Photon Detector Calibration/Monitoring System

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Talk Overview

- Motivation
- Overview of the Calibration System
- ProtoDUNE-SP Results with Calibration System
- Hardware Components
  - -Diffuser and CPA
  - -Fibers
  - -Calibration Module Electronics and Light Source
  - -Optical Feedthrough
- DUNE Implementation
- Summary and Next Steps

Photon-Detector Calibration and Monitoring

Motivation

- Use the UV-light calibration/monitoring system as the detector verification tool: before closing the cryostat, in the cool-down phase, and when filled with LAr- to test the photon detectors ("is the detector alive?").
- Measure the photon detector gain, cross-talk, linearity, time resolution, and time-delays.
- Monitor stability and response over time.
- Use in special study cases (study a pile-up, effective detection efficiency).
- Make use of it for quick reliable test of PDS when a change is made
  => Don't wait for cosmic muon coverage of entire detector.

R&D on Photon-Detector Calibration Monitoring

-ProtoDUNE-SP Calibration/Monitoring system successfully implemented and fully operational.

-Analyzed and used photon-detector calibration data in ProtoDUNE-SP (see: DUNE TDR, ProtoDUNE Performance Paper).

UV Light Calibration Monitoring System

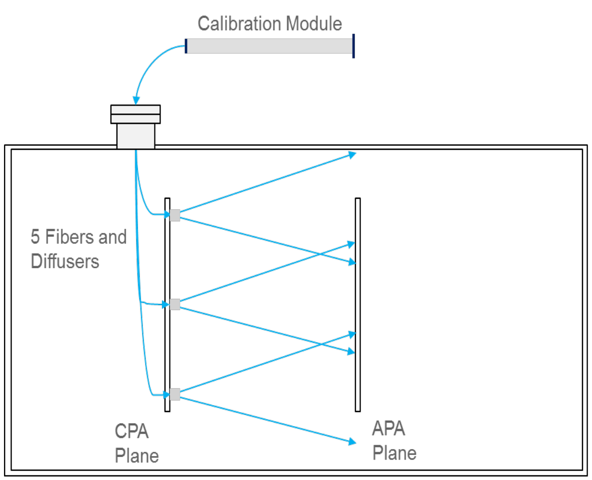
- Photon Detector Calibration Monitoring System has been realized in a form UV-light flasher calibration system
- UV light calibration system design:

-transports light from 275 nm UV LED sources (so-called Calibration Module) through quartz fibers to the TPC volume.

-diffuse light to the photon detection system collection elements located within APA.

-use UV light wavelength shifted with photon-collector components of photon detector

-observe SiPM response to shifted light.



- **Outer Components:**

-Calibration Module with 275nm LEDs

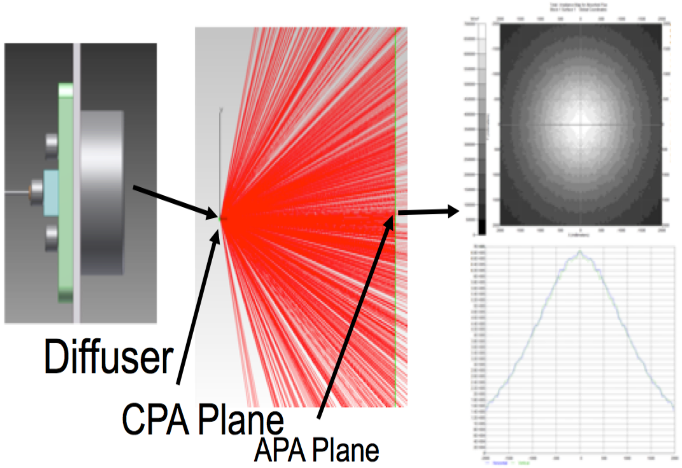
-Optical quartz fiber for light transport

- **Inner Components:**

-Flange with optical fiber feed-through

-Optical quartz fiber for light transport

-Light diffusers at CPA plane



Optical Simulation of Single Diffuser at APA distance

Status of Photon-Detector Calibration and Monitoring

- System presented at two recent reviews with very positive feedbacks

1) DUNE-SP PDS Conceptual Design Review (30% Design Review) – November 12-13, 2018
   https://indico.fnal.gov/event/18460/

2) DUNE Far Detector Scope Reviews - June 17-20, 2019
   https://indico.fnal.gov/event/20996/

"… This is the most advanced of all the calibration systems discussed at the June 18 workshop, having already undergone testing and prototyping with the 35t and the ProtoDUNE-SP detectors…"

Status of Photon-Detector Calibration and Monitoring

- We had a great operational experience with ProtoDUNE-SP
  - There are more than 100 runs with different settings of the Calibration Module.
  - System controlled through DAQ/SC, prepared dedicated run configurations

    -Runs from seconds to minutes (any duration) to get a sufficient statistics (light pulses at 1Hz - 1kHz)

    -Data volume "parasitic'

    -Results written as waveform histograms. Data accessible minutes after run completed; No major reconstruction needed. Look at waveform directly by ROOT.
- ProtoDUNE-SP uses:
  - Commission phase: test of readout system continuity, test photon-detector thresholds, dynamic range/gain tests
  - Operation phase: calibrate gains, measure stability, time-resolution, look at system delays/synchronization, relative efficiency of PDS channels.

- Based on this we are working to build a calibration plan for DUNE Far Detector

  -Philosophy builds from ProtoDUNE.

  -Started work with DAQ/SC to add the calibration runs into regular data stream.

  -Monitor light source stability via SC feedback loop.

  -Learn PDS response in the commissioning phase, evolve to stable operation conditions.

Status of Photon-Detector Calibration and Monitoring

- Capability:
  - System emits "very" short to "very" long pulses.
    -Covers single PE region all the way to the full dynamic range.
  - High stability and repeatability.
  - Generate correlated pulses for time measurements.

- Remaining R&D: add a feedback loop monitor absolute number of emitted photons.

- Operation done with 275 nm light; does not operate at 128 nm (LAr wavelength).
  - Not intended to measure absolute detection efficiency at 128 nm
  - "Does everything else" quickly and efficiently.

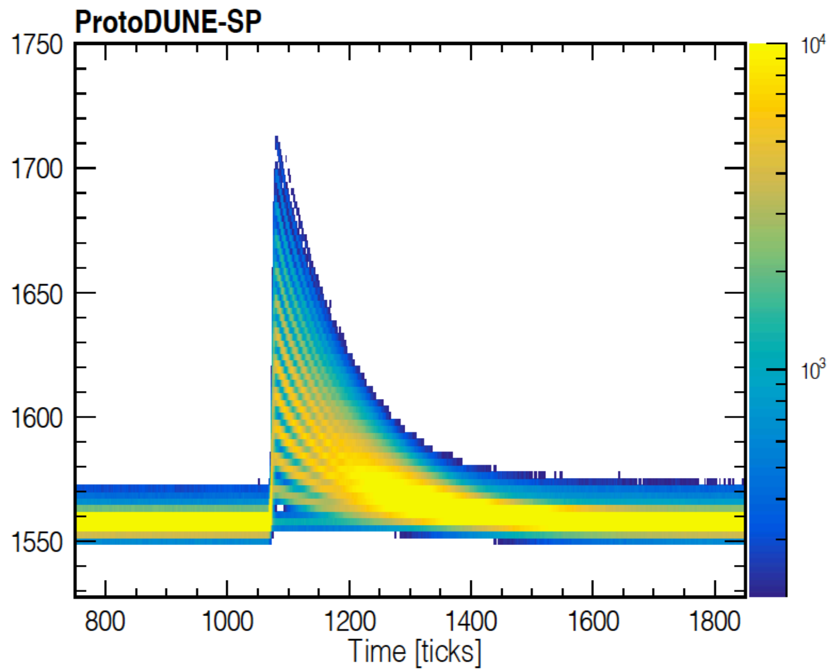
- Complementary to ionization laser and radioactive sources.
  - Laser to be explored for PDS and TPC synchronization.
    -Further studies needed to quantify if scattered/reflected 266 nm light dominates over the scintillation 128 nm light from laser-induced ionization tracks.
    -Perhaps the late scintillation light (laser-induced) could be used in PDS - TPC cross-calibration.
  - One of the topics to be addressed by calibration groups.
    -Develop optimal calibration plan for DUNE Far Detector.

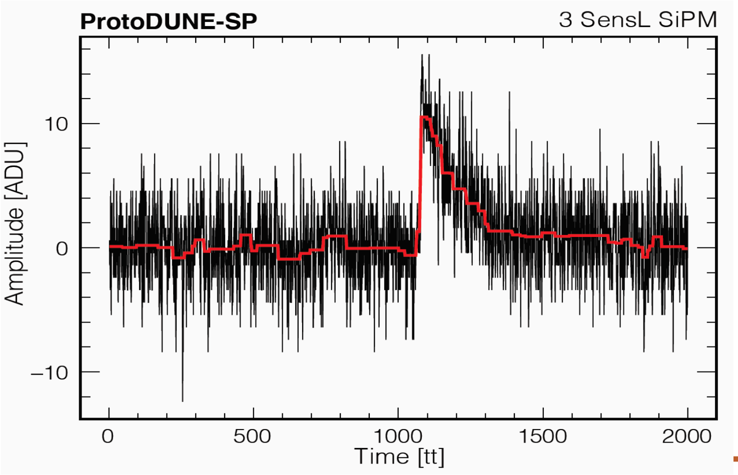
Photon-detector Response to Calibration System

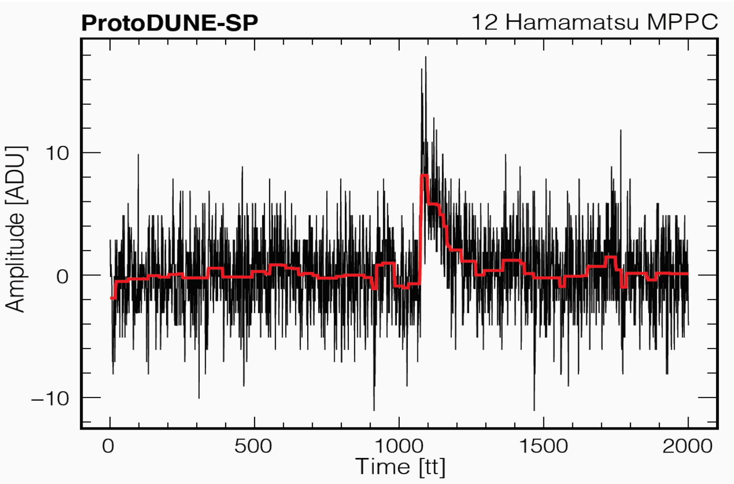
- ProtoDUNE-SP Results
  -All results in next pages shown with photon readout (SSP) synchronized with UV-light calibration system.

➢ Waveforms in the UV-calibration run displayed in persistence trace mode (right) showing recorded single and multi-photon signals.

➢ Sample waveforms of single photon signal from a 3-S-SiPM channel (bottom left) and 12-H-MPPC channel (bottom right)

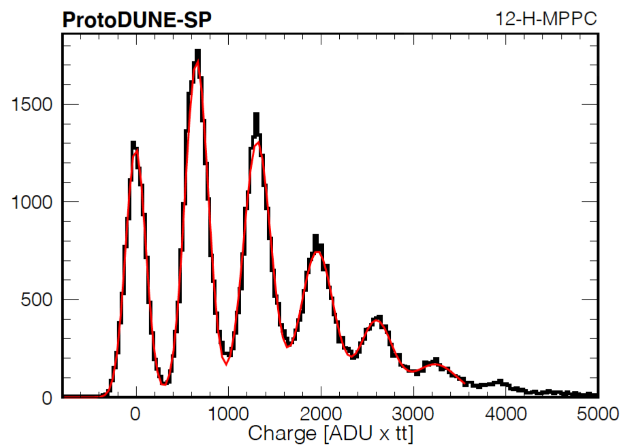


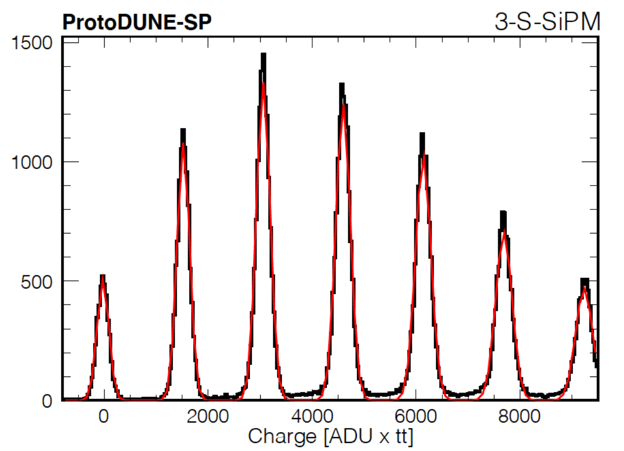




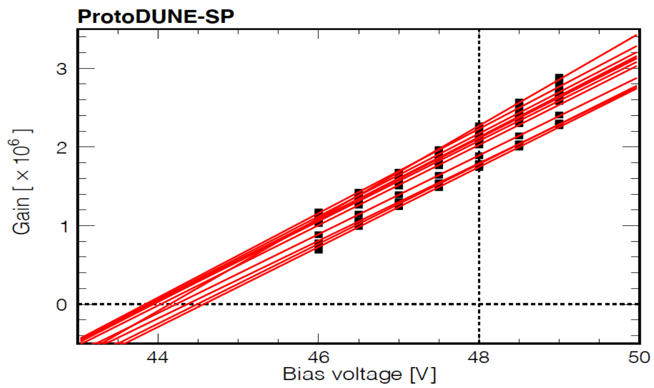
Gain Calibration

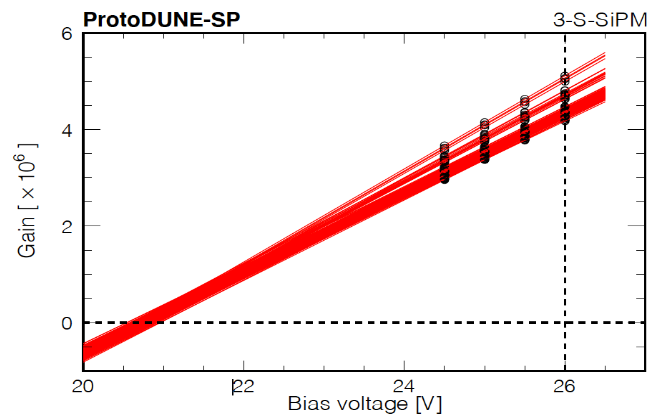
- Signal Integral distribution for typical 12-H-MPPC channel (top) ($V_B = 48V$) and 3-S-SiPM channel (bottom) ($V_B = 26V$) under low amplitude pulsed LED illumination.





- Gain as a function of applied bias voltage for 12-H-MPPC channels (top), and for3-S-SiPM channels (bottom). Linearity of individual channel response is shown by the linear fit (red line)across the points at different bias voltage setting.

