An overview of the LUX-ZEPLIN Experiment

Kimberly J. Palladino
for the LZ Collaboration

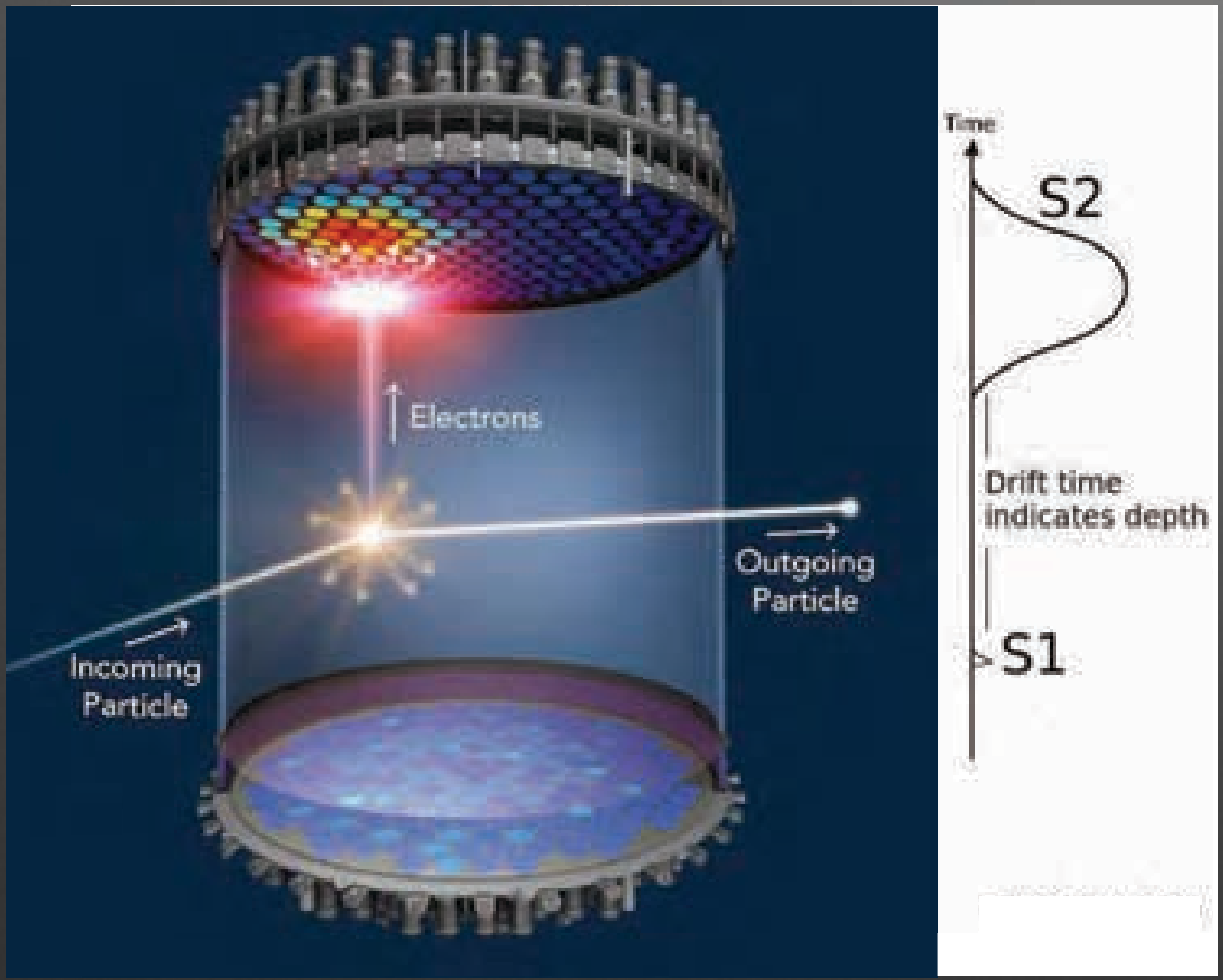
July 25, 2017

*Just a prototype in this photo!

LZ: 38 Institutions & 250 scientists, engineers and technicians

1) Center for Underground Physics (South 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)

Liquid Xenon TPC operations



- Well suited to search for WIMP induced nuclear recoils
- Discrimination against background electronic recoils
- Self-shielding, large fiducial masses
- Primary Scintillation (S1) with some recombination and de-excitation in the liquid
- Ions drift in TPC electric field
- Amplification region in gas creates proportional light (S2)
- S2/S1 provides particle ID
- Events are hundreds of microseconds (set by electron drift velocity)
- Strong position reconstruction

LZ @ SURF

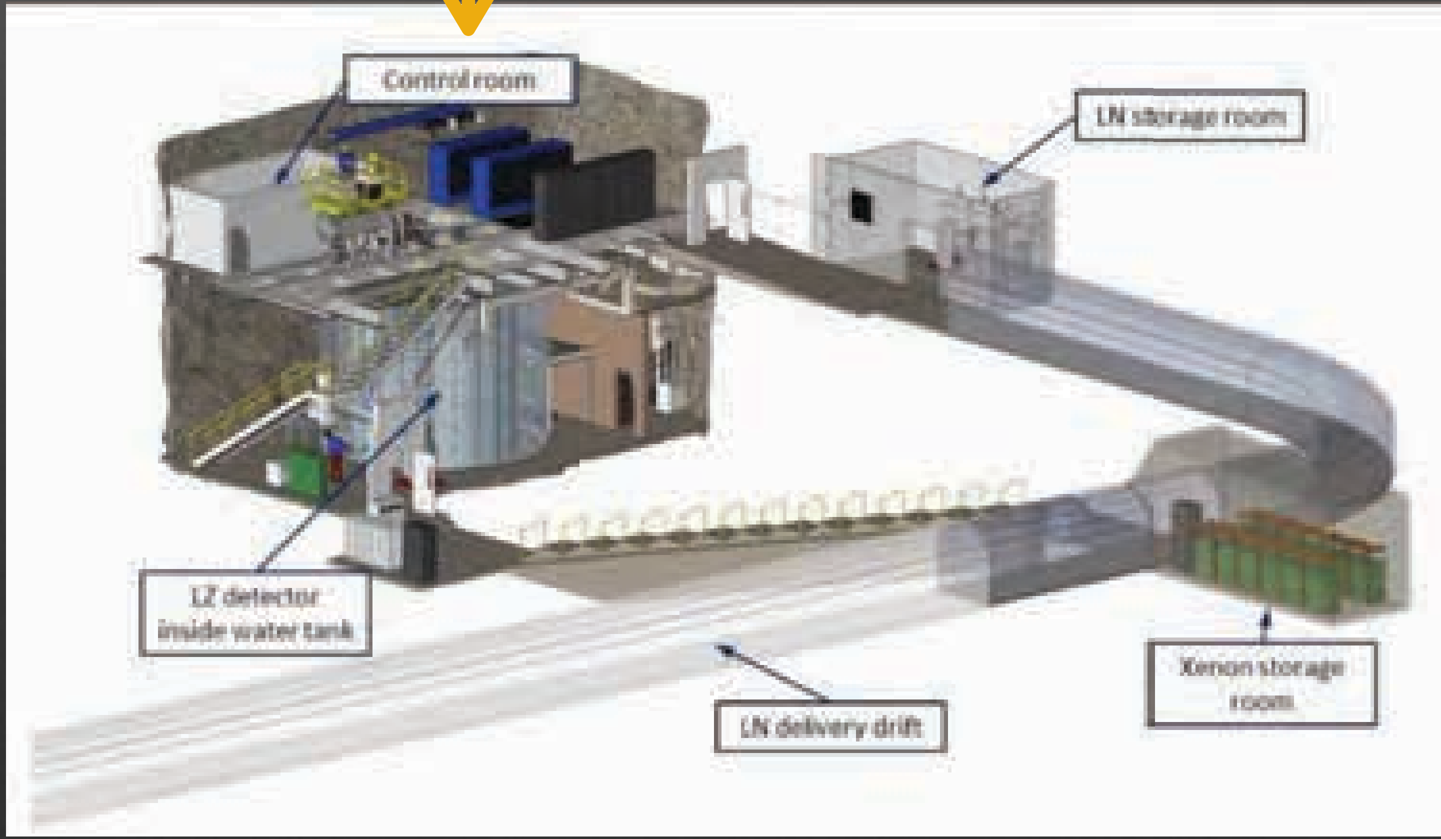
Davis Cavern 1480 m

(4200 m water equivalent)

