R&D Activities, Design and Value Engineering Options

Bo Yu

June 4, 2019

Outline

- Transition to a Revised Field Cage Design
  - Modify the mechanical support structure of all field cage modules. Electrically they are nearly identical to those of ProtoDUNE SP
  - Decouple ground planes from FC. Perhaps eliminate bottom ground plane and implement more localized protections.
- Planned R&D Activities
- Other Design Options
- Prototyping Plan

ProtoDUNE SP HVS Experience

The instability issues encountered in NP04 indicates a connection with charging up of insulator surfaces outside the field cage.

- Several days of quiet operation from a long HV shutdown
- Once a streamer is suppressed and HV restored, it takes a few hours to re-appear, at rather regular intervals.
- The streamer appearance is more frequent when the beam was running.

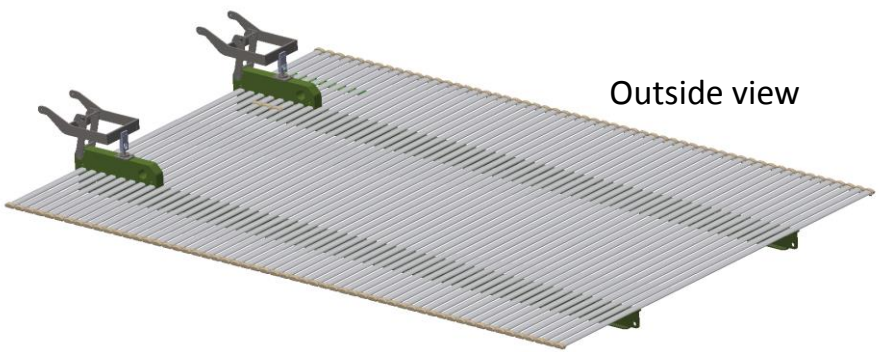
Based on these observations, and many lengthy discussions within the consortium, we decided it is a good idea to eliminate as much as possible the insulators on the outside of the field cage.

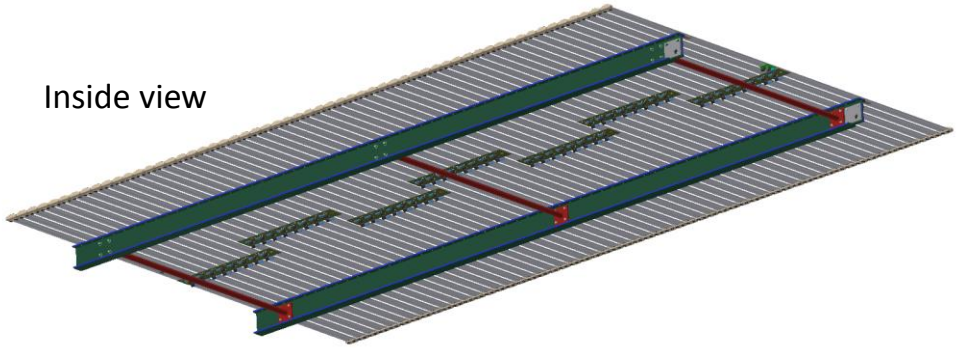
Fortunately for the DP FC+cathode, this is fairly straightforward and can be done perfectly. We are making this the baseline design for the DP HVS.

For SP, it is more complicated due to some unavoidable support structures.

Modification of the T/B FC Module

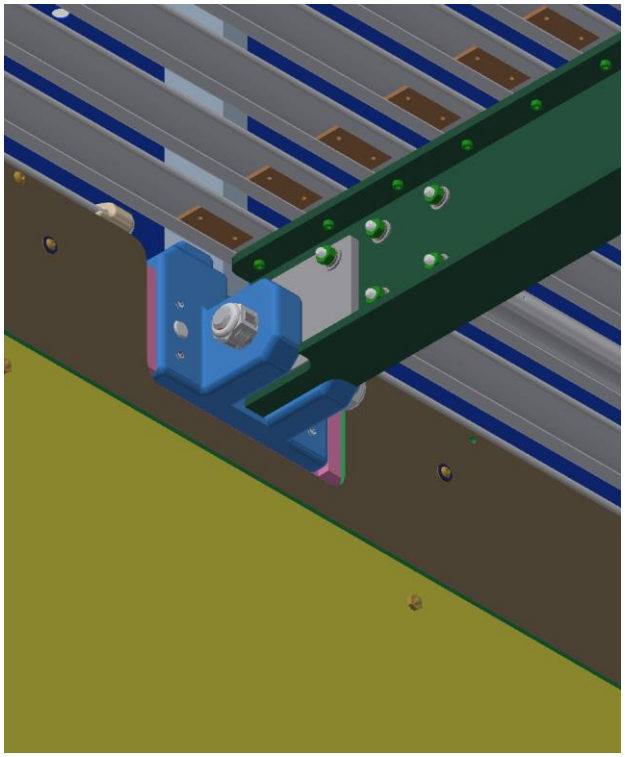
- Mount all FC profiles on the outside of the FRP I-beam flange instead of through slots on the web. To minimize the intrusion of I-beams into the active volume, the I-beams are changed to 4”x2”x1/4”. They will deflect ~ 5mm dry, 2mm in LAr.
- Use aluminum cross braces inside the FC to keep the two I-beams square. The braces are connected electrically to the nearby FC profiles.
- The hinges on the CPA side are simpler: no need for the large aluminum block on the FC. Add some local metal reinforcement around the hole on the web.
- Special APA latch support blocks are mounted on the APA end of the FC on the outside to accept the existing latches. These blocks preserves the current APA-T/B FC mechanical interface such that these modules are drop in replacement from the baseline design.
- No fiberglass rods/nuts in the assembly.

