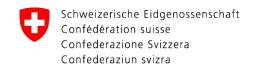


High Voltage Distribution: Design Overview

Saba Parsa, L3 HV Subsystem Lead ND-LAr Preliminary Design Review 28 June 2022







Who am I (or We with subsystem lead and engineer)

- Saba Parsa
 - Postdoc at University of Bern since April 2021



Outline

- Scope
- Requirements
- Interfaces
- Procurement, Manufacturing, QA/QC
- Risks and Prototyping
- Recommendations from Previous Reviews
- Cost and Schedule
- Summary

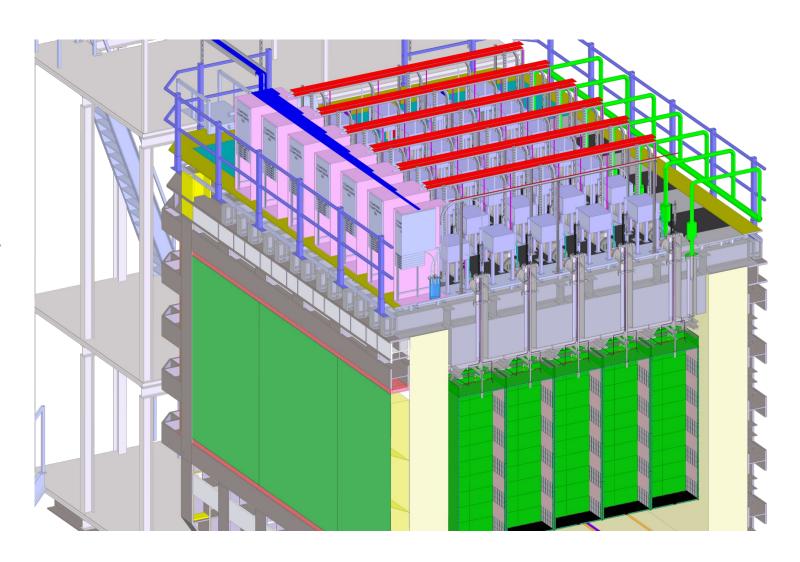


Subsystem Overview

ND-LAr TPCs will operate with a nominal E field of 0.5 kV/cm, similar to DUNE far detectors

Modular design results in Drift distance of <u>50</u> cm in each TPC, Nominal Cathode potential is <u>25 kV</u>

The HV distribution system has the role to provide stable 25 kV DC potential with very low noise to the module's Cathode planes



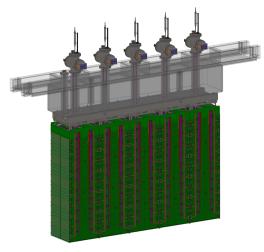


Subsystem Overview

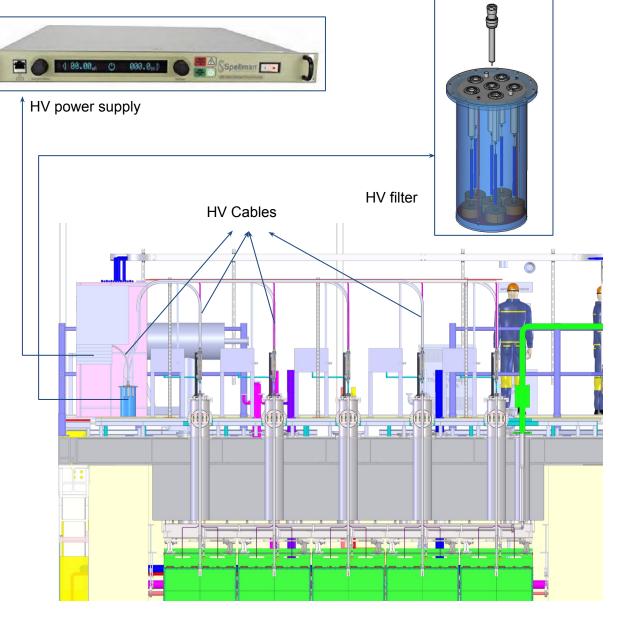
HV distribution system consists of 7 independent units, each serving a row of 5 ND-LAr Modules:

- **HV power supply (Spellman)** to supply 5 modules
- A low-pass filter-distributor (PFD-5), situated between the PS and the modules
- HV resistive cables

