DUNE ND Engineering Collaboration Meeting LArTPC Cryostat Design

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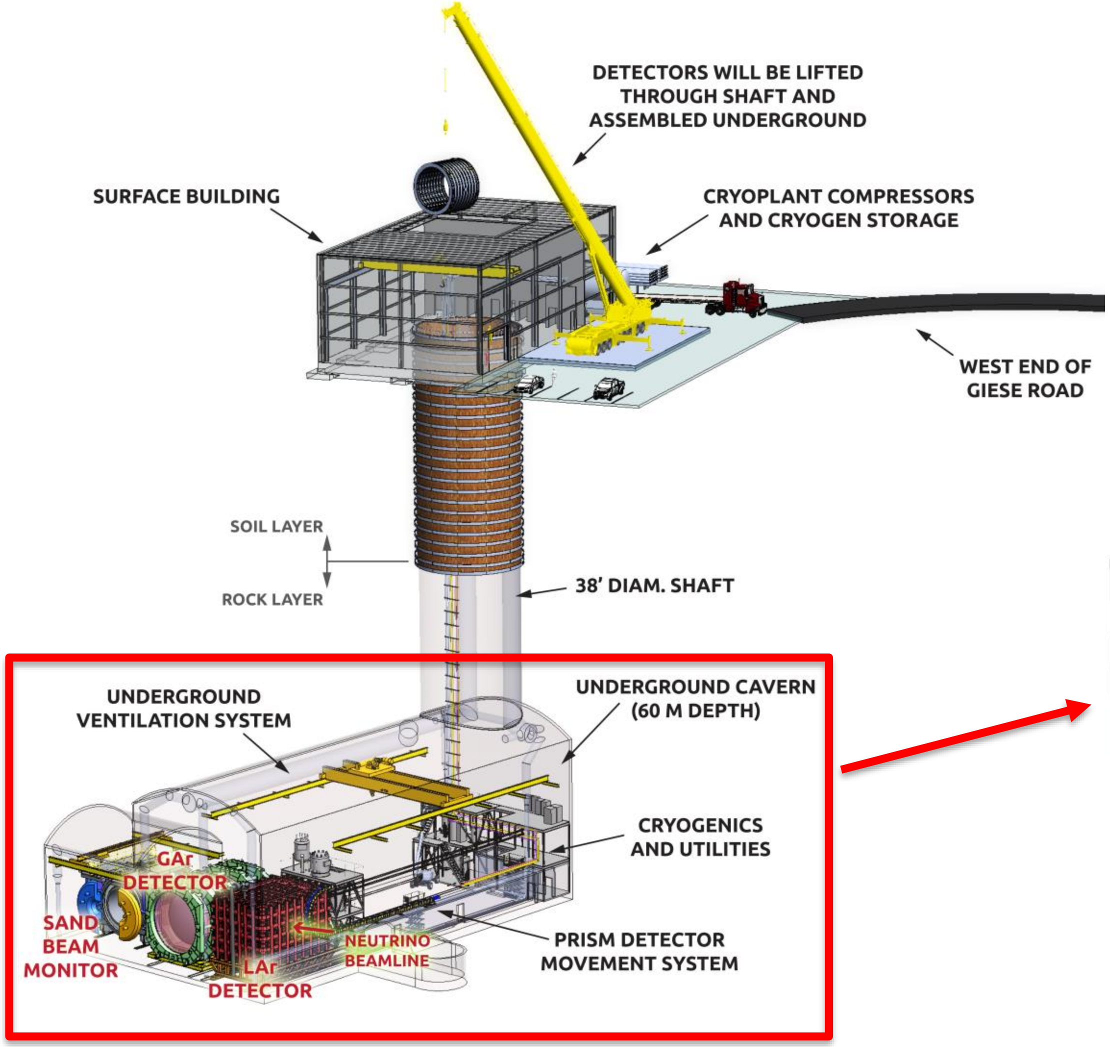
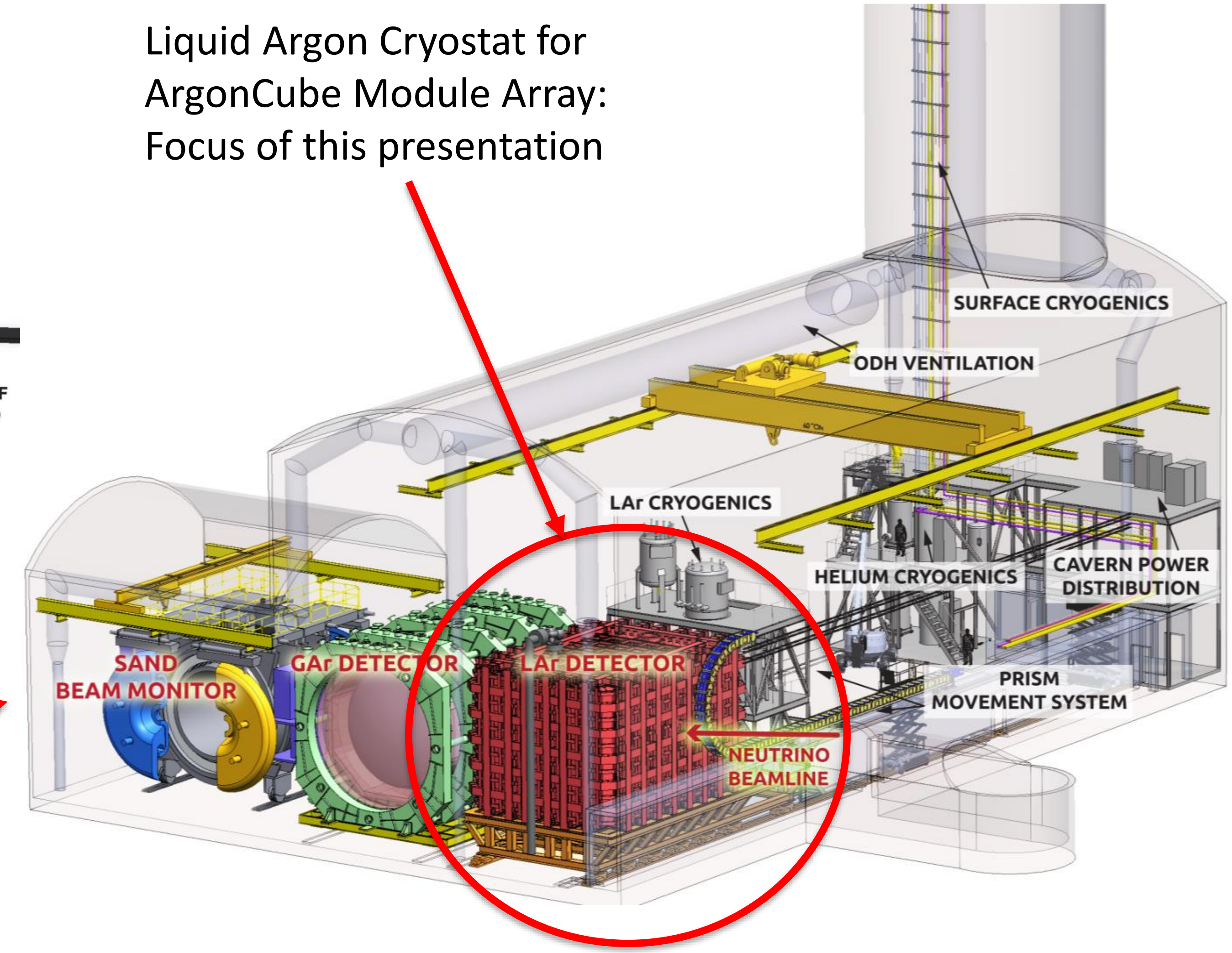
Agenda

- 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

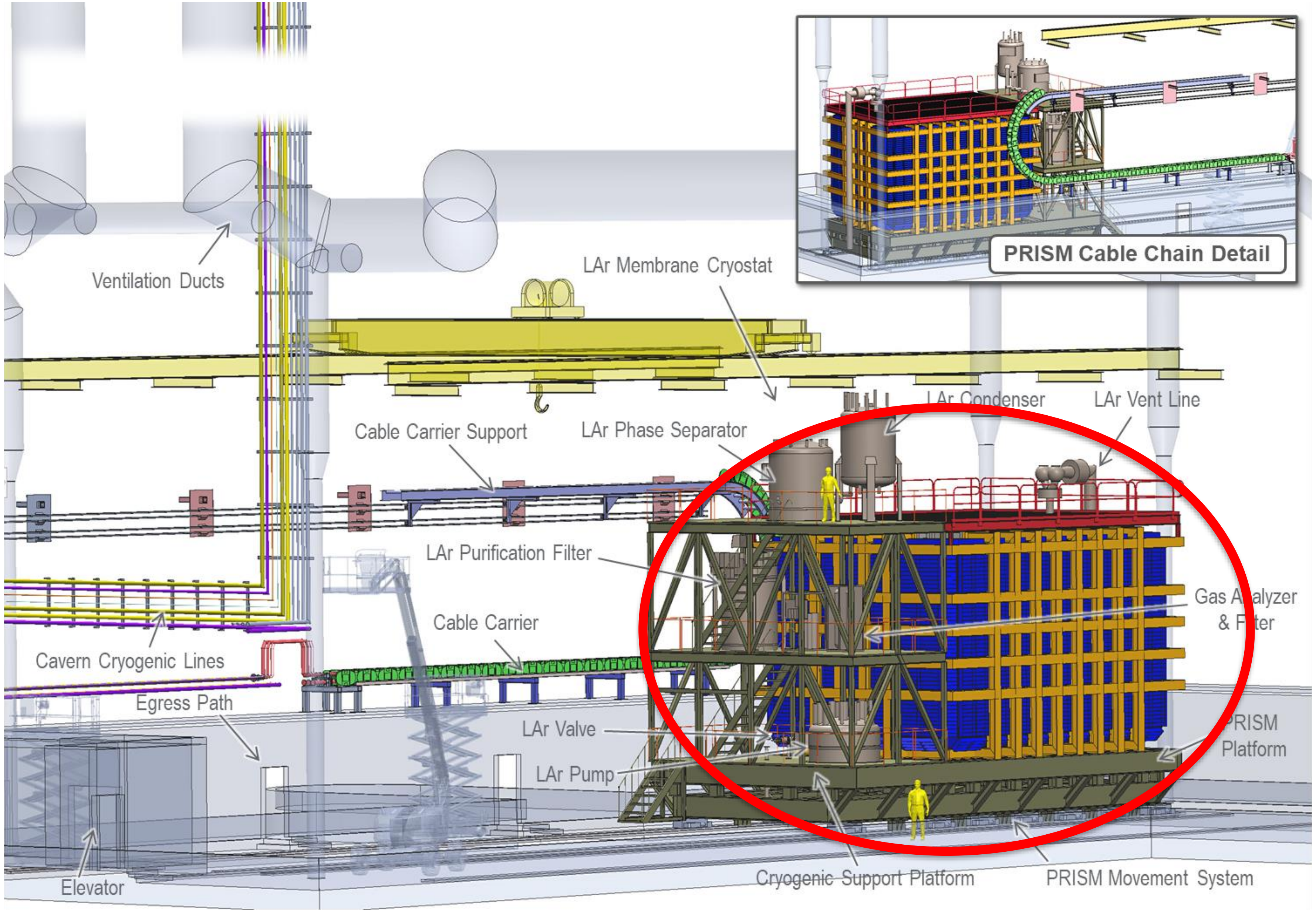


Liquid Argon Cryostat for ArgonCube Module Array: Focus of this presentation



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



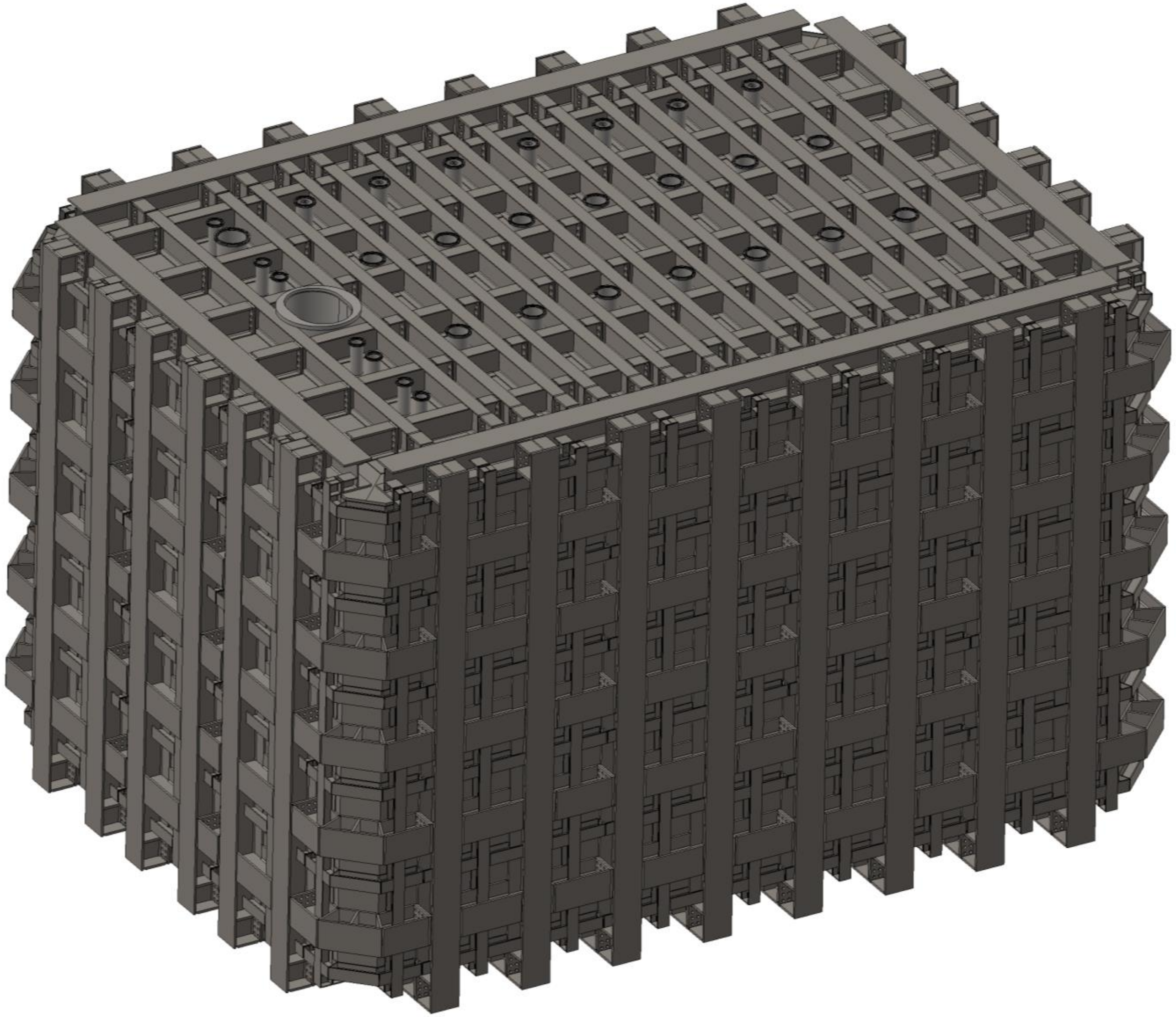
Physics Requirements

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 attentuate 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.

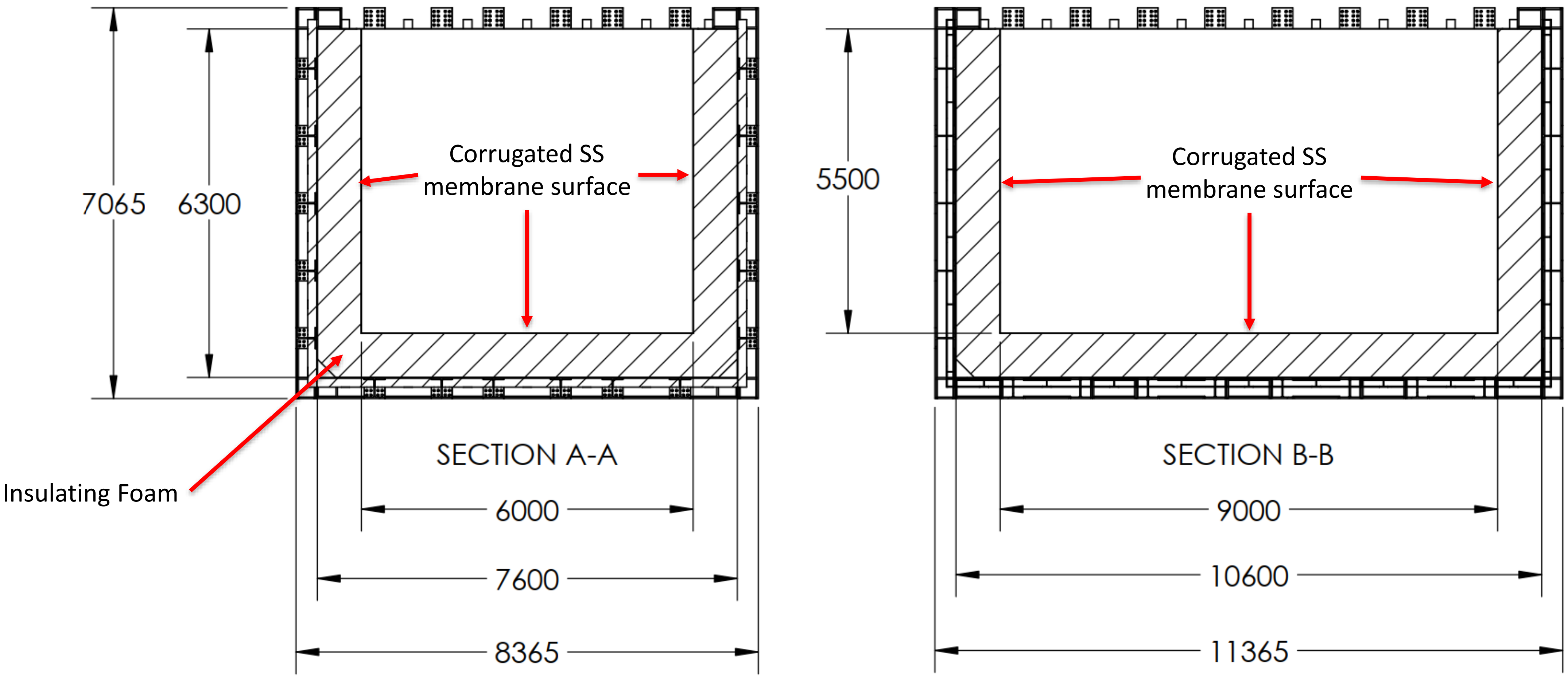
- Physics requirements flow down to engineering requirements
- Engineering requirement development for cryostat in process, working with physics team to ensure proper interpretation
  - Dimensions
  - Heat Leak
  - Mass
  - Required services
  - Etc.

