

DUNE ND Engineering Collaboration Meeting

LArTPC Cryostat Design

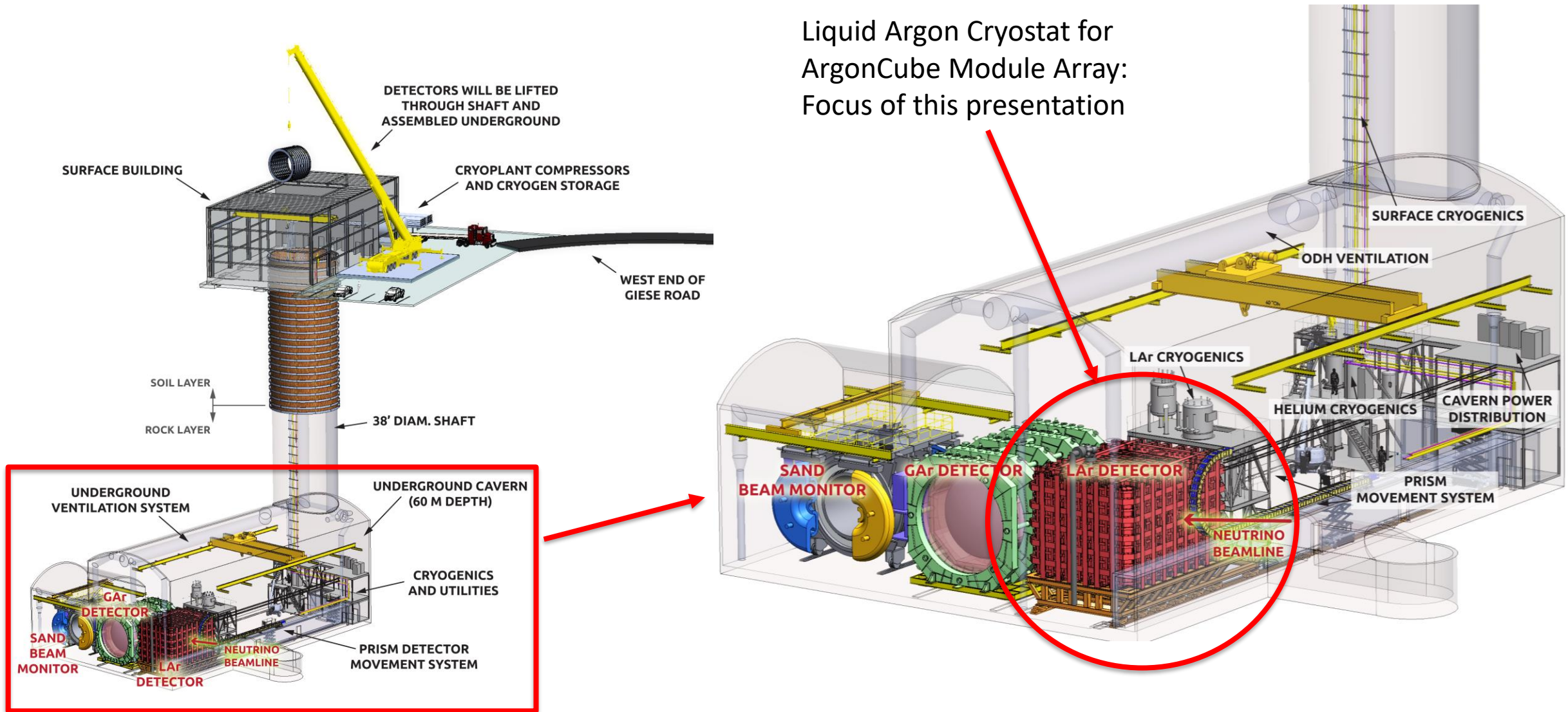
Andrew Lambert – Lawrence Berkeley National Laboratory

06/11/2020

Agenda

- LArTPC Cryostat
 - Introduction
 - Cryostat Design
 - Warm Structure
 - External Beam Structure
 - Composite Wall
 - Cold Structure
 - SS Membrane and Insulation
 - Modular Top Lid
 - Lid Section Design
 - Installation Sequence
 - Summary

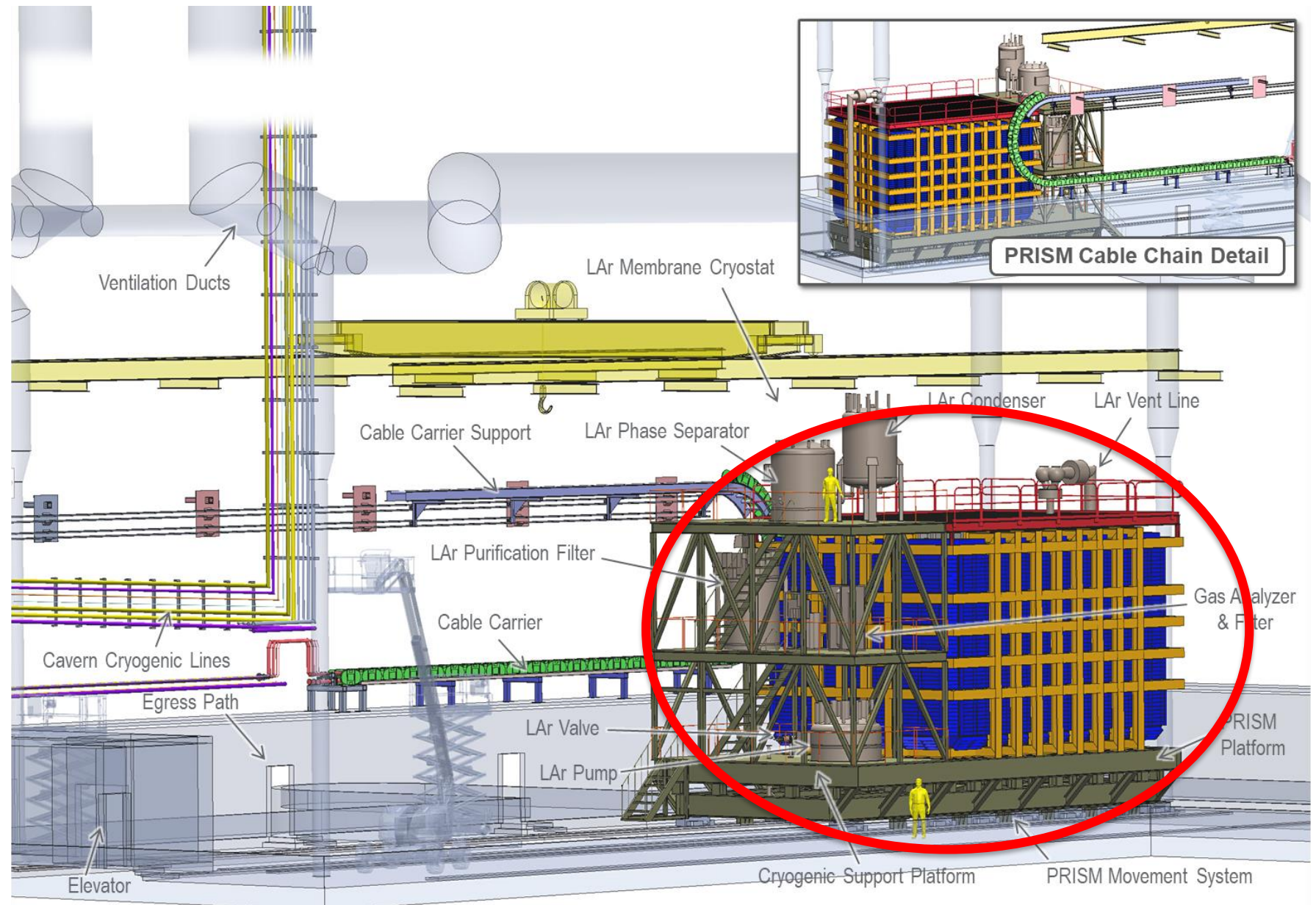
Introduction



Liquid Argon Cryostat for ArgonCube Module Array:
Focus of this presentation

Introduction

- LArTPC Cryostat installed to PRISM movement system to translate entire structure along length of ND cavern
- Cryogenic mezzanine travels with cryostat
- Cable chains are used to take up movement in electrical cabling and cryogen supply lines
- Cryostat is the structure circled in red – see human figures to get idea of scale



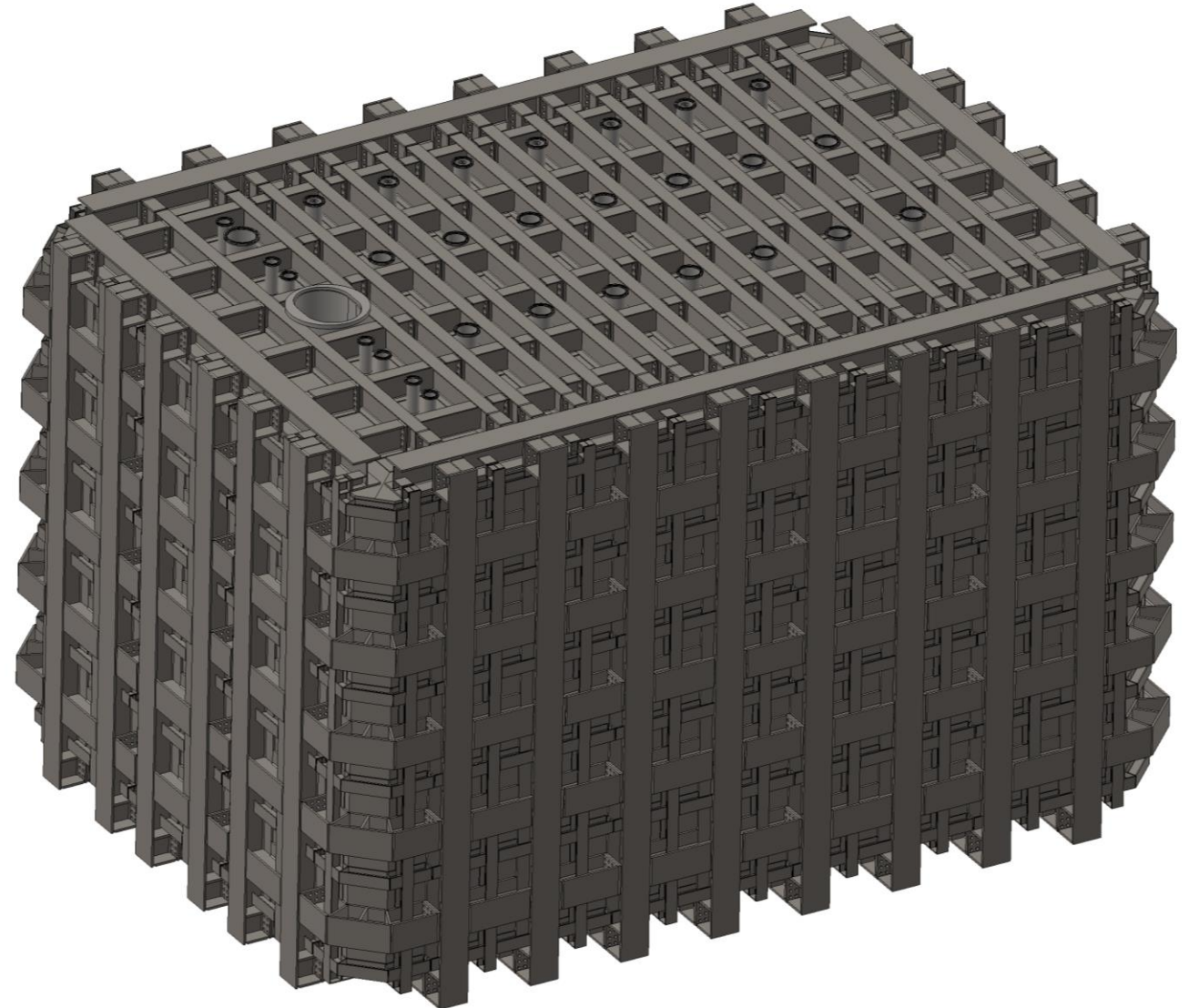
Physics Requirements

id	Artifact Type	Name	Primary Text
ND-T1.8.1	Specification	Cryostat Inner Dimensions	The ND LArTPC cryostat inner dimensions must be large enough to host the ND LArTPC detector system.
ND-T1.8.2	Specification	Downstream Passive Material	The downstream material of the ND LArTPC cryostat (cold structure, warm structure, plus inactive argon when filled) must not substantially attenuate neutrino-induced muons exiting the ND LArTPC.
ND-T1.8.3	Specification	Cryostat Robust to Movement	The ND LArTPC Cryostat shall be sufficiently robust such that off-axis (PRISM) movements do not substantially impact cryostat performance.

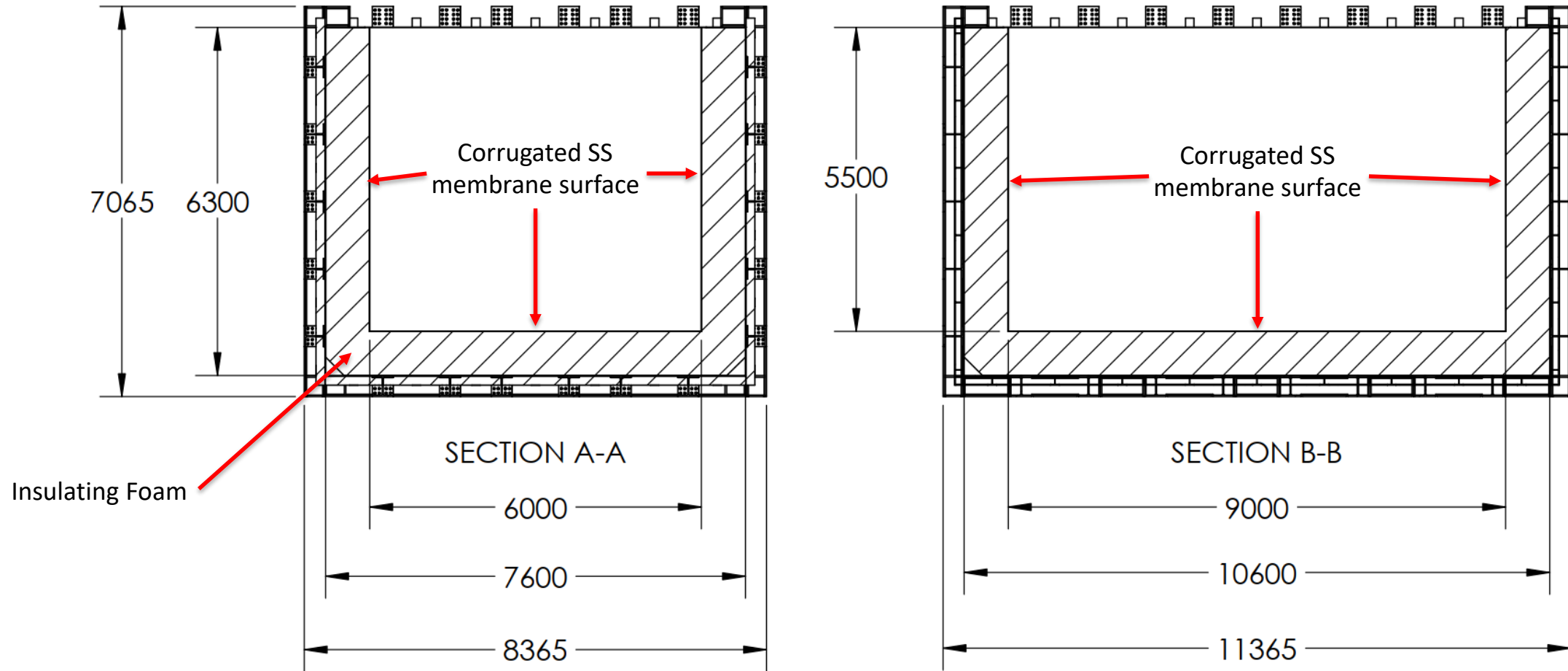
- Physics requirements flow down to engineering requirements
- Engineering requirement development for cryostat in process, working with physics team to ensure proper interpretation
 - Dimensions
 - Heat Leak
 - Mass
 - Required services
 - Etc.

