Dual Phase Field Cage

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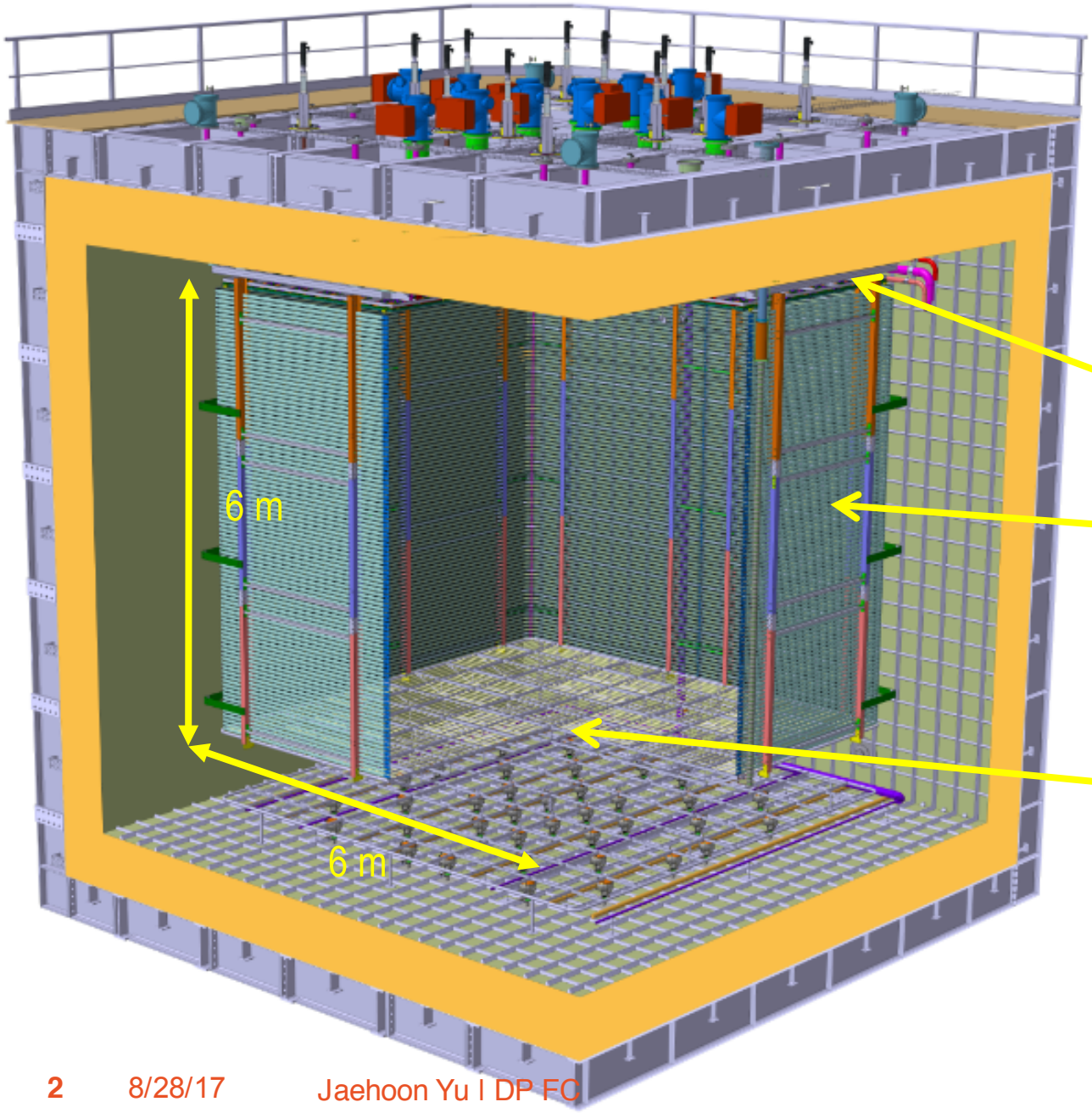
Field Cage in protoDUNE DP



- Field Cage and cathode hangs off of the ceiling
- Essential to have light yet sturdy structure
- Based on modular concept as SP

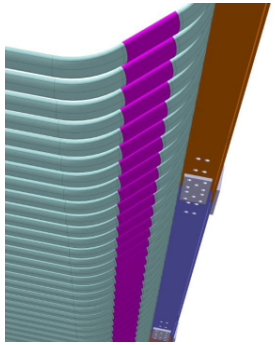
Charge Readout Planes

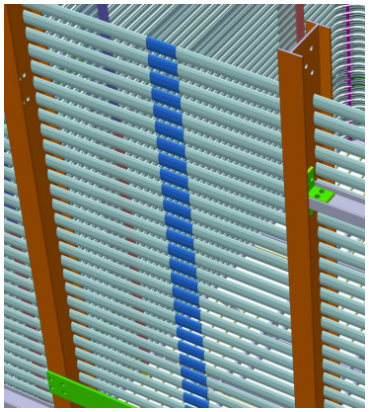
Field Cage (common structural elements with SP)

Cathode

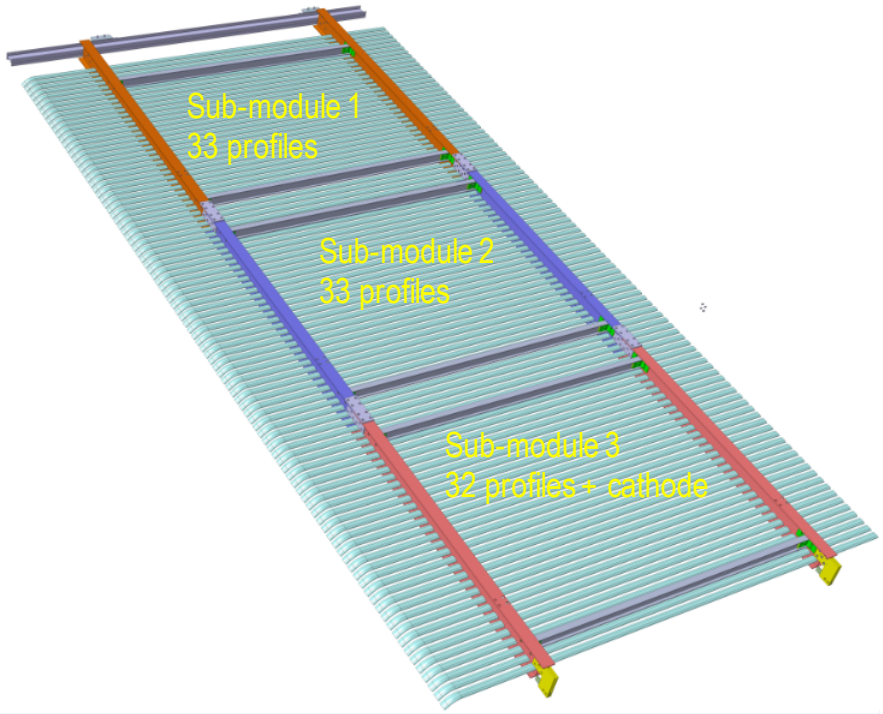
Field Cage Design

- Shares common basic structural elements w/ ProtoDUNE-SP
- Consists of 8 vertical modules of 6310 x 3010 mm^2 (2 modules per detector face)
- Each module is assembled out of 3 distinct sub-modules
- Three distinct types of sub-modules with 33, 33, and 32 profiles each held by a frame with two 6" and two 3" horizontal FRP I-beams
- 98 electrically continuous rings in 60mm pitch using straight aluminum clips
- Each profile is made of extruded aluminum with a supporting rib running in the middle
- 11 profiles with one end bent at 45 degrees are electrically connected by 2 divider boards
- Inter-module connections made with FRP plates connected with FRP threaded rods



