131.ND.02.09 ND-LAr TPC Integration and Installation

Andrew Lambert, ND-LAr Lead Engineer

ND-LAr Preliminary Design Review

29 June 2022

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

Introduction – Who am I?

Mechanical Engineer at Lawrence Berkeley Lab since October 2011

Joined DUNE in January 2020

Previous projects:

Dark Energy Spectroscopic Instrument (DESI): 2013-2019

- Contributed to Focal Plane, Fiber, and Spectrograph Systems – DESI Builder Award
- Conceptual design through instrument installation at Kitt Peak outside of Tucson, AZ

LUX-Zeplin (LZ) Dark Energy Experiment: 2016-2020

- Contributed to Thermosiphon, Signal Breakout, and LXe Systems

Project X Injector Experiment (PXIE): 2011-2014

- Analysis and fabrication of 162.5 MHz radio-frequency quadrupole (RFQ) for PXIE

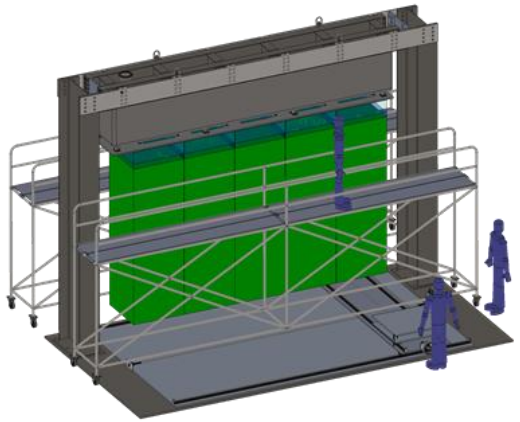
Other Projects: Muon Ionization Cooling Experiment (MICE), Zwicky Transient Facility (ZTF) Camera

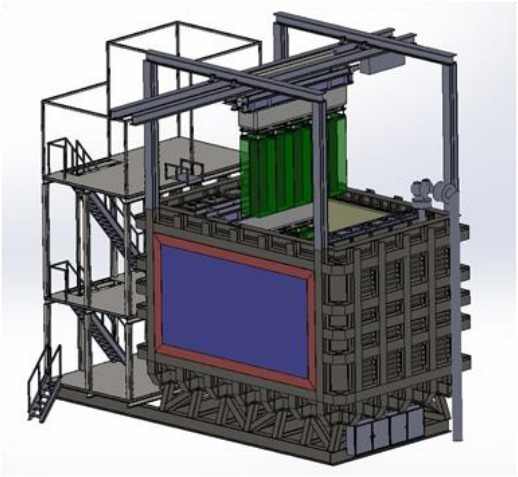
Outline

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

131.ND.02.09 ND-LAr TPC I&I Scope is well-defined in WBS Dictionary and TPC I&I Scope Table

Task/Item: ND-LAr TPC I&I Near Site Equipment, Procedures and Labor
Equipment
Module Storage Crates
Integration Fixture: Integrate Modules to Cryostat Lid
Support Fixture: Safety Hold Integrated Cryostat Lid and Modules
Lifting Fixture: Safely Lift Integrated Module Row
Installation Fixture: Install Module Rows to Cryostat
Metrology Equipment
Laser Nests & Totems
Electronics Racks
Cable Trays and Covers
Mock Modules for Prototyping
Procedures
Integration Fixture Assembly Procedure(s)
Support Fixture Assembly Procedure(s)
Installation Fixture Assembly Procedure(s)
Module Row Integration Procedure(s)
Module Row Installation Procedure(s)
Surface Building Module Crate Critical Lift Procedure
Surface Building Module Extraction Critical Lift Procedure
Surface Building Module Handling & Critical Lift Procedure
Surface Building Module Integration to Cryostat Lid Procedure
Surface Building Integrated Module Row Critical Lift Procedure
Cavern Shaft Integrated Module Row Critical Lift Procedure
Canvern Integrated Module Row Critical Lift Procedure
Module Row Metrology Plan/Procedure(s)
Module Array Metrology Plan/Procedure(s)
Cable Routing Procedure(s)
Electrical Safety Notes
Custom Lifting Fixture Notes





- WBS Dictionary: EDMS 2619609
- Scope Table: EDMS 2619606
- Key Deliverables
  - Integrate, Install and Verify 35 TPC Module Array for DUNE LAr Near Detector
    - Quality Control on received ND-LAr modules (35X) at the Near Detector
    - Fixtures/Procedures for Integration and Installation of Modules to Cryostat
    - Pre-Cooldown Checkouts
- Includes: Design, Prototyping, Procurement, and Test Assembly required to meet Key Deliverables

131.ND.02.09 TPC I&I Scope Table

Engineering Management:
Andrew Lambert (LBNL)

Subsystem Manager:
Prof. Jonathan Asaadi (UTA)

https://www.uta.edu/academics/faculty/profile?username=asaadij

UNIVERSITY OF TEXAS ARLINGTON

Engineering Lead:
TBD

Previously:
Rama Kuravi (LBNL)*
Thomas Rathmann (LBNL)*
Andrew Lawrence (LBNL)*

*No longer on LBNF/DUNE

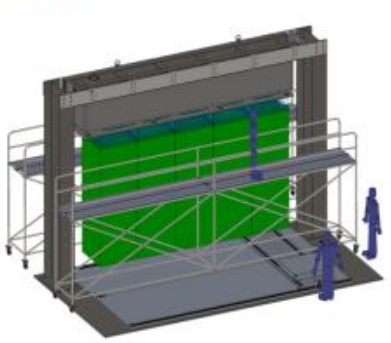
131.02.03.02.08: TPC Installation & Integration

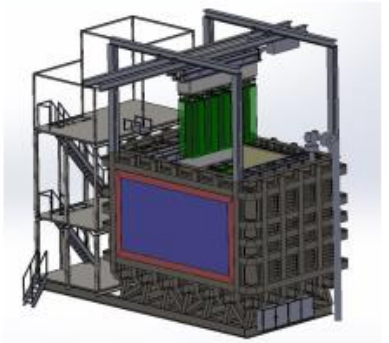
WBS Dictionary (Concise):

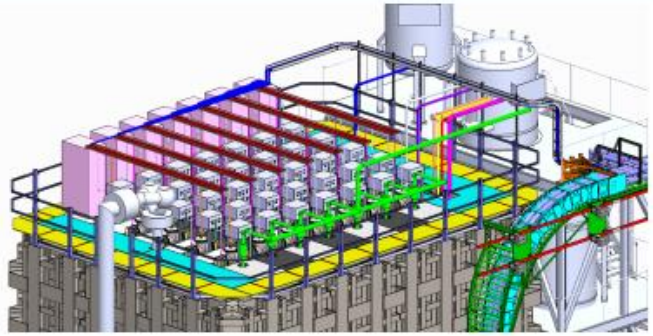
Installation and Integration program for the ND LArTPC detector at the Near Site
Includes:
- Receipt of TPC Modules from MAT Facility, packaging, transport to storage
- Transport of TPC modules from storage to Near Site
- Installation of TPC module row test equipment, and check-out
- Installation of TPC module rows to Cryostat lid segments, and check-out
- Coordination (with NS I&I, ND-LAr Cryostat) of Module row installation to Cryostat
- Installation of ND-LAr electronics (racks, electronics, cable trays, cables), and check-out
- Final check-out of ND-LAr detector
- ND-LAr detector commissioning
- Assembly, lifting fixtures, and other integration hardware
- TPC Module shipping/storage containers

EDMS 2619606

Reference CAD Image(s):

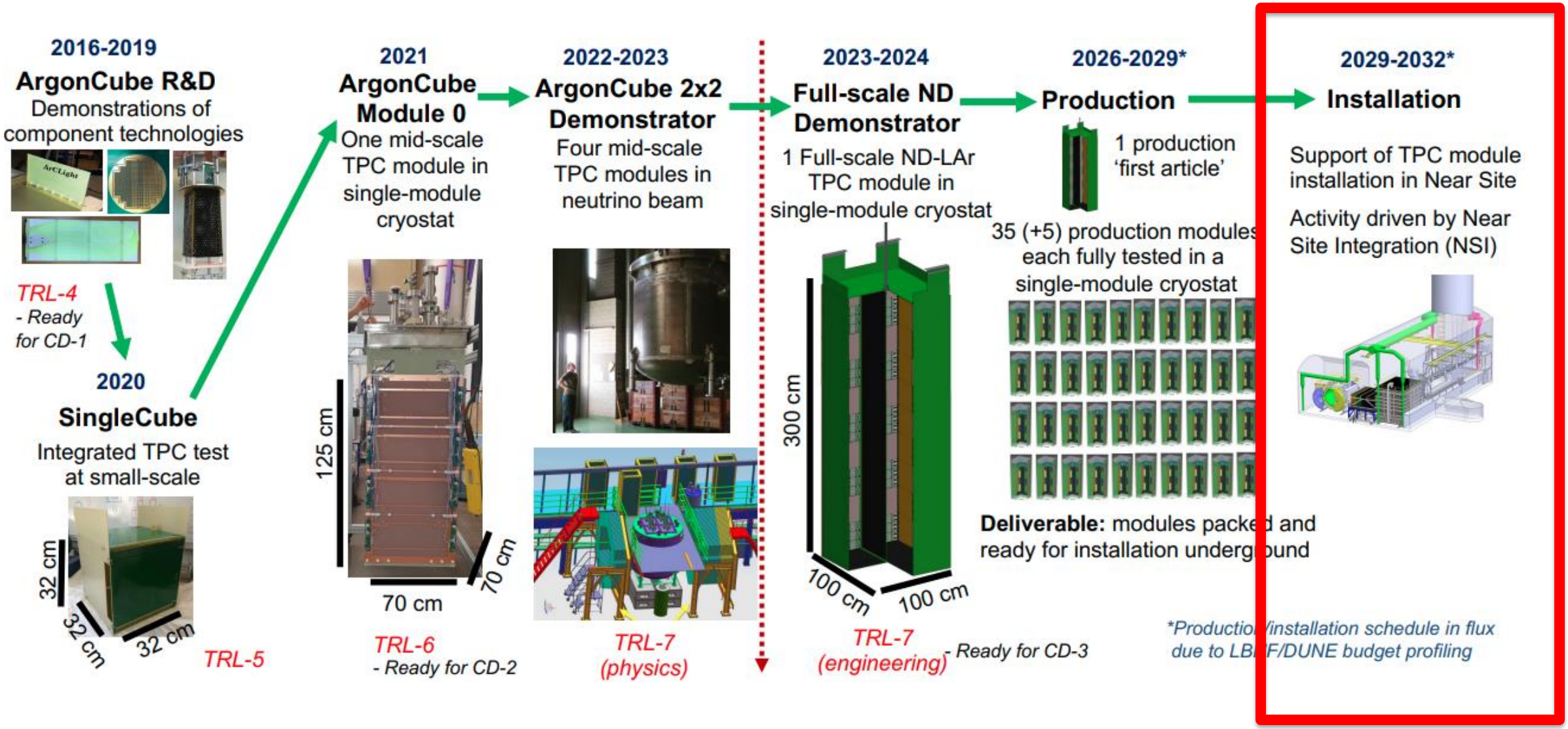






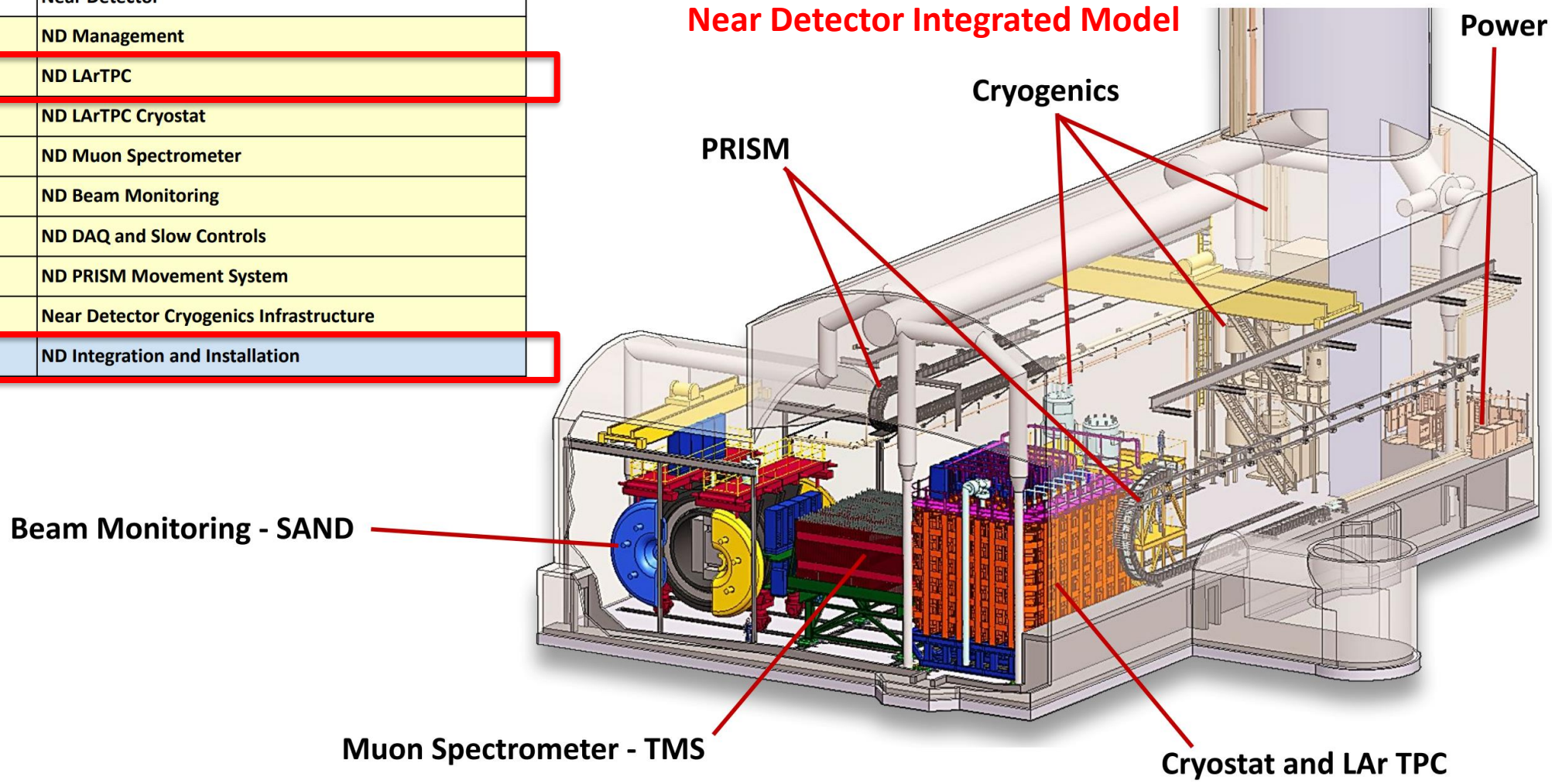
Task/Item: ND-LAr TPC I&I Near Site Equipment, Procedures and Labor	QTY.	Spares	Institutions	Funding Source	Funding Status	Detailed description
Equipment						
Module Storage Crates	35	0	LBNL	DUNE US Project	Allocated	Storage crates for the completed ND-LAr TPC modules
Integration Fixture: Integrate Modules to Cryostat Lid	1	0	LBNL	DUNE US Project	Allocated	Design, prototyping, procurement, assembly and testing, delivery to Near Site
Support Fixture: Safety Hold Integrated Cryostat Lid and Modules	2	0	LBNL	DUNE US Project	Allocated	Design, prototyping, procurement, assembly and testing, delivery to Near Site
Lifting Fixture: Safely Lift Integrated Module Row	2	0	LBNL	DUNE US Project	Allocated	Design, prototyping, procurement, assembly and testing, delivery to Near Site
Installation Fixture: Install Module Rows to Cryostat	1	0	LBNL	DUNE US Project	Allocated	Design, prototyping, procurement, assembly and testing, delivery to Near Site
Metrology Equipment	1	0	LBNL	DUNE US Project	Allocated	Procurement, inspection, delivery to Near Site
Laser Nests & Totems	50	10	LBNL	DUNE US Project	Allocated	Procurement, inspection, delivery to Near Site
Electronics Racks	7	1	LBNL	DUNE US Project	Allocated	Procurement, inspection, delivery to Near Site
Cable Trays and Covers	25	0	LBNL	DUNE US Project	Allocated	Procurement, inspection, delivery to Near Site
Mock Modules for Prototyping	5	0	LBNL	DUNE US Project	Allocated	Design, prototyping
Procedures						
Integration Fixture Assembly Procedure(s)	NA	NA	LBNL	DUNE US Project	Allocated	Procedure for fixture assembly
Support Fixture Assembly Procedure(s)	NA	NA	LBNL	DUNE US Project	Allocated	Procedure for fixture assembly
Installation Fixture Assembly Procedure(s)	NA	NA	LBNL	DUNE US Project	Allocated	Procedure for fixture assembly
Module Row Integration Procedure(s)	NA	NA	LBNL	DUNE US Project	Allocated	Planning, analyses, safety review per FESHM
Module Row Installation Procedure(s)	NA	NA	LBNL	DUNE US Project	Allocated	Planning, analyses, safety review per FESHM
Surface Building Module Crate Critical Lift Procedure	NA	NA	LBNL	DUNE US Project	Allocated	Planning, analyses, safety review per FESHM
Surface Building Module Extraction Critical Lift Procedure	NA	NA	LBNL	DUNE US Project	Allocated	Planning, analyses, safety review per FESHM
Surface Building Module Handling & Critical Lift Procedure	NA	NA	LBNL	DUNE US Project	Allocated	Planning, analyses, safety review per FESHM
Surface Building Module Integration to Cryostat Lid Procedure	NA	NA	LBNL	DUNE US Project	Allocated	Planning, analyses, safety review per FESHM
Surface Building Integrated Module Row Critical Lift Procedure	NA	NA	LBNL	DUNE US Project	Allocated	Planning, analyses, safety review per FESHM
Cavern Shaft Integrated Module Row Critical Lift Procedure	NA	NA	LBNL	DUNE US Project	Allocated	Planning, analyses, safety review per FESHM
Canvern Integrated Module Row Critical Lift Procedure	NA	NA	LBNL	DUNE US Project	Allocated	Planning, analyses, safety review per FESHM
Module Row Metrology Plan/Procedure(s)	NA	NA	LBNL	DUNE US Project	Allocated	Planning, analyses, safety review per FESHM
Module Array Metrology Plan/Procedure(s)	NA	NA	LBNL	DUNE US Project	Allocated	Planning, analyses, safety review per FESHM

131.ND.02.09 ND-LAr TPC I&I "finishes the race" for ND-LAr at the Near Detector



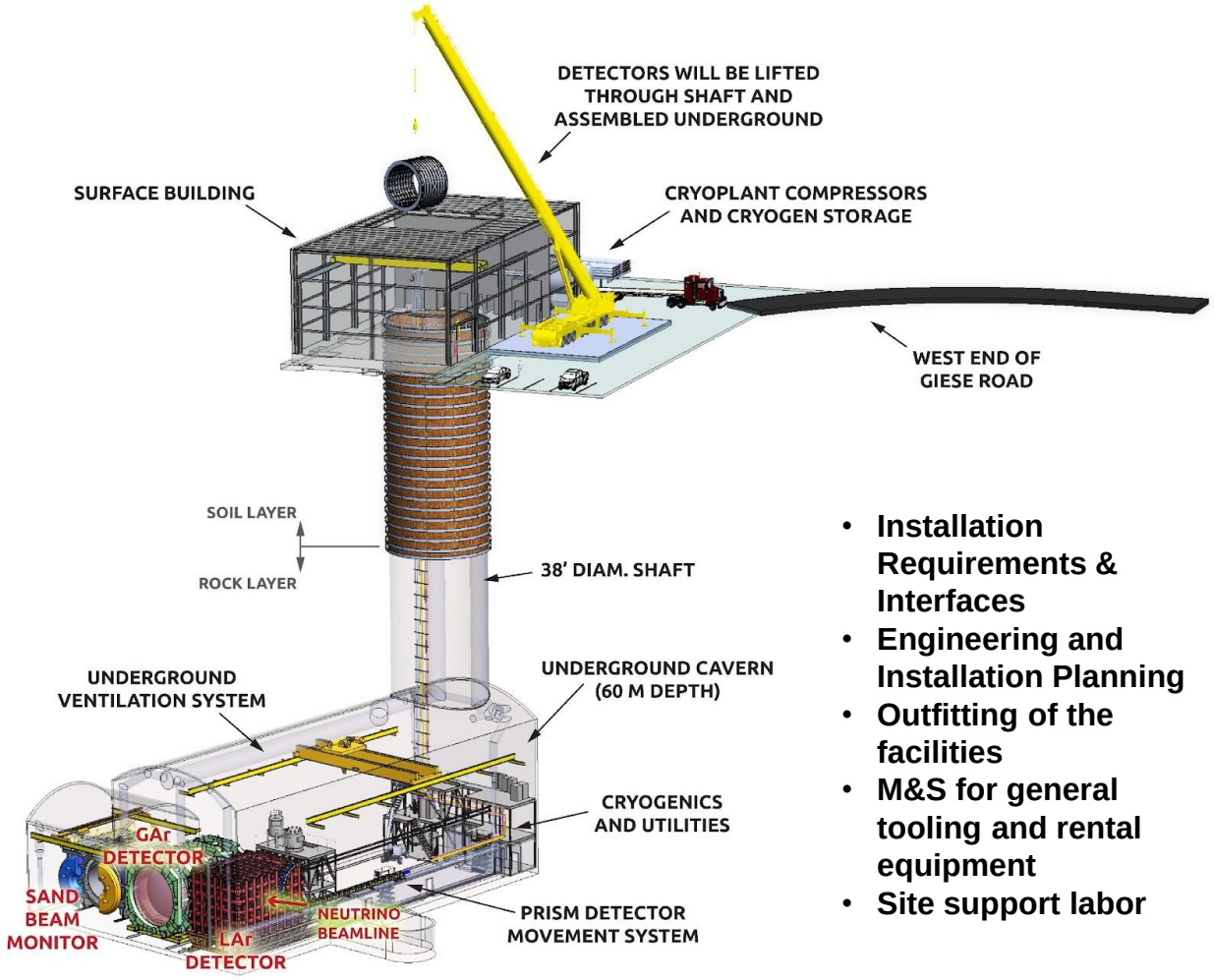
Near Detector Installation Context, ND-LAr and Near Detector I&I

