

Long Baseline Neutrino Committee

FERMILAB, December 2020

CLOSEOUT Report

December 4, 2020

Acknowledgements

The LBNC has enjoyed examining the advances being made the LBNF project and by the DUNE Collaboration. It was important to understand the plans with regard to establishing a baseline for the DOE project including the combination of the APA single phase approach with a new Vertical Drift approach. Important progress with the Near Detector CDR and Day-1 detector scope were discussed. The progress with plans for Computing and its approach to design reports were nicely laid out. New analysis results from ProtoDUNE SP were discussed. We thank DUNE for the clarity of their presentations and discussions.

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

LBNC Meeting Charge Draft 12/2/2020

- **As usual, the LBNC should construct a report in which it acknowledges, comments on, and where appropriate, makes recommendations following the presentations and discussions during the meeting.**
- **The progress of LBNF-DUNE towards a baseline for the DOE project is critically dependent on achieving a high degree of clarity with respect to the scope of the project. In the presentations, LBNF and DUNE should pay attention to this aspect of its progress. In its report, the LBNC should explicitly address this issue with respect to both the Far Detector scope and convergence, and for the Near Detector scope and convergence.**

LBNC Meeting Charge Draft 12/2/2020

- **The LBNC should hear about the general status of LBNF. Of continuing interest are the progress of and planning for DOE-IPRs, the current schedule, and any options for early delivery of beam. The discussion of the beamline progress should be addressed in a breakout session shared with Technical Coordination.**

LBNC Meeting Charge Draft 12/2/2020

- **The LBNC should hear from DUNE about its overall status and progress at a high level, and provide a basis for the details which follow. The situation with respect to the IPR process and the approach to a Baseline review should be updated and clarified. The overview should include discussion of the development path for a second technology as well as the approach to the Near Detector including its Day-1 incarnation.**
- **Time has been allotted including a share of a breakout session for discussions of the advances in the Technical Coordination of DUNE. In addition to the general issues, the preparations for ProtoDUNE II SP and for installation at SURF should be addressed.**

LBNC Meeting Charge Draft 12/2/2020

The LBNC should hear about the progress with the Far Detector Horizontal Drift SP technology. The presentation(s) should cover:

- a) Progress towards ProtoDUNE II SP.**
- b) Technical progress on the SP Far Detector, APAs, assembly etc**
- c) Progress on the TPC electronics development and the progress towards a choice.**
- d) Physics analysis of the PD-SP data.**

Substantial time has been reserved for dedicated SP Horizontal breakout discussions which should be used for some of these discussions. Time is reserved in the Computing Breakout for a presentation on the physics analysis and results.

LBNC Meeting Charge Draft 12/2/2020

- It is understood that, following completion of the ProtoDUNE Dual Phase running in NP02, the DUNE collaboration is discussing a substantial strategic change of direction, likely towards a Vertical Drift configuration. The LBNC should hear about these developments, and the planning for the Vertical Drift Workshop. It will be important to hear about the plans for taking decisions and setting directions. Not all the technical issues with the DP running were limited to the readout. Even with a major change, there will be several technical issues to be resolved. The LBNC should hear plans for resolution of these issues. In addition a perspective on the future plans for NP02 should be discussed.**

In the plenary session in-depth discussion may not be possible but that there is substantial dedicated breakout time.

LBNC Meeting Charge Draft 12/2/2020

- The revised version of the Conceptual Design Report for the Near Detector complex is anticipated. A description of both the documentation and the technical status should be heard. The LBNC will be presented with documentation describing the components and the strategy to be employed for a Day-1 Near Detector. A Charge for a separate LBNC review of this plan has been prepared by the Laboratory Director. At this juncture, the LBNC should hear as much of these plans as are permitted by the time available.**

There will then be breakout time which should be shared between these aspects of the Near Detector planning.

LBNC Meeting Charge Draft 12/2/2020

- The LBNC was very pleased with the progress made towards a coherent view of the computing and software project up to the September 2020 meeting. The LBNC should hear about any further progress. Of particular interest would be an understanding of the evolution of the staffing.**

With a basis for the computing structure in hand, the LBNC should hear about some of the particular technical issues currently being addressed and progress therewith.