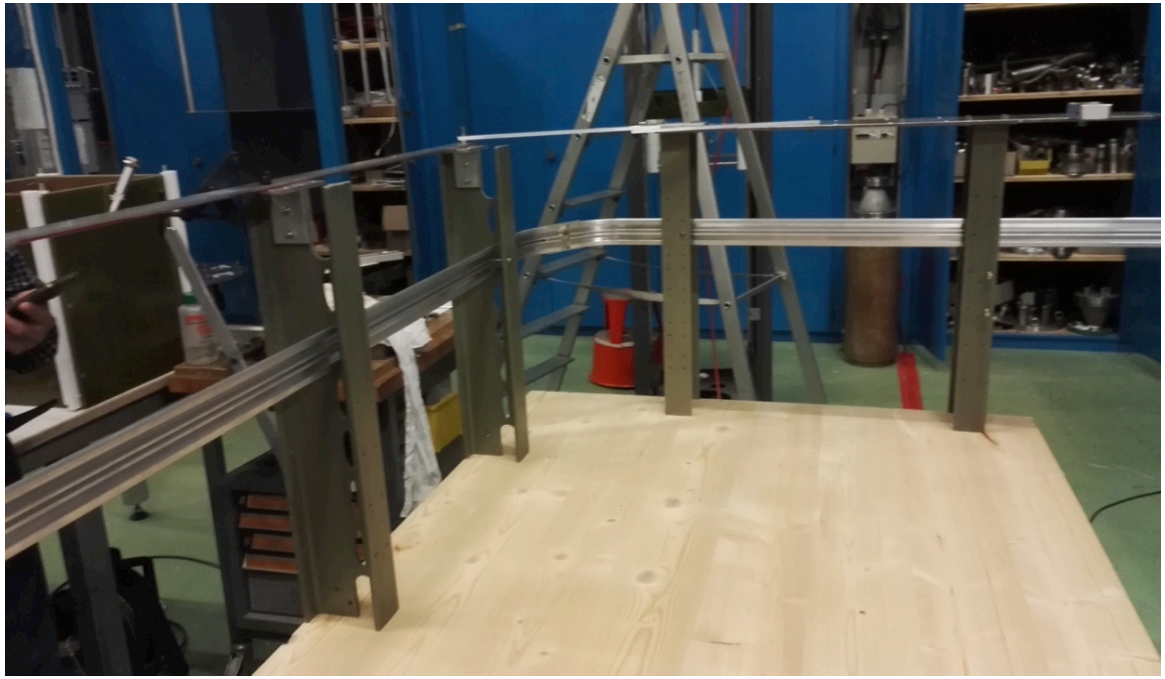


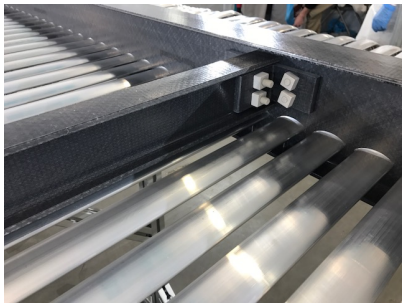
Continuity at center and borders w/ Al clips

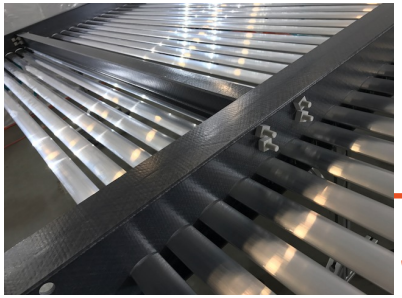


Profile Test Stand at CERN

- 50 3m long profiles bent at CERN
- One corner assembly tested at CERN w/ few elements using home roll formed clips and home made joining bars
  - profile alignment and bending angles successfully checked
- Full set of profiles sent to Texas to be used for Module 0 and pre-constructions of I-beam structures

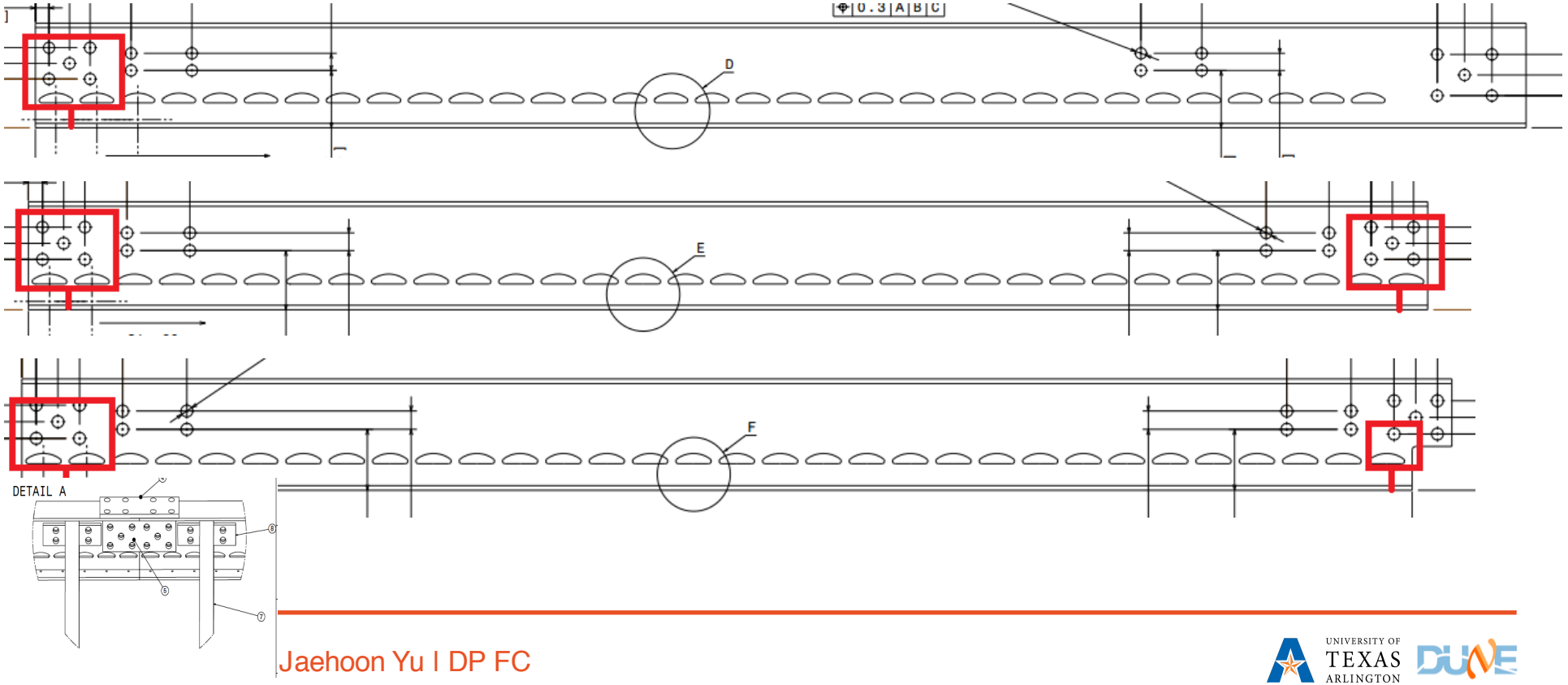






Critical Dimension Measurement

- Everything in red box on each 6” I-beams measured
  - To ensure inter-submodule alignment of the profiles
- Addition measurement on red line to ensure relative distance between the elements in the box to the edge of the beam
- Each position was measured 3 times