131.ND	Near Detector
131.ND.01	ND Management
131.ND.02	ND LArTPC
131.ND.03	ND LArTPC Cryostat
131.ND.04	ND Muon Spectrometer
131.ND.05	ND Beam Monitoring
131.ND.06	ND DAQ and Slow Controls
131.ND.07	ND PRISM Movement System
131.ND.08	Near Detector Cryogenics Infrastructure
131.ND.09	ND Integration and Installation



Near Detector I&I Scope is General Support and not specific to ND-LAr TPC I&I deliverables (not in scope of today's review)

- Site wide engineering and technician management oversight
- Support staff for all Near Detector detector groups
  - Rigging, Transport, Infrastructure
- High-level coordination and logistics planning
- Facility outfitting



- **Installation Requirements & Interfaces**
- **Engineering and Installation Planning**
- **Outfitting of the facilities**
- **M&S for general tooling and rental equipment**
- **Site support labor**

Scope Boundary between ND-LAr TPC I&I and Near Detector I&I is well defined and delineated; activities are coordinated in the resource loaded schedule with I&I

SPECIFIC SCOPE RELATED TO TPC MODULES BELONGS TO ND-LAr TPC I&I

Task/Item: ND-LAr TPC I&I Near Detector Equipment, Procedures and Labor
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Module Storage Crates
Integration Fixture: Integrate Modules to Cryostat Lid
Support Fixture: Safety Hold Integrated Cryostat Lid and Modules
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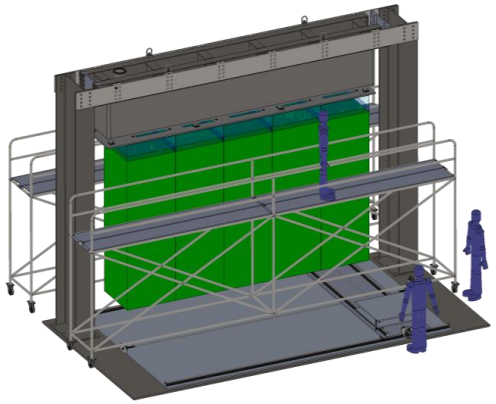
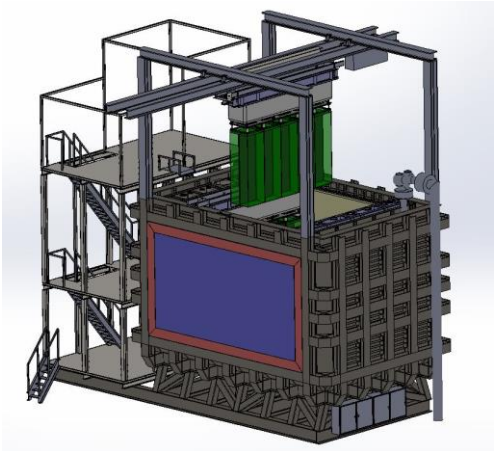
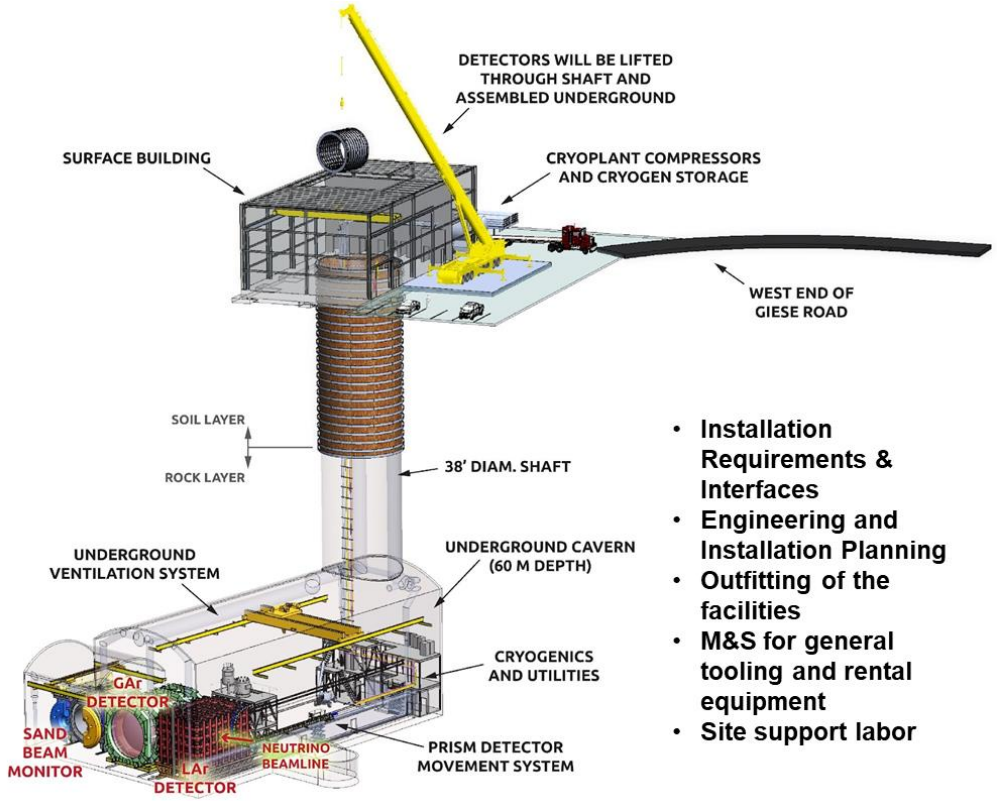
Electrical Safety Notes
Custom Lifting Fixture Notes





GENERAL (RIGGERS FOR CRANES, FORKLIFTS, INFRASTRUCTURE, LOTO) SUPPORT SCOPE BELONGS TO NEAR DETECTOR I&I



- Installation Requirements & Interfaces
- Engineering and Installation Planning
- Outfitting of the facilities
- M&S for general tooling and rental equipment
- Site support labor

Concrete example of scope division between 131.ND.02.09 ND-LAr TPC I&I and 131.ND.09 Near Detector I&I

This is a lift & requires a crane: I&I Rigger

This is a fixture operation: No I&I tech help

This is a lift & requires a crane: I&I Rigger

This is a fixture operation: No I&I tech help

ND-LAr Module Integration at Near Detector Surface Building							
TPC-WFS4: Extraction of ND-LAr Modules from Crate and Install to Rotation Fixture - Critical Lift	**Duration [Hours]**	**% ND-LAr Engineer**	**% ND-LAr Mech Tech**	**% ND-LAr Elec Tech**	**% I&I Tech/Rigger**	**% ND-LAr Physicist**	**% PostDoc/Student**
Install Rigging	0.50	100%	200%	0%	100%	0%	400%
Lift/Extract Module From Crate	0.50	100%	200%	0%	200%	0%	400%
Translate Module to Rotation Fixture	0.25	100%	200%	0%	200%	0%	400%
Lower/Install Module to Rotation Fixture	0.50	100%	200%	0%	200%	0%	400%
Remove Rigging	0.50	100%	200%	0%	100%	0%	400%
Stow Module Crate Using Forklift	0.25	100%	200%	0%	100%	0%	400%
Total WFS4 Hours	2.50	2.50	5.00	0.00	3.75	0.00	10.00

TPC-WFS5: Rotate ND-LAr Module 90 Degrees	**Duration [Hours]**	**% ND-LAr Engineer**	**% ND-LAr Mech Tech**	**% ND-LAr Elec Tech**	**% I&I Tech/Rigger**	**% ND-LAr Physicist**	**% PostDoc/Student**
Perform Pre-Rotation Checks on ND-LAr Module Structure	0.25	100%	200%	0%	0%	0%	400%
Slowly Rotate ND-LAr Module 90 Degrees to Upright Position	0.25	100%	200%	0%	0%	0%	400%
Perform Post-Rotation Checks on ND-LAr Module Structure	0.25	100%	200%	0%	0%	0%	400%
Prepare ND-LAr Module for Extraction from Rotation Fixture	0.25	100%	200%	0%	0%	0%	400%
Total WFS5 Hours	1.00	1.00	2.00	0.00	0.00	0.00	4.00

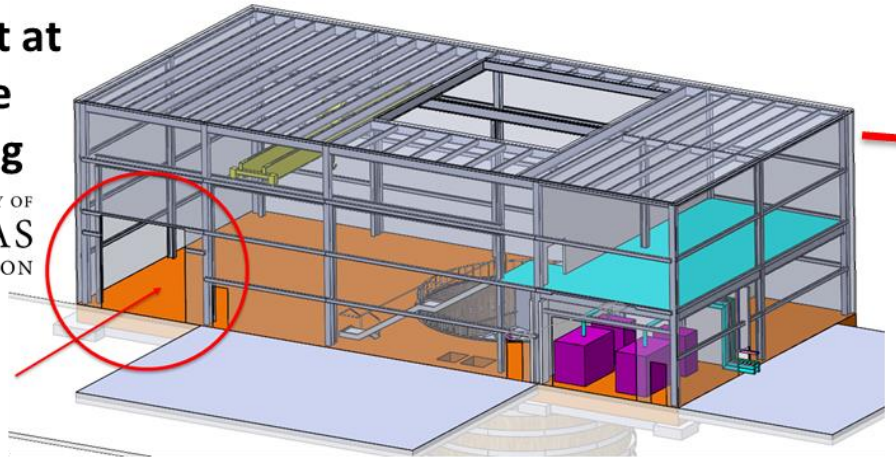
TPC-WFS6: Extract ND-LAr Module from Rotation Fixture and Install to Row Integration Fixture	**Duration [Hours]**	**% ND-LAr Engineer**	**% ND-LAr Mech Tech**	**% ND-LAr Elec Tech**	**% I&I Tech/Rigger**	**% ND-LAr Physicist**	**% PostDoc/Student**
Install Rigging for ND-LAr Module Extraction from Fixture	0.25	100%	200%	0%	100%	0%	400%
Slowly extract ND-LAr Module	0.25	100%	200%	0%	200%	0%	400%
Translate to Module Row Integration Fixture	0.25	100%	200%	0%	200%	0%	400%
Install ND-LAr Module to Row Integration Fixture	0.50	100%	200%	0%	200%	0%	400%
Remove Rigging and Stow Crane	0.25	100%	200%	0%	100%	0%	400%
Total WFS6 Hours	1.50	1.50	3.00	0.00	2.50	0.00	6.00

TPC-WFS7: Install ND-LAr Module to Row Array on Cryostat Lid Section	**Duration [Hours]**	**% ND-LAr Engineer**	**% ND-LAr Mech Tech**	**% ND-LAr Elec Tech**	**% I&I Tech/Rigger**	**% ND-LAr Physicist**	**% PostDoc/Student**
Actuate ND-LAr Module to Required Position	0.50	100%	200%	0%	0%	0%	400%
Translate Module to Row Slot	0.50	100%	200%	0%	0%	0%	400%
Use 6-struts to Raise and Align Module to Pins	0.50	100%	200%	0%	0%	0%	400%
Use 6-struts to From Final Joint	0.50	100%	200%	0%	0%	0%	400%
Install bolts to secure ND-LAr Module to Row Support Structure	0.25	100%	200%	0%	0%	0%	400%
Torque Bolts per Procedure	0.25	100%	200%	0%	0%	0%	400%
Detach Integration Fixture from Module and Retract	0.50	100%	200%	0%	0%	0%	400%
Prepare for Next ND-LAr Module Insertion	0.50	100%	200%	0%	0%	0%	400%
Total WFS7 Hours	3.50	3.50	7.00	0.00	0.00	0.00	14.00

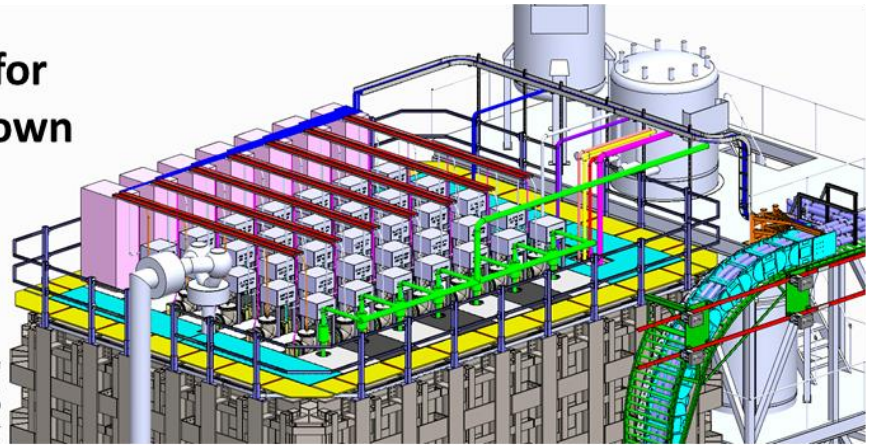
131.ND.02.09 TPC I&I at the Near Detector is focused on delivery of a 35 module detector array ready for cool-down and commissioning

EDMS 2459143

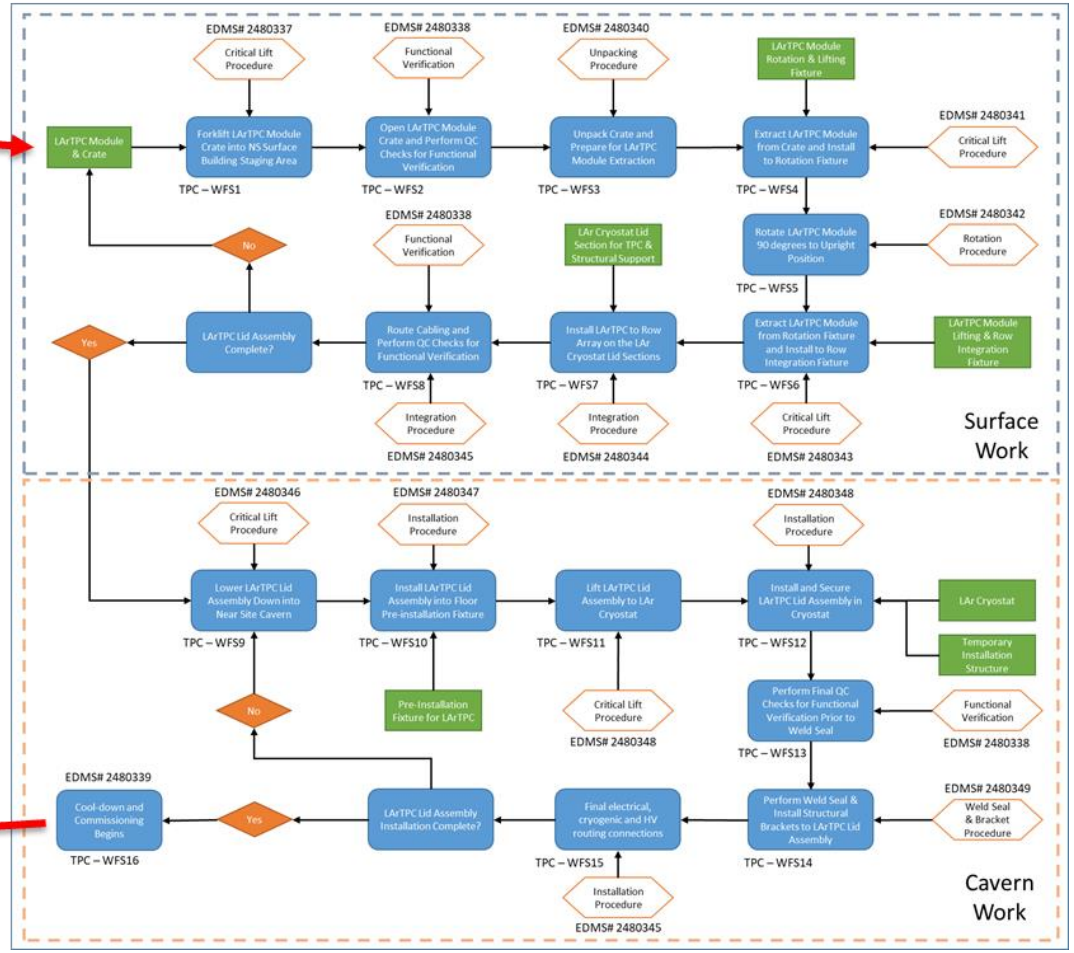
Receipt at Surface Building



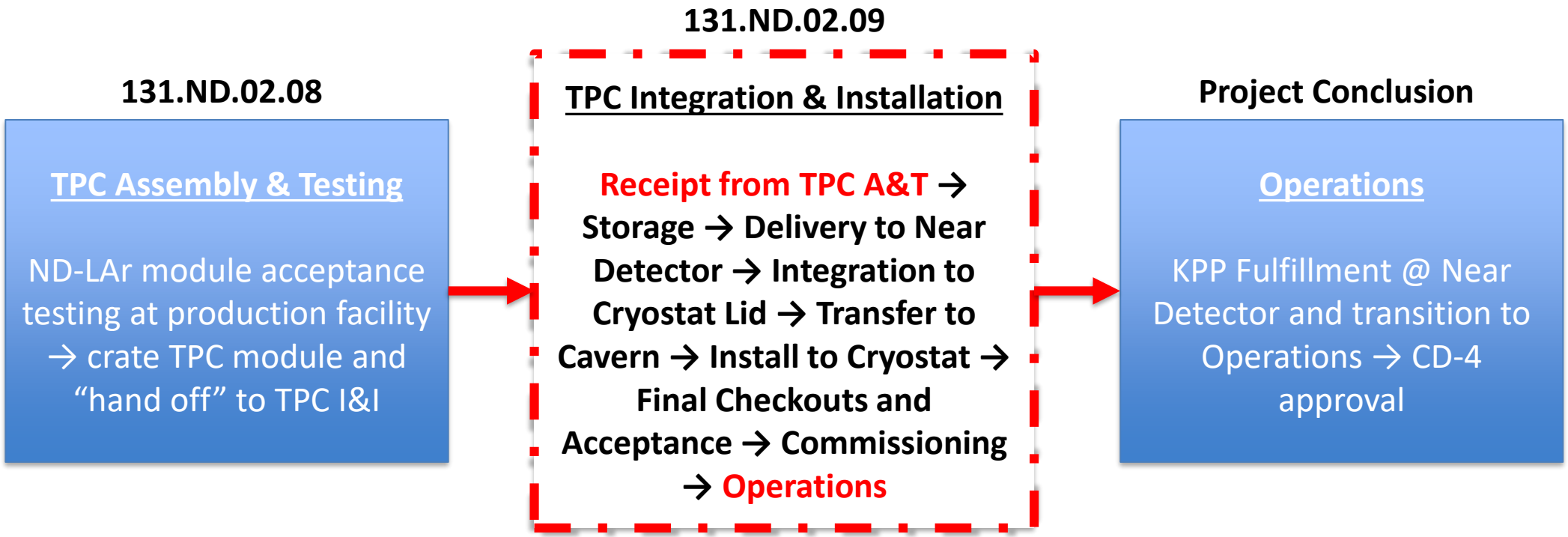
Ready for Cool-down



Near Site Activities



131.ND.02.09 TPC Integration and Installation Core Role, Start-to-Finish



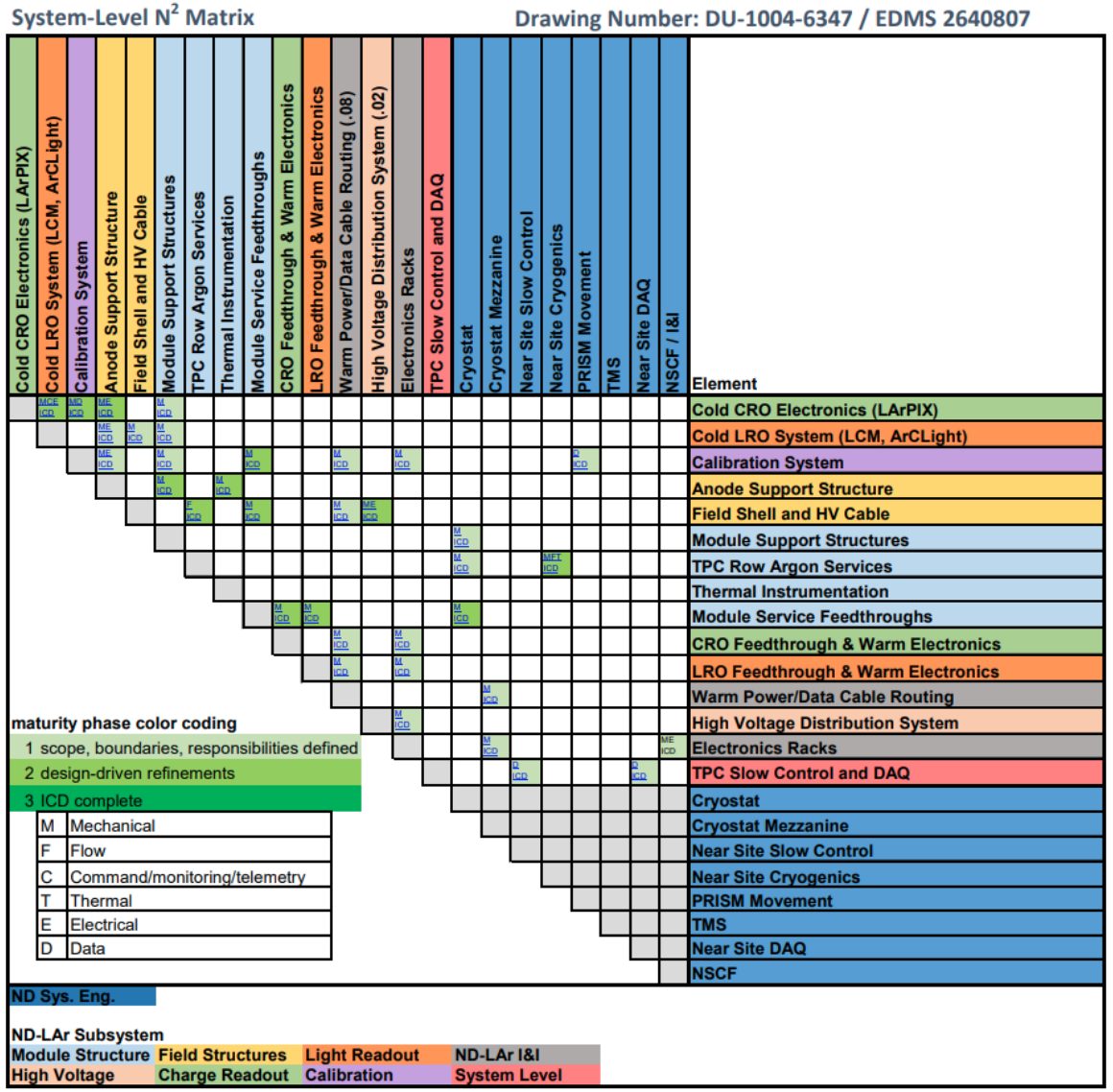
Key Requirements are defined and documented for ND-LAr TPC I&I

