# ProtoDUNE Photon-Detector System Status and Integration Plans: Readout Electronics

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Argonne National Laboratory at al.

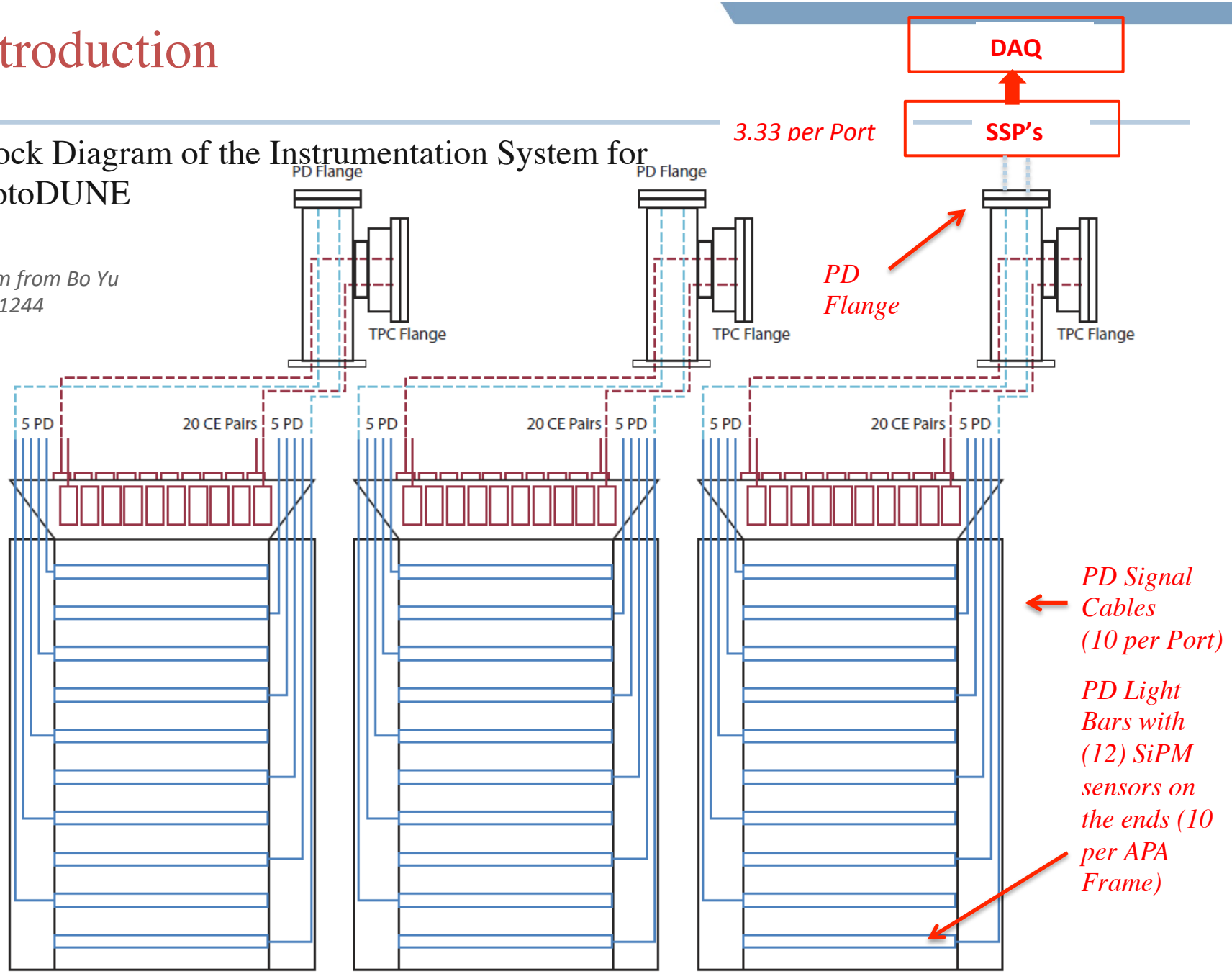
# Outline of Talk

- Introduction
- Status & Schedule
- Testing and Integration at CERN
- Summary

# Introduction

- Block Diagram of the Instrumentation System for ProtoDUNE

*Diagram from Bo Yu DocDB 1244*




*PD Flange*

*PD Signal Cables (10 per Port)*

*PD Light Bars with (12) SiPM sensors on the ends (10 per APA Frame)*

*Total of 240 PD readout channels distributed across 24 Readout Boards; No Cold Electronics in the PD system!*

# Current Status of Photon Detector Readout

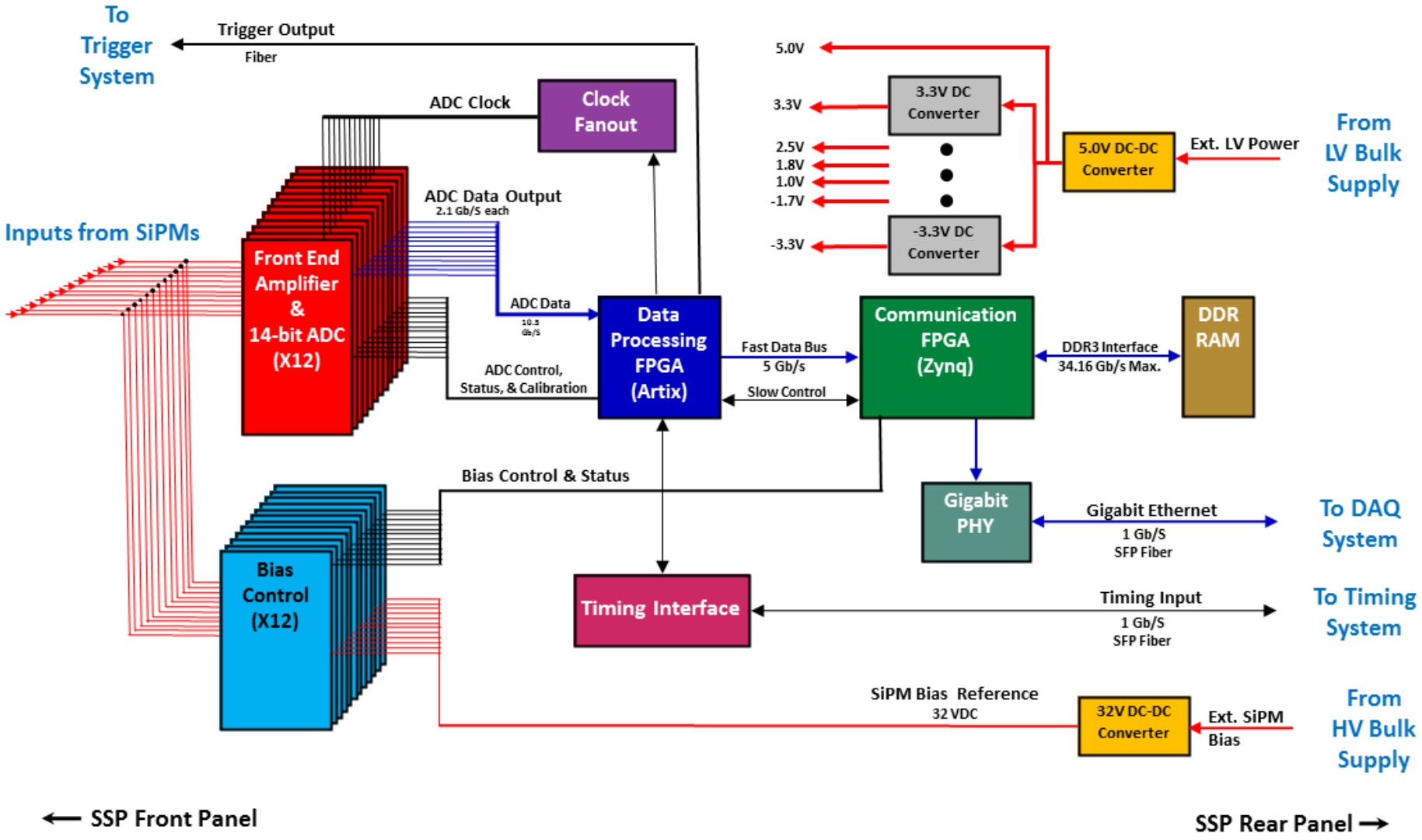
- Additional design changes approved 12/2016
  -Changes with respect to photon-detector R&D and 35-ton readout boards

