



**June 14<sup>th</sup>, 2019**

**Report of the Review of DUNE-SP High  
Voltage System**

**June 4-5, 2019  
CERN**

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## 1 Introduction

The High Voltage (HV) system for the DUNE Single Phase (SP) LAr-TPC Far detector includes all parts to generate, distribute, and regulate the voltages that create a stable and precise electric field within a SP module, namely the HV power supplies, services and Feedthrough into the cryostat, Cathode plane assembly (CPA) arrays held at HV, and the Field Cage (FC).

The preliminary Design Review (PDR) of this system was held on June 2019. The Review Committee (Appendix B) was requested to review the DUNE high voltage system design and determine if it meets the requirements of the preliminary mechanical and electrical design as outlined in the DUNE Far Detector Design Review Plan (DocDB-9564) and in the forthcoming TDR. Specifically, the Committee was asked to address 11-item Charge Questions (see Appendix A), and provide recommendations on the 3 HV sub-systems: CPA, FC and HV feedthrough and interconnects. The safety aspects were not reviewed, as a parallel engineering safety review was organized.

The Committee met with DUNE collaborators on June 4-5, 2019 at CERN. The Committee thanks the team for the effort invested in the preparation of this review. Documentation was provided in advance, the first day of the meeting was devoted to presentations and extensive discussions, and the second day was mostly used to clarify further some aspects of the designs. The preliminary outcome of the review was presented to the collaboration in a closeout session. The Committee recommendations for each of the HV subsystems are presented in the following sections, followed by the Committee answers to the Review Charge questions.

The Committee was very impressed by the enormous amount of work that was presented, and the well reflected lessons learned from the single-phase LAr time projection chamber protoDUNE (NP04) construction and operation at CERN, which results in very mature designs for the Dune HV system. It is noted that ProtoDUNE is only one of the very few projects of this complexity where HV performance has reached the design value. These could not be done without the extensive experience and long track record of the personnel involved.

The source of HV instabilities observed during the beam operation of protoDune is not yet fully understood but possible causes are identified and a detailed study plan has been worked out to improve the design. It includes specific tests with the protoDune detector and a full scale mockup protoDUNE II in the near future. It is not obvious to extrapolate the one year protoDUNE experience (deadtime, efficiency, etc) to the DUNE decade span, but the Committee thinks that the team has the expertise to minimize this impact.

## 2 CPA

### 2.1 Findings

- The Dune CPA design does not present major design changes with respect to protoDune, apart from the dimensions.
- The construction of a CPA of full length has been already done. The lessons learned about logistics and installation have been documented and become the baseline.

### 2.2 Comments

- The CPA assembly plan (alignments and pinning) seems effective to control flatness and straightness.

### 2.3 Recommendations

- FRP design relies mostly on tests, being as official guidelines exit instead of standards. The collaboration needs to make sure that the change of dimensions from protoDune to Dune are well evaluated and all validations tests, with proper safety factors, are well defined and integrate all possible scenarios validations. FRP is a brittle material, so it would be important to consider all opportunities to test expansion/contraction of the different assemblies and analyze (if possible) the possible stress concentrations added by the cool down - warm-up cycle. As DUNE will run for decades it would be good to test the FRP aging process in stable cryogenic temperatures.

- The CPA design is the same as protoDune nevertheless the new assembly process and insertion in the cryostat has some relevant changes when compared with the protoDune assembly process, and some aspects are still to be defined (e.g. handling 12 m objects, movement between the assembly wall to the insertion in the cryostat). Depending on methodology used additional load cases may need to be considered in the mechanical design.

### 3 Field Cage

#### 3.1 Findings

- The TDR FC design is adequate. The design is virtually the same as protoDUNE with some simple changes which aim at further reducing the external electrical field in the critical regions between the FC profiles and the ground planes to gain additional safety margins. These changes represent an improvement from the HV point of view.

