APA Mechanical Design

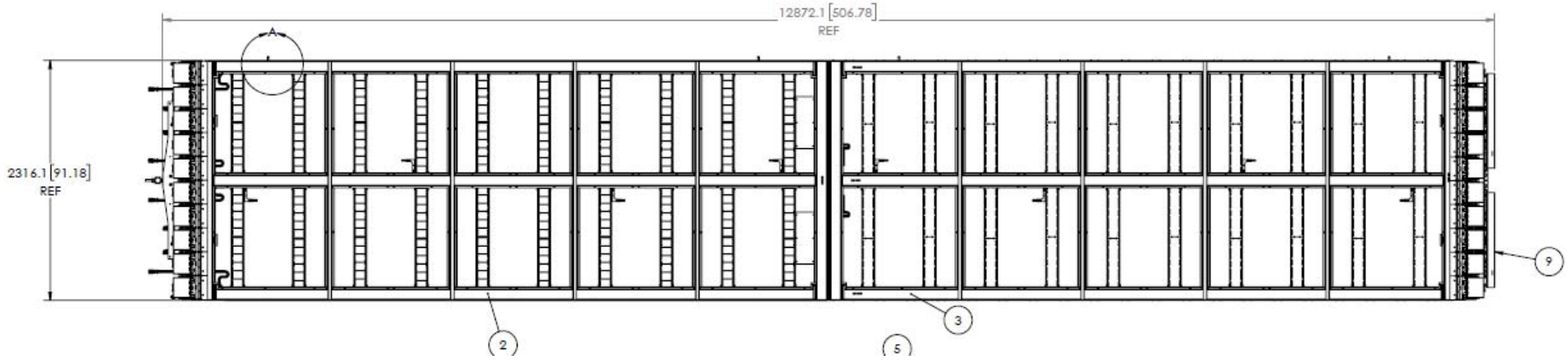
- APA General Design Features
- Frame Design
- Board Design
- Wire and Wire Joints
- Mesh Panels
- Integrated subsystems
  - CE and CE cables
  - PD and Temperature Sensors
  - FC support points
- APA in the installed state
- APA Documentation

Charge questions to be covered

1. How design choices satisfy the requirements.
2. The completeness of the documentation of mechanical specifications, the 3D model and 2D drawings for standard and custom components, and the Compliance Office review of the design covering safety and proper application of design codes and standards.

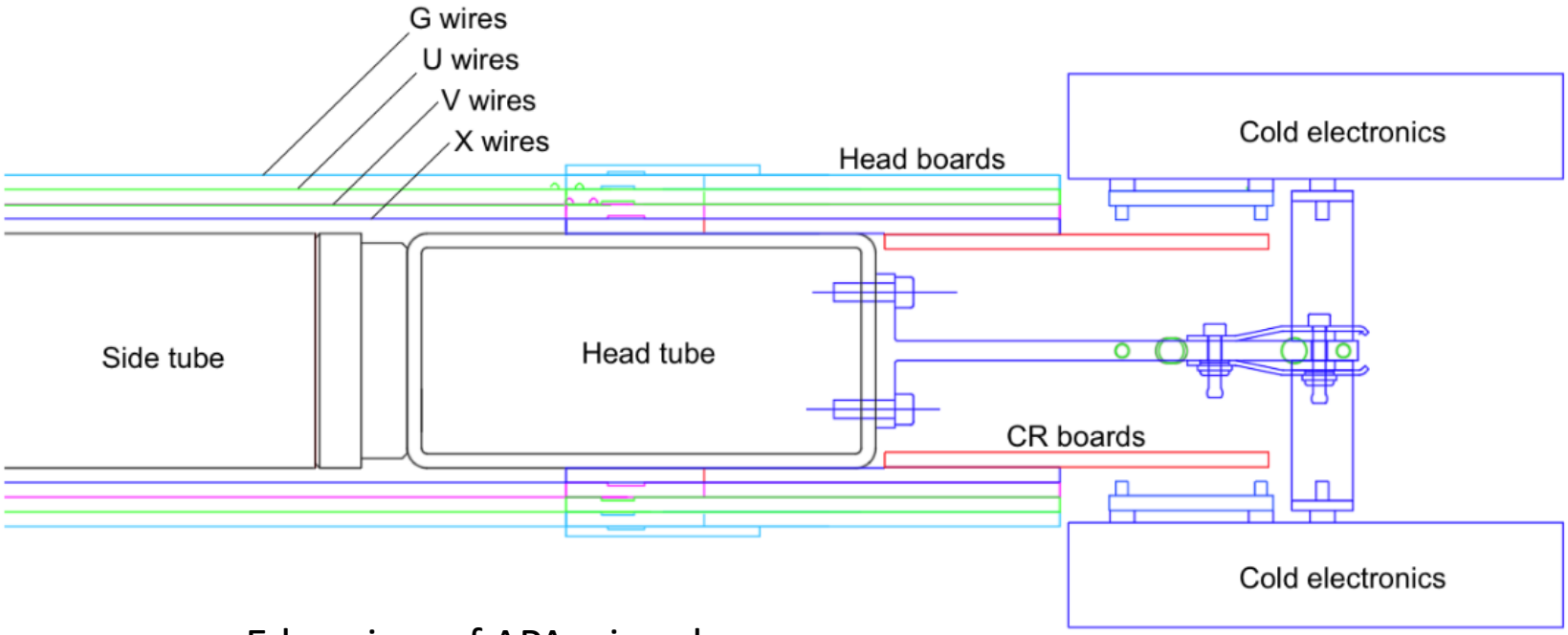
Dimensions

- APA - 6m tall x 2.316m wide x 0.19m thick (at the CE boxes)
- Active area 5.984m tall and 2.3 m wide
  - Defined as the outside edge of the frame on the sides and foot and the inside edge of the head board stack
- APA Pair – 12.872m tall x 2.316m wide x 0.19 thick. (See drawing 8760185 in EDMS #2116830)



Overall size of APA pair from drawing #8760185

Wire planes

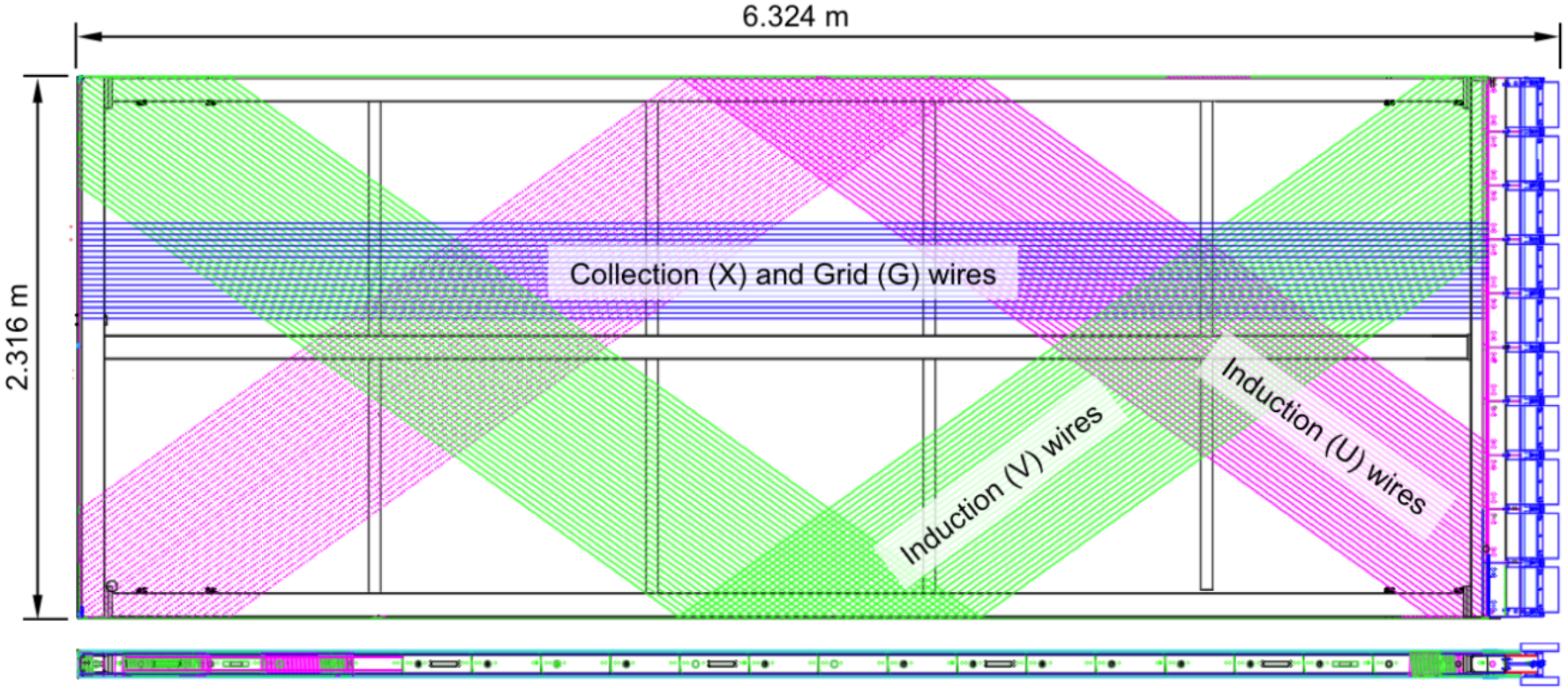


Edge view of APA wire planes

Four wire planes with 4.76mm +/- 0.5mm spacing between planes

Image from TDR

Wire planes



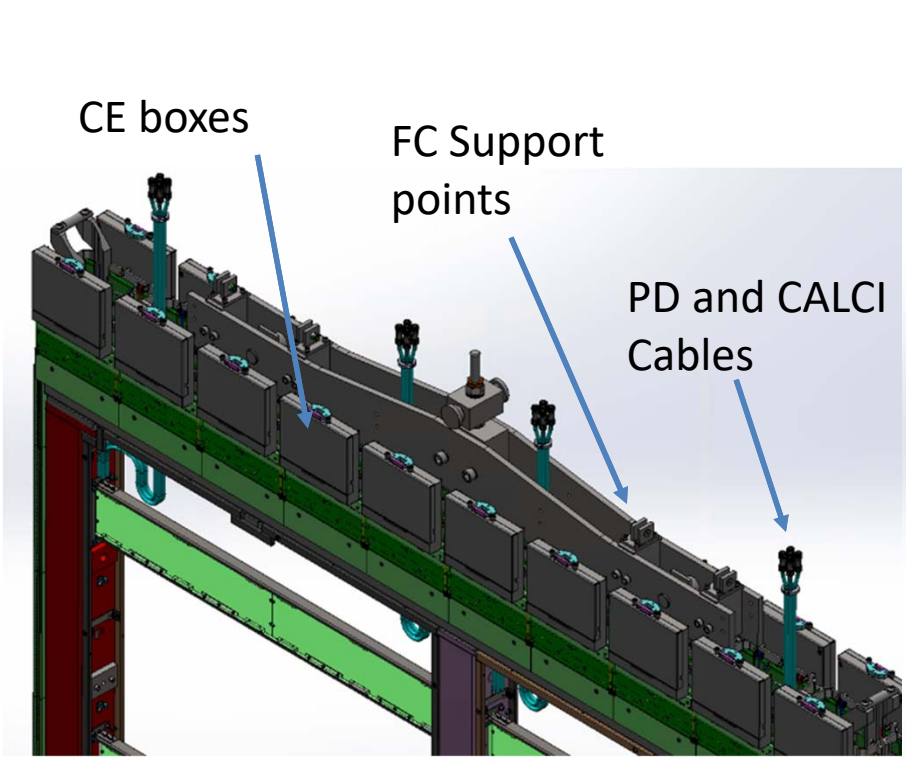
Front view of APA wire planes

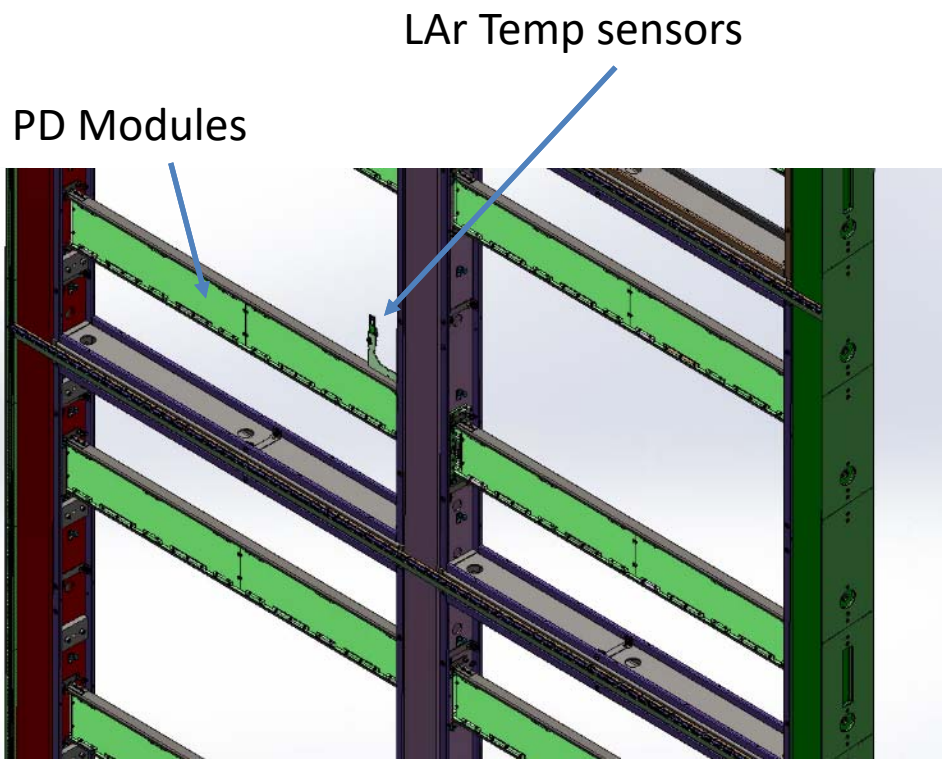
Spacing between x and g wires is 4.79+/-0.5mm
Spacing between u and v wires is 4.7+/-0.5mm
U and V wires wrap at +/- 35.7 degrees around the frame

Image from TDR

Integrated subsystems

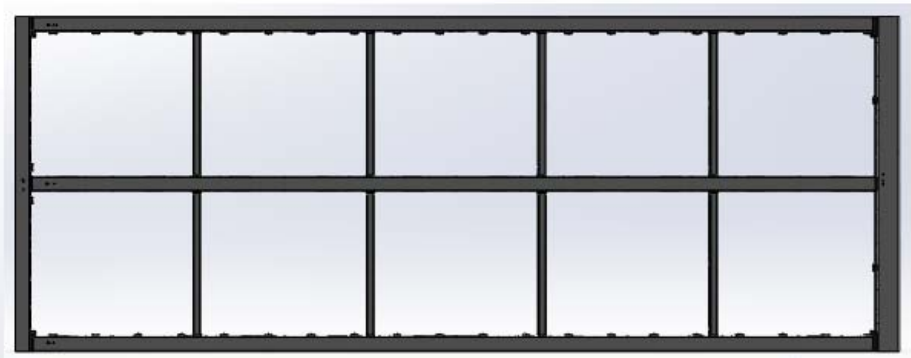
Cold Electronic (CE) Boxes and Cables (not shown)
Photon Detectors (PDs) and Cables
LAr Temperature Sensors and Cables (CALCI)
Field Cage (FC) Support points

