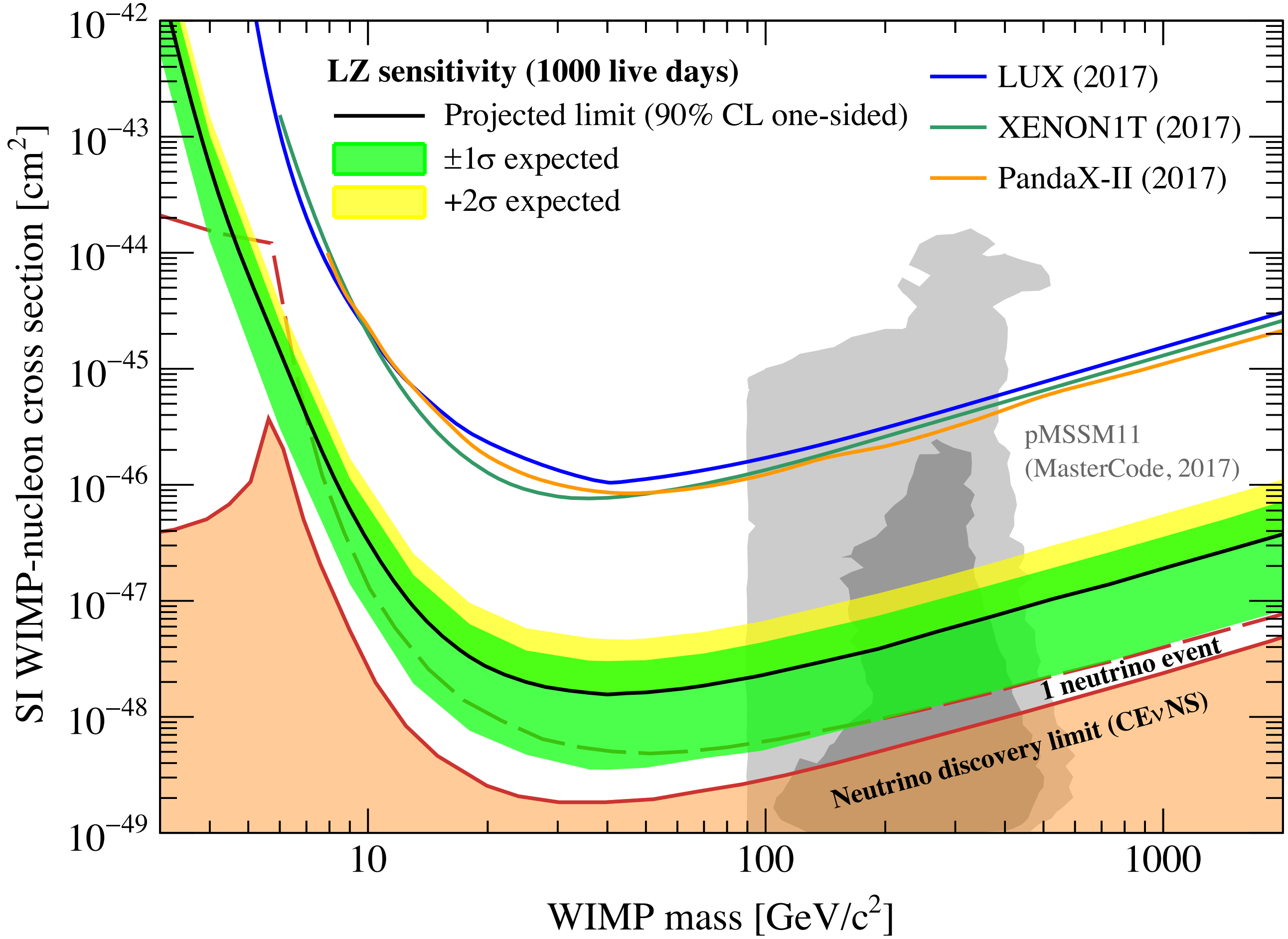
Coherent scattering of atmospheric ν's on Xe nuclei

arXiv:1802.06039

Background control strategy

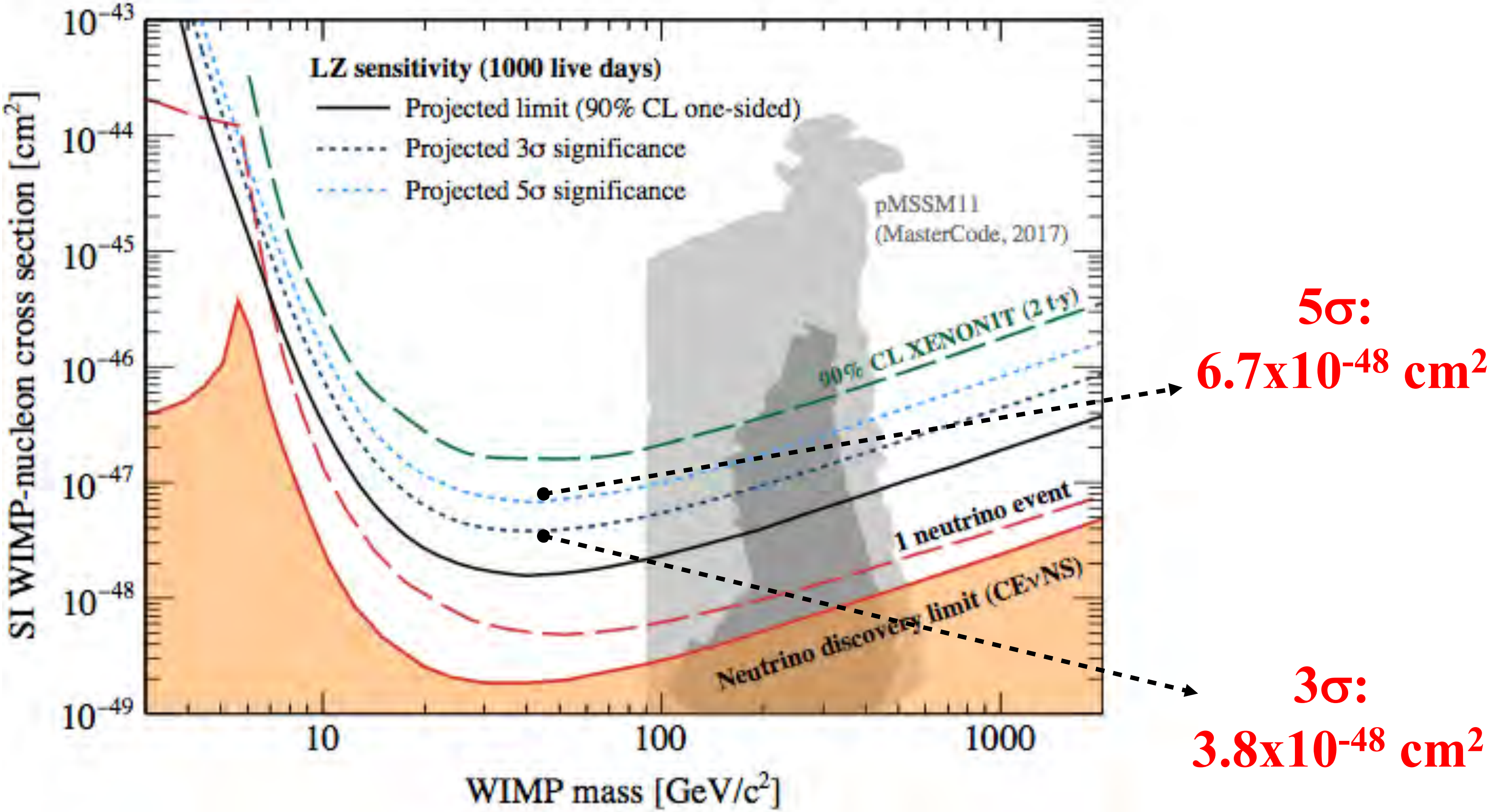
- Two active veto detectors to suppress and characterize backgrounds
  - Xe skin PMTs (Xe scintillation)
  - Gd-LS Outer Detector
- Rn emanation screening campaign
  - Four Rn screening sites
  - Target Rn activity = 2 μBq/kg
- Charcoal chromatography to remove ^{85}Kr and ^{39}Ar
  - Dedicated facility at SLAC
  - Final ^{nat}Kr/Xe 0.015 ppt (g/g)
- Radio-assay campaign for detector materials
  - γ-screening, ICP-MS, NAA.
- Surface cleanliness to control Rn daughters & dust
  - TPC Assembly in Rn-reduced cleanroom to limit daughter recoils on surfaces
  - Dust < 500 ng/cm^2 on all LXe wetted surfaces
  - Rn-daughter plate on TPC walls < 0.5 mBq/m^2