Cryostat Design

- External structure is based on the ProtoDUNE design
- I-beams used for external structure
- Modular design
- Reduced part #
- Wall weldments are divided into subassemblies that are joined via bolted connections on beams
- Wall weldments have 1.0 cm steel skin on backside, adjacent skins welded together to form moisture barrier
- Corner weldments identical at all corners
- Removable lid with feedthroughs for cryogenics, high voltage and detector DAQ

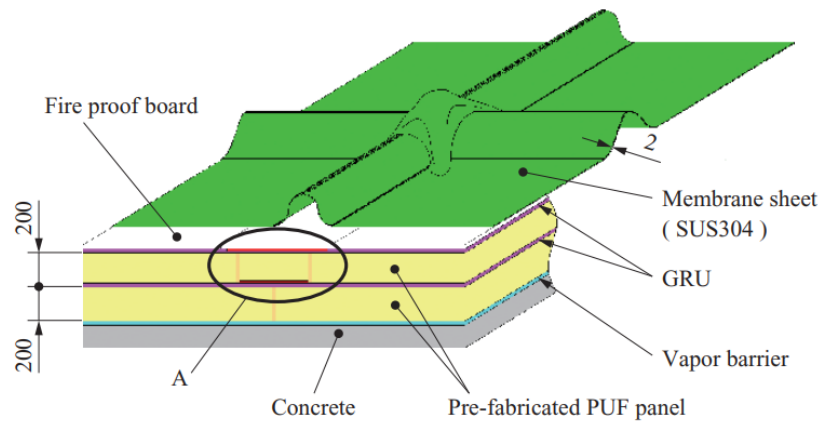
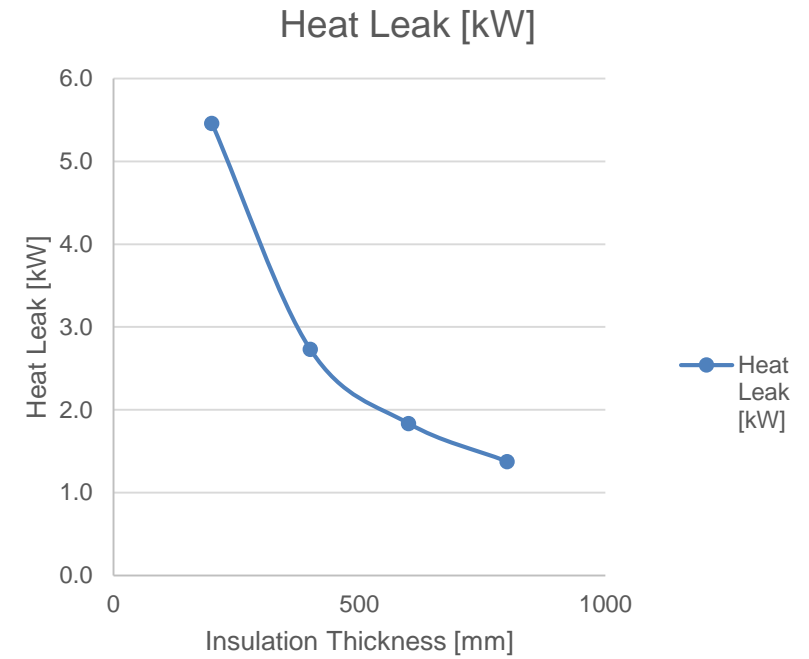
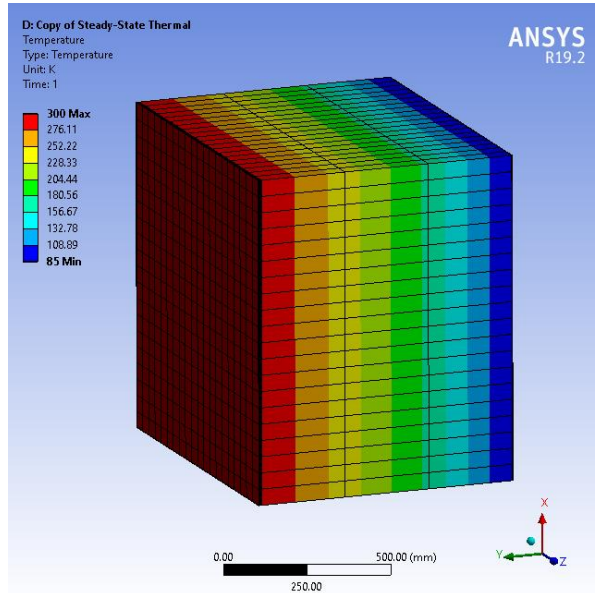
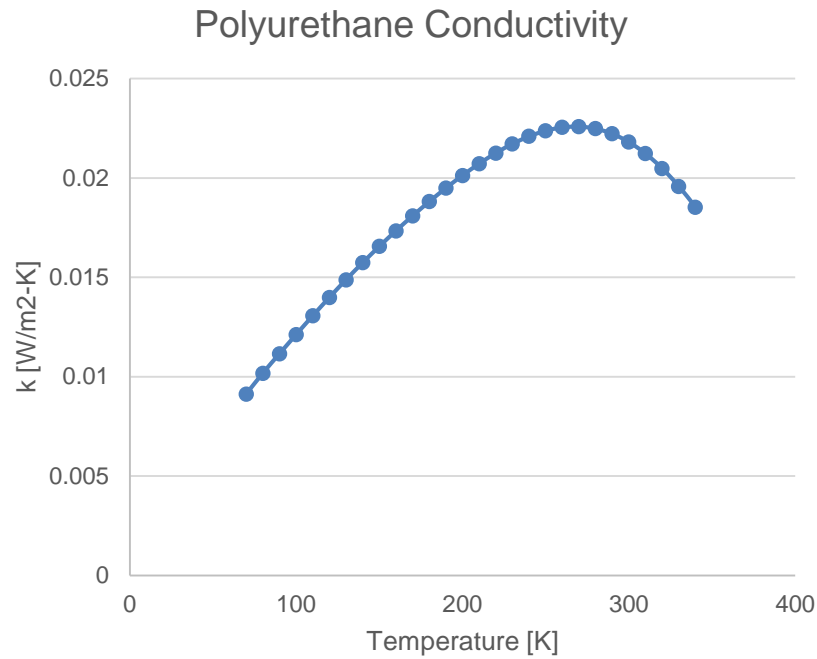


Overall Size



Parameter	Length [mm]	Width [mm]	Height [mm]
Membrane Flat Internal Dimensions	9000	6000	5500
10mm Steel Skin Internal Dimensions	10600	7600	6300
External Steel Structure Dimensions	11365	8365	7065

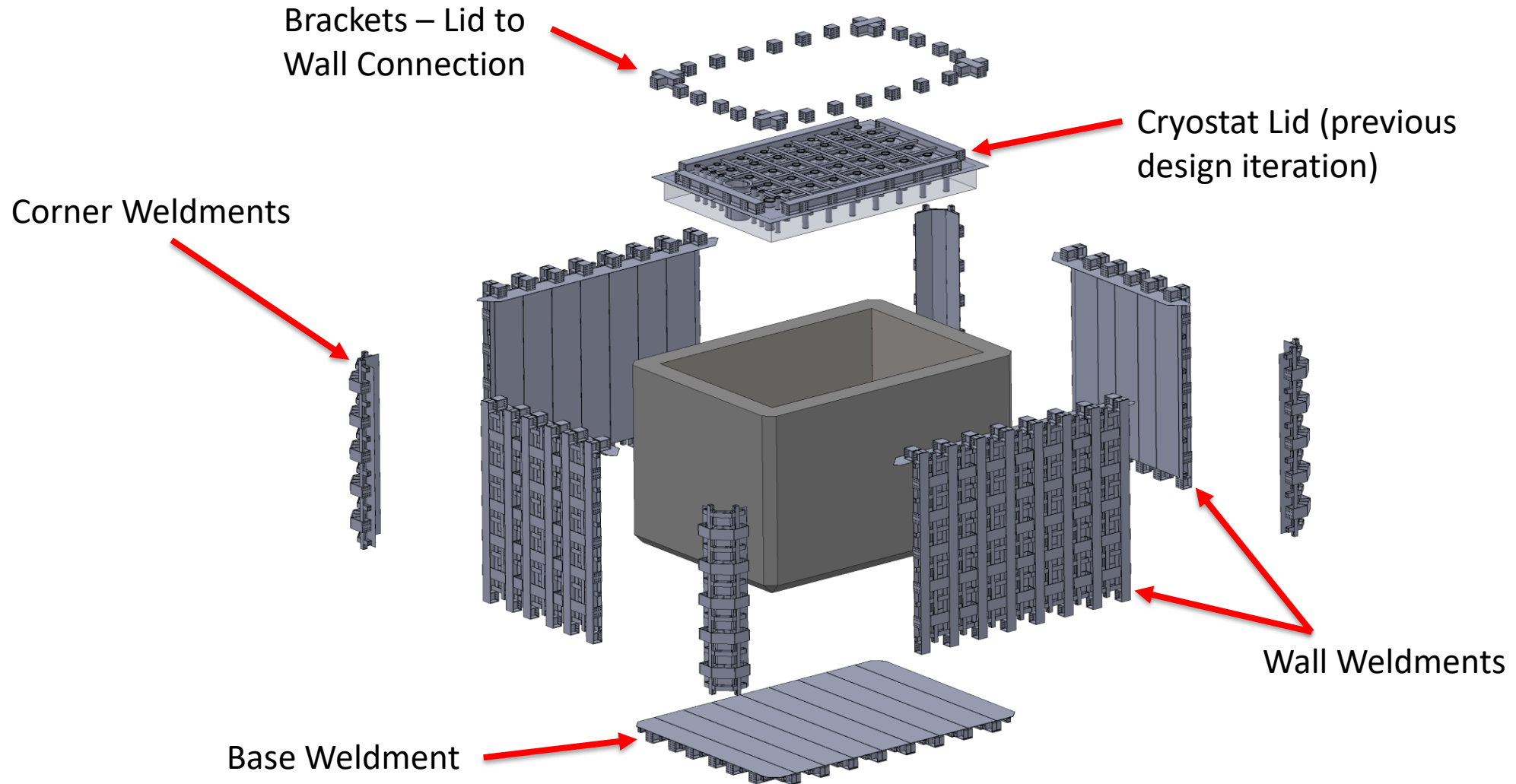
Desired Thickness of Insulation



Thickness [mm]	Surface Area [m ²]	Heat Flux [W/m ²]	Heat Leak [kW]
200	273	20.0	5.5
400	273	10.0	2.7
600	273	6.7	1.8
800	273	5.0	1.4

****Indicates that 600mm insulation thickness may be possible to save space**

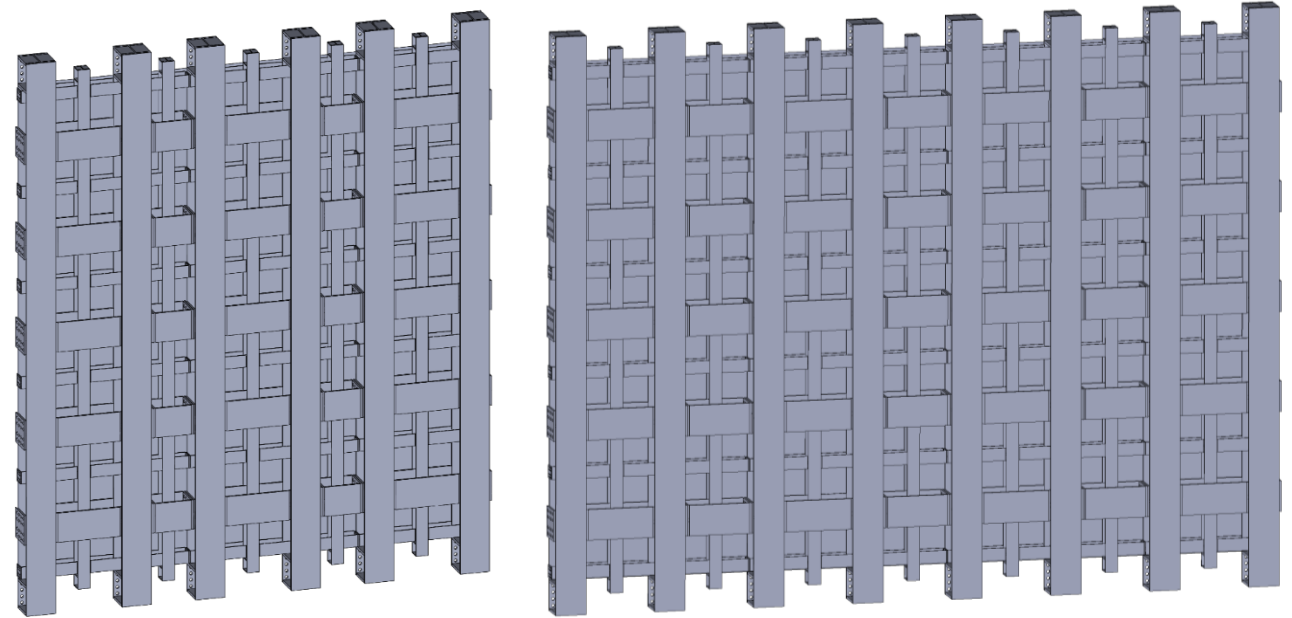
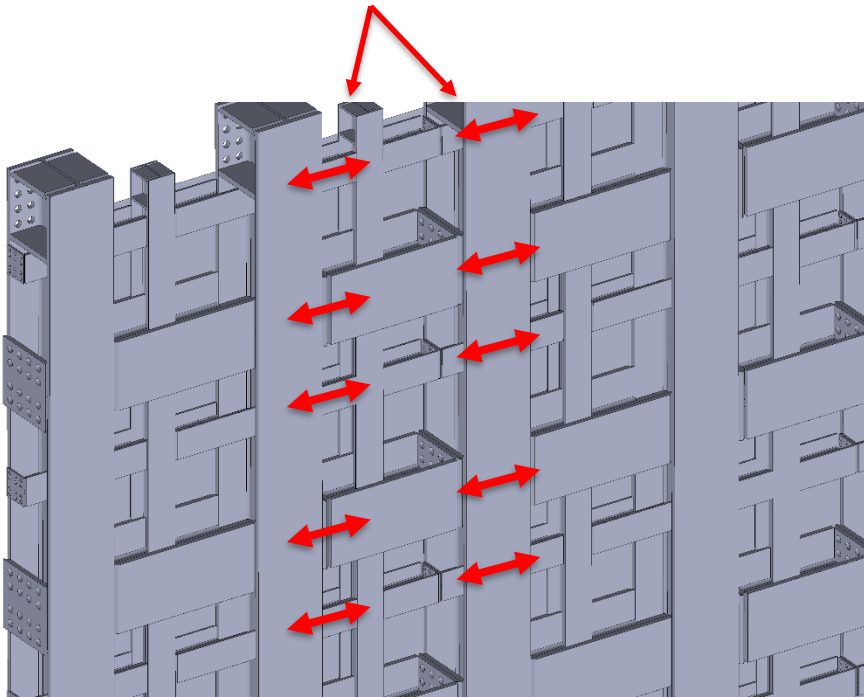
Exploded View



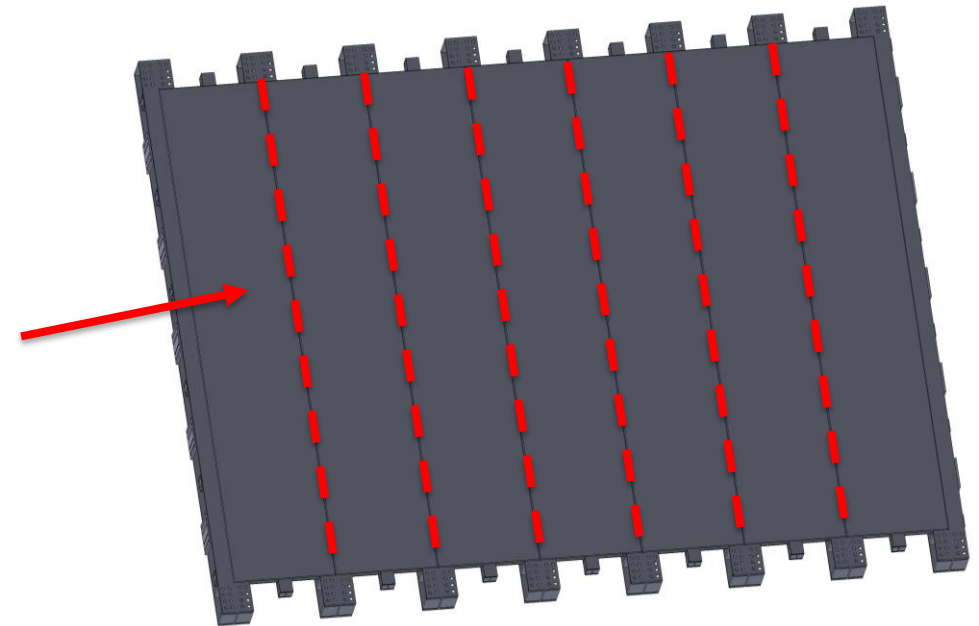
Wall Design

- Comprised of smaller subassemblies that are bolted & welded together

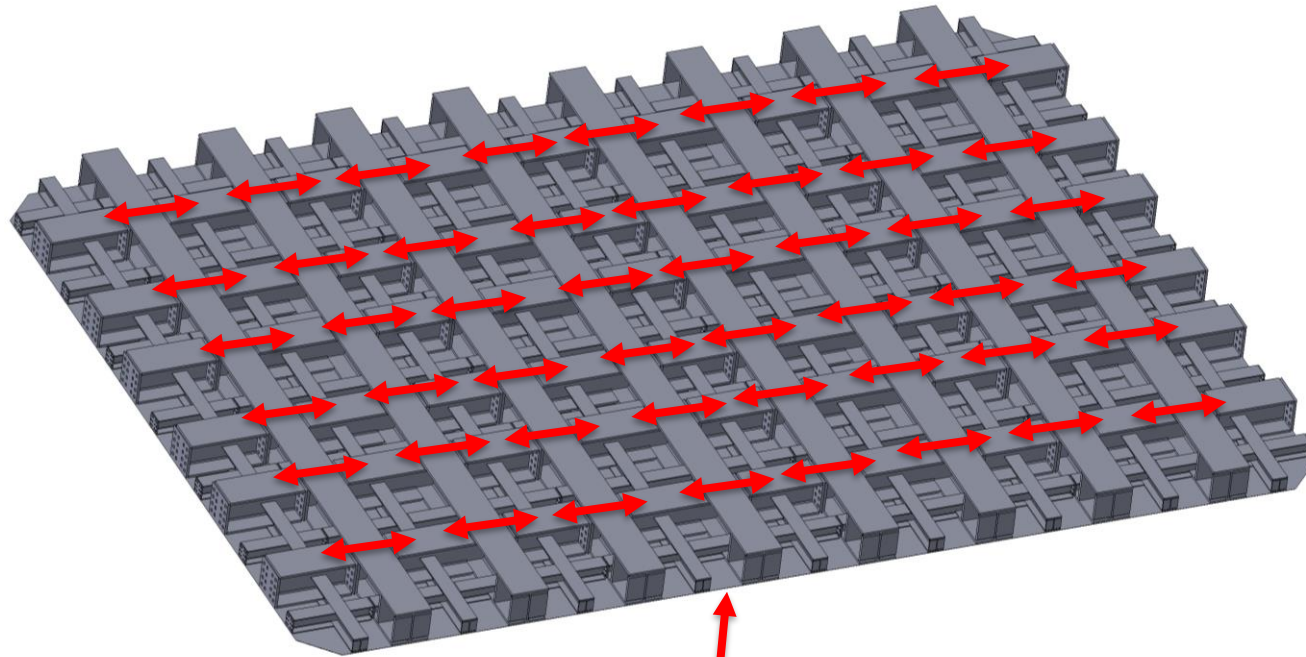
Bolted connections to join adjacent wall sections



