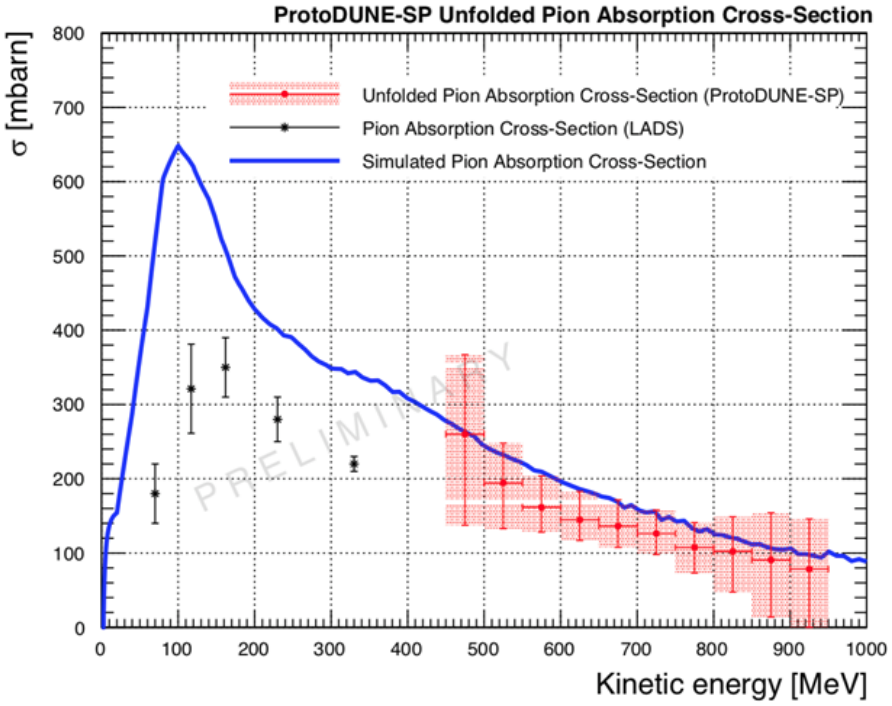
LBNC Meeting Report



December 1-3, 2021

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Introduction

The LBNC met December 1-3, 2021, the third and final meeting of 2021.

The attendees at the meeting, shown in Appendix I, included LBNC members and consultants, DUNE Collaboration spokespeople, Gina Rameika and Stefan Soldner-Rembold, and LBNF/DUNE members, Fermilab Director, Nigel Lockyer, and Fermilab CRO Kevin Pitts, Chair of the FNAL Physics Advisory Committee, Chair of the DUNE Resource Review Board, and representatives of the US DOE.

The activities of the LBNC are used to monitor the technical progress of the International DUNE collaboration and those aspects of the LBNF Project which have direct impact on the DUNE experiment. The latter is accomplished with a single presentation at the beginning of the meeting: at this meeting the discussion of progress with the beamline is also included in the LBNF report. The Fermilab Director requests assistance in this process from a number of experts, who supplement the expertise of the LBNC members in the scrutiny.

The project continues to make changes to match its organization to that of the LBNF/DUNE-US DOE project needs. The goal is to reach an agreed and sustainable path towards a baseline for each of the LBNF/DUNE Sub-projects.

The charge for this meeting, prepared with guidance and approval from the Director is shown in Appendix II. For this meeting there was emphasis on understanding the current staffing and schedule progress.

For each meeting the LBNC is organized into small groups which concentrate on particular components of the presentations and the discussions. The makeup of the teams for this meeting is shown in an Appendix III. The committee as a whole discusses and reaches a consensus for both the Closeout Report and the Meeting Report.

We hold three full meetings a year. In practice with progress in the several sub-projects and consortia, it is a rare trimester during which we do not have multi-hour interactions between the LBNC and DUNE teams. We appreciate the excellent tenor of those interactions. During the past couple of months, in order to follow closely the progress of R&D and design of the Far Detector Vertical Drift module, a supplementary meeting between the LBNC and the Vertical Drift team took place on November 15, 2021. The results of that review have been integrated into both the Closeout Report and the Meeting Report for this meeting.

At each meeting the LBNC makes the Closeout Report open to all, and subsequently prepares this LBNC Meeting Report. The agenda and presentations used for the meeting, the Closeout Report, and this report can be accessed at**:** https://lbnc.fnal.gov/

Again, for this meeting, the presentations have been excellent, and we are pleased that the profile of the physics analyses and the data acquisition was raised, it added diversity. For this, the LBNC thanks the DUNE and LBNF participants. Finally, the committee thanks Fermilab, its Directorate and support staff, for their assistance and support in making this meeting possible and productive in an unfriendly covid environment.