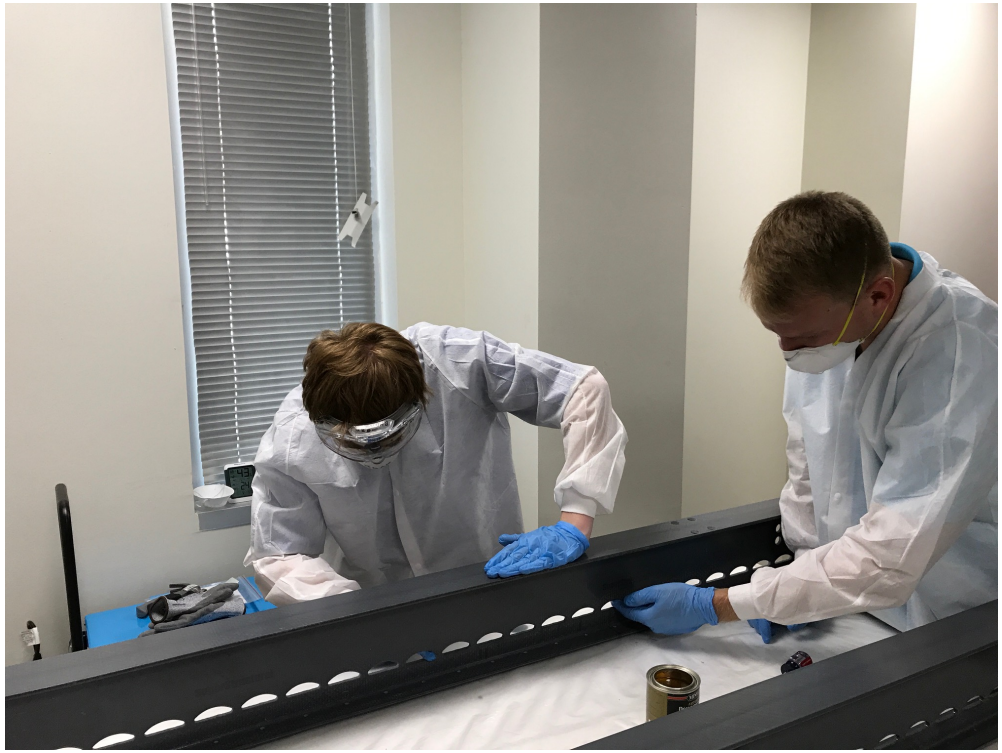


Deburring, defibering and sanding

- All I-beams have a yellow tag with a unique identifier (DP-FC-0XX-0NN)
- Once the critical measurement completes on an I-beam, they are tagged **orange** for dirty part of the cleaning process
- The **orange** tagged parts are then brought out for deburring, defibering and sanding (inspection done by completely different group)

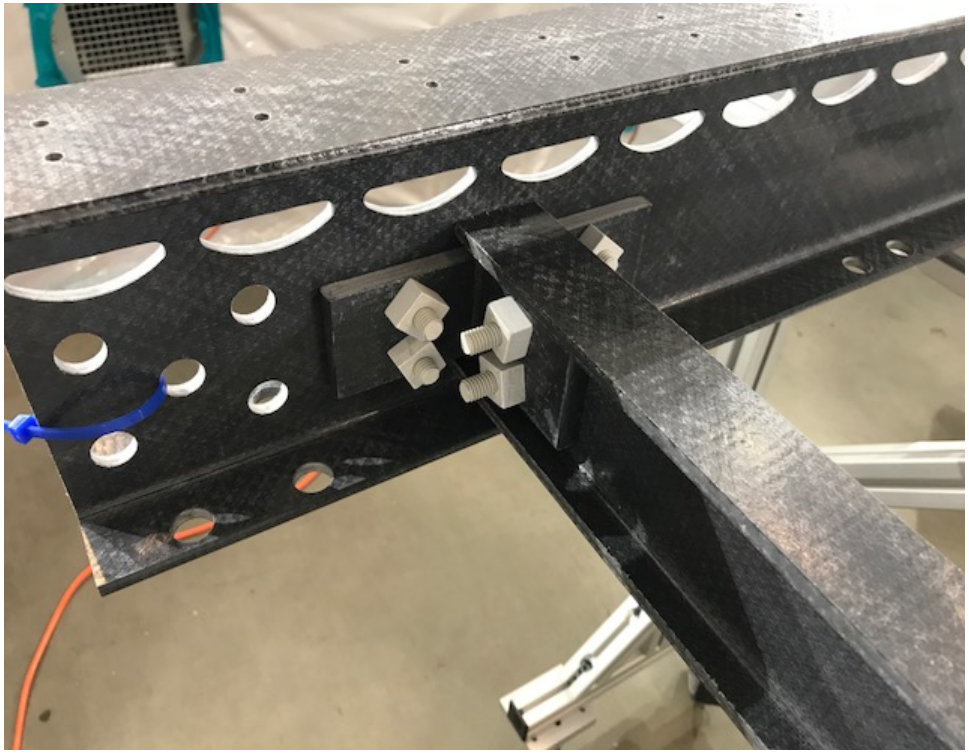
DC Production – Parts Cleaning

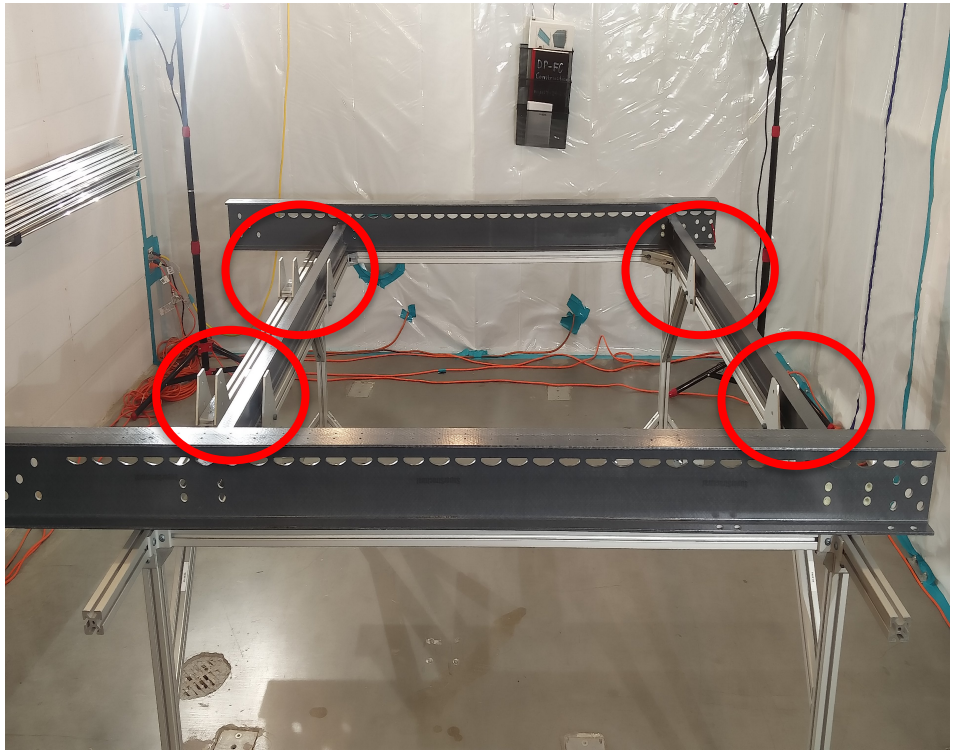
- Once the parts went through the dirty part of the cleaning
- Bring parts into the semi clean area for simple green and DIW cleaning
- Then the profile slots and the edge of the beams are sealed with polyeurethane (the same material as FRP) varnish
- The **orange** tag is replaced by the **green** tag and stored in the shelf at least for 24 hours