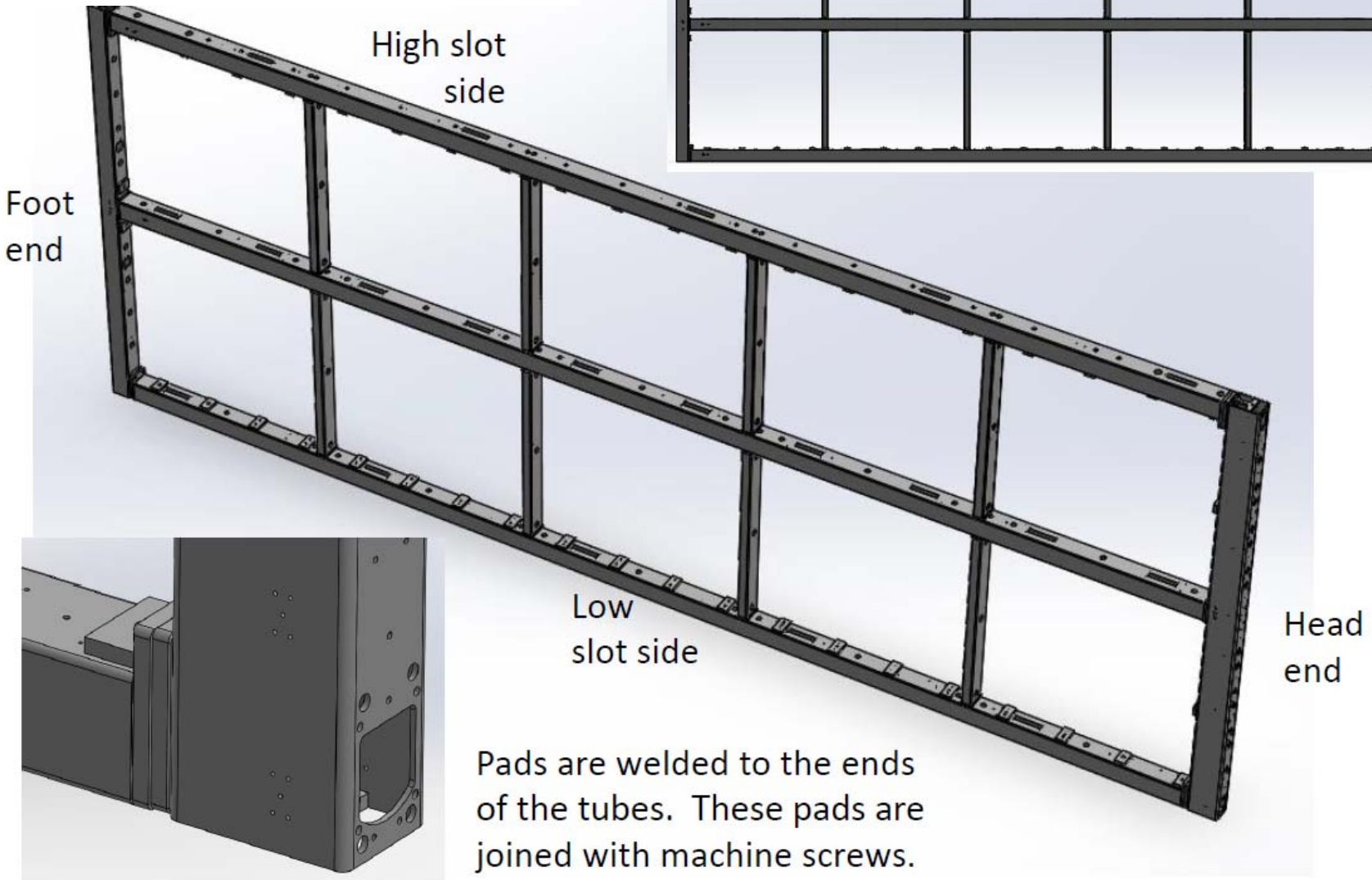




Frame Design

Material: 304 Stainless





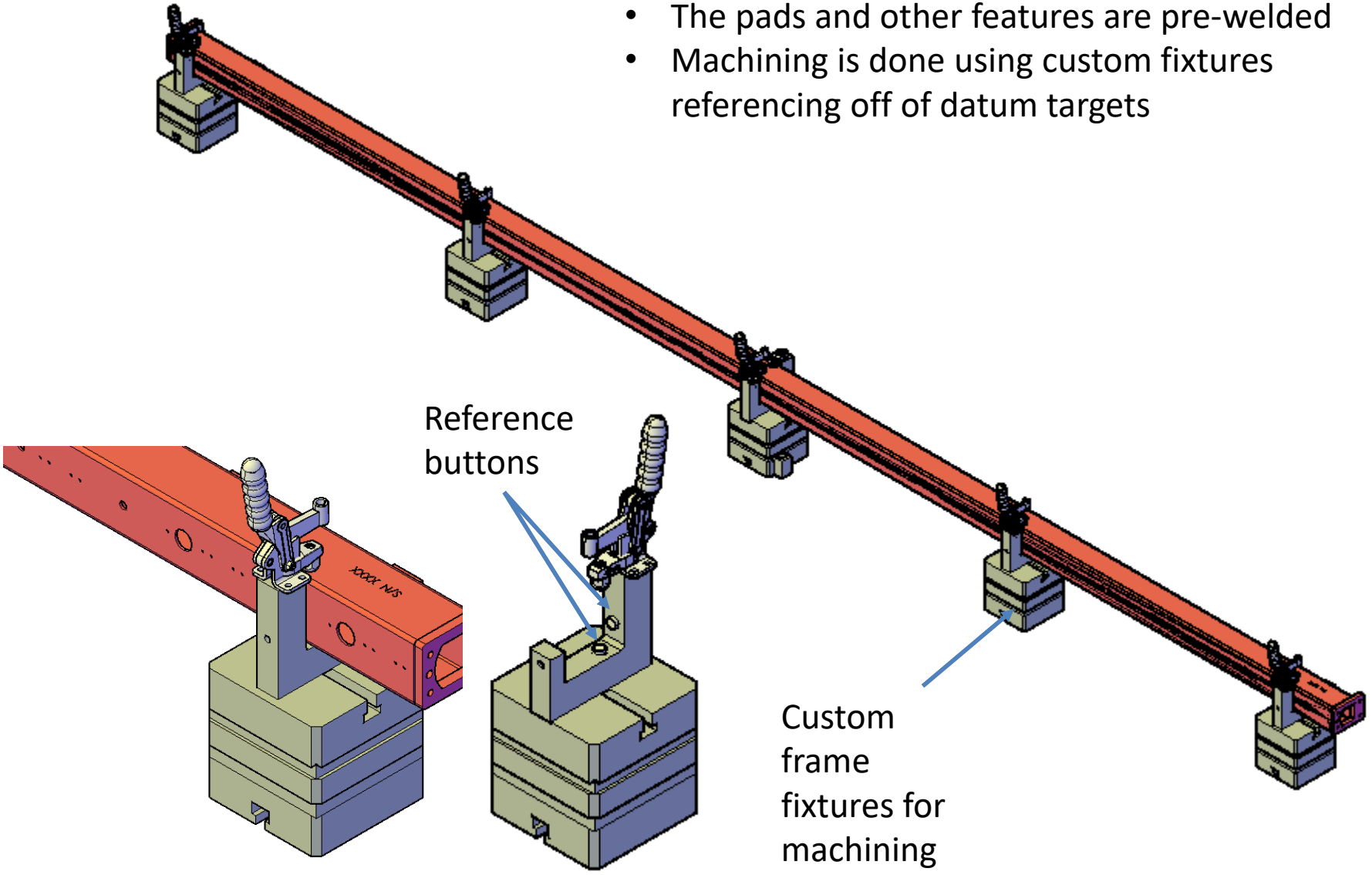
Pads are welded to the ends of the tubes. These pads are joined with machine screws.

All screws have retention washers.

Frame Fabrication

Process:

- The pads and other features are pre-welded
- Machining is done using custom fixtures referencing off of datum targets



Frame Tolerances

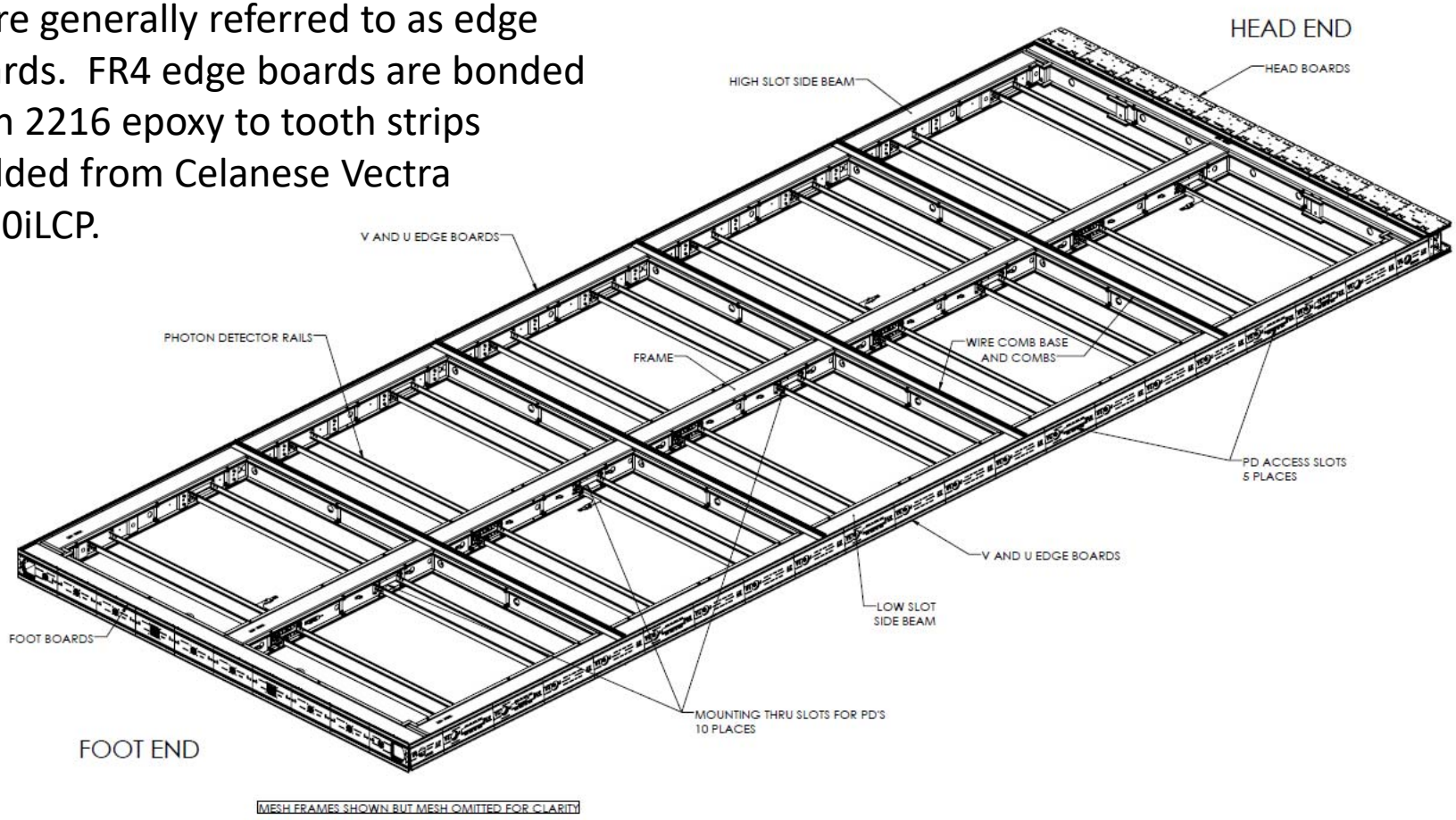
Measurement	Actual	Tolerance
Cross corner deviation		2.0 mm (1.0 target)
Straightness of left side		1.5 mm (1.0 target)
Straightness of right side		1.5 mm (1.0 target)
Overall Flatness		11.0 mm
Overall Bow		11.0 mm
Overall Twist		1.0 mm/m
Twist Zone 1		1.0 mm/m
Twist Zone 2		1.0 mm/m
Twist Zone 3		1.0 mm/m
Twist Zone 4		1.0 mm/m
Twist Zone 5		1.0 mm/m
Fold –back (datum) side		
Foot tube		1.2 mm
Rib 1		1.2 mm
Rib 2		1.2 mm
Rib 3		1.2 mm
Rib 4		1.2 mm
Head tube		1.2 mm
Fold – front side		
Rib 1		1.2 mm
Rib 2		1.2 mm
Rib 3		1.2 mm
Rib 4		1.2 mm
Maximum x deviation		Not defined
Maximum y deviation		Not defined

- Frame acceptance criteria is based on modes of distortion: Bow, Twist, and Fold. See “Layer distortion summary_6m frame” DUNE DocDB 1300.
- Applying standard tolerance methods are not appropriate.
- Frame is carefully mounted in “free state” and surveyed.
- Survey results are compared to acceptance criteria for bow, twist and fold.

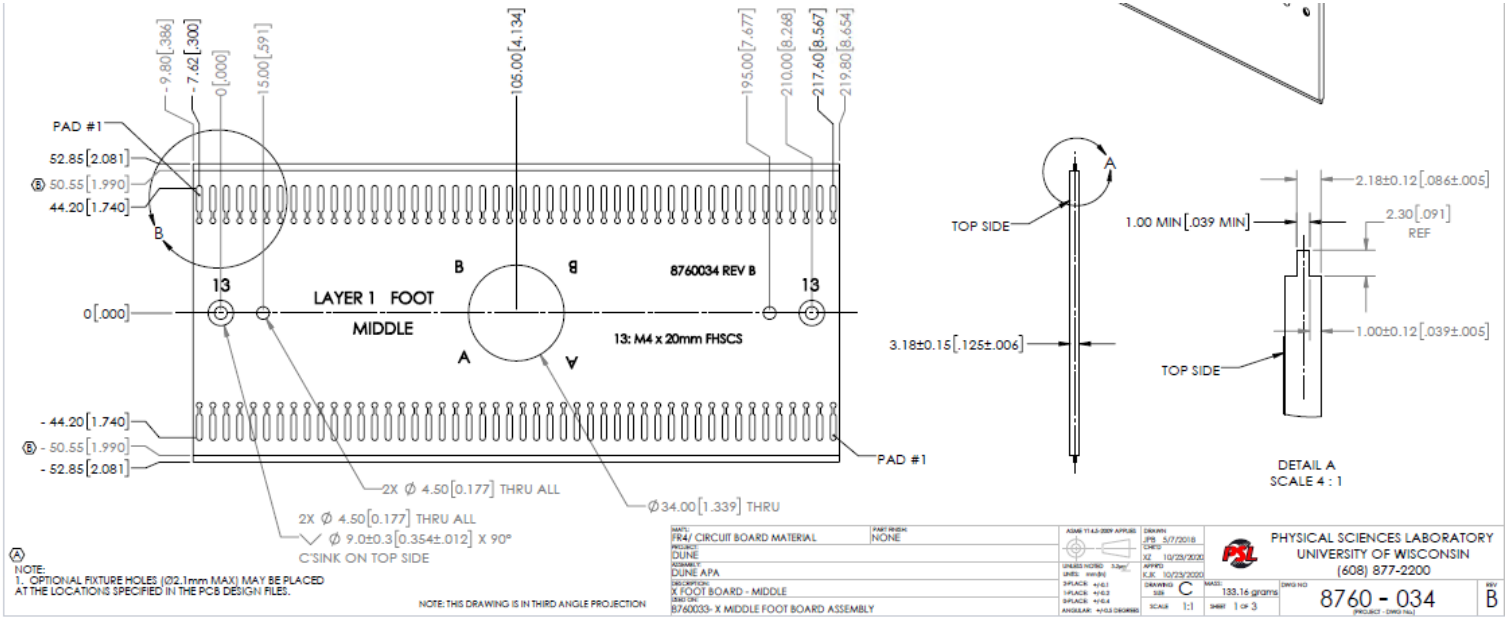
Board design

Board Material: FR4

Foot boards and side boards are more generally referred to as edge boards. FR4 edge boards are bonded with 2216 epoxy to tooth strips molded from Celanese Vectra E130iLCP.



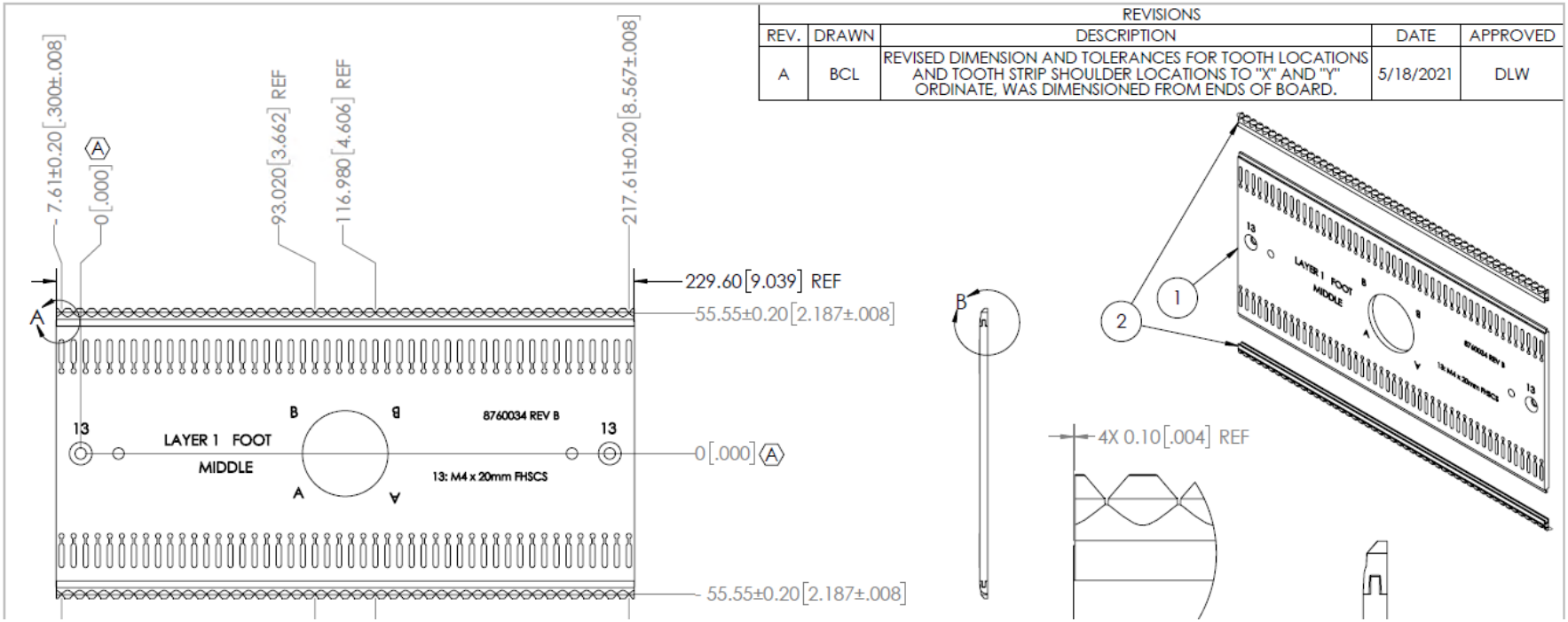
Edge Boards



Partial view of sheet 1 of 3 of 8760034

- Critical features are:
  - Tongue, shoulder, thickness, board locating holes
  - Tongue sides to 0.12
  - Shoulder to 0.1
  - Thickness to 5%
  - Locating holes are controlled to 0.1 in diameter
- Critical features are dimensioned from locating holes or the board mounting surface.

