Report from the LBNC Review of the DUNE SPVD Project

Review held April-May 2021

Final Report dated June 11, 2021

Introduction

The DUNE collaboration is proposing a Single-Phase Vertical Drift (SPVD) design for the second Far Detector module (FD2). SPVD builds on the earlier Dual Phase approach and the Single-Phase Horizontal Drift (SPHD) proposed for FD1, while employing a new innovative design for the charge readout in the TPC. DUNE plans to submit a Conceptual Design Report (CDR) for SPVD to the LBNC in summer 2021.

The present review covers the status, progress and plans for the SPVD design and R&D program, and preparations for the CDR. The charge for the review is attached in appendix 2.

The review was conducted in three video meetings, each covering different aspects of the project:

April 28	–	Technical Design and R&D Program
May 10	–	Simulation, Detector Performance and Physics
May 11	–	Detector Assembly, Project Planning and Schedule

Following each meeting a series of questions from the committee were addressed by DUNE via email, with 52 questions in total. The presentations at each meeting and the response to questions are linked on the agenda web pages, listed in appendix 3.

This report consists of an executive summary, followed by response to each of the nine questions in the charge.

Executive Summary

The committee commends the project on the rapid and impressive technical progress in developing the design, in planning and embarking on the R&D program, and in building an effective organization to support SPVD. The design is at an advanced conceptual level, and while the R&D schedule is tight, the project is making excellent progress.

The design preserves and capitalizes on the successes of ProtoDUNE-DP (NP02) and ProtoDUNE-SP (NP04), and addresses the major challenges of the Dual Phase design by shortening the drift distance, hence reducing the required HV, and by replacing the gas-gain readout with a new single phase charge collection scheme. This is enabled by the demonstration of excellent liquid purity attained in both the NP02 and NP04 cryostats.

The committee endorses the SPVD approach. The modular design using standard industrial PCB technology will allow more rapid parallel assembly. It uses the electronics developed and already prototyped for protoDUNE-DP and SPHD, and it includes a Photon Detector System (PDS) with detector modules based on the Arapuca system under development for SPHD. The cryostat, cryogenic and control systems, and DAQ are based on and are largely in common with the systems for SPHD and have been tested in the protoDUNE running in 2019.

The design features two horizontal anode planes (at ground potential), top and bottom of the liquid volume, that read out charge tracks in the TPC, with a central cathode plane (at 300 kV). The drift depth (cathode to anode) is 6.5m above and below the cathode. The PDS system is distributed on the cryostat side walls and within the structure of the cathode. While much of the design capitalizes on the extensive work for SPHD and DP, there are three challenging developments needed for SPVD that require R&D and study: (a) the 6.5m drift space requires an HV system that can supply 300kV to the cathode plane, (b) each of the anodes planes consists of 80 Charge Readout Planes (CRPs), the basic assembly unit for the TPC charge collection and readout, that use a new drilled PCB structure for charge collection, and (c) the Arapuca to be developed for the PDS provides electrical isolation to allow operation at 300 kV, when mounted on the cathode plane. In addition, the liquid argon (LAr) flow dynamics through the three horizontal planes (two anodes and cathode) must be fully studied to ensure adequate uniformity of the purity and thermodynamical characteristics of the liquid.

Two major design decisions remain: The first concerns the extent of coverage of the PDS. The reference design places the Arapuca modules on the membrane walls of the cryostat and within the cathode plane structure. This coverage provides the possibility of extending the DUNE physics capability to lower energy events but requires successful development of modules capable of operating at 300 kV. A fallback layout with a similar total number of modules but only mounted on the walls, will be adopted if this R&D does not succeed.

The second decision is the choice of 2-view or 3-view anode plane readout for the TPC. The 3-view seems to be the more natural and conservative choice from the performance point of view and so far the committee has not identified any risks that might be mitigated by choosing the 2-view design. The choice of the angles for the readout views is more of an optimization in the design and does not require significant additional R&D once the CRP design is validated.

The R&D and design validation is planned in two phases. The first includes validation for the CRP design and demonstration of Arapuca operation in a coldbox test, and a demonstration of the new field cage design and HV extender. This phase will be initially completed at the end of 2021, with further CRP and Arapuca tests continuing in 2022. These tests will provide confidence in the most challenging elements of the SPVD design and will support the Final Design Review process in 2022.

