Pulsed Neutron Source: Summary and Plans

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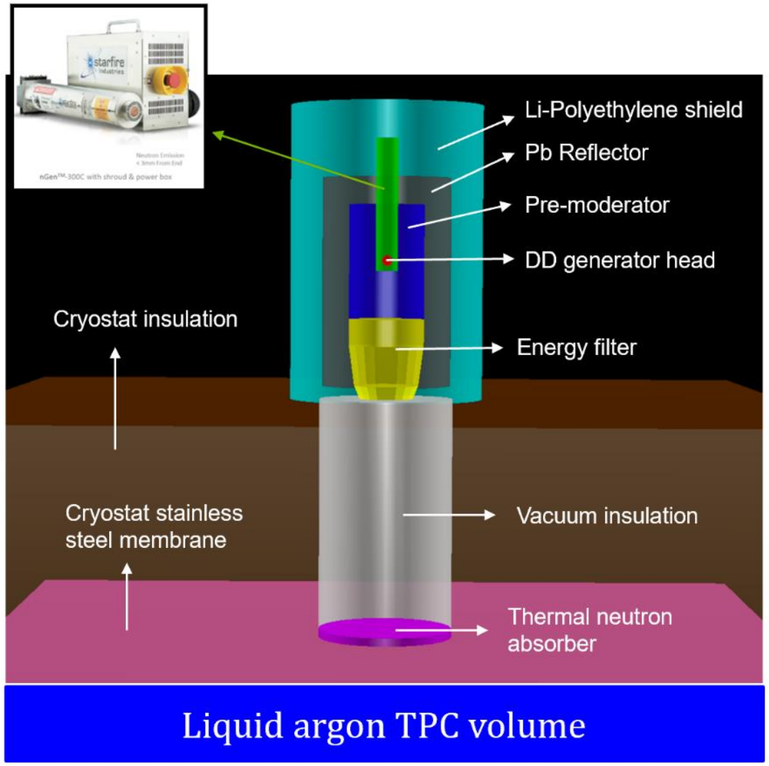
SOUTH DAKOTA MINES
An engineering, science and technology university

DUNE
DEEP UNDERGROUND NEUTRINO EXPERIMENT

UCDAVIS
UNIVERSITY OF CALIFORNIA

PNS for Calibration

- Neutrons can travel long distances in liquid argon
  - Fractional energy loss per scatter is only 4.8%
  - ~30m scattering length at 57 keV anti-resonance
- Neutron captures on ^{40}Ar (99.6%) release 6.1 MeV gamma cascade



$n + {}^{40}Ar = {}^{41}Ar + 6.1\ MeV$

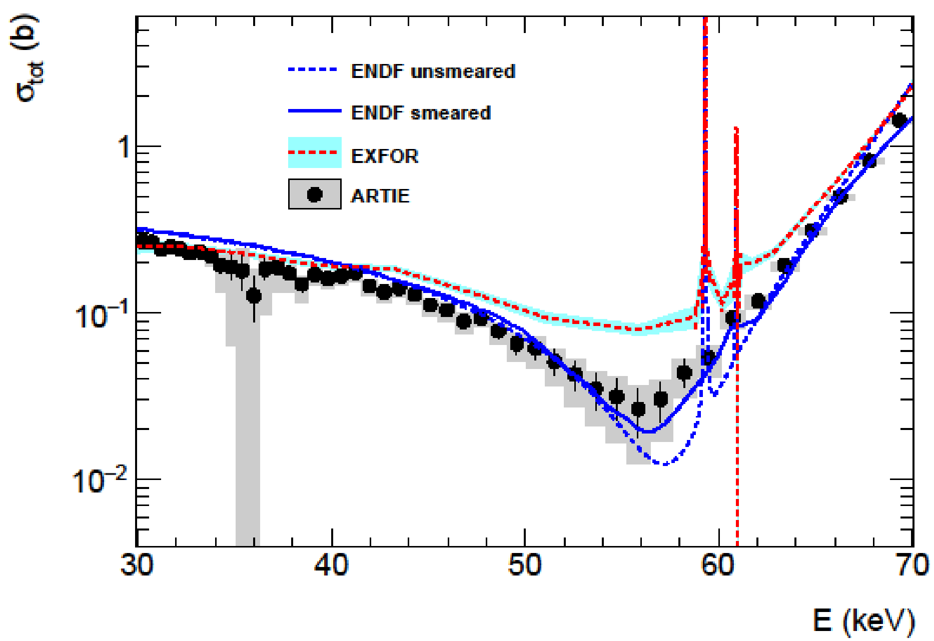
- External deployment: no need to open the cryostat
- Wide coverage: one external source covers 1/3 of the DUNE far detector module
- Adjustable neutron yield, pulse width and rate
- Frequent calibration runs allowed

Verification of 57 keV anti-resonance

- The depth of the 57 keV anti-resonance was identified as a risk in the TDR
- Argon Resonant Transport Interaction Experiment (ARTIE) measured the neutron total cross-section around 57 keV at LANL, which has verified the existence of the anti-resonance.
- Completed analysis of systematic uncertainties, and paper is in publishable format.

ARTIE liquid argon target setup

ARTIE preliminary



First Test of DDG at PD-I

- Main goal: verify the neutron transport model and develop analysis algorithms
- Test setup: DD generator deployed on top of the feedthrough port
- Data taking: over 10 days with different trigger modes and neutron intensities
- Neutron source and its deployment location were not ideal due to limited time and technical issues. Expect to improve in PD-II.