- The changes included the following:
  -modifications in power supply solutions,
  -re-definition of trigger/timing interface to the readout electronics (SSP),
  -formation of trigger output from SSPs,
  -changes the SSP data output interface,
  -firmware modifications in data readout mode and data format

- And also
  -cable/connector change
  -photon-detector feedthru design/fabrication (collaboration with BNL)

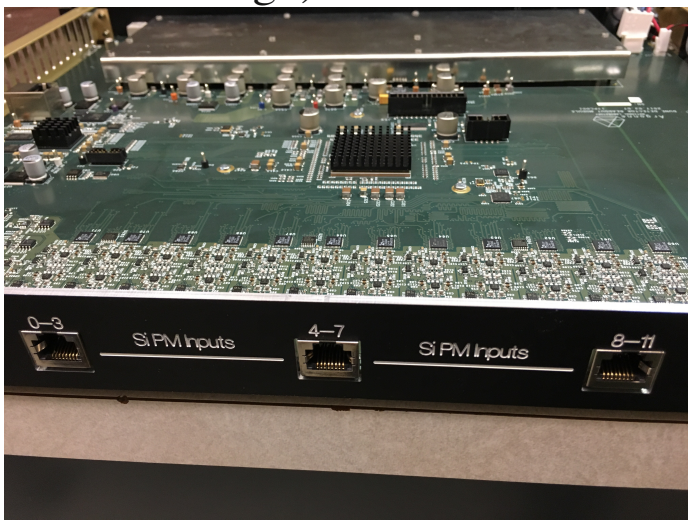
# Current Status of Photon Detector Readout

- SSP (SiPM Signal Processor) Block Diagram



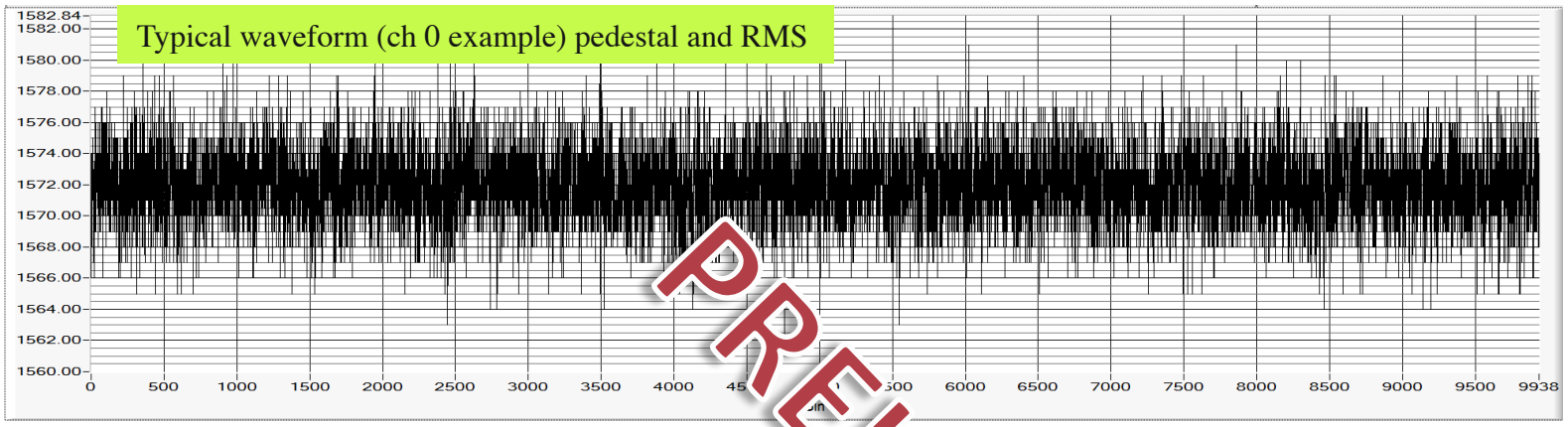
# New Readout Board Prototype Manufactured

- First two ProtoDUNE prototypes arrived at ANL (about two weeks ago)

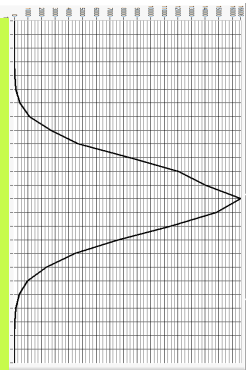


# New Readout Board Prototype Now Tested at ANL

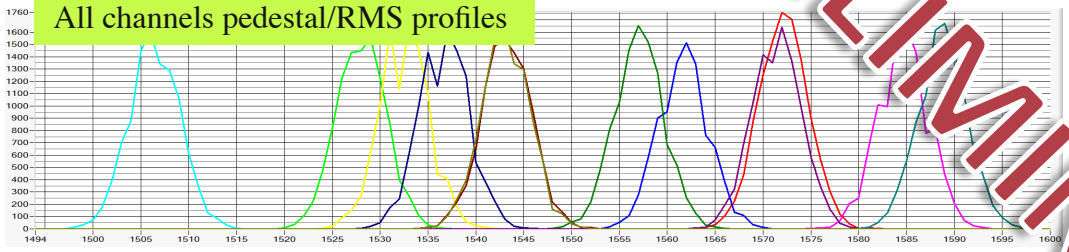
Typical waveform (ch 0 example) pedestal and RMS



