DUNE FD2 PDS Installation

Last Update: 03 April 2023
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Table of Contents

Revision Change Log

Date of Revision	Revision PoC	Revision Notes
03-Apr-2023	Ryan A. Rivera	Minimized activities in cavern clean room to assemble X-ARAPUCA. Added RMS CAD models.
24-Mar-2023	Ryan A. Rivera	Updated SURF installation schedule and details to match I&I expectations.
13-Mar-2023	Ryan A. Rivera	Updated cathode cryostat installation assumptions – cathode pairs in cryostat will be lifted into place by dedicated tooling. Added install steps for Cathode-mount XA fiber install and test during cathode and field cage final lift.
09-Mar-2023	Ryan A. Rivera	Initial draft for FD2 PDS Final Design Review

Introduction

This document describes the DUNE Far Detector 2 (FD2) Photon Detector System (PDS) plans and methods for installation at the Sanford Underground Research Facility (SURF). The photo-collector detector unit at the heart of the PDS is known as an X-ARAPUCA (XA). The FD2 PDS installation plan is for 672 XA to be distributed in liquid argon, in the FD2 cryostat, on the four walls of the cryostat membrane and on the cathode. Because the cathode operates at -300kV, the cathode XA will utilize Power-over-Fiber (PoF) and Signal-over-Fiber (SoF) for electrical isolation. This document will be updated throughout the FD2 PDS production phase as DUNE interfaces and constraints are modified.

The FD2 PDS consists of four primary subsystems which each have their own installation sequences:

1. Warm Electronics and DAQ interface
2. Membrane-mounted X-ARAPUCA photo-collectors
3. Cathode-mounted X-ARAPUCA photo-collectors
4. Response Monitoring System (RMS) light diffusers

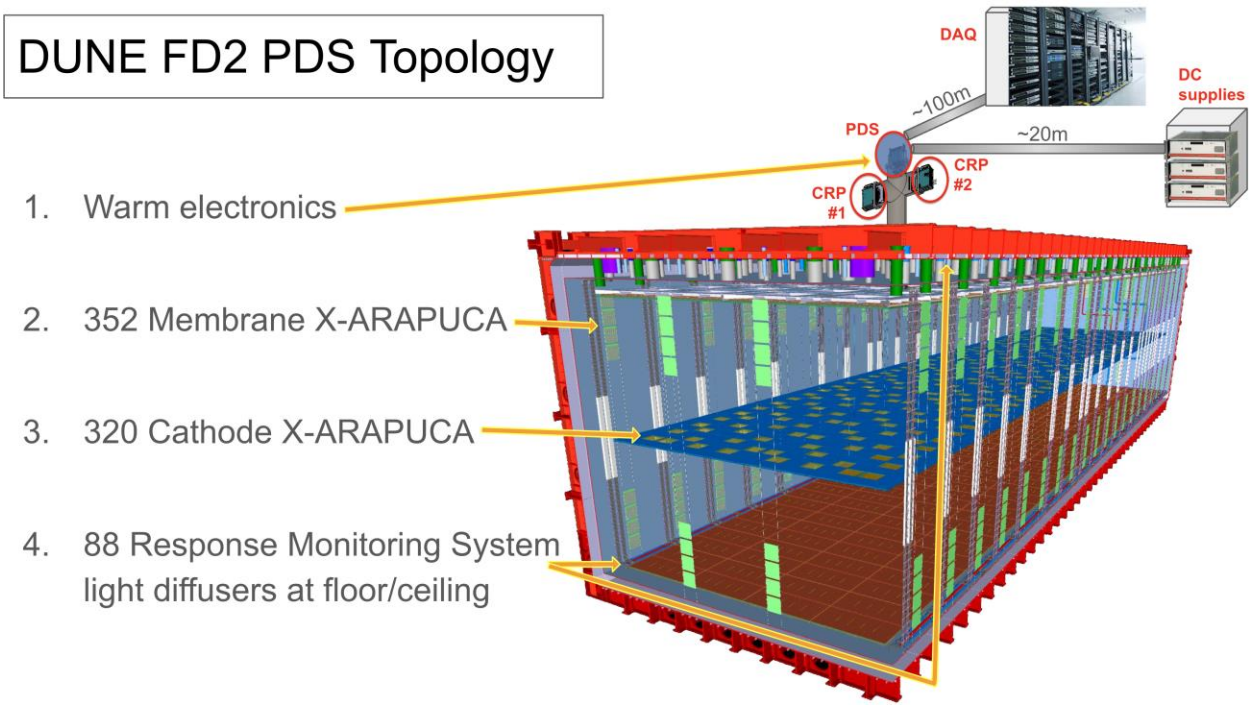

Figure 1. The FD2 PDS high-level component topology in the cavern at SURF.

Installation Assumptions

The list of FD2 PDS installation assumptions summarizes the fundamental decisions upon which the FD2 PDS installation plan is based. Changing any of the assumptions may have significant impact on the FD2 PDS installation cost, schedule, required personnel, and risks.

- The cavern clean room designated for XA assembly meets the DUNE requirements for cleanliness, floor and table space, and lighting.
- The Membrane-mounted XA are installed before the cathode and CRP.
- Individual maneuvering in the cryostat, at less than 2m elevation, is required of pairs of cathode modules (i.e., two 4x4 cathode cells corresponding to one FD2 PDS penetration) to accommodate final PoF and SoF optical fiber routing during the cathode + PDS installation sequence.
- After final Cathode-mounted XA PoF/SoF fiber routing, the cathode pairs are raised into position by dedicated tooling attached to scissor lifts. Then, once at full height, the cathode pair load is transferred to a suspension system connected to the top CRP superstructure. Then, once the field cage is at full height, the PoF/SoF fibers are dressed to the field cage support bars.
- The field cage is installed after the cathode.

Installation Schedule

The FD2 PDS subsystem high-level installation sequence is as follows:

1. Warm Electronics, warm cable connections, and DAQ integration
2. Membrane-mounted X-ARAPUCA and cable/fiber routing:
    a) RMS optical fiber dressed to membrane support structures.
    b) Cathode optical fibers dressed to membrane support structures.
3. Cathode-mounted X-ARAPUCA
4. RMS light diffusers final installation

The FD2 PDS installation is planned over 11 months from cavern occupancy approval to the fully commissioned system:

	Time 0	1-2months (2-months)	3-4 months (2-months)	5-6 months (2-months)	7 months (1-months)	8 months (1.5-months)	9-10 months (1.5-months)	11 months (1-months)	Time 11-months
Activity 1	Cavern occupancy approved	Develop cavern assembly and testing area	Install infrastructure and Warm Electronics	Commission basic Warm Electronics for install verification	Install and test rows 1-20 of Membrane-mounted XA	Complete rows 1-10 of RMS install and test	Complete rows 11-20 of RMS install and test	Complete flange and feedthrough install	FD2 PDS Commissioned
Activity 2						Install and test rows 1-10 of Cathode-mounted XA	Install and test rows 11-20 of Cathode-mounted XA		
Activity 3				Assemble and test 1-320 XA in clean room	Assemble and test 321-512 XA in clean room	Assemble and test 512-692 XA in clean room			
Activity 4					Optimize and debug DAQ interface software	Commission optimized Warm Electronics	Commission final DAQ interface to Membrane-mounted XA	Commission final DAQ interface to Cathode-mounted XA and RMS	

Table 1. FD2 PDS high-level installation schedule.

Additional high-level detail for each activity from Table 1 is provided below:

- *Develop cavern assembly and testing area*
    - Setup the tables, chairs, and computers to facilitate receiving, assembling, and testing of FD2 PDS components.
- *Install infrastructure and Warm Electronics*
    - For each of 40 penetrations, install the necessary infrastructure at the associated cryostat roof and Mezzanine location utilizing dedicated FD2 PDS rack space. The warm electronics will be used for final commissioning and installation validation of the Membrane-mount XA, Cathode-mount XA, and RMS.

- For more details, see *WARM ELECTRONICS INSTALLATION AND SETUP*.

- *Commission basic Warm Electronics for install verification*
  - For each of 40 penetrations, test and debug the suite of functionality required to conduct warm installation verification of the Membrane-mount XA, Cathode-mount XA, and RMS. Note that *basic* and *optimized* operational modes of the Warm Electronics are considered, where *basic* operation is the minimum required for installation verification and *optimized* operation is required for full FD2 PDS commissioning and satisfying the Key Performance Parameters (KPPs).

- *Assemble and test XA in clean room*
  - Assemble the X-ARAPUCA from pre-assembled sub-frames. The concept is for the X-ARAPUCA readout chain to be fully assembled (except for the dichroic filters and filter sub-frame), characterized, and cold tested in advance of arrival at SURF. Since the dichroic filters are fragile, they must be packaged separately for transport to SURF. Then in the clean room at SURF, the dichroic filter frames are assembled and the XA readout chain is verified before and after the filter sub-frames are added. Test and characterize the full readout chain by applying low voltage and SiPM bias voltage – for cathode XA use PoF; then measure the signal response. Record results in database.
  - For more details, see *X-ARAPUCA ASSEMBLY*.

- *Install and test rows of Membrane-mounted XA*
  - For each of 44 columns (i.e., 8 XA per column), repeat the Membrane-mounted FD2 PDS installation sequence. Note the DUNE multi-subsystem installation accounting is done by cathode/CRP rows, of which there are 20. For the FD2 PDS, however, there are 2 columns associated with each row *and* at each end-wall there are an additional 2 columns. There is one BDE+PDS penetration associated with each end of each row (i.e., 40 penetrations). This implies 1 additional column of cables must join the 4 corner penetration cable bundles as compared to the other central 36 penetrations.
  - Install the support suspension system.
  - Coordinate with the warm-side team to install the penetration septum; the septum is used to isolate fibers pulled up, later in the installation sequence, with the field cage (i.e., RMS fibers) from the primary fibers/cable pull with the BDE cable bundles. Install and dress, to the membrane suspension system, the Membrane-mounted XA cables, Cathode-mounted XA fiber, and RMS lower fiber such that cable/fiber PD bundles can be joined with BDE cables to be pulled up through the penetration and secured to the cable clamping plate at the bottom of the penetration. Install the 8 XA per column (4 upper XA and 4 lower XA). Coordinate with the warm-side team to test the full readout chain.

- Test the Cathode-mounted XA fiber coordinated with warm-side team. Fiber transmission is measured, and recorded in database, by using a light source on the warm side and an optical power meter on the cold side.
- For more details, see *MEMBRANE-MOUNTED X-ARAPUCA INSTALLATION AND SETUP*.

- *Install and test rows of Cathode-mounted XA*
  - For each of 40 pairs of high-voltage cathode modules (i.e., containing 8 XA), repeat the Cathode-mounted FD2 PDS installation sequence. Note the DUNE multi-subsystem installation accounting is done by cathode/CRP rows, of which there are 20. For the FD2 PDS, there are 2 pairs of high-voltage cathode modules associated with each row. There is one BDE+PDS penetration associated with each end of each row (i.e., 40 penetrations; one penetration per pair of high-voltage cathode modules).
  - *Install:* Coordinate with the high-voltage cathode team to install 8 tested XA in the two cathode modules while in the clean room at vertical orientation; there is no verification test planned for the XA in the clean room at vertical orientation – the cathode XA are tested with PoF individually in the clean room prior to cathode insertion. The conductive mesh sections over the XA are left partially installed for easy access to final optical fiber connections in the cryostat. The cathode team transports the pair of high-voltage cathode modules to the cryostat and elevates the cathode to working height of less than 2m. At less than 2m height in the cryostat, coordinate with the cathode team to complete the final PoF/SoF optical fiber routing through the cathode frame to the cold electronics of each of the 8 XA – maneuvering, as needed, the pairs of cathode modules before suspending from the CRP.
  - *Test 1:* Once the PoF/SoF fibers are connected to the cold electronics and the light-tight, cold electronics box is closed, coordinate with warm-side team to conduct the full-chain installation verification test procedure of the Cathode-mount XA by operating Class 4 PoF lasers to each XA and characterizing the returned SoF; document results in database.
  - *Test 2:* Complete the conductive mesh installation at each of the 8 XA cathode cells. Then the cathode can be transferred to the CRP suspension system, and the field cage can be lifted into place. Finally, the PoF/SoF optical fibers are dressed to the field cage and the final warm test is conducted of the Cathode-mounted XA installation by operating Class 4 PoF lasers to each XA and characterizing the returned SoF; document results in database.
  - For more details, see *CATHODE MOUNTED MODULE INSTALLATION AND SETUP*.

- *Complete RMS install and test*
    - For each of 44 columns (i.e., 2 RMS fiber diffusers per column), repeat the Response Monitoring System FD2 PDS installation sequence. Note the DUNE multi-subsystem installation accounting is done by cathode/CRP rows, of which there are 20. For the FD2 PDS, however, there are 2 RMS columns associated with each row *and* at each end-wall there are an additional 2 columns. There is one BDE+PDS penetration associated with each end of each row (i.e., 40 penetrations). This implies 1 additional column of RMS fibers must join the RMS fiber bundles at each of the 4 corner penetrations, as compared to the other central 36 penetrations.
    - The RMS fibers are part of the secondary cable/fiber installation through the penetration and, thus, utilize the dedicated septum to avoid interference with the primary BDE+PDS cable/fiber installation. Warm and cold-side teams must coordinate to pass RMS fibers down through the septum, then the cold-side team affixes the fiber diffusers to the top and bottom supports of the field cage before the field cage is lifted into place, while there is still access to the field cage top supports from within the cryostat. In coordination with warm-side team and field cage team, lift field cage while pulling RMS fiber slack through septum. Coordinate with warm-side team to conduct the full-chain installation verification test procedure of the RMS; document results in database.
    - For more details, see *RESPONSE MONITORING SYSTEM INSTALLATION AND SETUP*.
- *Complete flange and feedthrough install*
    - For each of 40 penetrations, test and debug the suite of functionality required to conduct warm installation verification of the Membrane-mount XA, Cathode-mount XA, and RMS. Note that *basic* and *optimized* operational modes of the Warm Electronics are considered, where *basic* operation is the minimum required for installation verification and *optimized* operation is required for full FD2 PDS commissioning and satisfying the Key Performance Parameters (KPPs).
- *Optimize and debug DAQ interface software*
    - Optimize and debug PDS consortium controlled DAQ plug-in software, for back-end and front-end user interface features, such that full support is implemented for commissioning activities of the Membrane-mount XA, Cathode-mount XA, and RMS. This work is anticipated to primarily be completed by remote PDS personnel in coordination with the DAQ team.
- *Commission optimized Warm Electronics*
    - In coordination with the DAQ team, utilize the PDS features of the DAQ system to commission the FD2 PDS Warm Electronics.