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 from moisture barrier
- Corner weldments identical at all corners
- Removable lid with feedthroughs for cryogenics, high voltage and detector DAQ

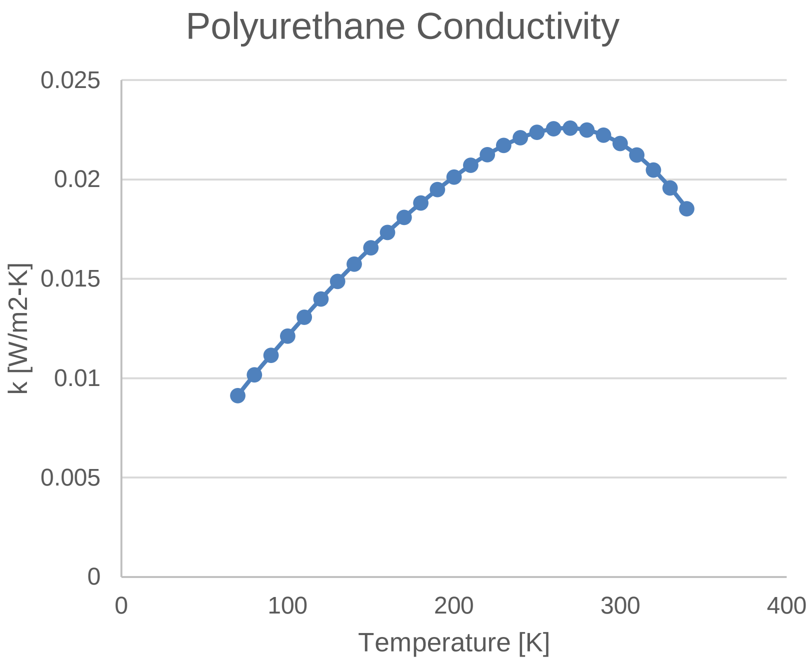


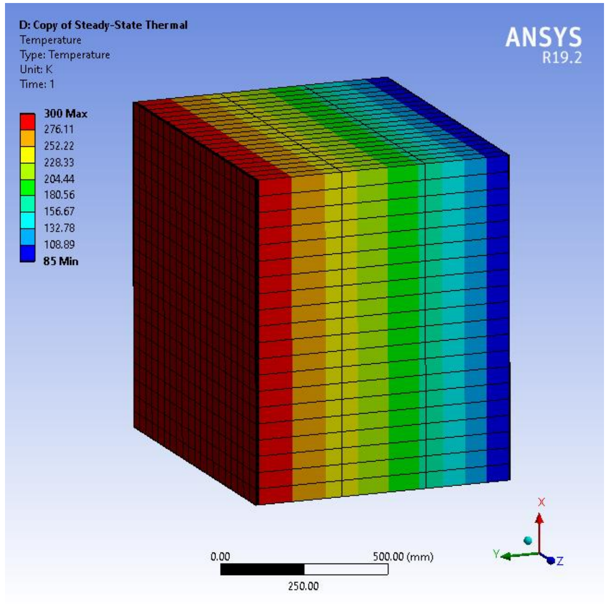
Overall Size

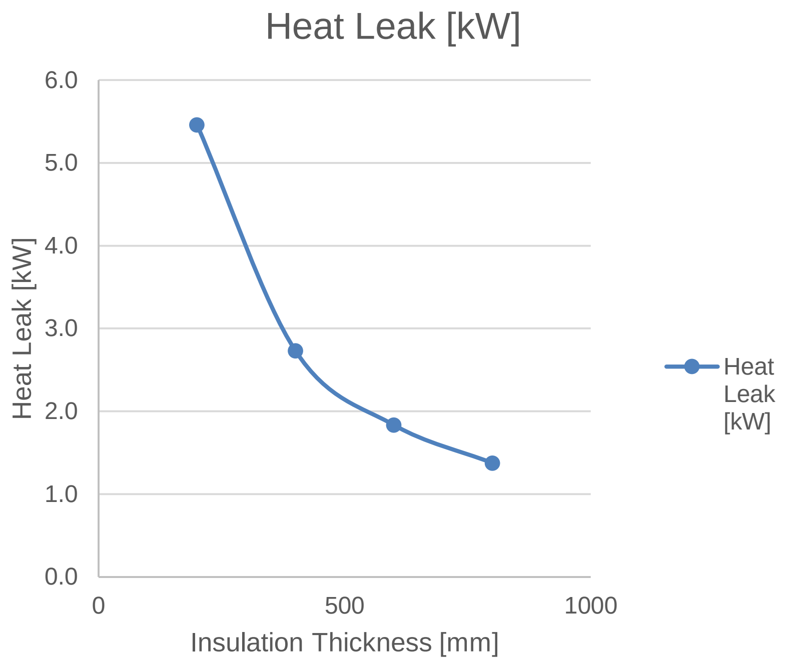


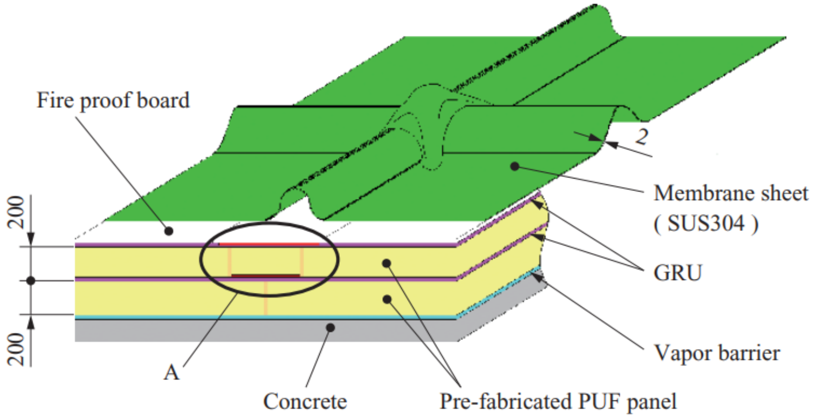
Parameter	Length [mm]	Width [mm]	Height [mm]
Membrane Flat Internal Dimensions	9000	6000	5500
10mm Steel Skin Internal Dimensions	10600	7600	6300
External Steel Structure Dimensions	11365	8365	7065

Desired Thickness of Insulation





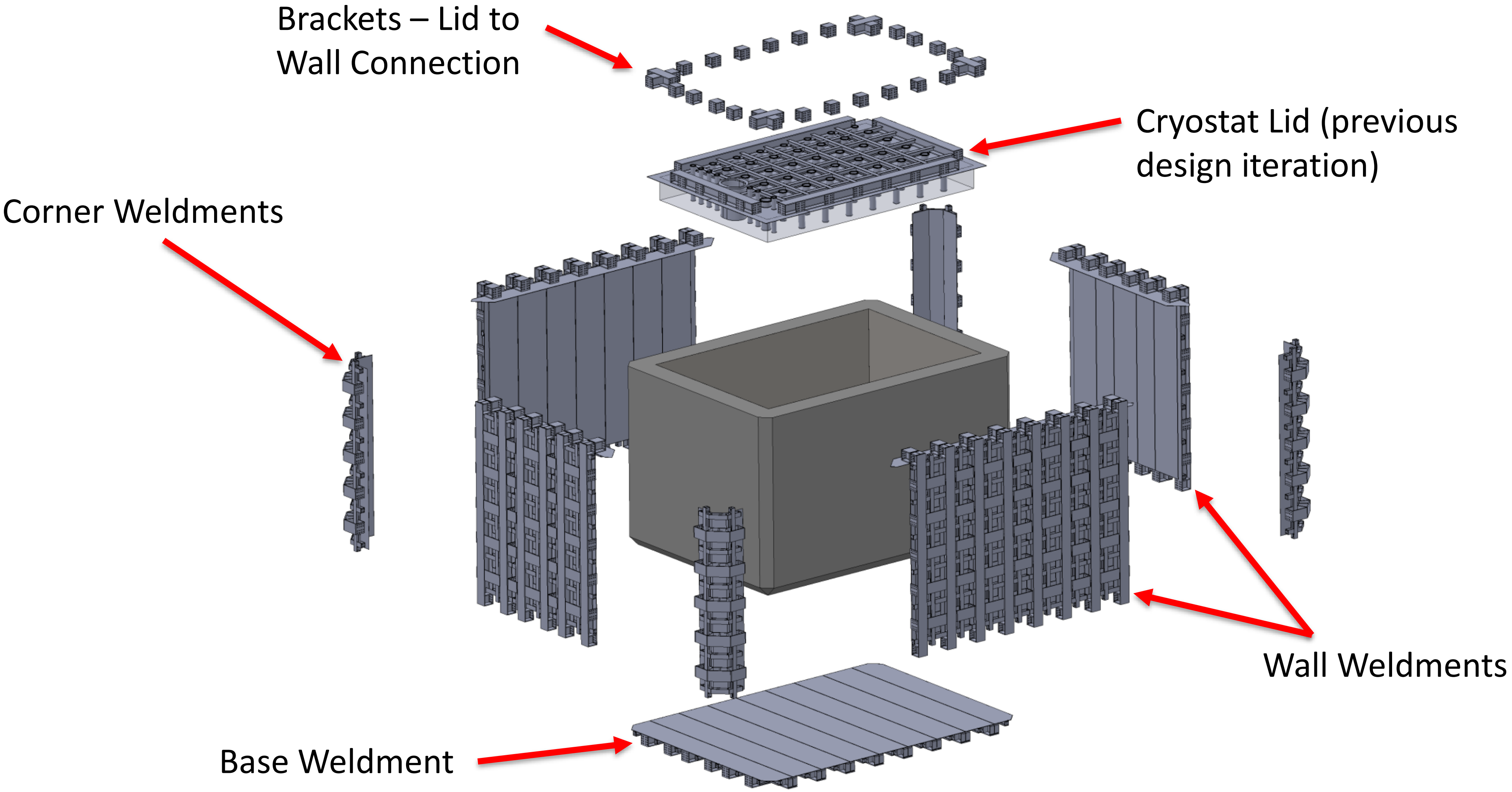




Thickness [mm]	Surface Area [m²]	Heat Flux [W/m²]	Heat Leak [kW]
200	273	20.0	5.5
400	273	10.0	2.7
600	**273**	**6.7**	**1.8**
800	**273**	**5.0**	**1.4**

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

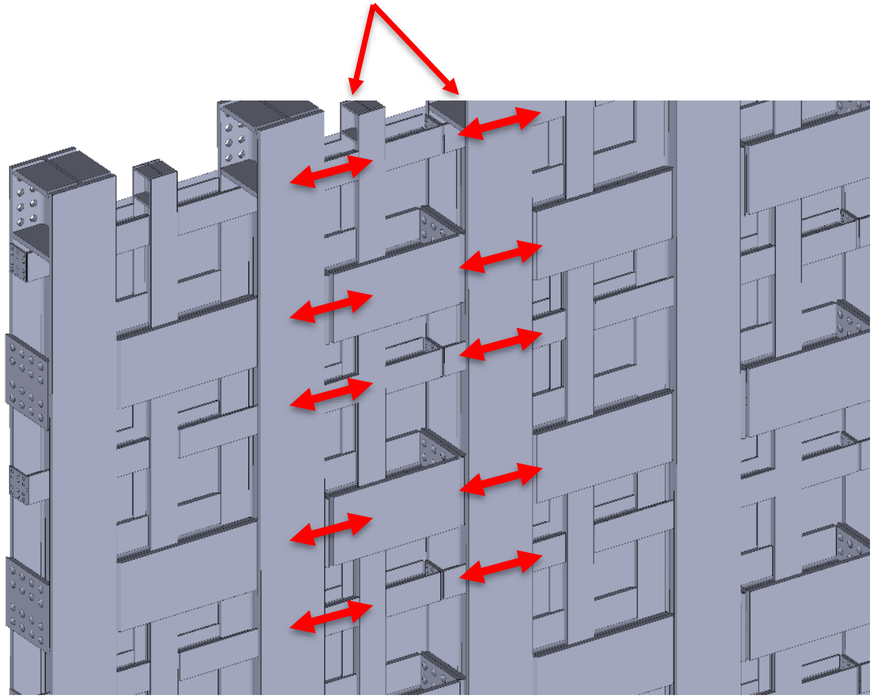
Exploded View

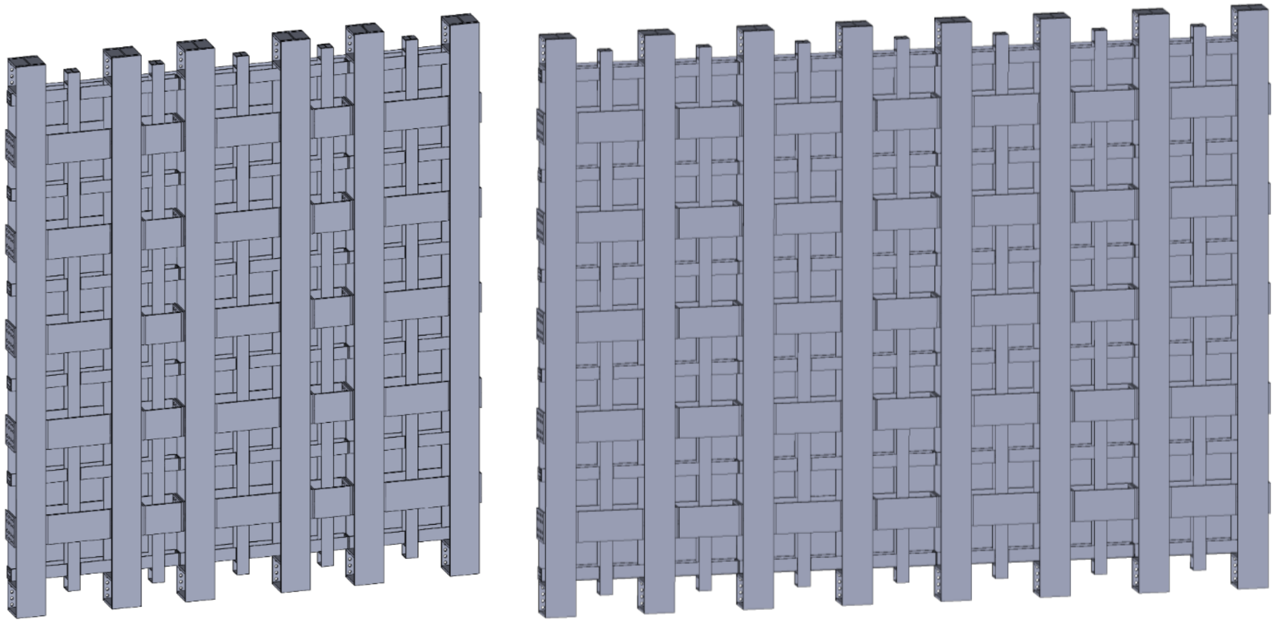


Wall Design

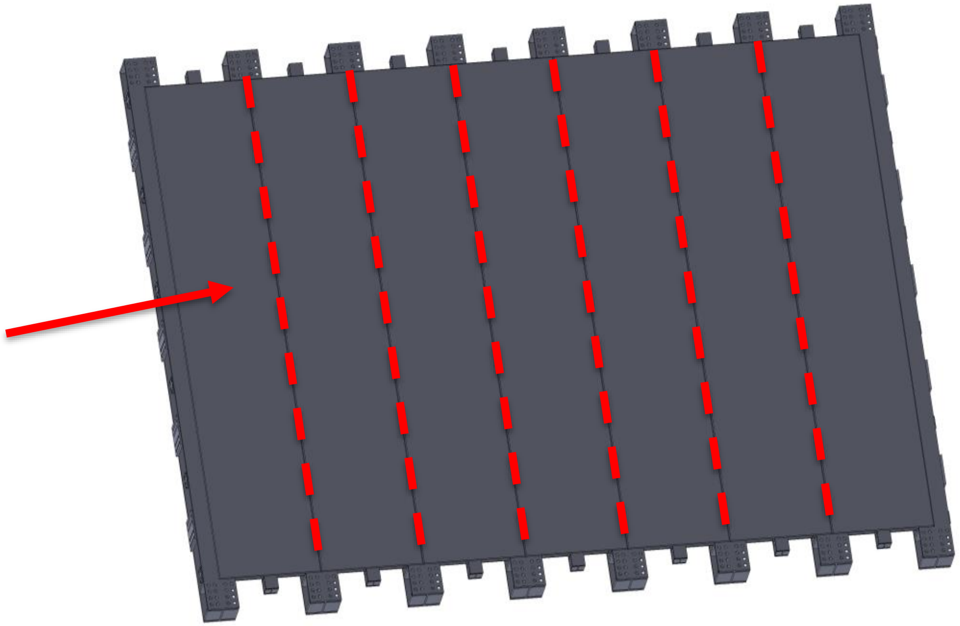
- Comprised of smaller subassemblies that are bolted & welded together

