

ProtoDUNE-SP Field Cage Internal Connections

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LSU

ProtoDUNE electrical connection review at CERN
September 26, 2017

Outline

- Resistive divider chain overview
- QC procedures and documentation

ProtoDUNE-SP Field Cage (FC) Geometry

Major mechanical units:

Top + bottom FC:

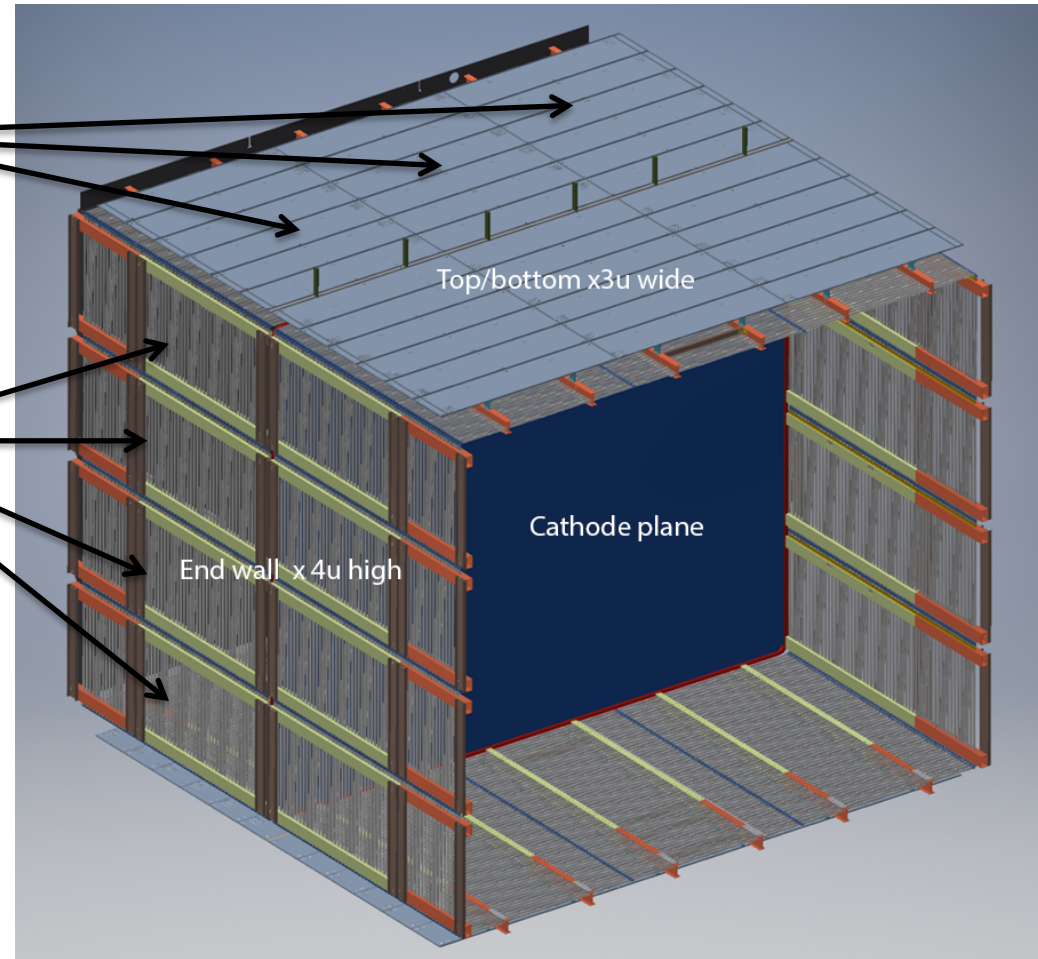
3 panels wide per drift volume
with mounted ground plane

Total quantity: 12

Endwall FC:

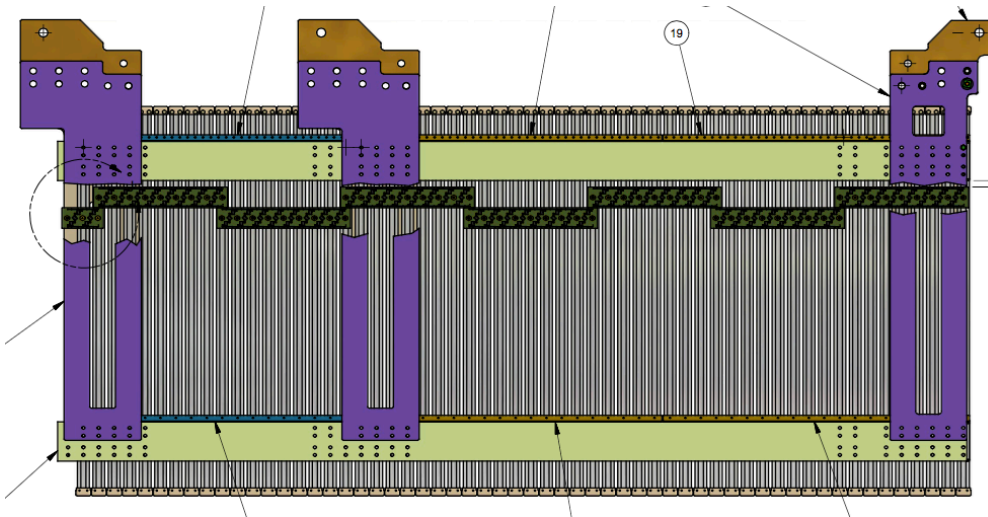
4 panels high per drift volume

Total quantity: 16

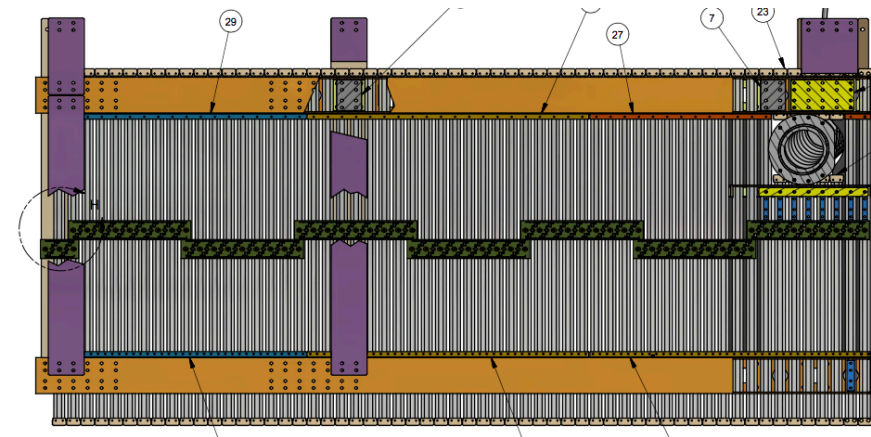


ProtoDUNE-SP Field Cage Endwall Panels

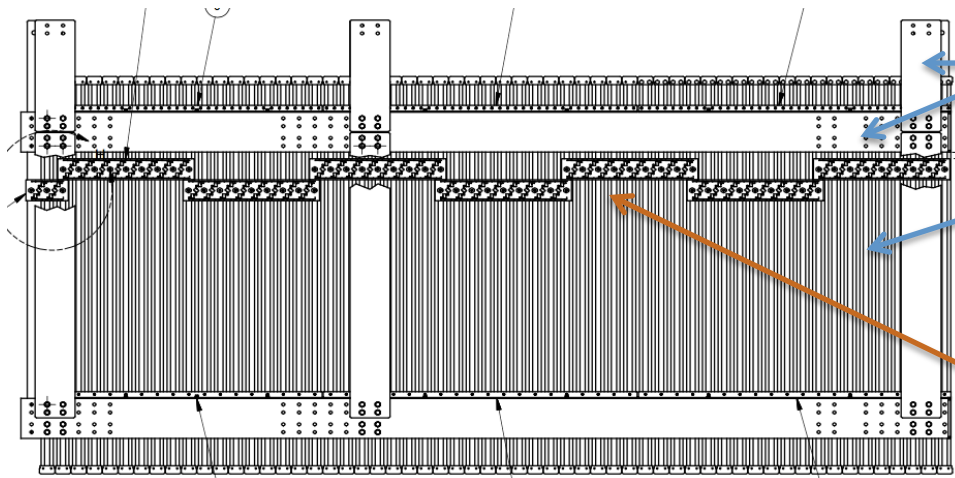
Top panel: Quantity: 4



beamplug panel: Quantity: 1



baseline panel: Quantity: 11



Fiber reinforced plastic (FRP)
box beams and plates

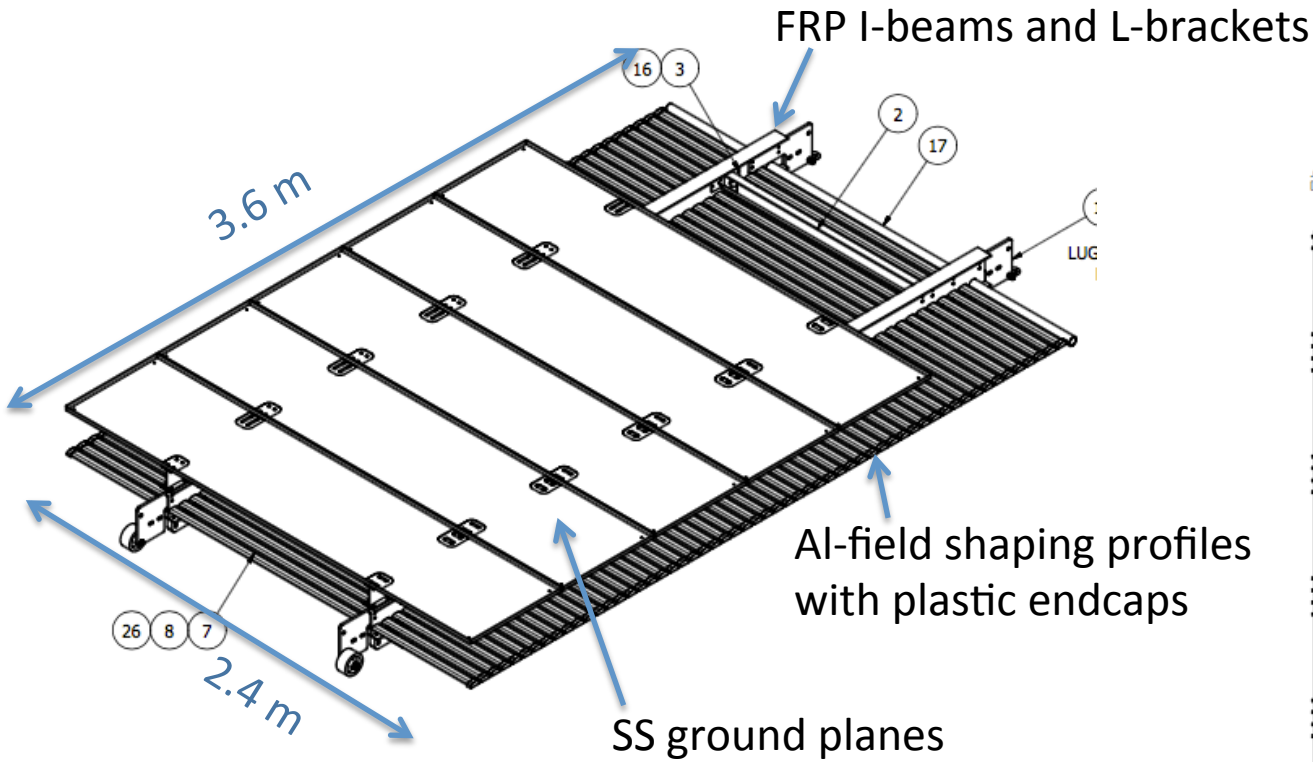
Al-field shaping profiles
with plastic endcaps