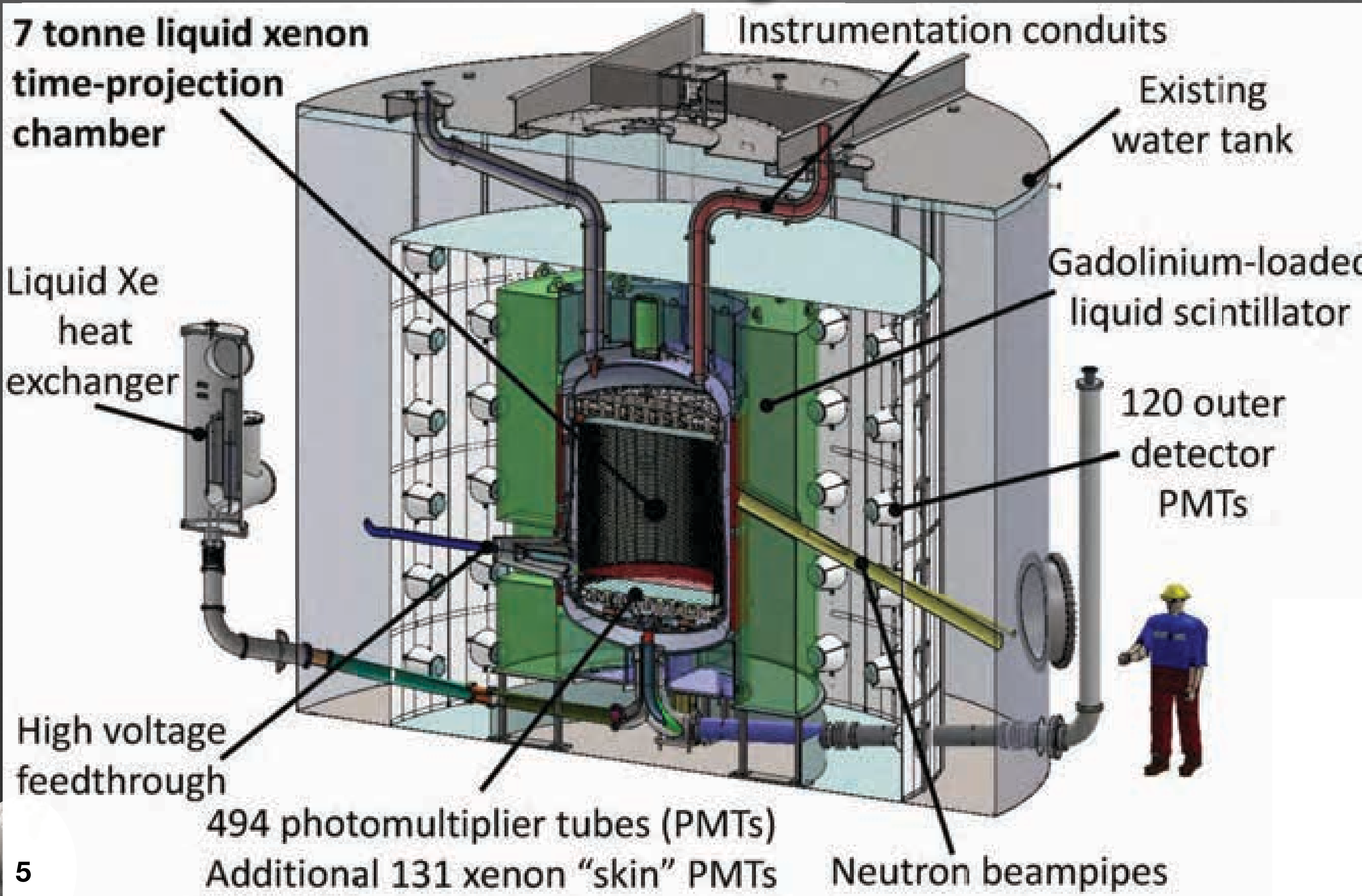
Sanford Underground Research Facility

Homestake Gold mine

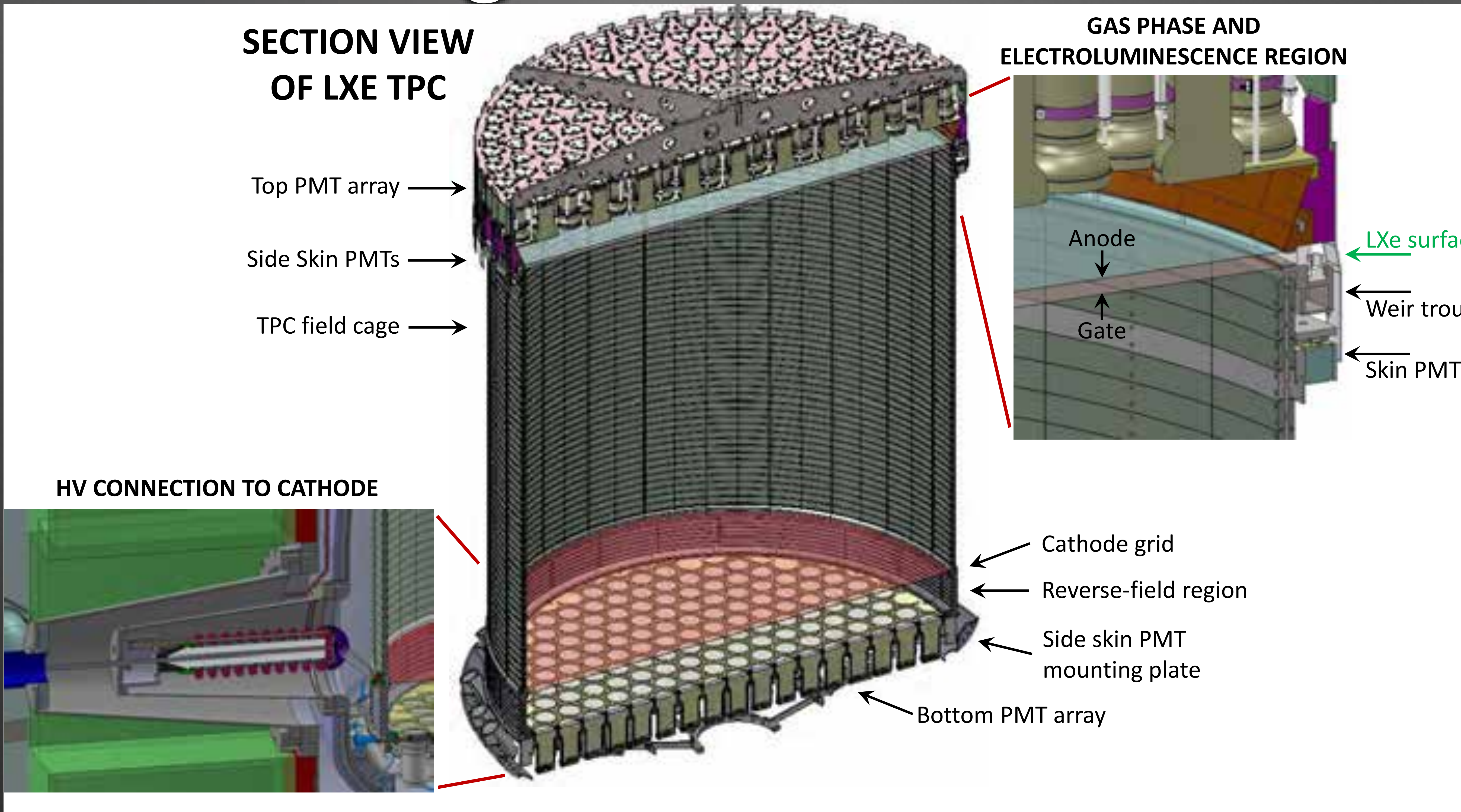
Lead, SD (near Deadwood)



