Field Cage Design

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VD HVS CDR Review

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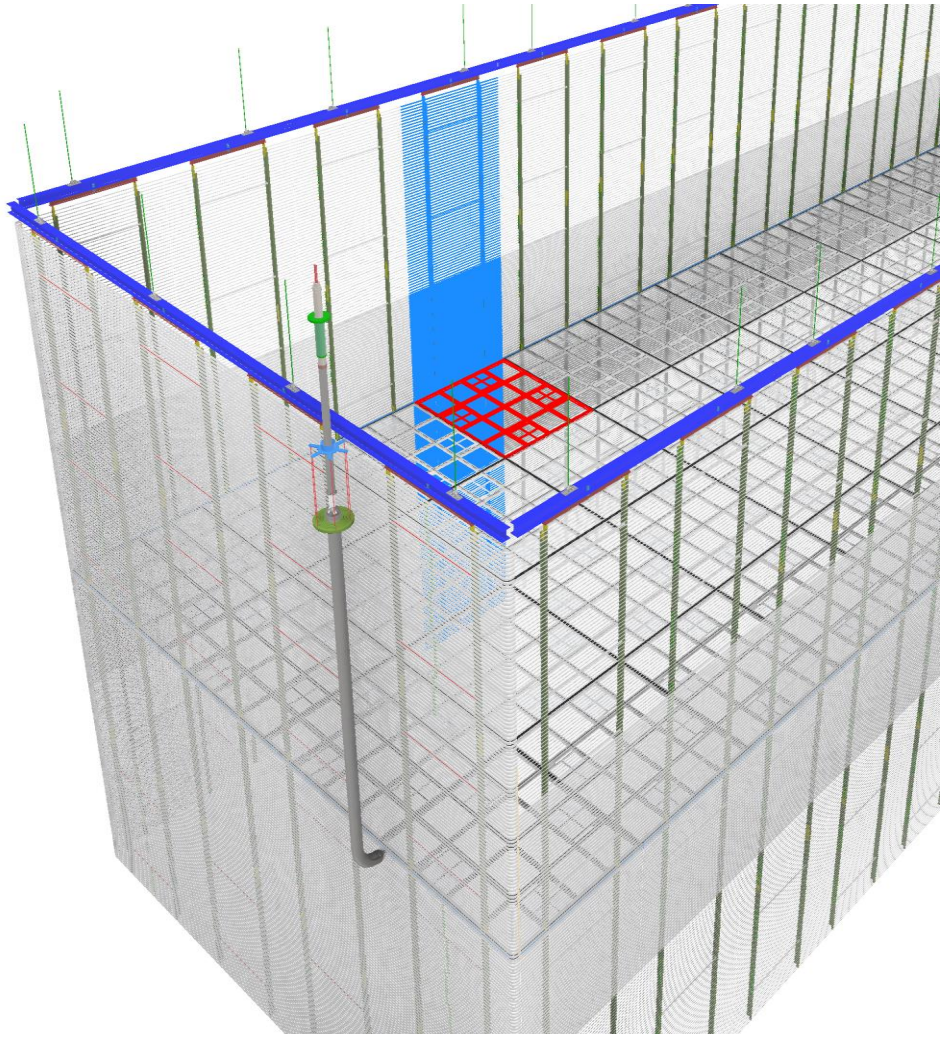
Outline

- Field Cage Module Design requirements and concepts
- FRP Frame and Its Fundamentals
- Al Profile Electrodes
- FC Module Configuration
- 70% Transparent Field Cage
- FC Supermodules
- HV Divider Board
- 70% Transparent FC Testing Program
- Summary

Field Cage Design Requirements

- Minimum drift E field: 250V/cm (goal: 500V/cm or 450V/cm?)
- Maintain E field in >99.8% of active volume uniform <+/-1%
- Local maximum E field <30kV/cm
- Detector up time >98%
- Prevent and protect from discharge
- Redundancy for reliable connection and operations
- Modular design for rapid and uniform parts production, processing and QA/QC
- Rapid and consistent module assembly & installation

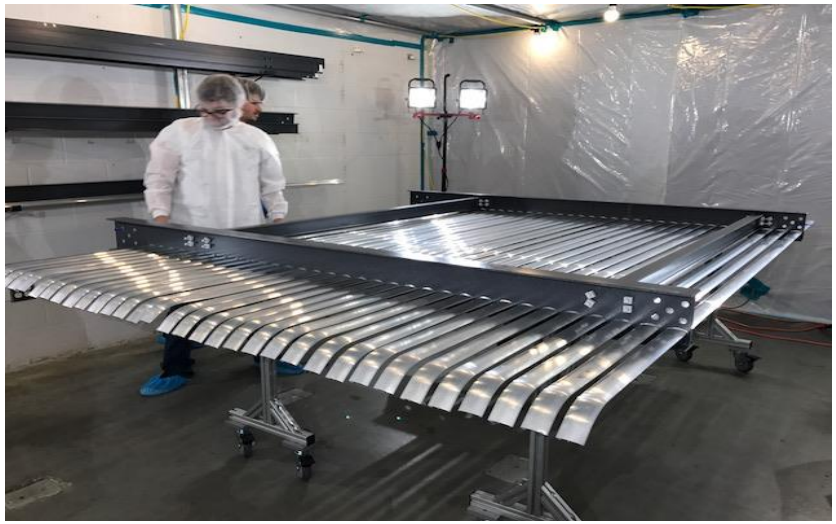


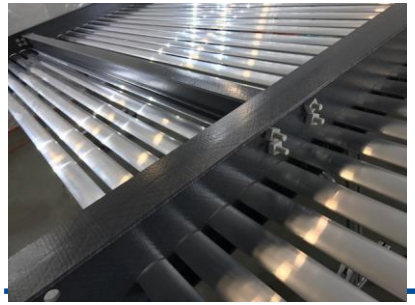
Field Cage Design Fundamentals

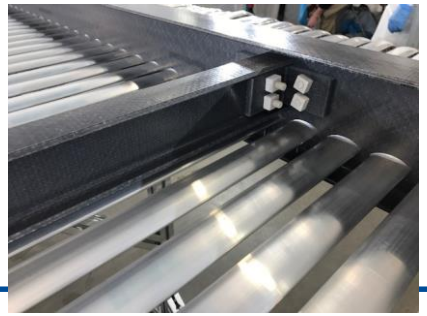
- Use Fiber Reinforced Plastic (FRP) I-beams
  - Dimension : 5cm wide 10cm tall with 0.64cm thickness
  - Two 3.3m long FRP I-beams used as the frame for the extruded Al profile electrodes to mount
  - Two 1.7m long metal cross bars of 25mm diameter connects the two FRP beams
- Extruded Al profiles of 46mm (15mm in the 70% transparency region) tall tightly mounted on one side of the I-beam frame using slip nuts
- Voltage gradient delivered by the HV divider boards
- Design reflects the lessons learned from ProtoDUNE SP operations