Following the success in the September meeting a substantial breakout session has been scheduled. During that breakout, the LBNC should also receive a presentation on the progress with analysis and results from the ProtoDUNE data taking.

LBNC Meeting Charge Draft 12/2/2020

- **The LBNC should develop a Closeout Report which it should deliver at 12:15 CDT December 04. Subsequently this should be refined into a LBNC Meeting report.**

LBNC Meeting Assignments 3/4/2020

LBNE Status	Laxdal, Charlton, Peterson
DUNE Status	Saoulidou, Gray, Kopp, Charlton,
Technical Coordination	Charlton, Laxdal, Peterson
APA Single Phase	Pitts, Fava, Liu, Parsons, Pla-Dalmau
Vertical Drift	Spalding, Behnke, Galbiati, Kajfasz, Para, Wood
Near Detector Status	Oser, Behnke, Mondal, Kopp, Saoulidou
Computing	Campana, Charlton, Gray

LBNC Meeting Assignments 3/4/2020

Breakouts

Vertical Drift	Spalding , Galbiati, Kajfasz, Para, Wood,
APA Single Phase	Pitts , Fava, Liu, Parsons, Pla-Dalmau
Near Detector	Oser , Behnke, Mondal, Kopp, Saoulidou
Beamline	Laxdal , Montgomery, Peterson
Computing	Campana , Charlton, Gray
ProtoDUNE Analysis	Gray , Campana, Charlton,

LBNF Status

Comments

LBNF continues to make significant and impressive progress at the far site with, among other deliverables, steady progress on rock conveyance infrastructure and the work to improve ventilation in the Raise Bore Chamber. Most importantly, the completion date of pre-excavation work, that had experienced previous delays due to CV-19 and reworks, is now holding steady at April 2021.

The DOE approval and subsequent awarding of the FS excavation contract marks a major project milestone. LBNC supports the demonstrated urgency of LBNF to complete pre-excavation and site preparation works by April 2021 and subsequent start of far site excavation as these are critical to hold the N/S cavern availability to the April 2024 goal.

The approval of the LN2 contract strategy by DOE and the completion of pre-works at the near site are also key achievements of the last period.

The LBNF management and CMGC should be congratulated on the good safety record at the FS and the demonstrated efficiency at managing the CV-19 issue.

We note that the resource ramp up of 20% in Fall 2020 as predicted in the Sept2020 LBNC did not materialize. Instead the ramp up has been pushed forward to the Spring 2021 period with a peak increase of 35% required. Any lessons learned over the previous period should be employed to achieve the required resource ramp for the next period. Most important of course is to attack the critical path.

The delay in the MI shutdown schedule for PIP-II installation has impacted the LBNF near site CF planning and schedule for the beamlines tie-in. There is some concern that this adds near site schedule risk as some work is shifted to 'just in time' completion. LBNC recommends that an alternative plan with optimized cash flow and optimized shut-down be developed at a conceptual level so that the FNAL management understands the opportunity of a dedicated LBNF shutdown should PIP-II be further delayed.

Recommendations

- Complete an alternative near site plan with optimized cash flow and shut-down to compare against the baseline.

Beamline

Comment:

The beamline team is making significant progress on designs with preliminary designs well advanced with some detail design and prototyping in progress. LBNC notes that 2021 is a critical year for Beamlines with several key reviews planned on the road to CD-2. The team looks to be advancing systematically on a credible plan and seems in good shape for CD-2. Kudos to the team for working with CF in value engineering to realize cost reductions.

Given the considerable scope from BARC, and the fact that BARC deliverables are near critical path, the stated goal from the team to escalate to regular remote meetings is commended.

The horn PS remains a critical component that sets the critical path for the development of the Horns. The lack of an experienced pulsed power engineer represents a considerable risk. LBNF should continue to explore (globally) potential high power pulsed power supplies that could be used for the Horn tests, even to qualify aspects of the design, while continuing with the design and development of the final article. Certainly, the addition of SLAC expertise is welcome but the search for a high power EE must proceed with high priority.

