Overview and Status of the LUX-ZEPLIN (LZ) Experiment

Amy Cottle, University of Oxford, 16th Patras Workshop
The Experiment

• LZ is designed to directly detect WIMPs but has considerable sensitivity to other new physics

• Dual phase xenon time projection chamber (TPC)

• Interactions in the xenon generate
  - Prompt scintillation (S1)
  - Charge, drifted and extracted into the gas to produce electroluminescence light (S2)

• 3D position reconstruction -> fiducialisation

• S2/S1 ratio -> discrimination between WIMPs (nuclear recoils, NRs) & γ rays (electron recoils, ERs)
The Collaboration

- 34 institutions from USA, UK, Portugal, Korea
- ~250 scientists, engineers and technical staff

LZ Overview & Status, 16th Patras Workshop
The Location

- Sanford Underground Research Facility (SURF) - Black Hills, South Dakota
- Situated in the Davis Cavern at the 4850 level (~1.5 km underground)
- 4300 metres of water equivalent overburden – reduces muon flux by $\sim 10^6$
The Detectors

Outer veto detector: Gd-doped liquid scintillator

Liquid xenon “Skin” veto detector

TPC

Outer veto detector PMTs

Water Tank

NIM A, 163047 (2019)
TPC in Detail

- 7t of active xenon, viewed by 494 PMTs top & bottom

- Grid electrodes help maintain field stability
  - Cathode nominal voltage of -50 kV
  - Extraction region for S2 defined by gate and anode

- Field cage for drift field, PTFE clad for light collection
Veto Detectors in Detail

- ~2 t LXe "Skin" detector surrounding the TPC
  - Lined with PTFE & observed by 131 PMTs
  - Anti-coincidence detector for $\gamma$ rays
- 17 t Gd-loaded LAB outer detector
  - Scintillator in acrylic vessels in water tank
  - Viewed by 120 8” PMTs situated in water
  - Observe ~8.5 MeV of $\gamma$ rays per thermal neutron capture
Material selection based on ~2000 assays with 13 HPGe detectors, ICPMS, neutron activation analysis

Four Rn emanation screening sites

TPC assembly in Rn-reduced cleanroom + cleanliness limiting dust (<500 ng/cm³), plate-out (<0.5 mBq/m²)

Charcoal chromatography @ SLAC to reduce xenon contaminants ($^{85}$Kr, $^{39}$Ar)

Online purification/radon reduction

Geant4-based simulation framework for background & sensitivity studies

**Backgrounds Control & Assessment**

*EPJC, Vol 80: 1044 (2020); j.astropartphys.2020.102480*
Veto Impact on Backgrounds

No vetoes: 10.4 NR cts/1000 days

With vetoes: 1.0 NR cts/1000 days

Combined veto system -> ~2x increase in fiducial volume to 5.6 t (80% of active volume)
WIMP Sensitivity

Background counts 1000 live days
non-vetoed single scatters
of energy 1.5-6.5 keV_{ee} (6-30 keV_{nr})
in 5.6 t fiducial volume

<table>
<thead>
<tr>
<th>Source</th>
<th>ER [cts]</th>
<th>NR [cts]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1588</td>
<td>0.97</td>
</tr>
<tr>
<td>+ 99.5% ER discrimination, 50% NR efficiency</td>
<td>7.94</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Radon comprises almost half our expected backgrounds in this region

PRD 101, 052002 (2020)
Extending to Lower Mass Candidates

- Lower the energy threshold
  - Reduce S1 coincidence requirement from 3 to 2 (exploiting PMT double photoelectric effect)
    - ~4x improvement at 2.5 GeV/c²
  - Conduct an S2-only search
    - Greater challenge for background discrimination -> use pulse width
- Sub-GeV masses accessible when considering Migdal electron emission

*ArXiv: 2101.08753*
Physics Via Low Energy Electron Recoils

World-leading sensitivities expected to a variety of different new physics accessible via ERs e.g. solar axions, axion-like dark matter, neutrino magnetic moment

ArXiv: 2102.11740
Neutrinoless Double Beta Decay

• Nominal 1% energy resolution at $^{136}\text{Xe}$ $Q_{\beta\beta}$ value (2458 keV)

• $T_{1/2}$ (90% C.L.) $> 1 \times 10^{26}$ years in 1000 live days in 1 t fiducial volume

PRC 102, 014602 (2020)
Timeline

- **CDR Q4 2015**
- **Titanium Paper; TDR Q1 2017**
- **WIMP Sensitivity Paper Q1 2018**
- **TPC Assembly Finished & Moved Underground Q3-4 2019**
- **Sims, Cleanliness; $^{136}$Xe 0vββ papers Q1-2 2020**
- **COVID-19 – Experiment in Safe Configuration**
- **Throughout 2021: Commissioning, first science run**

### Details:
- **2015**
  - CDR Q4 2015

- **2016**
  - Titanium Paper; TDR Q1 2017

- **2017**
  - WIMP Sensitivity Paper Q1 2018
  - TPC Assembly Finished & Moved Underground Q3-4 2019

- **2018**
  - Sims, Cleanliness; $^{136}$Xe 0vββ papers Q1-2 2020

- **2019**
  - COVID-19 – Experiment in Safe Configuration

- **2020**
  - Throughout 2021: Commissioning, first science run

- **2021**
  - $^{136}$Xe 0vββ papers Q1-2 2021

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TPC Assembly

- Detector integration started in Dec. 2018 at Surface Assembly Laboratory (SURF)
- Assembled in radon reduced environment during ~13,500 working hours
TPC Underground

- Inner cryostat vessel (ICV) moved underground & inserted into outer vessel late 2019
- High voltage installed, ICV sealed and under vacuum ahead of COVID early 2020
• Acrylic tanks underground early 2019; installation completed with PMT & Tyvek this year

• Optical calibration system* and liquid scintillator fill systems fully tested *ArXiv: 2102.06281
Tests, Cooldown & Commissioning

• Underground circulation commissioning completed last year in test cryostat
  - Rate of 500 SLPM - turnover full 10 t of xenon every 2.4 days

• TPC cooled down to ~185 K (cold gas close to operational temperature)

• First S2s seen from cold gas operations
Summary

• LZ is a multi-physics experiment, primed for the detection of WIMPs
• Long-term campaign for backgrounds control to ensure world-leading sensitivities
• Experiment is in its commissioning phase, with first science data expected this year
• A new chapter in dark matter physics is just on the horizon!
Back up
## Backgrounds Table

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<th>Source</th>
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<th>NR [cts]</th>
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<tbody>
<tr>
<td>Detector Components</td>
<td>9</td>
<td>0.12</td>
</tr>
<tr>
<td>Xenon Contaminants (Rn, Kr, Ar)</td>
<td>1276</td>
<td>0</td>
</tr>
<tr>
<td>Surface Contamination &amp; Dust</td>
<td>40</td>
<td>0.28</td>
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<tr>
<td>Laboratory &amp; Cosmogenics</td>
<td>5</td>
<td>0.06</td>
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<tr>
<td>Physics (2vBB decay, neutrinos)</td>
<td>258</td>
<td>0.51</td>
</tr>
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ER & NR Backgrounds