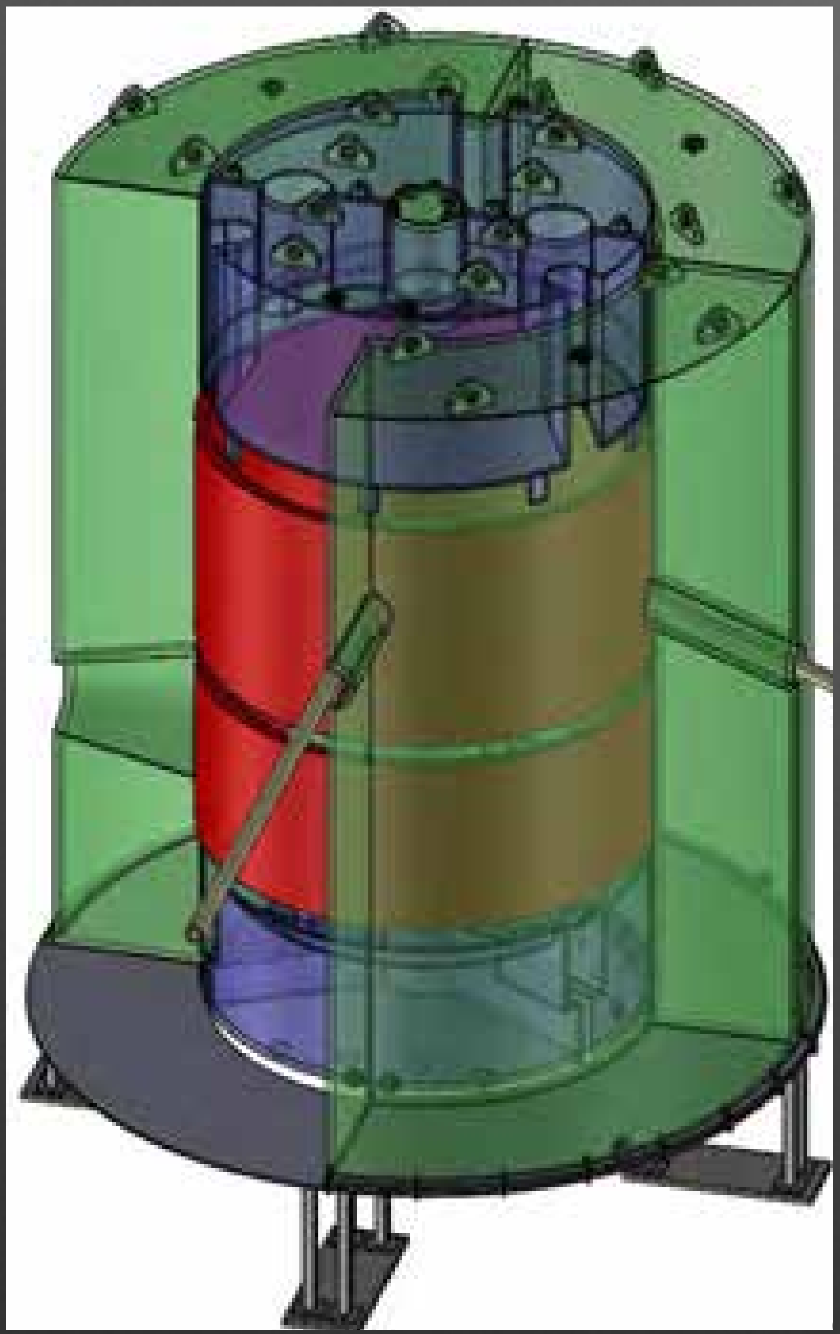
LZ detector design

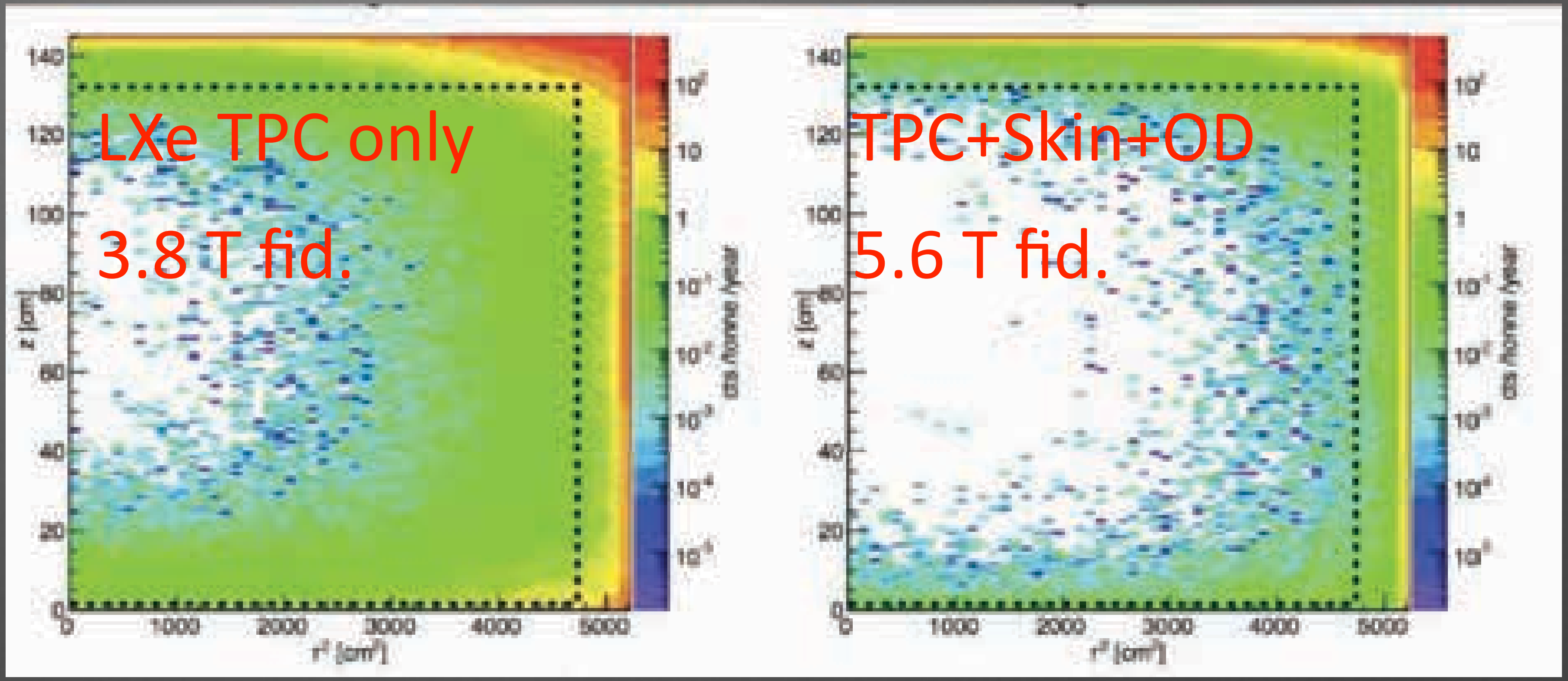


TPC design


SECTION VIEW
OF LXE TPC
Top PMT array
Side Skin PMTs
TPC field cage
GAS PHASE AND
ELECTROLUMINESCENCE REGION
Anode
Gate
LXe surfac
Weir troug
Skin PMT
HV CONNECTION TO CATHODE
Cathode grid
Reverse-field region
Side skin PMT
mounting plate
Bottom PMT array

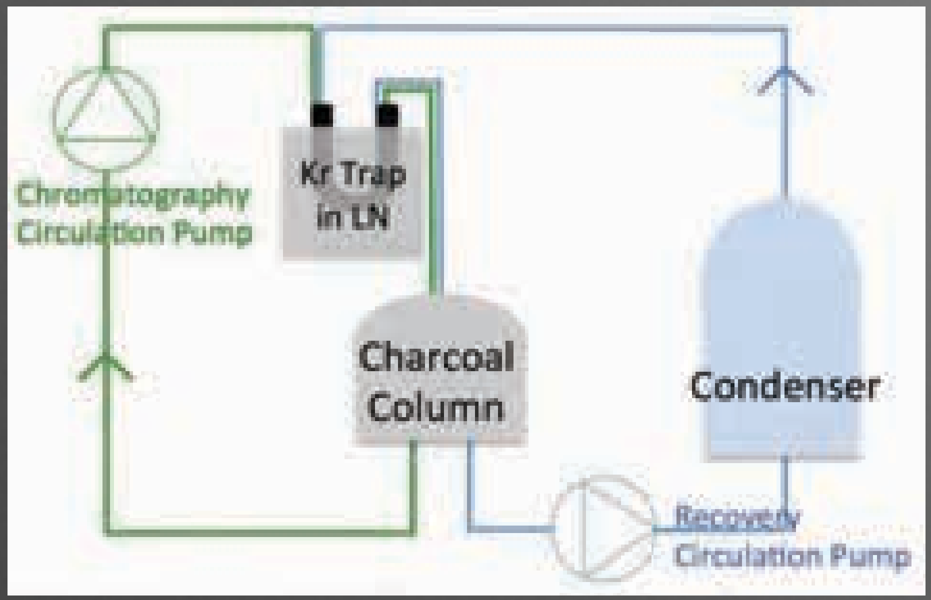
OD design and impact

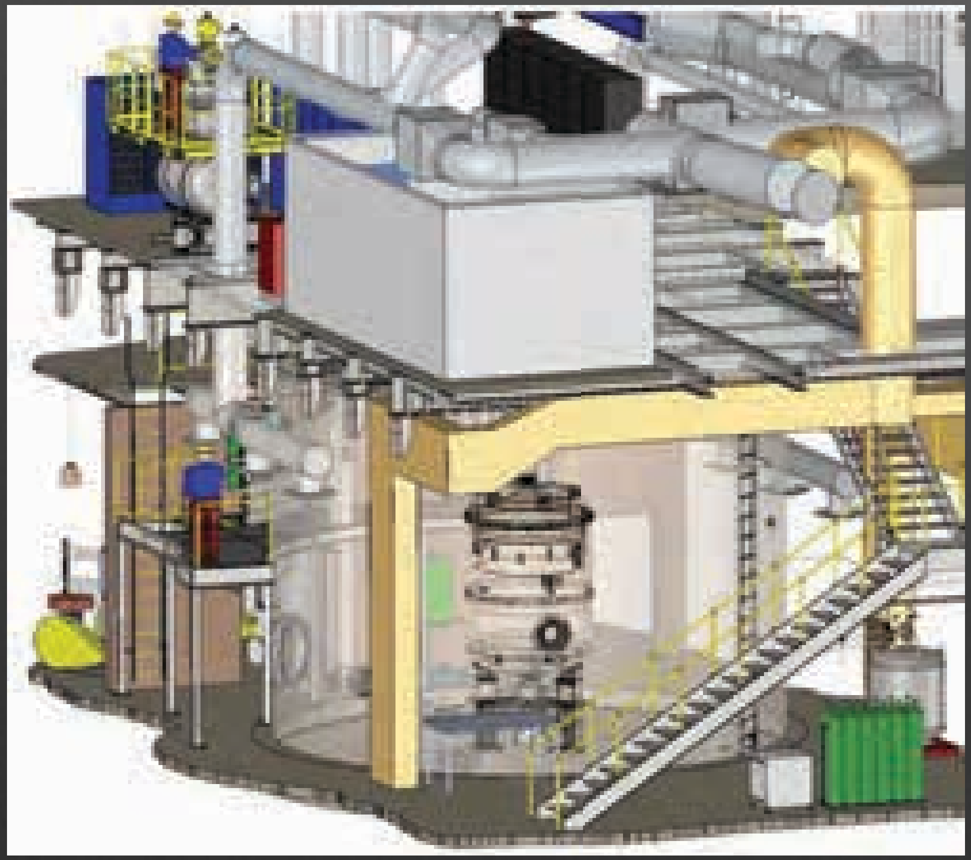




- External tagging allows greater fiducial volume for analysis
- 60 cm thick, 17.2 T of Gadolinium- loaded liquid scintillator, 120 8” PMTs
- 97% efficiency for neutrons
- Daya Bay legacy, scintillator & tanks (and people)