Executive Summary

The report from LBNF provided a broad view of the project, capturing the tailoring into sub-projects, the build out of the staffing of the new organization, and its interfaces with the DUNE collaboration structures. The excavation is proceeding apace, and the excavation of the north Main Cavern was started on November 18, 2021, this represents an important milestone.

The LBNF/DUNE Project Manager will retire in the near future; her replacement is important for the project.

There has been excellent technical progress in the beamline design, however, the impact of the planning to work with the DOE funding guidance will demand a hiatus in the beamline sub-project, which constitutes a long-term risk. The matrixed staffing will need to be carefully managed.

DUNE has continued to make excellent progress with the first two Far Detector modules, FD1-HD and FD2-VD, which now are parts of the same DOE sub-project of LBNF/DUNE-US. DUNE is also consolidating the plans for the Near Detector, again, in concert with the LBNF/US-DUNE project. The interfaces between the Project and DUNE, resulting from the re-organizations, which were reported at the September 2021 Meeting of the LBNC, appear to be working well.

The FD1-HD module is preparing the components, making final tests and checks, as it moves towards installation, of the FD1-HD Module 0 configuration, in NP04. They have experienced minor setbacks which have been resolved and valuable lessons learned.

The FD2-VD concept is barely 15 months old, but progress with the R&D programs has been exemplary. Important risks are being resolved and the LBNC is convinced that the path chosen is the right one. The Conceptual Design Report has been completed and reviewed and a close-to-final draft is in the hands of the LBNC. We anticipate recommending approval to the Director before the end of 2021 or soon thereafter.

Simulation of the Horizontal Drift module formed the basis of the understanding of the physics performance developed for the initial suites of Conceptual and Technical Design Reports. It is important that the great progress with the technical development of the FD2-VD be matched by an understanding of its performance. To that end, DUNE is developing detailed simulations of the Vertical Drift Time Projection Chamber and Photon Detector System. Progress has been good, but we are concerned that it be sufficiently well advanced for CD2.

Over the course of 2021, the Near Detector has completed a conceptual design for complete suite of detectors to a basis for a baseline. The physics permits a phased approach, which has led to the definition of a more modest initial detector suite, for which the resources have been largely identified. That detector configuration was reviewed by the LBNC which found that it could satisfy initial requirements. Following discussions with the DOE, an upgrade path to the detector, which would support goals at the level envisaged by P5, is under development.

We heard a comprehensive outline of the Data Acquisition plans, the first in some time. We recognised that a coherent plan is emerging. The DAQ is already functional at the level of the several cold boxes and at the level of the ProtoDUNE detectors. It is also intended to scale to that

of the DUNE Detectors. Work is still needed to ensure that the wide variety of interfaces needed are supported and also that the Near Detector systems can be well integrated. The LBNC looks forward to hearing more in future meetings.

The Computing Consortium has made excellent progress in acquiring dedicated support and funding for its efforts. These resources now contribute to its ability concurrently to support operations, developments of plans, for example for the software frameworks. However, we are disappointed with the lack of progress on the Conceptual Design Report. Such a comprehensive document is urgently needed to guide the efforts of the Computing Consortium and the DUNE collaboration more broadly.

ProtoDUNE Analysis was also promoted, for this meeting, to Plenary status. A discussion emphasizing both the technical reconstruction and fitting, but also bone fide physics measurements, was provided. These results have already provided the basis for several doctoral theses. Publications are happening and more are planned.

In our September meeting we heard about the funding profile advanced by DOE. In this meeting we have seen, in several areas, the difficulties that this leads to in the management of the project and the experiment, and the resulting impact on physics. DUNE has been designed with the P5 vision in mind and it was understood that, with competing programs and projects, and finite resources, the time to physics would be quite long. However, the LBNC sees that LBNF is developing the facilities, and DUNE is developing the experiment. Together they provide enormous breadth and depth and match the P5 vision. They will set the scene for several decades of neutrino physics. However, it cannot be ignored that the delays incurred in the schedule will have an impact especially on the initial physics; we urge the stakeholders to seek a remedy.

Overall, LBNF and DUNE continue to make enormous progress and we congratulate the presenters and their teams on the effort they have deployed so enthusiastically and effectively.