Bolted connections to join adjacent wall sections

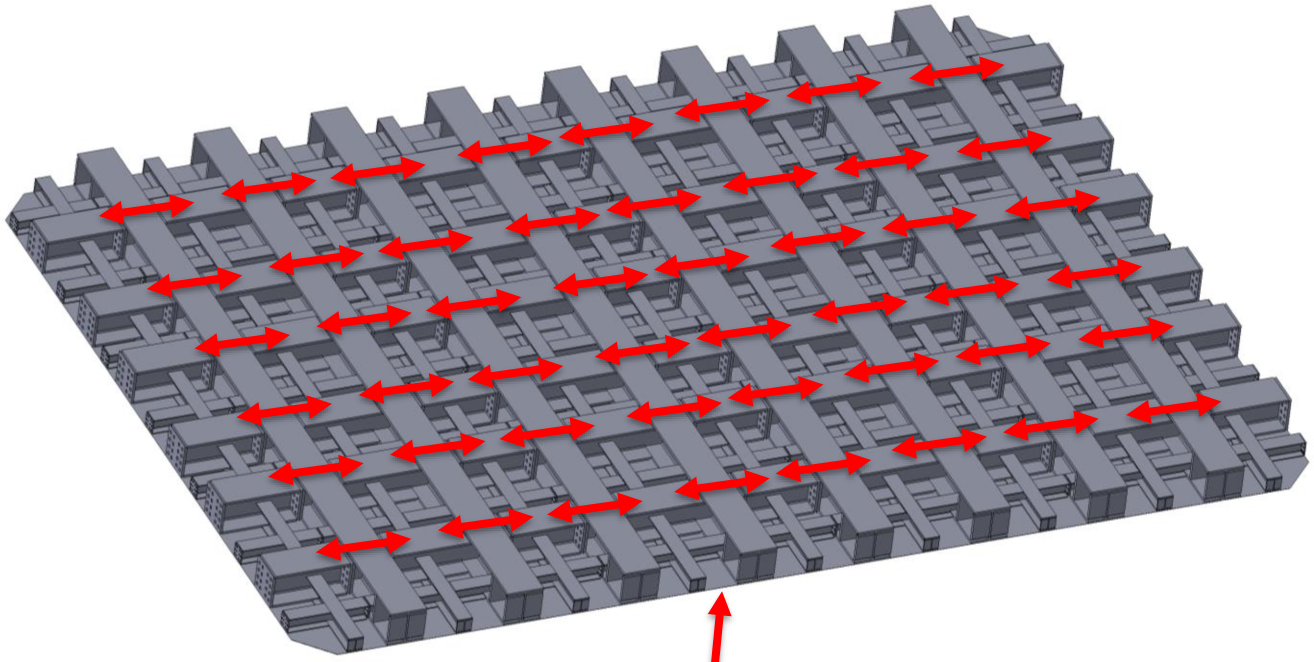




Weld seams on backside to form moisture barrier



Base Design



Weld seams on
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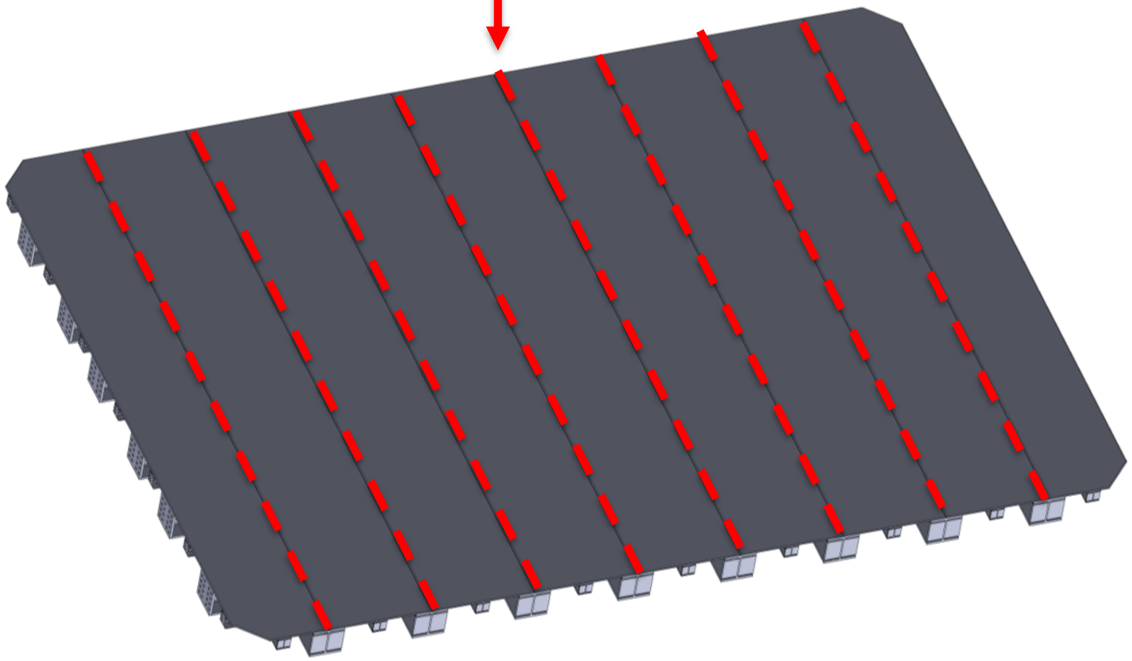
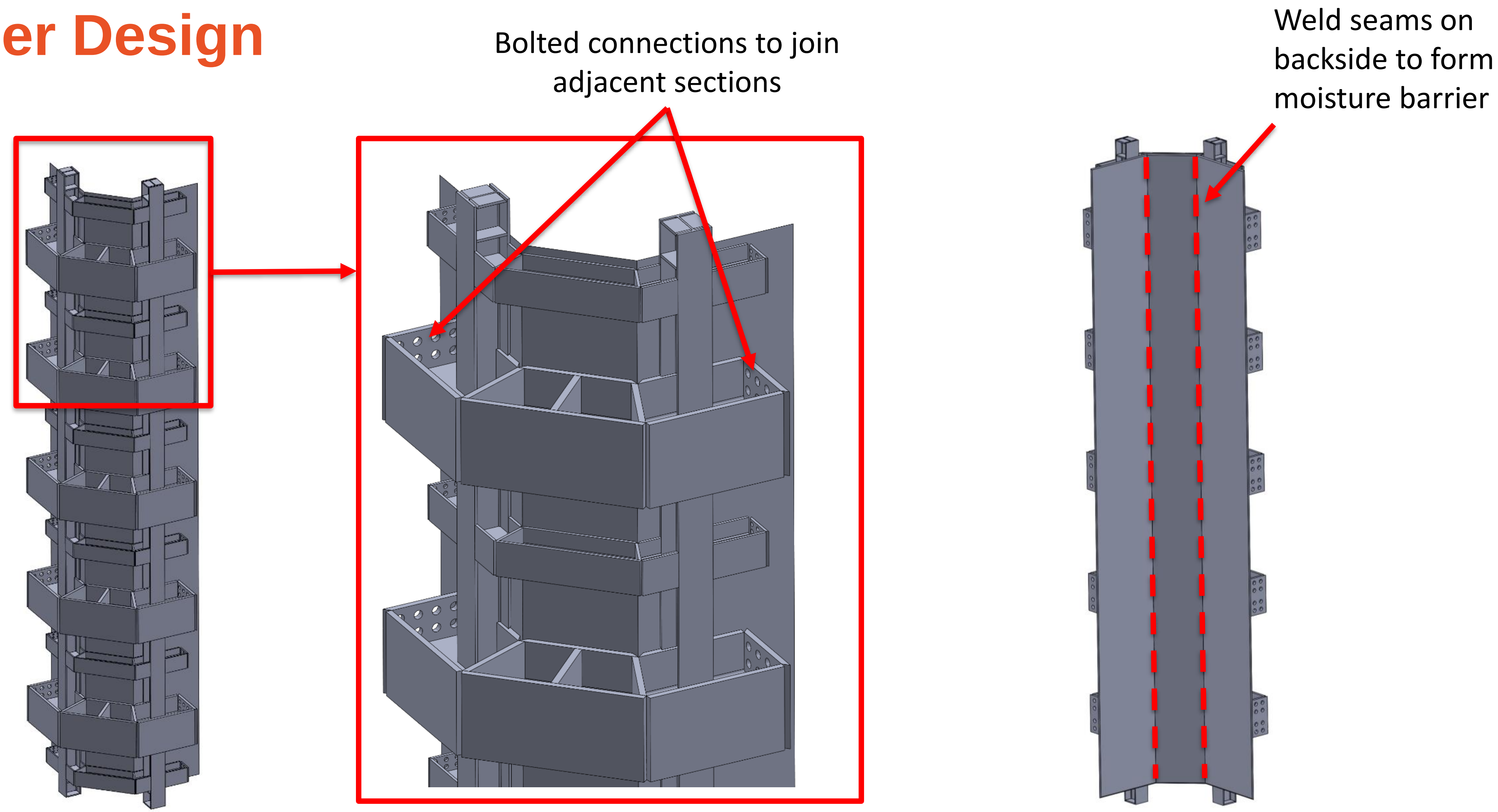


Bolted connections to join
adjacent sections

Corner Design

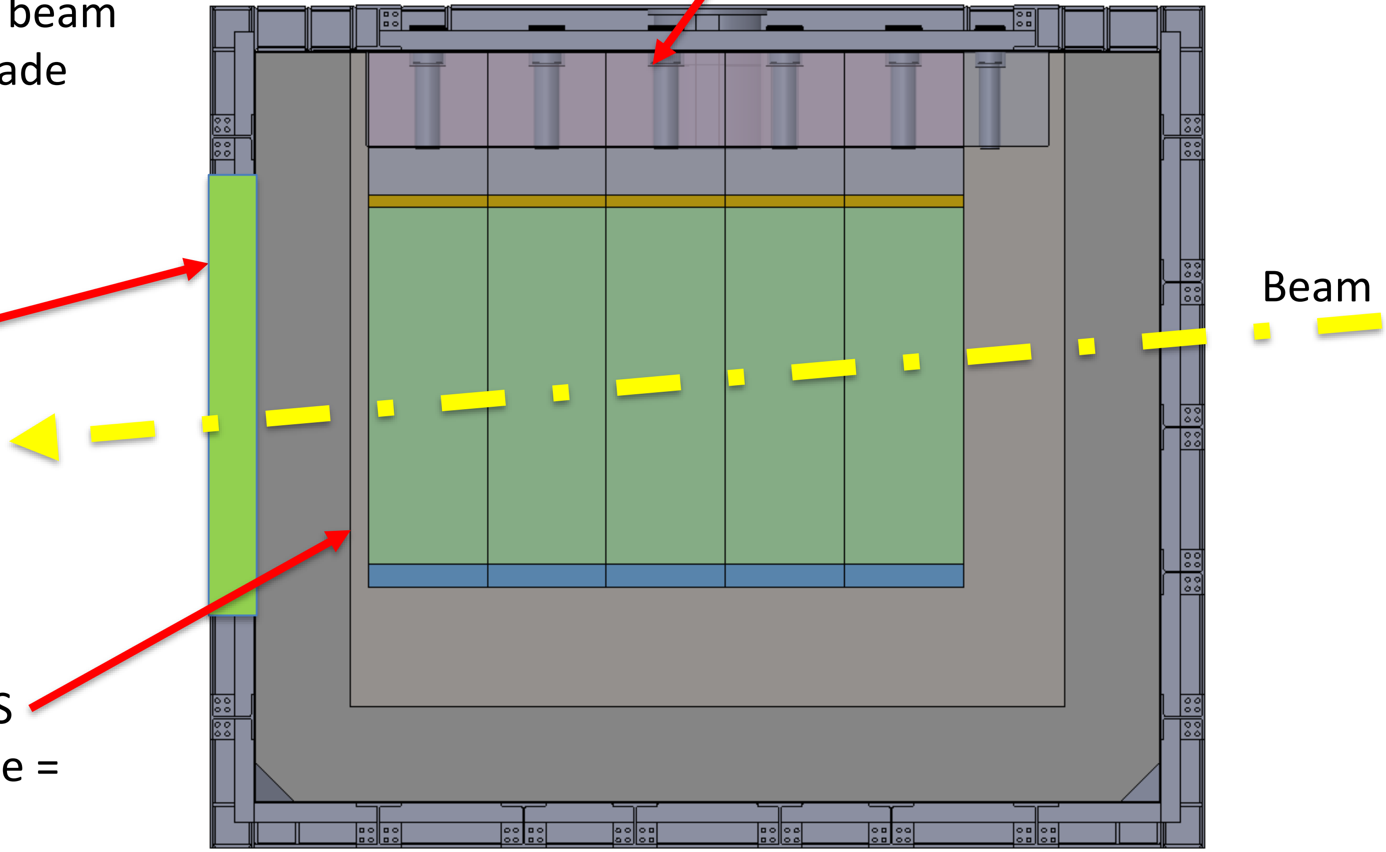


Downstream Composite Wall

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

Downstream Composite Wall

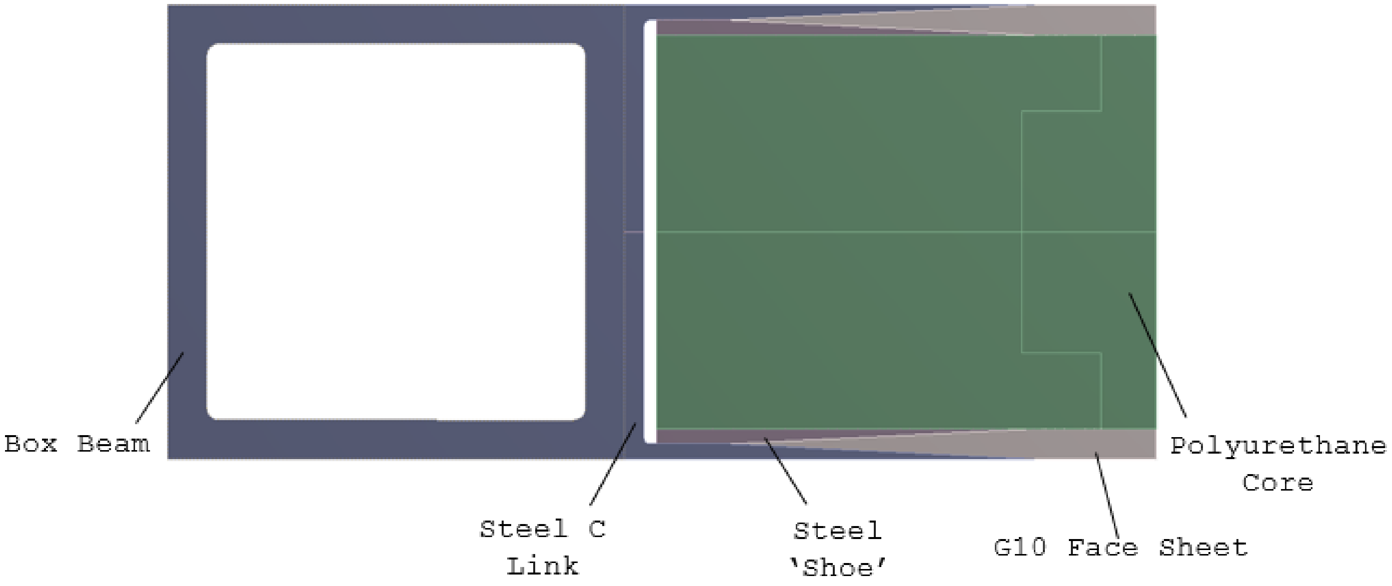


Beam

Distance from internal SS membrane flat to module = 300mm

Scarf Joint Design – Join Composite Window to Beam Structure

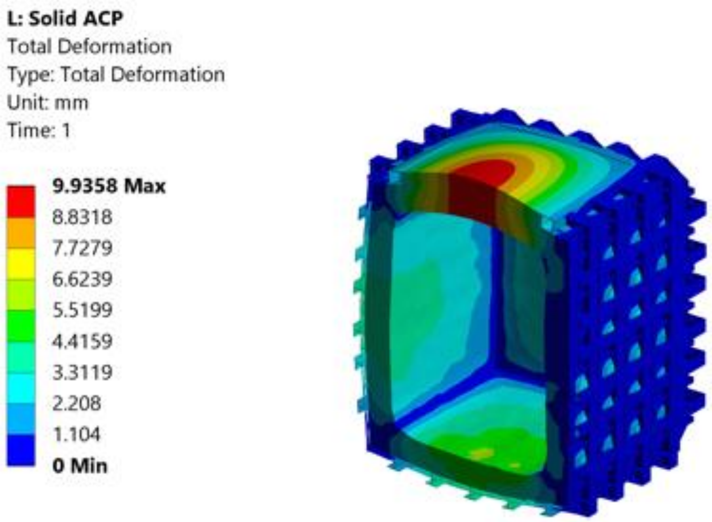
****Courtesy of G. Vallone**



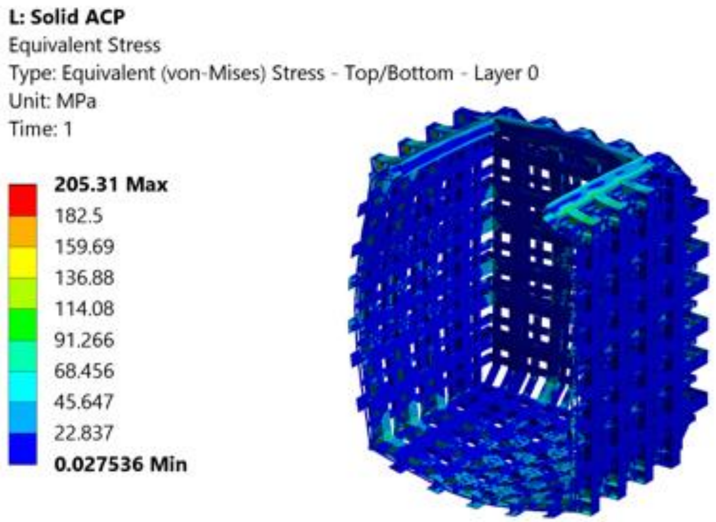
- The tapered lap joint is not able to satisfy the strength requirements (with a reasonable length)
- A scarf joint can sustain much higher loads
- Production process is more complicated

