




# The LUX-ZEPLIN Experiment

Ben Krikler  
for the LZ collaboration

1st July 2019 at PASCOS 2019



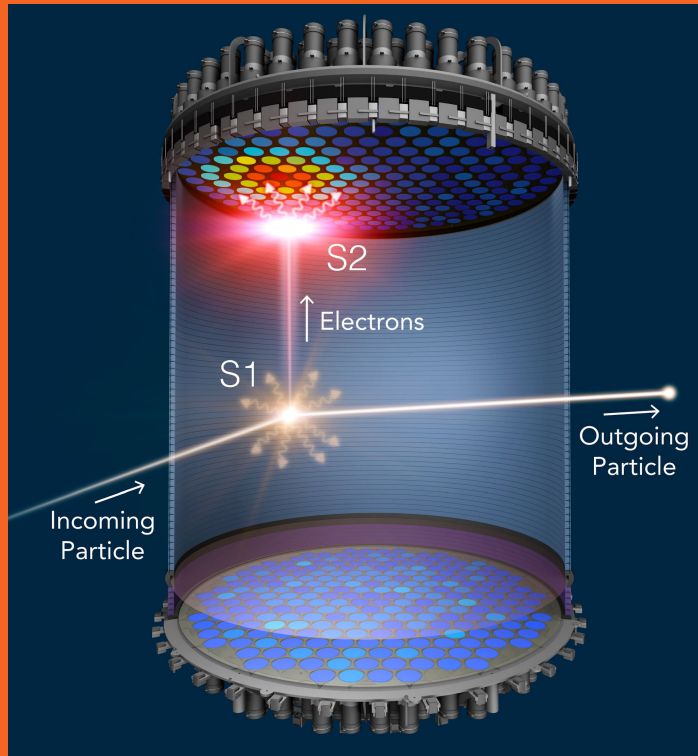
University of  
BRISTOL

- 
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  $4 \times 10^{-47} \text{ cm}^2$  by XENON1T
- Good sensitivity requires:
  - Large mass detector
  - Backgrounds suppressed to an even lower rate