LBNF Status

Findings:

- Reorganization into subprojects will allow the far site excavation activity (FSCF-EXC) to obtain full excavation construction authority. A DOE CD-2/3 IPR is scheduled for 10-12JAN2022.
- A CD-1R "Reaffirmation" review (CD-1RR) is planned for Q2CY2022 and will establish a revised point estimate and cost range. A successful review will require that there be no scope gaps or uncertainty.
- The Near Detector scope proposed to reach the ultimate physics goals does not match the scope that can be supported by the project. A phased plan is being developed which will prioritize delivery of scope capable of supporting initial physics requirements, followed by a path external to the project that leads to a more capable ND.
- Excavation work at the far site continues to make progress, with the subproject work presently 53% complete.
- Procurement of the N2 system is progressing. A Phase 1 pre-Front End Engineering Design (award expected Jan. 2022) will deliver technical studies and proposals for a follow-on Phase 2 base contract + options for full scope. The Phase 1 consent package is ready for DOE submittal, with deliverables due 4 months after award.
- Subprojects are laid out in an updated organizational structure.
- Project staffing needs are understood, and efforts are ongoing to fill the remaining holes. Concerns include impending PM vacancy and potential issues filling open NS openings due to the funding-limited, extended project timeline.
- A dual-objective funding profile has been implemented which shows a technically limited schedule for excavation and FD1&2 construction and a funding limited schedule for beamline and ND construction.
- The project continues to test alternate LAr purification media to mitigate any possible risks. In addition, value engineering is being done within the collaboration (such as for removal of N2 as well as O2) which, if eventually proven beneficial in large-scale testing at CERN, could be considered for the detectors.
- LBNF has been divided into subprojects with subproject leaders. This new organization and array of new personnel in LBNF has had a positive impact on Technical Coordination efforts. Technical Coordinators sit within both the collaboration management and subproject management teams to facilitate the integration of the non-DOE contributions to the detectors within the overall project structure.

Comments:

- The committee commends the project on the progress made, particularly on the excavation activities. Work is underway on several fronts, including the pilot drift on the North cavern, imminent completion of the permanent grizzly, and expansion of the south access drift.
- Planned February departure of the Project Manager from the senior leadership team is a concern and could represent a risk to the project.
- The far-site excavation logistics is complex with many project and EH&S risks attached.

The team should continue to manage risks and activities closely, especially until the Yates shaft service is restored.

Recommendation:

1. Prioritize the search for a new Project Manager to make the transition in this critical role as smooth as possible.

Beamline Status and Progress

Findings:

- Progress since the last LBNC:
  - Refining project estimates through the development of interfaces and BOEs
  - Horn and target (RAL) mechanical and electrical components and subsystems prototyping
  - Component development for magnetic shielding required in some areas of the beam line
  - Design development of the radioactive cooling water system
  - First results of radiation simulations in preparation for a major MARS campaign and refinement of the target shield pile design
  - Design completion for Target System Integration Building which will support horn and target integration/handling testing, target construction and development towards high-power
- Minor delays (about three months) in procuring some horn components have been encountered but no impact on the testing schedule is expected.
- The latest funding profile has been integrated into the beamline schedule, resulting in a 33 months delay and a significant dip in activities and resources in the 2024/2025 timeframe. Succession planning, as well as some details of the new sequencing are still being worked out.
- The accelerator shutdown schedule has not changed, but the scope has been adjusted. Now, a civil construction tie-in is planning for the long shutdown. Temporary radiation shielding will allow to continue component installation while beam is provided to Mu2e. This will be followed by beam line connection in a later (possibly slightly extended) shutdown.
- The PIP-II and Mu2e projects are not affected by the LBNF schedule changes.
- Most technical challenges have been addressed. Minor remainder is tritium mitigation in shielding gaps

Comments:

- Once more, the LBNC is impressed by the progress made since the last meeting and appreciates the transparent presentations including answers to our questions. Progress includes significant maturing of design, refinement of project estimates, successful component and subsystem prototyping, shielding simulations and the design completion of the important Target System Integration Building. It is good to see the 3D models maturing and substantial hardware being manufactured and tested.
- A proposed Target System Integration Building (TSIB), funded outside of the LBNF project, will provide a much-needed horn assembly area, as well as infrastructure for high-power target development, required for 2.4 MW. Not only will TSIB provide a nice facility for LBNF target system work, but it will serve as a long-term investment supporting this enabling technology.
- The LBNC is relieved to see that a long-standing top-level risks, availability of pulsed, high-power power supplies expertise, has been mitigated by leveraging collaborations and additional strategic hires.
- The main concern is the projected resource and effort dip in 2024 - 2025 as a result of

accommodating the newest funding profile. The LBNC endorses the plan to work towards completing designs without delay. However, the long gap before procurement, manufacturing, installation and commissioning poses a high risk as far as retention of critical expertise within the matrixed organization of this part of the project is concerned.

