

Long Baseline Neutrino Committee

FERMILAB, March 2020

CLOSEOUT Report

March 6

Acknowledgements

The LBNC has enjoyed examining the advances being made the LBNF project and by the DUNE Collaboration.

We were shown construction progress at SURF, analysis results from ProtoDUNE from both Far Detector technologies, and understanding of the path forward for the Near Detector design. We thank DUNE for the clarity of their presentations and discussions.

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

LBNC Meeting Charge Draft 3/2/2020

- The LBNC would like to hear about the general status of LBNF. Of particular interest are the planning for DOE-IPRs, the current schedule, and any options for early delivery of beam. The LBNC would appreciate hearing a short discussion of the projections as a function of time of the accelerator performance, in particular the power delivery, through PIP II.**
- The LBNC would like to hear from DUNE its overall status and progress from a high level, providing a basis for the details which follow. A discussion of the numbers and impacts of new collaborators should be covered. Given that the plans for Hyper-K appear to have progressed, the LBNC would like to hear the view of the DUNE collaboration.**

LBNC Meeting Charge Draft 3/2/2020

- Time has been allotted for discussions of the advances in the Technical Coordination of DUNE and of the development of the Resource/Responsibility Matrix.
- The LBNC would like to hear about the progress with the Far Detector SP technology. The presentation(s) should cover:
 - Operations of ProtoDUNE-SP during 2020 and the understanding of operating parameters for DUNE and the plans for ProtoDUNE II operations.
 - Physics analysis of the PD-SP data including charge and photon detection. A separate talk is envisaged in the draft agenda
 - SP technical progress including the TPC electronics development.
 - Progress in understanding of, and tests, of installation plans and procedures for DUNE.
 - Time has been reserved for breakout discussions which we suggest could be used for some of these discussions.

LBNC Meeting Charge Draft 3/2/2020

- **For the Far Detector Dual Phase technology, the presentations at this meeting follow a teleconference between the DP principals and the LBNC DP focus team. We anticipate that the “plenary” talk will cover progress through the LBNC Meeting. We have assigned a separate talk for the analysis. In the breakout, we anticipate discussions which follow on from the detailed issues addressed in the teleconference. The review group may have some specific questions.**

LBNC Meeting Charge Draft 3/2/2020

- **At its December 2019 meeting, the LBNC heard an extensive discussion of tentative planning for the detectors to be included in the Conceptual Design Report for the Near Detector complex. Anticipating the imminence of the CDR, the LBNC would like to hear about how the design has evolved over the past few months. In particular, anticipating that resources will be constrained, the LBNC would like to hear of any plans for descoping or staging. These should ideally include discussions of their impact on the eventual systematic uncertainties.**

LBNC Meeting Charge Draft 3/2/2020

- **The LBNC continues to be interested in the development of the Computing Consortium. This would ideally include a discussion of the scope of the consortium responsibilities vis-à-vis the full spectrum of DUNE capabilities and their organization and integration.**

- **The LBNC will develop a Closeout Report which it will deliver not later than 13:30 on Friday March 6. Subsequently this will be refined into a LBNC Meeting report.**

LBNC Meeting Assignments 3/4/2020

LBNF Status

Fuerst, Laxdal, Peterson

Power Delivery Projections & PIP II

Laxdal, Fuerst, Peterson

DUNE Status

Behnke, Kopp, Gray, Montgomery,
Saoulidou,

FD Dual Phase (All Status)

Spalding, Behnke, Galbiati, Kajfasz,
Para, Wood

FD Single Phase (All status)

Parsons, Pitts, Fava, Liu, Pla-Dalmau

Technical Coordination

Charlton, Fuerst, Laxdal, Peterson

Responsibility Matrices

Charlton, Fuerst, Laxdal, Peterson

ProtoDUNE SP Physics Analysis

Gray, Campana, Charlton, Kopp

ProtoDUNE DP Analysis

Gray, Campana, Charlton, Kopp

LBNC Meeting Assignments 3/4/2020

Near Detector Status (staging)

