# DUNE-ND LArTPC Cryostat Assembly Process

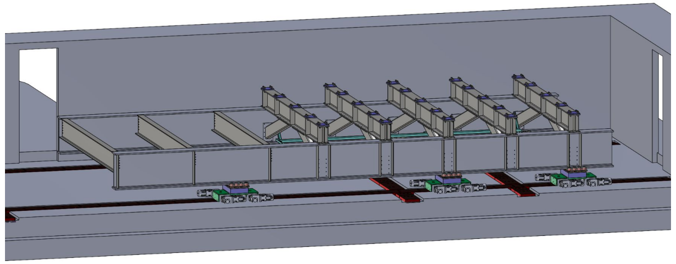
2024-09

Peter Tennessen, Joe Angelo, Fabrice Matichard

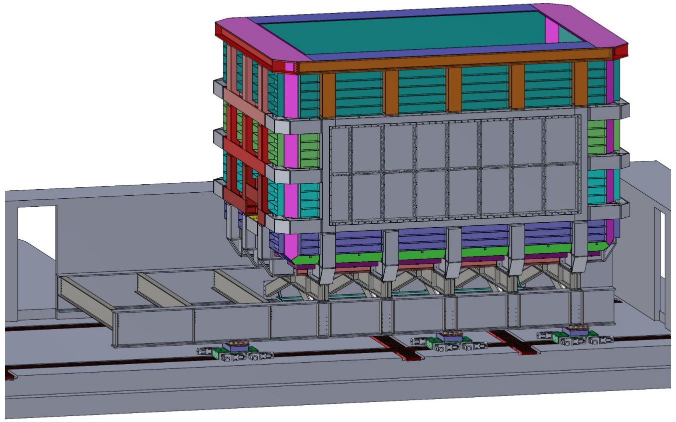
U.S. DEPARTMENT OF ENERGY | Office of Science
BERKELEY LAB

# Cryostat Assembly Sequence Overview

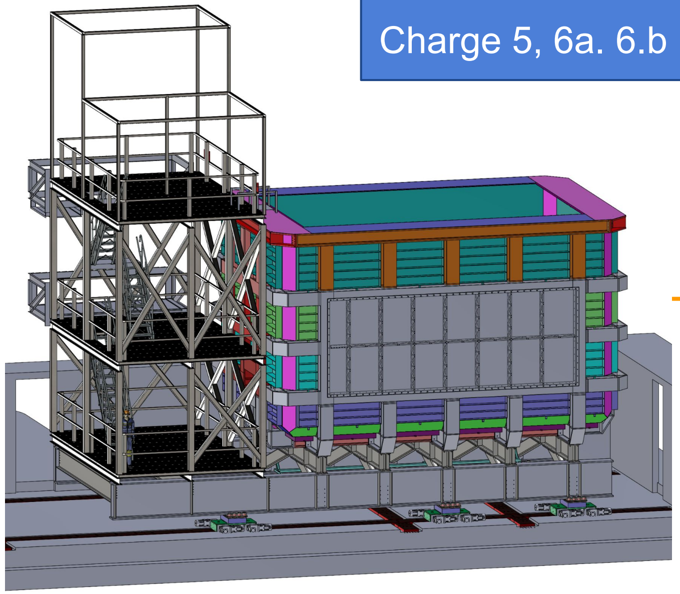
Charge 5, 6a. 6.b



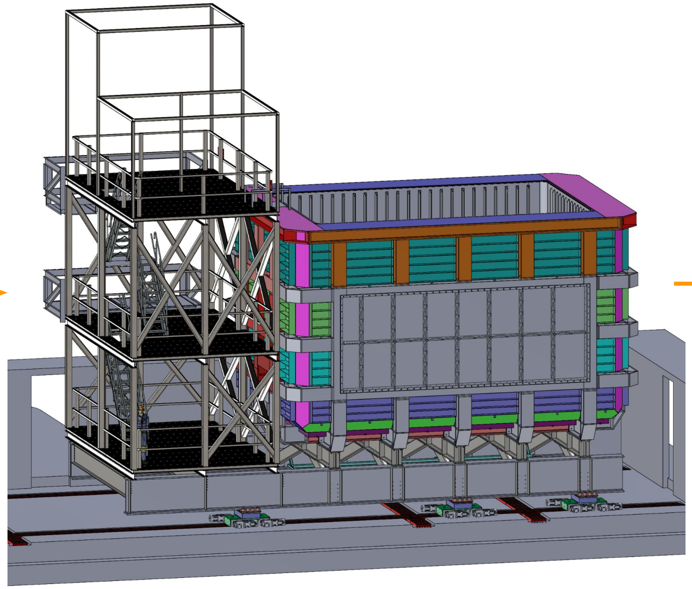
*PRISM Frame and Cryogenics Mezzanine Subframe Installed on PRISM Rollers*



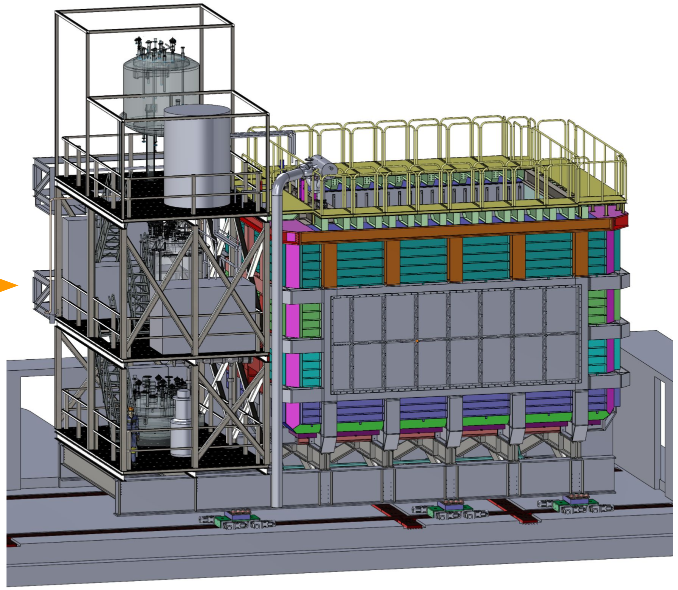
*Warm Structure Installed*



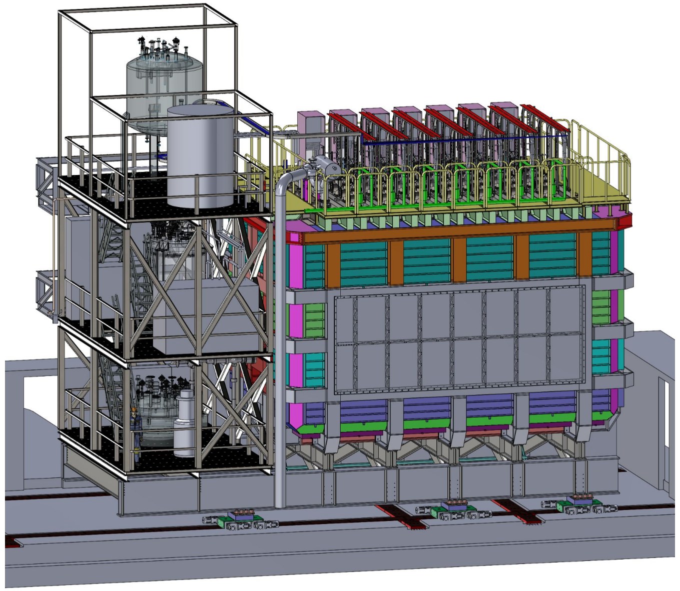
*Cryogenics Mezzanine Installed*



*Cold Membrane Installed by GTT-licensed Subcontractor*

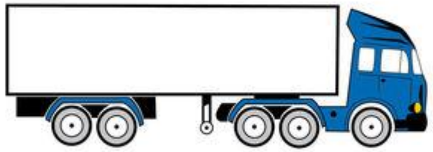


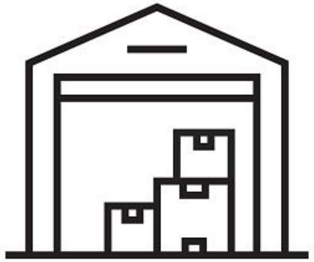
*TPC Mezzanine Perimeter Installed*



*Internal Piping and Lid Sections Installed*

# Parts are first delivered to storage at Fermilab, then moved to the ND service building and lowered into the cavern just in time for assembly



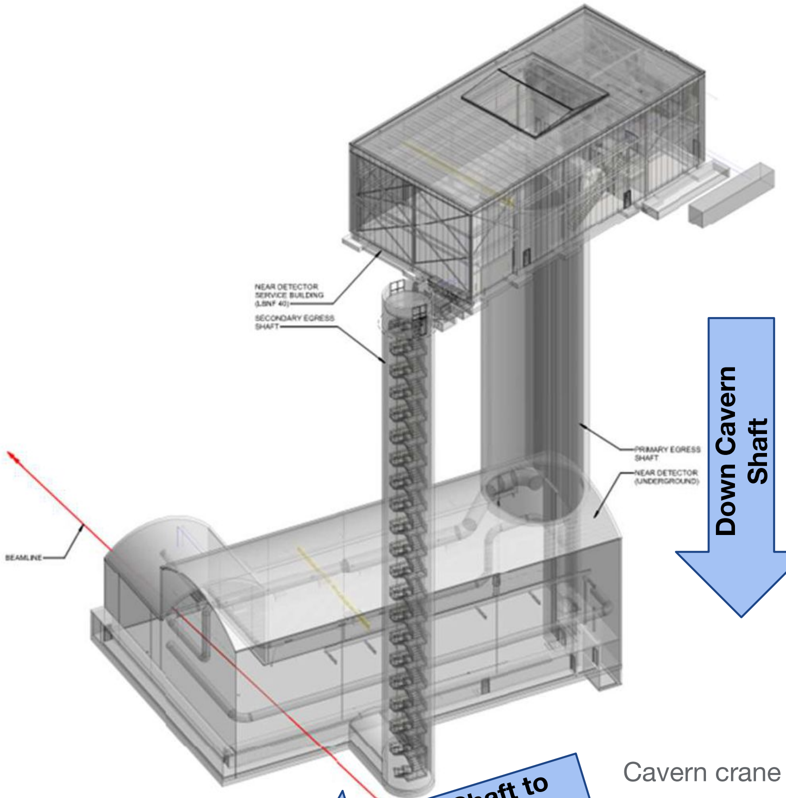


Forklift (crane for oversize or overweight parts)

Receiving to Warehouse

Forklift (crane for oversize or overweight parts)

Warehouse to Service Building




Down Cavern Shaft

Surface crane
15 US tons
[13.6 metric tons]

Cavern Shaft to Build Area

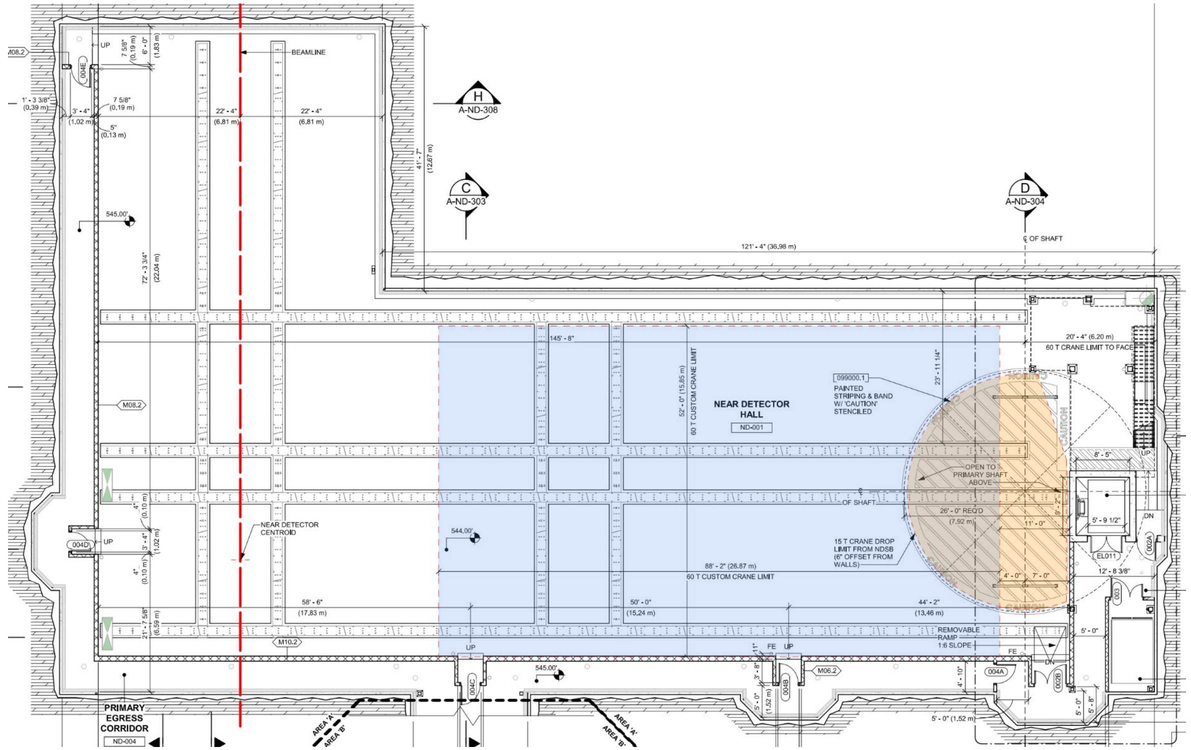
Cavern crane
60 US tons
[54.4 metric tons]

## Notes

- Maximum part size set by US flatbed trailer sizes
- Deliveries expected up to 1 year in advance
- Structural steel parts to be stored under tents or tarps (weather protected but not temperature controlled), then pressure washed before installation
- Cold membrane parts, instrumentation, and other sensitive components to be stored in warehouses

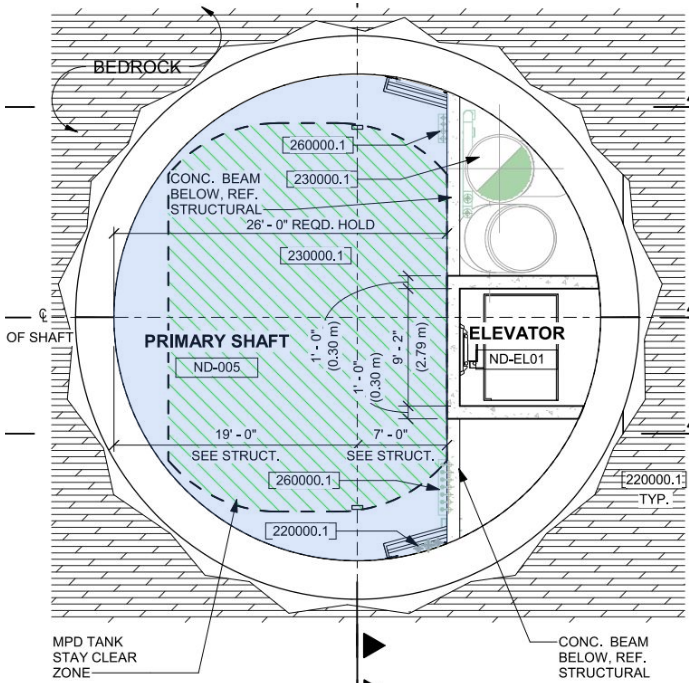
# Cryostat parts are designed with logistical size and weight limits in mind

| | *Imperial* | *Metric* | *Notes* |
|---|---|---|---|
| US Flatbed Trailer (Standard) | 48 x 8.5 x 8.5 ft | 14.6 x 2.59 x 2.59 m | Wall subassemblies can be stacked up to weight limit (see next slide) |
| US Flatbed Trailer (Double-Drop) | 29 x 8.5 x 12 ft | 8.8 x 2.59 x 3.66 m | Muon window (8.3 x 3.5 m) shipped diagonally (see next slide) |
| Service Building Door | 17 x 17 ft | 5.18 x 5.18 m | Exceeds flatbed truck size, no clearance issues |
| Cavern Shaft | 38 x 26 ft | 11.58 x 7.92 m | All parts clear but orientation of long parts must be controlled |
| Surface Crane | 15 US tons | 13.6 metric tons | Muon window is heaviest component at 13 US tons, still 2 below limit |
| Cavern Crane Capacity | 60 US tons | 54.4 metric tons | No issues lifting parts but finished assemblies can only move with PRISM |
| Cavern Crane Coverage | see diagram | see diagram | Cryostat and TMS trade off crane usage during installation |



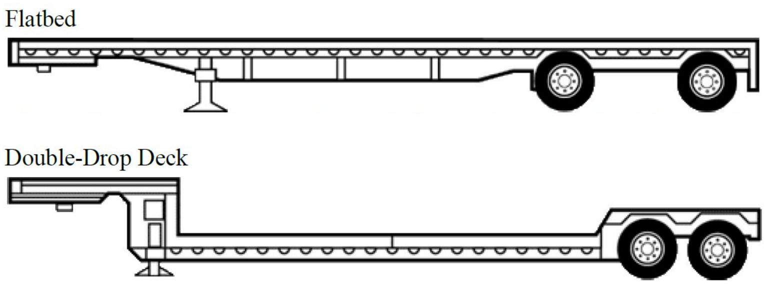

*Cavern crane covers ~60% of cavern length (blue). Surface crane drop zone limited by component clearance (orange).*

