ND-LAr: Module Assembly and Test Facility at IERC

Date: 29th June 2022

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U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Introduction – Who are we?
- Scope
- Requirements
- Interfaces
- P&ID
- Risks
- Cost
- Schedule
- Summary

Introduction – Who are we?

- We are a team of Fermilab scientists and engineers tasked to support (plan, design, procure, install and operate) a Module Acceptance Test Facility (MATF) for the purpose of testing of 35 production modules (and spares) to verify their performance.

  - Louise Suter: MATF coordinator – Scientist, 6 years at lab, 5 years as NOvA's Operations Manager, 2x2 QA/QC onsite co-coordinator

  - Cryogenic Engineers - Michael Geynisman & Michael Zuckerbrot - long history of expertise in cryogenic systems, including 35 ton, LARIAT, MicroBooNE, SBND, and ICARUS, iceberg

  - Leo Bellantoni: IERC coordinator – Senior scientist with 20 years of experience at the lab

WSB element for Module Assembly and Testing Facility

The MATF scope is defined through ***WBS 131.ND.02.10 – ND LArTPC Module Assembly and Testing Facility (MATF)***

- Module Assembly and Testing Facility
  - Supporting Infrastructure for ND-LAr Module Assembly
    - Does not include assembly, handling, or lifting fixtures – covered by Assembly and Testing
  - Cryo-Testing System for ND-LAr Modules
  - Supporting Infrastructure for Cryo-Testing System
  - Formal schedule and resource estimate updates

Assembly & testing program is not covered – that is covered by TPC Module Assembly and Testing

https://edms.cern.ch/document/2619605/1

Task/Item	Institutions	Funding Source
Cryostats (design)	CSU	DUNE-US Project
Cryostats (specification and procurement)	FNAL	DUNE-US Project
Cryostat lids (design)	CSU	DUNE-US Project
Cryostat lids (procurement)	FNAL	DUNE-US Project
Mezzanine (design)	CSU	DUNE-US Project
Mezzanine (procurement, installation)	FNAL	DUNE-US Project
Internal Cryogenics System	FNAL	DUNE-US Project
Proximity Cryogenics System	FNAL	DUNE-US Project
External Cryogenics System	FNAL	IERC S.S. Funds
Cryogenic Control System	FNAL	DUNE-US Project
Clean power and ground	FNAL	DUNE-US Project
Clean tent	FNAL	DUNE-US Project
Racks and cable trays	FNAL	DUNE-US Project
Facility installation and check-out	FNAL	DUNE-US Project
Facility operations support	FNAL	DUNE-US Project
Facility Integrated Design and Management	FNAL	DUNE-US Project

Module Assembly and Testing Facility outline

Modules (35 modules + spares) **will be assembled in a dedicated clean space at MATF. After assembly MATF will perform cold acceptance testing**

- Directly after assembly, TPC modules will be **tested in LN2**
  - Checks Basic functionality after component integration – validation of TPC module assembly process
  - Requirement: test at cold temperatures similar to those in ND-LAr cryostat
    - LN2 chosen over GN2 for faster testing timescale and uniformity of temperature profile across TPC module
  - If FSD indicates the need for a LAr, then the testing facility can be upgraded for LAr (included as risk)
- To fit the schedule **two cryostats** are planned for use at MATF
  - Talk two weeks to test one TPC module tested in one cryostat (allowing for time to debug any irregularities)
  - Therefor two cryostats
    - Allow for faster testing timescale of module per week
    - Reduce labor costs during operations (cryogenic engineer/technician can monitor activities in both cryostats at same time)
    - Added redundancy

MATF facility at Fermilab IERC building

Not in consortium

Location requirements (captured in requirements and MATF-IERC interface)

- ❑ High-bay sufficient for cleanroom for ~4m-tall module assembly, and storage for subsystem components, with a mezzanine structure for cryostat(s).
- ❑ Crane with ~4m clearance above cryostat for module installation/removal.
- ❑ External system for LN2 storage & delivery of liquid and gaseous nitrogen and venting of gaseous cryogens
- ❑ ODH safety system for the MATF hall

Consortium Scope

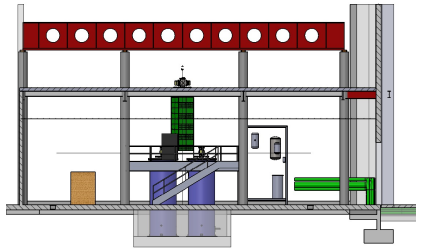
MATF requirements (captured in requirements and MATF-TPC A&T interface)

- ❑ Cryostats capable of hosting ~4m x 1m x 1m module. Two cryostats to parallelize assembly and testing.
- ❑ Internal system for LN2 distribution, cooldown and warmup of 2 x 7000 L cryostats
- ❑ Common process control system required for providing I/O management through PLCs-based controls and computers-based HMI.

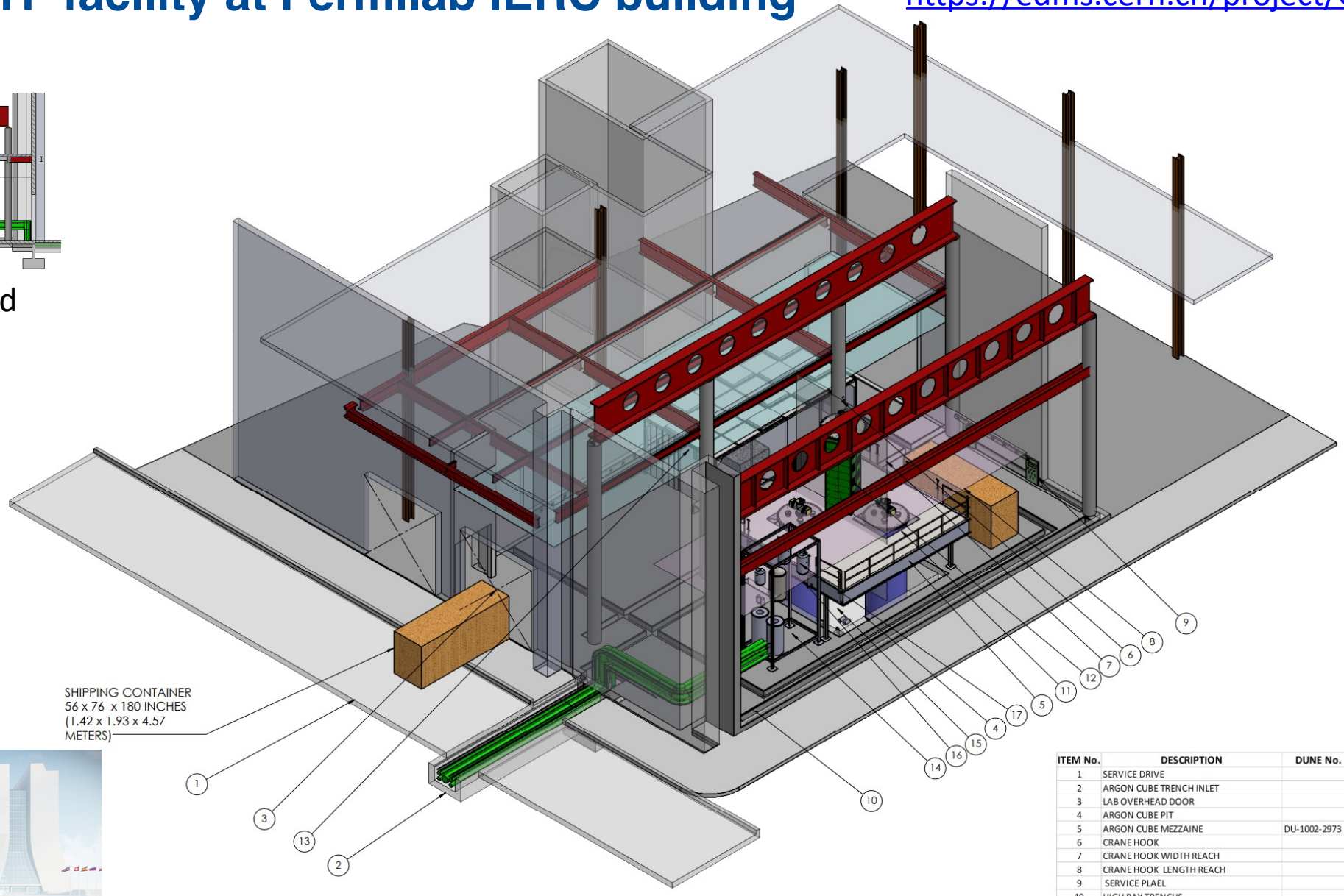
The facility at IERC is being built specifically for MATF and had consortium input through the design and build

