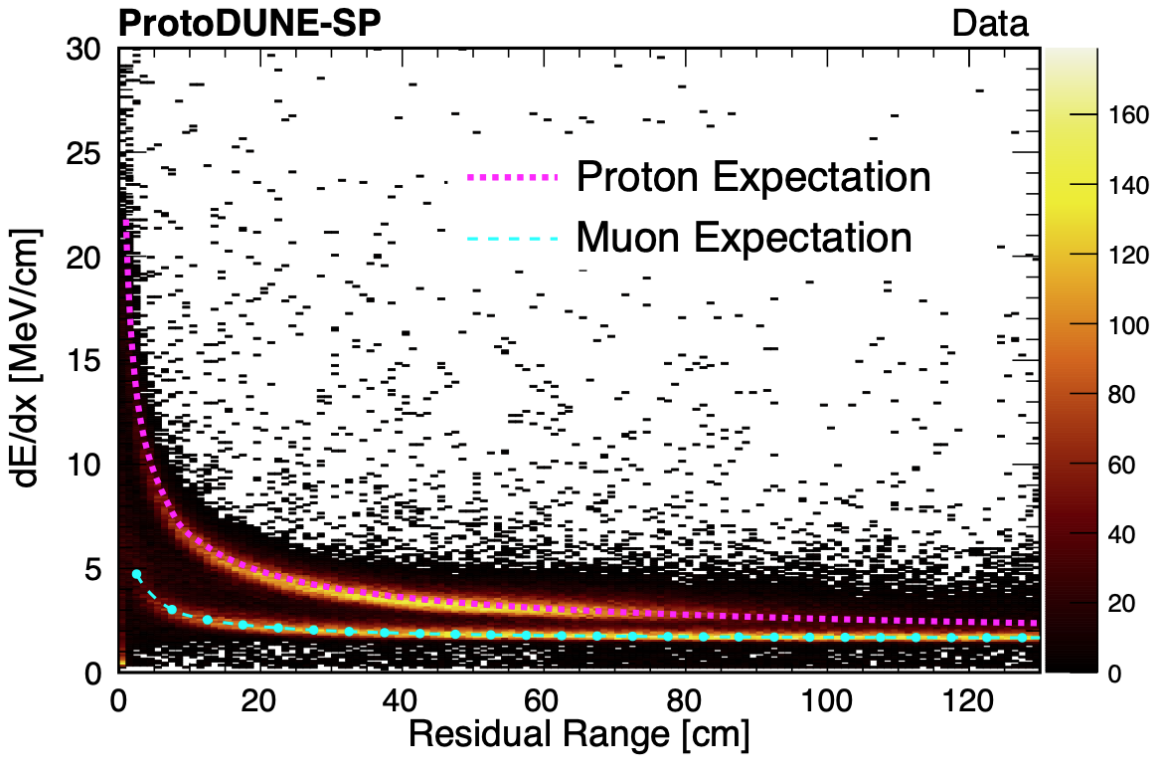
LBNC Meeting Report



March 4-6, 2020

FNAL

Introduction

The LBNC met March 4-6 in FNAL. This meeting continues the sequence of three meetings per year into 2020 following the meetings in March, July/August and December, during 2019.

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, the Fermilab Deputy Director, Joe Lykken, CRO and Deputy, Luciano Ristori and Greg Bock, and representatives of the US Department of Energy, Pepin Carolan and Bill Wisniewski.

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 supplementary presentation was made to discuss the anticipated power performance of the accelerator complex during the first years of operation. The Fermilab Director requests assistance in this process from a number of experts, who supplement the expertise of the LBNC members in the scrutiny.

Following progress with and the approval of four TDRs, the Single Phase technology is preparing for the "Module 0" phase of testing, and the preparations for construction and installation. The design emphasis is now on the Dual Phase Technology, the Near Detector, and the Computing capabilities.

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://web.fnal.gov/organization/LBNC/LBNC%20Meeting%20-%20March%202020/SitePages/Full%20Agenda.aspx.

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 the DUNE membership for the clarity of their presentations and discussions. Angela Fava, Scientific Secretary of the LBNC, who was instrumental in the compilation of the reports as well as actively participating in the discussions, was assisted in the closeout by Louise Suter.

Finally, the committee also thanks Fermilab, its Directorate and support staff, for their assistance and hospitality.

Executive Summary

The LBNF Project is daunting with an enormous scope. The pre-construction phase appears to be progressing well, and important procurements are reaching an advanced stage. Following the December 2020 Meeting, the LBNC was pleased to see the encouraging response to its request to understand the potential for advancement of the beamline completion. The discussion of the projected beam power during commissioning and initial years of beam operation with the PIP II (Proton Improvement Plan II) also seemed to offer potential advancement, were resources available. In the context of the approval of the Hyper-K project in Japan, continued exploration of such opportunities is strongly encouraged.

