131.ND.02.02 Module Structures Technical Description

Silas Bosco, Module Structures Lead Engineer

ND-LAr Preliminary Design Review

27 June 2022

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

Who am I

Silas Bosco
Mechanical Engineer at LHEP, Uni-Bern

Mechanical Engineer with diverse background in R&D

- 1997-2001 Apprenticeship as a mechanic
- 2001-2006 Dipl. Ing. FH in mechanical engineering
- 2007-2013: Project leading Engineer at Rychiger AG
  Filling and sealing machines for Nespresso
- 2013-2020: Engineer and testpilot at Advance Thun AG
  Paraglider development and testing
- 2020-2022: Product Engineer at 3S Swiss Solar Solutions
  R&D of mechanical parts for PV-systems

Outline

- Key Documents
- Requirements
- Design Elements & Status / CAD model
- Key Analyses / Performance Assessment
- EH&S / Codes & Standards
- Open design issues / Final Design plan
- 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
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: Requirements / technical specifications

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

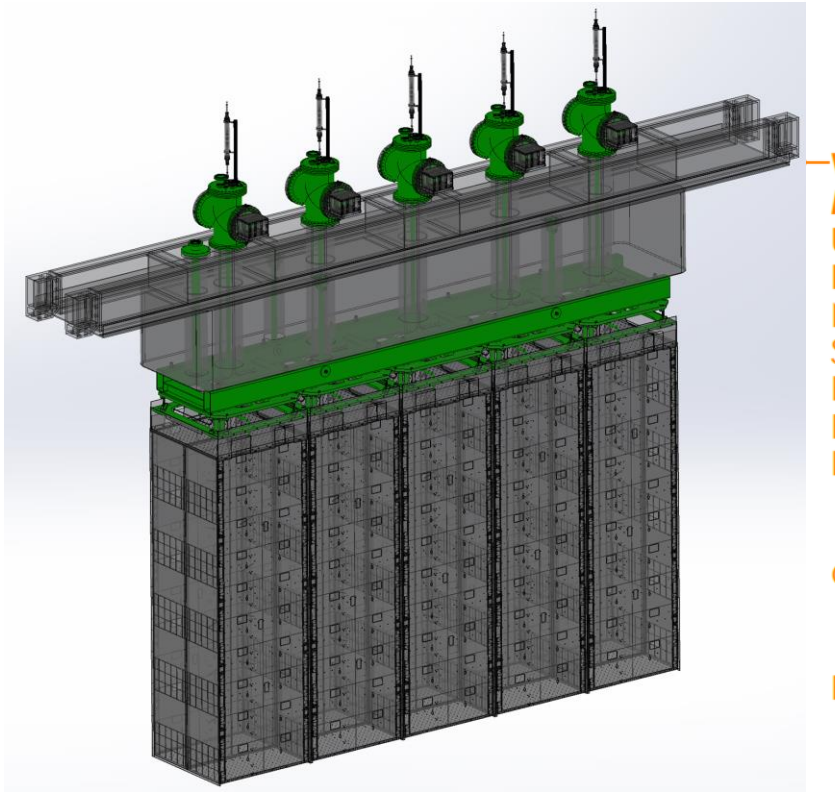
4	ID	Type	Component	Name	Primary Text	Design Value	Spec Status	Estimated Value (option)	Rationale
	MOD-001	Standard	Module Structures	Seismic	Design shall be complaint with FNAL Seismic Code FESHM	FESHM	TBD		FNAL Standards
	MOD-002	Requirement	Module Structures	Support Structure Operational Temperature Range	Structural support components shall be capable of operating between the stated temperature limits	80 K - 310 K	Proposed		Structure must meet performance requirements at all experienced temperatures
1	MOD-003	Specification	Module Structures	Support Row of Modules	The module support structure shall structurally support the specified number of modules	5	TBD		The module structure shall support the load of 5 modules, or damage components
2	MOD-004	Specification	Module Structures	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	Approved		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-005	Operations	Module Structures	Lifetime	The module structure shall survive 10 years	10	TBR	TBD	Operations Plan
	MOD-006	Specification	Module Structures	Material LAr Purity compatibility	The module structure shall not contain any materials that adversely impact liquid argon purity	NA	Proposed		Components must not be a source of LAr contamination
	MOD-007	Requirement	Module Structures	LAr Distribution	Module structure shall provide liquid argon distribution to the specified number of modules in a row assembly	5			Unven flow would result in irregualr cooling or purity of modules which could cause performance variations from module to module
3	MOD-008	Interface	Module Structures	LAr Flow Rate	LAr distribution shall provide 0.125kg/s/row of purified LAr	0.125kg/s/row	Approved		Flow rate for purity needed is derived from ProtoDUNE experience which state one volume change every 5 days. Also provides cooling for electronics.
	MOD-009	Requirement	Module Structures	Module to Module Pitch	Pitch between adjacent modules shall be equal to the given value	1 m	Proposed		Any misalignment of a module with respect to a neighbouring module would result in miss reconstruction of traversing events and their energy
4	MOD-010	Specification	Module Structures	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	TBR	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.
	MOD-011	Requirement	Module Structures	Piston Purge Compatibility	Cryogenic lines shall be capabale of a GAr flush, i.e. piston purge process, that removes 98% of contaminates	98%	TBD		System design needs to ensure that there are no potential areas to trap gases. Even flow to push contaminates out, Liquid argon needs to permeate evenly all of the spaces in the volume
	MOD-012	Design Choice	Module Structures	Module to Module Clearance	Module to Module clearance shall be equal to the given value +/- 10%	5 mm (OBS?) 4 mm (TBC)	Proposed		Modules need to have adequate clearance between each other both for integration purposes and to accomodate thermal + gravitational deflections
	MOD-013	Requirement	Module Structures	Module to Module Operational Clearance	Modules shall not deflect such that module to module clearances altered by more than the given value	50%	TBR		Provides a limit on changes to module to module clearance
	MOD-014	Requirement	Module Structures	Row Support Structure Deflection	The fully integrated the row support structure shall deflect less than the stated value under standard gravity	1.0 mm	Proposed		
	MOD-015	Requirement	Module Structures	Pressure Deflection Isolation	Modules shall be isolated from pressure-driven deflections of the cryostat	NA	Proposed		
	MOD-016	Requirement	Module Structures	Thermal Deflection Isolation	Modules shall be isolated from thermally-driven deflections of support structures and/or the cryostat	NA	Proposed		
	MOD-017	Specification	Module Structures	Module Row Support Mass	The module row support structure shall be capable of supporting the given mass of the TPC row and all it's connected components	EDMS 2458090	Proposed		
	MOD-018	Interface	Module Structures	Conductive stay-clear and sheilding near HV	Conductive material within module structures shall stay-clear or be properly shielded from high voltage components, including the field shell	NA	Proposed		Conductive material near components at HV could cause breakdown,
	MOD-019	Requirement	Module Structures	Lift points & handling procedure	Module Structures shall document provide lifting and handling provisions per Near Site ESH	FESHM	Proposed		Handling, transport, and installation
	MOD-020	Requirement	Module Structures	Pressure Safety	Components shall meets insitutional ESH requirements for pressure loaded components	FESHM	Proposed		

