DEEP UNDERGROUND NEUTRINO EXPERIMENT

**May 5, 2017**

# Report of the Design Review of

# ProtoDUNE Double Phase

**24–25 April 2017**

**CERN, Geneva, Switzerland**

## 1.0 Introduction

The committee appreciated the impressive amount of work done by the ProtoDUNE-DP team in preparation for this Review. The Team has nearly completed the final design of all TPC and PDS components. Procurement of the most urgent parts has already started and vendors have been properly identified.

The Technical Design is well advanced and the Committee supports proceeding toward construction. It suggests retaining flexibility in the production scheme to take advantage of the information that may come from the operation of the 3x1x1 $m^3$ prototype. The Committee is aware that the delay accumulated in the cryostat operation of the 3x1x1 $m^3$ prototype introduces an additional risk in the construction of the ProtoDUNE-DP detector. It hence encourages the Collaboration to develop a strategy in order to retrieve as much information as possible from the 3x1x1 $m^3$ prototype.

The Committee recommends that the team advances the discussions with CERN rapidly so that the design can be verified to meet CERN safety standards (see Sec.5), receive the safety agreement for the ProtoDUNE detectors and the authorization to deliver and install them at CERN.

For most items, Q/A and Q/C procedures have been identified and presented, and are considered appropriate for the construction phase of the detector. Similarly, the installation scheme has been presented in some detail and is considered appropriate, pending the above-mentioned Safety Review. We also suggest to prepare a summary list of the project requirements and how well the CRP, FEE and DAQ meet them, both for internal use and for future reviews

Some potentially critical items, especially on grounding, cleanliness standards, availability of full documentation to DUNE and pre-installation tests of parts were identified. The corresponding recommendations are detailed below.

## 2. CRP, electronics, DAQ

### 2.1 Findings

- The Executive designs were completed in Nov. 2016 and the completion of the detector installation, initially expected in Dec 2017, has now been updated to April 2018.
- The 3x1x1 $m^3$ prototype has already established the QA/QC for LEM production and other components: CRP cryogenic testing, installation, slow control, etc. However, new cold spots on the 3x1x1 $m^3$ cryostat appeared in April and the prototype has not operated with LAr yet (April 2017).
- The ICARUS cleanroom in bld. 185 is now available for ProtoDUNE-DP and installation tests of the CRP are commencing.
- The Front-End electronics working at 110 K at the bottom of signal chimneys is fully accessible even when the detector is cold.
- The production of the first CRP has started in April. The CRP frame construction in building 185 will start in June (expected rate: 1 CRP/month).
- LEM QA/QC is performed measuring the breakdown voltage and sparking rate in dry air and argon; some units are calibrated with an alpha source for gain.
- Brazing of the extraction grid wires is done to a metalized layer on fiberglass. The treatment of the wires (e.g. passivation) and cleaning procedures need to be developed. A detailed layout of the uTCA crates on top of the cryostat was shown. The DAQ system is dimensioned for the expected rates and data sizes at ProtoDUNE-DP and it is scalable to DUNE.
- The purchasing of commercial components for the final installation (storage, computers, and network) is well underway.

### 2.2 Comments

- The Collaboration will not wait for the 3x1x1 $m^3$ data to start production because this is incompatible with data taking in Long Shutdown 2 (LS2). They will start the CRP production for the 6x6x6 $m^3$ detector in April.
- Cold gas tests in the 3x1x1 $m^3$ to test LEM stability are of limited value as we do not expect enough ionization density from gas and the temperature profile is not the same as for standard runs.
- The Collaboration has started discussion with CERN on Safety but the formal process has not yet started.
- The installation team is considering protections for the CRP during the installation process, but these were not presented for review.
- Full cleanliness assessment (requirements, validation, etc.) are not defined, although it is not clear to what extent they are critical for ProtoDUNE-DP.
- The extraction wire tensioning system has not been fully validated. This is a critical issue since a single point failure may affect the entire detector.
- No emphasis was given in the presentations on the DAQ software and on quantitative tests on data taking stability and achieved performance.