Scope: MATF facility at Fermilab IERC building

https://edms.cern.ch/project/CERN-0000218344



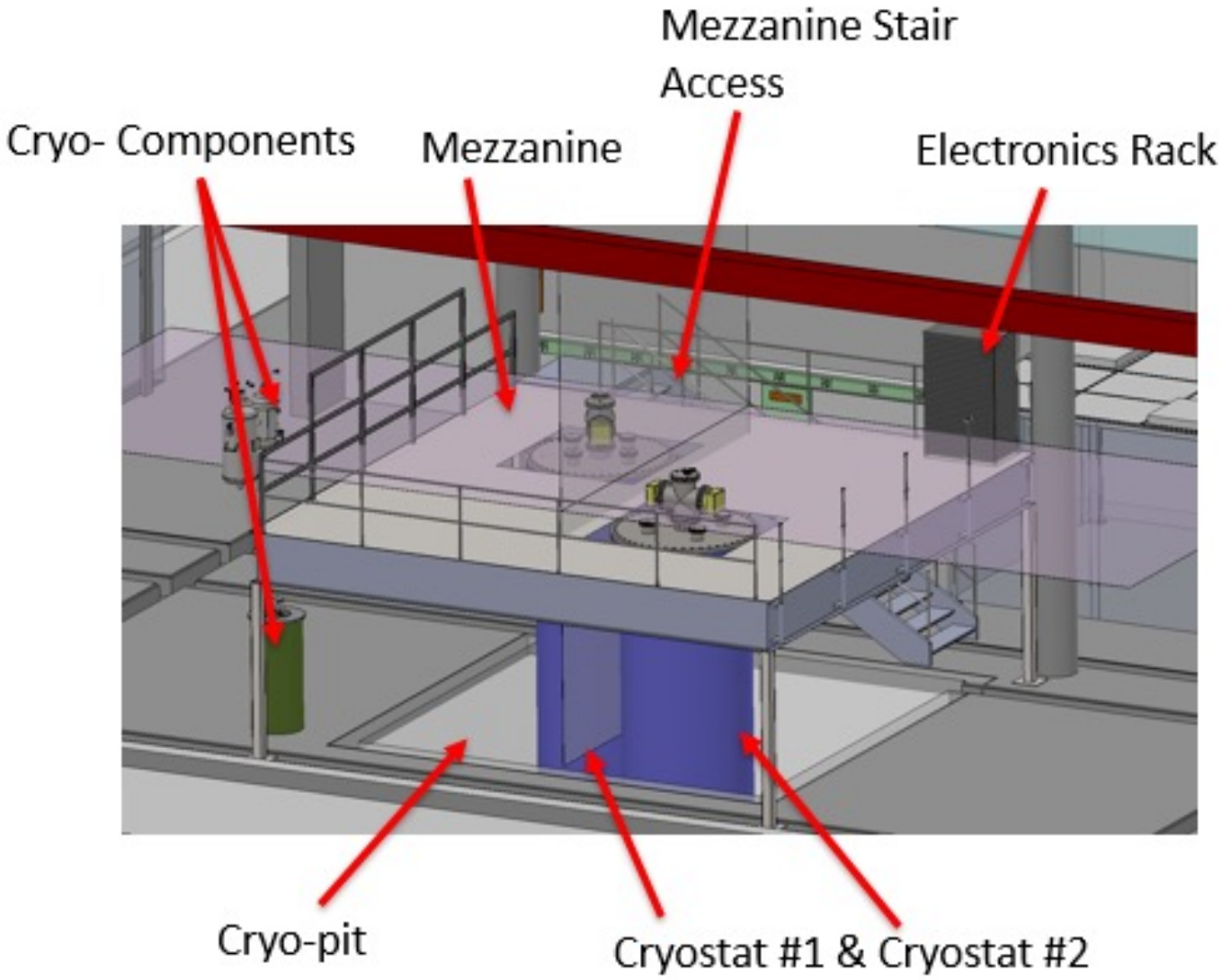
Cryostats located in pit to enable clearance

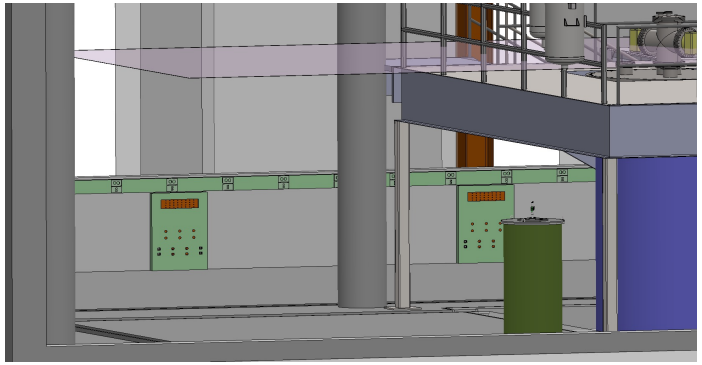


ITEM No.	DESCRIPTION	DUNE No.	REF. No.
1	SERVICE DRIVE		C2.1
2	ARGON CUBE TRENCH INLET		A50-50
3	LAB OVERHEAD DOOR		
4	ARGON CUBE PIT		A4-03,S10-10a,A10-02a,S81-03
5	ARGON CUBE MEZZAINE	DU-1002-2973	
6	CRANE HOOK		
7	CRANE HOOK WIDTH REACH		
8	CRANE HOOK LENGTH REACH		
9	SERVICE PLAEL		A50-51
10	HIGH BAY TRENCHS		S40-05
11	CRYOSTAT ASSY	DU-1002-2866	
12	CRYOSTAT SENSOR AARAY	DU-1002-1285	
13	CLEAN ROOM TENT	DU-1002-1272	
14	CRYOSTAT FILTRATION ASSY	DU-1002-6415	
15	ARGON PUMP ASSY	DU-1002-3552	
16	LAr CONDENSER	DU-1002-6414	
17	LN2 PHASE SEPARATOR	DU-1002-3521	DU-1002-2723

Scope: Module Assembly and Test Facility at FNAL https://edms.cern.ch/project/CERN-0000218344

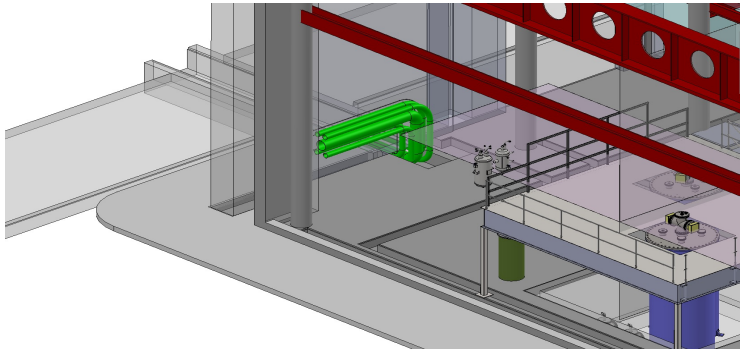
(Architectural drawings are in complete state and 3D model is in EDMS)