Weld seams on backside to form moisture barrier

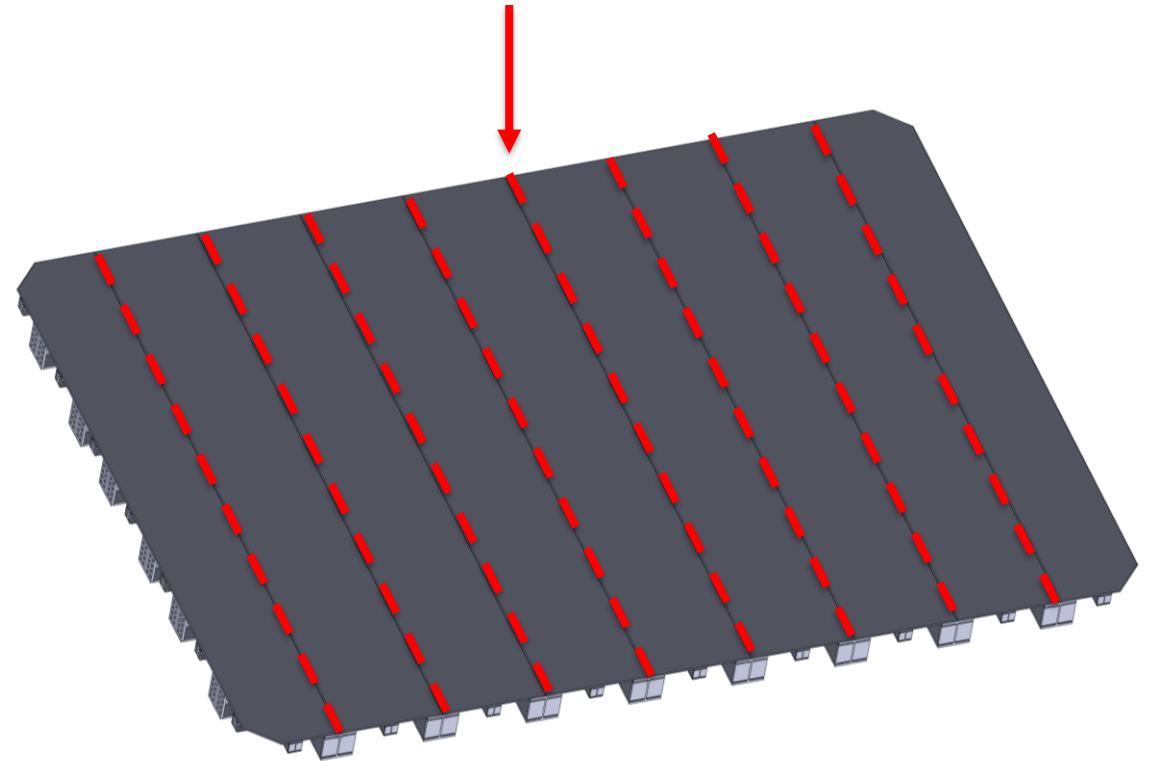


Base Design



Bolted connections to join adjacent sections

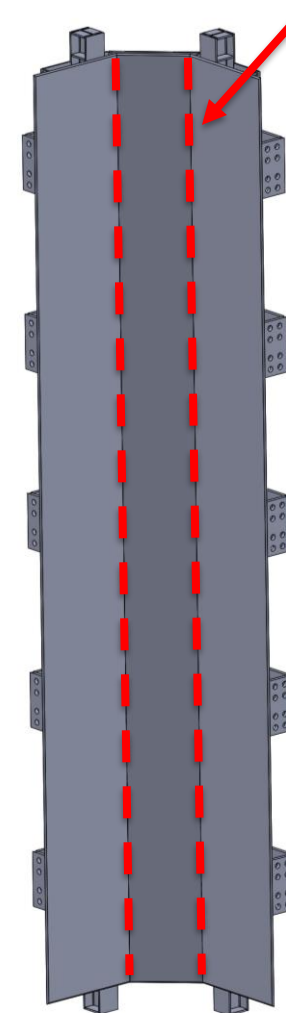
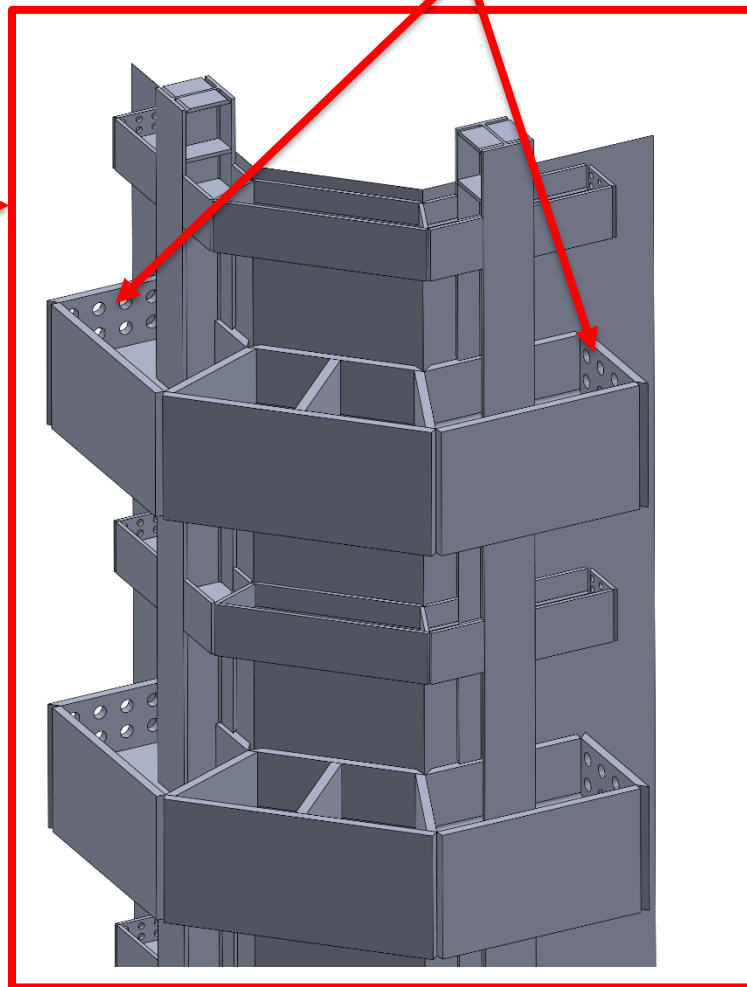
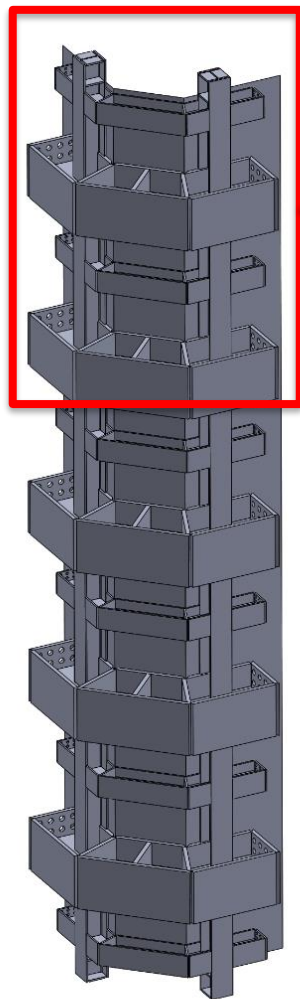
Weld seams on backside to form moisture barrier



Corner Design

Bolted connections to join adjacent sections

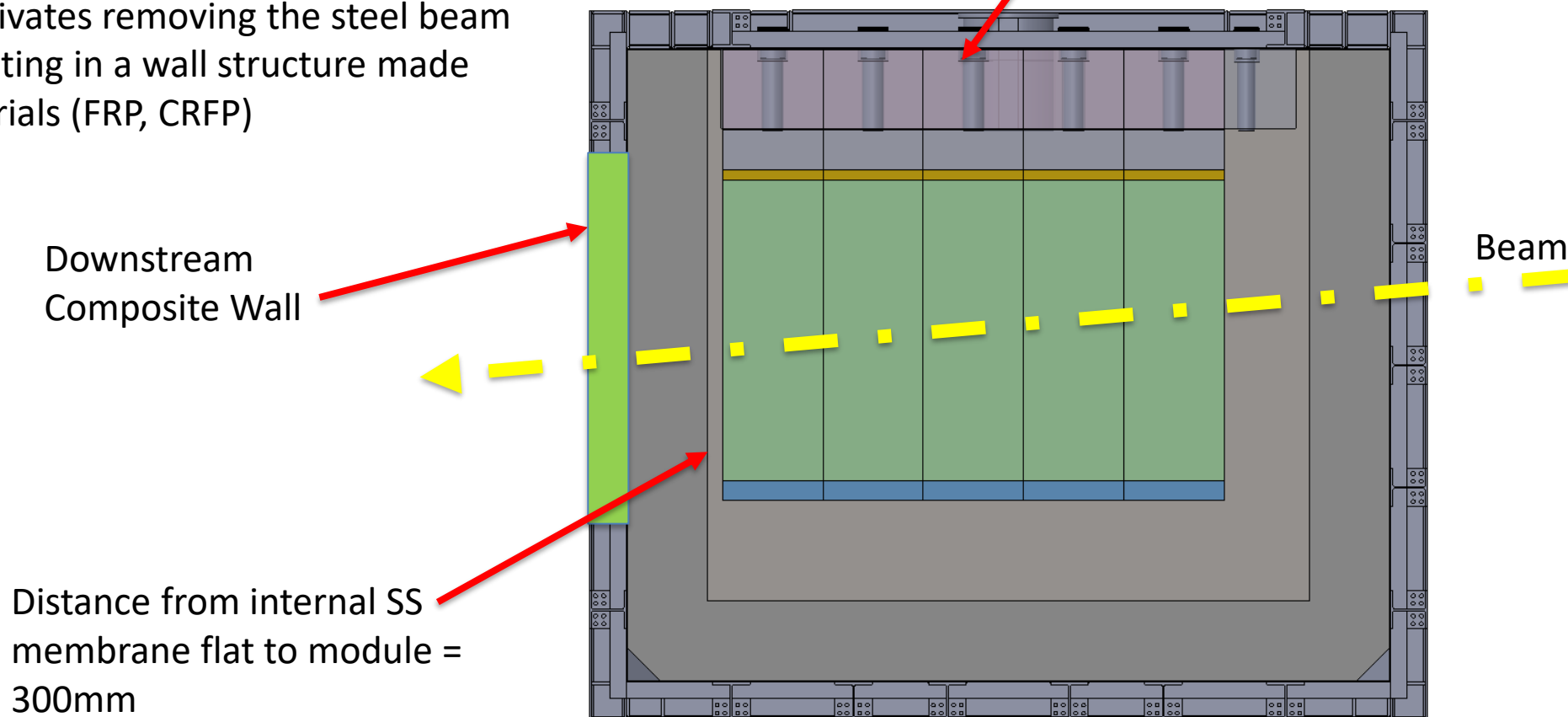
Weld seams on backside to form moisture barrier



Downstream Composite Wall

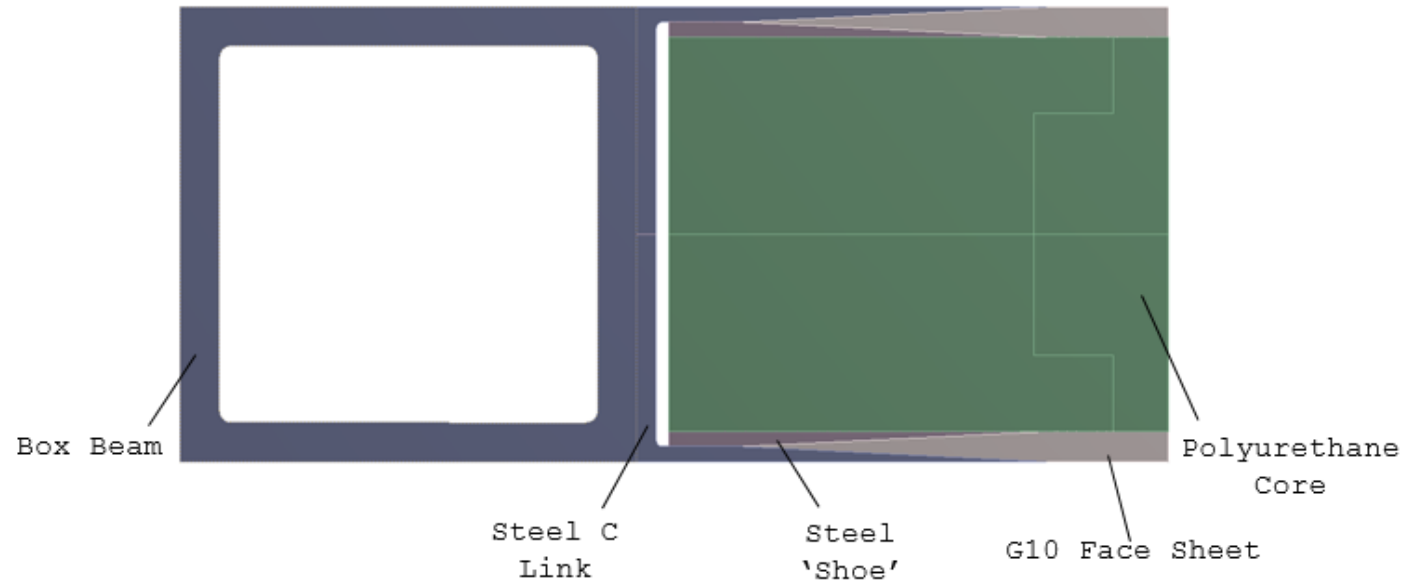
Motivation: To reduce muon losses downstream of the LArTPC, the intervening average mass (between active LAr volume and downstream GAr detector) must be minimized -> this motivates removing the steel beam structure and substituting in a wall structure made from composite materials (FRP, CRFP)

Modules are shifted off-center to minimize the thickness of the downstream LAr layer



Scarf Joint Design – Join Composite Window to Beam Structure

**Courtesy of G. Vallone

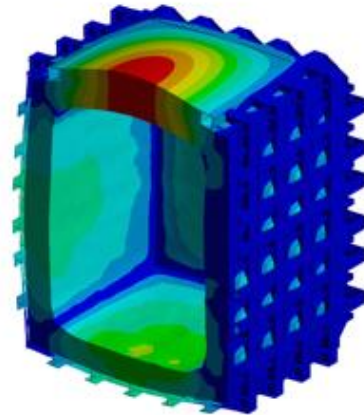
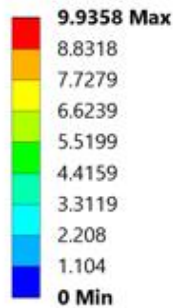


- The tapered lap joint is not able to satisfy the strength requirements (with a reasonable length)
- A scarf joint can sustain much higher loads
- Production process is more complicated

Preliminary Analyses – Beam Structure & Composite Wall

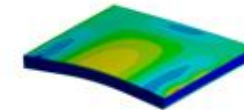
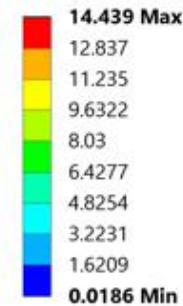
****Courtesy of G. Vallone**

L: Solid ACP
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1

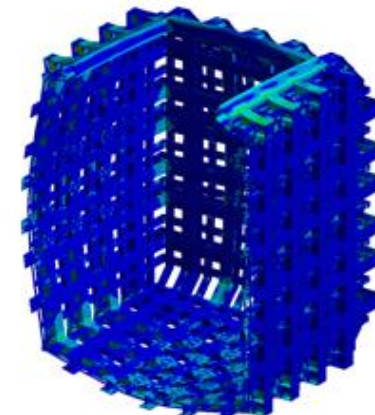
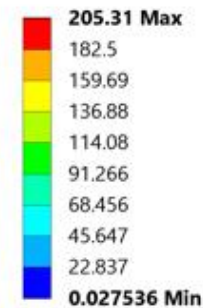


- Deformation within requirements
- Stresses in the composite plate are low
- Stresses in the steel structure are ~high
 - Mostly localized effects, primary stresses are low
 - We should put some care in the design of the joints

L: Solid ACP
Equivalent Stress 3
Type: Equivalent (von-Mises) Stress - Top/Bottom - Layer 0
Unit: MPa
Time: 1



L: Solid ACP
Equivalent Stress
Type: Equivalent (von-Mises) Stress - Top/Bottom - Layer 0
Unit: MPa
Time: 1

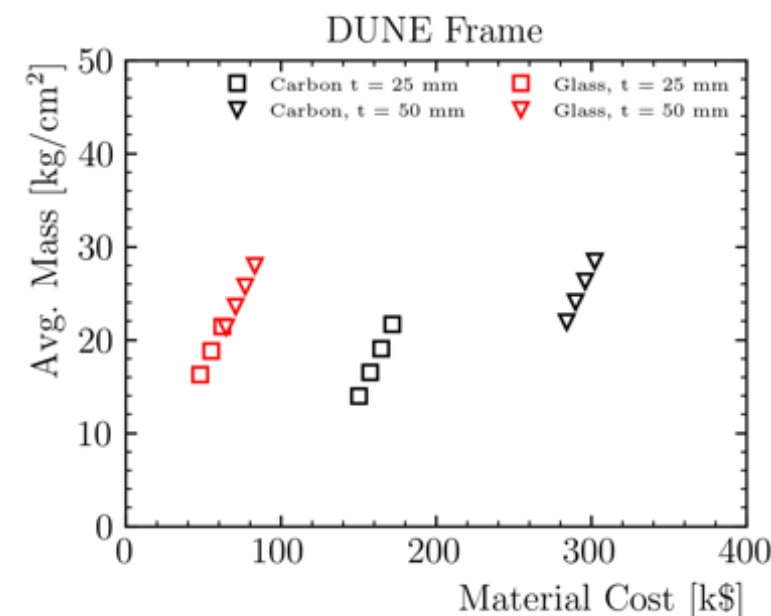


Average Mass through Window Thickness

**Courtesy of G. Vallone


Layer	Material	thickness	x0_s	rho	L	x0	X0	Contrib.	rho*t	Contrib.
/	/	mm	g/cm2	kg/m3	cm	cm/cm	%	%	g/cm2	%
Liquid	Argon	500	14	1396	10.029	4.99	499%	77.5%	69.8	73.7%
Plate	Steel	2	1.7	7000	0.243	0.82	82%	12.8%	1.4	1.5%
Insulation	Polyurethane	808	40.8	90	453.333	0.18	18%	2.8%	7.3	7.7%
Window	Composite	372				0.45	45%	6.9%	16.2	17.1%
Steel Eqv.	Steel	58.3	1.7	7000	0.243	24.00	2400%		40.8	
Total						6.43	643%	100%	94.70	100%

- Average mass through the window thickness
- Composite window contribution ~ 17% of the total
 - Advantage of steel is less evident (~factor 2.5)
 - This does not consider the fact that the steel is not uniformly distributed
- No reason to use carbon anymore, unless the joint submodel will show that we need it for strength
- Total target is ~ 50 g/cm2



Cold Structure – SS Membrane and Insulation

- Specification Document for the cryostat cold structure; document defines the following features of the cold structure
 - Overall requirements
 - Warm structure design
 - Cryostat lid design
 - Cold vessel features
 - Penetrations
 - Top lid & cryostat walls (LAr pump)
 - Deliverables for cold structure budgetary quote
 - Can be revised into final procurement spec eventually
- Engaged with IHI Corporation on June 4th to begin conversation on cold structure
 - Thank you to D. Montanari for help with IHI contact person & advice on required info for budgetary bid

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Title DUNE-ND / DUNE-ND - LAR DETECTOR GENERAL DUNE LARTPC CRYOSTAT COLD STRUCTURE SPECIFICATION					

DUNE LARTPC CRYOSTAT COLD STRUCTURE SPECIFICATION

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Cold Structure Specification Document – Released & sent to IHI, major milestone in cold structure development

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WINDCHILL TECHNICAL NOTE TEMPLATE

DUNE LARTPC CRYOSTAT COLD STRUCTURE SPECIFICATION

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WINDCHILL TECHNICAL NOTE TEMPLATE

REVISION HISTORY

Revision	Date	Changes
001	08/18/2017	Initial

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WINDCHILL TECHNICAL NOTE TEMPLATE

INTRODUCTION

This document defines the requirements for a stainless steel main body cryostat, constructed within the external support structure as detailed by LBNL for the Deep Underground Neutrino Experiment Near Detector (DUNE-ND) Liquid Argon Time Projection Chamber (LAR(TPC) detector) at FNAL, seen in Figure 1. The stainless steel main body cryostat contains liquid argon (LAr).