In the second phase, a large-scale system test in the NP02 cryostat at CERN will include operation of “module-0”, meaning final design assemblies. This protoDUNE run in 2022-2023 will validate the full-scale design ahead of the Production Readiness Review. The committee endorses this two-phase strategy.

Planning for the production has started. Project management tools and processes are under development. DUNE presented the overall status of the cost estimate and resource-loaded schedule. The present level of development is already appropriate for the CDR stage and is anticipated to mature further in the next few months.

The production schedule is being developed with a target to be ready for closing the detector at SURF by the end of 2027. An analysis of schedule risk, contingency, and options for mitigating potential slippage is ongoing.

The committee considers there to be a risk that the module-0 run will be later than planned, due to stretching of schedule for the PDS module R&D or the HV extender testing. This would put pressure on the juncture between development and production, and potentially risk rushing the FDR and PRR review process. The project should be prepared for this by preparing production and production quality control procedures ahead of time to the extent possible. DUNE indicates that this is indeed in their planning.

DUNE presented the current status of planning for integration and installation, which is quite advanced. The committee notes that the integration work underground at SURF is intense, although the modular design of SPVD for FD2 certainly helps. Detailed planning and strong management oversight across all the work (LBNF, FD1 and FD2) will be essential for efficient installation.

DUNE presented the organization which supports the SPVD work. The collaboration has fully embraced the new SPVD project. A new Technical Coordinator position will ensure appropriate oversight, and the support for the project is integrated into the present consortium structure, with new organization branches formed as needed. Labor resources appear to be adequate except in a few areas where there is an ongoing effort to grow. The consortia are engaged in the present design and R&D activities and in developing plans for the production phase.

A Physics Task Force has been formed. Simulation and physics performance studies are planned and will take 6-12 months to complete. These will support the design decisions ahead of module-0 construction. In the meantime, in order to support the CDR, the group will prepare a direct comparison of low level performance parameters expected for FD2 and FD1, allowing a qualitative comparison to the physics reach described in the FD1 TDR.

DUNE presented progress in preparing for the CDR. The LBNC looks forward to reviewing this document starting late summer.

In the following we address the charge questions in turn.

Charge Questions

1 Does DUNE have a clear, consistent, and realistic view of the major design aspects of the detector and its physics goals?

(a) On the design, yes. The conceptual design is well developed, with ongoing engineering studies and prototype development covering all aspects, from the sensors and readout electronics to the cryostat.

- The SPVD cryostat, controls and instrumentation build on the equivalent systems for the SPHD design for FD1, and on the experience with protoDUNE-SP and -DP. Work on the detailed specifications for the cryostat is targeting completion in the next 3-4 months, in time to capitalize on the cryostat contract for FD1.
- The anode readout planes are highly modular, assembled in 3m x 3.4m units (CRPs), each itself assembled from two Charge Readout Units (CRUs). The CRUs are assembled from industry standard PCBs providing 3-view readout. Initially the anodes boards in the CRU are a standard industrial size, with boards connected laterally. The plan is to work with vendors to develop larger PCBs of $1.7x1.5m^2$ to simplify assembly. The CRP is the base mechanical and electrical unit which is replicated in FD2, with 80 CRPs in each of the top and bottom anodes. A first prototype CRP will be tested in the coldbox cryostat at the end of 2021.
- The readout electronics for the top anode plane uses the system developed for the earlier DP design, and operated successfully in protoDUNE-DP, while the bottom anode plane uses the electronics developed for SPHD and FD1 and operated in protoDUNE-SP. While it may require additional resources to commission and operate two electronics systems, there are clear advantages to this approach. The bottom anode readout is by necessity submerged in the LAr, and hence the

SPHD system is a natural choice. The top anode however offers the opportunity to have the electronics accessible as in the DP design, mitigating risks in long term operation.