EDMS 2589287

Type	Requirement	Description	Val
Requirement	Installation Procedures	TPC I&I Installation shall adhere to Fermilab FESHM requirements	FESHM
Requirement	Lifting Fixture Design	TPC I&I lifting fixture designs shall adhere to Fermilab FESHM requirements	FESHM
Requirement	Integration and Installation Fixturing	TPC I&I fixture design shall comply with Fermilab FESHM requirements	FESHM
Requirement	Electrical Safety	TPC I&I shall comply to electrical safety requirements as specified in FESHM	FESHM
Requirement	Lifting Safety	TPC I&I shall comply to lifting safety requirements as specified in FESHM	FESHM
Requirement	Module Quality / Verification	TPC I&I shall verify module performance at Near Site prior to and during integration and installation	NA
Requirement	TPC Module Integration	TPC I&I shall integrate the stated number of LArTPC modules into the LAr Cryostat	35
Requirement	TPC Modules per Row	TPC I&I shall install the specificed number of modules per row	5
Requirement	Number of Module Rows to Integrate	TPC I&I shall install and integrate the specified number of module rows to the LAr Cryostat	7
Requirement	Module Storage and Protection	TPC I&I shall receive, store, and protect modules after TPC Assembly and Testing, yet prior to Near Site Installation	37
Requirement	Storage Environmental Requirements	Storage shall maintain the given temperature and humidity environment	25C +/- 2C (WAG) 55% RH +/- 5% (WAG)

Interfaces between TPC I&I and other systems are managed and tracked

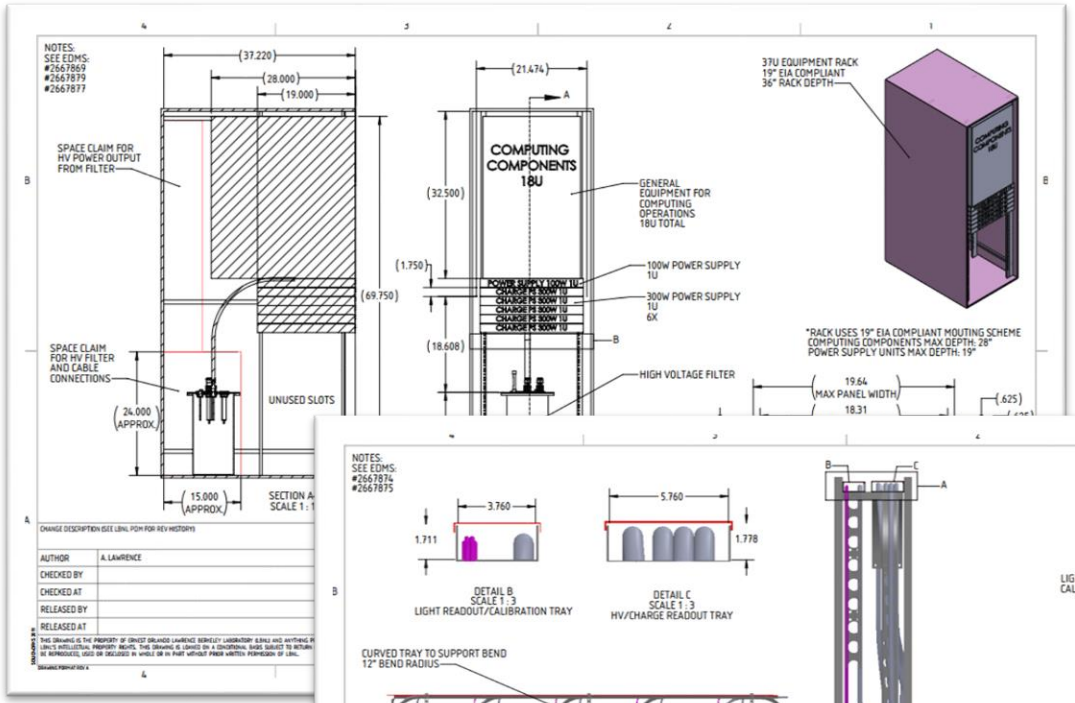
- Schedule interfaces prior to Near Detector
  - Receives acceptance tested modules from TPC Assembly and Test, stores until NS ready for TPC I&I
- Mechanical-Electrical interfaces at the Near Detector
  - Regular discussion on interfaces in weekly engineering meetings
    - Warm Cabling
    - Electronics Racks
    - Near Detector I&I
- Schedule / Construction interfaces at the Near Detector during module receipt, integration, installation, pre-commissioning
  - LAr Cryostat, LAr Cryogenics, TMS, NS I&I



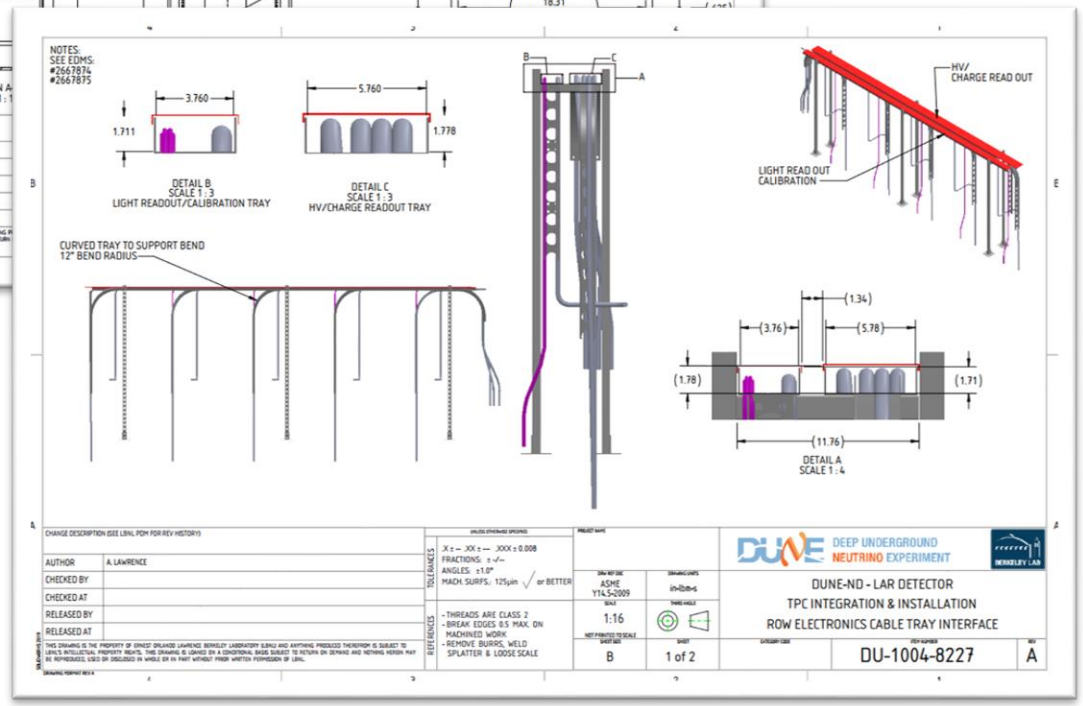
Interfaces at the Near Detector are well understood with ICDs in development

- Continuing interface development with:
  - ND-LAr Subsystems
  - LAr Cryostat: EDMS 2458099
  - LAr Cryogenics: EDMS 2458074
  - Near Detector I&I: EDMS 2730726

Cryostat



Electronics Racks



Cable Trays

Interface with Near Detector I&I can be found at [EDMS 2730726]

DEEP UNDERGROUND NEUTRINO EXPERIMENT

ND-LAr TO NEAR SITE INTEGRATION AND INSTALLATION ICD

A.LAMBERT
G.CLINE

Release Date:May 10 2022 3:20:08 PM PDT

LBNL Document Number: **DU-1004-8809**	Revision: **A.7**
CERN EDMS Document Number: **2730726**	Revision: **v.1**

Document Status: **Released**
Type: **INTERFACE**
LBNL Category Code: **DU2020**

4. INTRODUCTION

This document describes both the technical and programmatic interfaces between the referenced WBS elements below.

This document represents interfaces between the following two entities:	
WBS 131.ND.02 ND-LAr TPC Dan Dwyer (L2)	WBS 131.ND.06 Near Site I&I Fabrice Matichard (L2)

5. SCOPE OF INTERFACES

This document covers all technical and programmatic interfaces related to ND-LAr TPC integration and installation at the Near Site and related commissioning interfaces and operational interfaces.

6. INTERFACE TABLE

The interface tables below cover physical (structure), mass/momentum flow, energy flow, data flow, schedule, integration and installation, commissioning, operations and programmatic interfaces.

ID#	Item	WBS 131.ND.02 ND-LAr TPC Provides	WBS 131.ND.06 Near Site I&I Provides	Interface Drawing / Point
Near Site Personnel Labor				
001	Near Site Surface Personnel	ND-LAr personnel to receive modules and equipment at the surface and perform reception testing, visual inspections, integration activities	Rigging personnel to drive forklift, operate cranes and supervise / direct lifts. Spotters, safety watch. - Covers transport from storage to Near Site Surface Building - Covers material handling at Near Site Surface Building - Covers material handling in Near Site Shaft	Near Site Staffing Plan (TBC)

025	ND-LAr TPC Integration to Cryostat Lids at Near Site Surface Building	Required procedures and fixtures to integrate the ND-LAr TPC modules to cryostat lid sections Scaffolding (TBC)	Forklifts and/or pallet jacks Overhead cranes and general rigging equipment (slings, shackles, chainfalls) Scaffolding (TBC) Coordinate FNAL safety review of lift procedures	ND-LAr Near Site Document List (TBC)
026	Integrated ND-LAr TPC Lid Section Functional Checkouts at Near Site Surface Building	Required procedures and equipment to perform functional checkouts of successfully integrated ND-LAr TPC modules Scaffolding (TBC)	Supporting personnel (electricians?) to interface to facility electrical infrastructure? At what point is an electrician required for activities? LOTO? Scaffolding (TBC)	ND-LAr Near Site Document List (TBC)
027	Integrated ND-LAr TPC Lid Section Transfer to Cavern at Near Site	Required procedures and equipment to perform transfer of Integrated TPC lid sections from surface to cavern	Overhead cranes and general rigging equipment (slings, shackles, chain falls) Coordinate FNAL safety review of lift procedures	ND-LAr Near Site Document List (TBC)
Near Site Cavern Activities: Equipment, Materials, Procedures				
041	Integrated ND-LAr TPC Lid Section Handling in Near Site Cavern	Required procedures and fixtures for TPC lid section handling/lifting in the cavern	Overhead cranes and general rigging equipment (slings, shackles, chain falls) Coordinate FNAL safety review of lift procedures	ND-LAr Near Site Document List (TBC)
042	Integrated ND-LAr TPC Lid Section Lifting to LAr Cryostat in Near Site Cavern	Required procedures and fixtures for TPC lid section lifting to the LAr cryostat in the cavern	Overhead cranes, auxiliary crane, and general rigging equipment (slings, shackles, chain falls) Coordinate FNAL safety review of lift procedures	ND-LAr Near Site Document List (TBC)
043	Integrated ND-LAr TPC Lid Section Installation into LAr Cryostat in Near Site Cavern	Required procedures and fixtures to install integrated TPC lid sections into the cryostat	Overhead cranes and general rigging equipment (slings, shackles, chain falls) Coordinate FNAL safety review of lift procedures	ND-LAr Near Site Document List (TBC)

QAQC, Procurement, and Manufacturing Plans

- Preliminary quality control plans found at:
  - QAQC: EDMS 2609927
  - Procurement: EDMS 2609928
  - Manufacturing: EDMS 2609929

- QAQC focused on required documentation at Near Detector necessary to start and perform work, as well as required testing at the Near Detector to verify instrument functionality – **gaining experience with 2x2 program on this front (ORC process)**:
  - Inspection reports
  - Test reports
  - Test Procedures
  - Safety Notes
  - Etc.

Major Cost & Schedule Risks have been identified and captured in the Consortium Risk Registry (EDMS 2589288)

Title	Mitigation	Probability	Schedule Impact (Months)			Cost Impact ($k)		
Installation Schedule Longer than Anticipated	Prototyping of integration and installation fixtures and processes to refine schedule estimates	15%	1	2	3	$110.50	$221.00	$331.50
Insufficient storage space for fully tested LArTPC modules that are ready for installation	Planned Mitigation: Find and document committed storage location at FNAL	10%	3	6	9	$302.50	$605	$908
Unforeseen problems with TPC Integration and Installation Fixtures	ND-LAr TPC I&I subsystem will prototytpe fixturing and perform mock assembly of ND-LAr module row integration and ND-LAr module row installation to verify fixture performance	15%	3	6	12	$239	$478	$956
LArTPC modules are damaged during installation process	Prototyping of fixtures and installation process, production of spare module(s), engineered containers	20%	2	4	6	$70.56	$141.12	$211.68
LArTPC modules are damaged in transport from Module Integration Facility/Storage to Near Site	Prototyping of fixtures and installation process, production of spare module(s), engineered containers	15%	2	4	6	$153.33	$206.67	$260.00
Stored module contamination	Planned Mitigation: Store in environmentally controlled building/room, and/or design dust-proof or hermetic storage containers	10%	3	6	9	$352.80	$705.60	$1,058.40
ND-LAr Technical Labor at the Near Site exceeds Estimate Uncertainty Margin	TPC Installation WBS sub-system to specifically address Near Site Installation issues	25%	1	2	3	$30.00	$60.00	$90.00
Insufficient personnel for Module checkouts during/after installation	US consortia partners make agreements for in-kind student/postdoc labor	30%	1	2	3	$30.00	$60.00	$90.00

Prototyping and Testing of ND-LAr TPC I&I fixture designs and plans will help to reduce risk during Near Site activities and ensure proper development of procedures and plans

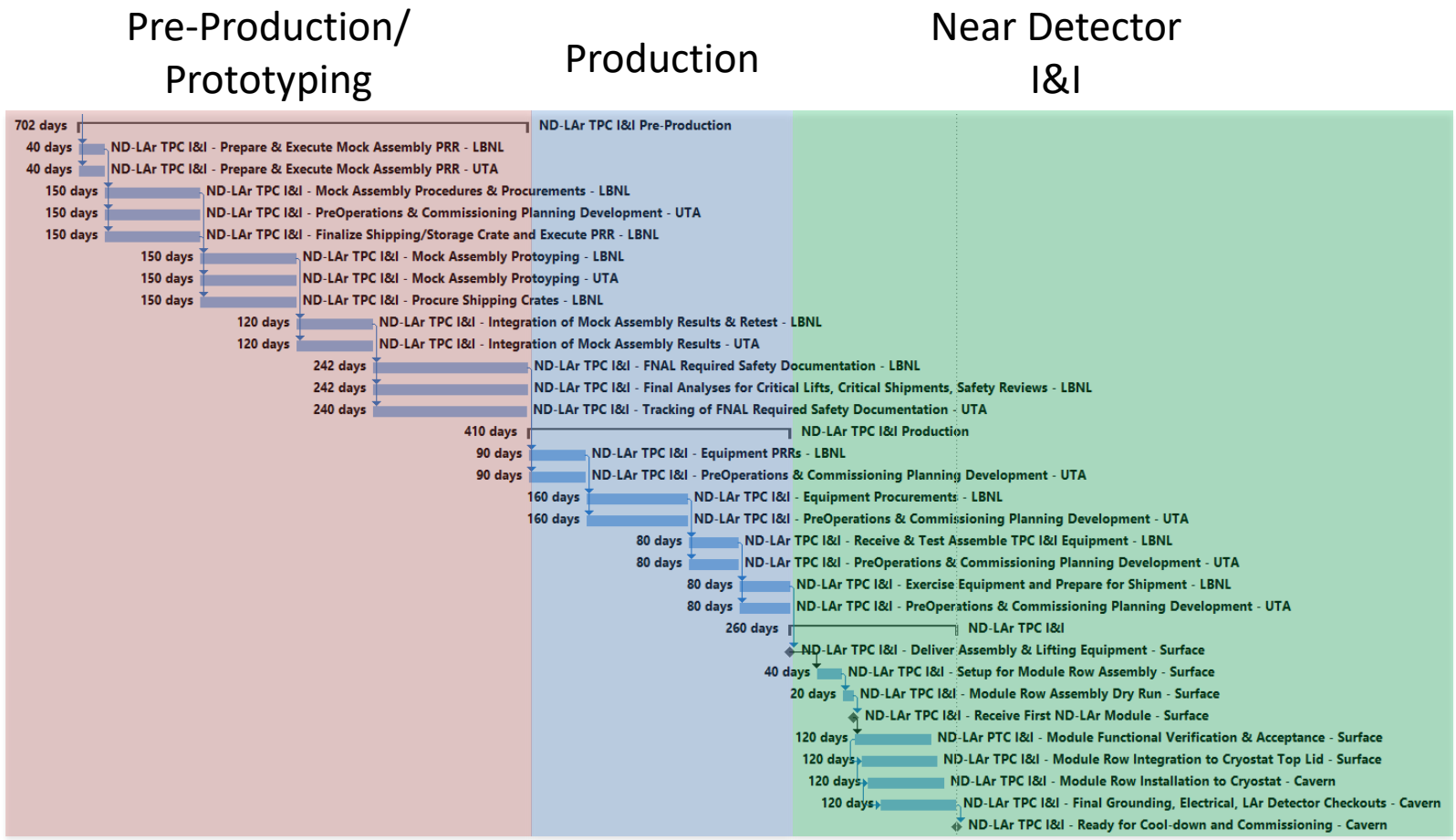
- I&I questions addressed by prototyping plans
  - Fixture ease-of-use and functionality → do they work as intended or are changes needed?
  - I&I timelines → better understanding of schedule
  - Risks to the instrument → may uncover design pitfalls that were not easy to assess without testing yet pose instrument risk and must be rectified
  - Proper procedure generation → test out procedures and identify areas of deficiency
  - Transportation risk → prototype crate and test shipments to identify load cases & resulting isolation

EDMS 2591433

Test	*Rationale*	*Material Cost*	*Labor Cost*	*Notes*
TPC to Lid Section Integration	-Alignment of TPCs to lid -Integration fixture dry run -Removal of single TPC for service	TPC integration fixture	2 techs + 1 eng, 1 month	Majority of integration fixture parts can be reused for actual build
TPC Cable Routing	-Feedthrough installation dry run -Strain relief and cable management	Feedthrough and wire harnesses	1 tech + 1 eng, 1 week	
TPC Row Lifting	-Lifting fixture dry run -Enable TPC Row to Cryostat installation test	Lifting fixture, rigging	2 techs + 2 eng, 2 months	Majority of hardware can be reused for actual installation
TPC Row to Cryostat Installation	-Transfer from lifting fixture to installation fixture -Installation fixture dry run -Alignment of TPC row to cryostat	TPC installation fixture		Majority of installation fixture parts can be reused for actual installation
TPC Row Fastening	-Transfer from installation fixture to cryostat	16x TPC Row Brackets		
TPC Row Welding	-Perimeter weld access during row installation -Weld grinding and row removal dry run		1 tech + 1 eng, 1 week	Could be addressed with benchtop prototype
TPC to Cryostat Grounding	-Grounding scheme for TPC, Lid Section and Cryostat		1 eng, 1 day	Assume quick multimeter / hi pot check by EE

Prototyping and testing plans should feed into production/procurement of final I&I equipment for Near Detector activities

- Prototyping activities should inform final production designs
  - Ideally prototyping fixture components can be re-used we acceptable
  - Two mock assembly runs
    - 1st run finds all the problems
    - 2nd run verifies the designed solution
- Close out of mock assemblies and transition to preparation for PRRs
  - Complete all FNAL safety documentation
  - Final updates to procedures



Key considerations or benefits of prototyping/testing of I&I fixtures and equipment

- **Mock Assembly fixtures prototyping full-scale geometries would be most efficient → re-use prototype fixtures during the production phase**
  - May consider buying a 2nd to be able to do some activities in parallel (row integration)
  - Required changes can be implemented in the prototype fixtures
- **Prototype transport/storage crate**
  - Prototype design and perform test shipments to verify performance → shock isolation, dust mitigation, protection → integrate data from test shipments for production crates
- **Documentation delivered during/at end of production**
  - All Near Detector activities will require formal documentation, the prototyping effort should both jumpstart and validate documentation for NS I&I, as well as provide adequate time for incorporation of proper FNAL required safety into the procedures (lifting, electrical, etc.)
  - All fixtures must arrive with the proper documentation or it must be provided beforehand
  - Compliance documentation must be complete

Responses to Previous Reviews (EDMS 2741842)

Recommendation / Comment	Responder(s)	Comments / Answers / Actions	Status
The prototyping plans for the integration and installation fixture test at LBNL will provide valuable information to reduce this risk, and those discussed in the next 2 sub-sections.	Lambert / Asaadi	Agreed. Unfortunately further design scope for fixtures has been delayed to 2024 due to funding profile issues. This also delays prototyping of fixtures and learning about any issues prior to Near Site activities. A risk has been added to reflect this.	Delayed
The installation team has developed a schedule at the conceptual design level. As the design of the fixturing progress the schedule needs to be further refined.	Lambert / Asaadi	Agreed. Unfortunately further design scope for fixtures has been delayed to 2024 due to funding profile issues	Delayed
The 2x2 prototype effort should provide valuable information to the installation team especially related to the testing needs and time requirements. It would be helpful in the presentations if the prototyping efforts are mentioned and the impact on the installation planning explained.	Lambert / Asaadi	Agreed. 2x2 experince will be incorporated into high-level planning for TPC I&I. Detailed planning will required restoration on design funds.	In-Progress / Delayed
It would be useful to know when the lessons learned from the different efforts are available to guide re-planning the schedule.	Lambert / Asaadi	Agreed. 2x2 and FSD activties should wrap up by 2024; final lessons learned can be acquired at this time. Additionally, experiences and knowledge gained leading up to 2024 can be incorporated where needed.	Closed
The labor below looks roughly reasonable to oversee the 20 scientists performing most the work., • Installation (2027 – 2029) ◦ 1.2 FTE Mechanical Engineer – Leading Surface Activities for ND-LAr (Lead Engineer leads Cavern Activities for ND-LAr) ◦ 2.7 FTE Mechanical Technician (75% FNAL Techs) – Execute Surface and Cavern Activities ◦ 1.0 FTE Electrical Technician (100% FNAL Techs) – Execute Surface and Cavern Activities ◦ ~20+ FTE Uncosted Graduate Students/PostDocs – Support This labor estimate relies critically on the availability of rigging and transport crews, cabling technicians, mechanical technicians from I&I, and transport infrastructure at FNAL. Knowledge of the planned I&I labor and the planned FNAL support services labor is required to judge the viability of the plan. Future presentation that show the big picture and then the installation piece will be helpful in judging the quality of the estimate.	Lambert / Asaadi	Agreed. Additional steps have been takedn to present TPC I&I in the context of the larger Near Site I&I team, particulary at the March 2022 US Cost Review. However, without a review dedicated to Near Site activities only it is difficult to capture the full scope. The TPC I&I team will discuss with Consortium Management and the Near Site I&I team how this might be better represented at the Preliminary Design Review.	In-Progress
Qa/QC: The EDMS documents linked to the work flow diagram are missing so the tests at each step are unclear.	Lambert / Asaadi	Agreed. This early in the design we are not yet ready to write dedicated EDMS documents for each procedure. These will developed when design funds resume in 2024 and fixture maturity is advanced.	Delayed
Additional work on the QC aspects of the installation are needed.	Lambert / Asaadi	Agreed. This can benefit from TPC A&T effort. Costed labor required to futher define QC aspects of the installtion are delayed to 2024. Uncosted labor efforts can continue.	Delayed

