DEEP UNDERGROUND NEUTRINO EXPERIMENT

HVS QA/QC Implementation

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Quality Assurance Measures
QC Examples
(Materials, Production, Installation)
QA/QC Implementation for HVS
Summary

Quality Assurance Measures

- Pre-production efforts
  - Mechanical analysis (stress tests of materials, etc.) HV Design Report in DUNE-doc-10452
  - Cold tests of small components (hardware, connections, etc.) CPA - DUNE-doc-2338
  - Installation tests of mechanical prototypes at Ash River (procedures, test fits, etc.) DUNE-doc-2012, -1876
- Prototyping
  - Blanche, MTS, etc. (small component testing in LAr)
  - 35 ton
  - ProtoDUNE

ProtoDUNE-SP

- Successful operation of HV System
- Documentation of component testing for ProtoDUNE-SP (e.g., DUNE-doc-14308)
- Use of paper checklists from production -> shipping -> installation at CERN (e.g., DUNE-doc-10452)
- Transferred to electronic documentation (e.g., DUNE-doc-8774)
- *Successful test of implementation of QA/QC plan -> optimize for HVS at DUNE*

QC Implementations for HVS in DUNE

Production Materials

- Frames (FC, CPA)
- Resistive Panels (CPA)
- Field Shaping Strips (CPA)
- Profiles (FC, CPA)
- HV Bus (CPA)

-> From vendors to central distribution center (lead factory) receives, runs QC procedures/ checklists and distributes to factories/Logistics Warehouse/SURF

Assumption - no individual marking of these components

Production

- Resistive Divider Boards (FC, CPA)
- CPA/Top and Bottom FC, EW FC Checklists

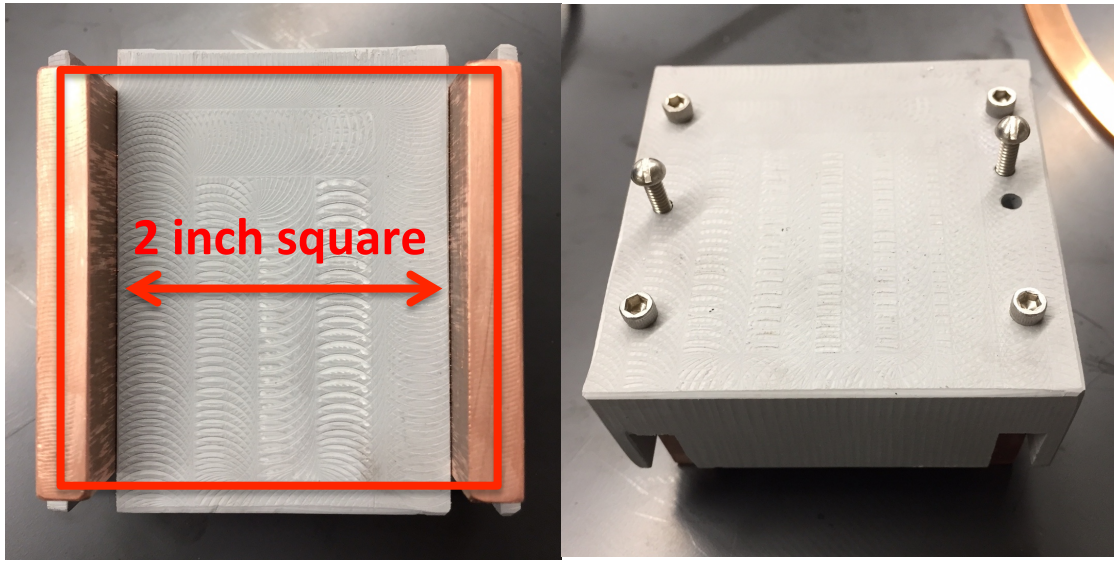
-> Checklists based on ProtoDUNE-SP production experience

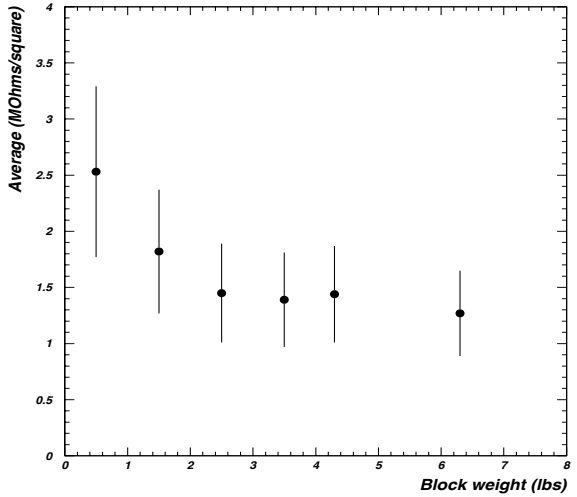
Installation

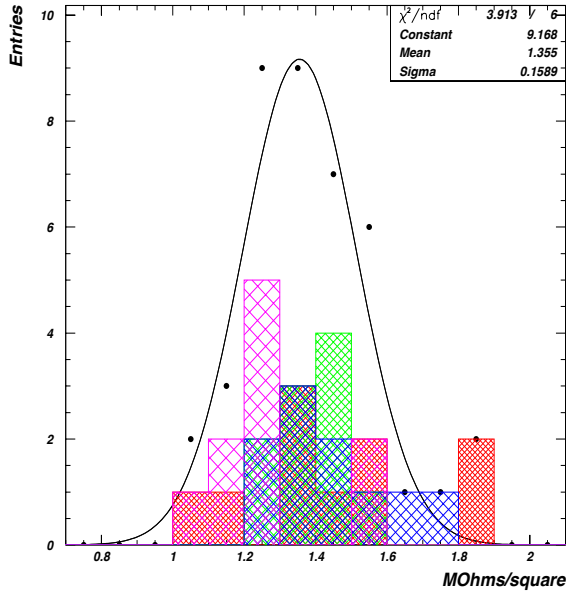
- Component receiving checklists
- CPA – T/B FC Connections Checklists
- CPA – EW FC Connections Checklists

-> Procedures and Checklists based on both Ash River trials and ProtoDUNE-SP experience

Resistive Panel, FSS Resistivity (MΩ/☐)







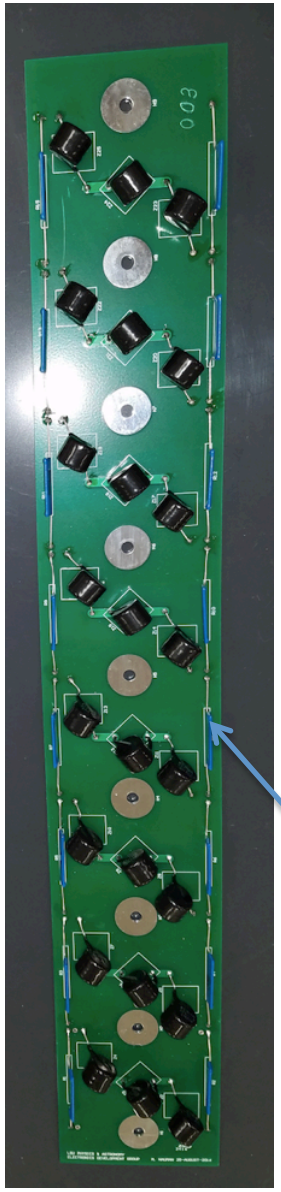
Measure surface resistivity of all Resistive Panels, Field Shaping Strips with a standard tool (all factories)