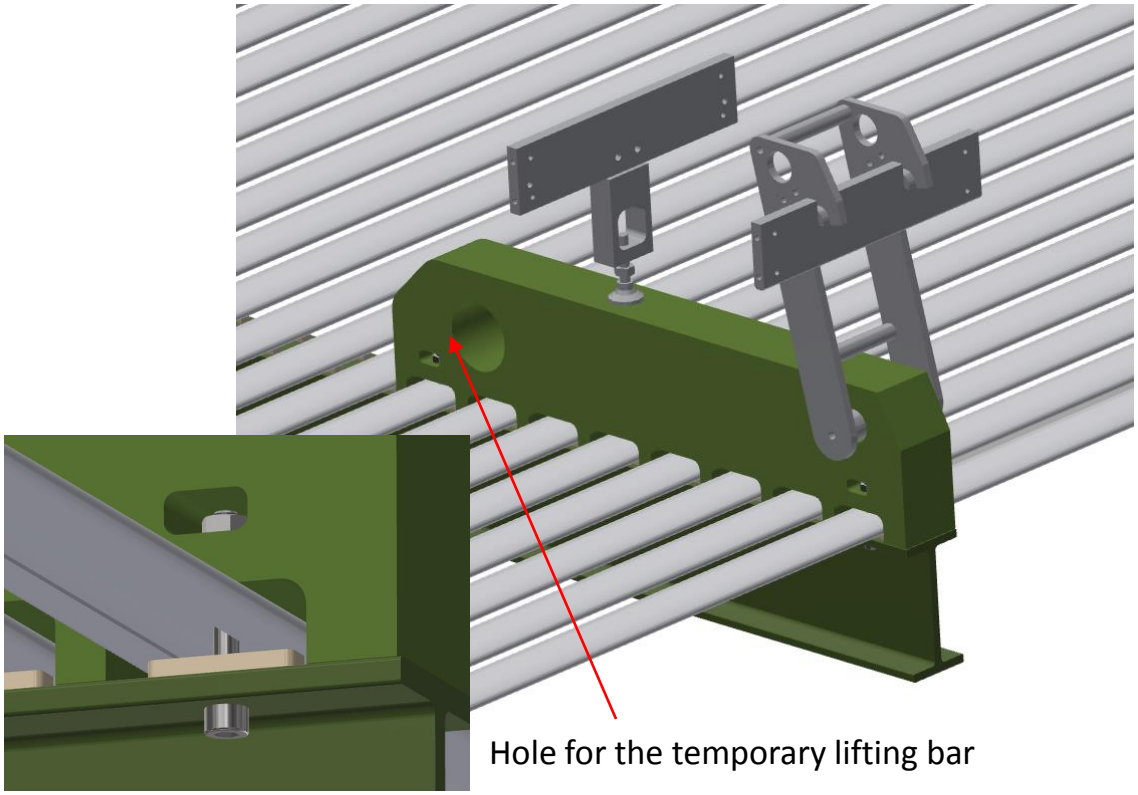




CPA Hinges and APA Latches

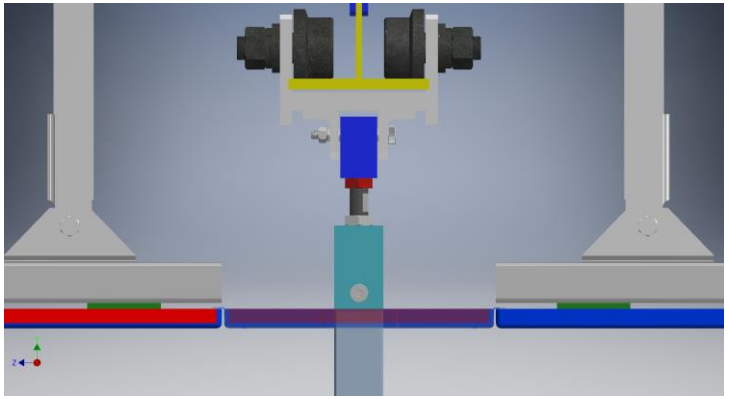
We can design the pivot points, and the APA latches on the T/B FC such that they are exactly in the same position as the current baseline design, therefore no changes on the mechanical interfaces.

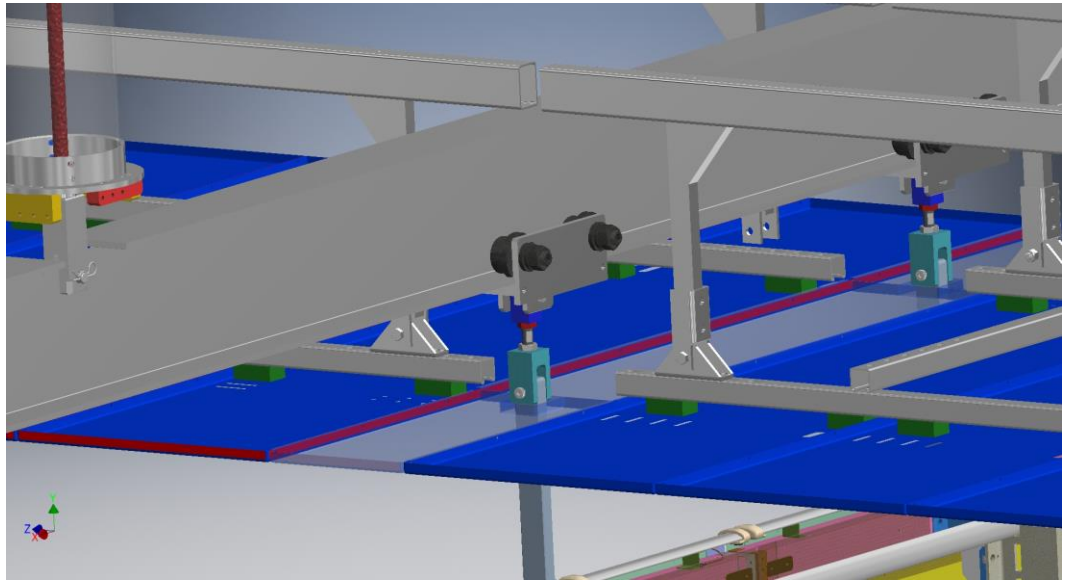




Top Ground Plane

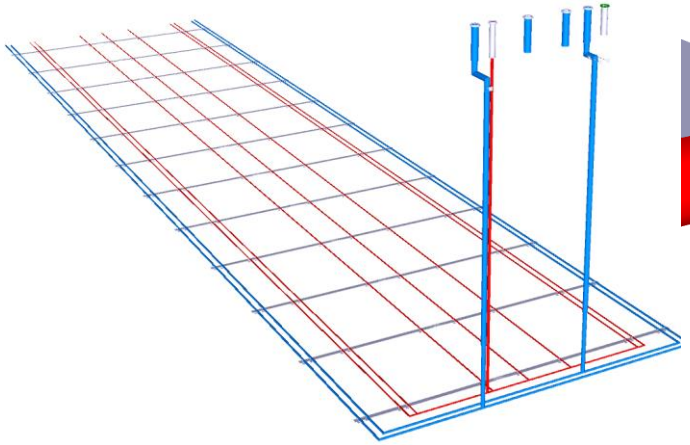
- In the baseline design, we have eliminated the FRP standoffs near the cathode, but we still need 2 in the not so low E field region.
- Since the bottom FC deployment scheme requires the installation of two transverse beams above the DSS beams, we have the opportunity to take advantage of this structure, and support the top ground plane directly under it.
- The GP module is assembled by attaching the GP tiles to a set of metal frames. Inside the cryostat, the GP assembly is hoisted up vertically, attached to the cross beams, then rotated into horizontal position and locked to hangers at the APA side.
- Need wide filler pieces in the middle

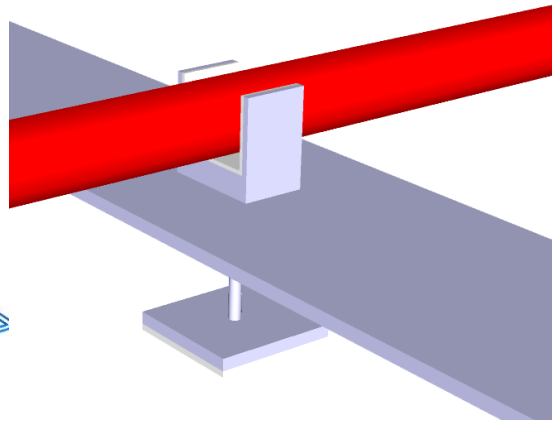


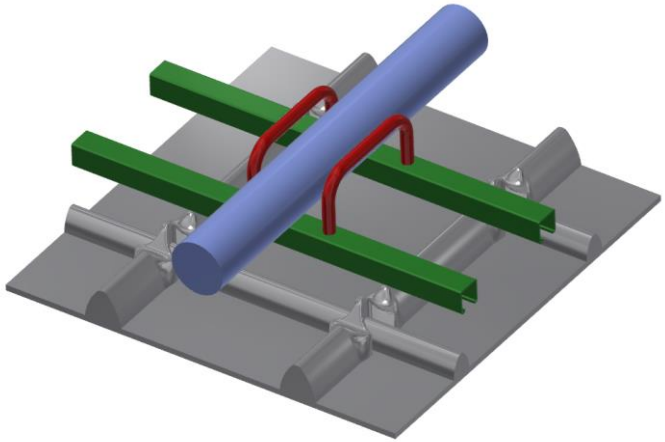


Bottom Ground Plane

- The clearance bottom FC to membrane flat is about 0.7m, much larger than the 0.4cm we have in ProtoDUNE SP upstream endwall. The E field on the knuckle is about 20kV/cm without a ground plane in between.
- On the bottom of the cryostat, there is a set of cryogenic pipes that runs the entire length of the cryostat at different distances from the cathode planes. On paper, they are not worse than the knuckles of the membrane in terms of E field. However, they are supported by a set of transverse frames for stability. They have sharp edges in the current design model.
- A simple modification to the pipe support structure could make the E field below 30kV/cm.
- We have to negotiate with the cryogenic group to find a solution.

