SOUTH DAKOTA MINES
An engineering, science and technology university

# PNS: Status and Plan

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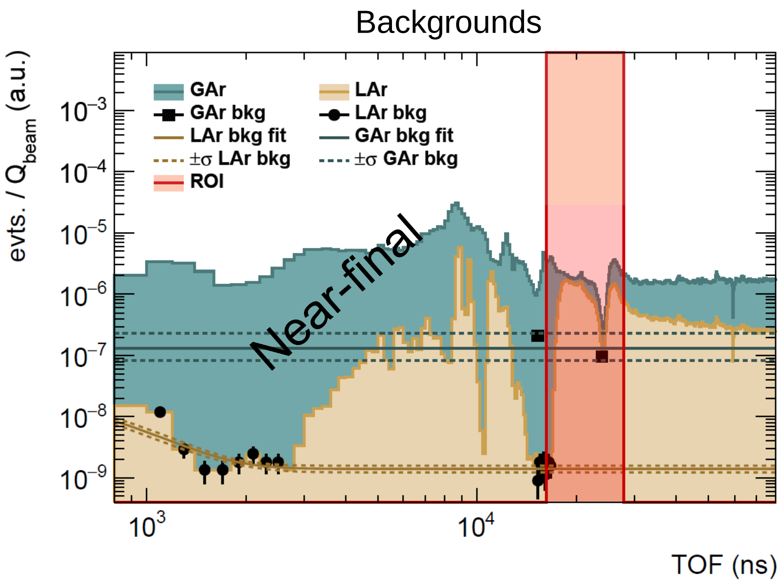
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

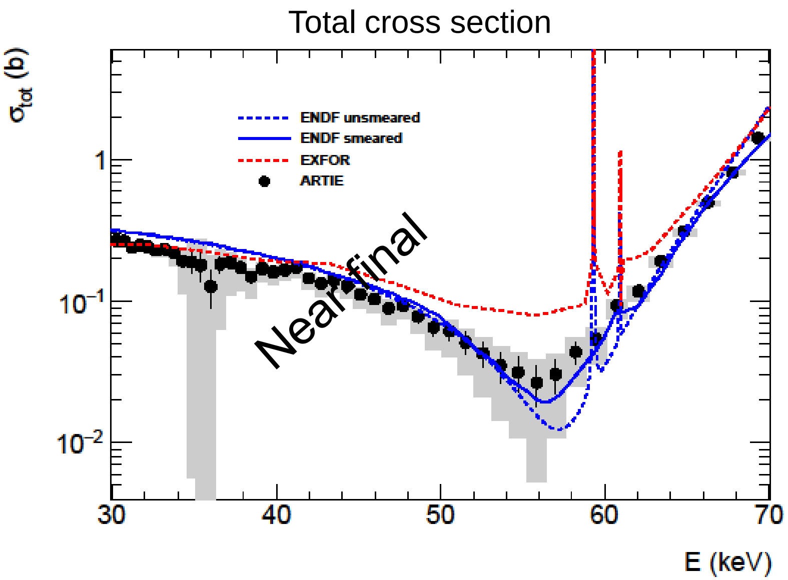
UCDAVIS UNIVERSITY OF CALIFORNIA

CALCI meeting, 06/17/2021

# ARTIE Result

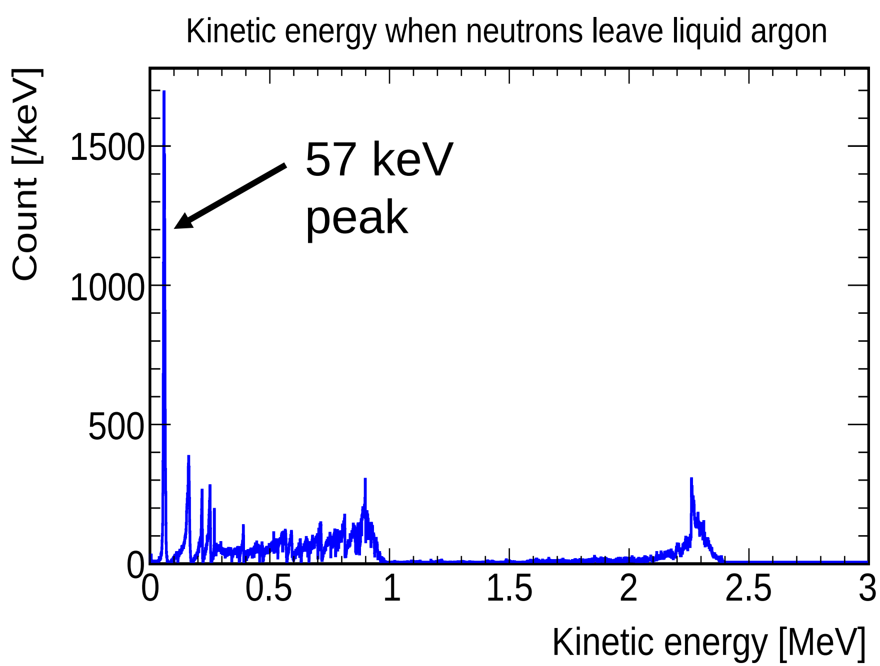
- Analysis is updated
  - The upper and lower bounds of the backgrounds are included as a part of the systematic error.
  - Data is compared with the smeared ENDF prediction (smeared by energy resolution)
- ARTIE result confirmed the ENDF anti-resonance at 57 keV

