Calibration of a Liquid Xenon Detector for the Search for Dark Matter with the LUX-ZEPLIN (LZ) Experiment at Sanford Lab

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for the LZ Collaboration

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SD Mines Campus on May 11 - 13, 2022

SOUTH DAKOTA MINES
An engineering, science and technology university

Major Professor / Co-Author Dr. Juergen Reichenbacher

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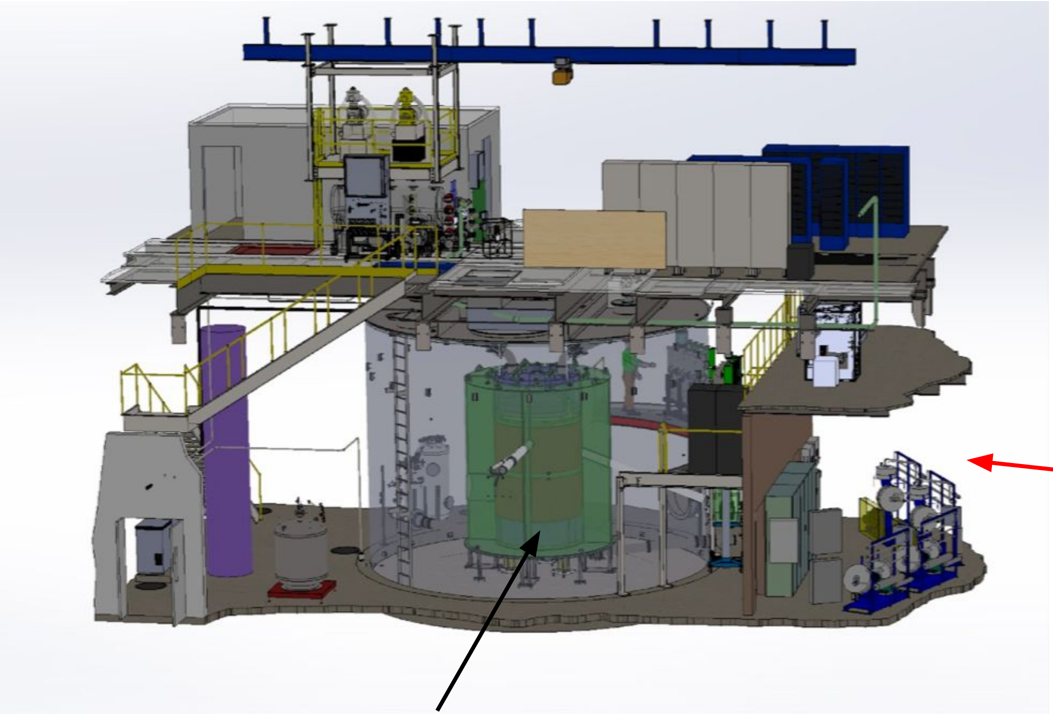
Outline:

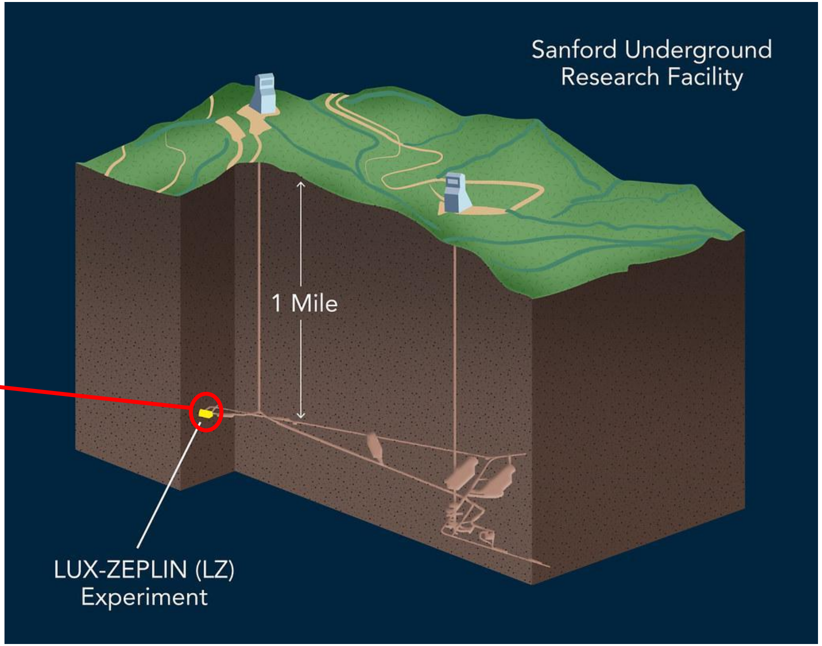
- Overview of the LZ (LUX + ZEPLIN) Detector
- Purity Monitoring (Electron-Lifetime Study)
- Nuclear Recoil (NR) Calibration of the LZ Detector with Neutron Sources
- Separation of Nuclear Recoil (NR) WIMP Dark Matter Signals from Electron Recoil (ER) Signals