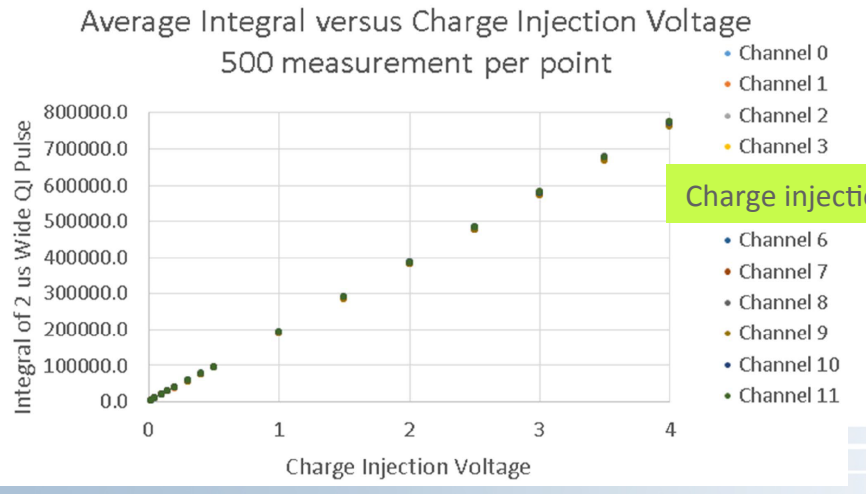
waveform RMS: 2.55 counts



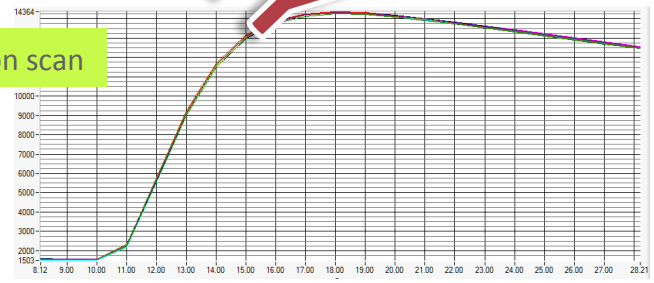
All channels pedestal/RMS profiles



PRELIMINARY




Charge injection scan



# New Readout Board Prototype Now Tested at ANL

- Initial Tests
  - -Able to acquire a waveform,
  - -Fiber ethernet working.
  - -Testing ADC and gain.
  - -Verified that the trigger fiber output works as expected.
  - -Bias DACs work as expected.
  - -Initial optical interface for timing/trigger test looks good
    - ➢ timing card needed for more complete tests; Timing card already shipped to ANL

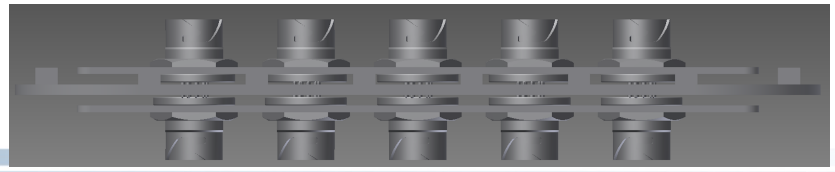
- Next Steps
  - -Need to integrate timing with SSP and integrate SSP with DAQ
    - ➢ Working on the plans for how and where to do this; most-likely attach it to the vertical-slice DAQ tests

# PD Signal Cable/Connector Status

- Signal cables and connectors for ProtoDUNE photon-detector readout decided
  - Cat6a cables, 100 ohm differential, 4 pairs per cable by Superior Essex
  - Will order all cable from 1 production lot
  - Will measure the impedance, and tune the SSP input impedance to within~1-2%
  - Cables will be tested for open and shorts by the fabrication vendor

(cable passed LAr oxygen contamination test: lartpc-docdb-465)

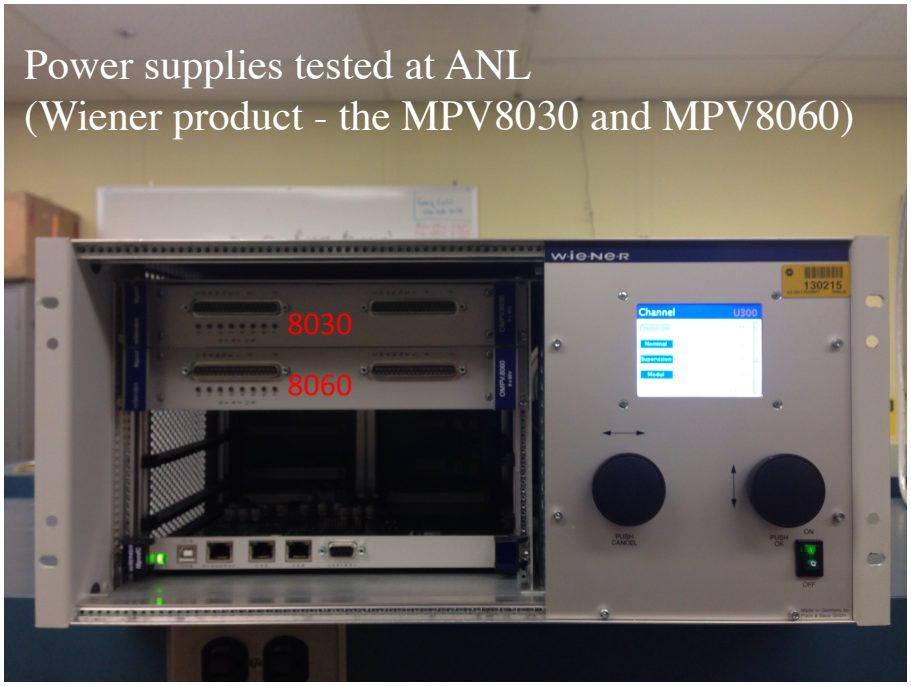
- PD Signal Cable length in cryostat determined to be 13.5 m (by Manhong, Warner)
- Mass-terminated, RJ45 Connectors on SiPM board & SSP; Bayonet connector for Flange

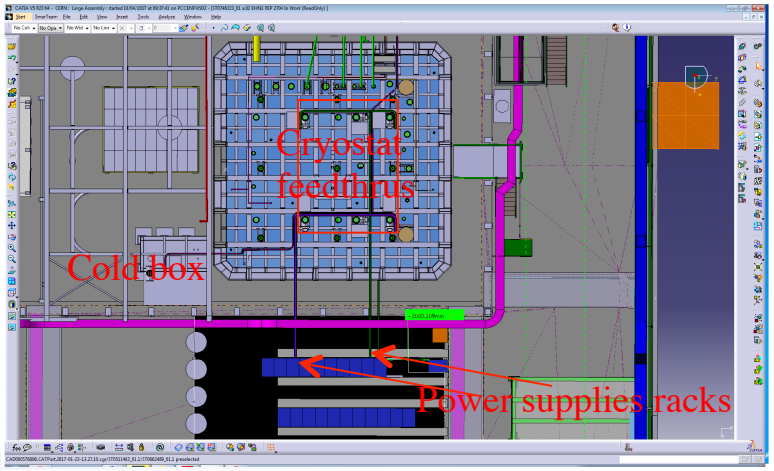


# PD Power Supply Status

- Power supplies for ProtoDUNE decided
  - -Pair of power supplies ordered for Integration Test
  - -0-30V/2.5A, 0-60V/1A

