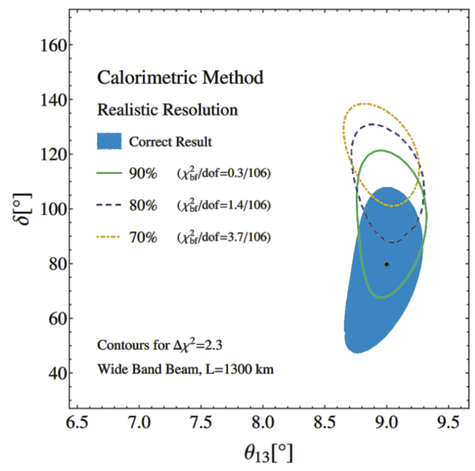
Neutron detection in the DUNE liquid argon near detector

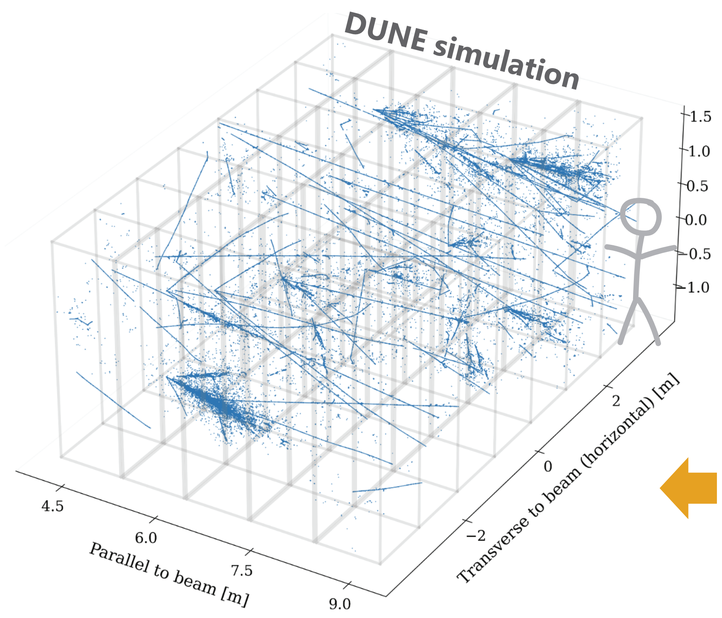
Marjolein van Nuland | Neutrino 2024 | Milano | mnuland@nikhef.nl
For the DUNE collaboration

DUNE is a next-generation long baseline neutrino experiment [1] to perform precision measurements of neutrino oscillations. The Liquid Argon Time Projection Chamber (LArTPC) of the DUNE near detector (ND-LAr) characterizes the beam before oscillations occur and is essential to constrain the systematic uncertainties of most DUNE measurements. ND-LAr will be a modular LArTPC with pixelated charge and high-coverage light readout systems.



Neutrons are invisible in the DUNE detector. They carry away up to 30% of the energy from the neutrino interactions. Missing energy has a large effect on measurements, e.g. δCP [2].

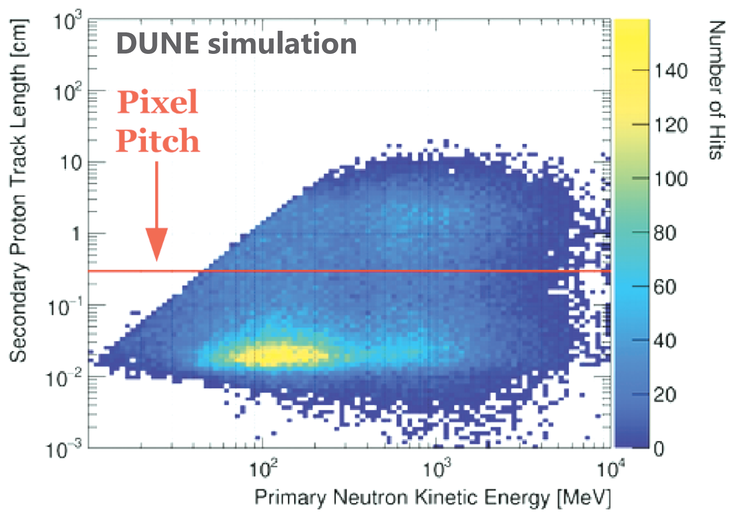
We need to find the invisible neutrons



Expect ~50 beam-related interactions per spill in ND-LAr. Extremely hard to find invisible neutrons. Optical segmentation of the detector into 70 TPCs reduces pileup to ~5 interactions per beam spill per TPC.

