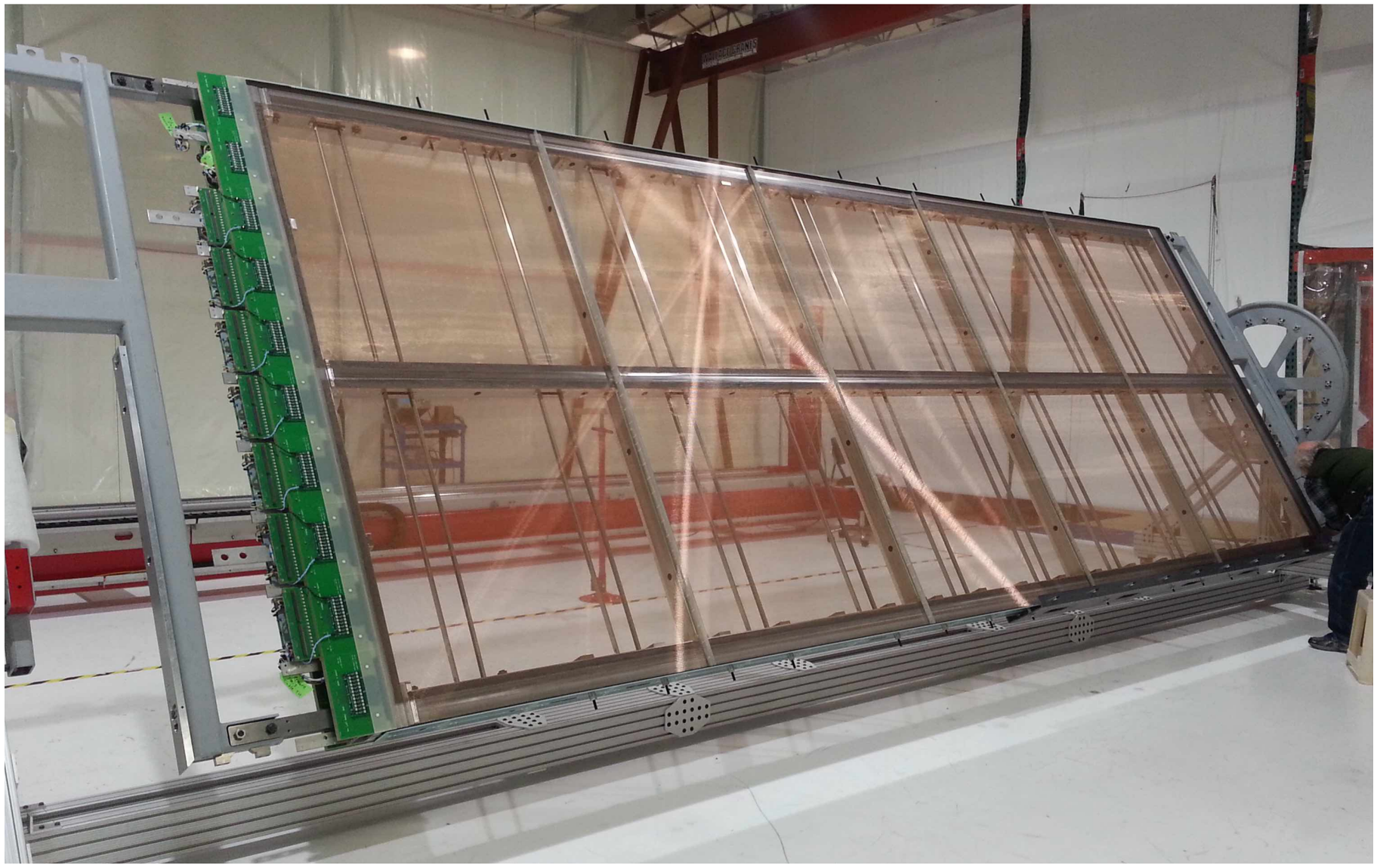


Quality Assurance and Quality Control protocols for DUNE APAs

Roxanne Guenette (for the APA team)
Harvard University

APA Final Design Review 31 August - 2 September 2021

Related to the review charge:

- 6. If draft documentation detailing plans for procurement, manufacturing, **quality control**, and part identifiers exists at a sufficient level of maturity for initiating module-zero production.

- 5. Future plans for testing in the EHN1-NP04 Cold Box and ProtoDUNE-II and whether **lessons learned from ProtoDUNE-SP and other prototypes have been incorporated within the current design.**

Outline

- **Quality Assurance**:

  Detailed description of what we have learned from protoDUNE, as this gives us confidence (QA) for DUNE

  Detailed protocols for some APA components to ensure quality

- **Quality Control**:

  Detailed description of the testing protocols for the APAs

Quality Assurance

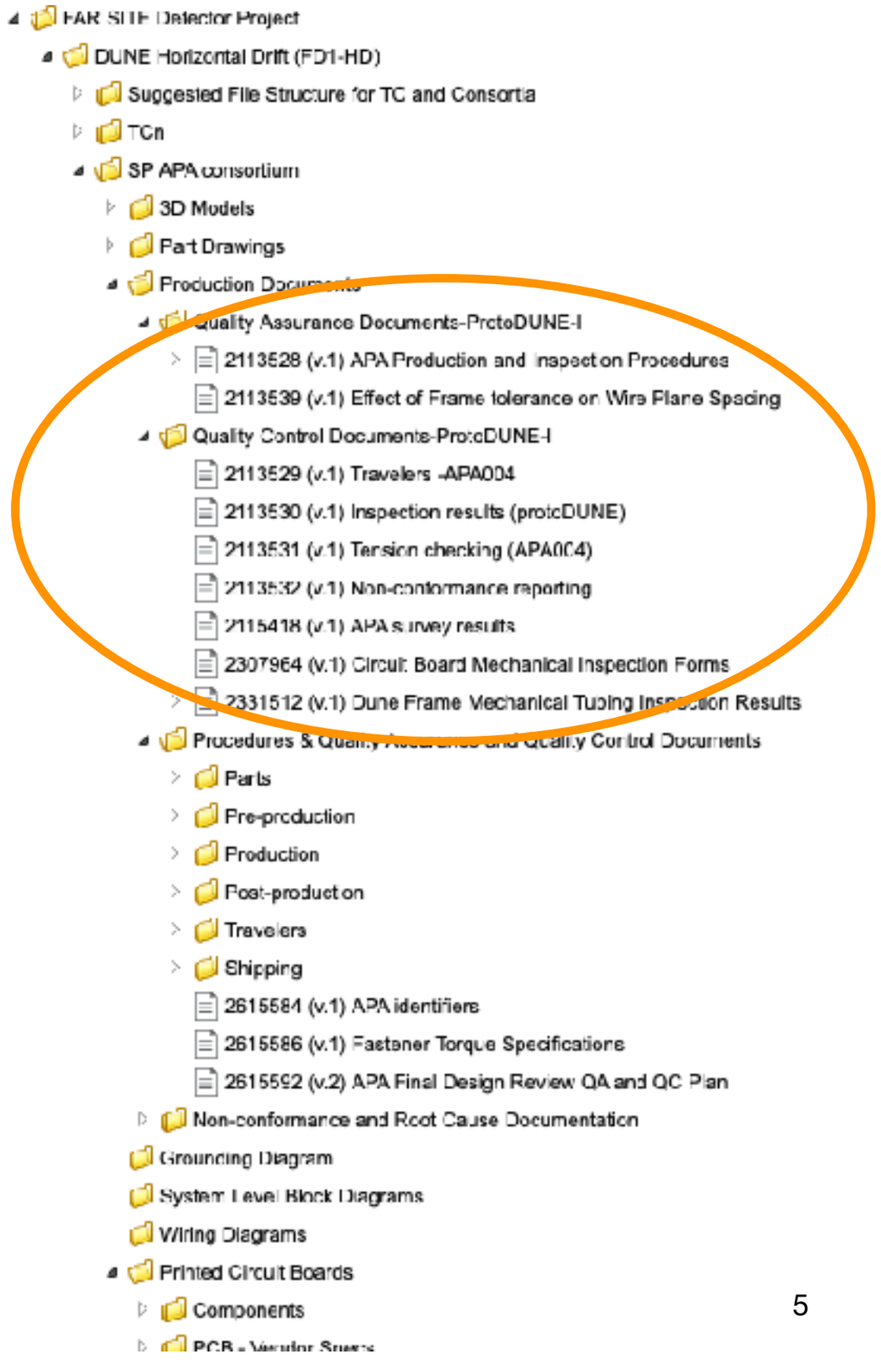
- Long history of wire plane construction (MicroBooNE, 35t, **protoDUNE (I & II)**, SBND)
- Two Production Sites (PSL and Daresbury) have extensive experience with APA construction from protoDUNE-I (6+1 APAs) and protoDUNE-II (1+ APAs to date)
- Robust construction process developed and tested
- Updated (and currently being tested) plans for latest (protoDUNE-II) APA design (larger frames, new geometry boards and fine-tuned wire-winding machines)

Quality Assurance (protoDUNE-I)

- Extensive information and documentation available from protoDUNE-I APA construction

- Detailed on QA work was presented at the last review (link)

- Talk from Justin Evan's on *Lessons Learned*



QA/QC Plan for APAs

- Each APA component has clear inspection and testing protocols

2615592 (v.2) APA Final Design Review QA and QC Plan

- Procedures divided by component:
  - ✓Printed circuit boards:
  - ✓Pins and sockets of the boards:
  - ✓Tooth strips:
  - ✓Photon Detector Hardware:
  - ✓Combs and components:
  - ✓Mesh panels:
  - ✓Frame Beams & Pads:
  - ✓Wire Tension:
  - ✓Channel continuity and isolation:
  - ✓Specific torque requirements on designated hardware:
  - ✓Final surveys of assembled APA for frame flatness and wire plane spacing:

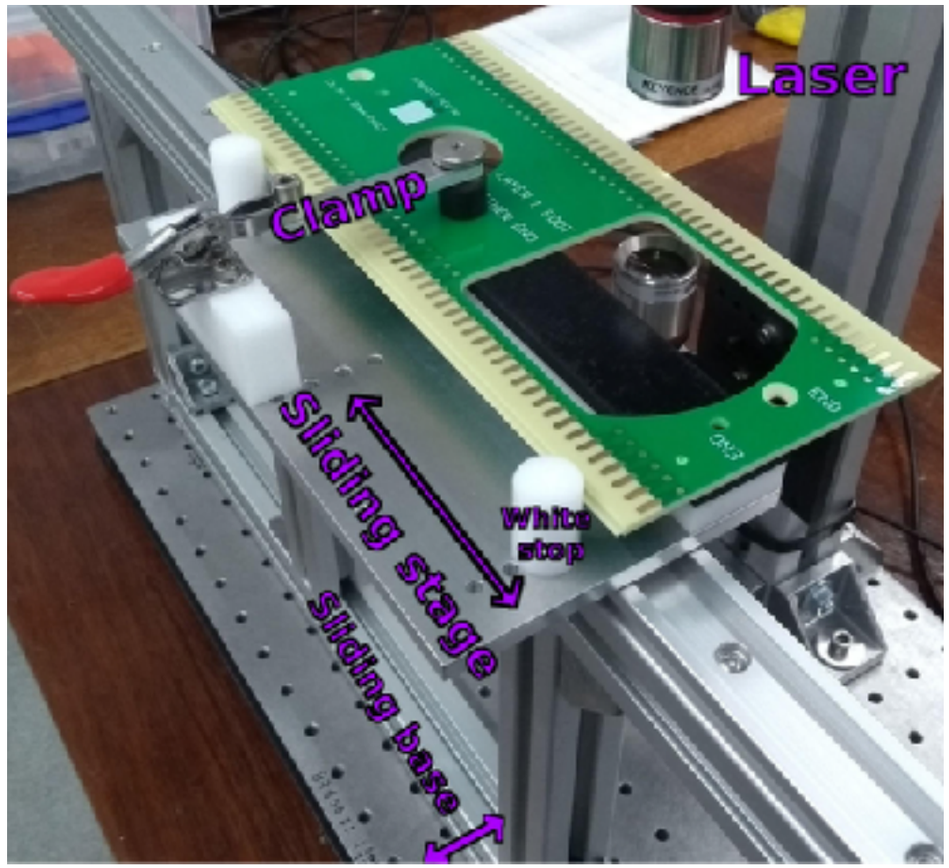
APA parts

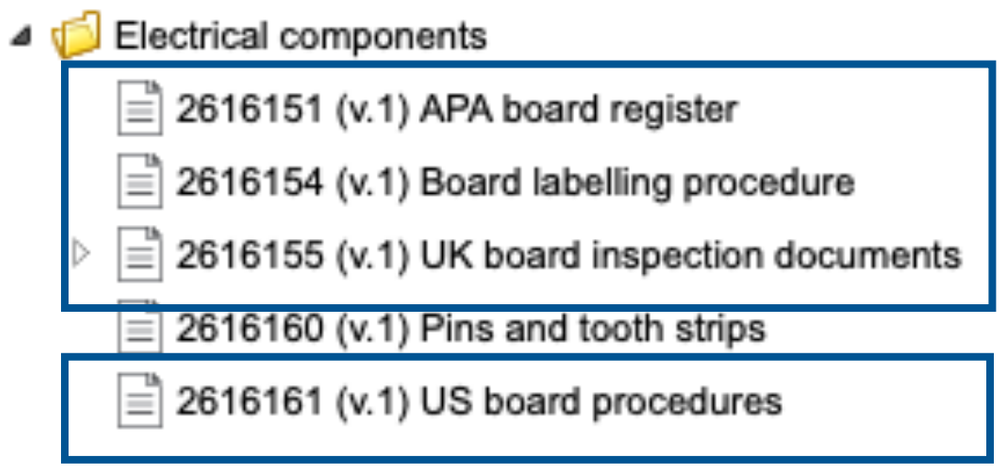
Assembled APA

Printed Circuit Boards*

- Board thickness
- Tongue thickness for edge boards
- Features (e.g. holes) positions
- Electrical performance checks for CR boards (doc in progress)

UK automated board measurement





US board measurement

* There are several different types of boards (head, foot, side, U,V,X,G,CR, cover…). Each have their dedicated inspection procedures

Example of documentation (PCBs)

6.7.3 Drawing for boards being inspected.
6.7.4 Digital calipers
6.7.5 Clean plastic bags for inspected boards.
6.7.6 Marker to label bags with board type, Rev, and serial number.
6.7.7 Light table.
6.7.8 Computer with access to digital spreadsheets.