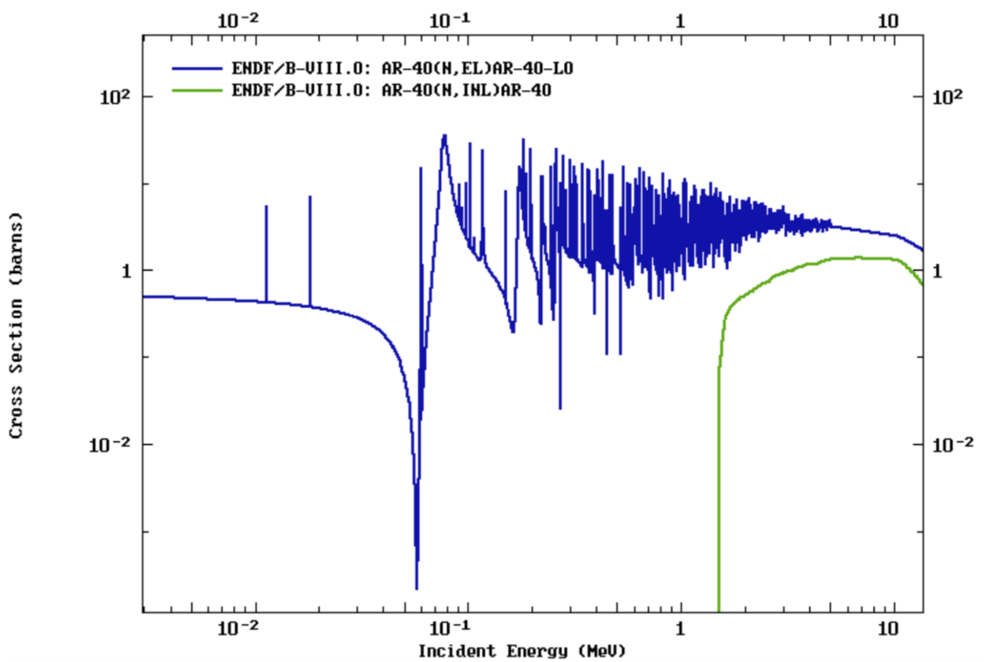


# Effect on PD-1 test

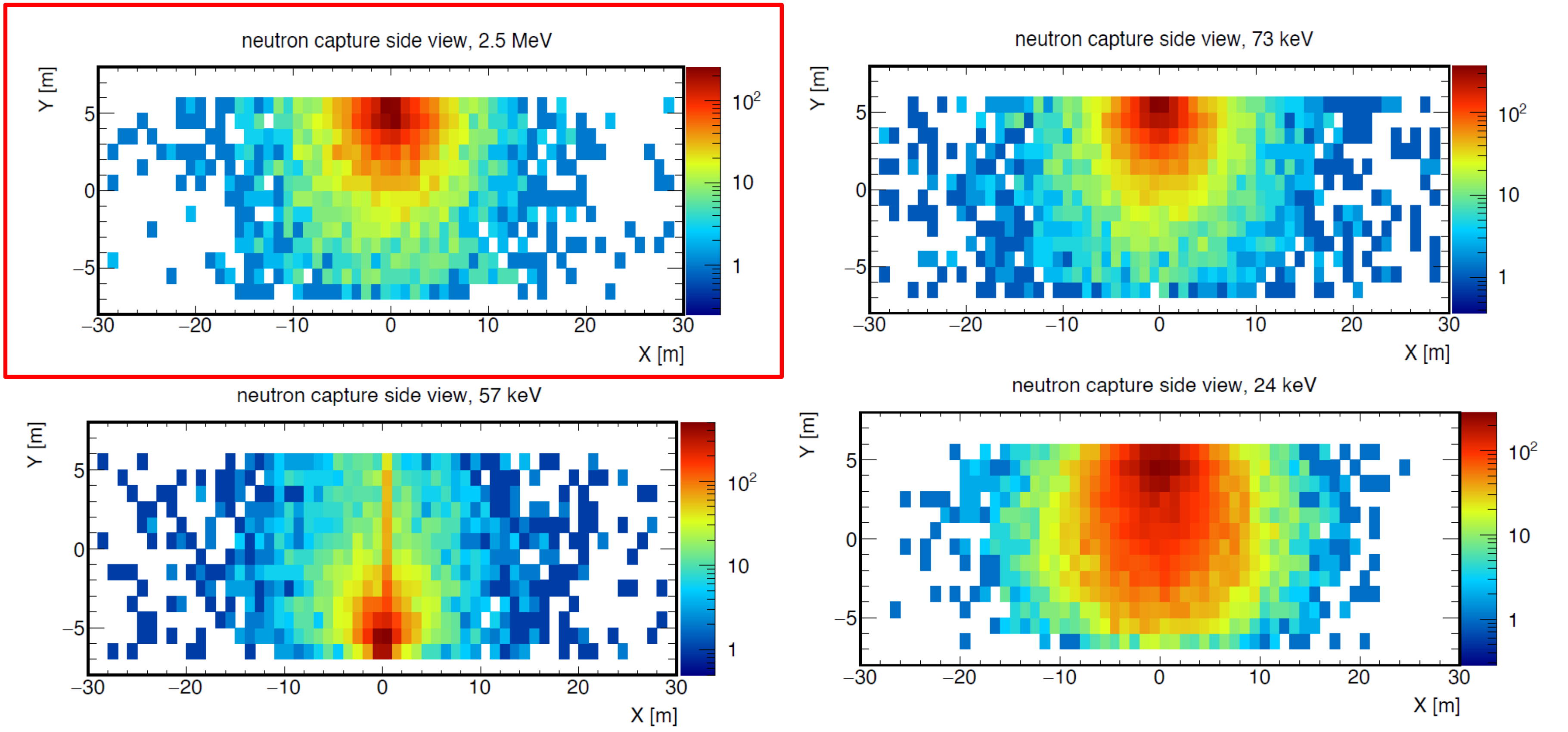
- In the infinite LAr volume, almost all the 2.5 MeV neutrons can fall into the 57keV antiresonance dip.
- In the DUNE-size LAr volume, about 85% of the neutrons leave the detector before falling down to 57 keV
- PD-1 test of 2.5 MeV neutrons is not so dependent on the 57 keV anti-resonance