The link of the near site beamline installation to the PIP-II shutdown will delay critical installations that may delay the project if any installation or commissioning issues emerge. It is recommended to at least document alternative plans should PIP-II be further delayed. The combined shutdown will also put high demand on technical people and so careful resource planning will be essential.

DUNE Status

- The LBNC is pleased to see a steady, continued growth of the collaboration, with new institutions with distinct roles and contributions joining the experiment.
- The LBNC commends DUNE for providing a clear management structure, with consortia of institutions formed and finalized having clear responsibilities for the design and construction of the different detector elements. The committee commends DUNE for continuing to seek and secure international funding and contributions for the FD and ND detectors.
- The LBNC commends DUNE for making significant progress on defining the “Day 1 ND”. The preliminary physics studies presented, which would need to be completed and documented in detail, indicate that this could be a viable detector option that can achieve the physics goals of the initial running period, where statistical uncertainties are such that an aggressive reduction of systematic uncertainties will not have a significant impact on the main oscillation measurements.
- The LBNC is pleased to see significant progress made towards the construction of Far Detector Module 0. The LBNC commends DUNE for developing a detailed plan to allow for the second far detector module to use the APA technology if needed.

DUNE Status

- The LBNC notes that the VD detector technology could provide a highly promising route to a possibly cheaper, faster-build, second far detector module. The LBNC appreciates the important initial work and studies performed so far, and reported to us. The committee does see significant potential benefits to the technology, in terms of cost and construction speed.
- The intense and aggressive R&D needed for proving the VD technology at scale will require detailed planning, and strong support from across the DUNE Collaboration. This work is critically important in 2021, and extends through to a successful ProtoDUNE (NP02) run in 2023. The LBNC looks forward to hearing more about all of this at the next meeting.
- The LBNC notes that the resources required to establish the VD technology, both human and financial, will need to be identified and realised on a very short timescale.
- The LBNC looks forward to seeing planning for modifications of the consortia responsibilities to incorporate the VD module at a future meeting.

Technical Coordination

- The LBNC notes the large amount of activity that will be needed at CERN in the years 2021-2023 to deliver critical R&D for the vertical drift module technology, at the same time as ProtoDUNE work. Close collaboration between the CERN activities and DUNE Technical Coordination will continue to be essential.
- The need for a large-scale test of the vertical-drift technology at ProtoDUNE suggests that operation of the ProtoDUNE-II single-phase ("APA-style") module, and the vertical drift ProtoDUNE module, may need to overlap. The challenges should be foreseen and addressed.
- The committee is concerned that the small core team of experts at CERN will be overloaded in the period from now until 2024, and urges Technical Coordination, and DUNE as a whole, to ensure that this team is expanded. In addition, strong support will be needed from multiple parts of the Collaboration, including the consortia, for both the R&D program and for preparation of the second-round ProtoDUNE tests.
- Noting the rapidly increasing range of activities for Technical Coordination, and the need to ensure sufficient attention to continuous routine work, as well as responding to new events and initiatives, the LBNC believes an increase in the size of the Technical Coordination leadership team should be considered.
- Given these increasing activities, the LBNC recommends that a comprehensive integrated resource loaded schedule is drafted with critical milestones.
- The LBNC repeats its wish to see schedule updates at each LBNC meeting, both for short and longer-term DUNE construction activities.

Recommendation

- Draft a comprehensive integrated resource-loaded schedule with critical milestones.

APA Single Phase

Findings

- ProtoDUNE-SP I a success. Work now toward ProtoDUNE-SP II and preparation for production
- APA Module 0 for ProtoDune II – started at Daresbury (UK)
- Electronics:
 - ColdADC 2nd prototype meets DUNE requirements
 - LArASIC (FE amplifier) latest prototype addresses problems observed in ProtoDUNE, but new issues have arisen that will require an additional iteration of the design to be submitted
 - CRYO making progress, but problems with coherent noise are not understood yet
- Photon Detection
 - 2-cell X-ARAPUCA tested with good efficiency level (~ 3%)
 - 6-cell X-ARAPUCA (supercell) is being assembled
 - Warm electronics – DAPHNE prototypes will be ready in early 2021
 - Cold electronics – integration test of all cold parts is ready
 - Photodetectors – 1 sensor/vendor selection planned for March 2021
- Considering scenarios for 2nd DUNE module, evaluating plans/options for 2nd APA-based module or vertical drift.

