DEEP UNDERGROUND NEUTRINO EXPERIMENT

**November 15, 2016**

# Report of the Design Review of the DUNE Single Phase Cathode Plane Assembly, Field Cage and High Voltage

## 9–10 November 2016

## CERN

# Outline

# 1 Introduction

The Review Committee (see Appendix B) was requested to evaluate the status of the design of the ProtoDUNE Single Phase cathode plane assembly (CPA), field cage (FC) and high voltage (HV) and determine if it is at a state commensurate with that needed for producing the equipment planned for the NP04 ProtoDUNE prototype detector operation at the CERN Neutrino Platform in 2018. Specifically, we were asked to address 14-item Charge questions (see Appendix A), and provide recommendations on those 3 sub-systems.

The Committee met with DUNE collaborators November 9-10, 2016 at CERN. Documentation was provided in advance. The first day of the meeting was devoted to presentations by DUNE and extensive discussion, both of which proved to be very informative. The Committee spent most of the second day discussing with the collaboration members and in internal discussion, and preparing the initial version of this report, which was presented to the collaboration in a closeout session. The committee recommendations are presented in the following sections.

The Committee was very impressed by the enormous amount of work that was presented, by the enthusiasm of the ProtoDune SP team and by the wealth of accumulated knowledge. The ProtoDUNE Single Phase CPA, FC and HV designs have reached a level of maturity to being able to establish sound production and assembly plans. All the relevant information has been collected in a long Design Report. The collaboration is ready to take few remaining decisions on some components designs, move to a pre-production phase and expedite the planned installation mock up. Production Readiness Reviews (PRR) at the construction sites or at CERN are advisable in early 2017.

# 2 CPA

## 2.1 Findings

1) Advanced mechanical design is proposed thru detailed 3D models and 2D technical drawings. The CPA technical design report includes analytical and FEA calculations validated through tests and supported by past experience on similar design applications.
2) QA/QC procedure has been proposed with solid backup plans specifically defined for high risks elements.
3) There are milestones that show solid plans for the CPA design.
4) The installation procedure of the mechanical components is shown and validated thru mockup.
5) The use of a novel resistive cathode for mitigation of discharges has been developed for ProtoDune SP requirements and thoroughly tested. The resistive cathode is based on a CERN-developed, proven technology for large-size MPGD components.
6) Safety:
    a. The CPA is considered a Major Safety Implication structure according to the CERN Mechanical Safety Rule (SR-M).
    b. Some of the construction materials used are not compliant with the CERN Safety Instruction 41 (IS41)
    c. It is unclear if the cable running along the CPA panels and to the outside is compliant with the CERN Safety Instruction 23 (IS23).
    d. Even if many operational risks have been already addressed a full risk assessment has yet to be completed. Some scenarios are still under definition, such as the installation procedures, so it understandable that there are still parts missing.

2.2 Comments

1) The technical drawings such as the fabrication drawings, the ICDs were not approved.
2) Most of the mechanical interfaces are well defined where some details might need to be modified to allow parallel activities.
3) Following the CERN Mechanical Safety Rule (SR-M) this structure has to be submitted for CERN HSE validation. It is clear that the project has many challenges and that other different options have been investigated, so we believe there is enough material to justify technically a derogation, but fire mitigation measures have still to be defined in such derogation.
4) It is understandable that the full risk analysis was not yet performed, but to ensure that all risks are addressed and mitigated, the project team shall document them all and list all the mitigation measures that have been translated into requirements to the risk mitigation and safety action matrix implementation.

2.3 Recommendations

1) Make sure to get approval for the fabrication drawing and the Interface Control Documents. This issue also applies to the FC design.
2) An integration document is needed to combine assembly mechanical drawing packages specially if made with different standards. This issue also applies to the FC design.
3) Perform the installation plans addressing all the implications between the CPA design and the top level assembly. These issues also apply to the FC design.
4) Subject electrical design of FC/CPA to an internal peer review.
5) Take into account the time needed for CERN HSE validation (average 14 working days) in the planning and submit the documentation well in advance to be able to have the validation before the PRR and hence before production is launched. *(Note: As the project schedule is very challenging, do not hesitate to start discussing with the CERN HSE Unit even before having the final versions of documents.)*
6) Ask already an official derogation from CERN HSE for the materials that are not compliant with the CERN Safety Rules e.g. materials containing halogen or presenting properties that are not compliant with the IS41 and IS23. *(Note: if in doubt, do not hesitate to get already in contact with the CERN HSE Unit).*

