ANNEX XXXX: ND-LAr Consortium

The DUNE detectors are delivered by International Detector Consortia, instituted and managed by the DUNE International Scientific Collaboration. The ND-LAr Consortium is responsible for design, production, and installation of the Near Detector Liquid Argon Time-Projection Chamber (ND-LAr) Detector, one of the three detectors at the DUNE Near Site.

This Annex describes the planned design, construction, and integration and installation for ND-LAr as well as the understanding of the share of deliverables and funding for the detector components.

Scope of Work

The ND-LAr detector scope consists of 35 TPC modules, including their associated electronics and cabling for readout, control, and power. Spares and parts for demonstrators should be provided to ensure operation and progress on technical maturation.

The active size of the ND-LAr TPC is based on the requirement to contain the hadronic particles from the neutrino interactions resulting in a lateral size of 7 m. The length in beam direction of 5 m is given by the muon energy containment up to an energy where the remaining muons can reach and be measured in a downstream detector. Due to the high intensity of the neutrino beam with up to 15 neutrino interaction per spill a modular approach based on the Argoncube technology is chosen.

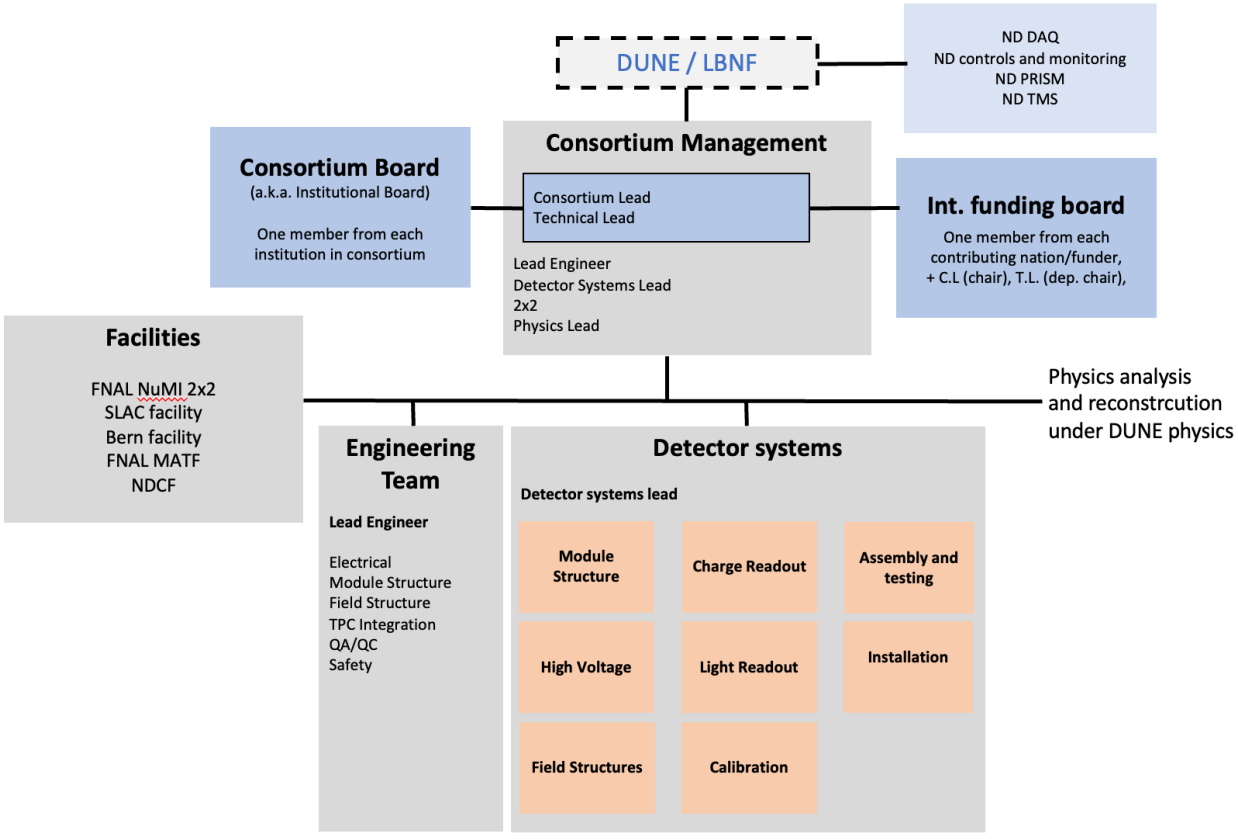
A more detailed ND-LAr Consortium Work Breakdown Structure Dictionary and associated subsystem scope tables are provided and maintained by consortium leadership in EDMS.

The cryostat, liquid argon cryogenics, DAQ, and Slow Controls systems are covered separately and are not in the scope of the ND-LAr Consortium. The Consortium provides specialized labor in support of detector installation, while generic labor (rigging, etc.) and overall coordination is provided by Near Site I&I. Details of the interfaces between the ND-LAr Consortium and these other scope areas are provided in the following Interface Control Documents: https://edms.cern.ch/project/CERN-0000219427.