# Neutron Spread Simulation

- Neutron transport in DUNE-size liquid argon volume was simulated for downward neutron beams with different energies
- keV neutrons are preferred as the spread is more uniform, but it's hard to make a moderator. PD-1 test was done with 2.5 MeV neutrons from a DD generator

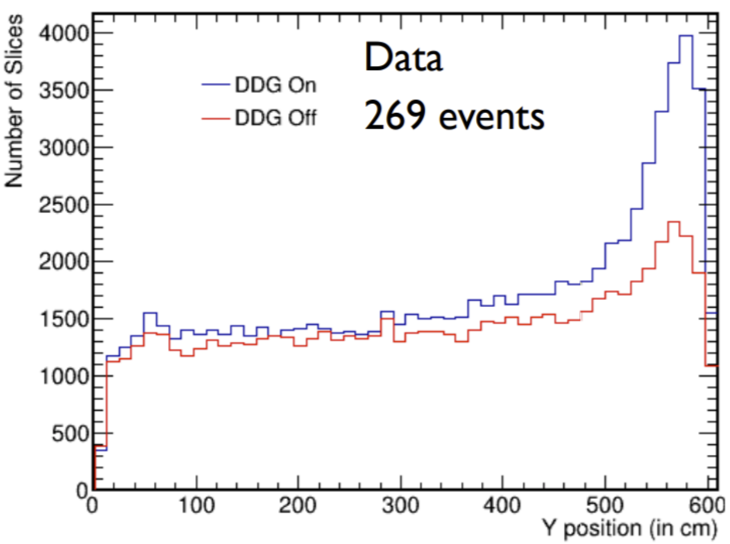


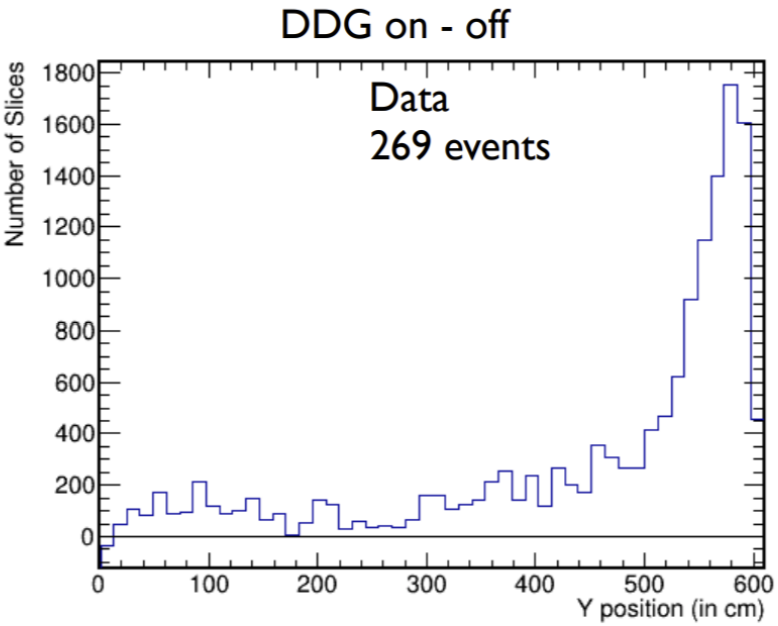
# PD-1 Run: Lessons Learned

- **The pulse rate of the LANL DD generator was too high**
  - The minimum pulsed rate of the generator was 250 Hz, well-above the rate that the DAQ system can handle. The 250 Hz pulses were rescaled to provide a 2 Hz trigger rate for the DAQ. There were many un-correlated neutrons coming from the following pulses after the trigger.
- **The neutron source suffered from high gamma contamination**
  - Due to the limited time and manpower, only pure polyethylene was used to shield the source (good for safety but not ideal for physics). There was no gamma shield, so the source was a combination of 2.5 MeV neutrons and 2.2 MeV gammas (from n-capture on H)
- **The neutron capture yield by the generator location**
  - Corner feedthrough (PD-1): neutron capture yield inside the active TPC is 0.11%
  - Beam plug (preferred for PD-2): neutron capture yield inside the active TPC is 0.37%

# PD-1 Analysis

- Analysis confirmed the presence of neutrons inside the liquid argon TPC.
