DUNE FD2-VD PDS:

PD Consortium-held Requirements and Specifications and

TB-held Requirements and Specifications

(*under development*)

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Revision Change Log

Date of Revision	Revision PoC	Revision Notes
5 April 2023	F. Cavanna	Document on Indico
31 March 2023	S. Kettel	TB-held Requirements (proposed by PD to TB)
29 March 2023	D. Warner	Edits for clarity
25-Mar-2023	F. Cavanna	Advanced Draft for FD2 PDS Final Design Review
10-Mar-2023	F. Cavanna	PD Consortium-held Requirements and Specifications (draft)

Introduction

This document provides

1. the Consortium-held Requirements for the DUNE Far Detector 2 (FD2) Photon Detector System (PDS), in a slim version with only the Primary Text reported for ease of fitting in a document format. The complete spreadsheet is available on EDMS (link given below).

2. The TB-held requirements as currently under development. The the DUNE FD2 TB and the PD Consortium have discussed and agreed on a list of technical solutions. The PD Consortium has proposed this list given below to be adopted as TB-held requirements.

PD Consortium-held Requirements and Specifications

Ref.: Consortium-held Requirements

Consortium-held Requirement and Specifications for FD2 PDS - approved by PD Consortium.

DOORS ID	TDR ID	PD Subgroup	Specification number	Spec. or Req. ?	Name	Primary Text
General						
Cathode-mount PD Module						
			1	R	Electric Isolation	Cathode-mounted modules must be electrically isolated - no copper cable connection to/from TPC cathode (at HV)
			2	R	Double sided	Light sensitive areas facing up and facing down must be provided for light collection from upper LAr volume above central cathode and from lower Volume below cathode
Membrane-mount PD Module						
			1	R	Electric Isolation is NOT required for membrane modules	Membrane modules can be connected with copper cables.

			2	R	Single sided	Light sensitive areas facing inward to the active LAr volume of the TPC - through Field Cage
	Photosensors					
			1	S	Same photosensors (Silicon based) as for FD1 PDS	FD1 PDS - SiPM optimisation carried out by FD1-PDS with industry is immediately available and applicable to FD2. Selecting the same SiPMs allows us to leverage this experience and reduce cost and risks.
		Electronics				
			1	R	Warm verification of the Cold electronics	The module readout electronics chain must be verifiable warm (continuity check and operation) for both membrane and cathode-mount modules to facilitate installation QC checks..
Monitoring/Calibration System						
			1	R	LED Flasher/ Diffuser system	A Monitoring and Photosensor/ Electronics response calibration system based on LED Flasher (warm) and Diffuser (cold) equivalent to FD1 PDS is required
Integration						
Cathode-mount PD Module						
			1	R	Cathode-mount Module dimension	Module must fit inside mechanical envelope in cathode-module
			2	R	Cathode-mount Module weight	Cathode-module shape deformation must remain within bounds set by HVS. Cathode-mount PD module weight must not induce cathode-module deformation

			3	R	Maintain cathode-to-PD clearance at LAr temperature	The cathode-mount PD fiber system must not limit the separation of the cathode during thermal expansion/contraction. The specification is driven by engineering to ensure no damage occurs.
			4	R	Faraday shield protection of sensors and electronics for cathode-mount modules	Faraday shield protection of sensors and electronics must be implemented to minimise risk of damage in case of cathode HV discharge
			5	R	Cathode-mount modules position on the cathode plane	No cathode-mount modules must be positioned at the edges of the cathode plane to minimise risk of damage in case of cathode HV discharge
Membrane-mount PD Module						
			1	R	Mechanical holding structure for Membrane-mount modules (behind FiedCage)	Independent holding structure supported by existing anchoring points of the membrane cryostat for Membrane-mount modules (behind field cage)
			2	R	Membrane-mount modules position behind Field Cage	Membrane-mount modules must be positioned at vertical distance from cathode plane, behind field cage with enhanced 70% transparency
			3	R	Ground mesh in front of membrane-mount modules	Ground mesh must be positioned in front of membrane-mount modules
		Cathode- and Membrane -mount modules				