The **LUX-ZEPLIN** (**LZ**) Experiment

located ~1 mile underground at Sanford Lab (Davis Campus), Lead, SD, USA



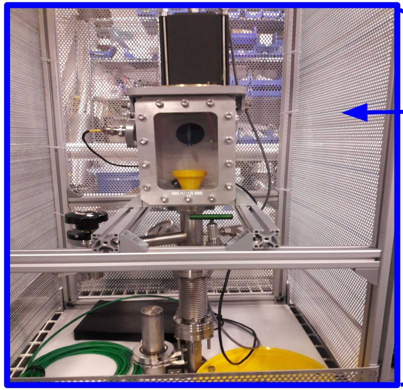
LZ Detector inside the water tank

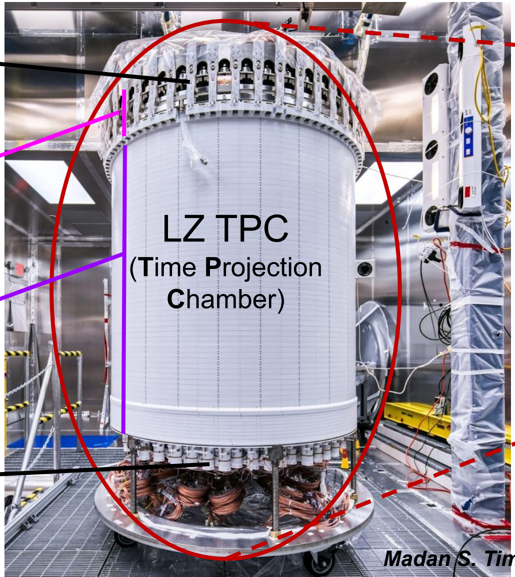


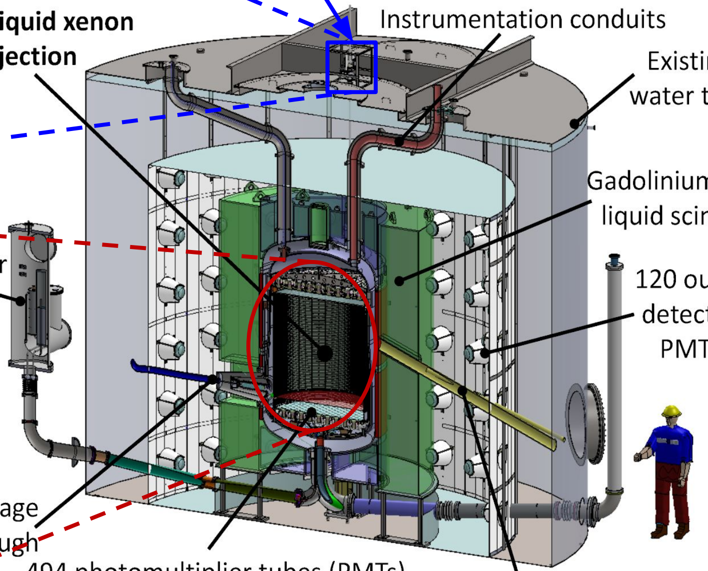
Full LZ experiment CAD model in the the Davis Campus at the 4850 Level of the Sanford Underground Research Facility. Figure credit to Matt Hoff (LBNL).

