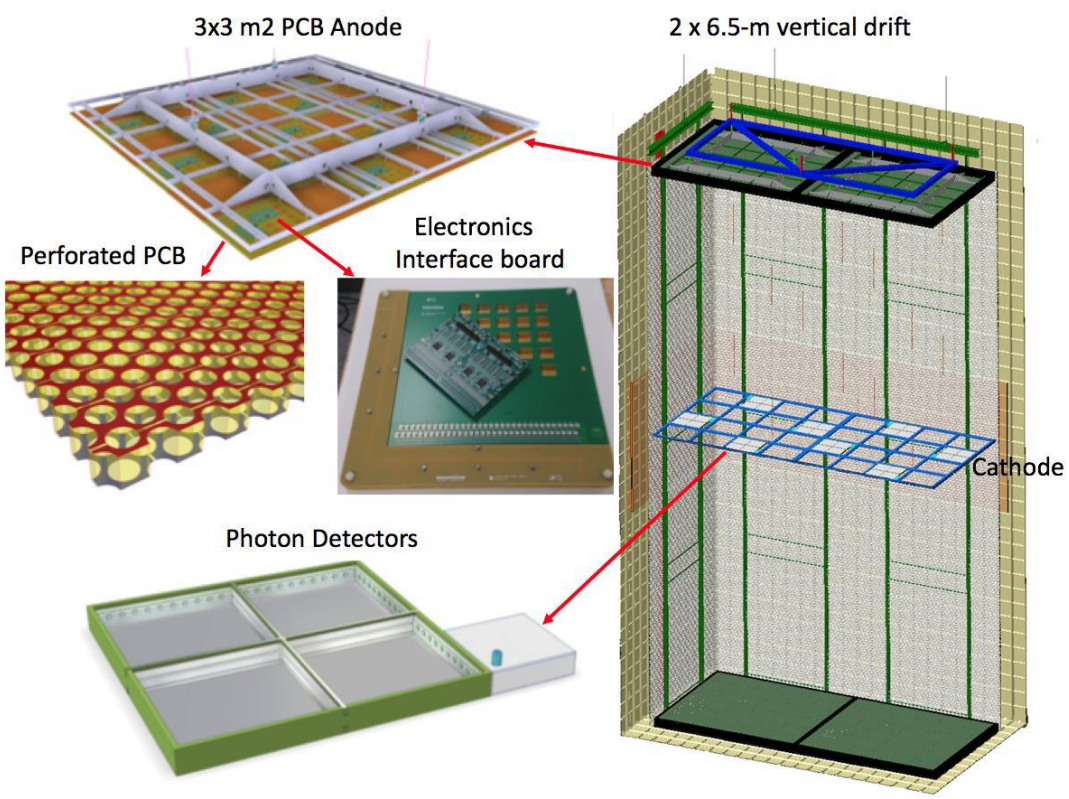
LBNC Meeting Report



December 2-4, 2020

FNAL (Remote)

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Introduction

The LBNC met December 2-4 remotely in FNAL. This is the final meeting of three held during 2020, two completely remotely.

The attendees at the meeting, shown in Appendix I, included LBNC members and consultants, DUNE Collaboration spokespeople, Ed Blucher and Stefan Soldner-Rembold, and members, Fermilab Director, Nigel Lockyer, Fermilab CRO and Deputy, Luciano Ristori and Greg Bock.

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

The Dual Phase R&D using NP02 at CERN, was completed in September and the results are being examined. This meeting reflected the emergence of a Vertical Drift single phase readout configuration as a likely candidate for the second Far Detector technology. The Near Detector Conceptual Design Report has been submitted, was reviewed by the LBNC and is under revision. The Day-1 configuration of the Near Detector constrained by resource availability was an important subject of discussion

The charge for this meeting, prepared with concurrence from the Director is shown in Appendix II.

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

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

The LBNC has enjoyed hearing about the substantial progress made during the past several months despite the impact of the Covid-19 pandemic. The presentations from LBNF and DUNE were to the point and fully addressed the charge. Progress across the full spectrum of activities LBNF, DUNE, Single Phase, Dual Phase, Near Detector, and Computing, was briefly and succinctly described in the Plenary sessions. In order to maximize the utility of the constrained agenda time, five substantial breakout sessions covering Beamline and Technical Coordination, Single Phase, Vertical Drift, Near Detector, and Computing and Analysis were held.

The committee thanks the DUNE and LBNF participants, Fermilab, its Directorate and support staff, for their assistance and support.