Responses to Previous Reviews (EDMS 2741842)

Recommendation / Comment	Responder(s)	Comments / Answers / Actions	Status
The installation team has defined the high-level requirements for installation. In general, the installation requirements are driven by the ability to install the detector so detailed requirements here are not normally needed. For installation the interfaces are far more critical.	Lambert / Asaadi	Agreed. Definition of installation scope and interface boundaries is underway.	In-Progress
The environmental requirements should be evaluated and included if required. These include temperature, humidity, air quality (dust) and UV protection for the photon system.	Lambert / Asaadi	Agreed. Dicussions with teams are on-going relating to environmental requirements.	In-Progress
If specific grounding needs or ESD protection measures are needed during installation then these should be included.	Lambert / Asaadi	Agreed. Grounding and shielding plans for the detector will be addressed at the system level. Specific requirements for TPC I&I shall be derived from this plan.	In-Progress
In general google docs are not appropriate for any document under document control. If google docs are referenced in presentations the plan for controlled documents should also be mentioned. System engineering practices will require an approval process with document release and a change log.	Lambert / Asaadi	Agreed and acknowledged. All documentation will be published to CERN EDMS for document control purposes. Change logs have been implemented in interface tracking documents. Approval processes will be required for PDR.	In-Progress
The interface and installation requirements defined in collaboration with I&I should serve as supporting documentation.	Lambert / Asaadi	Agreed. This documentation is now linked to ND-LAr EDMS.	Closed
The installation team has started the risk evaluation process and the efforts here need to continue. The impacted activities need to be defined for each risk in order to perform the Monte Carlo calculations.	Lambert / Asaadi	Impacted installation activties have been defined for the Monte Carlo analysis	Closed
The justification for the lack of in-kind contributed labor will need better defined to be able to model its impact.	Lambert / Asaadi	This risk has been redefined under a "build to cost" assumption	Closed
Potential additional risks could include: Schedule delay due to personal injury; Additional transportation costs inside FNAL; ESD damage during installation;	Lambert / Asaadi	These risks have been added to the registry	Closed
This will be the first time a large number of modules are operated together. Is there a risk that noise will develop as more modules are added to the system?	Lambert / Asaadi	Yes, however the 2x2 test program should provide valuable insight into this potential. We do have a risk in the registry that addresses sub-standard module performance.	In-Progress
Do you have a mechanism to seal the cryostat to get a low noise environment to test for noise sources?	Lambert / Asaadi	No. We have planned for faraday cages to be used on the modules during the surface and cavern work, but these are to be removed prior to installation to the cryostat. It may be possible to insert some shielding to provide this, but the requirements that necessitate this are unclear.	Delayed

Cost

EDMS 2742778

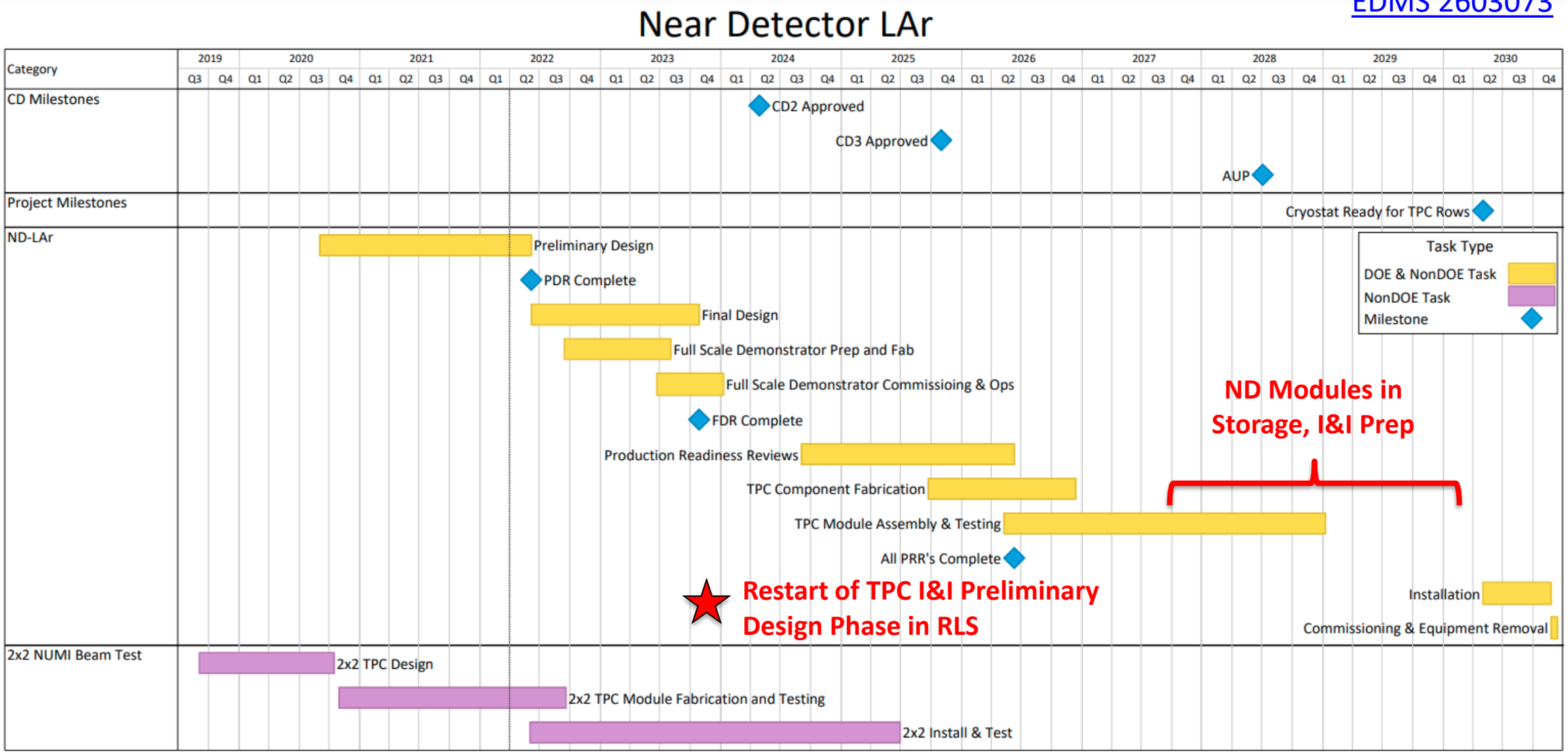
	Design & Prototyping				Production					
	On-Project		Off-Project		On-Project		Off-Project		On-Project	
131.ND.02: ND-LAr	M&S [CY-k$]	Labor [k-hrs]	M&S [CY-k$]	Labor [k-hrs]	M&S [CY-k$]	Labor [k-hrs]	M&S [CY-k$]	Labor [k-hrs]	Total Cost [FBAY-k$]	*Avg. Uncert.*
01 ND LArTPC Management	$401.5	18.3	-	43.9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

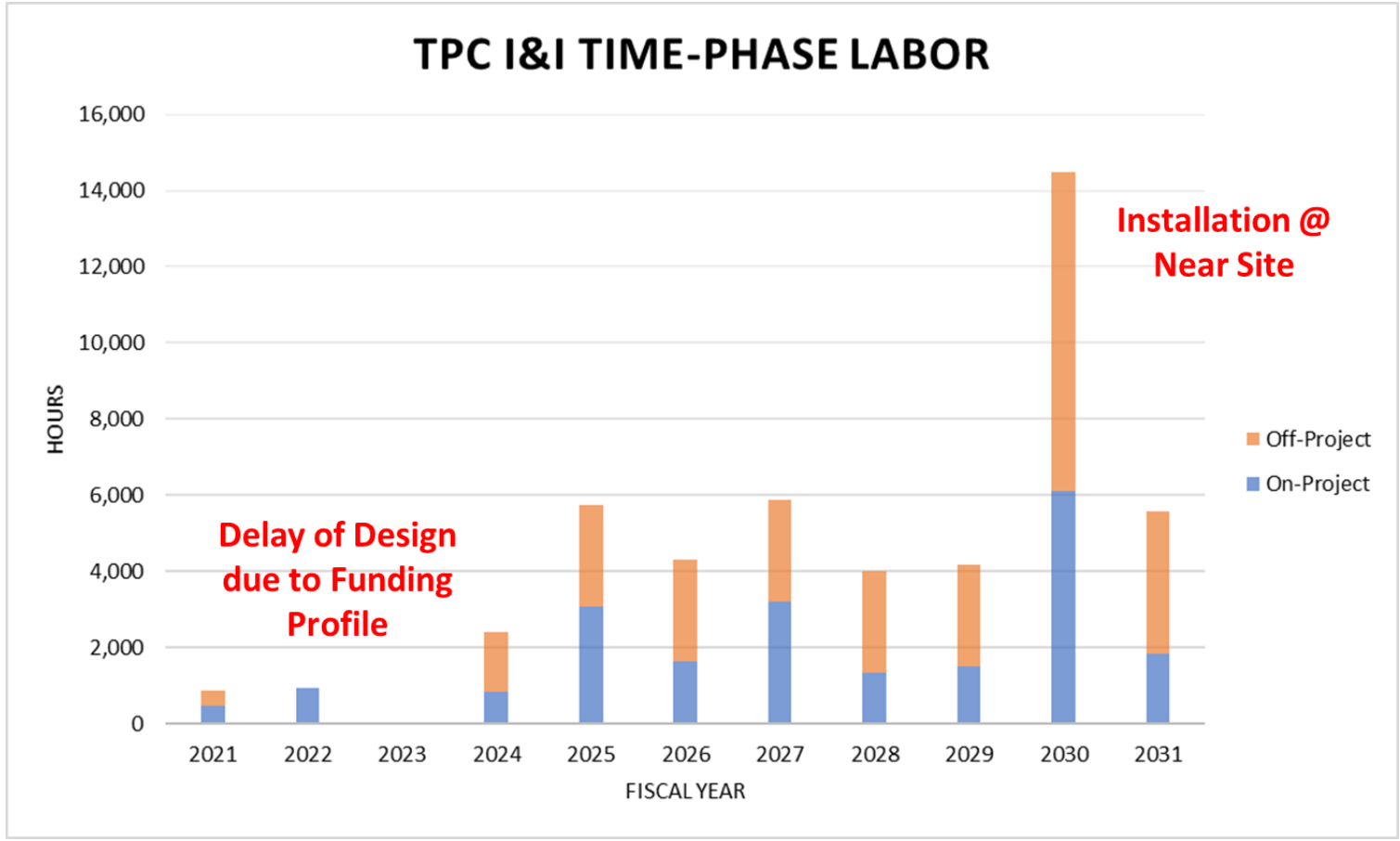
Schedule

EDMS 2603073



Concerns are related to delays in TPC I&I scope execution

- TPC I&I preliminary design scope delayed to 2024 due to budget profile issues



Summary

- TPC I&I scope is complete and well defined with scope boundaries delineated
- Requirements and interfaces are defined with documentation in place and under development
- Major risks are identified and entered in the Risk Registry
- Concerns about delays to TPC I&I scope have been communicated
- Prototyping efforts will help mitigate integration and installation risks

Outline

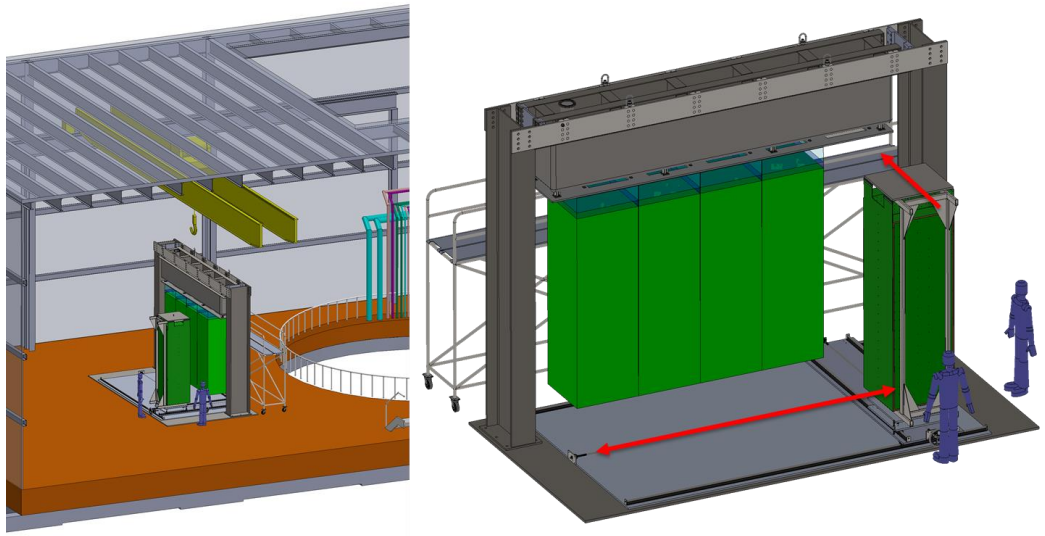
- Key Documents
- Design Elements / CAD Model
- Integration and Installation Plan
- Interfaces
- Documentation Tour
- EH&S / Codes & Standards
- Final Design plan
- Summary

Key Documents (EDMS 2611200)

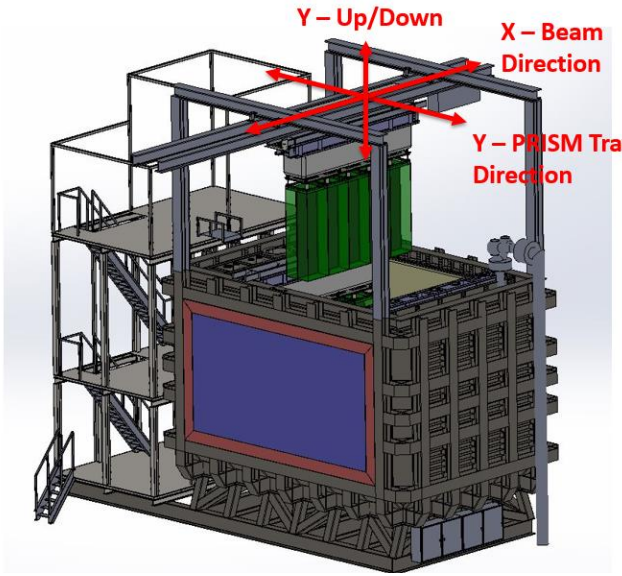
Folder/Document	Description	EDMS Link
TPC Integration & Installation Folder	Top level folder for TPC Integration & Installation documentation	https://edms.cern.ch/project/CERN-0000217532
Requirements	Spreadsheet with all ND-LAr requirements, see sheet "TPC Integration & Installation (09)"	https://edms.cern.ch/document/2589287
Internal ICDs	Interface control documents (ICDs) internal to the ND-LAr Consortium	https://edms.cern.ch/project/CERN-0000223195
Analyses	Collection of analyses write-up: FEAs, bench testing, 2x2 prototype evaluations	https://edms.cern.ch/project/CERN-0000231226
QAQC Plan	Subsystem QAQC plan with focus on high-level QAQC test plans	https://edms.cern.ch/document/2609927
Manufacturing Plan	Subsystem Manufacturing plan with focus on manufacturing methods of key items	https://edms.cern.ch/document/2609929
Procurement Plan	Subsystem Procurement plan with focus on procurement management of key items	https://edms.cern.ch/document/2609928
Integration and Installation Plan	Plan detailing TPC integration and installation at the Near Detector	https://edms.cern.ch/document/2742793
Previous Review Tracking	Spreadsheet with previous review recommendations, see "TPC Integration & Installation"	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 (Fixtures)	Solidworks "Pack & Go" and Parasolid exports of CAD models	https://edms.cern.ch/project/CERN-0000230732
Mechanical Component Drawings	Subsystem mechanical component drawings	https://edms.cern.ch/project/CERN-0000220716
Mechanical Assembly Drawings	Subsystem assembly drawing	https://edms.cern.ch/project/CERN-0000220717
Parts List	Subsystem parts list	https://edms.cern.ch/project/CERN-0000220718
Electrical Schematics and Board Layouts	Subsystem electrical schematics and board layouts	NA
Electrical Cabling and Wiring Specification	Specification of electrical cables/wiring	NA
Bill of Materials for Electronics Boards	Bill of materials for electroncis boards	NA

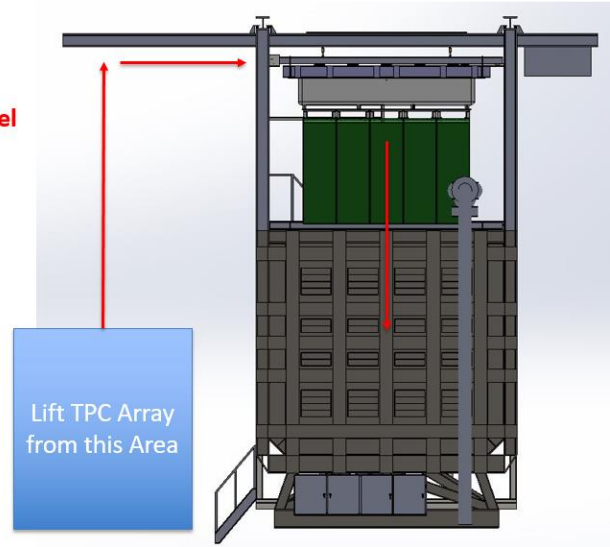
Design Status: I&I Fixturing

- ND-LAr TPC I&I fixtures largely unchanged since June 2021 Review (labor rampdown from TPC I&I of Mechanical Designer, T.Rathmann in Summer 2021; Mechanical Engineer, R.Kuravi in Fall 2021) – accomplished as much as possible with effort prior to ramp-down
  - Row Integration Fixture
  - Row Installation Fixture
  - Row Lifting Fixture



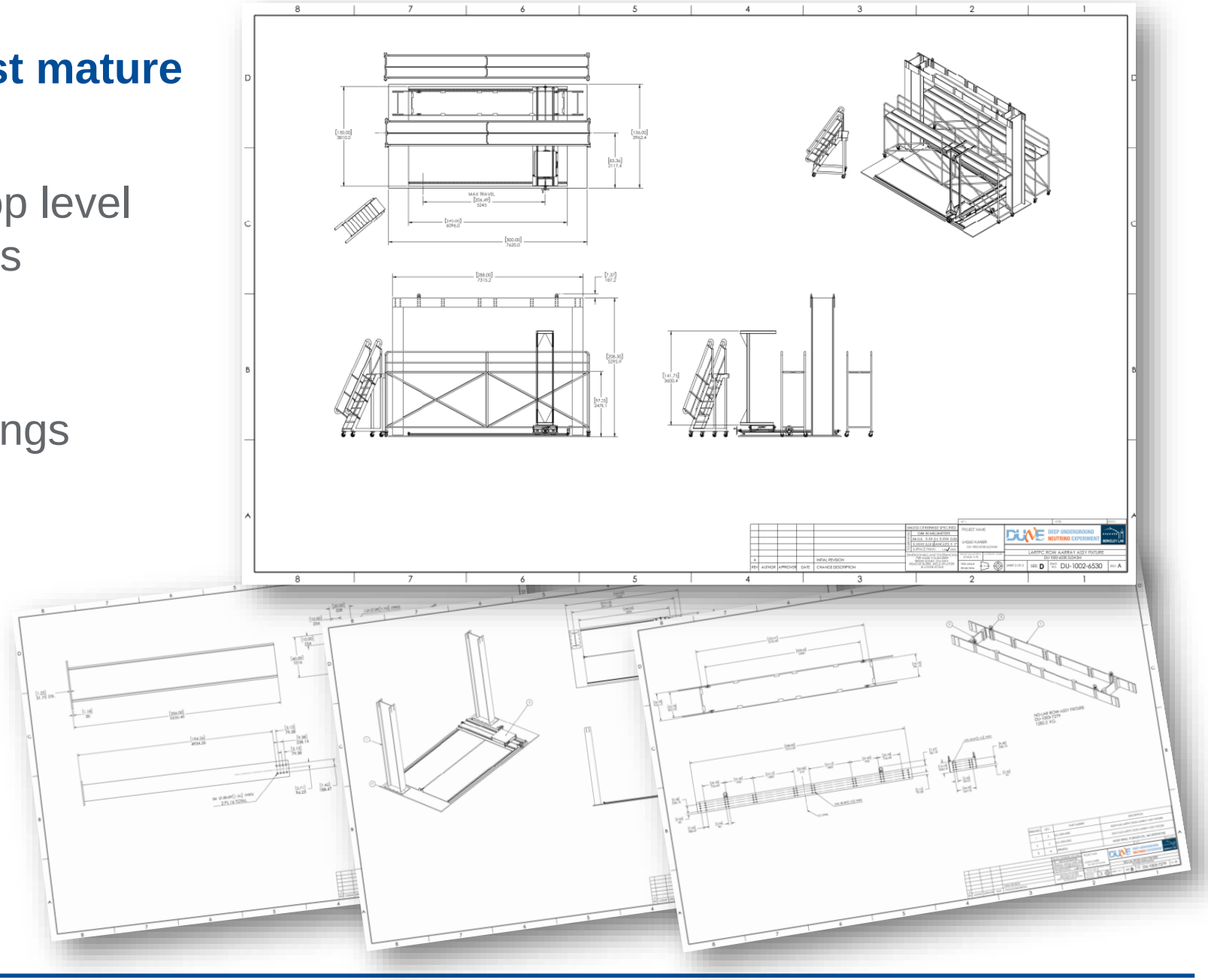
Add surface vs cavern work labels





Integration Fixture is the most mature fixture for TPC I&I

- Assembly drawing draft for top level assembly and sub-assemblies
  - EDMS 2749588
- Some component level drawings complete
  - EDMS 2749587
  - Not fabrication ready
- Maturity of Fixture
  - 40% level