The deployment location and the shield were not ideal, but this was the only chance before the detector shutdown

PNS Grp: UCDavis, LANL + CERN

Done in 2020 by M. Fani (LANL) and F. Pietropaolo (CERN)

PD-I Analysis Result

- Data/MC comparison:
  - Performed a χ^2 minimization to LArsoft simulation after background subtraction

$$\chi^2 = \sum_i \frac{\left[\left(D_{on,i} - D_{off,i}\right) - \beta\left(MC_{on,i} - MC_{off,i}\right)\right]^2}{D_{on,i} - D_{off,i}}$$

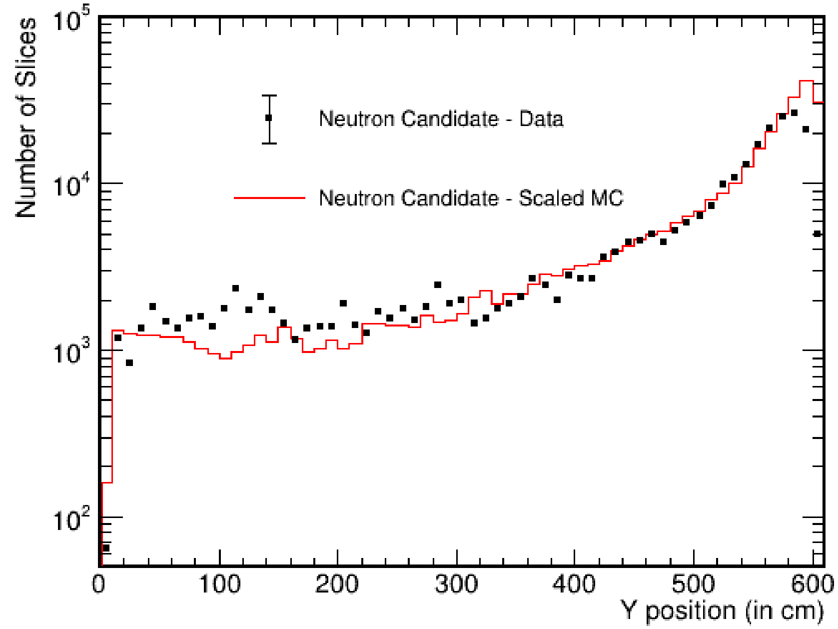
$D_{on,i}$: DDG On data

$D_{\mathrm{off},i}$: DDG Off data

$MC_{on,i}$: DDG On Simulation

$MC_{\mathrm{off},i}$: DDG Off Simulation

Vertical distribution of neutron candidate slices



- Findings:
  - Good overall agreement in vertical position distribution
  - MC simulation result needs to be scaled down to match data (β=0.74)
  - Observed possible inefficiency in data close to the top of the detector
  - Observed an excess of neutron candidates at the bottom of the detector

Work done by Y. Bezawada and J. Huang (UC Davis), See J.Huang's talk today

- Also see the machine-learning-based analysis result (done by L. Uboldi and P. Sala, CERN)

Lessons Learned from PD-I

- **DD generator pulse rate was too high for DAQ**
  - The minimum pulse rate of the generator was 250 Hz, well-above the rate that the DAQ system can handle. The 250 Hz rate was rescaled to selected several pulses per second to trigger the DAQ. All the remaining pulses were present as background
- **Capture signals were contaminated by external gammas**
  - Neutron shield was provided by polyethylene no gamma shield. The observed signals in the TPC was contaminated by 2.2 MeV external gammas (mostly from n-capture on the shield)
- **Capture yield was limited by nonideal deployment location**
  - Corner feedthrough (PD-1): footprint was close to the edge of the active TPC. neutron capture yield inside the active TPC is 0.11%