#### 3.2 Comments

- The new field cage configuration will require careful mechanical analysis, changes on the load cases considered in the past, a considerable amount of new drawings, and consequent update of all the assembly procedures.
- The FC profile caps are insulating (PE), do work well in protoDune but they charge up. A study to increase the conductivity has started and the committee encourages the collaboration to pursue this direction.
- For the reflectors PDS (plastic foil), they will charge up and distort the E-field. This again results in some solutions that need to be simulated, tested, validated in ‘quasi-real’ conditions, which demands the R&D to be completed in due time.
- The studies for the calibration laser penetrations in the top FC are ongoing. The path to decision has to be clear and timely.
- The value engineering presented might have a very positive impact on the improvement of the HV system and possibly eliminate the streamers. It is recommended to proceed with the planned R&D and complete the detailed value engineering.

#### 3.3 Recommendations

- The Committee encourages to continue the FC design optimization and thoroughly test the final design in protoDune II. A new set of drawings and stress/FEA analysis of the new FC design has to be done at same level of detail done for protoDune and be available well in advance the FDR.
- Scratches on the FC profiles are an issue as they damage the coating. Repair strategies have been successfully applied in protoDune (epoxy or unit replacement); a clear pass/no pass criteria for damages, and at which steps are controlled and repaired shall be defined. It is advised to define some protection for the regions exposed during assembly.
- Consider if the system of alignment and pinning developed for the CPAs can be applied to the FC. The current method of straightening seems difficult and time consuming.
- There was some lack of detail defining the many washers being used. Design/selection/applied torque should be added to the manufacturing specs.

### 4 HV feedthrough & Interconnects

#### 4.1 Findings

- The design of the HV feedthrough for DUNE-SP is based on the one used for protoDUNE-SP.
- Based on the protoDune experience, the Dune Power Supply will be tested and tuned well in advance.
- HV ripple noise filters shown problems but this is well understood now and discarded for Dune. The collaboration is working on developing custom-designed dry filters. Prototypes have been successfully tested and are being optimized for the resistance value.

#### 4.2 Comments

- The HV feedthrough length will be increased to augment the distance between the insertion flange of the cable male plug and the vacuum flange, to keep the male plug at higher temperature and avoid any condensation around it. This is a nice change of the design as the feedthrough, if needed be, can be removed without the icing issues. The design should be completed and validated.

#### 4.3 Recommendations

- The HV Feedthrough receptacle is made from a stainless steel donut with a flat bottom plate. The load on the donut is to be well understood. A key issue is to make sure that contact is guaranteed. It is recommended to expand the 2 cm spring load.
- The committee urges the collaboration to review the proposed replacement of wire ring terminals by forks.
- Review redundancy needs of all interconnections and for critical contacts, multiple redundant connections should be implemented.
- Produce a specific document listing all the requirements for the HV Feedthrough with all the design changes that have been presented and the validation/test strategy.
- Produce a document with the needs for instrumentation for the high voltage system, taking into account the needs defined and agreed with other consortia.

### 5 **Recommendations on System Aspects**

#### QA/QC

- The QA/QC validation process should be included in the QA/QC strategy. For the FDR, the QA/QC of all assembly levels should be clearly specified.
- Documentation is spread over mostly on DocDB and not much on the EDMS SP folders. A dedicated EDMS folder should host all QC/QA related procedures, pass/fail requirements definitions, checklists, etc.
- The information collected during the QA/QC process shall be used to debug issues like the ones observed in protoDune.
- The protoDune lifetime is not same as Dune (decades). This should taken into account in the qualification of the design (example: resistive layers lifetime, coatings...)

#### Design

- The foreseen cryostat feedthroughs should be reviewed to optimize their use to maximize monitoring capabilities an considering adding feedthrough ports that are parasitic with existing penetrations. Making connections to measure HV on the ground plane can be done easily.
- The redundancy of all connections should be reconsidered.
- The function (electrical/mechanical/grounding...) and design details of all the important connections between items, on boards, etc. should be clearly specified.