ND LArTPC Row Design (simplified)

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

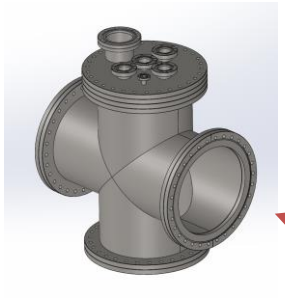
WBS Dictionary (Concise):

Design and production of the supporting structures for the ND LArTPC modules
Includes:
- Support structure for 5 module magazine
- Module cryocircuit, plumbing (cryo-side, including feedthroughs)
- Module instrumentation (temp, level, pressure, etc.), with readout systems
- Component testing/QC/QA, and associated tooling
- Prototypes for 2x2 and Full-scale Demonstrator
- Packaging and shipping
- Support personnel for prototyping, A&T, and I&I, and their travel



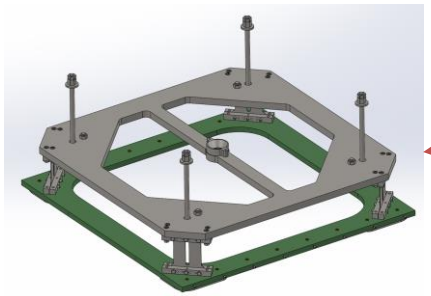
WBS 131.02.03.02.01 MODULE STRUCTURES - UNIVERSITY OF BERN
PER TPC ROW:
ND LARTPC ROW STRUCTURAL SUPPORT
HV, DATA, AND POWER FEEDTHROUGH (5X)
LIQUID ARGON DELIVERY (5X)
- 25 G/S (125 G/S TOTAL)
- 86 K - 90 K
GAS ARGON RETURN (5X)
- 50 MBARG
- 90 K - 300 K
PT100 STRING PER ANODE (10X)