Preliminary Analyses – Beam Structure & Composite Wall

**Courtesy of G. Vallone



- 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

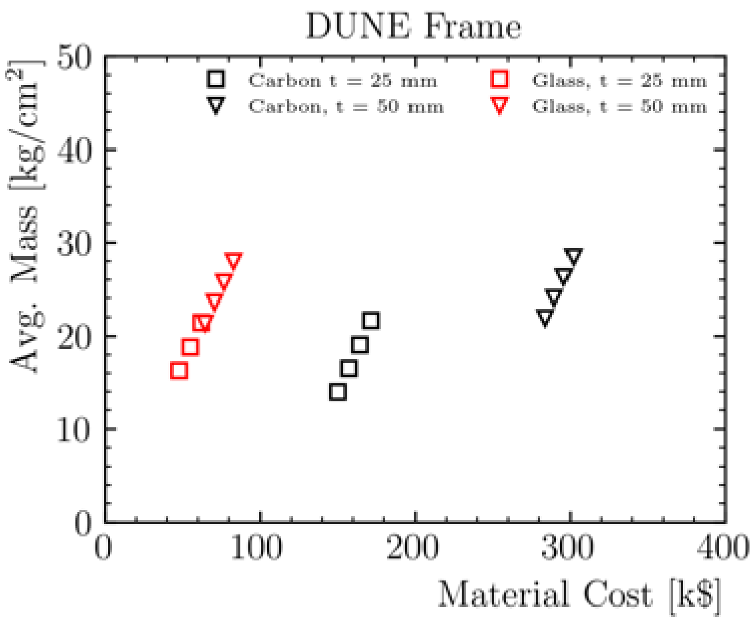


Average Mass through Window Thickness

****Courtesy of G. Vallone**

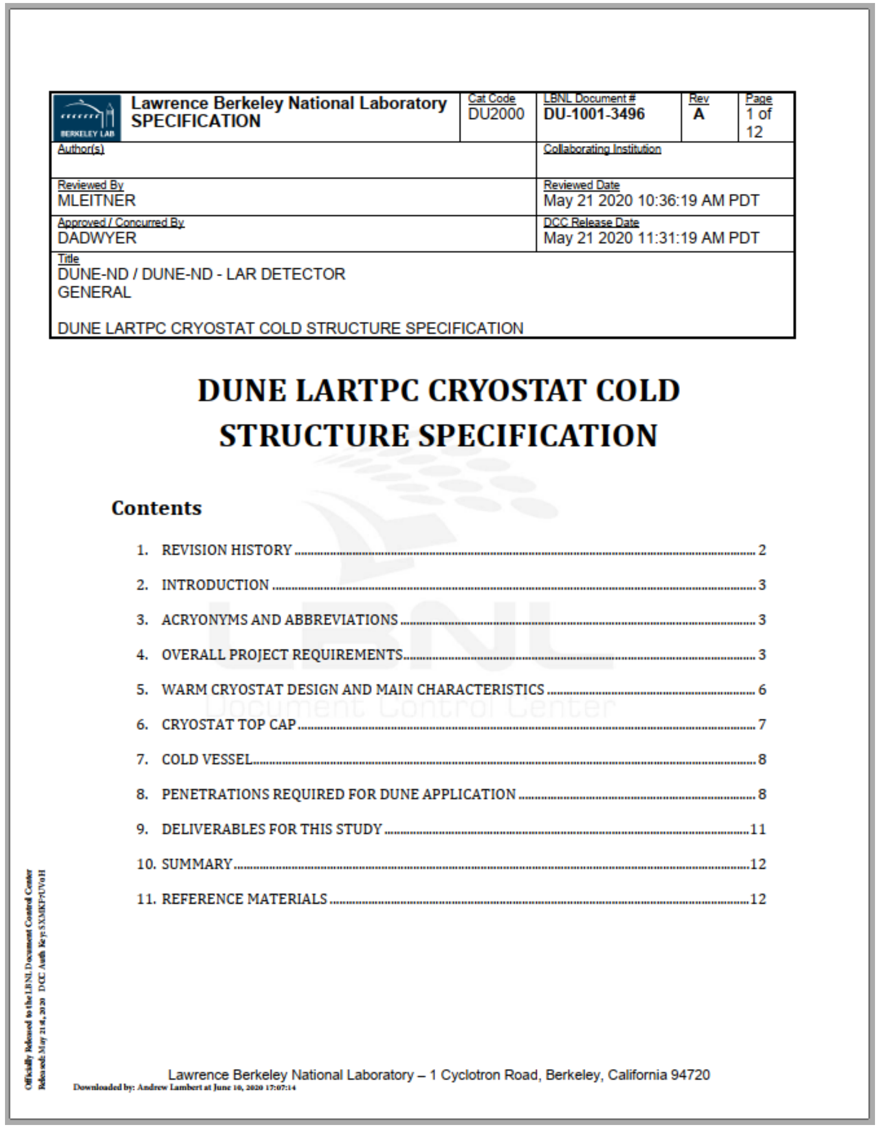
Layer	Material	thickness	x0_s	rho	L	x0	X0	Contrib.	rho*t	Contrib.
/	/	mm	g/cm2	kg/m3	cm	cm/cm	%	%	g/cm2	%
Liquid	Argon	500	14	1396	10.029	4.99	499%	77.5%	69.8	73.7%
Plate	Steel	2	1.7	7000	0.243	0.82	82%	12.8%	1.4	1.5%
Insulation	Polyurethane	808	40.8	90	453.333	0.18	18%	2.8%	7.3	7.7%
Window	Composite	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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DUNE LARTPC CRYOSTAT COLD STRUCTURE SPECIFICATION

Contents

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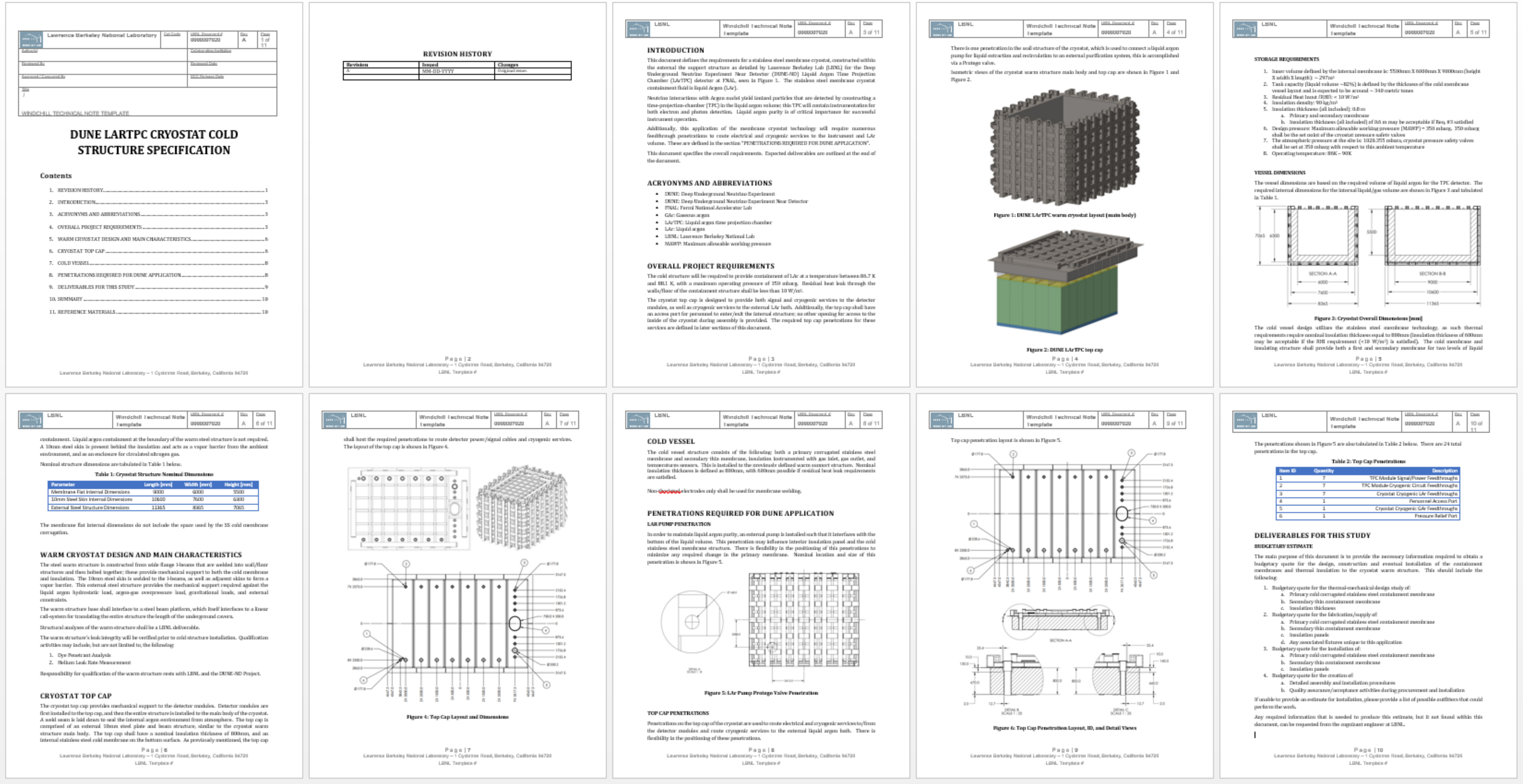
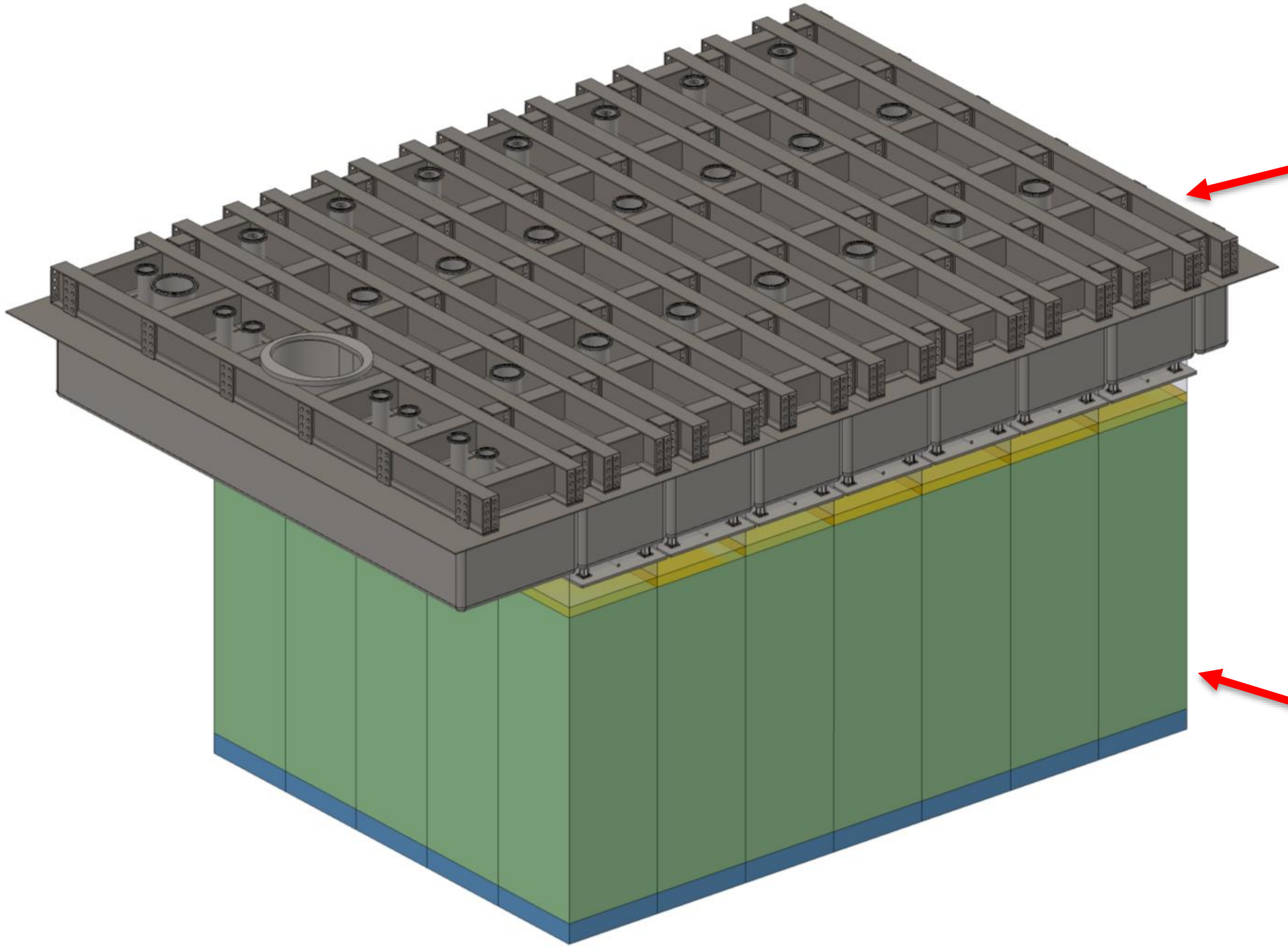
Cold Structure Specification Document – Released & sent to IHI, major milestone in cold structure development