*Cavern shaft usable area ∅38 ft [11.58 m] clipped by 12 ft [3.66 m]*

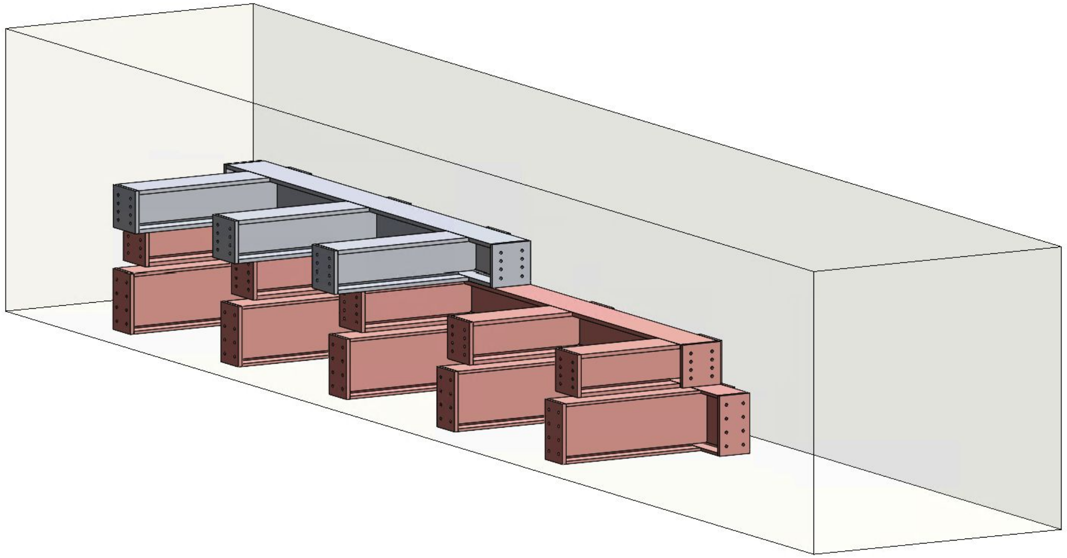


# To minimize cavern assembly work we will ship the largest subassemblies which still fit on flatbed trailers

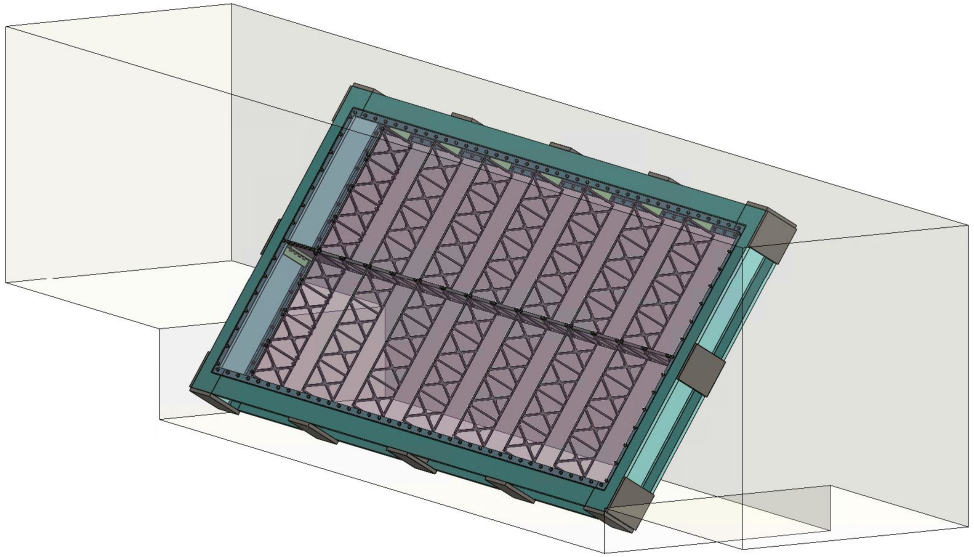
- Standard payload capacity of 22.5 to 24 US tons accommodates all parts and allows for most to be shipped in groups of 2 or more
- Muon window is the largest single component but still fits on a double drop trailer




Flatbed trailer types and sizes



*Warm structure walls fit on standard flatbed trailers and can be stacked as weight limits allow.*

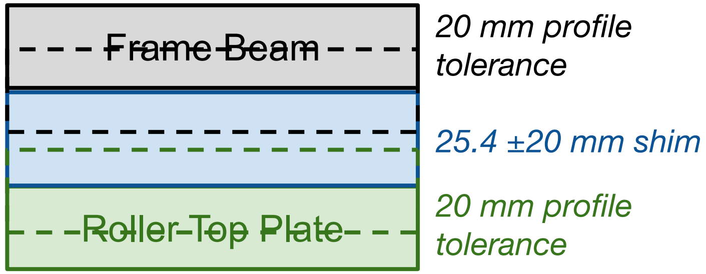


*Muon window fits diagonally on double drop trailer envelope with 16" of vertical space left for packaging. 137.5" tall window could also technically be shipped vertically or laid flat and shipped as oversize load (3' wider than 8.5' standard).*

# Detailed Cryostat Assembly Sequence

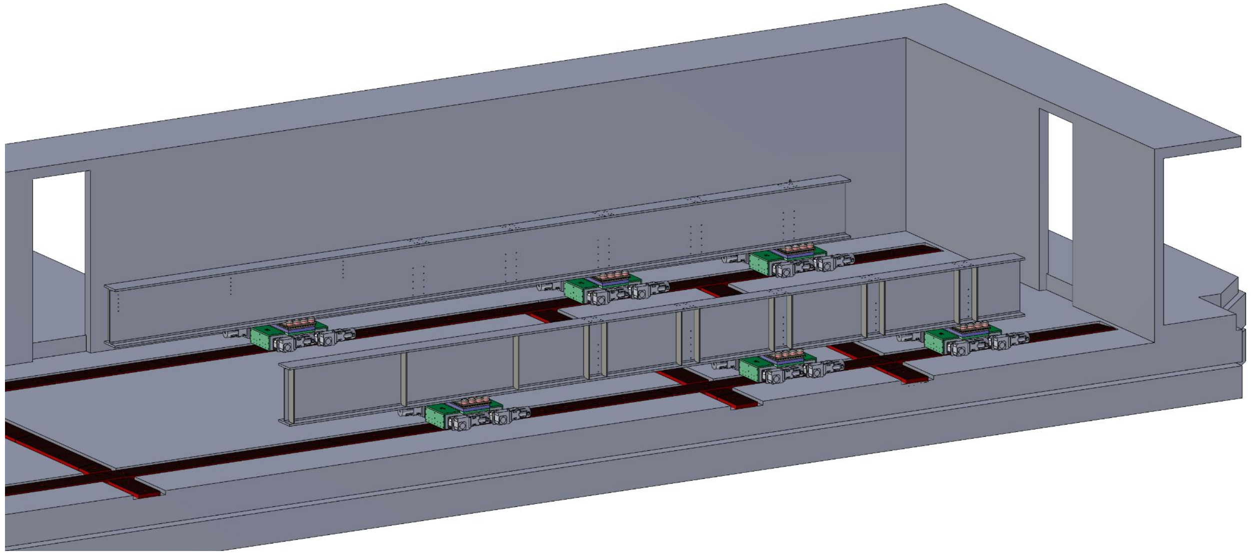
# Place PRISM Frame Long Beams on Rollers

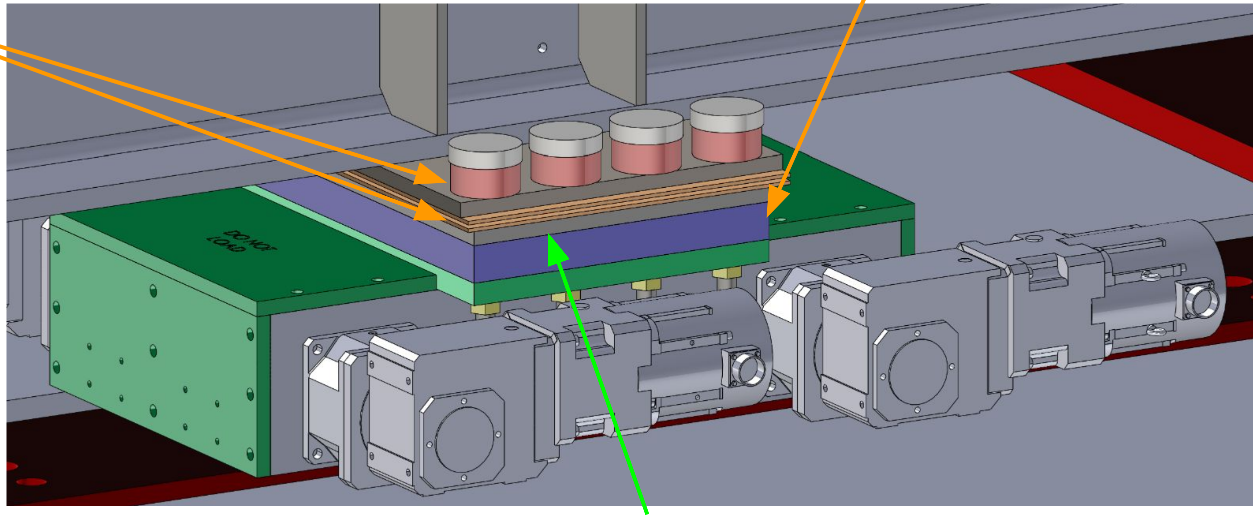
- Compare roller survey results to beam inspection reports to set shim sizes
  - 20 mm profile fabrication tolerance on bottom of beam
  - 20 mm assumed profile tolerance across tops of rollers (final value TBD)
  - ±20 mm adjustability from nominal 25.4 mm thick shim
  - Shims sized for 1 mm maximum gap at interfaces




*Fiberglass plates and sleeves isolate detector ground from facilities/roller ground*

*Compliant rubber pad accommodates rail flatness variation*





*Shim between rollers and PRISM frame*

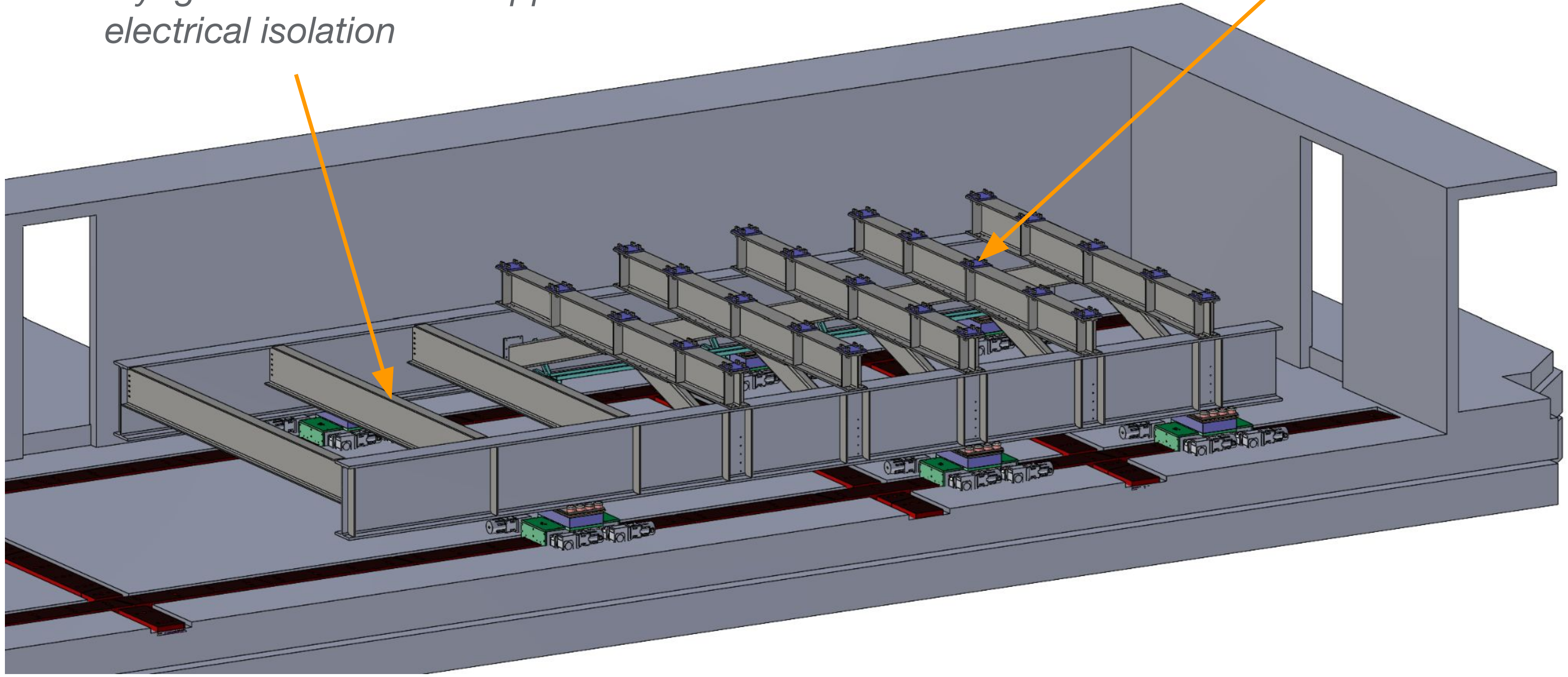
# Install PRISM Frame Rungs

Charge # 5, 6.b

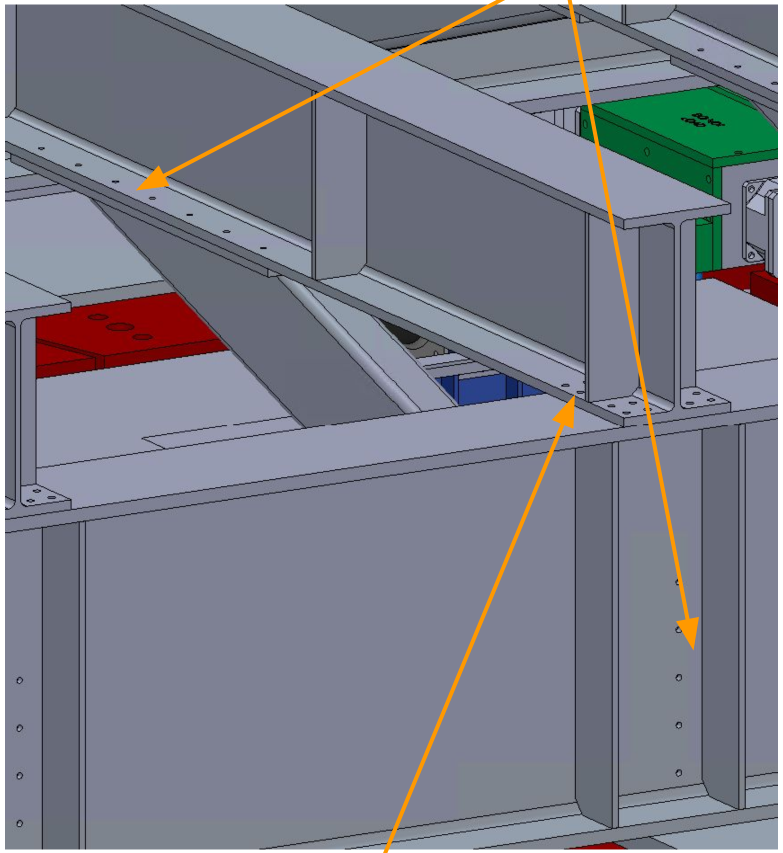
- Rungs placed on top of long beams one by one, starting from far end
- Diagonal support beams brought in by forklift and bolted in place
- Fiberglass beams used on cryogenics mezzanine side
- 15 mm profile assembled tolerance on tops of rungs
- Shims at interface locations correct flatness to 1 mm

*Fiberglass beams under cryogenics mezzanine support electrical isolation*

*Shims account for flatness variation*



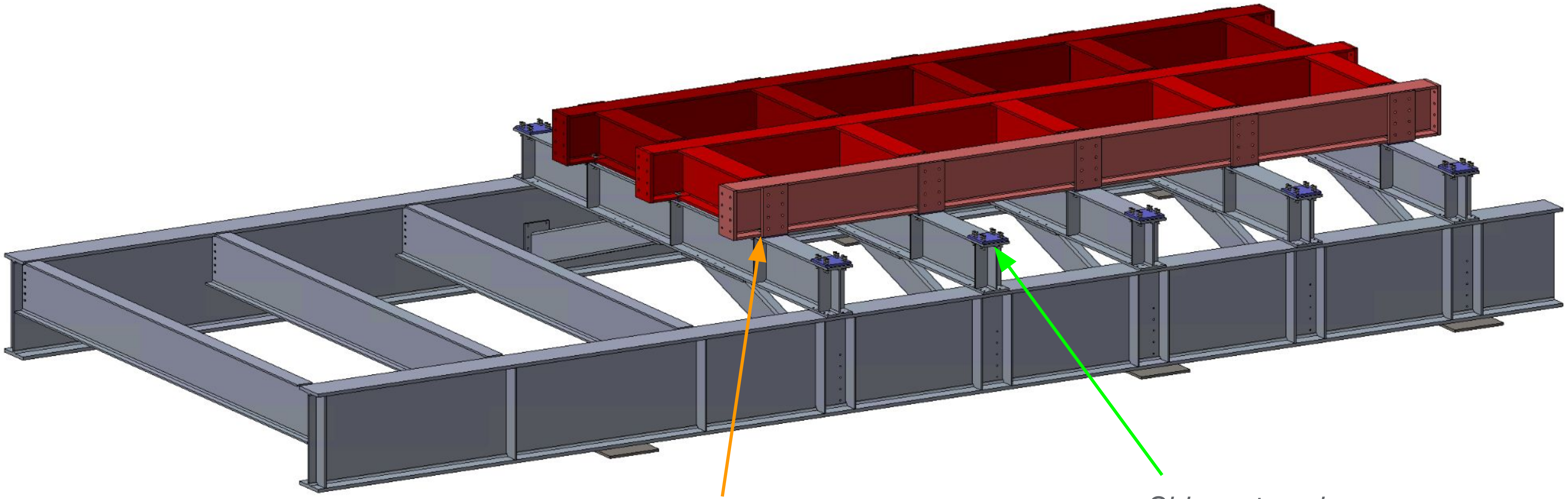
*Support beams have bolted joints on perpendicular surfaces to prevent overconstraint*