Spin-Independent WIMP Sensitivity
arXiv:1802.06039



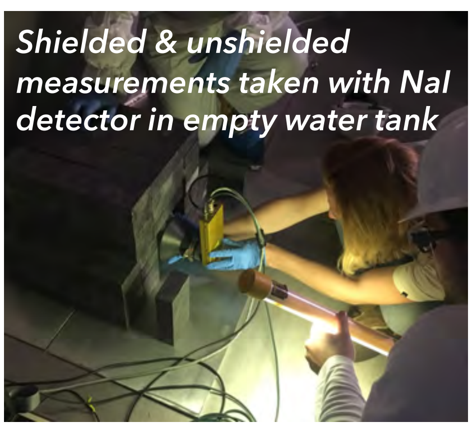
- Baseline WIMP sensitivity is 1.6×10^{-48} cm^2 @ 40 GeV/c^2.
- 1000 days, 5.6 tonne fiducial mass.

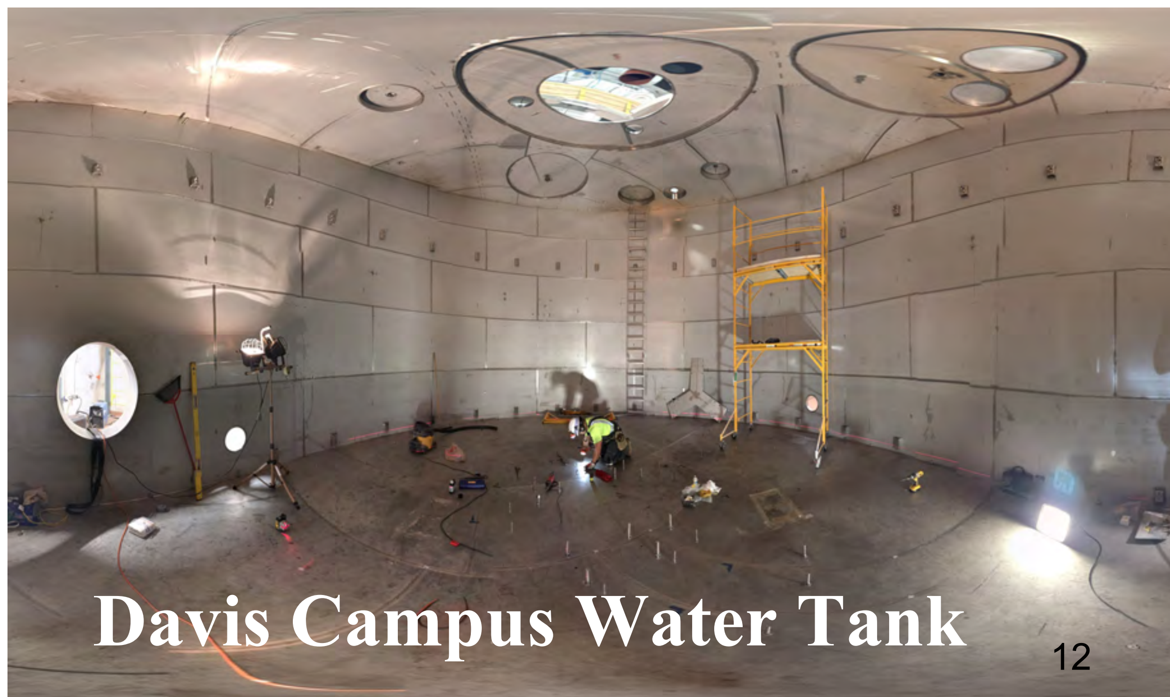
WIMP Discovery Potential
3σ and 5σ



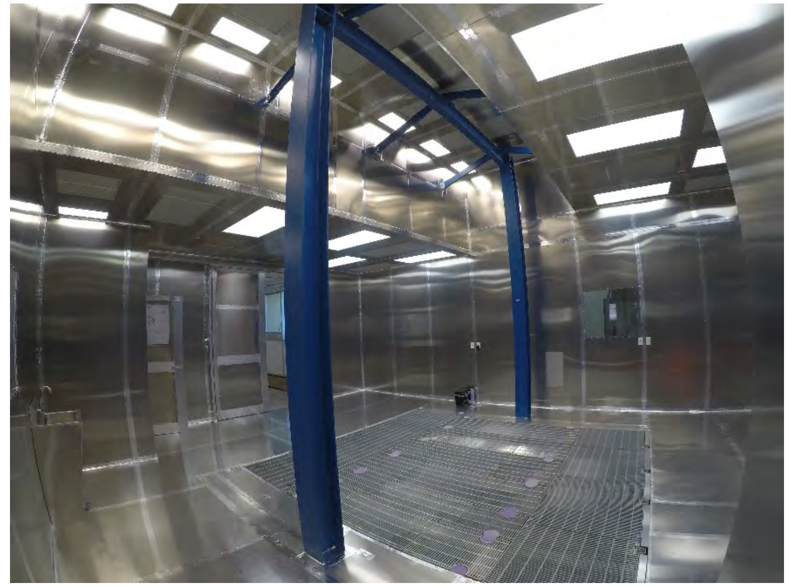
LZ has 5σ discovery potential well below the projected 2 tonne-year sensitivity of Xenon1T.