7.0 Requirements / Additional Information:

7.1 All circuit boards should be labeled in with a serial number in addition to the board type and Rev already printed on the board. This can occur before or after inspection. If after, the person performing the labeling operation should make sure the number matches the number on the board bag.

8.0 Preparation / Setup

8.1 Collect the circuit boards that are going to be inspected.
8.2 Depending on the board being inspected, collect the tools and equipment listed in the appropriate section of 6.1 through 6.7.
8.3 Wipe down all work surface areas with ethyl alcohol soaked lint-free wipes.

9.0 Procedure

9.1 **Inspecting All Boards**

9.1.1 Wear protective gloves while handling the circuit boards for all following steps.
9.1.2 If the boards are still in their packaging, remove them. If there are labels on the packaging, cut out the labels and secure them onto sheets in the Pre-Production APA binder in the board inspection room. If they have already had serial numbers engraved, the package labels should be with the boards.
9.1.3 Call up current spreadsheet for the board being inspected or create a new spreadsheet if the board is a new Rev version. If a dimension has changed, update the spreadsheet to match the drawing.
9.1.4 Record all values in the spreadsheet. Use the spreadsheet to guide you. Values will turn red if they are outside of the specified tolerance for each measurement. Some features just require checking and if all pass, put OK in the sheet.

9.2 **Inspecting Head Boards**

9.2.1 Check that solder mask is where it should be on the board according to the drawing.
9.2.2 Check the silkscreen printing on the front of the board and note any differences from the print other than the manufacture's logo.
9.2.3 Using the digital calipers, measure overall length (Figure 1).

Figure 1 – Horizontal overall length measurement.

9.2.4 Measure the overall width (Figure 2).
9.2.5 For **X boards**, measure the thickness of the tongue (yellow part at the top) on the left, middle, and right of the board (Figure 3). **For all V, U, and G**, measure the board thickness on the left and the right where both sides have solder mask, and measure the tongue thickness on the right and the left. The difference between these two measurements on each side should be between 0.10mm and .060mm. The calculation is built into the spreadsheet.
9.2.6 The **V and U boards** have cutoffs and fins on the sides of the boards. Confirm that they agree with the drawing.
9.2.7 Check the size of the lower corner cutouts by setting the calipers to the correct values or using a drawing for comparison (Figure 4).
9.2.8 Turn the board over and measure on the back side.
9.2.9 Measure the diameter of all 10 large holes near the top of the board (Figure 5). (Note that one hole is oval and not round. The location of the oval is different for each head layer and can be found in Table 1. Measure the diameter along the vertical and horizontal axis for this hole.)
9.2.10 Measure the distance from the edge of each hole to the left side of the board.
9.2.11 Measure the distance from the edge of each hole to the top of the board (Figure 6).
9.2.12 On the front side of the board, check the counter-bore diameter and depth on holes 3 and 8. The other two holes with counter-bores change with board type and are found in Table 1. If all are good, record OK.

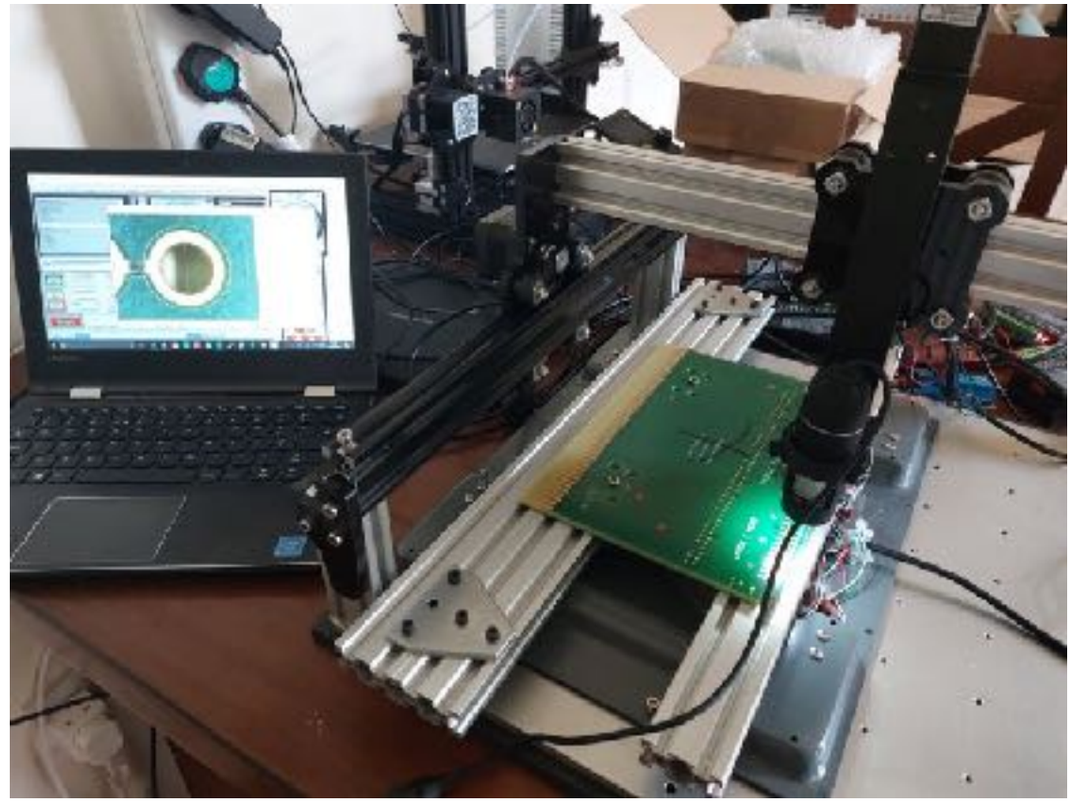
Figure 2 – Overall width measurement.

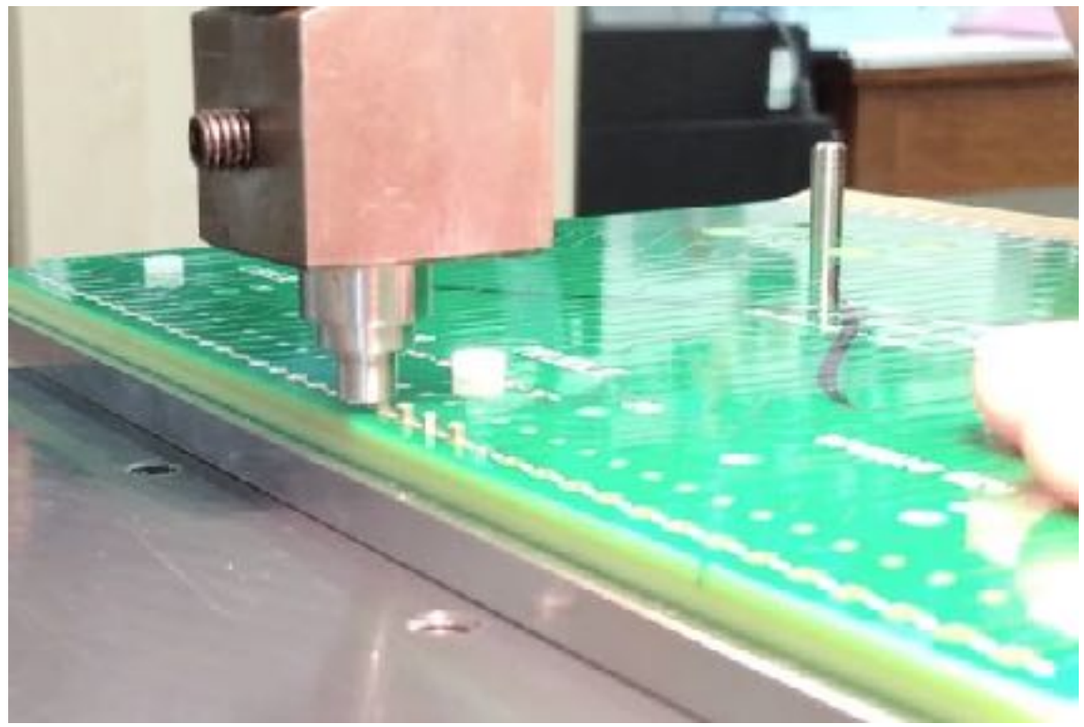
Figure 3 – Thickness of tongue measurement.

9.2.13 There are four larger holes in the line of holes near the bottom of the board as can be seen in Figure 5. From the back of the board, measure them with the calipers and if all are good, record OK.

Pins and sockets

- Pin insertion force and withstand force tests
- Pin & Socket mating force tests
- Visual inspection and continuity checks

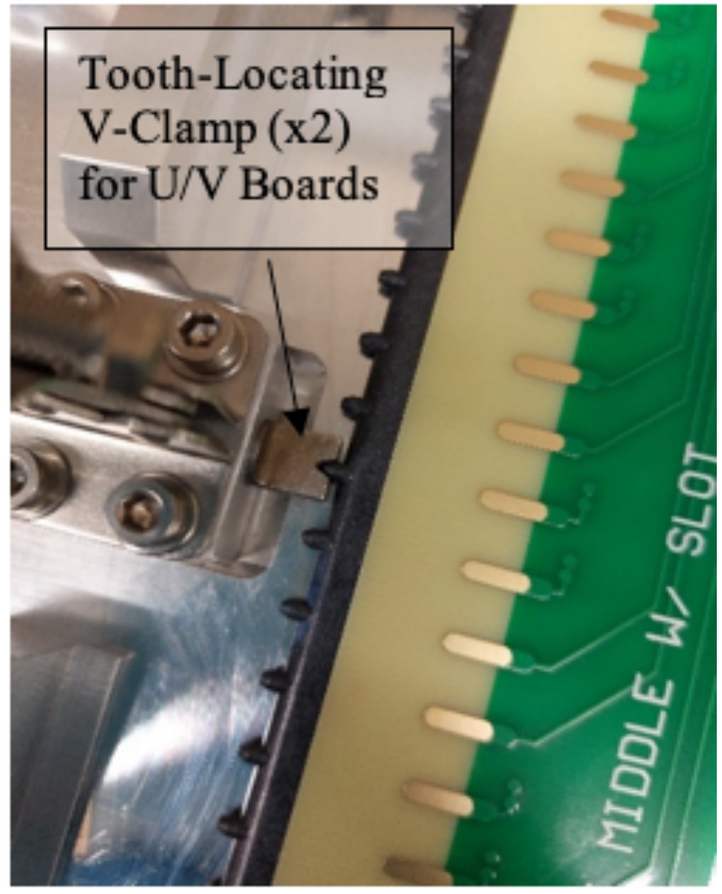


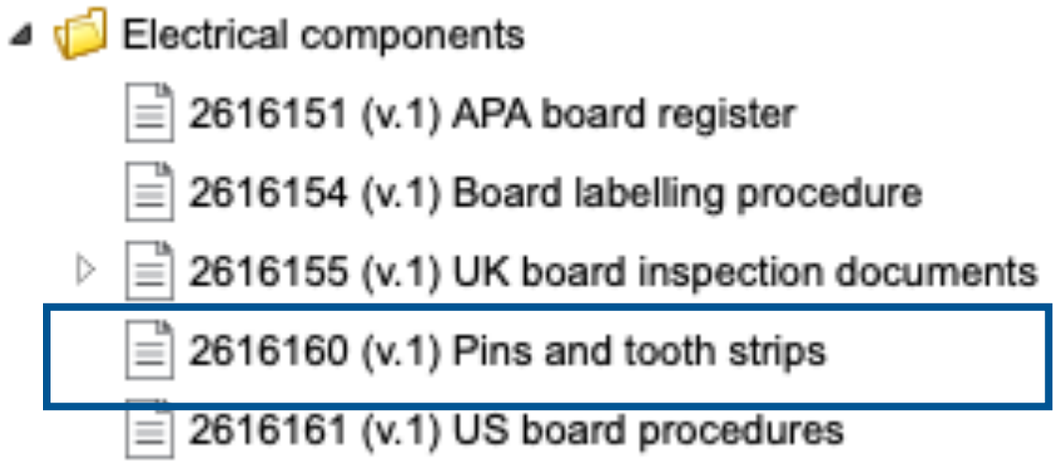


- Electrical components
  - 2616151 (v.1) APA board register
  - 2616154 (v.1) Board labelling procedure
  - 2616155 (v.1) UK board inspection documents
  - 2616160 (v.1) Pins and tooth strips
  - 2616161 (v.1) US board procedures

