The LUX-ZEPLIN Experiment

Ben Krikler
for the LZ collaboration

1st July 2019 at PASCOS 2019

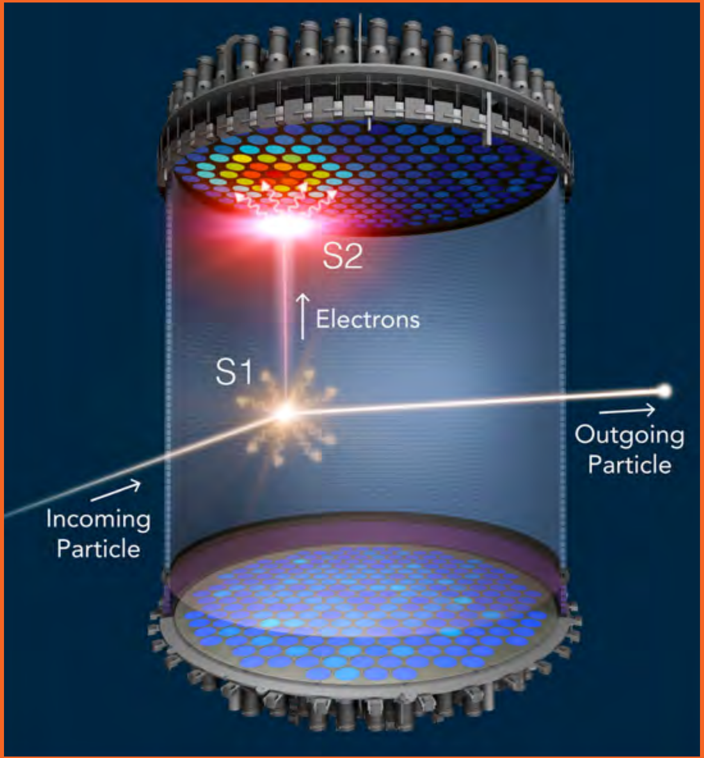
University of BRISTOL

1. Overview of LZ
2. Backgrounds and Sensitivity
3. Construction Status

Direct detection of Dark Matter

- If DM is a particle with a finite probability to scatter of SM particles...
- ... can we observe such interactions directly?
- Current limits for 30 GeV WIMP, spin-independent at 4×10^{-47} cm^2 by XENON1T
- Good sensitivity requires:
  - Large mass detector
  - Backgrounds suppressed to an even lower rate