- The PDS uses SPVD specific Arapuca modules that share many aspects with the Arapuca modules being developed for SPHD FD1 but require different geometry and optimization. The layout of the system is under study with performance simulations. The reference layout has modules mounted both on the side walls of the cryostat (outside the field cage) and on the cathode. The latter requires electrical isolation using optical powering and readout of the modules, R&D which is ongoing. While the PDS design is not finalized, the reference and fallback layouts are similar in size (640 tiles with 102,400 SiPMs, and 720 tiles with 115,200 SiPMs). This can be compared with the PDS for FD1 which has 288,000 SiPMs.
- The drift field specification for SPVD has been reduced from 500 kV/cm (as it is for FD1) to 450 kV/cm. This allows the use of an existing 300kV power supply design, and cable and feedthrough designs based on those in protoDUNE. This reduced specification meets physics performance requirements and is expected to be approved by the DUNE Executive Board imminently. Discussion with vendors is ongoing to investigate options for a ~350kV power supply which would provide operating headroom.
- The specification for LAr purity, in terms of drift lifetime, is >6ms. This is twice the value specified for the shorter drift in FD1, but well within the purity achieved in the protoDUNE cryostats. To improve light collection from the full drift depth, it is planned to introduce 15ppm Xe to the LAr.
- The design of the cathode plane and its suspension at mid height is under development, with FEA and investigation of candidate materials and support structure. The design of the HV extender that connects from the HV feedthrough to the cathode is well advanced. A prototype will be tested in the NP02 cryostat in late 2021.
- A new field cage design is well advanced with a small-scale demonstrator planned in early 2022. The new design has 70% open geometry, increasing light transparency to allow the PDS modules to be placed on the cryostat walls.
- While the design work on the above systems is well along, work on the calibration system is only just starting. This will be based on the extensive experience with protoDUNE-SP to a large extent.

(b) On the physics goals, yes. The primary physics goals for FD2 are identical to those for FD1. DUNE is comparing in detail the expected performance of the VD and HD designs to ensure that these goals will be met. Full studies of performance for different physics analyses will follow in the next 6-12 months.

The PDS reference design has better coverage than the fallback layout and will provide a more uniform sensitivity. This has the potential to enhance the sensitivity when the PDS information is combined with the TPC information. In addition, there is in principle a potential improvement in the low energy sensitivity. However, neither of these enhancements is yet demonstrated with simulation and it is unlikely that such will be ready before early-mid 2020. In particular, the enhancement of low energy triggering depends on both potential backgrounds and the low energy neutrino signals and requires detailed study.

2 Is the technical design and project planning at an appropriate level for a CDR?

Yes. As outlined above and below, the technical design is at an advanced conceptual level, the technical challenges have been identified and are being addressed with a targeted R&D program, and project planning is now at an appropriate level for the CDR and will be further matured in the next few months.

A series of internal Conceptual Design Reviews covering each subsystem is underway and will be completed by the submission of the CDR. The committee notes that DUNE plans a series of Preliminary Design Reviews starting by the end of 2021, as the engineering design and R&D mature.

DUNE is developing appropriate project management tools. The Work Breakdown Structure is in place, a Risk Register is well advanced for this stage of the project, and the cost estimate, resource-loaded schedule, and sharing of responsibilities are being developed. Progress is impressive. The cost and schedule modeling are expected to mature within the next few months. This is likely to exceed the level normally anticipated for a CDR.

3 What are the primary areas of R&D focus? What are the critical new aspects of the design, what key technical challenges, and are they being addressed?

The three key technical challenges are the CRP design, the development of Arapuca modules that can operate mounted on the cathode at 300kV, and the design of the HV extender. Additionally, design of the field cage, cathode structure and support and the study of the LAr flow with the horizontal multilayer anode and cathode planes require significant attention.

CRP

- The R&D program includes small scale tests in a 50L cryostat to study S/N (ongoing) and to demonstrate design elements such as inter-PCB connections (future). Performance testing of a full CRP in a large-scale coldbox is planned for late 2021, with further tests to follow to optimize the CRP design. This coldbox test is a major milestone for the project, and readiness of the coldbox itself is critical. The coldbox cryostat has recently been installed adjacent to NP02 and is currently being added to the NP02 cryo-control system. A dry-run cold operation is planned for July.
- While the anode planes employ industry standard PCB technology, albeit with a large number of holes to be drilled, the goal is to develop larger area boards ($1.5x.17m^2$) to greatly simplify CRU assembly. CERN is currently engaged with vendors on this development.
- The interconnections are challenging between the three board layers (two anode and one readout), and laterally between the anode boards in the CRU. R&D is underway to develop custom adaptation of industry standard connectors.