DUNE Status

The LBNC commends DUNE on very good progress made on several different fronts. More specifically on:

- Advancing ProtoDUNE-I analyses efforts
- Progressing with ProtoDUNE II installation in 2022
- Completing the FD2-VD CDR,
- Making significant progress, beyond expectations, on several FD2-VD R&D efforts
- Progressing on ArgonCube 2X2 demonstrator installation and operations at FNAL
- Having developed a viable plan for the FD2-VD Module 0 installation in 2023
- Tracking and presenting status and progress made on previous LBNC recommendations
- Continuing efforts towards attracting new Institutions, and better understanding of their contributions in both detector and physics-related work,
- Intensifying the efforts on DUNE's contributions to Snowmass, developing and delivering a coherent strong physics message, and
- On continuing to work on all necessary aspects (cost, schedule, organizational) needed for getting the LBNF/DUNE-US Project through a successful CD-1RR process.

The LBNC heard a discussion of the DUNE schedule. In its 2013/14 report P5 envisaged a schedule with a gradual ramp up of the sensitivity reaching full power with a complete detector by approximately 2035. The experiment would then have the capability, with a ~decade of operation, to determine the neutrino mass hierarchy and measure CP violation at 3-sigma over 75% of the possible parameter space. The experiment would also have an unmatched sensitivity to nucleon decay, neutrinos emanating from supernovae stellar explosions, and to physics beyond the standard description of neutrino interactions. As we opined in our September report, DUNE would be a 'best-in-class' experiment. The planned schedule, at that time, was constrained in part by the need to fit the funding profile within the competing needs of other large HEP projects such as the HL-LHC and the concomitant detector upgrades. Against that backdrop the progress of LBNF/DUNE and PIP II thus far has been somewhat slower but not dramatically inconsistent with such a vision.

The new DOE funding profile, imposes constraints that lead to a further delay in the completion of the beamline of order 3-4 years. With only two Far Detectors installed at that point, this results in a significant diminution of the initial impact on our timely knowledge of CP violation from the DUNE experiment. Given the international competition from Hyper-K, in Japan, on CP violation, and JUNO, in China, on the neutrino mass hierarchy, the LBNC is very concerned. In addition, this stretched funding profile adds significant risk to both the beam and the ND development, as well as to the related work, progress and retention of the needed level of engagement, of the physics groups. Therefore, the LBNC emphasizes the risk of losing an important fraction of the early physics impact of DUNE as a result of the funding plan, and the need for a remedy.

The LBNC acknowledges that DUNE, together with other LAr experiments (MicroBooNE, Icarus) has established the excellence of the LAr TPC design and is in a very good position to deliver the P5 goals. Related to this and concerning the Snowmass process, LBNC feels it would be helpful if DUNE could make sure that the breadth of the physics program is properly emphasized and

communicated, in addition to highlighting and re-iterating its very strong neutrino oscillation program and its ability to do precision neutrino oscillation physics due to the excellent detector capabilities.
For example, they should:

- Remind the community that for great discoveries, or confirmation of those, that involve delicate measurements, often complementary and orthogonal experiments are needed.
- Remind the community that, in addition to the neutrino oscillation capability, DUNE is a world-class multi-purpose experiment, an observatory, with a broad physics program
- Emphasize that observation of a Galactic SNB is likely during DUNE's lifetime
- Remind the community of the rich BSM physics program it can do with the Near Detector (Dark Photons searches, Axion-like particle searches, Z' searches, Heavy Neutral Lepton searches)
- Emphasize the suite of novel and unique Standard Model physics measurements it can perform with the Near Detector

Given the current funding profile, LBNC encourages DUNE to investigate and explore whether a faster ramp-up of the beam would be possible, since it would aid in a timely physics output given the international competition, and hence significantly advance DUNE's physics impact.

The LBNC encourages DUNE to continue the efforts to identify whether adequate resources are in place for all DUNE activities both near term, and long term, and for both detector and software and physics analysis related work. To that end, LBNC urges DUNE to identify and increase personpower for TMS, identify and strengthen, if necessary, analysis groups working on atmospheric neutrinos and other physics topics that do not require the neutrino beam. DUNE should also clarify what analysis efforts are included in the "BSM physics" category in order to better articulate what analysis efforts already exist, for example, on nucleon decay.

Given the importance of ND-GAr in achieving DUNEs ultimate physics goals, LBNC is pleased to see that ND-GAr is now being considered as the upgrade path of the Phase-1 Near Detector. To that end LBNC suggests that DUNE communicate the plan to the LBNC, when it is formed.

FD Horizontal Drift

LBNC very much congratulates the FD team on significant progress since the last meeting. Progress has been remarkable, and the project overall seems to be well on track. The cooperation and coordination between the two anticipated production sites in the UK and the US seems to function well. We note that the UK production site is ready to go, with two winding machines available.

A refined schedule for the APA production was presented to the LBNC, which now includes a much more sophisticated modelling of the production process, including a realistic model of the ramp-up-time for production. LBNC is pleased to see that the schedule now includes an overall contingency of about six month towards the anticipated delivery. The concept of shipping the modules to the US, storing them at Fermilab, and finally transporting them SURF seems realistic. We applaud the collaboration for the plans to execute a significant test of this procedure in the near future.