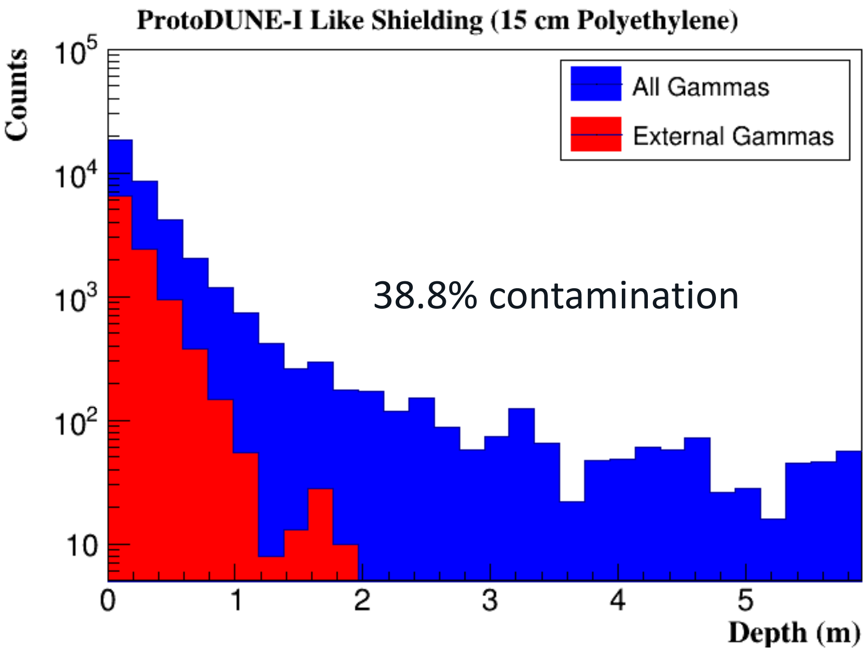
PD-II Plans

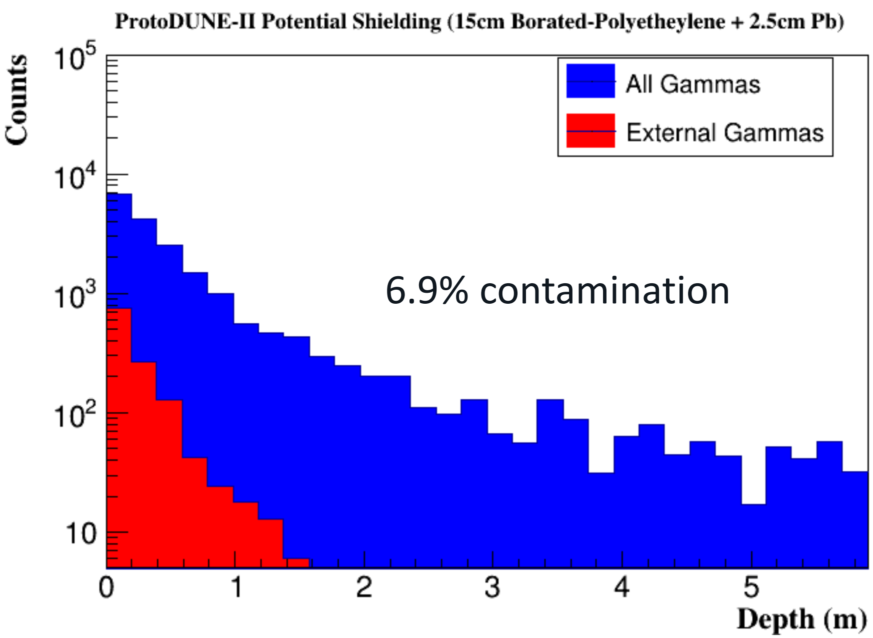
- Main goal: make improvements to acquire high quality data that allows looking for individual neutron captures for energy calibration
- Modify the LANL DD generator
  - Detach the electronics box to allow more space for moderator optimization
  - Upgrade the firmware to reduce the minimum pulse rate from 250 Hz to 1 Hz
- Improve the shielding configuration
  - Use borated polyethene for more efficient neutron shield
  - Use lead shield to reduce external gamma contamination
- Test at better deployment locations
  - Need to identify engineering constraints.
- **The LANL DD generator will arrive at SD Mines this week**. A full PNS prototype will be assembled and tested

Neutron Source Shielding

- Simulation was done for PD-I shielding and the planned PD-II shielding
  - PD-I: 15 cm pure Polyethylene
  - PD-II: 15 cm Borated-Polyetheylene + 2.5 cm Pb
- Contamination from external gammas is reduced from 38.8% to 6.9%

Hit candidates produced by neutron capture gammas on all materials

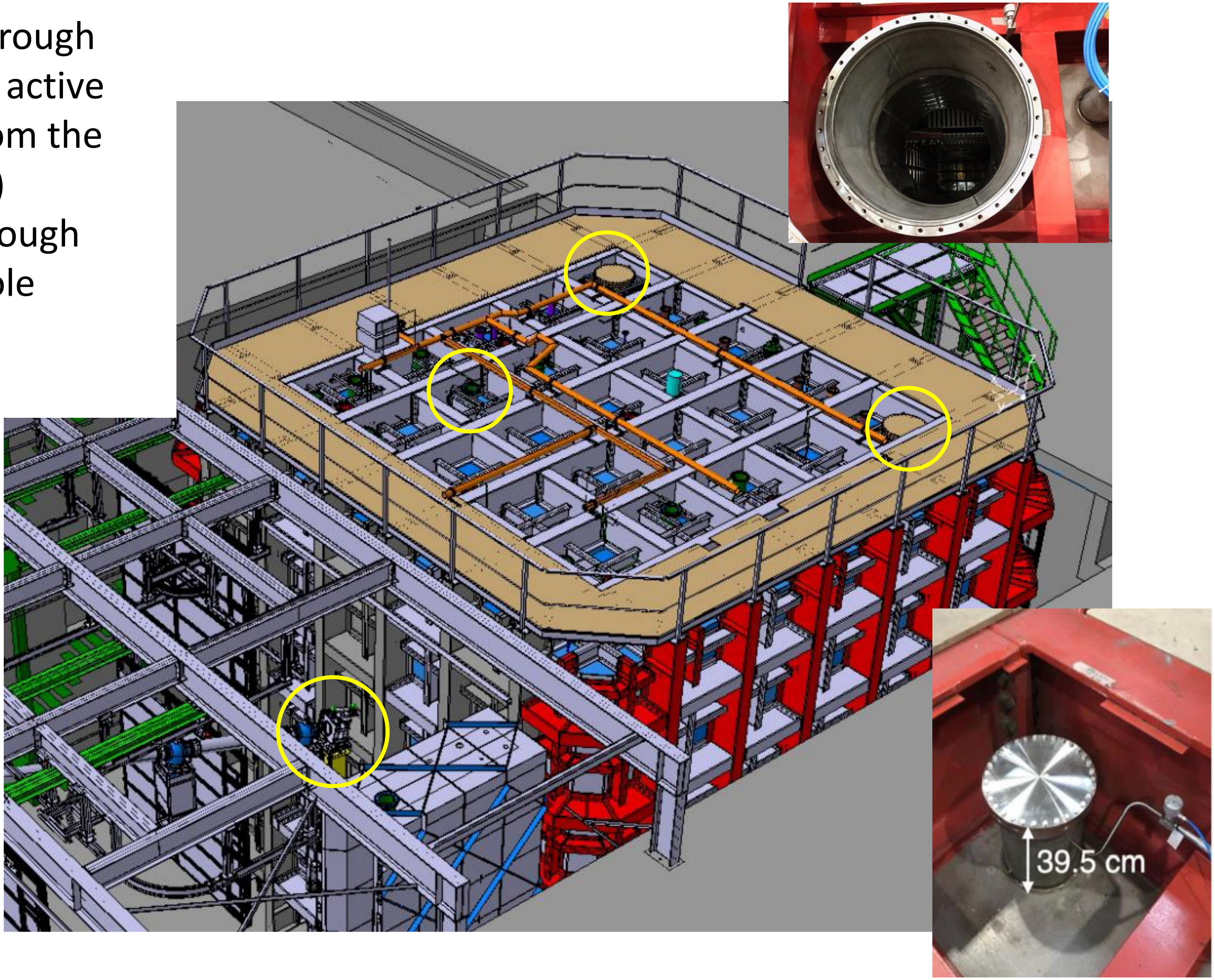




Work done by W.Johnson (SD Mines)

