DUNE Preliminary Design Review (60%) of Single Phase Cold Electronics Mechanical Systems

11-12 February 2019

Review panel: Jonathan Lewis, Alberto Marchionni, Jen Raaf (chair), Terry Tope, Dan Wenman, Theresa Shaw (ex-officio), Farshid Feyzi (ex-officio)

1 Introduction

This document is the report of the 60% Preliminary Design Review of the Single-Phase Detector Cold Electronics Mechanical Systems that was held 11−12 February 2019 at BNL. This review is part of the DUNE Far Detector Design Review Plan (DocDB-9564). The review covers the mechanical aspects of the cold electronics design, focusing on cold cables (bundle dimensions, routing, strain relief, and support system, mounting to CE box), cryostat penetrations (cable routing, mechanical CE-cryostat interfaces), and signal feedthrough assembly (flange, cable strain relief, flange board). The review charge indicated that the photon detector flange should also be reviewed, but this was not presented, and will need to be reviewed at a later date.

The committee congratulates the design team on a job well done in preparing for this review. Overall the committee finds that the design is well advanced and on the right track, and that there is a good team assembled for completing the testing, development, and design. Several recommendations are made to help guide the design.

According to the requirements listed in DocDB-9564, the deliverables for a 60% preliminary design are:

• Design choice identified;
• Detailed engineering drawings, schematics, and preliminary parts list;
• Interface documentation review with other systems;
• Complete engineering analyses and documentation;
• Incorporation of ProtoDUNE lessons learned;
• Finalization of applicable design codes and standards;
• Manufacturing methods and acquisition strategy;
• Plans for production and evaluation of prototypes;

• Draft manufacturing, quality assurance, testing and procurement plans;
• Installation plans including special tools and fixtures;
• Preliminary cost and schedule estimate;
• Value engineering exercise;
• Resolution of 30% review recommendations.

2 Technical Evaluation

General comments:

- Need better cross section drawings with identification of parts and dimensions
- Lessons Learned from ProtoDUNE have not been updated since May, and there were several missing LL that were discussed during the review:
  - The patch panel in the cold box is a new idea based on ProtoDUNE experience
  - The clamping plate was modified based on ProtoDUNE experience
  - The photon detector flange has a problem with leaks because of non-blind vias that were not soldered correctly
- It would be good, wherever possible, to use captive screws to minimize the chance of losing parts. Otherwise, lock washers or thread locker should be used to prevent fasteners from being loosened during transport.
- As new issues arise and are solved, be sure to check any new materials in the Materials Test Stand

2.1 Cold cable routing inside cryostat

Findings:

- The planned mock-ups will be very useful for cable routing tests

Comments:

- It will be important to use the mock-up to refine the process of routing the cables from the APA up through the feedthrough, and to show that the process of replacing CE boxes on the cryostat side is reasonable.
- It is important that the cable management hardware be mounted before the cables are routed.
- The cable protection channel on the bottom of the bottom APA is aluminum, and must be analyzed for differential contraction
- A mock-up of the lower APA should include a test of pulling up on the S-bend of extra cable to simulate the differential shrinkage of the cables relative to the APA, to see how the cable moves up into the conduit when contracting
- The scheme for taking up the slack from the 5 different cable distances for the lower APA on the top needs to be tested.
- The potential of trapped air inside of a tightly packed CE cable conduit in the APA frame should be evaluated

- The distribution of cable weight across the top of the APA during installation should be studied -- this will vary depending on the relative position of the APA and the crossing tube.

2.2 Cable bundles

Findings:

- CE cable tests were done at PSL and Ash River with conservative cable dimensions (dimensions may be smaller for chosen cables). The decision on cables will be finalized by the second half of 2020.
- The epoxy for the signal cables at the connection point to the FEMB has not yet been certified for operation in LAr.

