ProtoDUNE Photon-Detection Readout Integration Test Plan

J. Anderson, Z. Djurcic, G. Drake, M. Oberling P. DeLurgio et al., DUNE Photon Detector Group

Argonne National Laboratory

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1. Introduction

In this note we outline plan that leads to completion of integration tests of the photon-detector readout system at ProtoDUNE-SP at CERN. The photon-detector electronics group is currently developing the readout board with ProtoDUNE specifications and will deliver the instrumentation for vertical slice and cold-box integration tests in 2017. In early 2018 calendar year we will deliver the readout boards for the photon system commissioning and operation.

2. Current Status of the Photon Detector Readout Electronics Development

The areas of responsibility for the photon-detector group went from the development of the readout system tested and operated in recent 35-ton detector to develop a new design and fabricate system to meet the ptotoDUNE-SP requirements. These activities involved modifications in power supply solutions, re-definition of trigger/timing interface to the readout electronics (SSP), formation of trigger output from SSPs, firmware modifications in data readout mode and data format, and changes the SSP data output interface.
Therefore the current activities include the design, development, and production of the readout electronics (the SSPs), the specification and procurement of the PD signal cables, the specification and procurement of power supplies, the design, development, and production of the PD flange board (warm-cold interface). R&D activities have been concluding in these areas, and the current effort focused on fabricating first prototypes. This is a precursor to a small production run that will occur in early summer 2017, and then full production for ProtoDune, which is scheduled to begin in FY18. We plan to complete the first prototype by end of April, and deliver the small production of four SSPs by early July 2017 as needed for integration tests in the cold box at ProtoDUNE.

3. Photon Detector Readout Integration Tests

In this note we outline plans for basic system diagnostics tests and for more complex characterization and noise related tests. The purpose of initial ProtoDUNE integrations tests is to verify functionality and evaluate the noise performance of the photon-detector system alone, and as a part an integrated system with APA readout. Noise levels should be monitored systematically as the components are added to the system i.e. noise measurements must be recorded and analyzed after each step of installation to ensure the detector is not plagued by noise at the end of installation. Therefore the goal is not only to deliver our subsystem but to make sure the performance of the integrated system meets performance goals.

3.1 Basic System Diagnostics Tests

The goal of basic diagnostic tests is to verify functionality of the readout boards before the start of integration effort. These basic tests will be performed at CERN after SSPs are shipped from ANL, and will consist of a subset of originally performed checkout and characterization tests at ANL.
This set of tests will include the following:

1) Verify voltage-supply values at the receiving end of SSPs

2) Verify basic communication.
 -Record firmware IDs as read from devices.
 -Perform a basic communication tests with SSPs (by verifying read/write registers are operational)

3) Check analog DC offsets and noise levels. Perform a full pedestal run
 -With remote power supplies active with SSP alone (ie no cables attached)
 -Repeat with the cables hooked-up

4) Basic response tests
 -Use internal charge injection circuit to perform coarse gain/offset/noise measurements for each channel to SSP ADCs to verify functionality
 -Turn the SiPM bias voltages ON, with cables connected to SSPs, and verify the voltage values set by DACs are correct, and the current draw is within reasonable limits.

The test listed above should ideally use ProtoDUNE DAQ and/or use specific test programs, such as the one used in SOFTWARE-mediated tests at ANL.

At this point SiPMs are operational and the photon-detector system may proceed with more complex tests to address potential integration/noise issues. Additional tests may be included such as, for example, bandwidth tests and artDAQ compatibility tests.

3.2 Integration Tests and Noise Measurement Plan

Integration Testing is performed at CERN, on a subset of the full photon detector. In integration testing a set of four SSPs (and the calibration module, if available) operate as expected when connected to photon detector units mounted within APA frame. The APA with photon-detector

photo-sensors and light-collection bars, and photon-detector cables are located in a cold gas argon and read-out via the flange board. The SSPs operate with full interfaces to both trigger and timing systems. It is performed with the Cold Box setup, in a proximity to ProtoDUNE cryostat. The Cold Box integration tests start with the APA preparation in the clean room: photon-detector units are installed into APA frame; photon-detector cables are installed next; APA cold-electronics components with cables are installed next; the APA frames go into the Cold Box for integration testing and then directly into the cryostat. For the photon-detector it means that the same cables move from the Cold Box to the cryostat.
This set of tests will include the following:

1. PD System Baseline Test 1: Intrinsic SSP Electronics Noise.

This test should be performed after the SSPs are first installed, but before the signal cables are connected. Turn off the TPC electronics power. Turn off the power to all SSPs except one. Disconnect all signal input cables to the SSP back panel. Set the trigger to a time-stamped based trigger, with no threshold on the data. Take a pedestal run for all channels in the SSP. This test measures the intrinsic noise of the electronics with no load, no cable, and minimal external pick-up.

2. PD System Baseline Test 2: Intrinsic SSP System Noise.

Repeat test (1) with all of the SSPs associated with given flange, powered up. In the cold box case this will include all 4 SSPs dedicated to cold box. This test measures the contributions of noise in one SSP from the others. The expectation is that the SSPs do not interfere with each other.

