Calibration Systems of the Multi-Tonne Scale Xenon Detector in LZ

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On Behalf of the LZ Collaboration
Outline

● Direct Detection of Dark Matter with the LZ Experiment

● Calibration Systems of LZ
  ○ Internal Source Injection System
  ○ External Calibration Source Deployment
  ○ DD Neutron Generator
  ○ Photoneutron Delivery System

● Summary and Outlook
The LZ Detector

LZ
SURF, USA

Outer detector (OD):
17T Gd-loaded liquid scintillator

120 veto PMTs

Skin Detector:
2T LXe skin veto

131 skin PMTs

Calibration source deployment tubes (3 total)

60,000 gallons of ultrapure water

494 LXe PMTs

Time Projection Chamber (TPC):
7T active LXe target

Neutron calibration conduit (2 total)
Signal vs. background discrimination
○ Charge (S2)/ light (S1) ratio is different between electron recoils (ER) and nuclear recoils (NR)

Electrons and gammas interact with atomic electrons, produce ER
WIMPs (and neutrons) interact with Xe nuclei, produce NR

Ref: “First Science Results from the LZ Experiment”
## Calibration Sources in LZ

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Overview of LZ calibration systems

1. Internal Sources
   Introduced into the Xe circulation and carried into the TPC

2. Calibration Source Deployment (CSD)
   3 dedicated source tubes accessing the vacuum space between the cryostats

3. DD Generator
   Collimated by conduits through the side of the water tank

4. Photo-neutrons
   Lowered by a crane through a custom cut-out in the acrylic vessel

Internal Source Injection (SI) System

- Two categories of sources on the SI panel
  - Bottle sources
  - Generate sources (gaseous daughters from solid isotopes)

\[ \text{CH}_3\text{T} \]
Internal Source Injection (SI) System

- Precise dose control across a wide range of activities
  - $^{220}$Rn: Control carrier gas flow rate
  - $^{83m}$Kr: Control carrier gas amount
  - $^{131m}$Xe: Control activity build-up time
  - CH$_3$T: Control pressure in the dose volume

Mass Flow Control (MFC)

Carrier Xe Gas

To Main Circulation

Low-flow MFC
Internal Source Injection (SI) System

- In LZ there was no unexpected amount of residual tritium observed in other experiments previously
  - The use of a CH$_4$ purifier is essential
External Calibration Source Deployment (CSD)

- The CSD system is used for deploying external rod sources:
  - Gamma sources ($^{228}\text{Th}$, $^{22}\text{Na}$, $^{54}\text{Mn}$, $^{57}\text{Co}$)
  - AmLi/AmBe
- Three calibration tubes between the inner and outer cryostat
- mm-precision in deployment z-position enabled by a laser feedback system

Position reconstruction of $^{228}\text{Th}$ events in the TPC, Skin and OD:
Deuterium-Deuterium (DD) Neutron Generator

- Neutrons produced through deuterium-deuterium fusion:
  \[ ^2\text{D} + ^2\text{D} \rightarrow ^3\text{He} + \text{n} \]
- The generator can operate in different modes:
  - Direct mode: 2.45 MeV monoenergetic neutrons
  - Neutrons sent down a 3 m conduit through the water tank and OD
Deuterium-Deuterium (DD) Neutron Generator

- Neutrons produced through deuterium-deuterium fusion:
  \[ ^2\text{D} + ^2\text{D} \rightarrow ^3\text{He} + \text{n} \]
- The generator can operate in different modes:
  - Direct mode: 2.45 MeV monoenergetic neutrons
  - D-reflector: Neutrons reflected off a deuterium-loaded target; Dominantly 350±40 keV monoenergetic neutrons
  - H-reflector: Neutrons reflected off a hydrogen-loaded target; 10-200 keV neutrons
  - First use of neutron reflector modes in a large scale detector calibration

Figure credit: Jeanne Bang
Photo-neutron Source Delivery System

● $^{88}$YBe source
  ○ $^{88}$Y Gamma energy: 1.836 MeV (99.2%)
  ○ ~152 keV monoenergetic neutrons through ($\gamma$,n) reaction:
    $$\gamma + ^9\text{Be} \rightarrow n + ^8\text{Be}$$

● Lowered to the OCV top though a custom-cutout

● First use in a noble liquid dark matter experiment to calibrate $^8$B solar neutrinos CEvNS energies
Calibration data from LZ Science Run I

- Dark blue points: Tritium data
- Orange points: DD data
- NR/ER band is fitted using the Noble Element Simulation Technique* (NEST) model

* https://nest.physics.ucdavis.edu/

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Summary and Outlook

● LZ's intricate calibration systems played a crucial role in understanding the detector response, enabling its world-leading dark matter search results

● Other sources in progress for LZ
  ○ **AmBe with Tagging System**: Implementing an advanced AmBe calibration system with a tagging feature to enhance precise neutron selections
  ○ **SbBe for Low-Energy Calibration**: Incorporating SbBe sources for low-energy calibration, measuring detector response for the faintest dark matter signals

● Area of improvements for future calibration systems
  ○ **CSD Deployment Tube Length**: Optimizing the length of the CSD deployment tube to achieve even better spatial coverage
  ○ **DD Conduits**: Optimizing DD conduit placement to maximize neutron interactions in the fiducial volume and providing robust structural support to manage buoyancy in the water tank
  ○ **Water Tank Interlock System**: Developing an interlock system for the water tank to minimize mine air ingress after YBe calibration, ensuring a stable environment for subsequent measurements
LZ (LUX-ZEPLIN) Collaboration, 37 Institutions

250 scientists, engineers, and technical staff

- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King’s College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- Northwestern University
- Pennsylvania State University
- Royal Holloway University of London
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
- STFC Rutherford Appleton Lab.
- Texas A&M University
- University of Albany, SUNY
- University of Alabama
- University of Bristol
- University College London
- University of California Berkeley
- University of California Davis
- University of California Los Angeles
- University of California Santa Barbara
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- University of Maryland
- University of Massachusetts, Amherst
- University of Michigan
- University of Oxford
- University of Rochester
- University of Sheffield
- University of Sydney
- University of Texas at Austin
- University of Wisconsin, Madison

Thanks to our sponsors and participating institutions!

https://lz.lbl.gov/
Detector PMT and Optical Calibrations

Xe LED Calibration System
- 78 individually operable LEDs installed throughout the TPC and Skin
Detector PMT and Optical Calibrations

OD Optical Calibration System (OCS)
- LED light injected through optical fibres at 35 locations in the OD
D-reflector performance