- *Commission final DAQ interface to Membrane-mounted XA*
    - In coordination with the DAQ team, utilize the PDS features of the DAQ system to commission the FD2 PDS Membrane-mounted XA.
- *Commission final DAQ interface to Cathode-mounted XA*
    - In coordination with the DAQ team, utilize the PDS features of the DAQ system to commission the FD2 PDS Cathode-mounted XA.
- *FD2 PDS Commissioned*
    - In coordination with the DAQ team, utilize the PDS features of the DAQ system to commission all internal and external interfaces of the FD2 PDS including the interface to final multi-subsystem analysis.

Conditions at the Start of Warm Electronics Installation

The status at the start of the FD2 PDS Warm Electronics installation in SURF cavern is expected to be as follows:

- The DAQ has installed and tested a portion of the final system allocated for the FD2 PDS control, readout, and monitoring.
- Slow controls monitoring is debugged and operational.
- The cryostat/detector ground monitoring is functional.
- FD2 PDS allocated Detector Mezzanine rack space is operational (i.e., operational readiness clearance + no physical interference for PDS personnel access for DC power distribution installation).
- FD2 PDS allocated cryostat roof space at the 40 penetrations shared with the Bottom Drift Electronics (BDE) is operational (i.e., operational readiness clearance + no physical interference for PDS personnel access). Associated with each PDS cryostat roof penetration, is a 27U-rack populated with the PDS Warm Electronics, SoF conversion units, and PoF power distribution units (i.e., Class 4 lasers).
    - PoF Safety Note:
        - According to Wikipedia, "*Class 4 is the highest and most dangerous class of laser... By definition, a Class 4 laser can burn the skin, or cause devastating and permanent eye damage as a result of direct, diffuse or indirect beam viewing. These lasers may ignite combustible materials, and thus may represent a fire risk... Class 4 lasers must be equipped with a key switch and a safety interlock...*"

Conditions at the Start of Membrane-mounted XA Installation

The status at the start of the FD2 PDS Membrane-mounted XA installation is expected to be as follows:

- The FD2 PDS Warm Electronics, and necessary infrastructure, have been installed and tested sufficiently to conduct Membrane-mounted XA installation verification tests.
- Cryostat is leak tested and clean.
- Sufficient temporary floor inside the cryostat is installed to allow work near the membrane walls and FD2 PDS penetrations.
- Internal cryostat lighting is functional and filtered to remove UV.
- The inside of the cryostat is operating as an ISO-8 cleanroom.
- Detector Safety System is operational.
- Completely constructed and verified membrane-mount XA are available at a rate for the installation process such that their arrival in the cryostat is not the limiting factor.
    - Membrane-mount XA are anticipated to be constructed and verified prior to installation in a cavern clean room adjacent to the FD2 cryostat.

Conditions at the Start of Cathode-mounted XA Installation

The status at the start of the FD2 PDS Cathode-mounted XA installation is expected to be as follows:

- The FD2 PDS Warm Electronics, and necessary infrastructure, have been installed and tested sufficiently to conduct Cathode-mounted XA installation verification tests.
    - PoF Safety Note:
        - Cathode-mounted XA utilize PoF which is a Class 4 laser system. Safety procedures during Class 4 laser operation will be critical for the protection of equipment and personnel. In situ final installation validation requires full chain Class 4 laser operation (i.e., from cryostat roof warm electronics, under control of DAQ and slow controls, to XA front-end electronics, and SoF validation returned from front-end to DAQ).
- Cryostat is leak tested and clean.
- Sufficient temporary floor inside the cryostat is installed to allow work on the cathode XA installation.
- Internal cryostat lighting is functional and filtered to remove UV.
- The inside of the cryostat is operating as an ISO-8 cleanroom.
- Detector Safety System is operational.

- The cathode team has pre-installed fiber guides (1 per internal XA) and G10 XA mounting blocks (3 per XA) in the cathode modules.
- Completely constructed and verified cathode-mount XA are available at a rate for the installation process such that their arrival for cathode module installation is not the limiting factor.
    - Cathode-mount XA are anticipated to be constructed and verified prior to installation in a cavern clean room adjacent to the FD2 cryostat.
- Cathode-mount XA and bottom-RMS optical fibers are installed, tested, and stored along the cryostat wall.

Conditions at the Start of Response Monitoring System Installation

The status at the start of the FD2 PDS RMS installation is expected to be as follows:

- The FD2 PDS Warm Electronics, and necessary infrastructure, have been installed and tested sufficiently to conduct RMS installation verification tests.
- Cryostat is leak tested and clean.
- Internal cryostat lighting is functional.
- The inside of the cryostat is operating as an ISO-8 cleanroom.
- Detector Safety System is operational.
- Completely constructed and validated RMS components are available at a rate for the installation process such that their arrival in the cryostat is not the limiting factor.
- Bottom-RMS optical fibers are installed, tested, and stored along the cryostat wall.
- Field cage installation has begun.

Warm Electronics Installation and Setup

This section describes the installation and setup plan for the FD2 PDS Warm Electronics. The FD2 PDS Warm Electronics are replicated at each of the 40 shared BDE+PDS cryostat roof penetrations. The Warm Electronics components to be installed in support of each penetration include the following:

1. (1) 27U-rack kit
2. (1) DC power supply kit for digitizer module, in Mezzanine
3. (1) 120VAC PoF Class 4 laser transmitter kit
4. (1) SoF optical conversion kit
5. (1) Digitizer module with detector SiPM bias control
    - Note that *basic* and *optimized* operational modes are considered, where *basic* operation is the minimum required for installation verification and *optimized* operation is required for full FD2 PDS commissioning and satisfying the KPPs.
6. (1) RMS transmitter kit
7. (1) Conduit and cable kit for DC power distribution
8. (1) Conduit, patch panel, and fiber kit for Class 4 laser protection and PoF distribution
9. (1) Conduit, cable, and fiber kit for signal routing
10. (1) Conduit and fiber kit for RMS distribution

Warm electronics installation sequence

Below is the sequence of steps necessary to install the FD2 PDS Warm Electronics for *basic* operation:

Personnel and Shifts: 1x 10-hour shifts per day, **4 days a week**, 4 people per shift (i.e., 4 people living at SURF for 3 months). The 4 individuals are scientific staff experienced in FD2 PDS Warm Electronics installation and commissioning.

Total installation time for each of 40 penetration locations is considered below. The schedule for *basic* FD2 PDS Warm Electronics installation is 6 weeks, 4 days a week, for a total of 24 working days. The anticipated rate of penetration installation is **2 penetrations per day**, with a 4-day ramp-up period.

Installation Sequence:

1. Two teams of two, in parallel, each Move (1) 27U-rack kit, with (1) Digitizer module with detector SiPM bias control and (1) RMS transmitter kit, from cavern receiving area to associated penetration position. **Activity Time**: 30 minutes, **Running Time**: 30 minutes.

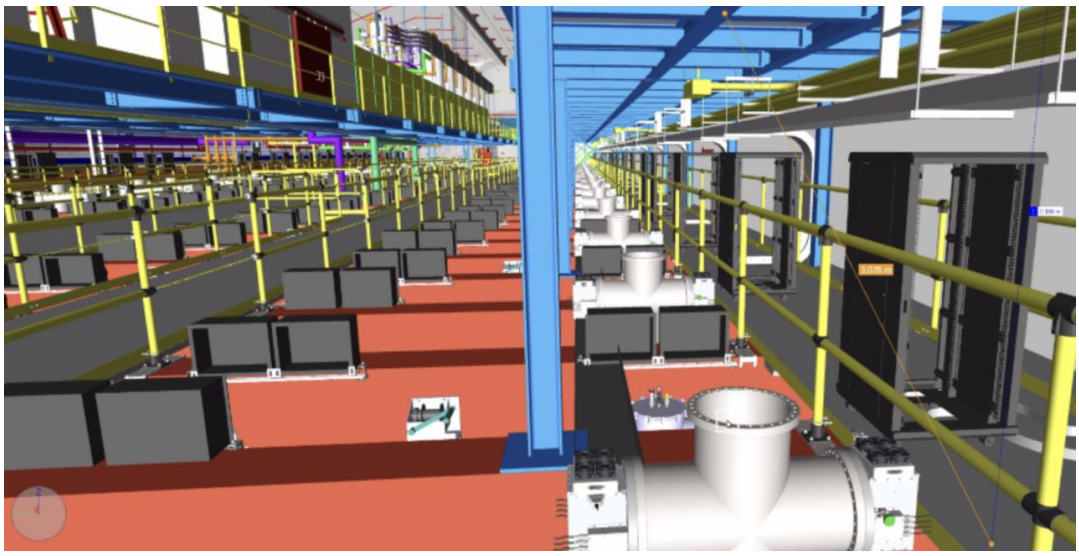

Figure 2. Integration model of the top of the cryostat with PDS racks and penetrations visible.

2. Two teams of two, in parallel, each Secure (1) Mini-rack kit, with (1) Digitizer module with detector SiPM bias control and (1) RMS transmitter kit, to associated penetration position. **Activity Time**: 30 minutes, **Running Time**: 1 hour.

	U	Watts
Space	1	
POF Crate	3	50
Space	1	
POF Crate	3	50
Space	1	
POF Crate	3	50
Space	1	
Fiber Fanout	1	
Fiber Fanout	1	
Fiber Fanout	1	
Space	1	
Timing System Fanout	1	
Space	1	
DAPHNE	2	50
Space	1	
Light Monitoring System	1	50
Fan Tray	1	90
Space	1	
	25	340

Figure 3. Rack plan for racks at each of 40 penetrations on the cryostat roof.

3. Two teams of two, in parallel, each Move (1) DC power supply kit from cavern receiving area to associated rack position on Mezzanine. **Activity Time**: 30 minutes, **Running Time**: 1.5 hours.
4. Two teams of two, in parallel, each Install (1) DC power supply kit in associated rack position on Mezzanine. **Activity Time**: 15 minutes, **Running Time**: 1.75 hours.
5. Break. **Activity Time**: 15 minutes, **Running Time**: 2 hours.
6. Two teams of two, in parallel, each Move (1) PoF Class 4 laser transmitter kit from cavern receiving area to associated penetration position. **Activity Time**: 30 minutes, **Running Time**: 2.5 hours.

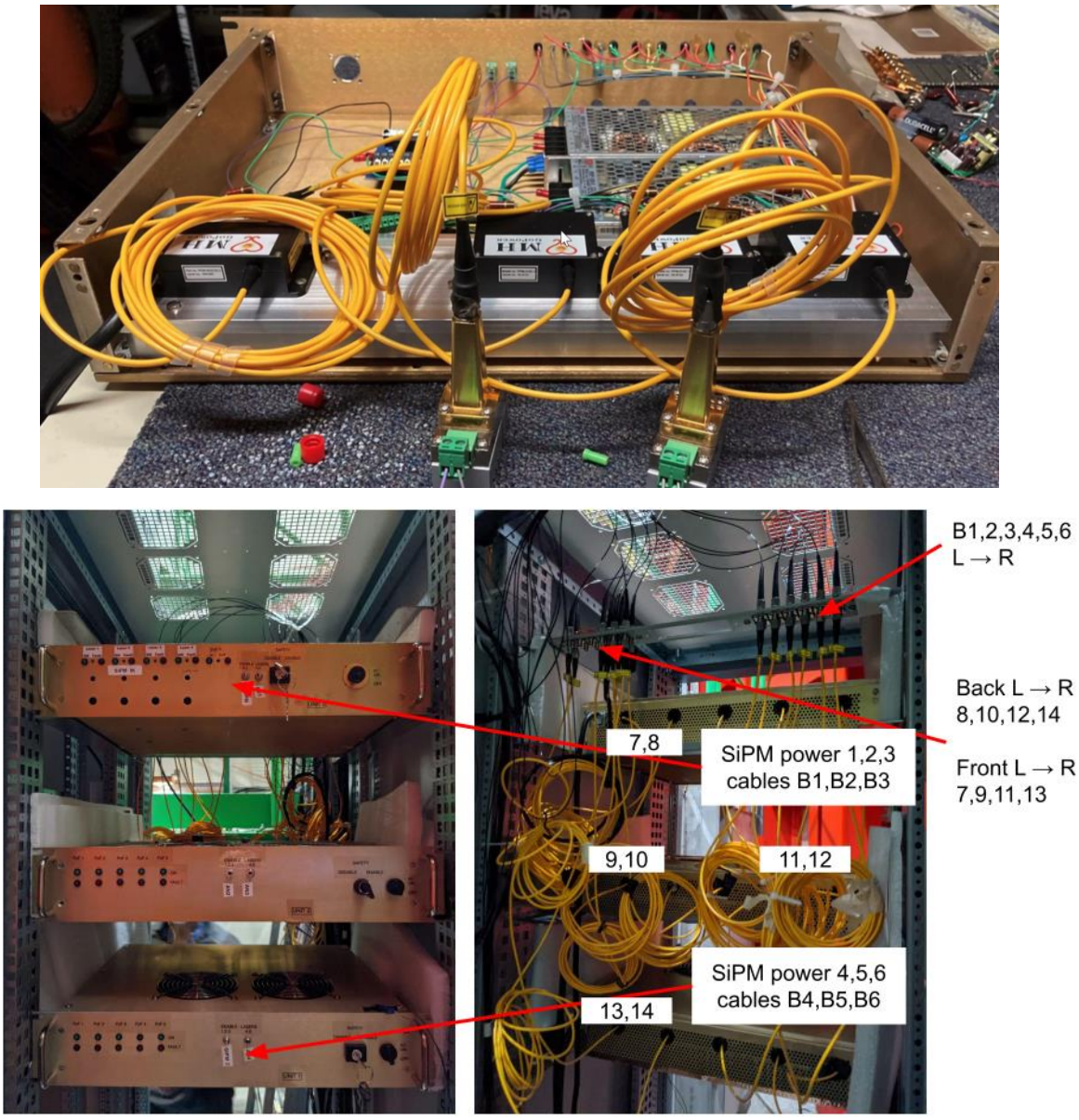

Figure 4. PoF Class 4 laser transmitter kit.

