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

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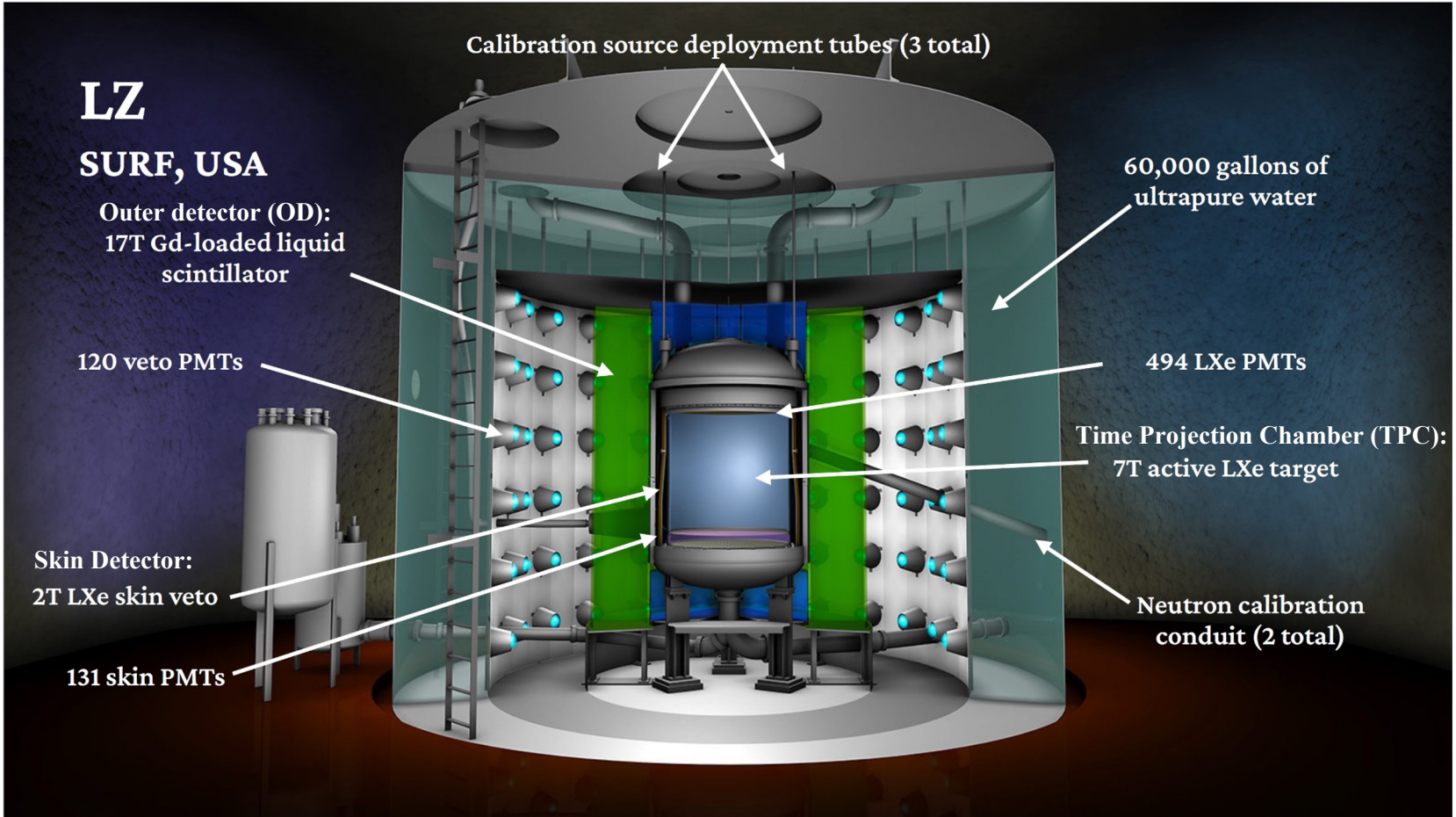
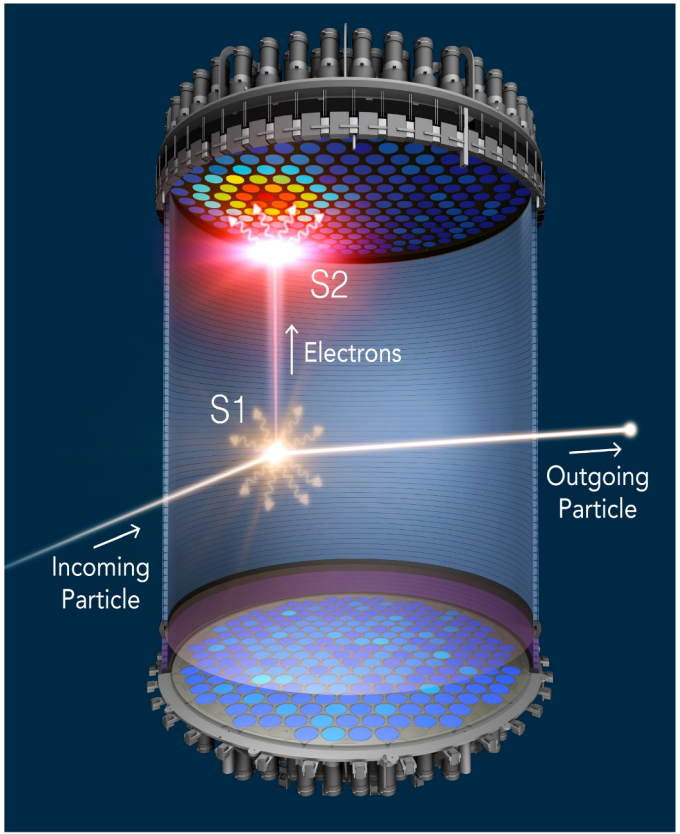
Outline