ND LArTPC module support structure

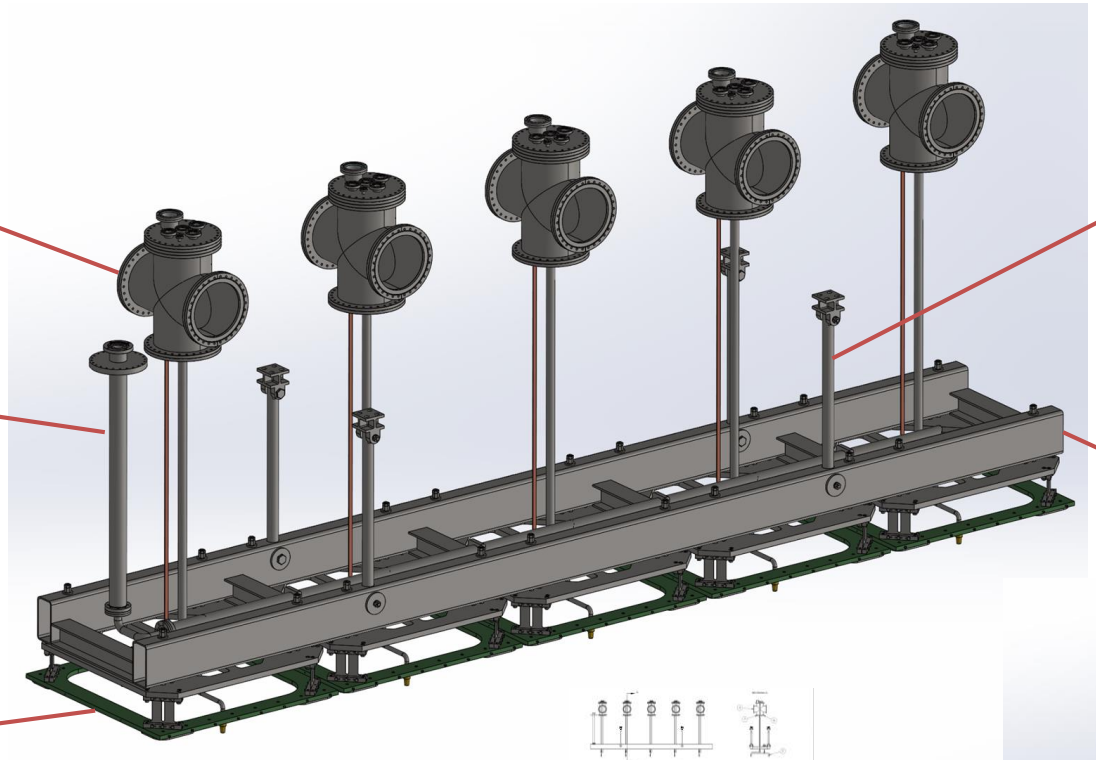


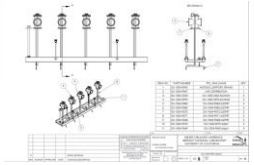
4-way-cross
feedthroughs
and top flange

Liquid Argon distribution



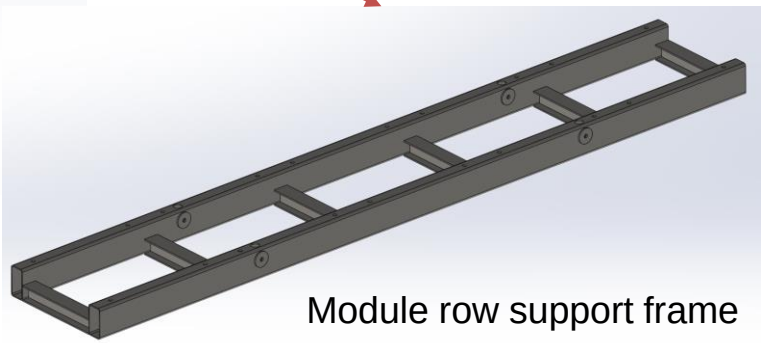
Module support





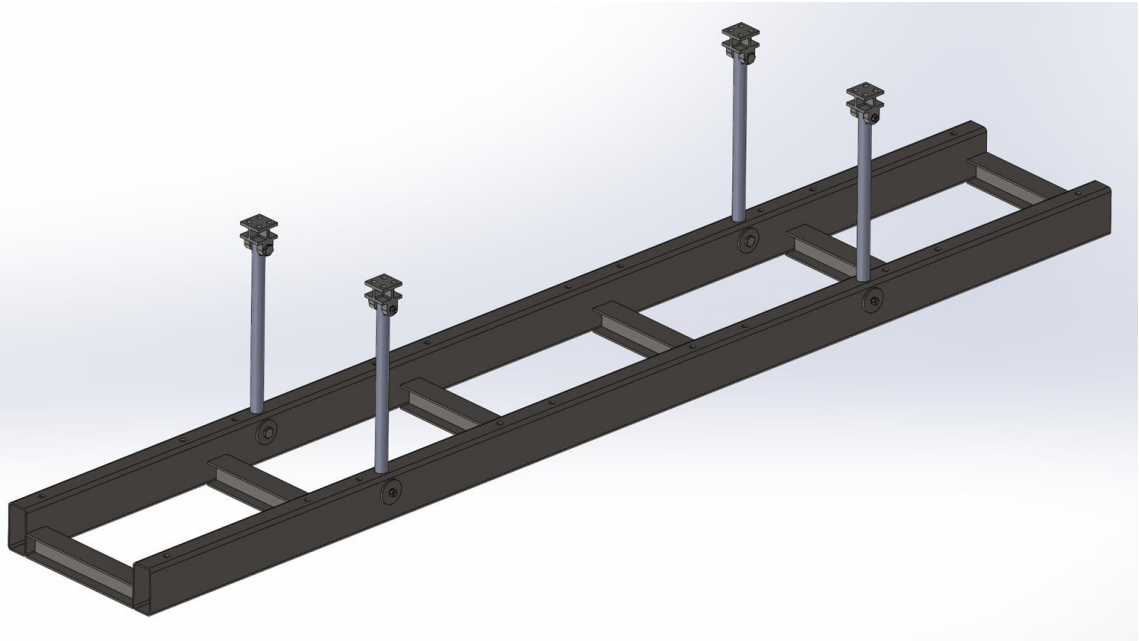
Link to assembly drawing:
https://edms.cern.ch/document/2742796/1

Support struts