Oser, Behnke, Mondal, Kopp,
Saoulidou

Breakout

Dual Phase

Spalding, Galbiati, Kajfasz, Para,
Wood,

Single Phase Electronics, Install
Near Detector Details

Parsons, Pitts, Fava, Liu, Pla-Dalmau
Oser, Behnke, Mondal, Kopp, Saoulidou

Computing/Analysis

Campana, Charlton, Gray

Findings:

- **Reliability projects** - \$36M in work is on-going - three are now complete – ORO Hondo, refuge chamber, transport skips - Still some on-going (Ross shaft refurbishment, cage replacement, hoist upgrades, crusher roof upgrade) with hoist motor refurbishment to be awarded soon.
- **Pre-excavation construction** - 36 work packages totaling \$120M were awarded to KAJV - Work is fully underway, expected completion date DEC2020- Ore pass excavation work complete - Next phase is the skip loaders fabricated and shipping in progress (this represents the critical path)- Tramway and ground level conveyor system are in progress - Completion date extended by 17 days - Safety – zero recordables - Budget 3% over generally due to unforeseen site conditions during the work - Billing is now at 40.7% (\$48.5M of \$119M) with contract duration at 61% (457 of 748 days).
- **FS Excavation** - proposals have been received from potential sub-contractors to CMGC contractor - CMGC is preparing a response to LBNF for Mar 20 - LBNF will then go to DOE May 1 - DOE approval July 24 to award KAJV Aug 10 with work initiated mid-DEC2020 (consistent with completion of pre-excavation) - the North cavern completion was reported last Dec. as stretching beyond Oct 2022 with efforts being pursued reduce the slippage – an expected date was not presented at this meeting.
- Continuing to try to shorten facilities schedule at far site using value engineering – this has led to a change in the LN2 facility procurement strategy with a potential saving of \$35M.
- **Near site** - 50% preliminary design review on Dec 31, 2019 - 100% preliminary design expected by end of March 2020 - Cost and schedule will be produced from this by May 2020 - Site preparation is reported as `on schedule' – moving cooling ponds, re-routing power and access roads.

Findings:

- **Beamline status** - Interface definitions >90% complete - design has advanced on Magnet stands, Stripline voltage tests and 3 horn common module design – baseline shows that target area is ready for beam-based alignment in Q2 2029 with availability for beam power ramp up 6 months later (Q4 2029).
- **Project schedule to first beam:** If cash-flow was not a constraint the project could advance the target area readiness by 13 months (to Q4 2028) and save \$34M integrated over the project - Would require more money over 2022-2025 - Critical path would move to horn production and not CF – early beam from PIP-2 could be available Q4 2027.
- **Project strategy** - IPR with DOE in Oct. 2019 produced 40 recommendations - Analysis by a Director's committee concluded that the most critical project effort should go into establishing cost certainty - Still ~\$130M in unassigned scope within LBNF - Aiming for CD-2 at the end of 2020.
- **LN2 system procurement** – The project has decided to re-locate the recycle compressors from above ground to underground. Management of risks for the LN2 system procurement is being partially mitigated by having multiple vendors do design work and evaluating their work in two phases prior to award of the final contract. Phase 1: Issue an RPF to industry for a 30% Preliminary Design by up to three firms. Phase 2: Receive proposals for the full scope using their technical solution. One company will be selected based their phase 2 proposal. The deadline for awarding the N2 system contract is SEP2022.