LZ Detector Overview

- ***Taking data now!***
- Largest Dual Phase LXe TPC
- 7 tonnes of Xe in TPC
- 5.6 tonnes fiducial
- 494 TPC PMTs

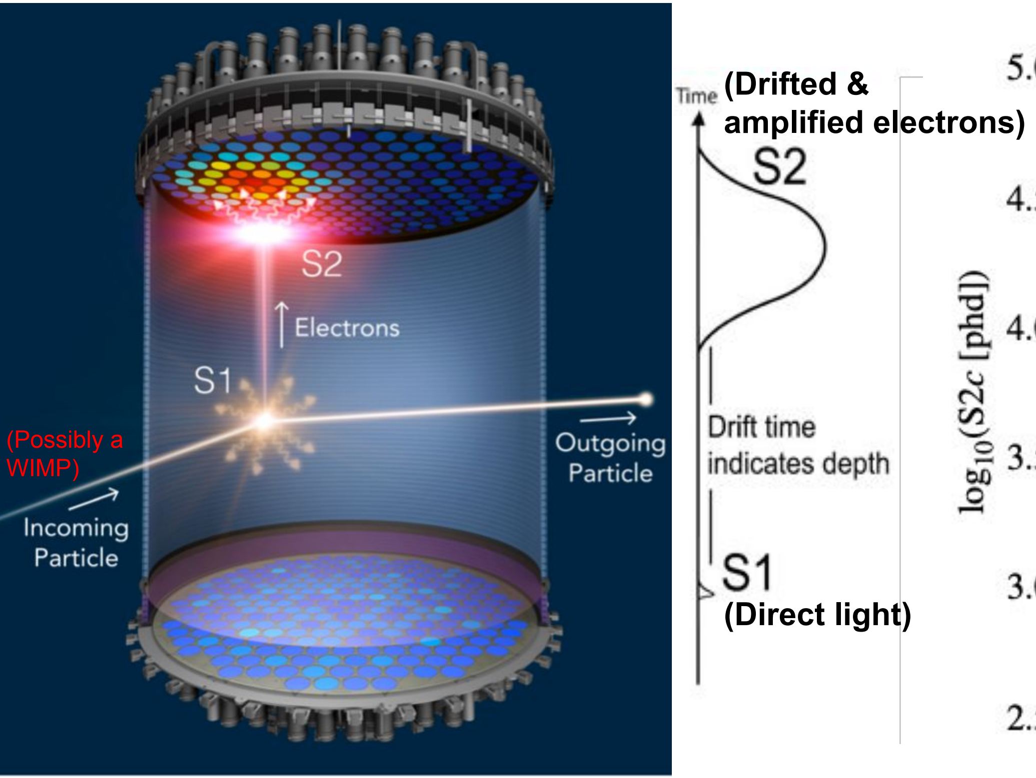




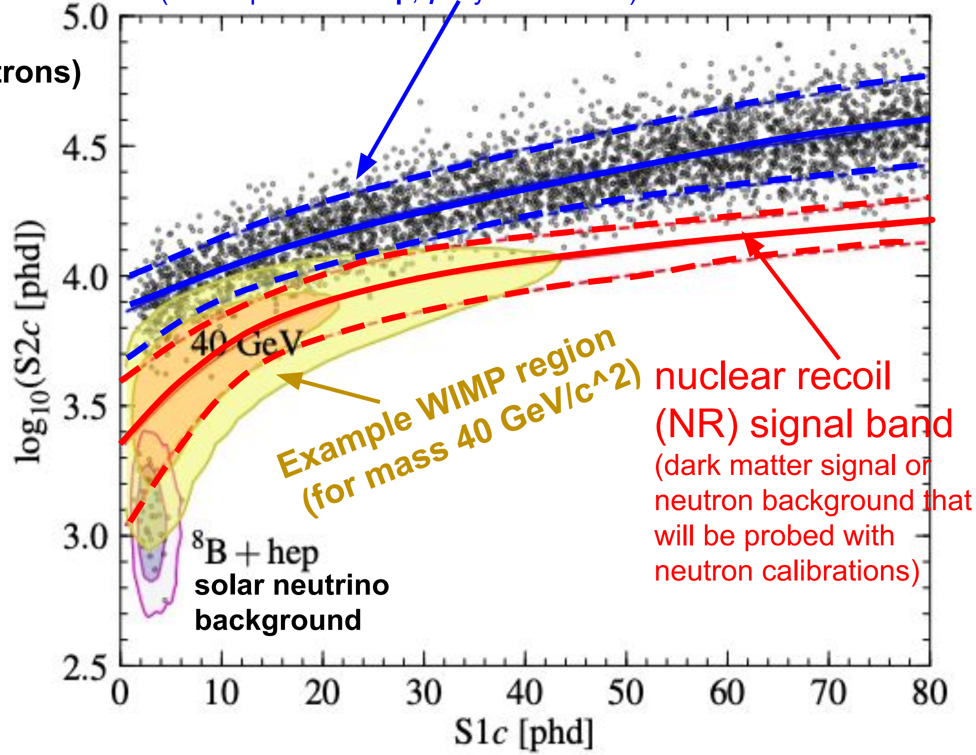