Executive Summary

Overall, LBNF/DUNE has evolved considerably over the past few months. A major advance is seen in LBNF. For DUNE there is considerable progress towards full definition of the Near Detector plan accompanied by a change in the strategic approach to the Far Detector planning.

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 advanced 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 will contain three primary elements:

Two Far Detector modules, as recommended by DOE reviews during 2020:

one module would use the established and proven 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 already in the first quarter of 2021.

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.

LBNF/DUNE is congratulated on its several major successes during the past few months and indeed through the whole of a year with difficult imposed challenges from the pandemic.

LBNF Status

Findings

•**Reliability projects**: Six projects are still on-going (as in Sept 2020). All projects are reported as on track for completion in April 2021

•**Pre-excavation construction:** Work is fully underway with an expected completion date remaining at April 2021 (as in Sept 2020). 90% of the work is completed combining both surface and underground projects. Examples include blasting to improve ventilation at the 4850L by creating a Raise Bore Chamber on the 3650L and continued progress on rock conveyors.

•**Far Site** (**FS) Excavation**: The excavation contract has been awarded to Thyssen Mining Inc in Oct 2020. Authorization from FRA to mobilize was given Nov 3, 2020. All LBNF staff are in place. >75% of far site Conventional Facilities (CF) construction work is under contract. Excavation for both caverns are shown as complete in April 2024. The FS critical path runs through excavation, cryostat #1 installation and detector #1 installation. The start of science milestone is in Q1 CY29. The Near Site (NS) remains the critical path for the project with beam checkout complete Q2CY29, CD4 early is Q4 CY29.

•**FS cryogenics:** Final design of cryostat is completed. The LN2 acquisition strategy has been approved by DOE in Oct 2020 as a design/build. The RFP was sent to DOE Nov 2020. The contract is to be awarded by Sept 2022.

•**Near Site design:** Final design of CF is 30% complete. The work is divided into two major contracts – beamline and detector facilities. CF is on track for final design complete by Aug. 2021. ND-hall crane has been upgraded from 15 ton to 60 ton.

•**Near Site preparation:** Site preparation is reported as completed on schedule. The work included moving cooling ponds, re-routing power and access roads. Near site LAr and LHe cryogenics designs are underway with a PDR completed in July 2020. Systems engineering is being done to integrate 30% NSCF with beamline and detector models and costs have been reduced.

•**LBNF strategy:** Released V7 integrated model for far site. Project successfully achieved approval for FS excavation. Several reviews (progress IPR, Director review) in 2021 will lead to CD-2/3b IPR for baselining in Dec 2021.

•**Resources:** Planned resource ramp-up in Fall 2020 (10000 hours to 12000 hours) mentioned in Sept2020 LBNC did not get realized in the past quarter. Projected resources need to ramp up from 10000 hours to 13500 hours in the next quarter.

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 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 main Injector (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 schedule with optimized cash flow and shut-down to compare against the baseline.

Beamline

Findings:

- preliminary designs are completed in magnets, modules, Hadron absorber, hatch-covers with final design progressing in Horn A, Target hall shielding, vacuum, primary water, beam instrumentation and some prototyping in progress
- beam window has a PDR this month
- value engineering is being done with CF to optimize layout and logistics and to scrutinize the 30% final design
- Horns are on the critical path
    - Horn A prototype is now in final design - requires testing before launching series production
    - Testing requires a high power pulsed power supply
        - FNAL is missing critical resource of experienced pulsed power engineer
        - kick-off meeting next week with SLAC and local team
        - final PS has 32 cells - a unit cell is planned to be ready in early 2022
    - Horn B&C are in preliminary design
- CD-2 readiness
    - IPRs are scheduled in Jan and summer 2021, Director's review in late summer/fall 2021, and CD2 IPR in Dec 2021
    - Beamlines will update P6 installation schedule in Jan 2021
    - beamlines is using firm fixed price contracts for skilled trades and design to cost strategy to rescue cost risk
    - 13 PDRs or FDRs scheduled in the next 8 months
    - documentation is reported as on track
- International scope - integrated unallocated international scope now absorbed by project
    - RAL (target, baffle), KEK (R&D on striplines and hatch cover) and BARC (main magnets) in progress – IHEP (corrector magnets) scope delivered and tested
    - BARC deliverable - PD complete - interface docs in progress - PDR scheduled for Jan 2021
    - RAL target review next week - regular remote meetings with RAL
- LBNF beamline completion constraint – plan to delay beamline tie-in to main-injector from the current Sep 2025 to June 2027 in LBNF plan, to between Jan 2027 to Mar 2029 to match PIP-II shutdown due to PIP-II delays
    - bring forward downstream beamline installation
    - main risk is in delayed CF work that matches near site critical path - now replanning
- Risks - commodity prices, tritium mitigation plan, availability of matrixed resources

Comment:

The beamline team is making significant progress 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.

