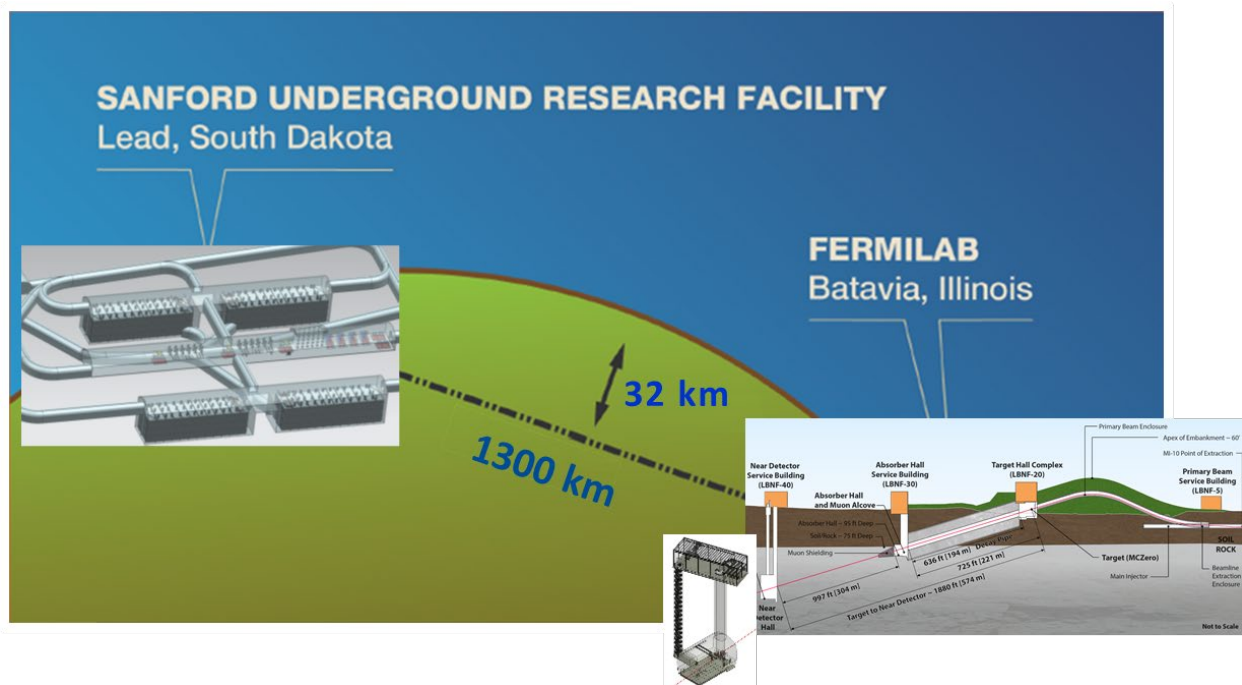


Report of the Long-Baseline Neutrino Committee

June 12-14, 2016



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Executive Summary

LBNF continues to make good progress towards approval and initiation of the long-lead time conventional facility construction at the Sanford Underground Research Facility. The team is developing the final design for pre-excavation activities at the Far Site; plans for rock disposal including securing agreements on an easement from the City of Lead for a rock conveyor system; working with DOE to complete the RFP for a Construction Manager/General Contractor (CMGC) for Far Site underground construction; establishing equivalences for international design codes and standards; and working closely with the DOE Site Office and DOE Headquarters on planning for the project in support of formal approval for CD-3a. LBNF executed a lease with SDSTA on 1 May 2016 for the underground space for caverns and drifts and the surface space for the control room, cryogenics support building, and parking. The SURF operations contract between FNAL and SDSTA is being put in place and will be managed under the FNAL COO Organization. The LBNC continues to be impressed with the strength and progress being made by LBNF management and the Far Site team in particular. Fermilab may consider strengthening the sophistication of procurement and contracting support to ensure that development and approval chains do not become schedule limiting steps in the future. Care should be exercised to ensure the coordination and integration of the SURF operations contracts within the COO organization and the LBNF improvement projects such as the Ross Shaft refurbishment.

DUNE continues to grow impressively as an organization, attracting substantial international interest to an outstanding science opportunity. A sound roadmap has been laid out for the steps between now and CD-2 in late FY2019, including assumptions and schedule, key goals and milestones, plans for prototypes, development of construction-phase resource matrix, neutrino beam design, development of a TDR, and enlarging the collaboration. One of the key steps in this plan was set in motion last September with the formation of three Task Force (TF) efforts (Far Detector, Near Detector and Beamline Optimization). These groups are focused on optimizing and maturing our understanding of the performance of DUNE. Significant progress has been made by all three, which appear to be on track to deliver their findings in March 2017. The LBNC notes the ongoing progress in automated event reconstruction of LAr TPC events and its initial use in simulation studies by the Far Detector TF. The VALOR framework in development for the Near Detector TF for full end-to-end simulation connecting the measurements in the near detector to the far detector systematics is largely functioning. Close interaction with reconstruction efforts should continue to be encouraged and maintained. The Beam Optimization TF in particular has identified an overall configuration of three horns that would produce substantial gains in sensitivity over the baseline beamline design if it is feasible from an engineering standpoint.