PDS

- The design of the new field cage with 70% optical transparency allows the Arapuca modules to be deployed on the membrane walls of the cryostat. The modules themselves will be similar to those being developed for SPHD, but are planned to be larger area and optimized for the 15 ppm Xe doping of the LAr. Deployment of modules on the cathode in the reference PDS layout requires modules that are sensitive to light from above and below, and the development of optical powering and readout. This electrical isolation is perhaps the most challenging aspect of the R&D program.

- The new generation of Arapuca tile is being developed using a different wave-length shifter and improved SiPM mounting, along with optimized tile geometry for SPVD application.
- Alternative metallization of the anode planes is under study and will be tested in the 50L cryostat. This has the potential to improve photodetection uniformity in the drift volume.
- Initial tests of 48v optical powering using commercial Power over Fiber (PoF) components are promising. A 5v system is also in consideration. For the optical readout, both analog and digital transmission are being studied. The plan is to test prototype modules in the coldbox at the end of 2021, and again in the early part of 2022.

HV Extender

- The HV extender which connects the HV feedthrough to the cathode is a completely new design. It is inaccessible and in principle a single-point failure in the HV system. To mitigate this risk the design includes redundancy where possible. A thorough testing program is essential.
- The interface to the feedthrough, considered to be one of the most challenging parts, is currently being tested. The complete extender will be assembled this summer for a full operational test in the NP02 cryostat in late 2021. This test will use the DP TPC and PDS, which remain installed in NP02 following protoDUNE-DP operation in 2019. This will allow measurement of tracks in the field and monitoring for any noise, sparking or instabilities. The tests will include long periods of operation and stress testing with multiple power cycles. Stress testing with a voltage higher than specification is not possible with the present power supply.

4 What are the key milestones associated with this R&D?

DUNE has a well-developed plan and timeline for the R&D, with demonstration of CRP and PDS prototypes in the coldbox and the HV extender in the NP02 cryostat. With this R&D, the decision on what to install in NP02 for the module-0 prototype run will be made summer-fall 2022 (including the orientation of the readout views in the CRP), and in particular whether to place PDS modules on the cathode structure. Module-0 operation is expected to commence in mid 2023.

The committee notes that there will undoubtedly be several issues to address in such R&D. While the timeline is credible there is risk of slippage.

The plan includes milestones associated with various test stages, analyses, and decision points. Appendix 1 lists the milestones that will be used by the LBNC to monitor progress towards module-0 demonstration.

5 What are the plans for the NP02 ProtoDUNE-VD? Are they credible? Are they consistent with the timeline outlined above?

Following tests of prototype CPRs and PDS modules in the coldbox, decisions will be made on the component designs to be installed in NP02. The NP02 run is considered a test of “module-0”, meaning that it will include the final design to be approved for production for the CPRs, the HV system (extender, cathode, and field cage) and the PDS. The plans for this run are under development, with the goal of testing as many aspects of the final design as feasible in the NP02 cryostat.

The configuration of the CRPs is under review by the collaboration. CRPs with both the top (DP style) and bottom (SPHD style) electronics will be included to test the final designs for both.

The PDS must include Arapuca modules on the cryostat wall, with at least one of the field cage walls changed to the new design. A go-ahead for the reference design rather than the fallback layout, will require that several modules be mounted on the cathode.

The R&D program outlined above targets all aspects necessary for a module-0 run in NP02. The plan is well developed. The timeline is self-consistent but carries schedule risk. The milestones noted in answer to question 4 are key to meeting this schedule. While the CRP R&D could take longer, the largest schedule risks are likely in completing the test program for the HV extender, and in developing the PDS system for the cathode location.

6 Does DUNE have a good plan for consortia contributions to the VD effort? What is the status of planning for construction and installation?

Yes. The DUNE collaboration is fully invested and integrated in the SPVD project. The appointment of a Technical Coordinator, dedicated to SPVD, ensures that the technical oversight and review processes of DUNE Technical Coordination are engaged. Similarly, the Integration and Installation Coordinator for DUNE is heavily involved in the SPVD R&D and planning. The consortia organizations are largely developed to support the project.