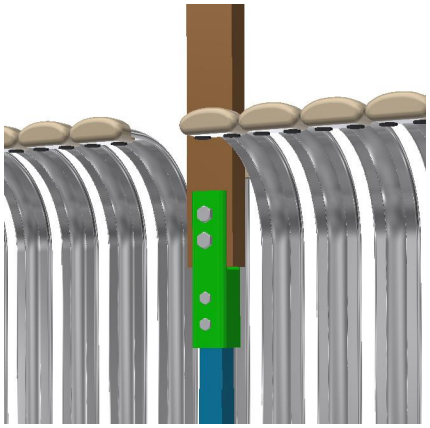






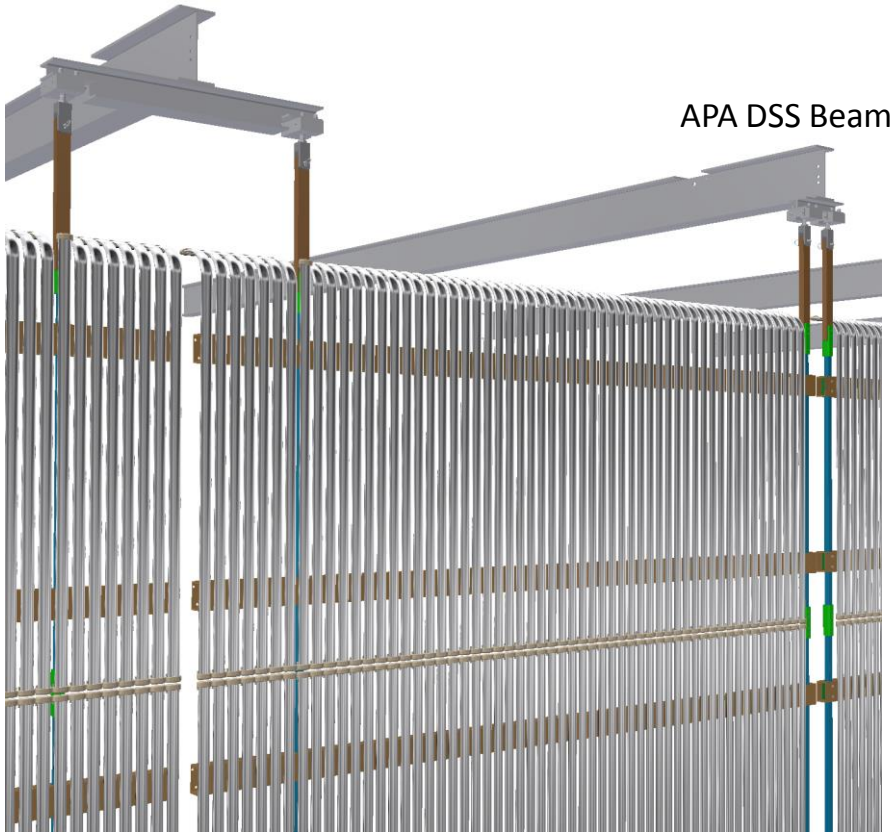
Modifications to the EW FC

- 3 different types of FC modules: top, middle, bottom.
- Remove “all” support structures facing the cryostat wall.
- Use 90 degree bent profiles at the top and bottom to close the large gaps to the T/B FC modules.
- Use metal bars as vertical support and interconnect between modules. They are biased at appropriate voltages through the voltage divider boards.
- Use thin G10 bar to support the CPA end of the FC. And move this support point away from the CPA as much as possible.
- No fiberglass bolts/rods/sleeves/nuts.



