Photon Detector System: PD Mechanical System Design

David Warner for the Photon Detector Consortium

SP Photon Detector System Final Design Review

Mechanical Sub-Systems

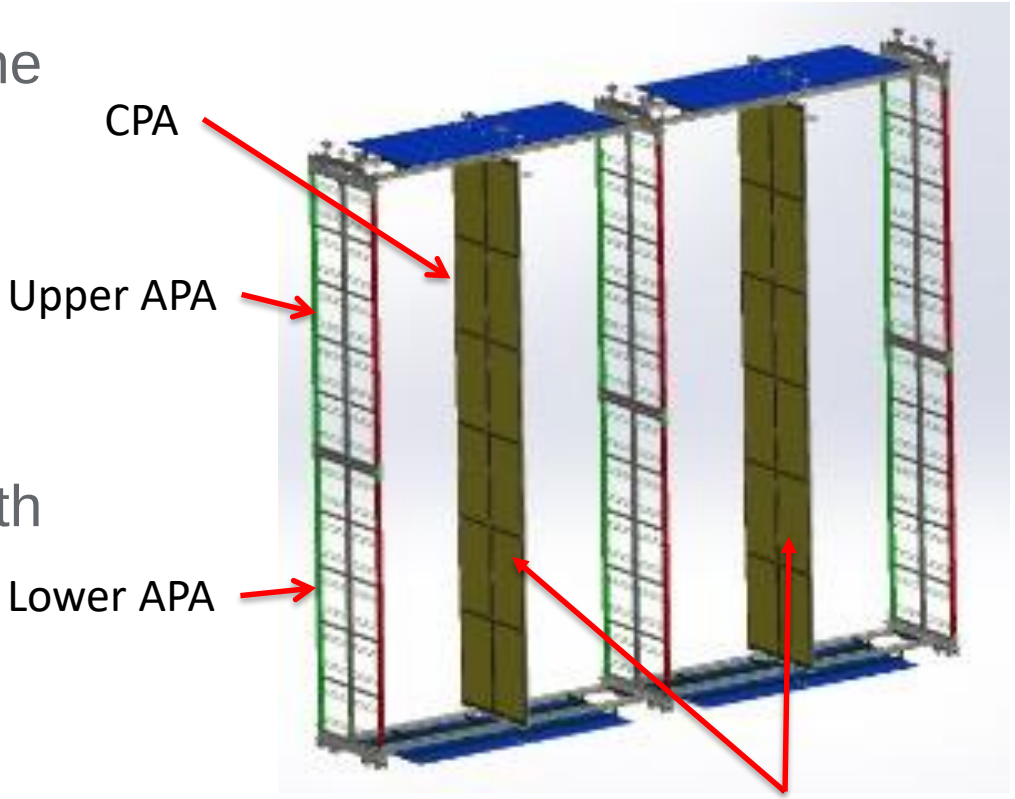
14-15 March, 2023

Outline

- Light collector system design concept:
  - Module positioning in APA
  - Cable routing
  - PD module design
    - Module 0 (FD1 ProtoDUNE 2 Design).
    - FDR module design
      - Overall Mechanical design
      - Electrical connections
  - Monitoring system design
  - Flange/cable routing design
- Module 0 (FD1 ProtoDUNE 2) mechanical lessons
- Schedule
- Summary

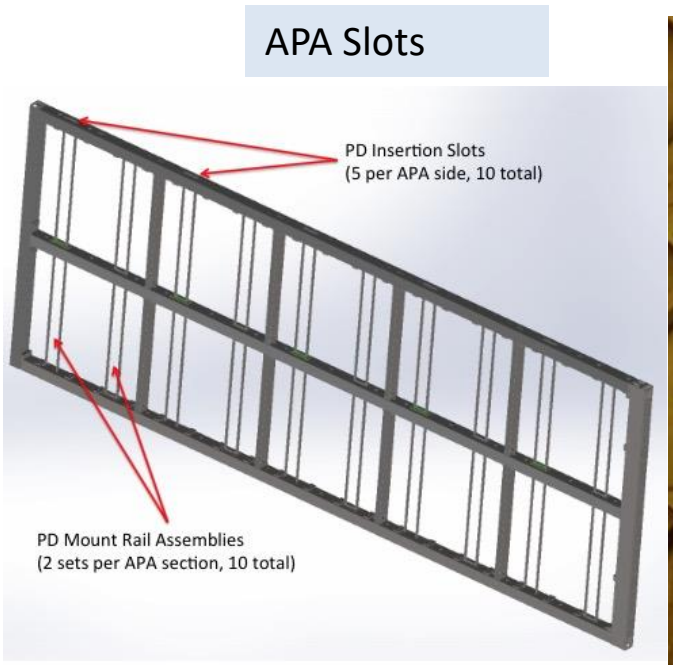
APAs Mounted in TPC slices

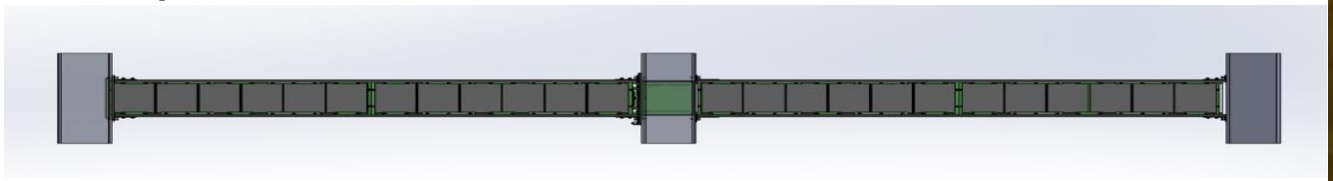
- In the DUNE FD, the APAs are stacked in pairs, and arranged in slices as in the figure.
  - *25 slices in FD1.*
- Note that this implies central APA PD modules must collect light from both directions.
- Also has implications for cable routing.



Photon Detector Mounting

- Photon detectors are supported in the APA frames.
- Mounted in stainless steel rails (10 per APA).
- Rail systems provided by PD consortium.
- Rail/cable system PRR completed 2022.

