131.ND.02.02 Module Structures: Overview

Igor Kreslo, Detector Subsystems Lead

ND-LAr Preliminary Design Review

27 June 2022

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

JINR
DUBNA

U.S. DEPARTMENT OF ENERGY | Office of Science

Who am I

Prof. Dr. Igor Kreslo
coordinator of detector development group at LHEP, Uni-Bern

Physicist (experiment) with technical and engineering background
R&D for LAr detectors in Neutrino physics - since 2007
ArgonTube
ArgonCube

Other detector R&D since 1992:
E289 SciFi vertex detector
Chorus SciFi capillary vertex detector
OPERA Scintillating target tracker
OPERA automated emulsion DAQ
uBooNE/SBND cosmic ray tagger

Outline

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

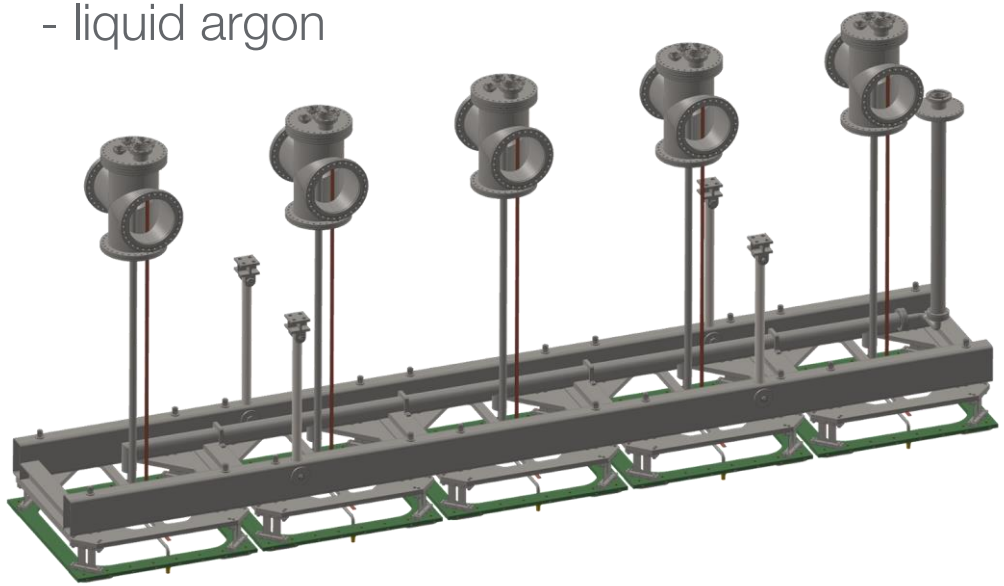
131.ND.02.02 Module Structures: Documentation Reference

Module Structures Documentation	Description	EDMS Link
Module Structures Folder	Top level folder for Module Structures documentation	https://edms.cern.ch/project/CERN-0000217524
Requirements	Spreadsheet with all ND-LAr requirements, see sheet "Module Structures (02)"	https://edms.cern.ch/document/2589287
Risk Registry	ND-LAr TPC Risk Registry	https://edms.cern.ch/document/2589288
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-0000230730
QAQC Plan	Subsystem QAQC plan with focus on high-level QAQC test plans	https://edms.cern.ch/document/2613192
Manufacturing Plan	Subsystem Manufacturing plan with focus on manufacturing methods of key items	https://edms.cern.ch/document/2613193
Procurement Plan	Subsystem Procurement plan with focus on procurement management of key items	https://edms.cern.ch/document/2613194
Previous Review Tracking	Spreadsheet with previous review recommendations, see "Module Structures"	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 (Row Assembly, TPC Assembly)	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-0000228155
Mechanical Assembly Drawings	Subsystem assembly drawing	https://edms.cern.ch/project/CERN-0000228156
Parts List	Subsystem parts list	https://edms.cern.ch/project/CERN-0000228161
Electrical Cabling and Wiring Specification	Specification of electrical cables/wiring	https://edms.cern.ch/project/CERN-0000228157