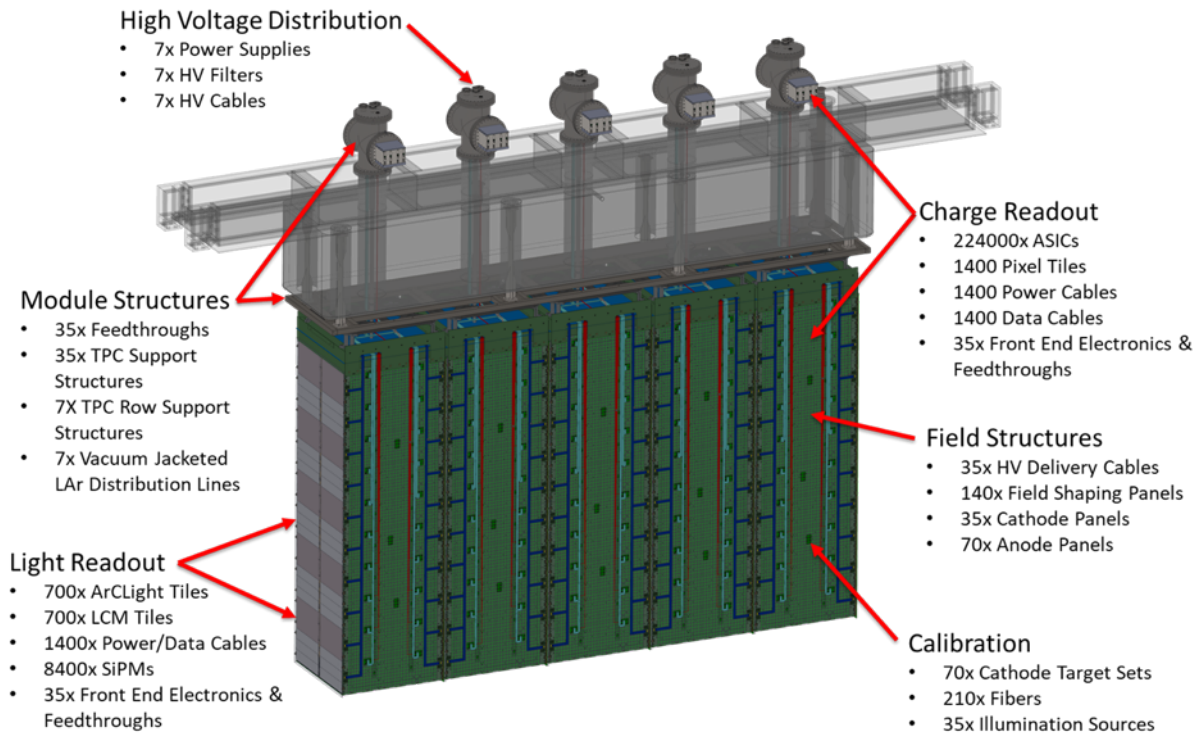
Consortium Leadership as of 2022

Role	Institution	Name
Consortium Lead	University of Bern, Switzerland	Michele Weber
Technical Lead	LBNL, USA	Dan Dwyer
Lead Engineer	LBNL, USA	Andrew Lambert
Detector systems Lead	University of Bern, Switzerland	Igor Kreslo
2x2 Lead	Fermilab, USA	Jen Raaf
Physics and reconstruction (under DUNE physics)	UCI, USA	Pedro Ochoa

Consortium Org chart



Consortium overview and subsystems



The image above shows one of the 7 rows of modules that make the ND-LAr detector with spares. Quantities provided in the diagram above are for 35 modules. The cryostat lid segment (in transparent grey) is outside of the ND-LAr Consortium scope.

The WBS items covered by this MoU are the core detector systems:
131.ND.02.02: Module Structure
131.ND.02.03: High Voltage
131.ND.02.04: Field Structure
131.ND.02.05: Charge Readout
131.ND.02.06: Light Readout
131.ND.02.07: Calibration

and assembly and integration/installation:
131.ND.02.08: TPC Assembly & Test
131.ND.02.09: TPC Integration & Installation.

Additional WBS items for management (131.ND.02.01) and prototyping/production facilities (131.ND.02.10—13) are defined in the consortium to track contributions of individual institutions or funding agencies. They are not covered by this MoU.

Areas of Support needed from Fermilab as Host Laboratory

Fermilab is hosting the Near Detector and is expected to provide facilities to store and handle detector elements as they are produced. Laboratory space for reception tests and servicing of detector modules will also be located at Fermilab. Support of technical and ES&H personnel is also expected, commensurate with Host Laboratory tasks. Additional regulations may be included in the general MoU of the DUNE collaboration.