(connection to cryostat lid)



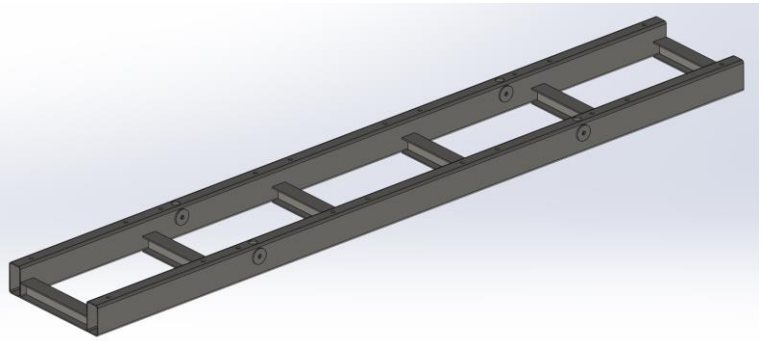
Module row support frame

ND LArTPC module support frame



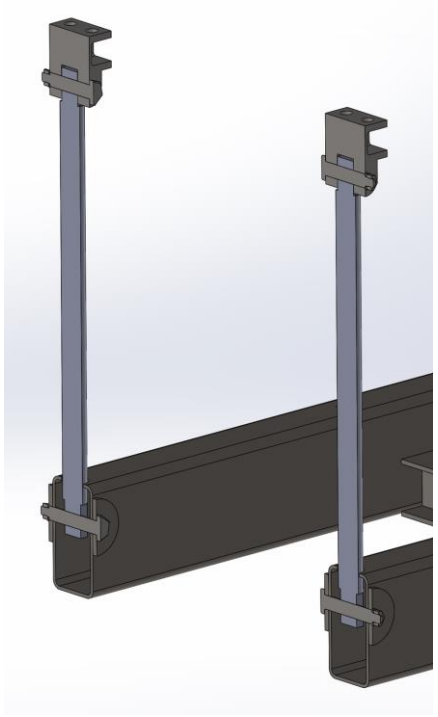
Requirements:

- Support for 5 modules (max. 500kg each) -> total ~2’500kg
- Deformation under load lower than 1mm
- Low heat transfer to cryostat lid through connections
- Temperature-induced deformation as uniform as possible