Neutron interactions with Argon nuclei yield ionized particles that are detected by constructing a time-projection-chamber (TPC) in the liquid argon volume; this TPC will contain instrumentation for both electron and photon detection. Liquid argon purity is of critical importance for successful instrument operation.

Additionally, the application of the main body cryostat technology will require numerous feedthrough penetrations to route electrical and cryogenic services to the instrument and LAr volume. These are defined in the section "PENETRATIONS REQUIRED FOR DUNE APPLICATION". This document specifies the overall requirements. Detailed drawings are outlined at the end of the document.

ACRONYMS AND ABBREVIATIONS

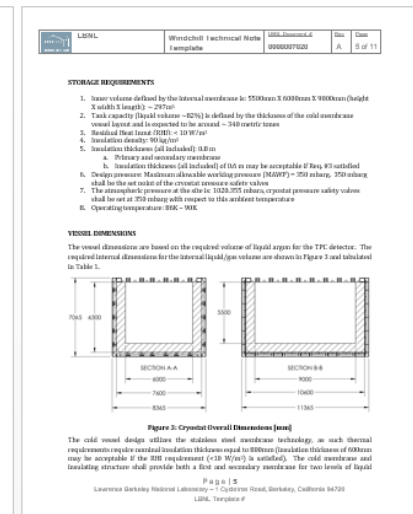
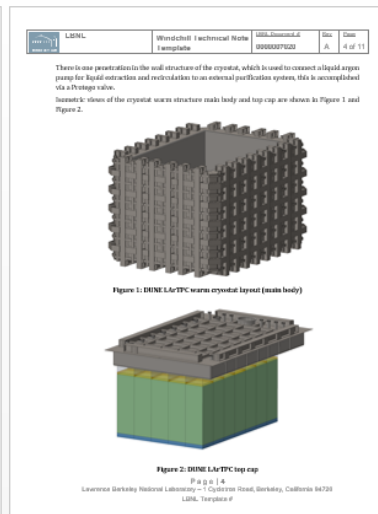
- DUNE: Deep Underground Neutrino Experiment
- DUNE: Deep Underground Neutrino Experiment Near Detector
- FNAL: Fermi National Accelerator Lab
- GA: Gaseous argon
- LAR(TPC): Liquid argon time projection chamber
- LAr: Liquid argon
- LBNL: Lawrence Berkeley National Lab
- MAWP: Maximum allowable working pressure

OVERALL PROJECT REQUIREMENTS

The cold structure will be required to provide containment of LAr at a temperature between 80.7 K and 81.2 K, with a maximum operating pressure of 350 mbar. Minimal heat leak through the walls/floor of the containment structure shall be less than 10 W/K.

The cryostat top cap is designed to provide both signal and cryogenic services to the detector modules, as well as cryogenic services to the external LAr bath. Additionally, the top cap shall have an access port for personnel to enter/exit the internal structure, so other opening for access to the inside of the cryostat during assembly is provided. The required top cap penetrations for these services are defined in later sections of this document.

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WINDCHILL TECHNICAL NOTE TEMPLATE

containment. Liquid argon containment at the boundary of the warm steel structure is not required. A 15mm steel skin is present behind the insulation and acts as a vapor barrier from the ambient environment, and as an enclosure for critical storage gas.

Neutral structure dimensions are tabulated in Table 1 below.

Parameter	Length [mm]	Width [mm]	Height [mm]
Membrane Flat Internal Dimensions	5100	6000	9000
15mm Steel Skin Internal Dimensions	10600	7000	6800
External Steel Structure Dimensions	11350	8500	7300

The membrane flat internal dimensions do not include the space used by the 20 cold structure corrugations.

WARM CRYOSTAT DESIGN AND MAIN CHARACTERISTICS

The warm structure is constructed from side flange beams that are welded into wall/floor structure and then bolted together. These provide mechanical support to both the cold membrane and insulation. The 15mm steel skin is welded to the flanges, as well as aluminum skin to form a vapor barrier. This external steel structure provides the mechanical support required against the liquid argon hydrostatic load, argon-gas overpressure load, gravitational loads, and external constraints.

The warm structure base shall interface to a steel beam platform, which shall interface to a linear rail system for translating the entire structure the length of the underground cavern.

Structural analysis of the warm structure shall be a LBNL deliverable.

The warm structure's leak integrity will be verified prior to cold structure installation. Qualification activities may include, but are not limited to, the following:

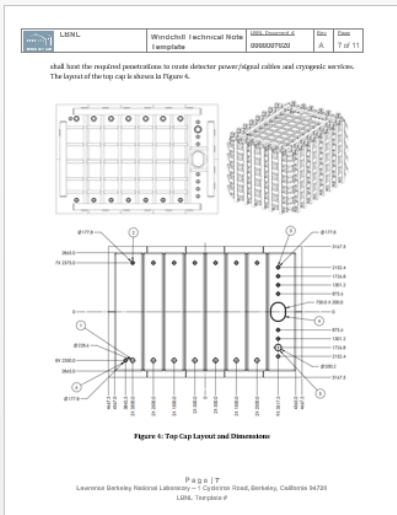
- Sty Treatment Analysis
- Helium Leak Rate Measurement

Responsibility for qualification of the warm structure rests with LBNL and the DUNE-ND Project.

CRYOSTAT TOP CAP

The cryostat top cap provides mechanical support to the detector modules. Detector modules are distributed over the top cap, and thus the warm structure is attached to the main body of the cryostat. A weld seam is laid down to seal the external argon environment from atmosphere. The top cap is comprised of an external 15mm steel plate and beam structure, similar to the external warm structure main body. The top cap shall have a neutral insulation thickness of 60mm, and an internal stainless steel cold membrane on the bottom surface. As previously mentioned, the top cap

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WINDCHILL TECHNICAL NOTE TEMPLATE

COLD VESSEL

The cold vessel structure consists of the following: both a primary corrugated stainless steel membrane and secondary thin membrane, insulation interposed with an inert, gas outlet, and temperature sensor. This is installed in the previously defined warm support structure. Neutral insulation thickness is defined in 8.00mm, with 60mm provided if needed heat load requirements are satisfied.

Non-**double** electronics only shall be used for membrane welding.

PENETRATIONS REQUIRED FOR DUNE APPLICATION

LAR(TPC) PENETRATION

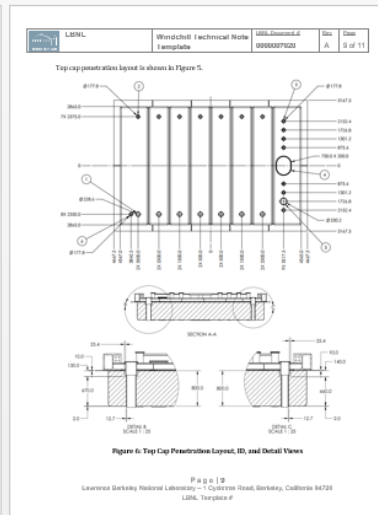
Isone to maintain liquid argon purity, automated pump is installed such that it interfaces with the bottom of the liquid volume. The penetration interface location panel and the cold stainless steel membrane structure. There is flexibility in the positioning of this penetration to minimize any required change in the primary membrane. Neutral location and size of this penetration is shown in Figure 5.

Figure 5: LAr Pump Penetration Valve Penetration

TOP CAP PENETRATIONS

Penetrations on the top cap of the cryostat are used to route electrical and cryogenic services from the detector modules and route cryogenic services to the external LAr argon bath. There is flexibility in the positioning of these penetrations.

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WINDCHILL TECHNICAL NOTE TEMPLATE

The penetrations shown in Figure 5 are also tabulated in Table 2 below. There are 24 total penetrations in the top cap.

Name ID	Quantity	Description
1	7	TPC Absolute Signal/Vacuum Feedthroughs
2	7	TPC Module Cryogenic Liquid Feedthroughs
3	7	Cryostat Cryogenic LAr Feedthroughs
4	1	Personnel Access Port
5	1	Cryostat Cryogenic Gas Feedthroughs
6	1	Pressure Relief Port

DELIVERABLES FOR THIS STUDY

SCOPE OF EFFORT

The main purpose of this document is to provide the necessary information required to obtain a budgetary quote for the design, construction and eventual installation of the containment membrane and thermal insulation on the cryostat warm structure. This should include the following:

- Budgetary quote for the thermal-mechanical design study of:
 - Primary cold corrugated stainless steel containment membrane
 - Secondary thin containment membrane
 - Insulation thickness
- Budgetary quote for the fabrication/assembly of:
 - Primary cold corrugated stainless steel containment membrane
 - Secondary thin containment membrane
 - Insulation panels
 - Any associated fixtures unique to this application
- Budgetary quote for the installation of:
 - Primary cold corrugated stainless steel containment membrane
 - Secondary thin containment membrane
 - Insulation panels
- Budgetary quote for the creation of:
 - Detailed assembly and installation procedures
 - Quality assurance/acceptance activities during procurement and installation

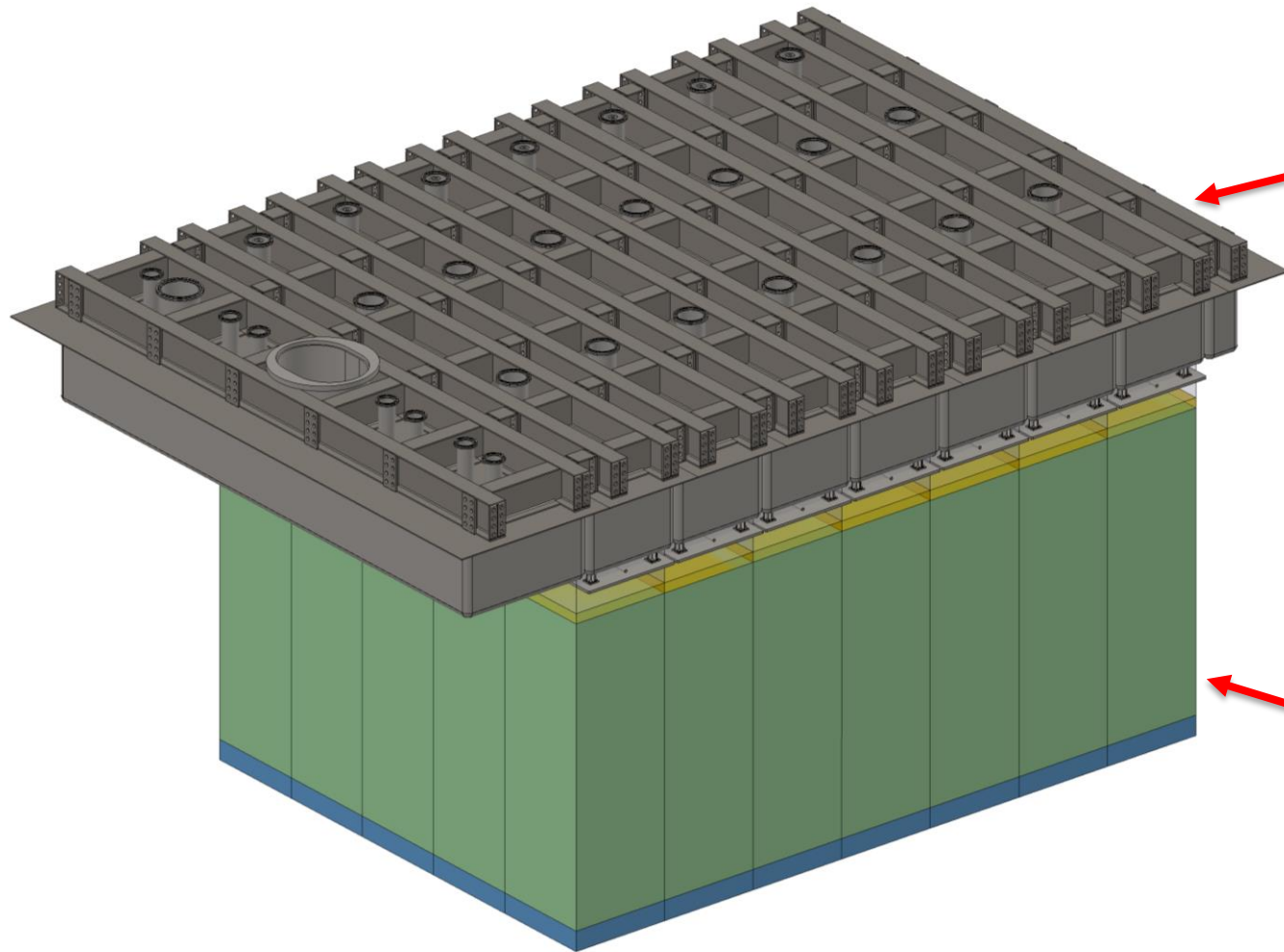
If unable to provide an estimate for installation, please provide a list of possible contractors that could perform the work.

Any required information that is needed to produce this estimate, but is not found within this document, can be requested from the signatory engineer at LBNL.

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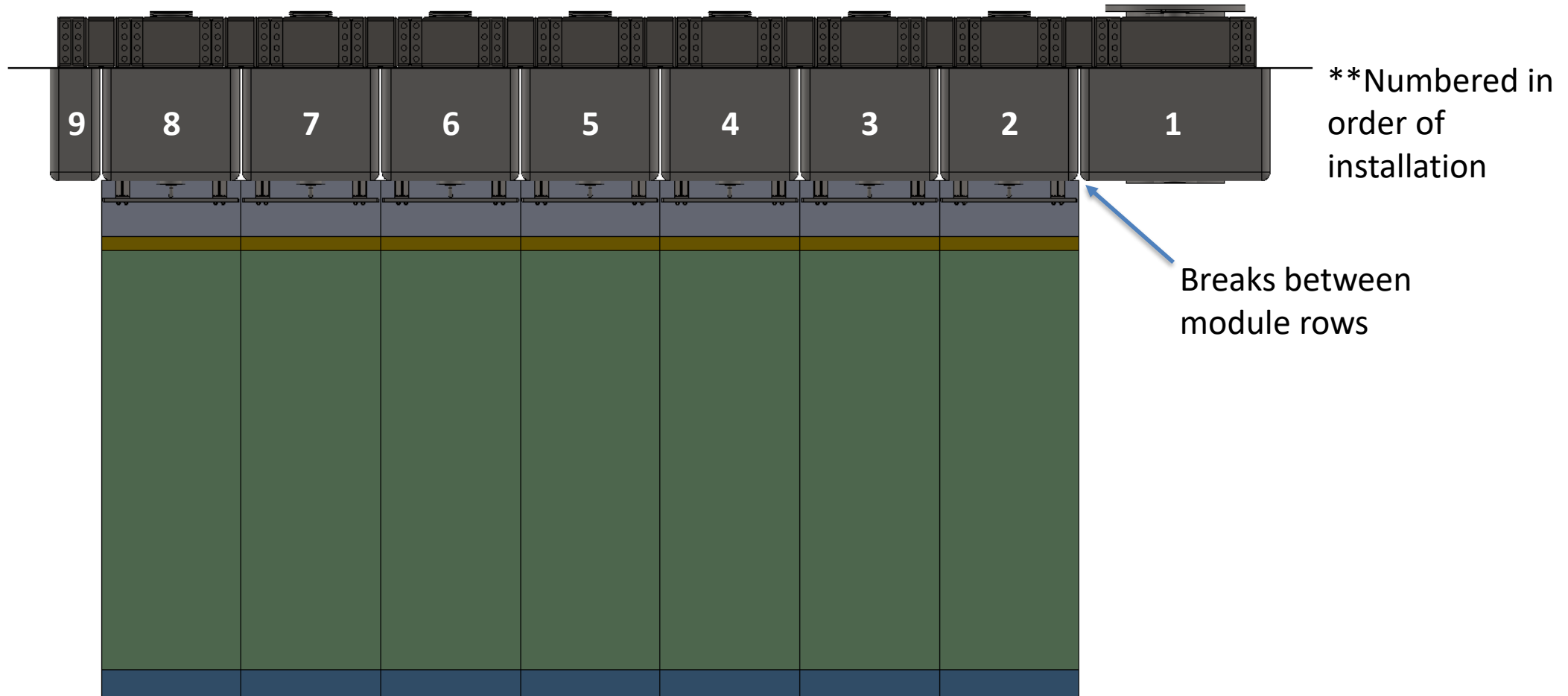
Top Lid Design – Modular Structure



Modular Lid Structure
Note: Lid is never lifted as a whole unit; only individual lid sections are manipulated at a time