Comments:

- There is a possibility of reduction in size of cable bundles, if the thinner cables are chosen. Designs have assumed the thicker cables, which gives a conservative estimate of available space.
- A drawing should be made showing the entire length of the cable bundle, with locations of cable grip, mesh, tape, and connector areas.
- Consider modeling the major steps of cable layout in CAD
- The fiberglass tape (proposed solution for cable mesh and cable grip attachment) should be considered carefully and discussed with physics groups. Fiberglass may contain non-negligible amounts of radioactive material, which could cause low energy photons (based on Super-K experience with Fiber-Reinforced Plastic (FRP) covers installed as shockwave mitigation on PMTs after the 2001 accident).
- It was mentioned during the review that the cable conduit may be perforated to help with Ar circulation. It was also mentioned that there may be slots for PD insertion after cable conduits are installed. Any perforation or slot could have sharp edges or burrs that could damage the cables, and so the CE and APA consortia should consider avoiding perforations or slots, however, if they are necessary, the manufacturing process should be guaranteed to result in smooth edges.

2.3 Cable support system

Findings:

- The CE consortium is responsible for the SHV cables (wire bias, field cage termination, electron diverter); it was noted that there was difficulty in making connections to the SHV board provided by the APA consortium
- The CE twinax/clock cables will need to perform well for 20+ years
- Initial tests of the cable grip to support the bottom CE cables look very promising
- The hook to support the cable grip is not yet designed

Comments:

- Details of the CE/APA interface for the SHV cables need to be worked out
- Mechanical stresses on the CE twinax/clock cables can affect cable performance. Tests should be done when the cables are constrained as expected, and when they are hanging unsupported for 12+ meters. Tests should include a bit error rate test at 2.56 Gbps.
- The cable grip must be cold-tested and purity tested. The CE consortium should provide to the APA consortium the support point locations, and the forces acting on the support point for the CE cable support cable grip.
- The worst case maximum offset of a feedthrough relative to the APA center should be tested in a mock-up. We were presented with a maximum offset of 1.6m between the center of the APA and the feedthrough location, but no details of the cable routing/support from the APA to the feedthrough, or how this may interfere with adjacent APAs. Can the cabling mockup be adapted to the different positions of the feedthrough relative to the APA?

2.4 Cable strain relief

Findings:

- The cables are strain relieved at the CE flange with brackets, at the bottom of the CE Crossing Tube with locking plates, in the cable trays and under the lower APA with cable ties appropriate for high purity cryogenic service, and above the APA conduit with a kevlar cable grip.

Comments:

- Hose clamps should not stress the cables and affect the twinax dielectric.
- Drawings should include teflon wrapping on the CE cables in the CE box strain relief
- The new strain relief idea for the CE boxes should be cold-tested
- The assembly sequence of the crossing tube cable support and strain relief system needs to be carefully evaluated. Can it be pre-assembled?

2.5 Mounting of CE box

Findings:

- The CE box is held to the APA via the “omega bracket”, which is attached to T-bracket weldments on the APA frame. The omega bracket has been tested in a vertical orientation during ProtoDUNE, but assembly will be done with the APA in a horizontal orientation before it is rotated to vertical.
- The CE team intends not to use the L-brackets for the CE boxes and adapter boards
- The design of the cold electronics boards that live inside the CE boxes is not yet finalized, but the size of the CE boxes will not be larger than the ProtoDUNE CE boxes.

- The interface of bubble management from the CE boxes to the APA is not yet defined.

Comments:

- The omega bracket design has been improved after ProtoDUNE experience, but the validity of the design should be checked in all orientations, and with consideration of vibrations during transport. Modifications to the omega bracket should be discussed with the APA consortium
- The T-bracket (CE box mounting hardware) is relatively rigid, and must be made to the appropriate tolerance to avoid installation and/or alignment problems. Required tolerances must be shared with the APA consortium. Since cooling may also affect the stress in the connectors, the effects of cooling should be evaluated.
- The decision not to use the L-brackets from the CE boxes and adapter boards will put installation forces through the CR boards and wire boards, may stress the APA board stack. The decision must be reviewed with the APA consortium.
- A detailed procedure for handling the CE boxes is needed, in order to prevent damage to the front-end amplifiers.
- Mounting holes in the CE box should be slotted to allow for proper seating of the connectors.