06.27.2022



HV delivery to a row of 5 modules (In Field Structure Scope)

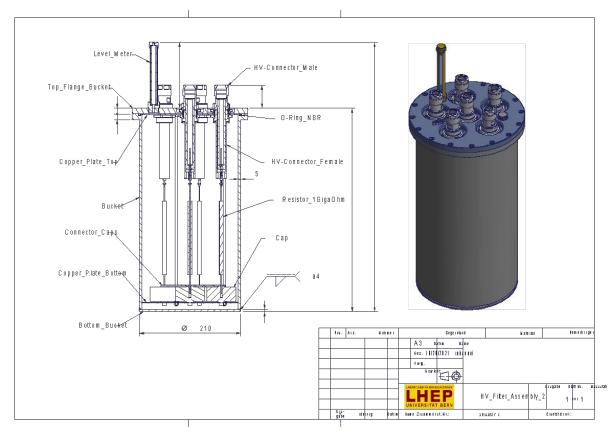


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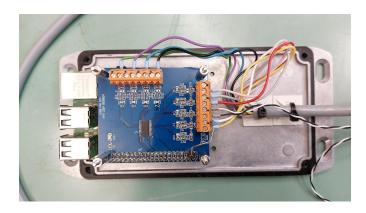


Subsystem Overview

- HV filter, PFD-5 (Potted Filter-Distributor with 5 channels)
 - One PFD-5 unit with the final design is constructed and tested



PFD-5 CAD drawing



HV Monitoring unit





PFD-5 outer and inner view



Scope

Detailed subsystem scope is defined

- Describes deliverables, quantities, responsible institutions, and funding source during design, prototyping, production and installation phases
- Informed by HV Filter prototypes constructed and tested during 2x2 Single module runs

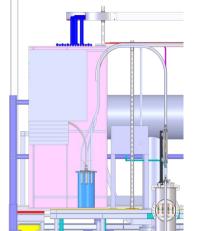




Scope

https://edms.cern.ch/document/2720713/1

HV Distribution subsystem ends at the HV cables connecting the PFD-5 to the modules. The HV feed-throughs are in the scope of the Field Structure Subsystem



Task/Item	Qty	Spares	Institutions	Funding Source	Detailed description
HV power supply	7	1	Unibe	Switzerland	Specification and Procurement
PFD-5 (Potted Filter Distributor)	7	1	Unibe	Switzerland	Design, production, assembly and testing
HV Cables (PS to PFD-5)	7	1	Unibe	Switzerland	Specification and Procurement
HV Monitor and control unit	7	1	Unibe	Switzerland	Design, production, assembly and testing
Packaging and shipment	<u> </u>	-	Unibe	Switzerland	packaging and shipment
Assembly procedures	-	-	Unibe	Switzerland	subsystem procedures for use during A&T and I&I
Support during ND A&T	-	-	Unibe	Switzerland	Technical/scientific support during TPC Module assembly and testing program at the DUNE Near Detector Site, including travel.
Support during ND I&I	-	-	Unibe	Switzerland	Technical/scientific support during TPC Module installation and integration at the DUNE Near Detector Site, including travel.

131.ND.02.03: High Voltage

WBS Dictionary (Concies):

Design and production of the HV supply and distribution for the ND LArTPC modules includes:

HV supplies and cables

HV filters

Control and monitoring instrumentation and readout

Component testing/CD/QA, and associated tooling

Prototypes for 22c, Full-scale Demonstrator

Packaging and shipping

Support personnel for prototyping, A&T, and I&I, and their travel

HV power supply	PFD-5	HV cables	HV monitor
(

Task/Item	Qty	Spares	Institutions	Funding Source	Funding Status	Detailed description
HV power supply	7	1	Unibe	Switzerland		Specification and Procurement
PFD-5 (Potted Filter Distributer)	7	3	Unibe	Switzerland		Design, production, assembly and testing
HV Cables PS to PFD-5	7	4	Unibe	Switzerland		Specification and Procurement
HV cable PFD to TPC	35		SLAC			
HV Monitor and control unit	7	1	Unibe	Switzerland		Design, production, assembly and testing
Packaging and shipment			Unibe	Switzerland		packaging and shipment
Assembly procedures			Unibe	Switzerland		subsystem procedures for use during A&T and I&I
Support during ND A&T			Unibe	Switzerland		Technical/scientific support during TPC Module assembly and te
Support during ND I&I			Unibe	Switzerland		Technical/scientific support during TPC Module installation and in
QA/QC and characterization Protoryping PFD-4 and PFD-5			Institutions unibe	Funding Source Switzerland	Funding Status allocated	Detailed description Sesign, production, and assembly
Test of PFD-4 during Module-0 run			unibe	Switzerland	allocated	Full Operation test in LAr
Test of PFD-5 during Module1-3 runs			unibe	Switzerland	allocated	Full Operation test in LAr
Test of the ND PFD-5s			unibe	Switzerland		Bench qualification tests
Test of all HV connectors			unibe	Switzerland		Bench qualification tests
Test of all HV cables			unibe	Switzerland		Bench qualification tests
Test of the monitoring and control uni	1		unibe	Switzerland		Bench qualification tests
Prototypes for 2x2			Institutions	Funding Source	Funding Status	Detailed description
HV power supply	1	0	unibe	Switzerland	allocated	Specification and Procurement
PFD-5 (Potted Filter Distributer)	1	0	unibe	Switzerland	allocated	Design, production, assembly and testing
HV Cables	5	1	unibe	Switzerland	allocated	Specification and Procurement
HV Monitor and control unit	1	0	unibe	Switzerland	allocated	Design, production, assembly and testing
Packaging and shipment			unibe	Switzerland	allocated	packaging and shipment
Assembly procedures			unibe	Switzerland	allocated	subsystem procedures for use during assembly
Support during 2x2 operation			unibe	Switzerland	allocated	Technical/scientific support during 2x2 operation, including trave