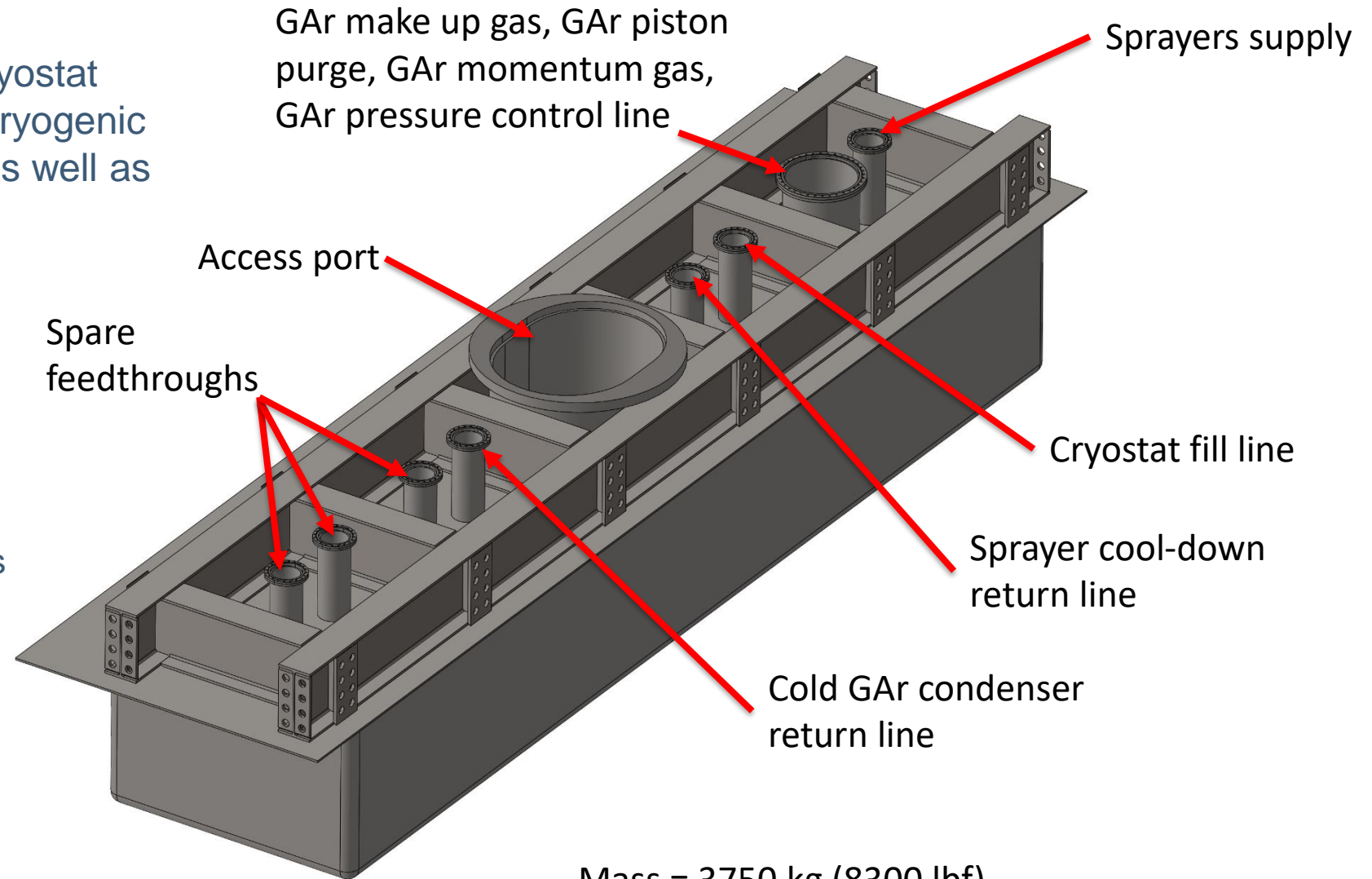
7 X 5 ArgonCube Module Array

Top Lid Isolated – Side View



Cryostat Lid Section – Cryo Feedthroughs & Access Port

- First section installed to main cryostat structure is the lid section with cryogenic feedthroughs for LAr and GAr, as well as access port for personnel
- Installation:
 - Lower into place
 - Weld & leak check
 - Install brackets and bolts
 - Install ladder for interior access
 - Install cryogenic lines

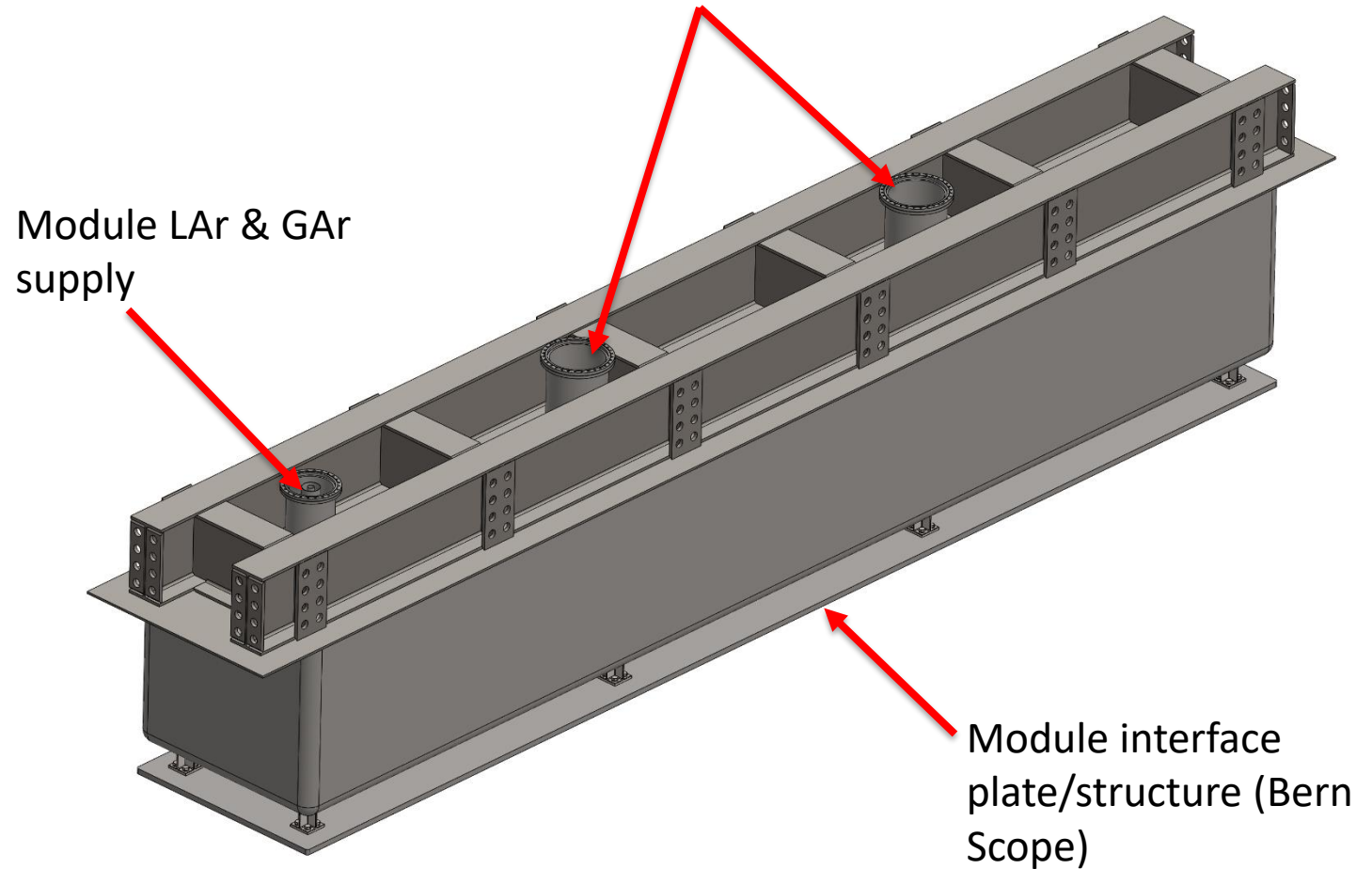


Mass = 3750 kg (8300 lbf)

ArgonCube Module Lid Section(s)

- Will support ArgonCube Module array
- Installation:
 - Lower into place
 - Weld & leak check
 - Install brackets and bolts
 - Route power & electronics
 - Connect cryogenics

Feedthrough ports for charge and light readout electronics, HV, and module GAr return



Mass = 3350 kg (7400 lbf)

ArgonCube Module Lid Section(s) - Feedthroughs

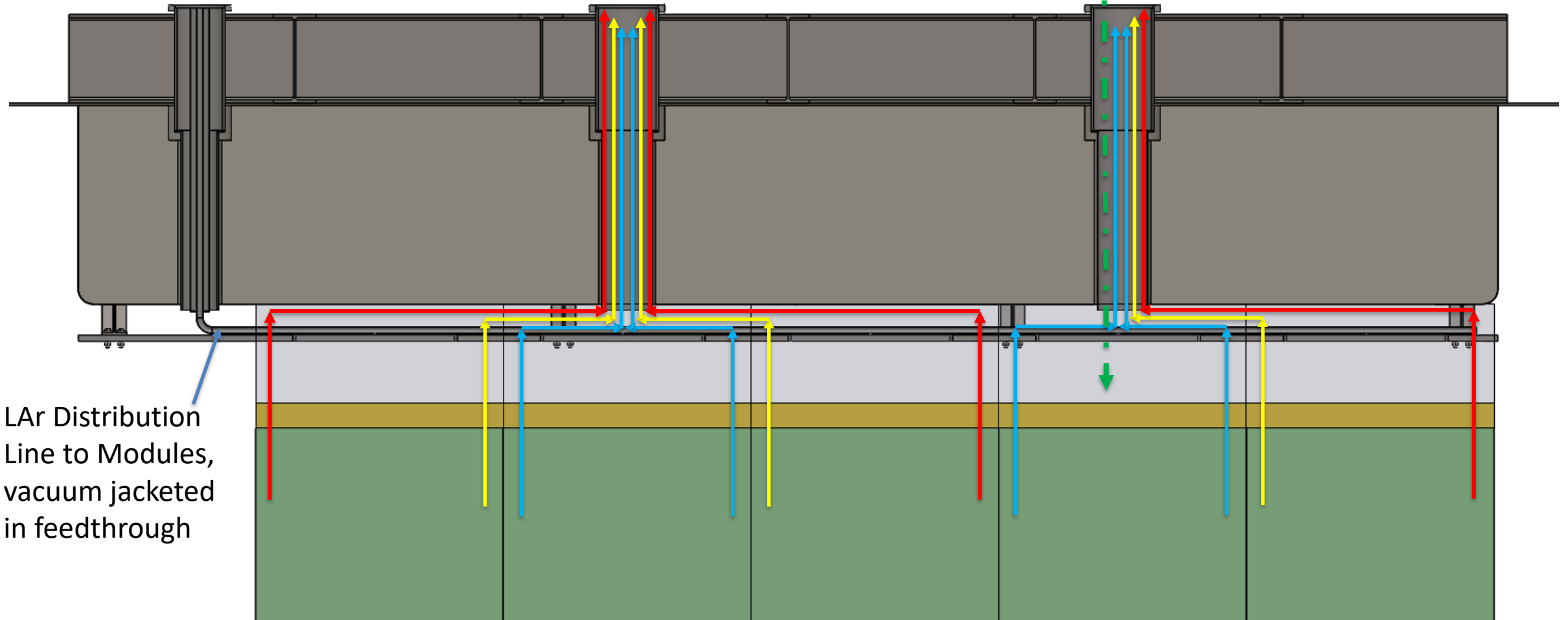
Charge/Light RO Cable Length Config 1

Charge/Light RO Cable Length Config 2

Charge/Light RO Cable Length Config 3

HV Input

Working on routing of services with ArgonCube members

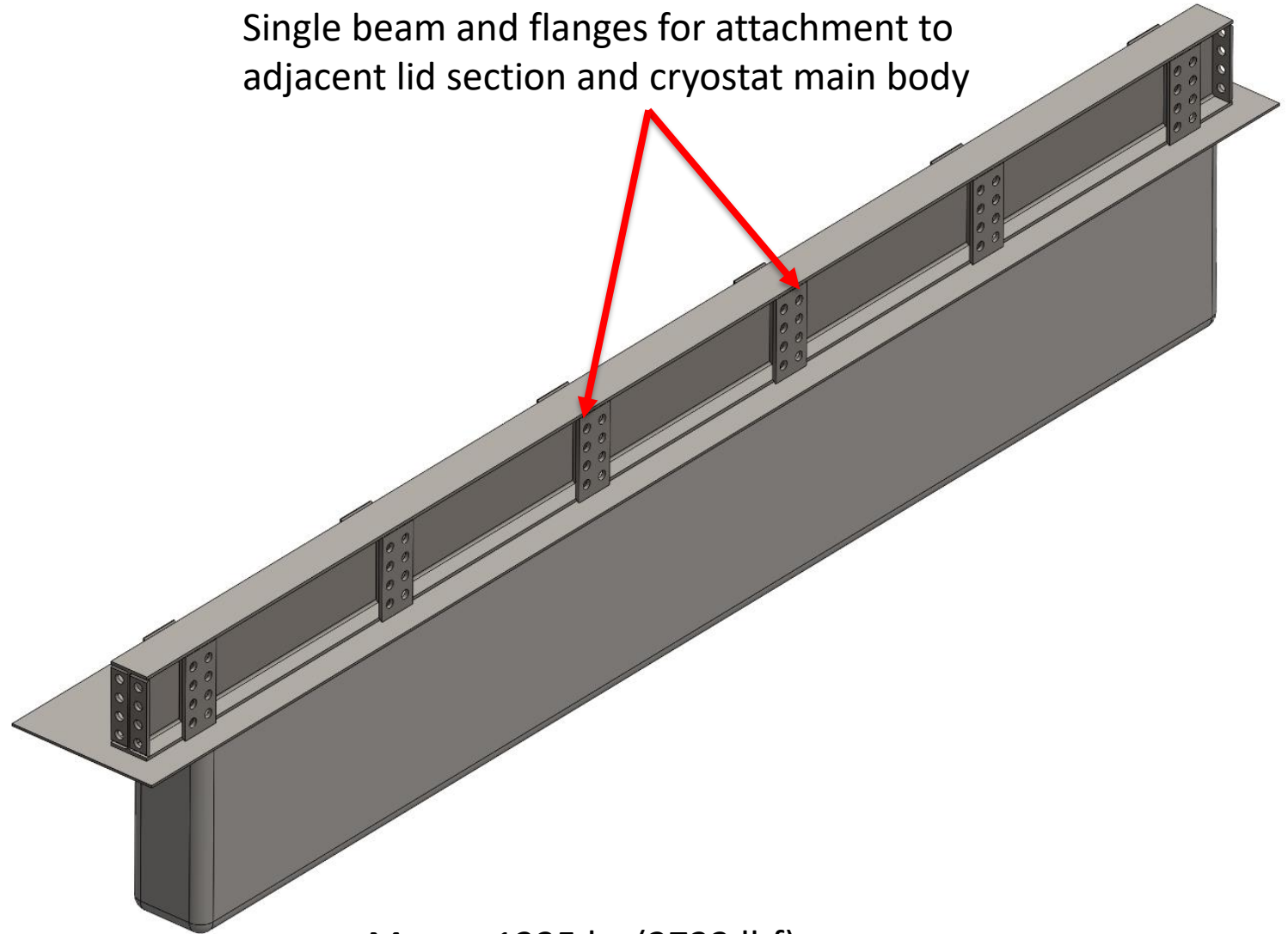


LAr Distribution Line to Modules, vacuum jacketed in feedthrough

Final Lid Section

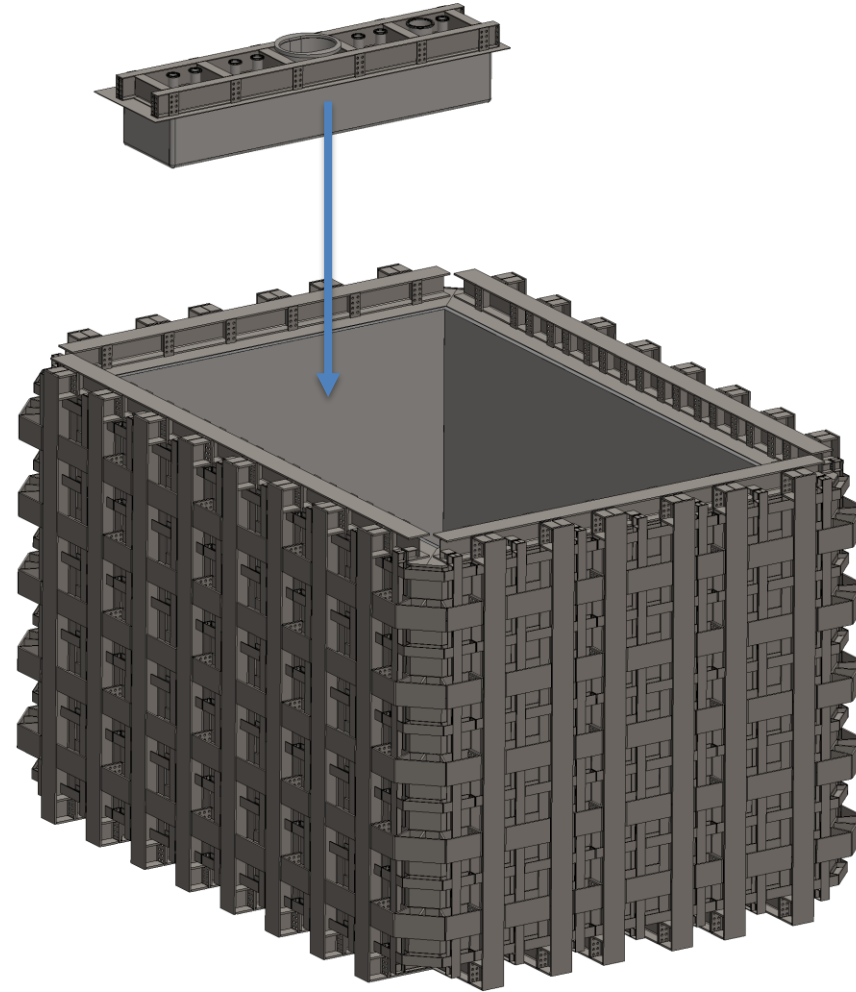
- Final lid section
- Installation:
 - Lower into place
 - Weld & leak check
 - Install brackets and bolts
 - Connect cryostat pressure relief
 - Need to model this in still

Single beam and flanges for attachment to adjacent lid section and cryostat main body