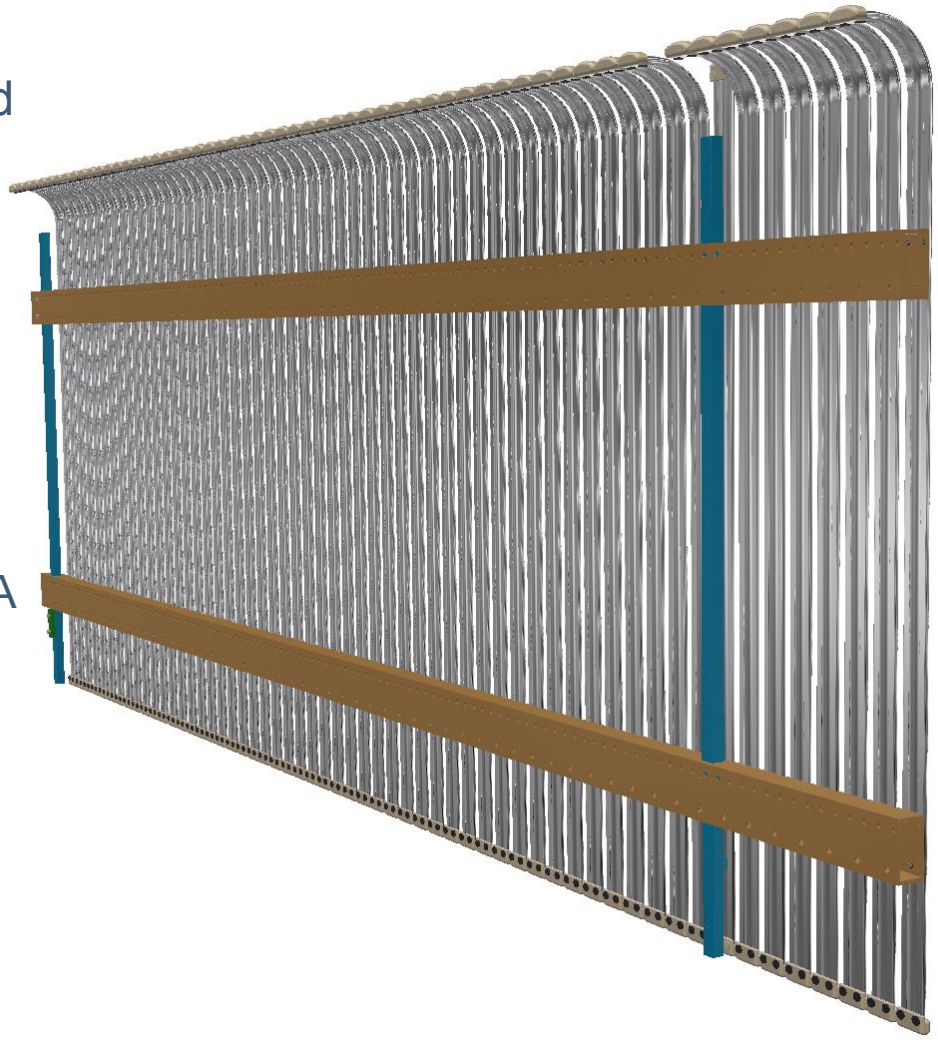
CPA DSS Beam

APA DSS Beam



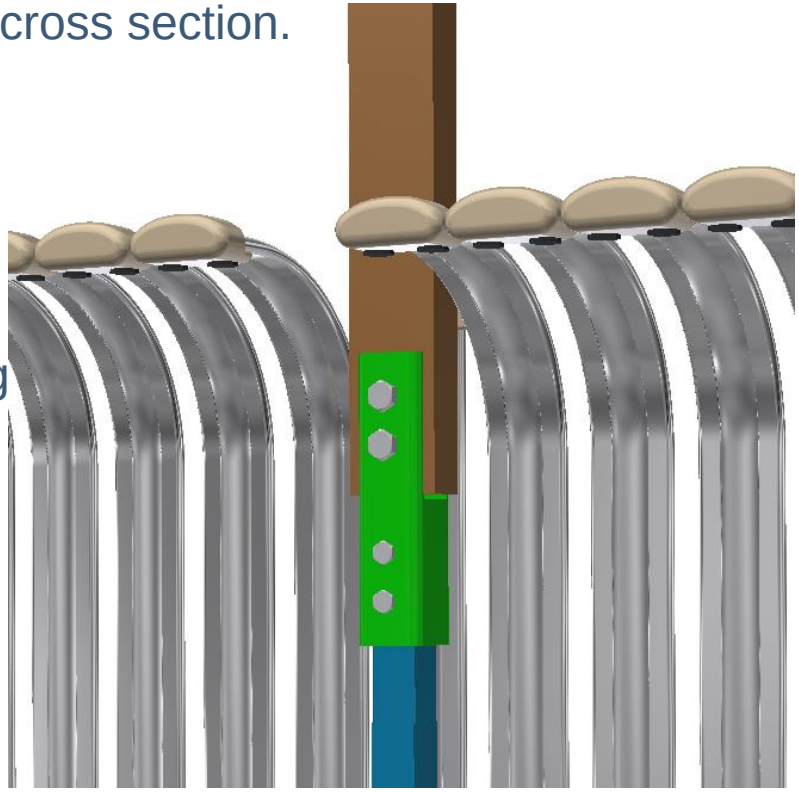
Inside FC View

- The vertical profiles are locked onto the upper 2”x4”x1/4” FRP beam, and constrained on the lower beam.
- The two FRP beams are linked by 2 metal bars using metal bolts and nuts. The CPA side metal bar is positioned behind a profile and electrically connected to have the same voltage. The APA side metal bar is within the thickness of the APA and grounded.
- If suitable aluminum bars are found to have sufficient strength, with similar CTE along the profiles and the structural bars, the profiles can be locked on both FRP beams and result in a much stiffer module.



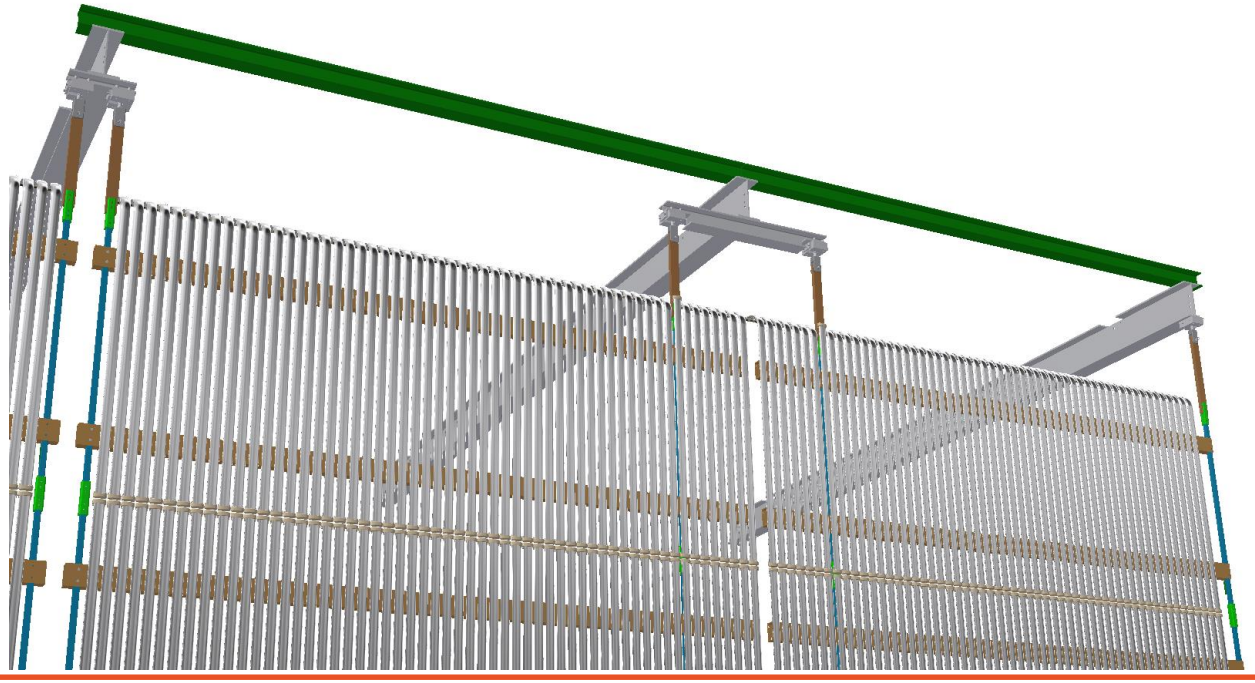
Load on the G10 Bar

- More than ½ of the weight of the EWFC is supported through this G10 bar. Based on our previous destructive tests on the G10 samples, each square inch cross section has a break load of more than 16000 kg.
- The entire 12m high stack of EWFC modules weighs about 500kg dry. In LAr, the structure loses nearly 2/3 of its weight. We appear to have large safety margins to use a bar with ~ 1 square inch cross section.
- The E field around this G10 bar is very similar to that of the CPA lifting bars. So far we have no indication that these CPA hangers were causing problems in NP04.
- Nevertheless, we are looking into if adding corrugations to the bars could improve their reliability.