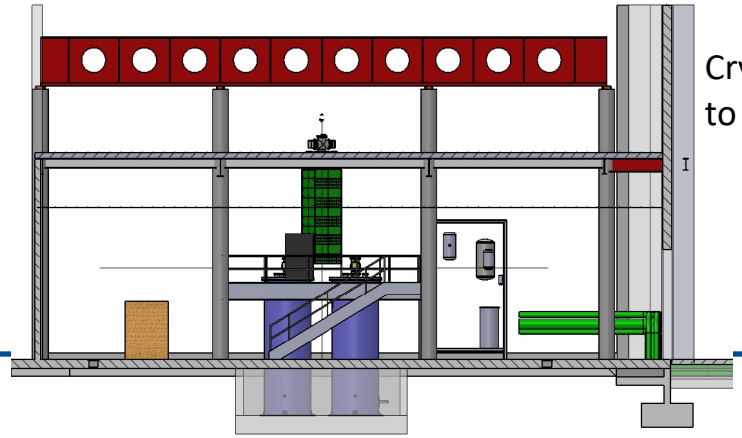


Channel Raceway
Provides Power & Data

Service Panels:
- Compressed Air
- Nitrogen
- Vacuum
- Water



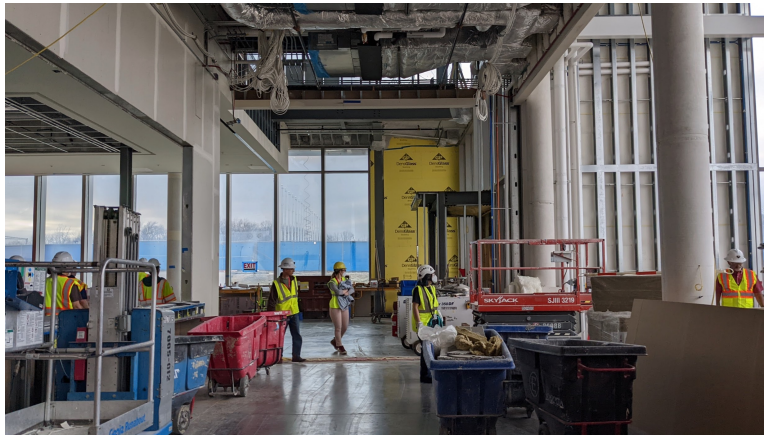
Incoming/Outgoing
Cryogenics



Cryostats located in pit
to enable clearance

Integration Research Engineering Center progress

Beneficial occupancy end of 2022, photos from June 2022
Lab will be used for other DUNE cryo R&D work until MATF



Requirements – General Facility

https://edms.cern.ch/document/2589287/1

Name	Primary Text	Value	Rationale	Parent Req/Spec ID(s)
MATF Facility Access	MATF shall provide access to FNAL and ND-LAr Consortium personnel for the given time window per day	8AM - 8PM	Required to meet production schedule	INT-001, INT-002
MATF Facility Support	MATF shall provide resources to support TPC A&T activities as they relate to usage of facility infrastructure	50% Cryo Eng 100% Mech Tech	Support for cyro-system is necesssary to avoid downtime	INT-001, INT-002
MATF Facility Management	MATF shall provide management for TPC A&T activities as they relate to the usage of facility infrastructure	100% Application Physicist		INT-001, INT-002
MATF Uninterrupted Power Source (UPS) for Short-term Power Failures	The MATF shall provide a UPS to mitigate power failures that are less than the given duration	30 minutes	Shorter duration power outages are likely with the ongoing construction for PIP-II; with continuous cryogenic operations this could impact system reliability and safety	INT-001, INT-002
MATF Temperature and Humidity range	MATF shall maintain the given temperature and humidity environment	25C +/- 2C (WAG) 55% RH +/- 5% (WAG)	Required to maintain dimensional stability of assembly components and keep water absorbtion by materials controlled	INT-001, INT-002
Lifting Capabilities for MATF Construction	MATF shall be capable of lifting components with maximum size (XX kg), maximum weight (W x H x L) and to a maximum height (H) during MATF construction	(1.5m X .5m X 3.5m) 100 kg to height Y - (TBC)	Necessary to construct facility	INT-001, INT-002
MATF Lifting Capabilities for ND-LAr Module	MATF shall be capable of lifting and inserting an ND-LAr module of maximum size (W x H x L) and maximum mass (XX kg) into the cryostat	1m X 1m X 4m EDMS 2458090 (mass budget)	Necessary to install/remove modules from cryostat	INT-001, INT-002

Requirements – Facility assembly areas

https://edms.cern.ch/document/2589287/1

Name	Primary Text	Value	Rationale	Parent Req/Spec ID(s)
MATF Clean Assembly Areas	MATF shall provide the given number of clean assembly areas of a minimum of the follow size (W x H x L)	2 areas of size 12' x 18' x 8'	Necessary to maintain module cleanliness and LAr purity	INT-023, INT-025
MATF Component Acceptance Check Areas	MATF shall provide the given number of component acceptance check areas of a minimum of the follow size (W x H x L)	2 areas of size 12' x 18' x 8'	Necessary for component reception and QC activties	INT-016
MATF Component Receipt Area	MATF shall be capable of receiving ND-LAr Components of the given maximum size (W x H x L) and maximum mass (XX kg) from Consoritum Sub-systems	(1.5m X .5m X 3.5m) 100 kg TBC	Necessary for component reception and QC activties	INT-016
MATF Assembled Module Storage Space	Amount of storage space at the MATF for fully-assembled TPC modules prior to testing	TBC		INT-017, INT-018
MATF Clean Assembly Area Classification	MATF shall provide clean assembly area of size (W x H x L) with the given ISO designation or better	12' x 18' x 8' ISO 8	Necessary to maintain module cleanliness and LAr purity	INT-024
MATF Low-Noise Detector Environment -	MATF shall provide low-noise environment for TPC testing at level of X	TBC	ND modules require low-noise environment	INT-001, INT-002

Requirements – Cryo and Mezzanine

https://edms.cern.ch/document/2589287/1

Name	Primary Text	Value	Rationale	Parent Req/Spec ID(s)
MATF Testing Cryogen	MATF shall provide the cryogen of the specific type	liquid Nitrogen	Based on outcome of testing task force	INT-001, INT-002
MATF Cryogen Liquid Volume	MATF shall provide a system of the given size	11 tons	Based upon initial system sizing	INT-001, INT-002
MATF Cryogen system design	MATF shall provide a system with the following number of cryostats	2	Based on throughput and number of modules in ND-LAr	INT-001, INT-002
MATF Module Cool-down	MATF cryo-plant shall be capabl cool-down of the ND-LAr module on the given timescale	48 hrs	Based upon recent prototype testing	INT-001, INT-002
MATF Module Cryo Temperature stability	MATF cryo-plant shall be capable of maintaining stable temperatures (within X degrees) during the given testing timescale	TBC	Based upon recent prototype testing	INT-001, INT-002
MATF Module Warm-up	MATF cryo-plant shall be capable of warm-up on the given timescale	48 hrs	Based upon recent prototype testing	INT-001, INT-002
MATF Cryo-Plant Thermal Management	MATF cryo-plant shall be capable of removing the stated maximum TPC heat load	EDMS 2458088	Based upon recent prototype testing, heat load must be rejected to maintain LAr temperature	INT-001, INT-002
MATF Cryostat & Cryostat Lid Access	The MATF shall provide a mezzanine that allows access to the cryostat and cryostat lids	NA	Access is required to install, test, and remove TPCs	INT-001, INT-002
Mezzanine Loading at MATF	The MATF mezzanine shall be capable of supporting the given loading conditions	TBC	Must support both component and personnel loading, assuming maximum number of individuals allowed on the structure at a given time	INT-001, INT-002
Mezzanine Access Area at MATF	The MATF mezzanine shall provide access over the given footprint	W X H X L - TBC	Access area required to perform work, egress governed by FESHM	INT-001, INT-002
Mezzanine Safety	The MATF mezzanine shall provide railings, fall protection and egress requirements per FESHM	NA	Required by FNAL FESHM and potentially DOE requirements	INT-001, INT-002