Possible Source Locations

1. On top of feedthrough (footprint within active TPC, different from the one used in PD-I)
2. Inside of feedthrough
3. On top of manhole
4. Inside manhole
5. Beam plug

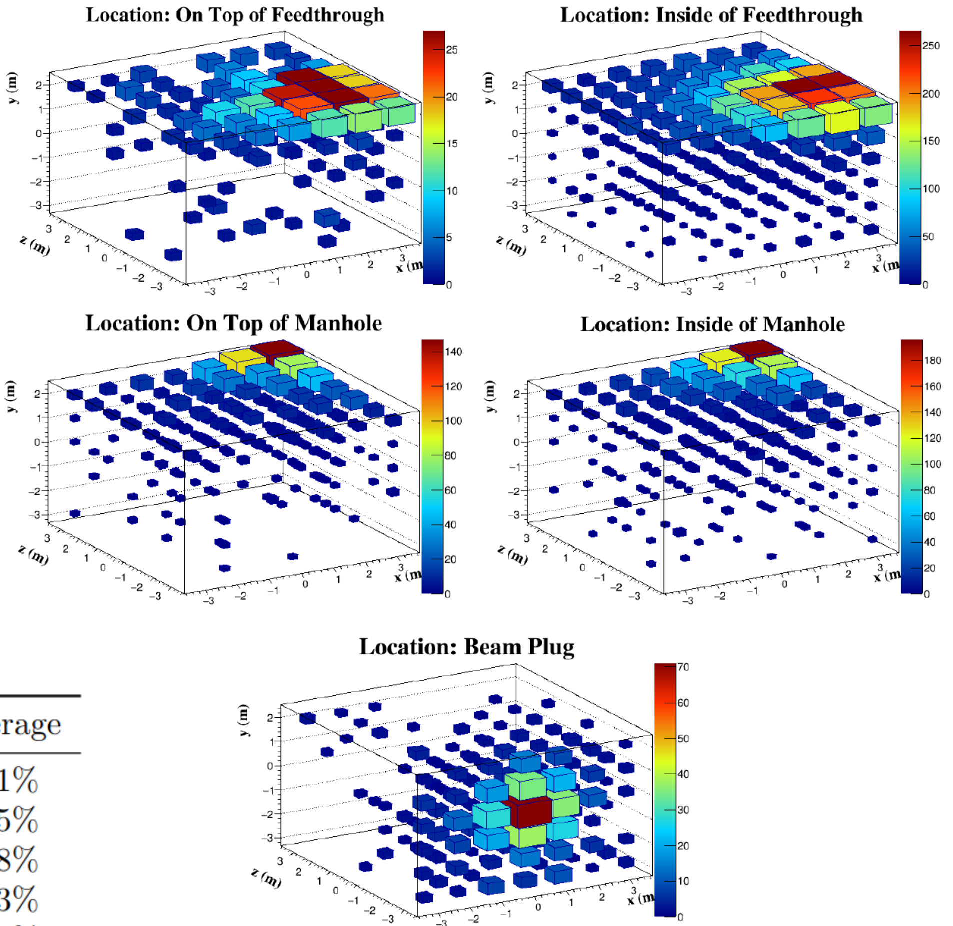


Simulations of Different Ports

- Simulated 10^5 DD neutrons for each port location
- Neutron capture yield is significantly improved compared to the 0.11% yield in PD-I

Location	Capture Yield
On Top of Feedthrough	0.470%
Inside of Feedthrough	5.217%
On Top of Manhole	1.065%
Inside of Manhole	1.560%
Beamplug	0.675%

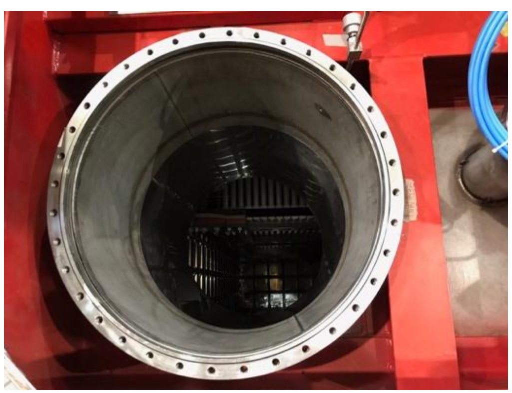
Location	Voxels With Captures	Coverage
On Top of Feedthrough	106	36.1%
Inside of Feedthrough	269	91.5%
On Top of Manhole	161	54.8%
Inside of Manhole	186	63.3%
Beamplug	150	51.0%



