High Voltage Distribution: Design Overview

Saba Parsa, L3 HV Subsystem Lead

ND-LAr Preliminary Design Review

28 June 2022

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
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U.S. DEPARTMENT OF ENERGY | Office of Science

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

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

Outline

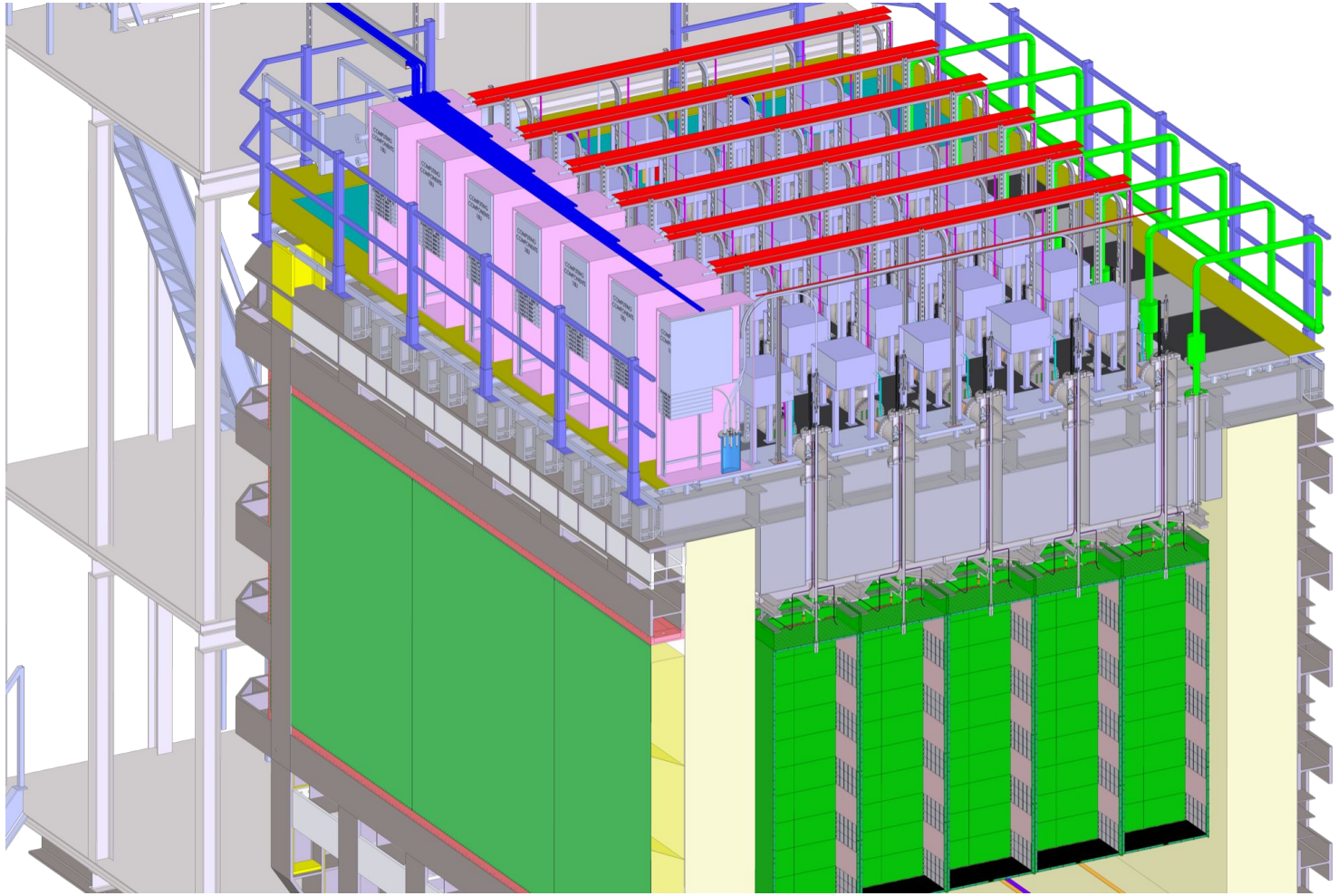
- Scope
- Requirements
- Interfaces
- Procurement, Manufacturing, QA/QC
- Risks and Prototyping
- Recommendations from Previous Reviews
- Cost and Schedule
- Summary