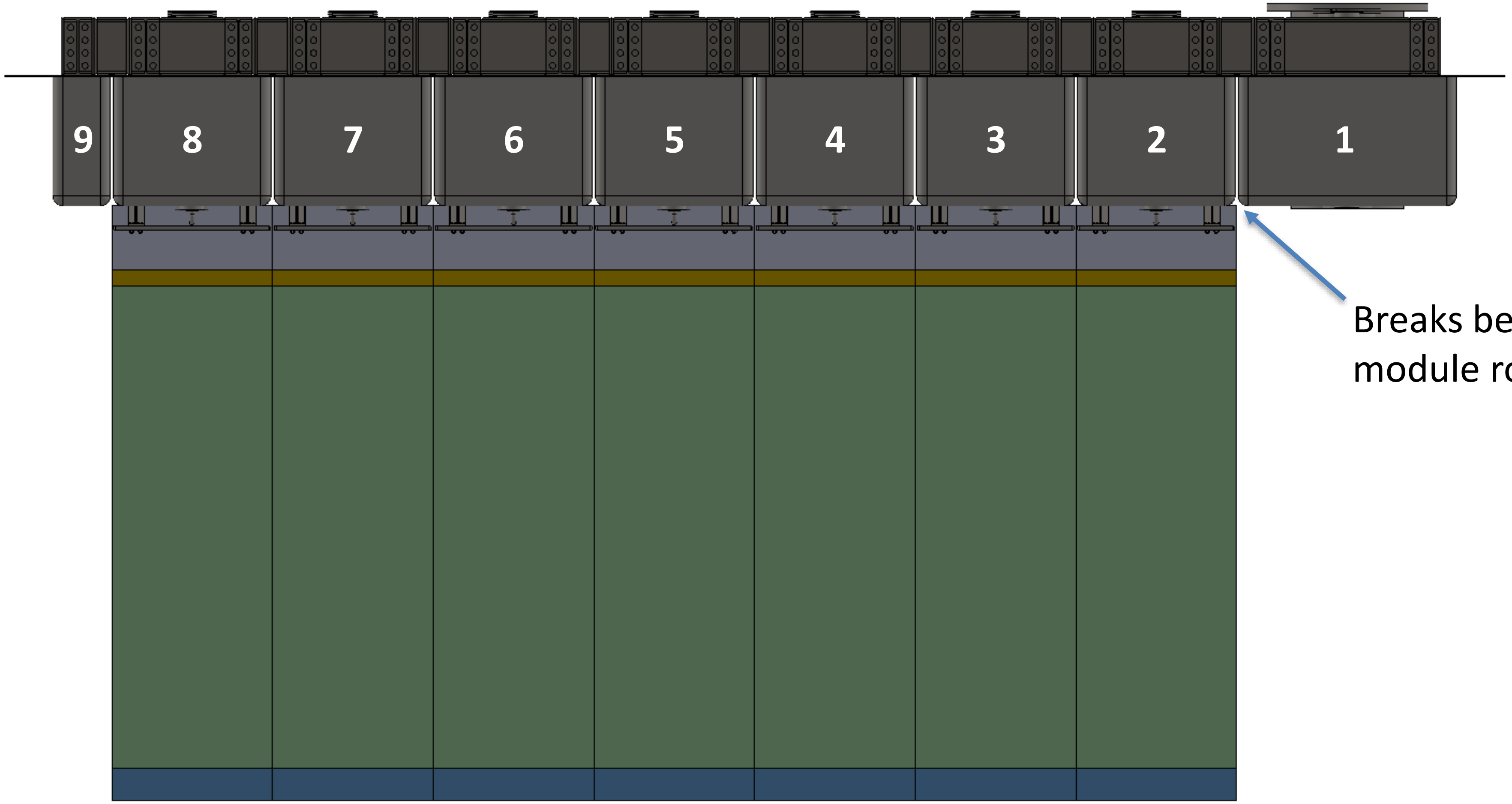
Top Lid Design – Modular Structure



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

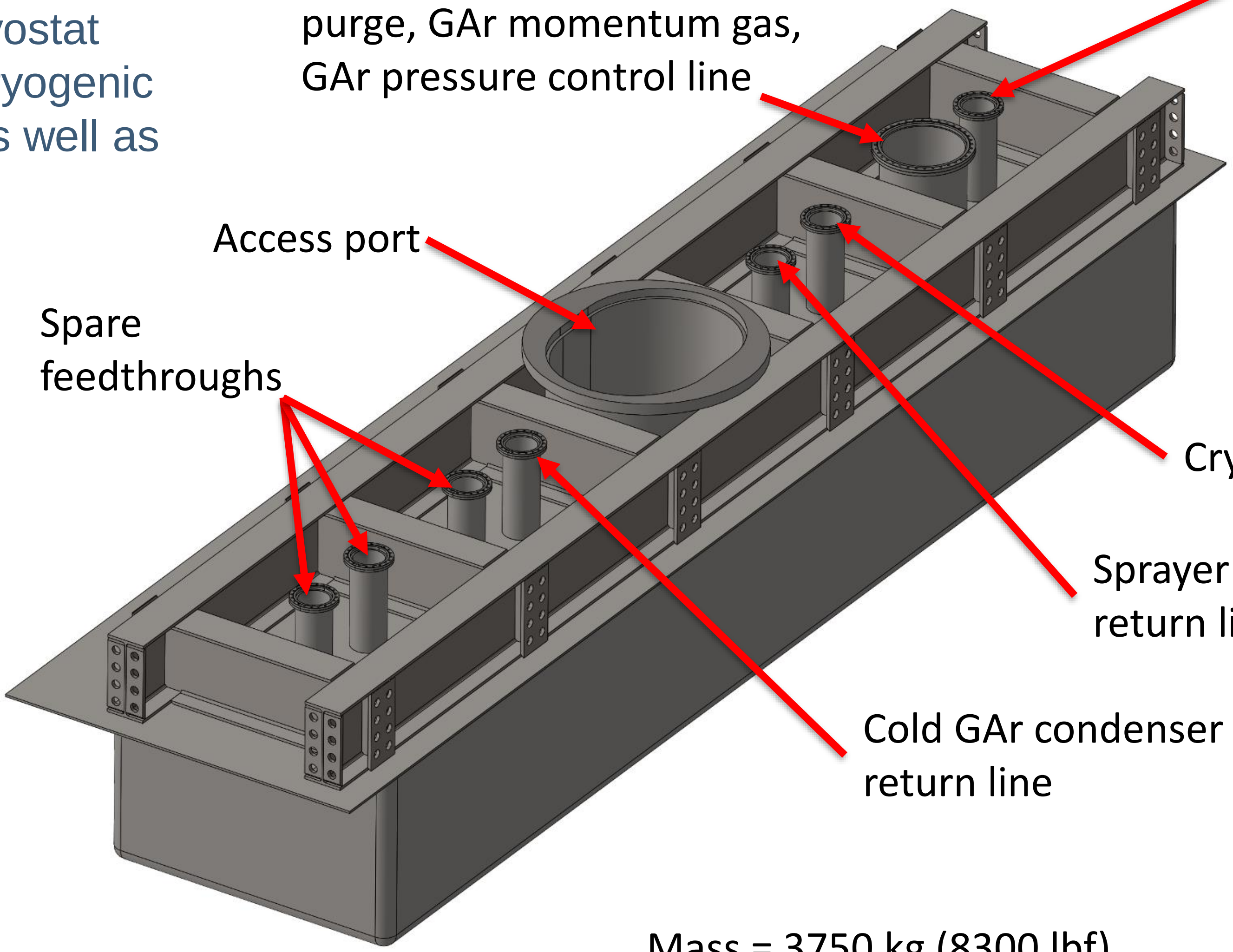


**Numbered in order of installation

Breaks between module rows

Cryostat Lid Section – Cryo Feedthroughs & Access Port

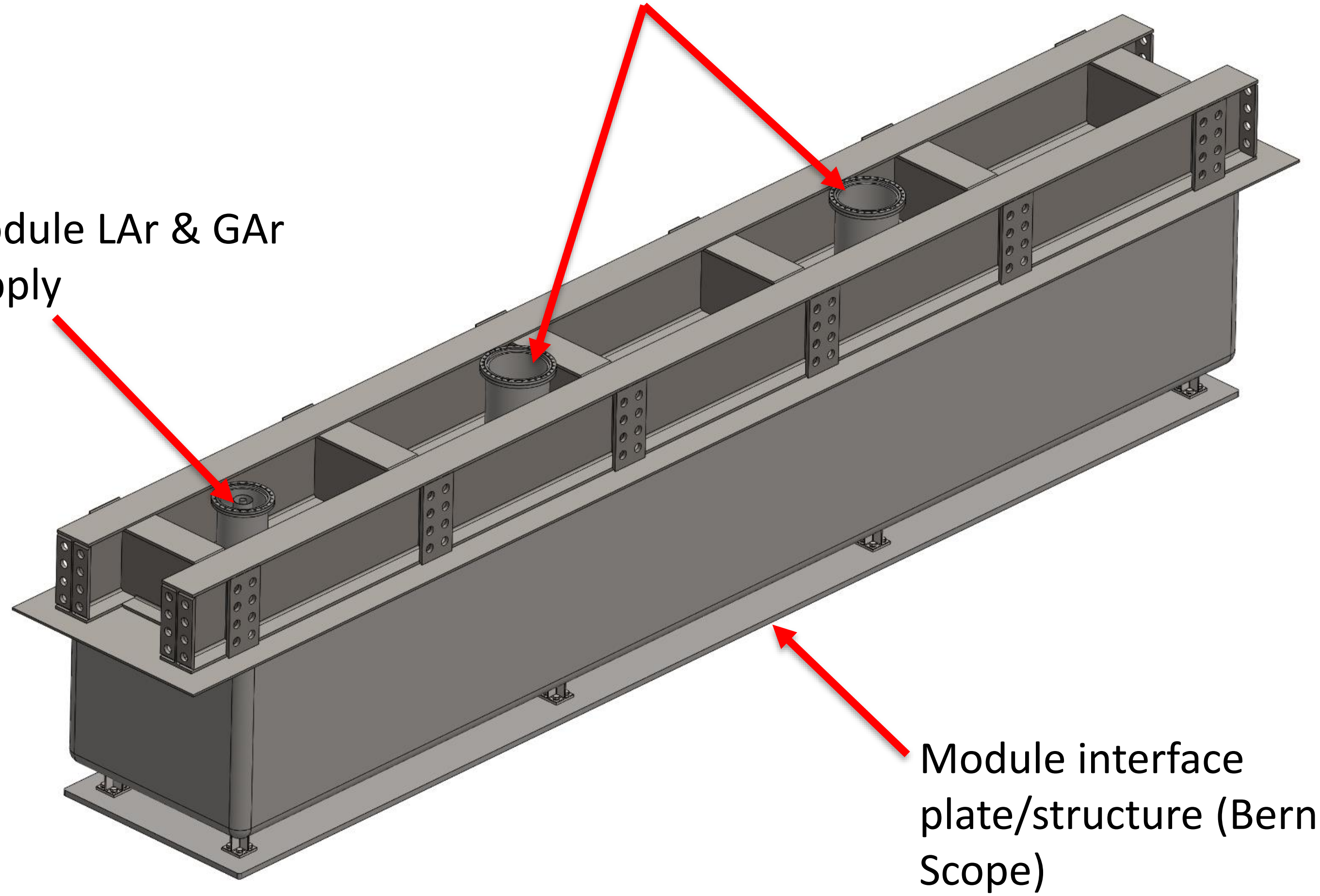
- First section installed to main cryostat structure is the lid section with cryogenic feedthroughs for LAr and GAr, as well as access port for personnel
- Installation:
  - Lower into place
  - Weld & leak check
  - Install brackets and bolts
  - Install ladder for interior access
  - Install cryogenic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



Mass = 3750 kg (8300 lbf)

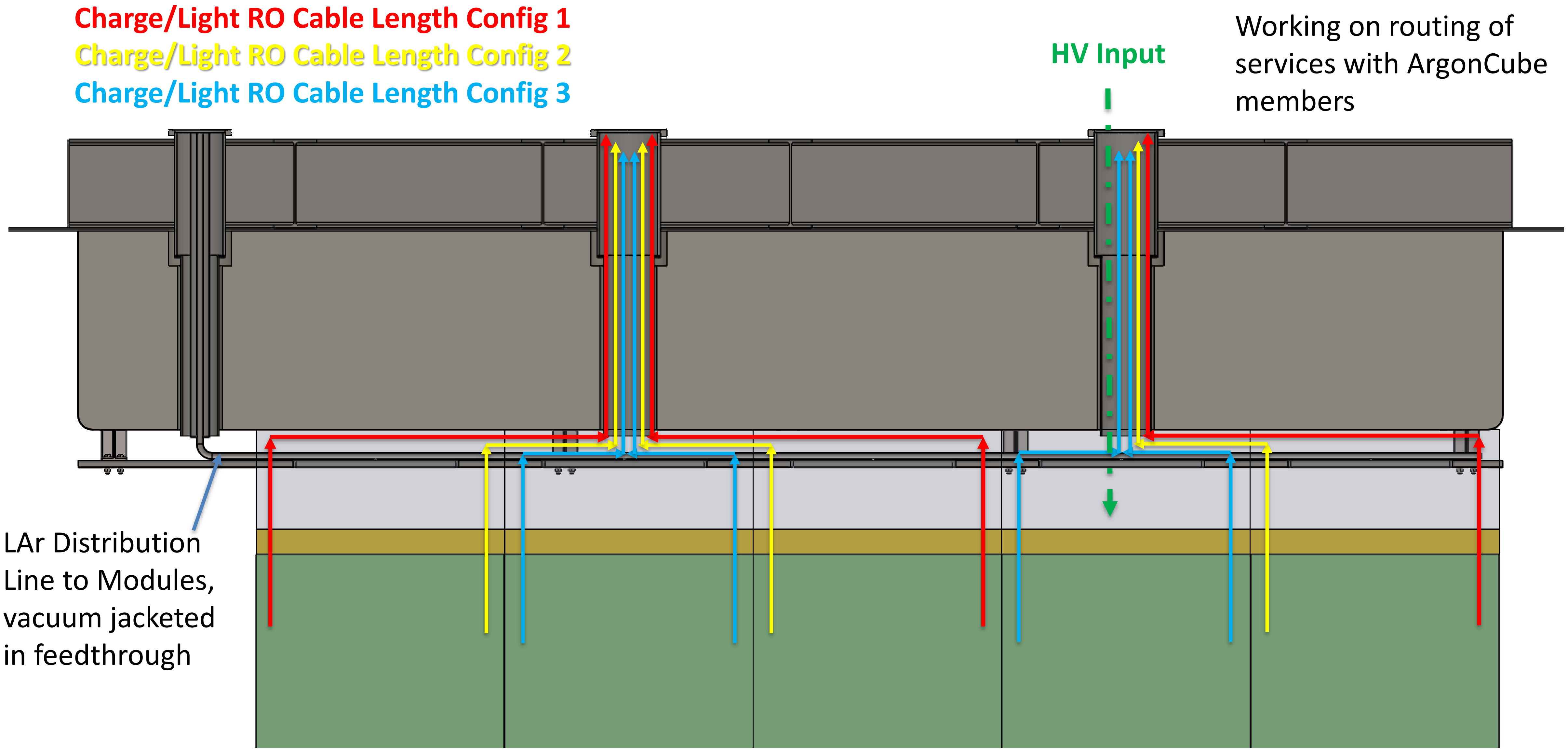
ArgonCube Module Lid Section(s)

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



Mass = 3350 kg (7400 lbf)

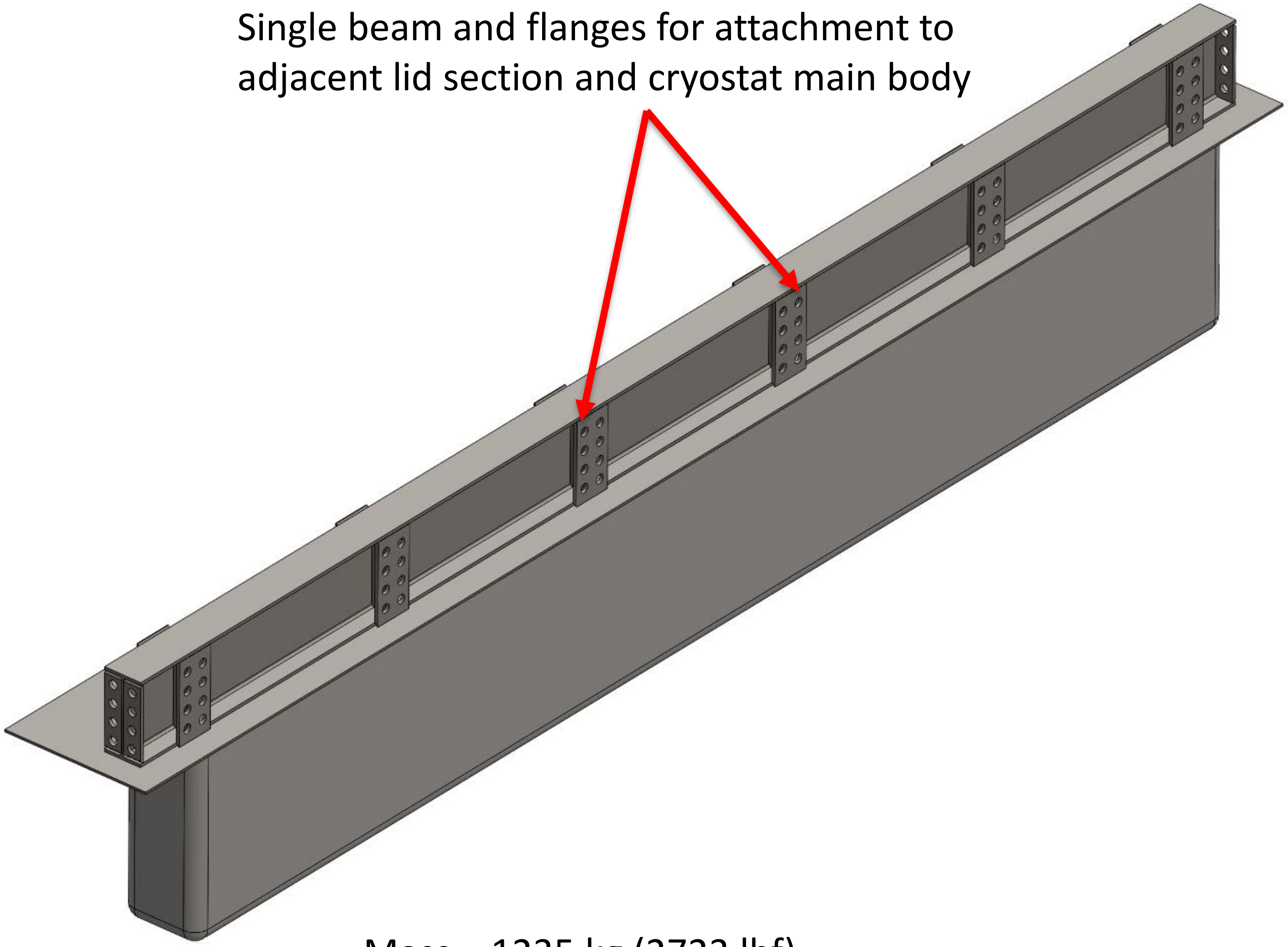
ArgonCube Module Lid Section(s) - Feedthroughs



Working on routing of services with ArgonCube members

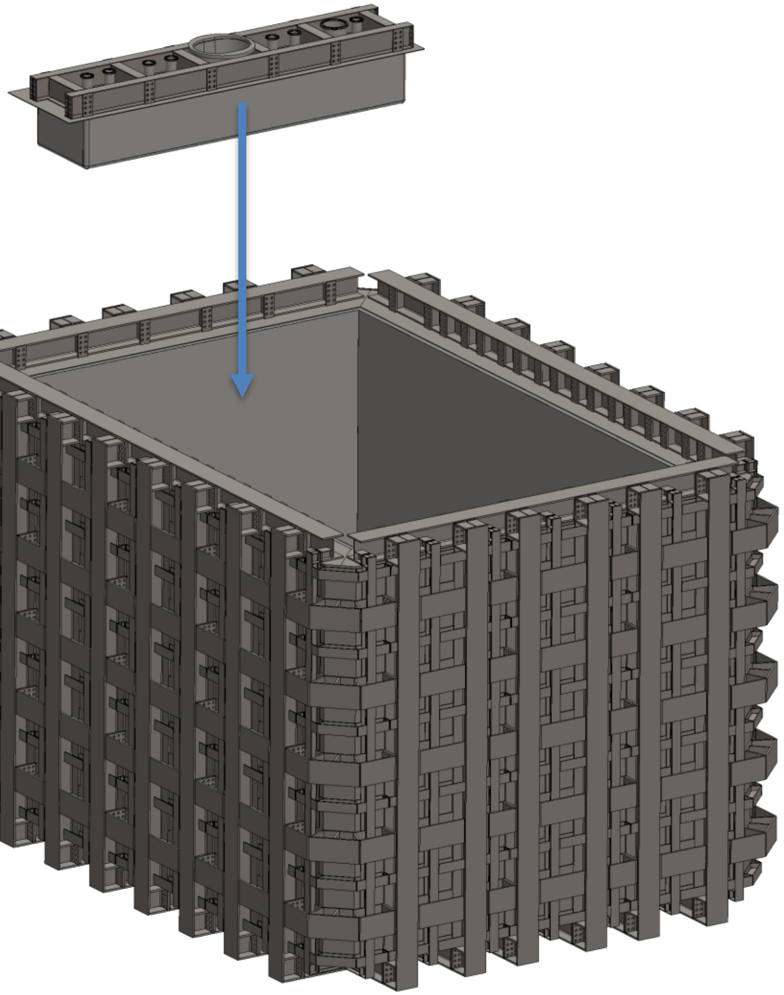
Final Lid Section

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

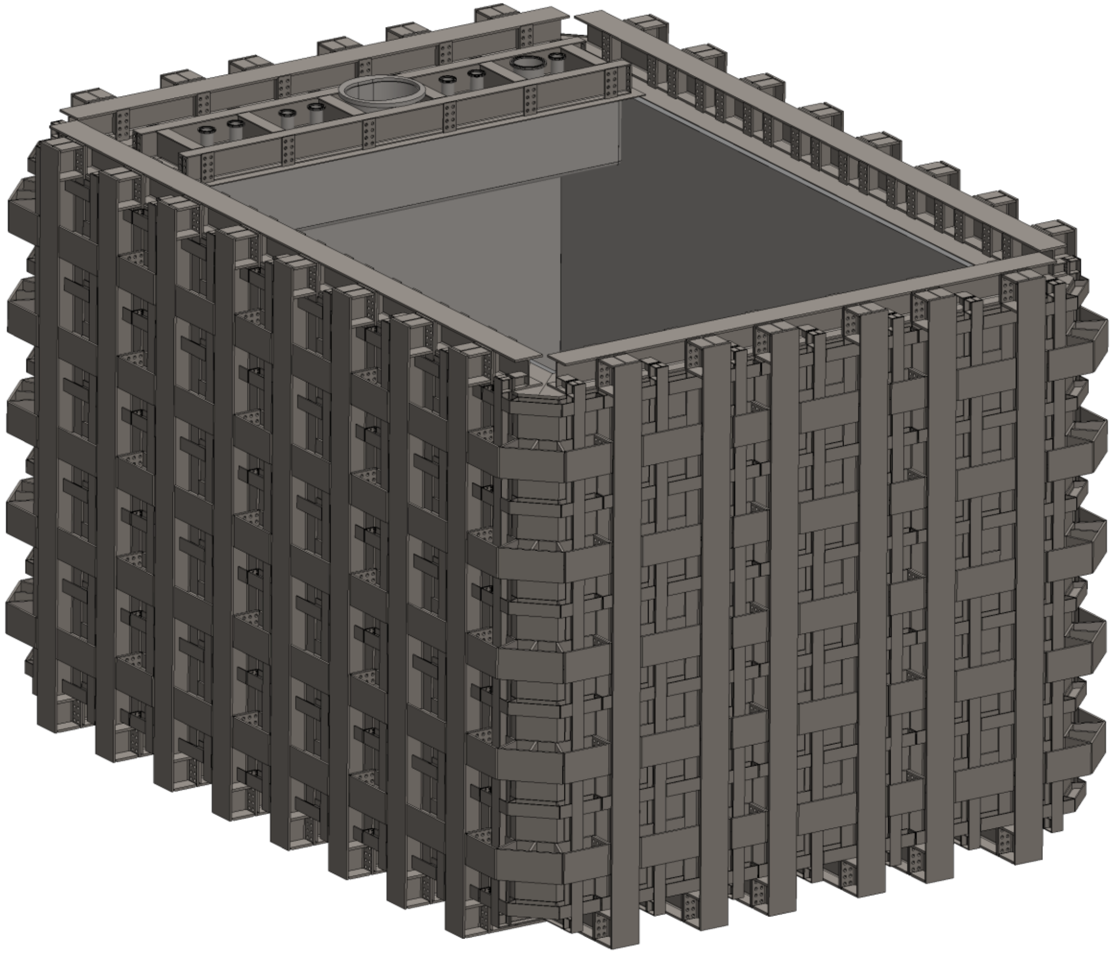


Mass = 1235 kg (2723 lbf)