A second key element of the strategic plan and a very visible first major project undertaken by DUNE is the design, construction, commissioning and operation of two full-scale engineering prototypes, protoDUNE-SP and protoDUNE-DP, at the Neutrino Platform at CERN by summer 2018. The prototyping effort will validate the engineering design and physics performance of the DUNE Far Detector design options, and provide a foundation for planning the full-scale production of TPC components. They also will enable a detailed understanding and calibration of LAr TPC response to beam particles. On the basis

of the detailed review of these projects, there are concerns about the ability of the DUNE to successfully execute on such an ambitious timescale. Some basic design decisions are still subject to R&D, such as the field cage design. Other systems, such as the electronics system for protoDUNE-SP, appear to have significant technical risks with little leeway to develop mitigating strategies. protoDUNE-DP has been developing an engineering design, with corresponding R&D, for several years and as a result the design is relatively mature. However, the short interval between commissioning the 3x1x1 m³ prototype and start of procurements for the larger 6x6x6 m³ device is very short. It does not appear that the process of forming system consortia will converge before end of summer, and there will still be funding support questions at that point. Plans for development of the beamlines, cryostats and cryogenic systems for the Neutrino Platform appear to be mature and senior CERN management has a proven record for the successful delivery of complex projects. DUNE management needs to respond decisively and use the engagement of the Fermilab Director and Fermilab as host lab to maximum advantage in resolving critical issues in order to put protoDUNE on a sound footing for delivery in summer 2018.

Introduction

On June 13-14, 2016, the LBNC conducted a face-to-face review at Fermilab of progress and development over the last 5 months by LBNF and DUNE. The review agenda is provided in Appendix 3 and participation by LBNC members is captured in Appendix 1. The LBNC heard reports from the LBNF Project Manager and the Far Site Manager, as well as from DUNE management, Task Force Coordinators, and Working Group coordinators for several key systems. The primary focus for LBNF was pre-excavation planning and design work at SURF, development of the RFP for identifying a Construction Manager/General Contractor (CMGC) for the Far Site underground excavation and related construction work, and ongoing planning for the overall LBNF project based on guidance from DOE in advance of formal CD-3a approval. The critical issues for DUNE were ongoing development of the collaboration organizational structure; development of a comprehensive roadmap to CD-2 with key milestones and goals; progress by the three Task Force efforts launched in September 2015; development of software, computing, and physics; and organization and planning for the protoDUNE effort (see below). Following a day of plenary presentations on June 13, the LBNC met with LBNF and DUNE management on the morning of June 14 for follow questions and discussion. The committee spent most of the remainder of the day preparing a closeout report, which was provided to the LBNF and DUNE teams at the end of the day. The closeout report is organized around the plenary talk themes, and consists of findings, comments, and recommendations that are also captured in this final report.

The main review was preceded by a partially overlapping mini-review on June 12-13 that was focused on overall planning, technical status, risk assessment, resource development, schedule and management of all aspects of the protoDUNE-SP and protoDUNE-DP engineering prototypes. These large-scale engineering prototypes are scheduled for deployment, commissioning and operation in 2018 at the CERN Neutrino Platform. The mini-review was designed to provide a detailed assessment of the current state of these projects by assembling a team of experts, with the intent of establishing a baseline for monitoring progress on these time-critical and very visible demonstration projects. Membership on the mini-review panel is provided in Appendix 1, the mini-review agenda is provided in Appendix 2, and the charge for the mini-review is provided in Appendix 4. Members of the mini-review panel contributed findings, comments, and recommendations in their areas of expertise. These assessments were then incorporated into the main closeout report and this written final report.

Review of LBNF

Overall Project

Findings:

- LBNF executed a lease with SDSTA on May 1, 2016 for the underground space for caverns and drifts and the surface space for the control room, cryogenics support building, and parking.
- Easements need to be set up for those areas within SURF that are outside of the leased area, but which are necessary for LBNF/DUNE success (e.g. shaft utility space).
- The SURF operations contract between FNAL and SDSTA is being put in place. It is separate from LBNF/DUNE and will be managed under the FNAL COO Organization.
- The LBNF plan is to have SDSTA perform project related SURF reliability activities.
- The CM/GC procurement process has consumed its entire schedule float. The goal is to have the CM/GC in place no later than Dec 6, 2016 to allow effective interaction with final excavation design effort. A draft RFP has been released and a pre-proposal conference is scheduled for July 19, 2016.
- LBNF Near Site / Beamline efforts are focused on beamline optimization trades that require analysis, conceptual development, and estimating to determine whether they should replace existing beamline approach.
- A radically different beamline approach was presented at May 2016 at the DUNE collaboration meeting. A first determination of potential viability will be made before the EFIG meeting in July 2016.
- Cryogenics work has focused on ProtoDUNE, both as an engineering prototype and as a design verification test.
- An RFI has been issued for LN₂ system and is being evaluated.
- Fermilab has finalized a process for establishing equivalences for international design codes and standards.
 - 1 equivalency review complete
 - 1 equivalency review underway
 - 4 others planned, not including electrical device standards
- LBNF continues to staff up; immediate hires completed or in process include:
 - LBNF/DUNE QA Manager
 - LBNF/DUNE Financial Manager
 - Senior Procurement Administrator
- LBNF continues an active risk management approach.
- LBNF is looking at contingent planning for FY2017 budget uncertainties.