Dual-Phase Xenon Detector (TPC)

(D.S. Akerib et al., Phys.Rev.D 101 (2020) 5, 052002 (DOI) arXiv: 1802.06039)



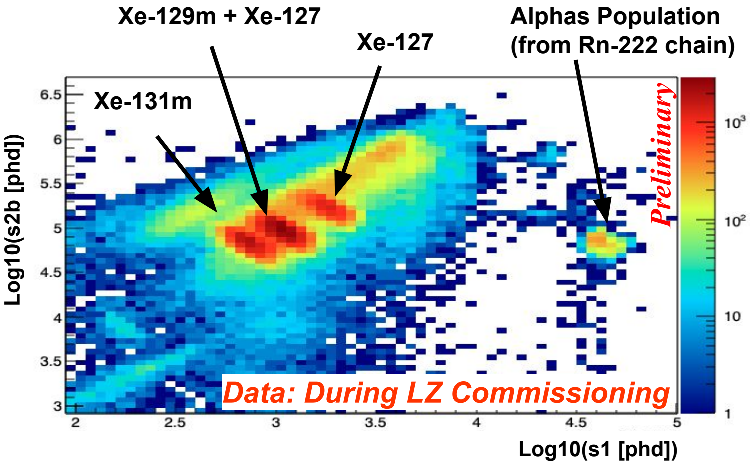
electron recoil background band
(will be probed with β, γ-ray calibrations)

