LBNC Review of DUNE's Day 1 Near Detector Plan
February 24, 2021

In response to a charge from FNAL Director Nigel Lockyer, the LBNC conducted a review of DUNE's planning for a Day 1 Near Detector suite, capable of giving DUNE three sigma sensitivity to maximal CP violation in the first few years of operation, during which the experiment will have limited statistics. This review was held on February 16-17, 2021 by Zoom. In advance of the review, DUNE submitted three documents: the near detector CDR, a rough draft of a PDR chapter describing the Temporary Muon Spectrometer (TMS), and a document prepared specifically for the review laying out the physics sensitivity of DUNE with the Day 1 Near Detector configuration. In addition, DUNE provided the LBNC in advance with slides for five presentations: three focusing on the TMS, ND-LAr, and SAND detectors, as well as a presentation describing the physics performance of DUNE with the Day 1 detectors and a presentation discussing the status and plans for completing a PDR by late 2021. The LBNC reviewed these slides and provided DUNE with questions about them in advance of the meeting. DUNE then presented replies to these questions during the Zoom sessions on February 16-17. The TMS and Physics Performance documents and a record of the Q&A exchange are appended to this report. The LBNC also met in an executive session with the DUNE spokespeople and select members of the project management team.

The charge from the Director for this review included three elements, which we shall address in turn. A copy of the full charge is appended at the end of this report.

1. **Will the proposed Day-One Near Detector meet the stated scientific objectives for the defined, initial period of detector operations?**

Yes.

DUNE's plan for the eventual near detector complex include a segmented liquid argon TPC detector (ND-LAr), a magnetized high-pressure gaseous argon TPC (ND-GAr), a magnetized spectrometer for beam monitoring using the KLOE magnet and ECAL (SAND), plus the capacity to move ND-LAr and ND-GAr off-axis in order to break degeneracies between neutrino flux and cross-section uncertainties (the PRISM technique). The LBNC has previously endorsed this detector concept.

While ideally this entire suite of detectors would be ready for the start of DUNE operations, resource limitations may require a staged approach. DUNE's baseline plan for a Day 1 detector would replace the ND-GAr magnetized gaseous TPC with a simpler Temporary Muon Spectrometer (TMS), built from steel and scintillator and containing a vertical magnetic field. The TMS is considered to be a well-costed and "safe" backup solution, based on established

technology and drawing heavily on the MINOS detector design. As the name suggests, the Temporary Muon Spectrometer would eventually need to be replaced by ND-GAr.

An alternative option, if partial funding for ND-GAr were available early enough, would be to instead build the ND-GAr magnet and to instrument its central volume with a minimal configuration of tracking planes (eg. scintillator or straw tubes). The advantage of this approach is that it provides a natural staging towards the construction of ND-GAr itself. The long-term cost of this option would be less expensive than building TMS, then scrapping it and replacing it with ND-GAr. The disadvantage is a higher initial cost. This option, sometimes called ND-GAr Lite, is an attractive alternative to TMS if resources permit. However, this option was not a focus of the review, and the LBNC did not receive details concerning it. For the purposes of establishing a baseline cost/schedule for US scope, DUNE has defined the TMS option as the baseline. The LBNC concurs with this approach.

Because the TMS is not the preferred option for Day 1, although it is a safe and well-understood option, DUNE has prepared a schedule showing the latest date at which it must commit to constructing TMS in order for it to be ready for Day 1. The collaboration's desire to defer pulling the trigger on TMS construction to allow time for an ND-GAr Lite option to be developed, is understandable. However, we caution that DUNE must be sure to be sufficiently conservative in its assumed schedule for TMS construction.

DUNE presented details of physics sensitivity studies, with a focus on whether the Day 1 detectors (ND-LAr, SAND, TMS, and PRISM movement system) would allow DUNE to achieve 3σ sensitivity to maximal CP violation after a few years of running. These studies build upon those done for the ND CDR, taking into account the differences in capability between ND-GAr and the TMS.