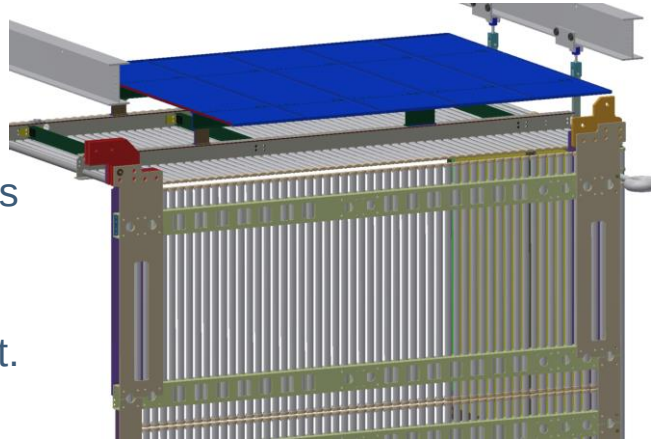
Installation and Load Transfer

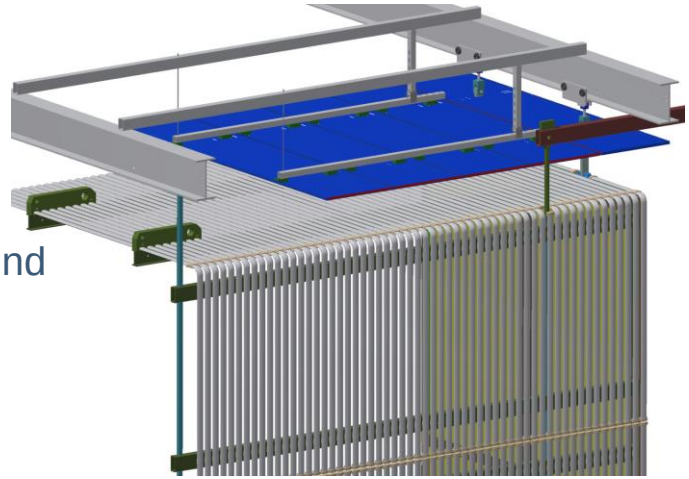
- Installation of the EWFC modules into a full height column is simpler than that of the NP04: only metal fasteners are involved and angular adjustment can be made to ensure flatness of the wall.
- Because the CPA side lifting bar is off the center of the DSS beam, two temporary support beams (green in this figure) spanning the APA and CPA DSS beams are needed to lift up the EWFC modules as they are being stacked. Once a pair of EWs on both sides of the CPA are in position, the load can be transferred to the short transverse beam, and the temporary beams removed.



Summary of Benefits of this FC Design

- Top and bottom FC modules have the same mechanical interfaces to CPAs and APAs. They are designed to be direct replacement of the baseline version.
- Eliminates the aluminum hinges on the top/bottom FC. Improves drift field uniformity near the CPA hinges.
- Decoupling of the GP from FC modules makes shipping and handling of the FC modules simpler, more compact and efficient.
- EWFC vertical load bearing parts are all metal (except the top most G10 bar), with metal fasteners. Top/bottom FC modules' cross bracing bars are now metal.
  - Eliminates all fiberglass threaded rods, bushings and nuts. Makes the assembly simpler and cleaner.
- Eliminates all the rectangular cutouts on the FRP beams, simplifies parts fabrication. No more threading profiles through cutouts: much faster module assembly.
  - We are looking into assembling the FC modules underground to avoid costly and risky shipping of assembled modules.
- Since all FRP parts are in low field region, no need for coating machined edges on the FRP beams.
- This is a good value engineering case.





R&D Activites and Design Options

We have a few on going technical activities aimed at understanding component behavior, and validating design options:

- Comparison of insulating caps vs. conductive caps in LAr under HV.
  - Completed two rounds of test: Insulating caps are not more likely to cause HV instabilities
- Evaluate higher resistivity (~1GΩ/sq) Kapton film, and alternative sources.
  - On going. GΩ/sq Kapton film available, but not at commercial production stage
- Evaluate characteristics and performance of WLS coated reflector foils in LAr aiming for installation on the cathode surfaces
  - Nearly complete. Results promising. Waiting for xenon doping results for comparison.
- Perform circuit analysis of the full HV system to better understand the large scale system behavior, identify system weaknesses, and explore further improvements.
  - On going, some early interesting results emerging.

R&D Activities and Design Options

- Develop a highly resistive profile cap as a possible replacement of the insulating FC profile cap
  - Aim at removing the last bit of insulator outside of the FC.
  - Early samples available
- Validate the 90 degree bent profiles at FC corners
- Upgrade the HV filter design
  - CERN has developed a promising dry filter design
- Discharge probability anode vs cathode
  - Ascertain the need for ground planes at the bottom of the cryostat, and GP edge protection
- Discharge probability vs pressure/depth
  - Ascertain the need for ground planes at the bottom of the cryostat
- CPA/FC insulating hanger options
  - The only insulators in the high field region that we cannot remove. Is there a safer hanger design?
- CPA FSS edge protection
  - Make them safe and production friendly

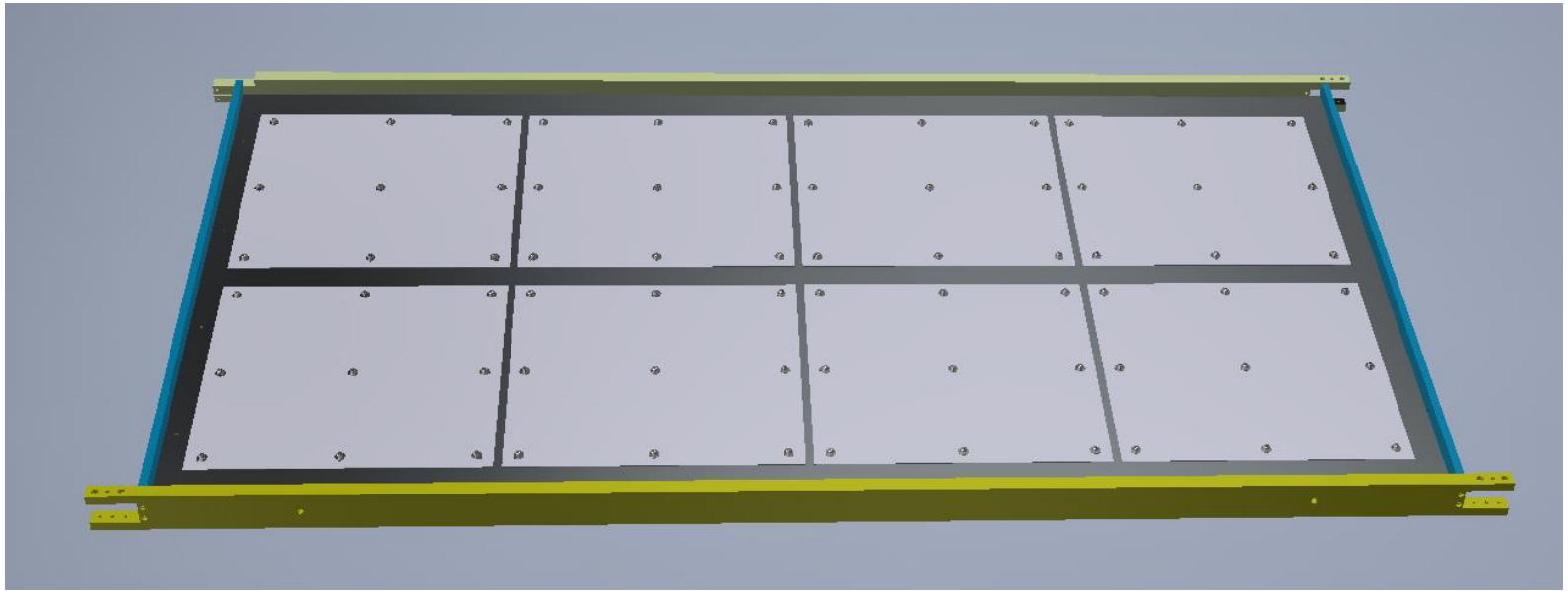
Other Design Feature Options

These features are requested by other consortia. We have initial interface documents regarding these feature. But they are not officially in the baseline design because the detailed specifications have not been determined.

1. Light diffusers on the CPA for PD calibration
   - Implemented in ProtoDUNE SP
   - Included in official interface document with PDS
   - Number of diffusers and their locations are not settled.
2. Reflector panels on the CPA to increase light sensitivity to CPA side events
   - A joint HVS-PDS R&D activity on effectiveness and E field compatibility
   - HVS to provide mounting features
   - No decision on implementation in 1st SP FD yet
3. FC penetrations to accommodate calibration laser heads
   - Need to have openings in the top FC modules
   - No decision on the EWFC openings
   - Interface document in the works.