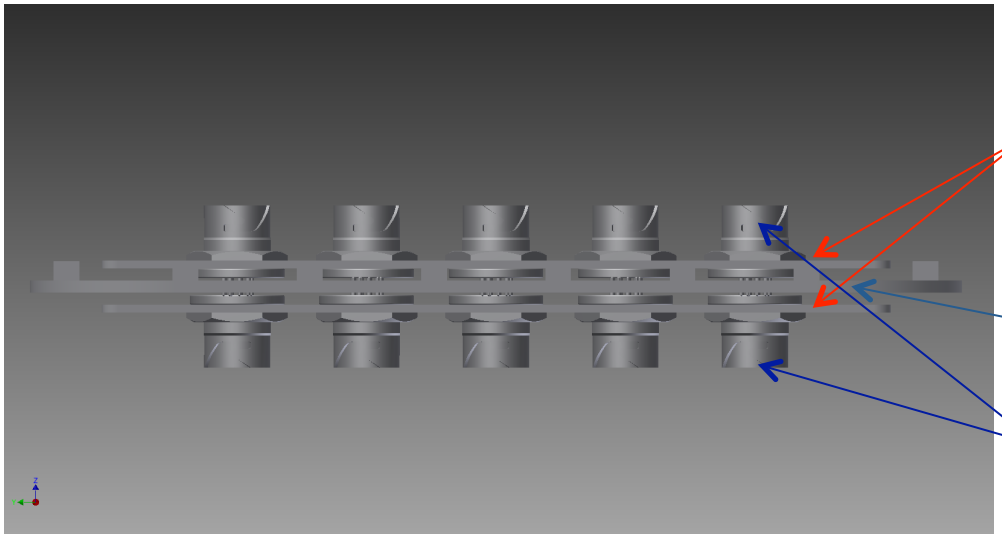
- Power cables from DC racks to SSPs needed as well
  - **-length not known yet = open issue**
  - -hope is to have it determined this week for integration tests (need 1 cable pair) and for cryostat (need 6 cable pairs)
  - -expected power cable length: ~10 meters
  - -Cables will have sense lines

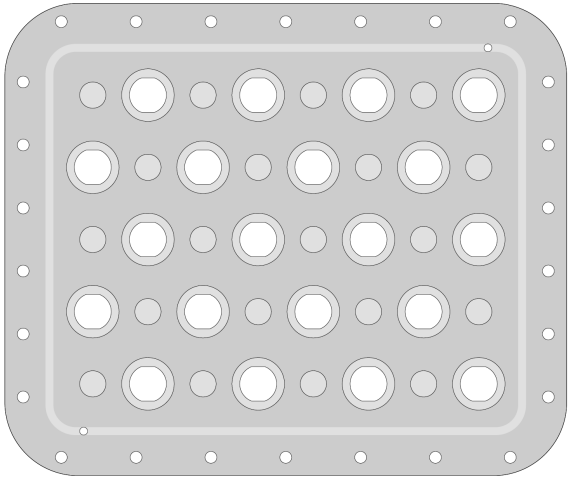


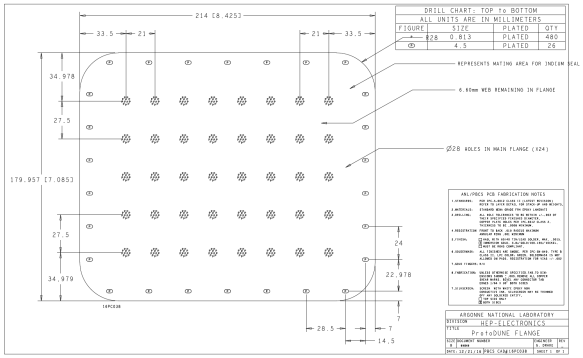



# PD Signal Feedthru Status

- ANL PD PCB design
  -will fit into BNL flange; BNL design signed off on ANL layout.





- Design supports 20 cables per flange
  -Need 10 per flange for ProtoDUNE
- 1st prototype being fabricated
  - First tests ~May 1
- Will test for opens/shorts at ANL
- Will send to BNL for vacuum testing

# Photon-Detector Readout (SSP) Production Schedule

- Additional design changes approved 12/2016
- Prototype Development 1/3/2017 – 4/31/2017
  - -SSP Design, Procurement, Fabrication & Debug
  - -Flange Board Design, Procurement & Fabrication
  - -Cable Procurement & Fabrication
  - -Bulk Power Supply Procurement
  - -System Testing

  Small Production 5/1/2017 – 7/15/2017
  - -SSP Procurement and Checkout
  - -Cable Procurement and Fabrication
  - -Installation, Commissioning, Shipping

  *=> Production Review somewhere here (initial discussions with Kevin Fahey)*

  *→ Do we wait for feedback on the VS before initiating the small production of SSP Modules? Need 6 weeks…*

- Calibration Module (without the rest of calibration system)
  - -Installation, commissioning, shipping 6/1/2017 – 6/30/2017
- Preparation for large production 8/1/2017 – 9/30/2017

# Testing and Integration at CERN

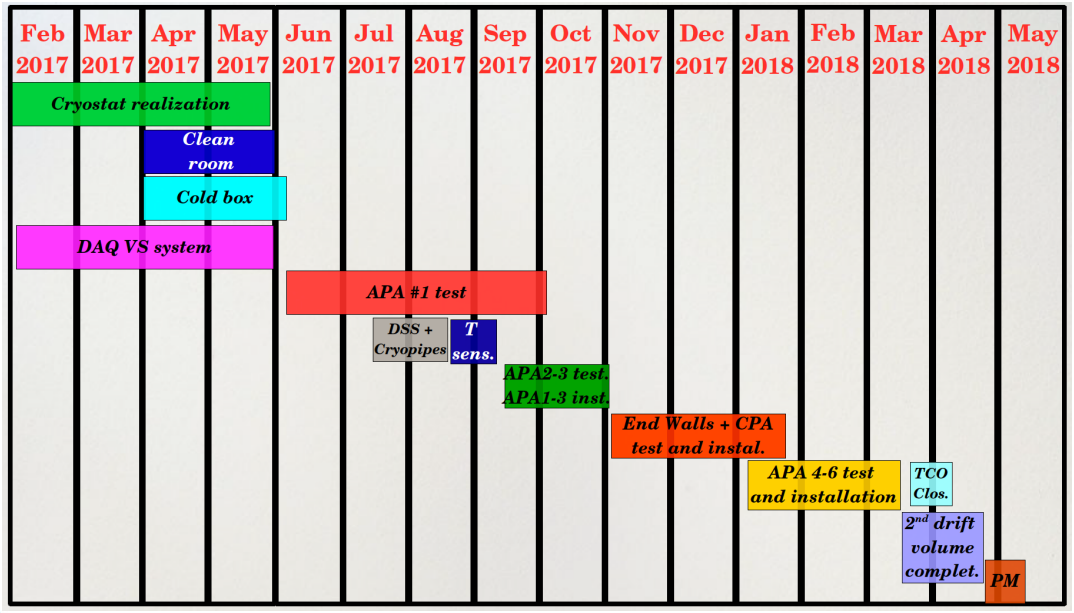
- Photon-detector readout integration part of overall effort that includes integration of mechanical components (see Ettore's talk on "PD System Installation and Test: Mechanic").