The LBNC finds that DUNE has made a convincing case that the Day 1 detectors will allow DUNE to achieve the stated sensitivity to CP violation, and so the answer to this charge question is "yes". The technical progress also seems to be advancing at a pace consistent with readiness for Day 1. While significant work remains to advance the conceptual design towards a technical design, we see no show-stoppers.

Although the Day 1 near detector configuration should be adequate for DUNE's initial physics goals, the physics studies that DUNE presented also demonstrate that the Day 1 suite is not sufficient in order to allow DUNE to achieve its final physics sensitivity. In particular, the TMS detector is not sufficiently capable to allow DUNE to detect CP violation at 5σ significance for more than 50% of the range of possible δ_{CP} values, for any amount of running time. Achieving such sensitivity requires the deployment of the ND-GAr magnetized high-pressure TPC. ND-GAr will provide critical information about the low energy hadrons produced in neutrino interactions on argon, which will be necessary in order to reduce uncertainties in neutrino interaction modelling that will otherwise limit DUNE's ultimate sensitivity. These systematic uncertainties are not an issue for small, statistically limited data sets, for which the TMS would suffice.

Studies presented by DUNE also indicate that the ND-GAr Lite option for Day 1 (i.e. instrumenting the magnet for ND-GAr with simple tracking as a magnetic spectrometer) would give comparable performance as a Day 1 detector, and so also can meet the requirements for a Day 1 detector.

2. Do Collaboration plans for advancing design work, carrying out prototyping activities, and performing physics studies provide confidence that a Preliminary Design Report (PDR) demonstrating the viability of the Day-One detector configuration can be finalized on the time scale of late 2021?

DUNE has recently completed its ND CDR, and showed the LBNC a table of contents for the PDR, which will be based on the CDR but will include additional materials required for the DOE CD approval process. Presentations on individual detectors outlined in detail the prototyping and design work planned for each component. Overall, the collaboration should be capable of completing a PDR by the end of 2021. The LBNC anticipates being asked to review this PDR, and notes that this review would likely need on the order of ~3 months to complete, based upon past experience with the CDR and taking into account the likely need to iterate with DUNE. The time for the review process should be taken into account when considering the timetable for finishing a complete draft of the PDR.

We note that, in order to achieve a PDR in 2021, DUNE will need to have a dedicated team committed to delivery of the PDR, and a component of that team must perform QA/QC on what is written, before submission to the LBNC.

We also comment that strong and coherent management of the ND effort will be required in order to meet the proposed timescale. We were encouraged to hear of DUNE's plans to appoint a deputy technical coordinator for the ND effort.

Recommendation: DUNE should present a draft schedule at the March 2021 LBNC meeting showing the steps and timetable needed to finish the PDR.

The PDR itself is of course not the only document needed for the CD2 approval process. The PDR will itself reference several other documents, which may continue to evolve as DUNE prepares the review. As these evolve, the PDR will need to evolve in turn. We do not anticipate that the LBNC will review all of these other documents, and do not think that is our role.

The plans for the Day 1 detector suite are closely coupled to the availability of international funding for ND-GAr or ND-GAr Lite, and a decision by the international DUNE collaboration to launch ND-GAr or ND-GAr Lite for Day 1 readiness. If this decision is made early enough, DUNE

would be well advised to skip the TMS and proceed directly to ND-GAr or ND-GAr Lite. The dependencies and assumptions behind this strategy will need to be articulated in the PDR. This requires not only understanding how long it takes to build TMS and what is the latest date at which DUNE must commit to its construction, but also understanding the schedule for the alternate options and therefore when the alternative must be launched. For example, if the latest date for committing to ND-GAr Lite in order to deliver that detector for Day 1 is earlier than the latest date at which DUNE would need to commit to constructing the TMS, then the earlier date should dictate the start of construction on TMS, in order to provide the maximum possible schedule contingency for its construction.

Recommendation: DUNE should work out a rough schedule for ND GAr-Lite, in order to understand how long it would take to complete and by what date a decision to build it must be taken in order for ND-GAr Lite to be available for Day 1.

DUNE should clearly articulate in writing the strategy and process to decide whether to proceed with TMS as the Day 1 detector or whether to switch to ND-GAr or ND-GAr Lite. This should be described in the PDR, explaining the dependencies on international contributions and decision process.