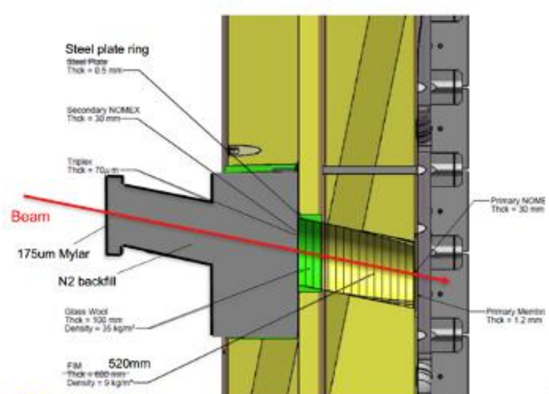
Preferred Ports in PD-II

- Plan is to do the manhole test during PD-II and the beam plug test before shutdown
- Preferred: On top of Manhole (X17 of PD-I)
  - Baseline TDR design, no need to open the cryostat; no interference with other systems
  - Expect 1.7% neutron capture yield
- Preferred: Beam plug location (X6 of PD-I)
  - A possible solution for vertical drift module, no need to open the cryostat;
  - The nitrogen backfill will be removed, and the DDG will be placed next to the glass wood (green).
  - Test will affect other systems, but can be done after the beam run
- Under study: Inside manhole or feedthrough