131.ND.02.02 Module Structures: purpose

Principal link between the TPC modules and external world via cryostat top lid

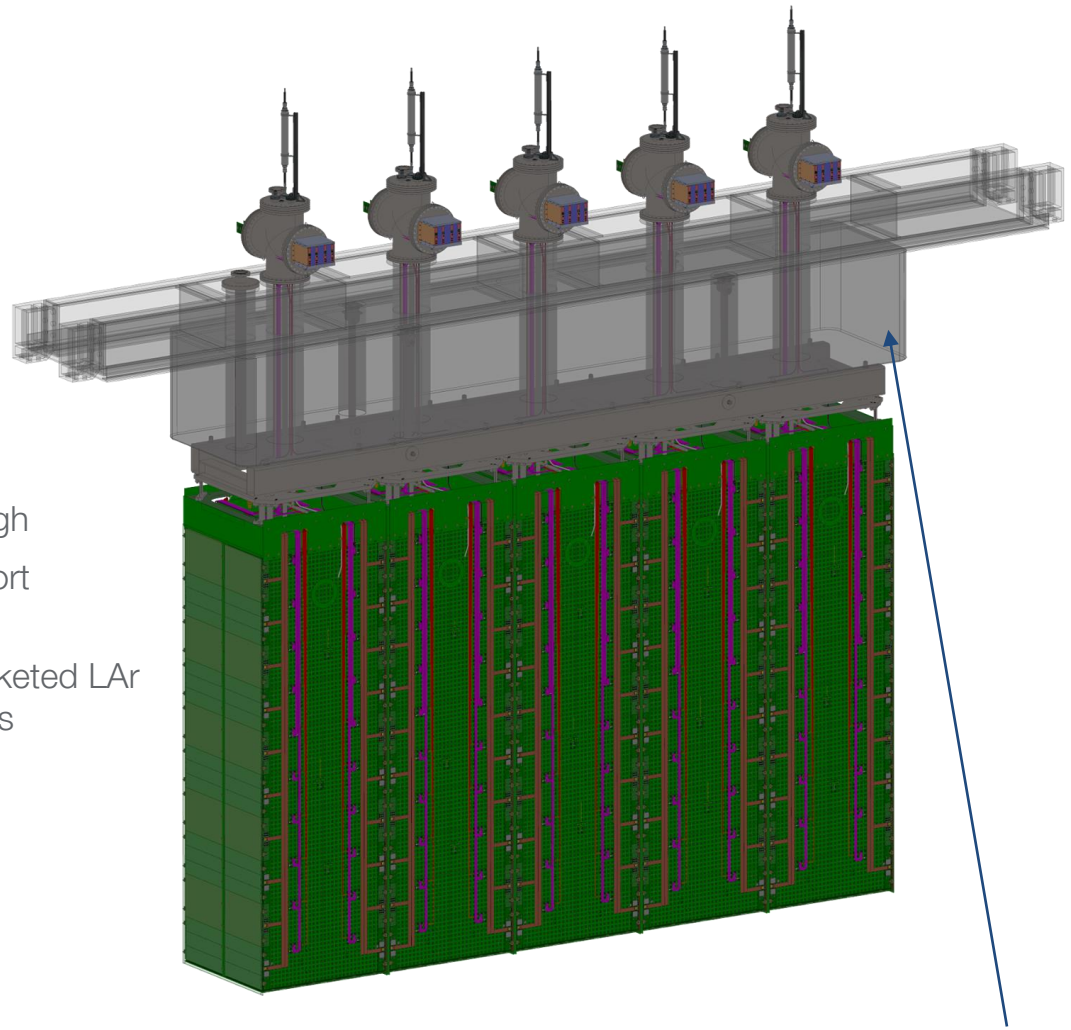
- mechanical
- electrical
- liquid argon



35x Feedthrough

35x TPC support structures

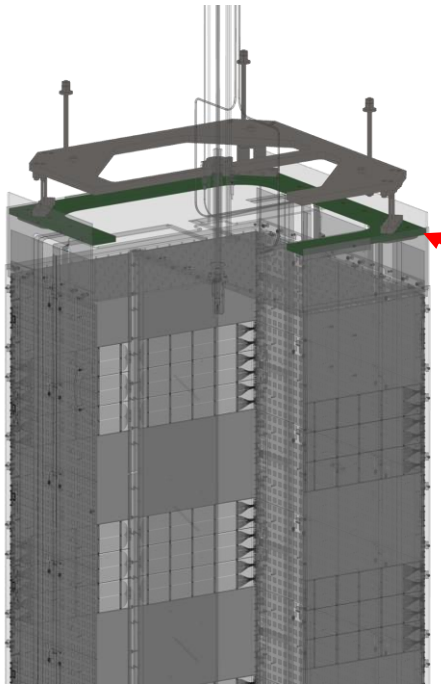
7x Vacuum jacketed LAr distribution lines