Tooth strips

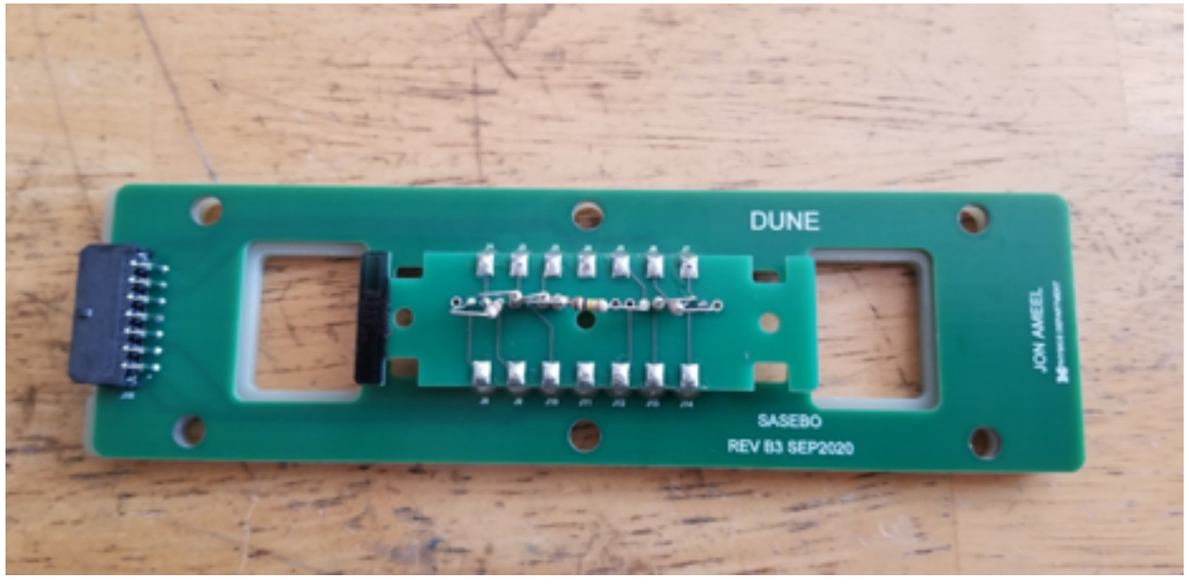
- Visual inspection
- Measurement of tooth strip position



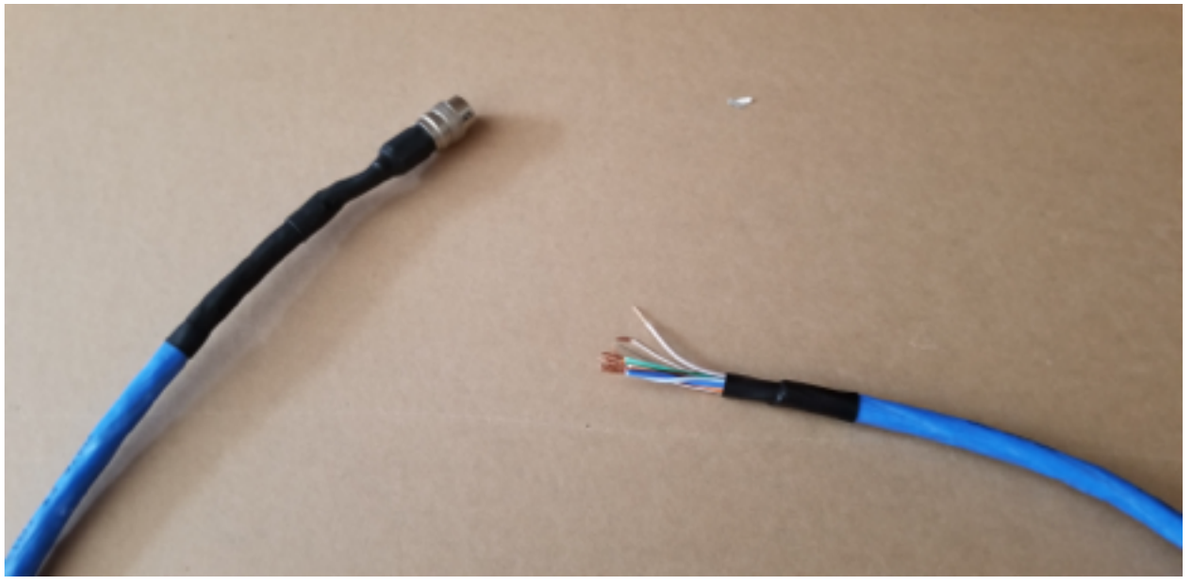


Photon Detector Hardware

- Interface with PD consortium
- Visual inspection of components
- Test readout cables

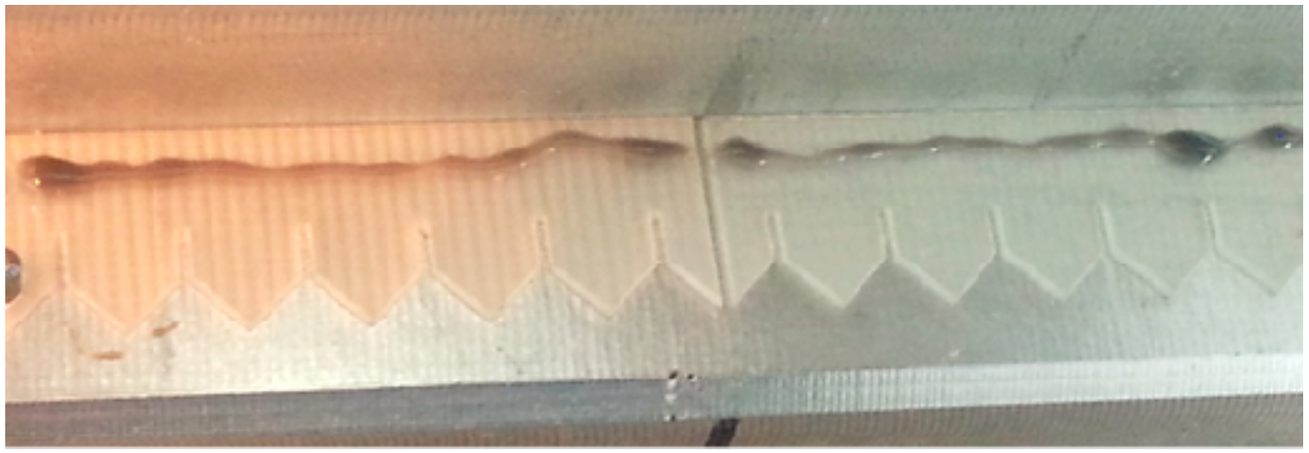


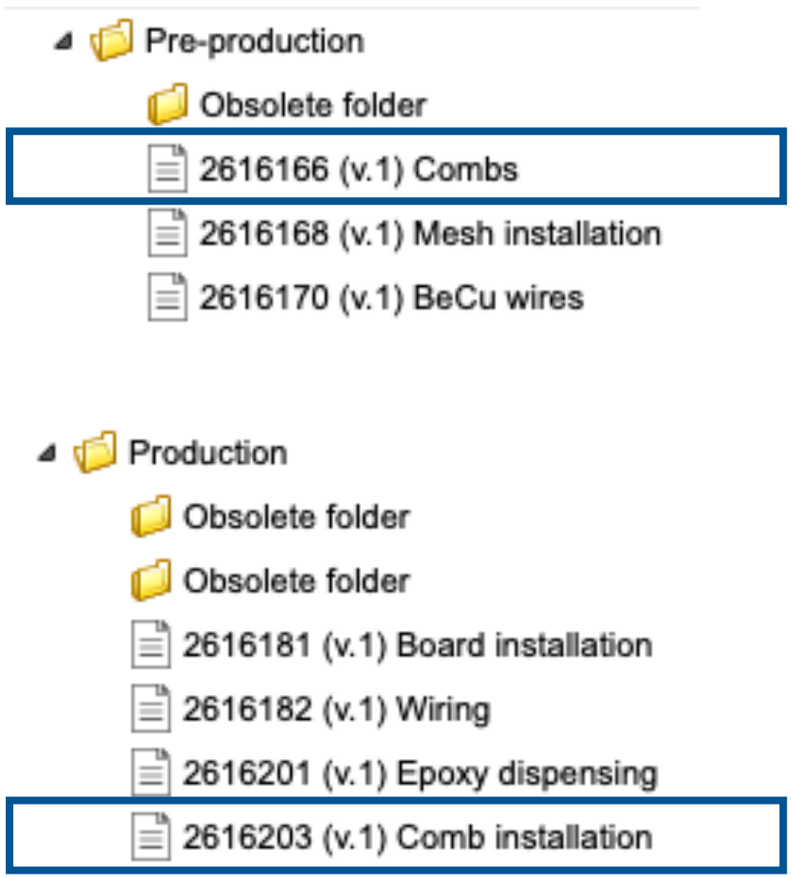
Interface Document: Photon Detector Cable Connection Test (R1.0)

