Snowmass2021 - Letter of Interest

[Long-Baseline Physics in DUNE]

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 long-baseline physics sensitivity of the experiment. DUNE has performed sensitivity analyses based on full, end-to-end simulation, reconstruction, and event selection of far detector Monte Carlo and parameterized analysis of near detector Monte Carlo. These studies include detailed uncertainties from flux, the neutrino interaction model, and detector effects, and demonstrate that DUNE will be able to measure δ_{CP} to high precision, unequivocally determine the neutrino mass ordering, and make precise measurements of the parameters governing long-baseline neutrino oscillation.

This Letter of Interest summarizes the conclusions presented in [1, 2]. The Deep Underground Neutrino Experiment (DUNE) is a next-generation, long-baseline neutrino oscillation experiment which will make significant contributions to the completion of the standard three-flavor picture by measuring all the parameters governing ν_1–ν_3 and ν_2–ν_3 mixing in a single experiment. Its main scientific goals include the definitive determination of the neutrino mass ordering, the definitive observation of charge-parity symmetry violation (CPV) for more than 50% of possible true values of the charge-parity violating phase, $\delta_{\rm CP}$, and precise measurement of oscillation parameters, particularly $\delta_{\rm CP}$, $\sin^2 2\theta_{13}$, and the octant of θ_{23}.

DUNE has a number of features that give it unique physics reach, complementary to other existing and planned experiments [3–5]. Its high-power neutrino beam, provided by LBNF [6], is peaked at $\sim$2.5 GeV but with a broad range of neutrino energies. This makes DUNE sensitive to the shape of the oscillation spectrum for a range of neutrino energies. The relatively high energy of the neutrino beam enhances the size of the matter effect and will allow DUNE to measure $\delta_{\rm CP}$ and the mass hierarchy simultaneously. The beam power is 1.2 MW, upgradeable to 2.4 MW. The 40-kt (fiducial) far detector (FD) is composed of four 10 kt (fiducial) LArTPC modules [7–9]. The FD, located at the 4850 ft level of Sanford Underground Research Facility (SURF), in Lead, South Dakota, USA, 1285 km from the neutrino production point, utilizes unique liquid argon time-projection chamber (LArTPC) detector technology that will enhance the resolution on DUNE's measurement of the value of $\delta_{\rm CP}$, and, along with the increased neutrino energy, gives DUNE a different set of systematic uncertainties to other experiments, making DUNE complementary with them. A highly capable near detector (ND), including the novel capability to make off-axis measurements of the neutrino flux, will constrain many systematic uncertainties for the oscillation analysis. All of these features must be realized to achieve DUNE's physics goals.

DUNE has performed sensitivity analyses based on full, end-to-end simulation, reconstruction, and event selection of FD Monte Carlo and parameterized analysis of ND Monte Carlo. A convolutional neural network has been developed to select ν_e- and ν_μ-CC events; the selection achieves greater than 85% efficiency for reconstructed energies between 2-5 GeV. [10]. Detailed uncertainties from flux, the neutrino interaction model, and detector effects have been included in the analysis. Sensitivity results are obtained using a sophisticated, custom fitting framework. These studies demonstrate that DUNE will be able to measure $\delta_{\rm CP}$ to high precision, unequivocally determine the neutrino mass ordering, and make precise measurements of the parameters governing long-baseline neutrino oscillation. A demonstration of DUNE's precision measurement capability is shown in Fig. 1.

Studies demonstrating the importance of near detector constraints and, in particular, robustness against insufficient modeling of neutrino interactions have been performed and analyses demonstrating how DUNE can improve interaction modeling and reduce model dependence have been developed. A demonstration the DUNE PRISM analysis making use of simulated off-axis data is in progress. An active analysis program is responsible for implementing, within the DUNE collaboration, reconstruction, calibration, and broader analysis techniques aimed at further developing detector performance.