# Two-phase xenon TPC



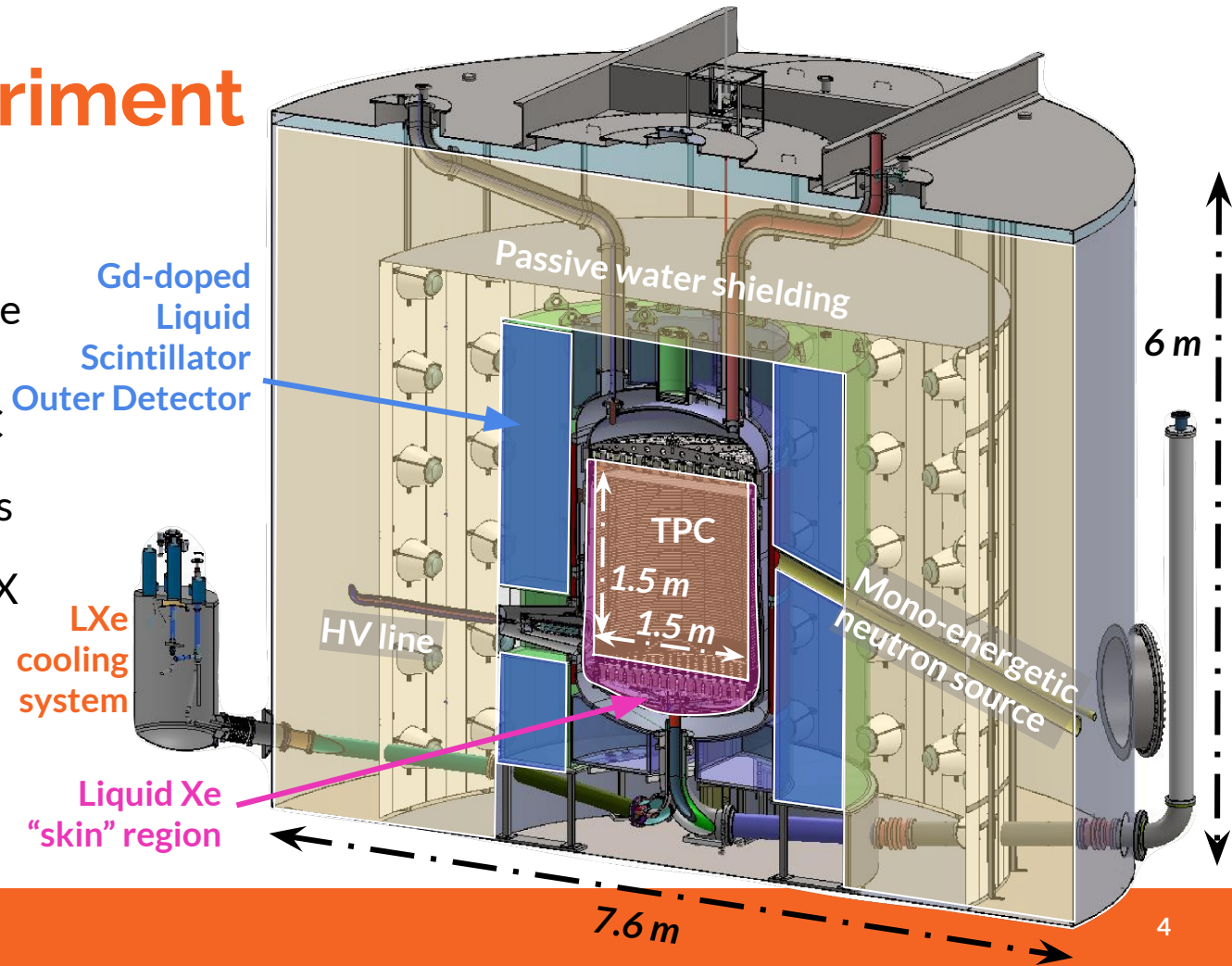
Electric  
Field



- 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)



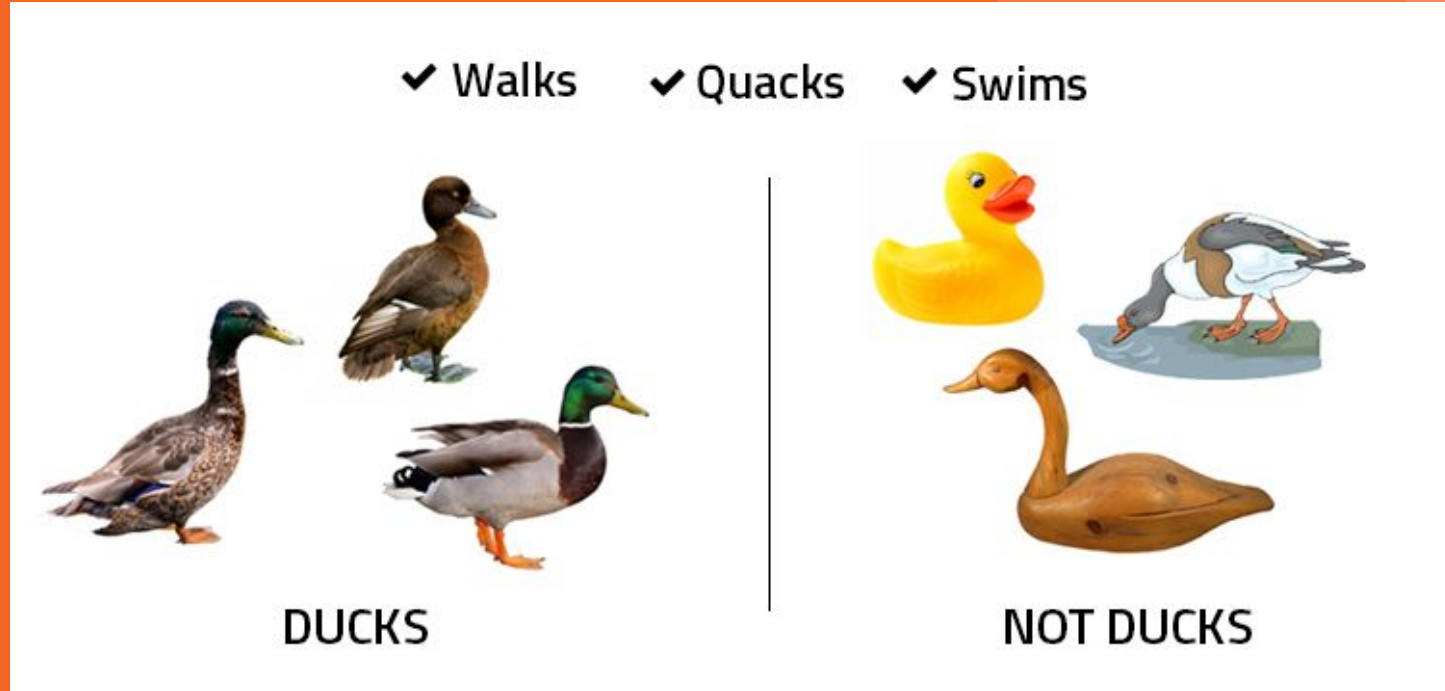
By Huebi - <https://commons.wikimedia.org/w/index.php?curid=1141214>



