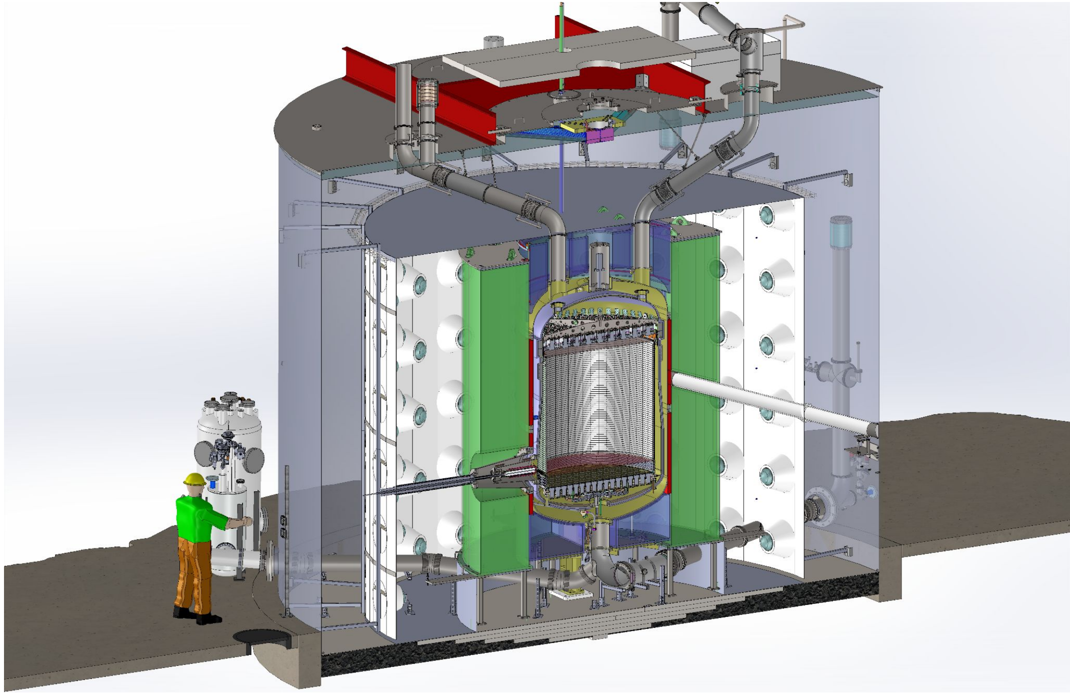
Electron Lifetime Measurements in the LUX-ZEPLIN (LZ) Dark Matter Experiment

Jack Genovesi, on behalf of the LUX-ZEPLIN Collaboration
CoSSURF hosted at South Dakota School of Mines and Technology
May 14-16, 2024, Rapid City, SD