7. Two teams of two, in parallel, each Install (1) PoF Class 4 laser transmitter kit. **Activity Time**: 30 minutes, **Running Time**: 3 hours.
8. Two teams of two, in parallel, each Lay out (1) conduit and cable kit for DC power distribution from Mezzanine to associated penetration along cryostat roof run. **Activity Time**: 30 minutes, **Running Time**: 3.5 hours.
9. Two teams of two, in parallel, each Lay out (1) conduit, patch panel, and fiber kit, for Class 4 laser protection and PoF distribution in position at penetration. The PoF fiber route is out through top of rack, over to penetration, and down. **Activity Time**: 30 minutes, **Running Time**: 4 hours.
10. Break. **Activity Time**: 30 minutes, **Running Time**: 4.5 hours.
11. Two teams of two, in parallel, each Secure and complete install of (1) conduit and cable kit for DC power distribution from Mezzanine to associated penetration along cryostat roof run. **Activity Time**: 30 minutes, **Running Time**: 5 hours.
12. Two teams of two, in parallel, each Test DC power distribution with test load to validate installation. **Activity Time**: 15 minutes, **Running Time**: 5.25 hours.
13. Two teams of two, in parallel, each Secure and complete install of (1) conduit, patch panel, and fiber kit for Class 4 laser protection and PoF distribution in position at penetration. **Activity Time**: 30 minutes, **Running Time**: 5.75 hours.
14. Two teams of two, in parallel, each Test, with optical power meter, the PoF distribution up to final FC-FC patch panel connection at the penetration. **Activity Time**: 15 minutes, **Running Time**: 6 hours.

Figure 5. FC-FC optical patch panel connection.

15. Break. **Activity Time**: 15 minutes, **Running Time**: 6.25 hours.
16. Two teams of two, in parallel, each Move (1) conduit, cable, and fiber kit for signal routing and (1) conduit and fiber kit for RMS distribution to penetration. **Activity Time**: 30 minutes, **Running Time**: 6.75 hours.
17. Two teams of two, in parallel, each Install (1) conduit, cable, and fiber kit for signal routing and (1) conduit and fiber kit for RMS distribution to penetration. **Activity Time**: 15 minutes, **Running Time**: 7 hours.

18. Two teams of two, in parallel, each Test SoF optical conversion, signal digitizer, and SiPM bias generator, using dummy load and voltmeter, with DC power supply to validate installation. **Activity Time**: 15 minutes, **Running Time**: 7.25 hours.
19. Two teams of two, in parallel, each Test RMS transmitter with optical power meter to validate installation. **Activity Time**: 15 minutes, **Running Time**: 7.5 hours.
20. Warm electronics installation at (2) penetrations, supporting *basic* operation, **complete**.

The steps necessary from *basic* functionality, for installation verification, to *optimized* functionality, for DUNE Operations, of the FD2 PDS Warm Electronics involve primarily firmware and software tasks that will be completed in conjunction with the DAQ team. The verification, debugging, and commissioning of the FD2 PDS custom firmware and software functionality is anticipated to be handled primarily by remote PDS Consortium personnel, with minor hands-on support from the cavern team.

X-ARAPUCA Assembly

This section describes the XA assembly activities that occur in advance and in parallel of the Membrane-mounted XA and Cathode-mounted XA installation. These XA assembly activities are to satisfy the cryostat installation necessary condition that *completely constructed and verified membrane-mount and cathode-mount XA are available at a rate for the installation process such that their arrival in the cryostat is not the limiting factor*.

The total number of XA to install in the cryostat is 672 XA (352 Membrane-mounted XA and 320 Cathode-mounted XA); the assembly plan allocates time for 768 XA to be assembled which allows for potentially 14% more XA assembled than needed, as a margin for human error during the assembly process. On each component of the XA assembly kit, 9% spares are planned to be purchased, and 3% spare XA (i.e., 10 Cathode-mount and 10 Membrane-mount) are planned to be fully assembled and tested.

For the purposes of the installation document, we will assume the assembly and test time in the cavern is the average time for Membrane-mounted and Cathode-mounted XA. Cathode-mounted XA will take longer to assemble because there are two dichroic filter frames (top and bottom) to assemble as compared to one filter frame for the Membrane-mounted XA.

The cavern clean room adjacent to the FD2 cryostat is where individual XA assembly and testing is planned. Once assembled and tested, XA must be safely stored (with consideration for cleanliness, humidity, and lighting) until needed for Membrane-mount or Cathode-mount installation.

X-ARAPUCA assembly schedule

Below is the schedule for assembling XA such that they are available for the FD2 PDS Membrane-mount and Cathode-mount installation sequence:

Personnel and Shifts:

- 1-month Ramp-up period:
    - Ramp-up period of **32 XA per week**. 128 XA (units #1-128) assembled and tested in 1 month. Two teams of 4, including 1 technician, learning from experienced XA assembly personnel from the PDS Consortium.
    - 2x 10-hour shifts per day (both are day shifts), **4 days a week**, 4 people per shift (i.e., 8 people living at SURF for 2 months). 8 shifts per week for 4 weeks, totaling 32 shifts. 4 XA assembled and tested per shift.
- 3-month Full-rate:
    - Full-rate period of **48 XA per week**. 564 XA (units #129-672 + 3% spare) assembled and tested in 3-months. Two FD2 PDS teams of 4, including 1 technician, independently (night and day **rotation**) assemble and test XA.
    - 2x 10-hour shifts per day (1 day and 1 night shift), **6 days a week**, 4 people per shift (i.e., 12 people living at SURF for 3 months and rotating shifts). 12 shifts per week for 12 weeks, totaling 144 shifts. 4 XA assembled and tested per shift.

At the conclusion of the 4-month XA assembly and testing period, 672 XA (352 Membrane-mounted XA and 320 Cathode-mounted XA), with an additional spare 10 Membrane-mount XA and 10 Cathode-mount XA, will be fully assembled and tested in the clean room adjacent to the FD2 cryostat.

X-ARAPUCA assembly and test sequence

Below is the sequence of steps necessary to complete final assembly and test two XA in parallel. The full assembly sequence begins at PD Consortium construction sites – only the final assembly of preassembled subframes is conducted in the cavern clean room. For more details on the full assembly sequence conducted at PDS construction sites, see https://edms.cern.ch/document/2791084. The individual XA components for final assembly in the cavern clean room include the following:

1. (1) pre-assembled primary XA subframe with cold electronics
2. (1) Bottom subframe (blank for Membrane-mounted XA, and with dichroic filters for Cathode-mounted XA) kit
3. (1) Top dichroic filter subframe kit

Personnel and Shifts: 4 people per shift supporting 2 XA workstations. A workstation is a tabletop with surface area sufficient for an assembled XA and XA component staging (i.e., twice the dimensions of an XA). At any given time, 2 XA will be in process in the cavern clean room adjacent to the cryostat. The 4 individuals are staff experienced in FD2 PDS XA assembly and testing, including 1 technician.

Total assembly and test time for each XA is considered below. The anticipated rate of XA assembly and testing is **4 XA per shift**.

Assembly Sequence:

1. In parallel (2 teams of 2) for each XA, move (1) pre-assembled primary XA subframe with cold electronics to the designated XA workstation. **Activity Time**: 30 minutes, **Running Time**: 30 minutes.

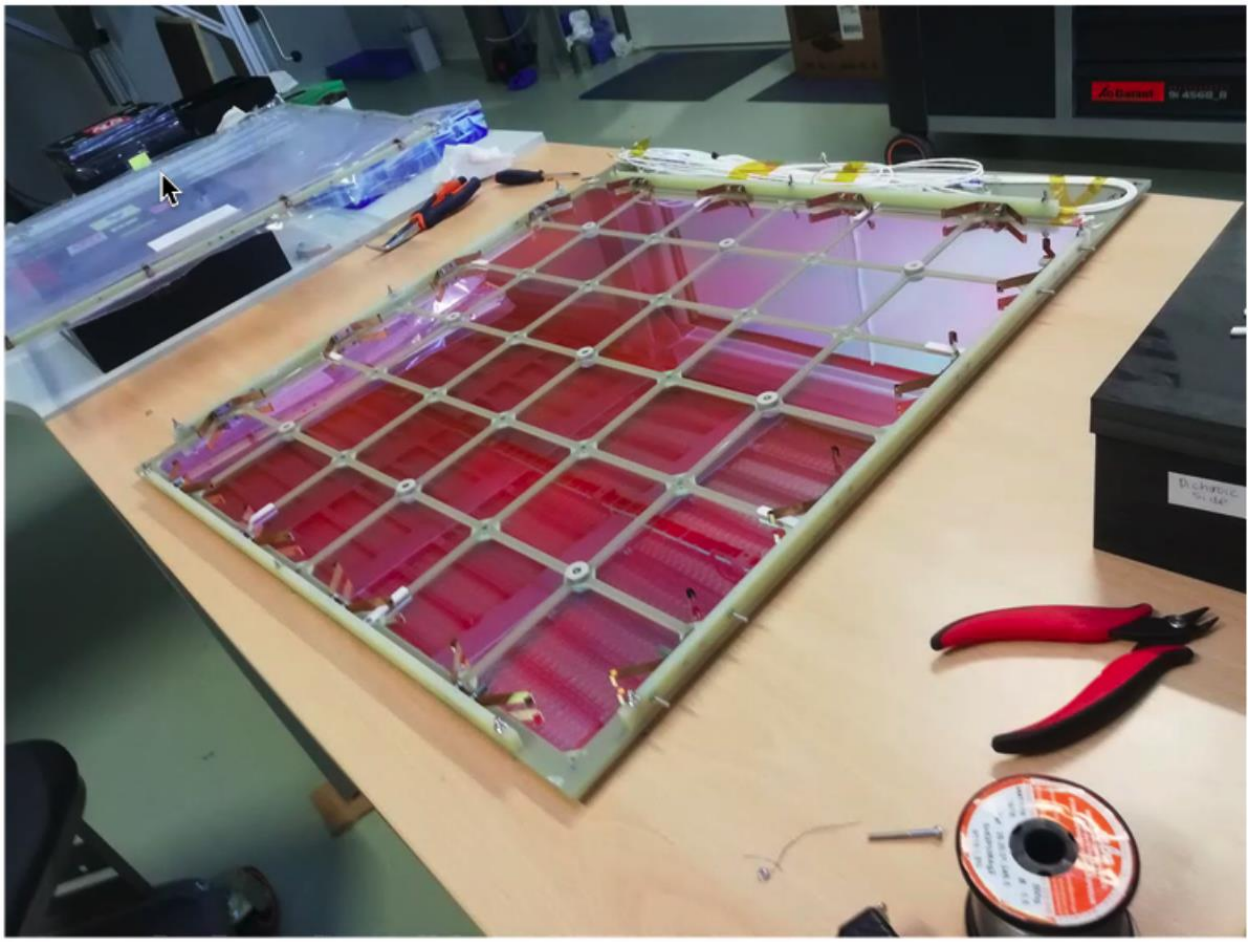

Figure 6. Example workstation for final XA assembly and component staging.

2. In parallel (2 teams of 2), pre-assembly test and characterize the full readout chain by applying low voltage and SiPM bias voltage – for cathode XA use PoF; then measure the signal response. Record results in database. Compare to expected results for pass/fail. **Activity Time**: 15 minutes, **Running Time**: 45 minutes.
3. In parallel (2 teams of 2) for each XA, move (1) bottom subframe kits to the designated XA workstation. **Activity Time**: 30 minutes, **Running Time**: 1.25 hours.
4. In parallel (2 teams of 2), conduct (1) bottom subframe kits assembly procedure. **Activity Time**: 60 minutes, **Running Time**: 2.25 hours.

Figure 7. Top subframe fastener pattern of M3 (red) and M4 (green) screws.

5. Break. **Activity Time**: 15 minutes, **Running Time**: 2.5 hours.
6. In parallel (2 teams of 2) for each XA, move (1) top subframe kits to the designated XA workstation. **Activity Time**: 30 minutes, **Running Time**: 3.0 hours.
7. In parallel (2 teams of 2), conduct (1) top subframe kits assembly procedure to complete XA assembly. **Activity Time**: 60 minutes, **Running Time**: 4.0 hours.
8. In parallel (2 teams of 2), final individual XA test and characterize the full readout chain by applying low voltage and SiPM bias voltage – for cathode XA use PoF; then measure the signal

response. Record results in database. Compare to expected results for pass/fail. **Activity Time**: 15 minutes, **Running Time**: 4.25 hours.

Figure 8. Electronics box kit attachment to the XA frame.

9. Break. **Activity Time**: 30 minutes, **Running Time**: 4.75 hours.
10. Repeat steps 1-8 for second pair of XA assembled and tested in parallel by the shift. **Activity Time**: 4.25 hours, **Running Time**: 9 hours.
11. Parallel assembly and test of (4) XA per shift in the clean room adjacent to the cryostat **complete**.

Membrane-mounted X-ARAPUCA Installation and Setup

This section describes the installation and setup plan for the FD2 PDS Membrane-mounted XA. The FD2 PDS Membrane-mounted XA components, and installation steps, are replicated at 44 columns (8 XA per column) along the perimeter vertical membrane walls of the cryostat. The Membrane-mounted XA components to be installed at each column include the following:

1. (2) Suspension cable support kits
2. (4) Cold-side power and signal cable/fiber kits (including cathode and bottom-RMS fibers)
3. (1) Flange and feedthrough kit
4. (4) Warm-side power and signal cable kits
5. (8) Membrane-mount XA and cold electronics kits
6. (4) XA HV-shield mesh kits

Membrane-mounted XA installation sequence

This section describes the sequence of steps necessary to install and test one column (8 XA) of the 44 Membrane-mounted XA columns. It is critical to note that the XA dichroic filters, which are anticipated to be exposed during cryostat installation, must be protected from VUV light.

