ProtoDUNE-SP Beam Line Instrumentation Review: Questions, Answers and Recommendations

The ProtoDUNE-SP Beam Line Instrumentation Review was convened at CERN, on April 27th, 2017. The members of the committee were Robert Carey (Boston University, Chair), Ilias Efthymiopolous (CERN), Konrad Elsener (CERN), Jack Fowler (Duke), Cheng-Ju Stephen Lin (Lawrence Berkeley Laboratory) and Theresa Shaw (Fermilab). The ProtoDUNE collaboration was represented by Dr. Paola Sala of INFN (Milano) and Dr. Jonathan Paley (FNAL). The goal of the review was to determine if the design of the beam line for ProtoDUNE-SP was adequate for its physics goals and whether progress was being made toward its successful operation in 2018. A complete copy of the charge is included in an appendix at the end of this document. Questions from the charge are interleaved below as part of the committee's report.

Answers to the Questions in the Charge

1. Does the Beam Instrumentation design meet the requirements? Are the requirements sufficiently complete and clear?

In principle, yes. But the connection between the requirements and the physics goals is sometimes murky. Regarding the beam line, the physics goals for this first run in NP04 are not fully defined. While the stated requirements for the instrumentation, in terms of particle ID capability or momentum resolution, are not extraordinary, the actual priorities aren't clear. This makes difficult the task of defining a commissioning plan, and, in turn creates risks for the schedule.

The individual elements of the instrumentation are at various stages of development. We address them each in turn.

The Prototype Large Area Picosecond Photodetectors (pLAPPDs) form an important part of the proposed particle ID system, particularly at higher momenta where O(ns) resolution is inadequate to separate out the various particles. Without the pLAPPDs, particle ID is problematic in some important momentum ranges. The committee notes important features of the proposed pLAPPD system.

- The pLAPPDs provide a promising means to obtain the required O(100 ps) timing resolution. The 5 GHz sampling of proposed readout electronics should easily yield timing precision better than 50 ps.
- The area covered by pLAPPDs is limited and their effect on the beam particles grows more significant as the momentum is reduced.

- With photon radiator, signals from existing pLAPPDs are small but adequate.
- There exist designs at FNAL for a multichannel TDC which can be used to provide δts and thus particle ID.
- Summed-signal should provide adequate trigger.

Although the pLAPPD idea looks viable, the committee has several concerns.

- The production of pLAPPDs (at ANL) is uncertain. It is difficult to estimate when sufficient numbers of working modules will be produced. Argonne should commit to a clear schedule of pLAPPD production.
- Even with a sure supply from Argonne, without modest additional support from FNAL, the pLAPPDs group will struggle to deliver a working system on time.
- The FNAL pLAPPD group should work more closely with CERN engineers and technicians to develop a strategy for mounting and read out. The space required should be available but must be staked out soon.
- Because the signals have very fast rise times, the pLAPPD group needs to better understand rack placement with regards to allowable cable lengths.
- The LAPPD system should stay on building ground, well-isolated from detector ground.

Overall, the experiment needs to devote more resources to the pLAPPD effort.

Cerenkov Detectors

Unless the pLAPPD system is ready, the Cerenkov detectors are essential for particle identification over the full momentum range of ProtoDUNE-SP. A standard Cerenkov chamber will suffice for distinguishing pions and electrons at low momentum ($p < 3$ GeV/c) but a second high pressure chamber will be required for separating out the pions at higher momentum ($p < 5$ GeV/c). While kaons cannot be distinguished from protons at lower momentum, the high pressure Cerenkov detector can be used to separate them for ($p > 5$ GeV/c). The EN/EA group has made considerable progress in the development of the new detectors and the committee is confident that the work will be completed successfully and in a timely manner.

Fiber Detectors: Profile Monitor, Tracking and Time-of-flight

Position measurements are an essential feature of the instrumentation: profiles for monitoring, tracking for determining the impact position of beam particles on the detector volume and tracking plus time-of-flight for particle identification.

Because of its good light production, fast rise and decay times, long (light) attenuation length, long radiation length, reasonable resistance to radiation damage, the instrumentation group has chosen to build scintillating fiber trackers. Scintillating fiber trackers can also operate in vacuum. Silicon photomultupliers will be used as photodetectors. A readout ASIC from Omega Microelectronics will be used to shape, preamplify, and read out signals from the SiPM. A prototype detector has been successfully tested in a beam of 180 GeV protons. Its performance at three intensities was superior to existing Delay Wire Chamber and Scintillating Counter filament detectors.

Fiber planes will also be used for the XBPF detectors, which measure both position and time, as well as the XSCINT detector which will provide a trigger. The mechanical design of the XSCINT is the same as the XBPF but with the light from the fibers all channeled to a single photomultiplier tube. Electronic readout boards for both XBPF and XSCINT already exist and the output data format (a FESA class) has been specified. Mechanical designs for mounting all three kinds of detectors in the beam line (under vacuum) were presented.