- Water tank modifications nearly complete.
- Passivation & water leak test scheduled for July.
- LZ Occupancy in August.





Surface Assembly Lab @ SURF
TPC assembly & integration site


- Low radon, class 100-1000 cleanroom
- Ateko Radon Reduction System operational & providing low radon air to the SAL.

Titanium Cryostat

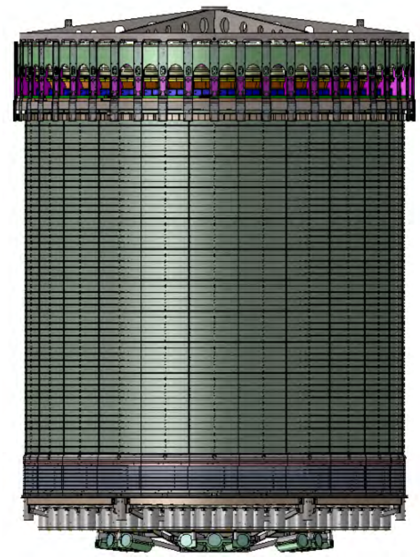
- UK deliverable to LZ.
- Intensive R&D program identified low activity titanium material (arXiv:1702.02646)
- Arrived at SURF May 14, 2018.
- LZ acceptance testing in Surface Assembly Lab at SURF.
- Outer vessel testing complete; inner vessel in progress.

Test fitting at Loterios in Milan

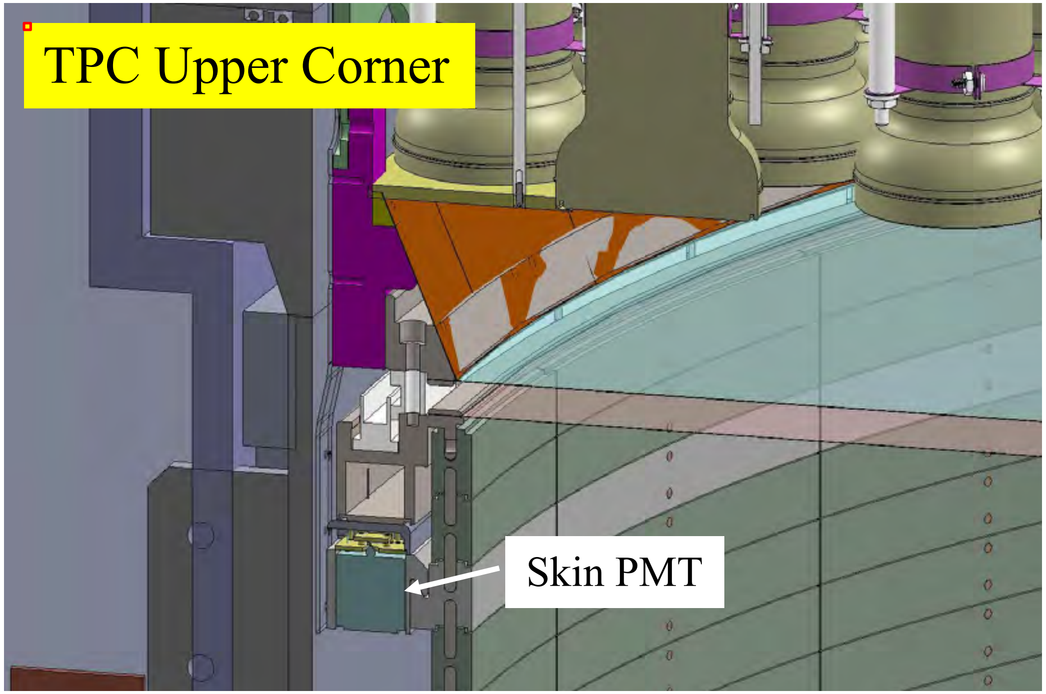
Outer cryostat vessel in the SAL at SURF