Recommendations

- none

DUNE Status

The committee greatly appreciated the presentation by the spokespersons on the status of DUNE on recent progress, developments, and near and longer term plans on several important issues. These included the finalization of the Near Detector "Day 1" configuration, and work towards critical choices ahead regarding the detector technologies for the first two Far Detector modules.

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 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 Far and Near detectors.

The LBNC commends DUNE for making significant progress on defining the "Day 1 ND". The preliminary physics studies presented, which will 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 the first DUNE far detector module. The LBNC commends DUNE for developing a detailed plan to allow the second far detector module to use the APA technology if needed.

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. At the same time, the committee notes that the resources required to establish the VD technology, both human and financial, will need to be identified and realized on a very short timescale

The LBNC notes that 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 this at the next meeting. To that end, the committee would also welcome a clear plan for modifications of the consortia responsibilities in order to incorporate the VD far detector module at a future meeting.

Technical Coordination

The LBNC noted that a large amount of activity will be needed at CERN in the next three to four years. There is a big program of R&D needed on the vertical drift technology, first to demonstrate the feasibility of the technology, then to provide a large-scale demonstration in a ProtoDUNE (NP02) run with the vertical drift technology installed. At the same time, substantial work is needed in parallel to prepare and install the modified components for the second run of the horizontal drift (APA readout-plane) ProtoDUNE (NP04) module. The need for rapid progress on both sides suggests that cold operation of the two ProtoDUNE modules may need to be at least partially concurrent in time. A close coordination and collaboration between the CERN activities and DUNE Technical Coordination will continue to be essential throughout this period, foreseeing and addressing challenges in advance as far as possible. Careful scheduling, considering personnel availability, will be essential.

The committee is especially concerned that the core team of experts at CERN will be overloaded in this period, from now until 2024, and urges Technical Coordination, and DUNE as a whole, to ensure that the 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.

Given all of these activities in addition to the construction of the DUNE components and other work going on in the consortia, the LBNC believes that an increase in the size of the Technical Coordination leadership team should be considered. Such growth would allow the full range of activities to be managed, especially considering that key people from the integration and installation team are also crucial to the vertical drift proposal development. New events, initiatives and challenges will arise, and will need to be handled while still ensuring sufficient attention to continuous routine work. The LBNC recommends strongly that a comprehensive integrated resource-loaded schedule is drafted with critical milestones, as a high priority.

The LBNC was shown some short-term outline schedules at this meeting, which is appreciated. However, the committee repeats its wish to see schedule updates at each LBNC meeting both for short and longer-term DUNE construction activities.

Recommendations

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

APA Single Phase

In this section, we report on the overall APA Single Phase status as presented by Gina Rameika, as well as detailed presentations in the breakout session on cold electronics, APA status, photon detection and installation. We congratulate the Collaboration and consortia on progress towards ProtoDUNE-II and the first DUNE module.

APA Single Phase Summary

Findings

- ProtoDUNE-SP I was 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

APA Single Phase 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 is a high priority as the components are quickly converging to the final versions.
- The cold electronics schedule remains tight, and it will be important to continue to manage all elements of it closely.

Recommendations

- None

APA Single Phase 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

APA Single Phase 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

APA Single Phase 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

A new concept for an FD module was presented: Vertical Drift (VD) technology is an evolution of the Dual Phase (DP) 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 of VD will be reviewed within the DUNE collaboration in the week of Dec 7th. The LBNC was given a preview, which is very much appreciated. 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.

Findings

- 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 photon detection system (PDS) is based on the ARAPUCA technology developed for SP.
- The design capitalizes on the experience from the SP Horizontal Drift (HD) 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 3m*3m units is expected to be cheaper and faster than the assembly and installation of the APA planes in the SP HD design.
- And the design has the potential for an increased fiducial volume relative to APA SP.
- 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
    - 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. Additional margin would allow component stress testing. The existing power supplies, one of which was used 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.

- 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.