### 2.3 Recommendations

1. Consider if alpha source testing could be done during acceptance testing of every LEM module so that operating and maximum allowable voltages can be determined accurately before installation.
2. A cleanliness program should be defined and it should be verified that the proposed assembly sequence meets its requirements - many particulates produced during installation will end up being captured at the liquid surface by the extraction grid combs.
3. Consider protecting the CRPs with a removable film after their installation.
4. Develop a tension verification system for the extraction grid wires to ensure that these are as designed and to avoid wires breaking with cooling as this would jeopardize the operation of the whole experiment.
5. Test the long-term creep of the brazed extraction grid wires and consider a secondary solder point to prevent detachment.

## 3. Photon Detection System, Slow Control

### 3.1 Findings

- The photon detection system is based on Hamamatsu 8’’ photosensors already successfully used in LAr
- The base employs positive HV with PMT signals read-out after a splitter. This system has been proved (at room temperature) by Double Chooz and was tested before TPB coating at room and liquid nitrogen temperature by ProtoDUNE-DP.
- Two options (laser-based and led-based) for the light monitoring and calibration are still open and tests are ongoing.
- The PMT readout is based on an ASIC+FPGA card served by a commercial mezzanine optimized for FPGA-based carrier board that is in prototyping phase.
- The Slow Control component sensors and actuators have been designed. The home-made LEM HV distribution system employed in the 3x1x1 prototype is now the baseline solution. A commercial based backup solution is under investigation, too.
- The Q/A and installation of the PMT and Slow Control has been defined and is mostly driven by the schedule of the TPC installation.

### 3.2 Comments

- The lateral forces due to LAr convection in the filling and running phase are not fully understood and calculated. So, gluing of the PMT support on the membrane is mandatory and it is the baseline option for the Collaboration.
- The PMT signal readout system is complex and requires prototyping and development but it is scalable to DUNE.  The first integration of the system with the DAQ will be tested not before January 2018.
- No direct tests of TPB thickness or quantum efficiency are foreseen after coating.
- Direct tests of the level meter, the adjustment system and other slow components will be available after the operation of the 3x1x1 detector

### 3.3 Recommendations

1. The specifications for the maximum weights and torque of the cable tray have to be calculated to properly dimension the PMT and Slow Control cabling
2. The possibility to perform thickness tests after the TPB coating employing ICARUS facilities at Padova should be investigated.
3. Finalize the design of the PMT attachment based on the cryogenic glue.

## 4. HV, Field Cage, Cathode

### 4.1 Finding

- The NP02 HV feedthrough has been tested in liquid argon up to 300kV in 0.1ppm O2 purity level.
- A voltage degrader column is designed to be attached to the bottom of the HV feedthrough to minimize the voltage differential between the degrader column and the field cage. The degrader has a set of conductor rings electrically connected to the corresponding field cage profiles. In doing so, however, it creates many very localized higher field regions near the degrader.
- The field cage electrode design is very similar to that of the NP04, i.e. extruded Al profiles supported by FRP I-beams. All profiles at the same height are both mechanically and electrically interconnected using aluminum clips.
- Two strings of resistive divider boards provide the voltage distribution to all the field cage profiles. On each divider board, 2 resistors and 4 serially connected varistors are used between taps.
- Most of the construction drawings for the field cage are provided to the reviewers.
- A cathode frame design with a combination of round and rectangular tubes were presented. However, during discussion, it was mentioned that a different design will be built instead.
- All electrostatic analyses presented at the review are with 300kV cathode voltage.

### 4.2 Comments

- Each field cage module ties two sets of components: aluminum profiles and FRP horizontal beams to two vertical FRP I-beams. The CTE of these two materials differ by a factor of two. It is worthwhile to understand the stress on the structure in LAr due to the differential CTE.
- The drawing of the clip connecting two FC profiles was shown. The design details such as the edge rounding radius and the gap between the clip and the profile must be validated through 3D FEA to ensure the E field at the clip edges are under control.
- The UTA group should verify that the through hole (solder bump) locations on the resistive divider boards are not shorting out or come close to the Al profile when mounted.
- The beam plug transfers a sizeable transverse load to the cryostat membrane. Obtain approval from CERN/GTT ASAP for the beam plug support structure to avoid last minute surprises.
- Venting holes on the cathode and ground grid structures are not shown in the current 3D model. Their locations and edge rounding details need to be verified to satisfy the E field limit.
- It will be important to obtain safety approval and use appropriate PPEs during sanding of the

FRP parts.