The collaboration continues to grow as groups join the successful enterprise. The conclusion of several TDRs in 2019 followed by the incipient conclusion of the ProtoDUNE I, SP and DP operations heralds a new phase for DUNE. The attention of the collaboration is shifting to:

Planning for the ProtoDUNE II (SP and DP) installation and operation,

Emphasis on establishing the Near Detector reference design and strategy

Preparations for installation at SURF.

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

Good progress has been made in the understanding of resources and 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 exercise benefits from the encyclopedic understanding of the Resource Manager. In this work, the vigorous participation of the consortium leadership in refining the scope and establishing the required resources is important and should be assured.

The Far Detector Single Phase technology has enjoyed considerable success in its ProtoDUNE I phase. The consortia must now work towards production through definition of ProtoDUNE II as the “Module 0”. The LBNC recognizes and strongly encourages this approach. There are however details:

The TPC electronics has multiple components and there remain 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.

The temptation to continue to pursue R&D goals represents a threat to this progress.

ProtoDUNE DP is being operated systematically to learn as much as possible about the Dual Phase technology. A number of difficulties have been uncovered and confronted. In order to understand the path forward for this technology, a detailed R&D plan needs to be clearly articulated, then reviewed, and evaluated formally, by the DUNE collaboration at a high level.

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. In its presentations, DUNE made it clear that 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. The LBNC feels that a clear description of the current status and a plan for progress towards different stages of design report, would benefit the development of the consortium. In this respect the Near Detector should join the Single Phase and Dual Phase as part of a coherent whole.

The ProtoDUNE DP showed 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 concerning understanding the match of simulations to observed detector performance and the inclusion of systematic uncertainties in the results. The team does appear to be addressing these points.

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 on all fronts. We are ready to lend our support for progress toward baselining of the project and launching the international construction phase for the experiment.

LBNF Status

Findings:

Reliability projects continue to make progress, with work on the Oro Hondo fan, the refuge chamber, and the transport skips complete. Ongoing work includes refurbishment of the Ross shaft, cage replacement, hoist upgrades, and upgrades to the crusher roof (work totaling about $36M) with hoist motor refurbishment to be awarded soon.

Pre-excavation construction awards to KAJV include 36 work packages totaling $120M. Work is fully underway, with an expected completion date of December 2020. Work on the ore pass excavation and skip loader fabrication has been completed. Skip loader shipping is currently in progress and represents the critical path. The tramway and ground-level conveyor systems are in progress although the completion date has been extended by 17 days. The budget has experienced a 3% overrun, generally due to unforeseen site conditions affecting the work. Billing is now at 41% ($48.5M of $119M) with the contract duration at 61% (457 of 748 days). There have been zero recordable safety incidents during this activity.

Proposals for the far site (FS) excavation have been received by the CM/GC contractor from potential subcontractors. The CM/GC is preparing a response to LBNF in March 2020 leading to a proposal to DOE in May, followed by approval in July and an award to KAJV on 10 August. Work would initiate in December of 2020, consistent with completion of pre-excavation. Completion of the North cavern was reported at the previous LBNC meeting as stretching beyond October of 2022, with efforts ongoing to reduce the schedule slippage. An update on this completion date was not provided at this meeting. The project continues to value-engineer the far site activity in an attempt to shorten the schedule. This effort has led to a change in the LN2 facility procurement strategy with a potential saving of $35M.

The near site conventional facilities 50% preliminary design was submitted on December 31, 2019 and an integrated review was held between January 6 and 17. A 100% preliminary design is expected to be submitted by the end of March 2020, from which cost and schedule will be developed by May. Site preparation activity is reported as on schedule and includes moving cooling ponds as well as re-routing power and access roads. With regard to beamline activity, interface definitions are >90% complete and design work has advanced on magnet stands, stripline voltage tests, and the 3-horn common module design. The baseline plan shows the target area ready for beam-based alignment in Q2 of 2029 with availability for beam power ramp-up six months later (Q4 2029).

In terms of the project schedule to first beam, if cash flow were not a constraint the project could advance the target area readiness by 13 months (to Q4 2028) and save $34M integrated over the project. However this would require more funding over the 2022-2025 timeframe. In this scenario, the critical path would move to horn production (instead of Conventional Facilities) and early beam from PIP-II could be available in Q4 2027.

The October 2019 DOE IPR produced 40 recommendations. Follow-on analysis by a Director's committee concluded that the most critical project effort should go into establishing cost certainty, as there is still ~$130M in unassigned scope within LBNF. The project strategy is to aim for CD-2 approval at the end of 2020.