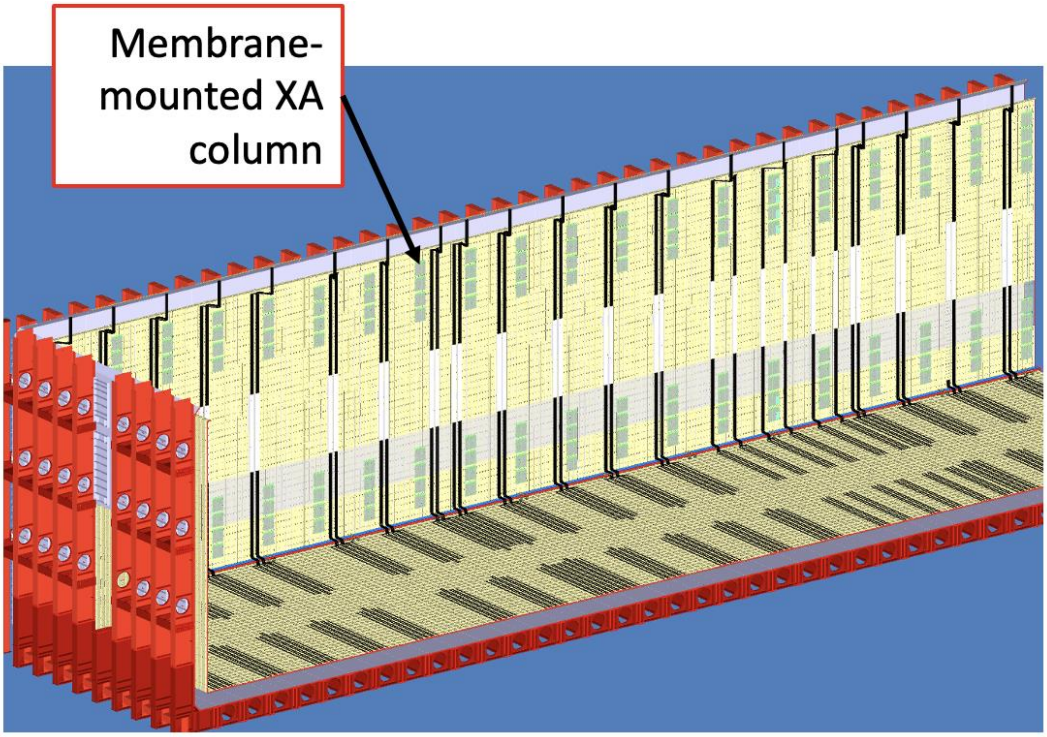

Figure 9. Perspective view of the relative position of Membrane-mounted XA columns in the cryostat.

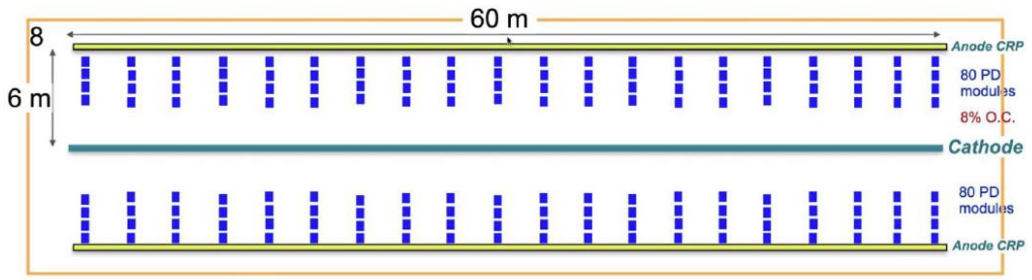

Figure 10. Membrane-mounted XA cryostat wall installation pattern.

Personnel and Shifts: The *cold-side* team is 2x 10-hour shifts per day (1 day and 1 night), **6 days a week**, 4 people per shift (i.e., 12 people living at SURF for 2 months and rotating shifts). The *warm-side* team is 2x 10-hour shifts per day (1 day and 1 night), **6 days a week**, 2 people per shift (i.e., 6 people living at SURF for 2 months and rotating shifts). 8 XA installed and tested per shift max rate. **96 XA per week max rate**. 12 columns per week max rate.

There are anticipated inefficiencies because of time-sharing with other subsystems working in the same area. On **average**, the installation schedule calls for **88 Membrane-mounted XA, in 11 columns, per week** to be installed and tested.

The *cold-side* team are scientific personnel from the PDS Consortium, with I&I technical support, experienced in FD2 PDS cryostat membrane installation. The *warm-side* team are scientific personnel from the PDS Consortium experienced in FD2 PDS warm electronics, DAQ interfacing, and detector validation.

Total installation time for each of the 44 column locations is considered below. The schedule for FD2 PDS Membrane-mounted XA installation is 4 weeks, 6 days a week, 2 10-hour shifts per day, for a total of 24 working days (48 shifts). The anticipated average rate of column installation is 2 columns per day (**1 column per shift**), with a 4-day ramp-up period.

Installation Sequence:

1. Cold-side team move (2) suspension cable support kits to associated column position inside cryostat. Warm-side team break. **Activity Time**: 30 minutes, **Running Time**: 30 minutes.

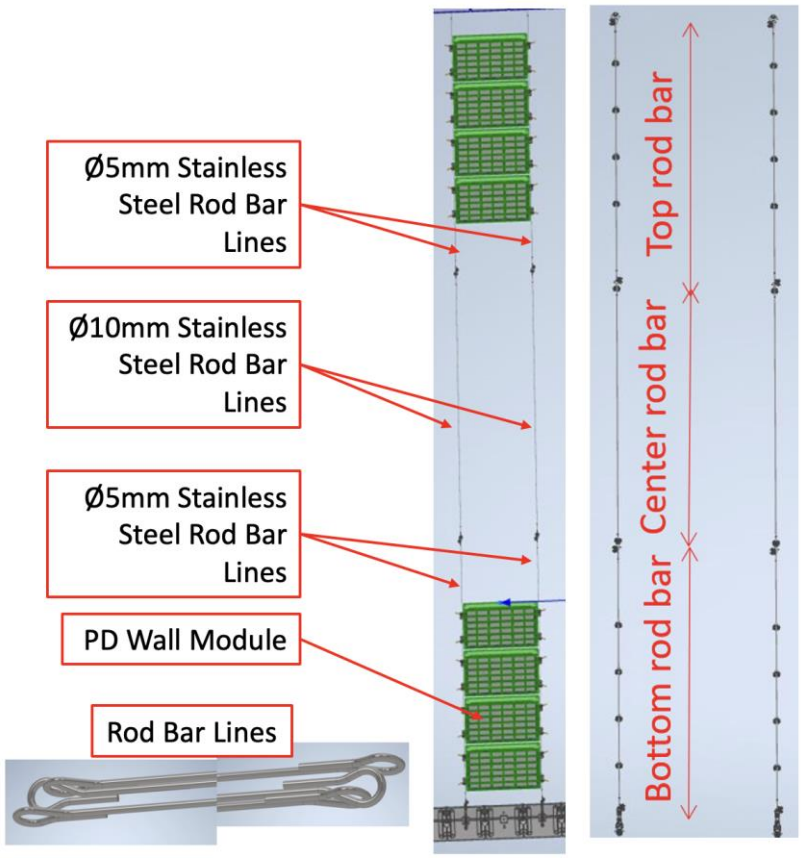

Figure 11. Components of the (2) suspension cable support kits (a left and right).

2. Cold-side team install (2) suspension cable support kits at associated column position inside cryostat using a scissor lift. Warm-side team break. **Activity Time**: 60 minutes, **Running Time**: 1.5 hours.

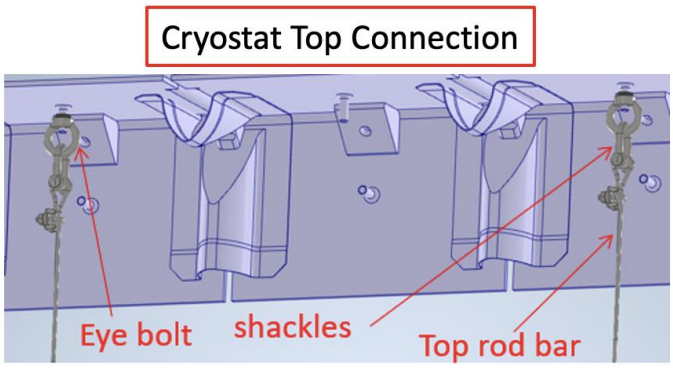

Figure 12. Cryostat interface top components of the (2) suspension cable support kits.

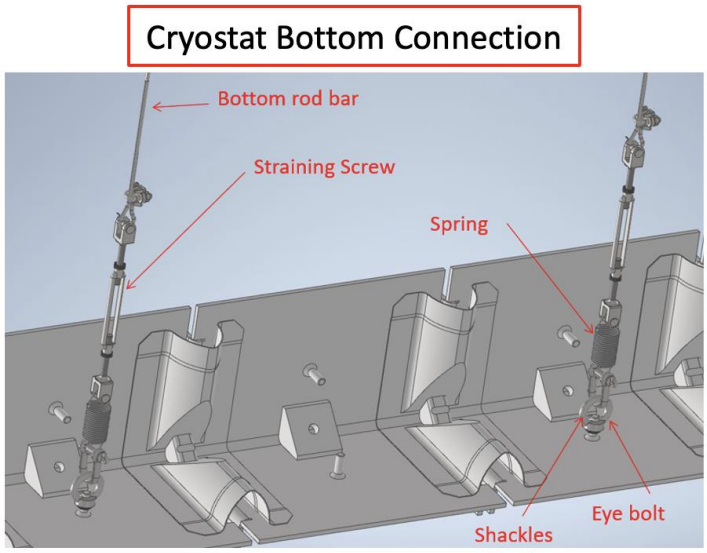

Figure 13. Cryostat interface bottom components of the (2) suspension cable support kits.

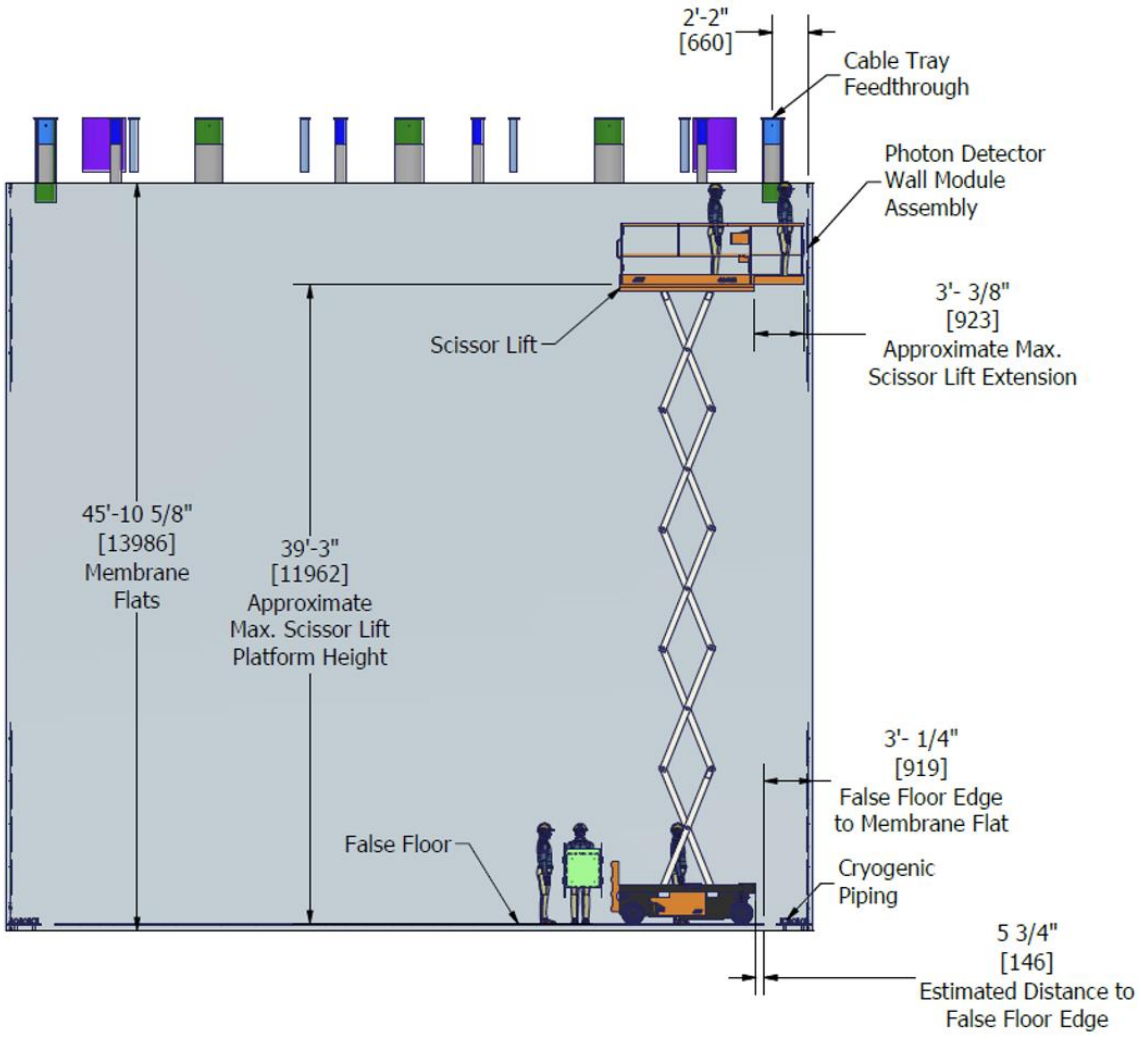

Figure 14. Scissor lift usage during Membrane-mounted XA column installation.

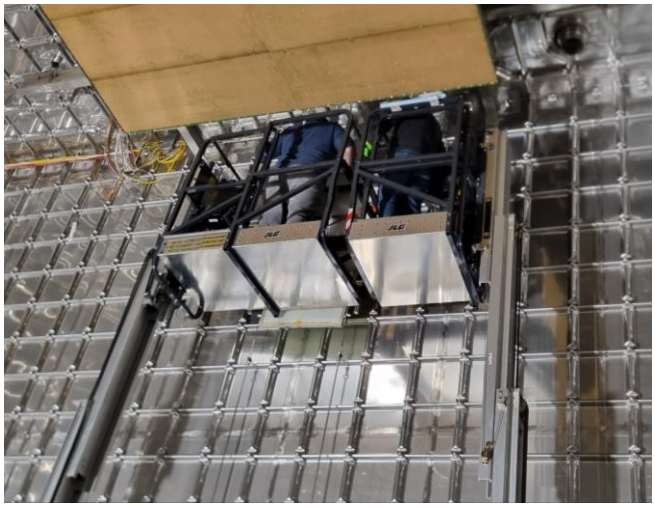

Figure 15. Dual scissor lift installation approach for membrane suspension system work.