- 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

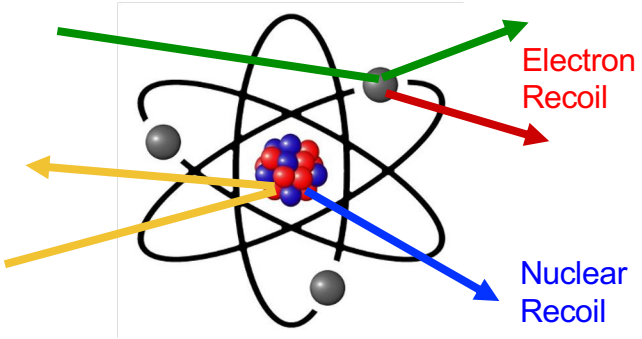
The LZ Detector



Dual Phase Xenon TPC



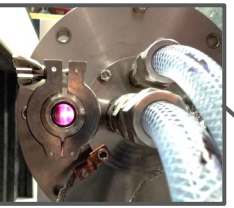
- Signal vs. background discrimination
  - Charge (S2)/ light (S1) ratio is different between electron recoils (ER) and nuclear recoils (NR)



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

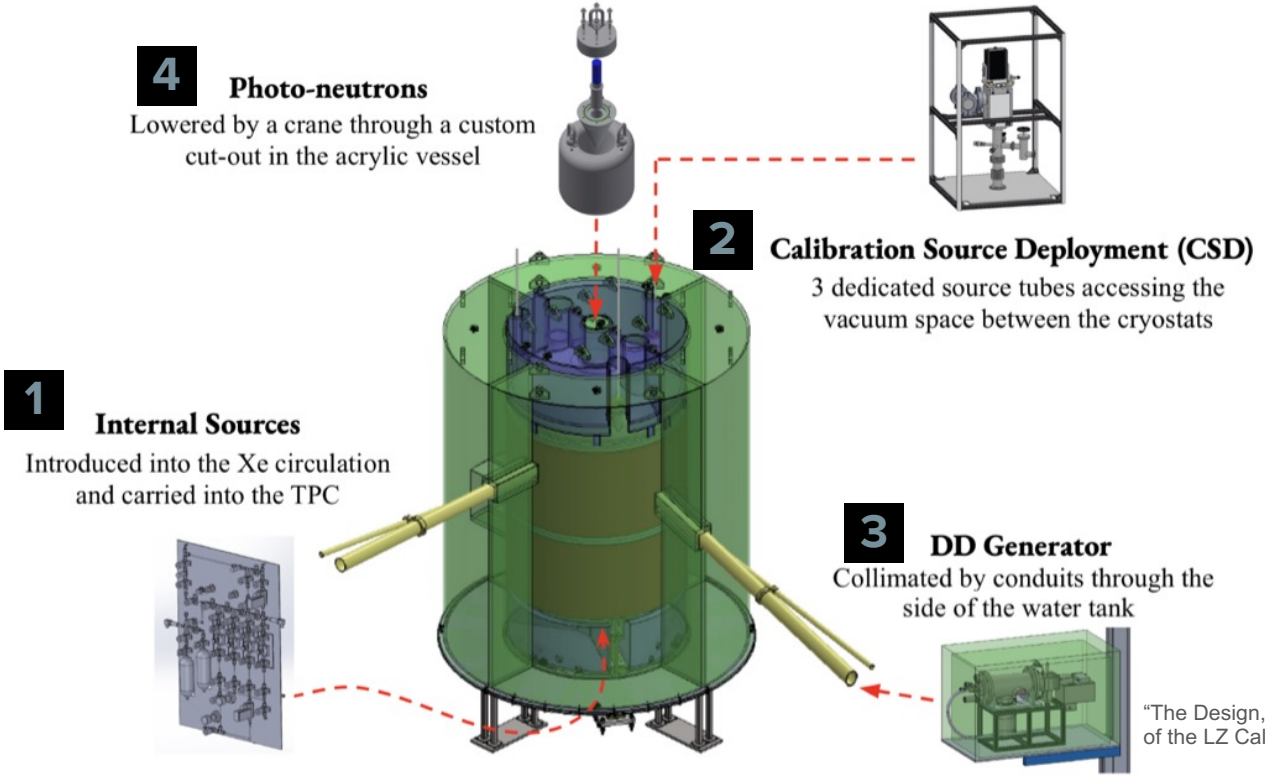
Ref: "First Science Results from the LZ Experiment"