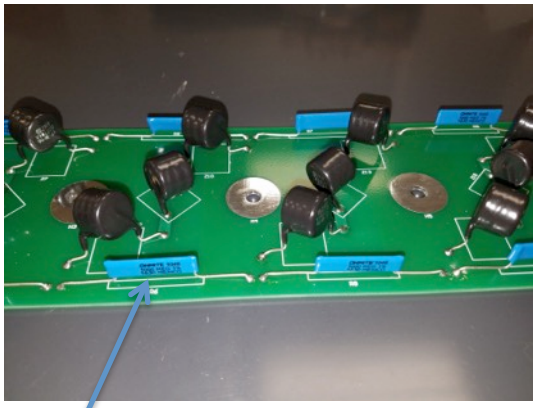
Dots on plot – data with >2 lb weight attached
Achieved > 1 MΩ/☐ for ProtoDUNE (> 1 GΩ/☐ for DUNE)

DUNE-doc-3962

QC Plans for FC resistor divider (LSU)

- Developed large scale component (resistors, varistors) testing & recording setup
- Performed thermal cycles of all components to accelerate mortality due to fabrication defects
- Performed thermal cycle of individual assembled divider board
- Developed test procedure for mounted divider boards

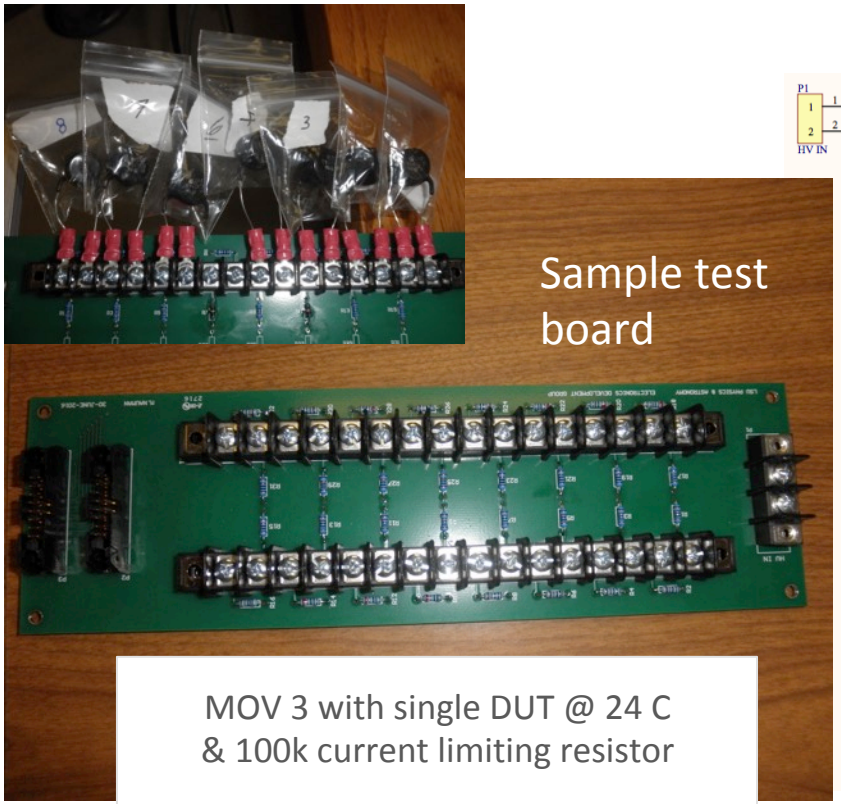


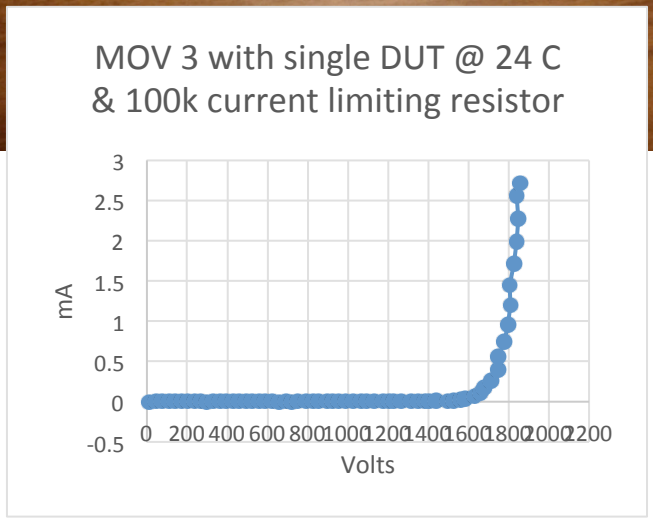


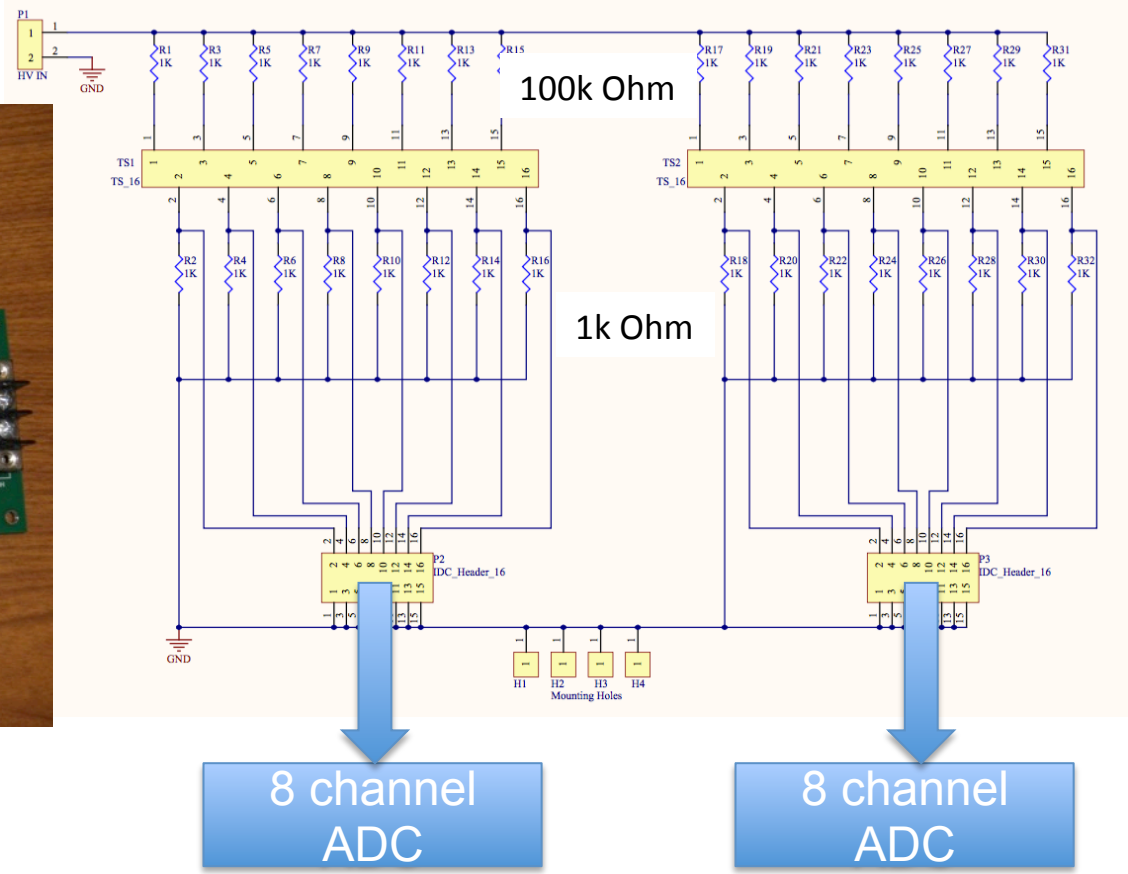
Resistors:
Ohmite Slim-Mox
SM104031007FE
5 G Ohm, 1% tolerance,
1.5 W