*Rungs rest on tops of long beams before being bolted in place*

# Install the Bottom Frame on top of the PRISM Frame (PRISM rollers and cavern graphics hidden for clarity)

- Shims used between PRISM frame and bottom panel to support leveling (details next slide)
- No shims within warm structure or PRISM frame assemblies



Charge # 5, 6.b

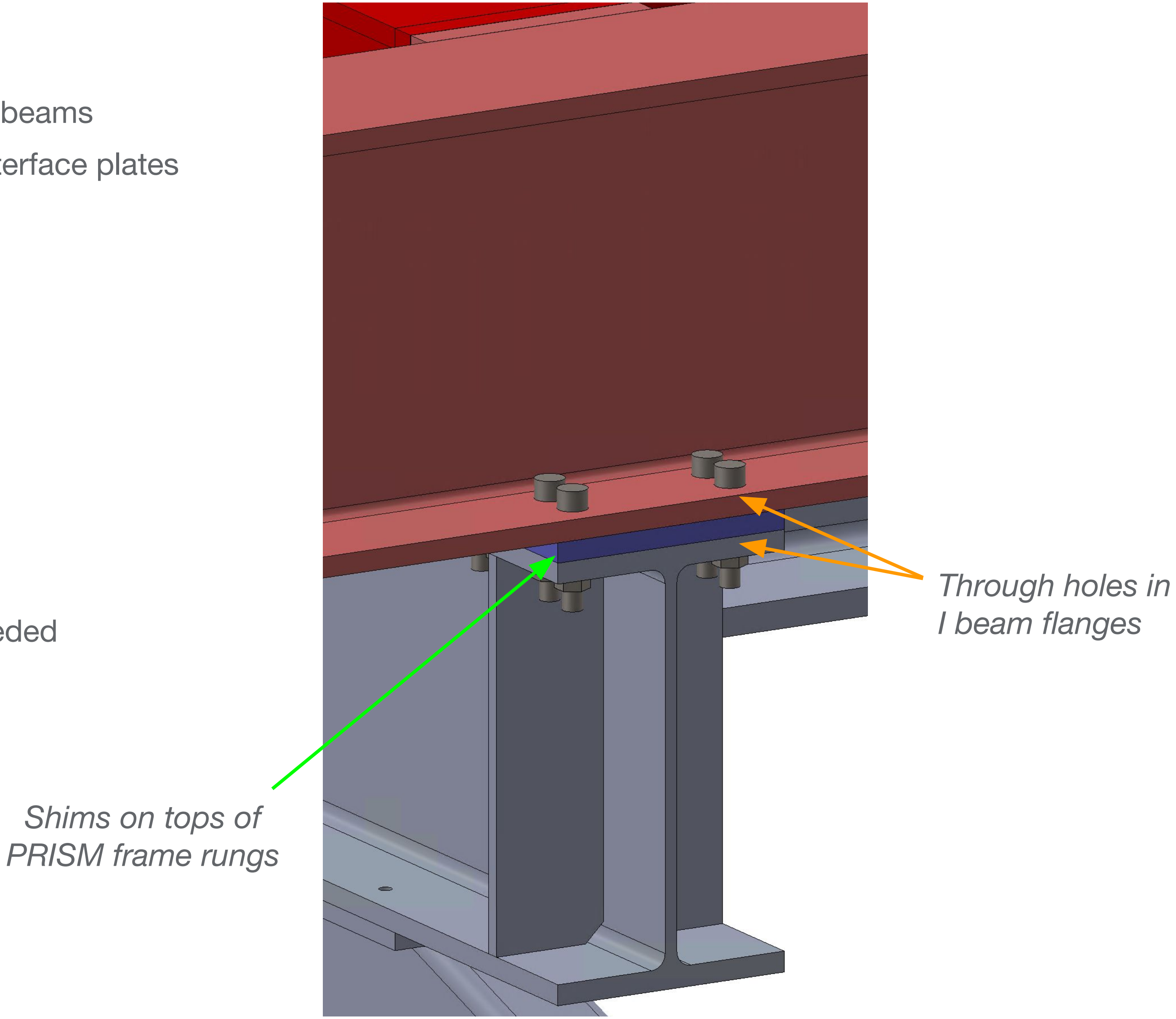
# Bottom Frame Shim Process

**At Factory**

1. 15 mm profile fabrication tolerance across bottom panel I beams
2. 15 mm profile assembly tolerance across PRISM frame interface plates
3. ±15 mm adjustability from nominal 19.05 mm thick shim
4. Shims sized for 1 mm maximum gap at interfaces

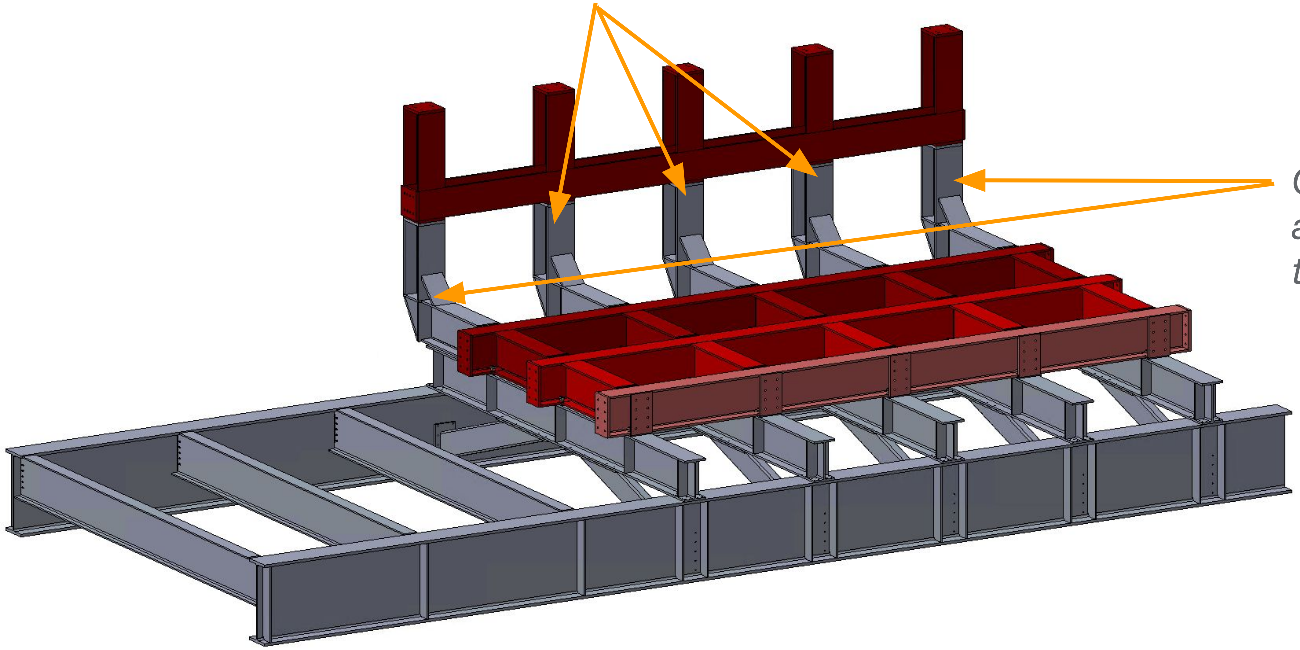
**In Cavern**

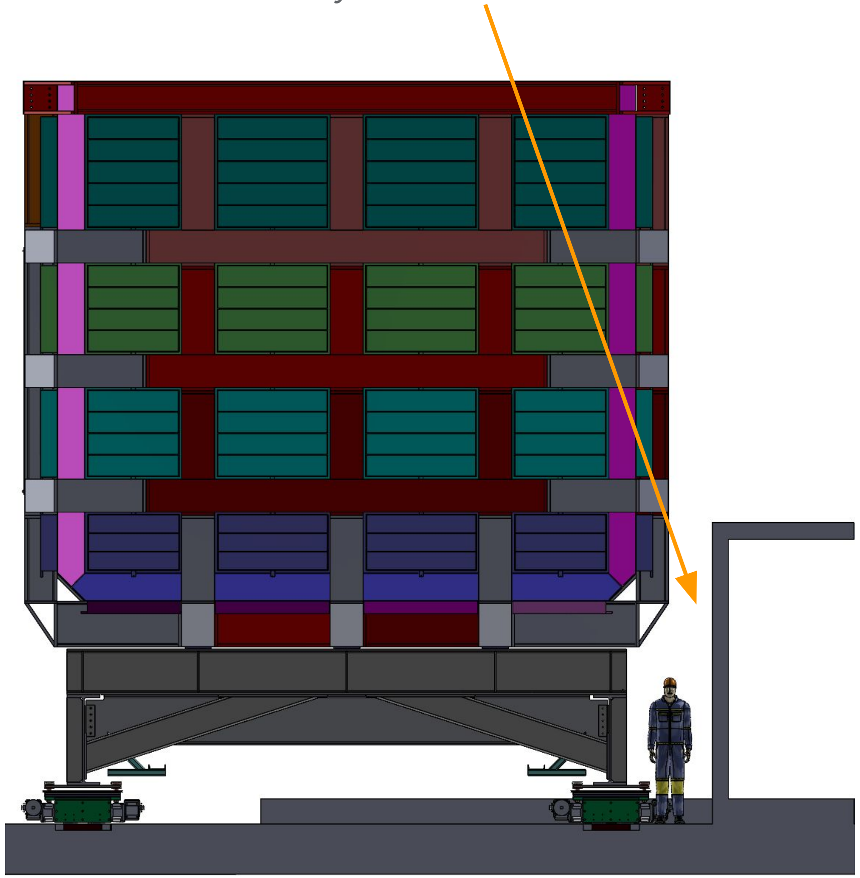
5. Place mating assemblies in contact
6. Hand tighten bolted joints
7. Measure gaps at interfaces
    a. Maximum 1 mm allowable
    b. If gap exceeds 1 mm, modify or replace shim as needed
8. Torque bolts to specification



# Install the Bottom-Upstream Assembly

1. Place all bottom corner assemblies with bolts hand tight
2. Torque bolts on outer corner assemblies to establish datum for upstream wall segment
3. Install upstream wall segment, resting on outer corner assemblies
4. Torque remaining bolts on all corner assemblies to spec



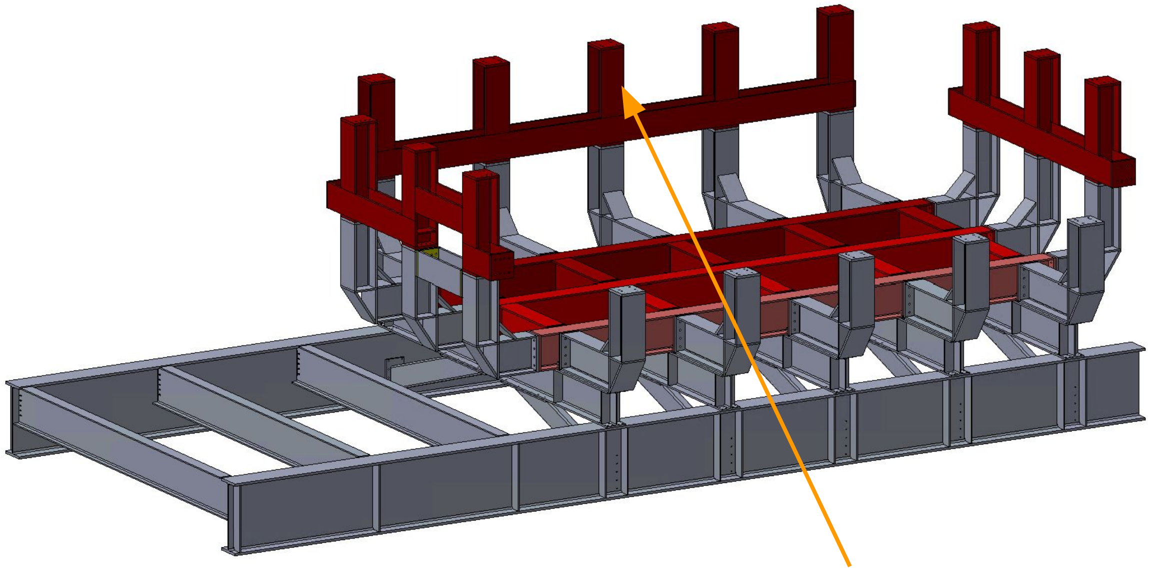




*Due to the tight clearance between the upstream side of the cryostat and the cavern wall, upstream components are installed early in the process*

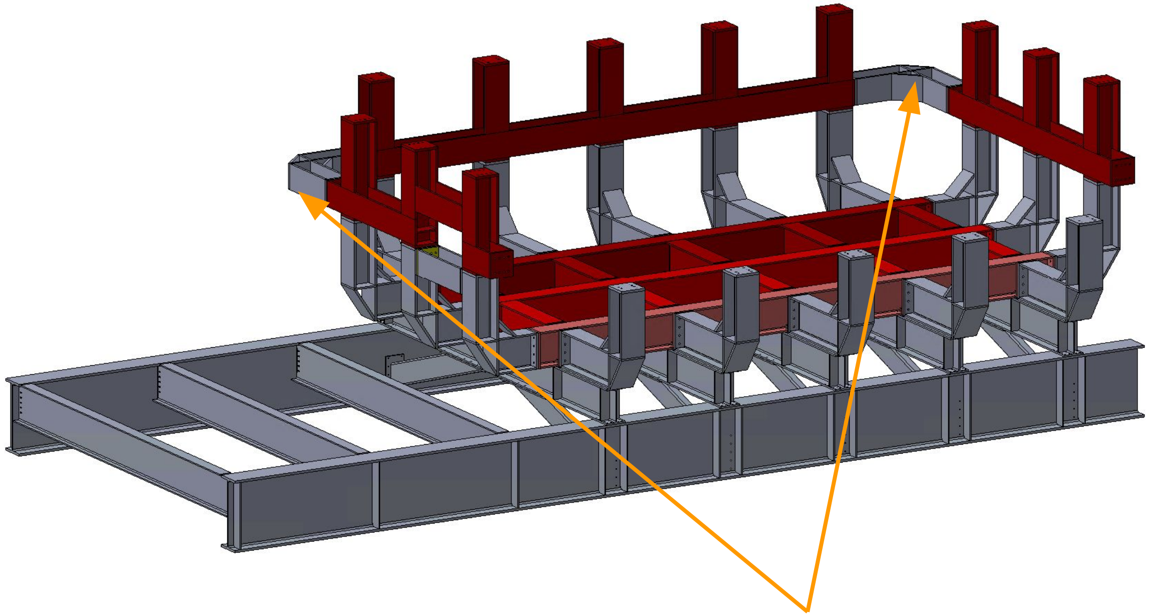
Charge # 2, 6.b

# Install Remaining Bottom Assemblies
# Install Vertical Corner Assemblies

- Remaining bottom assemblies follow same bolting procedure, with outer corners torqued first to drive placement of wall segments
- Vertical corners installed last, with generous clearance holes and orthogonal datum surfaces preventing overconstraint