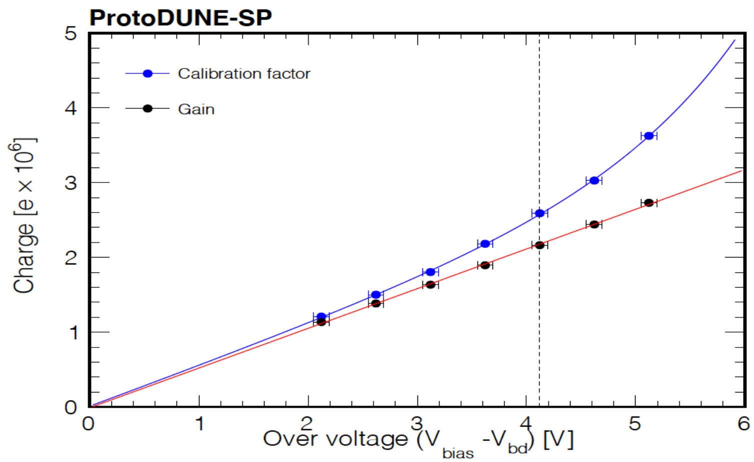


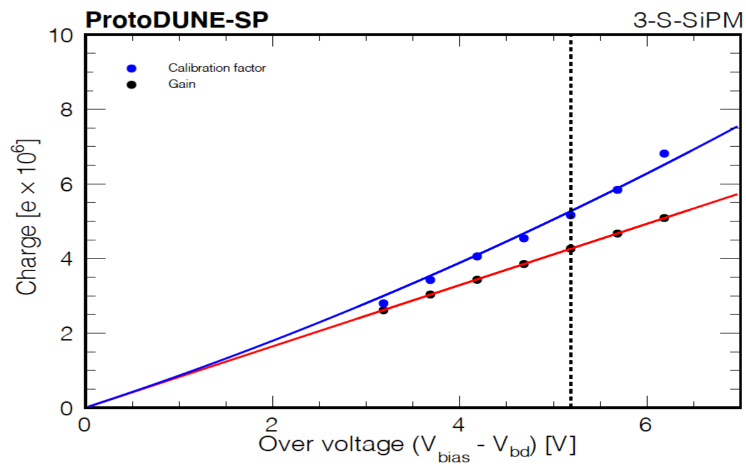


Light Calibration

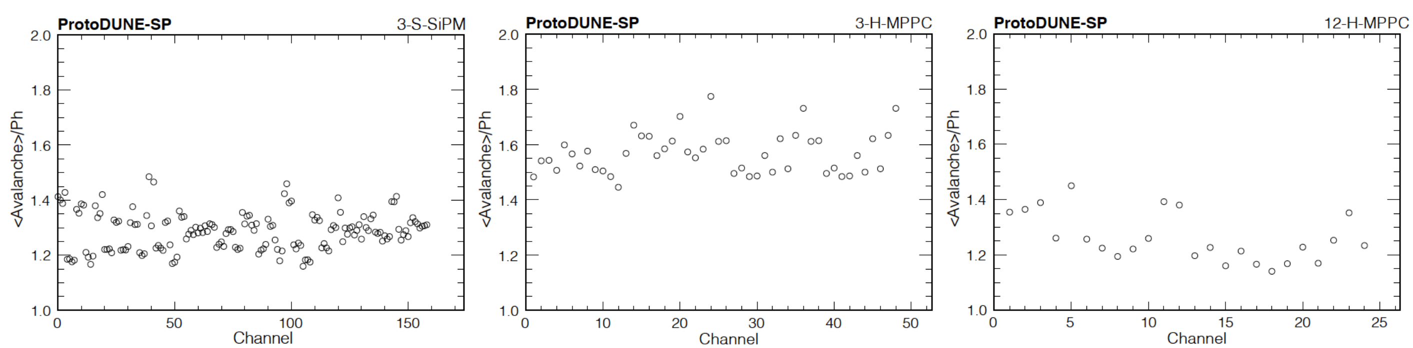
- Calibration of the light response is necessary to convert the charge signal from the photosensors into the corresponding number of photons detected. Requires a vert-low light intensity.

➢ Charge signal per detected photon (calibration factor) and Charge signal per avalanche (gain) as a function of applied over-voltage.





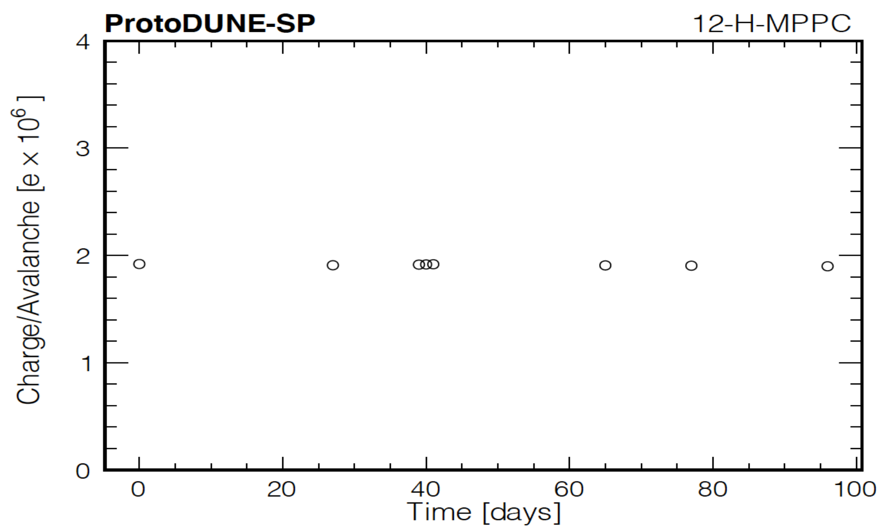
➢ After pulses and cross talk: expressed by the average number of avalanches generated per detected photon

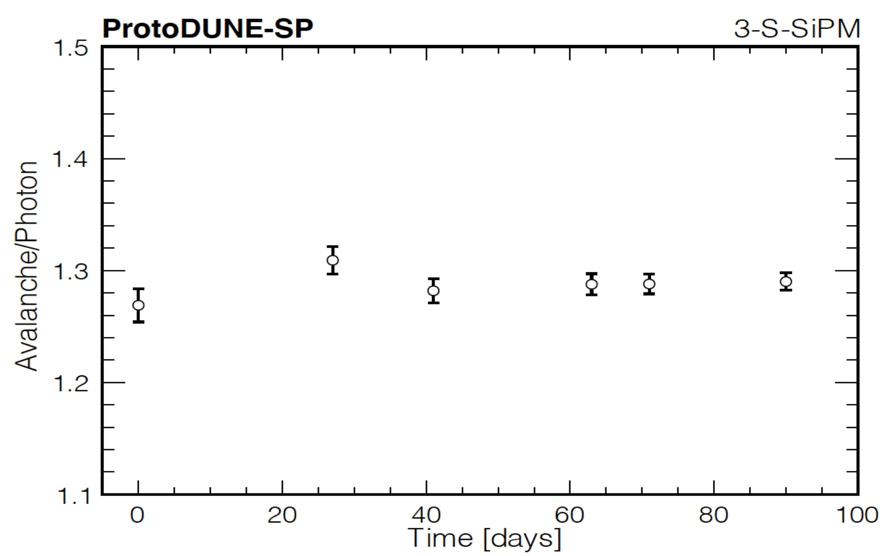


Stability of PD gain and cross-talk

- From calibration runs performed over 100 days of operation.

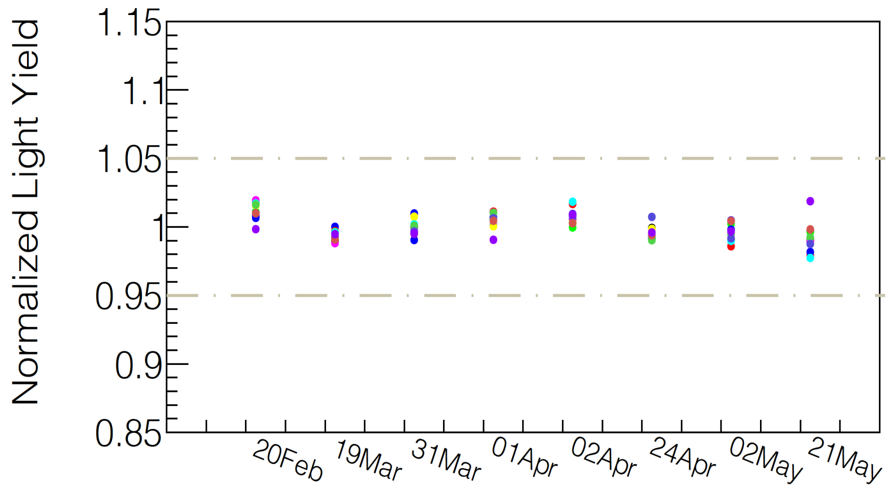
➢ Stability of the photo-sensor response over time:
  - -Gain stability (charge signal per avalanche)of a 12-H-MPPC typical channel (top)
  - -Crosstalk and after-pulse stability (charge per detected photon) for typical 3-S-SiPM channel (bottom).



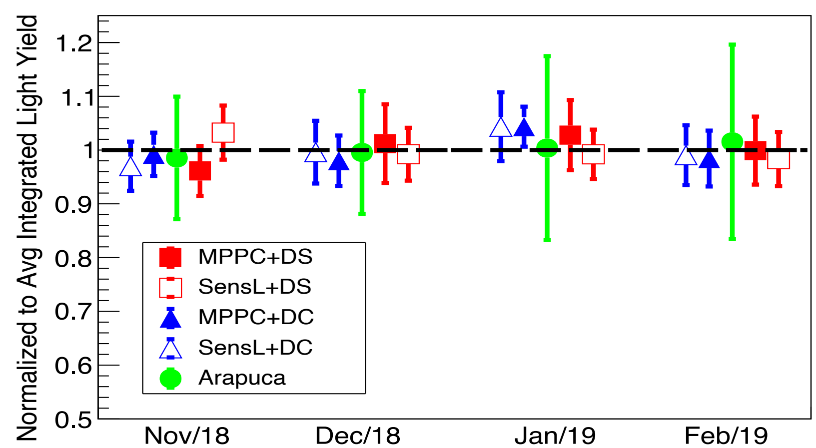


Stability of PD light response: ARAPUCA2 example

- **Stability of ARAPUCA light response measured by calibration system vs cosmic-ray muons.**



➢ **Stability of the S-ARAPUCA response** in APA 6 **measured with** the **UV-light calibration system (top)** and the stability measurements of all PD system channels in APAs 4-6 with **cosmic-ray muons** tagged by the CRT; S-ARAPUCA response shown in green **(right)**.



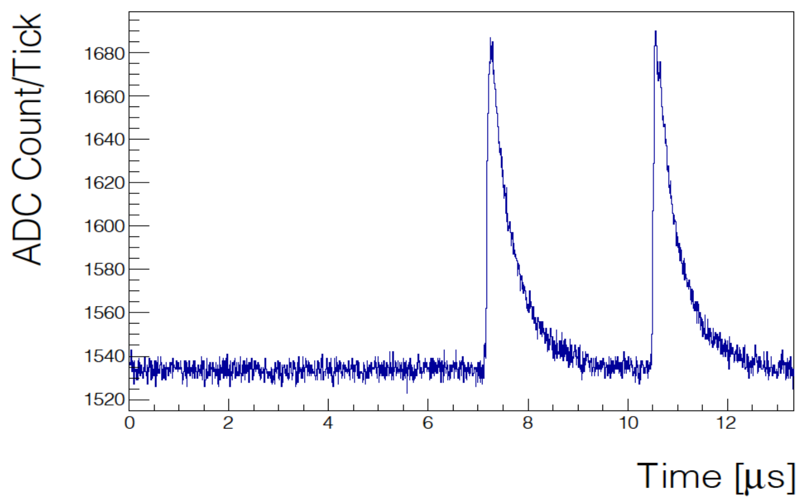
➢ integrated photon-detector light-yield as a response to cosmic-ray muon samples partitioned by collector and sensor technology.

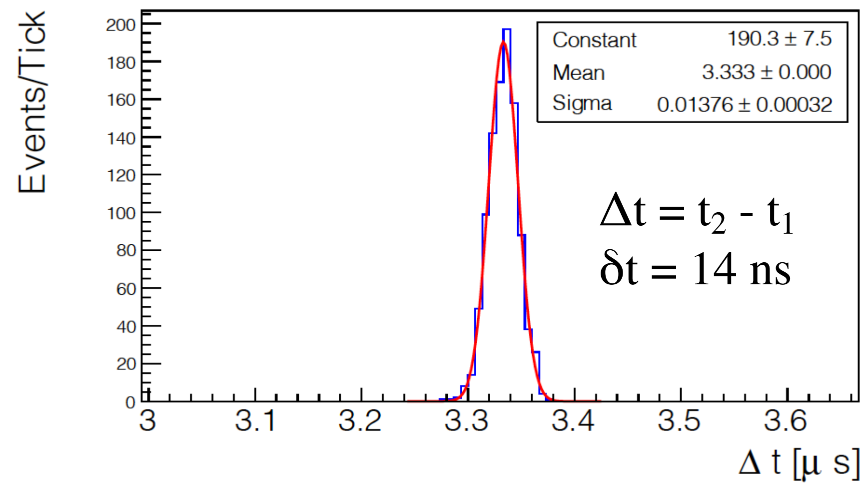
Timing measurements

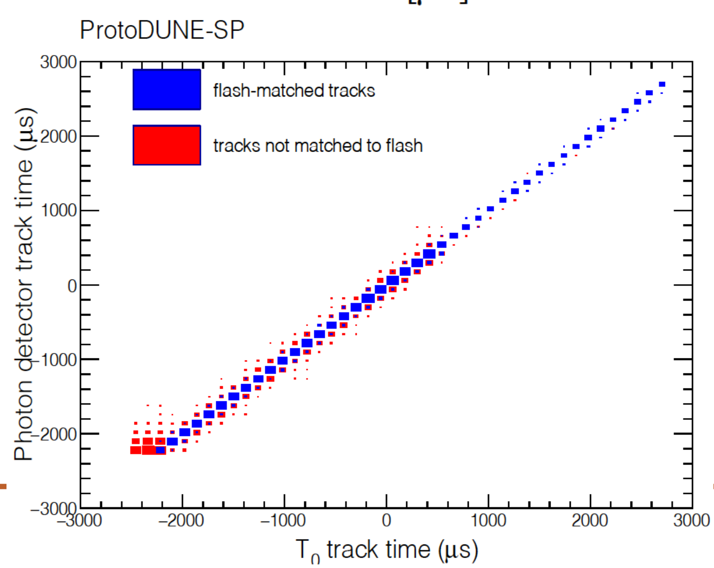
- PDS timing measurements

  -Time resolution in the time difference measurement between correlated light signals.

  -The rise time of each of the two signals from the common trigger was measured in the events collected with the calibration trigger







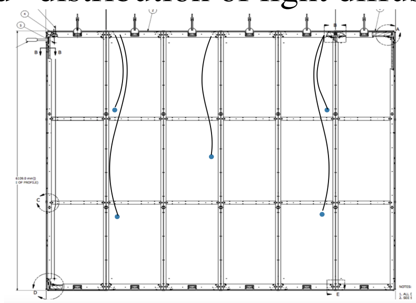
- PDS Timing Measurements: Correlation between the TPC track t0 time and the PDS flash time.

  => Not measured by calibration system but the calibration system helped us to know where to look.

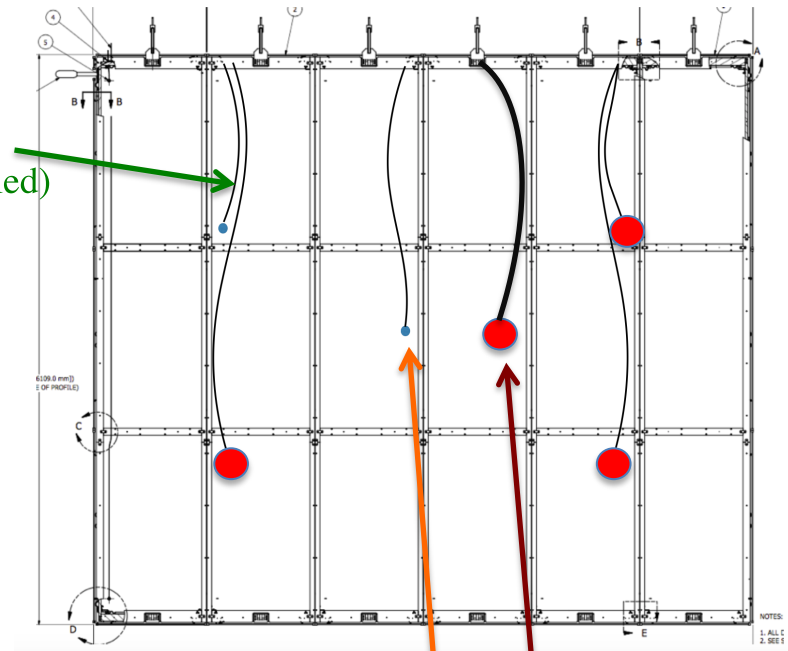
Bare Fiber Challenges

- ProtoDUNE Lessons Learned

  - “Planned” distribution of light diffusers at CPA



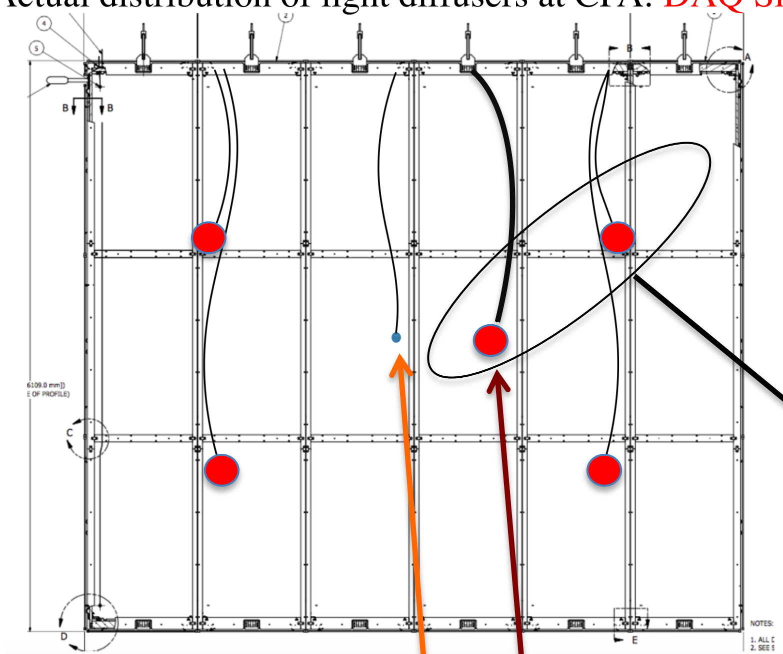
  - Actual distribution of light diffusers at CPA: Rack Side



