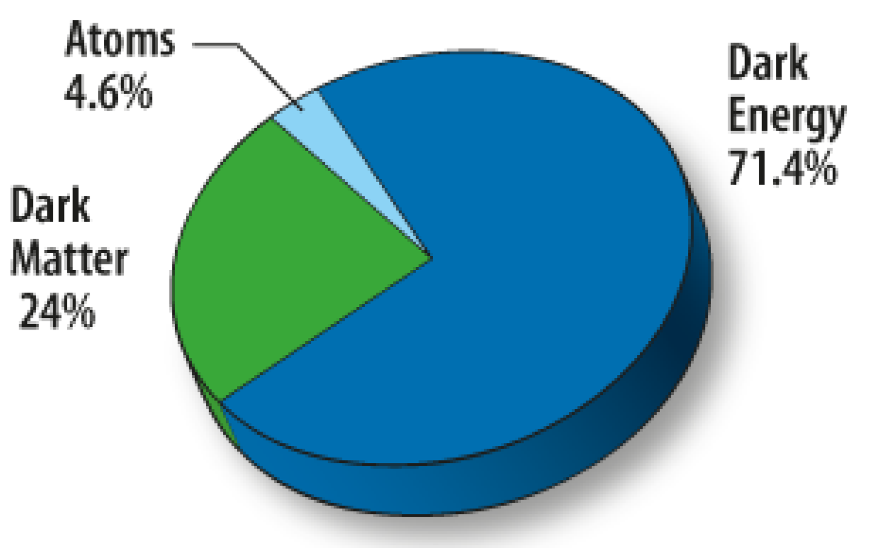
Supplemental Neutron Shielding for the LUX ZEPLIN (LZ) Experiment

David Wells, Yale University, david.wells@yale.edu, LZ Collaboration

David Woodward, Pennsylvania State University., LZ Collaboration

Introduction

- Dark Matter makes up about 24% of the energy universe, but scientists have no idea what it is!
- It is not a known fundamental particle!
- One candidate is a class of particles called Weakly Interacting Massive Particle, or WIMPs.



- WIMP search experiments require very sensitive detectors.
- One such Detector is Lux Zeplin, or LZ
- LZ Is a multi-detector system (fig. 1)
  - The TPC (Time Projection Chamber) observes WIMP events
  - The OD (Outer Detector) identifies and reduces false signals.