FC Production – Pre-assembly

- This process is done in a class 100,000 clean room.
- Two 6” I-beams with profile slots are connected with two 3” I-beams using 8 L-brackets, perma threaded rods and hex nuts
- Assembly done on a specially designed table with prepositioned slots for all I-beams and profile alignments





DP FC Sub-module

- Hung one sub-module to the crane to see how it would work

Packaging & Shipping

- We stack I-beams, L-brackets and the bags of screws, nuts, threaded rods, inserts & FRP nuts into a compact package
- This package will then be shrink wrapped, sealed in another layer of plastic bag and be plastic strapped before put into the wooden crates
- Final assembly will be in the CRB for ProtoDUNE

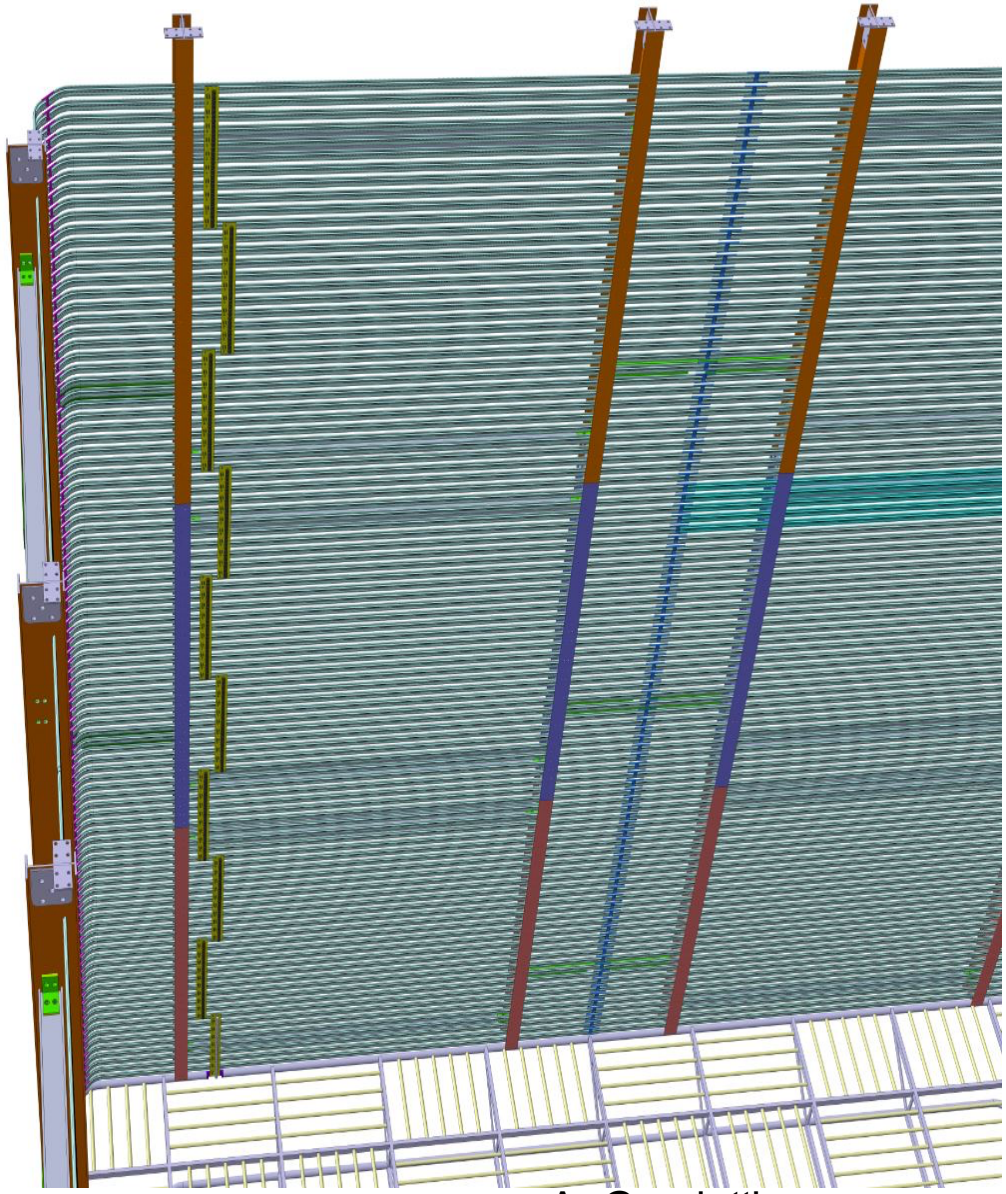
Time Needed for Each Sub-module

- Operating at least 1 – 2 team(s) of two for 8 hour shift
- Each sub-module consists of: two 6" and two 3" FRP I-beams, 8 L-brackets, 32 inserts, 32 threaded rods, 32 FRP nuts, 66 (64) M4 screws and 33 (32) slip nuts
- Initial inspection and critical dimension measurements: 4 MHr (or 4 per day for 2 people 8 hours)
- Deburring, defibering, cleaning, coating: 4 Mhr+24hr curing time
- Assembly: 2 Mhr, Disassembly: 1Mhr, Packaging: ~0.5Mhr
- We can complete the measurement and cleaning
  - 2 – 3 /day for 6" I-beams ➔ requires 18 days for cleaning all 54
  - 10 – 15/day for 3" I-beams ➔ requires 4 – 5 days for all 54
- Preassembly, disassembly and packaging: ~5/day ➔ 6days

HV Divider Board: Design Concept

- To generate uniform electric field of 500v/cm to 1kV/cm across the entire drift volume
- Use the printed circuit board as in the SP case
  - Easy handling and installation
  - Robust mechanical and electrical connections
  - Perform and survive in LAr for a long time
  - Introduce ample redundancy
- Important issues to consider in board design
  - Sustain 600kV operation (max voltage safety factor 1.5 ➔ 9kV rating)
  - Total number of profiles to be connected
  - 6cm center to center distance between the profiles
  - Anticipated current flow across the circuit and heat generated