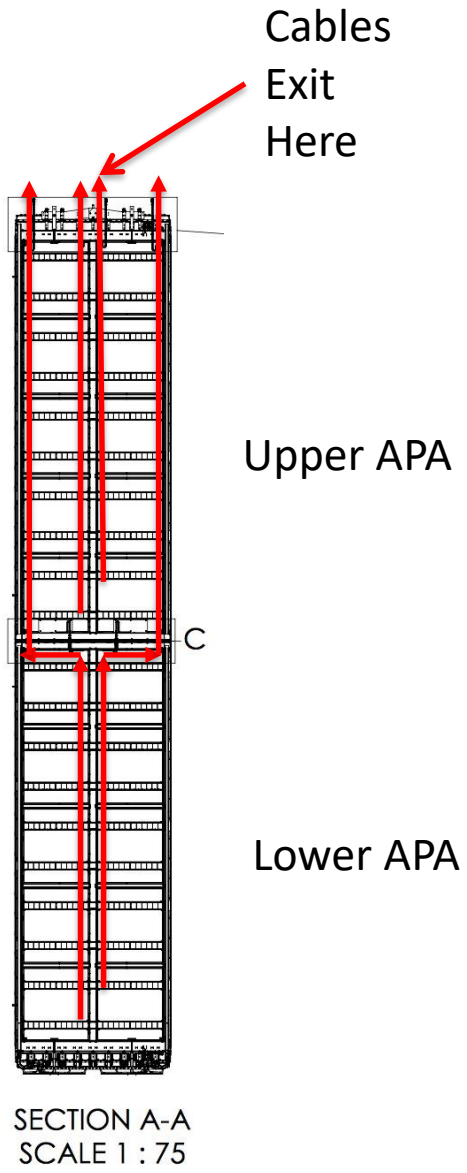




PD Module mounted in APA Rails

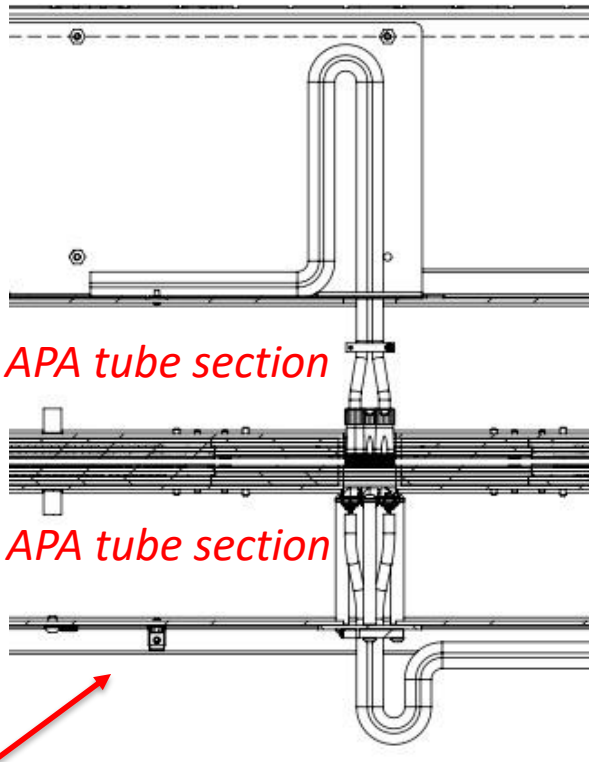
Cable Routing (i): Through APA Frame

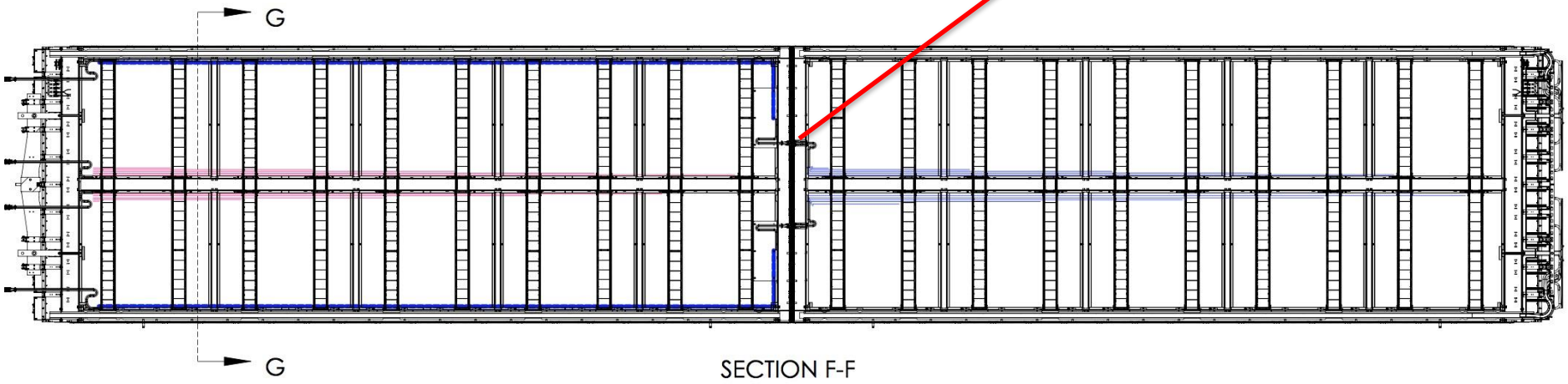
- APA frames joined vertically prior to insertion into cryostat.
- Cables from lower APA must route through upper APA.
- Requires two varieties of APA: Upper and lower.
- PD cable routing shared with CALCI temperature sensor cables. Addressed in Interface Control Document 2145137



Cable Routing (ii): Joining APA Frames

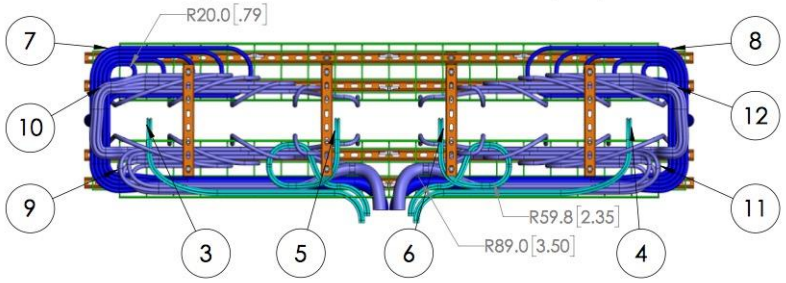
- Upper and lower APAs are joined using a custom interface block. Which was designed not limit APA separation. Prototype assembly tested at Ash River.
- Cables mounted in APA frames prior to wire wrapping.
- Clearance for 2% relative thermal contraction (cable/APA frame) allowed.

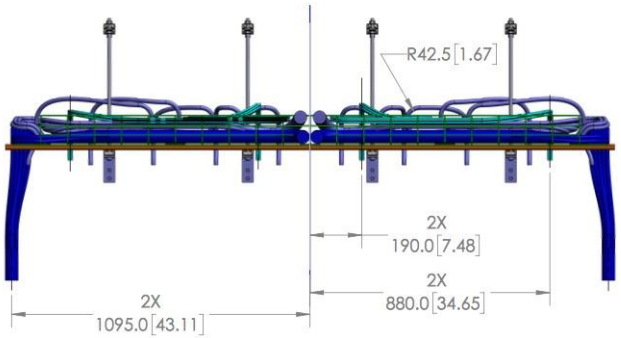


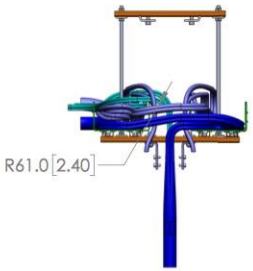


Cable Routing (iii): Shared Cable Tray with APA Cold Electronics

ITEM NO.	FILE NAME	DESCRIPTION	QTY.	DESIGN MIN BEND RADIUS (MM)	MIN ALLOWABL
1	CE CABLE TRAY ON CHANNEL	CABLE TRAY ON CHANNEL	1		
2	CE HANGER KIT	HANGER KIT	4		
3	PD BUNDLE IN TRAY LOWER - A	PD CABLE BUNDLE IN TPC TRAY FROM LOWER APA	1	100	
4	PD BUNDLE IN TRAY LOWER - B	PD CABLE BUNDLE IN TPC TRAY FROM LOWER APA	1	100	
5	PD BUNDLE IN TRAY UPPER - A	PD CABLE BUNDLE IN TPC TRAY FROM UPPER APA	1	100	
6	PD BUNDLE IN TRAY UPPER - B	PD CABLE BUNDLE IN TPC TRAY FROM UPPER APA	1	100	
7	CE CABLES IN TRAY LOWER - A	CE CABLES IN TRAY FROM LOWER APA	1	55	
8	CE CABLES IN TRAY LOWER - B	CE CABLES IN TRAY FROM LOWER APA	1	55	
9	CE CABLES IN TRAY UPPER - A1	CE CABLES IN TRAY FROM UPPER APA	1	50	
10	CE CABLES IN TRAY UPPER - A2	CE CABLES IN TRAY FROM UPPER APA	1	50	
11	CE CABLES IN TRAY UPPER - B1	CE CABLES IN TRAY FROM UPPER APA	1	50	
12	CE CABLES IN TRAY UPPER - B2	CE CABLES IN TRAY FROM UPPER APA	1	50	







Cable routing described In PDS/CE and PDS/I&I Interface documents

Cable routing performed By CE and I&I teams with PDS supervision

Module Structure Summary (by the numbers)

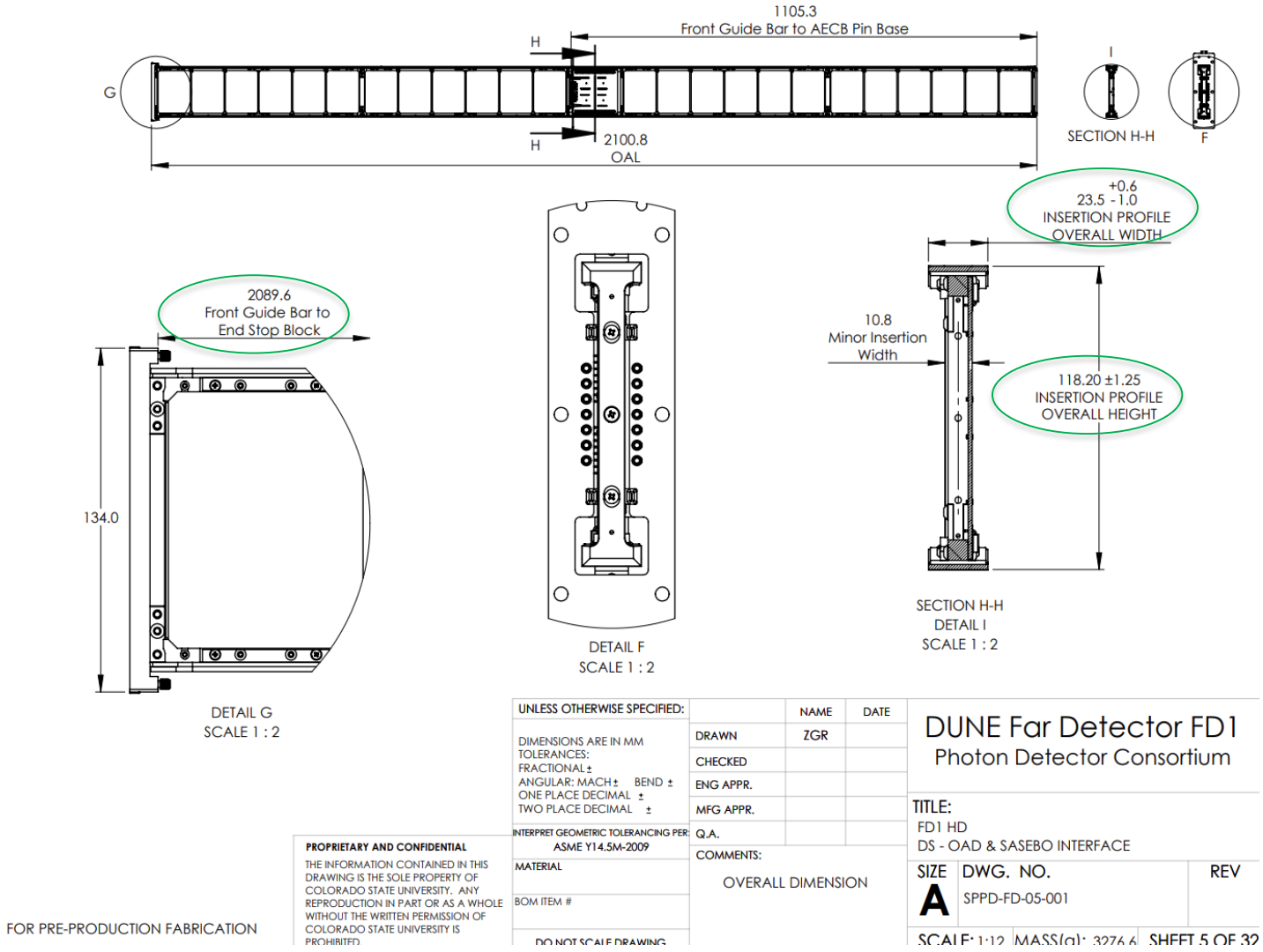
Item	Number (value)
Per Module	
Readout channels	4
Photosensors	192
Dichroic Filters	24 (48)
WLS plates	4
Readout Cables	1
Mass	3.2kg
Per APA	
PD modules	10
Readout cables	10 (lower), 20 (upper)
Per 10kt detector module	
PD modules	1,500
Readout channels	6,000
DAPHNE modules	150

PD Module Design: Module 0 (EDMS 2384656)

- 4 separate supercells.
  - Allowed Module 0 QC testing of supercells in smaller test beds.
- Centrally located readout.
- 4 routing PCBs along sides (2/side).
- Outer strengthening ribs (support against flexing).