Requirements

Key requirements of the HV distribution system

Key	Type	Component	Name	Description	Value	Rationale	Basis	Parent Roq/Spec ID(s)	Validation	Method		
					13	1.02.03.02: System Level						
YS-001	Requirement		ND LArTPC Fiducial Mass	The ND LArTPC shall provide >20 tons fiducial liquid argon target mass	>20 tons	To deliver the required statistical precision (<2%) for the measurement of neutrino-electron elastic scattering	To deliver the required statistical precision (<2%) for the measurement of neutrino-electron clastic scattering	ND-C12.1: Fiducial mass / statistics	Design	Test/Impection		
YS-862	Requirement		ND LACTPC Active	The ND LATTC active volume shall be ≥ 8 m in the beam direction, and ≥ 7 m x 3 m in ≥ 5 m in the beam direction, and ≥ 7 m to ≥ 5 m in the beam direction.		meatine intractions as sugge, except for forward-go more and energetic sources. The last is delivery to positioning exactivity to the temperature of the control of the control of the control of the control of the temperature of the control of th		The size is driven by maintaining sensitivity to the kinematic phase space of the cross-section, not by detector efficiency. Detector efficiencies as low as -5% can be	To sufficiently contain the ionization signal from bearn matrition interactions on angion, except for forward-going muons and energetic neutrons. The size is driven by maintaining sensitivity to the kinematic phase space of the cross-section, not by detective efficiency. Detector efficiencies as low as ~5% can be tolerand, as long as the detector is not bind to substantial (few-%) regions of the cross- section phase space.	ND-C.1.1: Classify interactions and measure outgoing particles in a LA-TPC with performance comparable to or exceeding FD	Design	Test Inspection
rs-003	Requirement		Piloup Rejection Efficiency	The ND LArTPC shall be able to associate ionization signals to fiducial sentrino irrientations with a purity, averaged over interactions, of > 97% by energy.	> 97% by energy	After the rejection of pileup, the residual pileup systematic uncertainties should be sub-dominant to other uncertainties in the prediction of the far detector signal based on near detector data.	After the rejection of pileup, the residual pileup systematic uncertainties should be sub-dominant to other uncertainties in the prediction of the fire detector signal based on near detector data.	ND-C.1.1: Classify interactions and measure outgoing particles in a LA/TPC with performance comparable to or exceeding FD	ScSimulations	ScSimulations		
YS-004	Requirement		3D Charge Imaging Accuracy	The ND LArTPC shall be able to associate ionization signals to fiducial sentrino interactions with completeness, averaged over interactions, of > 97% by energy.	> 97% by energy	Accurate 3D charge signal imaging is required in order to correctly associate charge depositions to their parent neutrino interactions in the high-sileux DN environment.	Accurate 3D charge signal imaging is required in under to correctly associate charge depositions to their parent neutrino interactions in the high-pileup ND environment.	ND-C.1.1: Classify interactions and measure outgoing particles in a LA-TPC with performance comparable to or exceeding FD	ScSimulations	ScSimulations		
YS-005	Requirement		Charge-Light Signal Matching Efficiency	The ND LACTPC shall be able to associate scintillation light signal times to ionization signal clusters from Educial neutrino interactions with an efficiency, averaged over interactions, of > 97% by energy.	> 97% by energy	Efficient matching of the charge signals with the fast (-na- scale) light signals enable accurate discrimination of the charge signals from the approximantly 50 neutrinos contributing to the charge signals per ~10us-wide beam spill.	Efficient matching of the charge signals with the fast (-ns-scale) light signals enable accurate discrimination of the charge signals from the approximately 50 neutrinos contributing to the charge signals per ~10as-wide beam spill.	SYS-003: Pileup Rejection Efficiency SYS-004: 3D Charge Imaging Accuracy	SeSimulations	SeSimulations		
YS-006	Design Choice		Detector Optical Modularity	The ND LArTPC shall have optically isolated regions, nominally 1.5 m ⁻³ , to facilitate matching between the charge and optical signals		Isolation of scintillation light within LA/TPC modules facilitates charge-light signal matching.	Isolation of scintillation light within LATPC modules facilitates charge-light signal matching.	SYS-005: Charge-Light Signal Matching Efficiency	Design	Test/Impection		
r'S-008	Requirement		ND LAFTPC performance after PRISM detector move	The ND LACTPC shall meet operational performance requirements (Electric field uniformity & stability, module alignment, noise, live pixels), within 1 hour after PRISM movement of the detection		1 hour	Start taking high quality data within an hour. This is a allocation of time to complete all activities associated with PRISM move within an 8 hour shift, driven by operational resource, and to achieve the required number of moves in a year with a 5% integrated downtime attributed to moving the detector (1 move/week).	Start taking high quality data within an hour. This is a allocation of inne to complete all activities associated with PRISM storce within an 8 hour shift, driven by operational resource, and to achieve the required number of nevers in a year with a 2% integrated deventions attributed to moving the detectic (1 more)week).	ND-C42: Maintain uniform detector performance across full range of movement	Etg Analysis	Eng Analysis	
r'S-009	Specification		Electric Field Strongth	The ND LArTPC shall be able to achieve an electric field strength >250 V/cm (goal 500 V/cm)	>250 V/cm (goal 500 V/cm)	Equivalent electric field as FD to enable operation of the near detector with equivalent levels of electron recombination and other field-dependent effects.	Equivalent electric field as FD to enable operation of the uses detector with equivalent levels of electron recombination and other field-dependent effects.		Eng Analysis	Full Scale Demonstrator		
				Validatio	n		Equivalent electric field uniformity as FD.	ND-C.1.1: Classify interactions and measure outgoing particles in a LArTPC with performance comparable to or exceeding FD; SP-FD-7	Eng Analysis	Full Scale Demonstrator		
ı f	or cl	harq	e R	Vandatio	'II		The IIV system should be engineered so that it is not a significant contributed, to overall system noise.	ND-C.1.1: Classify interactions and measure outgoing particles in a LArTPC with performance comparable to or exceeding FD	Eng Analysis	Test/Inspection		

ID	Requirement title	Description	Value	Rationale	Validation	LATTC with performance compared to the encoding Full Scale of the Compared to the encoding Full Scale of the Compared to the encoding Full Scale of the Compared to the Eng Analysis Demon
HV- 001	Range for cathode potential	HV range for cathode potential shall be between 15 to 50 kV	15 to 50 kV	Provide choise for charge R factor 0.6 to 0.7 for MIPs	Full scale Demonstrator	The IPV option should be regimened so that it is not considered to the construction of
HV- 002	HV long term stability	Variation of HV shall be 0.1% (0.5mm deviation at cathode or 0.01% in charge) at F<1 Hz	0.1% (0.5mm deviation at cathode or 0.01% in charge)	Coordinate accuracy < 1 mm Charge accuracy <0.1%	Full scale Demonstrator	required efficiency and accuracy in sharpe Net SYSSIGS. Charge-Light Signal Manager 195405. This profile from a model or accuracy to seven a model or according to the seven and the se
HV- 003	HV ripple/noise	Variation of HV shall be <4 mV (0.016fC or 100e) at 100kHz > f >1 Hz	<4 mV (0.016fC or 100e)	Noise induction to R/O	Full scale Demonstrator	Texture of the control of the contro
HV- 005	HV nominal ramp rate	Nominal ramp rate provided by HVPS shall be 300 V/s (~2pA per pixel)	300 V/s (~ 2pA per pixel)	Ramp up/down rate to limit recharging currents in the TPC to < 5 pA	Full scale Demonstrator	ND-71.5.1 RAD Printings Text loss