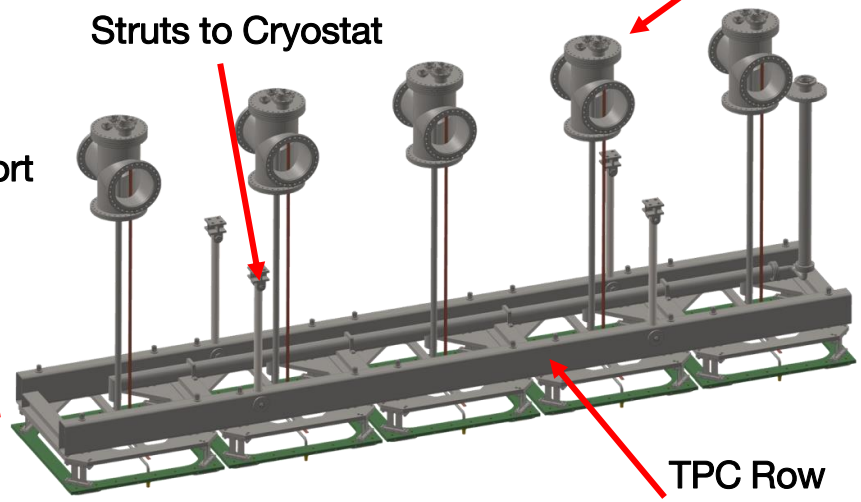


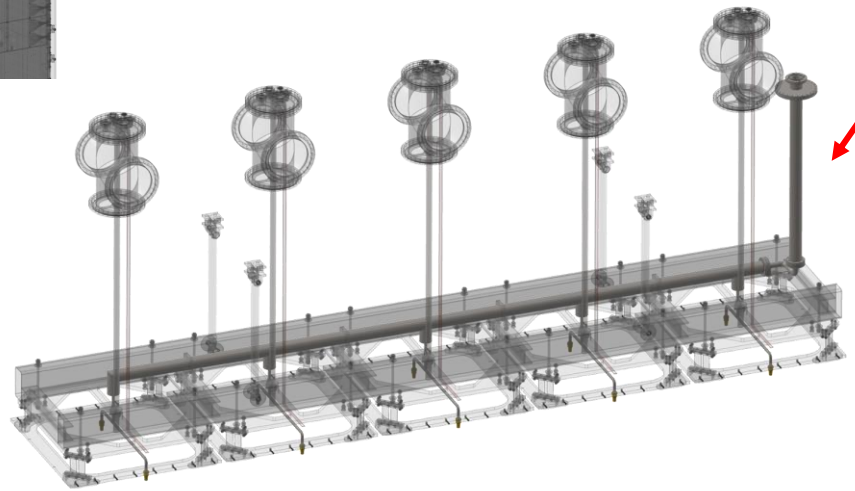
! Section of cryostat top lid with thermal insulation is not in the MS scope

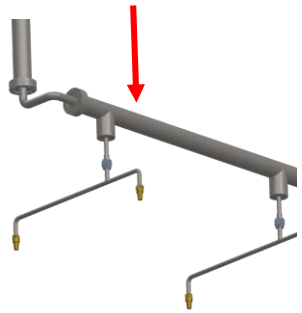
Top Level TPC Row Assembly, DU-1003-7330, EDMS 2737743

