Investigating the Simulation of Inelastic Neutron Scatters in the LUX-ZEPLIN Experiment

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1. Introduction to LUX-ZEPLIN (LZ)

Aim: Direct detection of dark matter particles (WIMPs).
Location: 4850ft underground at Sanford Underground Research Facility in South Dakota, USA.
Set-up: Experiment centered around dual-phase time projection chamber (TPC) filled with 7 tonnes of liquid xenon (**fig. 1**), surrounded by detectors and shielding for background vetoing [1].

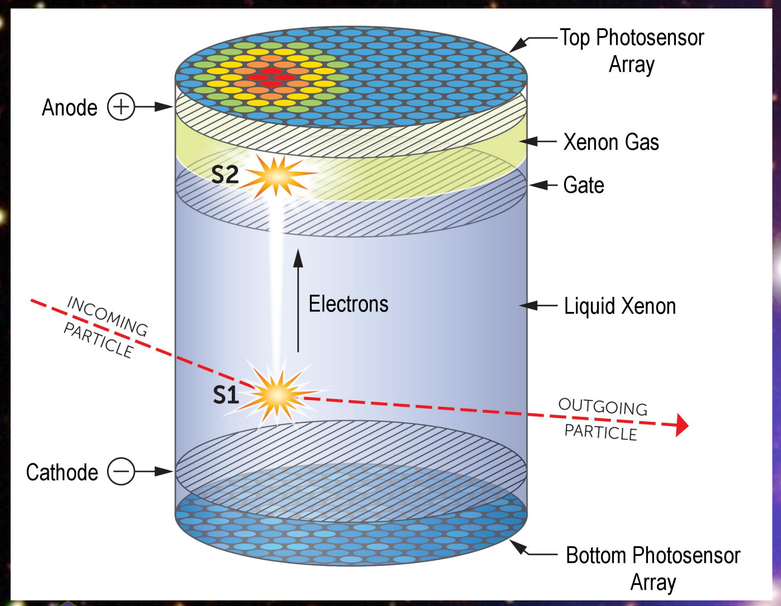


Fig. 1 Diagram of TPC showing recoil event which produces 2 signals:

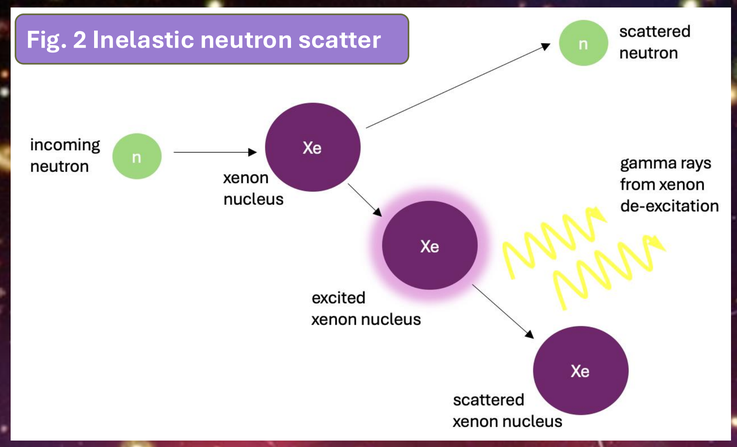
- **S1 - prompt scintillation signal**
- **S2 - delayed ionization signal**

These allow 3D position reconstruction and determination of nuclear or electron recoil. WIMP signal is a rare low energy nuclear recoil.

2. Project Motivation

- 10 times as many single inelastic neutron scatters (**fig. 2**) in data compared to sim meaning there is an issue in the sim which could have an impact on the neutron background predictions [2].
- Neutrons are a dangerous background because low energy elastic neutron scatters can look identical to a WIMP signal.

Fig. 2 Inelastic neutron scatter



3. Method

- Used custom LZ Geant4 simulation packages to run sim of 2.45MeV neutrons sent into LZ TPC.
- Analysed output using Python to check sim accuracy, selecting events where neutron reaches TPC without depositing energy and inelastic scatters on the xenon.