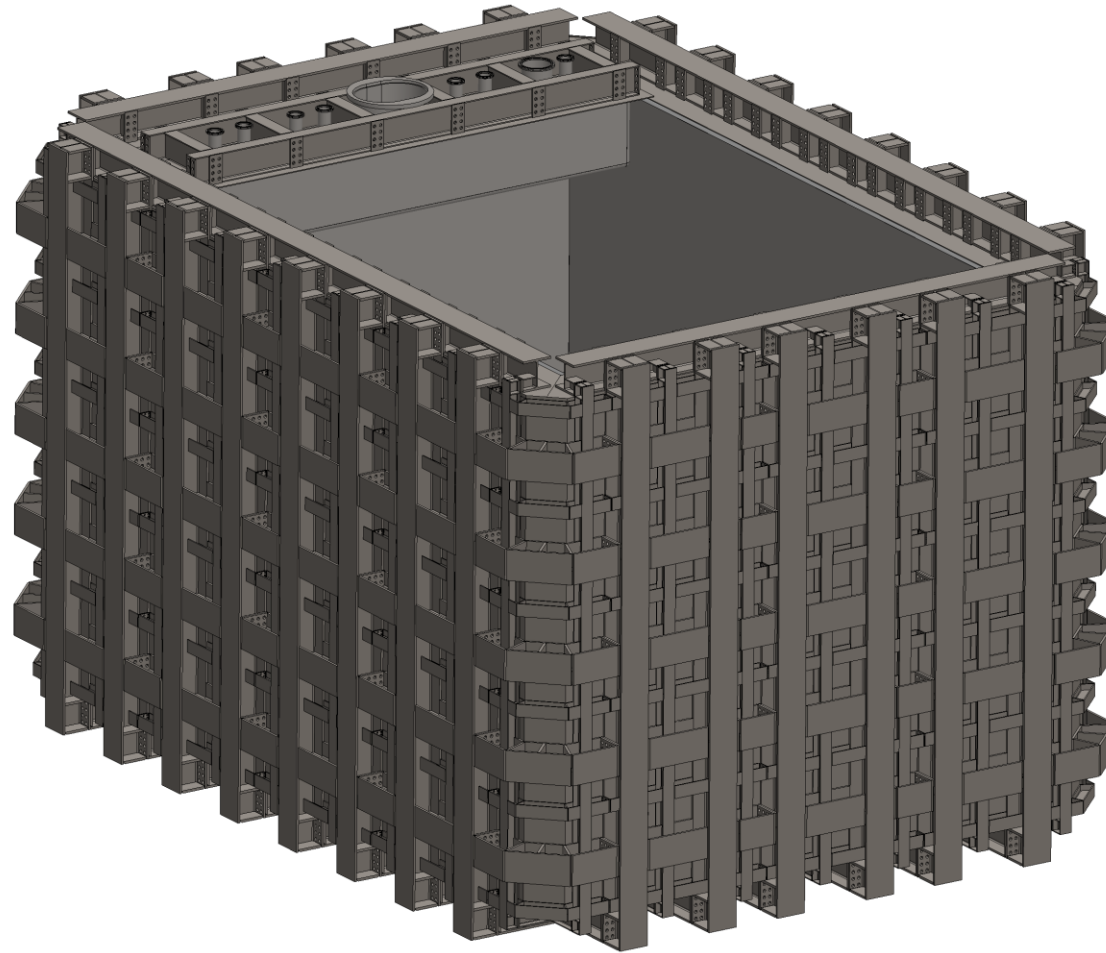


Mass = 1235 kg (2723 lbf)

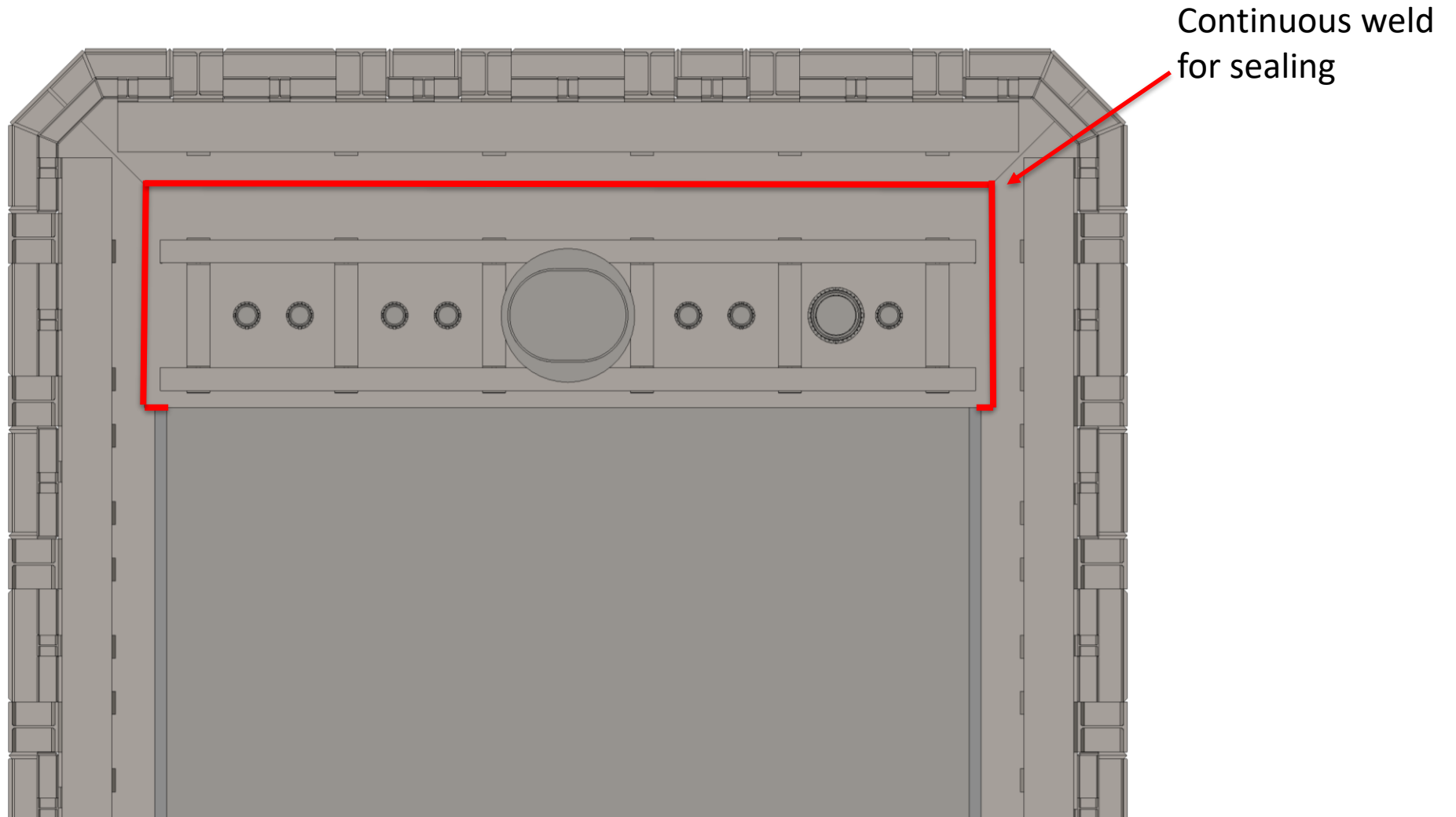
Lid Installation Sequence – Cryo Section



Lid Installation Sequence – Cryo Section

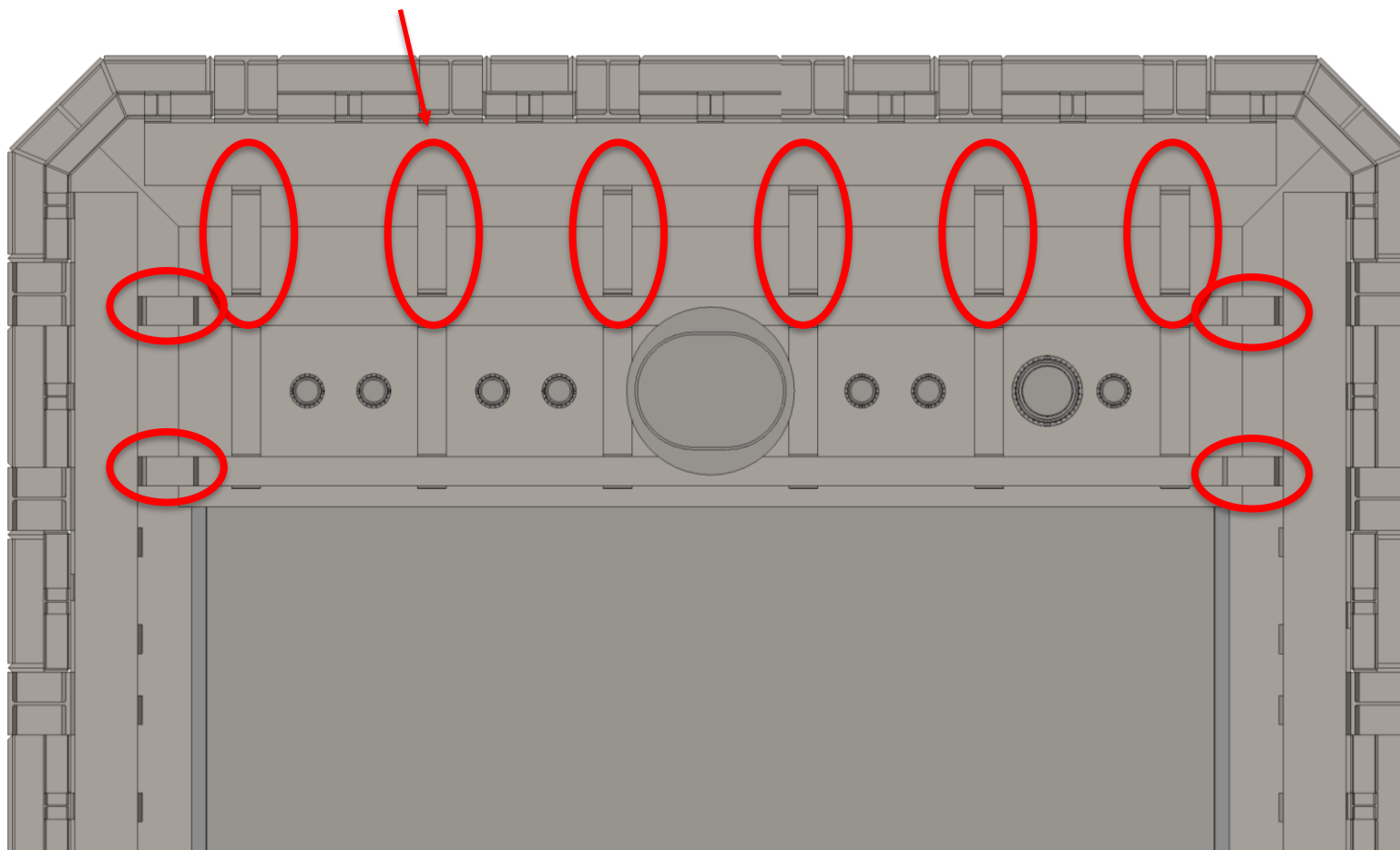


Lid Installation Sequence – Cryo Section



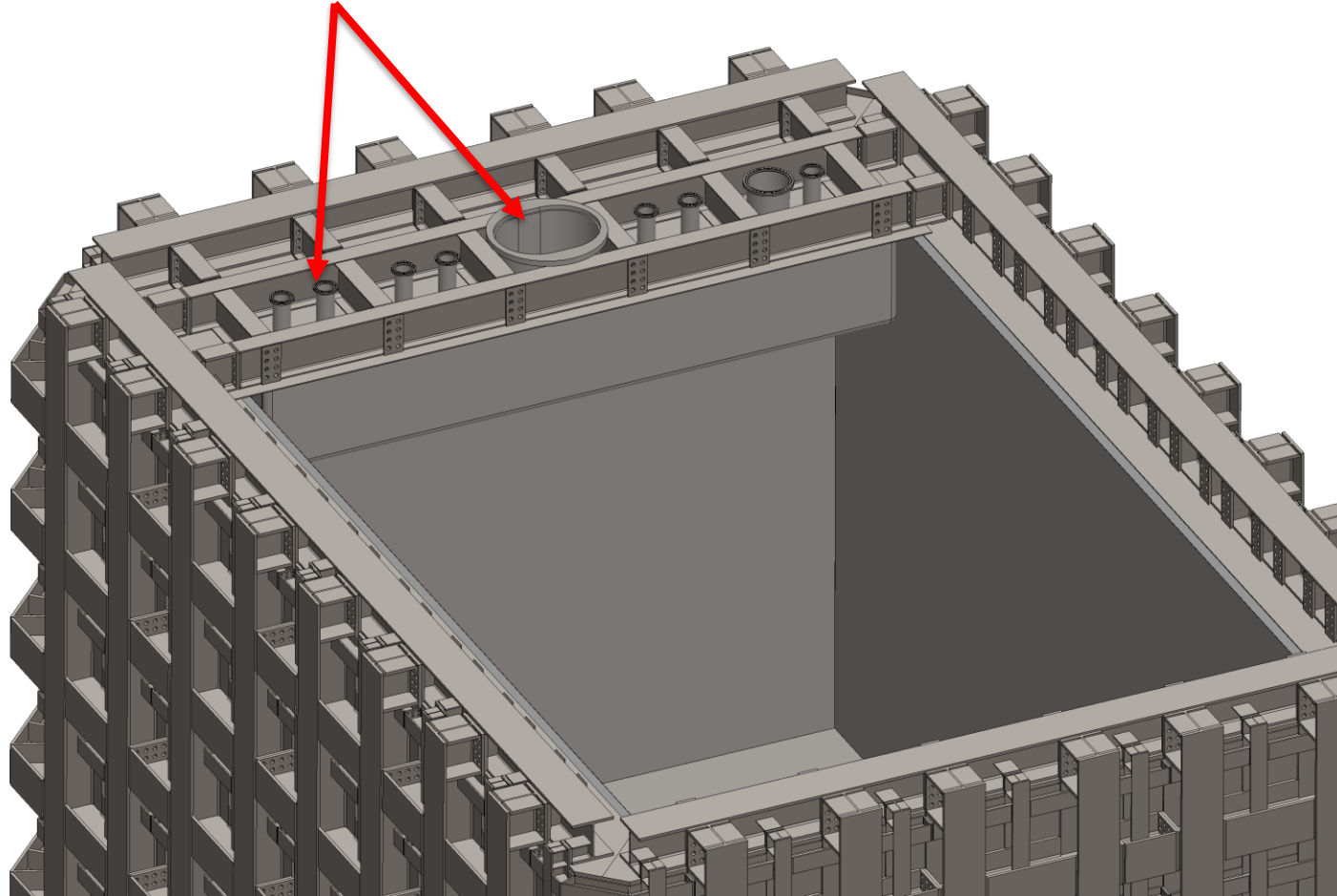
Lid Installation Sequence – Cryo Section