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 50 cm in each TPC, Nominal Cathode potential is 25 kV

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

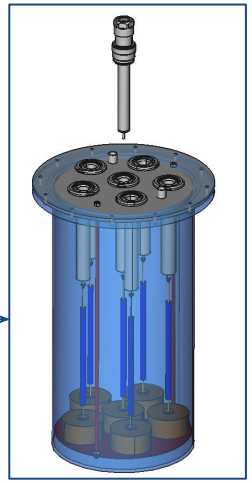


Subsystem Overview

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

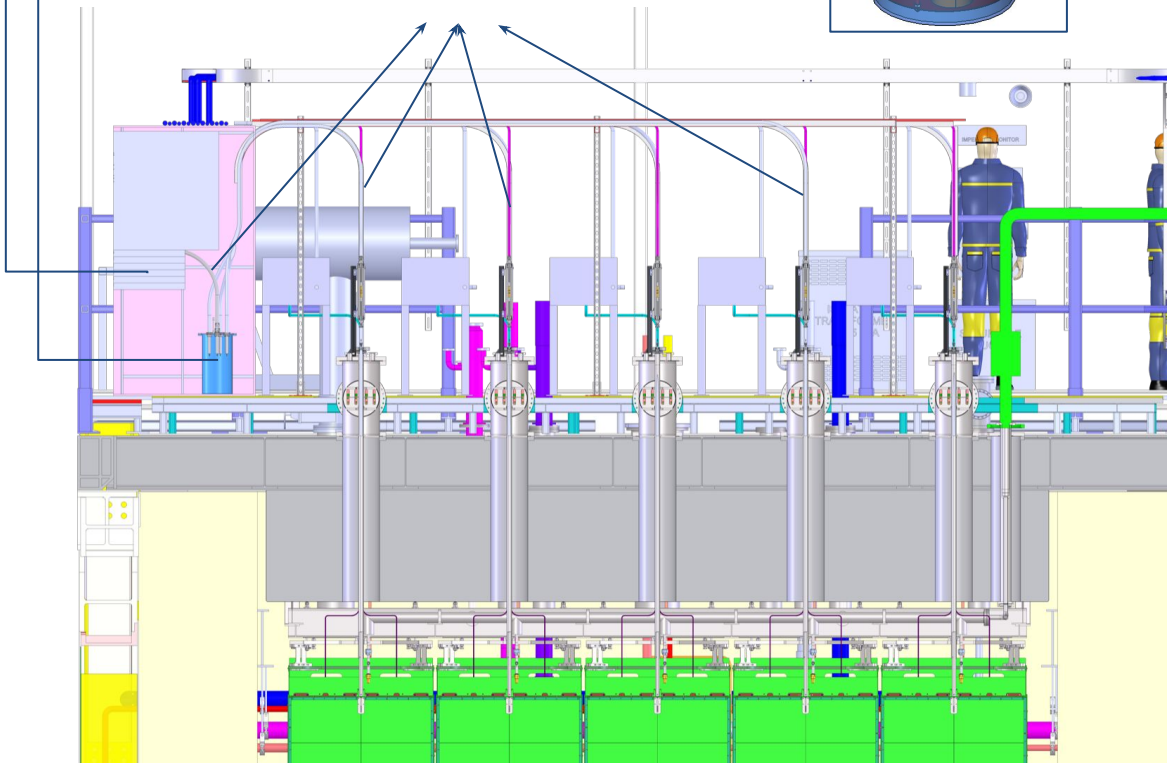
- **HV power supply (Spellman)** to supply 5 modules
- A **low-pass filter-distributor (PFD-5),** situated between the PS and the modules
- **HV resistive cables**