Xenon gas system



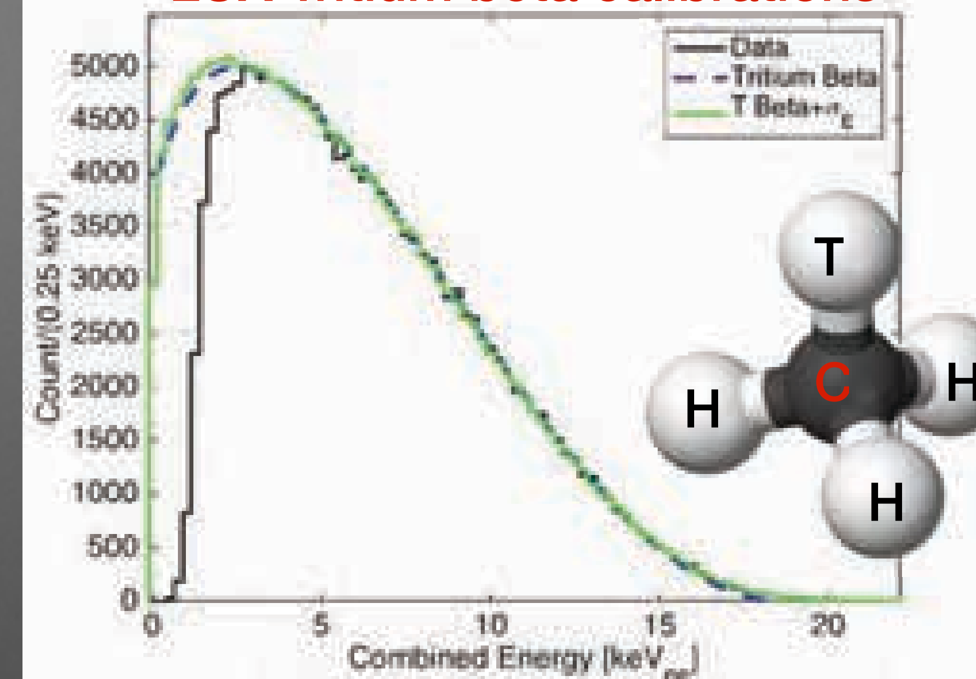


- Ex-situ removal of Kr via charcoal chromatography (SLAC)
- Constant removal of reactive impurities with a hot gas getter, flow at 500 slpm
- Gas circulation allows for injection of radioactive calibration sources
    - Kr83m, Xe131m workhorses
    - CH3T quarterly; must be removed with getter

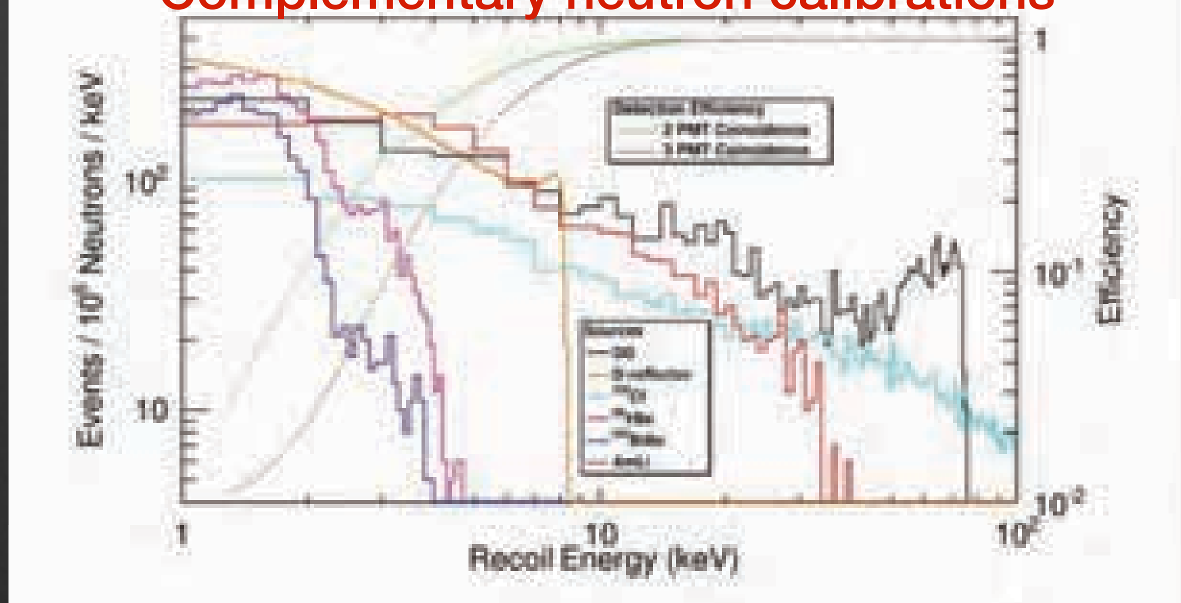
Calibrations

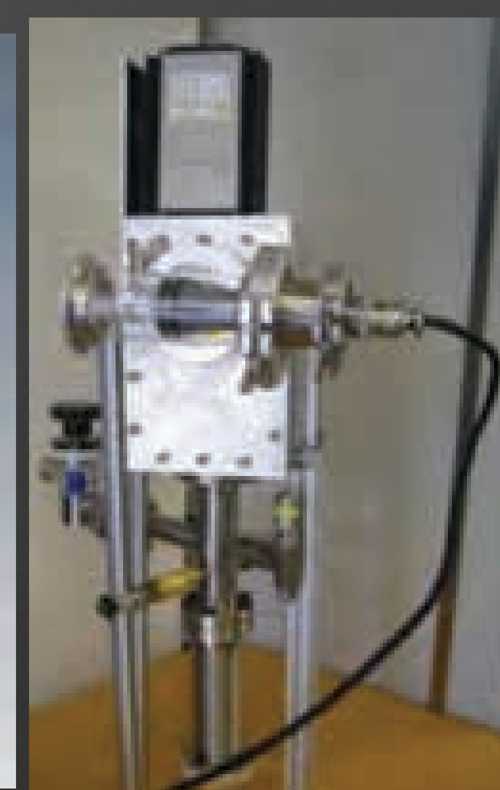
- Extensive calibrations utilizing:
  - Injected gaseous sources (betas, gammas, alphas)
  - External neutron sources
  - Calibration source deployment tubes (gammas, neutrons)
- Many calibrations
  - Main TPC: NR & ER bands
  - Main TPC: x, y, z & purity monitorring
  - Skin and OD: energy and threshold