Broken fiber
(when installed)

Fiber/diffuser moved from here to there (at installation stage; fiber likely cracked)

  - Actual distribution of light diffusers at CPA: DAQ Side



These two optical paths never connected
(from day 1…)

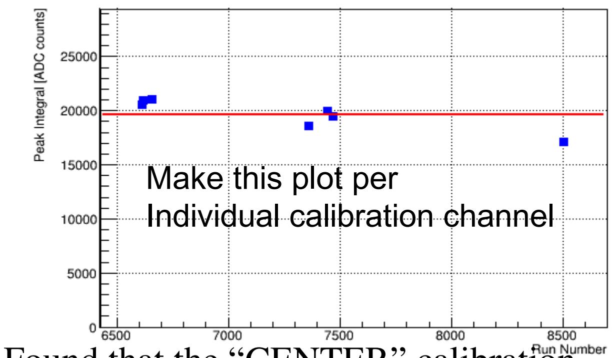
Fiber/diffuser moved from here to there (at installation stage)

Therefore, what worked from day 1
(and stayed working) is the the following
Calibration channels:
-DAQ side: UL, LL, LR
-Rack side: Center, LL, LR, UR

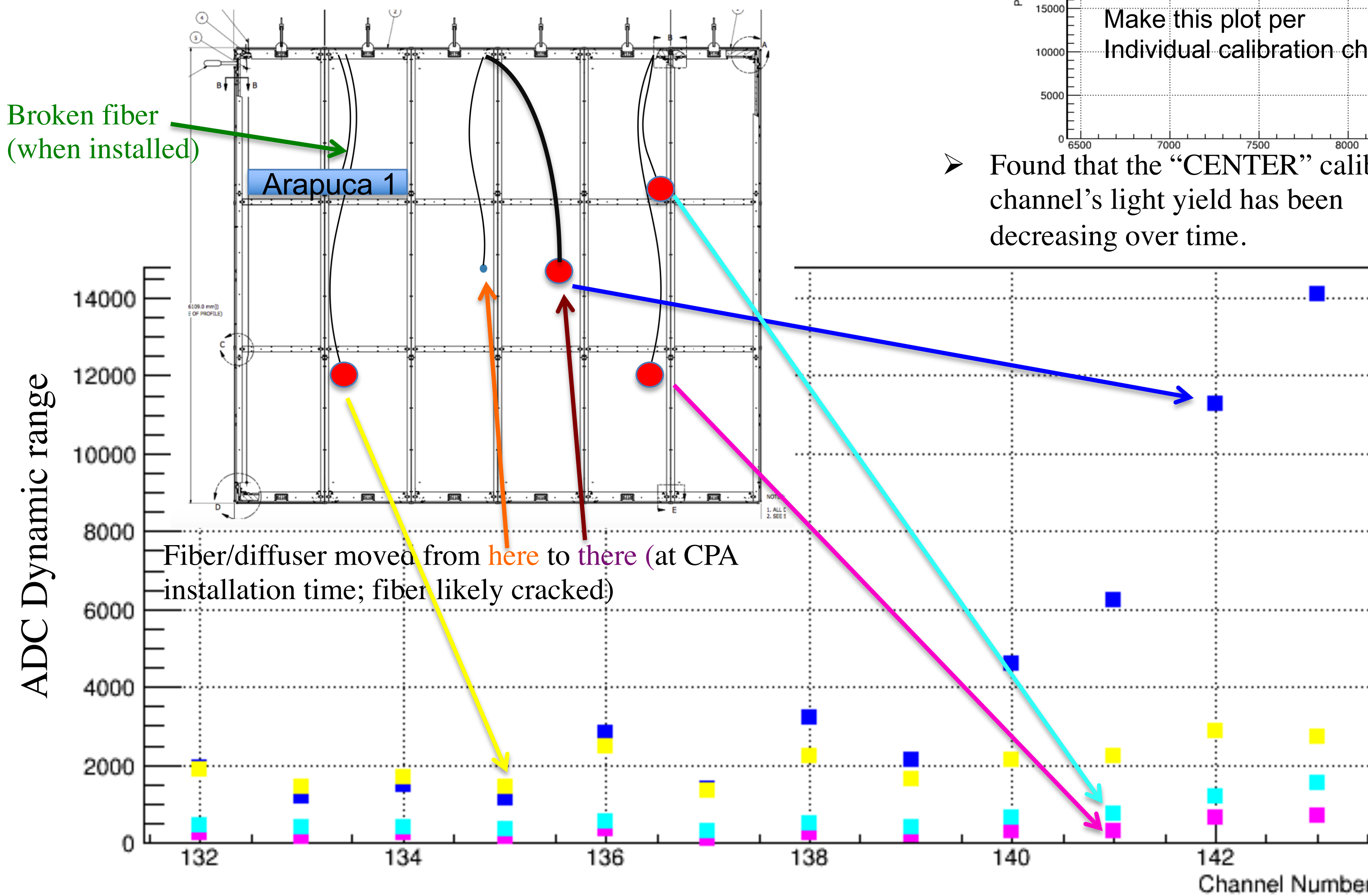
Bare Fiber Challenges (cont.)

- Special study: individual calibration channels vs sum
  - -single "CENTER" calibration channel's LY has been decreasing.

example: ARAPUCA 1 channel



- Found that the "CENTER" calibration channel's light yield has been decreasing over time.

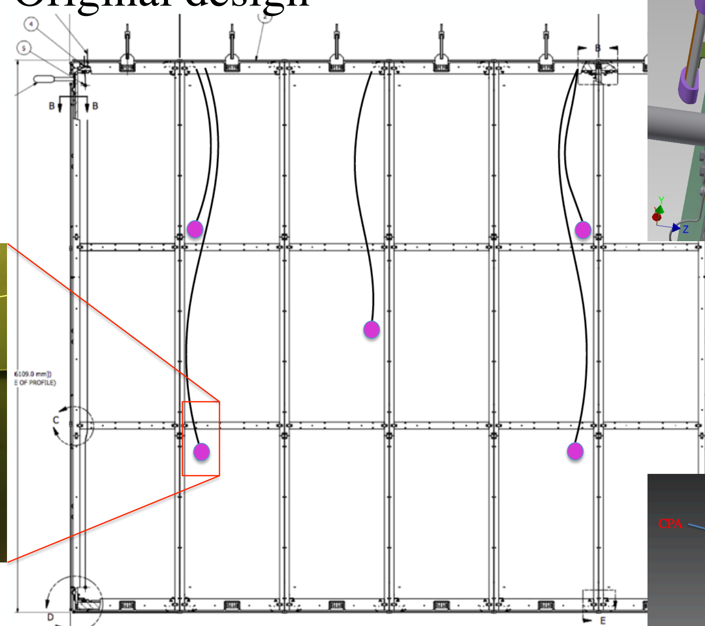


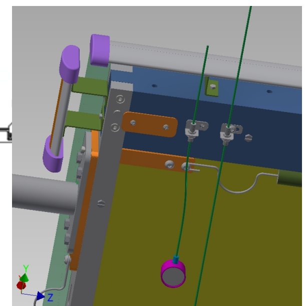
- From the plot above we learned that the single diffuser (1" design) effectively covers ~4 m x 4 m area.

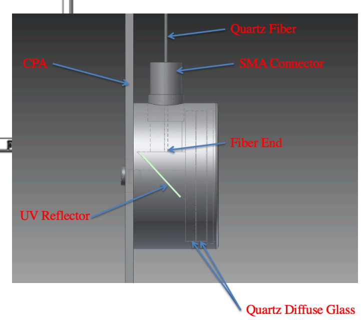
Diffuser Status

- Argonne and SDSMT joint effort on diffuser design, testing, and installation.
  - -Original Argonne design successful in ProtoDUNE-SP operation.
  - -A redesign of the original diffuser requested by CPA group (Magill et. al.); diameter modified from 1” to ¾” to meet the CPA installation requirements.
  - -New SDSMT design ready for prototyping (subject to available funds).

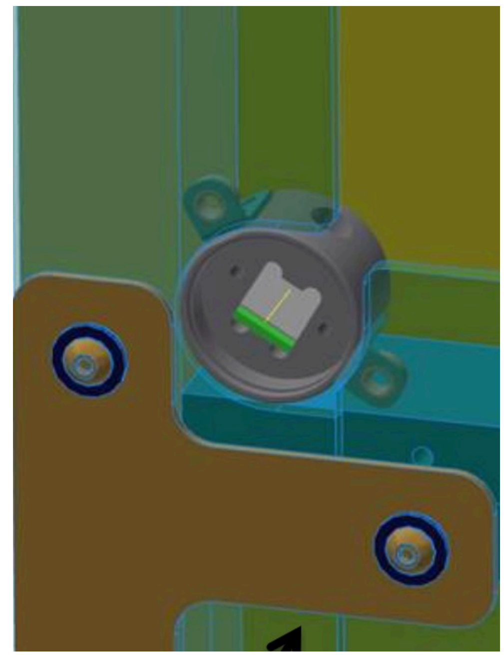
➢ Original design







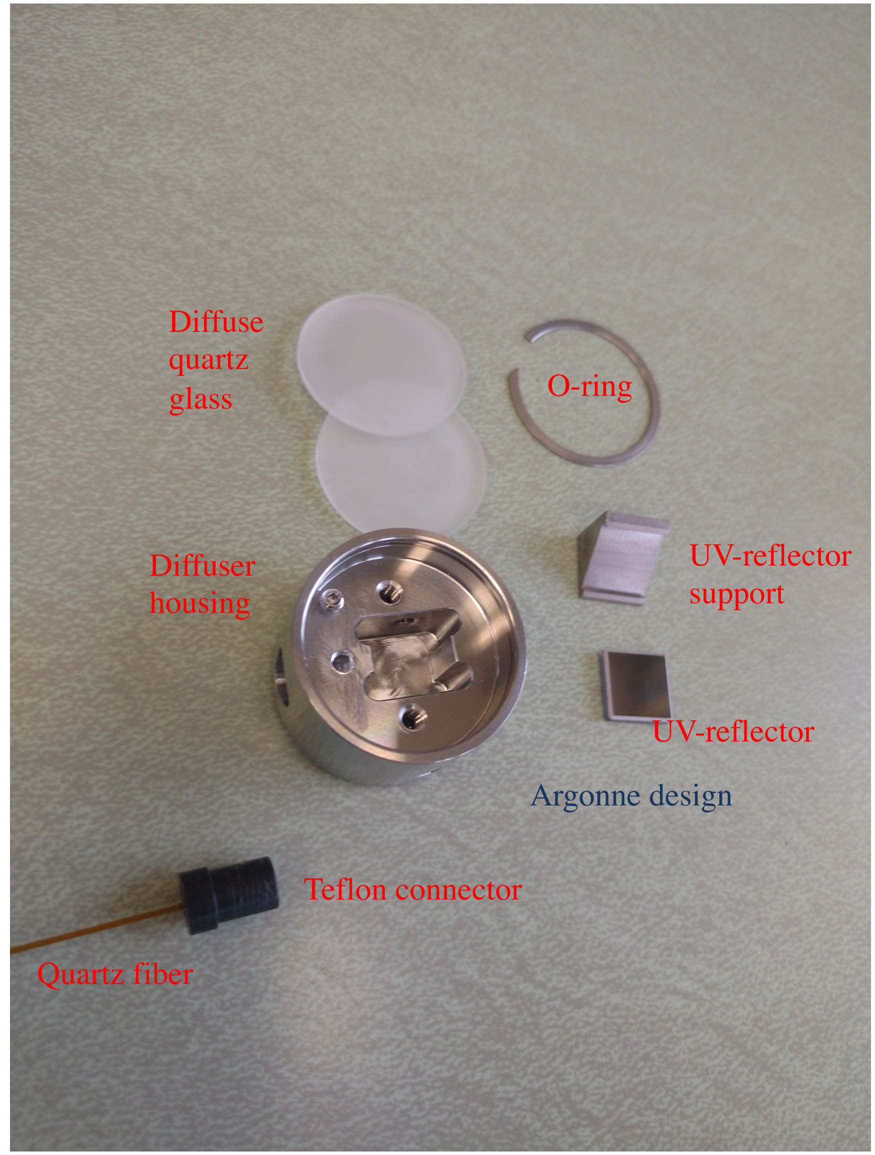
➢ Modified design



ProtoDUNE Design: Diffuser

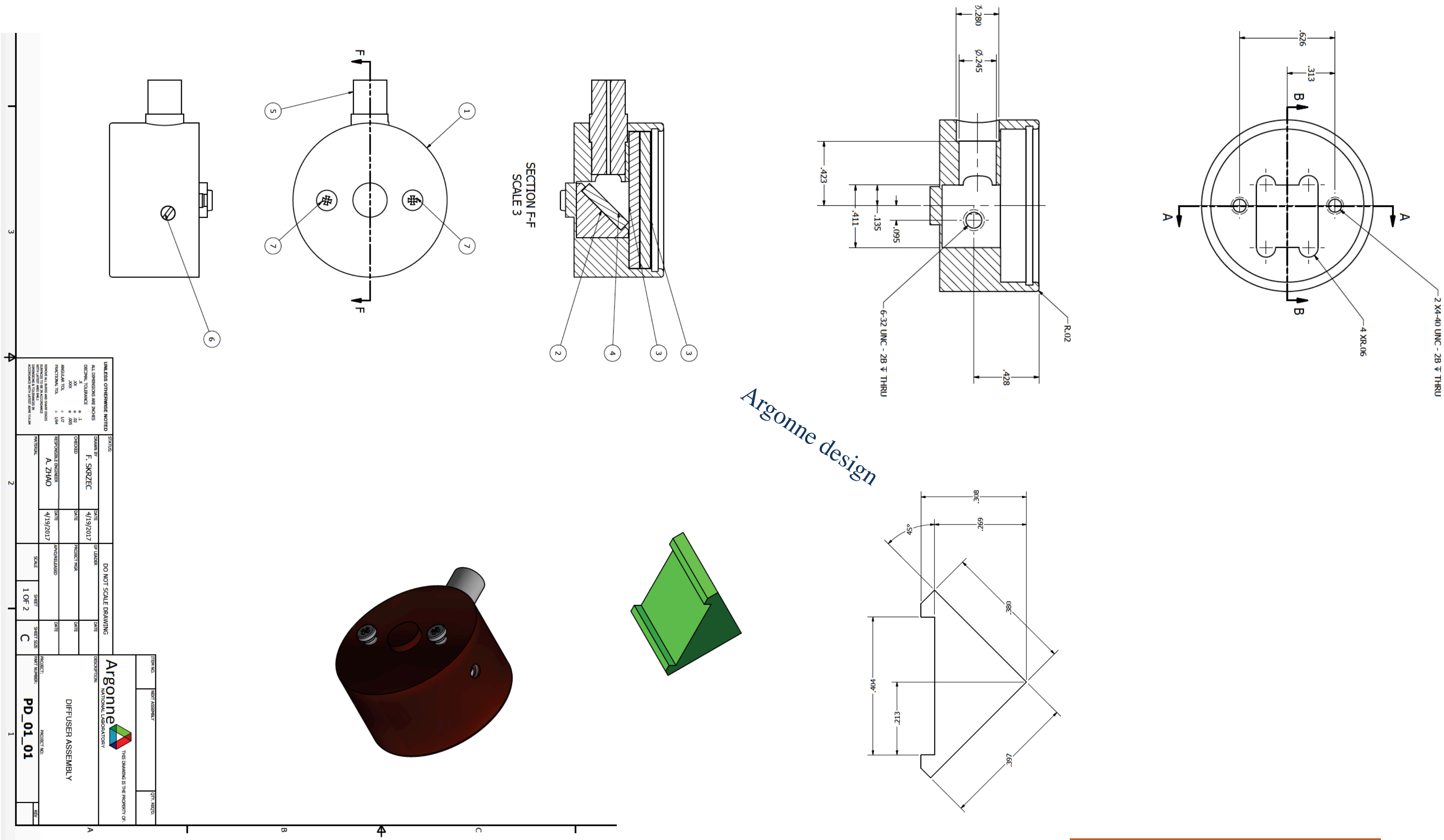
- Diffuser design implemented in ProtoDUNE