- CRP – A new working group and consortium are responsible for the design and R&D, and for developing the assembly plans.
- Top electronics – The consortium is inherited from the previous DP project.
- Bottom electronics – Responsibility is taken by the existing SPHD electronics consortium. Planning is well along for production of the electronics for both HD and VD.
- High voltage – The organization of the HV consortium includes groups dedicated to VD aspects, and where appropriate, groups with shared responsibility for VD and HD.
- PDS – The consortium organization has been recently expanded with dedicated groups for the development of the ARAPUCA system for SPVD. Working closely with the ARAPUCA development for SPHD, the VD organization includes 41 participating institutions. The level of effort still needs to grow to rapidly advance the optimization of large area Arapuca modules, and strong management will be needed to achieve the design and R&D program over the next year and a half. Planning for the production phase beyond the near-term R&D is ongoing.
- DAQ and Slow Controls – The systems are very similar for FD1 and FD2 and are supported by a single consortium that is already from protoDUNE operation.
- CALCI – Consortium support for SPVD is not yet formed. The specification and definition of the calibration systems for SPVD is still to be developed. It is likely that there will be significant overlap with the systems for SPHD, for example the ionization laser system and the pulsed neutron source. It is important to identify the calibration and requirements specific to the SPVD system and develop the necessary solutions.

For both the HV and PDS efforts, and DAQ, controls and CALCI, the committee notes the significant benefit for FD2 of the shared experience and expertise from FD1 in this consortium organization.

On the status of planning for construction, it is expected that the CRP and PDS production will drive the schedule. In the model developed for constructing the 160 CRPs, CERN provides central coordination and QC for vendor fabrication of the CRU anode and adapter boards. The CRPs themselves are assembled at four assembly sites (factories), likely two in the US and two in Europe. The possibility of one assembly site being hosted by the Neutrino Platform at CERN, is being explored. The steady state throughput is anticipated to be one CRP per week per factory for one-shift operation, 5-days per week. Preproduction series training, quality validation and production ramp-up are planned, and will be critical to meeting the schedule. The equivalent planning for construction of the PDS system is just beginning. It is not yet clear whether the CRP or PDS production will be the most critical in the construction timeline.

Detailed planning for integration and installation is ongoing. The work relies on staging the components and subassemblies on the surface at SURF, with final integration and installation inside the cryostat. The logistical and resource planning to date is at an appropriate level for the CDR. Further detailing and full integration with concurrent work for LBNF and SPHD is ongoing. While the timeline being developed is credible, there is concern that logistical bottlenecks may impact the schedule. The integration process will include significant testing throughout as access is lost to installed components at each phase of the installation. Training and stationing expert personnel will be key.

7 Does DUNE have sufficient personnel actively working on VD so that it can move forward on the anticipated timeline?

Largely yes, with a few areas of concern. As described in the answer above, the DUNE collaboration is fully engaged and the resources of the consortia brought to bear on the VD project. DUNE Technical Coordination, through the Technical Coordinator for SPVD, is providing oversight and coordination. Many areas of work appear to be appropriately resourced to move forward on the anticipated timeline. There are three areas of concern.

- The PDS development for SPVD is particularly challenging. It is encouraging that many groups have signed up and this dedicated consortium has grown quickly, however developing a fully effective management structure and workforce may take time. Production planning is not yet in place.
- The work on the calibration systems for VD needs to be organized and responsibilities established.
- The physics and simulation groups have started to develop plans and work on FD2, but the timeline is a concern. While the level of studies in the short-term may be sufficient to support the CDR, physics performance and simulation studies will be needed to support design decisions ahead of commitment to module-0 and to prepare for future reviews. These include 2-view vs 3-view and readout angle studies for the CRP design, and particularly the performance of the PDS layout options for the standard DUNE physics program and the possibility of extending the program to lower energies. This effort needs to ramp-up rapidly.

Finally, while the initial R&D has not required extensive travel, covid restrictions may impact the more integrated test program in the coldbox and NP02 cryostats.

8 Does DUNE have a plan for simulation and other studies which support the physics capabilities claimed?

Yes. DUNE has recently formed a Physics Task Force to support the SPVD project, engaging the physics and simulation groups. Regular meetings are held to map out the plans for supporting the CDR, the design decisions in early 2022, and eventually the TDR.

The near-term approach on the timescale of the CDR is to compare the expected detector performance at a basic level (for example the signal, S/N, pitch and resolution) for FD2 against FD1 and then qualitatively compare the physics performance for the standard DUNE physics program. The committee feels that this should be sufficient to provide confidence that FD2 can meet the general requirements for the standard DUNE physics program, but it does not quantify the actual physics performance.