Comments:

- The iterations with the DOE for approvals for the CM/GC contracting consumed all schedule float. This may reflect unfamiliarity of Fermilab with the demands associated with complex contracting instruments within the DOE system.
- Fermilab should look to strengthen the sophistication of procurement and contracting support to ensure that development and approval chains do not become schedule limiting steps in the future.
- Complications associated with easements and infrastructure improvements to non-Federal government property could easily represent a source of schedule risk if additional care and effort are not fully engaged.
- Fermilab should exercise care to ensure the coordination and integration of the SURF operations contracts within the COO organization and the LBNF improvement projects such as the Ross Shaft refurbishment.
- A formal MOU between FNAL COO and LBNF/DUNE should be considered, as has been done on other major system DOE-SC projects.
- Every effort to avoid any further delay in engaging the CM/GC should be pursued, since issues associated with this approach almost always are related to delay in engaging the CM/GC.
- LBNF should carefully set up “freeze” dates where major variations in the design can no longer be entertained or significant cost and schedule growth could result.
- LBNF should consider careful review of the reliability activities at SURF. Approaches and perspectives from past mining operations standpoint may not be adequate for fully appreciating reliability and availability requirements. SURF would likely appreciate a degree independent advising as it looks to strengthen its overall operations.

Recommendations:

- None

Far Site Construction

Findings:

- The final design plan is a standard design development process
 - 30%, 60%, 90%, and 100% design completion deliverables
 - CM/GC involvement and independent estimates as early as possible, as well as constructability reviews
- The design is divided into two major scope components:
 - Pre-excavation work (rock handling / utilities upgrade): 30% (March 2016); 60% (July 2016); 90% (Oct 2016); and 100% (Nov 2016)
 - Main Scope (excavation): 30% (March 2017); 60% (July 2017); 90% (Oct 2017); and 100% (Dec 2017)
- The construction sequence has been modified to avoid mobilizing the excavating contractor twice, which requires installing protection to the refurbished steel in the Ross Shaft (cost neutral).

- Blast vibration studies indicate that the Federal guidelines (related to cracking plaster) would restrict blasting to about ~2 ft. / blast. SNOLab experience indicates that closer to 8 ft / blast may be realized (impacting activities ~300 ft from blast).
- Lead, SD has approved the easement of the conveyor system to open cut disposal site.
- There has been further progress in planning for excavated rock handling.
- Ross Shaft refurbishment is at 73% complete and work is covered by the SURF operating contract.
- SDSTA plans on exercising an option to purchase 33.4 additional acres of adjacent land from Barrick. This will improve access.

Comments:

- The progress on the conveyor system is notable, and reduces uncertainty and risk to the project.
- The purchase of the 33.4 acres (Ellison tract?) by SDSTA for SURF is a very significant risk reduction action and will both simplify access and provide some lay down space.
- The blast study appears carefully developed, but care will need to be exercised in setting an acceptable overpressure specification for adjacent operations.

Recommendations:

- None

Review of DUNE

State of DUNE

Findings:

- DUNE Collaboration has continued to grow, with 856 collaborators from 149 institutions and 29 countries
- The present level of effort from the collaboration is estimated to be 240 FTEs
- DUNE provided responses to LBNC recommendations from the January 2016 meeting
- DUNE has developed a draft strategy document describing the goals, milestones and steps needed in preparation for CD-2
- Collaboration management has been stable since the January 2016 meeting, with the addition of Kam-Biu Luk to the ND WG
- A set of bottom-up priorities have been laid out for 2016, including advancing protoDUNE-SP and -DP, WG & TF progress, and resource development
- The organizational structure of the Software & Computing WG has been clarified to include interfaces to Physics, protoDUNE, and DUNE-wide support
- The two main goals for protoDUNE were stated as:
 - Engineering demonstration: mitigation of design risks, establishment of construction facilities, early detection of potential construction or performance issues
 - Calibration of detector response

Comments:

- DUNE management needs to be actively identifying and resolving critical technical and performance issues, e.g. with protoDUNE-SP cold electronics
- Presentations would be more useful if they include an identification of current problems, risks, and mitigating strategies or actions taken to solve problems, e.g., the protoDUNE-SP cold electronics

Recommendations:

- Develop a full assessment of risks and corresponding mitigation strategies for protoDUNE-SP and -DP
- Keep the LBNC informed of progress in dealing with critical issues
- Use the engagement of the Fermilab Director and Fermilab as host lab to maximum advantage in resolving critical issues

DUNE Strategy for CD-2

Findings:

- High-level goals for DUNE are delivering protoDUNE-SP and -DP (2018), a DUNE TDR for CD-2 (2019), 20-kt FD commissioning in 2024, and ND operation by first beam

- A Strategy and Implementation plan has been approved by the DUNE EC (DUNE-docDB-1050)
- The strategy includes: assumptions and schedule, key goals and milestones, plans for prototypes, development of construction-phase resource matrix, neutrino beam design, development of a TDR, and enlarging the collaboration
- A set of major milestones have been identified
- DUNE will follow the LHC detector strategy of organizing consortia of institutions to construct major detector sub-systems through a process of soliciting EOIs in 2017
- Preliminary design of the first 10-kt module is assumed in Q4 2017 and a design decision of the second 10-kt module in 2018
- A conceptual design choice for the ND is targeted for 2017, based on scientific arguments, technical readiness, institutional interest, and funding availability
- A path for development of the TDR is laid out, starting with establishing an editorial team in 2018
- Active steps to enlarge the collaboration were taken with a Latin America meeting (April 27-28) at Fermilab and a European meeting at CERN (April 7-8)
- The plan includes provision for LBNC review of the TDR in Q4/2019