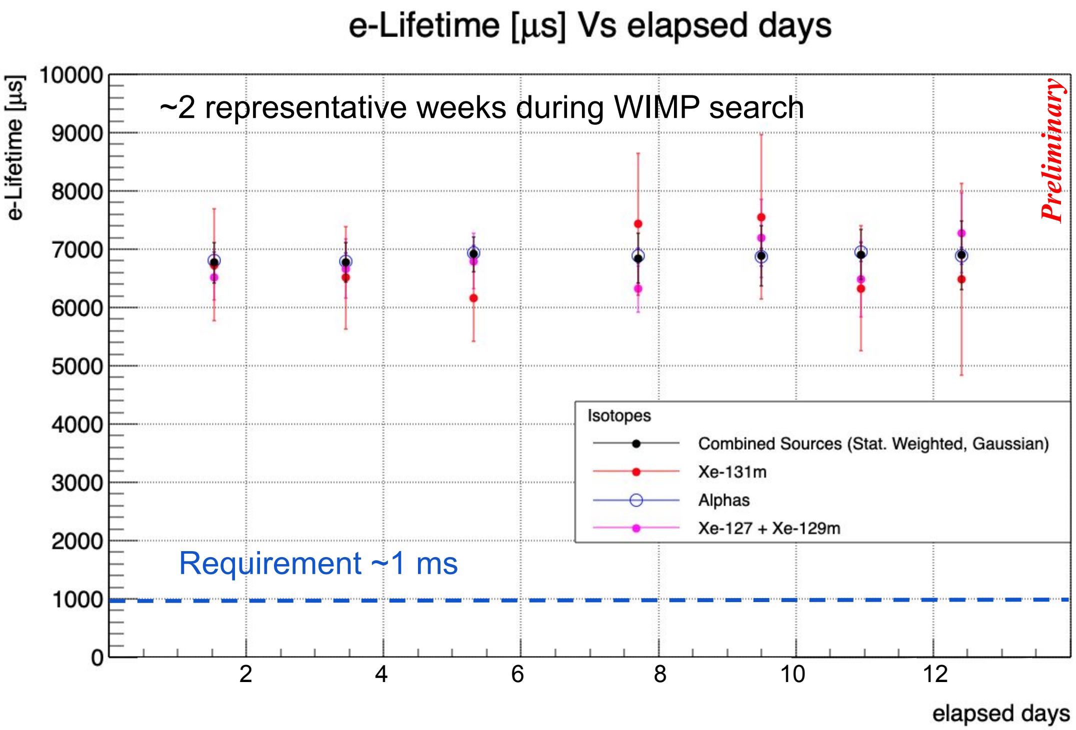


LZ simulated data set for 1000 live days

WIMPs: Weakly Interacting Massive Particle

Time-Dependent Signal Electron-Lifetime





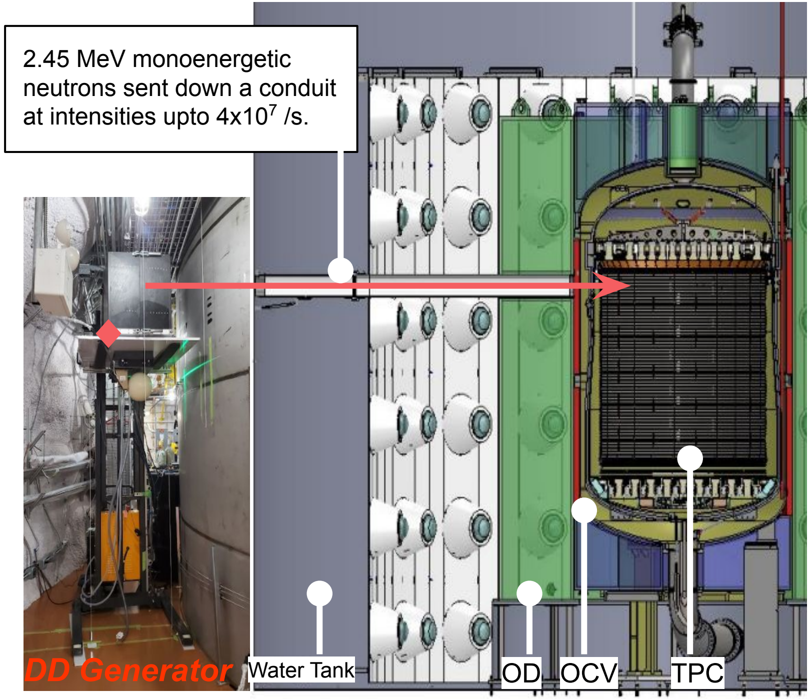
- Electron-Lifetime is the mean time of signal electrons that can survive as they drift through the LXe before attaching to any chemical impurity
- It is a very important technique to monitor the detector purity, to understand and correct for the detector response and essential for any LZ data analysis
- It is used for different calibration aspects, such as radial correction, spatial correction, position correction, S2 correction, salting and so on

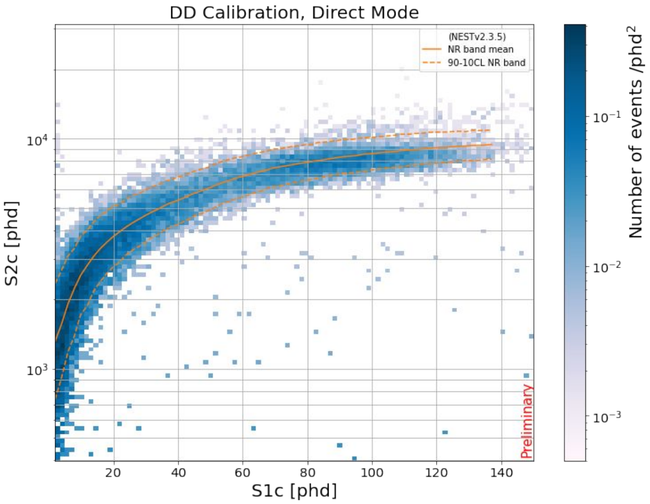
Madan S. Timalsina/SDSMT(LZ)