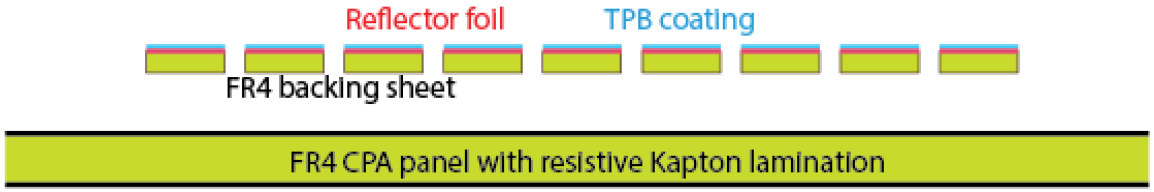
CPA with Reflector Foil Concept

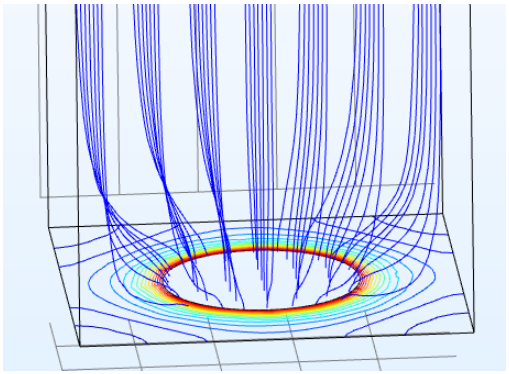
- The goal is to preserve the current CPA construction as much as possible, and to provide the option of implementing the reflector foils post CPA production.
- The preferred solution is to maintain the current CPA design, and include a set of attachment holes on each CPA resistive panel to allow the installation of reflector foils in smaller tiles on both sides of the CPA surfaces at ITF or in the UG cleanroom.



Reflector Module Option 3:

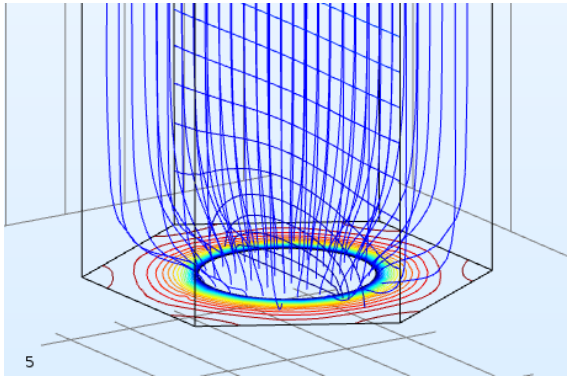
- Construction: Laminate the 3M reflector foil on a thin FR4 backing sheet, perforate the lamination with an array of holes to expose the resistive surface on the cathode, evaporate TPB on the reflector surface, mount the reinforced reflector foil on the CPA panel.
- Pros: reduces the magnitude of surface charging to avoid breakdown and drift field distortion
- Cons: more complex construction; reduced reflector coverage





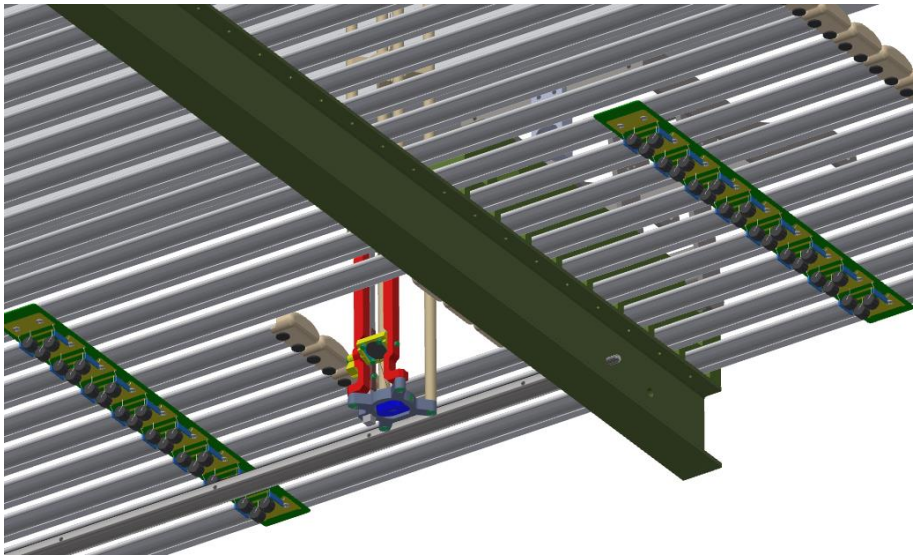
Potential distribution on a 1cm square cell with 5mm hole. The maximum voltage at the corners of the cell is 290V.

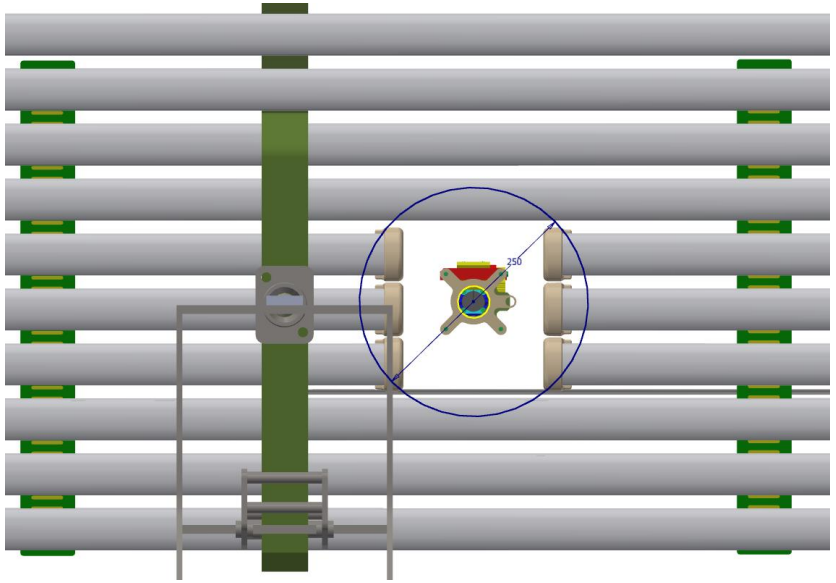
Potential distribution on a 1cm hex cell with 5mm hole. The maximum voltage at the corners of the cell is 220V.



Top FC Openings for Calibration Laser

- The calibration consortium has requested several cryostat penetrations designed into the current SP cryostat for calibration laser beams. Most of them are on top of the TPC, requiring openings in the top FC in order to lower the laser head into the active volume of the TPC.
- Our implementation at this location: Cut the profiles on FC module into two sections. Both sections are mounted on one I-beam, and stabilized by special double value R divider boards.





Plan for Down Select

- Design options:
  - Insulating profile caps vs resistive caps
  - Stay with current Kapton film (~MΩ/sq) or go with one with higher resistivity
  - HV ripple filter design (oil filled pot vs dry pipe)
  - CPA/FC hanger profile (with or without corrugations)
  - Bottom ground plane
  - Ground plane current monitor
  - Field cage termination bias power supplies
- Hold an internal review of HVS design options in early 2020 to make a decision on remaining design choices internal to the HVS consortium.
- PDS and Calibration options must be decided by Tech. Board in early 2020 if to be included in ProtoDUNE II.