Comments

- Clear progress on all APA single phase detector components
- Collaboration reacted quickly to changes in directive from DOE regarding 2nd FD & potential new detector technology
- Work & tests are happening in many places – procedures must follow strong configuration control standards
- DUNE should work with US and UK groups to further develop a strategy to produce APAs for a single far detector module on the timescale necessary, while maintaining capability to produce a 2nd set of APAs if the backup plan is needed. We hope that NSF support in the US can help enable this strategy.

Recommendations

- None

SP Breakout - Electronics

Findings

- ColdADC P2 - received in September
 - previous problems fixed – current chip version meets DUNE specifications
 - residual non-linearity observed, modest in size and stable, shown that a software correction can be performed.
- LArASIC P4 – received late October.
 - several issues (e.g. “ledge effect”) shown to be resolved
 - attempt introduced in new version to improve baseline uniformity problematic at cold temperatures, need to fall back to previous design for this part of the circuit
 - one more submission needed, early in 2021 ahead of ProtoDUNE-II
- Combined test of ColdADC P2 + LArASIC P4 showed good results
- COLDATA should be back mid-December. Expect fast testing turn-around, modifications were minimal.
- Reliability testing in ICEBERG and CERN cold box in the new year.
- CRYO – testing continues on nEXO optimized chip.
 - Uncorrelated noise low and as expected, correlated noise source not yet identified.
 - New submission - DUNE optimized - is ready but needs to wait for additional tests on correlated noise.
- Schedule was modified to wait for ProtoDUNE-II operation before submitting production ASIC orders – float reduced

Comments

- We congratulate the consortium on continued progress
- We support the strategy with LArASIC (one more submission) and ColdADC (make corrections for residual nonlinearity offline rather than modify ASIC design)
- Reliability testing a high priority as the components are quickly converging to the final versions.
- The cold electronics schedule remains very tight, and it will be important to continue to manage all elements of it closely.

Recommendations

- None

SP Breakout - APA

Findings

- Preparations at Daresbury Lab (DL) APA factory are under way for APA cold test at CERN in February
- Important milestones are in mind and on track
- APA frame, APA boards, and Transport box are near final design
- Suppliers – not a single source – comparable qualities
- Metrology – good correlation between DL and PSL measurements
- New wiring head – meets tension requirements in all planes

Comments

- We congratulate the consortium on continued progress
- Integration methods and tools are being established – It is the right time to setup integration habits and protocols
- Technical and mechanical aspects not affected by current VD considerations & uncertainties

Recommendations

- None

SP Breakout - Photon Detection

Findings

- X-ARAPUCA (baseline design) currently being validated
- 2-cell X-ARAPUCA built and tested at Milano Bicocca – 2.8% efficiency
- Supercell testing in LAr delayed due to COVID situation
- DAPHNE – internal reviews helped bring board to maturity
- Photosensors – 6 different types being considered
- Light waveguides – considering PS and acrylic instead of PVT – better temperature cycling and potentially better light collection

Comments

- We congratulate the consortium on continued progress
- We support the consideration of PVT alternatives
- No long-term testing results available – test start at Syracuse Univ. delayed due to COVID situation
- No new developments were reported related to Xe-doping
- Carry out tests for long-term stability of components

Recommendations

- None

SP Breakout - Installation

Findings

- Installation document in place – will be updated with pictures for March/April 2021 review
- Prototyping is continuing at Ash River – used to understand all the motions – completed assembly for phase 2 testing – row 25 will be the next test (late winter/spring 2021)
- Cavern is the critical step – when access to underground is given installation needs to be ready to go