# 3 Field Cage

3.1 Findings

1) The committee had some reservations on the electrical robustness of FC profiles and PE caps in very high field regions, but the concerns were all well addressed during the review.
2) Safety: The Field Cage is considered a Major Safety Implication structure according to the CERN Mechanical Safety Rule (SR-M). Like for the CPA, some components of the FC are made of materials that are not compliant with the CERN Safety Instruction 41 (IS41). The FC has some risks that are linked/common to the CPA due to their load connection, and also some that are specific to the FC.
3) Cold testing, 35T testing in January and its possible feedback, and test of full mockup at Ash River are in the critical path.

3.2 Comments

1) The committee very much likes the last version of the FC aluminum profiles. The question on possible Malter effect due to appearance of insulating layers does not seem a real showstopper. A test in the 50L LAr TPC is foreseen and we encourage them to consider

long-term operation and careful monitoring of relevant quantities in the setup. Special conductive coating of the profiles is also possible.

2) To avoid treating the same risk in different places, we believe that having a single/global risk assessment document addressing all identified risks, would reduce the possibility of omitting pertinent risks, specially those linked to the interfaces or co-activities.

### 3.3 Recommendations

1) Finalize the material, thickness, surface-finishing requirements of the FC profile, and use these profiles in all upcoming tests.
2) Create detailed method statements for the assembly and installation of the FC in the cryostat including all specific lifting and handling points in agreement with CERN safety policy.
3) Same Safety recommendations as for the CPA.

## 4 HV

### 4.1 Findings

1) The connection to earth of the full system was not explained. The corresponding electrical risk for people has to be addressed by the risk mitigation group/team and the global risk document.
2) The feedthrough is a critical component and so far only one company has been identified to be able to produce it.
3) The risk of loosing the connection to the control system of the power supply and the behaviour of the power supply if this happens have not been addressed.
4) The HV filtering system is well documented and under control. Concerning the grounding plane, we note that ICARUS has employed a similar design. However, the exact procedure of how uniform low impedance grounding is put in place is missing. This is true for the grounding planes and in general for the entire detector.
5) The electric fields of most of the components have been simulated and the components themselves have been quality checked in small setups. The result from the simulations show that all the local electric fields on the components are below 30 kV/cm which would allow safe operation even in the eventually of small localised boiling hot spots. Two potential exceptions have been noted however, which are the high voltage feedthrough and the beam plug.

### 4.2 Comments

1) The connection to earth and the electrical risk for people is an essential point that needs to be addressed. Again, CERN HSE shall be involved in this issue at the earliest possible date.
2) We expect that proper grounding of all components is essential for a detector that is so sensitive to electronic noise. It was not clear what requirements you have on the uniformity of the ground potential and how you plan to put in place the ground connections.
3) We understand it is technically very difficult to keep the field at the ground termination of the HVFT below 30 kV/cm. The only thing that can be done there is to make sure any HV components are kept as far as possible from this point. The beam pipe is another critical components with large implications in case of failure. It is important to keep the fields in this area if possible below the 30 kV/cm limit.

4) The Beamplug is very innovative and therefore needs careful revision as any future change of this part may impact the current design.

### 4.3 Recommendations

1) Test the behaviour of the power supply in the event of losing the communication with the control system.
2) We recommend documenting how technically you plan to put in place an adequate grounding link between the detector and the ground reference (cryostat). Some testing of the solution should be foreseen in the upcoming tests.
3) We would recommend too, as much as possible, design all components to keep the max field below 30 kV/cm since bubbling cannot be excluded on such a large system. We note that this cannot be achieved for the HVFT. A long-term test of the high voltage feedthrough at 180 kV in a dedicated setup would hence be recommended. Further FEA simulations of the beam pipe are needed as well as a test in close to realistic field conditions.
4) While the beamplug was not part of the review, we recommend a rigorous risk analysis of the current design be carried out, and proceed to review it after the results of tests in the 35T are known.