**4.3 Recommendations**

1. Establish a consistent electric field threshold to all subsystems
2. Perform a detailed 3D FEA of the E field near the bottom of the HVFT degrader and its interconnect to the cathode frame.
3. Increase the radius of curvature on the rectangular tube on the cathode frame
4. Provide more data to demonstrate the utility of the degrader rings
5. Ensure a safe /redundant termination to ground of the field-cage circuit.

**5. Safety and compliance with EU standards**

Documentation for all structural components relevant for safety and compliance with EU standards will be required for the acceptance of the TPC by the CERN safety authorities: the EP safety Office and the HSE (Health, Safety and Environment) Unit. These two units will work in close collaboration with the Neutrino Platform and with the ProtoDUNE-DP Collaboration to perform the various safety assessments of the TPC inside the cryostat and will provide the authorization of delivery of the equipment at CERN, the authorization of installation and finally the final Safety Clearance required for the equipment operation.

## 6. Answer to Charge Questions

1. Does the TPC design meet the requirements for ProtoDUNE-DP? Are the requirements/justifications sufficiently complete and clear?
**Yes. The requirements of the ProtoDUNE-DP TPC have been recently stated in DUNE DocDB-2765. Although they have not been discussed explicitly in the review presentations, the design presented is likely to meet the objective requirements.**

2. Does the documentation of the technical design provide sufficiently comprehensive analysis and justification for the design adopted and a good pathway to DUNE?
**Partly. The mechanical design seems complete although the full documentation was not examined for the review. Some aspects of the electrical design have been thoroughly addressed but parts of the design are not yet complete. The CRP, electronics, architecture of DAQ, field cage and HV feedthrough are a good pathway to DUNE. The cathode will need reconsideration.**

3. Are the TPC risks for ProtoDUNE-DP captured and is there a plan for managing and mitigating these risks?
**There is no formal process for managing/mitigating risks although the Collaboration is considering risks and mitigation strategies. A static list has been shown at the committee request. There was no presentation on this topic.**

4. Does the ProtoDUNE-DP design lead to a reasonable production schedule, including QA/QC, transport, installation and commissioning that will enable operation before LS2?

**Yes. The production schedule seems well planned and sensible QA/QC plans have been presented. The installation plan is well developed. The safety approval will have to be planned in a timely fashion.**

5. Are the drawings sufficiently complete to initiate production? Are potential vendors identified? Is the installation plan sufficiently far advanced to assure that the detector can be installed as designed? Is the design for the installation tooling adequate?
**Yes. The procurement and production plans are sufficiently far advanced to assure that the detector can be installed as designed. The installation tools seem adequate. However, compliance of the components with EU and CERN safety standards and the access plans during installation in the cryostat has to be reviewed with CERN (see Sec. 5).**

6. Are all internal interfaces between detector components (CRP, Drift Cage, Cathode, HV, photon system, slow control, frontend electronics, DAQ, trigger and online farm) and cryostat documented, clearly identified and complete?
**Partly. Most of the interfaces between detector components are understood. The interfaces between detector and cryostat, including the cable trays in the corners, beam plug, closure of the TCO, possible attachments to the bottom membrane and grounding, need to be clarified, agreed upon and documented.**

7. Is the TPC 3D model, top level assembly drawings, detail/part drawings and the material and process specifications documented and sufficiently complete to demonstrate that the design can be constructed and installed?
**We cannot answer this question directly. Most top level assembly drawings, detail/part drawings and the material and process specifications were not part of the documentation. The presentations indicate that an adequate level of detail has been achieved.**

8. Is the grounding and shielding of the TPC understood and adequate?
**Partly. The general scheme has been presented and the AC distribution and detector "isolated" ground will follow ProtoDUNE as documented in DUNE DocDB-879. A more detailed document on electrical connection has been presented at the committee request, which shows that the most relevant grounding issues are being addressed.**

9. Is the HV system design comprehensive? Are appropriate safety concerns incorporated into the design? Are the design radii, surface finish, cleanliness and QC standards of the components adequate to support operation at the design HV?
**Partly. The top level design of the HV has been presented. As mentioned, important details on HV distribution, some of which have safety aspects, have not been finalized. It would be beneficial to describe the cleanliness program and surface cleanliness requirements.**

10. Are operation conditions (loads, movement and temperature) listed, understood and comprehensive?
**The experiment understands what will be needed for getting operation clearance at CERN. The experiment will benefit from producing as complete a list of operations as possible and submitting it in a timely way to the relevant CERN authorities.**

11. Is the TPC quality assurance, quality control and test plan adequate? Have applicable lessons-learned from previous LArTPC devices been documented and implemented into the QA plan?