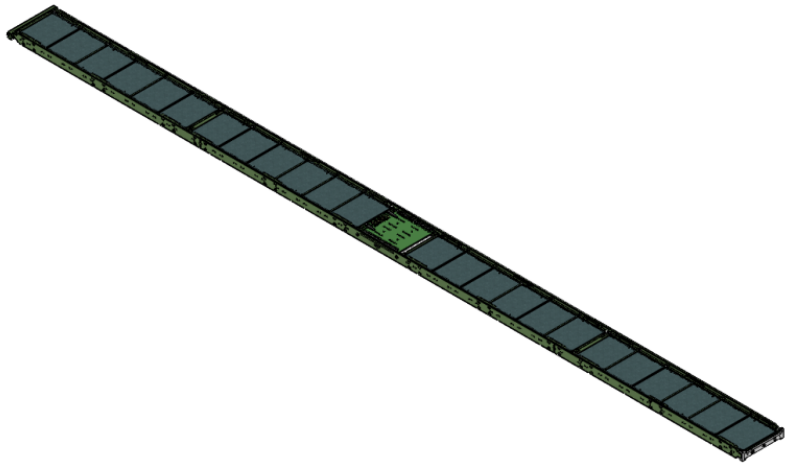
FDR Photon Detector Module– Conceptually largely unchanged since Module 0

- Fundamental external design unchanged.
  - 2101mm X 134mm X 23.5mm overall dimensions, (2090 X 118 X 23,5 inside APA rails).
- PD module still consists of 4 optically-isolated channels (Supercells).
- Module form factor allows installation into APA fame after wire wrapping.



FDR Photon Detector Module- BOM

ITEM NO.	PART NUMBER	DESCRIPTION	PARTNO	QTY.
1	SIPM PCB MOUNTING BLOCK	HORIZONTAL RIB JOINT	SPPD-FD-02-001	16
2	SIPM PCB MOUNTING BLOCK	DEFAULT CONFIGURATION	SPPD-FD-02-002	16
3	SIDE READOUT BAR	SLIDING PROFILE	SPPD-FD-02-003	4
4	SIPM MOUNTING BOARD	HPK	SPPD-FD-02-004	32
5	SUPERCELL CENTER END RAIL	END CAP	SPPD-FD-002-008	4
6	AECB SPACER	DEFAULT CONFIGURATION	SPPD-FD-002-010	1
7	ARAPUCA ELECTRICAL CONNECTOR ASSEMBLY	AECB	SPPD-FD-02-011	1
8	92010A120	M3X0.5 - 10mm FHMS	92010A120	5
9	COLD AMPLIFIER MOTHERBOARD ASSEMBLY	MOTHERBOARD	SPPD-FD-02-012	1
10	SASEBO ALIGNMENT BLOCK	MOLDED DESIGN	SPPD-FD-02-013	2
11	92095A181	M3X0.5 - 8mm BHCS	92095A181	21
12	92125A054	M2X0.4 - 8mm FHMS	92125A054	64
13	END MODULE SIDE SUPPORT BAR	SLIDING PROFILE	SPPD-FD-02-006	4
14	CENTER MODULE SIDE SUPPORT BAR	DEFAULT CONFIGURATION	SPPD_FD-02-007	2
15	SUPERCELL CENTER END RAIL	MID-WLS	SPPD-FD-002-009	2
16	WLS CONSTRAINT RAIL	DEFAULT CONFIGURATION	SPPD-FD-02-014	8
17	SRB MOUNTING BLOCK	DEFAULT CONFIGURATION	SPPD-FD-02-015	32
18	SRB MOUNTING BLOCK	CENTER	SPPD-FD-02-016	16
19	FD1 WLS	90.15	PPD-FD-02-017	4
20	92010A118	M3X0.5 - 8mm FHMS	92010A118	104
21	92010A122	M3X0.5 - 12mm FHMS	92010A122	2
22	92095A179	M3X0.5 - 6mm BHCS	92095A179	24
23	ACTIVE GANGING SUPPORT RAIL	DEFAULT CONFIGURATION	SPPD-FD-02-018	2
24	DICHROIC FILTER	DICHROIC FILTER - HD	SPPD-FD-02-019	24
25	DICHROIC CONSTRAINT	DEFAULT CONFIGURATION	SPPD-FD-02-020	72
26	DICHROIC CONSTRAINT	MID OFFSET	SPPD-FD-02-021	8
27	CORNER DICHROIC CONSTRAINT	DEFAULT CONFIGURATION	SPPD-FD-02-022	8
28	CORNER DICHROIC CONSTRAINT	MIRRORED	SPPD-FD-02-023	8
29	WLS STANDOFF	DEFAULT CONFIGURATION	SPPD-FD-02-024	64
30	FRONT GUIDE BAR	MOLDED SLIDING DESIGN	SPPD-FD-02-025	1
31	MODULE END STOP BLOCK	INTEGRATED STANDOFF	SPPD-FD-02-026	1
32	90843A350	M4X0.7 - 12mm SILVER PLATED CAPTIVE MACHINE SCREW	90843A350	2
33	92010A006	M2X0.4 - 12mm FHMS	92010A006	96
34	92095A453	M2x0.4 - BHCS	92095A453	80
35	G10 MOCK DICHROIC PLATE	DEFAULT CONFIGURATION	SPPD-FD-02-027	4



FOR PRE-PRODUCTION FABRICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±2°
ONE PLACE DECIMAL ±0.5
TWO PLACE DECIMAL ±0.25

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5M-2009

MATERIAL

BOM ITEM #

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ZGR	
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

DUNE Far Detector FD1
Photon Detector Consortium

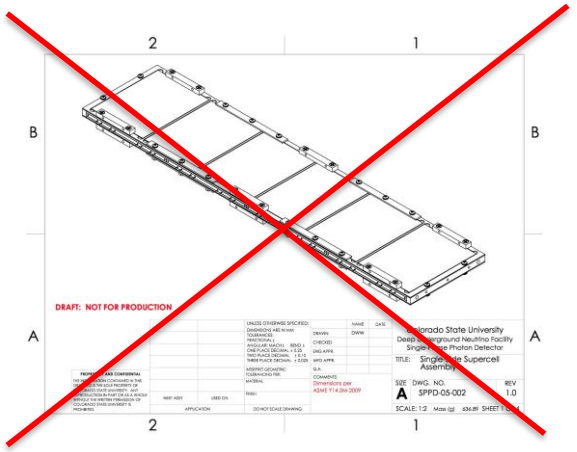
TITLE:
FD1 HD
SINGLE SIDED

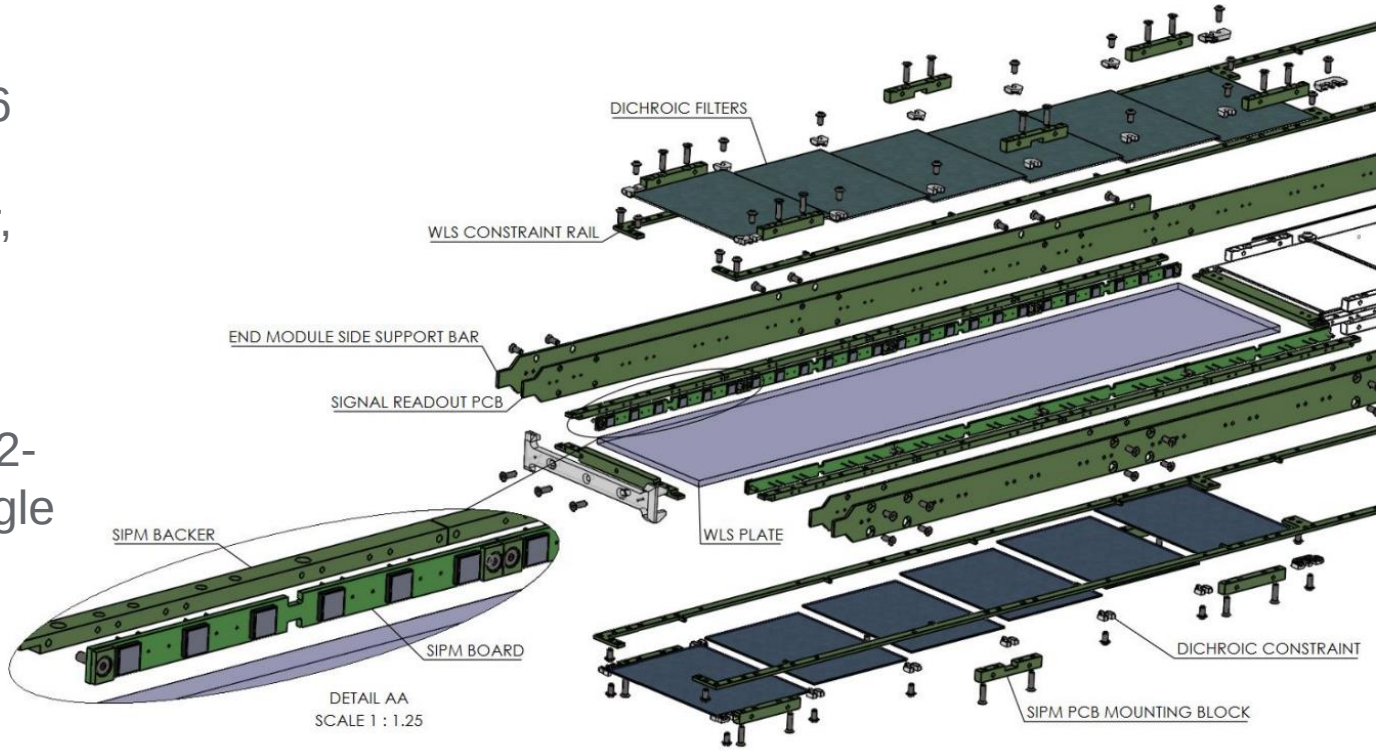
SIZE A | DWG. NO. SPPD-FD-05-002 | REV

SCALE: 1:12 | MASS:3124.3 | SHEET 2 OF 19

PD Module Design: Optical channel (Supercell)