WHAT HAPPENED HERE??

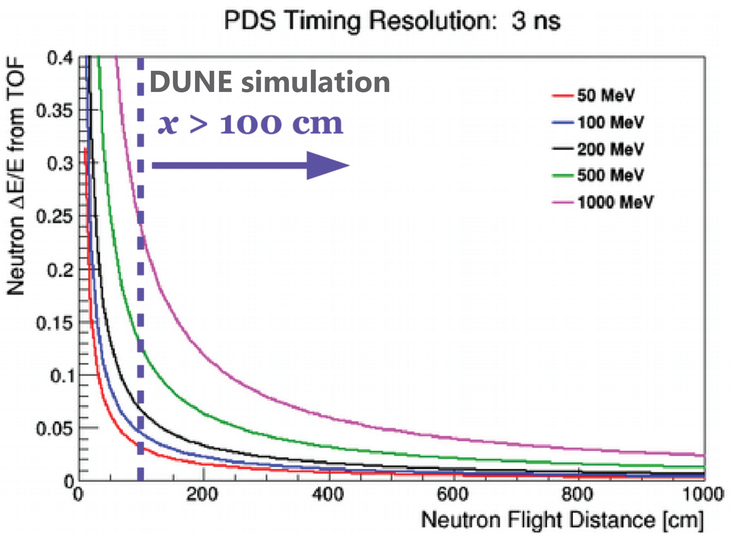
Optical segmentation to the rescue



Proton tracks produced by neutrons are usually short [4] and difficult to identify. Need dedicated proton reconstruction software, good time and spatial resolution, and background mitigation.

E.g. the demand of a track length >2 cm, halves our statistics in the 2x2!

Suppose we can find protons, we find neutrons and their energy!



$$v_n = \frac{d(v,p)}{t_p - t_v} \qquad E_n = \gamma mc^2$$

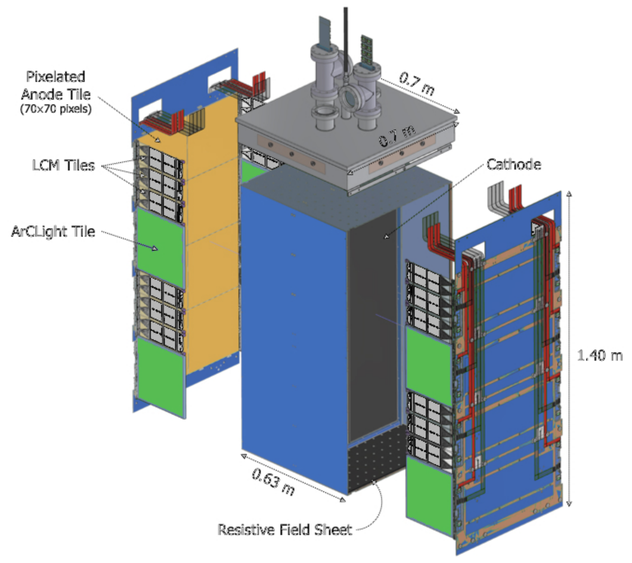
$$\phi(E,r) = \phi_0(E)e^{-n\sigma(E)r}$$

$$\sigma(E) = -\frac{1}{nr'}\left(\ln\left(N_{r>r',E}\right) - \ln(N_E)\right)$$

A measurement of the n-Ar cross-section with the 2x2 will allow us to cover the few-hundred MeV neutron energy region, on which no previous measurements exist.