Calibration Sources in LZ



Calibration Source	Purpose
CH_3T (continuum betas up to 18.6 keV)	Electron Recoil (ER) band calibration, S1 signal efficiency validation
^{220}Rn (betas from Pb212 up to 102 keV)	High energy ER calibration for EFT studies
^{83m}Kr (32.1 and 9.4 keV ER)	Energy scale and x-y spatial correction maps
^{131m}Xe (164 keV ER)	Energy scale and electron lifetime monitoring
Various gamma sources: ^{228}Th (2615 keV),^{22}Na (1275 keV), ^{54}Mn (835 keV), ^{57}Co (122 keV)	Energy scale and resolution; Inter-detector timing
Deuterium-Deuterium (DD) neutrons (Direct mode: 2.45 MeV, D-reflector: 270-420 keV, H-reflector: 10-200 keV)	TPC Nuclear Recoil (NR) band calibration, trigger efficiency, S1 cut acceptance
$^{241}AmLi$ (neutrons up to ~1.5 MeV)	OD calibration, neutron-tagging efficiency, S2 signal efficiency validation
$^{241}AmBe$ (neutrons up to ~11 MeV)	High E NR, OD calibration, neutron-tagging efficiency
^{88}YBe (152 keV neutron)	Low energy NR/^{8}B solar neutrino studies

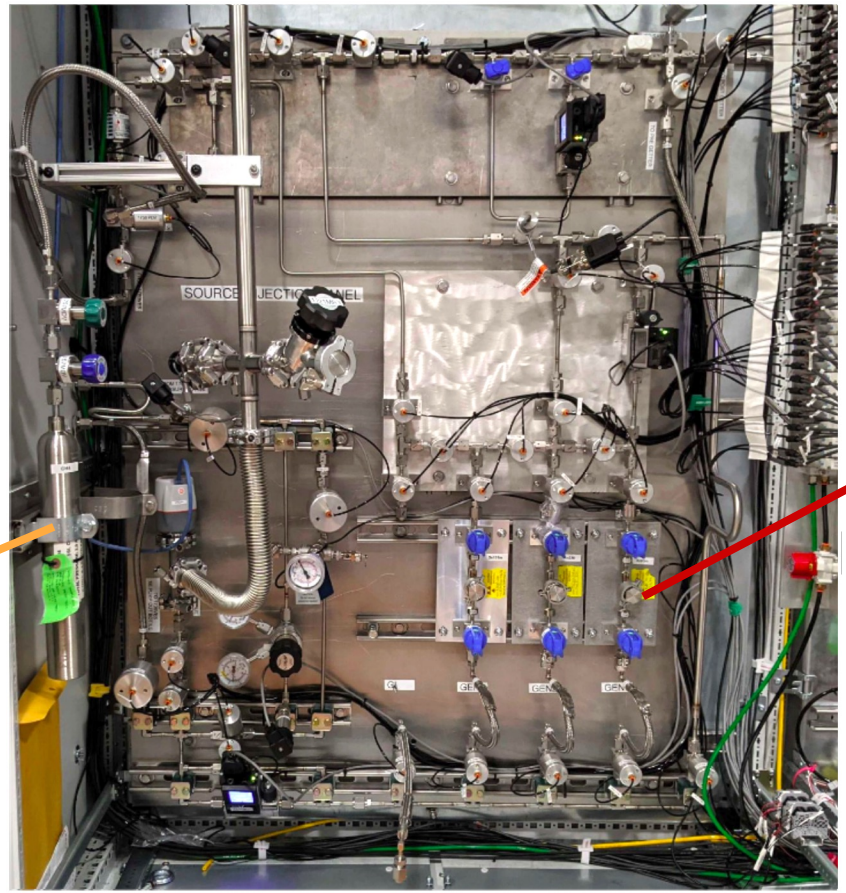
Overview of LZ calibration systems



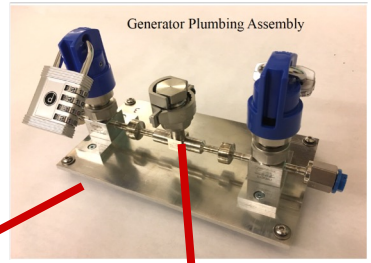
"The Design, Implementation, and Performance of the LZ Calibration Systems", in prep.