Preliminary ND-LAr Integration and Installation Plan

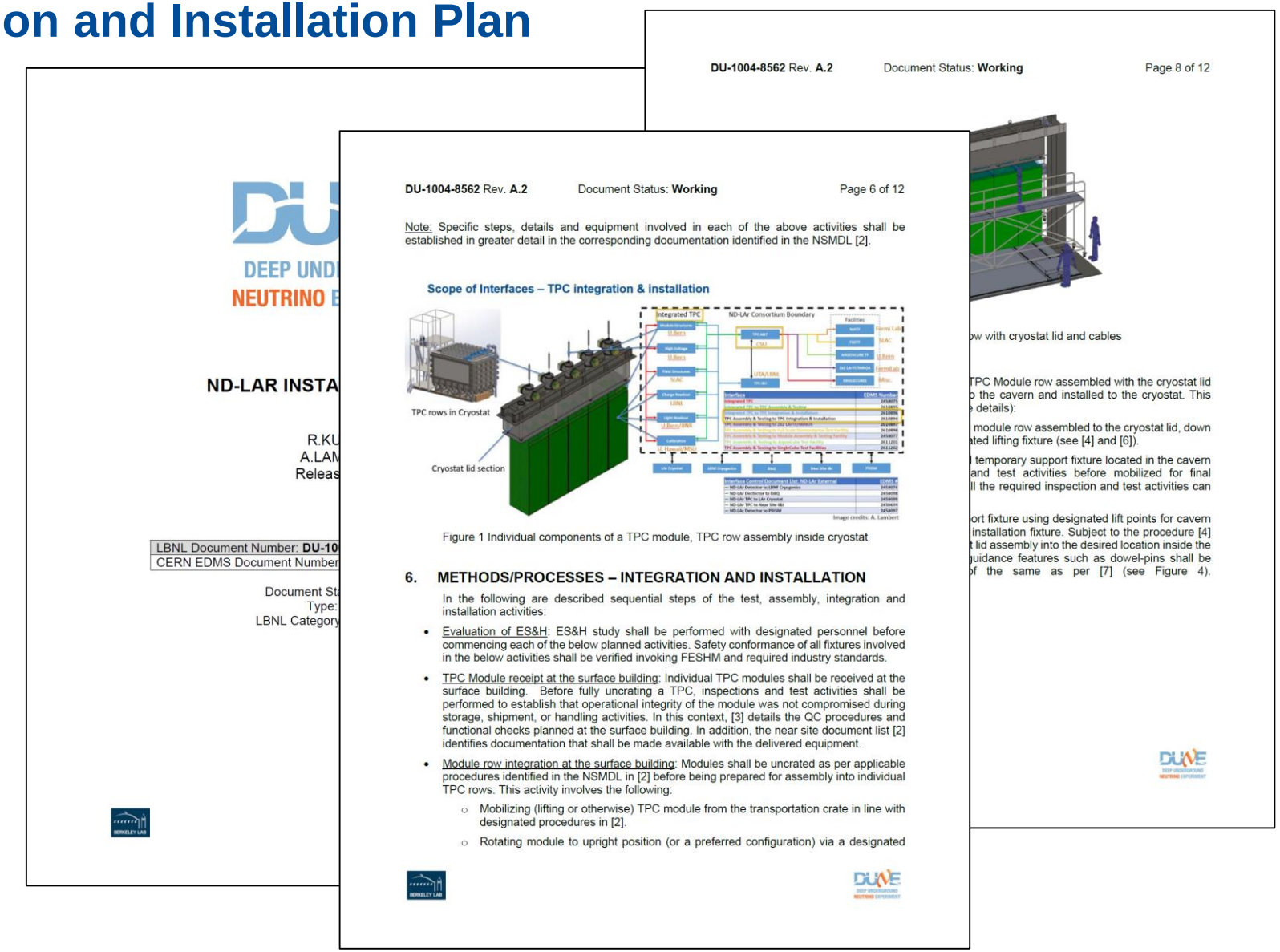
- Found at [EDMS 2742793]

  - High level summary of TPC integration and installation at Near Detector

  - Covers surface building and cavern work

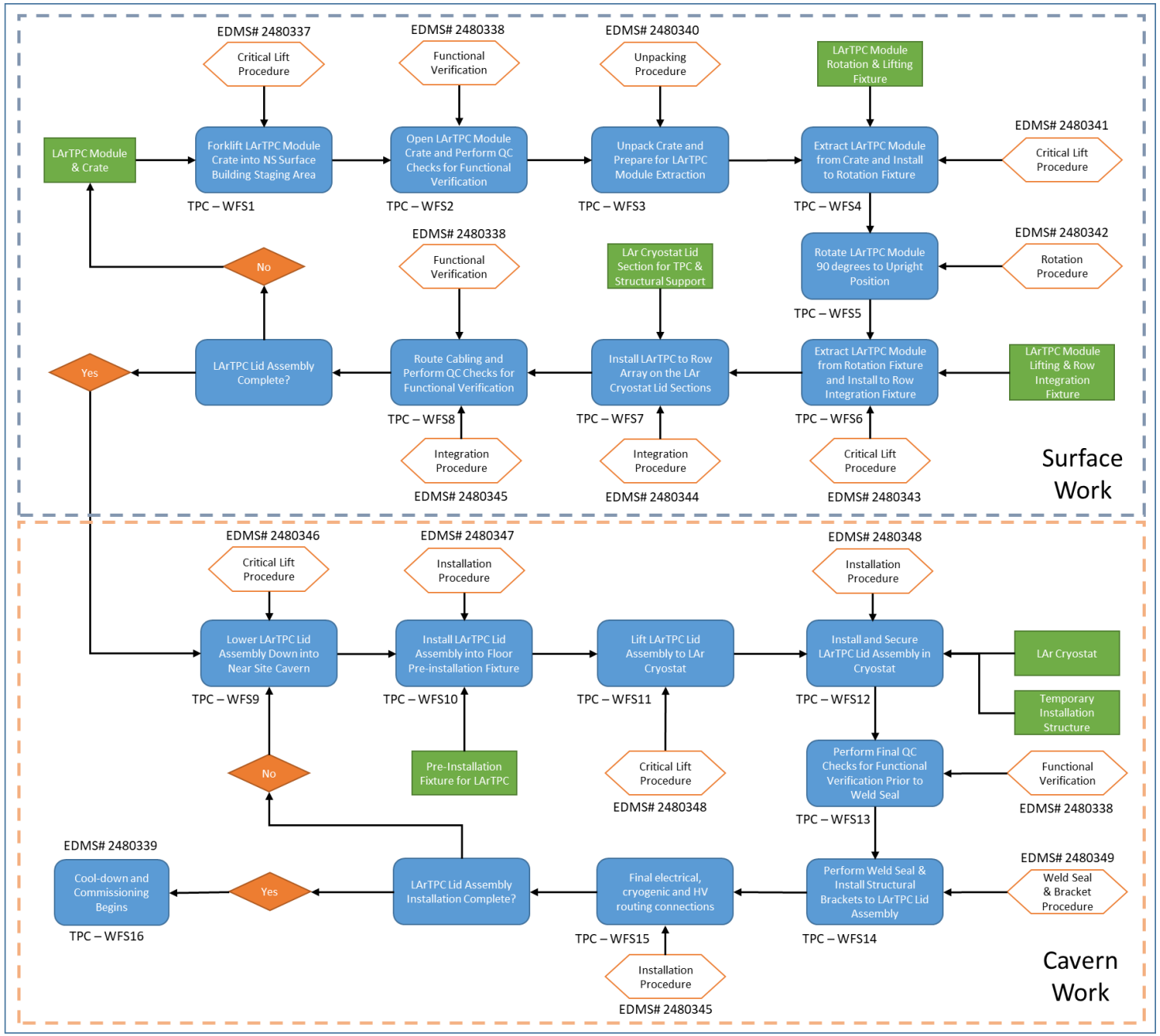
  - Details on following slides

- Work closely with ND I&I team, attend bi-weekly meetings

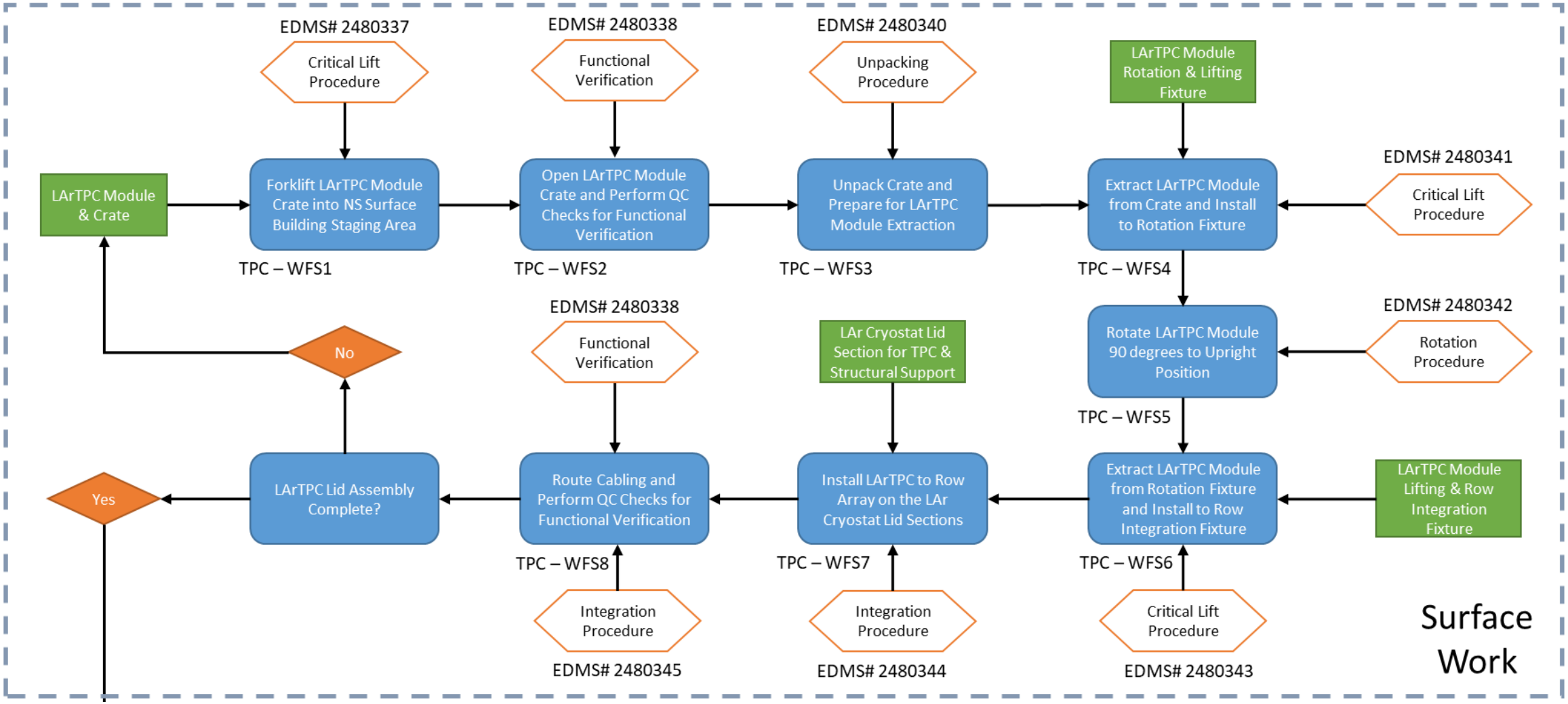


ND-LAr Workflow: TPC Integration & Installation Workflow Diagram

- ND-LAr TPC Workflow - High level summary of TPC Installation Activities from receipt of TPC modules to installation into the cryostat
  - EDMS 2480350
- Green Rectangles: Items that are to be integrated together
- Blue Rectangles: Integration & installation activities
  - WFS = “Work Flow Step”
- Orange Hexagons: Required procedures for a given activity
- Orange Diamonds: Binary decision trees
- EDMS #’s for procedures are placeholders, we do not have detailed procedures yet (will touch on this later)

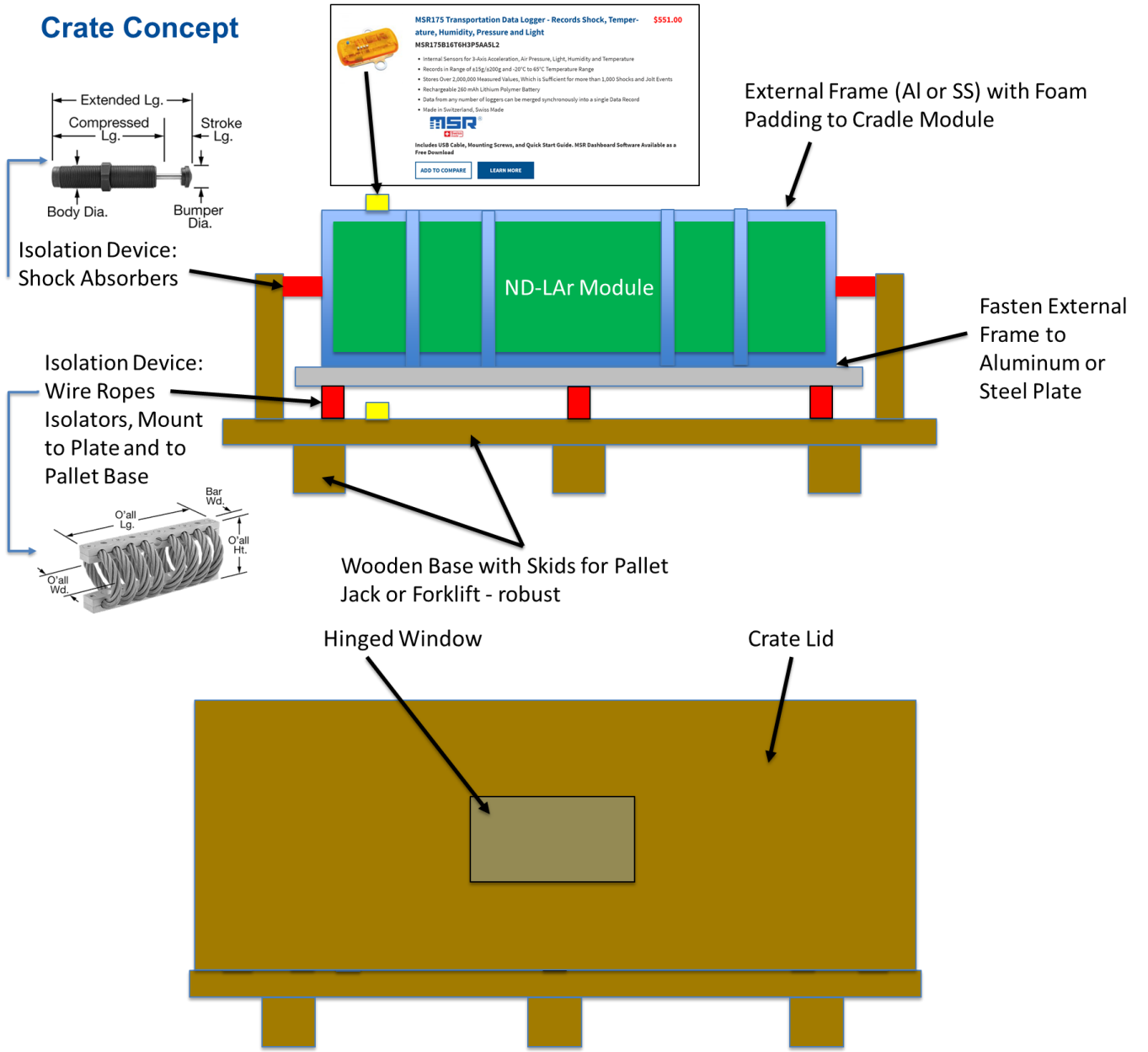


Surface Work is focused on integrating TPC rows and qualifying them for installation to the cryostat in the cavern



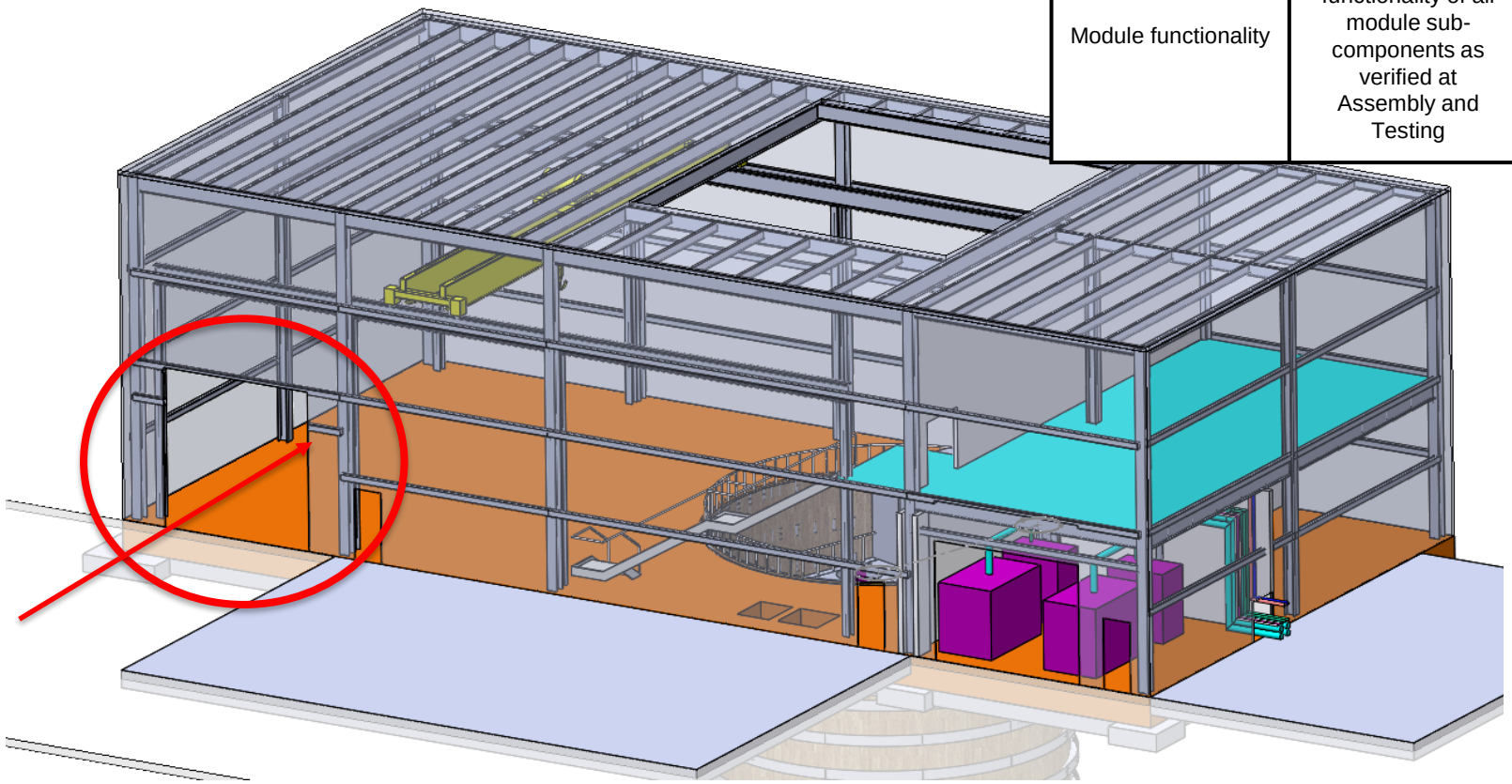
Storage Crate work

- 2x2 modules successfully shipped in load isolating crates (below) to FNAL
  - Shipped and stored in vertical orientation
- ND modules will need to be shipped and stored horizontally due to their overall size (right)
  - TPC A&T packs modules and “hands off” to TPC I&I for storage and transport to Near Detector



Module Receipt at Surface Building involves forklifting of module crates, staged unpackaging, and functional verification on module before integration

Name	Description	Value	Rationale	Notes
Module functionality	I&I will install, test, and maintain functionality of all module sub-components as verified at Assembly and Testing	- Charge R/O Channel integrity: XX% - Light R/O Channel integrity: YY% - HV/Field Cage Resistivity: ZZ%	Maintain fidelity of the modules following A&T	Requires documentation from A&T at the module-by-module level