The project has decided to relocate the liquid nitrogen (LN2) system recycle compressors from above ground to underground as a cost saving measure. Risk management for the LN2 system

procurement is being partially mitigated by having multiple vendors perform design work, which will be evaluated by the project in two phases prior to final contract award. In Phase 1, an RFP will be issued to up to three firms for a 40% Preliminary Design. In Phase 2, the project will receive proposals from these firms for the full system scope, with each vendor using their preferred technical solution after which one firm will be selected based on the Phase 2 proposal. The deadline for awarding the LN2 system contract is September 2022.

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

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

Power Delivery Projections and PIP-II

Production of the neutrinos for LBNF/DUNE will come from high energy protons bombarding the LBNF production target. The high energy protons will be produced in the FNAL accelerator complex, presently being upgraded to increase the beam power available for LBNF/DUNE. The most significant part of the upgrade is the addition of a new high intensity 800MeV H- linac as part of the PIP-II project. The H- ions from the linac are injected into the booster synchrotron that is being upgraded to 20Hz operation and finally into the main injector synchrotron to deliver 60-120GeV protons to the LBNF neutrino production target. The PIP-II goals are to achieve a beam power of 1.2MW onto the LBNF target that would be upgradeable in the future to multi MW. The Day 1 expectation as given by the threshold KPIs would be to deliver some beam at >600MeV to the linac dump with equipment installed to support 1.2MW operation. The `early

CD-4' completion date is scheduled for Q4 2027 while the project CD-4 date is 54 months later in Q2 FY32. These 54 months serve as a contingency imposed by DOE due to a perceived uncertainty of in-kind contributions.

Upon completion of the project the accelerator will be turned over to the FNAL operations team to ramp-up the available beam power. A preliminary power ramp up timeline was presented. The estimate is that it will take 4 years to get from Day 1 to 1.2MW with 63% or 750kW after 2 years and 92% after 3 years. The 750kW after 2 years matches the present power capability of the main injector. It was also stated that the power ramp-up could conceivably be reduced from 4 to 2.5 years if more resources than presently planned could be applied (preparing High Level Applications for example) in preparation for hardware readiness.

Not presented but estimated from presentations in a previous LBNC meeting are the expected completion dates of Dune Detector #1 at Q4 2027 and Dune Detector #2 of Q4 2028. These dates are arrived at assuming the LBNF T0 date for cavern readiness as Oct. 2022+6 months (Q2 2023) as reported in the Dec 2019 meeting. Also of interest, is the schedule for LBNF beamlines/target beam readiness date. The LBNF presentation gave a date of Q2 2029 for beamlines/target area ready for beam and conversations with Beamlines estimated that 6 months would be needed for beam-based alignment and final installation of the targets giving a date for readiness for power ramp-up of Q4 2029. An LBNF study also revealed that this date could be pulled back by 13 months to Q4 2028 if the cash flow could be optimized in the 2021-2024 time period.

These dates clearly show that there is a major science opportunity to 1. complete PIP-II 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 for at least part of the ramp-up, and 4. continue to further look for opportunities to advance completion of the target/beamlines area. These points are discussed below.

The baseline early completion of the accelerator complex is Q4 2027 with an anticipated ramp-up to ≥750kW in Q4 2029. Accelerating the ramp-up to higher powers (>1MW) after two years increases the science reach and so should be pursued but note that this is still two years after the first detector is expected to be 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 one year after PIP-II early completion with first meaningful neutrino rates in Q4 2030 assuming 2 years of ramp-up to ≥750kW. It is clear that there is still a science opportunity to advance the beamline further.

It would be advantageous for the accelerator complex to have a dedicated dump where FNAL could begin power ramp up independent of the beamline/target. If even the first year or two of power ramp-up could be done to an off-line dump the target area could move off the critical path and first meaningful science with ≥750kW could be in Q4 2029.

DUNE Status

The committee very much appreciated the presentation by the spokespersons on the status of DUNE, on recent developments within the collaboration, and on the plans for the coming months.

The DUNE Collaboration continues to grow. Since the last LBNC meeting 10 new groups have signed up. The LBNC acknowledges the brief description of the intended contributions to DUNE by the new groups. However, the LBNC would like to see this described in more detail next time, including an estimate of the number of collaborators composing the new groups along with the way they will contribute.

The committee congratulates Stefan Söldner-Rembold on his recent re-election as DUNE co-spokesperson and looks forward to continuing the close and fruitful cooperation. On this occasion the LBNC voices its strong concern that the current DUNE practice to limit the terms of the spokespeople to two 2-year periods might not be the best one for an experiment in the construction phase. Experience with other large collaborations has shown that during the construction phase a stable management and leadership team is important. We therefore strongly urge the DUNE Institutional Board to take this under serious consideration, recommending that during this phase the limit on the number of terms is removed.

The LBNC is pleased to see that the near detector organization is forming rapidly, and that consortia are being created. The LBNC, however, is concerned with the relatively fine-grained structure of consortia across all of DUNE, which carries the danger of making management, cross-coordination and communication more difficult. The committee would like to see a discussion on this point at the next meeting, including a presentation of the strategy the DUNE management team is following to ensure the successful cross-coordination, and communication between the different consortia, and proper transmission of critical information at higher levels.