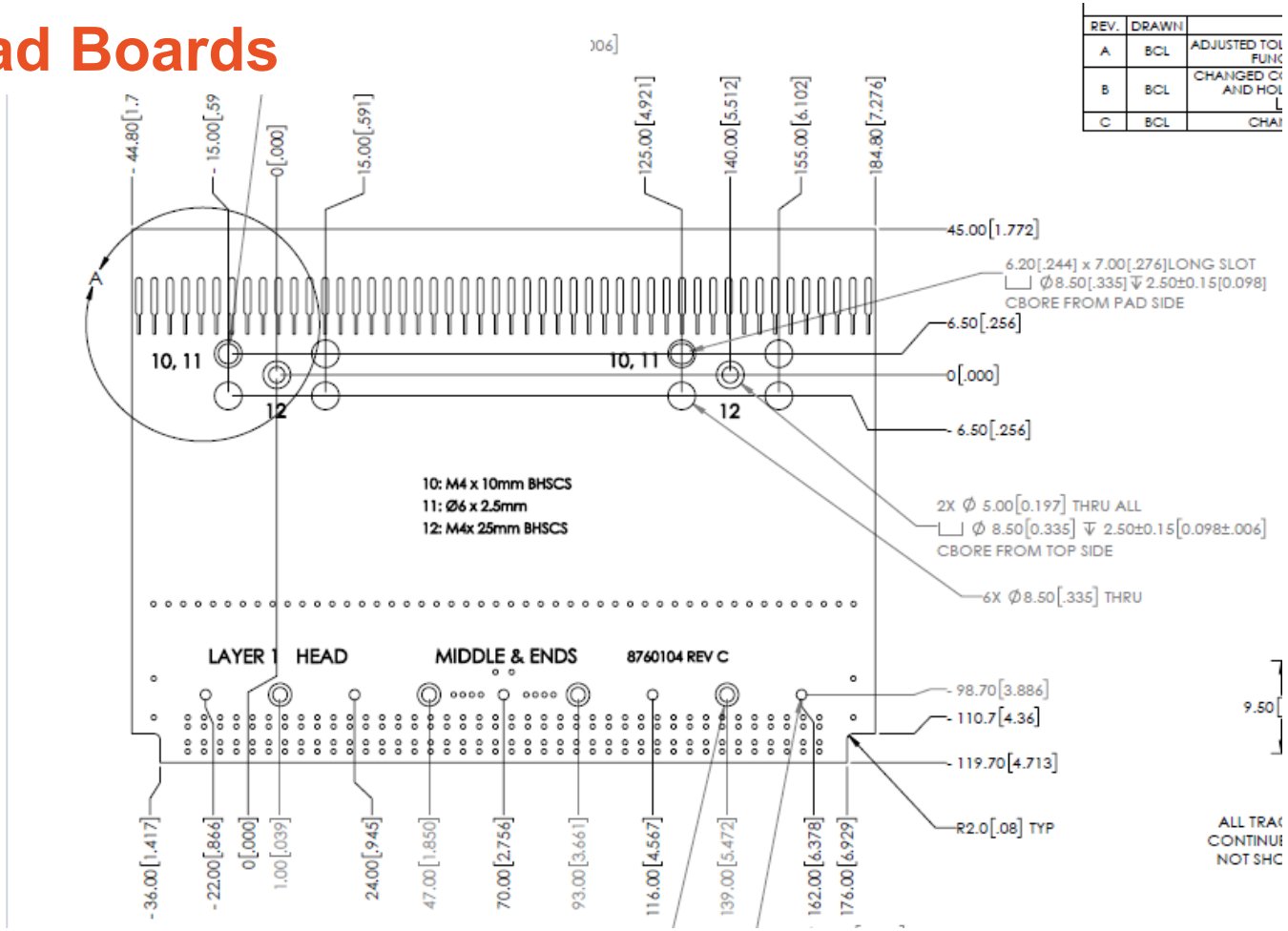
Edge board Assembly



Partial view of sheet 1 of 1 of 8760033

- Tooth strips are located and bonded
- Critical end teeth locations are defined with respect to mounting holes

Head Boards



Partial view of sheet 1 of 3 of 8760104

- Critical features are:
  - Thickness, Mill-Max pin holes, and board locating holes,
  - Mill-Max pin holes and board locating holes are controlled to 0.1 in position.
  - Thickness to 5%
- Critical features are dimensioned from locating holes.

Head Board Revisions to Address Broken Wire Issue:
To protect long v and u wires

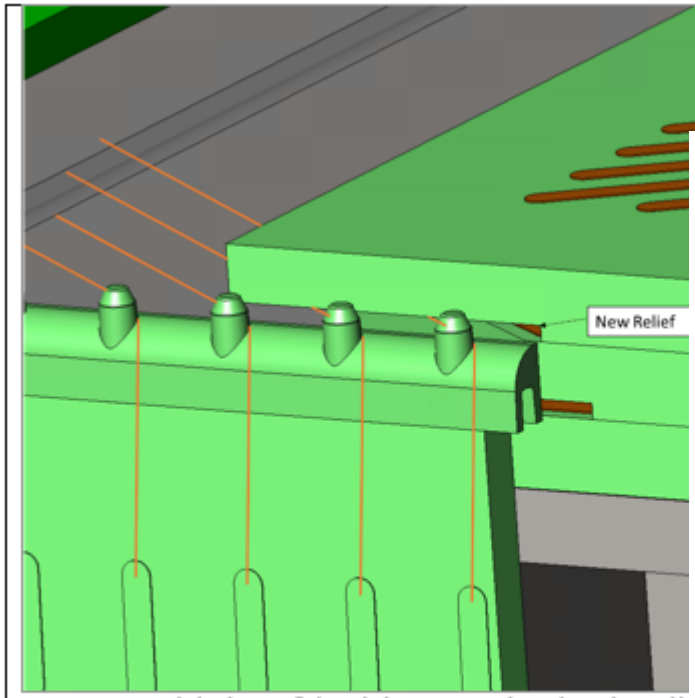


Figure 7: Model view of the right corner showing the reli
board protecting the long V wires

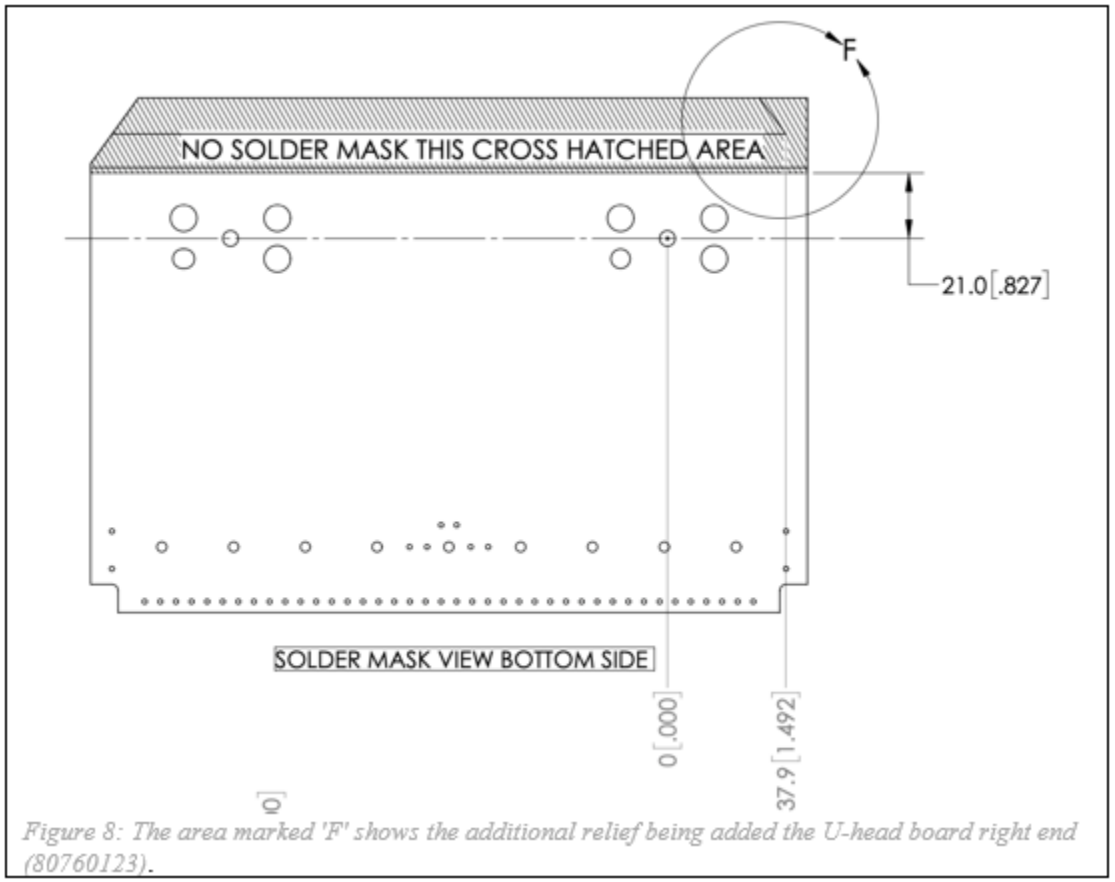


Figure 8: The area marked 'F' shows the additional relief being added the U-head board right end (80760123).

Note: Also reduced epoxy in solder groove near this area

To protect short v and u wires

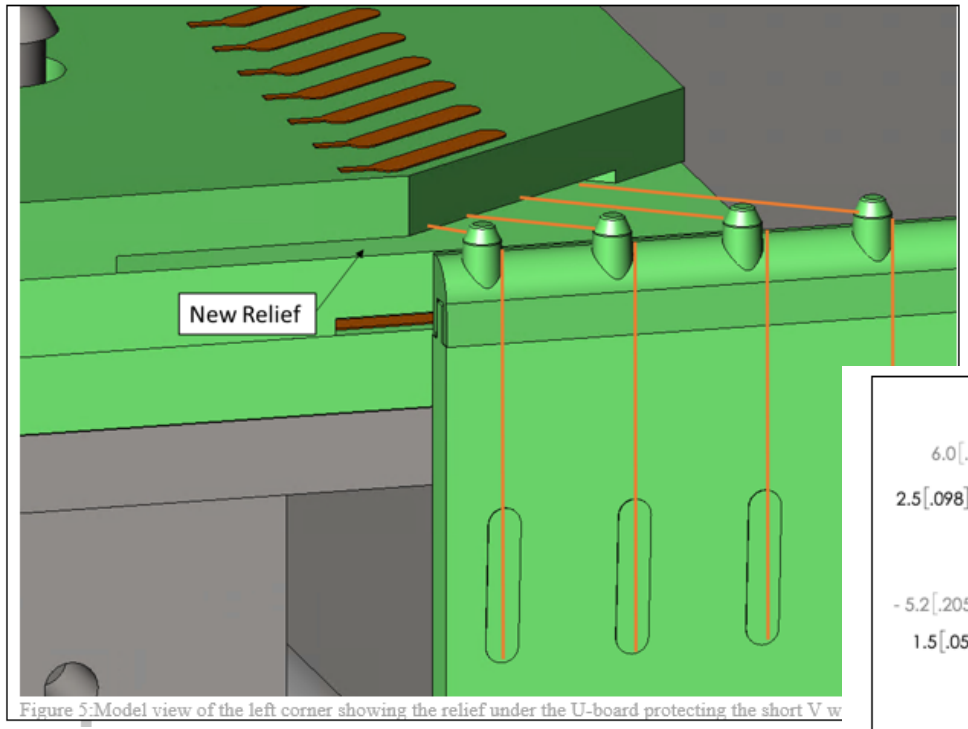


Figure 5:Model view of the left corner showing the relief under the U-board protecting the short V w

Note: Reduced epoxy near this area.
In addition, the short wire segment will be soldered without tension. This will also protect short wires.

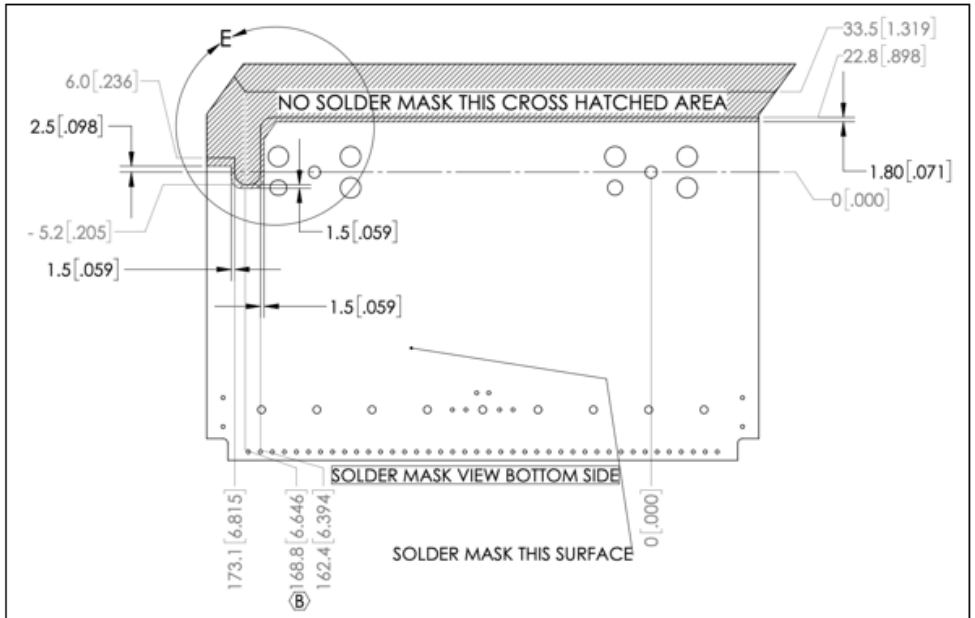


Figure 6: The area marked 'E' shows the additional relief being added the U-head board left end (80760119).

More specific information on the broken wires and board revisions can be found at:

Recent head board revisions

- 2570615 v.1 - "Modifications to U-layer and G-layer head boards in response to broken ProtoDUNE wires" : https://edms.cern.ch/document/2570615/1

APA Broken Wire Root Cause Analysis

https://edms.cern.ch/document/2614531/1

Board Stack-up Analysis

What was evaluated:

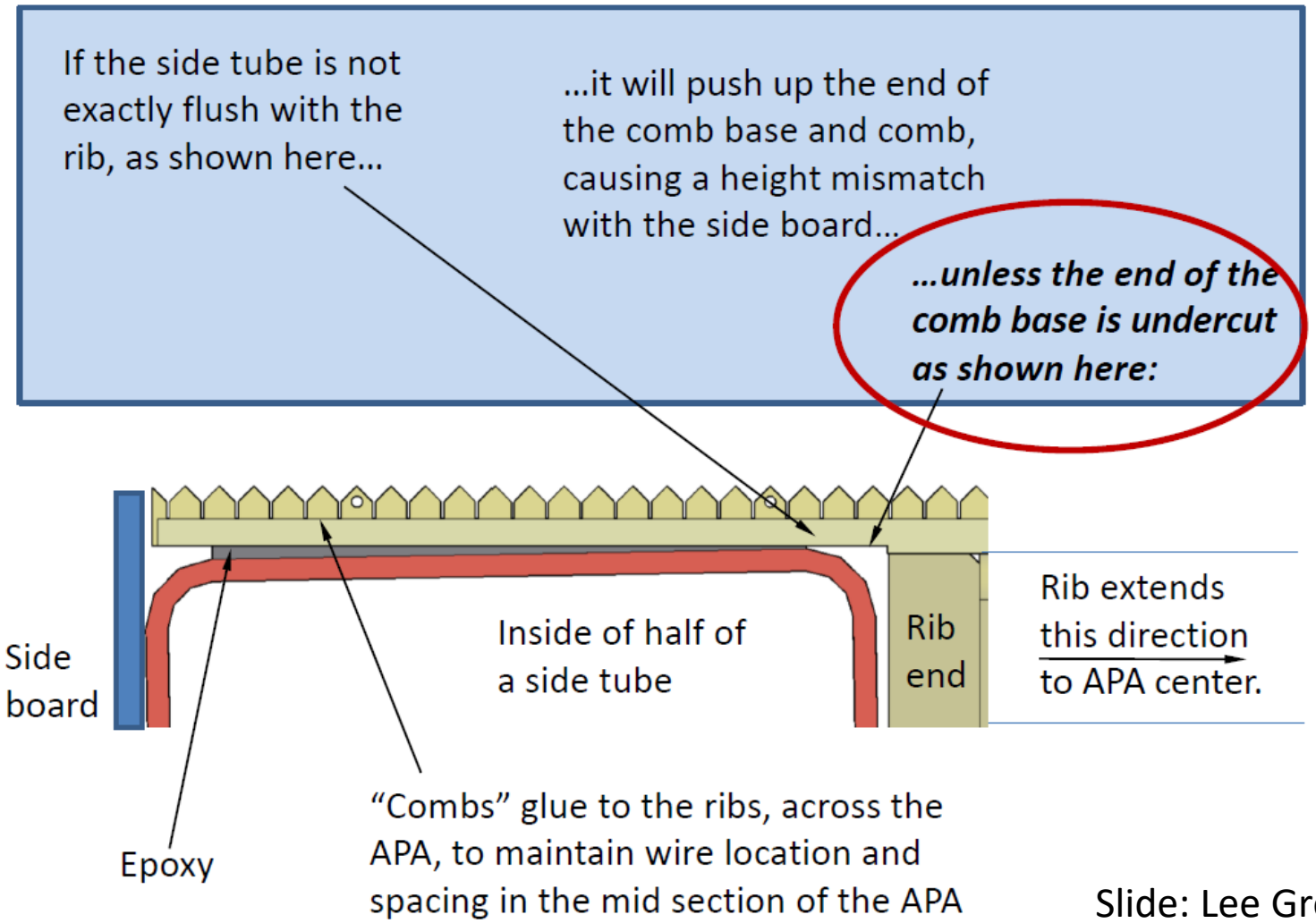
- Wire to wire spacing in various APA locations
- Plane to plane spacing in various APA locations
- Gap between boards
- Gap between tooth strips.

Board Stack-up Analysis: Used root sum square of tolerances

Summary of results of APA stack up analysis					
	sheet #	RSS	Require-ment	Board accuracy	Comment
Within a board stack					
Wire spacing					
Foot x and g	1a	0.09	0.5	n	
Foot u and v	1b	0.09	0.5	n	
Side	2	0.08	0.5	n	
head				*	
Plane to plane spacing					
Foot - new-tool	4a	0.29	0.5	y	
Foot - baseline	4b	0.84	0.5	y	New tool
Side - u to v	5a	0.29	0.5	y	
Side -v/x, u/g no bow	5b	0.28	0.5	y	
Side -v/x, u/g w/bow	5c	0.57	0.5	y	Very locatized effect
Head	6	0.24	0.5	*	
Between boards					
Wire spacing					
Foot x and g	7a	0.50	0.5	n	
Foot u and v	7b	0.24	0.5	n	
Side	8	0.34	0.5	n	
head - x and g	9a	0.35	0.5	*	
head - u and v	9b	0.41	0.5	*	
Gap between boards					
Foot	10	0.36	0.4	y	
Side	11	0.35	0.4	y	
Head - straight	12a	0.35	0.4	y	
Head - Angled	12b	0.41	0.4	y	
Tooth strip to tooth strip					
Foot x and g	13	0.50	0.5	n	
Foot u and v	13	0.50	0.4	n	Addressed at assy
Side	14	0.49	0.4	n	Addressed at assy

Based on 11mm bow which is not expected.