LUX Tritium beta calibrations



Complementary neutron calibrations





Background control and estimates

Intrinsic Contamination Backgrounds	Mass (kg)	Composite	U early (mBq/kg)	U late (mBq/kg)	Th early (mBq/kg)	Th late (mBq/kg)	Co60 (mBq/kg)	K40 (mBq/kg)	n/yr (inc. S.F. rej.)	ER (cts)	NR (cts) (w/ SF rej.)
Upper PMT Structure	48.7	Y	5.32	0.80	1.06	0.72	0.03	3.81	5.23	0.14	0.001
Lower PMT Structure	71.7	Y	2.62	0.24	0.41	0.30	0.00	1.33	8.57	0.08	0.001
R11410 3" PMTs	91.9	Y	71.63	3.20	3.12	2.89	2.81	15.41	[illegible]	1.47	0.013
R11410 PMT Bases*	2.8	Y	369.62	75.87	38.91	33.07	0.87	50.58	[illegible]	0.37	0.003
R8778 2" PMTs	6.1	Y	138.02	59.39	16.83	16.90	18.25	412.87	[illegible]	0.13	0.008
R8520 Skin 1" PMTs	2.1	Y	62.17	5.29	4.81	4.65	24.44	[illegible]	53.71	0.02	0.008
R8520 Skin PMT Bases*	0.2	Y	212.95	108.46	42.19	37.62	2.23	[illegible]	3.62	0.00	0.000
PMT Cabling	62.5	Y	5.81	7.05	1.24	1.62	[illegible]	6.30	0.75	0.68	0.000
TPC PTFE	184.0	N	0.02	0.02	0.03	0.03	[illegible]	0.12	22.54	0.06	0.008
Grid Wires	0.18	N	1.20	0.27	0.33	[illegible]	1.60	0.40	0.00	0.00	0.000
Grid Holders	92.3	Y	2.86	0.83	0.84	[illegible]	1.42	2.82	20.71	0.97	0.008
Field Shaping Rings	92.5	Y	5.49	1.14	0.72	[illegible]	0.00	2.00	41.04	0.98	0.016
TPC Sensors	4.45	Y	21.17	5.04	[illegible]	1.56	1.36	9.36	4.96	0.02	0.000
TPC Thermometers	0.57	Y	26.57	11.84	[illegible]	4.31	0.99	462.60	1.79	0.06	0.000
Xe Recirculation Tubing	15.1	Y	0.79	[illegible]	0.23	0.33	1.05	0.30	0.64	0.00	0.000
HV Conduits and Cables	137.7	Y	3.8	[illegible]	3.6	0.8	1.4	2.5	26.5	0.05	0.006
HX and PMT Conduits	199.6	Y	3.36	[illegible]	0.48	0.56	1.24	1.47	5.23	0.05	0.001
Cryostat Vessel	2705.3	Y	[illegible]	0.11	0.40	0.40	0.16	0.54	159.44	0.94	0.017
Cryostat Seals	33.7	Y	[illegible]	27.56	3.50	5.60	9.76	140.80	127.06	0.54	0.008
Cryostat Insulation	13.8	Y	85.84	36.55	11.44	9.15	3.40	78.87	35.33	0.46	0.004
Cryostat Teflon Liner	26.0	[illegible]	0.02	0.02	0.03	0.03	0.00	0.12	3.18	0.00	0.000
Outer Detector Tanks	4299.3	[illegible]	3.26	0.80	0.54	0.57	0.03	4.78	200.65	0.96	0.002
Liquid Scintillator	17640.3	Y	0.01	0.01	0.01	0.01	0.00	0.00	14.28	0.03	0.000
Outer Detector PMTs	204.7	Y	570	470	395	388	0.00	534	7 587	0.01	0.000
Outer Detector PMT Supports	770.0	N	12.35	12.35	4.07	4.07	9.62	9.29	258.83	0.00	0.000
Subtotal (Detector Components)										**8.01**	**0.101**
222Rn (1.63 μBq/kg)										588	-
220Rn (0.08 μBq/kg)										99	-
natKr (0.015 ppt g/g)										24.5	-
natAr (0.45 ppb g/g)										2.47	-
210Bi (0.1 μBq/kg)										40.0	-
Laboratory and Cosmogenics										4.3	0.06
Fixed Surface Contamination										0.19	0.39
Subtotal (Non-ν counts)										**787**	**0.55**
Physics Backgrounds											
136Xe 2νββ										67	0
Astrophysical ν counts (pp+7Be+13N)										255	0
Astrophysical ν counts (8B)										0	0**
Astrophysical ν counts (Hep)										0	0.21
Astrophysical ν counts (diffuse supernova)										0	0.05
Astrophysical ν counts (atmospheric)										0	0.46
Subtotal (Physics backgrounds)										322	0.72
Total										1 090	1.27
Total (with 99.5% ER discrimination, 50% NR efficiency)										5.44	0.63
										6.08	

Detector components from assays

Xenon contaminants

External backgrounds

Physics: Neutrinos!

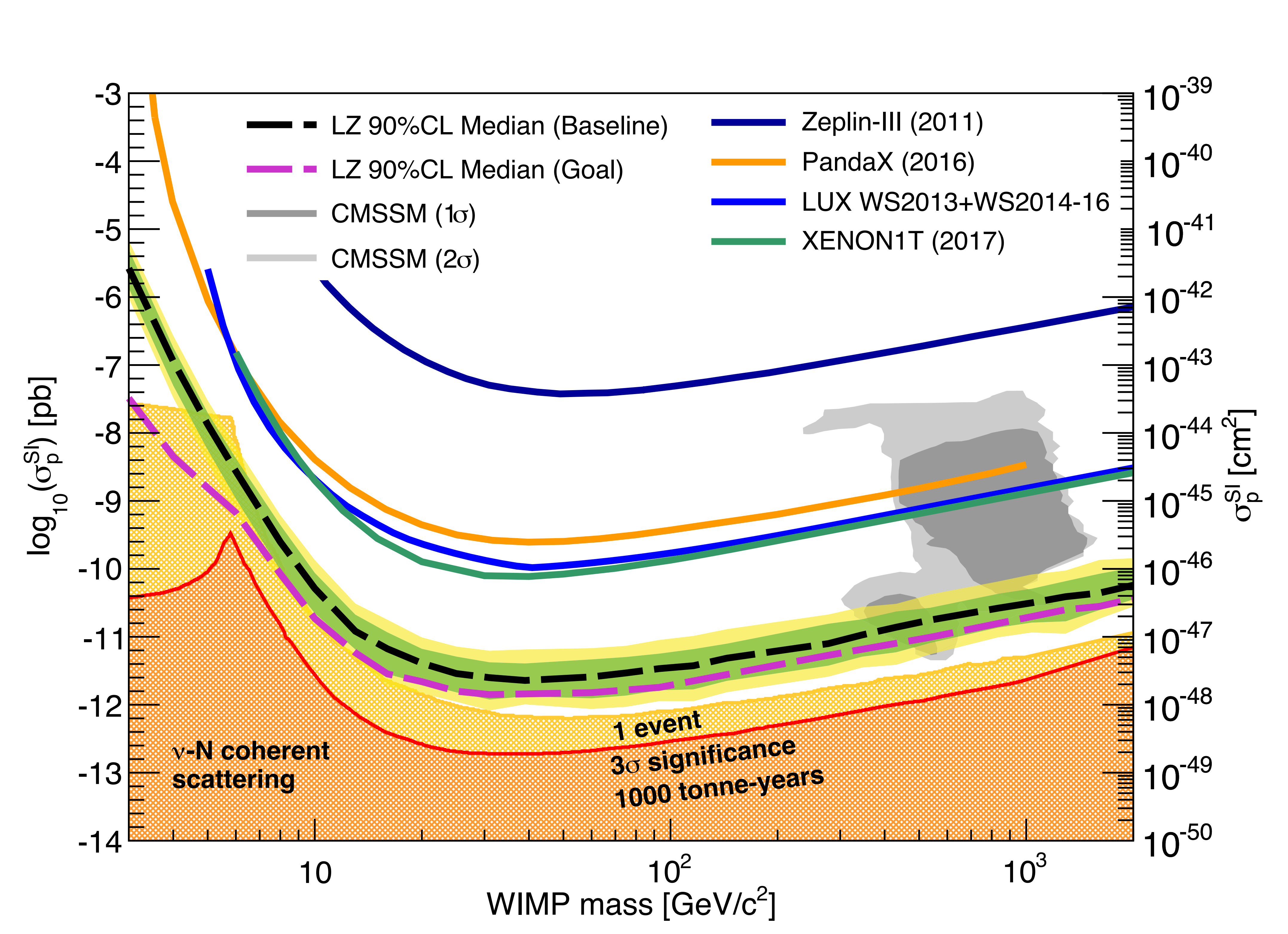
Full discussion in C. Ignarra's next talk

Performance drivers

Detector Parameter	Reduced	Baseline	Goal
Light collection (PDE)	0.05	0.075	0.12
Drift field (V/cm)	160	310	650
Electron lifetime (μs)	850	850	2800
PMT phe detection	0.8	0.9	1.0
N-fold trigger coincidence	4	3	2
^{222}Rn (mBq in active region)	13.4	13.4	0.67
Live days	1000	1000	1000