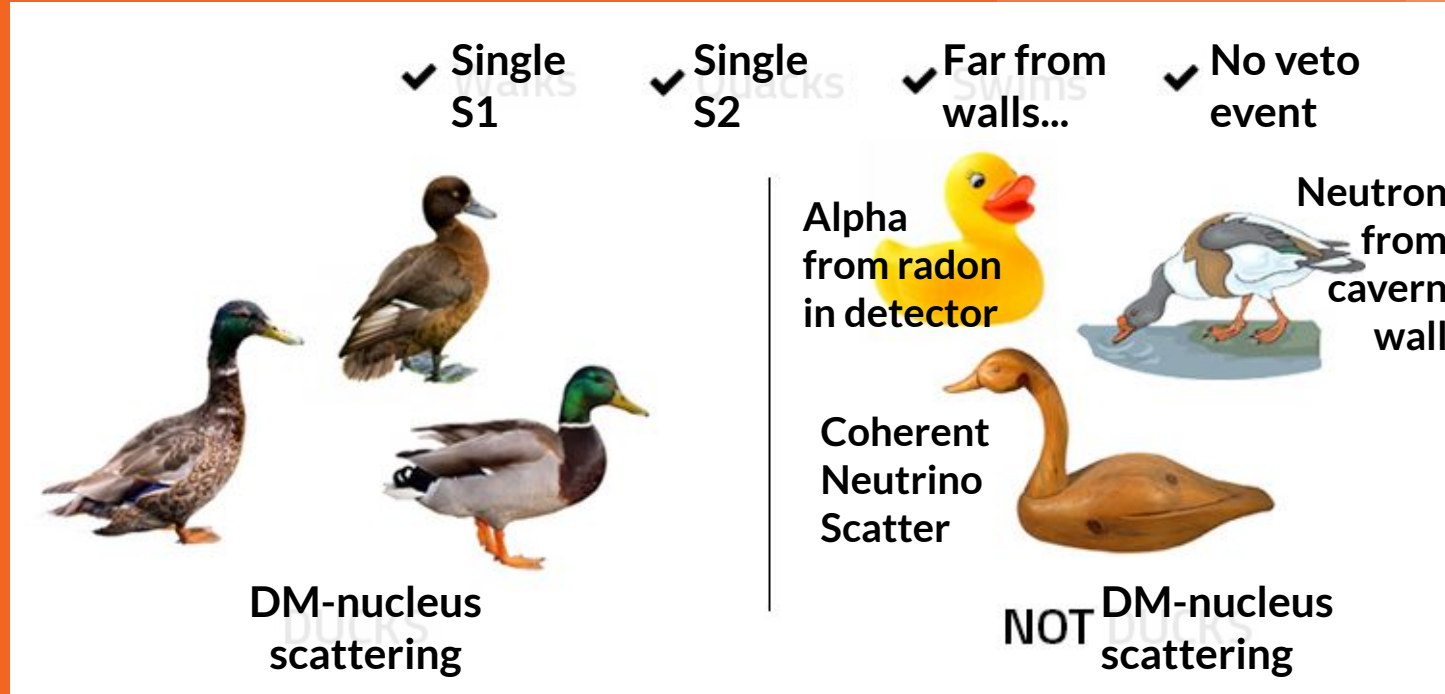
A close-up photograph of a copper-colored metal mesh with a regular pattern of small circular holes. A diagonal white line runs from the top left towards the bottom right, dividing the image. The text 'Backgrounds and Sensitivity' is positioned on the white background to the left of the mesh.

# 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



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



# Sources of Background

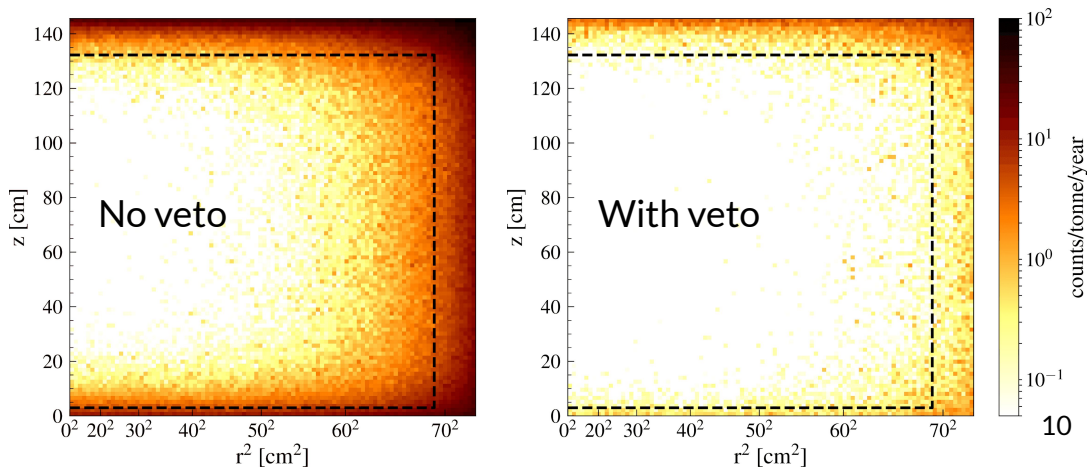
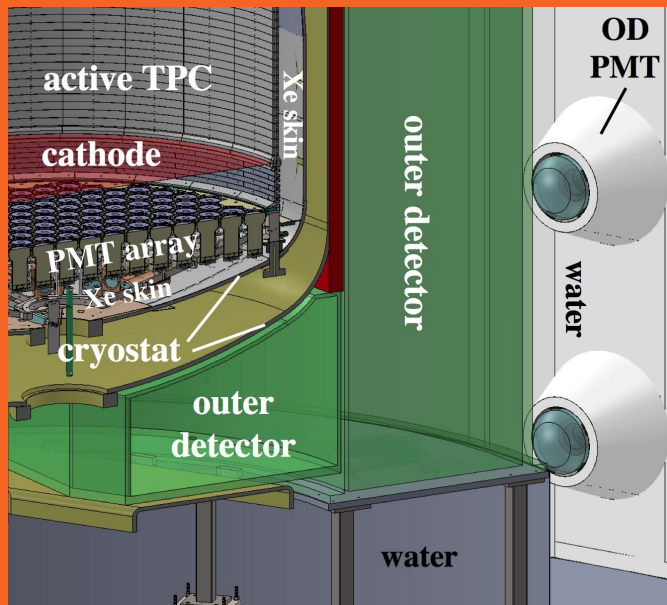
- External sources
  - Cosmogenics
  - Radiation from experiment cavern
  - Other new physics (e.g. neutrinos)
- Internal sources
  - Radioactive materials in detector components
  - Emanation of Radon from detector components
  - Radioactive dust on surfaces
  - Contaminants in the xenon