2.6 Cryostat penetrations

Findings:

- The design of the cryostat penetrations incorporates the experience from ProtoDUNE and other cryostats.
- The design accounts for access and serviceability issues within the available space on top of the cryostat.
- The cold electronics crossing tube (CECT) is inserted inside the cryostat crossing tube with a 5mm separation between the two tubes.

Comments:

- It is not clear if the flexible teflon duct is necessary. Its effectiveness in reducing outgassing should be evaluated by CFD.
- The interface with the cryostat design should be updated, and determined whether it is allowed to clamp around the cryostat crossing tube. The consortia, joint project office/LBNF, and technical coordination teams should all come to an agreement on this.
- The metal tubing of the flexible teflon duct is pinched at the end, representing a virtual leak. How will that be evacuated, cleaned, circulate LAr?
- The weld between the CECT and its adjustment flange needs to be analyzed in detail according to appropriate code, to show that the flange is adequate and can withstand stress from loading and clamping. The application of a notional lateral load results in a very high stress in the weld. This needs to be studied as part of the weld evaluation.
- The flange of the CECT has 3 alignment screws and 3 clamping screws in the circular bolt pattern. The alignment screws hold the CECT flange off the cryostat flange. When the clamping screws are tightened, the clamping force is reacted by bending the flange and stressing the weld. Shims under the clamping bolt would prevent this. Consider

shims under the clamping screws of the flange to minimize weld stresses, or the other option is to check the effect of this additional stress against the weld strength.
- Stress in the CECT fasteners should be evaluated for all potential loading conditions and the appropriate torque determined.
- The wall thickness of the CECT is 2.7 mm. Study if this can be increased.
- Allowable loads at the interface of the cross-shaped spool piece with the cryostat should be documented
- The mechanism to route cables through the cryostat penetrations needs to be studied
- The leak-rate specification needs to be better understood. A vacuum leak rate of 1E-9 bar is very stringent for this application. LBNF and/or the CERN team should specify the acceptance criteria for the CE cryostat penetrations, including the leak rates, whether X-ray inspections on welds are required, whether helium leak testing is sufficient, and whether pressure testing is required.
- Specifications of the flange on the cryostat that is used to support the CE cryostat penetrations should be agreed on by the CE and cryostat consortia and the Project team, to define the flatness of the flange relative to the surface of the cryostat and to define how vertical it is relative to the cryostat crossing tube.
- Quality control procedures for the cryostat penetrations should be defined together by the CE consortium and the Project team (LBNF/CERN/TC)

2.7 Signal feedthrough assembly

Findings:

- The design of the CE feedthrough flange is well advanced
- In ProtoDUNE, in some cases, the flange for the CE warm box or the mating flange on the feedthrough were not aligned which resulted in the CE warm box being at a slight angle. This must be avoided in DUNE.
- The design of the PDS flange was not presented in this review

Comments:

- The load case of the CE flange and crate in the service position should be evaluated for the cross-shaped spool piece.

3 Recommendations & Answers to Review Charge Questions

1. **Have design choices been fully identified and do they meet detector requirements?**

   Yes. The CE team has done a good job of identifying design choices to meet detector requirements, working from the elegant ProtoDUNE design that already meets most of the requirements for DUNE.
   <u>Comments:</u>
   - Several potential problems with the flexible teflon duct were observed by the committee, including forces on the cryostat crossing tube, and a virtual leak from the interior of the teflon duct's metal tubing

   <u>Recommendations:</u>
   - Perform a simulation to determine if the flexible teflon duct is necessary, or if its design may be simplified.