Prototyping Activities

- Recent activities @ Ash River
  - Demonstration of 12m CPA modules assembly and handling
  - Proof of concept for the baseline ground plane attachment scheme
  - Proof of concept for the new ground plane construction and installation
- Current activities
  - Proof of concept for the new FC design, module assembly time estimate-> update production time and cost estimates
- Future activities: FY2020
  - Construction of prototype T/B FC modules at FD production site (2 top + 2 bottom?)
  - Construction of prototype EW FC modules at FD production site (3.5m x 12m)
  - Construction of prototype CPA modules (2.3m x 12m)
  - Perform trial assembly @ Ash River
- Future activities: FY2021
  - Production for ProtoDUNE SP Run2

Summary

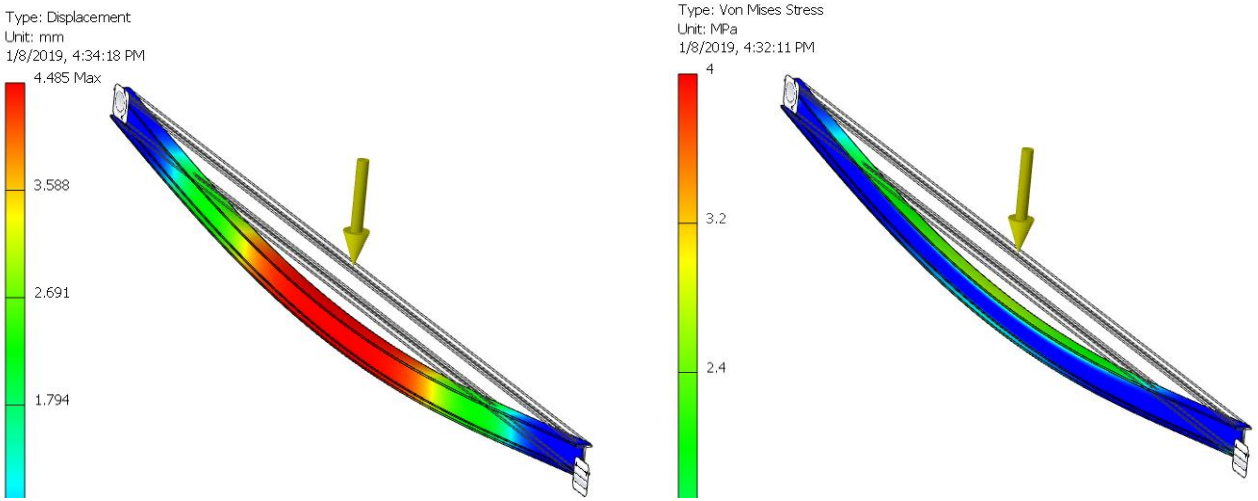
- The HVS Consortium has developed an upgrade to the baseline field cage design presented in this review. CPAs remain unchanged.
- The consortium has decided to adopt this design and fully develop it into the final design after this review. This final design will be implemented in ProtoDUNE SP Run 2.
- In the meantime, we are carrying out a set of R&D activities, aiming to better understand the electrical properties of the HV system from component to system level. Some of the new design features will also be validated at small scale, and may be included in NP04 Run 2.
- There are several design options requested by other consortia. The detail implementations have not been settled at this time, and will be included in the final design as the specifications of these features are finalized.
- We have planned one round of full scale mockup/prototyping @ Ash River. And the ProtoDUNE SP Run 2 will be the final validation of the design.

Backup Slides

Deflection of a 4” FRP I-Beam

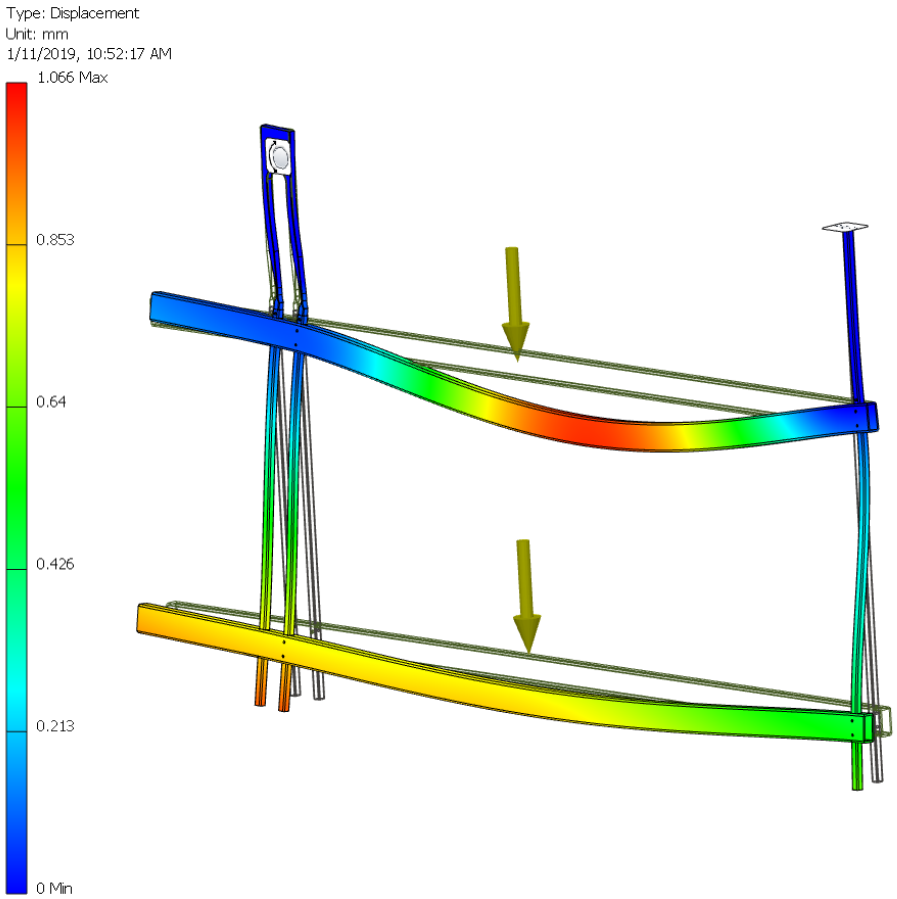
- Each NP04 profile with caps weighs 592g. Total weight of 57 profiles is 34kg.
- 4”x2”x1/4” FRP I-beam @ 3.6m long weighs about 7.7kg.
- Autodesk material library data for GFRP:
  - Young’s modulus: 13.9 GPa
  - Yield @ 58.1MPa