DUNE will be able to establish the neutrino mass ordering at the 5σ level for 100% of $\delta_{\rm CP}$ values within two to three years. CP violation can be observed with 5σ significance after $\sim$7 years if $\delta_{\rm CP} = -\pi/2$ and after $\sim$10 years for 50% of $\delta_{\rm CP}$ values. CP violation can be observed with 3σ significance for 75% of $\delta_{\rm CP}$ values after $\sim$13 years of running. For 15

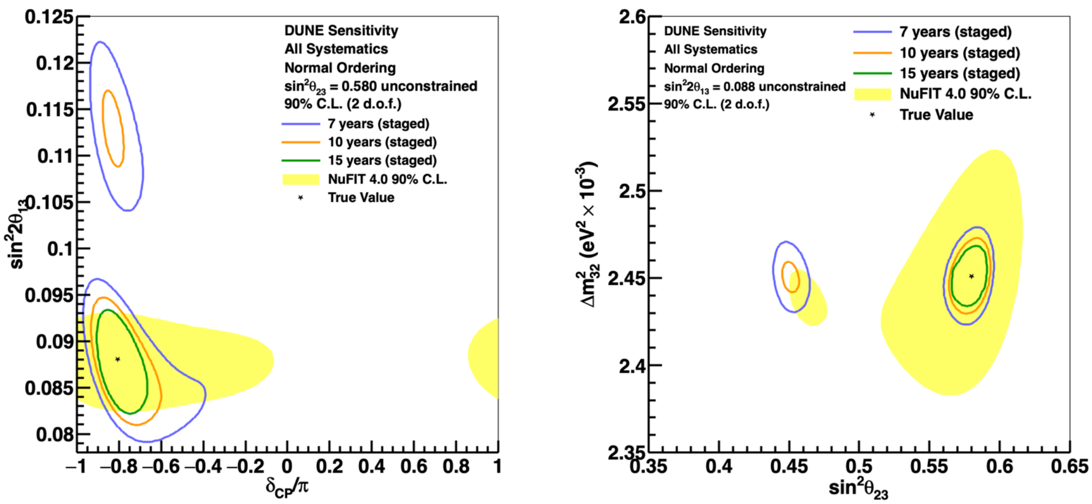

Figure 1: Two-dimensional 90% C.L. regions in the $\sin^2 2\theta_{13}$–$\delta_{\rm CP}$ (left) and $\sin^2\theta_{23}$–Δm^2_{32} (right) plane, for seven, ten, and fifteen years of exposure, with equal running in neutrino and antineutrino mode. The 90% C.L. region for the NuFIT 4.0 global fit is shown in yellow for comparison. The true values of the oscillation parameters are assumed to be the central values of the NuFIT 4.0 global fit and the oscillation parameters governing long-baseline oscillation are unconstrained.

years of exposure, $\delta_{\rm CP}$ resolution between five and fifteen degrees are possible, depending on the true value of $\delta_{\rm CP}$. The DUNE measurement of $\sin^2 2\theta_{13}$ approaches the precision of reactor experiments for high exposure, allowing measurements that do not rely on an external $\sin^2 2\theta_{13}$ constraint and facilitating a comparison between the DUNE and reactor $\sin^2 2\theta_{13}$ results, which is of interest as a potential signature for physics beyond the standard model. DUNE will have significant sensitivity to the θ_{23} octant for values of $\sin^2\theta_{23}$ less than about 0.47 and greater than about 0.55.

The measurements made by DUNE will make significant contributions to completion of the standard three-flavor mixing picture, and provide invaluable inputs to theory work understanding whether there are new symmetries in the neutrino sector and the relationship between the generational structure of quarks and leptons. The observation of CPV in neutrinos would be an important step in understanding the origin of the baryon asymmetry of the universe. The precise measurements of the three-flavor mixing parameters that DUNE will provide may also yield inconsistencies that point us to physics beyond the standard three-flavor model.

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