Manhole

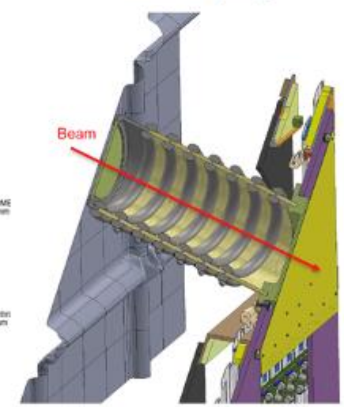


cryostat penetration



52 cm foam

Beam plug



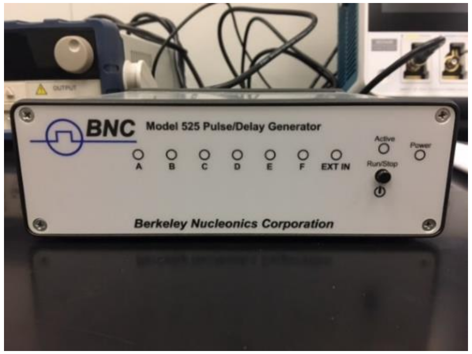
Lab Space at SD Mines

Equipment Needed for PD-II

LANL DD generator **Will arrive this week!**

Extension cables

BNC Pulse generator



SN-D-2™ Neutron Dose Probe

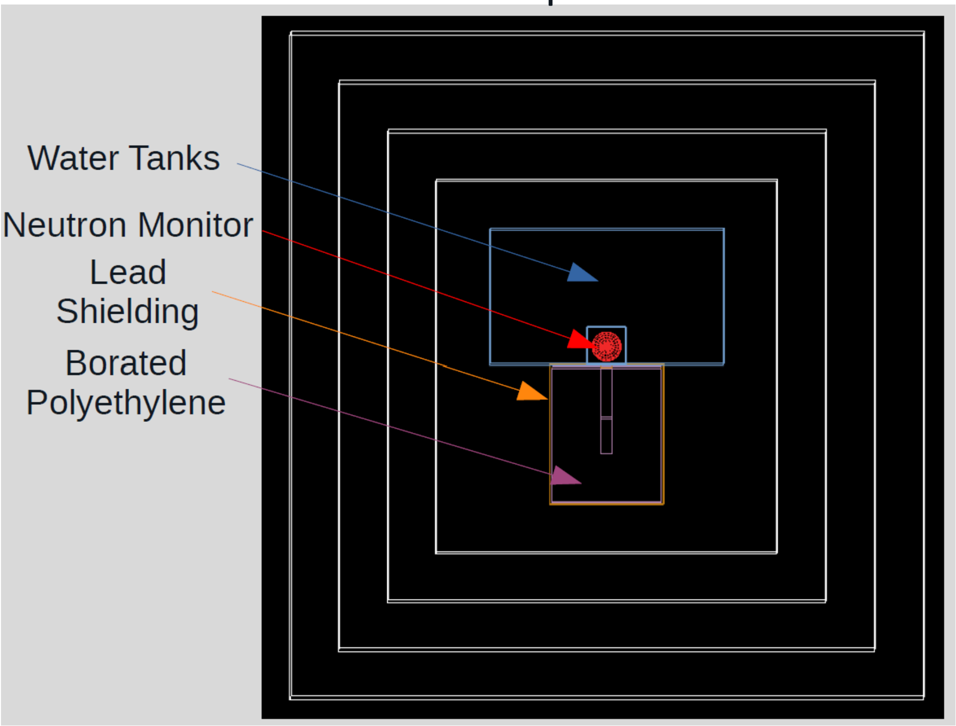
Lead bricks

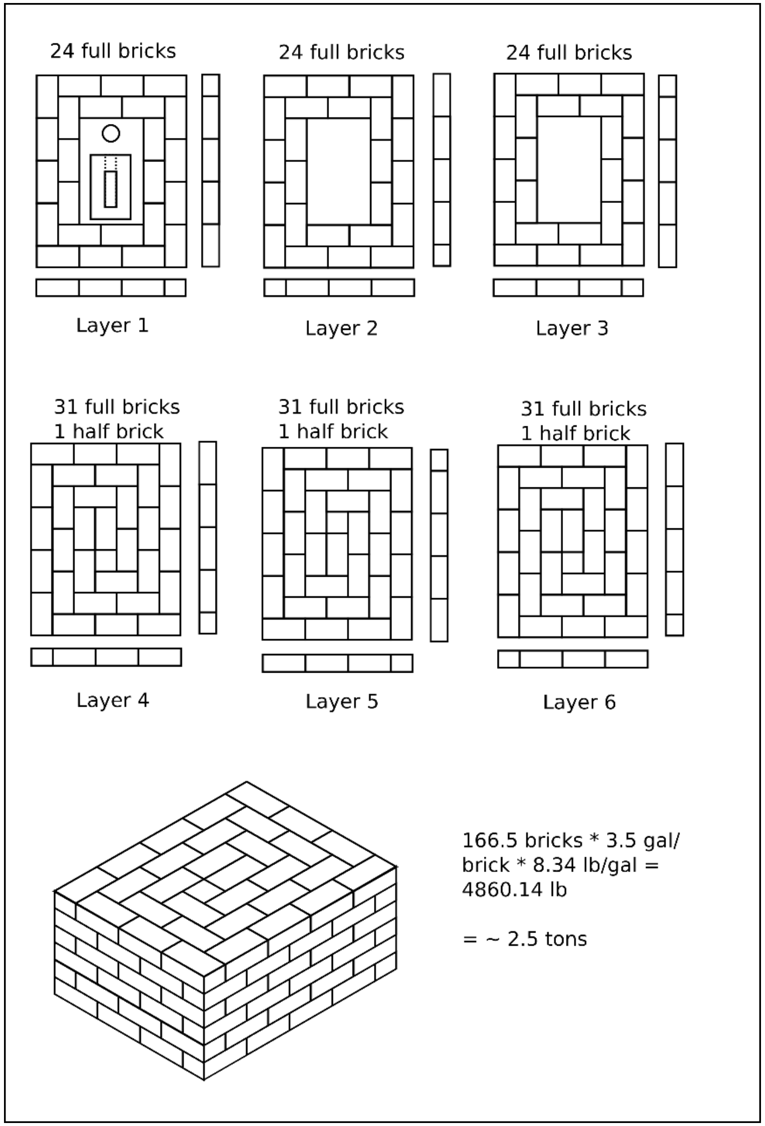
Borated Polyethylene

Tentative Shielding

- Shield design is driven by simulation
- Inner shield provided is by 40 cm borated polyethylene and 5 cm lead
- Outer shield for the neutron source and monitor is provided by 40 cm water

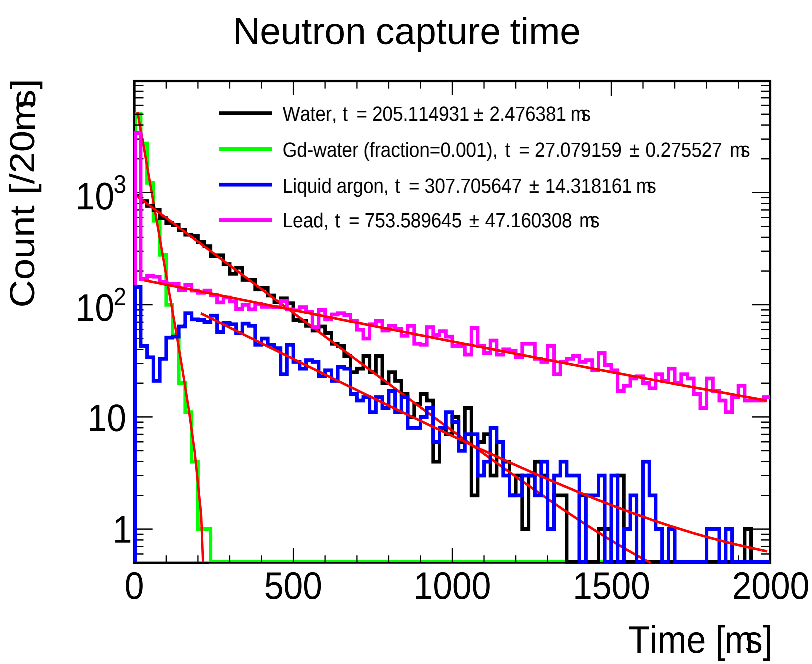
Top View

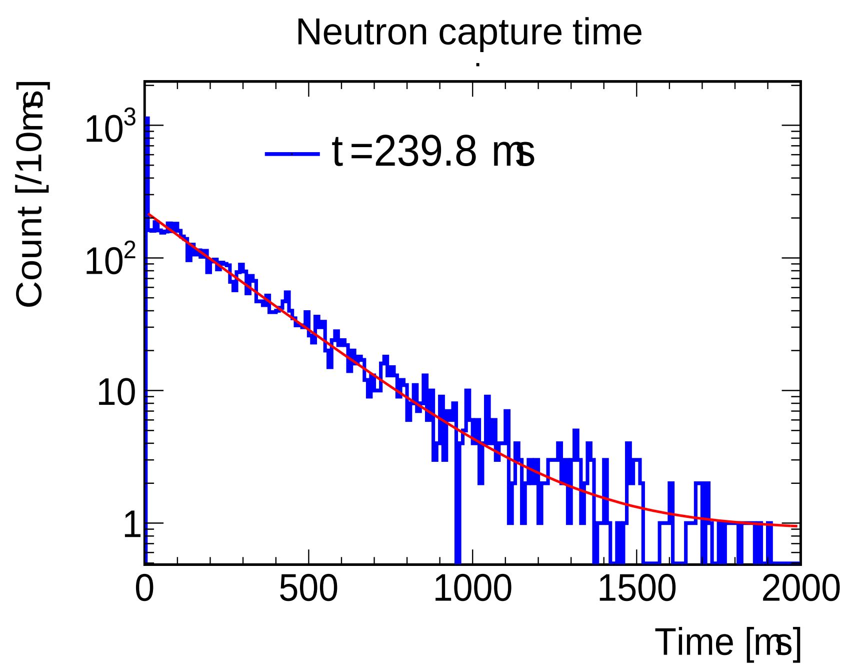




Other Possible Test at PD-II

- The simulated neutron capture time is shorter than the analytical calculation that suggests millisecond level
- Left: near-infinite liquid argon volume. 2.5 MeV neutrons generated in the middle. The neutron capture time constant is 307 μs
- Right: DUNE-size liquid argon volume. 2.5 MeV neutrons injected from the top. The neutron capture time constant is 240 μs.