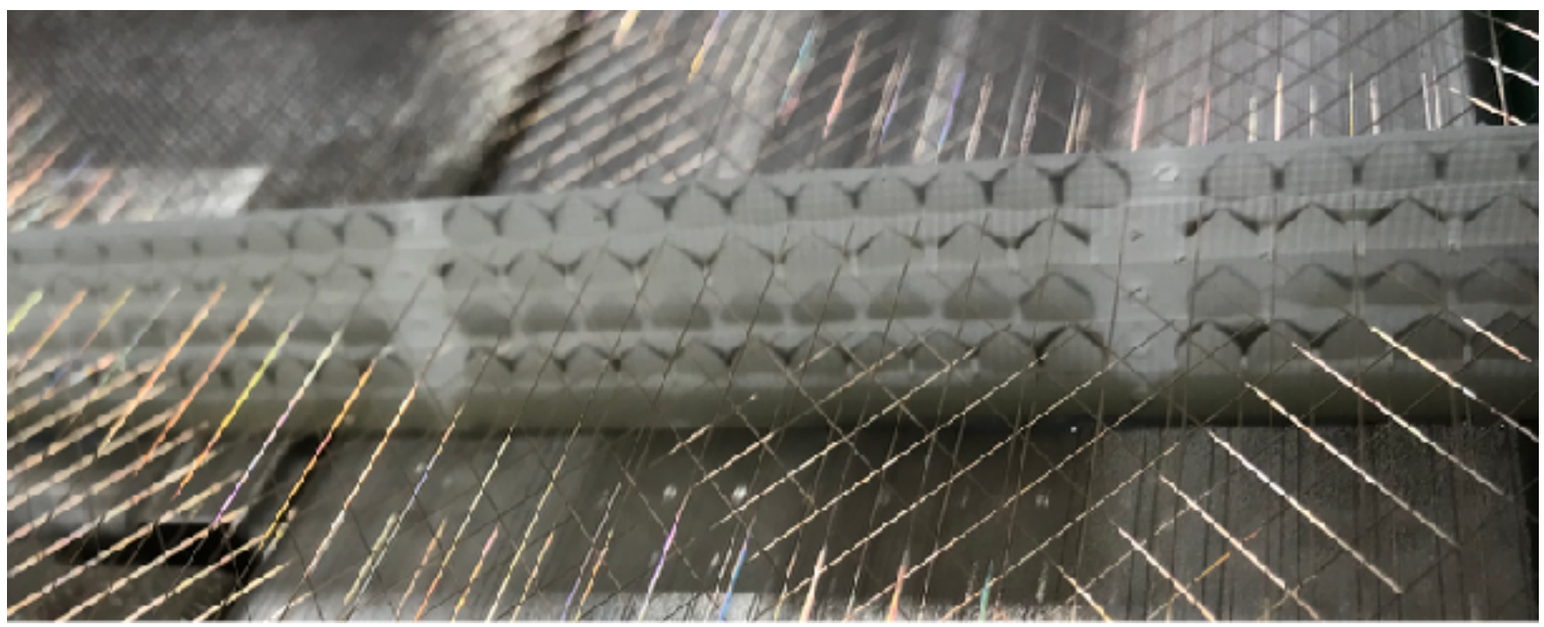


Combs

- Visual inspection

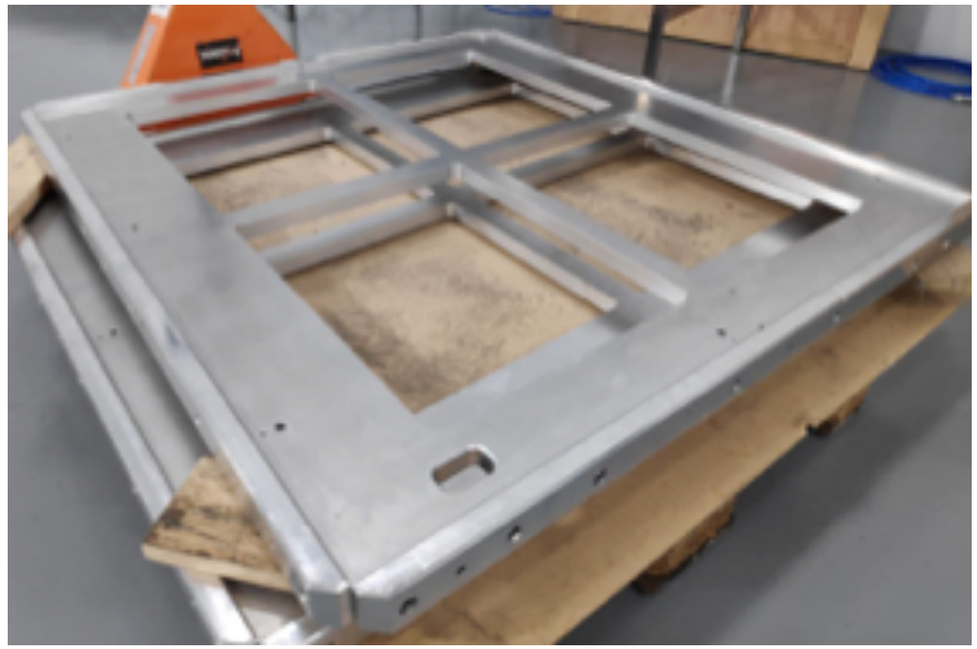




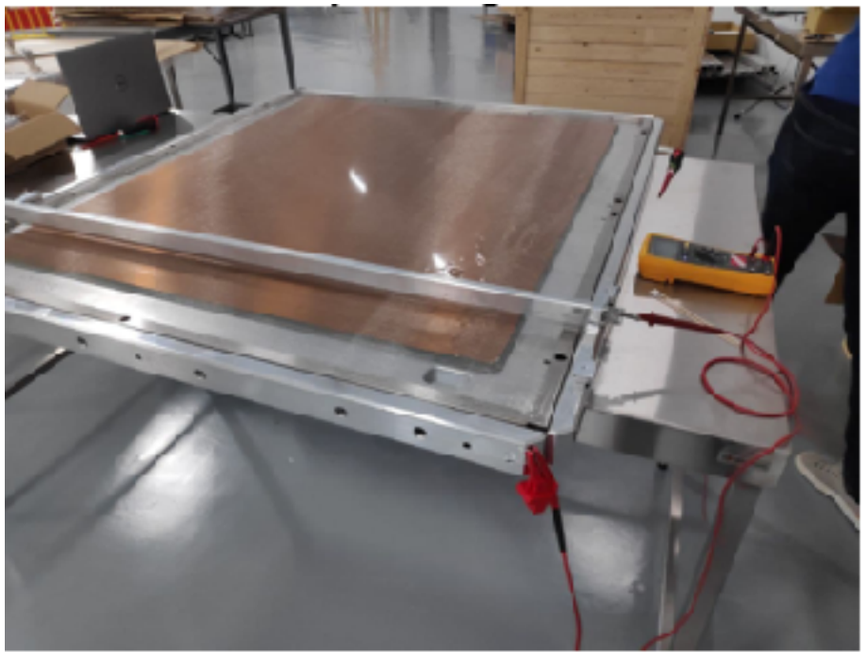


Mesh Panels

- Visual inspection
- Tests with jig (dimensions, flatness, deflection and deformation)



- Mesh
  - 2615582 (v.1) Mesh inspection procedure
  - 2615583 (v.1) Mesh inspection template
  - 2615591 (v.1) Mesh assembly procurement document



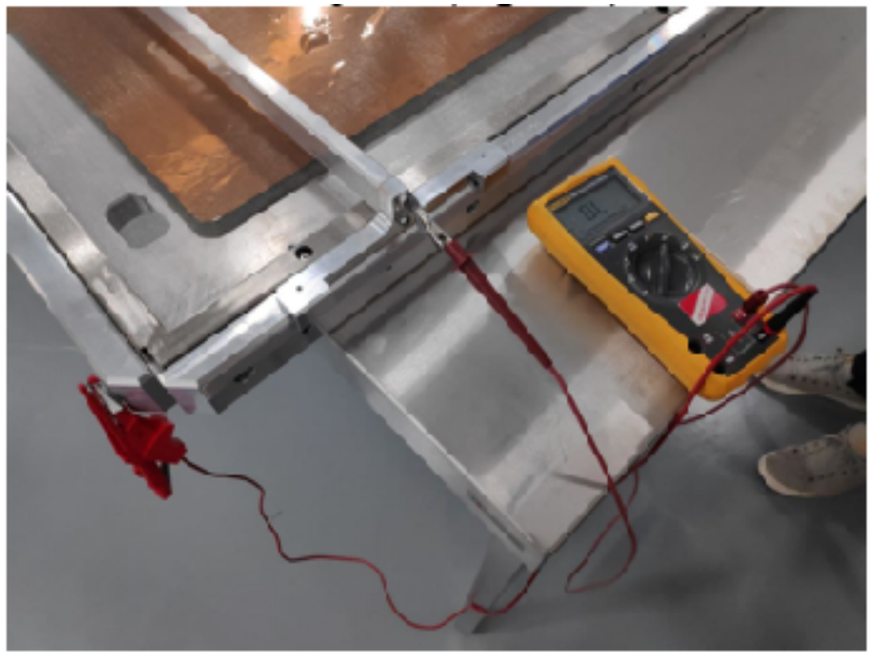
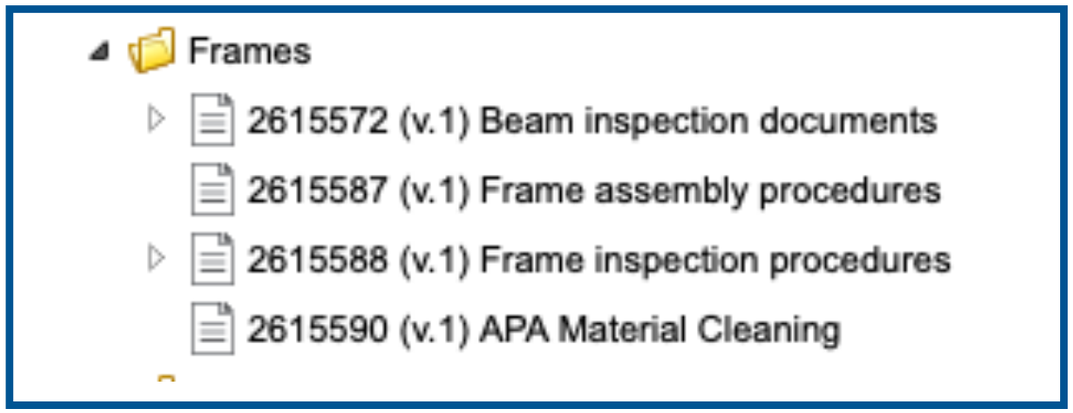
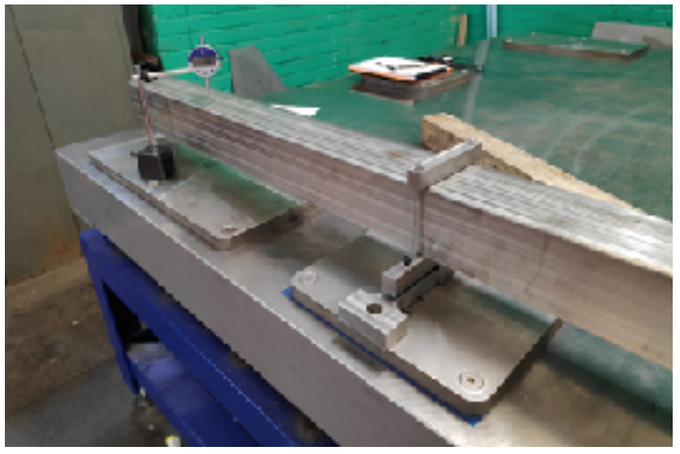


Figure 6 – Mesh deflection + deformation check with external electrode

Beams and Pads

- Visual inspection
- Dimension measurements (thickness, corner radius, lengths, cross section)
- Straightness and twists checks

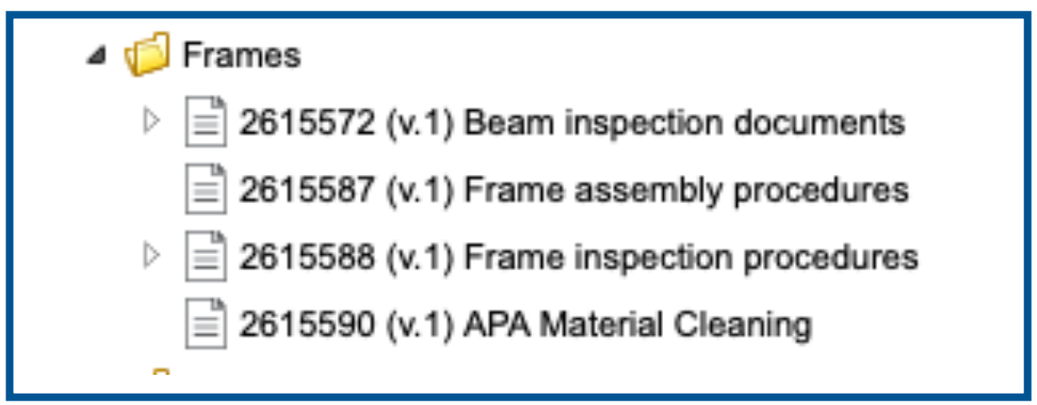




Frames

- Detailed study of frame distortion (bow, twist, fold)
- Frame planarity (twist limit)
- Inspection of hole sizes & positions

UK frame laser survey

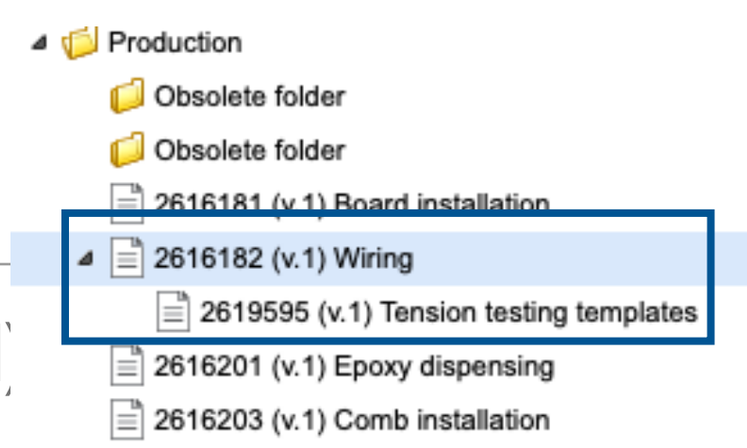


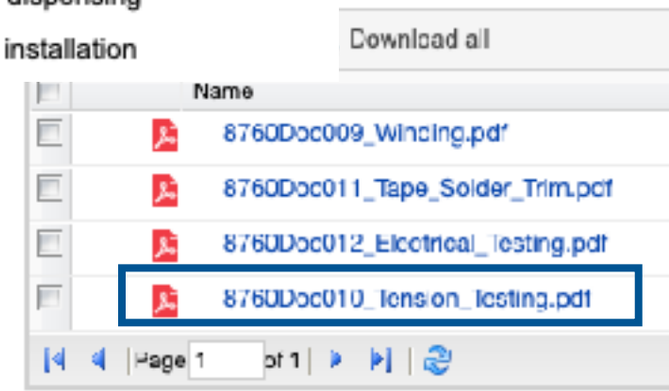
Wire tension

- Current official method: laser (manual)

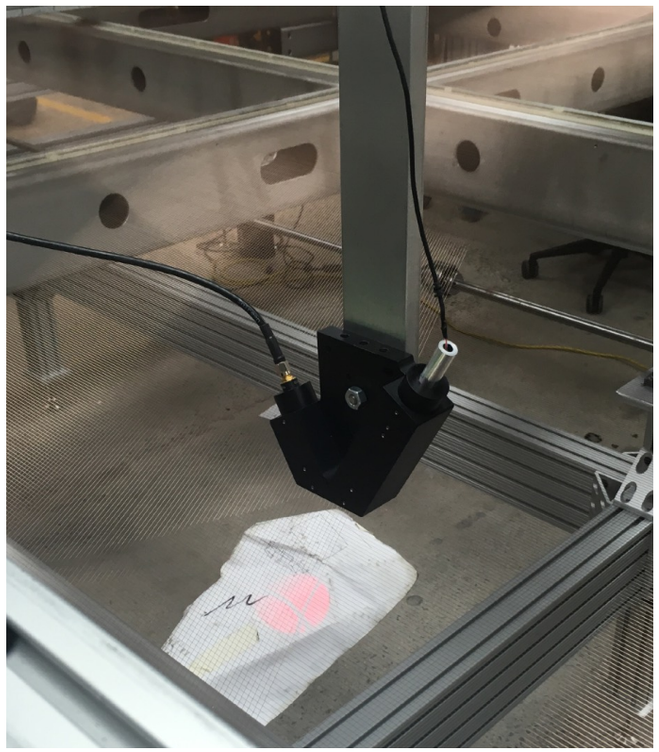
  More details in Hannah's talk

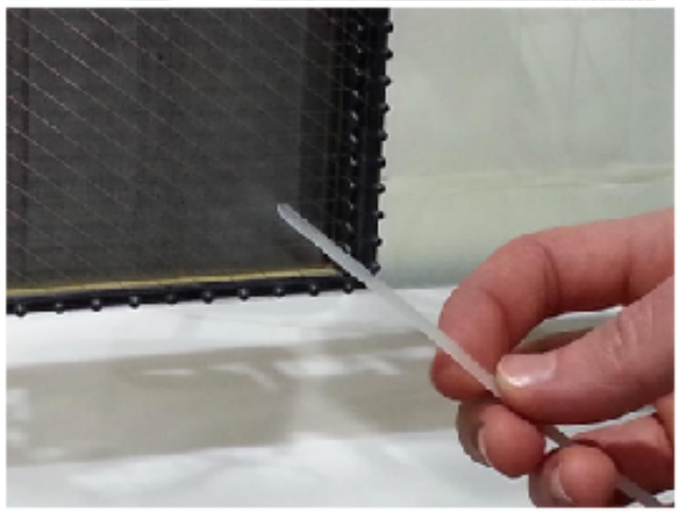
- Future method: electrical (semi-automated)