SOUTH DAKOTA MINES

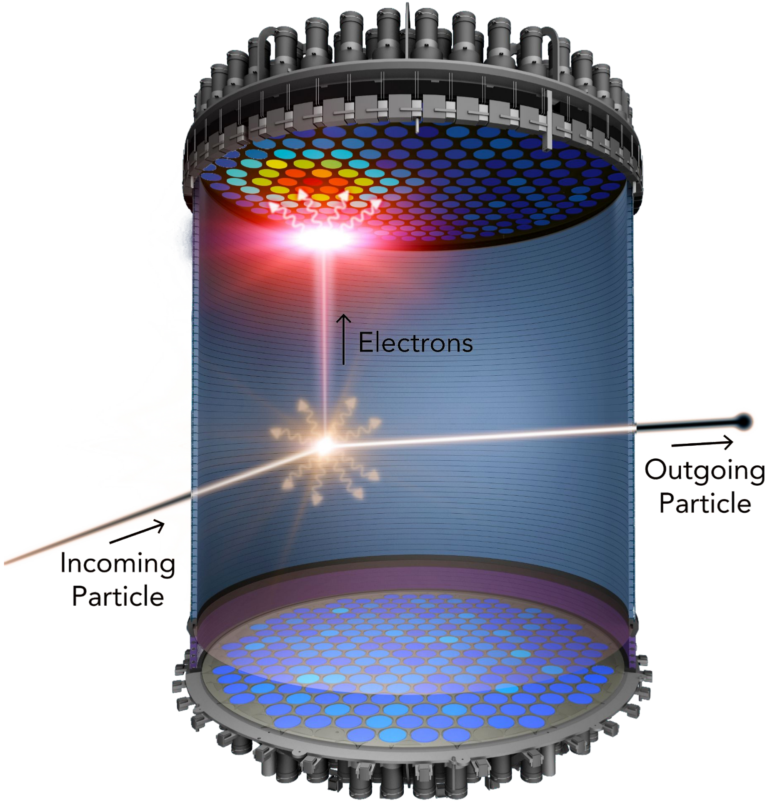
Introduction to the LZ Experiment

- Located 4,850 feet underground at the Sanford Underground Research Facility (SURF)
- Ultra-quiet dual-phase liquid-xenon time projection chamber (TPC)
- 10 tonnes of xenon, with 7 tonnes of active xenon and fiducial mass of 5.5 tonnes
- Most sensitive dark matter detector in the world!



Detector Method

- Incoming particle deposits energy in liquid xenon
- Xenon at interaction site is either excited or ionized
- De-excitation and recombination produces primary scintillation signal (S1)
- Freed electrons are drifted to extraction region to be amplified via electro-luminescence producing secondary scintillation signal (S2)



Xenon Purification System

- Xenon is purified by the use of a hot zirconium getter
- Electronegative impurities in the xenon can cause charge-loss by absorbing electrons from particle interactions
- Attenuation length λ is defined as the distance traveled d needed to have 1/e surviving electrons:

$$N_{e^-}(d) = N_{e^-}(0)e^{\left(\frac{-d}{\lambda}\right)}$$

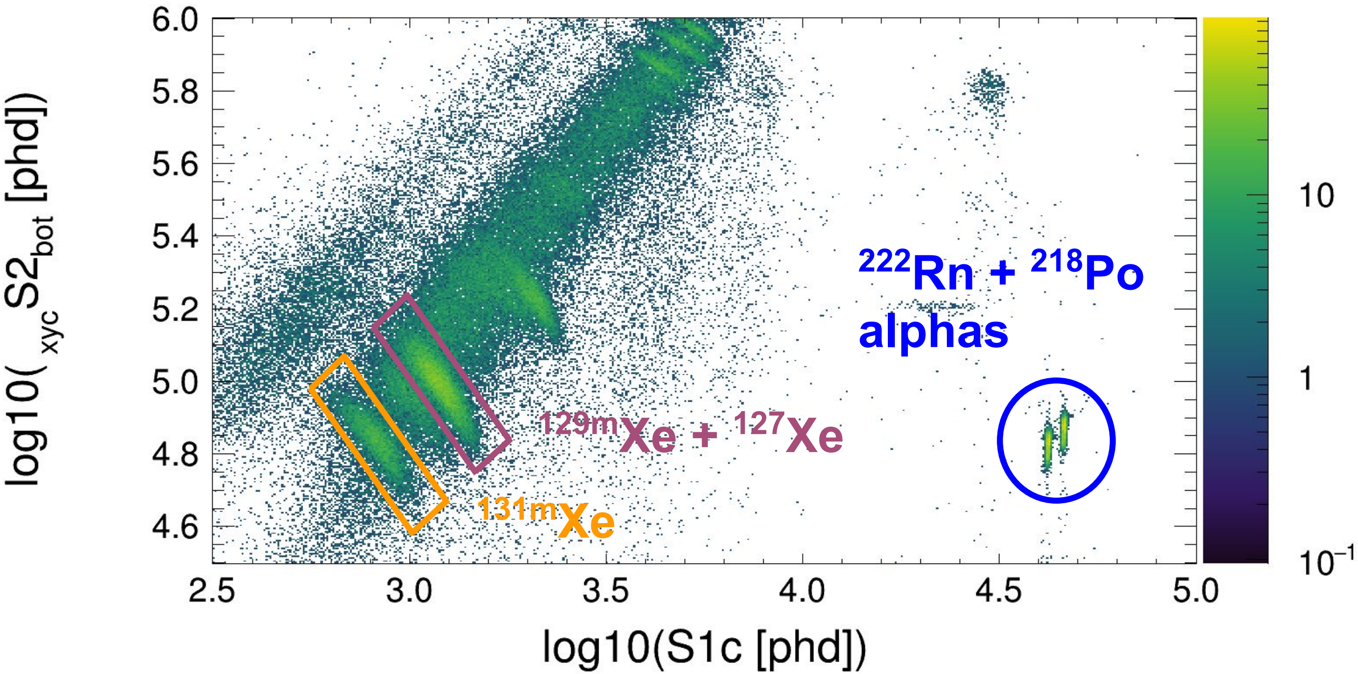
- Electron lifetime τ is calculated by dividing the electron attenuation length by electron drift velocity ν_d:

$$\tau = \frac{\lambda}{\nu_d}$$

- LZ's electron lifetime requirement is ~1 ms

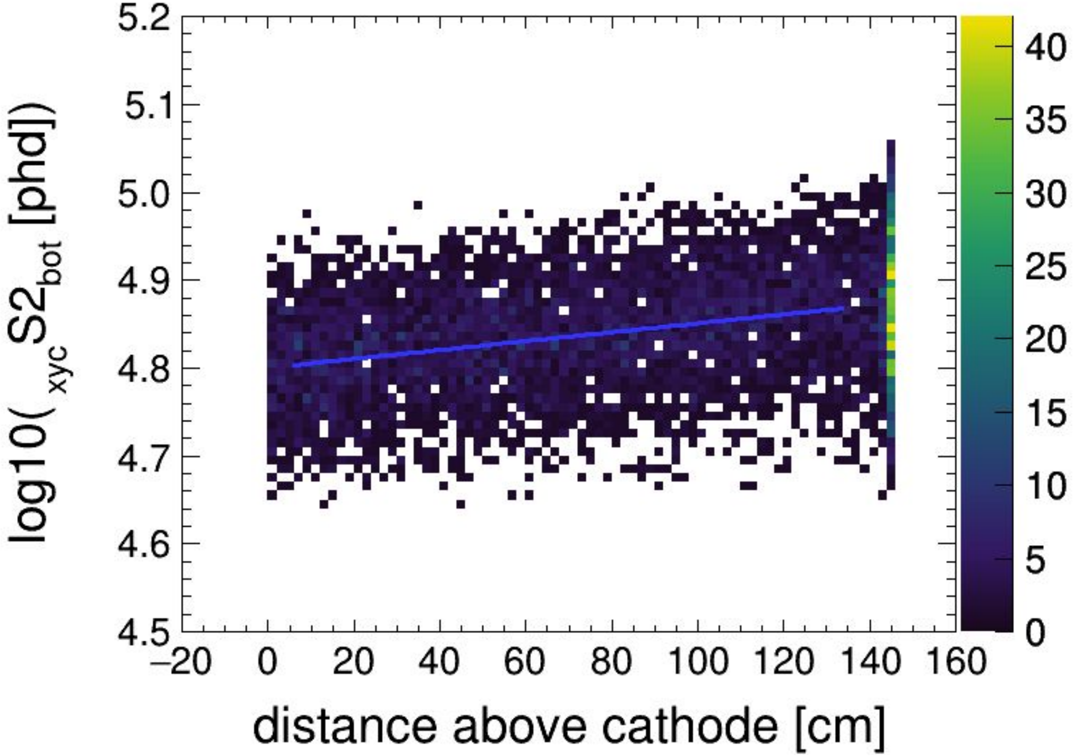
Candle Sources for Electron Lifetime Measurements

- Calibrations for the LZ detector are made with numerous sources
- Mono-energetic sources are used for electron lifetime calculations
- Can use sources with different lifetimes to explore purity in different partitions of the detector