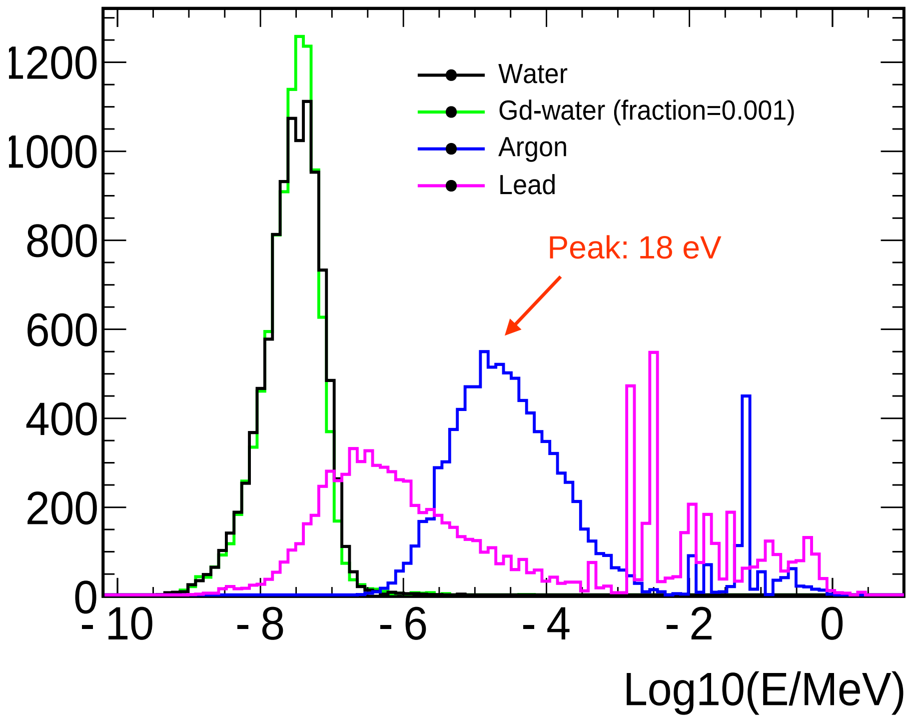




Work done by J. Wang (SD Mines)

Energy of Captured Neutron

- Finding: the neutrons in liquid argon does not need to be fully thermalized before capture. The average capture energy is 18 eV. Is this true?
- The neutron capture time in liquid argon was never measured before.
- Measurement of neutron capture time could be done with ProtoDUNE detector.

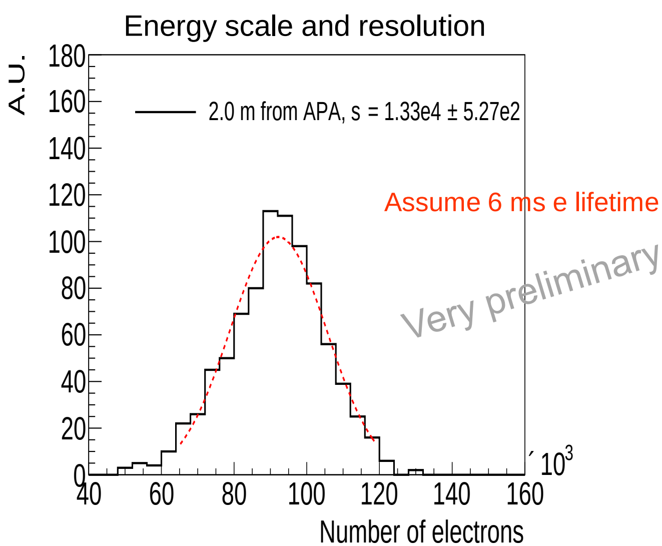


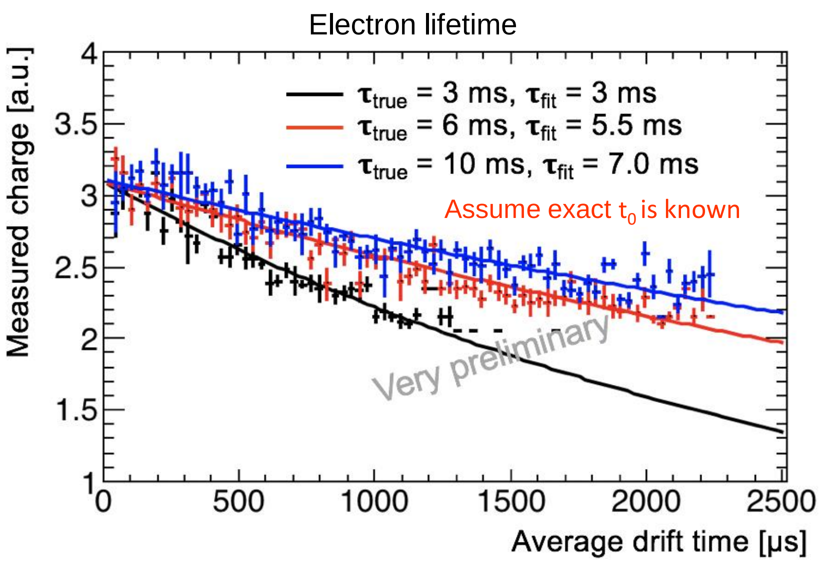
The PNS group has also started the investigation of doing the neutron capture measurement at DEAP-3600. Simulation results will be shown in the following WG meetings

Demonstration of FD calibration

- The ultimate goal is to reduce the energy scale uncertainty to 2%
- Idealized simulation of single neutron captures using PD-SP geometry has shown sensitivity to energy response and electron lifetime
- Need to run realistic far detector simulations of a burst of DD neutrons using the FD geometry
- Will put more effort on developing algorithms to identify 6.1 MeV gamma cascade.