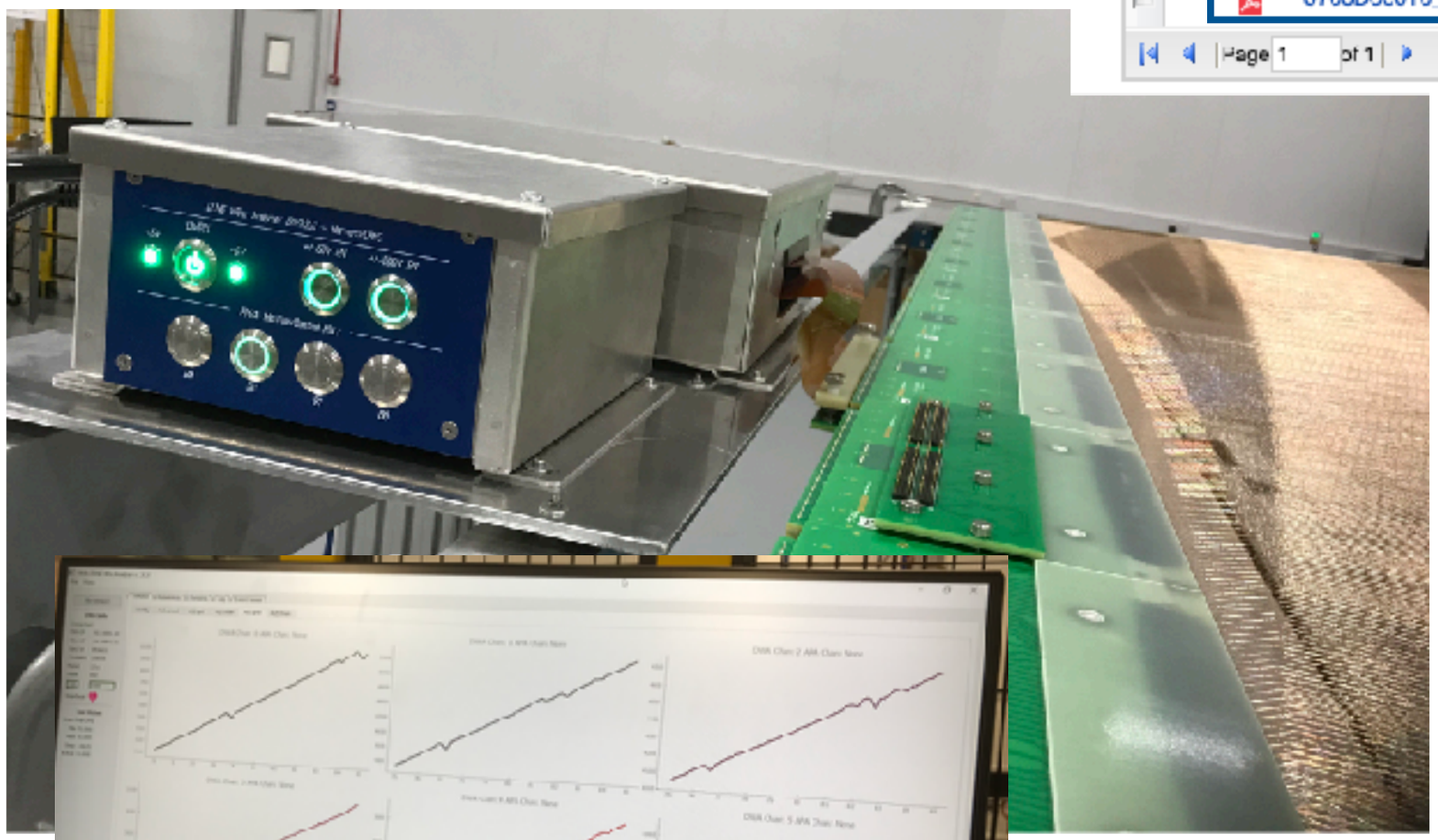


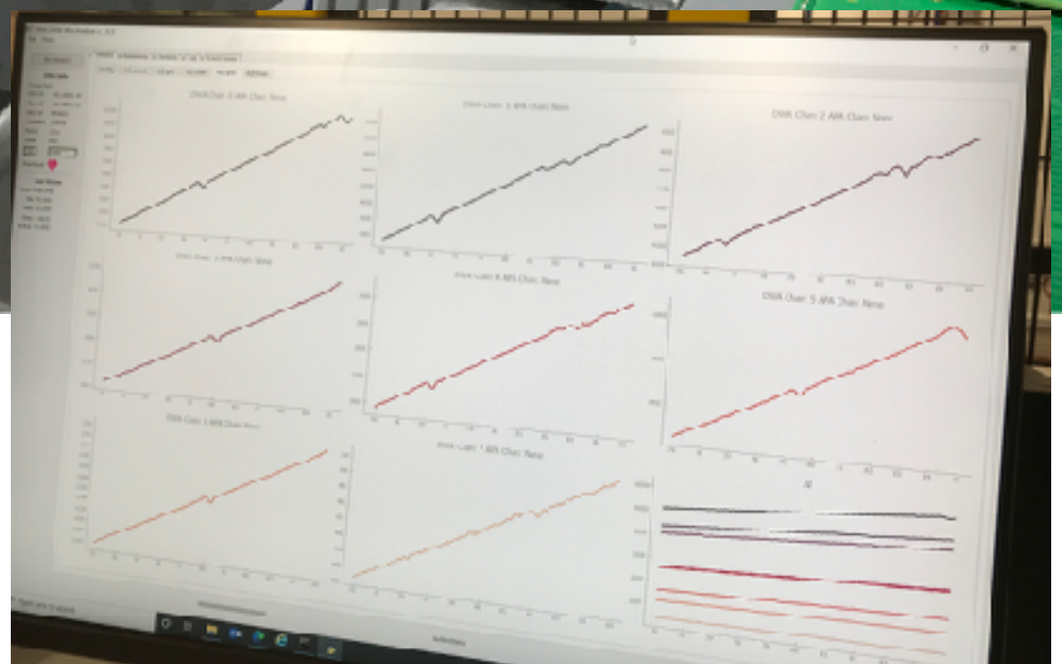
Laser method





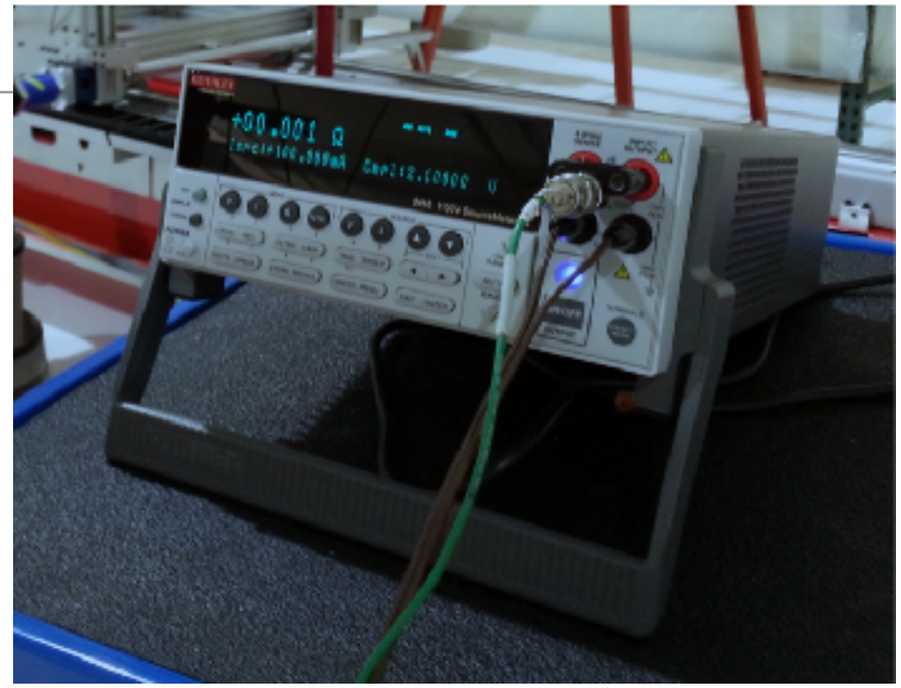
Digital Wire Analyzer (electrical method)