Schedule

PDR: June 2022
FDR: Q1 2024
Construction of detector parts: 2024—2026
PRR: 2024
Module construction: 2024—2027
Module QA/QC: 2025—2027
Row integration: 2026—2027 on a technically limited schedule
Installation: 2028, on a technically limited schedule

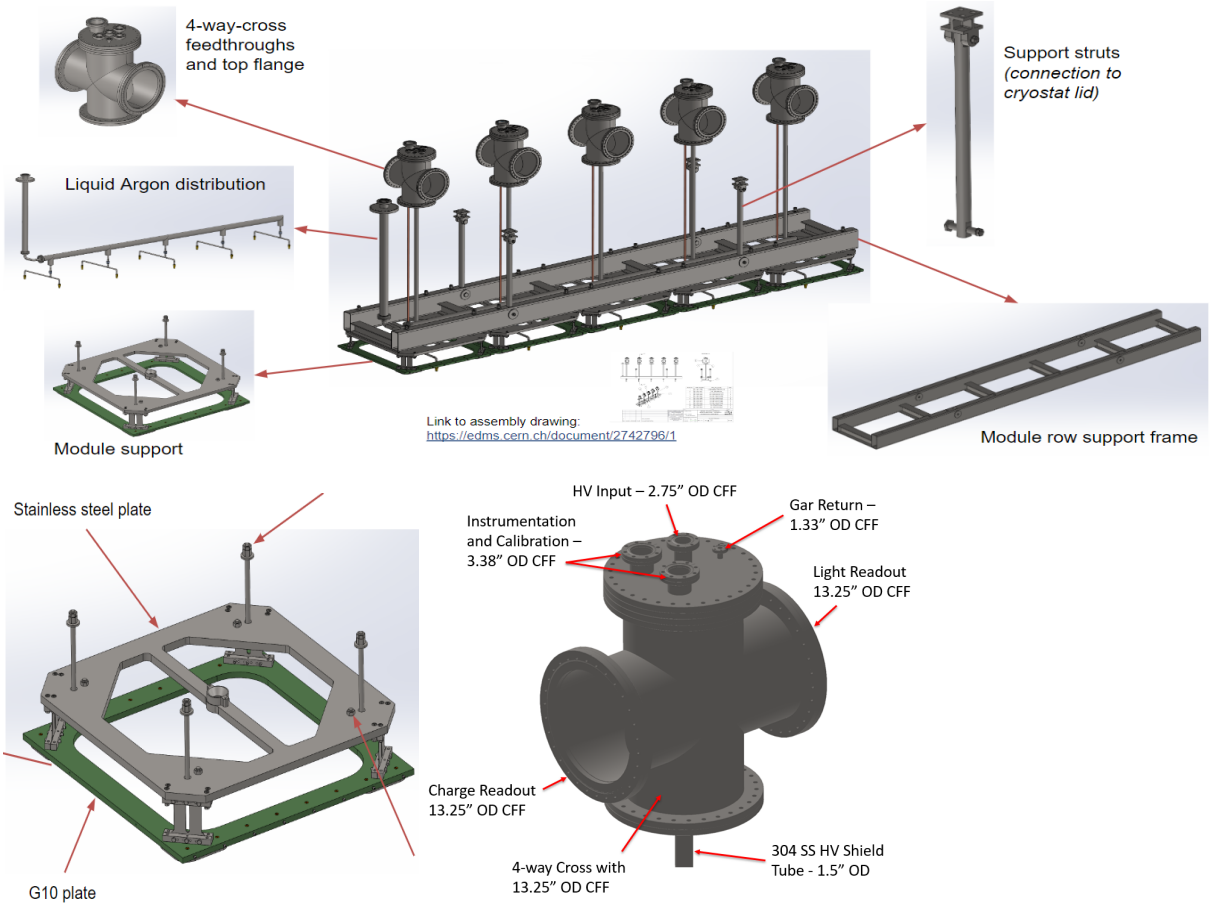
Consortium Contributing Institutions
Principal Investigators (PIs), and Areas of Contribution

Contributing Institution	Principal Investigator(s)	Areas of Contribution
Switzerland		
U. of Bern	Michele Weber	Module structure, HV, Light readout, calibration, assembly, testing, integration, installation
United States		
ANL	Zelimir Djurcic	Assembly and testing
BNL	Mary Bishai	Assembly and testing
Caltech	Ryan Patterson	Assembly and testing, Charge readout
CSU	Mike Mooney	Assembly and testing, Tooling, Field structures
Fermilab	Steve Brice	Assembly and testing, Installation and integration
U. of Houston	Lisa Koerner	Charge readout, Assembly and testing
U. of Iowa	Jane Nachtman	Assembly and testing
KSU	Tim Bolton	Assembly and testing
LBNL	Cheng-Ju Lin	Charge readout, Assembly and testing, installation and integration
U. of Minnesota Duluth	Rik Gran	Assembly and testing
MSU	Kendall Mahn	Calibration
U. of Pennsylvania	Christopher Mauger	Charge readout, Assembly and testing
U. of Rochester	Steve Manly	Assembly and testing
Rutgers University	Andrew Mastbaum	Charge readout, Assembly and testing
SLAC	Hiro Tanaka	Field structures, Assembly and testing, installation and integration
Syracuse University	Mitch Soderberg	Assembly and testing
Tufts	Hugh Gallanger	Assembly and testing
UC Berkeley	Kam-Biu Luk	Charge readout, Assembly and testing
UC Davis	Mike Mulhearn	Charge readout, assembly and testing