Comments:

- The strategy appears to capture the main goals and lays out a plausible pathway to a TDR and IPR in Q4/2019
- The call for DUNE FD construction EOIs in Q2/2017 overlaps the construction of protoDUNE-SP and –DP which may be a challenge
- The Collaboration currently sees a variety of factors in the technology choice for the second FD module, and does not want to lay out definitive criteria and a process at this time
- Development of the strategy document is responsive to the LBNC recommendation from Jan 2016 and will serve as an effective communication vehicle for the collaboration as a whole
- One of the more challenging elements of the plan is the development of a full funding matrix on the timescale of the TDR

Recommendations:

- Expand on this excellent start to incorporate alternatives planning, *e.g.*, if protoDUNE-SP does not demonstrate the required engineering performance

Far Detector Task Force update

Findings:

- Both nucleon decay and atmospheric neutrinos samples have now been simulated and reconstructed with LArSoft, along with background samples
- Supernova events have been generated, but standard reconstruction does not work for energies below 50 MeV

- A Long-baseline Oscillation Analysis Fitter (LOAF) has been developed
- Detector optimization studies have begun by looking at wire spacing and pitch
- Photon detection system studies have been added to the scope of the TF
- Event selection studies have begun for long-baseline oscillation analyses using multivariate techniques
- A dual phase simulation and reconstruction capability has been developed in LArSoft, although implementation of the light collection system remains to be done
- A preliminary TF report to be provided in September will include studies of lower level e/g separation and tracking efficiency but not optimization results based on sensitivity

Comments:

- While there is good overall progress being made by the TF, many important milestones have shifted from spring to summer
- Implementation of DP simulation and reconstruction is going well but not too surprisingly is delayed until fall
- It is not clear how effective the feedback loop is between reconstruction development and higher-level analysis efforts
- Ultimately detector design optimization will also need to weigh factors such as relative cost and technical risk vs TF physics performance results

Recommendations:

- Define a plan to address reconstruction below 50 MeV
- Review whether there is sufficient manpower to conduct the full range of physics studies laid out in the TF charge
- Review whether feedback from physics studies to reconstruction algorithm development is working effectively
- Update the LBNC with the status of actual versus planned manpower across the TF at the fall meeting

Near Detector Task Force update

Findings:

- Points of contact have been identified for all components of the TF effort, but additional manpower is needed for the three simulation efforts (FGT, LAr, GAR)
- Progress is being made relative to the plan of the TF, with a schedule that is tied to Collaboration meetings and incremental improvements
- A strategy of “cheating”, *i.e.*, informed guesses about reconstruction performance, will be used
- Currently there are technical issues with the VALOR fitting framework manifested by unrealistically small output uncertainties
- Cross section uncertainties are being implemented in a less model-dependent manner

- Optimized beam from the BOTF and non-beam backgrounds will be used for next development run
- Interactions between the TF and the ND Physics WG are occasional, although there will be upcoming consultation on cheating models for the three simulation efforts
- An initial TF report will be provided in September and a final report in March 2017
- A technology decision is not in the remit of the TF

Comments:

- Neutral particles are not accounted for in detail, *i.e.*, no specific detector treatment with resulting uncertainties in energy response, is implemented
 - Recent literature indicates that this can be a serious problem
- A valuable outcome from the TF, instead of just a comparison of ND technologies, could be a set of overall ND requirements independent of technology
- “Cheating” appears to be a response to the lack of manpower to develop suitable event reconstruction and the details of the assumptions made here may have significant impact on the reliability of the final result
- The attempt at including model-independent cross section errors is very valuable and can be easily extended to include uncertainties associated with neutral particles (see recent literature)
- Lessons learned from existing software solutions should be used to address current or future related technical problems VALOR may be trying to resolve

Recommendations:

- Clearly document “cheating” strategies and investigate sensitivity of results on those assumptions
- Properly include energy response uncertainties from neutral particles (“missing energy”)
- Investigate alternatives to the current framework if technical difficulties were to persist
- Consider extending the TF scope to deliver requirements for a near detector independent of any specific design
- Update the LBNC with the status of actual versus planned manpower across the TF at the fall meeting

Beamline Optimization Task Force update

Findings:

- An interim report was produced examining optimized designs for four system based on three 3-m long horns and a long target
- All options perform substantially better than the CDR conceptual design
- The recommended system uses a carbon fin target, but further work since the interim report suggests that using a beryllium sphere array target may be a better option

- Engineering analysis work has started based on a mechanical design for an idealized three-horn system
- This suggests that conductor and endcap thicknesses may be important factors in optimization
- A conceptual design for an optimized beamline is anticipated in August 2017 & planning for engineering resources is underway

Comments:

- BOTF is on track to meet its goals by March 2017

Recommendations:

- Complete assessment of the recent narrow-band beam option by mid-July

Software & Computing Working Group

Findings:

- An organizational structure with interfaces to Physics WGs and the protoDUNE effort has been developed
- A summary of computing resources required to support the 35Ton effort was provided
- An overview of event samples produced for FD/ProtoDUNE SP/35ton as part of Monte Carlo Challenge 6.0 was provided
- An analysis of computing resource requirements for ProtoDUNEs was presented, based on:
 - Initial event sample and measurement program
 - protoDUNE-SP trigger/DAQ requirements and data handling estimates
- A summary of personnel currently involved in software and computing was provided