- We obtained reasonable MC-data agreement (see talks in the May collaboration meeting for more details)
- Identifying single neutron capture is challenging due to the cosmic ray background




(Yash)

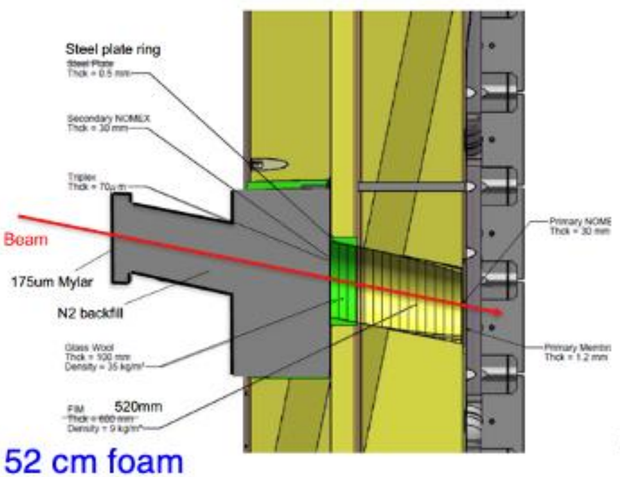
# PD-2 Planning

- The LANL DD generator will be shipped to SD Mines. We expect to receive it in July
- The LANL DD generator will be modified for PD-2 test.
  - Detach the electronics box from the generator tube.
  - Upgrade the firmware to allow external triggering with 1 Hz rate.
  - HV cables needs to be replaced for external pulsing mode
- The Pulsed Neutron Source in PD-2 will be fully shielded
  - DD generator with remote configuration
  - Borated polyethylene for neutron shield, lead for gamma shield
- Plan to use the beam plug and the manhole locations
  - Need to identify engineering constraints.

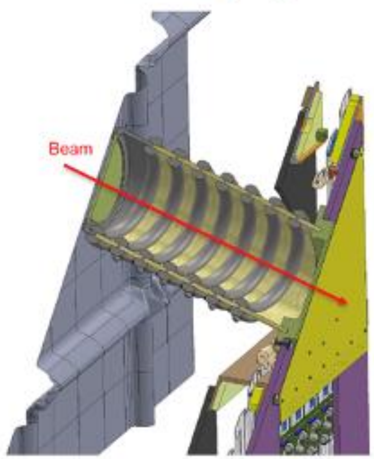
# PD-2 ports to be considered

- Regular calibration/cryostat port (as in PD-1). MC simulation shows a 0.11% capture yield inside the active TPC volume
- Beam plug location. The N2 backfill will be removed and the DDG will be placed next to the glass wood (green). MC simulation shows a 0.37% capture yield inside the active TPC volume
- Inside human access hole (manhole). DDG cannot work at temperature below -20 F, so a cupped support interface is necessary. 2.2% capture yield is expected
- Above human access hole. 0.44% capture yield is expected