Metal Oxide Varistors:
Panasonic
ERZ-V14D182
1800V clamping voltage

Component QC Test Board

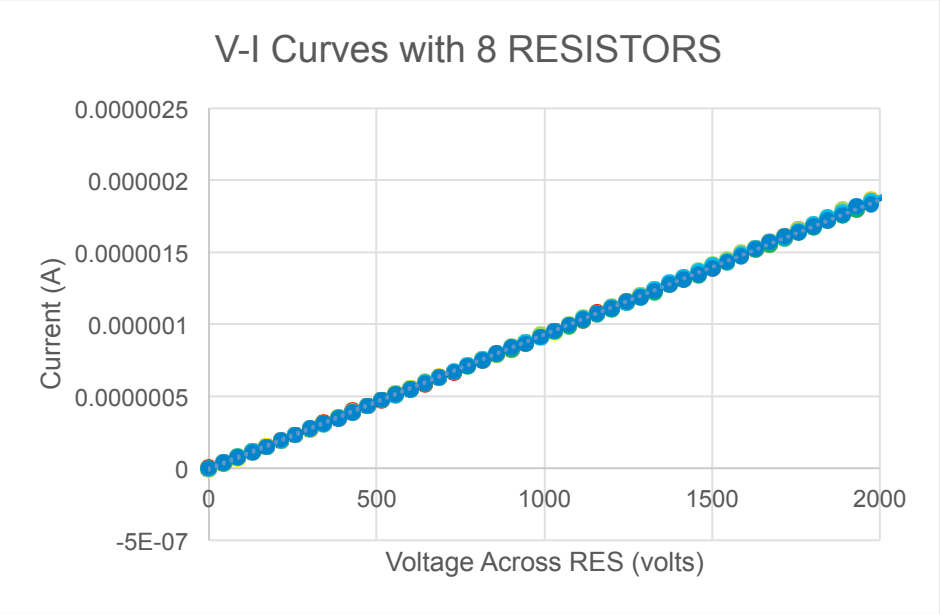


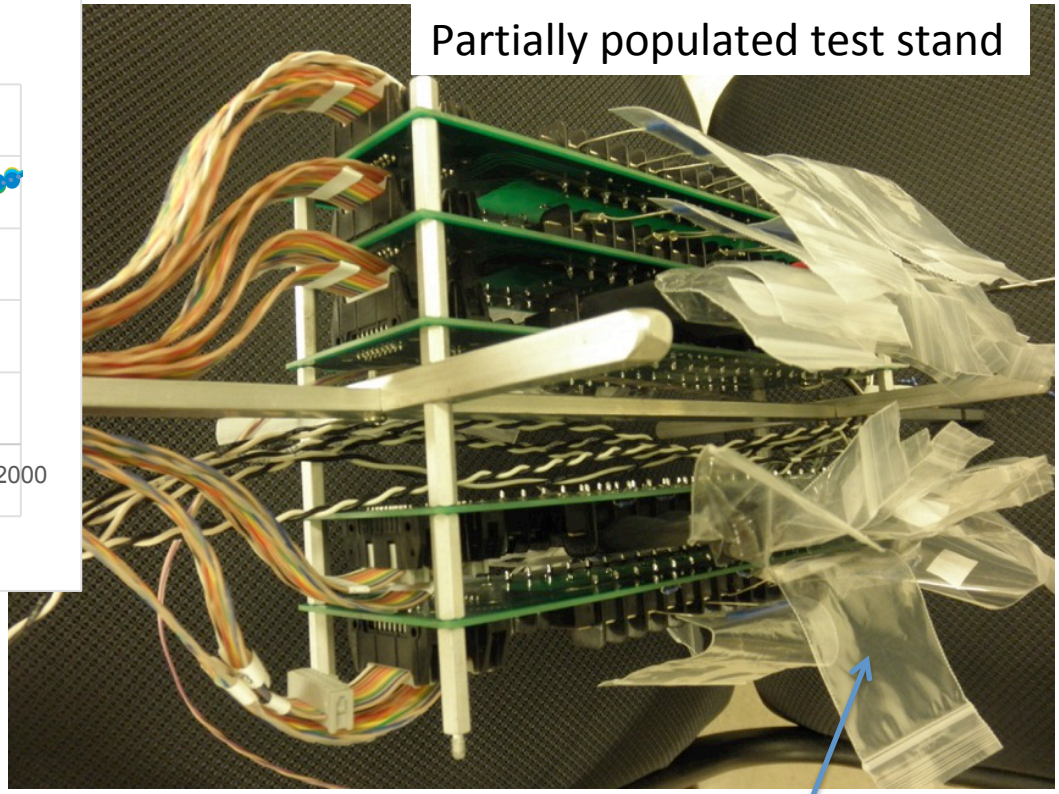




Data logging (and plotting) fully automated

Large Scale Component QC Test Stand





- → Can stack up to 5 PCBs high
- → Can have 2 stacks on mechanical mount
- → 16 resistors or 16 MOVs per board
- → Can test up to 160 resistors or MOVs per cool down cycle
- → Have 2 sets of test equipment to parallelize preparation and testing