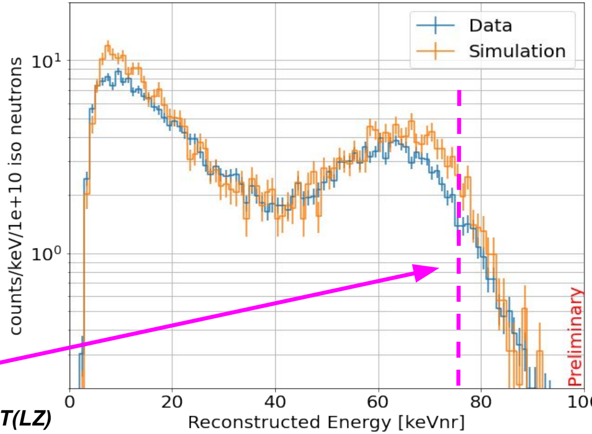
DD Neutron Calibration : LZ Dual-Phase Xenon Detector (TPC)

- Generates neutrons by deuterium-deuterium fusion
  - $^{2}D + ^{2}D \rightarrow ^{3}He + n$
  - Monoenergetic 2.45 MeV neutrons
  - Resulting a maximum NR of ~ 75 keV in LXe
  - Neutron production rate is up to 10^9 /sec.

More details on J. Bang's APS (April 2022) Presentation







Theoretical estimation of endpoint NR (~ 75 keV) in Xe

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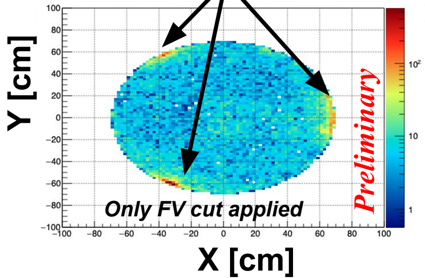
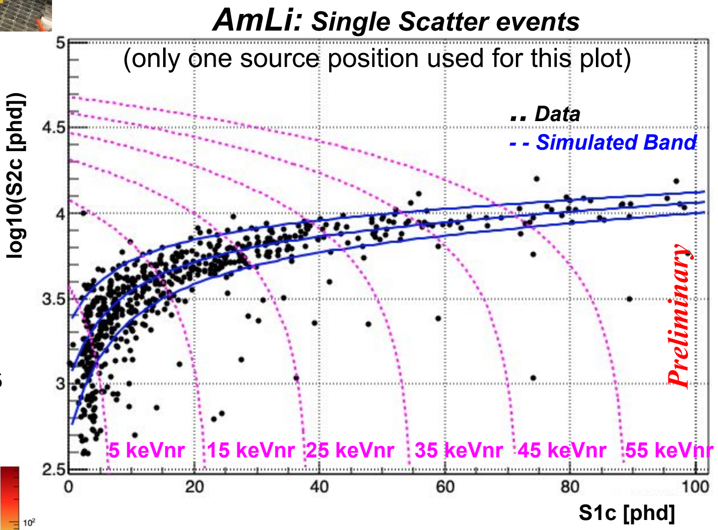
AmLi Neutron Calibration : LZ Dual-Phase Xenon Detector (TPC)