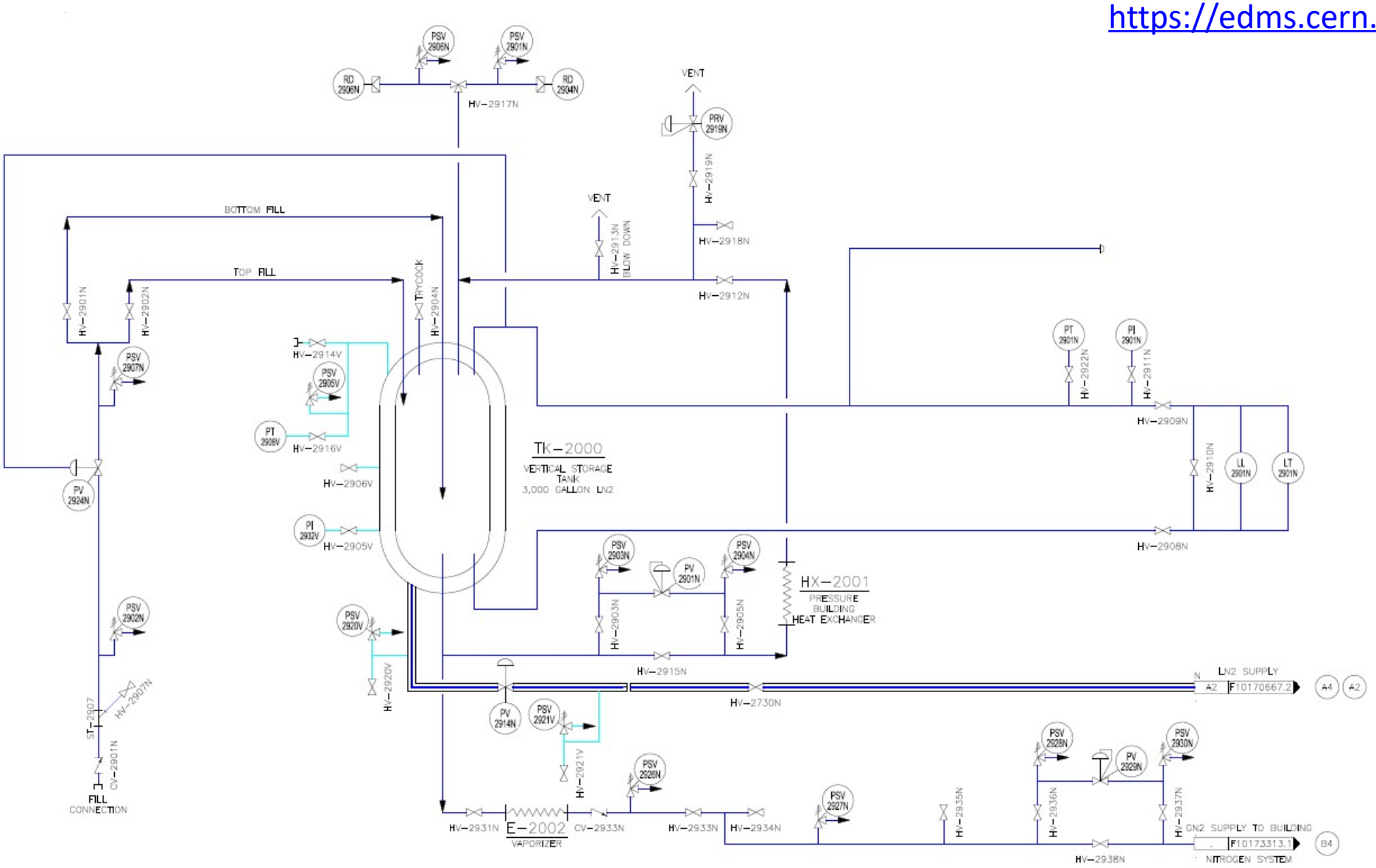
MATF Interfaces

- MATF to IERC - https://edms.cern.ch/document/2745422/1
  - MATF has well-defined interfaces to IERC to ensure that the lab as-built needs the requirements. Some of the main areas include:
    - Crane specs and clearance
    - cryogenics facilities
    - High bay, access, and clearance in the facility
    - ODH and safety process controls

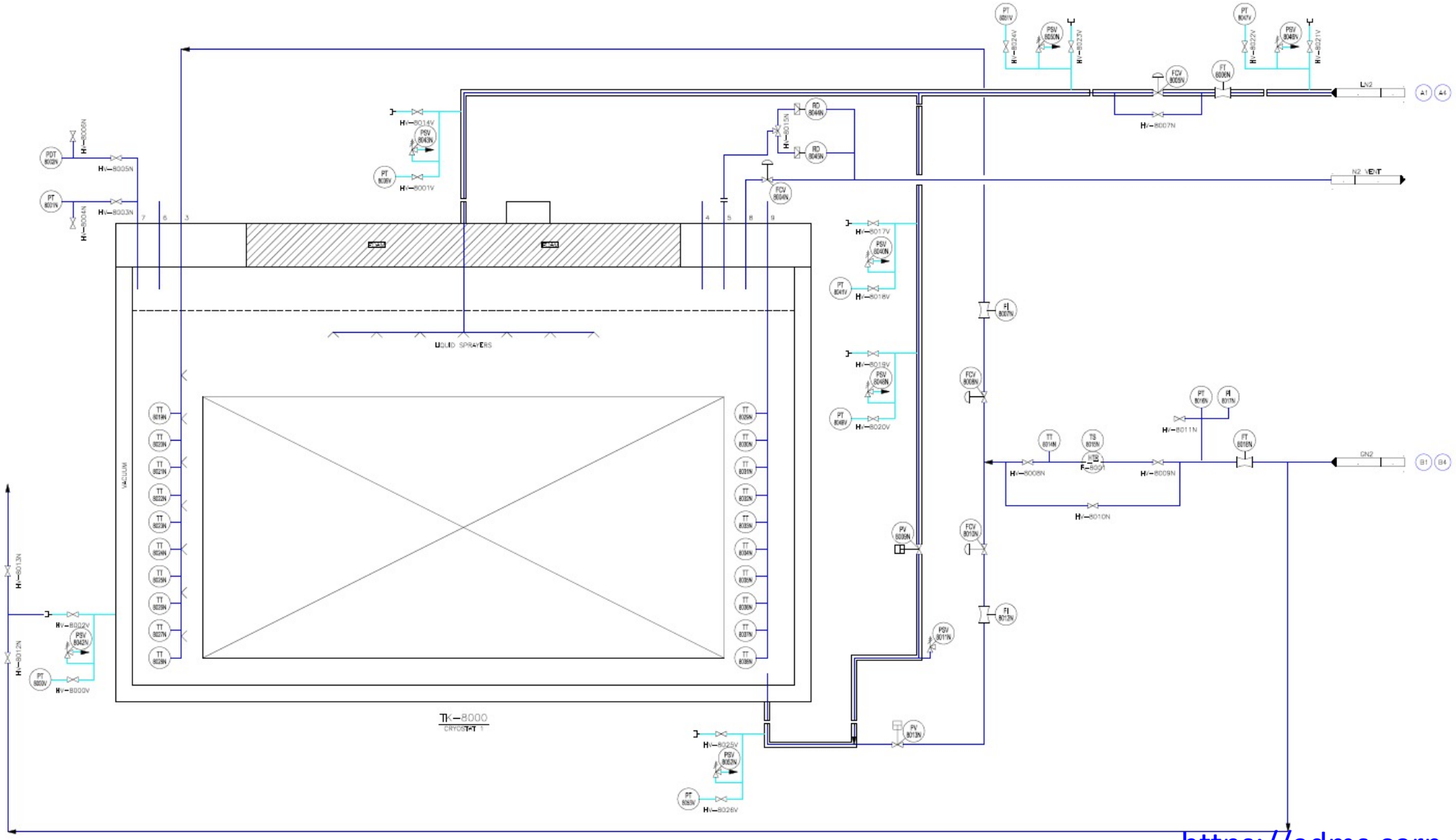
- MATF to TPC assembly and testing – https://edms.cern.ch/document/2741843/1
    - Facility access, power and environmental
    - Cryo system and process and controls
    - Assembly space and assembly and testing needs (cleanliness, clean power)