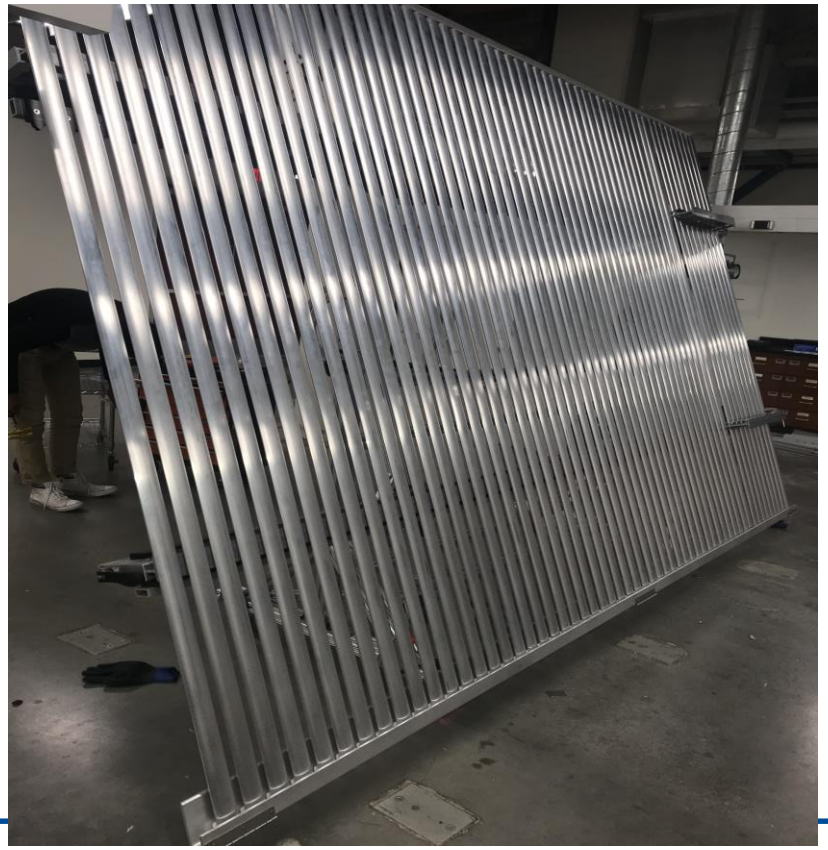
FC FRP Frame Design

- Previous FC design exploited slots in FRP beams, which Al profiles are fed through
  - Large amount of machined surfaces to debur, sand and coat for fiber suppression ➔ extended processing and QA time
  - Al profile surfaces and coating scraped due to the machined surfaces ➔ Extended assembly time
  - Large amount insulation toward the membrane ground ➔ charge build up
- New HDSP design mounts all Al profiles on one side of flange ➔ no threading in the main beams, much speedier processing and reduced insulator toward the membrane ground



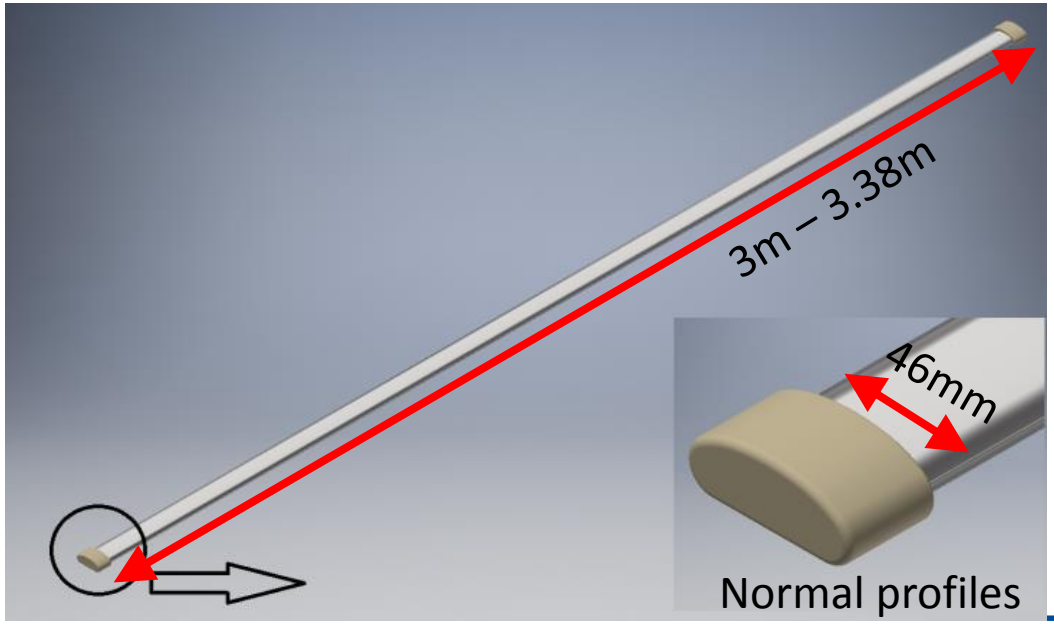




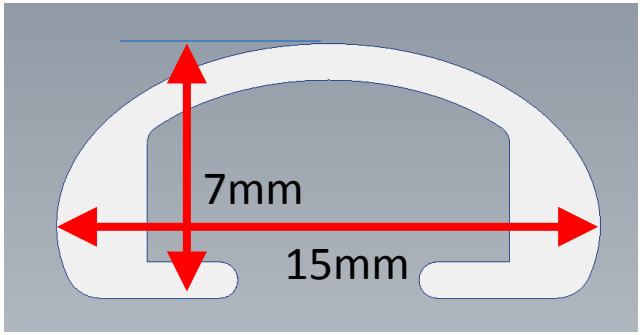


Al Profile Electrodes

- Anti-oxidation coated, extruded C-shaped Al profiles the same design as the HDSP with 46mm height and 15mm height for the 70% transparent region
- Dimensions
  - Long wall profiles: 3m straight; 15mm height for 70% transparent region and 46mm height for other regions
  - End wall profiles: 46mm height, 3.38m straight for the middle section and 3.38m with 90^{o} bend one side for the four corners

