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 $4 \times 10^{-47}$ 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)
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
Mitigating External Backgrounds

- Go deep underground
  - 4300 m.w.e. underground at SURF in Lead, SD

- 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

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![Diagram of detector setup with veto options](image.png)
Mitigating Internal Backgrounds

- **Detector materials**
  - Radio-assay campaign
  - Gamma-screening, ICPMS, NAA

- **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](https://doi.org/10.1016/j.nima.2018.06.076)

- **Radon daughters and dust on surfaces**
  - TPC assembly in Rn-reduced cleanroom
  - Dust < 500 ng/cm³ on all LXe wetted surfaces
  - Rn-daughter plate-out on TPC walls < 0.5 mBq/m²

- **Xenon contaminants – ^{85}\text{Kr}, ^{39}\text{Ar}**
  - Charcoal chromatography @ SLAC
  - Final natKr/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

<table>
<thead>
<tr>
<th>Background source</th>
<th>ER counts</th>
<th>NR counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector Components</td>
<td>9</td>
<td>0.07</td>
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<tr>
<td>Surface contamination</td>
<td>40</td>
<td>0.39</td>
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<tr>
<td>Xenon Contamination</td>
<td>819</td>
<td>0</td>
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<tr>
<td>Laboratory and cosmogenics</td>
<td>5</td>
<td>0.06</td>
</tr>
<tr>
<td>Physics</td>
<td>322</td>
<td>0.51</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1195</strong></td>
<td><strong>1.03</strong></td>
</tr>
<tr>
<td><strong>Total after 99.5% ER rejection and 50% NR efficiency</strong></td>
<td>5.97</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Sensitivity estimates

For WIMP of 40 GeV/c²

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

From “Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment” ArXiv:1802.06039
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 AndCommissioning 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

37 institutions; 250 scientists, engineers, technicians

1. IBS-CUP (Korea)
2. LIP Coimbra (Portugal)
3. MEPPhI (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)
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 $1.6 \times 10^{-48}$ cm$^2$
- $3\sigma$ discovery at $3.8 \times 10^{-48}$ 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

From “Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment” ArXiv:1802.06039
### Detailed background table

From “Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment”

ArXiv:1802.06039

<table>
<thead>
<tr>
<th>Background Source</th>
<th>Mass (kg)</th>
<th>$^{238}$U</th>
<th>$^{235}$U</th>
<th>$^{40}$K</th>
<th>$^{232}$Th</th>
<th>$^{238}$Th</th>
<th>$^{60}$Co</th>
<th>$n$/yr</th>
<th>ER (cts)</th>
<th>NR (cts)</th>
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</thead>
<tbody>
<tr>
<td>PMT systems</td>
<td>308</td>
<td>31.2</td>
<td>5.20</td>
<td>2.32</td>
<td>2.29</td>
<td>1.46</td>
<td>18.6</td>
<td>248</td>
<td>2.82</td>
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<td>TPC systems</td>
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<td>3.28</td>
<td>1.01</td>
<td>0.84</td>
<td>0.76</td>
<td>2.58</td>
<td>7.80</td>
<td>79.9</td>
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<tr>
<td>Cryostat</td>
<td>2778</td>
<td>2.88</td>
<td>0.63</td>
<td>0.48</td>
<td>0.51</td>
<td>0.31</td>
<td>2.62</td>
<td>323</td>
<td>1.27</td>
<td>0.018</td>
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<tr>
<td>Outer detector (OD)</td>
<td>22950</td>
<td>6.13</td>
<td>4.74</td>
<td>3.78</td>
<td>3.71</td>
<td>0.33</td>
<td>13.8</td>
<td>8061</td>
<td>0.62</td>
<td>0.001</td>
</tr>
<tr>
<td>All else</td>
<td>358</td>
<td>3.61</td>
<td>1.25</td>
<td>0.55</td>
<td>0.65</td>
<td>1.31</td>
<td>2.64</td>
<td>39.1</td>
<td>0.11</td>
<td>0.003</td>
</tr>
</tbody>
</table>

**Surface Contamination**
- Dust (intrinsic activity, 500 ng/cm$^2$): 0.2 cts
- Plate-out (PTFE panels, 50 nBq/cm$^2$): - cts
- $^{210}$Bi mobility (0.1 nBq/kg LXe): 40.0 cts
- Ion misreconstruction (50 nBq/cm$^2$): - 0.16 cts
- $^{210}$Pb (in bulk PTFE, 10 mBq/kg PTFE): - 0.12 cts

**Xenon contaminants**
- $^{222}$Rn (1.81 mBq/kg): 681 cts
- $^{220}$Rn (0.09 mBq/kg): 111 cts
- $^{36}$Kr (0.015 ppt g/kg): 24.5 cts
- $^{38}$Ar (0.45 ppb g/kg): 2.5 cts

**Laboratory and Cosmogenics**
- Laboratory rock walls: 4.6 cts
- Muon induced neutrons: - 0.06 cts
- Cosmogenic activation: 0.2 cts

**Physics**
- $^{136}$Xe 2v$\beta$3: 67 cts
- Solar neutrinos; $^{8}$Be,$^{13}$N: 255 cts
- Diffuse supernova neutrinos (DSN): - 0.05 cts
- Atmospheric neutrinos (Atm): - 0.46 cts

**Total**
- 1195 cts
- Total (with 99.5% ER discrimination, 50% NR efficiency): 5.97 cts
- Sum of ER and NR in LZ for 1000 days, 5.6 tonne FV, with all analysis cuts: 6.49 cts