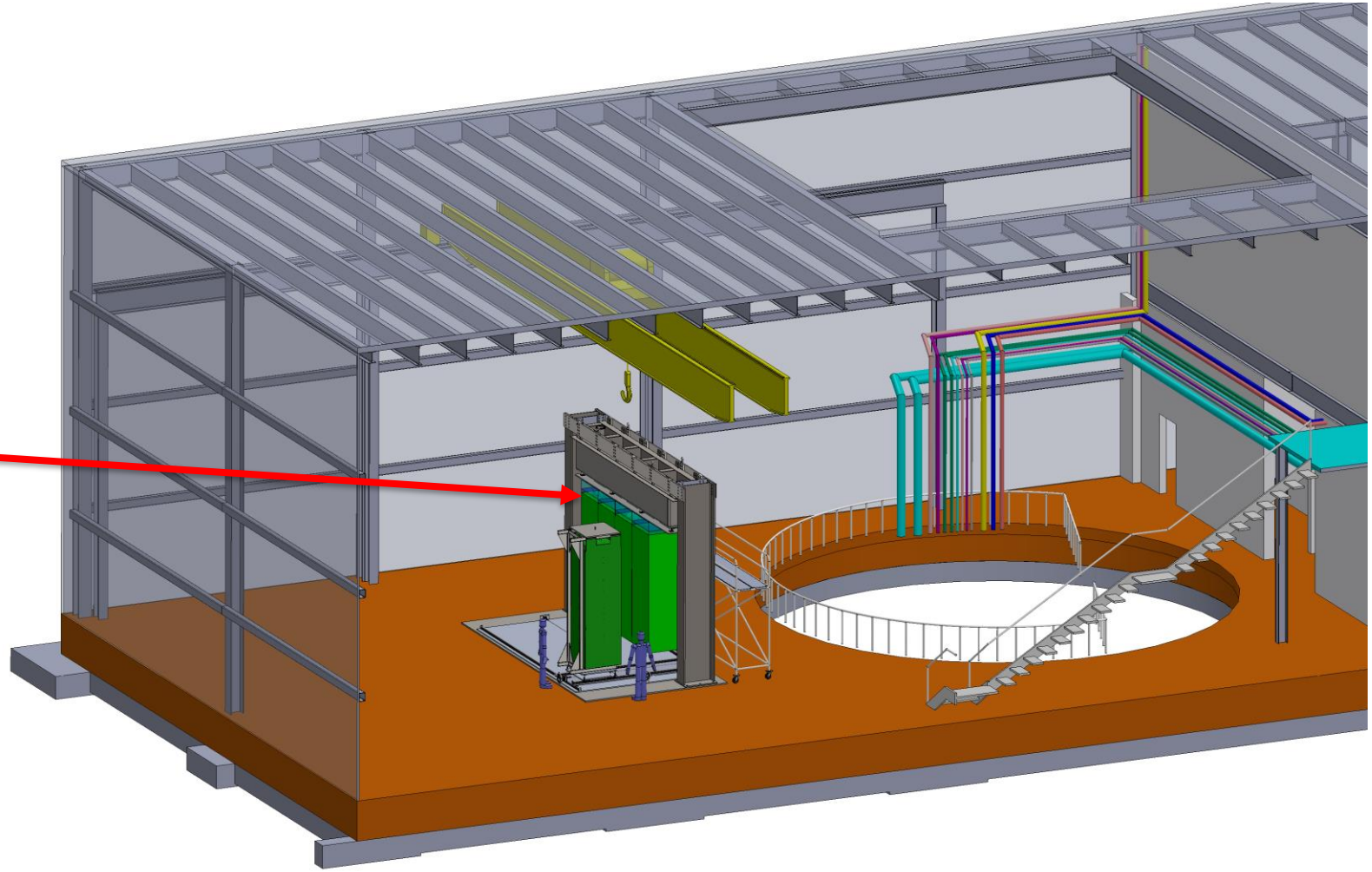
- When modules come in the door they require a series of room-temperature functional checks to verify that system status has not changed
  - Charge
  - Light
  - HV/Field Structures
  - Calibration
- If a module does not pass a functional check it will need to be replaced with a spare; the non-functional module will need to be assessed at a TBD location

After successful functional checks modules are fully unpackaged, inserted into rotation fixture (same as used in TPC A&T, Jay's talk), rotated, and prepared for row integration

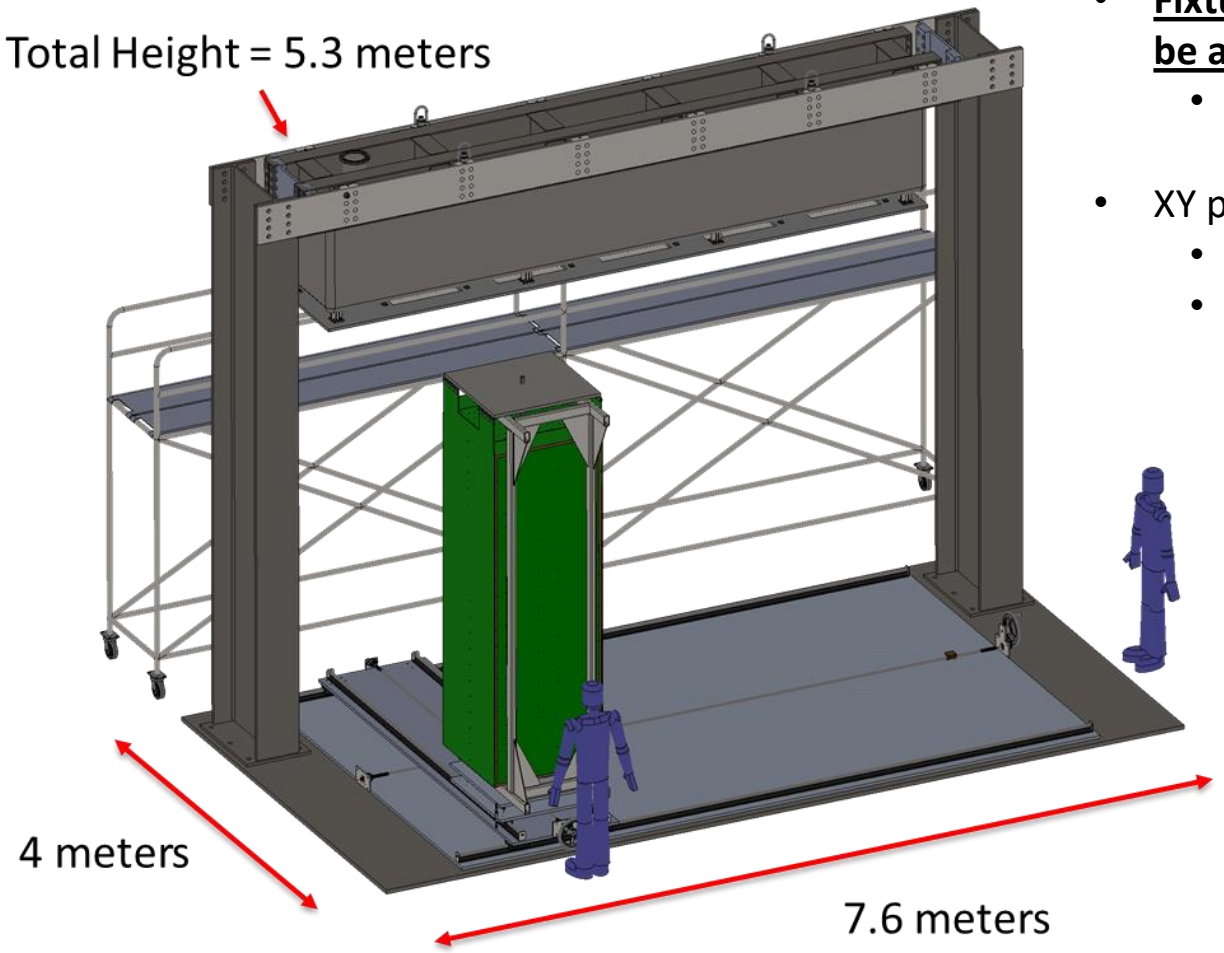
ND-LAr TPC module integration to cryostat lid sections in Near Detector Surface Building

Must also integrate:

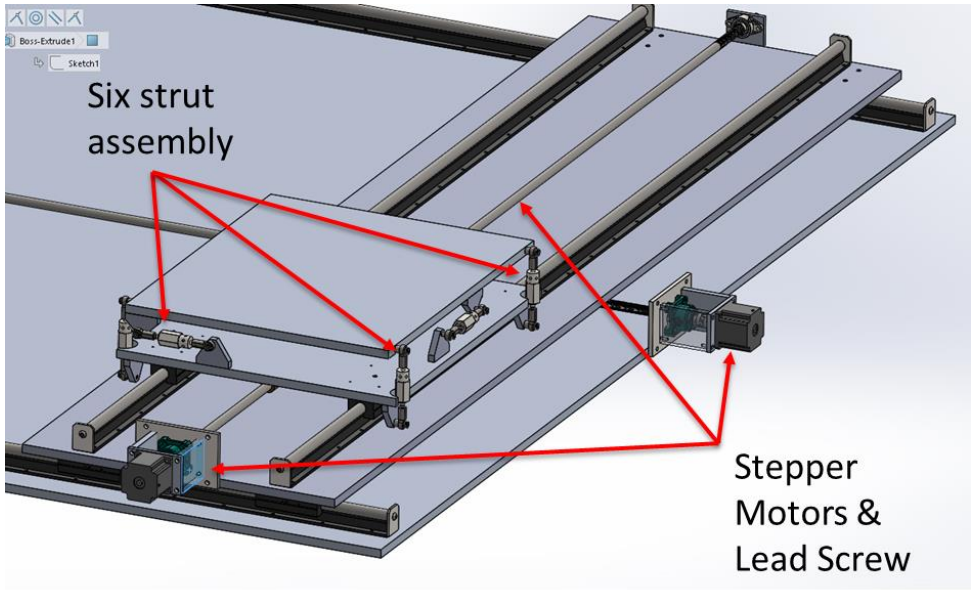
- LAr supply lines
- Supports to cryostat lid
- Row support frame



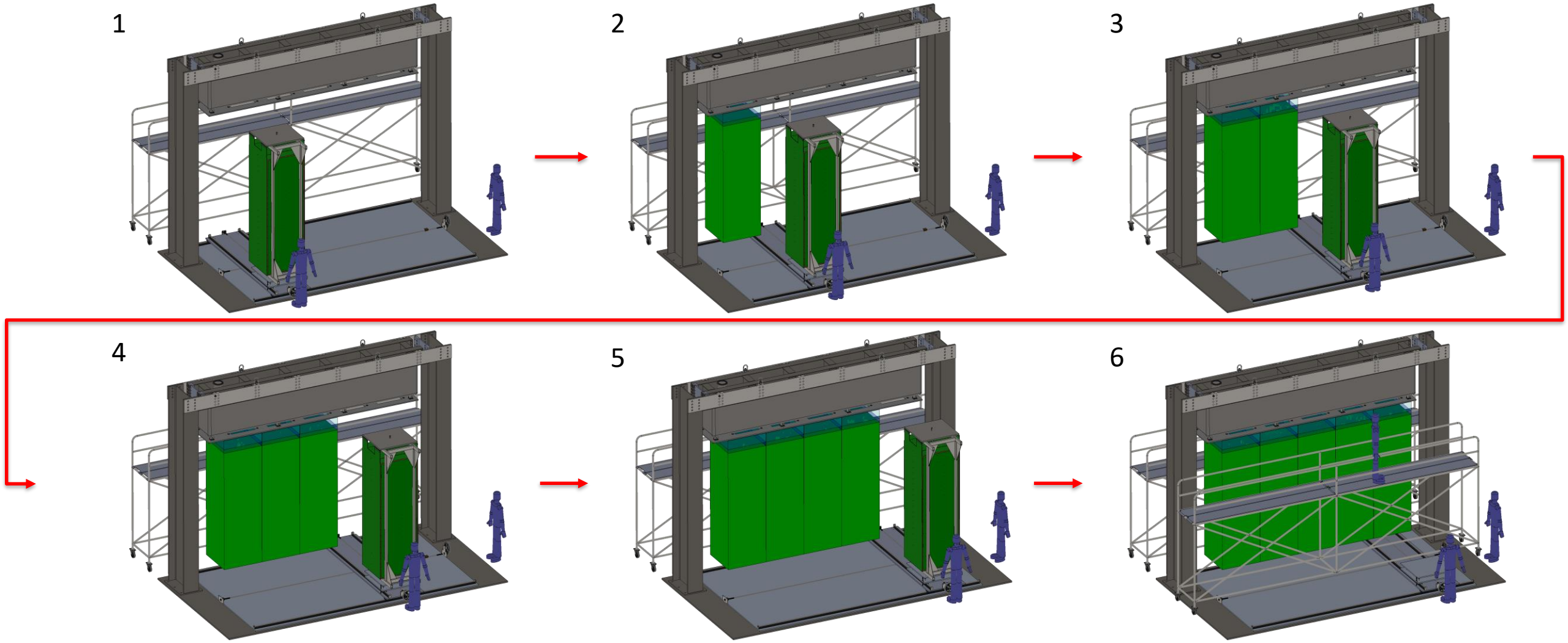
Module row integration is where ND-LAr and Cryostat WBS elements first meet at the Near Detector; must integrate module row services and TPCs to lids



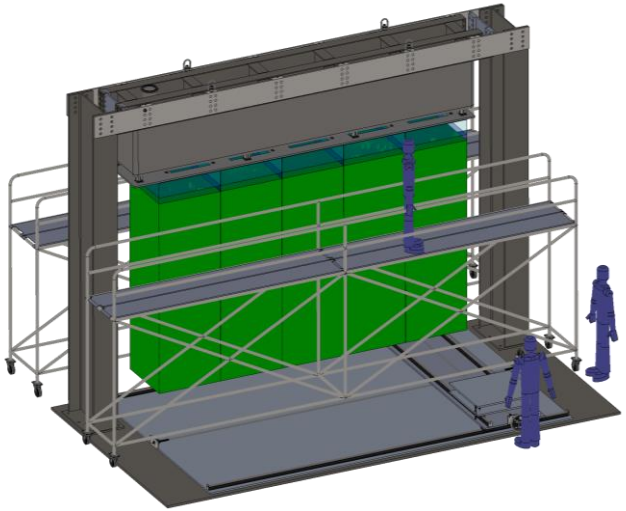
- **<u>Fixture to install 5X modules in a row to the cryostat lid section – must be able to both install and remove modules</u>**
  - **<u>Fixture also allows for install of LAr cooling lines and module row support structures</u>**
- XY positioning via stepper motors and lead screw
  - Allows for fine adjustment and control
  - Six strut assembly for final raising & adjustment of module to row support structure



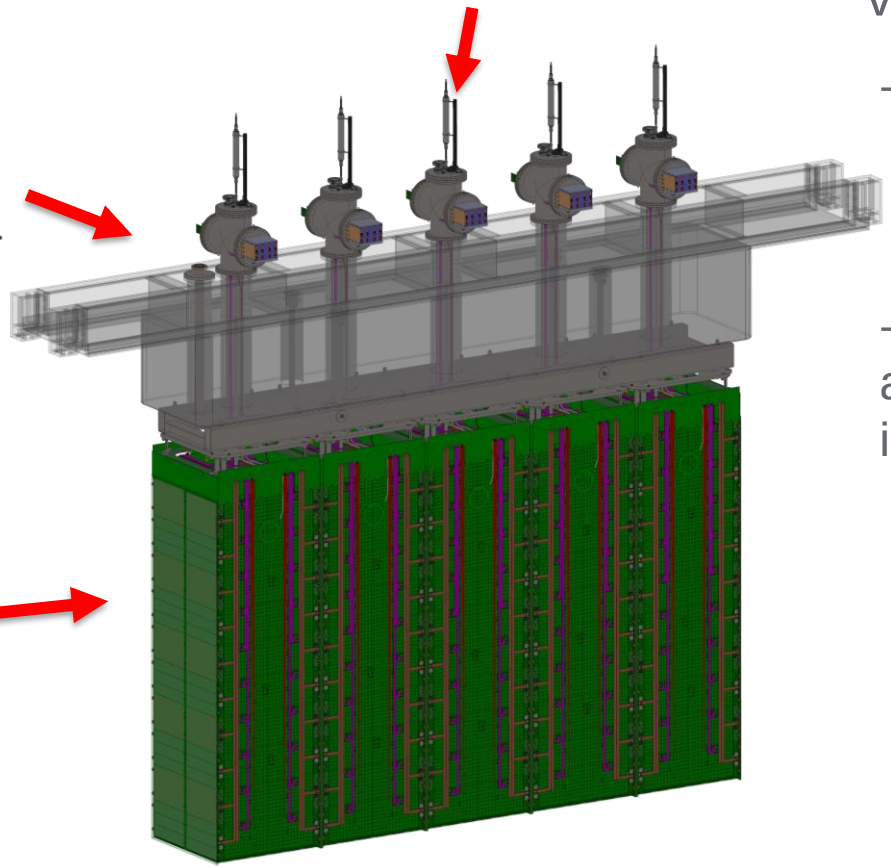
Modules are integrated sequentially; installed to row support, cables routed up through lid, feedthroughs installed, warm checks prior to cavern work



Integrated TPC rows go through warm checkout / functional verification before transfer to cavern; must avoid bringing a row back to surface for re-work



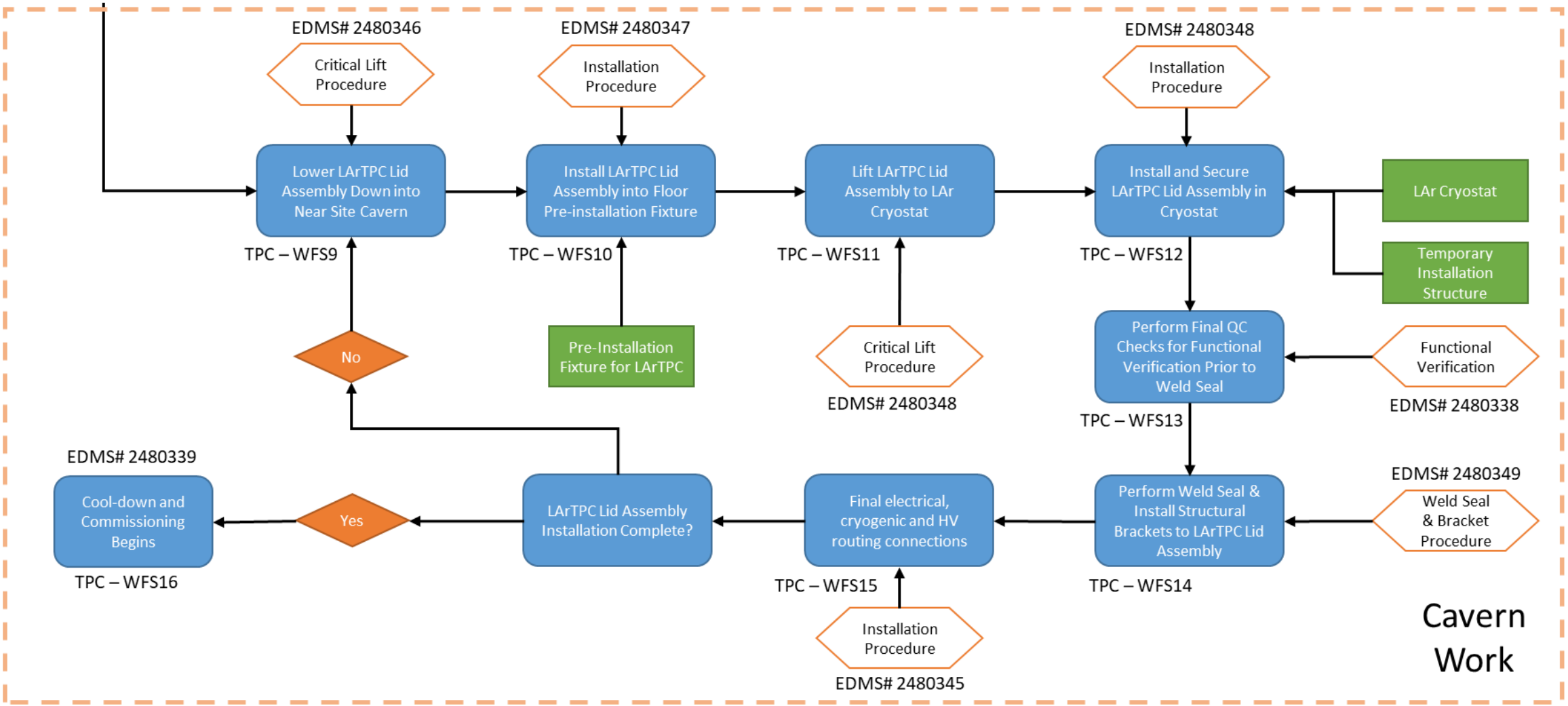
Feedthroughs installed, warm electronics installed



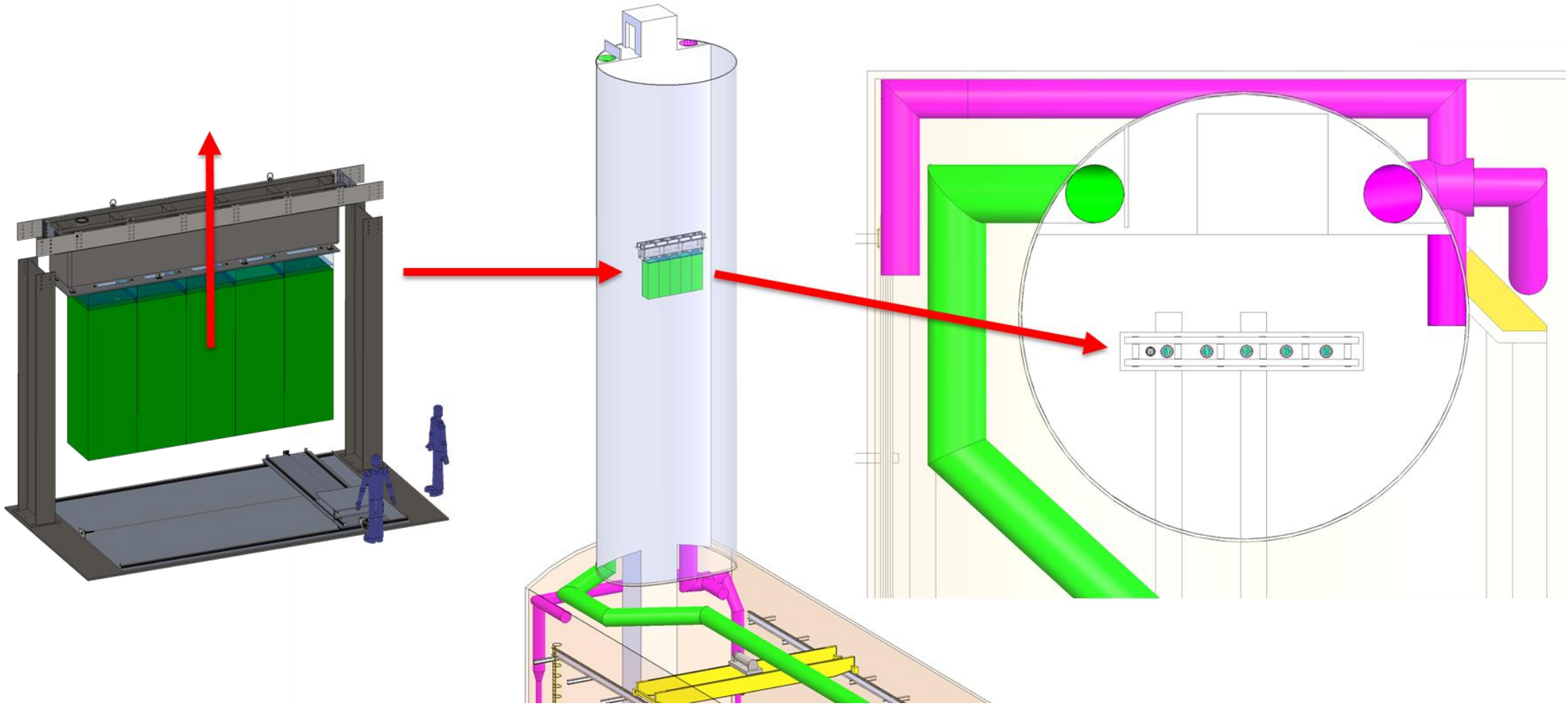
Power, ground, and data cables routed, fibers routed