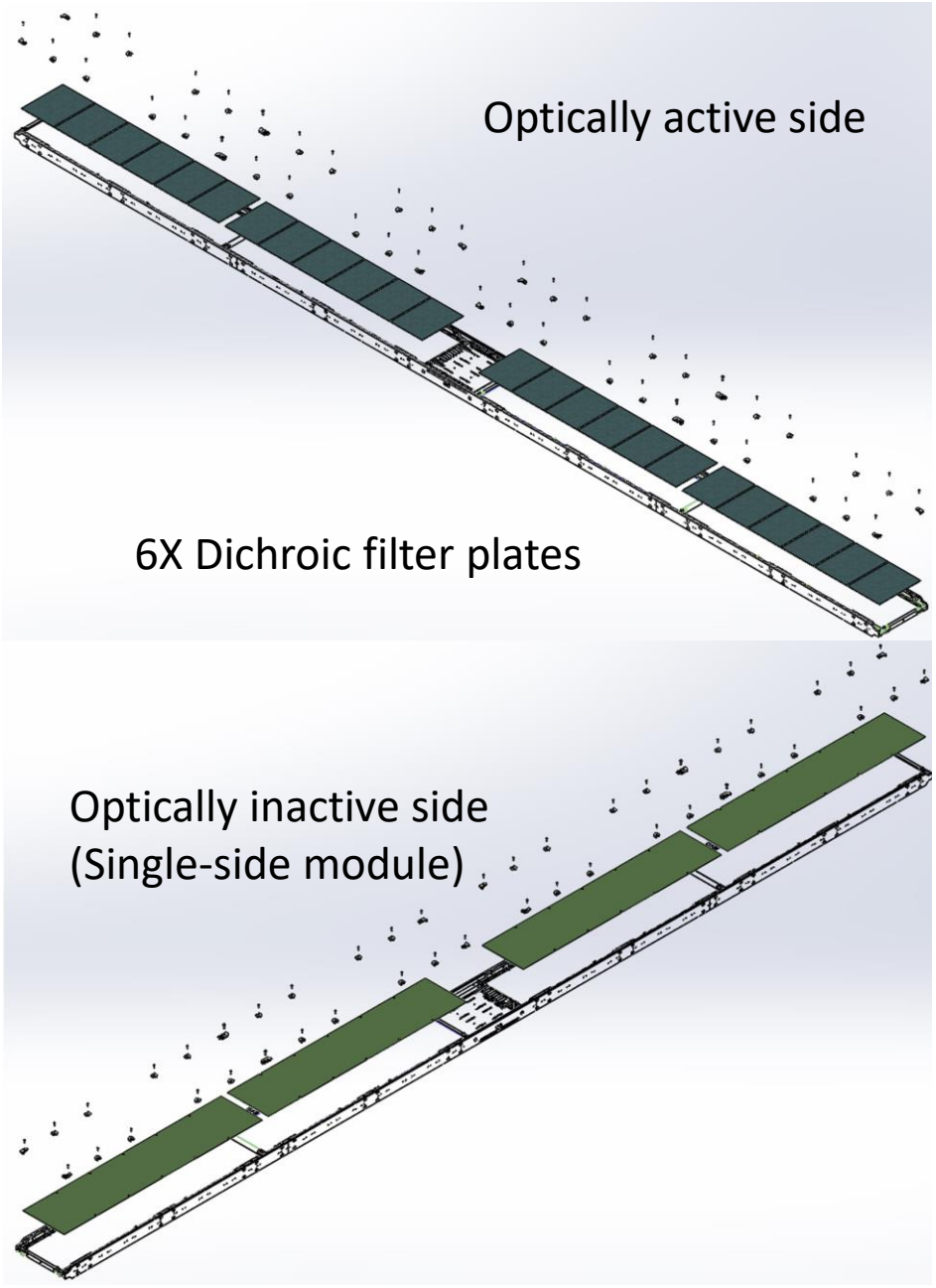
- Unlike Module 0 design, all 4 channels assembled at once (ease of assembly).
- Each supercell has 6 (or 12) dichroic filter windows, 1 WLS bar, and 48 SiPMs.
- Modules come in single-direction and 2-direction flavors (single and double-sided).





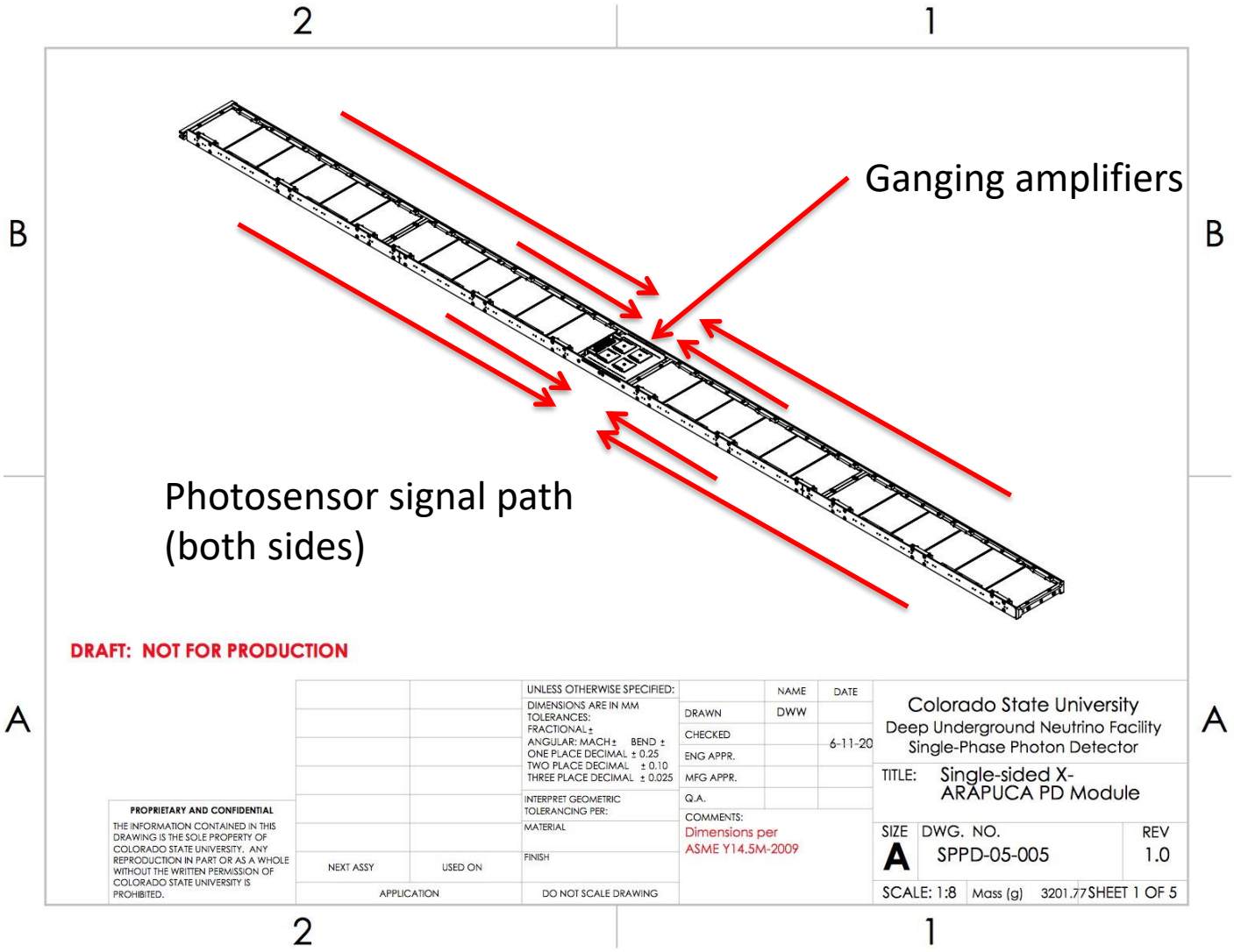
PD Module Design: Single vs. Double Sided

- Of the 1,500 modules required for DUNE FD1, 1000 are single-sided and 500 double-sided.
- The FD1 PDS module design does not require different frames or readout as a result of these differences.
- Single-sided modules replace six of the WLS plates with rectangular G10 plates, coated on one side with Vikuiti for reflectivity (as in ProtoDUNE 2).
- The same mounting hardware is used for the G10 plates as for dichroic filters.