Revision – Plane to plane at comb to side board interface



Slide: Lee Greenler

Wires and Wire Tension

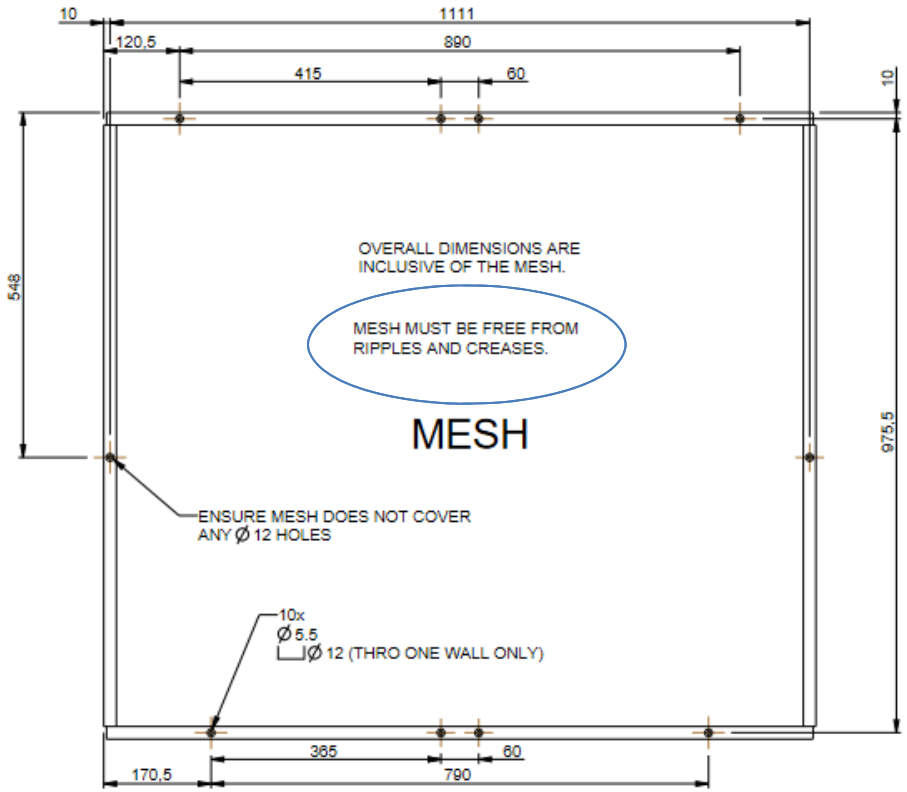
Wires

- Tempered (mill hardened) Alloy 25 C17200 beryllium copper wire (minimum tensile of 185ksi)
- Standard Temper Designation is TL08
- http://www.lfa-wire.com/tempered-alloy-25_c17200.htm
- Calculated Break strength = 23.3N
- Average Break Strength is ~ 24N
- Wires break before Wire solder/Epoxy joints fail
- Wire life test at 5 and 10N has been running for 6 years.

Wire Tension acceptance criteria

- Long Wires (length ≥500mm): 5.5-7.5 N
- Short Wires (length <500mm and ≥50mm): 4-7.5 N
- Very Short Wires (length <50mm): 0-7.5 N

Mesh Panels



NOTES.

1. REMOVE ALL BURRS & SHARP EDGES.
2. GENERAL SURFACE FINISH 3.2
   UNLESS OTHERWISE STATED.
3. WELDING SYMBOLS TO BS EN 22553
4. ENSURE WIRE ENDS ARE GROUND BACK.
5. MESH - 304 ST STEEL
   APERTURE - 0.93mm
   WIRE - 0.08mm
   OPEN AREA - 84.78%
6. MUST BE CLEANED AND DE-GREASED
   AFTER MANUFACTURE.

WELDING NOTE

WELDING OF THE MESH TO THE FRAME
MUST BE CONTINUOUS TO AVOID STRANDS
OF WIRE BREAKING FREE.

Mesh Panels

- Mesh panels are installed with an installation tool that re-establishes tension before fixing to frame
- Currently working with vendor to improve cleanliness of frame and consistency of mesh tension

Fastener Retention

All fasteners in a factory APA have a method of fastener retention

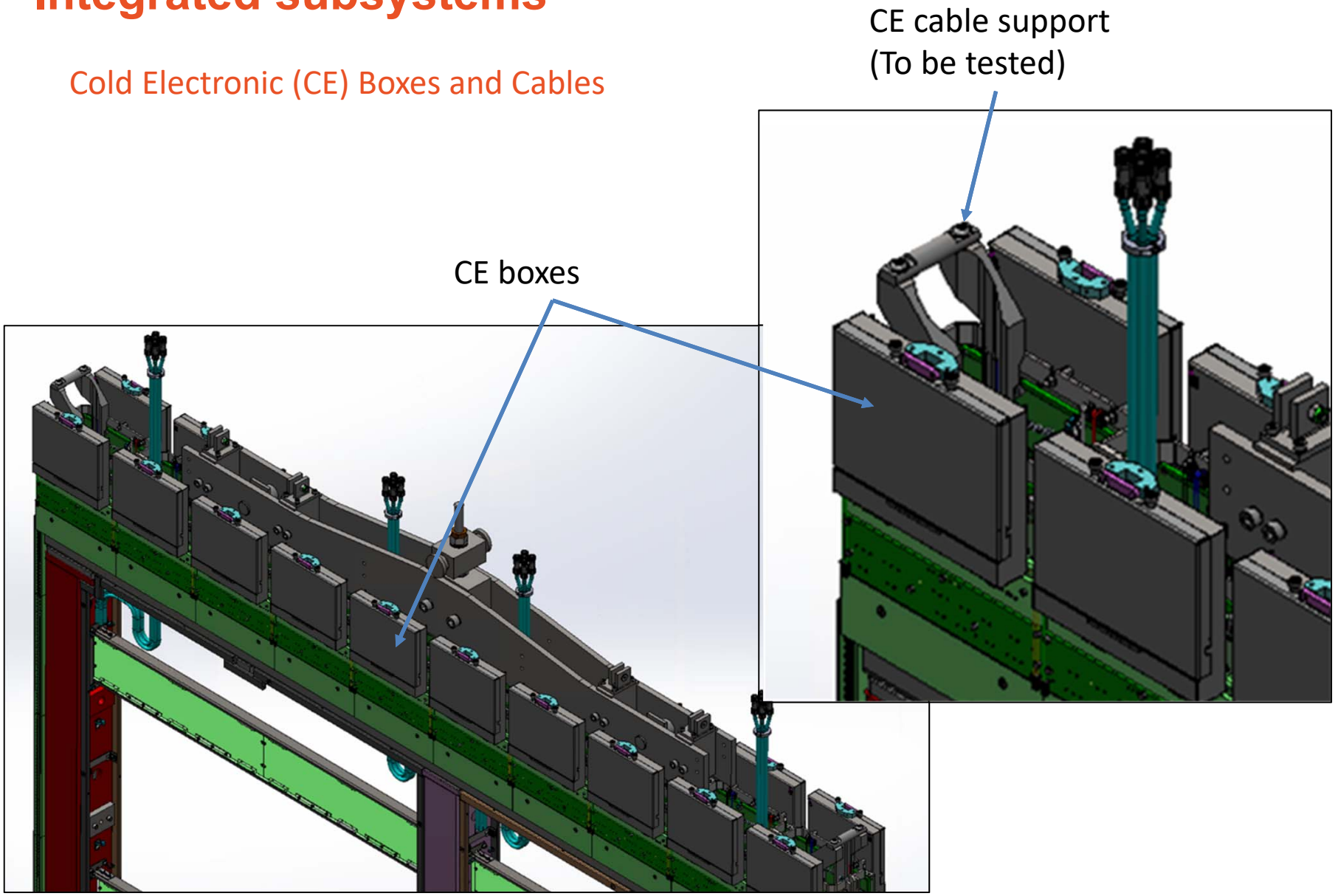
- Most fasteners use Schnorr Safety washers steel grade X5CrNi18-10 (1.4301) (Equivalent to AISI 304 (UNS S30400)
- Some critical locations use Nord-Lock Wedge-Lock style AISI 316 washers
- The fasteners use on the APA wire boards do not work with washers so they are epoxied in place.

Schnorr safety washer

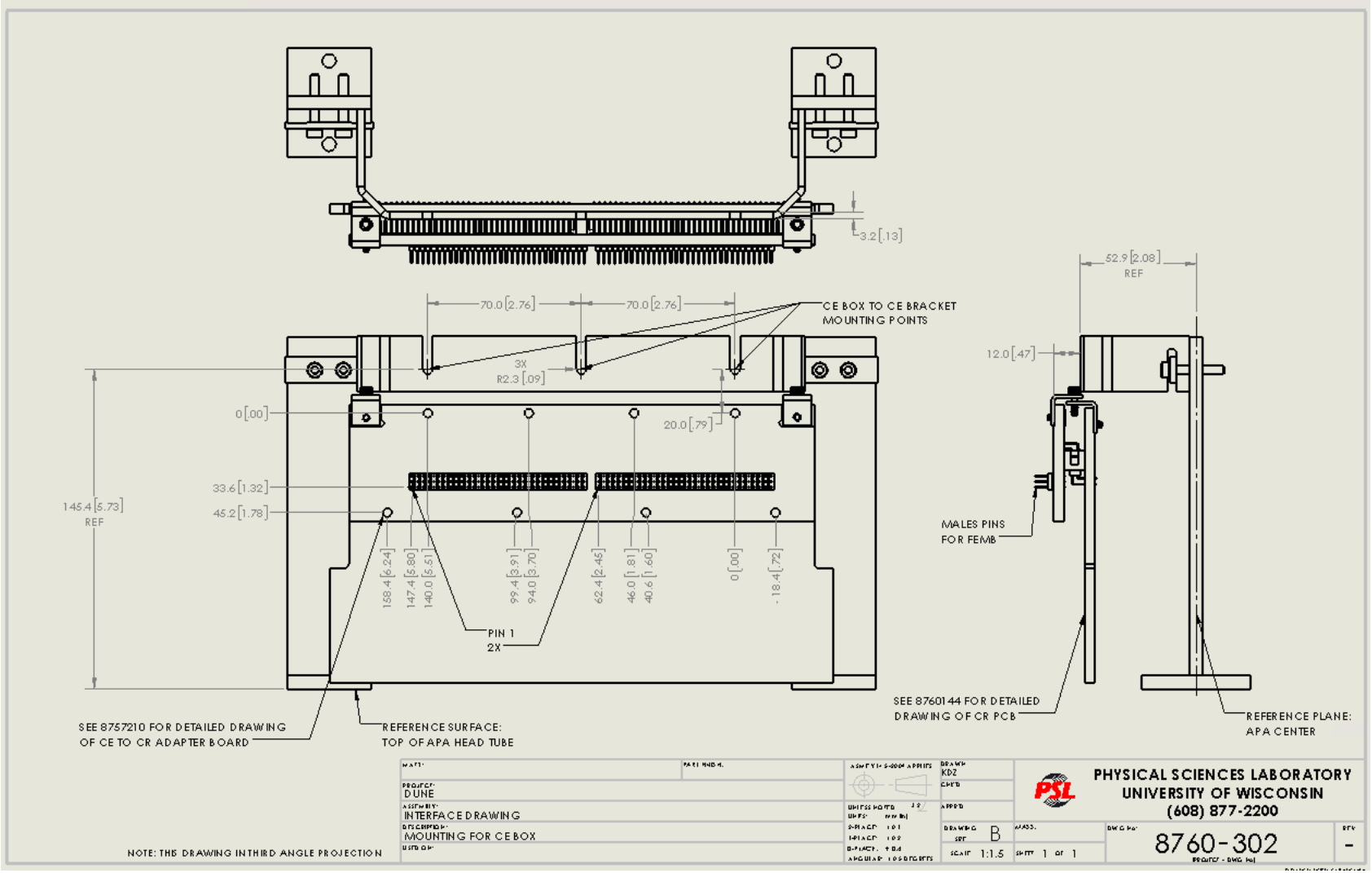
Nord-Lock Wedge - Lock washer

Integrated subsystems

Cold Electronic (CE) Boxes and Cables



CE box mounting

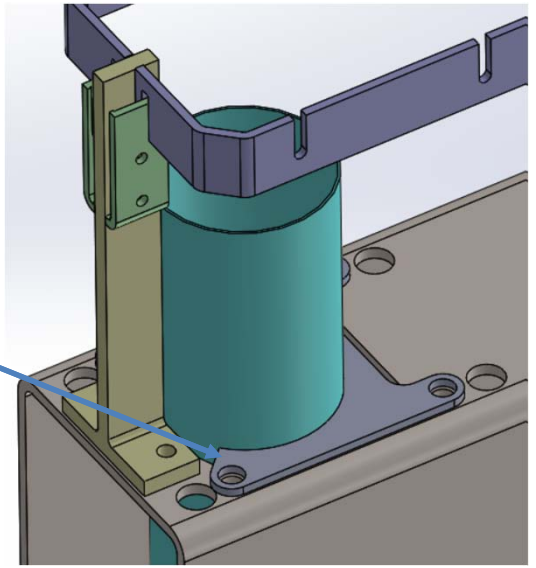


Interface drawing for mounting for CE boxes

CE cable conduit

- 2.5” OD x 0.065” SS tube for lower CE cables through the APA side tubes.
- Cutouts in conduit tube:
  - Access to lift points
  - Access for shipping mount points
  - PD installation

Plate at head end is welded to conduit tube. Plate is screwed to head tube.



CE cable support (to be tested)

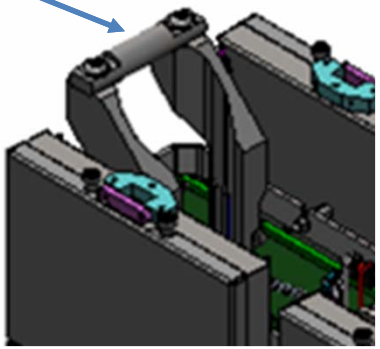
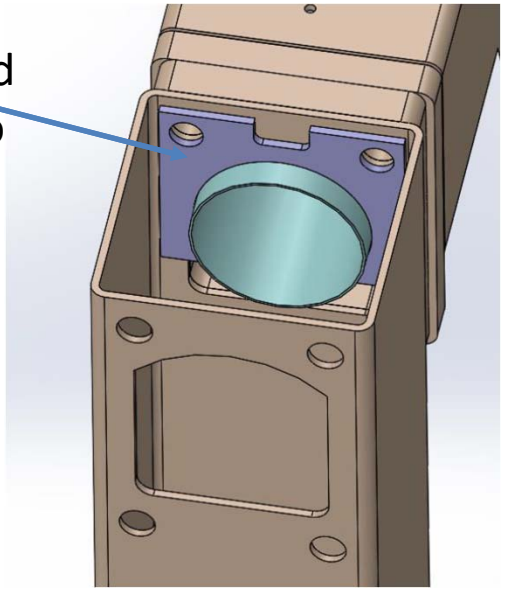
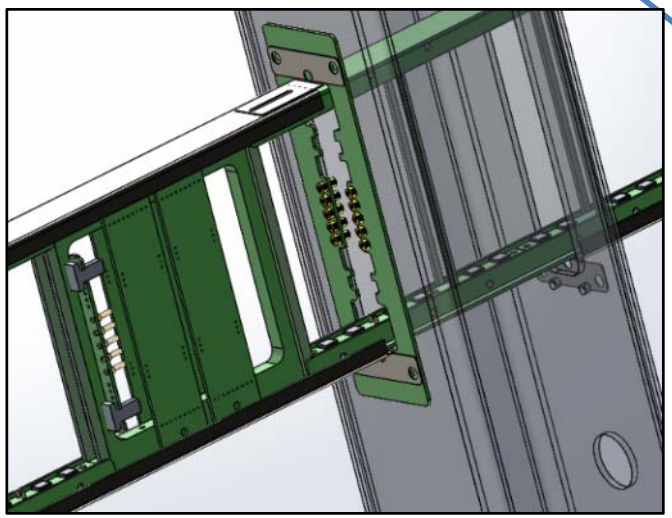


Plate at foot end is not welded to conduit tube.