Comments:

- MC Challenge 6.0 demonstrated the capability for producing large simulation samples with available resources
- No analysis of whether identified manpower is adequate to address high-priority S&C tasks was presented
- It is unclear how well experience from analysis of MC samples are fed back to the S&C group
- It is not clear how well ProtoDUNE-DP is integrated in the C&S WG

Recommendations:

- Provide an overview of high level computing infrastructure including how requests are made to the group and how feedback from the working groups is incorporated into software development planning
- Engage physics WGs in analysis of simulation samples and in providing feedback to the S&C WG
- Ensuring adequate support for protoDUNE(s) at CERN is high priority, including defining the Fermilab role

- Provide an update on ProtoDUNE-DP software integration and MCC production
- Provide an overview of strategy for addressing the different software release timelines and goals (*e.g.*, when the next software release is due and when the next MCC7 is planned)

Update on reconstruction development

Findings:

- Progress in automated reconstruction was reported in several areas: TPC SP signal processing, field response, pattern recognition and particle flow algorithms.
- Substantial progress in shower reconstruction was reported, including a 50% improvement in p^0 reconstruction efficiency
- Progress on the wire-cell reconstruction was reported

Comments:

- Impressive progress in event reconstruction since the last LBNC meeting
- It is not clear what is ready enough to be deployed in production and what is still under development

Recommendations:

- Provide an overview of reconstruction development tasks, with priorities in importance and schedule, along with personnel associated with each of these tasks
- Provide ongoing updates on the integration of dual phase software into LArSoft and status of reconstruction
- Track progress in terms of high level performance metrics

Physics Working Group

Findings:

- Continued progress has been made in organizing physics efforts with increased participation from collaboration members
- A BSM working group has been established and is very active
- Configuration information used for the CDR has been released publicly
- There still only limited manpower for atmospheric neutrinos
- Many analyses now include actual simulation of full events in the detector and reconstruction (as available)
- Progress in simulation and reconstruction of low-energy SN events is being made
- A successful VT SN workshop was held
- There is a plan for developing a Physics TDR prior to CD-2

Comments:

- Many of the BSM topics appear to be at the intersection between ND physics and the BSM group
- The SN workshops are a model that could be emulated in other areas
- Release of the CDR will serve well to engage the broader community
- The BSM working group has gotten off to a very good start and impressive progress is being made
- The participation of theorists in bi-weekly phone calls is commendable
- Despite good success in attracting more collaborators, manpower remains an issue in several areas and needs continued attention, especially in view of the planned TDR

Recommendations:

- Close interaction with reconstruction efforts should continue to be encouraged and maintained
- The low-energy reconstruction efforts should continue to be a priority given their importance for informing the detector design

protoDUNE-SP mini-review

Management

Findings:

- Major sub-system components for protoDUNE-SP will be delivered by hardware WGs within the FD WG (APAs, HV/FC/CP, Photon Detector, Cold Electronics)
- FD WGs are also responsible for coordination with protoDUNE-SP management in identifying system experts for assembly, integration and commissioning at CERN
- protoDUNE-SP management will form teams for DAQ, Installation, Calibration with large overlap with FD WG membership
- A set of five joint SP/DP working groups are envisioned: beam configuration & instrumentation, detector monitoring & slow controls, cryogenic systems, muon tagging detectors, online computing & storage
- There will be a set of teams with interfaces to physics and computing (measurements WG, computing infrastructure, software development)
- A physics workshop will be held later this month to better define the calibration and physics goals of the protoDUNE effort
- A call for EOIs in participating in the protoDUNE efforts was made in January
- DUNE WG leaders are responsible for bringing together interested institutes to facilitate formation of consortia; written proposals will be reviewed by the DUNE Technical Board
- The goal for the review process is to assign final responsibilities by late June
- DUNE Technical Board will review conceptual designs for protoDUNE detector components, while the project will be responsible for design and production reviews
- A schedule for design and production reviews has been laid out
- A uniform set of milestones is planned to monitor the project, in addition to the resource loaded schedule for protoDUNE-SP

- An initial risk table and mitigating strategies was prepared for this review
- A lessons-learned document has been prepared for the 35 Ton and a review was held at Fermilab (Jun 2-3)
- A task force is investigating grounding/shielding/noise problems with the 35 Ton
- A set of slice tests and integration tests are planned at Fermilab, CERN and other sites
- The integration, installation and protoDUNE operation at CERN will require the buildup of some 35 people on site

Comments:

- The management for protoDUNE-SP has not responded in a decisive fashion or elevated the response appropriately to the serious risks from the cold electronics system
- It is important to maintain engineering rigor in the design and production of components as planned
- There does not appear to be a single individual who is responsible for delivery of the cold electronics as a working system
- Some basic design decisions are still subject to R&D, such as the field cage design
- It does not appear that the process of forming consortia will converge before end of summer, and there will still be funding support questions at that point
- protoDUNE-SP is a critical part of the CD-2 preparation plan and a very visible first major project undertaken by DUNE

Recommendations:

- Put in place a single individual with appropriate expertise who is responsible for cold electronics (from wire signal to delivery of digital signals to DAQ) as a working system
- Clarify roles and responsibilities of the major participants in the cold electronics system and potentially revisit roles in the process
- Form a task force to devise a robust strategy for delivery of a cold electronics system for protoDUNE-SP
- Complete the development of a risk matrix and corresponding mitigation strategies, particularly for the cold electronics
- Take design decisions as early as possible, particularly in cases where choices will not impact significantly the overall goals of the protoDUNE effort
- Work with the funding agencies, including DOE, to make sure support for operations and the hiring of key personnel is realized in a timely fashion
- Develop and monitor an agreed upon set of key milestones associated with the protoDUNE-SP project by September 1

TPC

Findings:

- A stable APA design was presented
- Work on the APA has focused on an automated winding machine, bolted frames and electrical isolation
- The CPA design is for a solid G10 frame with G10 panels laminated with resistive Kapton foils
- The field cage design uses open metal profiles, segmented into four electrically isolated parts
- Outside ground planes are integrated into the design
- Trial assembly will take place at Ash River

Comments:

- The TPC team has presented an excellent summary of the construction plans
- The schedule is very tight, with no hidden contingency
- Potential human resources required to meet this schedule have in many places been identified, but many are not yet committed.
- Given the tight schedule and personnel constraints, the focus needs to shift from R&D and optimization to production. The team continues to explore manufacturing options on items which, though valuable for DUNE, are not required for protoDUNE success
- The design of the CPA is relatively mature, and the team should decide on a lamination process soon
- The team should develop a quantified failure mode analysis, including probability and impact of a broken wire in an APA.

Recommendations:

- Clearly identify the goals for the protoDUNE-SP TPC and focus resources where needed to achieve them
 - Understand and communicate the relative priorities of manufacturing process development, preproduction engineering for DUNE, and construction, installation, and commissioning of a TPC in time to validate operation and test calibration before the CERN long shutdown.
 - If the principle goal is for protoDUNE to be ready for beam in mid-2018
 - Refocus resources on R&D of direct relevance to protoDUNE
 - Have a clear de-scoping plan
- Develop a more quantitative failure mode analysis
- Develop and monitor an agreed upon set of key milestones associated with the TPC system by September 1

Electronics

Findings:

- The cold electronics system (CE) is composed of two custom ASICs, a front-end preamp and shaping amplifier, and a novel 12 bit ADC both realized as 16 channels per chip and a

commercial low drop out linear regulator mounted on a custom front end printed circuit board (the FEMB) and a commercial FPGA mounted on a second custom circuit board mounted as a mezzanine above the FEMB.

- The FEMBs connect to the TPC collection and induction wires through a “wire card” on the APA that provides DC bias to the TPC wires and HV decoupling before the FEMB.
- Prototypes of the custom ASICs and FEMBs were used in the 35Ton run in the first half of 2016.
- The 35Ton detector was the first liquid argon TPC to operate with digital elements in the cold and the performance did not meet expectations.
- Observed noise levels were very much worse than expected and the ADC showed “features” which kept it from producing anything close to 12 bit linearity.
- The 35Ton CE used version 5 of the cryogenic ADC. Recently a revised, version 6, device has been measured to have somewhat improved performance but still demonstrates serious problems in achieving the desired linearity.
- At least some of the low frequency noise seen in the 35Ton test is reasonably well known to be caused by small variations in the DC voltage provided by the commercial low drop out regulator.
- The CE group is expecting a revised version of the front end chip which includes a number of improvements approved in the review in January to be tested in the near future.
- The revised ADC chip is still under design with simulations ongoing and with the expectation at the moment that a revision will be submitted by the end of June.
- The slip in schedule by four months does not allow for another iteration of the ADC chip before production for protoDUNE-SP.

Comments:

- Communication between the CE designers and the rest of the DUNE collaboration needs improvement
- The recent involvement of MSU and Boston University is evidence of a new openness in collaboration
- It is not clear that all of the interactions / connections between the APA structure and the CE system are well defined or well understood
- Understanding of the “noise” problems observed in the 35Ton detector is only beginning and may never fully converge on the technical changes necessary to achieve acceptable performance in protoDUNE

Recommendations:

- Develop a method to improve the communications between the CE team and the rest of the collaboration
- Consider developing multiple mitigating strategies to ensure a working protoDUNE-SP electronics system:
 - Investigate the options (including the identification of possible design teams) for implementing the design of a cryogenic capable true 12 bit ADC using the same

interface as the present CE ADC but based on a more traditional and well-understood ADC architecture

- Investigate the options (including the identification of possible design teams) for implementing a cryogenic front-end design as a fully differential device (to improve the power supply rejection ratio) using the same interface as the present CE front-end chip
- Investigate the options (including the identification of possible design teams) for implementing a variant of the FEMB design
- Fully document and understand the planned electrical connections (DC and AC) between the detecting elements and the CE system and the cryostat shell and verify that the design is as robust as possible
- Develop and monitor an agreed upon set of key milestones associated with the CE and DAQ systems by September 1 and update if necessary

protoDUNE-DP mini-review

Findings:

- The dual-phase TPC design was said to offer several advantages: two collection views with no ambiguities, a tunable gain in the gas phase, reduced number of readout channels with accessible FE and digital electronics, and no materials in the active volume
- The original concept was pursued by a collaboration of 22 institutions from 10 countries (WA-105) before being integrated into DUNE planning as protoDUNE-DP
- The design is based around a modular 3x3m Charged Readout Plane (CRP) that has been extensively developed for the 3x1x1m prototype being assembled at CERN
- A mature design for the readout chain has been developed:
 - Cryogenic ASIC amplifiers on cards fixed to a plug-accessible from the outside
 - Warm digital electronics using mTCA architecture and held in crates at the cryogenic tank upper deck
- Fully engineered versions of many detector components exist, along with identified commercial vendors for components
- Pre-production and most implementation steps for installation and ancillary services have been developed
- All design, implementation, legal and contractual issues related to the construction of the membrane cryostat have been addressed in the implementation of the 3x1x1m prototype, to the benefit of both protoDUNEs
- A detailed schedule for construction of components and assembly of protoDUNE has been developed, including scope and sources of manpower
- The design study for the 6x6x6m cryostat have been concluded with GTT, including definition of all penetrations and interfaces
- Some aspects of the photodetection system (wavelength conversion plates) are still in R&D, with proposed implementation as transparent cathode plates with ITO coating

- Options for the field cage are still in development (in common with protoDUNE-SP) with the aim of a design decision in July
- Cold-FE electronics and DAQ have been in development since 2006
 - Full complement (700) cold ASIC amplifiers were produced at the end of 2015
 - Full complement of mTCA cards started at the end of 2015, and a pre-batch will be deployed on the 3x1x1m prototype
- A detailed installation plan has been developed including CRP pre-assembly at CERN (Building 185) and use of a clean room buffer near the 6x6x6 cryostat to stage installation
- The schedule assumes Building 185 clean room is available in January 2017
- A detailed beam time request was made to the SPSC encompassing 59 days of integrated beam delivery
- The online processing and storage facility required to acquire and locally store test beam data has been designed
- Offline computing plans include simulation production at CC-IN2P3 and analysis of a roughly 2.4 Pb dataset with QSCAN

Comments:

- protoDUNE-DP has been developing an engineering design, with corresponding R&D, for several years and as a result the design is relatively mature
- All aspects of the dual phase design appear to be well thought through, including details such as internal sensors
- There are still aspects of the design in R&D: *e.g.*, cathode plates and field cage (in common with protoDUNE-SP)
- The successful operation of the 3x1x1m prototype, as a large-scale demonstration of the dual phase technology, is crucial
- There may not be enough schedule time for commissioning and initial operation of the 3x1x1m prototype before the start of procurements for the 6x6x6m TPC components
- The 6x6x6m assembly schedule appears plausible, based on previous experience with commercial vendors and assembly of the 3x1x1m prototype
- There are critical dependences on CERN NP construction activities, starting with the availability of the Building 185 clean room in January 2017

Recommendations:

- Complete the development of a risk matrix and corresponding mitigation strategies
- Take design decisions as early as possible, particularly in cases where choices will not impact significantly the overall goals of the protoDUNE-DP effort
- Develop and monitor an agreed upon set of key milestones associated with the protoDUNE-DP project by September 1

protoDUNE cryogenics mini-review

Findings:

- The cryogenic system scope that includes membrane cryostats and cryogenic system is managed by CERN/NP leadership.
- The scope is managed internal to the CERN organization utilizing well established processes.
- We were assured that NP/CERN will manage the cost and schedule risks internal to the organization.
- The team includes four engineers and two designers from CERN, strong Fermilab collaboration, including an engineer from Fermilab stationed at CERN. Additionally, a new mechanical engineer with strong contract support experience has recently joined the team.
- System requirements, interfaces, constraints, and specifications are well documented within CERN EDMS.
- Cryogenic system engineering design is complete. A Functional Specification based contract is in process of being tendered by European industry.
- The contract deliverables include engineering, design, factory testing, installation, and site acceptance testing at CERN and Fermilab of forty-two (42) cryogenic valve boxes and sixty-nine (69) cryogenic transfer lines
- The tender for the cryogenic valve boxes and transfer lines was open at the end of May, 2016. Eight qualified vendors participated in the tendering conference at CERN.
- The tender is scheduled to close at the end of July 2016.
- Pending satisfactory outcome from the CERN finance committee, a contract will be executed in September 2016 for delivery in winter 2017, completion of installation by the end of 2017 and ready for cooldown in February 2018.
- Fermilab will supply four (4) circulating LAr pumps manufactured by US or European industry.
- The requisition for the pumps is being processed by LBNF procurement group. The anticipated award is in mid-July, 2016.
- The requested delivery of the pumps to CERN is 10 months ARO (late spring 2017).
- An engineering contract for the Membrane Vessels with GTT for the complete design of the two membrane cryostats will be completed in September 2106.
- The contract includes engineering and design of the two vessels (primary and secondary barrier)including penetrations, list of materials to be ordered (delivered end of March), detailed installation procedure (first version delivered this week), list of licenced assembly firms for the CERN tendering, structural analysis, and QA plan.
- Addition of the beam ports and pump connection on the side of the cryostat requires a local modification of the insulation panels and primary membrane.
- The project is working with experienced industrial vendors, GTT and Protego, to develop the appropriate design solutions for the membrane cryostat penetrations.
- The tender for material has been written and is ready for placing (pending CERN Finance Committee (FC) approval); the material is to be delivered by October 2016.