P&ID (external - LN2 and GN2 supply system – FNAL supported)

https://edms.cern.ch/document/2459144



P&ID (internal – showing single LN2 cryostat for simplicity ; dual cryostats are considered with LN2 transfer by pressure push)



https://edms.cern.ch/document/2459144

Risks and Opportunities

RI-ID	Title	Probability	Cost Impact	Schedule Impact
RT-131-ND-087	Uncosted Labor - CRO, Module Integration/assembly, Installation	25%	1000 -- 4000 -- 6000 k$	2 -- 3 -- 6 months
RT-131-ND-153	Module Testing Timescale at MATF Longer than Anticipated	25%	132 -- 198 -- 397 k$	2 -- 3 -- 6 months
RT-131-ND-151	Test Program Uncertainty	15%	3000 k$	0 -- 3 -- 12 months
RT-131-ND-114	Insuffient storage space for fully tested LArTPC modules	15 %	302 -- 605 -- 908 k$	3 -- 6 -- 9 months

Risks:

- Escalation of M&S prices forcing reduction of scope due to “build-to-cost” requirement
- Delays due to commissioning, procurement, installation, safety review, inefficient resources
- Safety issues, e.g. critical lifts
- Later state design changes due to results of FSD and 2x2
- Operations support shortages, external labor vs. Fermi labor based on cost and schedule
- Not enough available storge for completed modules

Opportunities:

Re-use of cryostats from FSD experiments and availability of “lessons learned” from SLAC FSD experiments

Recommendation from previous reviews

Held Internal review in 2021 that was a dry-run PDR

Review	Comment	Response
Internal review 2021	The MATF team and the installation team should band together to draft detailed testing goals, justifications, procedures, and the pass/fail criteria. The tests during module assembly and detector assembly are likely to be very similar from a QC perspective. This document will be important for justifying the cold test in pure liquid argon of all the modules.	Closed - Baseline is tests in LN2, therefore the comment is not relevant any more
Internal review 2021	Requirement for a fully redundant cryogenics system for the test facility should be reviewed and justified before the system goes to an external review.	Closed - Testing plan as been re-assessed to LN testing at reduced cost. This was presented at March 2022 US Cost Review
US ND Cost Review	Consider reuse of equipment and sites for FSD and MATF activities	Open – reuse of SLAC FSD cryostats or equipment has been discussed

ESH Codes and Standards

- Team has many years of experience safely building similar facilities at Fermilab.

- Cryogenic Engineers - Michael Geynisman & Michael Zuckerbrot - long history of expertise on cryogenic systems, including 35 ton, LARIAT, MicroBooNE, SNBD, and ICARUS.

- Fermilab based team well versed in FESHM and labs ESH procedures.
  - See list of relevant FESHM chapters

https://edms.cern.ch/document/2745423/1

Material Handling and Transportation
- Overhead Cranes and Hoists (FESHM 10100)
- Below – The – Hook Lifting Devices (FESHM 10110)
- Powered Industrial Trucks (FESHM 10120)
- Lift Plans (FESHM 10200)
- Slings and Rigging Hardware (FESHM 10130)

Mechanical, Cryogenic and Structural Safety per ASME BPVC Section VIII, B31.3, EN13480, API standards
- Pressure Vessels (FESHM 5031)
- Piping Systems (FESHM 5053.1)
- Inspection and Testing of Relief Systems (FESHM 5031.4)
- Low Pressure Vessels and Fluid Containment (FESHM 5031.5)
- Cryogenic System Review (FESHM 5032)
- Liquid Nitrogen Dewar Installation and Operation Rules (FESHM 5032.1)
- Low Pressure Vessels and Fluid Containment (FESHM 5031.5)

Structural safety
- Structures per FESHM 5100

Electrical Safety
- Electrical safety program (FESHM 9100)
- Grounding Requirements for Electrical Distribution and Utilization Equipment (FESHM 9190)
- Management and Use of Cable Tray Systems (FESHM 9130)
- High Voltage Coaxial Connectors (FESHM 9150)
- Uninterruptible Alternating Current Power Back-Up Systems (FESHM 9170)

Occupational Safety
- Fall Protection (FESHM 7060)
- Ladder and Scaffold Safety (FESHM 7070)

Fire Protection
- Concepts of Egress (FESHM 6020.4)