Comments

- LBNF continues to make significant progress at the far site with, among other milestones, the completion of the ore pass excavation.
- LBNC echoes the response from the Director's review committee concerning cost certainty and notes that maintaining LBNF on schedule and within budget is the best way to show that the project costs and schedule can stay within the envelope.
- While the reported 17-day slippage of the schedule since the last LBNC and 3% overage on budget are not alarming, the root causes should be noted – anything that can be learned in pre-excavation should be applied to the excavation phase.
- Making up any time on the previously reported 6-month delay of the North Cavern (beyond Oct. 2022) will be very challenging given the complicated integration path plus the uncertainty of sub-contractor schedules.
- LBNC thanks the team for exploring how the time to 'target ready' can be reduced by optimizing the cash flow – analysis of the estimated dates for DUNE readiness and PIP2 readiness shows that the target/beamline still represents the critical path to first science - given that Hyper-K is a reality, advancing first beam forward could be critical to DUNE leading the discovery science.
- The LBNF management and CMGC should be congratulated on the excellent safety record.

Recommendations

1. Continue to explore ways to advance the beamline/target schedule as it represents the critical path to world-leading science.

Findings:

- PIP-II goals are to achieve 1.2MW onto the LBNF target – upgradeable to multi MW
- The accelerator complex includes a new 800MeV H- linac, a booster upgraded to 20Hz (to 8GeV) and the main injector to produce 60-120GeV protons for neutrino production at the LBNF target
- Day 1 expectation would be to deliver some beam at >600MeV to the linac dump with equipment installed to support 1.2MW
 - Early CD-4 date is Q4 2027 (DOE CD-4 date is 54 months later Q2 FY32)
 - 54 months contingency imposed by DOE due to perceived uncertainty of in-kind contributions
- Power ramp up curve (responsibility of accelerator operations)
 - Estimate that it will take 4 years to get from Day 1 to 1.2MW
 - Estimate 63% beam power after two years (750kW – matches present beam power)
 - 92% at year 3
- Could potentially reduce ramp-up from 4 years to 2.5 years if more resources could be applied (HLAs etc) to preparation for operations
- Estimate DUNE detector#1 would be commissioned Q4-2027 and detector #2 Q4-2028 assuming north cave ready at T0=Oct. 2022+6 months and Nessi presentation July 2019
- Baseline schedule has Beamlines/target ready for beam power in Q4-2029 – from LBNF talk this could be pulled forward by 13 months so Q4-2028

Comments:

- Present projections show that one DUNE detector could be ready for neutrinos Q4 2027 and the second Q4 2028.
- These dates clearly show that there is a major science opportunity to 1. complete PIP2 at or near the early completion date 2. invest in an aggressive beam ramp-up strategy 3. explore/invest in beam ramp-up strategies with a beam destination independent of the target area 4. continue to further look for opportunities to advance completion of the target/beamlines area
- The baseline early completion of the accelerator complex is Q4 2027 with an anticipated ramp-up to $\geq 750\text{kW}$ in Q4 2029. Accelerating the ramp-up to higher powers ($>1\text{MW}$) increases the science reach. Note that this is still two years after the first detector is ready.
- The recent LBNF study showing that the beamline could be pulled forward by 13 months is noteworthy and encouraged but still means that the beamline would be ready for power ramp only in Q4 2028 with first science in Q4-2030 – it is clear that there is still a science opportunity to advance the beamline further
- It would be useful for the accelerator complex to have a dedicated dump where they could begin power ramp up independent of the beamline/target – this could help save another year to produce first meaningful science Q4-2029

DUNE Status

Behnke, Kopp, Gray, Montgomery, Saoulidou,

- The LBNC is pleased to see a continued growth of the collaboration. We encourage DUNE to indicate at the next meeting the level of contribution they expect from the new groups.
- LBNC is concerned with the current practice to limit the terms of the Spokesperson position. This practice matches more closely to that used by the collaborations once initial construction had been achieved. LBNC is convinced that during the construction phase a stable management is critically important.
- LBNC is pleased to see progress in better defining the structure of the collaboration. We like to stress the importance of frequent high-level communication between the different consortia to ensure that the different components work together seamlessly.
- LBNC notes the progress made in establishing funding, in particular regarding positive developments in France and Italy. To that end, we strongly encourage DUNE to continue the approach followed so far, by the DUNE resource manager, towards identifying areas and ways to increase the overall contributions to the project by DUNE institutions.