More complete simulation and performance studies will be needed and are planned to support design decisions and optimizations for both the TPC and PDS, and quantified physics studies will be needed to support a Technical Design Report and DOE-CD2. Detailed studies are needed to demonstrate the potential for extending the physics with low energy events in the PDS. This requires extensive study of triggering and event backgrounds for lower energies where backgrounds may limit the ability to extend below about 7 MeV for single events. This may be less problematic for supernova neutrino bursts.

DUNE indicates that the timescale for all these studies to be completed is early-mid 2022.

The PDS simulation utilizes parameterization and light transport studies for SPHD. The main difference is the light propagation with the Xe doping. Development of the Geant4 simulation is ongoing to include the region outside the field cage, reflection from the anode surfaces, and light escaping from the Arapuca modules. It is not planned to benchmark the performance with small tests in the coldbox since the geometry is so different. A full comparison to data must await module-0 operation.

It is very important that these studies continue with sufficient resources and oversight through the next year.

9 Is DUNE on track to complete the CDR on the proposed schedule?

Yes, DUNE has a plan and appears to be on track to deliver the document for review to the LBNC in summer 2021. An initial commentary from the LBNC can then be anticipated within a few weeks. The complete review process will then include one or more rounds of Q&A between the committee and the project and may take an additional few weeks.

A series of DUNE internal Conceptual Technical Reviews is underway to approve the technical content of the document. DUNE has formed an editorial board and established a review process for the internal review of the document.

Appendix 1
R&D Milestones 2021-2023

Milestones to be used by the LBNC for monitoring progress in the R&D phase. It is understood that being R&D, plans may develop as the work advances. The milestones will be updated as necessary.

DUNE Vertical Drift (FD2-VD) Milestones (2020-2023)

System codes: M=management, H=HV, C=CRP, P=PDS, S=simulations

Date	System		Milestone		Status
2020					
1-Nov-2020	C		Validate 2-view anode (0, 90) in 50l test		done
30-Nov-2020	M,C,H,P,S		Technical proposal distributed to DUNE and LBNC		done
1-Dec-2020	M,C,H,P,S		First reviews presented to LBNC, DOE and DUNE		done
2021					
31-Jan-2021	M,C,H,P,S		FD2-VD presented to DOE IPR		done
30-Apr-2021	C		Validate 3-view anode (0, 48, 90) in 50l test		done
31-May-2021	M,C,H,P,S		LBNC technical review complete		done
20-Jun-2021	H		HV coupler and feedthrough verified for NP02 test		
30-Jun-2021	M,C,H,P		All internal conceptual design reviews complete		
15-Jul-2021	P		R&D on PDS at 300kV results reviewed, decision on cold-box PDS layout		
31-Jul-2021	C,P		Cold-box dry run completed and cold-box meets requirements		
31-Jul-2021	H		NP02 closed for 300 kV HV tests		
15-Aug-2021	C		Validate 3-view anode (30, -30, 90) in 50l test		
18-Sep-2021	M,C,H,P,S		CDR posted for CD1-RR with LBNC report		
30-Sep-2021	C,P		Cold-box closed with first full CRP+cathode+PDS		
30-Sep-2021	S		First full samples available with reference geometry and basic reconstruction		
30-Sep-2021	S		Initial studies of low energy physics improvements with PDS		
15-Dec-2021	C		First validation of (0, 48, 90) CRP in cold-box test with HV and electron drift		
15-Dec-2021	P		First validation of PDS at 300kV in cold-box test		
31-Dec-2021	H		NP02 HV (300kV) stability validation, including 70% FC performance. Validate HV and 6m drift for *module-0*		
2022					
31-Jan-2022	S		Tuned/validated 3D reconstruction ready		
31-Jan-2022	S		Newly trained CVN selection for beam events		
15-Feb-2022	C		Decision on CRP layout (not strip orientation), electronics for *module-0*		
28-Feb-2022	S		Tests of low energy tracking performance with reference geometry		
31-Mar-2022	C		Initial validation of (30, -30, 90) CRP in cold-box		
31-Mar-2022	C,S		Decision on viability of 2-view alternative based on simulation		
30-Apr-2022	C,S		Decision on strip orientation for 3rd and 4th CRP for *module-0* based on simulation		
1-May-2022	P		Intermediate assessment of PDS in cold-box runs #1-2 and decision for CRP#3		
1-Jun-2022	H,P		Decision on *module-0* FC configuration		
30-Sep-2022	C		Initial validation of full top CRP with mechanical support in cold-box		
30-Sep-2022	P		Decision on *module-0* PDS layout		
1-Oct-2022	M		Ready for FD2-VD US CD-2, including PDR design reviews and full P6		
30-Nov-2022	C		Initial validation of full bottom CRP (from US factory) in cold		
2023					
15-Jan-2023	C,H,P		Start *module-0* installation		
1-Mar-2023	M		Ready for FD2-VD US CD-3, including all FDRs		
30-Sep-2023	C,H,P		*Module-0* closed and start cool-down		
1-Nov-2023	P		Assess PDS performance in *module-0* and decide on DUNE PDS/FC configuration		
1-Nov-2023	C		Assess CRP performance in *module-0* and decide on DUNE CRP configuration		
31-Dec-2023	M,C,H,P,S		FD2-VD PPRs completed		