Comments

- We are impressed on the progress and appreciate the strong coordination
- Careful attention is being paid to interfaces / integration

Recommendations

- None

Vertical Drift

Findings-1

- A new concept for an FD module was presented: Vertical Drift technology is an evolution of the Dual Phase concept. Whereas it preserves and capitalizes on the successes of Protodune-DP, it addresses the major challenges by shortening the drift distance, hence significantly reducing the required HV and by replacing the gas-gain readout by the well established single phase charge collection. The latter change is enabled by a successful demonstration of excellent levels of liquid purity attained in both Protodune SP and DP.
- A Technical Proposal will be reviewed within the DUNE collaboration next week. The LBNC was given a preview, which is very much appreciated.
- VD geometry: two anode planes (top and bottom) using a new PCB technology, a central cathode, SP-based electronics for the bottom anode and DP-based electronics for the top. The PDS is based on the Arapuca technology developed for SP.
- The design capitalizes on the experience from the SP and DP protoDUNE runs, utilizing many aspects which are well advanced. New developments requiring significant R&D include the anode plane design, the PDS which must operate on the 300kV cathode plane, and the HV system which will be an improvement of the DP design.
- The production, assembly and installation of the VD CRP, made from 3mx3m units is expected to be cheaper and faster than the assembly and installation of the APA planes in the SP design.
- And the design has the potential for an increased fiducial volume relative to APA SP.

Vertical Drift

Findings-2

- In supporting material DUNE presented and answered questions on several aspects of the design, the testing plans, and plans for simulation studies - LBNC much appreciates the interaction.
- The initial small scale test of the anode with 2-view readout already completed, included reconstruction of cosmic tracks, demonstrating that the concept can perform well in a TPC.
- The R&D and testing plan includes a series of component tests of the anode plane design (including small prototypes for both 2-view and 3-view readout), optical powering and readout of the Arapuca design, and a new design for the HV extender. This test program, plus simulation studies, will determine two design decisions: 2-view or 3-view readout for the anodes, and the extent of coverage for the PDS on the cathode and field cage walls.
- This program culminates with a mid-scale test of the TPC with one full-size CRP in a cold box, and a test of the HV extender in the NP02 cryostat, reusing the DP TPC to study the field properties.
- The specification for the HV system is for 325kV. Addition margin would allow component stress testing. The existing power supply for protoDUNE DP can supply 300kV. DUNE is in communication with vendors to investigate development of a higher voltage supply. Operation at 300kV would nevertheless provide adequate performance.

Vertical Drift

Findings-3

- The goal of the present R&D program is to demonstrate the key elements of the design by the end of 2021. Full scale components will then be fabricated for a protoDUNE run in NP02, anticipated for 2023-2024.
- While there is development needed for the anode design, the main technical risks are considered to be the development of the optical powering and readout of the Arapuca system, and demonstration of reliability of the HV design.
- The plan is to prepare a CDR by May (to be confirmed). This will then be reviewed by the LBNC.

Vertical Drift

Comments-1

- The LBNC commends the group on the impressively rapid technical progress - both in the conceptual design and in the initial anode tests.
- We consider the VD concept to be very promising for developing a second FD module design, incorporating many of the advantages of Dual Phase vertical drift while improving and simplifying the CRP design and incorporating proven aspects from SP.
- The R&D and testing plan seems well thought through, however the timeline appears to be aggressive. In particular the goals of the 2021 program, to validate key elements of the design before proceeding to build the large scale protoDUNE, may take longer to achieve - for technical and/or resource reasons.
- In addition, the preparation of documentation for project reviews will require significant effort.
- Rapid ramp up of the effort (organizational, human and financial resources) in the first months of 2021 is essential. We note that covid travel restrictions may make this more difficult.