DUNE Status

Behnke, Kopp, Gray, Montgomery, Saoulidou,

- The LBNC encourages DUNE to elaborate on the comparison between the DUNE and the HyperK sensitivity reach. A comparison under equal conditions would be very useful.
- The LBNC strongly encourages DUNE to continue pursuing a common approach to data analysis, simulation work and software, across the whole collaboration, and further exploit potential synergies in this area.
- LBNC is pleased to see the progress in terms of using physics requirements in order to optimize and determine the baseline DUNE ND. LBNC encourages the DUNE collaboration to continue down this path, following the recommendations from the December 2019 meeting.
- The LBNC is pleased to see DUNE continuing systematics tests towards understanding the DP technology related issues. LBNC strongly recommends that DUNE forms a clear R&D plan and timeline to determine the path forward for this technology.

Recommendations:

- **LBNC strongly recommends the Institutional Board of the Dune Collaboration to reconsider the current term limits applied to the Spokesperson position.**
- **LBNC requests that at the next meeting a discussion of the communication structure between and with the consortia is presented.**

- The strategy to treat Single-Phase ProtoDUNE-II as the first part of the DUNE construction (“Module-0”) was noted. The LBNC supports the collaboration in pursuing this strategy as far as possible, while noting that it is likely to pose many challenges in practice:
 - This strategy may require more schedule contingency, to allow delays to be worked out without “emergency procedures”
 - A potential pit-fall, based on the R&D culture currently existing in the collaboration, is that there will be requests for additions of opportunistic testing/hardware that is orthogonal to the “DUNE-0” motivation – to mitigate this, clear requirements/specifications/test plans should be documented and agreed by the collaboration
 - This strategy will likely require strengthening of the Technical Coordination team
- The proposed Single-Phase PD-II program looks well justified: for example using four APAs instead of six; installing some APAs as if in the lower orientation (“upside down”)
- The timescale for PD-II SP is stated to be set by the availability of the “module-0 version” of the cold electronics: this has the potential to cause schedule slippage which could introduce additional costs or risks for the main construction
- The LBNC notes that the schedule of the PD-II program needs to be agreed by the CERN SPSC, as beam schedules at CERN have changed and may change further

- The LBNC thanks the collaboration for the updated summary of the coverage, and opportunities, of responsibilities for construction of the first two single-phase detectors
- The cost books initially indicate a CORE cost of \$110M for the two detectors together. This has been reviewed initially by the NCG, and the analysis is being further developed.
- The process being followed by DUNE to establish firmer costs is appropriate
- The current coverage of the two-SP FD construction responsibility is 50-75% at various degrees of funding agency approval/review, with around 17% (~\$20M CORE) seen as an opportunity for new money and/or collaborators
- The collaboration is encouraged to prioritize new collaborators towards helping to address missing FD SP scope
- The collaboration is encouraged to make progress in planning for, and establishing the level of, the Common Fund for the construction phase; some parts of the calibration or cryogenic instrumentation systems, for example, may be appropriate for the Common Fund
- The ongoing development of institutional (or funding agency, where appropriate) responsibilities at a detailed level for both hardware and non-hardware deliverables is applauded.
- Inclusion of non-hardware deliverables in MOUs is also a very positive development.

FD Dual Phase Progress in ProtoDUNE

Spalding, Behnke, Galbiati, Kajfasz, Para, Wood

- The committee congratulates DP on significant progress in the protoDUNE run since the December LBNC meeting.
- At an interim video meeting on Feb 6 and in follow-up Q&A, DP provided the committee with detailed descriptions and discussion of the issues and progress to date. This was very much appreciated.
- We think a similar meeting in about 2 months would again be very useful.