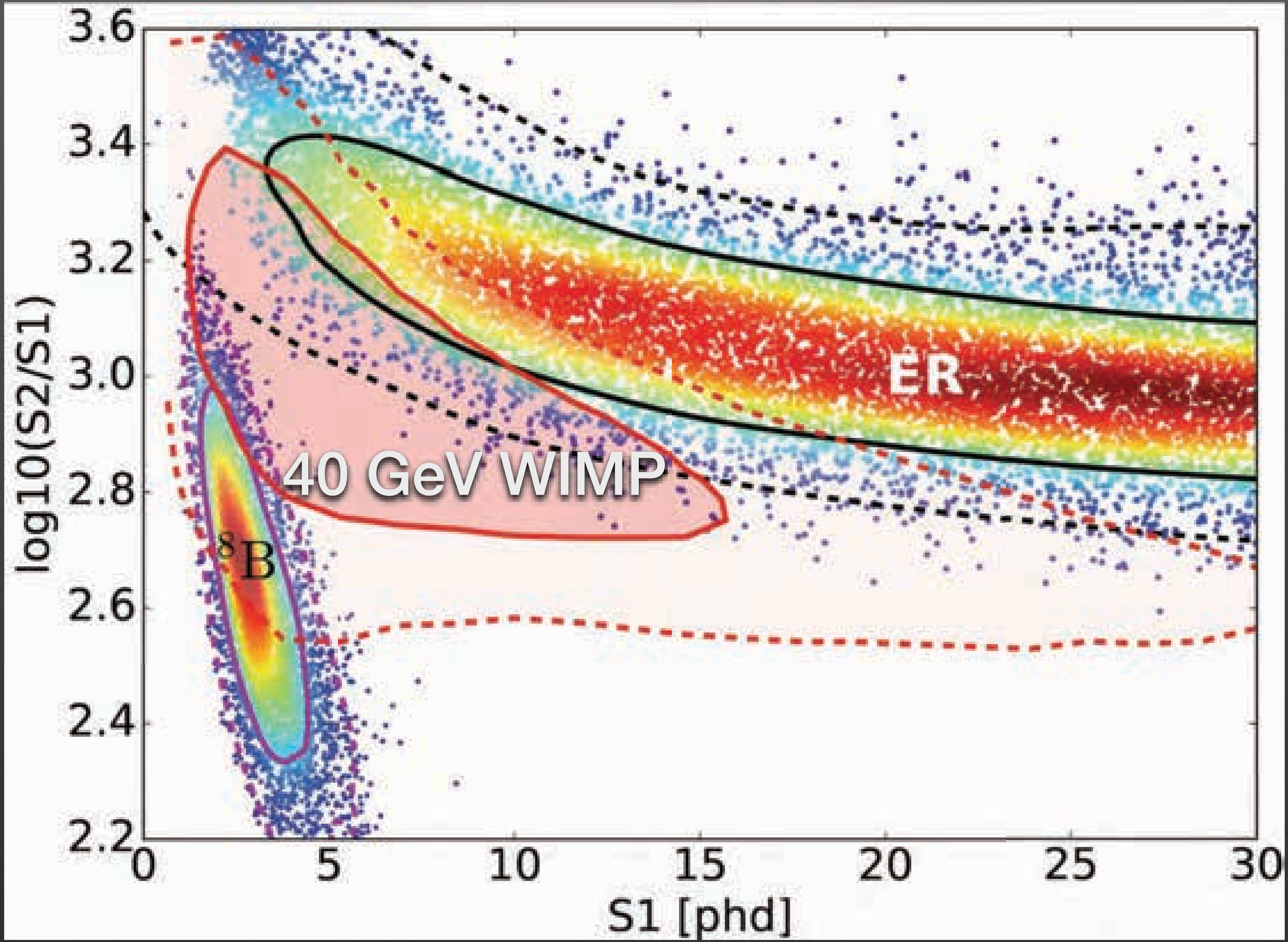
- 5.8 keVnr S1 threshold
- 310 V/cm driftfield, 99.5%ER/NR discrimination efficiency

LZ Projected Limit



Baseline sensitivity: 2.3×10^{-48} cm^2 40 GeV/c^2 WIMP from 5.6 T & 1000 livedays

LZ Simulated Signal Region

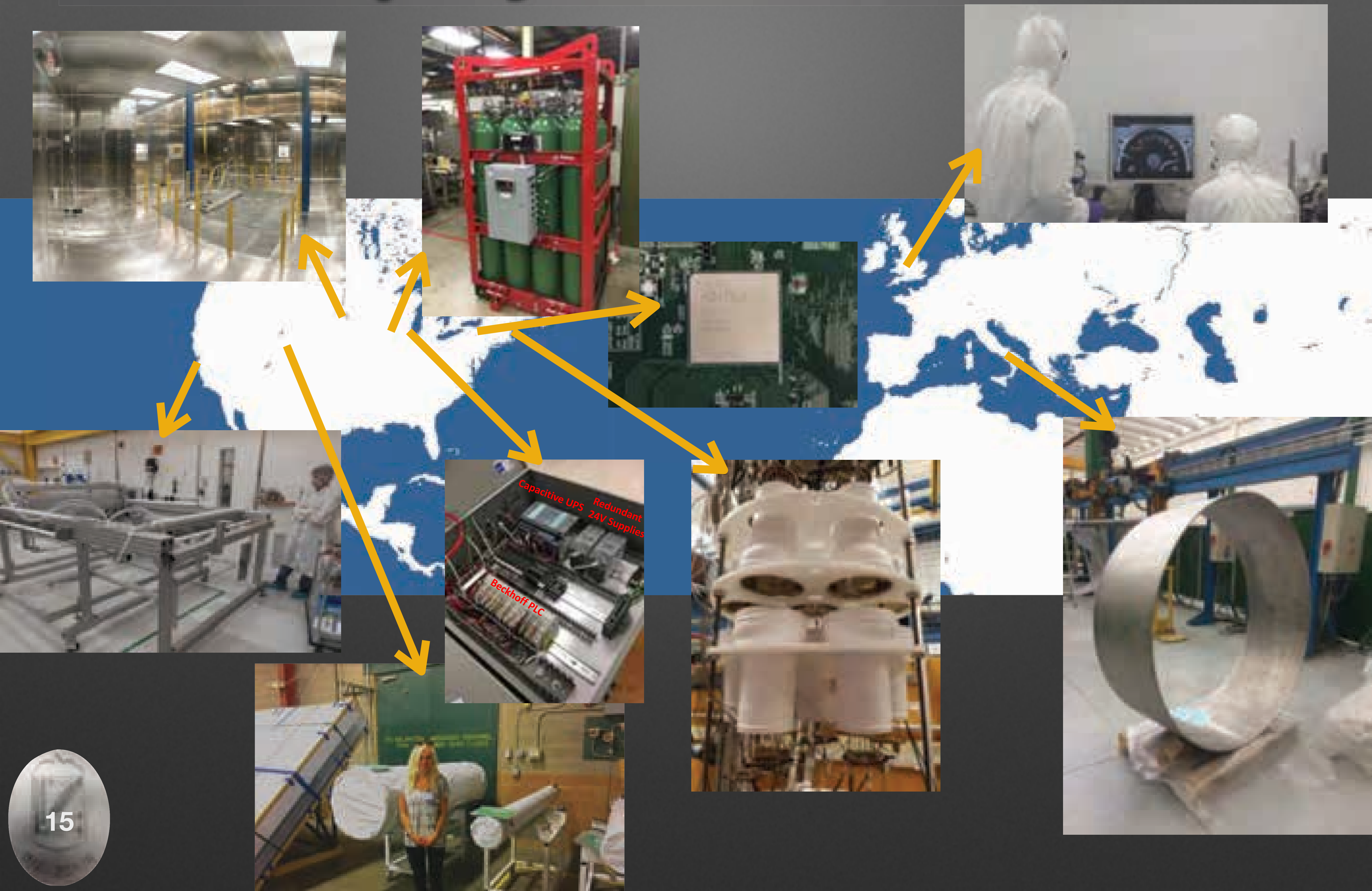


5x the expected ER background and 500x the expected NR background in the nominal LZ exposure

LZ Timeline

Year	Month	Activity
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
2016	August	DOE CD-2/3b approval
2017	February	DOE CD-3c approval
		Technical Design Report arXiv: 1703.09144
2017	March	LUX removed from underground
2017	June	Begin preparations for surface assembly
2018	July	Begin underground installation
2020		Begin commissioning
2021		Begin data taking for WIMP search
2024+		5+ years of operations

Recent project activities



Summary

- LZ dark matter experiment proceeds on schedule
  - Long lead-time item procurement underway: Xenon, PMTs, Cryostat vessel, facility prep, etc.
  - Simulations, analysis framework, and run control exercised
  - Quality assurance and control testing for hardware underway

- LZ benefits from LUX calibration techniques and understanding of backgrounds
  - Materials screening program busy