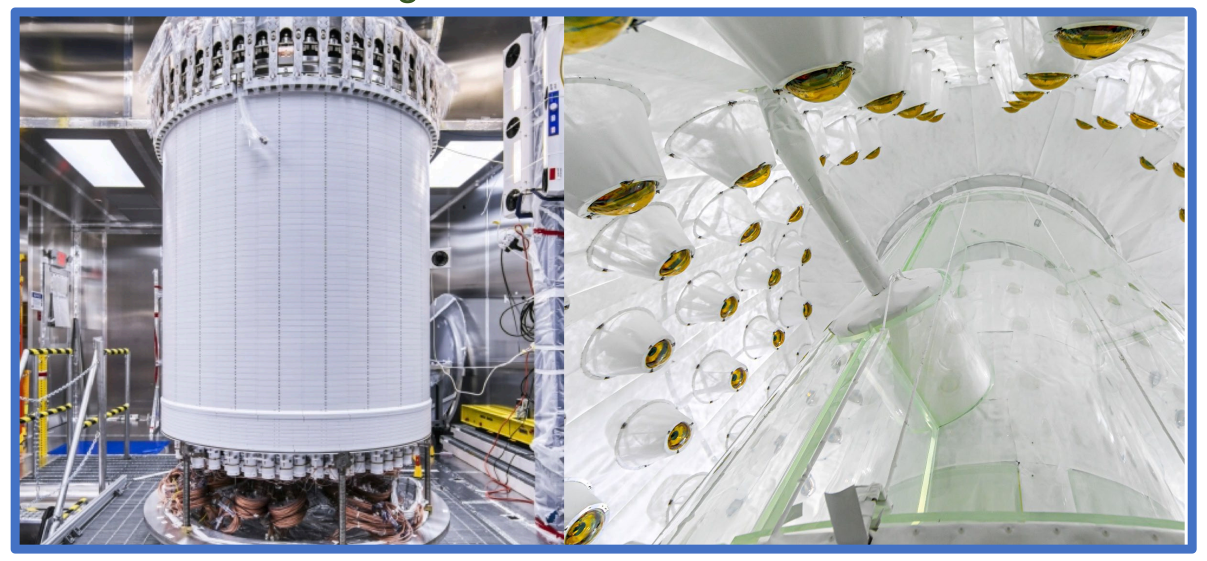


Figure 1: LZ TPC (left) and LZ outer detector (right)

- Detectors also see non-WIMP radiation
- This is called **background**
- How do we lower background? (figure 2)
  - Location/Shielding
  - Vetoing
  - Particle Discrimination

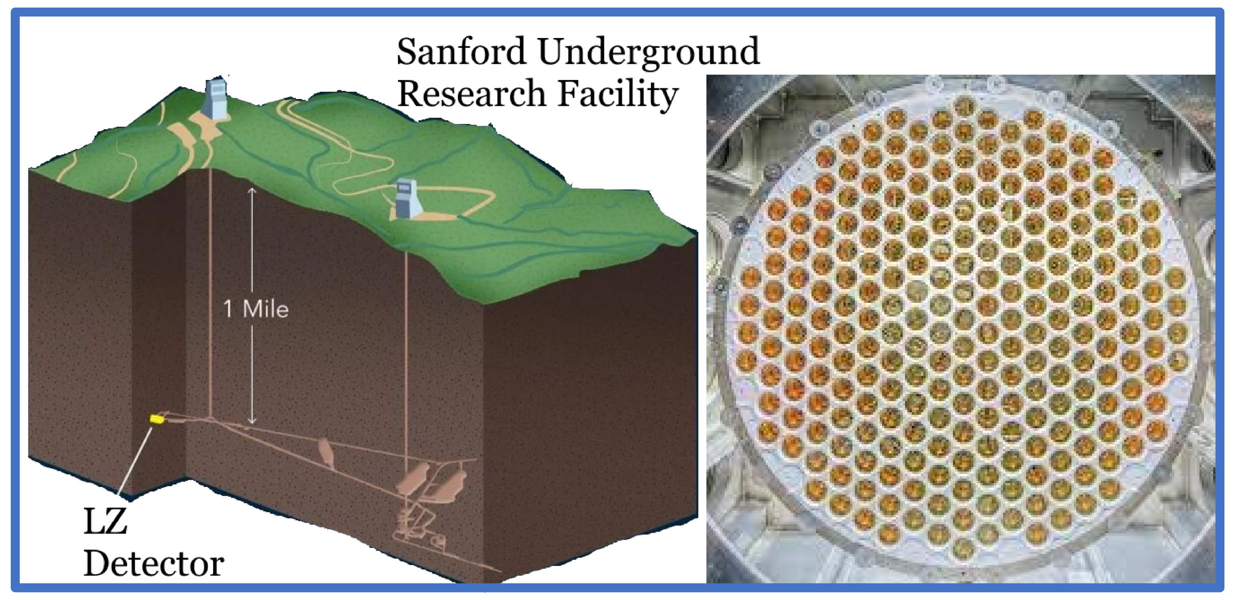
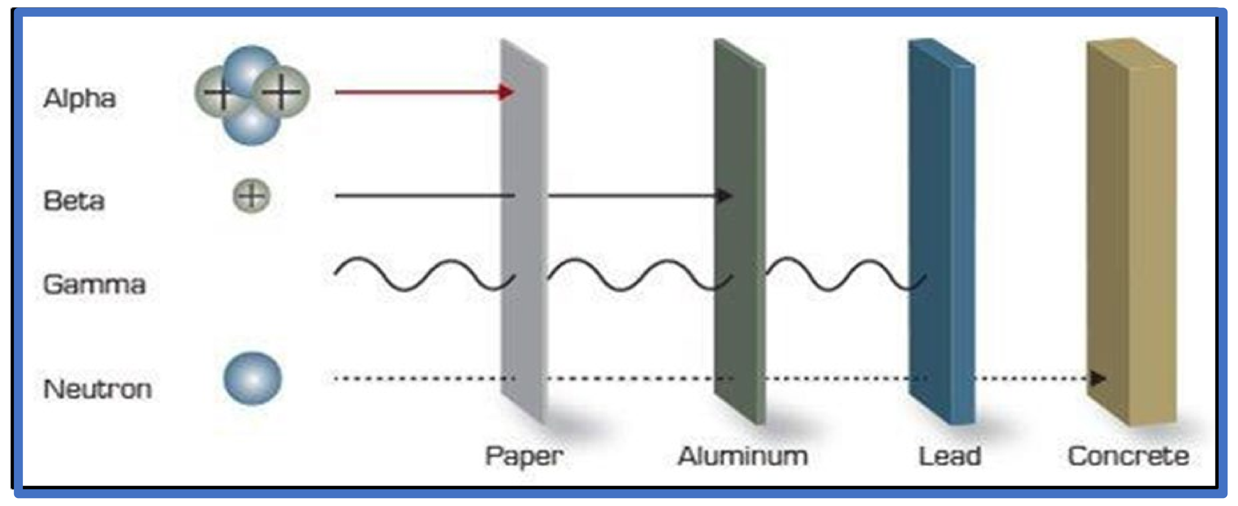