Cryo/Liquid Conditions

- Since November, repeated regeneration of a filter in the recirculation system is no longer necessary, leading to much more stable cryo conditions and allowing DP to make significantly more progress.
- Since then, the liquid purity has improved steadily. The long purity monitors indicate ~9 ms e-drift lifetime has been achieved.
- **Surface instabilities (both bubbles and ripples) continue to be concerns that impact stable CRP operation. Further studies are planned at protoDUNE and in an upgraded/new cold box.**
- **The committee considers it important to continue these studies and to foresee the surface behavior in the full scale module.**
- An operational procedure, applying overpressure for ~hours once per week, generally suppresses bubble formation for several days, allowing periods for studying CRP sparking and gain.
- Intervention surgery on the HV extender is planned to extend the drift field to full depth. The baseline plan requires removing ~25% of the liquid to allow the surgery, followed by refilling. The entire process is likely to take 2-3 months. An alternative approach that would perform the surgery in liquid is under consideration.

CRP Sparking

- The typical LEM spark rate is $\sim 3/\text{CRP}/\text{hr}$, with Grid sparks at $\sim 0.3/\text{CRP}/\text{hr}$. While the electronics is protected from LEM sparks, the 6kV Grid sparks permanently damage the readout ASIC. Sparks can be in bursts, with correlation between sparking involving multiple LEMs and the Grid – the mechanism is not yet understood.
- Studies include changes in the quenching resistors, introduction of capacitive coupling, and mapping HV settings – an extensive program.
- During these studies the electronics is disconnected for protection and is only connected for very limited periods for CRP performance studies - only several days in total so far.
- An increasing number of LEMs (currently 26 of the 72) are kept at reduced voltages to avoid repeated sparking, so excluded from performance studies.

CRP Performance

- The CRP gain fell by a factor ~ 2 in early operations, then plateaued. This behavior is consistent with prior bench tests and attributed to charge up effects.
- However the plateau value is about a factor two less than expectation based on bench tests (correcting for operating pressure). Voltage scans are planned to understand contributions to the gain to further study this.
- Noise characteristics indicate a microphonic/vibration between LEM surface and anode. While this should be understood and mitigated in the design, it this is not an issue for present studies.
- The short in the HV extender limits the depth of the uniform drift field to about 1m. The non-uniform field beyond this leads to clearly observed curvature in the tracks.

PDS

- Initial studies to date include fast/slow scintillation components and correlation with drift field and LAr purity, S1 and S2 signal correlation, TBM vs PEN WLS
- Ready now to take runs together with the charge readout, followed by combined data-taking with full drift depth after the HV surgery.
- **DP should continue to carefully manage the “budget” in grid spark damage to first complete CRP gain studies and then take this combined data.**

- **The committee considers that understanding the sparking issues and CRP gain are the highest priorities for the run.**
- Once these studies are complete, the HV surgery (which carries some risk) will allow important measurements, including developing tracking/analysis to full depth, mapping space charge effects on the field, and correlating the PDS with charge data.
- **We consider it very important that, if needed, the running period be extended to complete this full program.**

LEM/CRP R&D towards ProtoDUNE-II

- Design improvements and prototyping to address CRP deformation and sparking are underway.
- Initial plans were presented to develop new CRPs for a second protoDUNE run, including prototypes for improved LEMs and CRP mechanical structure, testing of a new CRP design (small prototype), and production of two full CRPs for protoDUNE.
- A new cold-box is needed to support the program of studies and extensive and long term testing of the new design.
- **The committee considers the new/upgraded cold box and associated cryo systems to be essential to this plan.**
- **The plan should include stress testing of a prototype and long term testing of the new CRP design.**
- **Specifications for the amplitude of surface irregularities that can be tolerated by the new CRP design should be developed.**

Recommendations

- If necessary, the present run should be extended to complete the program outlined.
- At completion of the run, DUNE should hold a technical workshop and review assessing what has been learned and R&D plans that can lead to a successful demonstration of final design in protoDUNE II.
- The R&D will require additional resources, including a new cold box and associated systems to support studies of the liquid surface, and demonstration of robustness of the new CRP design.