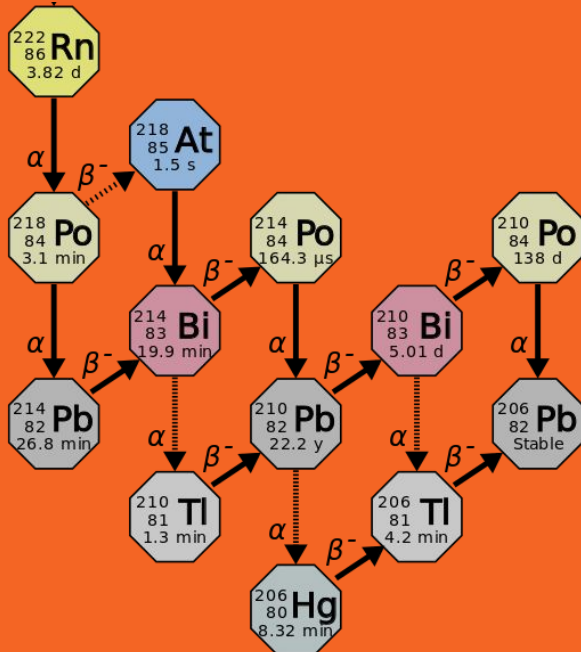
**NOT DUCKS**

# 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



- Detector materials
  - Radio-assay campaign
  - Gamma-screening, ICPMS, NAA
  - Screening Gd-LS: [ArXiv: 1808.05595](https://arxiv.org/abs/1808.05595)
- Radon emanation
  - Four screening sites and two portable assays
  - Target Rn activity: 2  $\mu\text{Bq/kg}$
  - Rn removal system: reduces Rn from warm components by  $> \times 10$ : [doi:10.1016/j.nima.2018.06.076](https://doi.org/10.1016/j.nima.2018.06.076)
- Radon daughters and dust on surfaces
  - TPC assembly in Rn-reduced cleanroom
  - Dust  $< 500 \text{ ng/cm}^3$  on all LXe wetted surfaces
  - Rn-daughter plate-out on TPC walls  $< 0.5 \text{ mBq/m}^2$
- Xenon contaminants –  $^{85}\text{Kr}$ ,  $^{39}\text{Ar}$ 
  - Charcoal chromatography @ SLAC
  - Final  $^{\text{nat}}\text{Kr/Xe}$  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
<b>Total after 99.5% ER rejection and 50% NR efficiency</b>	<b>5.97</b>	<b>0.52</b>

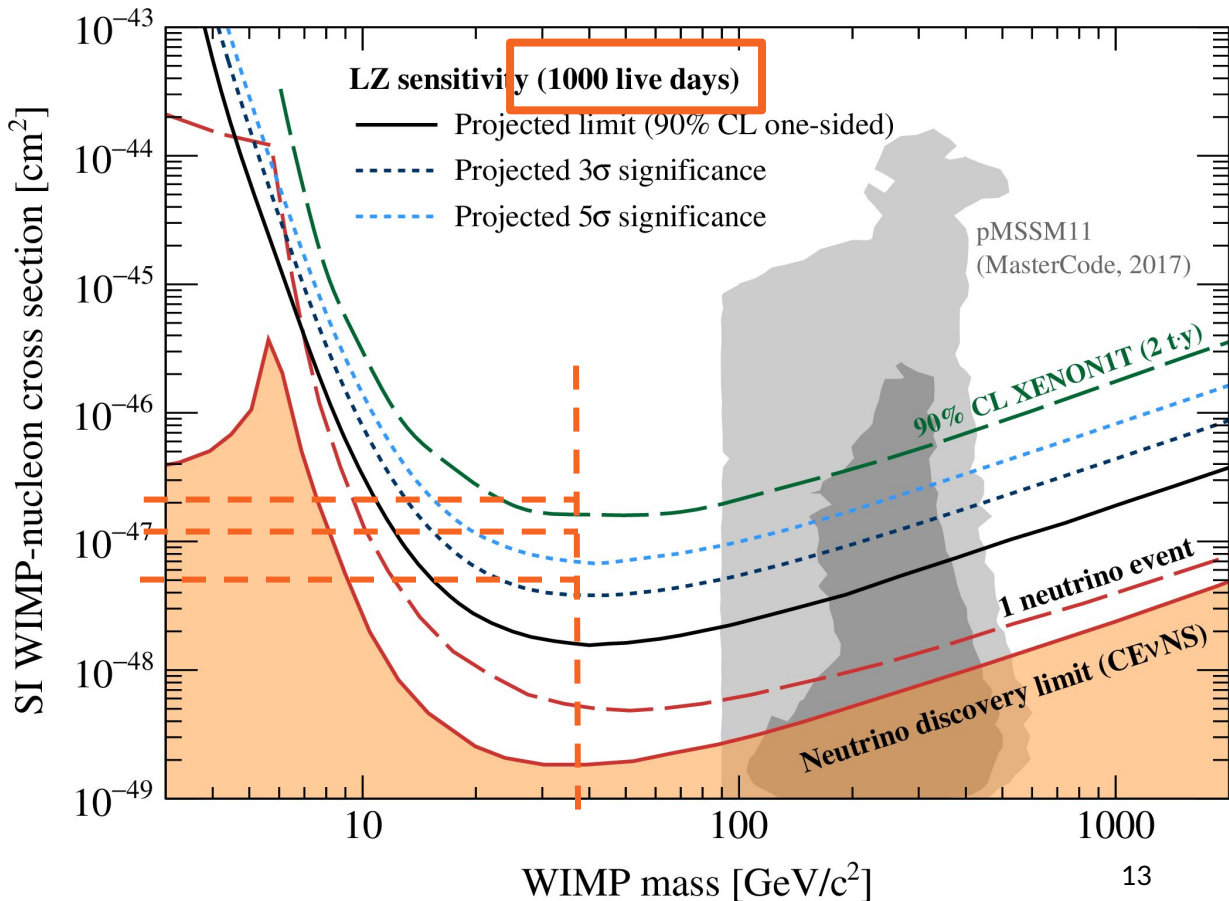
From “Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment” [ArXiv:1802.06039](https://arxiv.org/abs/1802.06039)

