

# HVS CONSORTIUM

# SINGLE PHASE FAR DETECTOR

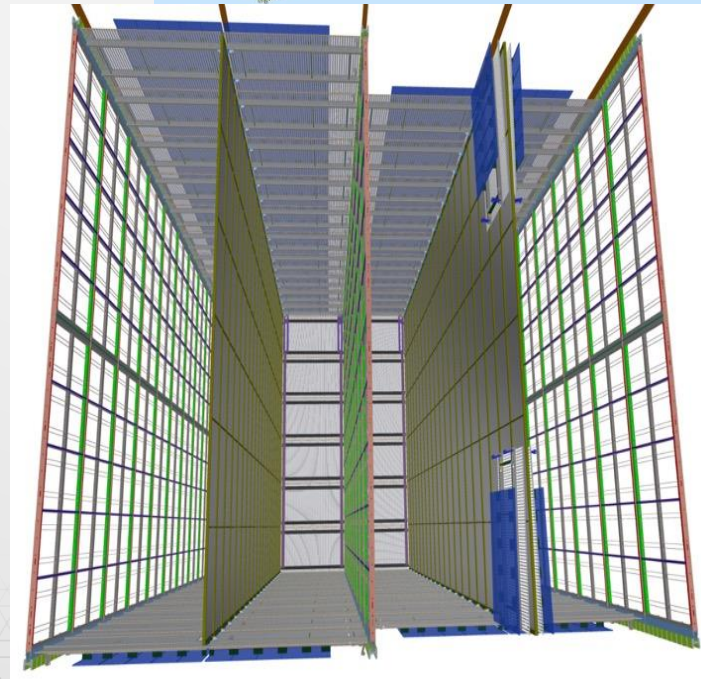
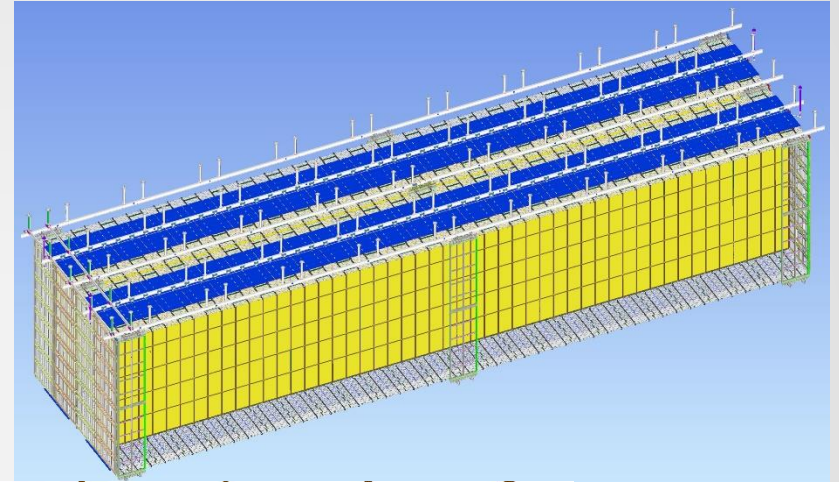
June 4, 2019

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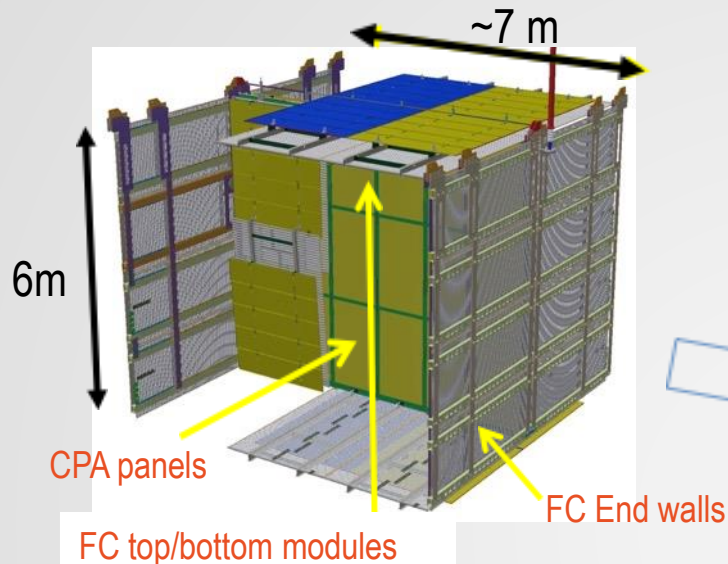


# OUTLINE OF TALK

- pDUNE to FD
- Lessons learned
- HV component design
  - CPA
  - Top and Bottom FC
  - Endwall
- Integration
- Assembly



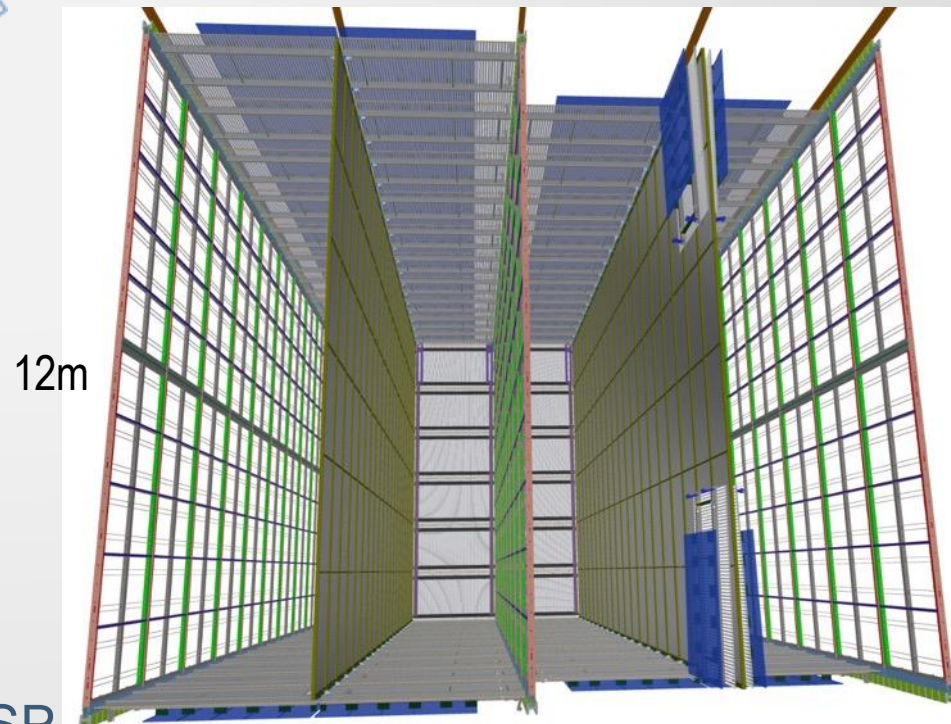
# DUNE SP HV SYSTEM



From ProtoDUNE to DUNE Far detector



- 50 CPA modules (12m high):
  - 300  $1.15 \times 2 \text{m}^2$  resistive panels
- 200 top/bottom FC modules
  - equipped with Ground Planes
- 64 End-wall FC modules
  - Each 1.5m tall
- Same modularity as ProtoDUNE SP





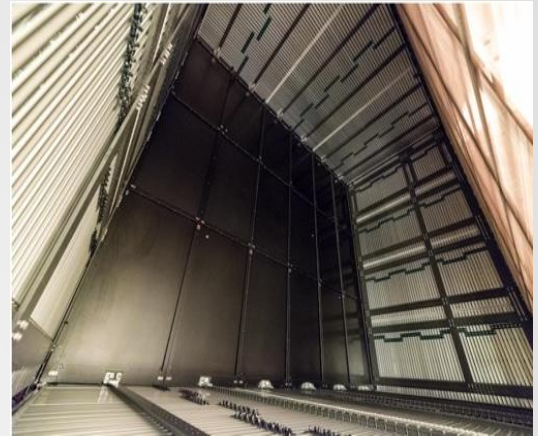
# NO MAJOR CHANGES FROM PDUNE

- Top/Bottom FC modules basically unchanged
  - Increased GP distance 100mm
  - Removed 1 GP panel
  - Changed how GP panels were electrically connected
- CPA basically unchanged except now is 12m tall
- End Wall Modules basically unchanged.
  - Updated EW Connections to allow easier connection
- Docdb 6260 shows baseline design
- *Lessons learned from assembly and installation (Docdb 8246)*



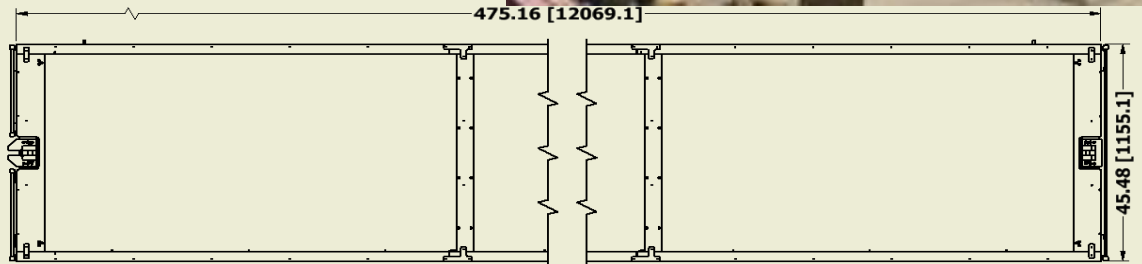
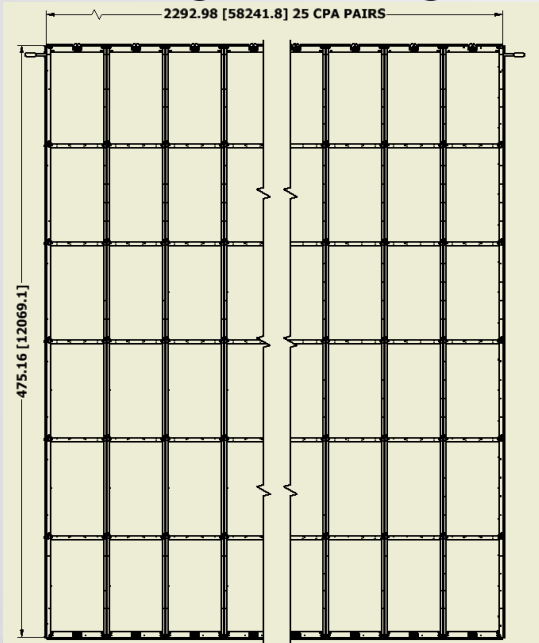
# CPA DESIGN

- Extensive material and physical testing was done before pDUNE.
- Extensive analysis of CPA structure and joints was done.
- Mechanical Design Complete -- full set of drawings/parts list are posted
- Design virtually unchanged from pDUNE
- HV Design integration complete



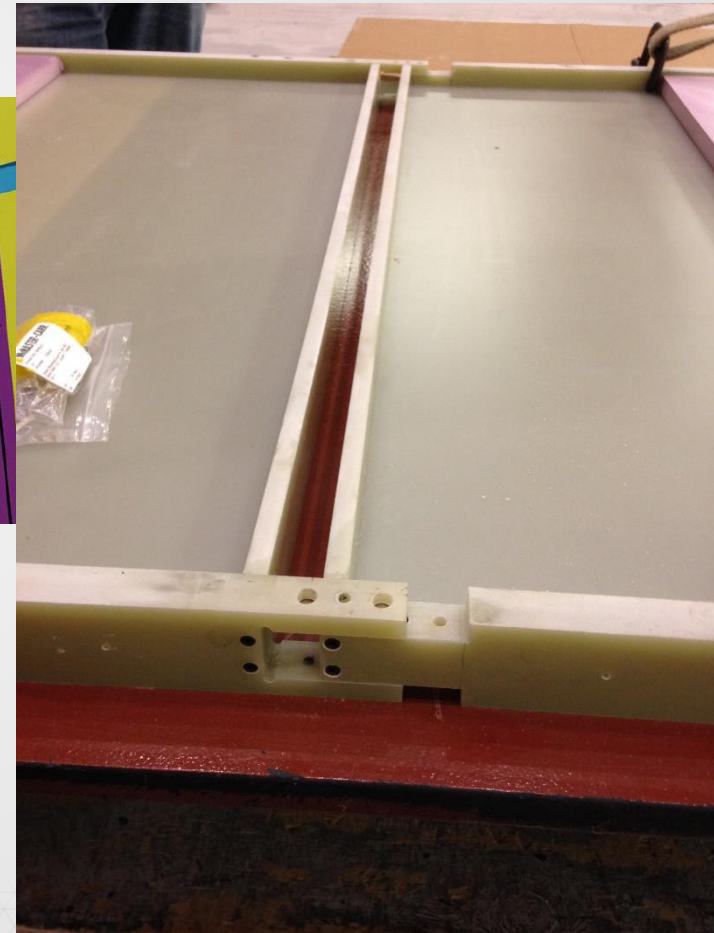
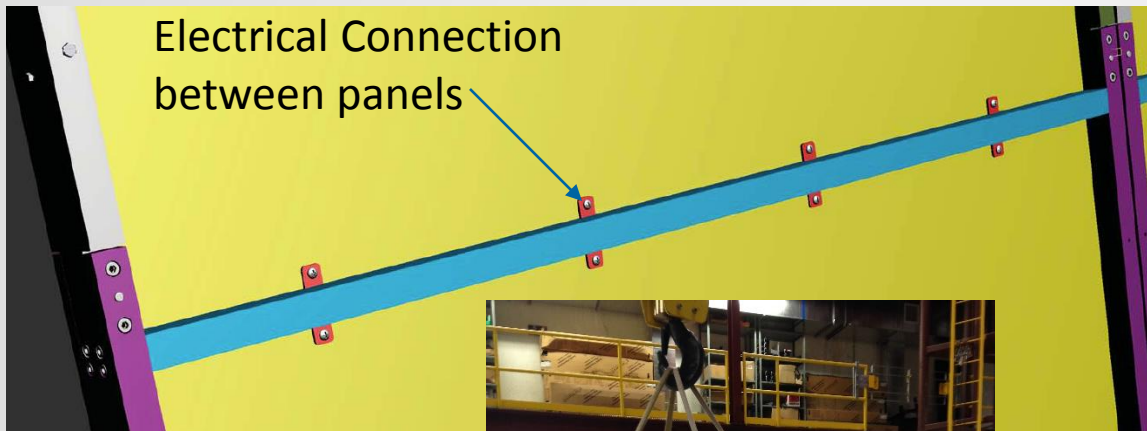
# CPA DESIGN

- CPA Panel is 1.15m x 12m
- Each CPA Panel is made up of 3 modules that are 1.15m x 4m
- Each module is a simple frame that captures the resistive panel in a groove
- Modules are attached to each other through a tongue/groove connection.