FD Single Phase (All status) **Parsons, Pitts, Fava, Liu, Pla-Dalmau**

- The comments here will be on both the ProtoDUNE operation and the data analysis as the two are closely related, but more from the point of view of FD Single Phase detector.
- The committee is very much impressed by the stable ProtoDUNE SP operation over more than one year, this is a major achievement.
- *CRT trigger data has been very useful in understanding the detector performance. In fact, it is so good that it makes one wonder how to do the same for DUNE where cosmic rate is low.*
- *The ProtoDUNE SP performance setting rather high standard for the new cold electronics currently being developed for FD Single Phase.*
- *It is not so clear how to measure the uniformity (or the lack of) of Xe diffusion using cosmic ray data at ProtoDUNE. In particular, how the results can be extrapolated to FD? How to measure/study it at FD Single Phase?*
- *The LBNC is looking forward hearing the details of the calibration and monitoring system design for FD Single Phase at next meeting.*

Single Phase Breakout, Electronics, Install **Parsons, Pitts, Fava, Liu, Pla-Dalmau**

SP Electronics

• *Findings:*

- The PDR for the FE ASICs and FEMB was held Feb. 5-7 at CERN. The prelim. report from the review was provided, and makes clear it was a very useful review. The report is positive overall, and provides a number of recommendations that are being followed up.
- The current plans call for submission of the next versions of the 3 ASICs as follows:
 - LArASIC – June (most changes implemented, still need to add single-ended to differential conversion; recommendation to increase ESD protection will be revisited after June submission)
 - ColdADC – April (most changes implemented already; some still being worked on)
 - ColdDATA – June (modifications needed to PLL, some issue with availability of EE designer)
- For CRYO, not much progress has been reported since the Oct presentation. In particular, it is not clear whether the noise issue is understood yet. As recommended by the PDR, the next submission will happen only after system tests are done (expected not before July).
- The current schedule calls for the ASIC down-select in February, followed by an engineering run (required to get enough chips for ProtoDUNE-II)
- An investigation of the ICEBERG incident that destroyed a number of FE chips has identified as the likely source a damaged cable delivering HV to the cathode. Improved procedures (including hardware interlocks) have been put in place, and ICEBERG is currently running stably
- The PDR of the WIB is scheduled for next week at BNL. While new WIB prototype boards have been built and tested, the required firmware development is starting only now

Single Phase Breakout, Electronics, Install **Parsons, Pitts, Fava, Liu, Pla-Dalmau**

SP Electronics

- *Comments:*

- The LBNC shares the view expressed by the PDR reviewers that ASIC (and other electronics) designs need to be openly shared within the collaboration (and during the review process required to properly validate the readiness for production)
- The submission schedule for the next ASIC submissions is tight, particularly for the LArASIC that is targeting April but does not yet have a complete layout, and for CRYO that is targeting July but needs system tests with the previous version to be completed before
- The Cold Electronics is on the critical path for ProtoDUNE-II, with the aim to have tested FEMBs ready for installation before end 2021. This schedule, which relies on the ASIC down-select in Feb. 2021, will be very challenging to meet (particularly if the next CRYO submission gets delayed past July).
- The LBNC agrees with the view presented by DUNE that operating with pre-production ASICs is a key goal of the ProtoDUNE-II program
- The late start of the firmware development for the new WIB puts under stress the need for this system to be ready to be used in tests starting in June, and should be followed closely
- We were told that removing the clock from the WIB could kill the power to the front-end boards. This unexpected behavior needs to be understood and resolved.

Single Phase Breakout, Electronics, Install **Parsons, Pitts, Fava, Liu, Pla-Dalmau**

SP Electronics

- *Recommendations:*

- Conclude and document the results of the investigation of the ICEBERG incident, and the lessons learned to ensure that no such incident can occur in DUNE
- Before the upcoming ASIC submissions, implement the recommendation from the ASIC PDR that: “The design methodologies and verification methodologies need to be clarified and improved for all the ASICs.”