UC Irvine	Pedro Ochoa	Charge readout, assembly and testing
UC Santa Barbara	Xiao Luo	Charge readout, assembly and testing
U. of Chicago	Ed Blucher	Assembly and testing
U. of Colorado Boulder	Alysia Marino	Field structures, Assembly and testing
U. of Hawaii	Jelena Maricic	Calibration
UTA	Jonathan Asaadi	Installation and integration, Charge readout
Wichita State	Mathew Muether	Assembly and testing
William and Mary	Mike Kordosky	Assembly and testing
Yale	Bonnie Fleming	Assembly and testing
United Kingdom		
Cambridge University	Melissa Uchida	Assembly and testing
Lancaster University	Jaroslaw Nowak	Assembly and testing
U. of Manchester	Stefan Soldner-Rembold	Assembly and testing
U. of Sheffield	Neil Spooner	Assembly and testing
U. of Warwick	John Marshall	Assembly and testing
Canada		
York	Debby Harris	Light readout, Assembly and testing
JINR		
JINR	Alexander Olshevskiy	Light readout, Assembly and testing, Integration and installation
Israel		
Tel Aviv University	Adi Ashkenazi	Assembly and testing

131.ND.02.02: Module Structure

Design sketches



Summary

Design and production of the supporting structures for the ND LArTPC modules, including parts for demonstrators. Deliverables are the support structure for the 5-module magazines, module cryo-circuits, plumbing (cryo-side, including feedthroughs), module instrumentation (temp, level, pressure, etc.) and associated readout systems. Component QA/QC, tooling, as well as packaging and shipping, and personnel for prototyping, A&T, and I&I.
In addition a whole spare row will be produced, which is the smallest replaceable unit for ND-LAr.

Deliverables

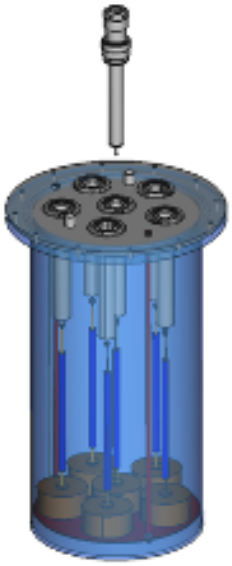
		Qty	Spares
1	Module Row Support Strut assembly	56	4
2	Module Support Flexures	140	20
3	Module Row Support Frame (Stainless Steel)	7	1
4	Module Support Plate (304 SS)	35	5
5	Module Support Frame (FR4)	35	5
6	LAr feed-through and VJ distribution lines	7	0
6	Module feed-in nozzles	35	5
7	TPC Thermal Instrumentation sets (PT100)	35	5
8	Module Service 4-way Cross (13.5" OD CF), with gaskets	35	5
10	Module Service Top Hat Assembly (13.5" OD CF blank with feedthroughs)	35	5
11	HV Cable Shield	35	2
12	CF Flange Hardware, QTY for Single Module (Bolts, Nuts, Washers, Gaskets)	35	5

Contributing institutions

Design: Bern
Delivery of components: Bern (all items)
QA/QC: Bern (all items)
Assembly: Bern
ND A&T: Bern (a fraction TBD)
ND I&I: Bern (a fraction TBD)

131.ND.02.03: High Voltage

Design sketches



Summary

Design and production of the HV supply and distribution for the ND LArTPC modules, including parts for demonstrators. Deliverables are the HV supplies and cables to the HV filters, the HV filters and corresponding control and monitoring instrumentation and readout. Component testing/QC/QA, packaging and shipping, as well as support personnel for prototyping, A&T, and I&I.

Deliverables

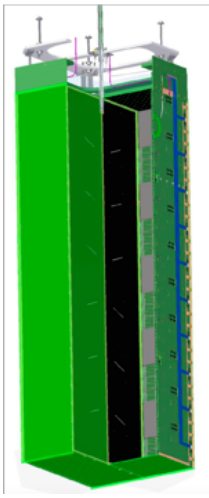
	Task/Item	Qty	Spares
1	HV power supply (could be 35 channels)	7	1
2	PFD-5 (Potted Filter Distributer), for 5 modules each	7	3
3	HV Cables PS to PFD-5	7	4
4	HV Monitor and control unit	7	1

Contributing Institutions

Design: Bern
Delivery of components: Bern (all items)
QA/QC: Bern (all items), Cambridge
Assembly: Bern, Cambridge
ND A&T: Bern, Cambridge
ND I&I: Bern, Cambridge

131.ND.02.04: Field Structures

Design sketches



Summary

Design and production of the TPC field system for the ND LArTPC modules, including parts for demonstrators. Deliverables are the HV feedthrough and HV delivery cable (from the filter), the cathode panels, field cage panels, the anode mechanical support panels, and attachment hardware (brackets, screws). Component testing/QC/QA, packaging and shipping, as well as support personnel for prototyping, A&T, and I&I, and their travel.