Install brackets to secure to cryostat
main body

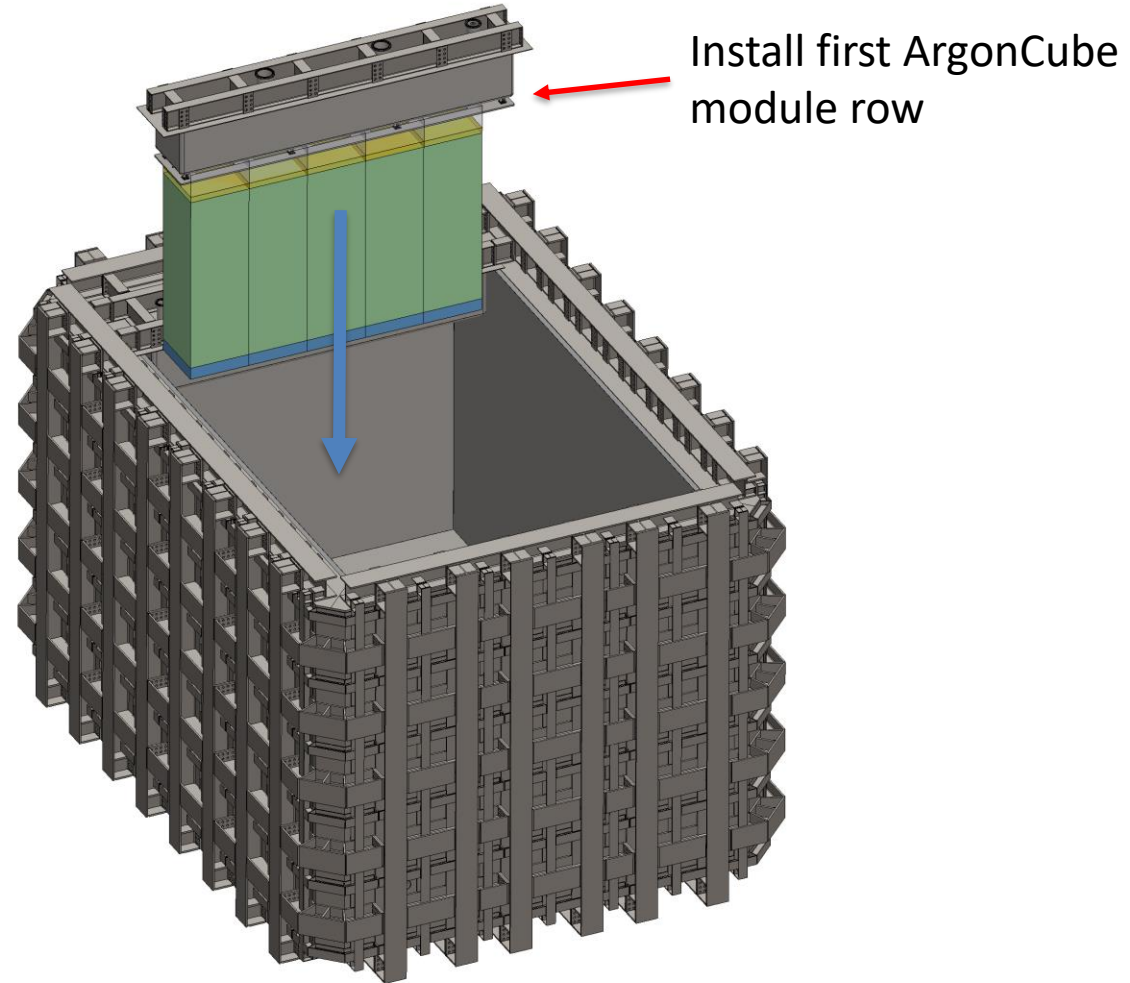


Lid Installation Sequence – Cryo Section

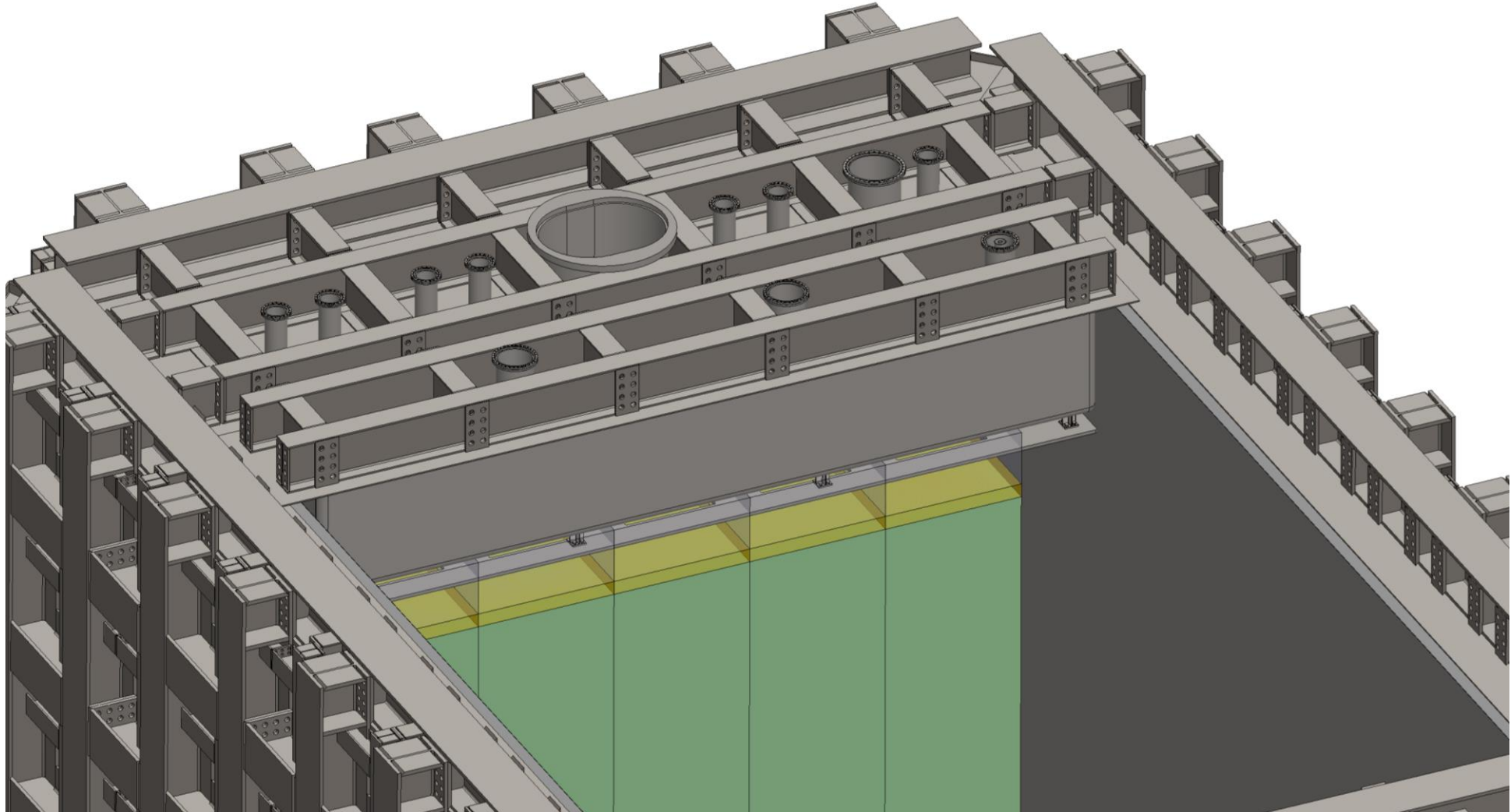
Can now install ladders or
cryogenic piping inside cryostat



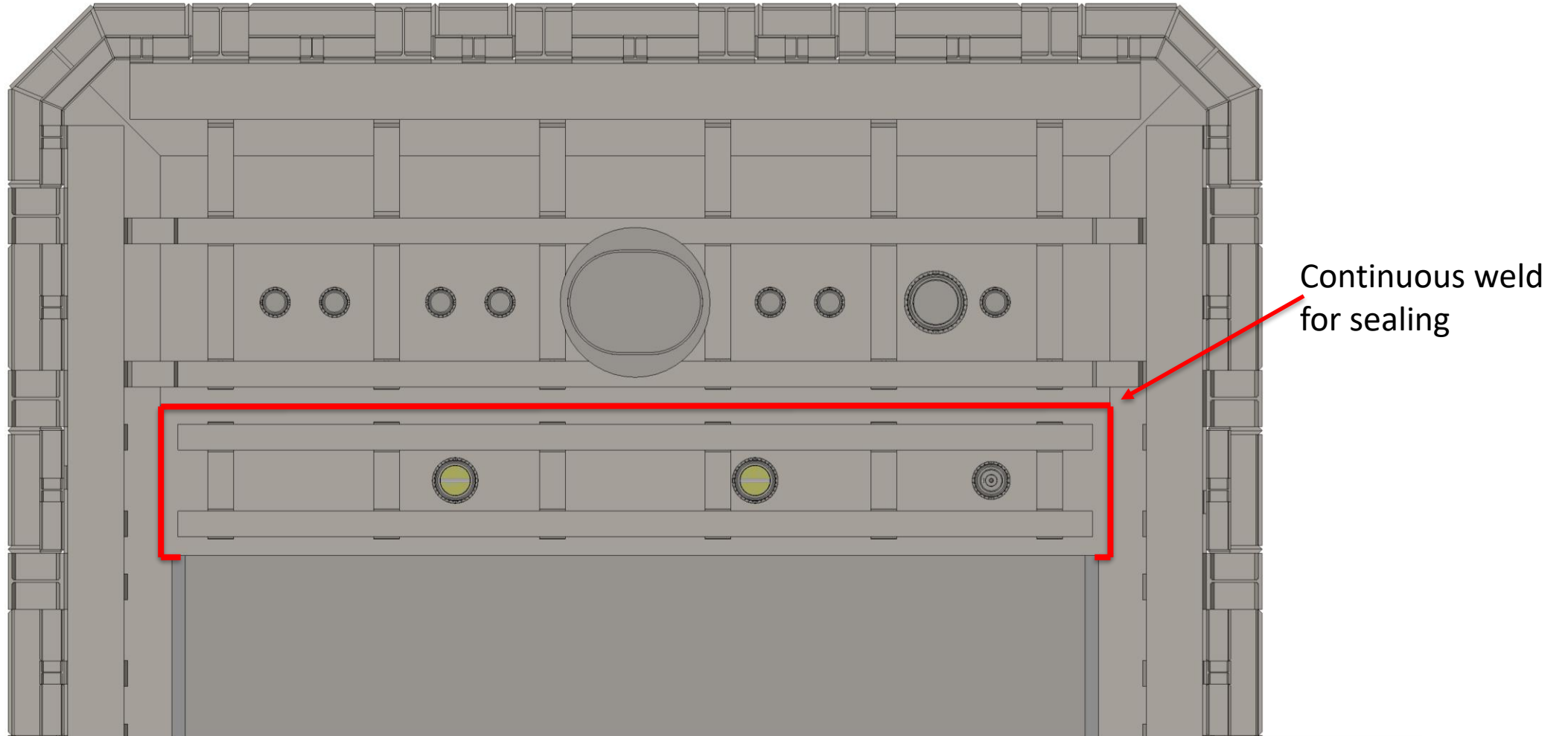
Lid Installation Sequence – Module Row 1



Lid Installation Sequence – Module Row 1

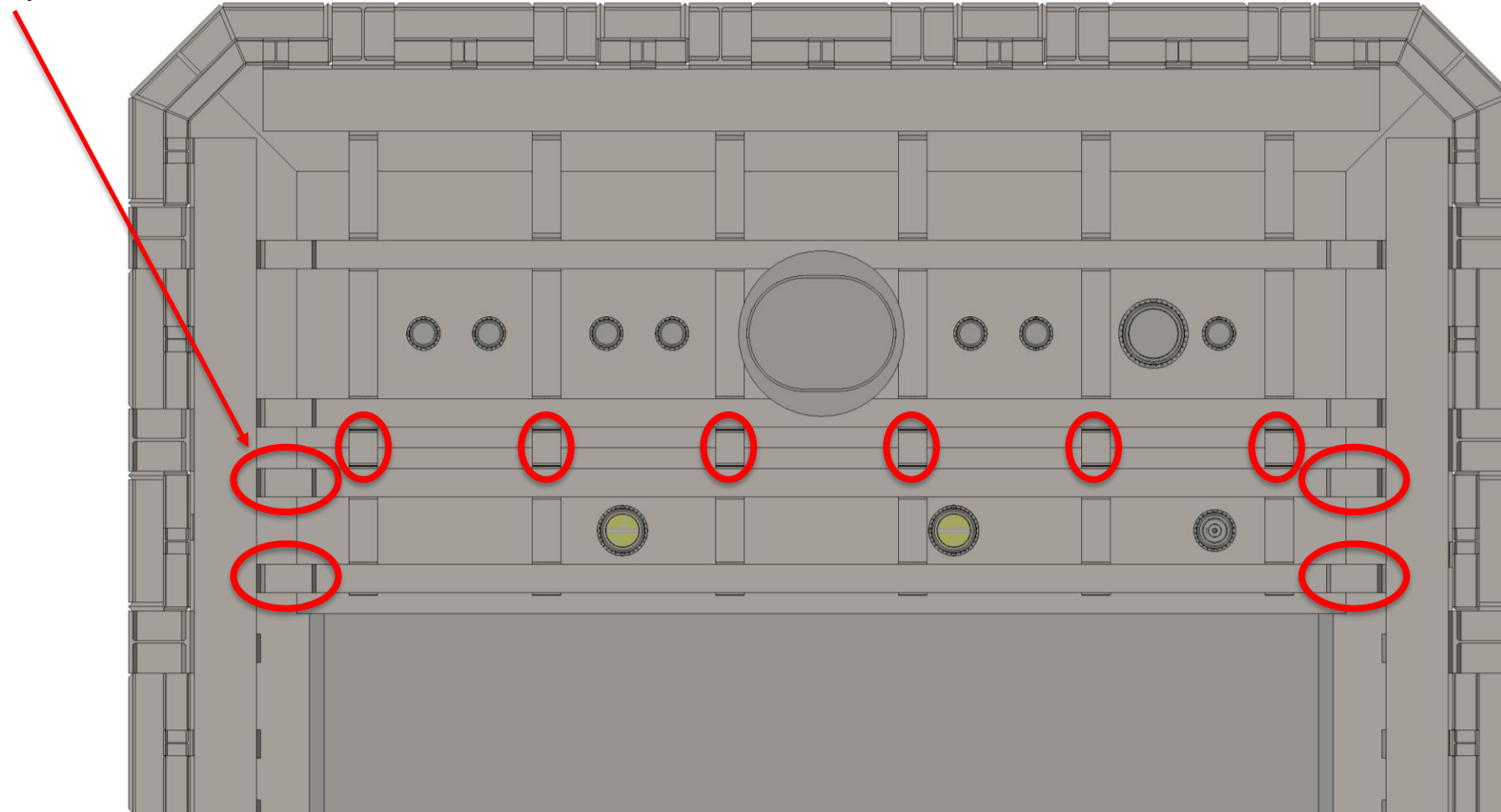


Lid Installation Sequence – Module Row 1

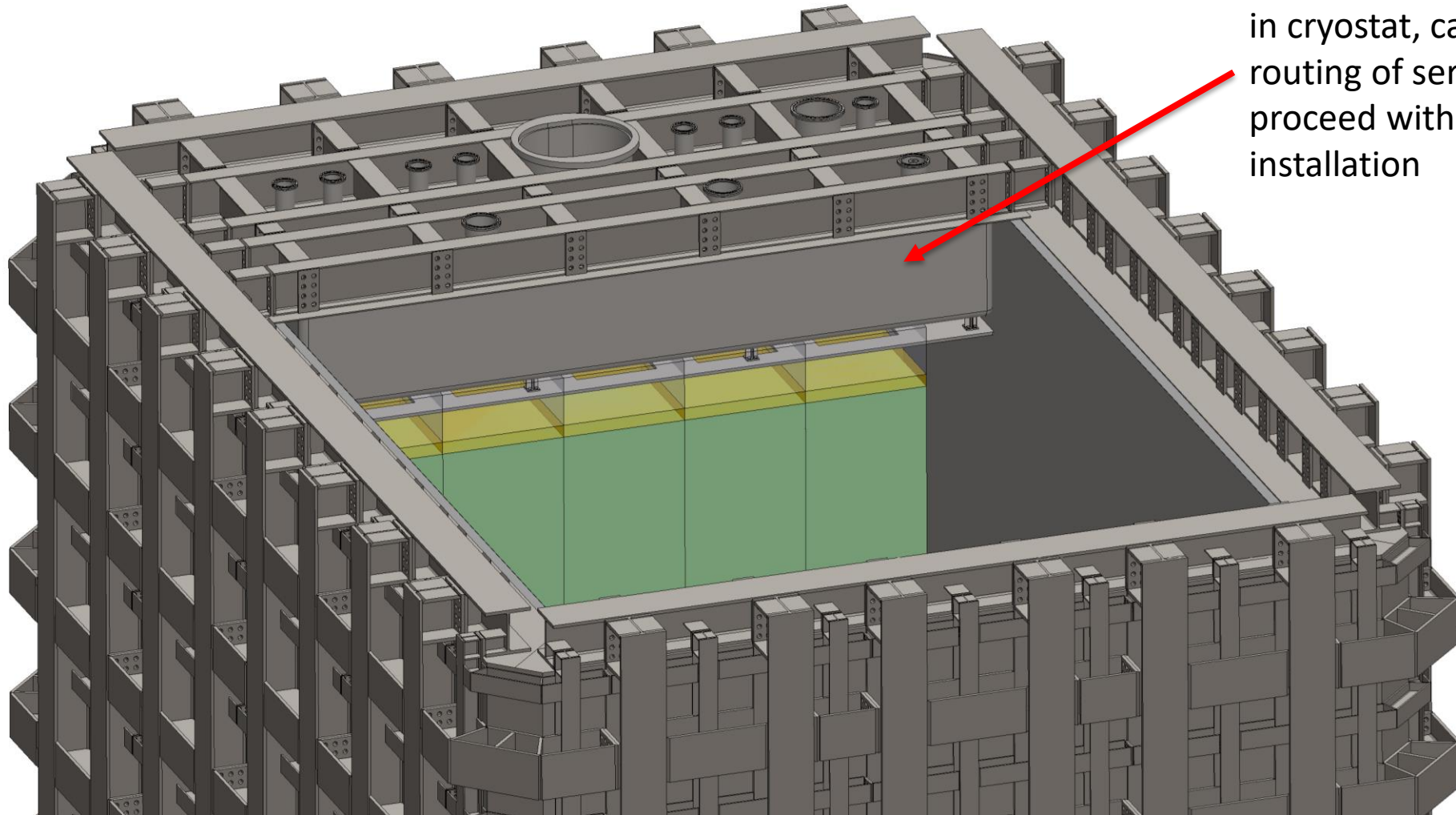


Lid Installation Sequence – Module Row 1

Install brackets to secure to cryostat main body

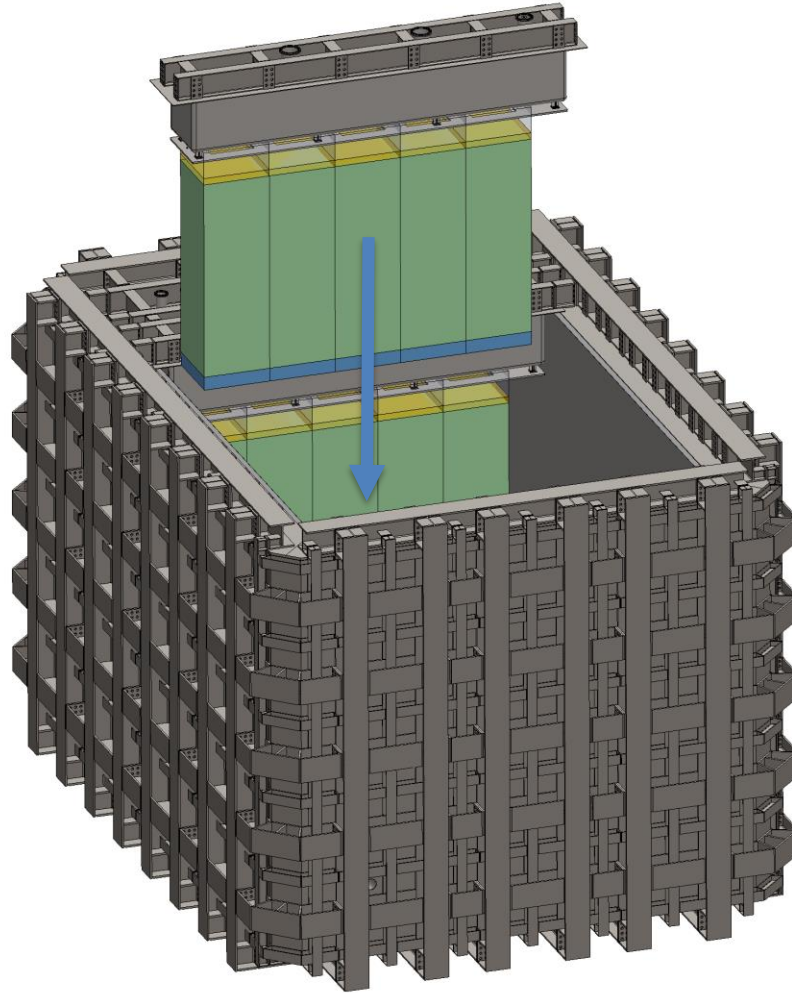


Lid Installation Sequence – Module Row 1

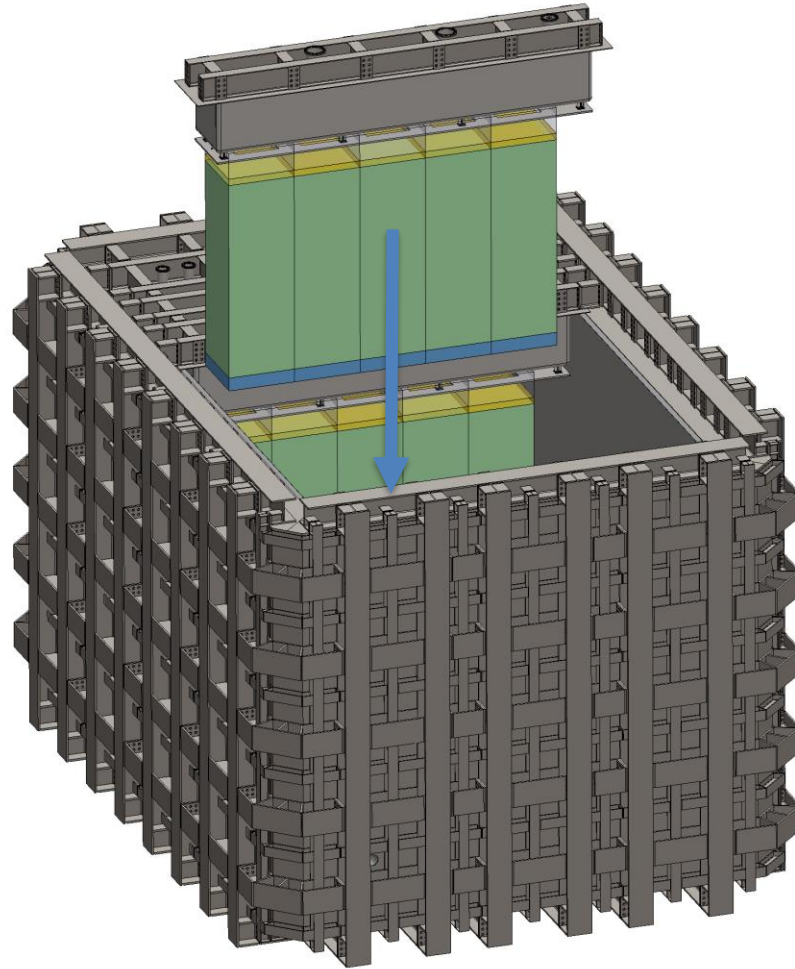


Module Row 1 now secured in cryostat, can begin routing of services or proceed with additional row installation