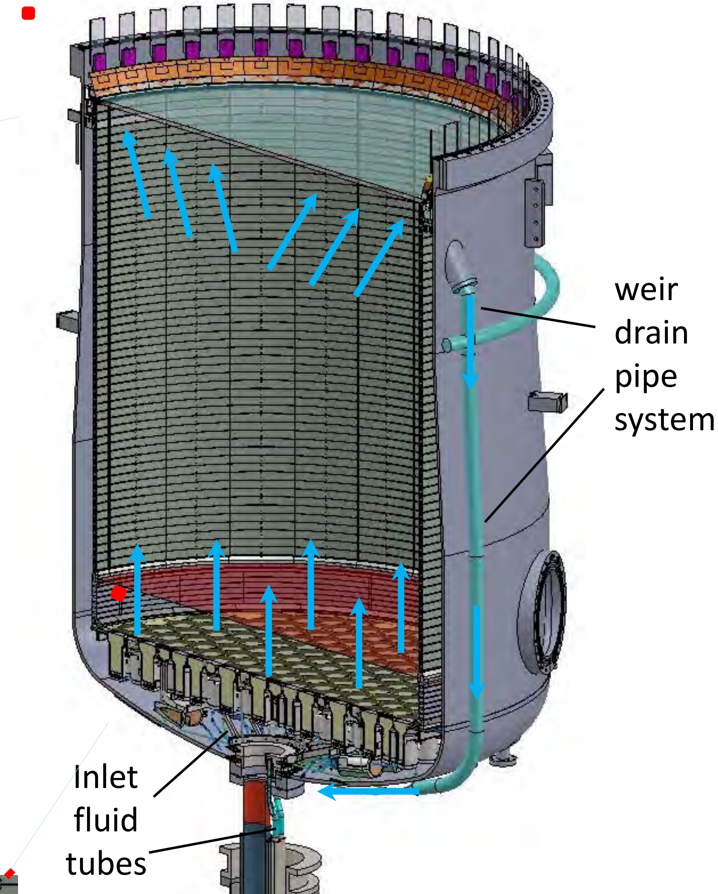
Liquid Xenon TPC

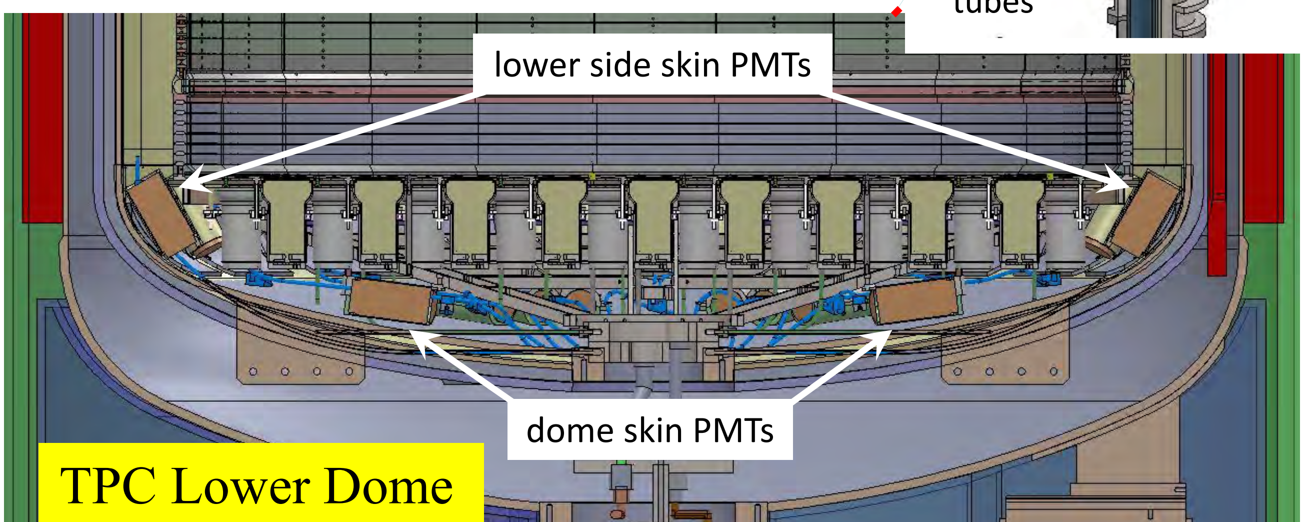
- 50 kV cathode high voltage
- PMTs
  - 493 3” PMTs in two arrays inside TPC
  - LXe skin – 93 1” PMTs, 38 2” PMTs
- TPC structure
  - PTFE segmented walls and Ti field rings
  - Ti/PTFE PMT array plates, top and bottom, holding roughly 250 3” PMTs each
  - Woven wire grids (bottom shield, cathode, gate, anode)
  - LED calibration, fluid flow structures, sensors for temperature, etc
- Logistics: TPC to be fully assembled and integrated into inner cryostat in the Surface Assembly Lab.