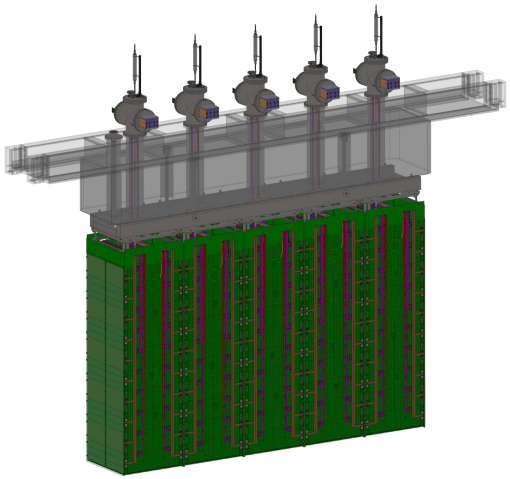
HV power supply



HV filter

HV Cables



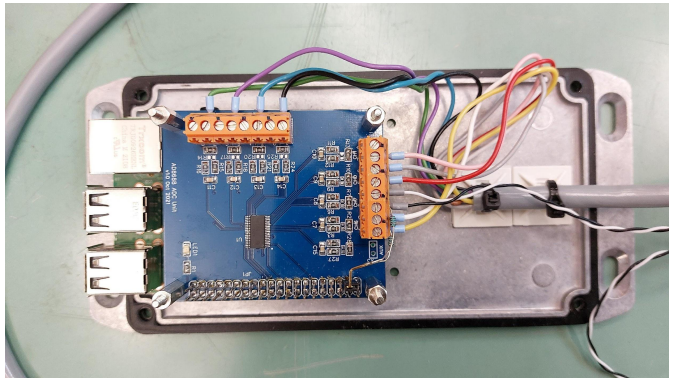


HV delivery to a row of 5 modules
(In Field Structure Scope)

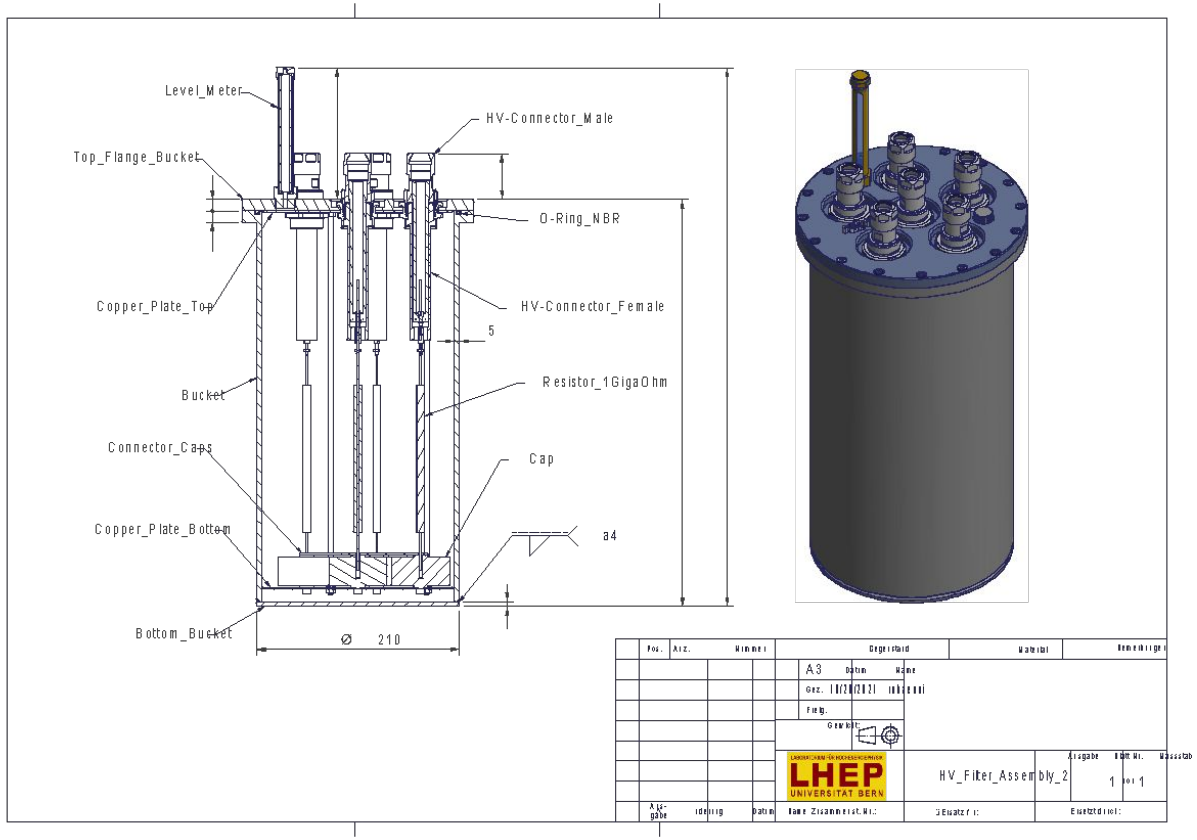
https://edms.cern.ch/document/2746041/1

Subsystem Overview

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



HV Monitoring unit



PFD-5 CAD drawing

PFD-5 outer and inner view

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

Scope

Detailed subsystem scope is defined

- Describes deliverables, quantities, responsible institutions, and funding source during design, prototyping, production and installation phases