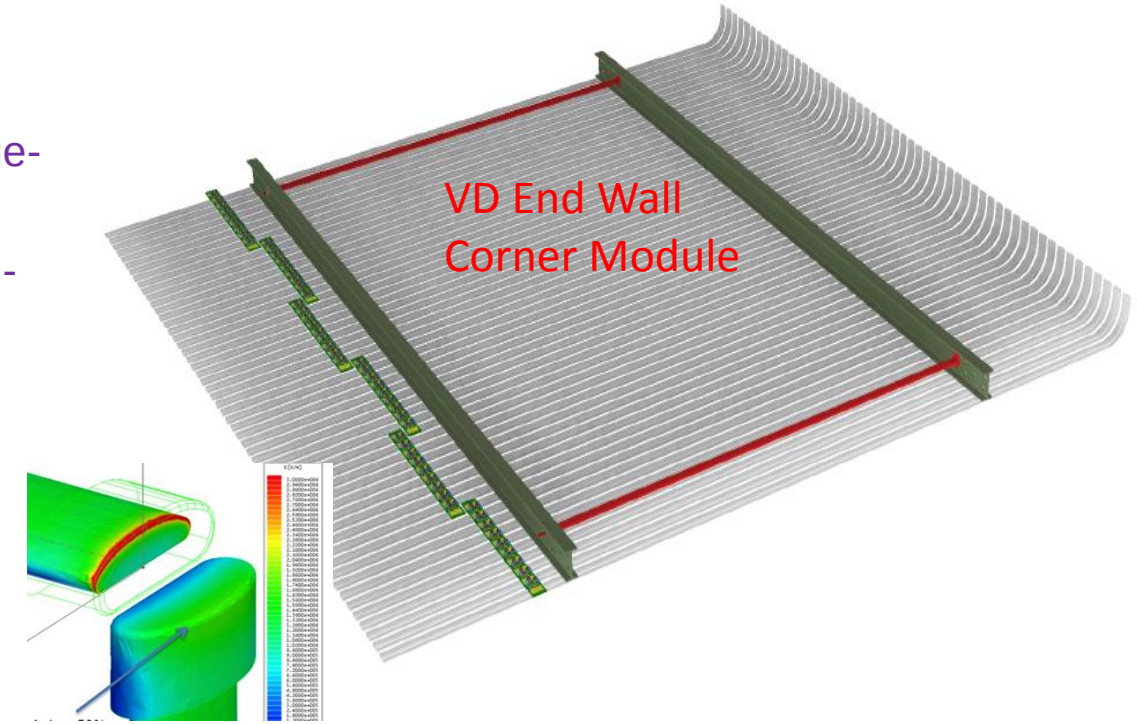


70% Xparency narrow profiles



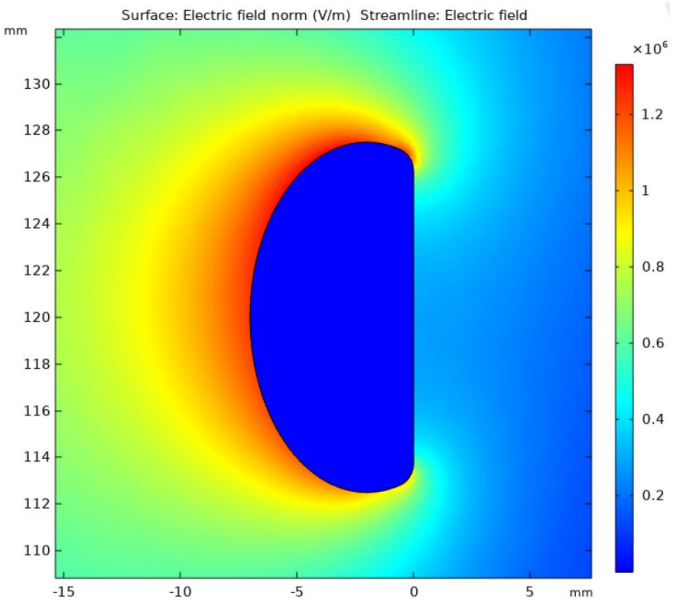
HV Field Cage (FC) Module Unit

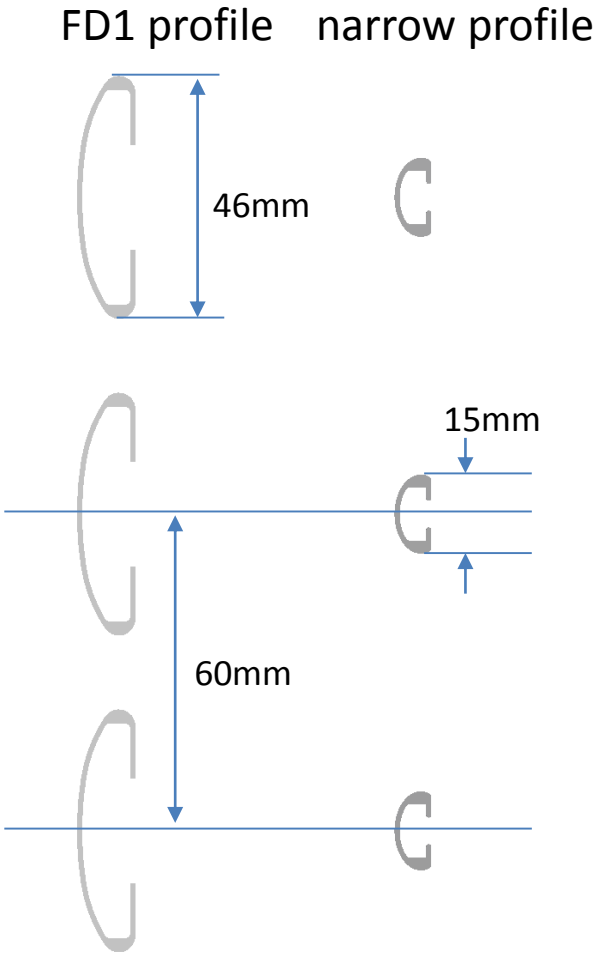
- Leverages the common basic structural elements and design as in HD
- Modular construction with two 5cm wide, 10cm tall, 3.3m long FRP I-beam frames 1.7 m apart with a 2.54cm diameter metal cross bar
- One module holds 55 extruded 46mm (15mm) aluminum electrodes in 6cm pitch mounted on the FRP I-beams using metal slip nuts
  - Long wall FC : 3.0m (W) x 3.25m (H) straight
  - End wall FC: 3.38m (W) x 3.25m (H) straight in mid-section and 90^{o} bend at the corner
  - Profiles mounted on the outer flange of the I-beam flange toward the cryostat wall, minimizing charge-up in insulator
  - Profiles secured tightly on one I-beam and lose on the other to compensate the different contractions due to vertical temperature gradient
  - Each end of the profiles are terminated in UHMWPE caps to prevent exposure of high E to LAr