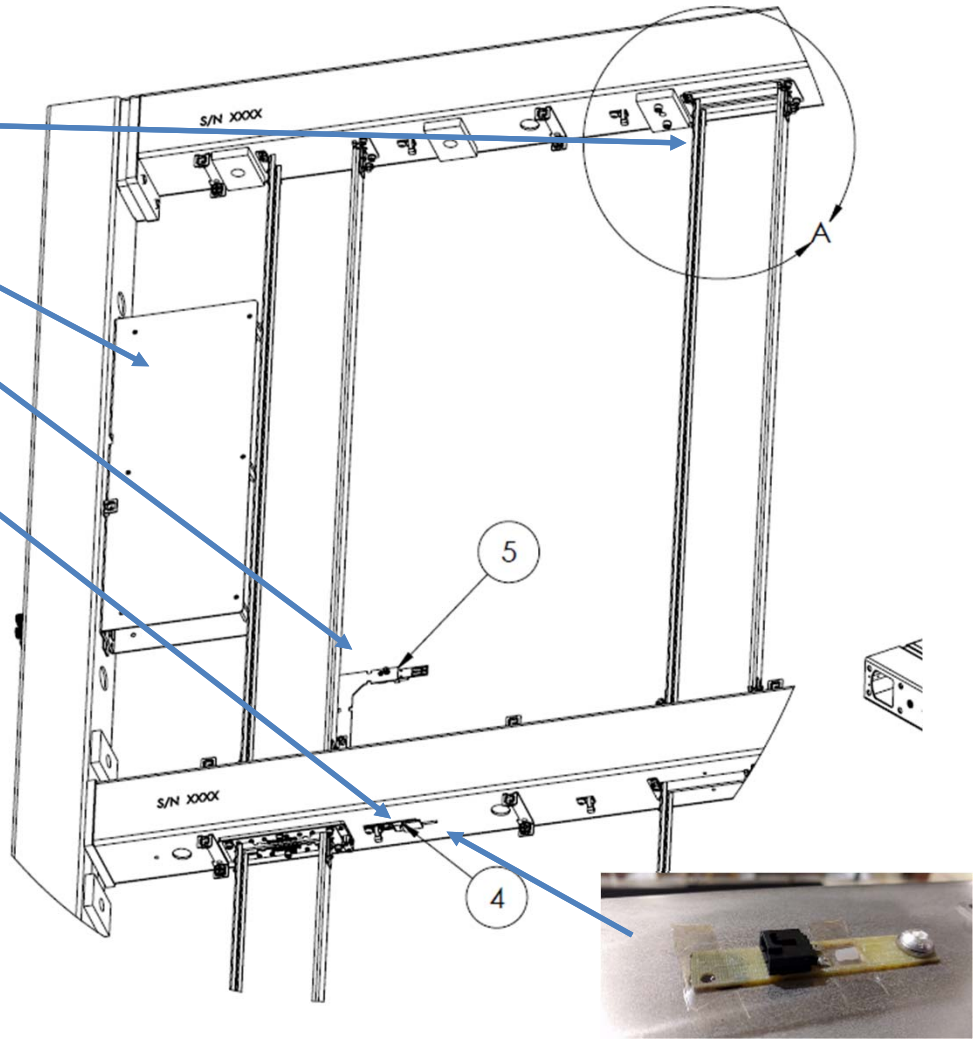


Photon Detectors rails and LAr temperature sensors

PD Rail
PD cable containment
LAr temperature sensor
APA frame temperature sensor



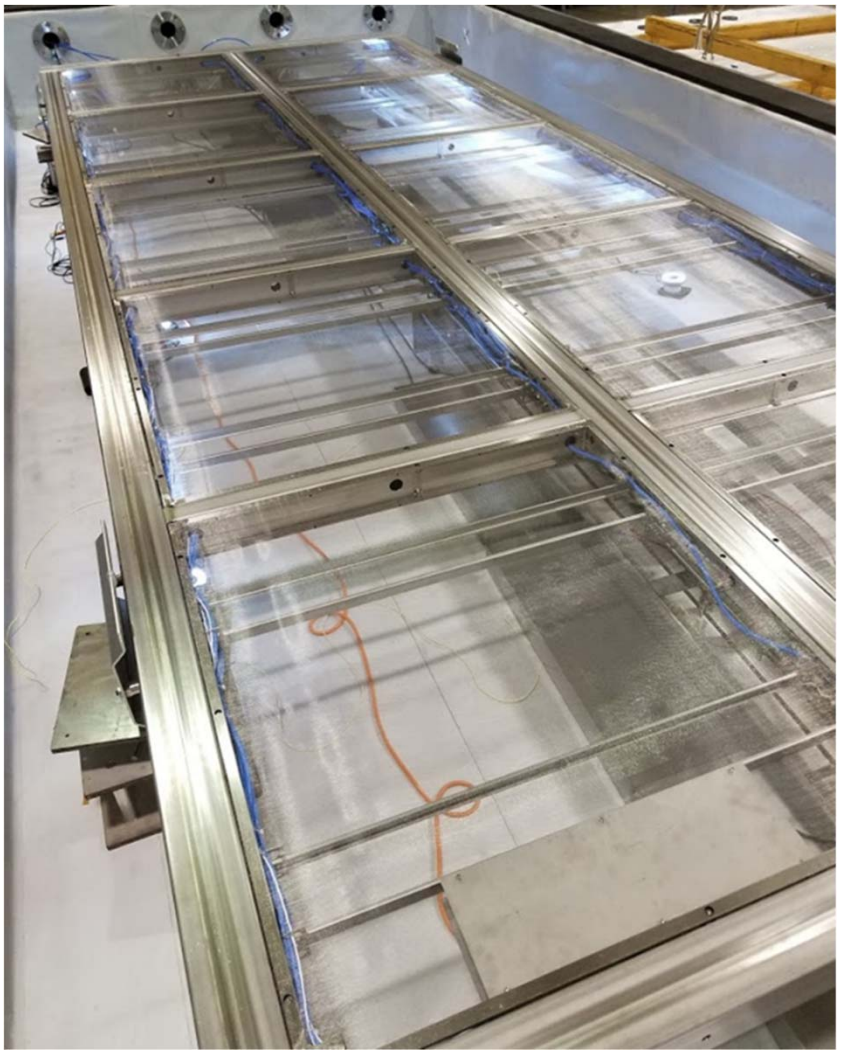
PD being inserted through side tube

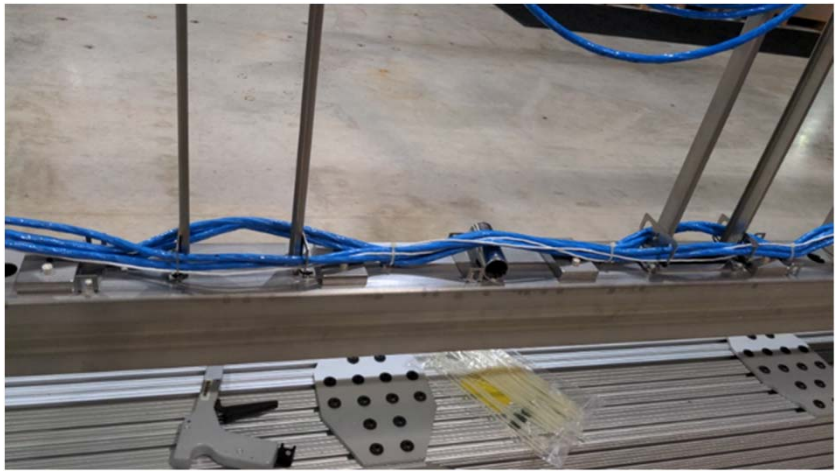


Detail from 8760055

PD and Temperature Cables

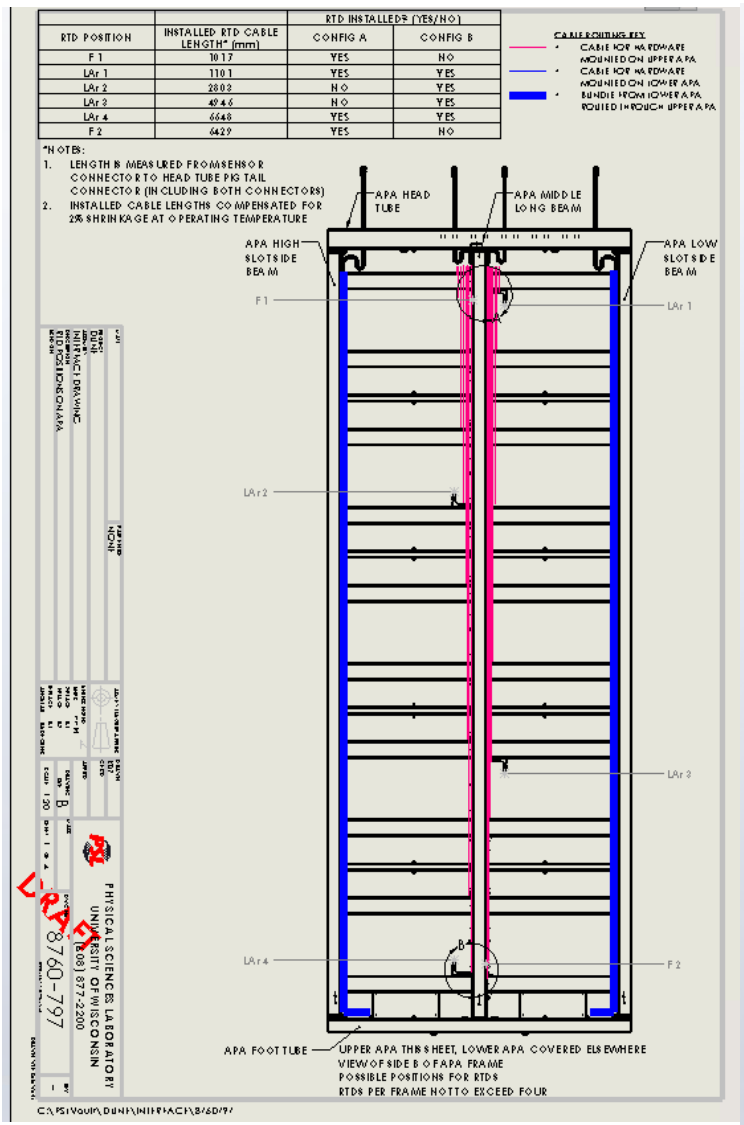
- Cables routed with 2% slack and successfully cold tested
- Continuity and isolation monitored
- Cable shrinkage monitored





Establishing 2% slack

Temperature Sensor Configurations



RTD POSITION	INSTALLED RTD CABLE LENGTH* (mm)	RTD INSTALLED? (YES/NO) CONFIG A	CONFIG B
F1	1017	YES	NO
LAr1	1101	YES	YES
LAr2	2803	NO	YES
LAr3	4946	NO	YES
LAr4	6648	YES	YES
F2	6429	YES	NO

CABLE ROUTING KEY
- CABLE FOR HARDWARE MOUNTED ON UPPER APA
- CABLE FOR HARDWARE MOUNTED ON LOWER APA
- BUNDLE FROM LOWER APA ROUTED THROUGH UPPER APA

*NOTES:
1. LENGTH IS MEASURED FROM SENSOR CONNECTOR TO HEAD TUBE PIG TAIL CONNECTOR (INCLUDING BOTH CONNECTORS)
2. INSTALLED CABLE LENGTHS COMPENSATED FOR 2% SHRINKAGE AT OPERATING TEMPERATURE

APA HEAD TUBE
APA MIDDLE LONG BEAM
APA HIGH SLOT SIDE BEAM
APA LOW SLOT SIDE BEAM
F1
LAr1
LAr2
LAr3
LAr4
F2
APA FOOT TUBE
UPPER APA THIS SHEET, LOWER APA COVERED ELSEWHERE
VIEW OF SIDE B OF APA FRAME
POSSIBLE POSITIONS FOR RTDS
RTDS PER FRAME NOT TO EXCEED FOUR

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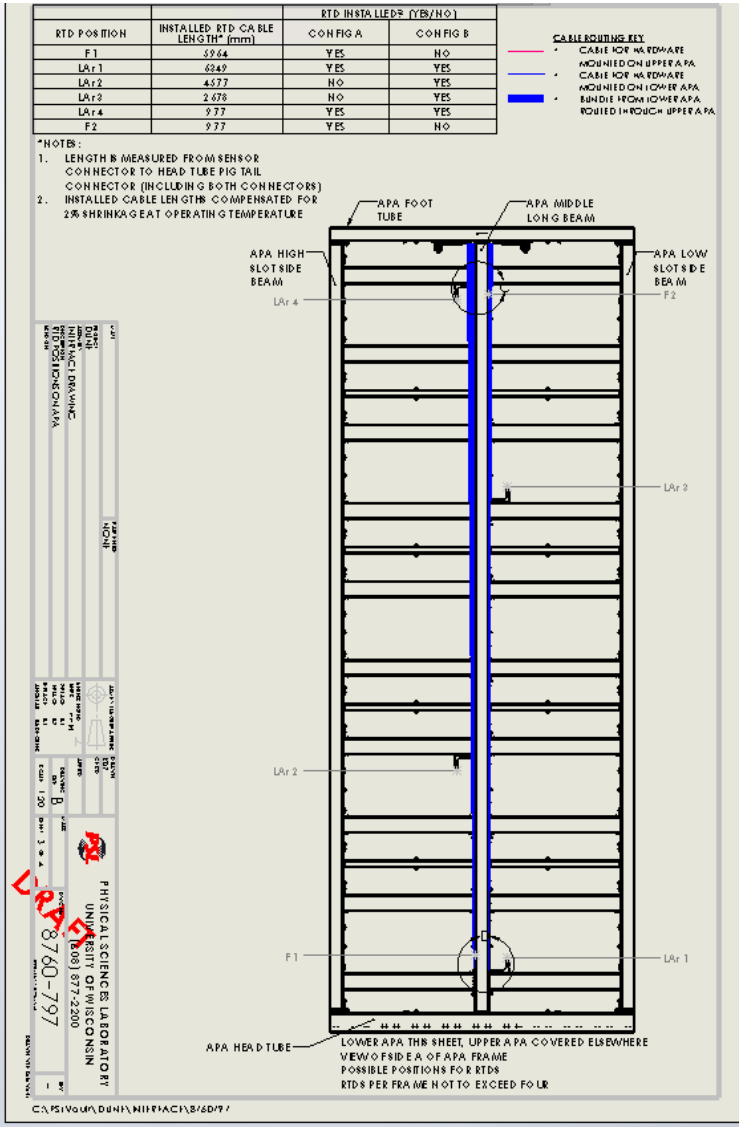

RTD POSITION	INSTALLED RTD CABLE LENGTH* (mm)	RTD INSTALLED? (YES/NO) CONFIG A	CONFIG B
F1	5964	YES	NO
LAr1	6249	YES	YES
LAr2	4577	NO	YES
LAr3	2678	NO	YES
LAr4	977	YES	YES
F2	977	YES	NO

CABLE ROUTING KEY
- CABLE FOR HARDWARE MOUNTED ON UPPER APA
- CABLE FOR HARDWARE MOUNTED ON LOWER APA
- BUNDLE FROM LOWER APA ROUTED THROUGH UPPER APA

*NOTES:
1. LENGTH IS MEASURED FROM SENSOR CONNECTOR TO HEAD TUBE PIG TAIL CONNECTOR (INCLUDING BOTH CONNECTORS)
2. INSTALLED CABLE LENGTHS COMPENSATED FOR 2% SHRINKAGE AT OPERATING TEMPERATURE

APA FOOT TUBE
APA MIDDLE LONG BEAM
APA HIGH SLOT SIDE BEAM
APA LOW SLOT SIDE BEAM
LAr4
F2
LAr3
LAr2
F1
LAr1
APA HEAD TUBE
LOWER APA THIS SHEET, UPPER APA COVERED ELSEWHERE
VIEW OF SIDE A OF APA FRAME
POSSIBLE POSITIONS FOR RTDS
RTDS PER FRAME NOT TO EXCEED FOUR

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Upper APA – 2 configurations

