Snowmass2021 - Letter of Interest

[DUNE Near Detector]

NF Topical Groups: (check all that apply □/■)

■ (NF1) Neutrino oscillations
□ (NF2) Sterile neutrinos
□ (NF3) Beyond the Standard Model
□ (NF4) Neutrinos from natural sources
□ (NF5) Neutrino properties
■ (NF6) Neutrino cross sections
□ (NF7) Applications
□ (TF11) Theory of neutrino physics
□ (NF9) Artificial neutrino sources
■ (NF10) Neutrino detectors
□ (Other) *[Please specify frontier/topical group(s)]*

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Abstract: Official DUNE LOI describing the near detector. DUNE includes a very capable near detector to facilitate the high precision extraction of oscillation parameters. The DUNE Near Detector measures the initial unoscillated (anti)neutrino energy spectra, provides essential input for the neutrino interaction model, measures and monitors the beam, and constrains systematic uncertainties. The DUNE ND has three primary detector components – ND-LAr, ND-GAr, and SAND – and the capability for two of those components to move off the beam axis – DUNE-PRISM. The detector components and capabilities serve important individual and overlapping functions with respect to the mission of the ND.

This Letter of Interest summarizes the designs described in [1]. DUNE is a long-baseline neutrino oscillation experiment that will take data in a wideband neutrino beam at Fermilab in the latter half of the 2020s. The experiment includes a very capable near detector to facilitate the high precision extraction of oscillation parameters. The DUNE Near Detector (ND) measures the initial unoscillated (anti)neutrino energy spectra, provides essential input for the neutrino interaction model, measures and monitors the beam, and constrains systematic uncertainties.

With finite energy resolution and non-zero biases, the reconstructed energy spectrum is an unresolved convolution of cross section, flux, and energy response. The DUNE ND must independently constrain each of those components and provide information that can be used to better model each component. Models of the detector, beam, and interactions fill in holes and biases left by imperfect understanding and they are used to estimate the size of many systematic effects. When imperfect models are not able to match observations, the ND must provide the information needed to deal with that and estimate its impact. The DUNE ND has three primary detector components and the capability for two of those components to move off the beam axis. The three detector components serve important individual and overlapping functions with respect to the mission of the ND.

The first component of the DUNE ND encountered by the beam is a large liquid argon detector, ND-LAr. This acts as the primary target for neutrino events contributing to the sample used to tune the model that governs the extraction of oscillation parameters from the observations at the far detector. This detector consists of 35 optically isolated 1m x 1m x 3m time projection chambers with pixelized readout operating in a single cryostat.

Just downstream of ND-LAr is a high-pressure gas TPC surrounded by an ECAL and magnet, called ND-GAr. The primary function of ND-GAr is to momentum analyze muons coming from neutrino interactions in ND-LAr that are not contained in ND-LAr. In addition, this detector provides a sample of neutrino interactions in argon gas where charged particle detection thresholds are low and there is less confusion caused by secondary interactions. This sample is expected to be valuable for tuning and refining the neutrino interaction model, as well as for studying systematic uncertainties.

ND-LAr and ND-GAr can take data at distances of up to 33 m transverse to the beam. This capability and the analyses enabled by by the off-axis samples are referred to as DUNE-PRISM. At increasing off-axis angles the neutrino beam spectrum peaks at lower energies and becomes narrower. This change in the beam spectrum can be used to deconvolute the beam and cross section models. The data sets taken with the different spectra can be combined linearly to create roughly monochromatic neutrino spectra useful for studying the detector response. They can also be combined to create spectra very similar to those expected in the far detector allowing for the extraction of oscillation parameters with minimal model dependence.

Finally, the DUNE ND has a component, called SAND, that stays on axis and monitors the stability of the beam spectrum. This device consists of a large magnet and ECAL surrounding a tracker. The primary function of the tracker is to facilitate the momentum analysis of muons from neutrino interactions for the spectral monitoring function. However, the tracker also contains non-argon nuclear targets and may be able to include neutrons in the event reconstruction. These capabilities are expected to be useful for refining and tuning the neutrino interaction model and for establishing the size of systematic uncertainties incurred by the use of the interaction model.

The DUNE ND design is driven largely by the needs of the three-neutrino long baseline neutrino oscillation physics program. However, in addition to this mission, the DUNE ND will have a physics program of standard model measurements, neutrino interaction physics, and searches for non-standard interactions, sterile neutrinos, dark photons, and other exotic particles. The 1.2 MW primary proton beam provides an intense source for the possible production of exotic particles. The detector suite contains massive detectors for detecting the interaction of these particles, while ND-GAr functions as an active volume where the kinematics of decaying exotic particles can be precisely analyzed. Furthermore, the movement of the detectors allows the production kinematics to be studied by detecting the particles at a range of angles relative to the beam axis. The detector system performances, coupled with a range of target nuclei within the SAND and LAr detectors, the possibility of introducing different target gas mixtures in the ND-GAr, and the off-axis movement will also enable a broad program of neutrino-nucleus interactions measurements with a unique and unprecedented suite of capabilities.

At the time of Snowmass 2021, it is expected that the DUNE collaboration will be doing detailed design, value engineering, and prototyping, as well as ongoing detector R&D for the near detector. A four-module LAr prototype and a high pressure TPC module will be running in the NuMI beam (ProtoDUNE-ND). It is difficult to anticipate the topics that will be of most interest to us during Snowmass. However, we expect some of the following will be among the topics we will want to explore:

- Sensitivity studies of increasing sophistication that can illustrate the value of aspects of the ND design, aimed toward helping with design optimization
- Beyond the standard model studies (sterile neutrinos, dark photons, etc.)
- Neutrino interaction model – updating the model with latest constraints and information from current experiments,
- Discussing needed improvements in the neutrino interaction model
- Discussing needed theoretical developments to help reduce anticipated interaction or nuclear physics systematic uncertainties in DUNE
- Possible staging scenarios as mitigation against budget or technical issues with the ND
- Study of ProtoDUNE-ND data to help inform the ND-LAr design optimization
- Particular hardware or design issues that are relevant in summer 2021
- Possible ND upgrade ideas to consider going forward

References

[1] **DUNE** Collaboration, B. Abi *et al.*, "Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume I Introduction to DUNE," `arXiv:2002.02967 [physics.ins-det]`.