https://edms.cern.ch/document/2742778

ND-LAr Total Resource by WBS

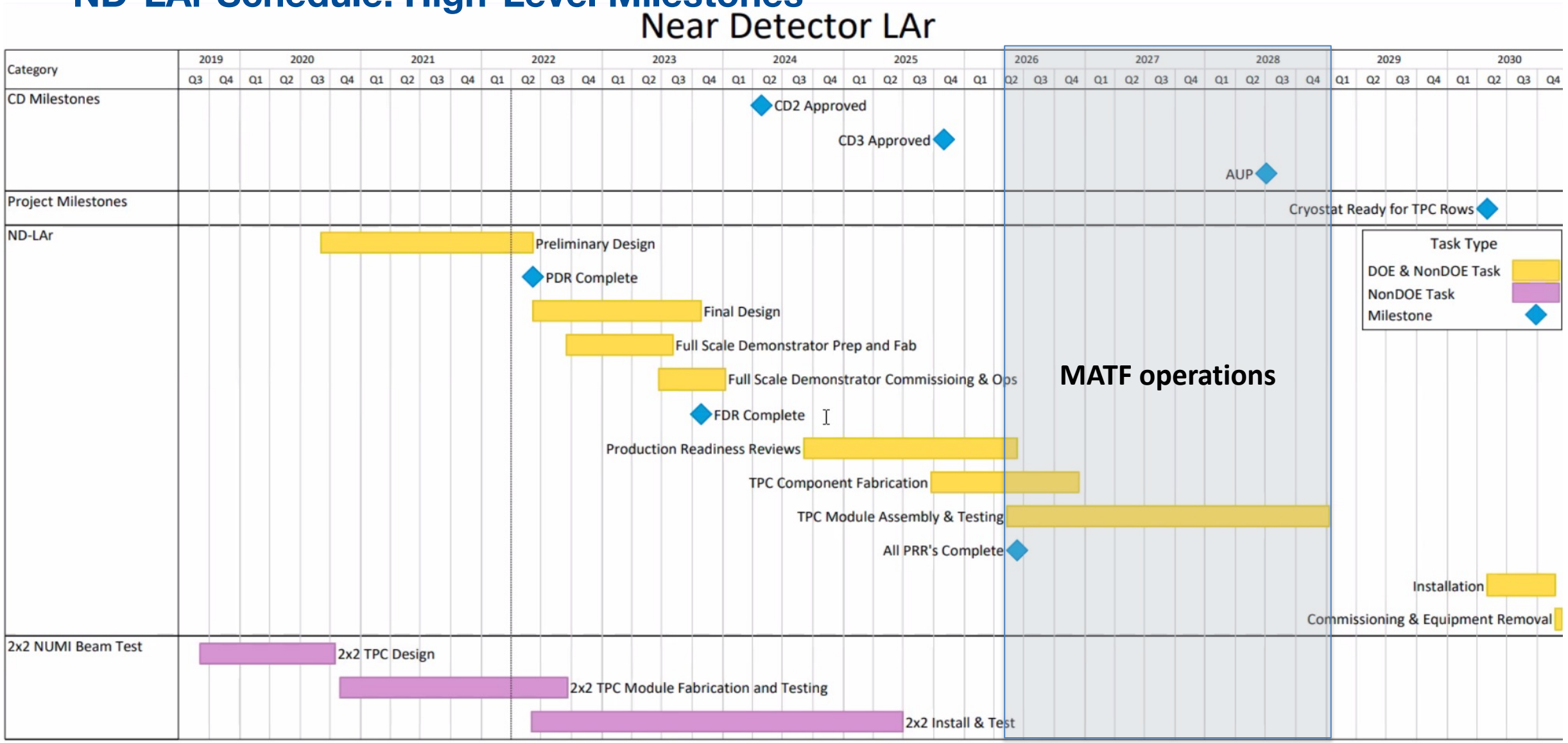
	Design & Prototyping				Production					
	On-Project		Off-Project		On-Project		Off-Project		On-Project	
131.ND.02: ND-LAr	M&S [CY-k$]	Labor [k-hrs]	M&S [CY-k$]	Labor [k-hrs]	M&S [CY-k$]	Labor [k-hrs]	M&S [CY-k$]	Labor [k-hrs]	Total Cost [FBAY-k$]	*Avg. Uncert.*
01 ND LArTPC Management	$401.5	18.3	-	43.9	$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 from current resource-loaded schedule (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.

ND-LAr Schedule: High-Level Milestones

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



Summary

- The location of MATF at the Fermilab IERC building will receive beneficial occupancy in 2022.
  - FNAL is supporting external cryogenics and ODH safety system and process control for the facility.
  - This new lab will be used for other R&D until MATF operations

- The MATF design is mature. It has been informed by 2x2 and we will continue to learn from FSD
  - The preliminary design of the cryogenic system is complete with a full set of process schematics and a list of valves and instrumentation, plus 3D model for the MATF hall.
  - The interface documents with IERC and TPC A&T have been produced.
  - A basic cost analysis has been produced.
  - A basic estimate of operational costs has been provided.
  - The risks have been evaluated

Summary of supporting material

MATF Documentation	Description	EDMS Link
MATF Folder	Top level folder for MATF documentation	https://edms.cern.ch/project/CERN-0000217534
Requirements	Spreadsheet with all ND-LAr requirements, see sheet "MATF (10)"	https://edms.cern.ch/document/2589287
Internal ICDs	Interface control documents (ICDs) internal to the ND-LAr Consortium	https://edms.cern.ch/project/CERN-0000223195
Analyses	ODH Analysis	https://edms.cern.ch/project/CERN-0000231265
QAQC Plan	ESH QAQC plan	https://edms.cern.ch/project/CERN-0000231266
Previous Review Tracking	Spreadsheet with previous review recommendations, see "MATF"	https://edms.cern.ch/document/2741842
Cost	High-level cost estimate for ND-LAr and subsystems	https://edms.cern.ch/document/2742778
Schedule	High-level "one-pager" schedule for ND-LAr Consortium activities	https://edms.cern.ch/document/2603073
CAD Model (Facility)	Solidworks "Pack & Go" and Parasolid exports of CAD models	https://edms.cern.ch/project/CERN-0000231267
Mechanical Assembly Drawings	Subsystem assembly drawing	https://edms.cern.ch/project/CERN-0000218344
Parts List	Subsystem parts list	https://edms.cern.ch/project/CERN-0000231268
P&ID Cryo System	Piping and Instrumentation Diagram for Cryogenics System	https://edms.cern.ch/document/2459144

Labor cost breakdown

- Labor is estimated based on previous experience at Fermilab and typical installations in 2019-2021 i.e. ICARUS, SBND, ICEBERG
- The labor covers required labor for all phases of design, procurement, and installation of the MATF Internal cryogenic system.
- Operations support includes Cryogenic engineers and mechanical technicians, but at least stage least mature due as the testing plan gets developed.
- Does include Grad student and post-doc uncosted labor, lack of availability of that labor is included as risk
- The labor gap in 2024 and 2025 creates issues with cryogenic engineers and techs transitioning focus to other projects and schedules for IERC opponency.