Lower APA - 2 configurations

Field Cage (FC) Support points – Upper APA

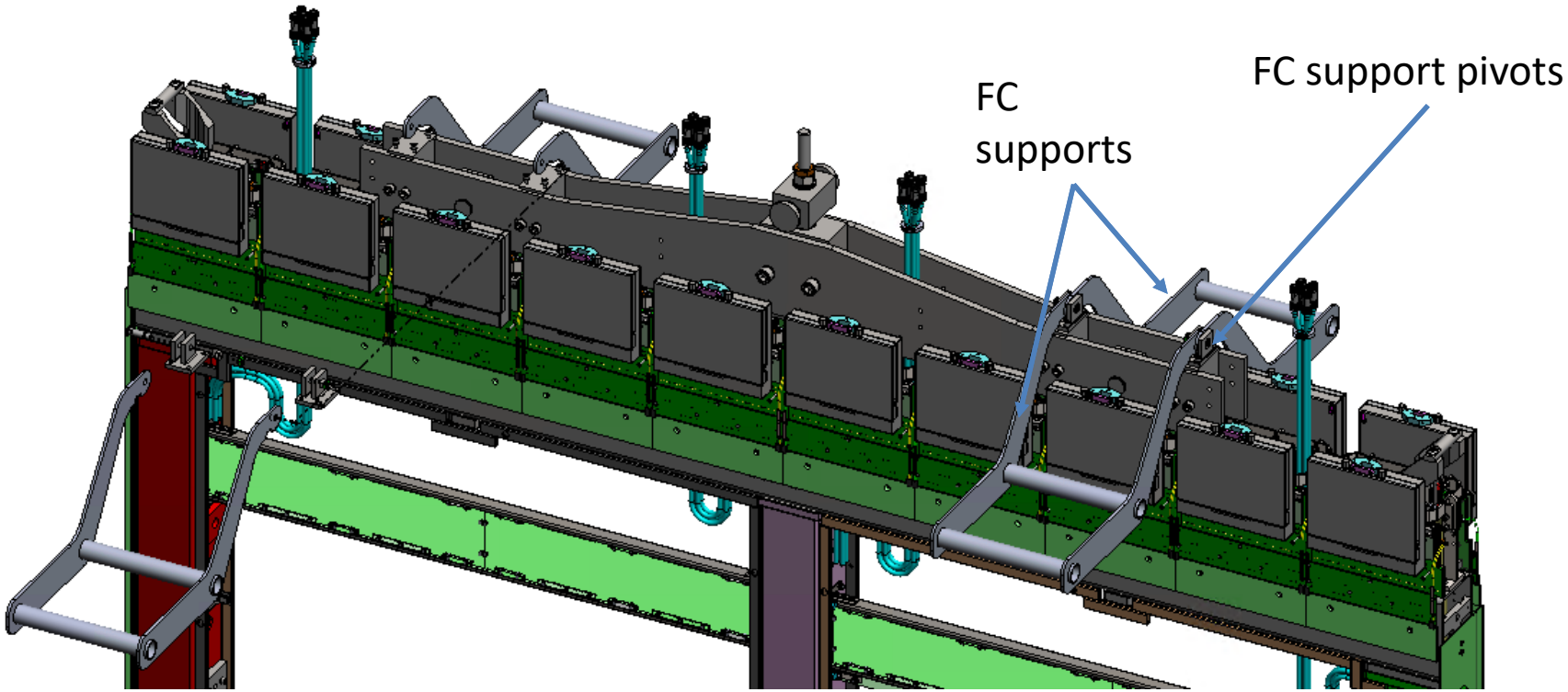


Image showing FC support points – Upper APA

Field Cage (FC) Support points – Lower APA

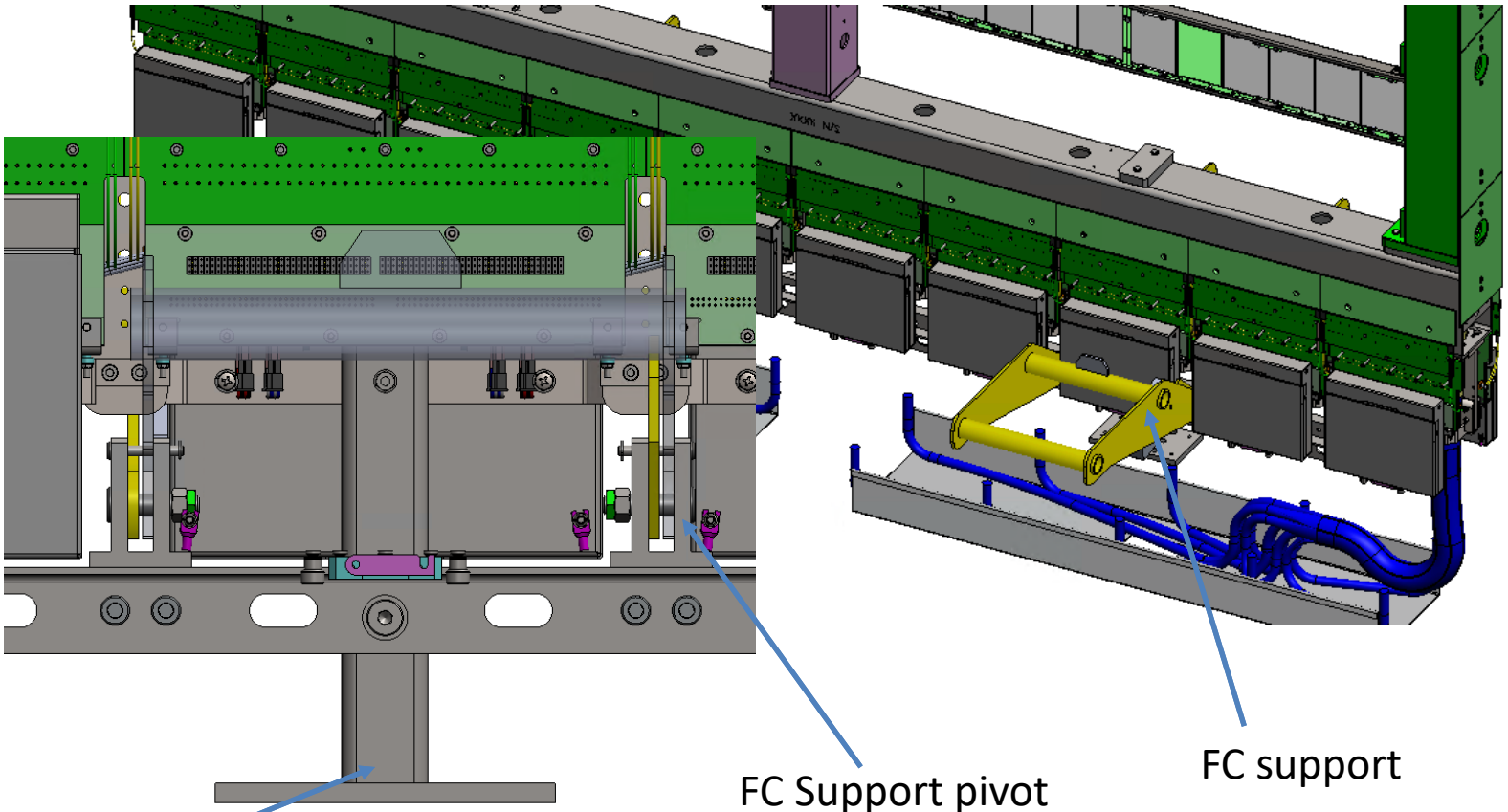
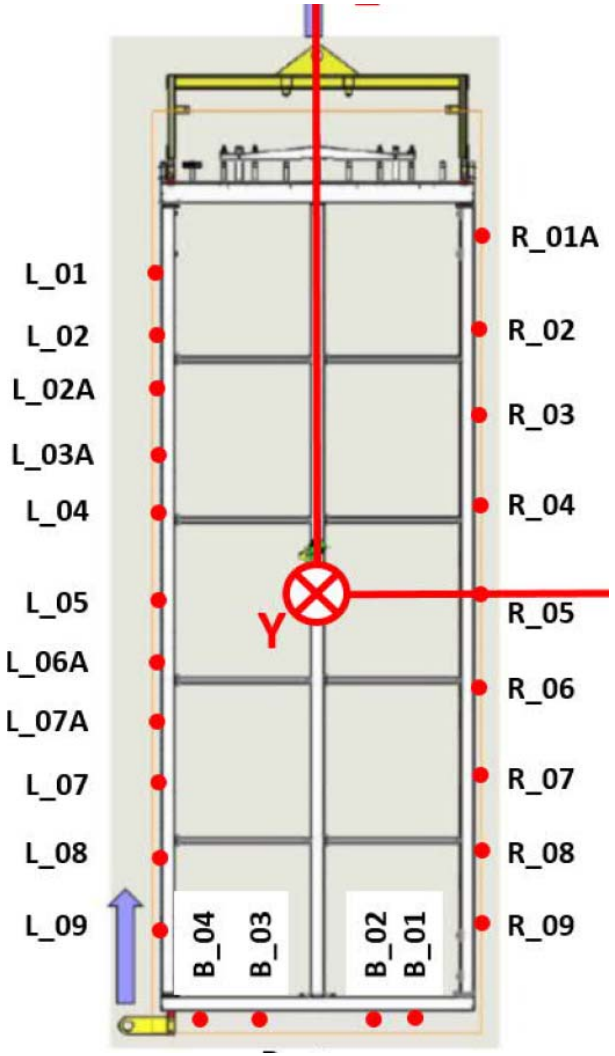


Image showing FC support points on lower APA

Provisions for Survey of APA

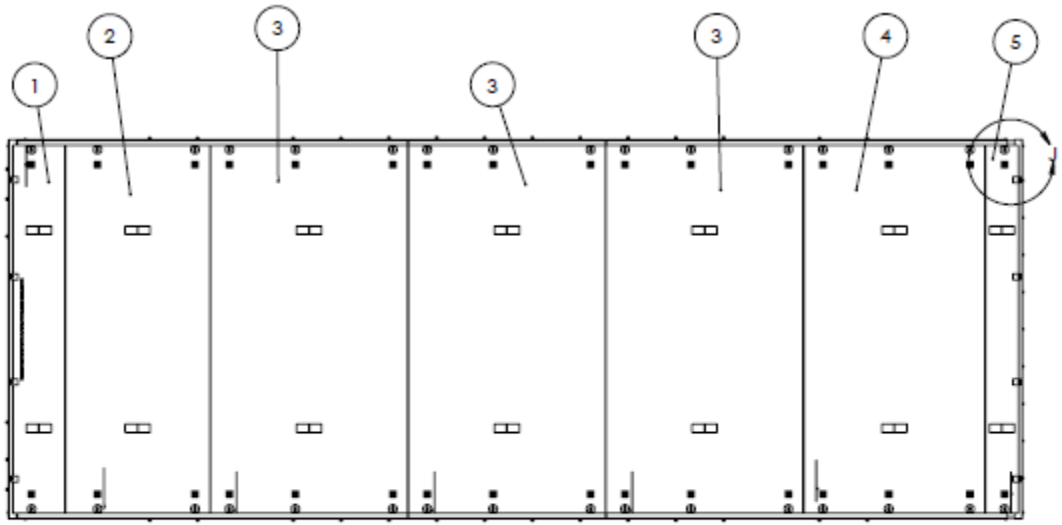


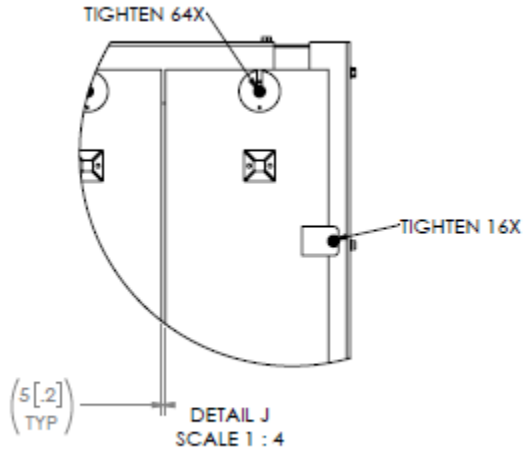
M10 Rivnuts on the side and foot tube provide locations to mount survey targets

"Landscape" orientation at the factories

Vertical orientation at installation site

APA Protection





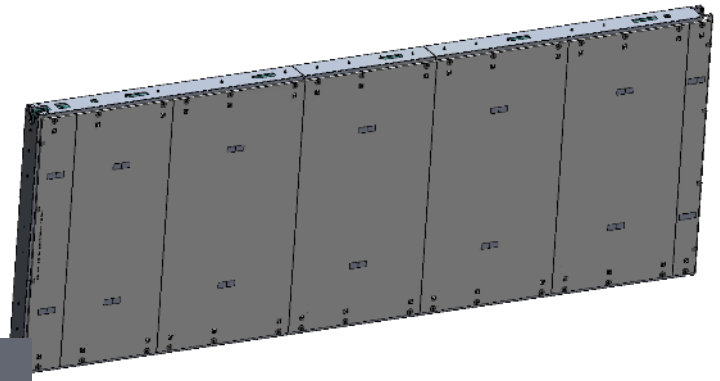
ASSEMBLY INSTRUCTIONS

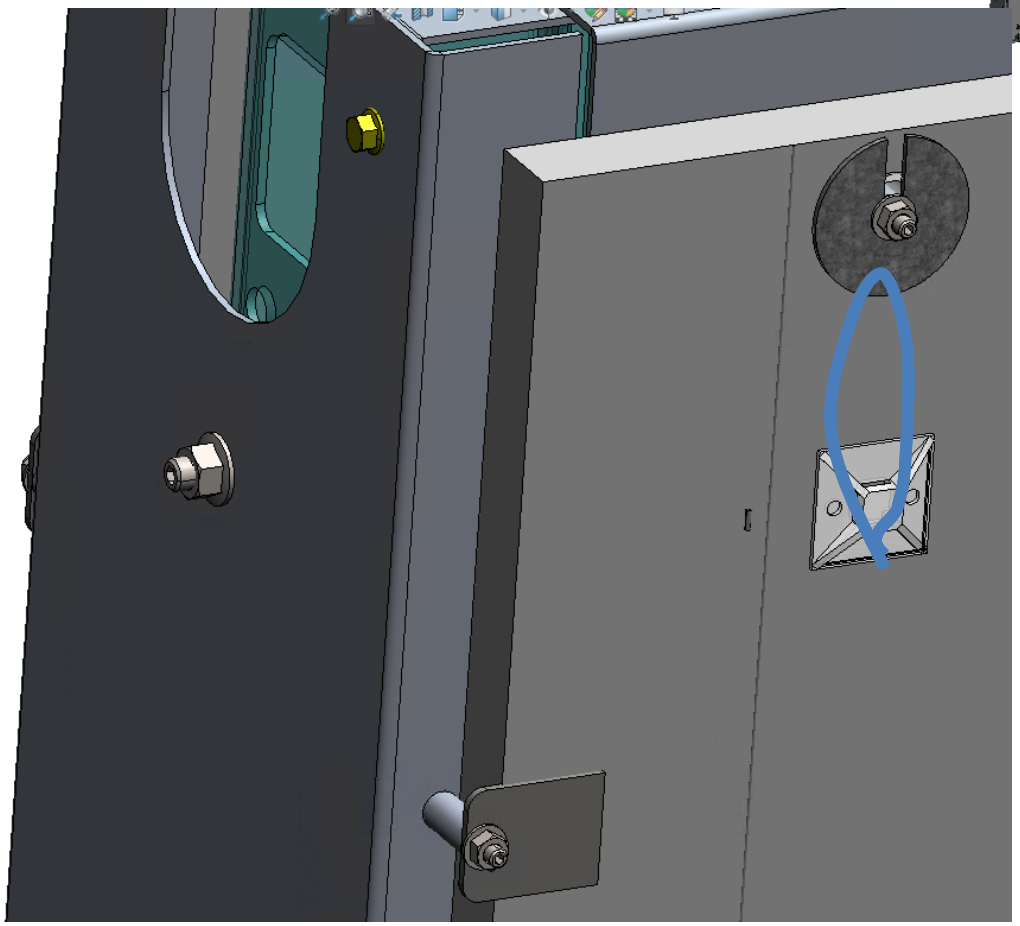
1. INSTALL ITEM 1 IN TWO PLACES-DO NOT TIGHTEN HARDWARE
2. INSTALL ITEM 5 IN TWO PLACES-DO NOT TIGHTEN HARDWARE
3. INSTALL REMAINING PANELS-DO NOT TIGHTEN HARDWARE
4. TIGHTEN ALL HARDWARE TO LOCK PANELS IN PLACE
5. WRAP PROTECTION USING U-LINE 2187 70 GAUGE CAST LLDPE STRETCH WRAP OR EQUIVALENT

Channel splits for removal under CE vertical cable tray

APA Protection

Panel mounting is similar to protoDUNE with some improvements



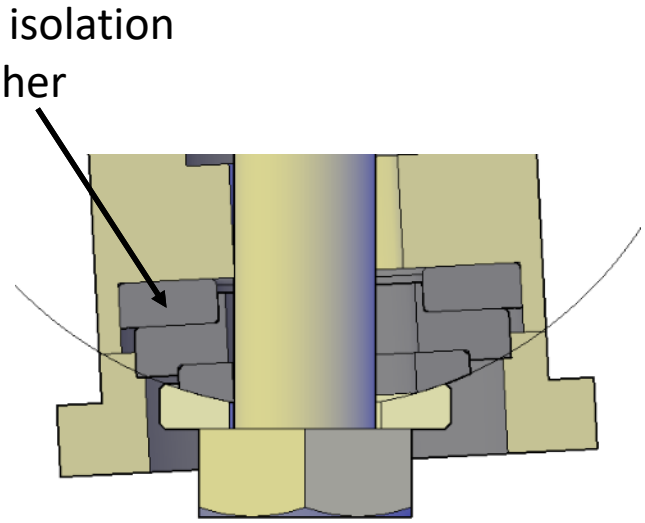


Features

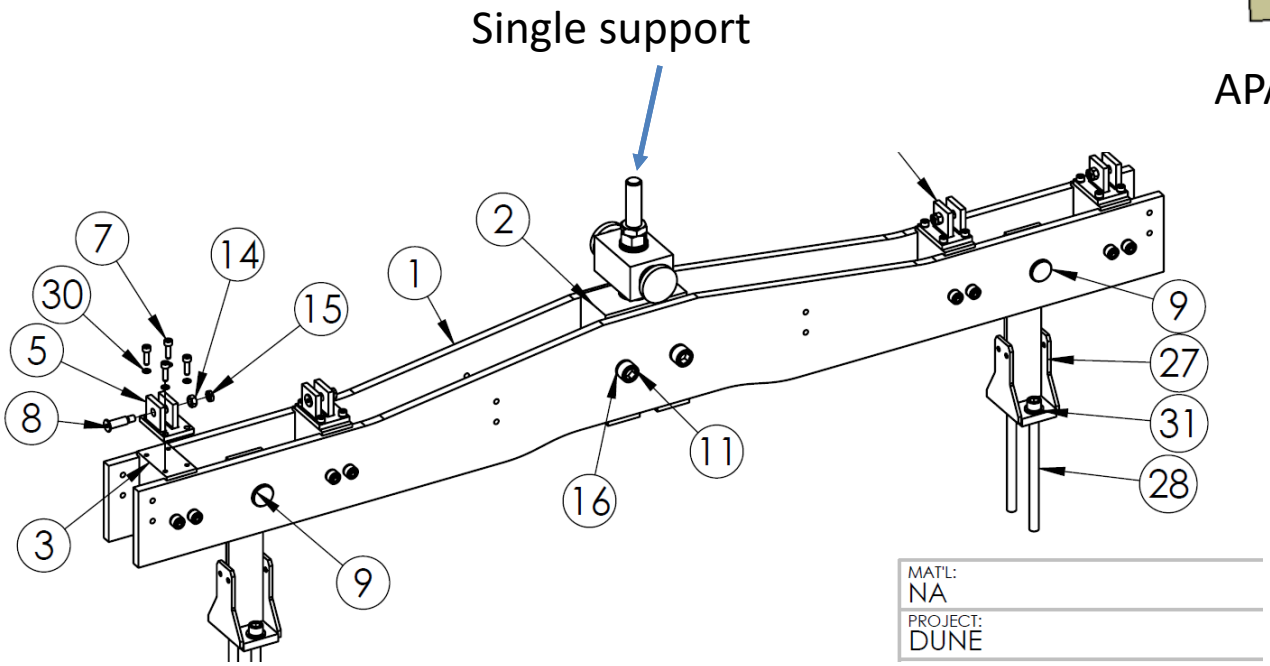
- All fasteners have a locking feature
- Top and bottom panels can be removed for access
- Top and bottom panels have a retainer that swivels out of the way
- All other panels have a slotted washer on lanyard.
- Minimal loose hardware

Installed APA – APA support

APA Pair hangs from a single support with a spherical joint to protect the support from moments
Total dry load on APA single support is 1471 kg