PD Module Design: Module Signal Routing (i)

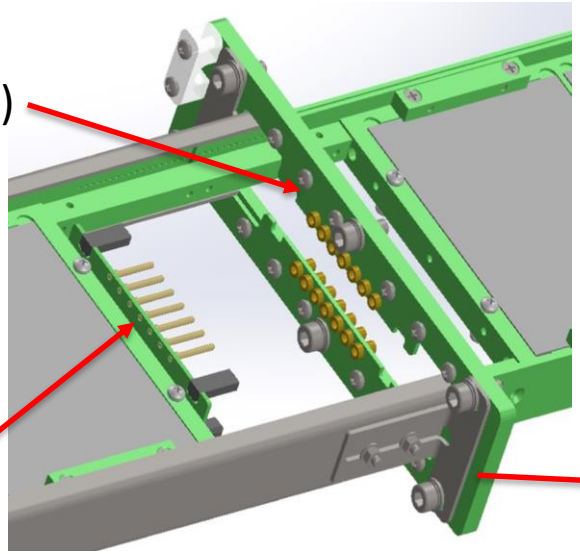
- Signals from each supercell are routed through PCBs on module sides (collected in center at cold amplifier card).
- 1m X 24mm routing boards.

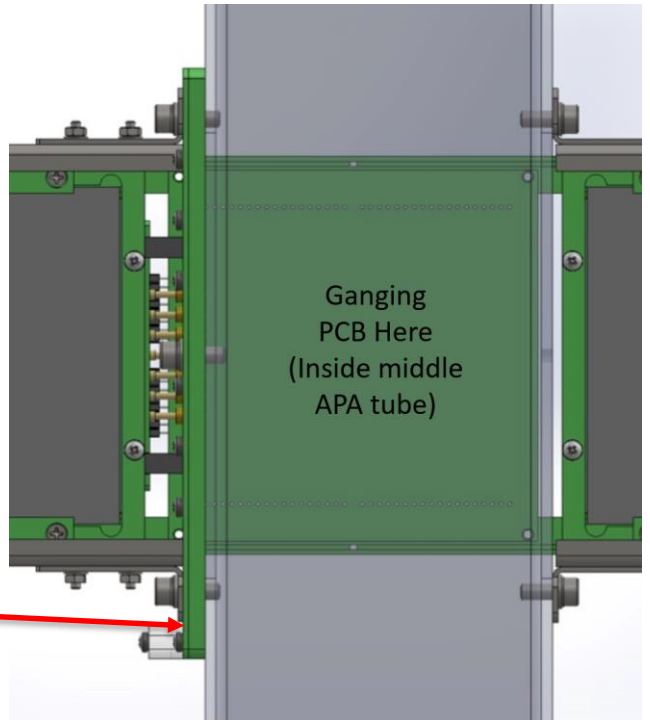


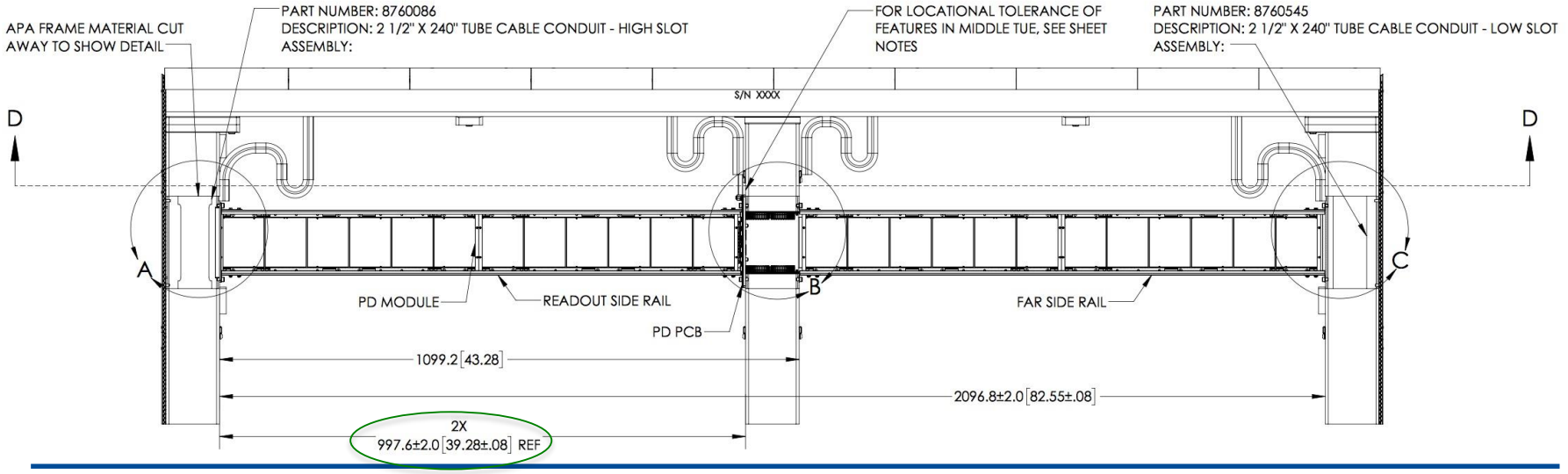
Module mounting and electrical connection (PRR complete)

SASEBO
(Mounted to APA)

AECB
(Mounted to Module)

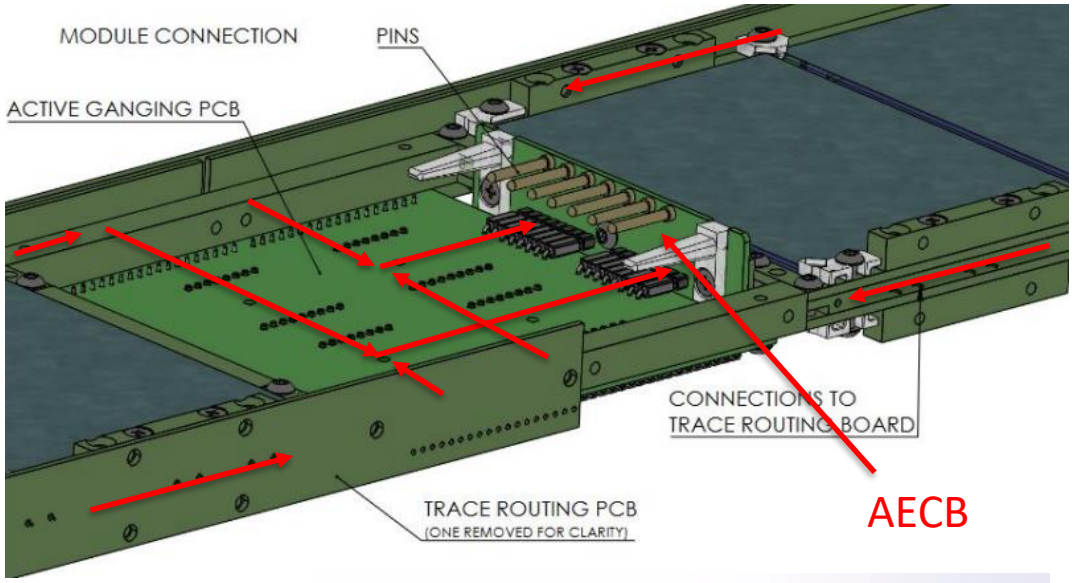


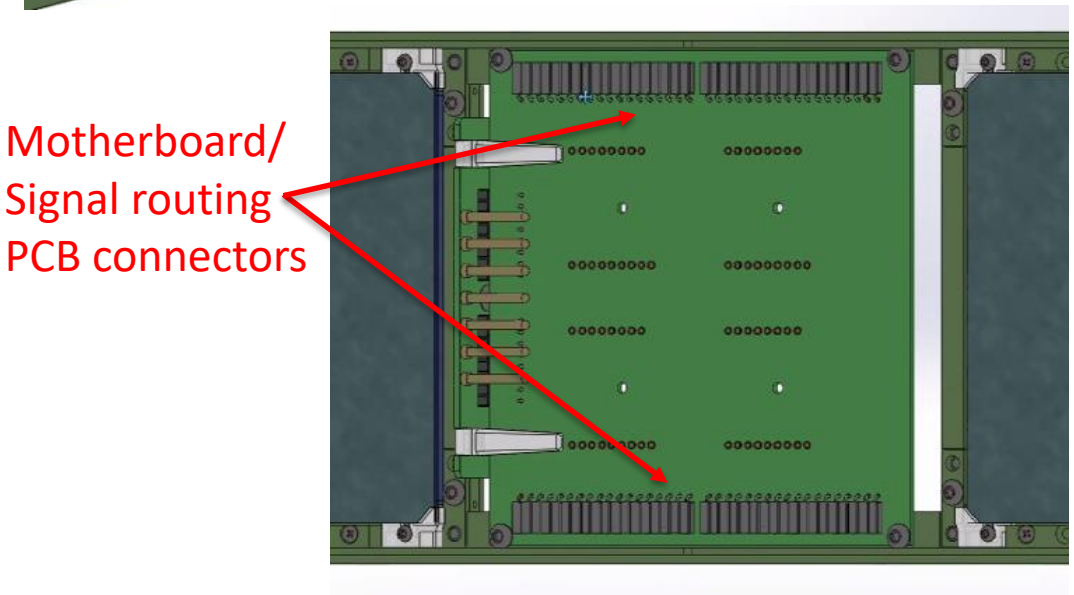




PD Module Design: Module Signal Routing (ii)