Idealized simulation with no noise or background added





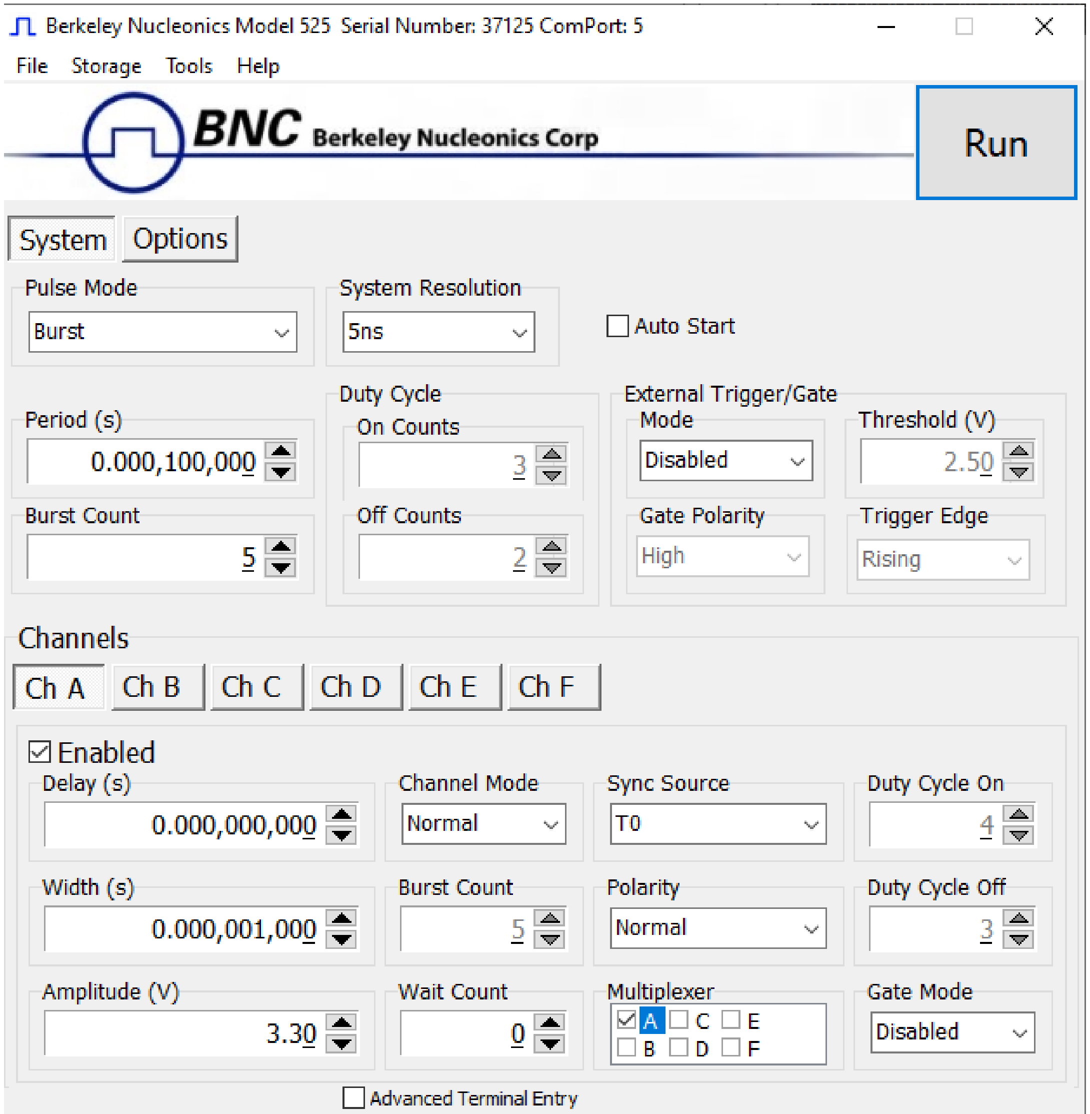
PNS Group

- **UC Davis**: Robert Svoboda, Mike Mulhearn, Junying Huang, Yashwanth Bezawada, Gian Vera, Nicholas Carrara
- **SDSM&T:** Jingbo Wang, Walker Johnson, Juergen Reichenbacher
- **LANL**: Sowjanya Gollapinni, Mattia Fani
- **LIP (Portugal)**: Jose Maneira, Sofia Andringa
- **University of Pittsburgh**: Donna Naples, Logan Rice

Summary

- PD-1 Analysis is finished and the result shows good agreement between data and MC
- Currently planning the test for PD-II. Manhole and beam plug are the preferred deployment locations
- Will assemble the Pulsed Neutron source at SD Mines very soon
- With new members joining the group, we will put more effort on far detector simulation.

Backup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File
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Tools
Help
BNC Berkeley Nucleonics Corp
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System
Options
Pulse Mode
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System Resolution
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On Counts
3
External Trigger/Gate
Mode
Disabled
Threshold (V)
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Burst Count
5
Off Counts
2
Gate Polarity
High
Trigger Edge
Rising
Channels
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Ch B
Ch C
Ch D
Ch E
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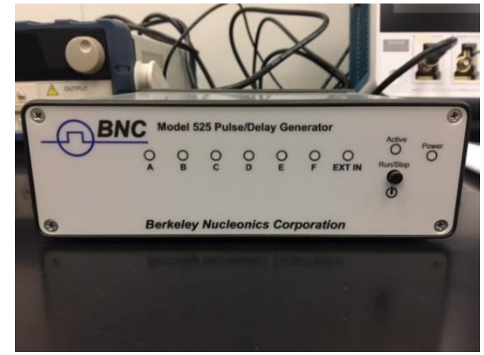
BNC
Model 525 Pulse/Delay Generator
Berkeley Nucleonics Corporation