Argonne design



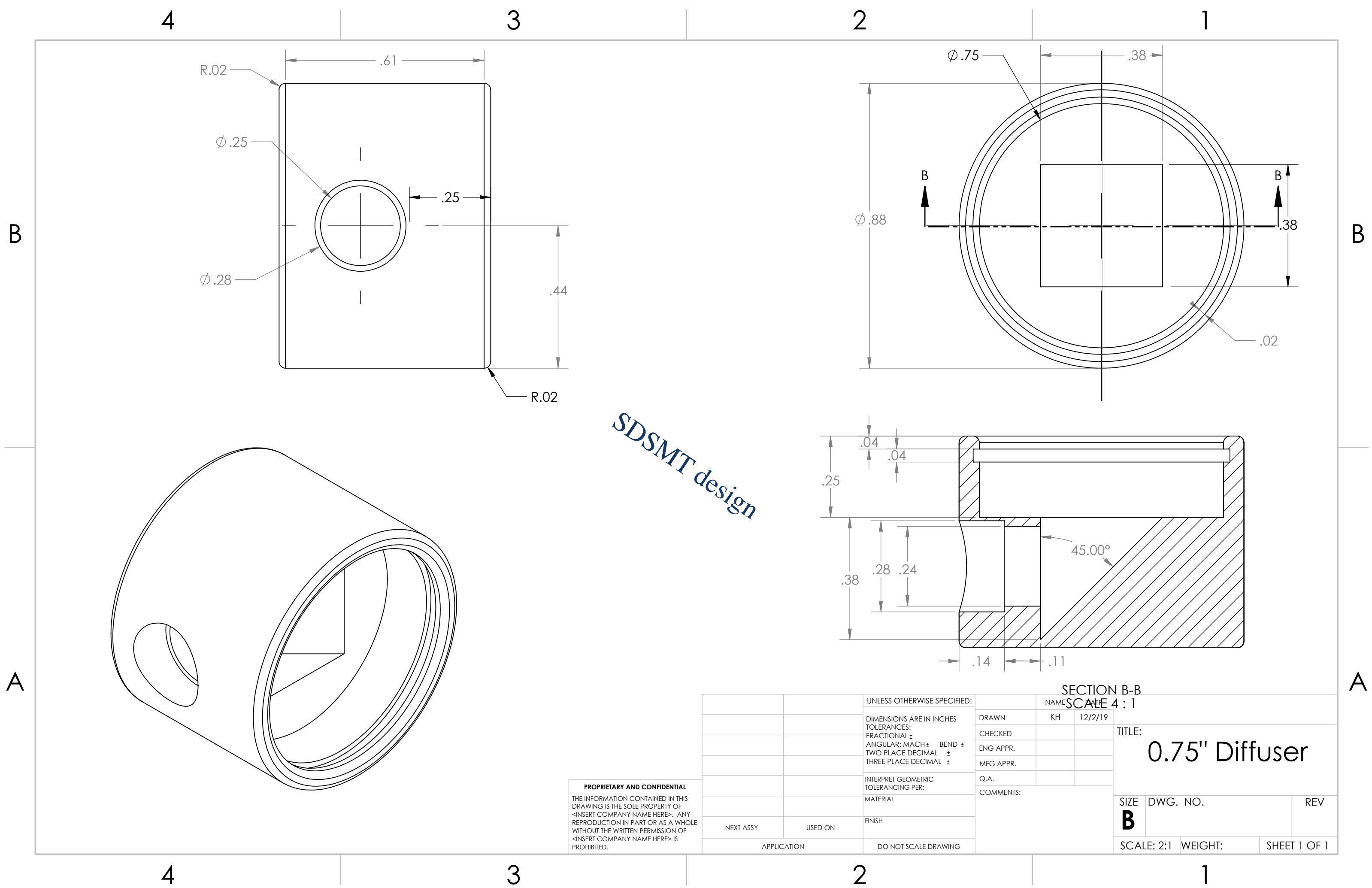
ProtoDUNE-SP Diffuser

- Diameter: 1”



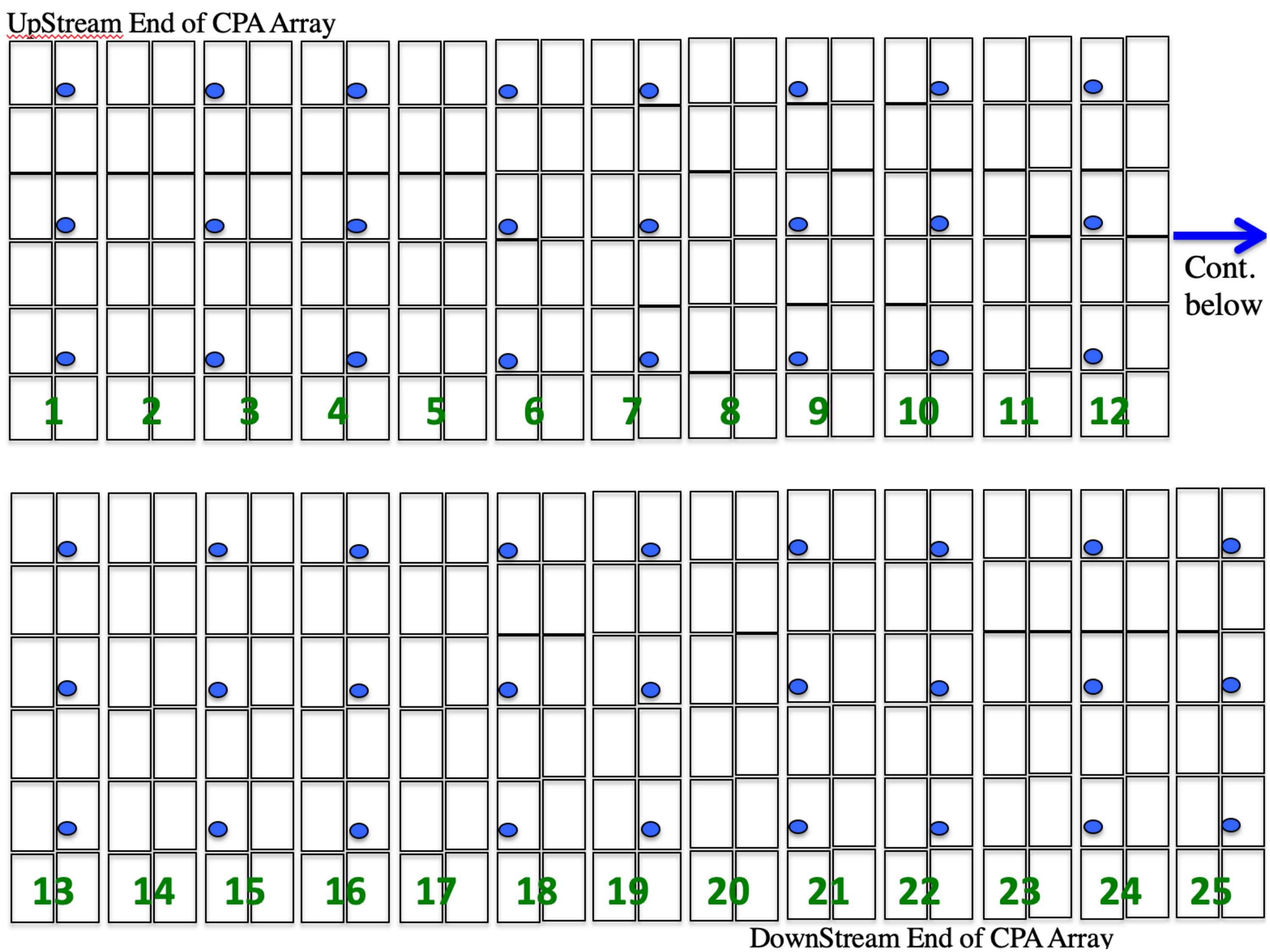
DUNE-SP Diffuser

- Diameter Modified from original 1" to proposed 3/4"
  -fit the diffuser under the CPA field strip



CPA Diffuser Configuration for DUNE FD

- A total of 51 diffuser per CPA side: a single diffuser covers ~3.6 m x ~4 m area
  -Need demonstrate capability with the ¾" diffuser.



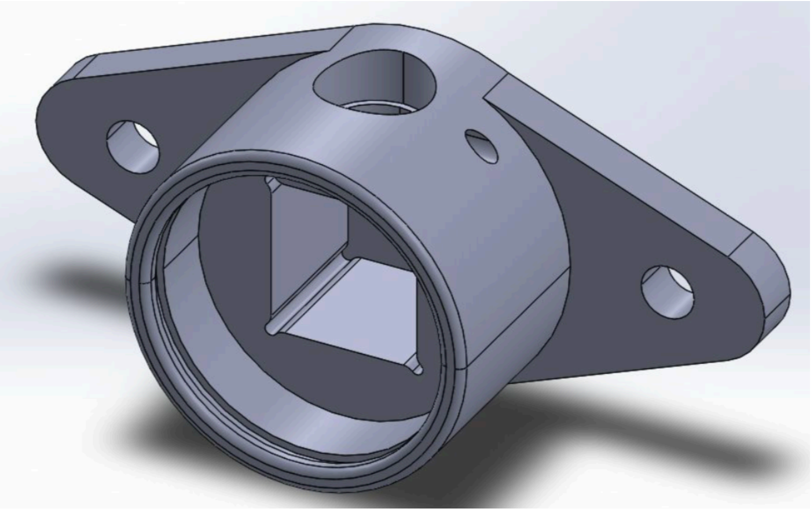
Alternative CPA Diffuser

- With availability of new technologies (ie: injection molding, 3D-priniting) consider alternative to SS-housing with a conventional machining
  -Injection molded diffuser housing as a possibility.

  -Injection molded diffuser housing is based on SDSMT drawing with addition of mounting ears on 2 sides.

  -Material could be PEEK or LCP (liquid crystalline polymer) – injection molded LCP part used on APAs mounted on a PC board.

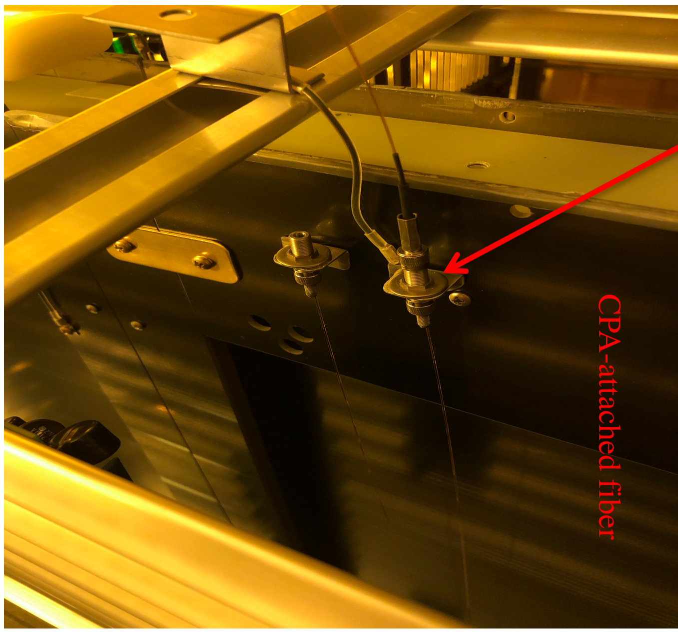
  -Plan to fabricate a diffuser sample at Argonne facility upon return to the lab; cost-effective?



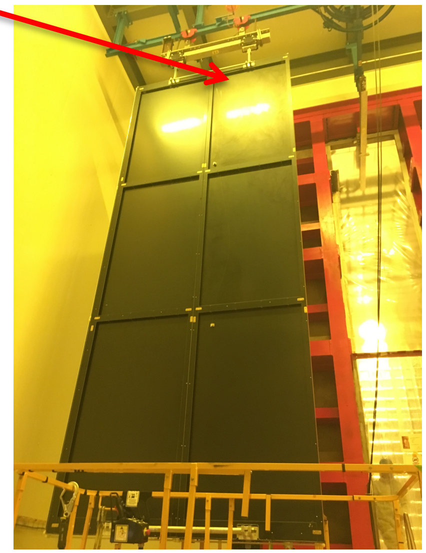
SDSMT Design

Cold Fiber Status

- ➢ Using this slide to illustrate ProtoDUNE-SP experience
  - -fiber installation (CPA fiber pre-installed with CPA, upper fiber pre-routed awaiting CPA).
  - -some of the lessons learned at ProtoDUNE (fiber connection, routing).



SMA connector bracket




molex

LASER COMPONENTS

Silica/Silica Optical Fiber
FDP-High-OH

Low-solarization Quartz Fibers

For fiber optic applications with light in the far UV range, the solarization effect has to be taken into account: in the optical fiber, the transmission of UV light at different wavelengths is reduced and can lead to inoperability (blindness) in unsuitable fibers.

FDP fibers, which are operational even after long periods of exposure to UV radiation, were specially developed for applications between 190 and 325 nm as a solution to the solarization effect.

Characteristics

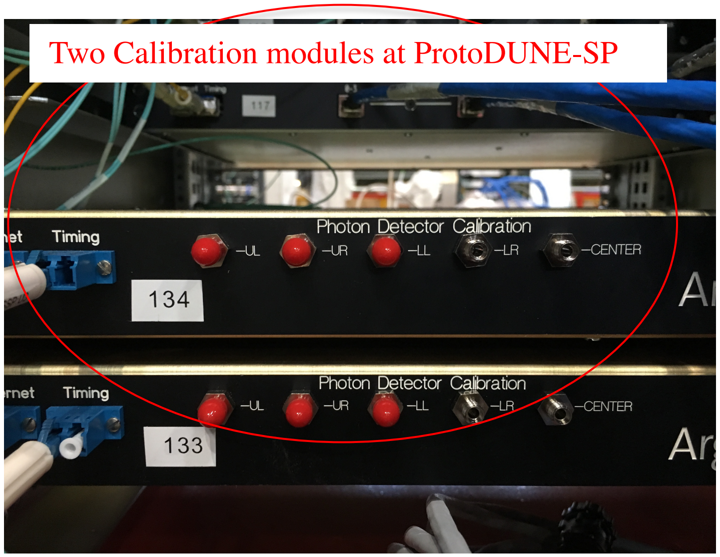
- Step index
- Numerical aperture: 0.22 ± 0.02
  full acceptance cone: 25.4 degrees
- Operating wavelength down to 190 nm
- Ultra high UV transmission
- Ultra low UV solarization
- Superior radiation resistance
- Sterilizable and bio-compatible – USP class VI*
- High laser damage threshold
- High -OH silica core, doped silica cad
- Polyimide buffer standard
- Polyimide concentricity < 3 μm
- Custom core sizes, buffers, and assemblies available
- Proof tested to 100 kpsi
- Operating temperature: -65 °C to +300 °C

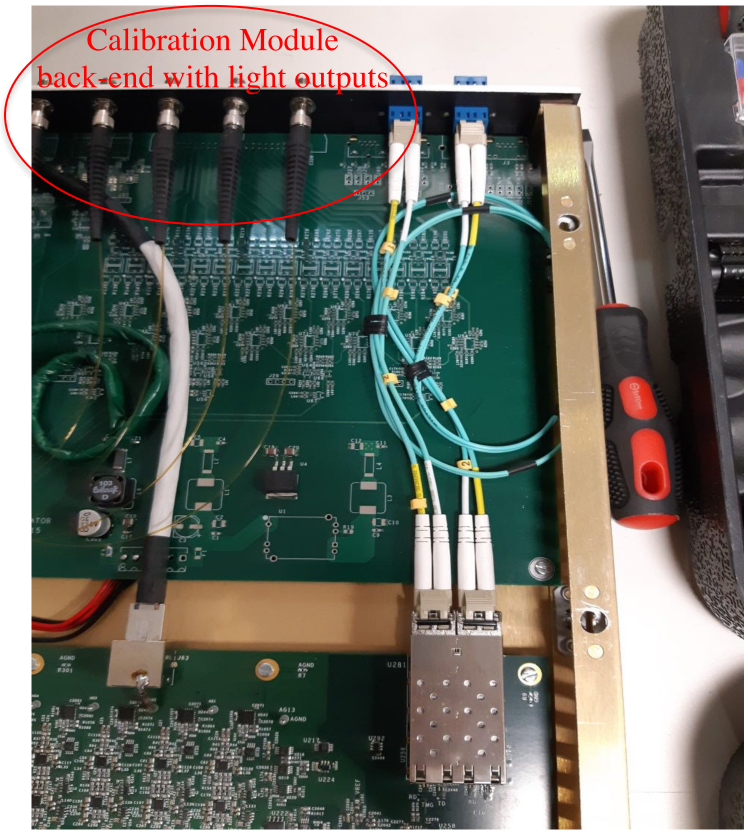
* The end manufacturer is responsible for bio-compatibility and sterilization testing and validation studies.