Transparent Field Cage

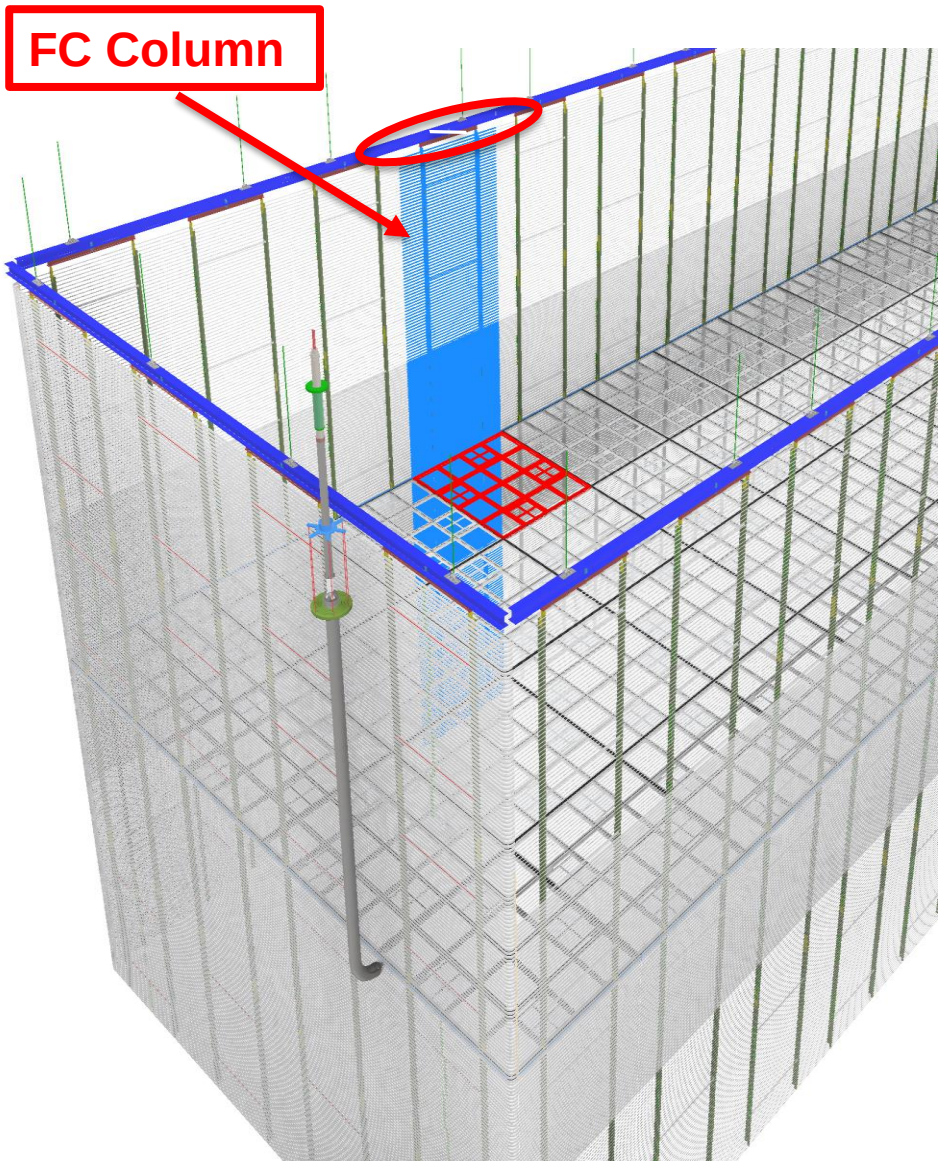
- Provides higher overall optical transparency (70%) to PDS
- Replace the normal 46mm width Al profiles with narrow 15mm width profiles in the same 6cm pitch
- FEA shows max local field at 13kV/cm with 15mm profile at the cathode height