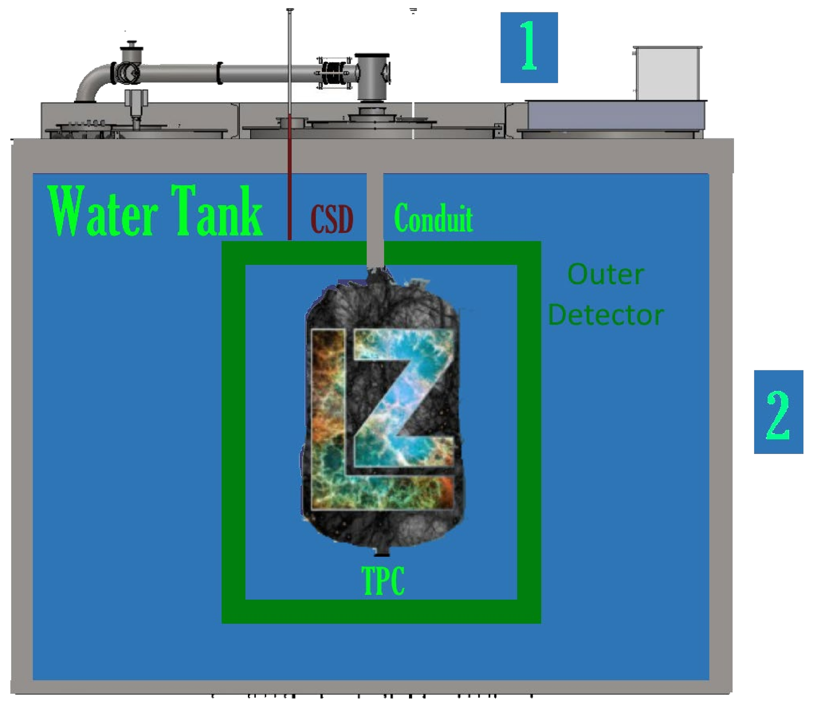
Figure 2: LZ location (left) and LZ Photomultiplier tube array (right), shielding (next column)



- Of these possible backgrounds, neutrons are the worst.
  - They can produce nuclear recoils that look like WIMP interactions.
- Unfortunately, SR1 data shows neutron backgrounds are 70 times higher than expected in the outer detector!
- The goal of this project is to add additional neutron shielding to the LZ detector and assess its effectiveness.