# CPA DESIGN

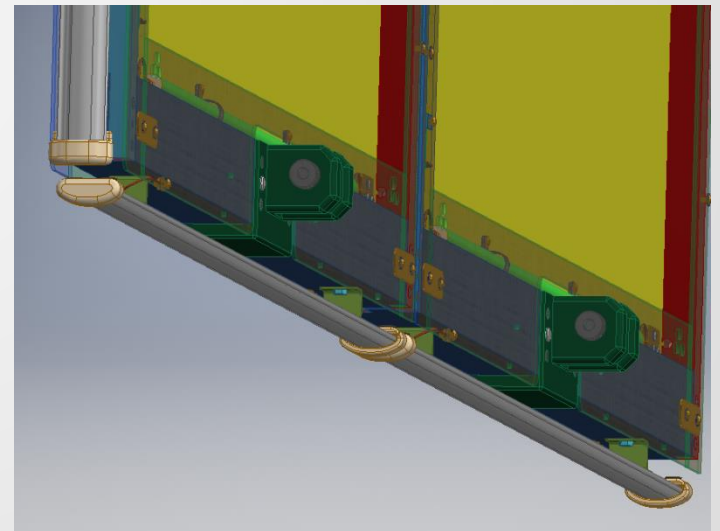
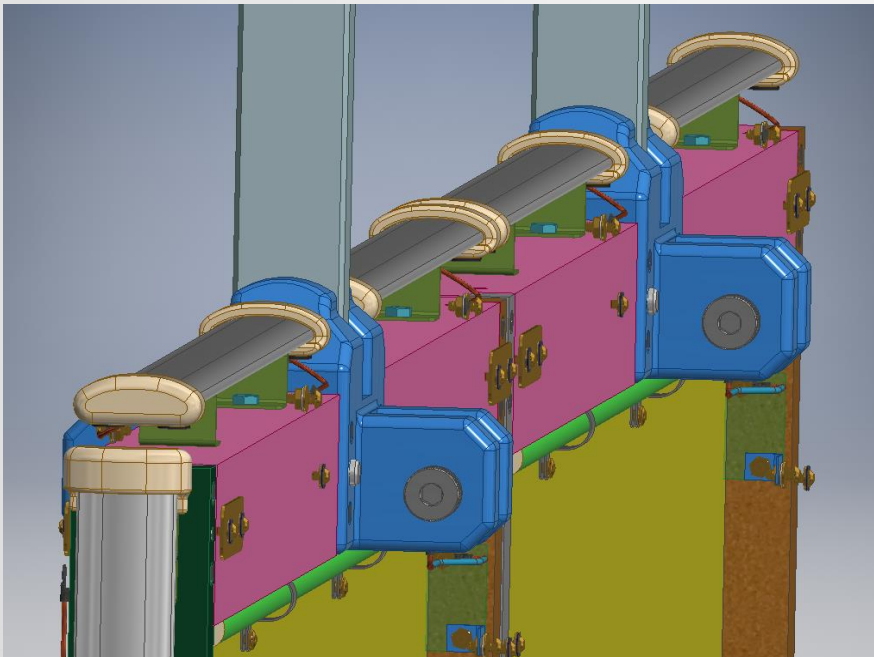
- Each module is a simple frame connected by a tongue and groove.
- After modules are mechanically connected they are connected electrically with tabs





# CPA DESIGN

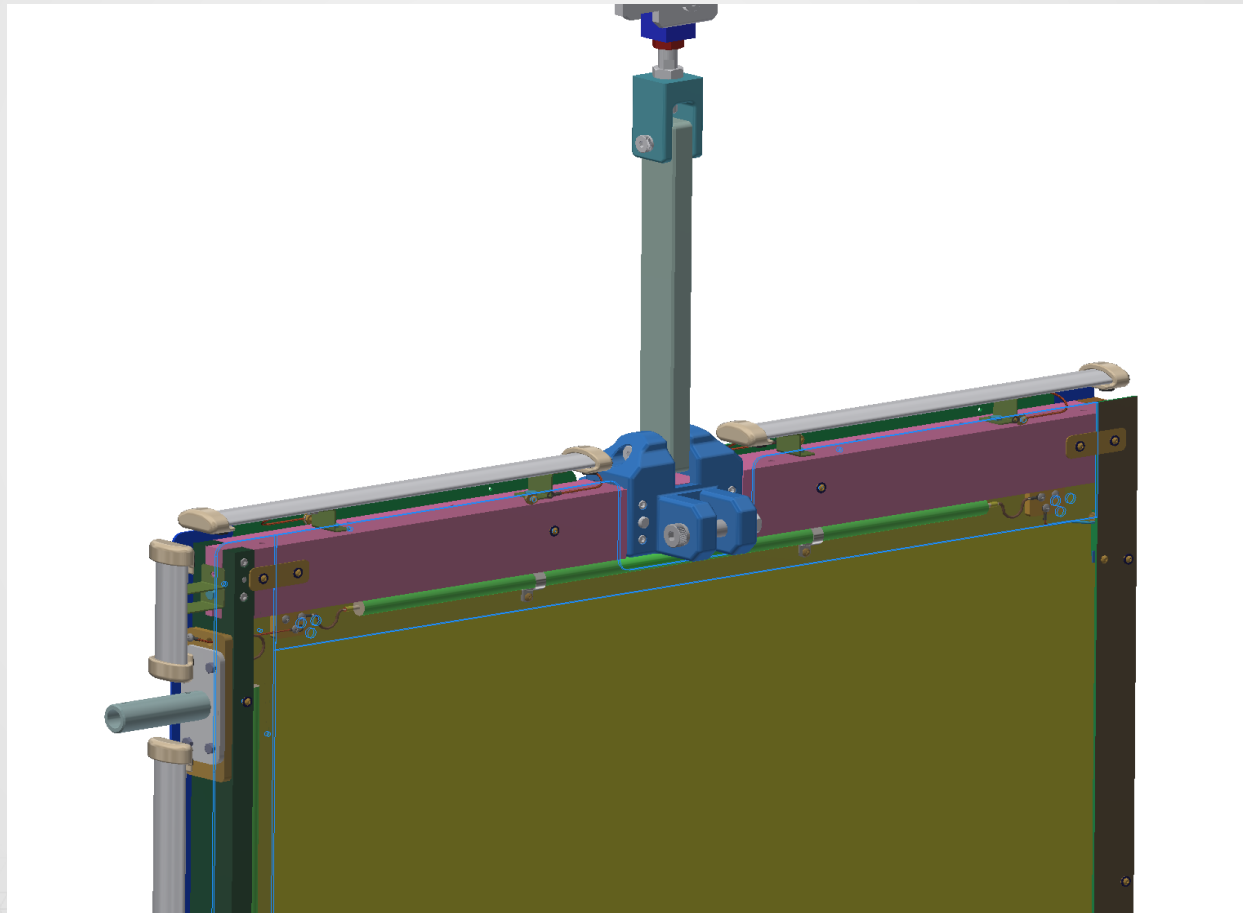
- Support at top acts at FC hinge and transfers load to DSS
- Support at bottom acts as hinge to carry weight of bottom FC modules





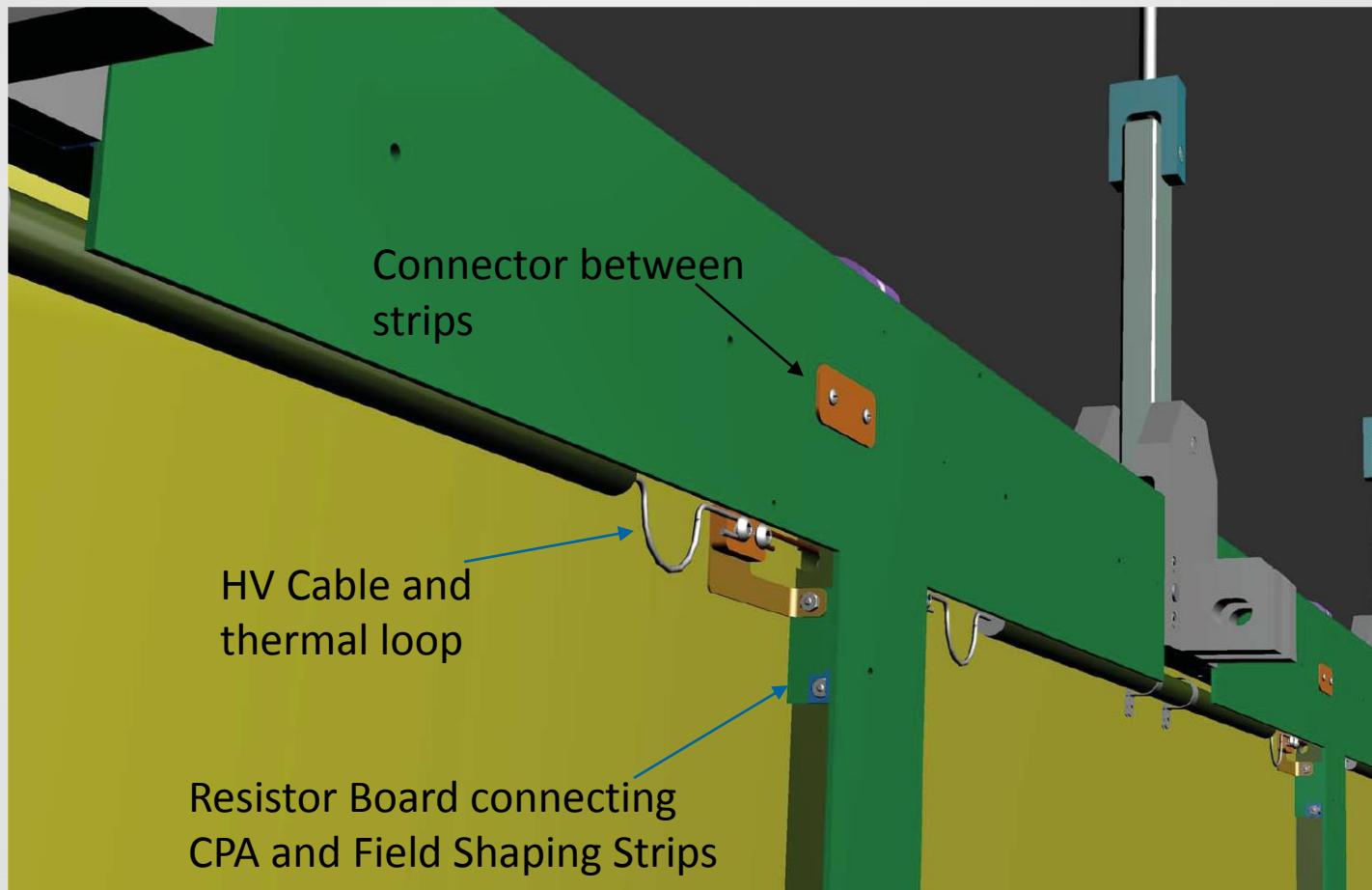
# CPA DESIGN

- CPA Panels supported by a FR4 Bar that connects to the DSS



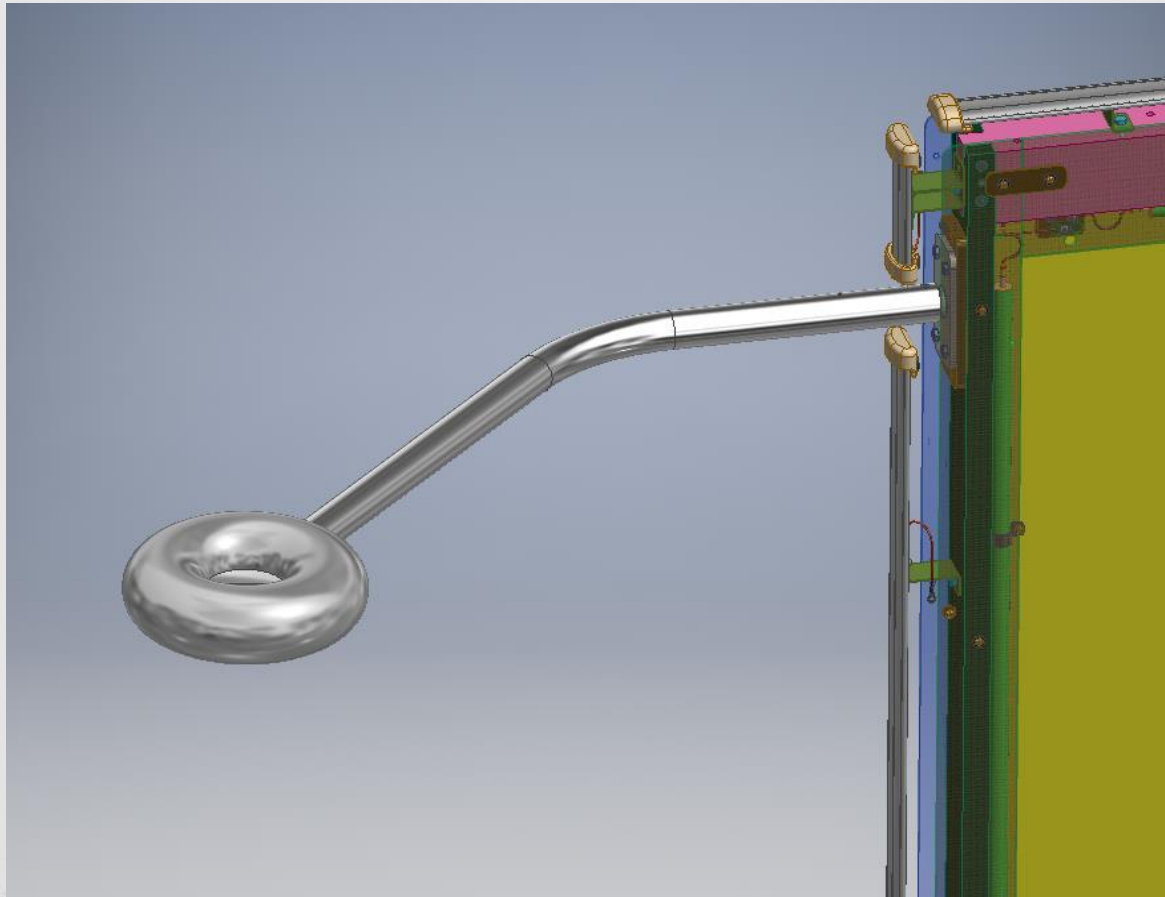
# CPA DESIGN - HV

- HV Connections are Integrated into CPA
- HV cables run along side of CPA and top/bottom



# CPA DESIGN - HV

- Feedthrough connects to donut which is secured to CPA frame
- HV cables are connected to donut frame

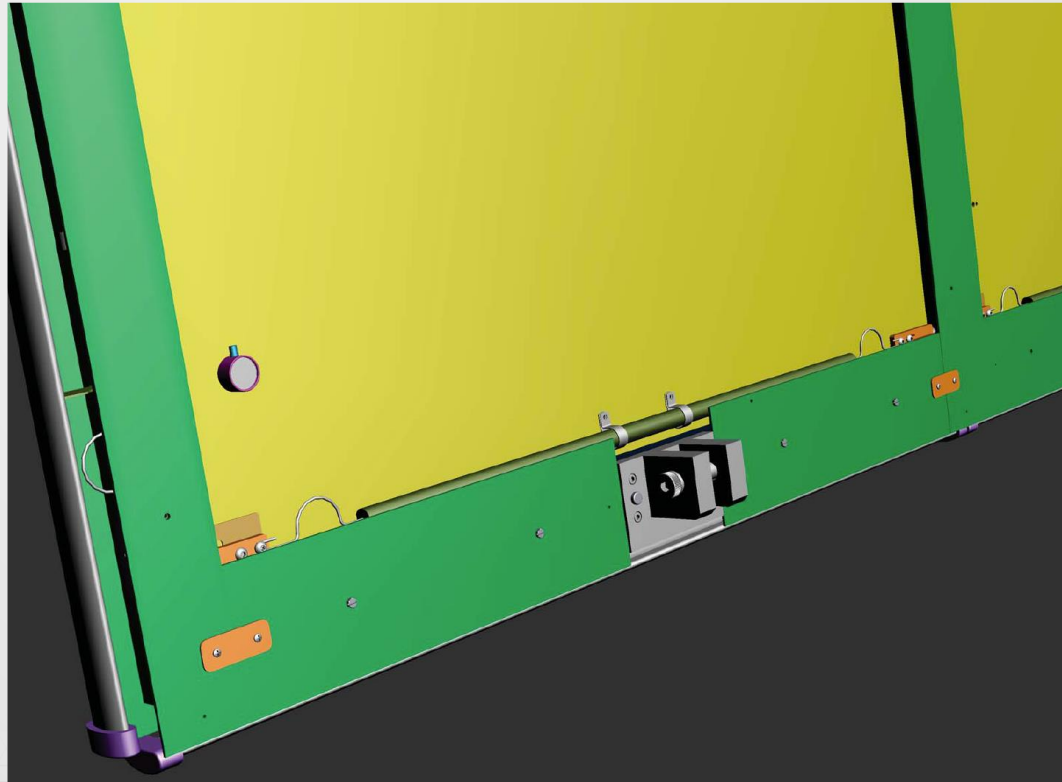




# FIELD SHAPING STRIPS

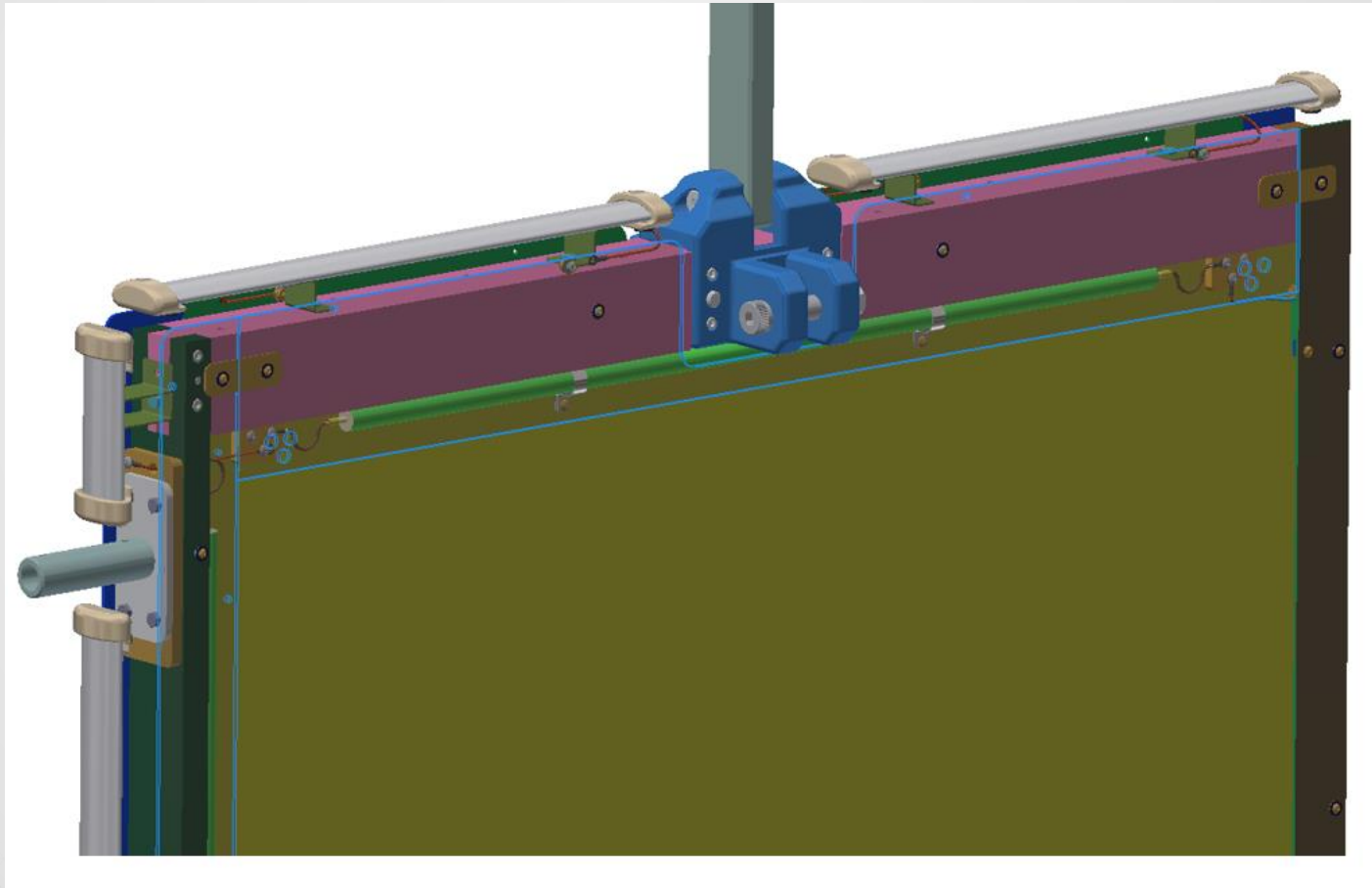
- The entire CPA Frame has strips that overlap the frame by 1" to shape the field.
- The strip potential is set by resistors connecting them to the CPA panel.
- Strips are 1/8" thick G10 with same resistive coating as cathode planes