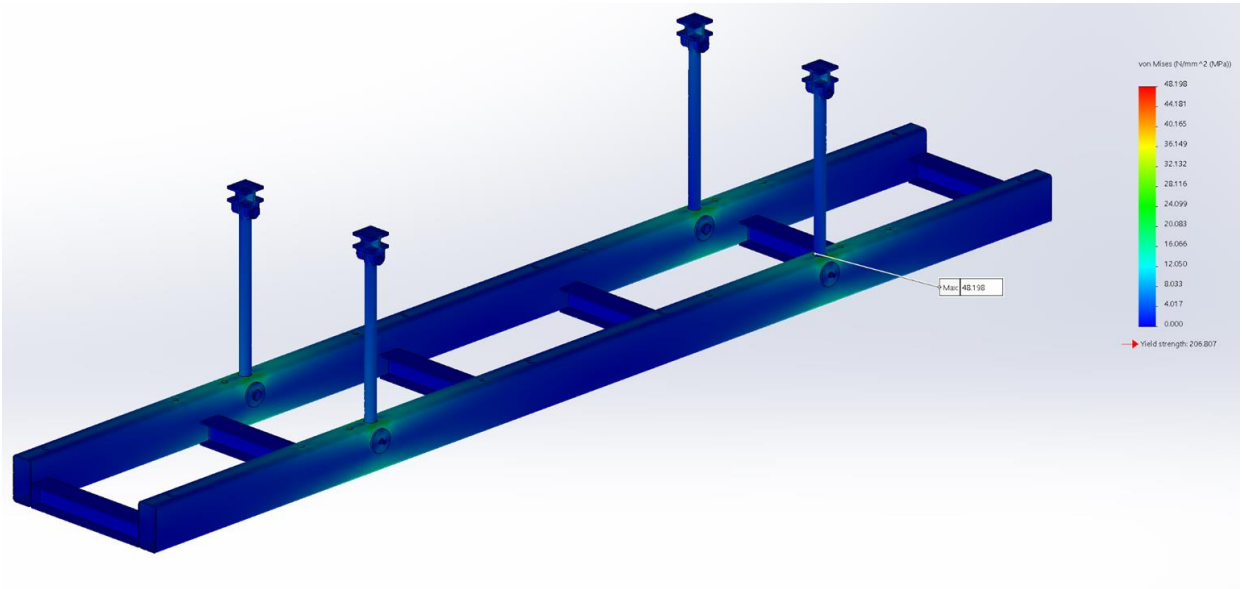
Welded frame made from rectangular stainless steel tubes, I-beams and shaft hubs

Support struts with joints for the connection to the cryostat lid



ND LArTPC module support frame

FEA load analysis:



Results:

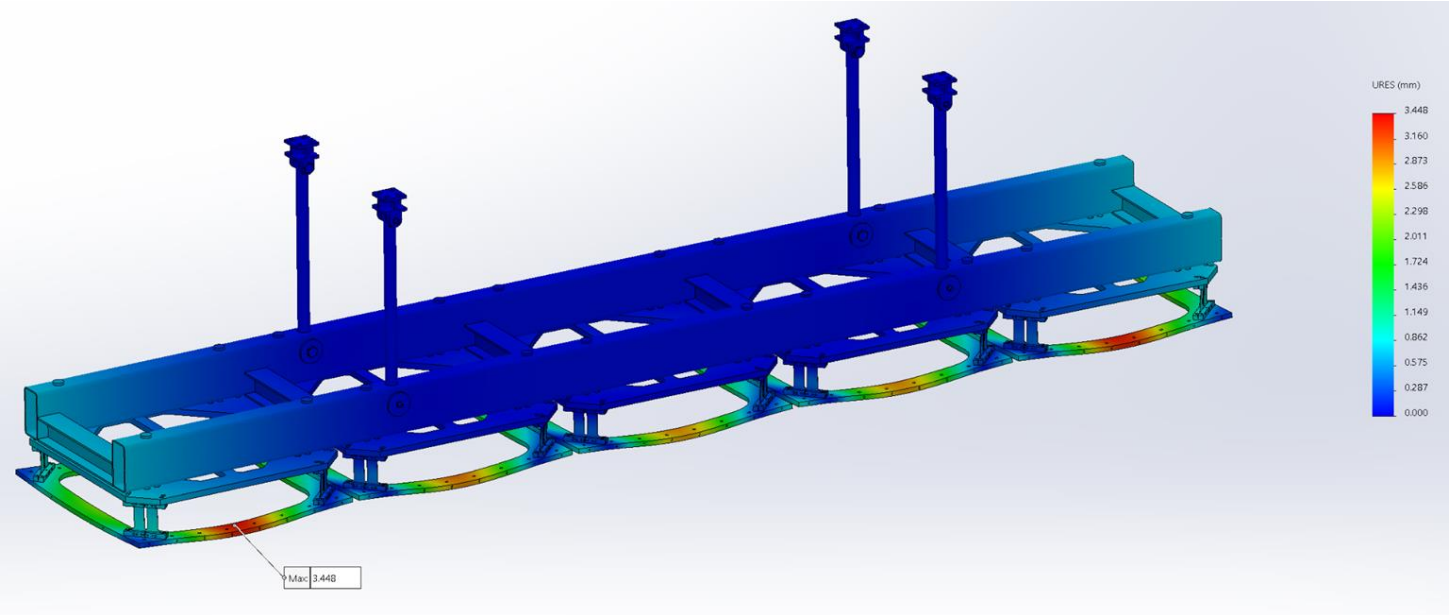
- Deformation under load: 0.74mm (Requirement < 1mm)
- Factor of safety > 4