Comments

- 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 HD.
- 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.
- 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 engages in this new project and organizes the required efforts. In particular, the needs of VD must be addressed for simulation, reconstruction and analysis, consortia support for the work on the SP and DP readout and the ARAPUCA and HV systems, and engineering support 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 HD (“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 horizontal drift SP, is achievable based on the experience with both ProtoDUNE cryostats.

- 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.

Recommendations

- Urgently articulate the resource needs in a detailed R&D plan in order to secure those resources and commitments from the stakeholders and to engage the resources from within the collaboration
- Organize 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 plus testing plan in early 2021, prior to receipt of the CDR.

Near Detector

Since the last LBNC meeting the DUNE near detector (ND) group has been revising its Conceptual Design Report (CDR) in response to detailed comments from the LBNC. These revisions are nearly complete, and submission of the revised version of the ND CDR to the LBNC should happen by mid-December, 2020. The LBNC will attempt to review this as expeditiously as possible, with the expectation that this will be the final version of the CDR.

A major focus of this LBNC meeting was discussion of the Temporary Muon Spectrometer (TMS). This temporary detector would be used in place of the ND-GAr high pressure gaseous argon TPC in the event that resource limitations prevent deployment of ND-GAr on day 1 of DUNE operations. The TMS is to be included in the US DOE scope for DUNE. The LBNC has previously endorsed the general strategy of the TMS, but this was the first time that technical details of the design have been presented. The LBNC commends DUNE for making significant progress on defining the design of the TMS

The TMS is based upon muon momentum measurement and sign determination in a magnetized steel and scintillator range stack. The design borrows significantly from the MINOS design, and uses conservative design choices to minimize technical and cost risks. Preliminary estimates indicate that the TMS would require 34 months to build once a decision is made to proceed with its construction, at a base cost of ~$6M. This timetable determines the point in time at which a decision must be made whether to proceed with construction, or alternatively to construct ND-GAr if resources are available.

Preliminary performance studies suggest that the TMS can measure muon momentum by range to approximately 5%, which is similar to the resolution achieved in the far detector, and which would be nearly sufficient for the initial stage of DUNE at which oscillation measurements are statistics limited. The design and reconstruction are however not yet optimized, and some effort may reduce the momentum resolution to a more comfortable 4%.

We acknowledge that an active R&D program is under way to optimize the design of the TMS further, and we look forward to seeing the results. DUNE may wish to explore the possibility of not gluing fibers into the extruded scintillator, greatly simplifying the detector assembly. Some consideration should be given to trying to reduce the tight bend radius of fibers near the end of some scintillator bars. Also, the thermal load produced by the magnetic coils is not negligible, and continued exploration of the cost/benefits of air cooling vs. water cooling is advisable.

The main physics capacity that is surrendered by using TMS in place of ND-GAr is the possibility of doing detailed studies of neutrino interactions on argon with optimal sensitivity to all final state particles. DUNE presented example scenarios in which uncertainties in the neutrino interaction physics would limit DUNE's ultimate sensitivity to neutrino oscillation in the absence of these measurements. In addition, the TMS may start to run into pileup issues at full beam power. For this reason the TMS will eventually need to be replaced by ND-GAr if DUNE is to achieve its planned sensitivity to neutrino oscillation, and DUNE is including the logistics of how to do this replacement in its planning for TMS and the ND hall.

The LBNC has been charged by the FNAL Director to carry out a review of the Day 1 configuration of the ND complex, to determine whether it is on track to produce a Preliminary Design Report for a CD2 review late in 2021. This review will include both technical assessments of the component detectors as well as whether the integrated system will allow DUNE to control systematics well enough in its initial stage to allow a 3 sigma detection of CP violation if the CP effect is maximal. Materials presented at this LBNC meeting give the LBNC optimism that this will be the case, but additional studies and documentation is required for a dedicated review planned for early in 2021. Particularly important are studies that address how the Day 1 detectors can achieve the needed physics sensitivity. Some of these physics studies may be beyond the scope of what would be planned for the PDR itself, and will require production of review documents geared specifically to the charge of the Day 1 detector review.

DUNE presented very recent prototyping results from the ND liquid argon TPC work, including first results from the SingleCube test setup and from a partially instrumented Module 0 prototype. We congratulate DUNE on the first operations of these prototypes, and look forward to more advanced results from them in 2021. An extensive testing program focused on SingleCube and especially Module 0 is planned and will be critical for demonstrating elements of ND-LAr. This should be a high priority for the ND team. Plans to operate the ArgoCube 2x2 prototype detector in the NuMI beam at FNAL have been pushed back to the end of 2021 or even 2022, due to COVID and need for continued technical development, but the testing program using Module 0 should be able to address most technical risks in the interim.