Deflection: 4.5mm

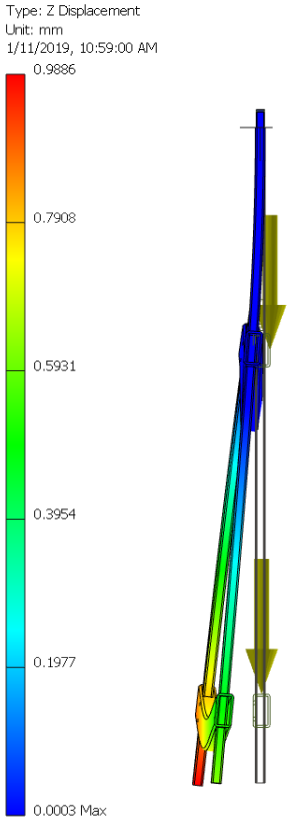


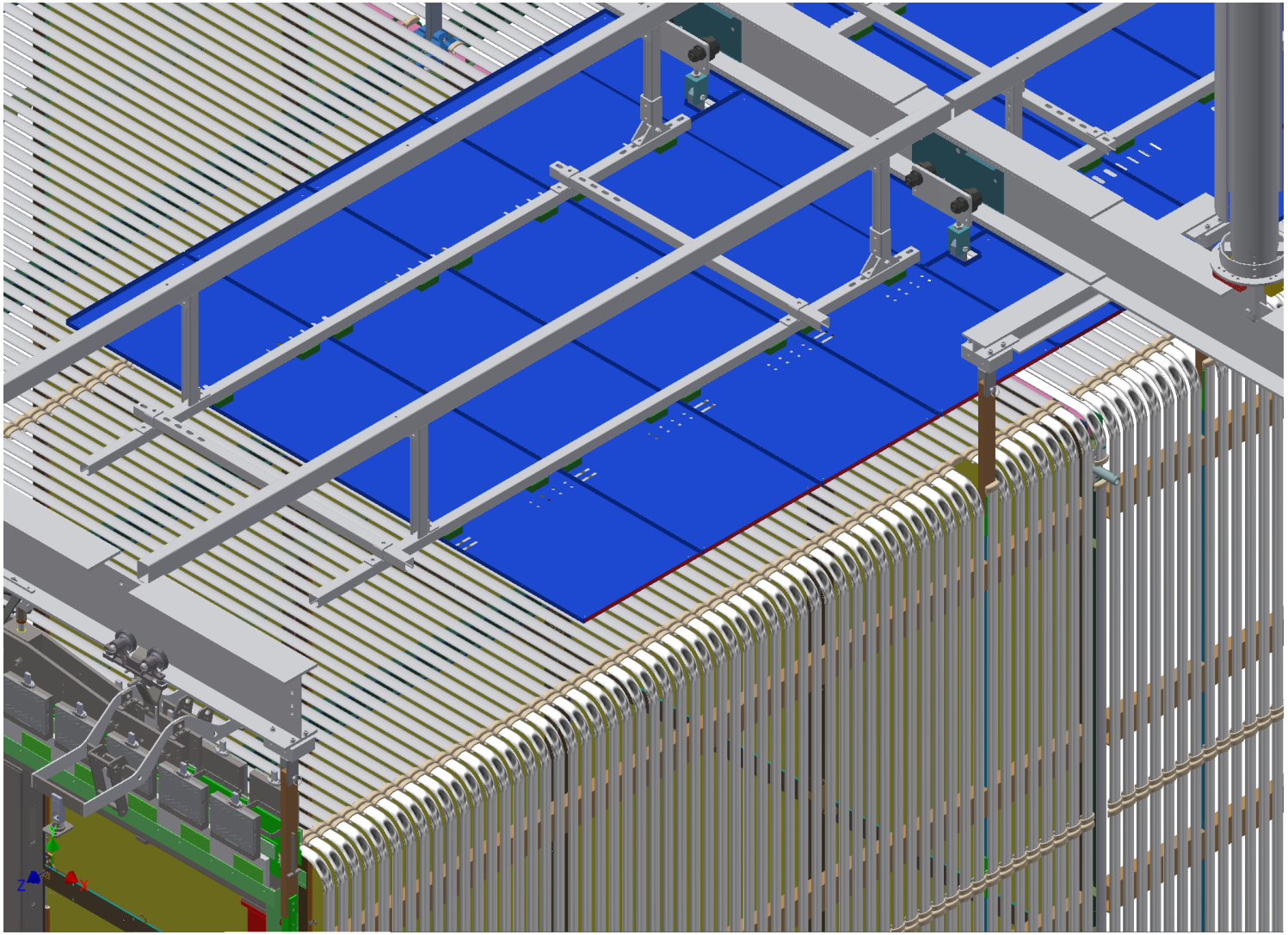
Deflection of the Structural Element of the EW

- Self-weight and 4N x 57 on the upper beam.

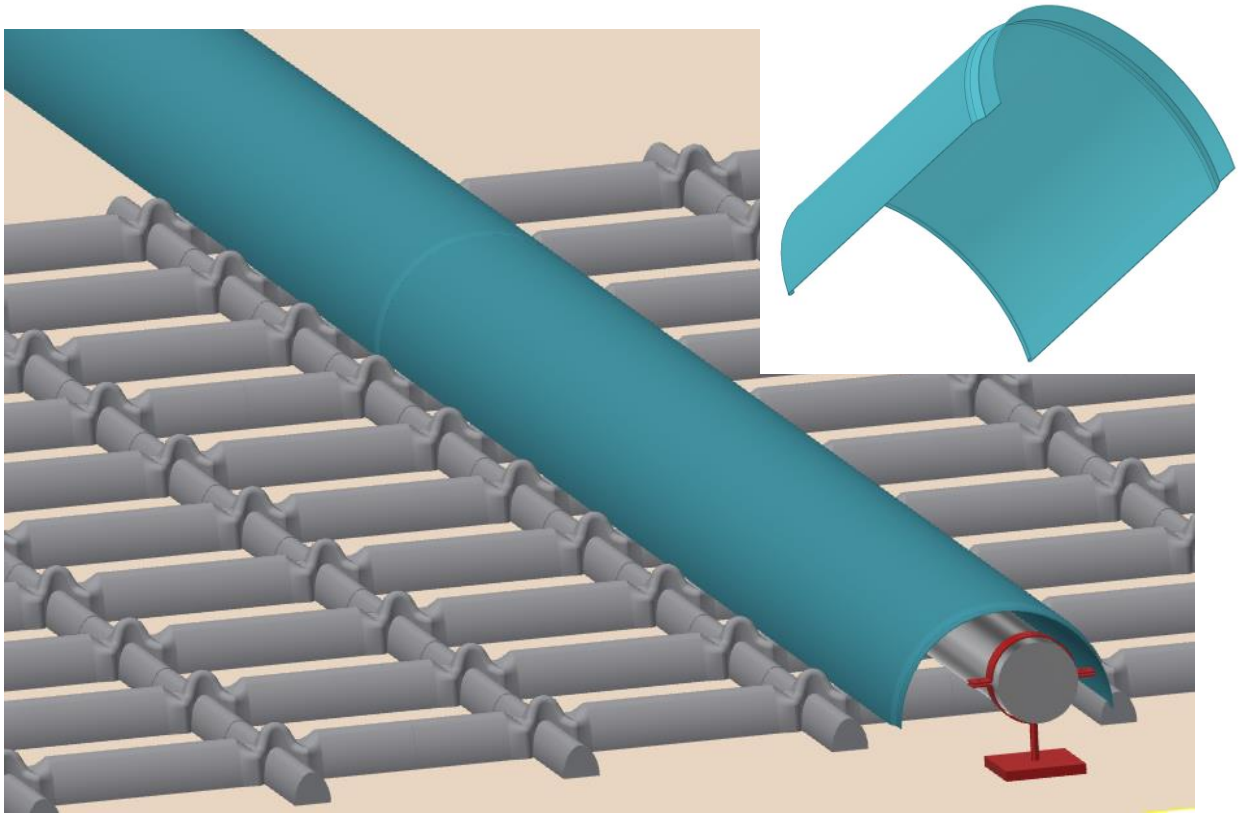


The CG is off the G10 sling about 3mm. It would exert a few newtons of force on the bottom of the CPA.





Shield placed over a pipe



Profile Caps

- With this design, other than the endwall lift rods that pass through the FC, the profile caps are the only insulating material on the FC facing out.
- Sarah has done several runs in the Blanche cryostat comparing the plastic caps with metal spheres and found no evidence to indicate the plastic caps are more likely to cause small discharges.
- We are working on prototyping a resistive plastic cap with a more rounded outer surface to see if they can be used to replace the current insulating cap.