-> Satisfies the requirements

Key structural elements calculation:
https://edms.cern.ch/document/2748423/1

ND LArTPC module support structure

FEA load analysis:



Results:

- Deformation of the G10 plate occurs in this simulation because the influence of the side walls is neglected (walls greatly stiffen the entire system)
- G10 plate will be thicker to get deformation smaller than 1mm (-> change after PDR)

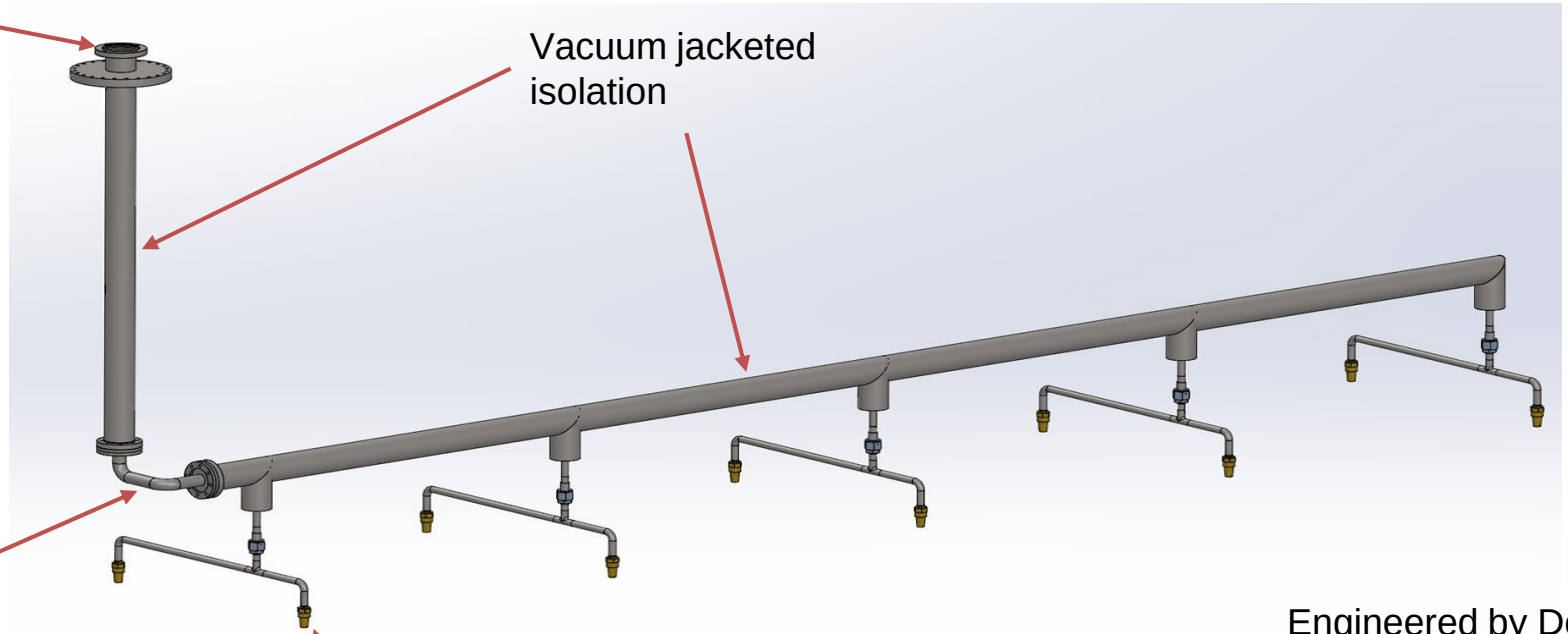
G10 Plate Thermal-Structural FEA:
https://edms.cern.ch/document/2748848/1

FEA - Report:
https://edms.cern.ch/document/2748848/1

Liquid Argon distribution

Johnston coupling
(interface to cryogenics)

Vacuum jacketed
isolation



Unisolated section
(easier and cheaper)