https://edms.cern.ch/document/2723207/1

HV subsystem design, tested with 2x2 program, meets all the requirement

							Uniformity of 96% of active volume shall be 95%	Scale Demonstrator	MIF Integrated Testing
CG-003	Requirement	Electric Field Strongth	The FS shall be able to support an electric field strength 500 V/cm	500 V/cm	Equivalent electric field as FD to enable operation of the near detector with equivalent levels of electron recombination and other field-dependent effects.		SYS-009 Electric Field Strength	Design/ Full Scale Demonstrator	MIF Integrated Testing
PCG-004	Requirement	Drift Field Volume	FC geometry shall create an active drift volume that encompasses all of the pixel plane or > 94.5m ³	94.5m*3	Full pixel plane should be useable without compromise from field distortions or physical obstructions. Otherwise, the effective dead region of the detector increases.		SYS-002 ND LArTPC Active Size	Design	Design
PCG-005	Requirement	Dead volume	The FS will not detract more than TBD% from the active volume	TBD%	ND-LAe should match the FD specifications accounting for the different geometry/readout systems.	Regions of field non-uniformity may become effectively unusuable volume of LAs.	SYS-007 Fraction of interior fiducial volume	Design	Design
FCG-010	Requirement	Contamination	LAr impurity contributions from components shall be <30 ppt	< 30 ppt	Field structure materials must not emassite impusities that affect LAr electron lifetime		SP-FD-26	Design/ Full Scale Demonstrator	MIF Integrated Testing
FCG-012	Interface	Structural Support for charge and light readout	The FC shall mechanically support the charge and light readout boards, cabling and feedthrus		The field cage provides the mechanical support as well as cable routing			Design/ Analysis	MIF Integrated Testing
PCG-037		Optical containment	The FS should be opaque and the maximum optical path to light detectors should below 66cm.	66 cm	To facilitate the measurement of prompt light signals, each TPC must be opaque to scintillation light and the optical path must be less than the Rayleigh scattering length in Argon.				
				13	11.02.03.02.04: Charge Readout				
CRO-002	Specification	Pixel Spacing	The pixel spacing for the ND readout shall provide spatial resolution < 4.7 mm	< 4.7 mm	The pixel spacing for the ND readout shall provide spatial resolution as good as the far detector.	Wire spacing in FD is 4.7mm	SYS-004 3D charge imaging accuracy	Design	Design
CRO-003	Specification	Pixel sampling time shall be < 3 µs	Pixel sampling time shall be < 3 µs	<3 µs	The pixel sampling time should provide equivalent spatial resolution in the drift direction as in the transverse directions.	Given an expected maximum drift velocity of 1.6 mm/us.	SYS-004 3D charge imaging accuracy	R&D Prototype	Test/Inspection
CRO-004	Specification	The noise (uncertainty) in the measurement of ND pixel charge shall be < 1000 electrons	The noise (uncertainty) in the measurement of ND pixel charge shall be < 1000 electrons	< 1000 electrons	The noise (uncertainty) in the measurement of ND pixel charge should be as good as the FD specification. The noise moust be low enough to onable stuble pixel self- traggering for 1/4-MBP eignals.		CRO-608 Pixel efficiency	R&D Prototype	Test Inspection
CRO-005	Specification	The pixel electronics shall have sufficient dynamic range such that it saturates at >180,000 electrons	The pixel electronics shall have sufficient dynamic range such that it saturates at >180, 000 electrons	>180,000 electrons	Pixel electronics should have sufficient dynamic range for high multiplicity heavily ionizing particles at the neutrino- vortex typical of LINP in no.4 interactions	One pixel should be able to measure energy from 5 simultaneous portens	SYS-004 3D charge imaging accuracy	Engineering Unit	Test Inspection
CRO-008	Specification	The pixel channels shall be > 95% efficient for signals greater than 1.14 MIP track traversing full pixel pitch	The pixel channels shall be > 95% efficient for signals greater than 1/4 MIP track traversing full pixel pixel.	> 92%	The channel efficiency should be high enough that we do not loss signal fidelity, particularly for MIP-level or larger signals.	Once you meet the other pixel requirements, then the pixel efficiency should be obtained	SYS-004 3D charge imaging accuracy	R&D Prototype	Test Inspection