Mounting AmLi neutron source inside a calibration system

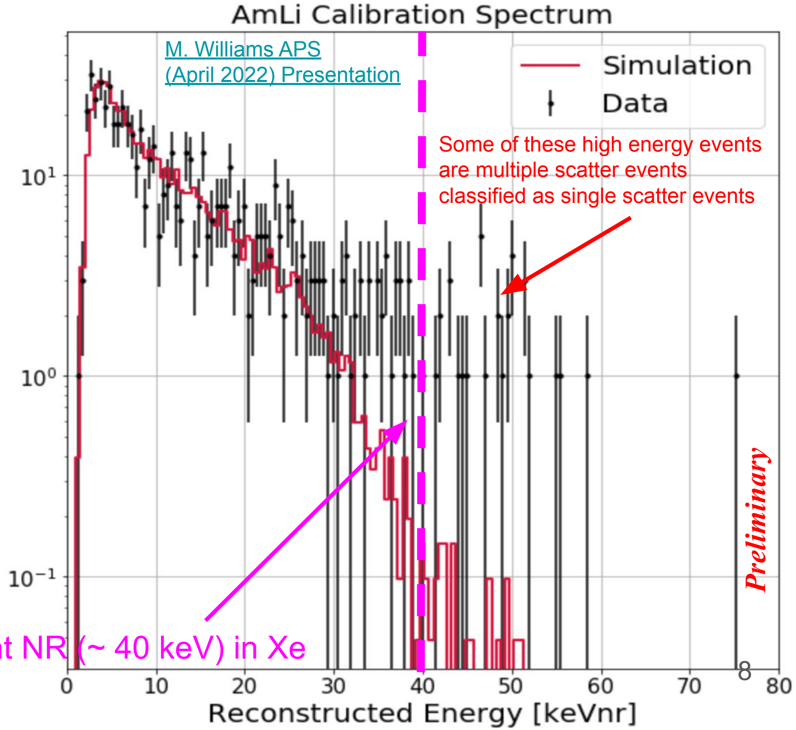
- Neutrons produced via Li(**α**,**n**) reactions, **α**'s from ^{241}Am (**α** + ^{7}Li → ^{11}B → ^{10}B + **n**)
- Maximum neutron energy is 1.5 MeV resulting a maximum NR of ~ 40 keV in LXe
- Total neutron emission rate of LZ AmLi sources are ~35 neutrons per second

3 AmLi neutron sources at 3 different position



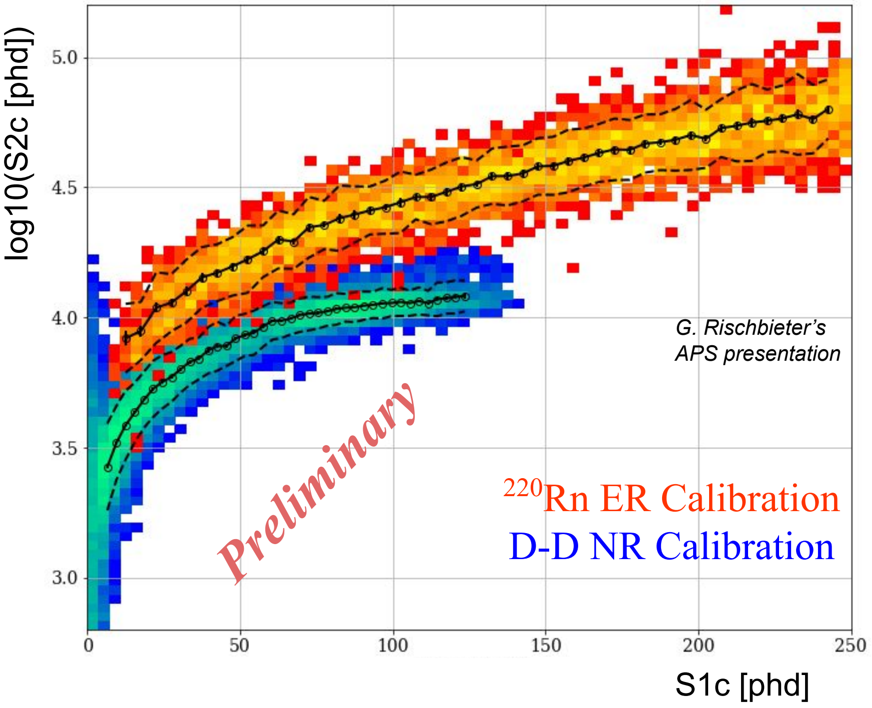


Planning to take more data to have better statistics!