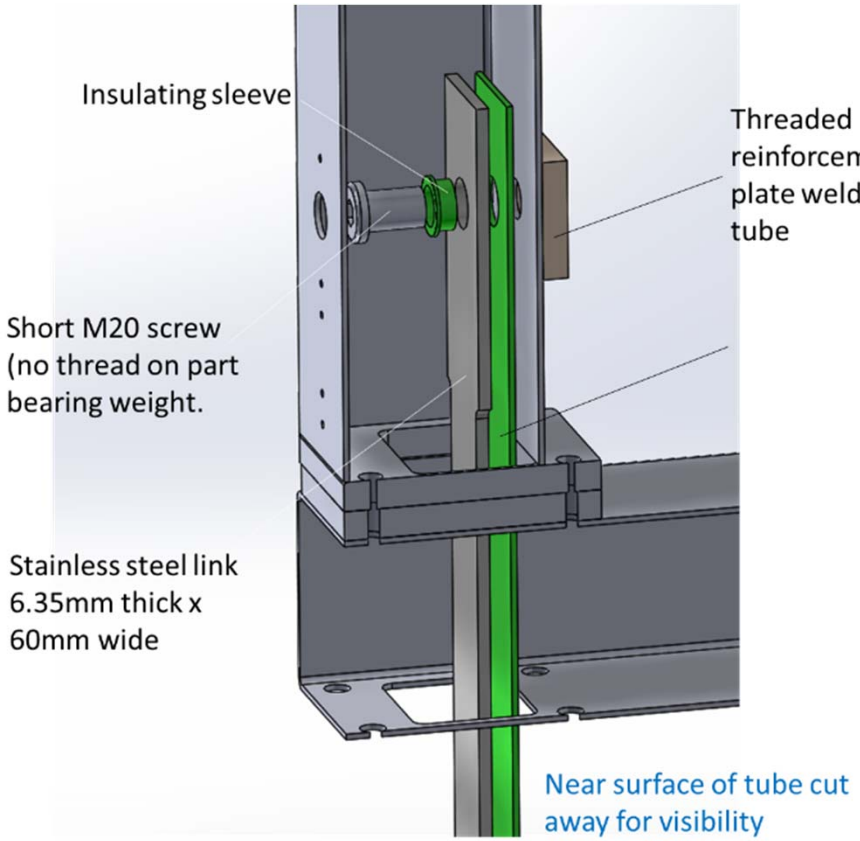


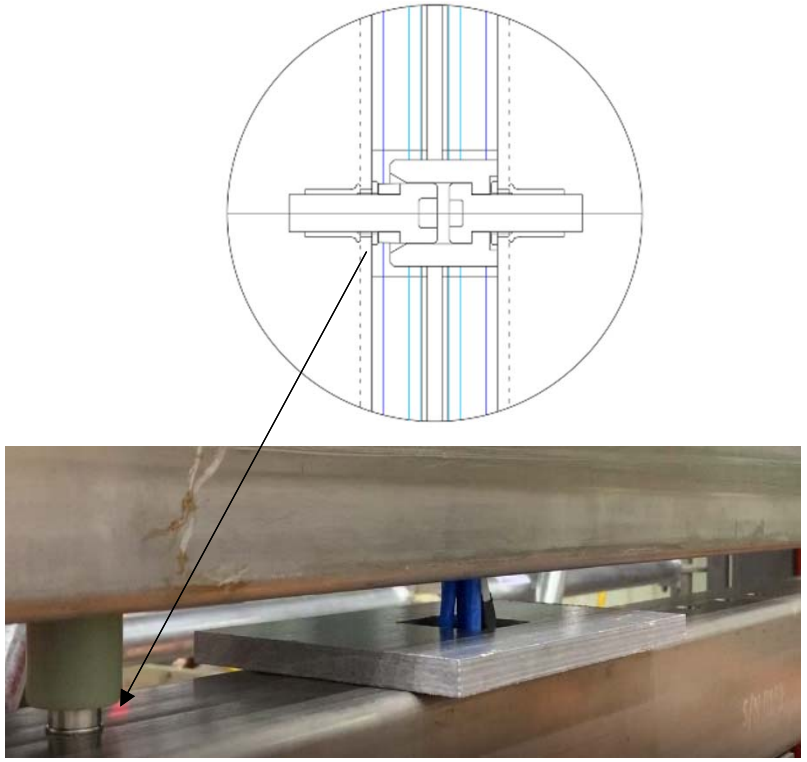
APA tipped 3 degrees



Connection between upper and lower APA

- APA to APA links support the lower APA.
- Alignment pins control the alignment between the top and bottom APA

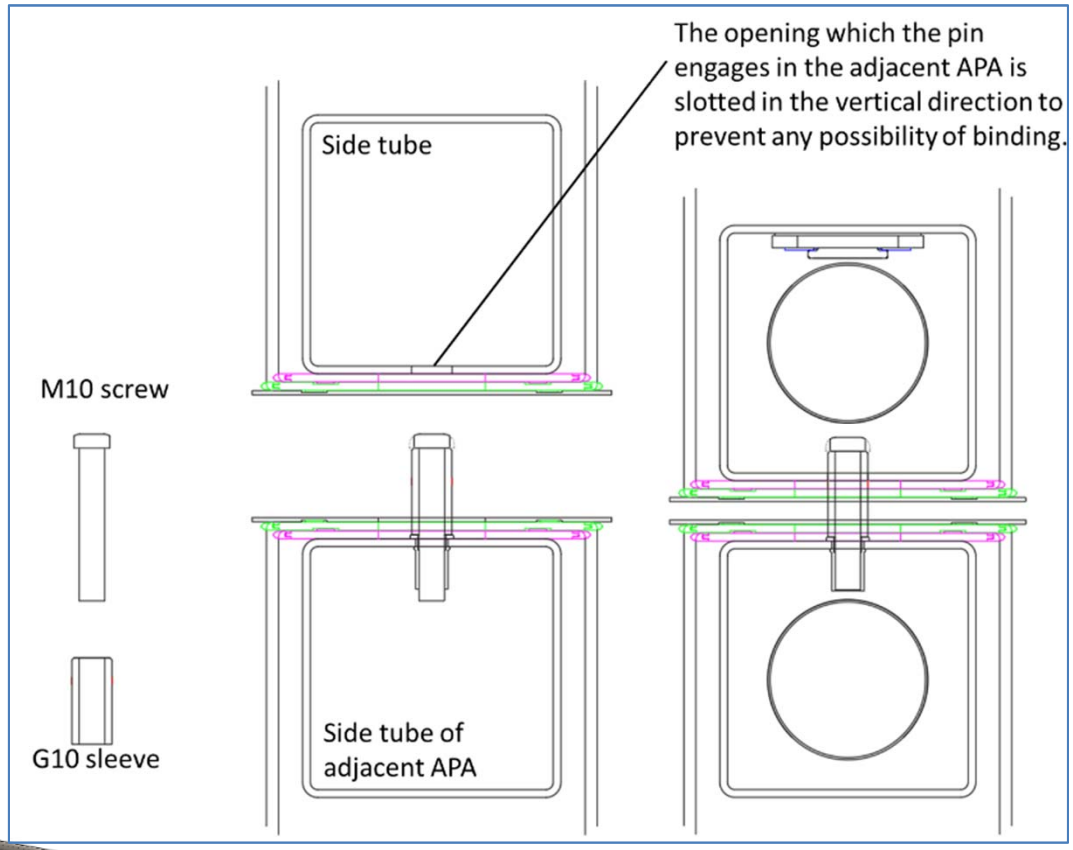


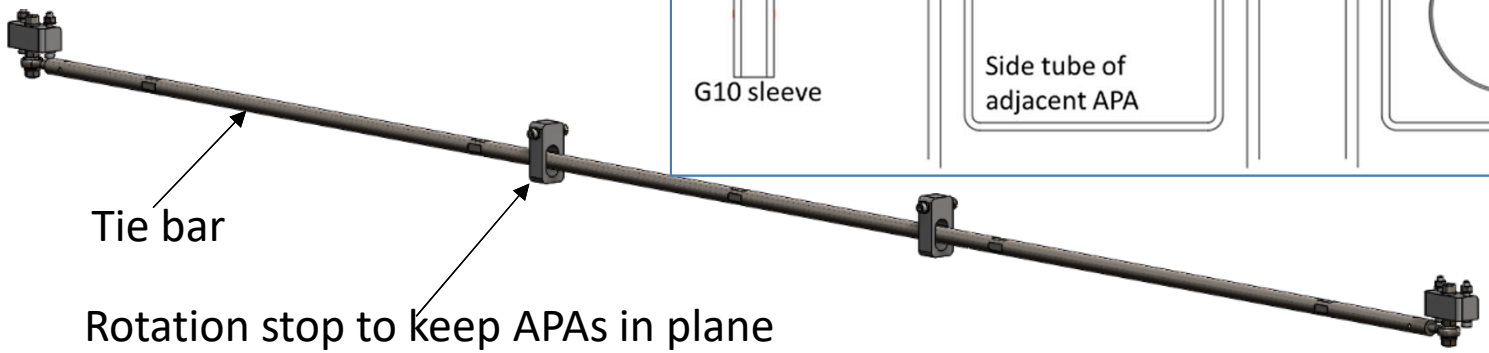


1 Pin-to-hole and 1 pin-to-slot engage and control alignment

Connections between APA pairs

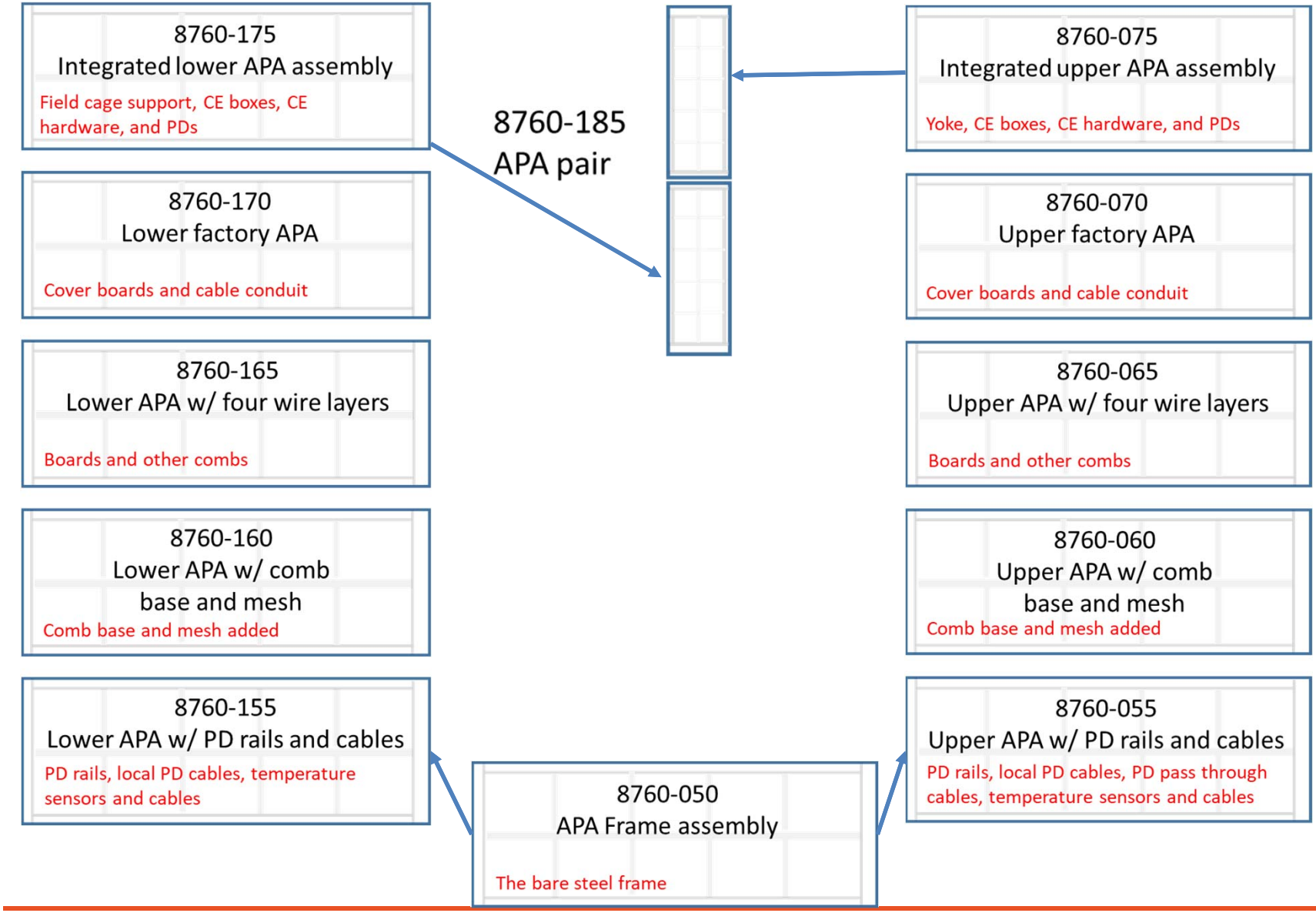
- Alignment pins to align edges of an APA to its neighbor
- Tie bars to maintain spacing and to keep the APAs in plane
  - Connect APA pairs mounted on a single DSS beam
  - Rotation stop is only used on center row of APAs
  - Outer APAs are kept in plane through Field cage connection





APA Assembly Levels – Drawing 8760440

https://edms.cern.ch/document/2620304/1



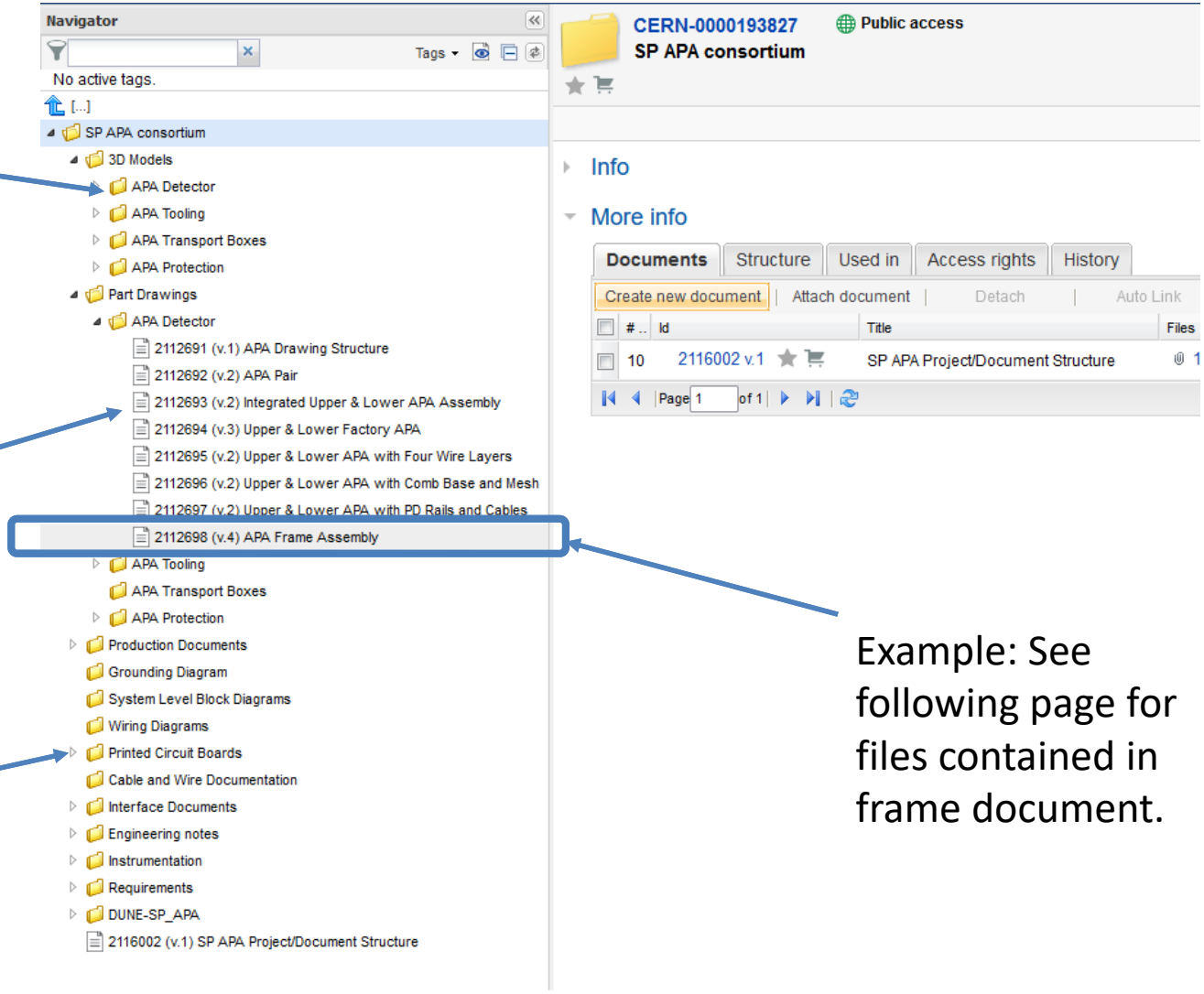
Link to SP APA Consortium

https://edms.cern.ch/project/CERN-0000193827

APA 3D Model files can be found here

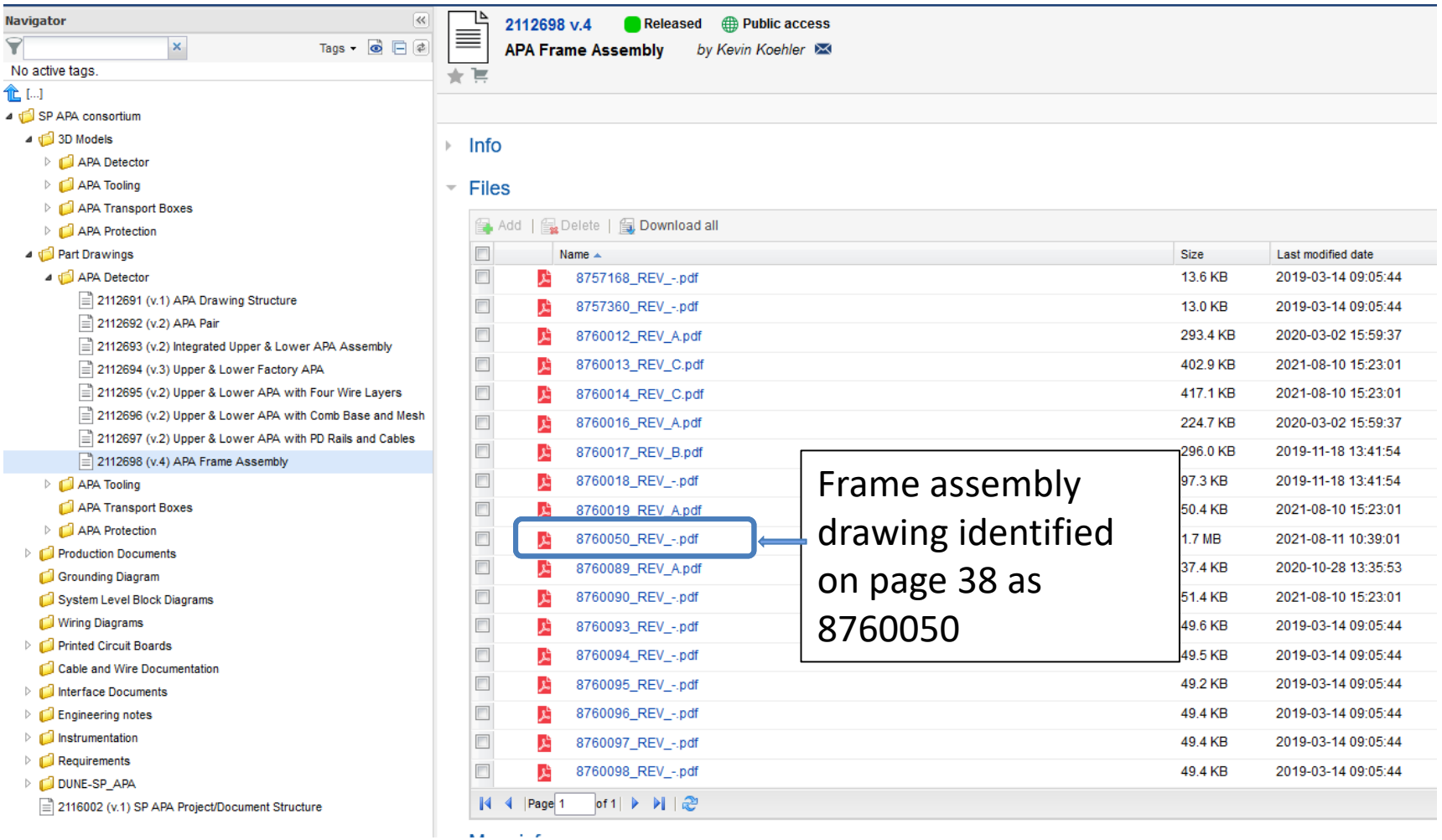
APA part and assembly drawings are organized by APA assembly levels (Defined on previous page)

APA board drawings and vendor specifications can be found here



Example: See following page for files contained in frame document.