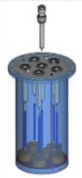
- Informed by HV Filter prototypes constructed and tested during 2x2 Single module runs

131.ND.02.03: High Voltage

WBS Dictionary (Concise):

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/QC/QA, and associated tooling
- Prototypes for 2x2, Full-scale Demonstrator
- Packaging and shipping
- Support personnel for prototyping, A&T, and I&I, and their travel

Reference CAD Image(s):

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 testing pr
Support during ND I&I			Unibe	Switzerland		Technical/scientific support during TPC Module installation and integrati

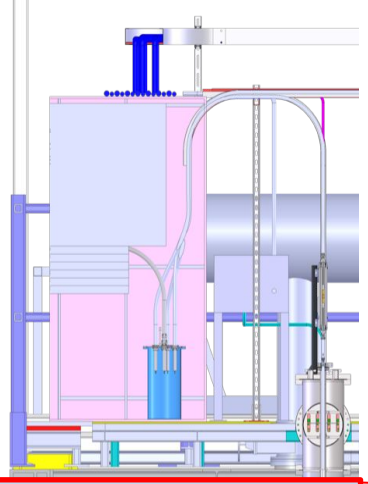
QA/QC and characterization			Institutions	Funding Source	Funding Status	Detailed description
Protoryping PFD-4 and PFD-5			unibe	Switzerland	allocated	Design, production, and assembly
Test of PFD-4 during Module-0 run			unibe	Switzerland	allocated	Full Operation test in LAr
Test of PFD-5 during Module1-3 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 unit			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 travel.

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



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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	-	-	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

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- Component testing/QC/QA, and associated tooling
- Prototypes for 2x2, Full-scale Demonstrator
- Packaging and shipping
- Support personnel for prototyping, A&T, and I&I, and their travel

Reference CAD Image(s):