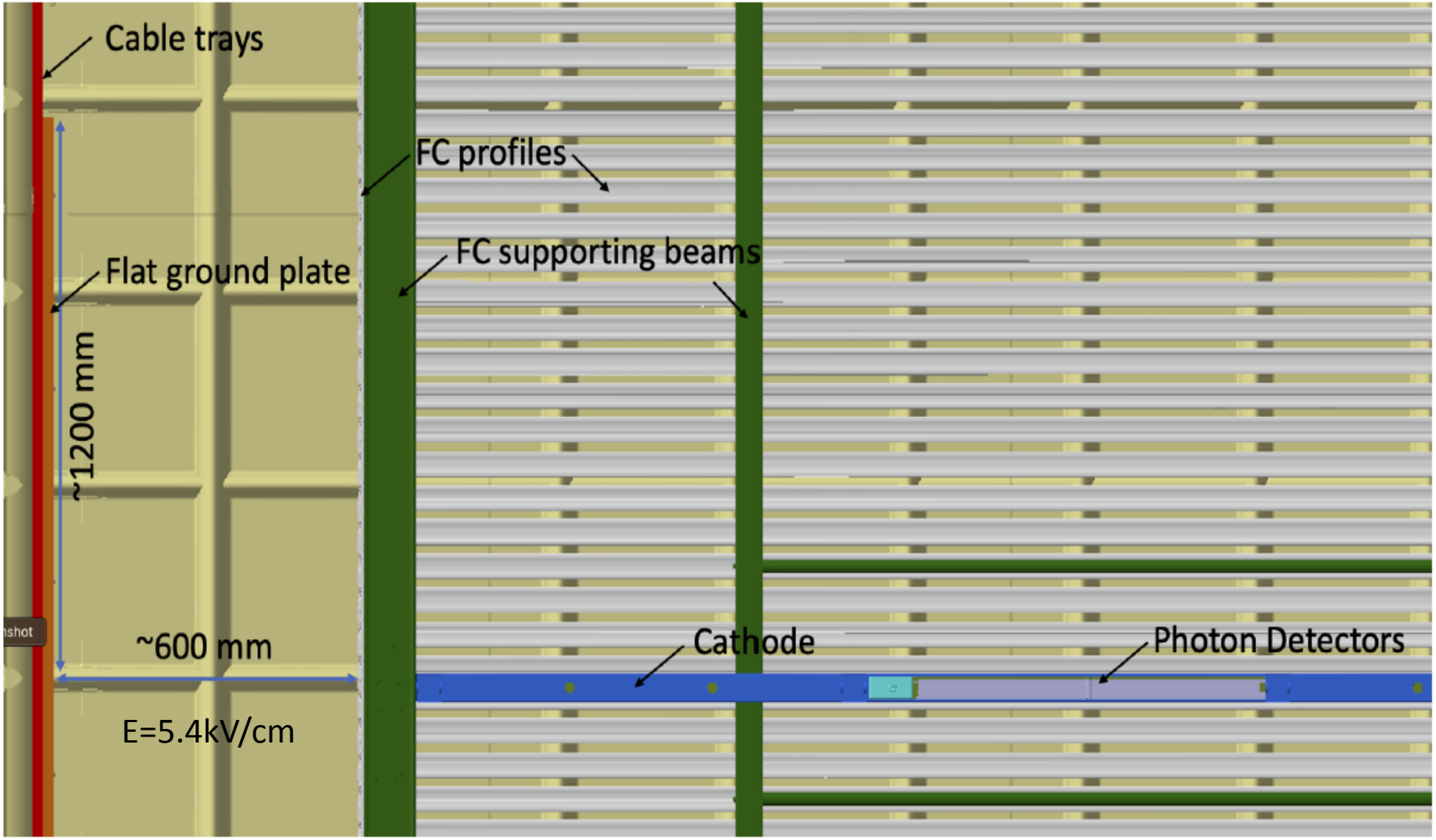


FCSupermodule & Hanging Structure

- 2(W)x4(H) formation of the FC forms a super-module
  - Long wall : 6m(W) x 13m (H)
  - End wall : 6.76m(W) x 13m (H)
  - 2 SM/End and 10 SM/Long wall
- Each super-module hangs from ceiling on two SS rods to SS I-beams
  - Compensating rocking mechanism for each FC column of 13m for potential tilt due to a roof deformation implemented
- The vertical installation scheme established and validated at NP02 PDDP
  - See Bo Yu's talk for the further optimized installation procedure and the hanging structure



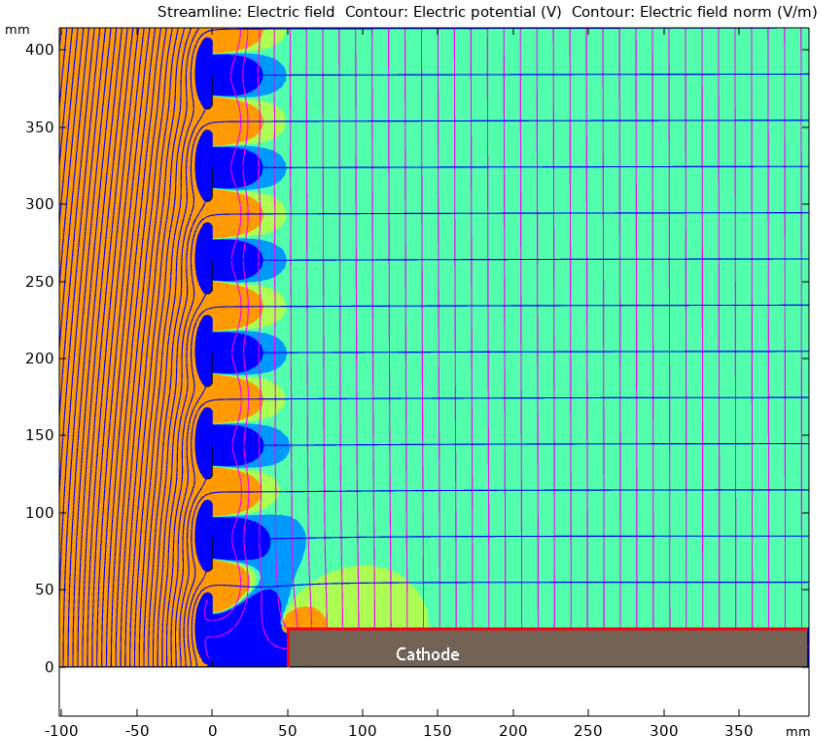
Cross-sectional View at the Cathode Level

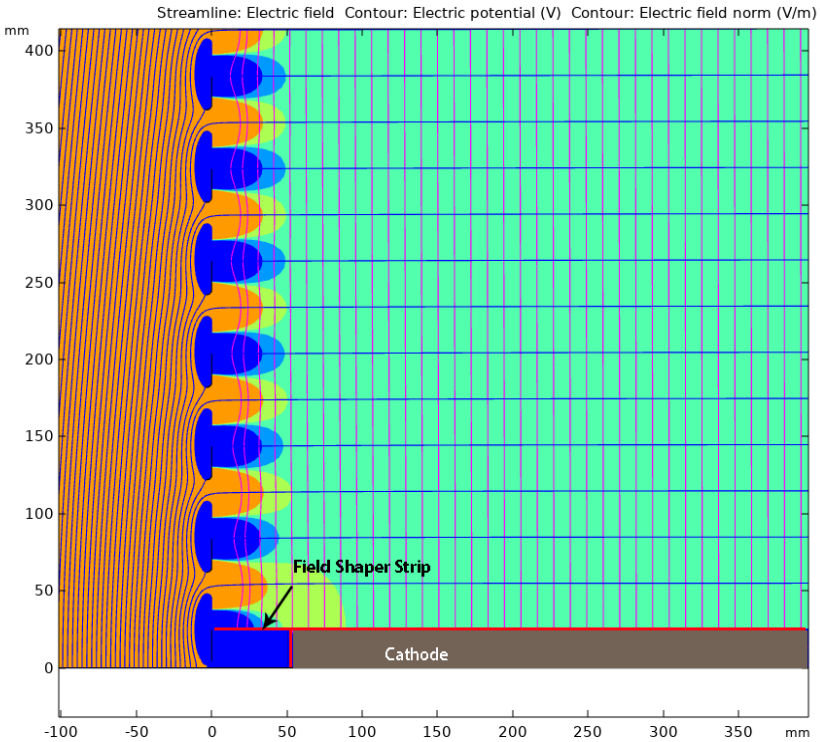


Recall: PDSP1 @200mm w/ V=180kV at the same parallel plate confg.