Per FC endwall panel:

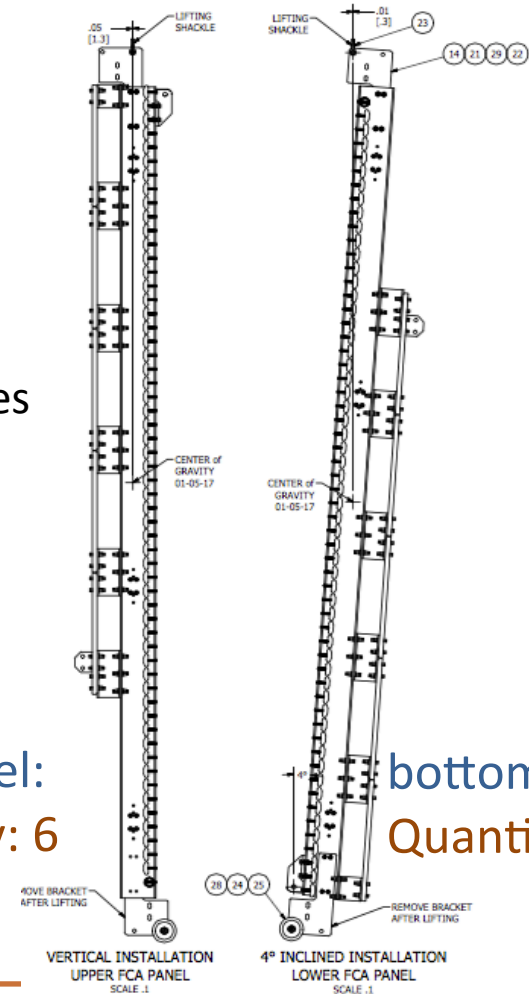
7 regular R-divider boards

1 short → but combine all 4 short
boards on lowest panel

ProtoDUNE-SP FC Top/Bottom Panels



Side view:

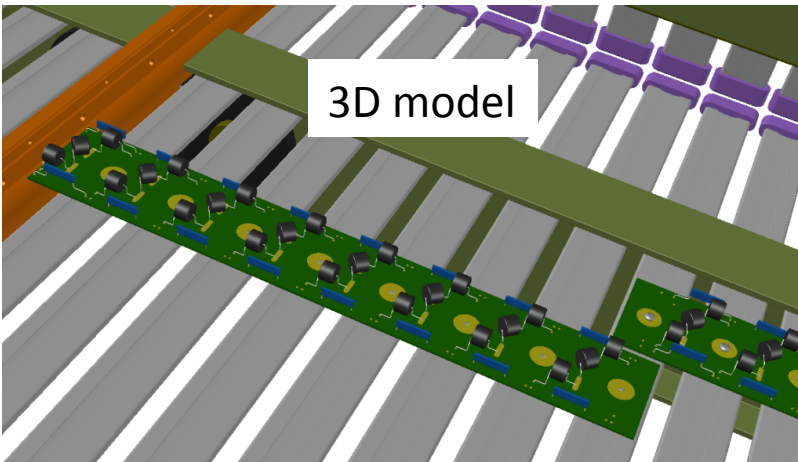


Per FC top/bottom panel:
7 regular R-divider boards
1 short

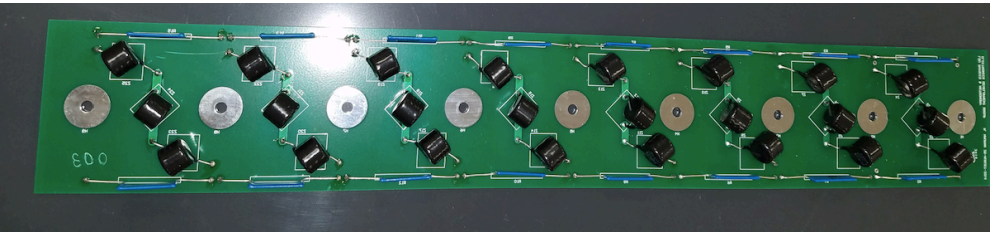
Top panel:
Quantity: 6

bottom panel:
Quantity: 6

Resistive Divider Chain

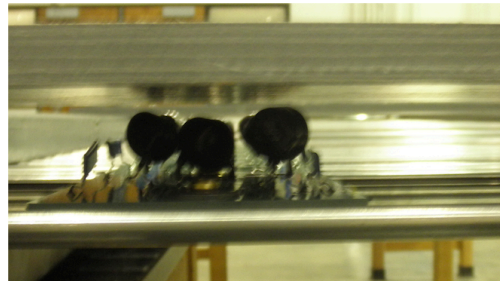
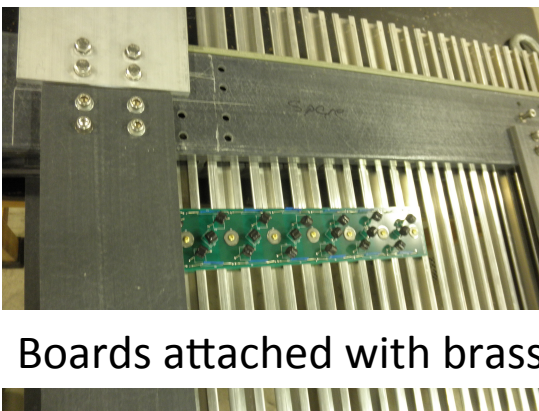


Divider boards can be mounted at different lateral positions along the metal profiles. Boards are staggered to provide a continuous chain.