HV Divider Board Mounting to DC

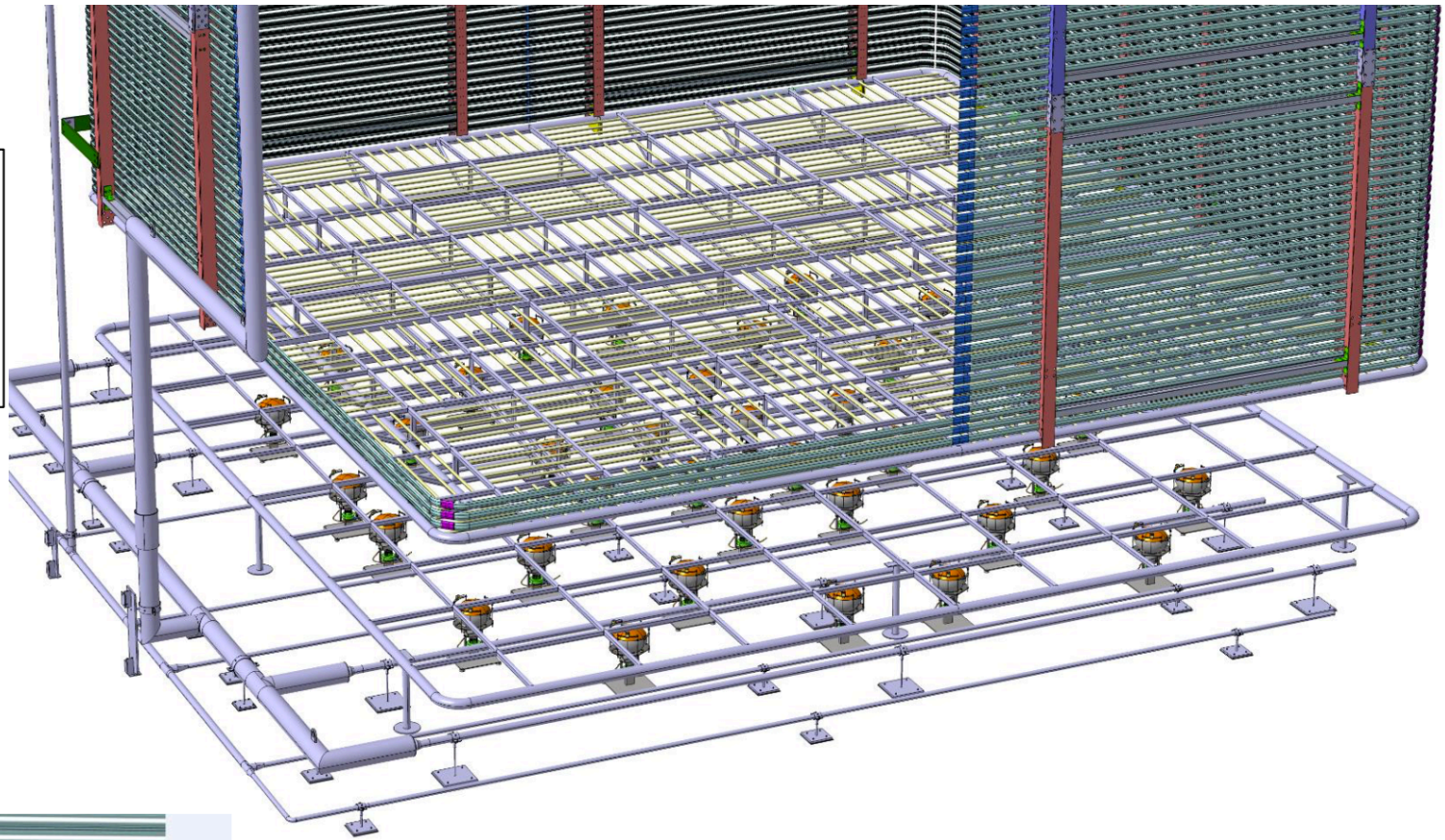


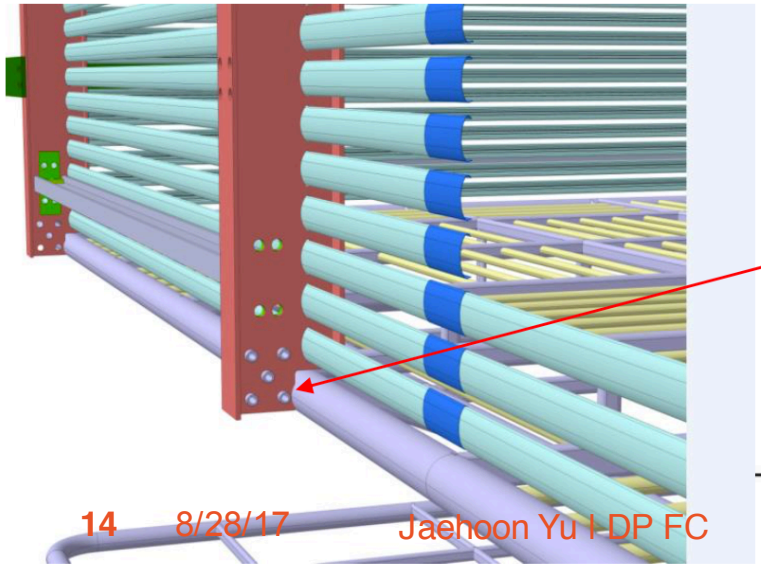
A. Gendotti

- Two parallel columns of 10 boards, totaling 20 boards
- The total potential from the extraction grid to cathode: 294kV to 588kV
- Two 2GΩ resisters each stage for each board, providing 0.5GΩ effective resistance per stage
- Current through the entire circuit: 6μA – 12 μA (100 times the expected current from cosmic rays)

DP Cathode and Ground Plane

Center «oval» tubes and Grid kept at the same height as for the previous cathode design in order to keep same distance distance between Cathode and last ALU field shaper





Due to the large new diameter of the round pipe there is a clash with the last 6inch vertical I-beam