HV power supply | PFD-5 | HV cables | HV monitor

Task/Item	Qty	Spares	Institutions	Funding Source	Funding Status	Detailed description
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HV cable PFD to TPC	35		SLAC			
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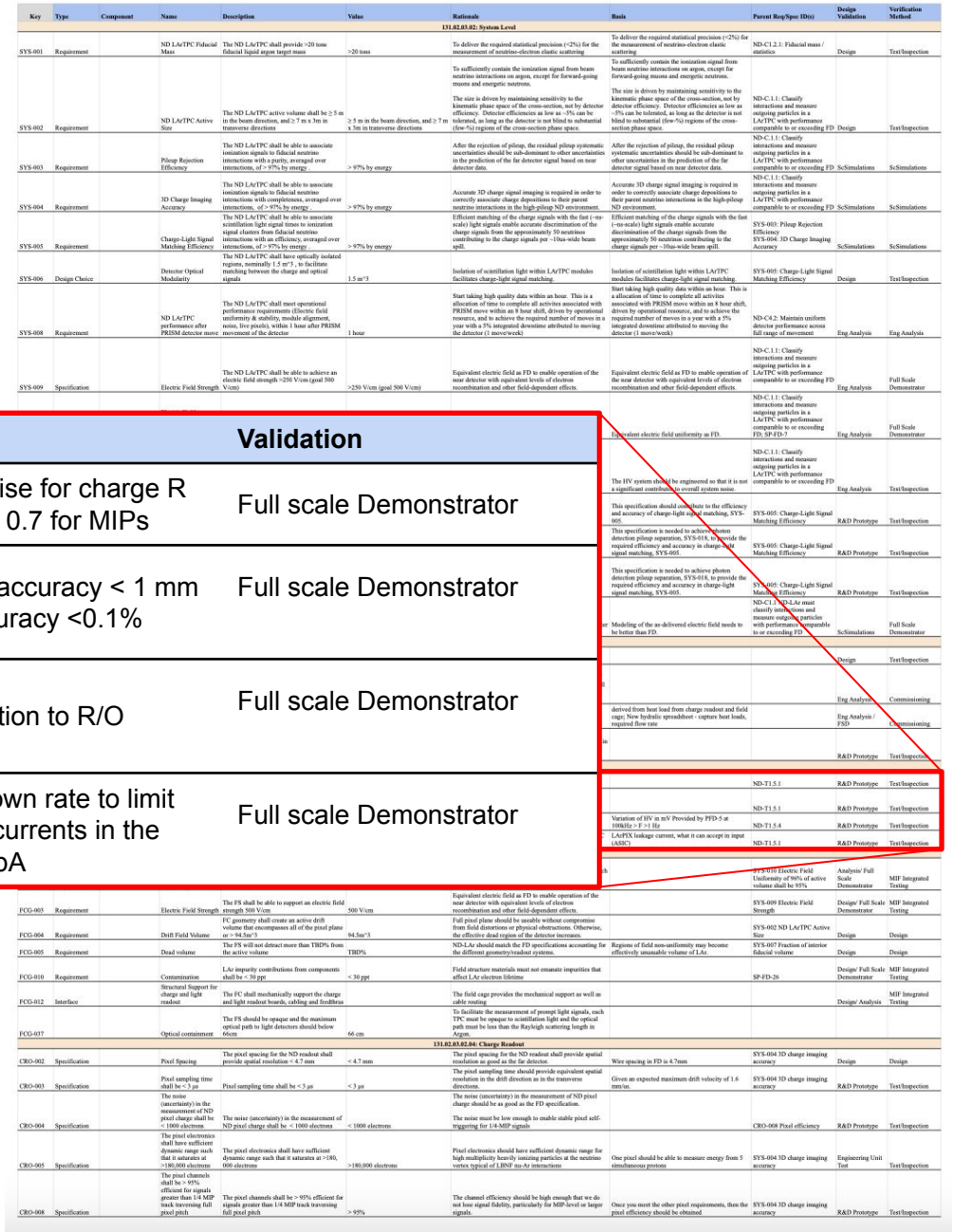
HV Cables	5	1	unibe	Switzerland	allocated	Specification and Procurement
HV Monitor and control unit	1	0	unibe	Switzerland	allocated	Design, production, assembly and testing
Packaging and shipment			unibe	Switzerland	allocated	packaging and shipment
Assembly procedures			unibe	Switzerland	allocated	subsystem procedures for use during assembly
Support during 2x2 operation			unibe	Switzerland	allocated	Technical/scientific support during 2x2 operation, including travel.

Requirements

Key requirements of the HV distribution system

ID	Requirement title	Description	Value	Rationale	Validation
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
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
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
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