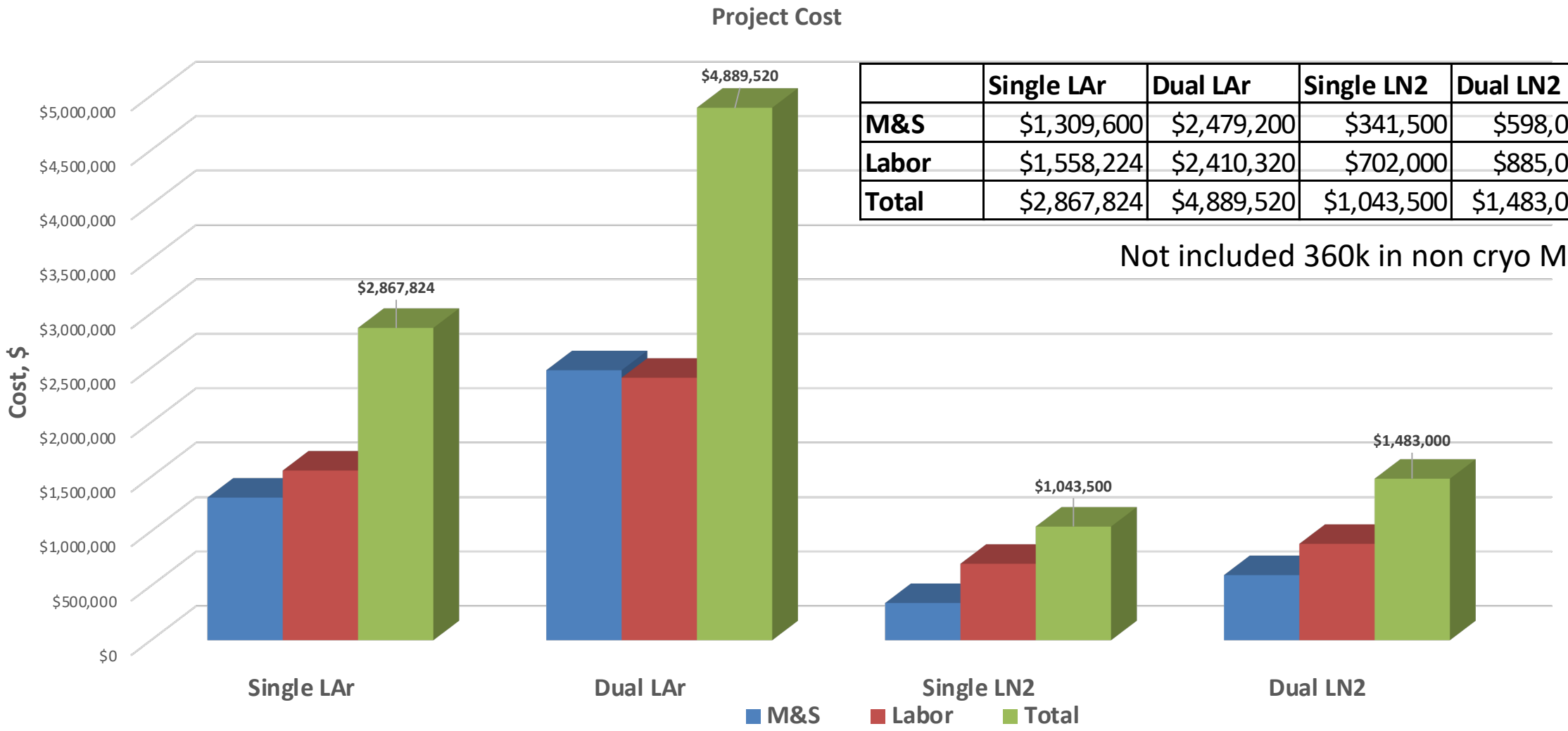
Sum of Units	FY		
	Labor	Nonlabor	Grand Total
WBS-Task-Resource			
SB Near Detector - ND LAr Sandbox	15,941	27,954	43,895
02 ND LArTPC	15,941	27,954	43,895
10 Module Assembly & Test Facility @ FNAL	15,941	27,954	43,895
01 ND-LAr MATF Preliminary Design	998	1,026	2,024
Cryogenics Engineer	*998*		*998*
Cryogenics Engineer - LBNL		*90*	*90*
Mechanical Designer - LBNL		*468*	*468*
Mechanical Engineer - LBNL		*468*	*468*
02 ND-LAr MATF Final Design	3,699		3,699
Cryogenics Engineer	*2,000*		*2,000*
Mechanical Design Engineer	*999*		*999*
Mechanical Designer	*700*		*700*
03 MATF Procurement, Fabrication and Assembly	5,244	14,928	20,172
Cryogenics Engineer	*1,234*		*1,234*
Electrical Technician	*200*		*200*
Grad Student Uncosted - Colorado		*8,352*	*8,352*
Grad Student Uncosted - Generic Univ		*1,600*	*1,600*
Mechanical Assembly Technician	*2,888*		*2,888*
Mechanical Design Engineer	*522*		*522*
Physicist Uncosted	*400*		*400*
Post Doc Uncosted - Colorado		*4,176*	*4,176*
Post Doc Uncosted - Generic Univ		*800*	*800*
04 MATF Operations Support	6,000	12,000	18,000
Cryogenics Engineer	*2,000*		*2,000*
Grad Student Uncosted - Generic Univ		*8,000*	*8,000*
Mechanical Assembly Technician	*4,000*		*4,000*
Post Doc Uncosted - Generic Univ		*4,000*	*4,000*

Example of current state of cryogenic cost breakdown for 2 cryostat N2 system

Equipment name	Quantity	Type of cost	Subsystem	Cost (new/used)	Total M&S cost	Total Labor	Existing or New	Vendor	BOE
Process control (Project responsibility)									
Process controls	1.5	M&S	all systems	$50,000	$75,000			Fermi	Fermi, SBN
Proces controls	45	Tech Labor days	all systems	$1,000		$45,000	new	Fermi	Fermi, SBN
				Sub cost =	$75,000	$45,000			
Proximity or Internal (Project responsibility)									
Coldbox (insulated) ASME	2	M&S	Internal	$165,000	$330,000		new	Cryofab	quote 2022
Cryostat top plate w/penetrations	2	M&S	Internal	$10,000	$20,000		new	Cryofab	best guess
Internal cryo piping	2	M&S	Internal	$5,000	$10,000		new	Fermilab	prior experience
Cryostat RDs w/o diverters	6	M&S	Internal	$1,500	$9,000		new	TBD	prior experience
							new		
Control valves	14	M&S	Internal	$5,000	$70,000		new	TBD	Velan
Hand valves	60	M&S	Internal	$500	$30,000		new	TBD	US typical
Instrumentation	120	M&S	Internal	$350	$42,000		new	TBD	Siemens
Reliefs for piping	40	M&S	Internal	$300	$12,000		new	CS	SBN
Piping, tubing, components	2	M$S	Internal	$30,000	$60,000		new	TBD	Fermi, SBN
				Sub cost =	$523,000	$0		$154,000	
Labor costs for design, procurement, supervision for instalaltion									
Proximity+Internal+Cryostat - Final design, procurement and overseeing installation costs (for all non-technician disciplines)	60.00	weeks @ $6000/week	All systems	$6,000		$360,000		Fermi labor - Project cost	Fermi, SBN
Labor costs for technical for instalaltion									
In-place installation costs (mech techs and welders) to integrate all 3 systems	200	Tech Labor days	All systems	$1,200		$240,000		Fermi labor (Fermi personnel, contract, etc)	Fermi, SBN
In-place installation costs (electrical techs and electricians) to integrate all 3 systems	200	Tech Labor days	All systems	$1,200		$240,000		Fermi labor (Fermi personnel, contract, etc)	Fermi, SBN

Note: see backup slide for comparison between the costs of a cryogenic system required for testing in purified argon versus in liquid nitrogen (single and duel cryostats for both)

Backup slide: estimation of costs for testing options (w/o operations)



	Single LAr	Dual LAr	Single LN2	Dual LN2
M&S	$1,309,600	$2,479,200	$341,500	$598,000
Labor	$1,558,224	$2,410,320	$702,000	$885,000
Total	$2,867,824	$4,889,520	$1,043,500	$1,483,000

Not included 360k in non cryo M&S

M&S cost breakdown

Total M&S Cost	QTY	Unit Cost	Total cost LAr	Total Cost N2 estmate	Total Cost	
Cryogenic System	0	$2,189,200.00	$2,189,200.00	$-	$ -	removed, added assumed cold box
LN2 two cryostat sytsem	1	$523,000.00	$-	S-	$523,000	based on estimate from fnal enginners
LN Cold Box system	0	$1,123,000.00	$-	$1,123,000.00	$0	based on FD cold box cost
Mezzanine	1	$80,000.00	$80,000.00	$80,000.00	$80,000	
CleanRoom	1	$50,000.00	$50,000.00	$50,000.00	$50,000	
Isolation Transformer	0	$30,000.00	$30,000.00	$30,000.00	$0	removed for N2
Saturable Inductor	0	$30,000.00	$30,000.00	$30,000.00	$0	removed for N2
General Tooling	1	$25,000.00	$25,000.00	$25,000.00	$25,000	
Storage Cabinets	5	$2,000.00	$10,000.00	$10,000.00	$10,000	
Workbenches	1	$5,000.00	$5,000.00	$5,000.00	$5,000	
Granite Table	1	$5,000.00	$5,000.00	$5,000.00	$5,000	
Liquid Argon	0	$75,000.00	$75,000.00	S-	$0	6X 25,000L fills @ $3/liter, removed for N2
Cold N2 gas system	1	$50,000.00	$-	$50,000.00	$50,000	Assumed cost of N2 gas system for cold box
Process controls	1	$75,000.00	$75,000.00	$75,000.00	$75,000	
Total			$2,574,200.00	$1,483,000.00	$823,000.00	