*Short horizontal wall segments are self supporting during assembly*

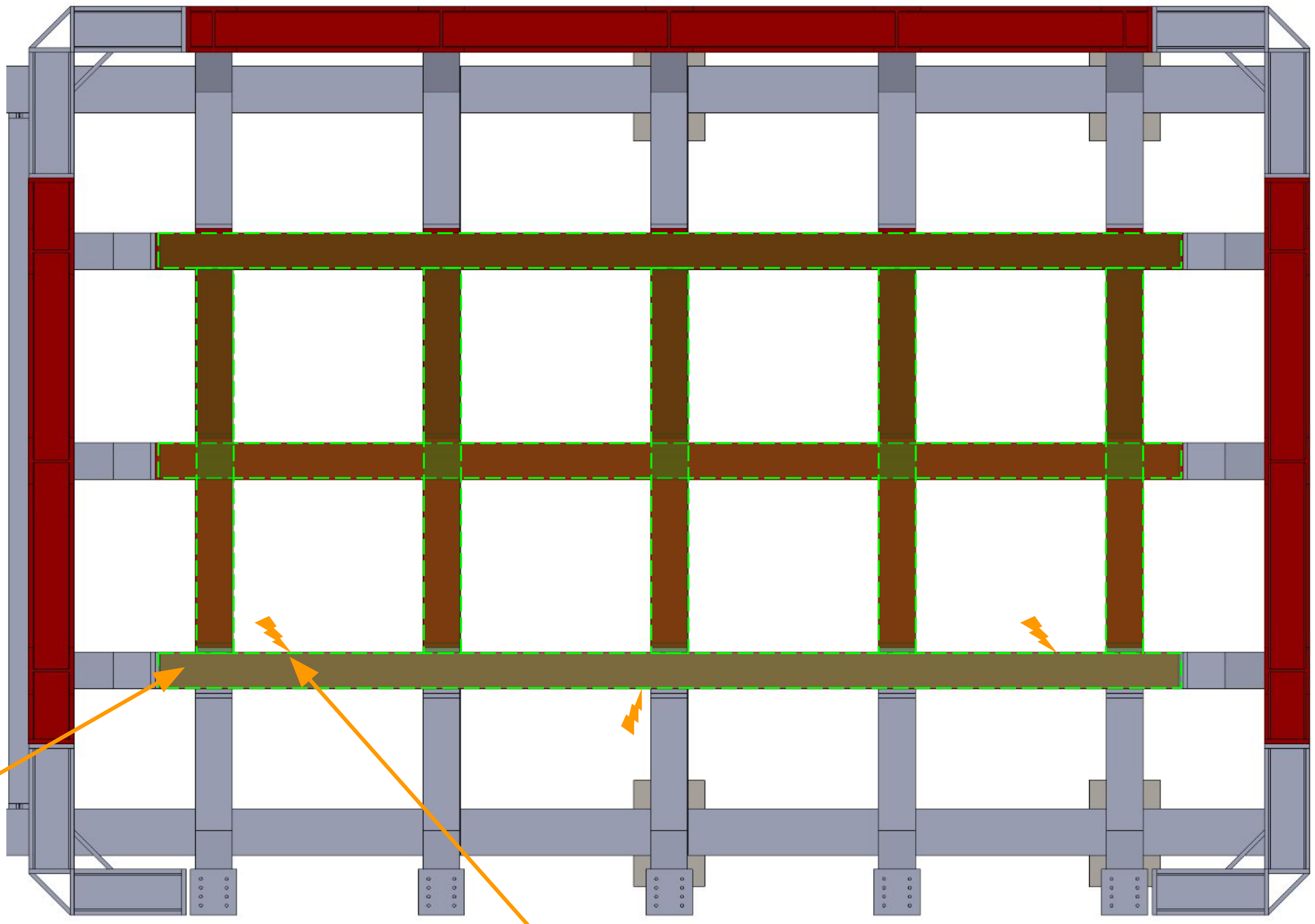


*Install vertical corner assemblies last, aligning them to wall segments*

Charge # 2, 6.b

# Place thin backer plates between I beams and skin panels to prevent welds from burning through

- ⅛” weld backer plates tack welded to I beam flanges
- Plates prevent continuous welds between ⅜” skin panels from welding to I beam flanges by mistake
- Tack welds break under significant strain differential between panels and I beams, preserving hermetic panel welds

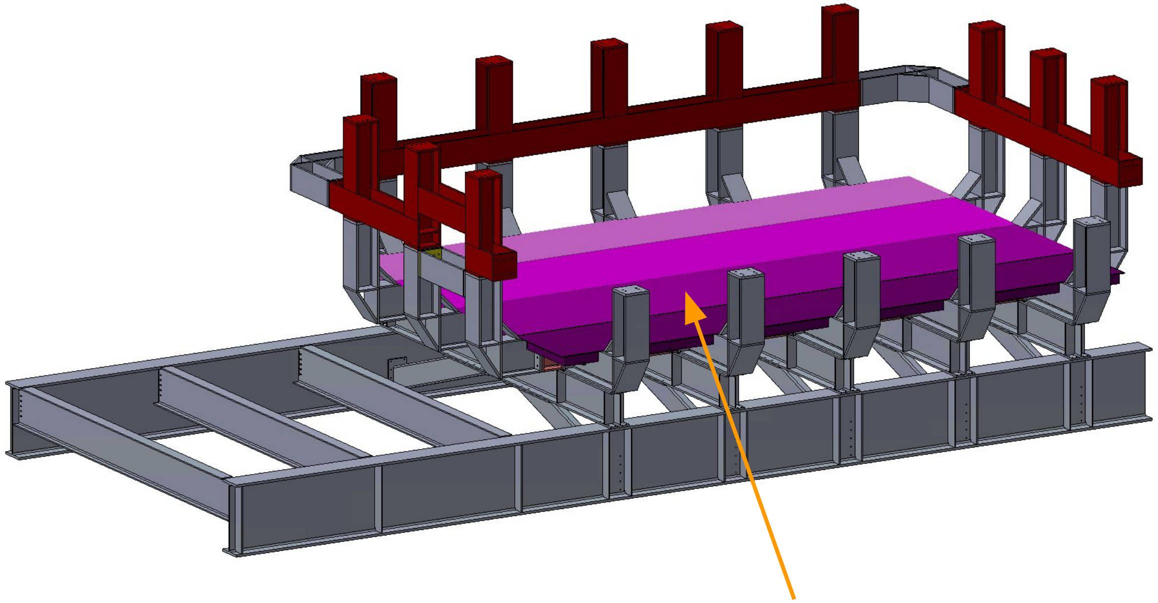


*⅛” thick backer plates placed on I beams before skin panel install*

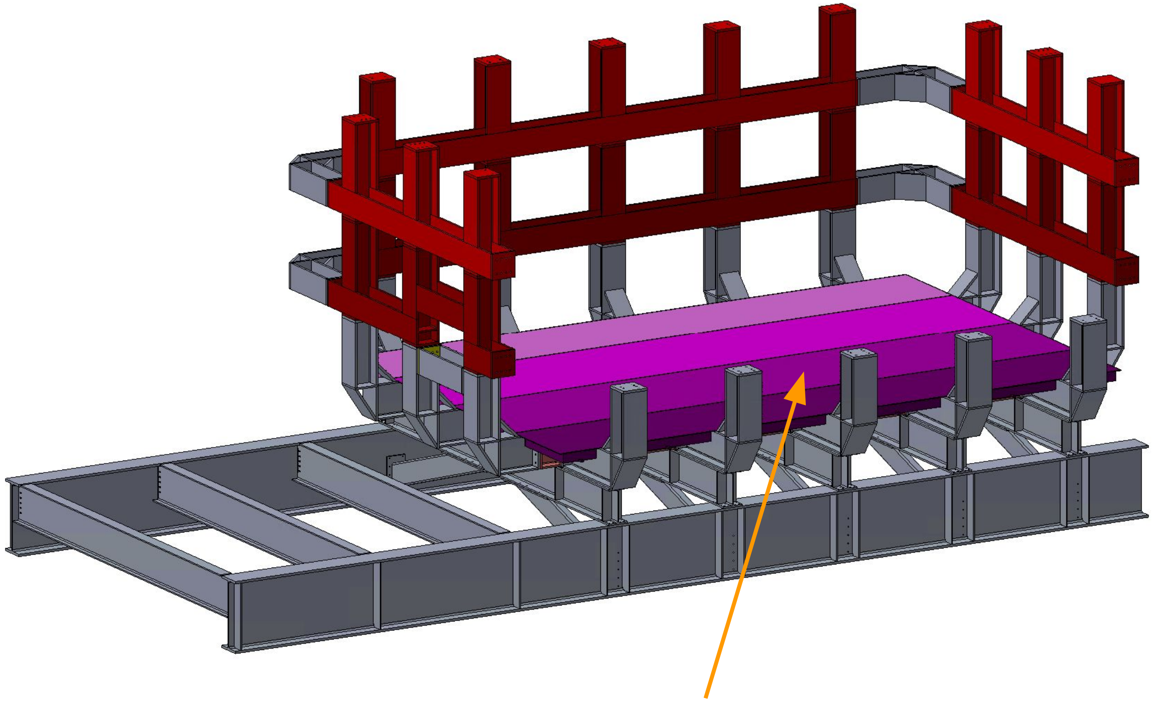
*Tack welds keep backer plates from shifting during installation*

# Install Bottom Skin Panels
# Install next layer of Wall Segments and Corner Assemblies

- Placing bottom skin panels allows for later assembly steps to be performed from inside
- Next layer of wall segments installed using same procedure as before



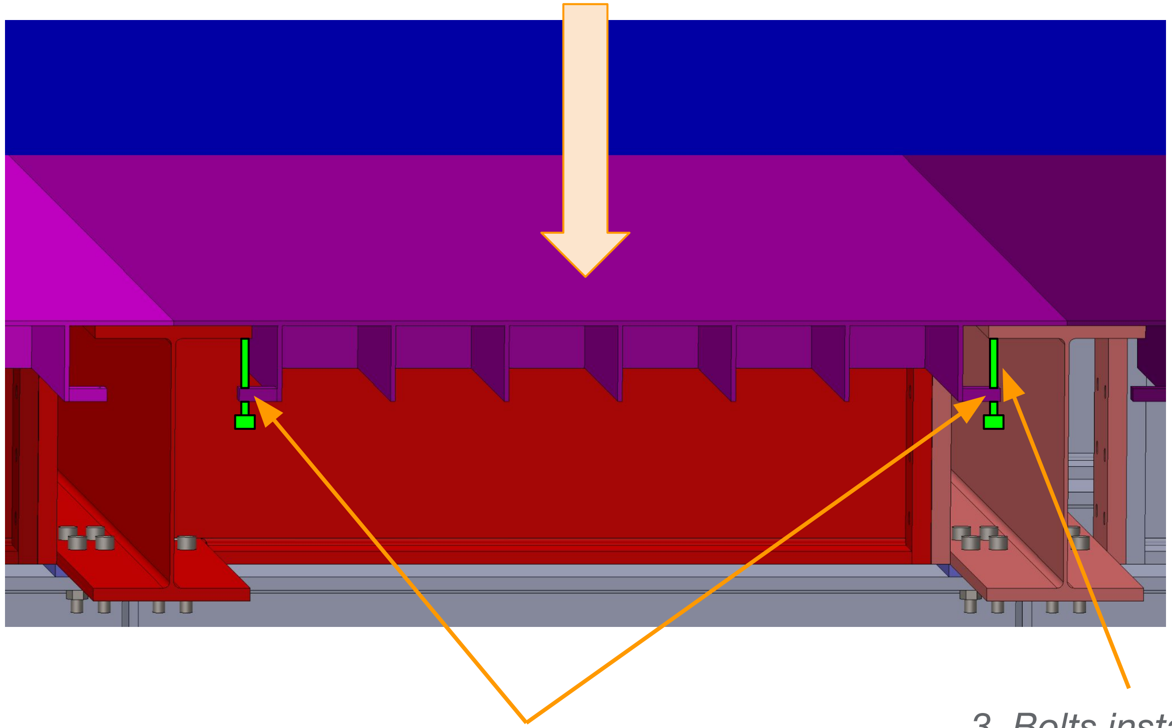
*Four skin panels placed and clamped but not yet welded to each other*



*Scissor lifts can now be driven inside to support access to elevated work areas*

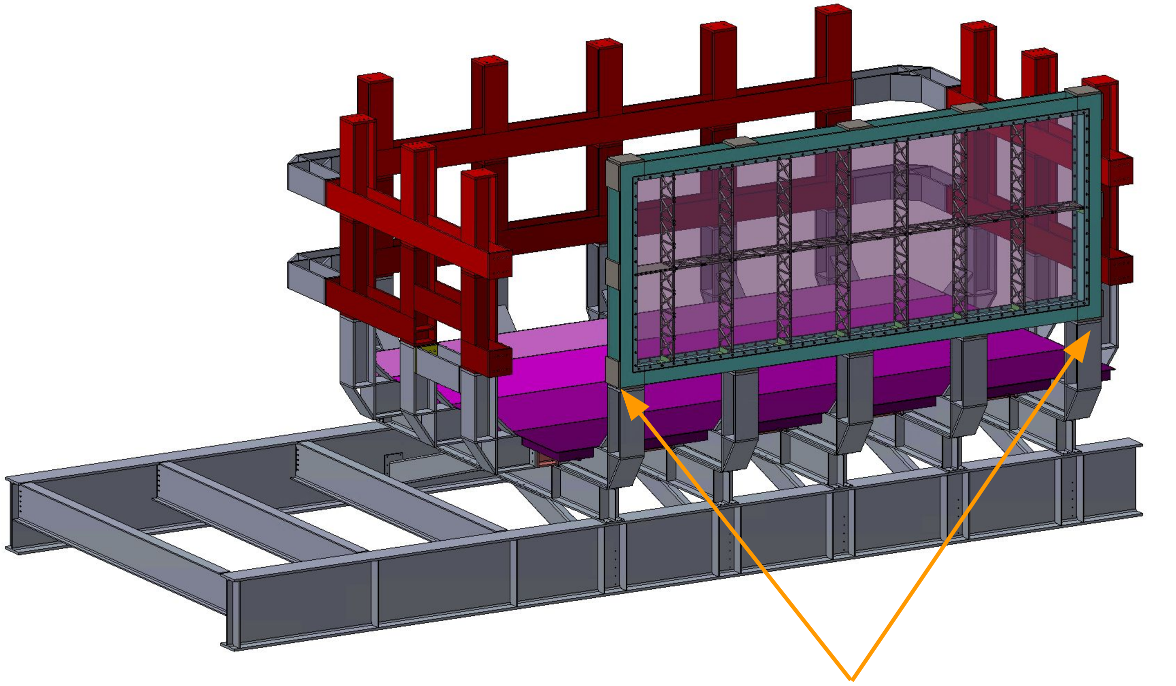
# Skin Panels are clamped to I beam flanges

- Clamps – not welds – hold skin panels in place
  - Welds are later added between panels to form vapor barrier, but no welds are performed between panels and I beams
- After panel is positioned, clamp is bolted on from outside
- Bolts thread into clamps and bear against I beam flanges, acting like set screws to pin skin panels into place

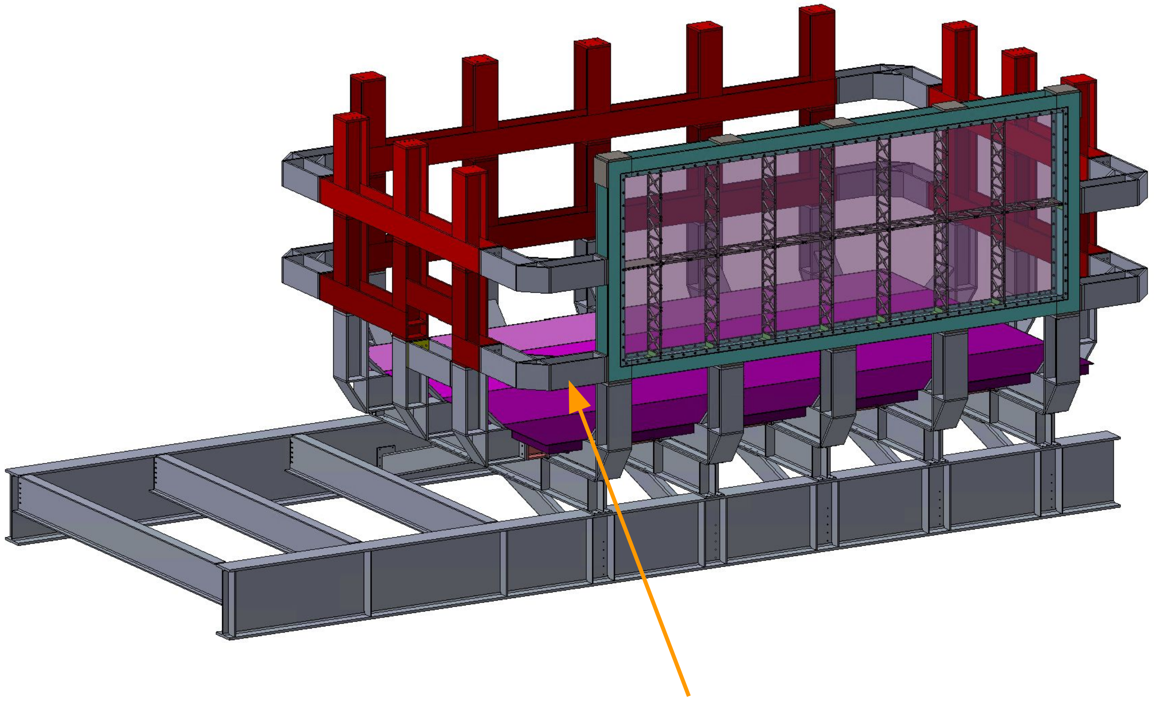


# Install Muon Window and corresponding Vertical Corner Assemblies

- Muon window bolted joints use same configuration as other wall segments



*Torque outer corner assemblies first to drive window position, then tighten others*