3. PD System Baseline Test 3: Intrinsic PD Noise with SiPMs OFF.

Turn off all SSPs except one. With the same operating conditions as test (1), connect the signal cables. It is assumed that the cryostat cables connect flange to the SiPMs, and warm cables connect flange to SSPs. It is also assumed that the cryostat is not filled at this point. Leave the SiPM bias power off. Take a pedestal run for all channels in the SSP. This test measures the intrinsic noise performance of the cables. It includes the noise components from (1), with the addition of: loading of the amplifier inputs; and the intrinsic noise pick-up by the cables & SiPM boards due to the environment.

4. PD System Baseline Test 4: Intrinsic PD Noise with SiPMs ON.

With the same operating conditions as test (3), turn ON the bias voltage to the SiPMs. (It is assumed that the SiPMs and scintillators are made dark to avoid noise from light contamination.) Take a pedestal run for all channels in the SSP. This test measures the intrinsic noise performance of the SiPMs under bias. It includes the noise components of (3) with the addition of: intrinsic dark noise from the SiPMs under warm conditions.

5. Repeat tests (3) & (4) for each SSP one at a time. Note any differences.

6. PD System Baseline Test 5: Intrinsic System Noise, No Bias.

Repeat test (3) with all SSPs associated with a particular flange connected and turned on (all SSPs are now turned on). Note any differences that might indicate a noise problem.

7. PD System Baseline Test 6: Intrinsic System Noise, With Bias.

Repeat test (4) with all SSPs associated with a particular flange on. Note any differences that might indicate a noise problem.

The tests listed above are performed with components of PD system ran alone. TPC electronics was powered off.

In the tests listed below the TPC electronics is powered up.

8. SSP susceptibility Test 1: Susceptibility to TPC Powering.

At this point, it is assumed that the full PD system is configured (cabled, and connected to the SiPMs.) Power on the TPC electronics, but not in data-taking mode. Take a pedestal run for all channels in the SSP. This test measures the noise pick-up in the SSPs from the TPC under power but not transmitting data. (Note: Serial links may be active under power.) If noise is observed, it may be desirable to selective power off sections of the TPC in the attempt to isolate the noise source. May need to repeat test with SiPM bias OFF/ON.

9. SSP susceptibility Test 2: Susceptibility to TPC Data Acquisition.

Repeat (8) with the TPC data acquisition active. It is sufficient to be reading pedestals through the TPC, or something equivalent that generates data readout. Take a pedestal run for all channels in the SSP. This test measures the noise pick-up in the SSPs from the TPC during data acquisition. Again, if noise is observed, it may be desirable to selective power off sections of the TPC in the attempt to isolate the noise source.

The tests described above should be carried out as part of the installation and commissioning, i.e., warm. Problems observed at this time may still be addressed before the detector is inaccessible. Periodic pedestal runs at various phases of the APA installation would be useful to monitor any changes in the noise environment. Once the detector is cold, periodic pedestal runs to monitor noise performance are useful. Although access to address problems will be limited.

4. Noise Measurement Tools

Much of the noise measurement analysis can be done using data analysis tools. For each of the test conditions listed, pedestal runs should be performed. The general conditions for a pedestal run are:

- No signal source, such as light injection or charge injection.
- Random (or pseudorandom) triggers
- Use the entire depth of the SSP data pipelines to capture consecutive samples. For the description that follows, this will constitute an "event" (one event per trigger.)
- The number of events per pedestal run is to be determined (based upon bandwidth, processing time, disk space), but should be of order ~1000 for good statistics.

It is desirable for the data acquisition to use the full DAQ system. However, for certain tests it may be expedient or prudent to use a local connection to the SSPs.

Generally, the analysis includes the following:

- Calculate RMS values for each event.
- Look at the distributions for each event and check for outliers.
- Calculate FFTs for each event.
- Calculate correlations between channels.
- Calculate the RMS of the ensemble of events for a pedestal run.
- Look at the distributions for the ensemble of events and check for outliers.

5. Additional Integration Tests

An additional test to characterize the photoelectron spectrum from every channel when connected to a cold detector through the full cable set, including flange board. A flasher such as the calibration module or a commercial pulse generator is used to generate light pulses. It assumes a fiber is provided to transport the light from pulser to the cold box interior and/or an LED is installed within the cold box. Such test will also determine the charge resolution of the readout system.

In addition to the cold box tests an opportunity to perform initial PD/TPC integration tests would be at Fermilab test stand under construction.

6. QA/QC Criteria in ProtoDUNE Integration Tests

As already described in the overview of "Quality Assurance and Control for the ProtoDUNE-SP Photon Detector Readout Electronics" it is expected that the protoDUNE initial QA/QC criteria will be based upon practical experience gained in previous setups such as the 35T test runs, Post-assembly and Characterization Test to be performed at ANL, and that such criteria will slowly evolve as operational experience is gained with the CERN Integration Test environment. As the evolution of protoDUNE QA/QC criteria occurs, a formal feedback process is required to communicate requests for changes to the pass/fail limits applied in Post-Assembly and Characterization and to record updates in all QA/QC databases both at protoDUNE and at ANL when/if any such changes in pass/fail criteria take effect.

(Should we add the list and/or table of measured quantities for Integration Tests?)

6. ProtoDUNE Installation Tests

Installation Testing is performed at CERN after the photon-detector components are installed in protoDUNE cryostat. It is using the experiment DAQ to read out groups and/or all the SSPs of the photon detection system and verify that the PD system works as a whole, and demonstrate there is no interference with other detector subsystems. Installation tests will be based on performed Integration tests, and experience gained in Integration Tests in terms of QA/QC criteria. Installation tests will be described in a separate document.