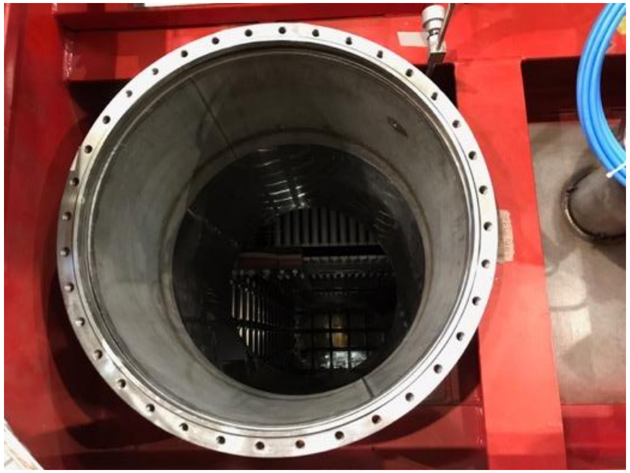
cryostat penetration




Beam plug




Manhole

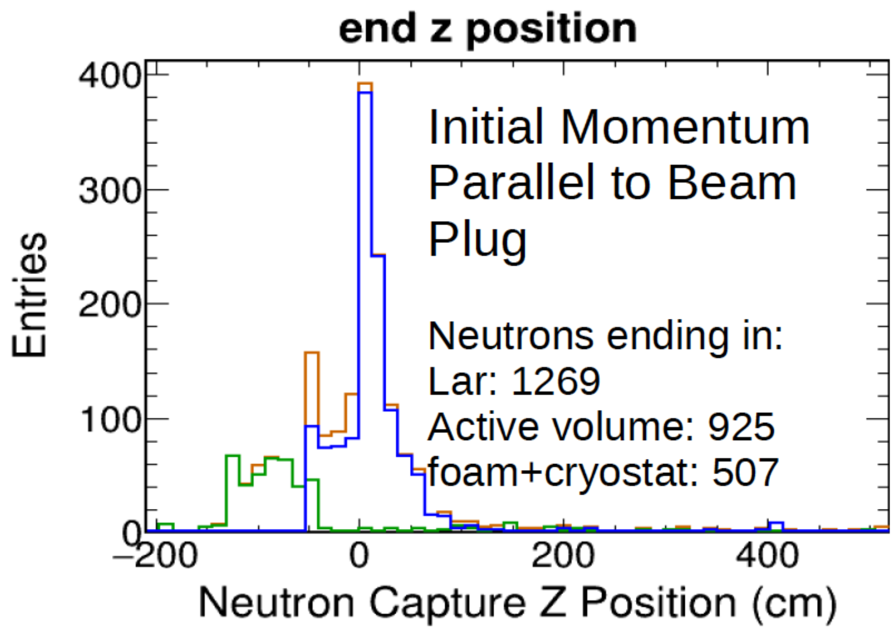


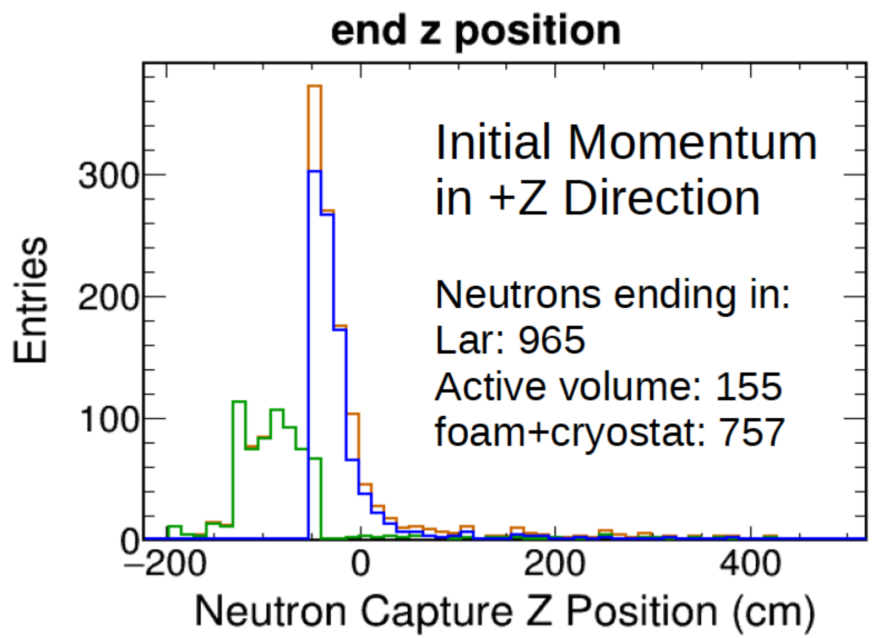
# LArSoft simulation

- Neutron cross sections used in the g4 stage come from ENDF-VIII.0 NeutronHP libraries.
- Neutrons are produced monoenergetically at 2.5 MeV
- Neutrons' initial position is in front of the beam window foam. ($x_0$ = -5.8, $y_0$= 446.6, $z_0$ = -128) cm
- Two neutron directions are simulated:
  - Neutrons' initial momenta is parallel to beam plug's long axis. Neutrons go through the beam plug to reach the active liquid argon volume inside the field cage.
  - Neutrons' initial momenta is parallel to z coordinate. Neutrons travel out of beam plug, and first reach the inactive liquid argon volume between the cryostat wall and the filed cage.
- Simulations are done with protodune_v7.gdml geometry

# 2.5 MeV neutron beam

Logan Rice (University of Pittsburgh)




How far do the neutrons go in the beam direction?

Neutron's whose end process is inelastic scattering (or capture) in foam insulation or cryostat steel
Neutron's whose end process is capture (or inelastic scattering in liquid argon)
All neutron's ending position for all processes in all materials.

# Hardware Status

- We expect to receive the LANL DD generator in summer
- Jingbo has received most of the required equipment for testing a DD generator
  - Borated Polythylene neutron shield
  - Lead neutron reflector and shield
  - Neutron/gamma dose rate monitor
  - Programable USB-driven pulsed generator
  - Extension HV cables for DD generator (quoted)
- Laboratory space at SD Mines will be renovated, and a radiation safety review is needed before we test the DDG.