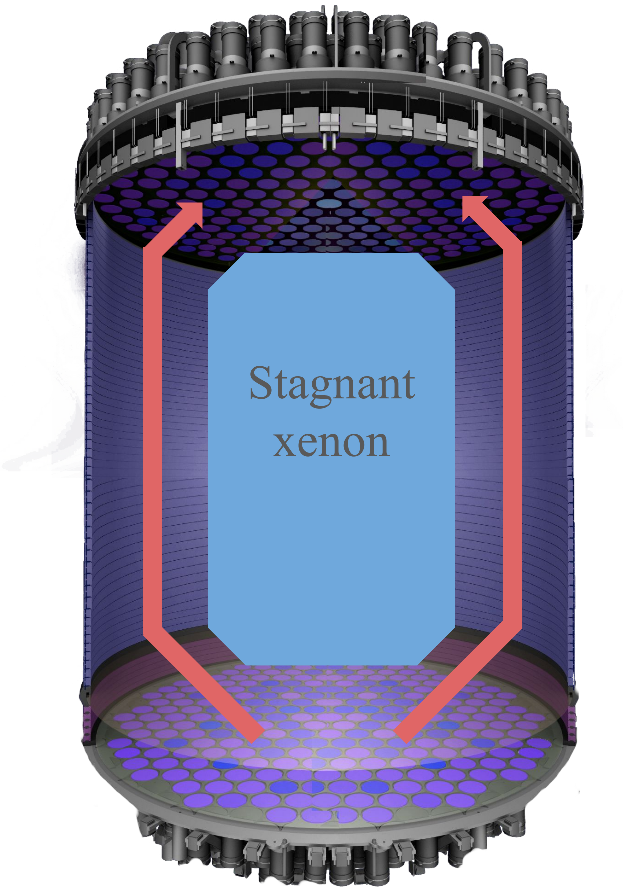
Charge-Loss Based on Event Depth for ^{131m}Xe Interactions

- Selected ^{131m}Xe events from SR1 data
- The loss of electrons leads to smaller S2 yields
- The deeper the event occurs, the larger the loss of electrons
- Electron lifetime for this data was 5.51 +/- 0.19 ms
    - Already far above LZ's electron lifetime requirement of ~1 ms!



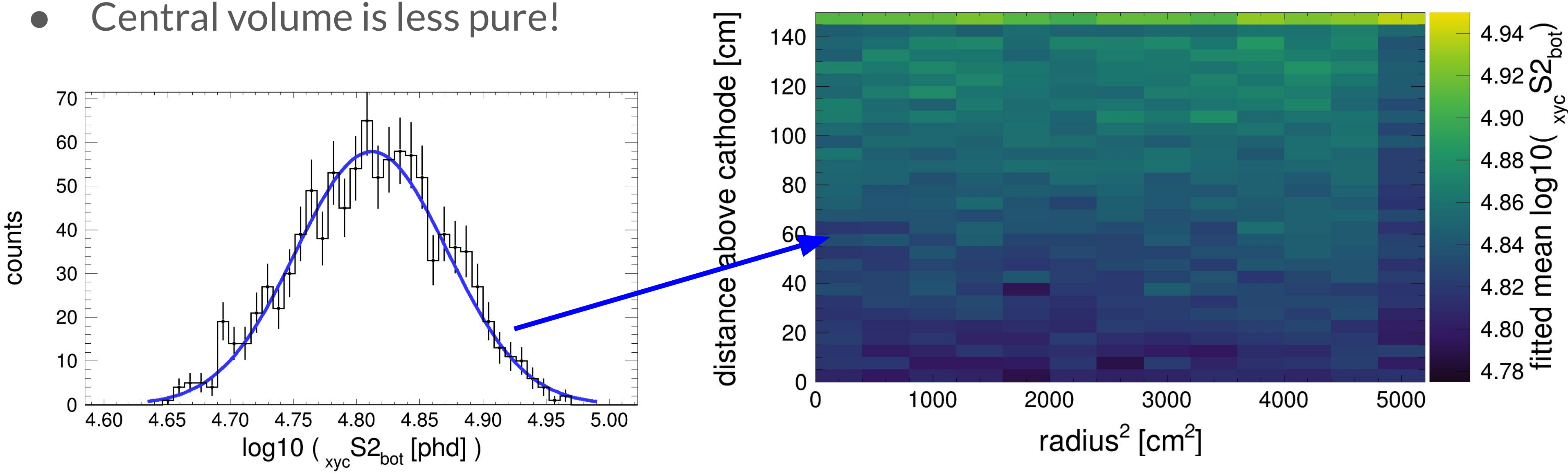
Xenon Non-Uniformity due to Mixing

- Xenon mixing can be manipulated by altering the heating of the TPC
- In SR1 we operated in an “isolated state” where the central volume was stagnant and purified less quickly
- Can measure purity in various detector partitions with various sources