#### Tests

- The committee stresses the importance of having final prototypes of all detector components for the second run of ProtoDUNE, and at the same time pursuing the integration tests at Ash River.
- Any design change shall be tested on protoDune II. Thus, a good plan and well defined scope of protoDune II should be made early enough to guarantee that it will validate all design changes. The evaluation of implementing additional diagnostics is recommended.
- The protoDune opening procedure should be well developed to make sure all possibly related parts suspected to cause/be involved in the streamers issue are collected and inspected properly.

#### Schedule and resources

- The schedule has been built under the assumption that the detector components need to be delivered in South Dakota a few weeks ahead of installation, without any buffer at the production sites. This assumption should be revisited, in coordination with the DUNE and LBNF management. The schedule should be designed with the goal of having a significant float for the availability of the detector

components prior to installation. The goal is to ensure that any issues that could arise during the production do not result in a delay of the detector installation.

- The HV consortium should inform LBNF of their storage needs in South Dakota, under the assumption that a significant fraction of the detector components (>50%) are delivered there prior to the beginning of the detector installation. If needed the use of temporary storage in one of the national laboratories in the US should be considered.
- The consortium appears to have the resources and the expertise required to investigate further design changes in the detector over the next 12-18 months and build new prototypes to be used for the second run of ProtoDUNE. The dates for the 2<sup>nd</sup> run of ProtoDUNE have been set arbitrarily and if the HV consortium needs more time to complete the design and construction, they should inform the DUNE management and Technical Coordination.
- A significant ramp-up of personnel is needed at the beginning of the production phase, and the consortium did not discuss whether the corresponding resources have already been identified. Distributing the procurements and the production over a longer time period could help in this respect. More detailed plans should be presented at the Final Design Review.
- It is also noted that efforts are being made to expand the consortium with new EU participants.

#### Other

- The committee stresses the importance of keeping a lessons learned document and fault tracking system to continuously document all issues encountered, given the long lifetime of this project.

## **6 Answers to Charge questions**

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

Yes. The requirements for the DUNE HV system are clear, complete and documented, and have been cleverly translated into a sound design. The design relies mostly on protoDune and incorporates the lessons learned during the construction and operation of the prototype.

A small number but challenging design optimizations and few options are being explored. The most important is the revised Field Cage Design, aiming at improving the HV stability to solve the instability issues encountered in NP04, which indicate a connection with charging up of insulator surfaces outside the field cage. The impact of the proposed design changes on any other systems/interfaces were well explained. The committee endorses the baseline design, as presented.

The protoDune II effort will be key for the validation of the proposed changes, thus a full understanding and decisions on all options presented at the review should be taken in Spring 2020 at the latest.

### **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?**

A large number of specifications and drawings were made available for review; the transition from DUNE db to EDMS is not yet fully completed, explaining probably the missing drawings in EDMS.

The cross references between drawings should be carefully checked, as some weaknesses were detected. This aspect is extremely important considering the amount of design changes foreseen with respect to protoDune. There is confidence that all drawings and specifications will be available for the Final Design Review.

A 3-step control process has been defined. We encourage the team to also apply the 3-step control approach to QA/QC documents and define the criteria/charge/responsibility for each control step.

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

Yes. All required interfaces have been identified and documented. A detailed detector/cryostat integration drawing specifies critical dimensions to the facility. A detailed drawing with key dimensions for the APA/CPA/FC/EW assembly provides dimensions relative to the design parameters from physics. More work and collaboration between HV and APA is needed to complete the APA and HV interface. Interface drawings for PD and CE are needed.

The system is tolerant of changes in other systems that result in “local” changes to the interface, but time is limited to make such changes. The system is not so tolerant of changes on larger scales such as changing the pitch between detector elements. Their level of flexibility is very reasonable for a preliminary design review.