- Photon-detector readout integration
  - Integrate Photon Readout with ProtoDUNE-SP DAQ
    -Integrate Interfaces

- For the Photon Detector Readout Integration we need:
  -Photon Detector photo-sensitive elements in APA frames
  -SSPs
    - Timing/Trigger Input Interface
    - Trigger Output
    - DAQ Readout/Control Interface
  -Power Supplies
  -Cables/Connectors (warm and cold)
  -Flange with Feedthrus
  -Calibration/Monitoring Module (with light flashers, or equivalent)

# Testing and Integration Schedule at CERN

- Initially perform Vertical Slice Test
  -First SSP prototype ready by April 2017, VS in May
- Cold Box Integration Test
  -4 SSPs + 1 Calibration/Monitoring from first mini-production ready early July 2017, deliver early July.
- Commissioning effort
  -Large scale production (24 SSPs total) for commissioning by early 2018




(chart from R. Acciarri)

# Cold Box / Clean Room Requirements

- The top cold-box port will have the PD flange attached: the feedthru will be rotated by 90° to ease the cable installation (won't make cables longer).

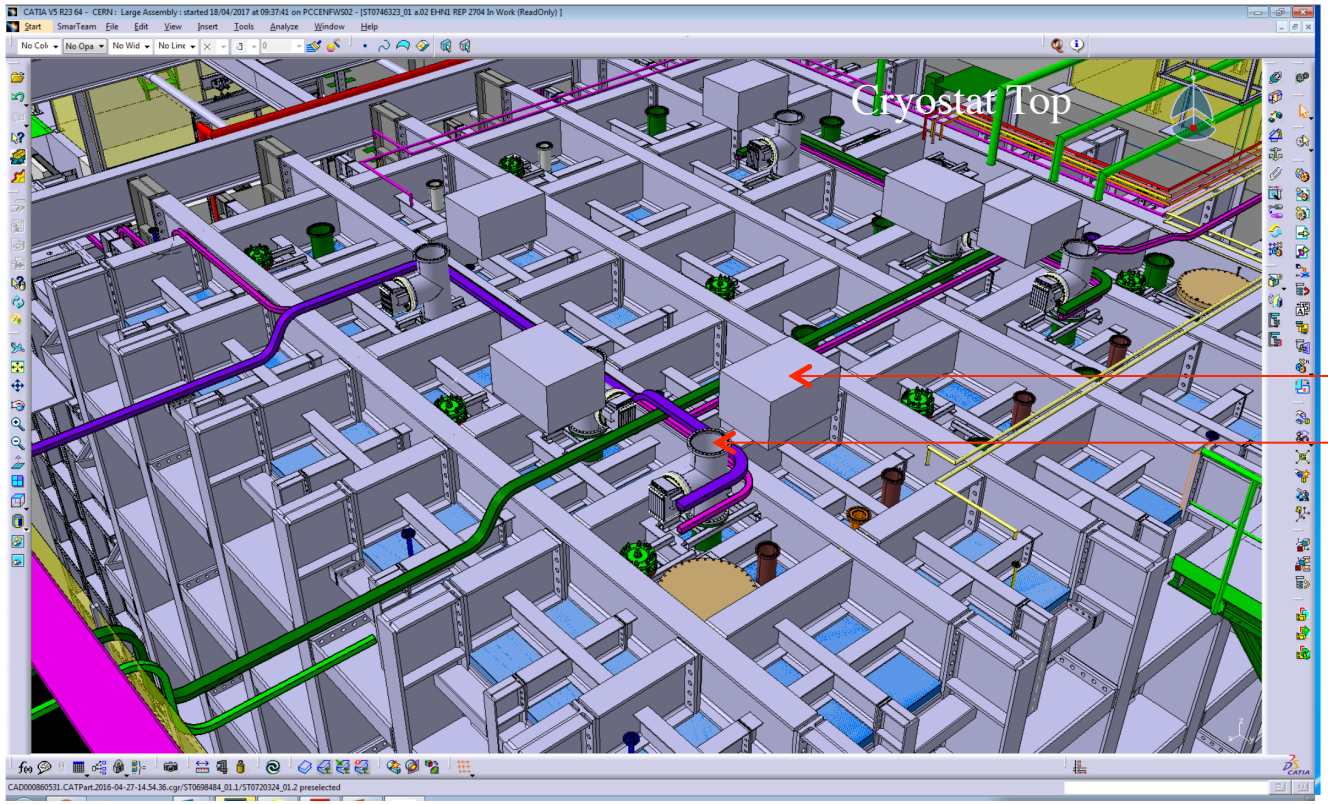
- For the SSP signal cables installation the space around the flange should be open to allow easy access to plug and unplug signal cables.
  -we may need to debug the electronics at the rack. We will need a place to stand, and space to have a scope.
  -we assume we would share infrastructure provided by CERN for CE

- In the process of finalizing the power cables
  -Current focus on 4-pair, halogen-free cable that is about 0.25" in diameter
  -One power cable per SSP, so 4+1 cables per rack
  -Assuming 10 meters power cable length based on preliminary discussion with Grounding & Shielding committee => need know exact length

- However, still need to settle on lengths of the cable runs
  -signal cables from the flange to the SSP mini rack => need know exact length (assume the same length for cryostat)
  -power cables from the SSP mini rack to the crate that will contain the bulk power supplies. => need know exact length.

# Cryostat (PD Cable) Requirements

- Need define signal cable length from the flange to the SSP mini rack = open question
  -possible to determine this quantity if Linda's layout is accepted




*Layout from Linda Bagby et al.*

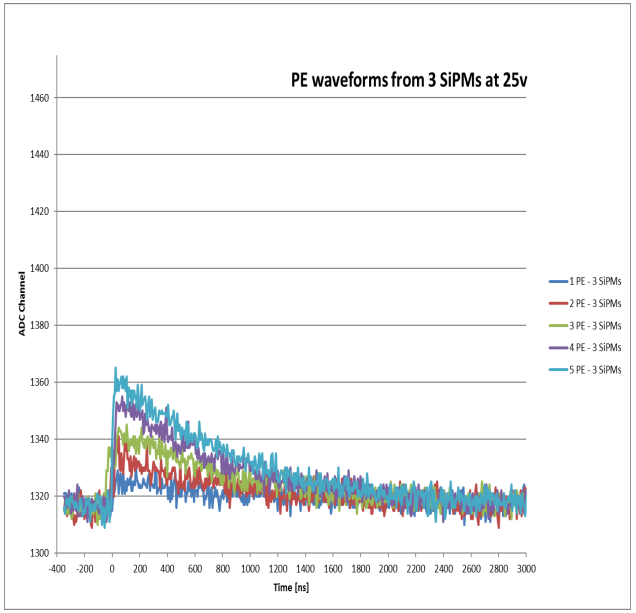
- It takes 6 weeks to order and fabricate cables with connectors
  -need input now

PD Minirack purchased for Cold Box

SMA20025

# Integration Tests

- What will be tested?
  - -Functionality of the system
    - Basic tests
    - I/O Interfaces (Trigger/Timing, Readout Protocols)
  - -Noise level
    - Interference with TPC CE?