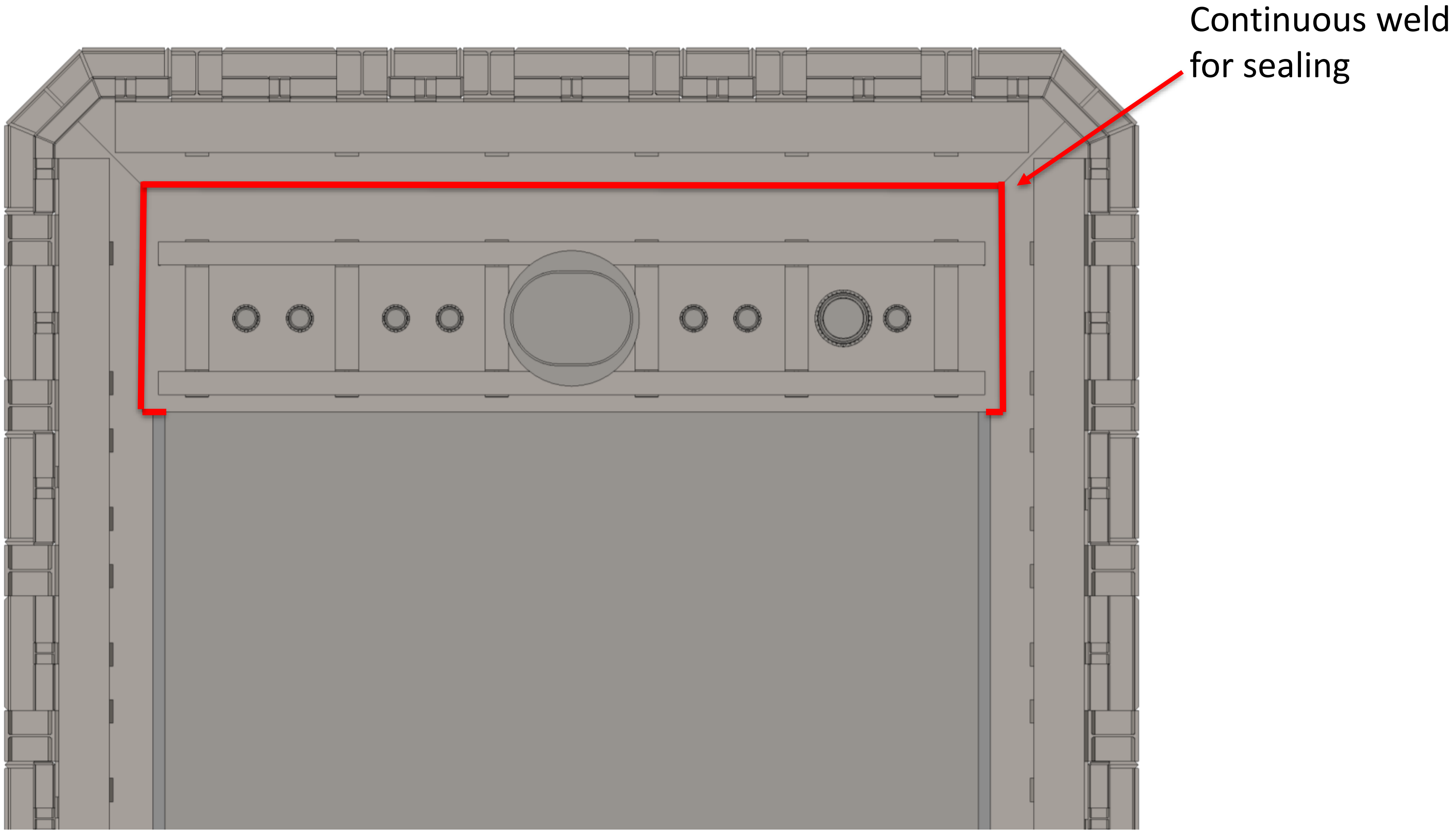
Lid Installation Sequence – Cryo Section



Lid Installation Sequence – Cryo Section

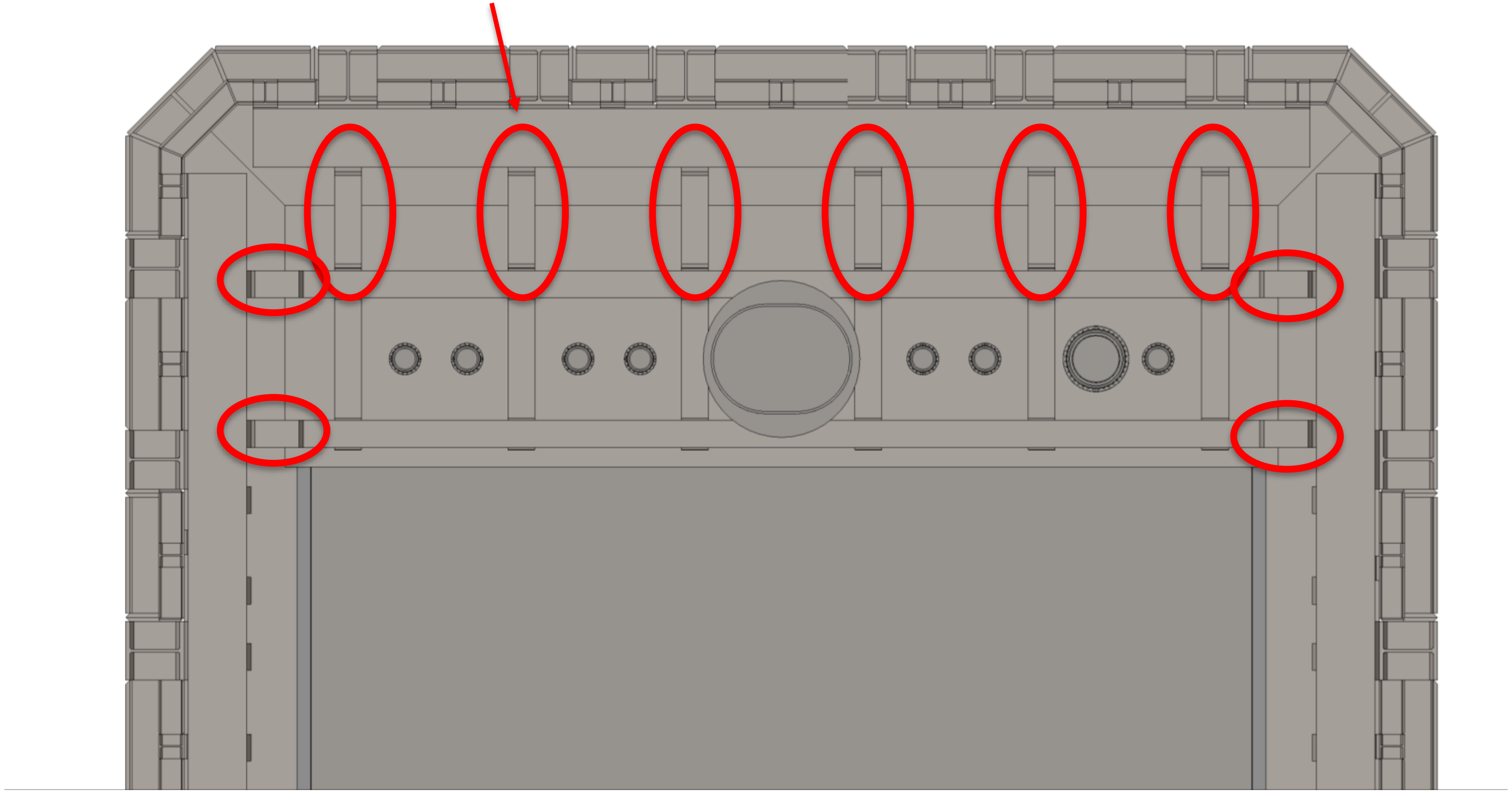


Lid Installation Sequence – Cryo Section



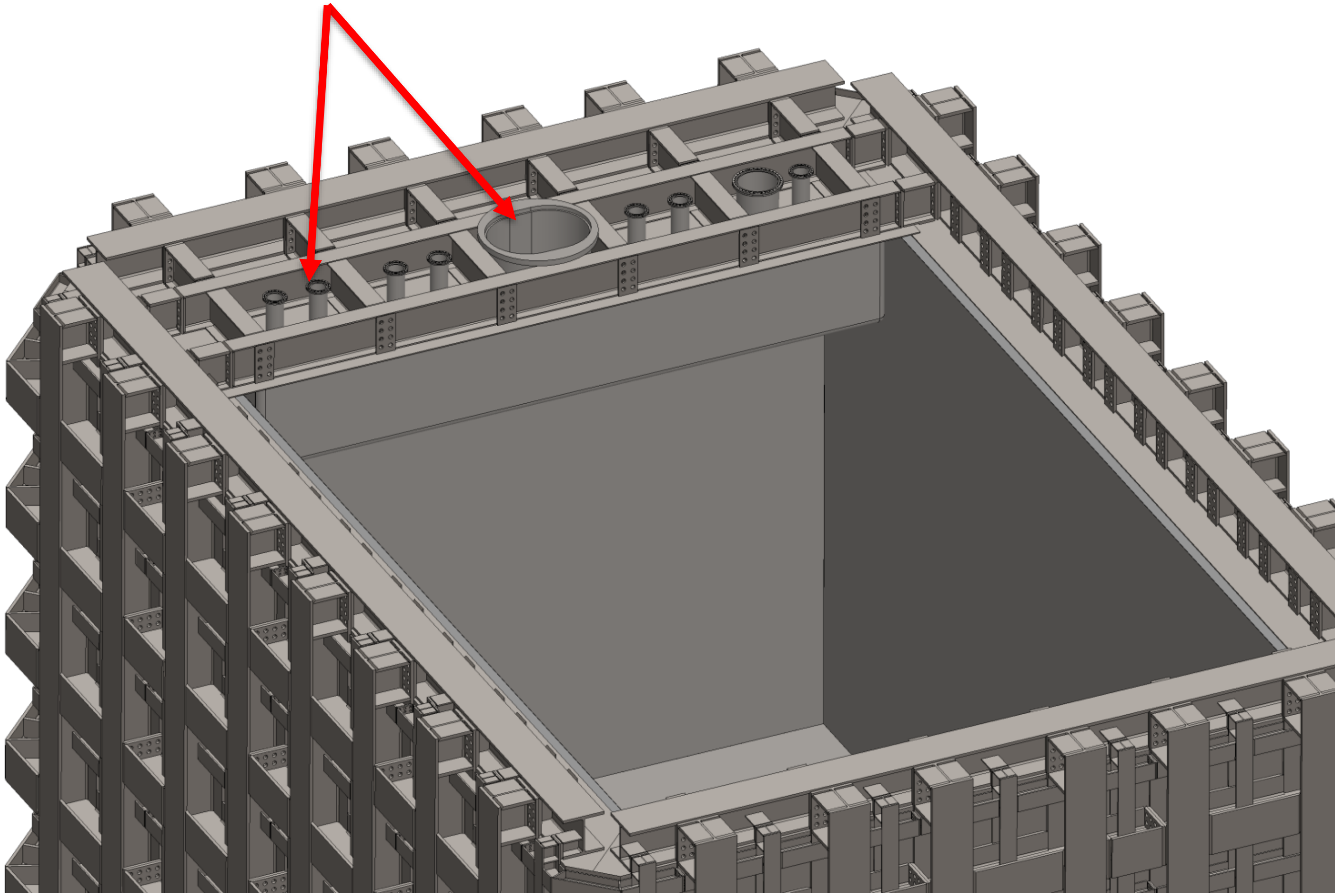
Lid Installation Sequence – Cryo Section