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

The Committee did not find evidence that the design is unsafe, but this aspect was not reviewed in detail given that a parallel engineering safety review was organized.

It was explained that there is a good communication established between the Engineering Safety Committee and the design team and that the different load cases and their validation are defined by the Engineering Safety Committee.

As a recommendation we would suggest to keep the test documents separated from the calculations document and use it as reference because performing tests will be carried out for long time, while the calculations should be validated before the FDR.

### **5. Are system grounding details documented and in EDMS? Are electrical connections specified and do schematics exists in EDMS? Are all wires, cables and connections documented?**



Yes. The committee commends the HV consortium for storing all the drawings in EDMS. These include documentation of all the grounding connections, of the connections between different detector components, as well as schematics for all the printed circuit boards. In some cases part of the information is not available directly from the drawings in EDMS, and is instead available in the engineering note that documents the design and the construction and testing procedures. Further checks on the documentation will take place during the electrical safety review.

**6. Is the design in accordance with possible procurement strategy scenari?**

At the PDR, the procurement plan was not reviewed in detail, but the current plan relies on the same suppliers used for protoDune, complemented with the active search of alternative suppliers. It would be advisable to define early enough the procurement strategy (centralized vs distributed) and document the reception/acceptance procedures.

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

The successful operation of protoDUNE demonstrates that the QA/QC level of work and detailed knowledge are definitely advanced enough. However it is noted that the QA/QC documentation may not be in the perfect form or well organized in a dedicated EDMS location.

The testing plans ahead are well defined. On one hand they target the understanding of the HV instabilities detected during protoDune operation. The team should proceed with the correctly identified R&D plan to eliminate the streamers. The final design should be proceeded with lab R&D tests back up so the full scale mock up can be tested in the ProtoDUNE II run. Secondly, a very complete DUNE-HV Trial Assembly at Ash River has been planned and consists of a full scale mockup to test all engineering steps, draft documentation, validate safety aspects, test of access equipment, labour estimates, etc.

**8. Have lessons learned from ProtoDUNE been implemented?**

Yes. ProtoDUNE-SP demonstrated that the high voltage system concept works well and its requirements are met. The construction of protoDune showed that consortium and distributed procurement, manufacturing, logistics, assembly strategies work well and lessons learned are well recorded for future incorporation and listed in the risk registry.

The lessons learned from building and operating ProtoDUNE are implemented on all the levels, from the design, construction and installation to the operation. The HV consortium implemented improvements, often only details, on most of their subsystems that will smoothen the assembly and operation of the detector. There are still open questions that are urged to be answered, for instance, the exact cause of the streamers observed at protoDUNE during the past months. The presented design copes with this unknowns in conservative fashion, trying to minimise all the dielectric surfaces in the high field regions, that are believed to be the sources of instabilities in protoDUNE. In addition, these lessons learned suggested for further developments that, if successful, would make the DUNE-SP HV system simpler to assemble and more robust.

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

Yes. There are a couple of minor changes being considered to accommodate other consortia. If adopted they will be implemented in protoDUNE II. Assembly and installation tests planned for Ash River also allow enough time to make minor changes for protoDUNE. Changes being considered for the supporting the FC and Ground Planes have potential technical and cost advantages, but require a timely completion of study and design. The design portion must include the completion of the corresponding revisions to the structural analysis.

**10. Are plans for the next post TDR design being sufficiently justified and presented?**

Yes.



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

Yes. The schedule and cost estimate are informed by the construction, testing, and commissioning of the corresponding detector elements in protoDUNE.