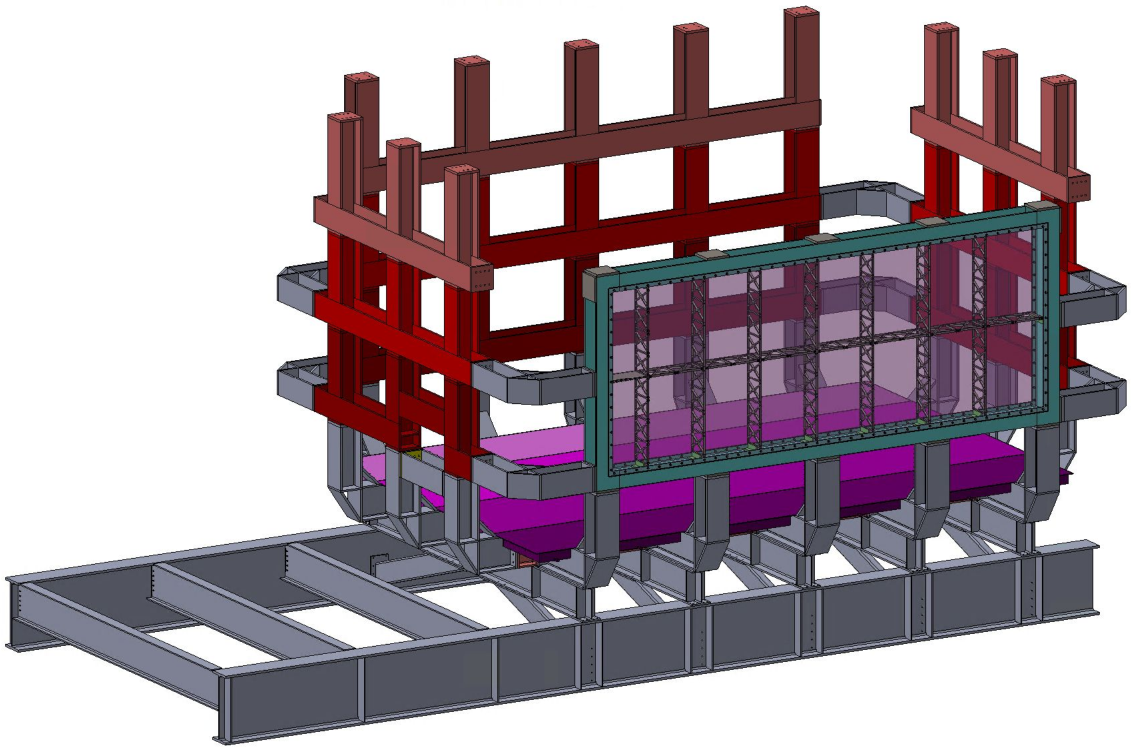


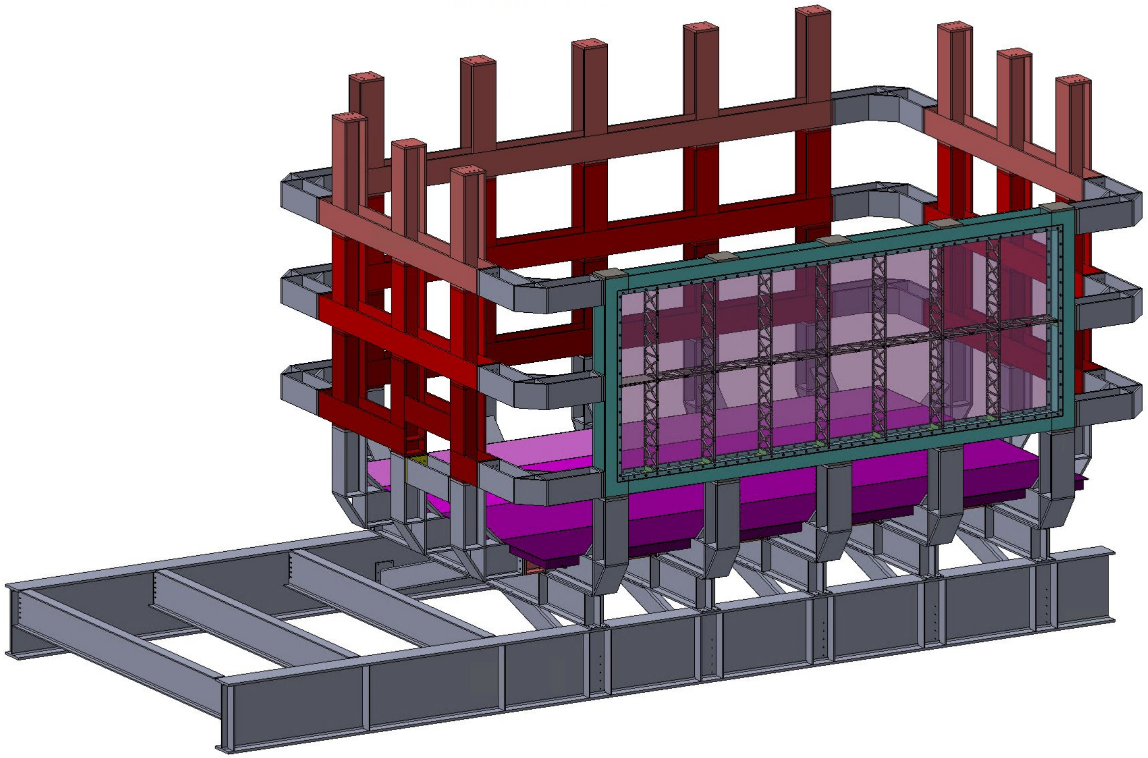
*Install 4x vertical corner assemblies last, aligning them to wall segments and window*

Charge # 2, 6.b

# Install next layer of Wall Segments and Corner Assemblies

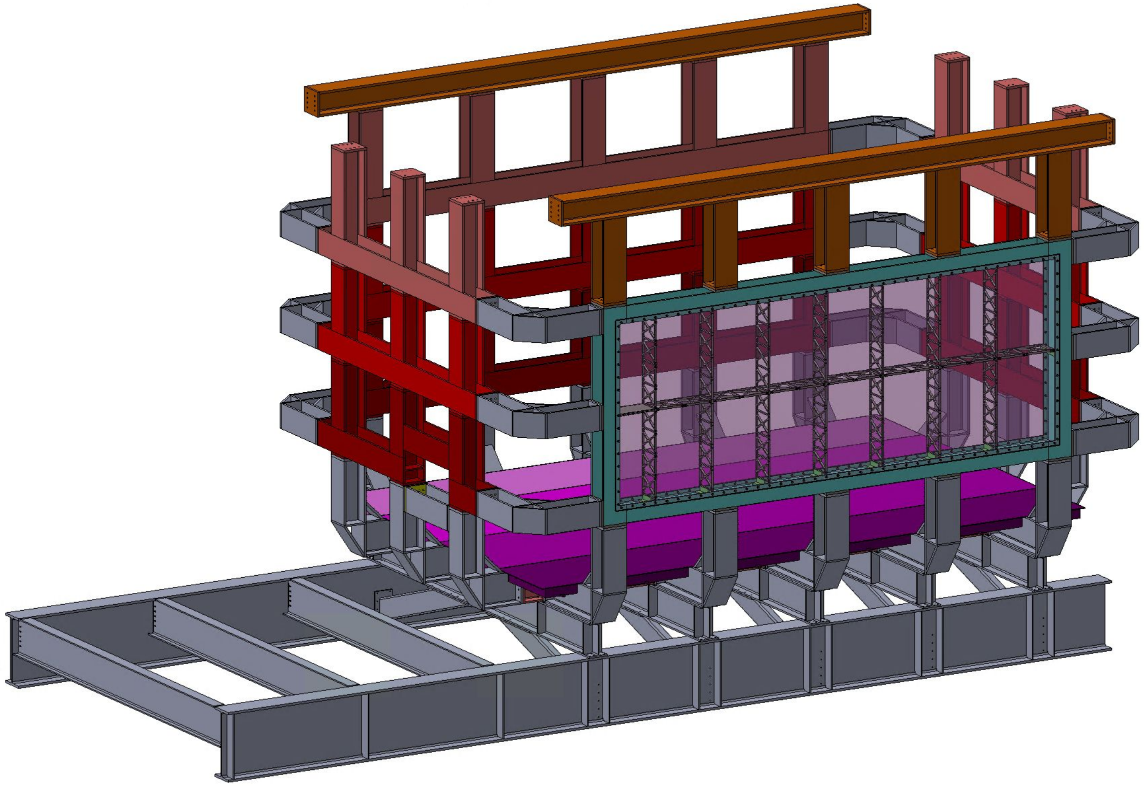
- Next layer of wall segments installed using same procedure as before

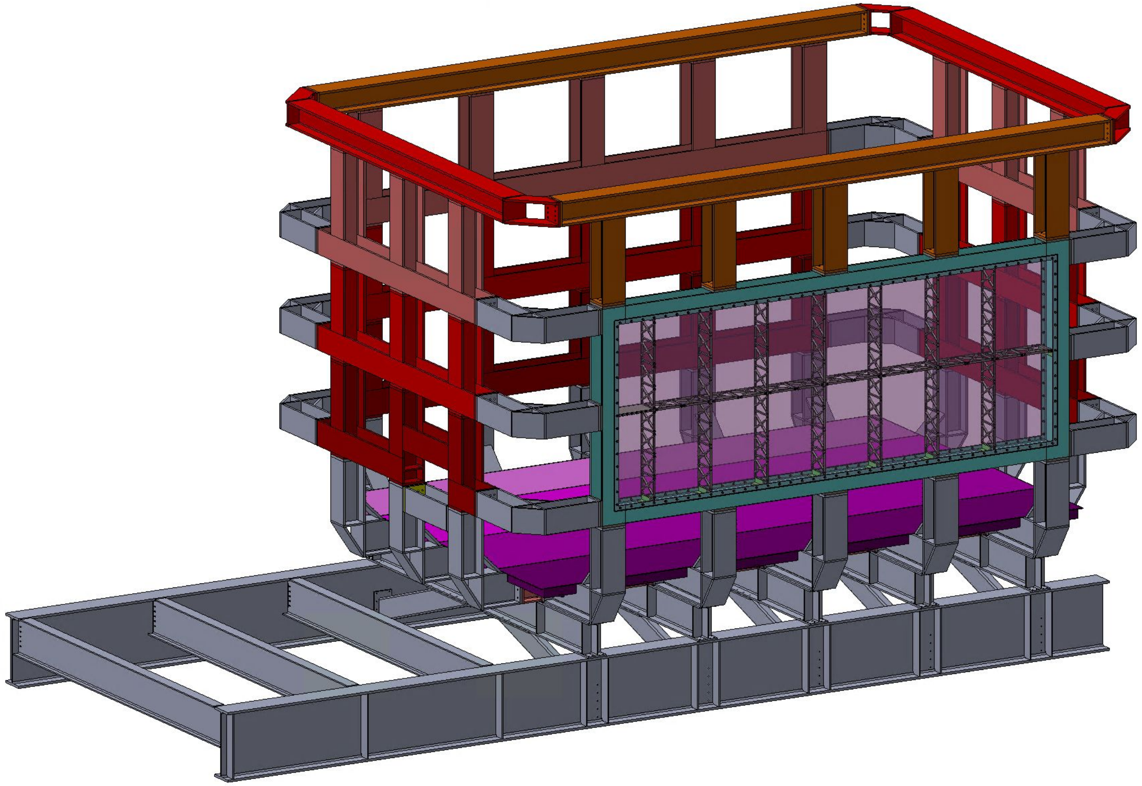




# Install Crown Assemblies

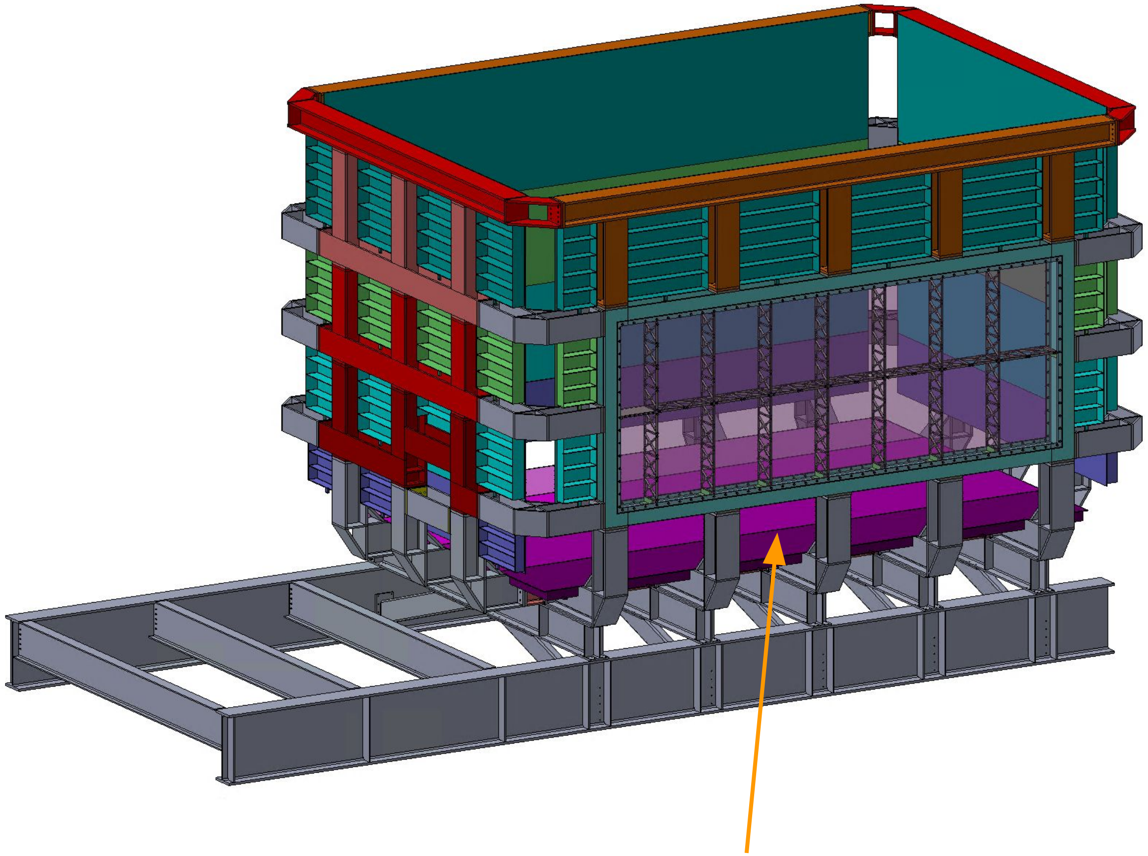
- No separate corner assemblies as crown essentially incorporates its own corners



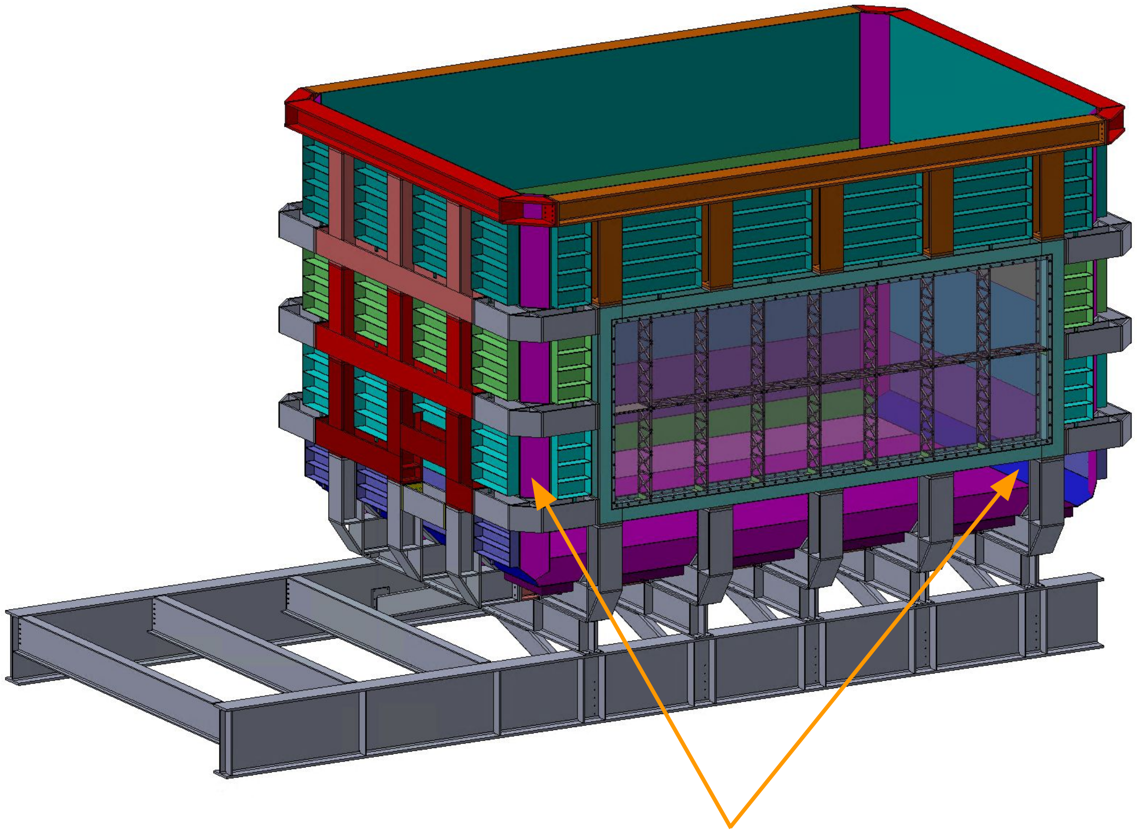


# Install Skin Panels, Corners Last

- Primary personnel access is through the gap in the frame below the Muon Window
- Secondary personnel access is over the top of the tub by cryogenics mezzanine and internal stair tower