The committee is impressed by the progress in the development of the fiber detectors. A few comments:

1. For the XSCINT trigger detector: is a fiber plane superior to a conventional sheet of scintillator?

2. Is the timing performance of the fiber detectors adequate for good TOF performance? To that end, could the pLAPPD electronics be used to read out the fiber detectors?

3. Although rate capability of the fiber tracker was superior to the DWC and FISC detectors, will it suffice for the high rates anticipated at the position of the most upstream detector?

2. Is the integration of the Beam Instrumentation provided by ProtoDUNE -SP with that provided by CERN appropriate and is the whole appropriate for the scientific requirements of ProtoDUNE-SP?

For the most part, yes. Open questions remain on the integration of the pLAPPDs. Will they be mounted in vacuum or in air, how are two pLAPPDs mounted together? But on the subject of integration, please see the General Recommendations at the end.

3. Does the design lead to a reasonable production schedule, including QA/QC, delivery, installation and commissioning?

Production, including QA.QC, delivery and installation all look good. Commissioning needs more attention. Although the accelerator team has estimates that 2-3 days will be required to commission the beam, such a brief commissioning period will be insufficient for establishing a complete understanding of beam performance (particle composition by momentum, correct operation of the spectrometer, backgrounds, etc.). The committee recommends that a first commissioning of the beam line be scheduled as early as possible. However, the time available for commissioning and a schedule for running with beam is entirely driven by possible delays in the preparation of NP04 itself rather than the beamline. It is therefore difficult for the committee make a definitive statement about the scheduling risks to the first run with beam. See the General Recommendations.

4. Is the installation plan sufficiently far advanced to assure that the detectors can be installed as designed?

Installation of platform and final beam elements by the accelerator group needs to be better coordinated with the NP04 detector installation group. A detailed plan was not presented but the committee is confident that the installation team has sufficient experience to carry out this task successfully.

5. Are the interfaces between components provided by ProtoDUNE-SP and CERN with the Cryostat and EHN1 infrastructure documented, clearly identified and complete? Are the interfaces to the trigger, DAQ and offline data understood? Is the interface of the beam instrumentation data to the detector data understood?

- Cryostat: The only interface to the cryostat is what is now the clean room.
- Detectors: It is not clear whether pLAPPDs and associated infrastructure have sufficient space staked out. There is no problem in finding space at the moment but free space may get filled with shielding block.
- Electronics, DAQ and offline Trigger, DAQ and offline data interfaces are understood but practical details need to be fleshed out. For example, the fiber tracker and Threshold Cherenkov data will be stored in the CERN Oracle database. The reconstructed beam instrumentation data (e.g. track trajectory, momentum, and particle ID) need to be made available to the physics analyzers. There were options presented in the review, but no clear path forward. See General Recommendations.

The accelerator group has urgently requested a decision on NP04's preferred zero field beam position, that is where the beam enters ProtoDUNE-SP when the current in the final bending magnet is zero. A decision will help them to finalize the beamline design, and in particular the exact dimensions of the

magnet supports. The committee also wishes to stress that, given the large beam spot, having a dedicated tracking station to measure the trajectory of particles striking the detector is extremely important.

6. Is the grounding and shielding of the Beam Instrumentation understood and adequate?

The grounding and RF-shielding look OK. All the beam instrumentation exists on building ground. The detector will be run on an isolated detector ground. It looks like there are no unintended connections between the two systems. We must make sure that the planned gap of 1.6 m between the beam pipe and beam window does not get closed and cause an unintended short.

7. Are operation conditions listed, understood and comprehensive?

General operating parameters (HV, gas pressure, magnet temperature) are listed and understood. The operations (how many counters, what gases and pressures to use) of the Threshold Cherenkov detectors need to be better defined for hadron beam from 1 to 7 GeV/c.

8. Does the design team understand the expected fluxes and rates to ProtoDUNE-SP as a function of momentum? Does the design team understand the shielding, punchthrough and halo?

Beam halo and background studies are ongoing and some results were presented at the review. Beam-line shielding has been studied using both G4Beamline and Fluka. The preliminary design was studied in 2016 and a subsequent design in 2017. The new design is in many ways an improvement on the original. Expected beam line fluxes and rates to ProtoDUNE-SP vs momentum are understood. Fluxes of charged hadrons into the ProtoDUNE sensitive volume, generally through shielding gaps in the former design, have been reduced by roughly a factor of 2. Nonetheless, studies should be repeated with an improved secondary beam dump design, with the beam dump closer to the target. Based on current simulation, beam halo looks manageable. But beam halo could be a practical problem at low momentum where hadron fluxes are low.

Simulations indicate a relatively high flux of high-energy muons into the space just above the ProtoDUNE cryostat. Although the estimate of high energy muon halo from the secondary target has been modeled, that from the corresponding double-phase secondary target and the primary targets have not been modeled. It was pointed out that the ProtoDUNE cosmic-ray veto system can serve as a beam-tuning and background monitor. The committee encourages the ProtoDUNE-SP and EN/EA teams to incorporate beam halo measurements into the commissioning plan.