## 5 Recommendations on System Aspects

1) Create a dedicated and global risk assessment document that addresses all the risks identified by the different teams and identifies the mitigation measures (including both detector safety and safety of personnel). Transmit the requirements to the risk mitigation group (control process or body you will use) and assign a responsibility to the monitoring of such mitigation measures. A first version of this document shall be available and validated before any future PRR, and it shall be revised frequently based on the CERN REM process (Records, Experience, Monitoring).
2) Produce a safety matrix resulting of a global risk analysis and understand how these requirements will translate in instrumentation or hardware needs that may modify the current design.
3) The installation plan is well developed but some more definition of the process, and following experience from the mockup at Ash River should be fed into the method statements.
4) To expedite the installation mock up at Ash River, taking into account space considerations that will be available in the real installation scenario. This will gain valuable information for operating inside the cryostat. Particular operations for investigation would be the final sections of the assembly, and cabling, when there is least operational space within the cryostat.
5) Work out repair access scenarios during assembly at CERN as this may already impact the design of tooling/fixtures/parts needed now for part production.
6) The units of measure need to be standardized across all institutes producing design drawings.

## 6 Additional suggestions

1) Study and document the implication on detector performance and physics if you are forced to operate at lower than the nominal HV.

2) At various places the full HV of 180 kV is degraded to ground along a 20 cm long piece of insulator. All these pieces are fully embedded in liquid Ar. We suggest proving with a long-term (several month) test at full HV to validate the design. Ideally would be to test a structure where two (Rogowski) electrodes, with 180 kV potential difference, clamping in the center a 13 cm long (cylindrical) piece of G10 or other interesting materials. We strongly recommend avoiding to subject the optical fibers to this stress.

## 7 Answers to Charge questions

1. Does the CPA/FC/HV design meet the requirements? Are the requirements/justifications sufficiently complete and clear?
   Yes. The requirements for all of these systems are well founded and were clearly presented. There is a significant body of prior and new work that demonstrates that these requirements can be met.

2. Are CPA/FC/HV risks captured and is there a plan for managing and mitigating these risks?
   The actual status of the document and what was presented during the review gives confidence that the operational risks have been already addressed or are being addressed with the different tests that are planned. For what concerns general safety risks (e.g. fire, co-activity, lifting, etc.), and schedule risks (e.g. failing in getting a component, transport from EU to USA and from USA to EU), we believe they still have to be addressed in a more detailed way.

3. Does the design lead to a reasonable production schedule, including QA, transport, installation and commissioning?
   Yes. The design of the CPA/FC/HV sub-systems is well advanced and leads to a well-defined construction and assembly sequence. QA and transport need additional development. Results of tests in the 35 ton TPC at Fermilab may lead to some minor design changes that could have an impact on the assembly. They can highly probably be accommodated in the current production schedule with minor impact on the dates agreed for delivering at CERN.

4. Does the documentation of the CPA/FC/HV technical design provide sufficiently comprehensive analysis and justification for the CPA/FC/HV design adopted?
   Yes. Summaries of many tests and analyses were presented during the review. The CPA/FC/HV technical design report is a 173-page document that describes the design in considerable detail. Extensive qualification tests of FR4 and FRP have been performed. Within ~months additional documentation will be required.

5. Are all CPA/FC/HV interfaces to other detector components (APA, detector support system and beam plug) and cryostat documented, clearly identified and complete? Does the TPC integrated 3D model adequately represent the mechanical interfaces to the CPA/FC/HV and between adjacent CPA/FC?
   Yes. For both the mechanical and electrical points of views the CPA/FC/HV interfaces to other detector components and TPC integrated 3D model are mature enough to allow parallel activities if needed to meet the schedules. As presented both the CPA/FC/HV interfaces and 3D models status did not show any critical warning and concerns, but more detail is needed in some parts, in particular the interfaces. The interface between the slow controls system and detector, and its possible implication on system design has to be better defined.

