Neutron Reconstruction via Blips in Liquid Argon Time Projection Chambers

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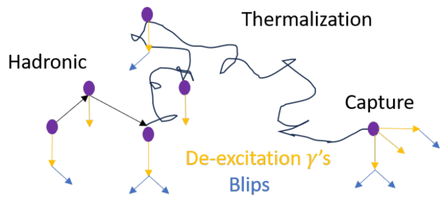
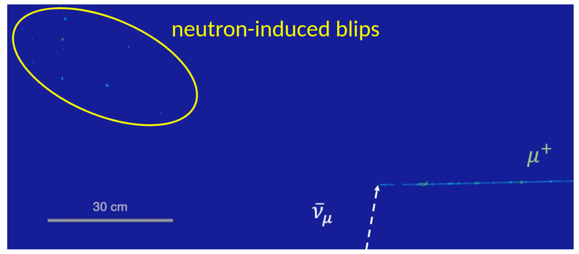
Motivation

- DUNE (Deep Underground Neutrino Experiment) combines a high-intensity neutrino beam with a large underground LArTPC detector, providing exceptional sensitivity to both beam and atmospheric neutrinos.
- Neutrons are common final-state particles in neutrino interactions. They are difficult to detect because they do not create direct ionization signals.
- Neutrons interactions produce low-energy nuclear recoils, gamma rays and electrons. Isolated energy depositions of energy “blips”.



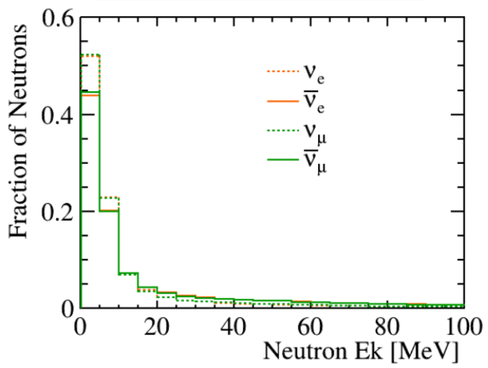


- These blips can be used for neutrino-antineutrino separation.

More Protons in final state !!!

$$\nu_l + n \rightarrow l^- + p$$

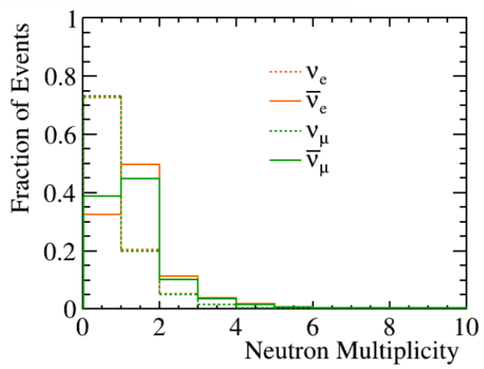
Sub-GeV neutrino process



More Neutrons in final state !!!

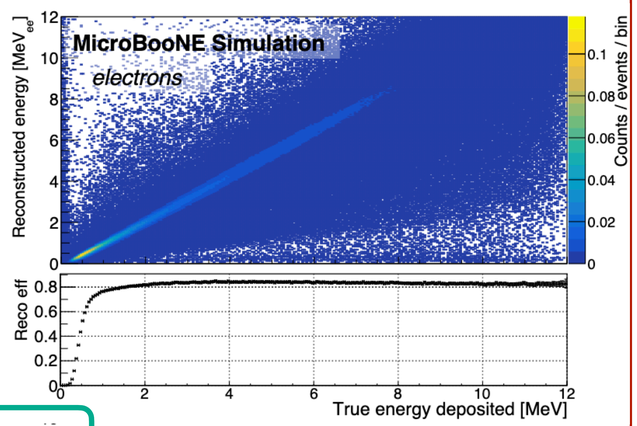
$$\bar{\nu}_l + p \rightarrow l^+ + n$$

Sub-GeV antineutrino process



Sub-GeV atmospheric ν simulation and Blip Reconstruction

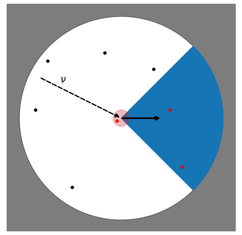
- FLUKA simulation of sub-GeV atmospheric neutrino interactions in argon. Neutrons and gamma rays are propagated, while electrons are produced but are not transported within FLUKA.
- GEANT4 electron propagation in a sensitive volume using the electron position, momentum, and energy from FLUKA.
- BlipReco is used for reconstruction of blips, providing reconstructed energies and 3D positions.