131.ND.02.02 Module Structures: Scope





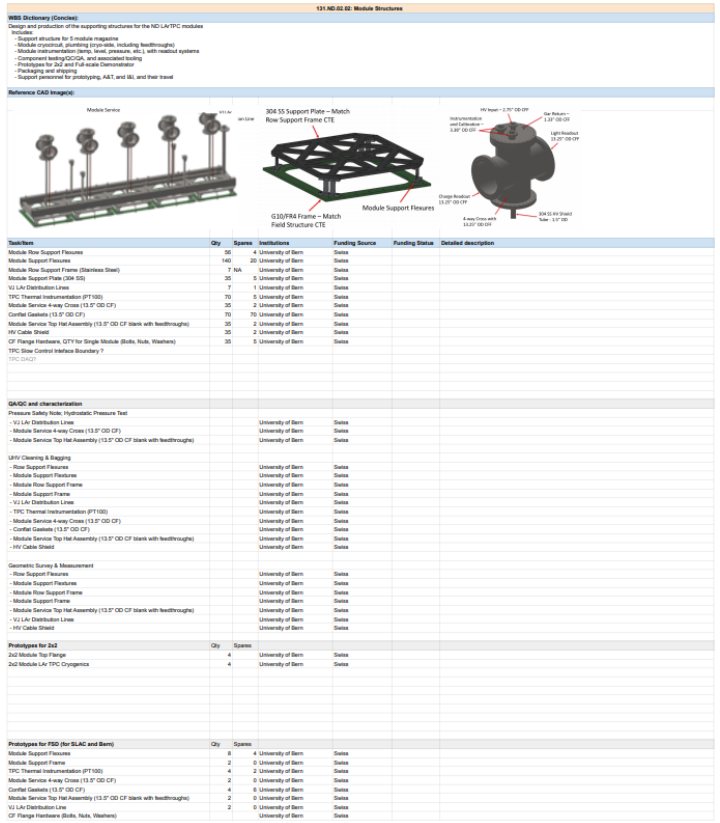




More technical details in the next talk

by S. Bosco

https://edms.cern.ch/document/2630602

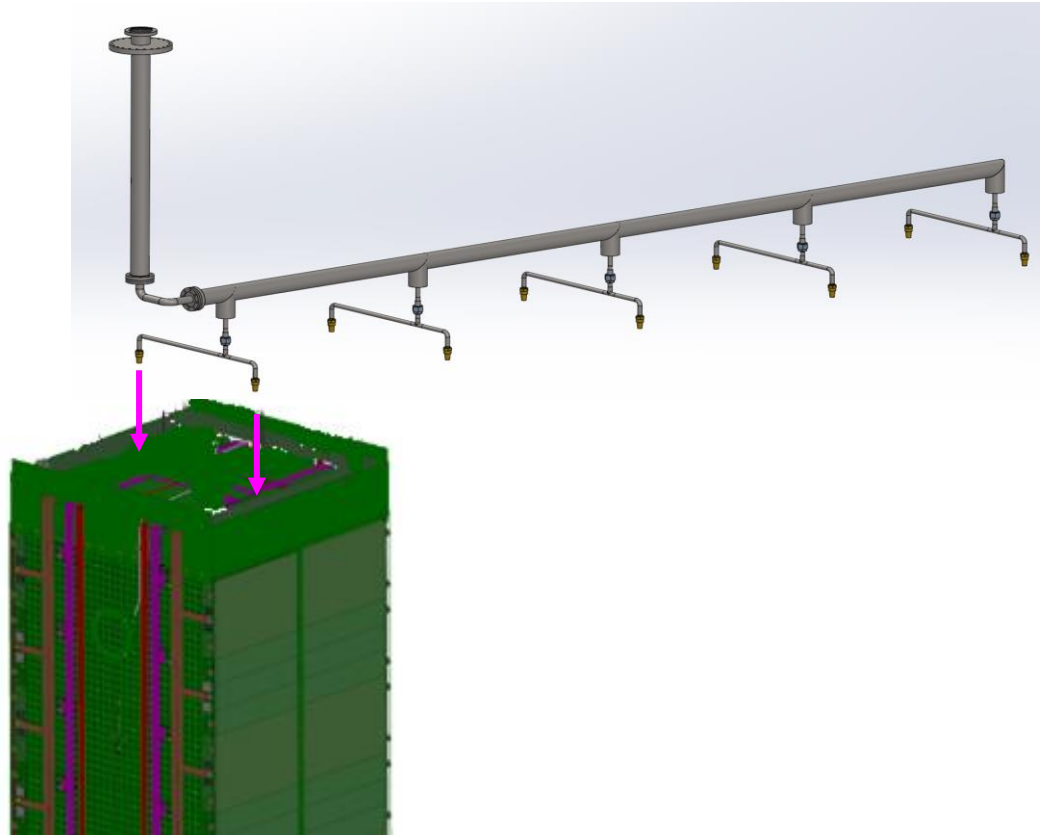


LBNF/DUNE

LAr flow distribution

LAr distribution shall provide 0.125 kg/s/**row** of purified LAr

Important for LAr **purity and cooling** of elecronics:
Laminar downward flow at
0.025 kg/s/**module** uniformly
distributed between the modules
and across each module



131.ND.02.02 Module Structures: Key Requirements

https://edms.cern.ch/document/2723207
https://edms.cern.ch/document/2589287/1

Example of selected entries:

MOD-003	Support Row of Modules	The module support structure shall structurally support the specified number of modules	5	The module structure shall support the load of 5 modules
MOD-004	TPC Module Placement	The module support structure shall determine the position of the TPC active volume to an accuracy of 2 cm within the Near Detector cryostat in the temperature range of 87 K to 300 K	2 cm	Unexpected deviations in module position complicate neutrino signal reconstruction. Accurate determination of the position of the active TPC volume within the Near Hall is particularly important for correlation of events between the ND LArTPC and downstream spectrometer.
MOD-008	LAr Flow Rate	LAr distribution shall provide 0.125kg/s/row of purified LAr	0.125kg/s/row	Flow rate for purity needed is derived from ProtoDUNE experience which state one volume change every 5 days. Also provides cooling for electronics. derived from heat load from charge readout and field cage; New hydralic spreadsheet - capture heat loads, required flow rate
MOD-010	Thermal monitoring	The thermal monitoring system shall be sensitive to gradients greater than 0.3 deg/cm across the TPC modules during cooldown and warmup.	0.3 deg/cm	The thermal monitoring system must provide feedback to the ND Cryogenics system during cooldown and warmup in order to avoid thermal-induced damage to sensitive elements of the TPC modules.

Requirements are validated by 2x2 prototyping programm and FEA analysis

Outstanding Requirements

Mechanical strength

Thermal effects on module gap

LAr flow rate uniform distribution (informed by 2x2 program)

Thermal monitoring (informed by 2x2 program)