Vertical Drift

Comments-2

- A strong commitment on funding and technical support for the R&D from labs and institutions is needed at the start. It is essential that the collaboration fully engage in this new project and organizes the required efforts. In particular for simulation, reconstruction and analysis, consortia support for the work on the SP and DP readout and the Arapuca and HV systems, and that engineering support is provided for the cryogenics.
- There is a need to integrate this program into overall planning that includes the time critical work towards the second protoDUNE run of SP (“module-0”) to manage any competition for resources. The VD R&D schedule should be integrated with the Technical Coordination schedule and the planning for critical decision points.
- DUNE provided a discussion of specifications and requirements. It is important that these be formally developed for the CDR. The committee notes that the requirement for LAr purity, while higher than the requirement for SP, looks well achievable based on the experience with both protoDUNE cryostats.

Vertical Drift

Comments-3

- The significant simplification of the detector design in comparison with the Dual Phase technology is a major advantage. Feasibility of most of the technological solutions can be demonstrated at the component level in cold box environment. However full system level validation is essential and will require an extensive protoDUNE run.

Vertical Drift

Recommendations

- Urgently articulate the resource needs in a detailed R&D plan
 - secure the resources and commitments from the stakeholders
 - engage the resources from within the collaboration
- Organise the consortium structure for the VD Design and R&D program as soon as possible, with clear leadership
- Formally plan the documentation campaign related to project approvals
- The LBNC requests a technical review of the design and R&D+testing plan in early 2021, prior to receipt of the CDR

Near Detector Status

Findings

- Delivery of the revised ND CDR is imminent. LBNC expects that this could be the final version, and will review it as expeditiously as possible.
- Details of the Temporary Muon Spectrometer (TMS) were presented. It borrows significantly from the MINOS design. It will require 34 months to build once a decision is made to do so, at a base cost of ~\$6M.
- The TMS measures momentum by range with a resolution of ~5%, but the design has not been optimized yet. This resolution is close to the requirement.
- TMS doesn't allow detailed studies of ν interactions in argon such as are possible with ND-GAr. The TMS will eventually need to be replaced by ND-GAr to achieve DUNE's ultimate CP sensitivity. TMS may also have pileup issues at full beam power, although it should operate fine at 1.2MW.
- We congratulate DUNE for recent advances in prototype tests of the ND-LAr design, including the first test results from the Module 0 prototype.
- Tests of the ArgoCube 2x2 prototype in the NuMI beamline have been pushed back to 2022, due to a combination of technical readiness and COVID. However, an extensive testing program using SingleCube and Module 0 is planned and will mitigate this to a large extent.
- DUNE is considered a new integrated design for ND-GAr's magnet vacuum vessel that would also provides pressure containment.

Near Detector Status

Comments

- The LBNC commends DUNE for making significant progress on defining the “Day 1 ND”. The preliminary physics studies presented, which would need to be completed and documented in detail, indicate that this could be a viable detector option for the initial running period.
- LBNC’s review of the Day 1 detector plan will require not only detector-level studies of TMS, ND-LAr, and SAND, but also “system-level” physics studies showing that the whole package, including the PRISM capacity, can achieve the needed sensitivity. Some of these physics studies go beyond what we see in the outline of the ND PDR.
- We acknowledge that an active R&D program is under way to optimize the design of the TMS further, and we are looking forward to see the results.
- We note that DUNE plans to decide on the inner tracking technology for SAND by April 30. This strikes us as uncomfortably late compared to the planned summer IPR.

Recommendations

- Produce documents describing the TMS technical design and physics studies of the capability of the Day 1 detector configuration in preparation of an LBNC review of the Day 1 detector strategy, by the end of January. This documentation should address how the Day 1 detectors will achieve 3 sigma sensitivity to CP violation in the initial stages of DUNE. These documents should address the charge of the Day 1 review.