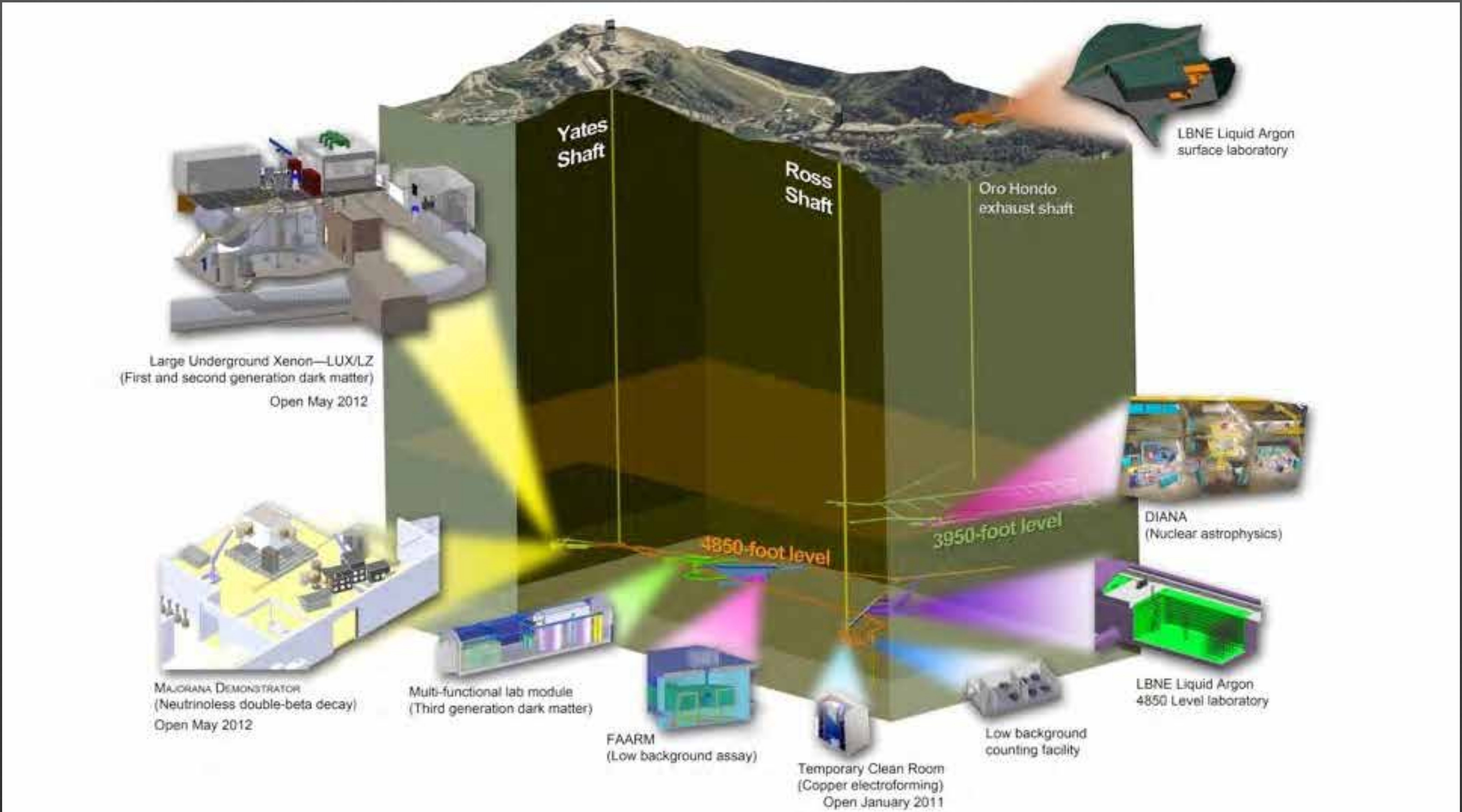
- WIMP sensitivity 2.3×10^{-48} cm^2 for a 40 GeV/c^2 WIMP mass with 1000 live days and 5.6 tonnes fiducial mass

Backup Slides

LZ Calibration Sources

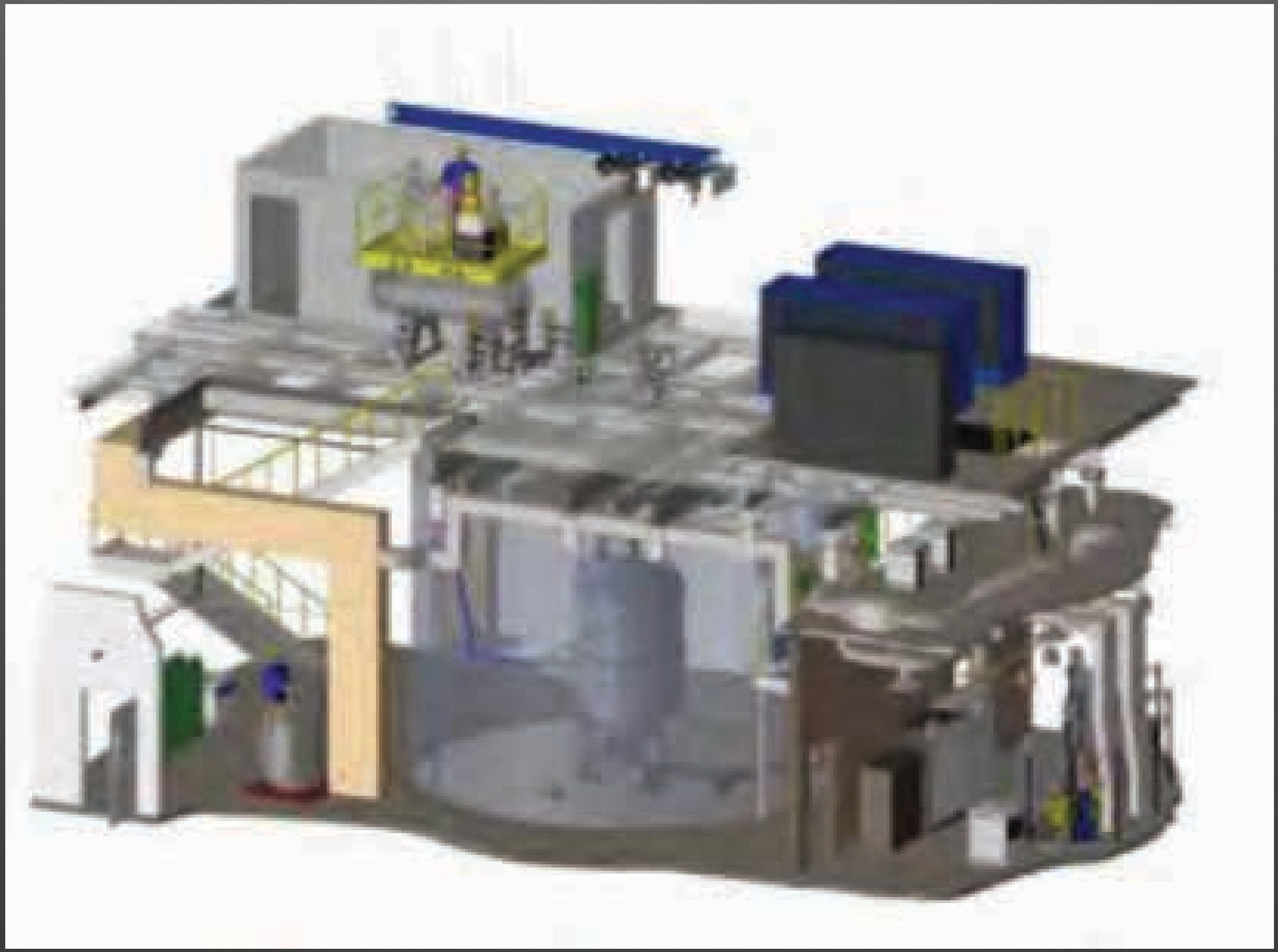
Isotope	What	Purpose	Deployment
Tritium	beta, Q = 18.6 keV	ER band	Internal
^{83m}Kr	beta/gamma, 32.1 keV and 9.4 keV	TPC (x, y, z)	Internal
^{131m}Xe	164 keV γ	TPC (x, y, z), Xe skin	Internal
^{220}Rn	various α's	xenon skin	Internal
AmLi	(α, n)	NR band	CSD
^{252}Cf	spontaneous fission	NR efficiency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