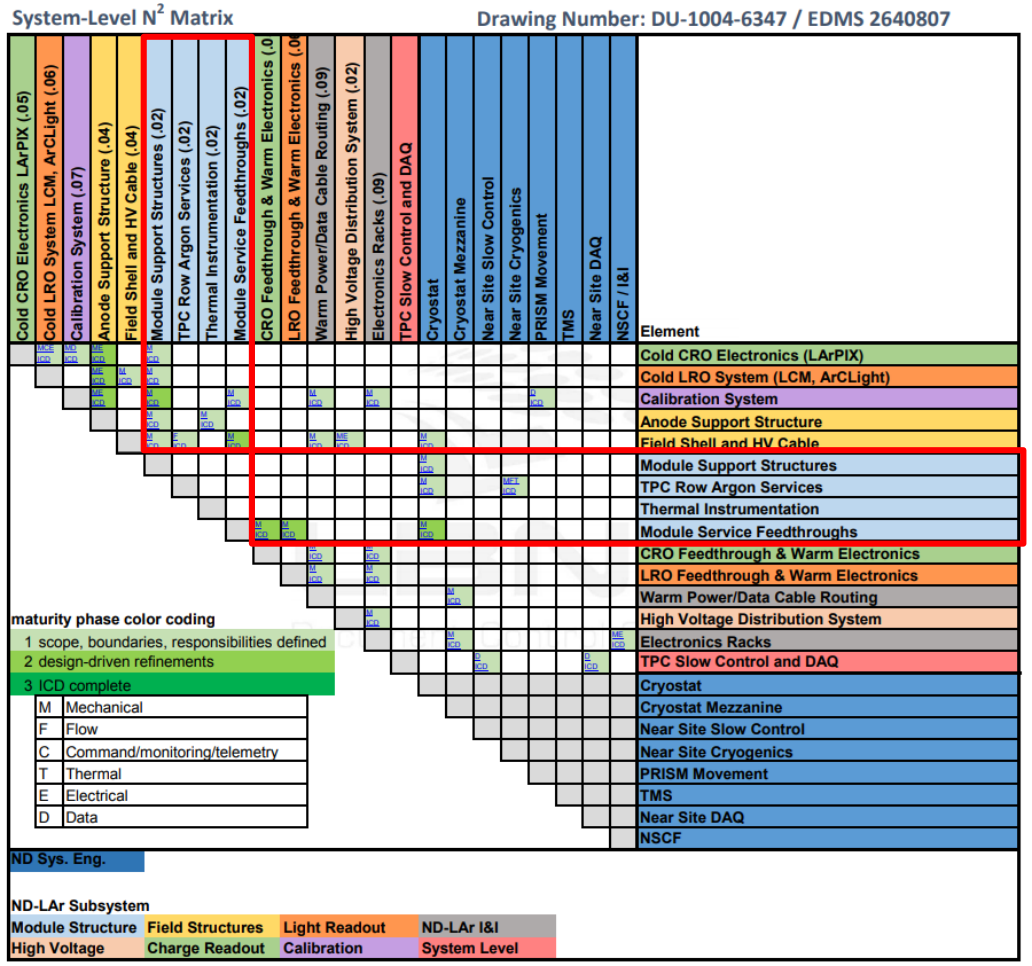
Elaboration on technical details in next talk by Silas Bosco

Interfaces

- Interface matrix: https://edms.cern.ch/document/2640807
- Interface control documents: https://edms.cern.ch/project/CERN-0000223195
- Engineering CAD model captures interfaces https://edms.cern.ch/project/CERN-0000226247
- Interfaces realized and validated in 2x2 program

Subsystem	Interface	Maturity
CRO/LRO electronics	Mechanical (cable routing)	Mature
Calibration system	Mechanical	Defined
Calibration system	Service feedthrough	Defined
Anode support structure	Mechanical	Defined
Anode support structure	Thermal instrumentation	Defined
Field shell and HV cable	Mechanical (routing and fixation)	Defined (CTE matching analysis in progress)
Field shell and HV cable	Electrical / Service feedthrough	Defined
Cryostat	Mech / LAr / Electrical	Defined
NS cryogenics	Mech / LAr / Electrical	Defined

Defined = meets preliminary design maturity



131.ND.02.02 Module Structures: QAQC, Procurement, Manufacturing

Procurement:

All key items to be procured by Bern using standard Offer-Order-Invoice scheme.

Manufacturing:

Parts will be manufactured by Bern and its Swiss subcontractors

Shipping shall be performed preferably by sea freight from Bern (CH) to FNAL (USA). The shipping cost is covered by the scope owner (University of Bern).

QA/QC:

Module Structures components shall obey the following standards when applicable: ISO, ANSI,ASTM,AWS

QC testing will be done at University of Bern and/or Contracted Vendors – either component suppliers or third-party vendors

QA/QC Procedures: https://edms.cern.ch/document/2613192

Procurement Plan: https://edms.cern.ch/document/2613194

Manufacturing Plan: https://edms.cern.ch/document/2613193

Table 1: Key items to be procured

Item	Name	Part #	Quantity	Cost [$k]	Vendor	Lead Time	Purchaser	Deliver to
1	TPC Cross Feedthroughs	-	40	-	-	16 weeks*	Bern	Bern/LBNL
2	Feedthrough Top Hat	-	40	-	-	18 weeks*	Bern	Bern/LBNL
3	Row Support Struts + Hardware	-	32	-	-	12 weeks*	Bern	Bern/LBNL
4	Row Support Frame + Hardware	-	8	-	-	24 weeks*	Bern	Bern/LBNL
5	Module Flexures + Hardware	-	160	-	-	12 weeks*	Bern	Bern/LBNL
6	TPC Support + Hardware	-	40	-	-	12 weeks*	Bern	Bern/LBNL
7	LAr Distribution Vacuum Jacketed Lines	-	8	-	-	16 weeks*	Bern	Bern/LBNL
8	Misc. Conflat Hardware	-	NA	-	-	12 weeks*	Bern	Bern/LBNL

6. MANUFACTURING PROCESSES

Manufacturing processes used for Module Structures components are enumerated below, final manufacturing processes shall be confirmed during production/manufacturing readiness reviews:

TPC Cross Feedthroughs – CNC machining, stainless steel fusion welding, UHV cleaning

Feedthrough Top Hat – CNC machining, stainless steel fusion welding, UHV cleaning

Row Support Struts + Hardware – CNC machining, UHV cleaning

Row Support Frame + Hardware – CNC machining, stainless steel welding, spot machining, UHV cleaning

Module Flexures + Hardware – CNC machining/EDM, UHV cleaning

TPC Support + Hardware – CNC machining, UHV cleaning

LAr Distribution Vacuum Jacketed Lines – CNC machining, stainless steel welding, liquid-oxygen (LOX) service cleaning