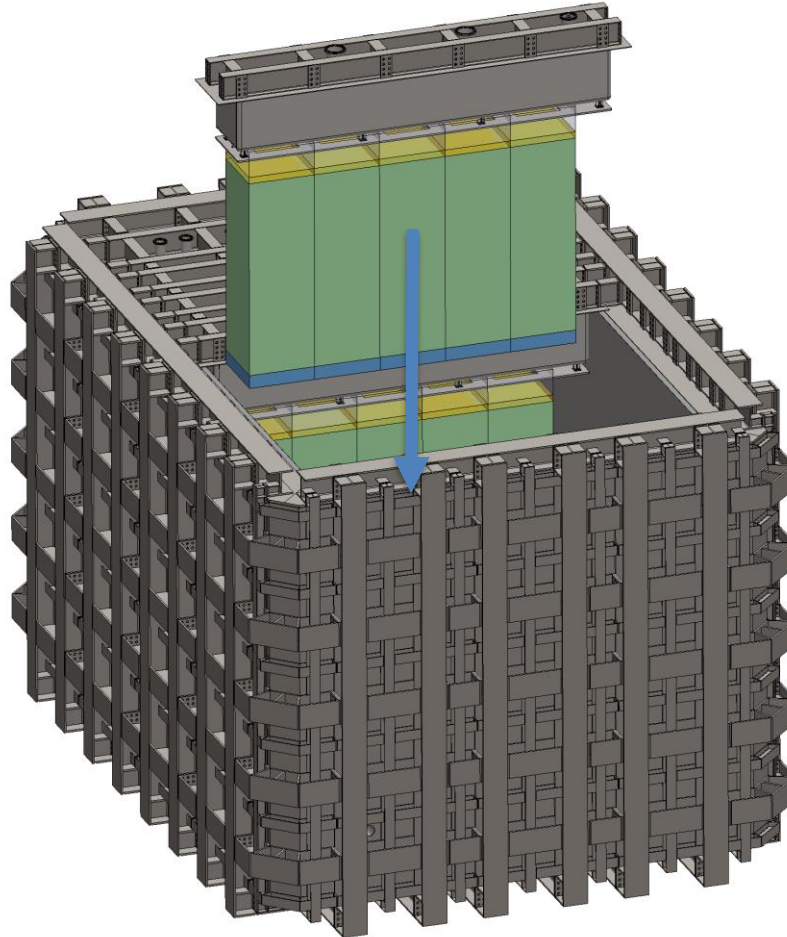
Lid Installation Sequence – Module Row 2



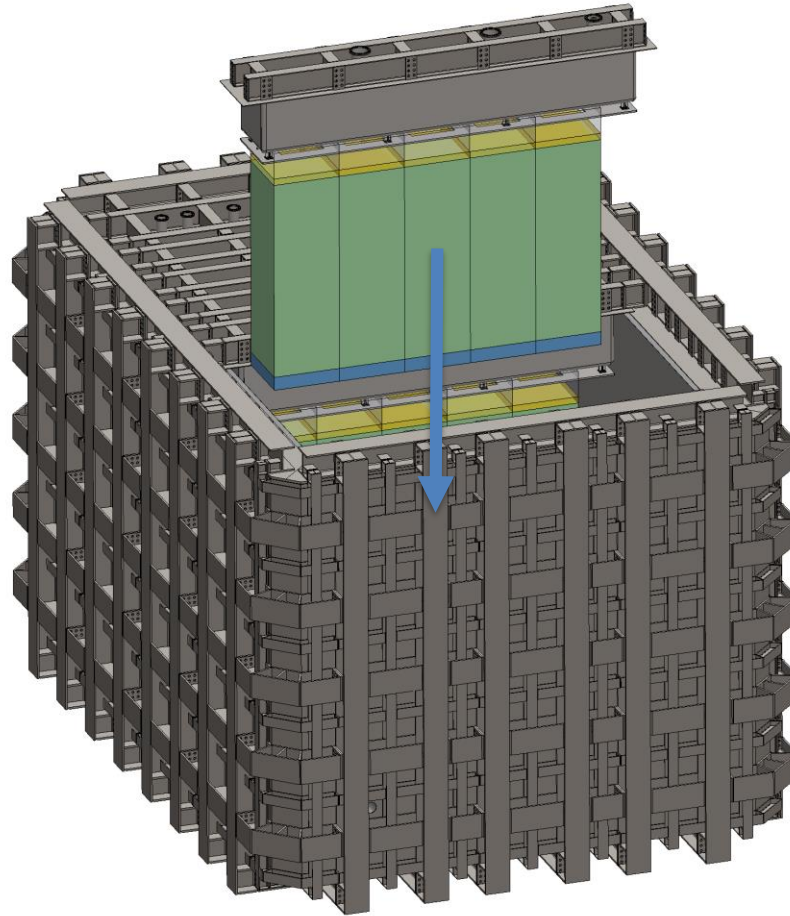
Lid Installation Sequence – Module Row 3



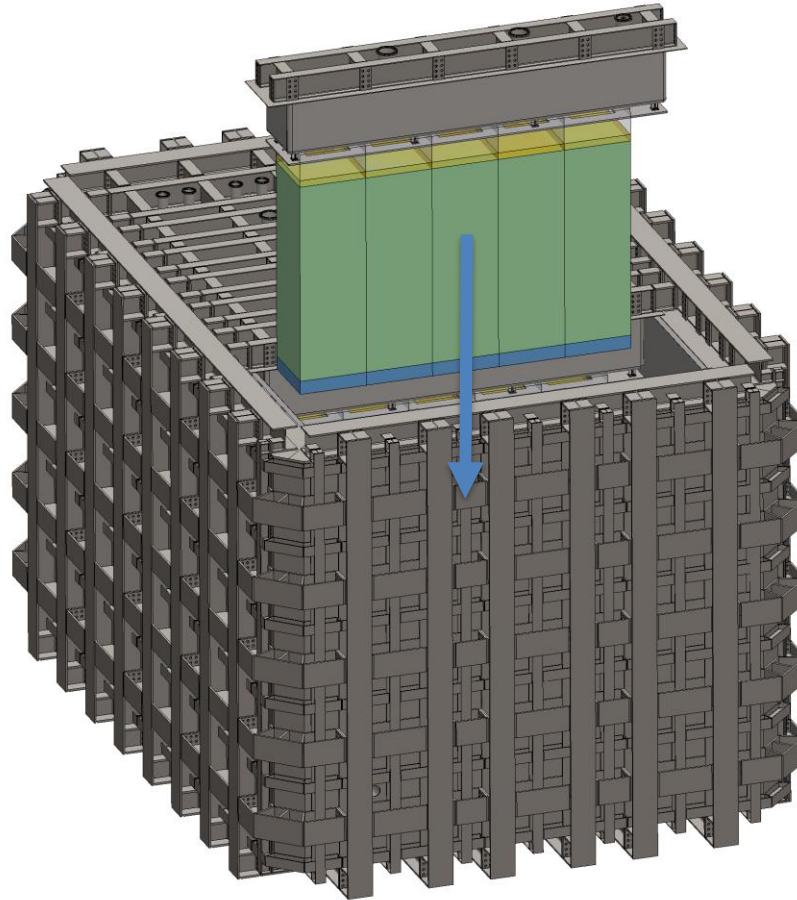
Lid Installation Sequence – Module Row 4



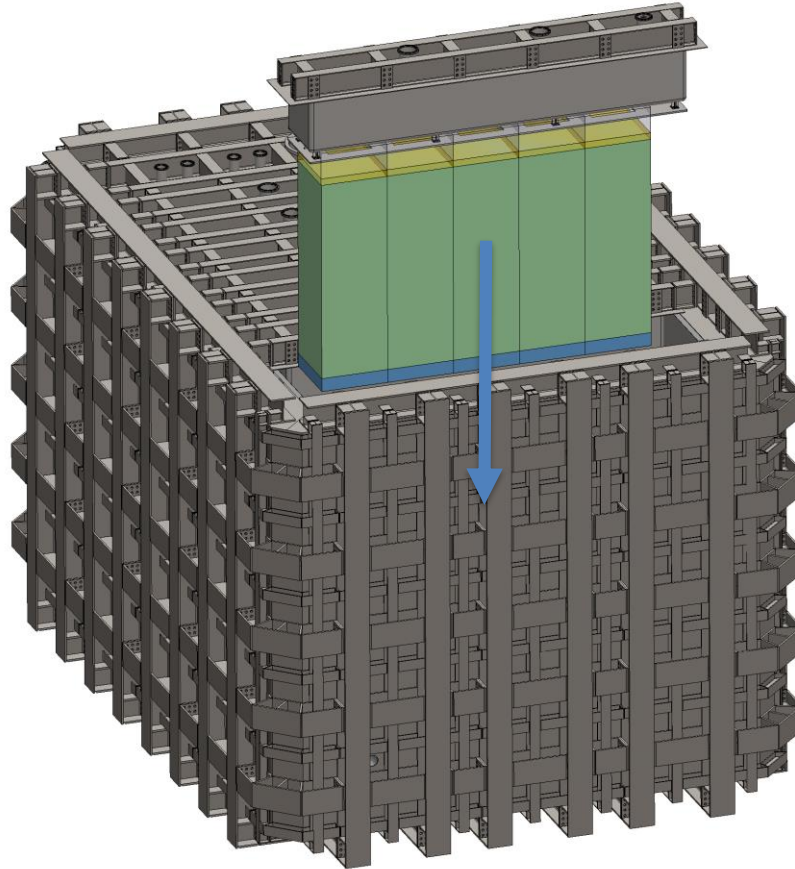
Lid Installation Sequence – Module Row 5



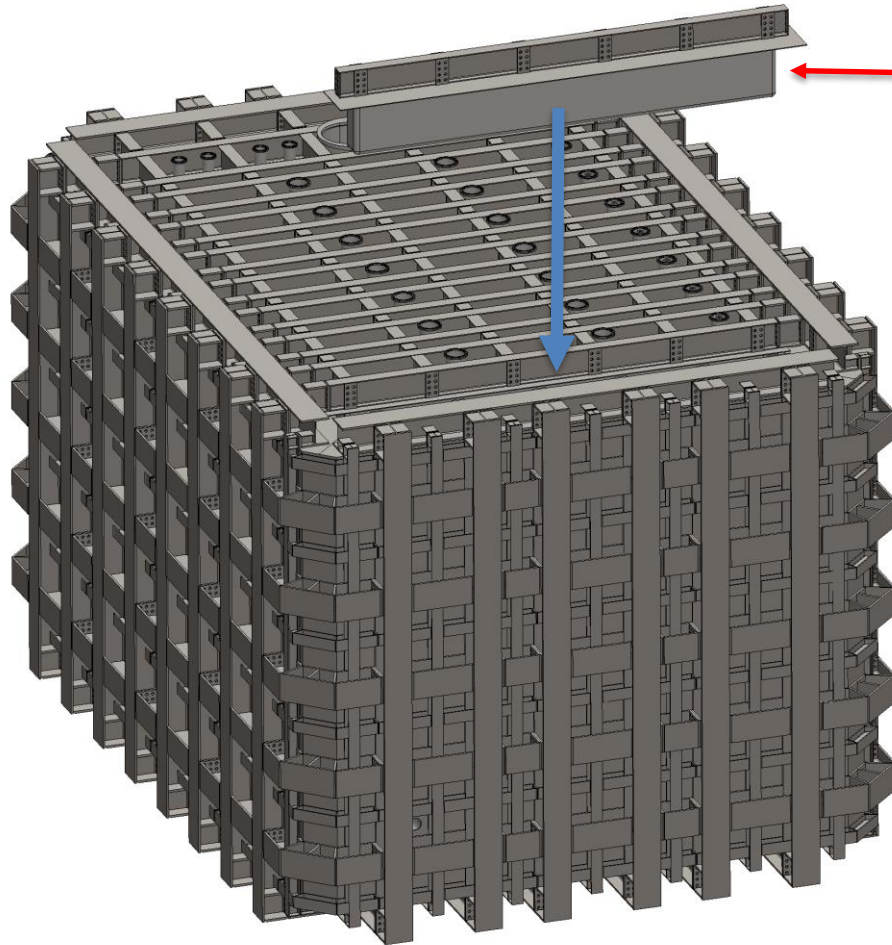
Lid Installation Sequence – Module Row 6



Lid Installation Sequence – Module Row 7



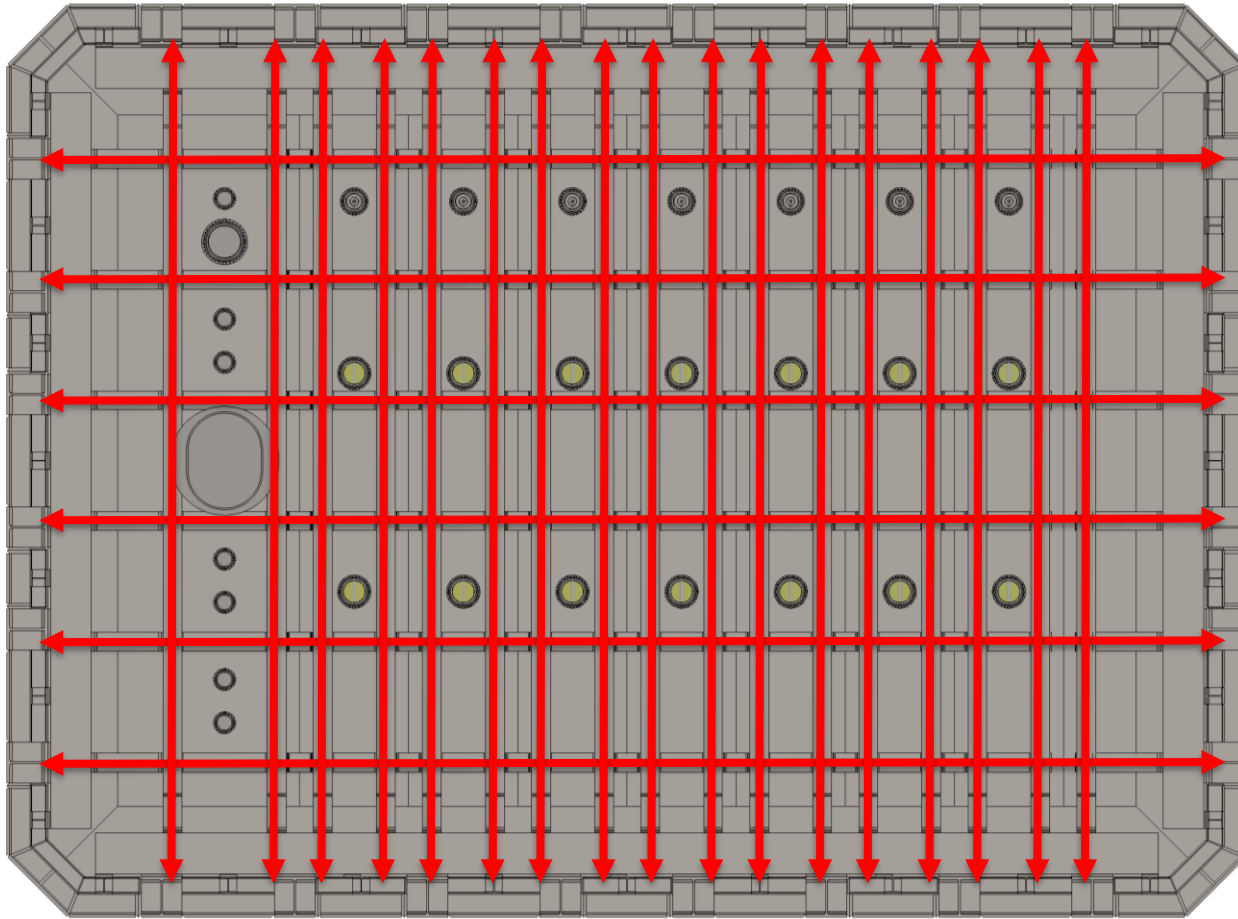
Final Section Installation



Note: couple of benefits of having this final section

- When the last module row is installed there will be some extra room for maneuvering
- Can do field machining of this final section to take up eventually tolerance stack-up misalignments from module row insertion

Top Down View of Full Lid



- Loading is transferred across the top lid via the beams and brackets
 - May need to add some additional beams lengthwise
- Top lid structure must resist wall bending loads from hydrostatic forces, overpressure, and module array weight
- Main body structure has been simulated with dummy lid that is similar in design to what has been shown today, however...
 - This most recent lid design requires FEA analysis
 - Will be done in near term by LBNL engineer

Summary

- Design of LArTPC Cryostat for the ArgonCube modules has made very significant progress over the last several months, at this point the design effort has defined:
 - External beam structure that is based on ProtoDUNE experience
 - Shows good structural performance in initial simulations (slide 15), wall weldment drawings created for budgetary quoting
 - Composite window design by LBNL Composites group with extensive analyses (future talk by G. Vallone)
 - Significant trade studies done by this group on materials and joint geometry (slide 14)
 - Cold structure specification document written and cold membrane company (IHI) engaged for initial discussions
 - Released specification document & under version control, can be edited into final procurement specification document in conjunction with cold membrane supplier
 - Major step in defining the cold structure
 - Modular top lid is designed to support ArgonCube module rows
 - Ability to install and extract individual ArgonCube rows; presents some challenges but a workable design has been presented and will be developed further
- FEA simulation of full cryostat structure is now required; this includes:
 - Exterior beam structure
 - Composite window
 - Modular top lid
- LArTPC cryostat design is integrated into the main ND hall assembly