Strips are in  
Green



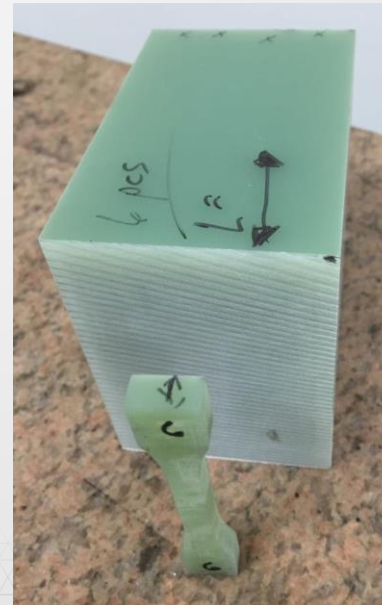
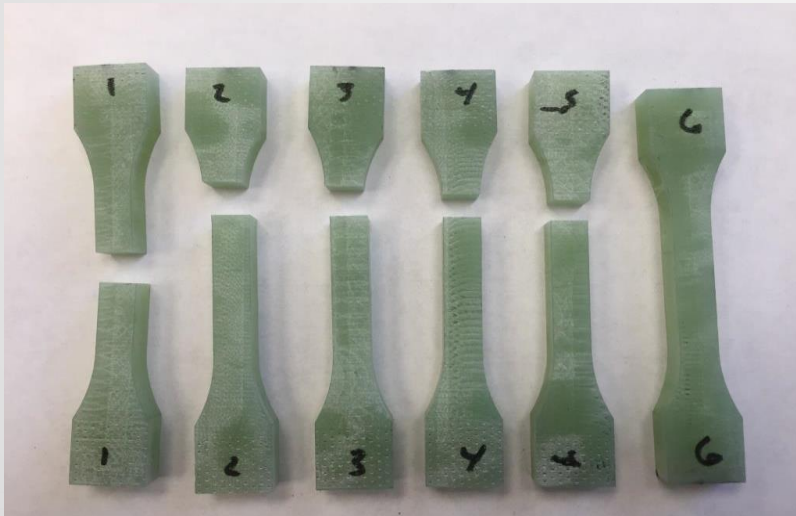
# CPA PROFILES

- The assembled CPA plane has profiles mounted around the perimeter to mimic the FC profiles.



# CPA MATERIAL AND TESTING

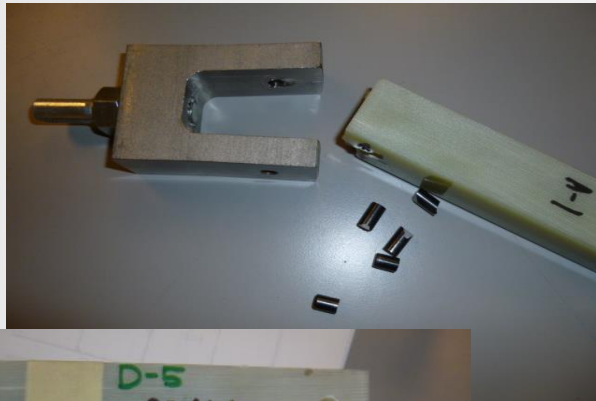
- We will be using FR4 and FRP material that meet the International Building Code classification for flame spread and smoke development of a Class A, as characterized by ASTM E84
- Both the FRP structural shapes and FR4 bar material shall be fire resistant and likely will be halogenated.
- Testing was performed to understand the strength of the material in every direction. (see details in design paper)





# CPA PHYSICAL TESTING

- Extensive testing was performed on connections (see design paper for details)



# CPA STRESS ANALYSIS

- Detailed analysis was performed on the structure and joints using beam elements, hand calculations (see design paper Appendix 1).
- CERN utilizes the JRC Science for Policy Report “Prospect for New Guidance in Design of FRP” as a guide for designing FRP structures.
  - This is not directly applicable to our unique structure
  - Used as a guide and determination of the safety factor of 3.75
- Calculations checked by physical testing determine the strength of the design.
- The highest loads occur during assembly. Load cases considered:
  - Rotation of the CPA from the assembly table to vertical
  - During installation when the CPA supports the entire weight of the FC modules
  - After deployment and a 200 lbs worker is standing on the bottom FC adjacent to the CPA.
- Load Cases
  - Case 1: Lifting of the 4m long CPA module from horizontal to vertical during installation
  - Case 2: CPA hanging while supporting two top FC modules that are not deployed.
  - Case 3: CPA hanging while supporting four FC modules that are deployed and have a 200 lbs worker standing at the center of a FC bottom I-beam
  - Case 4: Operational condition cold.
- All Load Cases exceed required safety factor of 3.75**

Load Case	Safety Factor
1	7.5
2	11.2
3	9.75
4	40.8

6.3.1 The allowable loads when the pin is parallel to the plane of the fibers

$$F1 := \frac{\sigma_{ultimate} \cdot \text{Thick} \cdot w \cdot (t - D_{pin})}{SF \cdot k} = 866.6 \text{ lbf} \quad \text{Tension strength of section -- greater than load so ok}$$

$$F2 := \frac{.6 \cdot \sigma_{ultimate} \cdot \text{Thick} \cdot (2 \cdot 0.75 \text{ in}) \cdot t}{SF \cdot k} = 742.8 \text{ lbf} \quad \text{Shear pull out -- greater than load so ok}$$

$$Fmax := \min(F1, F2) = 742.8 \text{ lbf}$$

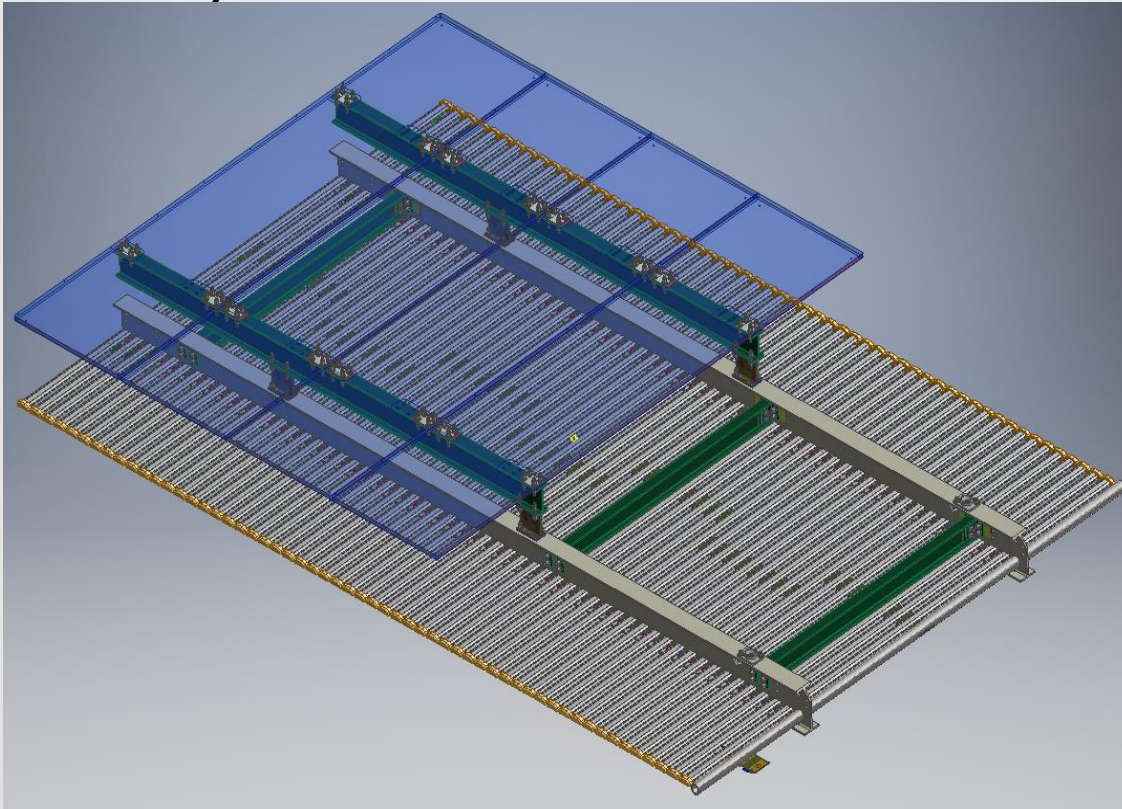
$$\text{Margin2} := \frac{Fmax}{W_{connection1}} = 2.74 \quad \text{Margin3} := \frac{Fmax}{W_{connection2}} = 1.45 \quad \text{Margin4} := \frac{Fmax}{W_{connection3}} = 6.14$$

Margin above allowable for Load Cases 2, 3 and



# TOP/BOTTOM FIELD CAGE (FC)

- Design virtually the same as pDUNE
- Only change is that the Ground Plane distance increased by 100mm



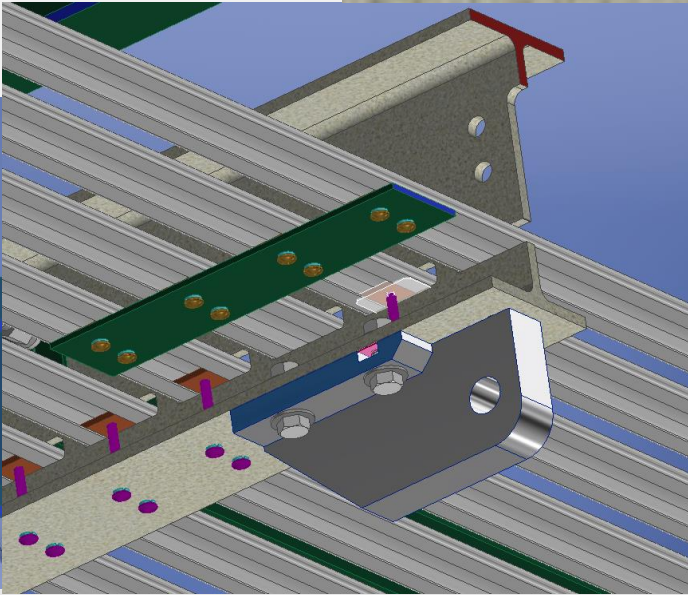
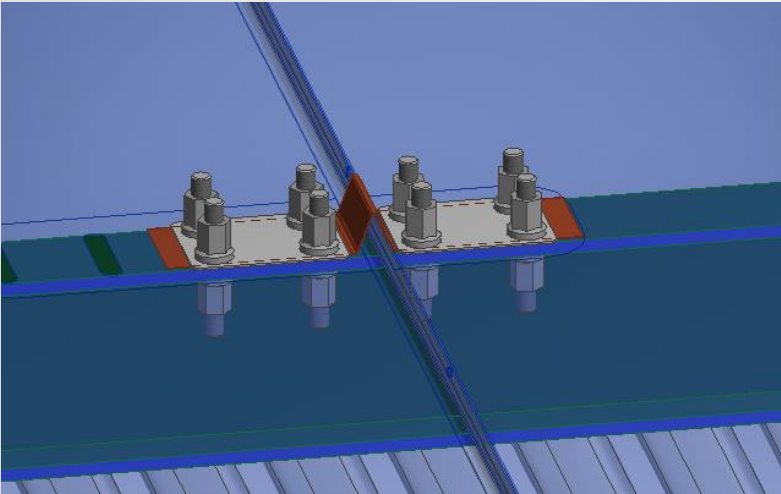
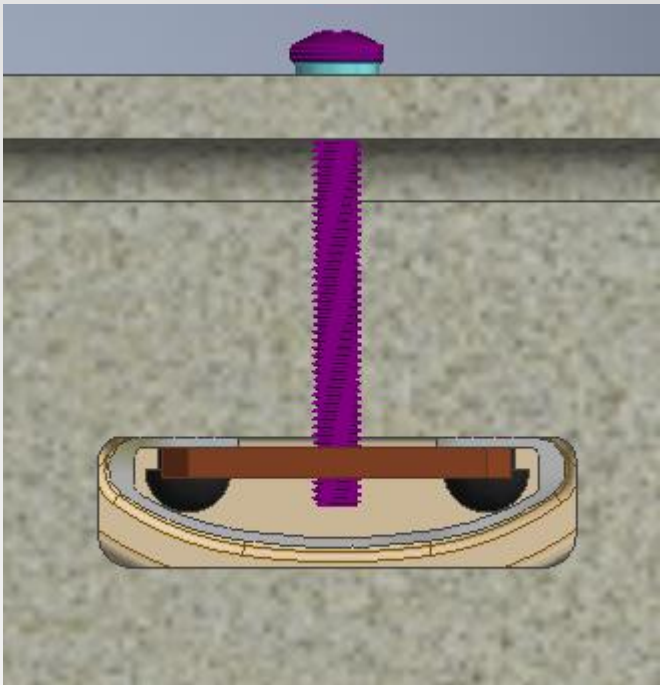


# GP-FC DESIGN UPGRADE

- Keep the basic design of the P-Dune FC but increase the distance of the GP to profiles
- Presently under study and test:
  - Reduce the number of spacers connecting the FRP I-beam to the GP I-beam
  - Place the spacers as far as possible from the high field region
  - Stability calculation and mockup tests underway
  - Same concept for top and bottom FC