131.ND.02.02 Module Structures: Risks and Prototyping

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

Uneven lar supply in row of modules	IF some modules are receiving larger volumes of cleaner and cooler LAr, THEN the electron lifetime may differ between modules changing the energy resolution, and the heat load in a module may increase	Design apertures into the LAr supply to provide equal flow to each module. ***Informed by 2x2 program. Will be updated to some extent by FSD.***
Support Plate thermal contraction	IF there is too much thermal contraction it will distort the module structure, THEN it may damage readout electronics and/or impact the drift field	Analyze the current concept and update design as needed. ***Informed by 2x2 program. Will be updated to some extent by FSD.***
Module Support Structural	If module support has a design or manufacturing flaw, then modules could distort more than anticiptaed or in worse case module could disengage from the support	Build redundancy into fixings. Design fixings to cope with dynamic loads as well as static. Coupled with thermal distortions Qualified engineer to design & analyze ***Informed by 2x2 program. Will be updated by FSD.***
HV breakdown in volume above TPCs	IF THEN Loss of field in detector volume	Define clearance volume around HV feed through - no conductors Dielectric protection for HV feedthrough - PTFE tube Ensure sufficient liquid level above cathode connection. ***Informed by 2x2 program. Will be updated by FSD.***

131.ND.02.02 Module Structures: Risks and prototyping

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

LAr distribution line: design informed by 2x2, key parameters are gauged in a range of flow regimes. FSD will allow to further mitigate (pin down intra-module flow model).

Support structure design is informed by 2x2, made to minimize effects of CTE mismatch. Deformation absorbers placed where needed. Validated by FEA (in progress). Next mitigation stage - FSD.

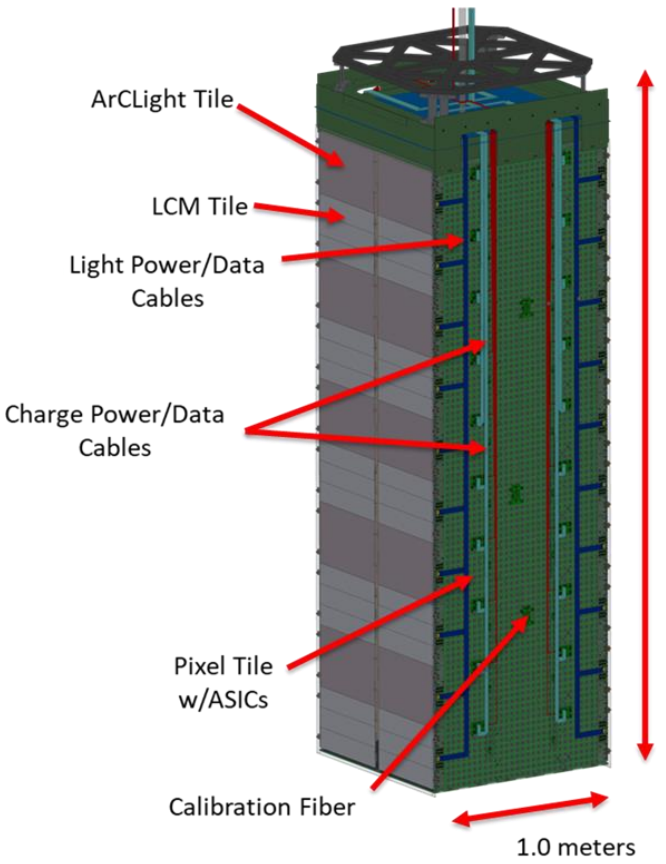
HV breakdown risk in the ullage - module related, massively informed by 2x2, FSD experience to retire this risk.

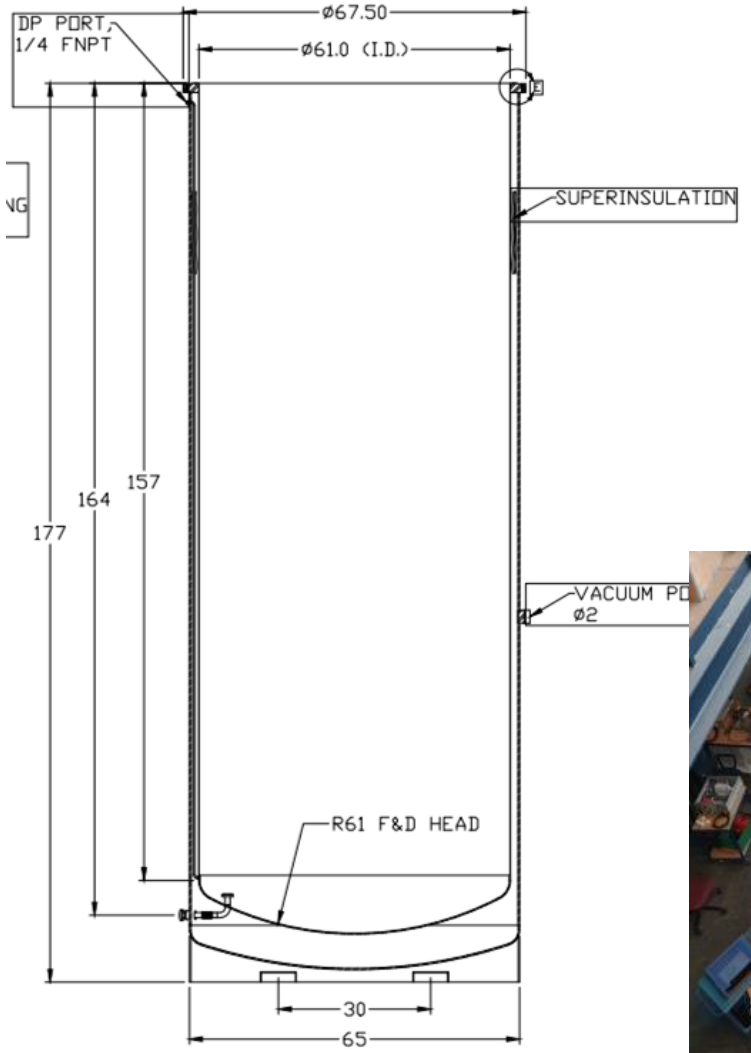
FDR will face three non-retired technical risks, with largely reduced probability thanks to 2x2 and FSD.