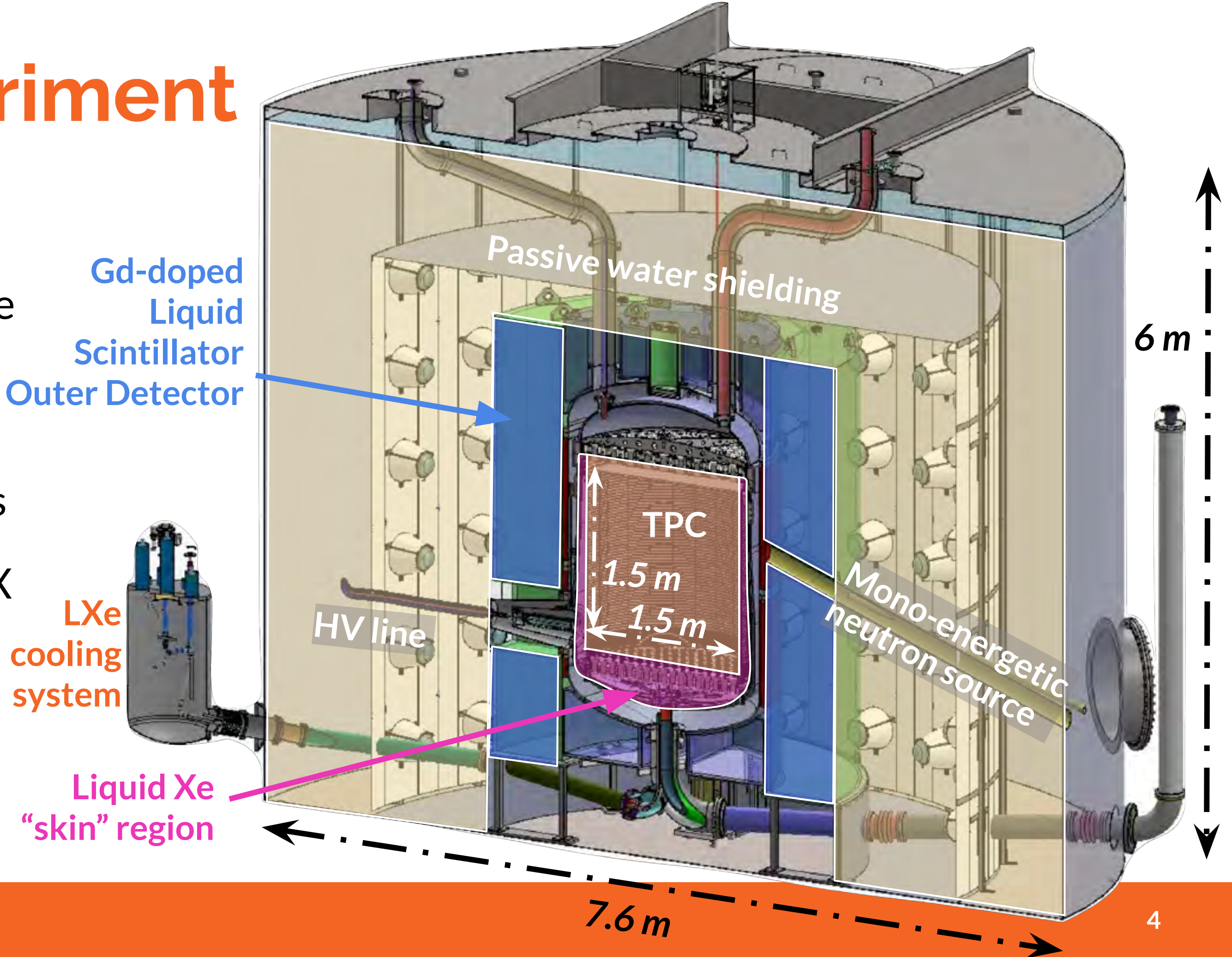
Two-phase xenon TPC



- Scattering off atom in liquid xenon
  - Recoil from nucleus (NR) or atomic electrons (ER)
- Produces light and free electrons / ions
  - Prompt light detected: “S1”
  - Electric field drifts electrons
- Charge reaches gas xenon
  - Amplification
  - Second delayed light: “S2”
- From S1 and S2:
  - Relative time: depth in detector
  - Transverse position
  - Type of interaction: ER vs NR
- Xenon naturally radio-pure

The LZ experiment

- Two-phase xenon TPC:
  - 7 tons liquid xenon
  - 5.6 t of fiducial volume
  - 50 kV cathode
  - 494 x 3" PMTs in TPC
- Veto and shield systems
- Same water tank as LUX



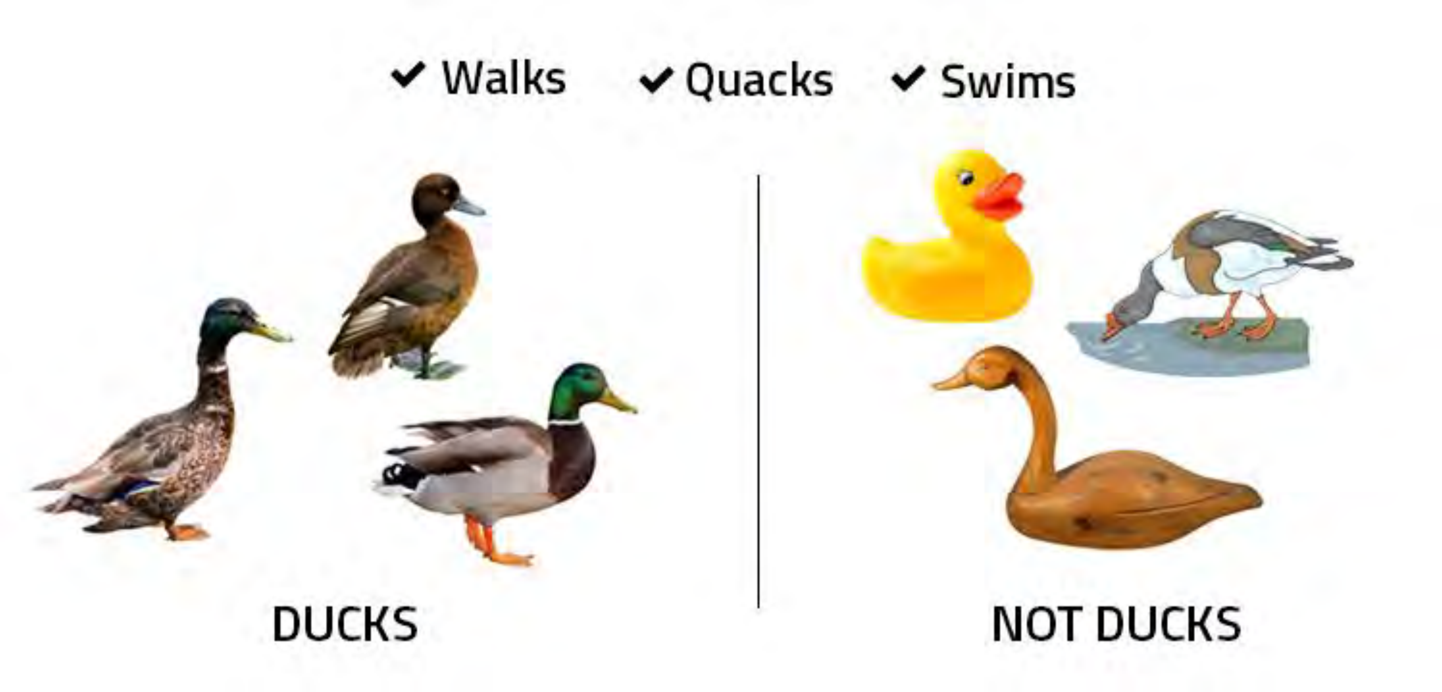
LZ at SURF

- Sanford Underground Research Facility (SURF)
  - Originally a gold mine
  - Previously home to Davis neutrino experiment
  - Soon to be home to DUNE
- 1 mile underground (4850 feet)

By Huebi - https://commons.wikimedia.org/w/index.php?curid=1141214

Backgrounds and Sensitivity

In particle physics, if it walks like a duck, and it quacks like a duck, it's probably still not a duck