			1	R	PD Module deflection	Module frame must not deflect under load and at any point dry or immersed in LAr.
			2	R	Cable conduit for fibres and cables	Cathode-mount and Membrane-mount PD modules fibers and cables must use conduits shared on the cryostat membrane with TPC bottom drift electronics, with no mutual interference
	Photosensors					
		Electronics (including Fibers and Cables)				
			1	R	Heat dispersion (and macroscopic bubble generation) by cathode-mount electronics	The cathode-mount electronics must minimise and disperse excess heat in such a way as to prevent (macroscopic) bubble generation at the cathode (~6m depth in LAr)
			2	R	Faraday shield boxes for Cold electronics boards	Electrical noise diffusion by electronics active components of cold electronics boards must be minimised - Cold electronics boards must be housed in Faraday shield boxes
			3	S	Fiber bending, protective black tubes for fibres and light tight boxes for fiber connectors	Optical noise from fiber and connector light leakage must be minimised - Fibres must be protected in black tubes and connectors on CE boards housed in light tight boxes. Power and signal optical fiber must not leak light of wavelengths and intensity that can impact X-ARAPUCA efficiency or other subsystems.
			4	R	Fiber routing	cathode-mount fiber routes must not affect Field Cage alignment. Field cage alignment must be preserved.

			5	R	Fiber mechanical strain	The relative expansion and shrinkage of the power and signal optical fiber must not impact the cathode frame, fiber routing supports, or cathode suspension cables.
			6	S	Warm Electronics chassis dimensions	Warm Electronics (DAPHNE boards) chassis must fit in standard mini-rack located at the feedthrough
			7	R	Warm Electronics grounding	Warm electronics board (DAPHNE and integrated daughter cards) ground must be connected to detector ground
			8	S	Electrical Power supplies Input Voltage	Power supplies requirement for external AC power
				S	Optical Power supplies (Laser) Input Voltage	Laser box requirement for external AC power
			9	S	(Electrical) Power supply dimension envelope	Electrical Power Supply must fit standard 19" eurorack format
				S	(Optical) Power supply dimension envelope	Laser Boxes (OptPwr Supply) must be 3U (5.25” height)
Monitoring/Calibration System						
			1	R	LED "warm" fiber jacketed	LED fiber at the cryostat top
			2	R	LED "cold" fiber jacketed	LED fiber inside the cryostat
			3	R	LED fiber Optical feedthrough	LED fiber Optical feedthrough must be located at PDS signal flange.
			4	S	LED Calibration Module	LED flash module supplies 12 diffusers
Design						

	PD Modules					
			1	S	Material selection - cryo-resilient	All materials must be cryo-resilient. All materials already selected for FD1 PD modules (XARAPUCA super-cell) should be used for FD2 PD modules (XARAPUCA mega-cell) where possible. Main components: mechanical frame, dichroic filter, WLS-1 film, WLS-2 plate, plastic reflector foils, SiPM photosensors.
			2	R	XARAPUCA mega-cell design and max photo-collection efficiency	New XARAPUCA mega-cell design should maximise photo-collection efficiency. Minimal dead space or shadow by mechanical frame, maximal exposed surface of dichroic filter area and WLS plate, maximal coverage of reflective area should be pursued at design level, optimal optical contact SiPM-WLS.
			3	S	Materials selection for Mechanical Frame	FR-4 G-10 and Stainless steel alloy 304 shall be the primary structural materials for PD modules
			4	R	FR-4 G-10 Warp Plane Alignment	All FR-4 module components shall be specified as to the warp(glass-fiber mat) plane orientation to allow better thermal expansion control
			5	S	Stainless steel hardware	All PD fasteners shall be stainless alloy 18-8 or 304 unless otherwise specified
			6	S	Anti-vibration fasteners	Lock washers (where possible), lock-tight thread, lock adhesive shall be used to protect against vibrational loosening
			7	S	Dichroic filters cutoff	Dichroic filters cutoff optimised for pTP emission stoctrum transmission and WLS-2 doped PMMA emission spectrum reflection inside the supercell.