Built R-divider boards:

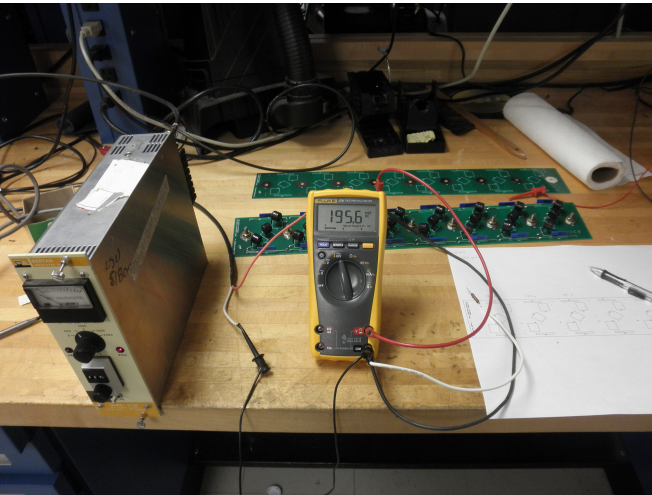
- 8 steps per regular board
- 2 steps per short board
- Per step:
 - 3 varistors in series
 - 2 resistors in parallel



Boards attached with brass screw to SS nut in profile

- Developed and commissioned component test stand
- Automated measurement procedure and data logging
 - performed measurements and analyzed data
- Defined component QC criteria

Board QC Measurements + Documentation



Board Number	-Group	MOV pos	PCB desig	MOV #	Resistor Pos	PCB desig	Resistor #	Test Voltage (mV)
122	-1	1	Z2	1998	1	R1	1775	196.6
		2	Z3	2000	2	R2	1776	
		3	Z4	2001				
122	-2	1	Z5	2002	1	R3	1777	196.6
		2	Z6	2003	2	R4	1778	
		3	Z7	2005				
122	-3	1	Z8	2006	1	R5	1779	195.8
		2	Z9	2007	2	R6	1780	
		3	Z10	2008				
122	-4	1	Z11	2009	1	R7	1781	195.6
		2	Z12	2011	2	R8	1782	
		3	Z13	2012				
122	-5	1	Z14	2013	1	R9	1783	196.4
		2	Z15	2015	2	R10	1784	
		3	Z16	2016				
122	-6	1	Z17	2017	1	R11	1785	195.6
		2	Z18	2018	2	R12	1787	
		3	Z19	2019				
122	-7	1	Z20	2020	1	R13	1788	195.6
		2	Z21	2021	2	R14	1789	
		3	Z22	2022				
122	-8	1	Z23	2023	1	R15	1790	195.9
		2	Z24	2025	2	R16	1791	
		3	Z25	2026				

Test Date: 12-Jun-2017
Name: Katherine Dugas

QC procedure:

Measure voltage drop for each individual stage, convert to current, calculate equivalent resistance R_A (nominal: 500 M Ω)

Results: see spreadsheet on right

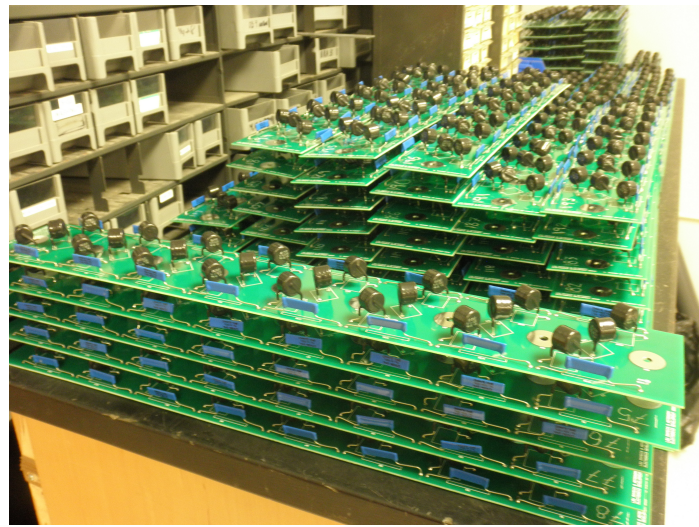
→ For all R-divider boards and steps

*MOV pos measured from left to right of each group
*Resistor pos measured from top to bottom on each group

Board Layout

LSU	Resistor pos 1 (R1)	Resistor pos 1 (R3)	Resistor pos 1 (R5)	Resistor pos 1 (R7)	Resistor pos 1 (R9)	Resistor pos 1 (R11)	Resistor pos 1 (R13)	Resistor pos 1 (R15)	
physics	MOV pos 3	MOV pos 3	MOV pos 3	MOV pos 3	MOV pos 3	MOV pos 3	MOV pos 3	MOV pos 3	
&	MOV pos 2	MOV pos 2	MOV pos 2	MOV pos 2	MOV pos 2	MOV pos 2	MOV pos 2	MOV pos 2	
Astronomy	MOV pos 1	MOV pos 1	MOV pos 1	MOV pos 1	MOV pos 1	MOV pos 1	MOV pos 1	MOV pos 1	
	Resistor pos 2 (R2)	Resistor pos 2 (R4)	Resistor pos 2 (R6)	Resistor pos 2 (R8)	Resistor pos 2 (R10)	Resistor pos 2 (R12)	Resistor pos 2 (R14)	Resistor pos 2 (R16)	board #
	group 1 (-1)	group 2 (-2)	group 3 (-3)	group 4 (-4)	group 5 (-5)	group 6 (-6)	group 7 (-7)	group 8 (-8)	