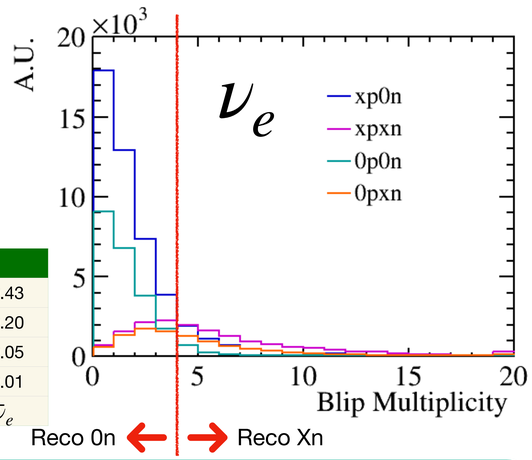
FLUKA → GEANT4 → BlipReco

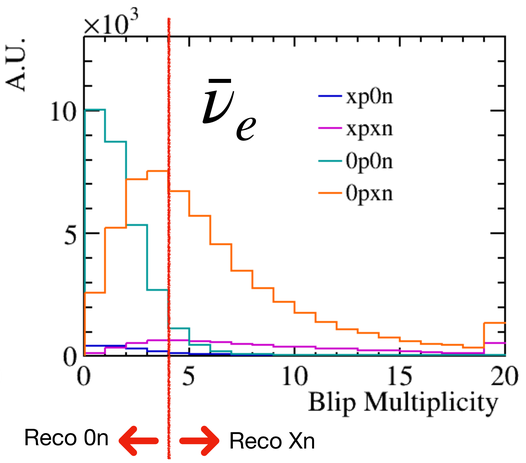
Figure from P. Abratenko et al. (MicroBooNE), Phys. Rev. D 111,032005 (2025), arXiv:2410.18419 [hep-ex].

Neutron Reconstruction and neutrino antineutrino separation

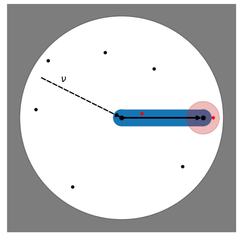


Topology	Efficiency		Purity	
0pXn	0.10	0.49	0.57	0.43
0p0n	0.24	0.41	0.80	0.20
XpXn	0.22	0.08	0.95	0.05
Xp0n	0.44	0.02	0.99	0.01
	ν_e	$\bar{\nu}_e$	ν_e	$\bar{\nu}_e$





Using neutron blips, the $\bar{\nu}_e$ purity can be improved from 28% to 43% !!!!!

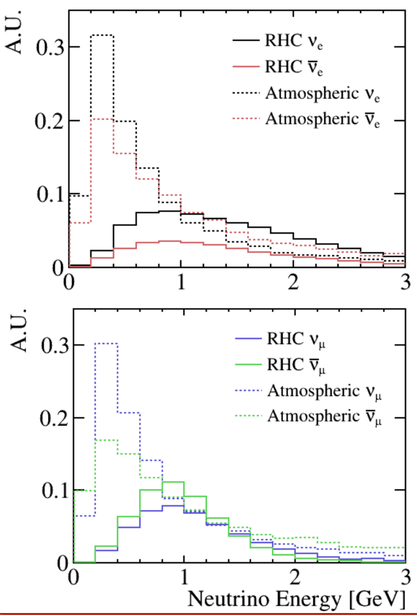


Topology	Efficiency		Purity	
0pXn	0.02	0.40	0.23	0.77
0p0n	0.05	0.33	0.44	0.56
XpXn	0.05	0.06	0.82	0.18
Xp0n	0.08	0.01	0.97	0.03
	ν_μ	$\bar{\nu}_\mu$	ν_μ	$\bar{\nu}_\mu$

- Blips provide access to otherwise invisible neutron activity.
- Neutron reconstruction is feasible in LArTPCs.
- Neutron-sensitive observables improve neutrino physics analyses.
- Neutron reconstruction improves separation between neutrino and antineutrino interactions

Using neutron blips, the $\bar{\nu}_\mu$ purity can be improved from 66% to 77% !!!!!

Reverse Horn Current (RHC) beam neutrinos



- The Sub-GeV atmospheric neutrino simulation is reweighted to match the BNB RHC neutrino flux.
- The neutron reconstruction algorithm and selection cuts developed for the atmospheric neutrino sample are applied to the reweighted sample to study $\nu/\bar{\nu}$ separation.

Topology	Purity		Purity	
0pXn	0.32	0.68	0.05	0.95
0p0n	0.59	0.41	0.11	0.89
XpXn	0.87	0.13	0.43	0.57
Xp0n	0.98	0.02	0.84	0.16
	ν_e	$\bar{\nu}_e$	ν_μ	$\bar{\nu}_\mu$

Neutron-induced blips provide a powerful new observable for $\nu/\bar{\nu}$ separation in Sub-GeV atmospheric and beam neutrino interactions.

The $\bar{\nu}$ purity from BNB RHC is even better than atmospheric neutrinos !!!!!

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Acknowledgments

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