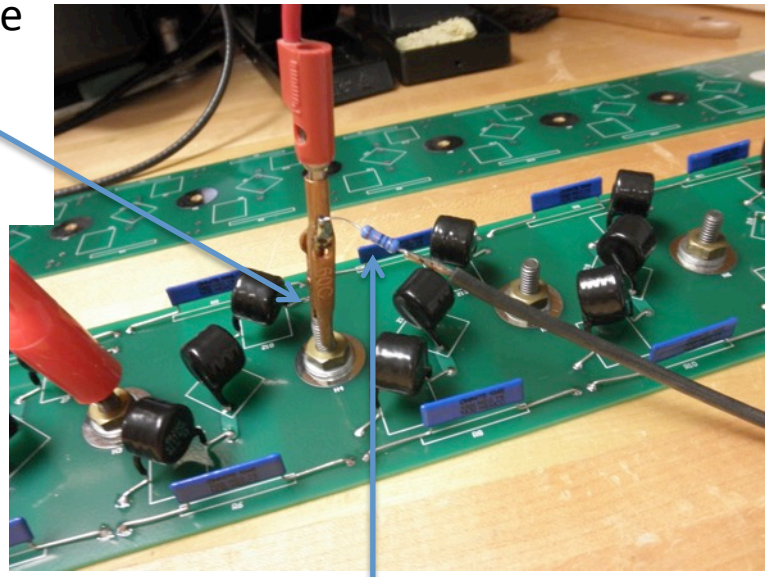
Components are individually bagged and serialized

Use very similar setup to test resistors and MOVs (based on same PCB)

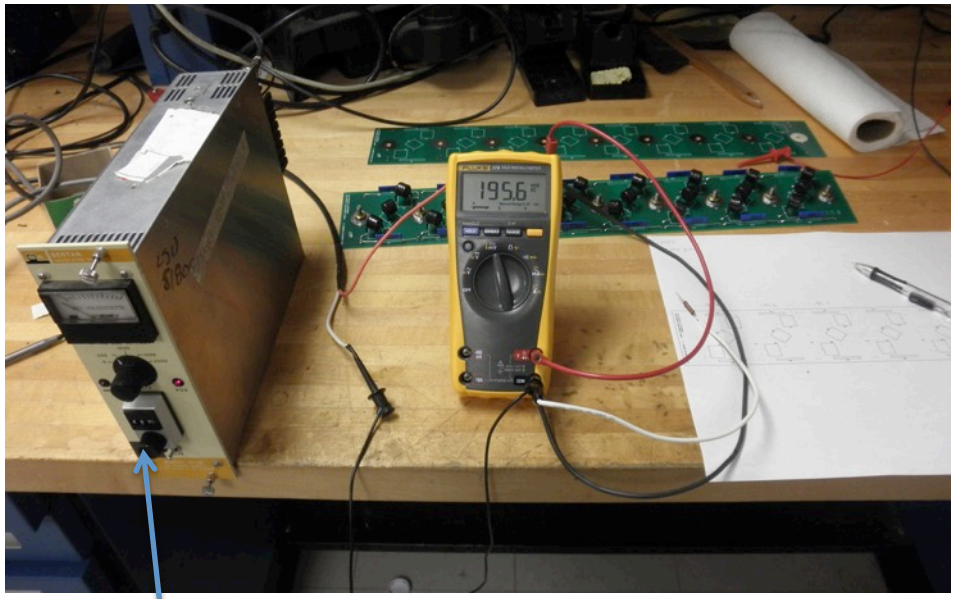
QC measurement setup (free boards)

Insert screws, washers and nuts into divider board to serve as attachment points

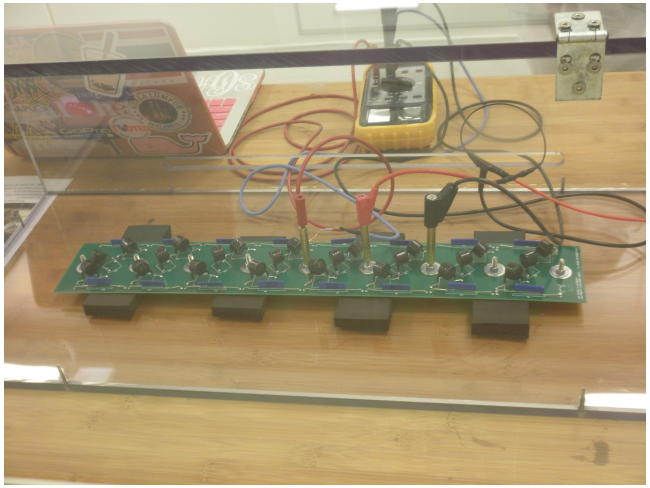
If mounted to profiles, attach alligator clamp directly to profile instead



100kΩ pick-off resistor



HV power supply: used at 1000 V



QC procedure:

Measure voltage drop for each individual stage, convert to current, calculate equivalent resistance R_A (nominal: 2500 MΩ)

Results: see separate spreadsheet

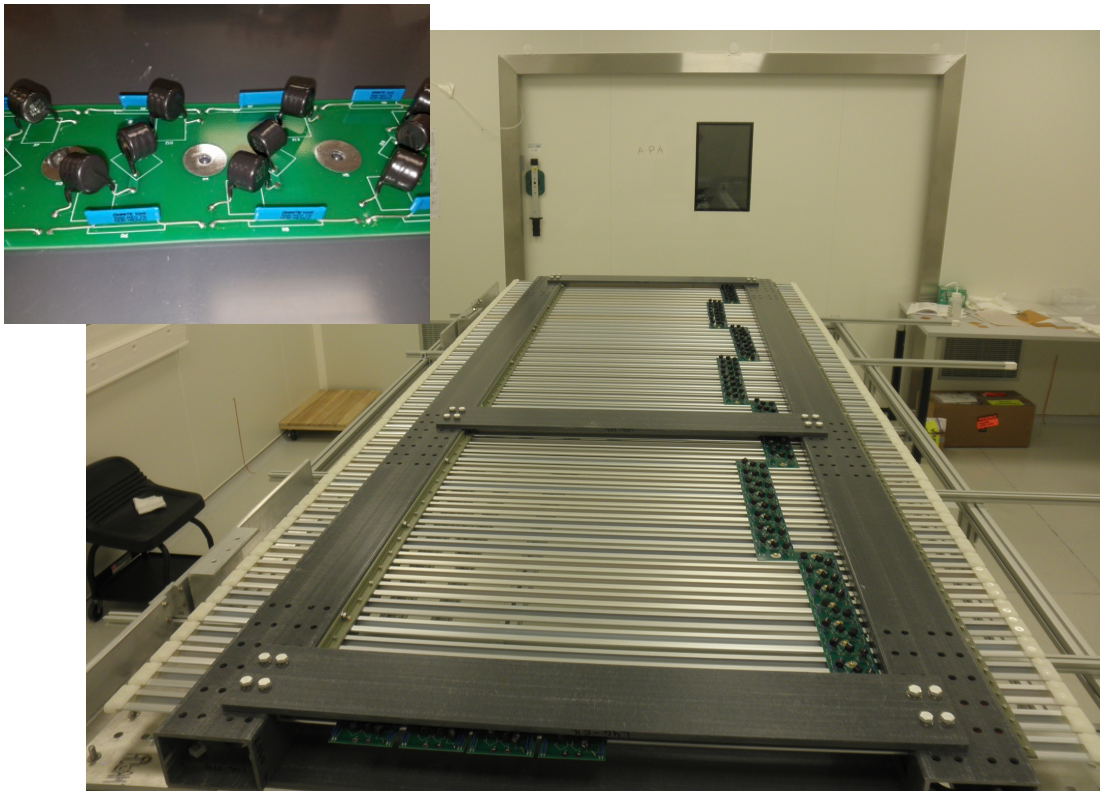
Visual inspection of solder joints/bumps