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

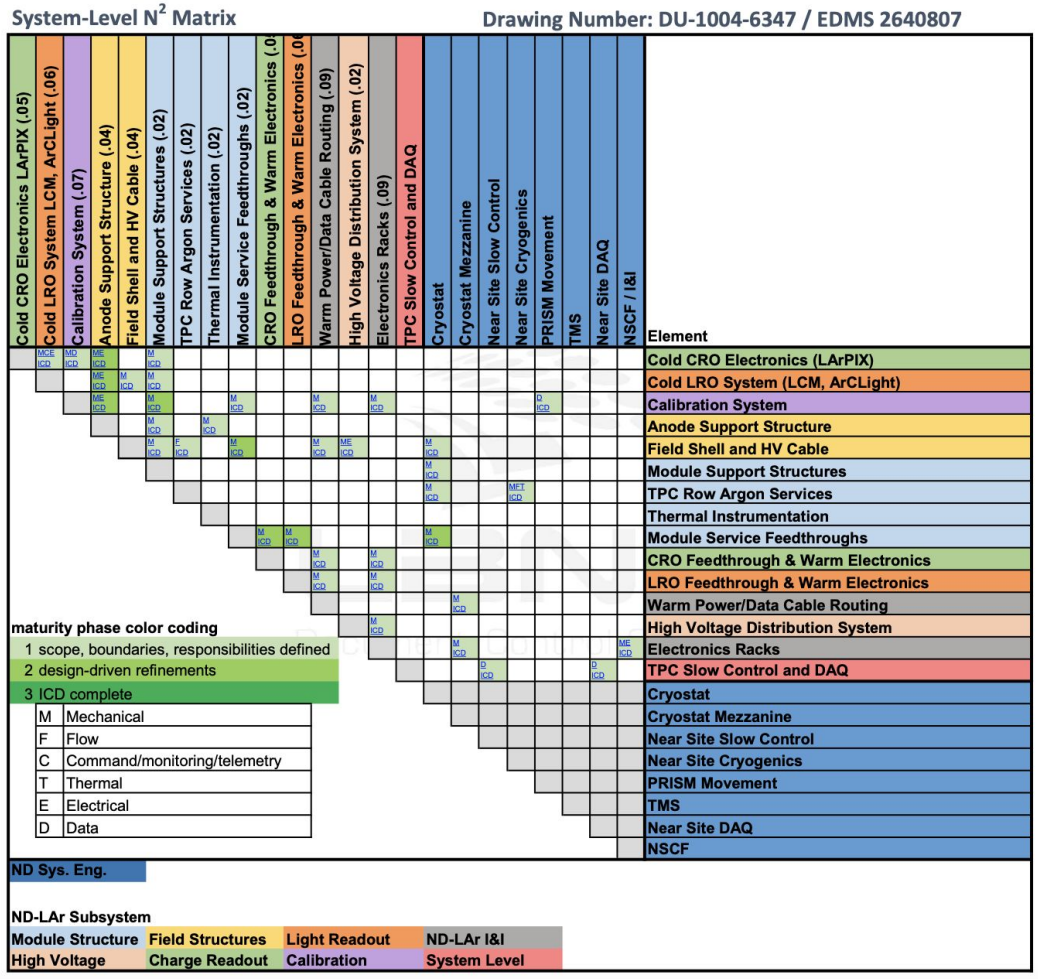
HV subsystem design, tested with 2x2 program, meets all the requirement

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

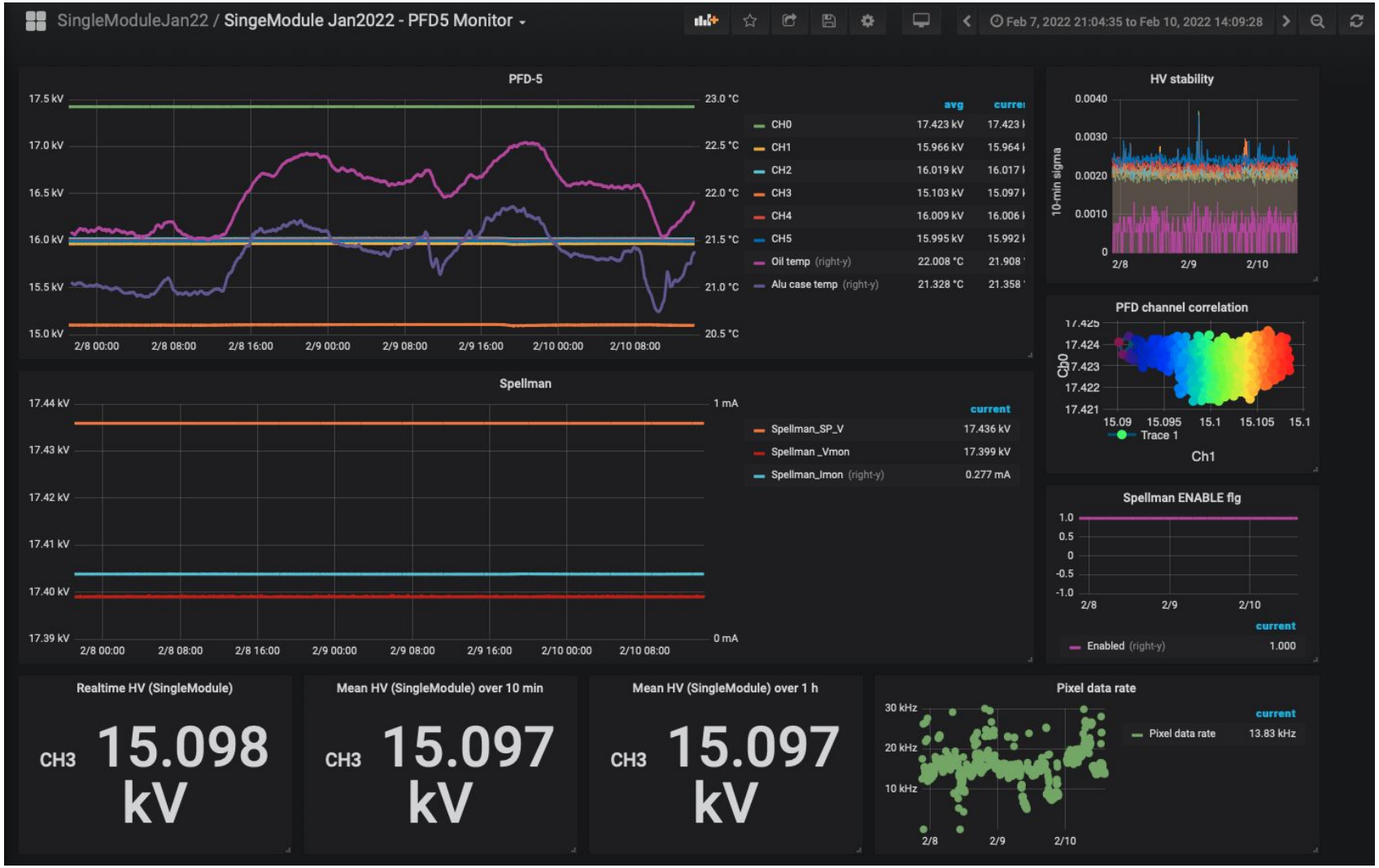
Defined = meets preliminary design maturity