2. **Are the specifications and drawings for standard and custom components substantially complete and available in EDMS? Are they of sufficient maturity to proceed to final design?**

   The drawings that were shown during the review are in an appropriate state of completion, and are available in EDMS. Specifications for components were not presented in detail. This needs to be done before the next review.
   <u>Comments:</u>
   - Not all drawings are currently available in EDMS, but a list of the necessary drawings was added to the engineering notes after the review

   <u>Recommendations:</u>
   - Upload all specifications and drawings to EDMS

3. **Have interfaces with other detector components been addressed and documented? Do risks of design changes in other systems have appropriate mitigation strategies?**

   Some interfaces have been addressed and well documented, but the areas listed below could be improved. The committee sees no significant risk due to design changes from other systems.
   <u>Comments:</u>
   - At the interface of the CE box and its electrical connection with the CR board and APA board stack, all mounting hardware and connectors should be documented in an interface drawing.
   - System grounding was not intended to be addressed in this review, however, it should be noted that good electrical grounding does not rely upon incidental mechanical connections. Consider use of ground braids (or star washers) when connecting the front end boards to the CE box and the CE box to the APA frame/Omega bracket.

- The bubble management interface should be revisited after the BNL bubble test
- The cryostat flange interface requires formal documentation and simulation
- The CE consortium should urgently provide to the APA consortium the forces and moments acting on the APA yoke from the CE cable tray during the installation phase
- The CE consortium should provide to the APA consortium the location of the cable grip support point and the forces acting on it
- The position of the cable grip on the cable is important, as there is little room for slack between it and the connectors. Requirements should be defined for positional accuracy of the cable grip along the cable length.
- The interface of the CE and the cryostat at the flexible teflon duct should be documented

<u>Recommendations:</u>

- Interface documents need to be updated and actively managed

4. **Are engineering analyses sufficient to ensure the design is safe during all phases, and have applicable design codes and standards been satisfied?**

Engineering notes have been prepared and are at the appropriate level of completion in order to describe the design in detail. The load cases and calculated stresses utilizing FEA appear to be reasonable. However, to fully answer the question, the engineering analysis must be done with the appropriate design code.

In the case of the CECT, a notional lateral force generates a very high stress in the weld area. This needs to be evaluated further and weld design needs to be analyzed according to design code.

<u>Comments:</u>

- The Project must inform the CE team which design codes are the standards to be used. Materials safety should also be included (e.g., fire codes)

<u>Recommendations:</u>

- Analyses should include weld stresses according to appropriate design code

5. **Does the design support a reasonable procurement strategy and manufacturing plan?**

Yes. The CE team has accumulated a substantial amount of experience from ProtoDUNE for procuring and manufacturing parts. In addition, lessons learned from ProtoDUNE have allowed improvements in the design and assembly of the CE boxes.

<u>Comments:</u>

- Assembly of the cable bundle will require testing

Recommendations:

- None

6. **Are quality assurance and testing plans sufficiently developed to proceed to final design?**

No formal QA plan was presented during the review, but the engineering and testing thus far demonstrates adherence to the principles of integrated quality.

Comments:

- The overall QA plan should include mechanical aspects of the CE installation

Recommendations:

- Follow through with plans to do bit error rate testing of cables under mechanical stress
- Document the QA and testing plan

7. **Have lessons learned from ProtoDUNE been implemented? Are the issues with the connectors on the FEMBs understood?**

Many of the lessons learned from ProtoDUNE have been implemented, but there were a few mentioned during the review that have not yet been added to the Lessons Learned document. The FEMB connector issue is well understood and a promising mitigation strategy has been implemented, but remains to be cold-tested.

Recommendations:

- Update the Lessons Learned document to capture all known lessons learned. Assign someone to curate this list.

8. **Are plans for additional prototyping reasonable and sufficient?**

The CE team has defined a set of mockups and tests that will be sufficient to reach final design. The committee suggests that the mockups and tests should also cover the areas discussed in the comments below.