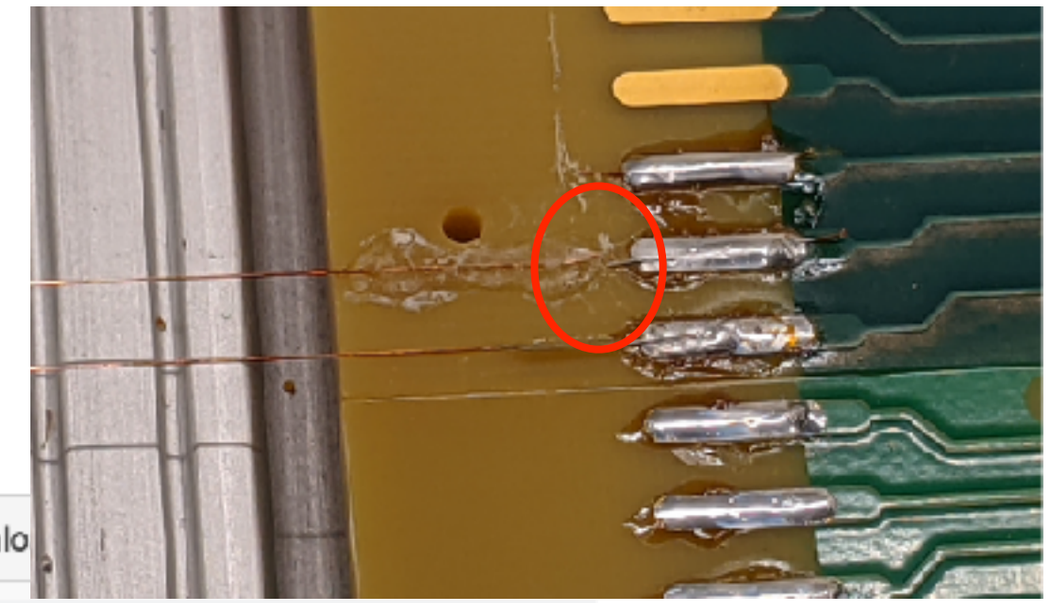


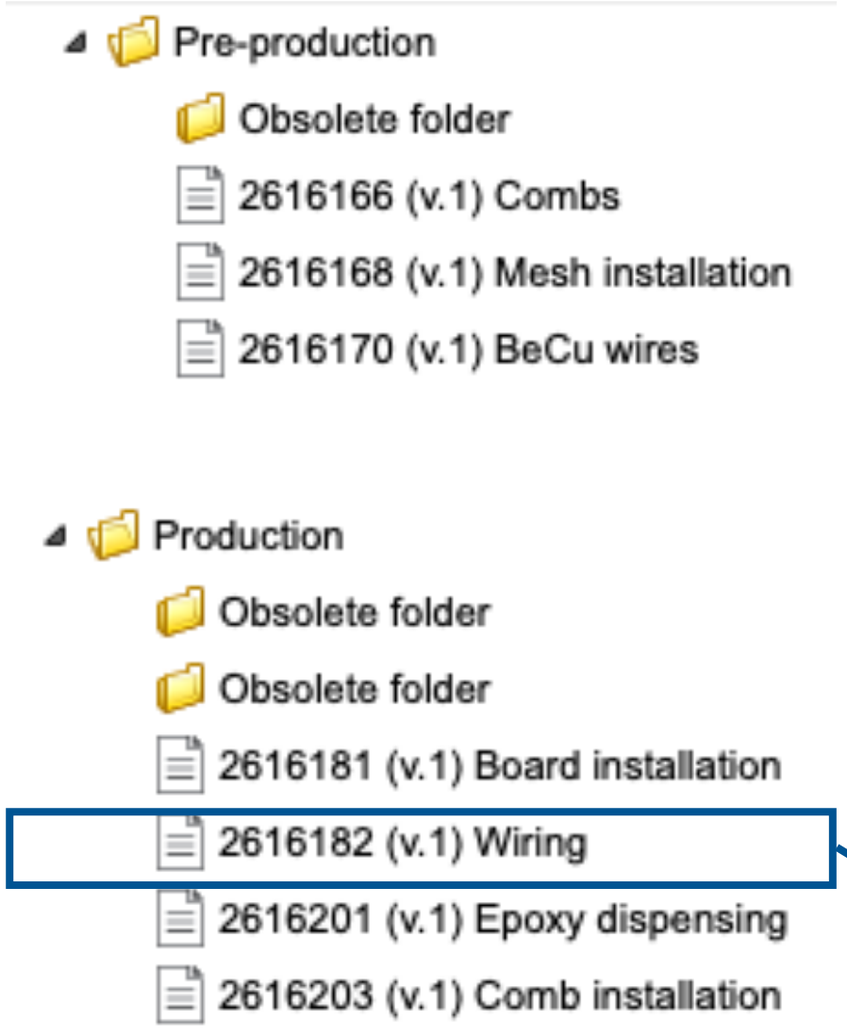


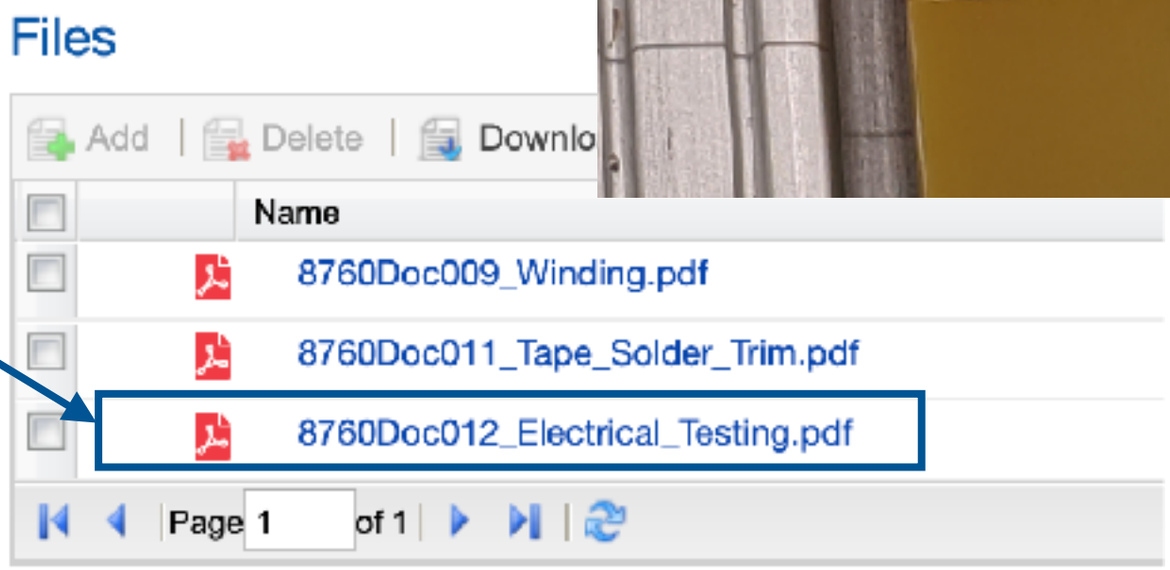
Channel Continuity and Isolation

- Current method: manual checks
- Future method: Use of DWA for continuity









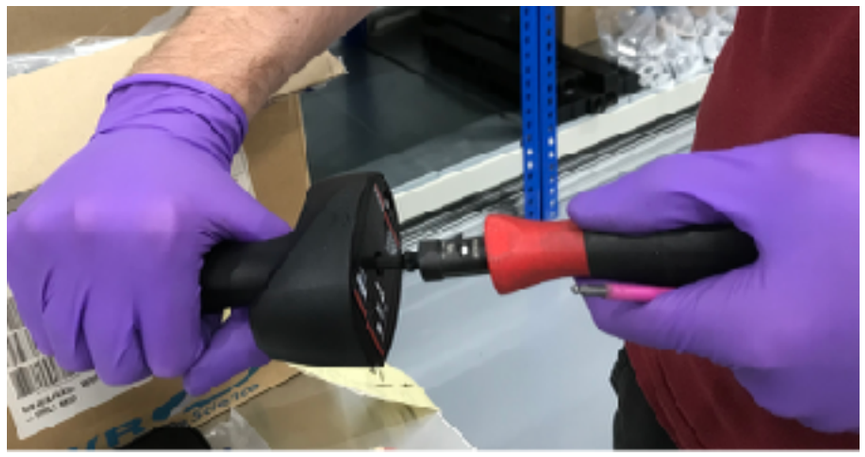
Torque Requirements

- Some fasteners for the APA frames need to have very specific torque values

2615586 (v.1) Fastener Torque Specifications

APA Frame and Yoke Torque Chart

	Torque in 3mm tube wall. These torque values have been validated with testing.		Torque in standard depth tapped hole.					
Fastener size	Value	Units	Value	Units	Value	Units	Value	Units
M4	2.03	N*m	18	lb-in				
M5	3.39	N*m	30	lb-in				
M6	4.75	N*m	42	lb-in	5.79	N*m	51	lb-in
M8					14.2	N*m	126	lb-in
M10					28.5	N*m	252	lb-in
M12					51.5	N*m	38	lb-ft
M16					120.2	N*m	89	lb-ft



Assembled APA flatness and wire plane spacing

- New updated document in progress

Tolerance:

- 6mm overall out-of-flatness in the frame due to twist
- 11 mm out-of-flatness due to bow
- 1.2 mm out-of-flatness due to a “fold” down the center

Summary of the documentation

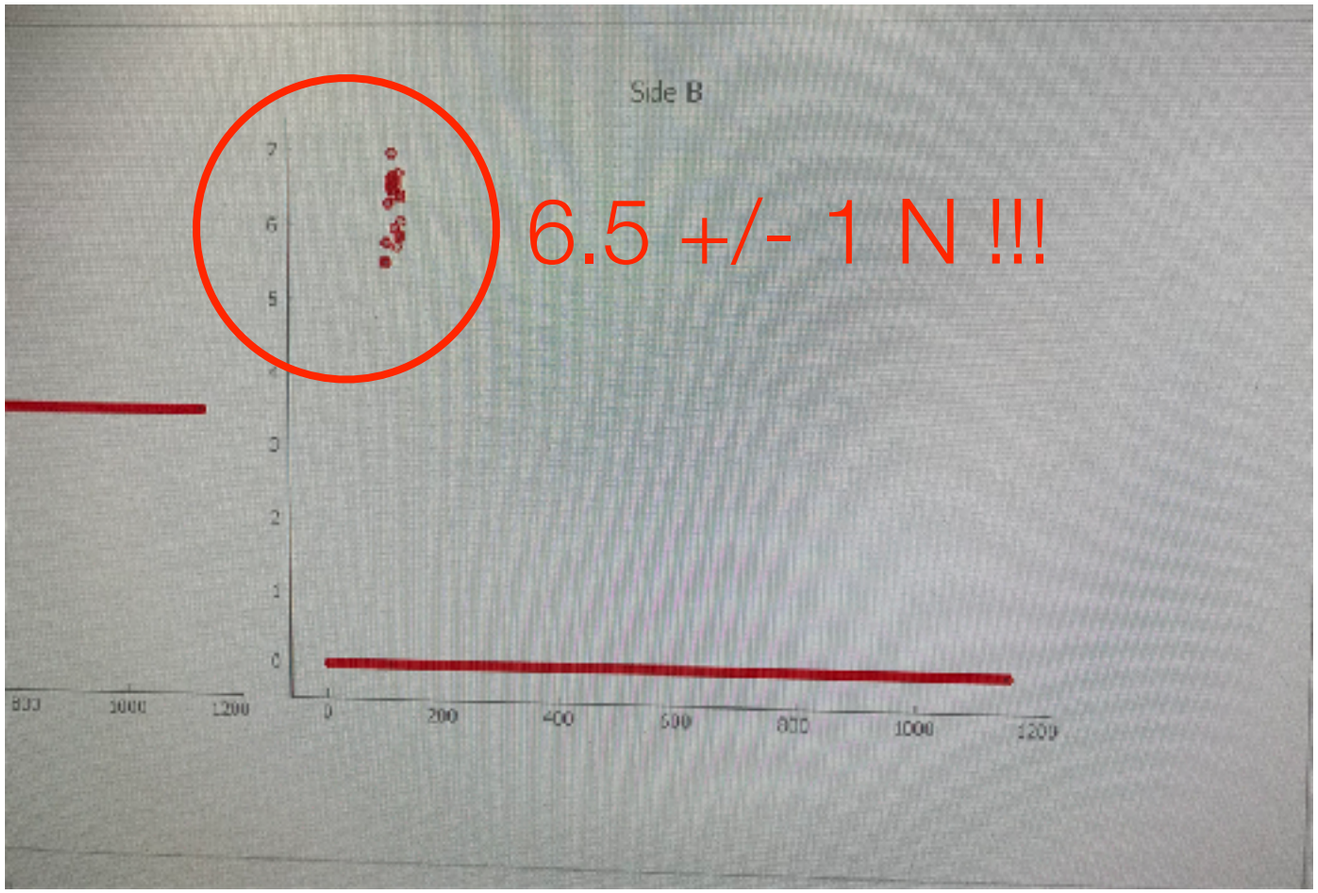
- Most procedure documents for QA/QC are on edms
- Tested the document review/approval sequence (sign off)
- QA/QC data is recorded on database
- Nonconformance documents
- Travelers are updated with the QA/QC results

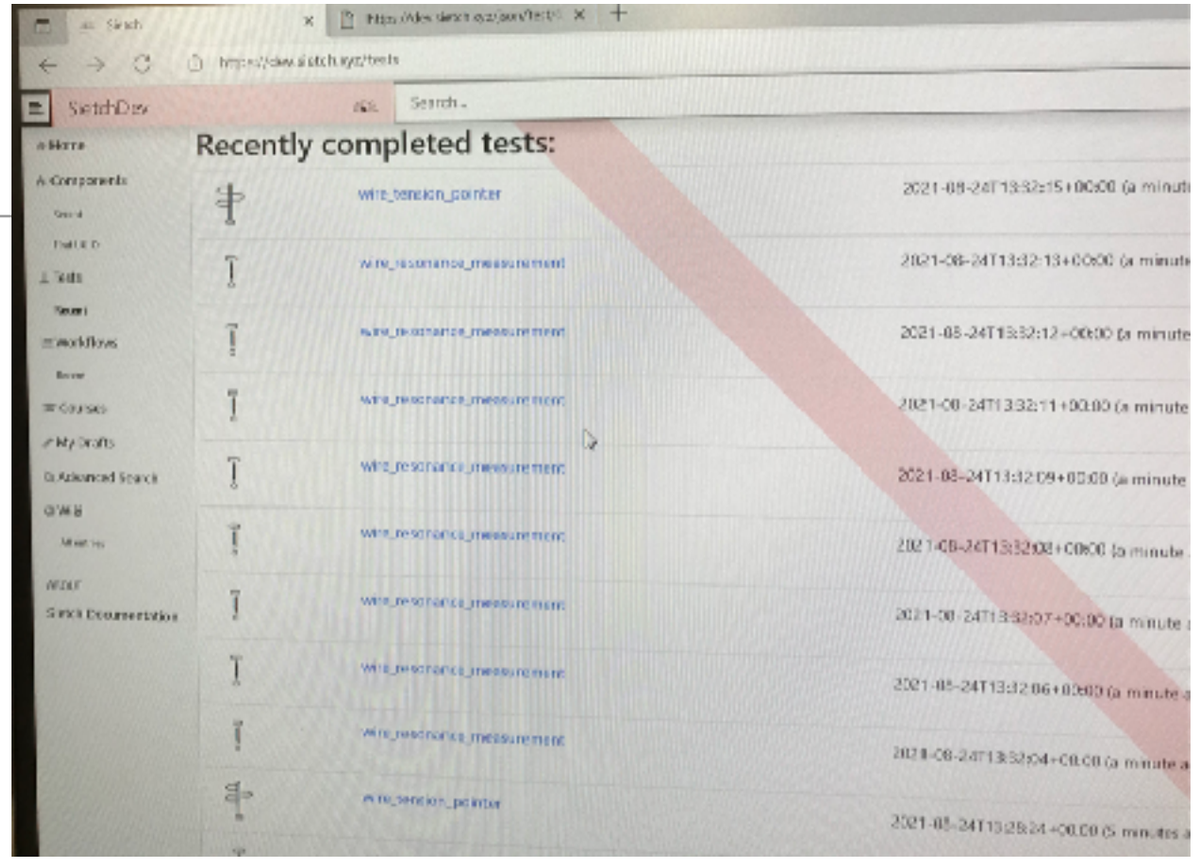
Document sign-off

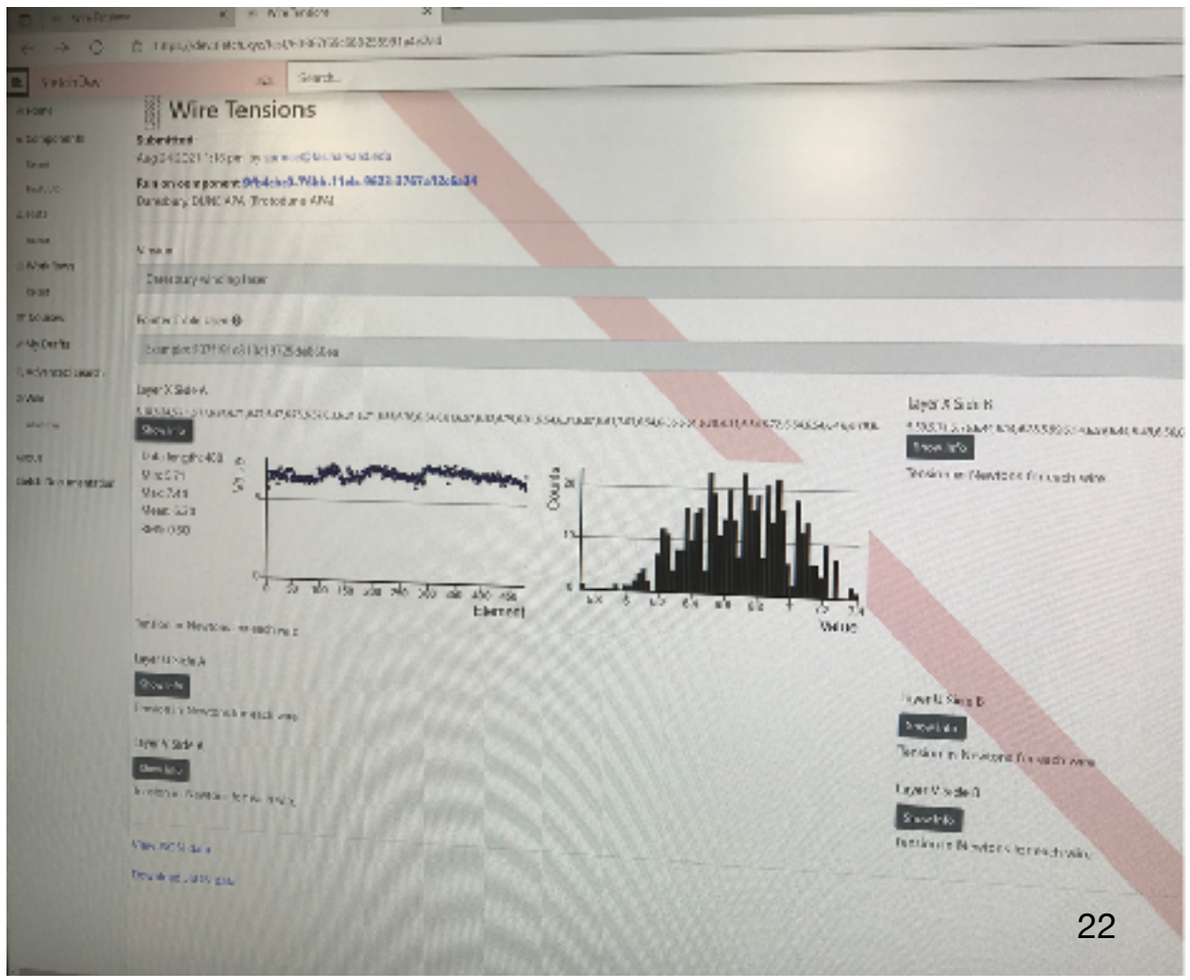
- Experts produce documentation and exchange draft procedures to finalise them
- Documents are sent to managers for revisions and iterations
- Documents are uploaded to *edms* with version number
- QA/QC group discuss the uploaded documentation and may propose comments/modifications (->re-iteration)
- Plan to have automatized notifications to all QA/QC team when new documents are uploaded
- Weekly (bi-weekly) discussions of documentation progress