The LBNC is pleased to see progress with regard to funding, with very positive developments from France and Italy. The LBNC encourages DUNE to continue the current practice, introduced by the DUNE resource coordinator, of identifying areas and ways to increase the overall contribution to the project by DUNE institutions.

The committee would like to urge the collaboration to work on performing comparisons between the DUNE and HyperK sensitivities on as much as possible an equal footing. A clear presentation of the assumptions made by each experiment on effective detector mass, beam power, and ramp-up profiles would be very helpful on this respect.

The LBNC strongly encourages DUNE to continue pursuing common approaches and synergies to data analysis, simulation, and software, across the different detector consortia. The LBNC acknowledges the significant progress DUNE has made, and the ND group in particular, in defining and using science requirements for the optimization of the near detector, and strongly encourages the collaboration to continue and expand on this approach.

The LBNC is pleased to see significant progress made on the issues related to the stable operation of the dual-phase ProtoDUNE detector. The LBNC strongly urges the collaboration to develop a clear R&D plan and accompanied timeline to determine the path forward for this technology.

Recommendations:

- LBNC strongly recommends that the Institutional Board of the DUNE Collaboration 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 within the consortia is presented.

Technical Coordination

A major activity for Technical Coordination at present is the preparation for the second phase of ProtoDUNE running at CERN ("ProtoDUNE-II"). The ProtoDUNE-II single-phase detector components will be replaced with pre-production units, effectively treating single-phase ProtoDUNE-II as the first part of the DUNE construction – a "Module-0". 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. The strategy may require more schedule contingency, to allow delays to be worked out without invoking 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, we discourage this, and recommend that it be mitigated by ensuring that clear requirements, specifications, and test plans are documented and agreed by the collaboration. The LBNC further notes that this strategy will likely require increasing the size of the Technical Coordination team.

The proposed single-phase ProtoDUNE-II program presented to the committee appears well justified, to exercise better techniques closer to the final DUNE configuration. Examples of changes presented include installing four APAs instead of six; and installing some APAs as if in the lower orientation ("upside-down"). The timescale for ProtoDUNE-II single-phase is stated as being set by the availability of the "Module-0 version" of the cold electronics. We are concerned that this has the potential to cause schedule slippage which could introduce additional costs or risks for the main construction, and urge every effort to maintain the cold electronics schedule

The LBNC further notes that the schedule of the ProtoDUNE-II program needs to be agreed by the CERN SPSC, as beam schedules at CERN have changed and may change further.

The LBNC also notes the Technical Coordination activity ongoing related to the dual-phase ProtoDUNE-II, and the substantial work related to the Near Detector design and prototyping. These are discussed later in this report.

Responsibility Matrix

The LBNC was pleased to be updated by the collaboration of the status of costing two single-phase DUNE detector modules, and for the updated summary of the coverage, and opportunities, of responsibilities for construction of these two detectors. The cost books initially indicate a CORE cost of $110M for the two detectors together: a first look has been given to these costs by the Neutrino Cost Group, and the analysis is being further developed.

The LBNC believes that the process being followed by DUNE to establish firmer costs is appropriate, and is impressed that 50% of the current coverage of the construction responsibility

for two single-phase modules has been formally agreed by funding agencies, with an additional 30% in, or being prepared for, funding agency review. Around 20% remains as an opportunity for new money and/or collaborators. Taking into account other plans in development, around 17% is seen as an opportunity for new money and/or collaborators. It is clear that an impressively detailed understanding of the anticipated responsibilities across international and US partners has been developed by the Resource Coordination team. The LBNC considers that it is important for the Consortium leaders to contribute strongly to understanding both the scope and the resources to which they are committing. The LBNC further encourages the collaboration to press new collaborators towards helping to address missing FD SP scope as a high priority. It looks very credible that the full funding and responsibility matrix for two single-phase detectors is attainable.

The collaboration is further encouraged to make progress in planning for, and establishing the level of, the Common Fund for the construction phase. The scope of items to be covered by the Common Fund will need to be established: the committee noted that parts of the calibration or cryogenic instrumentation systems, for example, could be appropriate use of the Common Fund.

The ongoing detailed development of institutional (or funding agency, where appropriate) responsibilities for both hardware and non-hardware deliverables is applauded: inclusion of non-hardware responsibilities goes beyond the model used by the LHC experiments, and has the advantage that substantial contributions to deliverables such as engineering, firmware and software can be acknowledged. The LBNC sees that the logical next step of inclusion of non-hardware deliverables in memoranda-of-understanding (MOUs) for construction is also a very positive development.