# Sensitivity estimates

For WIMP of 40 GeV/c<sup>2</sup>

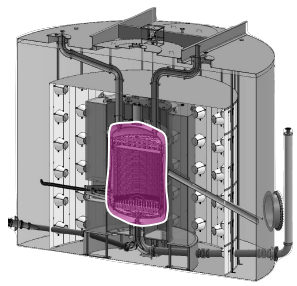
- Excluded at 90% C.L.:  
 $1.6 \times 10^{-48} \text{ cm}^2$
- $3\sigma$  discovery:  
 $3.8 \times 10^{-48} \text{ cm}^2$
- $5\sigma$  discovery:  
 $6.7 \times 10^{-48} \text{ cm}^2$

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



A close-up photograph of a copper-colored metal mesh with a regular pattern of circular holes. A diagonal white line runs from the top left towards the bottom right, separating the text area from the image.

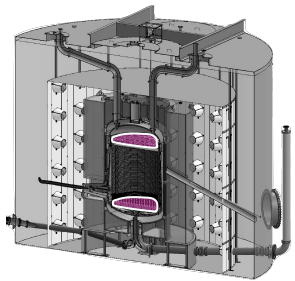
Construction,  
timeline, and  
flashy photos



# Cryostat preparation



- Intense R&D program found low activity titanium [DOI: 10.1016/j.astropartphys.2017.09.002](https://doi.org/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

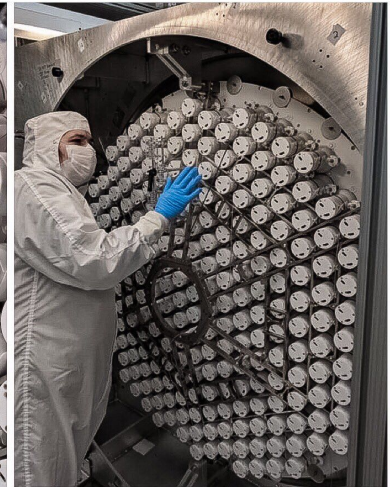
Many PMTs:

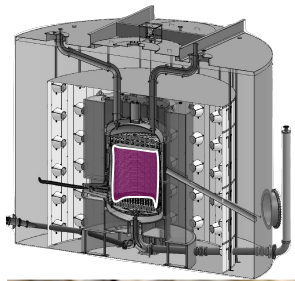
- 253 x 3" for top array
- 241 x 3" for bottom array
- 93 x 1" and 38 x 2" PMTs for top / bottom skin