https://www.moogsoft.com/blog/aiops/understanding-machine-learning-aiops-part-2

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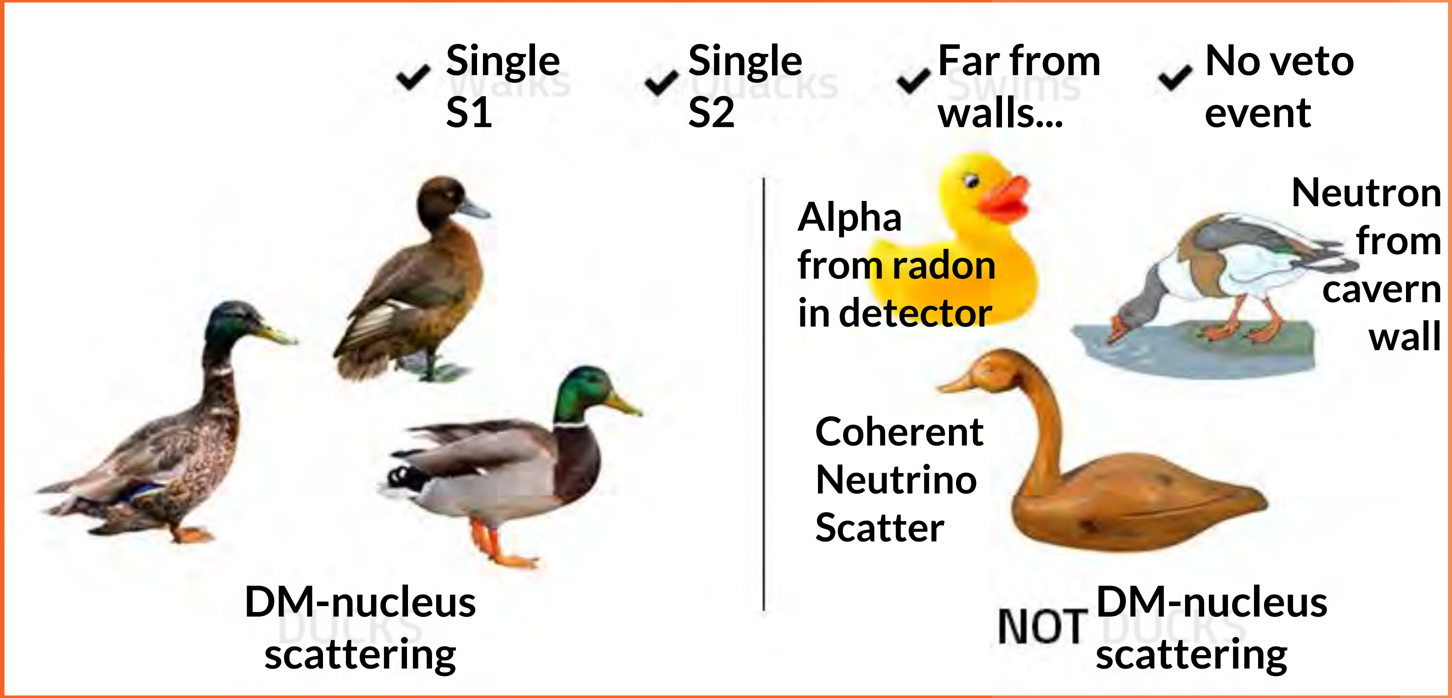

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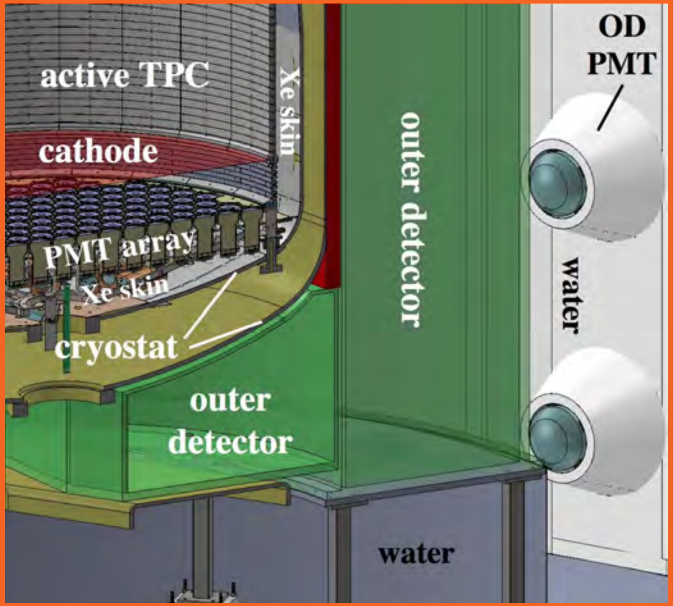
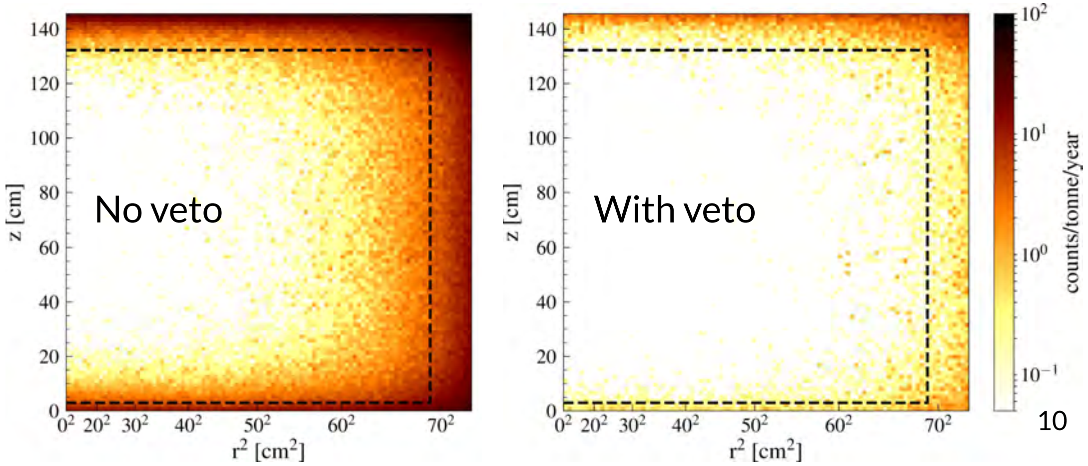
Sources of Background

- External sources
  - Cosmogenics
  - Radiation from experiment cavern
  - Other new physics (e.g. neutrinos)
- Internal sources
  - Radioactive materials in detector components
  - Emanation of Radon from detector components
  - Radioactive dust on surfaces
  - Contaminants in the xenon