https://edms.cern.ch/document/2459149

131.ND.02.02 Module Structures: Prototyping

FSD Module and cryostat



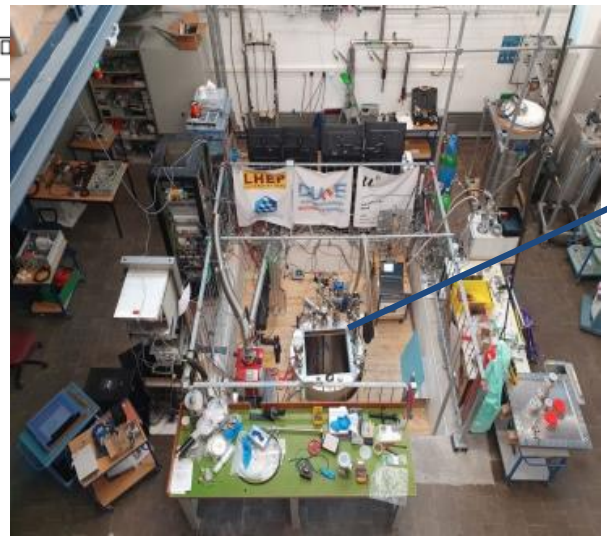


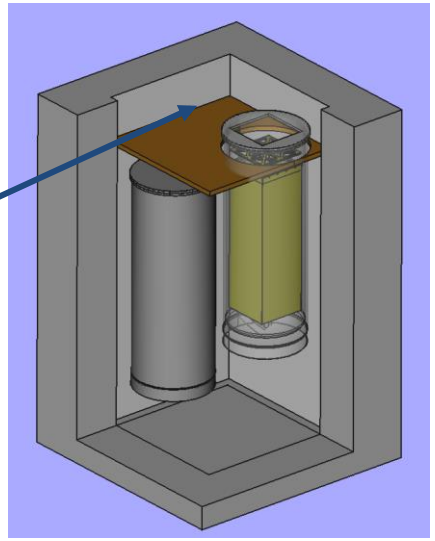
LAr distribution system: informed by 2x2 test program

Module support structure to be partly prototyped in FSD test program

2 cryostats of required size are ordered, delivery expected by February 2023

Facility upgrade starts right after completion of the 2x2 module assembly and test program.





Recommendation from previous reviews (dry run of PDR in 2021)

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

	Date added	Reviewer/Commettee	Recommendation / Comment	Responder(s)	Comments / Answers / Actions	Status	Expected date of resolution
Module Structures							
	24.05.2021	Jeff Cherwinka (PSL). Min Jeong Kim (FNAL). David Montanari (FNAL, Chair). Andy Stefanik (FNAL)	1) To meet the requirements of preliminary design (60%) as outlined in the LBNF/DUNE Review Plan (EDMS-2173197 & 2374096), we recommend to continue to develop and maintain the following documents (see status at point 23 in Comments section), as described in the presentations also: a) Requirements Documents [EDMS -2589287]. b) Interface [EDMS-2458075, 2458074]. c)Mechanical CAD model [EDMS-2588694]. d)Mechanical Engineering Drawings [EDMS-2588694]. e)Mechanical Assembly Drawings and Part Lists. f)Engineering Analysis Documents. g)Prototyping results and lessons learned. h)Risks/Opportunities [EDMS-2589288]. i)Tracking Documents.	I. Kreslo	Requested documentation is prepared in EDMS in preparation for the PDR in July 2022	Closed	
			2) Firm up the ND-LAr total heat load contribution (nominal and expected maximum) and, if needed, update the requirements to ND LAr Cryogenics.	I. Kreslo	https://edms.cern.ch/document/2458088	Closed	
			3) Address review recommendations that are past due in due time.	I. Kreslo	The recommendation 1 in the "ND-LAr Recommendations" sheet is addressed.	Closed	