- What to expect?
  - With three SiPMs ganged together
    1PE should be
    ~10 ADC count at 25 V bias
    ~12 ADC count at 26.5 V bias
    (current nominal bias = 25.5 V)
  - Nominal pedestal RMS ~3 ADC count

- The 35 ton detector was plagued by noise, but no clear understanding of what contributed to the noise to photon-detector system

  *=> as we integrate components of the readout system: perform functionality and "noise" tests*

# Integration Tests

- List of potential Basic System Diagnostic Tests (assume same for vertical slice tests)
  -use automated DUNEWare testing sequence or ProtoDUNE DAQ

  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

# Integration Tests

- Vertical slice test at CERN as initial phase of the Integration Tests
  -Bandwidth tests and artDAQ compatibility tests
  -Interface tests: SSP - Board Reader, Timing - SSP
  *=> At this point SiPMs are operational and the photon-detector system may proceed with more complex Integration tests to address potential interference/noise issues*

- Aside from CERN VS test setup there will be opportunity for a vertical slice tests at Fermilab's Faraday's cage setup (led by Linda, Terri)
  -Discuss this possibility in parallel

# Integration Tests

- List of potential System Performance and Noise Tests
  - *=> Measure pedestal/RMS data for each channel*
  - -start with SSPs alone (single vs all SSPs)
  - -add cables/flange/SiPMs to SSP (single vs all SSPs)
  - -measure SSPs response with TPC CE electronics on/off
  - -measure at room and cold temperature

- A draft of desired integration tests in DUNE DUNE-doc-3273.

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

=> Test 1 SSP at the time, no cables, turn off the TPC. (Warm test; Cold test).

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

=> Test all 4 SSPs (associated with the given flange) run simultaneously, turn off the TPC power. No cables connected to the flange. (Warm test/cold test). Inherits from test (1) going from single to all SSPs at the flange.

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

=> Test 1 SSP at the time, warm SSP cables connected to the flange, cryostat cables connect flange to the SiPMs, turn off the TPC power. SSP bias is OFF (Warm test/cold test).

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

=> Test 1 SSP at the time, warm SSP cables connected to the flange, cryostat cables connect flange to the SiPMs, turn off the TPC power. SSP bias is ON (Warm test/cold test).

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.

=> Test all 4 SSPs (associated with the given flange) run simultaneously, turn off the TPC power. SSP bias is OFF (Warm test/cold test). Inherits from test (3) going from single to all SSPs at the flange.

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

=> Test all 4 SSPs (associated with the given flange) run simultaneously, turn off the TPC power. SSP bias is ON (Warm test/cold test). Inherits from test (5) going from single to all SSPs at the flange.

8. SSP susceptibility Test 1: Susceptibility to TPC Powering. => Test all 4 SSPs (associated with the given flange) run simultaneously. Warm SSP cables connected to the flange, cryostat cables connect flange to the SiPMs. Turn ON the TPC power, TPC not taking data. SSP bias is OFF/ON (Warm test/cold tests).

9. SSP susceptibility Test 1: Susceptibility to TPC Data Acquisition. => Test all 4 SSPs (associated with the given flange) run simultaneously. Warm SSP cables connected to the flange, cryostat cables connect flange to the SiPMs. Turn ON the TPC power, TPC in data taking mode. SSP bias is OFF/ON (Warm test/cold test).

- Gain and Linearity measurements with calibration module

# QA/QC and Tests Documents

- A start on QA/QC and test documents DUNE-doc-3273.

## summary-document-on-SSP-qc

Quality Assurance and Control for the ProtoDUNE-SP Photon Detector Readout Electronics

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

April 17, 2017

### 1 Introduction

This document describes procedures used for the quality assurance and subsequent quality control procedures for the prototDUNE-SP photon detector readout electronics, so-called SSP (SiPM Signal Processor) Boards.

ANL HEP Neutrino Group is responsible for the development, fabrication, testing, integration, and commissioning of the ProtoDUNE-SP photon-detector readout system. Some of these responsibilities are shared with other ProtoDUNE-SP photon-detector groups within collaboration. In covering these tasks the areas responsibility of the 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 photon-detector readout system 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. The SSP design and interfaces will be described in separate documents and drawings [1], [2], [3].

Photon detector system components will be acquired or manufactured at various institutions throughout the photon group. As described in the overall photon-detector quality assurance and control plan [4], each institution will develop a quality assurance program for the system components in area of group's responsibility, leading to a corresponding set of quality control requirements and procedures.

### 2 Photon Detector Readout Electronics QC Procedures

We identify two levels of testing for the SSP, summarized as follows:

1. **Post-assembly Testing** is used by ANL personnel to perform engineering-level tests required to verify that a newly-assembled SSP works well enough to proceed to characterization & calibration testing.
2. **Characterization Testing** is performed by ANL personnel using a "standard" detector and/or "standard" signal generators to perform a series of performance measurements on a fully-functional SSP module, before delivery for ProtoDUNE at CERN.

Additionally, after delivery of any SSP unit to ptotoDUNE, additional tests shall be performed at CERN. These additional tests are beyond the scope of this paper, although summary descriptions are provided in section 5. These additional test regimes include Vertical-Slice testing, Integration testing and Installation testing.

The QA/QC repository of identified quantities of interest may include the following:

- board_sn

## DUNE-SSP-first-stage-test-procedure

**DUNE SiPM Signal Processor(SSP)**

**ECO/FCO Verification & initial checkout procedure**

Version 0.1 draft 1 Last Revision 20170412 JTA

**Module Serial Number:_____ Testing Date:_____ By:_____**

**Scope of Procedure**

***Predecessor : Specification Document: Quality Assurance and Control for the ProtoDUNE-SP Photon Detector Readout Electronics.***

***Successor Procedure : DUNE SSP POST-ASSEMBLY Manual Test Procedure.***

***The sequence of tests described herein is to be performed on any newly manufactured SSP module. Modules with no repair issue sent to ANL solely for firmware upgrade are not subject to re-testing at this level and may proceed directly to the POST-ASSEMBLY Manual Test procedure.***

***In every step of this procedure, if a measurement FAILS, immediately stop testing, de-power all circuits, and alert supervising engineer.***

***Initial Checkout after Assembly***

The module is assumed to be outside its box, with the external DC power and bias power cords removed. The board shall be in a completely *unpowered* condition. The bottom power supply shield should be mounted to the board but the top power supply shield should be removed.

___PASS____ FAIL 1. Verify that the PCB assembly is complete.
____ DONE a. Verify that the main board's serial number has been marked in the space below the Argonne logo on the component side of the PC board. Record at the top of this sheet.
____ DONE b. Verify that the bottom EMI shield has been mounted to the circuit board by 12 screws at 1/8th inch spacing from the board, all screws binding to standoffs on the component side of the board.
____ DONE c. Verify that *none* of the resistors associated with any chassis mount standoff position are installed. See Figure 1.