Appendix 2
Charge for the Review

Fermi National Accelerator Laboratory

Fermilab

11-Apr-2021

Charge Letter: LBNC Review of DUNE Vertical Drift Far Detector

Capitalizing on lessons learned from both ProtoDUNE detectors, as well as other work on the dual-phase concept, the DUNE Collaboration has adopted a Vertical Drift design for the second far detector module. The transition to this concept has occurred rapidly and considerable progress has been made over a short time.

After hearing about the Vertical Drift concept and strategy at their December 2020 and March 2021 meetings, the LBNC strongly endorsed vertical drift technology for the DUNE second far detector and went on to "commend DUNE on the impressive progress in developing the design, executing the R&D planned for this year, and building and expert team and organization." DUNE plans to submit a CDR for LBNC review by Fall 2021.

The LBNC pointed out that the R&D schedule is tight and made the following recommendation:

> "Work with the LBNC to schedule a review of technical progress and the plans and progress towards a Conceptual Design Report."

Following through on this recommendation, we ask the LBNC to review the Vertical Drift concept, status and plans, and preparation towards the CDR. The review will be held in a series of 3 sessions, to conclude by the end of May:

- Vertical Drift Technical Design, R&D
- Vertical Drift physics/simulation + assembly/installation/integration
- Vertical Drift timeline, schedule + follow-up Q&A

The LBNC is asked to look at the overall status, progress and plan for the Vertical Drift R&D program, simulation and performance metrics, and plan and timeline for the effort. In particular, we ask the LBNC to consider the following questions:

- Does DUNE have a clear, consistent and realistic view of the major design aspects of the detector and its physics goals?
- Is the technical design and project planning at an appropriate level for a CDR?
- What are the primary areas of R&D focus? What are the critical new aspects of the design, what key technical challenges, and are they being addressed?
- What are the key milestones associated with this R&D?
- What are the plans for the NP02 ProtoDUNE-VD? Are they credible? Are they consistent with the timeline outlined above?
- Does DUNE have a good plan for consortia contributions to the VD effort? What is the status of planning for construction and installation?
- Does DUNE have sufficient personnel actively working on VD so that it can move forward on the anticipated timeline?
- Does DUNE have a plan for simulation and other studies which support the physics capabilities claimed?
- Is DUNE on track to complete the CDR on the proposed schedule?

Although this review is of the international DUNE Vertical Drift effort, some aspects of the findings and recommendations will be of direct relevance to the DUNE-US project, including the CD-1 "refresh" that is expected to take place later in calendar year 2021. Also of relevance to DUNE-US project review and approval is the development of a CDR and the timescale for "baselining" (CD-2).

The Committee should plan to deliver a closeout report by June 1, 2021 and provide a full report by June 15.

Appendix 3
Links to the meeting agendas, including DUNE answers to the committee's questions

April 28 -- Technical Review: the design, R&D status and plans, plans for module-0
https://web.fnal.gov/organization/LBNC/April%2028,%202021/SitePages/Full%20Agenda.aspx

May 10 – Simulation, Detector Performance and Physics
May 11 – Detector Assembly, Project Planning and Schedule
https://web.fnal.gov/organization/LBNC/May%2010%20&%2011%202021%20VD%20Review/SitePages/Full%20Agenda.aspx

The documents containing DUNE answers to the committee questions are linked from each of the meeting agendas.