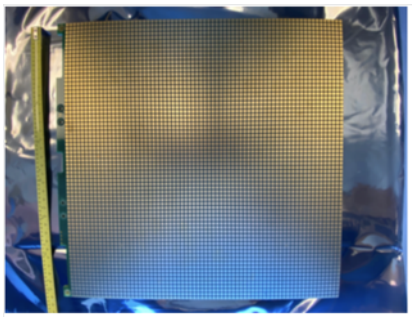
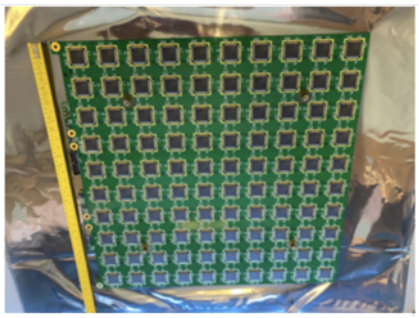
Deliverables

	Task/Item	Quantity	Spares
1	HV Cables (PFD-5 to module)	35	2
2	HV Feedthroughs	35	5
3	HV Cathode Attachments	35	5
4	Cathode panels	35	5
5	Field Cage panels, top	35	5
6	Field Cage panels, bottom	35	5
7	Field Cage panels, side	70	5
8	Anode Support panels	70	5
9	Field Structure Assembly	35	5
10	Attachment hardware	35 sets	5
11	Field Structure QA/QC tooling	1	N/A

Contributing institutions
Design: SLAC, MSU, CSU
Delivery of components: SLAC (all), MSU (4,9,11), CSU (9,11)
QA/QC: SLAC (all), MSU (all), UCBoulder (all)
Packaging and shipping: SLAC/MSU
Assembly Procedures: SLAC, MSU, UCBoulder
ND A&T: SLAC/MSU/UCBoulder (25%)
ND I&I: SLAC/MSU/UCBoulder

131.ND.02.05: Charge Readout

System pictures

Summary

Design and production of the charge readout system for the ND LArTPC modules, including parts for demonstrators. Deliverables are the Pixel ASICs, Pixel Anode Tiles, cabling and feedthroughs, the (warm) Control Interface electronics and enclosures with associated control, configuration, and readout software/firmware. Furthermore, the power supplies, power cables, clock distribution/synchronization system. Component testing/QA/QC, associated tooling, as well as packaging and shipping, and support personnel for prototyping, A&T, and I&I, and their travel.

Deliverables

	Task/Item	Qty	Spares
1	Pixel ASICs	320,000	66,691
2	Pixel Anode Tiles	1400	600
3	Tile Data Cables	1400	600
4	Tile Power Cables	140	28
5	Charge Readout Feedthroughs	35	5
6	PACMAN Controllers (hardware)	140	60
7	PACMAN Controllers (firmware)	N/A	N/A
8	PACMAN Enclosures	35	5
9	Power Supplies	7	1
10	Ethernet Cables	140	60
11	Data Cables	140	60
12	Clock System Fibers	140	60

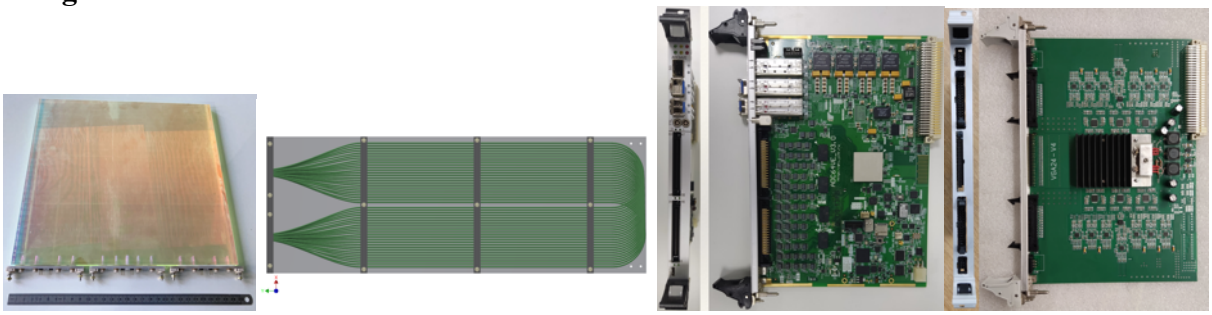
Contributing institutions
Design: LBNL
Delivery of components: LBNL (1,2,8,9,10,11,12), Rutgers (3,4,5) UC-Davis (6,7)
QA/QC:

QA/QC and characterization	
Pixel ASIC: Socket Test PCBs	U-Penn
Pixel ASIC: High-Volume Testing	Caltech
Pixel ASIC: Characterization	UCSB, UC-Irvine
Pixel Tile: RT Characterization	CSU/Yale/Syracuse
Pixel Tile: Cryo Characterization	CSU/Yale/Syracuse
Pixel Tile: Cryo-test TPCs	LBNL
Pixel Tile: Cryo-test Apparatus	LBNL
Pixel Tile: Room-temp QA/QC	LBNL
Pixel Tile: RT QA/QC Enclosures	LBNL
Pixel Tile: Cryo QA/QC	UTA
Pixel Tile: Cryo QA/QC Apparatus	UTA
Tile Data Cables: QA/QC	UCSB
Tile Power Cables: QA/QC	UCSB
CR Feedthroughs: QA/QC	Rutgers
PACMAN Controllers: QA/QC	LBNL/UC-Davis
Clock System: QA/QC	LBNL/UC-Irvine