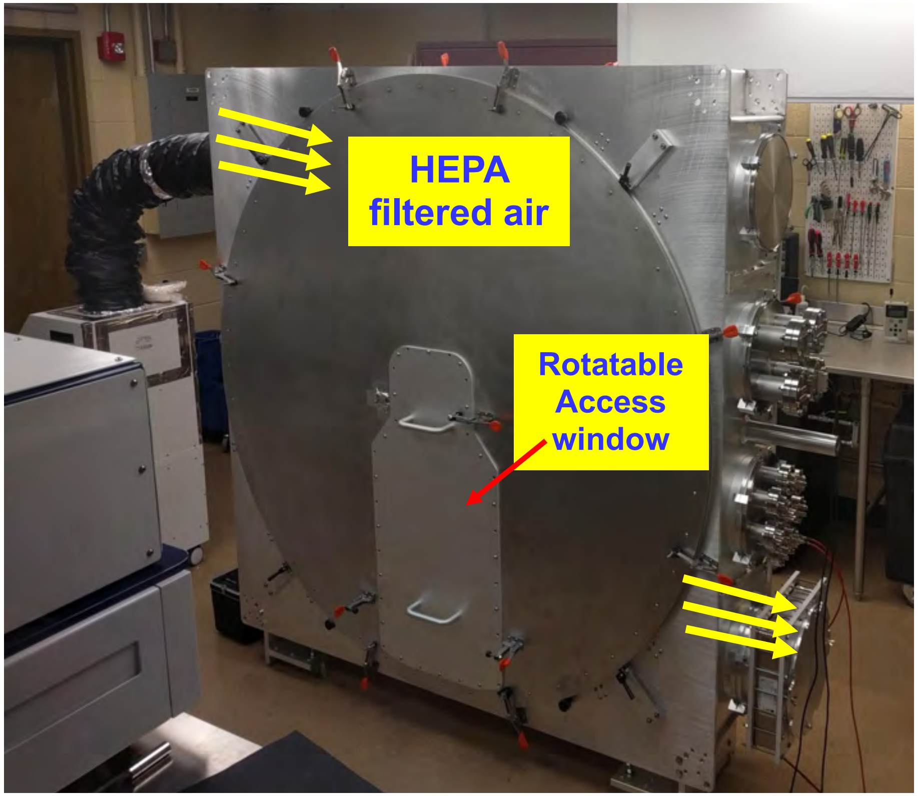
Liquid Xenon TPC





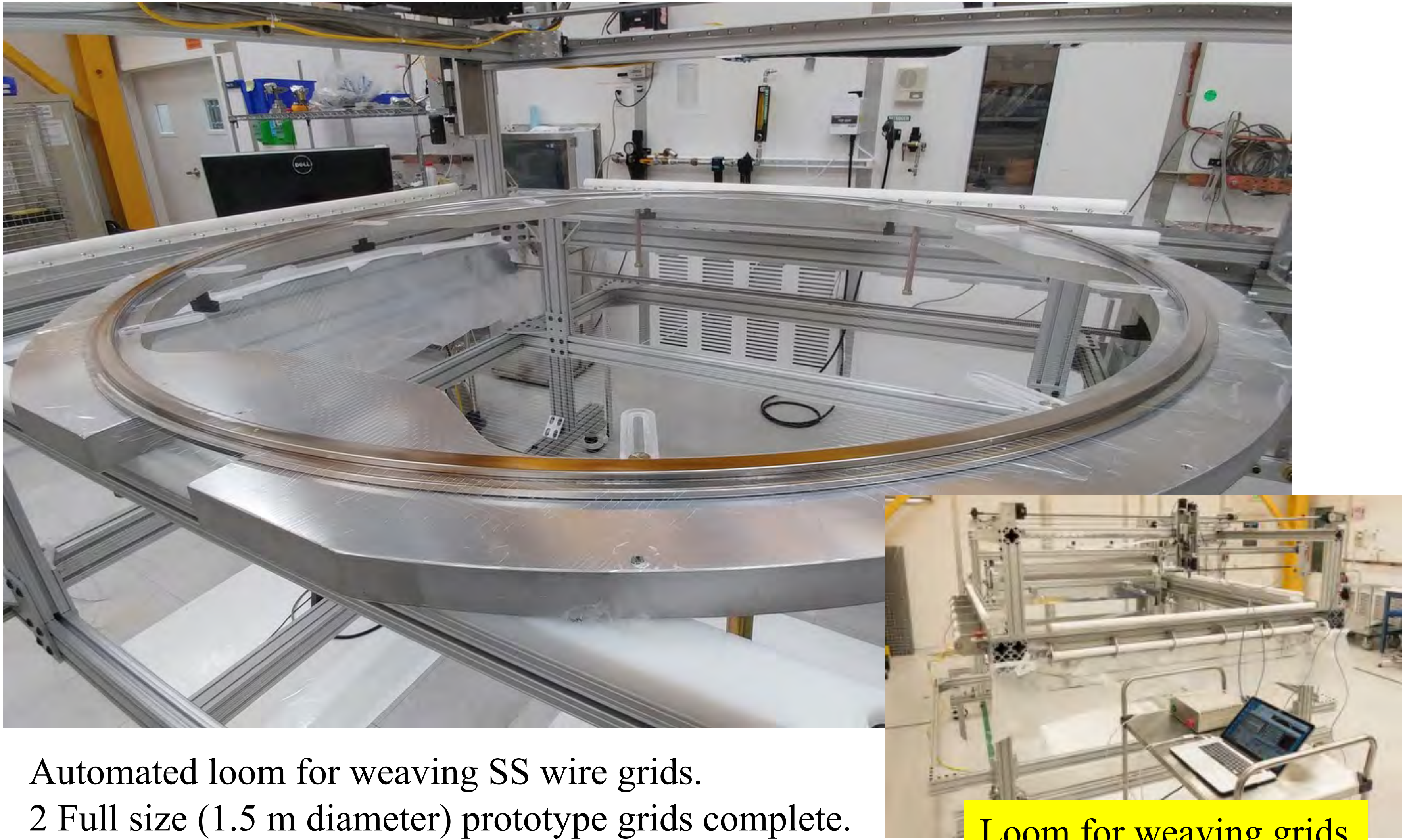


PMT Array Assembly at Brown University



- Above: 'PALACE', PMT dark electrical testing and shipping housing for upper and lower LZ PMT arrays (~250 PMTs per array)
- Clamps and seals provide dust and light-tight housing.
- Low airborne Rn, 2-4 Bq/m^3
- Dust control with HEPA filtered air.
- Witness plates for dust surveillance; measured dust levels meet the requirement.

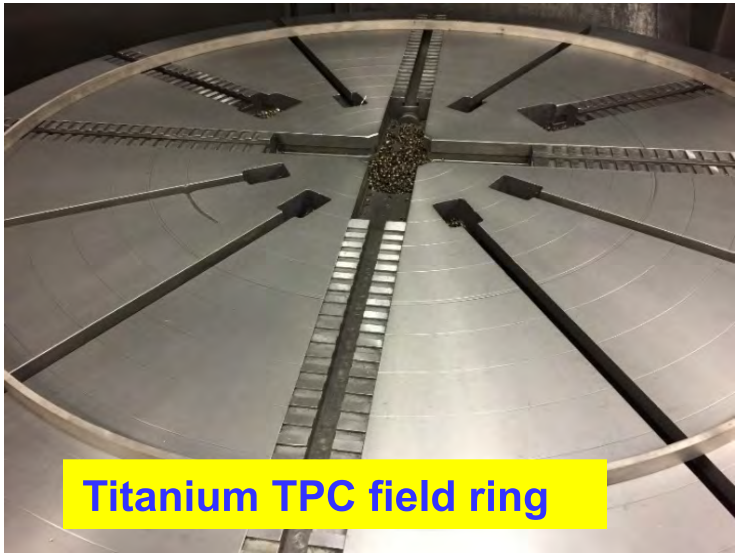
TPC grids under production



Loom for weaving grids

- Automated loom for weaving SS wire grids.
- 2 Full size (1.5 m diameter) prototype grids complete.
- Production grid rings being fabricated.
- Post-weaving wire treatment to reduce electron emission (arXiv:1801.07231).
- Loom in action: https://www.youtube.com/watch?v=yNycDcMQkss

TPC field cage components are in hand

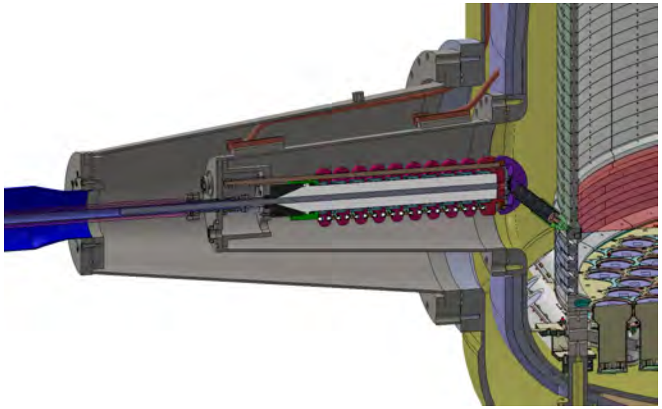


Titanium TPC field ring

- All TPC field cage parts are fabricated and delivered; trial assembly successful.
- Field cage assembly at SURF to begin in September 2018.

Trial assembly of Ti field rings and PTFE field cage elements at LBNL

TPC cathode high voltage



- Tests in liquid argon successfully reach 120 kV(50 kV required).
- Extensive Liquid Xenon prototyping at SLAC.
- High voltage grading structure for cathode assembled at LBL