FD Dual Phase

The committee congratulates the DUNE DP team on significant progress in the ProtoDUNE run since the December LBNC meeting. Filter contamination has been resolved, resulting in improved electron-drift lifetime. Cryogenic procedures have been developed that allow periods of several days for operation of the charge collection and photon detection systems. However, CRP operation has been hampered by increased spark rates, requiring the voltage to be reduced on some LEMs and the electronics to be unplugged during studies of the sparking phenomenon.

At an interim video meeting on February 6 and in follow-up Q&A, the DP group provided the committee with detailed descriptions and discussion of the issues and progress to date. This was very much appreciated. The committee believes that a similar meeting in about 2 months would again be very useful. This report also benefitted from an extensive breakout session which enabled very detailed technical discussions.

<u>Findings: ProtoDUNE-DP</u>

- Since November, the repeated regeneration of a filter in the recirculation system has no longer been necessary. This has led to much more stable cryogenic conditions and allowed the DP team to make significant progress. Nevertheless, the fact that the filter clogging disappeared abruptly without a full understanding of the mechanism is a concern.
- Since November, the liquid purity has improved steadily, and the long purity monitors indicate that an e-drift lifetime of approximately 9 ms has been achieved.
- Surface instabilities (both bubbling and ripples) continue to be concerns that impact stable CRP operation. Further studies are planned at ProtoDUNE and in an upgraded/new cold box.

- An operational procedure, applying overpressure for a few hours once per week, generally suppresses bubble formation for several days, allowing stable periods for studying CRP sparking and gain.
- Intervention surgery on the HV extender is planned to extend the drift field uniformity to full depth. The baseline plan requires removing ~25% of the liquid to allow the surgery, followed by refilling. This entire process is likely to take 2-3 months. An alternative approach that would perform the surgery without the liquid removed is under consideration.
- The typical spark rate for the LEMs is ~3/CRP/hr, and for the Extraction Grid the typical rate is ~0.3/CRP/hr. While the electronics is well protected from LEM sparks, the 6kV Grid sparks permanently damage the readout ASIC. Sparks can occur in bursts, with correlation between sparking involving multiple LEMs and the Grid. The Grid spark mechanism is not yet understood, and an extensive study program is ongoing.
- 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, and so are excluded from performance studies.
- The CRP gain fell by approximately a factor two in early operations (December-January), and then plateaued. This behavior is consistent with prior bench tests and attributed to charge up effects.
- However, the plateau gain value is about a factor two lower 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 that there is a microphonic/vibration between the top LEM surface and anode plane. While this should be understood and mitigated in the design, this is not an issue for present studies.
- The short circuit in the HV extender, reported at the December LBNC meeting, 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.
- Progress has been made in calibrating the Photon Detection System and in initial studies of the scintillation signals. The PDS is ready now to take runs together with the charge readout, followed by combined data-taking with full drift depth after the HV surgery.

<u>Findings: R&D Plans towards ProtoDUNE-II DP</u>

- 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-II.
- A new cold-box is needed to support this program.

<u>Comments</u>

- The committee concurs that understanding the CRP sparking issues and gain are the highest priorities for the run.
- It is important to continue studies of the surface behavior, regarding the bubbles and the ripple effects, and to foresee the surface behavior in the full-scale FD module.
- Once the CRP sparking and gain 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.

- The committee commends the DP team for their management of the "budget" in grid spark damage to first complete CRP gain studies. The approach taken is judicious.
- The committee considers it very important that, if needed, the running period be extended to complete the full program planned.
- Additional resources will likely be needed from DUNE to support the further R&D. In particular the committee considers that a new cold box and associated cryogenic system dedicated to the R&D of the dual phase detector will be essential.
- The R&D plans should include extensive stress testing of a prototype and long term testing of the new CRP design, before assembly of new CRPs for a protoDUNE-II run.
- Specifications for the amplitude of surface irregularities that can be tolerated by the new CRP design should be developed.

Recommendations

- The present run should be extended, if necessary, in order to complete the program of studies outlined in this review.
- The committee recommends that after completion of the run, DUNE management 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 review should include an estimate of resource needs and plans for support.

FD Single Phase

Plenary

Roberto Acciarri presented a status update for Proto-DUNE operation and data analysis. The committee is very much impressed by the stable ProtoDUNE SP operation over more than one year. We congratulate the Collaboration on the successful operation of ProtoDUNE. The comments here will be on both the ProtoDUNE operation and the data analysis as the two subjects are closely related, but more from the point of view of FD Single Phase detector.

Findings:

- Stable ProtoDUNE SP operation over more than a year. It is an impressive achievement.
- CRT trigger data have been very useful in understanding the detector performance. In fact, it is unfortunate that for DUNE the CR rate is low and such a system may not be implemented.