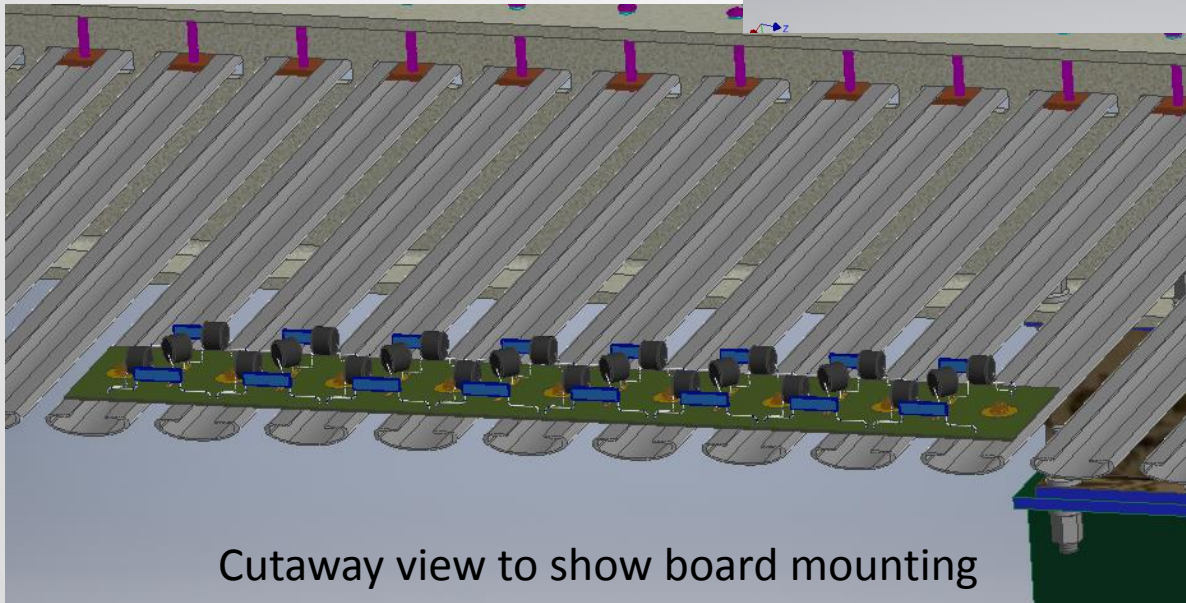
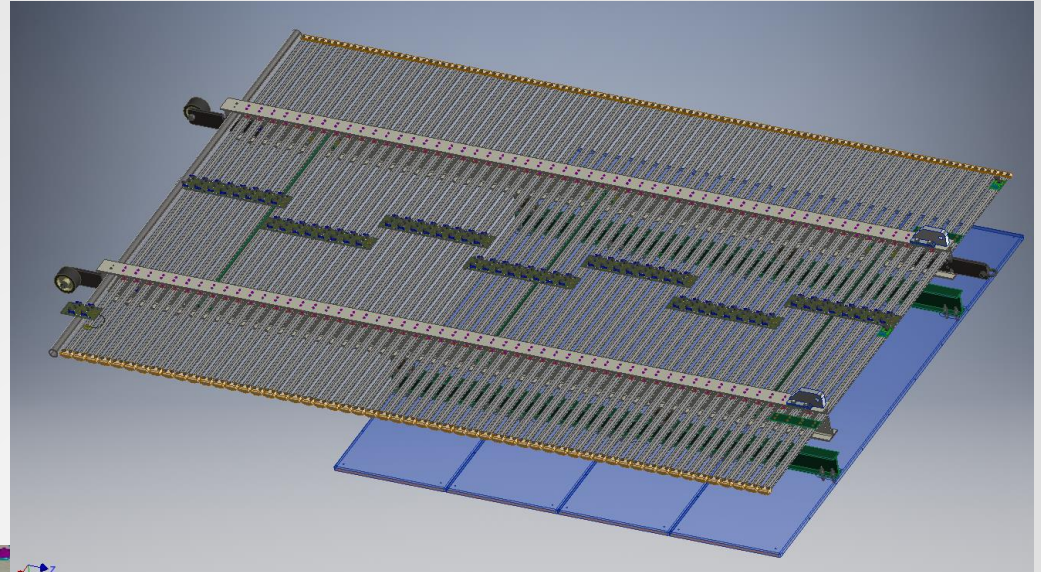
# FC DESIGN





# FC DESIGN

- Resistor Boards



Cutaway view to show board mounting



# FC STRESS ANALYSIS

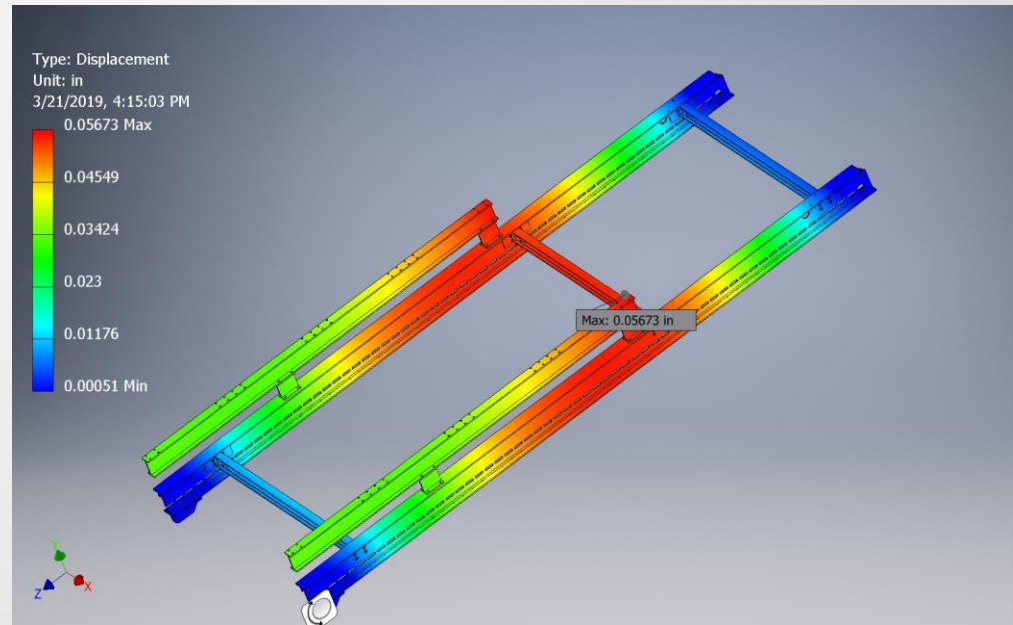
- Hand and FEA calculations were performed

- 3 Load Cases

- Case 1: Supported at ends horizontally in the installed dry configuration
- Case 2: Hanging from end in the installation orientation
- Case 3: Supported at ends horizontally in the installed wet configuration

- All load cases met the 3.75 safety factor

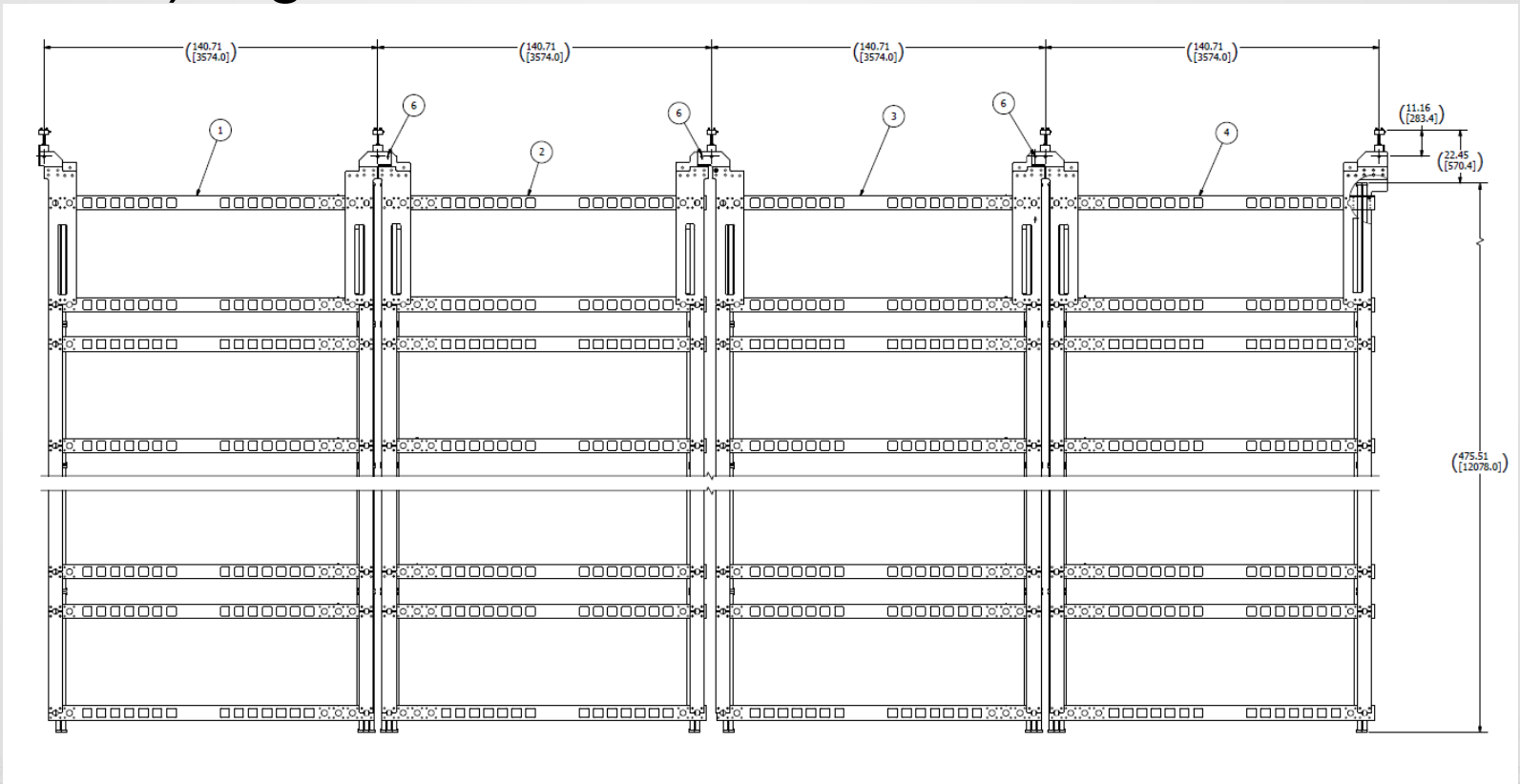
Load Case	Description	Safety Factor
1	Both ends support in the horizontal position (dry operational condition)	7 at hole stress concentration
2	Hanging vertically as supported during installation	7 at hole stress concentration
3	In wet operational condition	6.6 at hole stress concentration



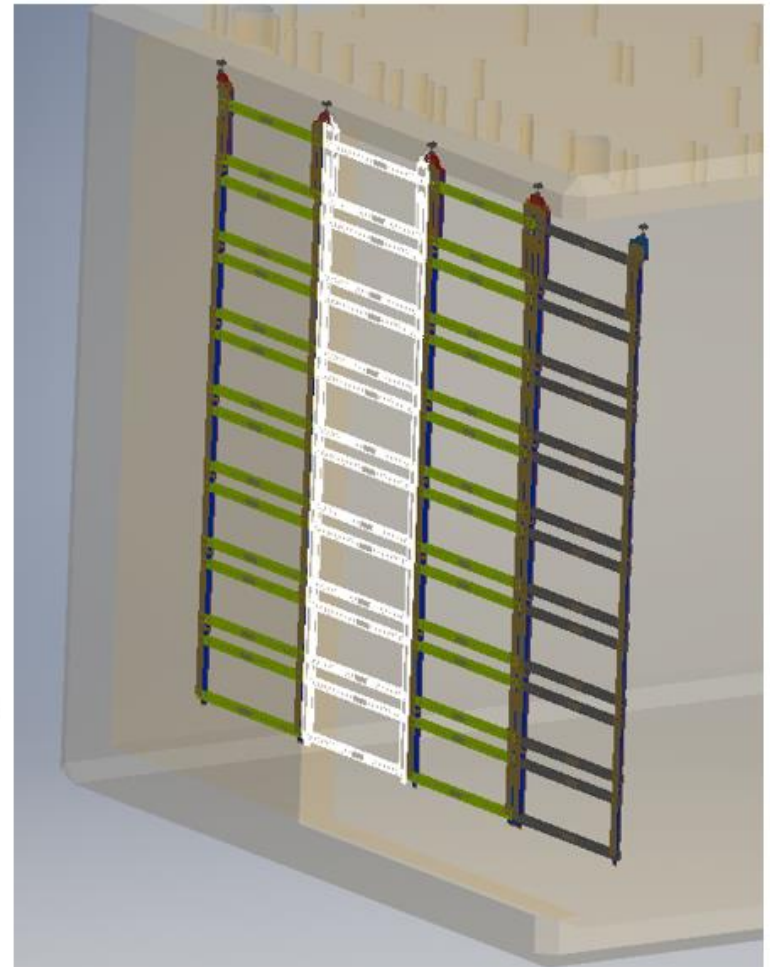
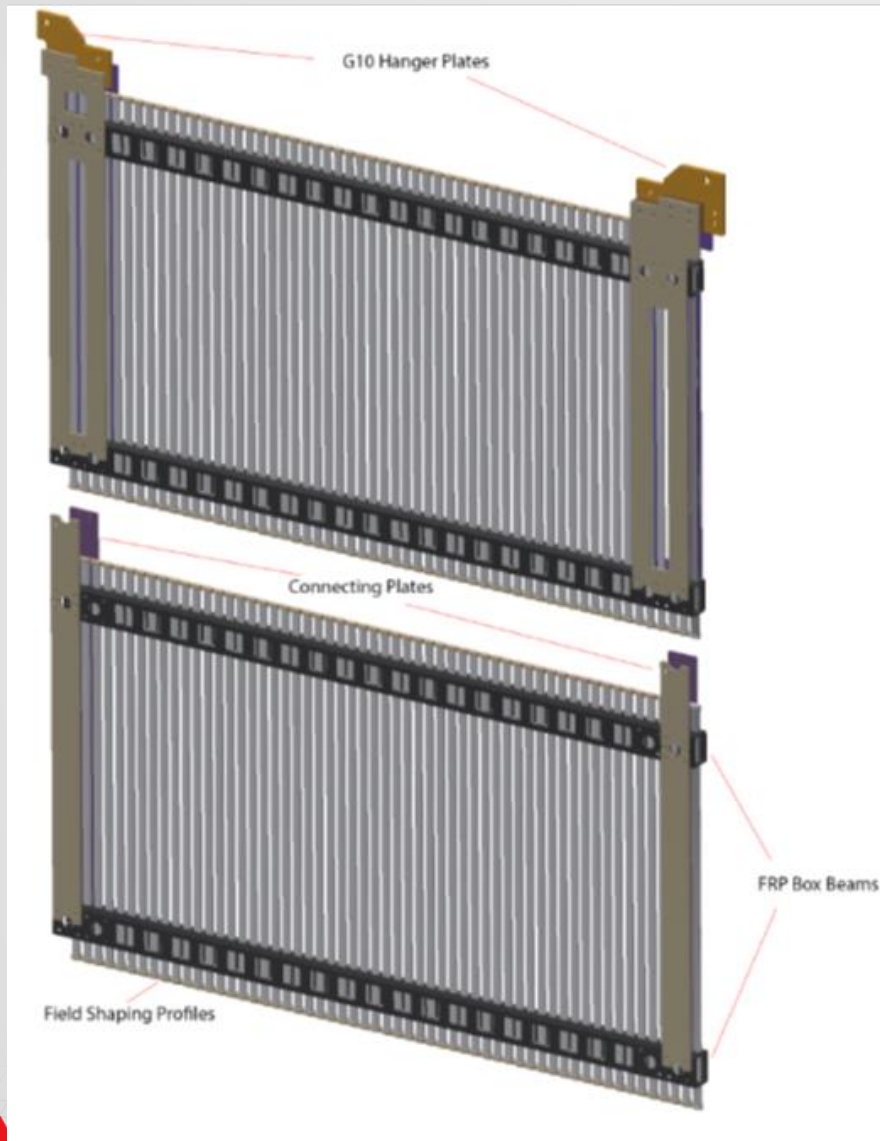


# ENDWALL FC

- Endwall design remains unchanged from pDUNE
- Now 12m (8 modules) high rather than 6m (4 modules) high

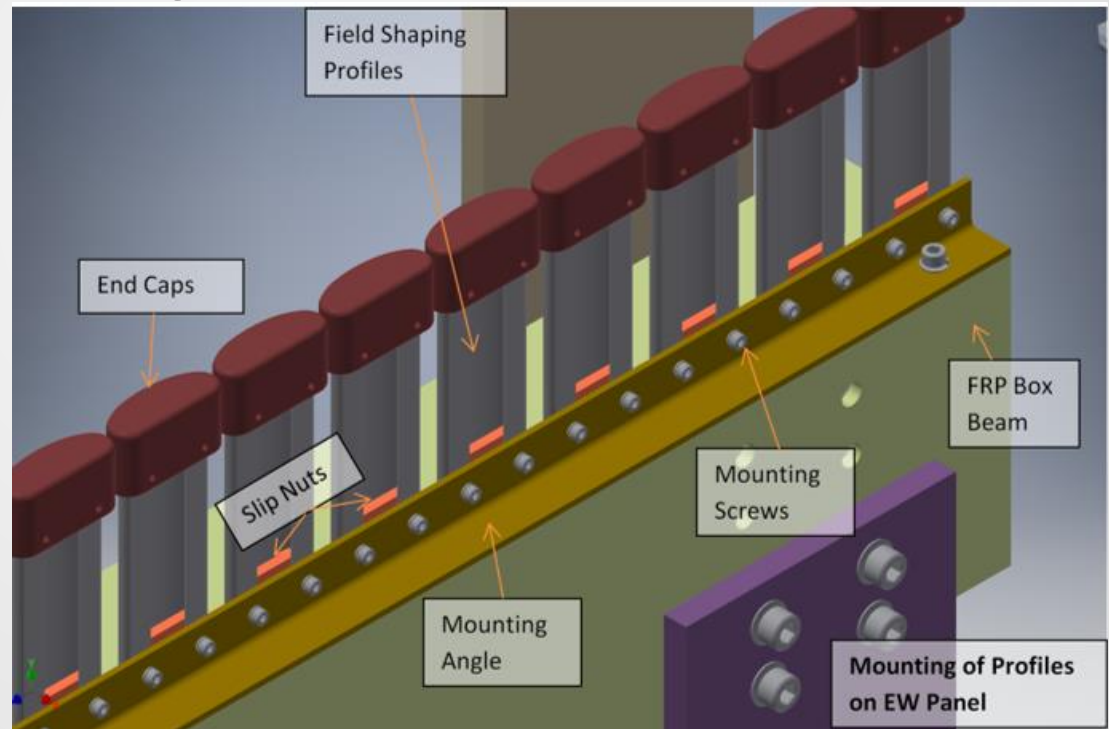
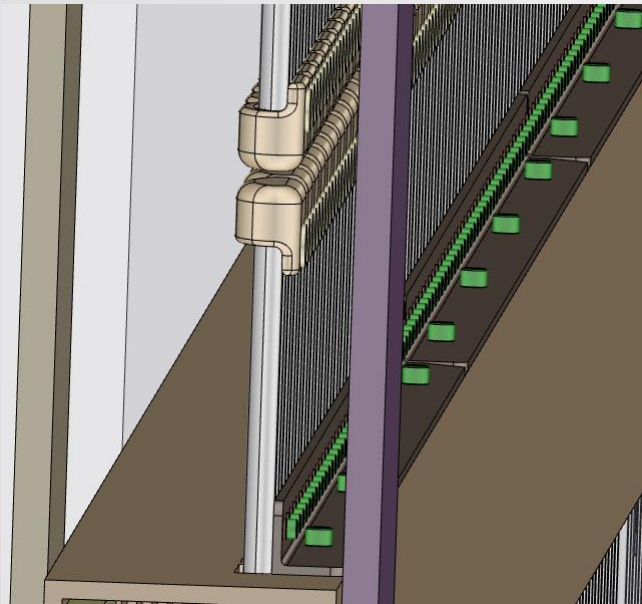