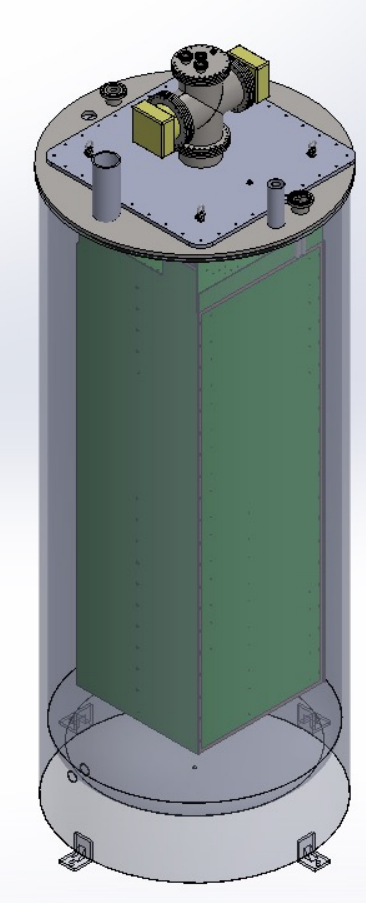
ND-LAr: On-Project Labor vs. Time

	Design and Prototyping					(Gap)	Production and Installation					
Fiscal Year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
ND LArTPC Total [FTE]	**3.1**	**4.9**	**14.6**	**11.3**	**5.1**	**3.6**	**5.7**	**8.3**	**6.3**	**4.7**	**6.2**	**0.5**
01 ND LArTPC Management	0.8	1.7	2.0	2.0	2.0	1.8	1.3	1.3	1.4	1.7	1.8	0.5
04 Field Structure	0.4	0.6	1.9	1.4	1.0	-	0.5	1.4	0.7	0.3	-	-
05 Charge Readout	0.8	1.2	5.4	2.8	0.3	0.2	1.2	1.3	0.3	0.2	0.2	0.0
07 Calibration	-	0.1	0.4	0.3	-	-	-	-	-	-	-	-
08 TPC Module Assembly and Testing	0.7	0.6	0.9	1.2	0.7	-	0.3	0.9	1.5	0.2	0.2	-
09 TPC Integration and Installation	-	0.3	0.5	-	0.9	1.6	1.1	1.6	0.8	1.1	4.0	-
10 Module Assembly & Test Facility	0.5	0.3	1.2	1.3	-	-	1.4	1.9	1.7	1.2	-	-
11 Full-scale Demonstrator Test Facility	-	0.3	2.3	2.3	0.2	-	0.0	0.0	-	-	-	-

Breakdown of on-project labor by fiscal year provided for reference.

- Resource smoothing is required, pending finalization of LBNF/DUNE budget profile

Requirements for US cryogenic contributions



- The requirements for the testing cycle include controlled cooldown of the TPC structure from ambient, testing in LN2 bath, and controlled warmup to ambient.
- The testing of the TPC modules will be done with dual identical cryostats (contribution #1) to speed up the entire testing campaign and provide for greater flexibility and reliability. The cryostats are technically defined
  - An opportunity exists to reuse one or both cryostats from FSD experiments conducted prior to MATF operations.
- The internal cryogenic system (contribution #2) is required to support testing of 35 production modules to verify their performance at cryogenic temperatures.
- Common process control system (contribution #3) required for providing I/O management through PLCs-based controls and computers-based HMI.

Cost Breakdown

- Original testing strategy was for testing all modules in LAr → cost prohibitive, task force to develop new strategy → de-scoped to testing all modules in LN2 bath
- M&S cost driven by cold-test system, This is a de-scope pre-conceptual level estimate based on FD cold box
- We have been working to produce a accurate cost for LN2 testing. Most of the component M&S are estimated based on previous experience at Fermilab and typical purchases in 2019-2021. Cost escalation is not applied to estimates.
- Detailed cost estimate for M&S is currently 823k for procurement, fabrication and facility prep. Will be updated in P6. LN2 cryo-system cost ~523k
  - Major cost driver are cryostat vessels per ASME BPVC → $165K each (*Cryofab quote 2022*).
  - The cost for M&S assumes new purchases (no re-use) for the components of the internal cryogenic system funded by the LBNF/DUNE Project.
  - M&S cost also cover process controls, mezzanine, cleanroom, general facility outfitting – tooling, cabinets

ND-LAr Resource Breakdown:
131.ND.02.10 – Module Assembly and Test Facility

	Design & Prototyping				Production			
	On-Project		Off-Project		On-Project		Off-Project	
131.ND.02.10: Module Assembly & Test Facility	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]
01 MATF Preliminary Design	-	2.0	-	-	-	-	-	-
02 MATF Final Design	-	3.7	-	-	-	-	-	-
03 MATF Procurement, Fabrication and Assembly	-	-	-	-	$1,408.0	4.8	-	15.3
04 MATF Operations Support	-	-	-	-	$75.0	6.0	-	12.0
Total:	**-**	**5.7**	-	-	**$1,483.0**	**10.8**	-	**27.3**

M&S cost driven by cold-test system, cryostat vessels per ASME BPVC → $165K each

Notes:

1. Extracted from current resource-loaded schedule (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.

Google sheet version:
https://docs.google.com/spreadsheets/d/148nVIj-4tz2FAodYlRAp29K3ZVE00Dw3HJ6oV-j5qXU

Cryostat quote

CRYOFAB, INC.
540 NORTH MICHIGAN AVE. • P.O. BOX 485
KENILWORTH, NEW JERSEY 07033
908-686-3636 x14 • FAX 908-686-9538
E-MAIL: tam@cryofab.com
WEBSITE: http://www.cryofab.com

To: Marco Oriunno , SLAC-Stanford University **From:** Tam Tu

Email: oriunno@slac.stanford.edu **Pages:** 1

Phone: **Date:** 2/16/2022

Re: Quotation for Dewar Flask **CC:**

☐ **Urgent** ☑ **For Review** ☐ **Please Comment** ☐ **Please Reply** ☐ **Please Recycle**

● **Comments:**

We are pleased to offer pricing for our CF series Dewar Flask that you had requested.

Item-1, Qty-1 Custom DUNE FSD Cryostat per your requirements.
Cryofab Model CF65148-F-BD Open Mouth LARG Dewar Flask with Top Flange
Notes & Exceptions:

- 65" nominally inner vessel diameter by 148" inner depth at full diameter
- 69" outer diameter by 172" overall height (est.)
- Top flange with double o-ring groove and bolt holes per spec
- 15 psig MAWP
- 1" O.D. bottom drain exits inner reservoir through the bottom dished head followed by a 90 degree elbow and then terminates at the outer vessel cylindrical shell with a DN25CF flange welded at the outlet.
- Inner vessel designed and tested per ASME Code sec VIII, Div.1
- The coverplate used for the hydrostatic pressure test would be supplied in lieu of the .125" thin lid required for shipping purposes.
- All shell and flange thicknesses to be determined by Cryofab and in accordance with ASME code requirements.
- Insulation and internal structural integrity designed per Cryofab standards
- No additional cleaning provided on inner vessel other than general wipe down with aqueous cleaning solution and rinse.

Unit Price: $162,450.00

Item-2 Shipping skid with saddles* $3,500.00

Delivery: 8 months ARO
F.O.B.: Kenilworth, NJ
Terms: 50% deposit with purchase order, Net 30 days balance.
Quoted prices are in US Dollars and valid for 90 days.

*Dewar is packaged horizontally and strapped to an oversized steel reinforced wooden skid on saddles. It would have to be shipped by either via a dedicated container/flatbed or by secured/sealed LTL freight trailer.

Regards,
Tam Tu