9. Are the analyses of the Beam Instrumentation components and their support sufficiently comprehensive for safe handling, installation and operation at the CERN Neutrino Platform?

CERN safety procedures regarding mounting of magnets, high voltage, high pressure should yield safe operating conditions for handling, installation and operation.

10. Is the Beam Instrumentation quality assurance, quality control and test plan adequate ? Have applicable lessons-learned from previous LArTPC devices and test beams been implemented into the design and operations plan?

The fiber monitor plan looks good. The accelerator group's experience with Cerenkov detectors is extensive and no trouble is expected. The conceptual design of the beam-line instrumentation evidently draws on experience from smaller-scale LArTPC R&D experiments, such as LArIAT. The backup plan for the time-of-flight system is adequate but will need a dedicated team.

General Recommendations

1. The committee recommends that ProtoDUNE-SP develop a staged approach for the beam instrumentation. What are the essential features that are needed on day one? What features might be added for possible subsequent runs? For example, to veto electrons in the low momentum hadron beam, it is essential to have a particle ID trigger ready on day one of ProtoDUNE running.

2. The committee also recommends that the Beam Line Instrumentation coconvenors for SP and DP form a small working group to sort out the gritty details of installation and commissioning, including online monitoring for beam-tuning in real time. We believe that the beam line and its instrumentation, as well as the DAQ, that is all the individual pieces will be ready on time. However, whether these disparate elements can be integrated into a detailed commissioning plan remains an open question.

3. The pLAPPD would significantly enhance the physics capability of ProtoDUNE-SP. However, more technical support is needed to ensure that the detectors are ready in time for next year's run.

Postscript

The committee would like to commend the representatives of ProtoDUNE-SP and the CERN Beam Line Instrumentation group for their hard work and the clarity of their presentations. Even as we understand that there are still many challenges ahead, we are confident that those challenges will be met

successfully. We would also like to thank the CERN Secretariat and the support staff of the Neutrino Division at FNAL for their help in organizing and supporting the review.

Charge to the Committee

The Committee is requested to review the ProtoDUNE Single Phase Beam Instrumentation design and determine if it is at a satisfactory level for planned NP04 ProtoDUNE-SP operation at the CERN Neutrino Platform in 2018.

1. Does the Beam Instrumentation design meet the requirements? Are the requirements sufficiently complete and clear?

2. Is the integration of the Beam Instrumentation provided by ProtoDUNE -SP with that provided by CERN appropriate and is the whole appropriate for the scientific requirements of ProtoDUNE-SP?

3. Does the design lead to a reasonable production schedule, including QA/QC, delivery, installation and commissioning?

4. Is the installation plan sufficiently far advanced to assure that the detectors can be installed as designed?

5. Are the interfaces between components provided by ProtoDUNE-SP and CERN with the Cryostat and EHN1 infrastructure documented, clearly identified and complete? Are the interfaces to the trigger, DAQ and offline data understood? Is the interface of the beam instrumentation data to the detector data understood?

6. Is the grounding and shielding of the Beam Instrumentation understood and adequate?

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7. Are operation conditions listed, understood and comprehensive?

8. Does the design team understand the expected fluxes and rates to ProtoDUNE-SP as a function of momentum? Does the design team understand the shielding, punchthrough and halo?

9. Are the analyses of the Beam Instrumentation components and their support sufficiently comprehensive for safe handling, installation and operation at the CERN Neutrino Platform?

10. Is the Beam Instrumentation quality assurance, quality control and test plan adequate ? Have applicable lessons-learned from previous LArTPC devices and test beams been implemented into the design and operations plan?

Review Agenda

Morning Session I

1. Executive Session
2. Introduction and Physics Overview: P. Sala (INFN Milano)
3. Beam Line Design: N. Charitonidis (CERN)
4. Beam halo and ongoing shielding design: E. Nowak (CERN and University of Science and Technology, Cracow)

Morning Session II: Beam Line Instrument Talks

1. Fiber Trackers: I Ortega (CERN)
2. Prototype Large Area Picosecond Photodetectors (pLAPPDs): J. Paley (FNAL)
3. Cerenkov Detectors: N. Charitonidis (CERN)

Afternoon Session I: Interfacing Issues

1. Beam Instruments - ProtoDUNE DAQ/Offline: J. Paley (FNAL)
2. Beam Instruments (ProtoDUNE - SP and CERN) - Cryostat and EHN1 infrastructure: G. Sylvain (CERN), L. Gatignon (CERN), N. Charitonidis (CERN)
3. Delivery / Installation / Coordination / Scheduling talk: Q. Bouirek (CERN), L Gatignon (CERN), N. Charitonidis (CERN)

Afternoon Session II:

1. Commissioning/Characterization of beam line and beam instrumentation: N. Charitonidis (CERN)
2. Committee Executive Session
3. Answers to Questions
4. Committee Executive Session
5. Closeout