# ENDWALL FC



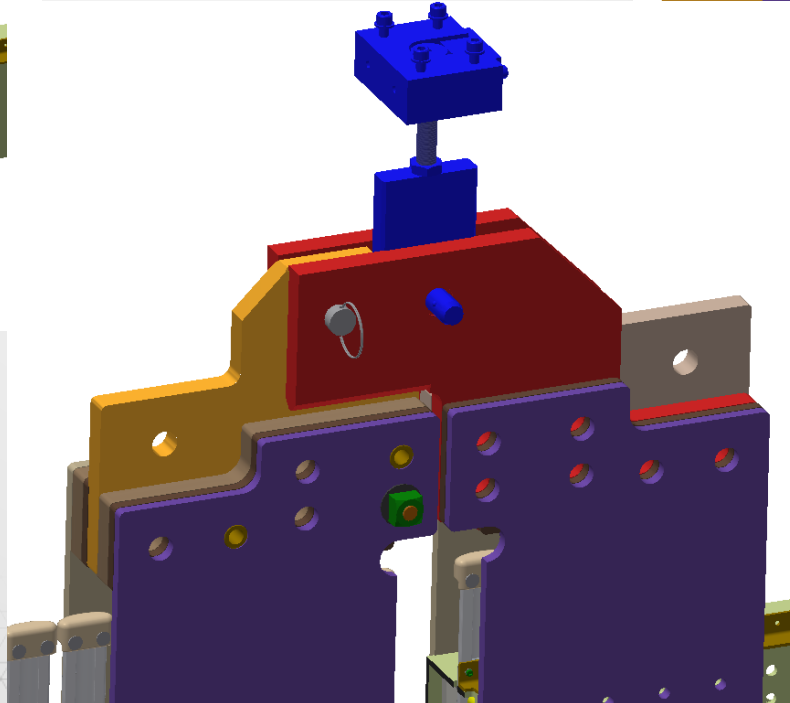
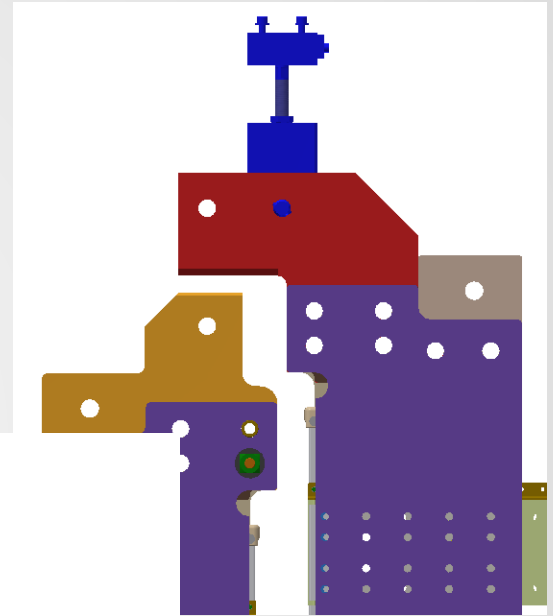
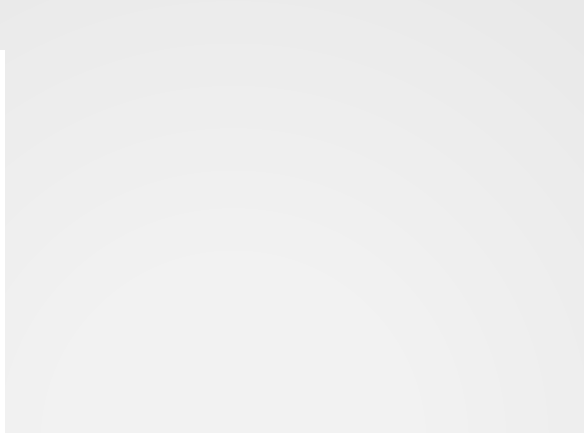
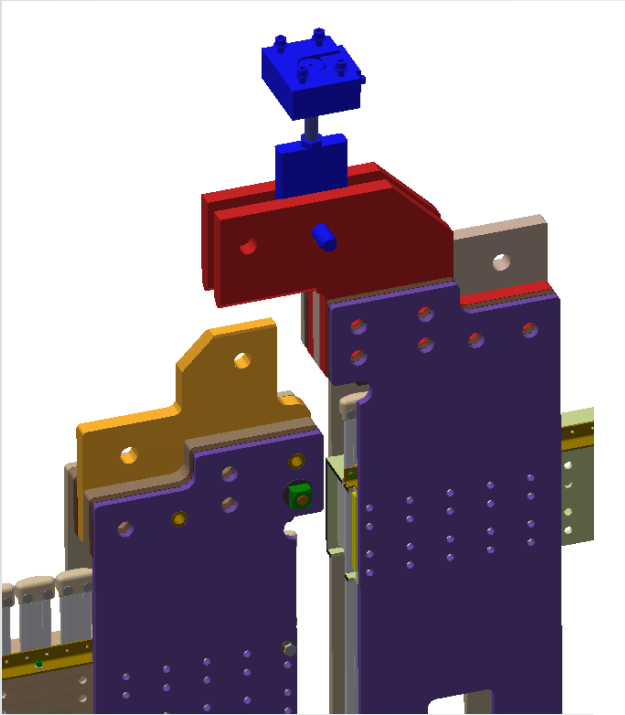
# ENDWALL FC

- Profiles secured to top beam
- Load transferred through pinned FR4 Plates



# EW CONNECTION DETAILS

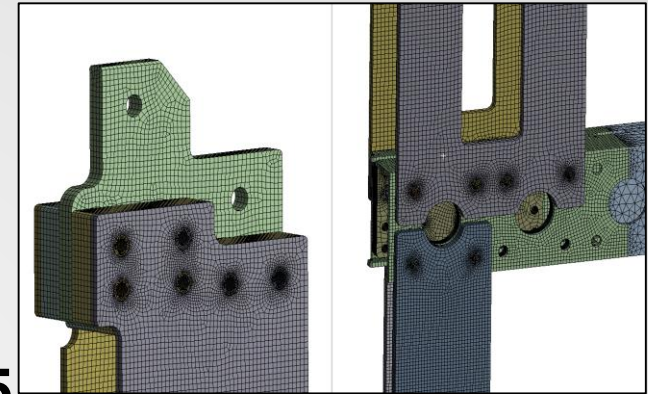
Hanging details updated based on pDUNE experience



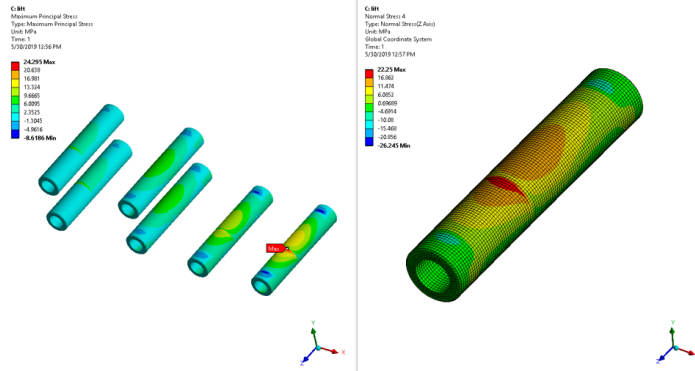


# EW STRESS ANALYSIS

- Detailed 3d FEA model created
- 3 Load Cases
  - Case 1: Lifting during installation
  - Case 2: Hanging in operational position
  - Case 3: Hanging in operational position wet
- **All Load Cases met safety factor of 3.75**

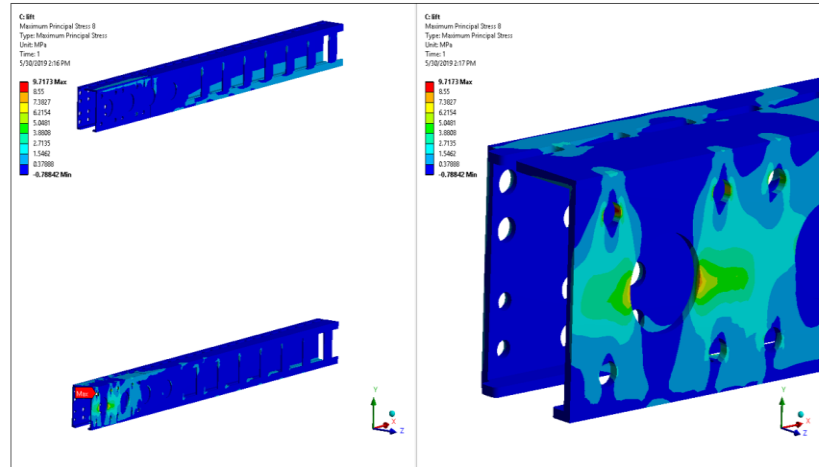


FR4 (G10) Top Hollow Pins  
Pins



- Maximum 1<sup>st</sup> principle stress in entire assy is 24.3 MPa on hollow pin.
- At that location  $\sigma_z = 22.25$  MPa, i.e, predominant stress is in z direction due to bending.
- If this is strong direction,  $S_u = 200$  MPa, if weak,  $S_u = 165.4$
- Safety Factor =  $165.4/22.5 = 7.35$

FRP Box Beams



- Highest 1<sup>st</sup> principle stress in box beam is 9.72 MPa at a pin hole.
- If this is strong direction,  $S_u = 206.8$  MPa, if weak,  $S_u = 48.2$
- Safety Factor =  $48.2/9.72 = 4.97$

Load Case	Description	Minimum Safety Factor
1	12m EW during installation	4.9 at FRP Pin holes
2	12m EW Hanging Dry	4.8 at FRP Box beam fillet
3	12m EW Hanging Wet	13.2 at FRP Box Beam hole



# INTEGRATION/INTERFACES

- A integration model of the detector has been created – see DocDb 6260
- Interface Control Documents have been started

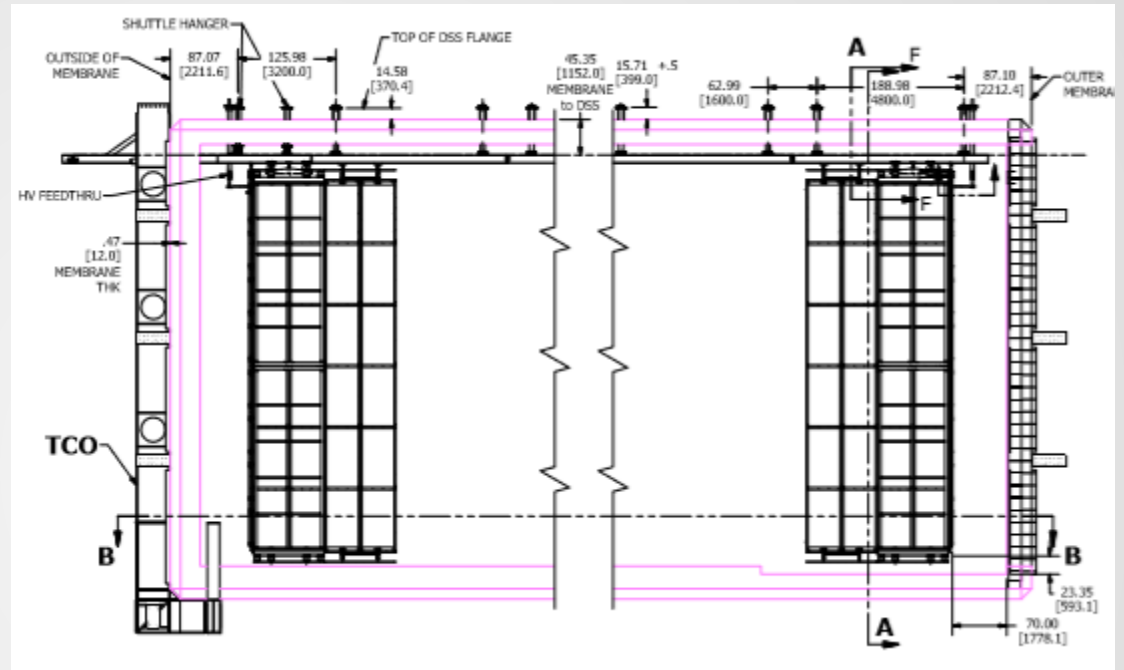
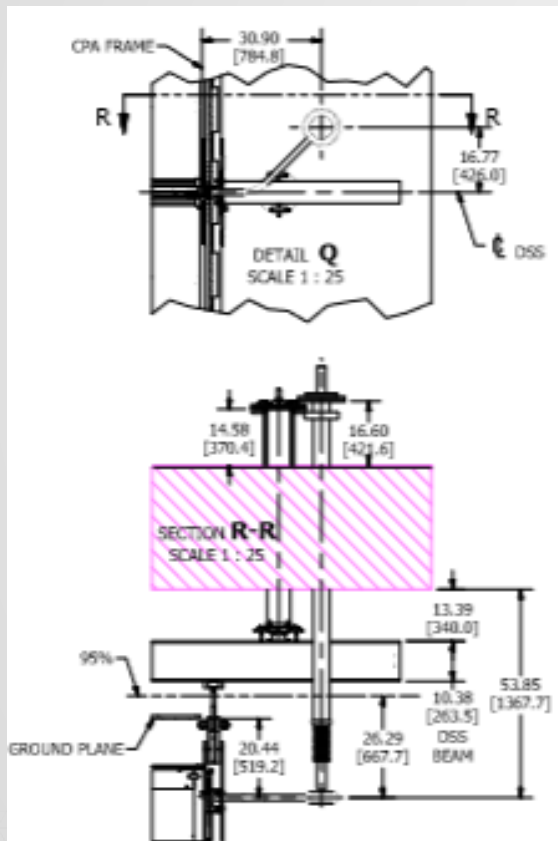
**DUNE Consortia to Consortia Interface Document Matrix**

	SP-PDS	SP-TPC	DP-CRP	DP-PDS	DP-TPC	JT-COM	JT-CAL	JT-DAQ	JT-HV	JT-CISC
SP-APA	<a href="#">2088735</a>	<a href="#">2088736</a>				<a href="#">2145145</a>	<a href="#">2145136</a>	<a href="#">2145158</a>	<a href="#">2088738</a>	<a href="#">2088739</a>
SP-PDS		<a href="#">2088720</a>				<a href="#">2145146</a>	<a href="#">2145137</a>	<a href="#">2088726</a>	<a href="#">2088721</a>	<a href="#">2088731</a>
SP-TPC						<a href="#">2145147</a>	<a href="#">2145138</a>	<a href="#">2088713</a>	<a href="#">2088706</a>	<a href="#">2088715</a>
DP-CRP				<a href="#">2145157</a>	<a href="#">2088743</a>	<a href="#">2145148</a>	<a href="#">2145139</a>	<a href="#">2145156</a>	<a href="#">2088744</a>	<a href="#">2088742</a>
DP-PDS					<a href="#">2088745</a>	<a href="#">2145149</a>	<a href="#">2145144</a>	<a href="#">2088747</a>	<a href="#">2088746</a>	<a href="#">2088748</a>
DP-TPC						<a href="#">2145153</a>	<a href="#">2145140</a>	<a href="#">2088749</a>	<a href="#">2145155</a>	<a href="#">2088750</a>
JT-COM							<a href="#">2145159</a>	<a href="#">2145151</a>	<a href="#">2145150</a>	<a href="#">2145152</a>
JT-CAL								<a href="#">2145141</a>	<a href="#">2145142</a>	<a href="#">2145143</a>
JT-DAQ									<a href="#">2145154</a>	<a href="#">2088741</a>
JT-HV										<a href="#">2088740</a>