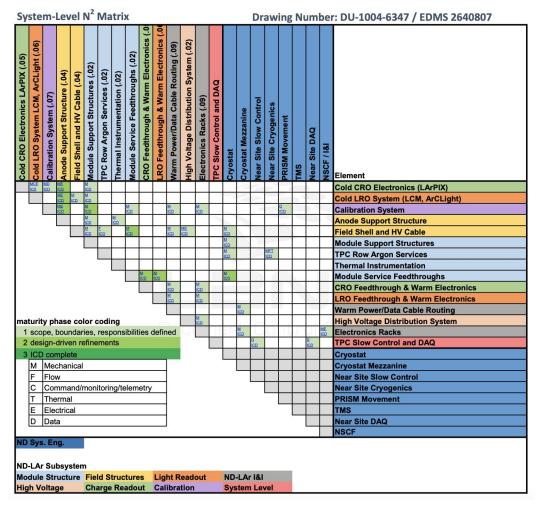


Interfaces

- Interface Control documents, https://edms.cern.ch/project/CERN-0000223195
- Engineering CAD model captures interfaces, https://edms.cern.ch/project/CERN-0000226247
- Interfaces realized and validated in 2x2 program

Corresponding system	Interface	Maturity
Field shell and HV cable	Mechanical	Defined
Electronics Rack	Mechanical	Defined
Slow control	Monitoring data	Partially defined

Defined = meets preliminary design maturity

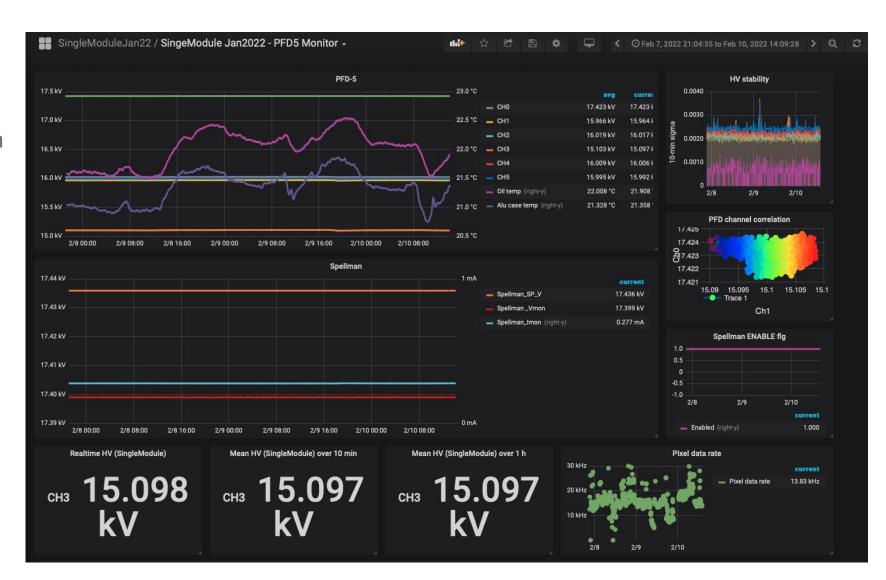




Slow control implementation at Bern

- Spellman remote control and Monitoring via Ethernet
- PFD-5 Monitoring via a Custom Unit+RPi
- Python scripts
- Data base: InfluxDB
- Visualization: Grafana

Similar dashboard to be integrated within the broader ND-LAr Slowcontrol





Procurement, Manufacturing, QA/QC

The procurement, manufacturing and QA/QC tests of the HV subsystem will be carried

out in-house at University of Bern.