- The tender for assembly is scheduled for completion in July 2016, to be placed in September 2016 after the next CERN FC.
- A contract for Warm Vessels has been let for the construction of the outer vessels that includes complete pre-assembly.
- The material has already been delivered to the company.
- First Warm Vessel delivery is scheduled in the beginning of August 2016; Second – beginning of October.
- Warm Vessel assembly in EHN1 is scheduled to start in August 2016
- Cold Vessel assembly is scheduled to start in October 2016

Comments:

- The senior management has a proven record for the successful delivery of complex projects.
- There seem to be sufficient man power dedicated to the cryogenic systems work.
- The cryostat and cryogenic system design leverages industrial expertise and experience with WA105.
- Cryogenic operations in Building 182 in September will validate many design solutions.
- Consideration for the cost and schedule risk mitigation solutions may include utilization of resources at CERN to assist vendors with project execution.

Recommendations:

- Develop and monitor an agreed upon set of key milestones associated with the cryogenic system before the end of the calendar year and update if necessary

Appendix 1: LBNC and protoDUNE mini-review membership

LBNC membership

- *Sampa Bhadra, York*
- Patrick Huber, Virginia Tech
- Mike Lindgren, Fermilab
- Francesca Lodovico, UC London
- David MacFarlane, SLAC
- Naba Mondal, TFIR
- *Tsuyoshi Nakaya, Kyoto*
- *David Nygren, Texas*
- Marco Pallavicini, Genova
- Stephen Pordes, Fermilab
- Kem Robinson, LBNL
- *Nigel Smith, SNOLab*
- *David Wark, Oxford*

Absent at June 13-14 LBNC meeting

protoDUNE mini-review membership

- Rick van Berg, Penn (Electronics)
- Arkadiy Klebaner, Fermilab (Cryogenics)
- Aseet Mukherjee, Fermilab (TPC)
- Michael Lindgren, LBNC
- Stephen Pordes, LBNC
- David MacFarlane, LBNC

Appendix 2: Agenda for protoDUNE mini-review

Speaker	Topic	Start	Duration
June 12			
Eric James	Overview of protoDUNE organization	9:00	40
Marzio Nessi	Planning for the Neutrino Platform at CERN	9:40	40
Flavio Cavanna	Planning for protoDUNE-SP	10:20	40
Breakouts: TPC, electronics, cryogenics	Q&A on protoDUNE-SP: organization, technical, manpower	11:00	90
	Lunch	12:30	50
Breakouts: TPC, electronics, cryogenics	Q&A on protoDUNE-SP: organization, technical, manpower	13:20	60
All	Q&A on protoDUNE-SP: overall schedule and planning	14:20	60
June 13			
Dario Autiero	Planning for protoDUNE-DP	7:30	40
All	Q&A on protoDUNE-DP: technical	8:10	45
All	Q&A on protoDUNE-DP: schedule & manpower	8:55	60

Appendix 3: Agenda for LBNC meeting

Speaker	Topic	Start	Duration
June 13			
Elaine McCluskey	Update on LBNF	8:30	45
Mike Headley	Far Site update and planning	9:15	30
Andre Rubbia	State of DUNE	9:45	45
	Break	10:30	20
Mark Thomson	DUNE strategy to CD-2	10:50	45
Lisa Whitehead	Far Detector Task Force update	11:35	45
	Lunch	12:20	60
Steve Brice	Near Detector Task Force update	13:20	45
Alfons Weber	Beamline Optimization Task Force update	14:05	30
Tom Junk	Software & Computing Working Group	14:35	45
Xin Qian	Update on reconstruction development	15:40	30
Jon Urheim	Physics Working Group	16:10	45
	LBNC Executive Session	16:55	90
June 14			
	Q&A session with DUNE/LBNF management	8:30	60
	LBNC Executive Session	9:30	150
	Lunch	12:00	60
	LBNC Executive Session	13:00	180
	Closeout	16:00	60

Appendix 4: Charge to the protoDUNE mini-review

protoDUNE represents a crucial step in further development of the DUNE project, both as a large-scale demonstration and validation of the engineering design for DUNE as well as a platform for understanding the capability of the DUNE TPC as an unprecedented instrument for neutrino physics. protoDUNE is the first major hardware project being undertaken by the DUNE Collaboration. It is also proposed on a very ambitious schedule in order to take beam data in summer 2018 at the CERN Neutrino Platform. CERN is investing heavily in development of the infrastructure for the Neutrino Platform, as well as the beam lines, cryostats, and cryogenics required. The protoDUNE projects are being executed as major international projects at a scale comparable to a major experiment.

Now that initial organization and planning is in place, it is critical to review in depth the protoDUNE projects. The goal of the LBNC mini-review is to provide an in depth review of the following areas of planning for execution of protoDUNE-SP and -DP projects:

- Organization, including common areas between the two projects, and project management, including design review planning, QA planning, change control, schedule and milestone planning;
- Adequacy of resource planning, status of filling key positions and plans for ramping up presence at CERN;
- Identification of major areas of technical risk and assessment of mitigation plans, R&D strategies, as well as the range of potential impacts on schedule or resources; and
- State of engineering design development for major systems, including the TPC hardware systems and the electronics system;
- State and plans for overall integrated system design and testing;
- Feasibility of planned schedule and range of uncertainties, including basis of estimate, identification of key milestones, options for schedule improvements through additional resources, options for mitigation based on major risks.

The mini-review should be prepared to discuss initial findings, comments, and recommendations with the LBNC on Monday evening, June 13.