Board QC Measurements + Documentation



QC procedure:

Measure voltage drop for each individual stage, convert to current, calculate equivalent resistance R_A (nominal: 500 M Ω)

Results: see spreadsheet on right

→ For all R-divider boards and steps

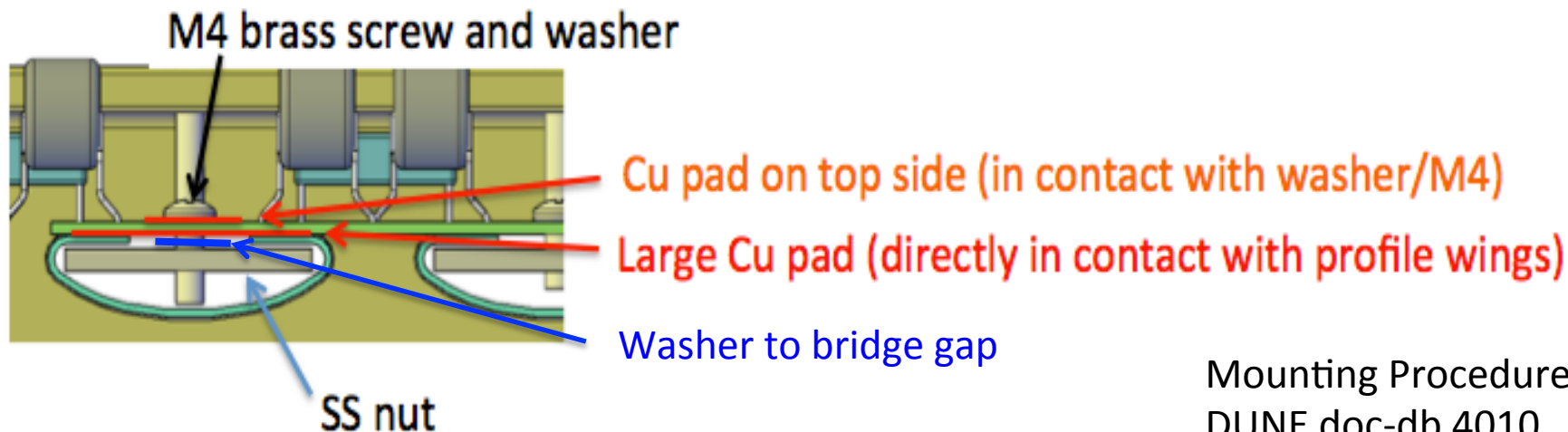
Data and procedure available in **DUNE doc-db 4400**

- Pre-shipment measurements
- Post-shipment/pre-installation measurements (not yet posted)

→ Good agreement

CURRENT MEASUREMENT TESTS								All Data is loaded from other sheets!	
DMM voltages (Vp) measured across 100.0 K Ω pickoff resistor.								Unit = mV	
Board #	V-1	V-2	V-3	V-4	V-5	V-6	V-7	V-8	
121	195.7	197.7	205.9	197.7	200.6	196.2	197.2	196.7	
122	196.6	196.6	195.8	195.6	196.4	195.6	195.6	195.9	
123	196.2	197.1	196.8	197.3	197.1	198.2	197.4	197.1	
124	195.8	195.6	196.6	196.5	196.3	196.7	195.6	195.8	
125	196.5	196.5	196.4	196.8	196.0	196.5	195.6	196.1	
126	195.5	195.7	195.5	196.4	196.7	195.5	195.9	195.9	
127	197.0	197.3	198.2	197.6	197.1	197.6	196.3	197.2	
S103	197.0	131.0							
Calculated current from above pickoff voltages								$I_c = V_p * 1000 / 99009.9$	
Board #	i-1	i-2	i-3	i-4	i-5	i-6	i-7	i-8	Unit = mA
121	1.97657	1.99677	2.07959	1.99677	2.02606	1.98162	1.99172	1.98667	
122	1.98566	1.98566	1.97758	1.97556	1.98364	1.97556	1.97556	1.97859	
123	1.98162	1.99071	1.98768	1.99273	1.99071	2.00182	1.99374	1.99071	
124	1.97758	1.97556	1.98566	1.98465	1.98263	1.98667	1.97556	1.97758	
125	1.98465	1.98465	1.98364	1.98768	1.97960	1.98465	1.97556	1.98061	
126	1.97455	1.97657	1.97455	1.98364	1.98667	1.97455	1.97859	1.97859	
127	1.98970	1.99273	2.00182	1.99576	1.99071	1.99576	1.98263	1.99172	
S103	1.98970	1.32310							
Calculated resistance from I_c								$R_a = (V_i - V_p) / I_c$	
Board #	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	Unit=M Ω
121	505.8279	500.7098	480.765	500.7098	493.4698	504.5386	501.9796	503.2558	
122	503.5119	503.5119	505.5695	506.0866	504.0247	506.0866	506.0866	505.3114	
123	504.5386	502.2343	503.0001	501.7251	502.2343	499.4464	501.4709	502.2343	
124	505.5695	506.0866	503.5119	503.7682	504.2815	503.2558	506.0866	505.5695	
125	503.7682	503.7682	504.0247	503.0001	505.0535	503.7682	506.0866	504.7959	
126	506.3455	505.8279	506.3455	504.0247	503.2558	506.3455	505.3114	505.3114	
127	502.4893	501.7251	499.4464	500.9632	502.2343	500.9632	504.2815	501.9796	
S103	502.4893	755.7018							
Test circuit has two 1 G Ω resistors in parallel in series with a 100.0 K Ω pickoff resistor.									
A DMM with a 10 M Ω input impedance is connected in parallel with the pickoff resistor									
Equivalent circuit from above is two resistors in series: $R_a = 500M\Omega$ and $R_b = 99.0099K\Omega$									
A +1 kV (V_i) test voltage is applied across R_a and R_b :									
The +HV lead from the HVPS is clipped to a bolt through one rectangular copper fill.									
The "+" lead from the DMM is clipped to a bolt through the next rectangular copper fill.									
A 100.0 k Ω resistor is soldered to the clip from the DMM. The HVPS ground is connected to the other end of this resistor as well as the "-" lead from the DMM.									
Current = DMM voltage / pickoff resistance ($I_c = V_p / R_b$)									