Document	Link to EDMS
Procurement plan	https://edms.cern.ch/document/2611199/1
Manufacturing plan	https://edms.cern.ch/document/2611198/1
QA/QC plan	https://edms.cern.ch/document/2611197/1













Manufacturing stages of the HV filter, PFD-5 Assembly of a PFD-5 takes about one week



Risks

Risks are actively tracked through Consortium risk registry.

Risk Title	Summary	Mitigation	Probability	Schedule Impact (Months)	Cost impact (\$k)	Technical Impact
HVPS delivery delay	IF the 9 HVPS are delivered with delay, THEN the detector commissioning is delayed as well	Perform Production Readiness Review well in advance and place the order for HVPS	10%	6	-	0 Negligible
Delays with PFD production	IF COVID situation in CH gets worse, THEN manufacturing of the 9 PFD-5 (Potted Filter Distribution) units will be delayed	Perform Production Readiness Review well in advance and start manufacturing a.s.a.p.	10%	6	63	0 Negligible
Change of filter requirements on Fcut	IF requirements of filter cutoff frequency changes, THEN values of R and C in PFD-5 will change, pulling changes in mechanical design	Implement reasonable safety margin (~1 order of mag), retired based on module-1 test	1%	5	30	1 Somewhat Substandard
Change of filter requirements on Vmax	IF requirements of filter max voltage changes, THEN specs of R and C in PFD-5 will change, pulling changes i mechanical design	Implement reasonable safety nmargin (factor of 2), retired based on module-1 test	0%	5	30	1 Somewhat Substandard
HV Breakdown (Recoverable)	IF changes from MOD0 to ND results in HV Recoverable Breakdown, THEN operation schedule delayed	FSD testing of ND, lowering operating voltage	5%	1	-	1 Somewhat Substandard
HV Instabilities	IF HV instabilities occur, THEN NDLAr TPC will not meet operational data performance will be reduced	FSD testing of ND	10%	-	-	1 Somewhat Substandard
HV Breakdown (Non-Recoverable)	IF HV Breakdown damages equipment, THEN operation cost & schedule is delayed and/or performance degradation	FSD testing of ND, spares	1%	6	200	0 Negligible
L	_essons learnt from 2x2 single module ru	uns, to be added to risk	registry			

Variation in Field shell resistance		Being tested in 2x2 program, QA for Field shell resistance, Splitting the filter into individual circuits, using separate power supplies for each module.	10%	4	130	1 Somewhat Substandard
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Recommendation from previous reviews

https://edms.cern.ch/document/2741842/1

Reviewer/Committee: Linda Bagby (FNAL), Francesco Pietropaolo (CERN), Bo Yu (BNL)

Recommendation / Comment	Responder(s)	Comments / Answers / Actions	Status
1. Provide redundancy for the PFD oil temperature monitor.	S. Parsa, I. Kreslo	Second thermocouple added to the PFD5	Closed
2. Provide hardware stack details for external PFD connections.		Acknowledged	In progress
3. Conduct a Grounding Review with the DUNE Grounding and Shielding Committee.		Acknowledged	In progress
4. Conduct a Safety review with the Electrical Safety subcommittee.		Acknowledged	In progress
5. Upload and maintain updates of all required documentation in EDMS within the dedicated folder for all the HV system components. Provide a summary table to help reviewers.		Acknowledged	In progress
6. Cost estimates and schedule should be made available and presented at the PDR.		Acknowledged	In progress
7. Test HV breakdown effect of one module on other channels		Acknowledged	In progress