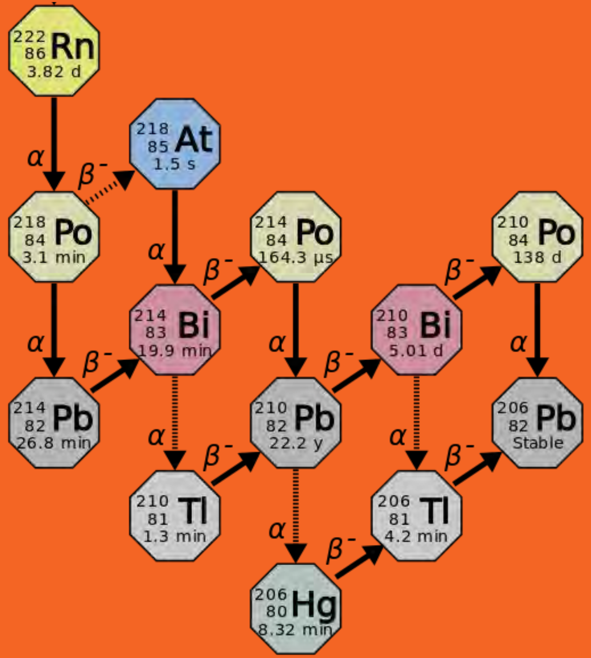
Mitigating External Backgrounds



- Go deep underground
  - 4300 m.w.e. underground at SURF in Lead, SD
  - Measure rock backgrounds: [ArXiv:1904.02112](https://arxiv.org/abs/1904.02112)
- Add three layers of outer shields:
  - Instrumented xenon skin around TPC
    ⇒ gamma ray scatters
  - Gadolinium-doped liquid scintillator tank
    ⇒ neutron tagging
  - Passive high-purity water



Mitigating Internal Backgrounds



By User:Tosaka - File:Decay chain(4n+2, Uranium series).PNG, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=33293646

- Detector materials
  - Radio-assay campaign
  - Gamma-screening, ICPMS, NAA
  - Screening Gd-LS: ArXiv: 1808.05595
- Radon emanation
  - Four screening sites and two portable assays
  - Target Rn activity: 2 µBq/kg
  - Rn removal system: reduces Rn from warm components by > x10: doi:10.1016/j.nima.2018.06.076
- Radon daughters and dust on surfaces
  - TPC assembly in Rn-reduced cleanroom
  - Dust < 500 ng/cm^3 on all LXe wetted surfaces
  - Rn-daughter plate-out on TPC walls < 0.5 mBq/m^2
- Xenon contaminants – ^{85}Kr, ^{39}Ar
  - Charcoal chromatography @ SLAC
  - Final ^{nat}Kr/Xe 0.015 ppt

Total backgrounds

- Assumes 1000 live days (full LZ run)
- Radon in the xenon dominates ER counts
- Coherent atmospheric neutrino scattering dominates NR
- Sub-dominant NR backgrounds
  - Alpha-n on PTFE from Pb-210
  - Ions reconstructed in fiducial volume

Background source	**ER counts**	**NR counts**
Detector Components	9	0.07
Surface contamination	40	0.39
Xenon Contamination	819	0
Laboratory and cosmogenics	5	0.06
Physics	322	0.51
Total	1195	1.03
Total after 99.5% ER rejection and 50% NR efficiency	**5.97**	**0.52**

From “Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment” [ArXiv:1802.06039](https://arxiv.org/abs/1802.06039)

Sensitivity estimates

For WIMP of 40 GeV/c^2

- Excluded at 90% C.L.: 1.6×10^{-48} cm^2
- 3σ discovery: 3.8×10^{-48} cm^2
- 5σ discovery: 6.7×10^{-48} cm^2