Comments:

- The excellent noise performance of ProtoDUNE SP is setting a high standard for the new cold electronics currently being developed for FD Single Phase.
- It was not clear how to measure the uniformity (or the lack of) of Xe diffusion using cosmic ray data at ProtoDUNE and how to extrapolate the results to FD. How would one measure/study the Xe uniformity at FD Single Phase?
- The LBNC is looking forward to hearing the details of the calibration and monitoring system design for FD Single Phase at next meeting.

Recommendations:

- None

SP Electronics

Marco Verzocchi was the presenter for the Electronics breakout session.

Findings:

- The PDR for the FE ASICs and FEMB was held Feb. 5-7 at CERN. The review committee consisted of experts in the field. The preliminary report from the review was provided to the LBNC. 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; the recommendation to increase ESD protection will be revisited after the June submission)
  - ColdADC – April (most changes implemented already; some still being worked on)
  - ColdDATA – June (modifications needed to the PLL; there is some issue with the availability of the EE designer)
- For the CRYO ASIC, not much progress has been reported since the October 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 2021, 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 Warm Interface Board (WIB) is scheduled for next week at BNL (note added later: the review was postponed due to the Covid-19 situation and will need to be re-scheduled). While new WIB prototype boards have been built and tested, the required firmware development is starting only now.

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 which is 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 in advance.
- 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 beyond 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.

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".

SP Installation

James Stewart gave the presentation for the Installation breakout session.

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 were added.
- Full-size APA and CPA were tested at Ash River which resulted in the following changes for the final production and assembly:
    - Conduit installation was moved to APA assembly factory.
    - The installation cleanroom layout will not include a movable platform.
- Ash River Installation Prototype Phase II design package is 90% complete.
- ProtoDUNE-II planning is underway.

Comments:

- The 3 recommendations made at the I&I review are important:
    - revisit project interfaces every 6 months,
    - update labor BOEs before the Director's Review,
    - work to understand large activities to reduce uncertainties.
- 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.
    - The managers are aware that the Ash River crew needs to work on NOvA first if there is a problem in the NOvA detector.

Recommendations:

- None

Near Detector Conceptual Design

The LBNC heard three plenary presentations on the DUNE Near Detector (ND), and had an especially productive breakout session discussion with the DUNE ND group for which we are thankful.

We had a comprehensive plenary presentation on the status of the ArgonCube detector. We notice that the ArgonCube 2x2 demonstrator schedule has slipped several months compared to what was presented in December 2019, but were told that the previous schedule had not been realistic. The current schedule seems realistic if no unexpected problems are encountered, but we suspect that it contains little contingency in case unexpected problems do arise.

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. Such a "Day 1 option" may be required if resources are limited, but we emphasize that the full MPD design offers significant power for understanding and reducing systematics that a muon range detector cannot provide, and we endorse the eventual construction of the full MPD.

The magnet design for the MPD is advancing rapidly. A reference design containing five superconducting coils has been settled. In addition, a new design with a partial iron yoke is under development. This latter design looks to provide some attractive features, such as smaller footprint and cost, and LBNC encourages DUNE to develop this further.

During the breakout session we discussed what kind of tracking would be required inside the KLOE magnet and ECAL for the SAND detector. It is agreed that the magnet itself provides enough target mass, but 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 beyond what can be done with the ECAL alone. That being said, the required tracking could be quite minimal (perhaps just a sparse set of tracking planes of gas or scintillator tracking), and might not require anything as complex as the baseline 3DST detector+gas tracking. This is a possible area for minimizing costs for a "Day 1" detector in case resource limitations mandate staging.

We also discussed the SAND detector's goals to provide access to event-by-event neutrons in reconstruction and to study nuclear dependence in the cross sections. Given the expected difficulty of using data on carbon to understand interactions on argon, and the SAND detector's inability to

make use of the off-axis PRISM technique, we feel that these goals, while possibly useful, should not be considered to be mandatory requirements for the on-axis beam monitor.

DUNE is quite close to having a full CDR for the LBNC to review, for which we congratulate them, and has discussed the idea of producing an IDR in time for a CD-2 review later this year. For such a review it may be sensible to just use the CDR supplemented with some addenda that spell out preliminary cost estimates as best as they are known. DUNE should consider what is really needed from the near detector for the CD-2 review, since the ND is largely an international contribution outside the US scope. DUNE should resist pressure to produce a TDR prematurely.

We note that separate consortia are being formed for some of the 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

The LBNC is not issuing any major new recommendations, but encourages the Collaboration to continue to work on those delivered in December 2019.

> As requested previously, we emphasize again the importance of extending the end-to-end oscillation analyses to include off-axis PRISM data to demonstrate quantitatively the benefits of the off-axis technique. No new studies have been presented to the LBNC on this point since last summer. As an initial step, we suggest that at least some off-axis samples be included in the end-to-end analysis (perhaps with parametrized detector response functions), with a basic model of systematics that will correlate between off-axis positions, to show quantitatively how well these samples can constrain degrees of freedom in the neutrino interaction models that are degenerate for on-axis only data**.** We strongly encourage the Collaboration to continue to develop in parallel a fully data-driven, hence model independent, prediction of the far spectrum (such as may be possible using linear superpositions of data taken at various off-axis angles) using the PRISM technique, although we recognize that this may take longer than simply including off-axis samples in the current oscillation analysis framework.