Method: Identifying Neutron entry points

- Place californium (Cf -252) source at various locations around the detector
  - Observe which location sees the highest rate



- Cf at point 1 results in an order of magnitude more neutrons than point 2
- Most effective shielding will be atop the water tank

Method: Shielding design

- We choose materials good at capturing neutrons
  - Boron and Water
- Special emphasis on areas where neutrons can "sneak by" water (figure 3)

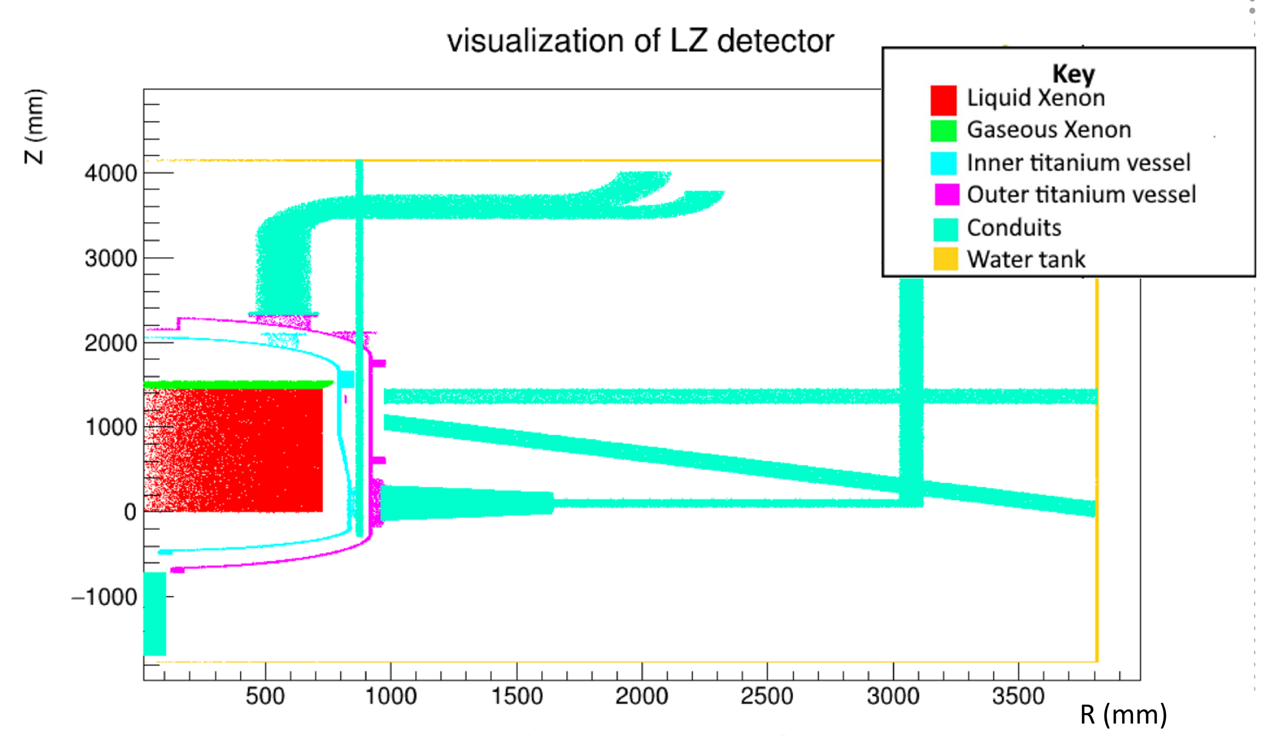


Figure 3: Visualization of LZ detector in Geant simulation

CAD MODEL OF TOP SHIELDING

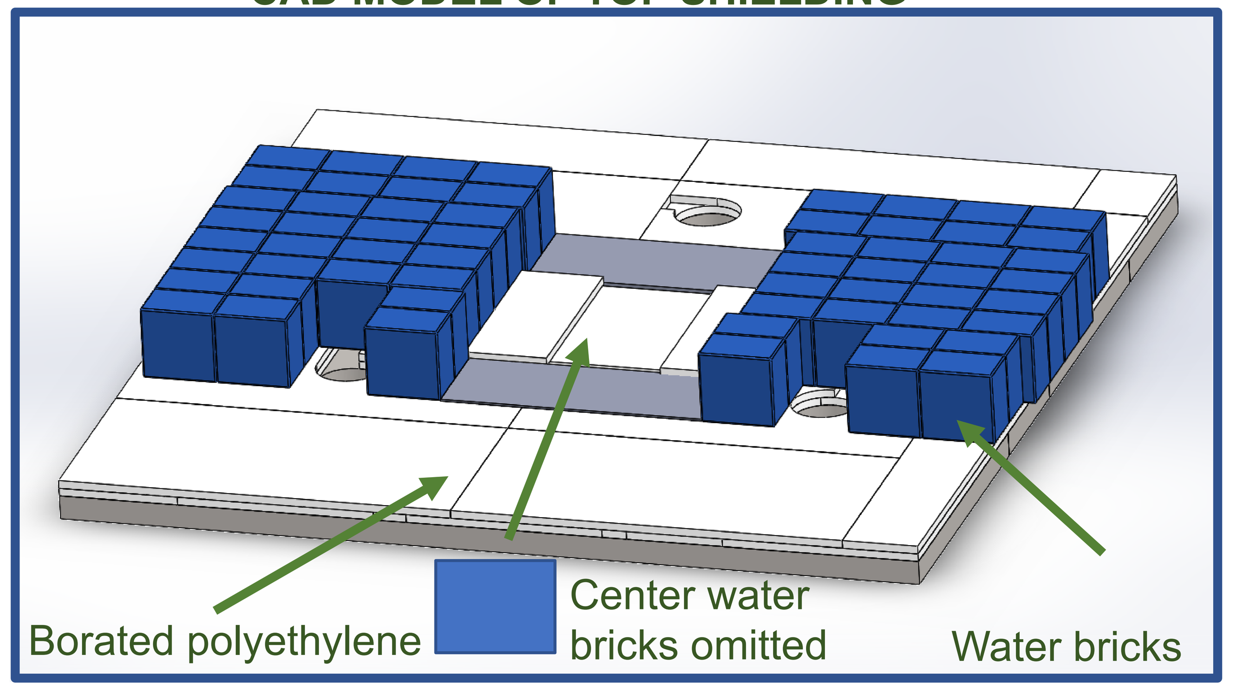


Figure 4: Visualization of top of water tank shielding

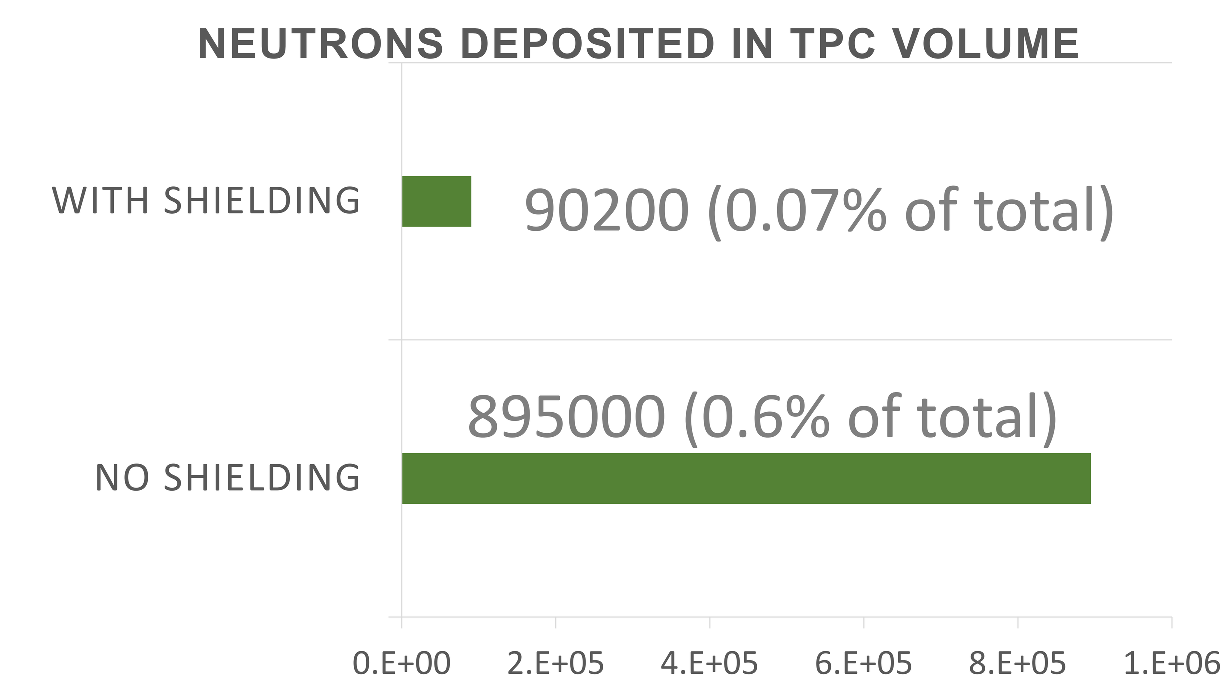
- In addition to the shielding in figure 4, we will also deploy shielding in the calibration tubes
  - "Neutron putty"
  - Shaped into a sausage and suspended by a string down the tube