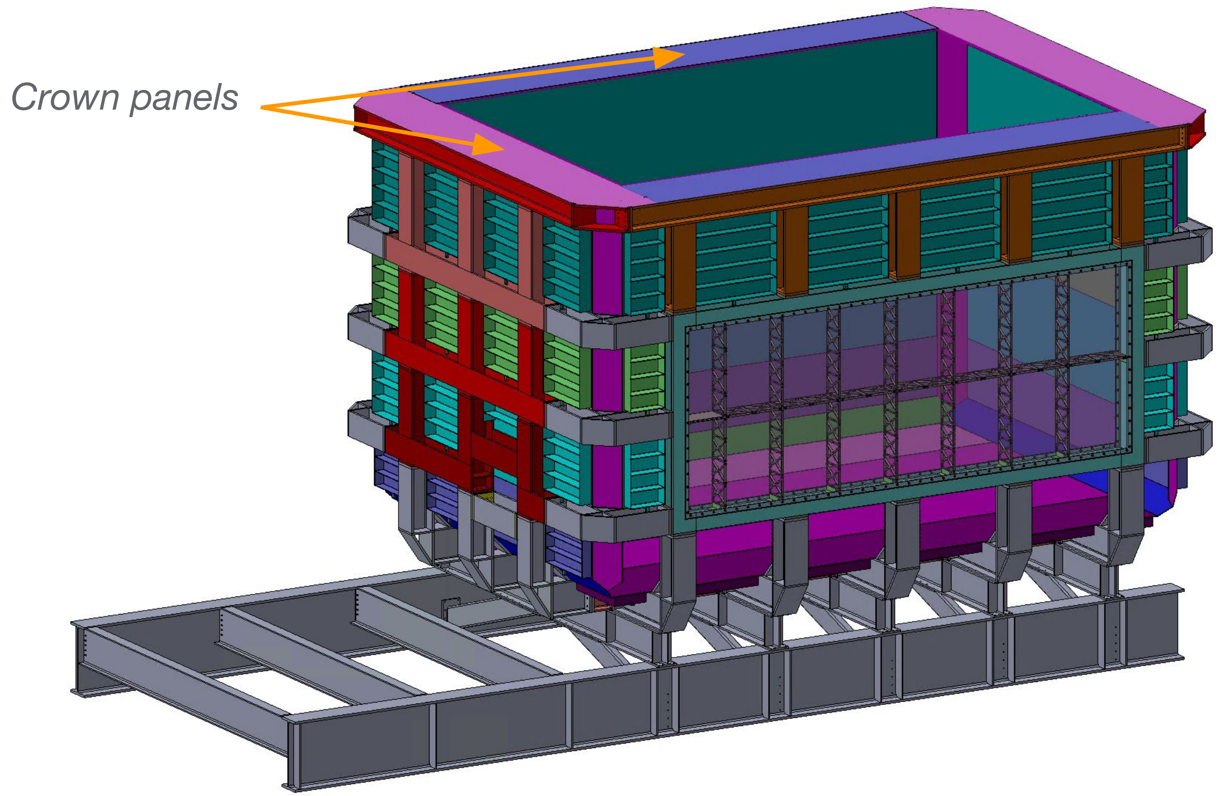
*Skin panel under muon window left off to allow for personnel access*

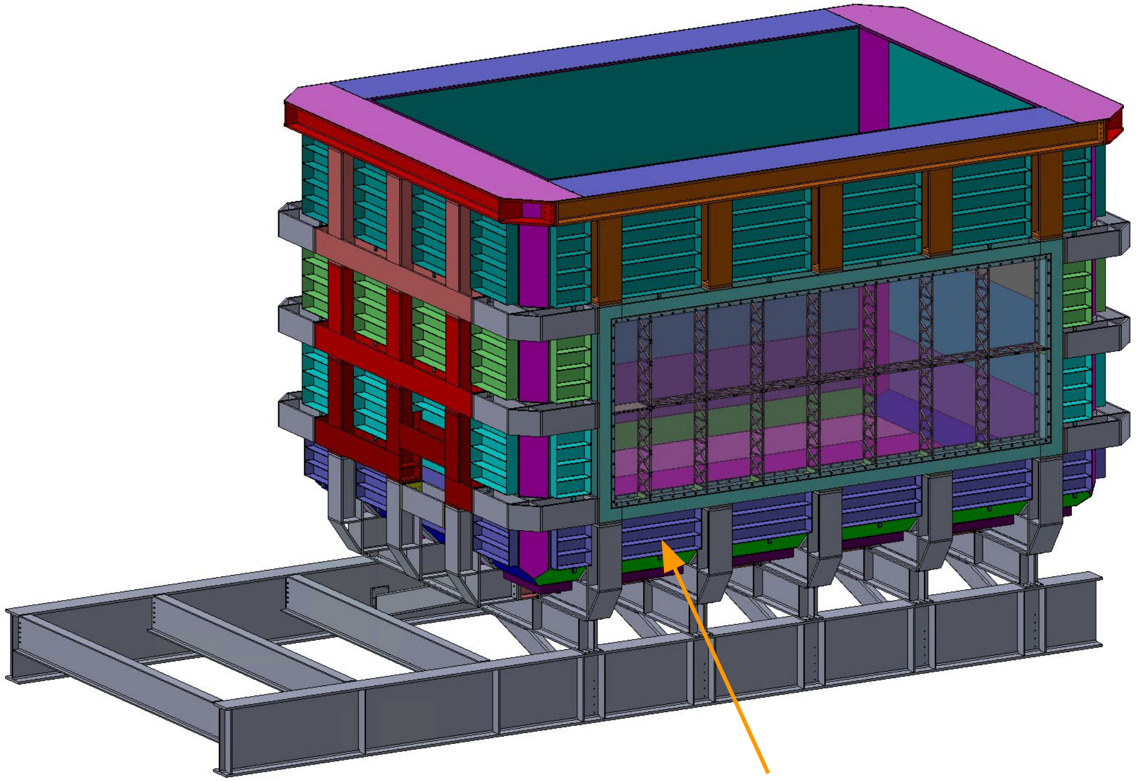


*Narrow, unstiffened corner panels installed last as they are easier to modify to fit*

# Install Crown Panels and final Skin Panels

- Crown panels provide interface surface for lid segments

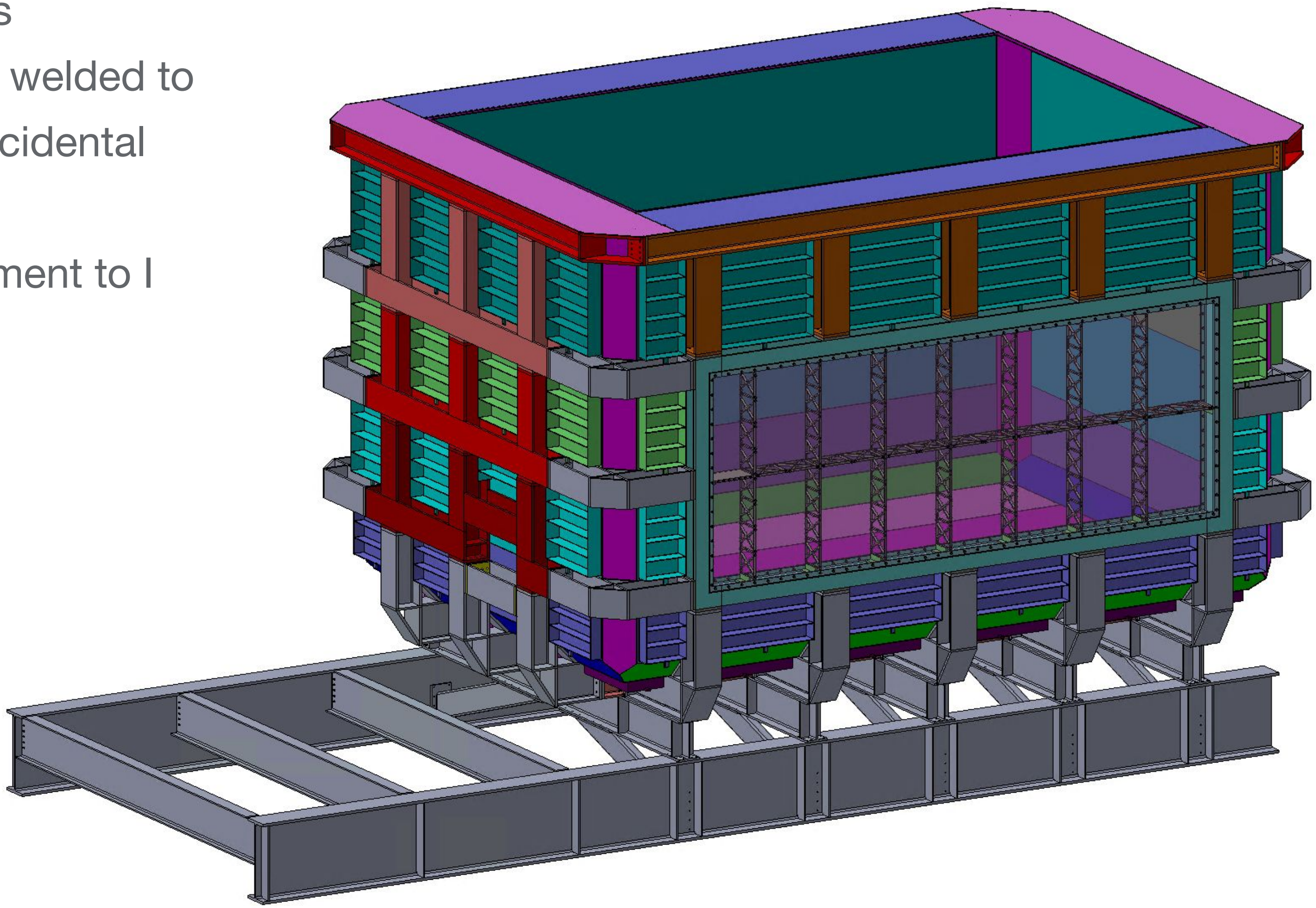


# Weld all Skin Panels to each other

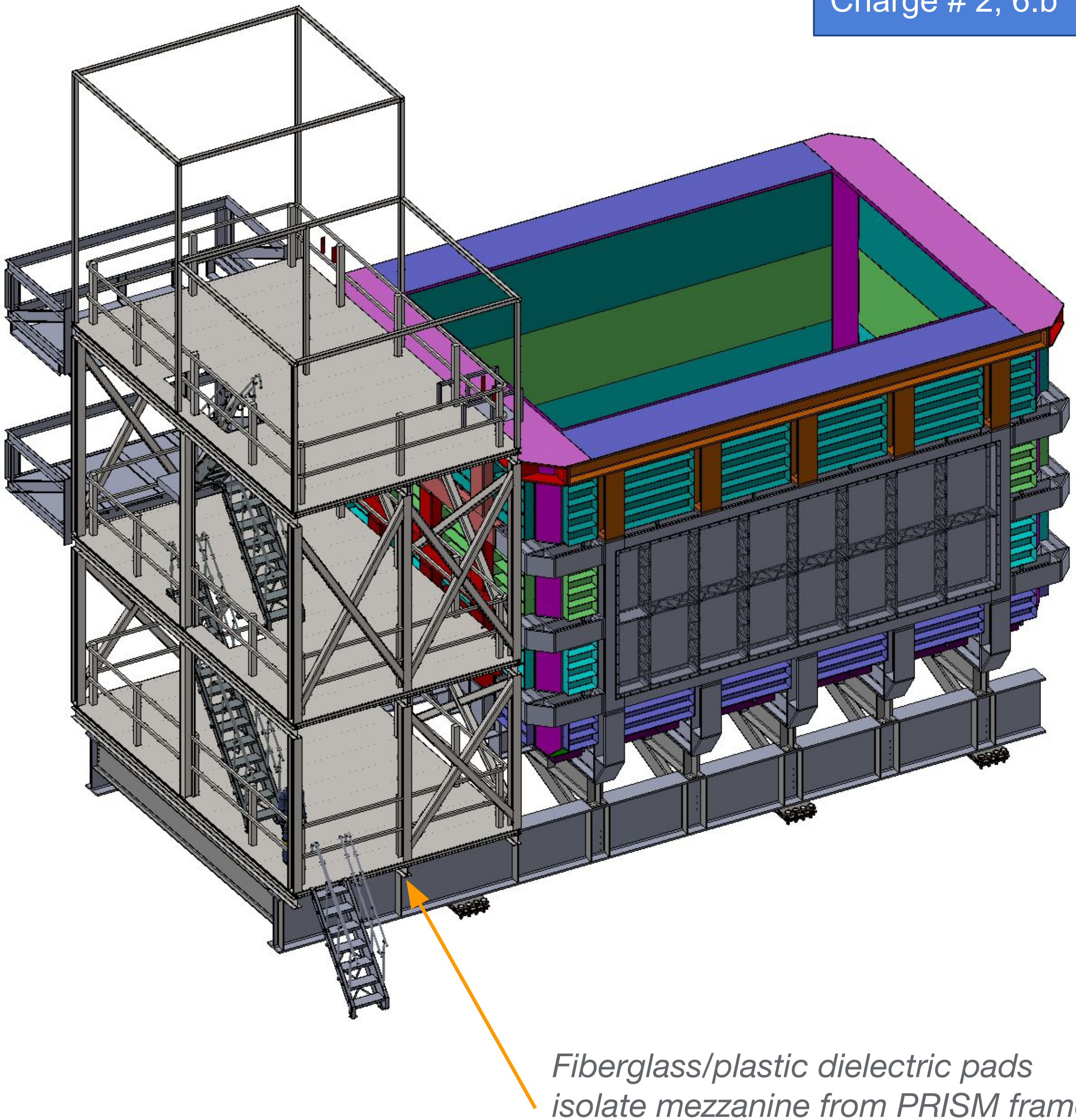
Charge # 2, 6.b

- Skin panels welded to each other to provide sealed volume for dry $N_2$ purge of cold membrane insulation
  - Skin panels not welded to I beam frames
    - 3 mm thick steel weld backers tack welded to inner I beam surfaces to prevent accidental welding of panels to I beams
  - Clamps provide only mechanical attachment to I beam frames
- 2x 100% weld inspection
  - First dye penetrant or magnetic particle
  - Then bubble test under vacuum



# Install Cryogenics Mezzanine

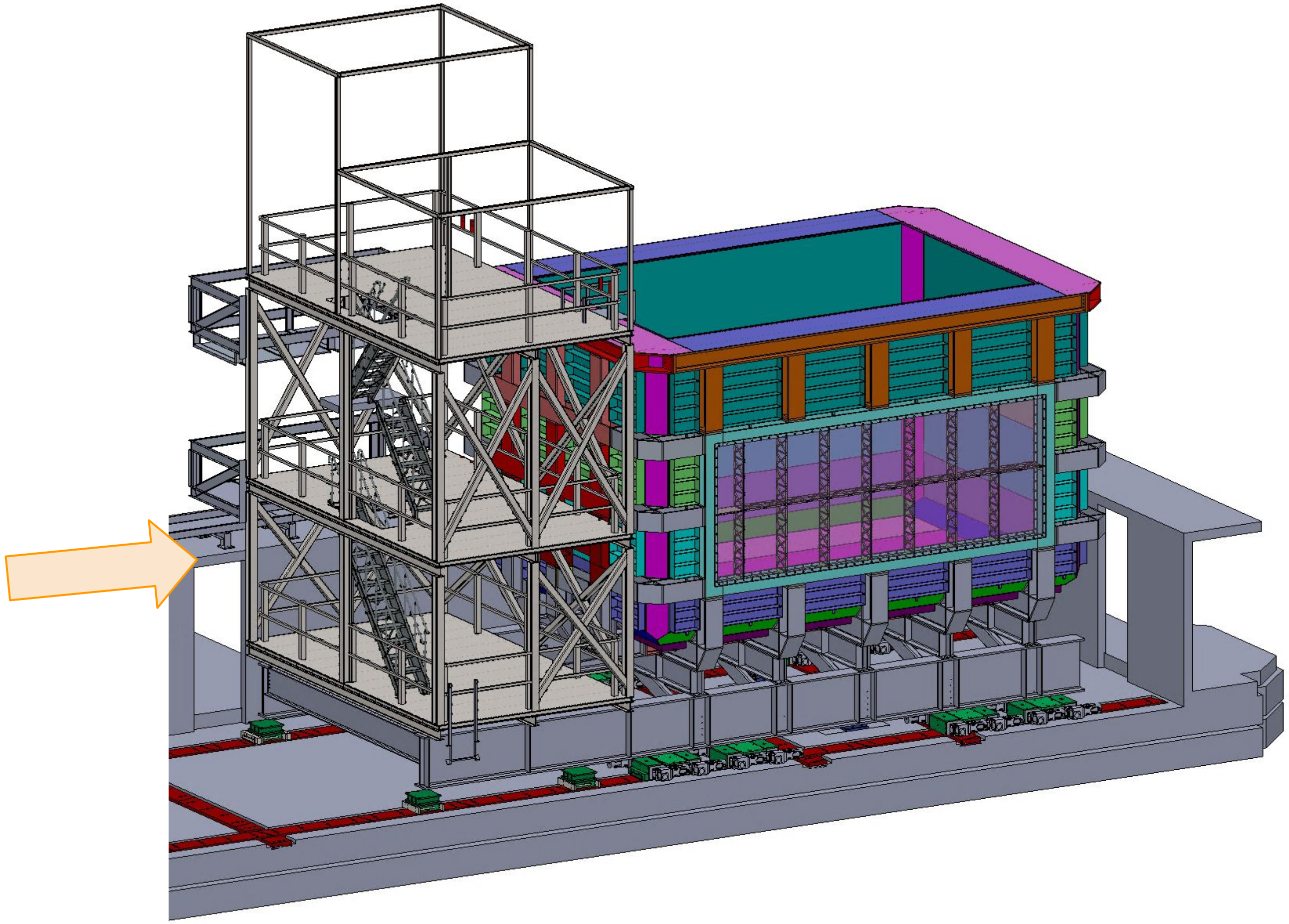
- Mezzanine serves as stair tower to access top of cryostat for later steps
- Entire mezzanine is at facilities ground, isolated from detector ground by fiberglass beams and dielectric pads
- Potential optimization: installing mezzanine earlier may enable cryogenics and electrical contractors to start populating mezzanine with components sooner. This option is being evaluated with the I&I and cryogenics teams.