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

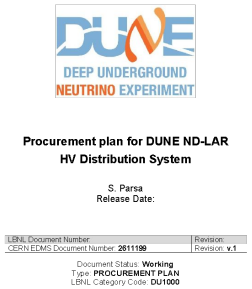
Similar dashboard to be integrated within the broader ND-LAr Slowcontrol



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.

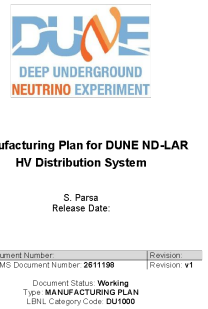
Document	Link to EDMS
Procurement plan	https://edms.cern.ch/document/2611199/1
Manufacturing plan	https://edms.cern.ch/document/2611198/1
QA/QC plan	https://edms.cern.ch/document/2611197/1


Procurement plan for DUNE ND-LAR
HV Distribution System

S. Parsa
Release Date:

LBNL Document Number: | Revision:
CERN EDMS Document Number: 2611199 | Revision: v.1

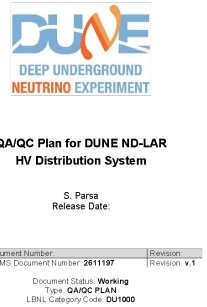
Document Status: Working
Type: PROCUREMENT PLAN
LBNL Category Code: DU1000


Manufacturing Plan for DUNE ND-LAR
HV Distribution System

S. Parsa
Release Date:

LBNL Document Number: | Revision:
CERN EDMS Document Number: 2611198 | Revision: v1

Document Status: Working
Type: MANUFACTURING PLAN
LBNL Category Code: DU1000


QA/QC Plan for DUNE ND-LAR
HV Distribution System

S. Parsa
Release Date:

LBNL Document Number: | Revision:
CERN EDMS Document Number: 2611197 | Revision: v.1

Document Status: Working
Type: QA/QC PLAN
LBNL Category Code: DU1000

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

https://edms.cern.ch/document/2589288

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 in mechanical design	Implement reasonable safety margin (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

Lessons learnt from 2x2 single module runs, to be added to risk registry

Variation in Field shell resistance	IF the modules have different resistances, THEN it is not possible to keep equal drift field in a row of TPCs	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