**The plans presented are adequate and reflect prior experience. It is unfortunate that the information from the 3x1x1 prototype, particularly the performance of the LEMs, is not available. This represents a clear risk and the collaboration needs to develop and present a strategy to deal with this situation.**

## A. Charge

## Design Review:
## ProtoDUNE Dual Phase Review
## 24–25 April 2017

**Charge**
The Committee is requested to review the ProtoDUNE-DP Time Projection Chamber technical design, including the CRP, drift cage, cathode, high voltage, frontend electronics, photon system, DAQ and slow control and determine if it is at a satisfactory level for NP02 ProtoDUNE-DP operation at the CERN Neutrino Platform in 2018.

In particular, the review team is asked to address the following questions:
1. Does the TPC design meet the requirements for ProtoDUNE-DP? Are the requirements/justifications sufficiently complete and clear?
2. Does the documentation of the technical design provide sufficiently comprehensive analysis and justification for the design adopted and a good pathway to DUNE?
3. Are the TPC risks for ProtoDUNE-DP captured and are there a plan for managing and mitigating these risks?
4. Does the ProtoDUNE-DP design lead to a reasonable production schedule, including QA/QC, transport, installation and commissioning that will enable operation before LS2?
5. Are the drawings sufficiently complete to initiate production? Are potential vendors identified? Is the installation plan sufficiently far advanced to assure that the detector can be installed as designed? Is the design for the installation tooling adequate?
6. Are all internal interfaces between detector components (CRP, Drift Cage, Cathode, HV, photon system, slow control, frontend electronics, DAQ, trigger and online farm) and cryostat documented, clearly identified and complete?
7. Is the TPC 3D model, top level assembly drawings, detail/part drawings and the material and process specifications documented and sufficiently complete to demonstrate that the design can be constructed and installed?
8. Is the grounding and shielding of the TPC understood and adequate?
9. Is the HV system design comprehensive? Are appropriate safety concerns incorporated into the design? Are the design radii, surface finish, cleanliness and QC standards of the components adequate to support operation at the design HV?
10. Are operation conditions (loads, movement and temperature) listed, understood and comprehensive?
11. Is the TPC quality assurance, quality control and test plan adequate? Have applicable lessons-learned from previous LArTPC devices been documented and implemented into the QA plan?

The committee should present its findings, comments, and recommendations in a closeout meeting with DUNE management on April 25. The committee should provide a final written report by May 5.

# B. Review Committee

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# C. Review Agenda

Design Review of the Dual Phase ProtoDUNE / Programme Monday 24 April 2017

## Design Review of the Dual Phase ProtoDUNE

## Monday 24 April 2017

Review Committee Executive Session (08:30-09:00)

ProtoDUNE dual-phase overview (09:00-10:00)

- Presenter: AUTIERO, Dario (Universite Claude Bernard-Lyon I (FR))

Coffee Break (10:00-10:30)

Performance of the 3x1x1 detector (10:30-11:30)

- Presenter: MURPHY, Sebastien (Eidgenoessische Technische Hochschule Zuerich (CH))

Installation overview (11:30-12:30)

- Presenters: GENDOTTI, Adamo (Eidgenoessische Tech. Hochschule Zuerich (CH)); DUCHESNEAU, Dominique (Centre National de la Recherche Scientifique (FR))

Lunch (on your own) (12:30-13:30)

Parallel session A (CRP, Electronics, DAQ): Design (13:30-15:05)

| time | [id] title | presenter |
|---|---|---|
| 13:30 | [11] LEM-Anode sandwiches design (20 minutes) | MURPHY, Sebastien (Eidgenoessische Technische Hochschule Zuerich (CH)) |
| 13:50 | [12] CRP design (35 minutes) | AIMARD, Benjamin (Centre National de la Recherche Scientifique (FR)) |
| 14:25 | [13] Charge readout FE electronics design (10 minutes) | AUTIERO, Dario (Universite Claude Bernard-Lyon I (FR)) |
| 14:35 | [14] Digital FE, DAQ and Online Processing (25 minutes) | AUTIERO, Dario (Universite Claude Bernard-Lyon I (FR)) |