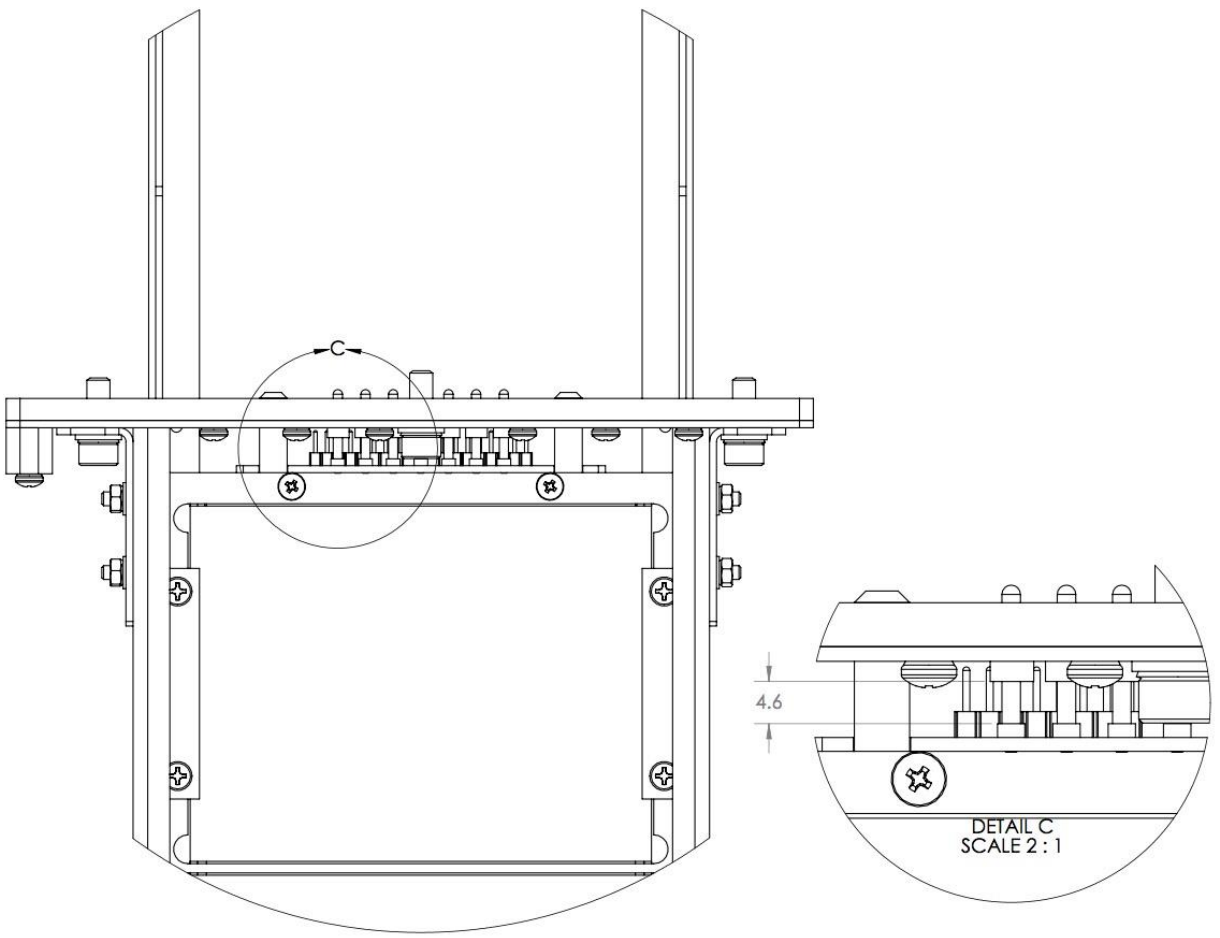
- Signals from the SiPM boards are routed to the ganging amplifiers mounted in the center of the module.
- Signals from eight passively-ganged SiPM boards are routed along the module sides (four boards per module side) and collected at the central cold amplifier PCBs.
- Readout from the module occurs via the centrally mounted AECB





Electrical Connections (Thermal effects) (iii)

- 4.6mm nominal gap left between pins and sockets when engaged (*APA/PDS* tolerances).
- Additional 5mm of engagement length beyond nominal insertion (*Thermal contraction*).
- Checked to satisfy tolerance stack-up and thermal variations.
- Pin-socket connections checked during multiple thermal cycles in test dewar.



PD System Engineering (i)

- PD frame constructed from FR-4 G-10.
  - Module dimensions in all 3 directions are controlled by in-plane (warp direction) FR-4. Warp direction indicated on component fabrication drawings.
  - This allows a close match between PD and APA frame thermal expansion.

Table 2 - Mechanical properties of PD system materials

Material	Density (g/cm^3)	Modulus of Elasticity (GPa)	CTE @ 87K ΔT = 87K-298K = -211 (1/K x K)	Yield Strength (MPa)	Ultimate strength (MPa)
FR4-G10	1.8	16.6	-6.2E-03 (normal) -2.1E-03 (warp)*	NA	165.4 (weak) 200 (strong) 64.7 (thickness)
SS 304	8.0	193	-2.7E-03	215	505

*Note: In this context "warp" refers to the Glass fiber plane

- Validated as part of Compliance Office design evaluation.

Engineering Analysis Documents (Compliance Office)

- Mechanical design for PD module supports and module thermal contraction effects completed by compliance office and available in EDMS:

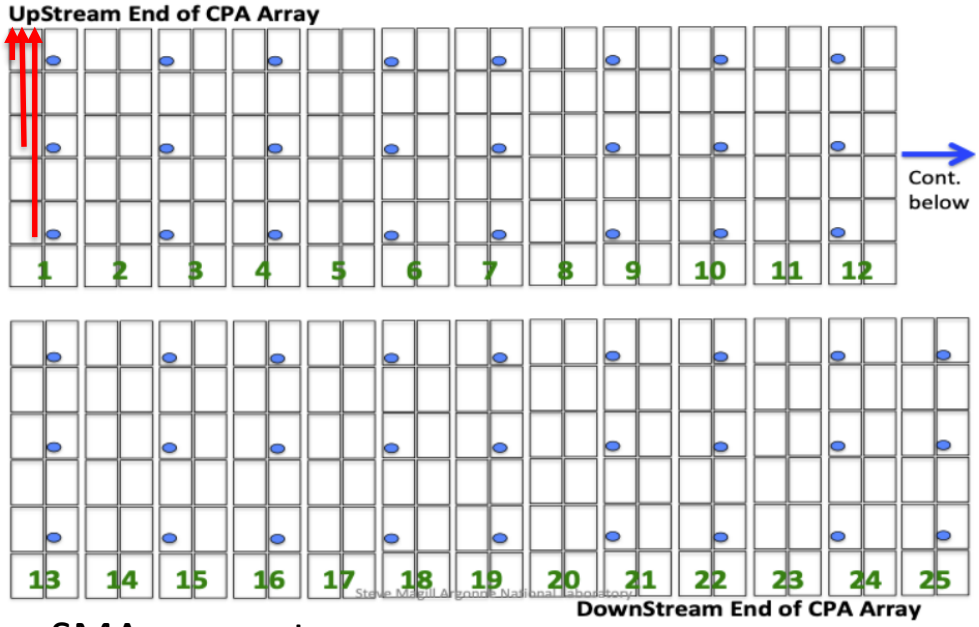
  - Analysis plan EDMS 2380161.
  - Structural analysis note EDMS 2380229 (static, thermal loading), EDMS 2766127 (dynamic loading).
  - Independent Review Reports EDMS 2877547.

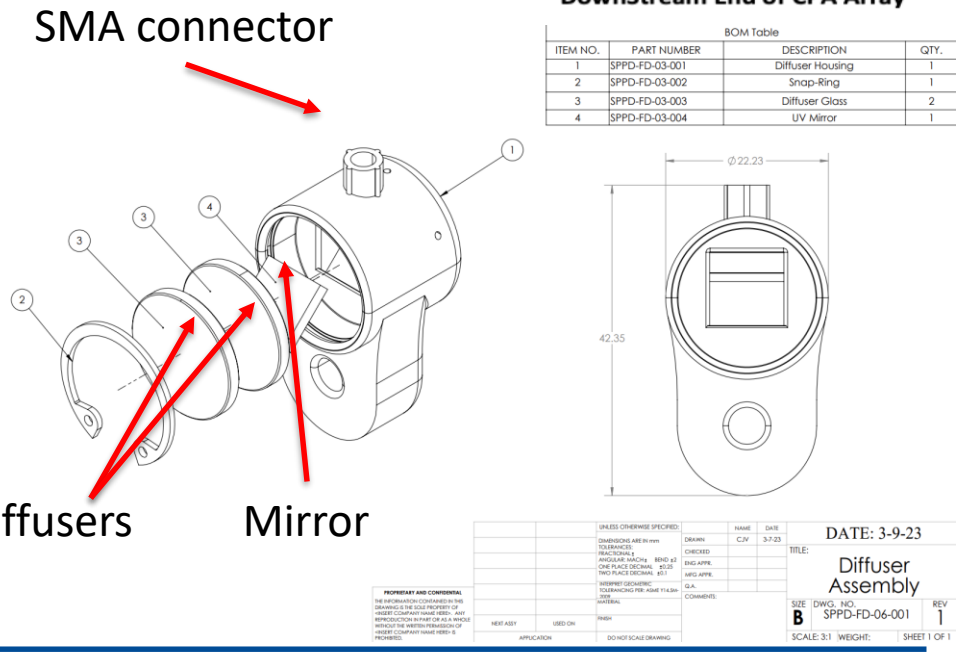
PD monitoring system mechanicals

- FD1 PDS monitoring system components closely follow Module 0 testing.
- 17 rows of 3 diffuser assemblies mounted to cathode as shown
- Fibers routed up cathode as shown, along DSS, and to PD flanges.