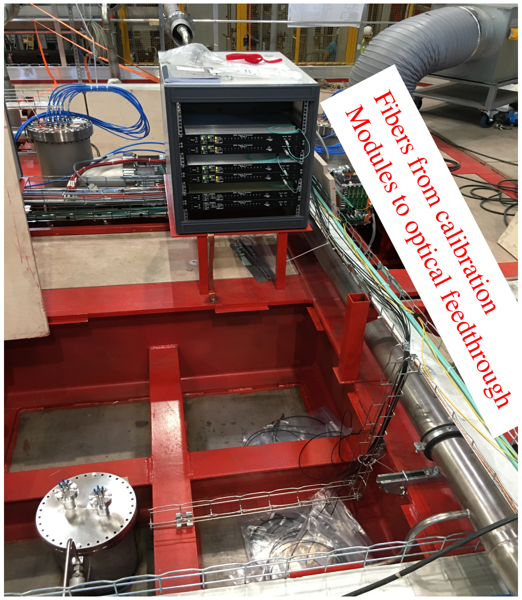
- A proposal was made to pack bare "cold" fibers into Teflon jackets
  - -Protect against cracks (for example: "warm" fibers packed in Teflon; no damage so far).
  - -Ease of installation in the cryostat.
  - -Production and testing of fiber samples at SDSMT when funds available.
- We will evaluate a possibility to use cheaper optical components
  - -Test a plastic fiber option vs quartz fiber option (possible with 355 nm LED).

Calibration Electronics Status

- Electronics modules with integrated UV-LEDs at ProtoDUNE-SP:
  - -Implemented grounding, all-on-fiber connections, floating power supplies.
  - -Implemented Trigger/Timing logic and interfaces.





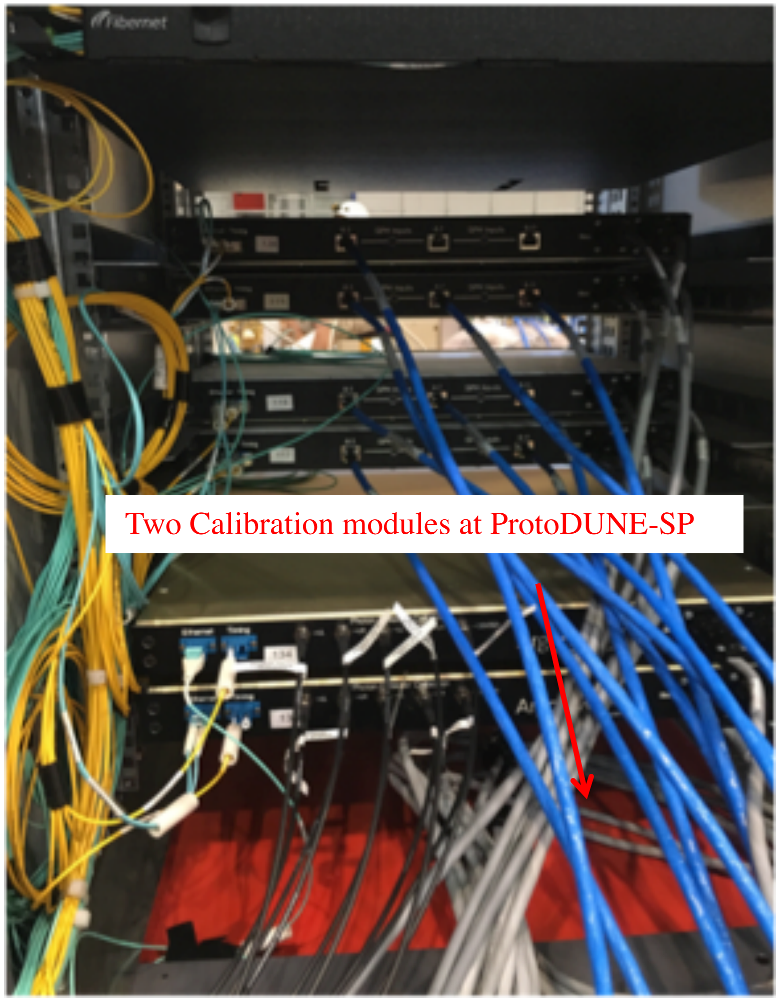


Calibration Electronics Status

- Both prototype modules fully operational
  -See results above.
  -ProtoDUNE-I based on the calibration module with five calibration channels per module.

- Plan for ProtoDUNE-II/DUNE:
  -Assume Calibration Module with 12 light output channels (per single calibration module)
  -Proposal: build a twelve-channel module and test/operate with ProtoDUNE-II

- Going to DUNE:
  -Modify existing SSP (photon-readout modules) to calibration modules by adding light sources and monitoring feedback.
  -Fully compatible with DUNE Timing and Slow Control.
  -Slow control documentation/interface defined.

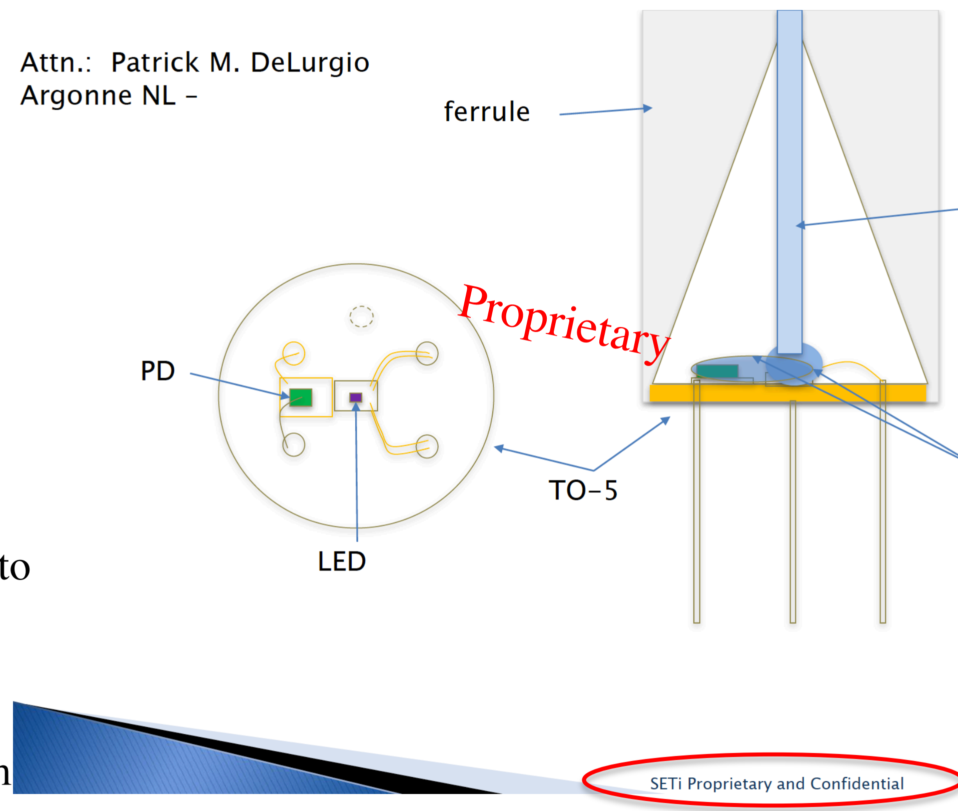


UV Light Source Status

- UV light source: ANL LED design developed with SETi at the time of ProtoDUNE-SP realization; was ready to go for DUNE Far Detector.
  - -Developed a high-power LED with monitoring photo-diode.
  - -Formerly predicted a cost for large quantity.
  - -However, SETi high power UV LED and feedback PD R&D abandoned ("too long to wait for orders").

- The light source we originally developed included
  1) custom high-power UV-LED 275 nm
  2) reference pin diode on the same chip
  3) ferrule for packaging and protection
  4) precisely aligned fiber (wrt LED)
  5) SMA connector on outer fiber end
  6) work on mounting and alignment

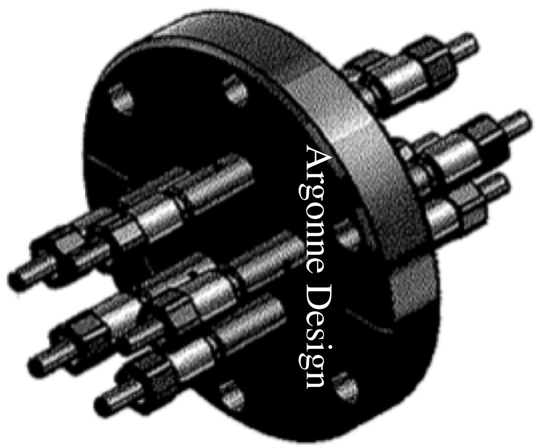
- Looking for alternative
  - -Started discussions with other vendors to evaluate a capability and cost.
  - -LED + feedback sensor.
  - -Will want to evaluate a possibility to use cheaper optical components:355 nm near-UV vs 275 nm deep-UV LEDs.
  - -Will continue with R&D funding.



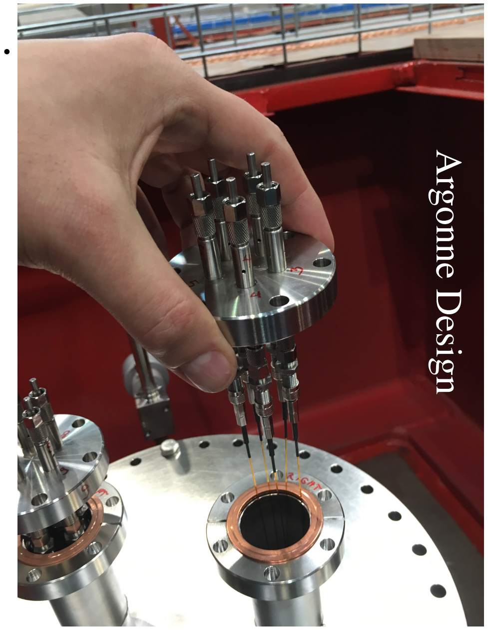
SETi Drawing

Optical Feedthrough Status

- Great positive experience with ProtoDUNE-SP optical feedthrough.



Five channel optical fiber feedthrough

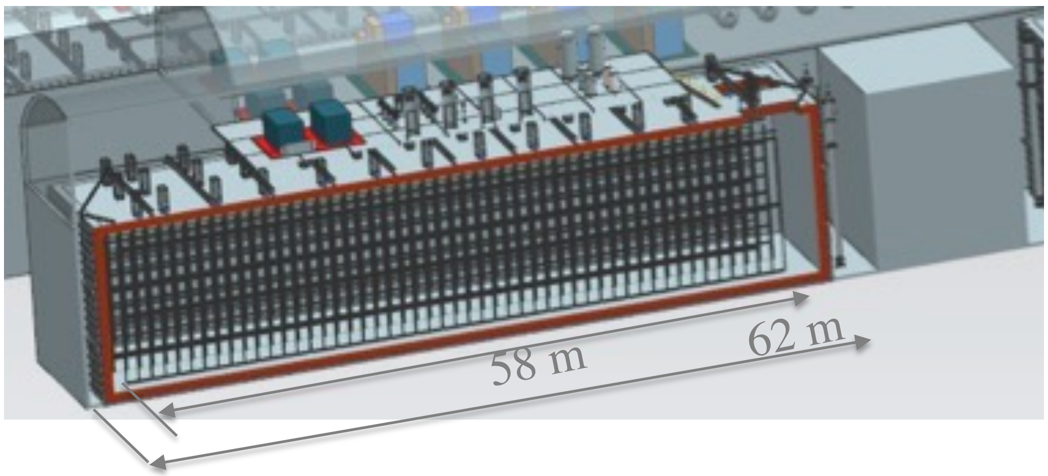


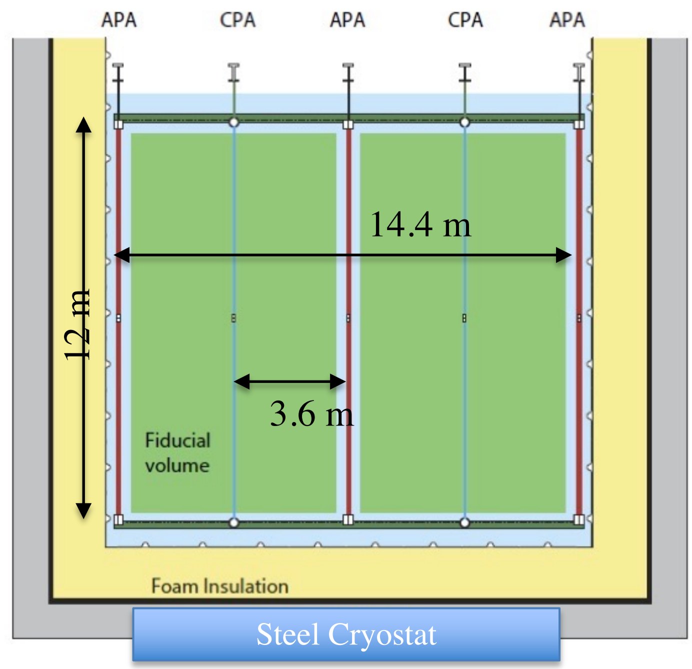
- Argonne group continued to work on the cost-reduction and to discuss a large quantity for DUNE Far Detector.

- A verbal communication with a potential vendor is promising
  - -Argonne will receive a drawing of re-designed optical feed-through upon purchase of first feedthrough samples, once the DUNE funds are approved.
  - -Need to test optical transparency and leakage (a vacuum test).
  - -Potentially significant cost reduction anticipated if new design verified.

DUNE Far Detector photon calibration system

- Use ProtoDUNE-SP baseline with experience/expertise for design of the DUNE photon-detector calibration/monitoring system
  -scale-up to DUNE