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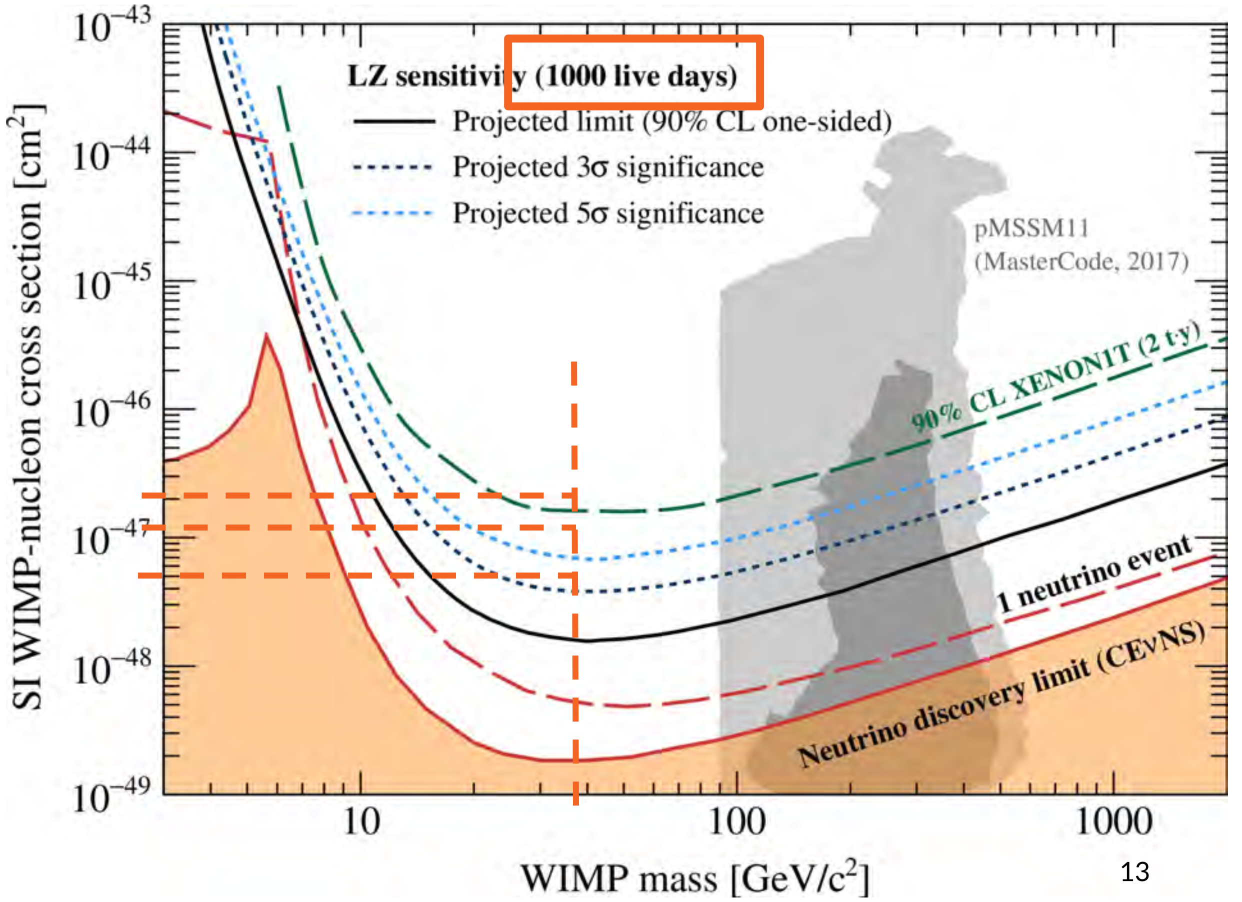
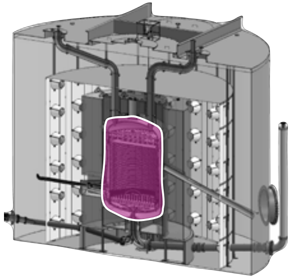
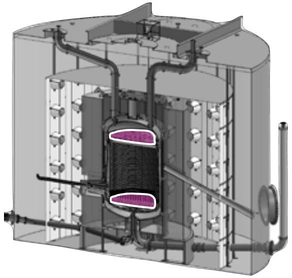


Construction, timeline, and flashy photos



Cryostat preparation

- Intense R&D program found low activity titanium DOI: 10.1016/j.astropartphys.2017.09.002
- Fabricated by Loterios, Italy
- Delivered to SURF May 2018
- Outer cryostat vessel (OCV):
  - Moved underground
- Inner cryostat vessel (ICV):
  - PTFE skin tiling of inner walls complete



LXe PMTs

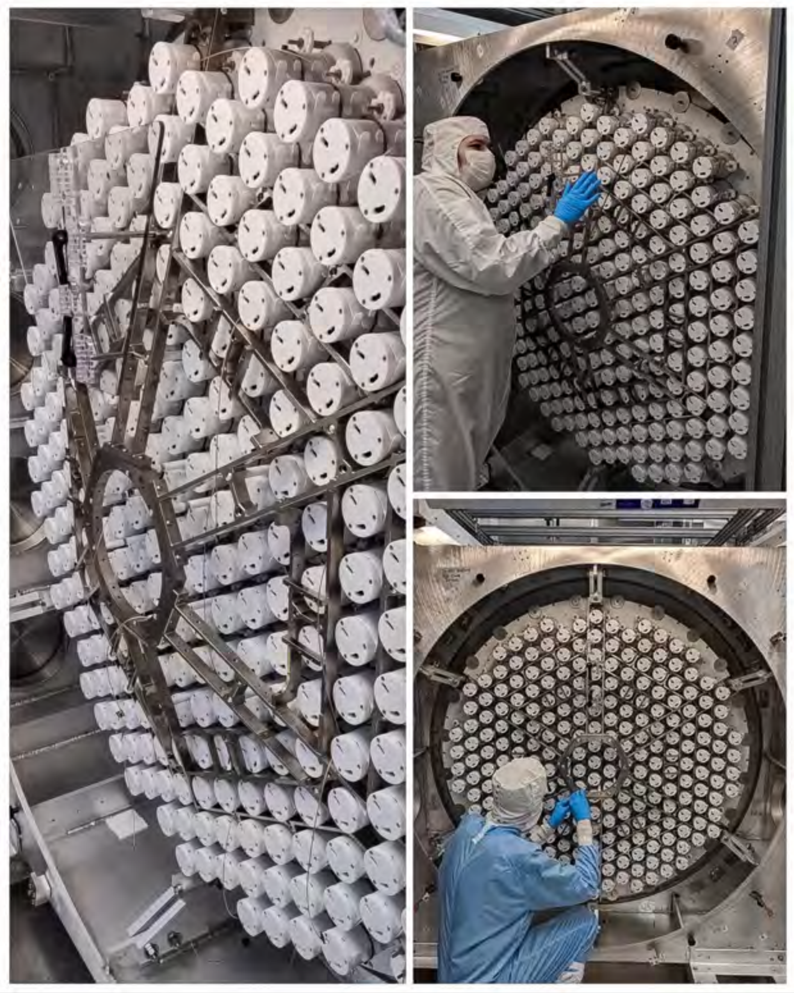
Many PMTs:

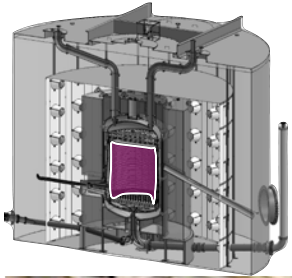
- 253 x 3” for top array
- 241 x 3” for bottom array
- 93 x1” and 38 x2” PMTs for top / bottom skin