The outline of the draft CDR that we were shown didn't include a separate section focusing on the power of the ND data in the oscillation analyses in terms of reducing systematic uncertainties at the desired level, although similar material is in the physics TDR. We recommend that the CDR also include a section about the effects of the ND data in an oscillation analysis. This could be based on the physics TDR material but extended to include any newer studies.

DUNE Computing/Analysis

The LBNC congratulates the Computing Consortium for enabling data analysis of both ProtoDUNE-SP and DP. Pandora plays an important role for the analysis activity, it is generally adopted in the SP community and being gradually introduced in DP analysis. We find SP and DP at different levels of maturity in computing and software tools, with SP more advanced. We

continue encouraging close collaboration and synergies between SP, DP and the ND communities in all aspect of computing and analysis, to leverage each other experience and software.

In response to a previous recommendation, the LBNC is pleased to see the planning for provisioning of the SURF-FNAL network connectivity. We suggest that the implementation of the plan be regularly monitored and reported on. We also suggest to start defining data challenges of increasing complexity to verify step-by-step the progress of the network commissioning. DUNE has shown clear scenarios, such as prompt processing of supernova candidate signals, to demonstrate the need of 100GE connectivity on this path. This will be required to fully exploit the potential of the DUNE physics program and also to play a role on a broader scientific scope such as multi-messenger astronomy. We note that such capacity would be beneficial already in 2026 for computing commissioning purposes.

The DUNE computing consortium has made considerable improvement in understanding the computing resource requirements of the experiment and their future evolution. A costing exercise evaluating the funding needs for DUNE computing in the US was presented. The study includes the cost of hardware and manpower for development, operations and support. The result shows a need for less than $10M over the next 10 years. We assume, as was clear from the discussion, that sizeable uncertainties exist on the manpower estimates. In particular, the need for software experts in addition to the contributions of physics postdocs and researchers was pointed out. The LBNC understands that such funding is critical for DUNE computing as a minimum requirement to carry on the activities of the consortium. As in the previous meeting, we note that the cost of analysis is not well understood. Also the reconstruction and simulation CPU needs for the Near Detector are currently not known and they might end up being considerable due to the more complex layout with respect to the Far Detectors. We therefore invite DUNE to progress in understanding those needs and we would be pleased to see some preliminary evaluation at the next meeting.

The LBNC supports the initiative of a Software Framework Task Force and would be interested to hear the progress at the next meeting. In particular, we would like to understand the future plans for the core software and the role of LarSoft. A re-engineering activity in this area will require considerable planning, sufficient resources and expertise. It also requires upfront strategic decisions about which existing components to leverage and adopt and which ones to implement within the community. The LBNC continues noting that reconstruction algorithms and simulation are today not included in the scope of computing in terms of organization. We believe a stronger link should be established and we encourage the DUNE Collaboration to develop and articulate an organization which ensures synergy, and provides recognition of long-term responsibilities in this area.

ProtoDUNE SP Physics Analysis

The LBNC congratulates the SP analysis group on the good progress on physics analysis and the paper preparation. In particular, a draft “First results on ProtoDUNE-SP LArTPC performance from a test beam run at CERN Neutrino Platform” has been completed and is under internal collaboration review. We look forward to the details about the estimation of the impact of systematic uncertainties in the physics paper. Work has begun on the technical paper: “Design, construction and operation of the ProtoDUNE-SP liquid argon TPC” led by Gina Rameika.

Key elements of physics analysis in the physics paper include characterization of the TPC and the photon detection system and studies of their response. An event display of a muon bundle event was presented. The TPC characterization reported an excellent signal-to-noise level and a strategy to remove coherent noise. Reconstruction is performed using WireCell and Pandora. The TPC response has been calibrated using cosmic muons and the calibration constants were demonstrated to be applicable to beam particles. The dE/dx distribution was presented and demonstrated a well-understood detector response to particles of different species.

The calorimeter was shown to provide excellent separation between muons/pions and protons. The characterization of the 3 light collectors and 3 photosensors of the photon detector were presented. Stable gain and a high signal-to-noise ratio were presented. The efficiency has been measured using electron and muon data. Good linearity in the energy response was shown for a single ARAPUCA module. Measurements of the electron lifetime from dQ/dx vs drift-time were presented. The idea is to use this measurement to calibrate the purity monitor measurement.