Model of test structure in liquid argon

Liquid argon cathode high voltage test facility at LBNL

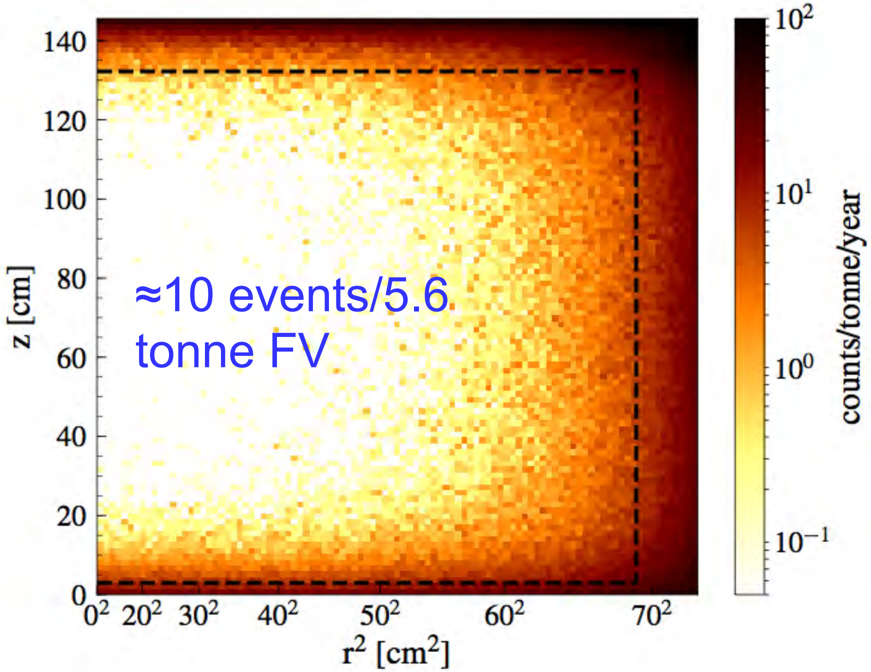
Outer Detector

- Acrylic vessel fabrication underway,
- Gd-LS production equipment being installed at BNL
- PMTs in hand, testing here at IBS is nearly done.

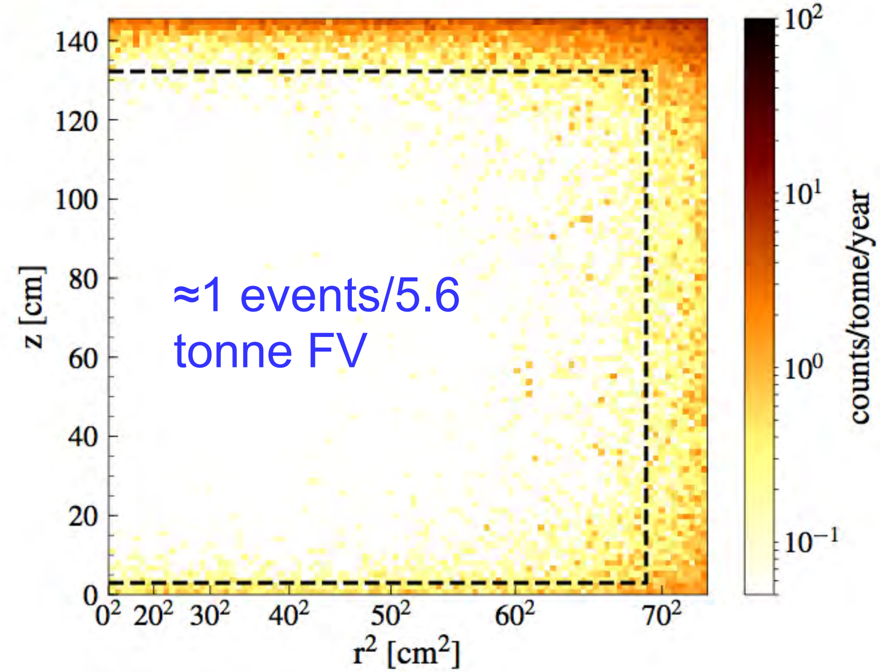
Veto System Performance

WIMP-like nuclear recoil backgrounds in 6-30 keV region of interest

Before vetos



After vetos

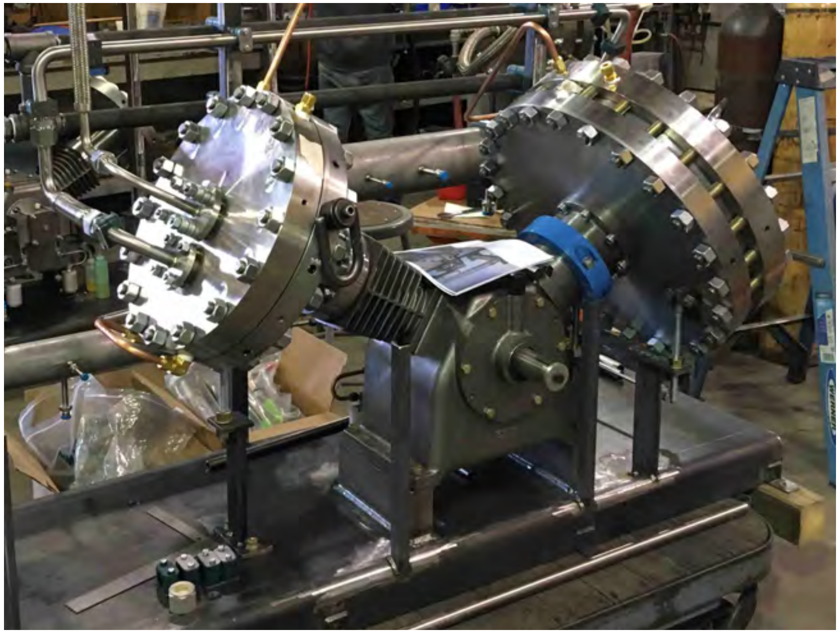


Fiducial would be reduced from 5.6 to 3.2 tonnes w/o Outer Detector & Xe skin vetoes.

Xe Handling & Purification

- 12 Custom Xe storage packs delivered to PSL for outfitting.
- 4 Xe gas compressors under final fabrication or delivered to PSL.
- 500 SLPM Xe gas circulation rate; 2.3 days to purify 10 tonnes.
- One large getter & efficient two-phase heat exchanger.

Getter at SURF


1 of 4 Xe gas compressors being fabricated


12 Xe storage gas packs

Xe acquisition & Kr removal

- All Xe either in-hand or fixed priced contract.
- Kr removal at SLAC on track to start by July 2019 and finish by end 2019.

~6.5 tonnes of Xe in hand.

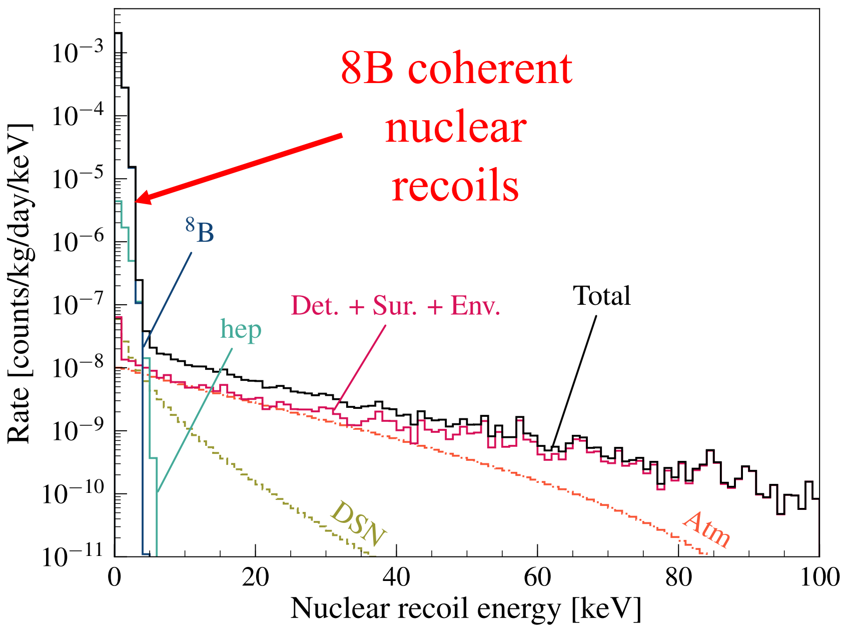
2 charcoal chromatography columns at SLAC.