Top and bottom arrays completed

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

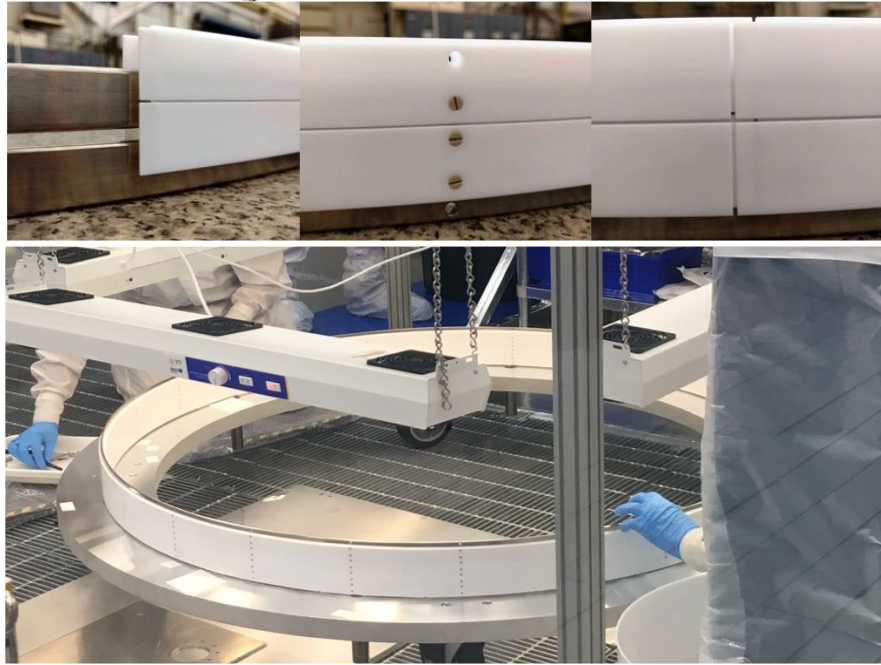
- Reduced dust and radon air
- Shipping enclosure
- Light-shielded electrical testing

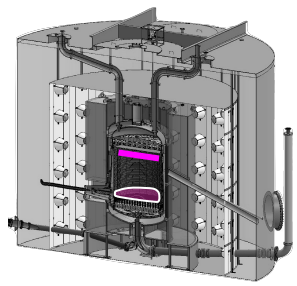




# TPC Field Cage

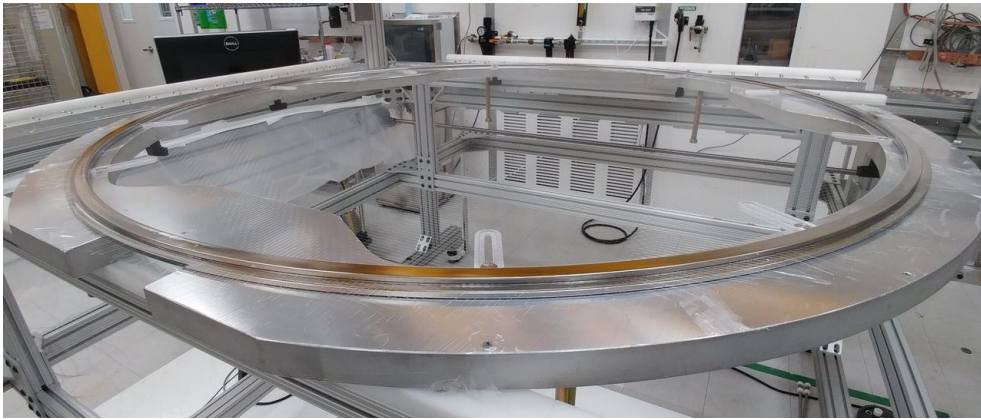
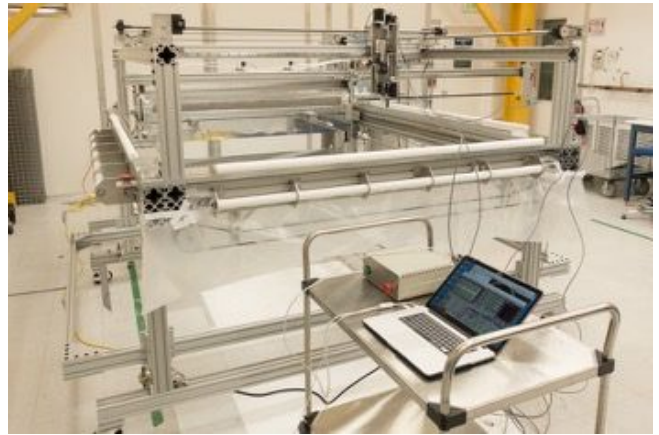
- 57 titanium field shaping rings
- PTFE for reflectivity and stability
- Completed December 2018
- Deionising tower to remove dust from PTFE

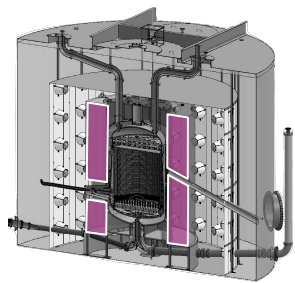




# TPC - wire grids

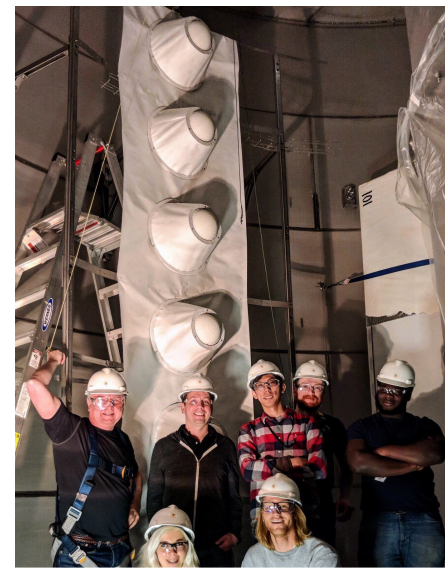
- Semi-automated loom to weave stainless steel wire
- Final grids (+ 2 full-size prototypes) completed (1.5 m diameter)
- Delivered to SURF