Internal Source Injection (SI) System

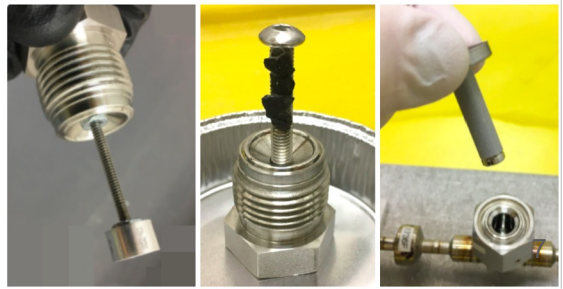
- Two categories of sources on the SI panel
  - Bottle sources
  - Generate sources (gaseous daughters from solid isotopes)



CH_3T

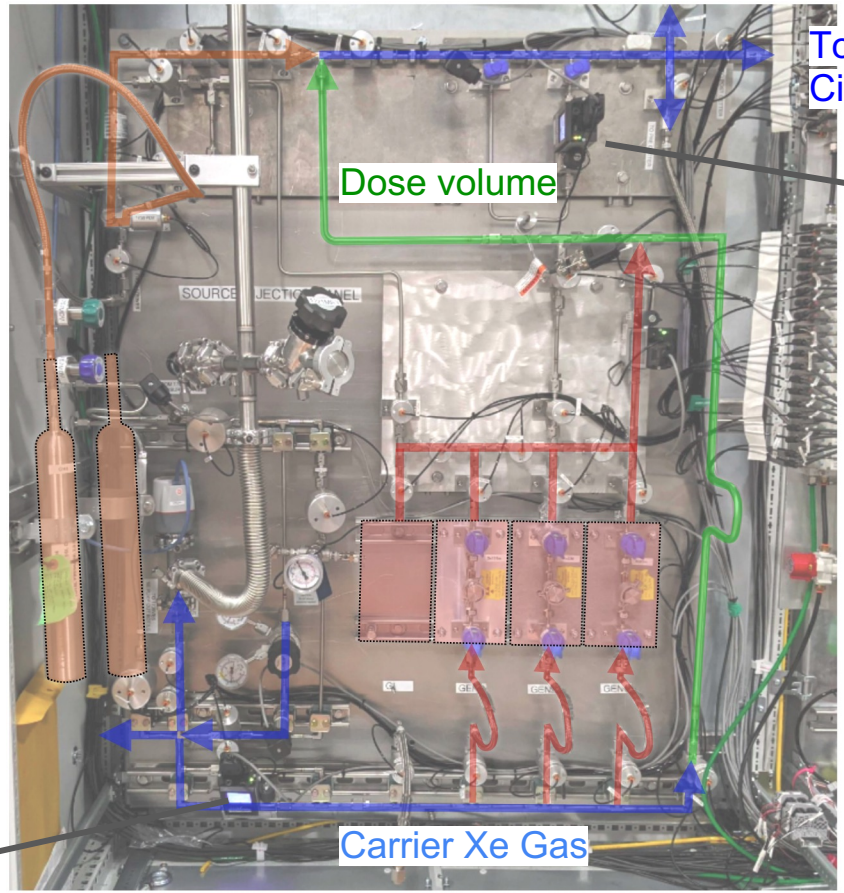


$^{228}Th \rightarrow {}^{220}Rn \quad {}^{83}Rb \rightarrow {}^{83m}Kr \quad {}^{131}I \rightarrow {}^{131m}Xe$



