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Studying MeV Scale Neutron Interactions in DUNE ND-LAr 2x2 Demonstrator

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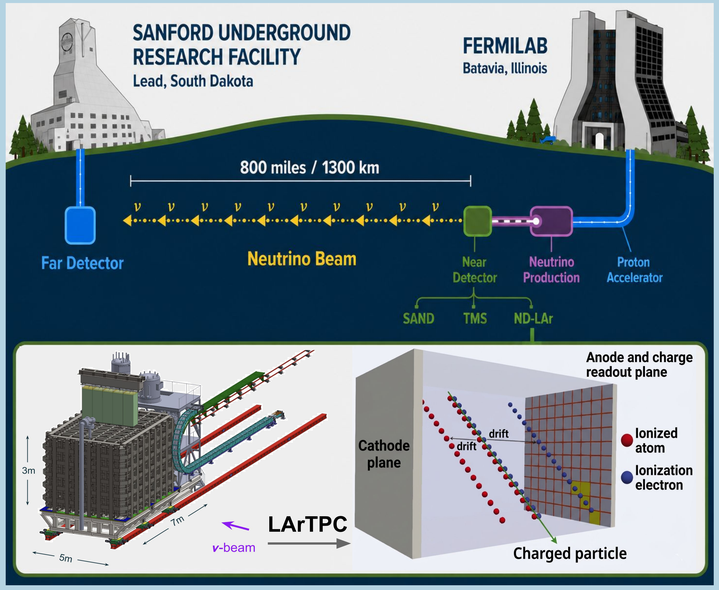
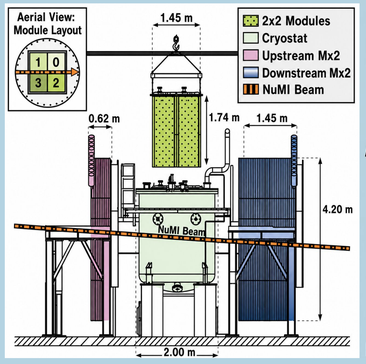
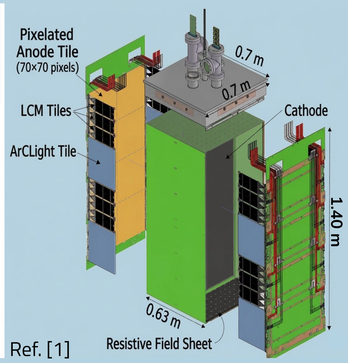
Introduction

The **Deep Underground Neutrino Experiment (DUNE)** is a long-baseline accelerator neutrino experiment studying neutrino oscillations.



To verify ND-LAr technology, the **2x2 Demonstrator** was built according to the ND-LAr design, using 4 1/3 scale modules, and situated in the NuMI beam.[1]



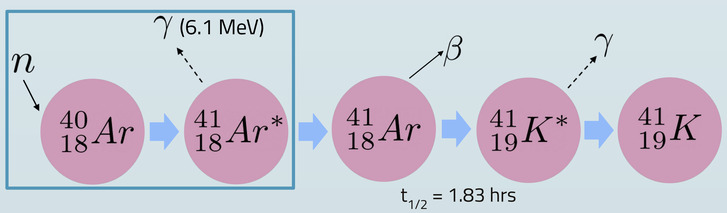


Ref. [1]

Why Study Neutrons?

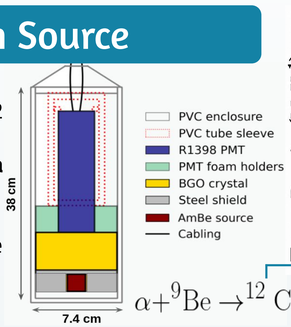
Neutron capture on Ar-40 produces a cascade of gamma rays that deposit small blips of charge in LAr.[4] Identifying low energy blip-like activities due to neutron enables:

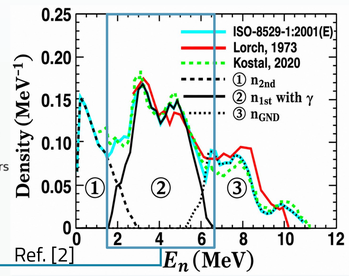
- Better background constraint on blip-like signals (BSM, Supernovae, etc.)
- Using neutron sources for detector calibration



AmBe Neutron Source

An AmBe source was deployed on top of the 2x2 cryostat, **producing 2-6 MeV neutrons each with a coincident gamma.**[2] A BGO crystal monitored by a PMT was used to tag the coincident gammas and produce triggers.