Mounting of Resistive Divider Boards

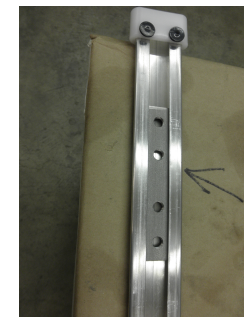


Mounting Procedure in
DUNE doc-db 4010

For top/bottom panels:
in addition used spring washer between screw head and flat washer

Mechanical strength test of connection (at RT and LN):

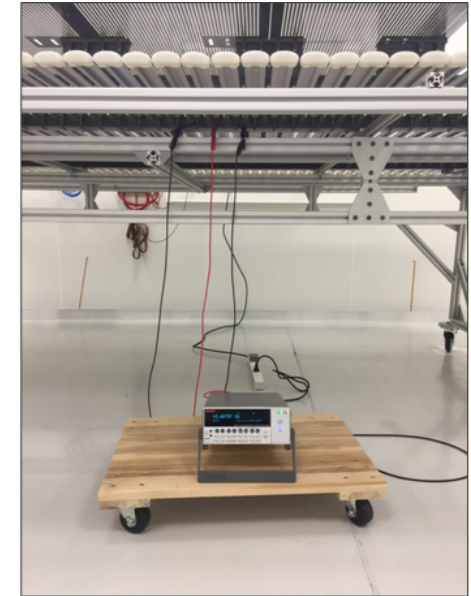
Performed mechanical stability tests of connection
at RT and after cooling to LN
→ No loosening of connection observed



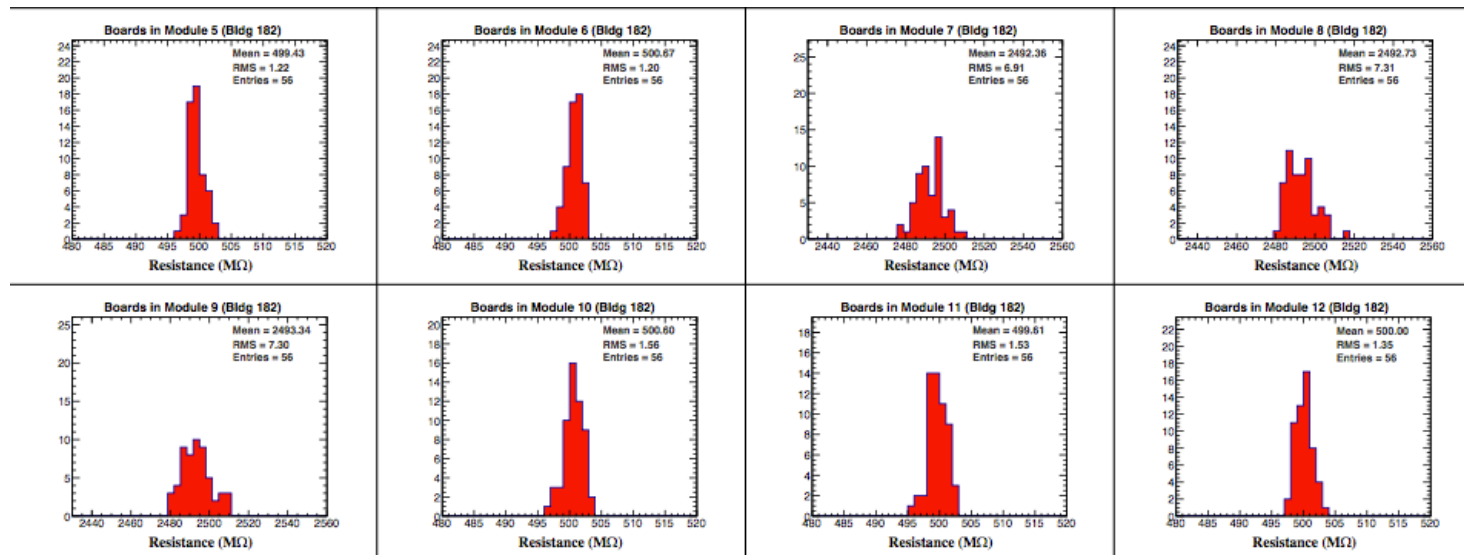
Final Board QC Measurements

QC procedure:

- Use Keithley multimeter for resistance measurement
- 20V across step under test, other profiles grounded
- Measurement precision of 1 MOhm