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

From Mar. 2022 cost review

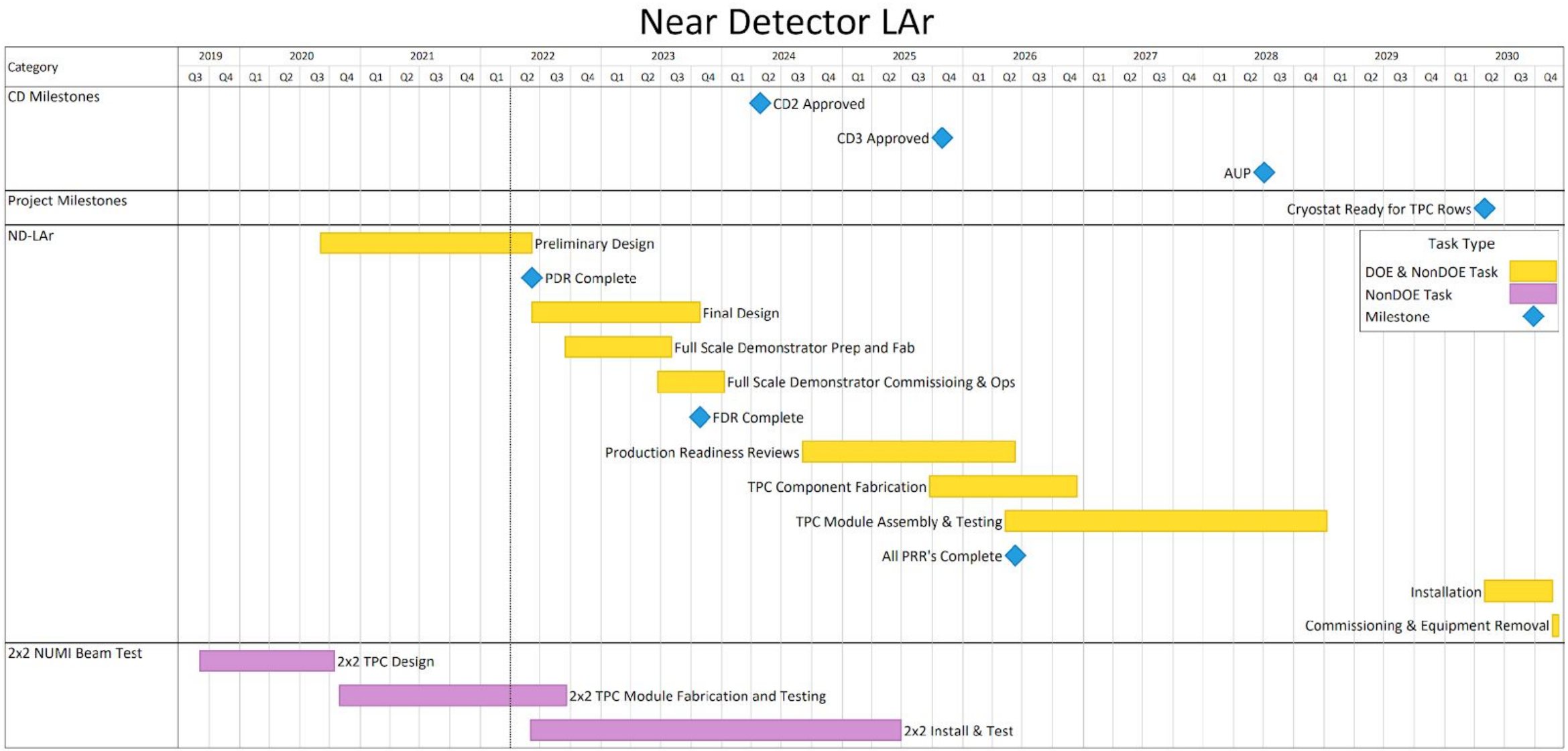
	Design & Prototyping				Production					
	On-Project		Off-Project		On-Project		Off-Project		On-Project	
131.ND.02: ND-LAr	M&S [CY-k$]	Labor [k-hrs]	M&S [CY-k$]	Labor [k-hrs]	M&S [CY-k$]	Labor [k-hrs]	M&S [CY-k$]	Labor [k-hrs]	Total Cost [FBAY-k$]	*Avg. Uncert.*
01 ND LArTPC Management	$401.5	18.3	-	43.9	$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					-	-
13 2x2 NUMI Test Beam Facility	-	-	$2,300.0	15.0				-	-	-
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.

https://edms.cern.ch/document/2603073

Schedule



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