Ref. [2]

$$\alpha + {}^{9}\mathrm{Be} \rightarrow {}^{12}\mathrm{C}^{*} + \mathrm{n} \rightarrow {}^{12}\mathrm{C} + \gamma(4.44\ \mathrm{MeV}) + \mathrm{n}$$

AmBe Source Simulation

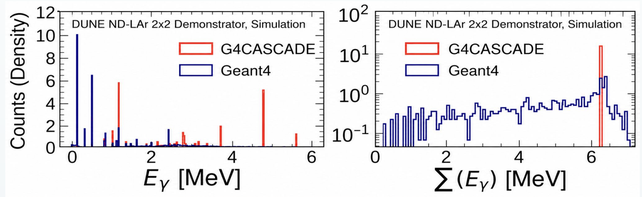
edepsim (Geant4) with custom physics list (G4CASCADE)

↓

larndsim (Detector Response)

↓

ndlar-flow (Standard ND-LAr Reconstruction)



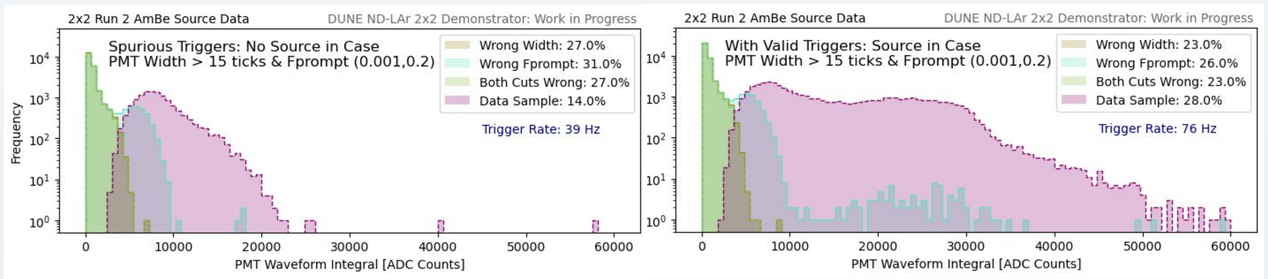
G4CASCADE physics list correctly simulates the total energy of gammas from neutron capture (6.1 MeV).[3]

Neutron Event Selection

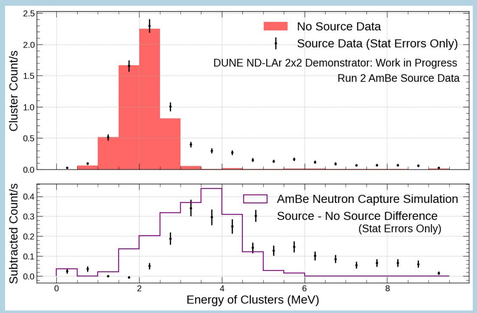
Trigger Selection

PMT waveforms from source-in and no-source datasets are compared with each other to define selection cuts for background rejection using pulse width and Fprompt (the ratio of prompt to total scintillation light).

Source-in triggers kept: 28.0%
Purity of kept triggers: 74.3%



Charge Reconstruction



Reconstructed charge hits are clustered using DBSCAN optimized for small blips of charge deposits.