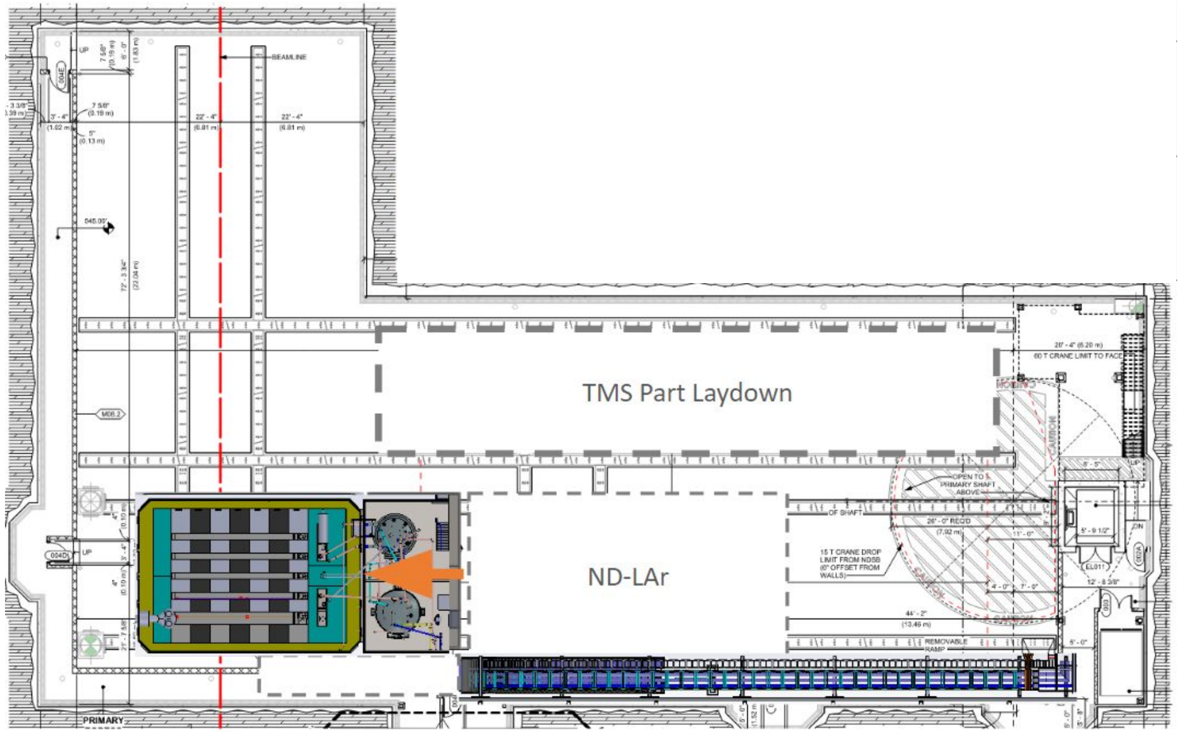


*Fiberglass/plastic dielectric pads isolate mezzanine from PRISM frame*

# Connect Energy Chain
# Test Drive PRISM System

- After test, Cryostat remains out of crane coverage for 8 months while TMS uses cavern crane for assembly



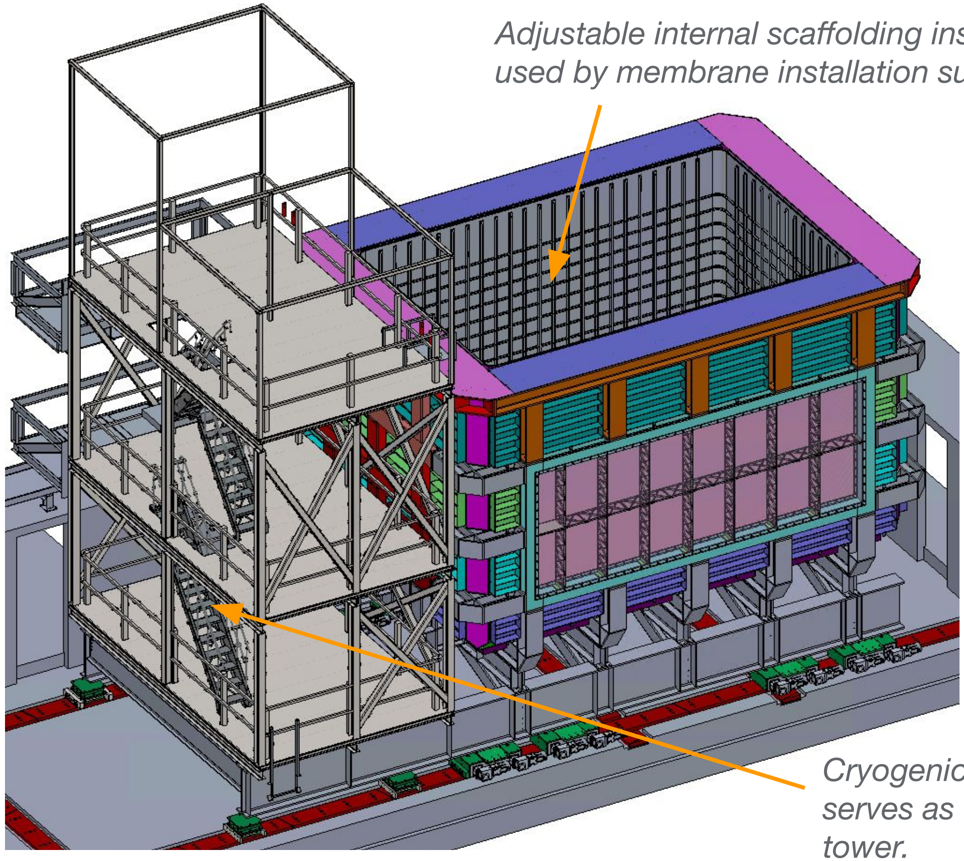


# Drive Cryostat Back Under Cavern Crane
# Install Cold Membrane

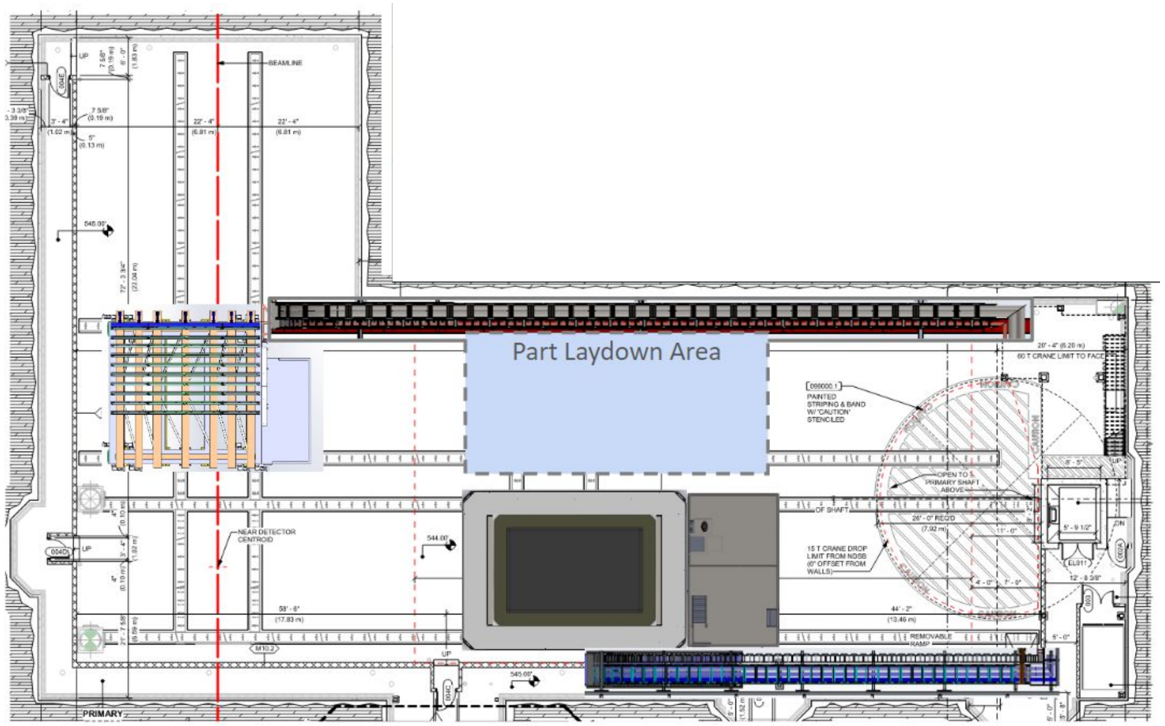
Charge # 2, 6.b

- Full time usage of cavern crane during cold membrane installation, 10-15 lifts per day
- Surface crane usage also heavy, 5-6 lifts per day

*Adjustable internal scaffolding installed and used by membrane installation subcontractor.*

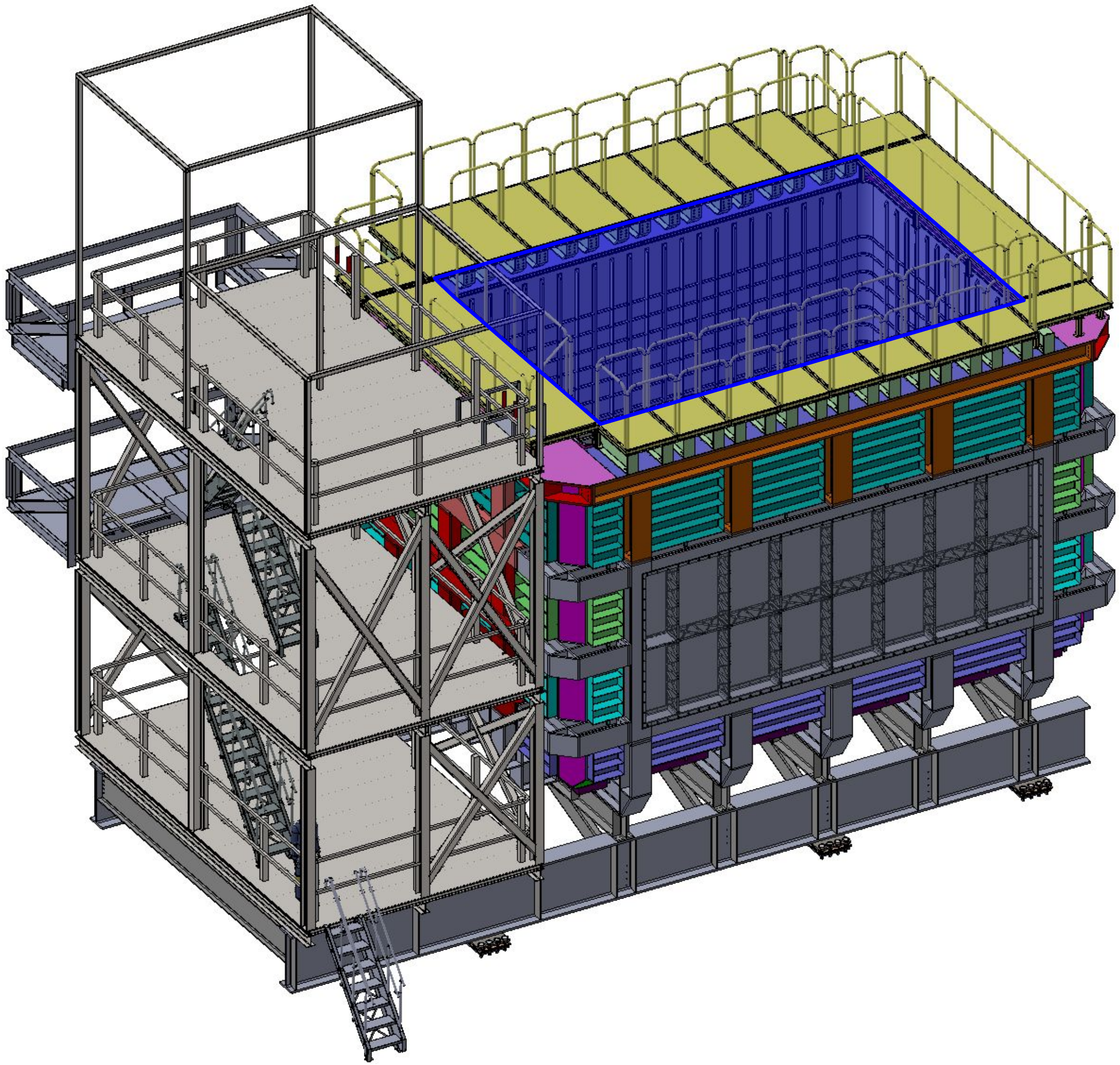


*Cryogenics mezzanine serves as external stair tower.*



# Install TPC Mezzanine Perimeter
# Install Lid cover

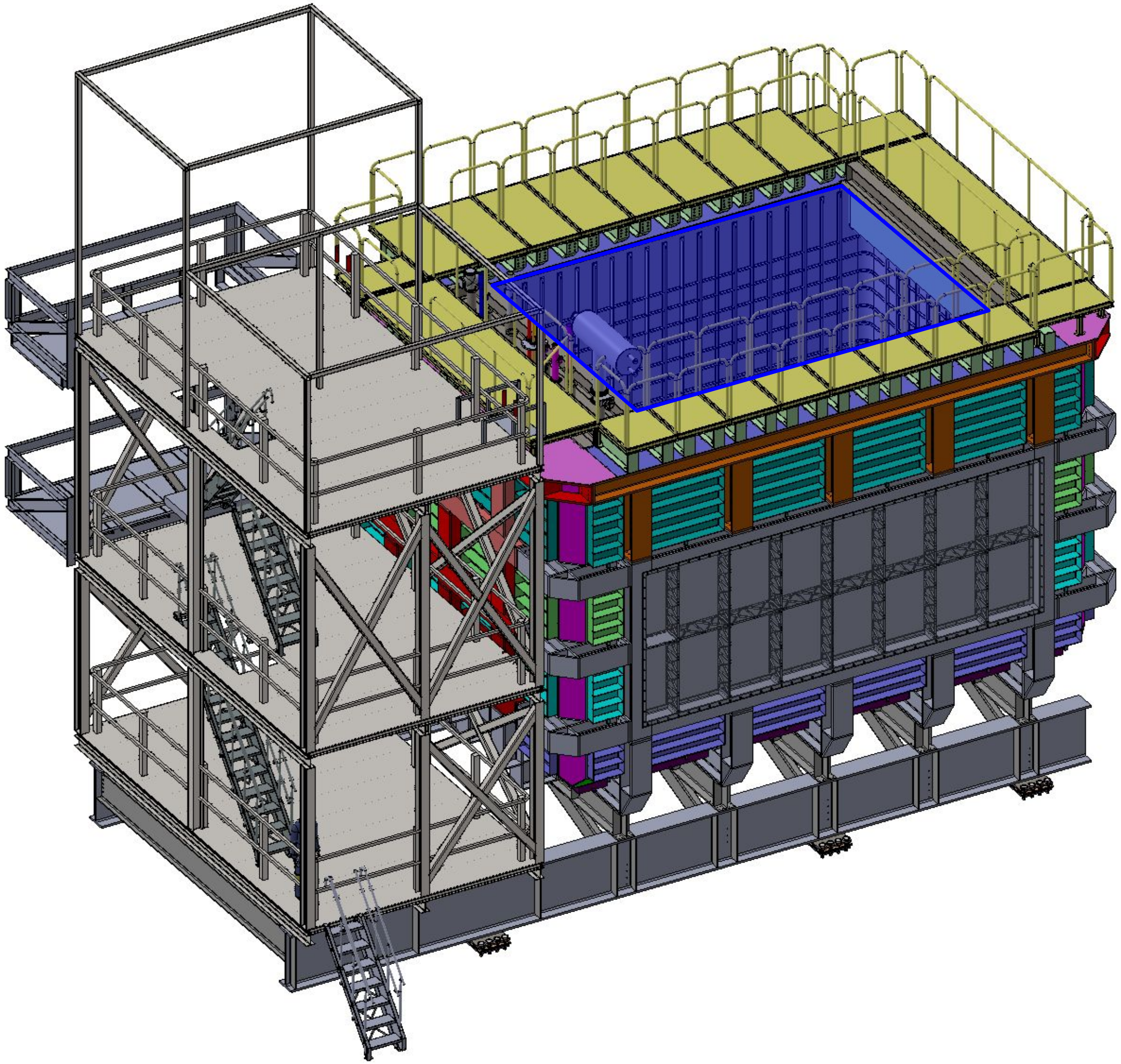
- Mezzanine perimeter serves as personnel access
- External and internal railings are in place for personnel safety
- Tarp (blue) covers open cryostat tub to prevent contamination from falling in