Engineered by DeMaCo,
D0735606

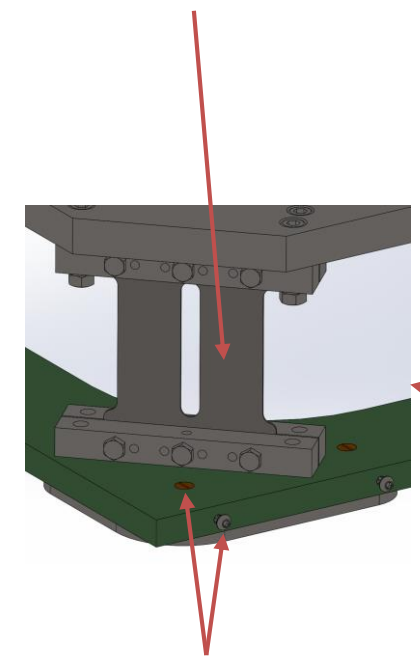
Phase separator
(Interface to field structures)

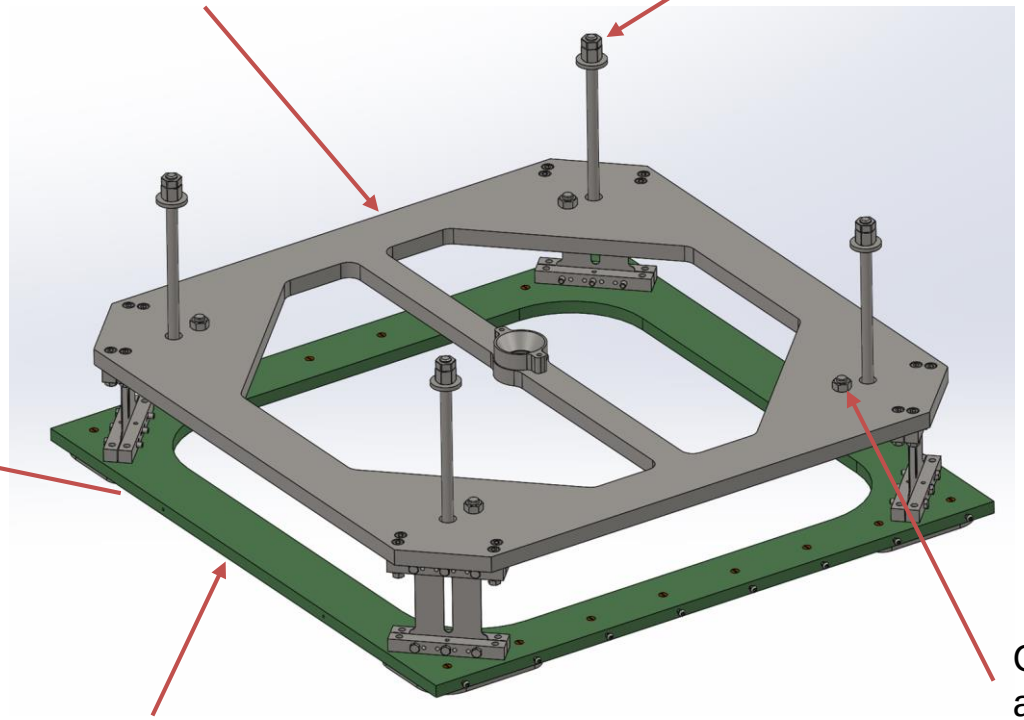
Module support

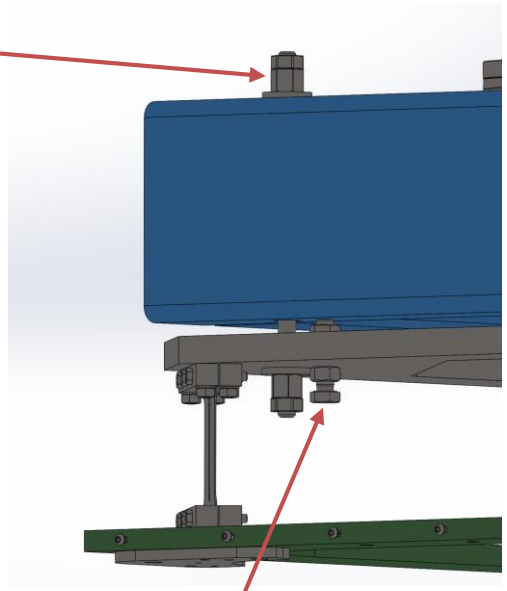
Flexures for uniform temperature equalisation and low heat transfer
(Calculations from K. Skarpaas)

Stainless steel plate

Concave and convex washers for angular adjustment







Nuts and screws
(Interface to field structures)