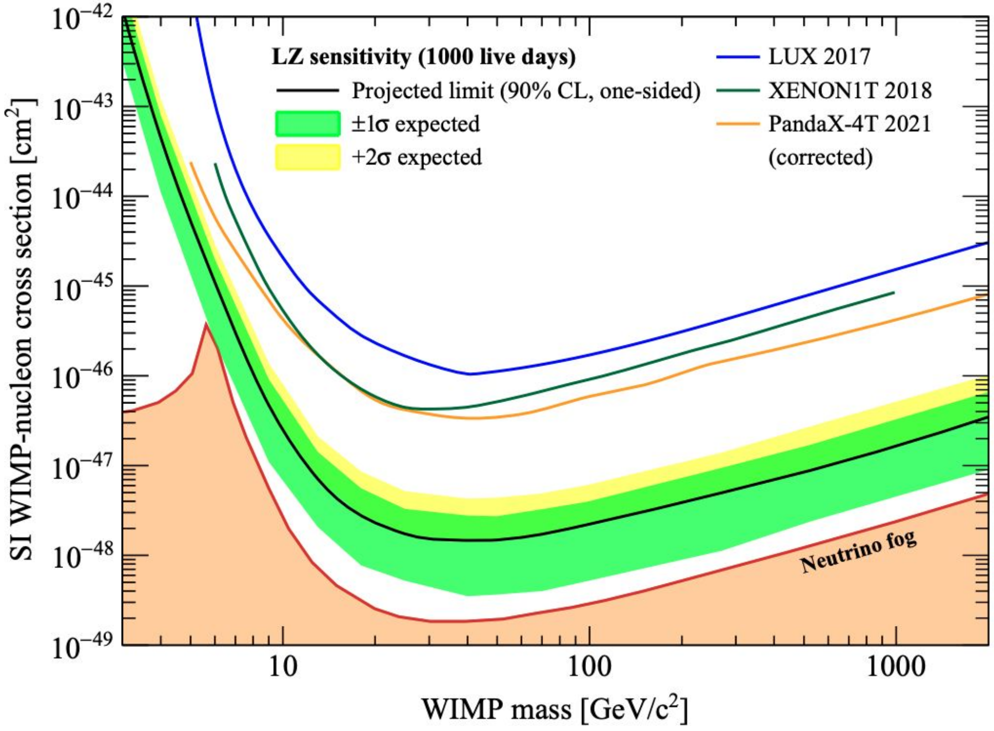
LZ Nuclear Recoil (NR) and Electron Recoil (ER) Initial Calibration

- Similar to NR we also have ER calibration to understand the radioactive background
- During early commissioning, test calibration data were acquired ^{220}Rn injection (β from ^{212}Pb) for electronic recoils (ER)
- We can see the separation of ER and NR bands
- Binning data sets into S1c "slices", Gaussian fits to the log10(S2c) distributions provide band means & widths
- ***During commissioning, detector configuration was not yet finalized***
    - ***<u>Therefore, results in this presentation are preliminary</u>***
    - ***We present the development of a robust tuning technique, which is efficient and easy to re-perform on later data acquisitions***



LZ Sensitivity in Comparison to Other Experiments

D.S. Akerib et al., Phys.Rev.D 101 (2020) 5, 052002 ([DOI]) arXiv: [1802.06039]



LZ projected sensitivity to SI WIMP-nucleon elastic scattering for 1000 live days and a 5.6 tonne fiducial mass

Soon we will look in the NR band from our WIMP search to infer either
a) an exclusion curve if we don't see anything above background OR
b) (if we are lucky) a possible first sign of WIMPs!

Summary:

- This is an exciting time for dark matter and noble element experiments, as the generation-2 of large xenon TPCs have begun collecting data

- LZ detector's liquid xenon is already very pure and collects WIMP search data, expected first science result within 2022

- LZ has clear discrimination between NR WIMP events and ER radioactive background events, so LZ detector is ready to observe potential dark matter signal via NR if WIMPs exist and their spin-independent WIMP-nucleon scattering cross section is significantly above LZ's sensitivity for exclusion (@ 90% C.L.) of 1.4×10^{-48} cm^2 @ 40 GeV/c^2 *(D.S. Akerib et al., Phys.Rev.D 101 (2020) 5, 052002 (DOI) arXiv: 1802.06039)*

LZ (LUX-ZEPLIN) Collaboration

@lzdarkmatter

https://lz.lbl.gov/

35 Institutions: 250 scientists, engineers, and technical staff

- Black Hills State University
- Brandeis University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial 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.
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