4. Results for Xe129 and Xe131

X Gamma energies: sim produced incorrect energies (**fig. 3**).
X Gamma emission times: timings were incorrect and known long-lived states were not present (**fig. 4**).
X Energy conservation: mostly good, but ~1% of events did not conserve energy.
✓ Reaction cross sections: elastic and inelastic scatter cross sections agreed with literature.
X Single and multiple scatters: misclassified in sim, developed a clustering algorithm to improve this.

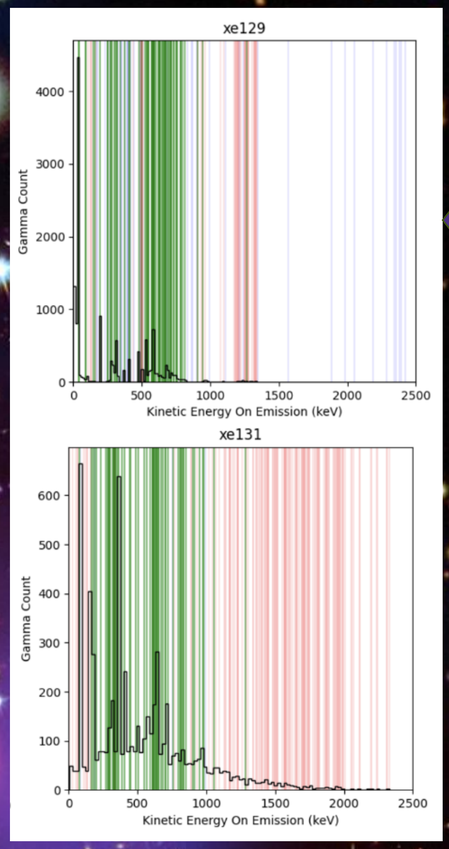
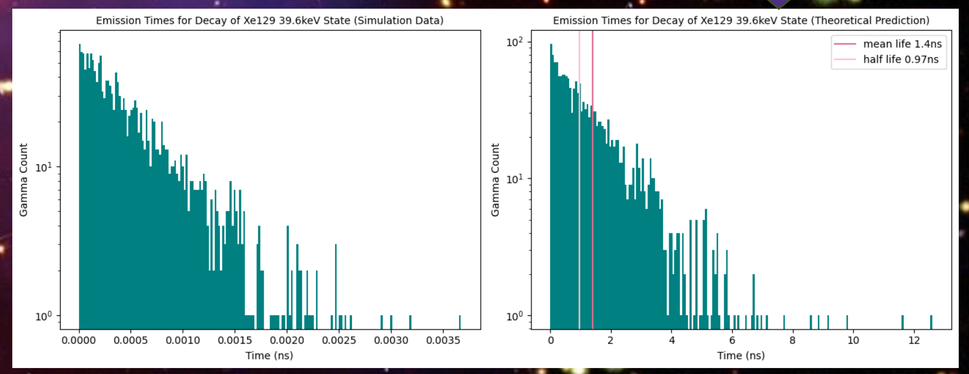


Fig. 3 Histograms of simulated gamma energies highlighting real (green) and erroneous (red) gamma energies for Xe129 and Xe131.

Fig. 4 Histograms showing simulated gamma emission times (left) and theoretical emission times (right) for 39.6keV state of Xe129.

Sim times are a lot shorter than they should be as shown by difference in x-axis scales.



5. Conclusion

- Cause of sim and data discrepancy was found to be caused by sim energy and timing problems.
- A potential fix was identified with Geant4 packages.
- Future work identified to look at implementing fix and quantifying effect on neutron background predictions.

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References:
[1] The LZ Collaboration. First dark matter search results from the lux-zeplin (lz) experiment. Phys. Rev. Lett., Jul 2023.
[2] J. Bang, "DD Neutron Inelastic Scatters in Simulation", *LZ internal presentation*, Nov 2023.