Cathode to FC Connection

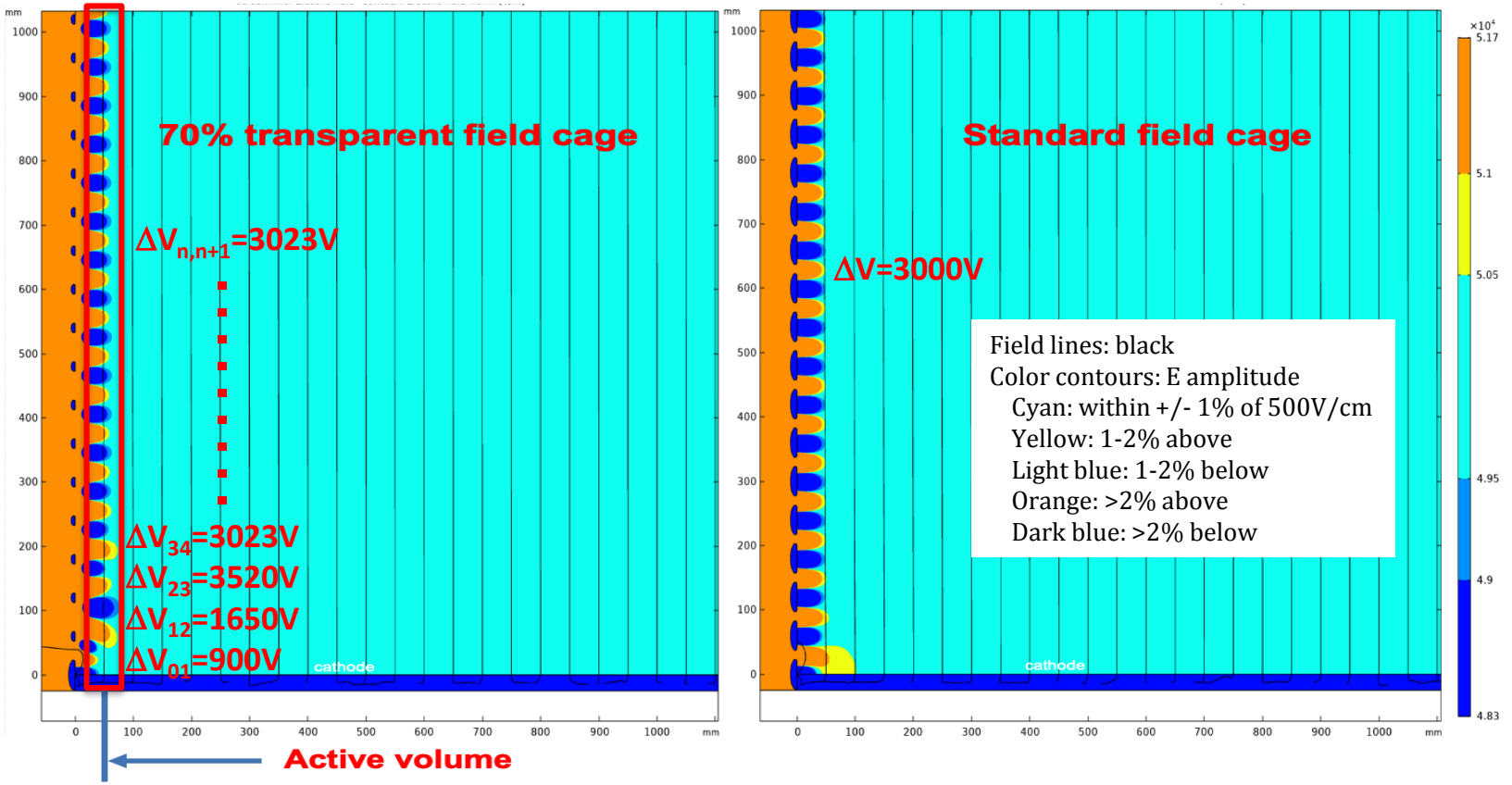
- HV extender brings the bias voltage (325kV or 300kV?) to cathode
- FRP beams will have a cutout at the cathode and at the T/B CRP to minimize the 10cm horizontal gap
- Lack of well defined electrodes at the cathode level causes the field distortion extends into active volume ➔ an additional field shaping strip to form a 5cmx5cm channel between FC and cathode perimeter smooths E