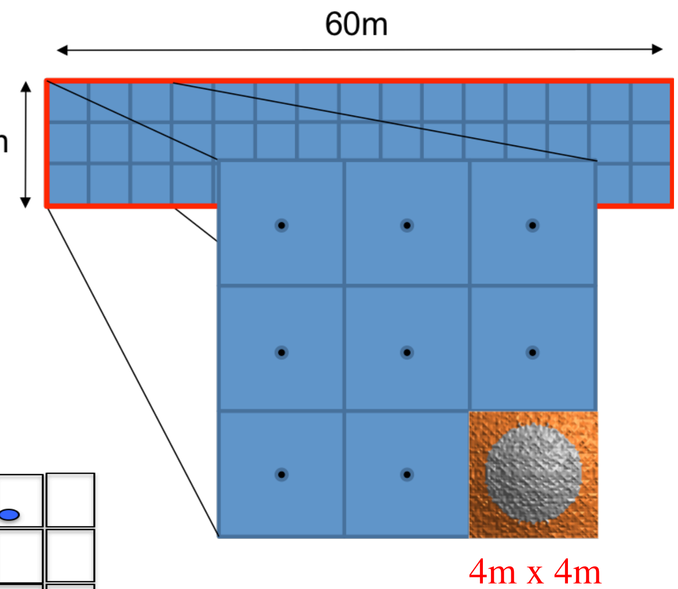


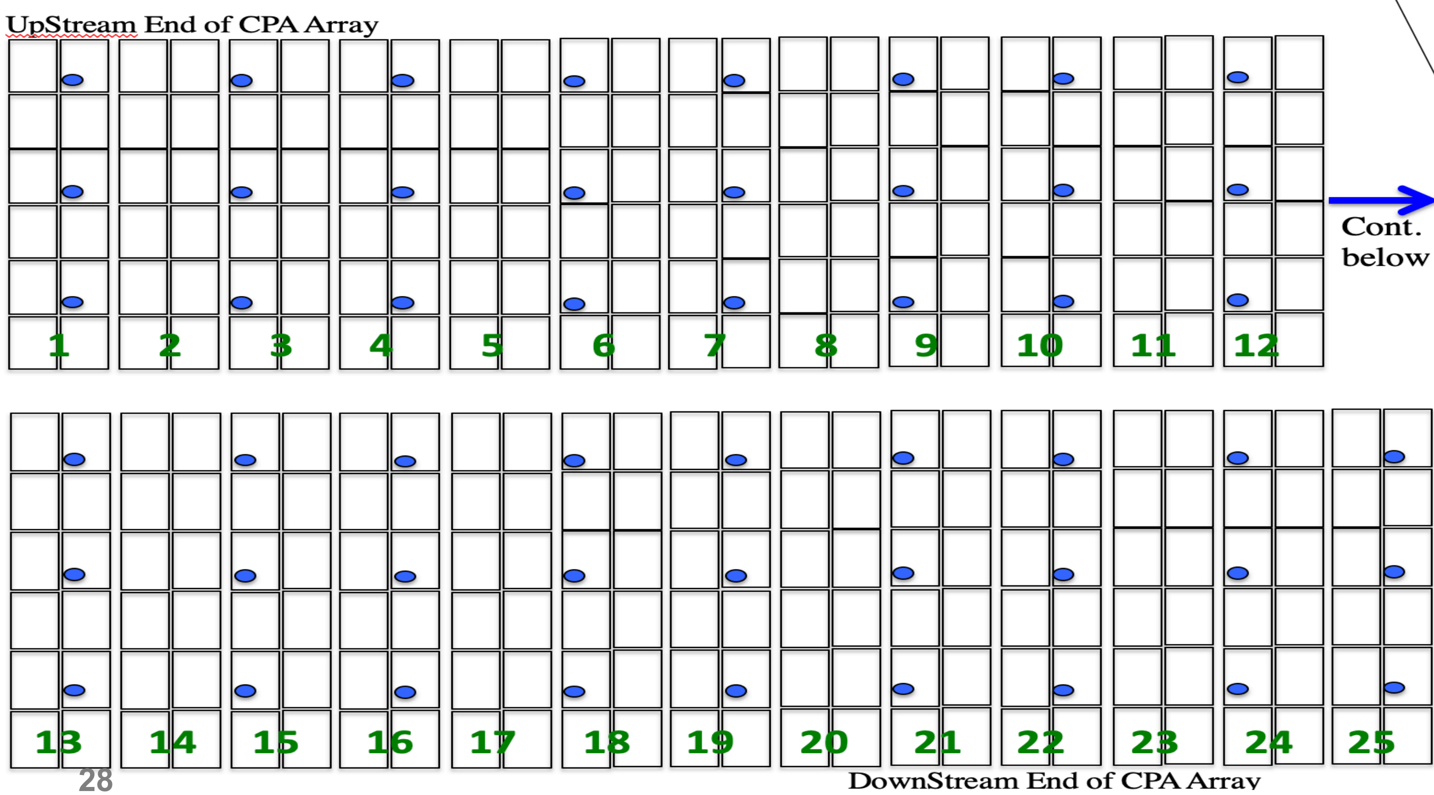


- Original proposal from 2019: Diffusers on both sides of each CPA.
  -However, X-ARAPUCA is "symmetric" for a light coming from both sides
  -It is possible to reduce cost: "CPA 1" covered by diffusers on both sides; "CPA 2" covered by diffusers on "outer" side only.
- Saves 25% of the total initial cost.

CPA Diffuser Configuration for DUNE FD

- A total of 51 diffuser per CPA side: a single diffuser covers ~3.6 m x ~4 m area
  - Need demonstrate capability with the ¾" diffuser.
  - Simulation (right) and analyzed data (see ProtoDUNE-SP results) show a single diffuser at CPA illuminates 4x4 m^2 on APA.
  - We would want to overlap of photons from adjacent diffusers for cross calibration.
  - This configuration offers such an opportunity.





Summary and Next Steps

- ProtoDUNE-SP Calibration/Monitoring system successfully implemented and fully operational.
- Analyzed and used photon-detector calibration data in ProtoDUNE-SP
  - -Collected calibration system data at various pulse heights, pulse widths, repetition rates.
  - -Characterized and calibrated photon-system: gain, cross-talk, time-resolution, channel-to-channel timing, and PDS stability; used in understanding of trigger time-delays.
- We assume 3 out of 4 CPA sides will be covered by diffusers
  - -Provides 25% cost saving.
  - -51 diffuser/side => 153 calibration channels.
  - -Requires same number of fiber sets, calibration module channels, optical feedthrough ch#.
  - -Spare components will be needed.
- We have access to PDS signal flanges; optical feed-throughs will be mounted there.
- Next steps:
  - Fabricate and test a new diffuser prototype.
  - Acquire a new optical feedthrough and perform optical and vacuum tests.
  - Fiber routing from feedthroughs to CPAs for DUNE will be defined.
  - We will evaluate a possibility to use cheaper optical components
    - -Test 355 nm near-UV light vs 275 nm deep-UV.
    - -Test a plastic fiber option vs quartz fiber option.
  - Build a new calibration module with 12 channels with optimized light source.
- Test the final system in ProtoDUNE-II and verify Far Detector design.

BACKUPS

Calibration Scope Review: Charge

- Photo-Detector Calibration System NOT initially planned in this workshop
  - -our system is in FD PDS scope
  - -asked to present on short notice

Charge for Calibration/Cryogenic Instrumentation Workshop

February 25, 2020

Context: Initial workshops focusing on the scope of calibration and cryogenic instrumentation systems for the DUNE Far Detectors were held on June 18-19, 2019 at CERN. Review committees were assigned for each topic and responded to sets of charge questions drafted prior to the workshop. The final reports from the calibration and cryogenic instrumentation review committees are posted to DUNE DocDB 15812 and DUNE DocDB 16034. Follow-up workshops on the time scale of 6-9 months were deemed necessary to address the issues raised by the review committees in these reports. DUNE is planning to hold these follow-up workshops on May 7-9, 2020 at CERN.

The initial operation of the ProtoDUNE-SP detector is expected to have ended prior to the upcoming workshop. Several different types of cryogenic instrumentation were deployed in ProtoDUNE-SP, for which performance information is available. DUNE also has some operational experience with alternative instrumentation currently deployed in the ProtoDUNE-DP detector. Except for the photon detection monitoring systems, no calibration systems were in place for the initial running of either ProtoDUNE detector. It is hoped that some testing of a Pulsed Neutron Source as a calibration source for the ProtoDUNE-SP detector can be accomplished prior to the upcoming workshop.

An established DUNE policy is that any piece of instrumentation to be deployed in the Far Detectors must first be deployed and validated in one of the ProtoDUNE detectors. A second period of ProtoDUNE-SP operations based on updated "Module Zero" far detector components is planned for 2022. All instrumentation to be installed in the ProtoDUNE-II SP detector must be produced and available at CERN by September 2021.

Currently, funding has been identified for only a small fraction of the proposed calibration and cryogenic instrumentation systems for the DUNE Far Detectors. Ideally, the CALCI consortium will work with DUNE management to identify institutions/funding agencies that can provide resources for currently unfunded systems. If there are essential systems for which resources cannot be identified, DUNE will need to look for alternative methods for delivering these systems such as tapping into common collaboration resources. Module Zero Far Detector components to be installed in ProtoDUNE-II SP are ideally to be provided by the institution/funding agency that will deliver these components for the DUNE Far Detectors. In the case of some critical systems for which funding has not yet been identified (e.g. the ionization laser system and pulsed neutron source), the DUNE-US project is currently supporting the development of necessary instrumentation for the ProtoDUNE-II SP detector with the expectation that another partner will be able to step in and deliver these systems for the Far Detectors.

Review Committee Charge – Part I: The review committees are asked to look at each of the proposed systems and evaluate the following:

Calibration Scope Review: Charge (II)

- Does the system have a well-justified role in safeguarding the far detectors and facilitating their operation, and if so, what is the minimum amount of system scope needed to carry out this role? (Cryogenic Instrumentation only)
- Does the system have a well-justified role in facilitating the analysis of far detector data, and if so, what is the minimum amount of system scope required to fulfill this role?
- Have all technical issues related to the feasibility of the system (including those raised in the previous workshops) been resolved?
- Are there any risks to overall detector performance associated with the implementation of the system, and if so, is there a plan in place for mitigating these risks?
- Is there a credible plan in place for demonstrating system performance in ProtoDUNE-II?
- Does the functionality of the system justify its overall cost?

Note that the workshop is not intended to serve as a design review for the systems under discussion. As stated above, the review committees should attempt to assess the technical viability of each proposed system but not worry directly about more detailed technical questions such as how cryostat penetrations will be allocated among the different systems. The intention is to first define the overall required scope for calibration and cryogenic instrumentation systems and then work to figure out how to best globally integrate them. If the committees believe that certain calibration and cryogenics instrumentation systems are likely to have interference issues with other existing detector systems, these concerns would be appropriately be addressed as part of their evaluation of potential risks to overall detector performance.

Review Committee Charge – Part II: Based on their evaluations of the individual systems, the review committees are asked to classify each of the proposed systems in terms of the following categorizations:

1. Essential – Experiment should not be run without this system in place.
2. Highly-desirable – Strong justification for including this system but not viewed as absolutely necessary.
3. Advantageous – Good arguments exist for why this system might be useful but not fully justified in terms of its contribution to overall detector performance.
4. Debatable – System could potentially be useful but not fully supportable based on current arguments.

Note that when making these assignments, the committees should do so within the context of the full list of proposed systems. If the functionality of one system is seen as fully or partially redundant with another on the list, this information should be accounted for when making the individual assignments. In some cases, it may also be appropriate to place a single system into multiple categories based on differing levels of scope. A hypothetical example would be if one were to classify an ionization laser system with 6 lasers as essential, with 12 lasers as highly-desirable, and with 20 lasers as advantageous. As a final step, we also ask the review committees to attempt to prioritize the systems that are assigned within each of the above categorizations. The current list of proposed calibration and cryogenic instrumentation systems are provided here for reference.

Proposed Calibration Systems:

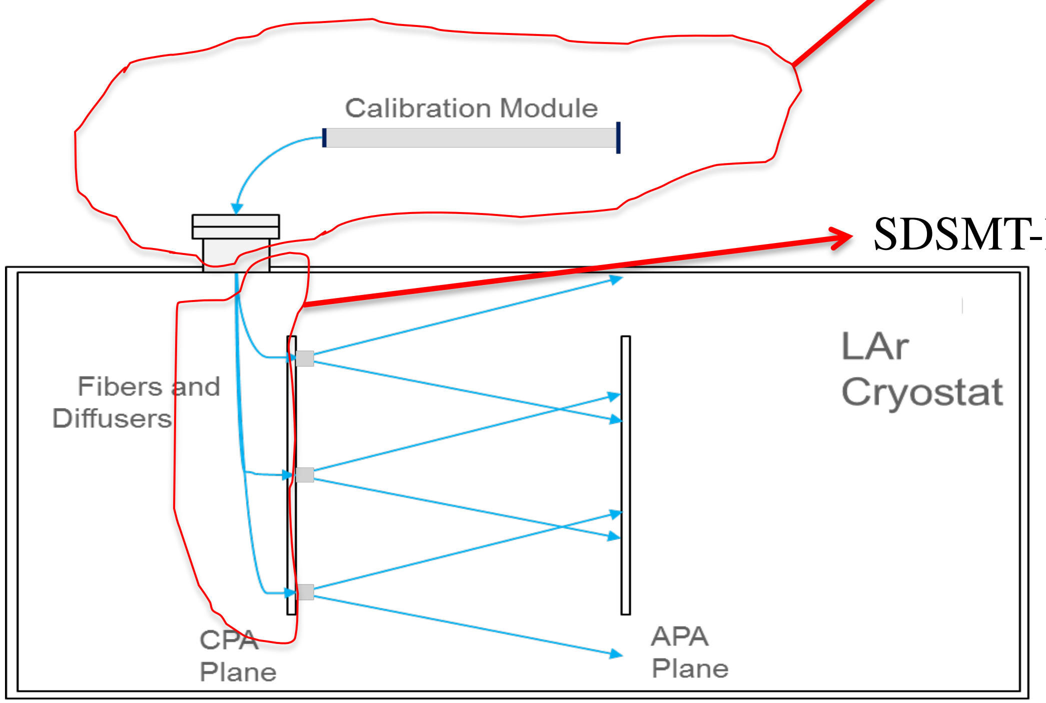
1. Ionization Laser System
   a. Twelve laser ports penetrating TPC through top field cage modules (baseline)
   b. Additional eight laser ports outside TPC volume that direct beams through the profiles of end-wall field cage modules (proposed upgrade)
2. Laser Beam Location Systems (proposed PIN-diode and Mirror options)
3. Photo-electron Laser System (fibers attached to APAs direct light onto photo-electric targets attached to CPA planes)
4. Pulsed Neutron Source
   a. Two sources located above two of the existing four cryostat manholes (baseline)
   b. Additional source locations in central region of cryostat (proposed upgrade)
5. Radioactive Source System (deployment system for lowering a radioactive source along outside ends of TPC drift volume)

Proposed Cryogenic Instrumentation Systems:

1. Temperature Sensors
   a. Within the TPC volume (attached directly to the APAs)
   b. Outside of the TPC volume
   c. Static temperature monitors
   d. Dynamic temperature monitors
2. Purity Monitors
   a. Inline monitors for cryogenic system
   b. Monitors sitting inside of cryostat (short and long options)
3. Level Meters
4. Cameras
   a. Warm (in ullage)
   b. Cold (in liquid)
5. Pressure Sensors
6. Gas Analyzers

Division of Effort

- Defined in meeting with the DUNE Project Leaders Eric James and Tim Bolton, held September 2019 at Fermilab
  - -supported involvement of SDSMT group, led by prof. David Martinez, to lead testing integration of optical fibers, and integration with CPA components (diffusers)
  - -ANL (Z. Djurcic et al.) responsible for calibration electronics and flange/feedthroughs, warm fibers
- SOWs in progress (since 10/2019)



ANL-led:

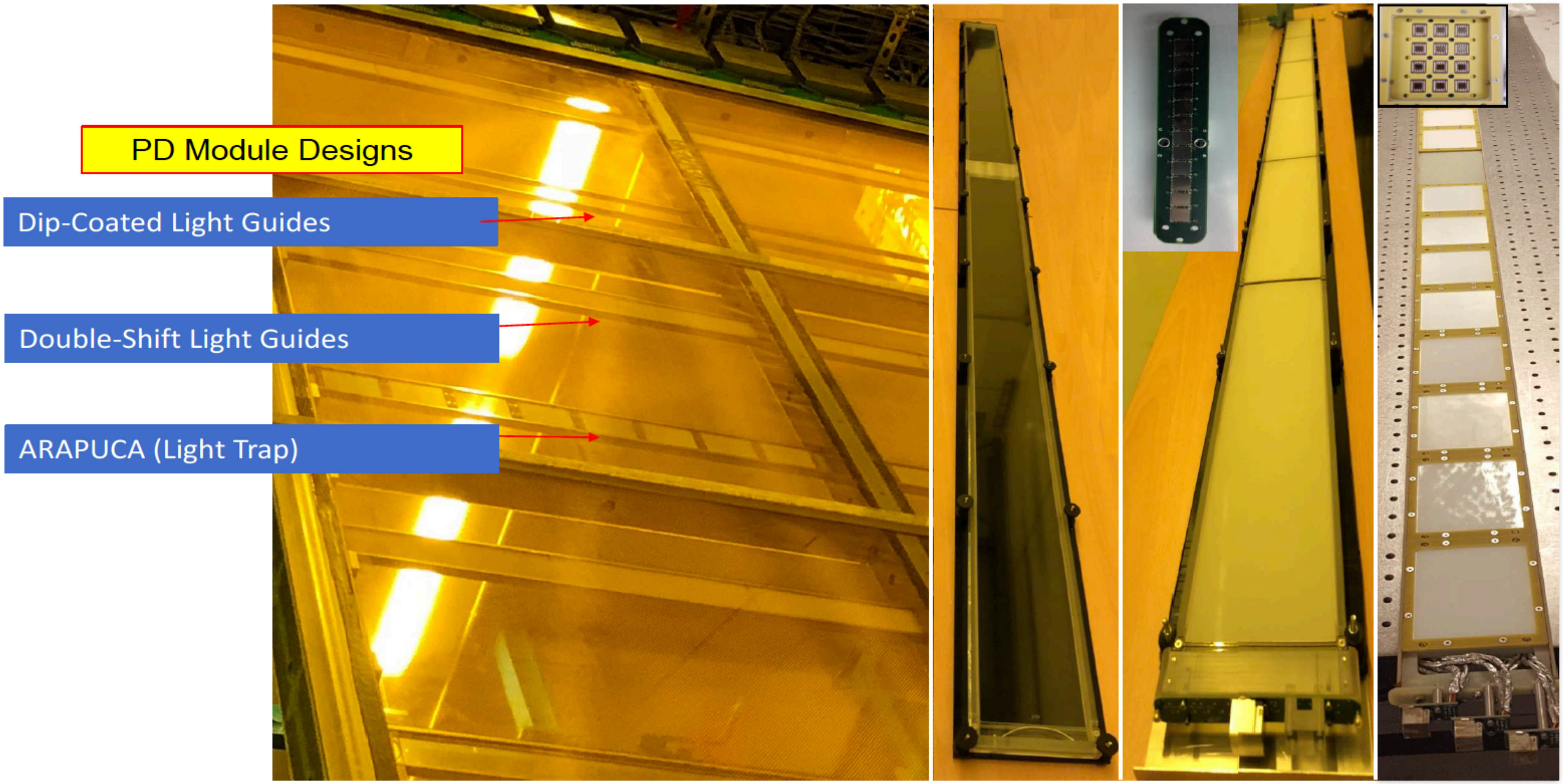
- Calibration Electronics
  - -electronics control/interface
  - -light sources
  - -feedback loop
- Optical feedthrough design fabrication
- "warm" fibers at cryostat top