Charge # 6.a , 6.b

# Install Internal Piping and Cryogenic Services Lid Section
# Install End Cap Lid Section

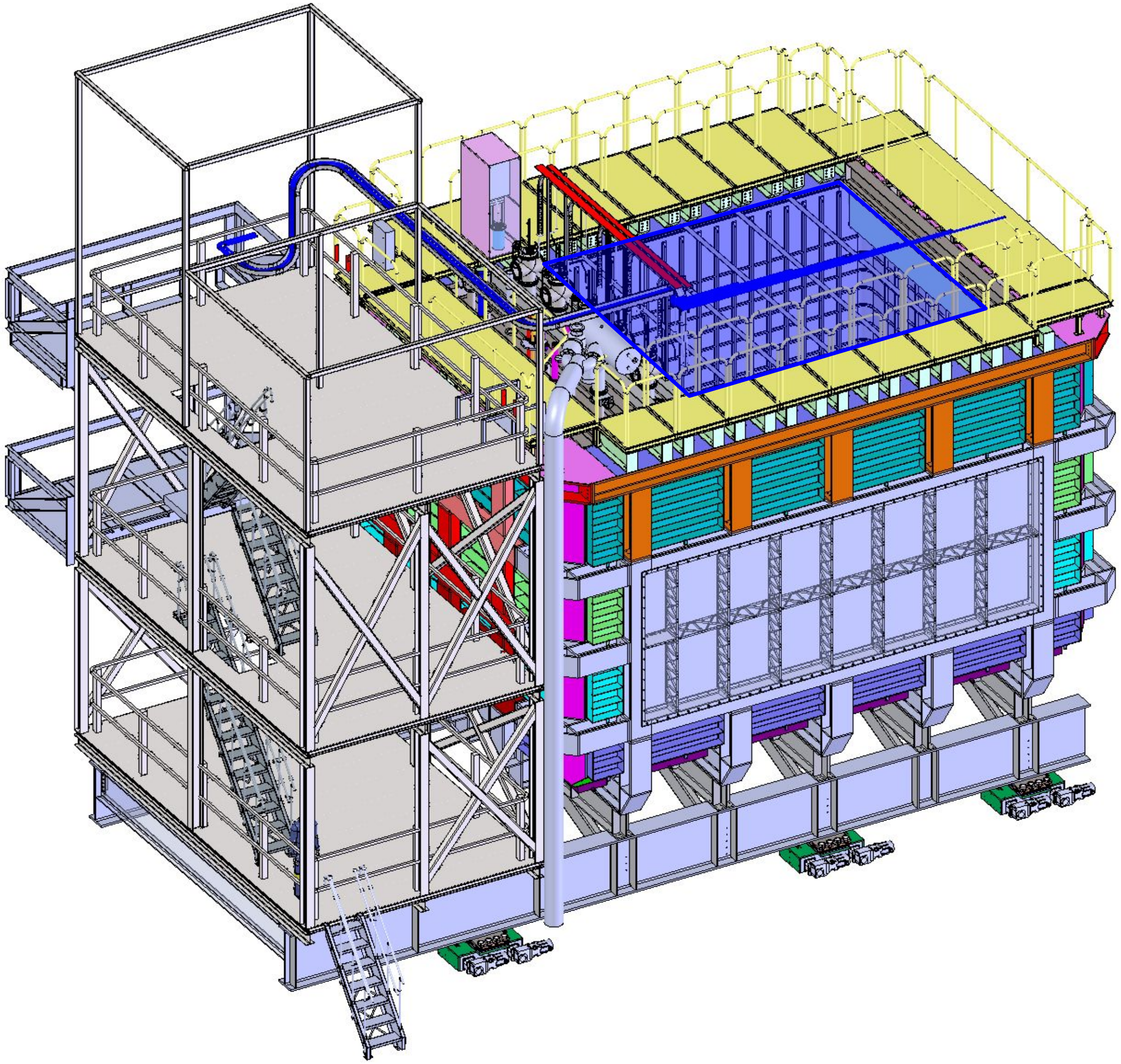
- Includes lid section welding
- ND-LAr team installs and connects electronics on top of TPC Row
- Cryostat stays out of crane coverage for 2 months after completion while TMS uses crane



Charge # 6.a , 6.b

# Install TPC Row 1

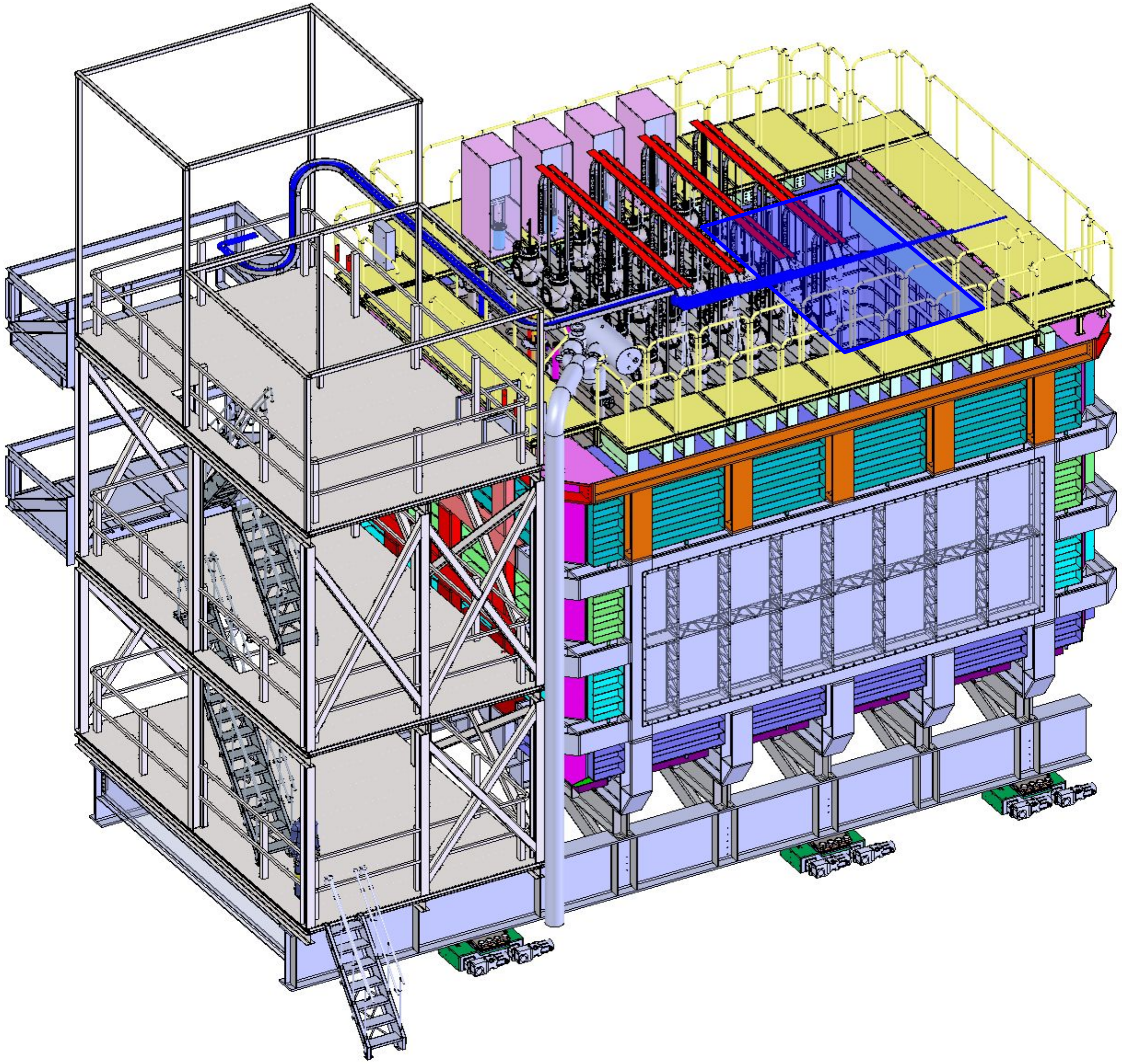
- Includes lid section welding
- Corresponding perimeter mezzanine panels are removed temporarily for access to fasteners and welds (details in lid presentation)
- ND-LAr team installs and connects electronics on top of TPC Row
- Cryostat stays out of crane coverage for 2 months after completion while TMS uses crane



# Install TPC Rows 2-4

Charge # 6.a , 6.b

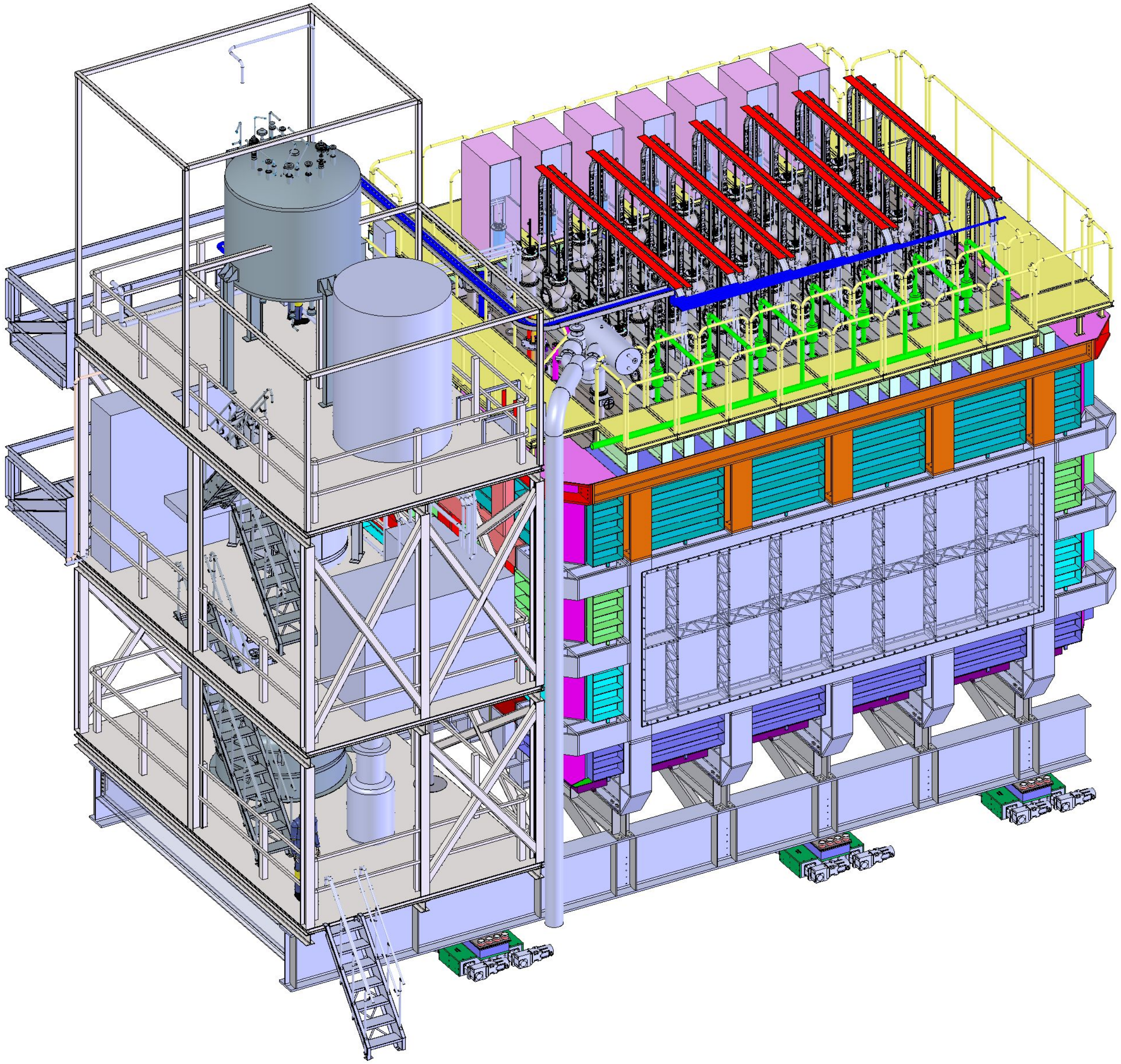
- Having learned from installing the first TPC Row, we move to installing batches of 3
- ND-LAr team installs and connects electronics on top of TPC Row
- Cryostat stays out of crane coverage for 2 months after completion while TMS uses crane



# Install TPC Rows 5-7

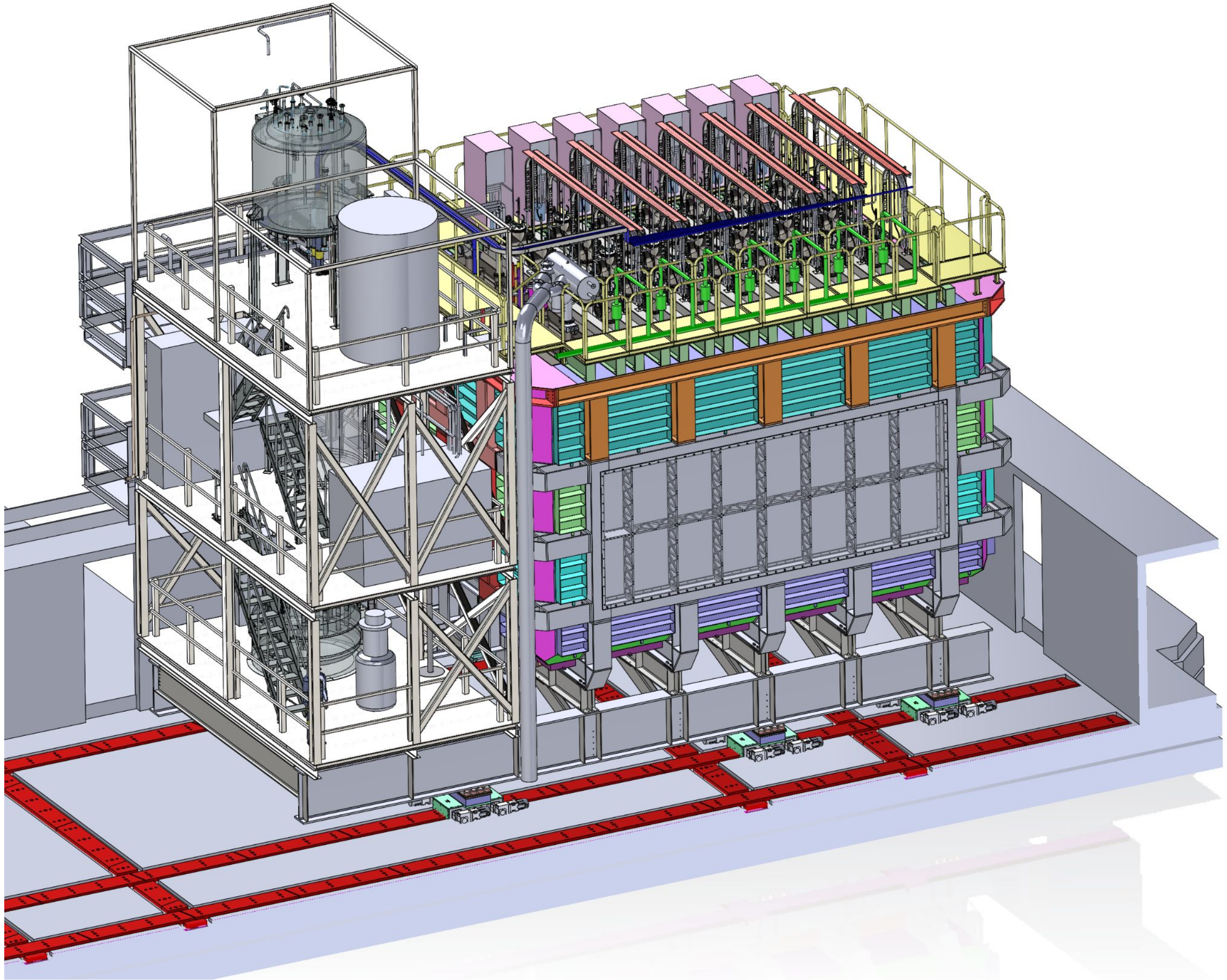
Charge # 6.a , 6.b

- ND-LAr team installs and connects electronics on top of TPC Row
- Cryogenics team connects LAr and GAr manifolds
  - LAr recirculation system installation performed in parallel with Cryostat assembly



# Perform Cryostat Pressure Test

- Apply 250 mbar $N_2$ gas pressure to verify successful assembly
  - High enough for measurable deflection but comfortably below 350 mbar pressure relief valve setting
- Compare pressure test results to FEA
  - Strain gauges on beams with highest expected strain
  - Survey wall deflection under load
- Pressure decay rate characterized but not evaluated as a true leak test
  - Temperature fluctuations and wall deflection will mask all but the largest possible leaks
  - Rely on earlier helium leak test results of cold membrane and lid welds



Charge # 2

# Path to Final Design

- Design assembly fixtures
  - Lid alignment guides
  - Collaborate with ND-LAr on TPC Row Integration fixtures and process
- Gather supplier feedback
  - Fabrication tolerance feasibility
  - Assembly process feasibility
- Review personnel access plans with FNAL safety