BNC Pulse generator

SN-D-2 on tripod

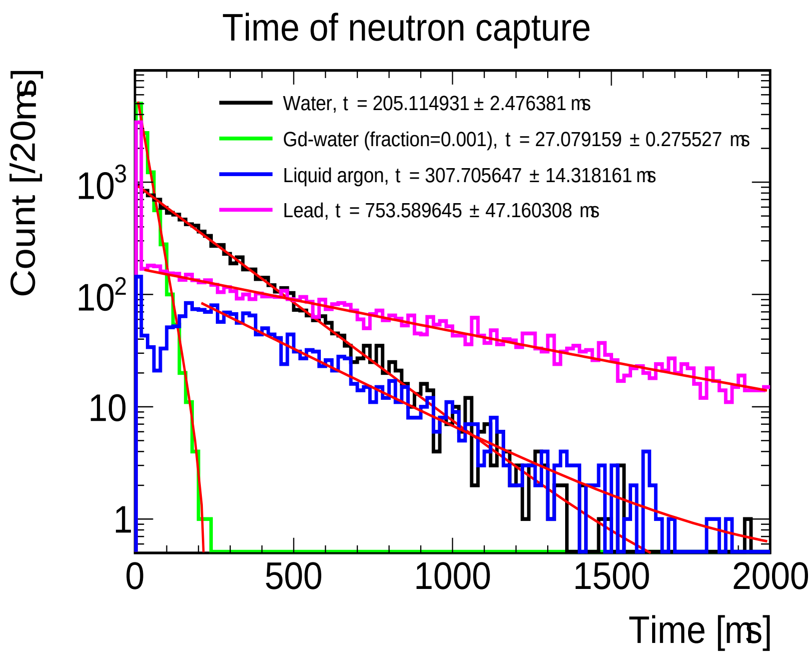
SN-D-2™ *Neutron Dose Probe*

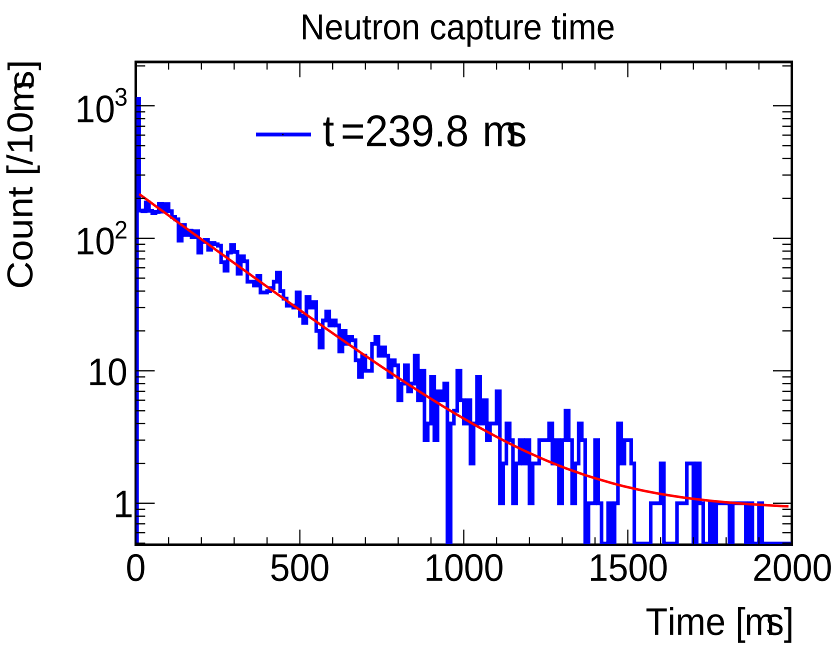
# Next steps

- Complete PD-1 analysis and write a technical report
- Compare different source locations with LArSoft Simulation and develop a test strategy.
- Study the background effect and develop a neutron capture identification algorithm.
- Study ways to moderate the neutrons
- Assemble the Pulsed Neutron source at SD Mines