			8	R	Dichroic filters refraction index	Dichroic filters refraction index optimised for liquid Ar to improve light collection efficiency
			9	R	Optical contact WLSplate-to-SiPM	SiPM mounting must be dynamic to preserve SiPM location through relatice material contraction during cooldown to 87 K.
			10	R	Non-conductive high reflective layer	All reasonable large internal surfaces of the mechanical frame must be coated with non-conductive high reflective layer - VIKUITI ESR foils should be used to improve light collection efficiency
	Photosensors					
			1	R	SiPM cryo-reliability	resilient to thermal stress during cooldown and long term stability
			2	S	SiPM PDE at 430 nm	compatible with light yield of the X-Arapuca
			3	S	SiPM operating voltage	
			4	S	SiPM correlated noise	
			5	S	SiPM dark count rate	should not contribute significantly to 39Ar background
Electronics (including Fibres and Cables)						
			1	S	Cold El. Motherboard	Dedicated CE motherboard with PoF-SignalConditioning-SoF stages for cathode-mount modules (no PoF and SoF stages are required for membrane-mount modules)
			2	R	S/N of CE	S/N of CE must be high enough for single PE sensitivity (in the whole waveform)

			3	S	Dynamic range of CE	Dynamic range of CE must be sufficiently extended to collect large signals (and reduce fraction of saturation to minimal). Beam events in the proximity of Cathode plane may generate very large signals. Fraction of beam events with over-range ADC limited to <20%
			4	R	Timing resolution of SiPM + CE r/o system	
			5	S	SiPM signal processing gain	Signal at the input to warm digitization electronics should have a dynamic range of <1V
			6	S	Warm electronics readout noise	Contribution to the noise from the warm readout electronics (DAPHNE)
			7	S	ADC dynamic range (Warm Electronics)	ADC dynamic range
			8	S	Warm Electronics timing resolution	Timing resolution for single photo-electrons passing through the entire electronics chain
			9	S	Power-over-Fiber (PoF) - Optical Power Converter (OPC) efficiency	Power-over-Fiber (PoF) - Optical Power Converter (OPC) efficiency must be as high as possible to reduce eccessive heat dissipation in LAr
			10	R	Signal-over-Fiber (SoF) - optical signal Transmitter linearity	Signal-over-Fiber (SoF) - optical signal Transmitter (Laser diode) must be operated in LAr in its linear range of operation and stable in LAr
			11	S	Cold Electronics (cathode-mount modules) power supply Voltage	

			12	S	Cold Electronics (cathode-mount modules) power supply Current	
			13	S	Cold Electronics (membrane-mount modules) power supply Voltage	
			14	S	Cold Electronics (membrane-mount modules) power supply Current	
			15	S	Maximum data transfer rate	Maximum data rate that DAPHNE can sustain sending to the DAQ
			16	S	Power Supply Voltage Stability	Per channel
			17	S	Power Supply Voltage Monitoring Resolution	Per channel
			18	S	Power Supply Voltage Monitoring Accuracy	Per channel
			19	S	Power Supply Current Limit	configurable, Per channel
			20	S	Power Supply Current Monitoring Resolution	Per channel
			21	S	Power Supply Current Monitoring Accuracy	Per channel
			22	S	Power Supply Voltage Dynamic Regulation	recover from a +/-25% load change
			23	S	Power Supply Voltage Recovery Time	recover from a +/-25% load change

			24	S	(Optical) Power Supply for cathode-mount modules	
			25	S	Class-4 Laser(s) in Optical Power Supply in shielded Box (w/ interlock and controls)	Enclosure minimizes downstream safety requirements for POF laser system.
			26	S	Optical Fibers for PoF (for cathode-mount modules)	Glass fibre, standard 67um, multimode, max 4 per CE board - Termination: FC Connector (preferable)
			27	S	Optical Fibers for SoF (for cathode-mount modules)	one per r/o channel (two per board) - Glass fibre, standard 67um, multimode,
			28	S	Electric cables (for membrane-mount modules)	Differential impedance of signal pairs in cables, Resistance of power supply lines in cable and other specs as for FD1 PD modules
Monitoring/Calibration System						
			1	S	Quartz fiber for LED monitoring System	High UV-range transmission
			2	S	Calibration light source	UV-light source 275 nm and Visible 320 nm
			3	S	Calibration Module	Electronics module with electronics moderboard, communication interfaces, and with light sources
			4	S	Optical FeedThrough	quartz fiber feedthrough
			5	R	Firmware	Calibration control firmware is compatible with the DAQ system.
Fabrication						
	PD Modules					