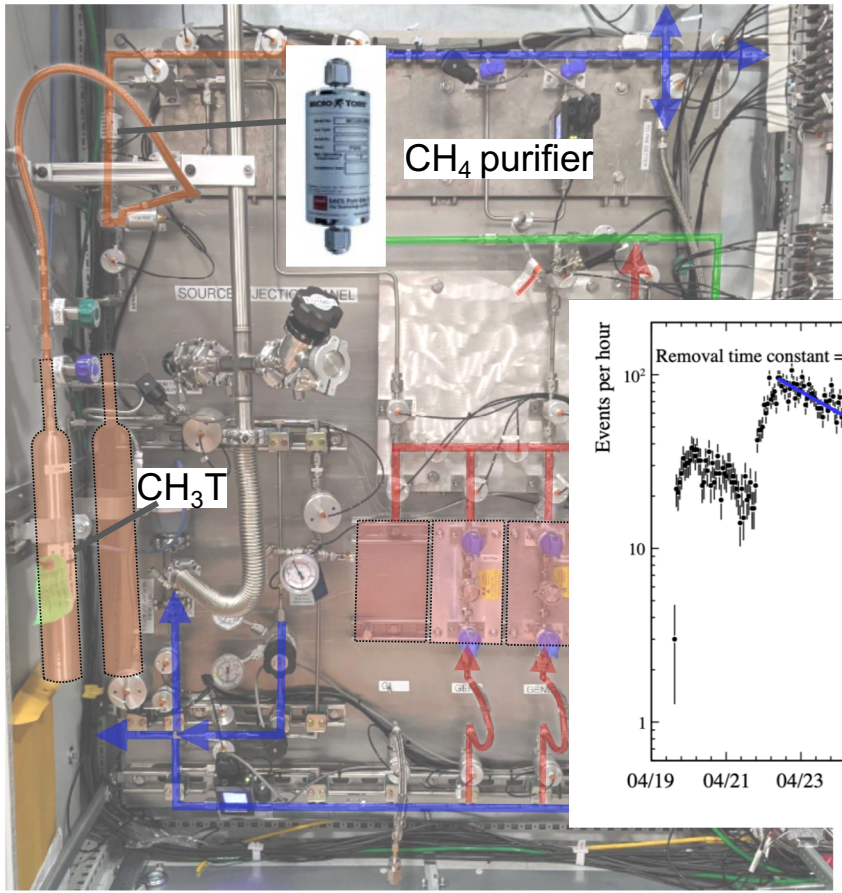
Internal Source Injection (SI) System

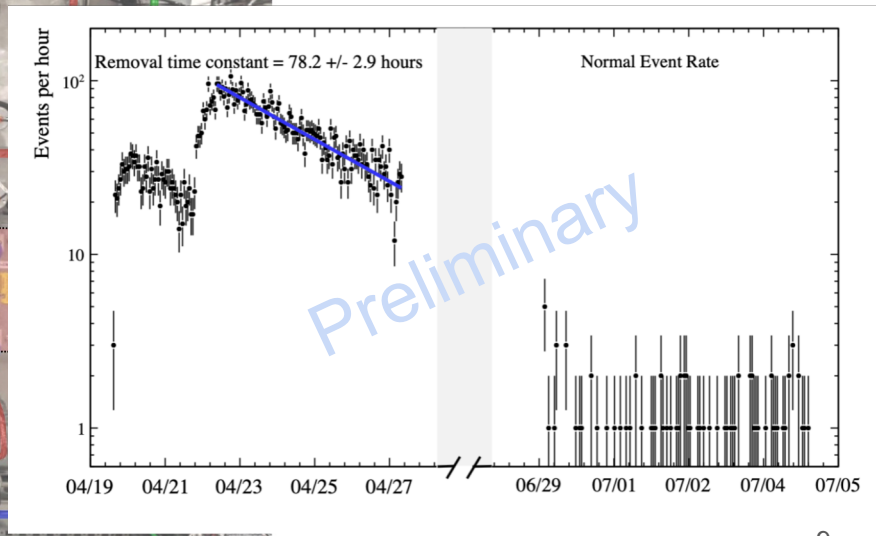
- Precise dose control across a wide range of activities
  - ^{220}Rn: Control carrier gas flow rate
  - ^{83m}Kr: Control carrier gas amount
  - ^{131m}Xe: Control activity build-up time
  - CH_3T: Control pressure in the dose volume



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

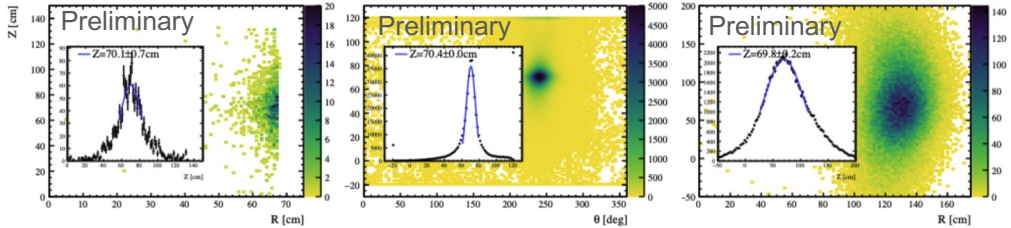




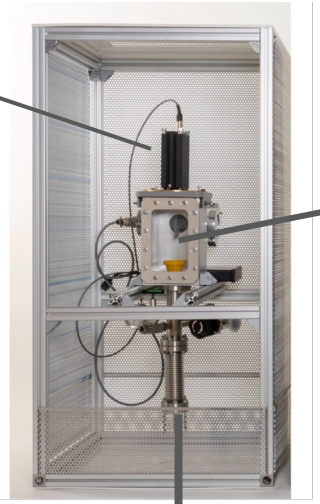
External Calibration Source Deployment (CSD)

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

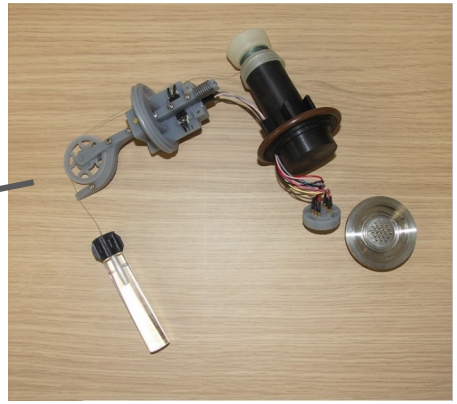
Position reconstruction of ^{228}Th events in the TPC, Skin and OD:



CSD chamber



Connected to the calibration tube



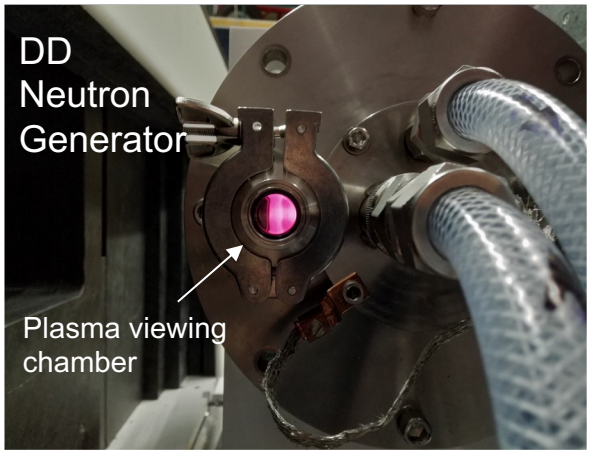
Stepper motor and deployment wheels/filament inside the chamber