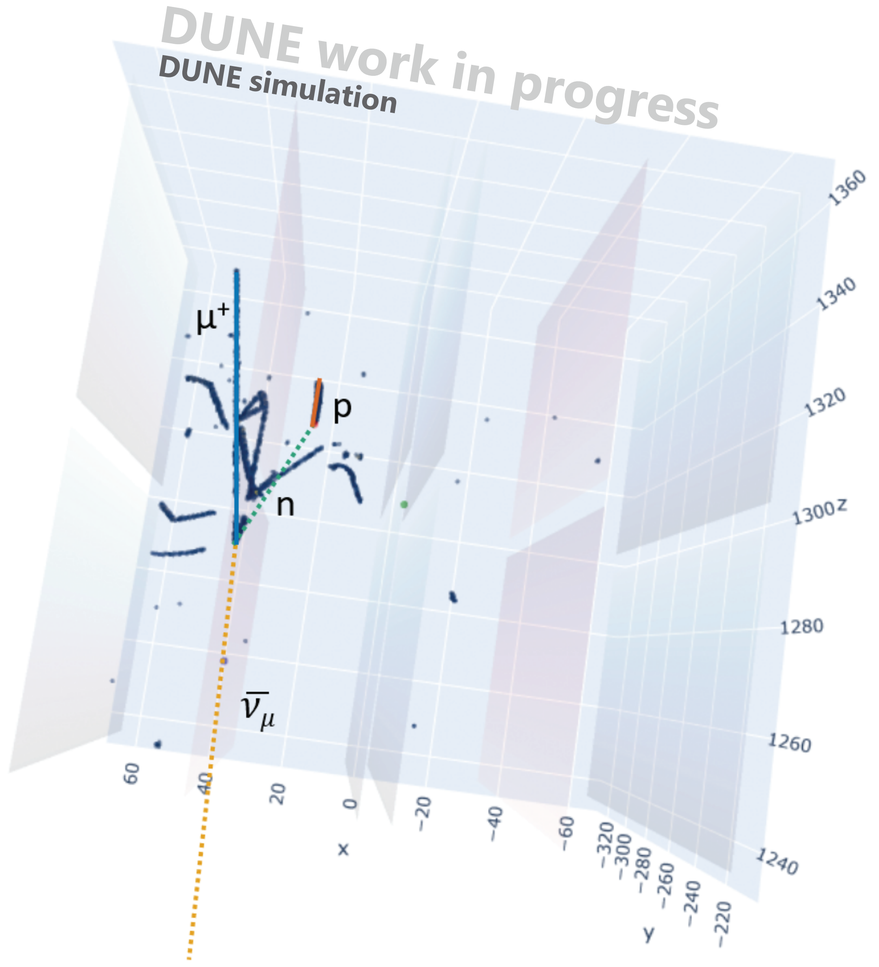
2x2 DEMONSTRATOR

Prototype at Fermilab in the Neutrinos at Main Injector (NuMI) beam to test effectiveness of optical segmentation. Consists of 4 modules [3] in a 2x2 arrangement.



Great for studying the neutron kinetic energy

- Anti muon neutrino beam
- Less pileup than ND-LAr
- Slightly higher beam energy
- Optical segmentation into 8 TPCs, with high light sensor coverage



Events where the neutron produces a proton in a separate TPC from the neutrino vertex allow precise timing from the light sensors to determine the neutron time-of-flight, and from there the neutron energy

[1] Abi, Babak, et al. Deep Underground Neutrino Experiment (DUNE), far detector technical design report, volume II: DUNE physics. arXiv preprint arXiv:2002.03005 (2020).
[2] A. M. Ankowski, P. Coloma, P. Huber, C. Mariani, and E. Vagnoni, Phys. Rev. D 92, 091301 (2015), 1507.08561.
[3] Abud, A. Abed, et al. Performance of a modular ton-scale pixel-readout liquid argon Time Projection Chamber. arXiv preprint arXiv:2403.03212 (2024).
[4] Abud, A. Abed, et al. Deep Underground Neutrino Experiment (DUNE) Near Detector Conceptual Design Report. Instruments 2021, 5, 31.

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