6. Are the CPA/FC/HV 3D model, top level assembly drawings, detail/part drawings and the material and process specifications sufficiently complete to demonstrate that the design can be constructed and installed?
   Yes. The design of the CPA/FC/HV is advanced with design documentation and drawings in a state that can be taken forward to advance the project. Handling and installation plans are still evolving. The units of measure need to be standardized across all institutes producing design drawings.

7. Is the grounding of the FC ground planes and to the APA and shielding/filtering of the HV understood and adequate?
   Essentially yes. Concerning the HV filtering system it seems to be well documented and under control. Concerning the grounding plane, we note that ICARUS has employed a similar design. However, the exact procedure of how an uniform low impedance grounding is put in place is missing. This is true for the grounding planes and in general for the entire detector.

8. Are the design radii, surface finish, cleanliness and QC standards adequate to support operation at the design HV?
   Essentially yes. The electrical fields of most of the components have been simulated and most of the components have been quality checked in small setups. The result from the simulations show that all the local electric fields on the components are below 30 kV/cm which would allow safe operation even in the eventually of small localized boiling hot spots.
   Two potential exceptions have been noted however, which are the HVFT and the beam pipe. The HVFT exceeds this value at its ground termination. The maximal field around the beam pipe is not known at the moment since no detailed field simulations have been provided.

9. Is the HV system design comprehensive and integrated? Are appropriate safety concerns incorporated into the design? Is the HV system monitoring properly integrated in the Detector Safety System? Is appropriate HV filtering in place to effectively reduce noise on cold electronics and photon system?
   The HV system itself as presented is comprehensive and seems well designed. A detailed HV design has been introduced. Various tests on different materials, geometries and procedures give confidence, that the proto type can be successful constructed as proposed. However, some additional tests should be performed before the final production starts.
   The HV system monitoring has not been presented in detail, nor the safety requirements have been discussed in detail.
   The required HV ripple is 1mV on the sense wire. To achieve this an additional HV filter has been presented to reduce the ripple of the HV power supply of $<10^{-5}$ by another factor of 2000.

10. Is the HV feedthrough design comprehensive and integrated?
    The HV feedtrough design is not yet fully finalized.  First tests on a real sized prototype have been performed at a HV close to 290 KV and look promising.

11. Are operation conditions (loads and temperature) listed, understood and comprehensive?
    Yes, the electrical and mechanical requirements of the CPA/FC/HV meet the operation conditions. The information is listed and available, understood and comprehensive. Note, use coherent standard of measuring units.

12. Are the CPA/FC/HV engineering analyses sufficiently comprehensive for safe handling, installation and operation at the CERN Neutrino Platform? Is the installation plan for the

CPA/FC/HVs sufficiently well developed? Is the design for the installation tooling adequate for installation of the CPA/FC/HV?
Yes. The installation plan is well developed but some more definition of the process and experience from the mockup at Ash River should be fed into the method statements. The tooling for installation, namely the rail system, is defined well and will provide the structure that will enable the installation of the CPA, FC assembly. Iterations of the three areas addressed in the charge question should develop through experience.

13. Is the CPA/FC/HV quality assurance, quality control and test plan adequate? Have applicable lessons-learned from previous LArTPC devices been documented and implemented into the QA plan? Does the plan appropriately account for CPA/FC/HV production at multiple international sites with different standards (metric/imperial) for available stock materials?
Yes, the CPA/FC/HV QA and QC to validate the design are addressed for most of the aspects. Several solutions (e.g. ground planes, donut) from other experiments experience (ICARUS and MicroBooNE) are adopted, well integrated in the design, and implemented in the QA plan. There is synergy between different experiments (e.g. HV feedthrough developed by DP protoDune). The QA and QC plan for production is being prepared, but all the requirements are well understood. A solid plan must be prepared and available before the PRR at the production sites and CERN.

14. Are the teams sufficiently resourced to deliver on time?
The teams in charge of production of parts have been identified and the work share is well defined. It is assumed that the production schedule presented has been carried out taking into account the available resources. The workload foreseen for the next months is considered to be enormous, and the management should guarantee that the existing resources remain available as needed to complete the project on time.
The effort to receive and proceed with the TPC assembly at CERN has not been discussed in tis review.