LBNC points out that the ultimate goal of 33 days per APA for the production is ambitious, though doable. Still the collaboration needs to watch this very carefully, to quickly spot possible delays.

We appreciate the work done to explore alternative material options for the CRP material. The collaboration explained the situation and lack of a realistic alternative. The decision to not follow up further on these options is supported by the committee.

The problems with the CRP boards came as a surprise, and we are pleased to see that a quick solution was identified. However, the fact that such an issue was missed points out that full system tests at every step are very important, and management needs to keep a close eye to ensure proper quality control.

We are very pleased to see progress with the ASIC sourcing and test. We remain concerned that other sourcing issues, for example, the capacitors for the boards, are potentially serious and need careful monitoring.

We appreciate the presentation on the state of the calibration system and the plans for installing this in ProtoDUNE II. We would like to point out that there are still many engineering challenges to solve, to arrive at a reliable and working system, although the principle of the calibration system is well established. We very much look forward to results from the test in protoDUNE II.

FD2 Vertical Drift

Progress on the R&D Program

The LBNC held a meeting with the DUNE-FD2 group on Nov 15 to update the committee on the R&D. The committee was very impressed by the technical progress, and very much appreciated the detailed and informative presentations and discussion. Some highlights from that meeting and from the breakout session at this meeting are noted below.

The milestones provided to the committee last April are being met - some a few weeks behind, and some ahead. Progress continues to be excellent, giving confidence in the planning towards module-0.

R&D highlights

Demonstration of the HV extender and 6m drift depth in NP02 is a crucial step, and the project has achieved a major milestone in operating the system at 300 kV and has verified that 40 cm of liquid argon between the extender and the membrane provides sufficient insulation. The new Field Cage design shows no excessive bubble streams (which was a problem in the original DP design), and a section with 70% transparency, needed to allow PDS module placement on membrane walls, is performing well. Intermittent small current glitches with typical rate of 1 per hour were observed at the insulated support at the top of the extender. While this is not a problem for NP02 operation, the project has a plan in place to understand and mitigate the behavior with additional dedicated tests. NP02 operation was interrupted by a failure that damaged the external feed cable and the HV feedthrough. A detailed failure analysis is ongoing, and it is expected that the problem will be understood and addressed. The system is currently being recommissioned with the previous feedthrough used for the first protoDUNE run.

The coldbox developed for validating the CRP and PDS designs is operating well. A series of four runs and design iterations is foreseen through 2022, including pretesting final assemblies for module-0. A full CRP with half instrumented with the top readout electronics and half with the bottom readout electronics, was successfully operated and tracks reconstructed, before being extracted for modifications that have reduced common mode noise. Operation will resume in mid-December.

The committee is very impressed with how well the construction of this first CRP proceeded. It illustrates both the expertise of the team and the well-developed design.

An initial configuration of PD modules is included in the coldbox with power-over-fiber and signal-over-fiber electrical isolation. Analog and digital readout options are being developed and will be tested in future coldbox runs, with a decision point for module-0 and the final design in mid-2022. The committee is pleased to see the increase in the number of groups contributing to the PDS development, and commitments for system production.

Progress on the Design

The CPR strip pitch, electronics channel and module count have been optimized (leading to significant cost savings). This update will be incorporated in the next prototype rounds in the coldbox.

The cryostat roof layout has been defined, and the engineering contract for the design will be released in December.

The project has organized a series of formal Preliminary Design Reviews for Jan-Apr, in order to prepare the technical design for baselining. In preparation for project baseline, the committee considers an assessment of the PDS prototyping in early summer to be a critical step. And the timeline for the performance studies is a concern (see the next section of this report).

Review of the Conceptual Design Report (CDR)

On November 24 DUNE provided a point-by-point response to the more than 300 comments and questions from the review of the first draft, along with a new release of the document with several updated sections. The committee is currently reviewing these. Further follow-up will likely be limited to a few specific points - we anticipate the review process can be completed in December.

Recommendation

At the next LBNC meeting, update the committee on the Preliminary Design Review process and provide the technical reports for each of the reviews to date.

Vertical Drift Simulation

The LBNC welcomed the two presentations about the status and plans for the vertical drift simulation.

The LArTPC geometry has been implemented and wire cell and signal processing configurations are available for all vertical drift designs. Hits are reconstructed using the GausHit algorithm. Pandora is used for pattern recognition and the larsoft interface has been adapted to accommodate the geometry. Tunings and training were copied from HD and validation and additional tuning will be performed. Calibration constants were tuned to obtain the expected dE/dx. Neutrino ID is performed using CVN, which uses images of hit clusters and outputs classification of neutrino flavors. An initial training of CVN was presented and the committee notes that the network is currently overtrained, which is understood to be due to the limited statistics available in the training sample. The plan to tune and validate the 3D reconstruction and retrain the CVN selection by the end of January is ambitious but is an important component towards obtaining an estimation of the oscillation sensitivities.