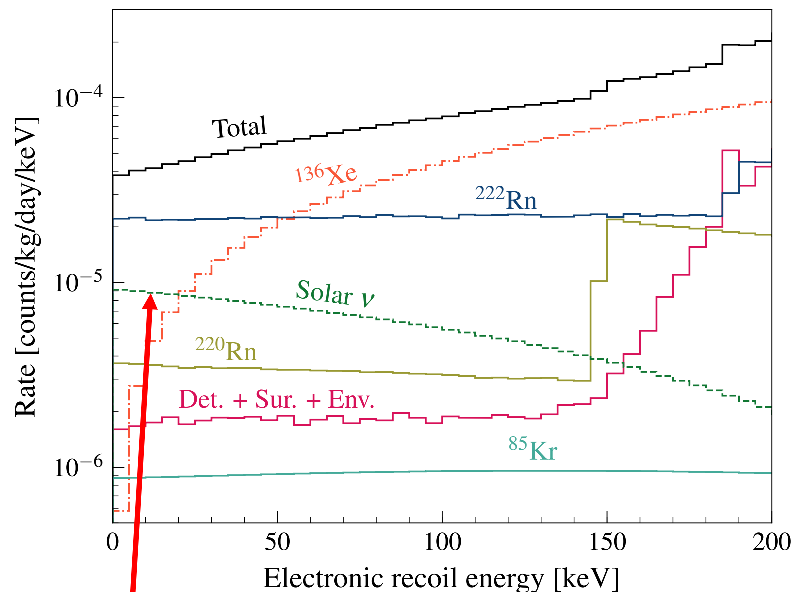
- Chromatography to separate Kr (and ^{85}Kr) from Xe.
- Demonstration of 0.075 ppt (g/g) in R&D at SLAC.
- Production system designed to remove to 0.015 ppt (g/g) (subdominant by >10x to radon).

Other physics signals?

Nuclear recoil background spectrum (MC)

Electron recoil background energy (MC)