Recommendation: Identify and describe the set of technical and schedule interfaces between US deliverables and the non-US parts of the project. These should be described in the PDR, with details and specifications in a separate interface document for CD2. (The technical specifications themselves may be under development at the time of CD2, but the list should be complete.) In the milestone and decision logic, US-DUNE should interface with the non-US parts by having a limited number of well-defined linking milestones.

3. Are there any redundant elements of the proposed Day-One Near Detector that could be installed later and not impact the collaboration's ability to meet its initial science objectives?

The SAND consortium is considering the installation of a small liquid argon target inside the KLOE magnet. While it is possible that a liquid argon target might expand the range of physics that can be done with this detector, it is not essential for achieving DUNE's physics goals, and therefore is not required for the Day 1 configuration of SAND.

DUNE is considering two options for a fully instrumented tracker inside the SAND detector's magnet. One option includes a 3D scintillator tracker (3DST) with gaseous TPCs. The other option is based on planes of straw tube trackers (STT) interspersed with thin passive target layers.

The SAND consortium is organizing a review of these two options and will make a technology recommendation to the DUNE Executive Board in April 2021.

However, both of these tracker options for SAND likely exceed the requirements for a Day 1 detector. SAND's primary role is to act as a beam monitor, and this likely could be achieved with a partially instrumented tracker with reduced cost. For example, one could consider a combination of sparsely spaced planes of STT or scintillating bars, or TPCs without the full 3DST, or some combination of these. While the collaboration of course aspires to have a fully instrumented inner tracker for SAND on Day 1, it is likely that a simpler or partially instrumented tracker volume inside the KLOE magnet and ECAL would suffice.

Recommendation: DUNE should carry out simulation studies of reasonable configurations of minimal inner tracker options for whichever technology solution is selected for SAND, in order to determine a minimal configuration that would be adequate for beam monitoring.

We reiterate that the Day 1 detector suite needs to include ND-LAr, the SAND beam monitor (with possibly reduced inner tracking, as discussed above), an adequate magnetic spectrometer behind ND-LAr (either TMS, ND-GAr Lite, or the full ND-GAr detector), and the PRISM movement system capable of moving ND-LAr and the magnetic spectrometer through the full range of off-axis angles.

Attachments:

Charge to the LBNC from Nigel Lockyer for the DUNE Near Detector Day 1 Review (see next page)

DUNE-US Near Detector Preliminary Design Report: TMS Chapter rough draft. Dated November 25, 2020.

Physics Performance of the Day-1 Near Detector. Dated February 1, 2021.

Questions from the LBNC in advance of the Day 1 Near Detector Review; Responses from DUNE. Dated February 19, 2021.

Charge to the LBNC from Nigel Lockyer for DUNE Near Detector Day 1 Review

The DUNE Collaboration has described the full Near Detector it believes is needed to execute its proposed program of oscillation measurements in the Near Detector Conceptual Design Report, currently under LBNC review. The measurement program will be executed over a time frame of multiple decades. Within that context and the necessity for optimization of currently available resources, the Collaboration has been asked to consider staging scenarios for the Near Detector under which a reduced set of Near Detector components could satisfy scientific objectives over the first several years of detector operation. The collaboration has proposed a "Day-One" Near Detector configuration that it believes can be built with currently available resources and will be sufficient for performing initial oscillation measurements, focusing on a potential three sigma observation of maximal CP violation, over the first 3-5 years of detector operations. The LBNC is requested to review the Collaboration-proposed staging plan for the Near Detector and provide feedback on the following:

(1) Will the proposed Day-One Near Detector meet the stated scientific objectives for the defined, initial period of detector operations?

(2) Do Collaboration plans for advancing design work, carrying out prototyping activities, and performing physics studies provide confidence that a Preliminary Design Report (PDR) demonstrating the viability of the Day-One detector configuration can be finalized on the time scale of late 2021?

(3) Are there any redundant elements of the proposed Day-One Near Detector that could be installed later and not impact the collaboration's ability to meet its initial science objectives?