DUNE SiPM Signal Processor ECO/FCO Verification & initial checkout procedure Page 1 of 9

## PhotonReadout_Integration_Testing

**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**

**April 2017**

**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

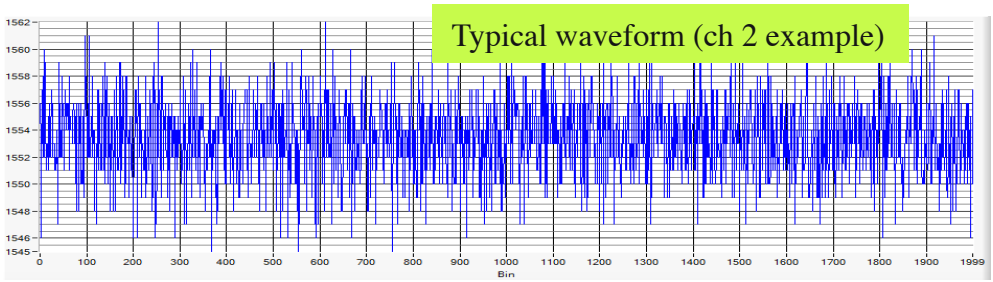
# Recent Performance Tests (modified SSP)

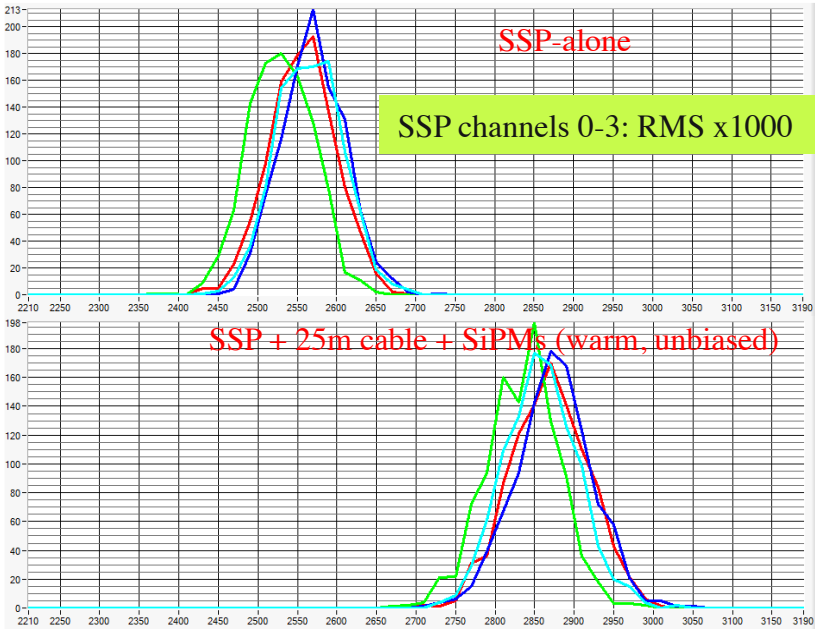
- Perform functionality and "noise" tests with modifications to the readout system
  -Will repeat characterization tests with new SSP as a part of integration tests

- Recent tests of SSP with modified front-end + new connectors and cables + new power supplies tested (but still old SSP)
  -Measure pedestal/RMS data for each channel, at room and cold temperature
- Example of recent measurements with old, modified SSP ( bias @ 26.5 V, warm/cold )
  - Pedestal RMS

-the SSP alone RMS ~ 2.55 counts
-SSP + long cable (25 m) RMS ~ 2.85 counts
-SSP + long cable + SiPM (unbiased) RMS ~ 2.85 counts
-SSP + long cable + Biased SiPM (warm, below breakdown) RMS ~ 2.85 count
-SSP + long cable + Biased SiPM (cold, below breakdown) RMS ~ 2.85 counts
-SSP + long cable + Biased SiPM (cold, above breakdown) RMS ~ 2.85 counts

  - Single PE ~ 12 counts



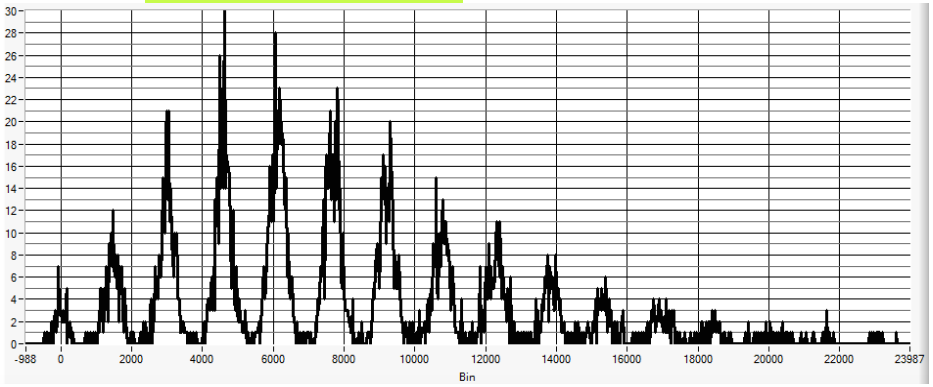




- Current testing experience input to Integration/Commissioning Tests at CERN

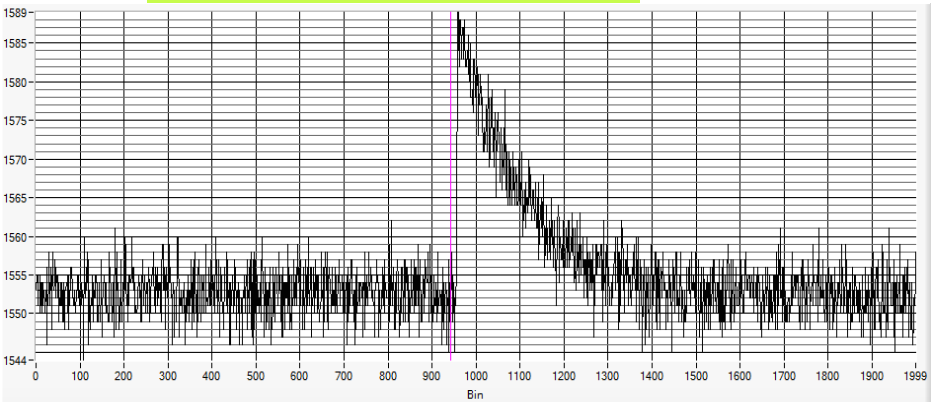
# Recent Performance Tests (modified SSP)

Another Example: SSP + long cable (25 m) + SiPMs (biased @26.5 V, cold) + LED Pulser

Channel 2 integral




Channel 2 waveform example



# Integration Tests

- The time scale defined in Integration/Installation Schedule

  -Vertical slice test in May will prepare us for integration tests

  -Integration tests will start in July with PD readout electronics (see R. Acciarri's schedule for details)
  - Will use first APA to gain experience/expertise for subsequent integration tests
    -Will inform commissioning tests/effort
    =>refine QA/QC/testing procedures, refine requirements

# Integration Tests

- Who will be present?

  -Photon detector integration will combine mechanical and electronics components
  - Current assumption is that the following crew will be present onsite at CERN
    -Zelimir Djurcic (photon-detector readout integration) ~ summer 2017
    + periodic trips thru year
    -Ettore Segreto (photon-detector mechanics) ~6 months starting in summer 2017
    -ANL postdoc (TBC) starting in summer 2017 => focus photon readout + CPA
    -Gary Drake ~ 2 weeks to help debugging first modules
    -Jaroslav Zalesak plans significant time spent at CERN: focus PD readout + calib.
    -Ana Machado ~6 months starting in summer 2017
    -Dave Warner, couple of weeks in June, couple of weeks in Sep/Oct
    -CSU Technician, couple of weeks in June, couple of weeks in Sep/Oct
    -Evan Niner, first ~2 months
    -Chris Macias, January – Sep 2018 (TBC)
    *=> short with sign-ups for 2018*

- Need invite new (yet to be formed) PD consortia people to come help in integration, commissioning, operations, data analysis.