PEEK light diffuser housing (3-d printed)

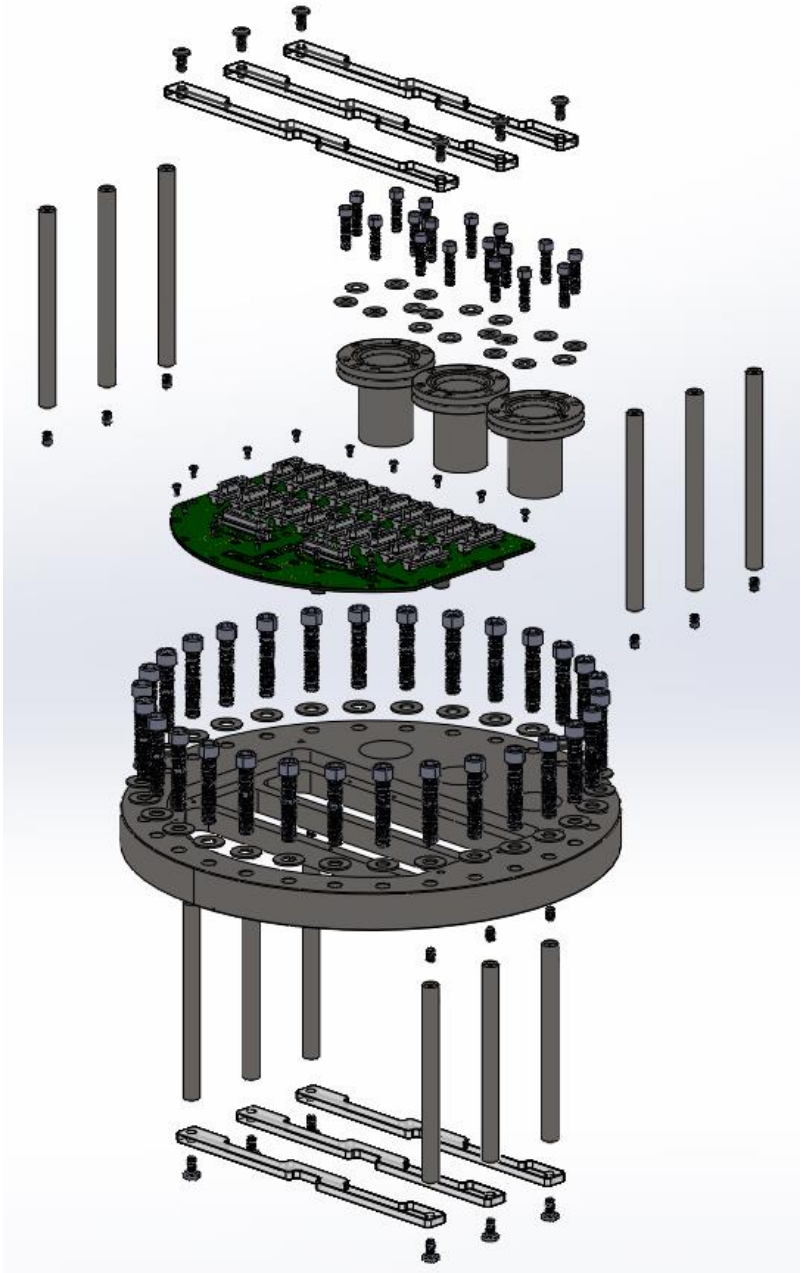
Diffuser positions (2 cathodes, 2 sides, 204 units)



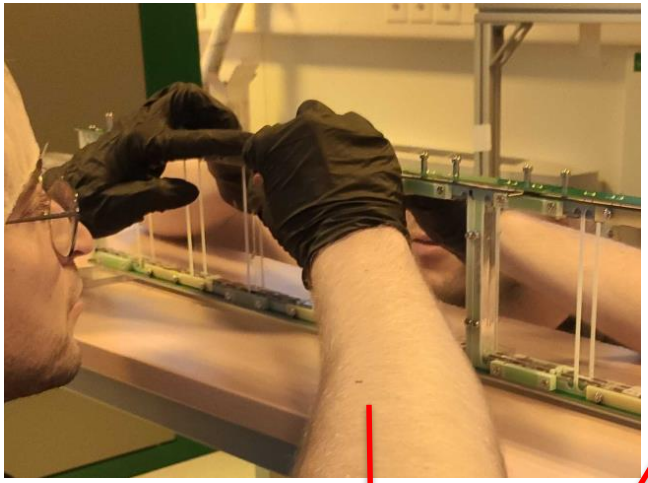


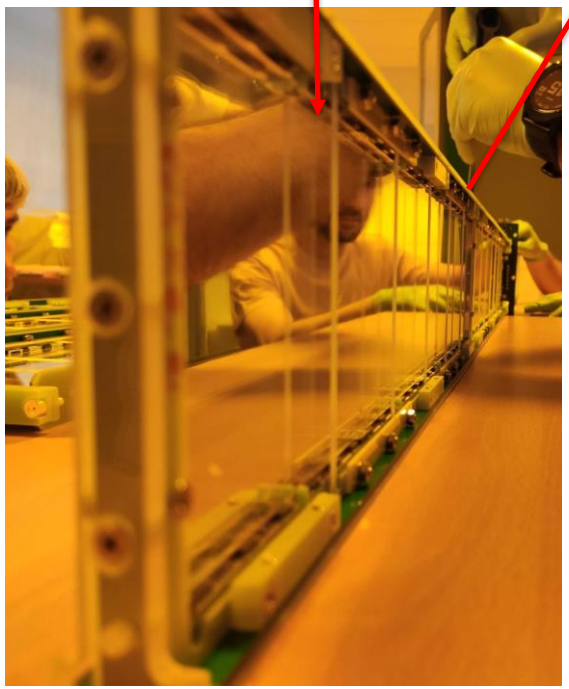
PD Cryostat Flange

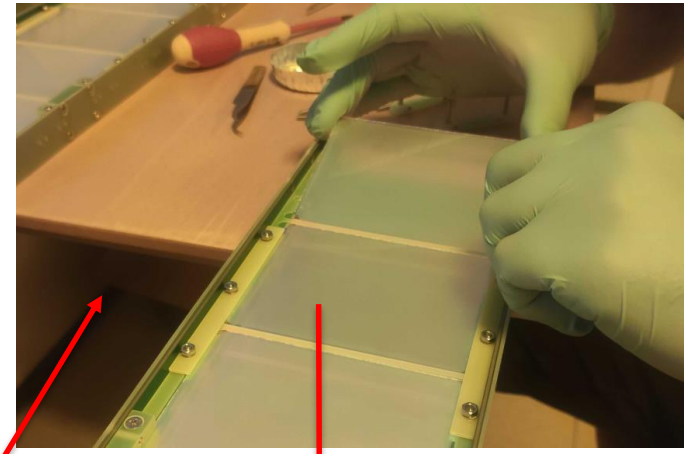
- The FD1 PDS cryostat flange follows the Module 0 design.
- Mechanical design documentation is available in the review document package.