Improved stability of the cosmic-ray telescope (CRT) readout was reported after the CRT was reactivated in Nov 2019 and three weeks of dedicated data-taking with the CRT triggers ensued. Excellent LAr purity was observed and no electron lifetime correction is needed. Ongoing analyses include measurements of the detector response and hadron-argon cross-sections, testing the new simulation and reconstruction tools and focusing on the connection to the DUNE far detector.

A novel method to measure space charge effects using anode-cathode-anode tracks was presented. The results were compared to an alternative approach using CRT tagged tracks. Some differences in the results between the two methods were shown. The bias in the electron energy measurement is understood, which is critical information for DUNE.

Clear separation between electron and photon dE/dx was shown. Some differences in the modeling between data and simulation were observed. Measurements of the Michel electron separation were presented. While good agreement between data and a tuned simulation is observed, neither distribution matches theoretical expectations and further understanding is needed.

Shower max distributions as a function of energy were presented. A convolutional neural net (CNN) to improve pion absorption measurements was presented. We note that the pion absorption data is also very important for performance studies of the near detector.

Tests of reconstruction tools for DUNE were presented, including a CNN to separate track and shower hits. Good performance was shown, however, significant differences between data and simulation were observed.

The LBNC encourages DUNE to continue to work to improve the agreement between the data and the simulation. We are glad to see that the simulation task force has been working to improve the agreement between data and simulation, for example in dE/dx We encourage DUNE to expand this effort to obtain a deeper understanding of the simulation, e.g. for the Michel electrons. Where the simulation needs to be tuned, we recommend that it is verified that the tuned parameters are physically meaningful and in agreement with known external constraints.

We encourage the SP and DP groups to continue moving towards using common tools for simulation, reconstruction and analysis as much as possible.

ProtoDUNE DP Analysis

The LBNC is happy to see progress on the DP analysis. The team reported that the offline analysis uses the DUNE framework based on the Art framework, which is in common with the ProtoDUNE SP, which allows them to share tools and reconstruction algorithms. The team holds a regular joint ProtoDUNE SP and DP reconstruction and analysis working group meeting.

The status of the implementation of the geometry was reported, including an issue with the treatment of the rotation of the coordinate for the drift. The dead areas of the LEM have been implemented and will allow future optimization. The highly non-uniform drift field in the TPC due to the HV short was reported, which curves cosmic tracks and is expected to impact purity estimations. Work is ongoing to import the ProtoDUNE DP field map into the DUNE framework.

The GaussHitFinder is currently under-evaluation as a replacement for the DPRawHitFinder, which appears to improve the tracking efficiency, but differences between the two are observed and need to be resolved.

Noise filtering algorithms are under-development but currently too slow to run on ProtoDUNE DP events. ProtoDUNE DP has been integrated into the Pandora framework and work is ongoing to adapt Pandora for ProtoDUNE DP. A loss in tracking efficiency when particles are parallel to wires is observed and increasing the hit granularity mitigates this issue to a large extent.

The angular distribution of cosmics was presented. The plans and challenges for the integration of the data streams from different detectors were presented. For example, for the CRT data, a more efficient way to access files is desired. Future analysis plans were presented.

We note that the DP analysis is less mature than the SP analysis and has a factor of two less effort. 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.

Appendix I: Attendees

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

Scientific Secretary: Angela Fava

Fermilab PAC Chair: Apology Received

DUNE/LBNF: Roberto Acciarri, Dario Auterio, Ed Blucher, Alan Bross, Flavio Cavana, Dave Christian, Vyacheslav Galymov(rem), Ines Gil-Botella (rem), Eric James, Mike Kordosky, Steve Manly, Chris Mossey, Francesco Pietropaolo (rem), Regina Rameika, Heidi Schellman (rem), Stefan Soldner-Rembold, Jim Stewart (rem), Hirohisa Tanaka, Marco Verzocchi, Alfons Weber (rem), Tingjun Yang.

FNAL Directorate/Management: N. Lockyer, H. Ramamoorthi.

DOE: P. Carolan, W. Wisniewski

Appendix II: Charge

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.

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:

a) Operations of ProtoDUNE-SP during 2020 and the understanding of operating parameters for DUNE and the plans for ProtoDUNE II operations.
b) Physics analysis of the PD-SP data including charge and photon detection. A separate talk is envisaged in the draft agenda
c) SP technical progress including the TPC electronics development.
d) 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.

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.

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.

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.

Appendix III: Assignments

Consultants shown in Italics

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
Near Detector Status (staging)		Oser, Behnke, Mondal, Kopp, Saoulidou
Breakout		
Dual Phase		Spalding, Galbiati, Kajfasz, *Para*, Wood,
Single Phase Electronics, Install		Parsons, Pitts, Fava, Liu, *Pla-Dalmau*
Near Detector Details		Oser, Behnke, Mondal, Kopp, Saoulidou
Computing/Analysis		Campana, Charlton, Gray