# Installation/Commissioning Plans

- Photon Detector Readout Installation and Commissioning Tests will be further clarified with input from integration effort.
  -not discussed today

- Readout for commissioning will be fabricated after we deliver 4 SSPs + Calib/Monitoring unit for cold box
  - Schedule for 24 SSPs for cryostat commissioning
    -Preparation for large production 8/1/2017 – 9/30/2017
    -Large production in fall 2017
    -Delivery to ProtoDUNE early 2018

- Continue development of the commissioning plan as go through the production and integration tests
  -write documentation with list of tests
  -continue develop QA/QC plan
  -keep communication going on: CE team, grounding team, DAQ groups.

# Summary

- Status & Schedule
  - -Prototype Development 1/3/2017 – 4/31/2017
  - *=> Vertical Slice test in May*
  - -Small Production 5/1/2017 – 7/15/2017
  - *=> Production Review somewhere here*
  - *=> Integration Testing from July*
  - -Preparation for large production 8/1/2017 – 9/30/2017

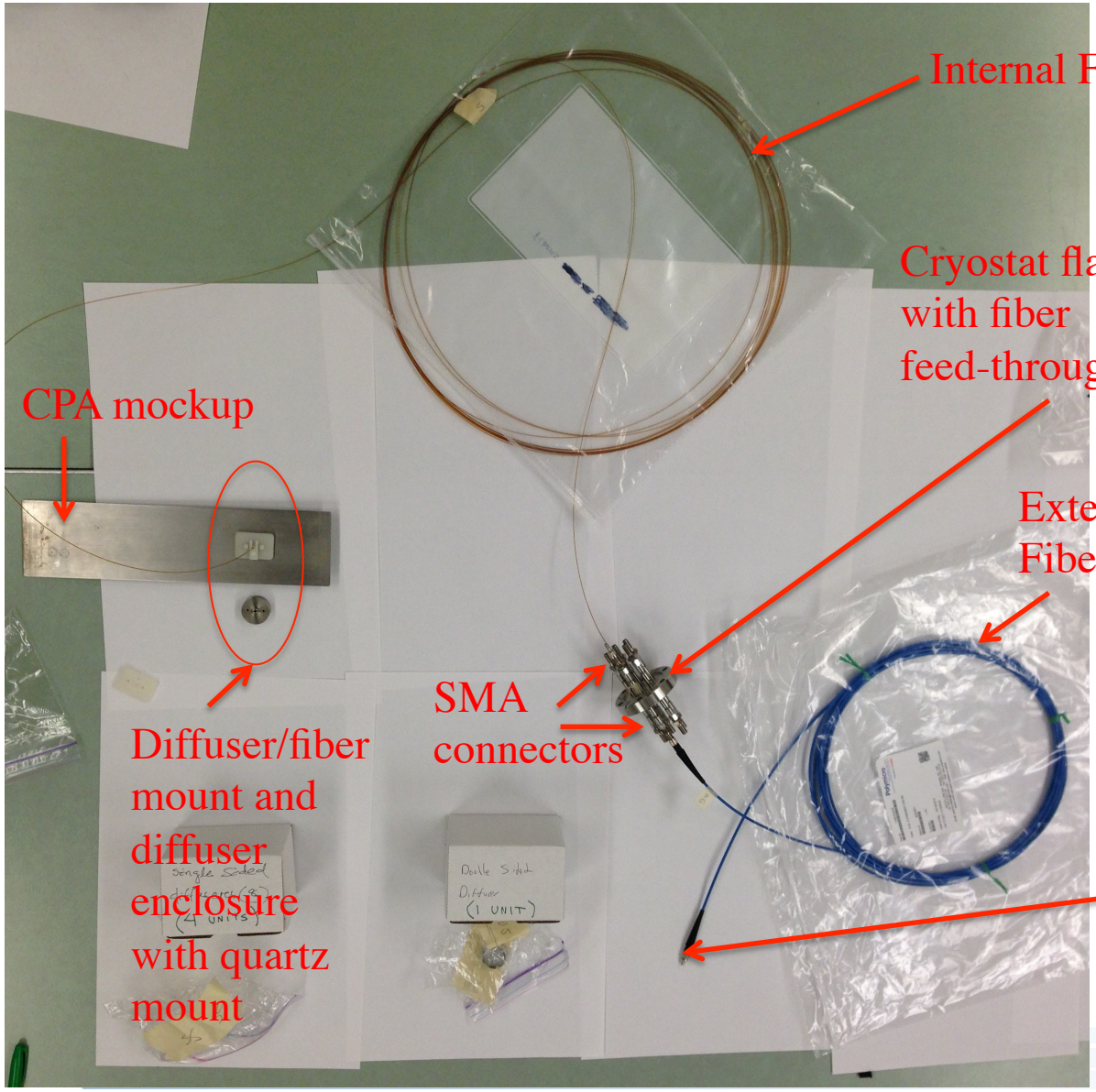
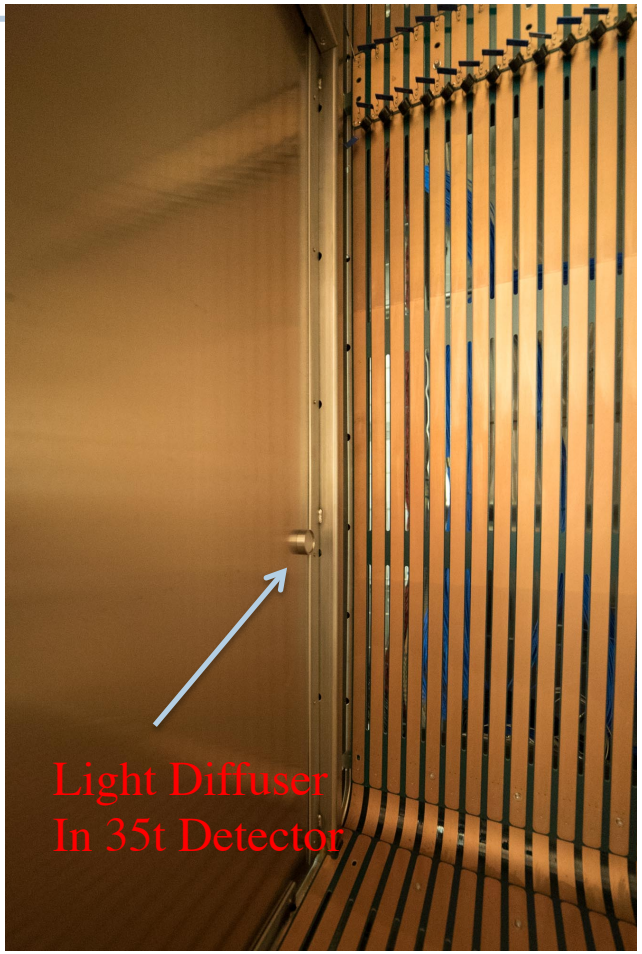
- Testing/Integration at CERN
  - -First SSP ready for vertical slice test May
  - -Four SSPs ready for Integration tests early July
  - -1 Calibration/monitoring module ready later

- List of test/integration measurements being developed
  - -Expertise from ongoing prototype/production tests

- Man-power for photon-detector integration at CERN being defined

- Will watch schedule for any changes

# Backup

# For Cold Box: Reuse Components of UV Calibration System

- Components installed with 35t DUNE prototype