SDSMT-led:

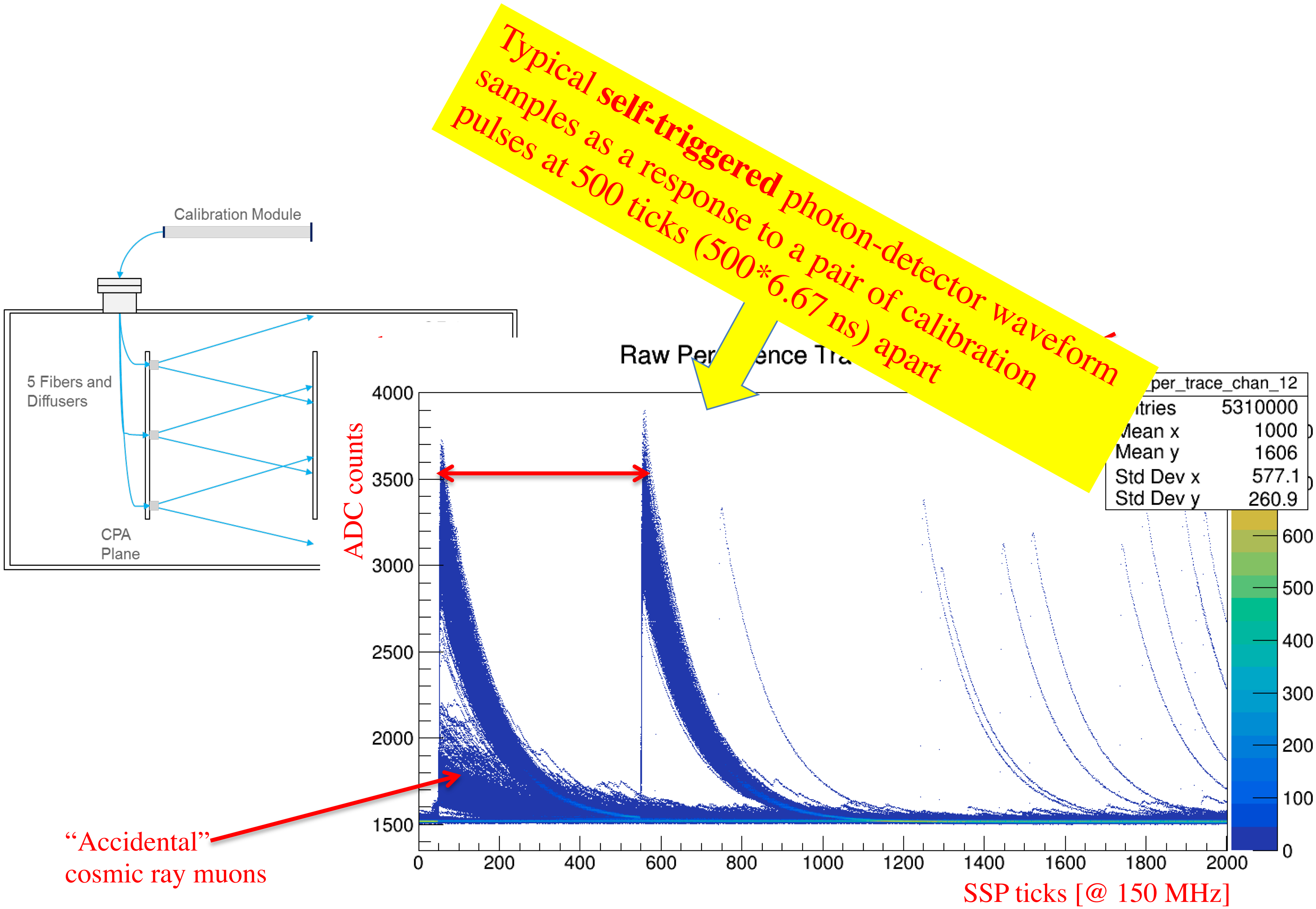
- "cold" fiber testing and fabrication
  - -feedthrough to CPA top fibers/routing
  - -optimization of fiber connections at CPA top
  - -CPA fiber fabrication
- Diffuser testing and fabrication
  - -ProtoDUNE-I design verification
  - -interface with CPA/ANL groups

(oversimplified schematics)

PD Module Designs: ProtoDUNE-SP



Muon signals vs double calibration system waveform



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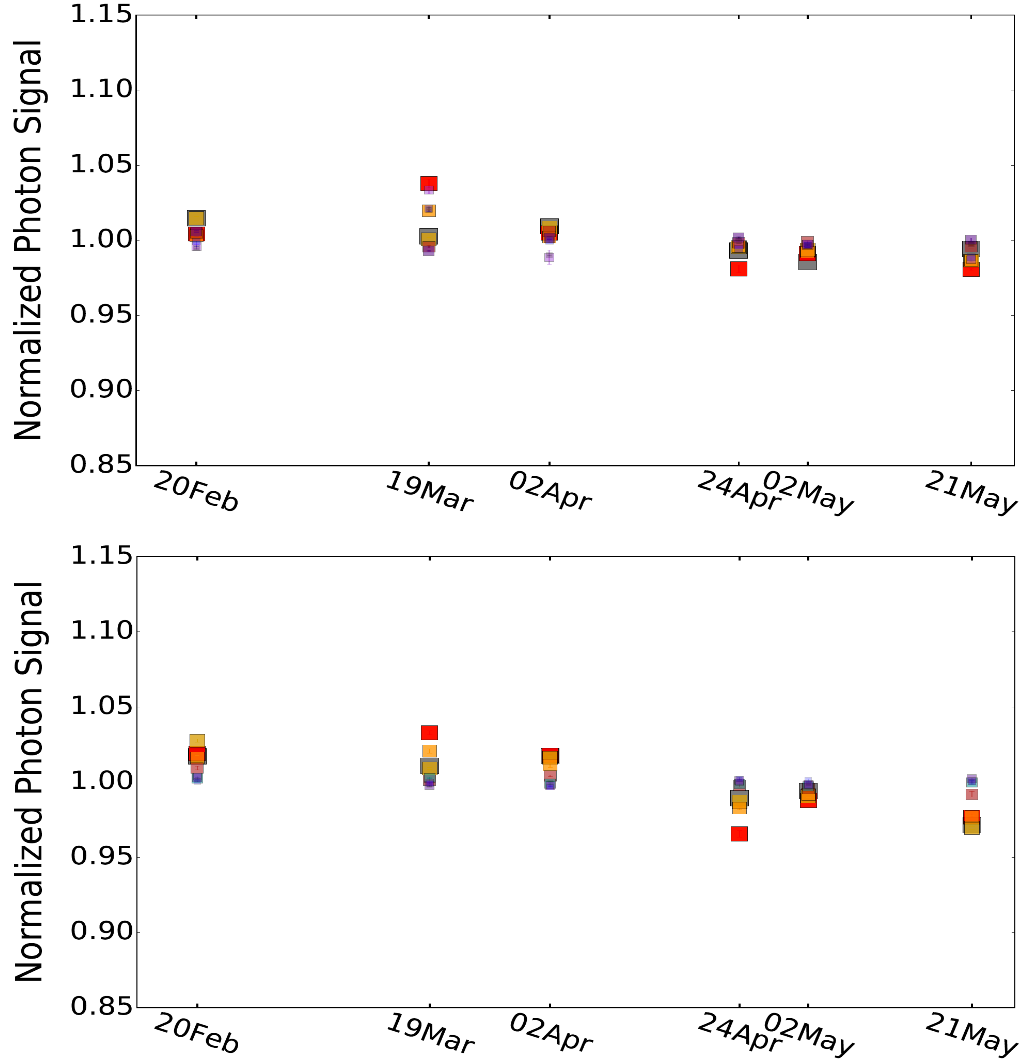
Stability of PD light response: Light-collection Bars

- Calibration system used to demonstrate the stability of the **light response** for two types of light-collection bars.



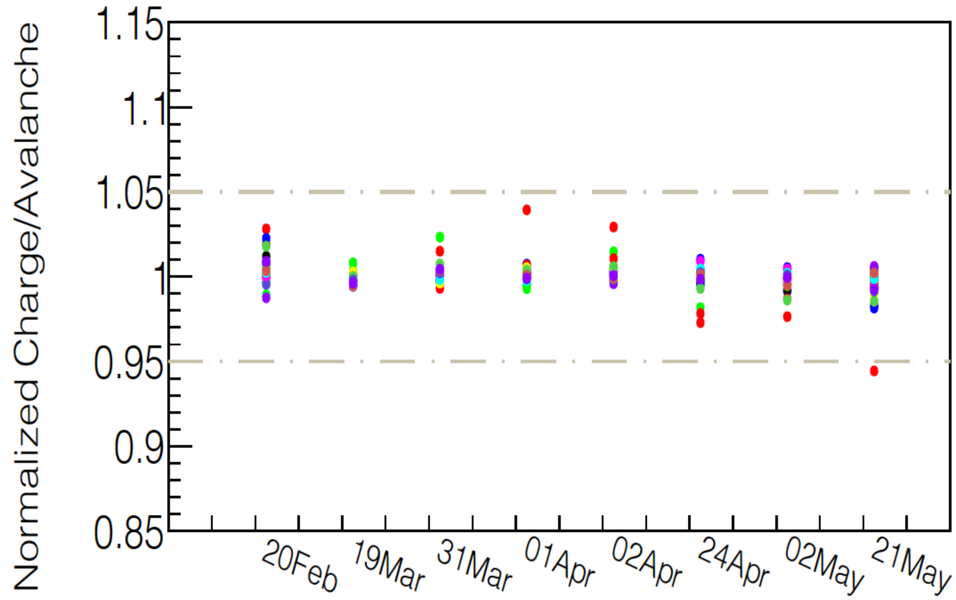
➢ Measurement of the signal from the calibration system using the dip-coated and double shift bars in APA 6 that have MPPC SiPMs (top) and in APA 4 that have SensL SiPMs (bottom).

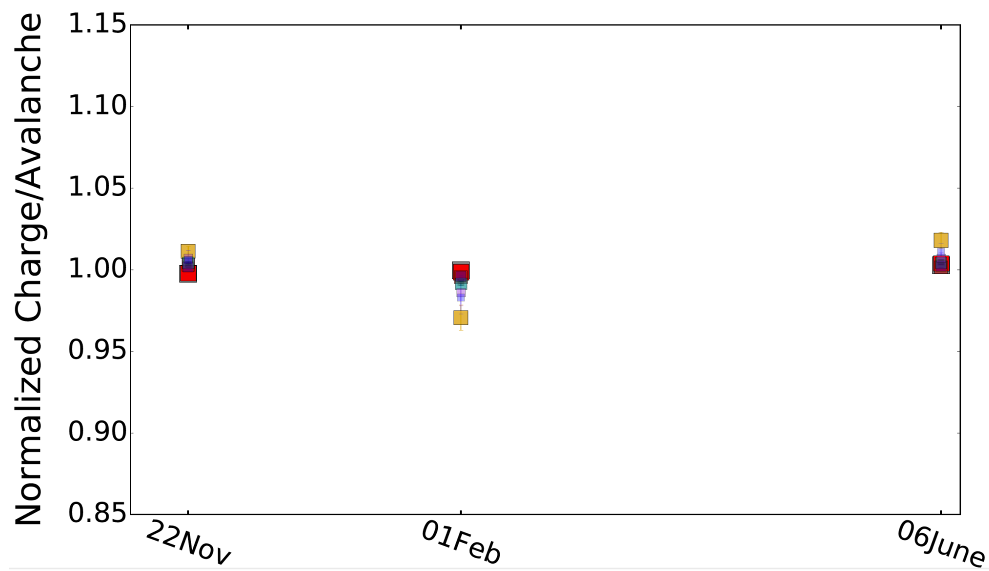
Stability of PD gain

- Calibration system used to demonstrate the stability of the **gain** for two types of SiMPs device operating in LAr.

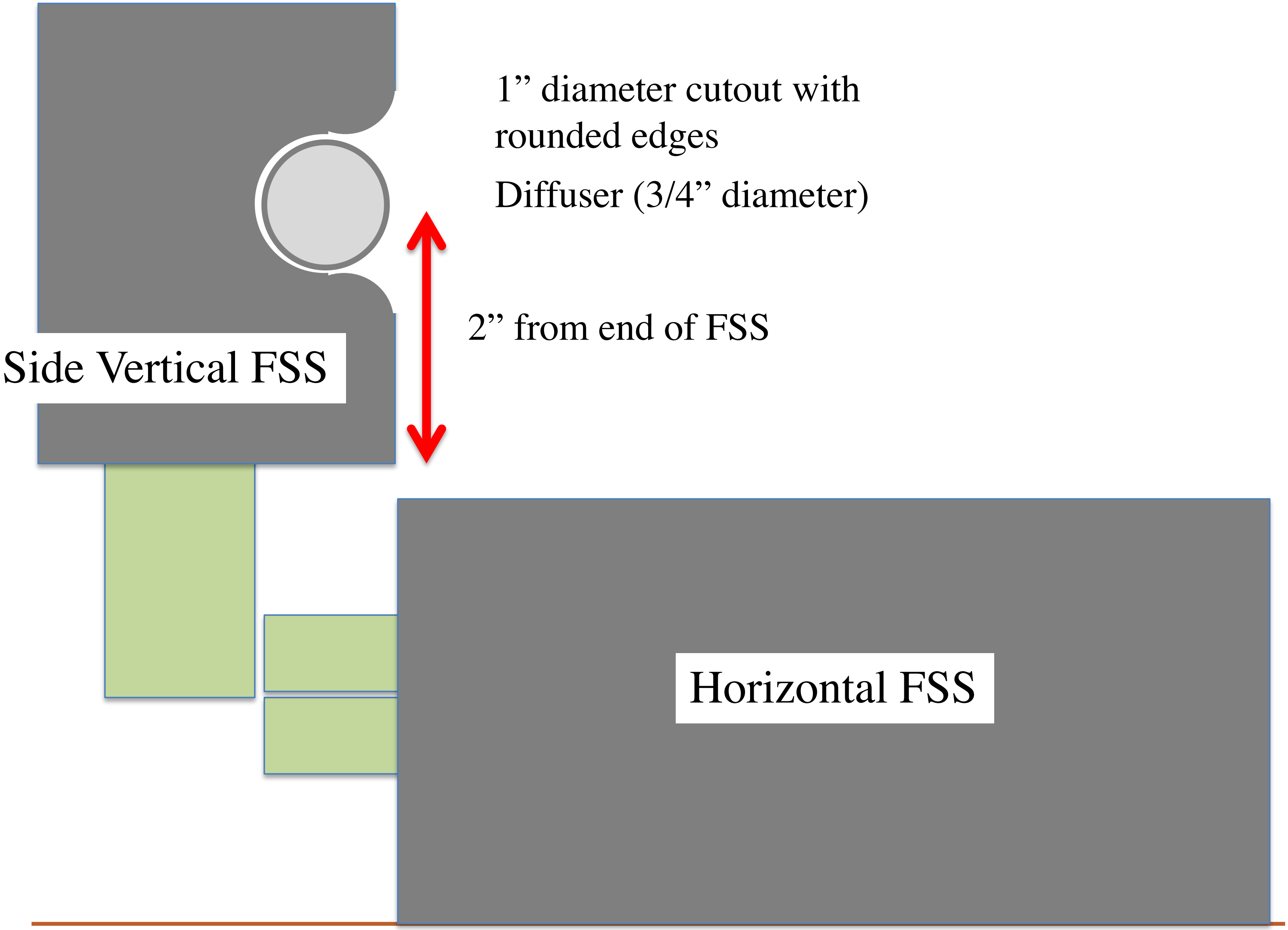
➢ Normalized gain measurements using the calibration system light pulses: MPPC SiPMs on the S-ARAPUCA modules (top).

➢ SensL SiPMs on the dip-coated and double-shift bars in APA 3 (bottom).