Parallel session B (Light readout, Slow Control): Design (13:30-15:00)

| time | [id] title | presenter |
|---|---|---|
| 13:30 | [18] PMTs and calibration system design (30 minutes) | LUX, Thorsten (Universidad Autonoma de Barcelona) |
| 14:00 | [19] Light readout electronics design (20 minutes) | PATZAK, Thomas (Universite de Paris VII (FR)) |
| 14:20 | [20] Slow Control system design (30 minutes) | CANTINI, Cosimo (Eidgenoessische Technische Hochschule Zuerich (CH)) |

Coffee Break (15:00-15:30)

Parallel session A (CRP, Electronics, DAQ): Production, QA (15:30-17:00)

| time | [id] title | presenter |
|---|---|---|
| 15:30 | [15] Quality assurance of LEM-Anode sandwiches at Saclay (15 minutes) | ZITO, Marco (CEA/IRFU,Centre d'etude de Saclay Gif-sur-Yvette (FR)) |
| 15:45 | [16] CRP Production, QA (50 minutes) | AIMARD, Benjamin (Centre National de la Recherche Scientifique (FR)) |
| 16:35 | [17] Charge readout and DAQ Production and QA (25 minutes) | AUTIERO, Dario (Universite Claude Bernard-Lyon I (FR)) |

Parallel session B (Light readout, Slow Control): Production, QA (15:30-17:00)

| time | [id] title | presenter |
|---|---|---|
| 15:30 | [21] PMT system production, QA and installation (30 minutes) | VERDUGO DE OSA, Antonio (Centro de Investigaciones Energ. Medioambientales y Tecn. - (ES)) |
| 16:00 | [22] LRO electronics Production and QA (20 minutes) | PATZAK, Thomas (Universite de Paris VII (FR)) |
| 16:20 | [23] Slow control system: production, QA, installation (30 minutes) | RIGAUT, Yann-Axel Franck (Eidgenoessische Technische Hochschule Zuerich (CH)) |

Parallel session B (Light readout, Slow Control): Discussion, Questions (17:00-18:00)

Discussion, Questions: Parallel session A (CRP, Electronics, DAQ) (17:00-18:00)

# Tuesday 25 April 2017

**Cathode, Drift Cage, High Voltage: Design** (08:30-10:30)

| time | [id] title | presenter |
|---|---|---|
| 08:30 | [24] Chimneys design (15 minutes) | GENDOTTI, Adamo (Eidgenoessische Tech. Hochschule Zuerich (CH)) SERGIAMPIETRI, Franco (Eidgenoessische Technische Hochschule Zuerich (CH)) |
| 08:45 | [25] Drift cage design (30 minutes) | GENDOTTI, Adamo (Eidgenoessische Tech. Hochschule Zuerich (CH)) PIETROPAOLO, Francesco (Universita e INFN, Padova (IT)) |
| 09:15 | [26] Design of field cage electrical elements (20 minutes) | CHATTERJEE, Animesh (University of Texas Arlington) |
| 09:35 | [27] Cathode design (25 minutes) | GENDOTTI, Adamo (Eidgenoessische Tech. Hochschule Zuerich (CH)) |
| 10:00 | [28] HV system design (30 minutes) | SERGIAMPIETRI, Franco (Eidgenoessische Technische Hochschule Zuerich (CH)) MOLINA BUENO, Laura (Eidgenoessische Technische Hochschule Zuerich (CH)) |

**Coffee Break** (10:30-11:00)

**Cathode, Drift Cage, High Voltage: Production, QA** (11:00-13:40)

| time | [id] title | presenter |
|---|---|---|
| 11:00 | [29] Chimneys production and QA (10 minutes) | GENDOTTI, Adamo (Eidgenoessische Tech. Hochschule Zuerich (CH)) SERGIAMPIETRI, Franco (Eidgenoessische Technische Hochschule Zuerich (CH)) |
| 11:10 | [30] Drift cage production, QA and installation (30 minutes) | PIETROPAOLO, Francesco (Universita e INFN, Padova (IT)) YU, Jae (University of Texas at Arlington (US)) |
| 11:40 | [31] Drift cage electrical elements production and QA (10 minutes) | CHATTERJEE, Animesh (University of Texas Arlington) |