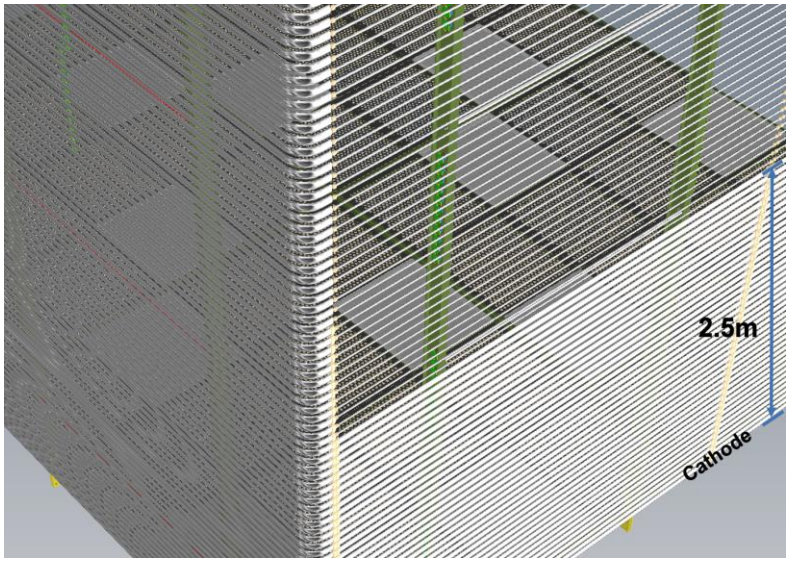
Transparent FC E Field Uniformity

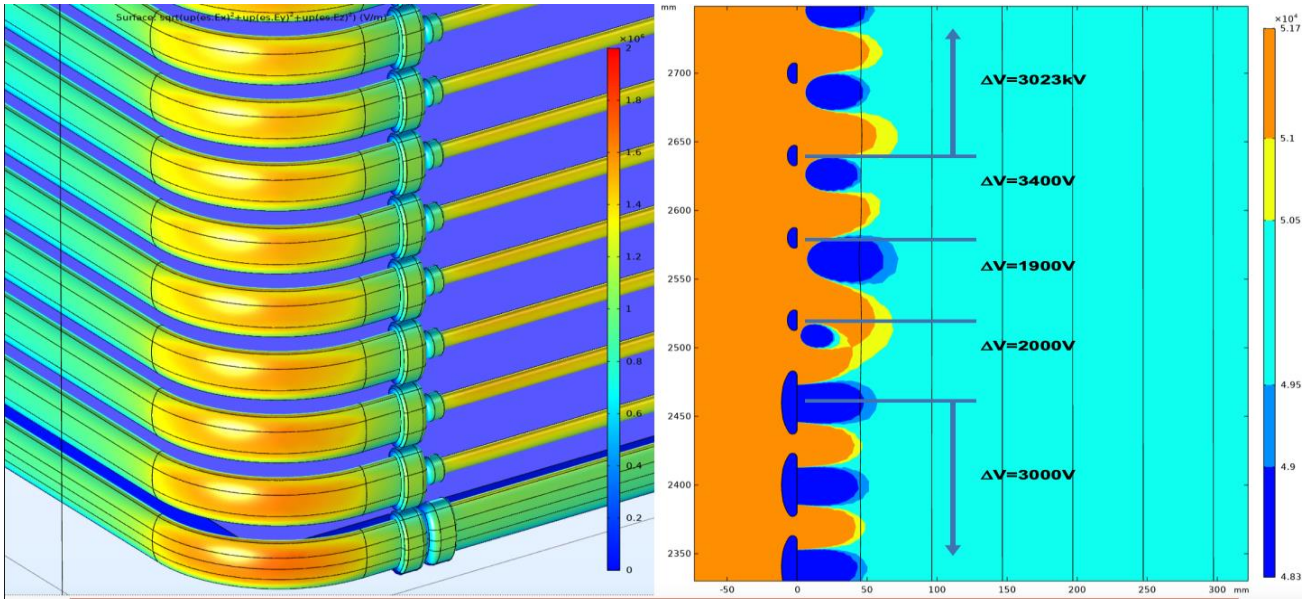
- It has been observed that the 15mm FC profiles biased at a constant voltage drop between profiles at the constant pitch, ~3% of the active volume E field deviate from nominal value over 1% and the field lines diverge as electrons leaving the cathode up to 10cm
- This non-uniformity can be corrected by adjusting the bias voltage drop on the first 3 narrow profiles near the cathode surface and keeping the voltage drop the same for the remaining gaps



Transparent Field Cage Implementation

- To provide higher optical transparency (70%) to PDS
- Replace the normal 46mm width Al profiles with narrow 15mm width profiles
- To minimize local fields across the FC volume, narrow profiles cover from +/- 2.5m to +/- 6.5m along the long wall only
- Careful resistor configuration needed to keep the field uniformity within +/1 1% of the nominal field at the transition region

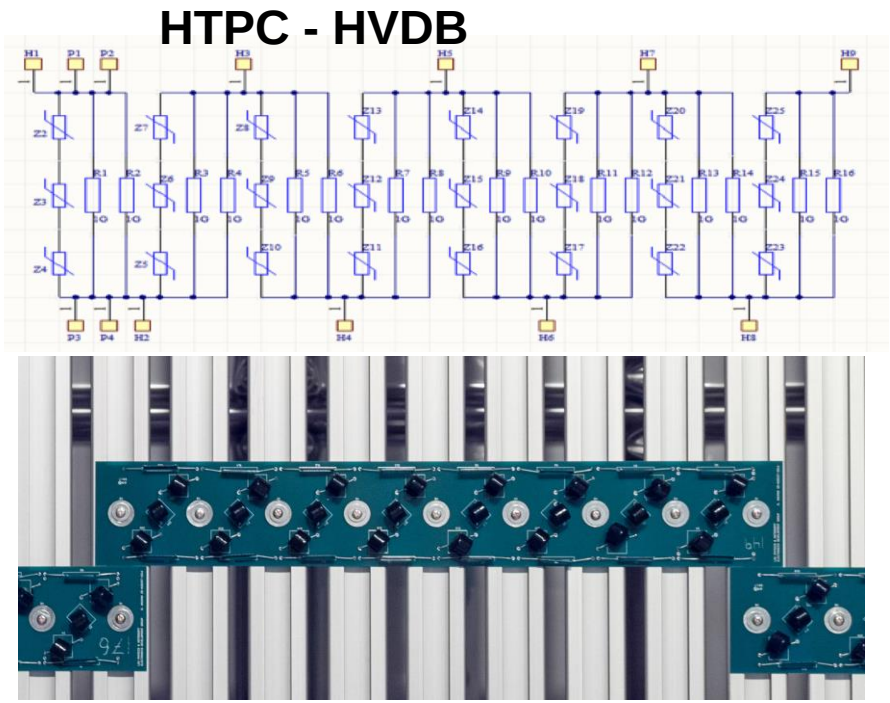




HV Divider Boards (HVDB)