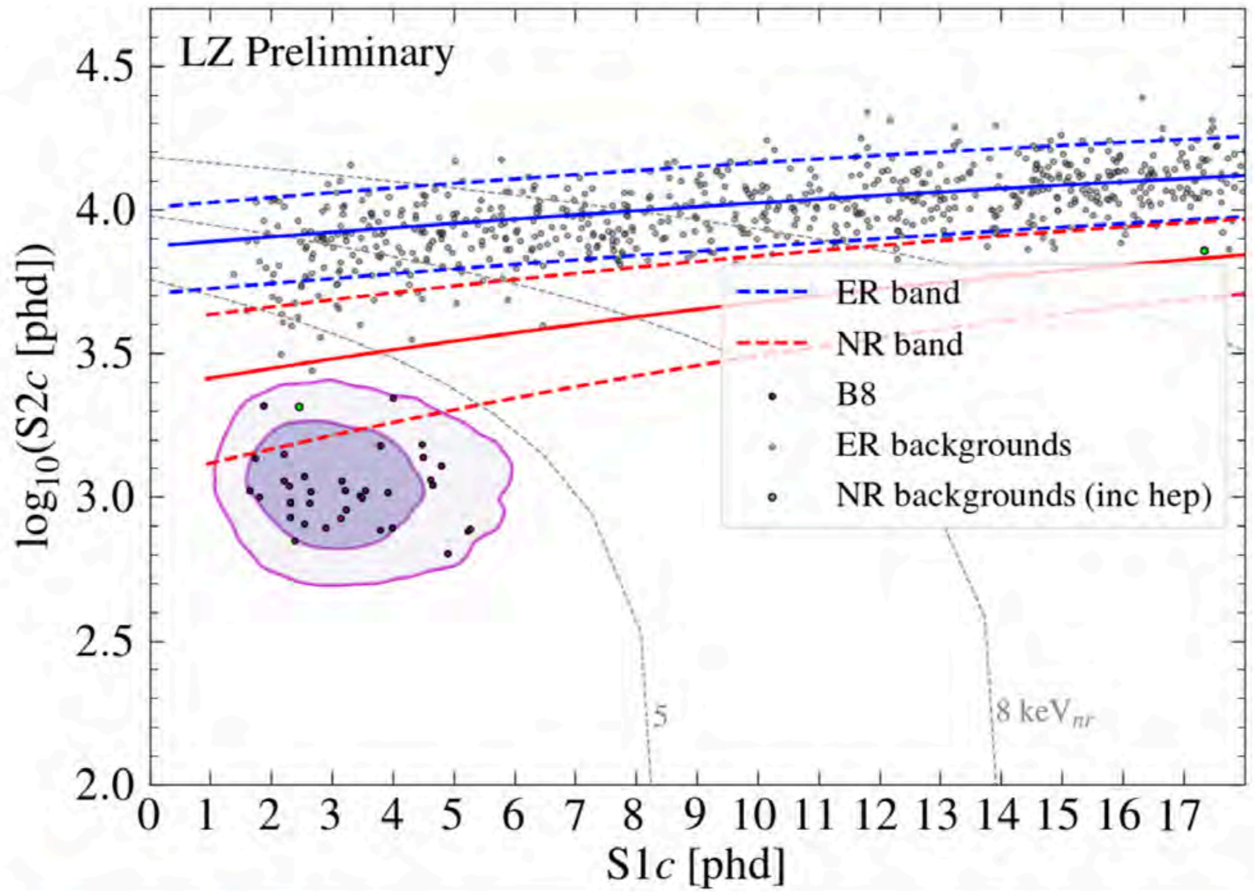




pp solar νe scattering

Coherent scattering of ^{8}B solar ν's on Xe nuclei

36 NR events in 5.6 tonnes and 1000 days



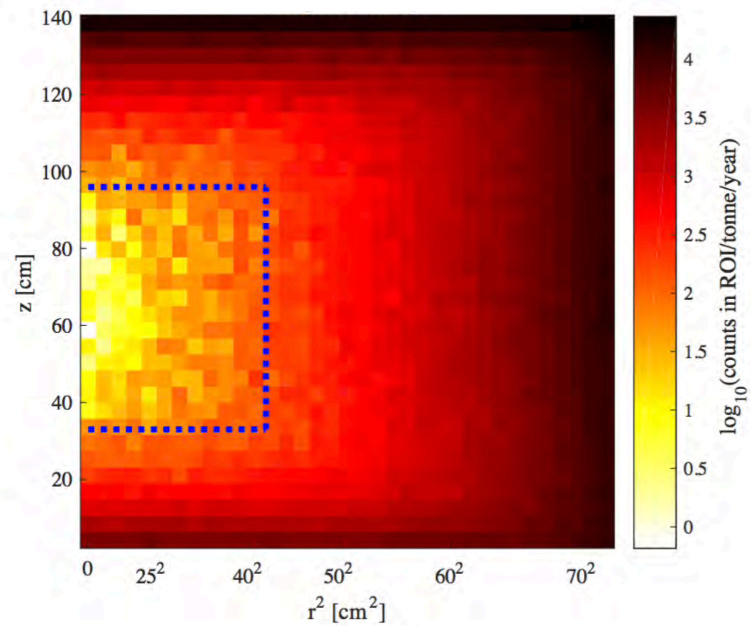
- 3 PMT S1 coincidence requirement. Detection efficiency is ~3 x 10^{-3}.
- Only observe ^{8}B events that fluctuate high in S1 light collection.
- Average light collection efficiency of 11.9%. Supported by cold measurements of the PMT QEs and PTFE reflectivity measurements in LXe.
- NR charge and light yields measured by LUX with DD neutron generator.

Preliminary Estimate of 0νββ Decay Backgrounds
Q value = 2457 keV, 8.9% ^{136}Xe

Item	Counts from ^{238}U	Counts from ^{232}Th	Other counts	Total Counts
TPC PMTs & bases	2.75	0.36	0.0	3.10
TPC PMT structures & cables	2.70	0.34	0.0	3.03
Skin PMTs & bases	0.47	0.02	0.0	0.49
PTFE walls	0.25	0.0	0.0	0.25
TPC sensors & thermometers	1.49	0.0	0.0	1.49
Field grids & holders	1.14	0.08	0.0	1.23
Field-cage resistors	1.47	0.05	0.0	1.51
Cryostat	4.27	0.86	0.0	5.14
Outer detector components	1.52	1.12	0.0	2.63
Other components	1.29	0.14	0.0	1.43
Cavern walls	<0.1*	2*	0.0	2*
$2\nu\beta\beta$	-	-	0.01	0.01
^8B solar neutrinos	-	-	0.07	0.07
Neutron-induced ^{137}Xe	-	-	<0.01*	<0.01*
Total	17.44	4.97	0.09	22.50

**preliminary estimate*

LZ Preliminary



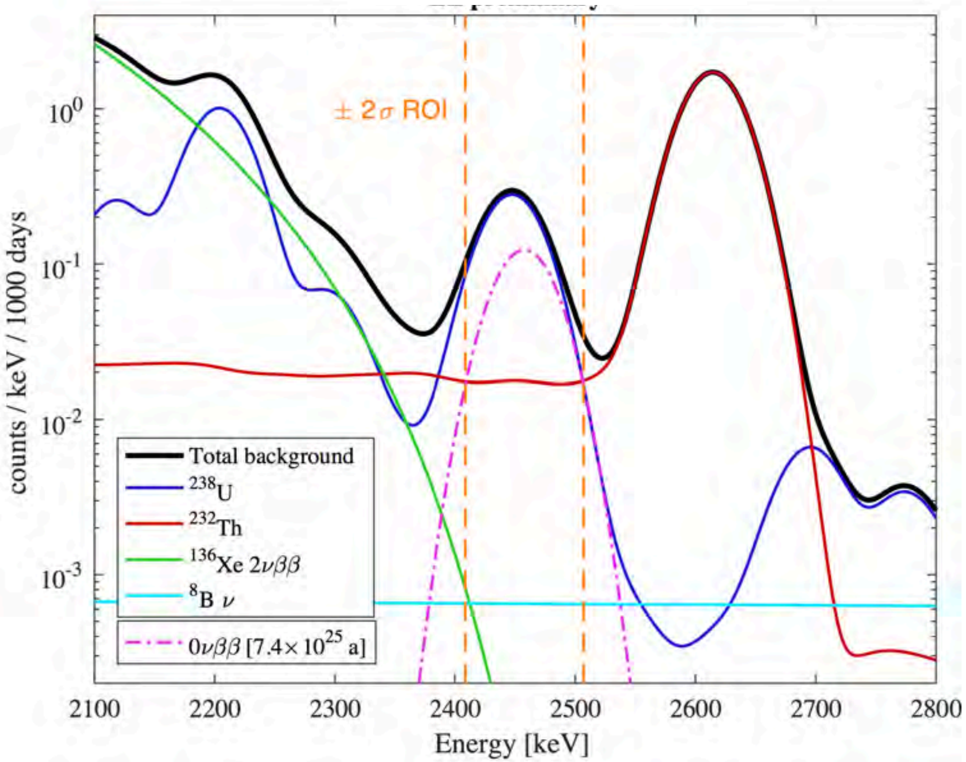
(a)

Assumptions:

1) 957 kg fiducial volume of ^{nat}Xe (85 kg of ^{136}Xe);
2) 1000 day observation
3) Single site cut in z only (0.3 cm).
4) +/-2σ ROI around Q value
5) 1% (σ) energy resolution; achievable with > 7.5% light collection efficiency (LZ projection is 11.9%).

Preliminary Estimate of 0νββ Decay Sensitivity

LZ Preliminary



- $T_{1/2}$ sensitivity = 0.74 x 10^{26} years at 90% C.L; better than currrent KamLAND-Zen sensitivity (0.56 x 10^{26} years).
- The LZ dataset will allow exploration of the two-phase technique for future double beta decay searches.

LZ timeline

Year	Month	Activity
2008	April	LZ collaboration forms
2012	September	CD-0 for G2 dark matter experiments
2013	November	LZ R&D report submitted to agencies
2014	May	P5 endorses G2 dark matter program
	July	LZ Project selected by US DOE, NSF, & UK STFC
2015	March	CD-1 Review – conceptual design
	September	Conceptual Design Report (arXiv:1509.02910)
2016	April	CD-2 Review – project baseline
2017	January	CD-3 Review – 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*

LZ collaboration

38 institutions

250 scientists, engineers, and technicians

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) Washington University in St. Louis (US)
38) Yale University (US)


LUX-ZEPLIN
S.U.R.F.

Other physics signals?

Electron recoil background energy (MC)