Method: Assessing effectiveness

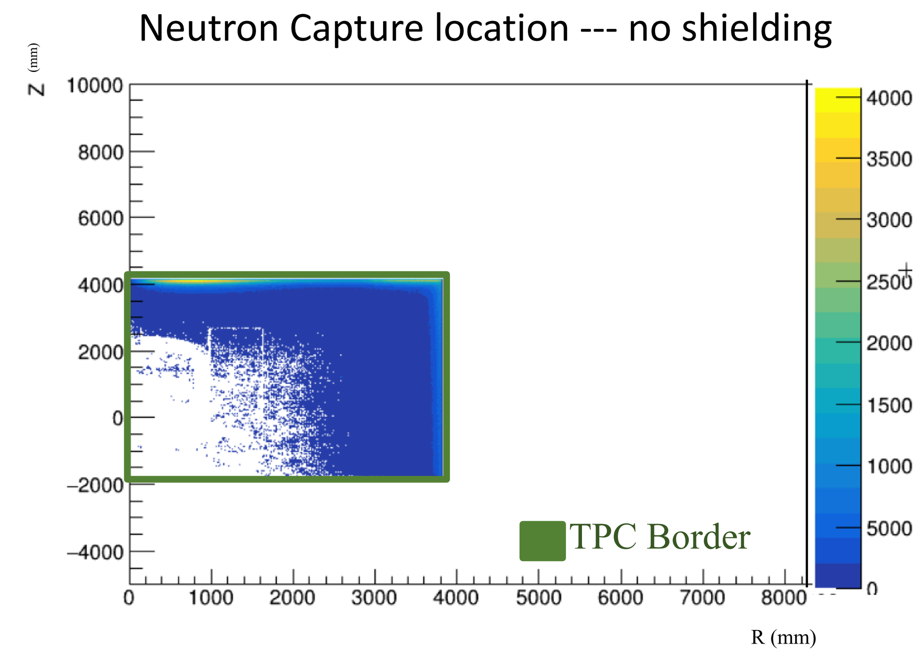
- Two ways to assess effectiveness
- Data-driven
  - Most accurate
  - Must install shielding
- Simulation (Geant4)
  - Quick and high-statistics
  - Easily changeable geometry
- We simulated a californium source with different shielding configurations while keeping all other variables constant to assess the effectiveness of the shielding.