Comments:

- The upper APA mockup should be done with all of the cables that will be used for a complete pair of APAs (upper, lower, and photon detection system cables). Tests should cover both the work done in the clean room, and the work done in the cryostat, making sure to apply appropriate space constraints. The cabling mockup should include the “worst case” maximum offset of a feedthrough relative to the APA center.
- The original design of the CE box mounting to the cryostat side of the APA was intended to allow replacement after installation of the cable trays -- this should be tested in the mockup.

- A mockup of the bottom APA should be done, including a test of pulling back the cable bundle to simulate shrinkage of the cables during cooldown (it is sufficient to do this test with shorter cables).
- The assembly of the CE box onto the APA and mechanical stability of the CE box during transport should be tested with the APA in the horizontal orientation
- The upper and lower cabling assemblies should be tested with the APA in vertical orientation
- A cold test of strain relief in the CE box should be done
- Mechanical stresses on the cables and the cable grip should be tested on a hanging bundle of long cables, if possible in cold. A longer-term (warm) test of hanging cables is desirable to evaluate changes in signal quality over time
- The cable grip should be tested under load in liquid argon (there has been concern raised in some forums about the lubricating properties of argon relative to air)
- Safety aspects of installation procedures in the future DUNE detector (which will involve activities happening much higher above the ground than in these tests) should be considered during the mockup tests

<u>Recommendations:</u>

- Proceed as soon as possible with the extensive set of assembly and installation tests on mockups

9. Have appropriate cost estimates and schedule been determined? Are plans for required technical and scientific resources consistent with scope of remaining work?

After the review, the CE team provided the following response via email. This is their list of resources that are committed for FY19 and an assessment of what is required to complete the design through the final design review (90%):

a) Cryostat penetrations: we had planned for 400h of engineering for the design, another 180h of engineering, 280h of technician, and $61k of M&S (the cost estimate for the cryostat penetration is about $15k, including all the parts, and the rest is meant for the supports - I WILL COME BACK TO THIS LATER)

b) Cabling (including changes to the FEMB and insertion tests): we had planned for 660h of engineering plus some technician time plus travel support for insertion tests at Ash River

c) We had not allocated time for the redesign of the CE boxes, this is something that had been noticed in an internal review, but we hadn't made the relevant change in our estimate of resources

d) Contrary to what I had said at the review, we had not budgeted the labor for producing drawings, but those resources were made available by BNL when requested (I did not remember correctly, because we had planned to have the designer time available only for the next phase, when we produce the final designs).

Going forward we have:

- 0.375 FTE of engineering available for the final design of the cryostat penetration, with an additional 0.125 FTE of designer, plus additional resources for testing prototypes
- 0.3 FTE of engineering for the final design of the cable plant and cable trays, including 0.1 FTE of design, and 0.1 FTE of technician time
- As above, we have not allocated resources for the redesign of the CE boxes, but we will make those resources available.

It is obvious from the discussion we had during the review that we need to allocate additional resources for the test stands, given that we are making more tests than originally planned. We are going to have a meeting in the coming days to estimate the additional resources required between now and the completion of the final design (there is going to be a significant increase in the cables that will be used to perform installation tests). There is already a commitment from BNL to provide all the support (in terms of engineering, technicians, designers) to complete the design of these detector components.

<u>Recommendations:</u>

- Complete the estimate of necessary labor and M&S required to carry out the test stand work and to reach final design, then allocate the required additional resources.

Appendices

Charge

DEEP UNDERGROUND NEUTRINO EXPERIMENT

DUNE Preliminary Design Review (60% Design Review)

Charge

Single Phase Cold Electronics Mechanical Systems

11-12 February 2019

The committee is requested to review the DUNE Single Phase TPC Cold Electronics (CE) design and determine if it meets the requirements of the preliminary design as outlined in the DUNE Far Detector Design Review Plan (DocDB-9564 [password link]). This review of the CE design is focused on the mechanical aspects of the project, including the dimensions of the cold cable bundles, cable routing inside the cryostat including the cable support system inside the cryostat and the cable mounting to the CE box and APA, cold cable strain relief, cryostat penetrations up to and including the flanges separating the cold volume from the top of the cryostat, the mechanism to route the cables through the cryostat penetrations, the signal feedthrough assembly (flange and flange board) and services on top of the cryostat (the warm interface crate is excluded from this review). This review includes the photon detector flange and cold cables.