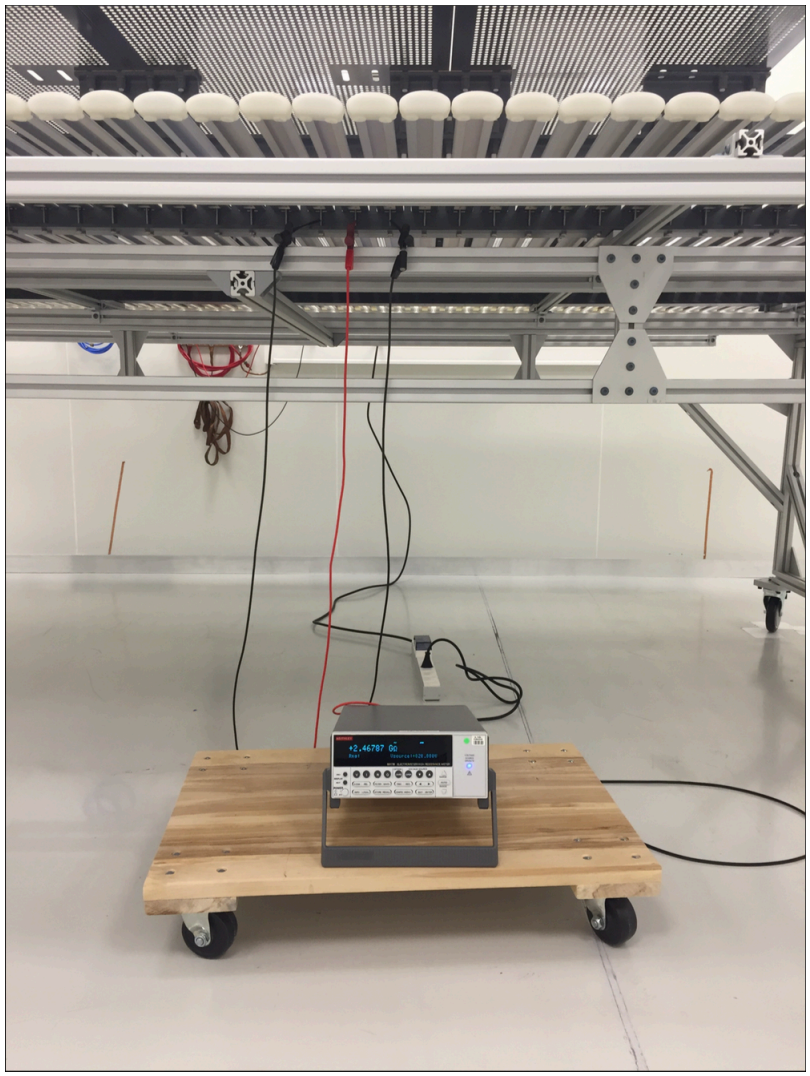
QC measurement setup (mounted boards)

Alternate QC procedure:

Measure resistance between adjacent profiles using a Keithley high resistance meter connected to Mounting screws of neighboring Al profiles

Determine resistance R_A (nominal: 2500 MΩ)





Sample spreadsheet for resistive divider board

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

Board Layout

LSU physics & Astronomy									
	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)	
	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	
	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)	

CURRENT MEASUREMENT TESTS

All Data is loaded from other sheets!

DMM voltages (Vp) measured across 100.0 KΩ pickoff resistor. Unit = mV

Board #	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
514	39.8	39.5	39.5	39.7	39.4	39.3	39.3	39.4
515	39.5	39.5	39.6	39.6	39.8	39.5	39.6	39.5
516	39.7	39.7	39.4	39.7	40.1	39.8	40.0	40.1
517	39.8	39.7	39.5	39.6	39.5	39.5	39.6	39.5
518	39.5	39.5	39.8	39.5	39.5	39.7	39.4	39.4
519	39.7	39.7	39.7	39.8	39.7	39.8	39.4	39.6
520	39.3	39.5	39.4	39.4	39.4	39.4	39.4	39.3
S502	39.7	26.7						

Calculated current from above pickoff voltages Ic = Vp*1000 / 99009.9 Unit = mA

Board #	i_1	i_2	i_3	i_4	i_5	i_6	i_7	i_8
514	0.40198	0.39895	0.39895	0.40097	0.39794	0.39693	0.39693	0.39794
515	0.39895	0.39895	0.39996	0.39996	0.40198	0.39895	0.39996	0.39895
516	0.40097	0.40097	0.39794	0.40097	0.40501	0.40198	0.40400	0.40501
517	0.40198	0.40097	0.39895	0.39996	0.39895	0.39895	0.39996	0.39895
518	0.39895	0.39895	0.40198	0.39895	0.39895	0.40097	0.39794	0.39794
519	0.40097	0.40097	0.40097	0.40198	0.40097	0.40198	0.39794	0.39996
520	0.39693	0.39895	0.39794	0.39794	0.39794	0.39794	0.39794	0.39693
S502	0.40097	0.26967						

Calculated resistance from Ic Ra = (Vi – Vp) / Ic Unit=MΩ

Board #	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
514	2487.58692	2506.480737	2506.480737	2493.853131	2512.842614	2519.236868	2519.236868	2512.842614
515	2506.480737	2506.480737	2500.15099	2500.15099	2487.58692	2506.480737	2500.15099	2506.480737
516	2493.853131	2493.853131	2512.842614	2493.853131	2468.975803	2487.58692	2475.14849	2468.975803
517	2487.58692	2493.853131	2506.480737	2500.15099	2506.480737	2506.480737	2500.15099	2506.480737
518	2506.480737	2506.480737	2487.58692	2506.480737	2506.480737	2493.853131	2512.842614	2512.842614
519	2493.853131	2493.853131	2493.853131	2487.58692	2493.853131	2487.58692	2512.842614	2500.15099
520	2519.236868	2506.480737	2512.842614	2512.842614	2512.842614	2512.842614	2512.842614	2519.236868
S502	2493.853131	3708.136945						