# 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



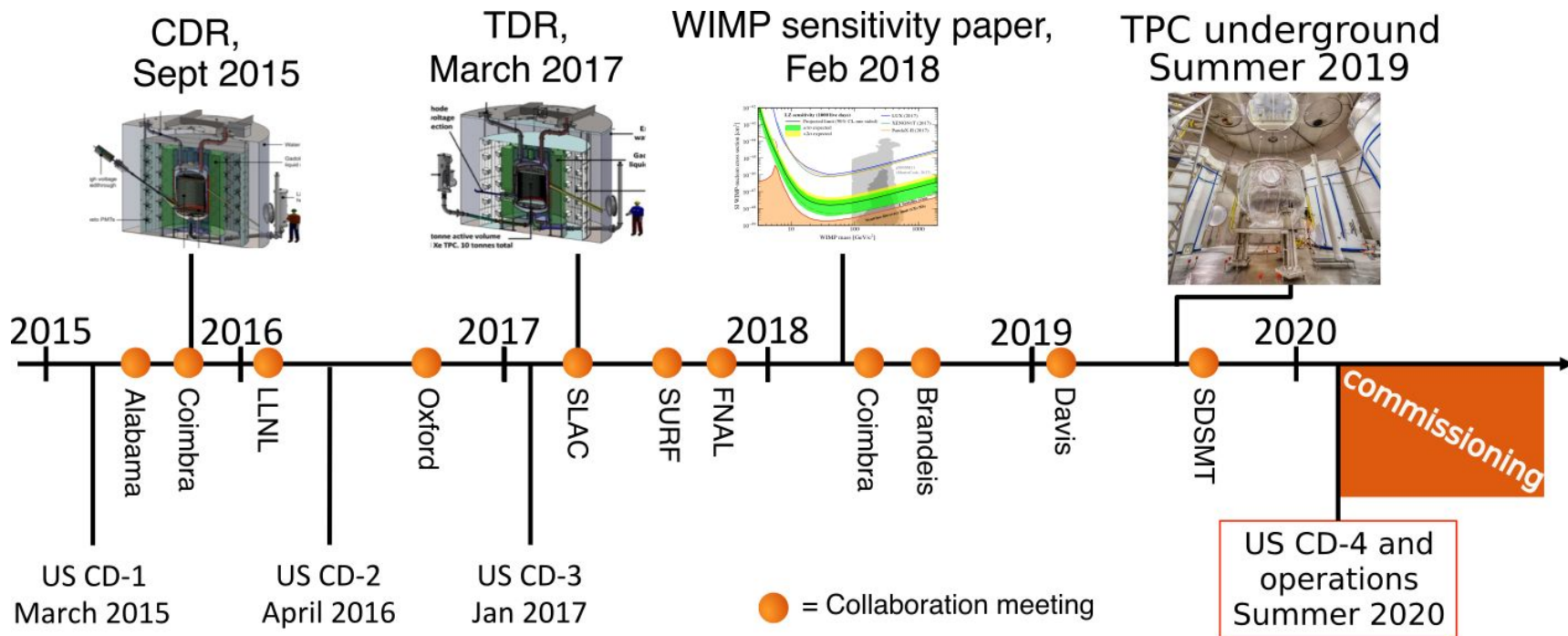
# The Collaboration



**37 institutions; 250 scientists, engineers, technicians**

- |   |  |  |
|---|--|--|
| 1. IBS-CUP (Korea)                          | 13. Black Hill State University (US)                   | 25. Texas A&M University (US)                    |
| 2. LIP Coimbra (Portugal)                   | 14. Brandeis University (US)                           | 26. University at Albany (US)                    |
| 3. MEPHl (Russia)                           | 15. Brookhaven National Lab (US)                       | 27. University of Alabama (US)                   |
| 4. Imperial College London (UK)             | 16. Brown University (US)                              | 28. University of California, Berkeley (US)      |
| 5. Royal Holloway University of London (UK) | 17. Fermi National Accelerator Lab (US)                | 29. University of California, Davis (US)         |
| 6. STFC Rutherford Appleton Lab (UK)        | 18. Lawrence Berkeley National Lab (US)                | 30. University of California, Santa Barbara (US) |
| 7. University College London (UK)           | 19. Lawrence Livermore National Lab (US)               | 31. University of Maryland (US)                  |
| 8. University of Bristol (UK)               | 20. Northwestern University (US)                       | 32. University of Massachusetts (US)             |
| 9. University of Edinburgh (UK)             | 21. Pennsylvania State University (US)                 | 33. University of Michigan (US)                  |
| 10. University of Liverpool (UK)            | 22. SLAC National Accelerator Lab (US)                 | 34. University of Rochester (US)                 |
| 11. University of Oxford (UK)               | 23. South Dakota School of Mines and Technology (US)   | 35. University of South Dakota (US)              |
| 12. University of Sheffield (UK)            | 24. South Dakota Science and Technology Authority (US) | 36. University of Wisconsin – Madison (US)       |
|   |  | 37. Yale University (US)                         |