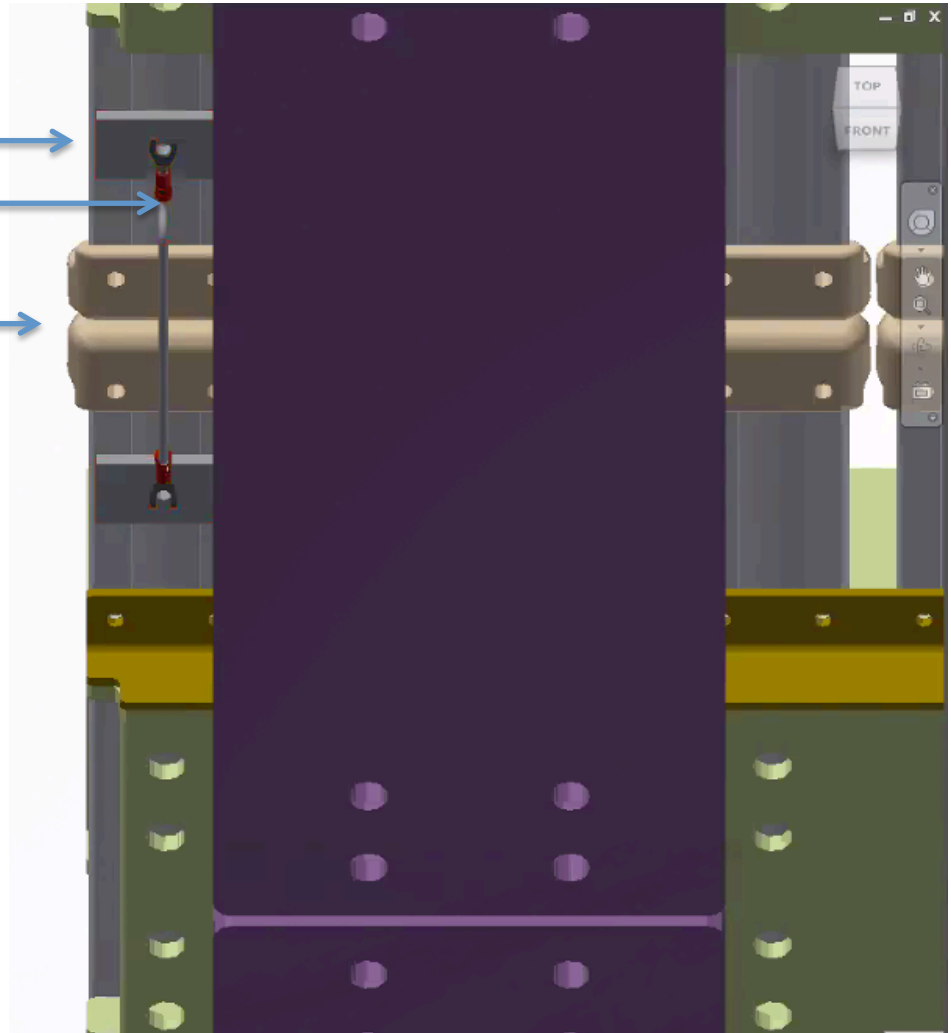
→ For all mounted R-divider boards and steps



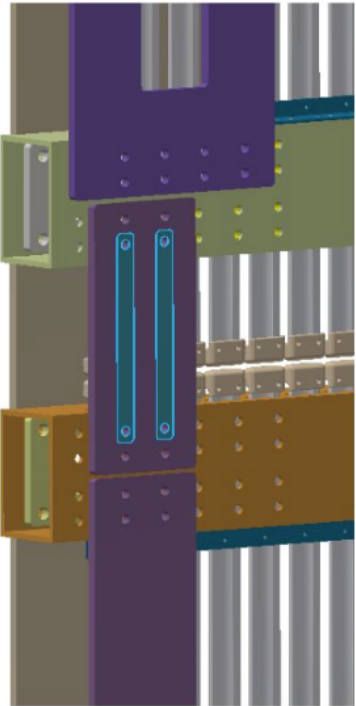
Other FC Internal Connections

Profile 1 connection on cathode side:

- Single hole slip nuts
- Interconnecting cable
- FC endwall panel to panel interface



Profile 57 + 58 connection on anode side:



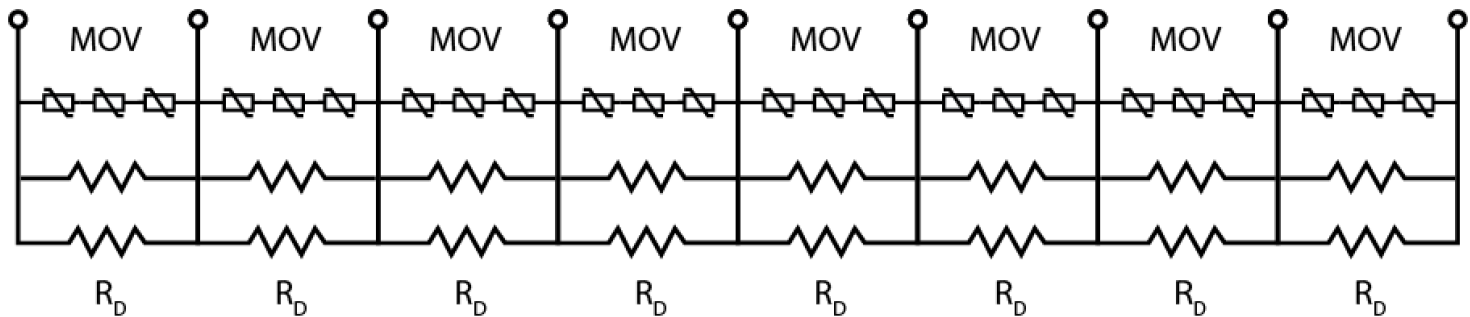
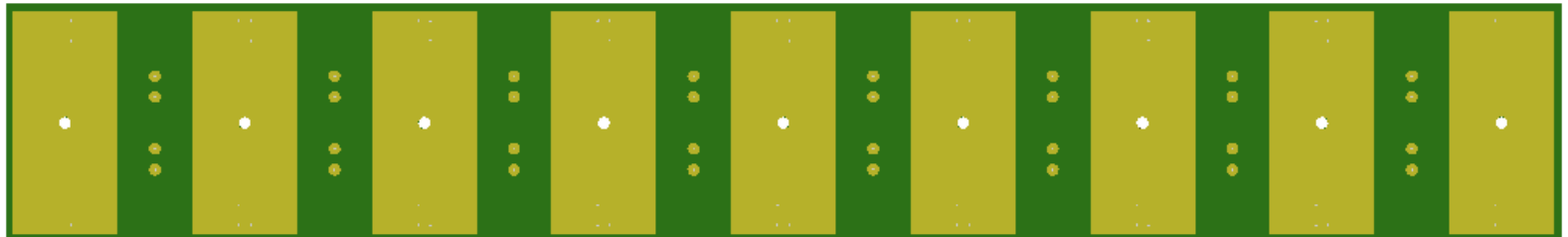
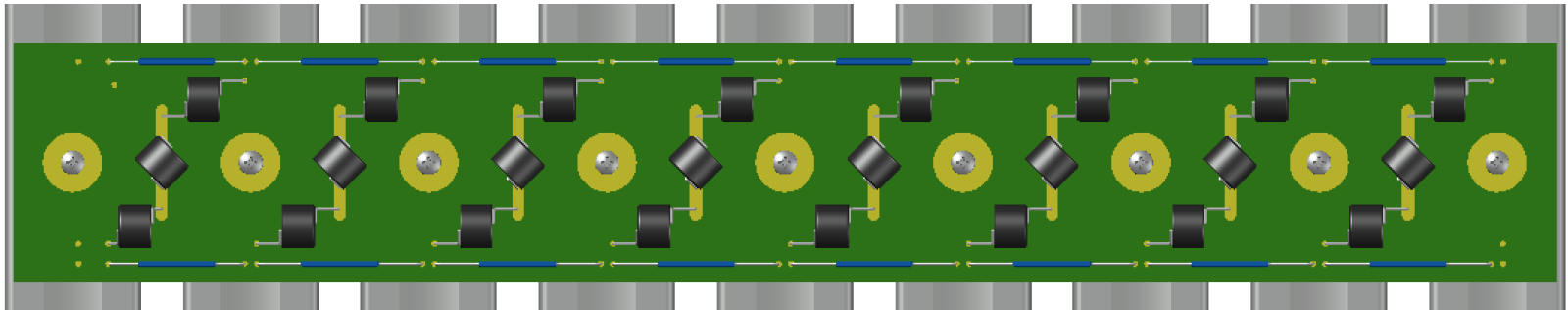
Summary and Conclusion

- Resistive divider boards have been and continue to be extensively tested
 - Electrical and mechanical connections

 - Resistive divider board mounting status
 - Complete for top and bottom FC panels
 - Started Monday for FC endwalls
- To date, no issues found during QC checks

Resistive Divider Board

- We need to use 3 such varistors in series between profiles if we want to have the ability to reach more than 500V/cm drift field in ProtoDUNE.
- Two resistors in parallel to provide redundancy.



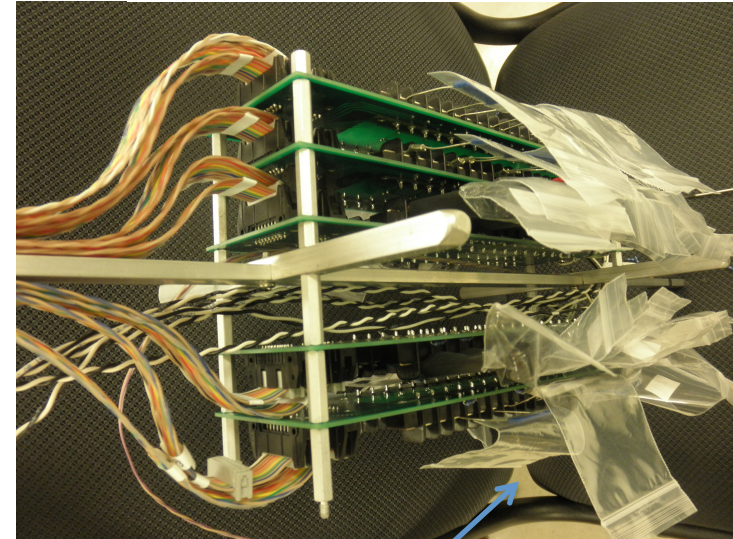
RD: SM104FE-1000M, MOV: ERZ-V14D182

Large Scale Component QC and test stand

Tested ~ 8000 MOV and ~ 4000 resistors

- Can stack up to 5 PCBs high, each with 16 MOVs or resistors → 80 devices per setup
- have multiple mechanical mounts
- Selected resistors and varistors that are within 2 sigma
- For the entire population (well within the 1% absolute Tolerance Specification)

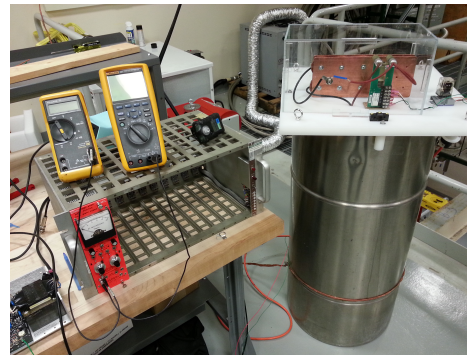
Partially populated test stand



Components are individually bagged and serialized

Status:

Assembled + cleaned boards and Performed QC on each step



Subset of divider boards exposed to sparks in dedicated discharge setup at Yale Univ. and also in 35t HV test setup