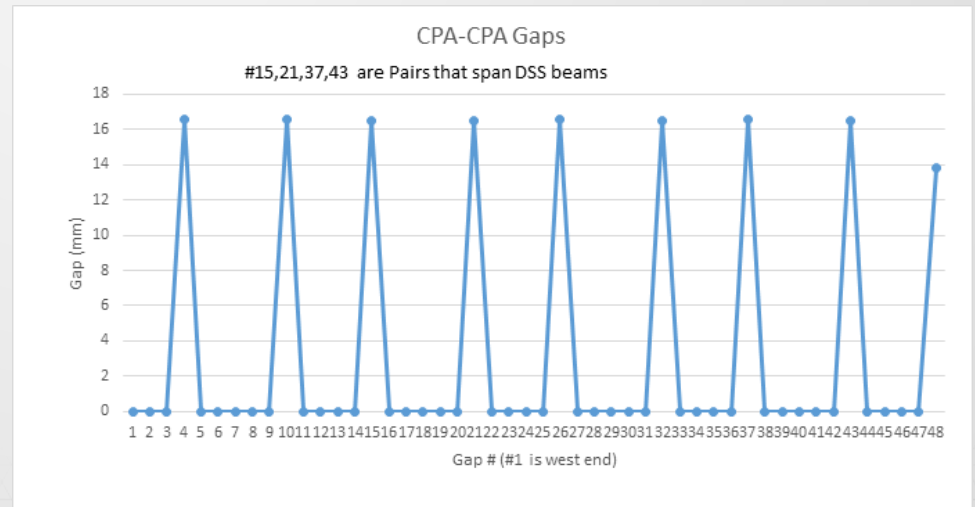
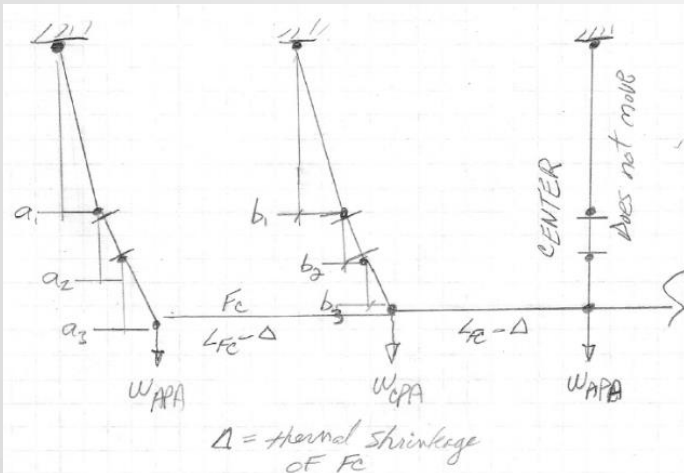
# INTEGRATION/INTERFACES

- DocDb 6260



# THERMAL EFFECTS

- Examined shrinkage in the beam direction
  - Stainless steel DSS beam shrink more than CPA
  - Gaps close between CPAs on the same DSS beam
  - Gaps open up between CPAs on adjoining beams – 17mm
- Examined shrinkage and movement in drift direction – each drive shrinks by 7.5mm



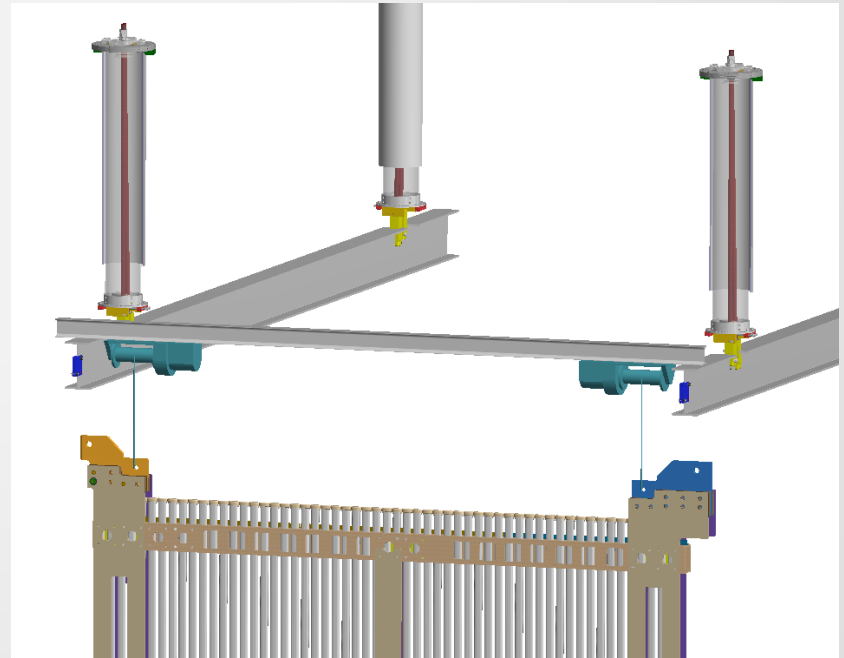
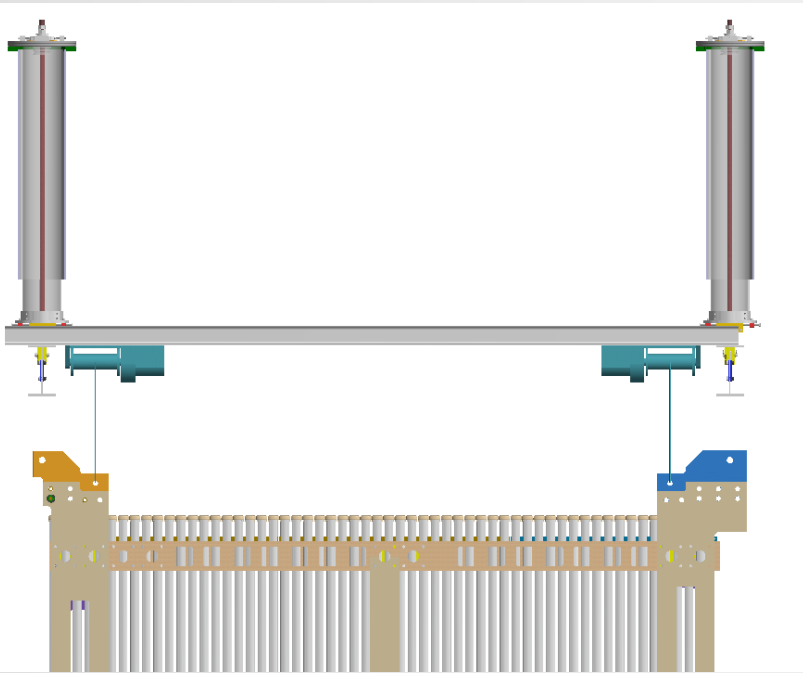


# INSTALLATION

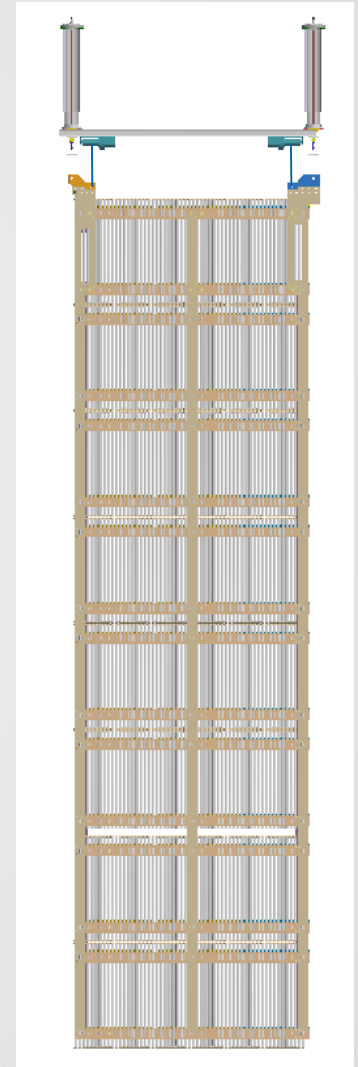
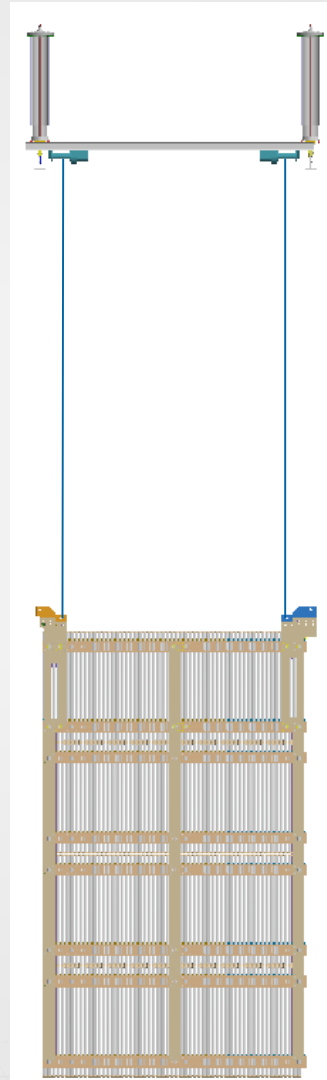
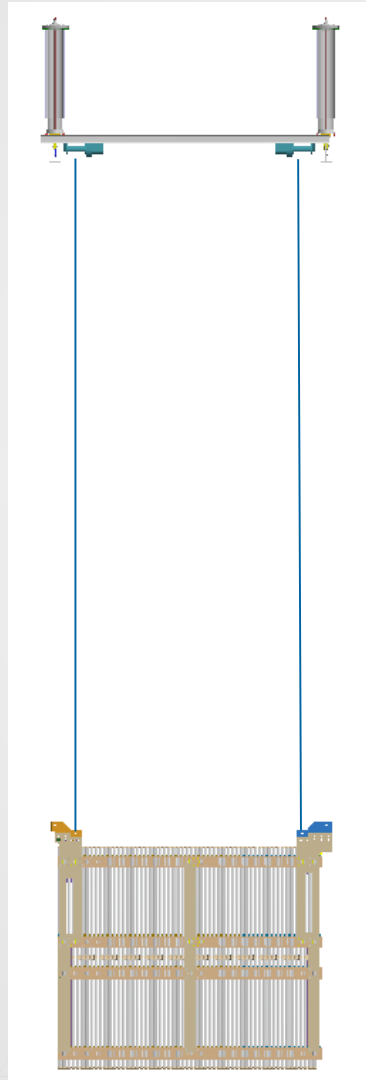
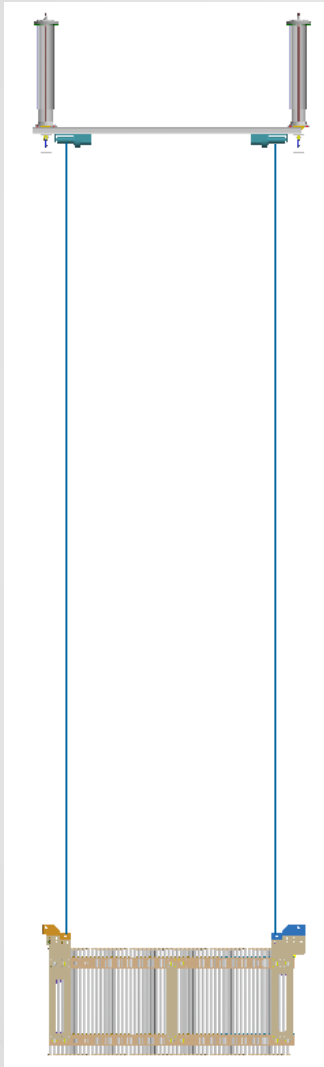
- Detector installation concept based on pDUNE
- Realistic concepts have been developed and have/will be tested at Ash River
- Working with Installation Group to finalize details