3. Cold-side team move (4) cold-side power and signal cable/fiber kits (including RMS bottom fiber diffusers and Cathode-mounted XA PoF/SoF fiber) to the associated column position in the cryostat. Warm-side team move (1) flange and feedthrough kit and (4) warm-side power and signal cable kits to the associated penetration position on the cryostat roof. **Activity Time**: 30 minutes, **Running Time**: 2 hours.

Figure 16. FD2 PDS flange and feedthrough kit for Membrane-mounted XA installation.

4. Cold-side team install and dress (4) cold-side power and signal cable/fiber kits (including RMS bottom fiber diffusers and Cathode-mounted XA PoF/SoF fiber), with consideration for joining, near the cryostat ceiling, the associated penetration bundles of BDE cables and Cathode-mounted XA fibers. Warm-side team install and dress (4) warm-side power and signal cable kits between the Warm Electronics rack termination and the termination at the (1) flange and feedthrough kit in its temporary installation verification position. **Activity Time**: 60 minutes, **Running Time**: 3 hours.

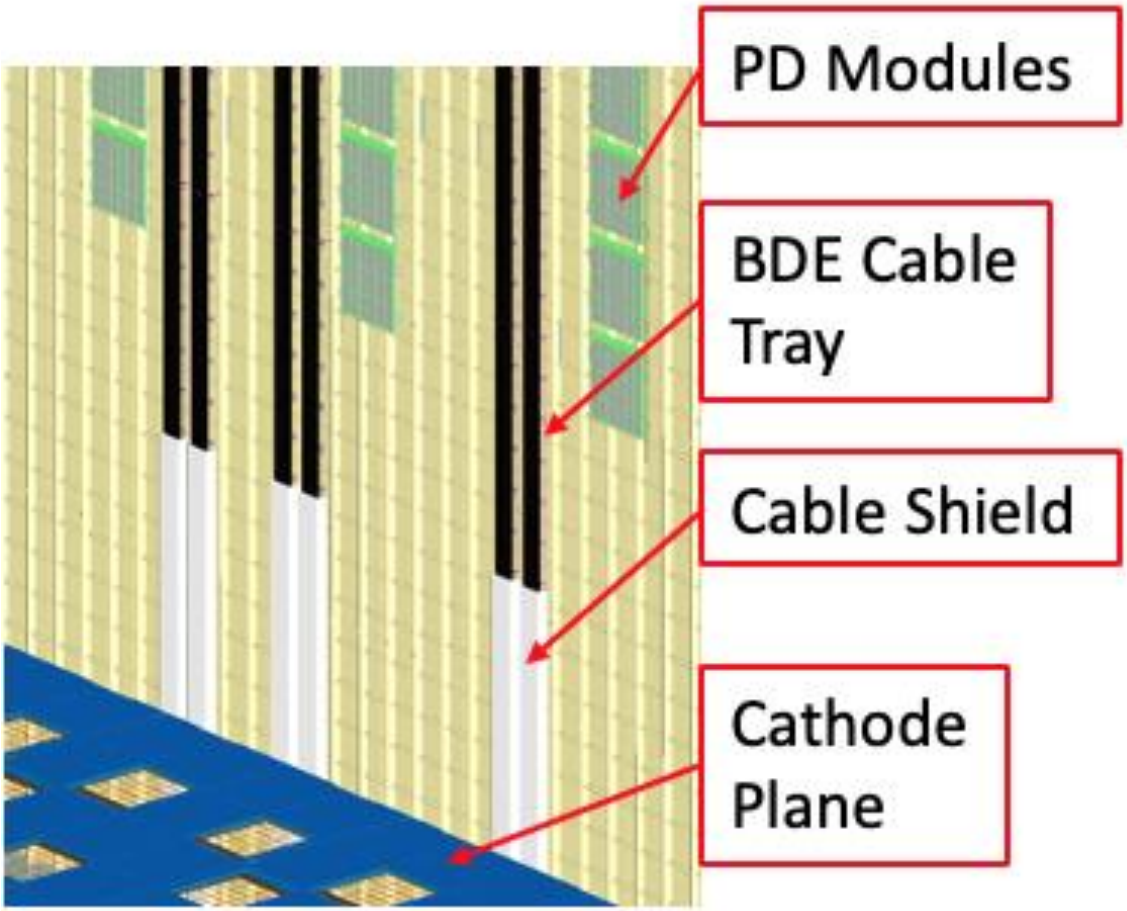

Figure 17. Relative position of components associated with cable/fiber install and dress.

Figure 18. View of the cable/fiber dressing down to the floor of the cryostat.

5. Break. **Activity Time**: 15 minutes, **Running Time**: 3.25 hours.
6. Coordinate and execute BDE+PDS cable/fiber bundle pull among BDE, PDS cold-side, and PDS warm-side teams. This primary cable/fiber bundle (i.e., not including PDS RMS fibers) is pulled through the primary area of the shared penetration, and then dressed to the cable clamp plate at the bottom of the penetration. Warm-side team starts feedthrough assembly at cryostat room for Membrane XA cables, Cathode XA fibers, and bottom-RMS fibers. **Activity Time**: 60 minutes, **Running Time**: 4.25 hours.

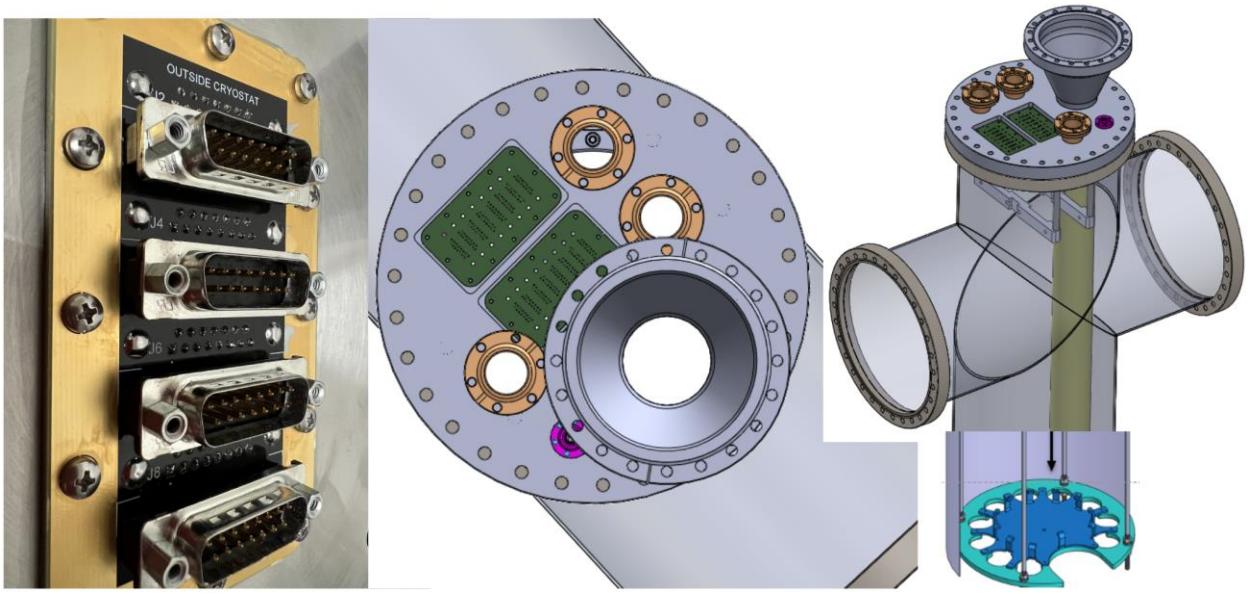

Figure 19. Membrane-mounted XA flange and feedthrough assembly.

7. Cold-side team move the (8) Membrane-mount XA and cold electronics kits, and (4) XA HV-shield mesh kits, to the associated column. Warm-side team completes feedthrough assembly at cryostat room for Membrane XA cables, Cathode XA fibers, and bottom-RMS fibers. **Activity Time**: 60 minutes, **Running Time**: 5.25 hours.

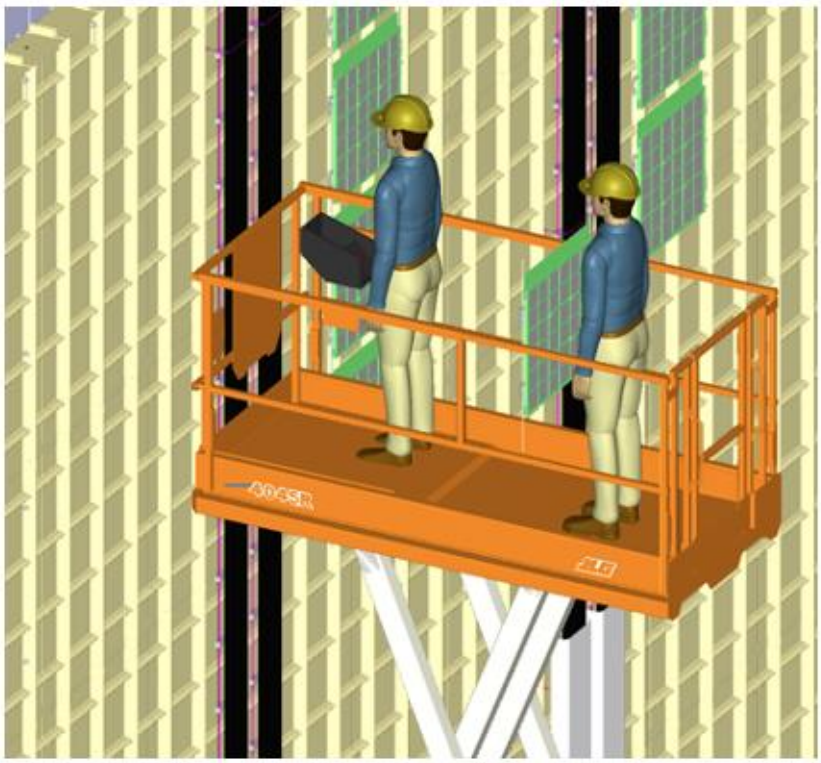

Figure 20. View of the top (4) Membrane-mount XA installation.

Figure 21. Cathode-mounted XA feedthrough for (8) SoF/PoF fibers before compression fit.

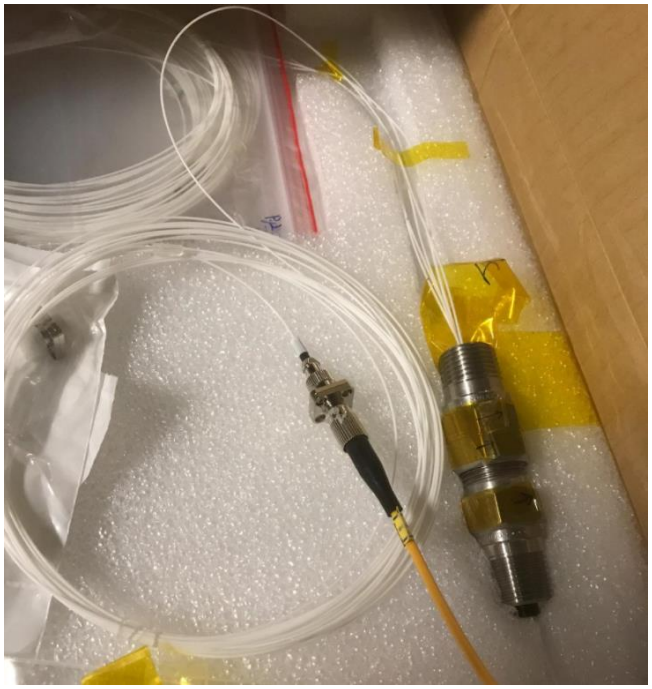

Figure 22. Cathode-mounted XA feedthrough for (8) SoF/PoF fibers after compression fit.

8. Cold-side team raise and affix the (8) Membrane-mount XA to the suspension system at associated column. Connect (4) cold-side power and signal cable kit to the (8) installed XA. Install (4) XA HV-shield mesh kits protecting the (8) Membrane-mount XA. Warm-side team executes flange and feedthrough leak check. **Activity Time**: 120 minutes, **Running Time**: 7.25 hours.

Figure 23. Fixation assembly for the Membrane-mounted XA to the suspension system.

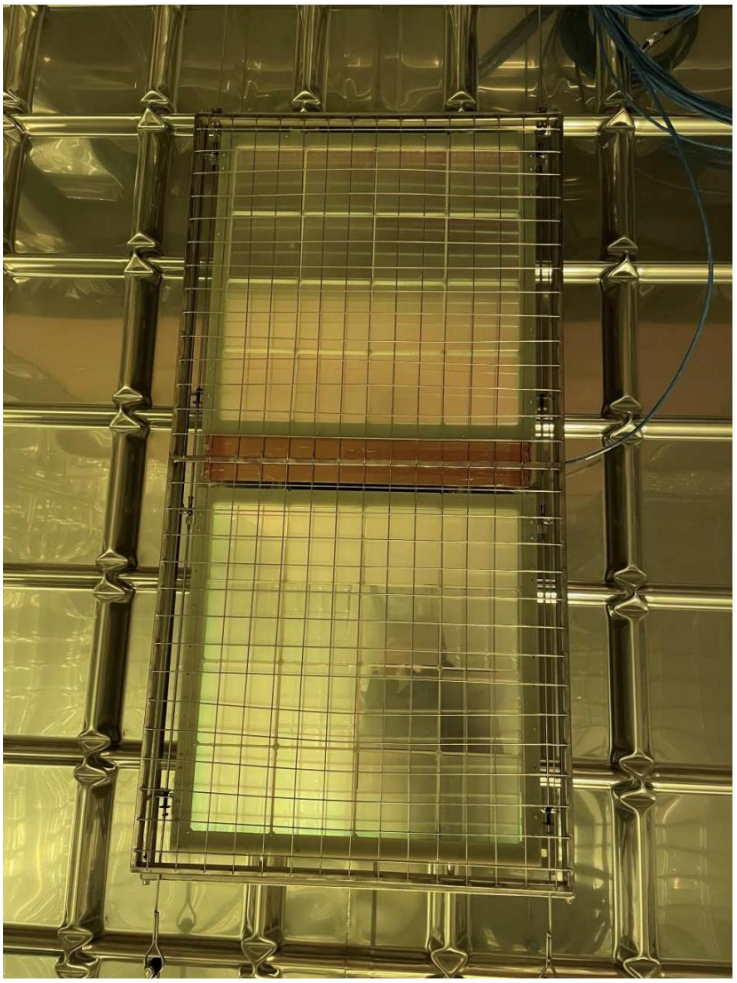

Figure 24. Membrane-mounted XA with HV-shield mesh protection.