# Timeline





# 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  $1.6 \times 10^{-48} \text{ cm}^2$
  - $3\sigma$  discovery at  $3.8 \times 10^{-48} \text{ cm}^2$
- 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

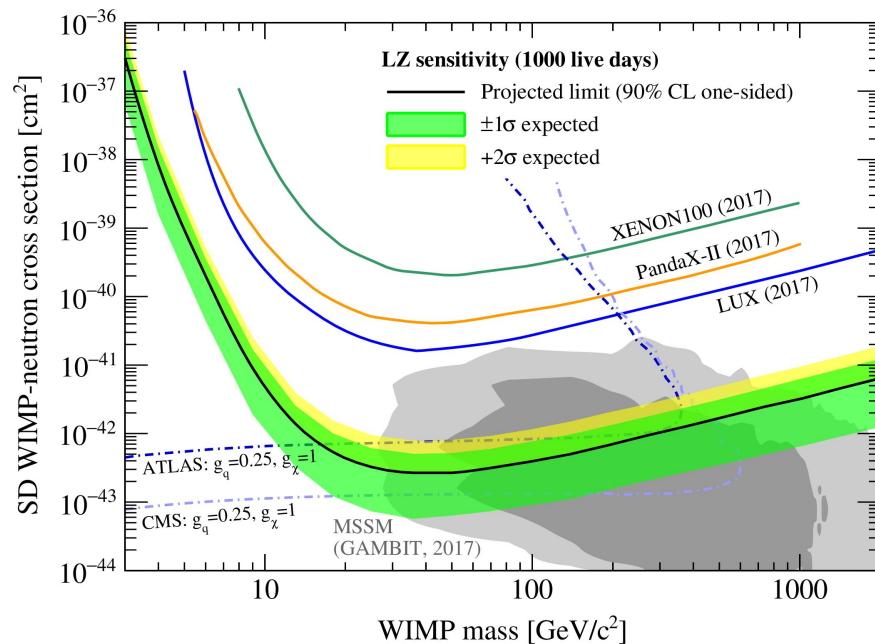
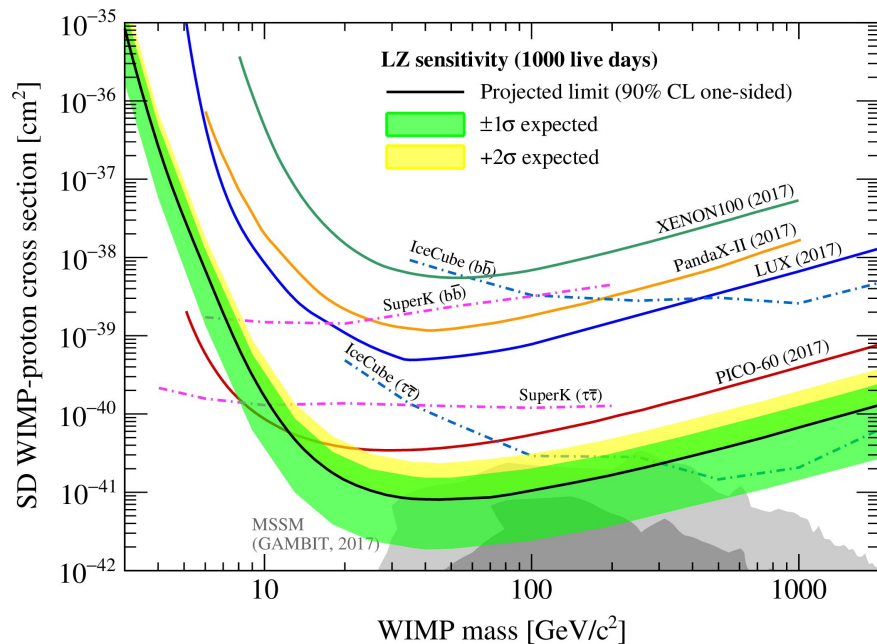
# Thank you



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

# Sensitivity

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



# 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)	<sup>238</sup> U <sub>e</sub>	<sup>238</sup> U <sub>l</sub>	<sup>232</sup> Th <sub>e</sub>	<sup>232</sup> Th <sub>l</sub>	<sup>60</sup> Co	<sup>40</sup> 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 <sup>2</sup> )									0.2	0.05
Plate-out (PTFE panels, 50 nBq/cm <sup>2</sup> )									-	0.05
<sup>210</sup> Bi mobility (0.1 μBq/kg LXe)									40.0	-
Ion misreconstruction (50 nBq/cm <sup>2</sup> )									-	0.16
<sup>210</sup> Pb (in bulk PTFE, 10 mBq/kg PTFE)									-	0.12
subtotal									40	0.39
Xenon contaminants										
<sup>222</sup> Rn (1.81 μBq/kg)									681	-
<sup>220</sup> Rn (0.09 μBq/kg)									111	-
<sup>nat</sup> Kr (0.015 ppt g/g)									24.5	-
<sup>nat</sup> 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										
<sup>136</sup> Xe 2νββ									67	-
Solar neutrinos: pp+ <sup>7</sup> Be+ <sup>13</sup> 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	