Packaging and shipping: LBNL, Rutgers, UC-Davis, U-Penn, Caltech, UCSB, UC-Irvine, CSU, Yale, Syracuse, UTA, UCSB
ND A&T: LBNL, Rutgers, UC-Davis, U-Penn, Caltech, UCSB, UC-Irvine, CSU, Yale, Syracuse, UTA, UCSB
ND I&I: LBNL, Rutgers, UC-Davis, U-Penn, Caltech, UCSB, UC-Irvine, CSU, Yale, Syracuse, UTA, UCSB

131.ND.02.06: Light Readout

Design sketches



Scope Summary

Design and production of the light readout system for the ND LArTPC modules, including parts for demonstrators. Deliverables are the LCM light traps and ArCLight light traps, SiPMs, SiPM circuit boards, cabling and feedthroughs, with SiPM biasing, readout, and control electronics and enclosures. The control and configuration software/firmware, the power supplies, the clock distribution/synchronization system for the light readout. Component testing/QC/QA, associated tooling, as well as packaging and shipping, and support personnel for prototyping, A&T, and I&I, and their travel.

Deliverables

	Task/Item	Qty	Spares
1	LCMs	2100	420
2	ArCLights	700	140
3	SiPMs	8400	1680
4	Cold-PCBs	2800	560
5	Light Readout Feedthroughs	70	14
6	Microcoax Cables (diff lenghts)	1400	280
7	SiPM PS (Biasing) modules	70	14
8	SiPM PS & VGA control units	35	7
9	VGA unit	280	56
10	ADCs (readout)	175	35
11	ADC sync and trigger units	35	7
12	WR switch	2	1
13	VXS crates	35	7

14	HV power units	35	7
15	Optical cables	245	49
16	LV power units	35	7
17	Power&Signal Adapter boards	280	56
18	LRO Slow control software	N/A	N/A
19	LRO DAQ software	N/A	N/A

Contributing Institutions

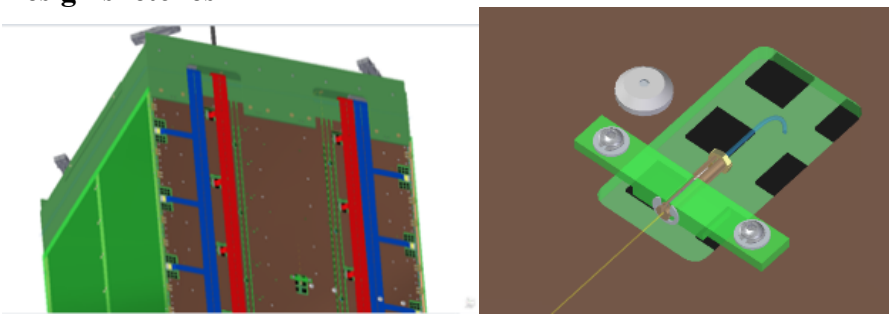
Design: Bern, JINR
Delivery of components: Bern (2), JINR (1,6,12,13,14,15,16,17,18,19), JINR/Marathon (4,5,7,8,9), JINR/AFI(10,11)
QA/QC:

QA/QC and characterization	
LCM Light Yield test	JINR/Marathon
LCM coating	JINR/Marathon
ArCLight LY test	Bern
ArCLight coating	Bern
LCM assembly: QA/QC	JINR/Marathon
ArCLight assembly: QA/QC	Bern
Microcoaxial cable assembly: QA/QC	JINR/Marathon
Cold electronics: QA/QC	JINR
VGA: QA/QC	JINR/Marathon
SiPM PS: QA/QC	JINR/Marathon
ADC and WR synchronization: QA/QC	JINR
Ribbon twisted pair cable: QA/QC	JINR/Marathon
Feedthrough QA/QC	JINR

Assembly: Bern, JINR
Packaging and shipping: Bern, JINR
ND A&T: Bern (fraction), JINR (fraction), FNAL
ND I&I: Bern (fraction), JINR (fraction, FNAL

131.ND.02.07: Calibration

Design sketches



Scope summary

Design and production of the calibration system for the ND LArTPC modules, including parts for demonstrators. Deliverables are the light, charge, field calibration system with cabling and feedthroughs and control and configuration software/firmware. Component testing/QC/QA, associated tooling, as well as packaging and shipping, and support personnel for prototyping, A&T, and I&I, and their travel.