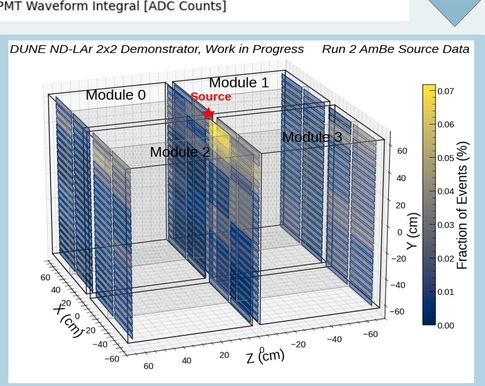
< 2MeV: Source & No Source data are correlated, indicating activities in this range are background

≥2MeV: A combination of neutron captures, as indicated by comparison with the simulation, and other higher energy activities which require further investigation

Light Reconstruction

Scintillation light from gamma-induced electron recoils can be identified by their pulse shapes using an Fprompt selection cut.

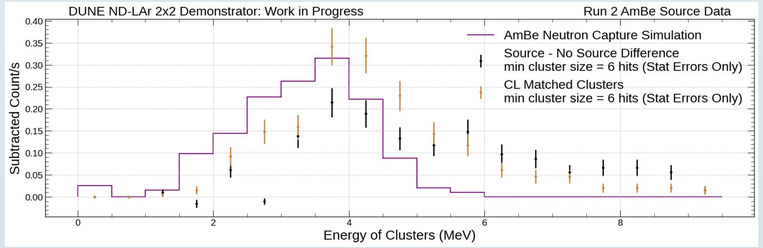
After selection, the location of increased light activities corresponds with the location of the AmBe source.

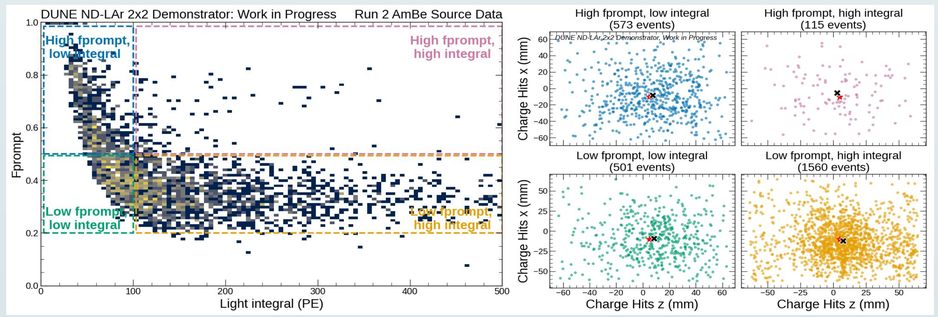


Charge-Light Matching

A charge-light matched dataset was created by selecting triggers with both charge clusters and light activities.

↓ Energy distribution of charge-light matched clusters with more than 6 hits corresponds well with Source-No Source difference and simulation





The majority of charge-light matched light events are in the low Fprompt regions, which corresponds to electron recoils from neutron capture gamma cascade. The corresponding charge clusters of these light events are also concentrated near the source location.

Conclusion

Utilizing a set of AmBe source data, we have developed a reconstruction procedure that **demonstrates capabilities of identifying neutron capture candidates in the 2x2 Demonstrator**. Moving forward, our primary goal is to further validate our reconstruction by improving our simulation, and produce measurements of AmBe source neutron production rate in the 2x2.

References & Acknowledgments

1 S. Abbaslu, et al. (DUNE Collaboration), "Operation of a Modular 3D-Pixelated Liquid Argon Time-Projection Chamber in a Neutrino Beam ," (2026).
2 Hiroshi Ito et al. "Analyzing the neutron and γ-ray emission properties of an535 americium–beryllium tagged neutron source". In: Nucl. Instrum. Meth. A 1057536 (2023)
3 Leo Weimer et al. "G4CASCADE: A data-driven implementation of (n, γ) cascades in Geant4" (2025).
4 W. Castiglioni, et al., "Benefits of MeV-scale reconstruction capabilities in large liquid argon time projection chambers," Phys. Rev. D 102(9), 092010 (2020).

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