- Prior to lowering into cavern, all TPC must have passed a functional verification
  - **When this verification step occurs:**
    - **After each TPC is installed & routed**
    - **After full row is integrated**
  - Ideal to do a functional verification with a power & DAQ setup close to the final installed configuration
    - **Re-use DAQ setup from TPC Assembly & Testing**

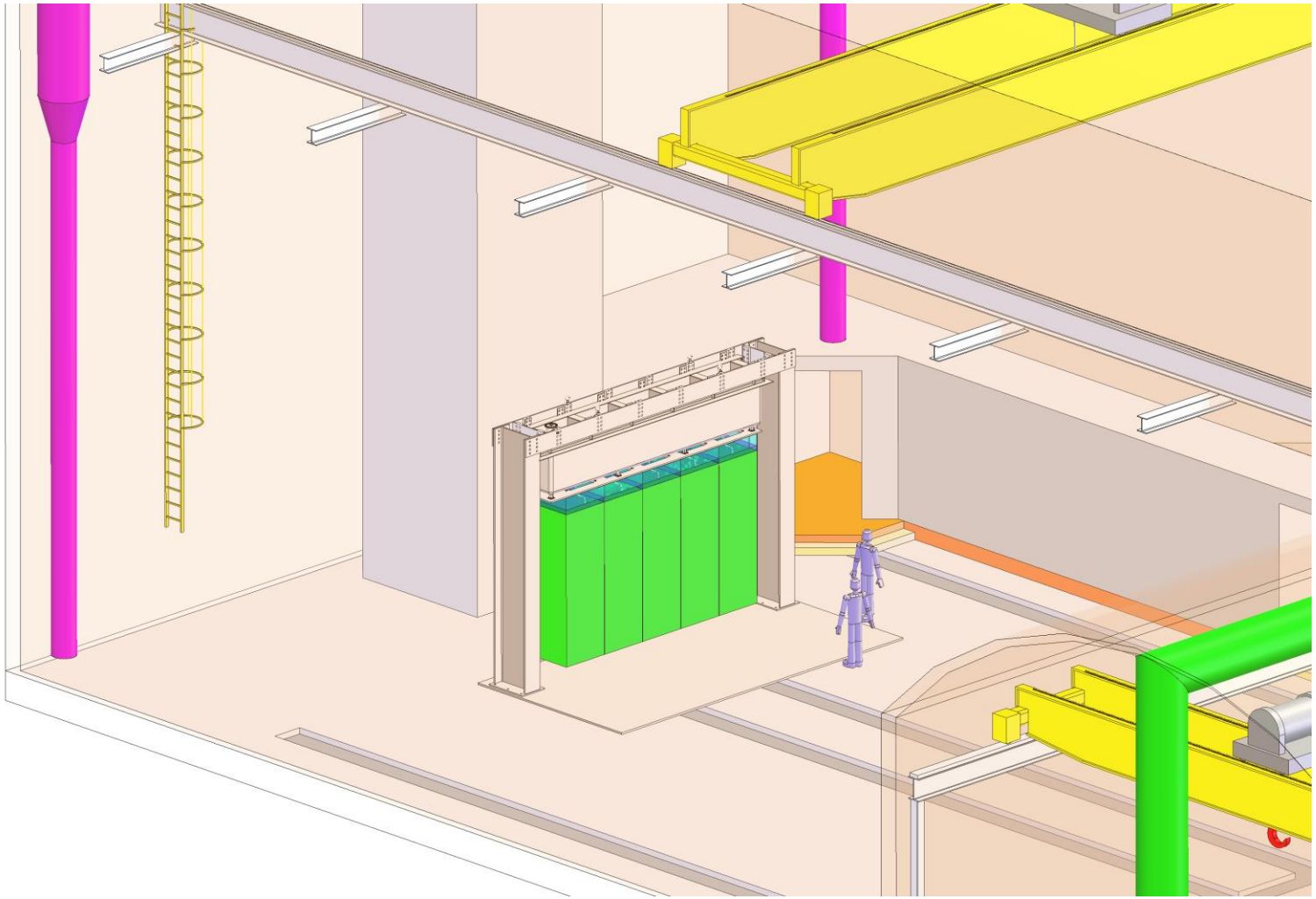
Cavern Work is focused on installing completed TPC rows to the cryostat, dressing the top of the detector with warm electronics, and commissioning



Module Row Lowered Down Cavern Shaft; this is most certainly a high-consequence / critical lift and will need to be closely coordinated with ND I&I



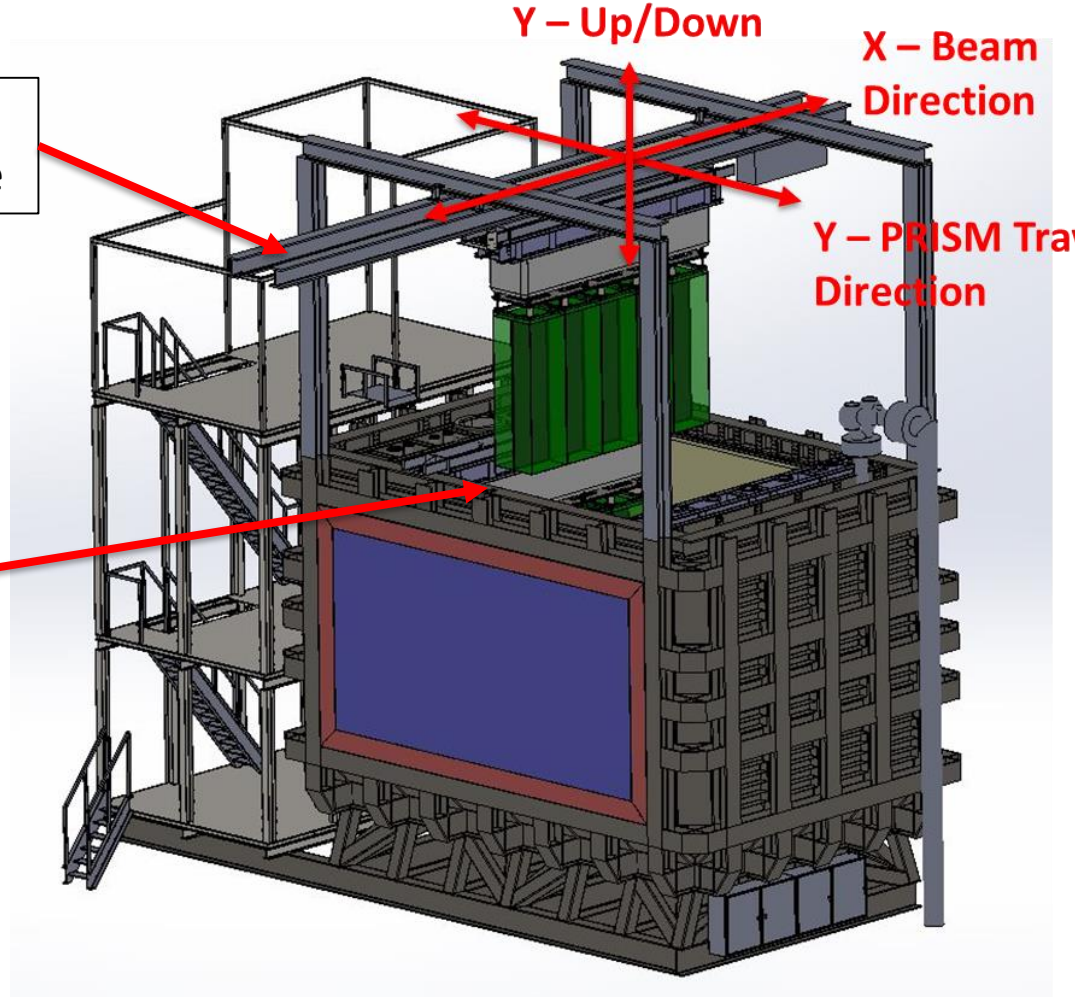
Module Row on Cavern Floor; verify no issues post lowering into cavern, if go-to-go prepare for installation to the cryostat

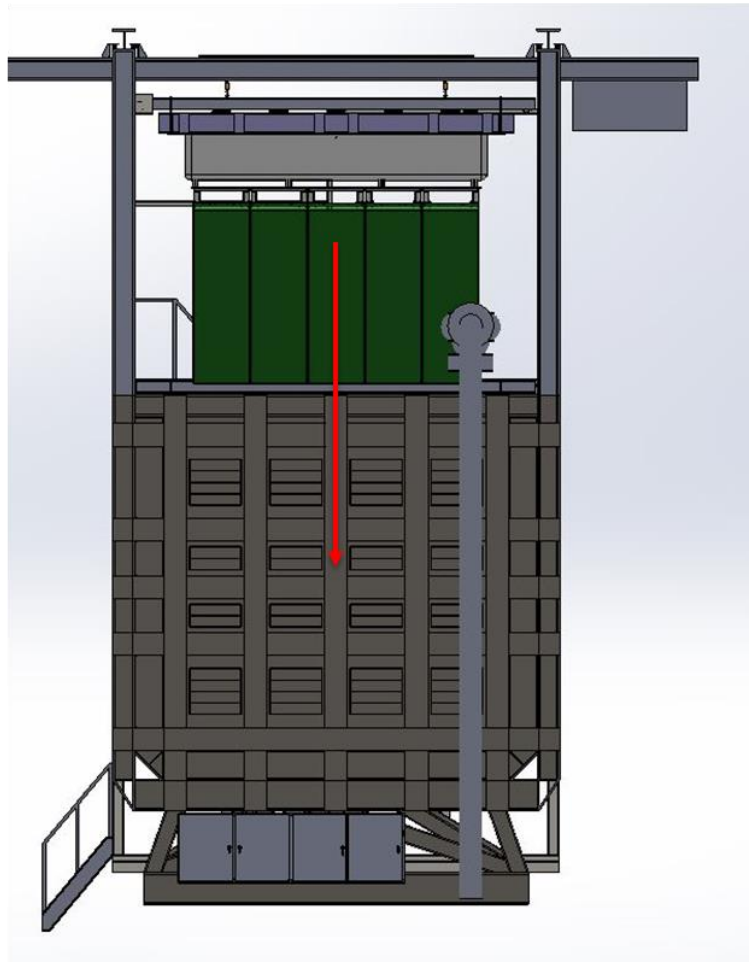


Use auxiliary crane on overhead bridge to pick-up, position, and lower TPC rows to LAr Cryostat → additional installation jigs/fixtures to guide lid section to final position

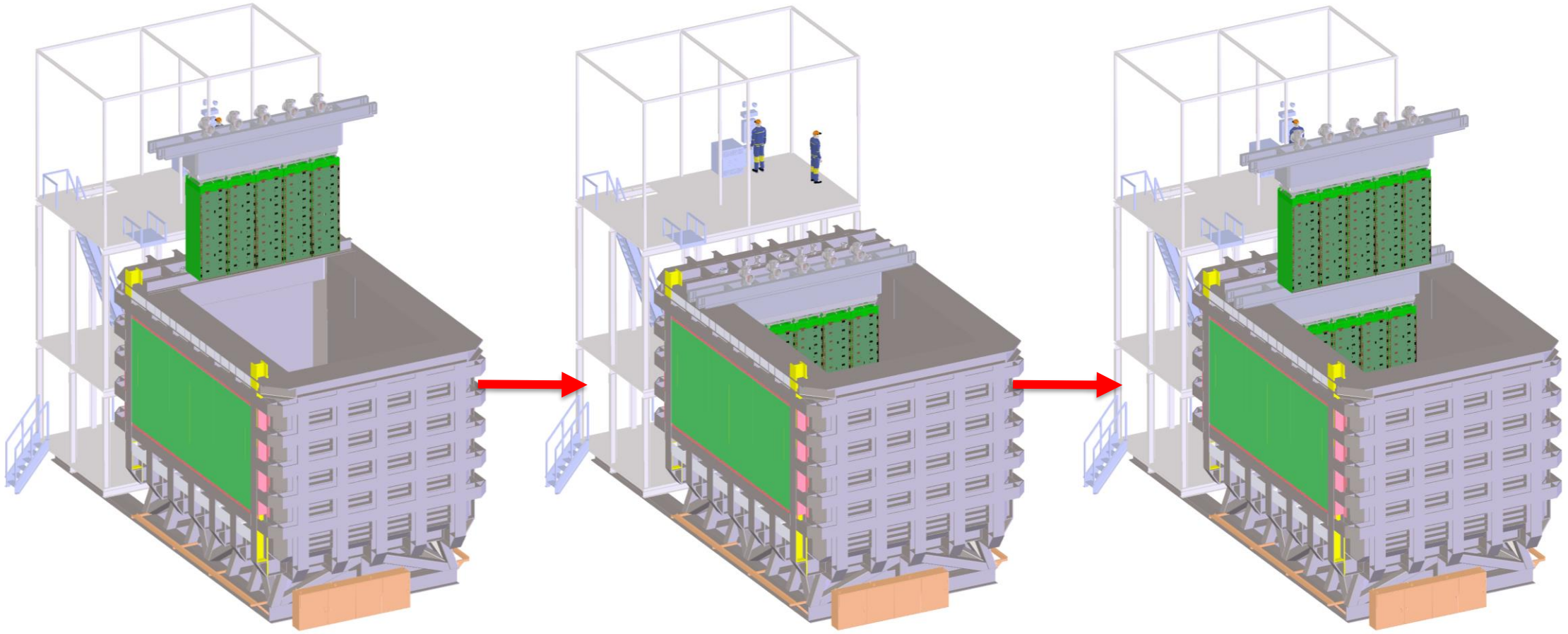
Proposed installation fixture

Additional fixturing / jigs near landing for final alignment

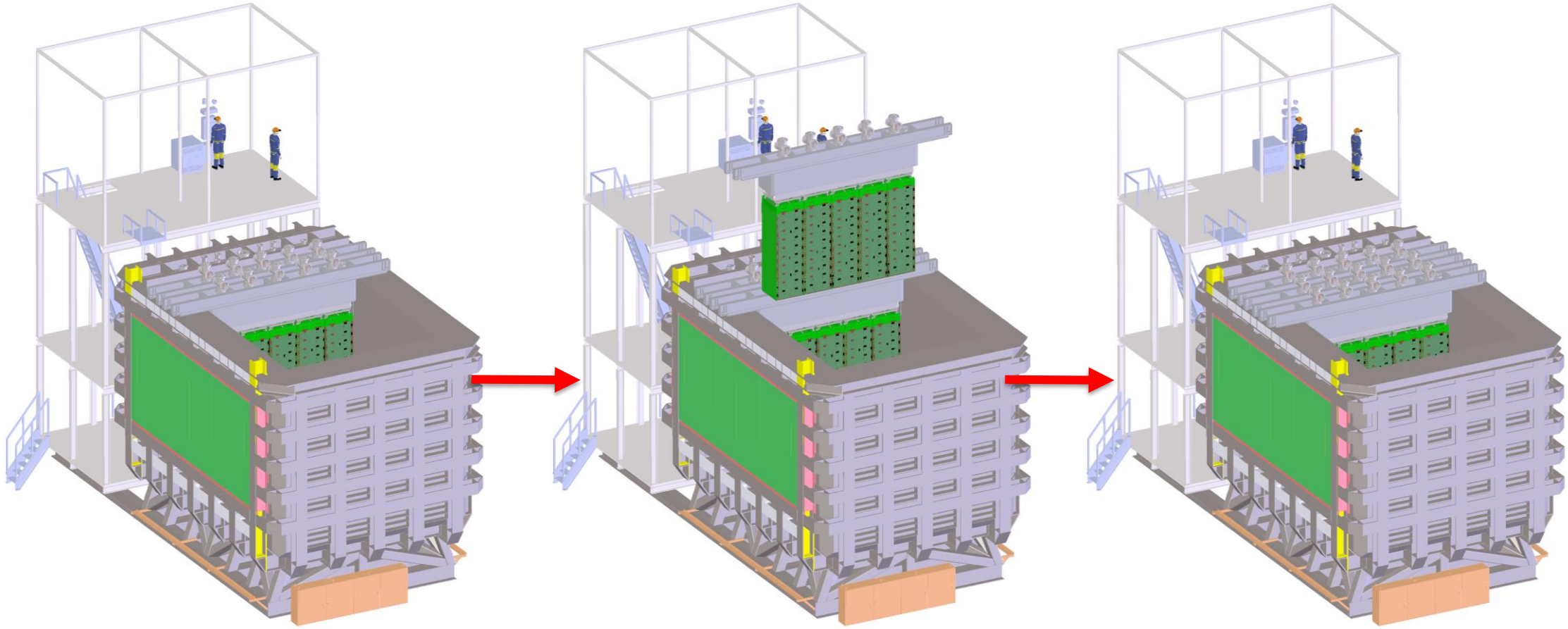




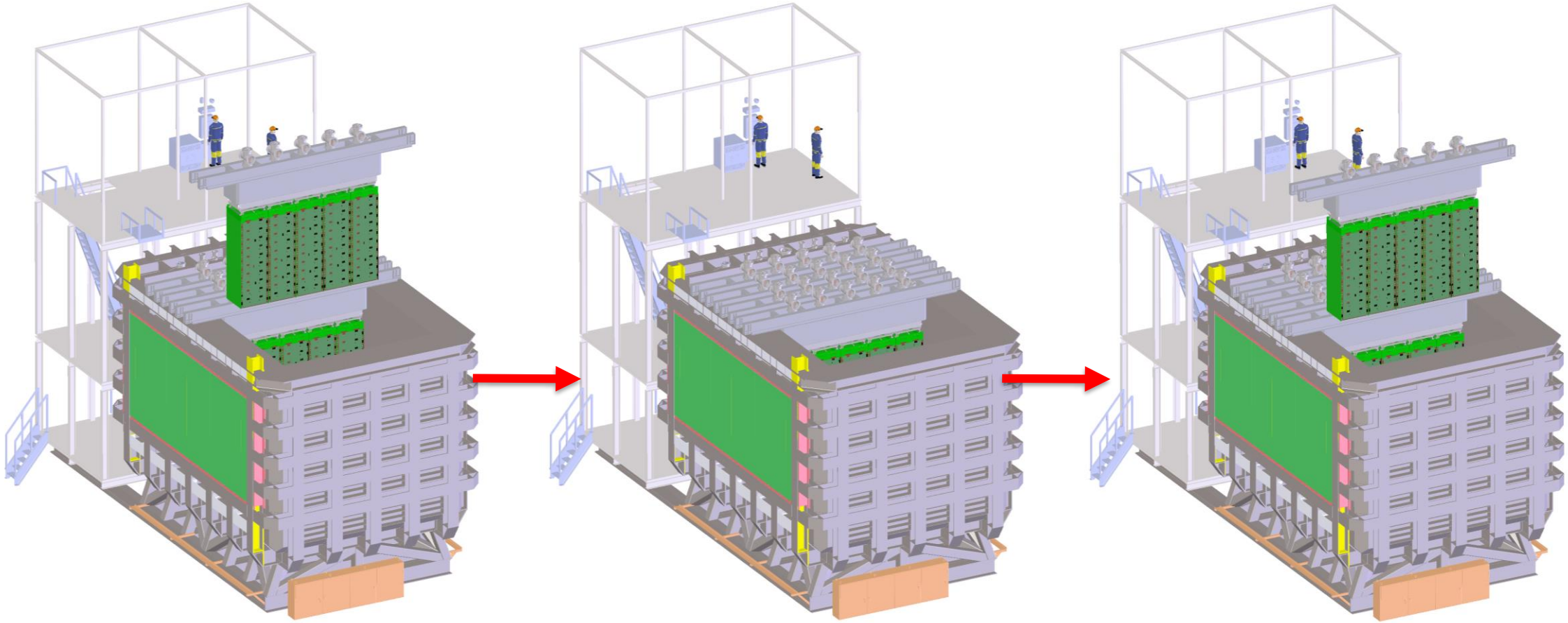
Installation sequence to LAr Cryostat; lid sections are segmented in similar design to SBND → Perform final functional checks on TPC prior to lid weld seal



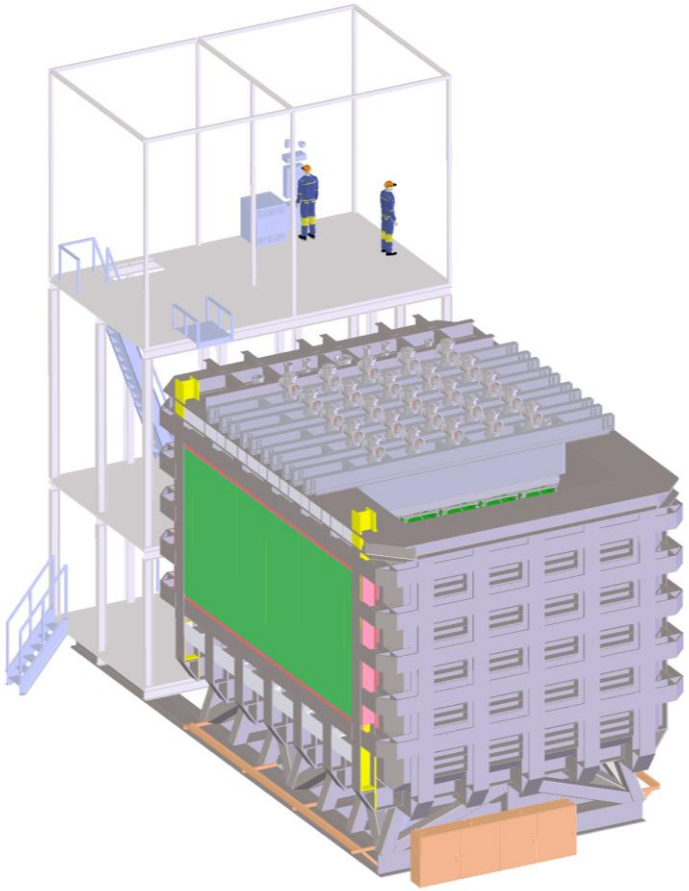
Installation to LAr Cryostat; remaining challenges are core mechanical engineering → Mechanical alignments, tolerances, fixtures, procedures, etc.