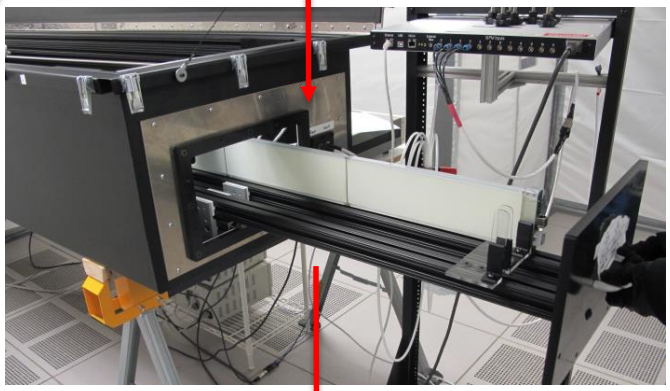


Module 0 Lessons Learned -Module Assembly

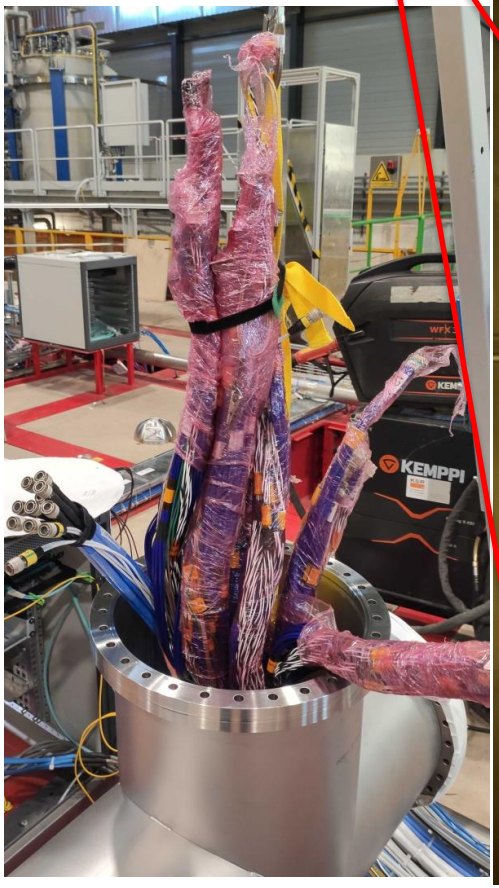


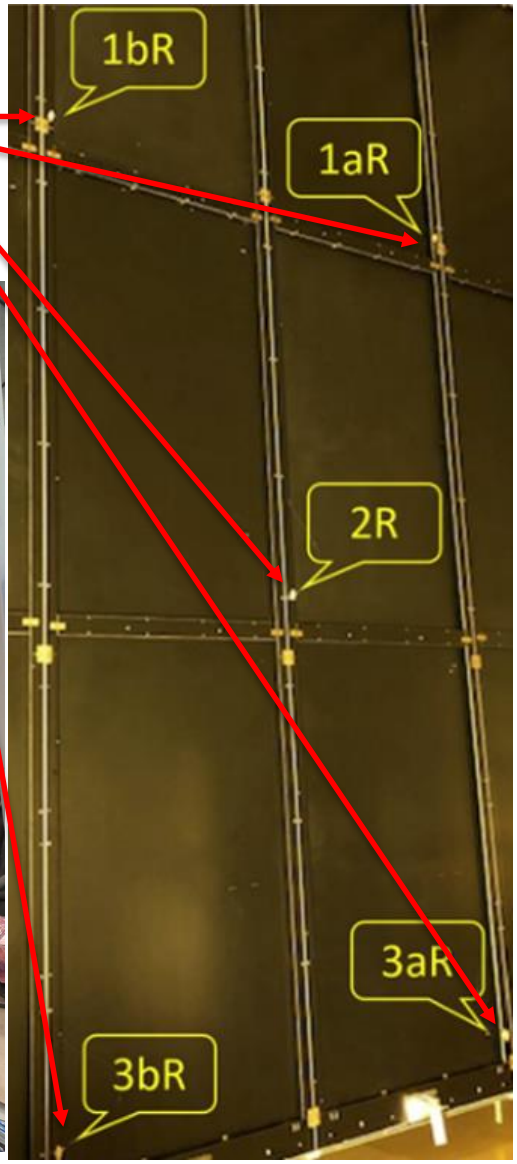






Module 0 lessons (Monitoring, cabling)



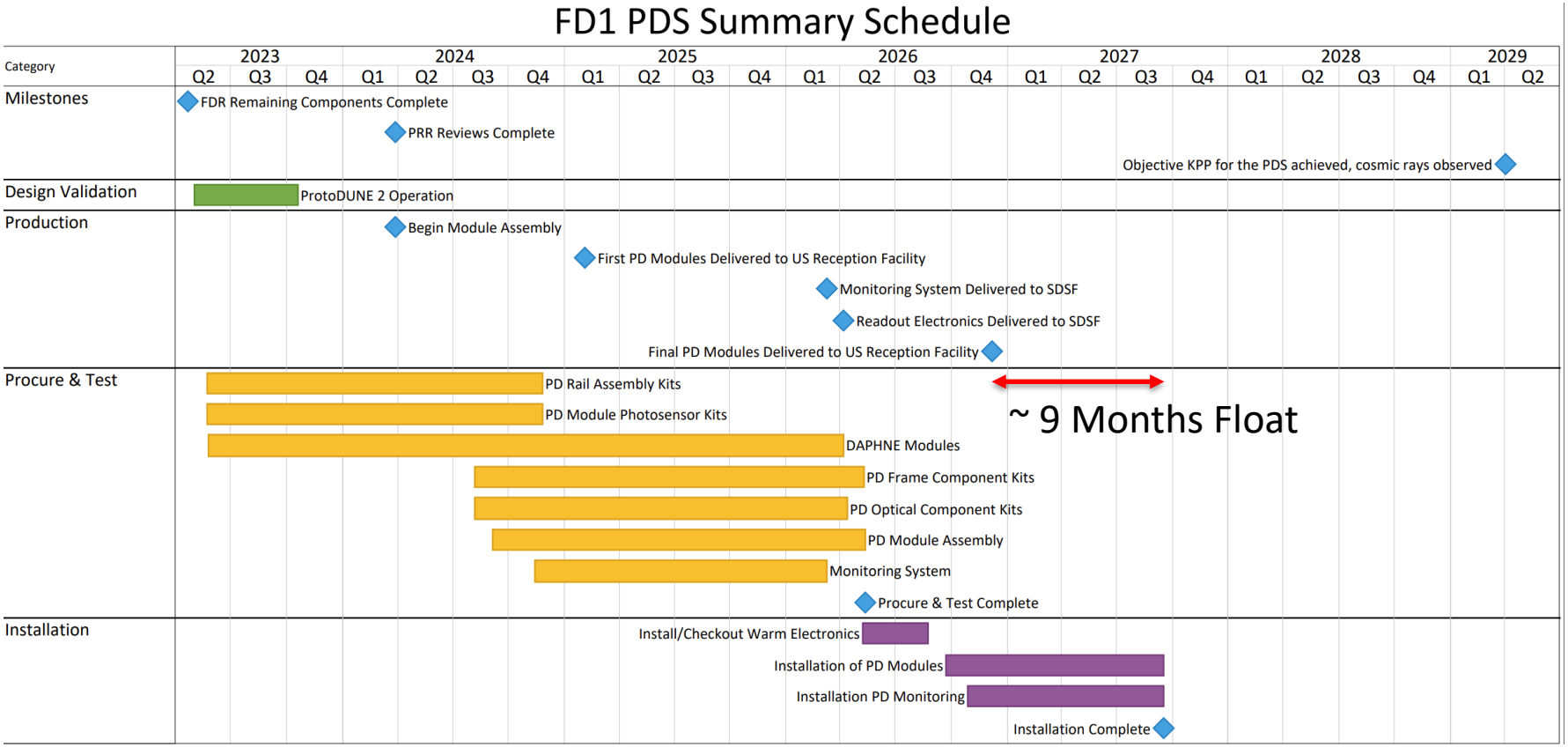


ProtoDUNE 2 Major Mechanical Lessons Learned

- Described in detail in QA/QC plan Chapter 9 (EDMS 2847126).
- Self-fixturing installation and electrical connections shown to work well.
  - Improved guide pieces to ease insertion and removal planned.
- Module assembly from supercells found to be very labor intensive.
  - Module design revised to eliminate assembly from completed supercells.
  - Install one SiPM board at a time!
- Separate functionality of filter plate clips from other module components to facilitate late installation and sever supply chain link.
- Improved tooling and installation plan for flange/cables needed.
  - Must ensure no person lift involved in supporting cables during installation .

Schedule & Critical Path

- General schedule flow: FDR – PRR – Production – Assembly
- Early PRR for rails/cables and SiPMs to retire production schedule risk.
- Plan completely documented in project P6 schedule.



Items of schedule concern at PDR:

- Schedule narrative in EDMS 2844174 describes the schedule in more detail. Great strides have been taken to advance items of concern since the PDR.

  - SiPMs: A Production Readiness Review occurred in late 2022, allowing the SiPMs to begin delivery in early 2023, and conclude in late 2024, well ahead of projected needs (>1 year float).

  - Dichroic filters: Approximately 54,000 (including spares) dichroic filters are required for FD1 PDS. The candidate manufacturer (OPTO, Brazil) has given us a production rate estimate of 820 filter plates per week (~73 weeks at 90% efficiency). The P6 schedule for this activity allows 85 weeks. Filter coating remains the link of concern. We may want conduct the filter plate PRR in Q3 or 4 2023 and begin production early.

  - WLS Plates: 6600 WLS plates are required for FD1 PDS. Vendor guidance from Glass to Power allows us to project 1 year for this task. 85 weeks are in the P6 schedule.

  - Module assembly: 1650 modules will be fabricated for FD1 PDS. Time and motion studies during Module 0 give us an estimated fabrication rate of 1.2 modules per day per 2-person team. 4 teams working require approximately 70 weeks. 85 weeks are scheduled for this task.

- 9 months float from last PD component delivery at SURF to installation completion!

SURF Installation Plan:

- FD1 PDS installation runs from November 2026 – August 2027.
- Installation based on 4 day work week, 2 X 10-hour shifts /day.
- Schedule calls for installing and testing PDs in 12 APAs in three (4-day) weeks, 1 APA per day. Based on ProtoDUNE validation.
- Personnel for a single shift consists of 4 FTEs: 1X post-doc, 1X technician, 2X grad students.
- Installation plan (EDMS 2233449) and installation QC plan (EDMS 2847126 Chapter 8) are available, and will be finalized before the I&I installation review.

Remaining Mechanical Validation

- Dichroic filters coating stability: Validated in ProtoDUNE 1 operations and ProtoDUNE 2 QC/cold box testing.
  - Additional testing underway of long-term coating stability through multiple thermal cycles (ProtoDUNE 1, ProtoDUNE 2 validation, UNICAMP long-term validation).
  - PTP dissolution in LAr (To be measured at UNICAMP).
- PRR module validation.
  - PRR validation module being fabricated now.
  - Will be tested in CERN cold box (inserted in APAs) Q2, Q3 2023.
- Module 0 (ProtoDUNE 2) operations.
  - Module 0 operation will provide final design validation prior to full-system PRR.
  - Delayed by availability of LAr for filling cryostat.
  - Possibility of filling in Q3 2023, operations Q4 2023, Q1 2024 (?).

Summary

- The baseline Photon Detector system design is complete at the FDR level and documented in EDMS.
- The design is significantly unchanged since the PDR.
- Critical design tolerances have been specified and confirmed with APA and TPC consortia.
  - Included in Interface Control Documents.
- While delays due to the COVID 19 crisis have slowed progress on ProtoDUNE 2, we anticipate using the planned late 2023-early 2024 run with PDS module 0 installed as our primary PRR validation.
- We are prepared to proceed to proceed to validation production planning for the Production Readiness Review!