# DUNE Far Detector East EW Installation



# DUNE Far Detector East EW Installation



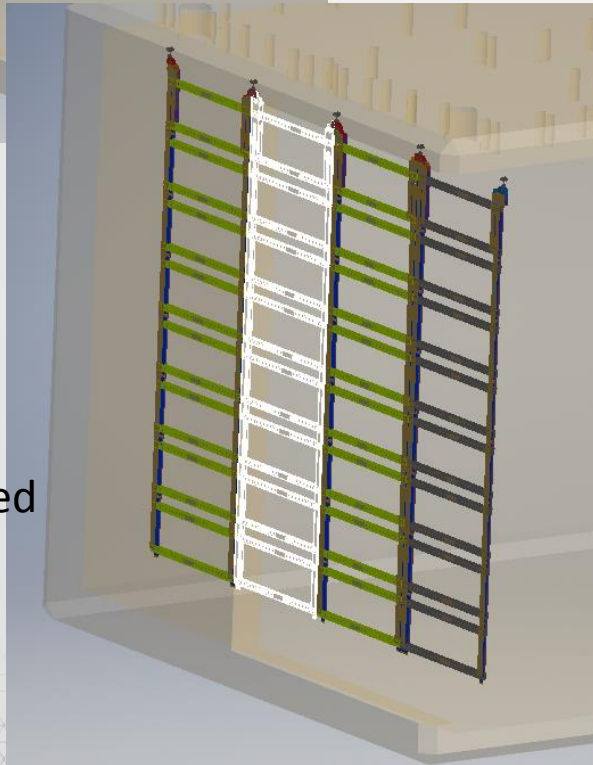
# DUNE FAR DETECTOR EAST EW INSTALLATION



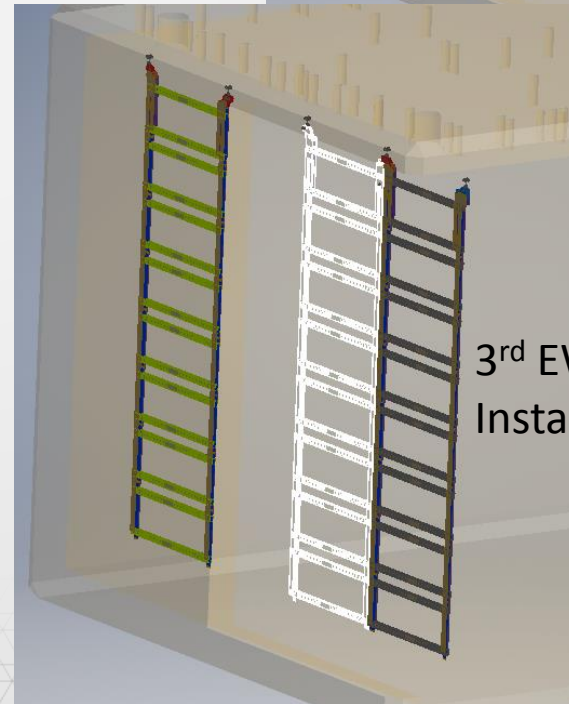
Sout-East EW  
Installed 1st



North-East  
EW Installed  
2nd



4<sup>th</sup> EW  
Installed



3<sup>rd</sup> EW  
Installed

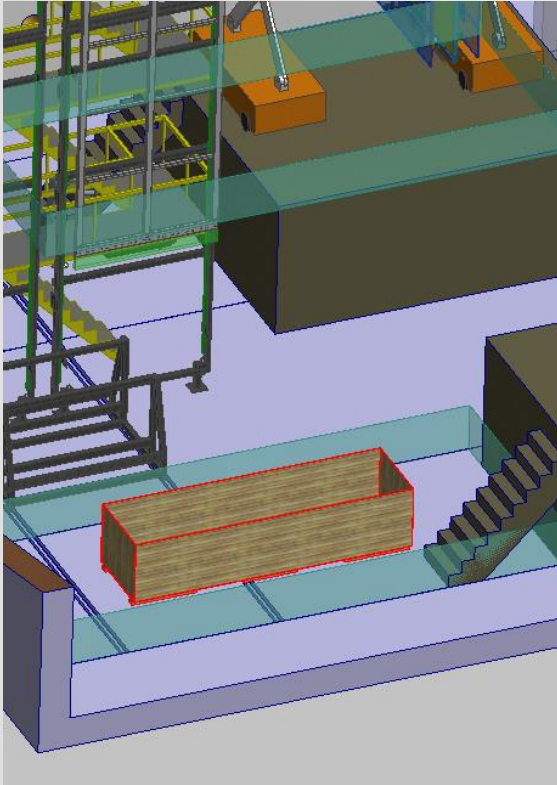




# APA/CPA/FC ROWS 1-24 INSTALLED

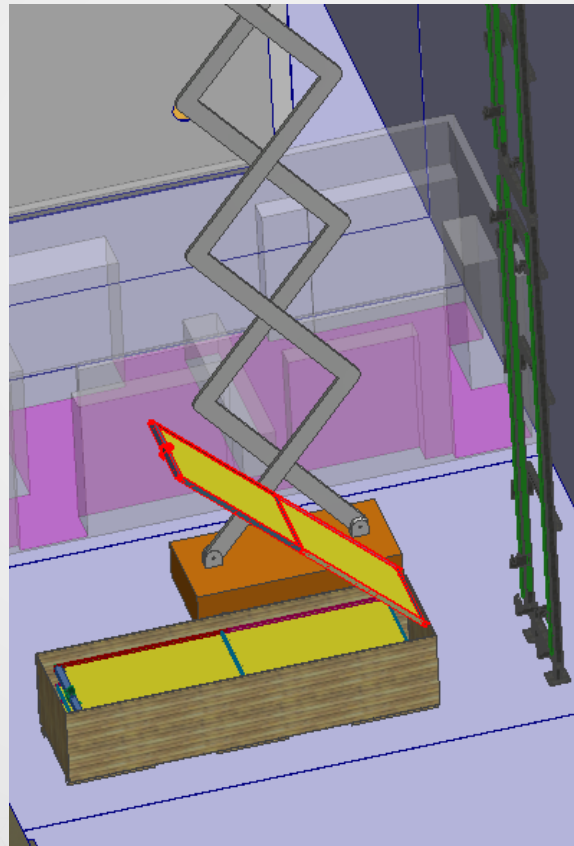


# CPA UNPACKING & ASSEMBLY

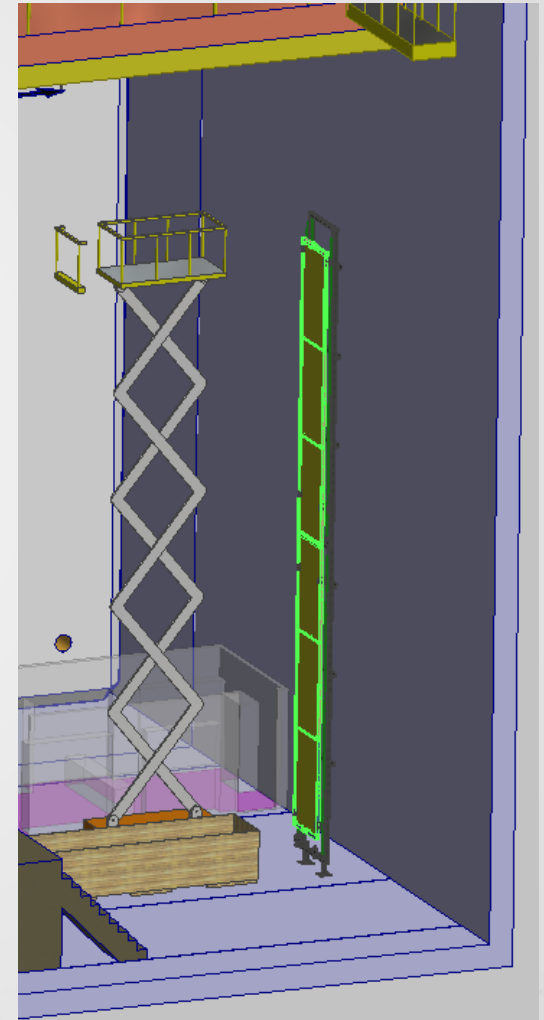


Boxed CPA lowered into SAS and moved to Assy Fixture in CR

Boxed CPA in position.  
1/3 panel being raised  
from crate



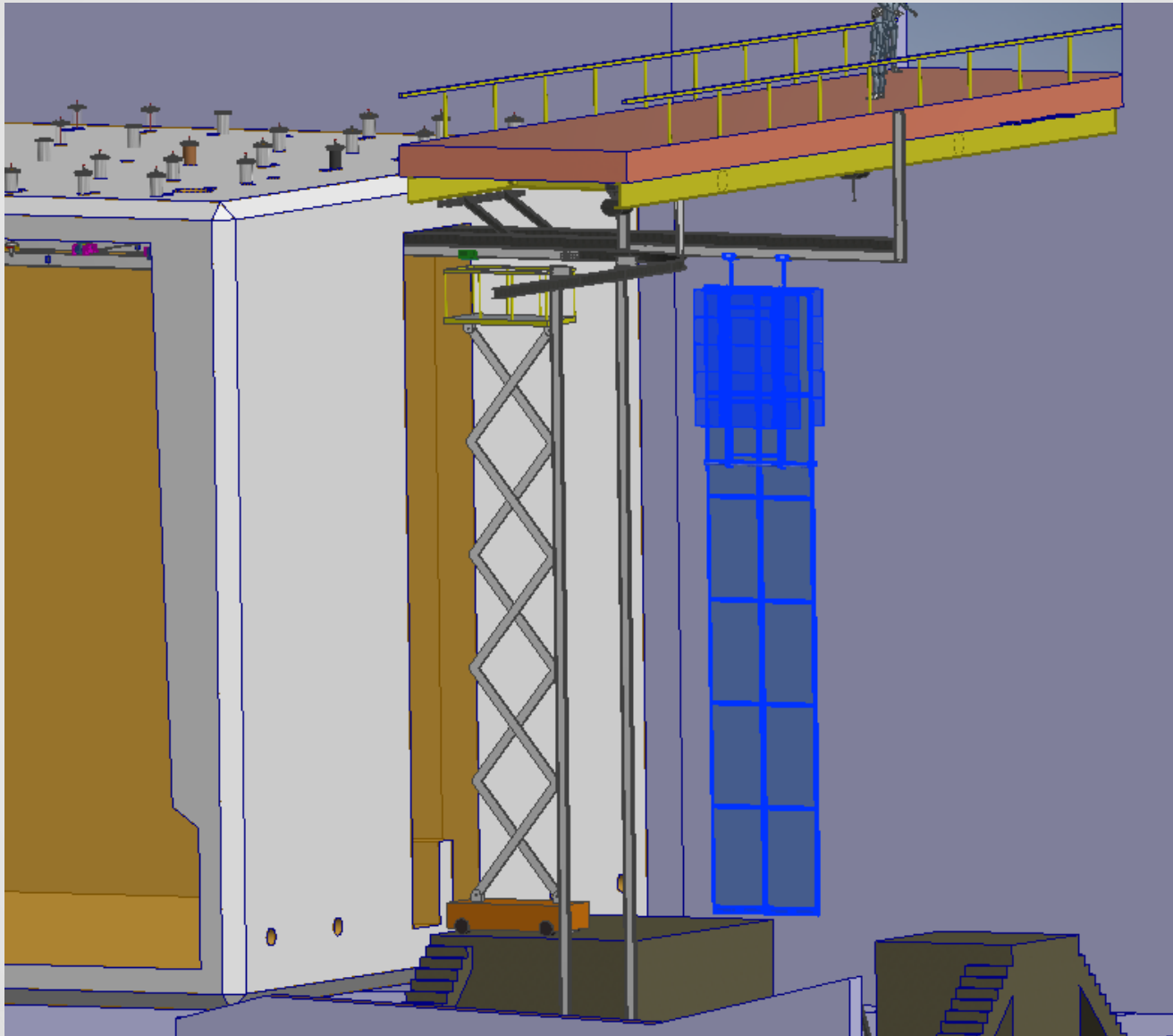
CPA panels placed into fixture



# DUNE FAR DETECTOR

\*Cryostat Steel not shown for clarity\*

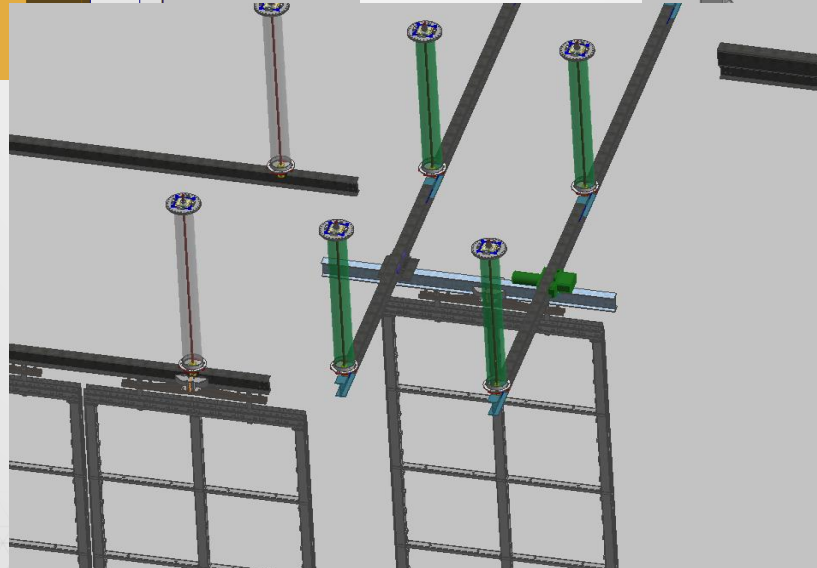
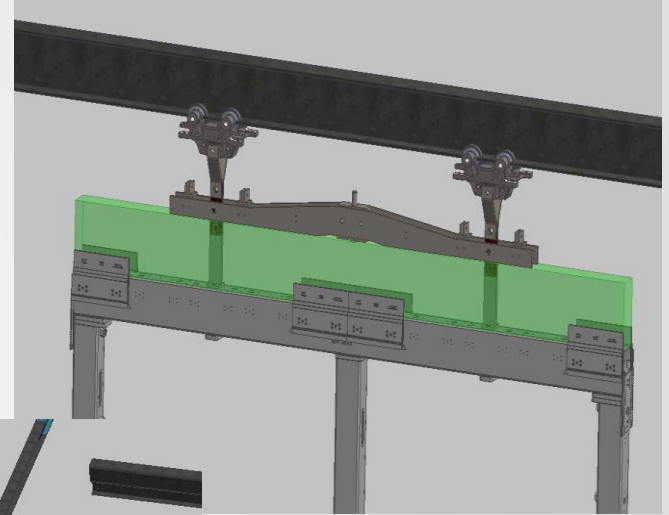
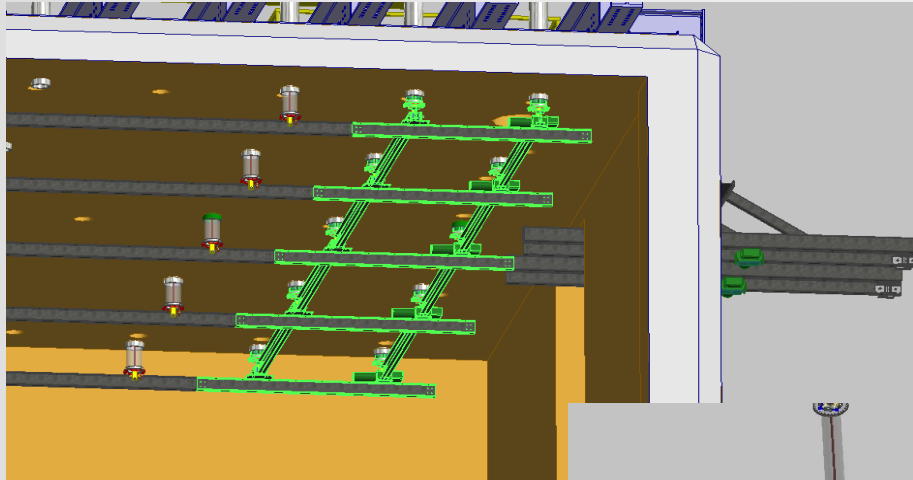
## CPA PAIR HUNG AND TOP FC ATTACHED