Database (Sietch)

- Example with DWA tests







Non-Conformance documents

Address	**Locker Group** Farrell St, Warrington WA1 2WW
Telephone	01925 406602

Non-conformance number	NC-UK-8760-03-001

Non-Conformance Report – Meshes

IDENTIFICATION	
Originator Name: Gwenn Mouster	Date: 15/07/2021
Contractor/Suppliers: Locker Group	PO No: 4070287418
Part description: Mesh frame	Qty: 20/20
Part number: 294-10560 to 294-10564	Dwg No: 294-10560 to 294-10564

Found during what activity:

☐ Items / Packing list / PO	☒ Mesh inspection	☒ Hole inspection
☒ Weld inspection	☐ Frame inspection	☐ Other: _____

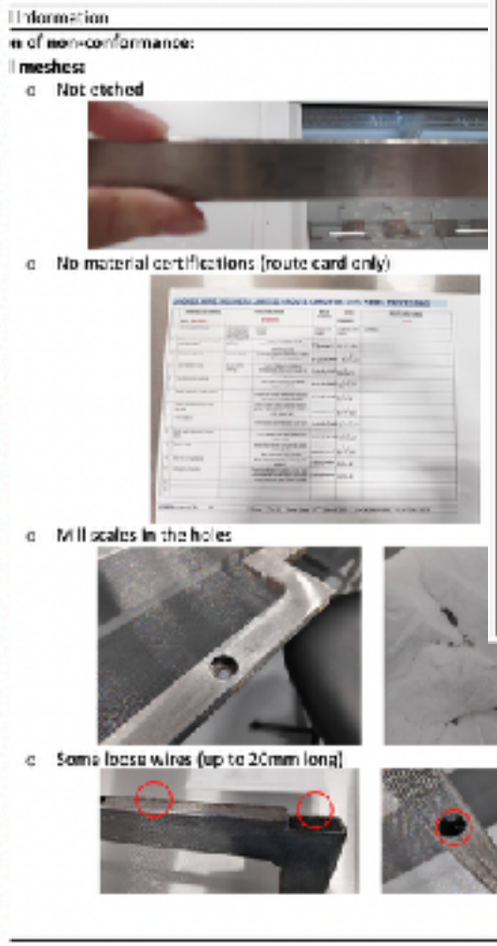
Description of non-conformance (use continuation page if necessary):
See continuation page + **document "QC mesh - ProtoDUNE-II - first mesh batch.xls"**

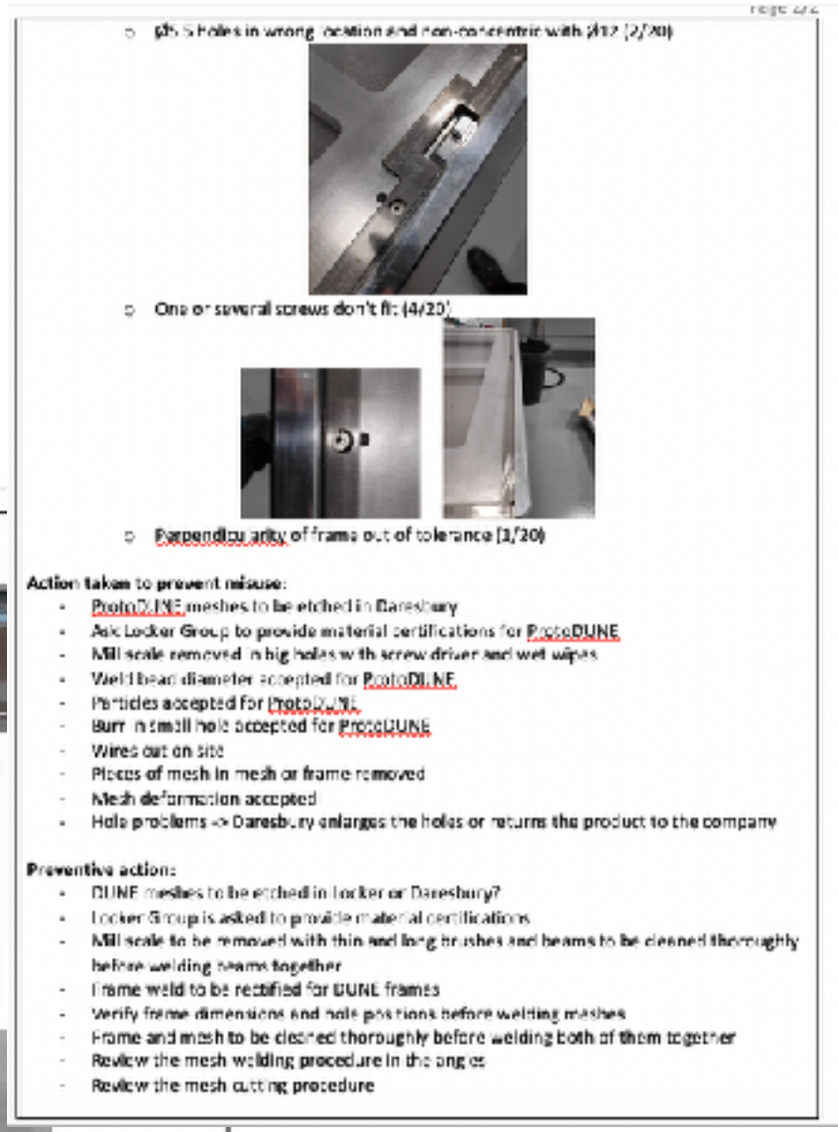
Action taken to prevent misuse (use continuation page if necessary):
See continuation page

DISPOSITION		
☐ Use-as-is	☒ Return to supplier	Comments: Rework 16/20 meshes, repair meshes 294-10563/001 and 294-1064/005, return to supplier meshes 294-10560/001 and 002
☒ Repair	☐ Reject/Re-purpose	
☒ Rework	☐ Scrap	

Quality Assurance	Project Engineer	Project Management
Name: Gwenn Mouster Date: 15/07/2021	Name: Date:	Name: Date:

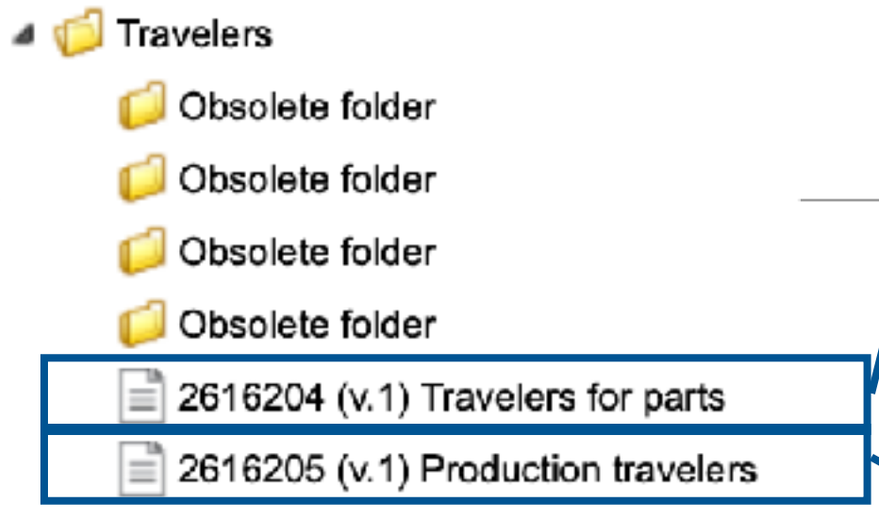
Other Project Personnel			
Name:	Date:	Name:	Date:





Documents reviewed by all QA/QC managers

Travellers


Travelers
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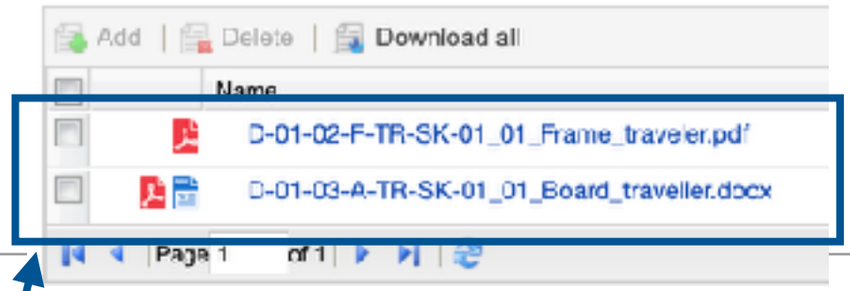
2616204 (v.1) Travelers for parts
2616205 (v.1) Production travelers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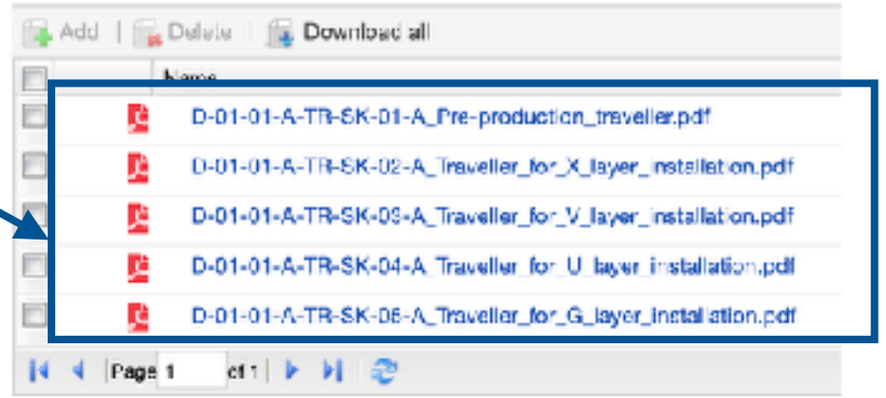
Page 1
of 1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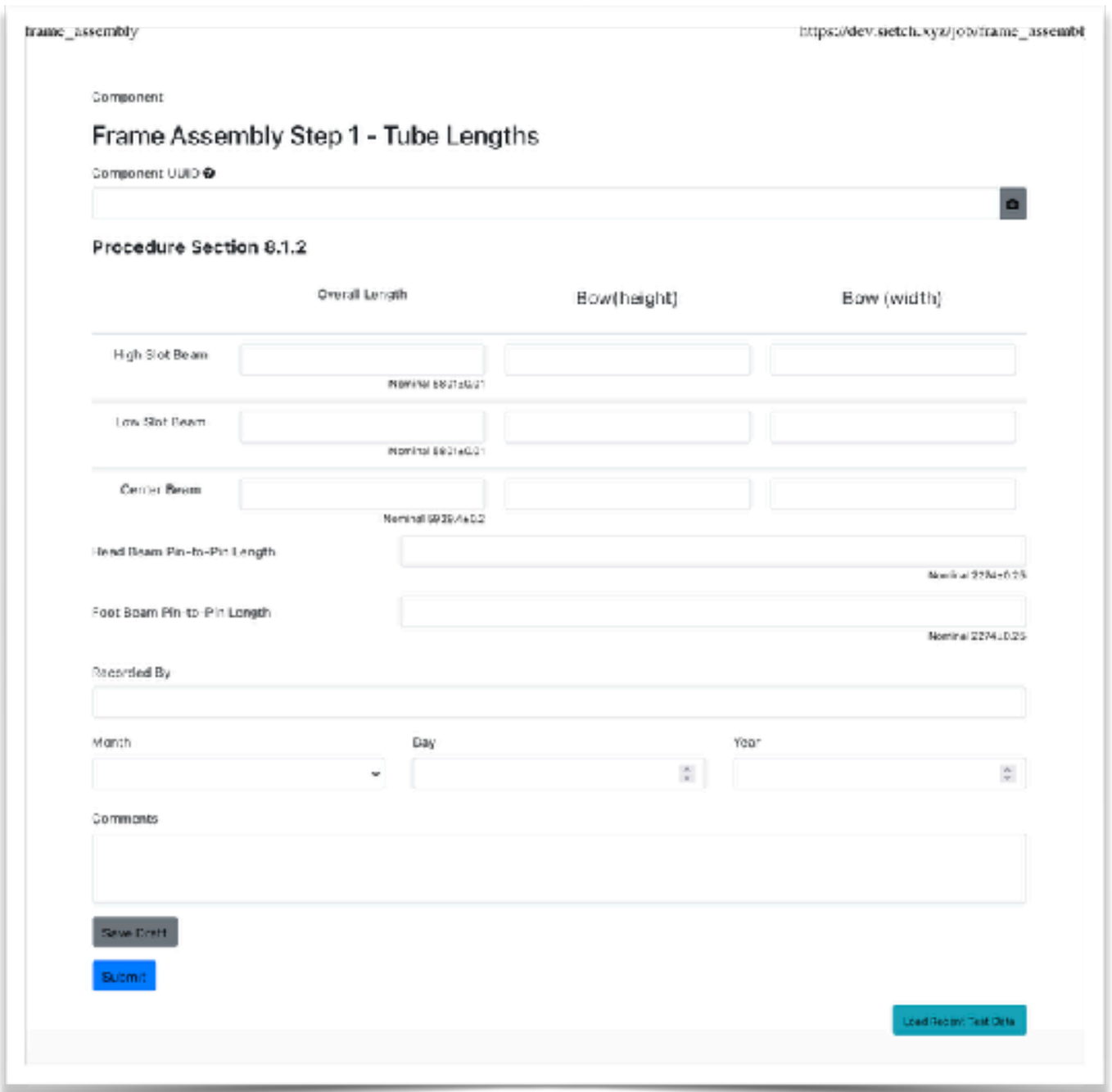
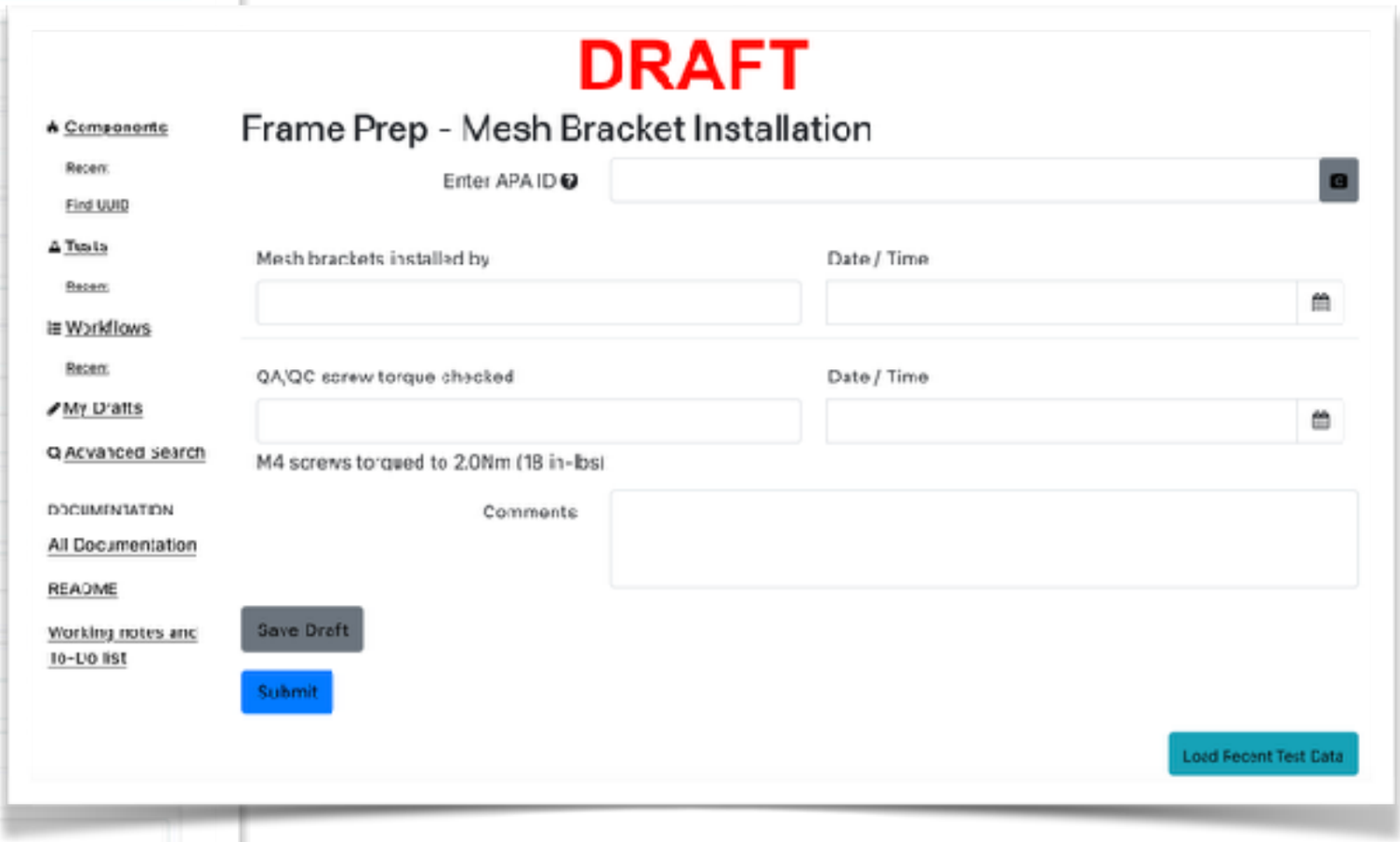
Download all
D-01-01-A-TR-SK-01-A_Pre-production_traveller.pdf
D-01-01-A-TR-SK-02-A_Traveller_for_X_layer_installation.pdf
D-01-01-A-TR-SK-03-A_Traveller_for_V_layer_installation.pdf
D-01-01-A-TR-SK-04-A_Traveller_for_U_layer_installation.pdf
D-01-01-A-TR-SK-05-A_Traveller_for_G_layer_installation.pdf
Page 1


frame_assembly
https://dev.sketch.xyz/job/frame_assembly
Component
Frame Assembly Step 1 - Tube Lengths
Component UUID
Procedure Section 8.1.2
Overall Length
Bow(height)
Bow (width)
High Slot Beam
Low Slot Beam
Center Beam
Nominal 9935/A-02
Head Beam Pin-to-Pin Length
Foot Beam Pin-to-Pin Length
Recorded By
Month
Day
Year
Comments
Save Draft
Submit

Travellers


DRAFT
Components
Recent
Find UUID
Tests
Recent
Workflows
Recent
My Drafts
Advanced Search
DOCUMENTATION
All Documentation
README
Working notes and To-Do list
X Layer - Side A Head Board Installation
Enter APA ID
<-- Low Slot Beam
Side A
High Slot Beam -->
Board 1
Board 2
Board 3
Board 4
Board 5
Board 6
Board 7
Board 8
Board 9
Board 10
Board 1 Serial Number
Board# 104
Board 2 Serial Number
Board# 104
Board 3 Serial Number
Board# 104
Board 4 Serial Number
Board# 104
Board 5 Serial Number
Board# 104
Board 6 Serial Number
Board# 104
Board 7 Serial Number
Board# 104
Board 8 Serial Number
Board# 104
Board 9 Serial Number
Board# 104
Board 10 Serial Number
Board# 104
Boards installed by
Date / Time
QA/QC Screw Torque Check
Date / Time
M4 screws torqued to 2.0Nm (18 lb-in)
Comments


DRAFT
Components
Recent
Find UUID
Tests
Recent
Workflows
Recent
My Drafts
Advanced Search
DOCUMENTATION
All Documentation
README
Working notes and To-Do list
Frame Prep - Mesh Bracket Installation
Enter APA ID
Mesh brackets installed by
Date / Time
QA\QC screw torque checked
Date / Time
M4 screws torqued to 2.0Nm (18 in-lbs)
Comments
Save Draft
Submit
Load Recent Test Data

Summary

- Most detailed QA/QC procedure documents have been developed (based on experience from protoDUNE-I and the new APAs for protoDUNE-II)

- Each component is individually checked and the assembled APA as well

- A 10% sample of APAs will be cold tested

- Wire tension (continuity/isolation) will also be tested after the cold tests and at installation

Backup

Example of documentation (PCBs)

Board Mechanical and Visual inspection Procedure

Step 0

Boards are received in Manchester from Lancaster in Batches.
Each board has an individual QR code, which identifies that board in Sietch.
Each batch of boards contains exactly one type of boards produced by one manufacturer and all arrived at Lancaster at one time.
The batch QR code is scanned which updates the board location to be in Manchester.
As the measurement process is started, each board is scanned, which updates the measurement status on sietch.

Step 1

Feature positions for **all boards** are measured according to the **XY Measurement Procedure (A)** attached below. The data is uploaded according to the **data export procedure (B)** attached below

Step 2

Board thickness for **all boards** is measured according to the **Thickness Measurement Procedure (C)** below.

Step 3

For **edge boards** the tongue depth is measured according to **Tongue Depth Measurement Procedure (D)** attached below.

Step 4

Production of travellers. For **all boards** the data from the above measurements is checked, and for all boards that pass, this is compiled into a traveller, using **Traveller Template document**, including any **Non-conformance documents**.

Step 5

All boards are packaged individually in bubblewrap packages and are shipped in batches (or sub-batches) as per the **Shipment Table (E)** below. Travellers are included with each batch of board as well as being found on Sietch.

Procedure C
Thickness measurement procedure

STEP 1 - "Calibration"

1. Open the program CL-NavigatorN
   The numbers will typically read ~0.26 mm before calibration
2. Position the sliding stage close to the lasers and place a gauge block hanging over the edge
3. In the program click "Zero" two times and check that the measurement oscillates around the nominal value of the gauge block
4. Bag the gauge blocks and store them. Close the CL-NavigatorN program.

STEP 2 - Setup

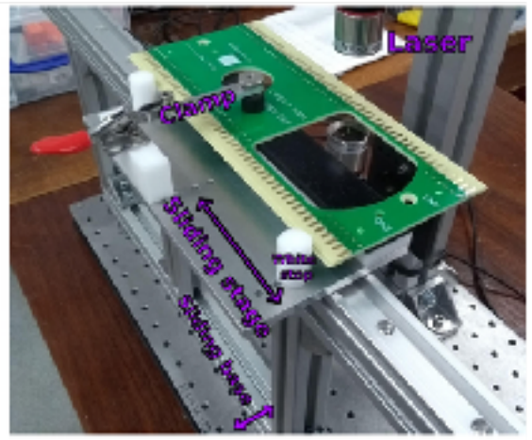
Step 2.1 - Change the clamp position if necessary

Some boards have a big hole in the middle, others on one side. You might need to adjust the clamp position so the clamp can hold the board in position

1. Place a board in the sliding stage so that its bottom edge is touching the white stops on the back and try to see if clamping is possible.
2. If not, remove the screws using a hex key and place the clamp in one of the other perforated holes.
3. Screw in the desired position (don't use too much pressure, the threads are delicate)

Step 2.2 - Draw scan line positions in the base

1. Draw marks in the base of the apparatus according to the positi
   defined for the board model.
   a. The scanline position values can be found here:
   https://docs.google.com/spreadsheets/d/1Bs0sQW3vvZE
   sQ/IK2-Z3wgM_FkYc/edit#gid=0 and on EDMS with the
   programmes.
   b. The marks are measured using a ruler.



Step 2.3 - Program setup

1. Open the "thickness_scan.vi" LabView Program (shortcut on the Desktop)
2. Open the scan line file corresponding to the board model you will measure
   a. Click the directory icon at the right of the "scan_file" white box on the top left of the main window
   b. The scanline files are located in "C:\Desktop\PCB_thickness_data\" and are named "<board>_scan_lines.txt"

APA key requirements

- Number of working channels > 99% (continuity, isolation, tension)
- Wire pitch (frame flatness, tension) ± 0.5 mm
- Plane spacing (frame flatness, tension) ± 0.5 mm

Label	Name	Specification (Goal)	Rationale	Validation
SP-FD-9	APA wire spacing	4.669 mm for U,V; 4.790 mm for X,G	Enables 100% efficient MIP detection, 1.5 cm yz vertex resolution.	Simulation
SP-FD-10	APA wire position tolerance	± 0.5 mm	Interplane electron transparency; dE/dx, range, and MCS calibration.	ProtoDUNE and simulation
SP-APA-5	Frame planarity (twist limit)	<5 mm	APA transparency. Ensures wire plane spacing change of <0.5 mm.	ProtoDUNE-SP
SP-APA-6	Missing/ unreadable channels	<1%, with a goal of <0.5%	Reconstruction efficiency	ProtoDUNE-SP

from TDR

Note on Frame Flatness QC (and wire plane spacing)

- We have concrete tolerance values for each of the possible deformation (twist, bow, fold) to keep the wire plane spacing within 0.5mm
  - **6mm overall out-of-flatness in the frame due to twist**
  - **11 mm out-of-flatness due to bow**
  - **1.2 mm out-of-flatness due to a "fold" down the center**
- Exact tolerance on multiple frame distortions is harder to quantify, but we know that they are not directly additive
- We also can measure directly the plane spacing post-construction
- If there are small deviation outside the tolerance, we still have a mitigation strategy to use higher bias voltage to ensure transparency. This will be studied in detail with dedicated protoDUNE data soon