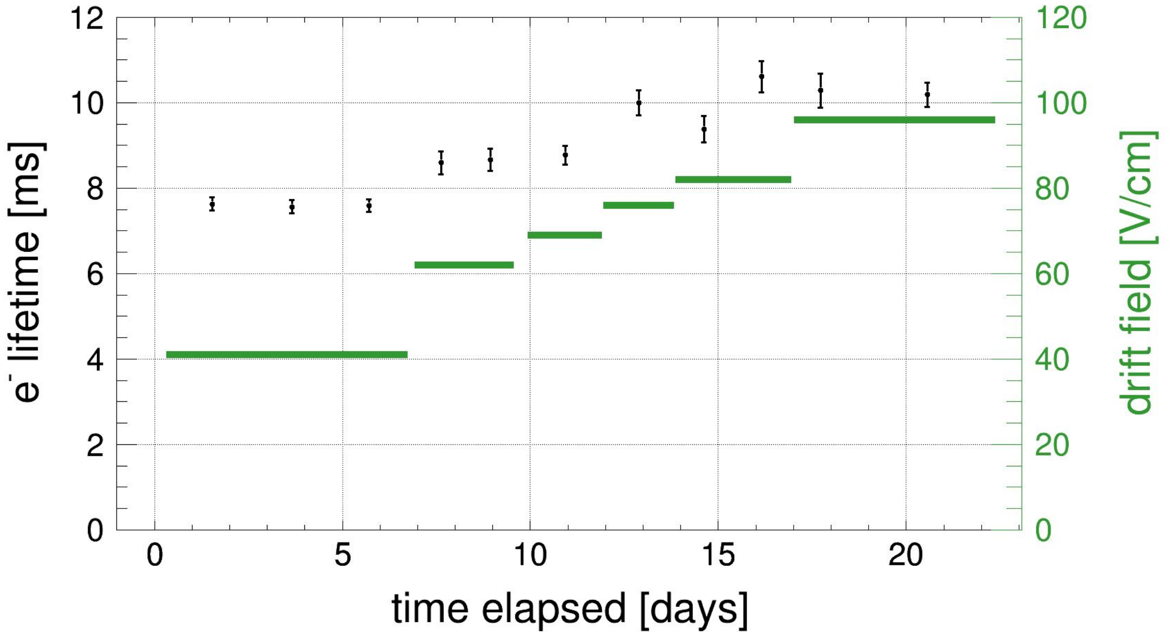
Spatial Measurements of S2 for ^{131m}Xe Events

- Fitted the mean S2 yield in volume slices for ^{131m}Xe events during SR1
- Volume slices are 400 cm^2 in Δradius^2 and 5 cm in Δz
- Central volume of the detector has lower mean S2, while the periphery and top of the detector have larger values
- Central volume is less pure!



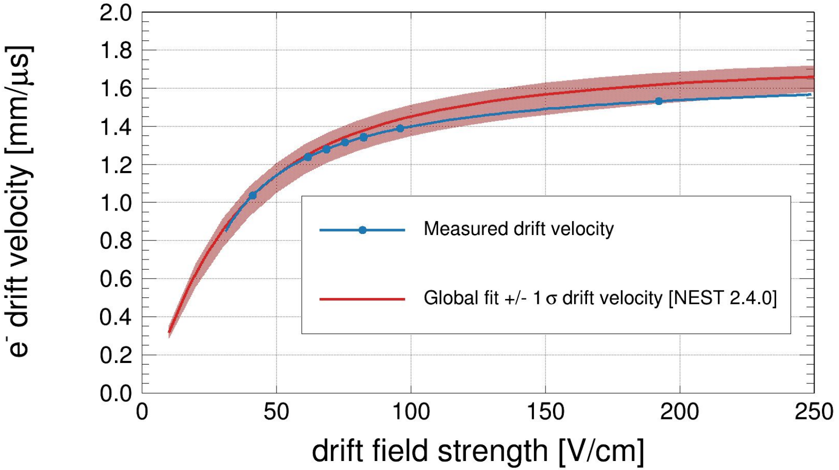
Exploring Various Detector Configurations