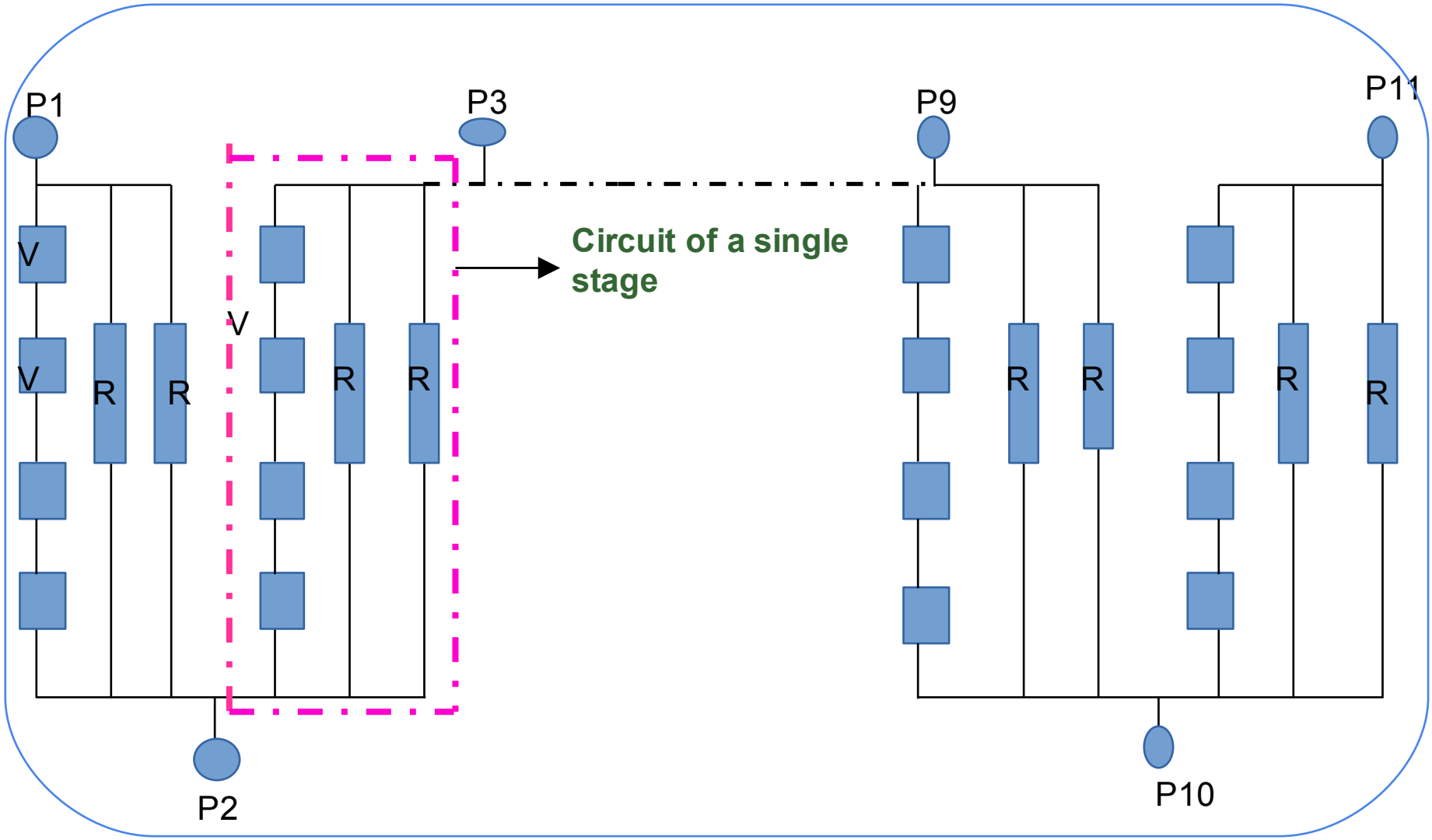
A. Gendotti

HV Divider Board at a Glance

- Each divider board connect 11 profiles total
- Top and Bottom profiles of the 11 profiles will have two boards connected each, completing the circuit
- Total number of the board needed: 20
- Electrical components on each board
  - Two 2GΩ resisters (rated 20kV, 1%, 2.5W, -55°C) in parallel each stage, 1GΩ effective resistance/HVDB/gap

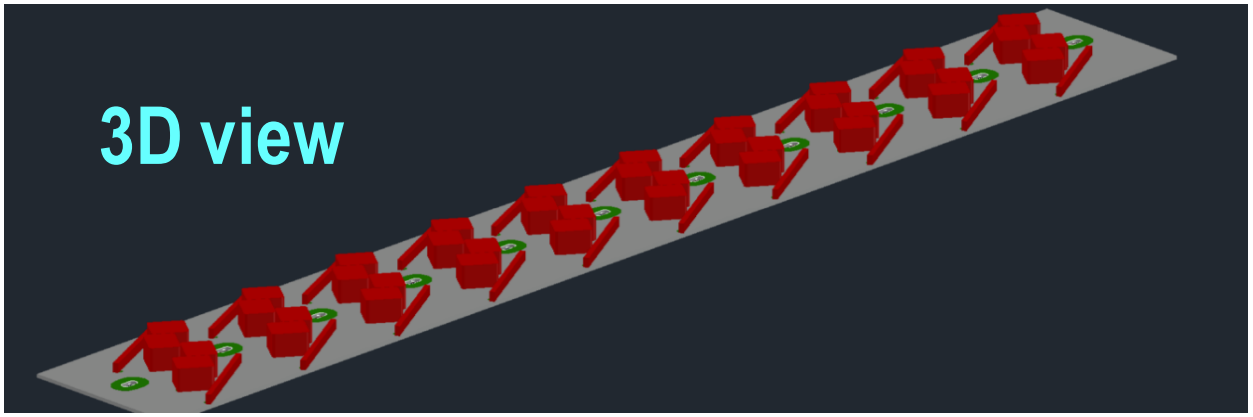
    Max heat generated at each resister 9mW
  - Four varistors with 1.8kV nominal clamping voltage each, giving 7.2kV clamping voltage in series for circuit protection
  - Varistor string is connected to the resisters in parallel