Deuterium-Deuterium (DD) Neutron Generator

- Neutrons produced through deuterium-deuterium fusion:

  $^2D + {}^2D \rightarrow {}^3He + n$

- 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

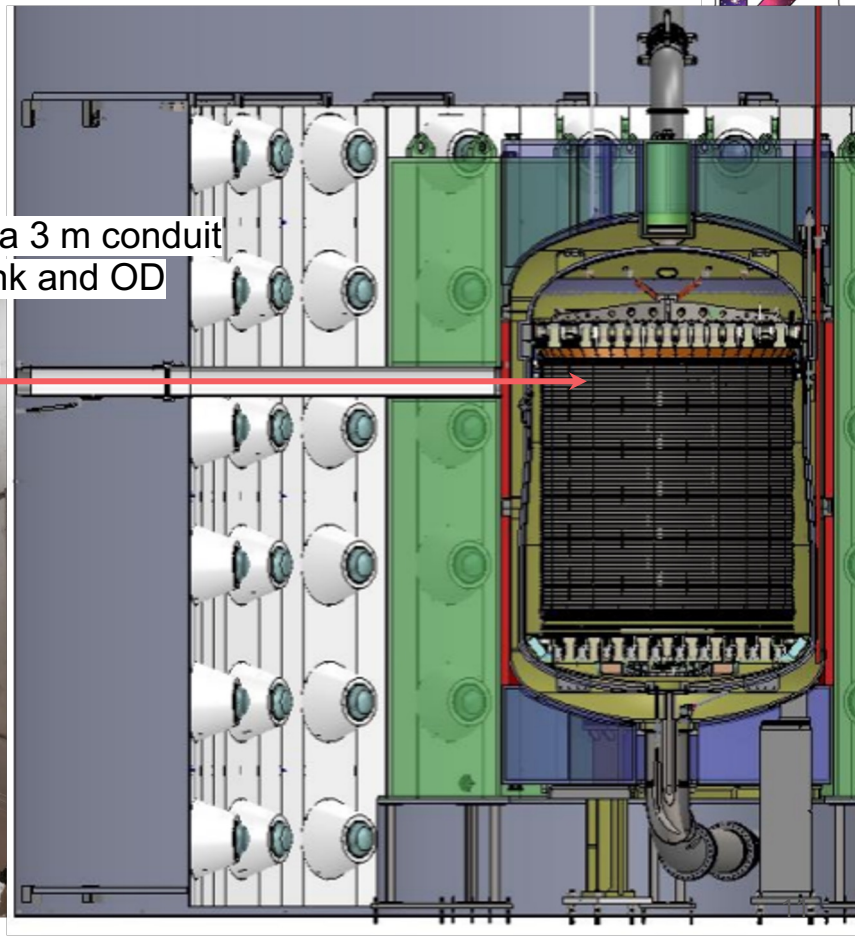


Figure credit: Jeanne Bang

Deuterium-Deuterium (DD) Neutron Generator

- Neutrons produced through deuterium-deuterium fusion:

  $^2D + {}^2D \rightarrow {}^3He + n$

- 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

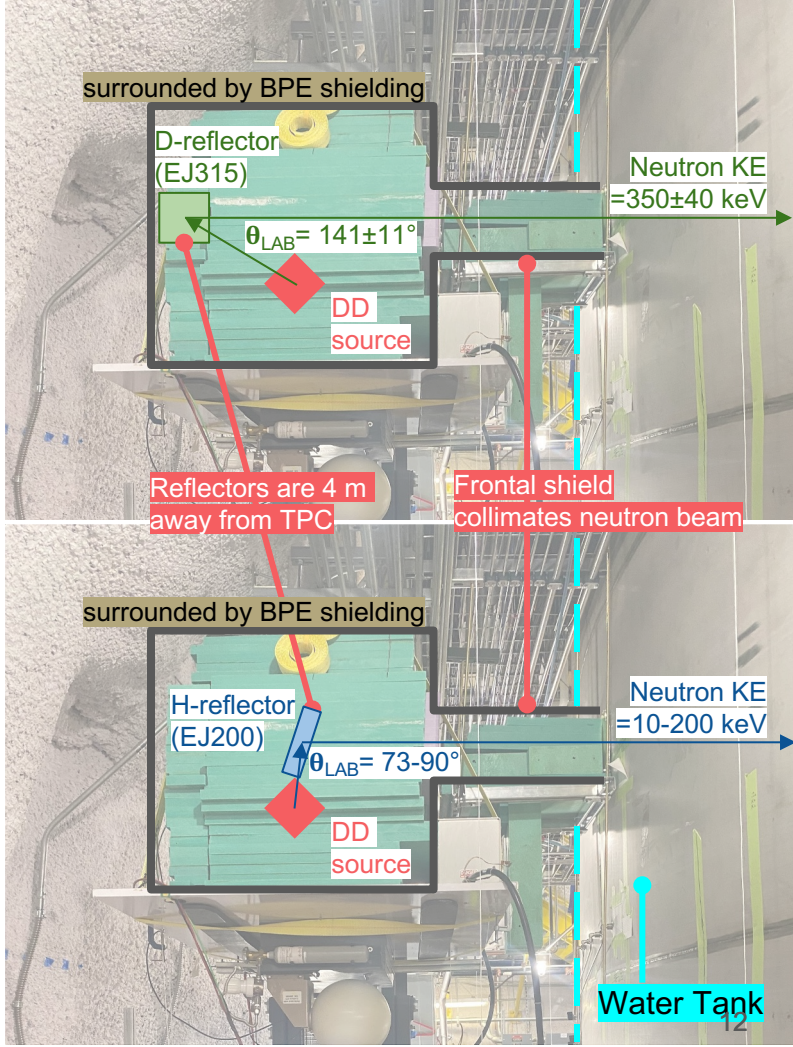


Figure credit: Jeanne Bang

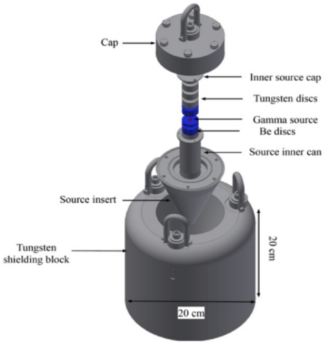
Photo-neutron Source Delivery System

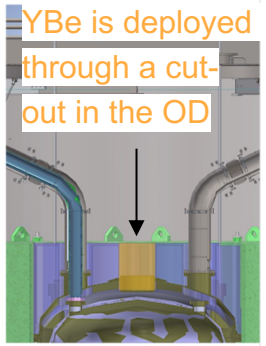
- ^{88}YBe source
  - ^{88}Y Gamma energy: 1.836 MeV (99.2%)
  - ~152 keV monoenergetic neutrons through (γ,n) reaction:

    $\gamma + {}^{9}\mathrm{Be} \rightarrow \mathrm{n} + {}^{8}\mathrm{Be}$

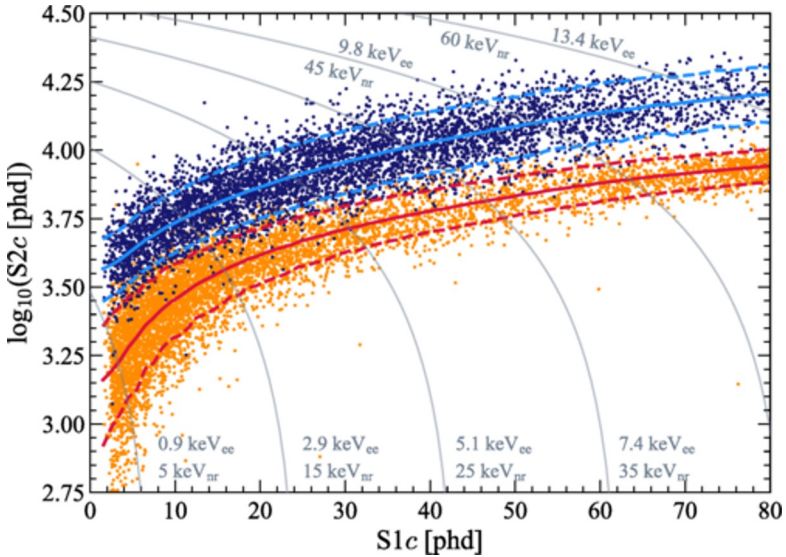
- Lowered to the OCV top though a custom-cutout

- 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

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https://lz.lbl.gov/

- 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.
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- Pennsylvania State University
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- South Dakota Science & Technology Authority
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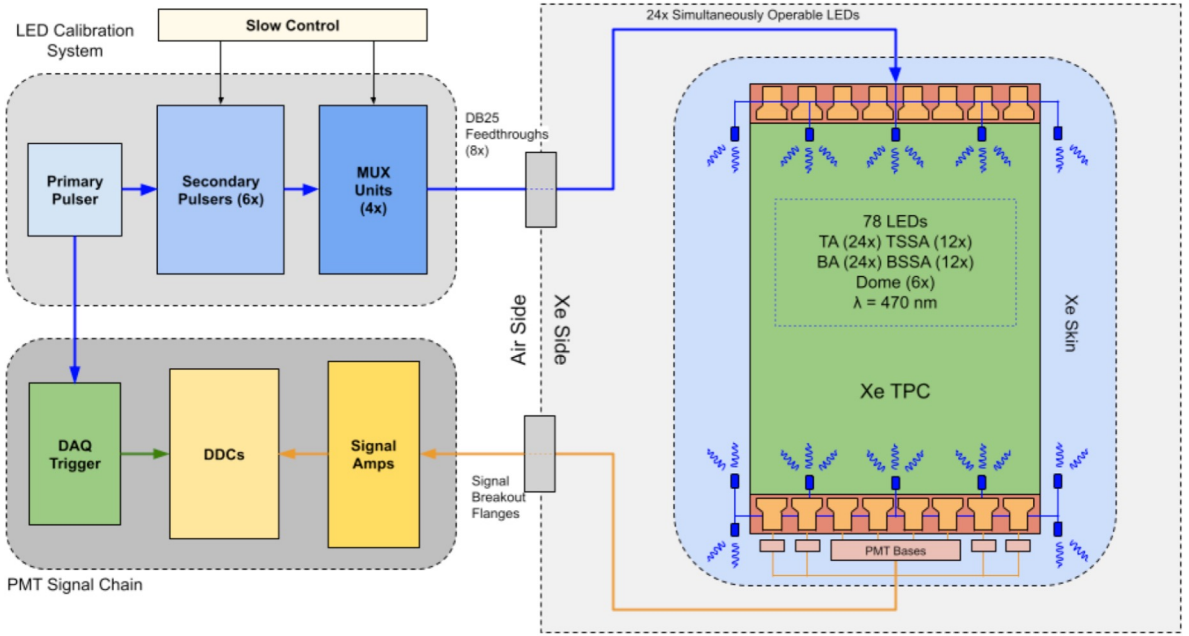
Thanks to our sponsors and participating institutions!