Top and bottom arrays completed

Assembled within the PMT Array Lifting And Commissioning Enclosure (PALACE)

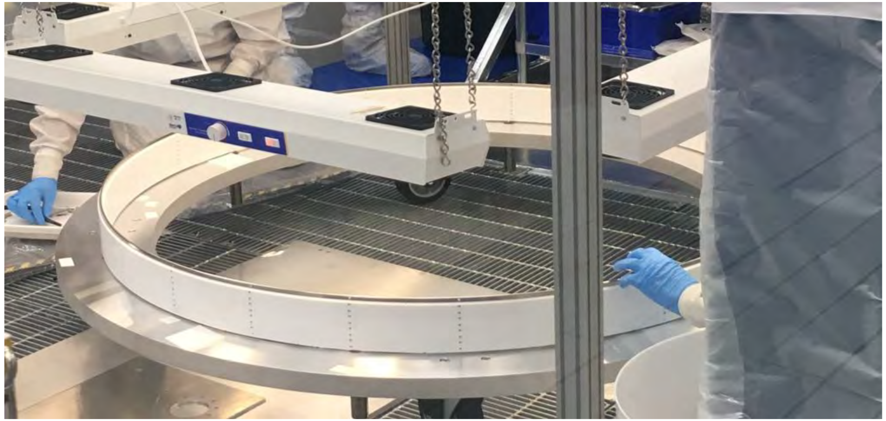
- Reduced dust and radon air
- Shipping enclosure
- Light-shielded electrical testing

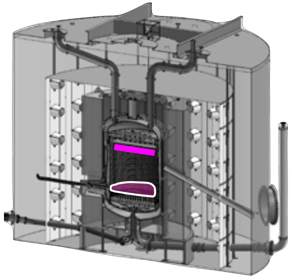




TPC Field Cage

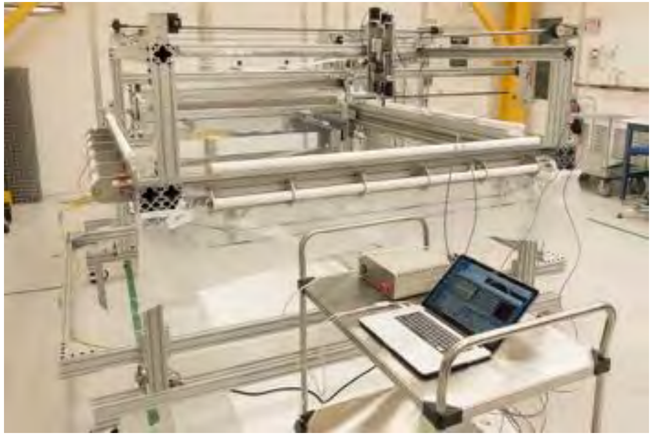
- 57 titanium field shaping rings
- PTFE for reflectivity and stability
- Completed December 2018
- Deionising tower to remove dust from PTFE

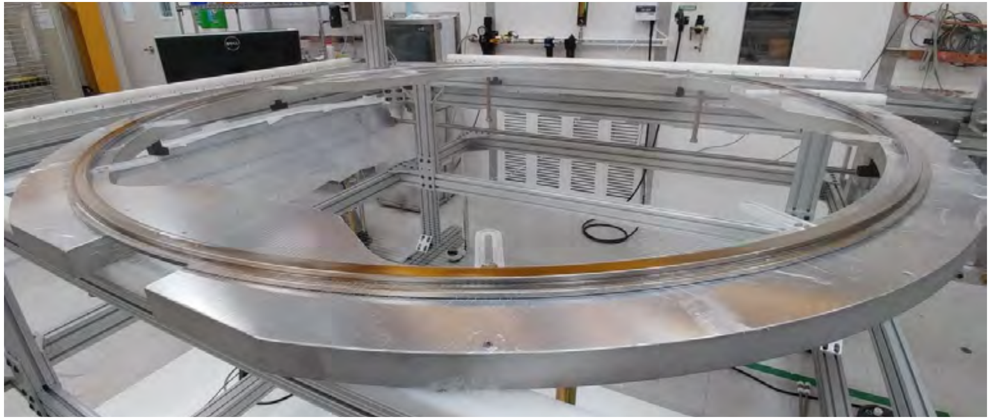




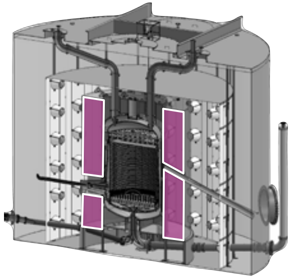
TPC - wire grids

- Semi-automated loom to weave stainless steel wire
- Final grids (+ 2 full-size prototypes) completed (1.5 m diameter)
- Delivered to SURF