# Other Possible Test

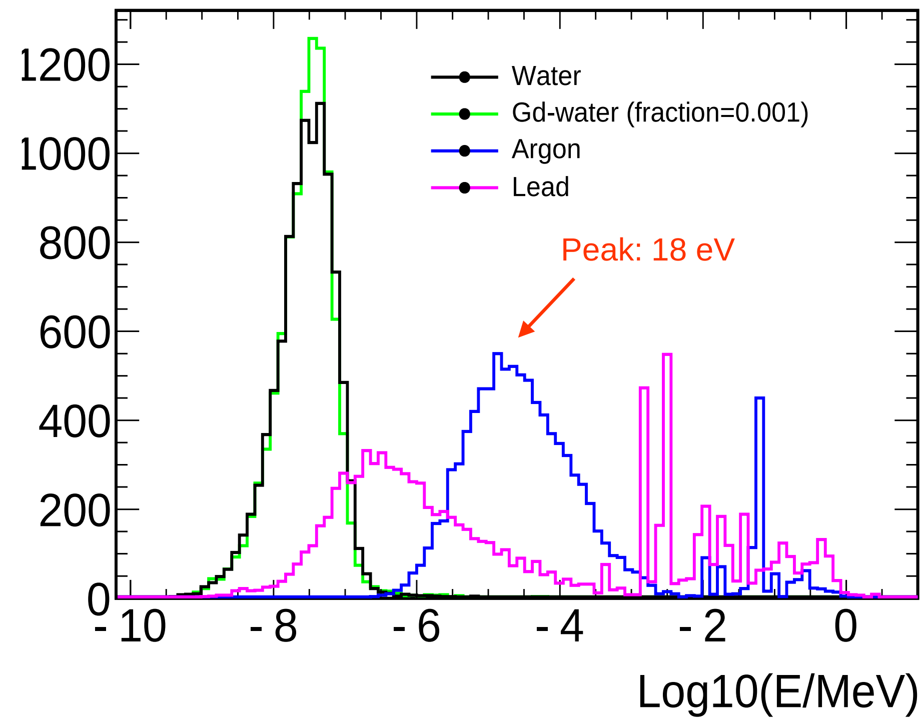
- Left: near-infinite liquid argon volume. 2.5 MeV neutrons generated in the middle. The neutron capture time constant is 307 $\mu s$
- Right: DUNE-size liquid argon volume. 2.5 MeV neutrons injected from the top. The neutron capture time constant is 240 $\mu s$. There is a bias coming from the selection of neutron capture inside the liquid argon volume. Neutrons with longer slowing-down time tend to escape the detector.



# Energy of Captured Neutron

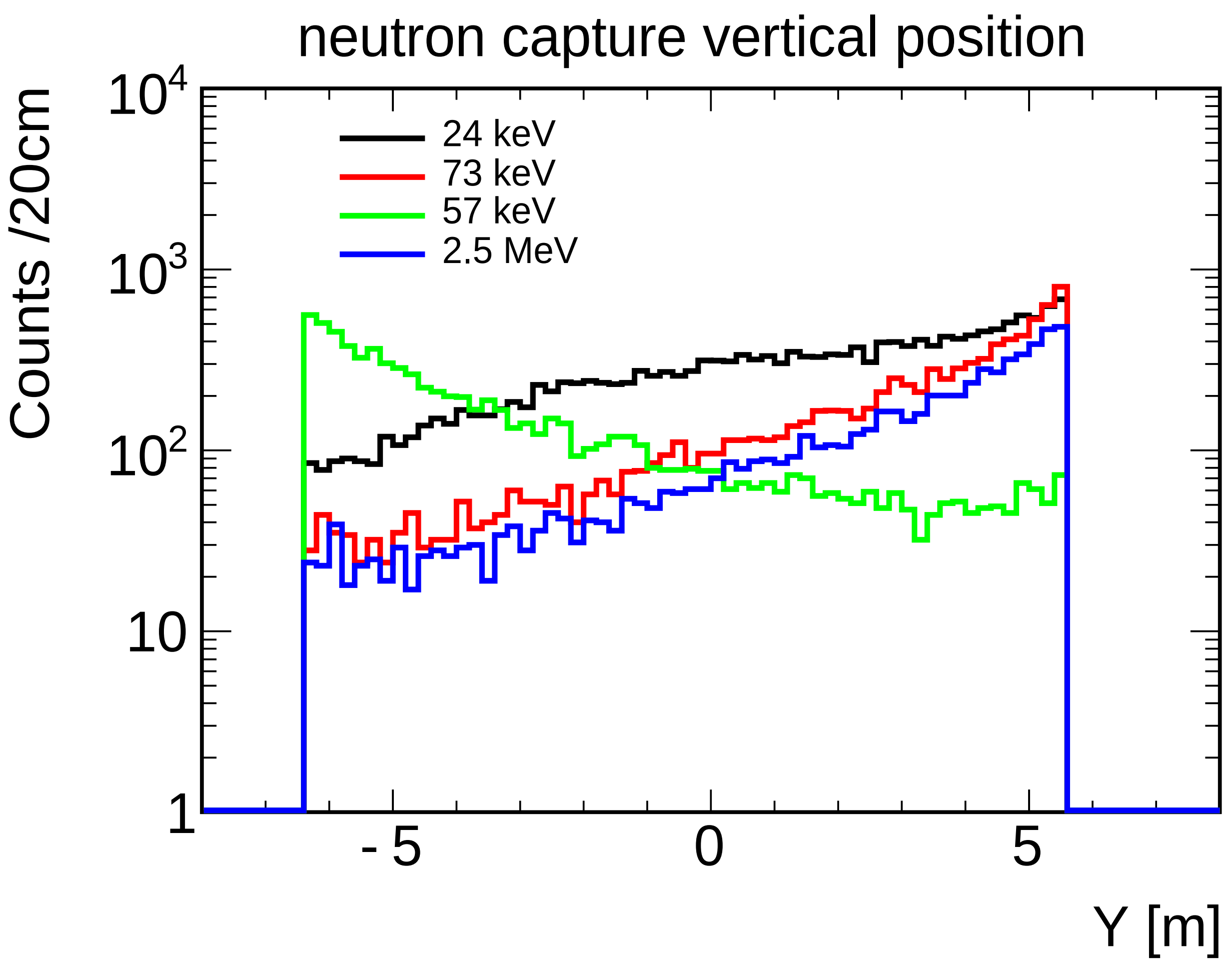
- Problem: the neutrons in liquid argon is not fully thermalized when they are captured. The average capture energy is 18 eV. Is this true?
- This can be studied by measuring the neutron capture time in liquid argon.