All resistive divider board data spreadsheets available at DUNE-doc-4400

QC Production Procedures

CPA Factory requirements

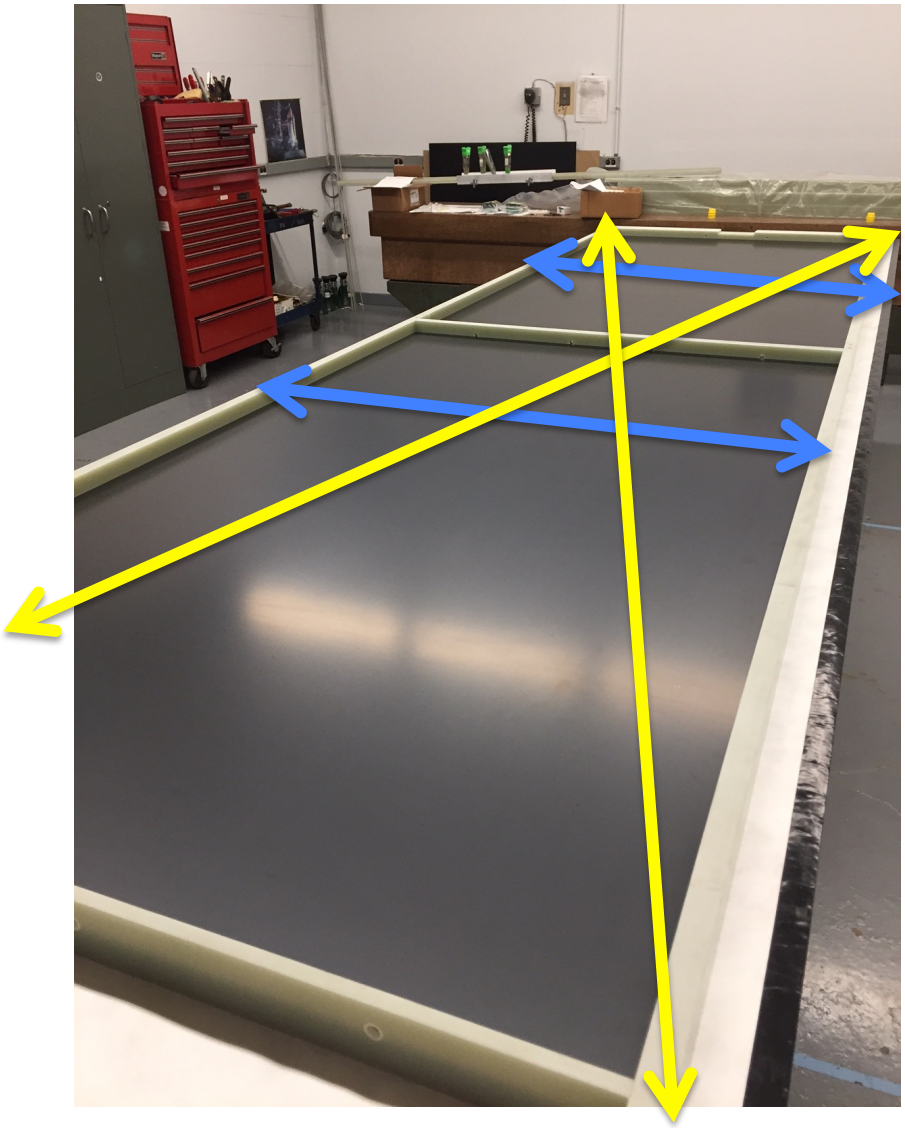
Assembly will occur in an isolated clean room. The clean room does not require an ISO rating – the requirement is that all parts should be cleaned by wiping with isopropyl alcohol to remove grease, dust and other particulates from the manufacturing processes and shipping before they enter the room. This room should have 1 – 40 foot long and 5 foot wide table providing a flat surface over the entire area to less than 1 cm. A suggested layout and minimum room

Room dimensions: 50 feet X 20 feet
Table dimensions: 40 feet X 5 feet
Module dimensions: 2 m X 1.2 m (~6.7 ft X 4 ft)
Crate dimensions: 14 feet X 4 feet
A-frame storage cart dimensions: 8 feet X 2.5 feet

Figure 1. Layout of clean room for CPA production showing 1 long table with 6 CPA modules assembled in pairs.

DUNE-doc-10452

QC During Production



CPA Unit (2 RP modules):

While laying flat on table and with side aligned with straight edge line :

Measure width, length and diagonals

For CPA Panel (3 CPA Units):

Measure width, length and diagonals

Drill pin holes at each module joint

Remeasure dimensions with pins installed

Checks:

- Flatness
- Straightness
- Squareness

Ensures that CPA Array is a flat, continuous wall

CPA Production Procedures

b) Assembly of Middle Unit (DFD-20-A200)

- Scan barcode on temporary tag starting new Unit checklist link.
- The top and bottom Intermediate Bars (DFD-20-A405) and the Side Middle Bars (DFD-20-A501, DFD-20-A502) are arranged with the RP in the slot and bolted together and then repeated for the second module as shown in drawing DFD-20-A200. This Unit has a Middle module (DFD-20-A500) attached to another Middle module (DFD-20-A500).
- Complete the CPA Unit Frame Dimensional Checklist.
- At this point, the Upper, Middle and Lower Units should be lifted onto wooden blocks, aligned with reference line on the table, bolted together and positioned for pin hole drilling. Drill out 10 pin holes (at each module connection) and fit SS pins.
- Complete CPA Panel Frame Dimensional Checklist.
- Remove pins (4) at Unit interfaces and separate 3 Units.
- Mount Vertical HV Bus cables (DFD-20-A505) along left inside of both modules.
- Attach 4 Section to Section Wires (DFD-20-A113) to RPs using machine screws with lock washers and nuts (DUNE-20-A200).
- Attach FSSs on the front surface (DUNE-20-A300) using machine screws and brass mounting straps (DUNE-1-23); flip the frame over and mount the FSSs on the back side. FSS drawings are DUNE-1-16, DUNE-1-18, DUNE-1-19.
- Flip Unit so that front side faces up.
- Complete CPA Unit Connections Checklist.
- Attach temporary tag to Middle CPA Unit.

DUNE-doc-10452

Reference to drawing labels and highlights required checklists in red.

Shipping instructions

Packing into crates for shipment

If production of CPA Units at the proposed 3 factories is staggered in time, only 20 reusable crates are needed to complete the total of 50 shipments needed. The crates will be constructed of plastic reinforced with metal edges so that they can be lowered into the staging area in front of the underground clean room at SURF. Their dimensions will be roughly 4 ft wide by 14 ft long by 2 ft deep. Attach a barcode sticker to the side of the crate and scan it and all tags of the crate contents while packing the crate. The contents of a crate are: 6 CPA Units each with a removable bar code tag, 2 bar-coded hardware bags and 4 bar-coded bags containing Support Blocks. The CPA Shipping Crate Inventory Checklist will automatically be generated and completed linking the crate bar code to the coded contents.