Time limitations prevented the meeting from focusing on the ND-GAr or SAND detectors in any detail. We learned that DUNE is considering a new design for the ND-GAr magnet's vacuum vessel that would also provide pressure containment for the TPC, but were not shown details of this. We note that the collaboration intends to choose the technology for the inner tracker in SAND by April 30, 2021. We have previously noted that there seem to be two viable technologies for SAND's inner tracker. We caution that deciding between these tracker technologies as late as the end of April will not provide much time before the planned summer IPR review, which DUNE hopes to use as preparation for the CD2 review. As much documentation preparation as possible should be done in advance of the technology selection, and DUNE may consider if it is at all possible to accelerate this decision, as the LBNC recommended at its last meeting.

Recommendations:

- DUNE should produce documents describing both the TMS technical design and physics studies of the capability of the Day 1 detector configuration in preparation for 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 as specified by the FNAL director.

Computing

The LBNC congratulates the computing consortium for the continuous improvements implemented in the system, and for providing a stable service for data management, simulation, processing and analysis. The current computing model is adequate to fulfill the needs of the collaboration in terms of data availability. DUNE expects to review it to best match future needs with available resources. We commend the recent progress of the Computing Contributions Board in establishing a model and the required tools to organise a more formal process for hardware resource commitment.

The recent pass-4 processing campaign provided the DUNE physics community with higher quality data, while offering an opportunity to get further operational experience with the computing services and tools. It was noted, for example, that the current DUNE simulation and processing jobs require a relatively large amount of memory (4 GB) with respect to what is available at DUNE sites. We were pleased to hear that there is an ongoing activity aimed at reducing the memory footprint. We support such activity as the current footprint might be limiting the amount of available resources to DUNE, particularly at facilities such as HPC centers.

DUNE has adopted a very flexible processing model, where data can be streamed from a remote storage into the application. Such flexibility needs to be traded with a possibly lower job efficiency due to network latency and bandwidth limitations. We encourage DUNE to measure the impact on efficiency in different scenarios and with different workflows. The impact of network bandwidth was observed also in accessing conditions data, despite their small size. We invite DUNE to investigate this further with the help of the facilities and particularly FNAL which is hosting the condition databases.

We continue supporting DUNE in its strategy to leverage, as far as possible, existing open source technologies, which are already in use in High Energy Physics and generally in scientific computing. DUNE is complementing such technologies with new services, developed for DUNE specific needs. In the area of metadata, for example, we were pleased to learn the recent developments in complementing Rucio with a DUNE metadata catalog that could be in future generalised and adopted by other communities.

We note from the discussion that the collaboration between the software and computing teams continues strengthening and we were pleased to see this reflected positively in many areas, for example the memory footprint activity mentioned above. DUNE recently established a new Software Liaison role and appointed an expert for this role, following one of the LBNC recommendations. We expect this will strengthen such collaboration further and we are eager to hear more progress in the next meetings.

DUNE is currently on schedule to provide a draft Computing CDR by Feb. 1st 2021, to be reviewed by the LBNC.

Recommendations

None

Simulation, Reconstruction and Data 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 work continues to improve the agreement between data and simulation. We would also like to congratulate the collaboration on their recent publication of the first results from ProtoDUNE in JINST.

We were happy to see the refactorization of larsim/LArG4, which can be expected to make the simulation more flexible and easier to maintain in the future. Significant progress in improving the simulation was demonstrated. Improvements include the use of a customized Bertini cascade model, a recombination model and a space charge effect correction. The refactored simulation was demonstrated to accurately model the dE/dx distribution and the hit tagging CNN score. Other important ongoing improvements to the simulation were discussed and we look forward to seeing the results after those improvements at future meetings.

Results of testing the hit-tagging CNN on single particle beam samples were shown. In general, good agreement was demonstrated, however, the positron sample was lacking in statistics. Two updates to the pandora reconstruction algorithm were shown: a generalised T0-tagging algorithm and an update to the particle classification. The new stitching technique allows the full track to be reconstructed across cathode and anode boundaries. We note that in certain regions of the t0 distribution the simulation underestimates the data, but in others it overestimates the data, and we encourage further studies to understand these differences. A new technique for particle classification was shown with a BDT approach replacing the previous cut-based approach. The new BDT was shown to double the efficiency at the cost of a small increase in the mis-reconstruction rate. Future planned updates to Pandora were presented and we look forward to hearing about those improvements at future meetings. Preliminary results from the pi0 analysis were shown. A clear mass peak was observed, but it appears to be slightly wider in the data. Results from the Michel electron analysis were shown and these demonstrated good agreement between data and simulation. Initial studies into measuring the cosmic ray seasonal variation were shown.