Drawings


Navigator
Tags
No active tags.
[...]
SP APA consortium
3D Models
APA Detector
APA Tooling
APA Transport Boxes
APA Protection
Part Drawings
APA Detector
2112691 (v.1) APA Drawing Structure
2112692 (v.2) APA Pair
2112693 (v.2) Integrated Upper & Lower APA Assembly
2112694 (v.3) Upper & Lower Factory APA
2112695 (v.2) Upper & Lower APA with Four Wire Layers
2112696 (v.2) Upper & Lower APA with Comb Base and Mesh
2112697 (v.2) Upper & Lower APA with PD Rails and Cables
2112698 (v.4) APA Frame Assembly
APA Tooling
APA Transport Boxes
APA Protection
Production Documents
Grounding Diagram
System Level Block Diagrams
Wiring Diagrams
Printed Circuit Boards
Cable and Wire Documentation
Interface Documents
Engineering notes
Instrumentation
Requirements
DUNE-SP_APA
2116002 (v.1) SP APA Project/Document Structure
2112698 v.4
Released
Public access
APA Frame Assembly
by Kevin Koehler
Info
Files
Add
Delete
Download all
Name
Size
Last modified date
8757168_REV_-.pdf 13.6 KB 2019-03-14 09:05:44
8757360_REV_-.pdf 13.0 KB 2019-03-14 09:05:44
8760012_REV_A.pdf 293.4 KB 2020-03-02 15:59:37
8760013_REV_C.pdf 402.9 KB 2021-08-10 15:23:01
8760014_REV_C.pdf 417.1 KB 2021-08-10 15:23:01
8760016_REV_A.pdf 224.7 KB 2020-03-02 15:59:37
8760017_REV_B.pdf 296.0 KB 2019-11-18 13:41:54
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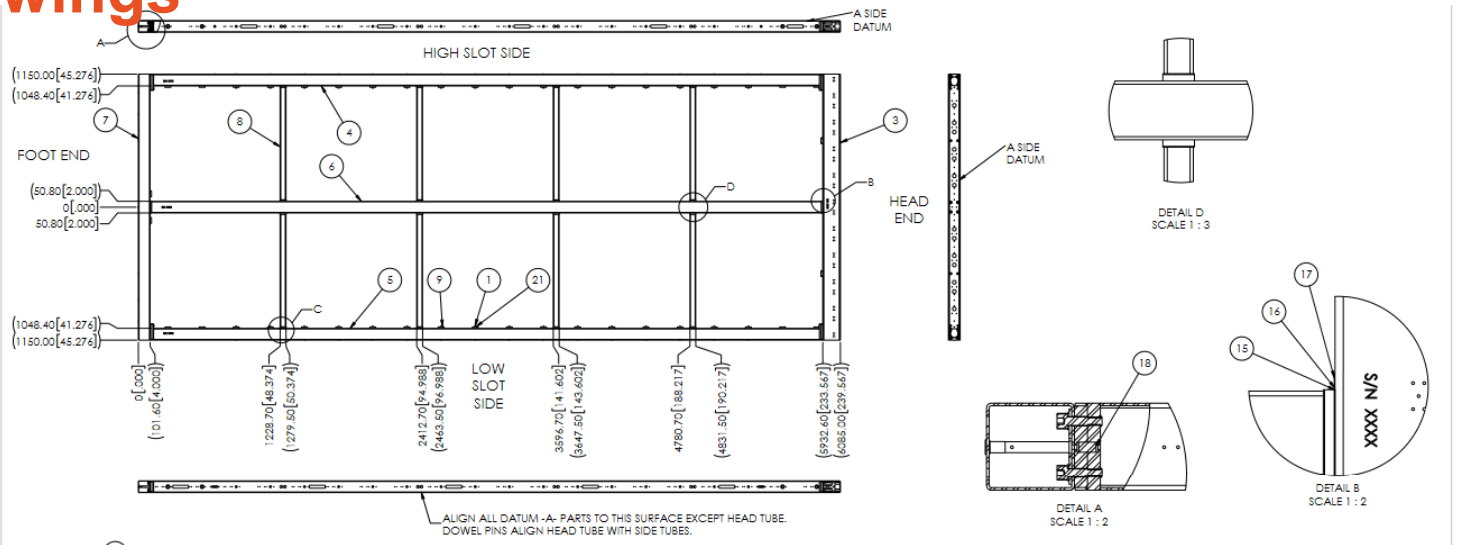
8760095_REV_-.pdf 49.2 KB 2019-03-14 09:05:44
8760096_REV_-.pdf 49.4 KB 2019-03-14 09:05:44
8760097_REV_-.pdf 49.4 KB 2019-03-14 09:05:44
8760098_REV_-.pdf 49.4 KB 2019-03-14 09:05:44
Page 1 of 1
Frame assembly drawing identified on page 38 as 8760050

Drawings



ITEM NO.	QTY.	PART NUMBER	DESCRIPTION
1	64	8757A168	M6-1.0 x 20 SHCS A2-70 SS SILVER PLATED
2	72	8757A360	M10-1.50 x 20 SHCS MODIFIED A2-70 SS SILVER PLATED
3	1	8760012	APA HEAD TUBE
4	1	8760013	APA HIGH SLOT SIDE BEAM
5	1	8760014	APA LOW SLOT SIDE BEAM
6	1	8760016	APA MIDDLE LONG BEAM
7	1	8760017	APA FOOT TUBE
8	8	8760018	APA RIBS
9	32	8760019	APA LIFT POINT REINFORCEMENT PLATE
10	2	8760089	FOOT CONDUIT BRACE
11	16	8760090	M12-1.75 x 40 SHCS A2-70 SS SILVER PLATED
12	8	8760093	DUNE SIDE SHIM 0.005 INCH THICK
13	8	8760094	DUNE SIDE SHIM 0.010 INCH THICK
14	8	8760095	DUNE SIDE SHIM 0.025 INCH THICK
15	2	8760096	DUNE END SHIM 0.005 INCH THICK
16	2	8760097	DUNE END SHIM 0.010 INCH THICK
17	2	8760098	DUNE END SHIM 0.025 INCH THICK
18	4	FASTENAL	#11113043 DOWEL PIN, 12mm DIA X 20mm LONG, SS A2
19	16	NORD-LOCK	#1103, NL12ss, 12mm WSHR (ALTERNATE: FASTENAL #0129544)
20	72	NORD-LOCK	#1099, NL10spss, 10mm WSHR (ALTERNATE: FASTENAL #0129540)
21	64	SCHNORR	#417900 M6, 6mm SS SAFETY WSHR (ALTERNATE: BELMETRIC #WSH6SS)
22	40	TUBTARA	#540_600 RIVNUT, M10-1.5, 304 STAINLESS STEEL, TYPE SPO35

All drawings with an 8757, 8760, or 8765 prefix are in the frame assembly document

Drawing Management

PSL drawings and documents are stored in SolidWork's Product Data Management System (PDM). Formal drawing release and revision procedures are followed.

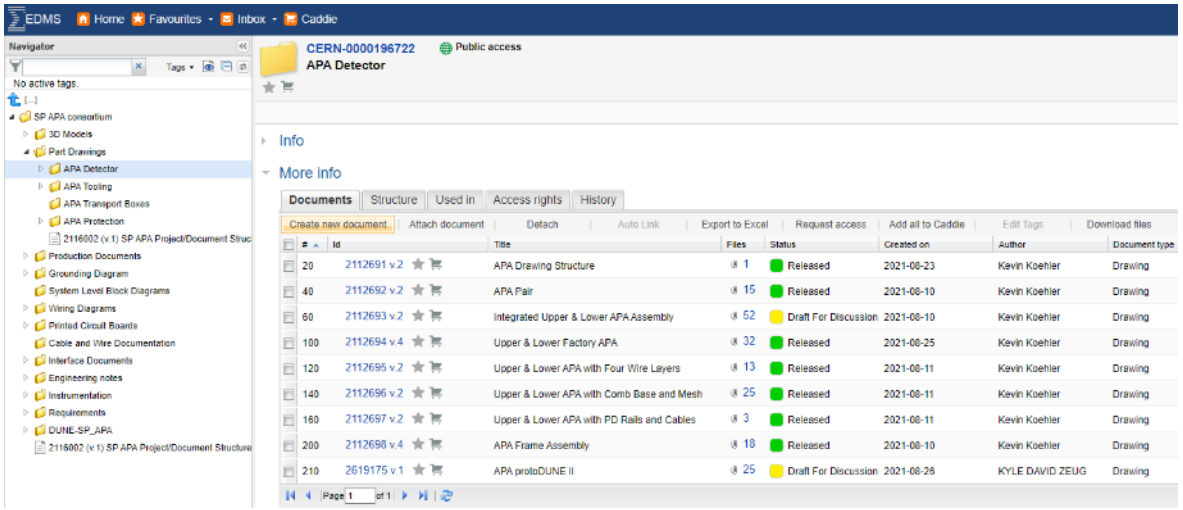
- Drawing release
  - Designer completes and checks drawings and then submits for "release checking".
  - Project engineer checks the drawing and requests edits or submits for "release approval"
  - Once submitted for release approval, Mechanical engineering manager (or designee) checks the drawings and requests edits or approves.
- Drawing revision
  - Follows a procedure similar to the drawing release procedure.
  - In addition, a description of the revision is documented in the revision block on the drawing.
- Electrical specifications
  - Formal procedure has been defined for checking the electrical specifications against the mechanical specifications before release.

Mechanical Drawing Status – APA Detector

All APA drawings are released in EDMS except for the drawings associated with Integrated Upper & Lower APA Assembly and APA protoDUNE II. These are in a “draft for discussion state” due to the following:

- Integrated Upper & Lower APA Assembly
  - 8765023 SIDE A - BIAS VOLTAGE WIRE BUNDLE Work In Progress in PSL system
  - 8765024 SIDE B - BIAS VOLTAGE WIRE BUNDLE Work In Progress In PSL system

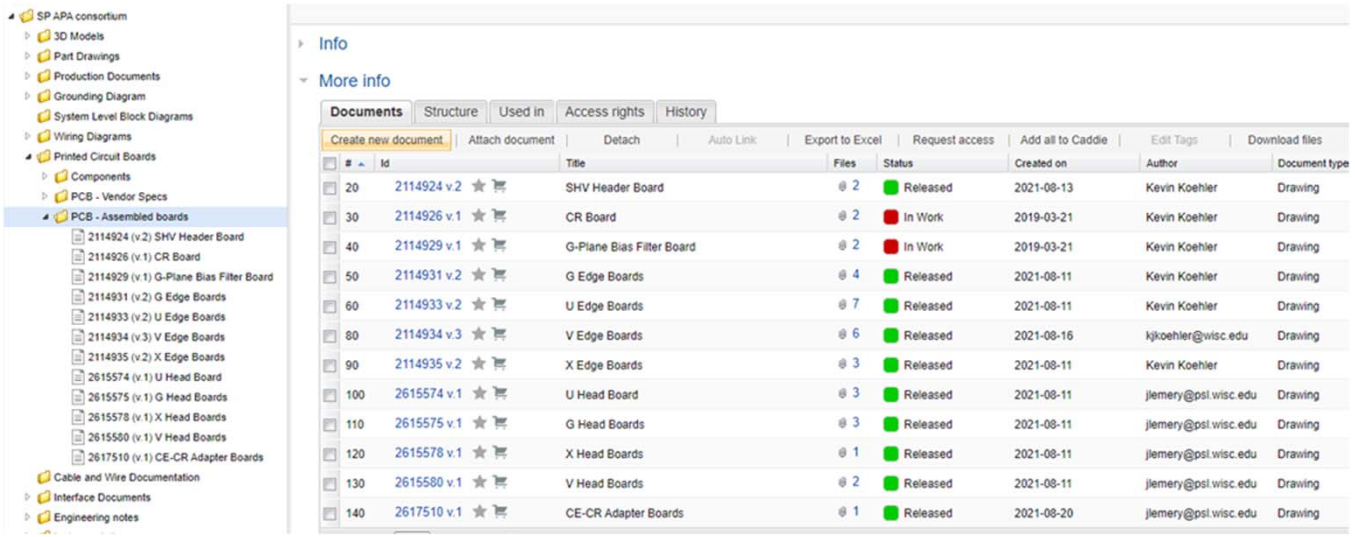
- APA protoDUNE II
  - Most drawings for components needed for testing at Ash River this year are released in PSL system.



Mechanical Drawing Status – PCB Assembled Boards

All drawings for **PCB Assembled Boards** are released in EDMS except for the following:

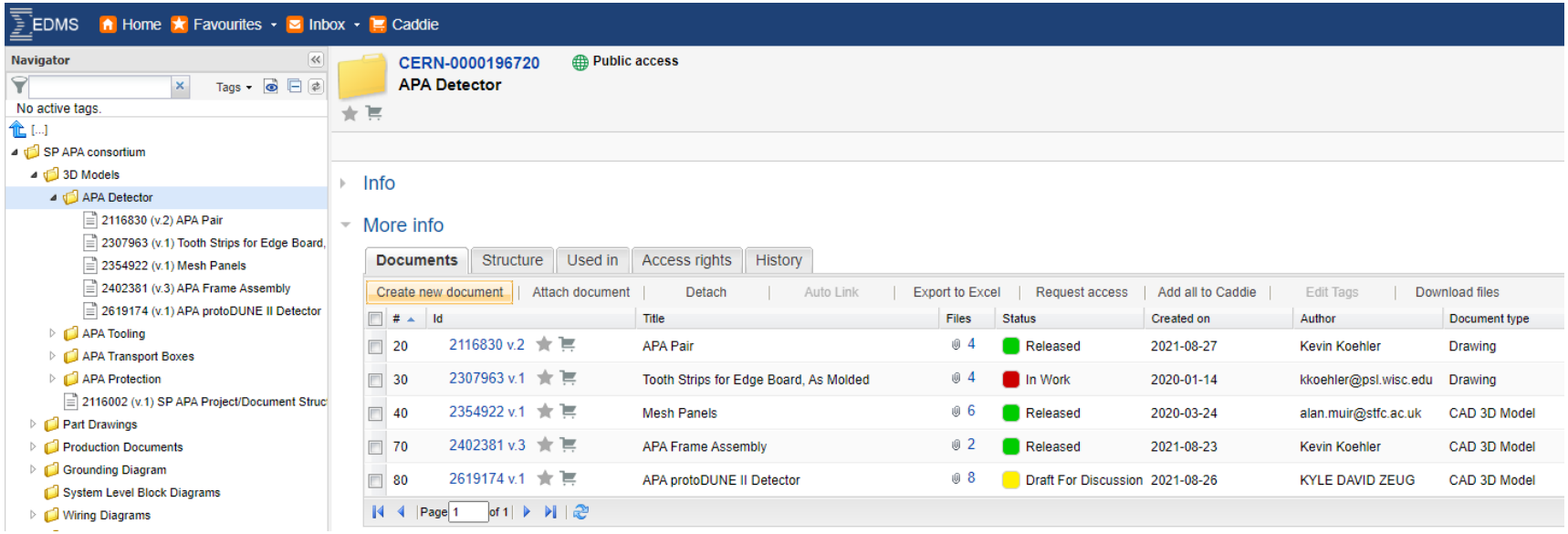
- CR Board – “In Work” on EDMS and needs the following drawings added/updated:
  - 8760145 CR PCB ASSEMBLY Released in PSL system
- G-Plane Bias Filter Board – “In Work” on EDMS and needs the following drawings added/updated:
  - 8760197 G BIAS FILTER BOARD ASSEMBLY Waiting for Release Checking in PSL system
  - 8765035 MODIFIED M3-0.5 X 9 SHCS, CAPTIVE, BRASS Waiting for Release Checking in PSL system
- G Head Boards – Released in EDMS, but need revision:
  - 8765007 G HEAD BOARD ASSEMBLY – LEFT END Needs Revision to add M3 insert
  - 8765008 G HEAD BOARD ASSEMBLY – MIDDLE Needs Revision to add M3 insert
  - 8765009 G HEAD BOARD ASSEMBLY – RIGHT END Needs Revision to add M3 insert



Mechanical Model Status – 3D Models, APA Detector

All APA Detector 3D Models are released in EDMS except for the following:

- Tooth Strip for Edge Board, As Molded
  - 8752827 8mm PITCH PIN STRIP STOCK On EDMS
  - 8752828 5.75mm PITCH PIN STRIP STOCK On EDMS
  - 8752829 BOTTOM PIN STRIP STOCK On EDMS
  - New Version of models which are scaled for better accuracy. Released in PSL system. To be uploaded soon.
- APA protoDUNE II Detector
  - Models will be released when drawings are complete.



Summary:

- The APA frame fabrication process has been defined to control the accuracy of the important features that affect the requirements of plane to plane spacing and wire to wire spacing.
- The design of the tooth strips bonded to the APA boards provides very good control of the wire to wire spacing within boards.
- The tolerances of the wire locating features on the boards, provides adequate control of the wire to wire spacing between boards and the wire plane to wire plane spacing.
- The cause of the broken protoDUNE wires has been investigated and modifications to the head board designs have been implemented to address the cause.
- Provisions for integrated subsystems (CE, PD, CALCI, FC supports) have been incorporated into the design of the APA.
- APA to APA connection hardware has been designed to safety control the planarity of the APA planes and the gaps between APAs.
- With the few exceptions identified, the mechanical drawings and models are released and uploaded to EDMS.