Deliverables

	Task/Item	Qty	Spares
1	Laser	7	1
2	Laser safety enclosure box	7	0
3	Powermeter	7	1
4	Multiplexer	7	1
5	Flanges	70	1
6	Quartz fibers (600 um core)	210	10
7	Fiber holder	210	10
8	Lenses and other optical elements	210	10
9	Photoelectric targets	10500	100
10	Fiber routing between flange and TPC	N/A	N/A
11	Wheel for fiber routing on TPC backplate	70	5

Contributing Institutions

Design: University of Hawaii, MSU

Delivery of components:
University of Hawaii (1, 2, 3, 4, 5, 6, 7, 8, 11), MSU (9, 10, 11)

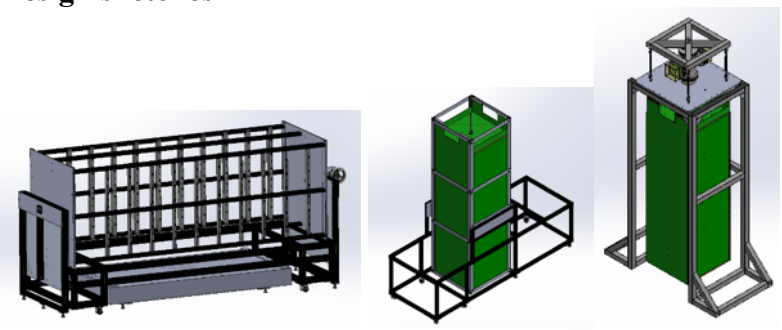
QA/QC:

QA/QC and characterization	
UV laser power and stability	University of Hawaii
Laser fiber connectors and attenuation	University of Hawaii
Optical feedthroughs on flanges throughput	University of Hawaii
Quartz rod light throughput, spread and illumination uniformity	University of Hawaii
Photoelectric target yield and uniformity	University of Hawaii/MSU
Attachment of targets on the cathode	MSU
Survey of the exact positions of the photoelectric targets on the cathodes prior to module assembly	MSU

Packaging and shipping: University of Hawaii/MSU
ND A&T: University of Hawaii/MSU
ND I&I: University of Hawaii/MSU

131.ND.02.08: Module assembly and testing

Design sketches



Scope Summary

Assembly & testing program for the TPC Modules of the ND LArTPC detector, including parts for demonstrators. Deliverables are the assembly & testing of SingleCube TPCs, 2x2 TPC modules (including Module 0), Full-scale Demonstrator TPC Module, and the assembly & testing of Production ND TPC Modules including the procedures and testing result reports. Scope includes the assembly, lifting fixtures, and other integration hardware.

Consortium Management structure will handle the overall coordination. Technical labor from the host laboratory (FNAL and Bern) and US institutions for basic technical support are negotiated separately.

Deliverables

	Task/Item:	Qty	Spares
	Equipment		
1	Module Assembly Fixture	2	1
2	Module Rotation Fixture	2	1
3	Module Lid Support Fixture	2	1
4	Module Lifting Fixtures	2	1
	Procedures		
5	Module Assembly Procedure	1	N/A
6	Module Rotation Procedure	1	N/A
7	Module Lifting Procedure	1	0
8	Module Travelers	35	5
9	Component QC/Verification Plan	6	0

10	Module QC/Acceptance Testing Plan	1	NA
11	Module to Cryostat Insertion/Extraction Critical Lift Procedure	1	NA
12	Module to Module Crate Critical Lift Procedure	1	NA
13	Acceptance Test Report	35	5

Contributing Institutions

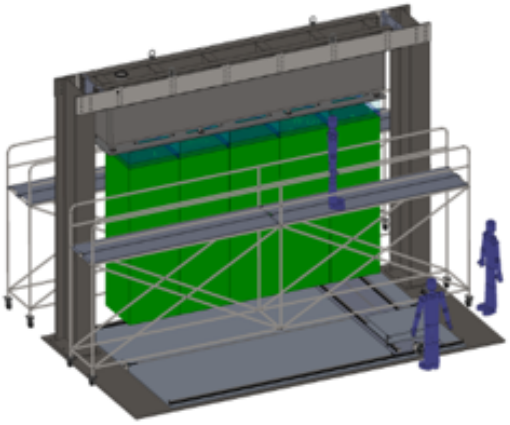
Design: CSU
Delivery of components: CSU (1 to 13)

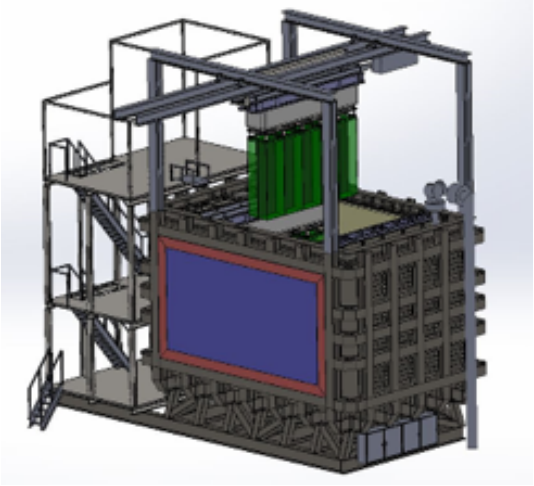
QA/QC:

	QA/QC and characterization			
	Reception Testing on Received Module Structure Components			Various
	Reception Testing on Received High Voltage Components			Various
	Reception Testing on Received Field Structure Components			Various
	Reception Testing on Received Charge Readout Components			Various
	Reception Testing on Received Light Readout Components			Various
	Reception Testing on Received Calibration Components			Various
	Reception Testing on all assembly fixtures			Colorado State University
	Acceptance Testing of Assembled TPC Modules			Various

131.ND.02.09: Integration and installation

Design sketches





Scope summary

The Installation and Integration program for the ND LArTPC detector at the Near Site Includes the reception of the TPC Modules from the MAT Facility, packaging, transport to storage. The transport of TPC modules from storage to Near Site and following installation of TPC module row test equipment, and check-out. Then the installation of TPC module rows to Cryostat lid segments (with check-out), the installation of ND-LAr electronics (racks, electronics, cable trays, cables) with check-out. Furthermore, assembly, lifting fixtures, and other special integration hardware an well as the TPC module shipping/storage containers are included.