Computing

- We commend the DUNE computing consortium for the many improvements introduced in the system, while continuing to provide a reliable service for data management and processing activities. The recent processing pass was a clear example of success.
- We are pleased to note the progress of the computing contributions board in establishing a more formal process for resource commitments
- We continue supporting DUNE computing in its strategy to leverage open source technologies, common with other experiments, complemented by DUNE specific services. The recent progress in the area of metadata and Rucio is a clear example.
- DUNE has adopted so far a flexible, network centric processing model. Such flexibility needs to be traded with possible inefficiencies due to remote data access. We invite DUNE to measure such inefficiencies for different workflows and present the results in one of the next meetings
- We support the efforts in DUNE in reducing the application memory footprint and we are keen to follow the progress. The current memory footprint might limit the amount of compute resources available to DUNE
- We are very pleased to learn about the newly appointed Software Liaison and we are eager to hear on this activity regularly

Simulation, Reconstruction, and Analysis

- The LBNC commends DUNE for making significant progress on the simulation, reconstruction, and physics analysis for ProtoDUNE-SP
 - We are pleased to note that this continues to improve the agreement between data and simulation and congratulate you on your recent publication
- The refactorization of G4 is a good development that can be expected to make the simulation more flexible and easier to maintain
- We note that in some regions of the t_0 distribution the simulation underestimates the data, but in others it overestimates the data, and encourage further studies
- We are happy to see the development of common analysis tools and look forward to seeing the outcome from the systematics task force
- We encourage the inclusion of more data, where available, especially in those plots with significant statistical fluctuations that are intended to be included in publications
- At upcoming LBNC meetings, we would be interested to see the status and plans for other detector technologies
 - In particular, we would like to see plans towards developing the simulation, reconstruction, and potential physics analyses for VD as this should be part of the technology evaluation

DUNE Executive Summary

LBNF has secured approval to move forward with the main excavation contract at SURF. This phase of the work will commence in Spring of 2021 and the underground facilities will be available by April 2024. This is a major achievement with enormous impact; we congratulate LBNF.

DUNE has moved forward on several fronts including continuing to expand the collaboration but most importantly, in cooperation with the Department of Energy, Fermilab and the international funding agencies, it is developing an approach to the overall experiment, which will result in a well constrained scope for the US-DUNE component of the LBNF-US-DUNE DOE Project.

The planned DUNE baseline scope contains three primary elements:

Two Far Detector modules:

one module would use the established APA Single Phase/Horizontal Drift design for which a Technical Design Report was completed and approved in early 2020.

the second module is envisaged to use a novel vertical drift design. This is a pivot from the dual phase design and will require a substantial but finite amount of development work. The design will benefit from successful aspects of both the ProtoDUNE detector developments. This concept has several attractive features but the path to a baseline is only now being charted.

A Day-1 Near Detector suite constrained by resources. In the first few years, this will support the establishment of CP violation if it is maximal. The layout derives from the full Near Detector design but replaces one sophisticated detector, which would require engineering and development, with a proven economic alternative. A dedicated review of the Day-1 Detector plan has been charged and will soon be scheduled. The LBNC feels the approach is a good one.

For the APA/Horizontal Drift Far Detector, good progress has been made with all of the ASIC electronic design, the APA finalization, and the Photon Detector in preparation for Phase II ProtoDUNE (Module 0) operation. Installation plans and tests, using the Ash River facilities continue to make good progress.

The LBNC heard a discussion of the key R&D issues associated with the Vertical Drift layout and nascent plans to demonstrate viable solutions. There will be an initial proving phase followed by integration at scale in NP02. The considerable effort needed will take a wholehearted commitment from the collaboration and the prompt assignment of the needed resources.

The full-scope Near Detector CDR was reviewed (very positively) by the LBNC and receipt of a version for final scrutiny is imminent.

DUNE computing is now managed within an understood framework which also facilitates discussions and response to recommendations. Delivery of a Conceptual Design Report is expected in February.

Dedicated time was allocated for a discussion of analysis software development and results. This was a valuable addition to the curriculum and will likely presage a systematic survey of all the analysis and algorithmic software developments. It is hoped that this can amplify the synergy between computing provision and exploitation.

The beamline work continues to make good progress. The risks are limited. The LBNC continues to pay attention to potential losses or gains resulting from the complex intermeshing of Near Site civil work, beamline construction and the PIP II Project.

The scope of Technical Coordination, for the Far Detector construction, for the ProtoDUNE Phase II efforts, for the Near Detector, and for a wide range of R&D, continues to grow. The resources available must be matched to the need; a comprehensive integrated resource loaded schedule is recommended.