HV Divider Board Schematic Diagram

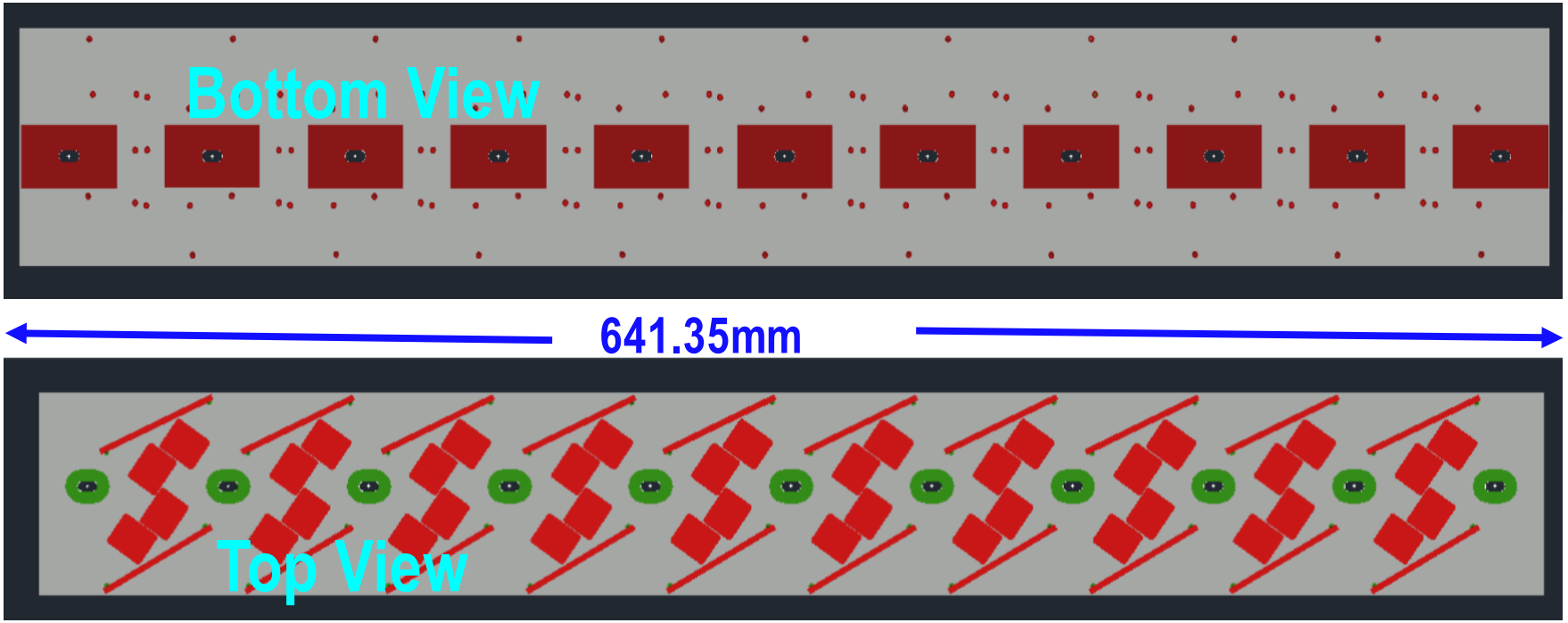


R: 2GΩ Resister, V: Varistor, P1 – P11: Connection to each profile

2D and 3D image of the board



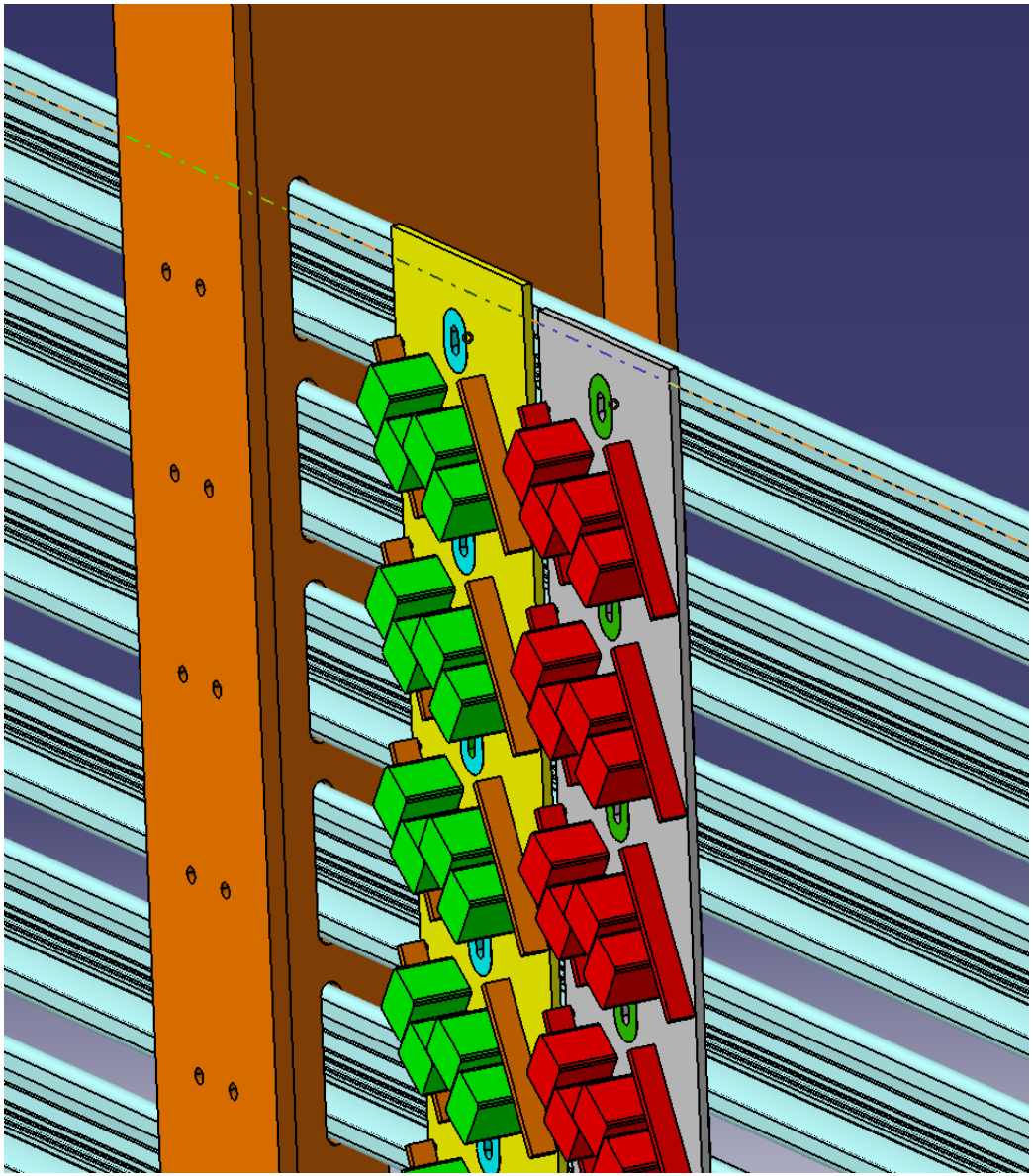
- Length of a single board 64 cm long, 7.5 cm wide, and 3mm thick
- Electrical connection with through M4 screw and 40 mm copper pad on the bottom of the board



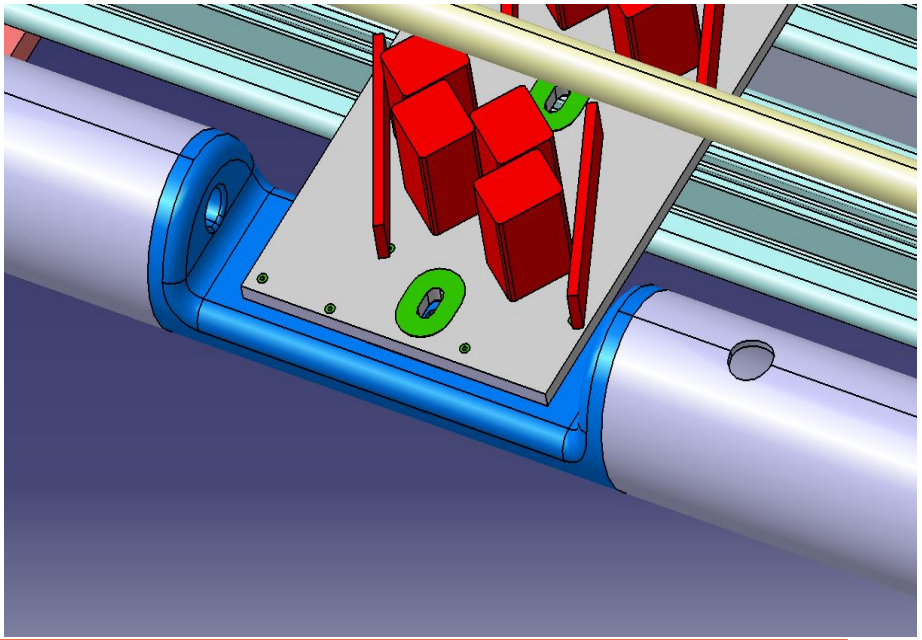
Two resistors in parallel

Four varistors in series

HVDB Connection on FC



- Boards align to the edge of the 1st and 11th profile
- Special shortened board for cathode connection



Components of the divider board

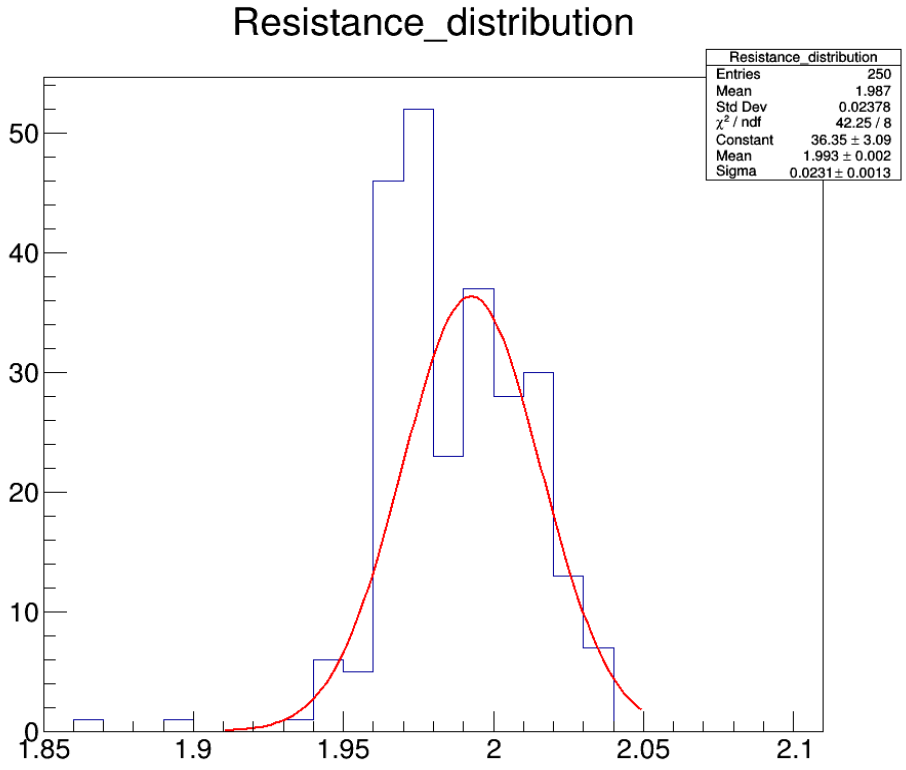
Elements	Values (unit)	Part#	Requirement for each board	#Total (with spare)	
Resistors	2 GOhm	SM108032007FE(2.5kW, 1%)	20	400 (600)	
Varistors	4 varistors in series	ERZV14D182	40	800 (1000)	
Connections with profiles	M4 size brass screw		22	220 (300)	
Nuts and washers			22	220 (300)	