Single Phase Breakout, Electronics, Install **Parsons, Pitts, Fava, Liu, Pla-Dalmau**

SP Installation

• *Findings:*

- Installation planning workshop was held in early February 2020
- External cost review of I&I took place in February 2020
- Risk workshop took place in early March 2020 – 6 new risks added
- Full-size APA and CPA tested at Ash River
 - Conduit installation moved to APA assembly factory
 - Some changes to installation cleanroom layout
- Ash River Installation Prototype Phase II – drawings 90% complete
 - Test rows 1 and 25 are part of Ash River Prototype Phase II
 - Test all components of protoDUNE II in Ash River Prototype Phase II
- ProtoDUNE-II planning is underway

• *Comments:*

- The 3 recommendations made at the I&I review are not surprising at this stage of the project – continued attention to interfaces and integration will remain of utmost importance
- Installation 3D modeling will be a useful tool. Of course, modeling of installation is not a substitute for actual tests / practice
 - Valuable lessons were learned in the tests at Ash River, and the Phase II experience there will also be important
 - If NOVA has a problem, the crew needs to work on NOvA first – it does not seem to be a worry → is it well understood? Enough time in schedule if delayed?

Findings:

- The ArgonCube 2x2 demonstrator schedule has slipped several months. The current schedule is realistic if no unexpected problems are encountered.
- The DUNE collaboration has made significant progress in defining physics criteria for the ND optimization. DUNE has already used these criteria to study the possibility of a MINOS-style magnetized iron+scintillator range detector (to be used temporarily in place of the MPD in case staging is required), finding that it can be adequate for momentum measurement, although its sign selection ability must still be studied.
- The magnet design for the MPD is advancing rapidly. A new design with a partial iron yoke is under development. This latter design looks to provide some attractive features and LBNC is pleased to see this developing.
- For the SAND detector, it seems likely that some minimal amount of tracking inside the magnet will be required beyond the KLOE magnet+ECAL alone in order to reject rock muon backgrounds and provide sufficient momentum resolution.

- For a CD-2 review late this year it may be sensible to use the CDR plus some addenda that spell out preliminary cost estimates.
- Consortia are being formed for ND components. DUNE must ensure that there is strong technical coordination between these consortia, which must operate in a coordinated manner and share infrastructure.

Recommendations

- No major new ones. LBNC encourages the Collaboration to continue to work on those received in December 2019
- A section in the CDR that focuses on the effects of the ND data in an oscillation analysis needs to be included.
- *LBNC reemphasized that the end-to-end oscillation analyses be extended to include off-axis PRISM data to demonstrate quantitatively the benefits of the off-axis technique.*

- We congratulate the Computing Consortium for enabling data analysis of ProtoDUNE-SP and DP, for which Pandora is an important component. We continue to encourage collaboration between SP, DP and ND in all aspect of computing and analysis
- We are pleased to see the planning for provisioning SURF-FNAL connectivity, in response of a previous recommendation. We suggest the evolution of the plan is regularly monitored and reported on. We believe the 100GE connectivity is required for the physics program of DUNE. We note that such capacity would be beneficial already in 2026 for computing commissioning purposes
- A US costing exercise for DUNE computing (hardware and operations) was presented, resulting in < \$10M over 10 years. We assume sizeable uncertainties particularly on the expert manpower estimates. We understand that such funding is critical for DUNE computing. We note that the cost of analysis and the cost of simulation, particularly for the ND is not well quantified and could be considerable
- We support the initiative of a SW Framework Task Force and are interested to hear the progress at the next meeting particularly on the future of LarSoft as core SW framework. We continue to believe that a stronger link between the simulation/reconstruction algorithms and the computing community should be established

- We congratulate the SP analysis group on the good progress on physics analysis and the paper preparations
- We look forward to the discussion of systematic uncertainties in the paper
- How will the CNN for the FD Single Phase be calibrated? Is it realistic to expect one calibration can be applied to all data
- The pion absorption data is also very important for near detector performance study
- We encourage you to continue to work to improve the agreement between data and simulation.
- We are glad to see the simulation task force and we encourage you to expand this effort to obtain a deeper understanding of the simulation, e.g. the Michel electrons
 - Where simulations need to be tuned, we recommend that it is verified that the tuned parameter values are physically meaningful and in agreement with external constraints
- We encourage the SP and DP groups to continue moving towards using common tools for simulation and analysis techniques as much as possible