The vertical drift photon detection system simulation is being prepared for the reference and the backup design. The fast simulation with a semi-analytic model is parametrized as a function of the photon wavelength, distance and angle based on the full G4 simulation and has been integrated into LArSoft. Events are reconstructed using hit finding (peaks), flash finding (coincident hits across multiple channels), and then the largest flash is matched to the original event.

Plans and a timeline were presented for initial physics sensitivity studies by October 2022 and a full assessment of the FD2 physics scope by 2023, which the LBNC notes would be after CD2 is currently scheduled. The LBNC feels this simulation needs additional emphasis. The LBNC would like to hear regular updates on the progress and staffing of the VD simulation and physics analysis plans.

Recommendation

We recommend that DUNE define a plan for VD simulation, indicating the main milestones and how they support the needs of the VD community as a whole. The plan should include staffing needed and what is available. We would expect to discuss this plan at the March LBNC Meeting.

Near Detector

DUNE is organizing an internal review of GRAIN, a proposed active liquid argon target for the SAND detector. This review is planned for early February 2022. DUNE will present results from this review to the LBNC at our March meeting, as requested by the LBNC at its September 2021 meeting. The scope of this review includes the physics case for GRAIN, technical requirements, and potential interferences with other systems. The LBNC looks forward to receiving the results of this review at our next meeting.

After receiving guidance from DOE, DUNE has reaffirmed that the Phase 1 Near Detector (ND) will include ND-LAr, DUNE-PRISM, SAND, and the Temporary Muon Spectrometer (TMS). ND-GAr may be proposed as a future upgrade, but is not included (even partly) in the Phase 1 scope. DUNE has determined that, due to resource limitations, ND-GAr-lite is not a viable alternative to TMS for Phase 1. TMS is needed in Phase 1 in order to achieve even minimal sensitivity to CP violation. ND-GAr itself will be needed during Phase 2 in order to reach DUNE's physics goals, as simulation studies show that TMS will not be sufficient to reach DUNE's ultimate sensitivity. The LBNC endorses the staged approach of TMS for Phase 1 and ND-GAr for Phase 2. We emphasize that ND-GAr *will* eventually be required, and urge DUNE and the funding agencies to make a roadmap for developing ND-GAr for Phase 2.

For the ND, DUNE expects to complete CD2/3A in FY23 & CD3 in FY24, but then no funding to begin construction will arrive until FY26. This lull in activity is a substantial challenge for DUNE collaborators in terms of maintaining engagement with the ND. Essentially all parts of the ND effort report difficulties due to this funding schedule. We note this with concern.

LBNC previously recommended that DUNE find additional technical effort for the TMS. Due to personnel issues there is uncertainty regarding the L2 management for the TMS, which DUNE is taking stock of. LBNC remains concerned that the TMS effort overall seems to be understaffed. We recognize that the firm decision that Phase 1 of DUNE *will* include TMS may help to improve this situation, although the funding profile for the ND makes it challenging to recruit new collaborators for TMS. The host lab may need to commit resources to strengthen the TMS effort.

There is a coverage gap in slow controls for ND. DUNE is working to produce an initial cost/resource estimate for the ND slow controls for CD1RR, after which DUNE will establish a formal collaboration effort on near detector slow controls.

As part of the ND-LAr effort, DUNE is preparing the ArgonCube 2x2 demonstrator for installation in the NuMI hall next fall and is planning a preliminary design review for ND-LAr itself in summer 2022. We see strong technical progress across ND-LAr. The new LArPix-v2b ASIC has been produced and tested, achieving its design targets. Weekly engineering meetings are advancing the ND-LAr design. Systems engineering and subsystem management give the appearance of being far advanced. Improving documentation for the PDR will be a focus over the next few months. DUNE notes that there is a lack of resources to work on TPC integration and installation due to the new funding profile.

Significant analysis development has been done on including the DUNE-PRISM approach in

oscillation analyses. This includes DUNE's first 'end-to-end' PRISM predictions with the full 7-year Near Detector MC production. The LBNC welcomes this progress.

Recommendation

We recommend that the TMS be constituted as a formal consortium within the ND group, and that DUNE management actively recruit additional groups to join the TMS effort who will make it their primary focus.