Requirements of the divider board

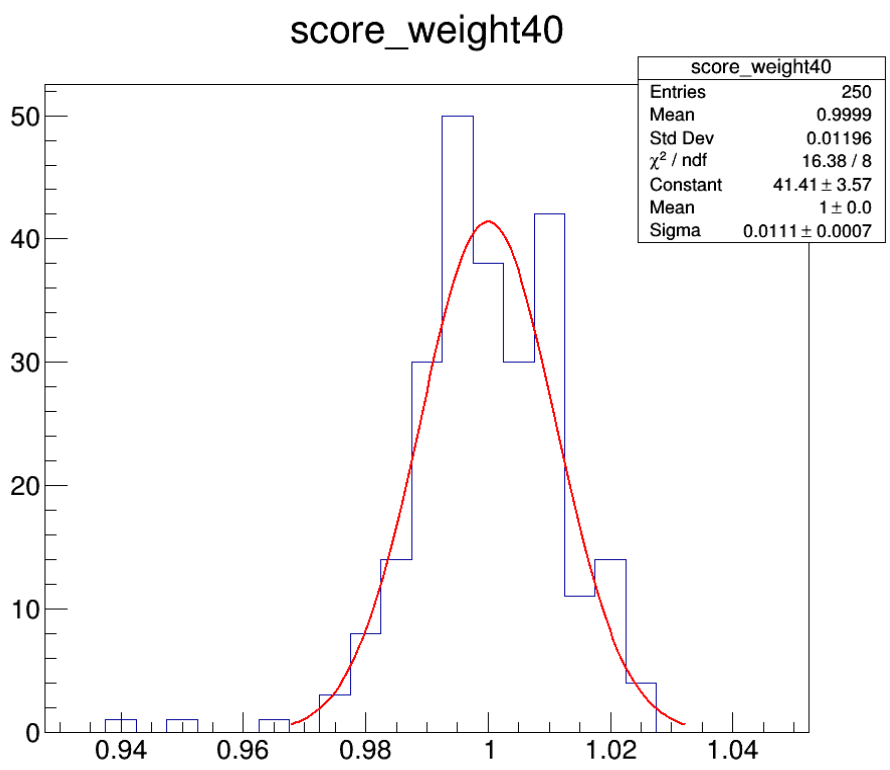
Parameter	Values	units	notes
FC-resistance tolerance per resistor	+- 1	%	
FC- total resistance tolerance for the board	+- 1	%	
FC max voltage per stage	150	%	9 kV
Maximum heat generated across a single resistors	9	mW	Much less than the resistor power rating

Test of Electrical components: Resistors

- Use Ohms law to measure the resistance
- Measure current flow the resistor in room temperature, in cold shock (liquid nitrogen) and after warm up at 0.5kV to 7.0kV in steps of 0.5kV three times at each voltage
- Developed a scoring system for resister selection (40% weight on 3kV and 6kV measurements) ➔ 1% selection allows 60% acceptance (40% rejection)



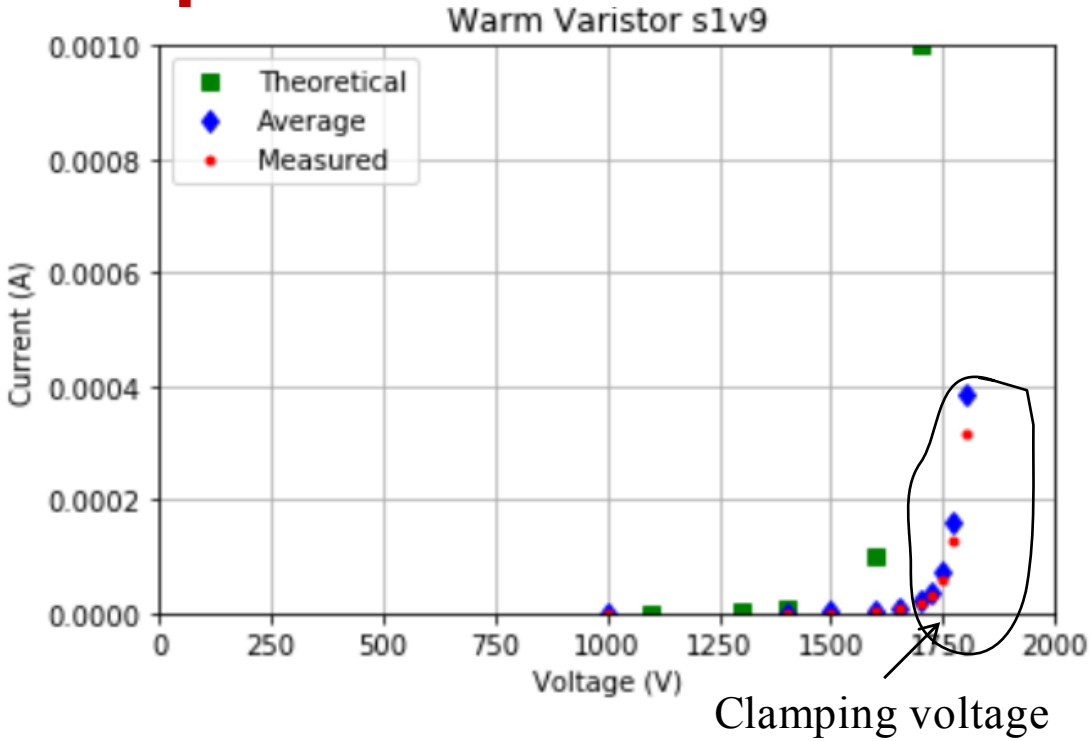
Distribution of the resistance



1% tolerance selected from score

Test of Electrical components: Varistors

- Test the varistors both in warm and in cold
- Measure the clamping voltage both in warm and in cold
- Compare the I-V curve with the data sheet to select appropriate



- HV Divider Board test :
- Bare boards will be in hand within 3-4 weeks (Sept 15)
- Test the bare and stuffs boards (at-least 3) both in warm and in cold
- Test each stage of the board with at-least up to 6 kV

HVDB Timeline and Milestone

- Board design revision in the final stage
- Once the order is placed, the boards will be in hand within 3-4 weeks (~Sept. 15)
- Complete test of all electrical components within a month in time for board delivery to the vendor
- Selected components will be shipped to the vendor for board stuffing ➔ Expect stuffing to be done within a week after the delivery of the parts
- Complete warm and cold tests of all stuffed boards by mid to late October
- Ship to CERN no later than mid Nov.

Summary

- DP FC designed based on SP design
- DP FC profiles deigned with a 45 degree bent and will be electrically connected throughout using Al clips
- The total weight corresponds to ~160kg per 3mx6m module
- All FRP parts for DP FC construction delivered
- DP HV Divider board designed for 1kv/cm maximum field
- HVDB to cover 11 profiles each and two rows will be used
  - Special board for 8 profile + cathode will be prepared
- HVDB design completed and mock fit to the mechanical engineering drawing shows a good fit
- Assembly will be carried out at the CRB for protoDUNE