Detector PMT and Optical Calibrations

Xe LED Calibration System

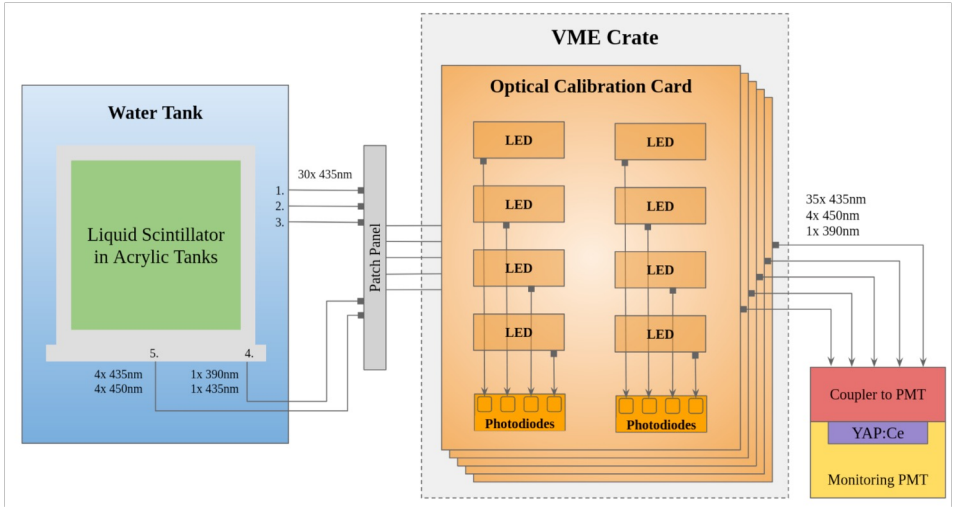
- 78 individually operable LEDs installed throughout the TPC and Skin

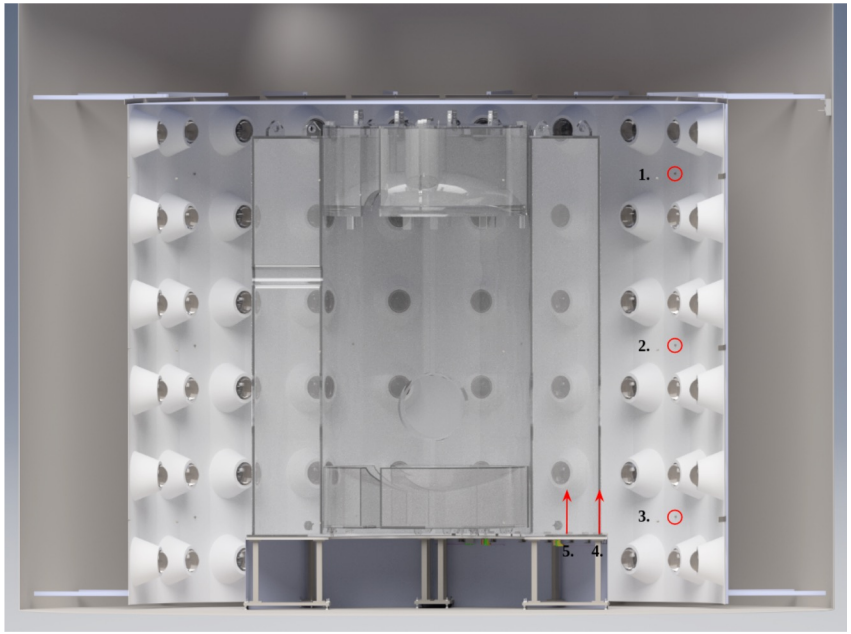


Detector PMT and Optical Calibrations

OD Optical Calibration System (OCS)

- LED light injected through optical fibres at 35 locations in the OD





D-reflector performance