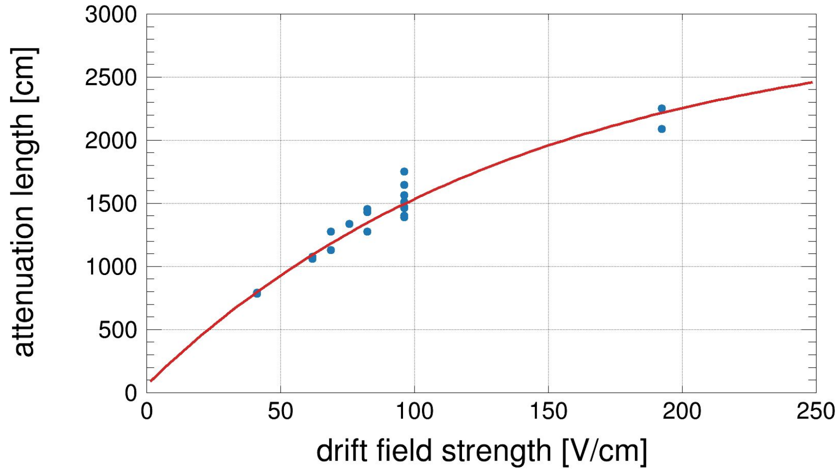
- After SR1, LZ took data at various drift-field strengths to explore detector response across different configurations
- Electron lifetime appears to be dependent on drift-field strength!



Electron Drift Velocity and Attenuation Measurements

- Plotted measurements of drift velocity and attenuation length of data taken after SR1
  - Statistical error bars are plotted, too small to be seen
- Drift velocity measurements agree with global fit of data from NEST 2.4.0
- Attenuation length appears to be field-dependent, likely due to electron attachment-rate dependence on drift-field to electronegative populations





Electron Attachment Rate as a Function of Drift Field

- Electron attachment rate to various impurities was measured by Bakale et al.
- Attachment rate depends on both the type of electronegative and on the drift field strength
- Oxygen is expected to be the most impactful electronegative in xenon TPCs, where the attachment rate decreases with stronger drift field strengths