The schedule has been built under the assumption that the detector components need to be delivered in South Dakota a few weeks ahead of installation, without any buffer at the production sites. This assumption should be revisited, in coordination with the DUNE and LBNF management, and the schedule should be designed with the goal of having a significant float for the availability of the detector components prior to installation. The goal is to ensure that any issues that could arise during the production do not result in a delay of the detector installation. The HV consortium should inform LBNF of their storage needs in South Dakota, under the assumption that the a significant fraction of the detector components (>50%) are delivered there prior to the beginning of the detector installation. If needed the use of temporary storage in one of the national laboratories in the US should be considered.

The consortium appears to have the resources and the expertise required to investigate further design changes in the detector over the next 12-18 months and build new prototypes to be used for the second run of ProtoDUNE. The dates for the 2<sup>nd</sup> run of ProtoDUNE have been set arbitrarily and if the HV consortium needs more time to complete the design and construction, they should inform the DUNE management and Technical Coordination. The committee stresses the importance of having final prototypes of all detector components for the second run of ProtoDUNE, and at the same time pursuing the integration tests at Ash River.

A significant ramp-up of personnel is needed at the beginning of the production phase, and the consortium did not discuss whether the corresponding resources have already been identified. Distributing the procurements and the production over a longer time period could help in this respect. More detailed plans should be presented at the Final Design Review. It is also noted that the consortium will likely expand to include new EU participants.

## **A. Review Charge**

DUNE Preliminary Design Review (60% Design Review)  
Single Phase Detector High Voltage 4–5 June 2019

### **Charge**

The committee is requested to review the DUNE high voltage system design and determine if it meets the requirements of the preliminary mechanical and electrical design as outlined in the DUNE Far Detector Design Review Plan (DocDB-9564) and in the forthcoming TDR.

Specifically:

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? Which applicable design codes and standards have been used?
5. Are system grounding details documented and in EDMS? Are electrical connections specified and do schematics exist in EDMS? Are all wires, cables and connections documented?
6. Is the design in accordance with procurement strategy scenario?
7. Are quality assurance and testing plans sufficiently developed to proceed to final design?
8. Have lessons learned from ProtoDUNE been implemented?
9. Are plans for additional prototyping reasonable and sufficient?
10. Are plans for the next post TDR design being sufficiently justified and presented?
11. Have appropriate cost estimates and schedule been determined? Are plans for required technical 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 June 5. The committee should provide a final written report by June 14.

## B. Review Committee

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## C. Review Agenda

CERN: <https://indico.cern.ch/event/813154/>

Mirror at FNAL: <https://indico.fnal.gov/event/20450/>

Tuesday, 4 June 2019		
08:00	Executive Session	Steve Herbert Kettell (Brookhaven National Laboratory (US))
08:30	System Overview and Requirements	Francesco Pietropaolo (CERN)
09:10	ProtoDUNE: Lessons Learned	Serhan Tufanli (Yale University (US))
10:00 Coffee break		
10:15	Electrical Design and Interfaces	Bo Yu (Brookhaven National Laboratory (US))
11:00	Mechanical Design, Interfaces, and Installation	Victor Guarino (High Energy Physics Division)
12:00	HV Feedthrough Design	Franco Sergiampietri (IFSI-INAF Istituto di Fisica dello Spazio Interplanetario (IT))
12:30 Lunch		
13:30	HV interconnects	Glenn Horton-Smith (Kansas State University)
14:00	Fabrication Plan and Schedule	Stephen Robert Magill (Argonne National Laboratory (US))
14:30	QA/QC	Stephen Robert Magill (Argonne National Laboratory (US))
15:15 Coffee break		
15:30	R&D, Value engineering	Bo Yu (Brookhaven National Laboratory (US))
16:15	Ash River tests	William Miller Jr (U. Minnesota)
16:30	Executive Session	Committee
17:15	Homework questions	Mar Capeans (CERN)
Wednesday, 5 June 2019		
09:00	Answers to questions	Francesco Pietropaolo (CERN), Bo Yu (Brookhaven National Laboratory (US))
10:00	Executive Session: report writing	Committee
12:00	Closeout	Mar Capeans (CERN)