9. Warm-side and cold-side teams coordinate to conduct (8) Membrane-mount XA electrical continuity test procedure. **Activity Time**: 30 minutes, **Running Time**: 7.75 hours.
10. Warm-side team execute (8) Membrane-mount XA installation verification and characterization procedure; document results in database. Cold-side team break. **Activity Time**: 60 minutes, **Running Time**: 8.75 hours.
11. Final installation and test of (1) Membrane-mount XA column (i.e., 8 XA) in cryostat **complete**.

Cathode-mounted Module Installation and Setup

This section describes the installation and setup plan for the FD2 PDS Cathode-mounted XA. The FD2 PDS Cathode-mounted XA components, and installation steps, are replicated at 40 pairs of high-voltage cathode modules. The Cathode-mounted XA components to be installed at each pair of high-voltage cathode modules include the following:

1. (1) Flange and feedthrough kit, in position from Membrane-mounted XA procedure
2. (8) PoF/SoF fiber bundles pre-installed with Membrane-mounted XA
3. (8) Cathode-mount XA and cold electronics kits

Cathode-mounted XA installation sequence

This section describes the sequence of steps necessary to install and test 8 XA into one pair of high-voltage cathode modules (1/2 row of the installation sequence's 20 rows) out of the 40 pairs of high-voltage cathode modules. It is critical to note that the XA dichroic filters, which are anticipated to be exposed during cryostat installation, must be protected from VUV light.

Personnel and Shifts: The *cold-side* team is 2x 10-hour shifts per day (1 day and 1 night), **6 days a week**, 4 people per shift (i.e., 12 people living at SURF for 2 months and rotating shifts). The *warm-side* team is 2x 10-hour shifts per day (1 day and 1 night), **6 days a week**, 2 people per shift (i.e., 6 people living at SURF for 2 months and rotating shifts). The *clean-room* team is the same team that is conducting XA assembly in the clean room adjacent to the cryostat. 4 XA installed and tested per shift max rate. **48 XA per week max rate**. 24 pairs of high-voltage cathode modules per week max rate.

There are anticipated inefficiencies in the work rate because of time-sharing with other subsystems working in the same area. On **average**, the installation schedule calls for **32 Cathode-mounted XA, in 4 pairs of high-voltage cathode modules, per week** to be installed and tested.

The *cold-side* team are scientific personnel from the PDS Consortium, with I&I technical support and cathode team support, experienced in FD2 PDS cryostat membrane installation. The *warm-side* team are scientific personnel from the PDS Consortium experienced in FD2 PDS warm electronics, DAQ interfacing, and detector validation.

Total installation time for each of the 40 pairs of high-voltage cathode modules is considered below. The schedule for FD2 PDS Cathode-mounted XA installation is 12 weeks, 6 days a week, 2 10-hour shifts per day, for a total of 72 working days (144 shifts). The anticipated average rate of Cathode-mounted XA installation targets one cathode module pair per day (**1 cathode module per shift**), with a 7-day ramp-up period.

Parallel Clean Room Installation Sequence:

1. In clean room, with cathode module-A vertical, clean-room team move (1) Cathode-mount XA and cold electronics kit to staging position. In clean room, warm-side team prepare clean room installation verification system for operation. **Activity Time**: 15 minutes, **Running Time**: 1st Shift -- 15 minutes.
2. In clean room, with cathode module A vertical, clean-room team install to position-A (1) Cathode-mount XA and cold electronics kit into dedicated cell with cathode module-A. Connect test PoF/SoF fibers. Warm-side team break. **Activity Time**: 60 minutes, **Running Time**: 1st Shift – 1.25 hours.

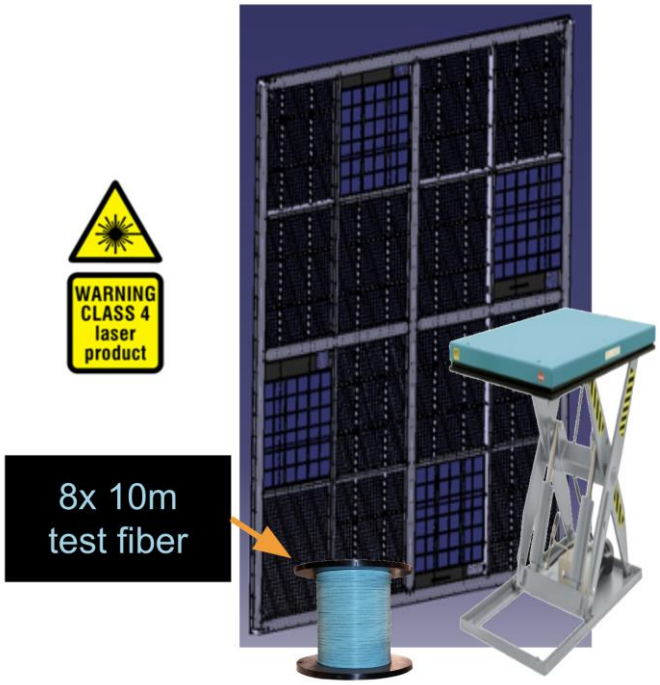

Figure 25. Single cathode module in vertical position with 4-positions for XA and test fiber.

3. In clean room, warm-side and clean-room teams coordinate to conduct position-A Cathode-mount XA power/signal continuity test procedure using test fiber and clean room test Warm Electronics. **Activity Time**: 15 minutes, **Running Time**: 1st Shift – 1.5 hours.
4. In clean room, warm-side team execute position-A Cathode-mount XA installation verification and characterization procedure; document results in database. Clean-room team break. **Activity Time**: 15 minutes, **Running Time**: 1st Shift – 1.75 hours.
5. In clean room, with cathode module-A vertical, clean-room team move (1) Cathode-mount XA and cold electronics kit to staging position. In clean room, warm-side team prepare clean room installation verification system for operation. **Activity Time**: 15 minutes, **Running Time**: 1st Shift – 2 hours.

6. In clean room, with cathode module A vertical, clean-room team install to position-B (1) Cathode-mount XA and cold electronics kit into dedicated cell with cathode module-A. Connect test PoF/SoF fibers. Warm-side team break. **Activity Time**: 60 minutes, **Running Time**: 1st Shift – 3 hours.
7. In clean room, warm-side and clean-room teams coordinate to conduct position-B Cathode-mount XA power/signal continuity test procedure using test fiber and clean room test Warm Electronics. **Activity Time**: 15 minutes, **Running Time**: 1st Shift – 3.25 hours.
8. In clean room, warm-side team execute position-A Cathode-mount XA installation verification and characterization procedure; document results in database. Clean-room team break. **Activity Time**: 15 minutes, **Running Time**: 1st Shift – 3.5 hours.
9. Break. **Activity Time**: 30 minutes, **Running Time**: 1st Shift – 4 hours.
10. In clean room, with cathode module-A vertical, clean-room team move (1) Cathode-mount XA and cold electronics kit to staging position. In clean room, warm-side team prepare clean room installation verification system for operation. **Activity Time**: 15 minutes, **Running Time**: 1st Shift – 4.25 hours.
11. In clean room, with cathode module A vertical, clean-room team install to position-C (1) Cathode-mount XA and cold electronics kit into dedicated cell with cathode module-A. Connect test PoF/SoF fibers. Warm-side team break. **Activity Time**: 60 minutes, **Running Time**: 1st Shift – 5.25 hours.
12. In clean room, warm-side and clean-room teams coordinate to conduct position-C Cathode-mount XA power/signal continuity test procedure using test fiber and clean room test Warm Electronics. **Activity Time**: 15 minutes, **Running Time**: 1st Shift – 5.5 hours.
13. In clean room, warm-side team execute position-C Cathode-mount XA installation verification and characterization procedure; document results in database. Clean-room team break. **Activity Time**: 15 minutes, **Running Time**: 1st Shift – 5.75 hours.
14. In clean room, with cathode module-A vertical, clean-room team move (1) Cathode-mount XA and cold electronics kit to staging position. In clean room, warm-side team prepare clean room installation verification system for operation. **Activity Time**: 15 minutes, **Running Time**: 1st Shift – 6.0 hours.
15. In clean room, with cathode module-A vertical, clean-room team install to position-D (1) Cathode-mount XA and cold electronics kit into dedicated cell with cathode module-A. Connect test PoF/SoF fibers. Warm-side team break. **Activity Time**: 60 minutes, **Running Time**: 1st Shift – 7.0 hours.
16. In clean room, warm-side and clean-room teams coordinate to conduct position-D Cathode-mount XA power/signal continuity test procedure using test fiber and clean room test Warm Electronics. **Activity Time**: 15 minutes, **Running Time**: 1st Shift – 7.25 hours.

17. In clean room, warm-side team execute position-D Cathode-mount XA installation verification and characterization procedure; document results in database. Clean-room team break. **Activity Time**: 15 minutes, **Running Time**: 1st Shift – 7.5 hours.
18. Cathode team moves cathode module-A from vertical position in clean room into associated cryostat position. 1st Shift complete.
19. 2nd Shift repeat 1st Shift for cathode module-B in vertical position in clean room. **Running Time**: 2nd Shift – 7.5 hours.
20. Cathode team moves cathode module-B from vertical position in clean room into associated cryostat position.
21. 2nd Shift complete.

Parallel Cryostat Installation Sequence:

1. In cryostat at <2m height, cold-side team coordinates with cathode and I&I teams to route and dress (8) PoF/SoF fiber bundles through cathode module pair A-B to their associated XA. Warm-side team, on cryostat roof, prepares Warm Electronics and PoF system for installation verification operation; verify fibers in associated feedthrough and connect to patch panel. Note the cathode fibers are pre-installed, with feedthrough leak check, during the Membrane XA installation sequence. **Activity Time**: 120 minutes, **Running Time**: 3rd Shift – 2.0 hours.

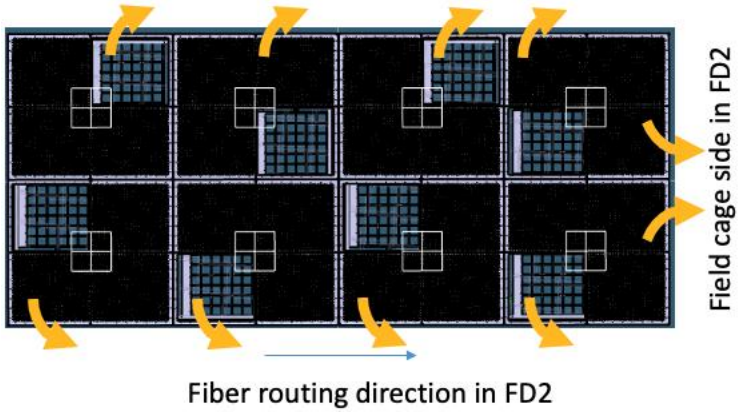

Figure 26. Fiber bundle exit points from a pair of high-voltage cathode modules.

Figure 27. Fiber bundle moved to cathode at <2m working height for routing on cathode.

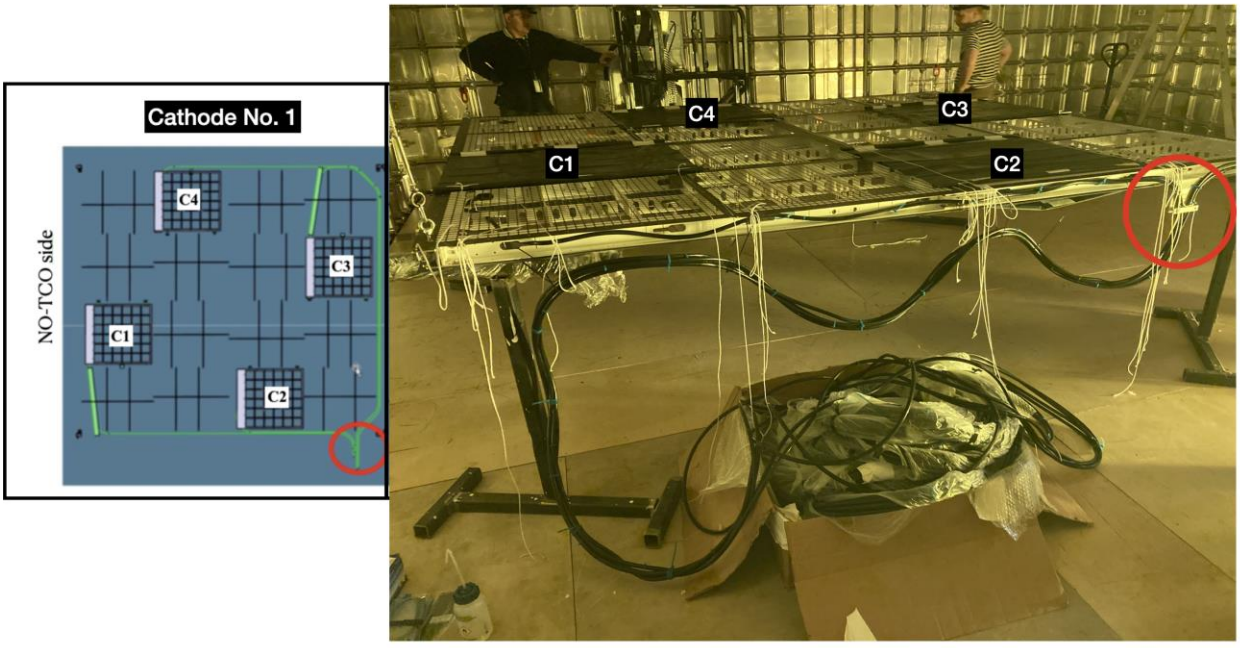

Figure 28. Fiber bundle XA destination mapping for the four XA locations.

