Long Baseline Neutrino Committee

FERMILAB, March 2023

ND CLOSEOUT Report

March , 2023

Acknowledgements

The LBNC appreciates interactions with DUNE. We are thankful to DUNE's prompt and helpful responses and replies in a short timescale on the questions posed by the committee in the context of this paper review

The committee thanks Fermilab, its Directorate, and its staff, for their continuing support.

Charge Letter: LBNC March 2023 Review

The LBNC is charged by the Fermilab Director to provide external scientific peer review and to monitor the technical progress of the International DUNE collaboration, and those aspects of the facility construction that have direct impact on the DUNE experiment.

Typically, the LBNC meets three times per year to hear and provide recommendations on the general status of LBNC and DUNE. Here we ask that the LBNC meet for an ad-hoc, “paper” review of the DUNE Near Detector (ND) subproject. This review is designed to address a request from the Department of Energy to Fermilab to evaluate the technical scope of the ND given that the needed resources supplied by DOE and international partners for the Near Detector will not cover its currently proposed scope.

The “paper” format for the review will take advantage of existing materials from the DUNE program and will include any needed discussions with subject matter experts (SME). It is not envisioned that the committee will hear a series of presentations but rather rely on these existing materials and SMEs to conduct the review.

Charge Letter: LBNC March 2023 Review

The review should concentrate on the physics capabilities of each detector system in the Near Detector. It is critical for this review to provide a prioritized list of the different Near Detector components in terms of meeting the DOE mission need in support of the Phase I physics goals of DUNE.

Specifically, we ask you to address the following:

1. Which of the three major Near Detector subsystems will have the largest impact on achieving the DOE mission need and which one will have the smallest?
2. If the least effective subsystem is eliminated to reduce costs, what impacts will that have on the overall detector's ability to meet mission need in support of the Phase I physics goals of DUNE?
3. Are there redundancies in the capabilities of each detector component and/or from other planned components of LBNF/DUNE?

The LBNC should develop a Closeout Report which it should deliver at the end of the review. Subsequently this should be refined into a LBNC final report.

The timely execution of this assessment is essential for the successful advancement of the entire LBNF-DUNE-US Project.

Which of the three major Near Detector subsystems will have the largest impact on achieving the DOE mission need and which one will have the smallest?

- The main role and goal of the DUNE Near Detector complex is to a) aid in predicting the unoscillated true neutrino energy spectra in the Far Detector, minimizing the large neutrino cross-section and flux systematic uncertainties, b) measure the intrinsic electron neutrino component of the neutrino beam, and c) estimate the NC induced background.

- Given the above, the individual DUNE ND subsystems have the following main roles:

  i) A **Liquid Argon (ND-LAr)** near detector, as similar as possible given its smaller size to the Far Detectors (FD), that will measure v-Ar interactions, and both reducible and irreducible backgrounds to the ν_e charged current rate of interactions.

  ii) A **muon spectrometer (TMS)** that will measure muon momenta and allow for the reconstruction of the unoscillated muon neutrino spectrum, and also measure the wrong sign background especially for the anti neutrino beam.

Which of the three major Near Detector subsystems will have the largest impact on achieving the DOE mission need and which one will have the smallest?

- The individual DUNE ND subsystems have the following main roles :

  iii) A **system that can move ND-LAr + TMS (PRISM)** through several off-axis locations that will leverage the variation of the neutrino energy spectrum with off-axis angle in order to substantially reduce flux uncertainties and aid in constraining neutrino cross section uncertainties, allowing the prediction of the unoscillated FD spectrum in a data-driven way. PRISM is also an integral part of the proposed ND installation process.

  iv) **An on-axis detector (SAND)** that will continuously monitor the neutrino beam on-axis including when ND-LAr + TMS are at the off-axis locations.

- Hence, the ND-LAr with TMS would have the largest impact in achieving the DOE mission need, PRISM would have the second largest impact, and SAND the third.

If the least effective subsystem is eliminated to reduce costs, what impacts will that have on the overall detector's ability to meet mission need in support of the Phase I physics goals of DUNE?

- The DUNE Phase I physics goals are i) to determine at 5σ the neutrino mass hierarchy for all values of δ_{CP}, and ii) to obtain a 3σ evidence on CPV if the δ_{CP} phase is maximum (-π/2).

- If SAND is omitted from Phase I, DUNE will still have the ability to meet the Phase I physics goals, albeit with an increased risk associated with not being able to detect possible beam changes.

- The LBNC thinks it unlikely that Phase II of DUNE can be successful without some kind of permanent on-axis beam monitor, which at a minimum must be capable of measuring changes in the on-axis neutrino spectrum on a few days' timescale. If an on-axis beam monitor is not present for Phase I, the possibility of installing one later must be maintained. This implies retaining the full logistic flexibility afforded by PRISM as well as installing a Phase I infrastructure and services framework compatible with a later on-axis system.

Are there redundancies in the capabilities of each detector component and/or from other planned components of LBNF/DUNE?

- To mitigate the risk associated with the absence of continuous monitoring on-axis, DUNE is technically capable of deploying an alternative running scheme of, e.g., two weeks with ND-LAr+TMS in an off-axis location followed by two weeks in the on-axis location, such that a) possible target-horn changes can be detected in a timely manner and b) at worst no more than two weeks' worth of ND data would be excluded from the overall oscillation analysis if beam conditions changed. We note here that not all the ND data are needed for the prediction of the unoscillated spectrum in the FD, and the FD is continuously taking data.

- The committee recognizes the role of on-axis beam monitoring and recommends that the DUNE collaboration explores other viable options, such as a simpler TMS-like detector, or other beam monitoring potentially provided by the LBNF complex.