CPA Production Checklists

Parts

FR4 Frames Checklist

Name _____

Date _____

Name	Drawing #	Visual	Length (see drawing)	Cleaned and Bagged
Main Support Bar	DFD-20-A402			
Upper Side Bar (LH)	DFD-20-A404			
Upper Side Bar (RH)	DFD-20-A406			
Intermediate Bar	DFD-20-A405			
Side Middle Bar (LH)	DFD-20-A502			
Side Middle Bar (RH)	DFD-20-A501			
Lower Side Bar (LH)	DFD-20-A602			
Lower Side Bar (RH)	DFD-20-A604			
Bottom Support Bar	DFD-20-A601			
Upper Side Bar (LH)	DFD-20-B404			
Side Middle Bar (LH)	DFD-20-B502			
Lower Side Bar (LH)	DFD-20-B602			

For each of the 12 types, check until 10 consecutive pieces satisfy length within 0.10 inch (reject outliers)

Visual – inspect for absence of crack or damaged faces or edges.

Length – length must lie within range according to drawing.

Cleaned and Bagged – check if cleaned in sonic bath, dried, ready for bagging and shipping

DUNE-doc-10452

Production

CPA Unit Connections Checklist

CPA Unit Type (UM, MM, ML) _____ Name _____

CPA Panel Type (A, B, C) _____ Date _____

Name	Drawing #	Connections designation	Continuity	Resistance (MOhms)
HV Bus				
HV Input plate to Top LH (A)/RH (C) Tab (UM)	DFD-20-			
Top input wire to Top LH Tab (B)	DFD-20-			
Top LH Tab to Top RH Tab (UM)	DFD-20-			
Top LH Tab to Bottom LH Tab – Top (UM,MM,ML)	DFD-20-			
Top module Tab to Bottom module Tab (UM,MM,ML)	DFD-20-			
Top LH Tab to Bottom LH Tab – Bottom (UM,MM,ML)	DFD-20-			
Bottom LH Tab to Bottom RH Tab (ML)	DFD-20-			
FSS, Profiles				
Top to vertical LH, RH	DFD-20-			
Vertical to vertical LH, RH	DFD-20-			
Mid Vertical to horiz. LH, RH	DFD-20-			
Bot Vertical to horiz. LH RH	DFD-20-			
Mini Resistor Boards				
Top Front (A,B,C) (UM)	DFD-20-040			
Top Rear (A,B,C) (UM)	DFD-20-021			
Bottom Front (A,B,C) (ML)	DFD-20-040			
Bottom Rear (A,B,C) (ML)	DFD-20-021			
RP-RP (UM,MM,ML)	DFD-20-(A,B,C)100			

Drawing # - add Panel type to drawing # (A, B, or C).

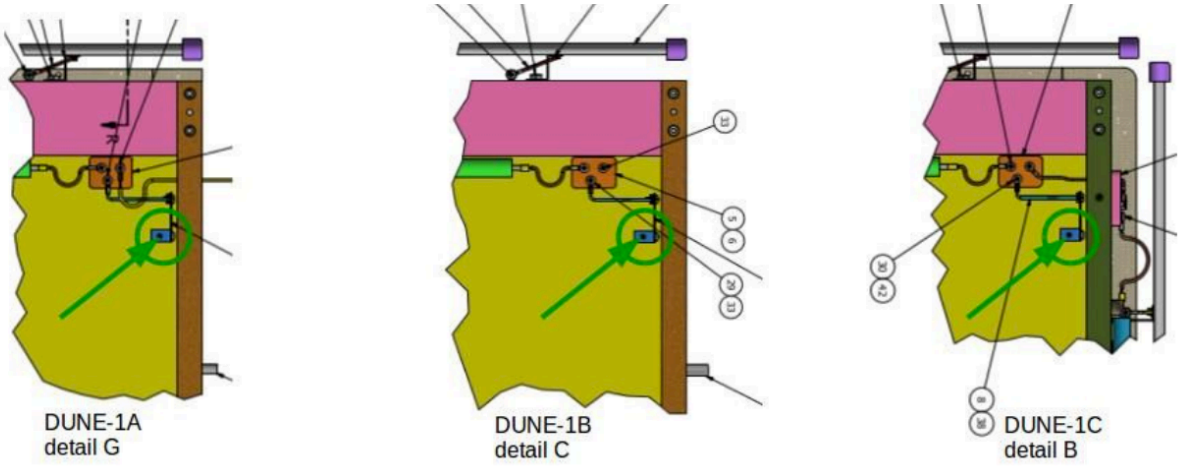
HV Bus – using digital meter, check connection continuity.

FSS, Profile – using digital meter, measure connection continuity of FSS-FSS and FSS-Profile.

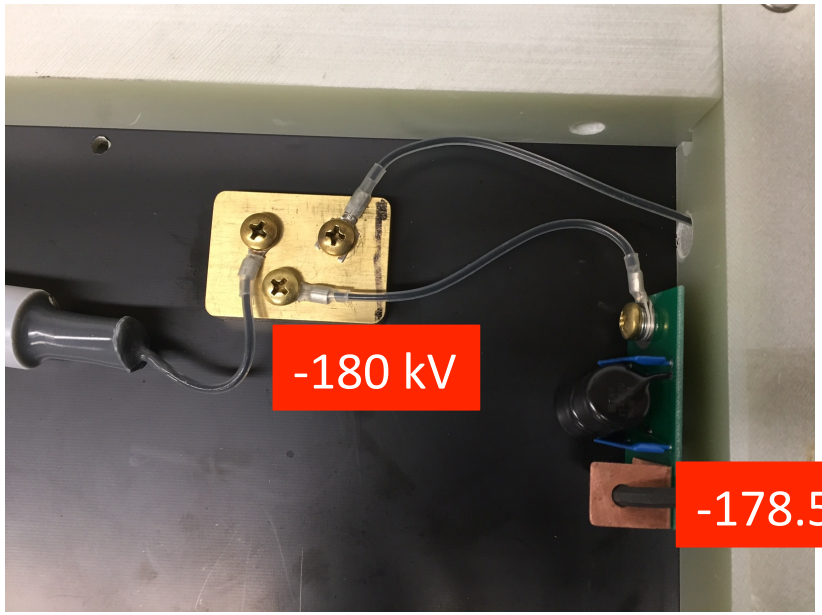
Mini Resistor Boards – using Megger, measure resistance of boards on CPA.

RP-RP Continuity – using digital meter, measure connection continuity between resistive panels.

CPA HV -> FSS, Profile Connection



Top of CPA Panels (A, 48*B, C)
HV -> FSS (-180kV -> -178.5kV)
Total of 400 Mini-resistor boards on CPAs - 2 on each side, top and bottom opposite corners.