SURF

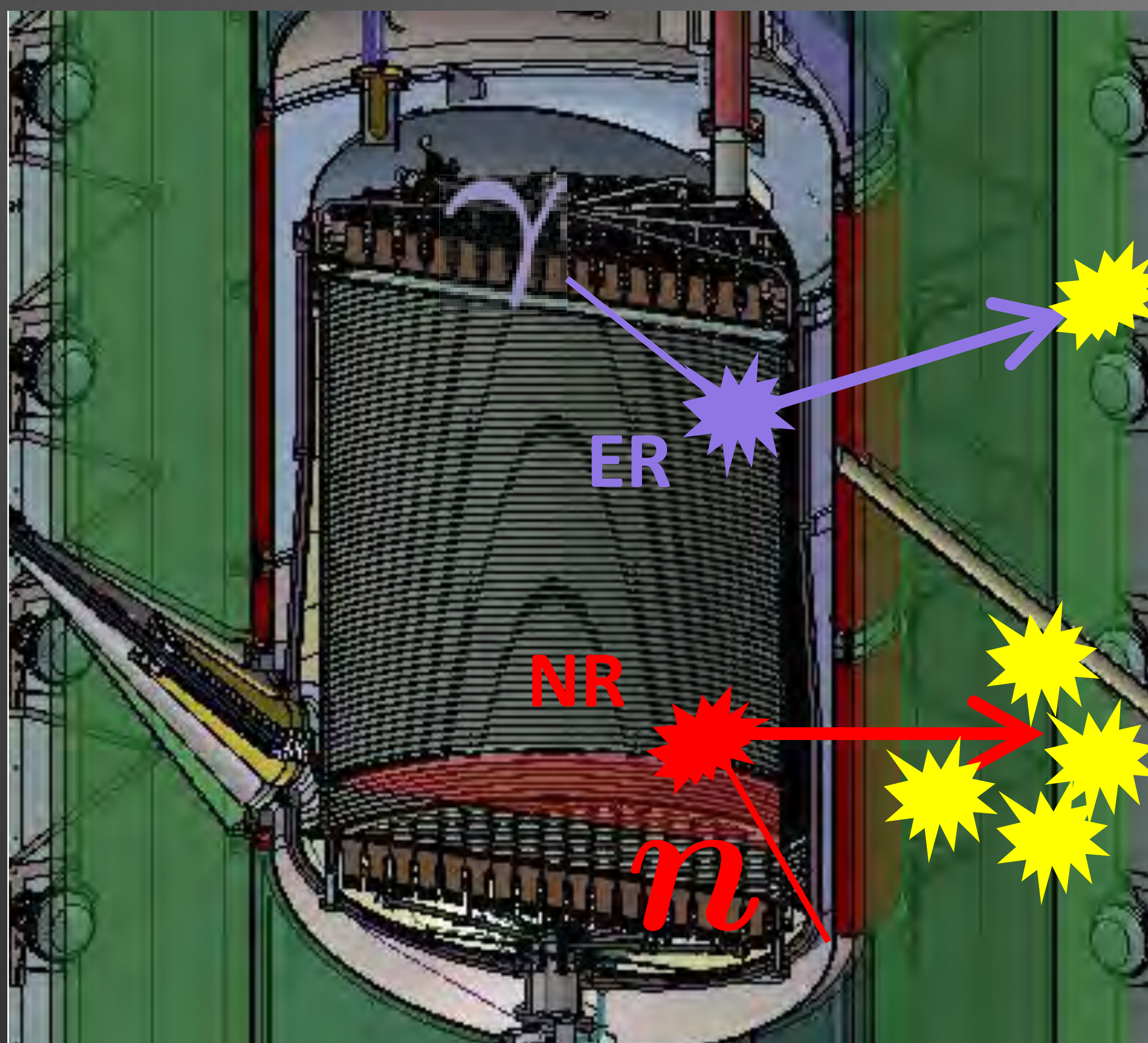


Yates Shaft
Ross Shaft
Oro Hondo exhaust shaft
LBNE Liquid Argon surface laboratory
Large Underground Xenon—LUX/LZ
(First and second generation dark matter)
Open May 2012
DIANA
(Nuclear astrophysics)
3950-foot level
4850-foot level
Majorana Demonstrator
(Neutrinoless double-beta decay)
Open May 2012
Multi-functional lab module
(Third generation dark matter)
FAARM
(Low background assay)
Temporary Clean Room
(Copper electroforming)
Open January 2011
Low background counting facility
LBNE Liquid Argon 4850 Level laboratory

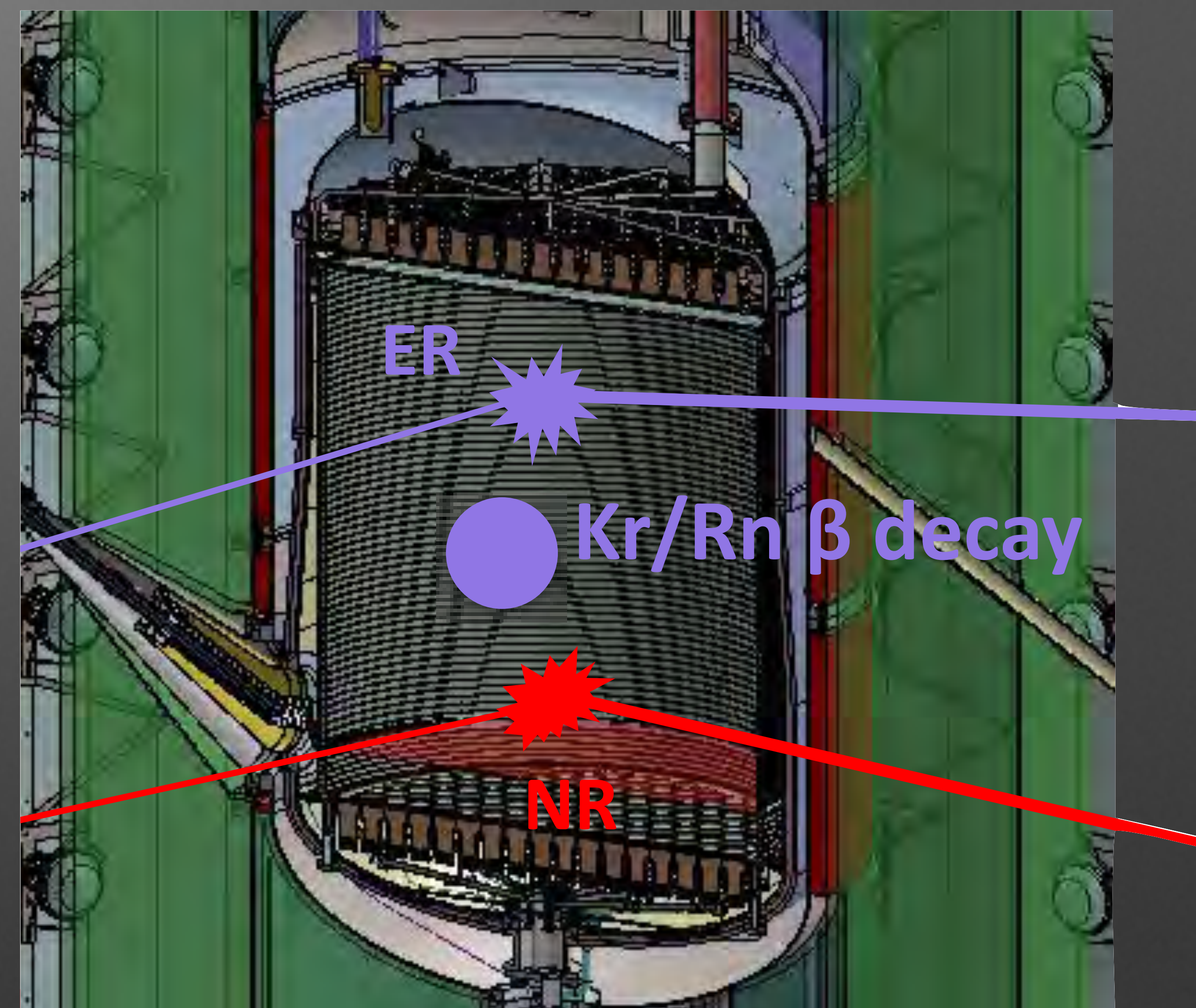
LZ @ Davis Cavern



LZ Backgrounds



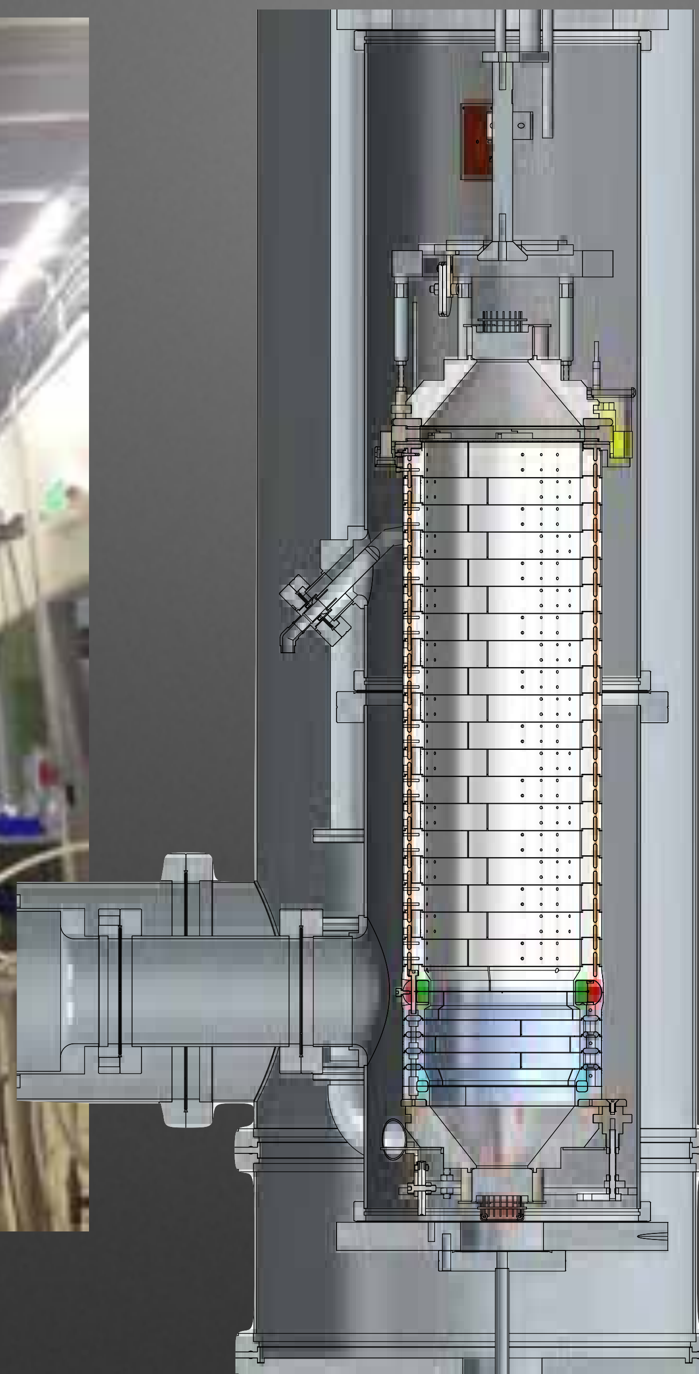
External Materials



Uniform in LXe

SLAC System Test Platform

System Test TPC



- Test Grid High Voltage with single photon and single electron sensitivity
- Prototype many subsystems: circulation, slow controls, sensors