			1	R	Assembly Clean Room	PD module assembly shall be conducted in a clean assembly area
			2	S	Environmental control/ Temperture	PD module assembly shall be conducted in a clean assembly area
			3	R	Environmental control/ Humidity	PD module assembly shall be conducted in a clean assembly area
			4	R	Environmental light exposure.	
Electronics (including Fibres and Cables)						
			1	S	Cryo-reliability of component	discrete component resilient to temperature change and long term operation at 87 K
	Photosensors					
			1	S	V breakdown uniformity	compatible with S/N requirement
			2	S	Cryo-reliability of component	resistent to temperature change and long term operation at 87 K
Calibration/Monitoring						
			1		Quartz fiber	Provided with protected jacket
Installation						
		Modules				
			1	R	Self-fixturing module installation	No external fixtures shall be required to install PD modules into cathode modules in their final orientation
		Electronics				
			1		Module-mount installation	Readout electronics mount to detector module frame.
			2	S	Supply Cable Length	
			3	S	Supply Cable Conductors	
			4	S	Supply Cable Shield	
	Photosensors					

			1	R	manipulation before installation	SiPMs provided from vendor attached to mounting PCBs
Calibration/Monitoring						
			1	R	Light continuity tests in open warm cryostat in installation phase	One or more calibration modules available at installation stage
Misc.						
		Modules				
			1	R	quality assessment before delivery to DUNE	Thermal cycling of detector frames
		Electronics				
			1	R	Remote Interface Support	Per Warm Electronics Crate
			2	R	Remote Interface Protocol	Per Warm Electronics Crate
			3	R	Remote Interface Method(s)	Per Warm Electronics Crate
	Photosensors					
			1	R	quality assessment before delivery to DUNE	I-V curve at room temperature
Calibration/Monitoring						
			1	R	Lab tests at ANL/SDSMT for QA/QC	Commissioning will confirm test results

TB-held Requirements and Specifications (under development)

Ref.: TB-held Requirements

TB-held Requirement and Specification for FD2 PDS - submitted by PD Consortium for approval by TB.

id	Artifact Type	Name	Primary Text	Rationale
2306	Specification	Dynamic Range in SP-PD	The dynamic range shall be large enough that no more than 20% of expected beam events have channels which saturate.	Saturating channels degrade the ability to reconstruct energy calorimetrically, but a small amount of saturation can be mitigated. The equivalent TPC requirement is 10%.
Tbd	Requirement	VD PD layout	Photon Detector modules located on the Cathode plane should be electrically isolated	No copper cable connection to/from TPC cathode (at HV) should be established serving PD modules
Tbd	Requirement	VD Cathode-mount modules position on the cathode plane	No cathode-mount modules must be positioned at the edges of the cathode plane to minimise risk of damage in case of cathode HV discharge	>60cm clearance from cathode edges (and any other significant value from discharge Models)
Tbd	Requirement	VD Membrane-mount modules position behind Field Cage	Membrane-mount modules must be positioned at vertical distance from cathode plane, behind field cage with enhanced 70% transparency	> 2.5 m vertical distance from cathode plane
Tbd	Specification	VD Membrane-mount modules layout	PD coverage should be extended to all 4 membrane sides behind FC (two long and 2 short membrane sides)	Optimize LY uniformity with minimal number of membrane-mount modules on short membrane wall.
Tbd	Requirement	Ground mesh in front of VD membrane-mount modules	Ground mesh must be positioned in front of membrane-mount modules	mesh should make no EF> 30kV/cm