Completed CPA Panels (w/o Lower FCs) are Moved thru TCO into Cryostat

# CPA MOVED INTO CRYOSTAT

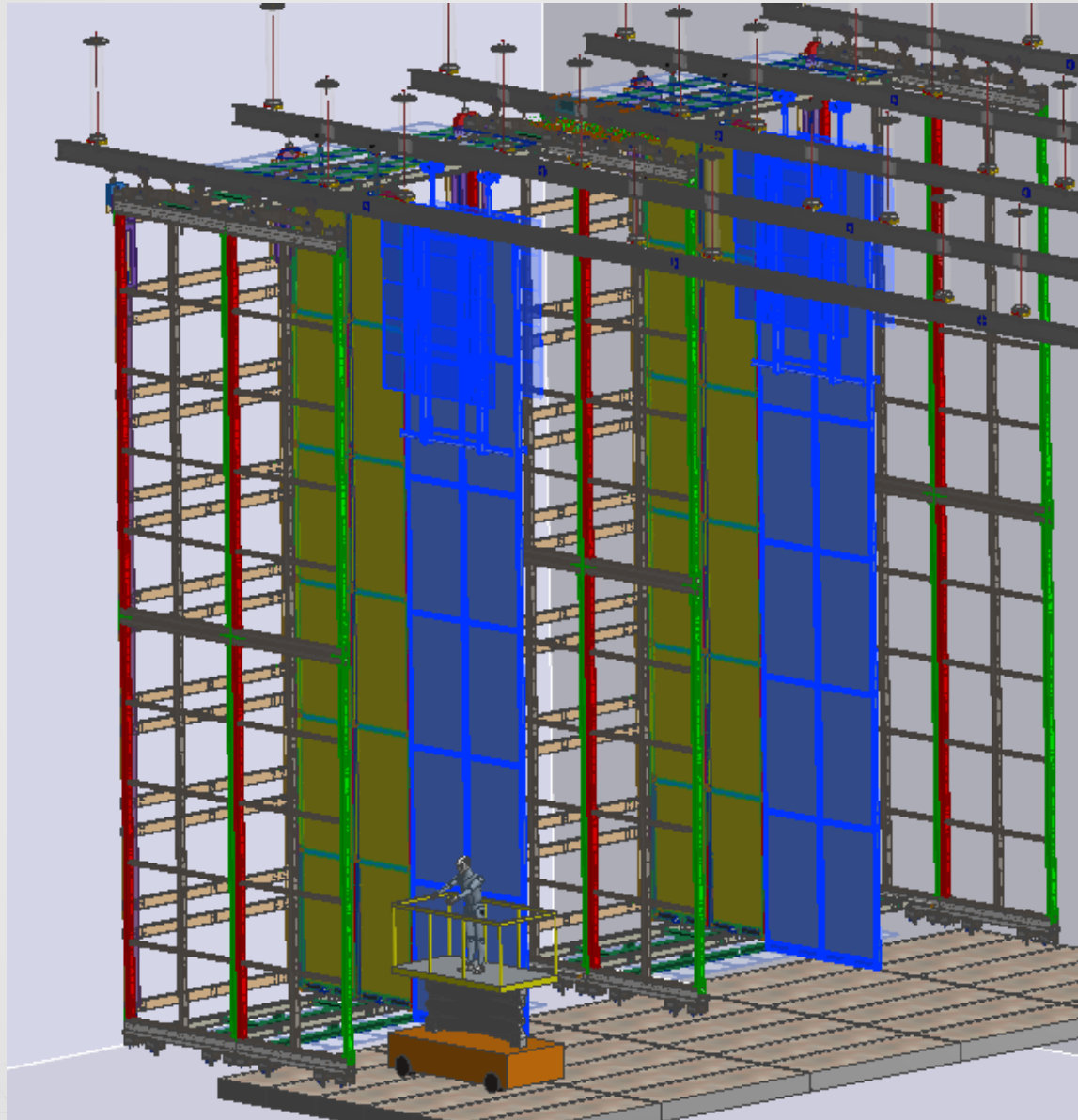
- Shuttle system positions CPA





\*Cryostat not shown for clarity\*

## CPA INSTALLATION

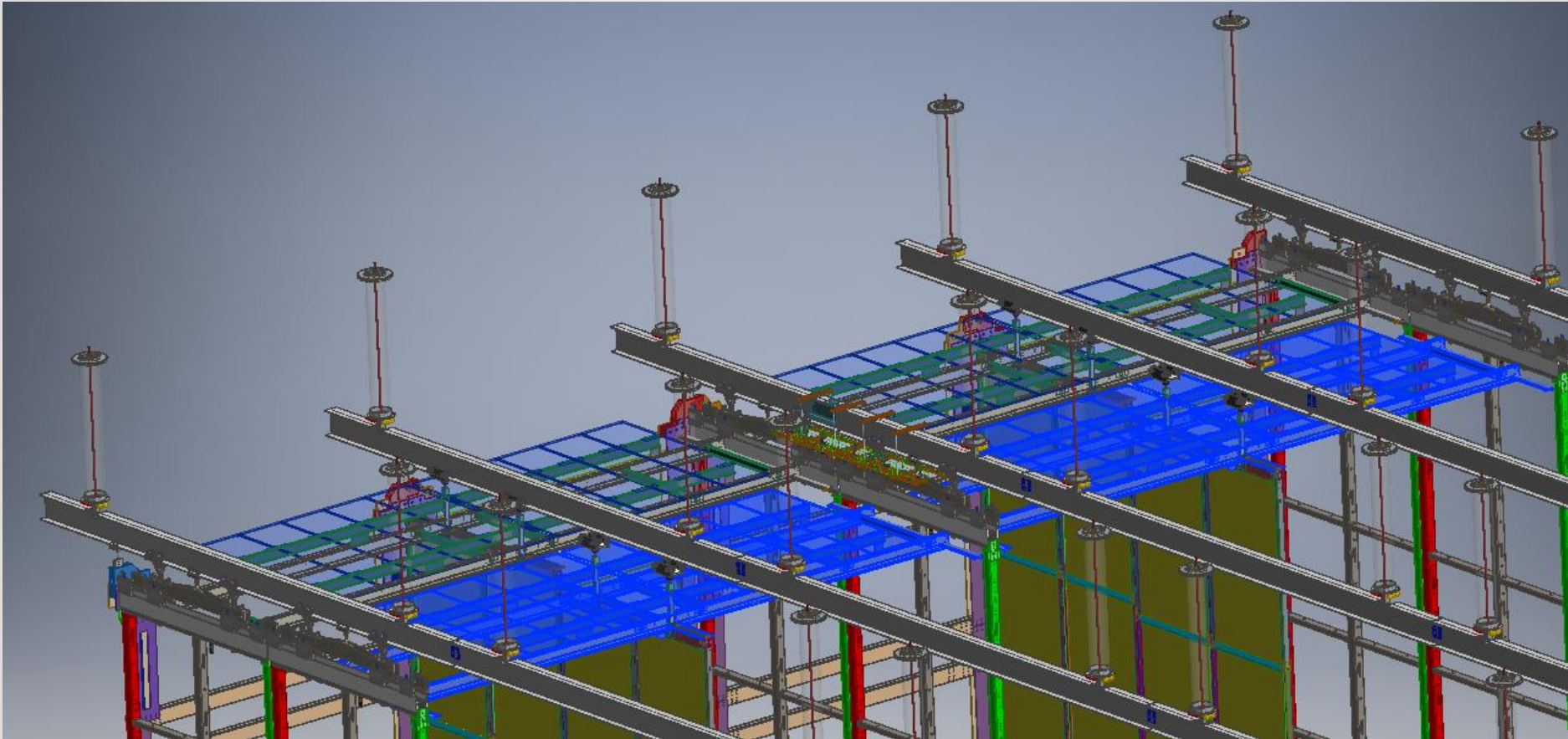


2X CPA Panels Moved into Position and Mounted to DSS

# DUNE FAR DETECTOR

\*Cryostat & Cave not shown for clarity\*

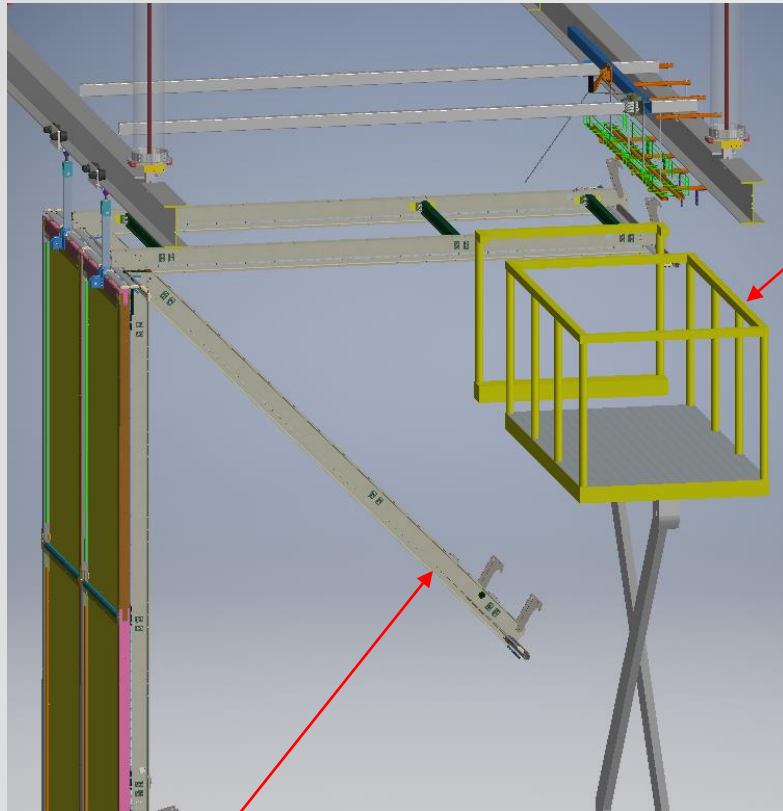
## UPPER FCS DEPLOYED



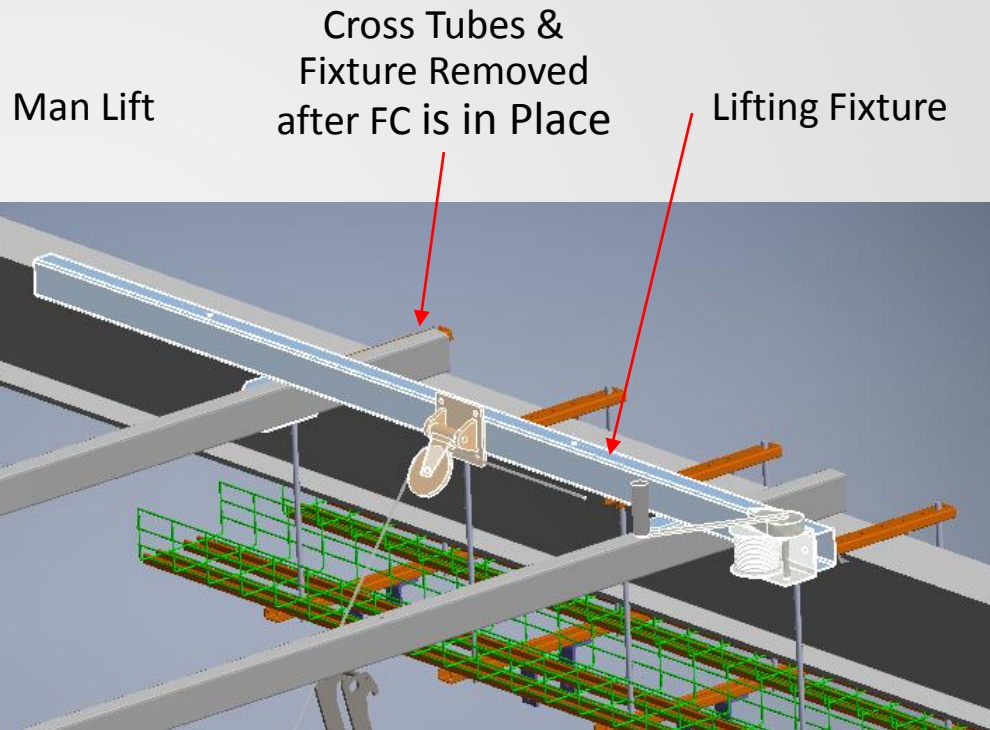
4X Upper FC Panels Deployed

# DUNE FAR DETECTOR

## UPPER FIELD CAGE DEPLOYMENT



FC Panel



Man Lift

Cross Tubes & Fixture Removed after FC is in Place

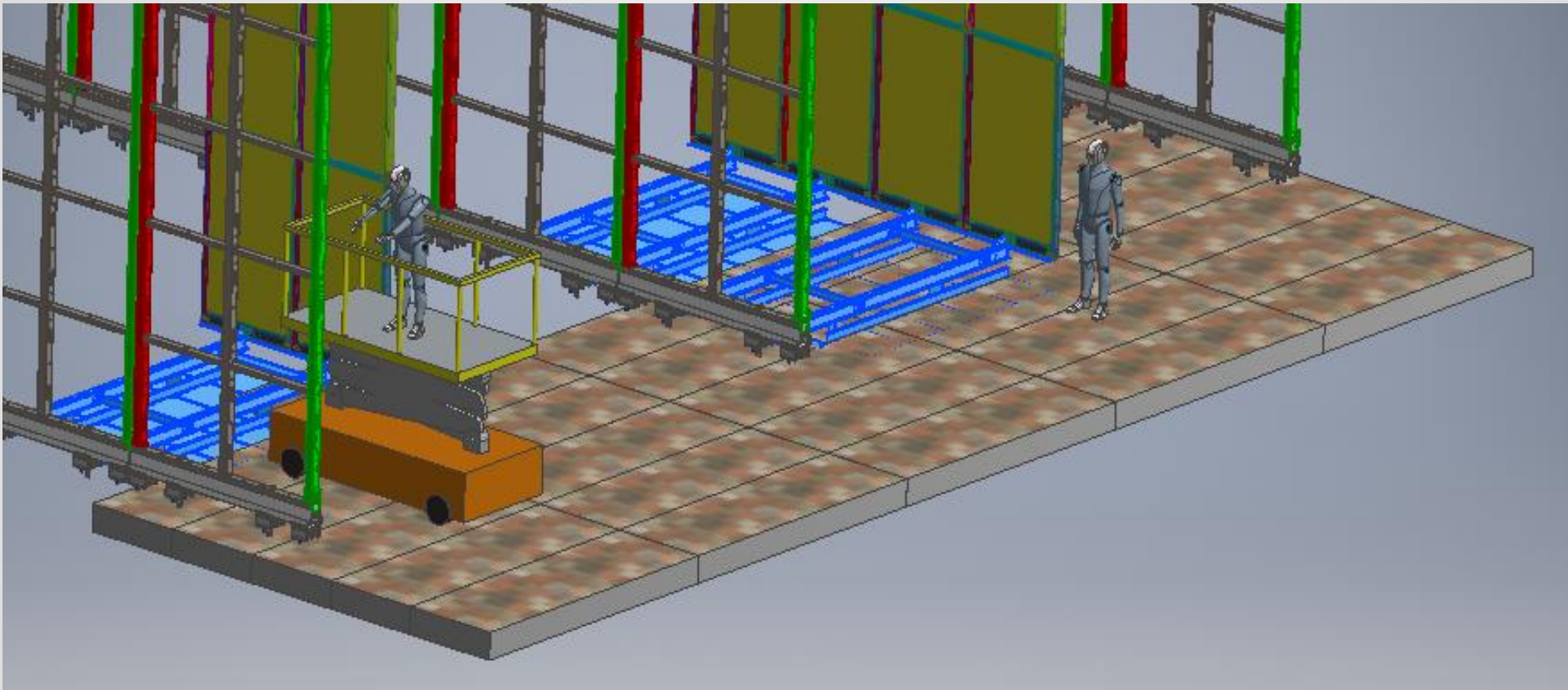
Lifting Fixture



# DUNE FAR DETECTOR

\*Cryostat & Cave not shown for clarity\*

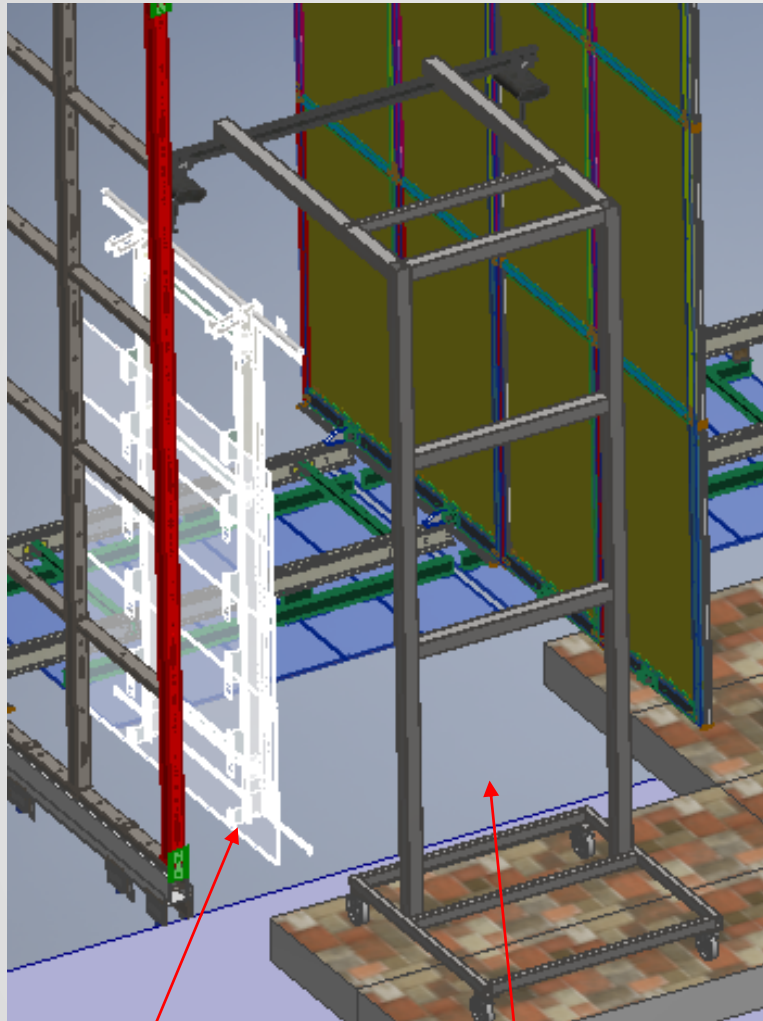
## EAST END (TCO AREA) INSTALLATION



APAs and CPAs continue to be mounted in the Cryostat  
Upper FCs deployed upon hanging of the CPAs  
Lower FCs installed (this process described elsewhere) as floor space  
becomes non-needed.

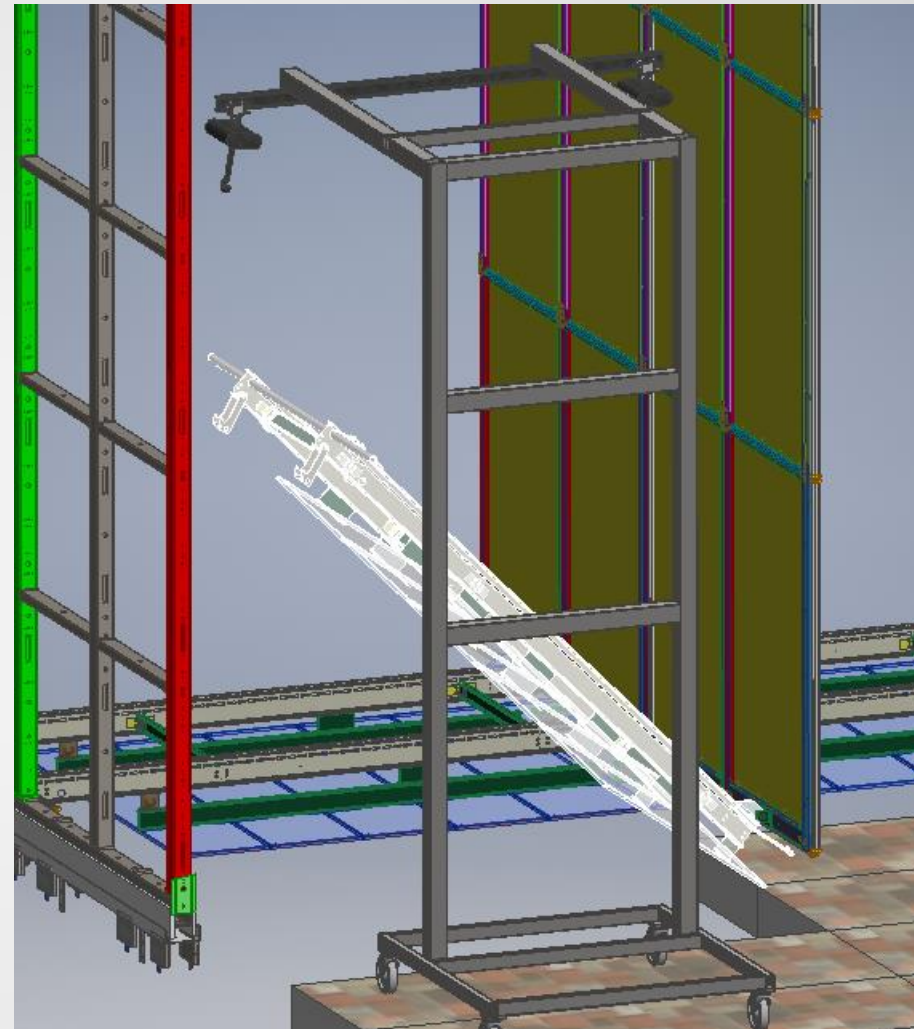


## LOWER FIELD CAGE INSTALLATION & DEPLOYMENT



FC Panel  
Moved

Floor Panels  
Removed



FC is Lowered into Place

# CONCLUSION

- A complete design has been developed.
- No significant design changes from pDUNE
- Extensive physical testing and analysis has been performed and shows we meet Safety Factors
- Developing assembly procedures in conjunction with Installation Group