DUNE Data Acquisition

At this meeting the LBNC heard a report on the status of the Data Acquisition (DAQ) consortium and its work. The committee very much appreciated this report and would like to be updated periodically in future. The practical progress reported was impressive, with prototypes being used to read out small systems in the cold boxes for both horizontal and vertical drift far detectors. The progress in defining the interfaces with external systems and with detectors is also striking. The committee is pleased to see that the requirements for SNBs are being built into the system from the start.

To understand and better monitor the progress, the LBNC would like to see the overall schedule and milestones for the DAQ project. It would also like to see an outline of the current mapping of responsibilities for the different items to institutes, to understand how well the different parts of the project are covered by available staff. The committee noted that the current staff levels are rather stretched.

The LBNC notes that while much of the DAQ project is made up of standard commercial components off-the-shelf, this is not true for critical parts, most notably the trigger system. The lead times for hardware and firmware design can be long, and so it is important to establish a detailed schedule. The LBNC would like to hear at a future meeting more on the planning for the trigger system.

The relatively early stage of much of the near-detector systems means that establishing their integration with the DAQ system will take time. The LBNC would like to see the plan for demonstrating such integration.

Computing

The DUNE computing consortium onboarded new effort for operations as well as for R&D activities. This new effort comes from existing institutes but also from new institutes that joined the consortium. In addition, a grant from the Department of Energy allowed hiring key person-power in critical areas of computing such as database development, software frameworks and data structures. The LBNC welcomes those positive developments allowing the consortium to progress faster in several areas. The consortium continues operating efficiently the computing systems of the DUNE experiment allowing protoDUNE data reconstruction and analysis. The staged ND production simulation and the pass 4a processing campaign are clear success examples. We applaud these successes.

DUNE is building more computing experience with data management and workload management services. This includes some pain points particularly in the data management area, facing unexpected usage scenarios. For example, it was reported how staging from archive media was problematic under high demand and the proper throttling mechanisms not yet being tuned. It is important that DUNE continue improving on those points and address the more challenging use cases. Beside those pain points, data management operations achieved very good stability and performance, particularly demonstrated transfer of 1.5 PB of analysis data over the Atlantic at sustained high rate. There is progress for providing the needed wide area network connectivity from SURF to FNAL and a timeline is in place. The 100 Gbps primary link seems to be adequate to the future DUNE's needs. The 10 Gbps backup link might imply a risk for data taking should the primary fail. We suggest this risk is better evaluated. We also suggest considering the challenges of remote detector controls in the network discussion.

We congratulate DUNE for the transparent integration of the GPU resources on the Google cloud and their use for reconstruction. It indicates the flexibility of the DUNE distributed computing framework to integrate heterogeneous resources. It also shows a degree of maturity of the DUNE software in leveraging accelerators such as GPUs.

There seems to be limited progress in editing the Conceptual Design Report, while considerable technical progress was shown at the meeting. We suggest that DUNE provides a descriptive outline of the CDR document by the middle of January 2022, identifying the main contributors. We expect the CDR to be delivered by early Spring 2022 as planned.

ProtoDUNE Physics Analysis

The LBNC is happy to see that substantial progress has been made on the protoDUNE physics analysis. Two papers are undergoing ARC review (Pandora reconstruction and hit-tagging CNN) and one paper (Michel electrons) is undergoing internal review. Measurement of hadronic cross sections and the cosmic ray seasonal variations analysis are in the final stages of development.

The Pandora reconstruction paper shows consistent efficiencies for data and simulation for a range of particle species. The hit-tagging CNN shows consistency to within 2% in hit classification for data and simulation, however, the shape of the CNN for protons has discrepancies. The LBNC understands that these can be corrected for at a later stage, however, we are glad to hear that DUNE will continue to investigate to improve the simulation.

Good agreement between data and simulation for the Michel electron energy distribution is observed. Hadronic cross sections are measured using the thin slice method in inclusive and exclusive channels. For the 1 GeV π^+ absorption channel interactions, the LBNC is happy to see measurements made using two different methods. It appears that the G4 cross section may be overestimated, and care should be taken to ensure that all systematic uncertainties for the template method are included.

In several analyses the systematic uncertainty due to limited statistics in the MC sample for unfolding is significant, so we encourage the team to use samples with higher statistics. Encouraging preliminary results for measurements of the proton and kaon inclusive cross sections, neutron cross sections and cosmic ray seasonal variations were shown. The LBNC notes that there are differences between ProtoDUNE and MiniCaptain in the measurement of the neutron cross section. The ProtoDUNE results suggest that the cross section is approximately a factor of 2 larger than that in G4 and the MiniCaptain results appear to require a cross section scaled by a smaller value. The LBNC looks forward to the final analysis.