Open issues and path towards FDR

- Further mature interface documents to FDR level (e.g. calibration and grounding)
- Optimisation regarding statics and heat transmission (e.g. G10 plate, connection legs)
- Build and assess an FSD module support frame, struts, LAr-distribution and feedthroughs
- Final CAD design, completion of all ICD and associated interface drawings, completion of production drawings for FSD module

131.ND.02.02 Module Structures: Cost

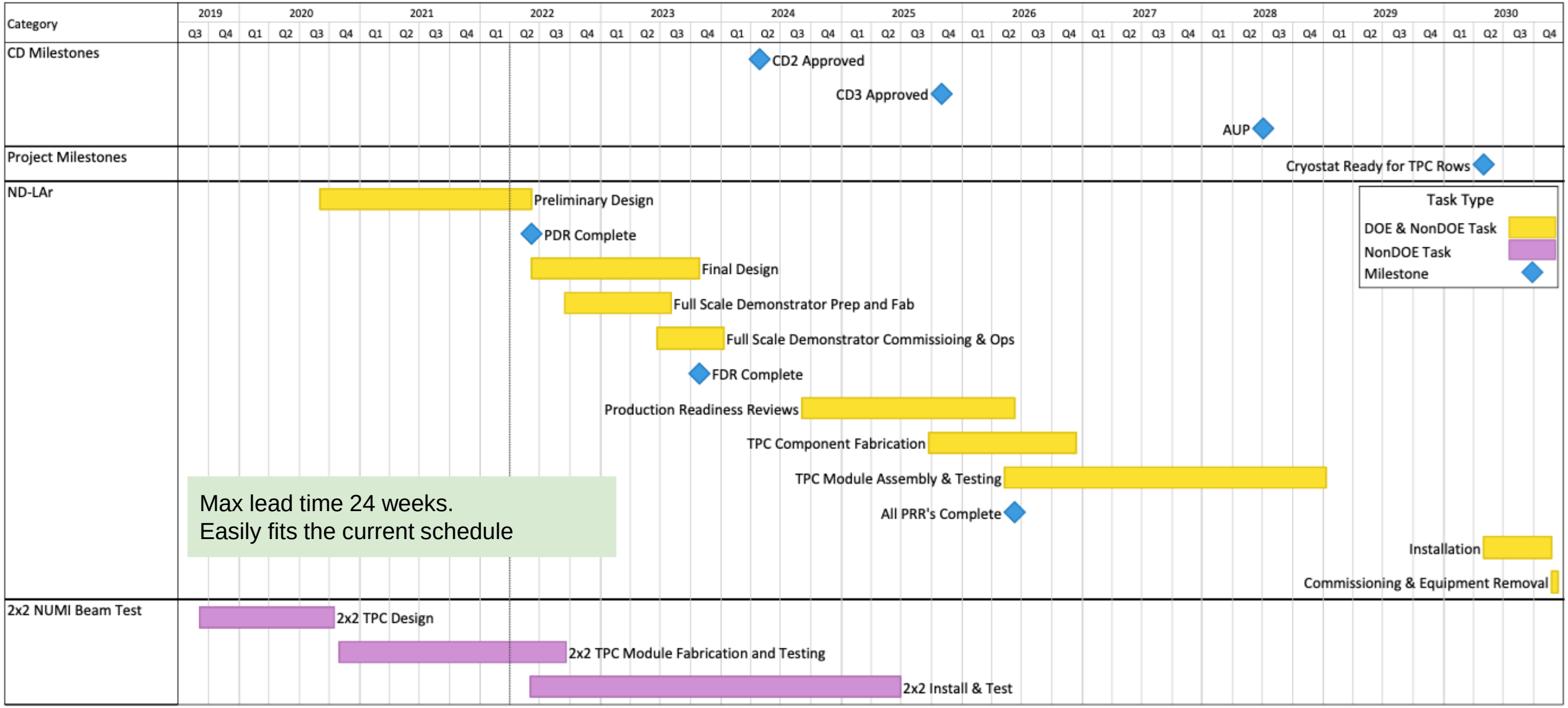
From Mar. 2022 cost review

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

Notes:

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

Schedule


Category
2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030
Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
CD Milestones
CD2 Approved
CD3 Approved
AUP
Project Milestones
Cryostat Ready for TPC Rows
ND-LAr
Preliminary Design
PDR Complete
Final Design
Full Scale Demonstrator Prep and Fab
Full Scale Demonstrator Commissioing & Ops
FDR Complete
Production Readiness Reviews
TPC Component Fabrication
TPC Module Assembly & Testing
All PRR's Complete
Installation
Commissioning & Equipment Removal
Task Type
DOE & NonDOE Task
NonDOE Task
Milestone
Max lead time 24 weeks.
Easily fits the current schedule
2x2 NUMI Beam Test
2x2 TPC Design
2x2 TPC Module Fabrication and Testing
2x2 Install & Test

Summary

System requirements evaluated with prototype data and FEA simulation

The risk mitigation strategy suitably employs engineering and prototyping to address design challenges. Prototyping plan adequately addresses major technical risks.

Cost and schedule estimates are adequate to proceed to final design. Scope is well-defined with no gaps. Intra-system and inter-system interfaces are well-understood

All recommendations from previous reviews has been adequately addressed and approved.

Demonstrated design maturity at the preliminary design level, ready for FSD & final design phase.