# Backup

# Neutron transport depth

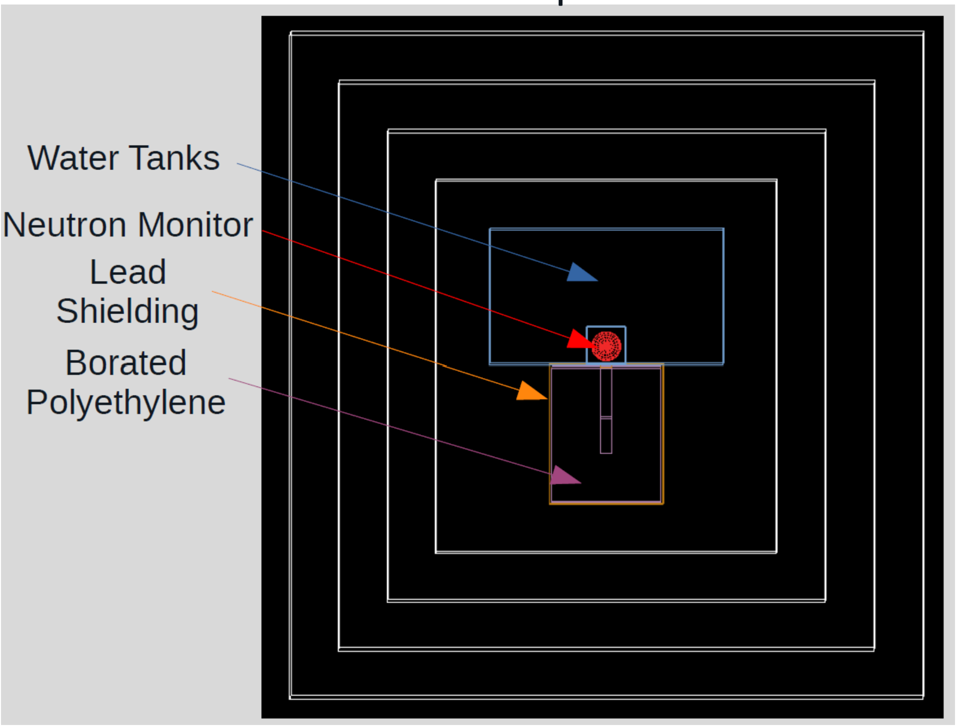
- Y position of neutron captures

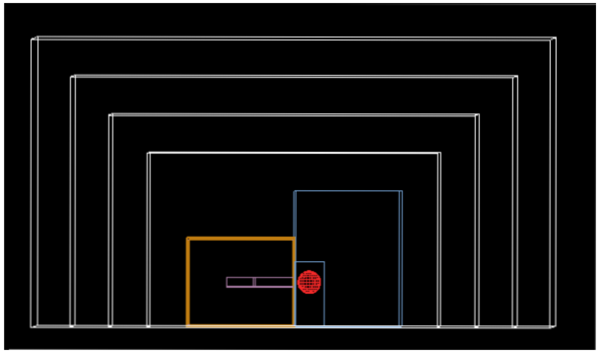


# Tentative Shielding Design

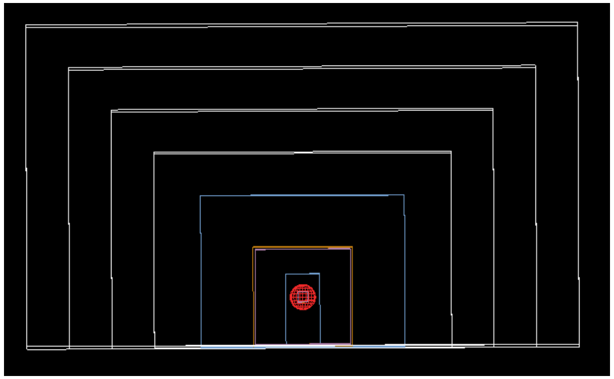
- The goal is to reduce the neutron/gamma dose rates below the allowed limits
- 40 cm borated polyethylene and 5 cm lead will be used to shield the DD generator
- The neutron rates are measured by a He-3 based  monitor.
- Extra shield for the neutron monitor is provided by 1 m water

Top View



Side View



Front View