Appendix I: Attendees

Committee: Ties Behnke, Simone Campana, Dave Charlton, Francesco Forti, Cristiano Galbiati, Alexander Gottberg, Heather Gray, Joachim Kopp, Gobinda Majumder, Hugh Montgomery, Scott Oser, *Adam Para,* Tom Peterson, Niki Saoulidou, Jeffrey Spalding, Eric Kajfasz, Darien Wood;

Scientific Secretary: Angela Fava

Fermilab PAC Chair: Hirohisa Tanaka

DUNE/LBNF (based mainly on registration: Regina, Rameika, Stefan Soldner-Rembold, Chris Mossey, Elaine McCluskey, Alan Bross, Alberto Marchionni, Alessandro Thea, Alfons Weber, Andrew Lambert, Andrew McNab, Bo Yu, Callum Wilkinson, Chris Backhouse, Chris Marshall, Ciaran Hasnip, Dan Dwyer, Dario Autiero, David Christian, Dominique Duchesneau, Elisabetta Pennacchio, Eric James, Flavio Cavanna, Francesco Pietropaolo, Giovanna Lehmann, Haiwang Yu, Heidi Schellman, Inés Gil-Botella, J. Pedro Ochoa, Jaehoon Yu, Janet Bishop, Jolie Macier, Leigh Whitehead, Luca Stanco, Luke Pickering, Marzio Nessi, Maxine Hronek, Michael Kirby, Michele Weber, Pete Clark, Ron Ray, Sandro Palestini, Sergio Bertolucci, Steve Kettell, Steven Manly, Steven Timm, Takuya Hasegawa, Thomas Junk, Tim Bolton, Vyacheslav Galymov

FNAL Directorate/Management: Nigel Lockyer, Joseph Lykken, Kevin Pitts, Gregory Bock

DUNE RRB: Alison Markovitz

DOE: Adam Bihary, David Lissauer, Simona Rolli

Appendix II:
Charge Letter: LBNC December 2021 Review, December 1-3, 2021

In this third and final meeting for calendar 2021, the LBNC will again meet virtually to review status and progress of LBNF and DUNE. As with other meetings, the LBNC should construct a report in which it acknowledges, comments on, and where appropriate, makes recommendations following the presentations and discussions during the meeting.

The LBNC should hear about the general status of LBNF and DUNE. Although the LBNC is charged to review the global LBNF/DUNE effort, of particular interest right now is the progress toward US DOE CD-1RR review, which is a re-evaluation of "Alternative Selection and Cost Range." Effort toward CD-1RR includes the tailored subproject strategy, a reorganization of the project management – including the interface to the DUNE collaboration – and assessment of the cost range and projected funding profile. The LBNC should hear about progress on these issues and provide input and feedback.

In considering the material provided, attention should be given to prior LBNC recommendations and actions that have been undertaken to address these recommendations. For the DUNE detectors and computing, we would also like to work toward a more uniform and regular reporting and tracking of major DUNE milestones.

In reviewing DUNE detector and computing efforts, particular attention should be given to near-term staffing issues. Does the Collaboration have sufficient personnel to carry out efforts over the next 12-18 months? These efforts include R&D, design, prototyping and pre-production work as well as integrated efforts, such as both ProtoDUNE-II detectors.

In addition to updates on major detector systems: FD-1, FD-2, ND, the LBNC should also receive updates on progress on ProtoDUNEs and LBNF Beamline. Other specific areas of review for this meeting should include data acquisition and calibration, where the LBNC should hear about the overall approach, strategy and plan for these areas.

The LBNC should also review progress on computing and the computing CDR, as well as other relevant documents that are under development.

The LBNC should develop a Closeout Report which it should deliver at 12:15 CST on December 3, 2021. Subsequently this should be refined into a LBNC Meeting report.

Appendix III: Assignments

Consultants shown in Italics

LBNF Status (Progress, Plans and Organization)	**Fuerst**, Peterson, Gottberg
DUNE Status	**Saoulidou**, Gray, Kopp
FD1 Horizontal Drift	**Behnke**, Fava, Majumdar
FD2 Vertical Drift	**Spalding**, Forti, Galbiati, Kajfasz, Para, Wood
Near Detector	**Oser**, Kopp Saoulidou
Computing (inc CDR Status)	**Campana**, Gray
ProtoDUNE Analyses	**Gray**, Campana, Charlton
DUNE Data Acquisition	**Charlton**, Campana, Kajfasz
Breakouts	
Beamline Status & Progress	**Gottberg**, Fuerst, Peterson
FD2- Vertical Drift Progress inc CDR	**Spalding**, Forti, Galbiati, Kajfasz, Para, Wood
Vertical Drift Simulations	**Gray**, Charlton, Campana
FD1- Horizontal Drift Progress	**Behnke**, Fava, Majumdar
Near Detector Progress	**Oser**, Kopp Saoulidou
DUNE Computing Progress;	**Campana**, Charlton, Gray