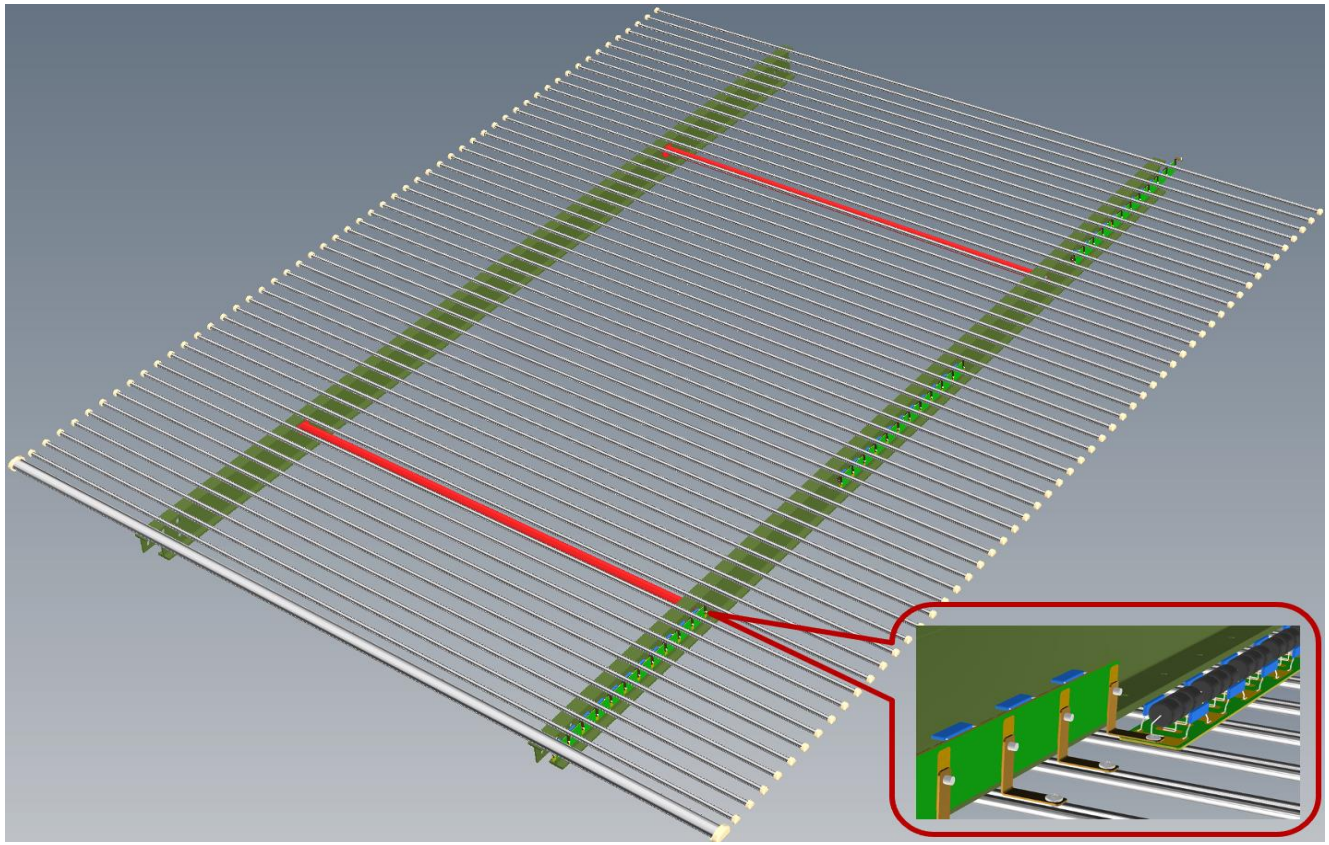
- Provides uniform voltage gradients across FC
- Leverages the same design concept developed for ProtoDUNE and in the DUNE HDSP TDR
- Each board has 10 junctions bridging 9 pairs of Al profiles
- Each gap is bridged by two 5GΩ resistors for redundancy & three varistors of 1.7kV clamping voltage for surge protection

- HVBD's will be mounted on each FC module as it is assembled
  - One HVDB chain per each of 48 the 6m tall half FC columns per active volume
  - Total current for VD FC is 115.2μA (57.6μA per active volume)
- Inter-module connections made at the time of the FC installation



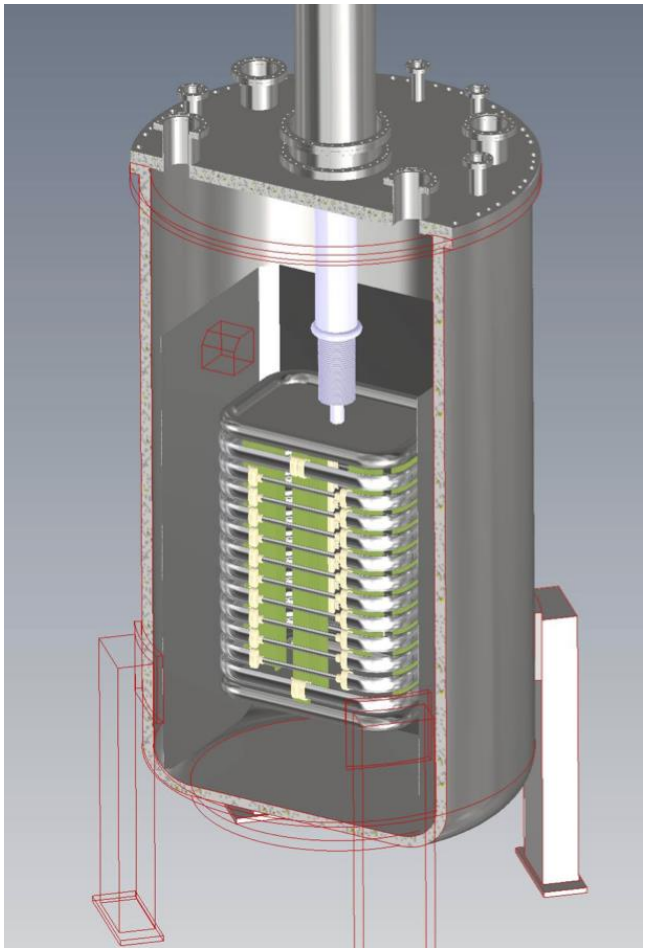
HVDB On Transparent FC Transition Region

- To maximize optical transparency, the HVDBs are mounted using a 90^{o} bracket along the FRP I-Beam frames
- The side of the board with resistors and varistors placed such that they are in the I-beam flange to minimize any further optical interference



70% Transparent FC Testing Program

- While the design fundamentals are the same, the 15mm height Al profiles for 70% optical transparency hasn't been tested before for its reliability and functionality
- FEA shows the max local E field <13kV/cm at the cathode level but is higher than the normal 46mm height profiles
- Requires testing at the nominal E field to ensure no unforeseen flaws
- Three phases of testing (see Filippo's talk for more details)
  - Mini FC surrounded by ground plane in high purity LAr in the 2t cryostat ➔ Uniform nominal E field reachable w/ 60-70kV on HVFT
  - 2m(H) x~2m(W) section of the NP02 field cage equipped with 15mm height profiles during the long term HV extender stability testing
  - One entire side of the FC replaced with 15mm height profiles in module 0 testing



Summary

- VD FC fully leverages prior experience both from DPDP and PDSP as well as the DUNE HD FD design
- 70% optically transparent FC design in +/- 2.5m - +/- 6.5m from cathode along the long wall implemented as the reference design
  - Max local E field seems to be well under 30kV/cm
  - An alternative design is to have the entire long wall 70% transparent
- Important for us to reach a conclusion on 450V/cm vs 500V/cm field goals
- HVS CDR Chapter reflects all new designs