# A. Review Charge

**DUNE Design Review:**
**ProtoDUNE Single Phase CPA/FC/HV**
**9–10 November 2016**

## Charge

The Committee is requested to review the DUNE cathode plane assembly (CPA), field cage (FC) and high voltage (HV) technical design and determine if it is at a state commensurate with that needed for producing the equipment planned for the NP04 ProtoDUNE prototype detector operation at the CERN Neutrino Platform in 2018.
In particular, the review team is asked to address the following questions:

1. Does the CPA/FC/HV design meet the requirements? Are the requirements/justifications sufficiently complete and clear?
2. Are CPA/FC/HV risks captured and is there a plan for managing and mitigating these risks?
3. Does the design lead to a reasonable production schedule, including QA, transport, installation and commissioning?
4. Does the documentation of the CPA/FC/HV technical design provide sufficiently comprehensive analysis and justification for the CPA/FC/HV design adopted?
5. Are all CPA/FC/HV interfaces to other detector components (APA, detector support system and beam plug) and cryostat documented, clearly identified and complete? Does the TPC integrated 3D model adequately represent the mechanical interfaces to the CPA/FC/HV and between adjacent CPA/FC?
6. Are the CPA/FC/HV 3D model, top level assembly drawings, detail/part drawings and the material and process specifications sufficiently complete to demonstrate that the design can be constructed and installed?
7. Is the grounding of the FC ground planes and to the APA and shielding/filtering of the HV understood and adequate?
8. Are the design radii, surface finish, cleanliness and QC standards adequate to support operation at the design HV?
9. Is the HV system design comprehensive and integrated? Are appropriate safety concerns incorporated into the design? Is the HV system monitoring properly integrated in the Detector Safety System? Is appropriate HV filtering in place to effectively reduce noise on cold electronics and photon system?
10. Is the HV feedthrough design comprehensive and integrated?
11. Are operation conditions (loads and temperature) listed, understood and comprehensive?
12. Are the CPA/FC/HV engineering analyses sufficiently comprehensive for safe handling, installation and operation at the CERN Neutrino Platform? Is the installation plan for the CPA/FC/HVs sufficiently well developed? Is the design for the installation tooling adequate for installation of the CPA/FC/HV?
13. Is the CPA/FC/HV quality assurance, quality control and test plan adequate? Have applicable lessons-learned from previous LArTPC devices been documented and implemented into the QA plan? Does the plan appropriately account for CPA/FC/HV production at multiple international sites with different standards (metric/imperial) for available stock materials?
14. Are the teams sufficiently resourced to deliver on time?

## B. Review Committee

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# C. Review Agenda

| TIME | Talk | Speaker |
|---|---|---|
| **Wednesday 9/11** | | |
| 8:30 – 9:00 | Review Committee Session | Reviewers |
| 9:00 – 9:30 | ProtoDune overview, CPA/FC/HV overview | F.Pietropaolo |
| 9:30 – 10:15 | Electrical Design | B.Yu |
| 10:15 – 10:30 | Coffee break | |
| 10:30 – 11:15 | CPA Mechanical Design | V.Guarino |
| 11:15 – 12:00 | FC Mechanical Design | R.Sharma |
| 12:00 – 12:45 | Lunch | |
| 12:45 - 13:30 | Interfaces | B.Yu |
| 13:30 – 14:00 | HV system | G.Horton-Smith |
| 14:00 – 14:30 | HV feedthrough design | F.Sergiampietri |
| 14:30 – 15:00 | Beamplug (information only) | T.Loew |
| 15:00 – 15:30 | Coffee | |
| 15:30 – 16:15 | Installation | D.Wenmann |
| 16:15 – 16:45 | Executive session | Reviewers |
| **Thursday 10/11** | | |
| 8:30 – 9:15 | Fabrication, Schedule | V.Guarino |
| 9:15 – 10:00 | QA/QC/Testing plans | F.Pietropaolo |
| 10:00 – 10:30 | Executive Session | Reviewers |
| 10:30 – 10:45 | Coffee | |
| 10:45 – 12:00 | Q&A | |
| 12:00 – 12:30 | Lunch | |
| 12:30 – 14:30 | Panel Writing | Reviewers |
| 14:30 – 15:00 | Close Out Session | |
| 15:00 – 16:00 | Final Report | |