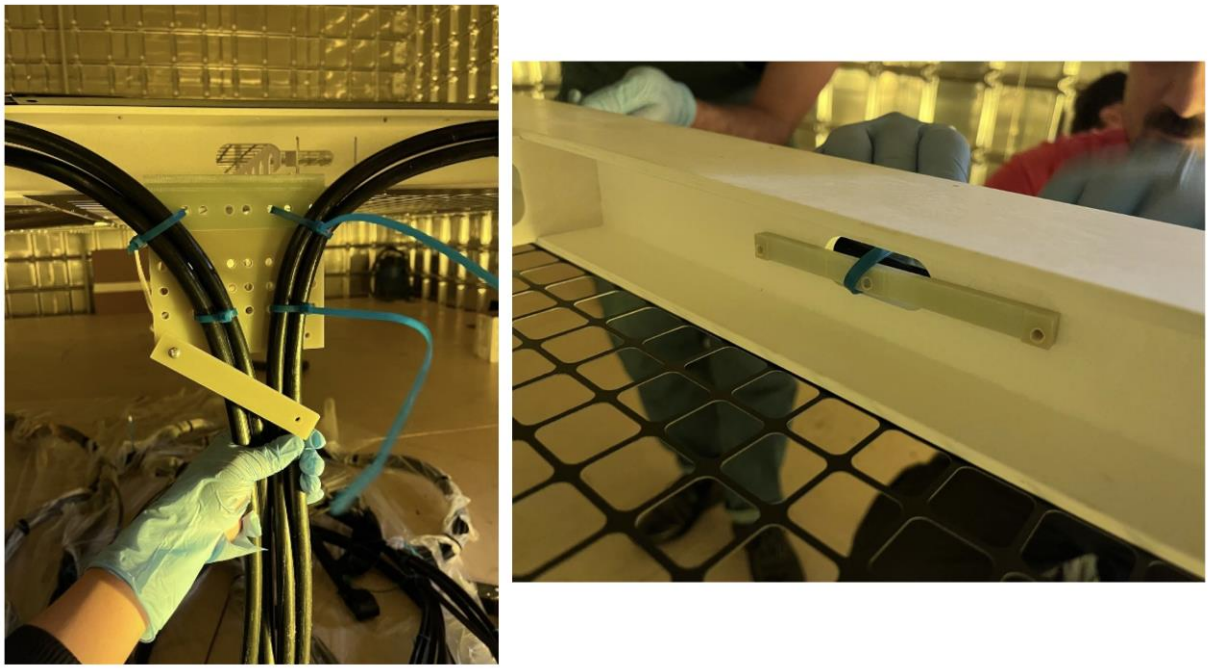

Figure 29. Fiber bundle dressing to the edge of the cryostat using tefzel zip ties secured to a G10 clamping plate.

2. In cryostat at <2m height, cold-side team makes final PoF/SoF fiber connection to the (8) Cathode-mount XA. Warm-side team support clean room parallel verification. **Activity Time**: 60 minutes, **Running Time**: 3rd Shift – 3.0 hours.
3. Coordinated with full FD2 installation activities (for Class 4 laser safety considerations!), execute Cathode-mount XA installation verification procedure using Class 4 PoF laser system and Warm Electronics. **Activity Time**: 15 minutes, **Running Time**: 3rd Shift – 3.25 hours.
4. Warm-side team document results in database. Cold-side team break and on stand-by for reconnection of PoF/SoF fibers. **Activity Time**: 30 minutes, **Running Time**: 3rd Shift – 3.75 hours.
5. Coordinated with full FD2 installation activities (for Class 4 laser safety considerations!), execute optional second test of Cathode-mount XA installation verification procedure using Class 4 PoF laser system and Warm Electronics. **Activity Time**: 15 minutes, **Running Time**: 3rd Shift – 4.0 hours.
6. Warm-side team document results in database. Cold-side team break and on stand-by for reconnection of PoF/SoF fibers. **Activity Time**: 30 minutes, **Running Time**: 3rd Shift – 4.5 hours.
7. Cold-side team, in coordination with I&I and cathode teams, complete conductive mesh installation over XA, complete fiber routing and fiber dressing, then clean Cathode-mount XA installation and remove tooling. Warm-side team break. **Activity Time**: 120 minutes, **Running Time**: 3rd Shift – 6.5 hours.

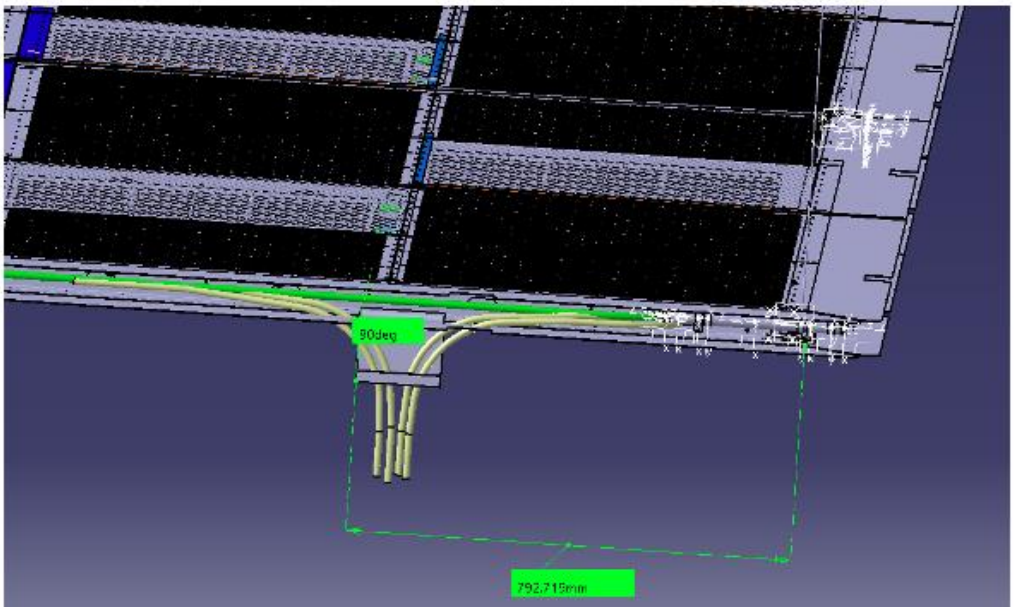

Figure 30. Fiber route exiting from a pair of high-voltage cathode modules.

8. 3rd Shift complete.

9. Cathode team lifts cathode pair A-B to final height in cryostat using dedicated tooling. Cold-side team monitors Cathode-mount XA PoF/SoF fiber bundles during lift. Warm-side team prepares for full-height verification test of Cathode-mount XA install. **Activity Time**: 120 minutes, **Running Time**: 4th Shift – 2.0 hours.

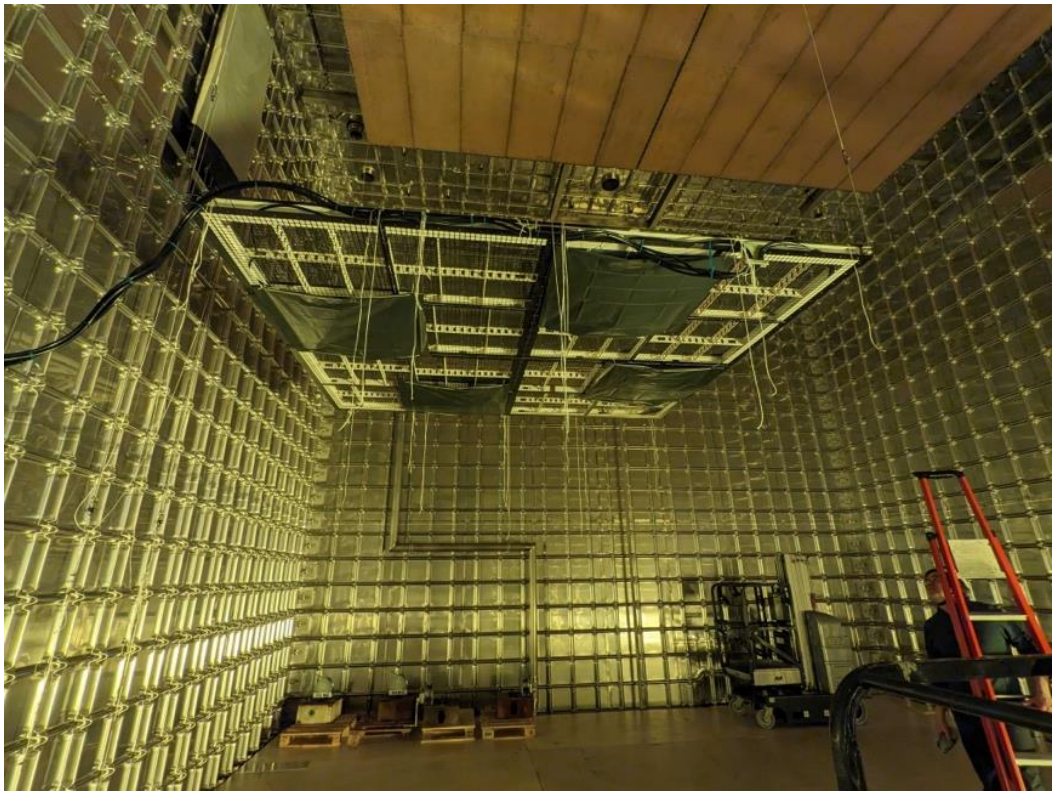

Figure 31. Lift of cathode module to full height with fiber bundle managed on the left.

10. Coordinated with full FD2 installation activities (for Class 4 laser safety considerations!), execute full-height verification test of Cathode-mount XA installation verification procedure using Class 4 PoF laser system and Warm Electronics. **Activity Time**: 15 minutes, **Running Time**: 4th Shift – 2.25 hours.
11. High-voltage field cage team installs associated field cage column. Cold-side team monitors Cathode-mount XA PoF/SoF fiber bundles during field cage install. Warm-side team break. **Activity Time**: 240 minutes, **Running Time**: 4th Shift – 6.25 hours.

Figure 32. Fiber bundle exit point from cathode to field cage and down to cryostat floor.

12. Cold-side team completes final dressing of PoF/SoF fiber bundles to active volume side of field cage and cryostat floor. Warm-side team break. **Activity Time**: 60 minutes, **Running Time**: 4th Shift – 7.25 hours.

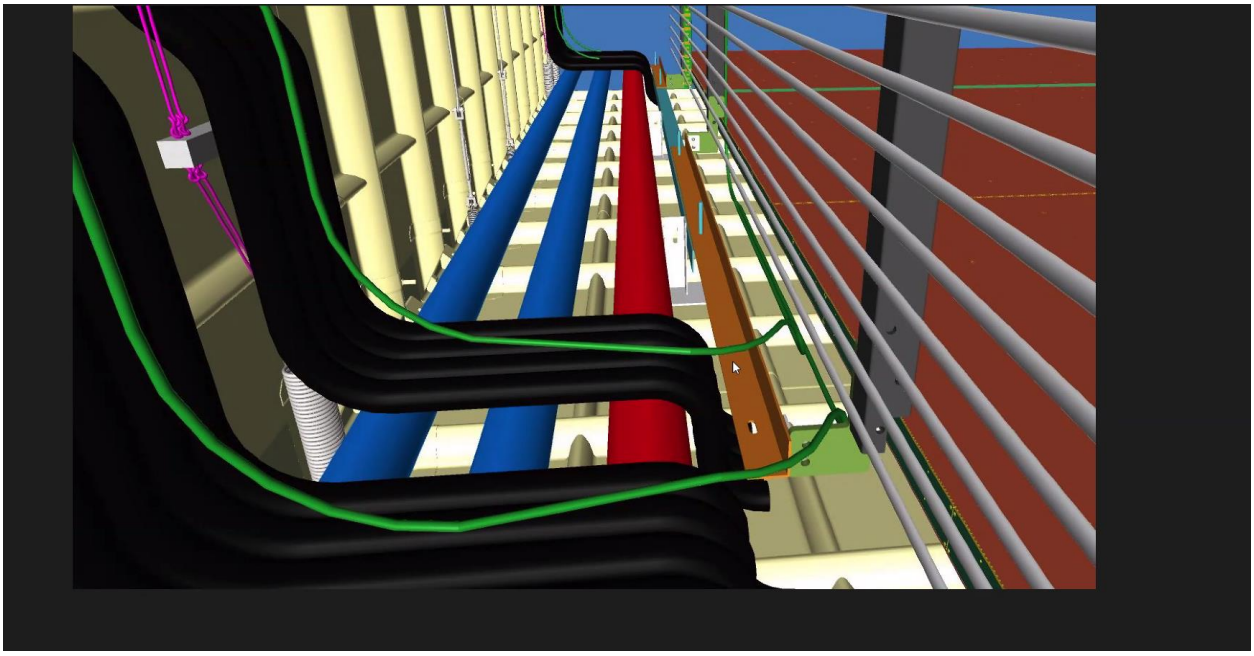

Figure 33. Final dressing of fiber bundle under the field cage.

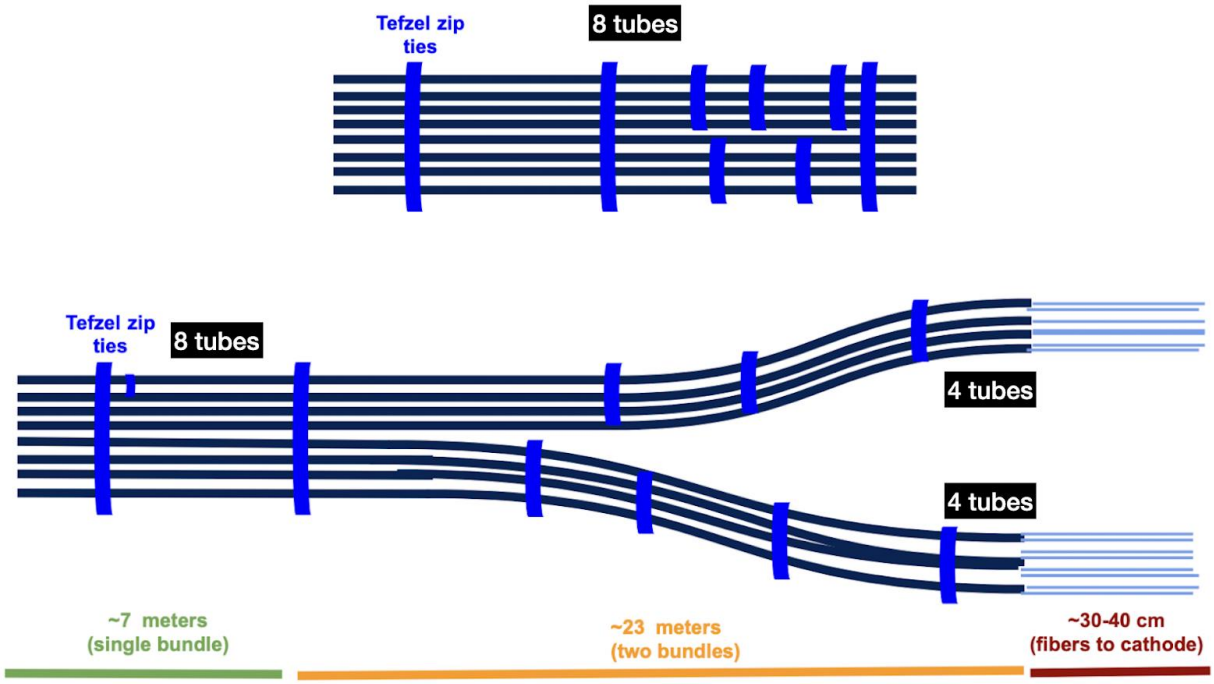

Figure 34. Diagram of fiber bundling approach transitioning from 8 tubes to 4 tubes for routing under field cage and up to cathode.