- We're happy to see progress on the DP analysis, but we note that this is less mature than the SP analysis and has a factor of two less in manpower
 - We suggest that additional support is obtained from software experts to strengthen the DP analysis team
- We encourage the SP and DP groups to continue moving towards using common tools for simulation and analysis techniques as much as possible

DUNE Executive Summary: **Montgomery et al**

- The **LBNF Project** is daunting with an enormous scope. It appears that the pre-construction phase is progressing well, and that important procurements are reaching an advanced stage.
 - The LBNC was pleased to see the encouraging response to its request to understand the potential for advancement of the beamline completion. Continued exploration of such opportunities is strongly encouraged.
- The conclusion of several TDRs in 2019 followed by the incipient conclusion of the ProtoDUNE SP and DP operations heralds a new phase for **DUNE**. The attention of the collaboration is shifting to:
 - Planning for the ProtoDUNE II phases
 - Emphasis on establishing the Near Detector reference design and strategy
 - Preparation for installation at SURF

The collaboration continues to grow as groups join this successful enterprise.

- **Technical Coordination** embraces a broad portfolio. The multiplicity of efforts in different stages from pre-production, Module-0 installation, and research & development demands an organization and management which is broad, strong and decisive to maintain attention and momentum on all fronts and may require expansion of the team.

DUNE Executive Summary: **Montgomery et al**

- Good progress has been made in the allocation of responsibilities for the construction of the initial Far Detector modules. The strategy for convergence to full coverage of the needed scope is understood. The whole benefits from the encyclopedic understanding of the **Resource Manager**. The participation of the consortium leadership in refining the scope and establishing the required resource is important and should be assured.
- The **Far Detector Single Phase** technology has enjoyed considerable success in its ProtoDUNE I phase. It must now work towards production through definition of ProtoDUNE II as the “Module 0”. The LBNC recognizes and encourages this approach. There are however details:
 - The TPC electronics has multiple components and some technology choices to be made. A fully functional and strong team is essential to continue the recent progress.
 - The Installation planning appears to be under control. It is benefiting from the opportunity of testing the procedures in ProtoDUNE II to supplement the work at Ash River.
- **ProtoDUNE DP** is being operated systematically to learn as much as possible about the Dual Phase technology. To understand the path forward for this technology, a detailed R&D plan needs to be articulated clearly, then reviewed, and evaluated formally, by the DUNE collaboration at a high level.

DUNE Executive Summary: **Montgomery et al**

- The development of the **Near Detector Conceptual Design** hews close to that originally presented in mid 2019, and retains the components and capabilities encouraged by the LBNC. The LBNC looks forward to receiving the CDR.
 - It is understood that, at day-1, resources may dictate the installation of a constrained capability. DUNE is working to understand, articulate and justify an initial detector suite.
- We recognize the progress made by the **computing** consortium:
 - The scope of the computing needs are now understood to be tractable.
 - There is progress toward the solution of the networking access to and from SURF. The coherence of the view and articulation of the whole computing and software enterprise could use improvement. In this respect the Near Detector could benefit from coherent inclusion.
- The **ProtoDUNE DP analysis** shows advances in the basic analysis of the data taken over the course of the past months. The LBNC believes that it sees opportunities for the DP analysis team to further derive support, expertise and advice from the SP team.
- The **ProtoDUNE SP analysis** has been an enormous success, first publications are well advanced. The committee probed some advanced issues and the team appears to be addressing these points.

DUNE Executive Summary: **Montgomery et al**

- Once again, in the few short months since the previous meeting in December 2019, the LBNC has seen the considerable progress made by LBNF and DUNE in all arenas. We are ready to lend our support for progress toward baselining of the project and launching the international construction phase for the experiment.