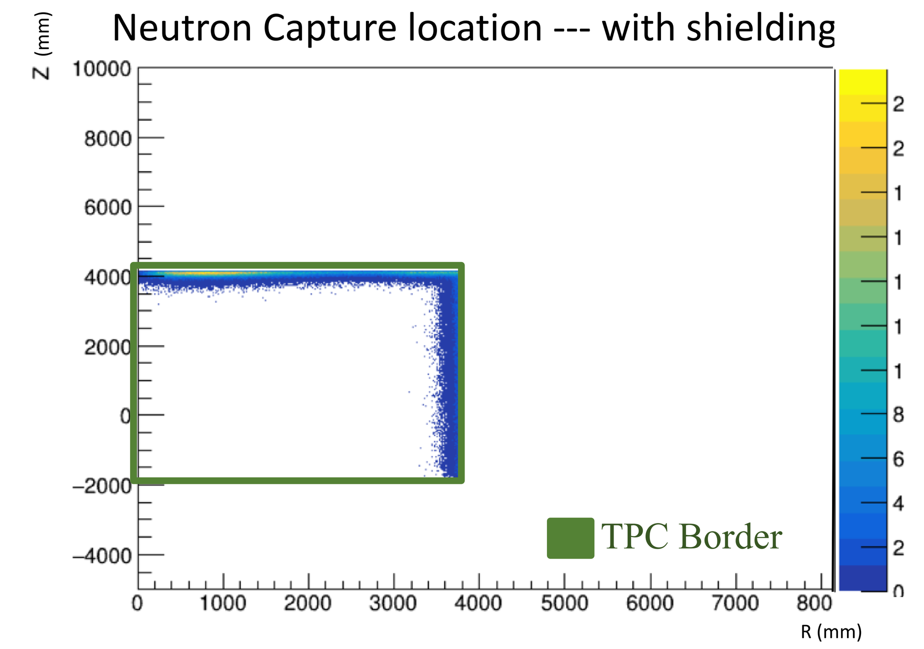
Results

- Simulation results indicate that neutron shielding on top of the water tank is very effective at reducing the number of neutrons entering the TPC and OD.



- This is a decrease of roughly 90%





- Data also show that neutrons that make it through the shielding are lower energy.
- Less Scattering inside TPC
- Captures closer to the edge of the TPC
- Means more space in the TPC is neutron free!

Limitations

- Simulation geometry has simplifications that make it not as accurate as real data
- Outer detector background is higher than expected during the design phase.
- Lack of space atop water tank

Conclusions

- Simulations indicate that Borated Polyethylene and Water Brick shielding on top of the LZ water tank will substantially reduce neutron flux in the outer detector.
- Lower flux mitigates neutron backgrounds in the TPC and increases sensitivity to WIMP interactions.
- Borated poly and water brick shielding may also be effective at other entry points
- Simulations show the effectiveness of shielding, which will be confirmed by data runs
- Potential entry points remain for future shielding
  - Bottom conduits
  - Insufficient bottom shielding

References & Acknowledgements

Egan, J. (2022, June). *Neutron Shielding For LZ. Neutron Excess Working Group.*

Nanografi-Blografi. (2019, November 15). *Graphene radiation shielding*. Medium. Retrieved July 22, 2022, from https://medium.com/@nanografi/graphene-radiation-shielding-c99ae7c68527

NASA. (2014, January 24). *WMAP- content of the universe*. NASA. Retrieved July 22, 2022, from https://wmap.gsfc.nasa.gov/universe/uni_matter.html

Shaw, S. (2021, June). *Neutron Excess in SR1. LZ Data Analysis / Veto Working Group.*

ShieldWerx. (n.d.). *SWX-261 neutron shielding*. Retrieved July 22, 2022, from https://shieldwerx.com/assets/SWX-261%202018.2.pdf

Stifter, K. (2n.d., June 11). *Instrumental backgrounds in the lux-ZEPLIN (LZ) dark matter detector*. INDICO. Retrieved July 22, 2022, from https://indico.fnal.gov/event/46286/contributions/201279/

This work was supported by NSF Award 2150517. Special thanks to: Dr. Brianna Mount, Charles Maupin, Geertje Heuermann, Joe Egan, Georgia McDowell, Reghan DeBoer, Lindsey Weeldreyer