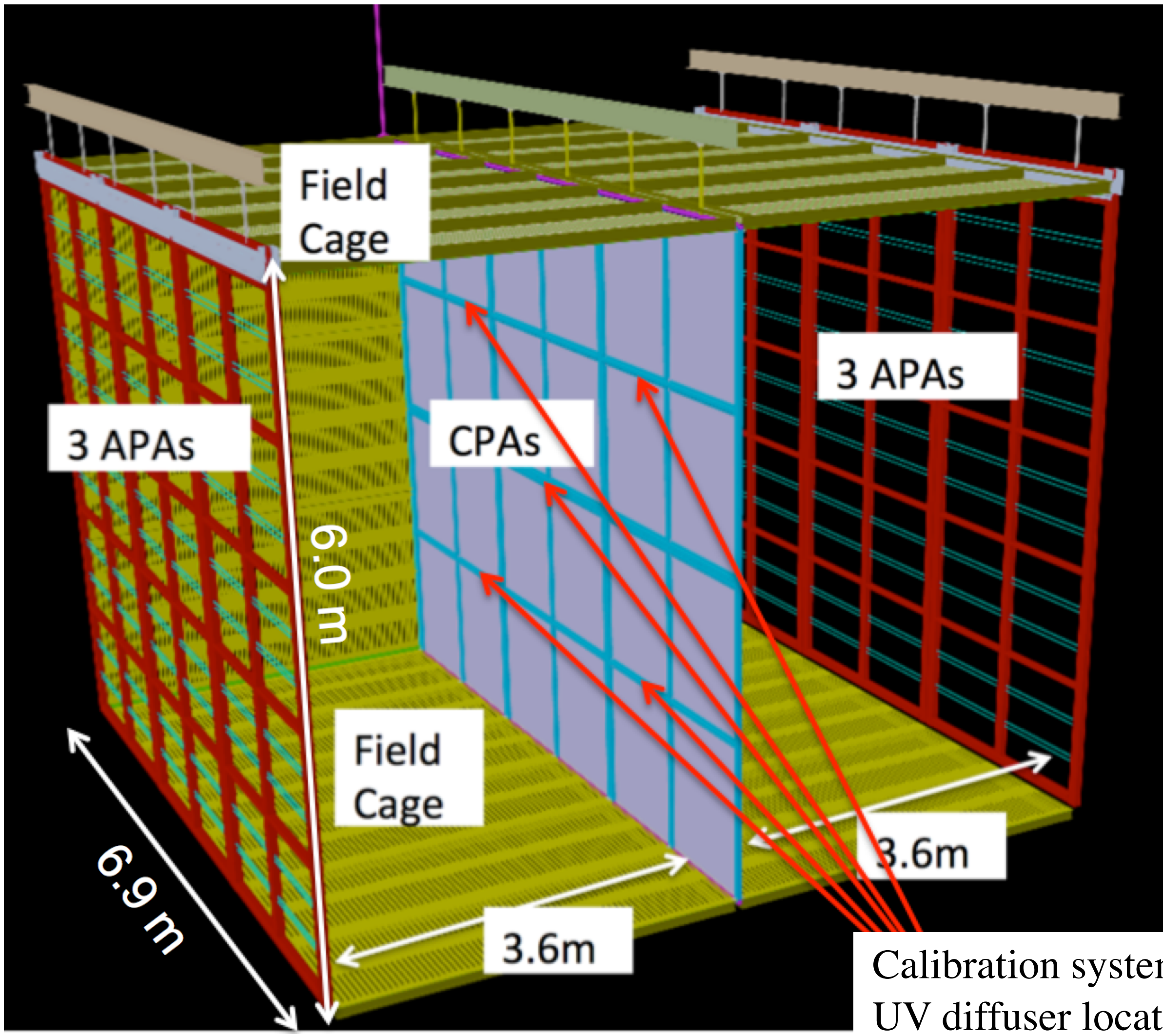


CPA Diffuser Configuration

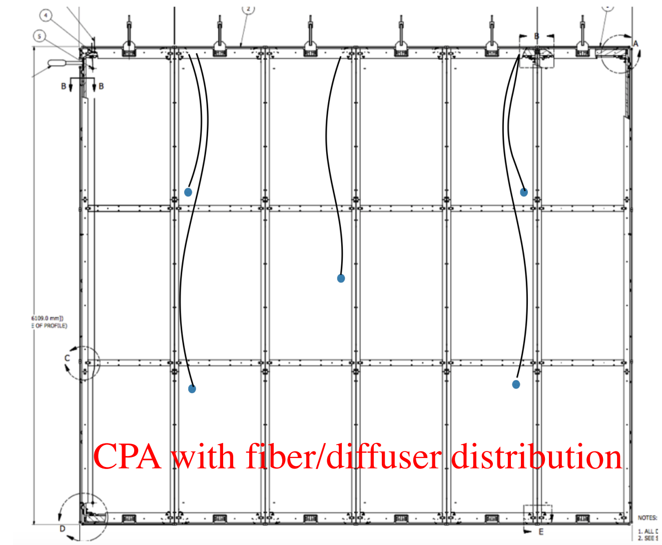


ProtoDUNE Design

- Photon-Detector Calibration system with light emitted from CPA to APAs



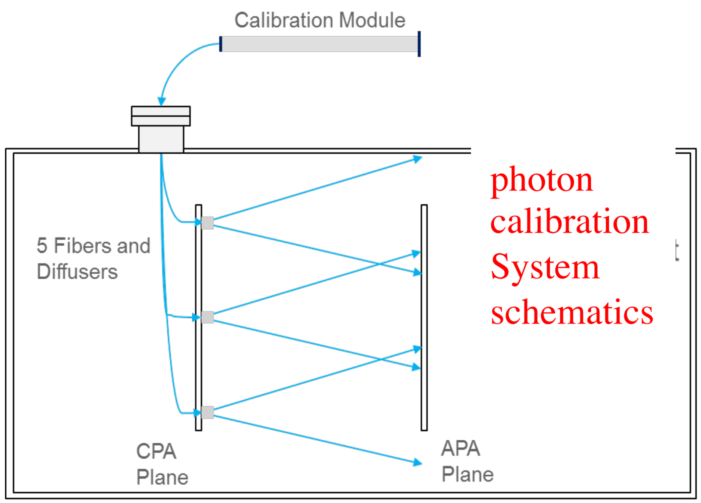
Calibration system:
UV diffuser locations
at ProtoDUNE-SP CPA

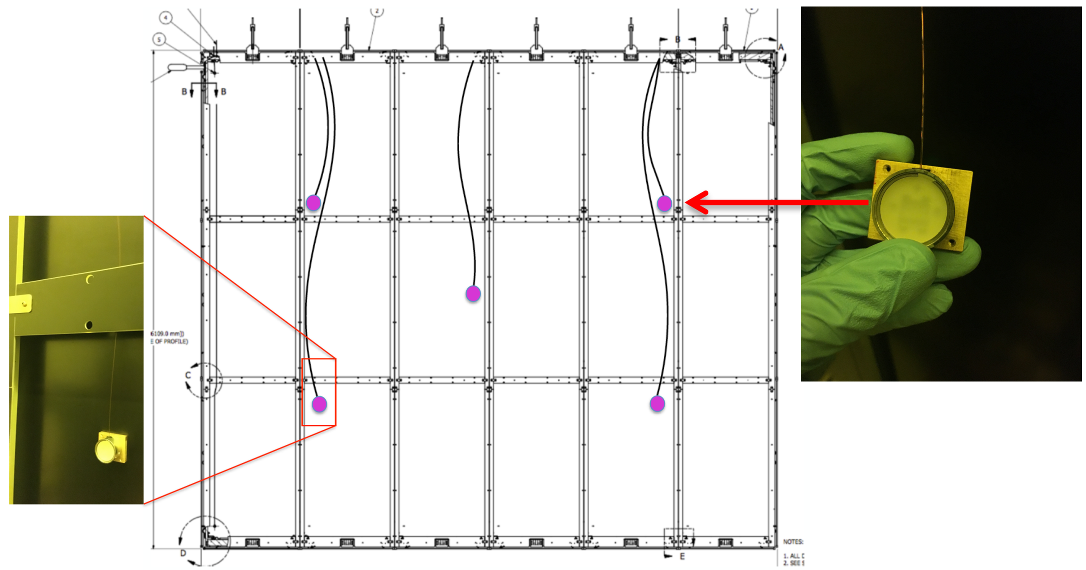


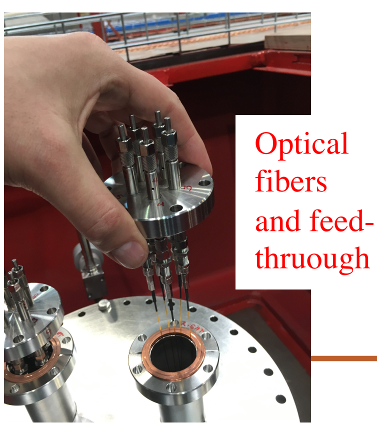
➢ you may also see the 35t experience in backup slides

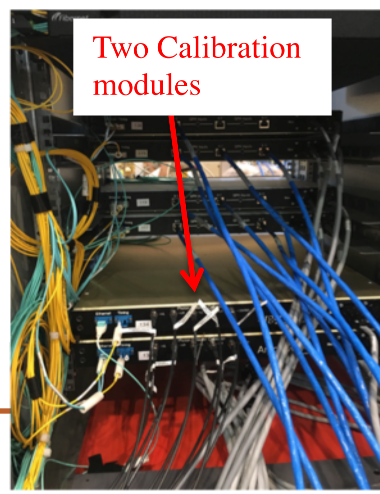
Overview

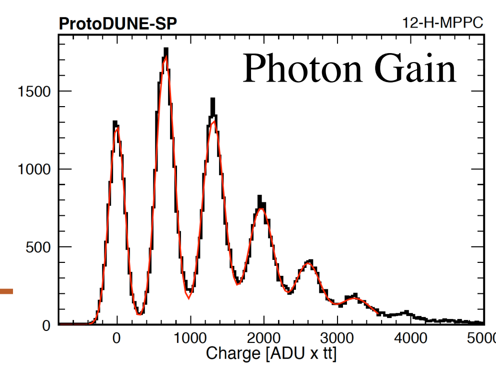
- DUNE photon-detector calibration system
  - The system emits UV-light: electronics module -> fiber (through cryostat) -> point-like diffusers
    -Result: distribute UV light from cathode to photon detector at anode
      -Fully integrated with DAQ/timing, emits light with desired intensity and repetition rate
      -Full test and verification completed with ProtoDUNE => will equip full DUNE SP FD

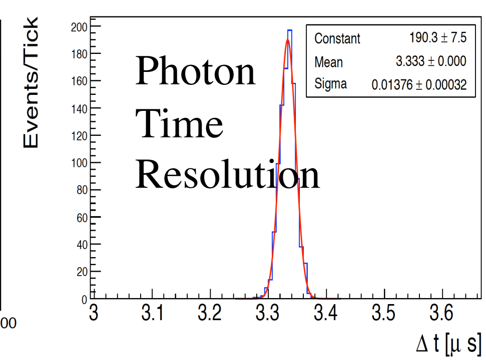




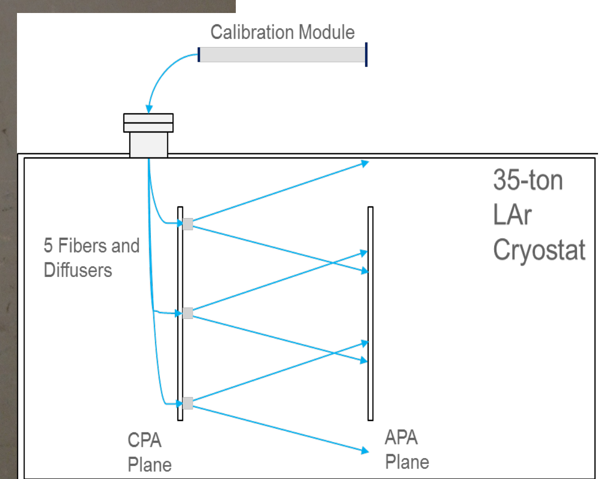






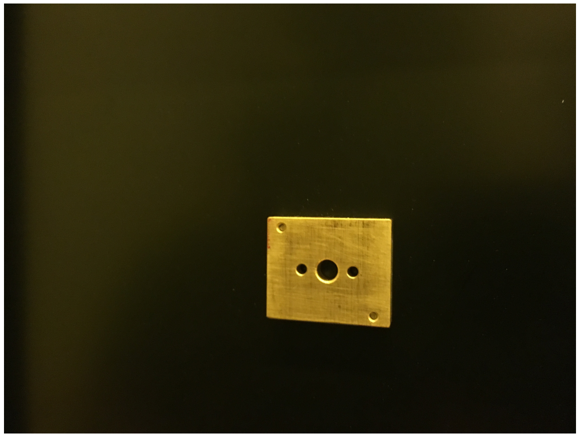


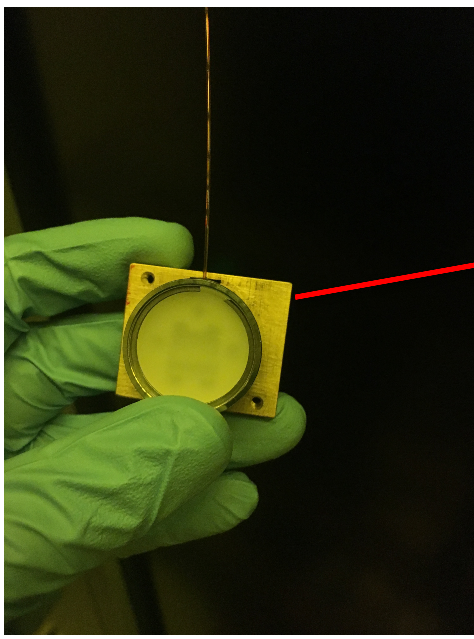
ProtoDUNE Design Components

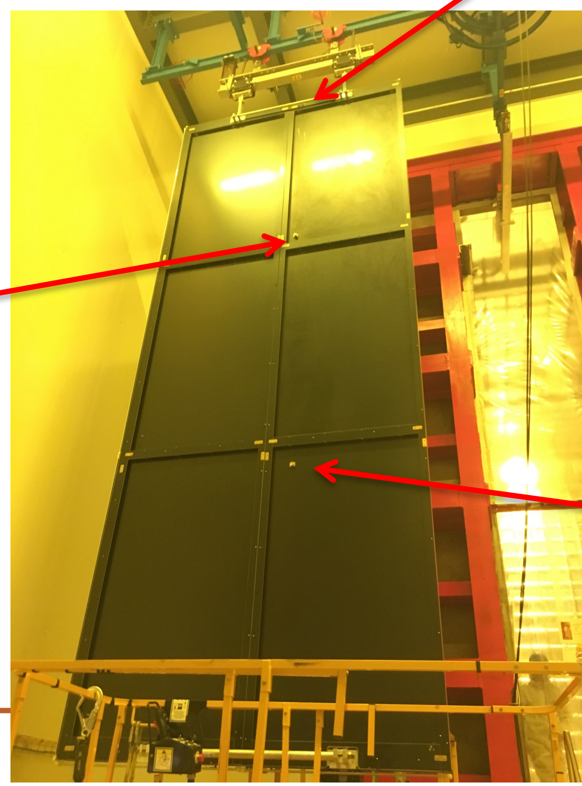


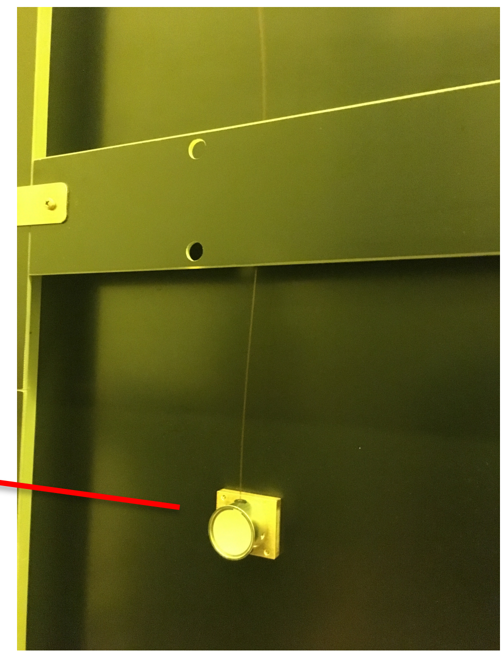
(ProtoDUNE) Installation of light diffusers

- Pictures of light diffusers and fibers integrated with one CPAs at CERN









Optical Feed-Through