13. Coordinated with full FD2 installation activities (for Class 4 laser safety considerations!), execute final verification test of Cathode-mount XA installation verification procedure using Class 4 PoF laser system and Warm Electronics. **Activity Time**: 15 minutes, **Running Time**: 4th Shift – 7.5 hours.
14. 4th Shift complete.
15. Final installation and test of one pair of high-voltage cathode modules (i.e., 8 XA) in cryostat **complete**.

Response Monitoring System Installation and Setup

This section describes the installation and setup plan for the RMS. The FD2 PDS RMS components, and installation steps, are replicated at 44 columns (2 RMS fiber diffusers kits per column) along the perimeter of the field. The RMS components to be installed at each column include the following:

1. (2) RMS fiber diffuser kits, bottom-RMS installed with Membrane-mounted XA
2. (1) Flange and feedthrough kit, in position from Membrane-mounted XA procedure

RMS installation sequence

This section describes the sequence of steps necessary to install and test one column (2 RMS fiber diffuser kits) of the 44 RMS columns.

Personnel and Shifts: The *cold-side* team utilizes the Membrane and Cathode cold-side teams of 2x 10-hour shifts per day (1 day and 1 night), **6 days a week**, 4 people per shift (i.e., 12 people living at SURF for 2 months and rotating shifts). The *warm-side* team utilizes the Membrane and Cathode cold-side teams of is 2x 10-hour shifts per day (1 day and 1 night), **6 days a week**, 2 people per shift (i.e., 6 people living at SURF for 2 months and rotating shifts). 1 RMS column installed and tested per day max rate. 6 RMS columns per week max rate.

The anticipated work rate is 25% duty cycle because of time-sharing with other subsystems working in the same area; the 25% duty cycle allows key personnel to split time with the FD2 PDS Membrane-mounted XA and Cathode-mounted XA installation sequences. The RMS installation sequence must be coordinated with the field cage installation as (1) RMS kit attaches to the top field cage support and (1) RMS kit attaches to the bottom field cage support, per column.

The *cold-side* team are scientific personnel from the PDS Consortium, with I&I technical support, experienced in FD2 PDS cryostat RMS installation. The *warm-side* team are scientific personnel from the PDS Consortium experienced in FD2 PDS warm electronics, DAQ interfacing, and RMS validation.

Total installation time for each of the 44 column locations is considered below. The schedule for FD2 PDS RMS is 8 weeks, 6 days a week, 2 10-hour shifts per day, for a total of 48 working days (96 shifts). The anticipated average rate of column installation is 1 column per day, with a 4-day ramp-up period:

1. Cold-side team move (2) RMS fiber diffuser kits to associated field cage column position inside cryostat. Field cage is at floor level before raising. Bottom RMS fibers already dressed membrane wall as part of Membrane-mounted XA installation. Warm-side team move (1) flange and feedthrough kit to associated penetration on cryostat roof. **Activity Time**: 30 minutes, **Running Time**: 1st Shift -- 30 minutes.

Figure 35. RMS fiber feedthrough.

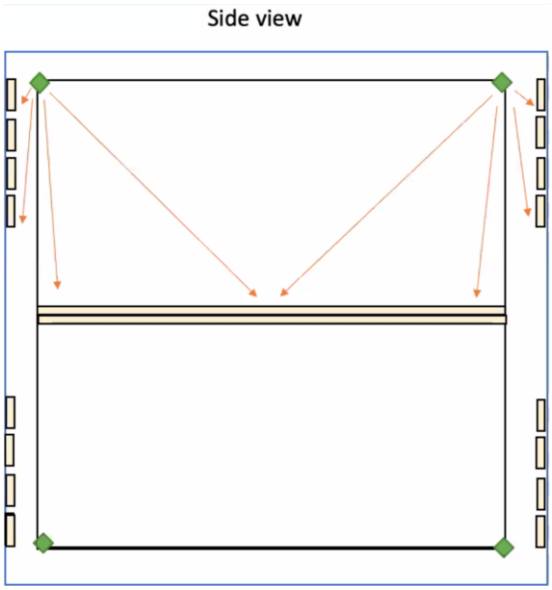

Figure 36. View from the short-side wall of the bottom and top RMS locations.

2. Cold-side team install (1) RMS fiber diffuser kit affixed to top field cage support beam and (1) RMS fiber diffuser kit affixed to bottom field cage support beam. Warm-side team prepare Warm Electronics for install verification operation. **Activity Time**: 60 minutes, **Running Time**: 1st Shift – 1.5 hours.

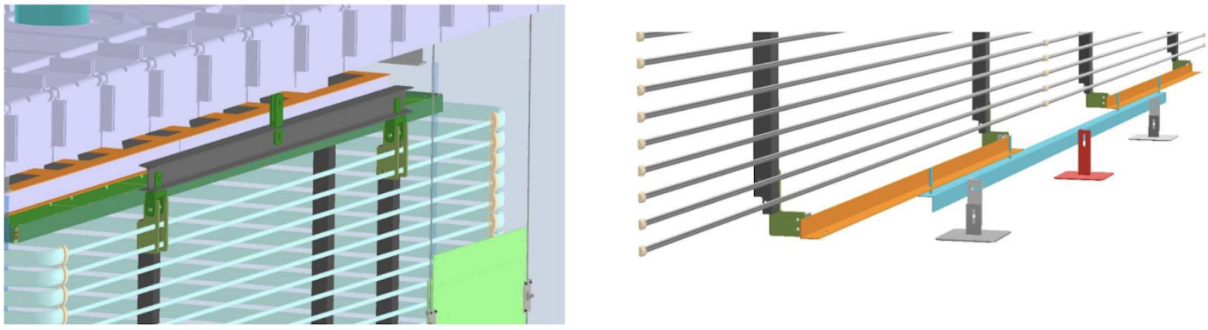

Figure 37. Top and bottom field cage support structures.

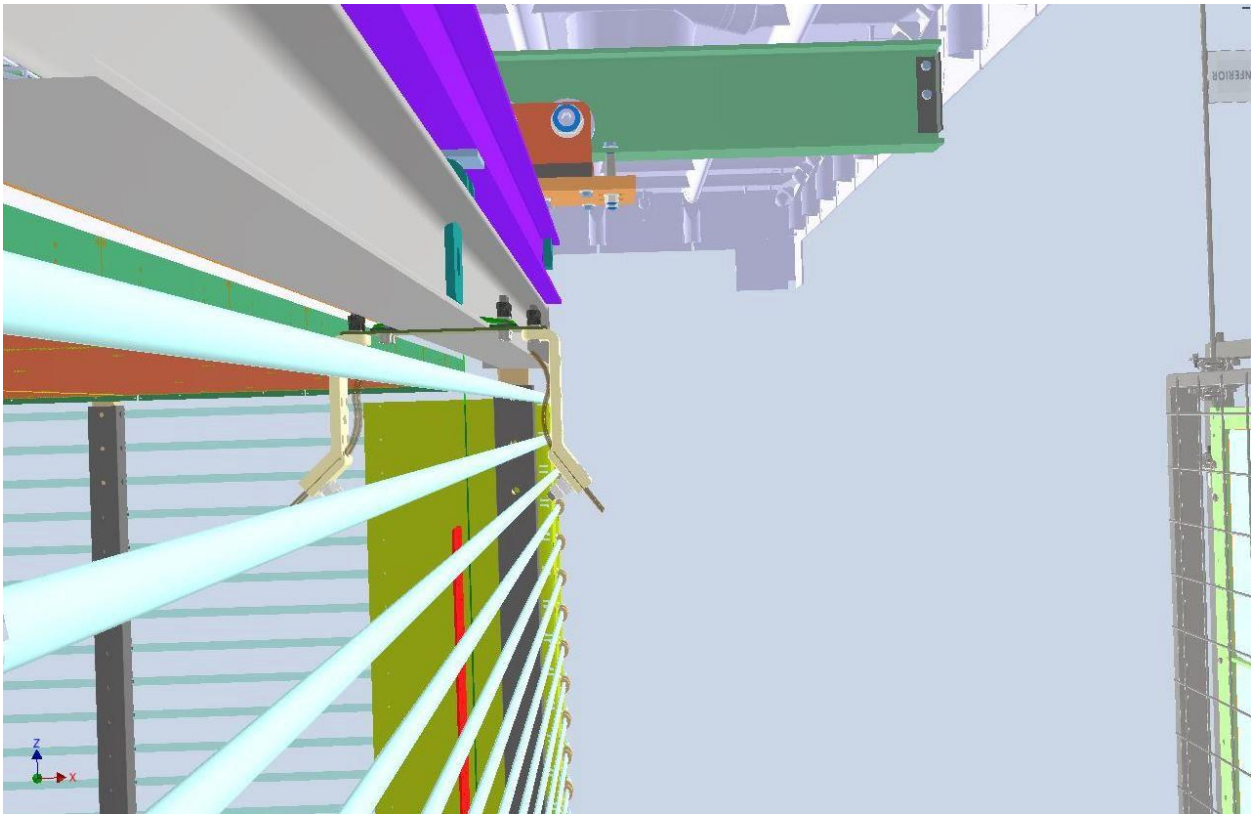

Figure 38. RMS fiber installation at top field cage support structure.

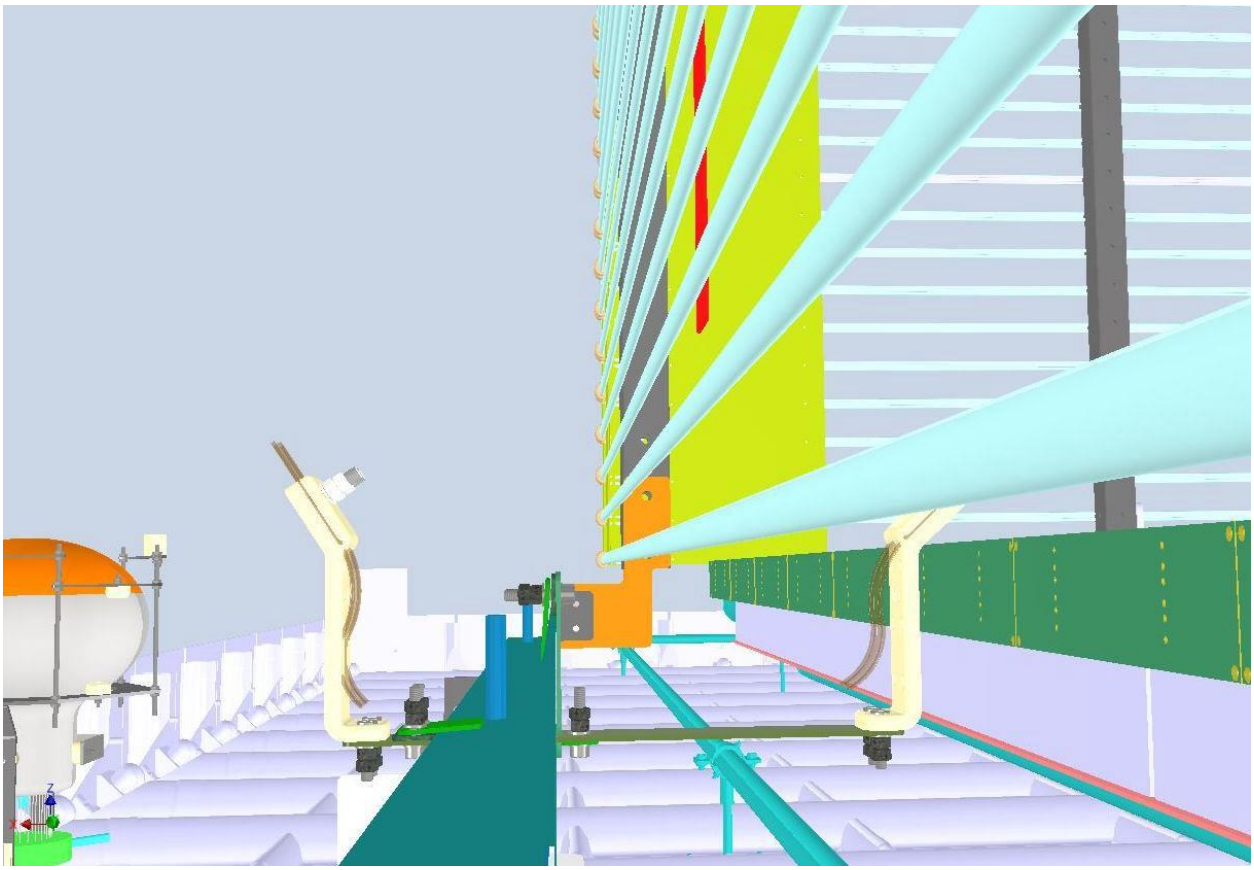

Figure 39. RMS fiber installation at bottom field cage support structure

3. Warm-side and cold-side team execute coordinated installation test procedure (i.e. continuity test); document results in database. **Activity Time**: 30 minutes, **Running Time**: 1st Shift – 2 hours.
4. Cold-side and warm-side team clean RMS installation and remove tooling. **Activity Time**: 60 minutes, **Running Time**: 1st Shift – 3 hours.
5. 1st Shift complete.
6. Coordinate with field cage team to raise top field cage support to final height. Execute RMS fiber pull through septum during lifting procedure.
7. 3rd, and 4th Shift is left for contingency due to the expectation for resource sharing (including I&I technical staff, field cage team, scissor lifts, and physical installation space) with other subsystems.
8. Final installation and test of (1) RMS column (i.e., 2 fiber diffusers) in cryostat **complete**.