Install brackets to secure to cryostat main body

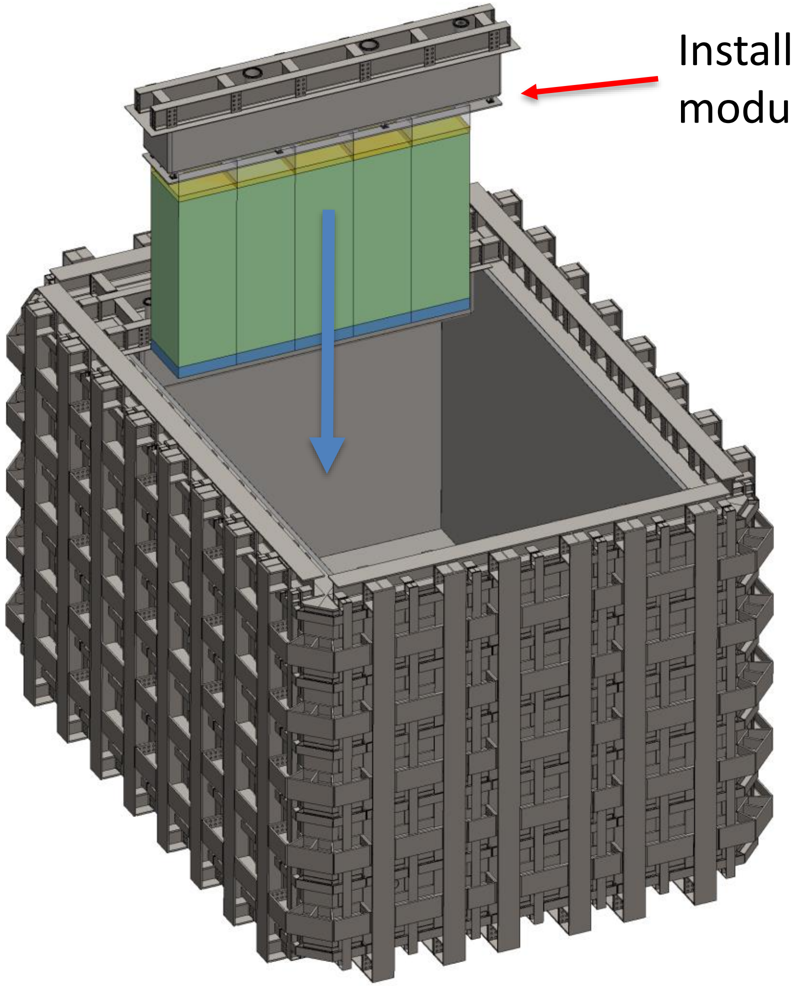


Lid Installation Sequence – Cryo Section

Can now install ladders or
cryogenic piping inside cryostat



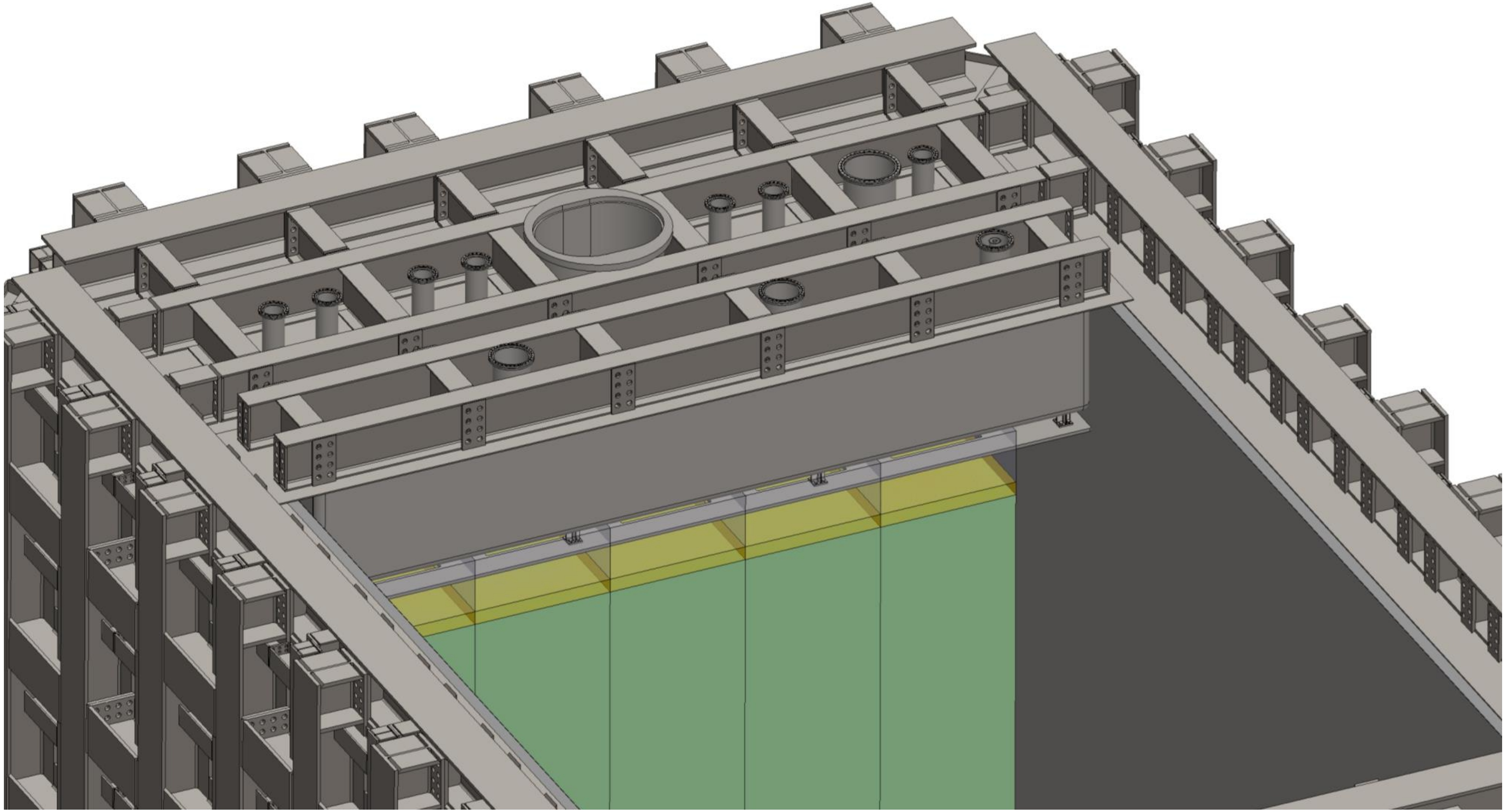
Lid Installation Sequence – Module Row 1



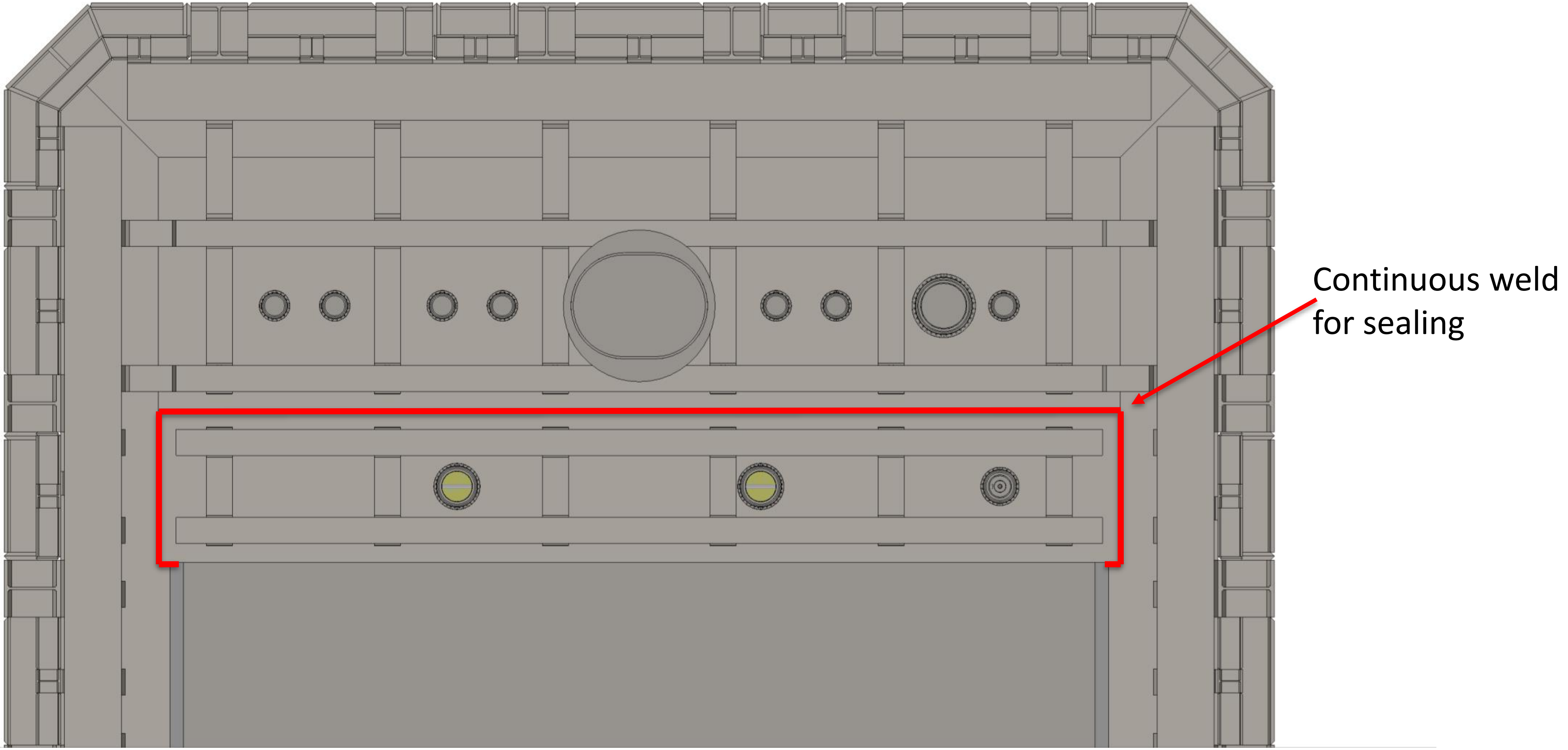
Install first ArgonCube module row

DUNE

Lid Installation Sequence – Module Row 1

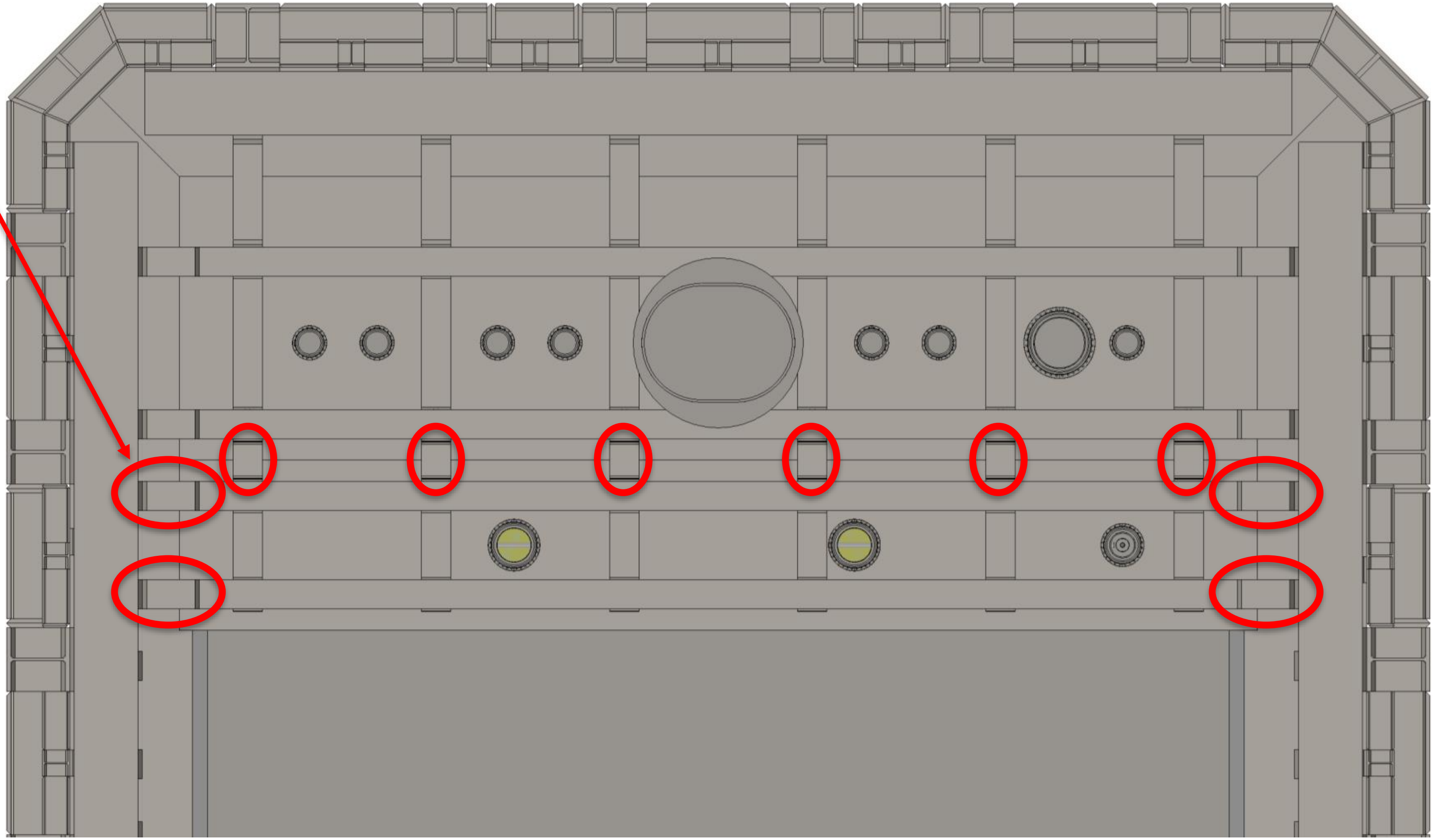


Lid Installation Sequence – Module Row 1

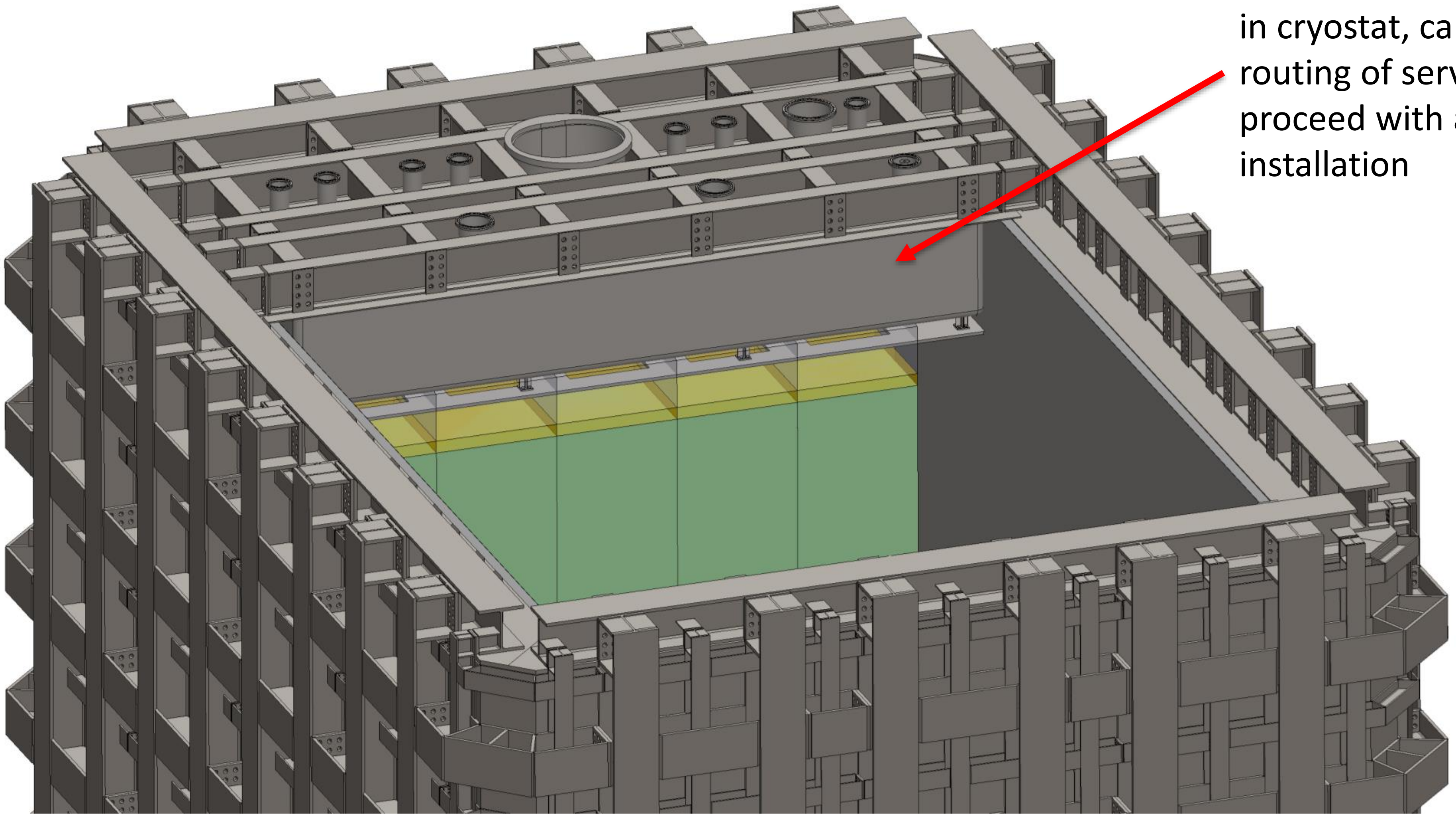


Lid Installation Sequence – Module Row 1

Install brackets to secure to cryostat main body

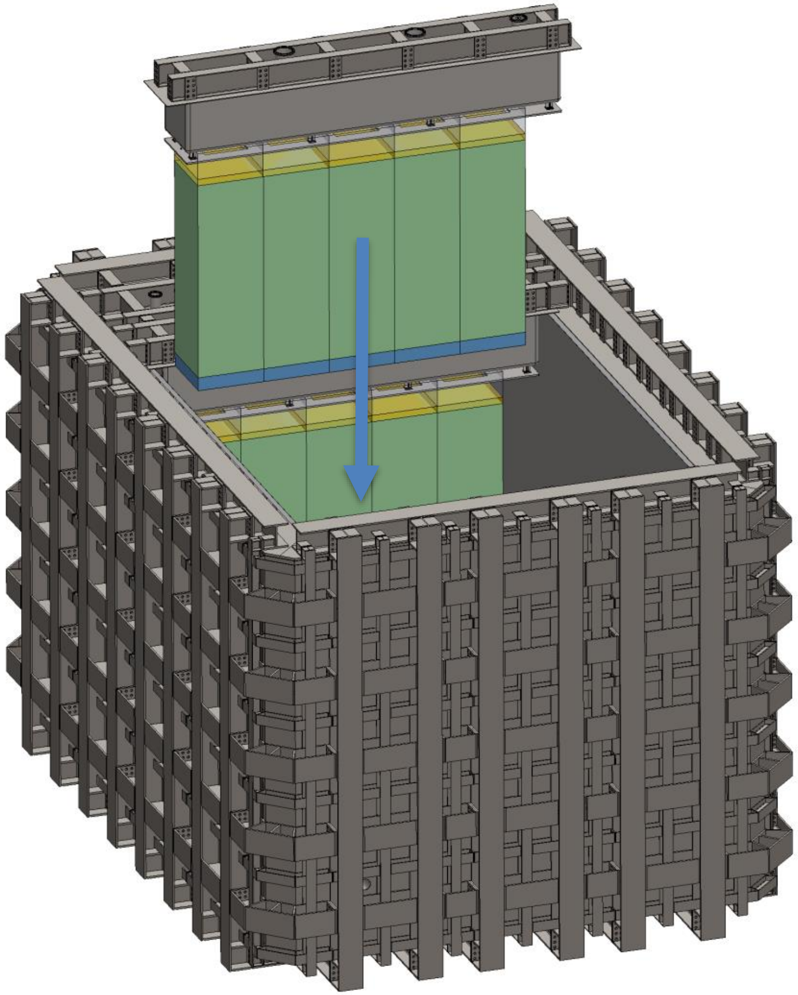


Lid Installation Sequence – Module Row 1

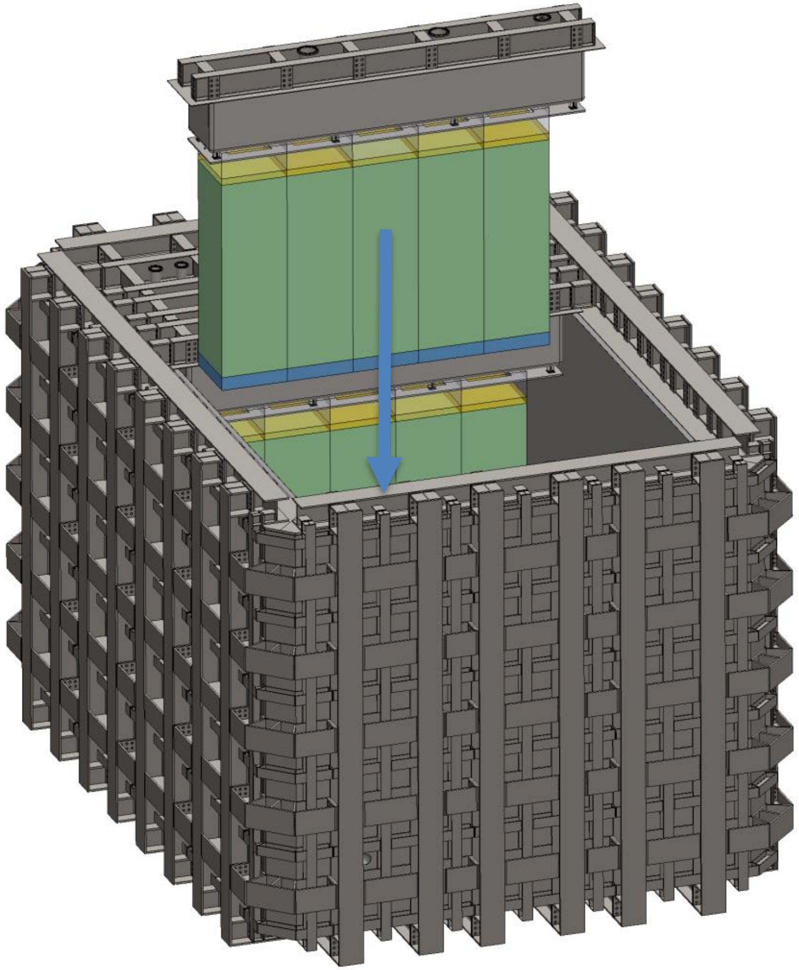


Module Row 1 now secured in cryostat, can begin routing of services or proceed with additional row installation