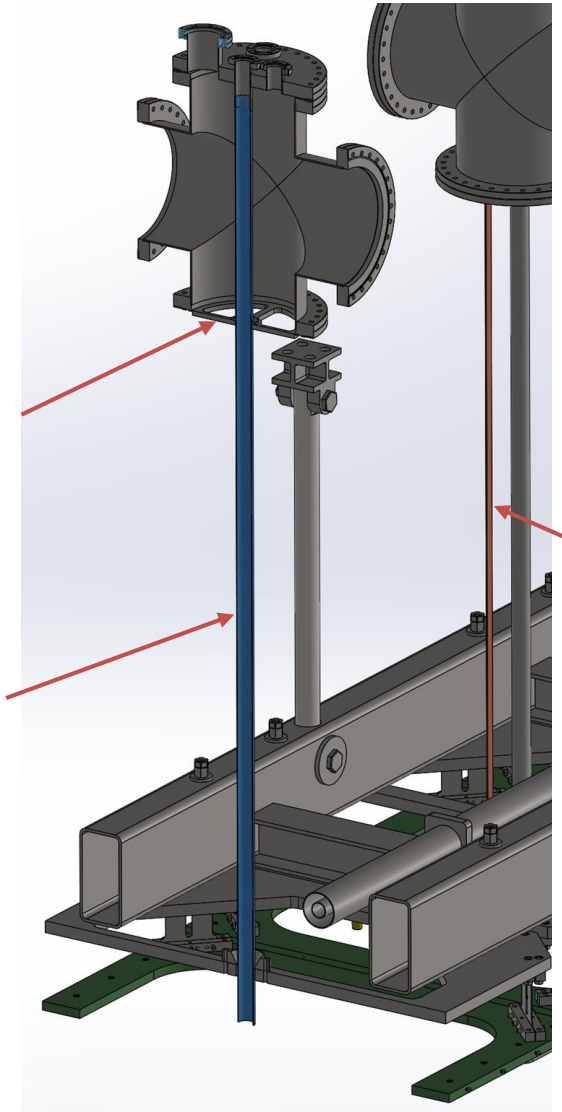
G10 plate

Countered screws for vertical adjustment

Feedthrough for HV , instrumentation and calibration

- Each TPC has a dedicated feedthrough for module services (35X)
  - Top Hat Flange
    - High Voltage
    - Calibration Fibers
    - Module Instrumentation
    - Gar Return
  - Charge Power/Ground & Signal
  - Light Power/Ground & Signal
- OTS 4-way cross with 13.25” OD Conflat flanges used to break out detector services
- Interfaces to ND-LAr cryostat lid → presents lid penetration and 13.25” OD CFF

-> Cable routing and installation procedure in I&I talk



ESH Codes and Standards

- Adheres to all ESH codes/standards established by LBNF/DUNE Project plus home institutional ESH requirements
- All Near Site deliverables must satisfy FNAL FESHM requirements
  - **2x2 Program providing experience through ORC process**
  - https://eshq.fnal.gov/manuals/feshm/
- Specifically ND-LAr has completed an initial review of applicable areas of FESHM, found at EDMS 2602421
  - Cryogenic System Review (FESHM 5032)
  - Feedthrough pressure rating & test (ASME Section VIII, non-standard devices)
  - Feedthrough flange pressure rating & test (ASME Section VIII, non-standard devices)
  - Cryogenic lines pressure rating & test (ASME B31.3)
  - Design and construction of structures at FNAL (FESHM 5100)
- ND-LAr has also completed a Hazard Registry in coordination with the ND sub-project, found at EDMS 2663898

Open Design Issues / Path to FSD & 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)
- Final CAD design, completion of all ICD and associated interface drawings, completion of production drawings for FSD module
- Build and assess an FSD module:

Prototypes for FSD (for SLAC and Bern)	Qty	Spares
Module Support Flexures	8	4
Module Support Frame	2	0
TPC Thermal Instrumentation (PT100)	4	2
Module Service 4-way Cross (13.5" OD CF)	2	0
Conflat Gaskets (13.5" OD CF)	4	6
Module Service Top Hat Assembly (13.5" OD CF blank with feedthroughs)	2	0
VJ LAr Distribution Line	2	0
CF Flange Hardware (Bolts, Nuts, Washers)		

Summary

- The CAD model and associated design documentation is developed and in-place to continue to final detailing and construction of the FSD module
- Remaining technical challenges will be addressed through continuation of prototyping program (2x2, FSD)
- Requirements and interfaces are at the appropriate level of maturity for preliminary design; systems and methods are in place to continue their maturation
- **Ready for the final design phase and construction of the FSD module**