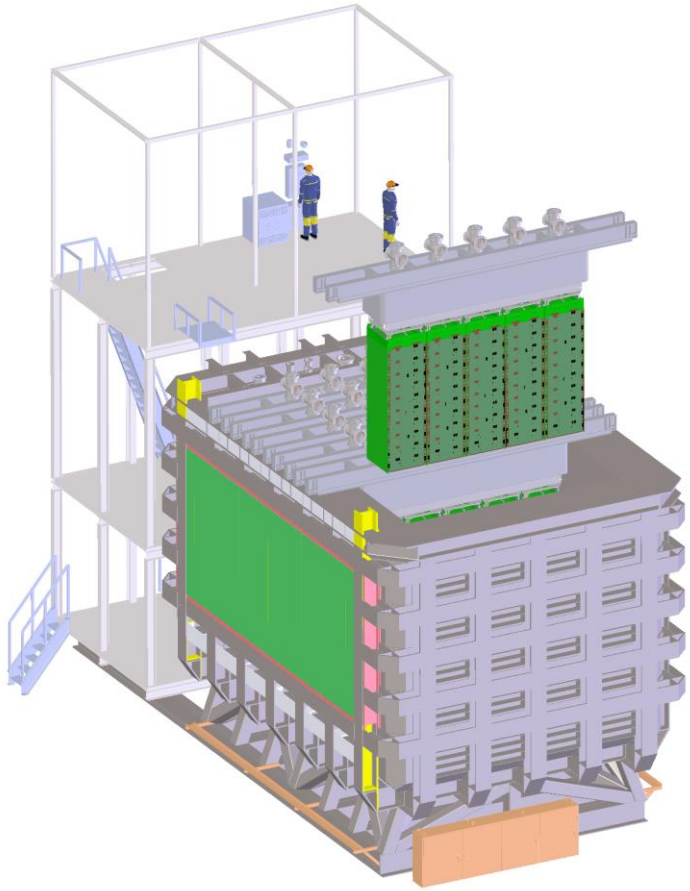


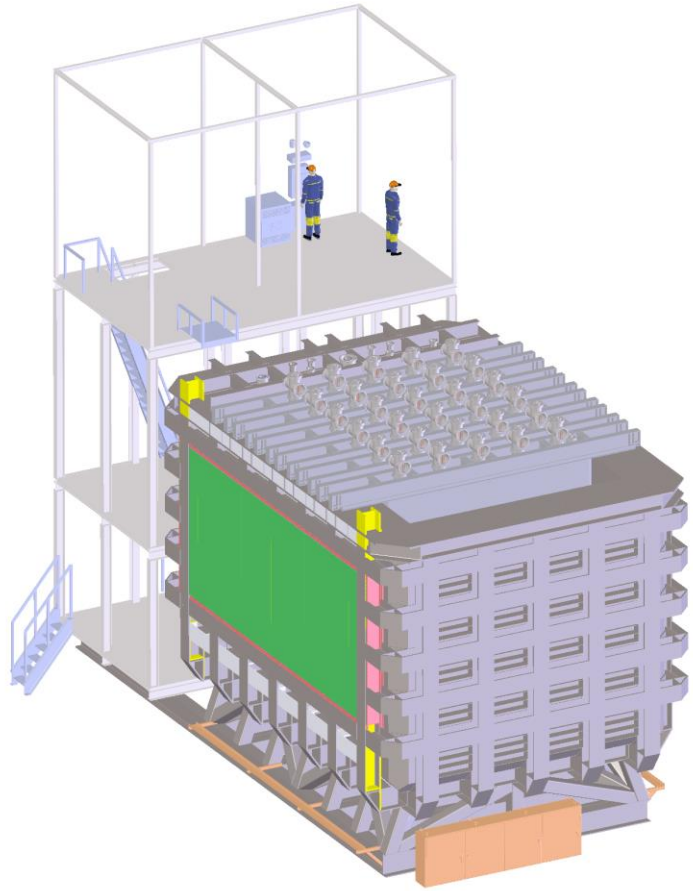
Installation sequence to LAr Cryostat; installation requirements are reasonable and ND-LAr can get it done → Incorporate experience from 2x2 and SBND



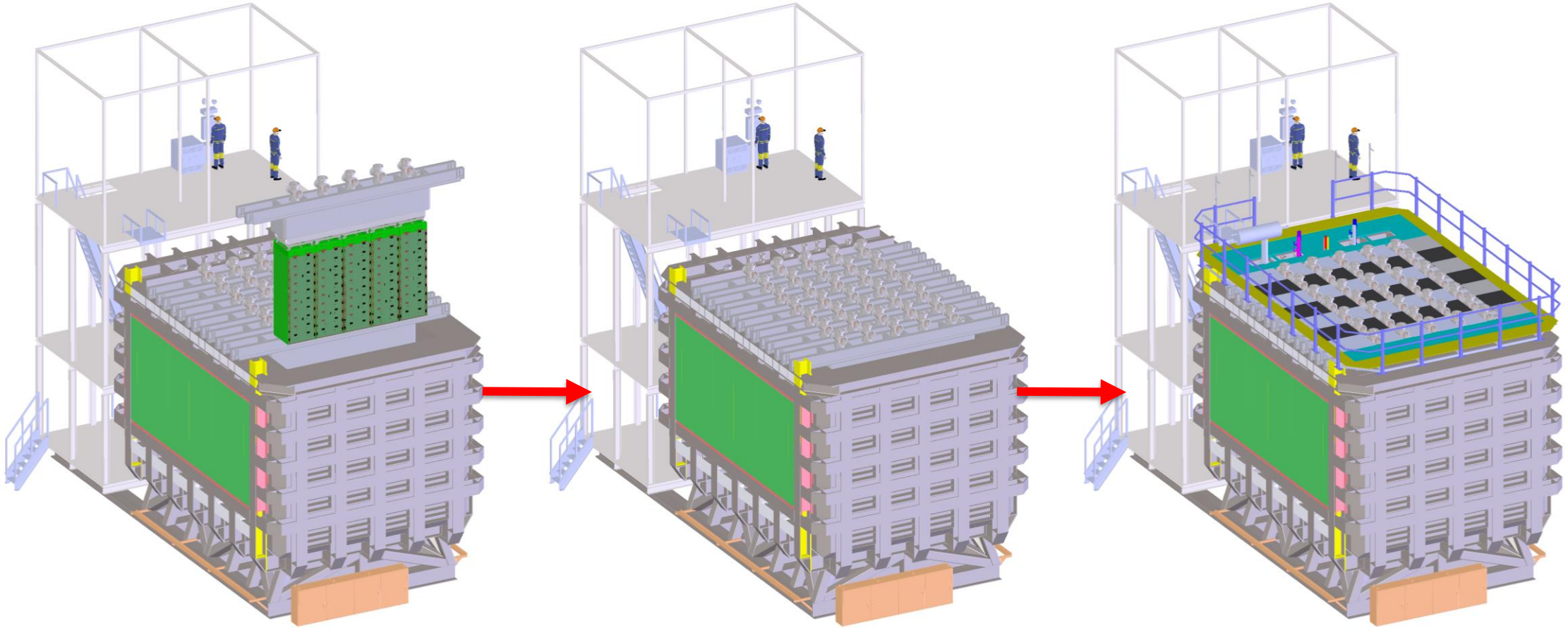
Installation sequence to LAr Cryostat; current plan is that post FSD funds materialize → pursue further design of I&I fixtures and execution of prototypes







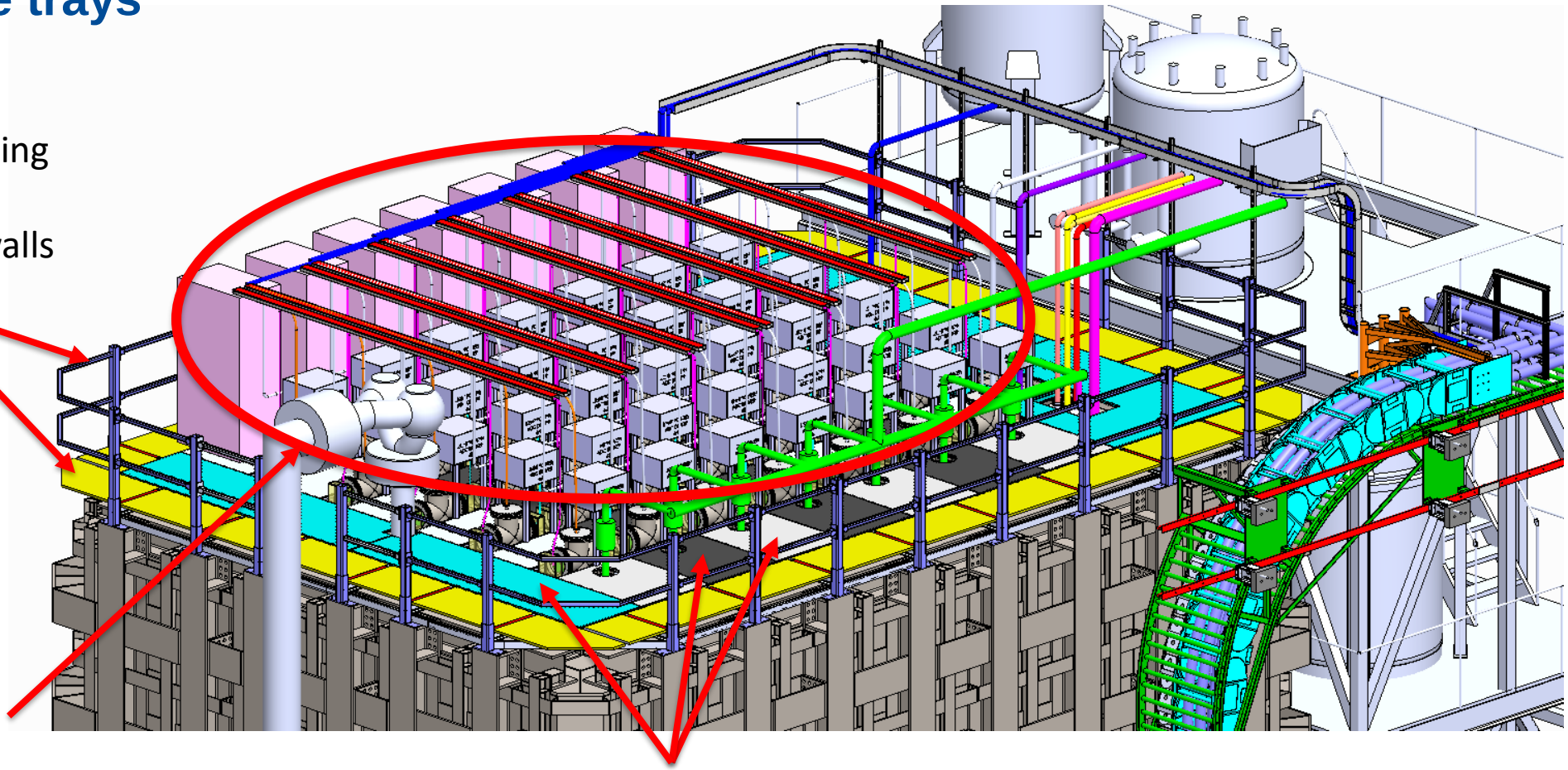
Installation sequence to LAr Cryostat; good communication between cryostat and ND-LAr engineers → combined prototyping efforts will prove most fruitful



After row installation is complete can being dressing the top of the cryostat with racks and cable trays

Mezzanine decking & railing around perimeter:

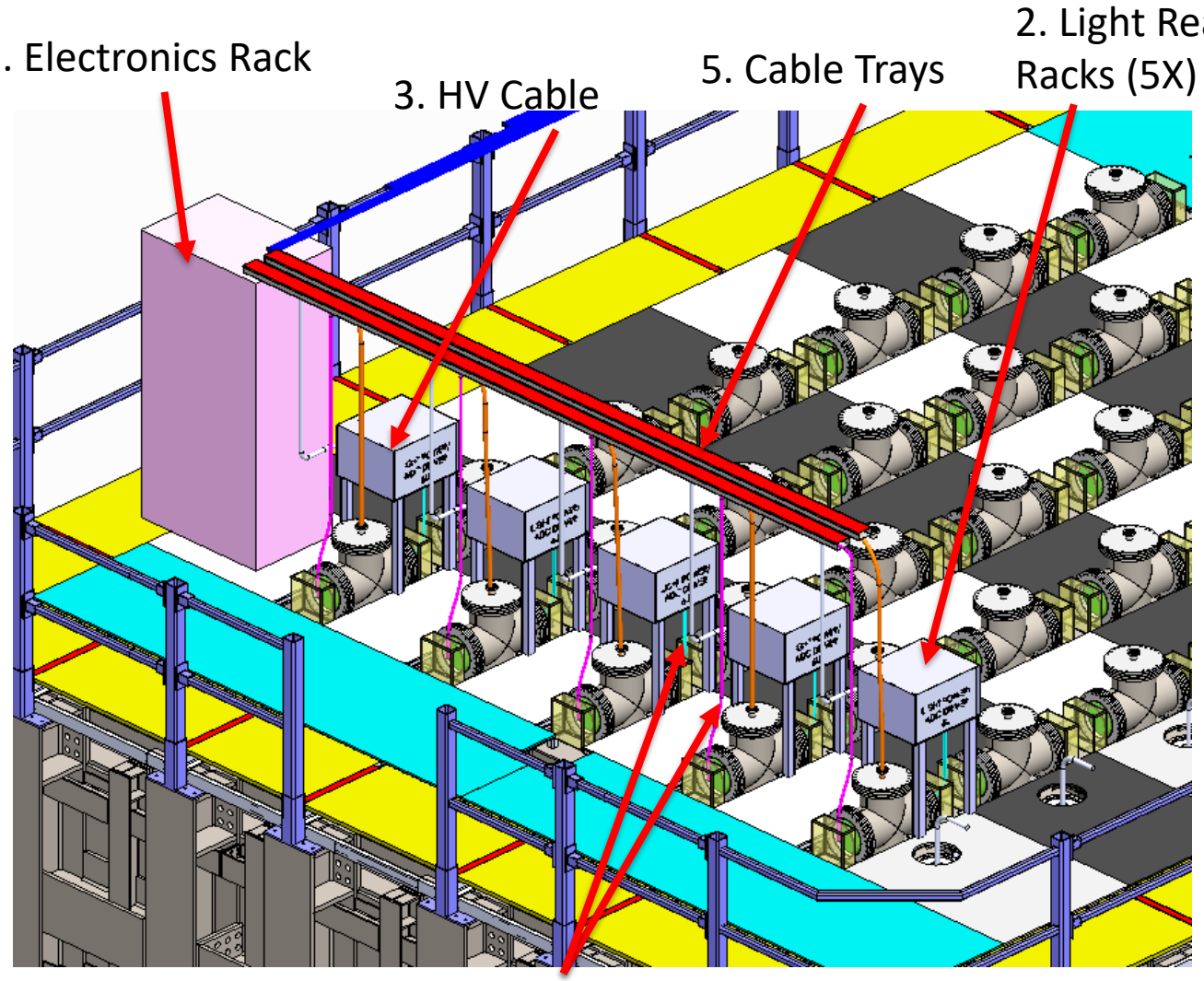
- Installed to cryostat walls
- Cryostat scope



ND-LAr TPC Warm Electronics

Panels above TPC sections and end sections are removable for access to feedthrough flanges or can be fully removed

ND LAr Row (7X) Component Breakdown



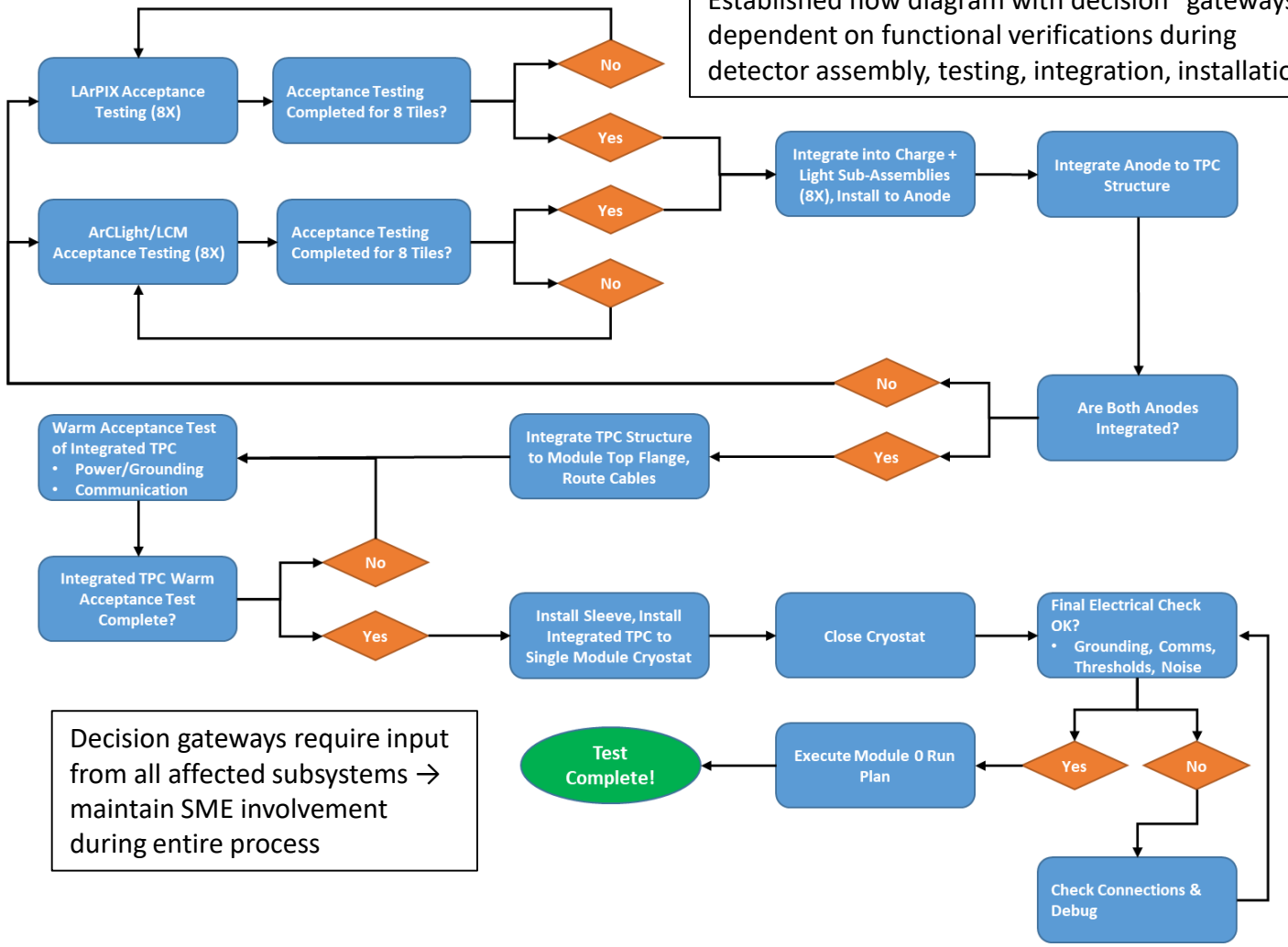
Components

1. Electronics Rack:
   - High Voltage
   - Charge Readout
   - Light Readout
   - Computing Hardware
2. Light Readout System Racks (5X)
3. High Voltage Distribution
4. Light/Charge Power/Data Lines
5. Cable Trays

ND-LAr commissioning will follow experience gained from operation of 2x2, FSD, and production TPCs; ND-LAr has implemented systematic checkouts on 2x2 modules

- ✓ **Warm Test of Components**
- ✓ **Warm Test of Integrated Module 0**: Pre-Sleeve Installation
  - ✓ Power, Grounding, Comms
  - ✓ Sub-systems shall give the "OK" to move from this test - #nd-lar-run SLACK Channel
- ✓ **Final Electrical Check**: Cryostat is closed, last check prior to evacuation & cool-down
  - ✓ Tests of Light System & Charge System Both
  - ✓ Power, Grounding, Comms, Noise, Thresholds
  - ✓ Sequentially re-check after cabling-up new electrical connections to top flange
  - ✓ Sub-systems shall give the "OK" to move from this test - #nd-lar-run SLACK Channel

Established flow diagram with decision "gateways" dependent on functional verifications during detector assembly, testing, integration, installation



Decision gateways require input from all affected subsystems → maintain SME involvement during entire process

ESH Codes and Standards

- Adheres to all ESH codes/standards established by LBNF/DUNE Project plus home institutional ESH requirements
- All Near Detector deliverables must satisfy FNAL FESHM requirements
  - **2x2 Program providing experience through ORC process**
  - https://eshq.fnal.gov/manuals/feshm/
- ND-LAr has completed an initial review of applicable areas of FESHM, found at EDMS 2602421
- ND-LAr has also completed a Hazard Registry in coordination with the ND sub-project, found at EDMS 2663898

TPC I&I involves work around large and heavy objects at a busy site → need to apply integrated safety management (ISM) approach to all work planning

- Lifting Safety
  - Development of lifting fixtures (FESHM 10110)
  - Development of lifting plans (FESHM 10200)
  - Slings and rigging hardware (FESHM 10130)
- Occupational Safety
  - Fall Protection (FESHM 7060)
  - Ladder and Scaffold Safety (FESHM 7070)
- Structural Safety
  - Design and construction of structures at FNAL (FESHM 5100)
- Electrical Safety
  - Electrical safety program (FESHM 9100)
  - Grounding requirements (FESHM 9190)
  - Cable Tray Systems (FESHM 9130)
- Fire Protection
  - Concepts of Egress (FESHM 6020.4)

Path to FDR → Prototyping of fixtures, final installation plans, required safety documentation

- **Integration fixture ease-of-use and time required to perform the module row integration**
  - Preparation of TPC module prior to integration
  - Ability to fit modules in tight clearance space
  - Survey / metrology plan
- **Installation fixture ease-of-use and time required to install a module row**
  - Details around cryostat lid section support at end of process → load transfer from fixture to cryostat
  - Overall safety assessment – structural, lifting, elevated work surfaces, electrical
  - Survey / metrology plan
- **Required functional verification**
  - Measurements taken, frequency, duration
- **Lowering down the cavern shaft (lifting fixture/plan)**
  - It is acknowledge that there are accepted practices, but ND-LAr will need guidance on these
- **Storage Crate Design**
  - Needs to protect module against transport loads and environmental concerns (dust)

Summary

- Near Detector workflow is well defined with key steps or dependencies understood
- Remaining work is very engineering focused and the requirements are reasonable
- Prototyping of fixtures and procedures will be critical to realizing efficient ND-LAr TPC I&I activities at the Near Detector
- TPCs are subjected to functional checks at key intervals during the I&I process to verify no change in performance
- Upcoming 2x2 and SBND program with provide more experience and understand with regards to installing multiple modules and installation of the cryostat lid sections
- Initial detector bring-up and commissioning will feed off the years of the experience developed by the ND-LAr Consortium, by that point in time