Cost

		Design & F	Prototyping			Produ	uction			
	On-P	roject	Off-Project		On-Project		Off-Project		On-Project	
131.ND.02: ND-LAr	M&S [CY-k\$]	Labor [k-hrs]	M&S [CY-k\$]	Labor [k-hrs]	M&S [CY-k\$]	Labor [k-hrs]	M&S [CY-k\$]	Labor [k-hrs]	Total Cost [FBAY-k\$]	Avg. Uncert.
01 ND LArTPC Management	\$401.5	18.3	-	43.9	\$412.5	13.8	-	72.5	\$10,114.9	10%
02 Module Structure	-	-	-	14.3	-	-	\$2,448.0	22.0	-	-
03 HV	-	-	-	10.5	-	-	\$816.0	14.0	-	-
04 Field Structure	\$159.1	9.4	-	0.6	\$3,560.1	4.9	-	6.5	\$7,642.6	60%
05 Charge Readout	\$1,331.3	17.7	-	16.6	\$3,366.0	5.5	-	20.8	\$10,741.6	35%
06 Light Readout	-	-	-	71.1	-	-	\$5,508.0	15.1	-	-
07 Calibration	\$193.7	1.3	-	33.1	-	-	-	20.3	\$414.0	50%
08 TPC Module Assembly and Testing	\$368.1	7.1	-	8.6	\$103.0	5.7	-	32.0	\$1,865.1	41%
09 TPC Integration and Installation	\$584.2	11.4	-	12.4	\$426.0	9.6	-	15.0	\$5,384.2	50%
10 Module Assembly & Test Facility	-	5.7	-	-	\$1,483.0	10.8	-	27.3	\$4,114.0	60%
11 Full-scale Demonstrator Test Facility	\$1,497.5	9.1	-	6.3					\$3,726.2	60%
12 ArgonCube Test Facility	-	_	\$1,250.0	20.9					-	Y.
13 2x2 NUMI Test Beam Facility	-	-	\$2,300.0	15.0				-	-	24
Total:	\$4,535.3	79.9	\$3,550.0	253.2	\$9,350.6	50.5	\$8,772.0	245.5	\$44,002.5	43%

Notes:

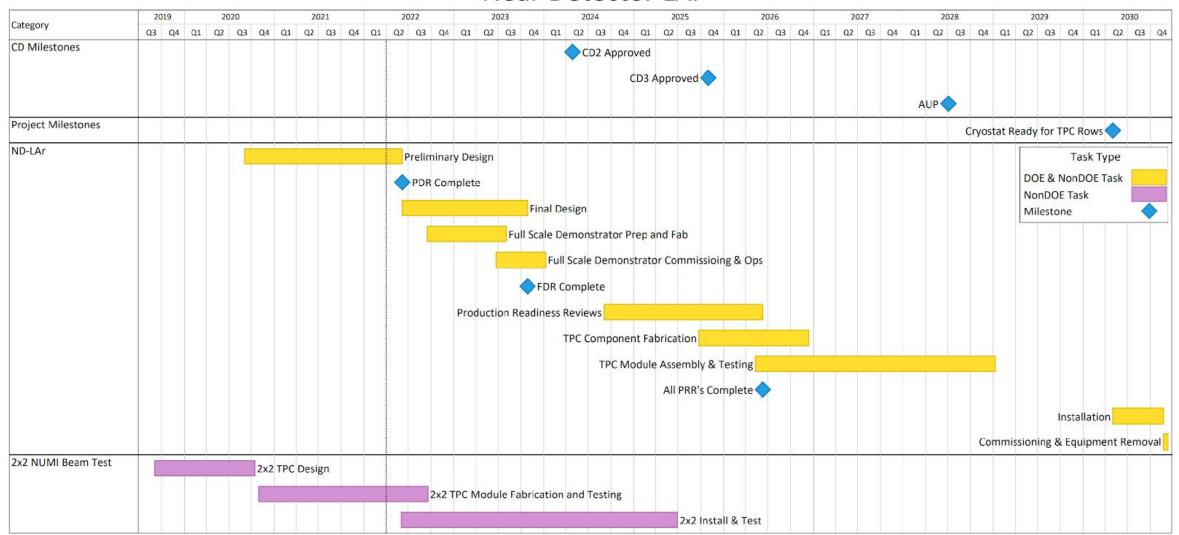
- 1. Extracted EAC from working resource-loaded schedule for internal cost review (P6/Cobra ND-LAr Sandbox, 22 Mar. 2022)
- 2. Includes all on-project and majority of off-project resource estimates for ND-LAr Consortium.
- 3. Off-project resources include both international and domestic investments
- 4. CY-k\$: Costs in current-year direct kilo-dollars. FBAY-k\$: Costs in fully-burdened at-year (escalated) kilo-dollars.



06.27.2022

Schedule

Near Detector LAr





Summary

- Validation and maturity of High Voltage system design exercised through 2x2 program
 - Scope is well-defined with no gaps
 - Intra-system and inter-system interfaces are well-understood
 - System requirements evaluated with prototype operation
 - Exercised parts production, QA, and QC with already constructed PFD-5 for Module-1 test
- HV distribution system is ready to move towards final design and production of FSD



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