1. Have design choices been fully identified and do they meet detector requirements?
2. Are the specifications and drawings for standard and custom components substantially complete and available in EDMS? Are they of sufficient maturity to proceed to final design?
3. Have interfaces with other detector components been addressed and documented? Do risks of design changes in other systems have appropriate mitigation strategies?
4. Are engineering analyses sufficient to ensure the design is safe during all phases, and have applicable design codes and standards been satisfied?
5. Does the design support a reasonable procurement strategy and manufacturing plan?
6. Are quality assurance and testing plans sufficiently developed to proceed to final design?
7. Have lessons learned from ProtoDUNE been implemented? Are the issues with the connectors on the FEMBs understood?
8. Are plans for additional prototyping reasonable and sufficient?
9. Have appropriate cost estimates and schedule been determined? Are plans for required technical and scientific resources consistent with scope of remaining work?

Review Findings:
The committee should present its findings, comments and recommendations in a closeout meeting with DUNE Technical Coordination on 12 February 2019. The committee should provide a final written report by 8 March 2019.

Review Website & Agenda

https://indico.fnal.gov/event/19084/

Go to day

Monday, February 11, 2019

08:00 - 08:30	Committee executive session (restricted) *30'* Speakers: Jennifer Raaf (Fermilab), Dr. Alberto Marchionni (Fermilab), Terry Tope (Fermilab), Steve Kettell, Steve Kettell (BNL), Dr. Eric James (Fermi National Accelerator Lab), Jonathan Lewis (Fermilab), Mr. Dan Wenman (University of Wisconsin - Madison), Farshid Feyzi, Farshid Feyzi (Universtiy of Wisconsin-Madiosn)
08:30 - 08:40	Introduction *10'* Speaker: Marco Verzocchi (Fermilab) Material: Slides
08:45 - 09:15	Lessons Learned from ProtoDUNE *30'* Speaker: Matthew Worcester Material: Slides
09:25 - 09:45	CE Integration and Installation Plan *20'* Speaker: Marco Verzocchi (Fermilab) Material: Slides
10:00 - 10:15	Status of Interface Documents *15'* Speaker: Marco Verzocchi (Fermilab) Material: Slides
10:25 - 10:45	Coffee break *20'*
10:45 - 11:10	Changes to the CE box design and to the FEMB/CE and CE box/APA interfaces *25'* Speaker: Manhong Zhao (BNL) Material: Slides
11:20 - 11:35	Reduction of the CE cable plant *15'* Speaker: Marco Verzocchi (Fermilab) Material: Slides
11:40 - 12:05	Review of cable routing tests *25'* Speaker: Manhong Zhao (BNL) Material: Slides
12:20 - 13:30	Lunch *1h10'*
13:30 - 14:00	Cable trays inside the cryostat *30'* Speaker: Manhong Zhao (BNL) Material: Slides
14:15 - 14:45	Cryostat penetrations and CE flanges *30'* Speakers: Bo Yu (Brookhaven National Lab), Manhong Zhao (BNL) Material: Slides
15:00 - 15:20	Cost and schedule *20'* Speaker: Marco Verzocchi (Fermilab) Material: Slides
15:30 - 15:45	Coffee break *15'*
15:45 - 17:00	Committee executive session *1h15'*
17:00 - 17:45	Joint session (committee/CE consortium) *45'*
18:30 - 20:30	Dinner *2h0'*

Tuesday, February 12, 2019

08:00 - 08:30	Committee executive session *30'*
08:30 - 09:30	Joint session (committee/CE consortium) *1h0'* Material: Slides
09:30 - 12:00	Committee writing session *2h30'*
12:00 - 12:30	Closeout *30'* Material: Slides