https://www.youtube.com/watch?v=yNycDcMQkss



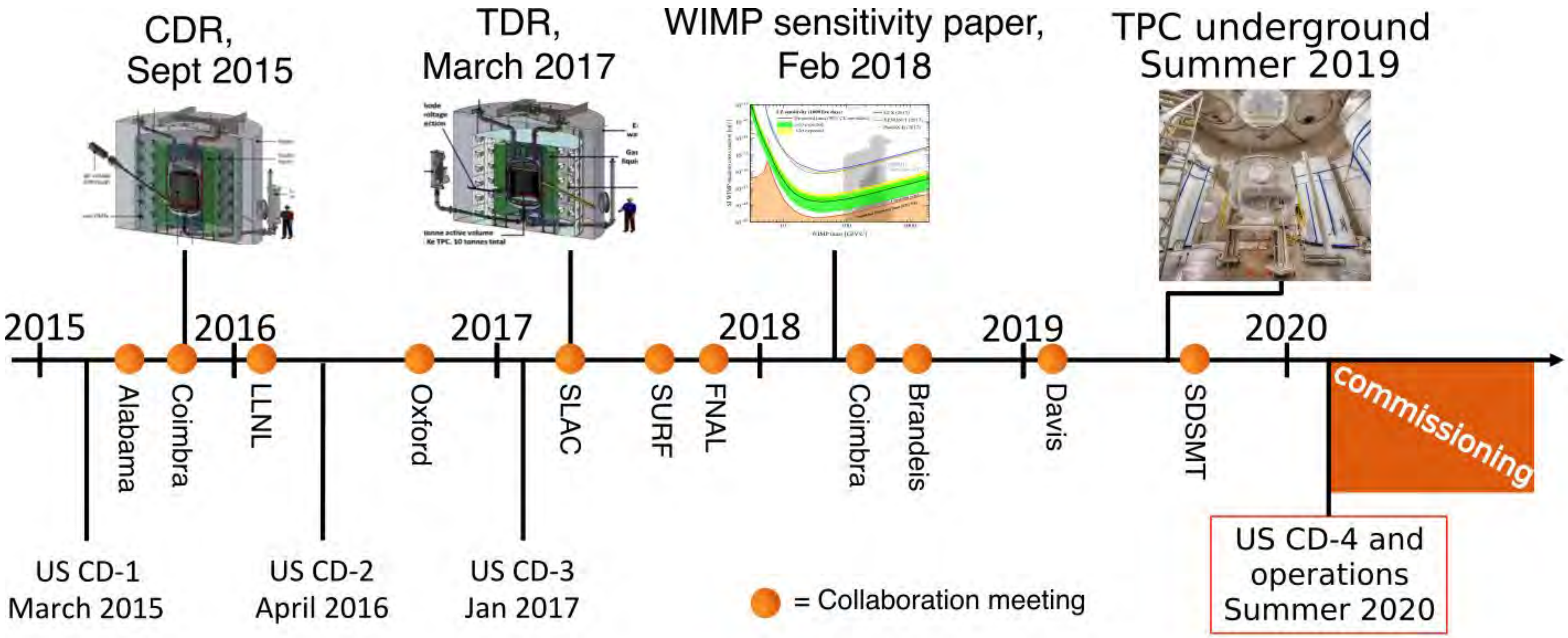
Outer Detector

- Acrylic vessels:
  - Side tanks (4) underground inside water tank
  - Top/bottom tank fabrication almost finished
- All outer detector PMTs in-hand:
  - Testing at IBS (Korea) complete
  - Mock PMT ladder installed inside water tank
- Gd-Liquid Scintillator production:
  - Equipment being installed at BNL

The 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)