We are happy to see the development of common analysis tools, including ntuples which significantly reduce the sample sizes for analysis, the Geant4Reweight tool and the Thin Slice Fitter tool. The Geant4Reweight tool can be used to reweight hadron tracks according to different cross sections to propagate systematics and tune Geant4. The Thin Slice Fitter is used to extract cross sections through approximating the detector with a set of thin slice targets. Updates on the measurements on the inclusive proton and pion cross sections, pion absorption and charge exchange, and the pion transverse kinematic imbalance were presented. We are happy to see that a new subgroup has been set up to study systematic uncertainties and we look forward to hearing about the results of that work at future meetings. We note that some of the distributions shown suffer from significant statistical fluctuations. We encourage the inclusion of more data, where available, especially in those plots that are intended to be included in future 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 the vertical drift because this should be part of the technology evaluation

Recommendations

None

Appendix I: Attendees

Committee: Ties Behnke, Simone Campana, Dave Charlton, Cristiano Galbiati, Alexander Gottberg, Heather Gray, Joachim Kopp, Bob Laxdal, Tiehui Liu, Naba Mondal, Hugh Montgomery, Scott Oser, *Adam Para*, John Parsons, Tom Peterson, *Anna Pla-Dalmau*, Kevin Pitts, Niki Saoulidou, Jeffrey Spalding, Eric Kajfasz, Darien Wood;

Scientific Secretary: Angela Fava

Fermilab PAC Chair: Hirohisa Tanaka

DUNE/LBNF: Ed Blucher, Eric James, Christopher Mossey, Marzio Nessi, Regina Rameika, Stefan Soldner-Rembold; Michael Andrews, Dario Auterio, Janet Bishop, Tim Bolton, Alan Bross, Jake Calcutt, Flavio Cavanna, David Christian, Dominique Duchesneau, Dan Dwyer, Robert Flight, Jack Fowler, Vyacheslav Galymov, Wenqiang Gu, Kenneth Herner, Steve Kettel, Michael Kirby, Nadine Kurita, Andrew Lambert, Thomas LeCompte, Giovanna Lehmann, Jonathan Lewis, Steve Manly, Alberto Marchionni, James Mateyak, Elaine McCluskey, Andrew McNab, Ting Miao, Bill Miller, Claudio Montanari, David Montanari, Duane Newhart, Sandro Palestini, Elizabetta Pennacchio, Francesco Pietropaolo, Brian Rebel, Filippo Resnati, Ettore Segreto, Heidi Schellman, Teresa Shaw, James Sinclair, Luca Stanco, James Stewart, Asegawa Takuya, Christofas Touramanis, Serhan Tufanli, Marco Verzocchi, David Warner, Alfons Weber, Michele Weber, Leigh Whitehead, Michael Wilking, Jaehoon Yu, Bo Yu, Jaroslav Zalesak

FNAL Directorate/Management: Nigel Lockyer, Greg Bock, Luciano Ristori

DUNE RRB: Alison Markovitz

DOE: Adam Bihary, David Lissauer, Bill Wisniewski

Appendix II: Charge December 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.

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.

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.

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.

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.

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.

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.

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.

Appendix III: Assignments

Consultants shown in Italics

LBNF Status	**Laxdal**, Peterson, Charlton
DUNE Status	**Saoulidou,** Gray, Charlton, Kopp
Technical Coordination	**Charlton**, Laxdal, Peterson
Single Phase	**Pitts**, Fava, Liu, Parsons,Pla-Dalmau
Dual Phase	**Spalding**, Behnke, Galbiati, Kajfasz, *Para*, Wood
Near Detector	**Oser,** Behnke, Mondal, Kopp, Saoulidou
Computing	**Campana**, Charlton, Gray
APA Single Phase (Breakout)	**Pitts**, Fava, Liu, Parsons, *Pla-Dalmau*
Vertical Drift (Breakout)	**Spalding**, Galbiati, Kajfasz, *Para*, Wood
Near Detector (Breakout)	**Oser,** Behnke, Mondal, Kopp, Saoulidou
Beamline	**Laxdal**, Fuerst, Peterson
Computing (Breakout)	**Campana**, Charlton, Gray
ProtoDUNE Analysis	Gray, Campana, Charlton