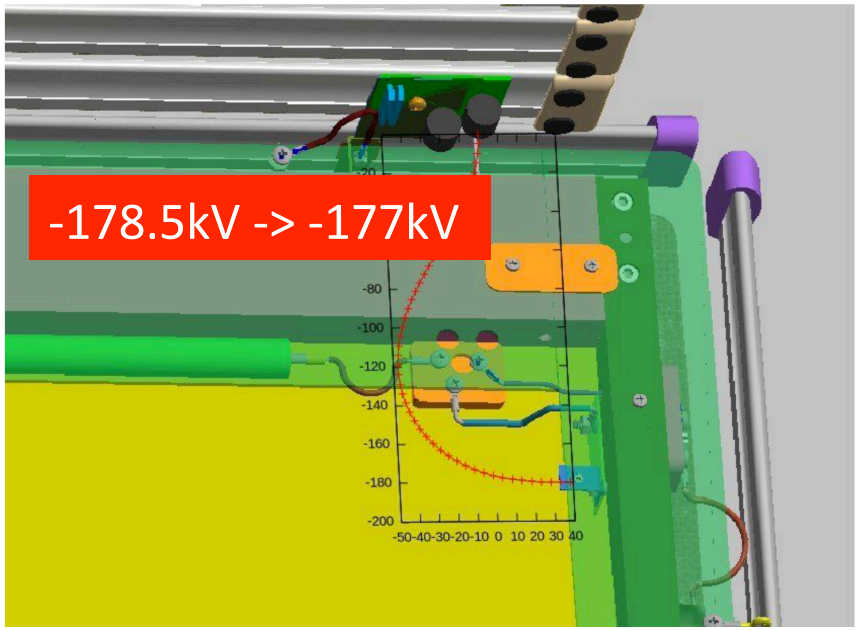
QC tests during production and installation

- Measure resistance between HV Bus and FSS, Profile
- Techniques as described for other RDBs

DUNE-doc-1870

Glenn Horton-Smith

CPA FSS -> FC Connection



Top FC folded against CPA showing RDB with attached jumper

Top connection is made 12 m above floor for 200 of these RDBs :

- Use a portable “Megger meter” to check connection
- Example – up to 10 GΩ, up to 1000V

PEAKMETER®

CE EMC&LVD IEC61010-1 CAT.III 1000V RoHS

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EndWall Production Checklists

Field Cage Endwall Production QC Checklists

Box Beams and Fiber Reinforced Plastic (FRP) Plates

Dimensional Inspection

Box Beam/FRP ID	Drawing No.	Cross sectional Dimensions for Rods and Bars Reference: Field Cage Endwall Panel Assembly Procedure Figure 1				
		Die Struck Dimension	Wall Thickness (Open Shape)	Thickness (Flat Sheets)		Wall Thickness (Closed Shape)
		+/-4% 0.094 (2.39 mm) max	+/-10% =/-0.010 (0.25 mm)	0.125 (3.175 mm) and under +/-15% +/-0.010 (0.25 mm) min	Over 0.125 (3.175 mm) +/-10% +/-0.050 (1.27 mm) max	+/-20% =/-0.010 (0.25 mm) min

Performed by: _____ Date: _____

M&TE _____ S/N_____ Calibration Due Date: _____

CPA/FC/EW Installation Procedures

CPAs arrive at LW (1 crate contains 6 - 2 module units which make up 2 CPA Panels (1 CPA Plane) for 1 CPA/FC installation assembly)

1. Scan crate Barcode.
2. Fill out LW Receiving Checklist (10 min)

CPA crate arrives at underground Bridge

1. Lower crate into Materials Airlock (SAS?)
2. Open crate to prepare for installation
3. Scan barcode on crate and fill out CPA Crate Receiving Checklist (10 min)

Assemble CPA Upstream Panel

1. Remove bottom unit from crate, remove from bag and attach to crane
2. Install bottom unit on CPA assembly frame
3. Remove middle unit from crate, remove from bag and attach to crane
4. Install middle unit on frame mating to bottom unit
5. Drive 0.25" diameter X 2.5" long SS dowel pins into frames at bottom/middle interface and bolt together with 1/4-20 X 2.25" SS socket head bolts
6. Install 4 brass tabs (T-shaped) on FSS on both sides of CPA units at the bottom/middle interface using #8-32 brass screws with two Belleville washers (32 in-lbf torque)
7. Remove top unit from crate, remove from bag and attach to crane
8. Install top unit on frame mating to middle unit
9. Drive 0.25" diameter X 2.5" long SS dowel pins into frames at top/middle interface and bolt together with 1/4-20 X 2.25" SS socket head bolts
10. Install 4 brass tabs (T-shaped) on FSS on both sides of CPA units at the top/middle interface using #8-32 brass screws with two Belleville washers (32 in-lbf torque)
11. Attach and scan tag to CPA Panel, scan and remove 3 CPA Unit tags.
12. Fill out remaining items in CPA Upstream Panel Checklist (20 min)
13. Lift completed CPA Upstream Panel into position on the transport beam - transfer load from crane and lifting fixture to trolley and CPA Hangar

Includes barcode scanning. Required checklists highlighted in red.

DUNE-doc-10452

QC Installation Checklists

LW Receiving Checklist

Name _____ Date _____

Name	Panels	Visual Inspection	Comments
Crate			

Scan barcode on crate and choose LW Receiving Checklist from list of options

Panels - fill out type of CPA Panels inside (AB, BB, or BC)

Visual Inspection – examine crate to make sure there is no damage or open sides

Comments - if Visual Inspection fails note why

CPA Crate Underground Receiving Checklist

Name _____ Date _____

Name	Scan Tag	Bag #	Visual Inspection	Comments
1st Panel (Upstream)				
Lower Unit 1st Panel				
Middle Unit 1st Panel				
Upper Unit 1st Panel				
2nd Panel (Downstream)				
Lower Unit 2nd Panel				
Middle Unit 2nd Panel				
Upper Unit 2nd Panel				
Hardware	---			

Verify contents of shipping crate during assembly

Scan Tag – as Units are removed, scan tag and choose CPA Crate Underground Receiving Checklist, when unpacking Upper Unit, scan Panel tag

Bag # - record Bag # of each Unit and Hardware

Visual Inspection - make sure all bags are sealed and contents has not been damaged during shipment

Comments - if Visual Inspection fails, note why

Checklists for verification of components received for installation – at Logistics Warehouse and underground at SURF

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QC Implementation

- Sequence of temporary QR or barcoded tags with links to procedures/ checklists.
- Large, bright tags that won't be left behind in cryostat – "Cattle Tags" come coded and are very cheap.
- All electronic using smartphones/tablets to scan tags and access checklists.
- Working with U Minn. to develop implementation of this scheme – should have a model to demonstrate this summer (based on NOvA experience).

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Structure of Component Database(s)

Production

- Unit Tag
  - Unit checklists
- Panel Tag
  - Panel checklist
- Plane Tag

Shipping

- Shipping Crate
- LW Receiving

Installation

- Panel Tag
  - Panel checklists
- Plane Tag
  - Plane checklists
- CPA/FC Tag
  - Checklists
- DSS Position Tag
  - Final checklist

Summary

- Successfully employed and demonstrated the effectiveness of QC procedures and checklists developed for ProtoDUNE-SP
- Devised QA/QC plan for the DUNE HVS based on scans of QR or barcodes on temporary tags linked to QC procedures and checklists
- Working on demonstration of actual QC procedures and checklists for production and installation of HVS components w/U Minnesota
  - All electronic system using smartphones or tablets (wireless not required in cryostat!)
- *Next collaboration meeting – HVS demonstration of QC model – propose DUNE-wide implementation*