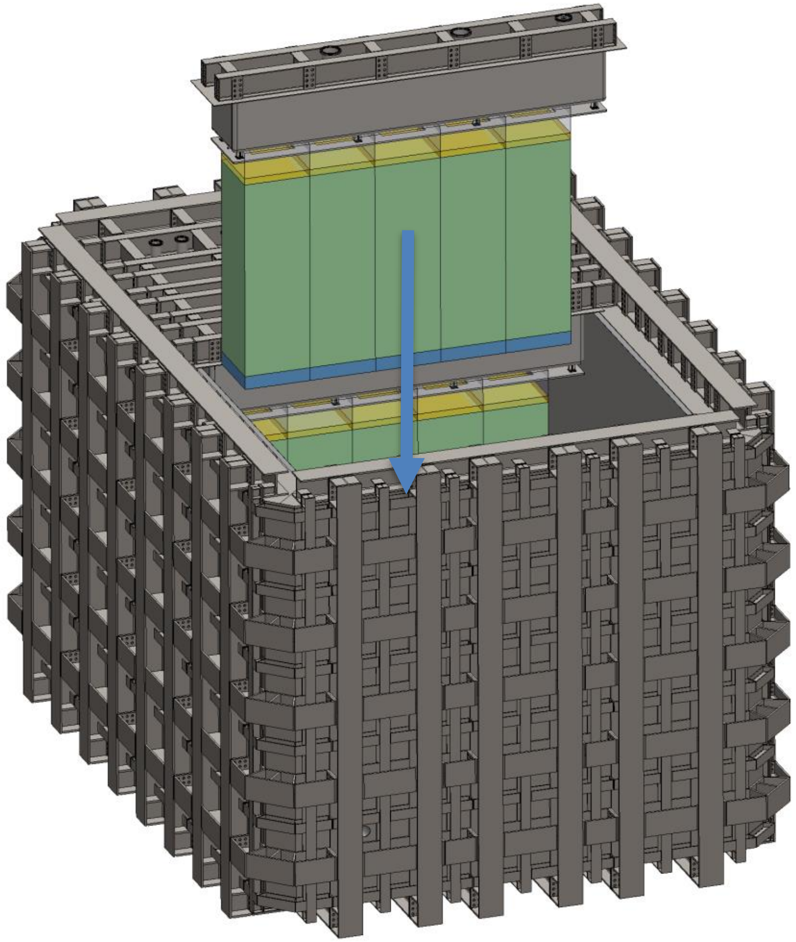
Lid Installation Sequence – Module Row 2



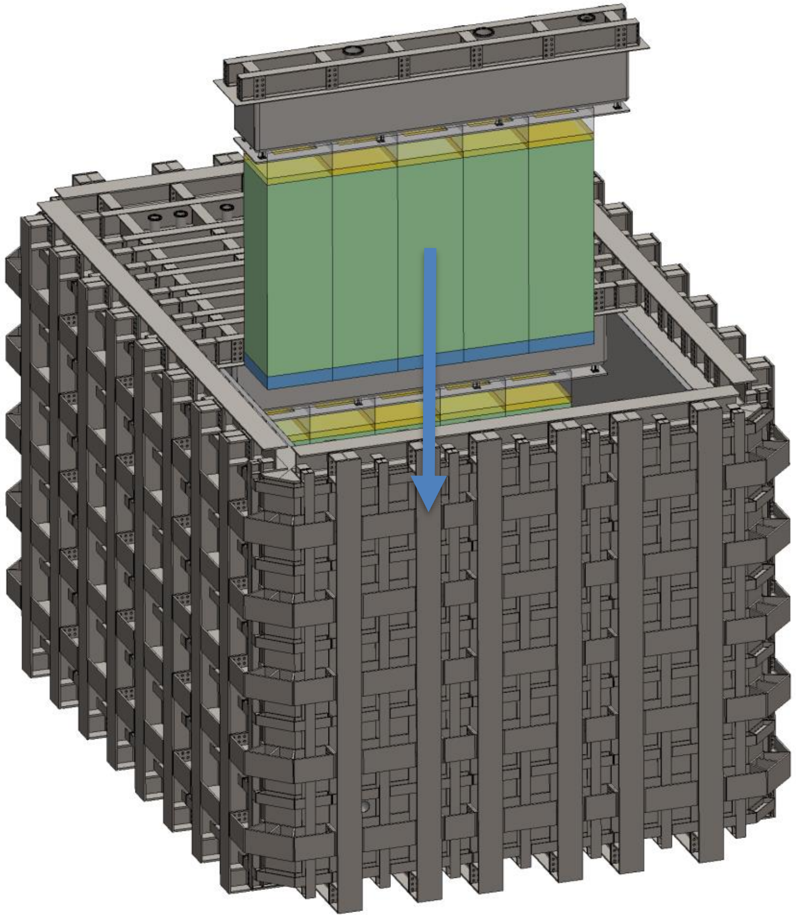
Lid Installation Sequence – Module Row 3



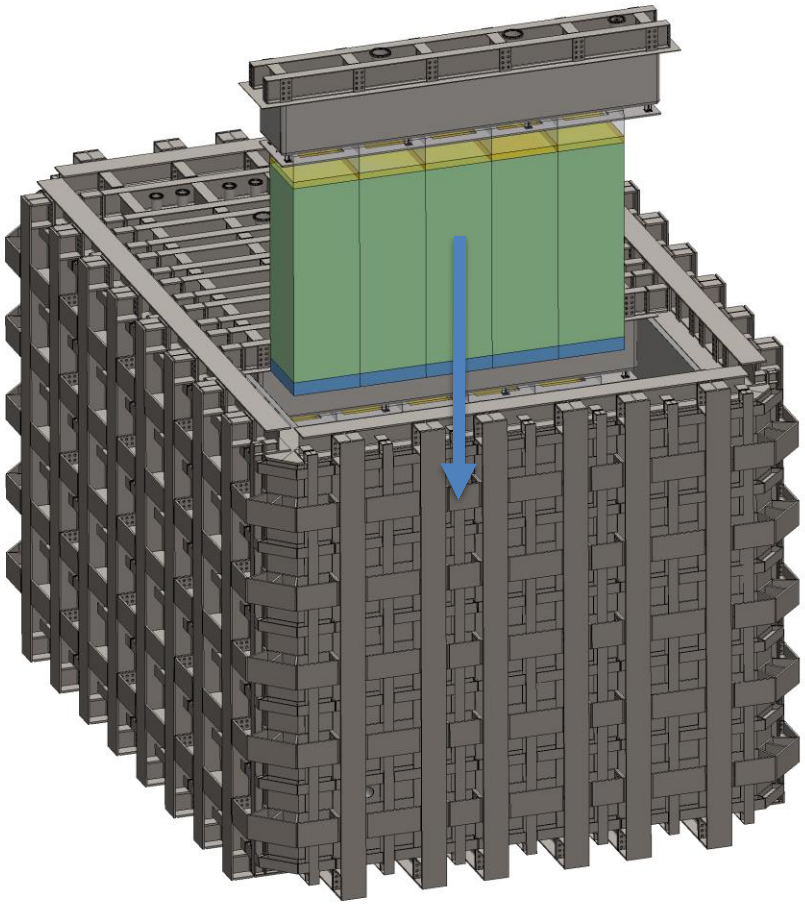
Lid Installation Sequence – Module Row 4



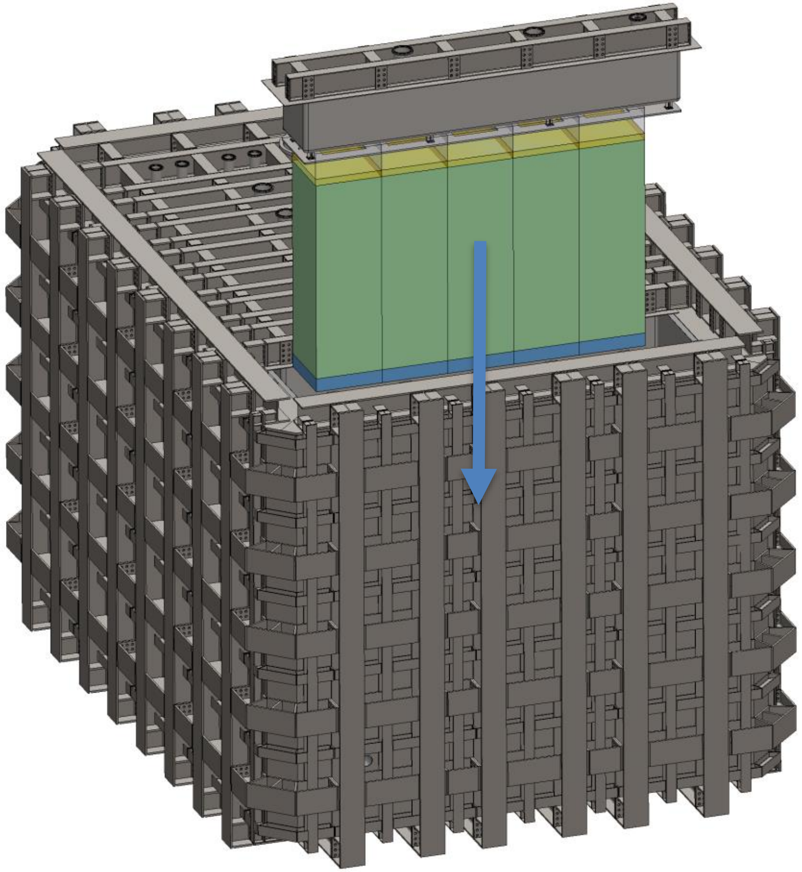
Lid Installation Sequence – Module Row 5



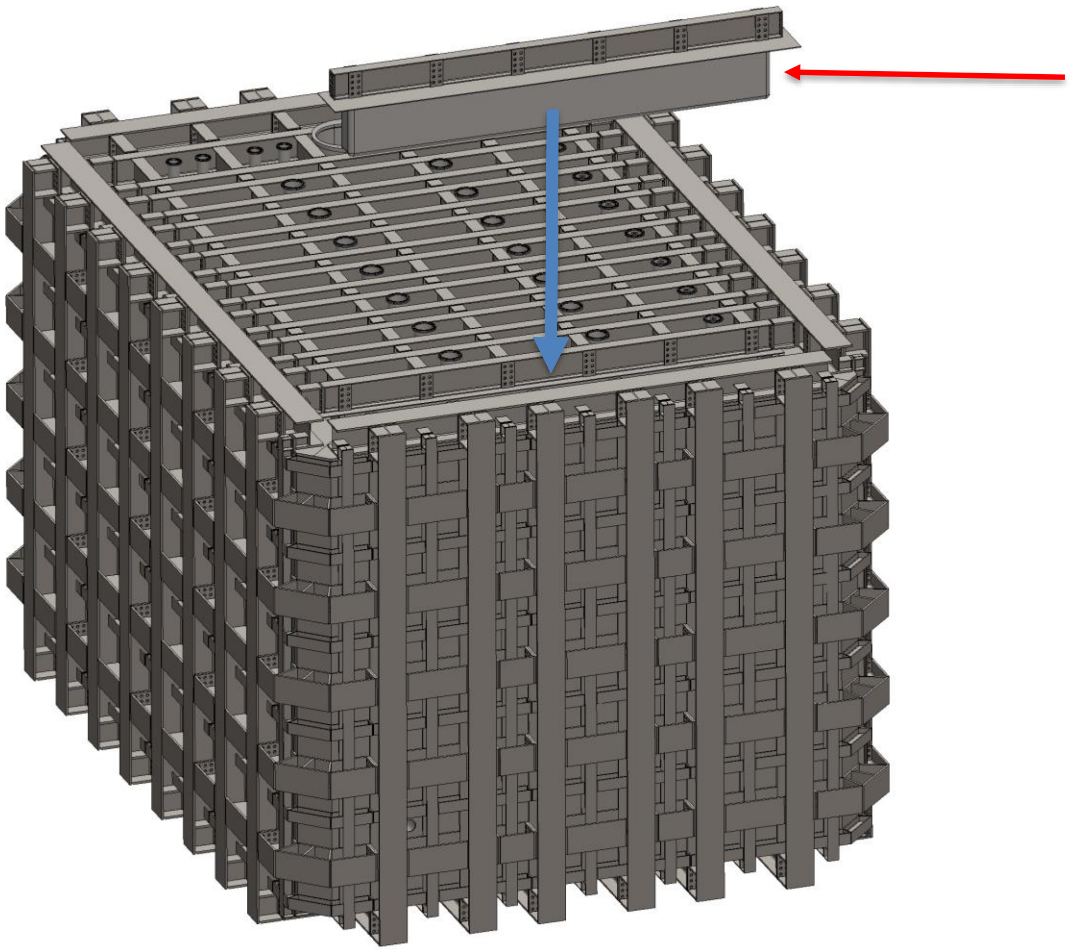
Lid Installation Sequence – Module Row 6



Lid Installation Sequence – Module Row 7



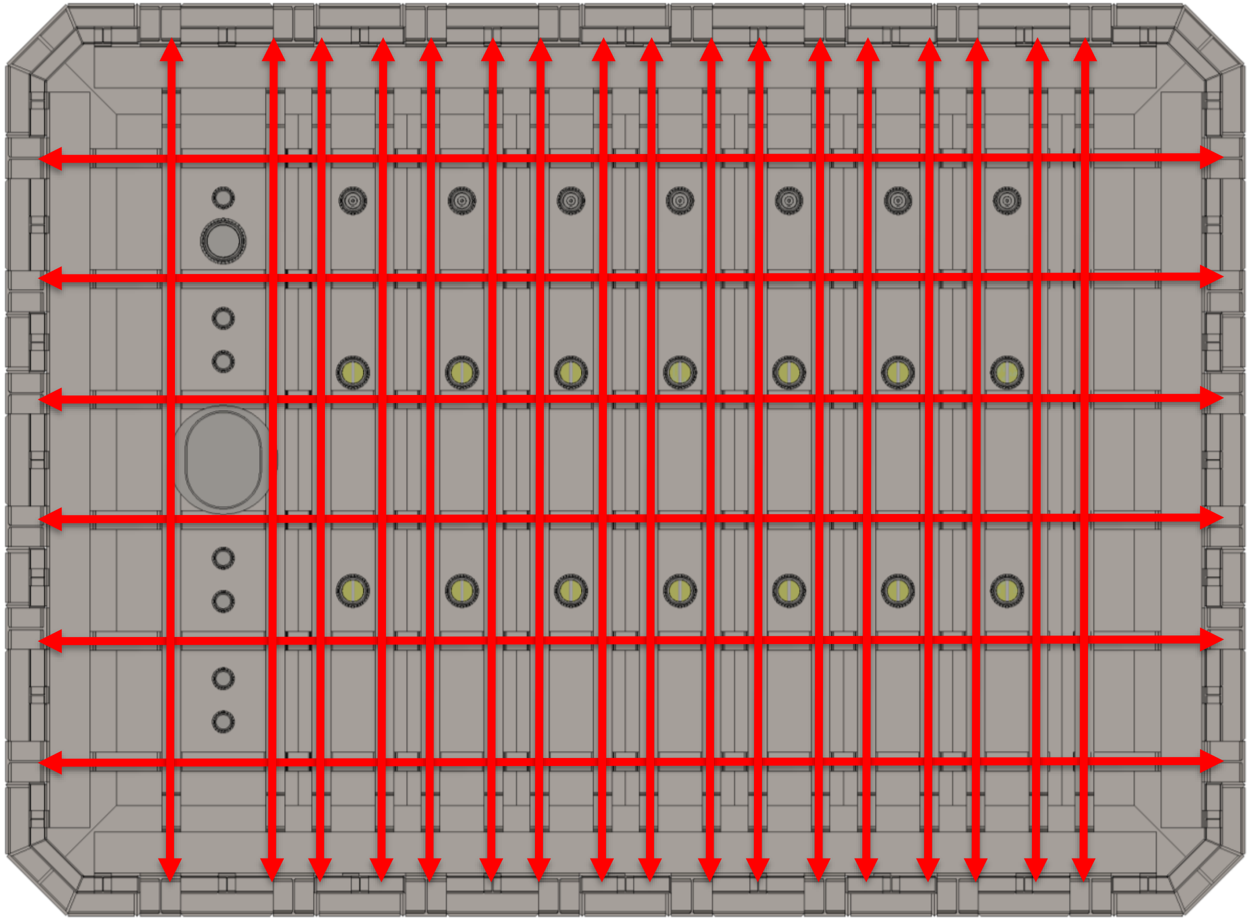
Final Section Installation



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