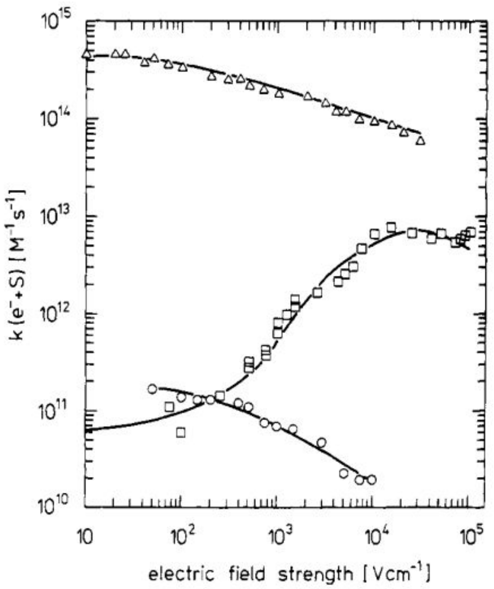
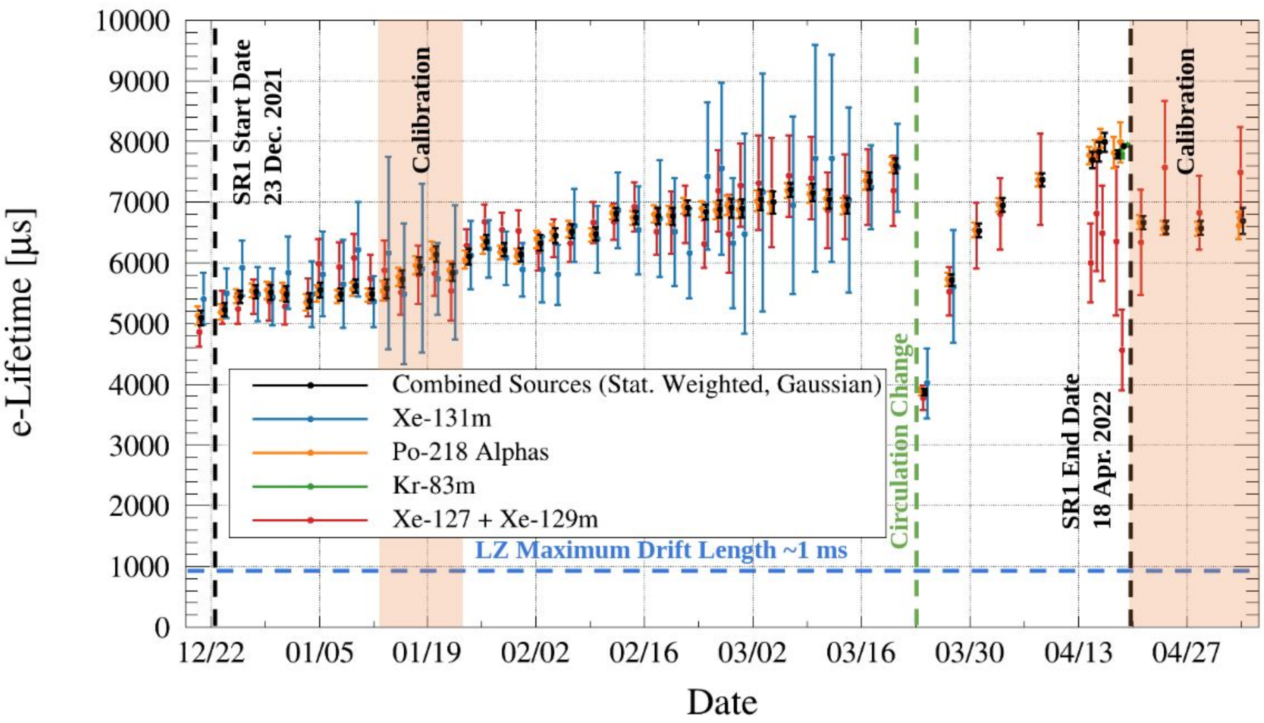


Figure 2. Rate constant for the attachment of electrons in liquid xenon (T = 165 K) to several solutes: (△) SF_6, (□) N_2O, (O) O_2. The solid line through the N_2O data corresponds to the cross section of Figure 4. The solid line through the SF_6 data corresponds to a $\sigma \propto v^{-2}$ dependence.

Figure from Bakale et al.: https://pubs.acs.org/doi/10.1021/j100564a006

LZ's SR1 Electron Lifetime

- LZ's itemized electron lifetime measurements agree well with each other
- Even before SR1 we greatly surpass our requirement
- Circulation changes and calibrations can impact purity, but we quickly regained it



Conclusion

- LZ attains high-purity of liquid-xenon through the demonstration of long electron lifetimes
- Non-uniformity in liquid-xenon purity can be measured with the use of various sources
- Electron lifetime appears to be dependent on drift-field strength likely due to capture cross-section of electronegative impurities being dependent on drift-field strength

jack.genovesi@mines.sdsmt.edu

LZ (LUX-ZEPLIN) Collaboration, 38 Institutions

- 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
- University of Liverpool
- 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
- University of Zürich

US Europe Asia Oceania

250 scientists, engineers, and technical staff

Science and Technology Facilities Council

FCT Fundação para a Ciência e a Tecnologia

Sanford Underground Research Facility

South Dakota Science and Technology Authority

ibs Institute for Basic Science

Thanks to our sponsors and participating institutions!