The scope covers the coordination with the Near Site Integration and Installation, ND-LAr Cryostat for the module row installation to the cryostat.

Deliverables

	Task/Item: ND-LAr TPC I&I Near Site Equipment, Procedures and Labor	QTY.	Spares
	Equipment		
1	Module Storage Crates	35	5
2	Integration Fixture: Integrate Modules to Cryostat Lid	1	0
3	Support Fixture: Safety Hold Integrated Cryostat Lid and Modules	2	0
4	Lifting Fixture: Safely Lift Integrated Module Row	2	0
5	Installation Fixture: Install Module Rows to Cryostat	1	0
6	Metrology Equipment	1	0
7	Laser Nests & Totems	50	10

8	Electronics Racks	7	1
9	Cable Trays and Covers	25	0
10	Mock Modules for Prototyping	5	0
11	Portable Module Testing Rig (Capable for 5 modules or just one?)		

	Procedures		
12	Integration Fixture Assembly Procedure(s)	NA	NA
13	Support Fixture Assembly Procedure(s)	NA	NA
14	Installation Fixture Assembly Procedure(s)	NA	NA
15	Module Row Integration Procedure(s)	NA	NA
16	Module Row Installation Procedure(s)	NA	NA
17	Surface Building Module Crate Critical Lift Procedure	NA	NA
18	Surface Building Module Extraction Critical Lift Procedure	NA	NA
19	Surface Building Module Handling & Critical Lift Procedure	NA	NA
20	Surface Building Module Integration to Cryostat Lid Procedure	NA	NA
21	Surface Building Integrated Module Row Critical Lift Procedure	NA	NA
22	Cavern Shaft Integrated Module Row Critical Lift Procedure	NA	NA
23	Cavern Integrated Module Row Critical Lift Procedure	NA	NA
24	Module Row Metrology Plan/Procedure(s)	NA	NA
25	Module Array Metrology Plan/Procedure(s)	NA	NA
26	Cable Routing Procedure(s)	NA	NA
27	Electrical Safety Notes	NA	NA
28	Custom Lifting Fixture Notes	NA	NA

Contributing Institutions

Design: Technical and Scientific labor to design all elements: LBNL (1 — 10, 12—28), UTA (11)

Delivery of components and labor:
Technical and Scientific labor to prototype, procure, assemble, test, and ship all Equipment: LBNL, CSU (items 1 — 10), UTA (11)

Module transport: LBNL
Module storage: LBNL

QA/QC:

ND-LAr TPC I&I Near Site QA/QC and Functional Verification			
Single Module Acceptance Checkout (Warm) Procedures	NA	NA	UTA
Module Row Functional Checkout (Warm) Procedures	NA	NA	UTA
Module Row Functional Checkout (Cold) Procedures	NA	NA	UTA

All of the consortium institutions will participate in the assembly and testing.

Commissioning plan:

ND-Lar Commissioning/Pre-Operations Equipment, Procedures, and Labor			
ND-LAr TPC Module Array Commisioning Plan	NA	NA	UTA

All of the consortium institutions will participate in the commissioning.

Consortium acceptance of this Annex:

_____ _____

Debbie Harris
Consortium Institute Board Chair

_____ _____

Michele Weber
Consortium Lead

_____ _____

Dan Dwyer
Consortium Technical Lead

Summary of cost and finance sources

The following table shows the estimate of the construction funds as of 2022 (no R&D). In order to obtain the values in the table the funding is translated to "M&S". Corresponding to "CORE" in CH/JINR accounting, and to an approximate extrapolation to comparable contributions from US accounting.

	K$	**CH**	**USA**	**JINR**	**Total**
131.ND.02.02: Module Structure	2661 (P6: 2448.0)	100%			**100%**
131.ND.02.03: High Voltage	1000 (P6: 816.0)	100%			**100%**
131.ND.02.04: Field Structure	3560		100%		**100%**
131.ND.02.05: Charge Readout	3366		100%		**100%**
131.ND.02.06: Light Readout	4662 (P6: 5508.0)	50%		50%	**100%**
131.ND.02.07: Calibration	500 (P6: 0)	100%			**100%**
131.ND.02.08: TPC Assembly & Test	103		100%		**100%**
131.ND.02.09: TPC Integration & Installation	426		100%		**100%**
TOTAL	**16'278**	**40%**	**45%**	**15%**	**100%**