Timeline

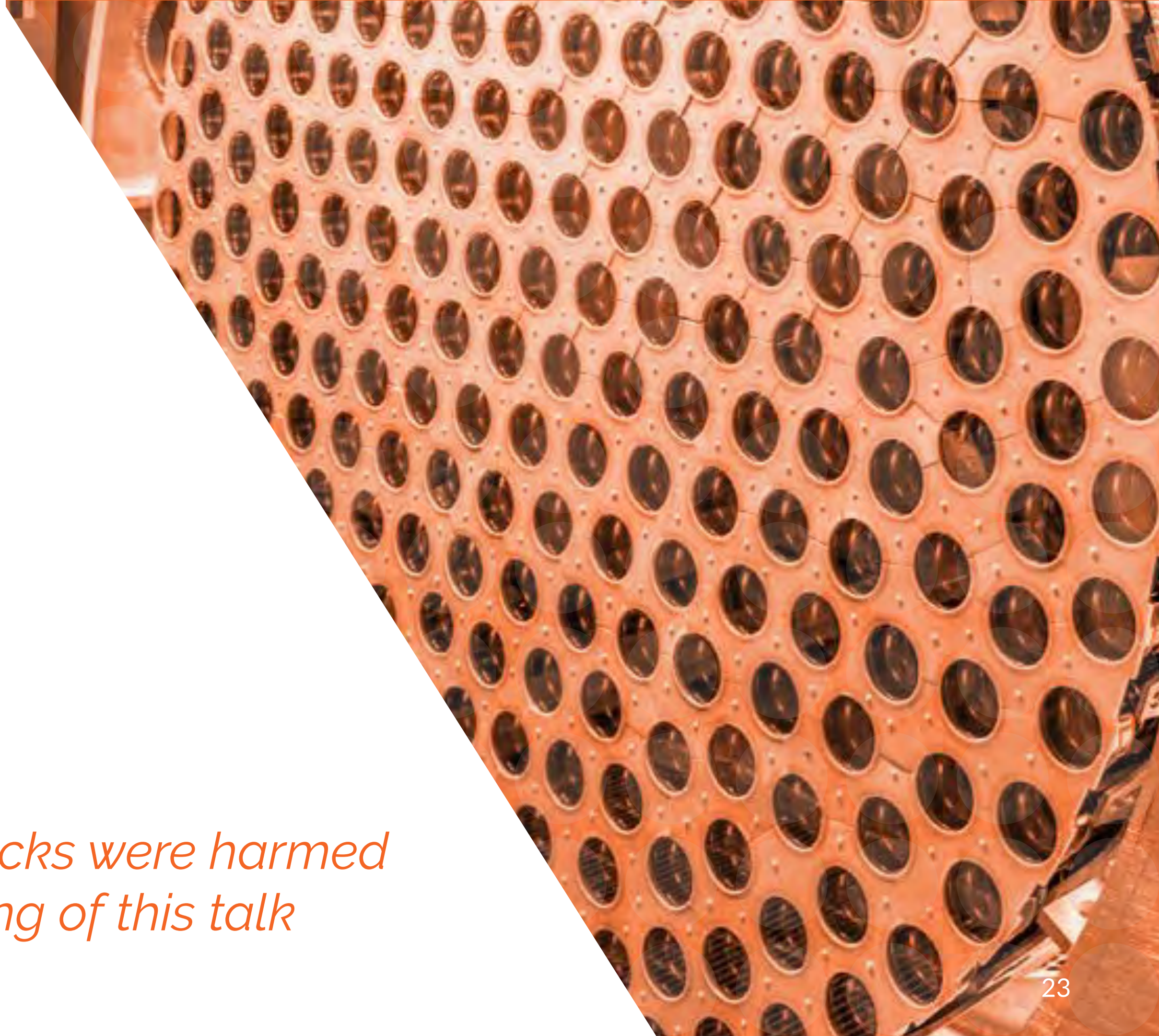

CDR,
Sept 2015
TDR,
March 2017
WIMP sensitivity paper,
Feb 2018
TPC underground
Summer 2019
2015
2016
2017
2018
2019
2020
Alabama
Coimbra
LLNL
Oxford
SLAC
SURF
FNAL
Coimbra
Brandeis
Davis
SDSMT
commissioning
US CD-1
March 2015
US CD-2
April 2016
US CD-3
Jan 2017
= Collaboration meeting
US CD-4 and
operations
Summer 2020

Summary

- **Presented the LUX-ZEPLIN experiment**
  - Based on two-phase xenon TPC
  - 5.6 fiducial tons of liquid xenon
- **World-leading results expected, e.g. for 40 GeV WIMPs**
  - 90% C.L. of exclusion at 1.6×10^{-48} cm^2
  - 3σ discovery at 3.8×10^{-48} cm^2
- **Broad non-WIMP DM program**
  - Talk: “A Hunt for Hidden Photons with the LZ Experiment” Mrs. Athoy NILIMA 15:10 Thursday
- **LZ has nearly completed construction**
  - Cryostat now underground; PMT arrays all assembled; TPC wire grids delivered
- **Operations to begin in summer next year**

Thank you

Note: no ducks were harmed in the making of this talk



Sensitivity

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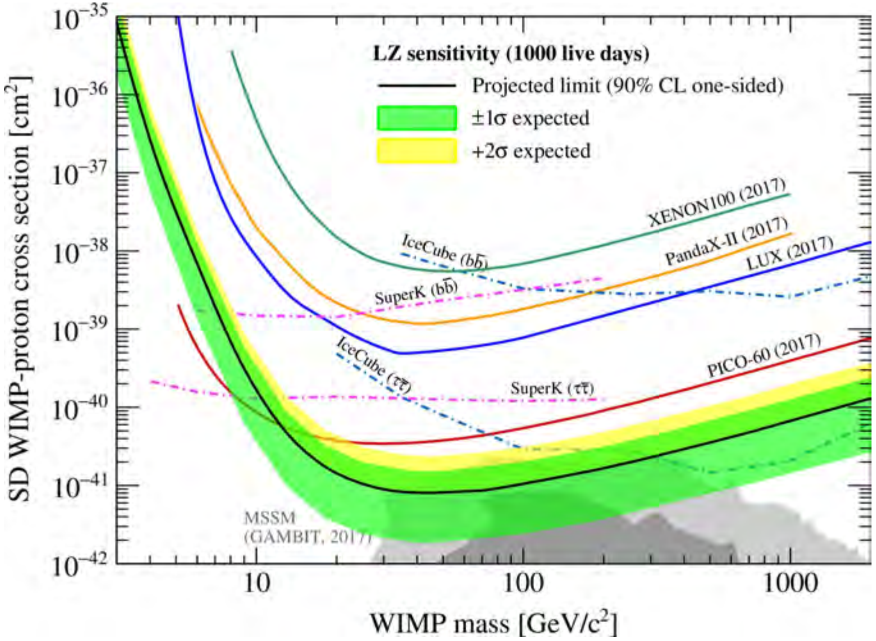

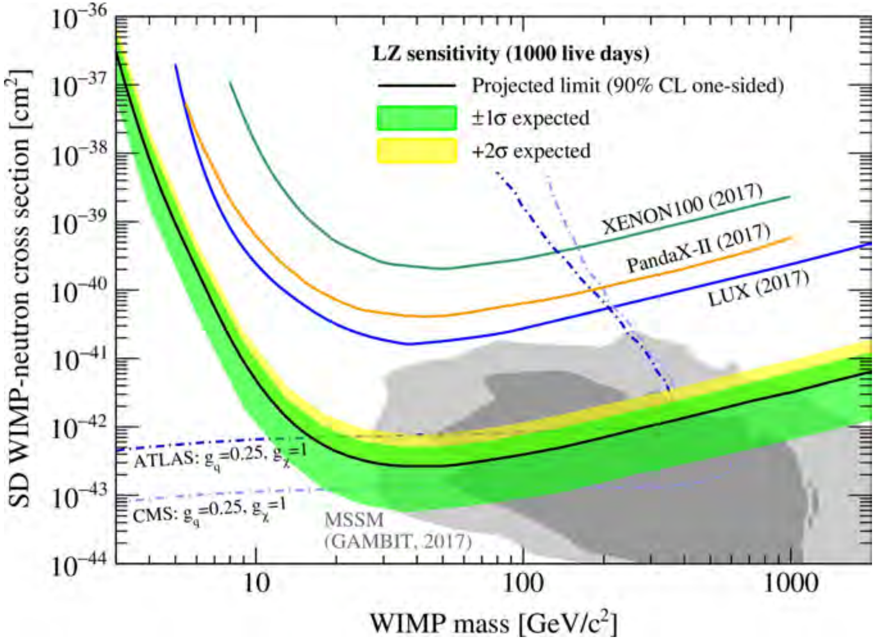

Detailed background table

From “Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment” [ArXiv:1802.06039](https://arxiv.org/abs/1802.06039)

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**	